Georg M. von Hippel

# Life on the Lattice

2005 – 2022. A blog-as-a-book

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Typeset in LaTeX by the author.

# Foreword

Life on the Lattice was a blog on lattice QCD, physics and life in general which was started by Matthew Nobes in 2003. When Matthew left academia and moved into finance in 2005, I took over the blog and ran it until 2022. The most famous feature was probably the annual conference blog from the Lattice conference, which many members of the lattice community who couldn't attend the conference for personal or financial reasons used to keep up to date. The second most famous feature was the series on lattice fermions, some posts of which ended up being the top hits in a Google search for the relevant terms, followed by the posts on Python and Fortran (which were consistently those getting the largest number of visits, although I expect visitors were mostly disappointed by the rather specific content).

As time passed by, I acquired additional responsibilities both professional and private, which caused my blogging activity to die down to the point where the conference blog became the only feature of the blog entirely, and with the move to online and hybrid conferences in the course of the Covid-19 pandemic this became unnecessary, since any interested party could attend the conferences remotely.

The blog therefore became quiescent in 2021/2022, and could well have stayed in that state indefinitely, joining the many blogs on "indefinite hiatus" on its hosting space Blogger (which had been acquired by Google). However, in 2023, German courts found that it is unlawful under the terms of the GDPR to make use of any Google services on a website without prior approval by the visitors (since their IP addresses will by necessity be transferred to Google). This makes the use of Blogger impossible, since even a notice to users would necessarily end up hosted on Google's systems. I was therefore left with no choice but to remove the blog from Blogger.

Given that the blog was quiescent anyway, I felt that the effort to find a GDPR-compliant blog host and to move the blog there was excessive. On the other hand, I felt that dropping 15 years of writing down the memory hole was also an excessive reaction to a somewhat dubious legal ruling. The logical consequence was that I had to find another lawful way to make the blog contents available, and the one I settled on was to convert the blog contents into a PDF file to be released on the internet for dissemination to and by any interested parties.

The content of the present “blog-as-a-book” is therefore a condensation of the contents of the blog achieved largely by using XSLT to transform the downloaded Blogger XML into LaTeX, followed by some semi-manual editing to treat special cases (in particular, some mathematical expressions were presented using named entities and/or italics in HTML and needed to be converted into TeX maths, mostly by regex replacements). The content is a condensation since some posts were of interest only for a short period of time and did not warrant preserving, and in particular since I lack the copyright in Matthew’s posts from 2003–2005 as well as in users’ comments (and hence had to restrict this book to only my own posts).

I hope that this effort to preserve the contents of Life on the Lattice will benefit at least some interested parties, and that the blog may have, so to speak, a good afterlife as a book.

*St. Ottilien, December 2023*

# Contents

# The final years: 2018–2022

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### Mathematicians show 4D φ⁴ theory is trivial

*2022-01-20T12:58:00.000+01:00*

There are rather few mathematically rigorous results on four-dimensional Quantum Field Theories: the CPT theorem and the spin-statistics theorem, for sure, but not that much more. It's therefore a pleasant surprise to see that mathematicians are now agreed that the continuum limit of $\phi^4$ theory formulated on a 4D lattice is indeed trivial. This is the main result of a paper by Michael Aizenman and Hugo Duminil-Copin that has been published in the Annals of Mathematics. Of course, every physicist outside a small circle of determined contrarians pretty much believed that based on the existing numerical evidence already, but it's good to have rigorous confirmation from the mathematicians.

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### Impressions from LATTICE 2021, Part II

*2021-07-30T13:56:00.001+02:00*

As it turns out, Gather is not particularly stable. There are frequent glitches with the audio and video functionality, where people can't hear or can't be heard. The platform also doesn't run particularly well on Firefox (apparently only Google Chrome is officially supported) –for a web-based platform that seems almost inexcusable, since the web is all about free and open standards. One possible reason for the glitches may be the huge number of tracking scripts, cookies, beacons and other privacy-invasive technology that Gather tries to afflict its users with. That being said, it is hard to imagine a much better principle for a virtual conference than the one Gather tries to implement, although I'm not entirely sure that automatically connecting to audio/video when simply walking past a person is necessarily the best approach. Moving past the technical surface to the actual content of the conference, one major difference between Lattice 2021 and the typical lattice conference is the emphasis on special sessions, many of which (like the career panels) specifically target a younger audience. This makes a lot of sense given that the tiny conference fee and non-existent travel costs make this conference particularly affordable for early-stage graduate students who would normally not have the means to attend a conference. It is very praiseworthy that the LOC made a refreshing lemonade out of some Covid-infested lemons and created a conference that takes advantage of the otherwise rather unfortunate situation we all find ourselves in!

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**Impressions from LATTICE 2021, Part I**

*2021-07-26T16:21:00.000+02:00*

Since this year's lattice conference is fully online, and anyone who can access my blog can also attend the conference, with the slides available on the Indico page, and the Zoom sessions recorded, I don't think that my blogging the conference in the usual manner would be as useful as in an ordinary year. This is especially true given that there are over 800 participants this year (which beats Lattice 2013 in Mainz for the record attendance at a lattice conference), so I think it is a fair assumption that everyone who cares about the finer points of lattice field theory is at the conference already and doesn't really need a detailed description of the contents of the plenary talks as filtered through my own preoccupations, preconceptions, and prejudices. I will thus just provide some brief impressions from the conference on this blog. The Zoom sessions with the talks worked very well so far, but the Gather environment seems to be a bit buggy still (sometimes people walking past dragged my avatar along, and the video/audio connections were slow to start and sometimes a bit laggy; also, private spaces seemed not to work as intended, and sometimes it was impossible to walk through a door into another room). Also, having to spread one's attention between up to three platforms (Zoom, Gather, Slack) makes the cognitive load a bit heavy at least for me. That being said, the organizers deserve great applause for having done their utmost to provide as "real" a conference experience as possible under the present circumstances.

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**LATTICE 2021 will be virtual**

*2020-11-21T13:07:00.006+01:00*

Not having heard anything about LATTICE 2021, which is to be hosted by MIT, for a while, I checked out their conference website, which used to say that participants of past conferences would be notified of details regarding registration etc. in summer (sc. this past summer). Doing so, I learned that LATTICE 2021 will now be a virtual conference and will be held in the week of July 25-31, 2021.

Given the current developments regarding the Covid-19 pandemic, this seems a reasonable thing to do; even though a vaccine is almost certain to be available by then, not everyone will have received it, and there will likely still be travel restrictions in place. Still, holding a conference online means missing out on the many important informal discussions in coffee break and over shared meals, the networking opportunities for younger researchers, and the general "family reunion" atmosphere that lattice conferences can often have (after all, the community isn't that huge, and it is overall a fairly friendly community). I hope the organizers have good ideas how to provide some of these in a virtual context.

The conference will apparently look a lot like some old 8-bit video game thanks to being hosted via *gather.town*, although talks will be delivered via Zoom. I suppose that does qualify as as good an attempt at providing the conference atmosphere in a virtual context as is currently possible. Given that there are no coffee, meals or other costly purchases required (only server space, electricity and licensing fees), the conference fee is a very modest $70. Add in the lack of travel costs, and this is certainly the cheapest lattice conference ever (and even so, there is still a reduced rate for students!).

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**Lattice 2020 cancelled**

*2020-04-24T13:50:00.001+02:00*

If you are at all connected to the lattice community, you will no doubt already know that Lattice 2020 has been cancelled due to the current COVID-19 pandemic.

That makes three lattice conferences in a row that I'm not attending, which means this blog is pretty devoid of content at the moment.

I wonder if someone shouldn't set up a virtual lattice conference for 2020; at our university, we have pretty good experiences with BigBlueButton as a remote presentation tool capable of running at least parallel-session-sized courses. Combined with some plain video streaming for the plenaries, that could make for a decent remote conference, I think (although the time-zone differentials would make participation a pain for at least one third of the worldwide community, I suppose, no matter what time-zone gets used for the server). Of course someone would have to bear the costs of hosting, which may be difficult to find funding for.

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## Looking for guest bloggers to cover LATTICE 2019

*2019-04-23T15:18:00.000+02:00*

My excellent reason for not attending LATTICE 2018 has become a lot bigger, much better at many things, and (if possible) even more beautiful — which means I won't be able to attend LATTICE 2019 either (I fully expect to attend LATTICE 2020, though). So once again I would greatly welcome guest bloggers willing to cover LATTICE 2019; if you are at all interested, please send me an email and we can arrange to grant you posting rights.

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## Looking for guest blogger(s) to cover LATTICE 2018

*2018-01-29T12:49:00.002+01:00*

Since I will not be attending LATTICE 2018 for some excellent personal reasons, I am looking for a guest blogger or even better several guest bloggers from the lattice community who would be interested in covering the conference. Especially for advanced PhD students or junior postdocs, this might be a great opportunity to get your name some visibility. If you are interested, drop me a line either in the comment section or by email (my university address is easy to find).

# 2017

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### Lattice 2017, Day Six

*2017-06-29T15:46:00.003+02:00*

On the last day of the 2017 lattice conference, there were plenary sessions only. The first plenary session opened with a talk by Antonio Rago, who gave a ”community review” of lattice QCD on new chips. New chips in the case of lattice QCD means mostly Intel’s new Knight’s Landing architecture, to whose efficient use significant effort is devoted by the community. Different groups pursue very different approaches, from purely OpenMP-based C codes to mixed MPI/OpenMP-based codes maximizing the efficiency of the SIMD pieces using assembler code. The new NVidia Tesla Volta and Intel’s OmniPath fabric also featured in the review.

The next speaker was Zoreh Davoudi, who reviewed lattice inputs for nuclear physics. While simulating heavier nuclei directly in the lattice is still infeasible, nuclear phenomenologists appear to be very excited about the first-principles lattice QCD simulations of multi-baryon systems now reaching maturity, because these can be use to tune and validate nuclear models and effective field theories, from which predictions for heavier nuclei can then be derived so as to be based ultimately on QCD. The biggest controversy in the multi-baryon sector at the moment is due to HALQCD’s claim that the multi-baryon mass plateaux seen by everyone except HALQCD (who use their own method based on Bethe-Salpeter amplitudes) are probably fakes or ”mirages”, and that using the Lüscher method to determine multi-baryon binding would require totally unrealistic source-sink separations of over 10 fm. The volume independence of the bound-state energies determined from the allegedly fake plateaux, as contrasted to the volume dependence of the scattering-state energies so extracted, provides a fairly strong defense against this claim, however. There are also new methods to improve the signal-to-noise ratio for multi-baryon correlation functions, such as phase reweighting.

This was followed by a talk on the tetraquark candidate $Z_c(3900)$ by Yoichi Ikeda, who spent a large part of his talk on reiterating the HALQCD claim that the Lüscher method requires unrealistically large time separations.

During the questions, William Detmold raised the important point that there would be no excited-state contamination at all if the interpolating operator created an eigenstate of the QCD Hamiltonian, and that for improved interpolating operators (such as generated by the variational method) one can get rather close to this situation, so that the HALQCD criticism seems hardly applicable. As for the $Z_c(3900)$, HALQCD find it to be not a resonance, but a kinematic cusp, although this conclusion is based on simulations at rather heavy pion masses ($m_\pi > 400$ MeV).

The final plenary session was devoted to the anomalous magnetic moment of the muon, which is perhaps the most pressing topic for the lattice community, since the new (g-2) experiment is now running, and theoretical predictions matching the improved experimental precision will be needed soon. The first speaker was Christoph Lehner, who presented RBC/UKQCD's efforts to determine the hadronic vacuum polarization contribution to $a_\mu$ with high precision. The strategy for this consists of two main ingredients: one is to minimize the statistical and systematic errors of the lattice calculation by using a full-volume low-mode average via a multigrid Lanczos method, explicitly including the leading effects of strong isospin breaking and QED, and the contribution from disconnected diagrams, and the other is to combine lattice and phenomenology to take maximum advantage of their respective strengths. This is achieved by using the time-momentum representation with a continuum correlator reconstructed from the R-ratio, which turns out to be quite precise at large times, but more uncertain at shorter times, which is exactly the opposite of the situation for the lattice correlator. Using a window which continuously switches over from the lattice to the continuum at time separations around 1.2 fm then minimizes the overall error on $a_\mu$.

The last plenary talk was given by Gilberto Colangelo, who discussed the new dispersive approach to the hadronic light-by-light scattering contribution to $a_\mu$. Up to now the theory results for this small, but important, contribution have been based on models, which will always have an a priori unknown and irreducible systematic error, although lattice efforts are beginning to catch up. For a dispersive approach based on general principles such as analyticity and unitarity, the hadronic light-by-light tensor first needs to be Lorentz decomposed, which gives 138 tensors, of which 136 are independent, and of which gauge invariance permits only 54, of which 7 are distinct, with the rest related by crossing symmetry; care has to be taken to choose the tensor basis such that there are no kinematic singularities. A master formula in terms of 12 linear combinations of these components has been derived by Gilberto and collaborators, and using one- and two-pion intermediate states (and neglecting the rest) in a systematic fashion, they have been able to produce a model-independent theory result with small uncertainties based on experimental data for pion form factors and scattering amplitudes.

The closing remarks were delivered by Elvira Gamiz, who advised participants that the proceedings deadline of 18 October will be strict, because this year's proceedings will not be published in PoS, but in EPJ Web of Conferences, who operate a much stricter deadline policy. Many thanks to Elvira for organizing such a splendid lattice conference! (I can appreciate how much work that is, and I think you should have received far more applause.)

Huey-Wen Lin invited the community to East Lansing, Michigan, USA, for the Lattice 2018 conference, which will take place 22-28 July 2018 on the campus of Michigan State University.

The IAC announced that Lattice 2019 will take place in Wuhan, China.

And with that the conference ended. I stayed in Granada for a couple more days of sightseeing and relaxation, but the details thereof will be of legitimate interest only to a very small subset of my readership (whom I keep updated via different channels), and I therefore conclude my coverage and return the blog to its accustomed semi-hiatus state.

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**Lattice 2017, Day Five**

*2017-06-25T08:30:00.001+02:00*

The programme for today took account of the late end of the conference dinner in the early hours of the day, by moving the plenary sessions by half an hour. The first plenary talk of the day was given by Ben Svetitsky, who reviewed the status of BSM investigations using lattice field theory. An interesting point Ben raised was that these studies go not so much ”beyond” the Standard Model (like SUSY, dark matter, or quantum gravity would), but ”behind” or ”beneath” it by seeking for a deeper explanation of the seemingly unnaturally small Higgs mass, flavour hierarchies, and other unreasonable-looking features of the SM. The original technicolor theory is quite dead, being Higgsless, but ”walking” technicolor models are an area of active investigation. These models have a $\beta$-function that comes close to zero at some large coupling, leading to an almost conformal behaviour near the corresponding IR almost-fixed point. In such almost conformal theories, a light scalar (i.e. the Higgs) could arise naturally as the pseudo-Nambu-Goldstone boson of the approximate dilatation symmetry of the theory. A range of different gauge groups, numbers of flavours, and fermion representations are being investigated, with the conformal or quasi-conformal status of some of these being apparently controversial. An alternative approach to Higgs compositeness has the Higgs appear as the exact Nambu-Goldstone boson of some spontaneous symmetry breaking which keeps SU(2)$_L\times$U(1) intact, with the Higgs potential being generated at the loop level by the coupling to the SM sector. There are also some models of this type being actively investigated.

The next plenary speaker was Stefano Forte, who reviewed the status and prospects of determining the strong coupling $\alpha_s$ from sources other than the lattice. The PDG average for $\alpha_s$ is a weighted average of six values, four of which are the pre-averages of the determinations from the lattice, from $\tau$ decays, from jet rates and shapes, and from parton distribution functions, and two of which are the determinations from the global electroweak fit and from top production at the LHC. Each of these channels has its own systematic issues, and one problem can be that overaggressive error estimates give too much weight to the corresponding determination, leading to statistically implausible scatter of results in some channels. It should be noted, however, that the lattice results are all quite compatible, with the most precise results by ALPHA and by HPQCD (which use different lattice formulations and completely different analysis methods) sitting right on top of each other.

This was followed by a presentation by Thomas Korzec of the determination of $\alpha_s$ by the ALPHA collaboration. I cannot really attempt to do justice to this work in a blog post, so I encourage you to look at their paper. By making use of both the Schrödinger functional and the gradient flow coupling in finite volume, they are able to non-perturbatively run $\alpha_s$ between hadronic and perturbative scales with high accuracy.

After the coffee break, Erhard Seiler reviewed the status of the complex Langevin method, which is one of the leading methods for simulating actions with a sign problem, e.g. at finite chemical potential or with a $\theta$ term. Unfortunately, it is known that the complex Langevin method can sometimes converge to wrong results, and this can be traced to the violation by the complexification of the conditions under which the (real) Langevin method is justified, of which the development of zeros in $e^{-S}$ seems to be the most important case, giving rise to poles in the force which will violate ergodicity. There seems to be a lack of general theorems for situations like this, although the complex Langevin method has apparently been shown to be correct under certain difficult-to-check conditions. One of the best hopes for simulating with complex Langevin seems to be the dynamical stabilization proposed by Benjamin Jäger and collaborators.

This was followed by Paulo Bedaque discussing the prospects of solving the sign problem using the method of thimbles and related ideas. As far as I understand, thimbles are permissible integration regions in complexified configuration space on which the imaginary part of the action is constant, and which can thus be integrated over without a sign problem. A holomorphic flow that is related both to the gradient flow and the Hamiltonian flow can be constructed so as to flow from the real integration region to the thimbles, and based on this it appears to have become possible to solve some toy models with a sign problem, even going so far as to perform real-time simulations in the Keldysh-Schwinger formalism in Euclidean space (if I understood correctly).

In the afternoon, there was a final round of parallel sessions, one of which was again dedicated to the anomalous magnetic moment of the muon, this time focusing on the very difficult hadronic light-by-light contribution, for which the Mainz group has some very encouraging first results.

**Lattice 2017, Days Three and Four**

*2017-06-23T14:20:00.002+02:00*

Wednesday was the customary short day, with parallel sessions in the morning, and time for excursions in the afternoon. I took the "Historic Granada" walking tour, which included visits to the Capilla Real and the very impressive Cathedral of Granada.

The first plenary session of today had a slightly unusual format in that it was a kind of panel discussion on the topic of axions and QCD topology at finite temperature.

After a brief outline by Mikko Laine, the session chair, the session started off with a talk by Guy Moore on the role of axions in cosmology and the role of lattice simulations in this context. Axions arise in the Peccei-Quinn solution to the strong CP problem and are a potential dark matter candidate. Guy presented some of his own real-time lattice simulations in classical field theory for axion fields, which exhibit the annihilation of cosmic-string-like vortex defects and associated axion production, and pointed out the need for accurate lattice QCD determinations of the topological susceptibility in the temperature range of 500-1200 MeV in order to fix the mass of the axion more precisely from the dark matter density (assuming that dark matter consists of axions).

The following talks were all fairly short. Claudio Bonati presented algorithmic developments for simulations of the topological properties of high-temperature QCD. The long autocorrelations of the topological charge at small lattice spacing are a problem. Metadynamics, which bias the Monte Carlo evolution in a non-Markovian manner so as to more efficiently sample the configuration space, appear to be of help.

Hidenori Fukaya reviewed the question of whether U(1)$_A$ remains anomalous at high temperature, which he claimed (both on theoretical grounds and based on numerical simulation results) it doesn't. I didn't quite understand this, since as far as I understand the axial anomaly, it is an operator identity, which will remain true even if both sides of the identity were to happen to vanish at high enough temperature, which is all that seemed to be shown; but this may just be my ignorance showing.

Tamas Kovacs showed recent results on the temperature-dependence of the topological susceptibility of QCD. By a careful choice of algorithms based on physical considerations, he could measure the topological susceptibility over a wide range of temperatures, showing that it becomes tiny at large temperature.

Then the speakers all sat on the stage as a panel and fielded questions from the audience. Perhaps it might have been a good idea to somehow force the speakers to engage each other; as it was, the advantage of this format over simply giving each speaker a longer time for answering questions didn't immediately become apparent to me.

After the coffee break, things returned to the normal format. Boram Yoon gave a review of lattice determinations of the neutron electric dipole moment. Almost any BSM source of CP violation must show up as a contribution to the neutron EDM, which is therefore a very sensitive probe of new physics. The very strong experimental limits on any possible neutron EDM imply e.g. $|\theta| < 10^{-10}$ in QCD through lattice measurements of the effects of a $\theta$ term on the neutron EDM. Similarly, limits can be put on any quark EDMs or quark chromoelectric dipole moments. The corresponding lattice simulations have to deal with sign problems, and the usual techniques (Taylor expansions, simulations at complex $\theta$) are employed to get past this, and seem to be working very well.

The next plenary speaker was Phiala Shanahan, who showed recent results regarding the gluon structure of hadrons and nuclei. This line of research is motivated by the prospect of an electron-ion collider that would be particularly sensitive to the gluon content of nuclei. For gluonic contributions to the momentum and spin decomposition of the nucleon, there are some fresh results from different groups. For the gluonic transversity, Phiala and her collaborators have performed first studies in the $\phi$ system. The gluonic radii of small nuclei have also been looked at, with no deviation from the single-nucleon case visible at the present level of accuracy.

The 2017 Kenneth Wilson Award was awarded to Raúl Briceño for his groundbreaking contributions to the study of resonances in lattice QCD. Raúl has been deeply involved both in the theoretical developments behind extending the reach of the Lüscher formalism to more and more complicated situations, and in the numerical investigations of resonance properties rendered possible by those developments.

After the lunch break, there were once again parallel sessions, two of which were dedicated entirely to the topic of the hadronic vacuum polarization contribution to the anomalous magnetic moment of the muon, which has become one of the big topics in lattice QCD.

In the evening, the conference dinner took place. The food was excellent, and the Flamenco dancers who arrived at midnight (we are in Spain after all, where it seems dinner never starts before 9pm) were quite impressive.

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**Lattice 2017, Day Two**

*2017-06-20T22:26:00.000+02:00*

Welcome back to our blog coverage of the Lattice 2017 conference in Granada.

Today's first plenary session started with an experimental talk by Arantza

Oyanguren of the LHCb collaboration on B decay anomalies at LHCb. LHCb have amassed a huge number of b-bbar pairs, which allow them to search for and study in some detail even the rarest of decay modes, and they are of course still collecting more integrated luminosity. Readers of this blog will likely recall the $B_s \to \mu^+\mu^-$ branching ratio result from LHCb, which agreed with the Standard Model prediction. In the meantime, there are many similar results for branching ratios that do not agree with Standard Model predictions at the $2-3\sigma$ level, e.g. the ratios of branching fractions like Br($B^+ \to K^+\mu^+\mu^-$)/Br($B^+ \to K^+e^+e^-$), in which lepton flavour universality appears to be violated. Global fits to data in these channels appear to favour the new physics hypothesis, but one should be cautious because of the "look-elsewhere" effect: when studying a very large number of channels, some will show an apparently significant deviation simply by statistical chance. On the other hand, it is very interesting that all the evidence indicating potential new physics (including the anomalous magnetic moment of the muon and the discrepancy between the muonic and electronic determinations of the proton electric charge radius) involve differences between processes involving muons and analogous processes involving electrons, an observation I'm sure model-builders have made a long time ago.

This was followed by a talk on flavour physics anomalies by Damir Bečirević. Expanding on the theoretical interpretation of the anomalies discussed in the previous talk, he explained how the data seem to indicate a violation of lepton flavour universality at the level where the Wilson coefficient $C_9$ in the effective Hamiltonian is around zero for electrons, and around $-1$ for muons. Experimental data seem to favour the situation where $C_{10} = -C_9$, which can be accommodated is certain models with a $Z'$ boson coupling preferentially to muons, or in certain special leptoquark models with corrections at the loop level only. Since I have little (or rather no) expertise in phenomenological model-building, I have no idea how likely these explanations are.

The next speaker was Xu Feng, who presented recent progress in kaon physics simulations on the lattice. The "standard" kaon quantities, such as the kaon decay constant or $f_+(0)$, are by now very well-determined from the lattice, with overall errors at the sub-percent level, but beyond that there are many important quantities, such as the CP-violating amplitudes in $K \to \pi\pi$ decays, that are still poorly known and very challenging. RBC/UKQCD have been leading the attack on many of these observables, and have presented a possible solution to the $\Delta I = 1/2$ rule, which consists in non-perturbative effects making the amplitude $A_0$ much larger relative to $A_2$ than what would be expected from naive colour counting. Making further progress on long-distance contributions to the $K_L - K_S$ mass difference or $\epsilon_K$ will require working at the physical pion mass and treating the charm quark with good control of discretization effects. For some processes, such as $K_L \to \pi^0\ell^+\ell^-$, even the sign of the coefficient would be desirable.

After the coffee break, Luigi Del Debbio talked about parton distributions in the LHC era. The LHC data reduce the error on the NNLO PDFs by around a factor of two in the intermediate-$x$ region. Conversely, the theory errors coming from the PDFs are a significant part of the total error from the LHC on Higgs physics and BSM searches. In particular the small-$x$ and large-$x$ regions remain quite uncertain. On the lattice, PDFs can be determined via quasi-PDFs, in which the Wilson line inside the non-local bilinear is along a spatial direction rather than in a light-like direction. However, there are still theoretical issues to be settled in order to ensure that the renormalization and matching the the continuum really lead to the determination of continuum PDFs in the end.

Next was a talk about chiral perturbation theory results on the multi-hadron state contamination of nucleon observables by Oliver Bär. It is well known that until very recently, lattice calculations of the nucleon axial charge underestimated its value relative to experiment, and this has been widely attributed to excited-state effects. Now, Oliver has calculated the corrections from nucleon-pion states on the extraction of the axial charge in chiral perturbation theory, and has found that they actually should lead to an overestimation of the axial charge from the plateau method, at least for source-sink separations above $2\ fm$, where ChPT is applicable. Similarly, other nucleon charges should be overestimated by $5-10$%. Of course, nobody is currently measuring in that distance regime, and so it is quite possible that higher-order corrections or effects not captured by ChPT overcompensate this and lead to an underestimation, which would however mean that there is some intermediate source-sink separation for which one gets the experimental result by accident, as it were.

The final plenary speaker of the morning was Chia-Cheng Chang, who discussed progress towards a precise lattice determination of the nucleon axial charge, presenting the results of the CalLAT collaboration from using what they refer to as the Feynman-Hellmann method, a novel way of implementing what is essentially the summation method through ideas based in the Feynman-Hellmann theorem (but which doesn't involve simulating with a modified action, as a straightforward application of the Feynman-Hellmann theorem would demand).

After the lunch break, there were parallel sessions, and in the evening, the poster session took place. A particular interesting and entertaining contribution was a quiz about women's contributions to physics and computer science, the winner of which will win a bottle of wine and a book.

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### Lattice 2017, Day One

*2017-06-19T22:40:00.000+02:00*

Hello from Granada and welcome to our coverage of the 2017 lattice conference.

After welcome addresses by the conference chair, a representative of the government agency in charge of fundamental research, and the rector of the university, the conference started off in a somewhat sombre mood with a commemoration of Roberto Petronzio, a pioneer of lattice QCD, who passed away last year. Giorgio Parisi gave a memorial talk summarizing Roberto's many contributions to the development of the field, from his early work on perturbative QCD and the parton model, through his pioneering contributions to lattice QCD back in the days of small quenched lattices, to his recent work on partially twisted boundary conditions and on isospin breaking effects, which is very much at the forefront of the field at the moment, not to omit Roberto's role as director of the Italian INFN in politically turbulent times.

This was followed by a talk by Martin Lüscher on stochastic locality and master-field simulations of very large lattices. The idea of a master-field simulation is based on the observation of volume self-averaging, i.e. that the variance of volume-averaged quantities is much smaller on large lattices (intuitively, this would be because an infinitely-extended properly thermalized lattice configuration would have to contain any possible finite sub-configuration with a frequency corresponding to its weight in the path integral, and that thus a large enough typical lattice configuration is itself a sort of ensemble). A master field is then a huge (e.g. $256^4$) lattice configuration, on which volume averages of quantities are computed, which have an expectation value equal to the QCD expectation value of the quantity in question, and a variance which can be estimated using a double volume sum that is doable using an FFT. To generate such huge lattice, algorithms with global accept-reject steps (like HMC) are unsuitable, because $\Delta H$ grows with the square root of the volume, but stochastic molecular dynamics (SMD) can be used, and it has been rigorously shown that for short-enough trajectory lengths SMD converges to a unique stationary state even without an accept-reject step.

After the coffee break, yet another novel simulation method was discussed by Ignacio Cirac, who presented techniques to perform quantum simulations of QED and QCD on a lattice. While quantum computers of the kind that would render RSA-based public-key cryptography irrelevant remain elusive at the moment, the idea of a quantum simulator (which is essentially an analogue quantum computer), which goes back to Richard Feynman, can already be realized in practice: optical lattices allow trapping atoms on lattice sites while fine-tuning their interactions so as to model the couplings of some other physical system, which can thus be simulated. The models that are typically simulated in this way are solid-state models such as the Hubbard model, but it is of course also possible to setup a quantum simulator for a lattice field theory that has been formulated in the Hamiltonian framework. In order to model a gauge theory, it is necessary to model the gauge symmetry by some atomic symmetry such as angular momentum conservation, and this has been done at least in theory for QED and QCD. The Schwinger model has been studied in some detail. The plaquette action for $d > 1 + 1$ additionally requires a four-point interaction between the atoms modelling the link variables, which can be realized using additional auxiliary variables, and non-abelian gauge groups can be encoded using multiple species of bosonic atoms. A related theoretical tool that is still in its infancy, but shows significant promise, is the use of tensor networks. This is based on the observation that for local Hamiltonians the entanglement between a region and its complement grows only as the surface of the region, not its volume, so only a small corner of the total Hilbert space is relevant; this allows one to write the coefficients of the wavefunction in a basis of local states as a contraction of tensors, from where classical algorithms that scale much better than the exponential growth in the number of variables that would naively be expected can be derived. Again, the method has been successfully applied to the Schwinger model, but higher dimensions are still challenging, because the scaling, while not exponential, still becomes very bad.

Staying with the topic of advanced simulation techniques, the next talk was Leonardo Giusti speaking about the block factorization of fermion determinants into local actions for multi-boson fields. By decomposing the lattice into three pieces, of which the middle one separates the other by a distance $\Delta$ large enough to render $e^{-M_\pi\Delta}$ small, and by applying a domain decomposition similar to the one used in Lüscher's DD-HMC algorithm to the Dirac operator, Leonardo and collaborators have been able to derive a multi-boson algorithm that allows to perform multilevel integration with dynamical fermions. For hadronic observables, the quark propagator also needs to be factorized, which Leonardo et al. also have achieved, making a significant decrease in statistical error possible.

After the lunch break there were parallel sessions, in one of which I gave my own talk and another one of which I chaired, thus finishing all of my duties other than listening (and blogging) on day one.

In the evening, there was a reception followed by a special guided tour of the truly stunning Alhambra (which incidentally contains a great many colourful - and very tasteful - lattices in the form of ornamental patterns).

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**Book Review: "Lattice QCD —Practical Essentials"**

*2017-01-12T17:37:00.001+01:00*

There is a new book about Lattice QCD, Lattice Quantum Chromodynamics: Practical Essentials by Francesco Knechtli, Michael Günther and Mike Peardon. At 140 pages, this is a pretty slim volume, so it is obvious that it does not aim to displace time-honoured introductory textbooks like Montvay and Münster, or the newer books by Gattringer and Lang or DeGrand and DeTar. Instead, as suggested by the subtitle "Practical Essentials", and as said explicitly by the authors in their preface, this book aims to prepare beginning graduate students for their practical work in generating gauge configurations and measuring and analysing correlators.

In line with this aim, the authors spend relatively little time on the physical or field-theoretic background; while some more advanced topics such as the Nielsen-Ninomiya theorem and the Symanzik effective theory are touched upon, the treatment of foundational topics is generally quite brief, and some topics, such as lattice perturbation theory or non-perturbative renormalization, are omitted altogether. The focus of the book is on Monte Carlo simulations, for which both the basic ideas and practically relevant algorithms —heatbath and overrelaxation for pure gauge fields, and hybrid Monte Carlo (HMC) for dynamical fermions —are described in some detail, including the RHMC algorithm and advanced techniques such as determinant factorizations, higher-order symplectic integrators, and multiple-timescale integration. The techniques from linear algebra required to deal with fermions are also covered in some detail, from the basic ideas of Krylov-space methods through concrete descriptions of the GMRES and CG algorithms, along with such important preconditioners as even-odd and domain decomposition, to the ideas of algebraic multigrid methods. Stochastic estimation of all-to-all propagators with dilution, the one-end trick and low-mode averaging are explained, as are techniques for building interpolating operators with specific quantum numbers, gauge link and quark field smearing, and the use of the variational method to extract hadronic mass spectra. Scale setting, the Wilson flow, and Lüscher's method for extracting scattering phase shifts are also discussed briefly, as are the basic statistical techniques for data analysis. Each chapter contains a list of references to the literature covering both original research articles and reviews and textbooks for further study.

Overall, I feel that the authors succeed very well at their stated aim of giving a quick introduction to the methods most relevant to current research in lattice QCD in order to let graduate students hit the ground running and get to perform research as quickly as possible. In fact, I am slightly worried that they may turn out to be too successful, since a graduate student having studied only this book could well start performing research, while having only a very limited understanding of the underlying field-theoretical ideas and problems (a problem that already exists in our field in any case). While this in no way detracts from the authors' achievement, and while I feel I can recommend this book to beginners, I nevertheless have to add that it should be complemented by a more field-theoretically oriented traditional textbook for completeness.

*Note that I have deliberately not linked to the Amazon page for this book. Please support your local bookstore —nowadays, you can usually order online on their websites, and many bookstores are more than happy to ship books by post.*

# 2016

## Lattice 2016, Day Six

*2016-07-30T22:50:00.002+02:00*

The final day of the conference started with a review talk by Claudio Pica on lattice simulations trying to chart the fundamental physics beyond the Standard Model. The problem with the SM is perhaps to some extent how well it works, given that we know it must be incomplete. One of the main contenders for replacing it is the notion of strong dynamics at a higher energy scale giving rise to the Higgs boson as a composite particle. The most basic "technicolor" theories of this kind fail because they cannot account for the relatively large masses of the second- and third-generation quarks. To avoid that problem, the coupling of the technicolor gauge theory must not be running, but "walking" slowly from high to low energy scales, which has given rise to a veritable industry of lattice simulations investigating the $\beta$ function of various gauge theories coupled to various numbers of fermions in various representations. The Higgs can then be either a dilaton associated with the breaking of conformal symmetry, which would naturally couple like a Standard Model Higgs, or a pseudo-Goldstone boson associated with the breaking of some global flavour symmetry. So far, nothing very conclusive has resulted, but of course the input from experiment at the moment only consists of limits ruling some models out, but not allowing for any discrimination between those models that aren't rules out.

A specific example of BSM physics, *viz.* strongly interacting dark matter, was presented in a talk by Enrico Rinaldi. If there is a new strongly-coupled interaction, as suggested by the composite Higgs models, then besides the Higgs there will also be other bound states, some of which may be stable and provide a dark matter candidate. While the "dark" nature of dark matter requires such a bound state to be neutral, the constituents might interact with the SM sector, allowing for the production and detection of dark matter. Many different models of composite dark matter have been considered, and the main limits currently come from the non-detection of dark matter in searches, which put limits on the "hadron-structure" observables of the dark matter candidates, such as their $\sigma$-terms and charge radii).

David Kaplan gave a talk on a new perspective on chiral gauge theories, the lattice formulation of which has always been a persistent problem, largely due to the Nielsen-Ninomiya theorem. However, the fermion determinant of chiral gauge theories is already somewhat ill-defined even in the continuum. A way to make it well-defined has been proposed by Alvarez-Gaumé *et al.* through the addition of an ungauged right-handed fermion. On the lattice, the U(1)$_A$ anomaly is found to emerge as the remnant of the explicit breaking of chiral symmetry by e.g. the Wilson term in the limit of vanishing lattice spacing. Attempts at realizing ungauged mirror fermions using domain wall fermions with a gauge field constrained to near one domain wall have failed, and a realizations using the gradient flow in the fifth dimension turns the mirror fermions into ”fluff”. A new realization along the lines of the overlap operator gives a lattice operator very similar to that of Alvarez-Gaumé by coupling the mirror fermion to a fixed point of the gradient flow, which is a pure gauge.

After the coffee break, Tony Hey gave a very entertaining, if somewhat meandering, talk about ”Richard Feynman, Data-Intensive Science and the Future of Computing” going all the way from Feynman's experiences at Los Alamos to AI singularity scenarios and the security aspects of self-driving cars.

The final plenary talk was the review talk on machines and algorithms by Peter Boyle. The immediate roadmap for new computer architectures shows increases of around 400 times in the single-precision performance per node, and a two-fold increase in the bandwidth of interconnects, and this must be taken into account in algorithm design and implementation in order to achieve good scaling behaviour. Large increases in chip performance are to be expected from three-dimensional arrangement of units, which will allow thicker and shorter copper wires, although there remain engineering problems to solve, such as how to efficiently get the heat out of such chips. In terms of algorithms, multigrid solvers are now becoming available for a larger variety of fermion formulations, leading to potentially great increases in performance near the chiral and continuum limits. Multilevel integration methods, which allow for an exponential reduction of the noise, also look interesting, although at the moment these work only in the quenched theory.

The IAC announced that Lattice 2018 will take place at Michigan State University. Elvira Gamiz as the chair of the Lattice 2017 LOC extended an invitation to the lattice community to come to Granada for Lattice 2017, which will take place in the week 18-24 June 2017. And with that, and a round of well-deserved applause for the organizers, the conference closed.

My further travel plans are of interest only to a small subset of my readers, and need not be further elaborated upon in this venue.

## Lattice 2016, Day Five

*2016-07-29T23:26:00.003+02:00*

Today was the day of finite temperature and density, on which the general review talk was delivered by Heng-Tong Ding. While in the meantime agreement has been reached on the transition temperature, the nature of the transition (crossover) and the equation of state at the physical quark masses, on which different formulations differed a lot in the past, the Columbia plot of the nature of the transition as a function of the light and strange quark masses still remains to be explored, and there are discrepancies between results obtained in different formulations. On the topic of U(1)$_A$ restoration (on which I do have a layman's question: to my understanding U(1)$_A$ is broken by the axial anomaly, which to my understanding arises from the path integral measure - so why should one expect the symmetry to be restored at high temperature? The situation is quite different from dynamical spontaneous symmetry breaking, as far as I understand), there is no evidence for restoration so far. A number of groups have taken to using the gradient flow as a tool to perform relatively cheap investigations of the equation of state. There are also new results from the different approaches to finite-density QCD, including cumulants from the Taylor-expansion approach, which can be related to heavy-ion observables, and new ways of stabilizing complex Langevin dynamics.

This was followed by two topical talks. The first, by Seyong Kim, was on the subject of heavy flavours at finite temperature. Heavy flavours are one of the most important probes of the quark-gluon plasma, and $J/\psi$ suppression has served as a diagnostic tool of QGP formation for a long time. To understand the influence of high temperatures on the survival of quarkonium states and on the transport properties of heavy flavours in the QGP, knowledge of the spectral functions is needed. Unfortunately, extracting these from a finite number of points in Euclidean point is an ill-posed problem, especially so when the time extent is small at high temperature. The methods used to get at them nevertheless, such as the maximum entropy method or Bayesian fits, need to use some kind of prior information, introducing the risk of a methodological bias leading to systematic errors that may be not only quantitative, but even qualitative; as an example, MEM shows P-wave bottomonium to melt around the transition temperature, whereas a newer Bayesian method shows it to survive, so clearly more work is needed.

The second topical talk was Kurt Langfeld speaking about the density-of-states method. This method is based on determining a function $\rho(E)$, which is essentially the path integral of $\delta(S[\phi] - E)$, such that the partition function can be written as the Laplace transform of $\rho$, which can be generalized to the case of actions with a sign problem, where the partition function can then be written as the Fourier transform of a function $P(s)$. An algorithm to compute such functions exists in the form of what looks like a sort of microcanonical simulation in a window $[E-\delta E; E+\delta E]$ and determines the slope of $\rho$ at $E$, whence $\rho$ can be reconstructed. Ergodicity is ensured by having the different windows overlap and running in parallel, with a possibility of "replica exchange" between the processes running for neighbouring windows when configurations within the overlap between them are generated. The examples shown, e.g. for the Potts model, looked quite impressive in that the method appears able to resolve double-peak structures even when the trough between the peaks is suppressed by many orders of magnitude, such that a Markov process would have no chance of crossing between the two probability peaks.

After the coffee break, Aleksi Kurkela reviewed the phenomenology of heavy ions. The flow properties that were originally taken as a sign of hydrodynamics having set in are now also observed in pp collisions, which seem unlikely to be hydrodynamical. In understanding and interpreting these results, the pre-equilibration evolution is an important source of uncertainty; the current understanding seems to be that the system goes from an overoccupied to an underoccupied state before thermalizing, making different descriptions necessary at different times. At early times, simulations of classical Yang-Mills theory on a lattice in proper-time/rapidity coordinates are used, whereas later a quasiparticle description and kinetic theory can be applied; all this seems to be qualitative so far.

The energy momentum tensor, which plays an important role in thermodynamics and hydrodynamics, was the topic of the last plenary of the day, which was given by Hiroshi Suzuki. Translation invariance is broken on the lattice, so the Ward-Takahashi identity for the energy-momentum tensor picks up an O(a) violation term, which can become O(1) by radiative corrections. As a consequence, three different renormalization factors are needed to renormalize the energy-momentum tensor. One way of getting at these are the shifted boundary conditions of Giusti and Meyer, another is the use of the gradient flow at short flow times, and there are first results from both methods.

The parallel sessions of the afternoon concluded the parallel programme.

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**Lattice 2016, Days Three and Four**

*2016-07-29T00:59:00.000+02:00*

Following the canonical script for lattice conferences, yesterday was the day without plenaries. Instead, the morning was dedicated to parallel sessions (including my own talk), and the afternoon was free time with the option of taking one of several arranged excursions.

I went on the excursion to Salisbury cathedral (which is notable both for its fairly homogeneous and massive architectural ensemble, and for being home to one of four original copies of the Magna Carta) and Stonehenge (which in terms of diameter seems to be much smaller than I had expected from photos).

Today began with the traditional non-lattice theory talk, which was given by Monika Blanke, who spoke about the impact of lattice QCD results on CKM phenomenology. Since quarks cannot be observed in isolation, the extraction of CKM matrix elements from experimental results always require knowledge of the appropriate hadronic matrix elements of the currents involved in the measured reaction. This means that lattice results for the form factors of heavy-to-light semileptonic decays and for the hadronic parameters governing neutral kaon and B meson mixing are of crucial importance to CKM phenomenology, to the extent that there is even a sort of "wish list" to the lattice. There has long been a discrepancy between the values of both $|V_{cb}|$ and $|V_{ub}|$ extracted from inclusive and exclusive decays, respectively, and the ratio $|V_{ub}/V_{cb}|$ that can be extracted from decays of $\Lambda_b$ baryons only adds to the tension. However, this is likely to be a result of underestimated theoretical uncertainties or experimental issues, since the pattern of the discrepancies is not in agreement with that which would results from new physics effects induced by right-handed currents. General models of flavour violating new physics seems to favour the inclusive value for $|V_{ub}|$. In $b \to s$ transitions, there is evidence for new physics effects at the $4\sigma$ level, but significant theoretical uncertainties remain. The $B_{(s)} \to \mu^+\mu^-$ branching fractions are currently in agreement with the SM at the $2\sigma$ level, but new, more precise measurements are forthcoming.

Ran Zhou complemented this with a review talk about heavy flavour results from the lattice, where there are new results from a variety of different approaches (NRQCD, HQET, Fermilab and Columbia RHQ formalisms), which can serve as useful and important cross-checks on each other's methodological uncertainties.

Next came a talk by Amy Nicholson on neutrinoless double $\beta$ decay results from the lattice. Neutrinoless double $\beta$ decays are possible if neutrinos are Majorana particles, which would help to explain the small masses of the observed left-handed neutrinos through the see-saw mechanism pushing the right-handed neutrinos off to near the GUT scale. Treating the double $\beta$ decay in the framework of a chiral effective theory, the leading-order matrix element required is a process $\pi^- \to \pi^+ e^- e^-$, for which there are first results in lattice QCD. The NLO process would have disconnected diagrams, but cannot contribute to the $0^+ \to 0^+$ transitions which are experimentally studied, whereas the NNLO process involves two-nucleon operators and still remains to be studied in greater detail on the lattice.

After the coffee break, Agostino Patella reviewed the hot topic of QED corrections to hadronic observables. There are currently two main methods for dealing with QED in the context of lattice simulations: either to simulate QCD+QED directly (usually at unphysically large electromagnetic couplings followed by an extrapolation to the physical value of $\alpha = 1/137$), or to expand it in powers of $\alpha$ and to measure only the resulting correlation functions (which will be four-point functions or higher) in lattice QCD. Both approaches have been used to obtain some already very impressive results on isospin-breaking QED effects in the hadronic spectrum, as shown already in the spectroscopy review talk. There are, however, still a number of theoretical issues connected to the regularization of IR modes that relate to the Gauss law constraint that would forbid the existence of a single charged particle (such as a proton) in a periodic box. The prescriptions to evade this problem all lead to a non-commutativity of limits requiring the infinite-volume limit to be taken before other limits (such as the continuum or chiral limits): QED$_{TL}$, which omits the global zero modes of the photon field, is non-local and does not have a transfer matrix; QED$_{L}$, which omits the spatial zero modes on each timeslice, has a transfer matrix, but is still non-local and renormalizes in a non-standard fashion, such that it does not have a non-relativistic limit; the use of a massive photon leads to a local theory with softly broken gauge symmetry, but still requires the infinite-volume limit to be taken before removing the photon mass. Going beyond hadron masses to decays introduces new IR problems, which need to be treated in the Bloch-Nordsieck way, leading to potentially large logarithms.

The 2016 Ken Wilson Lattice Award was awarded to Antonin Portelli for his outstanding contributions to our understanding of electromagnetic effects on hadron properties. Antonin was one of the driving forces behind the BMW collaboration's effort to determine the proton-neutron mass difference, which resulted in a *Science* paper exhibiting one of the most frequently-shown and impressive spectrum plots at this conference.

In the afternoon, parallel sessions took place, and in the evening there was a (very nice) conference dinner at the Southampton F.C. football stadium.

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**Lattice 2016, Day Two**

*2016-07-26T22:32:00.001+02:00*

Hello again from Lattice 2016 at Southampton. Today's first plenary talk was the review of nuclear physics from the lattice given by Martin Savage. Doing nuclear physics from first principles in QCD is obviously very hard, but also necessary in order to truly understand nuclei in theoretical terms. Examples of needed theory predictions include the equation of state of dense nuclear matter, which is important for understanding neutron stars, and the nuclear matrix elements required to interpret future searches for neutrinoless double $\beta$ decays in terms of fundamental quantities. The problems include the huge number of required quark-line contractions and the exponentially decaying signal-to-noise ratio, but there are theoretical advances that increasingly allow to bring these under control. The main competing procedures are more or less direct applications of the Lüscher method to multi-baryon systems, and the HALQCD method of computing a nuclear potential from Bethe-Salpeter amplitudes and solving the Schrödinger equation for that potential. There has been a lot of progress in this field, and there are now first results for nuclear reaction rates.

Next, Mike Endres spoke about new simulation strategies for lattice QCD. One of the major problems in going to very fine lattice spacings is the well-known phenomenon critical slowing-down, i.e. the divergence of the autocorrelation times with some negative power of the lattice spacing, which is particularly severe for the topological charge (a quantity that cannot change at all in the continuum limit), leading to the phenomenon of "topology freezing" in simulations at fine lattice spacings. To overcome this problem, changes in the boundary conditions have been proposed: open boundary conditions that allow topological charge to move into and out of the system, and non-orientable boundary conditions that destroy the notion of an integer topological charge. An alternative route lies in algorithmic modifications such as metadynamics, where a potential bias is introduced to disfavour revisiting configurations, so as to forcibly sample across the potential wells of different topological sectors over time, or multiscale thermalization, where a Markov chain is first run at a coarse lattice spacing to obtain well-decorrelated configurations, and then each of those is subjected to a refining operation to obtain a (non-thermalized) gauge configuration at half the lattice spacing, each of which can then hopefully thermalized by a short sequence of Monte Carlo update operations.

As another example of new algorithmic ideas, Shinji Takeda presented tensor networks, which are mathematical objects that assign a tensor to each site of a lattice, with lattice links denoting the contraction of tensor indices. An example is given by the rewriting of the partition function of the Ising model that is at the heart of the high-temperature expansion, where the sum over the spin variables is exchanged against a sum over link variables taking values of 0 or 1. One of the applications of tensor networks in field theory is that they allow for an implementation of the renormalization group based on performing a tensor decomposition along the lines of a singular value decomposition, which can be truncated, and contracting the resulting approximate tensor decomposition into new tensors living on a coarser grid. Iterating this procedure until only one lattice site remains allows the evaluation of partition functions without running into any sign problems and at only O(log $V$) effort.

After the coffee break, Sara Collins gave the review talk on hadron structure. This is also a field in which a lot of progress has been made recently, with most of the sources of systematic error either under control (e.g. by performing simulations at or near the physical pion mass) or at least well understood (e.g. excited-state and finite-volume effects). The isovector axial charge $g_A$ of the nucleon, which for a long time was a bit of an embarrassment to lattice practitioners, since it stubbornly refused to approach its experimental value, is now understood to be particularly severely affected by excited-state effects, and once these are well enough suppressed or properly accounted for, the situation now looks quite promising. This lends much larger credibility to lattice predictions for the scalar and tensor nucleon charges, for which little or no experimental data exists. The electromagnetic form factors are also in much better shape than one or two years ago, with the electric Sachs form factor coming out close to experiment (but still with insufficient precision to resolve the conflict between the experimental electron-proton scattering and muonic hydrogen results), while now the magnetic Sachs form factor shows a trend to undershoot experiment. Going beyond isovector quantities (in which disconnected diagrams cancel), the progress in simulation techniques for disconnected diagrams has enabled the first computation of the purely disconnected strangeness form factors. The sigma term $\sigma_{\pi N}$ comes out smaller on the lattice than it does in experiment, which still needs investigation, and the average momentum fraction $\langle x \rangle$ still needs to become the subject of a similar effort as the nucleon charges have received.

