LATTICE 13

JULY 29 – AUGUST 03 2013
MAINZ, GERMANY

Book of Abstracts

Algorithms and Machines

UV suppression by smearing and screening correlators
Nikhil Karthik, Sourendu Gupta
Mon, 14:00, Seminar Room D (RW5) – Parallels 1D

We investigate the mechanism of smearing in the APE, Stout, HYP and HEX schemes through their effect on glue and quark Fourier modes. Using this, we non-perturbatively tune the smearing parameters to their optimum values. Smearing causes a super-linear improvement in taste symmetry breaking in the high temperature phase of QCD. We use optimal smearing in the high temperature phase and find close agreement of meson screening masses with weak coupling predictions.

Testing reweighting method for truncated Overlap fermions
Ken-Ichi Ishikawa
Mon, 14:20, Seminar Room D (RW5) – Parallels 1D

It is a hard task to maintain the lattice chiral symmetry during the HMC algorithm. One possibility to reduce the total computational cost is to relax the requirement of the chiral symmetry and to use the reweighing method recovering the symmetry at the measurement phase. The HMC algorithm with the truncated overlap fermion with approximate lattice chiral symmetry has been proposed by Borici in terms of domain-wall type fermions. The reweighing factor is the determinant ratio between the truncated and exact overlap operators and is estimated by noise method. We implement the truncated overlap fermion in terms of the domain-wall fermions and test the behavior of the reweighing factor against the truncation level (fifth dimensional extent) on a set of small lattices.

Scaling, topological tunneling and actions for weak coupling DWF calculations

Greg McGlynn, Robert Mawhinney

Mon, 14:40, Seminar Room D (RW5) – Parallels 1D

We present results from a 2+1 flavor DWF calculation at 1/a = 3 GeV and discuss strategies for similar calculations at finer lattice spacings which will target charm physics. At weak coupling the autocorrelation time of the global topological charge becomes very long because the HMC algorithm has trouble moving between topological sectors. We report the results of simulations that test several ideas for reducing the autocorrelation time of topological charge. In weak coupling quenched simulations we find that the open boundary conditions suggested by Lüscher and Schaefer do not improve topological autocorrelation times. We present preliminary results from simulations using a "dislocation-enhancing determinant ratio" to improve topological tunneling.

Adaptive Aggregation Based Domain Decomposition Multigrid for the Lattice Wilson Dirac Operator

Matthias Rottmann, Andreas Frommer, Karsten Kahl, Stefan Krieg, Björn Leder

Mon, 15:00, Seminar Room D (RW5) – Parallels 1D

In this talk, we present a multigrid approach for the inversion of the lattice Wilson Dirac operator. It combines components that have already been used separately in lattice QCD, namely the domain decomposition method "Schwarz Alternating Procedure" as a smoother, also known from the "Inexact Deflation" method and the γ_5-preserving aggregation based interpolation, introduced by the Boston and Boulder group. We will point out the major differences to the existing hierarchical approaches and we will show numerical results from our MPI-C Code. Aspects from the recently published numbers in [arXiv:1303.1377] for the two-grid approach will be picked up but also new three-grid results will be shown.

HDCG: Hierarchically Deflated Conjugate Gradient algorithm for 5d Chiral Fermions

Peter Boyle

Mon, 15:20, Seminar Room D (RW5) – Parallels 1D

I present an algorithm for 5d Chiral Fermions that, after a modest subspace generation phase, accelerates the inversion of the Hermitian red-black preconditioned Hermitian operator (normal equations) for general Mobius fermions. The approach is an extension of the inexact deflation approach to this system of equations, but also bears some similarity to algebraic multigrid approaches. The little Dirac operator is expensive due to the next-to-next-to-next-to-nearest neighbour stencil. I find that preconditioned CG is remarkably stable against preconditioner noise and that flexible algorithms are not needed. By using the little Dirac operator solely as a preconditioner and adopting a three level deflation, the overhead is suppressed by two orders of magnitude compared to the inexact deflation approach. On small (16^3) volumes the approach is similar in performance to EigCG. On large (48^3) volumes and at the physical quark masses the approach is between 2x and 5x more effective then EigCG with much reduced set up cost, and 10x more effective than CGNR.

Optimization of the Oktay-Kronfeld Action Conjugate Gradient Inverter

Yong-Chull Jang, Jon Bailey, Carleton DeTar, Andreas Kronfeld, Weonjong Lee, Bugra Oktay

Mon, 15:40, Seminar Room D (RW5) – Parallels 1D

Carrying out the Fermilab improvement program to third order in heavy-quark effective theory yields the Oktay-Kronfeld (OK) action, a promising candidate for precise calculations of the spectra of heavy quark systems and weak matrix elements of heavy-light systems. We have optimized the OK-action conjugate gradient inverter in the SciDAC QOP/QDP library and are developing a GPU code. The OK action is rewritten and the needed gauge-link combinations are precalculated. This procedure accelerates the conjugate gradient by more than a factor of five. The remaining floating-point operations are simple matrix multiplications between gauge links and fermion vectors, which we accelerate with CUDA. We present preliminary results for the spectra confirming expected decreases of heavy-quark discretization errors.

One flavor mass reweighting: foundations
Björn Leder, Jacob Finkenrath, Francesco Knechtli
Mon, 16:30, Seminar Room D (RW5) – Parallels 2D

Reweighting is not a new method in lattice QCD, but a comprehensive analysis is missing in the literature. We close this gap by presenting: (i) a proof of an integral representation of the complex determinant of a complex matrix, (ii) a method to control the stochastic error of its Monte Carlo estimation, (iii) expansions of the stochastic error and the ensemble fluctuations of the one flavor reweighting factor. Based on (iii) we present a detailed scaling analysis and optimized reweighting strategies.

Towards Simulations of 1+1 Flavor QCD
Jacob Finkenrath, Francesco Knechtli, Björn Leder
Mon, 16:50, Seminar Room D (RW5) – Parallels 2D

Today's simulations in lattice quantum chromodynamics get closer and closer to the physical point by simultaneously minimizing the statistical errors. Small effects like isospin symmetry–breaking start becoming significant. Incorporating such effects into the Boltzmann factor by reweighting introduces fluctuations which increase with the volume. Correlations between parts of the lattice actions can be utilized to reduce this fluctuations significantly. We combine and compare approaches consisting of reweighting and a modified sampling for generating configurations. Employing these methods we can estimate non-perturbatively the effect of the sea quarks on isospin splitting.

Exact Pseudofermion Action for Hybrid Monte Carlo Simulation of One-Flavor Domain-Wall Fermion

Yu-Chih Chen, Wen-Ping Chen, Ting-Wai Chiu, Han-Yi Chou, Tung-Han Hsieh

Mon, 17:10, Seminar Room D (RW5) – Parallels 2D

We present a novel pseudofermion action for hybrid Monte Carlo simulation of one-flavor domain-wall fermion (DWF) in lattice QCD. This pseudofermion action is exact, without taking square-root, unlike the widely-used rational hybrid Monte-Carlo algorithm (RHMC). We compare the performance of one-flavor algorithm (OFA) with RHMC, and find that OFA outperforms RHMC, no matter in terms of the efficiency or the memory consumption. Using our one-flavor and the two-flavor algorithms, we perform HMC simulations of $2 + 1 + 1$ flavors lattice QCD with optimal domain-wall fermion. We outline our recent simulations on the $32^3 \times 64 \times 16$ lattice, using multiGPUs composed of Nvidia GTX-TITAN.

Simulating the Random Surface representation of Abelian Gauge Theories

Tomasz Korzec, Ulli Wolff

Mon, 17:30, Seminar Room D (RW5) – Parallels 2D

We present a Monte-Carlo algorithm for the simulation of the all-order strong coupling expansion of the Z2 gauge theory. This random surface ensemble is completely equivalent to the standard formulation, but allows to measure some quantities, like Polyakov loop correlators or excess free energies, with an accuracy that could not have been easily achieved with traditional simulation methods. One interesting application of the algorithm is the comparison of the D=3 model with predictions from effective string theories, for which we refer to the following talk by Ulli Wolff.

Simulated random surfaces and effective string models in 3d Z(2) gauge theory
Ulli Wolff, Tomasz Korzec
Mon, 17:50, Seminar Room D (RW5) – Parallels 2D

We apply an all-order strong coupling simulation algorithm presented in the previous talk by Tomasz Korzec to study the three dimensional Z(2) gauge theory. The Polyakov line correlation has constant and large signal to noise ratio for arbitrary separations at low temperature. Thus we can precisely estimate ground state energies of flux states which are related to the string tension and compare with effective string model predictions.

Applicability of Quasi-Monte Carlo for lattice systems
Andreas Ammon, Karl Jansen, Hernan Leovey, Andreas Griewank, Michael Müller-Preuÿker
Mon, 18:10, Seminar Room D (RW5) – Parallels 2D

This project investigates the applicability of Quasi-Monte Carlo methods to Euclidean lattice systems in order to improve the asymptotic error behavior of observables for such theories. The error of an observable calculated by averaging over random observations generated from ordinary Monte Carlo simulations behaves like $N^{-1/2}$, where N is the number of observations. By means of Quasi-Monte Carlo methods it is possible to improve this behavior for certain problems to N^{-1}, or even further if the problems are regular enough. We adapted and applied this approach to simple systems like the quantum harmonic and anharmonic oscillator and verified an improved error scaling.

2D and 3D Antiferromagnetic Ising Model with "topological"' term at $\theta = \pi$.
Gennaro Cortese, Vicente Azcoiti, Eduardo Follana, Matteo Giordano
Mon, 18:30, Seminar Room D (RW5) – Parallels 2D

In this work we study the Antiferromagnetic Ising model with an imaginary magnetic field $i\theta$ at $\theta = \pi$ in two and three dimensions. For this purpose we develop a new algorithm, not affected by the sign problem, that allows us to perform numerical simulations.

Lattice Simulations using OpenACC compilers
Pushan Majumdar
Tue, 16:20, Seminar Room G (HS III) – Parallels 4G

OpenACC compilers allow one to use Graphics Processing Units without having to write explicit CUDA codes. Programs can be modified incrementally using OpenMP like directives which causes the compiler to generate CUDA kernels to be run on the GPUs. In this presentation we will look at the performance gain in lattice simulations using OpenACC compilers for both pure gauge as well as dynamical fermions.

Twisted-Mass Lattice QCD using OpenCL
Matthias Bach, Christopher Pinke, Owe Philipsen, Volker Lindenstruth
Tue, 16:40, Seminar Room G (HS III) – Parallels 4G

Graphics Processing Units (GPUs) are by now an established tool for Lattice QCD applications. I present an update on our OpenCL based code for Lattice QCD with twisted-mass fermions. On current generation AMD GPUs we now reach 100 GFLOPS in double-precision Dslash and 70 GFLOPS in our double-precision inverter. For the hybrid Monte-Carlo (HMC) we improve energy-efficiency by a factor of four over a plain CPU system. We also found one 4-GPU node to provide about 12 times the throughput of a pure CPU system of comparable cost.

Mobius domain wall fermion method on QUDA

Hyung-Jin Kim, Taku Izubuchi, Chulwoo Jung, Eigo Shintani

Tue, 17:00, Seminar Room G (HS III) – Parallels 4G

Mobius Domain Wall Fermion(DWF) method is an extended form of Shamir's domain wall fermion action, which provides the same overlap action correspondence in the limit of $L_s \to \infty$ without increasing the numerical cost. Obviously, Mobius DWF has an advantage in smaller size of chiral violation effect coming from residual mass compared with Shamir's DWF. At $\alpha = O(L_s)$, $O(1/L_s)$ of M_{res} error in Shamir's DWF can be reduced by $O(1/L_s^2)$ in Mobius DWF method. This chiral enhancement on Mobius operator enables us to use the smaller 5th dimensional size of lattice data without scarifying the precision. Furthermore, smaller size of lattice data is very helpful to compute the DWF algorithm on GPU environment. Recently, GPU has been successfully used in lattice QCD applications. However, limited size of GPU memory makes the DWF computation especially difficult. To solve this problem, we have implemented Mobius DWF method based on the QUDA library. Optimization is still in progress. We will show preliminary hadron vacuum polarization data which is measured with Mobius DWF method in QUDA.

Adaptive Multigrid Algorithms on GPUs

M Clark, Michael Cheng, Richard Brower

Tue, 17:20, Seminar Room G (HS III) – Parallels 4G

Graphics Processing Units (GPUs) are an increasingly popular platform upon which to deploy LQCD calculations. While there has been much progress to date in developing solver algorithms to improve strong scaling on such platforms, there has been less focus on deploying mathematically optimal algorithms. A good example of this are hierarchical solver algorithms such as adaptive multigrid, which are known to solve the Dirac operator with optimal O(N) complexity. We describe progress to date in deploying adaptive multigrid solver algorithms to NVIDIA GPU architectures and discuss the suitability of heterogeneous architectures for hierarchical algorithms.

DWF Solvers and Clover for BGQ
Karthee Sivalingam, Peter Boyle
Poster Session

Solving QCD in lattice usually involves hundreds of thousands of inversions in a serialy dependent importance sampling of QCD path integral. The inverter performance is critical for any good simulation performance. The inverter of this sparse matrix involves using a iterative solver that involves repeated application of the operator. This work describes porting and optimisation of Clover inverter to Blue gene/Q architecture using BAGEL compiler. Also different iterative solvers for DWF are discussed and compared.

Performance of Kepler GTX Titan GPUs and Xeon Phi system
Hwancheol Jeong, Kwang-jong Choi, Joo Hwan Kim, Joungjin Lee, Weon-jong Lee, Young Woo Lee, Jeonghwan Pak, Sang-Hyun Park, Jun-sik Yoo
Poster Session

NVIDIA's GTX Titan of Kepler GPUs provides a high performance-to-price ratio for computing. Although it is a Geforce model, GTX Titan gives as high performance in double precision floating point calculation as the most recent Tesla K20X. Also, it offers a high memory bandwidth as well as additional cache. Along with hardware improvement, new CUDA programming technologies such as Direct Parallelism and GPU Direct communication are introduced. We analyze the performance of GTX Titan and these CUDA technologies. We also compare GTX titan GPUs with Xeon Phi coprocessor.

Getting Covariantly Smeared Sources into Better Shape
Georg von Hippel, Benjamin Jäger, Thomas Rae, Hartmut Wittig
Poster Session

The use of covariantly smeared sources in hadronic correlators is a common method of improving the projection onto the ground state. Studying the dependence of the shape of such sources on the gauge field background, we find that localized fluxes of magnetic field can strongly distort them, which results in a reduction of the smearing radii that can be reached by iterative smearing prescriptions, in particular as the continuum limit is approached. As a remedy, we propose a novel covariant smearing procedure ("free-form smearing") enabling the creation of arbitrarily shaped sources, including in particular Gaussians of arbitrary radius, as well as shapes with nodes, such as hydrogenic wavefunctions.

The openQCD code
Stefan Schaefer
Poster Session

OpenQCD is a code for QCD simulations with improved Wilson fermions. Its main features are the open boundary conditions in time, which solve the problem of topology freezing as the continuum limit is approached, a locally deflated SAP-GCR solver, which is very efficient for small quark masses, and twisted-mass reweighting, which stabilizes the simulations. Any number of quark flavors can be simulated, with single flavors implemented by the RHMC and Hasenbusch twisted-mass splitting for the degenerate flavors.

An implementation of hybrid parallel C++ code for the four-point correlation function of various baryon-baryon systems
Hidekatsu Nemura
Poster Session

We present our recent effort to develop the computational code written in C++ to calculate the four-point correlation functions of various baryon-baryon (BB) systems which is a primary quantity to study the nuclear force and hyperonic nuclear forces from lattice QCD. For the recent few years, the 2+1 flavor lattice QCD calculations have been widely performed. The flavor symmetry breaking effects would be a central issue so that a lot of BB channels have to be calculated. The situation is contrast to the study of flavor symmetric BB interactions where each channel is classified into only six kinds of flavor irreducible representation. This work is also aimed at the large volume calculation of the lattice QCD for the hyperonic nuclear forces which is performed at more closer point to the physical quark mass. A hybrid parallel code is implemented by utilizing the MPI and OpenMP together with the porting it to Bridge++ which is a recently developed new C++ code set for lattice QCD calculation. The present code now works on BlueGene/Q and shows better performance at a hybrid parallel execution rather than the flat MPI. In this contribution, we will discuss how the computational time is reduced for various BB channels by a diagramatic classification.

The new "Gauge Connection" at NERSC

Massimo Di Pierro, James Simone, James Hetrick, Carleton DeTar, Shreyas Cholia

Poster Session

We present a new and improved version of the "Gauge Connection", the web interface to the repository of lattice ensembles hosted at NERSC. The goal of the new version is to host lattice QCD ensembles as well as to allow users to search in one place for both local (NERSC-hosted) ensembles and remote (ILDG-hosted) ensembles. The system creates a local database image of remote ensembles from information obtained via ILDG web services, then uses the metadata to create searchable tags. Ensembles are searchable by name, location, and tags. Each ensemble is also associated to a wiki page which can be edited by users to document the ensemble. The system monitors and logs user activity for statistical purposes. The local files are stored on the NERSC HPSS tape storage system and can be downloaded using a provided download script, which can also convert file formats. We are currently implementing a mechanism to download files via Globus Online, a web-based interface for scheduling transfers across GridFTP sites. This will be added to the site in the near future.

JLQCD IroIro++ lattice code on BG/Q

Guido Cossu, Shoji Hashimoto, Takashi Kaneko, Junichi Noaki, Peter Boyle, Hidenori Fukaya

Poster Session

We will present our experience on the multipurpose C++ code IroIro++ designed for JLQCD to run on the BG/Q installation at KEK. We will discuss details on the code design, manageability and performance improvements specifics for the IBM Blue Gene Q.

Applications Beyond QCD

Graphene simulation on rectangular and hexagonal lattice
Mikhail Polikarpov, Pavel Buividovich, Maxim Ulybyshev, Elena Lushchevskaya, Victor Braguta, Oleg Pavlovsky
Wed, 08:30, Seminar Room E (RW6) – Parallels 5E

We report on the results of the numerical study of graphene simulations on rectangular and hexagonal lattice. The chiral symmetry breaking phase transition is much stronger on the rectangular lattice than on hexagonal lattice. We discuss the reason of this difference.

Monte-Carlo study of the semimetal-insulator phase transition in monolayer graphene with realistic inter-electron interaction potential
Maksim Ulybyshev
Wed, 08:50, Seminar Room E (RW6) – Parallels 5E

The results of the first-principle numerical study of spontaneous breaking of chiral (sublattice) symmetry in monolayer graphene due to electrostatic interaction are presented. The screening of Coulomb potential by electrons on ?-orbitals is taken into account. It's found that suspended graphene is in the conducting phase with unbroken chiral symmetry, in contrast to the results of previous numerical simulations with unscreened potential. This finding is in agreement with recent experimental results by the Manchester group. Further, by artificially increasing the interaction strength we demonstrate that suspended graphene is quite close to the phase transition associated with spontaneous chiral symmetry breaking, which suggests that fluctuations of chirality and nonperturbative effects might still be quite important.

Interaction of static charges in graphene within Monte-Carlo simulation

Victor Braguta, Semen Valgushev, Alexander Nikolaev, Mikhail Polikarpov, Maxim Ulybyshev

Wed, 09:10, Seminar Room E (RW6) – Parallels 5E

The study of the interaction potential between static charges within Monte-Carlo simulation of graphene is carried out. The numerical simulations are performed in the effective lattice field theory with noncompact $3 + 1$-dimensional Abelian lattice gauge fields and $2 + 1$-dimensional staggered lattice fermions. At low temperature the interaction is well described by the Coulomb potential reduced by some dielectric permittivity R . The dependence of the R on the dielectric permittivity of substrate is determined. In addition, the renormalization of the quasiparticle charge is studied. At large temperatures the interaction potential is well described by the two dimensional Debye screening. The dependence of Debye screening mass on the dielectric permivitity of substrate allows to determine the position of the insulator-semimetal phase transition. It is shown that in the semimetal phase graphene reveals the properties of the two-dimensional plasma of fermions excitations.

Lattice version of effective graphene field theory in terms of occupation numbers

Oleg Pavlovsky, Anna Sinelnikova, Maksim Ulybyshev

Wed, 09:30, Seminar Room E (RW6) – Parallels 5E

Lattice version of effective graphene field theory in terms of occupation numbers will discussed. Phase transitions this theory will studied.

Tight-binding model of graphene with Coulomb interactions
Dominik Smith, Lorenz von Smekal
Wed, 09:50, Seminar Room E (RW6) – Parallels 5E

We present first results of HMC simulations of the tight-binding model of graphene with electron-electron interactions, based on the framework of Brower, Rebbi and Schaich. Interactions are modelled by an instantaneous long-range Coulomb potential, which is expressed as a Hubbard-Stratonovich field. We show that sub-lattice symmetry can be spontaneously broken, which corresponds to a phase transition to an insulating phase. We compare the discretization effects of simple and improved discretization schemes. Our goal is to investigate the effect of electronic interactions on the Lifshitz phase transition, associated with the Van Hove singularity around the saddle point in the dispersion relation, which is known to occur in the pure tight-binding model.

Quantum Critical Behavior with massless Staggered fermions in Three Dimensions
Shailesh Chandrasekharan
Wed, 10:10, Seminar Room E (RW6) – Parallels 5E

We use the fermion bag approach to study a variety of quantum critical behavior with massless staggered fermions in three dimensions. First, with one flavor of massless staggered fermions we show that lattice Gross-Neveu models and lattice Thirring models have the same critical exponents. Second, we study a Z_2 phase transition with one flavor of massless staggered fermions which could not be studied earlier due to sign problems and extract the critical exponents. Based on this we argue that results from a previous work may be misleading. Finally, we argue that with two flavors of staggered fermions and a specific type of four-fermion interaction, a surprising phase transition to a massive fermion phase without any spontaneous symmetry breaking may occur.

Phase structure of topological insulators by lattice strong-coupling expansion
Yasufumi Araki, Taro Kimura
Wed, 11:00, Seminar Room E (RW6) – Parallels 6E

The phase structure of topological insulators under a sufficiently strong electron-electron interaction is investigated. Topological insulators are materials with gapless surface states topologically protected by the time-reversal symmetry. The effective theory of topological insulators can be established on honeycomb of square lattices in terms of the Wilson fermion. Here we incorporate the effect of the electron-electron interaction in terms of U(1) lattice gauge theory (quantum electrodynamics), and analyze the phase structure by the techniques of strong coupling expansion. As a result, the phase structure is modified from that in the non-interacting limit. In 2-dimensional topological insulators, a sufficiently strong electron-electron interaction leads to the in-plane (tilted) antiferromagnetism, which possesses a similar structure to the well-known "Aoki phase" in lattice QCD with the Wilson fermion. We will also consider the phase structure of 3-dimensional topological insulators, and mention some physical implications about the experimental behavior of the materials.

Topological Lattice Actions
Wolfgang Bietenholz, Michael Bögli, Urs Gerber, Ferenc Niedermayer, Michele Pepe, Fernando Rejón-Barrera, Uwe-Jens Wiese
Wed, 11:20, Seminar Room E (RW6) – Parallels 6E

A variety of lattice discretizations of continuum actions has been considered in the literature, usually requiring the correct classical continuum limit. Here we discuss "weird" lattice formulation without that property, namely lattice actions that are invariant under small deformations of the field configuration, in one cases even without any couplings. It turns out that universality is powerful enough to still provide the correct quantum continuum limit, despite the absence of any classical limit, or a perturbative expansion. We demonstrate this for a set of non-linear sigma-models. Amazingly, such "weird" lattice actions even have practical benefits, in particular an excellent scaling behavior.

MCRG Flow for the Nonlinear Sigma Model

Daniel Körner, Raphael Flore, Björn Wellegehausen, Andreas Wipf

Wed, 11:40, Seminar Room E (RW6) – Parallels 6E

A study of the renormalization group flow in the three-dimensional nonlinear O(N) sigma model using Monte Carlo Renormalization Group (MCRG) techniques is presented. To achieve this, we combine an improved block-spin transformation with the canonical demon method to determine the flow diagram for a number of different truncations. Systematic errors of the approach are highlighted. Results are dis- cussed with hindsight on the fixed point structure of the model and the corresponding critical exponents. Special emphasis is drawn on the existence of a nontrivial ultraviolet fixed point which is a desired property for theories modeling the asymptotic safety scenario of quantum gravity.

The gradient flow in a twisted box

Alberto Ramos

Wed, 12:00, Seminar Room E (RW6) – Parallels 6E

We study the perturbative behavior of the gradient flow in a twisted box. We apply this information first to define a running coupling using the energy density of the flow field and to study the size of cutoff effects to leading order in perturbation theory. Second, we study the step scaling function and the size of cutoff effects in SU(2) pure gauge theory. We finally comment on how the gradient flow can be used to improve other running coupling definitions.

Lattice Monte Carlo methods for systems far from equilibrium
David Mesterhazy, Luca Biferale, Karl Jansen, Raffaele Tripiccione
Wed, 12:20, Seminar Room E (RW6) – Parallels 6E

We present a new numerical Monte Carlo approach to determine the scaling behavior of lattice field theories far from equilibrium. The presented methods are generally applicable to systems where classical-statistical fluctuations dominate the dynamics. As an example, these methods are applied to the random-force-driven one-dimensional Burgers' equation – a model for hydrodynamic turbulence. For a self-similar forcing acting on all scales the system is driven to a nonequilibrium steady state characterized by a Kolmogorov energy spectrum. We extract correlation functions of single- and multi-point quantities and determine their scaling spectrum displaying anomalous scaling for high-order moments. Varying the external forcing we are able to tune the system continuously from equilibrium, where the fluctuations are short-range correlated, to the case where the system is strongly driven in the infrared. In the latter case the nonequilibrium scaling of small-scale fluctuations are shown to be universal.

Hydrodynamics as a Quantum Field Theory on the lattice
Giorgio Torrieri, Tommy Burch
Wed, 12:40, Seminar Room E (RW6) – Parallels 6E

As was known for some time, ideal hydrodynamics can be written as a field theory, suitable for quantization via the Feynman prescription [1]. Examining the fully quantum structure of ideal hydrodynamics can yield novel physical insights, including a "new way of thinking" about microscopic versus macroscopic dynamics and, perhaps, a new "quantum bound" for the viscosity over entropy density [2]. However, it is also clear that the quantum structure of this theory is highly non-perturbative [1,2]. In this work, we present our first effort to study ideal hydrodynamics as a field theory on the lattice. We will give an overview of the issues inherent in this analysis, define physically interesting observables, and present preliminary results, concentrating on averages of the scalar and tensor part of the energy momentum tensor of the ideal quantum fluid. [1] S. Endlich, A. Nicolis, R. Rattazzi and J. Wang, JHEP 1104, 102 (2011) [2] G. Torrieri, Phys.Rev. D85 (2012) 065006

The unitary Fermi gas on the lattice
Olga Goulko, Matthew Wingate
Poster Session

Many interesting problems in the field of cold atoms cannot be solved analytically and require a numerical treatment. A prominent example is the resonantly interacting Fermi gas. In such cases lattice field theory is a very useful tool, since it allows first principles calculations without uncontrolled assumptions. One of the major challenges of the method is to extract the physical quantities in continuum and for an infinite system size from discrete data obtained for finite systems. I will discuss different methods and error sources on the example of the unitary Fermi gas at temperatures beyond the critical point.

Confinement in deformed Yang-Mills theories
Helvio Vairinhos
Poster Session

We study the confining properties of Yang-Mills theory with double-trace deformations on $R^3 \times S^1$ on the center symmetric phase.

More about vacuum structure of Linear Sigma Model
Tomomi Sato, Norikazu Yamada
Poster Session

We analytically study two aspects of $U(N_f) \times U(N_f)$ Linear sigma model (LSM). The first one is related to the effective restoration of $U_A(1)$ symmetry. Motivated by recent lattice data suggesting that two-flavor QCD may not obey O(4)-scaling, we study the effect of anomaly to the order of chiral phase transition in U(2) x U(2) LSM. The analysis is carried out in epsilon-expansion with a mass dependent renormalization scheme. We derive the condition that the model experiences the first order phase transition. The motivation of the second part is concerning lattice simulations of many flavor QCD using Wilson fermions. To answer the question how conformal theories look like on the lattice with Wilson fermions, we introduce quark masses and lattice artifacts into LSM and analyze their effects to the vacuum structure.

Velocity renormalization in graphene from lattice Monte Carlo
Timo Laehde, Joaquin Drut
Poster Session

The Coulomb interaction between quasiparticles in graphene is expected to reshape the Dirac cones by means of a logarithmic running of the Fermi velocity. I will report a recent lattice Monte Carlo calculation of the quasiparticle dispersion relation in graphene, within the Dirac low-energy theory, augmented by an instantaneous, long-range Coulomb interaction.

Dynamical 2+1 flavor QCD + QED
Gerrit Schierholz
Poster Session

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Physics Beyond the Standard Model

Lattice study on chiral dynamics of two-color six-flavors QCD
Masaaki Tomii, Masashi Hayakawa, Ken-Ichi Ishikawa, Yusuke Osaki, Shinji Takeda, Norikazu Yamada
Mon, 14:00, Seminar Room F (HS II) – Parallels 1F

The electroweak symmetry breaking and origin of masses may be attributed to the breaking of chiral symmetry due to new strong gauge dynamics. Among several candidates of such gauge systems, we have focused on two-color QCD with $N_F = 6$ massless Dirac fermion in the fundamental representation, and study on whether this gauge dynamics triggers chiral symmetry breaking or not by simulating with Wilson fermions on lattices sized up to $L/a = 32$. We show the result obtained from analysis on quark mass and volume dependence of various quantities such as meson masses, decay constant, and by comparing these behaviors with the theoretical expectation in the presence of breakdown of chiral symmetry and that for the conformal dynamics in the infrared limit, respectively.

Two-Color Schrödinger Functional with Six-Flavors of Stout-Smeared Wilson Fermions
Gennady Voronov
Mon, 14:20, Seminar Room F (HS II) – Parallels 1F

We study the Schrödinger functional running coupling in the two-color gauge theory with six-flavors of massless fermions. The aim is to determine whether the above theory has an infrared fixed point (IRFP). With the standard Wilson gauge action and the stout-smeared Wilson fermion action, we see clear evidence of the renormalized coupling flowing from perturbatively weak coupling to a strength where it is expected that chiral symmetry is broken without encountering an IRFP. We therefore conclude that the $N_f = 6$ two-color theory is outside the conformal window.

Exploring for a light composite scalar in eight flavor QCD
Hiroshi Ohki
Mon, 14:40, Seminar Room F (HS II) – Parallels 1F

The eight flavor ($N_f = 8$) QCD is very attractive to a candidate of the walking technicolor model, where the light scalar (technidilaton) is predicted as a pseudo Nambu-Goldstone boson of the spontaneous scale symmetry breaking. We study a composite scalar in the $N_f = 8$ QCD using the HISQ action on several lattice sizes with various fermion masses. Measuring both the disconnected and connected diagrams of the flavor singlet scalar correlation function, we present our preliminary results of the scalar mass and its fermion mass dependence. Through the analysis, we investigate the property of the scalar as a composite Higgs boson.

Walking signals in $N_f = 8$ QCD on the lattice
Kei-ichi Nagai
Mon, 15:00, Seminar Room F (HS II) – Parallels 1F

We investigate walking signals of $N_f = 8$ QCD using HISQ action. Our data (the pion decay constant, the pion and ρ meson masses and the chiral condensate) for the $N_f = 8$ QCD are consistent with the spontaneously broken chiral symmetry in the chiral limit extrapolation of ChPT. Remarkably enough, while the $N_f = 8$ data near the chiral limit are well described by the ChPT, those for the relatively large fermion bare mass m_f away from the chiral limit actually exhibit a finite-size hyperscaling relation, suggesting a large anomalous dimension $\gamma_m \sim 1$. This implies that there exists a remnant of the infrared conformality, and suggests that a typical technicolor ("one-family model") as modeled by the $N_f = 8$ QCD can be a walking technicolor theory.

Eight light flavors on large lattice volumes
David Schaich
Mon, 15:20, Seminar Room F (HS II) – Parallels 1F

I will present initial results from large-scale lattice investigations of SU(3) gauge theory with eight light flavors in the fundamental representation. This work, carried out using leadership computing resources provided to the United States lattice gauge theory community, considers large lattice volumes up to L=48 in order to permit controlled chiral extrapolations. We generate configurations with improved staggered fermions, and carry out some measurements with valence domain wall fermions. I will focus on analyses of the light hadron spectrum, Dirac eigenvalues, and low-energy constants of chiral perturbation theory, including the electroweak S parameter.

Gluonic observables and the scalar spectrum of twelve-flavour QCD
Enrico Rinaldi
Mon, 15:40, Seminar Room F (HS II) – Parallels 1F

We measure glueball masses and the string tension in twelve-flavour QCD, aiming at comparing the emerging gluonic spectrum to the mesonic one. When approaching the critical surface at zero quark mass, the hierarchy of masses in the different sectors of the spectrum gives a new handle to determine the existence of an infrared fixed point. We describe the details of our gluonic measurements and the results obtained on a large number of gauge configurations generated with the HISQ action. In particular we focus on the scalar glueball and its mixing with a flavour-singlet fermionic state, which is lighter than the pseudoscalar (would-be pion) state. The results are interpreted in view of a light composite Higgs boson in walking technicolor theories.

Higgs Sector Spectroscopy
Axel Maas, Tajdar Mufti
Mon, 16:30, Seminar Room F (HS II) – Parallels 2F

Just like the weakly-interacting QED the weak and Higgs interaction can sustain bound states. Field-theoretical considerations suggest that these are deeply-bound, relativistic bound states, at least for a sufficiently light Higgs. Thus, they cannot be described using quantum mechanics. In the here presented lattice results these considerations are confirmed, and the low-lying spectrum of bound states is determined. It is shown how these relate to the observed Higgs and W/Z signals, being in agreement with present experimental results. Furthermore, first estimates for masses for a range of quantum numbers and, using Luescher's method, for excited states are provided. With the obtained widths preliminary estimates can be made on the experimental accessibility at both LHC and ILC.

The phase structure of a chirally-invariant Higgs-Yukawa model
Bastian Knippschild, Karl Jansen, Attila Nagy, C.-J. David Lin, Kei-ichi Nagai, Prasad Hegde, Kenji Ogawa
Mon, 16:50, Seminar Room F (HS II) – Parallels 2F

We present new results of our ongoing project on the investigation of the phase structure of the Higgs-Yukawa model at small and large bare Yukawa couplings. The critical exponents of the second order bulk phase transitions of this model are determined from finite size analyses and compared to the pure O(4)-model to test for triviality and the possibility of having a non-Gaussian fixed point. In addition, we will present a first study of Higgs boson and fermion masses.

Stabilizing the electroweak vacuum by higher dimensional operators in a Higgs-Yukawa model

Attila Nagy, Prasad Hegde, Karl Jansen, C.-J. David Lin

Mon, 17:10, Seminar Room F (HS II) – Parallels 2F

The Higgs boson-like discovery at the LHC with a mass of approximateley 126GeV suggests, that the electroweak vacuum of the standard model maybe metastable at high energies. However, any new physics beyond the standard model can change this picture. We want to adress this important question within a lattice Higgs-Yukawa model as the limit of the standard model (SM). In this framework we will probe the effect of a higher dimensional operator for which we take a (ϕ^6)-term. Such a term could easily originate as a remnant of physics beyond the SM at very large scales. As a first step we investigate the phase diagram of the model including such a (ϕ^6) operator. Exploratory results suggest the existence of regions in parameter space where first order transitions turn to second order ones, suggesting the existence of a tri-critical point. We will address the phase structure and the consequences for the stability of the SM both, analytically by analyzing the constrained effective potential in lattice perturbation theory and by studying the system non-perturbatively by means of lattice simulations.

Multi-boson spectrum of the SU(2)-Higgs model

Mark Wurtz, Randy Lewis

Mon, 17:30, Seminar Room F (HS II) – Parallels 2F

Lattice simulations are used to compute the spectrum of energy levels for all available angular momentum and parity quantum numbers in the SU(2)-Higgs model, with parameters chosen to match experimental data from the Higgs-W boson sector of the standard model. Creation operators are constructed for all lattice irreducible representations, and a correlation matrix is formed from which the spectrum is extracted using a variational analysis. Many multi-boson states are observed and careful analysis reveals that all are consistent with weakly-interacting Higgs and W bosons.

Progress in Gauge-Higgs Unification on the Lattice (I)
Kyoko Yoneyama, Nikos Irges, Francesco Knechtli, Peter Dziennik
Mon, 17:50, Seminar Room F (HS II) – Parallels 2F

In Gauge-Higgs unification model, the Higgs field is identified with (some of) the extra dimensional components of the gauge field. Perturbative studies indicate that spontaneous symmetry breaking (SSB) occurs when fermions are included. By using a mean-field expansion, we show that SSB occurs in a 5-dimensional pure SU(2) gauge theory on the S^1/Z_2 orbifold. We take the continuum limit in a regime on the phase diagram where the Higgs remains light and predict an excited state of the gauge boson at a mass of 1 Tev. We compare to results of the spectrum (Higgs, Z boson) obtained from Monte Carlo simulations.

Progress in Gauge-Higgs Unification on the Lattice (II)
Francesco Knechtli, Peter Dziennik, Nikos Irges, Kyoko Yoneyama
Mon, 18:10, Seminar Room F (HS II) – Parallels 2F

We study a five-dimensional pure SU(2) gauge theory formulated on the orbifold and discretized on the lattice by means of Monte Carlo simulations. The gauge symmetry is explicitly broken to U(1) at the orbifold boundaries. The action is the Wilson plaquette action with a modified weight for the boundary U(1) plaquettes. We study the phase transition and present results for the shape of the static potential in the hyperplanes orthogonal to the extra dimension, which is sensitive to the presence of a massive Z-boson. We compare to results from the case of periodic boundary conditions and from the direct measurement of the Z-boson mass presented in part (I). The results may support an alternative view of the lattice orbifold (stemming from its mean-field study) as a 5d bosonic superconductor.

Can a light Higgs impostor hide in composite gauge models?
Chik Him Wong, Julius Kuti, Dániel Nógrádi, Kieran Holland, Zoltan Fodor
Mon, 18:30, Seminar Room F (HS II) – Parallels 2F

Close to the conformal window, a gauge model model with a fermion doublet in the two-index symmetric (sextet) representation of the SU(3) gauge group has attracted considerable interest. Its flavor singlet scalar spectroscopy with Higgs quantum numbers is investigated in the report.

String tension vs critical temperature in walking regime
Kohtaroh Miura, Albert Deuzeman, Maria Paola Lombardo, Elisabetta Pallante, Tiago Nunes da Silva
Tue, 14:00, Seminar Room F (HS II) – Parallels 3F

The conformal and walking dynamics associated with the infra-red fixed point (IRFP) in many flavor QCD have received lots of attentions both theoretically and phenomenologically. In the six and eight flavor QCD, we evaluate the critical temperature (T_c) for the chiral phase transition at finite temperature and the string tension at zero temperature. We argue that the T_c in the unit of the UV scale r_x determined by the string tension gives a prove of the walking dynamics. We show our preliminary results on $(T_c * r_x)$ as a function of N_f, and discuss the onset of the walking dynamics.

Finite size scaling and the effect of the gauge coupling in 12 flavor systems
Anna Hasenfratz, Anqi Cheng, Gregory Petropoulos, David Schaich
Tue, 14:20, Seminar Room F (HS II) – Parallels 3F

We investigate finite size scaling in with 12 fundamental flavors at several gauge coupling values, from the weak coupling region to the edge of the bulk phase transition in the strong coupling. The data show strong scaling violations in the strong coupling where the predicted anomalous dimension depends on the observable considered and changes with the gauge coupling. We argue that the observed scaling violation effects are caused by the irrelevant but slowly running gauge coupling. Finite size scaling fits that take into account this effect predict a consistent picture with universal scaling curves with common anomalous dimension even in the strong coupling.

Step Scaling Study of SU(3) 12 Flavor Theory with Larger Lattice
Kenji Ogawa, C.-J. David Lin, Hiroshi Ohki, Eigo Shintani
Tue, 14:40, Seminar Room F (HS II) – Parallels 3F

The existence of the infrared fixed point in the SU(3) gauge theory with 12 flavors is still controversial. In this talk, we present our improved study of running coupling constant with Twisted Polyakov Loop scheme including the data of 24^4 lattice. It allows us a more detailed study of the lattice artefacts.

Composite flavor-singlet scalar in twelve-flavor QCD

Takeshi Yamazaki

Tue, 15:00, Seminar Room F (HS II) – Parallels 3F

We present our results of flavor-singlet scalar meson in twelve-flavor QCD with a HISQ type action at the several volumes and fermion masses. A large number of gauge configurations and a noise reduction method were employed to reduce statistical noise of the disconnected diagram. We found that the flavor-singlet scalar state is lighter than the pseudoscalar state, which is different from usual QCD. From the investigation of the fermion mass dependence, we show that the results are consistent with hyperscaling, which is expected in the conformal theory. Therefore we consider that the lightness of the flavor-singlet scalar state is due to the infrared conformality. This result shed some light on the possibility of a light composite Higgs boson in walking technicolor theories.

Fisher's zeros for SU(3) with Nf flavors and RG flows

Yuzhi Liu, Zechariah Gelzer, Yannick Meurice, Donald K. Sinclair

Tue, 15:20, Seminar Room F (HS II) – Parallels 3F

We calculate the Fisher's zeros for SU(3) with $N_f = 4$, 8 and 12 flavors of staggered fermions for various values the fermion mass. We discuss the finite size scaling near the end point of the line of discontinuity of psibar-psi in the beta-mass plane and in the larger beta-lower mass region. We discuss possible interpretations of these results in terms of Wilsonian RG flows and their possible relevance to construct composite Higgs models.

Improved Lattice Renormalization Group Techniques

Gregory Petropoulos, Anqi Cheng, Anna Hasenfratz, David Schaich

Tue, 15:40, Seminar Room F (HS II) – Parallels 3F

We compute the step scaling function for SU(3) lattice gauge theories with many fundamental fermions using a fully non-perturbative Wilson flow optimized Monte Carlo Renormalization Group technique. By using Wilson flow to approach the renormalized trajectory of a specific RG transformation we are able to determine the unique step scaling function of a fixed renormalization group scheme. We apply our Wilson Flow MCRG technique to SU(3) gauge theory with 12 flavors in the chiral limit and find an infrared fixed point. By choosing different renormalization group schemes we are able to move the fixed point but the existence of the fixed point is universal. Furthermore, different RG transformations predict a consistent value for the scaling dimension of the irrelevant gauge coupling.

