XVII Polish Workshop on Relativistic Heavy-Ion Collisions: Phase diagram and Equation of State of strongly interacting matter

Saturday 14 December 2024 - Sunday 15 December 2024

Warsaw University of Technology

Book of Abstracts

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Femtoscopy measurements of the p-Λ and d-Λ systems as a tool for studying the strong interaction parameters

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Relativistic heavy-ion collisions provide a way to study the properties of nuclear matter under extreme conditions. One method for investigating the characteristics of bulk matter is the femtoscopy technique. This method allows for the extraction of the space-time characteristics of the expanding fireball produced in heavy-ion collisions and to collect information on the interaction between particles. The correlation between two particles due to the strong interaction can be described by the Lednicky-Lyuboshitz equation, which takes into account two key parameters: the scattering length (f_0) and the effective range (d_0). Systems of particular interest are those where this interaction involves not just one, but two spin states, resulting in a larger set of parameters f_0 and d_0. Examples of such systems include p-Λ (singlet and triplet states) and d-Λ (doublet and quartet states).
This talk will present the first results of the d-Λ correlation functions in silver ion collisions at 1.58 AGeV measured by the HADES experiment.

Session 2 / 3

Isospin breaking in kaon multiplicities in heavy-ion collisions: status and consequences

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The NA61/SHINE collaboration recently reported an excess of charged versus neutral kaons that signals an unexpectedly large breaking of the isospin symmetry. Similar excesses were also present in previous experiments, but with larger errors. Models for hadron productions in heavy ion collisions systematically underestimate the measured charge-to-neutral kaon ratio. In this talk, we report on the present status of theoretical efforts for determining the charged-neutral kaon ratio. We also present a simple 'counting' model highlighting possible consequences of the isospin breaking.

Session 2 / 4

Entropy production and dissipation in spin hydrodynamics

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Motivated by evidence of spin polarization in particles produced in relativistic heavy ion collisions, there is growing interest in relativistic spin hydrodynamics. In this talk, we will present the key theoretical results derived from two different approaches: covariant thermodynamics and quantum-statistical mechanics.

Session 2 / 5

Production of ϕ(1020) meson in nucleus-nucleus collisions at the CERN SPS

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The ϕ meson is a resonance particle and the lightest particle with hidden strangeness, containing both s and $\bar{s}$ quarks. Strangeness enhancement is considered to be related to Quark-Gluon Plasma formation, making the ϕ meson a valuable probe due to its "double strangeness" in a partonic and zero net strangeness in a hadronic medium. Previous studies, such as EPJC 80 (2020) 199, demonstrated that the rapidity distribution widths for various particles produced in p+p and Pb+Pb collisions follow similar linear trends with increasing beam rapidity. Interestingly, while ϕ mesons from p+p collisions conform to this trend, those from Pb+Pb collisions exhibit a markedly faster increase, a phenomenon that remains unexplained. To explore this problem, we present the first-ever measurements of ϕ meson production in Ar+Sc collisions at three beam momenta: 150A, 75A, and 40A GeV/c, recently released as preliminary data by the NA61/SHINE collaboration. Utilizing the primary decay channel $\phi \longrightarrow K^+K^-$, invariant mass analysis, and the tag-and-probe method, we provide detailed double differential (y, pT) spectra, rapidity distributions, and total yields. These results are compared to previous ϕ meson production measurements in p+p and Pb+Pb collisions by NA61/SHINE and NA49, respectively. Special emphasis is placed on the rapidity spectra widths, offering new insights into the puzzling behaviour observed in heavy-ion collisions. This study advances our understanding of trangeness enhancement and the dynamics of ϕ meson production in nuclear collisions.

Session 3 / 6

Protons femtoscopy with 3D source in Au +Au collisions at $\sqrt{s_{NN}} = 2.4$ GeV

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The availability of multidimensional and multivariate data on femtoscopic radii in heavy-ion collisions (HIC) is marginal at centre-of-mass energies of a few GeV. It impairs the development of theoretical models that describe the particle dynamics of HIC at those energies. The currently available femtoscopic radii were primarily extracted from the measurement of identically charged pions, which are limited in statistics at these energies. Proton-proton correlations are more promising at these low energies. The high nuclear stopping in the few-GeV collisions implies a high abundance of protons and extends the possibilities of investigating particle production mechanisms. Aside from primordial and decay protons, we can expect participants to contribute significantly to the final correlation function.

