XQCD 2018

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Goethe University Frankfurt and FIAS

Book of Abstracts

Contents

Poster Session / 1

Information, dualities, and deconfinement

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The lack of an order parameter in Yang-Mills theory with dynamical fundamental quarks is a long-standing problem in QCD. We exploit a web of dualities and information-theoretic techniques to study the phase structure of QCD from a new perspective. In particular, we examine the deconfinement transition in a deformed model of QCD: this is QCD compactified over a circle and considered at temperatures near the confinement/deconfinement transition. This setup is equivalent, via dualities, to an "affine" XY spin system, which can be studied via Monte Carlo simulations. Our simulations show that mutual information/entanglement entropy calculations can be used as an alternative probe to designate different phases of QCD. This picture is further supported by analytical investigation of the dual Sine-Gordon model, which is also equivalent to the deformed QCD and XY spin system.

Contributed Talks / 2

The Equation of State for the Nucleonic and Hyperonic Neutron Stars

Author: Laura Tolos[1]

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We present a new equation of state for the nucleonic and hyperonic inner core of neutron stars that fulfills the 2 Msun observations as well as the recent determinations of stellar radii below 13 km. The equation of state is obtained from a new parametrization of the FSU2 relativistic mean-field functional that satisfies these latest astrophysical constraints and, at the same time, reproduces the properties of nuclear matter and finite nuclei while fulfilling the restrictions on high-density matter deduced from heavy-ion collisions. We also apply this new nucleonic and hyperonic equation of state for the analysis of the cooling of neutron stars with a hyperonic core.

Contributed Talks / 4

Gauge topology and heavy ion physics

Author: Edward Shuryak[1]

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A review of interrelation between those two fields consistes of two parts.
One covers recent progress in magnetic scenario", which treats QGP as
a dual plasma containing as quasiparticles not only quarks and gluons but
also magnetic monopoles, dominating the ensamble near T_c.
Recent account for monopoles contribution to jet quenching has solved
the problem with azimuthal distribution of it.

The second half describes recent works using semiclassical theory based oninstanton-dyons". Studies of their ensemble explains deconfinement and chiral transitions in a different settings, with and without dynamical quarks.

Contributed Talks / 6

Causal Charge Diffusion and Fluctuations in Heavy-Ion Collisions

Author: Joseph Kapusta[1]

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We present a relativistic causal description of conserved-charge diffusion for heavy-ion collisions and show that it produces measurable effects in observables such as the charge balance functions. Other descriptions, based on ordinary diffusion, are known to produce charge fluctuations which propagate with infinite velocity, thus violating a fundamental postulate of special relativity. We present an alternative approach based on Cattaneo diffusion which restores relativistic causality, and show how to generalize this approach to dynamical, rapidly evolving systems such as heavy-ion collisions. We demonstrate that this approach leads to measurable consequences for the balance functions constructed from electrically charged hadrons in a simple 1+1 dimensional Bjorken hydrodynamic model. We find that limiting the speed of propagation of charge fluctuations increases the height and reduces the width of these balance functions when plotted versus separation in rapidity. We conclude by estimating the numerical value of the associated diffusion time constant from AdS/CFT.

Poster Session / 7

vector meson productions from quark gluon plasma and electromagnetic fields in heavy ion collisions

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In semi-central AA collisions, both deconfined matter (QGP) and strong strong electromagnetic fields from fast moving charge nucleus can be produced when nuclei collide with each other. QGP with extremely large energy density result in strong color screening on the heavy quarkonium potential and quarkonium yield suppression. At the same time, abundant number of heavy(or strange) quarks inside QGP can also recombine to regenerate new quarkonium.

In the extremely low transverse momentum $p_T < 0.1$ GeV/c, additional contribution from electromagnetic fields can significantly enhance the final yields of vector mesons, which have been observed in RHIC and LHC experiments. We studied the vector meson (charmonium, phi meson) productions from both QGP and electromagnetic fields consistently, from peripheral to most central collisions within different p_T bins, and compare our theoretical results with the experimental data.

Contributed Talks / 9

Probing the longitudinal matter distribution in heavy ion collisions with heavy flavor

Authors: Piotr Bozek[1]; sandeep chatterjee[1]

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Non-central relativistic heavy ion collisions break longitudinal boost invariance due to forward-backward asymmetry in local participant densities. This gives rise to the observed rapidity-odd directed flow of charged particles. We demonstrate that the heavy flavor
v_1 due to the forward-backward asymmetric drag of the bulk is several times larger than that of the bulk v_1[1]. This makes the heavy flavor v_1 slope at mid-rapidity, a sensitive probe of the initial longitudinal distribution of the thermalized medium. Further, the electromagnetic fields of the initial stage can also give rise to rapidity-odd v_1 but of opposite signs for D and $\bar{D}$ mesons, unlike the tilt mechanism which provides same sign v_1 to both D and $\bar{D}$. We show that the measurement of the v_1 sum as well as difference of D and $\bar{D}$ can provide simultaneous constraint on the initial longitudinal asymmetry in matter distribution as well as the electromagnetic field
produced by the passage of the heavy nuclei.

[1]. S. Chatterjee and P. Bożek (2017), arXiv:1712.01189 [nucl-th]

Plenary Talks / 10

Extracting information on nuclear matter from binary neutron stars

Author: Luciano Rezzolla[1]

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I will discuss the rapid recent progress made in modelling these systems and show how the inspiral and merger of a binary system of neutron stars is more than a strong source of gravitational waves. Indeed, while the gravitational signal can provide tight constraints on the equation of state for matter at nuclear densities, the formation of a black-hole–torus system can explain much of the phenomenology of short gamma-ray bursts, while the the ejection of matter during the merger can shed light on the chemical enrichment of the universe.

Contributed Talks / 11

Magnetohydrodynamics with chiral anomaly: formulation and phases of collective excitations and instabilities

Authors: Ho-Ung Yee[1]; Koichi Hattori[2]; Yi Yin[3]; Yuji Hirono[4]

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We discuss chiral magnetohydrodynamics (MHD) which serves as a low-energy effective theory of the chiral matter in the presence of a finite chirality imbalance and dynamical magnetic field [1]. It may have applications not only to relativistic heavy-ion collisions but also condensed matter physics and astrophysics.

Based on our derivative expansion for the chiral MHD and the second law of thermodynamics, we show that a current in ordinary MHD is modified due to the chiral anomaly, which is identified as the chiral magnetic effect (CME). While the similar derivation of CME was performed by Son and Surowka, our derivative expansion is significantly different from theirs due to the presence of the dynamical magnetic field. Our result exemplifies the universal nature of the CME that persists in MHD.

We also discuss that, when the chirality imbalance exceeds a critical value, a new type of gapless collective excitation emerges as a result of the interplay among the magnetic field, flow velocity, and chiral anomaly, which we call the chiral magnetohelical mode (CMHM). These modes carry definite magnetic and fluid helicities, and either grow or dissipate exponentially in time, depending on the relative sign between their helicities and the chirality imbalance. The presence of exponentially growing CMHM indicates a new hydrodynamic instability.

[1] Koichi Hattori, Yuji Hirono, Ho-Ung Yee, Yi Yin, "Magnetohydrodynamics with chiral anomaly: phases of collective excitations and instabilities,"[arXiv:1711.08450 [hep-th]].