Further studies of QCD with sextet quarks

Donald Sinclair, John Kogut

Tue, 16:20, Seminar Room F (HS II) – Parallels 4F

QCD with 2 flavours of colour-sextet quarks is a candidate walking-technicolor theory. We are studying the position of the chiral-symmetry-restoration transition to determine whether it is a finite-temperature transition in the continuum limit or if it is a bulk transition. In the first case it would be a walking gauge theory; in the second case it would be a conformal gauge theory. The 3-flavour case is being studied for comparison. We simulate the lattice version of these theories with unimproved staggered quarks using the RHMC algorithm.

Gauge theories with fermions in two-index representations
Yigal Shamir, Benjamin Svetitsky, Thomas DeGrand
Tue, 16:40, Seminar Room F (HS II) – Parallels 4F

After a brief discussion of the methodology I will report results obtained using the Schrodinger functional technique for two gauge theories that are believed to lie near the bottom of the conformal window: the SU(3) theory with $N_f = 2$ adjoint Dirac fermions, and the SU(4) theory with $N_f = 6$ Dirac fermions in the two-index antisymmetric representation. In both cases we find a small beta function in strong coupling. We cannot confirm or rule out an infrared fixed point, though the SU(4) theory shows hints of walking. In both theories the mass anomalous dimension levels off, staying well below 0.5, much like the theories with fermions in the two-index symmetric representation investigated earlier.

Clover fermions in the adjoint representation and simulations of supersymmetric Yang-Mills theory
Stefano Piemonte
Tue, 17:00, Seminar Room F (HS II) – Parallels 4F

Lattice simulations of supersymmetry are available since the last two decades, but only recently the algorithmic improvements have allowed investigations close enough to the continuum limit. The Monte Carlo studies of SUSY have many peculiarities with respect to standard QCD. The quarks are replaced by gluinos, which are majorana fermions in adjoint representation. The finite lattice spacing breaks SUSY explicitly, therefore, it is crucial to remove the O(a) discretization errors from the action. Our current research is focused on the N=1 supersymmetric Yang-Mills theory and the talk will present our recent algorithmic progresses. In particular, the removal of O(a) discretization errors from the Dirac operator with the clover term will be presented.

First results for SU(2) Yang-Mills with one adjoint Dirac Fermion
Andreas Athenodorou, Ed Bennett, Georg Bergner, Biagio Lucini, Agostino Patella
Tue, 17:20, Seminar Room F (HS II) – Parallels 4F

We present the first exploratory results for the SU(2) gauge theory with one Dirac flavour in the adjoint representation. We provide initial results for the spectroscopy, static potential and the anomalous dimension for the fermionic condensate. Our results indicate that the theory is conformal with a fermionic anomalous dimension of order $\sim O(1)$. These findings are relevant for walking technicolor scenarios.

Large volume results in SU(2) with adjoint fermions
Luigi Del Debbio, Biagio Lucini, Agostino Patella, Claudio Pica, Antonio Rago
Tue, 17:40, Seminar Room F (HS II) – Parallels 4F

We present our latest results for the spectrum of SU(2) with two adjoint fermions, computed from numerical simulations on large lattices. We discuss the impact of finite volume effects on the scaling predicted from RG arguments, and review the determination of the mass anomalous dimension from measurements of the hadronic spectrum of the theory.

Conformality at large number of fermion flavors and composite Higgs

Terry Tomboulis

Wed, 08:30, Seminar Room F (HS II) – Parallels 5F

It has recently been shown, both by direct MC studies and fermion hopping expansion resummation techniques, that SU(N_c) lattice gauge theories can be in a chirally symmetric phase even at infinite gauge coupling provided the number of fermion flavors N_f is large enough. We briefly review the resummation argument that provides some intuitive understanding of the phenomenon. We then discuss proposals for the complete $(g, m, (N_f/N_c))$-phase diagram in light of the presently available information and open issues associated with it. Existence of a non-trivial conformal phase (non-trivial IR fixed point(s)) in (UV cutoff) gauge theories at large N_f/N_c, if confirmed by further studies, provides a potentially new paradigm of composite Higgs models where the putative Higgs is not a GN boson. Instead, naturally light and weakly coupled composite scalar states appearing in the spectrum become unstable under mass generation by the CW mechanism upon coupling to electroweak gauge fields.

Search for the end point of first order phase transition in many-flavor lattice QCD

Norikazu Yamada, Shinji Ejiri

Wed, 08:50, Seminar Room F (HS II) – Parallels 5F

As a first step to the feasibility study of the electroweak baryogenesis in technicolor scenario, we propose an easy-to-use approach to investigate the phase structure of $(2 + N_f)$-flavor QCD, where two light and N_f massive flavors exist. The approach is combining the reweighting and the histogram methods. By determining the location of the end point of the first order phase transition, we demonstrate that the approach works. We perform two lattice calculations, each of which uses staggered and Wilson fermion. The light quark mass dependence of the location of the end point is studied. Possible applications are also discussed.

More results on theories inside the conformal window
Tiago Jose Nunes da Silva, Albert Deuzeman, Maria Paola Lombardo, Kohtaroh Miura, Elisabetta Pallante
Wed, 09:10, Seminar Room F (HS II) – Parallels 5F

We report on the study of theories inside the conformal window that is being carried on within our collaboration. We are studying the SU(3) gauge theory with twelve and sixteen flavors of fundamental flavors and we present results that highlight the properties of such theories. We also comment on the role of improvement away from the perturbative limit.

Vector and axialvector currents in multi-species staggered fermions
Yasumichi Aoki
Wed, 09:30, Seminar Room F (HS II) – Parallels 5F

Flavor non-singlet vector current can be constructed for staggered fermions when multiple fermion fields are involved. The axial vector current which forms an exact multiplet with the vector current under the exact axial transformation can be made. The difference of the vacuum polarization functions with the vector and axial vector currents is free from power divergence. Applications of these currents include the Peskin-Takeuchi S parameter and vector meson decay constant. A practical way to calculate these quantities in multi-species HISQ formulation is discussed.

The Gradient Flow Coupling in Minimal Walking Technicolor
Jarno Rantaharju
Wed, 09:50, Seminar Room F (HS II) – Parallels 5F

We present a measurement of the running coupling in SU(2) with two adjoint fermions in the Yang-Mills gradient flow scheme. The simulations are performed with Schrödinger Functional boundary conditions using an improved HEX-smeared Wilson fermion action. We obtain a step scaling function by defining the coupling at a scale relative to the finite size of the lattice. We find a continuum limit with a non-trivial infrared fixed point.

Toward the Global Structure of Conformal Theories in the SU(3) Gauge Theory
Yoichi Iwasaki
Wed, 10:10, Seminar Room F (HS II) – Parallels 5F

We clarify the vacuum structure and properties of correlation functions in QCD with N_f flavors in fundamental representation from the viewpoint of the "conformal theories with an IR cutoff". We claim that the large N_f QCD (referred as Conformal QCD) with an IR cutoff and small N_f QCD at $T/T_c > 1$ (referred as High Temperature QCD) shows the common feature as the "conformal theories with an IR cutoff". We argue from our theoretical analysis based on the RG flow and our numerical simulations that there is a precise correspondence between the two in the correlation functions and phase structure under the change of the parameters N_f and T/T_c respectively: the one boundary is close to meson states and the other is close to free quark states. In particular, we find the correspondence between Conformal QCD with $N_f = 7$ and High Temperature QCD with $N_f = 2$ at $T \sim 2\,T_c$ being in close relation to a meson unparticle model. From this we estimate the anomalous mass dimension $\gamma^* = 1.2(1)$ for $N_f = 7$. We also show that the asymptotic state in the limit $T/T_c \to \infty$ is a free quark state in the Z(3) twisted vacuum. The approach to a free quark state is very slow; even at $T/T_c \sim 10^5$, the state is affected by non-perturbative effects. This explains the slow approach of the free energy to the Stefan-Boltzmann ideal gas limit. Our finding above is consistent with our conjecture that the lower critical flavor number $N_f^c = 7$ for the conformal window in the continuum limit.

Anomalous dimensions of four-fermion operators from conformal EWSB dynamics
Carlos Pena, Luigi Del Debbio, Liam Keegan
Wed, 11:00, Seminar Room F (HS II) – Parallels 6F

(Quasi)conformal scaling of composite operators from a strongly coupled EWSB dynamics helps to produce the characteristic hierarchies exhibited by the flavour couplings of the SM. It is however crucial to ensure that specific models satisfy bounds on Higgs and flavour dynamics; this in turn requires to control not only the anomalous dimensions of bilinears, but also those of higher-dimensional operators. We report on an ongoing effort to determine four-fermion operator anomalous dimensions, via Schrödinger Functional techniques, in the benchmark scenario of Minimal Walking Technicolour.

The anomalous mass dimension from the techniquark propagator in Minimal Walking Technicolor
Daniel August, Axel Maas
Wed, 11:20, Seminar Room F (HS II) – Parallels 6F

Minimal Walking Technicolor is a 2-color QCD-like theory with two quark flavors in the adjoint representation. We calculated the techniquark propagator in minimal Landau gauge, using lattice simulations of the standard Wilson action. This data enabled us to derive the anomalous mass dimension from a single lattice setup. We present results for a range of quark masses, and give estimate of the systematic errors. The results are compatible with previous determinations.

Determining the anomalous dimension through the eigenmodes of Dirac operator
Anqi Cheng, Anna Hasenfratz, Gregory Petropoulos, David Schaich
Wed, 11:40, Seminar Room F (HS II) – Parallels 6F

We extract the scale-dependent mass anomalous dimension from the eigenmode number of the massless Dirac operator, for SU(3) lattice gauge theories with many fundamental fermions. A stochastic algorithm allows us to efficiently measure the mode number up to the cutoff scale on lattices as large as L=32. By combining simulations on multiple lattice volumes, and when possible several gauge couplings, we are able to measure the anomalous dimension across a wide range of energy scales. The 4-flavor model behaves as expected for a QCD-like system, while our 12-flavor results suggest the existence of an infrared fixed point with the anomalous dimension 0.32(3). For the 8-flavor model we observe a large anomalous dimension across a wide range of scales. We also investigate the 16-flavor system which is known to be infrared conformal. Our method is universal and can be applied to any lattice model of interest.

The chiral condensate from the Dirac spectrum in BSM gauge theories
Kieran Holland, Zoltan Fodor, Julius Kuti, Dániel Nógrádi, Chik Him Wong
Wed, 12:00, Seminar Room F (HS II) – Parallels 6F

Chiral symmetry breaking in near-conformal gauge theories can be masked by the steep mass dependence of the chiral condensate. We discuss the renormalization group invariant mode number of the Dirac operator for the 2-flavor SU(3) sextet and the 12-flavor SU(3) fundamental models, and consistency with direct measurements of the chiral condensate.

SU(2) Adjoint MWT in the chirally rotated Schrödinger functional scheme

Claudio Pica, Rudy Arthur, Luigi Del Debbio, Biagio Lucini, Agostino Patella, Antonio Rago, Stefan Sint, Pol Vilaseca

Wed, 12:20, Seminar Room F (HS II) – Parallels 6F

I will present preliminary results for our ongoing simulations for the determination of the non-perturbative beta-function of the SU(2) Adjoint Minimal Walking Technicolor (MWT) model in the chirally rotated Schrödinger functional scheme.

The spectrum of supersymmetric Yang Mills theory – new results and recent measurements

Gernot Münster, Georg Bergner

Thu, 14:00, Seminar Room F (HS II) – Parallels 7F

Numerical simulations of supersymmetric theories on the lattice are intricate and challenging with respect to their theoretical foundations and algorithmic realization. Nevertheless, the simulations of a fourdimensional supersymmetric gauge theory have made considerable improvements over the recent years. In this talk I summarize the results of our collaboration concerning the mass spectrum of this theory. The investigation of systematic errors allows now a more precise estimate concerning the expected formation of supersymmetric multiplets of the lightest particles. These multiplets contain flavour singlet mesons, gluballs, and an additional fermonic state.

Loop formulation for the non-linear supersymmetric O(N) sigma-model

Kyle Steinhauer, Urs Wenger

Thu, 14:20, Seminar Room F (HS II) – Parallels 7F

In this contribution we present the fermion loop formulation of the Non-linear supersymmetric O(N) model on the lattice using Wilson fermions. The formulation provides an efficient way to simulate the fermionic degrees of freedom for arbitrary boundary conditions and at arbitrary mass values. We show in detail how the symmetry constraints induce flavour changing interactions between the bosons and fermions which may potentially lead to a sign problem. For N=2 first results such as the determination of the critical point and the spectrum of the bosons and fermions will be presented.

Eigenvalue spectrum of lattice N=4 super Yang-Mills
David Weir, Simon Catterall, Paul Damgaard, Thomas DeGrand, Dhagash Mehta
Thu, 14:40, Seminar Room F (HS II) – Parallels 7F

We present preliminary results for the eigenvalue spectrum of four-dimensional N=4 super Yang-Mills theory on the lattice. In particular, by studying the the spectral density a measurement of the anomalous dimension is made and found to be consistent with zero. Properties of the Pfaffian are also explored numerically to support the claim that the theory has no sign problem.

Euclidean 4D quantum gravity with a non-trivial measure term
Andrzej Görlich, Jan Ambjørn, Lisa Glaser, Jerzy Jurkiewicz
Thu, 15:00, Seminar Room F (HS II) – Parallels 7F

Dynamical Triangulations provide us with a lattice regularization of four-dimensional Euclidean quantum gravity within the realm of ordinary quantum field theory. We add a local measure term, which can also serve as a generalized higher curvature term, and explore an extended coupling constant space. We determine the phase diagram of this model using non-degenerated triangulations. A first order phase transition line is observed, but no second order transition point is located. As a consequence we cannot attribute any continuum physics interpretation to the so-called crinkled phase of 4D dynamical triangulations.

Gauge theory of Lorentz group on the lattice
Mikhail Zubkov
Thu, 15:20, Seminar Room F (HS II) – Parallels 7F

The model with the fermions coupled in the nonminiaml way to the gauge theory of Lorentz group is considered. The lattice regularization is suggested. It is argued that this model may exist in the phase with broken chiral symmetry and without confinement. We speculate about the possibility that this construction may serve as an origin of the dynamical electroweak symmetry breaking.

Euclidean Dynamical Triangulation revisited: is the phase transition really 1st order?
Tobias Rindlisbacher, Philippe de Forcrand
Thu, 15:40, Seminar Room F (HS II) – Parallels 7F

The transition between the two phases of 4D Euclidean Dynamical Triangulation is believed to be of first order [1, 2]. However, doubts on this conclusion can be raised because of the enormous critical slowing down observed in the simulations, the use of a potential term to control the volume fluctuations, and the definition of a sweep as N4 accepted moves. We re-investigate the order of the phase transition by using an optimized parallel tempering method as described in [3] with up to 48 replicas in order to decrease the auto-correlation time. A sweep we define as usual as N4 attempted moves in order to satisfy detailed balance and instead of using an additional potential, we allow the volume to fluctuate within a fixed interval while 4 is tuned to its pseudo-critical value. [1] P. Bialas, Z. Burda, A. Krzywicki, B. Petersson: Focusing on the Fixed Point of 4D Simplicial Gravity, hep-lat/9601024 [2] B. V. de Bakker: Further evidence that the transition of 4D dynamical triangulation is 1st order, hep-lat/9603024 [3] H. G. Katzgraber, S. Trebst, D. A. Huse, M. Troyer: Feedback-optimized parallel tempering Monte Carlo, cond-mat/0602085

1st order phase transition in the MSSM and baryogenesis
Kari Rummukainen, Germano Nardini, Mikko Laine
Thu, 16:30, Seminar Room F (HS II) – Parallels 8F

We study the cosmological electroweak phase transition in a MSSM-like theory using lattice simulations of a dimensionally reduced effective theory. The theory has a physical Higgs mass $m_H \sim 126$ GeV and a relatively light SU(3) coloured SU(2) singlet, right handed stop. The theory is observed to have a strong first order phase transition, sufficient for preventing baryon number erasure in electroweak baryogenesis scenarios

Predictions for LHC from SO(4) MWT

Ari Hietanen, Claudio Pica, Francesco Sannino, Ulrik Søndegaard

Thu, 16:50, Seminar Room F (HS II) – Parallels 8F

Among the relevant models of dynamical electroweak symmetry breaking is SO(4) MWT. It is an SO(4)-gauge theory with two fermions in vector representation, and it features dark matter candidates. We present preliminary results of calculation of the masses of vector and axial vector meson using Wilson fermions. The values of the masses are directly relevant for technicolor searches at the LHC.

Composite Dark Matter Exclusions from the Lattice

Michael Buchoff

Thu, 17:10, Seminar Room F (HS II) – Parallels 8F

One intriguing coincidence in cosmology is how the observed dark matter and baryonic densities are within a factor of 5 in magnitude. A natural explanation for such a coincidence is that the origin of the dark matter density is intimately related to the early universe processes that led to the baryon asymmetry. The majority of these "asymmetric" dark matter scenarios favor a strongly coupled composite sector ala QCD, where neutral, long-lived composites can survive to be observed today, but still have charged constituents to interact with early universe baryogenesis. As a result, these neutral composites are expected have non-zero electromagnetic properties, such as magnetic moments, charge radii, and polarizabilties, which can be observed in direct detection experiments. The values of these properties are inherent to the dynamics of these strongly coupled theories, where non-perturbative lattice methods allow for a reliable exploration with controlled systematics. In this talk, I will present some initial results for a three-color, QCD-like theory with two and six light fermion flavors, including implications on the latest exclusions from the Xenon100 collaboration.

Searching for a continuum 4D field theory arising from a 5D non-abelian gauge

Eliana Lambrou, Luigi Del Debbio, Richard Kenway, Enrico Rinaldi
Thu, 17:30, Seminar Room F (HS II) – Parallels 8F

The anisotropic 5D SU(2) Yang-Mills model has been widely investigated on the lattice during the last decade. In the case where all dimensions are large in size, it was previously claimed that a second order phase transition is present in the regime where the lattice spacing in the fifth dimension is much larger than in the other four dimensions. At a second order phase transition a 4D continuum theory could be defined. I will present the extension of the previous work to large lattices, at which we found a first order phase transition. This leaves the scenario that a 5D theory can be dimensionally reduced to a continuum 4D field theory, doubtful.

Four Fermion Interactions in Non Abelian Gauge Theory

Aarti Veernala, Simon Catterall
Thu, 17:50, Seminar Room F (HS II) – Parallels 8F

We show how a strongly coupled lattice theory consisting of just fermions and gauge fields can exhibit a dynamical Higgs mechanism through the formation of a gauge invariant four fermion condensate. Furthermore, we show evidence that this lattice Higgs phase survives into the continuum limit where the broken symmetries are to be interpreted as chiral gauge symmetries.

Single site model of large N gauge theories coupled to adjoint fermions

Rajamani Narayanan, Robert Lohmayer
Fri, 16:30, Seminar Room F (HS II) – Parallels 10F

We consider a single-site large-N gauge theory coupled to adjoint fermions at weak coupling. We study using a four-dimensional density function for the distribution of the eigenvalues of the link variables. We show that it is possible to recover the infinite-volume continuum limit for a certain range of fermion flavors if we use fermions with a bare mass of zero. We discuss the consequences of previous numerical work based on the conclusions reached in our study.

Mass anomalous dimension from large N twisted volume reduction
Liam Keegan, Margarita Garcia-Perez, Antonio Gonzalez-Arroyo, Masanori Okawa
Fri, 16:50, Seminar Room F (HS II) – Parallels 10F

In this work we consider the SU(N) gauge theory with two Dirac fermions in the adjoint representation, in the limit of large N. Taking advantage of large N twisted volume reduction we do this on a single site lattice, but we should still get infinite-volume physics in the large N limit. We describe our progress in extracting the mass anomalous dimension from the eigenvalue distribution of the adjoint Dirac operator, using data for N up to 289.

Twisted reduction in large N QCD with adjoint Wilson fermions
Masanori Okawa, Antonio Gonzalez-Arroyo
Fri, 17:10, Seminar Room F (HS II) – Parallels 10F

The twisted space-time reduced model of large N QCD with adjoint Wilson fermions is constructed applying the symmetric twist boundary conditions with flux k for various number of flavors. With two flavors, the string tension calculated at N=289 approaches zero as we decrease quark mass. On the contrary, the string tension for the case of a single adjoint Wilson fermion seems to remain finite as the quark mass decreases to zero. A preliminary result for the supersymmetric 1/2 flavor theory is also presented.

Large-N mesons
Gunnar Bali, Luca Castagnini, Biagio Lucini, Marco Panero
Fri, 17:30, Seminar Room F (HS II) – Parallels 10F

We compute the meson spectrum in SU(N) gauge theory, up to N = 17, and extrapolate this to predict the QCD meson spectrum in the limit of infinite N. Related quantities like decay constants are obtained as well and non-perturbatively renormalized. Implications on N=3 QCD as well as on models inspired by the gauge-gravity duality are discussed.

Phase structure and Hosotani mechanism in QCD-like theory with compact dimensions
Kouji Kashiwa
Fri, 17:50, Seminar Room F (HS II) – Parallels 10F

We investigated the phase diagram of SU(3) gauge theory in four and five dimensions with one compact dimension by using perturbative one-loop and PNJL-model-based effective potentials. The effect of the adjoint and fundamental fermion is investigated and then the rich phase structure in the quark-mass and compact-size space is realized. The chiral properties in these cases are also discussed. Our results are qualitatively consistent with the recent lattice calculations and clearly show that the calculations can be understood from Hosotani mechanism. Moreover, we will show the result obtained by using the flavor twisted boundary condition for fundamental fermion.

Lattice investigations of the Hosotani Mechanism of spontaneous symmetry breaking
James Hetrick
Fri, 18:10, Seminar Room F (HS II) – Parallels 10F

The Hosotani Mechanism is a method of dynamical gauge symmetry breaking which can occur in gauge theories with compact extra dimensions. Under certain conditions (fermion content and boundary conditions) the gauge field component in the compact dimension develops a VEV that is outside the center of the gauge group. Investigations of this phenomenon in 3+1 dimensions are reported, particularly the behavior of gauge correlators.

Hosotani mechanism on the lattice
Guido Cossu, Yutaka Hosotani, Etsuko Itou, Junichi Noaki, Hisaki Hatanaka
Fri, 18:30, Seminar Room F (HS II) – Parallels 10F

We present the first steps in understanding the non perturbative realization of the Hosotani mechanism. The Hosotani mechanism (Hosotani Phys.Lett.B126 -1983- 309) is a mechanism to get massive gauge bosons without an ad-hoc Higgs particle but embedding the gauge field in a multiply-connected space where the path-ordered line integrals along non-contractible loops become dynamical degrees of freedom. The simplest realization is in a flat space plus a space-like extra dimension S^1 where the fermions are periodic in the extra dimension. The one-loop effective potential shows that the lowest energy states can have a mass gap in some cases, e.g. gauge theory with adjoint fermions. The dynamical degrees of freedom that describe the phases are the eigenvalues of the Polyakov loop. We investigate non perturbatively the phase space of two flavor adjoint fermions, with periodic boundary conditions in the compact direction, to understand if the perturbative results persist in the strong coupling regime.

The anomalous dimension at the infrared fixed point of $N_f = 12$ SU(3) theory
Etsuko Itou
Poster Session

We propose a novel renormalization scheme for the wave function renormalization for the hadronic operators. We show the numerical simulation result for the anomalous dimension of the pseudo scalar operator. It is related with the mass renormalization factor of the fermion thought the partially conserved axial-vector current (PCAC) relation. We derive the mass anomalous dimension at the Infrared fixed point (IRFP) in the SU(3) gauge theory coupled to $N_f = 12$ fundamental fermions. Our numerical result is smaller than one of the previous works. We discuss a possible reason of the discrepancy.

N=1 supersymmetric Yang-Mills theory on the lattice
Gernot Münster, Georg Bergner, Istvan Montvay, Umut D. ÿzugurel, Stefano Piemonte, Dirk Sandbrink
Poster Session

N=1 supersymmetric Yang-Mills theory describes interacting gauge fields and their superpartners, the spin 1/2 gluinos. A gluino mass term breaks supersymmetry softly. In the supersymmetric limit, the physical particles are expected to form supermultiplets. In our recent numerical simulations we made progress in the study and reduction of systematic effects. The results are consistent with the formation of degenerate supermultiplets. This poster gives an overview of the project and its status.

Finetuning the continuum limit in low-dimensional supersymmetric theories
Daniel Körner, Raphael Flore, Björn Wellegehausen, Andreas Wipf
Poster Session

Supersymmetry is a prominent candidate for beyond the standard model physics. Experiments however have not confirmed the existence of superpartner particles that are predicted by susy models. In order to compute the spectrum of such theories, we employ nonperturbative lattice QFT techniques which due to the discretisation of spacetime violate supersymmetry at finite lattice spacing. Care has to be taken then to restore supersymmetry in the continuum limit. We discuss a discretisation of the supersymmetric Nonlinear O(N) Sigma model in two dimensions and argue that supersymmetry may be restored by finetuning of a single parameter. Furthermore, we show results for the spectrum of N=2 Super-Yang-Mills theory in 3 dimensions with emphasis on the Veneziano-Yankielowicz multiplet.

Lattice simulations with eight flavors of domain wall fermions in SU(3) gauge theory
Meifeng Lin
Poster Session

With the discovery of a Higgs-like boson at the Large Hadron Collider, the imminent task for the study of the beyond Standard Model theories is to find the candidate theories that may produce a light scalar particle to be consistent with the experimental observation. In the context of non-perturbative lattice gauge theory simulations, one of the first steps is to find possible non-QCD like behaviors in these theories. Over the past few years, the Lattice Strong Dynamics (LSD) Collaboration has worked extensively on the SU(3) gauge theories with many flavors of degenerate fermions, and found some interesting behaviors in theories of 6 and 10 flavors. Here we will present some latest results by the LSD collaboration from lattice simulations with 8 flavors of domain wall fermions in the SU(3) fundamental representation.

Chiral Symmetry

New actions for minimally doubled fermions and their counterterms
Stefano Capitani
Tue, 16:20, Seminar Room D (RW5) – Parallels 4D

Minimally doubled fermions provide a cheap and convenient way of simulating quarks which preserve chiral symmetry. It has been established that two actions of this kind (known as Borici-Creutz and Karsten-Wilczek) require the tuning of three counterterms in order to be properly renormalized. Here we construct some more general minimally doubled actions and investigate the properties of their counterterms.

Numerical studies of Minimally Doubled Fermions
Johannes Weber, Stefano Capitani, Hartmut Wittig
Tue, 16:40, Seminar Room D (RW5) – Parallels 4D

Minimally doubled fermions of the Karsten-Wilczek class have been studied for the first time in the quenched approximation. Non-perturbative renormalisation criteria are discovered by means of a detailed study of the parameter dependence of mesonic observables. Anisotropies are mapped out by a study of observables acquired through measurement of different euclidean components of the transfer matrix.

Lattice simulation of SU(2) gauge theory with chirally symmetric fermions
Hideo Matsufuru, Yoshio Kikukawa, Kei-ichi Nagai, Norikazu Yamada
Tue, 17:00, Seminar Room D (RW5) – Parallels 4D

SU(2) lattice gauge theory with chirally symmetric fermions is numerically studied. We generate dynamical configurations with two-flavors of domain-wall fermions. Using the overlap fermion operators in addition to the domain-wall, we investigate the chiral dynamics through the eigenvalue spectrum and meson correlators.

Lattice QCD with overlap fermions
Bjoern Walk, Hartmut Wittig
Tue, 17:20, Seminar Room D (RW5) – Parallels 4D

With the advent of Ginsparg-Wilson fermions problems involving chiral symmetry can be treated on the lattice with controllable error. One prominent solution to the Ginsparg-Wilson relation are overlap fermions. Unfortunately, simulations with chiral fermions are still extremely hard to simulate both in terms of computational demand and algorithmic reliability. In my talk, I want to present the experiences with our GPU-based implementation of overlap fermions. I both give details of our implementation and performance gain by the accelerator. I will also show results for physical applications, i.e. random matrix theory and our main goal, non-leptonic kaon decays and the $\Delta I = 1/2$-rule.

Large-scale simulations with chiral symmetry
Takashi Kaneko, Sinya Aoki, Guido Cossu, Hidenori Fukaya, Shoji Hashimoto, Junichi Noaki
Tue, 17:40, Seminar Room D (RW5) – Parallels 4D

We report on our large-scale simulations of three-flavor lattice QCD respecting chiral symmetry. We present our comparative study of HMC performance among various domain-wall-type formulations and report on our on-going large-scale simulations with our choice of lattice action.

The kaon mass in 2+1+1 flavor twisted mass Wilson ChPT
Oliver Bär, Ben Hörz
Wed, 08:30, Seminar Room D (RW5) – Parallels 5D

We construct the chiral low-energy effective theory for 2+1+1 flavor lattice QCD with twisted mass Wilson fermions. In contrast to existing results we assume a heavy charm quark mass such that the D mesons are too heavy to appear as degrees of freedom in the effective theory. As an application we compute the kaon mass to 1-loop order in the Aoki regime. Somewhat surprisingly, the result contains a chiral logarithm involving the neutral pion mass which has no analogue in continuum ChPT. Since the neutral pion mass is very light in actual lattice simulations our results predict significant corrections to the kaon mass, much larger than the statistical errors.

Applications of SU(3) ChPT including lattice data close to the SU(3) symmetric point

Andreas Schäfer, Peter Bruns, Ludwig Greil, Philipp Wein

Wed, 08:50, Seminar Room D (RW5) – Parallels 5D

Chiral perturbation theory (ChPT) is a valuable tool to controle systematic errors in LQCD calculations. However, SU(3)-ChPT has notoriously bad convergence properties. We demonstrate for a few examples, that inclusion of data close to the SU(3) symmetric point substantially improves the situation for primarily three reasons: First, and most importantly, no pseudo-Goldstone-boson masses larger than the physical eta mass are needed in the extrapolation from the symmetric point (where $m_u = m_d = m_s$, while $m_u+m_d+m_s$ is kept fixed at its physical value) to the physical point. Second, some combinations of low-energy constants which parametrize symmetry-breaking effects can be directly obtained quite accurately from the behavior of the observables close to the symmetric point. And third, the values of observables in the chiral limit (like baryon masses, or coupling parameters), which can not be directly measured on the lattice, can for most purposes be eliminated in favor of the values at the symmetric point in the extrapolation formulae. The latter values can be measured in (relatively cheap) lattice simulations, so that some uncertainty inherent in the extrapolation to the chiral limit is also eliminated.

Partially twisted boundary conditions for scalar mesons

Akaki Rusetsky, Dimitri Agadjanov, Ulf Meissner

Wed, 09:10, Seminar Room D (RW5) – Parallels 5D

The properties of scalar mesons with the mass around 1 GeV can be studied on the lattice by using coupled-channel Luescher equation. Analyzing synthetic data, it was shown that the use of twisted boundary conditions leads to a significant improvement of the accuracy of the method. Unfortunately, this statement refers to the full twisting, which is very expensive. In this work we discuss the possibility of partial twisting in the scalar meson sector by studying the problem within the framework of the effective field theories in a finite volume. Partially-twisted Luescher equation is derived. It is demonstrated that, despite the presence of annihilation diagrams, in the sector with the total isospin I=1 one may impose partially twisted boundary conditions so that the resulting Luescher equation coincides with the fully twisted one up to the exponentially suppressed corrections.

Sunset integrals at finite volume
Johan Bijnens
Wed, 09:30, Seminar Room D (RW5) – Parallels 5D

Chiral Perturbation Theory is a useful tool to aid in performing the various extrapolations needed in lattice QCD calculations of physical quantities. These include extrapolations in quark mass, finite lattice spacing and finite size of the lattice. Especially the latter will become more important when the quark masses on the lattice become smaller. The pion mass and decay constant in two-flavour QCD is known at finite volume to two loops. Here we develop the needed two-loop integrals at finite volume to do the calculations for masses and decay constants for all general mass cases and including moving frames and possible other boundary conditions. I will present results based on an expansion in Bessel functions as well as on a version using theta functions and compare their efficiency. Work is in progress to combine these results with two-loop ChPT calculations.

Chiral Symmetry Restoration from a Boundary
Brian Tiburzi
Wed, 09:50, Seminar Room D (RW5) – Parallels 5D

The imposition of Dirichlet boundary conditions in lattice computations obstructs the formation of a chiral condensate. We use chiral perturbation theory and meson models to address the effect of a Dirichlet boundary on chiral symmetry breaking. While pions are the longest-range modes in QCD, the restoration of chiral symmetry due to a boundary is shown not to depend upon the pion Compton wavelength but rather on that of the sigma meson. Power-law finite size corrections are exposed, and require prohibitively large lattices to overcome. We speculate on the frustration of the chiral condensate in some other cases.

Finite volume scaling of the electro-magnetic pion form factor in the epsilon regime
Takashi Suzuki, Hidenori Fukaya
Wed, 10:10, Seminar Room D (RW5) – Parallels 5D

We consider finite volume effects on the pion form factor near the chiral limit, in the so-called epsilon-regime. The pseudoscalar-vector-pseudoscalar three-point function is calculated in the epsilon expansion of chiral perturbation theory to the next-to-leading order. In the epsilon regime, the finite volume effects are non-perturbatively large in general. However, we find a way to remove its dominant part, inserting momenta to the correlators, and taking an appropriate ratio of them. The subleading contribution is, then, expected to be perturbatively small, and one can extract the form factor as in a similar way to that in the p regime.

Effects of Low vs High Fermionic Modes on Hadron Mass Generation
Mikhail Denissenya, Leonid Glozman, Christian Lang, Mario Schröck
Thu, 14:00, Seminar Room D (RW5) – Parallels 7D

We study the effects of the low-lying fermionic modes of the Dirac operator responsible for the chiral symmetry breaking. While these modes are crucial for the pion, they account only for 2/3 of the ρ and N masses. Unlike the high-lying modes the low-lying modes do not produce the b_1 bound state. The latter fact is interpreted as an indication that the low-lying modes do not encode the effect of confinement.

More effects of Dirac low-mode removal
Mario Schröck, Mikhail Denissenya, Leonid Glozman, Christian Lang
Thu, 14:20, Seminar Room D (RW5) – Parallels 7D

In previous studies we have shown that isovector hadrons, except for a pion, survive if we remove the lowest lying Dirac eigenmodes from the spectrum. The low-modes are tied to the dynamical breaking of chiral symmetry and thus we found chiral symmetry to be restored by means of matching masses of chiral partners like the vector and axialvector currents. Here we investigate the influence of removing the lowest part of the Dirac spectrum on the locality of the Dirac operator and, moreover, analyze the influence of low-mode truncation on the quark momenta and thereupon on the hadron spectrum.

The Effect of the Low Energy Constants on the Spectral Properties of the Wilson Dirac Operator
Savvas Zafeiropoulos, Mario Kieburg, Jacobus Verbaarschot
Thu, 14:40, Seminar Room D (RW5) – Parallels 7D

The successful application of Random Matrix Theory to the epsilon regime of QCD has led to new insights into the spectral properties of the Dirac operator. Lately random matrix ensembles were proposed to describe lattice artifacts. Especially Wilson fermions were studied with Random Matrix Theory. Quite recently we analyzed the effect of all three order a^2 terms of Wilson chiral Perturbation Theory on the infrared spectrum of the Wilson Dirac operator. In particular we calculated analytical results for the densities of the complex eigenvalues, of the real eigenvalues and of the distribution of the chiralities over the real eigenvalues. We analyzed the asymptotics of small and large lattice spacing and identified new, easily accessible observables to extract the low energy constants of Wilson chiral Perturbation Theory.

Investigating the Sharpe-Singleton scenario on the lattice by direct eigenvalue computation
Joni Suorsa, Kari Rummukainen, Kim Splittorff, David Weir, Teemu Rantalaiho
Thu, 15:00, Seminar Room D (RW5) – Parallels 7D

We investigate the presence of the Sharpe-Singleton scenario on the lattice. We calculate the fifty lowest lying eigenvalues of the Wilson-Dirac operator using a parallelized GPU-based arnoldi algorithm and witness the collective effect the quark mass has on the eigenvalue distribution as predicted by the Wilson chiral perturbation theory.

Chiral condensate from the Banks-Casher relation
Georg Engel, Leonardo Giusti, Stefano Lottini, Rainer Sommer
Thu, 15:20, Seminar Room D (RW5) – Parallels 7D

Based on the Banks-Casher relation, we determine the chiral condensate in two-flavor QCD using CLS-configurations with several quark masses and two different lattice spacings. We compute the mode number of the O(a)-improved Wilson-Dirac operator for several values of Λ, and we discuss different fitting strategies to extract the chiral condensate from its mass and Λ dependence.

Discretization Effects in the ϵ Domain of QCD
Jacobus Verbaarschot, Mario Kieburg, Kim Splittorff, Savvas Zafeiropoulos
Thu, 15:40, Seminar Room D (RW5) – Parallels 7D

At nonzero lattice spacing the QCD partition function with the Wilson Dirac operator, D_W, undergoes either a second other phase transition to the Aoki phase for decreasing quark mass, or shows a first order jump when the quark mass changes sign. What happens depends on the value of the low-energy constants. We discuss these phase transitions in terms of Wilson Dirac spectra and show that the first order scenario can only occur in the presence of dynamical quarks while in the quenched case we can only have a transition to the Aoki phase. The exact microscopic spectral density of the nonhermitian Wilson Dirac operator with dynamical quarks is discussed as well. We conclude with some remarks on discretization effects for the overlap Dirac operator.

Chiral behavior of pion properties from lattice QCD
Alfonso Sastre
Fri, 14:00, Seminar Room D (RW5) – Parallels 9D

I will present preliminary results of a study of the chiral behavior of the pion mass and decay constant, based on 2+1 flavor lattice QCD simulations. Performed at four values of the lattice spacing and all the way down to the physical value of the pion mass and even below, these calculations allow a detailed comparison with the predictions of SU(2) chiral perturbation theory and a determination of some of its low energy constants.

Overlap/Domain-wall reweighting
Hidenori Fukaya, Sinya Aoki, Guido Cossu, Shoji Hashimoto, Takashi Kaneko, Junichi Noaki
Fri, 14:20, Seminar Room D (RW5) – Parallels 9D

We investigate the eigenvalues of nearly chiral lattice Dirac operators constructed with five-dimensional implementaions. Allowing small violation of the Ginsparg-Wilson relation, the HMC simulation is made much faster while the eigenvalues are not significantly affected. We discuss the possibility of reweighting the gauge configurations generated with domain-wall fermions by those of exactly chiral lattice fermions.

Computation of the chiral condensate using $N_f = 2$ and $N_f = 2{+}1{+}1$ dynamical flavors of maximally twisted mass fermions
Elena Garcia Ramos, Karl Jansen, Krzysztof Cichy, Andrea Shindler
Fri, 14:40, Seminar Room D (RW5) – Parallels 9D

We apply the spectral projector method, recently introduced by Lüscher and Giusti, to compute the chiral condensate using $N_f = 2$ and $N_f = 2 + 1 + 1$ dynamical flavours of maximally twisted mass fermions. We present our results for several quark masses at three different lattice spacings which allows us to perform the chiral and continuum extrapolations. In addition we report our analysis on finite volume effects. We also study the effect of the dynamical strange and charm quarks by comparing our results for $N_f = 2$ and $N_f = 2 + 1 + 1$ dynamical flavours.

Topological susceptibility from twisted mass fermions using spectral projectors
Krzysztof Cichy, Elena Garcia Ramos, Karl Jansen
Fri, 15:00, Seminar Room D (RW5) – Parallels 9D

We present the results of our computation of the topological susceptibility with $N_f = 0$, $N_f = 2$ and $N_f = 2 + 1 + 1$ flavours of maximally twisted mass fermions. We perform a detailed study of the quark mass dependence and discretization effects. We confront our data with chiral perturbation theory and attempt an extraction of the chiral condensate from the quark mass dependence of the topological susceptibility. We compare it with the results of our direct computation from the slope of the mode number. We also compute the continuum limit of the quenched topological susceptibility and test the Witten-Veneziano formula that relates it to the masses of the kaon and the eta and eta prime mesons.

Study of Anomalous Mass Generation in $N_f = 1$ QCD
Luchang Jin
Fri, 15:20, Seminar Room D (RW5) – Parallels 9D

The $U(1)$ axial symmetry in QCD is anomalously broken, and in the case of one flavor, a fermion mass is generated by instanton-like gauge field configurations. Conventional continuum analysis shows that this anomalously generated mass term is “soft” and goes away at large momentum due to the low density of small instantons, distinguishing it from a normal mass term. However, it may possible that there are enough lattice-scale instantons / dislocations to generate a “hard” fermion mass, at least for a class of lattice gauge actions, leading to the mass ambiguity suggested by Creutz. We report on a study of this anomalous mass generation idea using Landau-gauge-fixed fermion propagators and examining the momentum dependence of the RI/MOM-defined fermion mass.

On the decoupling of mirror fermions
Joel Giedt, Chen Chen, Erich Poppitz
Fri, 15:40, Seminar Room D (RW5) – Parallels 9D

An approach to the formulation of chiral gauge theories on the lattice is to start with a vector-like theory, but decouple one chirality (the ”mirror” fermions) using strong Yukawa interactions with a chirally coupled ”Higgs” field. While this is an attractive idea, its viability needs to be tested with nonperturbative studies. The model that we study here, the so-called ”3-4-5” model, is anomaly free and the presence of massless states in the mirror sector is not required by anomaly matching arguments, in contrast to the ”1-0” model that was studied previously. We have computed the polarization tensor in this theory and find a directional discontinuity that appears to be nonzero in the limit of an infinite lattice, which is equivalent to the continuum limit at fixed physical volume. We show that a similar behavior occurs for the free massless Ginsparg-Wilson fermion, where the polarization tensor is known to have a directional discontinuity in the continuum limit. We thus find support for the conclusion that in the continuum limit of the 3-4-5 model, there are massless charged modes in the mirror sector so that it does not decouple from the light sector. The value of the discontinuity we obtain allows for two interpretations: either a chiral gauge theory does not emerge and mirror-sector fermions in a chiral anomaly free representation remain massless, or a massless vectorlike mirror fermion appears. We end by discussing some questions for future study.

Residual mass in five-dimensional fermion formulations
Shoji Hashimoto, Sinya Aoki, Guido Cossu, Hidenori Fukaya, Takashi Kaneko, Junichi Noaki, Peter Boyle
Poster Session

Using a general five-dimensional representation of the Ginsparg-Wilson fermion, we study the residual chiral symmetry violation and numerical costs of various fermion formulations including the domain-wall and overlap fermions as special cases.