In this work, we introduce the measurements of proton-proton femtoscopic correlations for √(s_NN

)=2.4 GeV Au+Au collisions as measured by the HADES collaboration with their dependence on transverse pair momentum and rapidity. Moreover, we introduce three-dimensional correlation functions with their dependence on the transverse momentum of a pair, pair rapidity, and pair azimuthal angle w.r.t. the event plane.

Session 2 / 7

Measurements of azimuthal anisotropy of charged particles in Pb+Pb collisions with the ATLAS detector

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The azimuthal anisotropy of the final-state particles in nuclear-nuclear collisions arises from the geometry of the quark-gluon plasma fireball. In this talk, I will present flow coefficients v_2 and v_3 of charged particles measured in the Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV recorded by the ATLAS experiment in 2018. This measurement uses the scalar product and multi-particle cumulant methods to probe the momentum dependency of the flow coefficients. Thanks to the high integrated luminosity, the data allows us to explore the high-p_{T} regime.
Moreover, I will discuss a method to reconstruct charged particles with low p_{T} in high-multiplicity events, enabling future measurement of the flow coefficients to cover an even broader range of p_{T}.

Session 1 / 8

Exploring the baryon correlation puzzle via angular correlations from ALICE

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One of the most effective techniques for investigating the mechanism of baryon
production is the study of angular correlations between two particles. Angular correlations represent a convolution of various physical processes, such as
mini-jets, Bose-Einstein quantum statistics, conservation of momentum, resonances, and other phenomena that contribute to the unique behavior observed
for different particle species. Experimental results from proton-proton collisions at 7 TeV have revealed a pronounced anticorrelation, a phenomenon that
had not been replicated by any Monte Carlo model. This triggered a series of
studies that helped create what is called the "baryon correlation puzzle".

In this work, the first ALICE measurements of the angular correlation functions for identical particles (such as π±, K±, and p-barp) in pp, p–Pb and Pb–Pb
collisions at LHC energies in various multiplicity/centrality classes are presented.
This new piece of the puzzle enhances the understanding of anticorrelation
and raises new questions. This will prompt theorists to implement and improve existing theoretical models in search of new answers.

Session 3 / 9

Towards more precise data analysis with machine-learning-based particle identification with missing data

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Identifying products of ultrarelativistic collisions, such as the ones delivered by the LHC and RHIC, is one of the crucial objectives of experiments such as ALICE and STAR, which are specifically dedicated to this task with a number of detectors allowing particle identification (PID) over a broad momentum range.

Recently, as a team of physicists and computer scientists at the Warsaw University of Technology, we have introduced a novel method for Particle Identification (PID) [1,2]. The ALICE experiment was used as R&D and testing environment; however, the proposed solution is general enough for other experiments with good PID capabilities (i.e. already mentioned STAR).

PID methods rely on hand-crafted selections, which compare experimental data to theoretical simulations. To improve the performance of the baseline methods, novel approaches use machine learning models that learn the proper assignment in a classification task. However, because of the various detection techniques used by different subdetectors, as well as the limited detector efficiency and acceptance, produced particles do not always yield signals in all of the ALICE components. This results in data with missing values. Out-of-the-box machine learning solutions cannot be trained with such examples without either modifying the training dataset or re-designing the model architecture.

In the presented work, we propose a new method for PID that addresses these issues and can be trained with all of the available data examples, including incomplete ones. The solution is inspired by a method proposed for medical diagnosis with missing data in patient records. In general, our approach improves the PID purity and efficiency of the selected sample for all investigated particle species (pions, kaons, protons).