Contributed Talks / 12

Explosions of massive blue-supergiant stars triggered by the QCD phase transition

Author: Tobias Fischer[1]

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Motivated from the observations of yet-unexplained explosive phenomena associated with massive blue-supergiant stars with zero-age main sequence (ZAMS) masses well above 40 $M_\odot$, we shed new light on the idea that the appearance of QCD degrees of freedom may explain such cosmic events [1]. Obeying chiral physics and taking yet-another important observation of the very existence of massive neutron stars of 2 $M_\odot$ seriously into account, puts sever constraints on the behavior of the equation of state at supersaturation density ($\rho_{\rm sat}$). In particular, sufficient stiffness with increasing density is required. Both aspects indicate rather high densities for the hadron-quark phase transition above $2 \times \rho_{\rm sat}$ (at zero temperature). As a consequence, this excludes low- and intermediate-mass stars ($\sim 10 - 30$ $M_\odot$) from the presence of 'exotic' high-density phases. On the other hand, during the evolution of very massive core-collapse supernova progenitors with ZAMS masses in excess of 40 $M_\odot$, significantly higher core temperatures and densities are reached, where the appearance of the hadron-quark phase transition triggers not only the supernova explosion onset but also a millisecond neutrino burst is released. The latter observable provides evidence not only for the presence of a $1^{\rm st}$–order phase transition at supersaturation density but contains also details about its properties. The future observation of such feature from the next galactic event will allow us to either confirm such scenario or, if not observed, rule out a (strong) $1^{\rm st}$–order phase transition at high densities encountered in astrophysics. In this talk I will review this scenario in the light of all presently known constraints from nuclear theory/experiments as well as observations, and

discuss implications for astrophysics, e.g., the remnants from such supernova explosions are massive neutron stars with quark-matter core of 2 $M_\odot$ at birth.

Keywords: core-collapse supernovae – equation of state

References

[1] T. Fischer, N.-U. F. Bastian, M.-R. Wu, S. Typel, T. Klähn, and D. B. Blaschke, "High- density phase transition paves the way for supernova explosions of massive blue-supergiant stars" 2017, ArXiv *e-prints*, astro-ph.HE/1712.08788

Contributed Talks / 13

QCD transition at zero and non-zero baryon densities

Author: Swagato Mukherjee[1]

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We will present new state-of-the-art lattice QCD results on the chiral crossover temperature of QCD for moderately large baryon chemical potential. Firstly, we will present a more precise updated result for the QCD pseudo-critical temperature at zero baryon chemical potential, obtained from all possible second-order chiral susceptibilities that diverge in the chiral limit. Then we will present new results on the QCD pseudo-critical temperature at non-zero baryon chemical potential, computed using Taylor-expansions of chiral condensate and chiral susceptibilities up to 4th-order in the chemical potential. Finally, we will present various second-order fluctuations along the QCD crossover line to look for possible signs of increased fluctuations with increasing baryon density.

Contributed Talks / 14

Collective modes in chiral relativistic plasmas

Author: Igor Shovkovy[1]

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By starting from the chiral kinetic theory in the relaxation-time approximation, an Israel-Stewart type formulation of the hydrodynamic equations for a chiral relativistic plasma is derived. By making use of the corresponding framework of dissipative chiral hydrodynamics, a range of various types of collective modes are studied.

Plenary Talks / 15

QCD thermodynamics with magnetic fields and Landau levels

Author: Falk Bruckmann[1]

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QCD with strong electromagnetic fields is relevant for heavy-ion collisions, the early universe and strongly magnetized neutron stars. Amenable to lattice simulations, its thermodynamics shows some unexpected features like inverse magnetic catalysis. I review our numerical results and show that many effects can be understood – at least qualitatively – by (otherwise free) fermions in magnetic fields. In the second part of my talk I discuss how the corresponding Landau level picture can be transfered from two to four dimensions and to what extent physical observables are dominated by the lowest Landau level.

Plenary Talks / 16

Heavy quarks in medium

Author: Mikko Laine[1]

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The behaviour of a heavy quark within a hot QCD plasma is characterized by its kinetic and chemical equilibration rates, whereas the properties of a quark-antiquark pair are encoded in spectral functions related to various composite operators. We discuss the physics motivation, recent lattice studies, and outstanding challenges related to these observables.

Plenary Talks / 18

Recent results for collective motion in heavy ion collisions

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Recent results for collective motion in heavy ion collisions will be presented

Contributed Talks / 19

QCD phase diagram from DSEs

Author: Christian Fischer[1]

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We summarise recent theoretical results on the QCD phase diagram and the properties of QCD's critical point based on a combination of lattice QCD and Dyson-Schwinger equations.
Using lattice input for the quenched gluon propagator, our approach correctly reproduced and predicted Nf=2+1 flavour lattice results for the quark condensate and the unquenched

electric and magnetic gluon propagator at zero chemical potential.
At chemical potential up to μ_B/T<3 our approach and extrapolations using lattice QCD both confirm an analytic crossover from the hadronic phase into the QGP. Beyond this region we see a critical end point at (T^c, μ_B^c)=(115,504) MeV [1], which is neither very sensitive to additional charm quark contributions [1] nor to corrections from virtual baryons [2].
We are currently studying the zero temperature, high density region; first results will be presented and discussed.

[1] C.S.Fischer, J.Luecker and C.A.Welzbacher, Phys.\ Rev.\ D {\bf 90} (2014) no.3, 034022
[2] G.Eichmann, C.S.Fischer and C.A.Welzbacher,Phys.\ Rev.\ D {\bf 93} (2016) no.3, 034013

Poster Session / 20

Scale invariant hard thermal loop resummation.

Author: jean-loic kneur[1]

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I will illustrate how our recently developed renormalization group optimized perturbation theory (RGOPT) resums perturbative expansions in thermal field theories. The convergence and scale dependence of RGOPT thermodynamical quantities are drastically improved as compared to standard perturbative expansions, and it cures the odd drastic scale dependence observed in other related methods such as the screened perturbation or (resummed) hard-thermal-loop (HTL) perturbation. I will present some recent results in scalar models, and first applications to HTL resummation for QCD thermodynamical quantities, also explaining the additionnal calculations needed in gauge theories with respect to standard HTLpt within our framework.

Contributed Talks / 21

Measuring the rate of isotropization of quark-gluon plasma using rapidity correlations

Author: George Moschelli[1]

Co-authors: Christopher Zin [2]; Sean Gavin [2]

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We propose that rapidity dependent momentum correlations can be used to extract the shear relaxation time τ_π of the medium formed in high energy nuclear collisions. The stress-energy tensor in an equilibrium quark-gluon plasma is isotropic, but in nuclear collisions it is likely very far from this state. The relaxation time τπ characterizes the rate of isotropization and is a transport coefficient as fundamental as the shear viscosity. We show that fluctuations emerging from the initial anisotropy survive to freeze-out, in excess of thermal fluctuations, influencing rapidity correlation patterns. We show that these correlations can be used to extract τ_π. In [1] we describe a method for calculating the rapidity dependence of two-particle momentum correlations with a second order, causal, diffusion equation that includes Langevin noise as a source of thermal fluctuations. The causality requirement introduces the relaxation time and we link the shape of the rapidity correlation pattern to its presence. Here we examine how different equations of state and temperature dependent transport coefficients in the presence of realistic hydrodynamic flow influence the estimate of τ_π. In comparison to RHIC data, we find that the ratio $\tau_\pi/\nu \approx 5-6$ where $\nu = \eta/sT$ is the kinematic viscosity.

