The 37th International Symposium on Lattice Field Theory (Lattice 2019)

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Book of Abstracts

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Trace anomaly under lattice regularization

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The trace anomaly is one of the most non-trivial property of QCD which violates the scale invariance from the traceless QCD Energy momentum tensor, and then give non-zero mass to nucleon in the chiral limit. It has been predicted by QCD for over forty years, and will be verified by the EIC/EicC experiments in the near future.

I will present several procedures and the related lattice calculation of the trace anomaly contribution to the hadron mass, including pion and nucleon.

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Resonance information from lattice energy levels using chiral EFT

Author: Zhi-Hui Guo[1]

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I will discuss my recent works on the determination of resonance properties from the lattice energy levels using the chiral effective field theory.

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Coupled-channel $\Lambda_c K^+ - PD_s$ interaction from lattice QCD

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We study S-wave interactions in the $I\,(J^p) = 1/2\,(1/2^-)$ $\Lambda_c K^+ - pD_s$ system on the basis of the coupled-channel HAL QCD method. The potentials which are faithful to QCD S-matrix below the pD^* threshold are extracted from Nambu-Bethe-Salpeter wave functions on the lattice. For the simulation, we employ the (2+1)-flavor gauge configurations on a $(2.9fm)^3$ volume at $m_\pi \simeq 700$ MeV. For the charm quark, the relativistic heavy quark action is employed to treat its dynamics on the lattice. We present our results of the S-wave coupled-channel potentials for the $\Lambda_c K^+ - pD_s$ system in the $1/2\,(1/2^-)$ state as well as scattering observables obtained from the extracted potential matrix.

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The Development of Hamiltonian Finite Volume Method of Two Body System within Partial Wave Mixing in Rest System

Authors: Yan Li[1]; Derek Leinweber[2]; Anthony Thomas[2]; Jiajun Wu[1]

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Hamiltonian effective field theory has been used for explaining Lattice data. We develop it within partial waves mixing in the rest frame. The dimension of the Hamiltonian can be highly reduced with the partial wave cut-off and rotation symmetry. We apply this method to extract the Pion-Pion s-, d- and f-wave phase shifts within Isospin=2 case.

Physics Beyond the Standard Model / 10

Baryonic states in supersymmetric Yang-Mills theory

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We study the bound states of three gluinos in $N = 1$ supersymmetric Yang-Mills theory (SYM) on the lattice, we call these states as baryonic states analogous to baryons in QCD. The gluino is a spin 1/2 Majorana particle in the adjoint representation of the gauge group, it is the superpartner of the gluon. The correlation functions of the corresponding baryonic operators contain a contribution represented by a "sunset diagram", and in addition, unlike in QCD, another contribution represented by a "spectacle diagram". We present preliminary results from an implementation and calculation of these objects, obtained from numerical simulations of SYM theory.

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Matching Quasi Generalized Parton Distributions in the RI/MOM scheme

Authors: Yu-Sheng Liu[1]; Wei Wang[2]; Ji XU[2]; Qi-An Zhang[3]; Jian-Hui Zhang[4]; Shuai Zhao[5]; Yong Zhao[6]

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Within the framework of large momentum effective theory (LaMET), generalized parton distributions (GPDs) can be extracted from lattice calculations of quasi-GPDs through a perturbative matching relation, up to power corrections that are suppressed by the hadron momentum. In this work, we focus on isovector quark GPDs, including the unpolarized, longitudinally and transversely polarized cases, and present the one-loop matching that connects the quasi-GPDs renormalized in a regularization-independent momentum subtraction (RI/MOM) scheme to the GPDs in MS-bar scheme. We find that the matching coefficient is independent of the momentum transfer squared. As a consequence, the matching for the quasi-GPD with zero skewness is the same as that for the quasi-PDF. Our results provide a crucial input for the determination of quark GPDs from lattice QCD using LaMET.

Nonzero Temperature and Density / 12

Stress distribution in quark—anti-quark and single quark systems at nonzero temperature

Author: Ryosuke Yanagihara[1]

Co-authors: Takumi Iritani [2]; Masakiyo Kitazawa [1]; Masayuki Asakawa [1]; Tetsuo Hatsuda [2]

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We explore the distribution of the energy momentum tensor (EMT) around quark—anti-quark and single quark at nonzero temperature in SU(3) Yang-Mills gauge theory. This is an extension of our previous study [1] on the EMT distribution in static quark—anti-quark systems in vacuum. We discuss the disappearance of the flux tube structure observed in the vacuum simulation. We investigate the total stress acting on the mid-plane between a quark and an anti-quark and show that it agrees with the force obtained from the derivative of the free energy. The color Debye screening effect in the deconfined phase is also discussed in terms of the EMT distribution.

[1] R. Yanagihara et al., Phys. Lett. B789 (2019) 210.

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Meson interactions at Large Nc from Lattice QCD

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The Large N_c limit is often invoked in phenomenological approaches. Even though it is a useful simplification of QCD, the systematic uncertainties of these large-N_c-inspired approximations to QCD remain unclear. Moreover, it fails in some observables, such as the ratio of isospin amplitudes in the $K \to \pi\pi$ weak decays. In this context, lattice QCD has a lot of yet unexplored potential to shed light on the Nc scaling of these observables. I will review in this talk some of our recent results

concerning weak decays, scattering parameters and meson decay constants at Large N_c from lattice simulations.

Poster / 14

Recent progress on (implementing) the relativistic three-particle quantization condition

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We describe progress during the last year on extending the range of applicability of the model-independent three-particle quantization condition and in implementing it in practice. Results include the extension of the formalism to allow subchannel resonances, which has been achieve in two different ways, and the inclusion of d-wave two- and three-particle interactions in practical implementation. We demonstrate in model examples how the quantization could be used in practice. We also emphasize that it can be used to study infinite-volume physics, one example being the possible binding of an Efimov-like trimer by d-wave interactions.

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Bethe-Salpeter wavefunctions of hybrid charmonia

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The charmonium-like hybrid mesons with $J^{PC} = (0, 1, 2)^{-+}$ and 1^{--} are investigated on anisotropic lattices in the quenched approximation. For these states, we construct spatially extended operators by splitting the $\bar{c}\Gamma cB$-type operators into two parts ($c\bar{c}$ and the chromo-magnetic field strength B) with different spatial distances r. In the Coulomb gauge, the matrix elements of these operators between the vacuum and the corresponding states are interpreted as Bethe-Salpeter (BS) wave functions, which can be extracted by fitting the correlation functions at different r simultaneously. After disentangling from the conventional charmonium states in 0^{-+} ,2^{-+} and 1^{--} channels, the spectrum and the BS wave functions of the hybrid states in the four channels are obtained. It is found that the ground state, the first excited state and even the second excited states of these channels are nearly degenerate in mass and have almost the same BS wave functions. Furthermore, the BS wave functions of the ground state, the first excited state and the second excited state have zero radial node, one radial node and two radial nodes, respectively. In the non-relativistic picture, this observation implies that the hybrid states in these four channels have similar infrastructure and the separation between the $c\bar{c}$ component and gluonic component (depicted by B operator) can be taken as a meaningful dynamical variable.

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Status of the muon g-2 hadronic vacuum polarization calculation by RBC/UKQCD

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I present the current status of the lattice QCD+QED calculation of the hadronic vacuum polarization contribution to the muon anomalous magnetic moment by RBC/UKQCD

Hadron Spectroscopy and Interactions / 17

The general formalism of momentum transformation in the moving finite volume

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In the two body system, the S matrix in the infinite volume is defined in the rest system, while to obtain more spectra in finite volume, people extract the energy spectrum of finite volume in the moving system. As a result, it needs momentum transformation to connect the energy spectrum in the moving finite volume and the S matrix in the infinite volume. In this work, we find a general formalism of such momentum transformation. In this formalism it has two changeable parameters, then we develop three different transformation equations. The two of them are used in the previous work, and the third one is a new form which will be helpful to develop the Hamiltonian approach in the moving two body system.

Hadron structure / 18

The hadronic contribution to the running of the electroweak mixing angle

Author: Marco Cè[1]

Co-authors: Antoine Gérardin [2]; Hartmut Wittig ; Harvey B. Meyer [3]; Jonas Wilhelm [4]; Kohtaroh Miura [5]; Konstantin Ottnad [6]; Miguel Teseo San José Pérez [7]

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The electroweak mixing angle, or Weinberg angle, θ_{W} is a parameter of the Standard Model that parametrizes the mixing between the electromagnetic and weak couplings.
We present a lattice study of the leading hadronic contribution to the running of $\sin^2\theta_{\mathrm{W}}$, given by the hadronic vacuum polarization (HVP) of the electromagnetic current with the vector part of the weak neutral current, estimated using the time-momentum representation (TMR) method. Both connected and disconnected contributions have been computed on $N_{\mathrm{f}} = 2+1$ non-perturbatively $\mathcal{O}(a)$-improved Wilson fermions ensembles from the Coordinated Lattice Simulations (CLS) initiative. The use of different lattice spacings and quark masses allows us to reliably extrapolate the results to the physical point.

Theoretical Developments / 19

Information, dualities, and deconfinement

Author: Mohamed Anber[1]

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Computing the entanglement entropy in lattice gauge theories is often accompanied by ambiguities. In this talk I argue that compactifying the theory on a small circle $\mathbb{S}^1$ evades these difficulties. In particular, I study Yang-Mills theory on $\mathbb{R}^3 \times \mathbb{S}^1$ with double-trace deformations or adjoint fermions and hold it at temperatures near the deconfinement transition. This theory is dual to a multi-component (electric-magnetic) Coulomb gas that can be mapped to an XY-spin model with $\mathbb{Z}_p$ symmetry-preserving perturbations. I study Renyi mutual information (RMI) of the XY-spin model by means of the replica trick and Monte Carlo simulations. These are expensive calculations, since one in general needs to suppress lower winding vortices that do not correspond to physical excitations of the system. I use a T-duality that maps the original XY model to its mirror image, making the extraction of RMI a much efficient process. The simulations indicate that RMI follows the area law scaling, with subleading corrections, and this quantity can be used as a genuine probe to detect deconfinement transitions. I also discuss the effect of fundamental matter on RMI and the implications of these findings in gauge theories.

Nonzero Temperature and Density / 20

Analytic continuation of Thermal Correlators

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We examine the analytic continuation of long-distance correlation functions of composite operators at finite temperature from Euclidean to Minkowski. There are two definitions of mass in each regime; in Euclidean these are the screening and pole masses. In a field theoretical model we show that the analytic continuation of these mass parameters is non-trivial and requires short-distance information. This is in contrast to the situation at zero temperature.

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Zb tetraquark channel and $B\bar{B}^*$ interaction

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Co-authors: Huseyin Bahtiyar [2]; Jan Petkovic [3]

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Belle experiment discovered two tetraquark candidates $Z_b(10610)$ and $Z_b(10650)$ with flavor structure $\bar{b}b\bar{d}u$ in 2011. We present the lattice study of the $\bar{b}b\bar{d}u$ system in the approximation of static b quarks. The ground and the excited eigenstates are extracted as a function of separation r between b and $\bar{b}$. The lower eigenstates at small r are related to a bottomonium and a pion, where the pion is at rest or in flight. Some of the higher eigenstates are related to the $\bar{B}B^*$ system. We extract the interaction of the $\bar{B}B^*$ system and present results concerning possible Z_b resonances or bound states in this channel.

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Interglueball potential in SU(N) lattice gauge theory

Authors: Nodoka Yamanaka[1]; Hideaki Iida[2]; Atsushi Nakamura[3]; Masayuki Wakayama[4]

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The glueballs in the SU(N) Yang-Mills theory are good candidates of dark matter.
An important feature to be discussed is the scattering between dark matter particles, which is constrained by observational data such as the galactic collisions.
In this work, we evaluate the interglueball potential in SU(2), SU(3), and SU(4) lattice gauge theories using the HALQCD method and derive the glueball scattering cross section.

Theoretical Developments / 23

Resurgence and fractional instanton of the SU(3) gauge theory in weak coupling regime

Author: Etsuko Itou[1]

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Motivated by recent studies on the resurgence structure of quantum field theories, we numerically study the nonperturbative phenomena of the SU(3) gauge theory in a weak coupling regime. We find that topological objects with a fractional charge emerge if the theory is regularized by an infrared (IR) cutoff via the twisted boundary conditions. Some configurations with nonzero instanton number

are generated as a semi-classical configuration in the Monte Carlo simulation even in the weak coupling regime. Furthermore, some of them consist of multiple fractional-instantons. We also measure the Polyakov loop to investigate the center symmetry and confinement. The fractional-instanton corresponds to a solution linking two of degenerate Z3-broken vacua in the deconfinement phase.

Theoretical Developments / 24

Lattice study on the twisted CPˆ{N-1} models on R x Sˆ1

Authors: TATSUHIRO MISUMI[1]; Etsuko Itou[2]; Toshiaki Fujimori[2]; Muneto Nitta[2]; Sakai Norisuke[2]

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We here focus on CPˆ{N-1} models on R x Sˆ1 with the Z_N twisted boundary conditions, whose importance has recently been increasing in terms of resurgence theory, volume independence and its relation to 4D gauge theory. We have performed lattice simulations for the models with N=3-20 on several lattice sizes (e.g. 40 x 8, 200 x 8, 400 x 12), with emphasis on Polyakov loop, Casimir energy and fractional instantons. In the talk, we will show our results on phase transition associated with the expectation value of Polyakov loop and Casimir energy associated with the vacuum energy. We will also discuss the existence of Q=1/N fractional instantons and bions, which play a pivotal role in the resurgent structure and the volume independence of the models.

Standard model parameters and renormalization / 25

Vector current renormalisation in momentum subtraction schemes using the HISQ action

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As the only lattice vector current that does not require renormalisation is the point-split conserved current it is convenient to have a robust, precise and computationally cheap methodology for the calculation of vector current renormalisation factors, Z_V. Momentum subtraction schemes, such as RI-SMOM, implemented nonperturbatively on the lattice provide such a method if it can be shown that the systematic errors, e.g. from condensates, are well controlled.
We present Z_V calculations in a variety of momentum subtraction schemes and for a variety of currents including the conserved current, using the HISQ action. We compare the results with each other, with previous HISQ determinations using form factors at $q^2 = 0$ and with perturbation theory. Our results show that momentum subtraction schemes, suitably defined, allow for good control of Z_V determination at small lattice spacings as well as the inclusion of electromagnetic effects. Both of these are potentially important for the Fermilab/HPQCD/MILC programme to calculate the leading order hadronic vacuum polarisation contribution to the anomalous magnetic moment of the muon, among other calculations.

Poster / 26

Lattice QCD on a modern vector processor

Authors: Benjamin Huth[1]; Nils Meyer[1]; Tilo Wettig[1]

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The NEC SX-Aurora Tsubasa is a novel PCI-Express accelerator design available since 2018. The vector architecture supports vector lengths of 16,384 bits and delivers up to 2.45 TFlop/s peak in double precision. It features outstanding memory throughput of up to 1.2 TB/s. In this contribution we discuss key aspects of the SX-Aurora Tsubasa, comment on integrating the architecture into the Grid Lattice QCD framework, and present initial benchmarks.

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Electromagnetic finite-size effects to the hadronic vacuum polarisation

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The present $3.5\,\sigma$ discrepancy between the theoretical prediction and experimental value of the muon anomalous magnetic moment requires improved accuracy for both measurements and calculations. On the theory side, the hadronic vacuum polarisation (HVP) is one of the main sources of uncertainty at the moment. This can be calculated in finite volume (FV) on the lattice, and in order to reach sub-percent precision on the HVP, $\mathcal{O}(\alpha)$ electromagnetic corrections need to be added. Due to the massless nature of photons the FV effects go as a polynomial in $1/L$, so including QED on the lattice is potentially problematic. We have analytically calculated the $1/L$ expansion of the HVP at NLO in the the electromagnetic coupling in QED_L and found it to start at $1/L^3$, i.e. suppressed by one power as compared to the a priori possible $1/L^2$. We have also shown that this is universal. The analytical $1/L$ expansion has been compared numerically with lattice perturbation theory as well as lattice calculations and there is good agreement.

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Hadronic Light-by-Light contribution to g-2 update

Authors: Thomas Blum[None]; Norman Christ[1]; Masashi Hayakawa[2]; Taku Izubuchi[3]; Luchang Jin[None]; Chulwoo Jung[3]; Christoph Lehner[4]

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We update our calculation of the hadronic light-by-light contribution to the muon anomalous magnetic moment. Our results comprise computations done on five gauge field ensembles employing 2+1 flavors of mobius domain wall fermions and Iwasaki and Iwasaki DSDR gluons, all with physical masses. Inverse lattice spacings range from 1 to 2.4 GeV, and lattice sizes from 4.8 to 6.4 fm. We present preliminary continuum and infinite volume limits for both finite and infinite volume QED.

Hadron Spectroscopy and Interactions / **29**

Theoretical and practical progresses in the HAL QCD mehod

Author: Sinya Aoki[1]

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We report recent theoretical and practical progresses in the HAL QCD potential method, which are summarizewd as follows.
(1) The explicit definition of the potential in terms of the derivative expansion.
(2) The construction of Hermite potentials from non-Hermite potentials.
(3) HAL QCD potentials from NBA wave fucntions in the moving systems.
(4) The partial wave decompositions on the finite box with the periodic boundary condition in the HAL QCD method.

Hadron structure / **30**

The hadronic contribution to the running of the electromagnetic coupling

Author: Miguel Teseo San José Pérez[1]

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The electromagnetic coupling that intervenes in the interactions between charged particles varies with the energy due to off-shell processes. In this work we compute the leading hadronic contribution to this running at low energies, where QCD is fully non-perturbative.

We employ a subset of CLS (Coordinated Lattice Simulations) ensembles with Nf = 2+1 and O(a) improved Wilson fermions in open boundary conditions in time and periodic in space. For each ensemble we extracted the vacuum polarization function, which is proportional to the running, using the time-momentum representation. The set of ensembles has different particle masses and four lattice spacings, in such a way that we have been able to perform the chiral and continuum extrapolation.

Theoretical Developments / 31

Phase structure and real-time dynamics of the massive Thirring model in 1+1 dimensions using the tensor-network method

Authors: C.-J. David Lin[1]; David T.-L. Tan[1]; Hao-Ti Hung[2]; Krzysztof Cichy[3]; Mari Carmen Banuls[4]; Ying-Jer Kao[2]; Yu-Ping Lin[5]

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In this talk, we present concluding results from our study of phase structure of the lattice version of the massive Thirring model in 1+1 dimensions. Employing the method of matrix product state (MPS), several quantities have been investigated, leading to firm numerical evidence of a Kosterlitz-Thouless phase transition. In particular, we examine two correlators and determine the relevant exponents. Exploratory results for real-time dynamics pertaining to this phase transition, obtained using the approaches of variational uniform MPS and time-dependent variational principle, will also be discussed.

Nonzero Temperature and Density / 32

Phase diagram of QCD in (B, T, μ) space from analytical continuation

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We study the phase diagram of QCD at nonzero temperature, chemical potential and magnetic field. Simulations are performed with $N_f = 2+1$ stout improved staggered quarks (with physical masses) and nonzero imaginary chemical potential. Results for real μ values are obtained by means of analytical continuation. By studying the renormalized chiral condensate and its dependence on the parameters of the system we measure the position and the width of the chiral phase transition. We determine the curvature of chiral pseudo-critical line (in the $T-\mu$ plane) of QCD and its dependence on the magnitude of the magnetic field.

Nonzero Temperature and Density / 34

Conductivity of quark-gluon matter in the external magnetic field

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We study the conductivity of quark-gluon matter in the presence of external magnetic field B within LQCD with dynamical staggered $2+1$ quarks at physical pion m_π and strange quark m_s masses in the deconfinement phase $T = 200\,\mathrm{MeV}$. We first measure the current-current Euclidean correlator, then extract the conductivity via analytical continuation within the Backus-Gilbert method. We observe that $\sigma_\parallel$ rapidly grows in the direction of magnetic field and that $\sigma_\perp$ on contrary decreases. This observation is in agreement with the Chiral Magnetic Effect (CME) predictions.

Hadron Spectroscopy and Interactions / 35

Scale setting for QCD with $N_f = 3+1$ dynamical quarks

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We present first results of the scale setting for QCD with $N_f = 3+1$ dynamical quarks on the lattice. We use a recently proposed massive renormalization scheme with a non-perturbatively determined clover coefficient. To relate the bare coupling of the simulations to a lattice spacing in fm, we use decoupling of charm at low energy and the value of a dimensionless quantity $\sqrt{(}t_0^\star)m_{had}$, where m_{had} is an experimentally accessible quantity and $t_0^\star$ is the flow scale t_0 at our mass point with $m_{up} = m_{down} = m_{strange}$ and a physical charm mass. We discuss the setup, tuning procedure, simulation parameters and measurement results for two ensembles with different volumes and present a charmonium spectrum.

Physics Beyond the Standard Model / 36

Towards a holographic description of cosmology (I): Phase diagram of 3d SU(N) matrix field theory

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The holographic principle allows us to study the physics of the early universe in terms of three-dimensional boundary quantum field theories. For instance, the power spectrum of the CMB at high multipoles has in this way been post-dicted successfully in terms of calculations for 2pt functions of the energy-momentum tensor (EMT) in perturbation theory. The lower end of the power spectrum maps onto dynamics non-perturbative in nature and are therefore best predicted by lattice simulations.

Here we study massless SU(N) scalar matrix field theory on the lattice as a first candidate theory. We present a comprehensive study of its critical properties in terms of a finite-size-scaling study and its large-N scaling both numerically and analytically.

In a next step we compute 2pt functions of the EMT in this theory which will allow us to make first lattice-based predictions for the spectrum of the CMB at low multipoles. Results for the EMT 2pt function and its renormalisation are discussed in the talk by Joseph Lee.

Physics Beyond the Standard Model / 37

Towards a holographic description of cosmology (II): Renormalisation of the 3D SU(N) scalar energy-momentum tensor

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In holographic cosmology, cosmological observables are described in terms of correlators of a three-dimensional boundary quantum field theory. In this talk, we study the renormalisation of the energy-momentum tensor 2 point function for 3D massless $SU(N)$ scalar matrix field theory. We present a non-perturbative procedure to remove divergences resulting from the loss of translational invariance on the lattice, by imposing Ward identities. This will allow us to make non-perturbative predictions for the CMB power spectrum at low multipoles, assuming the holographic theory describing the very early Universe is the 3D massless $SU(N)$ scalar matrix field theory.

Theoretical Developments / 38

Entanglement suppression and emergent symmetry

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Spin-flavor symmetries in hadronic physics have been thought to follow from large-N. However, lattice data suggests an SU(16) spin-flavor symmetry for baryons in the SU(3) limit that does not have a large-N explanation. We discuss how the enhanced symmetry corresponds to suppressed entanglement in scattering processes, and conjecture that the strong interactions may be dynamically suppressing entanglement. One can imagine additional lattice tests of this hypothesis, and other places unexpected symmetries might arise.

Poster / **39**

2019 update of ε_K with lattice QCD inputs

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We report recent progress in determining ε_K, the indirect CP violation parameter in neutral kaons, calculated using lattice QCD inputs including $\hat{B}_K$, ξ_0, ξ_2, $|V_{us}|$, $|V_{cb}|$, and $m_c(m_c)$. Recently Belle has updated results for exclusive $|V_{cb}|$ using both CLN and BGL method. They are used in this analysis.

Algorithms and Machines / **40**

Towards higher order numerical stochastic perturbation computation applied to the twisted Eguchi-Kawai model

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We have evaluated perturbation coefficients of Wilson loops up to $O(g^8)$ for the four-dimensional twisted Eguchi-Kawai model using the numerical stochastic perturbation theory (NSPT) in arXiv:1902.09847. In this talk we present the progress report on the higher order calculation up to $O(g^{63})$, for which we apply the fast Fourier transformation (FFT) based convolution algorithm to the multiplication of polynomial matrices in the NSPT to achieve higher order calculation.

Poster / **41**

Chiral Ward identities for Dirac eigenmodes with staggered fermions

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Co-authors: Sunghee Kim [1]; Weonjong Lee [1]

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There are several ways of distinguishing would-be zero modes of staggered fermions from non-zero modes of them. An intuitive approach is observing the taste symmetry on eigenvalue spectrum, but this fails in many cases and does not give much physical information.We are also able to identify those zero modes by measuring their chiralities, which has a better resolution for the identification and provides physical information such as the topological charge. We present results of the chirality measurement on quenched lattice ensembles using HYP-improved staggered fermions. In addition, we introduce chiral Ward identities derived from the conserved U(1) axial symmetry. We show that leakages of the chiralities indeed satisfy these Ward identities numerically. We also investigate the leakage pattern between symmetric pairs for the taste symmetry.

Hadron Spectroscopy and Interactions / 42

Two-pion scattering amplitude from Bethe-Salpeter wave function at the interaction boundary

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We observe that the ratio of the on-shell scattering amplitude to the Bethe-Salpeter (BS) wave function outside the interaction range is almost independent of time in our quenched calculation of the I=2 two-pion scattering with almost zero momentum. In order to discuss the time independence, we present a relation between the two-pion scattering amplitude and the surface term of the BS wave function at the boundary of the interaction range. Using the relation and some assumptions, we show that the ratio is independent of time if the BS wave function in early time is given by some scattering states with almost zero momentum.

Theoretical Developments / 43

Tensor network approach to real-time path integral

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In the talk, I will discuss how to obtain a tensor network representation for real-time path integral. As an example, I deal with 1+1 dimensional lattice scalar field theory with the Minkowski metric. I show some numerical results to assess the validity of the formulation.

Physics Beyond the Standard Model / 44

chiral condensate and suscptiblity of SU(2) $n_f = 8$ naive staggered system

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SU(2) 8 fundamental flavor system with naive staggered fermion has a phase transition or crossover at strong coupling, which seems to be a bulk transition.
By using chiral random matrix model we analyse the chiral condensate of this sytem.
We also report the chiral susceptibility and its volume dependence near the transition point.

Hadron Spectroscopy and Interactions / 45

Are dynamical charm quarks necessary?

Authors: Salvatore Cali[1]; Kevin Eckert[2]; Jochen Heitger[2]; Francesco Giacomo Knechtli[None]; Tomasz Korzec[3]

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Lattice QCD Simulations with Nf=2+1 dynamical quark flavors are quite common and,
due to the decoupling of the charm quark, sufficient for the study of low energy physics with energies far below the charm threshold. However when used in studies of charm physics, the quenching of the heavy quarks may introduce large uncontrolled systematic uncertainties. To assess how big these effects might be on quantities like the charmonium spectrum, the renormalized charm quark mass and the charmonia decay constants, we compare Nf=0 QCD with Nf=2 QCD, where the second theory contains two heavy quarks, with the mass of a charm quark. This setup, without the light quarks, allows us to isolate the charm loop effects to a very high precision.