[1] Miłosz Kasak, Kamil Deja, Maja Karwowska, Monika Jakubowska, Łukasz Graczykowski & Małgorzata Janik, "Machine-learning-based particle identification with missing data",Eur.Phys.J.C 84 (2024) 7, 691

[2] Maja Karwowska, Łukasz Graczykowski, Kamil Deja, Miłosz Kasak, and Małgorzata Janik, "Particle identification with machine learning from incomplete data in the ALICE experiment", JINST 19 (2024) 07, C07013
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[1] Miłosz Kasak, Kamil Deja, Maja Karwowska, Monika Jakubowska, Łukasz Graczykowski & Małgorzata Janik, "Machine-learning-based particle identification with missing data",Eur.Phys.J.C 84 (2024) 7, 691

[2] Maja Karwowska, Łukasz Graczykowski, Kamil Deja, Miłosz Kasak, and Małgorzata Janik, "Particle identification with machine learning from incomplete data in the ALICE experiment", JINST 19 (2024) 07, C07013

Session 2 / 10

Hadron resonance gas is bad model for hadronic matter in strong magnetic field

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We study the effect of magnetic field on particle ratios and charge fluctuations in hadron resonance gas. We argue that the big change in the pion to proton ratio is due to ill-defined description of higher-spin states, and that because of detailed balance, neutral resonances must be affected by the field too. The calculated fluctuations of conserved charges are likewise suspicious and must be treated with care.

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Comparative Analysis of Heavy-Ion Collision Results at RHIC and LHC

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This paper presents a comparative analysis of experimental results from heavy-ion collision experiments conducted at two of the world's leading research facilities: the RHIC (Relativistic Heavy Ion Collider) in the United States and the LHC (Large Hadron Collider) in Switzerland. These studies aim to investigate the properties of strongly interacting matter under extreme temperatures and densities, providing crucial insights into the phase diagram and the equation of state of quark-gluon plasma.

The report covers several key aspects: the energy dependence of phase transitions, including the transition from hadronic matter to quark-gluon plasma; differences in collective effects such as flow phenomena (azimuthal anisotropy) and fluctuations; and the role of strange and heavy hadrons in the thermalization of the system. Particular attention is paid to hydrodynamic modeling, which helps to reproduce experimental data and offers a deeper understanding of the dynamics of the expanding system.

Furthermore, the study discusses femtoscopic data, which provide estimates of the spatial and temporal parameters of collisions, as well as fluctuations and correlations that may be linked to the existence of a critical point in the phase diagram. Comparing results obtained at different collision energies at RHIC and LHC allows for conclusions about the properties of strongly interacting matter and the evolution of the phase state of the Universe during its early stages.

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The Role of Strange and Heavy Hadrons in Studying the Phase Diagram

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This paper explores the critical role of strange and heavy hadrons in studying the phase diagram of strongly interacting matter. Strange particles, such as kaons, hyperons, and multistrange baryons, are sensitive probes of the dense and hot environment created in heavy-ion collisions. Due to their unique production mechanisms and short lifetimes, strange hadrons provide crucial insights into the dynamics of quark-gluon plasma (QGP) formation and the subsequent hadronization process.

Heavy hadrons, including charmed and bottomed mesons and baryons, serve as excellent tools for studying the properties of QGP due to their large masses and relatively low thermal production rates. Their behavior helps in understanding energy loss mechanisms, transport coefficients, and the degree of thermal and chemical equilibrium reached during the collision.

The report delves into experimental data from facilities like RHIC and LHC, highlighting how the yields, spectra, and flow of strange and heavy hadrons vary with collision energy and system size. These variations offer valuable clues about phase transitions, including the possible existence of a critical point and the boundaries between hadronic matter and QGP.

In addition, theoretical models, such as lattice QCD and hydrodynamic simulations, are discussed to show how they complement experimental findings. The study emphasizes the importance of multiparticle correlations and fluctuation analyses in improving our understanding of the phase structure of strongly interacting matter. Ultimately, the insights gained from studying strange and heavy hadrons contribute significantly to mapping the QCD phase diagram and understanding the early universe's evolution.

Session 1 / 13

Search for the Critical Point in NA61/SHINE

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The existence and location of the QCD critical point are key topics of experimental and theoretical research in heavy ion collisions. The NA61/SHINE experiment at CERN SPS provides valuable data to study how different correlation and fluctuation observables depend on collision energy and the size of colliding nuclei.