We further make predictions for Pb-Pb collisions at the LHC.
[1] S. Gavin, G. Moschelli, C. Zin, Phys. Rev. C 94, 024921 (2016).

Contributed Talks / 22

Spectral function for over-occupied gluodynamics from real-time lattice simulations

Authors: Aleksi Kurkela[1]; Jarkko Peuron[2]; Kirill Boguslavski[2]; Tuomas Lappi[3]

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We study the spectral properties of a highly occupied non-Abelian non-equilibrium plasma that is expected to be created during the initial stages of heavy-ion collisions in the weak-coupling description of the collisions. The spectral function of this far-from-equilibrium plasma is measured by employing linear response theory in classical-statistical real-time lattice Yang-Mills simulations. We establish the existence of transversely and longitudinally polarized quasi-particles and obtain their dispersion relations, effective mass, plasmon frequency, damping rate and further structures in the spectral and statistical functions. Our results are consistent with hard thermal loop (HTL) effective theory but also indicate effects surpassing its leading order. The method can be employed beyond the range of validity of HTL.

Poster Session / 23

Dual QCD Fuzzy Bag and Strongly Interacting Quark-Gluon Plasma

Author: Garima Punetha[1]

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Utilizing the dual QCD model in terms of the magnetic symmetry structure of non-Abelian gauge theories, the modified version of the dual QCD hadronic bag has been constructed in term of fuzzy bag which mainly satisfy the main qualitative feature observed for a strongly interacting QGP. Such picture identifies the new degrees of freedom as thermal monopoles such that the QCD matter behaves as a Semi-Quark Gluon Plasma depicting the suppression of the color electric degrees of freedom and emergence of chromomagnetic monopoles. The analysis of trace anomaly, conformal measure, free energy change, plasma parameter and thermal monopole density around the critical temperature are in good agreement with the strongly interacting nature of QGP. The study of the non-equilibrium and
dissipative effects during the quark-hadron phase transition have been studied in terms of transport coefficients and their associated relaxation time which characterizes how strongly particle interact and move collectively around the transition region. Moreover, within the framework of dual QCD based hadronic and fuzzy bag, the electric and heat conductivity for the strongly interacting QGP phase has been investigated. The numerical estimation of these parameters provides a clear indication of the liquid regime of QGP phase leading to a non-conformal and non-monotonic behavior in QGP phase transition.

Poster Session / 24

Numerical computation of phase diagrams of QCD-inspired models in the large-N limit

Author: Marc Wagner[1]

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I discuss the computation of phase diagrams of theories, which have similar symmetries as QCD, like the Gross-Neveu model or the NJL model in the limit of an infinite number of fermion flavors using lattice field theory and related numerical approaches. Particular focus is put on phases, where condensates are spatially inhomogeneous. First results are presented.

Poster Session / 25

Relativistic perfect-fluid dynamics with spin

Authors: Amaresh Kumar Jaiswal[None]; Bengt Friman[1]; Enrico Speranza[2]; Radoslaw Ryblewski[3]; Wojciech Florkowski[4]

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[4] *IFJ Krakow / UJK Kielce*

A new framework for relativistic hydrodynamics with spin is proposed. It is based on the conservation laws for charge, energy, momentum, and angular momentum. The conservation laws lead to hydrodynamic equations for the charge density, local temperature, and fluid velocity, as well as for the polarization tensor. The resulting set of differential equations extend the standard picture of perfect-fluid hydrodynamics with a conserved entropy current in a minimal way.

Poster Session / 26

Constraining neutron star equation of state from astrophysics, high and low energy nuclear physics

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A novel equation of state with the surface tension induced by particles' interactions was generalized to describe the properties of the neutron stars. In this equation the interaction between particles occurs via the hard core repulsion by taking into account the proper volumes of particles. Recently, this model was successfully applied to the description of the properties of nuclear and hadron matter created in collisions of nucleons.

The new approach is free of causality problems and is fully thermodynamically consistent, which enables us to use it for the investigation of the strongly interacting matter phase-diagram properties in a wide range of temperatures and baryon densities, including neutron stars. The considered model with a small number of parameters, fully determined according to the experimental constraints, reproduces very well all the known properties of normal nuclear matter, provides a high quality description of the proton flow constraints, hadron multiplicities created during the nuclear-nuclear collision experiments and equally is consistent with astrophysical data coming from neutron star observations. Accordingly, we found parameter values that are in good agreement with the same ones obtained from the nuclear–nuclear collision data analysis.

Contributed Talks / 27

Photons as probes of gluon saturation in p+A collision

Authors: Kenji Fukushima[1]; Oscar Garcia Montero[2]; Raju Venugopalan[3]; Sanjin Benic[4]

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We compute the cross section for photons emitted from a $q\bar{q}$ pair produced from gluon splitting in proton-nucleus (p+A) collisions at ultra-relativistic energies [1]. The computation is performed within the dilute-dense kinematics of the Color Glass Condensate (CGC) effective theory. Although the result obtained is formally at next-to-leading order in the CGC power counting, it provides at higher energies the dominant contribution for central rapidities.
We present the first numerical results for the photon cross-section including both the leading order terms computed previously [2,3] supplemented by novel next-to-leading results [4]. We compare the relative contributions of the LO and the NLO terms at different collider energies, and present detailed comparisons to data from RHIC and LHC on p+p and p/d+A collisions.

References:

[1] S. Benic, K. Fukushima, O. Garcia-Montero, R. Venugopalan, JHEP 1701 (2017) 115

[2] J. Jalilian-Marian and A.H. Rezaeian, Phys. Rev. D 86 (2012) 034016

[3] B. Ducloué, T. Lappi, H. Mäntysaari, arXiv: 1710.02206

[4] S. Benic, K. Fukushima, O. Garcia-Montero, R. Venugopalan, (In preparation)

Poster Session / 28

Topological properties and string tension in QCD with nonzero chirality

Authors: Aleksandr Nikolaev[1]; Andrey Kotov[2]; Victor Braguta[2]

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Nonzero chiral density leads to a plenty of interesting unusual phenomena, including chiral catalysis, chiral magnetic effect and others. We study how nonzero chiral density affects topological and confinement properties of the system.
We present the dependence of the string tension and topological susceptibility on chiral chemical potential. We see that both observables grow with chiral density. Our results suggest strong correlation between string tension and topological susceptibility.