In keeping with the pattern of having large review talks immediately followed by a related topical talk, Huey-Wen Lin was next with a talk on the Bjorken-$x$ dependence of the parton distribution functions (PDFs). While the PDFs are defined on the lightcone, which is not readily accessible on the lattice, a large-momentum effective theory formulation allows to obtain them as the infinite-momentum limit of finite-momentum parton distribution amplitudes. First studies show interesting results, but renormalization still remains to be performed.

After lunch, there were parallel sessions, of which I attended the ones into which most of the $(g-2)$ talks had been collected, showing quite a rate of progress in terms of the treatment of in particular the disconnected contributions.

In the evening, the poster session took place.

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### Lattice 2016, Day One

*2016-07-25T23:58:00.001+02:00*

Hello from Southampton, where I am attending the Lattice 2016 conference.

I arrived yesterday safe and sound, but unfortunately too late to attend the welcome reception. Today started off early and quite well with a full English breakfast, however.

The conference programme was opened with a short address by the university's Vicepresident of Research, who made a point of pointing out that he like 93% of UK scientists had voted to remain in the EU - an interesting testimony to the political state of affairs, I think.

The first plenary talk of the conference was a memorial to the scientific legacy of Peter Hasenfratz, who died earlier this year, delivered by Urs Wenger. Peter Hasenfratz was one of the pioneers of lattice field theory, and hearing of his groundbreaking achievements is one of those increasingly rare occasions when I get to feel very young: when he organized the first lattice symposium in 1982, he sent out individual hand-written invitations, and the early lattice reviews he wrote were composed in a time where most results were obtained in the quenched approximation. But his achievements are still very much current, amongst other things in the form of fixed-point actions as a realization of the Ginsparg-Wilson relation, which gave rise to the booming interest in chiral fermions.

This was followed by the review of hadron spectroscopy by Chuan Liu. The contents of the spectroscopy talks have by now shifted away from the ground-state spectrum of stable hadrons, the calculation of which has become more of a benchmark task, and towards more complex issues, such as the proton-neutron mass difference (which requires the treatment of isospin breaking effects both from QED and from the difference in bare mass of the up and down quarks) or the spectrum of resonances (which requires a thorough study of the volume dependence of excited-state energy levels via the Lüscher formalism). The former is required as part to the physics answer to the ageless question why anything exists at all, and the latter is called for in particular by the still pressing current question of the nature of the XYZ states.

Next came a talk by David Wilson on a more specific spectroscopy topic, namely resonances in coupled-channel scattering. Getting these right requires not only extensions of the Lüscher formalism, but also the extraction of very large numbers of energy levels via the generalized eigenvalue problem.

After the coffee break, Hartmut Wittig reviewed the lattice efforts at determining the hadronic contributions to the anomalous magnetic moment $(g-2)_\mu$ of the muon from first principles. This is a very topical problem, as the next generation of muon experiments will reduce the experimental error by a factor of four or more, which will require a correspondingly large reduction in the theoretical uncertainties in order to interpret the experimental results. Getting to this level of accuracy requires getting the hadronic vacuum polarization contribution to sub-percent accuracy (which requires full control of both finite-volume and cut-off effects, and a reasonably accurate estimate for the disconnected contributions) and the hadronic light-by-light scattering contribution to an accuracy of better than 10% (which some way or another requires the calculation of a four-point function including a reasonable estimate for the disconnected contributions). There has been good progress towards both of these goals from a number of different collaborations, and the generally good overall agreement between results obtained using widely different formulations bodes well for the overall reliability of the lattice results, but there are still many obstacles to overcome.

The last plenary talk of the day was given by Sergei Dubovsky, who spoke about efforts to derive a theory of the QCD string. As with most stringy talks, I have to confess to being far too ignorant to give a good summary; what I took home is that there is some kind of string worldsheet theory with Goldstone bosons that can be used to describe the spectrum of large-$N_c$ gauge theory, and that there are a number of theoretical surprises there.

Since the plenary programme is being streamed on the web, by the way, even those of you who cannot attend the conference can now do without my no doubt quite biased and very limited summaries and hear and see the talks for yourselves.

After lunch, parallel sessions took place. I found the sequence of talks by Stefan Sint, Alberto Ramos and Rainer Sommer about a precise determination of $\alpha_s(M_Z)$ using the Schrödinger functional and the gradient-flow coupling very interesting.

# 2015

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### Fundamental Parameters from Lattice QCD, Last Days

*2015-09-15T13:56:00.003+02:00*

The last few days of our scientific programme were quite busy for me, since I had agreed to give the summary talk on the final day. I therefore did not get around to blogging, and will keep this much-delayed summary rather short.

On Wednesday, we had a talk by Michele Della Morte on non-perturbatively matched HQET on the lattice and its use to extract the b quark mass, and a talk by Jeremy Green on the lattice measurement of the nucleon strange electromagnetic form factors (which are purely disconnected quantities).

On Thursday, Sara Collins gave a review of heavy-light hadron spectra and decays, and Mike Creutz presented arguments for why the question of whether the up-quark is massless is scheme dependent (because the sum and difference of the light quark masses are protected by symmetries, but will in general renormalize differently).

On Friday, I gave the summary of the programme. The main themes that I identified were the question of how to estimate systematic errors, and how to treat them in averaging procedures, the issues of isospin breaking and scale setting ambiguities as major obstacles on the way to sub-percent overall precision, and the need for improved communication between the "producers" and "consumers" of lattice results. In the closing discussion, the point was raised that for groups like CKMfitter and UTfit the correlations between different lattice quantities are very important, and that lattice collaborations should provide the covariance matrices of the final results for different observables that they publish wherever possible.

## Fundamental Parameters from Lattice QCD, Day Seven

*2015-09-09T22:00:00.000+02:00*

Today's programme featured two talks about the interplay between the strong and the electroweak interactions. The first speaker was Gregorio Herdoíza, who reviewed the determination of hadronic corrections to electroweak observables. In essence these determinations are all very similar to the determination of the leading hadronic correction to $(g-2)_\mu$ since they involve the lattice calculation of the hadronic vacuum polarization. In the case of the electromagnetic coupling $\alpha$, its low-energy value is known to a precision of 0.3 ppb, but the value of $\alpha(m_Z^2)$ is known only to 0.1 ‰, and a larger portion of the difference in uncertainty is due to the hadronic contribution to the running of $\alpha$, i.e. the hadronic vacuum polarization. Phenomenologically this can be estimated through the R-ratio, but this results in relatively large errors at low $Q^2$. On the lattice, the hadronic vacuum polarization can be measured through the correlator of vector currents, and currently a determination of the running of $\alpha$ in agreement with phenomenology and with similar errors can be achieved, so that in the future lattice results are likely to take the lead here. In the case of the electroweak mixing angle, $sin^2\theta_w$ is known well at the $Z$ pole, but only poorly at low energy, although a number of experiments (including the P2 experiment at Mainz) are aiming to reduce the uncertainty at lower energies. Again, the running can be determined from the $Z-\gamma$ mixing through the associated current-current correlator, and current efforts are under way, including an estimation of the systematic error caused by the omission of quark-disconnected diagrams.

The second speaker was Vittorio Lubicz, who looked at the opposite problem, i.e. the electroweak corrections to hadronic observables. Since approximately $\alpha = 1/137$, electromagnetic corrections at the one-loop level will become important once the 1% level of precision is being aimed for, and since the up and down quarks have different electrical charges, this is an isospin-breaking effect which also necessitates at the same time considering the strong isospin breaking caused by the difference in the up and down quark masses. There are two main methods to include QED effects into lattice simulations; the first is direct simulations of QCD+QED, and the second is the method of incorporating isospin-breaking effects in a systematic expansion pioneered by Vittorio and colleagues in Rome. Either method requires a systematic treatment of the IR divergences arising from the lack of a mass gap in QED. In the Rome approach this is done through splitting the Bloch-Nordsieck treatment of IR divergences and soft bremsstrahlung into two pieces, whose large-volume limits can be taken separately. There are many other technical issues to be dealt with, but first physical results from this method should be forthcoming soon.

In the afternoon there was a discussion about QED effects and the range of approaches used to treat them.

## Fundamental Parameters from Lattice QCD, Day Six

*2015-09-07T19:00:00.000+02:00*

The second week of our Scientific Programme started with an influx of new participants.

The first speaker of the day was Chris Kelly, who spoke about CP violation in the kaon sector from lattice QCD. As I hardly need to tell my readers, there are two sources of CP violation in the kaon system, the indirect CP-violation from neutral kaon-antikaon mixing, and the direct CP-violation from $K \to \pi\pi$ decays. Both, however, ultimately stem from the single source of CP violation in the Standard Model, i.e. the complex phase $e^{i\delta}$ in the CKM matrix, which gives the area of the unitarity triangle. The hadronic parameter relevant to indirect CP-violation is the kaon bag parameter $B_K$, which is a "gold-plated" quantity that can be very well determined on the lattice; however, the error on the CP violation parameter $\epsilon_K$ constraining the upper vertex of the unitarity triangle is dominated by the uncertainty on the CKM matrix element $V_{cb}$. Direct CP-violation is particularly sensitive to possible BSM effects, and is therefore of particular interest. Chris presented the recent efforts of the RBC/UKQCD collaboration to address the extraction of the relevant parameter $\epsilon'/\epsilon$ and associated phenomena such as the $\Delta I = 1/2$ rule. For the two amplitudes $A_0$ and $A_2$, different tricks and methods were required; in particular for the isospin-zero channel, all-to-all propagators are needed. The overall errors are still large: although the systematics are dominated by the perturbative matching to the MSbar scheme, the statistical errors are very sizable, so that the $2.1\sigma$ tension with experiment observed is not particularly exciting or disturbing yet.

The second speaker of the morning was Gunnar Bali, who spoke about the topic of renormalons. It is well known that the perturbative series for quantum field theories are in fact divergent asymptotic series, whose typical term will grow like $n^k z^n n!$ for large orders $n$. Using the Borel transform, such series can be resummed, provided that there are no poles (IR renormalons) of the Borel transform on the positive real axis. In QCD, such poles arise from IR divergences in diagrams with chains of bubbles inserted into gluon lines, as well as from instanton-antiinstanton configurations in the path integral. The latter can be removed to infinity by considering the large-$N_c$ limit, but the former are there to stay, making perturbatively defined quantities ambiguous at higher orders. A relevant example are heavy quark masses, where the different definitions (pole mass, MSbar mass, 1S mass, ...) are related by perturbative conversion factors; in a heavy-quark expansion, the mass of a heavy-light meson can be written as $M = m + \Lambda + O(1/m)$, where $m$ is the heavy quark mass, and $\Lambda$ a binding energy of the order of some QCD energy scale. As $M$ is unambiguous, the ambiguities in $m$ must correspond to ambiguities in the binding energy $\Lambda$, which can be computed to high orders in numerical stochastic perturbation theory (NSPT). After dealing with some complications arising from the fact that IR divergences cannot be probed directly in a finite volume, it is found that the minimum term in the perturbative series (which corresponds to the perturbative ambiguity) is of order 180 MeV in the quenched theory, meaning that heavy quark masses are only defined up to this accuracy. Another example is the gluon condensate (which may be of relevance to the extraction of $\alpha_s$ from $\tau$ decays), where it is found that the ambiguity is of the same size as the typically quoted result, making the usefulness of this quantity doubtful.

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**Fundamental Parameters from Lattice QCD, Day Five**

*2015-09-04T20:00:00.000+02:00*

The first speaker today was Martin Lüscher, who spoke about revisiting numerical stochastic perturbation theory. The idea behind numerical stochastic perturbation theory is to perform a simulation of a quantum field theory using the Langevin algorithm and to perturbatively expand the fields, which leads to a tower of coupled evolution equations, where only the lowest-order one depends explicitly on the noise, whereas the higher-order ones describe the evolution of the higher-order coefficients as a function of the lower-order ones. In Numerical Stochastic Perturbation Theory (NSPT), the resulting equations are integrated numerically (up to some, possibly rather high, finite order in the coupling), and the average over noises is replaced by a time average. The problems with this approach are that the autocorrelation time diverges as the inverse square of the lattice spacing, and that the extrapolation in the Langevin time step size is difficult to control well. An alternative approach is given by Instantaneous Stochastic Perturbation Theory (ISPT), in which the Langevin time evolution is replaced by the introduction of Gaussian noise sources at the vertices of tree diagrams describing the construction of the perturbative coefficients of the lattice fields. Since there is no free lunch, this approach suffers from power-law divergent statistical errors in the continuum limit, which arise from the way in which power-law divergences that cancel in the mean are shifted around between different orders when computing variances. This does not happen in the Langevin-based approach, because the Langevin theory is renormalizable.

The second speaker of the morning was Siegfried Bethke of the Particle Data Group, who allowed us a glimpse at the (still preliminary) world average of $\alpha_s$ for 2015. In 2013, there were five classes of $\alpha_s$ determinations: from lattice QCD, $\tau$ decays, deep inelastic scattering, $e^+e^-$ colliders, and global Z pole fits. Except for the lattice determinations (and the Z pole fits, where there was only one number), these were each preaveraged using the range method – i.e. taking the mean of the highest and lowest central value as average, and assigning it an uncertainty of half the difference between them. The lattice results were averaged using a $\chi^2$ weighted average. The total average (again a weighted average) was dominated by the lattice results, which in turn were dominated by the latest HPQCD result. For 2015, there have been a number of updates to most of the classes, and there is now a new class of $\alpha_s$ determinations from the LHC (of which there is currently only one published, which lies rather low compared to other determinations, and is likely a downward fluctuation). In most cases, the new determinations have not or hardly changed the values and errors of their class. The most significant change is in the field of lattice determinations, where the PDG will change its policy and will no longer perform its own preaverages, taking instead the FLAG average as the lattice result. As a result, the error on the PDG value will increase; its value will also shift down a little, mostly due to the new LHC value.

The afternoon discussion centered on $\alpha_s$. Roger Horsley gave an overview of the methods used to determine it on the lattice (ghost vertices, the Schrödinger functional, the static energy at short distances, current-current correlators, and small Wilson loops) and reviewed the criteria used by FLAG to assess the quality of a given determination, as well as the averaging procedure used (which uses a more conservative error than what a weighted average would give). In the discussion, the points were raised that in order to reliably increase the precision to the sub-percent level and beyond will likely require not only addressing the scale setting uncertainties (which is reflected in the different values for $r_0$ obtained by different collaboration and will affect the running of $\alpha_s$), but also the inclusion of QED effects.

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**Fundamental Parameters from Lattice QCD, Day Four**

*2015-09-04T09:40:00.001+02:00*

Today's first speaker was Andreas Jüttner, who reviewed the extraction of the light-quark CKM matrix elements $V_{ud}$ and $V_{us}$ from lattice simulations. Since leptonic and semileptonic decay widths of Kaons and pions are very well measured, the matrix element $|V_{us}|$ and the ratio $|V_{us}|/|V_{ud}|$ can be precisely determined if the form factor $f_+^{K\pi}(0)$ and the ratio of decay constants $f_K/f_\pi$ are precisely predicted from the lattice. To reach the desired level of precision, the isospin breaking effects from the difference of the up and down quark masses and from electromagnetic interactions will need to be included (they are currently treated in chiral perturbation theory, which may not apply very well in the SU(3) case). Given the required level of precision, full control of all systematics is very important, and the problem of how to properly estimate the associated errors arises, to which different collaborations are offering very different answers. To make the lattice results optimally usable for CKMfitter & Co., one should ideally provide all of the lattice inputs to the CKMfitter fit separately (and not just some combination that presents a particularly small error), as well as their correlations (as far as possible).

Unfortunately, I had to miss the second talk of the morning, by Xavier

García i Tormo on the extraction of $\alpha_s$ from the static-quark potential, because our Sonderforschungsbereich (SFB/CRC) is currently up for review for a second funding period, and the local organizers had to be available for questioning by panel members.

Later in the afternoon, I returned to the workshop and joined a very interesting discussion on the topic of averaging in the presence of theoretical uncertainties. The large number of possible choices to be made in that context implies that the somewhat subjective nature of systematic error estimates survives into the averages, rather than being dissolved into a consensus of some sort.

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**Fundamental Parameters from Lattice QCD, Day Three**

*2015-09-04T09:23:00.001+02:00*

Today, our first speaker was Jerôme Charles, who presented new ideas about how treat data with theoretical uncertainties. The best place to read about this is probably his talk, but I will try to summarize what I understood. The framework is a firmly frequentist approach to statistics, which answers the basic question of how likely the observed data are if a given null hypothesis is true. In such a context, one can consider a theoretical uncertainty as a fixed bias $\delta$ of the estimator under consideration (such as a lattice simulation) which survives the limit of infinite statistics. One can then test the null hypothesis that the true value of the observable in question is $\mu$ by constructing a test statistic for the estimator being distributed normally with mean $\mu+\delta$ and standard deviation $\sigma$ (the statistical error quoted for the result). The $p$-value of $\mu$ then depends on $\delta$, but not on the quoted systematic error $\Delta$. Since the true value of $\delta$ is not known, one has to perform a scan over some region $\Omega$, for example the interval $\Omega_n = [-n\Delta; n\Delta]$ and take the supremum over this range of $\delta$. One possible extension is to choose $\Omega$ adaptively in that a larger range of values needs to be scanned (i.e. a larger true systematic error in comparison to the quoted systematic error is allowed for) for lower p-values; interestingly enough, the resulting curves of p-values are numerically close to what is obtained from a naive Gaussian approach treating the systematic error as a (pseudo-)random variable. For multiple systematic errors, a multidimensional $\Omega$ has to be chosen in some way; the most natural choices of a hypercube or a hyperball correspond to adding the errors linearly or in quadrature, respectively. The linear (hypercube) scheme stands out as the only one that guarantees that the systematic error of an average is no smaller than the smallest systematic error of an individual result.

The second speaker was Patrick Fritzsch, who gave a nice review of recent lattice determinations of semileptonic heavy-light decays, both the more commonly studied $B$ decays to $\pi\ell\nu$ and $K\ell\nu$, and the decays of the $\Lambda_b$ that have recently been investigated by Meinel *et al.* with the help of LHCb.

In the afternoon, both the CKMfitter collaboration and the FLAG group held meetings.

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**Fundamental Parameters from Lattice QCD, Day Two**

*2015-09-01T17:29:00.000+02:00*

This morning, we started with a talk by Taku Izubuchi, who reviewed the lattice efforts relating to the hadronic contributions to the anomalous magnetic moment (g-2) of the muon. While the QED and electroweak contributions to (g-2) are known to great precision, most of the theoretical uncertainty presently comes from the hadronic (i.e. QCD) contributions, of which there are two that are relevant at the present level of precision: the contribution from the hadronic vacuum polarization, which can be inserted into the leading-order QED correction, and the contribution from hadronic light-by-light scattering, which can be inserted between the incoming external photon and the muon line. There are a number of established methods for computing the hadronic vacuum polarization, both phenomenologically using a dispersion relation and the experimental R-ratio, and in lattice field theory by computing the correlator of two vector currents (which can, and needs to, be refined in various way in order to achieve competitive levels of precision). No such well-established methods exist yet for the light-by-light scattering, which is so far mostly described using models. There are however, now efforts from a number of different sides to tackle this contribution; Taku mainly presented the approach by the RBC/UKQCD collaboration, which uses stochastic sampling of the internal photon propagators to explicitly compute the diagrams contributing to (g-2). Another approach would be to calculate the four-point amplitude explicitly (which has recently been done for the first time by the Mainz group) and to decompose this into form factors, which can then be integrated to yield the light-by-light scattering contribution to (g-2).

The second talk of the day was given by Petros Dimopoulos, who reviewed lattice determinations of D and B leptonic decays and mixing. For the charm quark, cut-off effects appear to be reasonably well-controlled with present-day lattice spacings and actions, and the most precise lattice results for the D and $D_s$ decay constants claim sub-percent accuracy. For the b quark, effective field theories or extrapolation methods have to be used, which introduces a source of hard-to-assess theoretical uncertainty, but the results obtained from the different approaches generally agree very well amongst themselves. Interestingly, there does not seem to be any noticeable dependence on the number of dynamical flavours in the heavy-quark flavour observables, as $N_f = 2$ and $N_f = 2+1+1$ results agree very well to within the quoted precisions.

In the afternoon, the CKMfitter collaboration split off to hold their own meeting, and the lattice participants met for a few one-on-one or small-group discussions of some topics of interest.

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**Fundamental Parameters from Lattice QCD, Day One**

*2015-08-31T18:33:00.001+02:00*

Greetings from Mainz, where I have the pleasure of covering a meeting for you without having to travel from my usual surroundings (I clocked up more miles this year already than can be good from my environmental conscience).

Our Scientific Programme (which is the bigger of the two formats of meetings that the Mainz Institute of Theoretical Physics (MITP) hosts, the smaller being Topical Workshops) started off today with two keynote talks summarizing the status and expectations of the FLAG (Flavour Lattice Averaging Group, presented by Tassos Vladikas) and CKMfitter (presented by Sébastien Descotes-Genon) collaborations. Both groups are in some way in the business of performing weighted averages of flavour physics quantities, but of course their backgrounds, rationale and methods are quite different in many regards. I will no attempt to give a line-by-line summary of the talks or the afternoon discussion session here, but instead just summarize a few

points that caused lively discussions or seemed important in some other way.

By now, computational resources have reached the point where we can achieve such statistics that the total error on many lattice determinations of precision quantities is completely dominated by systematics (and indeed different groups would differ at the several-$\sigma$ level if one were to consider only their statistical errors). This may sound good in a way (because it is what you'd expect in the limit of infinite statistics), but it is also very problematic, because the estimation of systematic errors is in the end really more of an art than a science, having a crucial subjective component at its heart. This means not only that systematic errors quoted by different groups may not be readily comparable, but also that it become important how to treat systematic errors (which may also be correlated, if e.g. two groups use the same one-loop renormalization constants) when averaging different results. How to do this is again subject to subjective choices to some extent. FLAG imposes cuts on quantities relating to the most important sources of systematic error (lattice spacings, pion mass, spatial volume) to select acceptable ensembles, then adds the statistical and systematic errors in quadrature, before performing a weighted average and computing the overall error taking correlations between different results into account using Schmelling's procedure. CKMfitter, on the other hand, adds all systematic errors linearly, and uses the Rfit procedure to perform a maximum likelihood fit. Either choice is equally permissible, but they are not directly compatible (so CKMfitter can't use FLAG averages as such).

Another point raised was that it is important for lattice collaborations computing mixing parameters to not just provide products like $f_B\sqrt{B_B}$, but also $f_B$ and $B_B$ separately (as well as information about the correlation between these quantities) in order to help making the global CKM fits easier.

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**LATTICE 2015, Day Five**

*2015-07-18T15:19:00.002+02:00*

In a marked deviation from the "standard programme" of the lattice conference series, Saturday started off with parallel sessions, one of which featured my own talk.

The lunch break was relatively early, therefore, but first we all assembled in the plenary hall for the conference group photo (a new addition to the traditions of the lattice conference), and was followed by afternoon plenary sessions. The first of these was devoted to finite temperature and density, and started with Harvey Meyer giving the review talk on finite-temperature lattice QCD. The thermodynamic properties of QCD are by now relatively well-known: the transition temperature is agreed to be around 155 MeV, chiral symmetry restoration and the deconfinement transition coincide (as well as that can defined in the case of a crossover), and the number of degrees of freedom is compatible with a plasma of quarks and gluons above the transition, but the thermodynamic potentials approach the Stefan-Boltzmann limit only slowly, indicating that there are strong correlations in the medium. Below the transition, the hadron resonance gas model describes the data well. The Columbia plot describing the nature of the transition as a function of the light and strange quark masses is being further solidified: the size of the lower-left hand corner first-order region is being measured, and the nature of the left-hand border (most likely O(4) second-order) is being explored. Beyond these static properties, real-time properties are beginning to be studied through the finite-temperature spectral functions. One interesting point was that there is a difference between the screening masses (spatial correlation lengths) and quasiparticle masses (from the spectral function) in any given channel, which may even tend in opposite directions as functions of the temperature (as seen for the pion channel).

Next, Szabolcs Borsanyi spoke about fluctuations of conserved charges at finite temperature and density. While of course the sum of all outcoming conserved charges in a collision must equal the sum of the ingoing ones, when considering a subvolume of the fireball, this can be best described in the grand canonical ensemble, as charges can move into and out of the subvolume. The quark number susceptibilities are then related to the fluctuating phase of the fermionic determinant. The methods being used to avoid the sign problem include Taylor expansions, fugacity expansions and simulations at imaginary chemical potential, all with their own strengths and weaknesses. Fluctuations can be used as a thermometer to measure the freeze-out temperature.

Lastly, Luigi Scorzato reviewed the Lefschetz thimble, which may be a way out of the sign problem (e.g. at finite chemical potential). The Lefschetz thimble is a higher-dimensional generalization of the concept of steepest-descent integration, in which the integral of $e^{S(z)}$ for complex $S(z)$ is evaluated by finding the stationary points of $S$ and integrating along the curves passing through them along which the imaginary part of $S$ is constant. On such Lefschetz thimbles, a Langevin algorithm can be defined, allowing for a Monte Carlo evaluation of the path integral in terms of Lefschetz thimbles. In quantum-mechanical toy models, this seems to work already, and there appears hope that this might be a way to avoid the sign problem of finite-density QCD.

After the coffee break, the last plenary session turned to physics beyond the Standard Model. Daisuke Kadoh reviewed the progress in putting supersymmetry onto the lattice, which is still a difficult problem due to the fact that the finite differences which replace derivatives on a lattice do not respect the Leibniz rule, introducing SUSY-breaking terms when discretizing. The ways past this are either imposing exact lattice supersymmetries or fine-tuning the theory so as to remove the SUSY-breaking in the continuum limit. Some theories in both two and four dimensions have been simulated successfully, including N=1 Super-Yang-Mills theory in four dimensions. Given that there is no evidence for SUSY in nature, lattice SUSY is of interesting especially for the purpose of verifying the ideas of gauge-gravity duality from the Super-Yang-Mills side, and in one and two dimensions, agreement with the predictions from gauge-gravity duality has been found.

The final plenary speaker was Anna Hasenfratz, who reviewed Beyond-the-Standard-Model calculations in technicolor-like theories. If the Higgs is to be a composite particle, there must be some spontaneously broken symmetry that keeps it light, either a flavour symmetry (pions) or a scale symmetry (dilaton). There are in fact a number of models that have a light scalar particle, but the extrapolation of these theories is rendered difficult by the fact that this scalar is (and for phenomenologically interesting models would have to be) lighter than the (techni-)pion, and thus the usual formalism of chiral perturbation theory may not work. Many models of strong BSM interactions have been and are being studied using a large number of different methods, with not always conclusive results. A point raised towards the end of the talk was that for theories with a conformal IR fixed-point, universality might be violated (and there are some indications that e.g. Wilson and staggered fermions seem to give qualitatively different behaviour for the beta function in such cases).

The conference ended with some well-deserved applause for the organizing team, who really ran the conference very smoothly even in the face of a typhoon. Next year's lattice conference will take place in Southampton (England/UK) from 24th to 30th July 2016. Lattice 2017 will take place in

Granada (Spain).

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**LATTICE 2015, Days Three and Four**

*2015-07-17T15:16:00.002+02:00*

Due to the one-day shift of the entire conference programme relative to other years, Thursday instead of Wednesday was the short day. In the morning, there were parallel sessions. The most remarkable thing to be reported from those (from my point of view) is that MILC are generating a=0.03 fm lattices now, which handily beats the record for the finest lattice spacing; they are observing some problems with the tunnelling of the topological charge at such fine lattices, but appear hopeful that they can be useful.

After the lunch break, excursions were offered. I took the trip to Himeji to see Himeji Castle, a very remarkable five-story wooden building that due to its white exterior is also known the "White Heron Castle". During the trip, typhoon Nangka approached, so the rains cut our enjoyment of the castle park a bit short (though seeing koi in a pond with the rain falling into it had a certain special appeal to it, the enjoyment of which I in my Western ignorance suppose might be considered a form of Japanese *wabi* aesthetics).

As the typhoon resolved into a rainstorm, the programme wasn't cancelled or changed, and so today's plenary programme started with a talk on some formal developments in QFT by Mithat Ünsal, who reviewed trans-series, Lefschetz thimbles, and Borel summability as different sides of the same coin. I'm far too ignorant of these more formal field theory topics to do them justice, so I won't try a detailed summary. Essentially, it appears that the expansion of certain theories around the saddle points corresponding to instantons is determined by their expansion around the trivial vacuum, and the ambiguities arising in the Borel resummation of perturbative series when the Borel transform has a pole on the positive real axis can in some way be connected to this phenomenon, which may allow for a way to resolve the ambiguities.

Next, Francesco Sannino spoke about the "bright, dark, and safe" sides of the lattice. The bright side referred to the study of visible matter, in particular to the study of technicolor models as a way of implementing the spontaneous breaking of electroweak symmetry, without the need for a fundamental scalar introducing numerous tunable parameters, and with the added benefits of removing the hierarchy problem and the problem of$\phi^4$ triviality. The dark side referred to the study of dark matter in the context of composite dark matter theories, where one should remember that if the visible 5% of the mass of the universe require three gauge groups for their description, the remaining 95% are unlikely to be described by a single dark matter particle and a homogeneous dark energy. The safe side referred to the very current idea of asymptotic safety, which is of interest especially in quantum gravity, but might also apply to some extension of the Standard Model, making it valid at all energy scales.

After the coffee break, the traditional experimental talk was given by Toru Iijima of the Belle II collaboration. The Belle II detector is now beginning commissioning at the upcoming SuperKEKB accelerator, which will greatly improved luminosity to allow for precise tests of the Standard Model in the flavour sector. In this, Belle II will be complementary to LHCb, because it will have far lower backgrounds allowing for precision measurements of rare processes, while not being able to access as high energies. Most of the measurements planned at Belle II will require lattice inputs to interpret, so there is a challenge to our community to come up with sufficiently precise and reliable predictions for all required flavour observables. Besides quark flavour physics, Belle II will also search for lepton flavour violation in $\tau$ decays, try to improve the phenomenological prediction for $(g-2)_\mu$ by measuring the cross section for $e^+e^- \to$ hadrons more precisely, and search for exotic charmonium- and bottomonium-like states.

Closely related was the next talk, a review of progress in heavy flavour physics on the lattice given by Carlos Pena. While simulations of relativistic b quarks at the physical mass will become a possibility in the not-too-distant future, for the time being heavy-quark physics is still dominated by the use of effective theories (HQET and NRQCD) and methods based either on appropriate extrapolations from the charm quark mass region, or on the Fermilab formalism, which is sort of in-between. For the leptonic decay constants of heavy-light mesons, there are now results from all formalisms, which generally agree very well with each other, indicating good reliability. For the semileptonic form factors, there has been a lot of development recently, but to obtain precision at the 1% level, good control of all systematics is needed, and this includes the momentum-dependence of the form factors. The z-expansion, and extended versions thereof allowing for simultaneous extrapolation in the pion mass and lattice spacing, has the advantage of allowing for a test of its convergence properties by checking the unitarity bound on its coefficients.

After the coffee break, there were parallel sessions again. In the evening, the conference banquet took place. Interestingly, the (excellent) food was not Japanese, but European (albeit with a slight Japanese twist in seasoning and presentation).

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**LATTICE 2015, Day Two**

*2015-07-15T14:47:00.001+02:00*

Hello again from Lattice 2015 in Kobe. Today's first plenary session began with a review talk on hadronic structure calculations on the lattice given by James Zanotti. James did an excellent job summarizing the manifold activities in this core area of lattice QCD, which is also of crucial phenomenological importance given situations such as the proton radius puzzle. It is now generally agreed that excited-state effects are one of the more important issues facing hadron structure calculations, especially in the nucleon sector, and that these (possibly together with finite-volume effects) are likely responsible for the observed discrepancies between theory and experiment for quantities such as the axial charge of the nucleon. Many groups are studying the charges and form factors of the nucleon, and some have moved on to more complicated quantities, such as transverse momentum distributions. Newer ideas in the field include the use of the Feynman-Hellmann theorem to access quantities that are difficult to access through the traditional three-point-over-two-point ratio method, such as form factors at very high momentum transfer, and quantities with disconnected diagrams (such as nucleon strangeness form factors).

Next was a review of progress in light flavour physics by Andreas Jüttner, who likewise gave an excellent overview of this also phenomenologically very important core field. Besides the "standard" quantities, such as the leptonic pion and kaon decay constants and the semileptonic K-to-pi form factors, more difficult light-flavour quantities are now being calculated, including the bag parameter $B_K$ and other quantities related to both Standard Model and BSM neutral kaon mixing, which require the incorporation of long-distance effects, including those from charm quarks. Given the emergence of lattice ensembles at the physical pion mass, the analysis strategies of groups are beginning to change, with the importance of global ChPT fits receding. Nevertheless, the lattice remains important in determining the low-energy constants of Chiral Perturbation Theory. Some groups are also using newer theoretical developments to study quantities once believed to be outside the purview of lattice QCD, such as final-state photon corrections to meson decays, or the timelike pion form factor.

After the coffee break, the Ken Wilson Award for Excellence in Lattice Field Theory was announced. The award goes to Stefan Meinel for his substantial and timely contributions to our understanding of the physics of the bottom quark using lattice QCD. In his acceptance talk, Stefan reviewed his recent work on determining $|V_{ub}|/|V_{cb}|$ from decays of $\Lambda_b$ baryons measured by the LHCb collaboration. There has long been a discrepancy between the inclusive and exclusive (from $B \to \pi\ell\nu$) determinations of $V_{ub}$, which might conceivably be due to a new (BSM) right-handed coupling. Since LHCb measures the decay widths for $\Lambda_b$ to both $p\mu\nu$ and $\Lambda_c\mu\nu$, combining these with lattice determinations of the corresponding $\Lambda_b$ form factors allows for a precise determination of $|V_{ub}|/|V_{cb}|$. The results agree well with the exclusive determination from $B \to \pi\ell\nu$, and fully agree with CKM unitarity. There are, however, still other channels (such as $b \to s\mu^+\mu^-$ and $b \to c\tau\nu$) in which there is still potential for new physics, and LHCb measurements are pending.

This was followed by a talk by Maxwell T. Hansen (now a postdoc at Mainz) on three-body observables from lattice QCD. The well-known Lüscher method relates two-body scattering amplitudes to the two-body energy levels in a finite volume. The basic steps in the derivation are to express the full momentum-space propagator in terms of a skeleton expansion involving the two-particle irreducible Bethe-Salpeter kernel, to express the difference between the two-particle reducible loops in finite and infinite volume in terms of two-particle cuts, and to reorganize the skeleton expansion by the number of cuts to reveal that the poles of the propagator (i.e. the energy levels) in finite volume are related to the scattering matrix. For three-particle systems, the skeleton expansion becomes more complicated, since there can now be situations involving two-particle interactions and a spectator particle, and intermediate lines can go on-shell between different two-particle interactions. Treating a number of other technical issues such as cusps, Max and collaborators have been able to derive a Lüscher-like formula three-body scattering in the case of scalar particles with a $Z_2$ symmetry forbidding 2-to-3 couplings. Various generalizations remain to be explored.

The day's plenary programme ended with a talk on the Standard Model prediction for direct CP violation in $K \to \pi\pi$ decays by Christopher Kelly. This has been an enormous effort by the RBC/UKQCD collaboration, who have shown that the $\Delta I = 1/2$ rule comes from low-energy QCD by way of strong cancellations between the dominant contributions, and have determined $\epsilon'$ from the lattice for the first time. This required the generation of ensembles with an unusual set of boundary conditions (G-parity boundary conditions on the quarks, requiring complex conjugation boundary conditions on the gauge fields) in space to enforce a moving pion ground state, as well as the precise evaluation of difficult disconnected diagrams using low modes and stochastic estimators, and treatment of finite-volume effects in the Lellouch-Lüscher formalism. Putting all of this together with the non-perturbative renormalization (in the RI-sMOM scheme) of ten operators in the electroweak Hamiltonian gives a result which currently still has three times the experimental error, but is systematically improvable, with better-than-experimental precision expected in maybe five years.

In the afternoon there were parallel sessions again, and in the evening, the poster session took place. Food ran out early, but it was pleasant to see free-form smearing begin improved upon and used to very good effect by Randy Lewis, Richard Woloshyn and students.

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### LATTICE 2015, Day One

*2015-07-14T13:30:00.000+02:00*

Hello from Kobe, where I am attending the Lattice 2015 conference. The trip here was uneventful, as was the jetlag-day.

The conference started yesterday evening with a reception in the Kobe

Animal Kingdom (there were no animals when we were there, though, with the exception of some fish in a pond and some cats in a cage, but there were lot of plants).

Today, the scientific programme began with the first plenary session. After a welcome address by Akira Ukawa, who reminded us of the previous lattice meetings held in Japan and the tremendous progress the field has made in the intervening twelve years, Leonardo Giusti gave the first plenary talk, speaking about recent progress on chiral symmetry breaking. Lattice results have confirmed the proportionality of the square of the pion mass to the quark mass (i.e. the Gell-Mann-Oakes-Renner (GMOR) relation, a hallmark of chiral symmetry breaking) very accurately for a long time. Another relation involving the chiral condensate is the Banks-Casher relation, which relates it to the eigenvalue density of the Dirac operator at zero. It can be shown that the eigenvalue density is renormalizable, and that thus the mode number in a given interval is renormalization-group invariant. Two recent lattice studies, one with twisted-mass fermions and one with O(a)-improved Wilson fermions, confirm the Banks-Casher relation, with the chiral condensates found agreeing very well with those inferred from GMOR. Another relation is the Witten-Veneziano relation, which relates the $\eta'$ mass to the topological susceptibility, thus explaining how precisely the $\eta'$ is not a Goldstone boson. The topological charge on the lattice can be defined through the index of the Neuberger operator or through chain of spectral projectors, but a recently invented and much cheaper definition is through the topological charge density at finite flow time in Lüscher's Wilson flow formalism. The renormalization properties of the Wilson flow allow for a derivation of the universality of the topological susceptibility, and numerical tests using all three definitions indeed agree within errors in the continuum limit. Higher cumulants determined in the Wilson flow formalism agree with large-$N_c$ predictions in pure Yang-Mills, and the suppression of the topological susceptibility in QCD relative to the pure Yang-Mills case is in line with expectations (which in principle can be considered an *a posteriori* determination of $N_f$ in agreement with the value used in simulations).

The next speaker was Yu Nakayama, who talked about a related topic, namely the determination of the chiral phase transition in QCD from the conformal bootstrap. The chiral phase transition can be studied in the framework of a Landau effective theory in three dimensions. While the mean-field theory predicts a second-order phase transition in the O(4) universality class, one-loop perturbation theory in $4-\epsilon$ dimensions predicts a first-order phase transition at $\epsilon = 1$. Making use of the conformal symmetry of the effective theory, one can apply the conformal bootstrap method, which combines an OPE with crossing relations to obtain results for critical exponents, and the results from this method suggest that the phase transition is in fact of second order. This also agrees with many lattice studies, but others disagree. The role of the anomalously broken U(1)$_A$ symmetry in this analysis appears to be unclear.

After the coffee break, Tatsumi Aoyama, a long-time collaborator in the heroic efforts of Kinoshita to calculate the four- and five-loop QED contributions to the electron and muon anomalous moments, gave a plenary talk on the determination of the QED contribution to lepton (g-2). For likely readers of this blog, the importance of (g-2) is unlikely to require an explanation: the current $3\sigma$ tension between theory and experiment for $(g-2)_\mu$ is the strongest hint of physics beyond the Standard Model so far, and since the largest uncertainties on the theory side are hadronic, lattice QCD is challenged to either resolve the tension or improve the accuracy of the predictions to the point where the tension becomes an unambiguous, albeit indirect, discovery of new physics. The QED calculations are on the face of it simpler, being straightforward Feynman diagram evaluations. However, the number of Feynman diagrams grows so quickly at higher orders that automated methods are required. In fact, in a first step, the number of Feynman diagrams is reduced by using the Ward-Takahashi identity to relate the vertex diagrams relevant to (g-2) to self-energy diagrams, which are then subjected to an automated renormalization procedure using the Zimmermann forest formula. In a similar way, infrared divergences are subtracted using a more complicated "annotated forest"-formula (there are two kinds of IR subtractions needed, so the subdiagrams in a forest need to be labelled with the kind of subtraction). The resulting UV- and IR-finite integrands are then integrated using VEGAS in Feynman parameter space. In order to maintain the required precision, quadruple-precision floating-point numbers (or an emulation thereof) must be used. Whether these methods could cope with the six-loop QED contribution is not clear, but with the current and projected experimental errors, that contribution will not be required for the foreseeable future, anyway.

This was followed by another (g-2)-related plenary, with Taku Izubichi speaking about the determination of anomalous magnetic moments and nucleon electric dipole moments in QCD. In particular the anomalous magnetic moment has become such an active topic recently that the time barely sufficed to review all of the activity in this field, which ranges from different approaches to parameterizing the momentum dependence of the hadronic vacuum polarization, through clever schemes to reduce the noise by subtracting zero-momentum contributions, to new ways of extracting the vacuum polarization through the use of background magnetic fields, as well as simulations of QCD+QED on the lattice. Among the most important problems are finite-volume effects.

After the lunch break, there were parallel sessions in the afternoon. I got to chair the first session on hadron structure, which was devoted to determinations of hadronic contributions to $(g-2)_\mu$.

After the coffee break, there were more parallel sessions, another complete one of which was devoted to (g-2) and closely-related topics. A talk deserving to be highlighted was given by Jeremy Green, who spoke about the first direct calculation of the hadronic light-to-light scattering amplitude from lattice QCD.

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### Workshop "Fundamental Parameters from Lattice QCD" at MITP (upcoming deadline)

*2015-04-10T10:19:00.000+02:00*

Recent years have seen a significant increase in the overall accuracy of lattice QCD calculations of various hadronic observables. Results for quark and hadron masses, decay constants, form factors, the strong coupling constant and many other quantities are becoming increasingly important for testing the validity of the Standard Model. Prominent examples include calculations of Standard Model parameters, such as quark masses and the strong coupling constant, as well as the determination of CKM matrix elements, which is based on a variety of input quantities from experiment and theory. In order to make lattice QCD calculations more accessible to the entire particle physics community, several initiatives and working groups have sprung up, which collect the available lattice results and produce global averages.

The scientific programme "Fundamental Parameters from Lattice QCD" at the Mainz Institute of Theoretical Physics (MITP) is designed to bring together lattice practitioners with members of the phenomenological and experimental communities who are using lattice estimates as input for phenomenological studies. In addition to sharing the expertise among several communities, the aim of the programme is to identify key quantities which allow for tests of the CKM paradigm with greater accuracy and to discuss the procedures in order to arrive at more reliable global estimates.

The deadline for registration is *Wednesday, 15 April 2015*.

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### QNP 2015, Day Five

*2015-03-12T18:01:00.004+01:00*

The first talk today was by Guy de Teramond, who described applications of light-front superconformal quantum mechanics to hadronic physics. I have to admit that I couldn't fully take in all the details, but as far as I understood an isomorphy between AdS$^2$ and the conformal group in one dimension can be used to derive a form of the light-front Hamiltonian for mesons from an AdS/QCD correspondence, in which the dilaton field is fixed to be $\phi(z) = 1/2z^2$ by the requirement of conformal invariance, and a similar construction in the superconformal case leads to a light-front Hamiltonian for baryons. A relationship between the Regge trajectories for mesons and baryons can then be interpreted as a form of supersymmetry in this framework.

Next was Beatriz Gay Ducati with a review of the phenomenology of heavy quarks in nuclear matter, a topic where there are still many open issues. The photoproduction of quarkonia on nucleons and nuclei allows to probe the gluon distribution, since the dominant production process is photon-gluon fusion, but to be able to interpret the data, many nuclear matter effects need to be understood.

After the coffee break, this was followed by a talk by Hrayr Matevosyan on transverse momentum distributions (TMDs), which are complementary to GPDs in the sense of being obtained by integrating out other variables starting from the full Wigner distributions. Here, again, there are many open issues, such as the Sivers, Collins or Boer-Mulders effects.

The next speaker was Raju Venugopalan, who spoke about two outstanding problems in QCD at high parton densities, namely the question of how the systems created in heavy-ion collisions thermalize, and the phenomenon of ”the ridge” in proton-nucleus collisions, which would seem to suggest hydrodynamic behaviour in a system that is too small to be understood as a liquid. Both problems may have to do with the structure of the dense initial state, which is theorized to be a colour-glass condensate or ”glasma”, and the way in which it evolves into a more dilute system.

After the lunch break, Sonny Mantry reviewed some recent advances made in applying Soft-Collinear Effective Theory (SCET) to a range of questions in strong-interaction physics. SCET is the effective field theory obtained when QCD fluctuations around a hard particle momentum are considered to be small and a corresponding expansion (analogous to the 1/m expansion in HQET) is made. SCET has been successfully applied to many different problems; an interesting and important one is the problem of relating the ”Monte Carlo mass” usually quoted for the top quark to the top quark mass in a more well-defined scheme such as MSbar.

The last talk in the plenary programme was a review of the Electron-Ion Collider (EIC) project by Zein-Eddine Meziani. By combining the precision obtainable using an electron beam with the access to the gluon-dominated regime provided by a heavy ion beam, as well as the ability to study the nucleon spin using a polarized nucleon beam, the EIC will enable a much more in-depth study of many of the still unresolved questions in QCD, such as the nucleon spin structure and colour distributions. There are currently two competing designs, the eRHIC at Brookhaven, and the MEIC at Jefferson Lab.

Before the conference closed, Michel Garçon announced that the next conference of the series (QNP 2018) will be held in Japan (either in Tsukuba or in Mito, Ibaraki prefecture). The local organizing committee and conference office staff received some well-deserved applause for a very smoothly-run conference, and the scientific part of the conference programme was adjourned.

As it was still in the afternoon, I went with some colleagues to visit La Sebastiana, the house of Pablo Neruda in Valparaíso, taking one of the city’s famous *ascensores* down (although up might have been more convenient, as the streets get very steep) before walking back to Viña del Mar along the sea coast.

The next day, there was an organized excursion to a vineyard in the Casablanca valley, where we got to taste some very good Chilean wines (some of the them matured in traditional clay vats) and liqueurs with a very pleasant lunch.

I got to spend another day in Valparaíso before travelling back (a happily uneventful, if again rather long trip).

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**QNP 2015, Day Four**

*2015-03-06T13:13:00.003+01:00*

The first talk today was a review of experimental results in light-baryon spectroscopy by Volker Credé. While much progress has been made in this field, in particular in the design of so-called complete experiments, which as far as I understand measure multiple observables to unambiguously extract a complete description of the amplitudes for a certain process, there still seem to be surprisingly many unknowns. In particular, the fits to pion photoproduction in doubly-polarized processes seem to disagree strongly between different descriptions (such as MAID).

Next was Derek Leinweber with a review of light hadron spectroscopy from the lattice. The *de facto* standard method in this field is the variational method (GEVP), although there are some notable differences in how precisely different groups apply it (e.g. solving the GEVP at many times and fitting the eigenvalues vs. forming projected correlators with the eigenvectors of the GEVP solved at a single time – there are proofs of good properties for the former that don't exist for the latter). The way in which the basis of operators for the GEVP is build is also quite different as used by different groups, ranging from simply using different levels of quark field smearing to intricate group-theoretic constructions of multi-site operators. There are also attempts to determine how much information can be extracted from a given set of correlators, e.g. recently by the Cyprus/Athens group using Monte Carlo simulations to probe the space of fitting parameters (a loosely related older idea based on evolutionary fits wasn't mentioned).

This was followed by a talk by Susan Gardner about testing fundamental symmetries with quarks. While we know that there must be physics beyond the Standard Model (because the SM does not explain dark matter, nor does it provide enough CP violation to explain the observed baryon asymmetry), there is so far no direct evidence of any BSM particle. Low-energy tests of the SM fall into two broad categories: null tests (where the SM predicts an exact null result, as for violations of B-L) and precision tests (where the SM prediction can be calculated to very high accuracy, as for $(g-2)_\mu$). Null tests play an important role in so far as they can be used to impose a lower limit for the BSM mass scale, but many of them are atomic or nuclear tests, which have complicated theory errors. The currently largest tensions indicating a possible failure of the Standard Model to describe all observations are the proton radius puzzle, and $(g-2)_\mu$. A possible explanation of either or both of those in terms of a "dark photon" is on the verge of being ruled out, however, since most of the relevant part of the mass/coupling plane has already been excluded by dark photon searches, and the rest of it will soon be (or else the dark photon will be discovered). Other tests in the hadronic sector, which seem to be less advanced so far, are the search for non-(V-A) terms in $\beta$-decays, and the search for neutron-antineutron oscillations.

After the coffee break and the official conference photo, Isaac Vidaña took the audience on a "half-hour walk through the physics of neutron stars". Neutron stars are both almost-black holes (whose gravitation must be described in General Relativity) and extremely massive nuclei (whose internal dynamics must be described using QCD). Observations of binary pulsars allow to determine the masses of neutron stars, which are found to range up to at least two solar masses. However, the Tolman-Oppenheimer-Volkov equations for the stability of neutron stars lead to a maximum mass for a neutron star that depends on the equation of state of the nuclear medium. The observed masses severely constrain the equation of state and in particular seem to exclude models in which hyperons play an important role; however, it seems to be generally agreed that hyperons must play an important role in neutron stars, leading to a "hyperon puzzle", the solution of which will require an improved understanding of the structure and interactions of hyperons.

The last plenary speaker of the day was Stanley Brodsky with the newest developments from light-front holography. The light-front approach, which has in the past been very successful in (1+1)-dimensional QCD, is based on the front form of the Hamiltonian formalism, in which a light-like, rather than a timelike, direction is chosen as the normal defining the Cauchy surfaces on which initial data are specified. In the light-front Hamiltonian approach, the vacuum of QCD is trivial and the Hilbert space can be constructed as a straightforward Fock space. With some additional ansätze taken from AdS/CFT ideas, QCD is reduced to a Schrödinger-like equation for the light-cone wavefunctions, from which observables are extracted. Apparently, all known observations are described perfectly in this approach, but (as for the Dyson-Schwinger or straight AdS/QCD approaches) I do not understand how systematic errors are supposed to be quantified.

In the afternoon there were parallel talks. An interesting contribution was given by Mainz PhD student Franziska Hagelstein, who demonstrated how even a very small non-monotonicity in the electric form factor at low $Q^2$ (where there are no $ep$ scattering data) could explain the difference between the muonic and electronic hydrogen results for the proton radius.

The conference banquet took place in the evening at a very nice restaurant, and fun was had over cocktails and an excellent dinner.