This contribution will summarize the status of NA61/SHINE critical point searches in nucleus-nucleus collisions. Including proton and hˆ- intermittency analysis, studies of multiplicity and multiplicity-transverse momentum fluctuations, fluctuations of net-electric charge, and Bose-Einstein (HBT) correlations in femtoscopy analysis.

Session 3 / 14

Observation of top-quark pair production in heavy-ion collisions with the ATLAS detector

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Measurements of top-quark pairs in heavy-ion collisions are expected to provide novel probes of nuclear parton distribution functions as well as to bring unique information about the time evolution of strongly interacting matter. We report the observation of top-quark pair production in proton-lead collisions at the centre-of-mass energy of 8.16 TeV in the ATLAS experiment at the LHC. Top-quark pair production is measured in the lepton+jets and the dilepton channels, with a significance well above 5 standard deviations in each channel separately. The nuclear modification factor is measured for the first time for the top-quark pair process. Also, the first observation of top-quark pair production in lead-lead collisions at the centre-of-mass energy of 5.02 TeV is reported. Top-quark pair production is measured in the eμ channel, with a significance of 5.0 standard deviations. The result is compared to theory predictions based on different nuclear PDF sets.

Session 3 / 15

Compressed Baryonic Matter experiment at FAIR

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Compressed Baryonic Matter (CBM) is a fixed-target experiment that is part of the Facility for Antiproton and Ion Research (FAIR) that currently is under construction. Its primary objective is to investigate the phase diagram of strongly interacting matter (QCD) under conditions of high net-baryon density and moderate temperature. This will be achieved by studying heavy-ion and hadron collisions in the energy range sNN=2.9–4.9 GeV.

CBM employs advanced, fast, radiation-tolerant detector systems and an advanced data acquisition approach. With the ability to operate at interaction rates of up to 10 MHz, it performs real-time space-time event reconstruction and selection. This enables the study of rare phenomena, including

multi-strange hadrons, their antiparticles, multi-strange hypernuclei, and dileptons, many of which remain underexplored.

This talk will highlight CBM's scientific objectives, such as probing the equation of the state of compressed nuclear matter, searching for potential phase transitions between the hadronic and partonic phases, and exploring the restoration of chiral symmetry. The presentation will delve into CBM's physics capabilities in areas like (multi-)strange particle production, dilepton spectroscopy, collective flow, and femtoscopy. Additionally, the current progress in CBM's construction will be discussed, featuring performance studies of its components in FAIR Phase-0 experiments and results from the mCBM test setup using SIS18 beams.

Session 3 / 16

Antibaryon production in pp interactions at $\sqrt{s} \sim 10$ GeV: statistical hadronization and p+$\bar{p}$ scaling?

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The experimental particle yields (36 multiplicities in total) from pp interactions around $\sqrt{s} \sim 10$ GeV are reasonably described [1] within statistical hadronization model ThermalFist [2]. The volume for strangeness was used as an additional free parameter, essential for the quality of the reproduction of experimental results (-3$\pm$17 \% average relative difference). Among the measured yields, antibaryons (except antiprotons) are very rare. The multiplicity of antiprotons production is found to depend almost quadratically (1.86 ± 0.11) on the available energy corrected for the threshold energy of producing baryon-antibaryon pair. This energy dependence, with appropriate scaling, surprisingly well describes the yields of other antibaryons ($\bar{n}$, $\bar{\Lambda}$, $\bar{\Xi}$, $\bar{\Xi}(1520)$) calculated within the statistical hadronization model and/or obtained experimentally. However, this simple scaling does not apply to the energy dependence predicted for antideuterons.

Session 1 / 17

Towards accurate modeling of neutron star crust properties and what we can learn from them about the core

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The density functional theory (DFT) is one of physics's most popular methods for simulating systems' microscopic properties. It allows for studies of many-body Fermi systems' static, dynamic, and thermodynamic properties in a unified framework while keeping the numerical cost at the same level as the mean-field approach. The development of (super)computing techniques in the last decade allows for DFT approaches to track the microscopic dynamics of systems consisting of tens of thousands of strongly interacting particles. In this seminar, I will discuss joint progress in nuclear and ultracold Fermi gas physics and high-performance computing in the context of constructing a general-purpose tool for modeling neutron star crust 1. I will also present how the accurate modeling of neutron crust properties can constrain the properties of the star's core.