Hadron structure / 46

Quasi-PDFs with twisted mass fermions

Authors: Aurora Scapellato[1]; Constantia Alexandrou[None]; Fernanda Steffens[None]; Karl Jansen[2]; Krzysztof Cichy[None]; Kyriakos Hadjiyiannakou[3]; Martha Constantinou[4]

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We discuss the recent progress in extracting PDFs from the quasi-PDF approach, using twisted mass fermions. This concerns the investigation of several sources of systematic effects. Their careful analysis is a prerequisite to obtain precise determinations of PDFs from the lattice with realistic estimates of all uncertainties. Moreover, we present preliminary results from our new simulations at the physical point. They involve, additionally, the dynamical strange and charm quarks, as well as a larger volume and a smaller lattice spacing than in our previous computations.

Hadron Spectroscopy and Interactions / 47

Heavy four-quark and six-quark states from lattice QCD

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We present the results of a lattice calculation of four-quark states with quark contents $q_1 q_2 \bar{Q}\bar{Q},\ q_1, q_2 \subset u, d, s, c$ and $Q \equiv b, c$ in both spin one ($J = 1$) and spin zero ($J = 0$) sectors. For the spin one states we find that for both doubly heavy quarks and particularly for the doubly bottom quarks the ground state energy levels are below their respective thresholds. The ground state spectra of the spin zero four-quark states with various flavor combinations are seen to lie above their respective thresholds. We also present the results of heavy dibaryons where we find the ground state energy levels of a few six-quark combinations are below their respective thresholds. These calculations are performed on three dynamical $N_f = 2 + 1 + 1$ highly improved staggered quark ensembles at lattice spacings of about 0.12, 0.09 and 0.06 fm. We use the overlap action for light to charm quarks while a non-relativistic action with non-perturbatively improved coefficients is employed for the bottom quark.

Physics Beyond the Standard Model / 48

Investigation of N=1 supersymmetric Yang-Mills theory

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We summarize the latest results from our numerical simulations of supersymmetric Yang-Mills theory with two and three colors. For gauge group SU(2) we use an optimized variational method with an extended operator basis to extract the masses of groundstates and excited states in the scalar, pseudoscalar and spin 1/2 sector. The extrapolations to the chiral and continuum limits indicate the formation of supermultiplets for both ground and excited states. Further, due to the extended operator basis, we are able to investigate the mixing content of the physical states. For gauge group SU(3) we have extracted the ground state masses in the scalar, pseudoscalar and spin 1/2 channels. Using a combined extrapolation towards the chiral and continuum limit, we find the formation of a bound state supermultiplet, too.

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I=3/2 nucleon-pion scattering and the Delta(1232) resonance on 2+1 flavor CLS ensembles using the stochastic LapH method

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Preliminary results are presented for nucleon-pion scattering amplitudes in the $I = 3/2$ channel. The calculations are performed on a set of $N_\mathrm{f} = 2 + 1$ Wilson clover ensembles generated by the CLS initiative with pion masses down to $m_\pi = 200$MeV where the $\Delta(1232)$ state is unstable. The required hadron correlation functions are efficiently evaluated using the stochastic LapH method. Compared to meson-meson scattering, the temporal correlation matrices employed here require considerably more Wick contractions, each of which is computed by contracting hadron tensors of rank two and three. Our approach to these additional difficulties, which employs highly optimized BLAS libraries for correlation function construction, is also discussed.

Hadron structure / 50

Two-current correlation functions for the nucleon on the lattice

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We calculate correlation functions of two local operators within the nucleon carrying momentum. We resolve their dependence on the spatial distance of the currents. This is carried out for all Wick contractions, taking into account several operator insertion types. The resulting four-point functions can be related to double parton distributions as well as to parton distribution functions. For this first study, we employ an $N_F = 2 + 1$ CLS ensemble on a 96×32^3 lattice with lattice spacing $a = 0.0854$ fm and the pseudoscalar masses $m_\pi = 356$ MeV and $m_K = 442$ MeV.

Nonzero Temperature and Density / 51

The energy-momentum tensor in lattice QCD and the Equation of State

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We present a new theoretical and practical strategy to renormalize non-perturbatively the energy-momentum tensor in lattice QCD based on the framework of shifted boundary conditions. As a preparatory step for the fully non-perturbative calculation, we apply the strategy at 1 loop in perturbation theory determining the renormalization constants both of the gluonic and of the fermionic

components. Using shifted boundary conditions, the entropy density of QCD is directly related to the expectation value of the space-time components of the renormalized energy-momentum tensor. We then discuss first results of numerical simulations of QCD with 3 flavours of Wilson quarks for temperatures between 2.5 GeV and 80 GeV.

Physics Beyond the Standard Model / **52**

Toward the spectrum of the SU(2) adjoint Higgs model

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Higgs particles in the adjoint representation of a non-Abelian gauge theory play an important role in many scenarios beyond the standard model, especially grand-unified theories, partial compositeness models, and (broken) supersymmetric theories. However, recently new analytic results based on gauge-invariant perturbation theory have arisen, which require a reevaluation of the observable, physical spectrum of such theories.

Lattice methods are used to determine this spectrum, and test the underlying predictions. To this end, an SU(2) gauge theory with a single adjoint Higgs is simulated. In the Brout-Englert-Higgs phase it is predicted that this theory exhibits a massless, composite and gauge-invariant vector state. This model can then be a well defined way to obtain a low energy QED from a GUT that comprehends it.

It is needed to find simulation points where the Brout-Englert-Higgs effect is present. In these points the physical spectrum as well as the properties of the elementary particles will be investigated in multiple channels. We have found preliminary results about the presence of a massless vector bound state, and also about the phase diagram of the theory.

Theoretical Developments / **53**

Tensor network formulation of quantum gravity

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It is well known that the action for General Relativity (GR) can be rewritten in terms of a tetrad field e_μ and a spin connection ω_μ where the former is loosely a square root of the metric and the latter is a gauge field needed to ensure local Lorentz invariance. It is less well known that these two can be combined into a single gauge field associated with local (anti)de Sitter symmetry with the resultant gauge theory reducing to GR in a Higgs phase. In two dimensional Euclidean space the model appears as a novel form of $SU(2)$ gauge theory which can be reformulated as a tensor network. We describe analytic and numerical results obtained for this theory and its extension to four dimensions.

Poster / **54**

SO(4) invariant Higgs-Yukawa model with reduced staggered fermions

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We explore the phase structure of a four dimensional SO(4) invariant lattice Higgs-Yukawa model comprising four reduced staggered fermions interacting with a real scalar field. The fermions belong to the fundamental representation of the symmetry group while the three scalar field components transform in the self-dual representation of SO(4). The model is a generalization of a four fermion system with the same symmetries that has received recent attention because of its unusual phase structure comprising massless and massive symmetric phases separated by a very narrow phase in which a small bilinear condensate breaking SO(4) symmetry is present. The generalization described in this paper simply consists of the addition of a scalar kinetic term. We find a region of the enlarged phase diagram which shows no sign of a fermion condensate or symmetry breaking but
in which there is nevertheless evidence of a diverging correlation length. Our results in this region are consistent with the presence of a single continuous phase transition separating the massless and massive symmetric phases observed in the earlier work.

Poster / **55**

Lattice study of meson properties at fine temperature using the truncated overlap fermions

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We study the meson properties at fine temperature using the quenched simulations with truncated overlap fermion formalism. We explore the screening masses in rather heavy mass regions. We observe the tendency that the screening masses in all the channels are degenerate at high temperature.

Plenary / **56**

Hadronic Tensor and Neutrino-Nucleon Scattering

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We consider a novel approach of calculating inclusive neutrino-nucleon scattering cross sections at low energies via the hadronic tensor on the lattice. This is relevant to the neutrino-nucleus scattering experiments such as DUNE at Fermilab. All the elastic, resonance, shallow and deep inelastic contributions can be covered. The inverse problem encountered in the calculation and several methods aiming to solve this problem is discussed. Nucleon form factors will be calculated using this approach to verify that the elastic scattering cross section from the form factors agrees with that from the hadronic tensor.

Nonzero Temperature and Density / 57

Lattice computation of the quark propagator in Landau gauge at finite temperature

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We report on the computation of the quark propagator at finite temperature in the Landau gauge using quenched gauge configurations. The propagator form factors are computed for various temperatures, above and below the gluon deconfinement temperature T_c, and for all the Matsubara frequencies. Our results suggest a strong connection between quark and gluon deconfinement and favour chiral symmetry restoration above T_c.

Hadron structure / 58

Neutron Electric Dipole Moment from the θ Term

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We present our results on the neutron and proton electric dipole moments
from the θ term with the cluster decomposition error reduction (CDER) technique. The calculation is carried out on two domain-wall fermion lattices with
lattice spacing a = 0.114 fm and 0.145 fm and pion mass at 330 MeV and 170 MeV,
respectively. We use the overlap valence fermion and the topological charge is
calculated with the gradient flow.

Hadron Spectroscopy and Interactions / 59

Details of a staggered fermion data analysis

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We present technical details of an analysis of pseudo-scalar data from a QCD simulation with staggered fermions. The data were obtained close to the physical point with an inverse lattice spacing of about 3 GeV, and $N_f = 2 + 1 + 1$. We compare different methods of extracting effective masses and decay constants in lattice units. The results of several correlated and uncorrelated fitting methods are compared, both on the simulated data set, and on a synthetically generated data set.

Weak Decays and Matrix Elements / 60

The $B \to D^* \ell \nu$ semileptonic decay at nonzero recoil and its implications for $|V_c b|$ and $R(D^*)$

Authors: Alejandro Vaquero Avilés-Casco[1]; CARLETON DETAR[1]; Aida El-Khadra[2]; Andreas Kronfeld[3]; John Laiho[4]; Ruth Van de Water[3]

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We present nearly final results from our analysis of the form factors for $B \to D^* \ell \nu$ decay at nonzero recoil. Our analysis includes 15 MILC asqtad ensembles with N_f=2+1 flavors of sea quarks and lattice spacings ranging from $a \approx$ 0.15 fm down to 0.045 fm. The valence light quarks employ the asqtad action, whereas The b and c quarks are treated using the Fermilab action. We discuss the impact that our results will have on $|V_{cb}|$ and $R(D^*)$

Poster / 61

Leptonic decays of $B_{(s)}$ and $D_{(s)}$ using the OK action

Authors: Jon Andrew Bailey[1]; Tanmoy Bhattacharya[2]; Benjamin Jaedon Choi[1]; Rajan Gupta[3]; Yong-Chull Jang[4]; Seung-Yeob Jwa[1]; Sunkyu Lee[1]; Weonjong Lee[1]; Jaehoon Leem[5]; Sungwoo Park[6]

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We present recent progress in the lattice calculation of leptonic decay constants for $B_{(s)}$ and $D_{(s)}$ mesons using the Oktay-Kronfeld (OK) action for the charm and bottom quarks. We use MILC HISQ ensembles and the HISQ action for the light spectator quark. Results for spectrum of $B_{(s)}$, $D_{(s)}$, $B^*_{(s)}$, $D^*_{(s)}$ mesons with the nonperturbatively tuned heavy quark masses will be presented. We will

also present results for the SU(3) flavor breaking ratios f_{B_s}/f_B and f_{D_s}/f_D that are independent of the renormalization constant that is being calculated.

Hadron structure / 62

Nucleon isovector charges from physical mass domain-wall QCD

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The current status of nucleon isovector charges calculation from joint LHP+RBC Collaborations using the 2+1-flavor dynamical domain-wall lattice QCD ensemble generated by joint RBC+UKQCD Collaborations at 1.730(4)-GeV lattice cut off will be reported.

Theoretical Developments / 63

TKNN formula for general lattice Hamiltonian in odd dimensions

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Topological insulators in odd dimensions are characterized by topological numbers. We prove the well-known relation between the topological number given by the Chern character of the Berry curvature and the Chern-Simons level of the low energy effective action for a general class of Hamiltonians bilinear in the fermion with general U(1) gauge interactions including non-minimal couplings by an explicit calculation. A series of Ward-Takahashi identities are crucial to relate the Chern-Simons level to a winding number, which could then be directly reduced to Chern character of Berry curvature by carrying out the integral over the temporal momenta.

Nonzero Temperature and Density / 64

Critical endpoint in the continuum limit and critical endline at $N_t = 6$ of the finite temperature phase transition of QCD with clover fermions

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We investigate the critical endpoints of the finite temperature phase transition of QCD at zero chemical potential. We employ the renormalization-group improved Iwasaki gauge action and non-perturbatively O(a)-improved Wilson-clover fermion action. The critical endpoints are determined by using the intersection point of kurtosis, employing the multi-parameter, multi-ensemble reweighting method. We present results for the critical endline at N_t = 6 and the continuum extrapolation for the critical endpoint of the SU(3)-flavor symmetric point including newly generated data at $N_t = 12$.

Physics Beyond the Standard Model / 65

Meson spectrum of Sp(4) lattice gauge theory with two fundamental Dirac fermions

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We calculate the meson spectrum of Sp(4) lattice gauge theory coupled to two fundamental flavors of dynamical Dirac fermions, where we focus on the lowest (flavored) spin-0 and spin-1 states. Such theories are often considered in the phenomenological models of composite Higgs and self-interacting dark matter. We carry out continuum extrapolations using four different values of lattice couplings, and fit the resulting masses and decay constants to effective field theory. Our results are then compared with quenched ones and those of other similar gauge theories.

Nonzero Temperature and Density / 66

Partial Deconfinement

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We argue the existence of "partially deconfined phase"in some SU(N) gauge theories, that is in between the confined and deconfined phases.
We characterize this phase in terms of the Polyakov line phases and study examples of theories in which the partially deconfined phase exists. We find that this phase is closely related to the Gross-Witten-Wadia phase transition.
The partially deconfined phase is conjectured to be the counterpart of the small black hole phase in the context of the gauge/string duality. We also discuss possible applications in this context.

Poster / 67

Semileptonic decays $B_{(s)} \to D_{(s)}^{(*)}\ell\nu$ form factors using the OK action

Authors: Jon Andrew Bailey[1]; Tanmoy Bhattacharya[2]; Benjamin Jaedon Choi[1]; Rajan Gupta[3]; Yong-Chull Jang[4]; Seungyeob Jwa[1]; Sunkyu Lee[1]; Weonjong Lee[1]; Jaehoon Leem[5]; Sungwoo Park[6]

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We present recent progress in lattice calculations of semileptonic decays $B_{(s)} \to D_{(s)}\ell\nu$ form factors using the Oktay-Kronfeld (OK) action for the charm and bottom quarks. Data on four MILC HISQ ensembles: a12m310, a12m220, a09m310, a09m220 has been generated using the coherent sequential source to increase the statistics cost effectively. The excited states are controlled with multi-state fits to the 4 (or 6) source-sink separations. We will present the form factor for $B_{(s)} \to D^*_{(s)}\ell\nu$ at zero recoil, and the form factors for $B_{(s)} \to D_{(s)}\ell\nu$ at nonzero recoil. Current renormalization is underway using the nonperturbative RI-(S)MOM method. Results for the spectrum, decay constants and details of tuning the quark masses will be presented in a companion proceeding.

Hadron Spectroscopy and Interactions / 68

Nucleon Mass and Omega Mass with All-HISQ Fermions at the Physical Point

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We will present the first ever determination of the nucleon spectrum using HISQ valence quarks in combination with the (2+1+1) MILC-HISQ sea quarks ensembles at the physical point. We performed analyses with both Bayesian and GEVP methods to demonstrate control over excited states, and three lattice spacings, $\sim$0.15fm, $\sim$0.12fm, and $\sim$0.09fm, were used to extrapolate to continuum. With the experience gained from the nucleon, we will also present preliminary results of Ω baryon spectrum on the same set of ensembles, explored as an alternative method of scale setting.

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Study of the pion-pion scatterings with a combination of all-to-all propagators and the HAL QCD method

Author: Yutaro Akahoshi[1]

Co-authors: Kenji Sasaki [1]; Sinya Aoki [1]; Takaya Miyamoto [1]; Tatsumi Aoyama [2]

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In this talk, we show recent developments in the HAL QCD method including quark annihilation processes. We apply the hybrid method for all-to-all propagators, which combines a low-mode spectral decomposition of the quark propagator and noisy estimators for remaining high modes, to the HAL QCD potential for the first time. Using this combination, we investigate the $I = 1, 2$ $\pi\pi$ scatterings at $m_\pi \approx 870$ MeV. From these studies, we confirm that the hybrid method works for the potential, but it is also revealed that it needs large numerical costs for sufficient precision if there are quark annihilation contributions. We also discuss a promising calculation strategy, which may achieve both small numerical costs and good precision.

Hadron Spectroscopy and Interactions / 70

Baryon interactions from lattice QCD at m_pi = 0.27 GeV

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First-principles determination of baryon interactions plays a crucial role to build a bridge between particle, nuclear and astro-physics. In this talk, we will give an overview for our recent calculations at m_pi = 0.27 GeV, where the interactions are extracted from Nambu-Bethe-Salpeter (NBS) correlators by the time-dependent HAL QCD method. We also discuss quark mass dependence of baryon interactions combined with results obtained near the physical quark masses and at heavier quark masses.

Vacuum Structure and Confinement / 71

Quark confinement in the Yang-Mills theory with a gauge-invariant gluon mass in view of the gauge-invariant BEH mechanism

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In order to clarify the mechanism of quark confinement in the Yang-Mills theory with mass gap, we propose to investigate the massive Yang-Mills model, namely, Yang-Mills theory with "a gauge-invariant gluon mass term", to be deduced from a specific gauge-scalar model with a single radially-fixed scalar field under a suitable constraint called the reduction condition. The gluon mass term simulates the dynamically generated mass to be extracted in the low-energy effective theory of the Yang-Mills theory and plays the role of a new probe to study the phase structure and confinement mechanism.

In this talk, we first explain why such a gauge-scalar model is constructed without breaking the gauge symmetry through the gauge-independent description of the Brout-Englert-Higgs mechanism which does not rely on the spontaneous breaking of gauge symmetry. Then we discuss how the numerical simulations for the proposed massive Yang-Mills theory can be performed by taking into account the reduction condition in the complementary gauge-scalar model on a lattice. Here we

take care of the fact that massive Yang-Mills models of distinct type are obtained depending on representations of the scalar field. For the fundamental representation, the massive Yang-Mills model is expected to have a single confining phase with continuously connecting confining and Higgs regions as suggested by the Fradkin-Shenker continuity. For the adjoint representation, the two regions will be separated by the phase transition and become two different phases showing confinement and deconfinement even at zero temperature. Moreover, we point out that the adjoint case would gives an alternative understanding for the physical meaning of the gauge-covariant decomposition for the Yang-Mills field known as the Cho-Duan-Ge-Faddeev-Niemi decomposition, while the fundamental case would give a novel decomposition which has been overlooked so far.

Theoretical Developments / 72

Domain-wall fermion and Atiyah-Patodi-Singer index

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The Atiyah-Patodi-Singer index theorem describes the bulk-edge correspondence of symmetry protected topological insulators. In 2017, we showed that the same integer as the APS index can be obtained from the eta-invariant of the domain-wall Dirac operator. In this work, we invite three mathematicians to our group and prove that this correspondence is not a coincidence but generally true.

Weak Decays and Matrix Elements / 73

Charmonium contribution to $B \to Kl^+l^-$: testing the factorization approximation on the lattice

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We calculate the amplitude of $B \to Kl^+l^-$ through the charmonium intermediate state.
It may give a significant contribution near the charmonium resonances.
Away from the resonances, one needs a reliable theoretical estimate for the search of potential new physics, and our lattice calculation provides a test of the factorization approximation, which has been used in previous phenomenological analyses.
We focus on the low q^2 region with a b-quark mass smaller than its physical value.
We use the Mobius domain-wall fermion for heavy and light quarks. The lattice ensemble is also generated with 2+1 flavors of Mobius domain-wall fermions at a lattice spacing 0.055 fm.

Hadron structure / 74

Leading isospin breaking effects in the hadronic vacuum polarisation with open boundaries

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We discuss leading isospin breaking effects in the hadronic vacuum polarisation required for the investigation of the hadronic contribution to $(g-2)_\mu$. The calculation proceeds by expanding the relevant correlation functions around the isosymmetric limit. Isosymmetric observables are evaluated on CLS gauge ensembles with $N_f = 2+1$, $O(a)$ improved Wilson fermions and open boundary conditions. A particular emphasis is placed on the relevant quark-disconnected diagrams required for a complete treatment of leading isospin breaking effects in the valence quark sector. We provide a detailed discussion of the renormalisation of the vector current in QCD+QED taking operator mixing into account.

Nonzero Temperature and Density / 75

Lattice investigation of the phase diagram of the 1+1 dimensional Gross-Neveu model at finite number of fermion flavors

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We explore the phase diagram of the 1+1 dimensional Gross-Neveu model at finite number of fermion flavors using lattice field theory. Besides a chirally symmetric phase and a homogeneously broken phase we find clear evidence for the existence of an inhomogeneous phase, where the chiral condensate is a spatially oscillating function. We present numerical results for the phase diagram and visualize the shape of the expectation value of the chiral condensate in the inhomogeneous phase.

Nonzero Temperature and Density / 76

β dependence of the nuclear transition end points at finite quark masses

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Lattice QCD in a dual formulation with staggered fermions is well established in the strong coupling limit and allows to perform Monte Carlo simulations at finite baryon chemical potential.

We have recently addressed the dependence of the nuclear critical end point as a function of the quark mass m_q , and separately as a function of the inverse gauge coupling β in the chiral limit. Here we proceed to determine the dependence of the nuclear transition of both m_q and β on isotropic lattices and attempt to pinpoint the critical end point for various β where the sign problem is still manageable.

Nonzero Temperature and Density / 77

High temperature expansion method for QCD effective theories

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The high temperature expansion (HTE) had been widely used as a standard tool to study phase transitions in statistical mechanics. This method applied to QCD effective theories provides new insights to study quark matter at finite chemical potential. In this talk, the general idea of HTE for the Ising model is briefly reviewed and its applications to effective theories of QCD are described. We will present some promising results obtained from this approach. A method called Partial Differential Approximants, which is used to analyze series of several couplings, will be discussed. We will also indicate a couple of open problems.

Hadron structure / 78

QED corrections to hadronic observables

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We use our Nf=2+1+1 staggered lattice QCD configurations to compute the quantum electrodynamics and strong isospin breaking corrections to various hadronic observables. We use quark masses around their physical values, and include QED in our computations using the QED_L formulation.

Hadron Spectroscopy and Interactions / 79

The Rho Resonance Properties from N_f=2+1+1 Lattice QCD

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We present results of our study of the rho resonance properties based on N_f=2+1+1 gauge configurations produced by the ETMC. We investigate the p-wave phase shift for a range of pion mass values from about 200 to about 400 MeV and for three values of the lattice spacing. We perform an extrapolation to the chiral and continuum limit and extract resonance mass and width at the physical point.

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Stealth dark matter and gravitational waves

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I will present ongoing investigations into the finite-temperature dynamics of stealth dark matter, which adds to the standard model a new SU(4) gauge sector with four moderately heavy fundamental fermions. The lightest scalar SU(4) 'baryon' is the composite dark matter candidate. With the Lattice Strong Dynamics Collaboration, I am building on our past studies of direct detection and collider searches for stealth dark matter by analyzing the early-universe SU(4) confinement transition, which produces a stochastic background of gravitational waves if it is first order. I will present the parameter space in which we observe such a first-order transition, and discuss the quantities we are analyzing in order to predict the resulting gravitational wave spectrum.

Poster / 81

Thermal phase structure of a supersymmetric matrix model

Author: David Schaich[None]

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I will present lattice investigations of the Berenstein–Maldacena–Nastase deformation of maximally supersymmetric Yang–Mills quantum mechanics, focusing on its phase diagram in the plane of the temperature T and deformation parameter μ. By considering values of the dimensionless coupling $g = \lambda/\mu^3$ spanning more than two orders of magnitude, we find results for the deconfinement T/μ that interpolate between the $g \to 0$ perturbative prediction and recent large-N dual supergravity calculations in the limit $g \to \infty$. We analyze multiple lattice sizes up to $N_\tau = 24$ and numbers of colors up to $N = 16$, allowing initial checks of the large-N continuum limit.

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Update from FNAL/HPQCD/MILC on the hadronic vacuum polarization contribution to $(g-2)_\mu$"

Authors: Christine Davies[1]; Carleton DeTar[2]; Aida El-Khadra[3]; Steven Gottlieb[4]; Daniel Hatton[1]; John Laiho[5]; Craig McNeile[6]; Ethan Neil[7]; Doug Toussaint[8]; Ruth Van de Water[9]; Shuhei Yamamoto[2]

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We present an update on the Fermilab Lattice, HPQCD, and MILC Collaborations' ongoing calculations of the leading-order hadronic vacuum polarization contribution to the anomalous magnetic moment of the muon. Our project employs ensembles with four flavors of highly improved staggered fermions, physical light-quark masses, and a range of lattice spacings of $a \approx 0.06 - 0.15$˜fm.

Nonzero Temperature and Density / 83

Determination of the endpoint of the first order deconfiniement phase transition in the heavy quark region of QCD

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We study the endpoint of the first order deconfinement phase transition of two and 2+1 flavor QCD in the heavy quark region. We perform simulations of quenched QCD and apply the reweighting method to study the heavy quark region. The quark determinant for the reweighting is evaluated by a hopping parameter expansion. To reduce the overlap problem, we introduce an external source term of the Polyakov loop in the simulation. We study the location of critical point at which the first order phase transition changes to crossover by investigating the histogram of the Polyakov loop and applying the finite-size scaling analysis. We discuss the effect of the external source term on the overlap problem. We also evaluate the truncation error of the hopping parameter expansion, and study the lattice spacing dependence and the spatial volume dependence in the result of the critical point.

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QCD Topology to High Temperatures via Improved Reweighting

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At high temperatures, the topological susceptibility of QCD becomes relevant for the properties of axion dark matter. However, the strong suppression of non-zero topological sectors causes ordinary sampling techniques to fail, since fluctuations of the topological charge can only be measured reliably if enough tunneling events between sectors occur. We present an improvement of a technique the we recently developed to circumvent this problem based on a combination of gradient flow and reweighting techniques and quote first results of the topological susceptibility in pure SU(3) Yang-Mills theory up to 7 T_c.