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**QNP 2015, Day Three**

*2015-03-05T13:27:00.005+01:00*

Today began with a talk by Mikhail Voloshin on QCD sum rules and heavy-quark states. The idea of exploiting quark-hadron duality to link perturbatively calculable current-current correlators to hadronic observables and extract mesonic decay constants or quark masses is quite old, but has received a boost in recent years with the advent of three- and four-loop perturbative calculations in particularly from Chetyrkin and collaborators, which have also been used in conjunction with lattice results, e.g. by the HPQCD collaboration.

A review of hadron spectroscopy at B factories (including LHCb) by Roberto Mussa followed. The charmonium and bottomonium spectra are now measured to great detail, with recent additions being 1D and 3P states, and more states are also being discovered in the heavy-light (where the $B_c(2S)$ has recently been discovered at ATLAS) and heavy-quark baryon (where the most recent discovery was the $\Xi_b$) sectors, and many more transitions being discovered and studied.

The next speaker was Raphaël Dupré, who spoke about colour propagation and neutralization in strongly interacting systems. The idea here appears to be that in hadronization processes, quarks first loose energy by radiating gluons and thus turn into colourless pre-hadrons, which then bind into hadrons on a longer timescale, and there seems to be experimental evidence supporting this energy-loss model.

After the coffee break, Javier Castillo reviewed quarkonium suppression and regeneration in heavy-ion collisions. Quarkonia are generally considered important probes of the quark-gluon plasma, because the production of heavy quark-antiquark pairs is a perturbative process that happens at high energies early in the collision, while their binding is non-perturbative and is expected to be suppressed by Debye screening in the coloured plasma. As a consequence, more tightly bound quarkonia, like the Y(1S), can exist at higher temperatures, while the more lightly bound charmonia or Y(3S) states will ”melt” at lower temperatures. However, quarkonia can also be regenerated by thermalized heavy quarks rejoining into quarkonia at the phase boundary. Experimental data support the screening picture, with the $J/\psi$ being more suppressed at the LHC than at STAR (because of the higher temperature), the $\Upsilon(2S)$ more suppressed than the $\Upsilon(1S)$, and transport models with a negligible regeneration component describing the data well. The regeneration component increases at low $p_T$, and the elliptic flow of the charm quarks is inherited by the regenerated $J/\psi$ mesons. Some more difficult to understand effects of the nuclear environment, called Cold Nuclear Matter (CNM) effects are beginning to be seen in the data.

Next was Zoltan Fodor with a talk about Lattice QCD results at zero and finite temperature from the BMW collaboration. By simulating QCD+QED with 1+1+1+1 flavours of dynamical quarks, BMW have been able to determine the isospin splitting of the nucleon and other baryonic systems. This work, which appears set to become a cover story in ”Science”, had to overcome a number of serious obstacles, in particular long-range autocorrelations (which could cured by a Fourier-accelerated HMC variant) and power-law finite-volume effects (which had to be fitted to results obtained at a range of volumes) introduced by the massless photon. In the finite-temperature regime, the crossover temperature is now generally agreed to be around 150-160 MeV, but the position and even existence of the critical endpoint is still contentious (and any existing results are not yet continuum-extrapolated in any case).

After the lunch break, Yiota Foka gave an overview of heavy-ion results from RHIC and the LHC. The elliptic flow is still found to be in agreement with perfect hydrodynamics, but people are now also studying higher harmonics, as well as the interplay between jets and flow, which provide important constraints on the physics of the quark-gluon plasma. At the LHC, it has been found that it is the mass, and not the valence quark content, that drives the flow behaviour of hadrons, as the $\phi$ meson has the same flow behaviour as the proton.

The next speaker was Carl Gagliardi, who reviewed results in nucleon structure from high-energy polarized proton-proton collisions. Proton-proton scattering is complementary to DIS in that it gives access to the gluonic degrees of freedom which are invisible to electrons, and RHIC has a programme of polarized proton collisions to explore the spin structure of the nucleon. Without the RHIC data, the gluon polarization $\Delta G$ is almost unconstrained, but with the RHIC data, it is seen to be clearly positive and contribute about 0.2 to the proton spin. Using W production, it is possible to separate polarized quark and antiquark distributions, and there is more to come in the near future.

The last plenary speaker of the day was Craig Roberts, who reviewed the pion and nucleon structure from the point of view of the Dyson-Schwinger equations approach. In this approach, the pion is closely linked to the quark mass function, which comes out of a quark gap equation and describes how the running quark mass at high energies turns into a much larger constituent quark mass at low energies. Landau-gauge gluons also become massive at low energies, and confinement is explained as the splitting of poles into pairs of conjugate complex poles giving an exponentially damped behaviour of the position space propagator. While this approach seems to be able to readily explain every single known experimental result, I do not understand how the systematic errors from the truncation of the infinite tower of DSEs are supposed to be controlled or quantified.

After the coffee break, there were parallel sessions. An interesting parallel talk was given by Johan Bijnens, who has determined the leading logarithms for the nucleon mass (and some other systems) to rather high orders (which also for effective theories can be done using only one-loop integrals from a consistency argument by Weinberg).

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**QNP 2015, Day Two**

*2015-03-04T13:05:00.003+01:00*

Hello again from Valparaíso. Today's first speaker was Johan Bijnens with a review of recent results from chiral perturbation theory in the mesonic sector, including recent results for charged pion polarizabilities and for finite-volume corrections to lattice measurements. To allow others to perform their own calculations for their own specific needs (which might include technicolor-like theories, which will generally have different patterns of chiral symmetry breaking, but otherwise work just the same way), Bijnens & Co. have recently published CHIRON, a general two-loop mesonic $\chi$PT package. The leading logarithms have been determined to high orders, and it has been found that the speed of convergence depends both on the observable and on whether the leading-order or physical pion decay constant is used.

Next was Boris Grube, who presented some recent results from light-meson spectroscopy. The light mesons are generally expected to be some kind of superpositions of quark-model states, hybrids, glueballs, tetraquark and molecular states, as may be compatible with their quantum numbers in each case. The most complex sector is the $0^{++}$ sector of $f_0$ mesons, in which the lightest glueball state should lie. While the $\gamma\gamma$ width of the $f_0(1500)$ appears to be compatible with zero, which would agree with the expectations for a glueball, whereas the $f_0(1710)$ has a photonic width more in agreement with being an s-sbar state, in $J/\psi \to \gamma(\eta\eta)$, which as a gluon-rich process should couple strongly to glueball resonances, little or no $f_0(1500)$ is seen, whereas a glueball nature for the $f_0(1710)$ would be supported by these results. New data to come from GlueX, and later from PANDA, should help to clarify things.

The next speaker was Paul Sorensen with a talk on the search for the critical point in the QCD phase diagram. The quark-gluon plasma at RHIC is not only a man-made system that is over 300 times hotter than the centre of the Sun, it is also the most perfect fluid known, as it close to saturates the viscosity bound $\eta/s > 1/(4\pi)$. Studying it experimentally is quite difficult, however, since one must extrapolate back to a small initial fireball, or "little bang", from correlations between thousands of particle tracks in a detector, not entirely dissimilar from the situation in cosmology, where the properties of the hot big bang (and previous stages) are inferred from angular correlations in the cosmic microwave background. Beam energy scans find indications that the phase transition becomes first-order at higher densities, which would indicate the existence of a critical endpoint, but more statistics and more intermediate energies are needed.

After the coffee break, François-Xavier Girod spoke about Generalized Parton Distributions (GPDs) and deep exclusive processes. GPDs, which reduce to form factors and to parton distributions upon integrating out the unneeded variables in each case, correspond to a three-dimensional image of the nucleon performed in the longitudinal momentum fraction and the transverse impact parameter, and their moments are related to matrix elements of the energy-momentum tensor. Experimentally, they are probed using deeply virtual Compton scattering (DVCS); the 12 GeV upgrade at Jefferson Lab will increase the coverage in both Bjørken-$x$ and $Q^2$, and the planned electron-ion collider is expected to allow probing the sea and gluon GPDs as well.

After the lunch break, there were parallel sessions. I chaired the parallel session on lattice and other perturbative methods, with presentations of lattice results by Eigo Shintani and Tereza Mendes, as well as a number of AdS/QCD-related results by various others.

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**QNP 2015, Day One**

*2015-03-03T15:38:00.001+01:00*

Hello from Valparaíso, where I continue this year's hectic conference circuit at the 7th International Conference on Quarks and Nuclear Physics (QNP 2015). Except for some minor inconveniences and misunderstandings, the long trip to Valparaíso (via Madrid and Santiago de Chile) went quite smoothly, and so far, I have found Chile a country of bright sunlight and extraordinarily helpful and friendly people.

The first speaker of the conference was Emanuele Nocera, who reviewed nucleon and nuclear parton distributions. The study of parton distributions become necessary because hadrons are really composed not simply of valence quarks, as the quark model would have it, but of an indefinite number of (sea) quarks, antiquarks and gluons, any of which can contribute to the overall momentum and spin of the hadron. In an operator product expansion framework, hadronic scattering amplitudes can then be factorized into Wilson coefficients containing short-distance (perturbative) physics and parton distribution functions containing long-distance (non-perturbative) physics. The evolution of the parton distribution functions (PDFs) with the momentum scale is given by the DGLAP equations containing the perturbatively accessible splitting functions. The PDFs are subject to a number of theoretical constraints, of which the sum rules for the total hadronic momentum and valence quark content are the most prominent. For nuclei, on can assume that a similar factorization as for hadrons still holds, and that the nuclear PDFs are linear combinations of nucleon PDFs modified by multiplication with a binding factor; however, nuclei exhibit correlations between nucleons, which are not well-described in such an approach. Combining all available data from different sources, global fits to PDFs can be performed using either a standard $\chi^2$ fit with a suitable model, or a neural network description. There are far more and better data on nucleon than nuclear PDFs, and for nucleons the amount and quality of the data also differs between unpolarized and polarized PDFs, which are needed to elucidate the ”proton spin puzzle”.

Next was the first lattice talk of the meeting, given by Huey-Wen Lin, who gave a review of the progress in lattice studies of nucleon structure. I think Huey-Wen gave a very nice example by comparing the computational and algorithmic progress with that in videogames (I'm not an expert there, but I think the examples shown were screenshots of Nethack versus some modern first-person shooter), and went on to explain the importance of controlling all systematic errors, in particular excited-state effects, before reviewing recent results on the tensor, scalar and axial charges and the electromagnetic form factors of the nucleon. As an outlook towards the current frontier, she presented the inclusion of disconnected diagrams and a new idea of obtaining PDFs from the lattice more directly rather than through their moments.

The next speaker was Robert D. McKeown with a review of JLab's Nuclear Science Programme. The CEBAF accelerator has been upgraded to 12 GeV, and a number of experiments (GlueX to search for gluonic excitations, MOLLER to study parity violation in Møller scattering, and SoLID to study SIDIS and PVDIS) are ready to be launched. A number of the planned experiments will be active in areas that I know are also under investigation by experimental colleagues in Mainz, such as a search for the ”dark photon” and a study of the running of the Weinberg angle. Longer-term plans at JLab include the design of an electron-ion collider.

After a rather nice lunch, Tomofumi Nagae spoke about the hadron physics programme an J-PARC. In spite of major setbacks by the big earthquake and a later radiation accident, progress is being made. A search for the $\Theta^+$ pentaquark did not find a signal (which I personally do not find surprising, since the whole pentaquark episode is probably of more immediate long-term interest to historians and sociologists of science than to particle physicists), but could not completely exclude all of the discovery claims.

This was followed by a take by Jonathan Miller of the MINER$\nu$A collaboration presenting their programme of probing nuclei with neutrinos. Major complications include the limited knowledge of the incoming neutrino flux and the fact that final-state interactions on the nuclear side may lead to one process mimicking another one, making the modelling in event generators a key ingredient of understanding the data.

Next was a talk about short-range correlations in nuclei by Or Henn. Nucleons subject to short-range correlations must have high relative momenta, but a low center-of-mass momentum. The experimental studies are based on kicking a proton out of a nucleus with an electron, such that both the momentum transfer (from the incoming and outgoing electron) and the final momentum of the proton are known, and looking for a nucleon with a momentum close to minus the difference between those two (which must be the initial momentum of the knocked-out proton) coming out. The astonishing result is that at high momenta, neutron-proton pairs dominate (meaning that protons, being the minority, have a much larger chance of having high momenta) and are linked by a tensor force. Similar results are known from other two-component Fermi systems, such as ultracold atomic gases (which are of course many, many orders of magnitude less dense than nuclei).

After the coffee break, Heinz Clement spoke about dibaryons, specifically about the recently discovered $d^*(2380)$ resonance, which taking all experimental results into account may be interpreted as a $\Delta\Delta$ bound state.

The last talk of the day was by André Walker-Loud, who reviewed the study of nucleon-nucleon interactions and nuclear structure on the lattice, starting with a very nice review of the motivations behind such studies, namely the facts that big-bang nucleosynthesis is very strongly dependent on the deuterium binding energy and the proton-neutron mass difference, and this fine-tuning problem needs to be understood from first principles. Besides, currently the best chance for discovering BSM physics seems once more to lie with low-energy high-precision experiments, and dark matter searches require good knowledge of nuclear structure to control their systematics. Scattering phase shifts are being studied through the Lüscher formula. Current state-of-the-art studies of bound multi-hadron systems are related to dibaryons, in particular the question of the existence of the H-dibaryon at the physical pion mass (note that the dineutron, certainly unbound in the real world, becomes bound at heavy enough pion masses), and three- and four-nucleon systems are beginning to become treatable, although the signal-to-noise problem gets worse as more baryons are added to a correlation function, and the number of contractions grows rapidly. Going beyond masses and binding energies, the new California Lattice Collaboration (CalLat) has preliminary results for hadronic parity violation in the two-nucleon system, albeit at a pion mass of 800 MeV.

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**Back from Mumbai**

*2015-02-27T11:01:00.000+01:00*

On Saturday, my last day in Mumbai, a group of colleagues rented a car with a driver to take a trip to Sanjay Gandhi National Park and visit the Kanheri caves, a Buddhist site consisting of a large number of rather simple monastic cells and some worship and assembly halls with ornate reliefs and inscriptions, all carved out out of solid rock (some of the cell entrances seem to have been restored using steel-reinforced concrete, though).

On the way back, we stopped at Mani Bhavan, where Mahatma Gandhi lived from 1917 to 1934, and which is now a museum dedicated to his live and legacy.

In the night, I flew back to Frankfurt, where the temperature was much lower than in Mumbai; in fact, on Monday there was snow.

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**Perspectives and Challenges in Lattice Gauge Theory, Day Five**

*2015-02-20T13:02:00.002+01:00*

Today's programme started with a talk by Santanu Mondal on baryons in the sextet gauge model, which is a technicolor-style SU(3) gauge theory with a doublet of technifermions in the sextet (two index symmetric) representation, and a minimal candidate for a technicolor-like model with an IR almost-fixed point. Using staggered fermions, he found that when setting the scale by putting the technipion's decay constant to the value derived from identifying the Higgs vacuum expectation value as the technicondensate, the baryons had masses in excess of 3 TeV, heavy enough to not yet have been discovered by the LHC, but to be within reach of the next run. However, the anomaly cancellation condition when embedding the theory into the Standard Model of the electroweak interactions requires charge assignments such that the lightest technibaryon (which would be a stable particle) would have a fractional electrical charge of 1/2, and while the cosmological relic density can be made small enough to evade detection, the technibaryons produced by the cosmic rays in the Earth's atmosphere should have been able to accumulate (there currently appear to be no specific experimental exclusions for charge-1/2 particles though).

Next was Nilmani Mathur speaking about mixed action simulations using overlap valence quarks on the MILC HISQ ensembles (which include the radiative corrections to the lattice gluon action from the quarks). Tuning the charm quark mass via the kinetic rather than rest mass of charmonium, the right charmonium hyperfine splitting is found, as well as generally correct charmonium spectra. Heavy-quark baryons (up to and including the $\Omega_{ccc}$) have also been simulated, with results in good agreement with experimental ones where the latter exist. The mixed-action effects appear to be mild small in mixed-action $\chi$PT, and only half as large as those for domain-wall valence fermions on an asqtad sea.

In a brief note, Gunnar Bali encouraged the participants of the workshop to seek out opportunities for Indo-German research collaboration, of which there are still only a limited number of instances.

After the tea break, there were two more theoretical talks, both of them set in the framework of Hamiltonian lattice gauge theory: Indrakshi Raychowdhury presented a loop formulation of SU(2) lattice gauge theory based on the prepotential formalism, where both the gauge links and their conjugate electrical fields are constructed from harmonic oscillator variables living on the sites using the Schwinger construction. By some ingenious rearrangements in terms of ”fusion variables”, a representation of the perturbative series for Hamiltonian lattice gauge theory purely in terms of integer-valued quantum numbers in a geometric-combinatorial construction was derived.

Lastly, Sreeraj T.P. presented a derivation of an analogy between the Gauss constraint in Hamiltonian lattice gauge theory and the condition of equal ”angular impulses” in the SU(2) x SU(2) description of the SO(4) symmetry of the Coulomb potential to derive a description of the Hilbert space of SU(2) lattice gauge theory in terms of hydrogen atom (n,l,m) variables located on the plaquettes subject only to the global constraint of vanishing total angular momentum, from where a variational ansatz for the ground state can be constructed.

The workshop closed with some well-deserved applause for the organizers and all of the supporting technical and administrative staff, who have ensured that this workshop ran very smoothly indeed. Another excellent lunch (I understand that our lunches have been a kind of culinary journey through India, starting out in the north on Monday and ending in Kerala today) concluded the very interesting workshop.

I will keep the small subset of my readers whom it may interest updated about my impressions from an excursion planned for tomorrow and my trip back.

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**Perspectives and Challenges in Lattice Gauge Theory, Day Four**

*2015-02-19T19:32:00.002+01:00*

Today was dedicated to topics and issues related to finite temperature and density. The first speaker of the morning was Prasad Hegde, who talked about the QCD phase diagram. While the general shape of the Columbia plot seems to be fairly well-established, there is now a lot of controversy over the details. For example, the two-flavour chiral limit seems to be well-described by either the O(4) or O(2) universality class, it isn't currently possible to exclude that it might be Z(2), and while the three-flavour transition appears to be known to be Z(2), simulations with staggered and Wilson quarks give disagreeing results for its features. Another topic that gets a lot of attention is the question of $U(1)_A$ restoration; of course, $U(1)_A$ is broken by the axial anomaly, which arises from the path integral measure and is present at all temperatures, so it cannot be expected to be restored in the same sense that chiral symmetry is, but it might be that as the temperature gets larger, the influence of the anomaly on the Dirac eigenvalue spectrum gets outvoted by the temporal boundary conditions, so that the symmetry violation might disappear from the correlation functions of interest. However, numerical studies using domain-wall fermions suggest that this is not the case. Finally, the equation of state can be obtained from stout or HISQ smearing with very similar results and appears well-described by a hadron resonance gas at low T, and to match reasonably well to perturbation theory at high T.

The next speaker was Saumen Datta speaking on studies of the QCD plasma using lattice correlators. While the short time extent of finite-temperature lattices makes it hard to say much about the spectrum without the use of techniques such as the Maximum Entropy Method, correlators in the spatial directions can be readily used to obtain screening masses. Studies of the spectral function of bottomonium in the Fermilab formalism suggest that the Υ(1S) survives up to at least twice the critical temperature.

Sorendu Gupta spoke next about the equation of state in dense QCD. Using the Taylor expansion (which was apparently first invented in the 14th-15th century by the Indian mathematician Madhava) method together with Padé approximants to reconstruct the function from the truncated series, it is found that the statistical errors on the reconstruction blow up as one nears the suspected critical point. This can be understood as a specific instance of the ”no-free-lunch theorem”, because a direct simulation (were it possible) would suffer from critical slowing down as the critical point is approached, which would likewise lead to large statistical errors from a fixed number of configurations.

The last talk before lunch was Bastian Brandt with an investigation of an alternative formulation of pure gauge theory using auxiliary bosonic fields in an attempt to render the QCD action amenable to a dual description that might allow to avoid the sign problem at finite baryon chemical potential. The alternative formulation appears to describe exactly the same physics as the standard Wilson gauge action at least for SU(2) in 3D, and in 2D and/or in certain limits, its a continuum limit is in fact known to be Yang-Mills theory. However, when fermions are introduced, the dual formulation still suffers from a sign problem, but it is hoped that any trick that might avoid this sign problem would then also avoid the finite-$\mu$ one.

After lunch, there were two non-lattice talks. The first one was given by Gautam Mandal, who spoke about thermalization in integrable models and conformal field theories. In CFTs, it can be shown that for certain initial states, the expectation value of an operator equilibrates to a certain ”thermal” expectation value, and a generalization to integrable models, where the ”thermal” density operator includes chemical potentials for all (infinitely many) conserved charges, can also be given.

The last talk of the day was a very lively presentation of the fluid-gravity correspondence by Shiraz Minwalla, who described how gravity in Anti-deSitter space asymptotically goes over to Navier-Stokes hydrodynamics in some sense.

In the evening, the conference banquet took place on the roof terrace of a very nice restaurant serving very good European-inspired cuisine and Indian red wine (also rather nice – apparently the art of winemaking has recently been adapted to the Indian climate, e.g. the growing season is during the cool season, and this seems to work quite well).

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**Perspectives and Challenges in Lattice Gauge Theory, Day Three**

*2015-02-18T17:07:00.000+01:00*

Today's first talk was given by Rainer Sommer, who presented two effective field theories for heavy quarks. The first one was non-perturbatively matched HQET, which has been the subject of a long-running effort by the ALPHA collaboration. This programme is now reaping its first dividends in the form of very reliable fully non-perturbative results for B physics observables. Currently, the form factors for $B \to \pi\ell\nu$ decays, which are very important for determining the CKM matrix element $V_{ub}$ (currently subject to some significant tension between inclusive and exclusive determinations) are in the final stages of analysis. The other effective theory was QCD with $N_f < 6$ flavours – which is of course technically an effective theory where the heavy quarks have been integrated out! Rainer presented a new factorization formula that relates the mass of a light hadron in the theory with a heavy quark to that of the same hadron in a theory in which the heavy quark is massless by a factor dependent on the hadron and a universal perturbative factor. The factorization formula has been tested for gluonic observables in the pure gauge theory matched to the two-flavour theory.

After tea, we had a session focussed on algorithms and machines. The first speaker was Andreas Frommer speaking about multigrid solvers for the Dirac equation in lattice QCD. A multigrid solver consists of a smoother and a coarse-grid correction. For the smoother for the Dirac equation, the Schwartz Alternating Procedure (SAP) is a natural choice, whereas for the coarse-grid correction, aggregate-based interpolation (essentially the same idea as Lüscher-style inexact deflation) can be used. The resulting multigrid algorithm is very similar to the domain-decomposed algorithm used in the DD-HMC and openQCD codes, but generalizes to more than two levels, which may lead to better performance. Applications to the overlap operator were presented.

Next, Stephan Solbrig presented the QPACE2 project, which aims to build a supercomputer based on Intel Knight's Corner (Xeon Phi) cards as processors, where each node consists of four Xeon Phis linked to each other, a weak host CPU used only for booting, and to an Infiniband card via a PCIe switch. The whole system uses hot water cooling, building on experience gathered in the iDataCool project. The 512bit wide registers of the Xeon Phi necessitate several programming tricks such as site fusing to make optimal use of computing resources; the resulting code seems to scale almost perfectly as long as there are sufficient numbers of domains to keep all nodes busy. An interesting side note was that apparently there are extremophile bacteria that thrive in the copper pipes of water-cooled computer clusters.

Pushan Majumdar rounded off the session with a talk about QCD on GPUs. The special programming model of GPUs (small amount of memory per core, restrictions on branching, CPU/GPU data transfer as a bottleneck) makes programming GPUs challenging. The OpenACC compiler standard, which aims to offload the burden of dealing with GPU particulars onto the compiler vendor, may offer a possibility to easily port OpenMP-based code written for CPUs on GPUs, and Pushan showed some worked examples of Fortran 90 OpenMP code adapted for OpenACC.

After lunch, I had to retire to my room for a little (let me hasten to add that the truly excellent lunch provided by the extremely hospitable TIFR is definitely absolutely blameless in this), and thus missed the afternoon's first two talks, catching only the end of Jyotirmoy Maiti's talk about exploring the spectrum of the pure SU(3) gauge theory using the Wilson flow.

Gunnar Bali closed the day's proceeding with a very nice colloquium talk for a larger scientific audience, summarizing the Standard Model and lattice QCD in an accessible manner for non-experts before proceeding to present recent results on the sea quark content and spin structure of the proton.

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**Perspectives and Challenges in Lattice Gauge Theory, Day Two**

*2015-02-17T16:44:00.001+01:00*

Today's first session started with a talk by Wolfgang Söldner, who reviewed the new CLS simulations using 2+1 flavours of dynamical fermions with open boundary conditions in the time direction to avoid the freezing of topology at small lattice spacing. Besides the new kind of boundary conditions, these simulations use a number of novel tricks, such as twisted mass reweighting, to make the simulations more stable at light pion masses. First studies of the topology and of the scale setting look promising, and there will likely be some interesting first physics results at the lattice conference in Kobe.

After the tea break, Asit Kumar De talked about lattice gauge theory with equivariant gauge fixing. This is an attempt to evade the Neuberger 0/0 problem with BRST invariance on a lattice by leaving a subgroup of the gauge group unfixed. As a result, on gets four-ghost interactions in the gauge fixed action (this seems to be a general feature of theories trying to extend BRST symmetry; the Curci-Ferrari model for massive gauge fields also has such an interaction).

This was followed Mughda Sarkar speaking about simulations of the gauge-fixed compact U(1) gauge theory. Apparently, the added parameters of the gauge fixing part appear to allow for changing the nature of the phase transition between strong and weak coupling from first to second order, although I didn't quite understand how that is compatible with the idea of having all gauge-invariant quantities be unaffected by the gauge fixing.

After lunch, we had an excursion to the island of Elephanta, where there are some great temples carved out of the rock. Today was a festival of Shiva, so admission was free (otherwise the price structure is quite interesting: ₹10 for Indians, ₹250 for foreigners), and there were many people on the island and in the caves. The site is certainly well worth the visit, although many of the statues have been damaged quite severely in the past.

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**Perspectives and Challenges in Lattice Gauge Theory, Day One**

*2015-02-16T14:20:00.002+01:00*

Hello from Mumbai, where I'm attending the workshop "Perspectives and Challenges in Lattice Gauge Theory" at the Tata Institute for Fundamental Research. I arrived on Sunday at an early hour, and had some opportunity to see some of the sights of Mumbai while trying to get acclimatized and jetlag-free.

Today was the first day of the workshop, which started with a talk by Gergely Endrődi on the magnetic response of isospin-asymmetric QCD matter. This is relevant both for heavy-ion collisions and for the astrophysics of neutron stars, where in both cases strong magnetic fields interact with nuclear matter that has more neutrons than protons. From analytical calculations it is known that free quarks would form a paramagnetic state of matter, whereas pions would yield diamagnetism. As QCD matter at low energies should be mostly a hadron gas, and at high temperatures a quark-gluon plasma, the expectation would be that the behaviour of QCD at zero chemical potential changes from diamagnetic to paramagnetic as the temperature increases. On the other hand, at zero temperature and non-zero isospin chemical potential, at small isospin chemical potential the magnetic susceptibility vanishes (by the "Silver Blaze" effect), before suddenly going negative from pion condensation when the chemical potential exceeds half the pion mass, and again going positive as the chemical potential is increased further. Lattice simulations confirm this overall picture, although the susceptibility remains finite at $\mu_I = 1/2m_\pi$ since the pions already start to melt rather than to condense into a superconductor).

After the coffee break, it was my turn to talk about recent work we have done at Mainz regarding the importance of excited-state effects on nucleon form factors. Briefly summarized, the splitting to the first excited state (nucleon+pion P-wave, or nucleon+2 pions S-wave) gets very small in the chiral regime, but the errors on the nucleon two- and three-point functions grow exponentially as the source-sink separation is increased, making it very hard to find a Euclidean time region of both clean ground-state signal and reasonable statistical precision. Treating the excited states using different methods (summation method and explicit two-state fits) yields indications hinting that the current discrepancy between the nucleon charge radius obtained from lattice simulations and experiment may be due mostly to excited-state effects.

This was followed by Andreas Schäfer speaking about much more ambitious hadron structure observables, namely Transverse Momentum Distributions (TMDs), Parton Distribution Functions (PDFs) and Generalized Parton Distributions (GPDs). Knowledge of these is important to clarify systematics for some of the LHC measurements, so lattice results could certainly have a huge impact here, but the necessary calculations appear quite involved.

After the lunch break, Stefan Dürr reviewed some of the newer inhabitants of the fermion zoo, namely firstly the Brillouin fermions obtained by replacing the standard discretization of the Laplacian in the Wilson action with its Brillouin discretization, and the symmetric derivative with its isotropic alternative, and secondly the staggered Wilson fermions of Adams (Adams fermions). In particular for heavier quark masses, the Brillouin fermions seem to do much better than standard Wilson fermions, including by giving a much more continuum-like dispersion relation.

After a more technical talk on simulating the Gross-Neveu model with Boriçi-Creutz fermions by Jinshu Goswami, Kalman Szabo gave a colloquium for a more general audience explaining the origin of mass from QCD, electromagnetism and the Higgs effect (which is roughly the order of importance for ordinary matter), and how to determine the proton-neutron mass difference (which is after all of great anthropic significance, since an even slightly smaller value would leave hydrogen atoms unstable under inverse $\beta$-decay, whereas a somewhat larger value would create too much of a bottleneck in the creation of heavier elements) on the lattice. The lattice results are certainly impressive both in terms of the theoretical and computational effort needed to obtain them and in the accuracy with which they reproduce the experimentally-known situation.

# 2014

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### Scientific Program ”Fundamental Parameters of the Standard Model from Lattice QCD”

*2014-11-21T10:42:00.002+01:00*

Recent years have seen a significant increase in the overall accuracy of lattice QCD calculations of various hadronic observables. Results for quark and hadron masses, decay constants, form factors, the strong coupling constant and many other quantities are becoming increasingly important for testing the validity of the Standard Model. Prominent examples include calculations of Standard Model parameters, such as quark masses and the strong coupling constant, as well as the determination of CKM matrix elements, which is based on a variety of input quantities from experiment and theory. In order to make lattice QCD calculations more accessible to the entire particle physics community, several initiatives and working groups have sprung up, which collect the available lattice results and produce global averages.

We are therefore happy to announce the scientific program ”Fundamental Parameters of the Standard Model from Lattice QCD” to be held from August 31 to September 11, 2015 at the Mainz Institute for Theoretical Physics (MITP) at Johannes Gutenberg University Mainz, Germany.

This scientific programme is designed to bring together lattice practitioners with members of the phenomenological and experimental communities who are using lattice estimates as input for phenomenological studies. In addition to sharing the expertise among several communities, the aim of the programme is to identify key quantities which allow for tests of the CKM paradigm with greater accuracy and to discuss the procedures in order to arrive at more reliable global estimates.

We would like to invite you to consider attending this and to apply through our website. After the deadline (March 31, 2015), an admissions committee will evaluate all the applications.

Among other benefits. MITP offers all its participants office space and access to computing facilities during their stay. In addition, MITP will cover local housing expenses for accepted participants. The MITP team will arrange the accommodation individually and also book the accommodation for accepted participants.

Please do not hesitate to contact us at coordinator@mitp.uni-mainz.de if you have any questions.

We hope you will be able to join us in Mainz in 2015!

With best regards,

the organizers:

Gilberto Colangelo, Georg von Hippel, Heiko Lacker, Hartmut Wittig

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**LATTICE 2014, Day Six**

*2014-06-30T21:39:00.001+02:00*

The last day of the conference started out with a sequence of topical talks. First was Massimo D'Elia speaking about Lattice QCD with purely imaginary sources at zero and non-zero temperature. Contrary to what the name might suggest, an imaginary source is a source term that can be coupled to the action so as to keep $e^{-S}$ real and positive. Examples include an imaginary chemical potential, an imaginary $\theta$ term, or an external electromagnetic field with a real magnetic or imaginary electric field strength. Applications include the study of the curvature of the critical line near $\mu = 0$ and the nature of the Roberge-Weiss phase transition, and the determination of electric dipole moments and the magnetic properties of nuclear matter.

Next was Tilo Wettig introducing the QPACE 2. QPACE now stands for "QCD Parallel Computing Engine" (as there is no more Cell processor involved). Each compute card consists of four Xeon Phi Knights Corner processors linked by a PCI Express bus and a weak CPU, which is only used for booting. The compute cards use a novel patented "brick" concept and employ an innovative kind of water cooling. Each rack has a peak performance of 310 TFlops. To run optimally on this architecture, codes will need some adjustments employing ideas such as site fusing, half-precision gauge fields, and the use of lattice sizes with prime factors of 3 and 5, but with optimal use of the SIMD units, scaling is almost perfect. A future successor, QPACE 3, will use Knights Landing units instead of the Knights Corner ones, and should achieve a peak performance of 1 TFlop per rack.

This was followed by Masakiyo Kitazawa speaking about measurements of thermodynamics using the gradient flow. The small-flowtime expansion for the gradient flow allows to define a renormalized energy-momentum tensor in terms of the zero-flowtime limit of two flowed dimension-four operators. This has been applied to obtain results for the trace anomaly and the entropy density, but the difficulty lies in finding a plateau region in flow time where both lattice artifacts and finite-volume effects can be neglected, so as to allow a reliable extrapolation to zero flow time.

After the coffee break, Chris Sachrajda reviewed the state of the lattice determination of long-distance effects to flavour-changing processes. As no new physics has been discovered by the LHC so far, precision flavour physics is still the most promising avenue in the search for BSM effects. For some quantities in this area, particularly in the field of Kaon physics, long distance effects are of crucial importance. An example is neutral Kaon mass difference $\Delta m_K = m_{K_L} - m_{K_S}$; this involves four-volume integrals over the expectation value of matrix elements of electroweak operators between hadronic states, raising the problem of how to prepare such hadronic states in this context. The problem can be solved by taking the time integral over a largish interval, but placing the creation and annihilation operators well outside of the corresponding four-volume. The relevant correlation functions also contain terms growing exponentially with the time extent T,

which can be removed by adding suitably tuned terms to the electroweak Hamiltonian. UV divergences are eliminated the GIM mechanism together with the V-A structure of the electroweak currents. With all these theoretical developments in place, a calculation done at unphysical pion and Kaon masses gives a result for $\Delta m_K$ close to the physical value (which may of course still be a fortuitous coincidence), and exhibits an apparent violation of the OZI rule in that the contribution from the disconnected diagram is very significant to the final result. Another example given was the decay $K_L \to \pi^0\ell^+\ell^-$, for which the long-distance effects are known in $\chi$PT, and the question addressed by an exploratory study is whether the lattice can do better. Yet another example are the QED corrections to the pion decay constant, which contain IR divergences requiring a proper Bloch-Nordsieck treatment.

After some well-deserved applause for the organizers, the conference closed with the invitation to next year's lattice conference in Kobe, Japan, from 14th to 18th July 2014. The IAC also announced that the 2016 lattice conference will be hosted in Southampton, U.K., in the last week of July 2016.

As I had to fly back to Germany in the evening (a lecture having to be given on Monday), the posting of this and the previous day's summaries was delayed a little by travel and subsequent jetlag, but I am sure my readers will be delighted to know that I got home safe and sound, and with all my luggage intact.

## LATTICE 2014, Day Five

*2014-06-30T21:02:00.002+02:00*

The first plenary talk of the morning was by Sasa Prelovsek, who gave the review talk on hadron spectroscopy. In this area, the really hot topic is the nature of the $XYZ$ states, such as the $Z_c^+(3900)$, which decays into $J/\psi\pi^+$, and thus cannot be a simple quark-antiquark bound state. In order to elucidate this question, the variational method has to be used with a basis of operators containing both one- and two-meson operators as well as possible tetraquark operators, and this then requires the use of all-to-all propagators (with distillation now being the most commonly used approach) as well as a Lüscher-type method to treat the multiparticle states. These added difficulties mean that studies in this area are still a bit rough at the moment, with the physical-pion, large-volume and continuum limits generally not yet taken. For the $Z_c^+$, Sasa *et al.* find a candidate state only when including both two-meson and tetraquark operators in their basis. The more charmonium-like states, such as the $X(3872)$, are better studied, and the $X(3872)$ in particular appears likely to be mostly a $DD^*$ molecule. The greatest challenges in spectroscopy are the mixing between quarkonia and light hadron states, which is still mostly ignored, and the inclusion of more-than-two particle states, for which the theoretical tools aren't quite there yet.

A topical talk on new algorithms for finite-density QCD given by Denes Sexty followed. QCD at finite chemical potential $\mu$ suffers from the well-known sign problem; while there are a number of methods to evade it (in particular analytically continuing from imaginary $\mu$ and Taylor expansion methods), the newer methods attempt to address it directly. One of these is the complex Langevin method, which responds to the complex action by complexifying the fields and noise term in the Langevin equation (which for gauge links means continuing from SU($N$) to SL($N,\mathbb{C}$) and requires some means of restraining the links from wandering off too far into the unphysical part of the group manifold, e.g. by gauge cooling steps interspersed with the dynamical updates). In the past, this method was hampered by a lack of theoretical understanding and the presence of possibly unphysical runaway trajectories; now, it has been established that for holomorphic actions, the complex Langevin time average does converge to the ensemble average. Unfortunately, the action for QCD with a chemical potential is not holomorphic, but some studies indicate that this case may nevertheless be okay. The other new method to directly address the sign problem is the Lefschetz thimble, which relies on shifting the integration contour for the path integral into the complex plane, and for which simulation algorithms exist in the case of various toy models. For the complex Langevin method, there are now a number of results which look promising.

This was followed by another topical talk, Alberto Ramos speaking about the applications of the Wilson flow to scale setting and renormalization. It has long been known that the Wilson flow yields renormalized operators, and besides its use in setting the lattice scale, it is now widely used to define a renormalized coupling, where the renormalization scale is set by $\mu^2 = 1/(8t)$. To avoid the need for a window where both cut-off and finite-volume effects are small, one can tie the renormalization scale to the volume as $\mu = 1/(cL)$, however, this means that the boundary conditions become relevant. The errors on the Wilson flow coupling are orders of magnitude smaller than those on the Schrödinger functional coupling, but the SF coupling becomes less noisy at small coupling and thus provides information complementary to that from the WF coupling. Cut-off effects are important for Wilson flow observables, and tree-level improvement has a big effect there. There is a small-flowtime expansion analogous to the OPE, and a fermionic version of the flow can be used to determine the chiral condensate. All in all, this is a very active field of current research.

After the coffee break, the Ken Wilson Award was announced. The award goes to Gergely Endrődy for *significant contributions to our understanding of QCD matter in strong magnetic fields and to QCD thermodynamics*. Gergely gave his prize talk on the topic of QCD in magnetic fields, starting from Hofstadter's butterfly, which is a self-similar fractal describing the energy levels accessible to an electron in a crystal (which tries to enforce Bloch waves) in a magnetic field (which tries to enforce Landau levels). The Dirac operator for a free lattice fermion in a magnetic field has a similar structure, which however disappears in the continuum limit, since the magnetic flux through a plaquette scales as $a^2$. The quark condensate is related to the Dirac eigenvalues, and hence contains the same self-similar structure, which is washed out by the quark mass, however. When QCD interactions are turned on, these similarly wash out the fractal structure. What is left over is a growth of the quark condensate with the magnetic field at zero temperature ("magnetic catalysis"). At finite temperature, a similar effect was expected from models, but Gergely *et al.* have shown that in fact the opposite effect happens ("inverse magnetic catalysis").

This was followed by Tetsuya Onogi speaking about a hidden exact symmetry of graphene. Graphene, which is the most conductive material known under terrestrial conditions, has a band structure with a Dirac point resembling the dispersion relation for a massless relativistic fermion, with no gap. The symmetry preserving the vanishing of the gap against perturbations can be derived by treating the actual graphene lattice as a staggered version of a coarser hexagonal lattice, where six sites correspond to six internal degrees of freedom (three flavours, two spins), which then reveals a hidden flavour-chiral symmetry.

The afternoon saw the last set of parallel sessions. There were two more talks from members of the Mainz group (PhD student Hanno Horch and former postdoc Gregorio Herdoiza, now a Ramón y Cajal Fellow at the Universidad Autónoma de Madrid) on work related to (g-2) and the Adler function.

### LATTICE 2014, Days Three and Four

*2014-06-27T03:51:00.000+02:00*

Wednesday was the "short" day as has been customary for many years now. I gave my own talk in the hadron structure session and got a lot less criticism than I expected; apparently it has been widely accepted by now that excited-state effects can be large in nucleon matrix elements even if naively it looks like there aren't any.

In the afternoon, there were no organized excursions, so I spent the afternoon in the Metropolitan Museum and took a walk around Central Park and down Fifth Avenue after it closed.

Today was started by the first non-lattice talk, given by Anthony Mezzacappa of the CHIMERA collaboration, who spoke about simulating core collapse supernovae to ascertain the mechanism behind these massive stellar explosions. Core collapse supernovae happen when a very massive star has reached the final stage of its life, in which it has an onion-like structure, with a hydrogen envelope around a helium envelope around further layers of increasingly heavy elements around a central iron core which is about the size of the Earth, but so dense as to be about the mass of the Sun. When this central core becomes so compressed that it can no longer keep from collapsing until it reaches nuclear densities (turning into a neutron star or a stellar black hole as a result), the infall of matter is supersonic, but the bounce back is subsonic (because the speed of sound is higher in the denser matter inside), which causes a shockwave to spread that eventually blows the star apart. However, the real story is more complicated than that, because a lot of energy is radiated away in the form of neutrinos, which may cause the shockwave to become weakened and avoid the explosion. The most important question is therefore how the processes occurring in the star cause the shockwave to revive. The simulations to investigate this are become quite large, requiring on the order of 100 Megacore-hours per second of supernova simulated. To fully include all variables would likely require sustained Exaflops, so the problems are usually simplified. Spherical symmetry is a bad assumption apparently, because it leads to no explosion. Azimuthal symmetry gives an explosion, and the generic three-dimensional case is not quite resolved yet.

This was followed by a review of BSM physics from the lattice by Yasumichi Aoki. The main idea investigated in this area is walking technicolor, i.e. the search for a technicolor-type gauge theory that has a very slowly running coupling and large mass anomalous dimension in order to permit both the generation of a realistic mass spectrum for the Standard Model fermions and the suppression of flavour-changing neutral currents to a level compatible with experiment. Another problem is to have a light Higgs and no other light unobserved particles. A number of theories under investigation show spectra compatible with this, with the scalar much lighter than the pseudoscalar (as opposed to QCD, where the pion is much lighter than the $\sigma$ resonance).

After the coffee break, we had the experimental talk, by Brendan Casey on the FNAL E989 experiment and the anomalous magnetic moment of the muon. To understand the hadronic contributions much more work is needed, both on the theory side (where the work of my collaborators Anthony Francis and Vera Gülpers received well-deserved praise) and in experiment (where the R-ratio needs to be determined to sub-percent level, and where KLOE will investigate the leading contributions to hadronic light-by-light scattering). The new Fermilab (g-2) experiment is designed specifically to address many of the remaining sources of experimental error on the value (g-2) itself; the effort to get there has been quite impressive, with the pictures showing very nicely what kinds of huge projects even such relatively "small" experiments are.

The next talk was Antonin Portelli speaking about electromagnetic and isospin-breaking effects in lattice QCD. While isospin is a reasonably good symmetry of the strong interactions, it is broken at the sub-percent level, and the proton-neutron mass difference is an essential ingredient of the stability of matter. Understanding isospin-breaking effects (both from electromagnetism and from the difference between the up and down quark masses) is therefore a crucial endeavour for lattice theorist in the longer term. A number of collaborations are now simulating QCD+QED dynamically. Since QED does not have a mass gap, it tends to show long autocorrelations in Monte Carlo time; a new HMC Hamiltonian introduced by the BMW collaboration appears to get rid of this effect. The electromagnetic mass differences within the baryon octet are nicely reproduced by now, and the origin of the nucleon mass difference seems to become understood. For some reason, the $\Xi_{cc}$ mass difference is also of great interest to phenomenologists, and has also been computed on the lattice.

The last plenary of the morning was a review of quark masses by Francesco Sanfilippo. He stressed the importance of ratios of quark masses (where in a mass-independent scheme, the ratio of renormalized masses equals that of the bare ones, avoiding the need for accurate knowledge of renormalization constants), and reviewed a number of methods that have been used to determine heavy quark masses, including the HPQCD method of using moments of current-current correlators, the use of NRQCD with perturbative subtractions and of non-perturbative HQET, as well as the ETMC ratios method. In the light sector, simulations are now done close to the physical point, and the isospin-breaking u-d mass difference is being investigated in a realistic manner.

In the afternoon, there were parallel sessions again. Besides some NRQCD talks, including a very nice talk on bottomonium spectroscopy using free-form smearing, I attended a number of talks on the gradient flow.

In the evening, there was the dinner cruise for those who had bought tickets. I hadn't and, having waived any claim to a left-over free ticket so interested others could attend instead, arranged otherwise for dinner.

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**LATTICE 2014, Day Two**

*2014-06-25T04:08:00.001+02:00*

Hello again from New York. The first plenary of the morning was given by Nicolas Garron speaking about $K/\pi$ physics. After a summary of the most recent updates on the decay constants of the pion and Kaon and their ratio $f_K/f_\pi$, as well as the zero momentum transfer form factor $f_+(0)$ (which are increasingly so precise that the question of when the precision was enough was raised from the audience after the talk), he proceeded to discuss the general theory of CP violation in neutral Kaon mixing and the $\Delta I = 1/2$ rule in $K \to \pi\pi$ decays, and the ways in which lattice calculations are needed to understand these topics. A number of recent updates on the Kaon bag parameter $B_K$ were summarized, and the renormalization and mixing of the BSM operators entering neutral Kaon mixing (for which Mauro Papinutto showed some impressive results in one of the parallel sessions) were discussed. Finally, RBC/UKQCD now have results on the $\Delta I = 1/2$ and $\Delta I = 3/2$ amplitudes in $K \to \pi\pi$ decays at the physical pion mass, which strongly support the $\Delta I = 1/2$ rule at a level compatible with phenomenology.

This was followed by a talk on a somewhat related topic, namely Stephan Dürr speaking about the question of whether the validity of $\chi$PT extends even to the physical pion mass. Contrary to the often-quoted theorem that the answer to any title with a question mark in it is "no", the answer was "yes" in this case. While the chiral expansion breaks down completely at pion masses of around 500 MeV (where NNLO corrections grow to be larger than the NLO ones), two different analyses (one using staggered, and one using Wilson fermions) that Stephan showed indicate that the NLO low-energy constants can be extracted in a reasonably consistent manner from fits in the range $M_\pi = 135 - 400$ MeV. However, the low-energy constant $\ell_4$ showed a significant sensitivity to the range of pion masses used to fit.

The last talk before the coffee break was on Multigrid methods for lattice QCD and was given by Andreas Frommer. Multigrid methods have a long history in applied mathematics, where they are used more commonly in the context of finite-element methods (rather than the finite-difference approach used in lattice field theory). The basic ingredients from the applied mathematics point of view are a smoothing operation together with restriction and prolongation operations that allow to reduce the size of the problem to a level where it can be solved directly, and then to retrieve the solution of the original problem from this. Interestingly, this was somewhat reinvented in a way tuned to lattice QCD from the physics side, where Lüscher's inexactly deflated SAP-preconditioned GCR that is part of the DD-HMC and openQCD packages forms a two-level multilevel scheme that leads to a great improvement in runtime behaviour as the quark mass is decreased. The Wuppertal applied mathematics group has extended this to a generic multilevel scheme for QCD (where it is found that three levels are even better than two at small quark masses, but four seem not to help appreciably more). From the mathematical side, most of the existing multigrid theory does not apply to QCD, however, so further mathematical research seems required to fully understand why and when these approaches work for QCD.

After the coffee break, Raul Briceno spoke about few-body physics. In this area, significant theoretical progress seems to have been made recently and still to be under way, extending Lüscher's finite-volume formalism for scattering phase shifts in various directions.

This was followed by a talk on the closely related and somewhat overlapping topic of hadronic interactions by Takeshi Yamazaki, who presented recent results for various scattering lengths and phase shifts, as well as reviewing the alternative HALQCD method, which relies on reconstructing an interaction potential from multi-particle correlators.

In the afternoon there were parallel sessions again. I got to chair the session on renormalization from the Schrödinger functional approach, where there has been significant progress on the chirally rotated SF and on studying the mixing of four-quark operators. Another very interesting session later in the afternoon was concerned with the various methods to get at quark-disconnected contributions to hadron structure observables, and some of the results obtained using them.

In the evening, the poster session took place.

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**LATTICE 2014, Day One**

*2014-06-24T04:17:00.001+02:00*

Hello, faithful readers, and a cordial welcome to the annual lattice conference blog, this time form New York, where I arrived two days early in order to beat the jet lag. The jet-lag adjustment days were well-spent in the Metropolitan Museum.

The conference started with a reception (a very exclusive event, admission to which was controlled by rather fierce security guards, who at first wouldn't even let us into the building) on Sunday night.

Since the plenary talks will be livestreamed at livestream.com (search for ”Lattice2014”), you don't have to rely on my summaries of the talks this time, and in fact I would like to encourage you to cross-check them and post about anything you feel I missed or misrepresented in the comment section (please note that comments are moderated, so it may take a while for yours to turn up).

After a brief opening address by the Vice-President of Columbia University, the first plenary talk of the conference was given by Martha Constantinou, who gave a review talk on hadron structure. The most active subfield in this area is nucleon structure, to which accordingly the greater part of her talk was devoted. A crucial quantity there is the axial charge $g_A$ of the nucleon, which a number of groups have been investigating using a number of methods. (Since I have been involved in the Mainz effort on this front, I am certainly somewhat biased, so take what follows with a grain of salt.) Martha very nicely explained the existing results and discussed the sources of error in detail, but I'm afraid I have to slightly disagree with some of her assessments, in particular regarding excited-state effects (which I believe to be more important) and finite-volume effects (where I think that $M_\pi L > 4$ is required to be on the safe side). An interesting development is the Feynman-Hellmann approach, where a term coupling to the current of interest (the axial current in this case) is added to the action, and derivatives of the nucleon mass are taken with respect to the coefficient of that term in order to get at the matrix element of the current; this appears to allow for high statistical precision. Another area of high activity are the nucleon electromagnetic form factors (for which I also believe excited-state effects to be far more important than thought so far). Here, the disconnected contributions relevant for the proton (rather than isovector) form factors are now being computed by some groups, which requires very high statistics (O(100,000) was mentioned) and/or some clever new ideas (like hierarchical probing). For the quark momentum fraction $\langle x\rangle$, the importance of excited-state effects is uncontroversial, but the dominant error remains the renormalization. There are also increasingly results for the nucleon spin decomposition, although there are some open problems here, in particular with regards to the gluon angular momentum contributions and the resulting mixing. Beyond the nucleon, first results for hyperon form factors are now available. Further quantities discussed were the pion $\langle x\rangle$ and the electromagnetic form factors of the $\rho$ meson (there are three of them). Overall, simulations at or near the physical pion mass are now removing the uncertainties from chiral extrapolations (and discretization effects appear to be small in many nucleonic quantities), so that the confrontation with experiment becomes more acute, requiring full control of all other sources of error.

