# 19th International Conference on QCD in Extreme Conditions (XQCD 2023)

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XQCD 2023

19th International Conference on QCD in Extreme Conditions (XQCD 2023)

# Book of Abstracts

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**Poster session / 2**

## Systematic analysis of the impacts of symmetry energy parameters on neutron star properties

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The impacts of various symmetry energy parameters on the properties of neutron stars (NSs) have been recently investigated, and the outcomes are at variance, as summarized in Table III of Phys. Rev. D 106, 063005 (2022).
We have systematically analyzed the correlations of slope and curvature parameters of symmetry energy at the saturation density ($\rho_0 = 0.16\text{fm}^{-3}$) with the tidal deformability and stellar radius of non-spinning neutron stars in the mass range of $1.2 - 1.6M_\odot$ using a large set of minimally constrained equations of state (EoSs).
The EoSs at low densities correspond to the nucleonic matter and are constrained by empirical ranges of a few low-order nuclear matter parameters from the finite nuclei data and the pure neutron matter EoS from chiral effective field theory. The EoSs at high densities ($\rho > 1.5 - 2\rho_0$) are obtained by a parametric form for the speed of sound that satisfies the causality condition. Several factors affecting the correlations between the NS properties and the individual symmetry energy parameters usually encountered in the literature are considered. These correlations are quite sensitive to the choice of the distributions of symmetry energy parameters and their interdependence.
But, variations of NS properties with the pressure of $\beta-$ equilibrated matter at twice the saturation density remain quite robust which maybe due to the fact that the pressure depends on the combination of multiple nuclear matter parameters that describe the symmetric nuclear matter as well as the density dependence of the symmetry energy.
Our results are practically insensitive to the behavior of EoS at high densities.

**Invited Speaker Session / 3**

## Bose condensation in dense QCD

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In this talk, I will discuss recent progress in our understanding of pion and kaon condensation in dense QCD. Using chiral perturbation theory at finite isospin and strangeness density, we map out the phase diagram. We also include electromagnetic interactions. The equation of state, speed of sound, chiral and pion condensates are calculated to next-to-leading order in the low-energy expansion. The results are compared to recent high-precision lattice simulations and the results are generally in very good agreement.
We discuss the effective field theory that describes the Goldstone bosons arising from the spontaneous breakdown of U(1)-symmetry.
In the nonrelativistic limit, we recover the classic results for the dilute Bose gas. These include leading corrections to the mean-field result for the energy density as well as the damping rate of phonons.

**Poster session / 4**

# Analyzing the speed of sound in neutron stars using machine learning

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Sagnik Chatterjee, IISER Bhopal
The matter at Neutron star (NS) cores are at highly compressed state and due to gravity, the density can be built up to a few times the nuclear saturation density. They are very compact and have been observationally identified with pulsars with their mass being in the range from 0.7 - 3 solar masses and a radius between 10-15 km. They are therefore one of the best laboratories to test the theory of strong interaction at high-density low temperature regimes. The information about the structure of an NS can be given by their equation of states (EoSs). At high densities, the first principle pQCD calculations are consistent and at lower densities field theory calculations are consistent. The central density of the NS lies somewhere between these two densities and in this regime the lattice QCD calculations fail. Hence, we need to resort to model-based or agnostic approaches to construct EoSs. In this talk, I will present how we can effectively create several new EoSs from the information on the speed of sound. Using the created EoSs, we create several datasets to train our neural network. I will also talk about the neural network model using which we can effectively predict a new EoS. Using these we study the variation in the speed of sound inside the NS.

**Poster session / 5**

# Volume dependence of the critical endpoint and the baryon number fluctuations

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While in field theoretical calculations, being performed in the thermodynamic limit, the volume is infinite, the heavy-ion collisions always carry the effects of finite system size. It is expected that a sufficiently small volume can affect the thermodynamics and the phase diagram of the strongly interacting matter. These effects can be studied in effective models by taking into account the finite spatial extent of the system via the restriction of the momentum integrals with discretization or simpler using a low momentum cutoff. We investigated the finite-size effects in a vector meson extended Polyakov quark-meson model with both scenarios. It was found that the resulting modification of the phase diagram is highly influenced not just by the chosen momentum space constraint and the boundary condition but more importantly by the treatment of vacuum size. Our results also explain certain differences between previous calculations on finite-volume effects within different effective approaches. Moreover, we also studied the volume dependence of the baryon fluctuations both at vanishing baryochemical potential and in the neighborhood of the critical endpoint.

**Parallel session B / 6**

## Do hadronic stars and strange quark stars coexist?

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In the last years new and exciting data on neutron stars have been obtained by the observations of gravitational waves in merger processes, by the recent X-ray observations of NICER of the closest pulsars, by the multiple band observations of new kind of explosive events, namely the kilonova discovered in 2017. All these data show a (mild) tension among themselves: GW170817 requires a soft equation of state for dense matter, GW190814 might instead indicate that masses up to 2.6M_sun could exist, thus favoring a stiff equation of state. I will discuss a possible scenario that aims to provide a consistent picture of all the experimental and observational information, namely the two-families scenario. This scenario is based on the hypothesis that strange quark matter is absolutely stable. The consequences of this scenario are far reaching: the possible existence of strangelets would provide a significant component of dark matter in the universe.

**Parallel session B / 7**

## Centrality Dependence of Multistrange and Strange Antibaryon Production in Heavy-Ion Collisions at High Energies

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We consider the experimental data on yields of protons, strange $\Lambda$'s, and multistrange baryons ($\Xi$, $\Omega$), and antibaryons production on nuclear targets, and the experimental ratios of multistrange to strange antibaryon production, at the energy region from SPS up to LHC, and compare them to the results of the Quark-Gluon String Model calculations. In the case of heavy nucleus collisions, the experimental dependence of the $\Xi$+/$\Lambda$, and, in particular, of the $\Omega$+/$\Lambda$ ratios, on the centrality of the collision, shows a manifest violation of quark combinatorial rules.

**Plenary session / 8**

## Anomalous Electromagnetism in QCD at intermediate baryonic densities

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In this talk, the anomalous transport properties of the spatially inhomogeneous phase of dense quark matter known as the Magnetic Dual Chiral Density Wave (MDCDW) phase will be reviewed. I will

discuss several anomalous electromagnetic effects that can take place in this phase at low temperatures and intermediate baryonic densities. I will present the axion electrodynamics characterizing this phase. Then, going beyond mean-field approximation, I will show how linearly polarized electromagnetic waves that penetrate the MDCDW medium mix with the phonon fluctuations to give rise to two hybridized modes of propagation called axion polaritons. I will discuss how the formation of axion polaritons in the MDCDW core of a neutron star can add mass to the star via the Primakoff effect, which eventually can trigger the star collapse under the bombardment of gammaray bursts. This mechanism can provide a possible solution to the missing pulsar problem in the galactic center.

**Poster session / 9**

## Hybrid stars are compatible with recent astrophysical observations

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Compact stars (CSs) are stellar remnants of massive stars. Inside CSs the density is so high that matter is in subatomic form composed of nucleons. With increase of density of matter towards the centre of the objects other degrees of freedom like hyperons, heavier non-strange baryons, meson condensates may appear. Not only that at higher densities, the nucleons may get decomposed into quarks and form deconfined strange quark matter (SQM). If it is so then CSs may contain SQM in the core surrounded by nucleonic matter forming hybrid stars (HSs). However, the nature and composition of matter inside CSs can only be inferred from the astrophysical observations of these CSs. Recent astrophysical observations in terms of CS mass-radius (M-R) relation and gravitational wave (GW) observation indicate that the matter should be soft in the intermediate density range and stiff enough at higher density range to attain the maximum possible mass above 2 $M_\odot$ which is not compatible with pure hadronic equation of states (EOSs). Consequently, we study the HS properties with different models of SQM and find that within vector bag model considering density dependent bag parameter, the model goes well with the astrophysical observations so far.

**Plenary session / 11**

## Topology and robustness of a quark matter phase candidate for magnetars core

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One central question in nuclear astrophysics nowadays is determining the matter structure of neutron stars (NS). With the wealth of newly available and upcoming astrophysical observations, it is of most relevance to find ways to compare the characteristics of potential NS matter phase candidates with those gathered from NS observations. As part of these efforts, I will discuss how some unique topological properties of a spatially inhomogeneous, dense quark matter phase in a magnetic field lead to robustness and resilience against thermal phonon fluctuations, making it a plausible candidate for magnetars'inner core matter.

**Parallel session B / 12**

## QCD equation of state at finite isospin density from the linear sigma model with quarks

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Present abstract is based on our recent work [1] where we use the two-flavor linear sigma model with quarks to study the phase structure of isospin asymmetric matter at zero temperature. The meson degrees of freedom provide the mean field chiral- and isospin-condensates on top of which we compute the effective potential accounting for quark fluctuations at one-loop order. Using the renormalizability of the model, we absorb the ultraviolet divergences into suitable counter-terms that are added respecting the original structure of the theory. These counter-terms are determined from the stability conditions which require the effective potential to have minima in the condensates directions at the classical values, as well as the transition from the non-condensed to the condensed phase to be smooth as a function of the isospin chemical potential. We use the model to study the evolution of the condensates as well as the pressure, energy and isospin densities and the sound velocity as functions of the isospin chemical potential. The approach does a good average description up to isospin chemical potentials values not too large as compared to the vacuum pion mass.

[1] - QCD equation of state at finite isospin density from the linear sigma model with quarks: The cold case ; Alejandro Ayala, Aritra Bandyopadhyay, Ricardo L.S. Farias, Luis A. Hernández, José Luis Hernández ; Phys. Rev. D. 107 (2023), 074027 ; 2301.13633 [hep-ph]

**Plenary session / 14**

## Topological structure of the QCD vacuum at finite temperature

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The structure of the gluonic vacuum is examined at finite temperature in lattice QCD. The topological charge density on individual Monte Carlo gauge field configurations is calculated, and an algorithm is applied to detect topological objects associated with local extrema. These objects are found to have a distribution of fractional topological charge, and the nature of this distribution changes with the crossing of the critical temperature. Comparisons are made with model predictions, including an instanton-dyon model. The vortex content of these configurations is also studied after fixing to Maximal Centre Gauge. The dominant vortex cluster is observed to “melt” as the temperature crosses into the deconfined phase, causing a collapse in geometry such that centre vortices no longer percolate in all four dimensions.

**Poster session / 15**

## Quantum chaos in a minimalistic supersymmetric Yang-Mills-like model: from graviton gas to black holes and black branes

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We consider a minimalistic supersymmetric quantum mechanical model with two bosonic and one fermionic degree of freedom, and a Hamiltonian that resembles that of a dimensionally reduced super-Yang-Mills theory. Low dimensionality of the model allows for an exact diagonalization study, which reveals surprisingly rich dynamics. Studying the energy level statistics, we identify three distinct regimes which closely resemble the graviton gas, the Schwarzschild black hole, and the black D0-brane regimes of the holographic dual of compactified 10-dimensional N=1 Super-Yang-Mills theory (BFSS model). All three regimes feature growing Out of Time Order Correlators (OTOCs) and appear to be indistinguishable in thermodynamics observables but exhibit very different behaviors of entanglement entropy.
The model provides an interesting testbed for first-principle studies of quantum chaos in Yang-Mills-like models.

**Parallel session A / 16**

## Speed of Sound beyond the High-Density Relativistic Limit in Dense Two-Color QCD: Lattice Simulation Results

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We obtain the equation of state (EoS) for two-color QCD at low temperature and high density from the lattice Monte Carlo simulation. Two-color QCD is a good toy model of real three-color QCD. The advantage to study this model is that the sign problem is absent even in finite density regime because of the pseudo-reality of quark field. We find that the speed of sound exceeds the relativistic limit (c_sˆ2/cˆ2=1/3) after BEC-BCS crossover in the superfluid phase. Such an excess of the sound velocity is previously unknown from any lattice calculations for QCD-like theories. This finding might have a possible relevance to the EoS of neutron star matter revealed by recent measurements of neutron star masses and radii. This talk is based on PTEP 2022 (2022) 11, 111B01 (e-Print: 2207.01253) and its further updates.