Poster / 85

Thermal Quarkonium Mass Shift from Euclidean Correlators

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Brambilla et al. have derived an effective description of quarkonium with two parameters: a momentum diffusion term which has been widely explored within the community, and a real self-energy term. We derive a relation between the self-energy term and Euclidean electric field correlators along a Polyakov line, which can directly be studied on the lattice without the need for analytical continuation. We also discuss the problems in determining the correlator within the scope of the quenched QCD approximation.

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Real-Time-Evolution of Heavy-Quarkonium Bound States

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Elucidating the production process of heavy quark bound states is a central goal in heavy-ion collisions [1]. Two central questions exist: Do bound states of heavy quarks form in the early time evolution of the glasma? If so, in which time regime can that happen? An answer requires the development of a non-perturbative treatment of the real-time-dynamics of heavy quarkonia.
To answer those questions we have developed a novel real-time formulation [2] of lattice NRQCD [3,4] to order 1/(aMq)ˆ2 where we employ a classical statistical simulation for the early-time dynamics of the gauge fields [5].
Here we present results from a simulation of heavy quarkonium dynamics in the glasma.
By computing the time-evolution of spectral functions of heavy quarkonium channels we expect to identify the emergence of bound states and their formation time in the evolving glasma.
[1] G. Aarts et al., Eur. Phys. J. A 53 no.5, 93 (2017)
[2] A. L., A. Rothkopf (in preparation)

[3] G.P. Lepage et al., Phys.Rev. D 46, 4052 (1992)
[4] M. Berwein, N. Brambilla, S. Hwang, A. Vairo, TUM-EFT 74/15, 56 pp (2018)
[5] K. Boguslasvki, A. Kurkela, T. Lappi, J. Peuron, Phys.Rev. D98 no.1, 014006 (2018)

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Spectral quantities in thermal QCD: a progress report from the FASTSUM collaboration

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In order to study spectral quantities in thermal QCD, the FASTSUM collaboration employs anisotropic lattice simulations with Nf=2+1 flavours of Wilson fermions. Here we discuss our Generation 2 and Generation 2L ensembles, which differ in the pion mass. We focus on observables related to the light quarks and chiral symmetry restoration. Moreover, to prepare for the results to be discussed in the next talk, we examine the basics of mesonic correlation functions in QCD at small but nonzero baryon chemical potential using a Taylor expansion, including an analytical evaluation of the second-order term at very high temperature.

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News from bottomonium spectral functions in thermal QCD

Authors: Samuel Offler[1]; Gert Aarts[1]; Chris Allton[1]; Jonas Rylund Glesaaen[None]; Benjamin Jäger[1]; Seyong Kim[2]; Maria Paola Lombardo[3]; Sinead Ryan[4]; Jon-Ivar Skullerud[5]

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We present new results on bottomonium at nonzero temperature, using the FASTSUM Generation 2L ensembles. Preliminary results for spectral function reconstruction using the Maximal Entropy Method and Machine Learning are presented.

Nonzero Temperature and Density / 89

Mesonic correlators at non-zero baryon chemical potential

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In order to study the fate of mesons in thermal QCD at finite baryon chemical potential, we consider light mesonic correlation functions using the Taylor expansion to O$\left((\mu/T)^2\right)$, in both the hadronic and quark-gluon plasma phases. We use the FASTSUM anisotropic fixed-scale lattices with N$_f$=2+1 flavors of Wilson fermions. We find that mesonic correlators are sensitive to finite-density corrections and that the second-order terms notice the chiral crossover in the vector and axial-vector channels.

Hadron structure / 90

$N\pi$ excited state contamination in nucleon 3-pt functions using ChPT

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The $N\pi$ state contribution to nucleon 3-pt functions involving the pseudoscalar density P(x) and the time component $A_4(x)$ of the axial vector current are computed to LO in ChPT. In case of the latter the $N\pi$ contribution is O(M_N) enhanced compared to the single nucleon ground state contribution. In addition, a relative sign in two terms of the $N\pi$-state contribution leads an almost linear dependence on the operator insertion time, as it is observed in lattice data. In case of the pseudoscalar density the $N\pi$ contribution is strongly dependent on the momentum transfer, leading to a sizeable distortion of the pseudoscalar nucleon form factor. The role the $N\pi$ excited states play in violating the PCAC form factor relation is also discussed.

Hadron structure / 91

Matrix elements of bound states in a finite volume

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Recently, a framework was developed for studying form factors of two-body states probed with an external current. Finite volume matrix elements that may be computed via lattice QCD are converted to infinite volume generalized form factors. These generalized form factors allow us to study the structure of composite states. In this talk, we consider the application of this formalism to bound states, and compare the leading finite volume effects to the general results of the framework. Specifically, we pay close attention to the implication of this formalism for the extraction of the form factors of the deuteron.

Poster / 92

A Calculation of Higher Order Taylor Expansion Coefficients

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The long term goal of our current project is to provide a high-order Taylor expansion of the grand canonical partition function of QCD, at non vanishing chemical potential.
For our study we use (2+1)-flavor of highly improved staggered quarks
(HISQ) with physical light and strange quark masses.
In order to achieve that goal, we are further advancing the numerical
tools that allow for the calculation of up to tenth-order Taylor-expansion coefficients: in particular, we are improving the current measurement and sampling strategies.
Concerning the measurement, we are developing a way to apply deflation as variance reduction tool to the operators that appear in the coefficients of the expansion of the pressure. In particular, we are focusing on the quark number density operator (D_1), that is the main building block in the calculation of the expansion coefficients in the linear-μ framework. The spectrum of this operator is complex so, in order to evaluate a sufficient number of eigenvalues and eigenvectors to apply the deflation method, we are currently implementing an eigensolver algorithm for non-hermitian operators. Through this algorithm we want to calculate the smallest eigenvalues of D_1^{-1}, that correspond to the largest of D_1. Increasing the order of the coefficients, the smallest eigenvalues of D_1 will become more and more negligible, so once we have a sufficient number of large eigenvalues of the quark number density we will able to estimate coefficients to arbitrary order, at least in principle.
We also discuss the calculation of unbiased estimators for higher
moments of the trace of the quark-density operator.

Theoretical Developments / 93

Worldsheet formulation and topological terms in abelian lattice gauge theories

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Abelian lattice gauge theories can be reformulated exactly in terms of dual variables which are discretized worldsheets. An interesting question is how the topological terms can be incorporated in such a dual theory. We analyze the general structure of such terms and discuss some examples.

Theoretical Developments / 94

New developments for worldline and worldsheet representations of lattice field theories

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In recent years several lattice field theories were exactly rewritten in terms of so-called dual variables which are worldlines for matter fields and worldsheets for the gauge degrees of freedom. I discuss recent developments within this approach with a focus on topological terms and non-abelian symmetry groups.

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Calculation of pseudoscalar disconnected loop in Lattice QCD

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We use the symmetrical multi-point source method (SMP method) to calculate disconnected loops in lattice QCD. A comparison of the results between SMP method and the point source method is carried out. We also compare the results of SMP method with that of Z\left(2\right) noise method. It shows that Z\left(2\right) noise method is a good choice to calculate the scalar disconnected loop. However, SMP method is more efficient in the calculation of the pseudoscalar disconnected diagram. We study the correlation of the topological charge with the pseudoscalar disconnected loop, and renormalization constant Z_{p} is evaluated as well.

Vacuum Structure and Confinement / 96

Topology of Trace Deformed Yang-Mills Theory

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In this work we study, by means of Monte Carlo simulations, the topological properties of Yang-Mills (YM) theory in presence of the double trace deformation. The deformation consists of an extra piece added to the standard YM action, which forbids the deconfinement phase transition even at high temperature. We compute topological observables (such as the topological susceptibility and the first term of the theta expansion of the free energy) in the deformed theory and we compare them with the known values of the undeformed one in order to check if the trace deformation modifies such properties or not.

Nonzero Temperature and Density / 97

Reliability of CLE simulations and applications to full QCD at non-zero density.

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CLE is a well defined method providing a general instrument for ab initio, approximation free studies of realistic lattice models even for complex action. The latter include full QCD at finite densiy and CLE is the only method presently applied in this context. The complexification of the variable space required by a complex action introduces however special conditions to be satisfied in order to ensure correct convergence. Analysing thesse conditions led to the development of procedures and criteria which allow to control the simulations and define a reliability region. We here develop one essential condition to a general criterion applicable on-line also to QCD and discuss its relation to other criteria. We also present CLE results for the full QCD transition from the confinement to the plasma phase for 0 ≤ μ / T_c ≤ 5 (μ: chemical potential, T_c: μ=0 critical temperature).

Weak Decays and Matrix Elements / 98

Electromagnetic corrections to leptonic decays

Author: Antonin Portelli[1]

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In this talk we present the status of the RBC-UKQCD collaboration project to compute the QED corrections to light pseudo-scalar leptonic decay rates. This computation is using domain-wall fermions at close-to-physical quark masses. We summarise the overall strategy to obtain the relevant amplitude corrections from Euclidean correlation functions. These correlations functions are assembled using an all-to-all strategy including low-mode averaging using 2000 eigenvectors of the fermion matrix. We present preliminary results implementing this strategy.

Algorithms and Machines / 99

Hadrons: a Grid-powered workflow management system for lattice QCD measurements

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Hadrons is a free C++ framework based on the high-performance Grid library to implement lattice QCD measurement workflows. It is based on a modular dataflow programming approach to

accommodate with the heterogeneity of lattice measurements. The different measurement steps (inversions, contractions, I/O $\cdots$) are implemented as individual modules with inputs and outputs, and a measurement workflow forms a directed acyclic graph (DAG) of such modules. All the modules have access to a global environment for storing named objects. A global virtual machine takes care of scheduling the measurement, while minimising the memory consumption of the workflow through an optimisation of the module DAG and a garbage collection mechanism. Hadrons can be driven through a C++ API or an XML description of the DAG, more hybrid approaches can also be developed using the extensive serialisation features of Grid.

Nonzero Temperature and Density / 100

Conserved charge fluctuations with smaller-than-physical quark masses

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We present results from calculations of conserved charge fluctuations in (2+1)-flavor QCD using light quark masses in the range $m_s/160 \leq m_l \leq m_s/27$, with the strange quark mass (m_s) kept fixed at its physical value. This corresponds to a Goldstone pion mass in the range $55MeV \leq m_\pi \leq 140MeV$. The measurements have been done using HISQ fermion discretization and Symanzik improved gauge action. We discuss the quark mass dependence of up to 6th order cumulants and present first results on the separation of singular and regular contributions to these cumulants. From these results, we examine the nature of the chiral phase transition and the variation of the curvature of the crossover line as we approach the chiral limit.

Nonzero Temperature and Density / 101

Study of 2+1 flavor finite-temperature QCD using improved Wilson quarks at the physical point with the gradient flow

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We study thermodynamic properties of 2+1 flavor QCD with improved Wilson quarks applying the method of Makino and Suzuki based on the gradient flow. The method provides us with a general way to compute correctly renormalized physical observables irrespective of explicit violation of symmetries due to the regularization, such as the violation of Poincare and chiral symmetries on the lattice. We report on the status of our on-going project to compute the energy momentum tensor and the chiral condensate at the physical point.

Vacuum Structure and Confinement / 102

Spectral Projectors Method for Staggered Fermions

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We extend the spectral projectors method to staggered fermions. Applying the index theorem to the staggered Dirac operator it is possible to work out an expression for the topological susceptibility which depends only on the orthogonal projectors on quasi zero-modes, as it has already been done for Dirac-Wilson fermions.
Besides, we generalize this method deriving analogous expressions for all higher-order coefficients in the θ-expansion of the vacuum energy.

Nonzero Temperature and Density / 103

Tempered Lefschetz thimble method and its application to the Hubbard model away from half-filling

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Tempered Lefschetz thimble method (TLTM) [Fukuma and Umeda, arXiv:1703.00861] is a (parallel-)tempering algorithm to solve the sign problem in Monte Carlo simulations. It is implemented on the generalized Lefschetz thimble method (GLTM) by using the flow time of the antiholomorphic gradient flow as the tempering parameter. The TLTM is expected to versatilely solve the dilemma between the sign problem and the multimodal problem which inherently exists in the GLTM. In this talk, after briefly reviewing the TLTM, I apply the method to the quantum Monte Carlo simulation of the Hubbard model away from half-filling. I show that the TLTM certainly solves the dilemma and gives results that agree nicely with exact values. This talk is based on a paper in preparation [Fukuma, Matsumoto and Umeda].

Algorithms and Machines / 104

Sparsening Algorithm for Multi-Body Correlation Functions

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In recent years multigrid algorithms have dramatically reduced the cost of generating gauge field ensembles and quark propagators for lattice simulations including light quarks described by the Wilson and Wilson-clover fermion actions. As a result, we have observed in recent calculations of nuclear physics at the physical pion mass that assembling correlation functions from quark propagators is an increasingly costly aspect of these calculations. In this talk we will discuss a sparsening algorithm for building correlation functions describing multi-body systems of nucleons. This algorithm works by first block averaging lattice quark propagators, producing sparsened quark propagators defined on a coarsened lattice, and then computing correlation functions from these sparsened propagators at reduced computational cost. We have explored this approach by analyzing the low energy QCD spectrum, including systems as large as ${}^4_2\mathrm{He}$, on a single $32^3 \times 48$ Wilson-clover lattice ensemble with $m_\pi \approx 800$ MeV. We find that the ground state masses and binding energies we extract are consistent between correlation functions constructed from sparsened or full propagators. In addition, while we observe small, systematic biases in excited states for the sparsened correlation functions, we also find that these biases can be removed by computing an inexpensive correction term.

Standard model parameters and renormalization / 105

Towards the determination of the charm quark mass on $N_\mathrm{f} = 2{+}1$ CLS ensembles

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We present the current status of our determination of the charm quark mass using $N_\mathrm{f} = 2 + 1$ dynamical, non-perturbatively $\mathrm{O}(a)$-improved Wilson fermions. A subset of CLS ensembles with four different lattice spacings along the $\mathrm{Tr}[M_q] = \mathrm{const.}$ trajectory is used.
For the computation of the correlation functions involving valence charm quark propagators we employ distance preconditioning to gain the necessary precision. To stabilize the extrapolations to the physical point, we consider different definitions of the bare charm quark mass and corresponding renormalization procedures.

Weak Decays and Matrix Elements / 106

Calculation of the $K_L - K_S$ mass difference for physical quark masses

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We will present the status of our calculation of the difference between the masses of the long- and short-lived neutral K mesons, Δm_K, predicted by the Standard Model. This calculation is performed on an ensemble of 152, $64^3 \times 128$ gauge configurations with an inverse lattice spacing of 2.36 GeV and physical quark masses. The results from different methods of analysis and our progress toward obtaining a final result will be discussed.

Theoretical Developments / 107

Non-perturbative determination of anomalous dimensions of bound states in QCD and beyond

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Anomalous dimensions of composite operators like the scalar, tensor, or baryon are important to determine energy dependent renormalization constants. Until now only perturbative predictions were available.
The recent proposal [PRL 121 (2018) 201601] provides a non-perturbative determination of anomalous dimensions in conformal systems
by defining a continuous real-space renormalization group transformation from gradient flow.

In this work we generalize the method to determine the running anomalous dimensions in QCD-like systems and
present results for the scalar, tensor, and baryon anomalous dimensions as the function of the running coupling up to $g^2 \approx 10$.

We also investigate the emergence of chiral-spin symmetry suggested by Glozman et al.

Poster / **108**

SU(3) gauge system with twelve fundamental flavors

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We establish the conformal nature of an SU(3) gauge theory with twelve
fundamental flavors by presenting final results for our gradient flow
step-scaling calculation of the renormalization group beta function using domain wall fermions. The continuum limit of the $s = 2$ step scaling function exhibits a sign change (infra-red
fixed point) around $g_c^2 \sim 5.5$ in the $c = 0.25$ scheme. Our
calculation is based on a fully O(aˆ2) improved set-up with
Symanzik gauge action,
stout-smeared Möbius domain wall fermions, Zeuthen flow, and Symanzik
operator.
This setup has small cut-off corrections which leads to reliable continuum extrapolations.

In addition we present a new analysis of the continuous $s \to 0$ β function using the same set of ensembles.
This new analysis uses only volumes $L \geq 24$ and determines the β function in a different renormalization scheme.
The continuous β function also predicts the existence of a conformal fixed point.

Hadron Spectroscopy and Interactions / **109**

The light baryon spectrum in the continuum limit

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We present continuum limit results of the quark mass dependence of octet and decuplet baryon masses. These are obtained on large volumes, employing three different trajectories in the quark mass plane, including the physical point. The five different lattice spacings reach down to below 0.04 fm. This became possible by introducing open boundary conditions in time at the smaller lattice spacings, thereby eliminating the freezing of the topological charge. This is part of the CLS programme of simulating $N_f = 2 + 1$ flavours of non-perturbatively improved Wilson fermions. We also determine the scale and low energy constants.

Weak Decays and Matrix Elements / 110

Calculating the two-photon contribution to the real part of the $\pi^0 \to e^+e^-$ decay amplitude

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The important $K_L \to \mu^+\mu^-$ decay is complicated by the presence of intermediate states with the same or lower energy than the mass of kaon. To address one of these intermediate states, the two-particle $\gamma\gamma$ state, it is useful to work on a simpler problem which offers the same difficulty — the $\pi^0 \to e^+e^-$ decay. We hope to present preliminary results of a first-principles calculation of the real part of the $\pi^0 \to e^+e^-$ decay amplitude to demonstrate the effectiveness of our method.

Algorithms and Machines / 111

Leadership-Class Multi-Grid Algorithms for HISQ Fermions on GPUs

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With the latest generation of leadership-class machines, lattice QCD simulations are able to probe multi-scale physics with unprecedented resolution. These advancements come with super-linear increases in the costs of modern simulations due to the phenomena of critical slowing down. In the case of linear solvers for LQCD, the only robust solution to this challenge is the development and efficient implementation of effective multi-grid algorithms. In this talk we will discuss the latest developments for a multi-grid algorithm for both the naïve staggered and HISQ operator. We will present results from an MG implementation in the highly optimized QUDA library applied to ultra-fine and physical point configurations from the MILC collaboration. We will also discuss future steps towards integrating multi-grid into HISQ HMC.

Hadron structure / 112

Hyperon couplings from $N_f = 2 + 1$ lattice QCD

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The experimentally well known nucleon axial coupling g_A has been computed extensively on the lattice and serves as a benchmark quantity for lattice calculations. The axial couplings for the other octet baryons (hyperons), like e.g. Σ and Ξ baryons are less well known. We will present not only results for the hyperon axial charges but also for other isovector charges, e.g., the tensor charges. Our calculations were performed on a set of $N_f = 2 + 1$ CLS ensembles of non-perturbatively $\mathcal{O}(a)$ improved Wilson fermions with tree-level Symanzik improved gauge action. For the computation of the required three-point-functions we used a stochastic technique which enabled us to compute various combinations of currents and interpolators simultaneously.

Poster / 113

Mistaken Identity: The Multi-State Labeling Problem

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In lattice gauge theory, understanding contributions from excited states is imperative for achieving high precision calculations. A variety of methods are available to extract excited states, such as fitting to multiple exponentials, Prony's method, and Matrix Prony, correlator matrices, and generalized eigenvalue problems. A generic problem faced by all these methods is that the resulting states tend to have overlapping error ellipses (e.g. jackknife, bootstrap, cross-validation, etc.) making identification of states ambiguous. The problem may be alleviated somewhat by expert guidance in operator selection to minimize overlap for a few low-lying states, but this defeats the overall design goal of an automated black-box method. Instead, we face the overlapping states labeling problem directly. For example, using the bootstrapping method, resolving excited state energies and their error bars requires finding the most probable set of state labels for each bootstrap sample. We investigate several variants of expectation maximization clustering in attempt to find an efficient algorithm for bootstrap labeling and therefore state identification.

Standard model parameters and renormalization / 114

Strong coupling constant and heavy quark masses in (2+1)-flavor QCD

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I present a determination of the strong coupling constant and heavy quark masses in (2+1)-flavor QCD using lattice calculations with Highly Improved Staggered Quark (HISQ) action and calculate the moments of the pseudo-scalar quarkonium correlators at several values of the heavy valence quark mass. I determine the strong coupling constant in $\overline{MS}$ scheme at four low energy scales corresponding to m_c, $1.5m_c$, $2m_c$ and $3m_c$, with m_c being the charm quark mass. Using the moments and the $\Lambda_{\overline{MS}}$ I determine the heavy quark masses in $\overline{MS}$ scheme. In a complementary calculation I determine the strong coupling constant in (2+1)-flavor QCD using lattice calculations of the static energy.

Hadron structure / 115

Hadronic vacuum polarization in finite volume using NNLO ChPT

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We present results for the leading hadronic contribution to the muon g-2 from configurations with 2+1+1 flavors of HISQ quarks. The ensembles have been generated by the MILC collaboration at three lattice spacings. Using the time-momentum representation of the electromagnetic current correlator, we calculate the finite volume effects up to next-to-next-to-leading-order in Chiral Perturbation Theory.

Weak Decays and Matrix Elements / 116

$B_c \to B_{s(d)}$ form factors with NRQCD and HISQ

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We present results of the first lattice QCD calculation of $B_c \to B_s$ and $B_c \to B_d$ vector matrix elements with 4-momentum transfer across the entire physical range. Form factors are then extracted and combined with CKM matrix elements to predict the decay rates for $B_c^+ \to B_s^0 \bar{l}\nu_l$ and $B_c^+ \to B^0 \bar{l}\nu_l$. Results are derived from correlation functions computed with HISQ for light, strange, and charm quark propagators, and NRQCD for the bottom quark propagator. The calculation of correlation functions employs MILC Collaboration ensembles over a range of three lattice spacings. These gauge field configurations include HISQ sea quark effects of flavours charm, strange, and equal-mass up and down. We use ensembles with physically light up and down quarks, as well as heavier values.

Hadron structure / 117

Lepton anomalous magnetic moments in Lattice QCD+QED

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We present a lattice calculation of the Hadronic Vacuum Polarization (HVP) contributions to the anomalous magnetic moments of charged leptons a_ℓ and an estimate of the contribution to a_μ^{HVP} not covered by the MUonE experiment, including leading-order strong and electromagnetic isospin-breaking corrections from first principles. Our lattice results are obtained in the quenched-QED approximation using the QCD gauge configurations generated by the European Twisted Mass Collaboration (ETMC) with $N_f = 2 + 1 + 1$ dynamical quarks, at three values of the lattice spacing varying from 0.089 to 0.062 fm, at several lattice volumes and with pion masses in the range $M_\pi \simeq 220 - 490$ MeV.

Nonzero Temperature and Density / 118

One-thimble regularisation of lattice field theories: is it only a dream?

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Lefschetz thimbles regularisation of (lattice) field theories was put forward as a possible solution to the sign problem. Despite elegant and conceptually simple, it has many subtleties, a major one boiling down to a plain question: how many thimbles should we take into account? In the original formulation, a single thimble dominance hypothesis was put forward: in the thermodynamic limit, universality arguments could support a scenario in which the dominant thimble (associated to the global minimum of the action) captures the physical content of the field theory. We know by now many counterexamples and we have been pursuing multi-thimble simulations ourselves. Still, a single thimble regularisation would be the real breakthrough. We report on ongoing work aiming at a single thimble formulation of lattice field theories.

Hadron structure / 119

Accessing flavor-singlet quark and gluon parton distributions from lattice QCD

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Recent years have witnessed rapid progress on computing parton distribution functions (PDFs) from lattice QCD. Such computations have been focused on the isovector quark PDFs which do not involve mixing with gluon PDFs and therefore are the easiest to calculate. In this talk, I present recent developments that allow us to access flavor-singlet quark PDFs as well as gluon PDFs from lattice QCD.

Poster / 120

Gluonic Structure of Mesons

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Quantifying the structure of mesons in terms of their fundamental constituents is a major goal of hadron research. In the last decades extensive progress has been made in the calculation of quark structure, however very little is understood about the gluonic equivalent. One way of quantifying how quarks and gluons make up mesons is via the generalized parton distribution functions (GPDs). This poster presents recent results on the gluon moments of GPDs for different mesons, calculated on lattices of 0.12 fm spacing.

Nonzero Temperature and Density / 121

Heavy quark diffusion coefficient from lattice

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We report progress towards measuring heavy momentum diffusion coefficient from a correlator of colour electric fields attached to a Polyakov loop in pure SU(3) gauge theory. Using a multilevel algorithm and tree-level improvement, we study the behavior of the diffusion coefficient as a function of temperature in a range $1.5<T/T_c<15$ in order to compare it to the perturbative expansions existing at high temperature.

Poster / 122

Static force from lattice

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We present an novel calculation of the static force directly from the lattice. Compared to the usual approach of taking derivatives of static potential, a direct measurement of the force resolves the ambiguities related to integration constants when comparing to pNRQCD expansion. We have performed a set of SU(3) pure gauge simulations using the multilevel algorithm to test out this procedure.

Hadron structure / 123

The leading hadronic vacuum polarization contribution to $(g{-}2)_\mu$ using $N_f = 2+1$ O(a) improved Wilson quarks

Authors: Antoine Gérardin[1]; Marco Cè[2]; Georg Matthias Von Hippel[None]; Ben Hörz[3]; Harvey B. Meyer[4]; Daniel Mohler[5]; Konstantin Ottnad[6]; Jonas Wilhelm[7]; Hartmut Wittig[None]

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We present a lattice calculation of the leading hadronic vacuum polarization contribution to the muon anomalous magnetic moment. We use $N_f = 2+1$ Wilson quarks and apply the O(a)-improvement programme to reduce discretization effects. Four lattice spacings with several values of the pion mass down to its physical value are used to extrapolate to the physical point.
For the connected light quark contribution, affected by the signal-to-noise ratio problem at long distances, we present an auxiliary calculations of the timelike pion form factor in order to better constrain the tail of the isovector correlator and to correct its dominant finite-size effect.
In addition to the connected light, strange and charm quark contributions, our final estimate also includes a calculation of the quark disconnected contribution. Finally, we discuss prospects and ongoing efforts for determining a_μ^{hvp} with sub-percent precision.