This was followed by another review talk, on heavy flavours, given by Chris Bouchard. The decay constant of the $D_s$ meson has been the subject of much interest in the past, when a theory-experiment tension seemed to indicate a potential for new physics; that tension has mostly passed, but as a consequence there are now many recent results for $f_{D_s}$, which tend to meet an accuracy target of 1% required to have an impact at the level of experimental precision expected for 2020. For the decay constants of the B and $B_s$ mesons, there are now results from many different formulations (NRQCD, HQET, Fermilab, heavy HISQ, ratios with heavy twisted mass quarks), which all agree quite well. The extraction of $V_{cs}$ from semileptonic decays suggest a small tension with that using $f_{D_s}$, much as there is still some tension between the exclusive and inclusive determinations of $V_{ub}$ and $V_{cb}$. In testing for possible new physics, both rare decays (i.e. those that can occur only at the loop level in the Standard Model) and the mixing of neutral heavy-flavour mesons with the antiparticles are of particular relevance. Apparently, a recent calculation of $D^0$ mixing by ETMC is enough to exclude new physics contributions up to scales as high as thousands of TeV.

After the coffee break, Michael Müller-Preussker gave a talk in memory of Pierre van Baal (1955-2013), reviewing recent results on topology on the lattice. Since the topological properties of field configurations are defined in terms of winding numbers of maps between continuous spaces, the definition of topological quantities on the lattice (which is after all discrete) can be ambiguous. Techniques that are used include the direct approach (using a discretization of the continuum topological charge density and relying on some smoothing operation, such as link smearing, cooling or more recently the gradient flow, to bring the fields close enough to the continuum to make the topology unambiguous), the approach via the Atiyah-Singer index theorem (using the index of a Ginsparg-Wilson Dirac operator to define the topological charge), and the approach via spectral projectors (about which I unfortunately know more or less nothing).

The following talk was the review talk on finite-temperature (at vanishing chemical potential) results, which was given by Alexei Bazavov. In keeping with the location of the conference, he showed the Columbia plot before turning to results at the physical point, where the transition is a crossover and the transition temperature hence not so clearly defined. However, when looking for the peak of the chiral susceptibility, the results from different staggered formulations and more recently from domain-wall fermions at the physical pion mass agree quite well. An interesting observation appeared to be that in order for lattice results to match up with hadron resonance gas model predictions, the hadron resonance gas apparently also has to include the ”missing states” predicted by quark models, but not observed experimentally. Other results presented included a new method to determine the equation of state using shifted boundary conditions, and numerous new results for the heavy-quark potential and quarkonium spectral functions.

In the afternoon there were parallel sessions. I would like to highlight the (first of two) sessions dedicated to lattice results on the anomalous magnetic moment of the muon. There are now a number of different methods of getting at the leading hadronic contribution: by direct determination of the hadronic vacuum polarization, via a mixed-representation approach (where the subtracted vacuum polarization is expressed as an integral over the vector correlator), and from moments of current-current correlators. While in principle all of these process the same information (which is after all encoded in the vector-vector correlation functions), they seem to have different strengths and weaknesses. A first lattice estimate of the systematic error incurred by neglecting disconnected diagrams (whose contribution cannot yet be resolved with the currently available statistics) was presented by Mainz PhD student Vera Gülpers.

# 2013

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### LATTICE 2013 - The biggest Lattice conference so far

*2013-07-01T14:39:00.001+02:00*

With 510 registered participants and 476 submitted contributions (not counting the invited plenary talks), LATTICE 2013 is shaping up to be by far the biggest Lattice conference ever (at least so far). While this is of course great news for all lattice people (since it shows the rapid growth of the field) and a great honour for us as organizers, it also means that the parallel programme is under a lot of pressure. We have had to organize additional rooms for parallel sessions and to move some talks to a different topical stream than the one they were submitted under, but in the end there was no way to avoid having to move a few parallel talks to the poster session (which itself is under a lot of pressure given the finite volume of the exhibition hall); if you are one of the authors concerned by such rearrangements, we trust you will understand that there was no other way.

Likewise, we hope that all participants will be forgiving of unavoidable clashes between talks that are of equal interest to them. We have taken great efforts to avoid such situations, but given the various additional constraints (such as speakers only being present for part of the week and sessions likely to meet with greater interest having to be put into larger rooms) it is impossible to avoid all potential clashes. The same applies to those speakers whose requests for a rescheduling of their talk to a more convenient time slot could not be fulfilled – we have tried our best, but there is a limit to the number of times a programme with seven simultaneous parallel streams forming sixty-six parallel sessions can be rearranged to accommodate a single individual.

The parallel and poster programme is now finalized and will go to the printers soon. The only changes still possible will be cancellations (which we would greatly regret) and swaps (which should be arranged between the two speakers concerned and communicated to us by email to submission@lattice2013.uni-mainz.de). Any such changes received after Wednesday, 3rd July 2013, will not make it into the printed programme, but will of course be shown in the web version and advertised by flyers, slides and pin-board notices during the conference.

Finally, the large number of participants means that some queues at the conference office and at lunchtime will be unavoidable, so a certain amount of patience may be required in these situations. We will try our best to reduce waiting times as much as feasible, but 510 people is quite a lot after all.

We look forward to hosting you all in Mainz!

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## Lattice 2013 - Third Circular

*2013-05-01T12:55:00.003+02:00*

Abstract submission for the Lattice 2013 conference, which will be held in Mainz, Germany, from Monday, 29 July 2013, to Saturday, 3 August 2013, is now open. You can follow the "ONLINE REGISTRATION" link from the conference website to submit your abstract.

### *Fees and Deadlines*

The Early Bird conference fee of EUR 330 is still available until Wednesday, 15 May 2013. After this deadline, the fee rises to EUR 400.

The fee for an accompanying person is EUR 150.

Participants who have been approved for the reduced conference fee are reminded that the reduced fee must be paid by Wednesday, 15 May 2013, and that otherwise the regular fee of EUR 400 will have to be paid.

The deadline for both registration and abstract submission is Saturday, 15 June 2013.

### *Scientific Programme*

We are in the course of arranging an interesting and varied plenary programme.

For more information on the scientific programme please refer to our website, which will be updated regularly.

### *Travel, Visa and Accommodation*

Mainz is located extremely conveniently for international visitors: Frankfurt Airport (FRA), which is served by over 500 flights each day, is located only 30 minutes from Mainz on a direct local train service.

For budget flights from and to many European destinations, the airport Frankfurt-Hahn (HHN, served by Ryanair) is connected to Mainz by a non-stop shuttle bus.

For more details on how to get to Mainz, please refer to our website.

Most participants will not require a visa to enter Germany. If you are unsure whether you might need a visa, please refer to the German Foreign Office website for information.

If you require a visa, please let the LOC know as soon as possible by email to visaletters@lattice2013.uni-mainz.de with the Subject: "LATTICE2013 - request for invitation, YOUR NAME" so that we can issue you with a letter of invitation. Please do not forget to include your postal address, and keep in mind that both the international delivery of letters and the processing of visa applications takes some time.

Hotel reservations have to be made directly with the hotel of your choice. Our website provides information and links to local hotels offering special rates for the participants of Lattice 2013. Please note that the deadlines for the booking of accommodation vary between the different hotels.

All on-campus guest rooms are now fully booked. Another low-cost option for participants with very small budgets is the Mainz Youth Hostel, which can be found at the bottom of the "Accommodation" section of our website.

### *Venue and Organization*

A welcome reception and registration will be held on the evening of Sunday, 28 July 2013, from 6:00 pm to 9:00 pm at the bar/restaurant "Proviant-Magazin" in the city centre of Mainz.

The conference programme starts in the morning of Monday, 29 July 2013, and ends at lunchtime on Saturday, 3 August.

The conference will be held on the campus of the University of Mainz, which is conveniently located close to the city centre and can be reached easily using public transportation. A public transportation ticket valid during the conference will be included as part of the name tag.

A conference desk will be open for registration and enquiries during the entire duration of the conference.

Lunch will be served on campus in the university mensa, where a separate seating area for conference participants will be available. Meals will be paid using the mensa card contained in the registration package, which can also be charged and used to pay for snacks at the local cafeteria if so desired.

The afternoon of Wednesday, 31 July has been allocated for excursions, and you will be requested to select your choice of excursion when registering online. Options include guided tours of Mainz, Frankfurt, and Heidelberg, as well as a wine-tasting trip to the Rheingau, and a tree climbing adventure. Please note that for some excursions, only a limited number of places is available and that these will be allocated on a first-come, first-served basis.

The conference dinner will take place at 8:00 pm on Thursday, 1 August at the Electoral Palace ("Kurfürstliches Schloss") in Mainz. Details about the location and menu can be found on our website, where you can also find information about Mainz restaurants, bars and cafes, as well as further touristic opportunities and local attractions.

#### *Contact Information*

More information can be found on the conference web site, which is updated regularly.

If you need to contact us, please email the Conference Secretariat.

#### *Other Workshops*

Participants of Lattice 2013 might also consider attending the workshop "Extreme QCD (XQCD)", which will be held in Bern/Switzerland, from 5 to 7 August 2013.

Another QCD-related meeting being held in Europe in close temporal proximity to Lattice 2013 will be the workshop on "Nucleon Matrix Elements for New-Physics Searches" at the ECT* in Trento/Italy, from 22 to 26 July 2013.

We are looking forward to seeing you in Mainz.

The Lattice 2013 Local Organizing Committee,
Georg von Hippel, Harvey B. Meyer, Owe Philipsen, Lorenz von Smekal, Carsten Urbach, Marc Vanderhaeghen, Marc Wagner, Hartmut Wittig (chair)

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### Lattice 2013 - Second Circular

*2013-04-02T20:24:00.002+02:00*

Online registration for the Lattice 2013 conference, which will be held in Mainz, Germany, from Monday, 29 July 2013, to Saturday, 3 August 2013 is now open. You can follow the ”ONLINE REGISTRATION” link from the conference website to register.

#### *Fees and Deadlines*

The Early Bird conference fee is EUR 330.

The Early Bird Registration deadline is Wednesday, 15 May 2013.

After the Early Bird deadline, the fee rises to EUR 400.

The fee for an accompanying person is EUR 150.

A reduced conference fee of EUR 200 will be available upon application for students and other participants with very limited financial resources. Please email financial-support@lattice2013.uni-mainz.de with the Subject: ”LATTICE2013 - reduced fee application, YOUR NAME” to apply.

The deadline for reduced fee applications is Monday, 15 April 2013, and the reduced fee must be paid before Wednesday, 15 May 2013; otherwise the regular Late fee of EUR 400 will have to be paid.

Abstract submission will open on 1 May 2013.

The deadline for both registration and abstract submission is Saturday, 15 June 2013.

#### *Accommodation*

Hotel reservations have to be made directly with the hotel of your choice. Our website provides information and links to local hotels offering special rates for the participants of Lattice 2013.

Please note that deadlines for the booking of accommodation vary among the different hotels, and that the cheaper hotels tend to have earlier deadlines.

A very limited number of guest rooms on campus is available at low cost for participants who have been approved for financial support. Applications for such rooms can be made only after the reduced fee has been paid, and will be filled on a first-come, first-served basis.

#### *Visa Requirements*

Germany does not require visas from EU/EEA citizens for stays of any duration or for any purpose. Citizens of Australia, Brazil, Canada, Israel, Japan, New Zealand, South Korea, Taiwan, the US, and some others will also not require a visa for stays of up to 90 days.

More information can be found on the website of the German Foreign Office.

If you require a visa, please let the LOC know as soon as possible by email to visaletters@lattice2013.uni-mainz.de with the Subject: "LATTICE2013 - request for invitation, YOUR NAME" so that we can issue you with a letter of invitation.

Please remember that both the delivery of the letter by mail from Germany to your country and the processing of your visa application will take some time.

### *Venue and Organization*

On-site registration and a welcome reception will be held on the evening of Sunday, 28 July 2013, from 6:00 pm to 9:00 pm at the bar/restaurant "Proviant-Magazin" in the city centre of Mainz.

The conference programme starts in the morning of Monday, 29 July 2013, and ends at lunchtime on Saturday, 3 August.

The conference will be held on the campus of the University of Mainz, which is conveniently located close to the city centre and can be reached easily using public transportation. A public transportation ticket valid during the conference will be included as part of the name tag.

Lunch will be served on campus in the university mensa, where a separate seating area for conference participants will be available. Meals will be paid using the mensa card contained in the registration package, which can also be charged and used to pay for snacks at the local cafeteria if so desired.

### *Social Programme*

The afternoon of Wednesday, 31 July has been allocated for excursions, and you will be requested to select your choice of excursion when registering online.

Options include guided tours of Mainz, Frankfurt, and Heidelberg, as well as a wine-tasting trip to the Rheingau, and a tree climbing adventure.

Please note that for some excursions, only a limited number of places is available and that these will be allocated on a first-come, first-served basis.

The conference dinner will take place at 8:00 pm on Thursday, 1 August at the Electoral Palace ("Kurfürstliches Schloss") in Mainz.

For other touristic opportunities and local attractions, please check our website.

***Contact Information***

More information can be found on the conference web site, which will be updated regularly.

If you need to contact us, please email the Conference Secretariat.

***Other Workshops***

Participants of Lattice 2013 might also consider attending the workshop ”Extreme QCD (XQCD)”, which will be held in Bern/Switzerland, from 5 - 7 August 2013.

Another QCD-related meeting being held in Europe in close temporal proximity to Lattice 2013 will be the workshop ”Nucleon Matrix Elements for New-Physics Searches” at the ECT* in Trento, Italy, from 22 to 26 July 2013.

We are looking forward to seeing you in Mainz.

The Lattice 2013 Local Organizing Committee,
Georg von Hippel, Harvey B. Meyer, Owe Philipsen, Lorenz von Smekal, Carsten Urbach, Marc Vanderhaeghen, Marc Wagner, Hartmut Wittig (chair)

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**Lattice 2013 - First Circular**

*2013-01-31T15:03:00.001+01:00*

Lattice 2013, the 31st International Symposium on Lattice Field Theory will be held in Mainz, Germany, from Monday, 29 July 2013, to Saturday, 3 August 2013.

The conference will be held on the campus of the University of Mainz, which is conveniently located close to the city centre and can be reached easily using public transportation. All plenary and parallel sessions will take place in the same building.

Registration and reception will be held on the evening of Sunday, 28 July 2013, from 6:00 pm to 9:00 pm at the bar/restaurant ”Proviant-Magazin” in the city centre of Mainz.

The conference programme starts in the morning of Monday, 29 July 2013, and ends at lunchtime on Saturday, 3 August.

Mainz is conveniently located and can be reached in 30 minutes by a direct local train from Frankfurt airport.

More information can be found on the conference website, which will be updated regularly. If you need to contact us, please email the Conference Secretariat.

### ***Important Deadlines***

The Early Bird Registration deadline is Wednesday, 15 May 2013.

The Registration and Abstract Submission deadline is Saturday, 15 June 2013.

Registration and abstract submission will proceed via the conference web page, and an announcement will be made when these features become available.

Hotel reservations have to be made directly with the hotel of your choice. Our web site will provide information and links to local hotels offering special rates for the participants of Lattice 2013. Deadlines for the booking of accommodation vary among the different hotels. Full details will be provided when the list of hotels is online.

### ***Programme***

The programme will include plenary talks, parallel talks and a poster session on the following topics:

- Algorithms and machines
- Applications beyond QCD
- Chiral symmetry
- Hadron spectroscopy and interactions
- Hadron structure
- Nonzero temperature and density
- Standard model parameters and renormalization
- Theoretical developments
- Vacuum structure and confinement
- Weak decays and matrix elements

### ***International Advisory Committee***

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Stephen Sharpe (U. Washington)
Cecilia Tarantino (U. Roma Tre)

### *Financial Support*

A reduced conference fee will be available for a limited number of students, and for participants with very limited financial resources.

Applicants should send their application (with a brief motivation) by email to financial-support@lattice2013.uni-mainz.de with Subject: "LATTICE2013 - reduced fee application, YOUR NAME". Student applicants should provide proof that they are registered as students during the year 2013 or academic year 2012-2013 and a statement of support by their supervisor, as well as the title of any presentation they intend to give.

The deadline for reduced fee applications is 15 April 2013. Payment of the reduced fee must be received on 15 May 2013 at the latest. After that date the regular late fee has to be paid.

Please note that the reduced fee does not include expenses for travel and accommodation, and that the available number of reduced-fee places is limited; not all applications may be successful.

### *Travel Information*

Frankfurt Airport (FRA), which is served by over 500 flights each day, is located only 30 minutes from Mainz on a direct local train service.

For cheap connections from and to many European destinations, Hahn airport (HHN, served by Ryanair) is connected to Mainz by a non-stop shuttle bus.

Mainz also has excellent railway and motorway connectivity.

A local transportation ticket valid for the duration of the conference in all buses and trams in Mainz and the neighbouring town of Wiesbaden, is included in the registration pack. The registration pack also includes maps of the city and the university campus.

### *Excursions and Sightseeing*

Situated near the UNESCO world heritage site Upper Middle Rhine Valley, Mainz is in its origins a Roman city, which has been an episcopal see since 746 and since 1950 is the capital of the state of Rhineland-Palatinate.

The city is located on the bank of the Rhine. The neighbouring cities of Frankfurt and Wiesbaden are easily accessible via public transportation. The climate is among the warmest and driest in Germany, with average temperatures in July around 24°C (75°F) and a low chance of precipitation. The surrounding area is a wine region which is particularly renowned for producing excellent Rieslings.

Mainz by itself offers plenty of opportunities for sightseeing, including the Cathedral with its 10th century bronze gate, the church of St Stephan with its exquisite set of windows designed by Marc Chagall, as well as a number of Roman remains.

Museums in Mainz include the Gutenberg-Museum for the history of printing, and the Romano-Germanic Central Museum with its impressive collection of archaeological finds from the Roman and early medieval periods.

Beyond Mainz, there is Frankfurt with its world-famous museums, among them the Städel, which houses one of Europe's prime art collections including works by Vermeer, Botticelli, Duerer, Monet and Picasso, and the Senckenberg museum of natural history with its outstanding collection of dinosaur skeletons. The Alte Oper (old opera house) is a first-class concert venue.

The afternoon of Wednesday, 31 July has been allocated for excursions, and we are currently in the process of organizing a selection of options.

### *Other QCD Workshops*

Participants of Lattice 2013 might also consider attending the workshop "Extreme QCD (xQCD)", which will be held in Bern/Switzerland, from 5 to 7 August 2013.

Another QCD-related meeting being held in Europe in close temporal proximity to Lattice 2013 will be the workshop "Nucleon Matrix Elements for New-Physics Searches" at the ECT* in Trento, Italy, from 22 to 26 July 2013.

We are looking forward to seeing you in Mainz.

The Lattice 2013 Local Organizing Committee,
Georg von Hippel, Harvey B. Meyer, Owe Philipsen, Lorenz von Smekal, Carsten Urbach, Marc Vanderhaeghen, Marc Wagner, Hartmut Wittig (chair)

# 2012

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### Workshop links

*2012-12-18T19:12:00.001+01:00*

The week of July 22-26, 2013, i.e. the week immediately prior to the Lattice 2013 conference, there is a workshop on "Nucleon Matrix Elements for New-Physics Searches" scheduled at the ECT*, the organizers of which have requested that Lattice 2013 participants be made aware of it so as to avoid the potential for other scheduling conflicts.

Another interesting upcoming event should be the school/workshop "New Horizons in Lattice Field Theory", which will be held March 13-27, 2013, in Natal (Brazil). With lectures by Mike Creutz, Owe Philipsen, Chris Sachrajda, Steve Sharpe, and Rainer Sommer, this ought to be a highly instructive school for students wishing to study lattice topics in the tropics.

A propos schools, the slides of the INT Summer School on Lattice QCD for Nuclear Physics are up on the web, along with videos of the lectures, providing another excellent educational resource on lattice QCD.

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### Lattice 2012, Day Five

*2012-06-30T10:49:00.002+02:00*

Hello for a final time from Cairns. The first plenary session of the morning had a somewhat reduced occupation number, as is usual the morning after the banquet. The first speaker was Maria Paola Lombardo, who spoke about high-temperature QCD on the lattice. Finite-T results are still being dominated by the staggered results, although there is a noticeable discrepancy in the equation of state between HISQ and stout-smeared quarks, and Wilson simulations are beginning to catch up. There are still many open issues in this field, including the fate of the U(1)$_A$ symmetry at high temperature and the effects of a $\theta$ term and of magnetic fields. On the other hand, quarkonium suppression is predicted well by the lattice, and for fluctuations the lattice measurements and hard thermal loop calculations meet up at around 200 MeV.

The second talk was on strategies for finite chemical potential by Gert Aarts. At finite chemical potential, the fermionic determinant is complex, which precludes a simple probability interpretation, rendering ordinary Markov Chain-based Monte Carlo simulations impossible (the ”sign problem”). Replacing the complex determinant by its absolute value, a technique known as phase quenching, leads to poor overlap and the so-called ”Silver Blaze” problem, i.e. that extreme cancellations of highly oscillatory integrands are required to get the correct behaviour. It is therefore of interest to study models that have no sign problem, and these include two-colour QCD, and QCD with the gauge group $G_2$ (one of the exceptional simple Lie groups). For real-world QCD, which does have a sign problem, there are a number of approaches to avoiding it: some groups simulate at zero chemical potential and measure susceptibilities to perform a Taylor expansion in $\mu$, others use an imaginary chemical potential (where the fermion determinant is real) and try to analytically continue to real $\mu$. A completely different approach is given by complex Langevin dynamics, where all field variables are complexified and subjected to Langevin evolution. This method seems to work well in resolving the Silver Blaze problem for many models; however, it is known to sometimes converge to the wrong limit, so further theoretical work is certainly needed.

The second plenary began with a talk by Kim Splittorff about chiral dynamics with Wilson fermions. Here there are two competing scenarios for approaching vanishing quark mass, the Aoki phase and the Sharpe-Singleton scenario, where in the latter case the pion mass never vanishes. In the quenched case, only the Aoki phase exists, but in unquenched simulations both scenarios have been observed. In Wilson chiral perturbation theory, it turns out that the sign of a given combination of low-energy constants parameterizing the breaking of chiral symmetry by the Wilson term decides which scenario occurs. The eigenvalue density of the Dirac operator can also be determined analytically using Wilson $\chi$PT in the $\epsilon$-regime, and the analytical results agree with simulations, finding an $a/V^{1/2}$ scaling for the lowest eigenvalue.

Next was Masanori Hanada speaking about Monte Carlo approaches to string/M theory. Via the AdS/CFT correspondence, supergravity/string theories can be related to Super-Yang-Mills theories. In some regimes, the string theory is easier to calculate with, and hence string calculations can be used to make statements about some aspects of gauge theories. In other regimes, which apparently are of particular interest to string theorists, the SYM theory is easier to work with, and hence lattice simulations can be used to make predictions about aspects of string theory. In particular, a specific kind of Chern-Simons theory with matter (the ABJM theory) may apparently be the definition of M theory, the elusive unifying description of string theory. There also seems to be the possibility that simulations of certain zero-dimensional models may contain the key to why there are three spatial dimensions and the Universe is expanding.

After this, the Ken Wilson Lattice Award 2012 was announced: it goes to Blum et al. for their paper on $K \to \pi\pi$ decays.

Then an invitation was given to a summer school in Brazil, and finally your correspondent could invite the conference participants to Mainz for next year.

After the lunch break, there were parallel sessions, and after the coffee break, there was a final plenary session. The first speaker of the latter was Peter Boyle presenting the BlueGene/Q system. Lattice QCD presents a special design challenge to a designer of HPC systems, since in order to achieve scalability it requires that the network bandwidth and the memory bandwidth be about equal and closely matched to the FPU speed. With input from lattice physicists, this was realized in the BG/Q system. As a result, the BG/Q has been able to scale to unprecedented performances, smashing the Petaflop barrier by achieving 3.07 PFlop/s sustained performance, while being the most energy efficient computer in the world.

After this, Gilberto Colangelo presented the FLAG-2 group and its work. FLAG-2 has moved beyond FLAG by also including physicists from the US and Japan, and by broadening its mandate to include also heavy-quark observables and $\alpha_s$. FLAG-2 expects to publish a review of results published up to the end of 2012 in early 2013, and every two years thereafter. End users will always be reminded to cite not just the FLAG review, but also the original paper(s).

The last plenary talk was given by Tom Blum, who spoke about the anomalous magnetic moment of the muon. The $3.5\sigma$ tension (which is about two times the size of the electroweak corrections) between current theory and experiment is one of the biggest hints of BSM physics that exists so far. However, progress is hindered by the theoretical uncertainties, the leading contribution to which is the uncertainty on the hadronic effects. The leading hadronic effect is the hadronic vacuum polarization, on which much work is being done, including by the Mainz group and ETMC, with updated and improved results presented at this conference. Tom Blum presented another avenue towards improving the precision of the lattice predictions by using all-mode-averaging. The next-largest contribution is hadronic light-by-light scattering, which naively would be an infeasible O($V^2$) calculation, but which can be attacked using simulations of QCD+QED with muons. This is particularly important, since reducing the error on this contribution to 10% would increase the tension (assuming the means remained the same) to the $5\sigma$ (="discovery") level.

After the last plenary, Derek Leinweber spoke a few closing words and the lattice community scattered again, to reconvene next year in Mainz.

This ends our coverage of Lattice 2012. I will be putting up a summary of what I learned from Cairns for organizing Lattice 2013 in Mainz later, and I will keep you updated on the preparations for Lattice 2013 as it approaches.

## **Lattice 2012, Days Three and Four**

*2012-06-29T07:54:00.004+02:00*

Apologies for the late update. Last night I was too tired (or tipsy, your guess) to blog.

Wednesday was the customary short day; there were plenary talks in the morning and excursions in the afternoon. Having already had a look at the wonders of the Great Barrier Reef in better weather before the conference, I decided to go to the zoo. In case that sounds kind of boring, let me tell you that the Cairns Tropical Zoo hosts some rather impressive animals; the saltwater crocodiles in particular are scarily big (one of them was known to eat cattle before he got captured), and the many birds and lizards are just very different from anything on the Northern hemisphere (and there were koalas and kangaroos, too).

Thursday started with another experimental talk, presented by Justine Serrano of LHCb, who spoke about the many flavour physics observations made by that collaboration. Highlights included pushing the bounds for the branching ratio $B_s \to \mu\mu$ very close to the Standard Model prediction (this is an observable for which most of the uncertainty actually comes from lattice QCD predictions of $f_{B_s}$) as well as observing the decay $B \to \pi\mu\mu$ for the first time (this is the rarest B decay ever observed). New measurements of $\phi_s$ from $B_s \to J/\psi\phi$ and $B_s \to J/\psi\pi\pi$ are compatible with zero, and the parameter space for many new physics models has already now been tightly constrained by LHCb. There is some tension in the (poorly known) UT angle $\gamma$ and in the isospin asymmetry in $B \to K\mu\mu$ and $K \to K^*\mu\mu$, but the latter discrepancy seems most likely to be a fluctuation that will go away with more data. LHCb has also made the most precise measurements of B spectroscopy so far. With an upgrade intended to improve the acquisition rate to 10-20 times ahead, LHCb will certainly continue to impress in the future.

The next speaker was Cecilia Tarantino talking about the theoretical side of flavour physics. Here one of the most pressing issues is the inclusive-exclusive discrepancy in $V_{ub}$ and $V_{cb}$, where in each case the inclusive and exclusive measurements differ by more than $2\sigma$. A unitarity triangle analysis favours the exclusive value for $V_{ub}$ and the inclusive value for $V_{cb}$; in each case more precise lattice input for the exclusive determination is needed along with more experimental data for the inclusive one. Another tension that arises in the UT fit is coming from the branching ratio BR($B \to \tau\nu$); this cannot be explained in the 2-doublet Higgs model of type II, but more elaborate 2-doublet Higgs models might still explain it. Since $D$ mixing is now entering the stage, we might become sensitive to different potential new physics, since the charm is an up-type quark; the $f_{D_s}$ puzzle, on the other hand, has now been resolved: the lattice values went up and the experiments came down.

The second plenary opened with a talk by Huey-Wen Lin on hadron structure from the lattice, where there are a number of open puzzles, some of most pressing ones of which are the nucleon charge radii and the axial charge of the nucleon. It is likely that many systematic effects contribute here, including excited states effects, which can be overcome by using the summation method or by explicitly including excited states in fits.

This was followed by a talk by Ross Young about nucleon strangeness measurements and their impact on dark matter searches. The theoretical uncertainties of dark matter searches are dominated by the uncertainties of the nucleon sigma terms, in particular the strange sigma term. These can analysed both directly from an analysis of nucleon three-point functions, or indirectly via the Feynman-Hellmann theorem. Modern estimates of the nucleon strangeness (and their errors) are much lower than those of ten years ago, and lattice QCD can contribute significantly to reducing the uncertainties of searches for the stuff than makes up one quarter of the Universe, but of which so far we somewhat embarrassingly no idea what it actually is.

The last plenary talk of the morning was given by Walter Freeman, who spoke about determining electromagnetic sea effects on hadron polarizabilities by reweighting. He compared various approaches to reducing the noise of stochastic estimators for reweighting factors, finding that neither projecting out the low modes nor introducing intermediate reweighting steps helped for this case, but that looking at derivatives of the reweighting factors instead and performing a hopping parameter expansion did help.

In the afternoon there were parallel sessions. Mainz graduate student Vera Gülpers gave a very nice talk on measuring the scalar form factor of the pion. My own talk was just an update on the ongoing radiative improvement of NRQCD, so actually not terribly exciting.

In the evening there was the conference banquet, which was very good; however, the waiting staff took the slightly strange decision to serve the chicken or vegetarian entree and the meat or fish main course to people based on whether they were seated on even or odd seats (I have no idea whether this might be an Australian custom, though).

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**Lattice 2012, Day Two**

*2012-06-26T14:02:00.000+02:00*

Hello again from Cairns. The first plenary of the second day began with a talk by Joel Giedt on technicolor-related theories on the lattice. Since two of the main theoretical problems facing the Standard Model, namely the hierarchy problem and the triviality problem, are related to the existence of a fundamental scalar, a clean solution to those problems might be to assume that no fundamental Higgs field exists and chiral symmetry is instead broken by a vacuum condensate of some new fermion fields interacting under some new "technicolor" gauge interaction. In order for such a fermion condensate to be able to give masses not just to the W and Z bosons, but also to the Standard Model fermions, there must be some interaction ("extended technicolor") mediating four-fermion interactions between the new and SM fermions, and in order for the resulting fermion masses to not be unreasonably suppressed, the technicolor theory must be slow-running ("walking") or conformal with an IR fixed point. Possible candidates for such models include QCD with $N_f = 12$ flavours, or with adjoint fermions. It appears that different groups studying these models are so far obtaining results that are impossible to reconcile with each other, so the picture still seems to be fairly confused.

Next was the traditional experimental talk, delivered by Geoffrey Taylor of ATLAS. As we all know, the LHC is running admirably and has delivered an unprecedented luminosity, which has allowed the "rediscovery" of the Standard Model to be performed very rapidly. No signs of BSM physics have been found so far, but exclusion limits on many SUSY particles, Kaluza-Klein modes and assorted exotics have reached the 1 TeV-scale, and large regions of the parameter space of many SUSY models have been ruled out. Also, the Standard Model Higgs has been ruled out above a mass of 130 GeV, but there is a tantalizing excess of events across multiple channels in the 120-130 GeV range. If this excess is the Higgs, an excess above SM expectations in the $\gamma\gamma$ channel might suggest that this is either not the SM Higgs, or that there are new particles mediating the Higgs decays. Of course there wasn't going to be any big reveal from experiments at the lattice conference – that will be reserved (assuming there is anything to reveal already) for ICHEP: the presentation of the results from CERN will be live-streamed on 4th July 2012. Until then the bets as to the next Nobel Prize are still open ...

The second plenary started after the coffee break with Norman Christ speaking about kaon mixing and $K \to \pi\pi$ decays on the lattice. These are very hard observables to treat, but working at (almost) physical quark masses and with a chiral fermion formulation helps significantly; the use of non-perturbative renormalization and extensions to the Lüscher formula also contributed to make the recent results that were shown possible.

This was followed by a talk by Takumi Doi presenting the work of the HALQCD collaboration on nuclear physics from lattice QCD. HALQCD measure Bethe-Salpeter amplitudes on the lattice and infer a non-local potential from them, which can then be expanded into local interactions. Besides nucleon-nucleon interactions, they have also studied hyperon-nucleon potentials and three-nucleon forces. A new contraction algorithm has helped them to significantly reduce the computational effort for these multi-quark correlators.

The last plenary talk was given by Marco Panero who spoke about Large-$N$

gauge theories on the lattice. In the limit of an infinite number of colours and vanishing coupling (such that the 't Hooft coupling $\lambda = g^2N$ remains finite), gauge theories are known to simplify significantly – perturbatively, only the planar diagrams without dynamical fermion loops survive, with all other classes of diagrams suppressed by some power of $1/N$. Non-perturbatively, numerical studies at $N > 3$ suggest that the large-$N$ limit is approached smoothly, with many thermodynamic observables showing only a trivial $N$-dependence.

In the afternoon there were parallel talks, and after that the poster session (Australian snacks are tasty, and Australian wines drink nicely). Certainly one of the prettiest posters was the one of Benjamin Jäger and Thomas Rae (both from Mainz) who presented the proposal and first tests of an anisotropic smearing method designed to improve signal-to-noise ratio for hadron with non-vanishing momentum.

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**Lattice 2012, Day One**

*2012-06-25T13:47:00.001+02:00*

Hello from Lattice 2012 in Cairns, Queensland, Australia (the tropical "down under"). I suppose this year we will have particularly many readers on this blog, since so many people couldn't make the long trip; I will try not to disappoint them too much.

Having had a couple of days to get over the jetlag and the acclimatization to the tropical climate here in Cairns, as well as to recover from the 32+ hour trip, I was quite ready for the conference to start. The reception last night was pleasant, and the staff are doing a great job keeping everything well-organized.

Today, the first session (after the Welcome by Derek Leinweber) was started by Stefan Schaefer, who spoke about prospects and challenges of dynamical fermion simulations. Over the last few years, the parameters of what would be considered a typical dynamical simulation have been steadfastly approaching to the physical point in the pion mass while increasingly larger and finer lattices are being studied. This progress has been made possible not just by Moore's law and increases in parallelism, but also and even more significantly by algorithmic improvements in the MD integrators used in HMC simulations, the solvers and preconditioners used in solving the Dirac equation (such as local deflation), and the treatment of the fermion determinant (e.g. the Hasenbusch trick or the DD-HMC), all of which are to some extent interrelated (in particular Stefan pointed out that a good frequency splitting in the determinant reduces force fluctuations, thereby aiding Omelyan-type integrators by making the difference between the shadow Hamiltonian and the real one more constant). One major issue confronting dynamical simulations at fine lattice spacings is the slowing down of the topological charge as the continuum limit is approached and the topological sectors emerge, leading to potentially very long autocorrelation times. One possible solution to this problem is to simulate using open boundary conditions in time, as proposed by Martin Lüscher and now implemented in the openQCD program, and first results demonstrating the absence of the problem in this setup were shown. I suppose it remains to be seen how the effects of the open boundary conditions on hadronic correlators can be handled (they are probably quite suppressed in the central region for large enough time extent).

Next was Jo Dudek talking about spectroscopy, with a focus on resonances and more qualitative statements rather then on precision physics with stable states. This is an area in which a number of experiments (including glueX, COMPASS and BES-III) are interested, but in which theory is still ahead of experiment, in particular as far as the search for hybrids is concerned; exotic hybrids in particular would present a "smoking gun" evidence of gluonic excitations in an experiment, but have not yet been seen. The work of the HadSpec collaboration, which Jo mainly presented, relies on the "distillation" approach for building correlation functions, and on the variational method with an operator basis constructed from quark bilinears with some covariant derivatives added in and the resulting operators put into definite continuum irreps and subduced to the corresponding lattice irreps. The results then allow to identify the continuum spin from which a given lattice state (at least predominantly) came on the basis of the generalized eigenvectors going with it. Moreover, it is possible to identify likely hybrids as presumably mainly containing a chromomagnetic excitation in addition to their quark model content, and to make some phenomenological statements about excitation energies and quark model identifications. The advantages of the distillation approach were demonstrated in the example of the $\eta/\eta'$ system, where the disconnected parts are much less noisy in this way then with other approaches.

After the coffee break, Daniel Mohler continued the topic of resonances with his talk reviewing methods and results for determining resonance parameters. Besides the now widely-used Lüscher method, he explained the histogram method (which at least I had not yet heard of) and reviewed a study comparing the two. In addition, recent results for a number of resonances including the $\rho$, the $K\pi$, $D\pi$ and $D^*\pi$ channels, were reviewed, and some even compared to experiment (which seemed to agree unexpectedly well given the limitations of the lattice results). As Daniel summarized, this is an area that is still in its infancy, but making good progress, even though a firm theoretical basis for treating the inelastic case appears to be lacking.

The next speaker was Taku Izubushi, who spoke about QCD+QED on the lattice. Isospin symmetry is broken not just by the different up and down quark masses, but also by electromagnetic effects, which need to be treated in order to go beyond the isospin limit. Another reason for being interested in QED effects is that the hadronic contributions to the anomalous magnetic moment of the muon are the source of the dominant theoretical uncertainty for this precision observable, in which there is some persistent tension between SM predictions and experiment, and that the next-to-leading hadronic contribution involves the hadronic light-by-light scattering amplitude, which can probably only be computed in a QCD+QED simulation of some sort. By adding quenched non-compact QED fields onto an existing lattice ensemble and reweighting the individual configurations accordingly, it is now possible to simulate QCD+QED, and this has been used to determine the electromagnetic effects on masses and decay constants; the difference of the up and down quark masses has also been determined, along with its effects on the nucleon mass difference.

The last plenary speaker was Tatsu Misumi with a talk about new fermion discretizations. He summarized the recent developments in this field by demonstrating some of the connections between the different recent proposals of new fermion actions, including what he called "flavored mass" (which includes the staggered overlap fermions of Adams), the "central branch" (Wilson fermions without the on-site term) and the "flavored chemical potential" (minimally doubled fermions) formalisms. In particular the Adams case of the "flavored mass" formalism was shown to possess attractive features, such as reducing the numerical cost for overlap fermions and the taste breaking effects for staggered fermions, while exactly preserving hypercubic symmetry (which is broken e.g. for the minimally doubled fermions).

After the lunch break (let it be noted that eating out in Cairns [perhaps generally in Australia? – I wouldn't know] is rather expensive) there were parallel sessions. After the last of those, I had a slightly heated discussion about the one and only truly correct way to automate lattice perturbation theory (my sincere apologies to anyone offended by the raised voices – it was all settled peacefully in the end, possibly just in time before the Convention Centre staff would have thrown us out of the building to lock up).

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### Recent progress regarding the rooting procedure

*2012-04-12T16:45:00.001+02:00*

The fourth-root trick for the staggered determinant has long been controversial. Most recently, the debate has been rekindled by a series of papers by Mike Creutz, in which he argues that the rooting procedure fails in specific ways. While some of the arguments have been refuted by members of the staggered community, criticisms related to the question whether the rooted staggered theory can describe the axial anomaly correctly remain important. A direct physical probe of the axial anomaly is given by the $\eta' - \eta$ splitting. Unfortunately, the determination of this splitting requires the evaluation of disconnected contributions to the $\eta'$ correlator, which are very noisy and cannot be measured with sufficient precision to make a clear statement at the current time. In his recent paper, Stephan Dürr approaches the question of the correctness of the rooting procedure from the angle of a theory in which sufficient statistics can be readily obtained, namely the Schwinger model.

The Schwinger model is simply QED in 1+1 spacetime dimensions, as far as its action is concerned. Its physics is, however, radically different from that of QED in 3+1 dimensions, since firstly there is neither spin nor a physical gauge boson degree of freedom in 1+1d, and secondly the 1-dimensional Coulomb potential is linear and hence confining. The Schwinger model therefore has a spectrum similar to that of QCD, with a mass gap and meson degrees of freedom (note that there are neither baryons nor "photoballs" due to the abelian nature of the interaction [although there aren't any glueballs in 1+1d QCD either due to the absence of the gauge boson as a degree of freedom]), and can therefore serve as a laboratory for ideas in QCD. The basic meson $\eta$ of the Schwinger model, which Schwinger demonstrated to have a mass squared of $m^2 = e^2/\pi$ (where $e$ is the dimensionful gauge coupling in 1+1d), in particular, is an analogue of the $\eta'$ in QCD, since its mass is mainly due to the axial anomaly.

The Schwinger model is much easier to simulate than QCD both because two dimensions are easier than four, and also because it turns out that reweighting works very well in two dimensions where the fermionic determinant can be evaluated exactly due to its comparably small size, so that one can generate quenched ensembles and include the fermionic determinant via reweighting. In particular the latter feature allows the generation of huge statistics (80,000 configurations in this case). Dürr employs an algorithm incorporating the introduction of instantons and antiinstantons as well as parity transformations to optimize the sampling of topological sectors. The resulting ensembles are then used to simulate the $N_f = 1(2)$ Schwinger model via reweighting with the rooted (unrooted) staggered fermion determinant. The latter is correct by construction; testing the former is the motivation for the study.

Using all-to-all propagators and U(1)-projected triply APE-smeared gauge links, Dürr is able to show the validity of the staggered index theorem with impressive precision. Turning to the meson spectrum, he finds that the connected part of the $\eta$ has the same mass as the $N_f = 2$ $\pi$ meson up to cut-off effects, so that the mass of the physical $\eta$ in the chiral limit comes entirely from the disconnected part. The ratio of the disconnected to the connected Green's functions for the $\eta$ approaches the correct limiting value expected if the rooting trick works correctly. After a continuum and chiral extrapolation, he finds that the mass of the $N_f = 1$ $\eta$ meson agrees with Schwinger's analytical result.

This paper provides a very interesting study that adds to the empirical support for the correctness of the rooting procedure for staggered quarks. Of course it remains to see if this result will carry over to QCD, but I'd be honestly surprised if it didn;t. An analytical construction demonstrating the correctness of the rooted staggered formalism would of course be very welcome. Perhaps some of the recent results regarding the connection between staggered and overlap fermions will point the way in that regard.

# 2011

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### Lattice 2013 in Mainz

*2011-12-20T16:16:00.000+01:00*

If you are at all tuned in to the gossip of the lattice community, you will probably have heard that Mainz will be organizing the annual lattice conference in 2013. I can now confirm that LATTICE 2013 (The XXXI International Symposium on Lattice Field Theory) will take place at the Johannes-Gutenberg-University in Mainz in the week July 29 to August 3, 2013. We look forward to welcoming you here, and I expect to keep you updated on the progress of our preparations as the date approaches.

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### Lattice 2011, Day Six

*2011-07-17T04:15:00.001+02:00*

The last day of the conference had two last plenary sessions in the morning. The first began with a talk on lattice QCD with classical and quantum electrodynamics by Brian Tiburzi. In order to measure the electric polarizabilities of hadrons, their energy shift in a constant external electrical field is measured. Classical magnetic fields are also of interest, since they may affect the phase diagram of QCD by catalysing chiral symmetry breaking, possibly creating exotic superconducting phases of QCD matter. Quantum corrections to charged particle properties are also being studied using QED coupled to quarks, but this is still rather hard to do.

Next was John Bulava with a talk on excited hadrons. In order to study excited states, an approach like the GEVP is mandatory, which requires the measuring of multiple correlators with a suitable basis of operators. Since this basis eventually also needs to include multi-hadron states, some form of all-to-all propagators is needed, and John presented the distillation and the stochastic LapH approaches, which are based on an expansion in the low modes of the covariant Laplacian on a time slice.

After that, Dru Renner spoke about ETMC's recent work on QCD corrections to electroweak observables, in particular the (g-2) work for which they had been awarded the Ken Wilson Award, but also new work on hadronic contributions to the running of $\alpha_{e.m.}$ and new NLO results for (g-2), which however exclude the light-by-light contribution.

In the second plenary, Hartmut Wittig gave the review talk about low-energy particle physics and chiral extrapolations. The most recent results from the BMW collaboration on the light and strange quark masses are consistent with the FLAG averages, and this remains the case if BMW's lightest (physical and lighter) pion masses are omitted in the chiral extrapolation (or interpolation), indicating that pion masses below 250 MeV are light enough for few-percent accuracy in this area. There are, however, uncertainties in the overall scale of the pion and kaon decay constants which may be due to combined pion mass and discretization effects. Hartmut also presented recent progress in the determination of $g_A$ of the nucleon.

A review of kaon physics was given by Robert Mawhinney. I'm afraid I can't adequately summarize his talk (there was just too much material).

The final talk was given by Anna Hasenfratz, who spoke about reweighting in the quark mass. Reweighting is an old idea, but recently it has picked up steam in lattice QCD and is now widely used to achieve lighter quark masses, to stabilize simulations, or to incorporate electromagnetic effects. Since the overlap between the simulated and the target distribution must not be too small, the Hasenbusch trick has to be used when reweighting to small quark masses. A new, quadrature-based, approach avoiding the need for inversions has been introduced at this conference by Abdel-Rehim et al.

After this, the conference closed with a round of well-deserved applause for the Local Organizing Committee.

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**Lattice 2011, Day Five**

*2011-07-17T04:14:00.000+02:00*

Sorry for the delayed update; I was too tired to blog last night.

The first plenary of the fifth day started with a talk by David Kaplan with the intriguing title "Listening to Noise". The topic of the talk was in fact noise, which of course affects baryonic correlators particularly badly. Studying unitary fermions as a toy model, David Kaplan showed that the distribution of the measured correlator values approaches a log-normal distribution, i.e. their logarithms approach a normal distribution. Exploiting this, one can attempt to use the cumulants of the measured distribution to extract an effective mass with reduced noise, and this does indeed work in the case of unitary fermions. For QCD, additional tricks may be needed.

The next talk was given by Kostas Orginos, who gave a review of hadron interactions on the lattice. This is still a very difficult problem, and new and better methods will be needed to make progress.

The last talk before the break was on a non-scientific topic, namely the situation in Japan after the great earthquake, presented by Shojo Hashimoto. Besides the terrible loss of life and the large number of people made homeless by the tsunami, the subsequent nuclear meltdown at Fukushima has further worsened the impact of the disaster. Not only have numerous towns been contaminated by Cs-137 (it takes a real physicist to show a curve of the measured radiation and remark upon the perfect exponential curve described by the decay of I-131), but also the power supply has been adversely affected by the shutdown of the nuclear power plants; a shortfall of 10-15% is expected in the summer, and hence power-intensive scientific facilities such as PACS-CS can only run at night. The US and the UK have stepped into the gap and have donated computer time on their machines to Japanese colleagues.

The second plenary was devoted to flavour physics. Enrico Lunghi spoke about the tensions observed in the unitarity triangle fits between sin$(2\beta)$ and the branching ratio $B\to\tau\nu$, in $(g-2)_\mu$, $\phi_{B_s}$, and the branching ratio $B_s\to\mu^+\mu^-$. The LHCb experiment should be able to clarify the situation soon.

This was followed by a review of heavy-flavour physics on the lattice by Christine Davies, who summarized the different approaches (NRQCD, HQET, Fermilab, relativistic heavy quarks on fine lattices with highly improved actions) and results for the charm and bottom masses and the decay constants and form factors of charm and bottom mesons, as well as for the B meson mixing parameters.

The plenary session closed with the invitation to LATTICE 2012 to be held in Cairns, Australia, from 24th to 29th June 2012.

In the afternoon there were parallel sessions one last time (this included my own talk in the last possible slot).

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**Lattice 2011, Days Three and Four**

*2011-07-15T07:29:00.001+02:00*

Wednesday was the customary short day, without any plenaries and with morning parallel sessions. The afternoon was free for excursions. I joined some colleagues on a self-organized hiking trip on the Five Lakes Route, which was a short drive from the Village. The view from the upper parts of the trail was very nice, and the hike not too strenuous. At the end, the path got kind of lost in snow, so we only saw one of the five lakes before descending again.

Today's plenaries were almost entirely devoted to finite-temperature QCD. The first speaker of the first session was Ludmilla Levkova, who gave the review talk on finite temperature and density. Since it is always hard to summarize a summary, I'll refrain from trying, and instead just highlight some of the things in her talk that I found particularly interesting. One is that there are efforts to understand the effects of magnetic fields on the nature of the QCD phase transition; this never occurred to me as a question, but once you realize that the magnetic fields in off-axis heavy-ion collisions are of the order of $10^{14}$ T, it seems quite a natural problem. The other was that the equation of state obtained from different lattice actions comes out significantly different. Some hope to resolve those differences may come from a new method to determine the equation of state that has recently been introduced by Giusti and Meyer.

The next talk was another experimental talk, given by Barbara Jacak of the PHENIX experiment. It is now known that the quark-gluon plasma is a nearly perfect liquid, and there is evidence that all strongly coupled plasmas are alike in some sense. Important remaining questions on which input from the lattice is needed are whether there are quasiparticles in the QGP and if so, what they are, as well as whether there are any relevant screening lengths.

The second plenary was opened with Swagato Mukherjee speaking about fluctuations and correlations at finite chemical potential. Since the fermionic determinant is in general no longer real in the presence of a chemical potential, no direct Monte Carlo evaluation of the path integral is possible in this case. A way around this is to consider the Taylor-expansion around zero chemical potential, and in this case generalized susceptibilities arise as Taylor coefficients. These can be related to moments of fluctuations of the baryon number, which are accessible experimentally. In order to connect the experiments, which controlled by the center of mass energy $\sqrt{s}$, to theoretical determinations which are controlled by the temperature $T$ and the chemical potential $\mu$, the hadron gas model is used, apparently with good success.

