ExHIC-d workshop on QCD and hadronic dense matter (ExHIC-d 2025)

Saturday 15 November 2025 - Monday 17 November 2025

Uni hotel Jeju

Book of Abstracts

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Phase diagram of QCD matter with magnetic field: domain-wall Skyrmion chain in chiral soliton lattice

Authors: Kentaro Nishimura[1]; Minoru Eto[2]; Muneto Nitta[3]

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[2] *Yamagata University*

[3] *Keio University*

QCD matter in a strong magnetic field exhibits a rich phase structure. In the presence of an external magnetic field, the chiral Lagrangian for two flavors is accompanied by the Wess-Zumino-Witten (WZW) term containing an anomalous coupling of the neutral pion π^0 to the magnetic field via the chiral anomaly. Due to this term, the ground state is inhomogeneous in the form of either a chiral soliton lattice (CSL), an array of solitons in the direction of magnetic field, or domain-wall Skyrmion (DWSk) phase in which Skyrmions supported by $\pi_3[\mathrm{SU}(2)] \cong \mathbb{Z}$ appear inside the solitons as topological lumps supported by $\pi_2(S^2) \cong \mathbb{Z}$ in the effective worldvolume theory of the soliton. In this paper, we determine the phase boundary between the CSL and DWSk phases beyond the single-soliton approximation within the leading order of chiral perturbation theory. To this end, we explore a domain-wall Skyrmion chain in multiple soliton configurations. First, we construct the effective theory of the CSL by the moduli approximation and obtain the $\mathbb{C}P^1$ model or $\mathrm{O}(3)$ model, gauged by a background electromagnetic gauge field, with two kinds of topological terms coming from the WZW term: one is the topological lump charge in $2+1$ dimensional worldvolume and the other is a topological term counting the soliton number. The negative energy condition of the lumps yields the phase boundary between the CSL and DWSk phases. We find that a large region inside the CSL is occupied by the DWSk phase and that the CSL remains metastable in the DWSk phase in the vicinity of the phase boundary.

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Berry Curvature and Spin-One Color Superconductivity

Authors: Noriyuki Sogabe[1]; Yi Yin[2]

[1] *University of Illinois Chicago*

[2] *Chinese University of Hong Kong (Shenzhen)*

We explore the interplay between Berry curvature and topological properties in single-flavor color superconductors, where quarks form spin-one Cooper pairs. By deriving a new relation, we connect the topological nodal structure of the gap function in momentum space to the (non-Abelian) Berry flux associated with paired quarks. This generalizes the early work by Li and Haldane [1] to systems with additional internal quantum numbers, such as color. In the ultra-relativistic limit, we uncover rich topological structures driven by the interplay of spin, chirality, and color. Specifically, we identify chirality-induced topological nodes in the transverse (opposite chirality pairing) polar and A-phases. In contrast, the color-spin-locking phase lacks these nodes due to a non-trivial color Berry flux, which in turn induces gapless excitations with total Berry monopole charges of ±3/2–differing from conventional Weyl fermions. Our findings can be potentially extended to other fermionic systems carrying additional internal degrees of freedom. This work has been published in Physical Review Letters [2].

[1] Y. Li and F. Haldane, Phys. Rev. Lett. 120, 067003 (2018).
[2] N. Sogabe and Y. Yin, Phys. Rev. Lett. 134, 171903 (2025).

3

Physical conditions in intermediate-energy heavy-ion collisions: Estimates from JAM

Author: Hidetoshi Taya[1]

[1] *Keio University*

Understanding matter at high densities is one of the central goals of modern nuclear physics. Heavy-ion collisions at intermediate energies, $\sqrt{s_{NN}} = \mathcal{O}(2 - 10\ \mathrm{GeV})$, are the only terrestrial means to explore such extreme conditions. Several experimental programs plan to investigate this energy regime, including FAIR, NICA, HIAF, and J-PARC-HI. Before conducting these experiments and to stimulate related theoretical studies, it is essential to quantitatively clarify "what kind of physical environments can actually be achieved in intermediate-energy heavy-ion collisions."