1 D. Pęcak, A. Zdanowicz, N. Chamel, P. Magierski, G. Wlazłowski, Time-dependent nuclear energy-density functional theory toolkit for neutron star crust: Dynamics of a nucleus in a neutron superfluid, Phys. Rev. X 14, 041054 (2024)

Session 1 / 18

Quasiparticle second-order hydrodynamics at finite chemical potential

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We extend the derivation of second-order relativistic viscous hydrodynamics to incorporate the effects of baryon current, a non-vanishing chemical potential, and a realistic equation of state. Starting from a microscopic quantum theory, we build a quasiparticle approximation to describe the evolution of hydrodynamic degrees of freedom, highlighting its connection to the Wigner formalism. We perform a second-order hydrodynamic expansion to derive a closed set of equations for the components of the stress-energy tensor and the baryon current.

Session 3 / 19

Photon-photon femtoscopy in Ag+Ag collisions at \sqrt{s_{NN}}=2.55 GeV

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The study of femtoscopic correlations between photon pairs, although challenging from an experimental standpoint, can serve as a complementary approach to traditional hadron femtoscopy. Owing to the penetrative nature of photons, which are unaffected by strong or electromagnetic interactions, such measurements can be used to probe the early stages of heavy-ion collisions, prior to freeze-out. Furthermore, since femtoscopy is sensitive to the emission sequence of particles, it may provide the potential to distinguish between the femtoscopic signals of direct photons and decay photons, thus enabling the estimation of direct photon yields.

As part of the FAIR/GSI scientific complex, the HADES experiment focuses on detecting light vector mesons through dielectron ($e^{\pm}$) channels produced in high-energy heavy-ion collisions at energies of approximately 1–2 A GeV. With the presence of electromagnetic calorimeters, HADES is also capable of direct photon detection, facilitating femtoscopic measurements.

Preliminary results from Ag+Ag collision data at $\sqrt{s_{NN}} = 2.55$ GeV will be presented.

Session 2 / 20

Extension of the integrated HydroKinetic Model to BES RHIC and GSI-FAIR nuclear collision energies \

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The work presented is devoted to developing the integrated hydrokinetic approach (iHKM) for relativistic nucleus-nucleus collisions. While the previous cycle of works on this topic focused on ultra-relativistic collisions at the top RHIC and different LHC energies, the current work addresses relativistic collisions at the lower energies, specifically ranging from approximately 1 to 50 GeV per nucleon pair in the center-of-mass colliding system. The formation times for the initial state of dense matter in such collisions can be up to three orders of magnitude longer than those in ultra-relativistic collisions. This reflects a fundamentally different nature and formation process, particularly concerning the possible stages of initial state evolution, including thermalization (which may be only partial at very low collision energies), subsequent hydrodynamic expansion, and the final transition of matter evolution into a hadronic cascade. These stages, which are fully realized in ultra-relativistic reactions, can also occur within the energy range of BES RHIC, albeit with distinct time scales. This publication not only advances the theoretical development of iHKM (referred to, if necessary, as the extended version of integrated Hydrokinetic Model, iHKMe), but also provides examples of model applications for calculating observables. A systematic description across a wide range of experimental energies, which is preliminary yet quite satisfactory, for spectra, flow, and femtoscopy, will be also presented.

Session 1 / 21

Finite volume effects on the phase digram via momentum space constraints

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The QCD phase diagram is expected to be affected by the system size for small volumes. The most common strategy to study these effects in theoretical models is to consider the constraints in momentum space imposed by the finite spatial extension. The different approximations in the various models show similar behavior in some aspects but very different details for the phase diagram and the CEP. To understand these differences, we implemented several scenarios, including low-momentum cutoff and discretization with different boundary conditions, in an extended Polyakov quark-meson model in mean-field approximation [2307.10301]. We show that both the chosen momentum space constraint and the treatment of the vacuum term cause significant changes in the trajectory of the CEP and even in the fate of the chirally broken phase as the characteristic system size is changed.