Next was a talk about U(1)$_A$ in hot QCD by Prasad Hegde. At zero temperature, the axial U(1) symmetry of QCD is broken by the axial anomaly, which among other things gives rise to the $\eta/\eta'$ mass splitting. Since the spontaneously broken chiral SU($N_f$)$_L\times$SU($N_f$)$_R$ symmetry is restored at finite temperature, it may be natural to ask if the same happens for the axial U(1) symmetry. Indeed, since the axial anomaly is related to the topological charge of the fields, it is known that the axial U(1) symmetry is restored in the infinite-temperature limit by the screening of the chromoelectric fields (as the topological charge density is proportional to E.B). However, studies using both staggered and domain wall quarks indicate clearly that U(1)$_A$ remains broken above the critical temperature.

The last talk of the morning was by Balint Jóo, who gave a review of the role of GPUs in lattice simulations. By now, many lattice groups have discovered GPUs as a cost-effective means of accelerating computations, which however have their own issues (in particular related to the programming model and to the PCIe bus as a bottleneck in transferring data between GPUs and the CPU). A number of QCD codes have been or are being ported to GPUs (QUDA, QDP++ for GPUs).

In the afternoon there were parallel sessions again. In the evening, we took the cable car to High Camp, which is located at an altitude of about 8100 ft (ca. 2500 m) for the conference banquet. The buffet was good, the desserts very rich, the wine rather effective due to the reduced oxygen pressure at high altitude (for which reason I ask to be forgiven for any mistakes in this summary), and the view from the cable car truly spectacular.

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**Lattice 2011, Day Two**

*2011-07-13T17:15:00.000+02:00*

Hello again from Squaw Valley.

Today's first plenary was devoted entirely to beyond-the-Standard-Model physics. The first speaker was Aleksi Kurkela, who spoke about large extra dimensions and the lattice. Extra dimensions are phenomenologically appealing, but since gauge theories in $d > 4$ are non-renormalizable, they are defined only up to a regularization. Results from the $\epsilon$-expansion suggest the existence of a non-Gaussian UV fixed point in higher dimensions, but since $d = 5$ is well outside of the expected convergence radius of the expansion, lattice studies are needed to check this; for the isotropic case it does not appear to be true, but for the anisotropic case there is evidence that it is indeed true. When the fifth dimension is compactified, new effects arise; in some cases, knowledge of the correlation length of the dimensionally reduced theory can give bounds on the compactification radius.

The second plenary talk was the traditional experimental talk, delivered by Adam Martin from Fermilab. With $1\,\text{fb}^{-1}$ of data both ATLAS and CMS can exclude the Higgs mass range from 130 GeV to 460 GeV at the 95% confidence level; with $5-10\,\text{fb}^{-1}$, they should be able to either exclude the full mass range up to 600 GeV or else claim a $5\sigma$ discovery. In the low mass range, the Tevatron is currently still more sensitive; CDF has seen a bump in the $W/Z+jj$ cross section, which appears to be ruled out by D0, so this seems to be a case where backgrounds need to be understood better before reaching any conclusions. Other interesting discrepancies include the tt forward-backward asymmetry and the like-sign dimuon charge asymmetry. We should "stay tuned this summer for exciting results".

The BSM theme was continued in the second plenary. Ethan Neil gave a talk about new physics models on the lattice, giving an account of the ($N_c$,

$N_f$, representation) space of models studied in the search for the conformal window, and of the methods used to study them, including spectral studies, studies of finite-T phase transitions and the Monte Carlo Renormalization Group.

In the next talk, Daniel Nogradi spoke about a specific model that has particular phenomenological appeal, namely the SU(3) theory with $N_f = 2$ fermions in the sextet representation. This theory has exactly three Goldstone bosons, allowing for Higgs-less electroweak symmetry breaking, and may allow for a small S-parameter (unacceptably large values for the S-parameter being a problem plaguing many technicolor-like models).

At the end of the plenary sessions, the first Ken Wilson lattice award was awarded to Xu Feng, Karl Janssen, Marcus Petschlies and Dru Renner for their recent paper on the anomalous magnetic moment of the muon.

In the afternoon, there were parallel sessions, and in the evening, the poster session took place.

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**Lattice 2011, Day One**

*2011-07-12T07:25:00.000+02:00*

Hello from The Village at Squaw Valley, where I am at the Lattice 2011 conference. Having arrived late yesterday (actually early today), I still feel rather tired and would like to ask my readers to ascribe any glaring errors or omissions in todays post to that fact.

The welcome was in a different style from the usual speeches – we were shown a short movie by Massimo Di Pierro that combined elements of "Star Wars" and the "Powers of 10" educational film with images of topological charge densities measured on the lattice. Also unusual was the announcement of a Tesla card raffle sponsored by nVidia.

After that, the first plenary session started with a talk by Eigo Shintani on the determination of $\alpha_s$ from lattice QCD. In fact, currently lattice determinations are dominating the world average for $\alpha_s(M_Z^2)$, although there are some discrepancies with other methods. Shintani focussed mainly on the efforts of the JLQCD collaboration, which is based on measuring the light quark vacuum polarization using dynamical overlap fermions, which then can be compared directly to an operator product expansion performed in the continuum, and $\alpha_s$ can be determined by matching to continuum perturbation theory. Other determinations that have been performed have used the Schrödinger functional (ALPHA, PAC-CS), Wilson loops and lattice perturbation theory (HPQCD), and moments of heavy quark current-current correlators (also HPQCD).

The next speaker was Shou-Cheng Zhang from Stanford, who spoke about a topic condensed matter theory that has some interesting connections to lattice QCD, namely topological insulators and superconductors. These are ”materials that realize theoretical ideas” in that they cause concepts that are otherwise the realm of theory to appear in an experimentally accessible context. Examples included the appearance of the 3-dimensional Wilson-Dirac operator in the description of a two-dimensional topological insulator, the possibility to have a QED $\theta$-term with $\theta = \pi$ in a topological superconductor, or the appearance of a Dirac monopole as the image charge of a point charge in front of a topological superconductor. These materials also have the possibility to have an enormous technological impact by creating the possibility of having dissipation-free electron flows at room temperature, which could revolutionized electronics and lead to much faster computers.

The last speaker of the session was Mithat Ünsal talking on large-N volume independence and related ideas. Provided that translation invariance and centre symmetry are not spontaneously broken, there is the possibility of reducing QCD in the limit of infinitely many colours to a large-N matrix model. While the Eguchi-Kawai model and its various extensions have failed due to centre symmetry breaking, there appears to be some hope that some other kinds of matrix models could give new insights into gauge theories.

After the coffee break, the second plenary of the day began with Laurence Yaffe speaking about an approach to heavy-ion collisions that begins with simplifying the complicated situation to the much simpler of colliding shockwaves in $N = 4$ super-Yang-Mills theory, which has a dual description as a collision of gravitational waves via the AdS/CFT correspondence. After thus reducing a non-equilibrium problem in a strongly coupled QFT with an initial-value problem in a classical field theory, it turns out that after applying a number of tricks, Einstein’s equations for this situation can be converted into a set of nested ODEs that can be solved numerically.

Next was a talk by Jack Laiho on Asymptotic Safety and Quantum Gravity. The concept of asymptotic safety as introduced by Weinberg states that a perturbatively non-renormalizable theory may still be well-defined and possess predictive power if its renormalization group flow has an ultraviolet fixed point with a finite number of relevant directions. There is some numerical evidence that gravity might be asymptotically safe with only three parameters. In a Euclidean framework, asymptotic safety corresponds to the existence of a critical point. This scenario has been studied in a number of different formulations, including the Euclidean dynamical triangulations of Ambjorn et al. (which have a crumpled phase with infinite Hausdorff dimension and a branched polymer phase with Hausdorff dimension 2, separated by a first-order phase transition, and hence no hope to describe continuum physics) and the Causal Dynamical Triangulations of Ambjorn and Loll (which have a large-scale solution in the form of de Sitter space, and where the spectral dimension runs from 2 at short scales to 4 at large scales). Jack and his student have studied what happens if one adds a measure term to the Regge action, and have found that there are three phases (collapsed, extended, and branched polymer phase) with the possibility of a critical end point in the phase diagram, which could realize the scenario of asymptotic safety. There is also evidence that the spectral dimensions runs from 4 at large scales to 3/2 at short scales, where the dimension 3/2 would reconcile the requirements of holography and the Bekenstein-Hawking entropy.

The last plenary speaker of the day was Paul Rakow, who spoke about flavour-blindness and the pattern of flavour breaking in $N_f = 3$. Since the masses of the light and strange quarks are not identical, the SU(3) flavour symmetry is explicitly broken. Expanding in this breaking around the symmetric theory and exploiting the representation theory of SU(3) allows one to understand the way the physical point is approached in lattice simulations.

In the afternoon there were parallel sessions.

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**What's new at the fermion zoo?**

*2011-02-11T17:07:00.000+01:00*

If there is anything more typical of the landscape of lattice QCD than collaboration acronyms that mean something very different (like a car manufacturer, a color model, or an old DOS command), to people from outside the lattice community, it has to be the fact that each of the aforementioned collaborations uses a fermion action that is in some way different from those of all other collaborations. For gauge actions, there isn't all that much variety (Wilson, tree-level Symanzik, Lüscher-Weisz with or without O($N_f \alpha_s a^2$) corrections, and Iwasaki), but for fermions there is a veritable zoo.

Of course, for every zoo, there is a Linnean system establishing a taxonomy, so the fermion zoo can be ordered by grouping the fermion actions into different classes:

- **Wilson fermions** get rid of the doublers by adding a term (the Wilson term) to the action that explicitly breaks chiral symmetry and thus lifts the degeneracy of the doublers, giving them masses of the order of the cut-off. Wilson fermions can be subdivided further firstly into straight Wilson fermions (which have O(a) discretization effects and hence are rarely used) and O(a)-improved Wilson fermions, which add another term, the Sheikholeslami-Wohlert term, to reduce the lattice artifacts to be O($a^2$). The numerous individual actions being used then differ mainly by the kind of links that go into the discretized derivatives (and possibly into the SW term), whether they are thin links for rigorous locality and positivity properties, or different kinds of smeared links for empirically better statistical behaviour of various observables.

- **twisted-mass fermions** are close relatives of Wilson fermions, consisting of a doublet of unimproved Wilson fermions with a twisted mass term of the form $\tau_3\gamma^5$; the doublet is interpreted as the up/down isospin doublet. One of the attractive features of twisted fermions is that spectral observables are automatically O(a)-improved. On the other hand, isospin and parity are violated by cut-off effects, which leads to potentially undesirable features such as a neutral pion with the quantum numbers of the vacuum.

- **staggered fermions** reduce the number of doublers to four by redistributing the degrees of freedom between sites. Also here, improvement by adding an additional three-link term (the Naik term) is commonly employed. Significant use is made of smearing to reduce the impact of high-momentum gluons whose exchange results in interactions mixing the different ”tastes” of remaining doublers. An advantage of the staggered formalism is the preservation of a residual chiral symmetry; a disadvantage is the need to take the root of the determinant of the Dirac operator (unless one wants to simulate with $N_f = 4$ degenerate flavours), and issue that has been surrounded by some controversy. The actions in current use are the asqtad and HISQ actions.

- **overlap fermions** are constructed as an exact solution to the Ginsparg-Wilson relation by means of the overlap operator, which is essentially the matrix sign function of the Wilson Dirac operator. While having the obvious theoretical advantage of exact chiral symmetry at finite lattice spacing, overlap fermions are *very* expensive to simulate, and thus are not in widespread use yet.

- **domain-wall fermions** use a fictitious fifth dimension to realize chiral symmetry by localizing the opposite chiralities on different ”branes” or domain walls in the fifth direction. They are likewise rather expensive to simulate.

Of course, life being incredibly diverse, every taxonomist will sooner or later run into a creature which defies the existing taxonomic scheme. The past year has, I think, been such an occasion for the fermion zoo, which was increased by the addition of what may become two new families of fermions that straddle the boundaries between the classes outlined above.

One is the family of **minimally doubled fermions**, which are being championed by Mike Creutz and by people here at Mainz. The idea is to find an action which has the minimal number of doublers permitted for a chirally symmetric Dirac operator by the Nielsen-Ninomiya theorem, i.e. a doublet of fermions that can then be interpreted as the up/down doublet. There are two realizations of this idea, now known as Karsten-Wilczek and Creutz-Borici fermions, respectively, both of which rely on the addition of a Wilson-like term to the action. In a way, this puts them somewhere between Wilson and staggered fermions, the latter because of the existence of taste-changing interactions; of course, no rooting is required to simulate an $N_f = 2$ theory with minimally doubled fermions. The price paid is that, because the line connecting the two poles in momentum space defines a preferred direction, at least one of the discrete spatiotemporal symmetries must be broken; this leads to the possibility of generating additional (relevant in the RG sense) dimension-3 operators in the action, which have to be fine-tuned away. Simulations with minimally doubled fermions are in preparation and will have to deal with these questions; it remains to be seen if this formulation will have practical relevance beyond its obvious theoretical impact.

The other new fermion family are the **staggered overlap fermions** introduced at this year's lattice conference by David Adams, and which as suggested by the name close the gap between staggered and overlap fermions. The idea here is to perform a similar construction to that used to obtain the overlap operator from the Wilson Dirac operator, but taking the staggered Dirac operator as the starting point. As it turns out, this results naturally in a theory with two fermion flavours, so again no rooting is required to simulate an up/down doublet in this fashion.

Like all taxonomy-defying creatures, these new fermion actions hold the potential to reveal hitherto unknown connections between previously unconnected classes of entities, in this case perhaps by establishing new connections between the number of flavours, chiral symmetry, doubling and the staggered formalism.

# 2010

## Blogging ICHEP 2010

*2010-07-24T11:50:00.001+02:00*

I'm currently at the ICHEP 2010 conference in Paris, from where I'm blogging at the official ICHEP 2010 blog. I'll post a summary here later, but for now come over and follow me and the wonderful other bloggers at Blogging ICHEP 2010!

## Lattice 2010, Day Five

*2010-06-19T10:06:00.000+02:00*

The day started with plenary sessions again. The first plenary speaker was Chris Sachrajda on the topic of phenomenology from the lattice. Referring to the talks on heavy and light quarks, spectroscopy and hadron structure for those topics, he covered a mix of various phenomenologically interesting quantities, starting from those that have been measured to good accuracy on the lattice and progressing to those that still pose serious or perhaps even unsurmountable problems. The accurate determination of $V_{us}/V_{ud}$ from $f_K/f_\pi$ and of $V_{us}$ from the $K_{l3}$ form factor $f^+(0)$, where both the precision and the agreement with the Standard Model are very good, clearly fell into the first category. The determination of $B_K$ is less precise and there is a $2\sigma$ tension in the resulting value of $|\epsilon_K|$. Even more challenging is the decay $K \to \pi\pi$, for which however progress is being made, whereas the yet greater challenge of nonleptonic B-decays cannot be tackled with presently known methods. Chris closed his talk by reminding the audience that at another lattice conference held in Italy, namely that of 1989 (i.e. when I was just a teenager), Ken Wilson had predicted that it would take 30 years until precise results could be attained from lattice QCD, and that given that we still have nine years we are well on our way.

The next plenary talk was given by Jochen Heitger, who spoke about heavy flavours on the lattice. Flavour physics is an important ingredient in the search for new physics, because essentially all extensions to the Standard Model have some kind of flavour structure that could be used to find them from their contributions to flavour processes. On the lattice, "gold-plated" processes with no or one hadron in the final state and a well-controlled chiral behaviour play a crucial role because they can be treated accurately. Still, treating heavy quarks on the lattice is difficult, because on needs to maintain a multiscale hierarchy of $1/L \ll m_\pi \ll m_Q \ll 1/a$. A variety of methods are currently in use, and Jochen nicely summarized results from most of them, including, but not limited to, the current-current correlators used by HPQCD, ETMC's interpolation of ratios between the static limit and dynamical masses, and the Fermilab approach, paying special attention to the programme of non-perturbative HQET pursued by the ALPHA collaboration.

The second plenary session started with a talk by Mike Peardon about improved design of hadron creation operators. The method in question is the "distillation" method that has been talked about a lot for about a year now. The basic insight at its root is that we generally use smeared operators to improve the signal-to-noise ratio, and that smearing tends to wipe out contributions from high-frequency modes of the Laplacian. If one then defines a novel smearing operator by projecting on the lowest few modes of the (spatial) Laplacian, this operator can be used to reexpress the large traces appearing in correlation functions with smaller traces over the space spanned by the low-modes. If the smearing or "distillation" operator is $D(t) = V(t)V(t)^+$, one defines the "perambulator" $\tau(t,t') = V(t)^+M^{-1}(t,t')V(t')$ that takes the place of the propagator, and reduced operators $\Phi(t) = V(t)^+\Gamma V(t)$, in terms of which to write the small traces. Insertions needed for three-point functions can be treated similarly by defining a generalized perambulator. Unfortunately, this method as it stands has a serious problem in that it scales very badly with the spatial volume – the number of low-modes needed for a given accuracy scales with the volume, and so the method scales at least like the volume squared. However, this problem can be solved by using a stochastic estimator that is defined in the low-mode space, and the resulting stochastic method appears to perform much better than the usual "dilution" method.

The last speaker of the morning was Michele Pepe with a talk on string effects in Yang-Mills theory. The subject of the talk was the measurement of the width of the effective string and the observation of the decay of unstable k-strings in SU(2) gauge theory. By using a multilevel simulation technique proposed by Lüscher and Weisz, Pepe and collaborators have been able to perform these very challenging measurements. The results for the string width agree with theoretical expectations from the Nambu-Goto action, and the expected pattern of k-string decays ($1 \to 0$, $3/2 \to 1/2$, and $2 \to 1 \to 0$) could be nicely seen in the plots.

The plenary session was closed by the announcement that LATTICE 2011 will be held from 10-16th July 2011 at the Squaw Valley Resort in Lake

Tahoe, California, USA.

In the afternoon there were again parallel sessions.

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**Lattice 2010, Day Four**

*2010-06-18T12:06:00.000+02:00*

Today's first plenary session was started by Kazuyuki Kanaya with a talk on finite-temperature QCD. Many groups are looking for the transition temperature between the confined and deconfined phases, but since in the neighbourhood of the physical point, the transition is most likely a crossover, the value of the "critical" temperature found may be dependent on the observable studied. There was further some disagreement even between different studies using the same observables, but those discrepancies seem to have gone mostly away.

Next was Luigi Del Debbio speaking about the conformal window on the lattice. The motivation for those kinds of studies is the hope that the physics of electroweak symmetry breaking by originate not from a fundamental scalar Higgs, but from a fermionic condensate similar to the chiral condensate in QCD arising from a gauge theory ("technicolor") living at higher energy scales, perhaps around 1 TeV. To make these kinds of models viable, the coupling needs to run very slowly. One is then motivated to look for gauge theories having an infrared fixed point. Lattice simulations can help studying the question which combinations of $N_c$, the number of colours, and $N_f$, the number of fermion flavours, actually exhibit such behaviour. The Schrödinger functional can be used to study such questions, but while there are a number of results, no very clear picture appears to have emerged yet.

The second plenary session of the morning was opened with a talk on finite-density QCD by Sourendu Gupta. QCD at finite density, i.e. finite chemical potential, is plagued by a sign problem because the fermionic determinant can no longer be real in general. A number of ways around this problem have been proposed. The most straightforward is reweighting, the most ambitious a reformulation of the theory that manages to eliminate the sign problem entirely. On the latter front, there has been progress in that the 3D XY model, which also has a sign problem, has been successfully reformulated in different variables in which it does no longer suffer from its sign problem; whether something similar might be possible for QCD remains to be seen. Other approaches try to exploit analyticity to evade the sign problem, either by Taylor-expanding around zero chemical potential and measuring the Taylor coefficients as susceptibilities at zero chemical potential, or by simulating at purely imaginary chemical potential (where there is no sign problem) and extrapolating to real chemical potential. In this way, various determinations of the critical point of QCD have been performed, which agree more or less with each other. All of them lie in a region through which the freeze-out curve of heavy-ion experiments is expected to pass, so the question of the location of the critical point may become accessible experimentally. The last plenary talk of the morning was Takeshi Yamazaki talking on a determination of the binding energy of helium nuclei in quenched QCD. The effort involved is considerable (there are more than 1000 different contractions for $^4$He, and the lattices considered have to be very large to be able to accommodate a helium nucleus and to distinguish between true bound states and attractive scattering states), even though the simulations were quenched and the valence quarks used corresponded to a pion mass of about 800 MeV. The study found that helium nuclei are indeed bound.

In the afternoon there were parallel sessions.

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**Lattice 2010, Days Two and Three**

*2010-06-17T10:01:00.000+02:00*

Yesterday was an all-parallels day, so there are no plenary talks to summarize. In the evening there was the poster session.

The internet connection at the resort does not really have the capacity to deal with 360 computational physicist all reading their email, checking on their running computer jobs, browsing the hep-lat arXiv or writing their blog at the same time; this may lead to late updates from me, so please be patient.

Today's first plenary session was the traditional non-lattice plenary. The first talk was by Eytan Domany, who spoke about the challenges posed to computational science by the task of understanding the human genome. A large part of his talk was an introduction to the biological concepts involved, such as DNA, chromosomes, genes, RNA, transcription, transcription factors, ribosomes, gene expression, exons, introns, "junk" DNA, regulation networks and epigenetics. These days, it is possible to analyse the expression of thousands of genes in a sample by means of a single chip, and the data obtained by performing this kind of analysis on large numbers of samples (e.g. from different kinds of cells or from different patients) can be seen as an expression matrix with rows for genes and columns for samples. The difficult task is then to use this kind of large data matrix to infer regulation networks or connections between gene expression and phenotypes. Apparently, there are physicists working in this area together with the biologists, bringing in their computational expertise.

The second plenary talk was an LHC status summary given by Slawek Tkaczyk. The history of the LHC is of course well known to readers of this blog; so far, the first data are being analysed to "rediscover" the Standard Model with the aim of discovering new physics in the not too distant future, but there was no evidence of e.g. the Higgs or SUSY shown (yet?).

The second plenary session was devoted to non-QCD lattice simulations. The first talk was Renate Loll speaking on Lattice Quantum Gravity, specifically on causal dynamical triangulations. This approach to Quantum Gravity starts from the path integral for the Einstein-Hilbert action of General Relativity and regularizes it by replacing continuous spacetime with a discrete triangulation. The discrete spacetime is then a simplicial complex satisfying certain additional requirements, and the Wick-rotated path integral can be treated using Monte Carlo techniques. In one phase of the (three-parameter) theory, the macroscopic structure of the resulting spacetime has been found to agree with de Sitter-space. Another surprising and interesting result of this approach has been that the spectral dimension associated with the diffusion of particles on the discrete spacetime is continuously going from around 2 at short (Plackian) to 4 at large distances.

Next was a talk on exact lattice SUSY by Simon Catterall. Normally, a lattice regularization completely ruins supersymmetry, but theorists have found a way to formulate certain classes of supersymmetric theories (including N=4 Super-Yang-Mills) on a special kind of lattice, giving a local, gauge-invariant action with a doubler-free fermion formulation. This may offer a chance to study quantum gravity by simulations of lattice SUSY via the AdS/CFT correspondence.

In the afternoon there were excursions. I had signed up to the only excursion for which places were still available, which was a tour of a Sardinian winery with a wine tasting. The tour was not too interesting, as everything was very technologically modern, and as somebody said, we can go and look at the LHC if we want to see modern technology. The wines tasted were very nice, though.

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**Lattice 2010, Day One**

*2010-06-14T21:39:00.001+02:00*

Hello from the Atahotel Tanka Village Resort in Villasimius, Sardinia, Italy, where I am at the Lattice 2010 conference.

The conference started this morning with a talk by Martin Lüscher about ”Topology, the Wilson flow and the HMC algorithm”. It is by now well known in the lattice community that Monte Carlo simulations of lattice QCD suffer from a severe problem with long autocorrelations of the topological charge of the gauge field. This problem affects the HMC algorithm and its variants that are used in lattice simulations with dynamical fermions just as well as the simple link updating schemes (Metropolis, heat bath) that can be used for pure gauge or quenched calculations. The autocorrelation time of the topological charge grows roughly like the fifth power of the inverse lattice spacing $a$ as $a$ is taken to zero. This is a real problem because it indicates the presence in the system being simulated of modes that are updates only very slowly, and as a consequence the statistical errors of observables measured from Monte Carlo simulations may be seriously underestimated, because the contribution to the error coming from the long tails of the autocorrelation function that stem from those modes are not properly taken into account. Martin Lüscher then introduced the Wilson flow, which is an evolution in field space generated by the Wilson plaquette action, and which can in some sense be seen as consisting of a sequence of infinitesimal stout link smearings. For the case of an abelian gauge theory, the flow equation can be solved exactly via the heat kernel, and it can be shown that it gives renormalized smooth solutions. For QCD, the same can be seen to be true numerically. Defining a transformed field $V(U)$ by running with the Wilson flow for a specified time $t_0$, it can then be shown that the path integral over $U$ is the same as the path integral over $V(U)$ with an additional term in the action that comes from the Jacobian of the transformation and is proportional to $g_0/a$ times the integral of the Wilson plaquette action along the flow trajectory. As $a$ goes to zero, the latter term will act to suppress large value of the plaquette. An old theorem of Lüscher shows that the submanifold of field space with a plaquette values less than 0.067 divides into topological sectors, and hence the probability to be "between" topological sectors decays in line with the suppression of large plaquettes by the $g_0/a$ term. This explains the problem seen, but also offers hope for a solution, since one might now try to develop algorithms that make progress by making large changes to the smooth fields $V$. This was followed by two review talks. The first was a review of the state of the art in hadron spectroscopy and light pseudoscalar decay constants by Christian Hölbling emphasizing the reduction of systematic errors achieved by decreasing lattice spacings and pion masses and increasing simulation volumes.

The second review talk of the morning was given by Constantia Alexandrou, who reviewed hadron structure and form factor calculations from the lattice, drawing attention to the many remaining uncertainties in this important area, where in particular the axial charge $g_A$ of the nucleon is consistently measured to be significantly lower on the lattice than in nature.

The last plenary speaker of the day was Gregorio Herdoiza, who spoke about the progress being made towards 2+1+1 flavour simulations. The collaborations currently pursuing the ambitious goal of including a fully dynamic charm quark in their simulations are ETMC and MILC. MILC is using the Highly Improved Staggered Quark (HISQ) action to reduce discretization errors, whereas ETMC is relying on a variant of twisted mass fermions with an explicit breaking of the mass degeneracy for the strange/charm doublet. In the former case, the effects of reduced lattice artifacts are clearly seen, while in the latter case the O($a^2$) mass splitting between the neutral and charged pion increases with the number of flavours. In either case, a significant effort is necessary to tune the strange and charm quark masses to their physical values, but the effort is definitely well-spent if it leads to $N_f$=2+1+1 predictions from lattice QCD that include all effects of an active charm quark.

In the afternoon there were parallel talks. Two that I'd like to highlight were the talk of Bastian Knipschild from Mainz, who presented an efficient method to strongly reduce the systematic error on nucleon form factors coming from excited state contributions, and David Adam's talk in which he presented a generalization of the overlap operator to staggered fermions that gives a chiral two-flavour theory.

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**Another chink in the armor of the Standard Model?**

*2010-05-18T15:54:00.000+02:00*

Via Resonaances : The D0 collaboration has a new paper on the arXiv in which they present their observations of a like-sign muon charge asymmetry in B meson decays.

Neutral B mesons can decay into an antimuon, a mu neutrino and other stuff ($B^0 \to \mu^+ \nu_\mu X_c$) via the weak interaction $\bar{b} \to \bar{c} W^+$, and neutral anti-B mesons can accordingly decay into an muon, a mu antineutrino and other stuff. However, neutral B mesons can oscillate into their antiparticles and back, so that if a B-Bbar pair is created in a collision, and one particle of the pair decays into a muon-neutrino pair while in its original state whereas the other decays into a muon-neutrino pair while turned into the antiparticle of its original state, both of them will decay into muons, or both into antimuons – a like-sign muon decay.

If CP was an exact symmetry of nature, the rates for the oscillation and decays would be equal between B and anti-B mesons, but since it is not, CP violation leads to a difference in the rate at which the initial B-Bbar pair decays into positive and negative like-sign muon pairs – a charge asymmetry. The Standard Model predicts a very small such charge asymmetry stemming from the complex phase in theCKM matrix.

What the D0 collaboration have done is to measure the charge asymmetry, carefully subtracting all (hopefully) sources of background, and obtained a result that is about two orders of magnitude larger than the Standard Model prediction! Of course the experimental result has statistical and systematic errors, and thus the relevant measure of deviation from the Standard Model is only about $3\sigma$ ... still, this is another chink in the armor of the Standard Model.

What I find interesting is that all of the evidence of flavour physics beyond the Standard Model comes from particles containing a strange (rather than an up or down) quark besides a heavy flavour. The contribution to the charge asymmetry from $B_d^0$ decays is well constrained by other experiments, so most of the D0 result would appear to be coming from the $B_s^0$ system. I'm not a BSM phenomenologist, but I could imagine this to be relevant input for an understanding of possible BSM physics.

The Standard Model predictions rely on hadronic quantities such as decay constants, form factors and mixing parameters of the B meson, which must be determined nonperturbatively in lattice QCD. Better accuracy here could have real impact on the most stringent tests of the Standard Model that we have so far, and this is an area where significant progress is being made.

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#### ICHEP 2010 has a blog

*2010-05-06T17:10:00.001+02:00*

As my readers will know, this blog is most active during the conference season, when I blog from the annual lattice conference and possibly also from other meetings. I believe that conference blogging is both a service to those members of the physics community who for whatever reasons cannot personally attend the conference, and also to the wider public, who can get an insight into what scientists do and talk about at their meetings. It is thus a great pleasure for me to be able to announce that ICHEP 2010 will have an official conference blog, where bloggers from the high energy particle physics community will post on the conference and on current topics in high energy physics in general.

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#### Excited states from the lattice, 1 of n

*2010-01-29T19:12:00.000+01:00*

This post is intended as the first in a series about techniques for the extraction of information on excited states of hadrons from lattice QCD calculations.

As a reminder, what we measure in lattice QCD are correlation functions $C(t) = \langle O(t)O(0)\rangle$ of composite fields $O(t)$. From Feynman's functional integral formula, these are equal to the vacuum expectation value of the corresponding products of operators. Changing from the Heisenberg to the Schrödinger picture, it is straightforward to show that (for infinite temporal extent of the lattice) these have a spectral representation $C(t) = \Sigma_n |\psi_n|^2 e^{-E_n t}$, which in principle contains all information about the energies $E_n$ and matrix elements $\psi_n = \langle 0|O|n\rangle$ of all states in the theory.

The problem with getting that information from the theory is twofold: Firstly, we only measure the correlator on a finite number of timeslices; the task of inferring an infinite number of $E_n$ and $\psi_n$ from a finite number of $C(t_k)$ is therefore infinitely ill-conditioned. Secondly, and more importantly, the measured correlation functions have associated statistical errors, and the number of timeslices on which the excited states' ($n > 1$) contributions are larger than the error is often rather small. We are therefore faced with a difficult data analysis task.

The simplest idea of how to extract information beyond the ground state would be to just perform a multi-exponential fit with a given number of exponentials on the measured correlator. This approach fails spectacularly, because multi-exponential fits are rather ill-conditioned. One finds that changing the number of fitted exponentials will affect the best fit values found rather strongly, leading to a large and unknown systematic error; moreover, the fits will often tend to wander off into unphysical regions (negative energies, unreasonablely large matrix elements for excited states). This instability therefore needs addressing if one wishes to use a $\chi^2$-based method for the analysis of excited state masses.

The first such stabilization that has been proposed and is widely used is known as Bayesian or constrained fitting. The idea here is to augment the $\chi^2$ functional by prior information that one has about the spectrum of the theory (such as that energies are positive and less than the cutoff, but if one wishes also perhaps more stringent constraints coming e.g. from effective field theories or models). The reason one may do this is Bayes' theorem, which can be read as stating that the probability distribution of the parameters $M$ given the data $D$ is the product of the probability distribution of the data given the parameters times the probability distribution of the parameters absent any data: $P(M|D) = P(D|M)/P(D)P(M)$; taking the logarithm of both sides and maximizing of $M$, we then want to maximize $log(P(D|M)) + log(P(M))$. Now $log(P(D|M))$ is known to be proportional to $-\chi^2$, so if $P(M)$ was completely flat, we would end up minimizing $\chi^2$. If we take $P(M)$ to be Gaussian instead, we end up with an augmented $\chi^2$ that contains an additional term $\Sigma_n(M_n - I_n)^2/\sigma_n^2$ that forces the parameters $M_n$ towards their initial guesses ("priors") $I_n$, and hence stabilizes the fit – in principle even with an infinite number of fit parameters. The widths $\sigma_n$ are arbitrary in principle; fitted values $M_n$ that noticeably depend on $\sigma_n$ are determined by the priors and not the data and must be discarded. In practice the lowest few energies and matrix elements do not show a significant dependence on $\sigma_n$ or on the number of higher states included in the fit, and may therefore be taken to have been determined by the data.

Bayesian fitting is a very powerful tool, but not everyone is happy with it. One objection is that adding any external information, even as a constraint, compromises the status of lattice QCD as a first-principles determination of physical quantities. Another common worry is the GIGO (garbage in-garbage out) principle with regards to the priors.

A way to address the former concern that has been proposed is the Sequential Empirical Bayes Method (SEBM). Here, one first performs an unstabilized single-exponential fit at large times $t$, where the ground state is known to dominate. Then one performs a constrained two-exponential fit over a larger range of $t$ using the first fit result as a prior (with its error as the width). The result of this fit is then used as the prior in another three-exponential fit over an even larger time range, and so forth. (There is some variation as to the exact procedure followed, but this is the basic idea). In this way, all priors have been determined by the data themselves.

In the next post of this series we will look at a completely different approach to extracting excited state masses and matrix elements that does not rely on $\chi^2$ at all.

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**New book on the lattice**

*2010-01-08T17:06:00.000+01:00*

There was a time when the only textbooks on lattice QCD were Montvay& Münster and Creutz. Not so any more. Now the new textbook "Quantum Chromodynamics on the Lattice: An Introductory Presentation" by Christof Gattringer and Christian Lang (Lecture Notes in Physics 788, Springer) offers a thorough and accessible introduction for beginners.

Gattringer and Lang start from a derivation of the path integral in the context of Quantum Mechanics, and after deriving the naive discretization of lattice fermions and the Wilson gauge action present first the lattice formulation of pure gauge theory, including the Haar measure and gauge fixing, with Wilson and Polyakov loops and the static quark potential as the observables of interest. Numerical simulation techniques for pure gauge theory are discussed along with the most important data analysis methods. Then fermions are introduced properly, starting from the properties of Grassmann variables and a discussion of the doubling problem and the Wilson fermion action, followed by chapters on hadron spectroscopy (including some discussion of methods for extracting excited states), chiral symmetry on the lattice (leading through the Nielsen-Ninomiya theorem and the Ginsparg-Wilson relation to the overlap operator) and methods for dynamical fermions. Chapters on Symanzik improvement and the renormalization group, on lattice fermion formulations other than Wilson and overlap, on matrix elements and renormalization, and on finite temperature and density round off the volume.

The book is intended as an introduction, and as such it is expected that more advanced topics are treated briefly or only hinted at. Whether the total omission of lattice perturbation theory (apart from a reference to the review by Capitani) is justified probably depends on your personal point of view – the book clearly intends to treat lattice QCD as a fully nonperturbative theory in all respects. There are some other choices leading to the omission or near-omission of various topics of interest: The Wilson action is used both for gluons and quarks, although staggered, domain wall and twisted mass fermions, as well as NRQCD/HQET, are discussed in a separate chapter. The calculation of the spectrum takes the front seat, whereas the extraction of Standard Model parameters and other issues related to renormalization are relegated to a more marginal position.

All of these choices are, however, very suitable for a book aimed at beginning lattice theorists who will benefit from the very detailed derivations of many important relations that are given with many intermediate steps shown explicitly. Very little prior knowledge of field theory is assumed, although some knowledge of continuum QFT is very helpful, and a good understanding of general particle physics is essential. The bibliographies at the end of each chapter are up to date on recent developments and should give readers an easy way into more advanced topics and into the research literature.

In short, this book is a gentle, but thorough introduction to the field for beginners which may also serve as a useful reference for more advanced students. It definitely represents a nice addition to your QCD bookshelf.

# 2009

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### Silly science policies threaten progress

*2009-10-29T11:44:00.000+01:00*

Suppose you were a politician in charge of shaping your country's science policy. Let's also suppose you are actually interested in promoting the welfare of the nation and humanity at large (hopefully not all politicians are driven by sociopathic greed, and after all, we are talking about *you* here). Let's also suppose that you are not entirely stupid. What kind of science policy would you make?

Presumably, you would *not* come up with the kind of ultra-shortsighted policy that the UK has now come up with in determining to weight research proposals' (short-term) 'economic and social impact' by 25% in assessing their merits.

The point with fundamental research, however, is that one just simply cannot make any reliable statement about its likely impact on society. When Dirac postulated the existence of the positron on the basis of his equation, he didn't think of positron emission tomography revolutionizing cancer diagnostics. When Einstein described stimulated emission of radiation, he certainly didn't have DVDs in mind. And while Peter Grünberg might have had some applications in mind when he made his discovery of giant magnetoresistance, he probably didn't imagine the iPod (otherwise he'd be very, very rich).

The only research that will fare well under such a short-sighted policy is industrial and quasi-industrial research that has a clear product (i.e. a product that can be readily imagined with current knowledge) in mind. Such applied research is important, sure. But fundamental research is far more important for the overall progress of the human race, because it creates the foundations upon which the applied research of the future is going to rest. Moreover, applied research generates revenue for industry, and therefore it behooves industry to fund it. The government's job in science is the support of fundamental research that will not easily get industry support – corporations are notoriously short-sighted, rarely looking beyond next year's balance sheet. The government should have more foresight.

Nobel Laureates are leading the fight against this silly policy; you can hear from Chemistry Nobel Laureate Venki Ramakrishnan at nature.com. UK-based readers can sign a petition against the silliness at ucu.org.uk.

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### 我不去 LATTICE 2009 北京

*2009-06-14T15:20:00.000+02:00*

I hope I didn't maltreat the 汉字 above too badly in my ignorance – in any case, what I'm trying to say is that I am not going to the Lattice conference this year. Yes, that means no conference blog from me.

"But how are we going to survive without the annual conference blog?" I hear a reader exclaim. To which I reply, without so much as batting an eyelid: "You will have to write it yourself." Okay, I admit that imaginary exchange is just silly, but the reality is that I'd still like to cover the Lattice meeting in Beijing, but obviously can't do the reporting myself. So I would like to encourage my readers to volunteer as guest bloggers and cover a session or two from their own point of view. Any conference reports (except for those of a libelous or defamatory nature) submitted as comments or by email will be published, with or without attribution as desired by their respective authors.

To make this a more tempting offer I will add a prize for the most productive (by number of sessions covered, by words in case of equal numbers of sessions) guest blogger, who will win my Lattice 2008 Williamsburg baseball cap (autographed or unautographed at the winner's discretion).

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### Openness » fraud

*2009-05-17T20:52:00.000+02:00*

In the most recent edition of PhysicsWorld, there are two articles that on the face of it have little to do with each other: one is about Jan Hendrik Schön, the physicist formerly famous for creating the first organic superconductor and the first single-molecule transistor, and now most famous for having simply made up all of those results out of thin air, the greatest kind of scientific fraud in physics. The other article, by Michael Nielsen, is about how the internet is transforming scientific communications, looking at which new means of scientific communication failed (such as Physics Comments and scientists contributing to Wikipedia – although Scholarpedia is taking off quickly at the moment, probably because its signed and peer-reviewed authorship model is more in line with academic customs than Wikipedia's semi-anarchistic one) and which succeeded (the arXiv, of course) in making the dissemination of scientific results quicker and more transparent.

At first glance these two topics appear to have little to do with each other. At second glance, however, they are closely intertwined.

Schön's deception was only possible because the researchers who tried and failed to replicate his results didn't have access to his primary data. Once doubts had been raised over the appearance of two completely identical graphs supposedly representing two completely different sets of experimental data, Schön's primary data were subjected to close scrutiny and were found to be non-existent – his labbooks had been destroyed, and his samples were damaged beyond recovery. This raises the question whether it would have been possible to even contemplate such a fraud in an environment where scientists are genuinely expected to hide nothing, and in particular to make their primary data publicly available after publication.

The more radically open schemes, where raw data are being made public before publication, are unlikely to take off largely because of concerns over the enormous plagiarism potential. But once results have been published and priority has thus been established by the original authors, there is no immediately obvious reason not to allow other researchers to perform their own analyses of the primary data, either to confirm (or possibly to refute) the original analysis, or to use their own methods to obtain results from the data that the original authors didn't (either because they weren't interested or because they didn't have the relevant analysis methods at their disposal). Some access controls are needed, of course, in order to ensure that the later researchers will duly acknowledge the use of the original group's datasets.

It is hard to see how a fraud like the Schön case could have occurred under a scheme like this; the groups who wasted years on trying to replicate his results to no avail would likely have realized the fraud if they had had access to Schön's lab books.

Just like with the arXiv (which after all started out as a specialized High Energy Physics preprint server and now has revolutionized publishing in most of physics and mathematics, plus assorted other areas), particle physicists are pushing ahead with schemes to open access to raw data, and lattice QCD is right at the forefront of the movement: since the most expensive step in unquenched simulations is the actual generation of the gauge configurations, using those just once for whatever analysis or analyses interests one specific group would be an irresponsible waste of computer resources, postdocs' lifetime and taxpayers' money.

It has therefore been common for a long time now for lattice theorists to form larger collaborations that pool their resources to generate their configurations and then perform different analyses on them (policies differ: some collaborations publish all of their papers as a collaboration, some break up into smaller groups for most analyses). But with the huge effort needed for unquenched simulations on large ultrafine lattices with very light quarks, even that becomes inefficient; in particular, groups that don't belong to any of the major collaborations would be left out in the quenched darkness. Therefore, it is becoming an increasingly common policy to make gauge configurations available to the larger lattice community after performing some initial analyses that the collaboration generating the ensemble is particularly keen on doing (generally, that includes the hadron spectrum, plus some other stuff).

Configurations have been available for a while at NERSC's Gauge Connection, and are now quickly beginning to be available on the International Lattice Data Grid (ILDG). This way the many CPU cycles that have been invested in generating these ensembles are put to even better use by enabling other groups to run their analyses on them.

Just like in the case of the arXiv, it may take a while for other disciplines to follow suit, but it appears likely that if and when more and more scientists choose to make their raw data public after publication (and those that don't therefore become increasingly subject to suspicion by their peers), a fraud case like that of Jan Hendrik Schön will become quite impossible at some point in the future.

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**MAMI and beyond, Day Five**

*2009-04-04T19:45:00.001+02:00*

Today's first talk was by Savely G. Karshenboim (Garching and St Petersburg) who spoke about hadron physics' impact on precision in atomic physics. Atomic physics is famously precise in its measurements, with relative precisions of order $10^{-12}$ now being achieved for some quantities. The largest uncertainty in theoretical predictions there now comes from uncertainty about the effects of nuclear and proton structure.

The second speaker was Wolfgang Gradl (Mainz) with a talk on hadronic uncertainties in flavour physics. Flavour physics is about quark-level quantities (CKM matrix elements), but only hadronic decay and oscillation processes are experimentally accessible; thus one needs good control of QCD effects contained in form factors, decay constants and the B meson bag parameter. Lattice QCD is an important ingredient here, in particular when coupled with effective field theories such as HQET.

This was followed by discussion sessions about the prospects for MAMI, about the prospects for an electron-nucleon collider, and about the impact of hadronic physics on high-energy physics. The good news for lattice theorists is that there is a high demand for precise lattice predictions by experimentalists. The not so good news is that most of that demand is in areas where the lattice is not in a position to make accurate predictions in the near future, such as resonances, hadronic scattering lengths or hadronic light-by-light scattering amplitudes.

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**MAMI and beyond, Day Four**

*2009-04-02T19:58:00.001+02:00*

Today's first talk was Fabio Ambrosino (INFN Napoli) speaking about flavour physics at the 1 GeV scale. Of course, flavour physics here does not mean charm or B-physics – the topic was instead the accurate determination of $|V_{ud}|$ and $|V_{us}|$ from nuclear transitions and Kaon decays. The very accurate results obtained there confirm the unitarity of the first row of the CKM matrix to great accuracy, as well as confirming universality (via a comparison of $G_\mu$ and $G_F$).

The next talk was by Christoph Hanhart (Forschungszentrum Jülich), who spoke about QCD exotics such as hybrids, glueballs, tetraquarks and hadronic molecules. Here I learned what the physical difference between a tetraquark and a mesonic molecule (who after all both consist of two quarks and two antiquarks) is: since hadrons (as opposed to quarks) can go on-shell, the S-matrix elements for a hadronic molecule (but not a tetraquark state) would contain non-analyticities.

The remainder of the day had talks mostly about hypernuclear physics (hypernuclei are nuclei with a nucleon replaced by a strange baryon), which I feel unable to summarize (I only remember that hypernuclei are smaller and more tightly bound than normal nuclei), and accelerator physics, which I skipped in order to look after my email and a couple of papers that are in the final pre-arXiv stages of the pipeline.

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**MAMI and beyond, Day Three**

*2009-04-02T19:57:00.003+02:00*

Today's morning session was filled with experimental talks making the case for an electron-nucleon collider to study the structure of the nucleon.

The short afternoon session had a talk by Akaki Rusetsky (Bonn) about the determination of resonance properties from finite-volume spectroscopy using a combination of Lüscher's formula and heavy-baryon chiral perturbation theory applied to lattice simulations near (or ideally at) the physical quark masses.

After that there was an excursion to Kloster Eberbach, a nearby former Cistercian monastery, where a guided tour was combined with a wine tasting. After that, the conference dinner took place in a castle hotel on the Rhine.

## MAMI and beyond, Day Two

*2009-04-02T19:57:00.001+02:00*

Hello again from Mainz, where I am at the conference ”MAMI and beyond”.

Today’s first talk was by Barry Holstein (UMass Amherst), who spoke on ”Hadronic physics and MAMI: past an future”. The hadronic physics was cast mainly in the language of Chiral Perturbation Theory and its extensions. An interesting detail was the magnetic polarizability of the nucleon, which suggest that the nucleon in 10,000 times ”stiffer” electromagnetically than a typical atom; this is in spite of the fact that the ability of the nucleon to transition to a $\Delta$ resonance ought to give it strongly paramagnetic properties from the quark spins; heuristically this is countered by the diamagnetism of the nucleon’s pion cloud. Another feature that I found interesting was that the experimental determination of hadronic scattering lengths seems to be rather involved (possibilities mentioned involved the decay of pionium, or an analysis of the cusp structure in the energy dependence of $K \to 3\pi$ or $\eta \to 3\pi$ decays), and that the best way to determine them from theory is apparently from the lattice via Lüscher’s formula for the volume-dependence of two-particle state energies.

The next speaker was Rory Miskimen (also UMass Amherst) talking about the measurement of nucleon polarizabilities in real and virtual Compton scattering. Real Compton scattering is, well, Compton scattering, virtual Compton scattering is the production of a photon in the scattering of an charged particle by a proton: $\gamma^* p \to p\gamma$. Apparently the results from MAMI lie on a different curve from those from other experiments at other energies, which might suggest that there is something interesting happening around energies of $Q^2 = 0.3\,$GeV$^2$.

The next two talks were by Bernard Pire (CPHT/Polytechnique) and Diego Bettoni (INFN Ferrara), who both talked about timelike processes. Due to my limited understanding of the relevant physics, I feel unable to give a summary of those talks, except that apparently it is quite difficult to disentangle the different form factors experimentally.

After that Fred Jegerlehner (Katowice and DESY Zeuthen) spoke about the running of the fine structure constant $\alpha$. The running of $\alpha$, which at zero energy is known to astounding precision, is of particular interest around the muon mass (where it enters the determination of the muon anomalous magnetic moment) and around the $Z$ boson mass. The difficult part is to determine the contributions to the running of $\alpha$ coming from hadronic loops, the uncertainty about which causes a loss of five significant figures when evolving $\alpha$ from $0$ to $M_Z$. Using a method based on the Adler function (essentially a derivative of the self-energy with respect to the momentum squared), it should be possible to get a much more precise running of $\alpha$ by improving the understanding of low-energy hadronic contributions.

Since most of the information needed in this approach would come from the Euclidean momentum region, the lattice might be able to help here.

After the lunch break, I skipped a couple of experimental talks to go over to the IWHSS workshop held next door and listen to a talk by Chris Michael about hadronic physics on the lattice. Chris presented approaches that can enable the determination of the nature of resonances and even the description of $\rho \to \pi\pi$ decays on the lattice.

After the coffee break, the lattice session of the MAMI conference took place: Meinulf Göckeler gave a summary of recent work towards the determination of generalized parton distributions on the lattice; Dru Renner at DESY Zeuthen works on this kind of thing, so I have heard about it a few times; it seems very hard each time I hear it, but I suppose saying "let's wait a few more years before starting on something like this" is not really an option.

Mike Peardon spoke about hadron spectroscopy on the lattice, giving a great introduction to lattice spectroscopy for the non-latticists in the audience. The highlight for lattice theorists was his mention of a new method that might replace noisy estimators for all-to-all propagators: a redefinition of quark smearing as a projection on the subspace spanned by the low modes of the Laplacian on a timeslice, enabling one to then exactly calculate all elements of the quark propagator out of this (relevant) subspace. The results shown looked rather promising, and the cost for diagonalizing the Laplacian on a timeslice is of course much lower than that for diagonalizing the Dirac operator as needed for the Dublin method of all-to-all correlators with low-modes.

Andreas Jüttner gave a talk about ongoing work to study mesonic form factors and (g-2). Using twisted boundary conditions to induce a momentum, he obtained very nice pion and $K \to \pi$ form factors. The (g-2) work is still in progress, but looks promising.

Silvia Necco gave an introduction to the links between Lattice QCD and Chiral Perturbation Theory, covering the extraction of SU(2) and SU(3) low-energy constants from $N_f = 2$ and $N_f = 2+1$ lattice simulations, and of the leading-order couplings $\Sigma$ and $F$ from simulations in the $\epsilon$-regime.

Finally, Johann Kühn (Karlsruhe) spoke about precision physics in $e^+e^-$ interactions, where the perturbative determination of the hadron-to-muon ratio $R(s)$ has made it possible to precisely determine $\alpha_s$, $m_c$ and $m_b$ from experimental data (and the former two also from lattice simulations via the moments of current-current correlators).

In the evening, there was a social event: A string quartet played for us at the university's faculty of music in Mainz. The program was Mozart (Divertimento No. 1, KV 135), Schubert (String quartet No. 13 "Rosamunde") and Shostakovich (String quartet No 8 op. 110), the first two pieces quite pleasant, the last rather harrowing.