Spectral Properties of a 2d IR Conformal Theory
Wolfgang Bietenholz, B David Landa-Marban, Ivan Hip
Poster Session

The Schwinger model with two or more flavors is a simple example for an IR conformal gauge theory. We consider numerical data for two light flavors, based on simulations with dynamical overlap fermions. We test properties and predictions that were put forward for IR conformal models in the recent literature. In particular we probe the de-correlation of low lying Dirac eigenvalues, and we discuss the mass anomalous dimension and its IR extrapolation. Here we encounter subtleties, which may urge caution with analogous efforts in other models, such as multi-flavor QCD.

A determination of the Wilson Chiral effective theory constant c_2 using $n_f = 2$ CLS lattices
John Bulava
Poster Session

When performing chiral extrapolations it is helpful to estimate the contributions to chiral curvature due to lattice artifacts. With Wilson-type fermions these effects are parametrized by the parameter c_2, the coefficient in the chiral lagrangian of the symmetry breaking term due to finite lattice spacing. We present results for a determination of this term using $I = 2\ \pi - \pi$ correlation functions on ensembles of $n_f = 2$ clover-improved fermions generated through the CLS effort. For this discretization we demonstrate that c_2 is small and comment on its sign.

Non-zero Temperature and Density

Continuum EoS for QCD with $N_f = 2+1$ flavors
Stefan Krieg
Mon, 14:00, Seminar Room A (RW2) – Parallels 1A

We present and discuss continuum extrapolated results for the $N_f = 2+1$ equation of state. We compare our findings with our previously published results as well as other results in the literature.

Freeze-out parameters from continuum extrapolation
Szabolcs Borsanyi, Zoltan Fodor, Sandor Katz, Prof Claudia Ratti
Mon, 14:20, Seminar Room A (RW2) – Parallels 1A

Based on lattice simulations with stout staggered fermions we calculate the continuum limit for various second and higher order fluctuations of conserved charges, like electric charge, baryon number and strangeness. These can be related to direct experimental observables that have been measured by RHIC experiments. We give a numerical estimate for the freeze-out parameters as a function of beam energy and discuss the flavor specific nature of the calculated fluctuations.

Chiral phase transition of $N_f = 2 + 1$ QCD with the HISQ action
Heng-Tong Ding
Mon, 14:40, Seminar Room A (RW2) – Parallels 1A

We will present studies of universal properties of the chiral phase transition in $N_f = 2+1$ QCD based on the simulations using Highly Improved Staggered fermions on lattices with temporal extent $N_t = 6$. We analyze the quark mass and volume dependence of the chiral condensates and chiral susceptibilities in QCD with two degenerate light quarks and a strange quark. The strange quark mass is chosen to be fixed to its physical value (ms) and five values of light quark masses (ml) that are varied in the interval $1/20 \geq ml/ms \geq 1/80$. Here various quark masses correspond to pseudo Goldstone pion masses ranging from about 160 MeV to about 80 MeV. The O(N) scaling of chiral observables and the influence of universal scaling on physical observables in the region of physical quark mass values are also discussed. *This work is based on the collaboration with A. Bazavov, Y. Maezawa, S. Mukherjee, F. Karsch and P. Petreczky.

Quark number susceptibilities at high temperatures
Peter Petreczky
Mon, 15:00, Seminar Room A (RW2) – Parallels 1A

We present continuum extrapolated results of second order quark number susceptibilities from calculations using the HISQ action and of fourth order quark number susceptibilities from calculations using the p4 action in 2+1 flavor QCD in the high temperature region of 200 MeV $< T <$ 1 GeV. Simulations has been performed at nearly physical quark mass having $m_\pi L > 3$ with temporal extent $N_t = 6, 8, 10, 12$ and 16 using the HISQ action and with temporal extent $N_t = 6, 8$ and 12 using the p4 action. We compare the continuum extrapolated results with resummed perturbative calculations. Implications of our findings on the range of validity of high temperature perturbation theory will be discussed.

Charge Fluctuations as Thermometer for Heavy-Ion Collisions
Mathias Wagner
Mon, 15:20, Seminar Room A (RW2) – Parallels 1A

We present a determination of freeze-out conditions in heavy-ion collisions based on ratios of cumulants of net electric charge fluctuations obtained from lattice QCD. These ratios can reliably be calculated for a wide range of chemical potential values by using a next-to-leading order Taylor series expansion around the limit of vanishing baryon, electric charge and strangeness chemical potentials. We first determine the strangeness and electric charge chemical potentials that characterize the conditions in heavy ion collisions at RHIC and LHC. We then show that a comparison of lattice QCD results for ratios of up to third order cumulants of electric charge fluctuations with experimental results allows us to extract the freeze-out baryon chemical potential and the freeze-out temperature. We apply our method [1] to preliminary data of the STAR and PHENIX collaborations. [1] A.Bazavov et al., Phys.Rev.Lett.109, 192302 (2012).

The QCD Phase Transition with Domain Wall Fermions and Physical Pion Masses
Chris Schroeder
Mon, 15:40, Seminar Room A (RW2) – Parallels 1A

The HotQCD collaboration has extended its study of the finite temperature transition in 2+1 flavor QCD using domain wall fermions (DWF) to the physical point. With chiral fermions and three degenerate, physical-mass pions, these calculations are arguably the most realistic of their kind to date - enabled by the LLNL/IBM 20 Petaflops Sequoia Blue Gene/Q, highly optimized BAGEL/CPS software, and algorithmic advances, in particular, the dislocation suppressing determinant ratio (DSDR). All results are for a fixed temporal lattice size, $N_\tau = 8$, yet discretization effects, at least for the spectrum at zero temperature, are expected to be at the 5

Momentum broadening of partons on the light cone from the lattice
Marco Panero, Kari Rummukainen, Andreas Schäfer
Mon, 16:30, Seminar Room A (RW2) – Parallels 2A

The jet-quenching parameter describes the momentum broadening of a high-energy parton moving through the quark-gluon plasma. Following an approach originally proposed by Caron-Huot, we discuss how one can extract information on the collision kernel associated with the parton momentum broadening, from the analysis of certain gauge-invariant operators in dimensionally reduced effective theories, and present numerical results from a lattice study.

The sign problem and Abelian lattice duality
Michael Ogilvie, Peter Meisinger
Mon, 16:30, Seminar Room B (RW3) – Parallels 2B

For a large class of Abelian lattice models with sign problems, including the case of non-zero chemical potential, duality maps models with complex actions into dual models with real actions. For extended regions of parameter space, calculable for each model, duality resolves the sign problem for both analytic methods and computer simulations. Explicit duality relations are given for models for spin and gauge models based on Z(N) and U(1) symmetry groups. The dual forms are generalizations of the Z(N) chiral clock model and the lattice Frenkel-Kontorova model, respectively. From these equivalences, rich sets of spatially-modulated phases are found in the strong-coupling region of the original models.

Towards understanding thermal jet quenching via lattice simulations

Alexander Rothkopf, Mikko Laine

Mon, 16:50, Seminar Room A (RW2) – Parallels 2A

Motivated by its connection to the collisional broadening of jets in heavy ion collisions, we study the real-time evolution of a light-cone Wilson loop in classical lattice gauge theory. The associated transport coefficient, traditionally denoted by $\hat{q}$, is related to a collision kernel $C(\mathbf{x}_\perp)$ which in real time can be extracted from the damping rate of the light-cone Wilson loop. Numerical results for $C(\mathbf{x}_\perp)$ are contrasted with perturbative estimates. We also observe that tilting the Wilson loop beyond the light cone does not change its qualitative behaviour, which strengthens arguments in the literature on the applicability of dimensional reduction for a refined determination of $C(\mathbf{x}_\perp)$.

Dual Methods for Lattice Field Theories at Finite Density

Thomas Kloiber, Christof Gattringer

Mon, 16:50, Seminar Room B (RW3) – Parallels 2B

When studying (lattice) field theories at finite densities, the notorious complex action or sign problem arises, i.e., the action becomes complex for non-vanishing chemical potential. Therefore the Boltzmann factor also becomes complex, which spoils a probabilistic interpretation. To get rid of complex contributions to the partition function we reformulate the theory in terms of new degrees of freedom – so-called dual variables. In this representation the partition function consists of real, non-negative contributions only, such that a probabilistic interpretation is feasible. The fundamental degrees of freedom are then integer-valued and constrained. Here we treat a complex (charged) ϕ^4 theory, i.e., the relativistic Bose gas. We show how the dual representation is derived and discuss its numerical simulation which generates only admissible configurations. This is achieved with a generalized version of the Prokof'ev-Svistunov worm algorithm. Physical phenomena like the Silver Blaze problem and Bose condensation can then be studied efficiently. In addition, we present a method to extract n-point functions from the dual ensemble. Results for the field correlators and finite chemical potential spectroscopy calculations are shown.

Temperature dependence of electrical conductivity and dilepton rates from hot quenched lattice QCD
Olaf Kaczmarek
Mon, 17:10, Seminar Room A (RW2) – Parallels 2A

We present new results on the continuum extrapolation of the vector current correlation function in the deconfined phase for three temperatures close to the critical temperature utilizing quenched clover improved Wilson fermions and light quark masses. A systematic analysis on multiple lattice spacing allows to perform the continuum limit of the correlation function and to extract spectral properties in the continuum limit. These results provide constrains for the electrical conductivity and the thermal dilepton rates in the quark gluon plasma for the given temperature range. In addition preliminary results on the continuum extrapolation at finite momenta related to thermal photon rates will be presented.

A property of fermions at finite density by a reduction formula of fermion determinant
Keitaro Nagata, Shoji Hashimoto, Atsushi Nakamura
Mon, 17:10, Seminar Room B (RW3) – Parallels 2B

A reduction formula of the fermion determinant, which is derived by calculating temporal part of the fermion determinant analytically, provides a reduced matrix which describes the propagation of quarks from initial to final time. We derive the Gauss's law for a free energy and eigenvalues of the reduction formula. This provides a correspondence between the reduction formula and two dimensional electrostatic problem. We discuss a property of fermions using this correspondence for finite density QCD.

Transport Coefficients of the QGP
Alessandro Amato, Gert Aarts, Chris Allton, Pietro Giudice, Simon Hands, Jon-Ivar Skullerud
Mon, 17:30, Seminar Room A (RW2) – Parallels 2A

A lattice calculation is presented for the electrical conductivity of the QCD plasma at finite temperature, using a tadpole improved clover action with 2+1 dynamical flavours and conserved currents. The behaviour of this transport coefficient is shown over a wide range of temperatures, across the deconfining transition. The spectral functions relevant for the analysis are extracted using the MEM algorithm, with a detailed investigation of its systematics.

QCD at imaginary chemical potential with Wilson fermions
Andrei Alexandru, Anyi Li
Mon, 17:30, Seminar Room B (RW3) – Parallels 2B

The phase diagram for QCD at non-zero baryon density is difficult to explore using lattice QCD techniques due to the sign problem. One possible avenue to constrain the features in this diagram is through simulations at imaginary chemical potential where numerical simulations are possible. Most numerical investigations in this region use staggered fermions, which are problematic for systems where the number of flavors is not a multiple of four. In this study, we use Wilson fermions to investigate the phase diagram for QCD with three degenerate flavors of quarks. We use a determinant compression method to perform a multi-histogram reweighting in both temperature and imaginary chemical potential, which allows us to smoothly map out this region. We identify the endpoint of the Roberge-Weise transition line and determine its relation to the pseudo-critical curve that intersects the zero-density line. We compare these results with results from another study at real chemical potential.

Lattice computation of the transport coefficient kappa in pure Yang-Mills theory
Christian Schäfer, Owe Philipsen
Mon, 17:50, Seminar Room A (RW2) – Parallels 2A

From heavy-ion collision experiments we know that the quark-gluon plasma behaves almost like an ideal fluid and can be described by hydrodynamics. The dynamic properties of the quark-gluon plasma are determined by transport coefficients. The second order transport coefficient kappa is related to a momentum expansion of the euclidean energy-momentum tensor correlator at vanishing Matsubara frequency. The computation of the Fourier-transformed correlator in lattice gauge theory allows the determination of kappa from first principles. We present the results obtained by pure Yang-Mills lattice simulations in comparison to a computation in quasi-free lattice perturbation theory as well as the temperature dependence of the transport coefficient kappa.

The nature of the Roberge-Weiss transition in $N_f = 2$ QCD with Wilson fermions

Christopher Pinke, Owe Philipsen

Mon, 17:50, Seminar Room B (RW3) – Parallels 2B

QCD at imaginary chemical potential can be simulated without a sign problem and possesses a rich phase structure. In particular, the Roberge-Weiss transition between neighbouring $Z(N_c)$ sectors is connected to the analytic continuation of the chiral and deconfinement transitions at small and large quark masses, respectively, thus constraining the phase diagram at real chemical potential. We investigate the nature of this connection as a function of the quark mass using Wilson fermions and finite size scaling on $N_t = 4$ lattices.

Non-Equilibrium Fermion Production on the Lattice

Daniil Gelfand, Jürgen Berges, Florian Hebenstreit

Mon, 18:10, Seminar Room A (RW2) – Parallels 2A

We present a modern approach to far from equilibrium fermion production using real-time simulations. This method is applied to study quark production from bosonic instabilities in QCD and effective models as well as pair production in abelian gauge theories. We discuss the role of quantum effects in presence of non-perturbatively high bosonic fluctuations and compare to approximative descriptions based on homogeneous background fields. Both strongly and weakly coupled scenarios are considered and the emergence of power-law and Fermi-Dirac distributions of quark occupation numbers is observed. The latter result is being used to define a non-equilibrium quasi-temperature for quarks. In 1+1 dimensional QED we are able to investigate the build-up of a linear rising potential between produced fermion bunches and the striking phenomenon of dynamical string breaking, which strongly resembles the corresponding effect in QCD.

Singularities around the QCD critical point in the complex chemical potential plane

Hiroshi Yoneyama, Shinji Ejiri, Yasuhiko Shinno

Mon, 18:10, Seminar Room B (RW3) – Parallels 2B

The thermodynamic singularities appearing in the complex chemical potential μ plane provide us with useful information on the phase structure and also control the validity of the simulation method in the lattice calculations. In order to investigate the phase structure in the vicinity of the critical end point (CEP) in finite density QCD, we resort to an effective theory based on a mean filed approach, and discuss what the singularities are like in the complex μ plane. By focusing on the real part of the free energy described by the complex order parameter in the complex μ plane, we explicitly investigate the structure of the singularities and of the Stokes lines associated them. This provides us with useful information concerning the distributions of the Lee-Yang zeros in finite volumes. The behavior of the chiral and quark number susceptibilities around the singular point is also discussed.

Towards lattice studies of anomalous transport

Pavel Buividovich

Mon, 18:30, Seminar Room A (RW2) – Parallels 2A

The methods of studying anomalous transport phenomena (such as the chiral magnetic or the chiral vortical effects) in lattice gauge theories are discussed. Since anomalous transport is a ground-state property, it is ideally suited for lattice studies in Euclidean space - e.g. there is no need to perform analytic continuation in order to find the corresponding spectral functions. I discuss definitions of anomalous transport coefficients based on static current-current correlators and on the current expectation values in the presence of external magnetic field and clarify their relation to axial anomaly. It is argued that transport coefficients obtained from simulations with constant background magnetic field are incompatible with those obtained from static current-current correlators.

Lattice QCD at finite isospin chemical potential
Chiho Nonaka, Masaki Kondo
Mon, 18:30, Seminar Room B (RW3) – Parallels 2B

Many attempts have been made to solve the sign problem at finite density lattice QCD. Some of them succeed in applying to high temperature and low density region of the QCD phase diagram and giving us insight of the QCD phase transition. However they can not be applied to the low temperature and high density region where theories with positive fermion determinants such as imaginary chemical potential, two-color QCD and isospin chemical potential are useful. Here we investigate detailed meson properties at finite isospin chemical potential. We include the source term which breaks the explicit isospin symmetry into the Wilson fermion to keep the positive fermion determinant and carry out the hybrid monte carlo simulation. In particular, we will discuss the possibility of pion condensation and rho meson condensation at finite isospin chemical potential.

Meson screening masses at finite temperature with Highly Improved Staggered Quarks
Yu Maezawa
Tue, 14:00, Seminar Room A (RW2) – Parallels 3A

We study meson screening masses at finite temperature in 2+1 flavor QCD using the Highly Improved Staggered Quarks (HISQ) action. The screening masses are obtained from spatial meson propagators and enable us to probe the sensitivity of hadronic correlation functions to the quark structure in thermal matter. We calculate the meson screening masses on lattices with aspect ratio $N_s/N_t = 4$ in a larger temperature interval of 140-250 MeV for $N_t = 12$ and 250-740 MeV for $N_t = 4 - 10$. We focus on the strange and charmed flavor sectors and find that significant modifications of thermal masses in the strange quark sector appear even below the critical temperature (T_c), whereas for charmonium states modifications become significant only for $T > 1.2T_c$. We also present several other properties of meson states at finite temperature, e.g. modifications of amplitudes and the onset of spin and parity degeneracy at high temperature.

The thermodynamic and continuum limit of meson screening masses

Marcel Müller, Olaf Kaczmarek, Edwin Laermann

Tue, 14:20, Seminar Room A (RW2) – Parallels 3A

We present results on the thermodynamic and continuum limit of meson screening masses in the deconfined phase, using standard staggered and non-perturbatively clover-improved Wilson fermions in the quenched approximation with light quark masses. For two temperatures, $1.5T_c$ and $3.0T_c$, it is found that on finite lattices screening masses differ between the actions. We study if both actions reproduce the same masses in the continuum by employing different methods of extrapolation to the thermodynamic and continuum limit.

2+1 flavour thermal studies on an anisotropic lattice

Chris Allton, Gert Aarts, Alessandro Amato, Pietro Giudice, Simon Hands, Sinead Ryan, Jon-Ivar Skullerud

Tue, 14:40, Seminar Room A (RW2) – Parallels 3A

The FASTSUM collaboration has initiated a detailed study of thermal QCD using 2+1 flavours of Wilson quarks on an anisotropic lattice. Spatial volumes of 24^3 and 32^3 are used at fixed cut-off with temperatures ranging from 120 to 360 MeV (corresponding to temporal lattice extents of 48 to 16 lattice units). Results of the chiral susceptibility, deconfinement temperature, and restoration of chiral symmetry will be presented.

The strange degrees of freedom in QCD at high temperature
Christian Schmidt
Tue, 15:00, Seminar Room A (RW2) – Parallels 3A

We use appropriate combinations of conserved charge fluctuations up to the fourth order to probe the strangeness carrying degrees of freedom in QCD at high temperature. In particular, we use diagonal fluctuations of net strangeness as well as their correlations with net baryon number and net electric charge, which we have obtained from lattice QCD calculations using 2+1 flavor of highly improved staggered quarks (HSIQ) on $N_t = 6$ and 8 lattices. We show that up to the chiral crossover temperature (T_c) strange mesons and baryons, can be well described by an uncorrelated gas of hadrons. On the other hand, the strangeness carrying degrees of freedom inside the quark gluon plasma can be described by a weakly interacting gas of quarks only for temperatures larger than $2T_c$. In the intermediate temperature window these observables show considerably richer structures, indicative of the strongly interacting nature of the quark gluon plasma.

Thermodynamics with $N_f = 2 + 1 + 1$ twisted mass quarks
Florian Burger, Ernst-Michael Ilgenfritz, Maria Paola Lombardo, Michael Muller-Preussker
Tue, 15:20, Seminar Room A (RW2) – Parallels 3A

We present first results of QCD thermodynamics with dynamical first and second quark family obtained within the fixed-scale approach. We are investigating several small lattice spacings in order to check for and quantify discretization effects.

Update on the 2+1+1 flavor QCD equation of state with HISQ
Alexei Bazavov, Claude Bernard, Carleton DeTar, Justin Foley, Steven Gottlieb, Urs Heller, James Hetrick, Laiho Jack, Doctor Ludmila Levkova, James Osborn, Robert Sugar, Doug Toussaint, Ruth van de Water, Ran Zhou
Tue, 15:40, Seminar Room A (RW2) – Parallels 3A

We present recent results on the QCD equation of state with 2+1+1 flavors of highly improved staggered quarks (HISQ). We focus on three sets of ensembles with temporal extent $N_t = 6, 8$ and 10, that reach up to temperatures of 967, 725 and 580 MeV, respectively. The strange and charm quark masses are tuned to the physical values and the light quarks mass is set to one fifth of the strange. (This corresponds to the Goldstone pion of about 300 MeV.)

Scale hierarchy in high-temperature QCD

Philippe de Forcrand, Oscar Akerlund

Tue, 16:20, Seminar Room A (RW2) – Parallels 4A

Because of asymptotic freedom, QCD becomes weakly interacting at high temperature: this is the reason for the transition to a deconfined phase in Yang-Mills theory at temperature T_c. At high temperature $T \gg T_c$, the smallness of the coupling g induces a hierachy betwen the "hard", "soft" and "ultrasoft" energy scales T, gT and g^2T. This hierarchy allows for a very successful effective treatment where the "hard" and the "soft" modes are successively integrated out. However, it is not clear how high a temperature is necessary to achieve such a scale hierarchy. By numerical simulations, we show that the required temperatures are extremely high. Thus, the quantitative success of the effective theory down to temperatures of a few T_c appears surprising a posteriori.

Many-flavor Schwinger model at finite chemical potential

Robert Lohmayer, Rajamani Narayanan

Tue, 16:40, Seminar Room A (RW2) – Parallels 4A

We study thermodynamic properties of the massless Schwinger model on a torus at finite chemical potential. Generalizing the two-flavor case, we derive analytic expressions for an arbitrary number of fermion flavors and discuss physical results for three and four flavors in detail.

Nature of finite temperature and density phase transitions in many-flavor QCD

Shinji Ejiri, Norikazu Yamada

Tue, 17:00, Seminar Room A (RW2) – Parallels 4A

To discuss the feasibility of the electroweak baryogenesis in realistic technicolor scenario, we investigate the phase structure of $(2 + N_f)$-flavor QCD, where two light flavors and N_f massive flavors exist. Because an appearance of a first order phase transition at finite temperature is a necessary condition for the baryogenesis, it is important to study the nature of finite temperature phase transition. Applying the reweighting method, the probability distribution function of the plaquette is calculated in the many-flavor QCD. Through the shape of the distribution function, we determine the critical mass of heavy flavors terminating the first order region, and find it to become larger with N_f. We moreover study the critical line at finite density and the first order region is found to become wider as increasing the chemical potential. This may be a good test for the determination of boundary of the first order region in (2+1)-flavor QCD at finite density.

Surface worm algorithm for Abelian Gauge-Higgs systems at finite density

Ydalia Delgado, Christof Gattringer, Alexander Schmidt

Tue, 17:20, Seminar Room A (RW2) – Parallels 4A

We present the surface worm algorithm (SWA), which is a generalization of the Prokof'ev Svistunov worm algorithm concept to simulate abelian Gauge-Higgs models on a lattice which can be mapped to systems of surfaces and loops (dual representation). First we assess the performance of the SWA using a U(1) Gauge-Higgs model and compare it with a local update in the dual representation. Then we also perform simulations of scalar electrodynamics with two flavors at finite density, where the sign problem is overcome in the dual representation.

Solving the sign problem of scalar, two-flavored electrodynamics for finite chemical potential and exploring its full phase-diagram.
Alexander Schmidt, Ydalia Delgado, Christof Gattringer
Tue, 17:40, Seminar Room A (RW2) – Parallels 4A

On the lattice we explore two-flavored, scalar electrodynamics, which has a sign-problem for finite chemical potential. Rewriting the action in terms of dual variables we can solve this sign problem exactly. The dual variables are links and plaquettes, subject to non-trivial constraints, which have to be respected by the simulation-algorithm. We here use a local Monte-Carlo-algorithm to perform simulations in the dual representation and study the full phase-diagram of the model.

Simulating full QCD at nonzero density using The Complex Langevin Equation
Denes Sexty
Wed, 08:30, Seminar Room A (RW2) – Parallels 5A

We employ a new method, "gauge cooling", to stabilize complex Langevin simulations of QCD. First the heavy quark approximation is investigated, where results are checked against results obtained with reweigthing; then the method is extended to full QCD with light quarks. The method allows us to go to previously unaccessible high densities.

Magnetic-field induced (inverse) catalysis for gluons through an improved interaction measure
Falk Bruckmann, Gunnar S. Bali, Gergely Endrodi, Schafer Andreas, Florian Gruber
Wed, 08:30, Seminar Room B (RW3) – Parallels 5B

We analyze the influence of external magnetic fields on the gluonic action and the quark condensate at zero temperature – catalysis – and around the transition – inverse catalysis – from $N_f = 1 + 1 + 1$ staggered quarks of physical masses. We also show how both quantities can be used to improve the scaling properties of the interaction measure (trace anomaly).

Localised distributions in complex Langevin dynamics
Pietro Giudice, Gert Aarts, Erhard Seiler
Wed, 08:50, Seminar Room A (RW2) – Parallels 5A

Complex Langevin dynamics can solve the sign problem appearing in numerical simulations of theories with a complex action. In order to justify the procedure, it is important to understand the properties of the real and positive distribution, which is effectively sampled during the stochastic process. In the context of a simple model, we study this distribution by solving the Fokker-Planck equation as well as by brute force and relate the results to the recently derived criteria for correctness. We demonstrate analytically that it is possible that the distribution has support in a strip in the complexified configuration space only, in which case correct results are expected.

Inverse magnetic catalysis in QCD
Tamas G. Kovacs, Falk Bruckmann, Gergely Endrodi
Wed, 08:50, Seminar Room B (RW3) – Parallels 5B

We propose a physical mechanism for inverse magnetic catalysis, the suppression of the chiral condensate by an external magnetic field in QCD around the critical temperature. We show that this effect, seen in lattice simulations, is a result of how the sea quarks react to the magnetic field. We find that the suppression of the condensate happens because the quark determinant can suppress low quark modes by ordering the Polyakov loop. This mechanism is particularly efficient around T_c where the Polyakov loop effective potential is flat and the determinant can have a significant ordering effect. Our picture suggests that for the description of QCD in large magnetic fields it is crucial to properly capture the interaction between the Polyakov loop and the sea quarks, both in effective low-energy models and on the lattice.

Towards Continuum Limit for the QCD Critical Point
Rajiv V. Gavai, Saumen Datta, Sourendu Gupta
Wed, 09:10, Seminar Room A (RW2) – Parallels 5A

Results from our simulations of QCD with two light dynamical staggered flavours of mass $m/T_c = 0.1$ are presented. Employing our earlier proposed Taylor series method for the baryonic susceptibility, we estimate the radius of convergence by using terms up to the eighth order susceptibility, χ_8. Comparing with earlier results on coarser lattices, we find a very good agreement between the $N_t = 8$ and 6 lattices for its location in the $(\mu_B/T, T/T_c)$ plane, suggesting any cut-off effects to be encouragingly small.

Magnetization and pressures at nonzero magnetic fields in QCD
Gergely Endrodi, Gunnar Bali, Falk Bruckmann, Florian Gruber, Andreas Schaefer
Wed, 09:10, Seminar Room B (RW3) – Parallels 5B

We study the influence of strong magnetic fields on gluonic and fermionic observables in QCD. The magnetic field is found to induce an anisotropy between certain components of the QCD action. We show that on a finite lattice - where the magnetic flux is quantized - this anisotropy is related to the difference of pressures in the directions parallel and perpendicular to the magnetic field. From the pressure anisotropy, the QCD magnetization is estimated, indicating that QCD is paramagnetic.

Controlling errors in simulations for QCD at finite chemical potential
Sourendu Gupta, Saumen Datta, Rajiv V. Gavai
Wed, 09:30, Seminar Room A (RW2) – Parallels 5A

The control of errors in quantities determined at finite chemical potential through the Taylor series expansion requires some new techniques. We discuss these techniques and the scaling of errors. We also discuss how critical slowing down manifests itself when the critical point is only accessible through an extrapolation.

The quark-gluon plasma in an external magnetic field
Carleton DeTar, Doctor Ludmila Levkova
Wed, 09:30, Seminar Room B (RW3) – Parallels 5B

We present results of an exploratory study of the effect of a strong magnetic field on the equation of state of high temperature strongly interacting matter. Working with conventional gauge field ensembles at zero magnetic field, we compute terms up to second order in a Taylor series expansion of the pressure as a function of the magnetic field.

Finite size scaling for 3 and 4-flavor QCD with finite chemical potential

Shinji Takeda, Xiao-Yong Jin, Yoshinobu Kuramashi, Yoshifumi Nakamura, Akira Ukawa

Wed, 09:50, Seminar Room A (RW2) – Parallels 5A

We present a finite size scaling study for 3 and 4-flavor QCD with nonzero quark chemical potential by the grand canonical approach. We employ the Wilson-clover fermions and adopt the phase reweighting method where the phase factor is computed exactly. In 4-flavor study, we show the finite size scaling study for the moments of various physical quantities, which demonstrates a typical behavior of the 1st order phase transition as well as the crossover or weak 1st order phase transition. For 3-flavor study, we try to identify the critical end point in the parameter space of the hopping parameter, the gauge coupling and the chemical potential.

The magnetic susceptibility in QCD

Claudio Bonati, Massimo D'Elia, Marco Mariti, Francesco Negro, Francesco Sanfilippo

Wed, 09:50, Seminar Room B (RW3) – Parallels 5B

Recently much work has been devoted to the study of QCD coupled to a background magnetic field. Quarks and gluons act as a magnetic medium and a natural question arises: is this medium paramagnetic or diamagnetic? Despite the simplicity of this question, it is non trivial to get an answer by means of LQCD simulations. We will review the technical difficulties related to this problem and present the results of our study.

Results from combining ensembles at several values of chemical potential

Xiao-Yong Jin, Yoshinobu Kuramashi, Yoshifumi Nakamura, Shinji Takeda, Akira Ukawa

Wed, 10:10, Seminar Room A (RW2) – Parallels 5A

We have been studying QCD with finite temperature and density for 3 and 4 degenerate quark flavors using the Wilson-clover action with a phase-quenched fermion determinant. Typically, with a fixed quark mass and a lattice coupling, we have a few ensembles at distinct values of chemical potentials scattered around the transition/cross-over region. Reweighting from ensembles simulated at multiple parameter values enables us to achieve higher statistics and a better sampling of the configuration space. We are able to obtain the information of partition functions at various parameter values, as well as complex-valued partition functions in the complex parameter space. In this talk, we discuss our careful approach to multi-ensemble reweighting, and present results mainly on zeros of partition functions in the complex parameter space.

Electric charge catalysis by magnetic fields and a nontrivial holonomy

Tin Sulejmanpasic, Falk Bruckmann, Pavel Buividovich

Wed, 10:10, Seminar Room B (RW3) – Parallels 5B

We describe a generic mechanism by which a system of Dirac fermions in thermal equilibrium acquires electric charge in an external magnetic field. To this end the fermions should have an additional quantum number, isospin or color, and should be subject to a second magnetic field, which distinguishes the isospin/color, as well as to a corresponding isospin chemical potential. The role of the latter can be also played by a nontrivial holonomy (Polyakov loop) along the Euclidean time direction. The charge is accumulated since the degeneracies of occupied lowest Landau levels for particles of positive isospin and anti-particles of negative isospin are different. We discuss two physical systems, where this phenomenon can be realized. One is monolayer graphene, where the isospin is associated with two valleys in the Brillouin zone and the strain-induced pseudo-magnetic field acts differently on charge carriers in different valleys. Another is hot QCD, for which the relevant non-Abelian field configurations with both nonzero chromo-magnetic field and a nontrivial Polyakov loop can be realized as calorons - topological solutions of Yang-Mills equations at finite temperature. The induced electric charge on the caloron field configuration is studied numerically. We argue that due to the fluctuations of holonomy external magnetic field should tend to suppress charge fluctuations in the quark-gluon plasma and estimate the importance of this effect for off-central heavy-ion collisions.

Effective Polyakov line actions via the relative weights method

Jeff Greensite, Kurt Langfeld

Wed, 11:00, Seminar Room A (RW2) – Parallels 6A

We apply a novel method to determine the effective Polyakov line action corresponding to an underlying lattice gauge theory. The effective theory is tested by comparing Polyakov line correlators computed in the effective theory and the lattice gauge theory, and these correlators are found to agree quite well. For pure SU(2) gauge theory, the effective action turns out to be bilinear in the Polyakov lines, while matter fields add a center symmetry-breaking linear term.

Quark localization in QCD above T_c
Ferenc Pittler, Matteo Giordano, Tamas G. Kovacs
Wed, 11:00, Seminar Room B (RW3) – Parallels 6B

It was previously found that at high temperature the lowest part of the QCD Dirac spectrum consists of localized modes obeying Poisson statistics. Higher up in the spectrum, modes become delocalized and their statistics can be described by random matrix theory. The transition from localized to delocalized modes is analogous to the Anderson metal-insulator transition. Here we use dynamical QCD simulations with staggered quarks to study this localization phenomenon. We show that the mobility edge, separating localized and delocalized modes, scales properly in the continuum limit and rises steeply with the temperature. Using very high statistics simulations in large volumes we find that the density of localized modes scales precisely with the spatial volume and even at $T = 2.6T_c$ the lowest part of the spectrum extends all the way down to zero with no evidence of a spectral gap.

Effective lattice theory for finite temperature Yang Mills
Georg Bergner, Jens Langelage, Owe Philipsen
Wed, 11:20, Seminar Room A (RW2) – Parallels 6A

Effective Polyakov loop models are a useful tool for an investigation of pure Yang-Mills theory and full QCD. A systematic derivation of the effective action can be done in a strong coupling expansion. Quite accurate predictions for phase transition have been obtained in this approach. Further observables can be measured in the effective model. These provide additional tests for the reliability of the strong coupling approach and the truncation of the effective action. In this talk I will present recent results for these observables. In particular the free energy of the static quark-antiquark pair in the effective theory is compared with the results in full Yang-Mills theory.

Critical behaviour in the QCD Anderson transition
Matteo Giordano, Ferenc Pittler, Tamas G. Kovacs
Wed, 11:20, Seminar Room B (RW3) – Parallels 6B

We study the Anderson-type localisation-delocalisation transition found previously in the QCD Dirac spectrum at high temperature. Using high statistics QCD simulations with $N_f = 2+1$ flavours of staggered quarks, we discuss how the change in the spectral statistics depends on the volume, the temperature and the lattice spacing, and we speculate on the possible universality of the transition from Poisson to Wigner-Dyson in the spectral statistics. Moreover, we show that the transition is a genuine phase transition: at the mobility edge, separating localised and delocalised modes, quantities characterising the spectral statistics become non-analytic in the thermodynamic limit. Using finite size scaling we also determine the critical exponent of the correlation length, and we speculate on possible extensions of the universality of Anderson transitions.

Local Polyakov loop domains and their fractality
Hans-Peter Schadler, Christof Gattringer, Gergely Endrodi
Wed, 11:40, Seminar Room A (RW2) – Parallels 6A

We discuss center cluster properties of the local Polyakov loop in SU(3) lattice gauge theory at finite temperature. These center clusters are defined by the phase of the local Polyakov loops in the vicinity of center elements of the gauge group. We perform the analysis in a fixed scale approach and study various properties of the center clusters, e.g., percolation probability or fractality. Results and physical implications for temperatures below and above the phase transition are discussed.

Thermal field theories and shifted boundary conditions
Leonardo Giusti, Harvey Meyer
Wed, 11:40, Seminar Room B (RW3) – Parallels 6B

The analytic continuation to an imaginary velocity of the canonical partition function of a thermal system expressed in a moving frame has a natural implementation in the Euclidean path-integral formulation in terms of shifted boundary conditions. The Poincare' invariance underlying a relativistic theory implies a dependence of the free-energy on the compact length L0 and the shift xi only through the combination $\beta = L_0(1+\xi^2)^{1/2}$. This in turn implies a set of Ward identities among the correlators of the energy-momentum tensor which have interesting applications in lattice field theory. In particular, they offer identities to renormalize non-perturbatively the energy-momentum tensor and novel ways to compute thermodynamic potentials. At fixed bare parameters they also provide a simple method to vary the temperature in much smaller steps than with the standard procedure.

Deconfinement and theta dependence in SU(N) Yang-Mills theories
Francesco Negro, Claudio Bonati, Francesco Capponi, Massimo D'Elia
Wed, 12:00, Seminar Room A (RW2) – Parallels 6A

We study the dependence of the deconfinement temperature on the theta parameter for SU(N) gauge theories, with N = 2, 3, 4. Results have been obtained for imaginary theta and analytically continued to real theta, in order to determine the curvature of the critical line $T_c(\theta)$. A comparison with reweighting at real theta is performed to check for the validity of analytic continuation. We also discuss some general features of the phase diagram in the T-theta plane and the dependence of physical observables on the topological sector around the transition.

Finite temperature behaviour of glueballs in Lattice Gauge Theories

Roberto Pellegrini, Michele Caselle

Wed, 12:00, Seminar Room B (RW3) – Parallels 6B

We propose a new method to compute glueball masses in finite temperature Lattice Gauge Theories which at low temperature is fully compatible with the known zero temperature results and as the temperature increases leads to a glueball spectrum which vanishes at the deconfinement transition. We show that this definition is consistent with the Isgur-Paton model and with the expected contribution of the glueball spectrum to various thermodynamic quantities at finite temperature. We test our proposal with a set of high precision numerical simulations in the 3d gauge Ising model and find a good agreement with our predictions.

Theta dependence of 4D SU(N) gauge theories at finite temperature

Ettore Vicari, Claudio Bonati, Massimo D'Elia, Haralambos (Haris) Panagopoulos

Wed, 12:20, Seminar Room A (RW2) – Parallels 6A

The dependence of 4D SU(N) gauge theories on the topological theta term is discussed at finite temperature, and in particular in the large-N limit. Theoretical arguments and numerical analyses exploiting the lattice formulation show that it drastically changes across the deconfinement transition. The low-T phase is characterized by a large-N scaling with theta/N as relevant variable, while in the high-T phase the scaling variable is just theta and the free energy is essentially determined by the instanton-gas approximation.

Pursuing QCD Phase Transition with Lattice QCD and Experimental Data
Atsushi Nakamura, Keitaro Nagata
Wed, 12:20, Seminar Room B (RW3) – Parallels 6B

Recent RHIC Beam Energy Scan opens an exciting opportunity for us working in numerical simulations. First, the freeze-out temperature and chemical potential are estimated by several phenomenological analyses. Secondly and very importantly, they provide the net-proton multiplicity at each incident energy. From the data, we can construct the canonical partition functions, Z_n, which are a link between experimental and numerical approaches assuming that the number conserves after the chemical freeze-out. Once we have the Z_n, we can calculate a grand canonical partition function, $Z(\xi) = \sum_n Z_n \xi^n$, where $\xi = \exp(\mu/T)$. On the contrary, we can calculate $Z_n = \int \mathrm{d}\xi \exp(i\theta) Z(\theta)$, where $\theta = i\mu/T$. Namely in lattice QCD, we can calculate Z_n by integrating over the imaginary chemical potential where the fermion action is real. We show the Lee-Yang zero distributions both from experimental and lattice data, and compare them. The Lee-Yang zeros are fugacity ($\exp(\mu/T)$) points in the complex fugacity plane on which the grand partition function vanishes, $Z(\xi) = 0$. We also report a novel method which allows u to get all the Lee-Yang zeros safely and reliably.

Practical approach to the sign problem at finite theta-vacuum angle
Takahiro Sasaki, Hiroaki Kouno, Masanobu Yahiro
Wed, 12:40, Seminar Room A (RW2) – Parallels 6A

We investigate a way of circumventing the sign problem in lattice QCD simulations with a theta-vacuum term, using the Polyakov-loop extended Nambu-Jona-Lasinio model. We consider the reweighting method for the QCD Lagrangian after the $U_A(1)$ transformation. In the Lagrangian, the P-odd mass term as a cause of the sign problem is minimized. In order to find a good reference system in the reweighting method, we estimate the average reweighting factor by using the two-flavor Polyakov-loop extended Nambu-Jona-Lasinio model and eventually find a good reference system.

Continuity of the Deconfinement Transition in (Super) Yang Mills Theory

Thomas Schaefer

Wed, 12:40, Seminar Room B (RW3) – Parallels 6B

We study the phase diagram of SU(2) Yang-Mills theory with one adjoint Weyl fermion on $R^3 \times S^1$ as a function of the fermion mass m and the compactification scale beta. This theory reduces to thermal pure gauge theory as $m \to \infty$ and to circle-compactified (twisted) susy gluodynamics in the limit $m \to 0$. In the $m-L$ plane, there is a line of center symmetry changing phase transitions. In the limit $m \to \infty$, this transition takes place at $\beta_c = 1/T_c$, where T_c is the critical temperature of the deconfinement transition in pure Yang-Mills theory. We show that near $m = 0$, the critical scale β_c can be computed using semi-classical methods and that the transition is of second order. This suggests that the deconfining phase transition in pure Yang-Mills theory is continuously connected to a phase transition that can be studied in weak coupling. The center symmetry changing phase transition arises from the competition of perturbative effects, fractionally charged instantons, and instanton molecules. The calculation can be extended to higher rank gauge groups and non-zero theta angle. (This is work done in collaboration with M. Unsal and E. Poppitz).

The critical endpoint of the finite temperature phase transition for three flavor QCD with clover type fermions

Yoshifumi Nakamura, Xiao-Yong Jin, Yoshinobu Kuramashi, Shinji Takeda, Akira Ukawa

Thu, 14:00, Seminar Room A (RW2) – Parallels 7A

We investigate the critical endpoint of QCD at zero chemical potential. We employ the renormalization-group improved Iwasaki gluon action and both stout link smeared clover and non-smeared clover action with cSW determined non-perturbatively. The critical endpoint is determined by using the intersection points of the Binder cumulants at Lt=4, 6, 8 and extrapolated to the continuum limit.

1st or 2nd; the order of finite temperature phase transition of $N_f = 2$ QCD from effective theory analysis
Yusuke Taniguchi, Sinya Aoki, Hidenori Fukaya
Thu, 14:20, Seminar Room A (RW2) – Parallels 7A

In the preceding study we showed the $U(1)_A$ symmetry is presumably recovered in the $N_f = 2$ QCD at finite temperature $T > T_c$, where we used a fact that the $SU(2)_L \times SU(2)_R$ chiral symmetry is restored as an input and argued that every order parameter of the $U(1)_A$ symmetry made of (pseudo) scalar density vanishes if the thermodynamical limit is taken correctly. In this talk we use the low energy effective theory of the $N_f = 2$ QCD and adopt the fact that order parameters of the $U(1)_A$ symmetry vanish as an input. We first argue that the effective theory recovers at least $SU(2)_L \times SU(2)_R \times Z_8$ symmetry at $T > T_c$, where Z_8 is a subgroup of $U(1)_A$, in order to eliminate the $U(1)_A$ order parameters. Then we perform the renormalization group analysis of the IR fixed point at one loop, for which we do not find any stable one. Our conclusion is that the order of the finite temperature phase transition seems to be 1st.