**Parallel session B / 17**

## QCD with fundamental and adjoint matter

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Strongly-coupled gauge theories with fermions and/or scalars in mixed representations are endowed with a wealth of intricate phase structures. In this talk, I discuss the faithful global symmetries and ‘t Hooft anomalies of Quantum Chromodynamics (QCD) with matter in the fundamental-adjoint mixed representation. Then, I show how one can utilize the anomalies and effective field theory techniques to construct the infrared phase diagrams of this class of theories. The discussion covers the implications of the limiting scenarios of heavy adjoint or fundamentals, which align neatly with our current understanding of QCD with solely fundamental or adjoint matter.

**Parallel session B / 18**

## Towards a universal description of hadronic phase of QCD

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Mean-field model quantum field theories of hadrons were traditionally developed to describe cold and dense nuclear matter and are by now very well constrained from the recent neutron star merger observations. We show that when augmented with additional known hadrons and resonances but not included earlier, these mean-field models can be extended beyond its regime of applicability. Calculating some specific ratios of baryon number susceptibilities for finite temperature and moderate values of baryon densities within mean-field approximation, we show that these match consistently with the lattice QCD data available at lower densities, unlike the results obtained from a non-interacting hadron resonance gas model. We also estimate the curvature of the line of constant energy density, fixed at its corresponding value at the chiral crossover transition in QCD, in the temperature-density plane. The number density at low temperatures and high density is found to be about twice the nuclear saturation density along the line of constant energy density of $\epsilon = 348 \pm 41$ MeV/fm$^3$. Moreover from this line we can indirectly constrain the critical end-point of QCD to be beyond $\mu_B = 596$ MeV for temperature $\sim 125$ MeV.

**Poster session / 20**

## Inhomogeneous phases and non-monotonic dispersion relations in strongly-interacting matter

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In this talk, I discuss results about inhomogeneous chiral phases, where in addition to chiral symmetry also translational symmetry is broken, and the related moat regimes, where non-monotonic dispersion relations appear driven by a negative wave function renormalization. These phenomena may occur in strongly-interacting matter under extreme conditions such as finite baryon density and temperature. The possibility of inhomogeneous phases and moat regimes is studied in a variety of Four-Fermion and Yukawa theories, which are considered as low-energy effective models of QCD. Using the mean-field approximation, we analyze the stability of homogeneous condensates against inhomogeneous perturbations to draw conclusions about the phase diagrams of these theories. Also, we study the consequences of a negative wave function renormalization with respect to bosonic correlation functions in an effective O(N) model using lattice field theory.

**Poster session / 21**

## Jet quenching in evolving anisotropic matter

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Over the last decades, the theoretical picture of how hadronic jets interact with nuclear matter has been extended to account for the medium's finite longitudinal length and expansion. However, only recently a first-principle approach has been developed that allows to couple the jet evolution to the medium flow and anisotropic structure in the dilute limit. In this talk, we will show how to extend this approach to the dense regime, where the resummation of multiple in-medium scatterings is necessary. Particularly, we will consider the modifications of the single particle momentum broadening distribution and single gluon production rate in evolving matter. The resummation is performed by either computing the opacity series or starting from the all order BDMPS-Z formalism. We will also discuss the (novel) resulting modifications to jets' substructure.

**Parallel session C / 23**

## Propagation of gauge fields in hot and dense plasmas at higher orders

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Thermal field theory is indispensable for describing hot and dense systems. Yet perturbative calculations are often stymied by a host of energy scales, and tend to converge slowly. This means that precise results require the apt use of effective field theories. In this talk I describe how the effective description of slowly varying gauge fields, known as hard thermal loops, can be extended to higher orders. I also discuss how to consistently define asymptotic masses at higher orders; and how to treat spectral functions close to the lightcone.

**Poster session / 24**

## Chiral magnetic waves in quark matter inside neutron stars and gravitational waves

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It is important to unravel the internal structure of neutron stars in astrophysics. One effective way to study the interior of neutron stars is analyzing their seismic oscillations. Recently, the chiral magnetic wave (CMW), which is a density wave propagating along magnetic fields due to the chirality of fermions, has been studied in the context of the heavy ion collision experiments.

In this talk, we show that the CMW can appear as a seismic oscillation in quark matter, such as the two-flavor color superconductivity, inside neutron stars. We also discuss the frequency and amplitude of a new type of gravitational wave radiated by the seismic oscillation. This gravitational wave could be a new probe of the magnetic field and quark matter in neutron stars.

**Parallel session A / 25**

## What is the nature of the HESS J1731-347 compact object? Does it confirm the early deconfinement phase transition?

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Compact stars are the most exotic and dense laboratories in the Universe to test the properties of strongly interacting matter. Understanding the complex phenomena observed in neutron and hybrid stars requires profound knowledge in a wide range of scientific disciplines. In addition to the experimental data on nuclear and hadron matter, the realistic equation of state (EoS) should be consistent with the astrophysical, and gravitational wave observations. While details of the phase transitions and properties of quark matter are traditionally investigated in the accelerator experiments on heavy-ion collisions, compact astrophysical objects recently gained a big interest since observational data on their radii, masses, surface temperature, etc. significantly constrain the properties of strongly interacting matter. We will discuss the recently announced lightest compact star HESS J1731-347 which has raised a lot of questions about its nature. We will show the use of the latest data on the mass, radius, and surface temperature together with the multi-messenger observations of neutron stars and their mergers to investigate the possibility that HESS J1731-347 is the lightest observed neutron star, a strange star, a hybrid star with an early deconfinement phase transition, or a dark matter admixed compact star.

**Poster session / 26**

## Probing hybrid stars and the properties of the special points with radial oscillations

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We study the properties of hybrid stars containing a color superconducting quark matter phasevin their cores, which is described by the chirally symmetric formulation of the confining relativistic density functional approach. It is shown that depending on the dimensionless vector and diquark couplings of quark matter, the characteristics of the deconfinement phase transition are varied, allowing us to study the relation between those characteristics and mass-radius relations of hybrid stars. Moreover, we show that the quark matter equation of state can be nicely fitted by the AlfordBraby-Paris-Reddy model that gives a simple functional dependence between the most important parameters of the EOS and microscopic parameters of the initial Lagrangian. Based on it, we analyze the special points of the mass-radius diagram in which several mass-radius curves intersect. To find a distinguishable observational characteristic of the stars with the same mass and radius in the special

points and probe their interior composition we calculate the frequencies of the fundamental mode of radial oscillations.

**Poster session / 27**

## Constraining the Equation of State of Hybrid Stars Using Recent Information from Multidisciplinary Physics

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Abstract: At the ultrahigh densities existing in the core of neutron stars (NSs), it is expected that a phase transition from baryonic to deconfined quark matter may occur. Such a phase transition would affect the underlying equation of state (EoS) as well as the observable astrophysical properties of NSs. Comparison of EoS model predictions with astronomical data from multimessenger signals then provides us an opportunity to probe the behavior of dense matter. In this work, we restrict the allowed parameter space of EoS models in NSs for both nucleonic (relativistic mean field model) and quark matter (MIT bag model) sectors by imposing state-of-the-art constraints from nuclear calculations, multimessenger astrophysical data, and perturbative quantum chromodynamics (pQCD). We systematically investigate the effect of each constraint on the parameter space of uncertainties using a cutoff filter scheme, as well as the correlations among the parameters and with NS astrophysical observables. Using the constraints, we obtain limits for maximum NS mass, maximum central density, as well as for NS radii and tidal deformability. Although pQCD constraints are only effective at very high densities, they significantly reduce the parameter space of the quark model. We also conclude that astrophysical data supports high values of the bag parameter B and disfavors the existence of a pure quark matter core in hybrid stars.

**Poster session / 28**

## Baryonic screening masses at high temperatures from lattice QCD

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We present the first non-perturbative calculation on the lattice of the baryonic screening masses in a wide range of temperature from 1 GeV up to $T \sim 160$ GeV. The calculation has been carried out by Monte Carlo simulations and exploits a new strategy to simulate extremely high temperatures which was recently used to compute the non-singlet mesonic screening spectrum for the first time in the same range of temperatures. The baryonic screening masses have been computed with a few permille accuracy in the entire range of temperatures. On one hand the bulk of the masses is given by the free theory value $3\pi T$ plus a few percent contribution due to interactions which is still visible even at the highest temperature we simulated. On the other hand chiral symmetry restoration manifests itself through the degeneracy of the parity partners screening masses, as expected by Ward identities associated with the presence of chiral symmetry.

**Poster session / 29**

## Search for the critical point of strongly interacting matter by NA61/SHINE at the CERN SPS

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The existence and location of the QCD critical point are objects of both experimental and theoretical studies. The comprehensive data collected by NA61/SHINE at the CERN SPS during a two-dimensional scan in beam momentum (13*A*-150*A* GeV/*c*) and system size (*p*+*p*, *p*+Pb, Be+Be, Ar+Sc, Xe+La, Pb+Pb) allows for a systematic search for the critical point of strongly interacting matter through the analysis of the scaled factorial moments of the second and higher orders as a function of the phase space cell size in the transverse momentum plane.

The recent results will be presented for protons and negatively charged hadrons from Pb+Pb collisions at 13*A* ($\sqrt{s_{NN}}$ $\approx$ 5.1 GeV), 30*A* GeV/c ($\sqrt{s_{NN}}$ $\approx$ 7.6 GeV), and Ar+Sc at 13*A*, 19*A*, 30*A*, 40*A*, 75*A*, and 150*A* GeV/*c* beam momentum ($\sqrt{s_{NN}}$ $\approx$ 5.1-16.8 GeV). No intermittency signal is observed, which seems to be in tension with the corresponding results of the STAR Collaboration at the Relativistic Heavy Ion Collider (RHIC).

**Parallel session A / 30**

## Nontrivial topology in QCD, the Vacuum Energy and Large scale magnetic field of the Universe

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We discuss the dynamics of the topologically nontrivial sectors with non-trivial holonomy in strongly coupled QCD in the background of the expanding universe characterized by the Hubble scale $H \ll \Lambda_{QCD}$. We argue that the vacuum energy and the de Sitter phase emerge dynamically with the scale $\rho_{DE} \approx H\Lambda^3_{QCD} \approx (10^{-3}eV)^4$, which is amazingly close to the observed value. We argue that the key element for this idea to work is the presence of nontrivial holonomy in strongly coupled gauge theories. The effect is global in nature and cannot be formulated in terms of a gradient expansion in an effective local field theory. We also argue that anomalous coupling of the dark energy with electromagnetism generates the large cosmological magnetic field correlated on the scale of the visible Universe as observed. We test these ideas with solvable models for QCD being formulated on Hyperbolic space. We also comment on some lattice QCD results when the system is formulated on a curved background modelling the expanding Universe with nonzero $H$.

The talk is based on several recent papers:
1.Ariel Zhitnitsky, "Cosmological Magnetic Field and Dark Energy", Phys. Rev. D 99 (2019) 103518 , e-Print: 1902.07737
2.Ariel Zhitnitsky,"Dynamical de Sitter phase and nontrivial holonomy in strongly coupled gauge theories in an expanding universe,"
Phys. Rev. D 92, 043512 (2015), e-Print: 1505.05151

**Poster session / 31**

## Charged participants and their electromagnetic fields in an expanding fluid

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In high-energy heavy ion collisions, two relativistically moving nuclei collide with each other to form a hot dense matter known as quark-gluon plasma (QGP). Along with the QGP that is produced in the initial stage of heavy ion collisions, an intense and strong electromagnetic field is also thought to be produced, the main source of which are the spectators. Spectators are those which do not take part in the collision process whereas some nucleons do take part in the collision process which are known as the participants that form the fluid (QGP) which is also changed and can also produce an electromagnetic field during the entire process of the expansion. In this work, we study the electromagnetic fields produced by the charged participants in an expanding fluid. To gain analytical insight, we approximate the problem by solving the equations in a fixed background Bjorken flow, onto which we solve Maxwell's equations. The dynamical electromagnetic fields interact with the fluid's kinematic quantities such as the shear tensor and the expansion scalar, leading to additional non-trivial coupling. We use Green's function formalism to calculate the electromagnetic field for two test cases: a point source and a transverse charge distribution. The results show that the resulting magnetic field vanishes at very early times, grows, and eventually falls at later times. Interestingly the magnetic field does not die off fast enough as compared to that of the spectators.