Poster Session / 30

$\psi(2S)$ and $\Upsilon(2S)$ as important probe of QGP formation in p-Pb collisions at CERN LHC

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Quarkonia are produced in the heavy ion collisions and their production is modified compared with elementary collisions. This modification in the production of Quarkonia happens due to the presence of hot and dense QCD matter, named as quark-gluon plasma (QGP) formed in ultra relativistic heavy ion collisions. Existence of such kind of medium is observed in assymetric (p-Pb) collisions at 5.02 TeV collision energy at CERN Large Hadron Collider. Investigation of QGP in p-Pb collisions can be obtained by suppression of quarkonium higher resonaces such as 2S states which are are fine observable of QGP formation due their small dissociation temperature and short life time. We present here "Unified model of Quarkonia Suppression (UMQS)" a comprehensive study based on color screening, collisional damping and gluonic dissociation caused by absorption of gluon which led quark anti-quark pair transition from color singlet to color octet state. We have also taken cold nuclear matter effect, mainly shadowing effect, in our consideration as it modifies the quarkonia production in heavy ion collisions. We employ the above model to analyse the data on quarkonia suppression measured in terms of nuclear modification factor, versus transverse momentum, and centrality obtained from collisions at TeV LHC energy. We find that our model describes the LHC data reasonably well.

Contributed Talks / 32

S-matrix approach to the hadron gas

Author: Pok Man Lo[1]

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In this talk I shall discuss the S-matrix formulation of statistical mechanics, which connects the scattering matrix elements to the thermodynamic observables.

The approach allows a consistent treatment of broad resonances and purely repulsive channels, while correctly implementing the constraints from the chiral perturbation theory.
This provides a useful framework for identifying the limitations of the Hadron Resonance Gas model

and for incorporating additional effects from hadron physics to reliably describing the thermal medium.

We shall apply the method to study (1) the ρ-meson and (2) the pion-nucleon system. In the first case the importance of the non-resonant contribution will be demonstrated in correctly describing the soft part of the decay pion momentum spectra. For the latter we will describe how the natural implementation of the repulsive forces can help to better understand the lattice QCD result on the baryon electric charge correlation.

Lastly, I discuss some recent progress to include inelastic effects and $N > 2$-body scatterings.

Poster Session / 33

RHMC with block solvers and multiple pseudofermions

Authors: Liam Keegan[1]; Philippe de Forcrand[1]

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The dominant cost of most lattice QCD simulations is the inversion of the Dirac operator required to calculate the force term in the RHMC update.

One way to improve this situation is to use multiple psuedofermions, which reduces the force and hence allows a larger integration step size to be used, at the cost of having to invert the Dirac operator for each pseudofermion field.

Recently there has been renewed interest in the use of block krylov solvers, which can solve multiple right hand side vectors with significantly fewer iterations than are required if each vector is solved using a separate krylov solver.

We investigate combining these two ideas to speed up RHMC simulations.

Contributed Talks / 35

Stress-tensor distribution around flux tube in SU(3) Yang-Mills theory

Author: Masakiyo Kitazawa[1]

Co-authors: Masayuki Asakawa [2]; Ryosuke Yanagihara [1]; Takumi Iritani [3]; Tetsuo Hatsuda [3]

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We study the spatial distribution of the stress tensor around the quark–anti-quark system in SU(3) lattice gauge theory. The formation of the flux tube and its detailed structure after the continuum limit is revealed in terms of the stress tensor. The Yang-Mills gradient flow plays a crucial role to realize the analysis of the stress tensor on the lattice.
We also perform an analysis of the stress-tensor distribution in a dual-superconductor model. From the comparison with this model, we argue that the numerical results on the lattice suggest that the vacuum of SU(3) Yang-Mills theory is like a type-I superconductor.

Reference:
R. Yanagihara, et al., arXiv:1803.05656

Poster Session / 36

Chiral symmetry restoration by parity doubling and the structure of neutron stars

Authors: Chihiro Sasaki[1]; David Blaschke[1]; Krzysztof Redlich[1]; Michał Marczenko[1]

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Recent lattice QCD studies at vanishing density exhibit the parity-doubling structure for the low-lying baryons around the chiral crossover temperature. This finding is likely an imprint of the chiral symmetry restoration in the baryonic sector of QCD, and is expected to occur also in cold dense matter, which makes it of major relevance for compact stars. By contrast, the latter is typically studied in effective models that embody the chiral physics solely in the deconfined sector, with quarks as degrees of freedom. In this talk, we present a description of QCD matter based on the effective hybrid quark-meson-nucleon model. Its characteristic feature is that, under neutron-star conditions, the chiral symmetry is restored in a first-order phase transition deep in the hadronic phase, before the deconfinement of quarks takes place. We discuss the implications of the parity doubling of baryons on the mass-radius relation for compact stars obtained in accordance with the modern constraints on the mass from PSR J0348-0432, the compactness from GW170817, as well as the direct URCA process threshold. We show that the existence of high-mass stars might not necessarily signal the deconfinement of quarks.

Contributed Talks / 37

Does the chiral magnetic effect affect the dynamic critical phenomena in QCD?

Author: Noriyuki Sogabe[1]

Co-authors: Masaru Hongo [2]; Naoki Yamamoto [1]

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Two important goals of the Beam Energy Scan program are the searches for the chiral magnetic effect (CME) and the QCD critical point(s). Since dynamic critical phenomena of a system generally depends on low-energy gapless modes, it is a priori nontrivial whether the collective gapless mode called the chiral magnetic wave (CMW) that stems from CME affects the dynamic critical phenomena in QCD. Moreover, it is also a nontrivial question whether the CME coefficient is exactly fixed by the anomaly coefficient in the presence of the massless chiral order parameter. To address these questions, we study the critical dynamics near the chiral phase transition in massless two-flavor QCD under an external magnetic field. We find that a new dynamic critical phenomenon appears: the speed of the CMW tends to zero when the second-order chiral phase transition is approached. We also show that the CME coefficient is not renormalized by the critical fluctuations of the order parameter.

Poster Session / 39

The pseudocritical temperature of QCD in a magnetic background

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We study the effect of an external static magnetic field of strength comparable with the QCD scale $\Lambda_{QCD} \sim 200$ MeV on the deconfinement/chiral restoration transition. Lattice simulations have been carried out with $2+1$ flavours, Symanzik three-level improved gauge action and stout improved rooted staggered fermions. In particular, the dependence of the pseudocritical temperature T_c on the magnetic field strength has been investigated. The pseudocritical temperature has been measured through different fermionic observables such as the renormalized chiral condensate and chiral susceptibility.

Poster Session / 40

Topological Properties of SU(3) Yang-Mills theory with double trace deformation.

Author: Marco Cardinali[1]

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We study, by Monte-Carlo simulations, an SU(3) Yang Mills theory at finite temperature with a deformation proportional to the square of the trace of Polyakov loop. Due to this deformation, we can force the system to recover center symmetry even after the usual deconfinement transition. We analyse the properties of this new phase, in which center symmetry is not spontaneously broken, focusing our attention especially on the topological aspects.

Contributed Talks / 41

Universal quark/gluon ratio & turbulent nature of jet quenching

Author: Soeren Schlichting[1]

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We investigate the radiative break-up highly energetic quark and gluon jets due to medium-induced Bremsstrahlung in a high-temperature plasma. We find that within an inertial
range of momenta T « p « E, where E denotes the energy of the jet and T the temperature of of the medium, the quark/gluon ratio of fragments is identical for quark and gluon jets and approximately given by the ratio of moments of the in-medium splitting functions for the q -> qg and g -> qq processes. We demonstrate how this behavior can be understood analytically by considering the

turbulent nature of the radiative break-up process and discuss prospects for experimental measurements and implications for early time dynamics of heavy-ion collisions.