## MAMI and beyond, Day One

*2009-04-02T19:55:00.000+02:00*

Hello from Schloss Waldthausen near Mainz, where I am attending the conference ”MAMI and beyond”.

The meeting started this morning with welcome speeches by the VP for research of Mainz University, the VP of physics of the German Research Foundation, and the acting director of the Mainz nuclear physics institute. This was followed by the first talk, given by Ulf G. Meissner (Bonn University), who spoke about ”Hadron physics at the 1 GeV scale and its impact”. He paid particular attention to isospin violating effects, which can come from both QED and QCD sources, since the up and down quarks differ in both mass and charge. MAMI experiments could measure isospin violating effects in $\pi N$ scattering, $\eta \to 3\pi$ and $\eta' \to \eta\pi\pi$ decays, and in Kaon photoproduction on the proton, for all of which there are higher-order predictions from some versions of chiral perturbation theory. Beyond MAMI, interesting isospin violating effects are the mass splittings of heavy baryon multiplets, where the mass of the cdd $\Sigma_c^0$ is greater that that of the cud $\Sigma_c^+$, even though $m_d > m_u$, but the ordering of the $\Sigma_s$ baryons is the normal one, an effect that may be explained by the presence of a new operator appearing in the O($p^2$) $\chi$PT effective Lagrangian for heavy quarks, which has a different sign for $c$ and $b$ quarks because of their different electrical charge.

After the coffee break, Jens Erler (UNAM, Mexico) talked about ”Low-energy tests of the Standard Model and beyond”. Low-energy probes, such as leptonic decays, flavour-changing neutral current contributions to Kaon decays, first row CKM matrix unitarity tests, tests of CP violation, search of nucleon and lepton electric dipole moments, atomic parity violation, (g-2) measurements and many more from particle, nuclear and atomic physics, can surprisingly probe very high energies by placing extremely stringent limits on various kinds of beyond-the-Standard-Model physics, excluding in many cases BSM contributions from scales below a few 100 TeV or so. This makes them a very useful complement to high-energy collider experiments that search for BSM particles and processes in a more direct manner.

The next talk was an overview of form factors given by Carl Carlson (College of William and Mary). The point that stuck to my mind most prominently was that measurements of hydrogen hyperfine splitting when combined with proton structure measurements and calculations are accurately predicted to more than 1 p.p.m. and show now evidence of new physics to such accuracy.

After the lunch break, Constantia Alexandrou (Cyprus University) gave an overview of nucleon structure on the lattice, concentrating on $N_f = 2$

studies using dynamical twisted mass, Wilson clover or overlap fermions. Special attention was drawn to the fact that it is now becoming possible to simulate at the physical pion mass, and that the first such simulations have recently been done by the Wuppertal group.

This was followed by another experimental talk by Volker Burkert (Jefferson Lab). What I took home from this talk was that there is experimental support for the notion that the Roper resonance is a radial excitation of the nucleon, and that there is such a thing as femtotomography, where an image of the charge distribution inside a hadron is created from the Fourier transform of its structure functions.

After this, Mauro Anselmino (INFN Torino) spoke about the spin structure of the nucleon from a mostly theoretical point of view, followed after the coffee break by Klaus Rith (Erlangen-Nürnberg University) speaking about the same from a mostly experimental point of view. The ”spin crisis” caused by the discovery that the quark spins only contribute about 33% of the nucleon's spin still appears somewhat unresolved. The gluons appear to contribute very little, and the contributions of the angular momenta of up and down quarks, which must make up the remainder, interestingly have opposite sign. A lot of research still seems to be ongoing in this very complex area, and I honestly don't understand enough of it to be able to give a decent summary of the enormous amount of information contained in these talks.

The same is true (and to an even larger extent) of the experimental talks that followed, and to which I didn't pay the necessary attention in any case, since I had to deal with several pressing matters by email.

# 2008

## Lattice 2008, Day six

*2008-07-24T13:57:00.001+02:00*

Saturday was the last day of the conference. The first plenary, chaired by Andreas Kronfeld, was devoted to the quest for new physics. Luca Silvestrini spoke about the observed discrepancies between lattice and experiment: A $4.4\sigma$ difference in the CP asymmetries in $B \to K\pi$ decays, a $3.8\sigma$ difference in $f_{D_s}$, and a $3\sigma$ difference in the phase of the $B_s \to J/\psi\phi$ decay. Although the LHC is expected to give access to the low-lying part of the particle spectrum of the expected new physics, a Super-B factory will be needed to map the new physics out in detail (the MSSM has 160 parameters). Lattice QCD determinations of quantities of interest at the $< 1$% accuracy level will be needed for these purposes.

Then George Fleming spoke about strong interactions beyond the Standard Model, where technicolor is making a comeback, since only some QCD-like versions of it have been ruled out. The interest in this area centers on ”walking” theories with a very slowly running coupling. For SU(3), it is believed that there is a ”conformal window” of $N_f$, where the coupling runs to an IR fixed point in the infrared. Simulations using unrooted staggered fermions to simulate $N_f = 4, 8, 12, 16$ indicate that this window lies somewhere around $N_f = 12$.

The last plenary had Michael Teper speaking about Large-N QCD using old-fashioned OHP slides. $N = \infty$ QCD is a theoretical laboratory for ideas about QCD, both because it turns out that as far as the N-dependence of observables is concerned, $N = 3$ is close to $N = \infty$, and because at $N = \infty$, quenched QCD is full QCD, because fermion loops are infinitely suppressed by their colour factors; also, resonances become infinitely narrow as $N$ goes towards infinity, allowing accurate measurements of e.g. the $\rho$ mass, which turn out to be quite close to the real world at $N = \infty$.

This was followed by Hermann Krebs's talk about nuclear effective theories on the lattice. The lattice as a regulator is of course not unique to gauge theories, and nuclear theorists are now performing simulations of effective theories of pions and nucleons to determine the properties of light nuclei and nuclear matter from first principles. The low-energy constants can be either fitted to experiment by giving up an a number of predictions, or can be taken from lattice QCD (once they are determined accurately enough) for a truly first-principles treatment of nuclear physics.

After the end of the session, there was an announcement of the Les Houches Summer School on Lattice QCD in 2009. Then Kostas Orginos thanked the support staff and volunteers, before handing over to the representative of the Lattice 2009 organizing committee, who thanked Kostas and his team. Everybody got their well-deserved applause, and then the lattice community was invited to come to Beijing for the Lattice 2009 conference, which is to be held July 26-31, 2009. It was also announced that Lattice 2010 will be held at a yet-to-be-determined location in Europe. And then the conference was over, and everybody said their goodbyes before leaving.

Since my flight only left the next day, I took the opportunity to visit the "Colonial Williamsburg" open-air museum, which I liked a lot better than the Jamestown one, largely because the colonials/locals just went quietly about their business without too much show or spectacle, which I thought gave one a much better impression of what life in the American colonies might have been like.

My flight back went fine, but I didn't get to post the last two summaries earlier.

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**Lattice 2008, Day five**

*2008-07-24T13:56:00.001+02:00*

Friday's first plenary started with a summary talk on heavy-flavour physics on the lattice given by Elvira Gamiz. The most striking point there is what is now being called the "$f_{D_s}$ puzzle", i.e. the difference between lattice predictions (241(3) MeV [HPQCD $N_f = 2 + 1$], 249(11) MeV [FNAL/MILC $N_f = 2 + 1$], 244(4)(11) MeV [ETMC $N_f = 2$ preliminary], 251(6)(?) [Alpha $N_f = 2$ preliminary]) and experimental measurements (268(8)(4) MeV [CLEO-c, most recent]) of the $D_s$ meson decay constant, for which new physics is being invoked as an explanation by many. Other topics were semileptonic decays of heavy mesons, which are quite hard to study on the lattice, and B-Bbar mixing parameters, where some also raise the possibility of new physics to explain discrepancies between theory and experiment that have recently arisen.

The next talk was Laurent Lellouch speaking about Kaon physics, and comparing the usefulness SU(2) and SU(3) chiral perturbation theory.

The second plenary session was started by Rob Pisarski speaking about heavy-ion collisions at RHIC, where the study of the strongly interaction quark-gluon plasma (if it may be called that, since it does not really appear to be the state of matter formerly imagined under the name of quark-gluon plasma) requires methods from non-equilibrium thermodynamics and non-ideal hydrodynamics. One of the long-standing puzzles that appear to be experimental signatures of the QCD phase transition is the suppression of $J/\psi$ final states and jets. Some explanation for these phenomena in terms of the "elliptic flow" of the quark-gluon plasma seems to have been found, but it appears to me that a fundamental understanding of what is going on in these highly out-of-equilibrium situations involving strongly interacting matter is still a fair way off.

The next talk was related to this topic, as Harvey Meyer spoke about the extraction of hydrodynamical transport coefficients from the spectral functions of correlators of energy-momentum tensors, which requires some clever tricks to get the continuous spectral functions from the correlators measured only at a few discrete points.

After this, Yoshinobu Kuramashi gave a talk about PACS-CS's simulations of $N_f = 2+1$ QCD at and near the physical pion mass. They were thus able to test the applicability of SU(2) and SU(3) chiral perturbation theory, and my interpretation of their results was that both might not be sufficiently well-behaved to be truly valid even at the physical point.

The last talk of the session was given by Tomoteru Yoshie, who gave an introduction and status update on the International Lattice Data Grid (ILDG), which now contains 183 ensembles with a total of 193,000 configurations using 41 Terabyte of storage space.

In the afternoon, there were again parallel sessions, including one in which Rainer Sommer spoke about our group's recent work on the Generalized Eigenvalue Problem for correlator matrices and how to use it in the most efficient manner to get ground and excited state masses and matrix elements, both in QCD and in effective theories such as HQET, and another on in which I talked about a preliminary analysis of $D_s$ physics on the large and fine CLS lattices. Rainer's talk was certainly very well received, and since the potential criticisms of the work that I presented were easy to anticipate, I would say that my talk also went quite well.

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**Lattice 2008, Day four**

*2008-07-18T03:55:00.000+02:00*

Today was the customary short day. There were no plenaries, only parallel sessions. I went to the sessions on Standard Model parameters and renormalization, where Peter Lepage presented the HPQCD collaboration's new method and results for the heavy quark masses from moments of current-current correlators, and after the coffee break the session on weak decays and matrix elements where Paul Mackenzie presented the Fermilab group's new result for $f_{D_s}$, which is larger than, but in agreement with, the HPQCD result, but at the moment has larger error bars than the latter. Notable talks in these sessions were also given by Ian Allison on results from high-$\beta$ simulations and by Ruth van de Water on extracting an accurate number for $|V_{ub}|$ from QCD simulations by making use of variable transformations and complex fitting procedures.

After the end of the last session, we picked up our boxed lunches at the reception desk and climbed into the busses that took us to Jamestown settlement, where we got a tour of the museum, where the most remarkable exhibit were watercolours by John White, an artist who accompanied an early expedition to Virginia and depicted the flora, fauna and native population as they appeared to an English artist encountering the New World for the first time, while everything else was certainly informational and presented very nicely, but nothing unusual compared to the other historical museums. The reconstructed settlement was a bit too Disneylandish for my taste – while the ships and buildings certainly gave a good idea of life in an early English colony in North America, the costumed show was more funny than informational, although I am sure the kids who were there were having a lot of fun, which is probably the main purpose of these kinds of reenactments. After that, the busses took us to the historical site of Jamestown, where we could see the ruins of the buildings and the rebuilt church and walk around in the heat until the busses took us back.

The banquet was a buffet dinner in one of the big rooms that can be divided to serve as three meeting rooms each. The menu is likely of no interest to readers, so I'll end here for today.

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**Lattice 2008, Day three**

*2008-07-17T04:35:00.000+02:00*

Today's first plenary, chaired by Rainer Sommer, started off with the much-anticipated plenary talk about the state of dynamical fermion simulations given by Karl Jansen. Simulations with dynamical fermions are of course a hugely controversial subject in the community at the moment, with each group fiercely defending its particular fermion discretization as the best, or even the only way to solve QCD (whatever that may mean). Karl managed to navigate this minefield (or to stay closer to the analogies he had chosen for his talk, this swamp of alligators) with great impartiality and fairness, pointing out the strengths and potential weaknesses of each formulation in an accurate and diplomatic manner; even regarding the great staggered controversy, he was very fair to both sides, pointing out that the concerns raised by Mike Creutz almost certainly don't affect the simulations being done now, given that they are being performed at fermion masses which are safe with regard to maintaining the order of the continuum (first) and chiral (second) limits, but that these concerns are also valid and worthy of further investigation in the context of theoretical studies in which the order of the limits is intentionally violated. A very nice picture shown was the scaling of the nucleon mass in different lattice fermion formulations, which looked like great evidence of universality; unfortunately, the same picture for the pion decay constant looked a lot worse, possibly because some formulations with $Z_A$ not equal to one may have used incorrect value of $Z_A$. The progress made on reducing the cost of dynamical fermion simulations through algorithmic improvements (especially deflation) is also very impressive.

The next talk was Shoji Hashimoto speaking about simulations with dynamical overlap fermions. The overlap operator being the most expensive to simulate formulation of lattice fermions, the lattices being simulated are still pretty small, but it is nevertheless quite impressive that this has become possible at all.

After the coffee break, Ami Katz gave the non-QCD theory plenary talk, about AdS/QCD models. The AdS/CFT correspondence is maybe the most important (some might say the only) result coming out of string theory; as far as I understand it, it states that string theory in anti-de Sitter (AdS) space is dual in an apparently well-defined way to Large-N super-Yang-Mills theory on the boundary of AdS. A consequence of this appears to be that by introducing extended objects such as branes or black holes into AdS one can break the conformal symmetry or supersymmetry of the theory on the boundary, thus potentially being able to construct a supergravity theory that is dual to QCD. Since the AdS/CFT duality relates weak and strong coupling, this would allow to describe the low-energy spectrum of QCD by perturbative calculations in the dual theory. Some models that attempt to do this have achieved quite reasonable agreement with QCD spectra, but none of them are truly dual to QCD, so all of this amounts to model-building. I may well have misunderstood some things here, though, and corrections or better explanations in the comments are greatly appreciated.

The last plenary talk of the morning was Ken-Ichi Ishikawa talking about recent developments in the algorithms and machines field, such as the Cell processor, lattice QCD running on graphics cards, deflation and adaptive multi-grid methods for lattice QCD. His projections for the future seemed a little off, though: I am currently responsible for running a simulation which according to his final slides would require Petaflop computing.

After lunch, I attended the parallel session on hadron spectroscopy in which the different collaborations presented results on heavy-quark states. Christine Davies presented the HPQCD results on pseudoscalar decay constants, among which the result for $f_{D_s}$ is remarkable for showing a $3\sigma$ deviation from the experimental value, which some believe is a possible sign of new physics.

After the afternoon coffee break, there was a public lecture by Rajan

Gupta on the global energy problems facing the human species in the 21st century. The numbers are always very depressing, as is the political cloud of war, imperialism, famine and general oppression surrounding the fossile and nuclear energy resources of our planet. As a little contribution towards improving the level of discourse on energy issues he presented a project called OpenModel Global Observatory that aims to create a Wikipedia-like database of the global energy infrastructure as a tool for policymakers and an instrument of educating the public. The fact remains that if 8 billion people all are to live the American lifestyle including its (ab)use of non-renewable fossile resources, the next generation is probably going to be the last to be able to enjoy any kind of lifestyle above the level of "poor, nasty, brutish and short", if at all, so huge advances in energy efficiency and the use of renewable energies (photovoltaic, solarthermal, wind, hydro, tidal) will be absolutely crucial – economically viable fusion power would also be nice, but appears unlikely to appear soon enough to help us very much.

In order to cheer ourselves up after considering this, some colleagues and I had a beer with our dinner and discussed the most cheerful topics we could think of (which included cannibalism, assisted suicide and homelessness).

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**Lattice 2008, Day two**

*2008-07-16T04:20:00.000+02:00*

Today was a long day, so this will be a short summary. Any typos and inaccuracies in content are to be blamed exclusively on the wine served during the poster session.

After another continental breakfast, the first plenary session of the day chaired by John Negele, started with a talk by Marc Vanderhaegen about nucleon structure studies. This was this year's experimental talk, for which reason I find myself too ignorant to give a good summary of it; there were lots of plots of experimental results of observables such as the ratio of the electric to magnetic form factors of the proton (which appears to be quite different if measured by unpolarized or by polarized probes for reasons to do with two-photon exchanges), the generalized parton distributions of the nucleon, and the magnetic dipole moment of the $\Delta(1232)$ resonance (which is apparently very hard to measure, because the $\Delta$ decays strongly and hence is far too short-lived to measure its magnetic moment by the precession method that can be used for stable or quasi-stable particles).

Next was James Zanotti who gave an overview of the work that has been done on hadronic structure from the side of lattice QCD. Again there were lots of plots of the same quantities, this side from lattice simulations, but I have to freely admit that I am way too ignorant of hadronic structure studies to appreciate this work very well. A better summary of the progress in this area that might be given in the comments would be appreciated.

After the coffee break, the second plenary session of the morning continued with Martin Savage in the chair. The nuclear thread of the previous session was continued by Silas Beane speaking about Hadronic interactions and nuclear physics. This was probably the funniest talk I have ever heard at a lattice conference (it included *inter alia* a picture of a crying baby held by G.W. Bush, illustrating the exponential growth with time of noise in baryonic channels, and of a live rabbit being pulled from a top hat). Multi-hadron states are now being targeted by lattice simulations, but dealing with the noise will require petascale computing.

The final plenary talk of the day was by Colin Morningstar, who talked about studies of excited hadronic states. His talk concentrated almost exclusively on the very extensive work done in this area by his collaborators, who have indeed made some remarkable progress on this very difficult problem; however, there are also some other approaches to extracting information on excited states, which may well turn out to not be competitive with the variational method, but might still deserve a mention at least in this blog.

After lunch with some colleagues, taken at an Asian buffet place that was both better and much more reasonably priced than the university canteen, I attended parallel sessions. The more remarkable talks included Constantia Alexandrou presenting a new method to extract excited states, which seemed to work remarkably well given that it appeared to be largely a rather glorified form of uniform random search. Progress towards using the HISQ action for simulations with staggered quarks including dynamical charm was presented by Alexei Bazavov. Michael Clark spoke about adaptive multi-grid methods for QCD as potential competitors to deflation methods. A presentation an a new high-performance computing architecture was given by John Mucci, the CEO of SiCortex, the company producing it – it sounded a bit like marketing, but if their computers really only use 200 W per 100 GFlops and can run with ordinary air-cooling that would be quite amazing.

Finally, the poster session closed the day. My poster on the determination of the O($N_f \alpha_s a^2$) improvement coefficients for the Lüscher-Weisz action with dynamical HISQ fermions appeared to be received quite well by its intended audience. The food was gone quickly, and the wine not much more slowly. By an amusing coincidence there was a poster from another group about pretty much exactly the same work as I am doing with people at Zeuthen at the moment.

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**Lattice 2008, Day one**

*2008-07-15T01:14:00.001+02:00*

Hello from the College of William and Mary in Williamsburg, Virginia, where I am at the Lattice 2008 conference.

After a continental breakfast that was provided by the conference in the central meeting room, and registration (where we got a very nice conference bag, probably better even than the excellent one from Tucson), the meeting started with the usual welcomes from the Vice-Provost of Research and the head of the physics department.

Then the first plenary session started with Frithjof Karsch in the chair. The first talk was by Carleton DeTar, who talked about developments in finite-temperature QCD on the lattice. A he pointed out, the $N_\tau = 4$ simulations that were still fairly standard in that area rather recently correspond to lattice spacings of about $a = 0.27$ fm at $T = 180$ MeV, so by today's standards they are unacceptably coarse. A point of contention in finite-temperature QCD is the nature of the phase transition; while it is generally agreed to be a crossover and not a real transition at the physical point, for massless $N_f = 2$ QCD there are some who believe it to be first order, while most groups find it to be second order. The fact that the transition is a crossover at the physical point poses the problem of how to determine the critical temperature, since for a crossover there is no uniquely defined transition point. The observables used to study the critical temperature can be divided into confinement-type (such as Polyakov loops) and chiral-type (such as the chiral condensate). A chiral-type observable that has led to some uncertainty about the critical temperature is the chiral susceptibility, which can be understood as the integrated correlator of the chiral condensate. Since this needs to be renormalized, it picks up a mass dependence which makes it difficult to pin down its precise temperature-dependence, thus leading to systematic errors in the determination of the critical temperature from its peak. Other interesting points raised in this talk were the ongoing effort to try to extract information on the transport coefficients of the quark-gluon plasma from lattice simulations, and the observation that dimensional reduction seems to work surprisingly well down to about $T = 1.5T_c$, which is really completely unexpected, since dimensional reduction is strictly a high-temperature effective theory.

After that, Shinji Ejiri spoke about lattice QCD at finite density, an area that is known to be very difficult since the fermionic determinant becomes complex if the chemical potential is non-zero, thus ruining the probability interpretation of the path integral measure and making Monte Carlo simulations impossible without some groundbreaking new idea that has apparently not arrived yet.

The coffee break was followed by another plenary session, chaired by Richard Brower. The first speaker was Shailesh Chandrasekharan who spoke about the worldline approach to simulating lattice field theories as an alternative to cluster algorithms for scalar and fermionic models, with the possibility of extending it to gauge theories as a worldsheet approach.

The next talk was by Uwe-Jens Wiese who talked about lessons for QCD to be drawn from solid state physics. Various solid-state physics models, such as the Hubbard model on a hexagonal lattice, can be described in terms of effective theories strongly resembling chiral perturbation theory, which in term can be reduced to quantum mechanical rotors, whose spectra are known analytically. A similar reduction can be performed for $\chi$PT, and the nucleon can be incorporated in that approach as a Dirac monopole contained inside the sphere on which the rotor degrees of freedom live.

The final talk of the morning was Andre Walker-Loud speaking about Heavy Baryon Chiral Perturbation Theory. The main message I took from this talk was that a totally unphysical straight line fit appears to describe the pion-mass dependence of the nucleon mass just as well as involved HB$\chi$PT calculations, which is somewhat disconcerting.

After lunch with some colleagues at the somewhat expensive university canteen, the afternoon saw me attending parallel sessions. The cookies in the coffee creak were very delicious and probably had way too many calories. I also finally finished my talk. That's it for today, stay tuned for more tomorrow.

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**Trento**

*2008-05-18T20:48:00.000+02:00*

So I've obviously been a really bad blogger recently, but I was quite busy. One of things I was doing was attending a workshop at the ECT* (not sure what's up with the star; I suppose ECTRNPARA was a little too long, so they used a shell wildcard) in Trento, Italy. The workshop was sort of a miniature version of the lattice conference, with representatives from all major collaborations talking about the state of the art in simulations with dynamical fermions. I briefly considered live-blogging it like I do with the lattice conferences, but in the end decided against it for various reasons. The ECT* is very nicely located in a historical villa a little outside of Trento itself; the meeting room is in the basement of a side building, though, so there is nothing to distract one from the talks. The workshop was very well organized, with hotels, meals and everything arranged in advance, so five stars to the organizers and ECT* staff for that.

Contentwise, the workshop brought few real surprises, but a lot of confirmation of the fact that dynamical fermion simulations are now pretty far advanced due to a combination of algorithmic advances and ever greater and faster parallel computers. To all but eliminate systematic errors, ultimately, one will need to simulate at small lattice spacings (0.04 fm, say), large volumes (5 fm, say) and at the physical light quark masses. At the moment, each major group is accomplishing at least one of these, with some approaching two out of the three. In three or four years at the latest, somebody will have an ensemble of configurations fulfilling all three. Given that lattice spacings this small, or quark masses anywhere in the vicinity of the physical point, were considered completely out of reach just three years ago, it is fair to say that the lattice has come a long way in a short time.

Some people will therefore sometime use phrases like "when we will have solved QCD", but great as that sounds one first needs to consider what solving QCD means. Even when we have predictions for the hadronic ground state mass spectrum with essentially zero systematic error, there will still be excited states, decay constants and widths, scattering lengths, form factors, multi-hadron states and potentials, and so forth coming from QCD, and many of these will likely require considerable effort in terms of new theoretical developments in order to make it viable to extract them from lattice simulations. So unless "solving QCD" means "computing the hadronic ground state mass spectrum", we won't solve it for a fair while to come. Which is good news, because otherwise I'd really have to start looking for a different job, and I actually like this one.

And of course then there is the often-mentioned possibility that the LHC might find evidence of technicolor or some other new strongly coupled physics at higher energies, putting lattice theorists at the cutting edge of the energy frontier. That sounds more like some kind of dream though.

I've also been doing other interesting things, but I'll save those for a different post. If everything goes as hoped for, there may also be an exciting guest post on this blog in the not too distant future.

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**arXiv catchup**

*2008-02-14T11:05:00.001+01:00*

I have been too ~~lazy~~busy recently to blog anything. However, in the spirit of the day, I'd like to share a romantic little poem extolling the nonabelian nature of strong attraction:

> *Roses are red, violets are blue*
> *quarks come in colours, and so does glue.*

No, I won't give up physics and become a card designer for H$llm$rk, don't worry. But after softening your hearts with this touching verse, I'd like to blog about some rather old stuff, which I hope hasn't gone stale in the meantime.

One paper on the arXiv that struck me as interesting in the last couple of months was this paper by Jeffrey Mandula (of Coleman-Mandula No-Go fame), who discusses the consequences of Lü scher's nonlinear realization of chiral symmetry for Ginsparg-Wilson fermions. We recall that this symmetry can be written in two inequivalent ways by putting the phase factor $e^{i\alpha\gamma_5}$ either on the quark field $\psi$ or its conjugate $\bar{\psi}$. The crucial fact that Mandula points out is that both of these are independent symmetries of the lattice theory, and they don't commute! Hence, we have to look for the symmetry algebra generated by them, which turns out to be infinite-dimensional. Hence the lattice symmetry has an infinite number of conserved currents, a structure quite different from the continuum theory. However, it would really appear that the differences between any two of these lattice currents are just lattice artifacts of order $a$ or higher that should disappear in the continuum limit, if the latter is properly defined. So some of the objections that the paper raises are likely a lot less serious than stated (especially the non-locality exhibited for free overlap fermions [eq. (38)] goes away once one realizes that the continuum limit must be taken with the negative mass $s$ constant in *lattice* units), but it appears that Ginsparg-Wilson fermions may have their own set of problems beyond just being expensive to simulate. Any comments on this from Ginsparg-Wilson specialists would be of great interest.

Another interesting paper was this one by Mike Creutz who proposed a new fermion discretization based on features of the electronic structure of graphene. Apparently the low electronic excitations of a graphene layer are described by the massless Dirac equation, and a lattice model based on this (by reducing the links in one of the three graphene hexagonal directions to points, and rescaling everything to make the lattice rectangular again) exploits this to achieve the minimum number (two) of doublers permitted in an conventional chiral lattice theory by the Nielsen-Ninomiya theorem, and this construction can be extended to four dimensions and gauged to get a lattice discretization of QCD with two light quark flavours. This was quickly followed up by a similar proposal for a minimally-doubling quark action, and by this paper which shows that any minimally-doubling chiral lattice theory necessarily has to break either of the discrete symmetries P or T such that their product PT is broken; this allows the generation of additional (relevant) dimension 3 operators that have to be removed by fine-tuning, precluding the use of minimally-doubling chiral actions in practice (unless some additional non-standard symmetry should conspire to do that fine-tuning itself, a possibility hinted at in the conclusion).

# 2007

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### Algorithms for dynamical fermions – Hybrid Monte Carlo

*2007-12-09T17:49:00.000+01:00*

In the previous post in this series parallelling our local discussion seminar on this review, we reminded ourselves of some basic ideas of Markov Chain Monte Carlo simulations. In this post, we are going to look at the Hybrid Monte Carlo algorithm.

To simulate lattice theories with dynamical fermions, one wants an exact algorithm that performs global updates, because local updates are not cheap if the action is not local (as is the case with the fermionic determinant), and which can take large steps through configuration space to avoid critical slowing down. An algorithm satisfying these demands is Hybrid Monte Carlo (HMC). HMC is based on the idea of simulating a dynamical system with Hamiltonian $H = 1/2p^2 + S(q)$, where one introduces fictitious conjugate momenta $p$ for the original configuration variables $q$, and treats the action as the potential of the fictitious dynamical system. If one now generates a Markov chain with fixed point distribution $e^{-H(p,q)}$, then the distribution of $q$ ignoring $p$ (the "marginal distribution") is the desired $e^{-S(q)}$.

To build such a Markov chain, one alternates two steps: Molecular Dynamics Monte Carlo (MDMC) and momentum refreshment.

MDMC is based on the fact that besides conserving the Hamiltonian, the time evolution of a Hamiltonian system preserves the phase space measure (by Liouville's theorem). So if at the end of a Hamiltonian trajectory of length $\tau$ we reverse the momentum, we get a mapping from $(p,q)$ to $(-p',q')$ and *vice versa*, thus obeying detailed balance: $e^{-H(p,q)}P((-p',q'),(p,q)) = e^{-H(p',q')}P((p,q),(-p',q'))$, ensuring the correct fixed-point distribution. Of course, we can't actually exactly integrate Hamilton's in general; instead, we are content with numerical integration with an integrator that preserves the phase space measure exactly (more about which presently), but only approximately conserves the Hamiltonian. We make the algorithm exact nevertheless by adding a Metropolis step that accepts the new configuration with probability $e^{-\delta H}$, where $\delta H$ is the change in the Hamiltonian under the numerical integration.

The Markov step of MDMC is of course totally degenerate: the transition probability is essentially a $\delta$-distribution, since one can only get to one other configuration from any one configuration, and this relation is reciprocal. So while it does indeed satisfy detailed balance, this Markov step is hopelessly non-ergodic.

To make it ergodic without ruining detailed balance, we alternate between MDMC and momentum refreshment, where we redraw the fictitious momenta at random from a Gaussian distribution without regard to their present value or that of the configuration variables $q$: $P((p',q),(p,q)) = e^{-1/2p'^2}$. Obviously, this step will preserve the desired fixed-point distribution (which is after all simply Gaussian in the momenta). It is also obviously non-ergodic since it never changes the configuration variables $q$. However, it does allow large changes in the Hamiltonian and breaks the degeneracy of the MDMC step.

While it is generally not possible to prove with any degree of rigour that the combination of MDMC and momentum refreshment is ergodic, intuitively and empirically this is indeed the case. What remains to see to make this a practical algorithm is to find numerical integrators that exactly preserve the phase space measure.

This order is fulfilled by symplectic integrators. The basic idea is to consider the time evolution operator exp$(\tau d/dt) =$ exp$(\tau(-\partial_q H \partial_p + \partial_p H \partial_q)) =$ exp$(\tau h)$ as the exponential of a differential operator on phase space. We can then decompose the latter as $h = -\partial_q H \partial_p + \partial_p H \partial_q = P + Q$, where $P = -\partial_q H \partial_p$ and $Q = \partial_p H \partial_q$. Since $\partial_q H = S'(q)$ and $\partial_p H = p$, we can immediately evaluate the action of $e^{\tau P}$ and $e^{\tau Q}$ on the state $(p,q)$ by applying Taylor's theorem: $e^{\tau Q}(p,q) = (p, q + \tau p)$, and $e^{\tau P} = (p - \tau S'(q), q)$.

Since each of these maps is simply a shear along one direction in phase space, they are clearly area preserving; so are all their powers and mutual products. In order to combine them into a suitable integrator, we need the Baker-Campbell-Hausdorff (BCH) formula.

The BCH formula says that for two elements A,B of an associative algebra, the identity

$$log(e^A e^B) = A + (\int_0^1 ((xlogx)/(x-1))_{x=e^{adA}e^{tadB}} dt)(B)$$

holds, where $(adA)(B) = [A,B]$, and the exponential and logarithm are defined via their power series (around the identity in the case of the logarithm). Expanding the first few terms, one finds

$$log(e^A e^B) = A + B + 1/2[A,B] + 1/12[A-B,[A,B]] - 1/24[B,[A,[A,B]]] + ...$$

Applying this to a symmetric product, one finds

$$log(e^{1/2A} e^B e^{1/2A}) = A + B + 1/24[A + 2B,[A,B]] + ...$$

where in both cases the dots denote fifth-order terms.

We can then use this to build symmetric products (we want symmetric products to ensure reversibility) of $e^P$ and $e^Q$ that are equal to $e^{\tau h}$ up to some controlled error. The simplest example is

$$(e^{\delta\tau/2P}e^{\delta\tau Q}e^{\delta\tau/2P})^{\tau/\delta\tau} = e^{\tau(P+Q)} + O((\delta\tau)^2)$$

and more complex examples can be found that either reduce the order of the error (although doing so requires one to use negative times steps $-\delta\tau$ as well as positive ones) or minimize the error by splitting the force term $P$ into pieces $P_i$ that each get their own time step $\delta\tau_i$ to account for their different sizes.

Next time we will hear more about how to apply all of this to simulations with dynamical fermions.

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### Algorithms for dynamical fermions – preliminaries

*2007-11-29T22:06:00.000+01:00*

It has been a while since we had any posts with proper content on this blog. Lest my readers become convinced that this blog has become a links-only intellectual wasteland, I hereby want to commence a new series on algorithms for dynamical fermions (blogging alongside our discussion seminar at DESY Zeuthen/Humboldt University, where we are reading this review paper; I hope that is not too lazy to lift this blog above the waste level...).

I will assume that readers are familiar with the most basic ideas of Markov Chain Monte Carlo simulations; essentially, one samples the space of states of a system by generating a chain of states using a Markov process (a random process where the transition probability to any other state depends only on the current state, not on any of the prior history of the process). If we call the desired distribution of states $Q(x)$ (which in field theory will be a Boltzmann factor $Z^{-1}e^{-S(x)}$), and the probability that the Markov process takes us to $x$ starting from $y$ $P(x,y)$, we want to require that the Markov process keep $Q(x)$ invariant, i.e. $Q(x) = \Sigma_y P(x,y)Q(y)$. A sufficient, but not necessary condition for this is that the Markov process satisfy the condition of detailed balance: $P(y,x)Q(x) = P(x,y)Q(y)$.

The simplest algorithm that satisfies detailed balance is the Metropolis algorithm: Chose a candidate $x$ at random and accept it with probability $P(x,y) = min(1, Q(x)/Q(y))$, or else keep the previous state $y$ as the next state.

Another property that we want our Markov chain to have is that it is ergodic, that is that the probability to go to any state from any other state is non-zero. While in the case of a system with a state space as huge as in the case of a lattice field theory, it may be hard to design an ergodic Markov step, we can achieve ergodicity by chaining several different non-ergodic Markov steps (such as first updating site 1, then site 2, etc.) so as to obtain an overall Markov step that is ergodic. As long as each substep has the right fixed-point distribution $Q(x)$, e.g. by satisfying detailed balance, the overall Markov step will also have $Q(x)$ as its fixed-point distribution, in addition to being ergodic. This justifies generating updates by 'sweeping' through a lattice point by point with local updates.

Unfortunately, successive states of a Markov chain are not really very independent, but in fact have correlations between them. This of course means that one does not get truly independent measurements from evaluating an operator on each of those states. To quantify how correlated successive states are, it is useful to introduce the idea of an autocorrelation time.

It is a theorem (which I won't prove here) that any ergodic Markov process has a fixed-point distribution to which it converges. If we consider $P(x, y)$ as a matrix, this means that it has a unique eigenvalue $\lambda_0 = 1$, and all other eigenvalues $\lambda_i$ ($|\lambda_{i+1}| \leq |\lambda_i|$) lie in the interior of the unit circle. If we start our process on a state $u = \Sigma_i c_i v_i$ (where $v_i$ is the eigenvector belonging to $\lambda_i$), then $P^N u = \Sigma_i \lambda_i^N c_i v_i = c_0 v_0 + \lambda_1^N c_1 v_1 + ...$, and hence the leading deviation from the fixed-point distribution decays exponentially with a characteristic time $N_{exp} = -1/log|\lambda_1|$ called the exponential autocorrelation time.

Unfortunately, we cannot readily determine the exponential autocorrelation time in any except the very simplest cases, so we have to look for a more accessible measure of autocorrelation. If we measure an observable $O$ on each successive state $x_t$, we can define the autocorrelation function of $O$ as the $t$-average of measurements that are $d$ steps apart: $C_O(d) = \langle O(x_{t+d})O(x_t)\rangle_t / \langle O(x_t)^2\rangle_t$, and the integrated autocorrelation time $A_O = \Sigma_d C_O(d)$ gives us a measure of how many additional measurements we will need to iron out the effect of autocorrelations.

With these preliminaries out of the way, in the next post we will look at the Hybrid Monte Carlo algorithm.

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**Lattice 2007 – Day Six**

*2007-08-18T04:36:00.000+02:00*

The first plenary talk today was Walter Wilcox speaking about deflation methods for fermion inverters. Deflation methods like GMRES-DR are based on Krylov subspace ideas, where the Krylov space is augmented by some (approximate) eigenvectors to remove the corresponding eigenvalues from the system, thus improving convergence.

Next was Falk Bruckmann, who spoke about exploring the QCD vacuum with lattice QCD. The non-perturbative degrees off freedom relevant for the QCD vacuum are topological objects (vortices, monopoles and instantons). Studying these on the lattice is hard, but progress is being made.

The third talk of the session, about renormalization-group flows in multi-parameter in $\phi^4$ theories, was given by Ettore Vicari. Critical phenomena can be described in terms of a few critical exponent; one way to determine these is by looking at fixed points of renormalization group flows. Since there are only a certain number of universality classes into which those critical points can fall, one can study these by looking at $\phi^4$ models falling into different classes (Landau-Ginzburg-Wilson models); this may even have some applications to determining the nature of the QCD phase transition.

After the coffee break, Michele Della Morte got a plenary session of his own for his talk about determining heavy quark masses. A number of determinations of heavy-quark observables were summarized, and a more detailed overview of recent progress in determining the b-quark mass using HQET was given.

After that, the organizers thanked the staff who had made the conference possible, and they received a round of well-deserved applause. The organizers got some equally well-deserved applause of their own, and all participants were invited to attend Lattice 2008 in Williamsburg, VA, which will be held July 14-19, 2008. Looking forward beyond next year, Lattice 2009 was announced to take place in Beijing, and so the meeting adjourned.

Finally I had some time to look around the city properly, and so I visited the Johannes Kepler-Gedächtnishaus (Kepler's dying place, and today a museum about his life) with some colleagues. After that, highlights on our tour round the city were the romanesque Schottenkirche (the church of a monastery build in the 11th century by Iro-Scottish monks) and St. Emmeram (the church of a former monastery that now serves as the palace of the Princess of Thurn and Taxis). I will do some more sightseeing tomorrow morning, but since I don't think it will interest my readers too much, this closes my coverage of Lattice 2007.

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**Lattice 2007 – Day Five**

*2007-08-03T12:33:00.001+02:00*

The opulent banquet, late hours and probable overconsumption of Bavarian beer afterwards led to a notable decrease in the occupation number of the seats at the first plenary session today. The first plenary talk was Jo Dudek speaking about radiative charmonium physics. Experimentally theses are part of the research program at CLEO, but until now have been studied mostly in potential models. Radiative decays have now been studied on the lattice by analysing three-point function, but two-photon decays require some new theoretical developments based on combining

QED perturbation theory and the LSZ reduction formula with lattice simulations.

The second speaker was Johan Bijnens talking about quark mass dependence from continuum Chiral Perturbation Theory at NNLO. After a quick overview of Chiral Perturbation Theory ideas and methods, he presented the results that have been obtained in NNLO light meson $\chi$PT during the past few years.

Next was Silvia Necco who spoke about the determination of low-energy constants from lattice simulations in both the $p$- and $\epsilon$-regimes. The $\epsilon$-regime is particularly useful because the influence of higher-order LECs is small there, so that the leading-order LECs $\Sigma$ and $F$ can be determined accurately.

After the coffee break, Philip Hägler talked about hadron structure from lattice QCD, giving a review of recent determinations of hadron electric polarizabilities and form factors, the nucleon spin fractions and other hadron structure observables.

The next talk was by Sinya Aoki, who spoke about the determination of hadronic interactions from QCD. $\pi\pi$ scattering can be studied on the lattice using Lüscher's finite-volume method, and this has been used to obtain results for the $\rho$ meson decay width as well. Baryon-baryon potentials can be computed by computing the energy of a $Qqq - qqQ$ system as a function of $QQ$ separation, where $Q$ denotes static quarks, and similarly for mesons. A different approach defines a potential from a measured wavefunction and its energy via an auxiliary Schrödinger equation.

The last plenary speaker for today was Gert Aarts with a talk about transport and spectral functions in high-temperature QCD. A prominent topic in this field is the fate of charmonium states in the quark-gluon plasma state. Another is the hydrodynamics of the QGP, which has been observed to be a nearly ideal fluid experimentally. Key to solving these problems is the analysis of spectral functions, which can be obtained from lattice correlators by means of a maximum entropy method.

In the afternoon there were parallel session again. The most remarkable talk was a summary of a proposed proof that SU(N) gauge theory is confining at all values of the coupling using a renormalization group blocking technique by Terry Tomboulis. I am sure this proof will be closely scrutinized by the experts, and if it holds up, that would be a major breakthrough.

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**Lattice 2007 – Day Four**

*2007-08-02T12:30:00.000+02:00*

The first plenary session today started with a talk about Kaon physics on the lattice by Andreas Juettner. The leptonic decays of kaons are important in order to determine the CKM matrix element $V_{us}$. A large number of determinations of $|V_{us}|$ from $K\ell 2$ and $K\ell 3$ decays have been performed in the last couple of years, which are mutually compatible for the most part. An important feature of kaon physics is CP violation in neutral kaon decays. Determinations of $B_K$ have been done in a number of different formulations, which show a number of minor discrepancies due to different error estimates, although they all seem to be compatible with the best global fit.

Next was a survey of large-N continuum phase transitions by Rajamani Narayanan. Large-$N$ QCD in the 't Hooft limit ($g^2N$ fixed, $g \to 0$, $N \to \infty$) has been studied analytically in two dimensions where it can be reduced to an Eguchi-Kawai model, and numerically in three and four dimensions. It exhibits a variety of phase transitions in coupling, box size and temperature, too many in fact for me to properly follow the talk.

After the coffee break, a presentation on the BlueGene/P architecture and future developments was given by Alan Gara of IBM. The limits of the growth of supercomputer performance still seem to be far away, and Exaflop performance allowing dynamic simulations of $128^3 \times 256$ lattices was predicted for 2023.

A talk on QCD thermodynamics by Frithjof Karsch followed. The question he addressed was whether there was evidence for different temperatures for chiral symmetry restoration and deconfinement, or whether these two transitions coincided. On the relatively coarse lattices that are available, improved actions are needed to approach the continuum limit. In spite of progress in the analysis of the various sources of systematic error, there appears to be a discrepancy in the answer to this question obtained by different groups.

A second QCD thermodynamics talk was given by Zoltan Fodor, who also addressed the nature of the QCD phase transition, outlining the evidence that the transition is in fact a crossover at zero chemical potential. Since a crossover does not have a unique transition temperature, the different transition temperatures found using chiral and deconfinement observables could be physical.

In the lunch break I was picked up by the police again in order to look at the suspect they had arrested in the meantime. It was the guy who had robbed me, and he apparently confessed even before I arrived to identify him. He "apologized" on seeing me, but at the same time tried to excuse the robbery with my refusal to hand over cash when asked "nicely" – I suppose you can't afford to have too much of a conscience if your preferred lifestyle involves injecting yourself with illegal and poisonous substances on a regular basis. I must admit I feel a certain amount of pity for these guys, criminals though they are.

I also want to take this opportunity to sing the highest possible praises of the Regensburg police, who were incredibly polite and helpful and solved this case so quickly. Let me also add that apparently this kind of thing is very rare around here, so as not to give people a wrong impression of what is really a very lovely place.

There were two parallel sessions in the afternoon. Of note was the talk by Rob Petry, a graduate student at Regina, about work we had done on using evolutionary fitting methods to extract mass spectra from lattice correlators, which met with a lot of interest from the audience.

In the evening the conference banquet took place at ”Leerer Beutel”, apparently a former medieval storehouse that has been converted to an art gallery-and-restaurant. The banquet was a huge buffet dinner, with great German and Italian dishes, the surroundings were very nice, as was talking to people in a more relaxed environment.

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**Lattice 2007 – Day Three**

*2007-08-02T08:20:00.000+02:00*

Today was the traditional excursion day, so there were no plenaries in the morning. Instead there were parallel sessions, including the one with my talk (which went fine). A number of other lattice perturbation theory talks took place in the same session, and it was nice to see the methods from our paper get picked up by other groups.

At lunchtime, the police came to see me in order to have me pick the likely suspect in my robbery out of a photo array.

In the afternoon there were excursions. The one I was on went to Weltenburg Abbey, one of the oldest Benedictine abbeys north of the Alps, famous both for the beer from its 950 years old brewery, and for its beautiful baroque church, the latter a work of painter-architect Cosmas Damian Asam, his brother, sculptor Egid Quirin Asam, and his son, painter Franz Asam, members of the famous Asam clan of baroque churchbuilders in Germany. Particularly remarkable is the life-size statue of St. George on his horse, complete with dragon and saved princess. We went to the abbey by boat through the Danube gorge, a rock formation where the Danube broke through a layer of sedimentary rocks millions of years ago, drastically altering its course and leaving us both a testament to the earth-shaping power of water and a very scenic piece of valley. At the abbey, we had a guided tour of the church with a very nice and very well-informed guide who was apparently an art historian (a rather pleasant break from the common pattern of tour guides who could learn from some of the tourists they supposedly guide). After a pleasant snack and beer in the abbey’s beergarden, we went back the same way we came.

## Lattice 2007 – Day Two

*2007-07-31T09:41:00.001+02:00*

The second day started with the annual experimental talk, which was given by Diego Bettoni, who spoke about FAIR (Facility for Antiproton and Ion Research). After an overview of the accelerator facilities involved, he spoke about charmonium spectroscopy. The advantage of studying charmonium systems in $\bar{p}-p$ annihilation reactions is that states of all quantum numbers can be produced directly, as opposed to $e^{+}-e^{-}$ annihilation which gives only $1^{--}$ states directly and all others via radiative decays only. Studies of the $\chi_c$ and $\eta_c$ states were presented. Planned studies are searches for exotic charmonium hybrids and for glueballs, measurements of the in-nuclear-medium mass shifts of the $D$ meson mass, studies of double hypernuclei (nuclei with two nucleons replaced by hyperons), measurements of the proton form factor in the timelike region, and reversed deeply virtual Compton scattering, all at PANDA, and studies of nucleon structure with polarized antiprotons at PAX. As always, the experimental talk was somewhat sobering, as it pointed out the huge gaps in one's (or at least my) knowledge of experimental physics.

Next was Craig McNeile speaking about hadron spectroscopy. Topics were the $\eta$ and $\eta'$ mesons, the $0^{++}$ spectrum, the controversial $\kappa$ meson, distinguishing $q\bar{q}$ mesons from tetraquarks and molecules, the glueball spectrum and the search for glueballs within the meson spectrum, the changing and mixing in the $0^{++}$ spectrum from unquenching, the $f_0(600)/\sigma$ meson, and comparisons between different unquenched studies, including the different values obtained for $r_0$.

After the coffee break, we got to the "staggered wars" plenary. Mike Creutz opened with a talk on "why rooting fails". The crux of his argument as I understood it was that rooting averages over the four tastes, which have pairwise opposite chiralities, leading to a theory that is not a theory of a single chiral fermion. The postulated manifestation of this was an incorrect singular behaviour of the 't Hooft vertex in the rooted theory, which could lead to the wrong physics in singlet channels, particularly the mass of the $\eta'$.

The opposite point of view was presented by Andreas Kronfeld. He argued that the group structure of staggered symmetries is much more complex than usually considered, and that the "phantom" Goldstone bosons coming from the tastes removed by rooting cancel in physical correlation function. He then proceeded to counter the points raised in Creutz's criticism of rooted staggered quarks, arguing that rooting turns the quark mass $m$ into its absolute value $|m|$, that the staggered taste-singlet chirality is not the same as naive chirality, and does in fact track the topological index correctly if the chiral and continuum limits are taken in the right order.

The final plenary talk was an ILDG status report delivered by Carleton DeTar. The ILDG (International Lattice Data Grid) is the union of national grid applications from Europe, the UK, Japan, Australia and the US, which is intended to allow sharing of lattice configurations, and eventually propagators, between collaborations. They have developed portable data formats (a markup language called QCDml and a binary format for lattice configurations), as well as the grid software. While the permissions policies of the various collaborations are still an issue in some cases, the general tendency seems to be that it is now easier to download unquenched configurations than to generate quenched configurations, which will put the last nail into the coffin of the (already quite dead) quenched approximation over the next couple of years.

After the lunch break, there were parallel sessions. Some remarkable talks were about non-QCD physics on the lattice: Julius Kuti talked about getting Higgs physics from the lattice by using a lattice theory as the UV completion of the Standard Model, Simon Catterall talked about exploring gauge-gravity duality through simulations of $N = 4$ super-Yang-Mills quantum mechanics as the dual of a type IIa string theory with D0 branes, and Jun Nishimura talked about non-lattice Monte Carlo simulations of SYM quantum mechanics as the dimensional reduction of a theory that might be M-theory.

The poster session was interesting, if a tad chaotic, for which I blame the Bavarian beer. I didn't get to see all the posters, since I spent too much time talking to people I knew who had posters.

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### Lattice 2007 – Day One

*2007-07-30T09:47:00.001+02:00*

Hello again from Regenburg. The conference opened at 9 with a brief address by a representative of the university, who said the usual things about how wonderful it is to have us here and so on.

A few brief announcements from the organizers followed, and then the first plenary session started with a talk by Peter Boule speaking for the RBC and UKQCD collaborations about simulations with dynamical domain wall fermions. There was a lot of comparison between domain wall and overlap with their respective topological and chiral properties. Preliminary results for the SU(3) and SU(2) chiral perturbation theory low-energy constants were presented, as were preliminary predictions for pseudoscalar decay constants, light quark masses, $B_K$ and the $K_{l3}$ form factor. Nucleon form factors and structure were also mentioned, but I'm afraid a lot of it went too fast for me to follow, so you will have to wait for the proceedings.

Next was a talk about exploring the chiral regime with dynamical overlap fermions by Hideo Matsufuru speaking for the JLQCD collaboration. He started by discussing the properties of the overlap operator and the methods used to deal with the sign function discontinuity. The method they decided to use was including a topology fixing term. The results presented were for $N_f = 2$ (an $N_f = 2 + 1$ run is in progress), and included studies of the $\epsilon$-regime, physics at fixed topology and its relation to $\theta = 0$ physics, the topological susceptibility and chiral extrapolations at NNLO.