**Plenary session / 32**

# Jet quenching in glasma

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We discuss the transverse momentum broadening of hard probes traversing an evolving glasma, which is the earliest phase of the matter produced in relativistic heavy-ion collisions. The coefficient $\hat{q}$ is calculated using the Fokker-Planck equation, and an expansion in the proper time $\tau$ which is applied to describe the temporal evolution of the glasma. The correlators of the chromodynamic fields that determine the Fokker-Planck collision terms, which in turn provide $\hat{q}$, are computed to fifth order in $\tau$. The momentum broadening is shown to rapidly grow in time and reach a magnitude of several $\mathrm{GeV}^2/\mathrm{fm}$. We show that the transient pre-equilibrium phase provides a contribution to the energy loss of hard probes which is comparable to that of the long lasting, hydrodynamically evolving, equilibrium phase.

**Plenary session / 34**

# Helicity conservation in relativistic perfect fluids

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We show that in isentropic relativistic fluids the total helicity of a perfect electromagnetic fluid is conserved. The helicity conservation law can be reshaped in the form of a chiral anomaly equation. For systems made up by massless fermions, we study how the helicity conservation law is modified in the presence of a chiral misbalance, when one has also to consider the effects of the chiral anomaly equation. We discuss on possible consequences of our findings in several systems.

**Poster session / 35**

## Dynamics of QCD chiral transition with real-time functional renormalization group

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In the chiral limit the complicated many-body dynamics around the second-order chiral phase transition of two-flavour QCD can be understood by appealing to universality. We present a novel formulation of real-time functional renormalization group that describes the stochastic hydrodynamic equations of motion for systems in the same dynamic universality class, which correspond to Model G in the Halperin-Hohenberg classification, and preserves all the relevant symmetries of such systems with reversible mode couplings. We show that the calculations indeed produce the non-trivial value z=d/2 for the dynamic critical exponent, where d is the number of spatial dimensions. We also extract the critical momentum dependence of the charge diffusion coefficient. We keep the degrees of freedom of the order parameters general and show that for N=3 we recover standard Model G dynamics and for N=2 we recover Model E dynamics.

**Parallel session A / 36**

## Neutron star radial oscillations with Delta Baryons

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Employing the density-dependent relativistic mean-field model, we investigate the effect of delta baryons on the radial oscillations of neutron and hyperon stars. A unified approach is employed to calculate the baryon-meson coupling constants for the spin-1/2 baryonic octet and the spin-3/2 decuplet. By solving the Sturm-Liouville boundary value problem and verifying its validity, we

calculate the 20 lowest eigenfrequencies and related oscillation functions of delta-admixed nuclear (NΔ) and hyperonic matter (NHΔ).
We see that the presence of the delta and hyperonic admixtures causes the lowest mode frequencies for N+Δ and N+H EoSs to be higher than those for the pure nucleonic matter [1]. With the inclusion of hyperons and Δs, the distance between succeeding modes also increases.

References

1. Ishfaq A. Rather, K. D. Marquez, G. Panotopoulos, I. Lopes, arXiv preprint arXiv:2303.11006 (2023).

**Parallel session B** / **37**

## How baryons appear in low-energy QCD: Domain-wall Skyrmion phase in strong magnetic fields

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Low-energy dynamics of QCD can be described by pion degrees of freedom in terms of the chiral perturbation theory (ChPT). A chiral soliton lattice (CSL), an array of solitons, is the ground state due to the chiral anomaly in the presence of a magnetic field larger than a certain critical value at finite density. Here, we show in a model-independent and fully analytic manner (at the leading order of ChPT) that the CSL phase transits to a domain-wall Skyrmion phase when the chemical potential is larger than the critical value $\mu_c = 16\pi f_\pi^2/(3m_\pi) \sim 1.03\,\mathrm{GeV}$ with the pion's decay constant $f_\pi$ and mass $m_\pi$, which can be regarded as the nuclear saturation density. There spontaneously appear stable two-dimensional Skyrmions or lumps on a soliton surface, which can be viewed as three-dimensional Skyrmions carrying even baryon numbers from the bulk despite no Skyrme term. They behave as superconducting rings with persistent currents due to a charged pion condensation, and areas of the rings' interiors are quantized. This phase is in scope of future heavy-ion collider experiments.
This talk is based on arXiv:2304.02940 [hep-ph].

**Plenary session** / **38**

## Building a realistic neutron star from holography

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I will present latest results within the holographic Witten-Sakai-Sugimoto model for dense matter at nonzero baryon and isospin chemical potentials. In particular, I will discuss the phase structure including phases where baryonic matter and meson condensates coexist. As an application I will show that the results can be used to construct entire neutron stars, including the inhomogeneous crust. These 'holographic stars' obey the astrophysical constraints on mass, radius, and tidal deformability and can be used to make further predictions for these quantities.

**Parallel session A / 39**

## Hadron scatterings in small chemical potential

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We discuss hadron scatterings in zero temperature and small chemical potential ($\mu$). First, we derive the dispersion relation of a single hadron from the Euclidean-time dependence of the 2-point correlation function. It is found that the energy has linear behavior with respect to $\mu$. We then formulate the HAL QCD method in small $\mu$, where we extract scattering amplitudes via the interaction potentials. It indicates that the amplitude is independent of $\mu$ for any scattering unless the spontaneous breaking occurs. Furthermore, we demonstrate this conclusion by analyzing S-wave scatterings of two pions with isospin $I = 2$ and two scalar diquarks in two-color QCD using lattice simulation. The results of the scattering amplitudes in different chemical potentials agree with each other, which is consistent with our conclusion.

**Poster session / 40**

## Universality of jet energy loss in the quark-gluon plasma using Bayesian inference

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Experimental data on a wide range of jet observables measured in heavy ion collisions provide a rich picture of the modification of jets as perturbative probes and of the properties of the quark-gluon plasma that is formed in these collisions. However, their interpretation is often limited by the assumptions of specific quenching models, and it remains a challenge to establish model-independent statements about the universality of different jet quenching observables.

In this work, we address this issue by proposing a treatment that is agnostic to the details of the jet-medium interactions and relies only on the universality of quark and gluon quenching in different jet observables. We use Bayesian inference to constrain the parameterisation of the energy loss of quark- and gluon-initiated jets in a data-driven manner. This constraint is primarily performed using the inclusive jet pT spectrum, for which the quark/gluon fraction varies across rapidity. We then predict the observed jet asymmetry in di-jet and boson-jet measurements, providing evidence for the universality of quenching effects.

Furthermore, we examine the extracted Casimir scaling of jet quenching and the role of resolution effects in constraining the early, perturbative jet evolution using these data-driven methods. This study provides a new perspective on the universality of jet quenching in heavy ion collisions, free from the assumptions of specific models.

**Poster session / 42**

## QCD Anderson transition with overlap valence quarks on a twisted-mass sea

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In this work we probe the QCD Anderson transition by studying spectral distributions of the massless overlap operator on gauge configurations created by the *twisted mass at finite temperature collaboration* (tmfT) with 2+1+1 flavors of dynamical quarks and the Iwasaki gauge action. We assess finite-size and discretization effects by considering two different lattice spacings and several physical volumes, and mimic the approach to the continuum limit through stereographic projection. Fitting the inflection points of the participation ratios of the overlap Dirac eigenmodes, we obtain estimates of the temperature dependence of the mobility edge, below which quark modes are localized. We observe that it is well-described by a quadradic polynomial and systematically vanishes at temperatures below the pseudo-critical one of the chiral transition. In fact, our best estimates within errors overlap with that of the chiral phase transition temperature of QCD in the chiral limit.

arXiv-Link to the paper

**Parallel session A / 43**

## Three-gluon vertex in Landau gauge from lattice QCD: planar degeneracy and beyond.

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We present an extensive study of the three-gluon vertex in Landau-gauge using quenched lattice-QCD calculations. The main goal of this work is exploring the features of the vertex beyond the well-known symmetric and soft-gluon kinematical configurations, and extend the results for those two kinematics to the general case of three different momenta $q$, $r$ and $p$ are only restricted by the condition $q + r + p = 0$ imposed by momentum conservation. We will show how a rational use of Bose symmetry in the choice of the tensors used to develop the transversely projected vertex allows to unveil a quite simple description of the vertex form-factors in the non-perturbative regime of QCD in terms of a single momentum scale formed by the sum of the squares of the three incoming four-momenta $s^2 = (q^2 + r^2 + p^2)/2$. We will evidence as well a clear dominance of the tree-level form factor for any kinematical configuration, something that allows a quite simple description of the vertex in terms of this contribution. The phenomenological implications of these findings will as well be discussed.

**Poster session / 44**

## On gauge equivariant neural networks and global symmetries

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Recently, efforts have been increased to incorporate various symmetries into the architectures of neural networks. Lattice gauge equivariant Convolutional Neural Networks (L-CNNs) 1 are designed to respect local gauge symmetry, an essential component in lattice gauge theories. This makes them a promising approximator of gauge covariant functions on a lattice. In addition to local symmetries, many observables exhibit global symmetries. This calls for an extension of the L-CNN beyond translational symmetry to a more general symmetry group, including e.g. rotations and reflections [2].

In this talk, I will review some essential layers of the L-CNN and discuss why they can be used to approximate any gauge equivariant function on the lattice. Then, I will examine how these layers can be generalized to respect not only global translations, but also rotations and reflections. Finally, I will discuss globally and locally equivariant activation functions and pooling layers.

1 M. Favoni, A. Ipp, D. I. Müller, D. Schuh, Phys. Rev. Lett. 128 (2022), 032003, [arXiv:2012.12901]
[2] J. Aronsson, D. I. Müller, D. Schuh [arXiv:2303.11448]

**Poster session / 45**

## The QCD chiral phase transition for various numbers of flavors at imaginary baryon chemical potential

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In order to constrain the QCD phase diagram with physical quark masses, the QCD chiral phase transition in the massless limit is investigated, although this is a challenging problem for lattice QCD. In 1984, Pisarski and Wilczek predicted a first-order transition for $N_\mathrm{f} \geq 3$, based on RG investigations of a linear sigma model in three dimensions, which was supported by lattice QCD simulations on coarse lattices. However, recent lattice QCD results from our group provide strong evidence for a second order chiral phase transition for $N_\mathrm{f} = 2 - 6$ massless quark flavors. It was demonstrated that the first-order chiral transitions, observed on coarse lattices, terminate at a tricritical lattice spacing, and are thus not connected to the continuum chiral limit. As a consequence, the chiral transition in the continuum is of second order, as it is always approached from a crossover region. Adopting the same strategy, we investigate the nature of the chiral phase transition as a function of the number of quark flavors and the lattice spacing for a fixed imaginary baryon chemical potential. We find that first-order transitions, observed on coarse lattices, disappear towards the continuum limit, which coincides with the situation at zero density.

**Poster session / 46**

## The temperature of the QCD chiral transition at its tricritical point

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The nature of the QCD phase transition in the chiral limit constitutes a challenging problem for lattice QCD as it is not directly simulable. Its study, however, provides constraints on the phase diagram at the physical point. Recently, the lattice chiral limit was approached by mapping out the chiral critical surface separating the first-order region from the crossover region in an enlarged parameter space, which consists of the gauge coupling, a variable number of quark flavours, their masses, and the lattice spacing. Based on simulations of lattice QCD with standard staggered quarks, it was found that for all $N_f \leq 7$ there exists a minimal and tricritical lattice spacing $a^{tric}$, where the chiral transition changes from first order (above) to second order (below). The first-order region thus constitutes a cutoff effect and the transition in the continuum chiral limit is of second order for all $N_f \leq 7$. In the current work we determine the associated temperatures $T^{tric}(N_f, a^{tric})$ at those lattice spacings. Further simulations on finer lattices will allow us to determine the location of the tricritical point in the continuum limit.

**Poster session / 47**

## Dynamic critical behavior of the O(4) chiral transition

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Evidence suggest that in the chiral limit, the QCD phase transition becomes a second order phase-transition in the $O(4)$ universality class. Since real world QCD is not too far from the chiral limit, it is thus interesting to explore the consequences for static and dynamic correlation functions. Since, in the vicinity of the critical point, the physics is governed by universal scaling exponents and scaling functions, we can exploit this universality to address this question.
We employ classical-statistical real-time simulations to extract the dynamic critical behavior of an O(4) linear sigma model in the static and dynamic universality class of QCD in the chiral limit. By comparing results for the dynamics with and without a conversed energy and O(4) charges, we can realize the Model A and Model G dynamic universality classes in the classification scheme of Halperin and Hohenberg, for which we compute the dynamic critical exponent $z$ of and further extract the relevant dynamic scaling functions for the spectral function of the order parameter.