Session 2 / 22

Modeling resonance spectra in heavy-ion collisions at HADES

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The statistical hadronization model is known to describe very well the yields of particles produced in heavy-ion collisions at LHC, RHIC, and SPS over many orders of magnitude. Recently, we have shown [1,2] that at lower energies, not just yields but also spectra of the most abundant particles containing u and d quarks can be reproduced in the thermal model.

Strangeness, heavy compared to the temperature and rarely produced, is not expected to thermalize at low energies and cannot be used as additional observable in this study. Instead, further insights can be gained from baryonic resonances, which are excited in large amounts in the system at high μ_{B}.

In this talk, I will discuss Delta(1232) production using the thermal Monte Carlo event generator THERMINATOR 2, where we have implemented a finite width of the resonance based on the S-matrix theory [3]. Model predictions will be confronted with transport simulations and the unique set of experimental results published by the HADES collaboration [4].

References
1 S. Harabasz *et al.*, Phys.Rev.C **102** (2020) 5, 054903
[2] S. Harabasz *et. al.*, Phys.Rev.C **107** (2023) 3, 034917
[3] P. M. Lo *et al.*, Phys.Rev.C **96** (2017) 1, 015207
[4] J. Adamczewski-Musch *et al.* (HADES), Phys.Lett.B **819** (2021) 136421

Session 1 / 23

Heavy Flavor Production in Hot QCD Matter

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We investigate the evolution of charm quarks in hot QCD matter employing the effective quasi-particle approach. In this framework, the QGP comprises the quasi-quarks and -gluons with the dynamically generated masses linked to the lattice QCD equation of state. Using the kinetic rate equation, we study the production of the $(c\bar{c})$ pairs for two distinct scenarios of the QGP evolution: the longitudinal (1D) propagation of perfect fluid is juxtaposed to the (2+1)-dimensional expansion of the viscous medium.

Within the statistical errors, we find that the total number of charm quarks does not change through the entire 1D evolution of perfect QGP. This observation agrees with the predictions of the Statistical Hadronization Model. In viscous QGP expanding in 2+1 dimensions, the number of charm quarks slightly decreases towards T_c, indicating the influence of the dissipative phenomena.

Session 1 / 24

Probing hadron-quark phase transition in twin stars using f-modes

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Although it is conjectured that a phase transition from hadronic to deconfined quark matter is possible in the ultrahigh density environment in Neutron Stars, the nature of such a transition is still unknown. Depending on whether there is a sharp or slow phase transition, one may expect a third family of stable compact stars or "twin stars"to appear, with the same mass but different radii compared to Neutron stars. The possibility of identifying twin stars using astrophysical observations has been a subject of interest, which has gained further momentum with the recent detection of gravitational waves from binary neutron stars. In this work, we investigate for the first time the prospect of probing the nature of hadron-quark phase transition with future detection of gravitational waves from unstable fundamental f-mode oscillations in Neutron Stars. By employing a recently developed model that parametrizes the nature of the hadron-quark phase transition via "pasta phases", we calculate f-mode characteristics within a full general relativistic formalism. We then recover the stellar

properties from the detected mode parameters using Universal Relations in GW asteroseismology. Our investigations suggest that the detection of gravitational waves emanating from the f-modes with the third-generation gravitational wave detectors offers a promising scenario for confirming the existence of the twin stars. We also estimate the various uncertainties associated with the determination of the mode parameters and conclude that these uncertainties make the situation more challenging to identify the nature of the hadron-quark phase transition.

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Effects of jet-medium interactions versus vacuum like emissions on jet azimuthal angular decorrelations

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Jets of strongly interacting particles represent a useful means to examine particle interactions within the hot and dense medium of a quark gluon plasma (QGP)
that can be recreated by ultrarelativistic heavy ion collisions.
I present a Monte-Carlo algorithm, where jets evolve in the medium via the jet-medium interactions of scatterings and medium induced radiations as well
as vacuum like emissions of bremsstrahlung (VLE).
Numerical results were obtained for azimuthal angular correlations of jet-photon pairs in heavy-ion collisions.
These correlations exhibit a considerable broadening due to effects of VLEs in addition to already present effects of broadening from the jet medium interactions of
scattering and induced radiation.