Poster Session / 42

Topology in QCD at high T

Author: Antonino Todaro[1]

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We explore the feasibility of new algorithms, devised for an efficient sampling of the topological charge distribution in the high temperature phase of QCD, and present some preliminary results regarding the temperature dependence of the topological susceptibility

Poster Session / 43

Real-Time-Evolution of Heavy Quarkonium-Bound-States

Author: Alexader Lehmann[1]

Co-author: Alexander Rothkopf [1]

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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.

Here we present preliminary results from a simulation of bottomonium dynamics in the glasma, based on the concept of quenched, classical statistical simulations for the gauge fields [2]. We employ lattice real-time NRQCD to order $1/(aM_{\mathrm{q}})^2$ to describe the bottomonium evolution [3,4].

By computing the time-evolution of spectral functions of bottomonium-channels we expect to identify the emergence of bound states and their formation time in the evolving glasma.

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[4] A. L., A. Rothkopf (in preparation)

Poster Session / 44

Chiral kinetic theory in electromagnetic field and curved space-time

Author: Xu-Guang Huang[1]

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We develop a kinetic framework to describe the matter in which the fermions are chiral. We extend the previous works about the chiral kinetic theory in external electromagnetic field to the case of curved spacetime. The berry curvature and chiral anomaly are encoded automatically. We use our framework to analyze the chiral vortical effect (CVE) and show connections between CVE in rotating frame and in rotating fluid in inertial frame.

Poster Session / 45

Energy density and pressure of strong-coupling lattice QCD

Author: Dennis Bollweg[1]

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The color-singlet representation of lattice QCD with staggered fermions offers a framework to soften the sign problem at finite density. This allows for the computation of the complete QCD phase diagram at strong coupling as well as at $\mathcal{O}(\beta)$. Furthermore, the chiral limit is cheap and thermodynamic quantities such as the energy density and the pressure can be computed easily. Using recently obtained results on the nonperturbatively renormalised anisotropy $\xi(\gamma)$, we present first calculations of the energy density and pressure in the μ-T-plane in the strong coupling limit.

Poster Session / 46

Vector-interaction-enhanced bag model

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For quark matter studies in astrophysics the thermodynamic bag model (tdBag) has been widely used. It approximates the effect of quark confinement, but does not explicitly account for the breaking of chiral symmetry, an important property of Quantum Chromodynamics (QCD). It also doesn't account for repulsive vector interaction necessairy for astrophysical studies. vBag extends the tdBag approach by considering both dynamical chiral symmetry breaking and vector interactions. In this talk the impact of this novel approach on the QCD phase diagram and protoneutron star equation of state will be discussed as well as a finite temperature extension of the model for use in core-collapse supernova simulations.

Poster Session / 47

Signals of two QCD phase transitions at NICA-FAIR energies

Author: Kyrill Bugaev[1]

Co-authors: Aleksei Ivanytskyi [1]; Dirk Rischke [2]; Edward Nikonov [3]; Eugene Zabrodin [4]; Gennady Zinovjev [1]; Larissa Bravina [4]; Violetta Sagun [1]

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During last few years our group developed the most advanced model of
the hadron resonance gas [1] which not only allowed us to achieve the best description of all hadronic multiplicities measured from the lowest AGS to the highest RHIC energies, but also to reveal the remarkable irregularities at chemical freeze-out [2-5]. It is intriguing that in central nuclear collisions we found two sets of similar irregularities. The most prominent of them are the sharp peaks of the trace anomaly and baryonic charge density existing at chemical freeze-out at the center-of-mass energies 4.9 GeV and 9.2 GeV [2, 5]. They are accompanied by two sets of highly correlated quasi-plateaus in the collision energy dependence of the entropy per baryon, total pion number per baryon, and thermal pion number per baryon which are found at the center-of-mass energies 3.8–4.9 GeV and 7.6–9.2 GeV [2-4]. The low-energy set of quasi-plateaus was predicted a long time ago. On the basis of the generalized shock-adiabat model I show that the low-energy correlated quasi-plateaus give evidence for the anomalous thermodynamic properties inside the mixed phase found at the center-of-mass energies 4.3–4.9 GeV. Furthermore, based on the thermostatic properties of the mixed phase of a 1-st order phase transition and the ones of the Hagedorn mass spectrum I will explain, respectively, the reason of observed chemical equilibration of strangeness at the collision energy 4.9 GeV and above 8.7 GeV. Also I will argue that the both sets of irregularities possibly evidence for two phase transitions, namely, the 1-st order transition of chiral symmetry restoration in hadronic phase at low-energy range and the 2-nd order deconfinement transition at the higher one. In combination with a recent analysis of the light nuclei number fluctuations our results indicate that the center-of-mass collision energy range 8.8-9.2 GeV may be in the nearest vicinity of the QCD tricritical endpoint [5]. Also I will discuss the properties of the phase of massless hadrons existing between two phase transitions.

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Poster Session / 48

Real-Time-Evolution of Heavy Quarkonium-Bound-States

Author: Alexader Lehmann[1]

Co-author: Alexander Rothkopf [1]

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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.

Here we present preliminary results from a simulation of bottomonium dynamics in the glasma, based on the concept of quenched, classical statistical simulations for the gauge fields [2]. We employ lattice real-time NRQCD to order $1/(aM_{\mathrm{q}})^2$ to describe the bottomonium evolution [3,4].

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References

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[3] G.P. Lepage et al., Phys.Rev. D 46, 4052 (1992)

[4] A. L., A. Rothkopf (in preparation)

Poster Session / 49

QCD phase diagram for finite imaginary chemical potential with HISQ fermions

Author: Jishnu Goswami[1]

Co-authors: Anirban Lahiri [1]; Christian Schmidt [2]; Frithjof Karsch [2]

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The QCD phase diagram at finite temperature and density has a very rich physical structure which can be explored with first principle lattice QCD calculations.
Simulations of lattice QCD with non-vanishing real chemical potential (μ) suffer from the infamous "sign problem". However, one can perform simulations using purely imaginary chemical potentials where the "sign problem" is absent. Using an imaginary chemical potential allows to explore the QCD phase diagram as function of $-\mu^2$.
We study the QCD phase diagram in (2+1)-flavor QCD with imaginary chemical potential keeping the strange quark mass fixed to its physical value and reducing the light quark masses towards the chiral limit. We use the HISQ action for our study as it has reduced taste splitting violation effects compared to the unimproved staggered action and hence is expected to approach the continuum limit earlier.

Poster Session / 50

A covariant interacting Hadron-Resonance Gas model

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The Hadron-Resonance Gas (HRG) approach - used to model hadronic matter at small baryon potentials μ_B and finite temperature T - is extended to finite and large chemical potentials by introducing interactions between baryons in line with relativistic mean-field theory defining an interacting HRG (IHRG). Using lattice data for $\mu_B = 0$ as well as information on the nuclear equation of state at $T = 0$ we constrain the attractive and repulsive interactions of the IHRG such that it reproduces the lattice equation of state at $\mu_B = 0$ and the nuclear equation of state at $T = 0$ and finite μ_B. The formulated covariant approach is thermodynamically consistent and allows to provide further nformation on the phase boundary between hadronic and partonic phases of strongly interacting matter by assuming constant thermodynamic potentials.