**Poster session / 48**

## Thermalization and quark production in spatially homogeneous system of gluons

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We present a full set of the Boltzmann Equation in Diffusion Approximation (BEDA) for studying thermal equilibration and quark production in a system of quarks and gluons. With BEDA, we analyse the evolution of spatially homogeneous system initially populated bu gluons. We observe that soft partons, dominantly produced via medium-induced radiation, rapidly fill a thermal distribution with an effective (time-dependent) temperature and an effective Baryon chemical potential during the entire process. If quark production is not allowed, the thermalization is achieved after three distinct stages in the under-populated scenario, meanwhile it only requires of two phases for over-populated systems. When quarks appear in the calculation, the thermal evolution of the system is parametrically identical. In this case, quarks are produced initially due to $g \leftrightarrow q\bar{q}$ , and $gg \leftrightarrow q\bar{q}$ will appear later in the evolution as a relevant process.

**Parallel session B / 49**

## Towards a Stability Analysis of Inhomogeneous Phases in QCD

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Understanding the phase structure of Quantum Chromodynamics (QCD) is of paramount importance for nuclear and particle physics. At large densities and low temperatures, many complex phases are expected to appear. This is where the lattice sign problem is unavoidable and extrapolation methods such as Taylor expansions are out-of-bounds. Alongside colour-superconductivity, quarkyonic matter, and so on, the possibility of a crystalline phase has been studied for over twenty years. In simplified models of QCD such as NJL or quark-meson models, these phases are present. However, no unambiguous determination exists that they appear in QCD. In our work, we develop a method of stability analysis that is compatible with full QCD via Dyson-Schwinger Equations. We present some results for homogeneous phase transitions which illustrate well how the method works and discuss what is to be done for a definite stability analysis of inhomogeneous phases in QCD.

**Parallel session C / 50**

## Massive thermal loop integrals and bulk viscosity in quark matter

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Observations of neutron stars and their mergers have opened a new avenue and motivation for studying QCD matter at very high densities. When studying neutron star mergers in particular, it is vital to understand effects of both the temperature and, for transport quantities such as the bulk viscosity, the quark masses.

Unfortunately, in loop calculations at finite density and/or temperature, taking into account the masses of constituent particles generally leads to analytically intractable and often numerically cumbersome expressions.

By introducing an approximation scheme valid in regions of the phase diagram where a mass $m$ scales numerically with a power of the coupling, $m \propto g^r T$ or $m \propto g^r \mu$, such integrals can be expanded to what is often a much more efficient form, while sacrificing little accuracy.

The approximation has been applied to the thermodynamics of dense pQCD at finite density and temperature with a finite strange quark mass to NNLO, showing excellent agreement with full mass effects.

Moreover, in an ongoing work the scheme is used to study the bulk viscosity, with applications to neutron star mergers in mind. The perturbative values will be combined with results from holographic models, extendable to lower baryon densities, in order to find a prediction for the bulk viscosity valid at densities down to those of realistic merger scenarios

**Parallel session A / 51**

## QCD thermodynamics with dynamical chiral fermions

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We discuss the properties of Quantum Chromodynamics at finite temperature obtained by means of lattice simulations with the overlap fermion discretization. This fermion discretization preserves chiral symmetry even at finite lattice spacing. We present the details of the formulation and discuss the properties of the chiral thermal phase transition. We compare the results obtained with the chiral fermions with predictions by other fermion discretizations.

**Poster session / 52**

## Extreme plasma physics with QED effects on a quantum computer

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Quantum Electrodynamical effects are prevalent in the complex, nonlinear dynamics of plasmas in extreme astrophysical environments (neutron stars, pulsars, black-hole accretion disks) and intense laser interaction with matter. Understanding of these systems has advanced in parallel with the development of the particle-in-cell numerical framework, where the electromagnetic fields created by and interacting with the particles are mediated by a grid, thus reducing the computational complexity. This method shares some similarities with the lattice methods used in QCD/QED: both aim to achieve self-consistency in the simulations, they apply discretization/grid-based representation (either of the phase-space or of space-time), and have the ability to capture collective dynamics.

Despite the success of both numerical frameworks, it is believed that quantum computers can provide significant speedups and memory saving when simulating physical systems. However, these computers are naturally applicable only to a certain kind of problems, that can be expressed in a form equivalent to the linear Schrödinger equation. In the last few years many new algorithms

have been designed to map problems that do not strictly satisfy this condition to a quantum circuit. Current general public-access quantum computers only allow for ∼20 qubits at a time and short circuit depths (∼100 gates before results get corrupted by decoherence). This has restricted simulation capabilities on real quantum computers to testing toy models for most of the problems of interest. Variational algorithms are promising for the near term quantum computers as they present three main advantages: their circuits are shorter than in regular Hamiltonian simulation, they allow for reconstruction of the wavefunction at each timestep and they can be extended to nonlinear dynamics. While quantum algorithms have been successfully applied in areas such as quantum chemistry and quantum field theory, their study in plasma physics is still at its infancy.

In this work we apply quantum computing techniques to extreme plasma physics scenarios where QED phenomena are present and the dynamics is inherently nonlinear. By bridging the gap between traditional simulation methods and quantum frameworks, we aim to advance our understanding of plasma physics and its connection with quantum field theory.

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**Poster session / 53**

## Study of the p$\Lambda$ interaction in small collision systems using a common emission source

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In femtoscopy, the correlations between low relative momentum particles can be linked to their emission source function and final state interaction. In a recent precision measurement of the p$\Lambda$ correlation function at the LHC, a deviation was found from the state-of-the-art chiral effective field theory model. If this discrepancy is related to the p$\Lambda$ interaction, it would have important implications for the study of the nuclear equation of state and modeling of neutron stars.

This contribution introduces a new Monte Carlo model, called CECA, capable of evaluating the source function, by generating the spatial and momentum coordinates of single particles in small collision systems, at the time of hadronization. For this purpose, relativistic effects are taken into consideration, as well as the production of particles through intermediate short-lived resonances. Assuming a common emission source for all hadrons, measured proton-proton correlation functions by ALICE are used to constrain the source function. This allows the use of correlation techniques to access the p$\Lambda$ interaction in previously unexplored low-energy regions. The obtained scattering length is smaller than the currently accepted values, highlighting the importance of using femtoscopy data as a complementary way of constraining the theory.

**Poster session / 54**

## Inhomogeneous phases in dense nuclear matter

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Quantum Chromodynamics at high densities is likely to exhibit inhomogeneous phases. The chiral density wave is a simple ansatz for a class of such phases, and it has been extensively studied in

models based on quark degrees of freedom. We are exploring the possibility of a chiral density wave in a nucleon-meson model, taking into account the contribution of the Dirac sea. We find that for small pion mass, even though in the homogeneous case the chiral transition is a crossover, the chiral density wave is energetically favored in a certain density regime. Our model allows us to link the existence of this regime to the properties of nuclear matter at saturation. For the physical pion mass, we find that the chiral density wave is disfavored and more complicated inhomogeneous configurations may appear.

**Parallel session C / 55**

## Recent results from NA61/SHINE on the onset of deconfinement studies and particle production

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NA61/SHINE at the CERN SPS is a fixed-target experiment pursuing a rich physics program. The main goal of the NA61 ion program is to explore the most interesting region of the phase diagram of strongly interacting matter. Within the expected (T - mu_B) interval we plan to study the properties of the onset of deconfinement and to search for the signatures of the critical point. Such a 2D scan of the phase diagram is performed by varying beam momentum (13A-150(8)A GeV/c) and system size (p+p, p+Pb, Be+Be, Ar+Sc, Xe+La, Pb+Pb).

Thanks to its large acceptance and reasonable particle identification NA61/SHINE is well-suited for studies of particle production mechanisms. In this contribution results on the onset of deconfinement as well as on particle production will be reported.

**Poster session / 56**

## Spin polarization under gravity from Schwinger-Keldysh formalism

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We employ the Schwinger-Keldysh (SK) formalism to study the spin polarization in a medium induced by the metric perturbation diagrammatically. The results in the near-equilibrium limit can be used to describe the effects of hydrodynamic gradient on the polarization (e.g. shear-induced polarization). Moreover, the results obtained from SK formalism may apply to far-from-equilibrium situations that are relevant to the early stage of a heavy-ion collisions. We also demonstrate the matching between diagrammatic calculations and quantum kinetic theory.

**Parallel session A / 57**

## Relativistic description of neutron star matter with latest experimental and observational constraints

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Astrophysical observations of neutron stars allow us to study the physics of matter at extreme conditions which are beyond the scope of any terrestrial experiments. In this work, we perform a Bayesian analysis putting together the available knowledge from the nuclear physics experiments, observations of different X-ray sources, and gravitational wave events to constrain the equation of state of supranuclear matter. In particular, we employ a covariant density functional to incorporate the uncertainties of the saturation properties of nuclear matter i.e. the symmetry energy and its slope parameter, the incompressibility, the effective mass of the nucleon, the binding energy per nucleon, and the saturation density. Then, we investigate whether it is possible to reconcile the inferred values of those quantities from the multimessenger data, and finally compute a joint posterior distribution of these quantities incorporating all the available knowledge.

**Poster session / 58**

## Pressure of cold quark matter: Next-to-leading logarithm

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Accurately understanding the thermodynamics of cold and dense deconfined quark matter plays an essential role in constraining the behavior of QCD matter inside the ultra-dense cores of neutron stars. Indeed, the past few years have witnessed promising steps towards completing the $N^3LO$ term in the weak-coupling expansion of the cold and dense QCD pressure. In this talk, I will present the state-of-the-art result for the said quantity up to and including a new $\alpha_s^3 \ln \alpha_s$ term. This advancement has been made possible by the recently determined NLO hard-thermal-loop gluon self-energy, allowing the computation of the so-called mixed sector of the pressure arising from the interactions between long- and short-wavelength gluons. The new contribution decreases the uncertainty of the high-density pressure, and I will discuss its implications on the neutron-star equation of state.

**Parallel session A / 59**

## Delta baryons in (hot) neutron stars

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By applying a relativistic mean-field description of neutron star matter with density dependent couplings, we analyse the properties of nucleonic matter with delta baryons and nucleonic matter with hyperons and delta baryons. We calculate the baryon-meson coupling constants for the spin-1/2 baryonic octet and spin-3/2 decuplet in a unified approach relying on symmetry arguments such as the fact that the Yukawa couplings, present in the Lagrangian density of the Walecka-type models, must be an invariant under SU(3) and SU(6) group transformations. The coupling constants of the baryon with the scalar σ meson are fixed to reproduce the known potential depths for the hyperons and Δ resonances, in an approach that can be extended to all particles. We then apply the calculated coupling constants to study neutron star matter with hyperons and deltas admixed to its composition. We conclude that the Δ- is by far the most important exotic particle that can be present in the neutron star interior. It is always present, independent of the chosen parameterization, and might appear in almost every known neutron star, once its onset happens at very low density. Yet, its presence affects the astrophysical properties of the canonical 1.4 Mo star, and, in some cases, it can even contribute to an increase in the maximum mass reached. We also study the nuclear isentropic equation of state for a stellar matter composed of nucleons, hyperons, and Δ-resonances. We investigate different snapshots of the evolution of a neutron star, from its birth as a lepton-rich protoneutron star in the aftermath of a supernova explosion to a lepton-poor regime when the star starts cooling to a catalyzed configuration. We observe that Λ is the dominant exotic particle in the star at different entropies for both neutrino-free and neutrino-trapped stellar matter. For a fixed entropy, the inclusion of new particles (hyperons and/or delta resonances) in the stellar matter decreases the temperature. Also, an increase in entropy per baryon (1to2) with decreasing lepton number density (0.4to0.2) leads to an increase in stellar radii and a decrease in its mass due to neutrino diffusion. In the neutrino transparent matter, the radii decrease from entropy per baryon 2 to T=0 without a significant change in stellar mass.