After the coffee break, the theme of actions for light quarks continued with Carsten Urbach on behalf of the European Twisted Mass (ETMC) collaboration speaking about twisted mass QCD at maximal twist. After a brief overview of the general features of tmQCD at maximal twist, such as automatic O($a$) improvement, he explained how to tune to maximal twist and presented some results on the behaviour and performance of simulation algorithms. Finally, there were some $N_f = 2$ results for the pseudoscalar mass and decay constant including finite-size effects and comparisons with chiral perturbation theory. Other preliminary new results included a measurement of the pion mass splitting (which is difficult to measure because of disconnected contributions for the neutral pion), a study of the $\epsilon$-regime, and many others.

The plenary session concluded with a talk by Yoshinobu Kuramashi of the CP-PACS collaboration about using clover quarks and the Iwasaki gauge action to approach the physical point in $N_f = 2 + 1$ simulations using Lüscher's domain-decomposed HMC algorithm.

I had to see the police again during the lunch break in order to go through photo arrays of potential suspects (without much success; I couldn't identify the robbers in the database, but there was a recent arrest which included a person I think was one of them; if he has extremely bad teeth, the police think it will be a sufficient ID to charge him, but that means I'll have to go to the police yet again to identify him in person as having the right kind of bad teeth; the economic damage from this robbery in terms of my time and the cops' time probably already greatly exceeds the 100 Euro taken in value...). This meant that I also missed the first parallel session.

From the second parallel session of the afternoon, I found Ulli Wolff's talk about cluster simulations of two-dimensional fermions very interesting. Basically, the partition function for theories of 2d fermions can be reformulated as the partition function for a theory of non-intersecting loops, which can be reformulated as a theory of Ising spins, which then can be simulated efficiently using cluster algorithms. Of course, 2d fermions are very special, so this is unlikely to carry over to 4d QCD.

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**Lattice 2007 – Day Zero**

*2007-07-30T09:28:00.000+02:00*

Hello from Regensburg, where the Lattice 2007 conference started with an evening reception in the old town. Things got off to a nice start, and Regensburg is a very beuatiful town. Unfortunately, a certain dampener was put on my enthusiasm for it when it became the scene for my being robbed of 100 Euros at knifepoint on one of the high streets by a couple of thugs. While physically unharmed, I was understandably rather shaken, and being questioned about the event by police until well past midnight didn't really enhance the experience.

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**Unquenching meets improvement**

*2007-06-11T21:44:00.000+02:00*

In a recent post, I explained how the fact that the vacuum in quantum field theory is anything but empty affects physical calculations by means of Feynman diagrams with loops, and specifically how one has to take account of these contributions in lattice field theory via perturbative improvement. In this post, I want to say some words about the relationship between perturbative improvement and unquenching.

To obtain accurate results from lattice QCD simulations, one must include the effects not just of virtual gluons, but also of virtual quarks. Technically, this happens by including the fermionic determinant that arises from integrating over the (Grassman-valued) quark fields. Since the historical name for omitting this determinant is "quenching", its inclusion is called "unquenching", and since quenching gives rise to an uncontrollable systematic error, unquenched simulations are absolutely crucial for the purpose of precise predictions and subsequent experimental tests of lattice QCD.

However, the perturbative improvement calculations that have been performed so far correct only for the effects of gluon loops. This leads to a mismatch in unquenched calculations using the perturbatively improved actions: while the simulation includes all the effects of both gluon and quark loops (including the discretization artifacts they induce), only the discretization artifacts caused by the gluon loops are removed. Therefore the discretization artifacts caused by the quark loops remain uncorrected. Now, for many quantities of interest these artifacts are small higher-order effects; however, increased scaling violations in unquenched simulations (when compared with quenched simulations) have been seen by some groups. It is therefore important to account for the effects of the quark loops on the perturbative improvement of the lattice actions used.

This is what a group of collaborators including myself have done recently. For details of the calculations, I refer you to our paper. The calculation involved the numerical evaluation of a number of lattice Feynman diagrams (using automated methods that we have developed for the purpose) on a lattice with twisted periodic boundary conditions at a number of different fermion masses and lattice sizes, and the extrapolation of the results to the infinite lattice and massless quark limits. The computing resources needed were quite significant, as were the controls employed to insure the correctness of the results (which involved both repeated evaluations using independent implementations by different authors and comparison with known physical constraints, giving us great confidence in the correctness of our results). The results show that the changes in the coefficients in the actions needed for O($\alpha_s a^2$) improvement caused by unquenching are rather large for $N_f = 3$ quark flavours, which is the case relevant to most unquenched simulations.

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**New identifiers at the arXiv**

*2007-04-03T18:57:00.000+02:00*

The arXiv have changed their identifiers away from the familiar archive/YYMMNNN (e.g. hep-lat/0605007) format to a new YYMM.NNNN (e.g. 0704.0274) format, which will be used across archives; the change was implemented on April Fool's Day. One consequence of the new identifiers is that the preprint numbers within an archive are no longer consecutive, making the "previous" and "next" functions on the abstract listings rather less useful. Existing papers will retain their old-style identifiers, though. It will remain to be seen how the community likes the change.

Another change, which at least I like quite a bit, is the new presentation format for abstracts. With the more commonly required pieces of information at the top, it looks a lot neater than the old one, which had a lot of less useful things (submission history etc.) in the first few lines.

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**The Quantum Vacuum, Loops and Lattice Artifacts**

*2007-04-01T00:10:00.000+02:00*

*This post was written for a general audience, and hence is written in a rather more popular language than our usual fare at Life on the Lattice. If you are familiar with the basic ideas behind perturbative improvement, you may want to skip this post.*

When we think about the vacuum in classical physics, we think of empty space unoccupied by any matter, through which particles can move unhindered and in which fields are free from any of the non-linear interaction effects which make e.g. electrodynamics in media so much more difficult.

In Quantum Field Theory, the vacuum turns out to be quite different from this inert stage on which things happen; in fact the vacuum itself is a non-linear medium, a foamy bubble bath of virtual particles popping into and out of existence at every moment, a very active participant in the strange dance of elementary particles that we call the universe.

A metaphor which may make this idea a little clearer could be to think of the vacuum as a sheet of paper on which you write with your pen. Looked at on a large scale, the paper is merely a perfectly flat surface on which the pen moves unhindered. On a smaller scale, the paper is actually a tangle of individual fibers going in all directions and against which the pen keeps hitting all the time, thus finding the necessary friction to allow efficient writing.

In the case where the paper is the vacuum, the analogue of the paper fibres are the bubbles of virtual particle pairs that are constantly being created and annihilated in the quantum vacuum, the analogue of the pen is a particle moving through the vacuum, and the analogue of friction is the modification of the particle's behavior as compared with the classical theory which happens as a result of the particle interacting with virtual particle pairs.

At first sight, this description of the vacuum may appear like wild speculation, but it has in fact very observable consequences. In Quantum Electrodynamics (QED), the famous Lamb shift is a consequence of the interactions of the electron in a hydrogen atom with virtual photons, as are the anomalous magnetic moment of the electron and the scattering of light by light in the vacuum. In fact, none of the amazingly accurate predictions of QED would work without taking into account the effects of the quantum vacuum.

In lattice QCD, we care about the vacuum because it affects how the discrete lattice theory relates to its continuum limit. By discretizing a continuum theory, we introduce a discretization error: When comparing an observable $O_a$ measured on a lattice with lattice spacing $a$ with the same observable in the continuum $O_0$, we find that they are related as

$$O_a = O_0 + c_1(\mu a) + c_2(\mu a)^2 + \dots$$

where $\mu$ is some energy scale that is typical of the reactions contributing to the observable $O$. In the classical theory (or at "tree level" as we say because the Feynman diagrams corresponding to classical physics have no loops in them), we can then tune the lattice theory so that as many of the $c_i$ as we want to get rid of become zero, and the discrepancy between lattice and continuum becomes small.

At the quantum level, however, we get Feynman diagrams with loops in them that describe how particles traveling through the quantum vacuum interact with virtual particles; the problem with these is that the virtual particles exist at very short distances and hence can have very large momenta by virtue of Heisenberg's uncertainty relation. At very large momenta, the deviation of the lattice theory from the continuum becomes very evident, and hence the loops on the lattice contribute terms that differ a lot from what the same loops would contribute in the continuum. And then we find that this difference reintroduces the $a$-dependence that we got rid of classically by tuning our theory!

This is clearly no good. What we need to do is to get rid of the $a$-dependence (up to some order in $a$) in the quantum theory, too. There are a number of ways how to go about this, but the one most commonly used is called perturbative improvement. In perturbative improvement, we calculate the effect of the virtual particle loops by evaluating Feynman diagrams (a Feynman diagram isn't just a pretty picture: there is a well-defined mathematical expression corresponding to each Feynman diagram) on the lattice and extracting their contribution to the lattice artifacts $c_i$ to some order in $a$. Once we have these contributions, we can then tune our theory again so that these contributions to the $c_i$ are cancelled, and the discrepancy between lattice and continuum becomes small again.

Unfortunately, evaluating Feynman diagrams on the lattice is much harder than in the continuum in many ways, so that we need some rather advanced methods to do this, and there aren't very many people doing it. So this is an area where progress has been slow for a while. The next post will tell you how a group of collaborators including myself recently made some pretty significant progress in this field.

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**Fitness and Fitting**

*2007-03-12T20:57:00.000+01:00*

I promised there were going to be some interesting posts, and I feel this is one of them. I want to talk about harnessing the power of evolution for the extraction of excited state masses from lattice QCD simulations.

OK, this sounds just outright crazy, right? Biology couldn't possibly have an impact on subnuclear physics (other than maybe by restricting the kinds of ideas our minds can conceive by the nature of our brains, which could of course well mean that the ultimate theory, if it exists, is unthinkable for a human being, but that is a rather pessimist view; I am also talking about QCD here). Well, biology doesn't have any impact on what is after all a much more fundamental discipline, obviously, but Darwin's great insight has applications far beyond the scope of mere biology. This insight, which I will roughly paraphrase as "*starting from a set of entities which are subject to random mutations and from which those least adapted to some external constraints are likely to be removed and displaced by new entities derived from and similar to those not so removed, one will after a large enough time end up with a set of entities that are close to optimally adapted* *to the external constraints*", is of course the basis of the very active field of computer science known as evolutionary algorithms. And optimization is at the core of extracting results from lattice simulations.

What people measure in lattice simulations are correlators of various lattice operators at different (Euclidean) times, and these can be expanded in an eigenbasis of the Hamiltonian as

$$C(t) = \langle O(t)O(0) \rangle = \sum_n c_n e^{-E_n t}$$

(for periodic boundary conditions in the time direction the exponential becomes a cosh instead, but let's just ignore that for now), where the $c_n$ measure the overlap between the eigenstates of the operator and those of the Hamiltonian, and the $E_n$ are the energies of the Hamiltonian's eigenstates. Of course only states that have quantum numbers compatible with those of the operator $O$ will contribute (since otherwise $c_n = 0$).

In order to extract the energies $E_n$ from a measurement of the correlator $\langle O(t_i)O(0) \rangle$, one needs to fit the measured data with a sum of exponentials, i.e. one has to solve a non-linear least-squares fitting problem. Now, there are of course a number of algorithms (such as Levenberg-Marquardt ) that are excellent at solving this kind of problem, so why look any further? Unfortunately, there are a number of things that an algorithm such as Levenberg-Marquardt requires as input that are unknown in a typical lattice QCD data analysis situation: How many exponentials should the fitting ansatz use (obviously we can't fit all the infinitely many states)? Which range of times should be fitted (and which should be disregarded as dominated by noise or disregarded higher states)? A number of Bayesian techniques designed to deal with this problem have sprung up over time (such as constrained fitting), and some of those deserve a post of their own at some point.

From the evolutionary point of view, one can simply allow evolution to find the optimal values for difficult-to-optimize parameters like the fitting range and number of states to fit. Basically, one sets up an ecosystem consisting of organisms that encode a fitting function complete with the range over which it attempts to fit the data. The fitness of each organism is taken to be proportional to minus its $\chi^2$/(d.o.f.); this will tend to drive the evolution both towards increased fitting ranges and lower numbers of exponentials (to increase the number of degrees of freedom), but this tendency is counteracted by the worsening of $\chi^2$. The idea is that if one subjects these organisms to a regimen of mutation, cross-breeding and selection, evolution will ultimately lead to an equilibrium where the competing demands for small $\chi^2$ and large number of degrees of freedom balance in an optimal fashion.

After Rob Petry here in Regina brought up this idea, I have been toying around with it for a while, and so far I am cautiously optimistic that this may lead somewhere: for the synthetic data sets that I let this method look at, it did pretty well in identifying the right number of exponentials to use when there was a clear-cut answer (such as when only finitely-many were present to start with). So the general method is sound; it remains to be seen how well it does on actual lattice data.

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**New Book on the Lattice**

*2007-02-16T19:42:00.000+01:00*

There is a new book about lattice QCD by Tom DeGrand and Carleton DeTar (D& D). It is still quite new, and in fact I am still waiting for my copy to be delivered, but a senior colleague here in Regina was so nice to let me borrow his copy, so you can get my review.

D& D is a comprehensive overview of the current state of the art in lattice QCD. In the space of just 327 pages (excluding front and back matter) they manage to cover pretty much everything one needs to know about in order to be able to read the current research literature. To the best of my knowledge, this is the first lattice monograph to discuss such crucial topics as data analysis for lattice simulations, improved actions and operator matching, chiral extrapolations, and finite-volume effects.

Compared to Montvay and Münster (M& M) at 442 pages, and to Rothe at 481 pages, both of whom cover much less material, D& D are necessarily rather terse. There are no detailed derivations or proofs, and no discussion of the results of lattice simulations is given anywhere. The latter omission is very rightly justified by the authors, as to include them ”would be to invite obsolescence”. While the terseness of the presentation probably limits the usefulness of D& D as a graduate textbook, the authors' stated aim to bridge the gap between what a conventional (non-lattice) theorist already knows and the current research literature which often presupposes an enormous amount of specialized knowledge appear to have been met admirably well.

After a brief overview of continuum QCD and a quick introduction to path integrals for bosons and fermions, and to the renormalization group, D& D turn to introducing the lattice discretization of pure gauge theories, including topics such as gauge fixing and strong coupling expansions. A comprehensive overview of lattice fermion actions follows, covering naive, Wilson, twisted mass, staggered and exactly chiral fermions as well as heavy-quark actions (HQET, NRQCD and Fermilab action). This is succeeded by chapters discussing simulation algorithms for both gluonic and fermionic actions, including such state-of-the-art algorithms as RHMC, BiCGStab and Lüscher's implementation of Schwartz decomposition. Data analysis methods, including correlated fitting, bootstrap methods and Bayesian (constrained) fitting, are discussed in a chapter of their own. The design of improved lattice actions (covering both Symanzik and tadpole improvement, as well as ”fat link” actions) also gets a chapter of its own, as does the design of measurement operators for spectroscopic quantities. This is followed by a chapter on Lattice Perturbation Theory (which even cites this paper) and one on matching operators between the lattice and the continuum. Chiral perturbation theory, including such difficult subjects as quenched and staggered $\chi$PT, also gets a chapter, as do finite-volume effects and their applications. An overview of Standard Model observables amenable to testing via lattice simulations and a brief introduction simulations of finite-temperature QCD round off this very comprehensive book (including even such specialized topics as dimensional reduction of thermal QCD or the maximum entropy method for extracting spectral functions). The bibliography and the index, while also rather terse, appear useful.

In short, D& D have written a comprehensive introduction to state-of-the-art lattice QCD, which should serve both as a useful introduction to those who know a little, but want to know much more, and as a quick reference for active researchers (although a more extensive bibliography will be missed by the latter). This book definitely belongs on the bookshelf of every lattice theorist as an important contemporary counterpoint to M& M's classic.

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**Evil, bad, diseased, or just ugly?**

*2007-01-23T18:25:00.000+01:00*

"Evil" is a word rarely heard in scientific discourse, at least among physicists, whose subject of study is after all morally neutral for pretty much any sensible definition of "morally". "Bad", "diseased" or "ugly" might be heard occasionally. But having all of them applied to a topic as relatively arcane as the fourth-root prescription for staggered fermions is, well, staggering. At last year's lattice meeting there was a lot of discussion as to whether this prescription was diseased or merely ugly. Now Mike Creutz has taken the discussion from the medicinally-aesthetic to the moral level by suggesting that rooting is actually evil. The arguments are much the same as before: The rooted staggered theory has a complicated non-locality structure at non-vanishing lattice spacing, and there is no complete proof (although there are strong arguments that many find very convincing) that this non-locality goes away in the continuum level. The debate will no doubt simmer on until a fully conclusive proof either way is found; the question is only, what kinds of unusual title words are we still going to see?

# 2006

### Lattice QCD makes title page

*2006-12-07T20:28:00.001+01:00*

The latest issue of PhysicsWorld has a feature article on Lattice QCD by Christine Davies describing the recent progress made in confronting theory with experiment through unquenched lattice simulations. Among the highlights she mentions are the correct prediction of the mass of the $B_c$ and the fact that the determinations of the quark masses and the strong coupling constant $\alpha_s$ from unquenched lattice QCD are now more accurate than all other sources combined.

The article is very well written and should be easily understandable for anyone with a background in physics, and I would think that an informed layperson should also be able to learn something from it.

### Hadronic Physics from Lattice QCD

*2006-12-05T23:12:00.000+01:00*

As a matter of fact, I have no idea how my small circle of reader is composed with respect to physics expertise or professional position, but I like to pretend that some of my readers are physicists with a genuine interest in, but no real experience with, lattice QCD. It is to these (imagined, and perhaps imaginary) readers that I want to issue a book recommendation, just in time for inclusion on their holiday wishlist.

The book in question is "Hadronic Physics from Lattice QCD", edited by Anthony M. Green, published by World Scientific. The aim of this book is to provide an introduction to lattice QCD for non-specialist readers such as nuclear and particle physicists, and while it cannot replace one of the various introductory textbooks (such as Montvay and Münster or Rothe) as required reading for people interested in pursuing original research in the field, I think it succeeds very well at giving the non-specialist a much better idea of the how and what, the strengths and the limitations, of lattice QCD.

The book is a collection of independent chapters by different authors, each of which focusses on a specific issue of interest that can be studied using lattice QCD.

The first chapter, by Craig McNeile, starts with a basic introduction to lattice QCD and its methods, including a discussion of systematic errors including how they can be reduced via unquenching, improved actions and chiral perturbation theory. He then proceeds to give an overview of the masses of stable mesons and baryons that can be measured accurately, as well as an introduction to the use of maximal entropy methods to determine spectral functions from lattice data, and some of the methods used to incorporate electromagnetic effects and to study unstable particles on the lattice, both of which are rather hard problems.

The second chapter, by Chris Michael, is devoted to a discussion of exotics, or states that are neither conventional mesons nor baryons: glueballs, and their mixing with scalar mesons of the same quantum numbers, hybrid mesons (mesons that contain a gluonic excitation along with a quark-antiquark pair), and hadronic molecules (states consisting of several hadrons bound by their residual strong interactions).

The third chapter, by Gunnar Bali, discusses the quark-antiquark potential, starting from the static quark potential and its relation to Wilson loops, the strong coupling expansion on the lattice, the confining string picture and perturbative calculations of the potential, and going on to discuss some aspects of quark-antiquark and nucleon-nucleon potentials for non-stationary particles.

The fourth chapter, by Rudolf Fiebig and Harald Markum, is concerned with the difficult topic of hadronic interactions in lattice QCD. After describing some of the issues that arise in a 2+1 dimensional "toy" model, they discuss the highly sophisticated techniques that are used to extract information on pion-nucleon, nucleon-nucleon and pion-pion interactions from lattice QCD. This chapter has an appendix which describes aspects of improvement of lattice actions, an important ingredient in any lattice project aiming for precise predictions.

The fifth chapter, by Anthony Green, discusses "bridges" between lattice QCD and nuclear physics, such as nuclear effective field theories and potential models that are founded upon, or at least inspired by, QCD.

All chapters have extensive bibliographies that should function as excellent starting places for readers who wish to learn more about the subject.

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### The arXiv is changing

*2006-12-04T20:04:00.000+01:00*

Via Urbano Franca : The arXiv preprint archive is changing the way it labels papers with effect from 1st January 2007. The familiar **archive/YYMMNNN** identifiers like *hep-lat/0411026* will be gone (although they will be retained for old papers), and new identifiers of the form **YYMM.NNNN** will take their place. The stated reason for this is that the math archive is getting dangerously close to 1000 submissions a month, which would break the existing identifier system. The new identifiers will no longer be assigned on an archive-by-archive basis; including the archive will be done as in *0701.1234 [hep-lat]*. The new system is expected to be good for a number of years, and after that five-digit identifiers **YYMM.NNNNN** will be needed.

This change appears to be orthogonal to the other announced big change in the physics arXiv, although it is possible that the latter is considered redundant now. A slightly more open information policy on the part of the arXiv might be nice from time to time, but I suspect they are afraid that more openness might offer more inroads to cranks and crackpots, so I kind of understand their policy of semi-secret decision-making. Still, I think it probably couldn't hurt too much if they sent out informative emails to registered authors from time to time.

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### More on modern Fortran

*2006-11-28T21:48:00.000+01:00*

From the echo on my earlier post about why we use Fortran for number crunching applications, I gather that many people still associate Fortran with the worst features of the now mostly obsolete FORTRAN 77 standard (fixed source form, implicit typing) and are mostly unaware of the great strides the development of the Fortran standard has made in the past 30 (sic!) years. So I feel that this might be a good opportunity to talk a little about the advanced features that make Fortran 95 so convenient for developing computational physics applications. [Note that in the following Fortran 95 will be referred to simply as "Fortran" for the sake of brevity.]

To start with, there are Fortran's superior array features which greatly facilitate working with vectors, matrices and tensors: Being able to write vector addition as

```
a = b + c
```

instead of some kind of `for`-loop is a great boon in terms of code legibility.

Having the `sum`, `product`, `dot_product` and `matmul` intrinsic functions available to perform common mathematical operations on arrays using a (hopefully) efficient vendor-supplied math library also helps.

But where Fortran's array features really shine is when it comes to defining `elemental` functions and subroutines, which save a huge amount of coding. An elemental function or subroutine is one which is defined with scalar dummy arguments, but which fulfils certain technical conditions that allow it to be called with an array passed as the actual argument. When called in this way, an elemental function is evaluated on each element of the passed array argument, and the results are assembled into an array of the same shape. Most of the mathematical functions Fortran provides as intrinsics are elemental. So one can do something like

```
Pi = 4.*atan(1.)
x = (/ (i*Pi/n,i=0,n) /) ! array constructor with implied do-loop
y = sin(x)               ! an elemental assignment operation
```

to load `y(i)` with `sin(x(i))` for all i. And better yet, user-defined functions can also be elementary, so you only ever need to write the overloaded operators for your automatically-differentiating spinor type as scalars, and Fortran will take care of dealing with the arrays of those spinors that occur in your code.

Next in usefulness and importance comes the already mentioned support for overloading operators and intrinsic functions on user-defined types. Again, this provides a lot of convenience in terms of maintaining a coding style that stays as close to standard mathematical notation as possible, and of keeping the gory details of complex type operations (such as multiplying two automatically-differentiating spinors) transparent to the programmer/user on the next higher level. The ability to have public and private procedures and variables in modules also helps with this kind of encapsulation.

And that isn't all: `namelist` I/O provides a cheap kind of configuration files; `selected_int_kind` and `selected_real_kind` allow testing whether the system provides sufficient range/precision at compile time; the `forall` construct allows some measure of parallelization on parallel processors where the compiler supports it.

The next incarnation of the Fortran standard, Fortran 2003, exists only as a standard document at this time, although compiler vendors are beginning to add features from Fortran 2003 to their compilers in a piecewise fashion. Major new features include object orientation (single inheritance, polymorphism and deferred binding) and C interoperability (so you can call C system libraries from Fortran programs, and/or call your Fortran matrix-crunching code from a C application).

And after that, the future Fortran 2008 standard is expected to include co-arrays to support parallel and distributed computing, a bitfield type, a Fortran-specific macro preprocessor, among other things.

Advanced programmers keen to learn about Fortran 2003's new features may want to have a look at the Fortran 95/2003 book by Cohen, Metcalf and Reid. This is the successor to Metcalf and Reid's Fortran 90/95 book, which is still probably the best reference to modern Fortran, as most of the Fortran 2003 features aren't available on most platforms yet, whereas standard Fortran 95 is very portable.

For beginning programmers, or people who have never worked with any flavour of Fortran before, the book by Chapman (which I haven't read personally) may be a better idea from the reviews I've seen, but the reviews also indicate that it is not useful as a reference, so you may have to get the Metcalf et.al. book(s) anyway.

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**Lattice Forecast for 2056**

*2006-11-21T23:02:00.000+01:00*

Via Cosmic Variance and BioCurious : New Scientist has some well-known scientist forecast where science will be in 50 years.

A lot of the predictions are of the kind that people made 50 years ago for today: AIs more intelligent than people, permanent colonies on other planets, immortality drugs, contact with alien civilizations. They haven't come true in the past 50 years, and (exponential growth laws notwithstanding) I see no reason why they should come true in the next 50 years. The other kind of prediction seems much more likely to come true: detection of gravity waves, important discoveries at the LHC, significant progress in neuroscience, solutions for all of the Millennium problems, a firm understanding of dark matter and dark energy, a means to grow human organs in vitro, working quantum computers. And of course, just like nobody 50 years ago predicted the internet or the role of mobile phones in today's world, we should really expect that something completely unexpected will become the leading technology in 50 years.

What really irks me, though, is that there is no forecast from a lattice field theorist. After all, lattice QCD has made huge progress over the past decade, but apparently it isn't sexy enough for New Scientist these days. So here I am going to contribute my own 50-year forecast:

Over the next few decades, parallel computing will make huge advances, with machines that make today's TOP500 look feeble by comparison becoming readily affordable even to smaller academic institutions. As a consequence, large-scale simulations using dynamical chiral fermions will become feasible and will once and for all lay to rest any remaining scepticism regarding the reliability of lattice simulation results.

Predictions of "gold-plated " quantities will achieve accuracies of better than 0.1%, outshining the precision of the experimental results. If the limits of the Standard Model are at all accessible, discrepancies between accurate lattice predictions and experimental results in the heavy quark sector will be a very likely mode of discovering these limits, and will hint at what comes beyond. The use of lattice QCD simulations of nuclear structure and processes will become commonplace, providing a first principles foundation for nuclear physics and largely replacing the nuclear models used today.

On the theoretical side, the discovery of an exact gauge dual to quantum gravity will allow the study of quantum gravity using Monte Carlo simulations of lattice gauge theory, leading to significant quantitative insights into the earliest moments of the universe and the nature of black holes.

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**Why we use Fortran and Python**

*2006-11-02T20:40:00.000+01:00*

From Mark Chu-Carroll, a post on why C/C++ aren't always fastest, which is of course well known in (large parts of) the scientific computing community: Fortran compilers can perform much better optimization than C compilers, because Fortran has true arrays and loop constructs, as opposed to C's sugar-coated assembler. C is a great language to develop an operating system or a device driver, but not to write computationally intensive code that could benefit from parallelization, where Fortran beats it easily. And what about C++? The object-oriented features of C++ are nice for scientific applications, sure; you can have matrix, vector and spinor types with overloaded operators and such. But Fortran 95 has those things, too, but doesn't suffer from the problems that C++'s C-heritage brings. And Fortran 95 has even nicer features, such as elemental functions; that's something that no C-based language can give you because of C's poor support for arrays. And in case there is some object-oriented feature that you feel is missing in Fortran 95, just wait for Fortran 2003, which includes those as well.

But what about developing graphical user interfaces? Fortran doesn't have good support for those, now, does it? No, it doesn't, but that's besides the point; Fortran ("FORmula TRANslation") is meant as a number-crunching language. I wouldn't want to write a graphical user interface for my code in either Fortran or C/C++. For these kinds of tasks, I use Python, because it is the most convenient language for them; the user interface is not computationally intensive, so speed isn't crucial, and for the number crunching, the front end calls the fast Fortran program, getting you the best of both worlds – and without using any C anywhere (other than the fact that the Python interpreter, and probably the Fortran compiler, were written in C, which is the right language for *those* kinds of tasks).

Most lattice people I have personally worked with use Fortran, and a few use Python for non-numerical tasks. Of course there are large groups that use C or C++ exclusively, and depending on what they are doing, it may make sense, especially if there is legacy C or assembly code that needs to be linked with. But by and large, computational physicists are Fortran users – not because they are boring old guys, but because they are too smart to fall for the traps that the cool C++ kids run into. (Oh, and did I mention that Fortran 95 code is a lot easier to read and debug than C++ code? I have debugged both, and the difference is something like an hour versus a day to find a well-hidden off-by-one bug.)

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**Nobel Prize Winning Opera Singer**

*2006-10-17T19:53:00.000+02:00*

2004 Nobel Prize winner Frank Wilczek has started a new career as an opera singer, starring in the mini-opera "Atom & Eve" (no, not this one, but this one) at the 2006 Alpbach Technology Conference.

The opera tells the love story between Atom, the lonely oxygen atom, and Eve, the atomic physicist, whose rather significant scale disparity causes a few problems that are finally overcome by means of Bose-Einstein condensation which allows Atom to exist on a macroscopic scale. Apparently the libretto as performed differed from the one linked to above in having a happy ending. And, according to Physik Journal, Wilczek has already set his sight on the next great prize to win: a Grammy.

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**Lattice 2006 – Summary**

*2006-08-09T21:37:00.000+02:00*

As threatened earlier, here is my personal review of the Lattice 2006 conference, in the form of an incomplete list of disjointed observations:

Driven by the RHIC data, QCD at finite temperature and/or chemical potential is rapidly becoming a leading subfield within lattice QCD; at this meeting, seven out of 22 plenary talks were about some aspect of QCD thermodynamics, and the number of parallel talks on "High temperature and density" topics was second only to that of the traditionally most numerous spectroscopy talks.

The debate about the validity of the fourth-root prescription for staggered fermions, which an anonymous observer called "the staggered wars", shows no sign of coming to an end. Although a lot of progress has been made recently towards showing the correctness of the rooting prescription, a number of unattractive features have been found at the same time, fueling the flames.

Progress regarding more accurate determinations of CKM matrix elements from lattice QCD is slow, but steady; a lot of this work is very difficult, since getting high precision requires good control over perturbative errors and chiral extrapolations, and both lattice perturbation theory and chiral perturbation theory are hard and suffer from a lack of practitioners.

The AdS/CFT correspondence is beginning to become a topic of interest to researchers working on QCD, and string theory returns to its origins in the strong interactions where it may become a helpful tool to build and solve models of QCD.

Dynamical simulations with overlap fermions are arriving, but it will be a while until they get to the range of lattice spacings, lattice sizes and quark masses that have been studied using staggered fermions.

Everyone will be able to form their own opinion on what was new, what was hot and what was not, once the proceedings have been published by Proceedings of Science (and before that, when there will be a flood of new papers on the currently fairly quiet hep-lat arXiv).

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**Lattice 2006 – Day Five**

*2006-07-31T04:49:00.000+02:00*

Hello from Regina, where I have now recovered from my flight back from Tucson, and hence am ready to report on the last day of this year's lattice meeting.

The last day consisted of plenary sessions only. The first plenary, chaired by Anna Hasenfratz, was right after another indoors breakfast. The first speaker was Richard Brower, who gave a non-lattice talk about QCD and string theory, or more specifically the search for a dual description of QCD in the form of string theory on an AdS background. He started out by giving a historical overview of the development of string theory from its beginnings as an attempt to describe the strong interactions based on the observed behaviour of Regge trajectories and s-t duality, recounting the well-known failure of string theory to capture the correct hard scattering behaviour in strong interactions, along with the need to incorporate gravity. The situation changed with the discovery of dualities and the AdS/CFT correspondence: now string theory on an $AdS^5 \times S^5$ background is dual to N=4 Super-Yang-Mills theory in a 4d spacetime, with the strong coupling limit of SYM corresponding to the weak coupling limit of AdS. Of course we know that QCD is not a superconformal theory, so a description of QCD based on AdS/CFT has to break the conformal symmetry by introducing a boundary along the fifth-dimension of $AdS^5$; there are a number of models of this kind, and while they manage to reproduce some qualitative features of the QCD glueball spectrum as seen on the lattice, other features are qualitatively different, and the quantitative agreement is usually rather poor. However, there is some hope that an exact string dual of QCD might still be found, returning string theory to its origins as a theory of the strong interactions.

The second talk was by Mark Alford, who spoke about colour superconductivity. Colour superconductivity arises via the BCS mechanism just like ordinary superconductivity, but instead of a weakly attractive phonon-mediated attraction, quarks attract via the much stronger strong interactions, making Cooper-pairing even more efficient. Hence we expect QCD matter to be colour superconducting at large chemical potentials, making this phase probably relevant for the study of the interior of neutron stars. Unfortunately, that region of the QCD phase diagram is not (yet) accessible on the lattice due to the sign problem. In the limit of infinite chemical potential, perturbative descriptions are possible; NJL models provide another qualitative description of this phase. What is found is that in this limit, for $N_f = 3$ massless flavours, a curious phenomenon called colour-flavour locking (CFL) occurs: Light quarks of a given flavour only occur carrying a given colour charge, breaking the symmetry group from $SU(3)_c \times SU(3)_L \times SU(3)_R \times U(1)_B$ to $SU(3)_{CFL} \times Z_2$. The electromagnetic gauge group U(1)$_Q$, which was embedded in the $SU(3)_L \times SU(3)_R$ chiral group, is now changed into an U(1)$_{Q'}$ subgroup of SU(3)$_{CFL}$ due to photon-gluon mixing. This phase is therefore somewhat weird. It becomes complicated due to the fact that the strange mass isn't really zero, and also due to the weak interactions breaking flavour (while this is a weak effect, a compact star exists for a long time, giving the weak interactions time to act and affect the equilibrium); models indicate that this will lead to a complex phase structure in the regime of intermediate chemical potential. However, it is also known that a number of the phase found in the models, the so-called gapless phases, are artifacts and will not exist in full QCD; what will replace them is not known, and may not become known until a way to resolve the sign problem on the lattice is found.

After the coffee break the second plenary session was chaired by Peter Weisz, on behalf of the Local Organizing Committee for next year's lattice meeting to be held in Regensburg, Germany. The session started with Tommy Burch extending a warm invitation to Regensburg to everyone and extolling its virtues as a lovely city and excellent conference venue. Lattice 2007 will be at Regensburg from 30th July to 4th August 2007, dates that should be in every lattice theorists diary. Peter Weisz thanked the Local Organizing Committee in Tucson for organizing such a splendid conference, which was met with lots of applause.

The first talk of the last session was Urs Heller speaking about Lattice QCD at finite temperature (and zero chemical potential), concentrating especially on the nature of the transition as a function of the light quark masses, and on the QCD equation of state. On the first count, it seems conclusive by now that at the physical values of $m_{u,d}$ and $m_s$ the phase transition is in fact a crossover rather than a first-order transition. On the second count, the low-temperature description QCD matter by a hadron resonance gas and the high-temperature description by finite-temperature perturbation theory seem to match quite well onto the lattice data in their respective domains of validity. Some studies of non-static finite-temperature physics, such as transport coefficients, also are beginning to be undertaken on the lattice now.

The second speaker was Joel Giedt, who talked about lattice SUSY. Unfortunately this is a sufficiently technical field which is rather remote from my area of expertise, and thus I feel unable to give a reasonable summary of his talk. What I believed to understand was that a number of supersymmetric lattice theories are now known, that there is some problem with the Kähler potential being underconstrained by the symmetries and that actual lattice simulations might be helpful there, as well as in studying the AdS$^3$/CFT$_2$ correspondence.

The final talk was by Tom DeGrand, who was the only plenary (and probably simply the only) speaker to use foils and an overhead projector instead of a digital presentation to speak about the $N_f = 1$ quark condensate. In the $N_c \to \infty$ limit, it is found that $N_f = 1$ QCD with quarks in the antisymmetric representation corresponds to $N = 1$ Super-Yang-Mills theory. $N_f = 1$ QCD is peculiar in that there are no light pions, only a massive $\eta'$. When overlap fermions are being used to simulate at a fixed gauge topology, it becomes possible to determine the quark condensate via the spectrum of the overlap Dirac operator; in this way, the $1/N_c$ corrections to the $N_c \to \infty$ limit are found to be small even at $N_c = 3$.

At noon, the symposium was adjourned, and the participants began to scatter.

Since my flight only left in the evening, I managed to go and sneak a look at a very interesting historical monument located near Tucson, the San Xavier de Bac mission church. This mission was founded by the Jesuits in the late 17th century and completed by Franciscans in the mid-18th century. The church itself is built in a colourful version of the baroque style with many elements of ”naive” or peasant art in the ornamentation, suggesting that it was planned by the missionaries and executed by the local Natives, the Tohono O’odham, themselves. The white walls of the towers are visible from afar across the desert, giving this remarkable church the nickname ”white dove of the desert”.

As for the trip to Tucson, I feel little need to bore my readers with the details of our 15-hour zig-zag trip across the North American continent via L.A. and Toronto to Regina, and thus conclude my report on the Lattice 2006 meeting at this point. Thank you for reading; if and when I feel like it, I may follow-up with an overall summary of the conference later.

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**Lattice 2006 – Day Four**

*2006-07-28T06:37:00.000+02:00*

Hello again from Tucson. Today started off somewhat unusual – with rain, clouds and mist! So, no breakfast in the shade on the terrace; we didn’t have to go hungry, though, as it was just relocated to the dining room instead.

The first plenary session of the morning was chaired by Anthony Williams. The first speaker was Kostas Orginos, who talked about recent lattice results on nucleon structure. Nucleons are tricky, because they have only light quarks, and it is known that the sea quarks actually play a bigger role than the valence quarks in determining the structure of the nucleons. However, with a lot of hard work and clever methods, people have made a lot of progress towards getting accurate results for the nucleon structure functions, momenta of generalized parton distributions, and various other structure-related quantities, and these results may one day soon help to lead to an understanding of e.g. the proton spin crisis.

The second speaker was Christian Schmidt, who spoke about lattice QCD at finite density. As mentioned yesterday, finite density QCD is hard on the lattice, because the action becomes complex and direct Monte Carlo simulations are no longer possible at non-zero chemical potential $\mu$. The way to avoid this sign problem lies in one or another of a number of neat tricks such as reweighting configurations obtained at $\mu = 0$ to a finite value of $\mu$, measuring Taylor expansions around $\mu = 0$ and resumming the series, simulations at imaginary $\mu$ (where the action remains real) with subsequent extrapolation to real $\mu$, or some other method. A fair number of results exist now in this field, and while the quantitative precision still seems fairly low, there appears to be fair agreement on the qualitative features of the phase diagram. For large $\mu$, however, new methods appear to be needed.

After the coffee break, the second plenary session, chaired by Sinya Aoki, had three speakers: First was Pilar Hernández, who reported on progress she and her collaborators had made towards understanding the $\Delta I = 1/2$ rule. This rule, which states that Kaon decays in which isospin changes by more than $1/2$ are suppressed by a factor of approximately 20, is one of the longest-standing mysteries in QCD. Resolving it will require putting together a lot of work and know-how from both lattice QCD and chiral perturbation theory, and the people working on it seem to be far from a resolution in spite of a lot of recent progress.

Next was Michael Clark speaking about the Rational Hybrid Monte Carlo (RHMC) algorithm. This algorithm is a variation on the well-known HMC algorithm and uses a rational approximation to maintain the exact nature of the HMC algorithm (which is needed in a many cases), while outperforming the Polynomial HMC (PHMC) algorithm through the better approximation properties of rational functions as opposed to polynomials. Apparently, with the proper implementation, this algorithm can push Wilson fermions into a speed range where they become competitive with staggered fermions.

Finally, Mikko Laine talked about warm dark matter (WDM) and hot QCD. One interesting candidate for a WDM particle are sterile right-handed neutrinos. These would have been created thermally in the early universe. As it turns out, for right-handed neutrino masses in the keV range, the production range peaks at temperatures of around the QCD scale, so that QCD contributions to the production rate, e.g. via $u+d \to e^- + \nu_e$, $\nu_e \to N_1$ might be dominant.

After lunch, there were parallel sessions again, featuring amongst others my talk (which went fine, thanks for asking) about our recent work on determining the QCD/NRQCD matching coefficients for leptonic widths of heavy quarkonia to O($\alpha_s v^2$) for realistic lattice NRQCD actions.

After the parallel sessions, we heard this year's keynote talk, delivered by Ann Nelson, who extended an invitation to all lattice theorists to work on beyond-the-Standard-Model physics, where models such as composite Higgs models could benefit from lattice simulations.

The day closed with dinner. There are going to be more plenary talks tomorrow, but you will have to wait for me to get back to Regina before I can report about them.

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**Lattice 2006 – Day Three**

*2006-07-27T06:43:00.000+02:00*

Hello again from Tucson.

Day three was the odd one out in that the program today was arranged a little differently from the other days. As usual, the day started off with a plenary session, chaired by Philippe de Forcrand. The first speaker was Misha Stephanov, who talked about the QCD phase diagram. The general features of the phase diagram (confinement at low temperature and density, quark-gluon plasma at high temperature, colour superconductivity and colour-flavour locked phase at high density, and the phase transition lines separating these phases) are fairly well known by now. What is a lot less well known is the location of the critical point at which the phase transition line from the confined phase terminates and the transition turns into a crossover. A number of models have given wildly different predictions for its location, and since working at finite chemical potential on the lattice is only possible by some ingenious tricks (the action is no longer real with a real chemical potential, so Monte Carlo methods won't work directly), the lattice predictions are somewhat in disagreement with each other as well. On the experiments at RHIC are able to scan some region of the phase diagram by varying the center-of-mass energy in heavy ion collisions, so there is some hope of nailing it down in the near future, though.

Next came a much-expected talk by Stephen Sharpe, who summarized the debate on the validity of the fourth-root trick for staggered fermions. The options which he put up initially were "good" (works as desired without any problems), "bad" (wrong continuum limit, hence wrong physics) and ”ugly” (right continuum limit, hence ultimately right physics, but lots of complications and unexpected features). Since rooted staggered fermions have been shown to be non-local, the ”good” option was ruled out right away, which might seem worrying given that the stakes are so high with the best ensembles of configurations (by MILC) currently in existence relying on rooted staggered fermions. However, he pointed out that non-locality does not mean the theory is sick; an example were certain non-local Ising models which turn out to lie in the same universality class as the local model if the locality falls off fast enough at large separations. The replica trick and renormalization group analysis elaborated in the parallel talks by Bernard, Golterman and Shamir were explained again, and Mike Creutz's objections to a number of features of rooted staggered fermions were answered in the next sections of this talk. The summary was that rooted staggered fermions were not ”bad” (as shown by the Bernard-Golterman-Shamir analysis), but that they were ”ugly” (as pointed out by Creutz's criticisms).

After the coffee break, the program changed from its usual format: a parallel session replaced the usual second plenary session. That plenary session took place after lunch instead, with Shoji Hashimoto in the chair. The first speaker was Anthony Duncan, who spoke about applications of methods from lattice field theory to problems in the theory of Coulomb gases appearing in biophysics. These problems can be transformed into Feynman path integrals defined with a lattice cutoff by some ingenious transformations, and Monte Carlo methods developed for lattice QCD can then be used to treat them.

The second talk was the traditional experimental talk, delivered by Alessandro Cerri, who gave an overview of recent advances in flavour physics. I had to sneak out of the room at the end of this talk, and hence I cannot report anything on the third talk, entitled $Searchforgluonicexcitationsinlightunconventionalmesons$ by Paul Eugenio.

In the later afternoon and evening we had an excursion to the Arizona Sonoran Desert Museum, which was much, much better than the excursion on the first day. The desert museum is a combination of botanical garden and zoo, which features the astounding variety, breathtaking beauty and sheer strangeness of this most extraordinary landscape. There were dozens of different kinds of cacti, agaves and other desert plants, mountain lions, wolves, coyotes, javelinas, coati, hummingbirds and (yes, that is not a typo) otters and beavers, colourful minerals and fossils and the scorching heat of the sun, all of which combined to leave a remarkable impression (besides making me scold myself again for being stupid enough to forget my camera). The day closed with the banquet, which was held in the grounds of the desert museum and was very pleasant, even if the chocolate cake for desert was a little too delicious.

## Lattice 2006 – Day Two

*2006-07-25T22:33:00.000+02:00*

Hello again from the Lattice 2006 conference in Tucson, Arizona.

The second day started with plenary sessions again. The first session was chaired by Julius Kuti, and began with a talk by Leonardo Giusti about simulating light dynamical fermions on the lattice; the main focus of the talk was on new development using Wilson fermions, although some results on Ginsparg-Wilson and twisted mass fermions were mentioned as well, but staggered quarks were missing almost completely. Important areas covered were the need to control all systematic errors in a truly ”first principles” approach, and the problems that Wilson fermions face because their spectral gap is not always positive, along with some proposals as to how this problem might be resolved, as well as direct comparisons with chiral perturbation theory results for the finite-size errors (which seem to show some significant discrepancies in many cases).

Next was a talk by Hank Thacker, who spoke about new types of extended topological objects: If the topological charge density is determined from the spectrum of the overlap operator via the index theorem, what is found is that there appear to be no instantons, but instead thin extended three-dimensional sheets of coherent topological charge, with two sheets of opposite topological charge always next to each other. Two-dimensional $\mathbb{CP}^{N-1}$ (toy) models show similar structure for $N > 3$. These sheets may be identical to domain walls that appear in certain AdS/CFT models as the remnant of D6-branes wrapped around a 4-sphere, where they separate so-called $k$-vacua whose $\theta$-parameter differs by $2\pi k$. They may also be suggestive of some kind of relation between $N = 1$ SYM and $N_f = 1$ QCD. A point that was raised during questions was that, since the width of these sheets appears to be on the order of the lattice spacing, they don’t scale and in this kind of picture the continuum limit would either not exist or at least look very weird.

After the tea break, the second plenary session of the morning had Maria Lombardo in the chair. The first talk was by Tetsuo Hatsuda, who spoke about RHIC physics and hot QCD. At the center was the possibility of using heavy flavours as probes to look into the RHIC fireball. Relevant lattice results concern the temperature dependence of the Debye screening mass and the spectral functions of charmonia, which can be reconstructed via MEM. What is found there is that the $J/\psi$ and $\eta_c$ persist well up to temperature of about $1.5T_C$, whereas their orbital excitations disappear around $T_C$.

The last talk of the morning was by Tetsuya Onogi and was a review of progress in heavy flavour physics from the lattice. This is such a large and active field that he actually had to apologize to all the people (including myself) who had sent him materials which he had no time to include in his talk. The physics goal in this area is largely to overconstrain the elements of the CKM matrix through determinations of heavy meson decay constants and mixing parameters; this is exciting because it might lead to the discovery of new physics beyond the Standard Model, and also because the errors on these quantities are currently dominated by the theoretical errors. So the results presented were largely determinations of $f_B$, $f_{B_s}$, $f_D$, $f_{D_s}$, $B_B$ etc. and various ratios and combinations thereof. Other results included determinations of $m_b$ and various parameters in HQET.

After lunch there are going to be parallel sessions. Stay tuned.

**Update:** The afternoon parallel sessions are over now. One of them was almost entirely devoted to talks aiming to resolve the debate about staggered fermions outlined earlier on this blog. Essentially, as far as I understand the argument, what is claimed is that firstly, rooted staggered fermions are non-local because of taste-breaking, but that secondly, the continuum limit exists nevertheless and is in the right universality class by renormalization group arguments, and that thirdly, the correct chiral perturbation theory for rooted staggered fermions can be obtained from staggered chiral perturbation theory using a "replica trick" whereby one consider $n_R$ copies of the theory and takes $n_R = 1/4$ in the end. The speakers (Maarten Golterman, Yigal Shamir and Claude Bernard) got into some almost heated argument with Mike Creutz about the whole issue.

Still upcoming today: the poster session. Stay tuned.

**Update:** The poster session was only moderately exciting, which was probably due to the fact that there were a lot of posters that really were 20-page papers pinned to a wall, which I find rather deterring since you would have to read them in full before talking to the presenter. A good poster (at least in my opinion) is very different from a good paper; the poster should minimize the amount of unnecessary text and use figures and other graphical layout elements to emphasize the main point, since the details can always be filled in by the presenter.

There also was a little problem with the food, which was served only during the first hour of the session; this meant that people who presented their posters in the "A" section got nothing to eat.

The most unusual poster was a live presentation of the ILDG by people from the ILDG working group. Mike Creutz's poster on "diseases" with rooted staggered fermions also got a lot of attention. And the posters by the people from Regina were also nice, although I may of course be biased in their favour.

## Lattice 2006 – Day One

*2006-07-25T07:15:00.000+02:00*

Hello from Tucson, Arizona, where I am at the Lattice 2006 conference.

Unfortunately, I am facing a similar technical problem to that Matt experience last year in Dublin: the wireless age is not quite upon us yet (at least not unless one is willing to pay outrageous internet fees to the hotel), so I will have to report after the event, rather than blog live.

This year the lattice conference takes place here in the middle of the very picturesque Arizona desert (sorry, I forgot my camera at home – I'm already kicking myself for it, so you don't need to) at the extremely luxurious Starr Pass resort. Getting here from Regina was more than a little tedious, but I won't bore you with tales of endless lineups at US customs or long-delayed flights. Instead I'll jump *medias in res*:

After a welcome message from the President of the University of Arizona and a number of announcements (such as that we should remember to drink plenty of water), the first plenary session (chaired by Junko Shigemitsu) started with a talk by Weonjong Lee about recent progress in Kaon physics on the lattice. The main point of his talk was to emphasize how essential improvement is in order to reduce the impact of lattice artifacts, and to advertise HYP smearing over ASQTAD. The results presented included demonstrations of how taste-breaking effects in the pion spectrum with staggered fermions get suppressed by improvement, determinations of $f_\pi$ and $f_K$ in full QCD, of $B_K$ in quenched QCD with an outlook towards full QCD results that should become available next year, and of $K \to \pi\pi$ and $K_{\ell 3}$ decays. He closed by suggesting that the MILC collaboration should create a set of Fat7bar configurations in addition to their ASQTAD configurations to allow people to investigate the better suppression of lattice spacing artifacts expected there.