Effective lattice theory for finite density QCD: derivation
Jens Langelage, Mathias Neuman, Owe Philipsen
Thu, 14:40, Seminar Room A (RW2) – Parallels 7A

We discuss the derivation of the fermionic part of the dimensionally reduced effective action at small temperatures. The resulting expression is computed through three orders in a hopping parameter expansion and satisfies the Pauli principle. Afterwards we resum an infinite number of terms in order to improve convergence. Finally we remark on the inclusion of gauge corrections.

Onset Transition to Cold Nuclear Matter from Lattice QCD with Heavy Quarks
Mathias Neuman, Jens Langelage, Stefano Lottini, Owe Philipsen
Thu, 15:00, Seminar Room A (RW2) – Parallels 7A

In this talk we present the application of the complex Langevin algorithm to a three-dimensional effective lattice theory for heavy quarks. With this approach it is possible to avoid the sign problem and simulate the theory at all values of the baryon chemical potential. To confirm the correctness of the results, we check that the recently developed convergence criteria for Langevin simulations are met and compare with Monte Carlo data. Results for the onset transition to cold nuclear matter are presented.

The Phase Diagram of Strong Coupling QCD including Gauge Corrections

Wolfgang Unger, Philippe de Forcrand, Owe Philipsen, Jens Langelage, Kohtaroh Miura

Thu, 15:20, Seminar Room A (RW2) – Parallels 7A

The strong coupling limit of staggered lattice QCD has been studied since decades, both via Monte Carlo and mean field theory. In this model, the finite density sign problem is mild and the full phase diagram can be studied, even in the chiral limit. It is however desirable to understand the effect of a finite lattice gauge coupling beta on the phase diagram in the mu-T plane in order to see how it might be related to the phase diagram of continuum QCD. Here we discuss how to construct an effective theory for non-zero lattice coupling, valid to O(beta), and present Monte Carlo results incorporating these corrections, in particular for corrections to the chiral susceptibility and the baryon density.

QCD phase diagram at strong coupling including auxiliary field fluctuations

Terukazu Ichihara, Akira Ohnishi, Takashi Z. Nakano

Thu, 15:40, Seminar Room A (RW2) – Parallels 7A

We study the QCD phase diagram in the strong coupling lattice QCD by using an auxiliary field Monte-Carlo (AFMC) method, and search for a way to avoid the sign problem. In many of previous researches, the QCD phase diagram has been studied in the mean field approximation. Including fluctuation is now a theoretical challenge. However, we have the sign problem in both AFMC and the monomer-dimer-polymer (MDP) simulations. The sign problem is characterized by the difference of the free energy density, ϵ_f, in full and quenched MC simulations. We realize ϵ_f in AFMC is about twice as large as that in MDP. This means that our method has more severe weight cancellation than MDP. We reveal that this cancellation is caused by high momentum auxiliary field components, and qualitatively confirm the effects of the high momentum auxiliary fields. This analysis shows a possibility that we could investigate phase transition phenomena on a large lattice by cutting off or by approximately integrating out the high momentum auxiliary fields. In the presentation, we will briefly mention the AFMC method and show the cut-off momentum dependence of the weight cancellation. We will also discuss the possibility of investigating the QCD phase diagram on a larger lattice.

Susceptibilities in $N_f = 2$ QCD

Saumen Datta, Rajiv V. Gavai, Sourendu Gupta

Thu, 16:30, Seminar Room A (RW2) – Parallels 8A

We present results from our study of susceptibilities in QCD with two light flavors of quarks. Using $N_t = 8$ lattices and staggered quark action, and quark masses such that the pion mass is about 220 MeV, we calculate susceptibilities, and use them to calculate the pressure and the baryon number susceptibility at small values of μ_B, the baryon number chemical potential.

QCD thermodynamics with O(a) improved Wilson fermions at $N_f = 2$

Bastian Brandt, Anthony Francis, Harvey Meyer, Owe Philipsen, Hartmut Wittig

Thu, 16:50, Seminar Room A (RW2) – Parallels 8A

We present an update of our study of the phase diagram of two-flavour QCD at zero density with dynamical $O(a)$-improved Wilson quarks. All simulations are done on lattices with a temporal extent of $N_t = 16$ and spatial extent $L = 32, 48$ and 64, ensuring that discretisation effects are small and finite size effects can be controlled. In the approach to the chiral limit we currently have two scans along lines of constant physics at $m_\pi = 290$ and 200 MeV. In addition to Polyakov loop and chiral condensate, we also measure spectroscopic observables, such as screening masses, to investigate the pattern of chiral symmetry restoration. Furthermore, we measure temporal correlation functions to extract information about spectral functions in confined and deconfined phases and to learn about plasma properties close to the critical temperature.

Investigation of the $U_A(1)$ in high temperature QCD on the lattice
Sayantan Sharma, Viktor Dick, Frithjof Karsch, Edwin Laermann, Swagato Mukherjee
Thu, 17:10, Seminar Room A (RW2) – Parallels 8A

In this project we study the effects of the $U_A(1)$ anomaly for 2+1-flavour QCD at high temperature. We apply the overlap operator as a tool to probe the topological properties of gauge field configurations which have been generated within the Highly Improved Staggered Quark (HISQ) discretization scheme on lattices of size $32^3 times 8$ with $m_l/m_s = 1/20$, commonly used for the study of QCD thermodynamics. Although we have at present, only results for one value of the quark masses and thus cannot monitor the change of the eigenvalue distributions with the light quark mass, the distribution of the low-lying eigenvalues of the overlap operator suggests that the $U_A(1)$ is not restored effectively even at 1.5 times the pseudo critical temperature. The corresponding low-lying eigenmodes show localization properties.

QCD thermodynamics with dynamical overlap fermions
Balint Toth, Szabolcs Borsanyi, Ydalia Delgado Mercado, Stephan Durr, Zoltan Fodor, Sandor Katz, Stefan Krieg, Thomas Lippert, Dániel Nógrádi, Kálmán Szabó
Thu, 17:30, Seminar Room A (RW2) – Parallels 8A

We extend our study of QCD thermodynamics using two flavors of dynamical overlap fermions to $N_t = 10$ and $N_t = 12$. We work in a fixed global topology setting with a quark mass corresponding to a pion mass of 350 MeV.

Chiral symmetry and axial U(1) symmetry in finite temperature QCD with domain-wall fermion

Ting-Wai Chiu, Wen-Ping Chen, Yu-Chih Chen, Han-Yi Chou, Tung-Han Hsieh

Thu, 17:50, Seminar Room A (RW2) – Parallels 8A

We study the restoration of the spontaneously broken chiral symmetry and the anomalously broken axial U(1) symmetry in finite temperature QCD at zero chemical potential. We use 2 flavors lattice QCD with optimal domain-wall fermion on the $16^3 \times 6$ lattice, with the extent $N_s = 16$ in the fifth dimension, in the temperature range $T = 150 - 250$ MeV. To examine the restoration of the chiral symmetry and the axial $U(1)$ symmetry, we use diluted Z_2 noises to calculate the chiral condensate, and the chiral susceptibilities in the scalar and pseudoscalar meson channels, for flavor singlet and non-singlet respectively. From the degeneracy of the chiral susceptibilities around T_c, it suggests that the axial $U(1)$ symmetry is restored in the chirally symmetric phase. Moreover, we examine the spectral density $\rho(\lambda)$ of the overlap Dirac operator, which is obtained by computing zero modes plus 400 low-lying modes for each gauge configuration. The existence of a gap in the spectral density around $\lambda = 0$ for $T \simeq T_c$ provides a consistency check of the restoration of axial $U(1)$ symmetry in the chirally symmetric phase.

The chiral phase transition of $N_f = 2$ QCD at imaginary and zero chemical potential

Owe Philipsen, Claudio Bonati, Massimo D'Elia, Philippe de Forcrand, Francesco Sanfilippo

Thu, 18:10, Seminar Room A (RW2) – Parallels 8A

The chiral symmetry of QCD with two massless quark flavours gets restored in a non-analytic chiral phase transition at finite temperature and zero density. Whether this is a first order or a second order transition with O(4) (or O(2)) universality has not yet been determined unambiguously, due to the difficulties of simulating light quarks. We investigate the nature of the chiral transition as a function of quark mass and imaginary chemical potential, using staggered fermions on $N_t = 4$ lattices. At sufficiently large imaginary chemical potential, a clear signal for a first order transition is obtained for small masses, which weakens with decreasing imaginary chemical potential. The second order critical line $m_c(\mu_i)$, which marks the boundary between first order and crossover behaviour, extrapolates to a finite $m_c(0)$ with known critical exponents. This implies a definitely first order transition in the chiral limit on coarse lattices.

Banks-Casher-type relations for complex Dirac spectra
Tilo Wettig, Takuya Kanazawa, Naoki Yamamoto
Fri, 14:00, Seminar Room A (RW2) – Parallels 9A

For theories with a sign problem there is no analog of the Banks-Casher relation. This is true in particular for QCD at nonzero quark chemical potential. However, for QCD-like theories without a sign problem the Banks-Casher relation can be extended to the case of complex Dirac eigenvalues. We derive such extensions for the zero-temperature, high-density limits of two-color QCD, QCD at nonzero isospin chemical potential, and adjoint QCD. In all three cases the density of the complex Dirac eigenvalues at the origin is proportional to the BCS gap.

Sign problem and subsets in one-dimensional QCD
Jacques Bloch, Falk Bruckmann, Tilo Wettig
Fri, 14:20, Seminar Room A (RW2) – Parallels 9A

We present a subset method that solves the sign problem for QCD at nonzero quark chemical potential in 0+1 dimensions. The subsets of gauge configurations are constructed using the center symmetry of the SU(3) group. These subsets completely solve the sign problem for up to five flavors. For a larger number of flavors the sign problem slowly reappears and we propose an extension of the subsets that also solves the sign problem for these cases. The subset method allows for numerical simulations of the model at nonzero chemical potential.

Extended Mean Field Study of Complex ϕ^4-Theory at Finite Density and Temperature

Oscar Akerlund, Philippe de Forcrand

Fri, 14:40, Seminar Room A (RW2) – Parallels 9A

We apply the Extended Mean Field (EMFT) approximation to complex, scalar ϕ^4-theory. We determine the (T, μ) phase diagram and study the critical properties of the transition at zero and finite temperature. We are also able to determine finite volume corrections to the critical chemical potential μ_c. We obtain results which agree very well with recent Monte Carlo studies both at zero and non-zero temperature. Within our approximation we do not suffer from finite volume effects and can thus obtain results at lattice spacings unobtainable by present Monte Carlo simulations. We find that our approximation reproduces many phenomena of the exact model like the "Silver Blaze" behaviour at zero temperature and dimensional reduction at finite temperature. At finite temperature we find a weak first order transition where the expectation value of the field jumps proportionally to the temperature. Due to a jump in the free energy at the transition we conclude that this is caused by a failure of the approximation and should not be ascribed any physical meaning. It seems plausible that this pathology could be fixed by keeping more terms in the effective action.

The Lefschetz thimble and the sign problem

Luigi Scorzato

Fri, 15:00, Seminar Room A (RW2) – Parallels 9A

I introduce the "Lefschetz thimble" and explain how it can be used to perform Monte Carlo simulations of lattice quantum field theories (QFT) with a sign problem. The formulation of a QFT on the Lefschetz thimble does not coincide with the traditional formulation, exactly, but it is a legitimate, alternative regularization, on the basis of universality. In fact, I analyze the symmetries and the perturbative expansion of the new formulation. I also describe the algorithm that we proposed to sample the configurations from the thimble. A great advantage of this approach is its rather general applicability. In particular, I show that it is applicable, in principle, also to QCD at finite density.

Relativistic Bose gas on a Lefschetz thimble
Marco Cristoforetti
Fri, 15:20, Seminar Room A (RW2) – Parallels 9A

We study on the lattice a complex relativistic scalar field with quartic interaction. In this theory, as in QCD, the sign problem prevents the use of Monte Carlo methods for the study of phenomena emerging at finite chemical potential, such as the Silver Blaze problem. Integrating the complex extension of the partition function on Letschetz thimbles we will show that the sign problem can be solved and Silver Blaze phenomenon are well reproduced.

Towards a density of states approach for dense matter systems
Kurt Langfeld, Biagio Lucini, Antonio Rago, Jan Pawlowski, Roberto Pellegrini
Fri, 15:40, Seminar Room A (RW2) – Parallels 9A

The density-of-states method (Phys.Rev.Lett. 109 (2012) 111601) features an exponential error suppression and is not restricted to theories with positive probabilistic weight. It is applied to the SU(2) gauge theory at finite densities of heavy quarks. Key ingredient here is the Polyakov line probability distribution, which is obtained of over 80 orders of magnitude. We briefly address whether the exponential error suppression could be sufficient to simulate theories with a strong sign problem.

Heavy quark potential at finite imaginary chemical potential
Junichi Takahashi, Takahiro Sasaki, Keitaro Nagata, Takuya Saito, Hiroaki Kouno, Masanobu Yahiro, Atsushi Nakamura
Fri, 16:30, Seminar Room A (RW2) – Parallels 10A

We study the heavy quark potential at finite temperature and chemical potential by lattice QCD, using the Polyakov loop correlation function. We use a renormalization group improved gluon action and a clover-improved Wilson quark action of two flavors and perform the simulation on a $16^3 \times 4$ lattice. So far, the heavy quark potential has been studied mainly at zero chemical potential, because the quark determinant is complex at finite chemical potential. We calculate the heavy quark potential in various color channels at imaginary chemical potential where there is no sign problem. Moreover, we calculate Taylor expansion coefficients of the heavy quark potential up to forth order at imaginary chemical potential. Particularly, in the color-singlet and color-octet channels, we change the sign of the second order coefficient of the Taylor expansion in order to obtain the heavy quark potential at real chemical potential from that at imaginary chemical potential. In the color-sextet and color-anti-triplet channels, the heavy quark potential become complex at imaginary chemical potential, because the heavy quark potential is not invariant under the charge conjugation.However, this complex heavy quark potential become real at real chemical potential after the extrapolation from imaginary chemical potential to real chemical potential. We also discuss chemical potential dependence of color screening mass.

G2-QCD: Spectroscopy and the phase diagram at zero temperature and finite density
Björn Wellegehausen, Axel Maas, Andreas Wipf, Lorenz von Smekal
Fri, 16:30, Seminar Room B (RW3) – Parallels 10B

G2-QCD is a QCD-like theory with fermionic baryons and fundamental quarks. Unlike QCD it does not suffer from a fermionic sign problem at finite baryon density and therefore allows to investigate effects of fermionic baryons on the G2-QCD phase diagram with standard Monte-Carlo methods. In the talk our latest results on mass spectroscopy and the phase diagram at zero temperature and finite baryon density are presented.

P wave bottomonium spectral functions in the QGP from lattice NRQCD
Gert Aarts, Chris Allton, Jon-Ivar Skullerud, Sinead Ryan, Donald Sinclair, Seyong Kim, Maria Paola Lombardo
Fri, 16:50, Seminar Room A (RW2) – Parallels 10A

The melting pattern of bottomonium states in the quark-gluon plasma can provide information on the temperatures reached in heavy-ion collisions. Here results in the P wave channel, using NRQCD on a two-flavour background, are presented. We use the Maximum Entropy Method to construct spectral functions and pay attention to the stability under variation of input parameters.

SO(2N) and SU(N) gauge theories
Richard Lau, Michael Teper
Fri, 16:50, Seminar Room B (RW3) – Parallels 10B

We present our initial results of SO(2N) gauge theories, approaching the large-N limit. SO(2N) theories may help us to understand QCD at finite chemical potential since there is an orbifold equivalence between SO(2N) and SU(N) gauge theories at large N and SO(2N) theories do not have the sign problem present in QCD. We consider the mass spectra, string tensions, and deconfinement temperatures in the SO(2N) pure gauge theories in 2+1 dimensions, comparing them to their corresponding SU(N) theories.

Charmonium Potentials at Non-Zero Temperature
Wynne Evans, Chris Allton, Pietro Giudice, Jon-Ivar Skullerud
Fri, 17:10, Seminar Room A (RW2) – Parallels 10A

Inter-quark potentials from lattice QCD aid experimental investigations and improve the theoretical picture surrounding heavy quarkonia suppression. In this work, the charmonium potential is calculated using the HAL QCD method developed for nucleon-nucleon potentials. This requires correlators of extended charmonium operators as input. S-wave charmonium potentials are calculated at temperatures between 145MeV and 290MeV using 2+1 light dynamical quarks on anisotropic lattices. Results show a clear temperature dependence consistent with the expectation that the potential should become de-confining at high temperatures.

Staggered operator with topological SU(2) backgrounds at nonzero chemical potential
Rudolf Rödl, Falk Bruckmann, Tin Sulejmanpasic
Fri, 17:10, Seminar Room B (RW3) – Parallels 10B

We present zero modes of topological SU(2) backgrounds at nonzero chemical potential and temperature through the staggered operator. The latter possesses quartet quasi-zero modes, the profiles of which agree very well with continuum zero mode profiles (known analytically). These modes exhibit stronger peaks at the core and negative regions in their densities.

Lattice NRQCD study of in-medium bottomonium states using $N_f = 2+1, 48^3 \times 12$ HotQCD configurations
Seyong Kim, Peter Petreczky, Alexander Rothkopf
Fri, 17:30, Seminar Room A (RW2) – Parallels 10A

The behavior of bottomonium state correlators at non-zero temperature, $140.4(\beta = 6.664) \geq T \geq 221(\beta = 7.280)$ (MeV), where the transition temperature is 154(9) (MeV), is studied, using lattice NRQCD on $48^3 \times 12$ HotQCD HiSQ configurations with light dynamical $N_f = 2+1$ ($m_l/m_s = 0.05$) staggered quarks. In order to understand finite temperature effects on quarkonium states, zero temperature behavior of bottomonium correlators is compared based on 32^4 ($\beta = 6.664, 6.800$ and 6.950) and $48^3 \times 64$ ($\beta = 7.280$) lattices. We find that temperature effects on S-wave bottomonium states are small but P-wave bottomonium states show a noticeable temperature dependence above the transition temperaure.

Phase transitions in dense 2-colour QCD
Jon-Ivar Skullerud, Tamer Boz, Seamus Cotter, Leonard Fister
Fri, 17:30, Seminar Room B (RW3) – Parallels 10B

We investigate 2-colour QCD with 2 flavours of Wilson fermion at nonzero temperature T and quark chemical potential mu, with a pion mass of 700 MeV ($m_\pi/m_\rho = 0.8$). From temperature scans at fixed mu we find that the critical temperature for the superfluid to normal transition depends only very weakly on mu above the onset chemical potential, while the deconfinement crossover temperature is clearly decreasing with mu. We find indications of a region of superfluid but deconfined matter at high mu and intermediate T. We also present results for the Landau-gauge gluon propagator in the hot and dense medium.

Spectral functions of charmonium from 2 flavour anisotropic lattice data
Aoife Kelly, Jon-Ivar Skullerud, Dhagash Mehta, Bugra Oktay, Chris Allton
Fri, 17:50, Seminar Room A (RW2) – Parallels 10A

The spectral functions of QCD can give us insight into properties of hadrons, and they are useful in probing the QCD vacuum. I will discuss the correlators and spectral functions of charmonium in high temperature 2 flavour QCD. The spectral functions have been obtained using the Maximum Entropy Method from anisotropic lattice data.

Analytic continuation in two color QCD with clover-improved Wilson fermion at finite density
Yuji Sakai, Atsushi Nakamura
Fri, 17:50, Seminar Room B (RW3) – Parallels 10B

We test the method of analytic continuation from imaginary to real chemical potential in two-color QCD, which is free from the sign problem. We employ a clover-improved Wilson fermion action of two-flavors and a renormalization-group improved gauge action. In particular, we consider the analytic continuation of the critical line, the quark number density and meson correlations.

Bottomonium spectrum at finite temperature
Tim Harris, Gert Aarts, Chris Allton, Seyong Kim, Jon-Ivar Skullerud, Maria Paola Lombardo, Sinead Ryan
Fri, 18:10, Seminar Room A (RW2) – Parallels 10A

I will present some updated results from the FASTSUM collaboration on the bottomonium spectrum at finite temperature. In this work we use new ensembles of anisotropic gauge configurations with 2+1 flavours of dynamical Wilson clover quark. The heavy valence quarks are treated using an improved NRQCD action. The behaviour of the S- and P-wave correlators above and below T_c will be discussed. I will also include some preliminary results of the bottomonium spectral functions at finite temperature obtained using the maximum entropy method.

Chiral restoration and deconfinement in two-color QCD with two flavors of staggered quarks

David Scheffler, Christian Schmidt, Dominik Smith, Lorenz von Smekal

Fri, 18:10, Seminar Room B (RW3) – Parallels 10B

In preparation of lattice studies of the two-color QCD phase diagram we study chiral restoration and deconfinement at finite temperature with two flavors of staggered quarks using a RHMC algorithm on GPUs. We first present the chiral condensate, the Polyakov loop and corresponding susceptibilities. Using Ferrenberg-Swendsen reweighting we extract the maxima of the chiral susceptibility. We determine pseudo-critical couplings on various lattices with a chiral extrapolation in order to fix the relation between coupling and temperature. From the Polyakov loop distributions we obtain the constraint Polyakov loop potentials and via a Legendre transformation the effective Polyakov loop potential.

Quarkonium correlation functions at finite temperature in the charm to bottom region

Hiroshi Ono

Fri, 18:30, Seminar Room A (RW2) – Parallels 10A

Quarkonium correlation functions at finite temperature are studied in a region of the quark mass for charmonia to bottomonia in quenched lattice QCD with $O(a)$-improved Wilson quarks. Our simulations are performed on large isotropic lattices at temperatures in the range from about $0.75T_c$ to $1.5T_c$. We discuss temperature dependence as well as quark mass dependence of the quarkonium correlation functions at both vanishing and finite momenta.

Temporal mesonic correlators at NLO for any quark mass

Yannis Burnier, Mikko Laine

Fri, 18:30, Seminar Room A (RW2) – Parallels 10A

Charm quarks play an intriguing role in quark-gluon plasma physics, being neither light nor so heavy that they could be trivially decoupled. We present NLO perturbative results for temporal mesonic correlators in various quantum number channels as a function of the quark mass. The physics associated with these correlators includes charm quark transport and charmonium bound state properties. We discuss the renormalization of the different channels, compare our perturbative results with quenched data from fine lattices, and determine the resolution that needs to be achieved if non-perturbative charm and charmonium properties are to be reliably extracted from numerical measurements.

Determination of Karsch Coefficients for 2-colour QCD
Seamus Cotter, Pietro Giudice, Simon Hands, Jon-Ivar Skullerud
Fri, 18:30, Seminar Room B (RW3) – Parallels 10B

We calculate the Karsch Coefficients with 2 flavours of Wilson fermion in 2-colour QCD. This is done by measuring four observables, namely the lattice spacing using the static quark potential, the mass ratio and fermion anisotropy using the meson dispersion, and the gluon anisotropy using the sideways potential. The resulting numbers can be then be used by means of a 4-dimensional fit to give the Karsch Coefficients. These are then used to renormalise the energy density in the quark and gluon sectors.

Taylor- and fugacity expansion for the effective center model of QCD at finite density
Eva Grünwald, Christof Gattringer, Ydalia Delgado Mercado
Poster Session

QCD suffers from the complex action problem as soon as a chemical potential is introduced and has therefore not been treated successfully yet in Monte Carlo simulations. A promising way to avoid the complex action problem is to introduce new degrees of freedom, where an exact transformation to so called dual variables results in a partition sum which has only real and positive contributions and allows for the application of Monte Carlo techniques. In this manner, for some effective theories of QCD the complex action problem has already been solved. One of those theories is the effective center model for which the two main expansion techniques used in QCD, Taylor and fugacity expansion, are compared to the results of simulations in terms of dual variables in order to assess the quality of the perturbative approaches and to improve these techniques for applications in QCD.

Adaptive gauge cooling for complex Langevin dynamics
Lorenzo Bongiovanni, Gert Aarts, Ion-Olimpiu Stamatescu , Erhard Seiler, Denes Sexty
Poster Session

In the case of non abelian gauge theories with a complex weight, a controlled exploration of the complexified configuration space during a complex Langevin process requires the use of SL(N;C) gauge cooling, in order to minimize the distance from SU(N) . Here we show that adaptive gauge cooling can lead to an efficient implementation of this idea.

Scaling properties of the chiral phase transition in the low density region of two-flavor QCD with improved Wilson fermions

Takashi Umeda, Sinya Aoki, Shinji Ejiri, Tetsuo Hatsuda, Kazuyuki Kanaya, Yu Maezawa, Yoshiyuki Nakagawa, Hiroshi Ono, Hana Saito, Shinsuke Yoshida

Poster Session

We study scaling behavior of a chiral order parameter in the low density region, performing a simulation of two-flavor QCD with improved Wilson quarks. The scaling behavior of the chiral order parameter defined by a Ward-Takahashi identity agrees with the scaling function of the three-dimensional O(4) spin model at zero chemical potential. We extend the scaling study to finite density QCD. Applying the reweighting method and calculating derivatives of the chiral order parameter with respect to the chemical potential, the scaling properties of the chiral phase transition are discussed in the low density region. We moreover calculate the curvature of the phase boundary of the chiral phase transition in the temperature and chemical potential plane assuming the O(4) scaling relation.

Complex Langevin simulation for QCD-like models

Ion-Olimpiu Stamatescu, Gert Aarts, Lorenzo Bongiovanni, Jan Pawlowski, Erhard Seiler, Denes Sexty, Denes Sexty, Erhard Seiler

Poster Session

For theories with complex action, in particular QCD at non-zero density, the complex Langevin equation provides a unique simulation method. Its development and control is followed on some models of increasing complexity, for which some benchmark results are known by explicite calculations or by other methods. The methods shows in particular its capabilities in QCD with heavy quarks and full Yang-Mills action.

A test of fugacity-, Taylor- and improved Taylor-expansion
Max Wilfling, Christof Gattringer
Poster Session

We compare three different expansion methods for observables as a function of the chemical potential using free fermions as a first test case. In addition to the conventional Taylor series, we analyze fugacity expansion, which is a finite Laurent series in the fugacity parameter with expansion coefficients that are canonical determinants for a fixed net quark number. We furthermore suggest an improved Taylor series which captures aspects of both the conventional Taylor series and the fugacity expansion. Convergence and other properties are compared for the three series.

Towards the Continuum Limit in Transport Coefficient Computations
Thomas Neuhaus, Anthony Francis, Olaf Kaczmarek, Mikko Laine, Marcel Müller, Hiroshi Ono
Poster Session

The analytic continuation necessary for the extraction of transport coefficients is well-defined even in principle only when a continuous function of the Euclidean time variable is available. We report progress towards achieving the continuum limit for 2-point correlator measurements in pure SU(3) gauge theory, with specific attention paid to scale setting. As an application the determination of the heavy quark momentum diffusion coefficient from a correlator of colour-electric fields attached to a Polyakov loop is discussed.

Landau gauge gluon and ghost propagators from two-flavour lattice QCD at nonzero temperature
Michael Muller-Preussker, Rafik Aouane, Florian Burger, Ernst-Michael Ilgenfritz, Andre Sternbeck
Poster Session

The temperature dependence of Landau gauge gluon and ghost propagators is studied in lattice QCD with two flavours of maximally twisted mass fermions within the crossover range. We present and analyze data which correspond to pion mass values between 300 and 500 MeV and also compare them with our previous $N_f = 0$ results. For momenta between 0.4 and 3.0 GeV we are able to provide parametrizations of the lattice data which may serve as input for continuum functional methods, for example, for studies on the QCD phase diagram using Dyson-Schwinger equations.

Finite coupling and fluctuation effects on the QCD phase diagram at strong coupling

Akira Ohnishi, Terukazu Ichihara, Takashi Z. Nakano

Poster Session

QCD at finite baryon density is one of the largest theoretical challenges in subatomic physics. While the lattice QCD Monte-Carlo simulations are successful at low densities, it is not yet possible to obtain reliable results for cold dense matter due to the sign problem. Strong coupling lattice QCD is one of the promising methods at finite density. We first integrate out spatial link variables analytically at a given order of the inverse coupling, then the statistical weight cancellation is reduced. Following the pioneering works in the mean field treatment [1], fluctuation effects are recently taken into account [2,3]. The next challenge is to include both finite coupling and fluctuation effects. We develop a framework to include the fluctuation and Polyakov loop effects. We combine the Haar measure method of the Polyakov loop [4] and the auxiliary field Monte-Carlo method of fluctuation [3]. In the presentation, we discuss how we can combine these two, and we will show some numerical results. [1] H. Kluberg-Stern et al.,Nucl. Phys. B190(1981)504; N. Kawamoto and J. Smit, Nucl. Phys. B 192, 100 (1981). [2] F. Karsch and K. H. Mutter, Nucl. Phys. B 313, 541 (1989); P. de Forcrand and M. Fromm, Phys. Rev. Lett. 104, 112005 (2010); W. Unger and P. de Forcrand, J. Phys. G 38, 124190 (2011). [3] A. Ohnishi, T. Ichihara, T. Z. Nakano, PoS LATTICE 2012 (2012), 088. [4] T. Z. Nakano, K. Miura, A. Ohnishi, Phys. Rev. D 83 (2011), 016014.

Systematic Effects at Criticality for the SU(2)-Landau-Gauge Gluon Propagator

Tereza Mendes, Attilio Cucchieri

Poster Session

We analyze data from finite-temperature simulations of the gluon propagator in SU(2) Landau gauge on large lattices. We argue that the singular behavior seen previously in several studies of this quantity around the deconfinement transition is a lattice artifact.

Finite-Temperature Spectral Functions from the Functional Renormalization Group
Ralf-Arno Tripolt, Nils Strodthoff, Lorenz von Smekal, Jochen Wambach
Poster Session

The computation of real-time observables represents a common challenge within lattice calculations and other Euclidean frameworks, where analytical continuation methods are needed to obtain results in Minkowski space-time. We present a method to obtain real-time 2-point functions and spectral functions for finite temperatures within the functional renormalization group approach. Here, the analytical continuation is done on the level of the flow equations in contrast to a continuation of the Euclidean data by, e.g., the maximum-entropy-method. Results are shown for the mesonic spectral functions in the quark-meson model at finite temperatures. Different in-medium processes affecting the mesonic spectral functions as well as effects of chiral symmetry restoration are discussed. An extension of this approach towards finite chemical potential and non-zero external spatial momenta will allow us to study critical regions of the phase diagram as well as transport coefficients.

Measuring the entropy from shifted boundary conditions
Leonardo Giusti, Michele Pepe
Poster Session

We present preliminary results for the equation of state of the SU(3) Yang-Mills theory. In this study we consider the recent proposal of shifting the boundary conditions along the temporal direction to change the temperature of a relativistic quantum system. We perform an accurate investigation of the lattice artifacts in order to extract precise measurements in the continuum limit for a wide range of temperature values, while keeping finite size effects always under control.

A new Bayesian approach to the reconstruction of spectral functions
Alexander Rothkopf, Yannis Burnier
Poster Session

We present a novel approach for the reconstruction of spectra from Euclidean correlator data that makes close contact to modern Bayesian concepts. It is based upon an axiomatically justified dimensionless prior distribution, which in the case of constant prior function $m(\omega)$ only imprints smoothness on the reconstructed spectrum. In addition we are able to analytically integrate out the only relevant overall hyper-parameter α in the prior, removing the necessity for Gaussian approximations found e.g. in the Maximum Entropy Method. Using a quasi-Newton minimizer and high-precision arithmetic, we are then able to find the unique global extremum of $P[\rho|D]$ in the full $N_\omega \gg N_\tau$ dimensional search space. Several spectra are presented, which are reconstructed from realistic mock-data, based on the perturbative Euclidean Wilson Loop as well as the Wilson Line correlator in Coulomb gauge.

Benchmarking the Bayesian reconstruction of the non-perturbative heavy $Q\bar{Q}$ potential
Yannis Burnier, Alexander Rothkopf
Poster Session

The finite temperature complex heavy quark potential can be extracted form a spectral analysis of the lattice QCD Wilson loop. We benchmark this extraction strategy using leading order hard-thermal loop (HTL) calculations. Namely we calculate the Wilson loop and determine the corresponding spectrum. By fitting its lowest lying spectral peak we obtain the real- and imaginary part and confirm that the knowledge of the lowest peak alone is sufficient. We then deploy a novel Bayesian approach for the reconstruction of spectral functions from the HTL Euclidean correlators and observe how well the known spectral function and values for the real and imaginary part are reproduced. Finally we apply the method to quenched lattice QCD data and perform an improved estimate of both real and imaginary part of the non-perturbative heavy $Q\bar{Q}$ potential.

Electric charge susceptibility in 2+1 QCD on an anisotropic lattice
Pietro Giudice, Gert Aarts, Chris Allton, Alessandro Amato, Simon Hands, Jon-Ivar Skullerud
Poster Session

We present our first results of the electic charge susceptibility in QCD using 2+1 dynamical quark flavours of Wilson quarks on anisotropic lattices. Spatial volumes of 24^3 are used at fixed cut-off with temperatures ranging from T_c and $2T_c$.

Hadron Spectroscopy and Interactions

Cutoff effects on lattice nuclear forces
Takumi Doi
Mon, 14:00, Seminar Room G (HS III) – Parallels 1G

In the past years, there have been extensive studies on nuclear interactions in lattice QCD. In each of these studies, however, lattice simulations were performed only at single lattice spacing, and the effect of lattice discretization errors have not been examined. In this talk, we investigate the cutoff effects on nuclear forces on the lattice, where nuclear potentials are extracted from the Nambu-Bethe-Salpeter (NBS) wave functions by the HAL QCD method. Employing Nf=2 clover fermion configurations generated by CP-PACS Collaboration, we perform numerical simulations at three lattice spacings, $1/a = 0.92, 1.27, 1.83$ GeV, with a fixed volume of $L \sim 2.5$ fm and a quark mass corresponding to $m_\pi \sim 1.1$ GeV. We observe non-negligible cutoff effects on the short-range part of nuclear potentials. The results are discussed comparing with the prediction by the OPE (operator-product-expansion) calculation. Cutoff effects on the scattering phase shifts are also presented.

Correlation functions of atomic nuclei in Lattice QCD I
Jana Günther, Balint C Toth, Lukas Varnhorst
Mon, 14:20, Seminar Room G (HS III) – Parallels 1G

To determine the mass of atomic nuclei in lattice QCD one has to calculate the correlation functions of suitable combinations of quark field operators. However the calculation of these correlation functions requires the evalution of a large number of Wick contractions, which scales as the factorial of the number of nucleons in the system. We explore the possibilities to reduce the computational effort for the evaluation of correlation functions of atomic nuclei by exploiting certain symmetries of the systems. We discuss a recursive approach which respects these symmetries for the simplest case of identical quark sources.

Correlation functions of atomic nuclei in Lattice QCD II
Lukas Varnhorst, Jana Günther, Balint C Toth
Mon, 14:40, Seminar Room G (HS III) – Parallels 1G

We discuss generalizations of the recursive algorithm presented in the talk of Jana Günther. These generalizations include baryons from different sources and sinks and the projections to specific spin states. The construction of atomic nuclei as a special case is presented in detail.The computational cost for the recursive construction of correlation functions of atomic nuclei is compared with the cost of other techniques.

Equation of State of Nucleon Matters from Lattice QCD Simulations
Takashi Inoue
Mon, 15:00, Seminar Room G (HS III) – Parallels 1G

We study nucleon matters at zero temperature starting from QCD. By using nucleon-nucleon interaction extracted from lattice QCD simulations, we derive the equation of state of matters in the Brueckner-Hartree-Fock framework. We find that well known features of the symmetric nuclear matter, such as the self-binding and the saturation, are reproduced from QCD at some value of quark mass. We find also that the pure neutron matter become stiff at large density as quark mass decreases. We apply these equations of state to the TOV equation and obtain mass and radius of neutron stars.

Multi-nucleon bound states in $N_f = 2 + 1$ lattice QCD
Akira Ukawa, Takeshi Yamazaki, Ken-ichi Ishikawa, Yoshinobu Kuramashi
Mon, 15:20, Seminar Room G (HS III) – Parallels 1G

We present our results of bound states in multi-nucleon channels where the nuclear mass numbers are from two to four. The simulations are performed in $N_f = 2 + 1$ QCD with Iwasaki and non-perturbative improved Wilson fermion actions at the lattice spacing of a = 0.09 fm with quark mass of $m_\pi = 0.3$ GeV. The strange quark mass is close to the physical one. We will discuss the volume dependence of the energy difference between the ground state and the free nucleons by using the $(4.4\ \mathrm{fm})^3$ and $(5.8\ \mathrm{fm})^3$ lattices to distinguish a bound state from attractive scattering state. Furthermore the quark mass dependence of the energy difference will be discussed using our previous results of $m\_pi = 0.5$ GeV.

Lattice effective field theory for nuclei from A = 4 to A = 28
Timo Laehde, Evgeny Epelbaum, Hermann Krebs, Dean Lee, Ulf Meissner, Gautam Rupak
Mon, 15:40, Seminar Room G (HS III) – Parallels 1G

Lattice effective field theory is a relatively new method which combines the frameworks of effective field theory and lattice Monte Carlo in ab initio nuclear theory. I will present new results obtained within lattice effective field theory for systems ranging from helium-4 to carbon-12, with emphasis on the quark mass dependence of the triple alpha reaction rate, and discuss the implications for an anthropic view of the Universe. I will also present preliminary lattice effective field theory results for systems up to A = 28.

Fine lattice simulations with chirally symmetric fermions
Junichi Noaki, Sinya Aoki, Guido Cossu, Hidenori Fukaya, Shoji Hashimoto, Takashi Kaneko
Mon, 16:30, Seminar Room G (HS III) – Parallels 2G

We carry out numerical simulations of 2+1-flavor QCD with nearly chiral lattice fermions. Lattice spacing is taken at 1/a = 2.4 and 3.6 GeV, while keeping the condition $m_\pi L > 4$. Using the so-called Mobius-type 5D implementation of the Ginsparg-Wilson fermion, the residual mass is always kept lower than 0.5 MeV. In this talk, I report the first physics results including the determination of lattice spacing through the Wilson flow as well as the light hadron mass spectrum.

Preliminary results from maximally twisted mass lattice QCD at the physical point

Bartosz Kostrzewa, Karl Jansen, Roberto Frezzotti, Carsten Urbach, Giancarlo Rossi, David Palao, Petros Dimopoulos, Mariane Mangin-Brinet, Albert Deuzeman, Urs Wenger, Luigi Scorzato, Abdou Abdel-Rehim, Andrea Shindler, Gregorio Herdoiza, Istvan Montvay, Philippe Boucaud

Mon, 16:50, Seminar Room G (HS III) – Parallels 2G

In this contribution, first results of simulations with $N_f = 2$ dynamical flavours of maximally twisted mass fermions at the physical point are presented using a newly generated ensemble by the European Twisted Mass Collaboration (ETMC) at one lattice spacing. An overview is given of the newly chosen action, algorithmic stability and the tuning to maximal twist. As a first test, preliminary measurements of mesonic quantities are shown to indicate that the physical pion mass region has been reached on a large volume lattice. Finally, the extension of simulations to $N_f = 2 + 1 + 1$ is discussed and current progress is outlined.

2+1 flavor lattice QCD simulation on K computer

Yoshinobu Kuramashi, Sinya Aoki, Takumi Doi, Tetsuo Hatsuda, Noriyoshi Ishii, Ken-Ichi Ishikawa, Naruhito Ishizuka, Yoshifumi Nakamura, Yusuke Namekawa, Hidekatsu Nemura, Kenji Sasaki, Yusuke Taniguchi, Naoya Ukita, Takeshi Yamazaki

Mon, 17:10, Seminar Room G (HS III) – Parallels 2G

We first explain the HPCI (High Performance Computing Infrastructure) Strategic Program in Japan aiming to conduct innovative research in five research fields that were selected strategically. The fifth field "the origin of matter and the universe" covers the fundamental sciences consisting of elementary particle physics, nuclear physics and astronomy. We have chosen four research subjects among the field to be performed using a part of the K computer. One of them is a large scale simulation of lattice QCD. We present some preliminary results for 2+1 flavor QCD together with algorithmic details. Future physics plan is also discussed.

Spectrum of excited states using the stochastic LapH method
Colin Morningstar
Mon, 17:30, Seminar Room G (HS III) – Parallels 2G

Results for the spectrum of excited mesons obtained from the temporal correlations of spatially-extended single-hadron and multi-hadron operators on anisotropic $24^3 \times 128$ and $32^3 \times 256$ lattices are presented. A stochastic method of treating the low-lying modes of quark propagation which exploits Laplacian Heaviside quark-field smearing makes such calculations possible. Light-meson scattering phase shifts may also be presented.

Isospin breaking effect from lattice QCD and QED
Antonin Portelli
Mon, 17:50, Seminar Room G (HS III) – Parallels 2G

While electromagnetic and up-down quark mass difference effects on octet baryon masses are very small, they have important consequences. The stability of the hydrogen atom against beta decay is a prominent example. Here we include these effects by adding them to valence quarks in a lattice QCD calculation based on Nf =2+1 simulations with 5 lattice spacings down to 0.054 fm, lattice sizes up to 6 fm and average up-down quark masses all the way down to their physical value. This allows us to gain control over all systematic errors, except for the one associated with neglecting electromagnetism in the sea. We determine the up-down quark mass difference and the corrections to Dashen's theorem. We also compute the octet baryon isomultiplet mass splittings, as well as the individual contributions from electromagnetism and the up-down quark mass difference.

Determination of the non-degenerate light quark masses from electromagnetic mass splittings in 2+1 flavour lattice QCD+QED
Shane Drury
Mon, 18:10, Seminar Room G (HS III) – Parallels 2G

We report on a calculation of the effects of isospin breaking in Lattice QCD+QED. This involves using Chiral Perturbation Theory with Electromagnetic corrections to find the renormalized, non-degenerate, light quark masses. The calculations are carried out on QCD ensembles generated by the RBC and UKQCD collaborations using Domain Wall Fermions and the Iwasaki+DSDR Gauge Actions with unitary pion masses down to 170 MeV. Non-compact QED is treated in the quenched approximation. We use a 32^3 lattice size with $a^{-1} = 2.28(3)$ GeV (Iwasaki) and 1.37(1) (Iwasaki+DSDR). This builds on previous work from the RBC/UKQCD collaboration with lattice spacing $a^{-1} = 1.78(4)$ GeV.