Contributed Talks / 51

The critical line of QCD at small baryon density

Authors: Claudio Bonati[1]; Francesco Negro[2]; Francesco Sanfilippo[3]; Kevin Zambello[4]; Marco Mariti[1]; Massimo D'Elia[5]; Michele Mesiti[6]

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We will discuss the behaviour of the (pseudo)critical temperature of QCD as a function of the baryon chemical potential for physical quark masses. This behaviour has been extracted from 2+1 flavour lattice QCD simulations using both the imaginary chemical potential and the Taylor expansion approach; on the contrary of previous results in the literature, a good agreement between the two determinations is found.

Poster Session / 52

Investigations of strongly coupled gauge theories using holography

Author: Neha Bhatnagar[1]

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Strongly coupled systems are ubiquitous especially in the field of high energy and condensed matter physics. Investigation of these systems is complicated as conventional and perturbative methods fail to describe them. But with the introduction of AdS/CFT duality (or holography), it is now possible to capture the essential features of strongly coupled systems.

In this work, we study the transport properties of different strongly coupled systems using holography. We investigate the transport properties of (3+1) dimensional boundary system at finite

chemical potential using Einstein-Maxwell theory in bulk. We also explore the DC transport for non-relativistic condensed matter systems with hyperscaling violating geometry in the presence of the external magnetic field.

Contributed Talks / 53

An estimate for the thermal photon rate from lattice QCD

Authors: Aman Steinberg[1]; Tim Harris[2]; harvey meyer[3]

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We estimate the production rate of photons by the quark-gluon plasma in lat- tice QCD. We propose a new correlation function which provides better control over the systematic uncertainty in estimating the photon production rate at photon momenta in the range $\pi T/2$ to $2\pi T$. The relevant Euclidean vector current correlation functions are computed with Nf = 2 Wilson clover fermions in the chirally-symmetric phase. In order to estimate the photon rate, an ill-posed problem for the vector-channel spectral function must be regularized. We use both a direct model for the spectral function and a model- independent estimate from the Backus-Gilbert method to give an estimate for the photon rate.

Poster Session / 54

Rapidity decorrelation from hydrodynamic fluctuations in high energy nuclear collisions

Author: Azumi Sakai[1]

Co-authors: Koichi Murase [2]; Tetsufumi Hirano [1]

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Fluctuations have been playing an important role in understanding observables
in high-energy nuclear collisions.
Higher harmonics of azimuthal angle distributions, for example, can be attributed to
initial fluctuations of transverse profile from event to event.
In this presentation, we focus on thermal fluctuations
during hydrodynamic evolution
(i.e. hydrodynamic fluctuations)
of the QGP fluids in the intermediate stage
and investigate the effects of them on several
observables
in high energy nuclear collisions.

We employ an integrated dynamical model [2,3]
which combines full three-dimensional relativistic fluctuating hydrodynamics
with Monte-Carlo version of the Glauber model for
event-by-event initialization
and the hadronic cascade model in the late rescattering stage.
By using this model, we first adjust initial parameters
and transport coefficients to reproduce $dN_{\rm ch}/d\eta$
and centrality dependence of integrated v_2
in Pb+Pb collisions at the LHC energy.
We next analyze observables for longitudinal flow correlations of the n-th order higher harmonics
$R_{n;n|n;n}(\eta)$ [4]
for separation of the flow magnitude fluctuations
from the event-plane twist along the rapidity.
From this analysis, we see how hydrodynamic fluctuations
break longitudinal correlations of the magnitude and the event-plane angle
of anisotropic flow parameters.

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Contributed Talks / 55

Gaussian state approximation for real-time dynamics of gauge theories: Lyapunov exponents and entanglement entropy

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We describe a numerical method which allows to go beyond the classical approximation for the real-time dynamics of many-body systems by approximating the many-body Wigner function by the most general Gaussian function with time-dependent mean and dispersion. On a simple example of a classically chaotic system with two degrees of freedom we demonstrate that the Gaussian state approximation is accurate for significantly smaller field strengths and longer times than the classical one. We use this method to study quantum Lyapunov exponents and the generation of entanglement entropy in dimensionally reduced Yang-Mills theory and in 10d supersymmetric Yang-Mills theory (BFSS matrix model). We find that quantum corrections tend to decrease the Lyapunov exponents, and make them vanish in the low-temperature confining phase. This behavior ensures the validity of the Maldacena-Shenker-Stanford bound on Lyapunov exponents. Entanglement entropy production rate is found to be larger than the Lyapunov exponents, and consistent with quantum information scrambling. We further discuss the applicability of the Gaussian state approximation to real-time simulations of higher-dimensional Yang-Mills theory.

Poster Session / 56

Effective kinetic description of event-by-event pre-equilibrium dynamics in high-energy heavy-ion collisions

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We develop a macroscopic description of the space-time evolution of the energy-momentum tensor during the pre-equilibrium stage of a high-energy heavy-ion collision. Based on a weak coupling effective kinetic description of the microscopic equilibration process (\'a la "bottom-up"), we calculate the non-equilibrium evolution of the local background energy-momentum tensor as well as the non-equilibrium linear response to transverse energy and momentum perturbations for realistic boost-invariant initial conditions for heavy ion collisions. We demonstrate how this framework can be used on an event-by-event basis to propagate the energy momentum tensor from far-from-equilibrium initial state models, e.g.\ IP-Glasma, to the time τ_{hydro} when the system is well described by relativistic viscous hydrodynamics. The subsequent hydrodynamic evolution becomes essentially independent of the hydrodynamic initialization time τ_{hydro} as long as τ_{hydro} is chosen in an appropriate range where both kinetic and hydrodynamic descriptions overlap. We find that for $\sqrt{s_{NN}} = 2.76\,\text{TeV}$ central Pb-Pb collisions, the typical time scale when viscous hydrodynamics with shear viscosity over entropy ratio $\eta/s = 0.16$ becomes applicable is $\tau_{\text{hydro}} \sim 1$ fm/c after the collision.

Poster Session / 57

Significance of the (quark-) gluon plasma finite size for the equation of state, and related thermodynamic stability of thermal Casimir systems

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We first motivate the need for an improved equation of state, accounting for the finite size of hot, quantum and relativistic quark-gluon plasmas, such as created in modern Heavy Ion Collisions (HIC). We then focus on finite size corrections by means of relevant spatial compactifications, while considering a single non-interacting massless scalar field as a toy model. Consequently, we present various thermodynamic quantities, including subsequent statistical energy fluctuations for different finite volumes. Such thermal "Casimir" systems seemingly convey thermodynamic instability which, however, can be overcome by means of general and physically motivated additional mechanisms. We then present how such a mechanism permits for reconciling the second law of thermodynamics with the thermal Casimir effect, including our implementation of finite size corrections. This work can potentially affect future calculations and interpretations of physical observables, which characterize the presence of a quark-gluon plasma in HIC.