**Plenary session / 60**

## Hydrodynamics of fluctuations and maximum entropy freeze-out

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Fluctuations play crucial role in determining properties of the QCD equation of state and transport in heavy-ion collision experiments. Recent progress in understanding evolution of fluctuations in relativistic hydrodynamics aims at providing predictive description of the fluctuations, including their non-gaussianity. The problem of connecting the predictions of hydrodynamics with experimental measurements of fluctuations requires a description of freeze-out which, similar to hydrodynamics itself, fulfills conservation laws on event-by-event basis. The maximum entropy approach elegantly solves this long-standing problem.
1 An, Basar, Stephanov, and Yee, Phys.Rev.Lett. 127 (2021) 7, 072301 [arxiv:2009.10742]; arxiv/221213029
[2] Pradeep, Stephanov, Phys.Rev.Lett. 130 (2023) 16, 162301 [arxiv:2211.09142]

**Plenary session / 61**

## The critical endpoint at large N_c

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The phase diagram of QCD is investigated by varying number of colors N_c within a Polyakov loop quark-meson chiral model. In particular, our attention is focused on the critical point(s); the critical point present for N_c=3 moves toward the mu_q-axis and disappears as soon as the number of color is increased. Yet, a distinct critical point emerges along the temperature axis for N_c=53

and moves toward finite density when increasing N_c further. Thus, the phase diagram at large N_c looks different than the N_c=3 results, since in this case the first-order transition is in the upper-left, while the crossover is in the lower-right regions of the (mu_B-T)-plane. The N_c dependent pressure is also evaluated, which shows a scaling with N_c^0 in the confined and chirally broken phase and with N_c^2 in the deconfined one. Moreover, a chirally symmetric but confined "quarkyonic phase" can be seen at large density and moderate temperature with a pressure proportional to N_c.

**Parallel session B / 62**

## Does quark-gluon plasma feature an extended hydrodynamic regime?

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In the view that the short wavelength response can be important in small colliding systems and at early-times of a heavy-ion collision, we investigate the response of the near-equilibrium quark-gluon plasma (QGP) to perturbation at non-hydrodynamic gradients. We propose a conceivable scenario under which sound mode continues to dominate the medium response in this regime. Such a scenario has been observed experimentally for various liquids and liquid metals. We further show this extended hydrodynamic regime (EHR) indeed exists for both the weakly-coupled kinetic equation in the relaxation time approximation (RTA) and the strongly-coupled N=4 supersymmetric Yang-Mills (SYM) theory. We construct a simple but nontrivial extension of Müeller-Isareal-Stewart (MIS) theory, namely MIS*, and demonstrate that it describes EHR response for both RTA and SYM theory. Finally, we discuss the possible connection between the extended hydrodynamic regime and observed collectivity in small colliding systems.

Ref: Weiyao Ke and Yi Yin, ArXiv: 2208.01046, Phys.Rev.Lett in press

**Poster session / 63**

## Exploring the QCD Phase Transitions with Imaginary Rotation

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In this talk, I will report our recent achievements based on refs. [1,2]. Below are highlights from our results.

**Confinement under Imaginary Rotation**
STAR Collaboration found nuclear matter rotating at $\omega \sim 10^{22}\ s^{-1}$ in heavy ion collisions. Neutron stars can also spin at $\omega \sim 10^3\ s^{-1}$. It is interesting but difficult to unravel mysteries in understanding how quarks and gluons behave in rapidly rotating matter. In our study, we considered the

Polyakov loop potential at high $T$ with "imaginary"angular velocity. Imaginary rotation provides a well-defined formulation for investigating the QCD phase transition.

**Perturbative Realization of Confinement**
In ref. 1, we perturbatively calculated the Polyakov loop potential for the imaginary rotating Yang-Mills system. With increasing angular velocity, we found a phase transition to confinement around $\omega/T \simeq i\pi/2$. Furthermore, we argued that this perturbative confined phase can be smoothly connected to the hadronic phase, i.e., the adiabatic continuity can be realized.

**Chiral Symmetry Breaking**
In ref. [2], we introduce fermions at finite chemical potential and investigated the chiral phase transition. Our results show the spontaneous breaking of chiral symmetry in our previously found confined phase with imaginary angular velocity for any high $T$.

**Toward Real Rotation**
The physics goal is to analytically continue the results to real rotation, for which the system size must be finite due to the causality condition. In ref. [2], we discuss the boundary condition for the finite size system.

1 S. Chen, K. Fukushima, and Y. Shimada, *Perturbative Confinement in Thermal Yang-Mills Theories Induced by Imaginary Angular Velocity*, Phys.Rev.Lett. 129 (2022) 24, 242002.
[2] S. Chen, K. Fukushima, and Y. Shimada, *Chiral Symmetry Breaking with Perturbative Confinement at Finite Imaginary Angular Velocity*, in completion.

**Invited Speaker Session / 64**

## A novel technique to access the residual strong interaction among hadrons at the LHC

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The ALICE collaboration has delivered in recent years unprecedented precision information on the residual strong interaction for several hadron pairs in the strange quark sector. These results have been obtained by analyzing the momentum correlation of particle pairs produced in pp and p-Pb collisions at the LHC. In such colliding systems hadrons are emitted at relative distances of the order of 1 fm, therefore, the effect of the short range strong interaction is reflected in the measured correlation function. This observable has been employed to test for the first time lattice QCD calculations and also to challenge the effective field theory results. In this contribution, the first measurement of the p-ϕ and Λ–K± correlations in high-multiplicity pp collisions at √s = 13 TeV will be shown. The extracted scattering parameters will be presented and the implications for the corresponding theoretical models will be discussed. In particular, evidence of a spin-½ p-ϕ bound state has been recently found by interpreting the measured p-ϕ correlation function with the help of Lattice calculation for the spin 3/2 component. For Λ–K− system, the first experimental evidence of the Ξ(1620) decaying into Λ–K− pairs has been observed, with strong implications on the existing Λ-K̄ interaction models. In the last part of the talk, the extension of such correlation studies by ALICE to the three-body sector will be discussed. It will be demonstrated that three-baryon systems can be precisely measured at the LHC and that light nuclei can be exploited for such studies as well, offering a new opportunity to investigate many-body nuclear forces with innovative methods.

**Poster session / 65**

## Femtoscopic analysis of identical charged kaons in Pb–Pb collisions at 5.02 TeV.

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Femtoscopy is an important technique for studying space–time properties of emission source created in heavy-ion collisions such as spatial size, evolution time, collective flow effects, etc. In this contribution, we present the results of a femtoscopic analysis of identical charged-kaon pair correlations in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02~TeV. The results of the one- and three-dimensional analyses show that the kaon femtoscopic radii get smaller from central to peripheral collisions and decrease with increasing transverse momentum. According to hydrokinetic models, it might be explained by the radial expansion of a particle-emitting source. A comparison between the obtained three-dimensional radii and the integrated hydrokinetic model calculations for two particlization temperatures corresponding to two different equations of state has been performed. The extracted one-dimensional radii presented as a function of collision multiplicity are compared with kaon source sizes obtained for different energy, Pb–Pb at 2.76~TeV, and collision systems: p–Pb at 5.02~TeV, and pp at 7~TeV. The maximal emission times for kaons in a wide centrality range (from 0 to 90\%) are also extracted.

**Parallel session C / 66**

## K- nunleon/nuclei interactions studies by AMADEUS at DAFNE

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K- nunleon/nuclei interactions studies by AMADEUS at DAFNE

Experimental investigation of the strong interaction in the low-energy regime is mandatory to constrain models of the low-energy meson-baryon interaction, with implications in several fields, ranging from the search for exotic mesic nuclear bound states, to the structure of compact astrophysical objects like the neutron stars.
In this talk we will review the studies performed by the AMADEUS experiment, at the DAFNE collider of LNF-INFN, of the low-energy kaon-nucleon/nuclei interaction processes. More in detail we will report on the measurement of the non-resonant hyperon pion formation amplitude below the K-N threshold, of the branching ratios and of the low-energy cross sections of the K- multi-nucleon absorptions on various light nuclear targets. The recent, precise, determination of the $\mathrm{K}^{-}\mathrm{p} \rightarrow (\Sigma^0/\Lambda)\,\pi^0$ cross sections close to threshold will be shown. Future perspectives on the measurement of two- and three-body hyperon-nucleon interaction will be outlined.

**Parallel session A / 68**

## Higgs-confinement continuity in light of particle-vortex statistics

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In gauge theories with fundamental matters, the Higgs and confining regimes are believed to be smoothly connected. This Higgs-confinement continuity forms the foundation of the quark-hadron continuity conjecture, which is a crossover scenario from the nuclear superfluidity phase to the color superconducting phase in dense QCD. Certain superfluid gauge theories, including dense QCD, exhibit nontrivial Aharonov-Bohm (AB) phases around vortices in the Higgs regime. Recently, there has been a growing interest in the question of whether this nontrivial AB phase necessitates a Higgs-confinement transition. In this presentation, I will address this question in favor of Higgs-confinement continuity in relevant gauge-Higgs models. By explicit calculations in lattice models, we demonstrate that the AB phase remains continuous (or even constant when some symmetry constrains the AB phase) across a region bridging Higgs and confining regimes. This finding, in particular, supports the possibility of the quark-hadron continuity. This talk is based on arXiv:2303.02129.

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## How is Hydrodynamics in pp and pA collisions possible?

**Author:** Giorgio Torrieri[None]

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The observation, in hadronic collisions, of "ideal fluid" type behavior in systems of a comparatively small number of particles, presents a conceptual puzzle, since the way we usually derive hydrodynamics is via approximating "many" particles as a continuum. I will argue that making sense of this requires re-deriving relativistic hydrodynamics as a "bottom-up" theory, with no reference to microscopic physics except the local emergence of a thermalized system. We attempt to do this using basic statistical mechanics, and find the appearance of a gauge-like redundancy hidden within relativistic dissipative hydrodynamics, arising from the fluctuation-dissipation theorem. This might lead to the apparently counter-intuitive conclusion that in the small viscosity limit it might indeed be that smaller systems could thermalize faster via an "inverse attractor" mechanism.

Based on https://arxiv.org/abs/2109.06389

**Poster session / 70**

## Schwinger model at finite temperature and density using quantum imaginary time evolution

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We have studied the chiral and confinement-screening phase transitions in the Schwinger model at finite temperature and density using the quantum algorithm.
The theoretical exploration of the phase diagram for strongly interacting systems at finite temperature and density remains incomplete mainly due to the sign problem in the conventional Lattice Monte Carlo method.
However, quantum computation offers a promising solution to circumvent the sign problem as it deals with quantum field theories in the Hamiltonian formalism.

The preparation of thermal states on quantum circuits is a non-trivial challenge.
We have successfully implemented the thermal state preparation on quantum circuits using a theoretical framework known as Thermal Pure Quantum states (TPQs) and the Quantum Imaginary Time Evolution (QITE) algorithm.
The details of the algorithm, our improvements, and the results will be presented in the talk.

**Parallel session C / 71**

## Transient effects of charge diffusion on electromagnetic field in heavy-ion collision

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We study charge diffusion in relativistic resistive second-order dissipative magnetohydrodynamics. In this theory, charge diffusion is not simply given by the standard Navier-Stokes form of Ohm's law, but by an evolution equation which ensures causality and stability. This, in turn, leads to transient effects in the charge-diffusion current, the nature of which depends on the particular values of the electrical conductivity and the charge-diffusion relaxation time. The ensuing equations of motion are of so-called stiff character, which requires special care when solving them numerically. To this end, we specifically develop an implicit-explicit Runge-Kutta method for solving relativistic resistive second-order dissipative magnetohydrodynamics and subject it to various tests. We then study the system's evolution in a simplified 1+1-dimensional scenario for a heavy-ion collision, where matter and electromagnetic fields are assumed to be transversely homogeneous, and investigate the cases of an initially nonexpanding fluid and a fluid initially expanding according to a Bjorken scaling flow. In the latter case, the scale invariance is broken by the ensuing self-consistent dynamics of matter and electromagnetic fields. However, the breaking becomes quantitatively important only if the electromagnetic fields are sufficiently strong. The breaking of scale invariance is larger for smaller values of the conductivity. Aspects of entropy production from charge-diffusion currents and stability are also discussed.