To this end, I simulate intermediate-energy heavy-ion collisions using a hadronic cascade model JAM \[1\] and quantify the resulting physical environment \[2–4\]. In this talk, I will present some of the results obtained thus far. In particular, I will discuss: (1) The optimal collision energy for producing high-density matter appears to be around $\sqrt{s_{NN}} = 3 - 5$ GeV, where the system reaches several times the normal nuclear density over a macroscopically extended spacetime volume. Higher and lower energies are less favorable due to, respectively, shorter lifetimes and lower densities. (2) Intermediate-energy heavy-ion collisions are also of great interest for studying strong electromagnetic fields. The electromagnetic fields generated during the collisions significantly exceed the Schwinger limit of QED and may even reach the QCD/hadronic scale. (3) Event-by-event fluctuations are considerable, highlighting the importance of event selection in experimental analyses.

References:
\[1\] The latest version of JAM is publically available at https://gitlab.com/transportmodel/jam2.
\[2\] H. Taya, T. Nishimura, A. Ohnishi, "Estimation of electric field in intermediate-energy heavy-ion collisions," Phys. Rev. C. 110, 014901 (2024) \[arXiv:2402.17136\].
\[3\] H. Taya, A. Jinno, M. Kitazawa, Y. Nara, "Optimal collision energy for realizing macroscopic high baryon-density matter," to appear in Phys. Rev. C \[arXiv:2409.07685\].
\[4\] H. Taya, "Spacetime profile of electromagnetic fields in intermediate-energy heavy-ion collisions," to appear in Phys. Rev. C \[arXiv:2501.18171\].

4

Impact of Nuclear Symmetry Energy on the Neutron Dripline and Neutron Star Structure

Author: Yeunhwan Lim[None]

We study the impact of the nuclear symmetry energy and its density slope parameter on the location of the neutron dripline and on neutron star properties using a semi-classical liquid drop model (LDM) in conjunction with energy density functionals constrained by chiral effective field theory. The symmetry energy at saturation density is fixed, and the surface tension parameters are optimized to minimize the root-mean-square deviation of binding energies across a dataset of 2208 nuclei. Within this calibrated framework, we explore correlations between the symmetry energy parameters and several key observables: the neutron dripline location, the crust-core transition density in neutron stars, and the radius of a 1.4 M⊠ neutron star. Furthermore, we investigate how macroscopic properties, such as neutron star radii (R1.4), correlate with microscopic nuclear observables, including the number of bound isotopes and the location of the last bound nucleus for elements with proton number Z = 28. Our results provide insight into the interconnected nature of finite nuclei and neutron star structure through the lens of nuclear symmetry energy.

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Role of $\Sigma^*(1385)$ on Λ hyperon polarization in relativistic heavy ion collisions

Authors: Haesom Sung[None]; Che-Ming Ko[None]; Su Houng Lee[None]

The effect of $\Sigma^*(1385)$ baryon resonance on the time evolution of the Λ hyperon polarization in hadronic matter is studied using a kinetic approach. This approach explicitly includes the production of the Σ^* resonance from the $\Lambda-\pi$ and $\Sigma(1192)-\pi$ scatterings as well as its decay into $\Lambda+\pi$ or $\Sigma+\pi$. The resulting coupled kinetic equations governing the time evolution of Λ, Σ and Σ^* numbers and polarizations are solved for Au-Au collisions at $\sqrt{s_{NN}} = 7.7$ GeV and 20-50\% centrality, using initial values determined by thermal yields and the thermal vorticity at chemical freeze-out temperature. As the hadronic matter expands and cools, the Λ polarization is found to increase slightly during early times and then decreases very slowly afterwards, while the Σ polarization remains nearly constant and the Σ^* polarization continuously decreases. Including feed-down contributions to the Λ polarization from the decays of partially polarized Σ^0, Σ^*, and $\Xi(1322)$ hyperons, where the Ξ polarization is obtained by solving coupled kinetic equations for the Ξ and $\Xi^*(1532)$ system, the resulting Λ polarization becomes smaller and decreases over time. In both cases, however, the time variation of the Λ polarization is sufficiently small to support the assumption of an early freeze-out of Λ spin degree of freedom in relativistic heavy ion collisions.

6

Using low-energy nuclear collisions to study the behavior of vector and axial-vector mesons in nuclear matter

Author: Philipp Gubler[1]

[1] *JAEA*

At present, there is no clear consensus regarding how the mass and width of the phi meson are modified in a dense environment such as nuclear matter, nor on the strength of its chiral mixing with the axial-vector chiral partner. Although a number of theoretical studies have addressed these questions, establishing a direct connection with experimental observables remains a significant challenge. This difficulty arises in part because the phi meson in nuclear matter is typically produced in proton–nucleus (pA) reactions, which are inherently non-equilibrium processes.
In this talk, I will review the current status of theoretical research on the in-medium properties of the phi meson, with a particular emphasis on ongoing transport simulations of pA reactions that produce phi mesons inside nuclei. These reactions are being explored experimentally at KEK E325 and in the J-PARC E16 and E88 experiments.