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Rreliminary Analysis of Femtoscopic Correlations in p+p Collisions at 4.5 GeV at HADES

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Femtoscopic correlations allow us to probe into the space-time structure of the source of particle emission, which appears after a heavy-ion collision. Most analyses focus on collisions of heavier elements or high energies (or both) as it allows for the usage of so-called smoothness approximation. In this work, the applicability of this approximation will be tested, as it does not work at low multiplicities, allowing for an interesting insight into cases that are usually omitted in femtoscopic correlations.

In this presentation, preliminary results obtained from UqQMD simulations will be presented, focusing mainly on proper background estimation and qualitative analysis of same-sign pion correlations in the obtained data.

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Abrupt switching from hadronic to partonic degrees of freedom at smooth chiral crossover

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Based on a generalized Beth-Uhlenbeck approach to thermodynamics of QCD we explain why the abundances of hadrons produced in ultrarelativistic heavy-ion collisions are well described by the hadron resonance gas (HRG) model with a sudden chemical freeze-out at a well-defined hadronization temperature despite the fact that state of the art results of lattice QCD indicate a smooth chiral crossover. The hadrons are treated as color singlet multiquark clusters in medium with a background gluon field in the Polyakov gauge coupled to the underlying chiral quark dynamic based on a confining density functional approach. Restoration of chiral symmetry at high temperatures triggers the Mott dissociation of multiquark clusters and deconfinement of quark-gluon plasma (QGP). While perfectly reproducing the smooth behavior of entropy density and chiral condensate of lattice QCD, the approach indicates an abrupt switching between the hadrons and partons. This is manifested by a rapid change of the ratio of baryon number susceptibilities χ_4^B/χ_2^B from the value of HRG to the one of QGP. We report for the first time that χ_4^B/χ_2^B shall not be mistaken for a measure of the fraction of hadrons in the system. Its deviation from unity below the chiral restoration temperature can actually quantify a repulsive residual interactions in the HRG. We associate it with the effects of Pauli blocking and model by a temperature dependent correction to the phase shift of baryons, in accordance with lattice QCD results on χ_4^B/χ_2^B.

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Spin hydrodynamics in heavy-ion collisions - recent numerical applications

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We present the first solution of (3+1)-dimensional ideal spin hydrodynamics embedded within a realistic hydrodynamic background. Using a suitable choice of initial conditions, we achieve a simultaneous description of bulk and polarization observables, successfully reproducing the correct sign of longitudinal polarization. The findings point to delayed spin thermalization, implying that dissipative effects play a significant role predominantly during the early stages of the fireball evolution.

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Differential study of Λ-hyperon polarization in central heavy-ion collisions

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We present a differential study of Λ hyperon polarization in central Au+Au collisions at $\sqrt{s_{NN}} = 7.7$ GeV, employing the microscopic transport model UrQMD in conjunction with the statistical hadron-resonance gas model. The resulting thermal vorticity configuration effectively manifests as the formation of two vortex rings in the forward and backward rapidity regions. We show that the polarization of Λ hyperons exhibits oscillatory behaviour as a function of the azimuthal angle, offering a novel means to probe the structure of the fireball in central heavy-ion collisions.

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Chemical Freeze-out in the QCD Phase Diagram

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After a short introduction to the structure of the QCD phase diagram and the status of its exploration, we focus on the discussion of chemical freeze-out (cfo) in the temperature - chemical potential and temperature - density planes. While in the meson-dominated part of the phase diagram the cfo appears to be tied to the hadronization and chiral symmetry breaking, we present a new insight for understanding cfo in the baryon-dominated region for heavy-ion collision experiments at energies below about 8 GeV in the nucleon-nucleon center of mass system. There, the cfo appears strongly correlated with the Mott transition lines for light nuclear clusters such as alpha particles. We discuss cfo as "inverse Mott dissociation" in the QCD phase diagram and argue that a microscopic formulation of this non-equilibrium process can be given within the Zubarev approach of the non-equilibrium statistical operator [1,2,3].