Symanzik flow on HISQ ensembles
Nathan Brown
Mon, 18:30, Seminar Room G (HS III) – Parallels 2G

We present a determination of the Symanzik flow and the w_0 scale (proposed by the BMW collaboration) on 2+1+1-flavor HISQ ensembles generated by the MILC collaboration. Continuum extrapolated values are compared to the BMW collaboration's results for stout-smeared staggered and HEX-smeared Wilson-clover fermions, and to HPQCD's results with Wilson flow on some of the same HISQ ensembles. Analysis of quark mass dependence of the scale and autocorrelation length versus flow time will also be presented.

A relativistic, model-independent, three-particle quantization condition: (I) Derivation
Maxwell Hansen, Stephen Sharpe
Tue, 14:00, Seminar Room G (HS III) – Parallels 3G

We present a generalization of Lüscher's relation between finite-volume spectrum and S-matrix, to energies above inelastic threshold. Specifically, we consider a scalar field theory, which has a G-parity-like symmetry that prevents even/odd coupling but is otherwise arbitrary. Assuming center of mass energies between three and five particle masses, we evaluate a three-to-three finite-volume correlator to all orders in perturbation theory. Here terms which are exponentially suppressed in volume are neglected. From the poles in the finite-volume correlator we then determine the relation between finite-volume spectrum and scattering amplitudes. Both two-to-two and three-to-three amplitudes enter the final result.

A relativistic, model-independent, three-particle quantization condition: (II) Threshold expansion
Stephen Sharpe, Maxwell Hansen
Tue, 14:20, Seminar Room G (HS III) – Parallels 3G

We describe how the general result obtained in the talk of Max Hansen can be expanded near to the three-particle threshold and compared to the non-relativistic result of Beane et al. This provides an important cross-check on our general result.

Extension of the HAL QCD approach to inelastic and multi-particle scatterings in lattice QCD
Sinya Aoki
Tue, 14:40, Seminar Room G (HS III) – Parallels 3G

We propose an extension of the HAL QCD method, which successfully describes two hadron interactions below inelastic thresholds in terms of corresponding potentials, to inelastic and multi-particle scatterings. We first derive asymptotic behaviors of the Nambu-Bethe-Salpeter (NBS) wave function at large separation for systems with more than 2 particles in quantum field theories. We express asymptotic behaviors of the NBS wave function for n particles at low energy in terms of parameters of T-matrix such as phase shifts and mixing angles. We next construct energy-independent but non-local potentials above inelastic thresholds in terms of NBS wave functions in QCD. These properties are two essential ingredients of the HAL QCD method to define potentials, and justify the HAL QCD's method for 3 or more particles in lattice QCD.

A comparative study of two lattice approaches to two-body systems
Bruno Charron
Tue, 15:00, Seminar Room G (HS III) – Parallels 3G

Two-body systems are often studied through the temporal dependence of lattice correlators, which allow the extraction of the first few lattice eigenstates' energies. These energies are related, under some assumptions on the interaction, to the infinite volume binding energies or phase shifts by Luescher's finite size formula or one of its extensions. Another approach is to approximate a non-local interaction kernel common to all lattice eigenstates' Nambu-Bethe-Salpeter amplitudes under the inelastic threshold. One can then obtain approximate amplitudes for these lattice eigenstates and compute the corresponding infinite volume binding energies or phase shifts from their spatial dependence outside the interaction. We study, for a few systems, the relations between the two methods, the challenges in their application and the validity of the approximations.

Phase shifts in $I = 2$ $\pi\pi$-scattering from two lattice approaches
Thorsten Kurth, Noriyoshi Ishii, Takumi Doi, Sinya Aoki, Tetsuo Hatsuda
Tue, 15:20, Seminar Room G (HS III) – Parallels 3G

We present a lattice QCD study of the phase shift of I=2 $\pi\pi$ scattering on the basis of two different approaches: the standard finite volume approach by Luscher and the recently introduced HAL QCD potential method. Quenched QCD simulations are performed on a $32^3 \times 128$ lattice with lattice spacing $a = 0.115$ fm using a heavy pion mass of $m_\pi = 940$ MeV. Results of the phase shift and the scattering length are shown to agree quite well between these two methods. In case of the potential method, the error is dominated by the systematic uncertainty associated with the violation of rotational symmetry due to finite lattice spacing. In Luscher's approach, such systematic uncertainty is difficult to be evaluated and thus is not included in this work. In case of the potential method, the phase shift can be calculated for arbitrary energies below the inelastic threshold. In that context, the phase shift obtained from the nonrest-frame extension of Luscher's method obtained at a particular center-of-mass momentum lies on top of the curve predicted by the potential method.

Two-Nucleon Systems in a Finite Volume
Raul Briceno, Zohreh Davoudi, Thomas Luu
Tue, 15:40, Seminar Room G (HS III) – Parallels 3G

I will briefly motivate the study of two-nucleon systems in a finite volume and review issues regarding partial wave mixing in a finite volume for both two and three-body systems. I will outline the derivation of the the quantization condition for two nucleons in a finite volume with periodic boundary conditions. The result holds for arbitrary isospin, parity, and momenta below the two-pion production threshold. I will pay close attention to the positive parity sector and consider the implication of the quantization condition for the three smallest boosts. Finally, I will discuss the implications for the two-nucleon spectrum at the physical point.

Interactions of Charmed Mesons with Light Pseudoscalar Mesons from Lattice QCD and Implications on the Nature of the $D^*_{s0}(2317)$
Liuming Liu, Kostas Orginos, Feng-Kun Guo, Christoph Hanhart, Ulf Meissner
Wed, 08:30, Seminar Room G (HS III) – Parallels 5G

We study the scattering of light pseudoscalar mesons (π, K) off charmed mesons (D, D_s) in full lattice QCD. The S-wave scattering lengths are calculated using Lüscher's finite volume technique. We use a relativistic formulation for the charm quark. For the light quark, we use domain-wall fermions in the valence sector and improved Kogut-Susskind sea quarks. We calculate the scattering lengths of isospin-3/2 $D\pi$, $D_s\pi$, D_sK, isospin-0 $D\bar{K}$ and isospin-1 $D\bar{K}$ channels on the lattice. For the chiral extrapolation, we use a chiral unitary approach to next-to-leading order, which at the same time allows us to give predictions for other channels. It turns out that our results support the interpretation of the $D^*_{s0}(2317)$ as a DK molecule. At the same time, we also update a prediction for the isospin breaking hadronic decay width $\Gamma(D^*_{s0}(2317) \to D_s\pi)$ to (133 ± 19) keV.

***D K* scattering and the D_s spectrum**
Daniel Mohler, Christian Lang, Luka Leskovec, Sasa Prelovsek
Wed, 08:50, Seminar Room G (HS III) – Parallels 5G

We present preliminary results from lattice QCD calculations of the low-lying charmed-strange meson spectrum using two types of Clover-Wilson lattices. In addition to quark-antiquark interpolating fields we also consider meson-meson interpolators corresponding to D K scattering states. To calculate the all-to-all propagation necessary for the backtracking loops we use the Distillation technique. For the charm quark we use the Fermilab method. Preliminary results for the $J^P = 0^+$ and 1^+ charmed-strange mesons are presented.

Twisted mass lattice computation of charmed mesons with focus on D_s^{**}

Martin Kalinowski, Marc Wagner

Wed, 09:10, Seminar Room G (HS III) – Parallels 5G

We present results of a 2+1+1 flavor twisted mass lattice QCD computation of the spectrum of D mesons and D_s mesons and of charmonium. Particular focus is put on the positive parity D and D_s states (so-called D_s^{**} mesons) with quantum numbers $J^P = 0^+$, 1^+ and 2^+. Besides computing their masses we are also separating and classifying the two $J^P = 1^+$ states according to the angular momentum/spin of their light degrees of freedom (light quarks and gluons) $j = 1/2$, $3/2$.

Excited spectroscopy of mesons containing charm quarks from lattice QCD

Graham Moir, Michael Peardon, Christopher Thomas, Sinead Ryan, Liuming Liu

Wed, 09:30, Seminar Room G (HS III) – Parallels 5G

We present highly excited spectra of mesons containing charm quarks computed using the dynamical anisotropic lattices of the Hadron Spectrum Collaboration. The use of novel techniques has allowed us to extract these spectra with a high degree of statistical precision, while also enabling us to observe states as high as spin 4 and candidate gluonic excitations. The phenomenology of these spectra and new calculations of scattering of charmed mesons will be discussed.

Hadron spectra from overlap fermions on HISQ gauge configurations.

Nilmani Mathur, Subhasish Basak, Saumen Datta, Andrew Lytle, Padmanath Madanagopalan, Pushan Majumdar

Wed, 09:50, Seminar Room G (HS III) – Parallels 5G

Adopting a mixed action approach, we report here results on hadron spectra containing one or more charm quarks. On a background of 2+1+1 flavours HISQ gauge configurations of MILC collaboration, we use overlap fermions for valence quarks. We also study the ratio of leptonic decay constants, fD/fDs. Results are obtained at two lattice spacings.

Rho - meson in external magnetic field
Elena Lushchevskaya
Wed, 10:10, Seminar Room G (HS III) – Parallels 5G

Correlators of vector and pseudoscalar currents have been calculated in external strong magnetic field in SU(2) gluodynamics on the lattice. Different spin components of rho meson mass were explored in dependence on the magnetic field. The mass of vector meson with zero spin projection to the direction of the magnetic field decreases lenearly with increasing of the field for available values of the field on the lattice $eB < 2 - 2.5\ \mathrm{GeV}^2$, such behavior is necessary for a condensation of rho mesons in strong magnetic field.

Structure of the sigma meson from lattice QCD
Masayuki Wakayama, Chiho Nonaka, Atsushi Nakamura, Motoo Sekiguchi, Hiroaki Wada, Shin Muroya, Teiji Kunihiro
Wed, 11:00, Seminar Room G (HS III) – Parallels 6G

Our purpose is to obtain insights of structure of the sigma meson from the first principle calculation, lattice QCD. At present we do not reach a conclusive understanding of nature of the sigma meson. Currently it is considered as a usual two-quark state, four-quark states such as a tetraquark and mesonic molecules or superposition of them. Besides, the mixing with glueballs is one of important and interesting ingredients for structure of the sigma meson. Furthermore, a disconnected diagram of the sigma meson plays an important role in the structure of the sigma meson. However, to evaluate the disconnected part of the propagator is not an easy task in lattice QCD calculation. To compute the disconnected part of the propagator, we use the Z2 noise method with the truncated eigenmode acceleration and the time dilution for estimating the all-to-all quark ropagators. Here, we focus on four-quark states in the sigma meson. From investigation of two-quark and four-quark states with the inclusion of disconnected diagrams, we will discuss mass of the sigma meson, and the mixing ratio between the two-quark states and four-quark states.

Study of the scalar $a_0(980)$ on the lattice

Abdou Abdel-Rehim, Constantia Alexandrou, Marc Wagner, Luigi Scorzato, Carsten Urbach, Mario Gravina, Mattia Dalla Brida, Joshua Berlin, David Palao

Wed, 11:20, Seminar Room G (HS III) – Parallels 6G

Understanding the quark substructure and spectrum of light scalar mesons on the lattice is both interesting and challenging. It has been argued that these states are mixtures of conventional quark-antiquark and tetraquarks. In this talk we present results for the $a_0(980)$ state using a variational approach with quark-antiquark, diquark-antidiquark as well as meson-meson molecule interpolating field operators. The spectrum is computed on gauge configurations with 2+1 clover quarks generated by the PACS-CS collaboration at pion mass of about 300 MeV. Both connected as well as disconnected quark loops are included. We also plan to show preliminary results for an ensemble at near physical pion mass.

K pi scattering from Lattice QCD

David Wilson

Wed, 11:40, Seminar Room G (HS III) – Parallels 6G

We study the correlation functions obtained on 16^3, 20^3 and 24^3 anisotropic lattices with the quark content and quantum numbers relevant to $K\pi$ scattering. We work using a large basis of operators including variationally-optimised projected operators that overlap strongly onto single-particle meson states. We use the distillation framework developed by the Hadron Spectrum Collaboration which enables efficient and precise determination of lattice energy levels. As is expected, the energies are shifted from their non-interacting single-particle counterparts. We apply the Luescher method to these results to obtain the phase shifts.

$K\pi$ scattering in moving frames

Christian Lang, Sasa Prelovsek, Luka Leskovec, Daniel Mohler
Wed, 12:00, Seminar Room G (HS III) – Parallels 6G

We extend our study of the $K\pi$ system to moving frames and present an exploratory extraction of the masses and widths for the K^* resonances by simulating $K\pi$ scattering in p-wave with $I = 1/2$ on the lattice. Using $K\pi$ systems with non-vanishing total momenta allows the extraction of phase shifts at several values of $K\pi$ relative momenta. A Breit-Wigner fit of the phase renders a $K^*(892)$ resonance mass and $K^* \to K\pi$ coupling compatible with the experimental numbers. We also determine the $K^*(1410)$ mass and width assuming that the scattering is elastic in our simulation. We contrast the resonant $I = 1/2$ channel with the repulsive non-resonant $I = 3/2$ channel, where the phase is found to be negative and small, in agreement with experiment.

Search for possible bound Tcc and Tcs on the lattice

Yoichi Ikeda
Wed, 12:20, Seminar Room G (HS III) – Parallels 6G

One of the interesting subjects in hadron physics is to look for the possible multiquark configurations that are stable against strong decays. One of the example is the bound H-dibaryon (udsuds) and the possibility of the bound H-dibaryon has been recently studied from lattice QCD [1,2]. In the present study, we extend the HAL QCD method to define potential between hadrons [3,4] to the meson-meson systems including charm quarks to investigate the possible bound Tcc ($ud\bar{c}\bar{c}$) and Tcs ($ud\bar{s}\bar{c}$) on the $32^3 \times 64$ $N_f = 2+1$ full QCD gauge configuration generated by PACS-CS Collaboration[5]. We also introduce the relativistic heavy quark action [6] as for the charm quarks. We report our results of the s-wave meson-meson potentials that are relevant to the Tcc and Tcs with pion mass $m_\pi = 410$, 570, 700 MeV. The scattering phase shifts and scattering lengths obtained from our lattice potentials are also presented. [1] T. Inoue et al. [HAL QCD Collaboration], Phys. Rev. Lett. 106 (2011) 162002. [2] S.R. Beane et al. [NPLQCD Collaboration], Phys. Rev. Lett. 106 (2011) 162001. [3] N. Ishii, S. Aoki and T. Hatsuda, Phys. Rev. Lett. 99 (2007) 022001. [4] N. Ishii et al. [HAL QCD Collaboration], Phys. Lett. B712 (2012) 437. [5] S. Aoki, Y. Kuramashi and S.-i. Tominaga, Prog. Theor. Phys.109 (2003) 383.

Lattice study of pion-pion scattering in the rho channel with quark masses close to their physical values
Thibaut Metivet
Wed, 12:40, Seminar Room G (HS III) – Parallels 6G

Thibaut Métivet for the Budapest-Marseille-Wuppertal collaboration. We present preliminary results of pion-pion scattering in the rho channel on 2HEX smeared gauge configurations generated with Nf=2+1 clover improved Wilson fermions. Using Luscher's formalism, we extract the rho resonance parameters from the volume dependence of the energies of low-lying eigenstates in that channel. We perform the calculation for a variety of pion masses (200 to 450 MeV) and attempt an extrapolation of these parameters to the physical mass point.

Exploring the Roper resonance in Lattice QCD
Waseem Kamleh
Thu, 14:00, Seminar Room G (HS III) – Parallels 7G

Using a correlation matrix analysis consisting of a variety of smearings, the CSSM Lattice collaboration has successfully isolated the Roper resonance and other "exotic" excited states such as the Lambda(1405) on the lattice at near-physical pion masses. We explore the nature of the Roper resonance by examining the eigenvectors that arise from the variational analysis, demonstrating that the Roper is dominated by the χ_1 nucleon interpolator and only poorly couples to χ_2. By examining the probability distribution of the Roper on the lattice, we find a structure consistent with a constituent quark model. In particular, the Roper d-quark wave function contains a single node consistent with a 2S state. A detailed comparison with constituent quark model wave functions is carried out, validating the approach of accessing these states by constructing a variational basis composed of different levels of fermion source and sink smearing.

The Roper Puzzle
Keh-Fei Liu
Thu, 14:20, Seminar Room G (HS III) – Parallels 7G

The Roper resonance calculated with Wilson and Clover fermions are higher than that calculated with the overlap fermion by 400-600 MeV for the range of pion mass below 600 MeV in both the quenched and dynamical fermion calculations. Furthermore, the lowest state in the S_{11} channel with the overlap fermion is the S-wave πN state; whereas, the lowest one in the Wilson and Clover fermion appears to be $S_{11}(1535)$ for pion mass below 300 MeV. We address these puzzles with the study of Roper in both the variation and sequential Bayesian fitting methods as well as in terms of the role of chiral dynamics.

Spectroscopy of doubly and triply-charmed baryons from lattice QCD
Padmanath Madanagopalan, Robert Edwards, Nilmani Mathur, Michael Peardon
Thu, 14:40, Seminar Room G (HS III) – Parallels 7G

We present the ground and excited state spectra of doubly and triply-charmed baryons by using dynamical lattice QCD. A large set of baryonic operators that respect the symmetries of the lattice and are obtained after subduction from their continuum analogues are utilized. Using novel computational techniques correlation functions of these operators are generated and the variational method is exploited to extract excited states. The lattice spectra that we obtain have baryonic states with well-defined total spins up to $\frac{7}{2}$ and the low lying states remarkably resemble the expectations of quantum numbers from SU(6) $\times$ O(3) symmetry. Various energy splittings between the extracted states, including splittings due to hyperfine as well as spin-orbit coupling, are considered and those are also compared against similar energy splittings at other quark masses.

Charmed Bottom Baryon Spectroscopy
Zachary Brown, Kostas Orginos, Stefan Meinel, William Detmold
Thu, 15:00, Seminar Room G (HS III) – Parallels 7G

The arena of doubly and triply heavy baryons remains experimentally unexplored to a large extent. This has led to a great deal of theoretical effort being put forth in the calculation of mass spectra in this sector. Although the detection of such heavy particle states may lie beyond the reach of experiments for some time, it is interesting to compare results between lattice QCD computations and continuum theoretical models. Several recent lattice QCD calculations exist for both doubly and triply charmed as well as doubly and triply bottom baryons. In this work we present results from the first lattice calculation of the mass spectrum of doubly and triply heavy baryons including both charm and bottom quarks. The wide range of quark masses in these systems require that the various flavors of quarks be treated with different lattice actions. We use domain wall fermions for 2+1 flavors (up down and strange) of sea and valence quarks, a relativistic heavy quark action for the charm quarks, and non-relativistic QCD for the heavier bottom quarks. The calculation of the ground state spectrum is presented and compared to recent models.

SU(3) flavour symmetry breaking and charmed states
Roger Horsley
Thu, 15:20, Seminar Room G (HS III) – Parallels 7G

By extending the SU(3) flavour symmetry breaking expansion from up, down and strange sea quark masses to partially quenched valence quark masses we propose a method to determine charmed quark hadron masses. Initial results for some singly and doubly charmed baryon states are encouraging and demonstrate the potential of the procedure.

Baryon properties in meson mediums from lattice QCD
Amy Nicholson, William Detmold
Thu, 15:40, Seminar Room G (HS III) – Parallels 7G

We calculate the ground state mass shifts of various baryons due to the presence of a medium of pions or kaons using lattice QCD. We use a canonical approach to produce the medium by calculating correlators with a fixed number of meson propagators. From the ground state energies we calculate two- and three-body scattering parameters. We also extract low energy constants by comparing our results to tree level Chiral Perturbation Theory at non-zero isospin/kaon chemical potential.

Lattice study on exotic vector charmonium relevant to X(4260)
Ying Chen, Wei-Feng Chiu, Long-Cheng Gui, Jian Liang, Zhaofeng Liu, Yibo Yang
Thu, 16:30, Seminar Room G (HS III) – Parallels 8G

In the quenched approximation and with very high statistics, a heavy vector charmonium state, with a mass of roughly 4.30(5) GeV, is disentangled from conventional vector charmonia by using spatially extended hybrid-like interpolating field operators. The leptonic decay width of this state is also investigated through a simultaneous fit of correlation functions built from defferent operators.

η and η' masses from lattice QCD with 2+1+1 quark flavours
Carsten Urbach, Chris Michael, Konstantin Ottnad
Thu, 16:50, Seminar Room G (HS III) – Parallels 8G

We investigate the masses of eta and eta' mesons using the Wilson twisted mass formulation with 2+1+1 dynamical quark flavours based on gauge configurations of ETMC. We show how to efficiently subtract excited state contributions to the relevant correlation functions and estimate in particular the eta' mass with improved precision. After investigating the strange quark mass dependence and the continuum and chiral extrapolations, we present our results at the physical point.

Pseudoscalar flavor-singlet mixing angle and decay constants from $N_f = 2+1+1$ WtmLQCD
Konstantin Ottnad, Chris Michael, Carsten Urbach
Thu, 17:10, Seminar Room G (HS III) – Parallels 8G

Considering matrix elements in the quark-flavor basis, one expects the mixing in the eta,eta'-system to be described reasonably well by a single mixing and two decay constants f_l, f_s. I discuss how these quantities are determined from pseudoscalar matrix elements in $N_f = 2+1+1$ Wilson twisted mass lattice QCD and present results for three values of the lattice spacing and values of M_{PS} ranging from 230-500 MeV. The required accuracy of the matrix elements is guaranteed by an improved analysis method involving an excited state subtraction in the connected pieces of the correlation function matrix. Besides the mixing angle, the parameters f_l, f_s are of phenomenological interest, e.g. they are related to the decay widths of $\eta \to \gamma\gamma$ and $\eta' \to \gamma\gamma$.

Charmonium-like states from scattering on the lattice
Sasa Prelovsek, Luka Leskovec, Daniel Mohler
Thu, 17:30, Seminar Room G (HS III) – Parallels 8G

We extract charmonium and charmonium-like states by simulating the corresponding scattering in a number of channels with different quantum numbers. Among others, we address also experimentally well-established X(3872) and the recently discovered and manifestly exotic $Z_c^+(3900)$.

O(a^2)-improved actions for heavy quarks
Yong-Gwi Cho, Shoji Hashimoto, Junichi Noaki
Thu, 17:50, Seminar Room G (HS III) – Parallels 8G

We investigate a new class of improved relativistic fermion action on the lattice with a criterion to give excellent energy-momentum dispersion relation as well as to be consistent with tree-level O(a^2)-improvement. Main application in mind is that for heavy quark for which ma O(0.5). We present tree-level results and a scaling study on quenched lattices.

On the $B^{*'} \to B$ transition
Antoine Gerardin, Benoit Blossier, John Bulava, Michael Donnellan
Thu, 18:10, Seminar Room G (HS III) – Parallels 8G

We present a first lattice determination of the $B^{*'}B\pi$ coupling which parametrizes the strong decay of a radially excited B^* meson into the ground state B meson. The simulations are performed using CLS gauge configurations with $N_f = 2$ non-pertubatively $\mathcal{O}(a)$ improved Wilson-Clover fermions and Heavy Quark Effective Theory in the static limit. Four lattice ensembles, with three lattice spacings in the range [0.05-0.08] fm and pion masses down to 310 MeV, allow us to perform the continuum extrapolation and check the quark mass dependence. Moreover, to handle with exited states, we solved a Generalized Eigenvalue Problem (GEVP).

Omega-Omega interaction on the Lattice
Masanori Yamada
Fri, 16:30, Seminar Room C (RW4) – Parallels 10C

We investigate the Omega-Omega baryon interaction in lattice QCD. In the past studies, the hyperon interactions, which become important in hight density matters such as the core of the neutron star, have been investigated mainly for the octet sector, while a very few investigations have been made for the decuplet sector since almost all decuplet baryons are unstable due to decays via the strong interaction. An exception is the Omega decuplte baryon, which is stable against the strong decays, so its interaction is suitable to be investigated. It is, however, still difficult to investigate the Omega-Omega interaction experimentally due to its short-life time via weak decays. Therefore, the lattice QCD study for the Omega-Omega interaction is necessary and important. We calculate the Omega-Omega potential by the HAL QCD method, where the potential is extracted from the Nambu-Bethe-Salpeter (NBS) wave function. Our numerical results are obtained from 2+1 flavor full QCD gauge configurations at $m_\pi \sim 875$ MeV and $m_\Omega \sim 2108$ MeV, generated by the CP-PACS/JLQCD Collaboration. We find that the Omega-Omega interaction is strong attractive. Using the potential obtained, we also calculate the phase shift of Omega-Omega scattering and discuss a possibility of an existence for a shallow Omega-Omega bound state.

Lattice QCD studies of multi-strange baryon-bayon interactions
Kenji Sasaki
Fri, 16:50, Seminar Room C (RW4) – Parallels 10C

Derivation of baryon-baryon interactions from lattice QCD is highly awaited to investigate hypernuclear and/or neutron star structure and mechanism of supernova explosions since their experimental data are scarce. Owing to developments of computer performances and simulation techniques, lattice QCD calculations allow us to understand nuclear physics in terms of fundamental theory of the strong interaction (QCD). Our approach to baryon-baryon interactions is deriving a potential from inverting Schroedinger equation using NBS wave function simulated by lattice QCD. This approach have been extended to the coupled channel formalism. Using the coupled channel approach, we investigate multi-strange baryon-baryon interactions by lattice QCD simulation. Our numerical results are obtained from 2+1 flavor QCD gauge configuration provided by the PACS-CS Collaboration. The scattering parameters by these potentials are also discussed.

The anti-symmetric LS potential in flavor SU(3) limit from Lattice QCD
Noriyoshi Ishii, Keiko Murano, Hidekatsu Nemura, Kenji Sasaki
Fri, 17:10, Seminar Room C (RW4) – Parallels 10C

Parity-odd hyperon potentials including the anti-symmetric LS potential is calculated in the flavor SU(3) limit with HAL QCD method by using 2+1 flavor gauge configuration on the $16^3 \times 32$ lattice generated by CP-PACS/JLQCD coll. Due to the calculational cost, we restrict ourselves to the S=-1 sector, which makes it possible to access the irreducible representations of 27, 10^*, 10, 8S and 8A of the flavor SU(3) group. These potentials are rotated to the particle basis to discuss a possible cancellation between the symmetric and the anti-symmetric LS potentials in the NLambda sector, which is phenomenologically expected from the spectrum of hyper-nuclei.

Quark mass dependence of Spin-Orbit force in parity-odd NN system from 2+1 flavor QCD
Keiko Murano
Fri, 17:30, Seminar Room C (RW4) – Parallels 10C

We report our recent study of Spin-Orbit force between two nucleons in the parity-odd sector from Lattice QCD. In the previous talk, where we reported our first result of Spin-Orbit force calculated at $m_\pi = 1133$ MeV, we found that, while the qualitative behavior of resultant potentials are consistent with phenomenological potentials, these potentials are still weak, probably due to the heavy quark mass employed in our simulations. In this talk, we examine the quark mass dependence of Spin-Orbit force. We reconstruct Spin-Orbit force from 3P0, 3P1 and 3P2 Nambu-Bethe-Salpeter wave functions calculated from Lattice QCD in lighter quark mass region at $m_\pi = 701-411$ MeV. The calculation is performed on Blue Gene/Q at KEK by using Nf=2+1 PACS-CS gauge configuration generated by O(a) improved wilson quark action with RG improved (iwasaki) gauge action. We find that the potentials tend to become stronger as the quark mass decreases.

Pion-nucleon scattering in Lattice QCD
Valentina Verduci, Christian Lang
Fri, 17:50, Seminar Room C (RW4) – Parallels 10C

Almost all the hadrons of the QCD spectrum are unstable under strong interactions and their resonant nature has to be taken into account for a complete study in lattice QCD. Thanks to improved computational resources and developed theoretical tools, in the last years multi-particle states started to be a new frontier in lattice studies. We examine, for the first time on the lattice, the pion-nucleon system in s-wave (negative parity). We compare the energy levels measured in the one-particle setup with the spectrum of the coupled system. Additional information on the N* resonance are achieved through a phase shift analysis. This work is intended to be an exploratory study of the meson-baryon system on the lattice and a boost for further studies in this direction.

Looking for a Quarkonium-Nucleus Bound State on the Lattice
Saul Cohen
Fri, 18:10, Seminar Room C (RW4) – Parallels 10C

The interaction between quarkonia and nuclei will reveal new information about the properties of QCD. Since such systems are composed of hadronic states having no common valence quarks, they interact mainly by multi-gluon exchanges, analogous to a color van der Waals force. Although twenty years have passed since the existence of a bound nucleus-quarkonium state was proposed, model calculations give diverse results. Experiments, such as ATHENNA at JLab or CBM at FAIR, will provide experimental data in the near future. In this talk, we present a first lattice-QCD calculation of the interaction of strange quarkonia with light nuclei, using ensembles with pion masses at the SU(3)-symmetric point. We determine the energies of these multiparticle systems and probe the existence of bound states.

The Hadronic Decays of Decuplet Baryons
Paul Rakow, Raffaele Millo, Roger Horsley, Holger Perlt, Gerrit Schierholz, James Zanotti
Fri, 18:30, Seminar Room C (RW4) – Parallels 10C

We report on a project to measure the hadronic decays of the decuplet baryons, for example Delta to N pi and its hyperon analogues, based on 2+1 flavour lattice simulations. We are following two paths towards determining the coupling constants. One is to carefully measure the energies of the ground state and first few excited levels, to see how far they are shifted by the interaction. The other approach is to measure transition rates directly from the time dependence of Greens functions linking the parent baryon at the source and its decay products at the sink.

Rho and A-mesons in external magnetic field in SU(2) lattice gauge theory
Olga Larina, Elena Lushchevskaya
Poster Session

Correlators of vector, axial and pseudoscalar currents have been calculated in external strong magnetic field in SU(2) gluodynamics on the lattice. The masses of rho and A-meson s with a zero spin projection s = 0 to the z axis parallel to the external magnetic field B were explored in dependence on the magnetic field. The mass of the corresponding spin component of vector meson decreases with increasing of the magnetic field for available values of the field on the lattice $eB \sim 2 - 2.5$ GeV^2, such behavior is necessary for a condensation of rho mesons in strong magnetic field.

The Oscillatory Behavior and The Logarithmic Unphysical Pole of the Domain Wall Fermion
Raza Sufian, Michael Glatzmaier, Keh-Fei Liu
Poster Session

Domain wall fermion formulation can suffer from an unwelcome oscillatory behavior in the hadron correlators which appears when the transfer matrix is complex. In this work, we study the origin of this unphysical pole from the free quark propagator using several different DWF actions, e.g. Shamir, Boriçi, and the Mobius domain wall fermion action. We find that the unphysical mode depends on the domain wall height M, as well as on coeffieicents b_s and c_s for Mobius action. We determine the specific ranges of these parameters which give rise to oscillatory behavior.

SU(2) Lattice Gluon Propagator and Potential Models
Willian M. Serenone, Attilio Cucchieri, Tereza Mendes
Poster Session

We use lattice data for the gluon propagator as an input to model the heavy quark-antiquark potential. Since the approach is based on the one-gluon-exchange approximation, a linear term must be included explicitly, to account for non-pertunative effects. The string tension is left as a free parameter to be determined from fits to experimental results. We present an application to the spectrum of the bottomonium and compare to other methods.

Glueballs in charmonia radiative decays
Chuan Liu, Ying Chen, Yibo Yang, Yu-Bin Liu, Jian-Ping Ma, Jian-Bo Zhang
Poster Session

The radiative decay of J/ψ into a pure gauge scalar or tensor glueball is studied in the quenched lattice QCD formalism. The corresponding phenomenological implication of these results is also discussed.

Flavored pion and kaon masses at next-to-leading order in mixed-action staggered chiral perturbation theory
Jon Bailey, Jongjeong Kim, Weonjong Lee, Hyung-Jin Kim, Boram Yoon
Poster Session

Differently improved staggered fermions can be used in mixed-action calculations to reduce discretization effects and simplify analyses. After recalling the generalization of staggered chiral perturbation theory to the mixed-action case, we describe a calculation of the masses of the flavored pseudo-Goldstone bosons to next-to-leading order. The results can be used to improve determinations of quark masses, Gasser-Leutwyler couplings, and other parameters important for phenomenology.

Testing the stochastic LapH method in the twisted mass formulation
Christian Jost, Bastian Knippschild, Carsten Urbach
Poster Session

We present first results using the stochastic Laplace-Heaviside (LapH) method in the twisted mass formulation. The calculations are performed on gauge configurations provided by the ETM collaboration with 2+1+1 dynamical quark flavours at a single value of the lattice spacing. In particular, we compute disconnected contributions to flavour singlet pseudo-scalar mesons and compare LapH to standard volume noise methods.

Bottomonium results from lattice QCD
Christine Davies, Brian Colquhoun, Ben Galloway, Rachel Dowdall, Jonna Koponen, Peter Lepage, Craig McNeile
Poster Session

We discuss a number of different results in bottomonium physics using the HISQ or NRQCD actions for the b quark.

Hadronic light-by-light contribution to the muon $g-2$ with charged sea quarks
Tom Blum, Masashi Hayakawa, Taku Izubuchi
Poster Session

We update our calculation of the hadronic light-by-light contribution to the muon anomalous magnetic moment, using increased statistics and more values of momentum transfer, for neutral sea quarks. We use domain wall fermions, Iwasaki gluons, and quenched (non-compact) photons on a lattice of size $24^3 \times 64 \times 16$, $m_\pi = 330$ MeV, $m_\mu = 170$ MeV, and $a^{-1} = 1.73$ GeV. The AMA technique is employed to efficiently improve statistical precision. In addition, we describe our new calculation method including charged sea quarks and all diagrams entering at $O(\alpha^3)$.

Two-Baryon Correlation Functions in 2-flavor QCD
Chuan Miao, Anthony Francis, Thomas Rae, Hartmut Wittig
Poster Session

We present an initial study of two-baryon correlation functions with the aim of explaining potential dibaryon bound states, specifically the H-dibaryon, which is a hypothesized bound state of QCD. In particular, we comment on our first results for two-baryon correlation functions ($\langle C_{XY}(t)C_{XY}(0)\rangle$, where $XY = \Lambda\Lambda, \Sigma\Sigma, N\Xi, \cdots$), which combine to form the H-dibaryon. The results are obtained using a 'blocking' algorithm to handle the contractions, which may easily be extended to N-baryon correlation functions. We also comment on its application to the analysis of single baryon masses (n, Λ, Ξ, $\cdots$). This study is performed on an isotropic lattice with $m_\pi = 460$ MeV, $m_\pi L = 4.7$ and $a = 0.063$ fm. The measurements are calculated using the CLS ensembles with non-perturbative $\mathcal{O}(a)$ improved Wilson fermions in $N_f = 2$ QCD.

Testing mixed action approaches to meson spectroscopy with twisted mass sea quarks
Joshua Berlin, David Palao, Marc Wagner
Poster Session

We explore several mixed action approaches including Wilson and Wilson twisted mass quarks with and without Clover term. Our main goal is to reduce lattice discretization errors in mesonic spectral quantities, particularly reducing twisted mass parity and isospin mixing.

Investigating a mixed action approach for η and η' mesons in $N_f = 2 + 1 + 1$ lattice QCD
Falk Zimmermann, Konstantin Ottnad, Carsten Urbach
Poster Session

We test Osterwalder-Seiler valence quark action to reproduce eta, eta' meson quantities from twisted mass lattice configurations with 2+1+1 dynamical quark flavours. Flavour singlet quantities gain significant contributions from the sea and the valence quark sector and are, therefore, sensible to mixed regularisations. In particular we employ the freedom to tune the the valence strange quark mass to match pure twisted mass with the mixed action approach. Two matching procedures are proposed and shown to agree in the continuum limit of the eta-meson masses and additional mixing quantities.

Vacuum polarization function in $N_f = 2 + 1$ domain-wall fermion
Eigo Shintani, Hyung-Jin Kim, Tom Blum, Taku Izubuchi
Poster Session

We will show preliminary results of calculation of vacuum polarization function (VPF) of vector-current in Nf=2+1 domain-wall fermion. In this calculation we use the all-mode-averaging to extremely suppress the statistical noise, and show the precise calculation of strong coupling constant using Adler function after taking account of the lattice artifacts with two different cut-off scales. We also discuss the precise calculation of muon g-2 using VPF and address the possible systematic errors.

Meson Spectroscopy using Stochastic LapH Method
Chik Him Wong, Colin Morningstar, David Lenkner, Brendan Fahy, You-Cyuan Jhang, Justin Foley, Jimmy Juge, John Bulava
Poster Session

Excited states of mesons on anisotropic $24^3 \times 128$ and $32^3 times 256$ lattices are obtained from single-hadron and multi-hadron operators by utilizing a stochastic method that exploits the Laplacian Heaviside quark-field smearing. Preliminary light-meson scattering phase shifts may also be presented.

Pseudoscalar Decay Constants of D-Mesons in Lattice QCD with Domain-Wall Fermion

Ting-Wai Chiu, Tung-Han Hsieh, Yu-Chih Chen, Han-Yi Chou, Wen-Ping Chen

Poster Session

We study the masses and decay constants of pseudoscalar mesons in 2 flavors lattice QCD with optimal domain-wall fermion. The gauge ensembles are generated on the $24^3 \times 48$ lattice with the extent in the fifth dimension $N_s = 16$, and the plaquette gauge action at $\beta = 6.10$, for three sea-quark masses corresponding to the pion masses in the range 280-450 MeV. We compute point-to-point quark propagators and measure the time-correlation functions of the pseudoscalar and vector mesons. The inverse lattice spacing is determined by the experimental input of the pion decay constant, while the strange quark and the charm quark masses are determined by the masses of vector mesons $\phi(1020)$ and $J/\psi(3097)$ respectively. In this talk, we outline the salient features of our simulations and present our preliminary results of the masses and decay constants of the charmed mesons D and D_s.

Charmonium, D_s and D_s^* from overlap fermion on domain wall fermion configurations

Yibo Yang, Ying Chen, Zhaofeng Liu

Poster Session

With data on ensembles of two lattice spacings and three sea masses each, we use the masses of D_s, D_s^* and J/ψ to determine $m_c^{\bar{M}S}$(2GeV, $m_s^{\bar{M}S}$(2GeV) and r_0. With those input, we predict the hyperfine-spiltting of charmonium, f_{D_s}, and the masses of P-wave charmonium in the chiral and continuum limits. We also discern the quark mass dependence of the hyperfine-spiltting between pseudo scalar and vector mesons, from light to heavy.

Hadron Structure

Pion electromagnetic form factor from full lattice QCD
Jonna Koponen, Francis Bursa, Christine Davies, Rachel Dowdall
Mon, 16:30, Seminar Room C (RW4) – Parallels 2C

We present the first calculation of the pion electromagnetic form factor at physical light quark masses. This form factor parameterises the deviations from the behaviour of a point-like particle when a photon hits the pion. These deviations result from the internal structure of the pion and can thus be calculated in QCD. We use three sets (different lattice spacings) of $n_f = 2+1+1$ lattice configurations generated by the MILC collaboration. The Highly Improved Staggered Quark formalism (HISQ) is used for all of the sea and valence quarks. Using lattice configurations with u/d quark masses very close to the physical value is a big advantage, as we avoid the chiral extrapolation. We study the shape of the vector (f_+) form factor in the q^2 range from 0 to -0.35 GeV^2 and extract the mean square radius, $\langle r_v^2 \rangle$. The shape of the vector form factor and the resulting radius is compared with experiment. We also discuss the scalar form factor and radius extracted from that, which is not directly accessible to experiment.

The scalar radius of the pion in two-flavor Wilson lattice QCD
Vera Guelpers, Georg von Hippel, Hartmut Wittig
Mon, 16:50, Seminar Room C (RW4) – Parallels 2C

We present an update of our calculation of the scalar charge radius of the pion using $N_f = 2$ dynamical flavors of non-perturbatively $O(a)$-improved Wilson fermions, extending the calculation to a wider range of pion masses for a fixed lattice spacing a. We find that the disconnected contribution to the scalar radius is not negligible especially for smaller pion masses, and is required in order to obtain the behavior expected from next-to-leading order (NLO) Chiral Perturbation Theory (χPT). The low energy constant $\bar{\ell}_4$ is determined from a fit to NLO χPT.

Lattice study of the Boer-Mulders transverse momentum distribution in the pion
Michael Engelhardt
Mon, 17:10, Seminar Room C (RW4) – Parallels 2C

The Boer-Mulders transverse momentum-dependent parton distribution (TMD) characterizes polarized quark transverse momentum in an unpolarized hadron. Techniques previously developed for lattice calculations of nucleon TMDs are applied to the pion. These techniques are based on the evaluation of matrix elements of quark bilocal operators containing a staple-shaped Wilson connection. Results for the Boer-Mulders transverse momentum shift in the pion, obtained at a pion mass of 518 MeV, are presented and compared to corresponding results in the nucleon.

Lattice study of quark distribution amplitudes in the pion and its excitations
Ekaterina Mastropas, David Richards
Mon, 17:30, Seminar Room C (RW4) – Parallels 2C

Lattice QCD serves as a computational framework capable of predicting the spectrum of hadronic excitations from first principles. Our desire to describe the wealth of existing experimental data on the spectrum and to predict the outcomes of future experiments poses numerous challenges. Thus, obtaining an accurate resolution of excited states using methods of LQCD is complicated due to the faster decay of excited state correlation functions in Euclidean space in comparison with those of ground states, which we overcome through the use of anisotropic lattices with a finer temporal than spatial discretization. The aim of this project is to go beyond the spectrum to discern the structure of the states through the computation of the quark distribution amplitudes for both the ground and excited pion states on improved anisotropic lattices developed by the Hadron Spectrum Collaboration. Application of variational method allows us to extract the excited-state spectrum. When combined with undergoing parallel perturbative study of renormalization coefficients for quark bilinear operators, this work will enable us to explore the internal structure of the excited states, and to investigate the approach to a quark and gluon description of hadrons when probed at high-momentum transfers.