Next was a talk by Stefan Schaefer about algorithms for dynamical simulations with overlap fermions. While overlap fermions have the advantages of preserving chiral symmetry exactly, possess automatic O(a) improvement and their spectrum has an exact relation to gauge field topology via the index theorem, they are extremely expensive to simulate, due to the appearance of the operator sign function in the overlap Dirac operator. One cause of this is that the exact link with topology implies that the overlap operator is discontinuous at the surfaces in the space of gauge connections that separate different topological sectors. Three possibilities to treat this have been proposed: the first is to modify the time evolution algorithm that generates the configurations by taking the existence of these surface into account and to properly reflect or refract a trajectory that would cross them; this has the advantage of being exact, but is very expensive because it requires a full inversion of the overlap operator each time a sector boundary is crossed. The second possibility is to approximate the sign function by some smooth function; this is much easier to implement, but has to deal with large forces near sector boundaries where the approximation becomes steep, and also needs a good approximation of the determinant function to work. The third alternative are topology-preserving gauge actions, which are set up so as to disallow transitions between topological sectors. In summary, while a lot of progress has been made, large volumes are still unattainable with overlap fermions at this time.

After a tea break there was a second plenary session, chaired by Mike Peardon. The first talk, by Kim Splittorf, was about the sign problem in the epsilon regime of QCD at finite chemical potential. The problem there is that at finite chemical potential, the discontinuity of the chiral condensate at zero quark mass cannot be understood in the same terms (via the Banks-Casher relation) as at zero chemical potential, because the eigenvalues can now be complex. Instead, the spectral density also becomes complex and develops oscillations that lead to the discontinuity.

The next speaker was Carlos Pena, who talked about determinations of weak matrix elements using twisted mass lattice QCD, especially about results that the ALPHA collaboration has obtained for $B_K$, and results for $B_B$ that are expected next year.

The session was rounded off by Karl Jansen presenting the status of the ILDG. For those not active in the field, the International Lattice Data Grid is a grid framework that allows lattice theorists to share and access their configurations between countries and collaborations by linking the different national grids into a global grid. This requires agreeing on some common data format, a way to describe metadata (such as lattice size, actions used etc.) by means of an XML schema defining a language known as QCDml, and various layers of software linking it all together. The people working on this have done a lot of hard work for the benefit of the lattice community, and by giving people outside the large collaborations access to unquenched configurations on large lattices using their action of choice, this should help a lot to advance the state of the field.

In the afternoon there were two parallel session with a break for refreshments and informal conversations in between. I see little point in recounting which talks I went to, since that would at most reflect my biases rather than anything about the work being done by others in general.

In the evening there was an excursion dinner to Old Tucson, which is a movie set outside Tucson, where Westerns have been produced since the 1930s. The excursion featured some nice food, almost unbearable heat, a staged shootout between Western actors, some fairly bizarre and allegedly funny goings-on on the stage of the local Saloon, and a bit of stargazing. If that sounds odd, it doesn't half reflect how odd it really was (or at least how odd I thought it to be, which again may simply reflect my cultural biases). I might try and obtain some pictures from those who managed to bring their cameras, and if I succeed, some pictures may be posted on this blog.

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**Peer review and Trial by jury**

*2006-06-14T18:18:00.000+02:00*

There has been a big ~~shouting match~~ debate going on in the physics blogosphere over the last couple of days. The topic under discussion is the role that democracy plays, can play or should play within science.

Now, it is easy to make up various kinds of strawmen and bash them to death, e.g. the idea of determining the values of the Standard Model parameters by public voting (which nobody advocates), or the notion of a scientific dictatorship where one single person decides on what is science and what isn't (which hopefully also nobody advocates).

To actually perform a serious analysis of what we want the scientific community to look like is much more difficult: On the one hand, there is clearly a lot to be said in favour of a scientific aristocracy of experts; on the other hand, do we really want some small self-recruiting in-group to decide about everyone else's funding, especially given that they will still be human and hence their decisions may be guided by personal like or dislike of a person just as well as by scientific analysis of his or her proposal?

These are not easy issues to discuss and decide (and of course any discussion of them in the blogosphere is going to have virtually no effect at all, given that the physics blogosphere is dominated by lowly postdocs, or at most assistant professors, and hence does not exactly represent the views of the major policy-makers within the community).

Here, I would just like to point out that the use of the word "democracy" may be slightly misleading, at least as far as common connotations go. Most people, when hearing "democracy", will think of voting, and possibly the absence of an individual or group with dictatorial powers, leading quickly to the kind of strawman arguments that dominated this debate. However, there is another crucial feature of (at least British and American) democracy: I'm speaking of trial by jury. This is a profoundly democratic institution; nobody can be found guilty of and punished for a crime, unless he either admits it himself by pleading guilty, or the prosecution manages to convince a panel of twelve people chosen at random from among the accused's peers (rather than some group of politicians or experts) of his guilt.

This is in many ways a much better analogy for the kind of democracy that can, should, and in fact does exist in the scientific community. Peer review is not that different from trial by jury, with the reviewers acting as the equivalent of jurors (randomly chosen peers of the author), and the editor as the equivalent of the judge. There are even appeals, and many journals have a kind of *voir dire* where potential conflicts of interest are examined before selecting referees. Of course the analogy is not perfect, because there are no opposing parties to the proceedings, but this is (at least in my opinion) a much closer analogy. In fact, in many respects the work of the scientist is somewhat similar to that of the judiciary (weighing evidence and coming to a conclusion), just as it is hugely different from that of the legislative and executive branches (which are used as flawed analogies in the strawman arguments mentioned above).

Comments are welcome.

**Update:** More on the debate in a new post by Sabine (to whom we extend our warmest congratulations on her recent marriage) on Backreaction.

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**Quarkonia and MEM**

*2006-06-09T20:42:00.000+02:00*

On the arXiv today is a paper by Peter Petreczky about the spectral functions of heavy quarkonia at finite temperature.

People generally expect that at high temperatures, heavy quarkonia will be suppressed, because the gluons will be screened by thermal effects (Debye screening, and possibly chromomagnetic screening as well), leading to an exponential fall-off of the interquark potential at large distances and hence allowing the heavy quarks to drift apart. This suppression of quarkonia is supposed to be an important signature of the formation of a quark-gluon plasma, and hence confirming it in a model-independent way is important. One way to do this is to look at the spectral functions for the corresponding correlators and to see whether the peaks in the spectral function that correspond to the bound states in that channel will broaden and eventually vanish as the temperature is increased.

The results in this case are that the 1P charmonia (the

$$J/\psi$$

and its kin) do dissolve just above the deconfinement transition, whereas other quarkonia appear to persist up to considerably higher temperatures.

Now how do people obtain these kinds of results? The spectral function is the function $\sigma(\omega)$ appearing in the Euclidean periodic-time equivalent of the Källén-Lehmann spectral representation

$$D(t) = \int_0^\infty d\omega \sigma(\omega) \frac{\cosh(\omega(t-\beta/2))}{\sinh(\omega\beta/2)}$$

where the latter expression is the correlator for a free particle of mass $\omega$, with $\beta$ being the extent in the Euclidean time direction. So if you have measured the correlator $D(t)$, you just invert this to get the spectral function, which contains all the information of the spectrum of the theory.

There is one lie in this last sentence, and that lie is the little word "just". The reason is that you are trying to reconstruct a continuous function $\sigma(\omega)$ from a small number of measured data points $D(\beta i/N_t)$, making this an ill-posed problem.

The way around that people use lies in a method called Maximum Entropy Method (MEM) image restoration, which is also used to restore noisy images in astronomy. (Unfortunately it is bound by the rules of logic and hence cannot do all the wonderful and impossible things, such as looking through opaque foreground objects or enlarging a section to reveal details much smaller than an original pixel, that the writers of *CSI* or *Numb3rs* are so fond of showing to an impressionable public in the interest of deterrence, but it is still pretty amazing – just google and look at some of the "before and after" pictures.)

The basis for MEM is Bayes' theorem

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

which relates the conditional probability for A given B to that for B given A. Using Bayes' theorem, the probability to have the spectral function $\sigma$ given the data $D$ and fundamental assumptions $H$ (such as positivity and high-energy asymptotics) is

$$P(\sigma|D,H) = P(D|\sigma,H)P(\sigma|H)$$

where conventionally $P(D|\sigma,H)$ is known as the likelihood function (it tells you how likely your data are under the assumptions), and $P(\sigma|H)$ is known as the prior probability (it tells you how probable a given $\sigma$ is prior to any observation $D$). The likelihood function may be taken to be

$$P(D|\sigma,H) = Z \exp\left(-\frac{1}{2}\chi^2\right)$$

where $\chi^2$ is the standard $\chi^2$ statistic for how well the $D(t)$ given by $\sigma$ fits your data $D(\beta i/N_t)$, and $Z$ is a normalization factor. For the prior probability, on takes the exponential

$$P(\sigma|H) = Z' \exp(\alpha S)$$

of the Shannon-Jaynes entropy

$$S = \int_0^\infty d\omega \left[ \sigma(\omega) - m(\omega) - \sigma(\omega) \log \left( \frac{\sigma(\omega)}{m(\omega)} \right) \right]$$

where $m$ is a function called the default model, and $\alpha$ is a positive real parameter.

The most probable "image" $\sigma_\alpha$ for given $\alpha$ (and $m$) is then the solution to the functional differential equation

$$\frac{\delta Q_\alpha}{\delta \sigma_\alpha} = 0$$

where

$$Q_\alpha = \left( \alpha S - \frac{1}{2}\chi^2 \right)$$

The parameter $\alpha$ hence parameterizes a tradeoff between minimizing $\chi^2$ and maximizing $S$, which corresponds to making $\sigma$ close to $m$. Some MEM methods take $\alpha$ to be an arbitrary tunable parameter, whereas in others, to get the final output $\sigma_{MEM}$, one still has to average over $\alpha$ with the weight $P(\alpha|D, H, m)$, which can be computed using another round of Bayes' theorem. In practice, people appear to use various kinds of approximations. It should be noted that the final result

$$\sigma_{MEM}(\omega) = \int d\alpha \sigma_\alpha(\omega) P(\alpha|D, H, m)$$

still depends on $m$, although this dependence should be small if $m$ was a good default model.

This is pretty cool stuff.

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**Non-Relativistic QCD**

*2006-05-29T22:20:00.001+02:00*

This is another installment in our series about fermions on the lattice. In the previous posts in this series we had looked at various lattice discretizations of the continuum Dirac action, and how they dealt with the problem of doublers posed by the Nielsen-Ninomiya theorem. As it turned out, one of the main difficulties in this was maintaining chiral symmetry, which is important in the limit of vanishing quark mass. But what about the opposite limit – the limit of infinite quark mass?

As it turns out, that limit is also difficult to handle, but for entirely different reasons: The correlation functions, from which the properties of bound states are extracted, show an exponential decay of the form $C(T,0) \sim e^{-maT}$, where $t$ is the number of timesteps, and $ma$ is the product of the state's mass and the lattice spacing. Now for a heavy quark, e.g. a bottom, and the lattice spacings that are feasible with the biggest and fastest computers in existence today, $ma \approx 2$, which means that the correlation functions for an $\Upsilon$ will decay like $e^{-4T}$, which is way too fast to extract a meaningful signal. (Making the lattice spacing smaller is so hard because in order to fill the same physical volume you need to increase the number of lattice points accordingly, which requires a large increase in computing power.)

Fortunately, in the case of heavy quark systems the kinetic energies of the heavy quarks are small compared to their rest masses, as evidenced by the relatively small splittings between the ground and excited states of heavy $Q\bar{Q}$ mesons. This means that the heavy quarks are moving at non-relativistic velocities $v \ll c$ and can hence be well described by a Schrödinger equation instead of the full Dirac equation after integrating out the modes with energies of the order of $E \geq M$. The corresponding effective field theory is known as Non-Relativistic QCD (NRQCD) and can be schematically written using the Lagrangian

$$\mathcal{L} = \psi^\dagger \left(\Delta_4 - H\right) \psi$$

where $\psi$ is a non-relativistic two-component Pauli spinor and the Hamiltonian is

$$H = -\frac{\Delta^2}{2M} + \text{(relativistic and other corrections)}$$

In actual practice, this is not a useful way to write things, since it is numerically unstable for $Ma < 3$; instead one uses an action that looks like

$$\mathcal{L} = \psi^\dagger \psi - \psi^d ag \left(1 - \frac{a\delta H}{2}\right) \left(1 - \frac{aH_0}{2n}\right)^n U_4^\dagger \left(1 - \frac{aH_0}{2n}\right)^n \left(1 - \frac{a\delta H}{2}\right) \psi$$

where $H_0 = -\frac{\Delta^2}{2M}$ whereas $\delta H$ incorporates the relativistic and other corrections, and $n \geq 1$ is a numerical stability parameter that makes the system stable for $Ma > 3/(2n)$.

This complicated form makes NRQCD rather formidable to work with, but it can be and has been successfully used in the description of the $\Upsilon$ system and in other contexts. In fact, some of the most precise predictions from lattice QCD rely on NRQCD for the description of heavy quarks.

It should be noted that the covariant derivatives in NRQCD are nearest-neighbours differences – the reasons for having to take symmetric derivatives don't apply in the non-relativistic case; hence there are no doublers in NRQCD.

## Analytical (3+1)d Yang-Mills and ontology

*2006-05-18T20:31:00.000+02:00*

A little while ago, there were two papers by Leigh, Minic and Yelnikov, in which they expanded on the previous work done by Karabali, Kim and Nair towards an analytical solution for (2+1)-dimensional pure Yang-Mills theory. By re-expressing the theory in terms of appropriate variables, they were able to find an ansatz for the vacuum wavefunctional in the Schrödinger picture which they could solve analytically, enabling them to find the spectrum of glueball masses. But can the same be done for the physical case of (3+1) dimensions?

In this paper, Freidel, Leigh and Minic seem to say "probably". Their generalization to (3+1) dimensions is based on the idea of "corner variables", which are essentially untraced Wilson loops lying within the coordinate planes which go through the point at infinity. If the theory is expressed in terms of these, there are a lot of formal algebraic analogies with the (2+1)-dimensional case, which renders them hopeful that it may be possible to treat the (3+1)-dimensional theory in an analogous fashion. In this case the only problem left to solve would be to determine the kernel appearing in the ansatz for the wavefunctional.

There seems, however, to be a very important difference between the (2+1)d and (3+1)d cases, which they also mention but appear to consider as a relatively minor inconvenience that will be worked out: in (2+1) dimensions, the gauge coupling has a positive mass dimension: $[g_3^2] = [\text{Mass}]$, so the generation of a mass gap is expected on dimensional grounds just from looking at the Lagrangian, and it is even possible to compute the mass gap semi-perturbatively using self-consistent approximations. In (3+1) dimensions, there is no dimensionful parameter in the Yang-Mills Lagrangian, so the existence of a mass gap is really an unexpected surprise. Of course an arbitrary mass scale will be introduced by regularization, but even if this mass scale cancels from all mass ratios (as Freidel et al. appear to assert it will), its arbitrariness still means that the overall mass scale of the theory will remain completely undetermined by the kind of analysis they propose. I am not sure if this can be a consistent situation.

The corner variables they use reminded me of a talk by the philosopher Holger Lyre given at a physics conference in Berlin in 2005. He discussed the Aharonov-Bohm effect and exhibited three possible ways of interpreting electrodynamics ontologically, which he called the A-, B- and C-interpretations. In the A-interpretation, the gauge potential A is assumed to be a real physical field: that is probably what most working physicists would reply when asked for the first time, and it has the advantage of making the locality of the interaction explicit; on the other hand, how can a quantity that depends on an arbitrary gauge choice be physically real?

In the B-interpretation, the field strength B (and E) is considered to be physically real; this means physical reality is gauge-invariant, as it should be, but the interaction with matter becomes maximally nonlocal, which is very bad. In the C-interpretation, finally, the holonomies (C is for curves) of the gauge connection are taken to be the only physically real part of the theory: this leads to gauge-invariance and a form of locality (not a point interaction, but a *Nahewirkungsprinzip*). Ultimately, the C-interpretation would therefore appear to be the most palatable ontology of gauge theories. Finding a quantum formulation of gauge theories in the continuum that contains only Wilson loops as variables would be very desirable from this philosophical point of view alone, even if it does not lead to an analytical solution.

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**A debate about staggered fermions**

*2006-04-24T20:24:00.000+02:00*

Recently, there have been a number of short papers on the arXiv that discussed some potential problems that the usual procedure of taking the fourth root of the staggered fermion determinant to obtain a single-flavour theory might bring with it.

As a little reminder, staggered fermions are obtained from naive fermions by redistributing the spinor degrees of freedom across different lattice sites. As a result, staggered fermions describe a theory with four (rather than the 16 naive) degenerate fermion flavours, usually called "tastes" to distinguish them from real flavours. In order to obtain a theory with a single physical flavour, one usually takes the fourth root of the fermionic determinant for staggered fermions; this is correct in the free theory and in perturbation theory, but nobody really knows whether it makes sense nonperturbatively.

In the paper starting this recent debate, Creutz claimed that this procedure leads to unphysical results. His argument is based on the observation that with an odd number of quark flavours, physics is not invariant under a change of sign of the quark mass term, and hence the chiral expansion must contain odd powers of the quark mass. Since the staggered theory is invariant under a change of sign of the quark mass, so will be its fourth-rooted descendant, and hence it can only pick up even terms in the chiral expansion. Thus, Creutz claims, staggered fermions describe incorrect physics.

Within a week, there was a reply from Bernard, Golterman, Shamir and Sharpe, who claim that Creutz's argument is flawed since the quark mass in the theory corresponding to the continuum limit of the rooted staggered theory is always positive, regardless of the sign of the original quark mass, and since moreover the non-analyticity inherent in taking a root leads to the emergence of odd powers of the (positive) mass in the continuum limit.

This was followed by third paper by Dürr and Hoelbling, in which they show how one may define ”smart” determinant for staggered fermions (by including a phase factor that depends on the topological index of the gauge field background) that allows to reach the regime of negative quark masses. I have to admit that I do not fully understand this work, and enlightenment from readers is appreciated.

The debate over the correctness of the fourth root trick for staggered fermions is likely to go on for a while, particularly given the fact that the choice of fermion discretization has become an almost religious issue within the lattice community. Personally, I certainly hope that staggered fermions give the correct physics, but I am not sure whether I actually have enough evidence or understanding to have an opinion either way.

**Update:** The paper by Creutz has been updated with a reply to the objections raised by Bernard et al. (leading to the rather strange situation of circular citations between papers bearing different date stamps). Creutz now argues that while the problems he mentions may go away in the continuum limit, observables that develop a divergent dependence on a regulator at isolated points (such as the chiral condensate at m=0) are an ”absurd behaviour” for a regulator, and that Wilson fermions are preferable in this regard. I am not entirely sure in how far the existence of exceptional configurations is a less absurd behaviour, though. I suppose there may be another round in this debate (with yet more circular citations).

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### More on (2+1)d glueballs

*2006-04-11T19:35:00.000+02:00*

In a new paper, Leigh, Minic and Yelnikov give a more detailed follow-up on their earlier paper about the analytical solution of (2+1)-dimensional pure Yang-Mills theory.

Their basic setup is as before, but they give a lot more details: They start with the functional Schrödinger picture analysis of (2+1)d pure Yang-Mills theory performed by Karabali, Kim and Nair to re-express the theory in terms of new variables, and then make a generalized Gaussian ansatz for the vacuum wave functional containing an undetermined kernel $K(\Delta/m^2)$. The Schrödinger equation is then turned into an ordinary differential equation for $K(L)$, which can be solved in terms of Bessel functions. It follows that the glueball masses can be written as products of a sum of Bessel function zeros and the Karabali-Kim-Nair mass. Leigh, Minic and Yelnikov compare their predictions to lattice results and get mostly good agreement (with some uncertainty about the correct identification of excited states in the lattice simulations in a few cases).

Finally, they note and discuss the almost degeneracy of the glueball spectrum that follows from the asymptotic form of the Bessel function zeros, as discussed here.

These are very interesting results and their work may be considered a major breakthrough, although I remain sceptical as to whether we are going to see anything similar in the (3+1)d case anytime soon (or ever).

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**Twisted Mass Fermions**

*2006-03-29T00:43:00.000+02:00*

Time for another post in our series about lattice fermions. In this post, we are going to take a look at a still fairly new approach to lattice fermions that is known under the name of twisted mass QCD (tmQCD).

What one does in this approach is to take the Dirac operator for a flavour doublet of fermions and add to it a chirally twisted mass term

$$D_{tw} = D + i\mu\gamma^5\tau^3$$

where the $\tau^3$ acts in flavour space. This extra term together with the doublet structure has the consequence that the worrisome exceptional configurations that plague Wilson quarks (remember, those were the configurations where the additive mass renormalization that is allowed for Wilson fermions because they violate chiral symmetry takes the renormalized mass through zero) no longer exist, since the twisted Dirac operator has positive determinant:

$$det[D_{tw}] = det[D^\dagger D + \mu^2] > 0$$

and hence does not have any zero eigenvalues.

A flavour-dependent chiral rotation

$\psi \mapsto \exp(i\alpha\gamma^5\tau^3/2)\psi$

leaves the continuum action with an added twisted mass term invariant, but mixes the ordinary mass $m$ with the twisted mass $\mu$. Hence one can see the twisted mass action for a given $\mu$ as being the result of applying this chiral rotation to the ordinary continuum QCD action, and vice versa. The basis in which the $\mu$ term vanishes is known as the physical basis.

On the lattice, the twisted mass is usually added to the Wilson Dirac operator (which needs it most, since it suffers from exceptional configurations). The resulting action can then be used to study quarks at small masses, where the Wilson action itself would fail. It also has the added benefit that certain observables are automatically free of $O(a)$ lattice artifacts with a twisted mass.

The twisted mass theory has its own problems, though: The appearance of $\tau^3$ in the twisted mass term means that the up- and down-type quarks have opposite signs of the twisted mass, and hence isospin is no longer conserved. Also, the appearance of $\gamma^5$ implies that parity is no longer a symmetry, although a generalized parity operation involving the twist angle can be defined as a symmetry of the twisted theory.

In closing, it should be stressed again that the exact meaning and properties of twisted mass are still a very active field of research, and some surprises may still be expected. I should also add that I am not really an expert on tmQCD (though other people here in Regina are), so corrections and additional remarks are particularly welcome on this post.

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**Topology and masses**

*2006-03-08T18:04:00.000+01:00*

In this post I'd like to talk about some papers I stumbled across recently which both have to do with topological quantities and masses in gauge theories, although in a completely unrelated way.

The first paper is this one by a group of Italian and Greek researchers, in which they study the dependence of the string tension and lowest glueball mass on the vacuum angle $\theta$. Unfortunately, it is not really possible to simulate the QCD action with a $\theta$-term included, since the topological structure of a lattice gauge configuration is necessarily trivial since the lattice is finite and discrete. They bypass this by considering small values for $\theta$ and studying the expansion around $\theta = 0$ to order $\mathcal{O}(\theta^2)$. The coefficients in that expansion can then be expressed in terms of correlators involving the topological charge operator. Measuring that on lattice is still not an easy task, because it has essentially to be reconstructed from what its value would be in the continuum, but a number of methods based either on the concept of "cooling" or on the spectrum of the Dirac operator (via the Atiyah-Singer index theorem) exist. Using a cooling-based method, the authors find that the $\theta$-dependence of their observables is rather small (the $\mathcal{O}(\theta^2)$ coefficients are of order -0.01 to -0.1) and decreases with an increasing number of colours roughly like $1/N^2$, which is expected from the large-$N$ limit.

The other paper is this one by Dvali, Jackiw and Pi, who show a way to extend the topological mass generation mechanism of the Schwinger model from two to four dimensions. The photon part of the Lagrangian of the Schwinger model can be rewritten in terms of the square of the Pontryagin density and the Chern-Simons current, where the latter is coupled to the anomalously non-conserved axial vector current. The resulting equation of motion plus the anomaly equation then combine to give a mass to the Pontryagin density, which can be considered as a massive pseudoscalar field. It is this formulation which the authors lift to four dimensions (subject to some relatively unimportant technicalities, and with the caveat that the resulting 4D action is non-renormalizable) to find that a mass for the Pontryagin density is also created in four dimensions. Phenomenologically, this is identified as a possible part of an effective field theory for the $\eta'$ by the authors.

At first I wasn't sure whether calling this a topological mechanism is entirely correct, since the anomaly equation for the axial vector current is needed to make it work, but I finally realized that, as the integral of the axial anomaly is equal to the index of the Dirac operator, it is of course truly topological by the Atiyah-Singer index theorem. This is actually quite astonishing (at least to me), since the usual diagrammatic treatment of the axial anomaly completely obscures its topological connection.

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### arXiv trackback controversy

*2006-02-27T16:53:00.000+01:00*

A lively controversy has recently broken out in the physics blogosphere regarding the recently revealed (and previously somewhat mysterious) trackback policy on the arXiv. For some time, the arXiv has had a mechanism by which approved blogs could post trackbacks to preprints on the arXiv. This would allow researchers looking at a paper to see that and where it is being discussed on physics blogs, and help bring people interested in discussing it together on the same discussion boards. Seems like a good idea, right? Now the problem is of course which blogs to approve for posting trackbacks. There are a lot of cranks, lunatics and plain idiots populating the web, and many of them have their own ideas about fundamental physics (anybody remember Archimedes Plutonium?), which you would definitely not want to be linked to from the arXiv. So the arXiv board decided to vet blogs before allowing them to post trackbacks. So far everything seems fine.

Enter Peter Woit, whose blog Not Even Wrong is very strongly critical of String Theory, suggesting that it is, in Wolfgang Pauli 's words, not only not right, but "not even wrong". That kind of criticism is obviously not welcomed by string theorists, many of whom therefore consider Woit a crank (even though he holds a permanent position in mathematics at Columbia University). So what happens when Peter Woit tries to post a trackback to the arXiv? It gets rejected, and since the arXiv trackback policy is sort of secret at that point, Peter feels justified to complain about censorship by string theorists on his blog. His case is taken up by Cosmic Variance, prompting Jacques Distler to reveal the arXiv's trackback policy on his blog.

It turns out that the arXiv trackback policy is to allow trackbacks only from currently active researchers (as judged by the number of their papers on the arXiv). Since Peter Woit apparently has only two papers on the arXiv, his blog does not qualify, and there is apparently no censorship involved.

However, the question arises of how useful this kind of policy actually is. For example, this post on a well-known physics blog simply tries to ridicule the work of people the author disagrees with, but since the author is an active researcher it generates a trackback. On the other hand, this post and this post are perfectly reasonable and non-cranky, and the latter one even sparked a long and technical (if somewhat heated) discussion, but they can't generate trackbacks. Not all active researchers are always interested in a serious discussion, and someone who hasn't recently published any papers may still be able to start a useful discussion.

This blog, for example, probably does not qualify for arXiv trackbacks, since Matthew has left the field and my publication record probably does not meet the required standards at this point in time. I do not believe that makes either of us a crank with nothing worthwhile to say. And any crank who gets someone to endorse his papers for the arXiv (which does happen) might still pass muster as an active researcher and be allowed to post trackbacks. Maybe a more reasonable policy would be to allow trackbacks from blogs written by people who have an official affiliation with a university or public research institution.

The arXiv people definitely have a very tough job, and I do not envy them for it. And whatever specific criticisms one may want to raise, on the whole they ought to be congratulated on doing their job very well and providing a hugely important resource to the physics community. The trackback issue is really relatively minor, but like all things in the blogosphere that exceed a certain critical mass, it is currently undergoing a chain reaction. But it is important that these issues are discussed, because any kind censorship of undesired views or results has to be totally unacceptable in science, and it is important that even the slightest suspicion that legitimate work might be suppressed is investigated and laid to rest.

On a totally unrelated topic: There is a cool post on quantum interrogation (a way to use quantum mechanics to obtain the answer to a question without ever really asking it, roughly speaking) over at Cosmic Variance. The explanation given there involves puppies and the new discipline of quantum cooking, where meals are prepared in superpositions of different recipe states.

**Update:** As Peter Woit pointed out in a comment, the arXiv trackback policy was in fact not first revealed on Jacques Distler's blog, but in a comment on Cosmic Variance by Ethan Vishniac of the arXiv advisory board.

**Update:** It was pointed out by Jacques Distler that Life on the Lattice is allowed to post trackbacks to the arXiv on the basis of Matthew's publication record, and using Haloscan I have been able to verify that this is indeed the case.

**Update:** As Jacques has asked for ideas about how to improve the trackback system, here is my proposal, which I have also submitted as a comment on his blog (replies to go there please): Each arXiv user gets to put the URL to their blog or homepage into their arXiv user profile along with their email address. Each time someone posts a paper, they receive a number of trackback credits (five, say), which can then be used to post trackbacks to papers. No credit, no trackbacks. This would formalism the "active researcher" criterion in an objective manner, while being inclusive of researchers with short publication records and keeping the signal-to-noise ratio high, since you wouldn't want to waste your hard-earned credits.

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### An interview with Matthew Nobes

*2006-02-15T20:48:00.000+01:00*

Life on the lattice founder Matthew Nobes, now a Quantitative Analyst with a firm in London, England, kindly agreed to give us an e-mail interview. Interviewing him is Life on the lattice's Georg von Hippel.

**Georg:** While I assume that 'Life on the Lattice' readers will know you, maybe you would like to briefly introduce yourself?

**Matt:** My name is Matthew Nobes, I grew up in Southern Ontario, and studied undergraduate physics at the University of Waterloo. I did an MSc and PhD at Simon Fraser University (SFU), in Vancouver. Following that I did just over a year of postdoctoral work at Cornell University.

**Georg:** What brought you into physics originally? And what made you choose to specialize in Lattice QCD?

**Matt:** I had very good physics teachers at the high school level, which is what got me interested in physics, over another science. As for Lattice QCD, I got into that through my PhD supervisor, Howard Trottier, who was a very inspirational teacher. Howard taught an introductory Quantum Field Theory course my first year at SFU. From that I knew I wanted to work with him. That's how I got started in Lattice QCD.

**Georg:** Maybe you would like to tell our readers a little about the research you have performed or participated in during your life on the lattice.

**Matt:** My major focus was on the perturbative improvement of the actions and operators we use in Lattice QCD. In simple terms Lattice QCD is an approximation to the real world, and as such it has errors. One can correct the errors systematically using perturbation theory, however it is quite difficult. My research involved developing methods to streamline and automate these perturbative calculations.

This is a very important thing to be doing, as many of the recent HPQCD results have errors dominated by the lack of perturbation theory results.

**Georg:** Recently, you have changed careers and locations; now you are working as a Quantitative Analyst in London. What is that kind of work like, and how does it differ from being in a physics department?

**Matt:** The work is very different than academic physics. For one, the pace is much faster, people expect results on a much quicker time scale. Also, the number of things you have on the go at any one time is larger. In addition the work is far less specialized. I've had to use many skills which I haven't had to use in years.

**Georg:** Would you say that studying particle physics, and Lattice QCD in particular, was a good preparation for the work you are doing now? And if so, what kind of skills or knowledge acquired on the lattice are you using in your present position?

**Matt:** I would say yes, it was good preparation. There's lots of numerical analysis tasks in my new work, for which a background in Lattice was very good preparation. In addition, the general theoretical physics training gives one a very good set of tools and methods which can be applied to finance.

**Georg:** Where do you see yourself in ten years? And where do you see Lattice QCD going in the same timeframe?

**Matt:** I have no idea where I'll be in ten years :) Happy in a Quant position somewhere, I suppose.

As far as Lattice QCD, I imagine in ten years the field will have moved on quite a bit. Two areas of growth, I think, are into very complex QCD problems. Exploring the boundary of QCD and Nuclear physics, for example. Another area would be Lattice QFT more generally. If the LHC hits upon strongly coupled new physics, the Lattice will prove a valuable tool.

**Georg:** Do you have any other messages you would like to pass to our readers?

**Matt:** I hope everybody is well. And a big thanks to you for carrying the blog on very ably.

**Georg:** It's a pleasure. Matthew, thank you very much for the interview.

**Matt:** You're welcome, anytime.

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### Physics blogs and physicists' blogs

*2006-02-03T21:28:00.000+01:00*

Looking at the physics blogosphere, there is a notable tendency for those blogs that receive the most attention in terms of readers, commenters and incoming links to be physicists' blogs rather than physics blogs. By a physics blog I understand a blog whose contents are devoted to physics, as in physicists advertising their research, teaching the wider public about physics, etc. A physicist's blog, on the other hand, is a blog authored by a physicist, which may well mainly discuss politics, economics, religion, ideology, terrorism, war, drugs, sex, rock'n'roll, stamp collecting and other such contentious issues. From what I see, it appears pretty clear that many more people read the latter kind of blog than the former.

While I understand that in the current global situation people (and especially people in the US, which still seems to dominate the global blogosphere) become much more worked up about the daily issues in politics, economics, religion etc. than about even the most long-standing physics problems (with the notable exception of anthropic arguments and the landscape), what I don't understand is why they would consider the political, economic or religious views of a particle physicist over e.g. those of an entomologist, an electrical engineer or a seismologist, or even over those of a historian, economist or theologian. I know that theoretical physicists (and most physics bloggers appear to be theorists) have the (partially deserved) reputation of being the professional and academic community with the highest IQ, percentile by percentile, but that does not mean that theoretical physicists are any more likely to be experts on political etc. matters than e.g. limnologists, which as far as I know do not have the same reputation for brilliance.

My point is that being more intelligent in and of itself does not mean being more knowledgeable or having a more balanced point of view; in fact a normally intelligent person with a degree in international history probably has a much better chance of making an important contribution to the debate about, say, the Iraq war, than a highly intelligent rocket scientist, simply because they have the greater wealth of pertinent knowledge on which to base their opinion, and because they are more used to drawing the kind of inferences and analogies that are needed in that context. Even the most brilliant string theorist will need to do some serious study of, say, granular flows before making a serious contribution to that field. The same applies to these debates.

Now, of course, it was noted as early as the days of Socrates that in matters of public policy everybody is assumed to be entitled to hold a point of view, whereas in other areas (Plato mentions shipbuilding and architecture, if I recall correctly) every sensible person defers to the experts. I don't disagree with that at all; in fact I hold strong views on contentious issues myself, and I have no problem stating them where they are asked for, or where I feel that I can make a contribution. But I wouldn't normally proffer them on a global forum like a blog, because I recognize that having a PhD in Theoretical Physics (even if it is from Cambridge) does not make me an expert on foreign relations or the global economy, and I am simply amazed at the number of people who seem to believe that academic credentials in a physics subject confer some degree of importance to writers' views on topics far outside the scope of physics.

So this was a bit of a rant. Anyway, Life on the Lattice is a proud physics blog, and has no intention of becoming a mere physicists' blog. If that means fewer readers, so be it. At least I can rest safe in the assumption that I won't have to be ashamed of what I wrote here in ten years time.

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### Exactly chiral fermions

*2006-02-02T22:37:00.000+01:00*

In the last post in this series, we looked at the Ginsparg-Wilson relation and how it might provide a way to get past the Nielsen-Ninomiya theorem. In this post we shall have a look at how this can happen in practice.

One way in which a four-dimensional theory of a chiral fermion can be realized is by dimensional reduction from a five-dimensional theory. Let us consider the five-dimensional continuum theory of a Dirac fermion coupled to a scalar background field depending on only the fifth dimension $s$:

$$D = \gamma_\mu \partial_\mu + \gamma_5 \partial_s - \phi(s)$$

where the scalar field is assumed to be a step function of the same general form as $\phi(s) = M \tanh(Ms)$. The plane $s = 0$ can be understood as a domain wall of width $M$ separating domains of $\phi \sim M$ and $\phi \sim -M$. The case of interest has $M$ large.

From the square of the Dirac equation, we have for a fermion with four-momentum $p = (iE, \mathbf{p})$, $p^2 = -m^2$, $\psi(x,s) = \exp(ipx)\chi(s)$, that

$$\left[-\partial_s^2 + \gamma_5 \partial_s \phi(s) + \phi(s)^2\right] \chi(s) = m^2 \chi(s)$$

and the allowed masses on the four-dimensional domain wall are determined by the eigenvalue spectrum of a differential operator in $s$. All non-zero eigenvalues are of order $M$ and hence large. For the zero eigenvalues, the Dirac equation can be decoupled into

$$\left[-\gamma_5 \partial_s + \phi(s)\right] \chi(s) = 0 \gamma_\mu p_\mu \chi(s) = 0$$

with solutions

$$\chi(s) = \exp\left(\pm \int_0^s \mathrm{d}t \; \phi(t)\right) u \gamma_\mu p_\mu u = 0 ¶_\pm u = u$$

Of these, only the negative chirality solution is normalizable, and hence the low-energy spectrum on the domain wall consists of a single left-handed chiral fermion.

The presence of the scalar background field $\phi$ is a little awkward, but we may simplify the situation to the case of an ultra-massive five-dimensional fermion

$$D = \gamma_\mu \partial_\mu + \gamma_5 \partial_s - M$$

in the half-space $s \geq 0$ subject to the Dirichlet boundary condition

$P_+ \psi(x, s)|_{s=0} = 0$

and perform the same analysis with $\phi$ replaced by $M$.

In the early nineties, Kaplan discovered that the same domain wall effect still occurred on a lattice when the Wilson operator was used to discretize the five-dimensional theory. The apparent violation of the Nielsen-Ninomiya theorem is due to the fact that the four-dimensional theory is not the whole story: with a finite extent $L_5$ in the fifth direction, there will necessarily be another domain wall with opposite orientation, on which a massless chiral fermion of opposite chirality will live, thus fulfilling both the Nielsen-Ninomiya theorem in the five-dimensional theory and ensuring the mutual cancellation of the chiral anomalies stemming from either fermion. The anomalous divergence simply becomes a flow of charge onto and off the domain wall from the extra dimension.

Around the same time, Narayanan and Neuberger discovered a formulation of chiral fermions in terms of the overlap between the ground states of two Hamiltonians representing "time" evolution to $\pm\infty$ along the fifth direction. Later, Neuberger discovered a way to write the overlap as the determinant of a Dirac operator, the overlap operator

$$D = \frac{1 + \epsilon(D_w)}{2} epsilon(H) = \frac{H}{\sqrt{H^\dagger H}}$$

where $D_w$ is the Wilson Dirac operator. This formulation avoids the need for an explicit fifth dimension, but at the expense of introducing the slightly awkward operator sign function $\epsilon(H)$.

Later, it was shown that the domain wall and overlap formulations were essentially equivalent. It can also be shown that both the overlap operator and the effective Dirac operator for fermions on the domain wall satisfy the Ginsparg-Wilson relation, thereby allowing to describe exactly chiral fermions on the lattice.

So what is the bad news? The bad news is that these exactly chiral fermion formulations are extremely hard to simulate. Domain wall fermions need to be simulated in five dimensions, greatly increasing the computational demand, and for overlap fermions the operator sign function is rather difficult to compute. So while these actions are exactly chiral, and hence in way closer to the real continuum physics, simulating them at reasonable sizes and lattice spacing will require a huge computational effort. If one considers to what effort MILC had to go to get 1% level predictions using staggered fermions (which are very efficient to simulate), it becomes clear that high-precision predictions from dynamical simulations using exactly chiral fermions are still a fair while in the future.

In the next, and probably final post in this series, we will go and have a look at a fairly new lattice fermion action, known as twisted mass.

# 2005

## The Ginsparg-Wilson relation

*2005-12-21T21:43:00.000+01:00*

Time for another post in our series about lattice fermions.

In the previous post in this series we had a look at the Nielsen-Ninomiya theorem, which stated that any acceptable lattice fermion action for which the Dirac operator anticommuted with $\gamma^5$ had to have doubler fermions. On the face of it that seems to imply a stark choice between chiral symmetry and freedom from doublers.

There is, however, an interesting way around this apparent dilemma. This was discovered by Ginsparg and Wilson in a 1982 paper, were they studied the result of performing a spin-blocking step on a chirally symmetric continuum fermion action. What they discovered was that the Dirac operator of the blocked theory obeyed the anticommutation relation

$$\{\gamma^5, D\} = 2aD\gamma^5 D$$

now known as the Ginsparg-Wilson relation.

This relation has a number of interesting consequences: Firstly, it implies that the propagator $\tilde{S}(p) = \tilde{D}(p)^{-1}$ obeys the anticommutation relation

$$\{\gamma^5, \tilde{S}(p)\} = 2a\gamma^5$$

and hence in coordinate space

$$\{\gamma^5, S(x-y)\} = 2a\gamma^5\delta(x-y)$$

i.e. the propagator is chirally invariant at all non-zero distances. Secondly, Lüscher discovered in 1998 that the Ginsparg-Wilson relation leads to a non-standard realization of chiral symmetry in the theory, which is invariant under the infinitesimal transformations

$$\psi \mapsto \psi + \epsilon\gamma^5 \left(1 - aD\right) \psi bar\psi \mapsto \bar{\psi} + \epsilon\bar{\psi} \left(1 - aD\right) \gamma^5$$

The fermion measure, however, transforms anomalously under this symmetry, and a little calculation shows that this gives precisely the correct chiral anomaly.

On the other hand, since the Wilson operator no longer anticommutes with $\gamma^5$, the conditions of the Nielsen-Ninomiya theorem no longer apply, and there is hence no reason to expect the existence of any doubler fermions.

What all this means is that the correct chiral physics can be obtained from a lattice theory, provided one is able to find a solution to the Ginsparg-Wilson relation. The next post in this series will look at some of the fermion actions that arise from this.

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### Analytical results for the glueball spectrum

*2005-12-12T23:40:00.000+01:00*

In a recent paper, Leigh, Minic and Yelnikov present an *analytical* result for the glueball spectrum in (2+1) dimensions. They employ a Hamiltonian formalism pioneered in a series of papers by Karabali, Kim and Nair. The main result is that the glueball spectrum of (2+1)-dimensional pure Yang-Mills theory can be expressed in terms of the zeros of the Bessel function $J_2(z)$. In particular, the masses of $0^{++}$ states can be written as the sum of two Bessel zeros:

$$m(0^{++*^r}) = (j_{2,n_1} + j_{2,n_2})\frac{g^2N}{4\pi}$$

where $n_1$ and $n_2$ can be determined from $r$, and it is to be noted that the gauge coupling in (2+1) dimensions has the dimension of $\sqrt{Mass}$. Similarly, the masses of $0^{--}$ states can be written as the sum of three Bessel zeros:

$$m(0^{--*^r}) = (j_{2,n_1} + j_{2,n_2} + j_{2,n_3})\frac{g^2N}{4\pi}$$

Their results agree reasonably well with lattice simulations of (2+1)-dimensional pure Yang-Mills theory.

There are some interesting implications of their results which are not discussed in their paper (they say they are going to publish another, more detailed, one). In particular, since for large m the Bessel zeros go like $j_{m,n} \simeq \left(n + \frac{m}{2} + \frac{1}{4}\right)\pi$ for large excitation numbers, there will be almost degenerate states separated by gaps of $g^2N/4$, with the (almost) degeneracy of the r-th state given by the number of ways to partition (r+1), or (r+2), into two or three integers, respectively.

Another interesting implication of their results is that the mass difference between successive states of even parity and that of successive states of odd parity should be the same. This does not quite agree with what is found on the lattice, where the mass difference for the ++ states is about 1.6 times that for the – states (which is similar to the difference in results obtained for the gluonic mass in (2+1) dimensions using self-consistent resummation methods with parity-even and parity-odd mass terms, respectively). From the analytical results this parity-dependence of the mass gap would appear to be some sort of artifact.

It will be interesting to see what is in Leigh, Minic and Yelnikov's detailed paper, in particular how the higher-spin glueballs turn out.

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### The Nielsen-Ninomiya theorem

*2005-12-05T22:44:00.001+01:00*

In recent posts in this series, we have been looking at naive, Wilson and staggered fermions. One of the things we have seen is how difficult it is to get rid of the doubler fermions; staggering did a good job at this, but still retained some of the doublers with all the problems they bring, while the Wilson term got rid of the doublers, but only at the expense of spoiling chiral symmetry, which brought on even worse problems. Why should the discretization of fermions be so hard?

The answer lies in a theorem about lattice fermions, the celebrated Nielsen-Ninomiya no-go theorem, which states that it is impossible to have a chirally invariant, doubler-free, local, translation invariant, real bilinear fermion action on the lattice. The theorem comes from topological arguments: A real bilinear fermion action can be written as

$$S = \sum_{x,y} \bar{\psi}(x) M(x,y) \psi(y)$$

with hermitian $M$. Translation invariance means that $M(x,y) = D(x-y)$ and locality requires that the Fourier transform $\tilde{D}(p)$ of $D(z)$ be a regular function of p throughout the Brillouin zone. Chiral symmetry

$$\{\tilde{D}(p), \gamma^5\} = 0$$

requires that

$$\tilde{D}(p) = \sum_{\mu} \gamma_\mu d_\mu(p)$$

Since the Brillouin zone has the topology of a 4-torus, we thus have a vector field $d_\mu$ on the torus. Now it is possible to assign an "index" of +1 or -1 to every zero of this vector field, and the Hopf-Poincare index theorem states that the sum over the indices of the zeros of a vector field on a manifold is equal to the Euler characteristic of the manifold. The Euler characteristic of any n-torus is zero, and therefore the zeros of $d_\mu$ must come in pairs of opposite index, which is precisely the origin of the doublers.

OK, so what does all this mathematics mean? Well, prima facie it seems to leave us with the choice between chiral symmetry and freedom from doublers (since locality, translation invariance and hermiticity are too important to abandon). There is, however, a clever way around this, which will be the topic of our next post.

## More about staggered quarks

*2005-12-02T21:40:00.000+01:00*

A while back, Matthew was running a number of pedagogical articles on fermions on the lattice. Since I think that those articles were a good idea, I will endeavour to continue them. Obviously there may be some differences in outlook and style, but that is the beauty of diversity.

Matthew's last post in the series was about staggered quarks. To remind ourselves, when we put fermions on the lattice naively, we find that the fermion propagator has extra poles at momenta of order $\pi/a$, leading to the emergence of 16 degenerate quark flavours, or "doublers", from a single quark action. Staggering gets rid of some of those doublers by redistributing the fermionic degrees of freedom across different lattice sites. In the end, one is left with 4 degenerate quark flavours, usually referred to as "tastes" to distinguish them from physical quark flavours, with the added bonus of retaining a remnant of chiral symmetry that forbids the generation of an additive mass renormalization.

There is a downside to all this, however. Since the different components of the staggered quark field live on different lattice sites, they experience a slightly different gauge field, which leads to a breaking of their naive degeneracy. This becomes even clearer when looking at it from a momentum space point of view: A pair of quarks with momenta close to 0 can exchange a gluon with momentum around $\pi/a$ to change into a pair of quarks with opposite momenta of order $\pm\pi/a$, and these correspond to quarks of a different taste from the original pair. The interaction has changed the taste of the quarks!

These taste-changing interactions are the source of a number of problems: naively, we would expect a theory of four degenerate quark flavours to have 16 degenerate pions. These pions, however, are mixed by the taste-changing interactions, and their degeneracy is therefore lifted. Only one of the 16 pions will be the (pseudo-)Goldstone boson whose mass goes to zero with the quark mass; the others will remain massive in the chiral limit. This also adversely affects the discretization errors from the finite lattice spacing $a$.

The influence of the taste-changing interactions can be suppressed by adding additional terms to the lattice action. This leads to improved staggered quarks, and we will hear more about those in a future post on improved actions.

Another potentially problematic feature of staggered quarks is that they come always in four tastes. Nature, however, has not been so generous as to provide us with four degenerate, or even nearly degenerate, quark flavours. So how do we simulate a single flavour with staggered quarks?

Remember that the fermionic path integral could be done analytically:

$$\int DUD\bar{\psi}D\psi exp(-S_G - S_F) = \int DU det(M[U]) exp(-S_G)$$

The fermionic determinant can be put back into the exponent as

$$\int DU det(M[U]) exp(-S_G) = \int DU exp(-S_G - S_{GF})$$

where

$$S_{GF} = -log(det(M[U]))$$

incorporates the fermionic contributions to the action. This is additive in the number of quark flavours, so we can get from four staggered tastes to one physical flavour by dividing $S_{GF}$ by four, which is equivalent to taking the fourth root of the fermion determinant.

Taking the fourth root of the determinant introduces a non-locality, and currently nobody knows with certainty whether that non-locality will go away in the continuum limit $a \to 0$, but empirical evidence suggesting that it does is accumulating.

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### Dirac eigenvalues

*2005-11-24T19:10:00.000+01:00*

In a recent talk entitled "Fun with Dirac eigenvalues", Michael Creutz discusses some issues arising in the study of the Dirac spectrum. The discussion involves a number of deceptively simple arguments on a rather complicated matter, and you should read it (and think about it) for yourself. The chiral condensate and the Banks-Casher relation, in particular, are discussed in a way that is obviously intended to first confuse, then astonish and finally enlighten the reader. Other points which I never thought about before are how the number of flavours influences the density of low-lying eigenvalues via the effects of the high eigenvalues on the gauge fields, and why topologically non-trivial configurations' contributions to correlation functions can be a problem in numerical simulations.

The discussion is kept in the context of the overlap operator, which makes sense for an analytical discussion of chiral properties. For an investigation of many of these issues in the context of the more widely used staggered quarks, see this paper by members of the HPQCD and UKQCD collaborations, where they show that, with improvement, staggered quarks exhibit all the properties expected of the Dirac spectrum, including obeying the Atiyah-Singer index theorem.

### A new determination of light quark masses

*2005-11-18T18:28:00.000+01:00*

In a recent paper (hep-ph/0511160), members of the HPQCD collaboration have presented the most precise determination of the light (up, down and strange) quark masses to date.

This required both extensive unquenched simulations of QCD using some of the lightest (and hence hardest to work with) quark masses used so far, and a massive perturbative calculation at the two-loop order. The perturbative calculation is needed in order to connect the lattice-regularized bare quark masses to the masses as defined in the usually quoted MS-bar scheme. The bare-quark masses required as input to the perturbative calculation come from simulations performed by the MILC collaboration, who use a highly-efficient formalism with so-called “staggered” quarks, with three flavors of light quarks in the Dirac sea.

Putting all these ingredients together, they find the MSbar masses at a scale of 2 GeV to be

$$m_s = 87(0)(4)(4)(0)$$

MeV,

$$m_u = 1.9(0)(1)(1)(2)$$

MeV and

$$m_d = 4.4(0)(2)(2)(2)$$

MeV. The respective uncertainties are from statistics, simulation systematics, perturbation theory, and electromagnetic/isospin effects.

This means that the errors on the still rather contentious strange quark mass, for which a number of incompatible results exist, have been greatly reduced. This is a very major result, and a great success for Lattice QCD.