Weak Decays and Matrix Elements / 124

Charm CP & the lattice

Author: Amarjit Soni[1]

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Recently LHCb announced a 5-sigma exciting observation of direct CP in D0 decays to KK/pipi. Computations of direct CP remain an outstanding important challenge for theory for a variety of fundamental reasons. Here a rough estimate of the observed size of the asymmetry will be explained. Although 1st principle calculations of direct CP in D^0 to KK/pi pi cannot be done by known lattice methods, there are many features of the underlying dynamics that is being proposed here that may well be amenable to lattice simulations and are strongly encouraged

Algorithms and Machines / 125

Formulating Lattice Field Theory for a Quantum Computer

Authors: Richard Brower[1]; David Berenstein[2]

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The quantum link (or QCD abacus) Hamiltonian was introduced as a classical algorithm representing both gauge and matter fields by single bit fermion operators in an extra dimension. This formalism is recast for quantum computing, as a Hamiltonian in Minkowski space for real time Qubit simulations. The advantages of pseudo-fermions to implement the Jordan Wigner transformation and the Trotter expansion in local gauge invariant local kernels is discussed. For U(1) compact QED the kernels on a triangular lattice are defined and a Qubit circuit implementation given to test on existing hardware.

Theoretical Developments / 126

The meson spectrum of large N gauge theories

Authors: Antonio Gonzalez-Arroyo[1]; Masanori Okawa[None]; Margarita Garcia Perez[2]

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We present results for meson masses in the continuum limit for pure Yang-Mills theory in the large N limit. The results are obtained with both Wilson fermions and twisted mass. Some preliminary results for meson masses in large N gauge theories with dynamical fermions are also given.

Poster / 127

Staggered Fermions using Grid

Authors: Patrick Steinbrecher[1]; Swagato Mukherjee[1]

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I present an overview of the implementation of the HISQ RHMC using the Grid framework and report performance of key kernels on recent CPU and GPU architectures.

Algorithms and Machines / 128

Accelerating topological transitions in the 2D Schwinger Model.

Authors: Dean Howarth[1]; Richard Brower[1]

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We present a method for accelerating topological transition in the 2D Schwinger model with a compact U(1) gauge and Wilson fermions by coupling the 2D lattice via a 3rd dimension with open boundary conditions. The fermions live on the central slice. This allows topological charge to flow into the central slice, which maintains an integer valued winding. The resulting effective action on the central slice is mapped to an effective 2D action of the canonical Schwinger model. The rate of topological transition for that effective action is significantly increased, modifications to the short range action are suppressed, and the expected long behaviour is preserved. Generalisation to 4 dimensional theories with SU(N) gauge groups may offer a solution to the HMC topological freeze-out observed in current lattice QCD simulations.

Physics Beyond the Standard Model / 129

Constructing a composite Higgs model with built-in large separation of scales

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Experimentally a light 125 GeV Higgs boson has been observed but so far no other heavier resonances. Viable models to describe the Higgs boson as composite particle require hence to exhibit a large separation of scales which e.g. occurs in systems located near a conformal fixed point.

First I present our nonperturbative gradient flow step-scaling calculation of the renormalization group beta function for an SU(3) gauge theory with 10 massless, fundamental flavors. The steps of our calculation are detailed and the quality of our set-up using stout-smeared Möbius domain wall fermions with Symanzik gauge action combined with Zeuthen flow measurements is demonstrated. Taking advantage of our step-scaling results, I will use the same set-up to construct a mass-split composite Higgs model with large scale separation, show first results, and demonstrate some of its features. This work is part of the research program by the LSD collaboration.

Theoretical Developments / 130

Spectral Methods and Running Scales in Causal Dynamical Triangulations

Authors: Giuseppe Clemente[1]; Massimo D'Elia[2]; Alessandro Ferraro[3]

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We will present recent results of the application of spectral analysis in the setting of the Monte Carlo approach to Quantum Gravity known as Causal Dynamical Triangulations (CDT), discussing the behaviour of the lowest lying eigenvalues of the Laplace-Beltrami operator computed on spatial slices. We will show that such a kind of analysis can provide information about running scales of the theory and about the critical behaviour around a possible second order transition in the CDT phase diagram, where a continuum limit could be defined.

Nonzero Temperature and Density / 131

Baryon bag simulation of QCD in the strong coupling limit

Authors: Oliver Orasch[1]; Christof Gattringer[1]; Pascal Toerek[1]; Shailesh Chandrasekharan[2]

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We explore the possibility of a simulation of strong coupling QCD in terms of baryon bags. Since the gauge action is missing in the strong coupling partition sum, the integration over the gauge group is possible and the remaining Grassmann integral can be mapped to a statistical system of monomers, dimers and loops. Rather recently it was shown that the contributions from the baryons, i.e., the tri-quark monomers, dimers and loops, can be collected in so-called baryon bags. Within the bags the baryons propagate freely whereas the rest of the lattice is solely filled with interacting meson terms, i.e., quark and di-quark monomers and dimers. We perform a simulation directly in the baryon bag language and show first results in two dimensions.

Poster / 132

Semileptonic form factors for exclusive Bs -> K l nu and Bs -> Ds l nu decays

Authors: Jonathan Flynn[1]; Ryan C. Hill[1]; Andreas Juettner[None]; AMARJIT Soni[2]; J Tobias Tsang[3]; Oliver Witzel[4]

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We present our nonperturbative Lattice QCD calculation to determine semileptonic form factors for exclusive $B_s \to K\ell\nu$ and $B_s \to D_s\ell\nu$ decays. Our calculation is based on RBC-UKQCD's set of 2+1 dynamical flavor gauge field ensembles and in the valence sector we use domain wall fermions for up/down, strange, and charm quarks, whereas bottom quarks are simulated with the relativistic heavy quark action. The continuum limit is based on three lattice spacings and form factors over the full q^2 range are shown.

These form factors are the basis to predict ratios studying lepton flavor universality or, when combined with experimental results, to obtain CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$. Due to different experimental and theoretical set-ups, these alternative b-decay channels may also help to shed light on the tension between the analysis of inclusive and exclusive decays or may further serve as proxy for corresponding B decays.

Hadron structure / **133**

Lattice "Cross-Sections" - Pion PDFs from Pseudo-PDFs and Pseudo-Structure Functions

Author: Colin Egerer[1]

Co-authors: David Richards [2]; Joseph Karpie [1]; Raza Sufian [3]; Kostas Orginos [4]; Jianwei Qiu [2]; Balint Joo [2]; Anatoly Radyuskin [2]; Md Tanjib Atique Khan [5]; Savvas Zafeiropoulos ; Frank Winter [2]

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A general framework for the study of hadronic structure from Lattice QCD, dubbed "good lattice cross-sections", leverages QCD collinear factorization and ideas from the global PDF fitting community to reliably extract the full x-dependence of PDFs from the lattice. The calculation of pseudo-PDFs and gauge invariant two-current correlations within a hadron are two established realizations of this framework. In this presentation, we highlight recent results for pion PDFs obtained through each of these calculational schemes. Results are presented on several lattice ensembles, thereby addressing finite-volume, discretization and quark mass effects in the extracted distributions. Consideration is given to discretization effects and the potential to simultaneously analyze each data set.

Hadron structure / **134**

Parton Distribution Functions from Euclidean-Space Correlation Functions in Ioffe Time

Authors: Colin Egerer[1]; Balint Joo[2]; Joseph Karpie[1]; Tanjib Khan[3]; Kostas Orginos[4]; Jianwei Qiu[2]; Anatoly Radyushkin[5]; David Richards[2]; Raza Sufian[6]; Frank Winter[2]; Savvas Zafeiropoulos[None]

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The hadronic matrix elements of bi-local operators at short Euclidean separations evaluated as a function of Ioffe time can be related to the convolution of the universal parton distribution functions (PDFs) and a short-distance kernel. In this talk, we describe the method, beginning with the needed renormalizations for the case of quark and antiquark fields separated by a Wilson line, and for the case of two gauge-invariant currents. We then proceed to discuss the techniques developed to address the "inverse problem" needed to obtain the PDFs from the hadronic matrix elements calculated on the lattice. Finally, we present our programme of calculations for the pion and for the nucleon, and possible extensions to explore the three-dimensional structure of hadrons.

Physics Beyond the Standard Model / 135

Case studies of near-conformal and conformal beta-functions

Author: Kieran Holland[None]

Co-authors: Julius Kuti ; chik him wong [1]; Zoltan Fodor [2]

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We give an update on our lattice studies of the beta-function for near-conformal and conformal gauge theories. These include 10, 12 and 13 flavors in the fundamental representation, and 2 flavors in the sextet representation of SU(3). We discuss the overall trends and new developments.

Algorithms and Machines / 136

Disconnected Loop Subtraction Methods in Lattice QCD

Authors: Suman Baral[1]; Travis Whyte[1]; Walter Wilcox[1]; Ron Morgan[1]

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To compute disconnected quark loop operators, stochastic noise methods are generally used. In order to strengthen the physical signal projected out from these noisy methods, various subtraction techniques may be employed. We use the GMRES-DR and MINRES-DR algorithms to solve for the linear equations of the non Hermitian Wilson and Hermitian Wilson matrices, while simultaneously calculating low lying eigenmodes. This deflation helps to increase the rate of convergence of the linear equations as well as decreases noise introduced via stochastic methods. We demonstrate a subtraction method that combines deflation of the low lying eigenmodes of the Hermitian Wilson matrix and polynomial approximations to produce an extremely powerful noise suppression technique, termed Hermitian Forced Polynomial Subtraction (HFPOLY). The effectiveness of this algorithm is demonstrated on ensembles in the quenched approximation, as well as with dynamical ensembles generated by the MILC Collaboration, where the HISQ action was employed. We observe strong low eigenmode dominance of the Hermitian Wilson matrix at vanishing quark mass in the variance of the vector and scalar operators in the quenched approximation, and similar reduction in the variance is observed using the dynamical ensembles.

Physics Beyond the Standard Model / 138

Resonance study of SU(2) model with 2 fundamental flavours of fermions.Resonance study of SU(2) model with 2 fundamental flavours of fermions.

Authors: Tadeusz Janowski[None]; Vincent Drach[1]; Sasa Prelovsek[None]

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Composite Higgs models are very promising candidate models to address
the long-standing naturalness problem in the Standard Model.
Among them, the most minimal one is the SU(2) with 2 flavours of
fermions in the fundamental representation of the gauge group.
An important prediction in these models is the existence of resonance
spectrum in vector boson scattering. In this talk I will describe our
study of the lowest such resonance, which is the equivalent of rho
resonance in QCD.
I will describe the scan of the parameter space using the
clover-improved Wilson fermions with Symanzik improved gauge action and
then show the first results for the mass and width of the rho resonance
in this model.

Poster / 139

Laplace Operator On Discretized 3 Sphere's

Authors: Daniel Berkowitz[1]; Richard Brower [2]; George Fleming[3]

[1] *Yale University*

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"Applying lattice field theory to curved Riemannian manifolds opens up the doors to investigating some highly interesting physical systems, including the cylindrical manifolds of radial quantization $R \times S^{D-1}$. Substantial effort has already produced results on $R \times S^2$ and we would like to take a

step towards higher dimensions. We tessellate the tetrahedral cells of the 600-cell using a tetrahedral-octahedral honeycomb lattice projected onto the surface of the 3-sphere and compute the spectrum of its laplacian using the methods of discrete exterior calculus."

Theoretical Developments / 140

$(1+1)$-d $U(1)$ Quantum Link Models from Effective Hamiltonians of Dipolar Molecules

Author: Jiayu Shen[1]

Co-authors: Bryan Clark ; Brian DeMarco ; Aida El-Khadra [2]; Bryce Gadway ; Michael Highman ; Di Luo

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Dipolar molecular platforms provide a possibility of realizing analog quantum simulators for quantum field theories such as quantum link models, a discrete version of lattice field theories in terms of the degrees of freedom for each link variable. We apply the method of effective Hamiltonians to a system of dipolar molecules with electric dipole-dipole interactions with tunable parameters to obtain the $U(1)$ quantum link models in $1+1$ dimensions.

Physics Beyond the Standard Model / 141

Constraining EFTs in a Theory with Light Composite Scalars

Author: George Fleming[1]

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The Lattice Strong Dynamics (LSD) collaboration has been studying SU(3) Yang-Mills with eight light flavors of Dirac fermions. This theory has accumulating numerical evidence for near conformal dynamics and a light composite isosinglet scalar meson. It could serve as a prototype of a composite Higgs sector if a reliable low-energy Effective Field Theory (EFT) could be identified. Several candidate EFTs have been proposed. I will summarize our efforts to constrain these EFTs using computed observables, including pion and scalar masses, decay constants and scattering lengths.

Applications Beyond QCD / 142

Lattice Analysis of SU(2) with 1 Adjoint Dirac Flavor

Authors: Anthony Grebe[1]; David Murphy[1]; Gurtej Kanwar[2]; Michael Wagman[None]; Patrick Ledwith[1]; Zhen Bi[1]

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In some proposed condensed matter systems, SU(2) with one massless adjoint Dirac quark flavor emerges as an effective theory of the critical point. Condensed matter theorists Bi and Senthil have conjectured that a composite fermion composed of two quarks and an antiquark becomes massless and non-interacting as the quark mass goes to zero, whereas the other particles in the theory all have masses bounded away from zero. In contrast, a previous lattice study by Athenodorou et al. suggests that SU(2) with one adjoint Dirac flavor is a conformal theory, so the entire spectrum becomes massless as the quark mass vanishes. A third possibility is that the theory undergoes spontaneous symmetry breaking, with a single Goldstone boson (the scalar diquark) and its antiparticle going light. Here, we expand upon Athenodorou's investigation by including the composite fermion and a larger range of quark masses in order to determine which of these three potential scenarios accurately describes the theory.

Weak Decays and Matrix Elements / 143

Lattice QCD calculation of the two-photon contributions to K_L to mu+ mu- and pi0 to e+ e- decays

Authors: Norman Christ[1]; Yidi Zhao[1]

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The rare second-order weak decay $K_L \to \mu^+\mu^-$ is precisely measured and sensitive to the structure of the weak interactions at short distances. However, these effects are obscured by a large third-order, long-distance contribution to this decay in which the muon pair is created by two photons. We will discuss the prospects for computing this third-order electroweak process using lattice QCD. As a first step in such a calculation a method will be presented for the lattice calculation of the simpler two-photon decay $\pi^0 \to e^+e^-$.

Weak Decays and Matrix Elements / 144

Update on the improved lattice calculation of direct CP-violation in K decays

Author: Christopher Kelly[1]

Co-author: Tianle Wang [1]

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We provide an update on the RBC & UKQCD lattice calculation of the measure of Standard Model direct CP-violation in kaon decays, \epsilon'.

Physics Beyond the Standard Model / 145

Fits of SU(3) N_f=8 data to dilaton-pion effective field theory

Authors: Maarten Golterman[1]; Yigal Shamir[2]

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We report on fits of the SU(3) N_f=8 LSD spectral data to chiral perturbation theory with a dilatonic meson. These fits confirm that current simulations are in the "large-mass" regime, with approximate hyperscaling as the leading mass dependence. We find that the leading-order effective field theory describes the data well. In particular, the effective field theory allows us to understand the staggered taste splitting, explaining the pattern observed in the LSD data, which looks different from QCD.

Hadron structure / **146**

Nucleon axial and electromagnetic form factors from 2+1+1-flavor QCD

Authors: Yong-Chull Jang[1]; Rajan Gupta[2]; Huey-Wen Lin[3]; Boram Yoon[None]; Tanmoy Bhattacharya[4]

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Results for the nucleon isovector form factors for the vector and axial-vector currents will be presented. The calculations are done using clover valence quarks on 11 ensembles, including two physical pion mass ensembles, generated with 2+1+1 flavors of HISQ fermions by the MILC collaboration. High statistics are achieved using the truncated solver method with bias correction, and the coherent sequential source method.
Extrapolation to the physical limit includes leading order discretization, chiral and finite volume effects. In addition, we will present z-expansion analysis with unitarity and sum rule constraints.

Hadron structure / **147**

Nucleon isovector couplings from 2+1 flavor lattice QCD at the physical point

Authors: NATSUKI TSUKAMOTO[1]; Yasumichi Aoki[2]; Ken-Ichi Ishikawa[3]; Yoshinobu Kuramashi[4]; Shoichi Sasaki[1]; Eigo Shintani[2]; Takeshi Yamazaki[4]

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We report the recent progress on our study of the nucleon couplings including the axial, tensor and scalar couplings on a $(10.8\mathrm{fm})^4$ lattice using the PACS10 gauge configuration generated by the PACS Collaboration with the stout-smeared $\mathcal{O}(a)$ improved Wilson fermions and Iwasaki gauge action at $\beta = 1.82$ corresponding to the lattice spacing of 0.084fm. We also estimated the renormalization constant in the RI/SMOM scheme which stands for Regurization Independent Symmetric MOMentum-subtraction scheme. Using the matching and evolution factors obtained from the perturbation theory, we then evaluated the renormalized nucleon couplings in the $\overline{\mathrm{MS}}$ scheme at the renormalizaion scale of 2 GeV.

Hadron Spectroscopy and Interactions / 148

First study of $N_f = 2 + 1 + 1$ lattice QCD with physical domain-wall quarks

Author: Ting-Wai Chiu[1]

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Using a cluster of Nvidia DGX-1 (8*V100 interconnected by the NVLink), TWQCD Collaboration has generated the first gauge ensemble of $N_f = 2+1+1$ lattice QCD with physical domain-wall quarks, on the $L^3 \times T = 64^3 \times 64$ lattice with lattice spacing $a \sim 0.064$˜fm ($L > 4$ fm, and $M_\pi L > 3$). The gauge ensemble constitutes of ˜200 gauge configurations, resulting from ˜1000 HMC trajectories by sampling one configuration every 5 trajectories. The salient features of the HMC simulation are: to perserve the chiral symmetry to high precision, and to sample all topological sectors ergodically. In this talk, I will outline the HMC simulation and the generation of the gauge ensemble. Moreover, I will present the first physical results (e.g., the mass spectra of charmed mesons and baryons) from this $N_f = 2 + 1 + 1$ gauge ensemble with physical domain-wall quarks.

Weak Decays and Matrix Elements / 149

Radiative leptonic decays on the lattice

Authors: Stefan Meinel[1]; Christopher Kane[2]; Christoph Lehner[3]; AMARJIT Soni[3]

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Adding a hard photon to the final state of a leptonic pseudoscalar-meson decay lifts the helicity suppression and can provide sensitivity to a larger set of operators in the weak effective Hamiltonian. Furthermore, radiative leptonic B decays at high photon energy are well suited to constrain the first inverse moment of the B-meson light-cone distribution amplitude, an important parameter in the theory of nonleptonic B decays. We present our progress with lattice-QCD calculations of the hadronic matrix elements describing radiative leptonic decays of light and heavy mesons.

Standard model parameters and renormalization / 150

Renormalization of bilinear and four-fermion operators through temporal moments

Authors: Tsutomu Ishikawa[1]; Katsumasa Nakayama[None]; Shoji Hashimoto[2]

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We propose a renormalization scheme that can be simply implemented on the lattice. It consists of the temporal moments of two-point and three-point functions calculated with finite valence quark mass. The scheme is confirmed to yield a consistent result with another renormalization scheme in the continuum limit for the bilinear currents. We apply a similar renormalization scheme for the non-perturbative renormalization of four-fermion operators appearing in the weak effective Hamiltonian.

Hadron structure / 151

Nucleon Charges and Form factors from 2+1 clover ensembles

Authors: Boram Yoon[None]; Rajan Gupta[1]; Sungwoo Park[2]; Tanmoy Bhattacharya[3]; Yong-Chull Jang[4]

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We will present results on the nucleon charges and form factors on five ensembles generated using 2+1 clover fermions by the Jlab/W&M/LANL collaborations. These results will be compared with similar calculations done using 2+1+1 flavor HISQ ensembles.

Poster / 152

Structure functions from the Compton amplitude

Authors: Gerrit Schierholz[1]; Holger Perlt[2]; James Zanotti[3]; Kim Somfleth[3]; Paul Rakow[4]; Roger Horsley[5]; Ross Young[3]; Yoshifumi Nakamura[None]

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We have initiated a program to compute the Compton amplitude with the Feynman-Hellman method. This amplitude is related to the structure function via a Fredholm integral equation of the first kind. It is known that these types of equations are inherently ill-posed - they are, e.g., extremly sensitive

to perturbations of the system. We discuss some methods which are candidates to handle these problems. Among them we investigate simple model-fitting, singular value decomposition and Bayesian approaches with the maximum entropy method. Special attention is drawn to the physical region of the omega parameter, where we have to take the principal value.

Theoretical Developments / 153

Critical behavior of 4-dimensional Ising model with higher-order tensor renormalization group

Author: Shinichiro Akiyama[1]

Co-authors: Takumi Yamashita [2]; Yoshinobu Kuramashi [3]; Yusuke Yoshimura [3]

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Critical behavior of 4-dimensional Ising model has been attracting the interest of particle physicists for a long time in the context of the triviality of the φˆ4 theory. The perturbative renormalization group analysis predicts logarithmic corrections to the mean-field type of scaling properties for this model. Although a lot of numerical work have been carried out to make a nonperturbative verification of the logarithmic corrections, it is still a difficult task to confirm them. To this problem we apply the higher order tensor renormalization group (HOTRG), which is one of the tensor network schemes allowing us to perform the finite size scaling study (FSS) with much larger volumes than the Monte Carlo simulations. We discuss a possible scenario for the phase transition of this model.

Weak Decays and Matrix Elements / 154

$B \to D^{(*)}\ell\nu$ form factors from lattice QCD with relativistic heavy quarks

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We report on our calculation of the $B \to D^{(*)}\ell\nu$ form factors in 2+1 flavor lattice QCD. The Moebius domain-wall action is employed for light, strange, charm and bottom quarks. At lattice cut-offs $a^{-1} \sim$ 2.4, 3.6 and 4.5 GeV, we simulate bottom quark masses up to 0.8 a^{-1} to control discretization errors. The pion mass is as low as 230 MeV. We discuss the heavy quark symmetry violation in the form factors extrapolated to the continuum limit and physical quark masses.

Hadron Spectroscopy and Interactions / 155

Study of finite size effect on hadron masses and decay constants with (5.4fm)^4 and (10.8 fm)^4 lattices at the physical point in 2+1 flavor QCD

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We investigate finite size effect on hadron masses and decay constants using a subset of the PACS10 configurations which are generated keeping the space-time volumes over (10 fm)^4 at the physical point in 2+1 flavor QCD with the Wilson-type quarks. We have tried two kinds of analyses fixing the κ values or the measured axial Ward identity quark masses. The finite size effect is discussed by comparing the results on (5.4 fm)^4 and (10.8 fm)^4 lattices at the cutoff scale of 1/a=2.333 GeV with emphasis on the pseudoscalar meson sector and the Omega baryon.

Poster / 156

Proton decay matrix elements with physical quark masses

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Proton decay matrix elements in QCD are indispensable quantities to constrain GUT models through the lower bound of the proton lifetime measured in the current and future underground experiments. Results obtained with lattice QCD so far have largest systematic uncertainty on the chiral extrapolation. We report on the relevant form factors of the dominant decay processes: a proton to a pseudoscalar and an anti-lepton, for every possible pseudoscalar state and three-quark operator, calculated on the physical-point, improved Wilson-fermion configurations generated by the PACS collaboration at the lattice spacing of 0.084fm.

Weak Decays and Matrix Elements / 157

S-wave pi-pi I=0 and I=2 scattering at physical pion mass

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The pi-pi scattering phase shifts for both the s-wave I=0 and I=2 channels are determined from a lattice calculation performed on 741 gauge configurations obeying G-parity boundary conditions with a physical pion mass. The phase shifts are determined for both stationary and moving pi-pi systems, at four different center of mass momenta. We implement three interpolating operators including a sigma operator. We use both correlated fitting and the generalized eigenvalue treatment and compare these two methods. A detailed systematic error analysis is included as well as a comparison with the prediction of Roy's equation.

Weak Decays and Matrix Elements / 158

$B \to \pi \ell \nu$ form factors and $|V_{ub}|$ with Möbius domain wall fermions

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We report on the JLQCD Collaboration's calculation of form factors for the exclusive semileptonic decay of B meson to pion on $2+1$-flavour lattices with lattice spacings from 0.080 fm down to 0.044 fm. Using the Möbius domain wall fermion action for both sea and valence quarks, we simulate pions with masses down to 230 MeV. By utilizing a range of heavy quark masses up to 2.44 times the mass of the charm quark we can extrapolate to the physical b quark mass. We discuss the dependence of the form factors on the pion mass, heavy quark mass, lattice spacing and the momentum-transfer. We extract the CKM matrix element $|V_{ub}|$ through a simultaneous fit with the $B \to \pi$ differential branching fractions provided by the Belle and BaBar collaborations after a chiral-continuum and physical b quark extrapolations of our lattice data.

Theoretical Developments / 159

Tailoring Non-Abelian Gauge Theory for Digital Quantum Simulation

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Lattice gauge theory calculations exponentially hard on today's machines could become a reality with the advent of quantum computation. To get there, the choice of variables optimal for exploiting the quantum advantage will likely be quite different than what we are accustomed to. We give a construction of a non-Abelian gauge theory with quark matter using a loop-string formulation that has many desirable features from the viewpoint of digital quantum simulation. I will explain those features and why we believe this reformulation is the optimal Kogut-Susskind-equivalent paradigm currently available for simulation by universal quantum computers.

Theoretical Developments / 160

Numerical study of ADE-type $\mathcal{N} = 2$ Landau–Ginzburg models

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It is believed that the two-dimensional massless $\mathcal{N} = 2$ Wess–Zumino model becomes the $\mathcal{N} = 2$ superconformal field theory (SCFT) in the IR limit. We examine this theoretical conjecture of the Landau–Ginzburg (LG) description of the $\mathcal{N} = 2$ SCFT by numerical simulations on the basis of a supersymmetric-invariant momentum-cutoff regularization. We study one or two supermultiplets with various superpotentials. From a two-point correlation function in the IR region, we measure the central charge, which is consistent with the conjectured LG description of the ADE minimal models. Our result supports the theoretical conjecture and, at the same time, indicates a possible computational method of correlation functions in the $\mathcal{N} = 2$ SCFT from the LG description.

Weak Decays and Matrix Elements / 161

Extraction of CKM matrix elements from lattice QCD results using dispersion relations

Author: De-Liang Yao[None]

The form factors in the semileptonic decays of heavy B/D meson decays can be represented by dispersion relations, by which the kinematics in the decay region are related to the ones in the scattering region. By fitting to the lattice QCD data on the form factors, the subtraction constants in their dispersive representations can be determined such that the form factors in the whole kinematical region are obtained. Cabibbo–Kobayashi–Maskawa elements can be extracted with form-factor values at $q^2 = 0$.