Magnetic polarizability of hadrons in the background field method
Scott Moerschbacher, Frank Lee, Andrei Alexandru, Michael Lujan
Mon, 17:50, Seminar Room C (RW4) – Parallels 2C

We report the extraction of hadron magnetic polarizability from small mass shifts in the presence of a constant external field in lattice QCD. The calculations are done on $24^3 \times 48$ lattices at 0.1 fm spacing using standard Wilson actions, with pion mass down to about 400 MeV. Both neutral and charged hadrons are considered. Issues such as the quantization of the field, boundary conditions, U(1) gauge dependence, and Landau levels are investigated.

Electric Polarizability of hadrons with nHYP-Clover fermions
Michael Lujan, Andrei Alexandru, Walter Freeman, Frank Lee
Mon, 18:10, Seminar Room C (RW4) – Parallels 2C

Electric polarizability is an important parameter for the internal structure of hadrons. It quantifies the ability of the electric field to deform them. For the nucleon, it is very sensitive to the quark mass and is expected to diverge in the chiral limit. Previous studies of polarizabilities have been done at relatively heavy pion masses, leaving the chiral region largely unexplored. Here we present a study using two flavors of dynamical nHYP-clover fermions with two different dynamical pion masses (250 and 300 MeV) and several partially quenched valence masses. In addition, we also study the volume dependence using elongated lattices where the elongation is in the direction of the electric field.

Sea Contributions to the Electric Polarizability of Hadrons using Reweighting
Walter Freeman, Andrei Alexandru, Michael Lujan, Frank Lee
Mon, 18:30, Seminar Room C (RW4) – Parallels 2C

One of the most challenging aspects of a physically-complete calculation of electric polarizability using the background field method is to capture the interaction of the sea quarks with the background electric field. One way to do this is via reweighting in the sea quark electric charge. However, the standard stochastic estimate of the weight factor is quite noisy. We instead use a perturbative estimator whose variance can be reduced by several techniques to create a power series for the weight factor in terms of the background field. We present results from this approach for the sea contributions to the nucleon and neutral pion polarizability, and discuss the cause of the large stochastic fluctuations in the estimator.

Looking at the gluon moment of the nucleon with dynamical twisted mass fermions

Christian Wiese, Constantia Alexandrou, Vincent Drach, Kyriakos Hadjiyiannakou, Karl Jansen, Bartosz Kostrzewa

Tue, 14:00, Seminar Room B (RW3) – Parallels 3B

To understand the structure of hadrons it is important to know the parton distribution function (PDF) of their constituents, i.e. quarks and gluons. In our work we aim at computing the first moment of the gluon PDF $_g$ for the nucleon. We follow the approach of using the Feynman-Hellmann theorem, as suggested in arXiv:1205.6410, to compute the proton-gluon three-point function in order to extract the gluon moment. In this talk preliminary results computed on $24^3 \times 48$ lattices will be presented employing $N_f = 2 + 1 + 1$ maximally twisted mass fermions. We will also report on an attempt to compute the three-point function with the direct method on similar lattices.

Moments of structure functions for $N_f = 2$ near the physical point.

Sara Collins, Gunnar Bali, Benjamin Glässle, Johannes Najjar, Meinulf Göckeler, Rudolf Roedl, Andreas Schäfer, Wolfgang Soeldner, Andre Sternbeck

Tue, 14:20, Seminar Room B (RW3) – Parallels 3B

We report on our on-going study of the lower moments of iso-vector polarised and unpolarised structure functions, g_A and $\langle x \rangle_{u-d}$, for $N_f = 2$ non-perturbatively improved clover fermions. With pion masses which go down to about 160 MeV, we systematically investigate finite volume and excited state contributions.

Nucleon generalized form factors from lattice QCD near the physical quark mass

Andre Sternbeck, Gunnar Bali, Sara Collins, Benjamin Glässle, Johannes Najjar, Meinulf Göckeler, Rudolf Rödl, Andreas Schäfer, Wolfgang Söldner, Philipp Wein

Tue, 14:40, Seminar Room B (RW3) – Parallels 3B

We present new $N_f = 2$ data for nucleon (generalized) form factors, varying volume, lattice spacing and pion mass, down to below 160 MeV. We will also include an update of our (direct) calculation of the nucleon sigma term for a range of pion mass values.

Nucleon structure with twisted mass fermions
Constantia Alexandrou, Martha Constantinou, Vincent Drach, Karl Jansen, Christos Kallidonis, Giannis Koutsou
Tue, 15:00, Seminar Room B (RW3) – Parallels 3B

We present results on the nucleon form factors, momentum fraction and helicity moment for Nf=2 and Nf=2+1+1 twisted mass fermions for a number of lattice sizes and lattice spacings. The implications of these results on the spin content of the nucleon are discussed. We also plan to show preliminary results for a new Nf=2 ensemble at the physical pion mass.

Calculating the x Dependence of Nucleon Parton Distribution Functions
Huey-Wen Lin
Tue, 15:20, Seminar Room B (RW3) – Parallels 3B

We present a first direct lattice-QCD calculation of the x dependence of nucleon structure functions. By taking a nucleon with a large momentum boost, we are able to connect light-cone quantities to lattice-QCD nonlocal but time-independent matrix elements. Since the largest attainable momentum is limited, we correct for the sizable leading momentum dependence. In this talk, we present an exploratory study of the quark density, helicity and transversity distributions using $N_f = 2+1+1$ HISQ lattice gauge ensembles and clover valence fermions at pion mass 310 MeV. We demonstrate that using this methodology, our distributions reproduce the first moments determined by conventional lattice methods using the same parameters. Even at this pion mass, we are able to make significant observations and predictions about the nucleon sea flavor structure.

Nucleon transversity generalized form factors with twisted mass fermions
Martha Constantinou, Constantia Alexandrou, Karl Jansen, Giannis Koutsou, Haralambos (Haris) Panagopoulos
Tue, 15:40, Seminar Room B (RW3) – Parallels 3B

We compare results extracted using the summation and plateau methods for a number of connected three-point functions associated with nucleon matrix elements. We present results on the nucleon tensor form factors and first moment of the transversity generalized parton distribution for Nf=2+1+1 twisted mass fermions. We also plan to add a new ensemble at the physical pion mass.

The quark contents of the nucleon and their implication for dark matter search
Vincent Drach, Constantia Alexandrou, Martha Constantinou, Karl Jansen, Giannis Koutsou, Alejandro Vaquero
Tue, 16:20, Seminar Room B (RW3) – Parallels 4B

We present results concerning the light and strange quark contents of the Nucleon using $N_f = 2 + 1 + 1$ flavours of maximally twisted mass fermions. The corresponding sigma-terms are casting light on the origin of the nucleon mass and their values are important to interpret experimental data from direct dark matter searches. We provide our results of the sigma terms and of the strangeness parameter including a detailed and comprehensive analysis of systematic uncertainties arising in our computations.

Strange and Charm Spin in the Nucleon with Overlap Fermion
Ming Gong
Tue, 16:40, Seminar Room B (RW3) – Parallels 4B

The strange and charm spin contributions to the nucleon spin are calculated with overlap fermion on DWF configurations. This work is done by calculating the disconnected three point correlation functions through the anomalous Ward identity. The quark loop of the pseuscalar density is calculated with low-mode average and grid-noise estimate for the high modes. The overlap operator is used for the topological charge density.

Wave functions of the Nucleon and the $N^*(1535)$
Rainer Schiel, Vladimir Braun, Sara Collins, Meinulf Göckeler, Andreas Schäfer, Andre Sternbeck, Philipp Wein
Tue, 17:00, Seminar Room B (RW3) – Parallels 4B

The wave functions of the nucleon and its parity partner, the N*(1535), in the infinite momentum frame can be computed from Lattice QCD. We have used Nf = 2 flavors of dynamical Clover fermions to determine the normalization constants of the leading and next-to-leading twist wave functions as well as moments of the leading twist wave functions, also known as distribution amplitudes. Here, we present our latest results which include data from lattices with almost physical pion mass and a variational method approach to improve the signal of the N* (1535) state.

Neutron and proton EDM with $N_f = 2+1$ domain-wall fermion
Eigo Shintani, Tom Blum, Taku Izubuchi, Amarjit Soni
Tue, 17:20, Seminar Room B (RW3) – Parallels 4B

We will present the recent calculation of neutron and proton EDM and EDM form factor with Nf=2+1 domain-wall fermion including the θ-term. Applying the all-mode-averaging technique in this measurement enables us to have a solid estimate of EDM from lattice QCD. We also check the excited state contamination and variance of transfer momentum of EDM form factor. We will discuss the chiral behavior and future plans.

Neutron Electric Dipole Moments from Beyond the Standard Model Physics
Tanmoy Bhattacharya, Vincenzo Cirigliano, Rajan Gupta
Tue, 17:40, Seminar Room B (RW3) – Parallels 4B

Neutron Electric Dipole Moments (nEDM), a generic feature of CP-violation, is predicted to be very small in the Standard Model, but can be much larger in most extensions of the model. In this talk, I will discuss the classification of the CP violating operators up to dimension 6 that can give rise to nEDM, and describe their mixing and their renormalization structure in both dimensional and cutoff regularizations in general terms. Finally I will describe how to connect the dimension 5 operators, in particular, the Chromoelectric Dipole Moment of the quarks, between MSbar scheme and a Regularization Independent prescription, in the chiral limit.

Computation of disconnected contributions to nucleon observables
Alejandro Vaquero, Constantia Alexandrou, Vincent Drach, Kyriacos Hadjiyiannakou, Karl Jansen, Giannis Koutsou
Thu, 14:00, Seminar Room B (RW3) – Parallels 7B

We compare several methods for computing disconnected fermion loops contributing to nucleon three-point functions. We obtain high statistics results using $N_f = 2+1+1$ twisted mass fermions for which some of the methods developed are optimal. The computations are performed using code implemented for GPUs, which will be pesented in the dedicated code-development session.

Nucleon structure from stochastic estimators

Johannes Najjar, Gunnar S. Bali, Sara Collins, Benjamin Glässle, Meinulf Göckeler, Rudolf Rödl, Andreas Schäfer, Andre Sternbeck, Wolfgang Söldner

Thu, 14:20, Seminar Room B (RW3) – Parallels 7B

Using stochastic estimators for connected meson and baryon three-point functions has successfully been tried in the past years. Compared to the standard sequential source method we trade the freedom to compute the current-to-sink propagator independent of the hadron sink for additional stochastic noise in our observables. In the case of the nucleon we can use this freedom to compute many different sink-momentum/polarization combinations, which grants access to more virtualities. We will present preliminary results on the scalar, electro-magnetic and axial form factors of the nucleon in $N_f = 2 + 1$ lattice QCD.

A high-statistics study of the nucleon axial charge and quark momentum fraction

Benjamin Jäger, Stefano Capitani, Thomas Rae, Michele Della Morte, Georg von Hippel, Bastian Knippschild, Harvey Meyer, Hartmut Wittig

Thu, 14:40, Seminar Room B (RW3) – Parallels 7B

We present updated results for the nucleon axial charge [arXiv:1205.0180] using non-perturbatively O(a) improved Wilson fermions with two dynamical quarks on the CLS ensembles. This update includes a substantial increase of statistics (up to 4000 measurements) and four more chiral ensembles with pion masses down to 195 MeV. We show that excited states can be controlled by using the summed operator insertion method. In addition, we present preliminary results for quantities involving derivatives, such as the average momentum fraction carried by a quark in a nucleon.

A high-statistics study of nucleon electromagnetic form factors

Thomas Rae, Stefano Capitani, Michele Della Morte, Georg von Hippel, Benjamin Jäger, Bastian Knippschild, Harvey Meyer, Hartmut Wittig

Thu, 15:00, Seminar Room B (RW3) – Parallels 7B

We present updated results for the nucleon electromagnetic form factors, which include a significant increase in statistics for all ensembles (to up to 4000 measurements), as well as the addition of an ensemble with a near-physical pion mass ($m_\pi \sim 195$ MeV). Our previous form factor calculations [arXiv:1211.1282] indicated a significant systematic effect due to excited state contaminations, similar to those observed for the nucleon axial charge [arXiv:1205.0180]. The new data allows us to perform a thorough study of the potential systematic effects encountered in the lattice extraction, through a comparison of the 'plateau fit' method (using several different time separations between the operators at the source and sink (the largest ~ 1.1 fm)) and the summed operator insertion method (which provides a mechanism to suppress the contamination). Any systematic effects will impact the Q^2-dependence of the form factors and derived quantities, both of which will be discussed. The measurements are calculated using the CLS ensembles with non-perturbatively $O(a)$ improved Wilson fermions in $N_f = 2$ QCD.

Nucleon axial charge in 2+1-flavor dynamical DWF lattice QCD (for RBC and UKQCD Collaborations)
Shigemi Ohta
Thu, 15:20, Seminar Room B (RW3) – Parallels 7B

We report the current status of nucleon isovector axial charge, (g_A), and vector charge, (g_V), calculated using recent RBC/UKQCD 2+1-flavor dynamical domain-wall fermions (DWF) lattice QCD ensembles: with Iwasaki gauge action at lattice cutoff, (a^{-1}), of about 1.7 GeV, linear lattice extent, (L), of about 2.8 fm, pion mass, (m_π), of about 420 and 330 MeV, and with Iwasaki+DSDR gauge action at (a^{-1}) of about 1.4 GeV, (L) of 4.6 fm, (m_π) of 250 and 170 MeV. The calculations have been refined with enhanced statistics through successful application of the all-mode-averaging (AMA) technique. Precision agreement seen in the charge ratio, (g_A/g_V), of 1.17(2) for 420-MeV and 1.18(4) for 250-MeV ensembles that share the finite-size scaling parameter ($m_\pi L$) of about 5.8 further corroborate our scaling conjecture. We also present study on the dependence on source-sink separation that excludes excited-state contamination in these and earlier calculations of ours that share similarly careful planning and execution. We will also report the isovector quark momentum and helicity fraction moments of nucleon structure functions.

Nucleon form factors with 2+1 flavors of domain wall fermions and All-Mode-Averaging
Meifeng Lin
Thu, 15:40, Seminar Room B (RW3) – Parallels 7B

We report recent progress in the calculations of the isovector nucleon electromagnetic and axial form factors using 2+1 flavors of domain wall fermions at pion masses of 170 MeV and 250 MeV. The lattice size is fixed at $32^3 \times 64$ with a lattice cutoff scale of 1.37(1) GeV. For the 170-MeV ensemble, we employed the All-Mode-Averaging (AMA) technique, which led to roughly a factor of 20 improvement in computational efficiency and has reduced the statistical errors in our results significantly. We were also able to do calculations at different source-sink separations without much additional cost by reusing the low eigen-modes stored for the AMA calculations. We will present results for the isovector form factors and their derived quantities, including the Dirac and Pauli radii, anomalous magnetic moment, and the axial radius, and discuss the effects of possible excited-state contaminations. Prospects and future plans will also be briefly discussed.

Nucleon form factors with light Wilson quarks
Jeremy Green, Michael Engelhardt, Stefan Krieg, John Negele, Andrew Pochinsky, Sergey Syritsyn
Thu, 16:30, Seminar Room B (RW3) – Parallels 8B

Observables including nucleon isovector Dirac and Pauli form factors will be presented from calculations using 2+1 flavors of Wilson quarks. These include an ensemble with pion mass 149 MeV and box size 5.6 fm, which nearly eliminates the uncertainty associated with extrapolation to the physical pion mass. The results show agreement with experiment for the vector form factors, which occurs only when excited-state contributions are reduced.

Probing the nucleon and its excitations in full QCD
Ben Owen, Waseem Kamleh, Derek Leinweber, Selim Mahbub, Ben Menadue
Thu, 16:50, Seminar Room B (RW3) – Parallels 8B

In this presentation we discuss how correlation matrix techniques enable precision calculations of the form factors of hadronic ground state properties and new access to the corresponding properties in hadronic excitations. In particular, we will focus on the nucleon and present results for the electromagnetic form factors and axial charges of the ground state nucleon and its excitations using the PACS-CS (2+1)-flavor full-QCD ensembles.

SU(3) flavour breaking and baryon structure
James Zanotti
Thu, 17:10, Seminar Room B (RW3) – Parallels 8B

The QCDSF Collaboration has recently proposed a new method for performing nf=2+1 simulations along a quark mass trajectory that starts at the SU(3)-flavour symmetric limit and moves towards the physical point while keeping the singlet quark mass fixed. In this talk, I will report on how baryon octet matrix elements change as we move along this trajectory.

Sigma-terms and axial charge for hyperons and charmed baryons
Kyriakos Hadjiyiannakou, Constantia Alexandrou, Karl Jansen, Christos Kallidonis, Alejandro Vaquero
Thu, 17:30, Seminar Room B (RW3) – Parallels 8B

We discuss methods for the stochastic evaluation of baryon three-point functions using the nucleon as a test case. We present results on the sigma-terms and axial charge of hyperons and charmed baryons using $N_f = 2 + 1 + 1$ twisted mass fermions.

Electromagnetic Structure of the $\Lambda(1405)$

Ben Menadue, Derek Leinweber, Waseem Kamleh, Selim Mahbub, Ben Owen

Thu, 17:50, Seminar Room B (RW3) – Parallels 8B

The electromagnetic form factors of a hadron can be used to provide insight into its internal structure and quark distribution. Continuing to build on our successful technique to isolate the otherwise-elusive $\Lambda(1405)$ using correlation matrix techniques and multiple source and sink smearings, we present calculations of quark sector contributions to the electric and magnetic form factors of the $\Lambda(1405)$. We use the PACS-CS (2+1)-flavour full-QCD ensembles available through the ILDG. Our preliminary results are consistent with the development of an important $\bar{K}N$ molecular-type contribution to the as the pion mass approaches the physical value.

Determination of Delta resonance parameters from lattice QCD

Marcus Petschlies, Constantia Alexandrou, John Negele, Alexei Strelchenko, Antonios Tsapalis

Thu, 18:10, Seminar Room B (RW3) – Parallels 8B

We discuss a method suitable for extracting the resonance parameters of unstable baryons in lattice QCD. The method is applied to the strong decay of the Delta to a pion-nucleon state, for which case we extract the pion-nucleon - Delta coupling constant and Delta decay width.

Tests of the vacuum polarization fits for the muon $g-2$

Santiago Peris, Maarten Golterman, Kim Maltman

Fri, 14:00, Seminar Room B (RW3) – Parallels 9B

Using accurate experimental spectral data, supplemented by a well motivated (and phenomenologically successful) parameterization for the high-s region not covered by the data, we construct a physically constrained model of the isospin-one vector channel polarization function. At low euclidean Q^2, the model is strongly dominated by the measured experimental data, and allows us to explore the systematic error associated with the Q^2 fit in existing lattice determinations of the hadronic vacuum polarization contribution to $(g-2)_\mu$. We find that a final error in this quantity of the order of a few percent is not presently possible, given the lack of precise information about momentum of the order of the muon mass.

Leading-order hadronic contribution to the anomalous magnetic moment of the muon from $N_f = 2 + 1 + 1$ twisted mass fermions
Grit Hotzel, Florian Burger, Xu Feng, Karl Jansen, Marcus Petschlies, Dru Renner
Fri, 14:20, Seminar Room B (RW3) – Parallels 9B

We present results for the leading anomalous QCD correction to the magnetic moment of the muon including the first two generations of quarks as dynamical degrees of freedom. Several light quark masses are examined in order to yield a controlled extrapolation to the physical pion mass. We analyse ensembles for three different lattice spacings and several volumes in order to investigate lattice artefacts and finite-size effects, respectively. We also plan to provide preliminary results for this quantity for two flavours of mass-degenerate quarks at the physical value of the pion mass.

First-order hadronic contributions to muon $g - 2$ from HEX-smeared clover fermions
Eric Gregory, Zoltan Fodor, Christian Hoelbling, Stefan Krieg, Laurent Lellouch, Rehan Malek, Craig McNeile, Kalman Szabo
Fri, 14:40, Seminar Room B (RW3) – Parallels 9B

We present preliminary lattice results for the leading-order hadronic contribution to the muon anomalous magnetic moment, calculated with hex-smeared clover fermions. In our analysis we include 2+1-flavor ensembles with pions at the physical mass.

The hadronic vacuum polarization with twisted boundary conditions
Christopher Aubin, Thomas Blum, Maarten Golterman, Santiago Peris
Fri, 15:00, Seminar Room B (RW3) – Parallels 9B

The leading-order hadronic contribution to the anomalous magnetic moment is given by a weighted integral over the subtracted hadronic vacuum polarization. This integral is dominated by euclidean momenta of order the muon mass which are not available on current lattice volumes with periodic boundary conditions. Twisted boundary conditions can in principle help access momenta of any size even in a finite volume. We investigate the implementation of twisted boundary conditions both numerically (using all-mode averaging for improved statistics) and analytically, and present our initial results.

Computing the Adler function from vacuum polarization

Hanno Horch, Gregorio Herdoiza, Andreas Jüttner, Michele Della Morte, Benjamin Jäger, Hartmut Wittig

Fri, 15:20, Seminar Room B (RW3) – Parallels 9B

We use lattice data for the hadronic vacuum polarization tensor to study the associated Ward identities and to determine the Adler function. The vacuum polarization tensor is computed from a combination of point-split and local vector currents, using two flavours of Wilson fermions. Partially twisted boundary conditions are employed to obtain a fine momentum resolution. The approach towards the continuum Ward identities can be monitored using data computed for three values of the lattice spacing. We determine the Adler function from the derivative of the vacuum polarization tensor. A large range of momenta is considered to analyze the size of cutoff effects.

Adler function and hadronic vacuum polarization from lattice vector correlators in the time-momentum representation

Anthony Francis, Harvey Meyer, Hartmut Wittig, Benjamin Jäger

Fri, 15:40, Seminar Room B (RW3) – Parallels 9B

We study a representation of the hadronic vacuum polarization based on the time-momentum representation of the vector correlator. This representation suggests a way to compute the hadronic vacuum polarization and the associated Adler function for any value of virtuality, irrespective of the flavor structure of the current. We present results on both of these phenomenologically important functions, derived from local-conserved two-point lattice vector correlation functions, computed on a subset of light two-flavor ensembles made available to us through the CLS effort. In addition we comment on the finite-size effects of our particular representation of the Adler function based on theoretical arguments.

Finite volume renormalization scheme for fermionic operators

Kostas Orginos, Christopher Monahan

Poster Session

We present a proposal for a new finite volume renormalization scheme. This scheme, much like the Schrodinger functional method, allows for a nonperturbative determination of the running of operators using a step scaling approach and is based on the Wilson flow applied to both fermion and gauge fields. We give some preliminary results for quark bilinears in the quenched approximation and for matching to the MS-bar scheme.

Fitting the lattice vacuum polarisation function to perturbation theory

Gregorio Herdoiza, Michele Della Morte, Hanno Horch, Benjamin Jäger, Andreas Jüttner, Hartmut Wittig

Poster Session

The hadronic vacuum polarisation function computed with two flavours of improved Wilson fermions is studied in the large momentum region. Three values of the lattice spacing are used to monitor the size of discretisation effects. A comparison to perturbative QCD expressions including the contributions from the Operator Product Expansion is performed. The dominant systematic effects present in this matching to perturbation theory are explored.

First and second moments of the disconnected sea partons from overlap fermion on DWF configurations

Mingyang Sun, Ming Gong, Keh-Fei Liu

Poster Session

We present a calculation of $\langle x \rangle$ and $\langle x^2 \rangle$ of the proton for the disconnected insertion. We adopt overlap fermion on 2 + 1 flavor domain-wall fermion configurations on the $24^3 \times 64$ lattice. Smeared sources are used for nucleon propagator. Low-mode average togather with an even-odd grid source and time-dilution with stochastic noise for the high modes are utilized to calculate the quark loop.

Fitting strategies to extract the axial charge of the nucleon from lattice QCD

Jiayu Hua, Georg von Hippel, Benjamin Jäger, Harvey Meyer, Thomas Rae, Hartmut Wittig

Poster Session

We report on our fit methods for the nucleon axial charge g_A in QCD with two flavours of dynamical quarks. The plateau method, the summation method and a new "midpoint" method are used to investigate contributions from excited states which affect the determination of g_A. We also present a method to perform correlated fits when the standard estimator for the inverse of the covariance matrix becomes unstable.

Pion structure from lattice QCD
Narjes Javadi-Motaghi, Gunnar Bali, Sara Collins, Benjamin Glaessle, Meinulf Göckeler, Wolfgang Söldner, Andre Sternbeck
Poster Session

We report on lattice calculations of the lowest moment of pion structure functions and (generalized) form factors at several values of momentum transfer. We use Nf=2 flavors of O(a) improved Wilson-Clover fermions. Our preliminary results are for pion masses down to 160 MeV.

Time-like pion form factor in lattice QCD
Xu Feng, Sinya Aoki, Shoji Hashimoto, Takashi Kaneko
Poster Session

We present a lattice QCD calculation of the time-like pion form factor with 2+1-flavors of overlap fermions. In a finite box, the virtual-photon-to-two-pion amplitude is altered by a finite-size effect. Using the method proposed by Meyer and its extension to various moving frames, we can determine these finite-size corrections properly and thus relate the finite-volume calculation of the two-pion decay amplitude to the wanted time-like pion form factor in the infinite volume.

Standard Model Parameters and Renormalization

Computation of the strong coupling in $N_f = 4$ QCD
Marina Marinkovic
Mon, 14:00, Seminar Room C (RW4) – Parallels 1C

We present a non-perturbative computation of the running of $N_f = 4$ QCD coupling with four flavours of O(a) improved Wilson fermions and Wilson plaquette action. The Schrödinger functional strategy is used to overcome the multi-scale problem in QCD and keep full control over the systematic errors. We check that cutoff effects in the step scaling function are weak by taking one more resolution compared to a previous computation. Finally, we show an improved result of the Lambda parameter in four flavor QCD in the units of hadronic scale L_{max}.

Studying the gradient flow coupling in the SF
Patrick Fritzsch, Alberto Ramos
Mon, 14:20, Seminar Room C (RW4) – Parallels 1C

We discuss the setup and features of a new definition of the running coupling in the Schroedinger functional scheme based on the gradient flow. Its suitability for a precise continuum limit in QCD is demonstrated on a set of $N_f = 2$ gauge field ensembles in a physical volume of $L \sim 0.4$ fm. Moreover, we report on preliminary results of its step-scaling function at one value of the coupling in SU(3) pure gauge theory.

Vector correlator and scale determination in lattice QCD
Harvey Meyer, Georg von Hippel, Fred Jegerlehner, Anthony Francis
Mon, 14:40, Seminar Room C (RW4) – Parallels 1C

We implement a proposal made in 1107.4388 to determine the lattice spacing by matching the lattice vector correlator at a reference distance scale with the same correlator obtained by a dispersion relation based on the R ratio determined experimentally. We work with the isovector current, requiring a separation of the isovector hadronic final states on the phenomenological side. We also discuss the finite-size effect on the correlator, which must be controlled in order for the method to be applicable.

On the N_f-dependence of gluonic observables
Mattia Bruno
Mon, 15:00, Seminar Room C (RW4) – Parallels 1C

We compute gluonic observables at finite Gradient flow time for two flavour QCD. Despite significant autocorrelations, the use of the full CLS ensembles together with a careful error analysis allows to extract interesting quantities and to approach the continuum limit of the two flavour theory. A proper comparison to $N_f = 0$ results shows the size of sea quark effects.

Finite size effects in lattice RI-MOM
Francesco Di Renzo, Michele Brambilla
Mon, 15:20, Seminar Room C (RW4) – Parallels 1C

RI-MOM (or its RI'-MOM variant) is one of the most polular renormalization schemes for Lattice QCD; being regulator independent, it can be effectively adopted in a lattice regularization. RI-MOM is defined in infinite volume. This is in principle a fundamental problem for the lattice, since any simulation is performed in a finite volume. From a practical point of view, one most often verifies a posteriori (by performing computations on different physical volumes) the expectation that renormalization constants, determined in the RI-MOM scheme at large momenta, should not be affected by significant finite size effects. In the context of Numerical Stochastic Perturbation Theory, we have in recent years devised a novel method to explicitly look and correct for finite size effects (in a convenient window). We review this method, discussing how it can be applied in a non-perturbative formulation as well.

Renormalization of the momentum density on the lattice using shifted boundary conditions

Daniel Robaina, Harvey Meyer

Mon, 15:40, Seminar Room C (RW4) – Parallels 1C

In order to extract transport quantities from energy-momentum-tensor (EMT) correlators in Lattice QCD there is a strong need for a non-perturbative renormalization of these operators. This is due to the fact that the lattice regularization explicitly breaks translational invariance, invalidating the non-renormalization-theorem. Here we present a non-perturbative calculation of the renormalization constant of the off-diagonal components of the EMT in SU(3) pure gauge theory using lattices with shifted boundary conditions. This allows us to induce a non-zero momentum in the system controlled by the shift parameter and to determine the normalization of the momentum density operator.

Combined Lattice and Continuum Analysis of the Light Quark $V - A$ Correlator at NNLO in ChPT

Kim Maltman, Peter Boyle, Luigi Del Debbio, Nicolas Garron, Jamie Hudspith, Eoin Kerrane, James Zanotti

Wed, 08:30, Seminar Room C (RW4) – Parallels 5C

The light quark V-A correlator is analyzed at NNLO in the chiral expansion using a combination of continuum and lattice input. It is shown how lattice data with variable quark masses allows for a determination of a crucial combination on NNLO LECs inaccessible in the continuum approach, while the high precision determination of the correlator for physical quark masses provided by the dispersive continuum representation, plus additional continuum sum rule inputs for a second combination of NNLO LECs, further sharpens the lattice determination. The result is the first NNLO determination of the NLO LEC $L_1 0$ having all NNLO uncertainties under full, explicit control.

Non-perturbative renormalization of overlap quark bilinears on domain wall fermion configurations

Zhaofeng Liu, Ying Chen, Shao-Jing Dong, Ming Gong, Anyi Li, Keh-Fei Liu, Yibo Yang

Wed, 08:50, Seminar Room C (RW4) – Parallels 5C

We present calculations of the renormalization constants of overlap quark bilinear operators using the RI/MOM scheme. The matching to the MSbar scheme is then obtained by conversion ratios from continuum perturbation theory. The calculations are on $24^3 \times 64$ and $32^3 \times 64$ lattices with several valance and sea quark masses. The 2+1-flavor configurations are from the RBC/UKQCD collaboration.

NPR of bilinear operators with improved staggered quarks

Jangho Kim, Jongjeong Kim, Weonjong Lee, Stephen Sharpe, Boram Yoon

Wed, 09:10, Seminar Room C (RW4) – Parallels 5C

Matching introduces a significant systematic uncertainty in the lattice calculation of quark mass, and B_K with improved staggered fermions. We present matching factors for the bilinear operators obtained using the non-perturbative renormalization method (NPR) for improved staggered fermions on the MILC asqtad lattices. We obtain the wave function renormalization factor from the conserved vector current. We also study the operator mixing. Preliminary results of bilinear matching are reported.

Nonperturbative tests of the renormalisation of mixed clover-staggered currents in lattice QCD

Bipasha Chakraborty, Christine Davies, Gordon Donald, Rachel Dowdall, Jonna Koponen, G. Peter Lepage

Wed, 09:30, Seminar Room C (RW4) – Parallels 5C

The Fermilab Lattice and MILC collaborations have shown in one-loop lattice QCD perturbation theory that the renormalisation constants of vector and axial-vector mixed Clover-Asqtad currents are closely related to the product of those for Clover-Clover and Asqtad-Asqtad (local) vector currents. To be useful for future higher precision calculations this relationship must be valid beyond one-loop. We test its validity nonperturbatively by using the temporal-axial and local vector currents made of Clover strange quarks, Highly Improved Staggered (HISQ) strange quarks and mixed Clover-HISQ strange quarks. We utilise the fact that the HISQ temporal-axial current is absolutely normalised and that the local vector currents can be normalised at zero momentum transfer. We have used three full lattice QCD ensembles with widely differing lattice spacings generated by the MILC collaboration. We find that the renormalisation of the mixed current differs from the square root of the product of the pure HISQ and pure clover currents by 2-3

Perturbatively improving renormalization constants

Holger Perlt, Martha Constantinou, Marios Costa, Meinulf Goeckeler, Roger Horsley, Haralambos Panagopoulos, P.E.L. Rakow, Gerrit Schierholz, Arwed Schiller

Wed, 09:50, Seminar Room C (RW4) – Parallels 5C

The determination of renormalization factors is of crucial importance in lattice QCD. They relate the observables obtained on the lattice to their measured counterparts in the continuum in a suitable renormalization scheme. Therefore, they have to be computed as precisely as possible. A widely used approach is the nonperturbative Rome-Southampton method. It requires, however, a careful treatment of lattice artifacts. We investigate a method to suppress these artifacts by subtracting one-loop contributions to renormalization factors calculated in lattice perturbation theory. We compare results obtained from a complete one-loop subtraction with those calculated for a subtraction of contributions proportional to the square of the lattice spacing.

Determination of c_A in three-flavour lattice QCD with Wilson fermions and tree-level improved gauge action
Christian Wittemeier, John Bulava, Michele Della Morte, Jochen Heitger
Wed, 10:10, Seminar Room C (RW4) – Parallels 5C

We report on an ongoing non-perturbative determination of the improvement coefficient of the axial current, c_A, with three flavours of dynamical O(a) improved Wilson quarks and tree-level Symanzik improved gauge action. Our computations are based on simulations with the openQCD code. The improvement condition for a range of couplings is formulated with Schrödinger functional boundary conditions and imposed along a line of constant physics in parameter space. Our analysis involves correlation functions with boundary wave functions such that a large sensitivity to c_A can be reached by exploiting the PCAC relation with two different pseudoscalar states.

A determination of the average up-down, strange and charm quark masses at $N_f = 2 + 1 + 1$
Paolo Lami, for the ETM Collaboration
Fri, 14:00, Seminar Room C (RW4) – Parallels 9C

We present a Lattice QCD determination of the average up-down, strange and charm quark masses based on simulations performed by the European Twisted Mass Collaboration with $N_f = 2 + 1 + 1$ dynamical fermions. We simulated at three different values of the lattice spacing, the smallest being approximately 0.06 fm, and with pion masses as small as 230MeV.

A $N_f = 2 + 1 + 1$ "twisted" determination of the b quark mass
Eleonora Picca, for the ETM Collaboration
Fri, 14:20, Seminar Room C (RW4) – Parallels 9C

I present a preliminary lattice QCD determination of the b quark mass performed with $N_f = 2 + 1 + 1$ twisted mass Wilson fermions. Simulations at three values of the lattice spacing and with light quark masses corresponding to $M_\pi \approx 230$ MeV have been performed, and the results are extrapolated to the continuum limit. The two point correlation functions used in the analysis are calculated with an optimized smearing technique. An interpolation in the heavy quark mass between the charm region and the infinite mass limit has been performed using suitable ratios with known static limit (the so called ratio method).

Pseudoscalar decay constants f_K/f_π, f_D and f_{D_s} with $N_f = 2+1+1$ ETMC congurations
Lorenzo Riggio, for the ETM Collaboration
Fri, 14:40, Seminar Room C (RW4) – Parallels 9C

We present a Lattice QCD calculation of the pseudoscalar decay constants f_π, f_K, f_D and f_{D_s} performed with $N_f = 2+1+1$ dynamical fermions by the European Twisted Mass Collaboration. We simulated at three di fferent lattice spacings, the smallest being apporximately 0,06 fm, and with pion masses down to 230 MeV.

Chiral behaviour of the pion decay constant in $N_f = 2$ QCD
Stefano Lottini
Fri, 15:00, Seminar Room C (RW4) – Parallels 9C

As increased statistics and new ensembles with light pions have become available within the CLS effort, we complete previous work by inspecting the chiral behaviour of the pion decay constant. We discuss the validity of Chiral Perturbation Theory (ChPT) and examine the results concerning the kaon decay constant, the ratio f_K/f_π, and the ensuing lattice spacing determination; along the way, the relevant low-energy constants of SU(2) ChPT are estimated. All simulations were performed with two dynamical flavours of nonperturbatively O(a)-improved Wilson fermions, on volumes with $m_\pi L \geq 4$, pion masses $\geq$ 192 MeV and lattice spacings down to 0.047 fm. The careful error analysis takes into account the effect of slow modes in the autocorrelations.

The chromomagnetic operator on the lattice

Haralambos (Haris) Panagopoulos, Martha Constantinou, Marios Costa, Roberto Frezzotti, Vittorio Lubicz, Guido Martinelli, Davide Meloni, Silvano Simula

Fri, 15:20, Seminar Room C (RW4) – Parallels 9C

We study matrix elements of the "chromomagnetic" operator on the lattice. This operator is contained in the strangeness-changing effective Hamiltonian which describes electroweak effects in the Standard Model and beyond. Having dimension 5, the chromomagnetic operator is characterized by a rich pattern of mixing with other operators of equal and lower dimensionality, including also non gauge invariant quantities; it is thus quite a challenge to extract from lattice simulations a clear signal for the hadronic matrix elements of this operator. We compute all relevant mixing coefficients to one loop in lattice perturbation theory; this necessitates calculating both 2-point (quark-antiquark) and 3-point (gluon-quark-antiquark) Green's functions at nonzero quark masses. We use the twisted mass lattice formulation, with Symanzik improved gluon action.

Renormalization of HQET $\Delta B = 2$ operators: O(a) improvement and $1/m$ matching with QCD

Mauro Lucio Papinutto, Anastassios Vladikas, Carlos Pena, Gregorio Herdoiza

Fri, 15:40, Seminar Room C (RW4) – Parallels 9C

We determine a basis of dimension 7 operators which arise at O(a) in the Symanzik expansion of the DB=2 operators with static heavy quarks. Light quarks are either Wilson (including fully twisted mass) or Ginsparg-Wilson. In both these regularizations we have the same number of closely related O(a) counterterms. Only a subset of these operators has previously appeared in the literature. The O(1/m) operators contributing beyond the static approximation are also discussed.

Perturbative renormalization of staggered fermion operators with stout improvement: Application to the magnetic susceptibility of QCD

Marios Costa, Gunnar S. Bali, Falk Bruckmann, Martha Constantinou, Gergely Endrodi, Sandor Katz, Haralambos (Haris) Panagopoulos, Andreas Schaefer

Poster Session

We calculate the fermion propagator and the quark-antiquark Green's functions for a complete set of ultralocal fermion bilinears using perturbation theory up to one-loop and to lowest order in the lattice spacing. We employed the staggered action for fermions and the Symanzik improved action for gluons. From our calculations we determine the renormalization factors for the quark field and for all ultralocal taste-singlet bilinear operators. The novel aspect of our calculations is that the gluon links which appear both in the fermion action and in the definition of the bilinears have been improved by applying a stout smearing procedure up to 2 times, iteratively. The renormalization functions are presented in the RI' scheme; the dependence on all stout parameters, as well as on the coupling constant, the number of colors, the lattice spacing, the gauge fixing parameter and the renormalization scale, is shown explicitly. We apply our results to a nonperturbative study of the magnetic susceptibility of QCD at zero and finite temperature.

Quantifying Discretization Errors for the Gluon and Ghost Propagators using Stochastic Perturbation Theory

Jakob Simeth, Andre Sternbeck

Poster Session

The subtraction of hypercubic lattice corrections, calculated at 1-loop order in lattice perturbation theory (LPT), is common practice, e.g., for determinations of renormalization constants in lattice hadron physics. Providing such corrections beyond 1-loop order is however very demanding in LPT, and numerical stochastic perturbation theory (NSPT) might be the better candidate for this. Here we report on a first feasibility check of this method and provide the lattice corrections up to 3-loop order for the SU(3) gluon and ghost propagators in Landau gauge in an parametrization for arbitrary values of the lattice coupling. These propagators are ideal for this check as they are available from lattice calculations to high precision and can be combined to a renormalization group invariant product (Minimal MOM coupling) for which it has been seen that the corresponding 1-loop LPT corrections are insufficient to remove the bulk of the hypercubic lattice artifacts from the data.

The Kaon Bag Parameter at Physical Mass
Julien Frison
Poster Session

We present preliminary results for the calculation of the Kaon Bag parameter B_K in $N_f = 2 + 1$ lattice QCD, using Möbius Domain Wall Fermion ensembles generated by the RBC-UKQCD collaboration. This computation is done directly at physical pion mass, so that we do not have to rely on chiral perturbation theory or any other mass extrapolation. In parallel, the four-quark operator is renormalised through the Rome-Southampton technique. Finally, we compare our value with previous results and draw some conclusions about the remaining dominant contributions in our error budget.

Critical slowing down and the gradient flow coupling in the Schroedinger functional
Felix Stollenwerk
Poster Session

We study the sensitivity of the gradient flow coupling to sectors of different topological charge and its implications in practical situations. Furthermore, we investigate an alternative definition of the running coupling that is expected to be less sensitive to the inability of the HMC algorithm to sample all topological sectors.

Theoretical Developments

Space-time symmetries and the Yang-Mills gradient flow
Agostino Patella, Luigi Del Debbio, Antonio Rago
Mon, 14:00, Seminar Room B (RW3) – Parallels 1B

The latest developments have shown how to use the gradient flow (or Wilson flow, on the lattice) for the exploration of symmetries, and the definition of the corresponding renormalized Noether currents. In particular infinitesimal translations can be introduced along the gradient flow for gauge theories, and the corresponding Ward identities can be derived. When applied to lattice gauge theories, this approach leads to a set of possible strategies to renormalize the energy-momentum tensor nonperturbatively, and to study dilatations and scale invariance.

The Schrödinger Functional in Numerical Stochastic Perturbation Theory
Dirk Hesse, Mattia Dalla Brida, Stefan Sint, Francesco Di Renzo, Michele Brambilla
Mon, 14:20, Seminar Room B (RW3) – Parallels 1B

The Schrodinger functional (SF) is a widely used tool, playing a key role in many lattice studies. While the SF is non-perturbatively defined, perturbation theory plays an important role and analytic calculations have even been pushed to two-loop order. Here we explore the prospect of applying numerical stochastic perturbation theory in this framework. In the pure SU(3) gauge theory we demonstrate the correctness of our implementation by comparing results for the SF coupling up to two-loop order with known results from the literature (for an application to the gradient flow cf. M. Dalla Brida's talk and for more details on the code in use c.f. the talk by M. Brambilla).

Numerical Stochastic Perturbation Theory and the Gradient Flow
Mattia Dalla Brida, Dirk Hesse
Mon, 14:40, Seminar Room B (RW3) – Parallels 1B

The gradient flow in lattice gauge theories allows for finite volume definitions of running couplings which combine a number of advantages. Here, we use numerical stochastic perturbation theory to study the recently proposed gradient flow coupling in a finite volume with Schroedinger functional boundary conditions (see Dirk Hesse's talk for other applications of numerical stochastic perturbation theory to the Schroedinger functional). We present results for pure SU(3) gauge theory up to two-loops in perturbation theory and for various lattice sizes. The results are compared with known analytic results and Monte Carlo simulations at high values of beta.