Contributed Talks / 58

Observation of deconfinement in a cold dense quark medium

Authors: Aleksandr Nikolaev[1]; Alexander Molochkov[1]; Andrey Kotov[2]; Ernst-Michael Ilgenfritz[3]; Victor Braguta[2]; Vitaly Bornyakov[4]

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We present the recent results on the confinement/deconfinement transition in lattice SU(2) QCD with two flavors of quarks
at finite quark density and zero temperature. In the region μ_q ~ 1000 MeV we observe the confinement/deconfinement
transition which manifests itself in rising of the Polyakov loop and vanishing of the string tension σ. After the deconfinement
is achieved at μ_q > 1000 MeV we observe a monotonous decrease of the spatial string tension σ_s which ends up
with σ_s vanishing at μ_q > 2000 MeV. To study the properties of cold dense quark medium we measure the
dependence of chiral and diquark condensates, quark density, topological susceptibility and other physical quantities on the
chemical potential.

Poster Session / 59

Screening masses and quark free energy at small baryon density

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We will discuss some results about the behaviour of the screening properties of
high-T QCD at finite density. More precisely we will report on the dependence on the baryon chemical potential of the QCD screening masses and of the heavy-quark free energy, as extracted from 2+1 flavours Lattice QCD
simulations at the physical point. While for the screening masses a particularly interesting region to be studied is the one close to the Roberge-Weiss transition, the heavy-quark free energy displays a peculiar behaviour at the
pseudocritical point of the mu_B=0 theory.

Poster Session / 60

QCD phase diagram for nonzero isospin-asymmetry

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The QCD phase diagram is studied in the presence of an isospin asymmetry using continuum extrapolated staggered quarks with physical masses. In particular, we investigate the phase boundary between the normal and the pion condensation phases and the chiral/deconfinement transition. The simulations are performed with a small explicit breaking parameter in order to avoid the accumulation of zero modes and thereby stabilize the algorithm. The limit of vanishing explicit breaking is obtained by means of an extrapolation, which is facilitated by a novel improvement program employing the singular value representation of the Dirac operator. Our findings indicate that no pion condensation takes place above T 160 MeV and also suggest that the deconfinement crossover continuously connects to the BEC-BCS crossover at high isospin asymmetries.

Poster Session / 61

Quark matter nucleation within cold nuclear matter

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The formation of quark matter in core-collapse supernovae and neutron star mergers could leave interesting
observable imprints on the resulting electromagnetic, gravitational and neutrino emissions. In fact, simulations
have shown that the early formation of quark matter could have a significant impact upon the dynamics of
core-collapse supernovae, including a characteristic second neutrino burst. Nevertheless, first-order transitions
demand time and the possibility of phase conversion depends on whether the available timescales, of tens to
hundreds of milliseconds, are long enough for nucleating quark-matter droplets. We estimate
the surface tension and nucleation time for the high-density transition between nuclear and chirally symmetric
matter within a nucleon-meson model. While these quantities have been calculated before, our results are the
first to simultaneously consider both chiral symmetry and nuclear saturation in a cold and dense environment.

Poster Session / 62

Isospin asymmetric, chiral imbalanced dense quark matter in the framework of NJL$_4$ model.

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Isospin asymmetry is the well-known property of dense quark matter, which exists in the compact stars and is produced in heavy ion collisions. On the other hand, the formation of dense quark matter in both of these cases is usually accompanied by a magnetic field strong enough to promote chiral magnetic effect (CME).

To investigate quark matter under these conditions, we take into account barion – μ_B, isospin – μ_I and chiral isospin – μ_{I5} chemical potentials and study QCD phase diagram using NJL$_4$ model generalized to two massive u- and d- quarks that could condense into the pion condensation.

At first, we have shown that the chiral isospin chemical potential μ_{I5} generates pion condensation in isospin asymmetric quark matter. Also, we have found some interesting discrete symmetry (duality) between chiral and pion condensates in the case of massless quarks, which stay relatively instructive even if the quarks are massive.

To describe hot dense quark matter, in addition to the above-mentioned chemical potentials, we introduce non-zero temperatures into consideration and compare our NJL$_4$-model results with the known lattice investigations. For example, we have shown that dependences of the critical temperature T_c on the chiral chemical potential for lattice and NJL$_4$ are qualitatively similar.

Poster Session / 64

The phase diagram of QCD from lattice simulations

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The phase diagram of QCD is one of the most interesting problems in modern physics
which so far has not been sufficiently investigated from first principle calculations at mu/T > 1,
mainly due to the sign problem of lattice QCD.
One of the most promising methods to tackle the sign problem in lattice simulations is the complex Langevin method,
which recently has been successfully applied to QCD in many interesting paremeter regions.
Here we give preliminary results of simulations with moderately heavy Wilson fermions in different regions of the phase diagram with rather large mu/T.
The long term prospect is mapping out the phase diagram and also go to lower masses.

Contributed Talks / 65

QCD equation of state at finite baryon density with Cluster Expansion Model

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QCD equation of state at finite baryon density is studied in the framework of a Cluster Expansion Model (CEM), which is based on a fugacity expansion of the net baryon density.
CEM uses the leading two Fourier coefficients from lattice simulations at imaginary μ_B as the only model input. Excellent description of the available lattice data at both $\mu_B = 0$ and at imaginary μ_B is obtained. Questions regarding the radius of convergence of the Taylor expansion, the analytic structure of CEM, and the effective parameterization of QCD equation of state at finite μ_B are discussed.

Poster Session / 66

Hybrid Monte Carlo study of competing order in the extended hexagonal Hubbard model in 2+1 dimensions

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Hybrid Monte Carlo is traditionally employed in lattice QCD calculations. In principle, however, its applicability extends to a wide range of other interacting Fermion systems. One such system which can be simulated without a fermion-sign problem is the extended Hubbard model at half-filling, which describes electrons that can hop between the sites of a crystal lattice and includes on-site (U) and nearest-neighbor (V) interaction terms. This model is of great interest in condensed matter physics, as it describes a wide range of electronic systems in good approximation. The extended Hubbard model on the hexagonal lattice in 2+1 space-time dimensions is of interest also to high-energy physicists, as its low-energy excitations provide a realization of Dirac fermions. In the case of strong coupling, various types of transitions to electronic gapped phases can occur, which possess analogies to chiral-symmetry breaking. - In this work we study the competition between spin-density wave and charge-density wave order in the $U - V$ plane through HMC. Our simulations do not include any explicit symmetry-breaking terms and are thus completely unbiased. We find an extended phase of spin-density wave order and determine that its border is characterized by critical scaling in the Gross-Neveu universality class.

Poster Session / 68

Predicting QCD phase diagram with chiral relativistic mean field model fitted to $\mu_B = 0$ lattice data

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The SU(3) flavor parity-doublet quark-hadron model is used to investigate the phase diagram of QCD matter. The quark sector of the model is tuned to the $\mu_B = 0$ lattice QCD data on trace anomaly. The structure of the baryon number susceptibilities in the temperature/chemical potential plane is studied in some detail.
The model predicts three phase transitions - nuclear first-order liquid-gas phase transition, chiral symmetry restoration, and deconfinement transition.
At $\mu_B = 0$, a good agreement with the corresponding lattice data is obtained.
The deviations from the free hadron gas baseline in the crossover temperature region at $\mu_B = 0$ are mainly attributed to the leftover of the liquid-gas transition in nuclear matter, the chiral phase transition determines the baryon fluctuations at much higher μ_B, and at even higher baryon densities the behavior of fluctuations is controlled by deconfinement transition.