Theoretical Developments / 162

The Anomaly Inflow of the domain-wall fermion in odd dimension

Authors: Hidenori Fukaya[None]; Makito Mori[None]; Naoki Kawai[1]; Satoshi Yamaguchi[1]; Tetsuya Onogi[1]; Yoshiyuki Matsuki[1]

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A long ago, Callan and Harvey showed a view of gauge anomaly as a missing current into an extra-dimension, and the total contribution, including the Chern-Simons current in the bulk, is conserved. But in their computation, the edge and bulk contributions are separately evaluated and their cross correlations, which should be relevant at boundary, are simply ignored. In this talk, we revisit this issue with a complete set of eigenstates of free domain-wall Hamiltonian and study how the gauge anomaly is canceled at the microscopic level.

Weak Decays and Matrix Elements / 163

Study of intermediate states in the inclusive semi-leptonic B -> X_c l \nu decay structure functions

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We analyze the inclusive semi-leptonic $B \to X_c \ell \nu$ structure
functions in 2+1-flavor lattice QCD. The M\"obius domain-wall fermion action is used for light, strange, charm and bottom quarks. The structure function receives contributions from various exclusive modes, including the dominant S-wave states $D_s^{(*)}$ as well as the P-wave states D_s^{**}. We can identify them in the
lattice data, from which we put some constraints on the $B_s \to D_s^{**} \ell \nu$ form factors.

Theoretical Developments / 164

Atiyah-Patodi-Singer index theorem on a lattice

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Atiyah-Singer index theorem on a lattice without boundary is well understood owing to the seminal work by Hasenfratz.
But its extension to the system with boundary (the so-called Atiyah-Patodi-Singer index theorem), which surprisingly plays a crucial role in T-anomaly cancellation between bulk- and edge-modes in 3+1 dimensional topological matters, is known only in the continuum theory and no lattice realization has been made so far.
In this work, we try to non-perturbatively define an alternative index from the lattice domain-wall fermion in 3+1 dimensions. We will show that this new index in the continuum limit, converges tothe Atiyah-Patodi-Singer index defined on a manifold with boundary, which coincides with the surface of the domain-wall.

Hadron Spectroscopy and Interactions / 166

High precision determination of w_0

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To perform high precision calculations in lattice QCD for observables of physical interest, it is important to determine the lattice spacing with high accuracy. A convenient choice for scale setting is the observable w_0 which is based on the Wilson flow. However the value of w_0 is not determined

experimentally and therefore the value of w_0 in physical units has to be be computed by lattice simulations before it can be used to set the scale in subsequent
calculations. We present a lattice calculation aiming to determine w_0 with high precision. It takes QED effects beyond quenched approximations into account.

Nonzero Temperature and Density / 167

Exploring the QCD phase diagram at finite density by the complex Langevim method on a 16ˆ3 x 32 lattice

Authors: Shoichiro Tsutsui[1]; Yuta Ito[None]; Hideo Matsufuru[2]; Jun Nishimura[2]; Shinji Shimasaki[None]; Asato Tsuchiya[3]

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We explore the QCD phase diagram at finite density with four-flavor staggered fermions using the complex Langevin method (CLM), which is a promising approach to overcome the sign problem. In our previous work [arXiv:1811.12688] on an $8^3 \times 16$ lattice at $\beta = 5.7$ with the quark mass $m = 0.01$, we have found that the baryon number density has a clear plateau as a function of the chemical potential suggesting the formation of nuclear matter in a small box. Here we use a $16^3 \times 32$ lattice to reduce finite volume effects and find that the plateau structure survives. Moreover, the number of quarks in the plateau region turns out to be 24, which is exactly the same as the one obtained previously on the $8^3 \times 16$ lattice.

Algorithms and Machines / 168

Flow-based generative models for MCMC in lattice field theory

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Markov Chain Monte Carlo (MCMC) allows efficient estimation of observables in many lattice theories. However, as a critical point in parameter space is approached, typical MCMC algorithms suffer from critical slowing-down: autocorrelation lengths in the chain diverge for all observables, demanding increasingly more computational cost to achieve the same statistical power. In lattice QCD, for example, critical slowing-down presents a significant barrier to approaching the continuum and physical point. We present a new class of MCMC algorithms that allow systematic improvement of autocorrelation lengths by optimizing (training) a variational model. Specifically, a machine-learned normalizing flow is used to propose lattice configurations according to an approximate distribution that is made exact by a Metropolis accept/reject step. In this Markov chain, autocorrelation time of all observables is equal and we prove a bound on this autocorrelation according to a KL divergence between the machine-learned and true distributions. In a ϕ^4 scalar field theory, we show observables produced by the proposed method agree with standard results and show control over the autocorrelation time in regions of paramter space where standard MCMC methods suffer from critical slowing-down.

Plenary / 169

Quantum computing zeta-regularized vacuum expectation values

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The zeta-regularization allows to establish a
connection between Feynman's path
integral and Fourier integral operator
zeta-functions. This fact can be utilized to perform a
regularization of vacuum expectation values in quantum field theories.
In this talk, we will describe the concept of this
zeta-regularization, give a simple example and demonstrate
that quantum computing can be employed to numerically evaluate
zeta-regulated vacuum expectation values.

Poster / 170

Status of Riemann Manifold Hybrid Monte Carlo

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We report on the ongoing study of Riemann Manifold Hybrid Monte Carlo (RMHMC) for Lattice QCD. The effect of Fourier acceleration with RMHMC are studied
on both quenched and 2+1-flavor dynamical ensembles by measuring autocorrelations on topological charge and wilson flow scales, as well as topological diffusion coefficients.

Nonzero Temperature and Density / 171

The chiral phase transition temperature in (2+1)-flavor QCD

Author: Christian Schmidt[1]

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We present a lattice QCD calculation with (2+1)-flavor of highly improved staggered quarks (HISQ). The light quark masses are chosen predominantly lighter than physical, i.e. they correspond to a Goldstone pion mass in the range of 58 MeV < m_π < 163 MeV. The strange quark mass is kept at its physical value. We propose two novel estimators for the transition temperate, based on the scaling behavior of the chiral susceptibility. We extrapolate our results to the thermodynamic, chiral and continuum limit by making use of universal scaling functions. In the extrapolation we control finite size effects by using spatial lattice extents in the range of 2.8-4.5 times the inverse of the pion mass. The lattice cut-off is controlled by using lattices with temporal extent $N_\tau = 6, 8$ and 12. After thermodynamic, continuum and chiral extrapolations we find the chiral phase transition temperature $T_c^0 = 132^{+3}_{-6}$ MeV. We also comment on implications of this findings for the location of a possible chiral critical point in the QCD phase diagram at non-zero baryon chemical potential.

Poster / 172

QUDA 1.0

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Eleven years after its inception, the QUDA library for Lattice QCD on NVIDIA GPUs has achieved a historic 1.0 release. In this span QUDA has evolved into an open-source framework for full QCD simulations. The library has been fully re-written in a new highly optimized C++11 framework, superseding python-generated routines and ushering in a new age of rapid algorithm prototyping and development. QUDA supports nearly all fermion discretizations, features cutting-edge algorithms such as adaptive multigrid, deflation, and block Krylov-space methods, and contains native support for mixed precision and symmetry-inspired data compression. In preparation for the exascale era, there is full-featured support for communication-mitigating methods, intra-node peer-to-peer support, and inter-node GPUDirect MPI. On this poster we will explicate these features, reinforced by performance results on state-of-the-art hardware. We strongly encourage discussions about user requests and contributions.

Algorithms and Machines / 173

Classifying topological sector via machine learning

Authors: Masakiyo Kitazawa[1]; Takuya Matsumoto[1]; Yasuhiro Kohno[1]

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We employ machine learning techniques to estimate the topological charge Q of gauge configurations in SU(3) Yang-Mills theory. As a first trial, four-dimensional convolutional neural networks are trained to estimate the topological charge from the topological charge density on gauge configurations. The value of Q measured by the gradient flow is used for the definition of the correct value. We, however, find that the neural network completely fails in the classification in this approach.

Next, we feed the topological charge density at nonzero but small flow times t as inputs for the neural network. Dimensional reduction is also performed as well as the four-dimensional analysis. We find that, by the combination of the topological charge densities at $t/a^2 \leq 0.3$, the trained neural network can estimate the correct value of Q with more than 95% accuracy, although the distribution of the Q value at $t/a^2 = 0.3$ does not well converge to integer values. This result suggests that the value of Q obtained at large gradient-flow time can be well estimated from the information obtained

at small flow time, and thus the numerical costs to estimate the value of Q in the gradient flow method can be substantially reduced with the aid of the machine learning.

It is also found that the best accuracy is obtained when the dimension of the input is reduced to zero, i.e. when the four-dimensinal integral of the topological charge density is used for inputs of the neural network. This result shows that the neural network cannot finds any useful feature from the spatial structure of the topological charge density.

The dependences on lattice spacing, spatial volume, and numerical costs for training will also be discussed.

Algorithms and Machines / 174

Frequency-splitting estimators of single-propagator traces

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In this talk I will discuss the recently introduced frequency-splitting estimators of quark-line disconnected diagrams in lattice QCD. The evaluation of these diagrams is required for many phenomenologically interesting observables, but suffers from large statistical errors due to the vacuum and the random-noise contributions to their variances. Multi-level integration
has the potential to improve dramatically the precision of the computation of these observables once the random noise due to auxiliary stochastic fields is kept below the intrinsic gauge noise.
After reviewing the theoretical analysis of the variances, I will introduce a new family of stochastic estimators of single-propagator traces built upon a frequency splitting combined with a hopping expansion of
the quark propagator, and test their efficiency in two-flavour QCD with pions as light as 190 MeV.
The use of these estimators reduces the cost of computing single-trace propagators by one to two orders of magnitude over standard estimators depending on the fermion bilinear.
As a concrete application, I will show the impact of these findings on the computation of the hadronic vacuum polarization contribution to the muon anomalous magnetic moment.

Hadron structure / 175

Strange nucleon form factors and isoscalar charges with $N_f = 2+1$ $\mathcal{O}(a)$-improved Wilson fermions

Author: Jonas Wilhelm[1]

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We report on our calculation of the strange contribution to the vector and axial vector form factors. The strange charge radii, magnetic moment, and axial charge are extracted by model independent z-expansion fits to the Q^2-dependence of the respective form factors. Furthermore, the isoscalar contribution to the axial and tensor charge is investigated by combining the calculation of connected and disconnected diagrams. The required renormalization is performed with the Rome-Southampton method. We make use of the CLS $N_f = 2 + 1$ $\mathcal{O}(a)$-improved Wilson fermion ensembles. Results are reported for pion masses in the range $m_\pi = 200 - 360\,\mathrm{MeV}$ and lattice spacings $a = 0.05 - 0.086\,\mathrm{fm}$.

Hadron Spectroscopy and Interactions / 176

The S-wave $K\pi$ amplitude and the $K_0^\star(700)$ resonance in $2+1$ flavor QCD

Authors: Gumaro Rendon[1]; Luka Leskovec[2]; Stefan Meinel[3]; John Negele[4]; Srijit Paul[5]; Marcus Petschlies[6]; Andrew Pochinsky[4]; Giorgio Silvi[7]; Sergey Syritsyn[8]

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Parameterizing low-lying scalar resonances remains a challenge. Such is the case for $K_0^\star(700)$ for which the near threshold experimental results for the corresponding $K\pi$ scattering amplitude are limited. However, production channel data, e.g. $D \to K\pi\pi$, from experiments BES and E791 show clearer evidence of the existence of this resonance. I will present our results for the S and P-wave elastic scattering amplitudes obtained from multi-hadron spectroscopy on the lattice using Lüscher's method. I will comment on the dependence of the S-wave amplitude and the $K_0^\star(700)$ pole position, if identifiable, on the different parameterizations. These calculations were done for two different ensembles with pion masses of $317(2)$ and $178(2)$ MeV. The need for these scattering amplitudes for the infinite volume determination of $B \to K\pi\ell^+\ell^-$ matrix elements is also discussed briefly.

Weak Decays and Matrix Elements / 177

Neutral meson mixing and related observables in the D(s) and B(s) meson systems

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In this talk we will give a brief review of our recent computation of ratios of decay constants and neutral meson mixing parameters for $B_{(s)}$ and $D_{(s)}$ mesons (1812.08791).
We will present our efforts to extend this calculation to the individual decay constants and bag parameters and outline the wider heavy flavour physics Domain Wall Fermion program.

Physics Beyond the Standard Model / 178

Walking, the dilaton, and complex CFT (II)

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After developing the full implementation of the Implicit Maximum Likelihood Method, we discuss new tests of the dilaton low-energy effective field theory in the near-conformal paradigm with emergent light scalars in the sextet and eight-flavor models.

Weak Decays and Matrix Elements / 179

Radiative Corrections to Semileptonic Decay Rates

Author: Christopher Sachrajda[1]

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During the last few years we have developed the theoretical framework for including radiative corrections to lattice computations of the $\pi_{\ell 2}$ and $K_{\ell 2}$ leptonic decay rates and performed the corresponding numerical calculations. This necessarily includes the treatment of infrared divergences. In this talk we discuss the extension of this framework to semileptonic decays, such as $K_{\ell 3}$ decays. We show that the $1/L$ finite-volume corrections in the QED_L formulation of lattice QED are universal but depend on the derivatives of the QCD form-factors with respect to the square of the momentum transfer q^2. We also discuss the consequences of the presence of intermediate states which have energies which are smaller than those of the external states.

Nonzero Temperature and Density / 180

Continuous Time Simulations of Strong Coupling LQCD at Finite Baryon Density

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We study lattice QCD in the limit of infinite gauge coupling on a discrete spatial yet continuous Euclidean time lattice at finite baryon chemical potential μ_B. The continuous time framework is based on sending $N_\tau \to \infty$ and the bare anisotropy to infinity while fixing the temperature in a non-perturbative setup. This leads to a sign problem free algorithm that allows us to study the whole μ_B-T plane. We measure the pressure and energy density at finite temperature and baryon density in the chiral limit. We compare with Taylor coefficients from the measurement of baryon fluctuations. Calculations are based on our worm type Monte Carlo algorithm featuring a polymer resummation scheme that improves accuracy.

Nonzero Temperature and Density / 181

Non-perturbative study of heavy quark anti-quark potential at finite temperature

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For the phenomenology of quarkonia in quark-gluon plasma, a convenient tool is to define an "in-medium potential". Formally, such a potential can be defined through the long-time behavior of a timelike Wilson loop.
A non-perturbative estimate of such a potential from lattice QCD is difficult, as on lattice we can only study Wilson loops in Euclidean time, in the range [0, 1/T) where T is the temperature of the medium. The analytical continuation to real time is involved, and usually relies on Bayesian analysis. Here we will present a new, more direct method of extraction of the $Q\bar{Q}$ potential from the Euclidean data. Results for the potential in a gluon plasma, extracted from spatially smeared Wilson loops calculated on anisotropic lattices, will be presented. We will also compare these results with those calculated from Coulomb gauge fixed Wilson line correlators.
For quarkonia phenomenology, it is also important to understand the nature of the medium binding for the $Q\bar{Q}$ in an octet state. The octet state on the lattice is not gauge invariant. To make it gauge invariant we have attached a gluonic operator with the link. We will discuss the construction, and present results for the $Q\bar{Q}$ potential in this configuration.

Plenary / 182

GPUs for Lattice Field Theory

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The past ten years has seen GPUs evolve from a niche architecture to the de facto parallel computing platform in HPC. We report on the latest developments in the use of GPUs for lattice field theory computations, with focus on algorithmic and scaling work by the community.

Chiral Symmetry / 183

Properties of the η and η' mesons

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We present results for η and η' masses and their four independent decay constants, determined directly from the axialvector channels.
We perform our analysis on the CLS 2+1 flavour ensembles, from pion masses of 420 MeV down to the physical mass point. Four lattice spacings and two distinct mass trajectories allow to take the continuum limit and chiral interpolation with care, providing first results for some of the from phenomenology lesser known low energy constants that appear in NLO large-N_c ChPT.
As a by-product, we test the flavour-singlet PCAC relation, probing the purely gluonic contribution to the singlet decay constants.

Theoretical Developments / 184

Accessing 3D CFTs in Radial Quantization on the Lattice

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Cardy (1985) pointed out that radial quantization may provide a useful numerical approach to study CFTs compared to traditional finite size scaling techniques. The problem that the cylindrical manifold $R \times S^{d-1}$ is curved for $d > 2$ has been ameliorated – and perhaps solved – for renormalizable QFTs by the development of the quantum finite element (QFE) method in recent years. QFE provides a nonperturbative lattice regularization for renormalizable QFT on an arbitrary smooth Riemannian manifold. We present results for the 3D Ising fixed point in real scalar ϕ^4 theory, focusing on the recovery of isometries in the continuum limit and the extraction of some initial nonperturbative CFT data. We also discuss an alternative approach to extracting conformal scaling dimensions by making connection with the large charge expansion, and an effort to study the $O(N)$ model in radial lattice quantization at finite density.

Algorithms and Machines / 185

Distance between configurations in MCMC simulations and the geometrical optimization of the tempering algorithms

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In papers [Fukuma, Matsumoto, Umeda, arXiv:1705.06097, arXiv:1806.10915], we defined for a given Markov chain Monte Carlo (MCMC) algorithm a distance between two configurations that quantifies the difficulty of transition from one configuration to the other configuration. In this talk, we discuss its application to the optimization of parameters in various tempering algorithms. Examples include the standard simulated/parallel tempering algorithms with respect to energy potentials, and also the tempered Lefschetz thimble method for the sign problem which uses the flow time as a tempering parameter. This talk is based on a paper in preparation [Fukuma, Matsumoto].

Weak Decays and Matrix Elements / 186

An exploratory study of heavy-light semileptonics using distillation

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We present our exploratory study with the aim of simulating heavy-light semileptonics as part of the RBC-UKQCD charm (to bottom) physics programme. We are using a distillation-based setup as a strategy to get optimised plateaus in semi-leptonic $D_{(s)}$ and $B_{(s)}$ decays. The study will be done in a centre-of-mass frame and several moving frames and will use an $N_f = 2+1$ domain wall fermion lattice with a pion mass of $340\ \mathrm{MeV}$, with the aim of extending the study to a physical-point domain-wall ensemble.

Poster / 187

Flux tube with dynamical fermions from high temperature SU(3) lattice gauge theory

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We explore the profiles of the flux tube connecting a quark and an antiquark in high temperature SU(3) lattice gauge theory in close vicinity to the critical temperature of the phase transition. In this work, we consider the more realistic case of the flux tube with dynamical quarks, extending the previous study to SU(3) gauge group and making use of the Gradient flow method in smoothing procedure for noise reduction. The profiles of the chromoelectric and chromomagnetic field strengths in the flux tube have been measured from Polyakov loop-plaquette correlations using the highly improved staggered quark (HISQ) action on lattice with temporal extent $N_\tau = 8$. We present preliminary results for distances up to 2.5 fm and temperatures up to $1.13T_c$.

Algorithms and Machines / 188

Breaking the latency barrier: Strong scaling LQCD on GPUs

Authors: Kate Clark[1]; Mathias Wagner[1]; Evan Weinberg[2]

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The ability to strong scale is crucial for Lattice QCD simulations. Since the creation of the QUDA library for Lattice QCD on NVIDIA GPUs, this has always been a key development goal. Techniques like GPUDirect RDMA and NVLink allow for fast intra-node and inter-node data transfer and QUDA makes extensive use of them. However, API overheads and necessary synchronizations between GPU and CPU are increasingly limiting the ability to strong scale with MPI communication. Fine-grained GPU-centric communication provides a way out as it completely removes these bottlenecks by moving the communication to the GPU kernels. We will discuss the techniques that QUDA implements to achieve the best scaling with MPI and novel improvements using NVSHMEM for GPU-centric communication. Finally, we will show scaling results on x86 and POWER systems.

Vacuum Structure and Confinement / 189

Does confinement imply CP invariance of the strong interactions?

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Using the gradient flow, the strong coupling constant alpha_s and the vacuum angle theta of the SU(3) Yang-Mills theory are investigated in the infrared limit. It appears that theta tends to zero (mod 2 pi), thus restoring CP invariance, while alpha_s shows power-law divergence, which naturally leads to a linear confining potential.

Hadron Spectroscopy and Interactions / 190

Spectroscopy of mesons with bottom quarks

Author: Sinead Ryan[1]

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Preliminary results for the spectra of excited and exotic hidden and open bottom mesons are presented. The calculation on dynamical anisotropic ensembles exploits distillation enabling the use of a large basis of interpolating operators including operators proportional to the gluonic field strength which are relevant for hybrid states. A comparison of results with similar calculations in the light and charm sectors is made.

Standard model parameters and renormalization / 191

Non-perturbative matching of three/four-flavor Wilson coefficients with a position-space procedure

Author: Masaaki Tomii[None]

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We construct a strategy to non-perturbatively convert Wilson coefficients in the four-flavor theory to those in the three-flavor theory. This non-perturbative matching is expected to reduce one of the biggest systematic uncertainties in RBC/UKQCD's previous $K \to \pi\pi$ calculation, where the matching was performed perturbatively at scales below the charm threshold. Since our method uses two-point functions in position space, which are a gauge-invariant and are free from contact terms, it prevents irrelevant mixing with gauge noninvariant operators and operators that vanish by the equations of motion.
In this talk, we present the strategy and our preliminary results for the non-perturbative matching of the Wilson coefficients that multiply the $\Delta S = 1$ four-quark operators associated with $K \to \pi\pi$ decays.

Physics Beyond the Standard Model / 192

Continuum limit of SU(3) N=1 supersymmetric Yang-Mills theory and supersymmetric gauge theories on the lattice

Authors: Georg Bergner[1]; Stefano Piemonte[2]; Gernot Münster[3]; Istvan Montvay[4]; Henning Gerber[3]; Philipp Scior[5]; Sajid Ali[6]; Camilo Lopez[1]

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In this presentation I will provide an overview of our investigations of supersymmetric gauge theories. I summarize our final results of SU(3) $\mathcal{N} = 1$ supersymmetric Yang-Mills theory that allow for the first time an extrapolation to the continuum limit. This result shows that the symmetry is recovered in the continuum limit. I will review our recent approaches towards a simulation of more general supersymmetric gauge theories. This includes the first tests of simulations with dynamical overlap fermions.

Plenary / 193

Recent progress on in-medium heavy flavor physics from lattice QCD

Author: Hiroshi Ohno[1]

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Heavy quarks and heavy-flavor mesons are essential probes to investigate quark-gluon plasma produced in ultra-relativistic heavy ion collisions. On the other hand, extracting spectral properties from lattice heavy-flavor correlation functions to understand dissociation patterns of the bound states and heavy quark transport is a challenging subject in lattice QCD. In this talk, recent progress in lattice studies on in-medium properties of heavy quarks as well as open and hidden heavy flavor are reviewed and discussed. In particular, different efforts of spectral reconstruction from lattice correlation functions are highlighted and corresponding results on dissociation of the heavy-flavor mesons and heavy quark transport coefficients are addressed.

Physics Beyond the Standard Model / 195

Sp(2N) Yang-Mills towards large N.

Authors: Ed Bennett[1]; Jack Holligan[None]; Deog-Ki Hong[2]; Jong-Wan Lee[2]; C.-J. David Lin[3]; Biagio Lucini[1]; Maurizio Piai[1]; Davide Vadacchino[4]

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Owing to their importance for BSM model building, understanding the non-perturbative physics of Sp(2N) gauge theories is of high importance due to their large-N extrapolations. In this talk, we examine the glueball spectrum of Yang-Mills theories based on symplectic groups. Glueball masses are calculated numerically with a variational method from Monte Carlo generated gauge configurations. After performing a continuum extrapolation for N=1,2,3 and 4, we use the obtained continuum limit to determine masses at large N. We compare the resulting spectrum with that of SU(N) in the same limit.

Nonzero Temperature and Density / 196

Axial U(1) symmetry and mesonic correlators at high temperature in $N_f = 2$ lattice QCD

Authors: Kei Suzuki[1]; Sinya Aoki[2]; Yasumichi Aoki[3]; Guido Cossu[4]; Hidenori Fukaya[5]; Shoji Hashimoto[6]; Christian Rohrhofer[5]

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We measure the connected and disconnected mesonic correlators and screening masses in the high-temperature phase of $N_f = 2$ QCD. Gauge ensembles are generated with Mobius domain-wall fermions, while the observables are calculated with a reweighting to achieve more precise chiral symmetry. We confirm the restoration of axial $U(1)$ symmetry for small quark masses. At a larger quark mass, the $U(1)_A$ is broken and long-distance correlations are observed in the isospin singlet channels.

Applications Beyond QCD / 197

Lattice study of the 2-flavor U(1) gauge Higgs model at topological angle $\theta = \pi$

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We study the 2-d $U(1)$ gauge Higgs model with 2 flavors on the lattice. We simulate at topological angle $\theta = \pi$ and overcome the sign problem with a worldline representation of the theory. Using a novel definition of the theta-term, in terms of a Villain-type action, gives rise to a lattice discretization of the topological charge as an integer and thus, exactly implements the charge conjugation symmetry at $\theta = \pi$.
We introduce a new coupling g in the 2-flavor quartic self interaction that allows us to deform the full $SU(2)$ flavor symmetry to $\mathbb{Z}_2 \times U(1)$. We study the phase diagram of this system as a function of g and the mass parameter and determine the critical lines as well as the order of the phase transitions using finite size scaling.

Standard model parameters and renormalization / 198

Non-perturbative renormalization of Kaon B parameter using gradient flow

Authors: Yusuke Taniguchi[1]; Atsushi Baba[None]; Shinji Ejiri[2]; Kazuyuki Kanaya[1]; Masakiyo Kitazawa[3]; Asobu Suzuki[1]; Hiroshi Suzuki[4]; Takashi Umeda[5]

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We calculate the Kaon B parameter by using the Wilson type quark.
We adopt the gradient flow method as a non-perturbative renormalization scheme.
The calculation is performed on Nf=2+1 full QCD configuration generated with the Iwasaki gauge action and the non-perturbatively improved clover action.
We adopt a fine lattice spacing a=0.07 (fm).
The ud quark mass is rather heavy with $m_\pi/m_\rho \simeq 0.63$ while the s quark mass is set to approximately its physical value.

Standard model parameters and renormalization / 199

Quark masses and decay constants in Nf=2+1+1 isoQCD with Wilson clover twisted mass fermions

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In this contribution we present a preliminary data analysis of the pion, kaon and D-meson masses and decay constants, as well as preliminary results for light, strange and charm renormalized masses. The analysis is based on the gauge ensembles produced by ETMC with Nf=2+1+1 flavours of Wilson clover twisted mass quarks, which cover a range of lattice spacings from ˜0.10 to 0.07 fm and include configurations at the physical pion point on lattices with linear size up to L ˜ 5.6 fm.