On a development of the phenomenological renormalization group
Oleg Borisenko, Vladimir Kushnir, Volodymyr Chelnokov
Mon, 15:00, Seminar Room B (RW3) – Parallels 1B

We propose a modification of the Nightingale renormalization group for lattice spin and gauge models by combining it with the cluster decimation approximation. Essential ingredients of our approach are: 1) exact calculation of the partition and correlation function on a finite lattice strip; 2) preservation of the mass gap or the second moment correlation length, computed in the infinite strip length limit, on each decimation step. The method is applied for studying general two and three dimensional Z(N) models. A perfect agreement with exact results (whenever available) is found. An extension of the method to models with a continuous symmetry is briefly discussed.

Schrödinger functional boundary conditions and improvement of the SU(N) pure gauge action for $N > 3$

Tuomas Karavirta, Ari Hietanen, Pol Vilaseca

Mon, 15:20, Seminar Room B (RW3) – Parallels 1B

The leading method to study the running of the coupling of gauge theories is based on Schrödinger Functional scheme. However, the boundary conditions and order a improvement have not been systematically generalized for theories with more than three colors. These theories have applications in BSM model building as well as in large N limit. We have studied the boundary conditions and improvement of the gauge fields within SF scheme. We have determined for all values of N the SF boundary fields which provide high signal/noise ratio. Additionally, we have calculated the improvement coefficient c_t for the pure gauge to one loop order for SU(N) gauge theories with $N = 2, \ldots, 8$.

Comparing Tensor Renormalization Group and Monte Carlo calculations for spin and gauge models

Yannick Meurice, Alan Denbleyker, Zechariah Gelzer, Yuzhi Liu, Judah Unmuth-Yockey, Tao Xiang, Zhiyuan Xie, Ji-Feng Yu, Haiyuan Zou

Mon, 15:40, Seminar Room B (RW3) – Parallels 1B

We show that the Tensor Renormalization Group method can be applied to O(N) spin models and abelian gauge models on (hyper) cubic lattices. This method allows to blockspin with a better control than the Migdal-Kadanoff approximation and is suitable to study conformality. It also allows to overcome the sign problem, for instance to do calculations at complex values of beta or with a chemical potential. We discuss recent numerical and analytical results regarding the critical properties of the 2D O(2) nonlinear sigma model and 3D Z2 and U(1) gauge models.

Subtleties of simulating gauge theories with atomic lattices
Peter Orland
Tue, 16:20, Seminar Room E (RW6) – Parallels 4E

Recently, many physicists have become interested in the possibility of building non-Abelian gauge magnets/quantum-link models in cold atomic lattices. The simplest models of this kind appear to have non-relativistic gluons (in the spin-wave approximation), as was first noted by D. Rohrlich and me. Nonetheless, such systems should display confinement of color. Related models have relativistic gluons, but the nature of the continuum field theory at a nearby fixed point is subtle.

Quantum Simulation of Non Abelian Lattice Gauge Theories
Michael Bögli, Debasish Banerjee, Marcello Dalmonte, Enrique Rico, Pascal Stebler, Uwe-Jens Wiese, Peter Zoller
Tue, 16:40, Seminar Room E (RW6) – Parallels 4E

To construct a quantum simulator for $U(N)$ and $SU(N)$ lattice gauge theories, we use quantum link models (QLMs). These models replace Wilson's classical link variables by quantum link operators, reducing the Hilbert space to finite dimensions. We show how to embody QLMs with fermionic matter in ultracold alkaline-earth atoms in optical lattices. These systems share qualitative features with QCD, including chiral symmetry breaking and restoration at non-zero temperature or baryon density. Unlike classical simulations, a quantum simulator does not suffer from sign problems and can address the corresponding chiral dynamics in real time.

Matrix Product States for Lattice Field Theories
Mari Carmen Banuls, Krzysztof Cichy, Karl Jansen, Ignacio Cirac
Tue, 17:00, Seminar Room E (RW6) – Parallels 4E

The term Tensor Network States (TNS) refers to a number of families that represent different ansaetze for the efficient description of the state of a quantum many-body system. Matrix Product States (MPS) are one particular case, and has become the most precise tool for the numerical study of one dimensional quantum many-body systems, as the basis of Density Matrix Renormalization Group methods. Lattice Gauge Theories, in their Hamiltonian version, offer a challenging scenario for these techniques. While the dimensions and sizes of the systems amenable to TNS studies are still far from those achievable by 4-dimensional systems, Tensor Networks can be readily used for problems which more standard techniques cannot easily tackle, such as the presence of a chemical potential, or out-of-equilibrium dynamics. We have explored the performance of Matrix Product States (MPS) in the case of the Schwinger model, as a widely used testbench for lattice techniques. Using finite-size, open boundary MPS, we are able to determine the low energy states of the model away from any perturbative regime. The precision achieved by the method allows for accurate finite size and continuum limit extrapolations of the ground state energy, but also of the mass gaps, thus showing the feasibility of these techniques for gauge theory problems.

Crystalline confinement
Debasish Banerjee, Uwe-Jens Wiese, Philippe Widmer, Fu-Jiun Jiang
Tue, 17:20, Seminar Room E (RW6) – Parallels 4E

Quantum Link models are generalizations of the Wilson formulation of lattice gauge theories, but have finite dimensional Hilbert spaces for gauge fields on the links. The U(1) quantum link model, with quantum spins $S = 1/2$, for example, has a 2d Hilbert space on each link, yet retains an exact $U(1)$ gauge symmetry. A recently constructed efficient cluster algorithm has been used to study the phase diagram of the model in (2+1)-dimensions, complementing the results already obtained from exact diagonalization and effective theory analysis (see talk by Philippe Widmer). The algorithm is the first efficient cluster algorithm for a U(1) quantum link model and relies on an exact dualization of the model to a height model. There are two different confining phases, both of which have linearly rising potential, but have different bulk structure due to breaking of different symmetries. Confinement occurs via multi-stranded strings in these phases. At high temperatures, there is a Coulomb phase characterized by a logarithmic potential. These features should be visible in a quantum simulator with ultra-cold atoms in optical lattices.

Emergence of a pseudo-Goldstone Boson in a (2+1)-d U(1) pure gauge theory

Philippe Widmer, Uwe-Jens Wiese, Debasish Banerjee, Fu-Jiun Jiang

Tue, 17:40, Seminar Room E (RW6) – Parallels 4E

We use a generalization of Wilson's formulation of lattice gauge theories known as quantum link models (QLM) in which the classical gauge fields are replaced by quantum operators, in the U(1) case e.g. by quantum spins $S = 1/2$. This leads to a finite-dimensional (in this case 2-d) Hilbert space per link. The gauge symmetry itself however remains exact. This allows the use of quantum simulators to extract results of interest in particle physics that are not accessible using Monte Carlo simulations, like e.g. real-time evolution of correlation functions for physical operators. We investigated this model using a newly developed, efficient cluster algorithm (see the talk by Debasish Banerjee) and exact diagonalization methods. We find a spontaneously broken approximate SO(2) symmetry emerging at a quantum phase transition separating two different confining phases distinguished by different symmetry breaking patterns. The emergent symmetry can be described by an effective theory that will be derived in the talk and whose low energy parameters are calculated using the exact diagonalization results. The quantum phase transition masquerades as a so-called deconfined quantum critical point. However, since the emergent symmetry is only approximate, the emergent pseudo-Goldstone boson does not qualify as a dual photon.

Large N Volume Independence vs. Hagedorn (in)stability

Mithat Unsal

Thu, 14:00, Seminar Room E (RW6) – Parallels 7E

Large-N volume independence in circle-compactified QCD with $N_f \geq 1$ adjoint Weyl fermions implies the absence of any phase transitions as the radius is dialed to arbitrarily small values. This class of theories are believed to possess a Hagedorn density of hadronic states. These properties are in apparent tension with each other, because a Hagedorn density of states typically implies a phase transition at some finite radius. This tension is resolved if there are degeneracies between the spectra of bosonic and fermionic states, as happens in the $N_f = 1$ supersymmetric case. Resolution of the tension for $N_f > 1$ then suggests the emergence of a fermionic symmetry at large N, where there is no supersymmetry. We can escape the Coleman-Mandula theorem since the $N = \infty$ theory is free, with a trivial S-matrix. We show an example of such a spectral degeneracy in a non-supersymmetric toy example which has a Hagedorn spectrum.

Monte Carlo studies on the expanding behavior of the early universe in the Lorentzian type IIB matrix model

Yuta Ito, Sang-Woo Kim, Jun Nishimura, Asato Tsuchiya

Thu, 14:20, Seminar Room E (RW6) – Parallels 7E

Superstring theory is known as the most promising candidate for a unified theory including quantum gravity. The theory requires 10d spacetime, and by compactifying the extra six dimensions, one can obtain various quantum field theories with various gauge groups and matter contents. The problem is that there are too many ways to do that leading to too many different physics at low energy as far as one takes perturbative approaches. On the other hand, if we can construct superstring theory nonperturbatively, we may obtain uniquely our 4d spacetime with the Standard Model particles propagating on it. The type IIB matrix model was proposed as such a nonperturbative formulation of superstring theory. In particular, the model describes 10d spacetime as the eigenvalue distribution of matrices. Recent Monte Carlo studies of the Lorentzian version of the model showed that only three out of nine spatial directions start to expand after a critical time. We extend this work by studying the expanding behavior for much longer time to see whether inflation and the Big Bang occur. We find that the 3d space indeed expand exponentially for some time, which is reminiscent of the inflation. Moreover, by simulating simplified models, which captures important properties of the original model, we observe that the expansion later changes into a power-law behavior $R(t) = ct^{1/2}$, which is consistent with that of the FRW universe in the radiation dominated era.

Perturbative analysis of twisted volume reduced theories

Margarita Garcia-Perez, Antonio Gonzalez-Arroyo, Masanori Okawa

Thu, 14:40, Seminar Room E (RW6) – Parallels 7E

We present the results of a perturbative analysis of pure Yang-Mills theories on a torus with twisted boundary conditions, for generic group SU(N) and non-trivial magnetic flux, generalizing previous results in the literature. The case of large N twisted reduced models will also be considered. In particular, we derive a compact formula for the gluon-self-energy correction at one-loop and discuss the perturbative expansion of Wilson loop expectation values. In this context, the appearance of tachyonic instabilities in the gluon dispersion relation and its consequences for volume reduction are analyzed. In 2+1 dimensions our predictions are compared with the results of a lattice determination of the electric-flux spectrum.

Lattice simulation of lower dimensional SYM with sixteen supercharges

Daisuke Kadoh, Syo Kamata

Thu, 15:00, Seminar Room E (RW6) – Parallels 7E

We report on simulations of d=1+0 supersymmetric Yang-Mills theory with sixteen supercharges. We employ the lattice action with two exact supercharges, constructed by F.Sugino. The temperature is introduced through the compactification of the time direction. In the context of gauge/gravity duality, the gauge theory corresponds to N D0-branes in type IIA superstring/supergravity. At large N and low temperature, it is expected that the gauge theory describes physics of black hole. We examine the validity of gauge/gravity duality from comparison between our numerical results of gauge side and analytic solutions of gravity side. In particular, we determine temperature dependence of black hole internal energy and Schwarzschild radius, etc beyond the leading order.

Rank and volume dependence in large N gauge theories

Antonio Gonzalez-Arroyo, Masanori Okawa

Thu, 15:20, Seminar Room E (RW6) – Parallels 7E

We present the results of our analysis on the dependence of certain observables on the rank N of the SU(N) gauge group and on the lattice volume. Our effort aims at clarifying the connection among these two dependencies and, as a side effect, on the validity of the large N reduction idea. Our results include both periodic and twisted boundary conditions. The latter produces a substantial improvement and its use is strongly favoured.

Action of gauge field on the lattice of twistor space
Takayuki Baba
Thu, 15:40, Seminar Room E (RW6) – Parallels 7E

Recently, twistor theory has become a powerful tool to study scattering amplitudes and correlation functions in N=4 super Yang-Mills theory. For example, a direct derivation of Maximally Helicity Violating tree amplitude is given using twistor theory, and the correspondence between correlation functions of certain Wilson loops and scattering amplitudes can be shown. Even though it is a powerful tool, this theory has a problem of regularization in momentum space integral of scattering amplitude. Twistor theory is also interesting from the viewpoint of lattice theory. The coordinate in twistor theory are 2-spinors with SU(2)*SU(2) Lorentz symmetry. Because of this, the lattice of twistor space is constructed by descretizing the spinor coordinates. As a first step towards regularizing the twistor theory, we construct the lattice action of gauge field on twistor space. By analyzing this action, we see some interesting features. The number of doublers of fermion decrease to 3. There are doublers also for bosons and the gauge symmetry is enhanced because of this.

The Integrable Bootstrap Program at Large N and its Applications in Gauge Theory
Axel Cortes Cubero
Thu, 16:30, Seminar Room E (RW6) – Parallels 8E

We study the large N limit of the (1+1)-dimensional principal chiral sigma model. This Model has an $N \times N$ matrix-valued field, whose excitations are massive and asymptotically free. All the form factors and the exact correlation functions of the Noether-current operator and the energy-momentum tensor are found using the integrable bootstrap program. We study (2+1)-dimensional Yang-Mills theory as an array of principal chiral models with a current-current interaction. We discuss how to use our new form factors to calculate physical quantities in the gauge theory.

Radial Quantization for Conformal Field Theories on the Lattice
Richard Brower
Thu, 16:50, Seminar Room E (RW6) – Parallels 8E

Lattice radial quantization is introduced as a nonperturbative method intended to numerically solve Euclidean conformal field theories that can be realized as fixed points of known Lagrangians. As an first example , we employ a lattice shaped as a cylinder with a 2D Icosahedral cross-section to discretize dilatations in the 3D Ising model. Base on this study and analytical methods for the 2D O(N) model at large N, we consider improvements using Finite Element Methods (FEM) to approach the Wilson Fisher fixed point. Possible extensions to infrared conformal fixed points and near conformal theories of interest to Beyond the Standard Model strong gauge dynamics are discussed.

A possible new phase in non-perturbatively gauge-fixed Yang-Mills theory
Maarten Golterman, Yigal Shamir
Thu, 17:10, Seminar Room E (RW6) – Parallels 8E

The standard expectation is that gauge fixing cannot alter the physics in the physical sector of a Yang-Mills theory. In this talk, I argue that this may not always be true: in an SU(2) Yang-Mills theory in which the SU(2)/U(1) coset is non-perturbatively gauge fixed, we find that a new phase, with spontaneous symmetry breaking, appears to be a possibility.

A classification of 2-dim Lattice Theory
Mario Kieburg, Jacobus Verbaarschot, Savvas Zafeiropoulos
Thu, 17:30, Seminar Room E (RW6) – Parallels 8E

The random matrix approach in the low energy regime of QCD has led to deep insights of non-perturbative effects and has yielded analytical relations between observables and the low energy constants. Recently Random Matrix Theory was extended to lattice QCD as well. In this talk a classification of the naive and, thus also, of the staggered fermions for 2-dim QCD-like theories will be presented. This classification is based on the global symmetries of the lattice models and is shared by Random Matrix Theory. We have compared the random matrix predictions for the spectral statistics with lattice simulations of the quenched theory and found astoundingly good agreement for the lowest eigenvalues in almost all universality classes.

A new approach to the two-dimensional σ model with a topological charge

Christian Torrero, Oleg Borisenko, Vladimir Kushnir, Bartolome Alles Salom, Alessandro Papa

Thu, 17:50, Seminar Room E (RW6) – Parallels 8E

Based on character decomposition, a dual transformation is introduced leading to two formulations of the theory which should allow for a removal/softening of the sign problem in the original version. Very preliminar numerical results are commented and remaining problems discussed.

Studying and removing effects of fixed topology in a quantum mechanical model

Arthur Dromard, Marc Wagner

Thu, 18:10, Seminar Room E (RW6) – Parallels 8E

At small lattice spacing, or when using e.g. overlap fermions, lattice QCD simulations tend to become stuck in a single topological sector. Physical observables then differ from their full QCD counterparts by 1/V corrections. Brower et al. and Aoki et al. have derived equations by means of a saddle point approximation, to determine and to remove these corrections. We extend these equations and apply them to a simple toy model, a quantum mechanical particle on a circle in a square well potential at fixed topology. This model can be solved numerically up to arbitrary precision and allows to explore effects arising due to fixed topology. We investigate the range of validity and accuracy of the above mentioned equations to remove such fixed topology effects. We also speculate about implications regarding fixed topology simulations in QCD.

Non-$\gamma_5$hermiticity minimal doubling fermion
Syo Kamata, Hidekazu Tanaka
Fri, 14:00, Seminar Room F (HS II) – Parallels 9F

A non-$\gamma_5$hermiticity lattice fermion has a serious problem called sign problem. In finite density system, a fermion determinant always has a complex phase because lattice actions have a chemical potential term which breaks $\gamma_5$hermiticity. Therefore it is trouble to estimate observable in strong density region. In this talk, we will talk about whether we can estimate observables using non-$\gamma_5$hermiticity fermion or not. We constructed two-dimensional $\gamma_5$hermiticity fermions based on minimal doubling fermion. The fermions preserve chiral symmetry but break discrete symmetry. Firstly, we estimate eigenvalue distributions. And we determine if or not such the fermions are appropriate for use in practical calculations. Next, we investigate the parity-broken phase called Aoki phase for a non-$\gamma_5$hermiticity fermion by using the Gross-Neveu model. And we will discuss a generalization to higher dimension system.

Lattice QCD with Staggered Wilson Fermions: An Exploratory Numerical Investigation
David Adams, Dániel Nógrádi, Andriy Petrashyk, Christian Zielinski
Fri, 14:20, Seminar Room F (HS II) – Parallels 9F

Results on the computational efficiency of 2-flavor staggered Wilson fermions compared to usual Wilson fermions in quenched lattice QCD simulations are reported. The computations are done for two lattices, $12^3 \times 32$ and $16^3 \times 32$, at $\beta = 6$, using the Chroma/QDP software for lattice QCD. We determine, as a function of the pion mass, the condition number of the lattice fermion matrix in the conjugate gradient computation of the quark propagator for both staggered Wilson and usual Wilson fermions. The condition number is found to be less by a factor of more than 3 for staggered Wilson fermions on both our lattices; this factor has only a mild dependence on the pion mass. Combining this with computations of the number of floating point operations per lattice site for matrix-vector multiplication with the lattice fermion matrices, we derive a theoretical estimate that staggered Wilson fermions are almost 6 times more efficient than usual Wilson fermions (without preconditioning for either of them). We compare this to a direct measurement of the efficiency in terms of CPU time for the quark propagator calculations, which shows an efficiency factor of around 4.5 (4) on our larger (smaller) lattice. That this is less than the theoretical estimate can be explained, at least partly, by implementation details of the staggered Wilson fermions, which we expect can be improved.

Non-perturbative fermion mass generation in Wilson lattice QCD
Roberto Frezzotti, Giancarlo Rossi
Fri, 14:40, Seminar Room F (HS II) – Parallels 9F

Based on theoretical arguments and numerical evidence we argue that a phenomenon of dynamical mass generation for fermions, driven by the Wilson term, occurs in lattice QCD with Wilson quarks. The potential implications of this remark for the construction of a renormalizable field theory where a hierarchy of particle masses naturally arises from interactions are discussed in a simple model.

Quantum Mechanics à la Langevin and Supersymmetry
Stam Nicolis
Fri, 15:00, Seminar Room F (HS II) – Parallels 9F

We study quantum mechanics in the stochastic formulation, using the functional integral approach. The noise term enters the classical action as a local contribution of anticommuting fields. The full action, at the classical level, is invariant under N=1 SUSY, under periodic boundary conditions or when the fields vanish at the boundaries. Under antiperiodic boundary conditions for the fermions, supersymmetry is broken by a boundary term, unless the fermions vanish there. We define combinations that scale appropriately, as the lattice spacing is taken to zero and the lattice size to infinity and provide evidence, by numerical simulations, that the correlation functions of the auxiliary field do satisfy Wick's theorem. We show, in particular, that simulations can be carried out using a purely bosonic action.

Cyclic Leibniz rule: a formulation of supersymmetry on lattice
Hiroto So, Mitsuhiro Kato
Fri, 15:20, Seminar Room F (HS II) – Parallels 9F

For the purpose of constructing supersymmetric(SUSY) theories on lattice, we propose a new type relation on lattice -cyclic Leibniz rule(CLR)- which is slightly different from an ordinary Leibniz rule. Actually, we find that the CLR can enlarge the number of SUSYs from N=1 to N=2 in the quantum-mechanical model.

Phase transitions in the three-dimensional Z(N) models
Volodymyr Chelnokov, Oleg Borisenko, Gennaro Cortese, Mario Gravina, Alessandro Papa, Ivan Surzhikov
Fri, 16:30, Seminar Room E (RW6) – Parallels 10E

Phase transitions in zero-temperature 3-d Z(N) lattice gauge theories are studied. We use a cluster algorithm defined for the dual formulation of the models. We also attempt to explain the nature of the intermediate continuously symmetric phase, which appears for $N > 5$. The critical indices are calculated. The results obtained are used to study scaling of critical points with N as well as scaling of finite-temperature critical points with N_T.

A study of massive gauge theories on the lattice (I)
Pilar Hernandez
Fri, 16:50, Seminar Room E (RW6) – Parallels 10E

We consider the lattice formulation of an SU(2) massive gauge theory, which can be interpreted as a gauge plus scalar field theory. Starting from the symmetry properties and the assumption of the existence of a continuum limit within a Higgs phase, we conjecture the structure of the Wilsonian effective theory. Based on this analysis, we define a line of constant physics and study via numerical simulations the existence of such a scaling region.

A study of massive gauge theories on the lattice (part II)
Michele Della Morte
Fri, 17:10, Seminar Room E (RW6) – Parallels 10E

We consider the lattice formulation of an SU(2) massive gauge theory, which can be interpreted as a gauge plus scalar field theory. Starting from the symmetry properties and the assumption of the existence of a continuum limit within a Higgs phase, we conjecture the structure of the Wilsonian effective theory. Based on this analysis, we define a line of constant physics and study via numerical simulations the existence of such a scaling region.

Does Yang-Mills theory describe quantum gravity?
Masanori Hanada, Yoshifumi Hyakutake, Goro Ishiki, Jun Nishimura
Fri, 17:30, Seminar Room E (RW6) – Parallels 10E

The strongest version of the gauge/gravity duality conjecture relates the 1/N correction to super Yang-Mills theory and the quantum correction to superstring theory. We test this conjecture by studying the D0-brane matrix quantum mechanics and the black zero-brane in type IIA superstring theory.

Rotating lattice
Arata Yamamoto, Yuji Hirono
Fri, 17:50, Seminar Room E (RW6) – Parallels 10E

We formulate lattice QCD in rotating frames to study the physics of QCD matter under rotation. We construct the lattice QCD action with the rotational metric and apply it to the Monte Carlo simulation. As the first application, we calculate the angular momenta of gluons and quarks in the rotating QCD vacuum. This new framework is useful to analyze various rotation-related phenomena in QCD.

Continuum limit of the index of the staggered Wilson Dirac operator
Reetabrata Har, Yiyang Jia , Christian Zielinski, David Adams
Poster Session

An analytic calculation of the continuum limit of the index of the staggered Wilson Dirac operator is presented.

Critical properties of 3D Z(N) lattice gauge theories at finite temperature
Alessandro Papa, Oleg Borisenko, Volodymyr Chelnokov, Gennaro Cortese, Mario Gravina, Ivan Surzhikov
Poster Session

The phase structure of three-dimensional Z(N¿4) lattice gauge theories at finite temperature is investigated. Using the dual formulation of the models and a cluster algorithm we locate the critical points of the two transitions, determine various critical indices and compute average action and specific heat. Results are consistent with two transitions of infinite order, belonging to the universality class of two-dimensional Z(N) vector spin models.

A method of analytic continuation for computing the hadronic vacuum polarization function
Karl Jansen, Xu Feng, Grit Hotzel, Shoji Hashimoto, Marcus Petschlies, Dru Renner
Poster Session

We describe a method to make use of continuous photon momenta to analyze the hadronic vacuum polarization function bridging smoothly between the space-like and time-like regions. We show at the example of the leading-order QCD correction to the muon anomalous magnetic moment that this approach can provide a valuable alternative method for calculations of physical quantities where the hadronic vacuum polarization function enters.

Lattice study of the Schwinger model at fixed topology
Christopher Czaban, Marc Wagner
Poster Session

At small lattice spacing QCD simulations are expected to become stuck in a single topological sector. Observables evaluated in a fixed topological sector differ from their counterparts in full QCD, i.e. at unfixed topology, by volume dependent corrections. We investigate these corrections in the two-flavor Schwinger model, which is in several aspects similar to QCD, using Wilson fermions. We also try to remove these corrections by suitable extrapolations to infinite volume.

Vacuum Structure and Confinement

Coulomb gauge on the lattice: From zero to finite temperature
Hannes Vogt, Giuseppe Burgio, Markus Quandt, Hugo Reinhardt
Mon, 14:00, Seminar Room E (RW6) – Parallels 1E

We extend our previous studies of Coulomb gauge Yang-Mills theory on the lattice by comparing the static gluon propagator at zero and finite temperature in SU(2), SU(3) and SU(4). In SU(2) we also compare the $\langle U_0 U_0 \rangle$-correlator with the $\langle A_0 A_0 \rangle$-correlator (temporal gluon propagator) and the Coulomb potential V_C at zero temperature. To compute observables at higher temperatures we introduce anisotropic lattices, which allow lower momenta at a higher temporal resolution. On these lattices the static gluon propagator, the ghost propagator and the Coulomb potential are studied at temperatures up to $6T_c$. We also investigate the effect of Gribov copies on the Coulomb potential.

Confinement in Coulomb gauge
Giuseppe Burgio, Markus Quandt, Hugo Reinhardt, Mario Schröck, Hannes Vogt
Mon, 14:20, Seminar Room E (RW6) – Parallels 1E

We review our lattice results concerning the Gribov-Zwanziger confinement mechanism in Coulomb gauge. In particular, we verify the validity of Gribov's IR divergence condition for the Coulomb ghost form factor. We also show how the quark self energy is, like that of the transverse gluon, IR divergent, thus effectively extending the Gribov-Zwanziger scenario to full QCD.

On two- and three-point functions of Landau gauge Yang-Mills theory
Markus Huber, Lorenz von Smekal
Mon, 14:40, Seminar Room E (RW6) – Parallels 1E

Green functions of Yang-Mills theory are useful quantities whose applications range from bound state calculations to investigations of the phase diagram of quantum chromodynamics. I will present results of non-perturbative continuum calculations of the propagators and the ghost-gluon vertex which are in good, even quantitative agreement with corresponding lattice results. The mid-momentum behavior, which is affected most by truncations, can effectively be controlled via the employed three-gluon vertex model which is inspired by lattice results.

Spectral densities from the lattice
Paulo Silva, David Dudal, Orlando Oliveira
Mon, 15:00, Seminar Room E (RW6) – Parallels 1E

We discuss a method to extract the Kallen-Lehmann spectral density of a particle (be it elementary or bound state) propagator by means of 4d lattice data. We employ a linear regularization strategy, commonly known as the Tikhonov method with Morozov discrepancy principle. An important virtue over the popular maximum entropy method is the possibility to also probe unphysical spectral densities, as, for example, of a confined gluon. We apply our proposal to the SU(3) glue sector.

Crossing the Gribov horizon: an unconventional study of geometric properties of gauge-configuration space in Landau gauge
Attilio Cucchieri, Tereza Mendes
Mon, 15:20, Seminar Room E (RW6) – Parallels 1E

We present a lower bound for the smallest nonzero eigenvalue of the Landau-gauge Faddeev-Popov matrix in terms of the smallest nonzero lattice momentum and of a parameter characterizing the geometry of the first Gribov region. This allows a simple and intuitive description of the infinite-volume limit in the ghost sector. In particular, we show how nonperturbative effects may be quantified by the rate at which typical thermalized and gauge-fixed configurations approach the Gribov horizon. Our analytic results are verified numerically through an informal, "free and easy" approach.

Gluon mass at finite temperature in Landau gauge
Pedro Bicudo, Nuno Cardoso, Orlando Oliveira, Paulo Silva
Mon, 15:40, Seminar Room E (RW6) – Parallels 1E

Using lattice results for the Landau gauge gluon propagator at finite temperature, we investigate its interpretation as a massive type bosonic propagator. In particular, we estimate a gluon mass from Yukawa-like fits to the lattice data and study its temperature dependence.

$q\bar{q}$-potential
Giancarlo Rossi, Massimo Testa
Mon, 16:30, Seminar Room E (RW6) – Parallels 2E

We show how to define and compute in a non-perturbative way the potential between q and $\bar{q}$ colour sources in the singlet and octet (adjoint) representation of the colour group.

The colour adjoint static potential from Wilson loops with generator insertions and its physical interpretation
Marc Wagner, Owe Philipsen
Mon, 16:50, Seminar Room E (RW6) – Parallels 2E

We discuss the non-perturbative computation and interpretation of a colour adjoint static potential based on Wilson loops with generator insertions. Numerical lattice results for SU(2) gauge theory are presented and compared to corresponding perturbative results in various gauges.

The static quark self-energy and the Plaquette at large orders in perturbation theory
Antonio Pineda, Gunnar Bali, Clemens Bauer
Mon, 17:10, Seminar Room E (RW6) – Parallels 2E

We compute the coefficients of the perturbative expansions of the plaquette, and of the self-energy of static sources in the triplet and octet representation, up to very high orders in perturbation theory. We use numerical sthocastic perturbation theory and lattice regularization. We explore if the results obtained comply with expectations from renormalon dominance, and what they may say for a model independent and nonperturbative determination of the value of the gluon condensate.

Recent progress in the effective string theory description of LGTs.
Michele Caselle, Marco Billò, Ferdinando Gliozzi, Marco Meineri, Davide Fioravanti, Roberto Pellegrini, Roberto Tateo
Mon, 17:30, Seminar Room E (RW6) – Parallels 2E

In presence of a static pair of sources, the spectrum of low-lying states of whatever confining gauge theory in D space-time dimensions is described, at large source separations, by an effective string theory. Recently two important advances improved our understanding of this effective theory. First, it was realized that the form of the effective action is strongly constrained by the requirement of the Lorentz invariance of the gauge theory, which is spontaneously broken by the formation of a long confining flux tube in the vacuum. This constraint is strong enough to fix uniquely the first few subleading terms of the action. Second, it has been realized that the first of these allowed terms - a quartic polynomial in the field derivatives - is exactly the composite field $T\bar{T}$, built with the chiral components, T and $\bar{T}$, of the energy-momentum tensor of the 2d QFT describing the infrared limit of the effective string. This irrelevant perturbation is quantum integrable and yields, through the Thermodynamic Bethe Ansatz (TBA),the energy levels of the string which exactly coincide with the Nambu-Goto spectrum. In this talk we first review the general implications of these two results and then, as a test of the power of these methods, use them to construct the first few boundary corrections to the effective string action.

Fine structure of the confining string in an analytically solvable 3D model
Davide Vadacchino, Michele Caselle, Marco Panero, Roberto Pellegrini
Mon, 17:50, Seminar Room E (RW6) – Parallels 2E

In the U(1) lattice gauge theory in three spacetime dimensions, confinement can be analytically shown to persist at all values of the coupling. Furthermore, the explicit predictions for the dependence of string tension and mass gap on the coupling allow one to tune their ratio at will. These features, and the possibility of obtaining high-precision numerical results via an exact duality map to a spin model, make this theory an ideal framework to test the effective string description of confining flux tubes. In this contribution, we discuss our investigation of boundary- and next-to-leading-order corrections to the confining potential, and of the finite-temperature behavior of the flux tube width. Our data represent a very stringent test of the theoretical predictions for these quantities.

Analytical relation between the Polyakov loop and the Dirac eigenvalues in temporally odd-number lattice QCD

Hideo Suganuma, Takahiro Doi, Takumi Iritani

Mon, 18:10, Seminar Room E (RW6) – Parallels 2E

We analytically derive an identity between the Polyakov loop and Dirac eigenvalues in temporally odd-number lattice QCD. For the temporal lattice with an odd-number N, the Polyakov loop L_P is expressed with the Dirac eigenvalues λ_n: $L_P = \text{const} \sum_n \lambda_n^{N-1} (n|U_4|n)$. Thus, for the Polyakov loop, the contribution from the low-lying Dirac eigenvalues is found to be negligibly small in this sum. Since the low-lying Dirac modes are essential for chiral symmetry breaking, this identity indicates no one-to-one correspondence between confinement and chiral symmetry breaking, as was numerically shown in a different manner [1][2]. [1] S. Gongyo, T. Iritani and H. Suganuma, Phys. Rev. D86 (2012) 034510. [2] T. Iritani and H. Suganuma, arXiv:1305.4049[hep-lat].

A direct relation between confinement and chiral symmetry breaking in temporally odd-number lattice QCD

Takahiro Doi, Hideo Suganuma, Takumi Iritani

Mon, 18:30, Seminar Room E (RW6) – Parallels 2E

We derive an identity connecting Polyakov loop and Dirac modes in temporally odd-number lattice, where the temporal length is odd in lattice unit. The Polyakov loop is an order parameter for quark confinement. On the other hand, according to Banks-Casher relation, low-lying Dirac modes are important for chiral symmetry breaking. Thus, the above identity describes the relation between confinement and chiral symmetry breaking. From this identity, we conclude that there is no one-to-one correspondence between confinement and chiral symmetry breaking. We have numerically confirmed this identity. Moreover, modifying Kogut-Susskind formalism for even lattice, we develop the method for spin-diagonalizing Dirac operator in the temporally odd-number lattice.

Analysis of topological structure of the QCD vacuum with overlap-Dirac operator eigenmode

Takumi Iritani, Shoji Hashimoto, Guido Cossu

Mon, 18:50, Seminar Room E (RW6) – Parallels 2E

We investigate topological structure of the QCD vacuum using eigenmodes of the overlap-Dirac operator, which keeps exact chiral symmetry on lattice. Based on a Dirac eigenmode expression of field-strength tensor $F_{\mu\nu}$, we analyse instanton-like behavior of the QCD vacuum, topological charge distribution and topological susceptibility. We also analyse contributions of the overlap-Dirac eigenmode to color-flux tube, which leads to confining force between quark and anti-quark.

Non-Abelian dual Meissner effect and confinement/deconfinement phase transition in SU(3) Yang-Mills theory

Akihiro Shibata, Kei-Ichi Kondo, Seikou Kato, Toru Shinohara

Tue, 14:00, Seminar Room E (RW6) – Parallels 3E

The dual superconductivity is a promising mechanism for quark confinement. We presented the non-Abelian dual superconductivity picture for SU(3) Yang-Mills theory, which demonstrated the restricted field dominance, called conventionally "Abelian" dominance and non-Abelian monopole dominance in the string tension. In the last conference, we have demonstrated by measuring the chromoelectric flux that the non-Abelian dual Meissner effect exists and determined that the type of vacuum for SU(3) case is type I, which is in sharp contrast to the SU(2) case: the border of type I and type II. In this talk, we focus on the confinement/deconfinemen phase transition and the non-Abelian dual superconductivity at finte temperature: We measure the hromoelectric flux between a pair of static quark and antiquark at finte temperature, and investigate its relevance to the phase transition and the non-Abelian dual Meissner effect.

Study of thermal monopoles in lattice QCD

Vitaly Bornyakov

Tue, 14:20, Seminar Room E (RW6) – Parallels 3E

We present results of the ongoing study of the properties of the thermal Abelian color-magnetic monopoles in the maximally Abelian gauge in the deconfinement phase of the lattice SU(3) gluodynamics and $N_f = 2$ lattice QCD. We compute density, correlators, interaction parameters of the thermal Abelian monopoles in these two theories.

Surface operator study in an SU(2) gauge field theory
Alexander Molochkov, Vladimir Goy
Tue, 14:40, Seminar Room E (RW6) – Parallels 3E

The most important probes for the phase states of a four-dimensional gauge field theory are the Wilson and t'Hooft line operatros that are difined on one-dimensional curves in the space-time. For example, these line-operators define order parameters for the confinemnet-deconfiment phase transition of the QCD vacuum. However, for more detail understanding of four-dimensional gauge field theory dynamics and vacuum topology we need additional probes expressed by operators defined on the subspaces with higher dimensions. Possible candidates are operators that are defined on the two-dimensional surface in the four-dimensional space-time. In the present work the surface operator in an SU(2) non-Abelian gauge field theory is studied. We analyze abelian projection of the SU(2) symmetry to the U(1) group calculating the Witten parameter using multilevel and multi-hit algorithms for the sake of statistical confidence. The Witten parameter dependence on the surface area and volume studied in confinement and deconfinement phases. It is shown that at the deconfinement phase the spatial surface operator exhibits non-trivial area dependence. In the confinement phase the operator is trivial with no area and volume dependence. It is shown also that the temporal surface operator exhibits the same phase behavior.

Effective theta term by CP-odd electromagnetic background fields.
Marco Mariti, Claudio Bonati, Guido Cossu, Massimo D'Elia, Francesco Negro
Tue, 15:00, Seminar Room E (RW6) – Parallels 3E

We present our study of QCD in the presence of CP-odd electromagnetic (em) background fields. We investigate the propagation of the CP-odd term from the em sector to the strong sector, inducing an effective theta term. We discuss the method we have used in our lattice QCD simulations, and the results of our analysis, which are relevant to the determination of the effective pseudoscalar QED-QCD interactions. We also explore the distribution of the fermion zero modes and of the topological charge in presence of external em fields.

Fractional Charge and Confinement of Quarks

Philipp Scior, Sam R. Edwards, Lorenz von Smekal

Tue, 15:20, Seminar Room E (RW6) – Parallels 3E

In quantum chromodynamics with static quarks the confinement-deconfinement phase transition is connected to the spontaneous breaking of a global Z_3 center symmetry. This symmetry is lost when one considers dynamical quarks. Owing to the fractional electric charge of quarks, we recover a global Z_6 center symmetry when QCD is regarded as a part of the Standard Model. We will present results from QCD-like theories extended by electromagnetic interactions and show that the weak coupling limit of the QED part of the model results in a center-like symmetry with disorder in the vacuum. This can be seen explicitly in a character expansion of the fermion determinant. Further, we will show that corresponding center averages project the fermion determinant on N-ality zero. We will also discuss whether the additional center symmetry can be used to eliminate the fermion sign problem in QCD with fundamental quarks.

Vortex liquid in superconducting vacuum of QCD induced by strong magnetic field.

Andrey Kotov, Victor Braguta, Pavel Buividovich, Maxim Chernodub, Mikhail Polikarpov

Tue, 15:40, Seminar Room E (RW6) – Parallels 3E

In the background of the strong magnetic field the vacuum is suggested to possess an electro- magnetically superconducting phase characterised by the charged ρ mesons condensate. The ρ- meson condensates are inhomogeneous due to the presence of the stringlike defects which are parallel to the magnetic field. In agreement with these expectations, we have observed the presence of the ρ vortices in numerical simulations of the vacuum of the quenched two-color lattice QCD in strong magnetic field background. We have found that in the quenched QCD the ρ vortices form a liquid.

Correlation functions and confinement in scalar QCD
Tajdar Mufti, Axel Maas
Poster Session

One of the choices to understand a theory, and hence the physics involved, is understanding the correlation functions. QCD in confinement regime serves as one of the ideal areas for non-perturbative calculations since they are not accessible in perturbative sense. A number of scenarios have been proposed about QCD confinement, thus necessitating non-perturbative calculations to be performed in order to check which one(s) of them is(are) acceptable. Since the physics of QCD confinement does not depend upon the number of colors and whether the matter fields are scalars or not, cheaper computation can be carried out using lattice methods with scalar matter fields and 2 colors in order to be able to address the problem mentioned above. Propagators and interaction vertices of matter and gauge fields, calculated in Landau gauge, are presented.

Measuring the ground-state wave functional of SU(2) Yang-Mills theory in 3+1 dimensions: Abelian plane waves
Stefan Olejnik, Jeff Greensite
Poster Session

A method of measuring relative probabilities of various gauge-field configurations in the Yang-Mills vacuum was proposed long ago [Greensite and Iwasaki, Phys. Lett. B 223 (1989) 207]. We apply this method to compute the square of the YM vacuum wave functional (VWF) in numerical simulations of SU(2) lattice gauge theory in 3+1 dimensions for sets of Abelian plane waves. The results are compared to predictions based on various VWF proposals in the literature. None of them describes the data satisfactorily at large plane-wave momenta.

Flux tubes and coherence length in the SU(3) vacuum
Francesca Cuteri, Paolo Cea, Leonardo Cosmai, Alessandro Papa
Poster Session

An estimate of the London penetration and coherence lengths in the vacuum of the SU(3) pure gauge theory is given downstream an analysis of the transverse profile of the chromoelectric flux tubes. Within ordinary superconductivity, a simple variational model for the magnitude of the normalized order parameter of an isolated vortex produces an analytic expression for magnetic field and supercurrent density. In the picture of SU(3) vacuum as dual superconductor, this expression provides us with the function that fits the chromoelectric field data. The smearing procedure is used in order to reduce noise.

The static potential from the selected intermediate states of gluons
Yoshiaki Koma, Miho Koma
Poster Session

By employing the multilevel algorithm, we investigate the static inter-quark potential from the Polyakov loop correlation function (PLCF) constructed from the selected intermediate states of gluons. While the use of partial intermediate states cannot guarantee gauge invariance of the PLCF, we find that the functional forms of the PLCF and then the static potential are unchanged from the gauge invariant ones if certain intermediate states are selected. We discuss its implication and possible applications.

Classification of quark-antiquark sources in Yang-Mills Theories
Andrea Guerrieri, Silvano Petrarca, Argia Rubeo, Massimo Testa
Poster Session

We present preliminary results of a lattice numerical investigation of the structure of physical states contributing to the sector of a pure Yang-Mills Theory, in the presence of infinitely heavy quark-antiquark sources, based on G.C.Rossi, M.Testa Phys.Rev.D87, 085014 (2013).