Poster Session / 69

Identifying QCD transition in a hybrid model with deep learning

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A deep convolutional neural network (CNN) is constructed and trained in supervision to identify the QCD transition from the averaged final-state pion spectra ρ(pT,φ) in simulations of heavy-ion collisions with a hybrid model (iEBE-VISHNU), which couples (2+1)-D relativistic viscous hydrodynamics to a hadronic cascade "afterburner" (UrQMD). Hidden correlations in ρ(pT,φ) are captured by the neural network, which serves as an effective "EoS-meter" in distinguishing the nature of the QCD transition. The EoS-meter is robust against many simulation inputs, such as the collision energy, fluctuating initial conditions, equilibration time, shear viscosity and switching criterion. Thus the EoS-meter provides a powerful tool as the direct connection of heavy-ion collision observables with the bulk properties of QCD.

Poster Session / 71

Reweighting Lefschetz thimbles

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One of the main challenges in simulations on Lefschetz thimbles is the computation of the relative weights of contributing thimbles. In this work we propose a solution to that problem by means of computing those weights using a reweighting procedure. Besides we present recipes for finding parametrizations of thimbles and anti-thimbles for a given theory. Moreover, we study some approaches to combine the Lefschetz thimble method with the Complex Langevin evolution. Our numerical investigations are carried out by using toy models among which we consider a one-site z^4 model as well as a U(1) one-link model.

Contributed Talks / 72

Exploring the phase structure and dynamics of QCD

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I give an update on the phase structure of QCD at vanishing and finite temperature and density with functional methods. Specifically results are discussed for the confinement-deconfinement and chiral phase transitions, the nature of these transitions and their interrelation, as well as the thermodynamics and fluctuations observables of QCD.

The results on correlation functions are also used for the computation of gluon spectral functions and transport coefficients, as well as an input for QCD-assisted transport equation. First results for skewness and kurtosis in a system passing through the
phase boundary are presented.

Poster Session / 73

Complex Langevin simulations and the QCD phase diagram

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The sign problem emerges in lattice QCD as soon as non-vanishing Baryon chemical potential is studied. This prevents direct simulations of the phase structure of strongly interacting matter. Complex Langevin simulations have been successfully used for various models or approximations of QCD. However, in some scenarios it converges to incorrect results. Here I will discuss a new method that keeps complex Langevin simulations close to the SU(3) manifold and thus improving the convergence. I will further discuss its application towards the ultimate goal of simulating fully dynamical QCD.

Plenary Talks / 74

Pushing the hard thermal loop theory with effective field theory methods

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We show that effective field theory techniques can be applied in the high temperature T regime of plasmas to improve the accuracy of the physics of the hard scales (or scales of order T), and as a by-product, also that of the soft scales (or scales of order gT). At leading order in the coupling constant the hard scales of the plasma can be viewed as on-shell classical particles. Based on this observation, and without any reference to the state of the system, we derive an effective field theory describing the quantum fluctuations around an on-shell fermion with energy p, described as a set of high dimension operators over the on-shell energy p. When applied to systems close to thermal equilibrium, where for most on-shell particles p ~T, we show that the on-shell effective field theory (OSEFT) properly describes the HTL photon polarization tensor of QED, and its power corrections. We also present compact expressions for the power corrections to the HTL Lagrangian of QED in d space dimensions. The OSEFT is also used to derive corrections beyond the classical approximation of transports equations valid for QED.

Poster Session / 75

Complex Langevin simulations of a finite density matrix model for QCD

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We study the Stephanov model, which is a Random Matrix Theory model for QCD at finite baryon density, using the Complex Langevin algorithm. Naive implementation of the algorithm shows convergence towards the phase quenched or quenched theory rather than to the intended theory with dynamical quarks. A detailed analysis of this issue various potential resolutions of the failure of this algorithm are discussed.

Poster Session / 76

The nature of the QCD thermal transition as a function of quark flavours and masses

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Attempts to extract the order of the chiral transition of QCD at zero chemical potential, with two dynamical flavours of massless quarks, from simulations with progressively decreasing pion mass

have remained inconclusive because of their increasing numerical cost. In an alternative approach to this problem, we consider the path integral as a function of continuous number N_f of degenerate quarks. If the transition in the chiral limit is first-order for $N_f \geq 3$, a second-order transition for $N_f = 2$ then requires a tricritical point in between. This in turn implies tricritical scaling of the critical boundary line between the first-order and crossover regions as the chiral limit is approached. Non-integer numbers of fermion flavours are easily implemented within the staggered fermion discretisation. Exploratory simulations at $\mu = 0$ and $N_f = 2.8, 2.6, 2.4, 2.2, 2.1$, on coarse $N_\tau = 4$ lattices, indeed show a smooth variation of the critical mass mapping out a critical line in the (m, N_f)-plane. For the smallest masses the line appears consistent with tricritical scaling, allowing for an extrapolation to the chiral limit.

Poster Session / 77

Time-evolution of fluctuations as signal of the phase transition dynamics in a QCD-assisted transport approach

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For the understanding of the fluctuation measurements in heavy-ion collisions it is crucial to develop quantitatively reliable dynamical descriptions. In order to study the phase transition, both in crossover regime as well as near the conjectured QCD critical point, the non-perturbative nature needs to be fully included. In this talk, we outline a novel QCD-assisted transport approach based on non-equilibrium chiral fluid dynamics and the effective action of low energy QCD. This approach makes use of the full equilibrium correlation functions and includes dissipation and stochastic noise.

We test the new framework within a low energy effective mesonic theory. For this case, we discuss the time evolution of fluctuation observables based on the higher-order moments such as the skewness and kurtosis as the system passes through the phase boundary. In this way, we can study details of the equilibration of the order parameter and of higher-order correlations, as well as the impact of critical slowing down on the correlation length. The underlying theory naturally includes critical and non-critical contributions. We can, therefore, explicitly test the size of the critical region, where scaling and dynamical scaling hold. Finally, the relative effect of critical versus baseline contributions to the fluctuation dynamics is quantified.

Plenary Talks / 78

Fate of axial U(1) symmetry at two flavor chiral limit of QCD in finite temperature

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Axial U(1) symmetry is broken by anomaly in QCD. In finite temperature, contribution to the order parameter of this symmetry from topologically non-trivial vacua may be suppressed and the symmetry could be effectively restored. This has been tested in lattice QCD simulations. But, the situation is still elusive. The fate of the axial U(1) symmetry is important in axion cosmology, universality class of the phase transition, and remotely related to the order of the QCD phase transition. An overview will be given on the current status of this topic.

Plenary Talks / 79

SU(3) equation of state on the lattice: status and new methods

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In the last few years highly precise determinations of the equation of state of the SU(3) Yang-Mills theory have become available from different methods. Indeed, the purely gluonic sector of QCD provides a perfect framework for testing new computational techniques, while avoiding most of the technical challenges of the theory with dynamical fermions. In this talk I will present an overview of recent developments, with a particular focus on a novel method based on Jarzynski's equality, and I will discuss the status of the latest numerical results.