Hadron structure / 200

Structure and transitions of nucleon excitations via parity-expanded variational analysis

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The recently-introduced Parity Expanded Variational Analysis (PEVA) technique allows for the isolation of baryon eigenstates on the lattice at finite momentum free from opposite-parity contamination. We find that this technique introduces a statistically significant correction in extractions of the electromagnetic form factors of the ground state nucleon.

It also allows first extractions of the elastic and transition form factors of nucleon excitations on the lattice. We present the electromagnetic elastic form factors and helicity amplitudes of two negative-parity excitations of the nucleon. These results provide valuable insight into the structure of these states, and allow for a connection to be made to quark-model states in this energy region.

Nonzero Temperature and Density / 201

The path optimization for the sign problem of low dimensional QCD

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The path optimization has been proposed to weaken the sign problem which appears in some field theories such as finite density QCD. In this method, we optimize the integral path in the complex plain to enhance the average phase factor. This method has been applied to a one dimensional integral [1], finite density complex scalar field [2], and the Polyakov loop extended Nambu-Jona-Lasinio model with and without vector type interaction [3, 4]. In these cases, the average phase factor is enhanced significantly. In this talk, we discuss the application of this method to low dimensional QCD as a first step towards finite density QCD.

[1] Y. Mori, K. Kashiwa, A. Ohnishi, Phys. Rev. D 96 (2017), 111501(R).
[2] Y. Mori, K. Kashiwa, A. Ohnishi, PTEP 2018 (2018), 023B04.
[3] K. Kashiwa, Y. Mori, A. Ohnishi, Phys. Rev. D 99, no. 1, 014033 (2019).
[4] K. Kashiwa, Y. Mori, A. Ohnishi, arXiv:1903.03679 [hep-lat].

Weak Decays and Matrix Elements / 202

Semileptonic B decays with RHQ b quarks

Authors: Jonathan Flynn[1]; Ryan Hill[1]; Andreas Juttner[2]; AMARJIT Soni[3]; J Tobias Tsang[4]; Oliver Witzel[5]

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This talk will focus on RBC/UKQCD's most recent analysis for $B \to \pi l \nu$ and $B \to D l \nu$ semileptonic form factors. Heavy quarks have been simulated with the Columbia formulation of the relativistic heavy quark (RHQ) action, and light quarks with a domain-wall fermion action. The decays have been investigated over six ensembles. The form factor dependence on the three RHQ action parameters and its contribution to the error budget will be presented, as well as preliminary results. This work forms part of RBC/UKQCD's larger effort on predicting semileptonic $B_{(s)}$ decay form factors with RHQ b quarks.

Weak Decays and Matrix Elements / 203

A strategy for the calculation of disconnected contributions to QED and strong isospin-breaking effects.

Author: James Richings[1]

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When calculating isospin-breaking corrections to hadronic quantities, sea quark effects are often neglected. In this work by the RBC/UKQCD collaboration, based on their domain-wall fermion ensembles combined with an all-to-all approach, we discuss our strategy for computing the disconnected isospin-breaking contributions to light pseudo-scalar meson masses and matrix elements. We will present our strategy for the calculation of disconnected quantities and discuss results for isospin-breaking corrections to light pseudo scalar meson masses using an all-to-all approach and low-mode averaging.

Weak Decays and Matrix Elements / 204

K_{l3} form factors in $N_f = 2+1$ QCD at physical point on large volume

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Co-authors: Ken-Ichi Ishikawa [2]; Naruhito Ishizuka [3]; Yoshinobu Kuramashi [3]; Yoshifumi Nakamura ; Yusuke Namekawa [4]; Yusuke Taniguchi [3]; Naoya Ukita ; Takeshi Yamazaki ; Tomoteru Yoshie [3]

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We present our results of the K_{l3} form factors on the volume of configuration more than L =10 fm, with the physical pion and kaon masses using the stout-smearing clover $N_f = 2+1$ quark action and Iwasaki gauge action at $a^{-1} = 2.333$ GeV.

The K_{l3} form factor at zero momentum transfer is obtained from fit results using the NLO formula in SU(3) chiral perturbation theory with NNLO analytic terms. In addition, we estimate systematic errors of the form factor, such as ones coming from excited state contamination and finite size effect.

We also determine the value of $|V_{us}|$ by combining our result with the experimental K_{l3} form factor and check the consistency with the standard model prediction. The result is compared with the previous lattice calculations.

Nonzero Temperature and Density / 205

The Phases of Thermal QCD

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We study thermal phases of QCD via scaling properties of glue fields at long spatial distances. Interesting phase structure emerges.

Theoretical Developments / 206

Logarithmic Corrections to a^2 scaling in lattice Yang Mills theory

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We analyse the leading logarithmic corrections to the a^2 scaling of lattice artefacts in QCD, following the seminal work of Balog, Niedermayer and Weisz in the O(n) non-linear sigma model. Limiting to contributions from the action, the leading logarithmic corrections can be determined by the anomalous dimensions of a minimal on-shell basis of mass-dimension 6 operators. We present results for the lattice SU(N) pure gauge theory. In this theory the logarithmic corrections reduce the cutoff effects. These computations are the first step towards a study of full lattice QCD at O(a^2), which is in progress.

Nonzero Temperature and Density / 207

Exploring the QCD phase diagram via reweighting from isospin chemical potential

Authors: Sebastian Schmalzbauer[1]; Gergely Endrődi[1]; Bastian B. Brandt[1]; Francesca Cuteri[1]

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We investigate the QCD phase diagram close to the isospin chemical potential axis. Simulations directly along this axis are not hindered by the sign problem and pion condensation can be observed at high enough values of the isospin chemical potential. We study how the related phase boundary evolves in the baryon and strangeness chemical potential directions via reweighting in the quark chemical potentials and discuss our results. Furthermore, we develop an alternative method to approach nonzero baryon chemical potentials. This involves simulations including auxiliary quarks of an extended isospin doublet and decoupling them by increasing their mass, again via reweighting.

Nonzero Temperature and Density / 208

Schwinger-Keldysh formalism for Lattice Gauge Theories

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It is important to compute transport coefficients in QCD at finite temperature and density. When the imaginary-time formalism of Lattice QCD is used, the spectral functions have to be reconstructed by

supplementing certain Ansatze for correlation functions on the lattice. On the other hand, real-time Green's functions can be obtained directly in the Schwinger-Keldysh (SK) formalism. But the SK formalism has not been constructed so far for QCD non-perturbatively.
In this work we formulate the SK formalism for Lattice QCD by constructing the transfer matrix in the direction of real time for gauge link field and Wilson fermion. We examine the spectral functions and other real-time Green's functions in weak gauge-coupling limit. We also obtain the Kubo formulae in this framework as a summation of the real-time Green's functions on the closed time path.

Standard model parameters and renormalization / 209

Calculation of PCAC mass with Wilson fermion using gradient flow

Authors: Atsushi Baba[1]; Shinji Ejiri[2]; Kazuyuki Kanaya[1]; Masakiyo Kitazawa[3]; Asobu Suzuki[1]; Hiroshi Suzuki[4]; Yusuke Taniguchi[1]; Takashi Umeda[5]

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We calculate the PCAC mass for $N_f = 2 + 1$ flavor full QCD with Wilson fermion. We adopt the gradient flow method as a non-perturbative renormalization scheme. Our calculations are performed on two different mass parameters; heavy ud quark with $m_\pi/m_\rho \simeq 0.63$ and almost physical s quark, and physical quarks. We compare the results with those renormalized with the Schrodinger functional scheme. We also present our preliminary calculation performed on large ($L \sim 5$ fm) lattice with physical quark mass.

Nonzero Temperature and Density / 210

Caloron gas, quark localization and chiral symmetry in high-T QCD

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Across the finite temperature transition to the quark-gluon plasma, the QCD topological susceptibility decreases sharply. Thus in the high temperature phase the remaining topological objects (possibly calorons) form a weakly interacting dilute gas. The overlap Dirac operator, through its exact zero modes, allows one to measure the net topological charge. We show that separately the number of positively and negatively charged topological objects can also be extracted from the low-end of the overlap Dirac spectrum. We study the dynamics of these topological objects and speculate on how they

might affect quark localization and through that deconfinement and chiral symmetry restoration.

Theoretical Developments / 211

Stabilised Wilson fermions for QCD on very large lattices

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Rough gauge fields are an obstacle in large-scale dynamical fermion simulations with Wilson quarks when the pion mass is lowered and the gap of the lattice Dirac operator shrinks. In this talk, a reformulation of the O(a) improved Wilson-Dirac operator is given which is largely protected from numerical instabilities during the molecular dynamics evolution. First results are very promising as physical-point simulations in three-flavour QCD at lattice spacings as large as 0.095 fm become feasible. The implementation comes without additional cost and is a crucial ingredient towards master-field simulations with fermions.

Nonzero Temperature and Density / 212

Polyakov loop susceptibility and correlators in the chiral limit

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In quenched QCD the Polyakov loop is an order parameter of the deconfinement transition, but with decreasing quark mass the peak in the Polyakov loop susceptibility becomes less pronounced and it loses its interpretation as an indicator for deconfinement. In this study we examine the dependence of the susceptibility on the light quark mass, following it toward the chiral limit. In particular we are interested in whether one finds a peak in the susceptibility in this limit at all, and therefore whether the susceptibility plays any role at the chiral phase transition. Closely related is an investigation of the dependence of Polyakov loop correlations on light quark mass; our preliminary results show no dependence. From the Polyakov loop correlations one can calculate the singlet quark-antiquark free energy F_1, and the Debye mass m_D can be extracted from its long-distance behavior. Extraction of m_D is challenging because F_1 exhibits large statistical error bars at large r. We attempt to improve the signal using the gradient flow, which should leave long-range physics relatively unharmed.

Hadron structure / 213

Developments in the position-space approach to the HLbL contribution to the muon $g-2$ on the lattice.

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The anomalous magnetic moment shows a three to four standard deviations tension between its experimental value and theory predictions, and therefore demands further investigation. Experiments at Fermilab and J-PARC aim to reduce the uncertainty by a factor of four. The theoretical uncertainty has to be reduced in equal measure. It is dominated by the hadronic vacuum polarization (HVP) and hadronic light-by-light (HLbL) contribution. We will present developments in the position-space approach to the HLbL contribution.

Standard model parameters and renormalization / **214**

Non-perturbative renormalization in QCD+QED and its applications to weak decays

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We present a new strategy to extend the usual non-perturbative renormalization procedure, performed on the lattice in the RI'-MOM scheme, in order to include electromagnetic corrections at first order in perturbation theory. We show the first numerical estimates for the QED corrections to the renormalization constants of quark bilinears and four-fermion operators (two quarks and two leptons). Since the non-perturbative renormalization is an important step in the numerical calculation of hadronic decay rates, we discuss the application of this strategy to light-meson leptonic decays. The numerical results are obtained using gauge ensembles produced by the European Twisted Mass Collaboration with $N_f = 4$ dynamical quarks.

Poster / **215**

Full $\mathcal{O}(a)$ improvement in EQCD

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EQCD is a 3D bosonic theory containing SU(3) and an adjoint scalar, which efficiently describes the infrared, nonperturbative sector of hot QCD and which is highly amenable to lattice study. We improve the matching between lattice and continuum EQCD by determining the final unknown coefficient in the $\mathcal{O}(a)$ matching, an additive scalar mass renormalization. We do this numerically by using the symmetry-breaking phase transition point of the theory as a line of constant physics. This prepares the ground for a precision study of the transverse momentum diffusion coefficient $C(q_\perp)$ within this theory. As a byproduct, we provide an updated version of the EQCD phase diagram.

Weak Decays and Matrix Elements / 216

New approaches to semileptonic decays

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We present a proposal to compute on the lattice $B \to \pi$ form factors in the full momentum range. We also discuss some new results for the $B \to D, D^*$ semileptonic form factors.

Theoretical Developments / 217

Gradient flow equation in SQCD

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We construct a gradient flow equation in N=1 SQCD. The flow is supersymmetric in a sense that the flow time and the supersymmetry transformation commute with each other up to a gauge transformation. We also discuss the UV property of flowed correlators.

Nonzero Temperature and Density / 218

Computing general observables in lattice models with complex actions

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The study of QFTs at finite density is hindered by the presence of the so-called sign problem. The action definition of such systems is, in fact, complex-valued making standard importance sampling Monte Carlo methods ineffective.
In this work, we shall review the generalized density of states method for complex action systems and the Linear Logarithmic Relaxation algorithm. We will focus on the recent developments regarding the bias control of the LLR method and the evaluation of general observables in the DoS+LLR framework. Recent results on the well-known relativistic Bose gas will be presented, proving that in our approach the phase factor can be consistently evaluated over hundreds of orders of magnitude. A first exploratory study on the Thirring model in the DoS formalism will be presented as well.

Physics Beyond the Standard Model / 219

$\mathcal{N}=1$ Supersymmetric SU(3) Gauge Theory with a Twist

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We investigate the pure gauge sector of Super-QCD, i.e. Super-Yang-Mills (SYM) theory, with focus on the bound states. To improve chiral symmetry as well as supersymmetry at finite lattice spacing, we use a deformed SYM lattice action. It contains a twist term, similar to the lattice formulation of twisted mass QCD. We present the status of our theoretical and numerical investigation.

Poster / 220

χSF near the electroweak scale

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We employ the chirally rotated Schroedinger functional (χSF) to study two-point fermion bilinear correlation functions used in determination of $Z_{A,V,S,P,T}$, on a series of well-tuned ensembles generated using the Schroedinger Functional (SF) and which span renormalisation scales from 4 to 70 GeV. We carry out a detailed comparison with the expectations from one-loop perturbation theory.

Hadron structure / 221

Nucleon scalar charge with overlap fermions

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In this talk I present the result on nucleon isovector scalar charge using overlap fermions on 2+1 flavor domain-wall configurations generated by RBC/UKQCD collaboration. The ensembles span four lattice spacings 0.06, 0.08, 0.11 and 0.14 fm and five pion masses in the range from the physical value to 370 MeV. The scalar charge is extracted from the ratio of 3pt and 2pt functions by two-state fit. Extrapolation to the physical pion mass, continuum limit and infinite volume is performed by simultaneously fit in the three variables. Our result is in agreement with previous lattice determinations.

Nonzero Temperature and Density / 222

Euclidean correlation functions for transport coefficients under gradient flow

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In this talk we report the progress of our studies on the temporal correlation functions under gradient flow from lattice QCD. The operators to construct the correlation functions under consideration include the energy-momentum tensor and color-electric field. These calculations are the first step in our long-term project of estimating some important quantities: shear&bulk viscosities and heavy quark momentum diffusion coefficient as they could be obtained from the spectral functions extracted from the corresponding correlation functions. In our calculations the gradient flow technique is applied to improve the signal in measuring the correlation functions. We will study the effect of the gradient flow on the small distance part of the correlators in comparison to perturbative estimates and the improvement of the signal at large distances.

Algorithms and Machines / 224

QCD on the Modular Supercomputer

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I discuss motivations for generalizing QCD simulations for heterogeneous clusters, and identify possible models of LQCD simulations suitable for a modular supercomputing environment. The

Jureca cluster at the Juelich Supercomputing Centre, with Haswell, KNL, and GPU-enabled compute nodes, serves as a test bed for modular supercomputing strategies. I describe initial tests with the MILC code and Chroma, with minor alterations to the USQCD software stack.

Nonzero Temperature and Density / 225

Large N_c behaviour of an effective lattice theory for heavy dense QCD

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Combining strong coupling and hopping expansion one can derive a dimensionally reduced effective theory of lattice QCD.
This theory has a reduced sign problem, is amenable to analytic evaluation and was successfully used to study the cold and dense regime of QCD for sufficiently heavy quarks.
We show the derivation and evaluation of the effective theory for arbitrary N_c up to κ^4.
The inclusion of gauge corrections is also investigated.
We find that before the onset, the baryon number density is exponentially suppressed for growing N_c even for $T \neq 0$. This suggests that in the large N_c limit the onset transition is first order up to the deconfinement transition.
After the onset, the pressure is shown to scale as $p \sim N_c$ at all available orders. Possible implications on quarkyonic matter are discussed.

Nonzero Temperature and Density / 226

Thermal modifications of quarkonia and heavy quark diffusion from a comparison of continuum-extrapolated lattice results to perturbative QCD

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We will present our analysis of continuum extrapolated charmonium and bottomonium correlators calculated from very large and fine lattices in the pure SU(3) plasma using clover-improved Wilson valence quarks, extending the study of the pseudo-scalar channel [1].
Two sources of systematic errors may arise in the comparison. On the lattice side, the renormalization constants are not exactly known, while on the perturbative side thermal mass shifts appear. To account for this, we introduce two factors, an overall renormalization factor and a mass shift, which are determined in a fit of the perturbative model to the correlator. As a cross-check the results of this fit are then compared to MEM results. We begin with the investigation of the pseudoscalar channel as done in [1] and extend the knowledge gained there to the vector channel, where in addition to the analysis of the thermal modification of heavy quark bound states we try to get an estimate of the heavy quark diffusion coefficient.

[1] Y. Burnier, H.-T. Ding, O. Kaczmarek, A.-L. Kruse, M. Laine, H. Ohno, H. Sandmeyer, Thermal quarkonium physics in the pseudoscalar channel. JHEP 2017, 11, 206, doi:10.1007/JHEP11(2017)206

Theoretical Developments / 227

Tensor network study of two dimensional complex ϕ^4 theory at finite density

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We study the complex ϕ^4 theory with finite chemical potential. To closely understand nontrivial effects such as the Silver Blaze phenomenon, experimental studies on the lattice will give some knowledge; however, on account of the finite chemical potential, there is a sign problem in Monte Carlo simulations. In this study, to overcome the problem, the tensor renormalization group approach is employed, and we give some numerical results surrounding the phenomena in the finite density system.

Standard model parameters and renormalization / 228

Non-perturbative renormalization by decoupling

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We show that the strong coupling can be accurately determined with the help of the running coupling in the pure gauge theory. We use a low energy scale computed in the three-flavor theory with heavy quarks, together with the non-perturbative running in pure gauge from 800 MeV to the electroweak scale to determine the three-flavor Lambda parameter accurately and in agreement with current knowledge. The method is quite general and can be applied to solve other renormalization problems (like the determination of quark masses), using finite or infinite volume intermediate renormalization schemes.

Poster / 229

Quarkonium suppression in non-equilibrium quark-gluon plasma

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Quarkonium suppression in quark-gluon plasma has been investigated since original work by Matsui and Satz [1]. This topic remains actual due to the need of quark-gluon plasma diagnostics. In fact, both quarkonium suppression in quark-gluon plasma and recombination during hadronisation remain to be key open questions [2]. The bound state of quarkonium is theoretically well investigated in the case of equilibrium quark-gluon plasma [3]. However, the experimentally produced quark-gluon plasmas is strongly non-equilibrium. Therefore, in this work we present results for the quarkonium suppression in streaming quark-gluon plasmas. For this propose we use the concept of dynamical screening using the dielectric function of collisional quark-gluon plasma.

[1] T. Matsui and H. Satz, Physics Letters 178, 416 (1986)
[2] Jurgen Schukraft, Nuclear Physics A 967, 1 (2017)
[3] R. Rapp and X. Du, Nuclear Physics A 967, 216 (2017)

Nonzero Temperature and Density / 230

Gauge Corrections to Strong Coupling LQCD on Anisotropic Lattices

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Lattice QCD with staggered fermions can be formulated in dual variables to address the finite baryon density sign problem. In the past we have performed simulations in the strong coupling regime, including leading order gauge corrections. In order to vary the temperature for fixed beta it was necessary to introduce a bare anisotropy. In this talk we will extend our work to include results from a non-perturbative determination of the physical anisotropy $a/a_t = \xi(\gamma, \beta)$, which is necessary to unambiguously locate the critical end point and the first order line of the chiral transition.

Nonzero Temperature and Density / 231

On the Lefschetz thimbles structure of the Thirring model

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The complexification of field variables is an elegant approach to attack the sign problem. In one approach one integrates on Lefschetz thimbles: over them, the imaginary part of the action stays constant and can be factored out of the integrals so that on each thimble the sign problem disappears. However, for systems in which more than one thimble contribute one is faced with the challenging task of collecting contributions coming from multiple thimbles.

The Thirring model is a nice playground to test multi-thimble integration techniques; even in a low dimensional theory, the thimble structure can be rich. It has been shown since a few years that collecting the contribution of the dominant thimble is not enough to capture the full content of the theory. We report preliminary results on reconstructing the complete results from multiple thimble simulations.

Standard model parameters and renormalization / 232

Non-perturbative renormalization of $\mathrm{O}(a)$ improved tensor currents

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We present our progress on the non-perturbative $\mathrm{O}(a)$ improvement and renormalization of tensor currents in three flavor lattice QCD with Wilson-clover fermions and tree-level Symanzik improved gauge action. While the $\mathrm{O}(a)$ improvement factor of the tensor currents is determined via a Ward identity approach, their RG group running is calculated via recursive finite-size scaling techniques, both implemented within the Schrödinger functional framework. We also address the matching factor between bare and renormalization group invariant currents for a range of lattice spacings relevant for applications from large-volume simulations.

Nonzero Temperature and Density / 233

Evading the model sign problem in the PNJL model with repulsive vector-type interaction via path optimization

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It is important to investigate the sign problem around the phase transition region, where the sign problem is serious. We investigate the model sign problem in the Polyakov loop extended Nambu-Jona-Lasinio (PNJL) model with repulsive vector-type interaction at finite temperature and density by using the path optimization method [1]. The Polyakov loop and the repulsive vector-type interaction have been known to cause the model sign problem in the path integral [2,3]. We have studied the sign problem in PNJL by using the path optimization method [2], in which the integration path in the complexified variable space is optimized to enhance the average phase factor [4,5]. Since the vector-type interaction is necessary to explain the repulsion at high density and also make the sign problem more serious, we now investigate the model including both the Polyakov loop and vector-type repulsion [1]. We find that the sign problem is more serious when we include both especially around the phase transition region. We demonstrate that complexification of the temporal gluon field and the vector-type auxiliary field together with optimizing the path can increase the average phase factor and we can control the model sign problem.

[1] K. Kashiwa, Y. Mori, A. Ohnishi, arXiv:1903.03679 [hep-ph].
[2] K. Kashiwa, Y. Mori, A. Ohnishi, Phys. Rev. D 99 (2019), 014033 [arXiv:1805.08940 [hep-ph]].
[3] Y. Mori, K. Kashiwa, A. Ohnishi, Phys. Lett. B 781 (2018), 688 [arXiv:1705.03646 [hep-lat]].
[4] Y. Mori, K. Kashiwa, A. Ohnishi, Phys. Rev. D 96 (2017), 111501(R [arXiv:1705.05605 [hep-lat]].
[5] Y. Mori, K. Kashiwa, A. Ohnishi, Prog. Theor. Exp. Phys. 2018 (2018), 023B04 [arXiv:1709.03208 [hep-lat]].

Hadron structure / 234

Nucleon Sigma Terms

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The BMW collaboration's recent calculation of the nucleon sigma terms, based on the Feynman-Hellmann theorem, will be presented. In different stages of the calculation advantages of staggered and Wilson fermions are exploited by fitting data generated with both fermion action. The fitting methods will be explained and the implications of the findings for the quark masses' contributions to the nucleon masses will be briefly discussed.

Vacuum Structure and Confinement / 235

How to extract the "Abelian" part of double-winding Wilson loop

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It is known that the naive Abelian Wilson loop defined by the Abelian projection cannot reproduce the correct behavior of the double-winding Wilson loop. It is also known that the naive Abelian Wilson loop cannnot reproduce the correct behavior of the Wilson loops in higher representations, but this problem was recently solved by using the redefiend "Abelian" Wilson loop.
In this talk, we will give another reason why this redefined "Abelian" Wilson loop behaves correctly, and by following the same line of the argument, we will propose redefined "Abelian" double-winding Wilson loop which is considered to behave correctly.

Hadron Spectroscopy and Interactions / 236

Resonances in coupled-channel meson-meson scattering from lattice QCD

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Recent results will be presented of computations of meson-meson scattering processes in several partial waves containing unstable resonances. We will cover πK scattering at several pion masses from arXiv:1904.03188, and an extraction of the b_1 resonance seen in dynamically-coupled ${}^3S_1$-${}^3D_1$ $\pi\omega$ scattering coupled to $\pi\phi$, from arXiv:1904.04136.

Theoretical Developments / 237

The twisted gradient flow running coupling in SU(3): a non-perturbative determination

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We report some preliminary results of our ongoing non-perturbative computation of the twisted 't Hooft running coupling in a particular set-up, using the gradient flow to define the coupling and step scaling techniques to compute it. For the computation we considered a pure gauge SU(3) theory in four dimensions, defined on the lattice on an asymmetrical torus endowed with twisted boundary conditions in a single plane, and related the energy scale of the coupling to an effective size combining the size of the torus and the rank of the gauge group. Additionally, we explore some of the effects of the freezing of the topology on the computation of the coupling.

Hadron structure / 238

Quark momentum and angular momentum fractions at physical pion mass

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We present a preliminary calculation of the quark energy momentum tensor form factors $T_1(Q^2)$ and $T_1(Q^2) + T_2(Q^2)$ at physical pion mass with valence overlap fermions on 2+1 flavor domain-wall $24^3 \times 64$ configurations with $a = 0.194$ fm, $m_\pi = 137$ MeV generated by RBC/UKQCD collaboration. With z-expansion fits of the sum of connected and disconneted contributions, we extract the unrenormalized quark momentum and angular momentum fractions.

Nonzero Temperature and Density / 239

Euclidean correlation functions of the topological charge density

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We will present first results of our study of the Euclidean topological charge density correlator.
In order to get a well defined topological charge density and to improve the signal of the correlators at large distances we make use of the gradient flow.
We investigate the flow-time dependence on large and fine quenched lattices and compare to results of 2+1-flavor HISQ lattices. The final goal of this study is to perform a continuum extrapolation for the pure SU(3) plasma, the relevance of the results to full QCD and to extract the related transport coefficient, the sphaleron rate.

Hadron structure / 240

Determining the glue component of the nucleon

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Computing the gluon component of momentum in the nucleon is a difficult and computationally expensive problem, as the matrix element involves a quark-line-disconnected gluon operator which suffers from ultra-violet fluctuations. But also necessary for a successful determination is the non-perturbative renormalisation of this operator. We investigate this renormalisation here by using two methods: enforcing the energy-momentum sum rule and also by direct computation in the RI mom scheme. A clear statistical signal is obtained in the direct calculation by an adaption of the Feynman-Hellmann technique. In the case of quenched fermions good agreement is found between both approaches.