Confinement From The Gauge Invariant Abelian Decomposition
Nigel Cundy, Yongmin Cho, Weonjong Lee
Poster Session

A common approach while considering confinement is to study the dominance of an Abelian subgroup of the SU(3) gauge Links. A good way to find the Abelian component of the field is through the Cho-Guan-De gauge invariant Abelian Decomposition, which uses a carefully chosen direction vector n to split the gauge field into an Abelian restricted field and a remnant coloured field. The restricted field can be further subdivided into topological and non-topological terms. We show that there is a choice of n which allows us to exactly represent the Wilson Loop of full QCD as a function of only the restricted Abelian field without requiring any path ordering or additional path integrals. We present numerical evidence showing that the topological part of the restricted field dominates the string tension. We also show that n contains certain topological objects, which, if they exist, will be at least partially responsible for confinement. These leave distinctive patterns in the restricted field strength, and we search for these structures in quenched lattice QCD.

Towards the continuum limit of SU(2) Landau gauge gluodynamics
Igor Bogolubsky, Ernst-Michael Ilgenfritz, Andre Sternbeck
Poster Session

We give an update on our long-term project to provide properly continuum-limit extrapolated data for the Landau-gauge gluon and ghost propagators of SU(2) lattice gauge theory. In our simulations we keep the physical volume fixed at $(9.6\ \mathrm{fm})^4$ and vary the lattice coupling parameter such that lattice spacings from 0.17 down to 0.09 fermi are reached. We will discuss the difficulties one encounters with the renormalization caused by lattice discretization artefacts.

't Hooft loop and the phases of SU(2) lattice gauge theory
Giuseppe Burgio
Poster Session

We analyze the vacuum structure of SU(2) lattice gauge theories in different dimensions, concentrating on the stability of 't Hooft loops. We recognize three, well separated phases as the couplings vary; high precision calculations to identify their boundaries have been performed in d=2+1, but similar results hold also for d=3+1 and d=1+1. We discuss the impact of our findings on the continuum limit of Yang-Mills theories.

Stable and Quasi-Stable confining SU(N) strings in D=2+1
Andreas Athenodorou, Michael Teper
Poster Session

We investigate the low-lying spectrum of closed confining flux tubes that wind around a spatial torus in D=2+1 and carry flux in different representations of SU(N). We focus on our most recent calculations on N=6 and beta = 171, where the calculated low-energy physics is very close to the continuum and large-N limit. We investigate the adjoint, 84, 120, k=2A, 2S and k=3A, 3M, 3S representations and show that the corresponding flux tubes do exist. Similarly to the results for the fundamental representation, the ground state of a flux tube with momentum along its axis appears to be well described by Nambu-Goto all the way down to very short flux tubes. In contrast, excited states have much larger deviations from Nambu-Goto. We discuss whether these states are non-string-like associated to excitations of massive flux-tube modes.

SU(3) quark-antiquark QCD flux tube
Pedro Bicudo, Nuno Cardoso, Marco Cardoso
Poster Session

We compute the quark-antiquark flux tube for pure gauge SU(3) in spacetime 3 + 1 dimentions. To increase the signal over noise ratio, we apply the improved multihit and extended smearing techniques. We fit the field densities with an appropriate ansatz and we observe both the screening of the colour fields and the quantum widening of the flux tube in the mediator plane.

Form factor and width of a quantum string

David Weir, Kari Rummukainen, Arttu Rajantie

Poster Session

We show how the form factor for a quantum string can be obtained from field correlation functions calculated in lattice Monte Carlo simulations. As an example, we apply this technique for simulations of the Ising model. We demonstrate that the form factor shows the same logarithmic broadening as observed by other quantities. Various difficulties in finding the intrinsic width of a string are discussed.

Weak Decays and Matrix Elements

Chiral and continuum extrapolation of B-meson decay constants computed using domain-wall light quarks and nonperturbatively tuned relativistic b-quarks

Oliver Witzel

Tue, 14:00, Seminar Room C (RW4) – Parallels 3C

We report on our progress to obtain the decay constants f_B and f_{B_s} from lattice-QCD simulations on the RBC and UKQCD Collaborations 2+1 flavor domain-wall-Iwasaki lattices. Using domain-wall light quarks and relativistic b-quarks we analyze data with several partially quenched light-quark masses at two lattice spacings of a 0.11 fm and a 0.08 fm. We perform combined chiral and continuum extrapolations using chiral perturbation theory.

The form factor for B to π semileptonic decay from 2+1 flavors of domain-wall fermions

Taichi Kawanai

Tue, 14:20, Seminar Room C (RW4) – Parallels 3C

We study the $B \to \pi$ semileptonic decay process using lattice QCD with domain-wall light quarks and relativistic b-quarks. The lattice calculation of the $B \to \pi$ form factor is needed to extract the CKM matrix element $|V_{ub}|$ from experimental measurements of the branching fraction. We use the 2+1 flavor domain-wall Iwasaki gauge configurations generated by the RBC and UKQCD collaborations at two lattice spacings (a 0.08fm and 0.11fm) and several sea-quark masses, and compute the form factors $f_0(q^2)$ and $f_+(q^2)$ with several partially-quenched valence quark masses. Our lightest pion mass is about 290MeV. For the bottom quark, we use the relativistic heavy-quark action and tune the parameters of the anistotropic clover action nonperturbatively. We present preliminary results for the chiral and continuum extrapolations of the $B \to \pi$ form factor using SU(2) Chiral perturbation theory.

A new computer algebra system for (lattice) perturbation theory and the RBC/UKQCD heavy quark physics program
Christoph Lehner
Tue, 14:40, Seminar Room C (RW4) – Parallels 3C

I discuss a new computer algebra system optimized for automated perturbation theory for a wide range of regulators both in the continuum and using a lattice. The current implementation includes support for Wilson-type fermions, DWF, and the Schroedinger Functional. I will present details of applications within the heavy quark physics program of the RBC and UKQCD collaborations.

On one-loop corrections to the matching conditions of Lattice HQET including $1/m_b$ terms
Piotr Korcyl
Tue, 15:00, Seminar Room C (RW4) – Parallels 3C

HQET is an effective theory for QCD with $N_f \geq 1$ light quarks and a single massive quark if the mass of the latter is bigger than $\Lambda_Q CD$. As any effective theory, HQET is predictive only when a set of parameters have been determined through a process called matching. The non-perturbative matching procedure including 1/mb terms, applied by the ALPHA col- laboration, consists of 19 carefully chosen observables which are precisely computable in lattice QCD as well as in lattice HQET. The matching con- ditions are then a set of 19 equalities which relate the QCD and HQET values of these observables. We present a study of one-loop corrections to the matching conditions used to fix the renormalization constants of axial and vector currents. Our results enable us to quantify the quality of the relevant observables, also in view of the envisaged non-perturbative implementation of this matching procedure.

B-physics with $N_f = 2$ Wilson fermions

Fabio Bernardoni, Patrick Fritzsch, Georg von Hippel, Michele Della Morte, Jochen Heitger, John Bulava, Nicolas Garron, Rainer Sommer, Hubert Simma, Antoine Gerardin, Benoit Blossier

Tue, 15:20, Seminar Room C (RW4) – Parallels 3C

We report the final results of the ALPHA collaboration for some B-physics observables: fB, fBs and mb. We employ CLS configurations with 2 flavors of O(a) improved Wilson fermions in the sea and pion masses ranging down to 190 MeV. The b-quark is simulated in HQET to order 1/mb. The renormalization the matching and the improvement were performed non-perturbatively, and three lattice spacings reaching a=0.048fm are used in the continuum extrapolation.

B-physics computations from $N_f = 2$ tmQCD

Petros Dimopoulos, Nuria Carrasco Vela, Roberto Frezzotti, Vicent Gimenez Gomez, Gregorio Herdoiza, Vittorio Lubicz, Eleonora Picca [for the ETM Collaboration], Giancarlo Rossi, Francesco Sanfilippo, Silvano Simula, Andrea Shindler, Cecilia Tarantino

Tue, 15:40, Seminar Room C (RW4) – Parallels 3C

We present a lattice QCD computation of the b-quark mass, the B and B_s decay constants, the B-mixing bag parameters for the full four-fermion operator basis as well as estimates for ξ and $f_{Bq}\sqrt{B_q}$ extrapolated to the continuum limit and the physical pion mass. We have used $N_f = 2$ dynamical quark gauge configurations at four values of the lattice spacing generated by ETMC. Extrapolation in the heavy quark mass from the charm to the bottom quark region has been carried out on ratios of physical quantities computed at nearby quark masses, as they have an exactly known infinite mass limit.

B decay to radially excited D
Benoit Blossier, Damir Becirevic, Antoine Gerardin, Francesco Sanfilippo, Alain Le Yaouanc
Tue, 16:20, Seminar Room C (RW4) – Parallels 4C

There is a strong conjecture that radial excitations of D mesons are a significant component of the hadronic final state in B decay. Still, their properties need to be examined with some care: indeed a comparison of experimental data with a valuable class of quark models results in a quite larger width of the D' $2S$ state than expected. The hypothesis of a large form factor in $B \to D'$ semileptonic decay can be tested on the hadronic decay $B \to D'\pi$. Indeed, the same form factor enters the so-called class I process, with the pion emission, assuming the validity of the factorization approximation. However, in the case of $B^- \to D'^0\pi^-$, it is necessary to evaluate the so-called class III process, with the D' emission, that is parametrized by the decay constant $f_{D'}$. We present an estimate of this constant on $N_f = 2$ lattice simulations and discuss the phenomenological consequences of our findings on $B \to D'$ semileptonic decay.

The $B^*B\pi$ coupling with relativistic heavy quarks
Ben Samways
Tue, 16:40, Seminar Room C (RW4) – Parallels 4C

We report on a calculation of the $B^*B\pi$ coupling in Lattice QCD. This involves determining the strong matrix element $\langle B\pi|B^*\rangle$, which is directly related to the leading order LEC in Heavy Meson Chiral Perturbation Theory (HMχPT) for B-mesons. We carry out our calculation directly at the b-quark mass using an improved relativistic heavy quark action and domain wall light quarks. We use 2+1 flavour RBC/UKQCD gauge ensembles at two lattice spacings of $a^{-1} = 1.73(3)$ GeV and $a^{-1} = 2.28(3)$ GeV with unitary pions masses down to 290 MeV.

Probing TeV scale physics in precision UCN decays
Rajan Gupta
Tue, 17:00, Seminar Room C (RW4) – Parallels 4C

I will describe calculations of matrix elements of quark bilinear operators in nucleon states being done by the PNDME collaboration to probe physics beyond the standard model. Results on iso-vector and iso-scalar charges, electric and magnetic form-factors and charge radii will be presented. These calculations are being done using clover valence fermions on 2+1+1 HISQ ensembles generated by the MILC collaboration at two values of light quark masses corresponding to pion masses of 310 and 220 MeV and at two values of the lattice spacing of 0.12 and 0.09 fm. We demonstrate control over systematic errors due to excited state contamination and renormalization constants and preliminary estimates of discretization errors.

Neutral B meson mixing with static heavy and domain-wall light quarks
Tomomi Ishikawa, Yasumichi Aoki, Taku Izubuchi, Christoph Lehner, Amarjit Soni
Tue, 17:20, Seminar Room C (RW4) – Parallels 4C

Neutral B meson mixing matrix elements and B meson decay constants are calculated. Static approximation is used for b quark and domain-wall fermion formalism is employed for light quarks. The calculations are made on 2+1 flavor dynamical ensembles generated by RBC-UKQCD Collaborations, whose lattice spacings are 0.086fm and 0.11fm with a fixed physical spatial volume of about $(2.7\text{fm})^3$. In the static quark action, link-smearings are used to improve the signal-to-noise ratio. We employ two kinds of the link-smearing and their results are combined in taking a continuum limit. For the matching between the lattice and the continuum theory, one-loop perturbative O(a) improvements are made to reduce discretization errors. We also show statistical improvements by the all-mode-averaging method.

D and D_s decay constants from a chiral analysis on HISQ ensembles
Claude Bernard, Jongjeong Kim, Javad Komijani, Doug Toussaint
Wed, 11:00, Seminar Room C (RW4) – Parallels 6C

We present a determination of the decay constants of charmed pseudoscalar mesons on the ensembles with four dynamical quarks that have been generated by the MILC collaboration. The HISQ action is used for both the valence and sea quarks. The lattice data is fit to chiral expressions that have been recently derived in staggered chiral perturbation theory for heavy-light mesons composed of two staggered quarks. Since a subset of our data is at physical values of the light quark masses, it is possible to make an alternative, more straightforward, analysis (to be presented by D. Toussaint) that focuses on the physical-mass data and does not require chiral fitting. However, the chiral analysis allows us to use all our data, thereby reducing statistical errors and allowing better control of some of the systematic errors.

D_s to ϕ and other transitions from lattice QCD
Gordon Donald, Christine Davies, Jonna Koponen
Wed, 11:20, Seminar Room C (RW4) – Parallels 6C

The weak semileptonic Ds to phi decay is a pseudoscalar to vector meson transition and the decay rate contains vector and axial vector form factors. We calculate these form factors using lattice QCD with HISQ valence quarks on MILC gauge configurations containing 2+1 flavours of asqtad sea quarks. We discuss how to normalise the various discretisations used for vector and axial vector currents with staggered quarks. The form factors are calculated over the physical range of q2 and we compare our results for the decay rate to experiment to extract the CKM element Vcs. We use the same normalisation techniques to calculate the rate for $J/\psi \to \eta_c\gamma$ as a test of lattice QCD.

Semileptonic D-decays with twisted mass QCD on the lattice
Francesco Sanfilippo, Vittorio Lubicz, Damir Becirevic
Wed, 11:40, Seminar Room C (RW4) – Parallels 6C

We compute the hadronic matrix elements relevant to the semileptonic $D \to \pi/K$ and $D_s \to K$ decays. Besides the usual vector and scalar form factors, we also present the first lattice results for the penguin induced form factor. Our results are obtained from the simulations of twisted mass QCD with $N_f = 2$ dynamical quarks and at several lattice spacings allowing us to make the smooth extrapolation to the continuum limit.

$D_s \to \eta(')$ semi-leptonic decay form factors
Issaku Kanamori
Wed, 12:00, Seminar Room C (RW4) – Parallels 6C

We report on our on-going study of the $D_s \to \eta(')$ semi-leptonic decay form factors with $n_f = 2+1$ configurations. We include disconnected fermion loop diagrams, which give large contributions to the $D_s \to \eta'$ form factor.

K and D oscillations in the Standard Model and its extensions from $N_f = 2+1+1$ Twisted Mass LQCD
Nuria Carrasco Vela, Petros Dimopoulos, Roberto Frezzotti, Vicent Gimenez Gomez, Vittorio Lubicz, David Palao, Giancarlo Rossi, Francesco Sanfilippo, Silvano Simula, Cecilia Tarantino
Wed, 12:20, Seminar Room C (RW4) – Parallels 6C

We present results for the B-parameters of the complete basis of four-fermion operators needed to study the neutral K and D meson oscillations within the Standard Model and its extensions. We perform numerical simulations using Nf=2+1+1 maximally twisted sea quarks generated by the ETMC and Osterwalder-Seiler valence quarks. With this setup we achieve both O(a) improvement and continuum-like renormalization pattern for the relevant four-fermion operators. The analysis includes data at three values of the lattice spacing and pion masses as low as 230 MeV, allowing for accurate continuum limit and chiral extrapolation. The computation of the renormalization constants of the complete operator basis is performed non perturbatively in the RI-MOM scheme using dedicated simulations with Nf=4 degenerate sea quark flavours.

The D_s,D, B_s and B decay constants from 2+1 flavor lattice QCD
James Simone
Wed, 12:40, Seminar Room C (RW4) – Parallels 6C

We present an update of our study of the D and B leptonic decay constants on the MILC Nf=2+1 asqtad gauge ensembles using asqtad-improved staggered light valence quarks and clover heavy quarks in the Fermilab interpretation. Our previous analysis [Phys.Rev. D85 (2012) 114506] computed the decay constants at lattice spacings a $= 0.15$, 0.12 and 0.09 fm. Our current analysis addresses many important sources of uncertainty in our first analysis by: extending the simulations to more ensembles including finer a $= 0.06$ and 0.045 fm lattice spacings, increasing statistics, better tuning of the quark masses and better determinations of the axial-vector current matching.

Kaon semileptonic form factors with $N_f = 2+1+1$ HISQ fermions and physical light quark masses
Elvira Gamiz
Thu, 14:00, Seminar Room C (RW4) – Parallels 7C

We present results for the form factor $f_+^{K\pi}(0)$, needed to extract the CKM matrix element $|V_{us}|$ from experimental data on semileptonic K decays, on the HISQ $N_f = 2$+1+1 MILC configurations. In this calculation the HISQ action is also used for the valence sector. The set of data presented includes three different values of the lattice spacing and data at the physical light quark masses. We discuss the different approaches for the chiral and continuum extrapolation, a preliminary error budget, and how this calculation improves over our previous determination of $f_+^{K\pi}(0)$ on the asqtad $N_f = 2+1$ MILC configurations.

Kaon semileptonic decay from the SU(3)-symmetric point down to physical quark masses
Andreas Juettner
Thu, 14:20, Seminar Room C (RW4) – Parallels 7C

We present the RBC/UKQCD collaboration's results for the $K \to \pi$ semileptonic vector form factor. We are simulating chiral fermions from close to the SU(3)-symmetric point down to physical parameters for three lattice spacings in large volume. Using partially twisted boundary conditions we calculate the form factor directly at zero momentum transfer. The comprehensive set of data points allows for turning the extrapolation in the quark mass into an interpolation around the physical point thereby removing the dominant systematic uncertainty in previous results. We discuss our prediction in view of Standard Model phenomenology.

Calculating the $K_L - K_S$ mass difference and ϵ_K to sub-percent accuracy

Norman Christ

Thu, 14:40, Seminar Room C (RW4) – Parallels 7C

The real and imaginary parts of the KL-KS mixing matrix receive contributions from all three charge-2/3 quarks: up, charm and top. These give both short- and long-distance contributions which are accessible through a combination of perturbative and lattice methods. We will discuss a strategy to compute both the mass difference, ΔM_K, and ϵ_K to sub-percent accuracy, looking in detail at the contributions from each of the three CKM matrix element products $V_{id}^* V_{is}$ for i=u, c and t as described in arXiv:1212.5931 [hep-lat].

K_L-K_S mass difference from Lattice QCD

Jianglei Yu

Thu, 15:00, Seminar Room C (RW4) – Parallels 7C

We will report on the first full calculation of the K_L-K_S mass difference in lattice QCD. The calculation is performed on a 2+1 flavor, domain wall fermion, $24^3 \times 64$ ensemble with a 329 MeV pion mass and a 575 MeV kaon mass. Both double penguin diagrams and disconnected diagrams are included in this calculation. The calculation is made finite through the GIM mechanism by introducing a 949 MeV valence charm quark. While the double penguin diagrams contribute a very small fraction to the mass difference, there is a large cancellation between disconnected diagrams and other types of digrams. We obatain the mass difference $\Delta M_K = 3.24(29) \times 10^{-12}$ MeV for these unphysical kinematics.

Finite-volume effects in the evaluation of the K_L-K_S mass difference

Christopher Sachrajda, Norman Christ, Guido Martinelli

Thu, 15:20, Seminar Room C (RW4) – Parallels 7C

The flavour physics programme of the RBC-UKQCD collaboration includes the evaluation of the long-distance contributions to the K_L-K_S mass difference, ΔM_K. The long-distance contributions lead to the presence of finite-volume corrections which generally do not decrease exponentially with the volume of the lattice, but as inverse powers. The evaluation of these corrections for the case when the masses and volume are tuned so that M_K is equal to the energy of one of the discrete two-pion states was presented at Lattice 2010. In this talk I discuss the finite-volume corrections in the general case, where there is no such degeneracy and suggest an optimal choice of volumes such that the corrections are exponentially small.

Kaon Mixing Beyond the Standard Model

Andrew Lytle, Nicolas Garron, Renwick Hudspith, Peter Boyle, Christopher Sachrajda

Thu, 15:40, Seminar Room C (RW4) – Parallels 7C

We report on the calculation of hadronic matrix elements needed to parameterize $K - \bar{K}$ mixing in generic BSM scenarios, using domain wall fermions (DWF) at two lattice spacings. We use Nf=2+1 DWF with Iwasaki gauge action at inverse lattice spacings of 2.28 and 1.73 GeV, with multiple unitary pions on each ensemble, the lightest being 290 and 330 MeV on the finer and coarser of the two ensembles respectively. Results on each ensemble are extrapolated to the physical pion mass, and the continuum limit is taken. Renormalization is carried out in the RI/MOM scheme and then converted perturbatively to MSbar. This extends previous work by the addition of a second lattice spacing ($a^{-1} \approx 1.73$ GeV), allowing the determination in the continuum limit.

Progress Towards an ab Initio, Standard Model Calculation of Direct CP-Violation in K decay
Christopher Kelly, (RBC & UKQCD Collaboration)
Thu, 16:30, Seminar Room C (RW4) – Parallels 8C

The RBC & UKQCD collaborations recently published the first direct lattice calculation of the $K \to \pi\pi$ decay amplitude in the I=2 channel. In order to compare the parameter epsilon', the measure of direct CP-violation in $K \to \pi\pi$ decays, with the prediction of the Standard Model, a calculation must also be performed in the I=0 channel. To obtain physical kinematics in this channel without the need for multi-exponential fits or a moving initial kaon state, we will use G-parity boundary conditions on the quarks to remove the state with stationary pions and to tune the two pion energy to equal the kaon mass. I will describe our implementation and understanding of this choice of boundary conditions, and describe the status of the project.

Determination of the A_2 amplitude of $K \to \pi\pi$ decays
Tadeusz Janowski
Thu, 16:50, Seminar Room C (RW4) – Parallels 8C

I review the status of recent calculations by the RBC-UKQCD of the complex amplitude A_2, corresponding to the decay of a kaon to a two pion state with total isospin 2. In particular, I present the preliminary results from two new ensembles: 48^3 with $a^{-1} = 1.73$ GeV and 64^3 with $a^{-1} = 2.3$ GeV, both at physical kinematics. These results, combined with our earlier ones on a 32^3 lattice with $a^{-1} = 1.36$ GeV, enable us to significantly reduce the discretization errors. The partial cancellation between the two dominant contractions contributing to $\mathrm{Re}(A_2)$ has been confirmed and we propose that this cancellation is a major contribution to $\Delta I = 1/2$ rule.

Using all-to-all propagators for $K \to \pi\pi$ decays
Daiqian Zhang
Thu, 17:10, Seminar Room C (RW4) – Parallels 8C

In order to determine the direct CP-violation parameter ϵ' from first principles, the decay amplitude for $K \to \pi\pi(\Delta I = 1/2)$ must be calculated on the lattice, where the main difficulty is the disconnected diagrams appearing in the correlation function. In order to control the statistical fluctuations in these disconnected diagrams, we will use all-to-all propagators, which allow the construction of $\pi\pi$ operators with reduced coupling to the vacuum. The resulting I=0 $\pi\pi$ scattering phase shift obtained using this methods shows that it works as we expected. We will also describe the current progress in implementing this method for $K \to \pi\pi$ decays.

Weak Decay Measurements from 2+1 flavor DWF Ensembles
Robert Mawhinney
Thu, 17:30, Seminar Room C (RW4) – Parallels 8C

The RBC and UKQCD Collaborations have generated 2+1 flavor DWF ensembles, with physical quark masses and spatial volumes of $(5.5fm)^3$, at two lattice spacings, $1/a = 1.7$ and 2.3 GeV. Measurements of light hadron masses and decay constants, as well as B_K, $f^+_{K\pi}(0)$ for $K\ell 3$ decays and $\mathrm{Re}(A_2)$ and $\mathrm{Im}(A_2)$ amplitudes for $K \to \pi\pi$ decays are being done using the EigCG algorithm and all-mode-averaging. These techniques have sped the measuremnts up by a factor of ≈ 10. Details of the measurement strategy will be discussed, along with some preliminary results. Further details about indiviudal observables will be presented in other talks by the RBC and UKQCD collaboration.

Strange and charmed pseudoscalar meson decay constants from simulations at physical quark masses

Doug Toussaint, Claude Bernard, Jongjeong Kim, Javad Komijani, Ruth van de Water

Thu, 17:50, Seminar Room C (RW4) – Parallels 8C

We update our determinations of f_K, f_D, f_{D_s} and quark mass ratios from simulations with four flavors of dynamical quarks at the physical quark masses. The availability of ensembles with light quarks near their physical mass means that instead of a chiral extrapolation to the physical light quark mass, we only need small corrections for sea quark mass mistuning. This analysis is complementary to an analysis of f_D and f_{D_s} using partially-quenched staggered chiral perturbation theory (to be presented by C. Bernard). While the ChiPT analysis allows us to use data at unphysical quark masses where statistical errors are often smaller, the analysis presented here allows us to combine all of the scale setting, quark mass tuning and decay constant determinations into a unified analysis, which simplifies the handling of many of the systematic errors.

B, B_s, K and π weak matrix elements with physical light quarks

Rachel Dowdall, Christine Davies, Ronald Horgan, G. Peter Lepage, Craig McNeile, Christopher Monahan, Junko Shigemitsu

Thu, 18:10, Seminar Room C (RW4) – Parallels 8C

I report on HPQCD calculations of meson decay constants and bag parameters using NRQCD heavy and HISQ light quarks on MILC Nf=2+1+1 gauge ensembles that include physical light quark masses.

$B \to \pi$ semileptonic form factors from unquenched lattice QCD
Daping Du, Jon Bailey, Alexei Bazavov, Aida El-Khadra, Steven Gottlieb, Rajendra Jain, Andreas Kronfeld, Yuzhi Liu, Yannick Meurice , Ruth van de Water, Ran Zhou
Fri, 16:30, Seminar Room D (RW5) – Parallels 10D

We update the lattice calculation of the $B \to \pi$ semileptonic form factors which are important for determining the CKM matrix element $|V_{ub}|$ and using the $B \to \pi\ell^+\ell^-$ decay mode to constrain new physics. We use the MILC asqtad 2+1 flavor lattice ensembles, with four lattice spacings (about 0.12, 0.09, 0.06 and 0.045 fm) and up/down quark over strange quark mass ratios as low as 0.05. We extrapolate the lattice data using staggered chiral perturbation theory in the hard pion and SU(2) limits. To extend the result to the full kinematic range, we introduce a new functional method to reparameterize the extrapolation in q^2 using the model-independent z expansion. We also present a preliminary error budget for the calculation.

$B_s \to D_s\ell\nu_\ell$ near zero recoil from tmQCD
Mariam Atoui, Damir Becirevic, Vincent Morénas, Francesco Sanfilippo
Fri, 16:50, Seminar Room D (RW5) – Parallels 10D

We study the form factors relevant to the theoretical description of the semileptonic decays $B_s \to D_s\mu\nu_\mu$ and $B_s \to D_s\tau\nu_\tau$, in and beyond the Standard Model. We focus to the region near the zero-recoil and evaluate the form factors without recourse to heavy quark effective theory. The quark action used in this work is twisted mass QCD and the configurations are those with $N_f = 2$ dynamical quark flavors.

Semileptonic decays $B \to D\ell\nu$ at nonzero recoil
Siwei Qiu, Carleton DeTar, Laiho Jack, Ruth van de Water, Andreas Kronfeld (Fermilab Lattice and MILC Collaborations)
Fri, 17:10, Seminar Room D (RW5) – Parallels 10D

The Fermilab Lattice-MILC collaboration has completed its analysis of the semileptonic decays $B \to D^{(*)}\ell\nu$ using the MILC (2+1)-flavor asqtad ensembles with lattice spacings as small as 0.045 fm and light-to-strange-quark mass ratios as low as 1/20. We use the Fermilab interpretation of the clover action for heavy valence quarks and the asqtad action for light valence quarks. We compute the hadronic form factors for $B \to D$ at both zero and nonzero recoil and for $B \to D^*$ at zero recoil. We report our result for $|V_{cb}|$.

Heavy-meson semileptonic decays for the Standard Model and beyond

Andreas Kronfeld, Yuzhi Liu, Ran Zhou

Fri, 17:30, Seminar Room D (RW5) – Parallels 10D

We calculate with lattice QCD the form factors for the semileptonic decays $B_s \to K\ell\nu$ and $B \to K\ell\ell$. The first calculation, when combined with potential measurements at Belle II or LHCb, would provide a new way to determine the CKM matrix element $|V_{ub}|$. The second process arises at the one-loop level in the Standard Model and is, thus, a probe of new physics. We work at several lattice spacings and a range of light quark masses, using the MILC $2+1$-flavor asqtad ensembles. We use the Fermilab method for the b quark. We obtain chiral-continuum extrapolations for E_K up to ~ 1.2 GeV and then extend to the kinematic range with the model-independent z expansion.

B and B_s semileptonic decay form factors with NRQCD/HISQ quarks

Chris Bouchard, Peter Lepage, Christopher Monahan, Heechang Na, Junko Shigemitsu

Fri, 17:50, Seminar Room D (RW5) – Parallels 10D

We discuss our ongoing effort to calculate form factors for several B and B_s semileptonic decays. We have recently completed the first unquenched calculation of the form factors for the rare decay $B \to K\ell^+\ell^-$. Extrapolated over the full kinematic range of q^2 via model-independent z expansion, these form factor results allow us to calculate several Standard Model observables. We compare with experiment (Babar, Belle, CDF, and LHCb) where possible and make predictions elsewhere. We discuss preliminary results for $B_s \to K\ell\nu$ which, when combined with anticipated experimental results, will provide an alternative exclusive determination of $|V_{ub}|$. We are exploring the possibility of using ratios of form factors for this decay with those for the unphysical decay $B_s \to \eta_s$ as a means of significantly reducing form factor errors. We are also studying $B \to \pi\ell\nu$, form factors for which are combined with experiment in the standard exclusive determination of $|V_{ub}|$. Our simulations use NRQCD heavy and HISQ light valence quarks on the MILC 2+1 dynamical asqtad configurations.

Status of Semileptonic Hyperon Decays from Lattice QCD using 2+1 flavor Domain Wall Fermions

Shoichi Sasaki

Fri, 18:10, Seminar Room D (RW5) – Parallels 10D

We report the current status of hyperon semileptonic decays from fully dynamical lattice QCD. The calculations are carried out with gauge configurations generated by the RBC and UKQCD collaborations with (2+1)-flavors of dynamical domain-wall fermions and the Iwasaki gauge action at two couplings, $\beta = 2.13$ and 2.25. Our results show that a sign of the second-order correction of SU(3) breaking on the hyperon vector coupling $f_1(0)$ is negative at simulated pion masses of M_π=330-558 MeV. The size of the second-order corrections observed here is also comparable to what is observed in lattice calculations of kaon semileptonic decays. We also evaluate the systematic uncertainty on $f_1(0)$ due to the lattice discretization error.

Lattice calculation of BSM B-parameters using improved staggered fermions in $N_f = 2+1$ unquenched QCD

Boram Yoon, Taegil Bae, Yong-Chull Jang, Chulwoo Jung, Hwancheol Jeong, Hyung-Jin Kim, Jangho Kim, Jongjeong Kim, Kwangwoo Kim, Sunghee Kim, Jaehoon Leem, Jeounghwan Pak, Stephen Sharpe, Weonjong Lee

Poster Session

We present the beyond the Standard Model (BSM) B-parameters calculated using improved staggered fermions in $N_f = 2+1$ flavors. The matching factors are perturbatively calculated at the one-loop level, and the valence quark masses are extrapolated to the physical values using SU(2) staggered chiral perturbation theory. The continuum and sea quark mass extrapolations are performed using four lattice spacings (a=0.12, 0.09, 0.06 and 0.045 fm) and several different light sea quark masses. We present the B-parameters at 2GeV and 3GeV in the MS-bar scheme with naive dimensional regularization. By combining with experimental value of ϵ_K, the results can put strong constraints on the BSM physics.

Calculations of $K \to \pi\pi$ decay amplitude with improved Wilson fermion
Naruhito Ishizuka, Ken-Ichi Ishikawa, Akira Ukawa, Tomoteru Yoshie
Poster Session

We present results of our trial calculations of the $K \to \pi\pi$ decay amplitude. Calculations are carried out with $N_f = 2+1$ gauge configurations previously generated by the PACS-CS Collaboration with the Iwasaki gauge action and nonperturbatively $O(a)$-improved Wilson fermion on $La = 2.9fm$ at $m_\pi = 300, rmMeV$.

Charm quark mass and D-meson decay constants from two-flavour lattice QCD
Jochen Heitger, Georg von Hippel, Stefan Schaefer, Francesco Virotta
Poster Session

We present a computation of the charm quark's mass and the leptonic D-meson decay constants f_{D} and $f_{\mathrm{D_s}}$ in two-flavour lattice QCD with non-perturbatively $\mathrm{O}(a)$ improved Wilson quarks. Our analysis is based on large-volume CLS configurations at two lattice spacings ($a = 0.066, 0.049$ fm, where the lattice scale is set by f_{K}) and pion masses ranging down to ~ 190 MeV at $Lm_\pi \geq 4$, in order to perform controlled continuum and chiral extrapolations with small systematic uncertainties.

Recent update on B_K and ε_K with staggered quarks
Weonjong Lee, Taegil Bae, Yong-Chull Jang, Hwancheol Jeong, Chulwoo Jung, Hyung-Jin Kim, Jangho Kim, Jongjeong Kim, Kwangwoo Kim, Sunghee Kim, Jaehoon Leem, Jeonghwan Pak, Stephen Sharpe, Boram Yoon
Poster Session

We present results of B_K and ε_K calculated using improved staggered quarks on the MILC asqtad lattices. Since Lattice 2012, we have added a number of new measurements on the fine ($a \approx 0.09$ fm) ensembles and superfine ($a \approx 0.06$ fm) ensembles. This allows us to perform a new simutaneous analysis on the dependence on light sea quark masses and on scaling violation (i.e. discretization error of $\mathcal{O}(a^2)$). We report an updated version of the error budget of this analysis.

Matrix elements for D- and B-Mixing from 2+1 flavor lattice QCD
Chia Cheng Chang, Claude Bernard, Chris Bouchard, Aida El-Khadra, Elizabeth Freeland, Elvira Gamiz, Andreas Kronfeld, Laiho Jack, Ruth van de Water
Poster Session

We present the status of the Fermilab Lattice and MILC collaboration's calculation of hadronic matrix elements for D- and B-mixing. We use the asqtad staggered action for light valence quarks in combination with the Fermilab interpretation of the Sheikoleslami-Wohlert action for heavy quarks. The calculations use MILC's 2+1 flavor asqtad ensembles. Ensembles include four lattice spacings from 0.125 – 0.045 fm and up/down to strange quark mass ratios as low as 0.05. Our calculations cover the complete set of five local operators needed to describe B meson mixing in the Standard Model and Beyond. In the charm sector, our calculation of local mixing matrix elements may be used to constrain new physics models. We will present final B-mixing correlator fit results for the full data set and preliminaries for the D-mixing calculation.

Radiative Decays in Non-Relativistic QCD
Ciaran Hughes, Rachel Dowdall, Ronald Horgan, Matthew Wingate
Poster Session

Radiative transitions between bottomonium states offer an insight into the internal structure of heavy-quark bound states within QCD. Babar has evaluated the branching fraction of $\Upsilon(2s), \Upsilon(3s) \to \gamma\eta_b(1s)$. The measured hyperfine splittings also provide a better understanding of the non-relativistic bound states and the role of spin-spin interactions in quarkonium models. I report progress of an exploratory calculation that studies radiative decays in the bottomonium system, where we use non-relativistic QCD including u, d, s and c HISQ quarks in the sea.

Flavour Symmetry Breaking in Octet Hyperon Matrix Elements

Ashley Cooke

Poster Session

We investigate the effects of SU(3) flavour symmetry breaking on octet baryon diagonal and transition matrix elements. Results from 2+1 flavours of dynamical O(a)-improved Wilson (clover fermions) for hyperon form factors will be discussed and our simulation techniques outlined. SU(3) flavour symmetry breaking is explored by keeping the singlet quark mass fixed. We use 5 individual choice of quark masses on $24^3 \times 48$ lattices with a lattice spacing of 0.078fm.

Special Session: Coding Efforts

PRACE: Partnership for Advanced Computing in Europe
Claudio Gheller
Fri, 14:00, Seminar Room G (HS III) – Parallels 9G

tba

PLQCD library for Lattice QCD on multi-core machines
Abdou Abdel-Rehim, Constantia Alexandrou, Giannis Koutsou, Nikos Anastopoulos , Nikela Papadopoulou
Fri, 14:20, Seminar Room G (HS III) – Parallels 9G

PLQCD is a stand alone software library developed under PRACE for lattice QCD. It provides an implementation of the Dirac operator for Wilson type fermions and few efficient linear solvers. The library is optimized for multi-core machines using a hybrid parallelization with openMP+MPI. The main objectives of the library is to provide a scalable implementation of the Dirac operator as well as to speed the computation of the quark propagator. In this talk a description of the PLQCD library is given together with some test results.

Recent development in the tmLQCD software suite
Carsten Urbach
Fri, 14:40, Seminar Room G (HS III) – Parallels 9G

tmLQCD is a software suite for lattice QCD simulations. It offers a wide range of options for simulations with Wilson type fermions. We present an overview of recent developments in the tmLQCD software suite. In particular, we will discuss the performance obtained on BG/Q and other architectures. Moreover, we review the implemented dirac operators and actions.

Bridge++: an object-oriented C++ code for lattice simulations
Satoru Ueda, Sinya Aoki, Tatsumi Aoyama, Kazuyuki Kanaya , Hideo Matsufuru, Shinji Motoki, Yusuke Namekawa, Hidekatsu Nemura, Yusuke Taniguchi, Naoya Ukita
Fri, 15:00, Seminar Room G (HS III) – Parallels 9G

We are developing a new code set “Bridge++” for lattice simulations aiming at extensible, readable, and portable workbench, while keeping a high performance at the same time. Bridge++ covers most conventionally used lattice actions and numerical algorithms, and works on massively parallel machines with or without arithmetic accelerators such as GPGPUs. In this talk, we explain our strategy and the basic design of Bridge++, as well as our current status of this project, including results of the sustained performance on several systems.

Overview of Columbia Physics System(CPS)
Chulwoo Jung
Fri, 15:20, Seminar Room G (HS III) – Parallels 9G

I will give an overview of Columbia Physics System (CPS), a C++ based code suite developed for LatticeQCD mainly by members of Columbia University, Brookhaven National Laboratory and Edinburgh University. CPS has been and is being used extensively for ensemble generation and measurements done by RBC and UKQCD collaborations.

Experiences with Lattice QCD on the Juelich BG/Q
Stefan Krieg, Kalman Szabo
Fri, 15:40, Seminar Room G (HS III) – Parallels 9G

The implementation and tuning of the Wuppertal software suite “dynqcd” on BG/Q is discussed and performance results are shown.

Experiences with OpenMP in tmLQCD
Bartosz Kostrzewa, Albert Deuzeman, Carsten Urbach
Fri, 16:30, Seminar Room G (HS III) – Parallels 10G

In this contribution, the introduction of OpenMP into a lattice QCD code is exemplified on the basis of the tmLQCD software suite by the European Twisted Mass Collaboration (ETMC). Using specific examples from a number of routines, one possible approach for the addition of multi-threading through OpenMP is constructed and the perceived benefits of this particular method are clarified. As a particular focus area, problems of data concurrency, race conditions and subtle probabilistic program errors are analyzed and possible approaches for their mitigation are discussed. Finally, a short overview of overheads on different architectures is given and possible improvements of the approach are presented retrospectively.

The QUDA library for QCD on CUDA
M Clark
Fri, 16:50, Seminar Room G (HS III) – Parallels 10G

The exponential growth of floating point power in GPUs, combined with high memory bandwidth, has given rise to an attractive platform upon which to deploy HPC applications. We review the QUDA library which is a domain-specific library designed to accelerate legacy lattice quantum chromodynamics application through providing a rich library of the common performance-critical algorithms, including highly optimized sparse linear solvers.

QDP-JIT: A QDP++ Implementation for CUDA-Enabled GPUs
Frank Winter
Fri, 17:10, Seminar Room G (HS III) – Parallels 10G

QDP++ provides parallel data types and operations suitable for lattice gauge theory similar to high-level domain-specific languages. Heterogeneity with massively multi-core accelerators is becoming ubiquitous and offers tremendous computational power. However, current parallel programming models like the CUDA architecture expose many low-level programming details to the user opening a gap between high-level usability and low-level programmability. QDP-JIT leverages a novel approach to bridge this gap. While maintaining the full QDP++ API high-performance compute kernels are generated and launched on-the-fly. Low-level GPU programming details are completely concealed from the user.

Implementation of the twisted mass fermion operator in QUDA library

Alexei Strelchenko, Constantia Alexandrou, Giannis Koutsou, Alejandro Vaquero

Fri, 17:30, Seminar Room G (HS III) – Parallels 10G

In this report we present results of implementation of twisted mass fermion operator within the QUDA framework, an open source library for performing calculations in lattice QCD on Graphics Processing Units (GPUs) using NVIDIA's CUDA platform. Performance analysis is provided for both degenerate and non-degenerate cases.

A QUDA-branch to compute disconnected diagrams in GPUs

Alejandro Vaquero, Constantia Alexandrou, Kyriacos Hadjiyiannakou, Giannis Koutsou, Alexei Strelchenko

Fri, 17:50, Seminar Room G (HS III) – Parallels 10G

Although QUDA allows for an efficient computation of many QCD quantities, it is surprinsingly lacking tools to evaluate disconnected diagrams, for which GPUs are specially well suited. We aim to fill this gap by creating our own branch of QUDA, which includes new kernels and functions required to calculate fermion loops using several methods and fermionic regularizations.

Code development (not only) for NSPT
Michele Brambilla, Dirk Hesse, Francesco Di Renzo
Fri, 18:10, Seminar Room G (HS III) – Parallels 10G

In recent years NSPT was proven capable of providing high order perturbative results more easily than traditional approaches. The technique is based on the numerical integration of the equations of stochastic quantization; one thus gets perturbative results in a way which is alternative to standard Feynman diagrams. One actually needs to solve a hierarchy of stochastic differential equations, the solution being looked for as a perturbative expansion. The key point for an efficient solution is a framework in which everything is computed order by order. We are currently developing "parmalgt", a general C++ framework, mainly intended for NSPT computations. Programs are highly templated and c++11 compliant in order to achieve good performances without loss of readability. Multithreading (via OpenMP) and MPI parallelization (the latter at the moment at a preliminary stage) are hidden to the user. Some results obtained with the current implementation of the code are presented in the talks by D. Hesse and M. Dalla Brida. The Parma group is also involved in other code oriented activities. In particular, some efforts are devoted to the general framework of multithread+multiprocess parallelization. An approach to hide inter-process communications in order to improve performances will be briefly discussed.