1 D. Blaschke et al., Cluster production and the chemical freeze-out in expanding hot dense matter, arXiv:240801399
[2] O. Vitiuk et al., Nonequilibrium phenomenology of identified particle spectra in heavy-ion collisions at LHC energies, arXiv:2409.09019
[3] G. Röpke et al., Heavy element abundances from a universal primordial distribution, arXiv:2411.00535

Session 3 / 32

Quantum sensors for HEP: DRD-5: Detector R&D Collaboration for quantum sensors at CERN

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The second quantum revolution is opening new avenues for development. The three main pillars which sustain the current effort are quantum telecommunication, quantum computing and quantum sensing. The three fields are tightly connected to each other and advances in any of them move the boundaries of the whole field. On an international scale, there is an ongoing effort to bridge the technological readiness level of quantum sensing prototypes to make them available to the community. In this sense, quantum sensing techniques will be developed within the recently approved Detector R&D Collaboration (https://cds.cern.ch/record/2901426for) quantum sensors (DRD-5) with more than 100 institutes united under the umbrella of CERN, in Geneva. The Collaboration will implement the European Strategy for Particle Physics R&D plan of the European Committee for Future Accelerators (ECFA) in the domain of quantum technologies which potentially can revolutionize frontier research. At the same time, local initiatives as the Polish Quantum Technology infrastructure progresses in acquiring competences to lead this field in the future. Part of such efforts are related to the development of open software and hardware solutions used in quantum computers and experiments.

Session 2 / 33

Diagram of high-energy nuclear collisions and two families of horns

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TBD

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The earliest phase of relativistic heavy ion collisions

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TBD

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Light and heavy flavour thermalisation in high-energy collisions

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TBD

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Combinants and correlation functions in nuclear collisions: some intriguing properties of multiplicity distributions

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TBD

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Fluctuations and correlations of baryonic chiral partners

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TBD

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Alice Forward Calorimeter Upgrade

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TBD

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Integrable equation of state and finite size effect

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We analyze an effective statistical model for nuclear matter based on a virial-type expansion for the internal energy. In the thermodynamic limit, the order parameter satisfies an integrable partial differential equation, whose solution is a family of equations of state unveiling nuclear and quark-hadron phase transitions through gradient catastrophe and shock formation. We further demonstrate that corrections to the critical behavior, accounting for a finite number of particles in the system, are not just non-negligible but also important in heavy-ion-collision experiments.

Session 3 / 40

Probing QGP through correlations and fluctuations of collective observables

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The matter produced in an ultra-relativistic heavy-ion collision, dubbed as the QGP, posses a temperature 10^5 times that of Sun's core and survives for a very short time (10^{-22} s), producing thousands of particles which exhibit collective motion described by some global observables, e.g. charged particle multiplicity(N_{ch}), mean transverse momentum per particle ($[p_T]$), harmonic flow (V_n) etc. Fluctuations and correlations between these observables contain crucial information of the QGP medium as well as of the nuclear properties. We study in hydrodynamic model p_T-dependent event-by-event fluctuation of V_n probed by the factorization breaking coefficient, which shows decorrelation at higher p_T-bins. We study the fluctuation of $[p_T]$ in ultra-central Pb+Pb collision and explain the sudden fall in the ATLAS data over a narrow range of multiplicity. We show in our model that this sharp fall is a consequence of the underlying thermalization assumption of the system. We also study the observable $v_0(p_T)$, first introduced by Teaney et al., which is similar to anisotropic flow in terms of its collective nature and, it correlates the spectra with the event-by-event mean transverse momentum per particle ($[p_T]$). We present model predictions for charged and identified particles. Additionally, we show how $v_0(p_T)$ can be used to capture the p_T-acceptance effect of different collective observables. Through these above-mentioned studies, we present an overall picture how correlations and fluctuations of the collective observables can be used to study the dynamics and properties of the QGP medium.

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Info about dinner

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XVIII Polish Workshop in 2025

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