**Poster session / 72**

## Reanalysis of critical exponents for the O(N) model via a hydrodynamic approach to the Functional Renormalization Group

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We compute the critical exponents of the O(N) model within the Functional Renormalization Group (FRG) approach. We use recent advances which are based on the observation that the FRG flow equation can be put into the form of an advection-diffusion equation. This allows to employ well-tested

hydrodynamical algorithms for its solution. In this study we work in the local potential approximation (LPA) for the effective average action and put special emphasis on estimating the various sources of errors. Our results complement previous results for the critical exponents obtained within the FRG approach in LPA. Despite the limitations imposed by restricting the discussion to the LPA, the results compare favorably with those obtained via other methods.

**Poster session / 73**

## From fluid dynamics to RG flow studies of phase transitions

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We employ a numerical method borrowed from fluid dynamics to solve functional renormalization group flow equations for systems with multiple competing order parameters. We demonstrate the application of our approach with the aid of zerodimensional quantum field theories which allow us to mimic specific situations also encountered in higher-dimensional theories. Our results suggest that this novel approach indeed represents a promising tool for investigations of spontaneous symmetry breaking and phase transitions in the theory of the strong interaction.

**Poster session / 74**

## Speed of Sound of strong-interaction matter at supranuclear densities

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Towards the equation of state of neutron stars, we present results for the zero-temperature thermodynamics of strong-interaction matter at high densities which have been obtained based on first-principles functional Renormalization Group studies. In particular, we discuss gluon vacuum polarization effects on the equation of state and the speed of sound in a (semi-)perturbative manner. Eventually, we present consistent constraints for the speed of sound at supranuclear densities by taking into account results from studies based the existence of a (color-) superconducting gap.

**Parallel session B / 75**

## The sharpness of the quark-hadron transition and the properties of hybrid stars

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In this work we propose a new type of hybrid star and study its properties. The quark phase is described by the MIT bag model with repulsive vector interactions and the hadron phase is described by the HLPS model, which is consistent with chiral effective field theory. In the junction of the two

phases there can be a discontinuity (a "jump") in the energy density, which is related to the latent heat of the strongly interacting matter. We use a prescription to match the two phases, in which we can control the sharpness of the transition. We study how changes in the sharpness affect the mass, radius, tidal deformability and the speed of sound in the star.

**Plenary session / 76**

## Magnetic enhancement of baryon confinement modeled via a deformed Skyrmion

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The gigantic magnetic field, $B$, is expected in the heavy-ion collision and in the neutron star cores. The phase structure under $B$ has been well investigated, but the hadron properties are not fully understood. Recently, the lattice QCD found that even neutral meson masses are significantly affected by the $B$ effects. Then, what about baryons?

In this talk, I would like to emphasize that the $B$-modified baryon properties are far more nontrivial than naively thought. In particular, I propose a new approach to think about the baryon confinement based on our paper, e-Print:2303.04692 [hep-th].

– *Confinement from the Pressure Balance* –

The pressure distribution inside the proton is measurable by the deeply virtual Compton scattering, and the confinement means that the inner positive pressure is balanced by the outer confining negative pressure, i.e.,
$\int d^3x\, p(x) = 0,$
which can be confirmed in concrete calculations, e.g., in the Skyrme model. This pressure balance is guaranteed by the virial theorem.

– *Magnetic Enhancement of Confinement* –

The above sum rule is changed by $B$, in an intriguing way as
$\int d^3x\, p(x) = -\frac{2}{3}$
$boldsymbol\mu \cdot$
$boldsymbol B,$
where $\mu$ is the magnetic moment. Using the deformed Skyrmion under $B$, we found that
$boldsymbol\mu \cdot$
$boldsymbol B < 0$, which means that confinement is assisted by an extra pressure from the magnetic field!

In this talk, I will report this novel view of confinement as well as exciting results for the quantization (protons and neutrons), the mass changes, and the magnetic moments as functions of $B$.

**Parallel session C / 77**

## Observable consequences of partial thermalization in relativistic nuclear collisions

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The discovery of flow-like azimuthal correlations in pA and high-multiplicity pp collisions raises profound questions about the onset of collective flow and its relation to hydrodynamics. We seek independent experimental information on the degree of thermalization in order to identify those hydrodynamic collision systems in which flow is sensitive to equilibrium QCD properties. We aim to develop a protocol for identifying the degree of thermalization using a combination of momentum and multiplicity correlation. To study the effect of thermalization on these correlations, we use Boltzmann equation in the relaxation time approximation with Langevin noise. We derive a new non-equilibrium transport equation for the two-body distribution function that is consistent with the conservation laws obeyed by microscopic scattering processes. We find that transverse momentum fluctuations in peripheral PbPb collisions at LHC markedly deviate from equilibrium behavior. We propose new measurements that can provide more refined information. *This work is supported in part by NSF-PHY1913005 (G.M.)

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## Quarkonium spectral functions in a bulk-viscous quark gluon plasma

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In recent years, the bulk viscosity of a quark gluon plasma is gaining
increasing attention concerning the beam energy scan program, since the bulk viscous effect is expected to be enhanced near a critical point. Here we address the question of whether heavy quarkonia, which are
produced at the early stage of the heavy ion collisions, are sensitive
to the bulk viscous nature of the quark gluon plasma. If this is the case, we might be able to use heavy quarkonia as a probe of the non-equilibrium properties of the plasma. We incorporate the bulk-viscous
nature of the medium by deforming the distribution functions of
thermal quarks and gluons, with which the dielectric permittivity is computed within the hard thermal loop approximation. The modified dielectric permittivity is used to calculate the in-medium heavy quark complex potential, which includes both perturbative Coulombic as well
as non-perturbative string-like terms. Based on the modified heavy quark complex potential, we compute the quarkonium spectral function, with which the physical properties such as binding energies and decay widths are computed. We estimate experimental observables such as
the $\psi'$ to $J/\psi$ ratio and the nuclear modification factor $R_{AA}$ and discuss the implication of bulk viscous effect on them.

**Parallel session B / 79**

## Heavy Quarkonia in magnetized matter –effects of (inverse) magnetic catalysis

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The partial decay widths of charmonium (bottomonium) states to DDbar (B Bbar) mesons in magnetized (nuclear) matter using a field theoretical model of composite hadrons with quark (and antiquark) constituents. These are computed from the mass modifications of the decaying and produced mesons within a chiral effective model, including the nucleon Dirac sea effects. The Dirac sea contributions are observed to lead to a rise (drop) in the light quark condensates (given in terms of the scalar fields in the chiral effective model) as the magnetic field is increased, an effect called the (inverse) magnetic catalysis. These effects are observed to be significant and the anomalous magnetic moments (AMMs) of the nucleons are observed to play an important role. For ρB=0, there is observed to be magnetic catalysis (MC) without and with AMMs, whereas, for ρB = ρ0, the inverse magnetic catalysis (IMC) is observed when the AMMs are taken into account, contrary to MC, when the AMMs are ignored. In the presence of a magnetic field, there are also mixings of pseudoscalar (P) and vector (V) meson (PV mixing) which modify the masses of these mesons. The heavy Quarkonia mass shifts in the magnetized matter modify the radiative decay widths (Γ(V ⟶ P γ)), in addition to modifying the decay widths of heavy Quarkonia to open heavy flavor mesons. The magnetic field effects on the heavy quarkonium decay widths should have observable consequences on the production the heavy flavor mesons, which are created in the early stage of ultra-relativistic peripheral heavy ion collisions, at RHIC and LHC, when the produced magnetic fields can still be extremely large.

**Poster session / 80**

## Unmasking strange dwarfs with gravitational-wave observations

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The advent of space-based gravitational-wave detectors like the Laser Interferometer Space Antenna will allow to observe signals most of which are expected to be emitted by white-dwarf binaries. Among these systems could be hidden another kind of compact objects, postulated by Glendenning, Kettner and Weber in 1995, containing a small core made of strange quark matter surrounded by layers of hadronic matter reaching densities much higher than in white dwarfs. These so called strange dwarfs cannot be easily distinguished from white dwarfs through electromagnetic observations alone: their outermost envelopes are expected to have the same composition and their radii are quite similar (except for low masses). However, future measurements of the tidal deformability through gravitational-wave observations could provide a new way to reveal their existence.

**Poster session / 81**

## Towards the equation of state of color-superconducting strong-interaction matter

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We investigate the formation of a color superconductor in dense strong-interaction matter as associated with the dynamical generation of a gap in the quark excitation spectrum. To this end, we employ the Wetterich equation and solve it with numerical methods borrowed from fluid dynamics, without making any further assumptions about the form of the effective potential. We critically assess approximation artefacts by comparing qualitative and quantitative differences between mean field and local potential approximation flows.

**Poster session / 82**

## Infrared Subtleties and Chiral Vertices at NLO: An Implicit Regularization Analysis

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We employ implicit regularization (IReg) in quark-antiquark decays of the Z, or of a scalar (CP-even or odd) boson at NLO, and compare with dimensional schemes to reveal subtleties involving infrared divergence cancellation and $\gamma_5$-matrix issues. Besides the absence of evanescent fields in IReg, such as $\epsilon$-scalars required in certain schemes that operate partially in the physical dimension, we verify that our procedure preserves gauge invariance in the presence of the $\gamma_5$ matrix without requiring symmetry preserving counterterms while the amplitude is infrared finite as required by the KLN theorem.

**Parallel session A / 83**

## Exploring external field related phenomena in full lattice QCD

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I will summarize the effort of our group to explore new phenomena showing up in external electromagnetic fields in full QCD on the lattice. In particular, I will discuss our effort of studying anomalous transport phenomena such as the chiral separation effect (CSE) as well as the modification of the topological susceptibility in external electromagnetic fields. The latter can be used to extract the contribution of the strong interactions to the axion-photon coupling from first principles. Furthermore, as a proxy for more realistic settings with respect to off-central heavy-ion collisions, we investigate the effects of spatially varying external magnetic fields on the chiral condensate and the Polyakov loop.

**Plenary session / 84**

## Inhomogeneous meson condensation

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The meson condensed phase is an interesting portal on the properties of QCD in a regime in which various methods, including lattice QCD, are reliable.
We discuss inhomogeneous topologically nontrivial configurations of the pion fields
in the framework of chiral perturbation theory.
Solitons characterized by a nonvanishing topological charge naturally emerge. These states that can be identified with baryons surrounded by a bath of pions, meaning that the system has an effective nonvanishing baryonic density.

**Poster session / 85**

## Unveiling the shear viscosity to entropy density ratio with gravity analogs

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One of the most intriguing aspects of strongly coupled quark gluon plasma is near perfect fluidity observed
in relativistic heavy-ion collisions. One way of quantifying this property is by means of the shear viscosity
to entropy density ratio $\eta/s$. Within the AdS/CFT correspondence, it has been conjectured by Kovtun, Son
and Starinets that a universal lower bound $1/4\pi$ exists. We present a new perspective on this matter in the
framework of analogue gravity models, focusing on relativistic fluids with transonic flow. Quantum fluctuations
at the acoustic horizon, the fluid analog of the event horizon of a black hole, result in a thermal radiation of
phonons, the sonic analog of the Hawking radiation. Adopting a covariant relativistic kinetic theory, we describe
the Hawking emission as a dissipative process. Neglecting phonon's self interactions, we find the saturation
of $\eta/s$. We connect the KSS bound to the absence of a gap in the low energy spectrum of long-wavelength
excitations.

**Parallel session C / 86**

## Estimating transport coefficients of strongly interacting matter with an extended NJL model

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We present some results for transport coefficients in strongly interacting mattter in the light quark sector (up, down and strange) obtained with a novel regularization of the quark polarization functions using an extended version Nambu–Jona-Lasinio model which includes a ‘t Hooft determinant and eight quark interactions at finite temperature and chemical potential. This new regularization solves some inconsistencies in previously used techniques and has a significant impact in some of the cross-sections which enter into the evaluation of the quarks and antiquarks relaxation times and, as a consequence, in the evaluation of transport coefficients.

**Poster session / 87**

## Incorporating Mass Effects of Plasma Constituents in Heavy Fermion Energy Loss Calculations in hot QED and QCD

**Author:** Marc Comadran Casas[None]

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In this short talk, I will review the energy loss experienced by an energetic fermion with mass (M) traversing a hot QED/QGP plasma at finite temperature (T). These kind of computations were carried for the first time more than 30 years ago by Bjorken, were later reviewed by Braaten and Thoma and more recently by Peshier and Peigné. In those computations, the mentioned authors assumed that the fermionic constituents of the plasma are massless, as this is a reasonable approximation in the scenarios were those computations are relevant.