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3D Pion crystal from the chiral anomaly

Authors: Andreas Schmitt[1]; Geraint Evans[2]

[1] *University of Southampton*

[2] *Academia Sinica*

By including the effects of the chiral anomaly in Chiral Perturbation Theory at finite baryon chemical potential, it has been 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, suggesting that an inhomogeneous phase of superconducting charged pion exists beyond this point. Applying similar methods originally used by Abrikosov, I will present results where we've constructed such a phase and show the region where it is preferred in the baryon chemical potential-magnetic field phase diagram at zero temperature. This new phase has a non-zero baryon number density which is periodic in all three spatial dimensions.

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Status of the NICA-MPD experiment at JINR

Author: Chi Yang[1]

[1] *Shandong University*

The Nuclotron-based Ion Collider fAcility (NICA) is a new accelerator complex currently under commissioning at JINR, designed for collisions of heavy ions and polarized particles. The Multi-Purpose Detector (MPD) experiment at NICA aims to explore the rich phase structure of QCD at finite temperature and baryon chemical potential. Optimized to fully exploit NICA's physics potential, MPD will measure a broad range of observables from heavy-ion collisions, enabling studies of the QCD equation of state and critical phenomena, in-medium modifications of hadron spectral functions, and hyperon-nucleon interactions.

This talk will provide an overview of the detector's assembly status and plans for first data taking of NICA-MPD, highlighting key aspects of the MPD physics program. Feasibility studies for selected observables at NICA energies will be presented and discussed.

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Quark-number susceptibilities and baryonic excitaions in heavy-quark QCD

Author: Kei Tohme[1]

Co-authors: Chihiro Sasaki ; Krzysztof Redlich [2]; Masakiyo Kitazawa ; Takahiro Doi [3]

[1] *Kyoto University*

[2] *University of Wroclaw*

[3] *Japan/Kyoto University*

We investigate the thermodynamic properties of baryonic excitations in heavy-quark QCD. Based on a lattice QCD with N_f-flavor Wilson fermions, we derive an expression for the grand potential in terms of loop operators with the hopping parameter expansion (HPE) and the cumulant expansion. Using this grand potential, we analytically compute the baryon number susceptibilities and demonstrate that the ratio of the fourth- to second-order susceptibility drops sharply from unity in the confined phase to 1/9 in the deconfined phase at the leading order of the HPE. This behavior is interpreted as a transition of the charge carriers from baryons to quarks and is consistent with lattice QCD results at the physical point. Energies of excitations are also investigated within a lattice Boltzmann gas picture. We derive an analytic expression for a quark excitation in the deconfined phase, while in the confined phase, the expression for baryonic excitations is decomposed into contributions from flavor multiplets including the N_f-flavor counterparts of the octet and decuplet baryons. Their properties are qualitatively analyzed in the strong-coupling limit. The multiplets corresponding to the octet and decuplet yield finite contributions, from which their energies and spins are calculated, whereas the contribution from the flavor-singlet channel vanishes in this limit.

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Physics Opportunities at CBM FAIR

Author: György Wolf[None]

In this talk, the physics opportunities offered by the CBM detector will be presented.

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Generally covariant fluctuating hydrodynamics in small systems

Author: Giorgio Torrieri[None]

We discuss the problem of hydrodynamics in small systems, and argue that to understand it a radical reassessment of the role of statistical fluctuations and the concept of equilibrium is necessary.
We should that defining hydrodynamics at the level of a partition function in every cell, and imposing general covariance, could result in an effective theory of fluctuating hydrodynamics, orthogonal to the usual gradient based approach, which might be more suited in this context.
We close with a discussion on extending to spin hydrodynamics, where this approach could help resolve the pseudogauge issue.