Poster / 241

QED effects on the decay of charged pions and kaons

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The major decay rates of the charged pion and kaon mesons are to the end state of a muon and neutrino. This mode contributes over 99.9 percent to the pion decay, and about 64 percent to the kaon decay.

Analysing this decay on the lattice could lead to improved values for the meson decay constants and the parameters in the CKM matrix. High accuracy predictions will need to have QED effects included. We present some initial simulations taking account of the QED corrections by including a partially quenched muon propagator with its photon cloud.

Applications Beyond QCD / 242

Quantum Critical Phenomena in an O(4) Fermion Chain

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We construct an interacting spin $\frac{1}{2}$ fermion model with an $O(4)$ symmetry, motivated by the ability to study its physics using the meron cluster algorithm. By adding a strong repulsive Hubbard interaction U, we can transform it into the regular Heisenberg anti-ferromagnet. While we can study our model in any dimension, as a first project we study it in one spatial dimension. We discover that the model is massive and breaks a $\mathbb{Z}_2$ translation symmetry at low temperatures when U is small. Since at large values of U the model is equivalent to a spin-half anti-ferromagnetic chain which is massless for topological reasons, our finding implies that our model has a quantum phase transition from a massive $\mathbb{Z}_2$ broken phase to a topologically massless phase as we increase U. The existence of these two phases is consistent with the Lieb-Schultz-Mattis theorem and our model allows us to study the phase transition between. We present results obtained from our quantum Monte Carlo method near this phase transition.

Nonzero Temperature and Density / 243

Simulating gauge theories on Lefschetz Thimbles

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Lefschetz thimbles have been discussed recently as a possible solution to the complex action problem (sign problem) in Monte Carlo simulations. Here we discuss the structure of Lefschetz thimbles for pure pure Yang-Mills theories with a complex gauge coupling β and show how the gauge degrees of freedom alter the thimble decomposition. We propose to simulate such theories on the union of the tangential manifolds to the thimbles at all critical points. We construct a local Metropolis-type algorithm, that can either be constraint to a specific thimble or simulate across thimbles. However,

the more thimbles are included in the simulation, the larger will be the sign problem. We demonstrate the algorithm on a (1+1)-dimensional U(1) model. We also discuss how, starting from the main thimble result, successive sub-leading thimbles can be taken into account via a re-weighting approach.

Plenary / **244**

Recent Developments of Muon g-2 from Lattice QCD

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One of the most promising quantities for the search of signatures of physics beyond the Standard Model is the anomalous magnetic moment g-2 of the muon, where a comparison of the experimental result with the Standard Model estimate yields a deviation of about 3.5 sigma. On the theory side, the largest uncertainty arises from the hadronic sector, namely the hadronic vacuum polarisation and the hadronic light-by-light scattering. I will review recent progress in calculating the hadronic contributions to the muon g-2 from the lattice and discuss the prospects and challenges to match the precision of the upcoming experiments.

Nonzero Temperature and Density / **245**

Lattice QCD estimate of the quark-gluon plasma photon emission rate

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We estimate the photon emission rate of the quark-gluon plasma in lattice QCD. At leading order in the electromagnetic coupling, the photon rate is proportional to the vector-channel spectral function evaluated on the light cone. The determination of the spectral function from lattice correlator data represents an ill-posed problem, which we address by introducing a Padé ansatz for the spectral function. We measure on the lattice a newly-proposed correlation function, suggesting physics-motivated constraints on the parameters of the Padé ansatz. A previous analysis conducted at fixed spatial momentum provided preliminary constraints on the value of the photon rate. We present new results obtained by a simultaneous analysis of data at different spatial momenta.

Theoretical Developments / 246

A qubit realization of O(N) sigma models

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We construct a qubit formulation of the lattice $O(N)$ non-linear sigma model in $d+1$ dimensions. For the $O(3)$ model, our construction uses two qubits per lattice site. We show that this Hamiltonian in two spatial dimensions has a quantum critical point where the well known scale invariant physics of the Wilson-Fisher fixed point is reproduced. Free massive bosons arise in three spatial dimensions. Simple modifications to our Hamiltonian also give us $O(2)$ and Z_2 qubit models.

Nonzero Temperature and Density / 247

Symmetries of the light hadron spectrum in high temperature QCD

Authors: Christian Rohrhofer[1]; Yasumichi Aoki[2]; Guido Cossu[3]; Hidenori Fukaya[None]; Christof Gattringer[4]; Leonid Glozman[None]; Shoji Hashimoto[5]; Christian Lang[None]; Kei Suzuki[6]

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Properties of QCD matter change significantly around the chiral crossover temperature, and the effects on $U(1)_A$ and topological susceptibilities, as well as the meson spectrum have been studied with much care. Baryons and the effect of parity doubling in this temperature range have been studied perviously by various other groups employing different setups. Here we construct suitable operators to investigate chiral and axial $U(1)$ symmetries in the baryon spectrum. Measurements are done with two flavors of chirally symmetric domain-wall fermions at temperatures above the critical one, for different volumes and quark-masses. The possibility of emergent $SU(4)$ and $SU(2)_{CS}$ symmetries will be discussed.

Plenary / 248

$B \to D^*$ form factors, $R(D^*)$, and $|V_{cb}|$

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I will discuss progress in lattice calculations of $B \to D^* \ell v$ form factors, and related decays involving a $b \to c$ transition. These are important for the precision determination of $|V_{cb}|$ in the Standard Model (SM), and a possible key to resolving long-standing discrepancy between inclusive and exclusive determinations. I will also discuss their relevance for understanding the SM anomalies in R-ratios, $R(B \to D^{(*)})$ and $R(B_c \to J/\psi)$.

Physics Beyond the Standard Model / 249

Gauge-invariant path-integral measure for the overalp Weyl fermions in 16 of SO(10) and the SM

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We consider the lattice formulation of the SO(10) chiral gauge theory with left-handed Weyl fermions in the sixteen dimensional spinor representation (16)/the Standard Model in the framework of the Overlap fermion/the Ginsparg-Wilson relation. We define a manifestly gauge-invariant path-integral measure for the left-handed Weyl field using all the components of the Dirac field, but the right-handed part of which is just saturated completely by inserting a suitable product of the SO(10)-invariant ‘t Hooft vertices in terms of the right-handed field. We also discuss the relations of our formulation to other approaches/proposals to decouple the species-doubling/mirror degrees of freedom. Those include Eichten-Preskill model, Ginsparg-Wilson Mirror-fermion model, Domain wall fermion model with the boundary Eichten-Preskill term, and 4D Topological Insulator/Superconductor with gapped boundary phase. We clarify the similarity and the difference in technical detail and show that our proposal is a well-defined and unified testing ground for that basic question.

Chiral Symmetry / 251

Zero modes of the domain wall operator for 2+1 flavor lattices with $a^{-1} \approx 1$ GeV

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We explore the topological properties of lattices without cooling through measurements of the zero modes of the domain wall operator. We investigate the eigenvalue spectrum and the space-time properties of the zero modes. We study the relationship between the zero modes and the η’ mass.

Algorithms and Machines / 252

Improved algorithms for generalized thimble method

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Questions about quantum field theories at non-zero chemical potential and/or real-time correlators are often impossible to investigate numerically due to the sign problem. A possible solution to this problem is to deform the integration domain for the path integral in the complex plane. Sampling configurations on these manifolds is challenging. In this talk I will discuss some of these problems, present solutions we have found and the directions we are currently pursuing.

Weak Decays and Matrix Elements / 253

Investigating Rare Kaon Decays with the All-to-All Method

Author: Fionn O hOgain[None]

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The rare kaon decay $K \to \pi \ell^+ \ell^-$ is a flavor changing neutral current process which is forbidden at tree level in the Standard Model. The amplitude that describes the long distance part of this decay is given in terms of the form factor $V(z) = a + bz + V_{\pi\pi}(z)$, where z is the dilepton invariant mass in unit of the kaon mass and $V_{\pi\pi}$ is the long distance two-pion contribution. This decay is currently being measured at the NA62 experiment in CERN. The values of a and b are known only through experimental results, though there are large uncertainties associated with them and only the absolute values are know.

I will present preliminary results of a lattice QCD calculation of $V(z)$ at the physical point using the "All-to-All" method. This method, which has been implemented in the open source C++ framework, Hadrons, can generate arbitrary solutions to the Dirac equation by decomposing propagators into exact low modes of the operator and a stochastically sample high mode contribution.

Hadron Spectroscopy and Interactions / 254

Pion-Pion Scattering with Elongated Boxes

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The pion-pion channel is the benchmark for lattice QCD scattering calculations. In the isospin limit, three channels describe $\pi\pi$ scattering completely, having distinct properties in each channel. The attractive $I = 0$ and $I = 1$ channels are dominated by the broad σ and narrow ρ resonances, respectively, while the $I = 2$ channel has no low energy resonance. Our group has calculated the σ and ρ resonance properties using elongated boxes to scan the relevant kinematic region at two pion masses. Here we present new results for the isospin-2 channel, thus completing the full study of $\pi\pi$ scattering. In addition, we establish a link to the physical point of all three channels simultaneously using the Inverse Amplitude Method.

Poster / 255

Heavy semileptonics with a fully relativistic mixed action

Authors: Julien Frison[1]; Andrea Bussone[2]; Gregorio Herdoiza[None]; Carlos Pena Ruano[3]; Javier Ugarrio[2]; Jose Angel Romero[4]

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The first phase of a heavy quark program based on twisted mass valence quarks has been presented at last year's lattice conference. The CLS $N_f = 2+1$ ensembles were used for their fine lattice spacing, while twisting the masses is expected to reduce discretisation errors even further and allow for a fully relativistic calculation. In this poster, we present our first preliminary results on three point functions, corresponding to $D \to K$ and $D \to \pi$ semileptonic decays. We discuss our discretisation errors and the perspectives for the determination of $|V_{cs}|$ and $|V_{cd}|$, as well as for future uses of this framework for other semileptonic decays.

Physics Beyond the Standard Model / 256

A study of thermal SU(3) supersymmetric Yang-Mills theory and near-conformal theories from the gradient flow

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In recent years, gradient flows of Yang-Mills and spinor fields have opened new possibilities in lattice simulations. I will focus on two applications of this method. Firstly, it has been shown that flowed composite local operators, like condensates and currents, are renormalised independently of the regularisation scheme. This facilitates the study of thermal phase transitions, e.g. in supersymmetric theories. In previous studies we had found that the restoration of the non-anomalous chiral symmetry and the breaking of the centre symmetry occur simultaneously in SU(2) supersymmetric Yang-Mills theory. I will show new results for the gauge group SU(3). The gradient flow is also tightly related to renormalisation group transformations. This can be exploited to directly compute the spectrum of operator dimensions in quantum field theories with an IR conformal point. In this regard I will discuss the computation of the mass anomalous dimension in near-conformal adjoint QCD with $\mathrm{N}_f = 2$ and $\frac{3}{2}$.

Weak Decays and Matrix Elements / 257

B-meson semileptonic form factors on (2+1+1)-flavor HISQ ensembles

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We report updates to an ongoing lattice-QCD calculation of the form factors for the semileptonic decays $B \to \pi\ell\nu$, $B_s \to K\ell\nu$, $B \to \pi\ell^+\ell^-$, and $B \to K\ell^+\ell^-$. The tree-level decays $B_{(s)} \to \pi(K)\ell\nu$ enable precise determinations of the CKM matrix element $|V_{ub}|$, while the flavor-changing neutral-current interactions $B \to \pi(K)\ell^+\ell^-$ are sensitive to contributions from new physics. This work uses MILC's (2+1+1)-flavor HISQ ensembles at approximate lattice spacings between 0.057 and 0.15 fm, with physical sea-quark masses on four out of the seven ensembles. The valence sector is comprised of a clover b quark (in the Fermilab interpretation) and HISQ light and s quarks. We present preliminary results for the form factors f_0, f_+, and f_T, including studies of systematic errors and z-expansion methods.

Physics Beyond the Standard Model / 258

The flavor dependence of m_ϱ/f_π

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The dimensionless ratio m_ϱ/f_π is computed in the continuum and chiral limit for SU(3) gauge theory coupled to $N_f = 2, 3, 4, 5, 6$ fundamental fermions. All systematics (finite volume, finite fermion mass, finite cut-off) are controlled and the final results show no statistically significant N_f-dependence.

Physics Beyond the Standard Model / 259

Non-perturbative renormalization of proton decay matrix elements

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We present lattice calculation results for the proton decay matrix elements along with preliminary result of non-perturbative renormalization. The computation is done by using 2+1 flavor dynamic domain wall fermions at the physical point on the $24^3 \times 64$ lattice with lattice spacing a^{-1} = 1GeV. The matrix element computations was done with 121 gauge configurations and non-perturbative renormalization was done with 30 gauge configurations. All of the computation employed 32+1 All-Modes-Averaging(AMA) method.

Weak Decays and Matrix Elements / 260

$B \to \pi\ell\nu$ and $B \to \pi\ell\ell$ decay form factors from HISQ/NRQCD valence quarks on the $N_f = 2+1$ asqtad ensembles

Authors: Chris Bouchard[1]; Peter Lepage[2]; Chris Monahan[None]; Junko Shigemitsu[3]

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Form factors and related phenomenology for the $B \to \pi\ell\nu$ and $B \to \pi\ell\ell$ decays will be presented. The simulations use HISQ light and NRQCD b valence quarks on the MILC $N_f = 2+1$ asqtad ensembles, with pion momenta covering the full kinematic range for the decays. Large pion momenta (up to 2.6 GeV) data are analyzed via the hard pion ChPT motivated modified z-expansion. The leading sources of uncertainty and the next generation of calculations to address them will be discussed.

Hadron structure / 261

Exclusive Channel Study of the Muon HVP

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The Hadronic Vacuum Polarization (HVP) is a dominant contribution to the theoretical uncertainty of the muon anomalous magnetic moment. The uncertainty in lattice QCD calculations of the HVP are dominated by the long-distance contribution to the vector correlation function. With explicit studies of the exclusive channels of the HVP diagram, it is possible to reconstruct the long-distance behavior of the correlation function. This has the effect of replacing the large statistical uncertainty of the correlation function with a significantly smaller uncertainty from the reconstruction. In this talk, I will present preliminary results of an exclusive study of the vector-vector correlation function using the distillation technique. The computation is performed on 2+1 flavor Mobius Domain Wall Fermion ensembles with physical pion mass. Reconstruction of the long-distance correlation function will enable lattice-only calculations of the HVP to achieve precision similar to estimates of the HVP from the R-ratio method on the timescale of the new experimental measurements of the muon anomalous magnetic moment.

Algorithms and Machines / 262

2+1 Flavor Domain Wall Fermion QCD Lattices: Ensemble Production and (some) Properties

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The RBC and UKQCD Collaborations continue to produce 2+1 flavor domain wall fermion ensembles, currently focusing on an ensemble with a $96^3 \times 192$ volume on SUMMIT at ORNL with $1/a = 2.8$ GeV, and smaller ensembles at stronger couplings. The $1/a = 2.8$ GeV ensemble uses the Exact One Flavor Algorithm for the strange quark, along with the Multisplitting Preconditioned Conjugate Gradient for solving the Dirac equation. We report on our progress and experience with the $1/a = 2.8$ GeV ensemble, along with results from studying the diffusion of topological charge on a variety of our coarser ensembles.

Physics Beyond the Standard Model / 263

Towards a composite Higgs and a partially composite top quark

Author: Benjamin Svetitsky[1]

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We have calculated quantities of interest to a theory of compositeness. The lattice model, approximating the candidate theory, is the SU(4) gauge theory coupled to fermions in two color representations. For the composite Higgs, a current correlator gives one of the ingredients of the effective Higgs potential. For the partially composite top quark, we have hyperbaryon matrix elements that govern mixing of the fundamental quark with its heavy composite partner. The matrix elements turn out to be so small that the theory is disfavored as a source of a realistic top mass.

Plenary / 264

Models of strong electroweak symmetry breaking.

Author: Vincent Drach[1]

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Strongly coupled gauge theories can be used in various context to build models that addresses some of the issues of the Standard Model. After reviewing the various scenarios of electroweak symmetry breaking models based on new strongly interacting sector, I will present the variety of challenges they offer to the lattice community. I will then review the on-going lattice efforts to explore the mechanisms at work and to provide reliable results relevant for the phenomenology of new physics beyond the Standard Model.

Hadron structure / 265

Neutron Electric Dipole Moments with Clover Fermions

Authors: Boram Yoon[1]; Tanmoy Bhattacharya[2]; Vincenzo Cirigliano[1]; Rajan Gupta[3]

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Neutrons can have nonvanishing electric dipole moment (EDM) when the theory has broken P and T symmetries. Since the CP violation (CPV) arising from the standard model (SM) is small or strongly suppressed at high temperature, new CPV from beyond the SM (BSM) is needed to explain the baryogenesis, and EDMs of elementary particles, such as the neutron, are good probes of such BSM physics. In this talk, we present results for contributions to the neutron EDM arising from the QCD theta-term, the Weinberg three-gluon operator and the quark chromo-EDM from our ongoing lattice calculations using clover valence quarks on the MILC HISQ lattices. We use the Schwinger source method to incorporate the chromo-EDM term in the proagaror and the gradient-flow technique to smooth the gluonic operators.

Plenary / 266

Delineating the properties of neutron star matter in cold, dense QCD

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The properties of dense QCD matter are delineated through the construction of equations of state which should be consistent with QCD calculations in the low and high density limits, nuclear laboratory experiments, and the neutron star observations. These constraints, together with the causality condition of the sound velocity, are used to develop the picture of hadron-quark continuity in which hadronic matter continuously transforms into quark matter (modulo small 1st order phase transitions).The resultant unified equation of state at zero temperature and beta-equilibrium, which we call Quark-Hadron-Crossover (QHC18 and QHC19), is consistent with the measured properties of neutron stars and in addition gives us microscopic insights into the properties of dense QCD matter. In particular to 10n0 the gluons can remain as non-perturbative as in vacuum and the strangeness can be as abundant as up- and down-quarks at the core of two-solar mass neutron stars. Within our modeling the maximum mass is found less than 2.35 times solar mass and the baryon density at the core ranges in 5-8n0.

Nonzero Temperature and Density / 267

Applying Complex Langevin to Lattice QCD at finite mu.

Authors: Donald Sinclair[1]; John Kogut[2]

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We will present current status of our simulations of Lattice QCD at finite baryon-number density using complex Langevin methods, including use of actions enhanced using dimension 6 operators.

Physics Beyond the Standard Model / 268

Walking, the dilaton, and complex CFT (I)

Author: Julius Kuti[None]

Co-authors: Zoltan Fodor ; Kieran Holland ; chik him wong [1]

[1] *University of Wuppertal*

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We compare the absence of the conformal fixed point in the near-conformal gauge theory paradigm with the alternate hypothesis where a complex conjugate pair of conformal fixed points drives the slow scale-dependence (walking) of the renormalized gauge coupling. The complex conformal fixed points would control the scale-dependent anomalous dimensions and the EFT of Goldstone pions coupled to the emergent light scalar, perhaps the dilaton of scale symmetry breaking.

Plenary / 269

Review of results of recent nucleon structure & matrix element calculations

Author: Tanmoy Bhattacharya[1]

[1] *T-2*

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I will review recent lattice calculations of nucleon structure and matrix elements between nucleons.

Algorithms and Machines / 270

OpenMP Offloading in Grid QCD Library

Author: Meifeng Lin[1]

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OpenMP is a programming model that has been widely used for multi-threaded computations on multicore and many-core CPUs. However, its support for GPU accelerated computing was not available until OpenMP 4.0. Since then, many new features and capabilities have been added to the OpenMP standard to enable GPU offloading in response to the popularity of GPU computing. In this presentation, we will describe our experience with using OpenMP GPU offloading directives in the Grid code, which is a C++ lattice QCD library developed by Peter Boyle et al.

Hadron structure / 271

Taming statistical and systematic uncertainties in the hadronic vacuum polarization contribution of light quarks to the muon $(g-2)$

Author: Laurent Lellouch[1]

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To deliver a precise determination of the hadronic vacuum polarization contribution of light quarks to the muon $(g-2)$, lattice calculations must overcome a number of challenges. These include a signal-to-noise problem, finite-volume effects and, when staggered fermions are used, significant taste-breaking effects. I will present some of the solutions which the BMW collaboration has been investigating to mitigate these problems.

Theoretical Developments / 272

The Hubbard model in the canonical formulation

Authors: Urs Wenger[1]; Sebastian Burri[1]

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We formulate the many-body system of non-relativistic fermions (Hubbard model) in the canonical formulation using transfer matrices in fixed fermion number sectors. By analytically integrating out the auxiliary Hubbard-Stratanovich field due to the four-fermion interaction, we express the system in terms of discrete, local fermion occupation numbers which are the only remaining degrees of freedom. We show the close relation to the fermion loop and the fermion bag formulation. Then we demonstrate and prove that in 1+1 dimension the fermion sign problem is absent. Finally, we construct improved estimators for fermionic correlation functions and for the chemical potential, and present results for arbitrary densities, spin-polarizations and mass-imbalances.

Nonzero Temperature and Density / 273

Meson masses in external magnetic fields with HISQ fermions

Authors: Akio Tomiya[1]; Heng-Tong Ding[2]; Swagato Mukherjee[3]; Xiaodan Wang[4]

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We studied the temporal correlation functions for mesons in different channels in (2+1)-flavor QCD in the presence of external magnetic fields at zero temperature. The simulations were performed on $32^3 \times 96$ lattices using the Highly Improved Staggered Quarks (HISQ) action with m_π around 230 MeV. The strength of magnetic fields range in $0 < |eB|$ 3 GeV^2. We found that the effective mass of π_0 obtained from connected part of Green function decreases as the magnetic field grows. We also studied the meson mass in the vector channel and will discuss the possible relation with superconductivity under a strong external magnetic field.

Nonzero Temperature and Density / 274

Dirac Eigenvalue spectrum of N f =2+1 QCD toward the chiral limit using HISQ fermions

Authors: Akio Tomiya[1]; Frithjof Karsch[2]; Heng-Tong Ding[3]; Olaf Kaczmarek[4]; Swagato Mukherjee[2]; Yu Zhang[3]

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We utilize eigenvalue filtering technique combined with the stochastic estimate of the mode number to determine the low-lying eigenvalue spectrum of the Dirac operator. Simulations are performed with (2 + 1)-flavor QCD using the Highly Improved Staggered Quarks (HISQ/tree) action on N_τ = 8 and 12 lattices with aspect ratios N_σ/N_τ ranging from 5 to 7. In our simulations the strange quark mass is fixed to its physical value m_s^{phy}, and the light quark masses m_l are varied from $m_s^{phy}/40$ to $m_s^{phy}/160$ which correspond to pion mass m_π ranging from 110 MeV to 55 MeV in the continuum limit. We calculate the chiral condensate, the disconnected chiral susceptibility, and $\chi_\pi - \chi_\delta$ from the eigenvalue spectrum via Banks-Casher relations. We compare these results with those obtained from a direct calculation of the observables which involves inversions of the fermion matrix using the stochastic "noise vector" method. We find that these approaches yield consistent results. Furthermore, we also investigate the quark mass and temperature dependences of the Dirac eigenvalue density at zero eigenvalue.

Nonzero Temperature and Density / 275

The sign problem and the Lefschetz thimbles in two dimensional Hubbard model

Authors: Semeon Valgushev[1]; Maxim Ulybyshev[2]

[1] *Brookhaven National Laboratory*

[2] *Wurzburg Universitat*

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In the talk we discuss the sign problem and the possibility to alleviate it with the help of methods related to Lefschetz thimbles in the space of complexities field variables. In particular, we consider two-dimensional Hubbard model at finite density. We analyze the model on the square lattice

combining semi-analytical study of saddle points and thimbles on a small lattice and results of test Monte-Carlo simulations. We investigate different representations of the path integral and find a particular representation which supposedly leads to the presence of a single dominating thimble even for larger lattices. Finally, we derive a novel non-Gaussian representation of the four-fermion interaction term, which also exhibits decreased number of Lefschetz thimbles.

Plenary / **276**

Hadron Spectroscopy from Lattice QCD

Author: Robert Edwards[1]

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There has been recent, significant, advances in the determination of the hadron spectrum. Current efforts have focused on the development and application of finite-volume formalisms that allow for the determination of scattering amplitudes as well as resonance behavior in coupled channel systems. I will review some of these recent developments and outline future directions of research.

Theoretical Developments / **277**

The nature of spontaneous and dynamical gauge symmetry breaking

Authors: Jeff Greensite[1]; Kazue Matsuyama[1]

[1] *San Francisco State University*

Corresponding Authors: kazuem@sfsu.edu, greensit@sfsu.edu

The Elitzur theorem does not rule out the breaking of a global subgroup of a gauge group in some gauge, either spontaneously or dynamically. But it is known that such breaking occurs at different couplings in different gauges, and is not necessarily associated with a thermodynamic transition. In this talk I will outline a gauge invariant distinction between the unbroken and Higgs regions of a gauge-Higgs theory, based on the concept of custodial symmetry.

Plenary / **278**

Physics Program and the Status of EicC

Author: Yutie Liang[1]

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Electron Ion Collider (EIC), regarded as the ”super electron microscope”, can provide the clearest image inside of the nucleon. It is the most ideal tool to understand the internal structure of the nuclear matter, especially the quark-gluon structure of the nucleon and nuclei. Polarized EICs are the next generation ”multi-dimensional electron microscopes”that are most effective in studying the deep structure and strong interactions of particles. Based on the Heavy Ion High Intensity Accelerator

Facility which is under construction since the end of 2018 in Huizhou, the IMP is proposing to build a high luminosity polarized EIC facility in China, named "EicC", to carry out the frontier research on nucleon structure studies. In this talk, the current status of the EicC will be presented, including the considerations on detector design and the physics programs.

Hadron Spectroscopy and Interactions / 279

Exploration of a singly-bottom tetraquark on 2+1 flavour lattices

Authors: Brian Colquhoun[1]; Anthony Sebastian Francis[2]; Renwick James Hudspith[3]; Randy Lewis[1]; Kim Maltman[1]

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The likelihood that doubly-heavy tetraquarks will be strong-interaction stable is already suggested by features of heavy baryon phenomenology, and confirmed by recent lattice results. Phenomenological input in this case is possible because the light-quark configurations present in a putative tetraquark state are also present in heavy baryons. There are, however, additional light-quark configurations possible in the field of a heavy quark source that are not accessible to ordinary heavy baryon or meson systems. Among these is the $ud\bar{s}\bar{b}$ channel. We present the results of our first investigations of this channel, including an investigation of whether it might support a strong-interaction stable tetraquark state.