In our recent work, we generalize those energy loss computations including a perturbative small mass (m) for the plasma constituents, susch that m « T. We also give the necessary ingredients to carry out the computations for values of the mass close to the temperature.

Our findings reveal that for fermion masses around the soft scale eT, mass corrections are in line with pure perturbative corrections. However, as the fermion mass increases, the impact of mass corrections become dominant. Additionally, we assess the implications of these corrections on collisional energy loss in a QCD plasma.

**Parallel session A / 88**

## Kinetic/chemical Equilibration of Heavy DM Particles in Expanding Universe via Langevin equation simulation

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Recently, a question about how far chemical freeze-out of heavy Dark Matter (DM) particles can be pushed down in temperature has been raised. In this case, kinetic equilibration of heavy DM through elastic collisions with strongly interacting Standard Model particles such as quarks and gluons at the temperature of a few GeV could potentially complicate the consideration. Thus, we study kinetic equilibration of heavy dark matter particles in non-perturbative regime using Langevin equation simulation. We note that the kinetic equilibration of slowly moving DM particle in the thermal bath of SM particles is analogous to kinetic equilibration of heavy quarks in Quark-Gluon Plasma and that Langevin equation method is superior to a standard formulation based on Boltzmann equation because Langevin simulation allows systematic study even in non-perturbative regime. As a concrete numerical example, we consider a scalar singlet DM particle interacting with quarks and gluons and find that the momentum distribution of DM particle retains the Gaussian form although the spectrum becomes red-tilted and its overall effect on the chemical equilibration of DM particles to be {\cal O} (20) %.

**Parallel session B / 89**

## Causality and stability in first-order conformal anisotropic hydrodynamics

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My talk focuses on the first-order dissipative anisotropic hydrodynamic theory of a relativistic conformal uncharged fluid, which generalizes Bemfica-Disconzi-Noronha-Kovtun's (BDNK) first-order viscous fluid framework. I explain how the well-known causality problem of Navier-Stokes hydrodynamics of Landau-Lifshitz and Eckart is remedied in the BDNK approach such that the theory also maintains causality in the nonlinear regime with or without general relativity coupling. As a result of outlining the approach, I discuss how causality and stability impose constraints on the behavior of the early-time attractor by applying our newly developed first-order anisotropic theory to the Bjorken flow.

**Parallel session C / 90**

## Insights from D-meson femtoscopy using T-matrix calculations

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In this presentation I will unveil our initial findings on $D$-meson / light-meson femtoscopy. Our analysis employs unitarized effective hadron interactions derived from an off-shell $T$-matrix calculation in a coupled-channel framework. We have obtained the correlation function of heavy-light mesons accounting for Coulomb interaction in the relevant channels, and have analyzed the impact of inelastic processes. I will present a set of results that can be directly compared with experimental data from the ALICE experiment. These involve net strangeness like $D^+K^+$ (+ charge conjugate) and $D^+K^-$ (+ charge conjugate) and zero strangeness like $D^+\pi^+$ (+ charge conjugate) and $D^+\pi^-$ (+ charge conjugate). Additionally, our study encompasses predictions involving novel channels

involving $D_s$ mesons. Our original research contributes to a deeper understanding of heavy meson-light meson interactions via femtoscopy measurements.

**Poster session / 91**

## Spectra and flow of magnetised lepton pairs

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Recently, we have calculated the dilepton rate coming out of a hot and dense QCD medium under an arbitrary strength of magnetic field 1. A considerable amount of enhancement in the rate has been observed in the presence of the magnetic field. We calculate the p_T spectra and the anisotropic flow of dileptons using a hydrodynamical model framework and the new rate [2]. Both spectra and anisotropic flow are found to be affected significantly due to the presence of the background field. We discuss the implications of our findings and the possibility of using magnetised dileptons as magnetometers for heavy-ion collisions.

1. Das et al [Phys. Rev. D 106, 056021 (2022)]
2. Das et al [In preparation]

**Poster session / 93**

## Superconducting baryon crystal induced via the chiral anomaly

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Determining the phase structure of nuclear and quark matter in external magnetic fields is not only of theoretical interest but also experimentally motivated by the large magnetic fields found in heavy-ion collisions and compact star physics. By including the effects of the chiral anomaly within Chiral Perturbation theory at zero-temperature and non-zero baryon chemical potential, it can be shown that neutral pions form an inhomogeneous phase dubbed the "Chiral Soliton Lattice" (CSL) above a certain critical magnetic field. Above a second, even higher critical field, the CSL becomes unstable to fluctuations of charged pions implying they condense.

I will point out the similarity of this second critical field to the upper critical magnetic field in conventional type-II superconductors. By applying similar methods originally used by Abrikosov, I will construct an inhomogeneous, superconducting baryon crystal phase existing above this point which is preferred in the chiral limit. An update will be given on current progress of results outside the massless pion approximation.

**Poster session / 94**

## Pseudogauge freedom and the SO(3) algebra of spin operators.

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The energy-momentum and spin tensors for a given theory can be replaced by alternative expressions that obey the same conservation laws for the energy, linear momentum, as well as angular momentum but, however, differ by the local redistribution of such quantities (with global energy, linear momentum, and angular momentum remaining unchanged). This arbitrariness is described in recent literature as the pseudogauge freedom or symmetry. In this letter, we analyze several pseudogauges used to formulate the relativistic hydrodynamics of particles with spin 1/2 and conclude that the canonical version of the spin tensor has an advantage over other forms as only the canonical definition defines the spin operators that fulfil the SO(3) algebra of angular momentum. This result sheds new light on the results encountered in recent papers demonstrating pseudogauge dependence of various physical quantities. It indicates that for spin-polarization observables, the canonical version is fundamentally better suited for building a connection between theory and experiment.

**Poster session / 95**

## Renormalization group consistent treatment of neutral color-superconducting matter

**Authors:** Hosein Gholami[1]; Marco Hofmann[1]; Michael Buballa[1]

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The phase diagram of dense matter relevant for neutron stars is typically studied with effective models. These models are nonrenormalizable and must be regularized in order to obtain finite results, leading to regularization artefacts near the cutoff. We study neutral dense matter in a three-flavour Nambu-Jona-Lasinio type model that includes a diquark interaction leading to the formation of color superconducting condensates at high densities. Regularizing the model, e.g. with a sharp three momentum cutoff, leads to a decrease of the color superconducting condensate at large baryon chemical potential. We show how this cutoff artefact can be cured in a renormalization group consistent way based on the scheme developed by Braun et al. We present the resulting phase diagram and give a short outlook on the implications for the neutron star equation of state.

**Poster session / 96**

## Mean transverse momentum fluctuations with string percolation model at LHC energies

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Initial state effects in Heavy Ion Collisions play an important role in the quark-gluon plasma formation. Moreover, recent experimental studies have shown that these initial state effects become more relevant in small collision systems where the characterization of medium formed is still an open question. We present predictions of the initial state effects on the small collision systems for the mean transverse momentum fluctuations in for pp, pA, OO and pO at LHC energies, as a function of the number of particles produced in the framework of the String Percolation Model Percolation Color Sources and PYTHIA. Where, similarly to nuclei collisions, signatures of a collective medium are observed and strongly suggest quark-gluon plasma formation at small collision systems by observing a change in slope in the region of high multiplicity events.

**Poster session / 97**

## The Phase Diagram of the Gross-Neveu-Yukawa Modell in (2+1) Space-Time Dimensions using Functional Renormalization Group

**Author:** Keiwan Jamaly[None]

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In this study, the phase structure of the Gross-Neveu-Yukawa model in (2 + 1) dimensions for $\mu$ and $T$ is explored. This work complements previous works in 1+1 dimensions for finite N and 2+1 mean field as well as finite $N_f$ results (at zero chemical potential). The Functional Renormalization Group is used to calculate the effective potential. With the use of the Local Potential Approximation (LPA), the computation of the effective action can be further simplified to a diffusion type equation with a sink/source. The resulting heat equation is then solved with existing hydrodynamic solving techniques. With this setup, the phase diagram in the $\mu$-$T$ plane is calculated.

**Poster session / 98**

## Determining the EoS of neutron stars using bayesian neural networks

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Neutron stars are a remarkable object towards the study of nuclear matter properties under extreme conditions. To extract these properties, we employ Bayesian Neural Networks (BNN) that take Mass-Radius pairs observables as input. The BNN output the speed of sound squared for 15 distinct values of baryonic density energy. Our primary objective encompasses two aspects: obtaining the equation of state for neutron stars and achieving a reliable uncertainty quantification. This allows us to assess the level of confidence in our model predictions and determine if our data is free from noise. Through the implementation of BNNs, we can explore the intricate nature of nuclear matter and go further by extracting the uncertainties that come with it.

**Parallel session C / 99**

## Resummation of the soft and hard logarithms in Cold and Dense QCD

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We will discuss the recent developments in perturbative QCD at zero temperature and high barionic densities notably how can we effectively resum the so-called soft, hybrid, and hard leading logarithms. We pave the way to the resummation of the next-to-leading logarithms by identifying the anomalous dimensions of the mixed sector in QCD.

By identifying {\em massive} renormalization group (RG) properties within the hard thermal loop (HTL)
formalism, we resum to all orders αpS,p≥3 the leading and next-to-leading logarithmic soft mode contributions to the cold and dense QCD pressure
at high baryon chemical potential μB.
We obtain noticeably reduced residual scale dependence with respect to the state-of-the art results.
Extension to the resummation of the so-called hybrid logarithms and hard logarithms is discussed.
We finish by paving the way to the evaluation of the anomalous dimensions of the mixed sector, required for the full resummation of the next-to-leading logarithms in QCD.

Mostly based on L. Fernandez and J.-L. Kneur, arXiv:2109.02410 and more recent work in progress with Risto Paatelainen, Saga Säppi, Kaapo Seppänen and Aleksi Vuorinen.

**Parallel session B / 100**

## Universal properties of ideal hydrodynamic evolution near the QCD critical point

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The hydrodynamic evolution of the quark-gluon plasma (QGP) created in the initial stage of heavy-ion collisions can be approximated by tracking the lines on the QCD phase diagram where the entropy per baryon, s/n, are fixed and conserved at the initial values. The universality of critical phenomena enables us to describe the thermodynamic properties near the QCD critical point using the critical exponents and mapping parameters to the 3D Ising universality class. Our study aims to investigate the universal properties of isentropes near the QCD critical point, specifically focusing on the universal ridge topography of s/n on the phase diagram and its resulting hill shape (local maximum) along the first-order phase transition line on either side of the QGP or hadron phases. We examine the applicability of our model-independent formula to specific examples of the equation of state, including those studied by the Beam-Energy-Scan-Theory (BEST) collaboration.

**Poster session / 101**

## Study of initial state fluctuations in pp and pPb collisions

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Heavy-ion collisions create an environment characterized by extremely high energy density and temperature, leading to the formation of a deconfined state of matter known as quark-gluon plasma (QGP), where quarks and gluons move freely. Recently, collective effects have also been observed in proton-proton (pp) collisions, specifically in events with a high particle production rate. To gain further insights into the origins of these collective effects, the thermal state generated by such collisions is investigated using soft probes.
This study focuses on analyzing the thermal fluctuations of the initial state in collisions involving proton-proton (pp), proton-lead ($pPb$), and lead-lead ($PbPb$) systems at the energies of the Large Hadron Collider (LHC). The aim is to examine the state formed during high multiplicity events in these systems and explore whether it corresponds to the quark-gluon plasma. The analysis includes studying fluctuations associated with the initial state, such as variations in the multiplicity spectrum. This investigation enables the examination of temperature, energy density, and species characterization, both locally and globally, for each collision event.
The analysis is conducted using the Color String Percolation Model (SPM), which proposes transverse momentum fluctuations. The results obtained are compared with the Tsallis distribution, known for its successful representation of transverse momentum spectra in both pp collisions and heavy-ion collisions.

**Parallel session B / 102**

## Interferometry in a Moat Regime

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The QCD phase diagram at large chemical potential is largely uncharted territory. Based on model studies, there are various phases that could occur in this regime. Among them are phases related to spatial modulations, such as inhomogeneous/crystalline phases, liquid crystals or a quantum pion liquid. A common feature of all these phases is that particles can have a moat dispersion, where the energy is minimized at nonzero momentum. This can directly affect particle production in heavy-ion collisions and leads to characteristic signatures in particle correlations. I will discuss the underlying physics and present a formalism to study particle spectra on general hypersurfaces in a medium. Using this formalism, I will show that the correlations generated by the Hanbury-Brown-Twiss effect are promising probes for a moat regime in heavy-ion collisions.