Based on https://arxiv.org/abs/2504.17152 and ongoing work

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Strangeness baryon production in relativistic heavy-ion collisions

Author: Bong-Hwi Lim[1]

[1] *University of Tokyo (JP)*

The study of strangeness baryon production in relativistic heavy-ion collisions provides unique insights into the properties of strongly interacting matter at extreme temperature and density. Strangeness enhancement was among the earliest proposed signatures of the formation of the quark-gluon plasma (QGP), and over the past decades, systematic measurements from SPS, RHIC, and LHC experiments have revealed characteristic trends in the yields, spectra, and collective behavior of strange and multi-strange baryons. In particular, the production of hyperons and their resonance states sheds light on the interplay between partonic degrees of freedom and hadronic interactions during the evolution of the fireball.

In this talk, I will present recent results on strangeness baryon production from heavy-ion collisions at the LHC, focusing on the production of hyperons, multi-strange baryons, and strange baryon resonances. Comparisons across beam energies and collision systems allow us to trace the onset of de-confinement, the role of hadronic re-scattering, and the possible formation of exotic bound states.

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Future High-Energy Nuclear Physics Experiments at HIAF

Author: Aiqiang Guo[1]

[1] *Institute of Modern Physics, Chinese Academy of Sciences*

The High-Intensity heavy-ion Accelerator Facility (HIAF) in Huizhou, China, is poised to become a world-class platform for nuclear physics research. Two key experimental programs are being developed to leverage its unique capabilities: the Hyperon-Nucleon Spectrometer (H-NS) fixed-target experiment will study hyperon polarization in pp collisions and global polarization in AA reactions, providing new insights into spin dynamics; while the planned Electron-Ion Collider in China (EicC), a future HIAF upgrade, will probe nucleon structure through sea quark measurements and investigate short-range nucleon correlations to advance our understanding of QCD in nuclear matter. Both projects feature innovative detector designs targeting these fundamental physics questions.

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Phase shifts and baryon momentum distributions in dense matter

Author: Toru Kojo[1]

[1] *KEK*

Recently we argued that baryons feel the quark substructure constraints at density around a few times the nuclear saturation density. If confinement is assumed to persist, the constraints push up the baryon momenta and make those baryons relativistic. In this talk I discuss how to derive these behaviors in a field theoretic approach, employing the phase shift representation of the thermodynamic potential. The relation to quark-hadron effective models is also discussed.

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Color superconductivity revisited

Author: Naoki Yamamoto[None]

This talk will cover selected topics in color superconductivity in high-density QCD, with a particular focus on our work:
–Quark–hadron continuity and the potential existence of the high-density critical point
–Finite-temperature color superconducting phase transitions
–Quantum Hall liquids as vector mesons in the two-flavor color superconducting phase

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Study of Charm Baryon Measurements at the LHC

Author: Krista Lizbeth Smith[1]

Co-author: Sanghoon Lim [1]

[1] *Pusan National University (KR)*

Quark-antiquark pairs close in phase space that recombine to form a quarkonia state, also known as coalescence, are often discussed in terms of quark-gluon plasma effects on charmonia production in heavy-ion collisions. Recent LHC measurements of the charm baryon-to-meson ratios in high multiplicity *p*-*p* collisions, however, suggest coalescence as a potential hadronization mechanism. A majority of the major experiments at the LHC have measured charm baryons. In addition to *p*-*p* collisions, ALICE and CMS have also published results in the heavy-ion *p*-Pb and Pb-Pb collision systems. In this study, we discuss recent charm baryon multiplicity measurements as well as the charm baryon-to-meson ratio from the LHC experiments and compare and contrast the results in different collision systems and energies.

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Studies of the in-medium modification of the ϕ meson mass in nuclei at J-PARC

Author: Hiroyuki Sako[1]

[1] *Japan Atomic Energy Agency*

J-PARC E16 and E88 experiments aim to study the in-medium modification of ϕ mesons in e^+e^- and K^+K^- decays in proton-nucleus collisions to study the effect of the chiral-symmetry restoration. In the past KEK-E325 experiment, the mass reduction of ϕ was observed at low velocity in p+Cu collisions in the e^+e^- decay. E16 will measure several thousand $\phi \to e^+e^-$ events in p+C and p+Cu in the first physics run planned in 2026-2027. E88 will measure about one million $\phi \to K^+K^-$ events in p+C, p+Cu, and p+Pb collisions complementarily. By measuring the mass dependence on the momentum (dispersion relation) in both experiments, the $\bar{s}s$ condensate in nucleons will be evaluated by evaluating the mass shift at zero momentum. E88 also aims to measure the dependence of the mass shifts on the ϕ polarity for the first time.
E16 and E88 share part of the experimental setup. Electron identification performance has been evaluated in the E16 commissioning runs. In the trigger-study run in 2024, the ω and ϕ peaks in the e^+e^- invariant mass spectra have been observed. Kaon identification performance for E88 was also evaluated.
In this talk, we will show the physics goals, the experimental design, the feasibility, and the status of both experiments.