Hadron structure / 280

CalLat elastic nucleon structure, 1

Author: André Walker-Loud[1]

[1] *Lawrence Berkeley National Laboratory*

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I will discuss various aspects of the CalLat MDWF on gradient flowed HISQ program including an updated determination of the nucleon axial charge along with a direct comparison with the more standard three-point function calculations.

Plenary / 281

The Muon g-2 experiment at Fermilab and the First Physics Run

Author: Dikai Li[None]

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Measurement of the muon anomalous magnetic moment (muon g-2) is a sensitive tool for testing the Standard Model (SM) and searching for new physics. It is an important and complementary tool to probe the high energy frontier. In this talk, I will provide an overview on the Fermilab Muon g-2 experiment, which aims to perform the measurement the muon g-2 with a precision goal of 140 parts per billion, a fourfold improvement over the previous BNL measurement. The first physics run finished in 2018 collecting a data sample with similar size of the BNL measurement. The current experimental status and prospects of the experiment will also be discussed

Weak Decays and Matrix Elements / 282

Electromagnetic corrections to leptonic pion decay from lattice QCD using infinite-volume reconstruction method

Authors: Norman Christ[1]; Xu Feng[2]; Luchang Jin[None]; Chris Sachrajda[3]

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We present a lattice procedure to calculate the leptonic pion decay width with only exponentially-suppressed finite-volume errors using the infinite-volume reconstruction method. Three technical points: 1) the inclusion of pion wave function renormalization factor, 2) the cancellation of infared divergence and 3) the connection between Euclidean-space correlation function and the relevant matrix element in Minkowski space will be discussed.

Poster / 283

Neutrinoless Double Beta Decay Amplitude of pi- -> pi+ e e from Infinite-volume Reconstruction Method.

Authors: Luchang Jin[None]; Xin-yu Tuo[None]; Xu Feng[1]

[1] *Peking University*

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Using the infinite volume reconstruction method, we present a lattice QCD calculation of neutrinoless double beta decay $\pi^- \to \pi^+ ee$ with only exponentially suppressed finite volume effects. We compare these results with the conventional QED_L method. Our calculation can provide the low-energy constants for chiral perturbation theory. Besides, combining with our previous study on $\pi^-\pi^- \to ee$ decay, these results can provide us a better understanding on the double beta decay in the pion sector.

Poster / 284

Two-photon decay of the neutral pion from a coordinate-space method

Authors: Norman Christ[1]; Xu Feng[2]; Luchang Jin[None]; Cheng Tu[None]; Yidi Zhao[1]

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The conventional method to calculate $\pi \to \gamma\gamma$ decay width is to study the momentum dependence of the pion form factor $F_{\pi\gamma\gamma}(p^2, q^2)$ with p, q the momenta of two photons and perform an extrapolation to the on-shell limit, $p^2, q^2 = 0$. In alternative, we propose a novel, simple approach to determine the decay width directly from the hadronic function in Euclidean coordinate space.

Hadron structure / 285

Hadronic Tau deay and muon g-2

Authors: Taku Izubuchi[1]; Christoph Lehner[2]; Mattia Bruno[3]; Aaron Meyer[1]

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We report about calculations of hadronic decay of tau lepton and related topics for muon's anomalous magnetic moment.

Hadron structure / 286

Updates on CalLat elastic nucleon form factors, II

Author: Chia Cheng Chang[1]

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Following previous work on the calculation of the nucleon axial coupling using domain-wall valence on HISQ gauge configurations, I will present an overview on our recent progress towards determining more general elastic nucleon form factors. These preliminary results will be based at heavier pion masses, and will focus on overall computational and analysis strategy.

Standard model parameters and renormalization / 287

Yang Mills short distance potential and perturbation theory

Authors: Rainer Sommer[1]; Alessandro Nada[2]; Nikolai Husung[3]; Philipp Krah[1]

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We compute the coupling α_{qq} defined in terms of the static quark force by simulating the SU(3) Yang Mills theory at lattice spacings down to 10^{-2}fm, keeping the volume large. Open boundary conditions avoid the freezing of topology. We can thus investigate the applicability of perturbation theory, extract the pure gauge Λ-parameter and compare to Λ obtained with other methods.

Weak Decays and Matrix Elements / **288**

Semileptonic $D \to K$ decay from full lattice QCD with HISQ

Authors: Bipasha Chakraborty[1]; Christine Davies[2]; Jonna Koponen[3]; Peter Lepage[4]

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We present a lattice QCD calculation of both scalar and vector form factors associated with the D→Klν semileptonic decay over full range of q^2. We extract the central CKM matrix element, V_{cs} in the Standard Model, by comparing the lattice QCD results for the form factors and the experimental decay rates. This calculation has been performed on the $N_f = 2 + 1 + 1$ MILC HISQ ensembles including the ones with the physical light quark masses.

Plenary / **289**

Recent developments in LQCD studies on tetraquarks

Authors: Anthony Sebastian Francis[1]; Renwick James Hudspith[2]; Randy Lewis[3]; Kim Maltman[3]

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Heavy flavor exotic hadrons, and in particular tetraquarks, continue to challenge our understanding and elude explanation from theory. In this contribution we discuss and review the progress and status in studying doubly heavy tetraquark states with $J^P = 1^+$ on the lattice. In particular, we focus on our recent efforts using 2+1 flavor lattice QCD with pion masses of 164, 299 and 415 MeV at fixed lattice spacing and lattice volume, L=32, to study the ground states of the flavor channels $ud\bar{b}\bar{b}$, $\ell s\bar{b}\bar{b}$ as well as $ud\bar{c}\bar{b}$, with $\ell = u, d$. In our work the heavy quarks are handled using non-relativistic QCD for the bottom and the Tsukuba formulation of relativistic heavy quarks for the charm quarks. Signals for $ud\bar{b}\bar{b}$ and $\ell s\bar{b}\bar{b}$ tetraquarks are found with binding energies 189(10) and 98(7) MeV below the corresponding free two-meson thresholds at the physical point. This indicates they can decay only weakly. Further evidence for binding is found in the $ud\bar{c}\bar{b}$ channel at the level of 15-61MeV, close to the electromagnetic stability threshold. Studying the heavy quark mass dependence we find our results closely follow a behaviour argued from phenomenological considerations of the heavy baryon spectrum. First studies of the volume dependence of the determined energy spectrum show tentative hints confirming stability for the $ud\bar{b}\bar{b}$, $\ell s\bar{b}\bar{b}$ as well as $ud\bar{c}\bar{b}$ channels. Gathering and

comparing recent results from the community where possible a consistent picture for doubly heavy tetraquarks is emerging.

Nonzero Temperature and Density / **290**

The order of phase transition in three flavor QCD with background magnetic field in crossover regime

Authors: Akio Tomiya[1]; Heng-Tong Ding[2]; Swagato Mukherjee[3]; Christian Schmidt[4]

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We investigate the order of phase transition in
three flavor QCD with a background $U(1)$ magnetic field using
the standard staggered action with the plaquette gauge action.
We perform simulations for three volumes $N_\sigma = 8, 16, 24$ with fixed mass $ma = 0.030$ and temporal extent $N_\tau = 4$, which is expected to show crossover for vanishing magnetic field.
We apply physically same magnitude of magnetic field $\hat{b} = 0.9 = \sqrt{2\pi N_b/N_\sigma^2}$ for each volume. We measure the chiral condensates and
Polyakov loop and calculate their susceptibility and Binder cumulant.
We find that the transition becomes first order like transition with hysteresis in the Monte-Carlo history
from crossover for non-zero magnetic field on the system.

Plenary / **292**

Theoretical Developments of the LaMET Approach to Parton Physics

Author: Yong Zhao[1]

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The large-moment effective theory (LaMET) is a systematic approach to extract light-cone parton distributions from equal-time matrix elements, or quasi parton distributions, that are calculable in lattice QCD. Recent years have seen rapid developments in the LaMET approach which have been applied to various lattice calculations and led to much promising progress in this field. In this talk, I will describe the formalism of LaMET and its extension to parton distributions for the transverse structures, which are essential steps in the road map to obtaining the three-dimensional tomography of the nucleon from lattice QCD.

Hadron Spectroscopy and Interactions / **293**

Periodic Pion-Pion Scattering at the Physical Point: Update

Author: Daniel Hoying[1]

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We present updated results on the scattering of pseudoscalar, vector, and scalar mesons on a physical pion mass, 2+1 flavor mobius-DWF, ensemble with periodic boundary conditions (PBCs) generated by the RBC and UKQCD collaborations. Using all-to-all propagators, we produce thousands of correlator momentum combinations. Energy spectra and phase shifts, including excited states, are then extracted via the solutions of a generalized eigenvalue problem. Included in this talk will also be an overview of improved analysis techniques and a second lattice spacing. These studies are intended to serve as groundwork for a full PBC calculation of direct CP violation in K->pipi later this year.

Hadron structure / 294

Pion Valence Quark from quasi-PDF and pseudo-PDF

Author: Charles Shugert[1]

Co-authors: Nikhil Karthik [2]; Sergey Syritsyn [3]; Taku Izubuchi [2]; Peter Petreczky [4]; Luchang Jin ; Swagato Mukherjee [2]

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We present results of the pion valence-quark PDF using quasi-PDF and pseudo-PDF methods. Using quasi-PDF's one relies on highly-boosted hadronic states in order for LaMET to reliably match the quasi-PDF to the light-cone PDF. Alternativly one can study pseudo PDF's, Fourier-transforms of the pseudo Ioffe-Time distribution from ν-space to x-space at fixed z^2 with z being the quark-antiquark separation. From here one can take the $z^2 \to 0$ limit to obtain the light-cone PDF. Benifits and drawbacks of each method are explored. This calculation was done using a HISQ sea ensemble with Wilson-Clover valence quarks, on a $48^3 \times 64$ size lattice with a lattice spacing $a = 0.06$ fm, using a 300 MEV pion mass.

Poster / 295

Parton distribution functions of Deltaˆ+ on the lattice

Authors: Shicheng Xia[1]; Yahui Chai[1]; Yuan Li[1]; Xu Feng[1]; Chuan Liu[1]

Co-authors: Constantia Alexandrou ; Kyriakos Hadjiyiannakou [2]; Karl Jansen [3]

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We present the unpolaried parton distribution functions of Δ^+ baryon in lattice simulation based on large momentum effective theory. We use $N_f = 2 + 1 + 1$ twist mass fermion with colver term and pion mass is 260 MeV. The simulation is done using fixed sink sequential inversion method with Gaussian-momentum-smeared source while the largest baryon momentum is 1.2GeV .By comparing the $\bar{d} - \bar{u}$ content in the proton with Δ^+ baryon,the role of chiral symmetry in generating the sea flaovr asymmetry is tested.

Nonzero Temperature and Density / 296

Canonical partition functions in lattice QCD at high temperature

Authors: Vitaly Bornyakov[1]; Denis Boyda[2]; Vladimir Goy[None]; Alexander Molochkov[2]; Atsushi Nakamura[3]

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We improve our computation of canonical partition functions Z_n in lattice QCD at high temperature using method of Fourier transformation at imaginary chemical potential. In particular, we explain the appearance of negative Z_n and find the way to avoid their appearance. We also suggest another method to compute Z_n at high temperature and demonstrate very good agreement between results obtained by two methods.

Algorithms and Machines / 297

Machine Learning in Lattice QCD: Confinement/Deconfinement classification in SU(2) and SU(3).

Authors: Alexander Molochkov[1]; Denis Boyda[1]; Vladimir Goy[None]; Maxim Chernodub[2]

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We investigate power of Machine Learning for Lattice QCD problems. We used three set up. First, we used bare configurations of gauge fields and trained ML model to calculate Polyakov loop: trained at two betas it predicts correct critical value. Second, we used set of Wilson loops for classification of phases: trained in SU(2) ML model gives some signal in SU(3). And third, with spacial distribution of some gauge invariant object we predict phase transition in SU(3) with ML model trained in SU(2).

Plenary / 298

Recent results from BESIII experiment

Author: Changzheng YUAN[1]

[1] *IHEP, Beijing*

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BESIII is an experiment running at tau-charm energy region at the Beijing Electron Positron Collider (BEPCII). Since the first data taking in 2009, BESIII has accumulated the world's largest data samples of D and D_s meson decays, 10 billion J/ψ and 450 million $\psi(3686)$ events, and about 100 million events with center-of-mass energy between 4 and 4.6 GeV for studies of nonstandard hadrons and the Λ_c. In this talk, the most recent results on the exotic charmoniumlike XYZ states, light hadron spectroscopy, the weak decays of the charmed hadrons will be reported. The measurements where lattice QCD calculations are needed will be emphasized.

Plenary / 299

Constraining the phase diagram of QCD at finite temperature and density

Author: Owe Philipsen[1]

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Because of the severe sign problem afflicting lattice QCD at finite
baryon density, still little is known from first principles about the
phase diagram as a function of temperature and baryon chemical potential.
In order to understand its relation
to the underlying symmetries, it is necessary to study QCD in a wider
parameter space with varying
numbers of flavours and quark masses and, in particular, the chiral limit.
I review recent results in QCD at finite temperature and/or density that
help to constrain the phase diagram of physical QCD.

Plenary / 300

Recent developments in LQCD studies of hadron interactions

Author: Michael Wagman[1]

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Lattice gauge theory studies of hadron-hadron interactions, hadron interactions with electroweak and beyond the Standard Model currents, and the structure of interacting multi-hadron systems, are providing qualitative insights into the dynamics of quarks and gluons as well as quantitative predictions for high-energy colliders, medium-energy neutrino experiments, low-energy searches for fundamental symmetry violation, and everything in between. I will review some recent work in these directions.

Plenary / 301

Lattice QCD Impact on Determination of CKM Matrix: Status and Prospects

Author: Steven Gottlieb[1]

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Lattice QCD is an important tool for theoretical input for flavor physics. There have been four reviews by the Flavour Lattice Averaging Group (FLAG). This talk will review the current status of the magnitude of eight of the nine CKM matrix elements, borrowing heavily from the most recent FLAG review (co-authored by the speaker). Future prospects for improving the determination of the CKM matrix will be discussed.

Plenary / 302

Prospects for large N gauge theories on the lattice

Author: Margarita Garcia-Perez[1]

[1] *Instituto de Fisica Teorica UAM-CSIC*

Corresponding Author: margarita.garcia@uam.es

I will review recent progress on addressing large N gauge theories on the lattice. The focus will be put on the use of volume independence as a tool to tackle otherwise unreachable large number of colours. Future prospects and challenges for the study of large N QCD and various extensions will also be discussed.

Plenary / 303

Developments in lattice computation of parton distributions

Author: Nikhil Karthik[1]

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I will review the latest developments in lattice computations of the x-dependent parton structure of hadrons using quasi-PDF, pseudo-PDF, good lattice cross-section approach as well as using the moments of PDF. I will also focus on the practical aspects of LaMET approach such as the validity of 1-loop perturbative matching, control of the excited states of boosted hadrons and the different approaches to the inverse problem of matching Euclidean quasi-PDFs to PDFs.

Hadron structure / 304

Scaling and higher twist in the nucleon Compton amplitude

Authors: Ross Young[1]; Roger Horsley[2]; Yoshifumi Nakamura[None]; Holger Perlt[3]; Paul Rakow[4]; Gerrit Schierholz[5]; Kim Somfleth[6]; James Zanotti[1]

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The partonic structure of hadrons plays an important role in a vast array of high-energy and nuclear physics experiments. It also underpins the theoretical understanding of hadron structure. Recent developments in lattice QCD offer new opportunities for reliably studying partonic structure from first principles. He we report on the use of Feynman-Hellmann to study the forward Compton amplitude in the unphysical region. This amplitude provides direct constraint on hadronic inelastic structure functions. The use of external momentum transfer allows us to study the Q^2 evolution to explore the onset of asymptotic scaling and reveal higher-twist effects in partonic structure.

Hadron Spectroscopy and Interactions / 305

Towards the spectrum of flavour-diagonal pseudoscalar mesons in QCD+QED

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The low-lying hadron spectrum has been of tremendous phenomenological significance in resolving the nature of quark masses in strong interaction dynamics. In particular, the pseudoscalar mesons provide the foundation of the framework of chiral perturbation theory, the low-energy effective theory of QCD. Modern lattice calculations of pure QCD now provide excellent precision in the resolution of quark masses. In order to match this theory onto the observed mass scales of the standard model at sub-percent precision, it is essential to discriminate electromagnetic effects. When simulating the In this work, we explore the spectrum of the flavour-diagonal pseudoscalar mesons on dynamical QCD+QED lattices. To reduce the familiar statistical noise associated with annihilation diagrams we utilise exact colour and spin dilution with a spatial interlacing for our Z_2 noise sources. In comparison with results from pure QCD, we make first estimates of the contribution of electromagnetic effects in the π_0-η splitting.

Poster / 306

Lattice QCD results on bottomonia at high temperatures

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We explore the S- and P-states for bottomonia at high temperatures, above the critical temperature T_c, using non-relativistic QCD (NRQCD). We extract the spectrum as a function of temperature using smeared source correlators. We push to the limit of NRQCD for $N_\tau = 12$ which allows us to find the bottomonium spectrum up to a temperature of 334MeV.

Plenary / **307**

Three particles on the lattice

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In recent years, the finite-volume Lüscher formalism has become a well-established tool to study the two-body scattering processes on the lattice. The formalism has been generalized to the case of the coupled two-body channels and has been successfully applied for the analysis of the lattice data for different scattering processes. A closely related method, known under the name of the Lellouch-Lüscher approach, is being used for the extraction of the decay matrix elements with the two-body final states.

In difference to this, the progress in the study of the systems with three and more particles on the lattice lies behind, albeit a number of important results have been obtained lately. In my talk, I plan to review the basic ideas, which provide basis for the extraction of the physical observables, defined in the infinite volume, from the finite-volume lattice spectra. Various approaches to this problem will be considered and compared. In particular, the three-body quantization condition will be discussed in detail. Perturbative expansion of the energy levels will be performed, and the optimal strategies for the analysis of data will be worked out. As an illustration, the recent lattice results in the three-body sector will be presented. In conclusion, the perspectives of the further development in the field will be briefly discussed.

Plenary / **308**

Recent progress of two-baryon problem and ΩΩ interaction on the lattice

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I will present recent progress of baryon-baryon interaction from lattice QCD. So far, there are two methods to study the interaction: The direct method based on Luscher's finite volume formula which extracts eigen energies from the plateaux of the temporal correlation functions and the HAL QCD method which extracts observables from the non-local potential associated with the tempo-spatial correlation function. Despite that the two methods should give the same results theoretically, qualitative difference for observables has been reported numerically. In the first part of my talk, I will clarify the origin of this discrepancy and discuss the validity of both methods. In the second part of my

talk, I will discuss ΩΩ interaction in the 1S0 channel from lattice QCD using a large volume 8.1fm, and nearly physical pion mass m_pi˜146 MeV. The interaction is qualitatively similar to the central potential of the nucleon-nucleon interaction, i.e., the short range repulsion and the intermediate range attraction. I will show that the attraction leads to the most strange dibaryon, di-Omega, which is located near the unitary limit.

Nonzero Temperature and Density / 309

Chiral magnetic effect in a lattice model

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In this talk, we will present our study on the chiral magnetic effect in a lattice model. We study analytically the one-loop contribution to the chiral magnetic effect (CME) using lattice regularization with a Wilson fermion field. In the continuum limit, we find that the chiral magnetic current vanishes at nonzero temperature but emerges at zero temperature consistent with that found by Pauli-Villas regularization. For finite lattice size, however, the chiral magnetic current is nonvanishing at nonzero temperature. But the numerical value of the coefficient of CME current is very small compared with that extracted from the full QCD simulation for the same lattice parameters. The possibility of higher-order corrections from QCD dynamics is also assessed.

Reference: B.Feng, DF.Hou, H.Liu, HC. Ren, et al, PHYSICAL REVIEW D 95, 114023 (2017)

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Topological component of Yang-Mills fields: from lattice to collider

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It has been long and widely believed that topological configurations play crucial roles in the nonperturbative phenomena of QCD and that of Yang-Mills fields in general. Unprecedented amount of high precision data from lattice gauge theories as well as from collider experiments at RHIC and

LHC have provided opportunities for nailing down the topological component and characterizing its properties. In this talk, we discuss several examples of progress along this line. We first show how the various features of confinement phase transition in the SU(2) Yang-Mills theory can be quantitatively described by a statistical model of correlated instanton-dyon ensemble. We then demonstrate how the global RHIC+LHC data on jet energy loss observables unambiguously points to the necessity of a non-perturbative topological component in the quark-gluon plasma particularly in the vicinity of (pseudo-)transition temperature. In the last part we briefly discuss the recent exiting progress in the experimental search of gluon topological fluctuations via quark chirality dynamics that can be measured through anomalous transport processes such as the Chiral Magnetic Effect.
[Refs] arXiv:1903.02684; 1808.05461; 1804.01915; 1711.02496; 1611.04586; 1611.02539.

Algorithms and Machines / 311

Lattice QCD codes on Taihu-Light Supercomputer

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We present a preliminary code package designed for Sunway infrastructure of Taihu-Light supercomputer. Meta-programming and genetic algorithm on a new designed virtual machine layer are adopted to investigate the feasibility of a general automatic optimization scheme.

Algorithms and Machines / 312

GPU inverters on ROCm

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The open source ROCm platform for GPU computing provides an uniform framework to support both the NVIDIA and AMD GPUs, and also the possibility to porting the CUDA code to the ROCm-compatible one. We will present the porting progress on the Overlap fermion inverter (GWU-code) based on thrust and also a general inverter package - QUDA.

Theoretical Developments / 313

Stochastic RG and Gradient Flow in Scalar Field Theory

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A renormalization group transformation defined as a simple stochastic process is proposed, and its relation to functional RG is described. The transformation leads to a new instantiation of Monte Carlo Renormalization Group that is amenable to lattice simulation by performing a Langevin equation integration on top of the ensemble of bare fields generated by traditional MCMC methods. The emergence of gradient flow (GF) as a means of computing the quantities in the effective theory determined by the stochastic RG transformation will be outlined. Lastly, preliminary results in the test case of scalar fields in three dimensions is presented.

Theoretical Developments / 314

Merons as the Relevant Topological Charge Carriers in the 2-d O(3) Model

Authors: Wolfgang Bietenholz[1]; Joao C. Pinto Barros[2]; Stephan Caspar[2]; Manes Hornung[2]; Uwe-Jens Wiese[2]

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The $2-d\,O\,(3)$ model shares many features with $4-d$ non-Abelian gauge theories, including asymptotic freedom, a nonperturbatively generated mass gap and a nontrivial topological charge Q. By an analytic rewriting of the partition function, we identify merons (a particular type of Wolff clusters with $Q=\pm 1/2$) as the relevant topological charge carriers.
In contrast to semiclassical instantons, merons are uniquely identified in the fully nonperturbative functional integral. While instantons are smooth $2-d$ objects, merons are physical objects with a fractal dimension $D=1.88(1)$, which also exist in the continuum limit. This result follows from the observed scaling of the meron cluster-size distribution. Consistently, the merons of different size exhibit the same fractal dimension. Small merons give rise to a logarithmic divergence of the topological susceptibility which turns out to be entirely physical. In particular, lattice artifact dislocations, which would give rise to power-law divergence, do not seem to contribute in the quantum continuum limit. Furthermore, merons are also responsible for nontrivial theta vacuum effects and explain why the mass gap vanishes at $\theta=\pi$. Our study raises hopes that a solid field theoretical identification of the relevant topological degrees of freedom may also be achievable in non-Abelian gauge theories.

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Cluster-size scaling in O(N) non-linear sigma models

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In O(N) models, the multi-cluster algorithm generates spins
clusters, which are usually considered as purely algorithmic
objects. We show that the histograms of their sizes scale

towards a continuum limit, with a fractal dimension D, which
suggests that these clusters do have a physical meaning.
We demonstrate this property for the quantum rotor in separate
topological sectors (where D=1), for the 2d XY model in the
massive and in the massless phase (where D<2, and where we
also define a cluster vorticity), and in the 3d O(4) model
(where we relate D to the critical exponents).
The latter represents an effective theory for 2-flavor
QCD in the chiral limit, at high temperature, where the
topological charge corresponds to the baryon number.
For a suitable lattice actions, it can be traced back to
the topological charge assigned to the clusters.
Clusters are therefore the physical carriers of topology
and vorticity, beyond semi-classical approximations.

Plenary / 316

Computing Nucleon Electric Dipole Moment from lattice QCD

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High precision study of nuclear physics is a vital part of searches for new physics beyond the standard model.
In particular, observation of permanent electric dipole moments (EDMs) of nucleons (and nuclei) can be direct evidence for violation of CP symmetry. Connecting the quark- and hadron-level effective interactions that include CP violating sources is an important task for lattice QCD.I will review recent progress on lattice calculations of nucleon EDM induced by lowest-order quark-gluon operators and chromo-electric interactions and their implications for EDM experiments. I will also show preliminary results and discuss the issues and future prospects of the lattice calculations of the nucleon EDM.

Plenary / 317

KWA session

Plenary / 318

China's effort on Supercomputing: progress and applications

Public lecture / 319

100 Years of Proton

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Protons were created shortly after the Universe began when the Quantum Chromodynamic (QCD) confinement forces went to effect. As a constituent of all atomic nuclei, they were first discovered by

Rutherford in 1919. For the last 100 years, experimental and theoretical explorations of the proton structure have led to many important discoveries, some of which are reviewed in this talk. As of today, however, we are still grappling with an accurate description of the proton's fundamental properties, such as its mass and spin. Exa-scale computing plus a new generation of experiments may provide the final answer to the question "how does the Nature build the proton?"

Nonzero Temperature and Density / 320

Meson Screening Masses in 2+1-Flavor QCD

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Screening masses are useful observables since they provide information regarding the various excitations in the QGP, as well as regarding the restoration of various symmetries. They are also easier to calculate in lattice QCD as compared to temporal correlators. We present results from a high statistics determination of various meson screening correlators for temperatures between approximately 140 MeV and 2.5 GeV. Using lattices with Nt = 6 - 16, we also provide a continuum extrapolation for the masses. We comment upon the implications of our results regarding the restoration of chiral and axial symmetry in the quark-gluon plasma. Our lattices were generated using the 2+1-flavor HISQ action, with the strange quark fixed to its physical value and the light quark taking one of two values: ml = ms/20 and ml = ms/27.