**Parallel session A / 103**

## Is matter inside massive neutron stars not hadronic?

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The behavior of the nuclear equation of state (EOS), which plays a crucial role in describing the properties of neutron stars (NSs), is extensively investigated using a Bayesian approach applied to various classes of relativistic mean field models. These models encompass density-dependent meson couplings (DDH), interactions with non-linear characteristics, and the Chiral Mean Field

(CMF) Model. By employing Bayesian analysis, we explore the parameter space of these models and assess their compatibility with observational data. The Bayesian framework employed in this study incorporates a few essential nuclear saturation properties, such as binding energies, symmetry energy as well as constraints from the observation of neutron stars with masses exceeding 2M⊙. Furthermore, the equation of state at low densities, specifically the pure neutron matter EOS, is included by utilizing a precise N3LO calculation within chiral effective field theory.

One of the key aspects examined in this investigation is the possible presence of hyperons within neutron stars and how different sets of models account for their onset. Hyperons are exotic particles containing strange quarks that may appear at high densities. By comparing the predictions of various models, we can discern whether hyperons are likely to exist within neutron stars and assess their influence on the EOS.

Our approach based on microscopic models of hadronic matter allows us to discuss the composition of neutron stars and to establish a reference with respect to agnostic descriptions of the equation of state connecting the low-density EoS to perturbative quantum chromodynamics (pQCD) results, which aim at identifying signatures of deconfinement.

We analyze the compatibility of the different models considered with pQCD, which provides a framework for understanding the strong nuclear force at high energies. We can evaluate the degree to which the hadronic models studied are aligned with fundamental particle physics principles by looking at the agreement between them and pQCD. Additionally, measures of conformality and the normalized trace anomaly are calculated for the model sets under consideration.

The findings of our study indicate that pQCD favors models that exhibit a substantial contribution from the nonlinear vector field term or incorporate hyperons. This suggests that the inclusion of these features in the models leads to better agreement with fundamental principles and observations. We consider that a thorough discussion of the hadronic EOS will help identify a deconfinement phase transition.

**Poster session / 104**

## On the application of gauge equivariant neural networks to the generation of field configurations

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A strategy that has been increasingly and successfully employed over the last few years in the design of neural network architectures is the implementation of layers that inherently respect a specific symmetry. In the context of lattice gauge theories, local symmetries are a crucial element. Lattice gauge equivariant neural networks (L-CNNs) 1 are designed to preserve such symmetries and have proven to be outperforming traditional convolutional neural networks in the prediction of physical observables. Here, we report our recent developments in the application of L-CNNs to the generation of gauge field configurations. Specifically, we use the framework of neural ordinary differential equations in combination with L-CNNs to modify configurations in a gauge equivariant way.

1 M. Favoni, A. Ipp, D. I. Müller, D. Schuh, Phys.Rev.Lett. 128 (2022), 032003, [arXiv:2012.12901]

**Poster session / 105**

## Mean field approximation for effective theories of lattice QCD

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For the exploration of the phase diagram of QCD, effective Polyakov loop theories derived from lattice QCD provide a valuable tool in the heavy quark mass regime. In practice, the evaluation of these theories is complicated by the appearance of long-range and multipoint interaction terms. On the other hand, it is well known that for theories with such kind of interactions mean field approximations can be expected to yield reliable results. Hence, the evaluation of the effective theories within the mean field framework is discussed.

**Poster session / 106**

## Implicit Regularization in a QCD decay of the Higgs boson

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Implicit Regularization (IReg) is a regularization scheme that works in the physical dimension of the theory and allows for the separation of the ultraviolet (UV) and infrared (IR) divergences of an amplitude. We compute the Higgs decay into gluons using an effective Higgs–Yang-Mills interaction in the limit of infinite top quark mass by using a dimension five operator. The decay rate for H⟶gg(g) is calculated in this strictly 4-dimensional set-up to α_sˆ3 order in the strong coupling. We use spinor-helicity formalism to include the processes that contribute at the same perturbative order in the real emission channels consisting of 3 gluons and a gluon and quark-antiquark final states with light (zero mass) quarks. Unambiguous identification and separation of UV from IR divergences is achieved putting at work the renormalization group scale relation inherent to the method. UV singularities are removed by renormalization and the IR divergences are cancelled due to the method's compliance with the Kinoshita-Lee-Nauenberg (KLN) theorem. The remaining finite integral contributions are evaluated using Package-X. We verify that no evanescent fields such as scalars need be introduced as required by some mixed regularizations that operate partially in the physical dimension.

**Plenary session / 107**

## Quarks in a finite volume and deconfinement as percolation of center-electric fluxes in QCD

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In order to understand the puzzle of the free energy of an individual quark in QCD, we explicitly construct ensembles with quark numbers [illegible][illegible]≠0mod3, corresponding to non-zero triality in a finite subvolume [illegible] on the lattice. We first illustrate the basic idea in an effective Polyakov-loop theory for the heavy-dense limit of QCD, and then extend the construction to full Lattice QCD, where the electric center flux through the surface of [illegible] has to be fixed at all times to account for Gauss's law.

This requires introducing discrete Fourier transfroms over closed center-vortex sheets around the spatial volume ⊠ between all subsequent time slices, and generalizes the construction of 't Hooft's electric fluxes in the purge gauge theory. Moreover, clusters of the same center-electric fluxes are shown to undergo a percolation phase transition in the effective theory in which we can follow the corresponding Kertesz line through the Z3-crossover region, from the endpoint of the first-order line all the way to the massless limit. The best we can offer to study the same deconfinement phase transition in full QCD, at the moment, is the gauge-invariant definition of clusters of electric flux and their spanning probabilities which appear prohibitively expensive to measure, however.

**Parallel session B / 108**

## Color-superconductivity of asymptotically conformal quark matter as a portal between astrophysics and heavy ions collisions

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I present a relativistic density functional approach to color superconducting quark matter that mimics quark confinement by a fast growth of the quasiparticle self-energy in the confining region 1. The approach is shown to be equivalent to a chiral model of quark matter with medium dependent couplings. The approach to the conformal limit at asymptotically high densities is provided by a medium dependence of the vector-isoscalar, vector-isovector and diquark couplings motivated by non-perturbative gluon exchange [2]. While the (pseudo)scalar, vector-isoscalar and vector-isovector sectors of the model are fitted to the mesonic mass spectrum and vacuum phenomenology of QCD, the strength of interaction in the diquark channel is varied in order to obtain the best agreement with the observational constraints from measurements of mass, radius and tidal deformability of neutron stars. These constraints favor an early onset of deconfinement and color superconductivity in neutron stars with masses below one solar mass. I also discuss a new two-zone interpolation scheme for the construction of the hadron-to-quark matter transition [3] that allows to test different structures of the QCD phase diagram with one, two or no critical endpoints in simulations of supernova explosions, neutron star mergers and heavy-ion collisions. I argue that the formation of color-superconducting quark matter drives the trajectories of its evolution in supernovae and neutron star mergers towards the regimes reached in terrestrial experiments with relativistic heavy ion collisions.

1 O. Ivanytskyi and D. Blaschke, Phys. Rev. D 105, 114042 (2022)
[2] O. Ivanytskyi and D. Blaschke, Particles 5, 514 (2022)
[3] O. Ivanytskyi and D. Blaschke, Eur. Phys. J A. 58, 152 (2022)

**Parallel session A / 111**

## Rebuilding Neutron Star EoSs from Observations with Deep Learning

**Author:** Lingxiao Wang[1]

**Co-authors:** Horst Stoecker ; Kai Zhou ; Shriya Soma ; Shuzhe Shi

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We present a novel deep learning approach to optimize the equation of state (EoS) for probing neutron star observables. By leveraging an automatic differentiation framework, our method solves inverse problems and achieves accurate EoS optimization. Through training a neural network on a comprehensive dataset, we develop a predictive EoS model that yields precise relationships between pressure, speed of sound, and mass density. Our results align with conventional approaches and are consistent with the observed tidal deformability from the gravitational wave event, GW170817.

**Invited Speaker Session / 112**

## A short walk through the physics of neutron stars

**Author:** Isaac Vidana[1]

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In this talk I will shortly review several aspects of the physics of neutron stars. After an introduction Particularly, I will review few aspects of their observation discussing, namely, the different types of telescopes that are used in their observation, the many astrophysical manifestations of these objects, and several observables such as masses, radii or gravitational waves. Finally, I will briefly present some of theoretical issues like their composition, structure equations, equation of state, and neutrino emission and cooling.

**Invited Speaker Session / 113**

## Machine learning for lattice field theory and back

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Recently, machine learning has become a popular tool to use in fundamental science, including lattice field theory. Here I will review on some recent ideas, including normalising flow, phase classification and quantum-field theoretical machine learning. The latter combines insights of lattice field theory and machine learning to provide a fresh perspective on (hopefully) both.

**Invited Speaker Session / 114**

## Anomalous kaon correlations measured in Pb-Pb collisions at the LHC as evidence for the melting and refreezing of the QCD vacuum

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Measurements of the dynamical correlations between neutral and charged kaons in central Pb-Pb collisions at √s_NN = 2.76 TeV by the ALICE Collaboration display anomalous behavior relative

to conventional heavy-ion collision simulators. We consider other conventional statistical models, none of which can reproduce the magnitude and centrality dependence of the correlations. The data can be reproduced by either strange Disoriented Chiral Condensates or by non-strange Disoriented Isospin Condensates from domains which grow in number and volume with increasing centrality. Both mechanisms are associated with the melting and refreezing of the QCD vacuum.

**116**

## XQCD Conference: Welcome and Opening

**117**

## IAC meeting

**Invited Speaker Session / 119**

## Recent progress in lattice QCD at non-zero temperature and density

**Author:** Peter Petreczky[None]

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I will review the progress in lattice QCD at non-zero temperature and density, including the calculations of the equation of state at non-zero baryon density, the nature of the chiral transition as function of the quark mass and quantitates related to heavy flavor probes of hot matter. The latter includes, the lattice calculation of the heavy quark diffusion constant, heavy quark potential and quarkonium properties at high temperatures.

**Poster session / 121**

## Heavy Baryons in Warm Stellar Matter

**Author:** Tiago Custódio[1]

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Light nuclei can be found in core-collapse supernova matter and in binary star mergers. Their presence may impact the evolution of these systems. The presence of degrees of freedom such as hyperons, hyperclusters and Delta isobars may as well impact the composition of these systems at temperatures as high as T˜50-100 MeV achieved in both supernova and binary systems.

**Poster session / 122**

## Does pQCD constrain the neutron star equation?

**Author:** Milena Albino[1]

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Knowing the QCD phase diagram is one of the biggest physics challenges we have nowadays.
Neutron stars are true laboratories that test extreme conditions, essential to determine the QCD phase diagram.
In their core, the density can reach $n_B \approx 3{-}8n_s$ (where $n_s = 0.16fm^{-3}$ is the saturation density), a range of densities where QCD is unknown.
Ab-initio calculations determine the EoS for densities $n_B > 40n_s$, where perturbative QCD (pQCD) is valid, and for $n_B < 1.1n_s$, where the EoS is determined using chiral effective field theory (cEFT).
Is it possible to restrict the region of $1.1n_s < n_B < 40n_s$ using the information we have about pQCD and cEFT?
In DOI: 10.1103/physrevlett.128.202701, Komoltsev & Kurkela restrict the unknown region of the QCD phase diagram using thermodynamic relations and the pQCD and cEFT EoS together with i) the causality condition; ii) the thermodynamic relation $n = dP/d\mu$.
We review this work and we apply the constraints to a Relativistic Mean Field (RMF) model.

**Poster session / 123**

## Deconfinement in pure gauge SU(3) Yang-Mills theory: the ghost propagator

**Authors:** Vítor Paiva[1]; Orlando Oliveira[None]; Paulo Silva[None]

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The ghost propagator in Landau gauge is studied at finite temperature below and above Tc using lattice QCD simulations. For high temperatures, we find that the ghost propagator is enhanced, compared to the confined phase. The results suggest that the ghost propagator can be used to identify the phase transition, similarly to the gluon propagator case.