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Two-color QCD as a laboratory to explore cold and dense medium: Numerical experiments and effective models

Author: Daiki Suenaga[1]

[1] *KMI, Nagoya University*

Two-color ($N_c = 2$) QCD world is one of the useful testing grounds to delineate cold and dense QCD matter, since the lattice QCD simulation is straightforwardly applicable thanks to the disappearance of the sign problem. Motivated by recent numerical experiments from the lattice QCD activities, I am being investigating properties of dense two-color QCD by constructing the linear sigma model (LSM), as a reasonable low-energy EFT. In this talk, I summarize my recent works based on my LSM, such as the modifications of hadron mass spectrum, topological susceptibility, and the sound-velocity peak in cold and dense two-color QCD.

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Speed of Sound in Neutron Stars and Its Consequences

Author: Suman Pal[None]

Co-author: Gargi Chaudhuri [1]

[1] *Physics Group, Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata 700064, India*

Compact stars serve as exceptional astrophysical laboratories for probing the properties of dense nuclear matter. Observational studies of pulsars, together with gravitational wave detections, have already imposed valuable constraints on the nuclear equation of state (EOS). Among thermodynamic quantities, the speed of sound plays a crucial role, particularly in the context of neutron star physics. In this work, we employ a parametrized density-dependent speed of sound to generate a family of neutron star EOSs, which exhibit close agreement with realistic EOSs obtained from relativistic mean-field (RMF) theory. We demonstrate that each model parameter captures distinctive features connected to compact star properties.

We conduct a detailed investigation of the thermodynamic structure of the speed of sound and its decomposition, revealing that the curvature term undergoes a sign change in hadronic EOSs even without reaching the conformal limit or undergoing a phase transition. This behavior is linked to the maximum of the first derivative of the energy per nucleon. In addition, we analyze the behaviour of the trace anomaly and polytropic index both for RMF models and within the density-dependent sound-speed framework. Our study shows that the sign of the trace anomaly at high densities depends on whether the EOS is stiff or soft. Observational constraints from mass–radius measurements and tidal deformability further narrow down the allowed parameter space of the proposed speed of sound model.

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QCD at FAIR: A cross-community network for hadron physics

Author: Johan Messchendorp[None]

The newly launched "QCD at FAIR"network targets to address open questions in the field of non-perturbative QCD leveraging high-intensity (anti)proton, deuteron and secondary pion beams at GSI/FAIR aligned with state-of-the-art theoretical advances. The program includes precision studies of hadron–hadron interactions, baryon spectroscopy, transition form factors, and in-medium modifications under extreme conditions, with implications for the nuclear equation of state, neutron star physics, and searches for physics beyond the Standard Model. In this talk, I will present the planned physics program and the roadmap currently being consolidated in a White Paper to be released soon.

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Explore Hadron Structure and QCD Phase Structure at HIAF

Authors: Nu Xu[1]; Nu Xu[None]

[1] *Lawrence Berkeley National Lab. (US)*

The new accelerator complex: Highly Intensity Accelerator Facility (HIAF) has been under construction since 2018 at Huizhou, China and its commissioning has been scheduled at the end of 2025. In the range of few GeV per nucleon, the HIAF will accelerate protons and ions, up to uranium, with intensities of 10^{12} and 10^{10} ppp, respectively. In this talk, after brief introductions of relevant physics issues and the concept of a new spectrometer: Hyperon-Nucleon Spectrometer (H-NS) we will discuss the physics program, including both hadron structure with proton induced interactions as well as the physics of the QCD phase structure in high-energy nuclear collisions. Upgrade options with the HIAF will also be outlined.

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Searching for rare particles in heavy ion collisions

Author: Pengfei Zhuang[None]

The abstract: Considering the off-diagonal interaction in high energy nuclear collisions, rare particles are significantly enhanced in heavy ion collisions. I will consider the \Omega_ccc and true muonium production in heavy ion collisions at RHIC and LHC energies in this talk.

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HIC at J-PARC

Author: Masakiyo Kitazawa[None]

TBA

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Dense quark matter

Author: DF Hou[None]

TBA

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Scale symmetry in medium

Author: Yong-Liang Ma[None]

TBA