HIPSTARS 2020 - Workshop on Heavy Ion Physics and Compact Stars

Tuesday 1 December 2020 - Friday 4 December 2020

Book of Abstracts

The event is a virtual spin-off of the series of meetings STARS/SMFNS gathering scientists from all over the world, with the purpose of establishing connections between the different communities within the scope of the conference and encouraging the participation of students and young researchers. The meeting sessions will consist of contributed talks covering recent developments in the following topics: Heavy ion collisions and the formation of the quark-gluon plasma, relativistic and nuclear astrophysics, compact stars, gravitation and related topics.

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Extreme ultra-soft X-ray variability in an eROSITA observation of the narrow-line Seyfert 1 galaxy 1H 0707-495

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The ultra-soft narrow-line Seyfert 1 galaxy 1H 0707−495 is a well-known and highly variable active galactic nucleus (AGN), with acomplex, steep X-ray spectrum, and has been studied extensively with XMM-Newton. 1H 0707−495 was observed with the extendedROentgen Survey with an Imaging Telescope Array (eROSITA) aboard the Spectrum-Roentgen-Gamma (SRG) mission on October11, 2019, for about 60,000 seconds as one of the first calibration and pointed verification phase (CalPV) observations. The eROSITAlight curves show significant variability in the form of a flux decrease by a factor of 58 with a 1σerror confidence interval between31 and 235. This variability is primarily in the soft band, and is much less extreme in the hard band. No strong ultraviolet variability has been detected in simultaneous XMM-Newton Optical Monitor observations. The UV emission is 1044erg s-1, close to the Eddington limit. 1H 0707−495 entered the lowest hard flux state seen in 20 years of XMM-Newton observations. In the eROSITA All-Sky Survey (eRASS) observations taken in April 2020, the X-ray light curve is still more variable in the ultra-soft band, but with increased soft and hard band count rates more similar to previously observed flux states. A model including relativistic reflection and a variable partial covering absorber is able to fit the spectra and provides a possible explanation for the extreme light-curve behaviour. The absorber is probably ionised and therefore more transparent to soft X-rays. This leaks soft X-rays in varying amounts, leading to large-amplitude soft-X-ray variability

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Neutron star kick velocity induced by neutrino chirality flip and a lower bound for the neutrino magnetic moment

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We study the neutrino chirality flip during the birth of a neutron star, produced in a core made of strange quark matter. This mechanism is applied to the neutron star kick velocity problem and we show that it is efficient when the neutrino magnetic moment is not smaller than $4.7 \times 10^{-15}\mu_B$, where μ_B is the Bohr magneton. When this lower bound is combined with the most stringent upper bound, our results set a range for the neutrino magnetic moment given by $4.7 \times 10^{-15} \leq \mu_\nu/\mu_B \leq (0.1-0.4)\times 10^{-11}$. The obtained kick velocities for natal conditions are consistent with the observed ones and span the correct range of radii for typical magnetic field intensities.

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Astrophysical jet formation from a magnetized npe-gas

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We study the quantum magnetic collapse of a partially bosonized npe-gas and obtain that this type of collapse might be one of the mechanisms behind matter expulsion out of compact objects. We check also that this gas might form a stable stream of matter whose collimation is due to its strong self-generated magnetic field. Possible astrophysical applications of these results, in particular related to jet formation and its maintenance, are discussed.

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Thermodynamics of a magnetized neutral vector boson gas

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We study the thermodynamic properties of a magnetized neutral vector boson gas at any temperature, with the aim to provide equations of state that allow more general and precise descriptions of astrophysical phenomena. The all-temperature analytical expressions for the thermodynamic magnitudes, as well as their non-relativistic limits, are obtained starting from the energy spectrum given by Proca's theory. With these expressions, and considering the system under astrophysical conditions (particle densities, temperatures and magnetic fields in the order of the estimated for Neutron Stars), we investigate the Bose-Einstein condensation, the magnetic properties and the equations of state of the gas, making a special emphasis on the influence of antiparticles and magnetic field. In all cases, the results are compared with their analogues in the low temperature and the non-relativistic limits. This allows us to establish the ranges of validity of these approximations and to achieve a better understanding of their effects on the studied system.

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Observables of spheroidal magnetized strange stars

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We study stable spheroidal configurations of magnetized strange stars using an axially symmetric metric in spherical coordinates that uses a gamma parameter to link the anisotropy in the equation of state due to the magnetic field with the deformation of the star. The stars are composed by magnetized Strange Quark Matter described within the framework of the MIT-bag model. Their masses, radii, eccentricity, redshift and mass quadrupole moment are computed. Results are compared with spherical Strange Stars solutions obtained with TOV equations and observational data of Strange Stars candidates. In the spheroidal model the observables depend directly on the deformation of the stars, and even though it is small, the observables strongly deviate from the corresponding spherical configurations. Thus, the highest values of the mass quadrupole moment correspond to the intermediate mass regime. These differences might allow to discriminate between models with/without magnetic field when compared with observations.

2

Exploring the mechanisms generating the directed flow in relativistic nuclear collisions

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The quark-gluon plasma (QGP) is intensively studied since decades in Heavy-Ion Collisions (HICs) at high energy and recently also in high-multiplicity events of relativistic proton-nucleus collisions. Both collision systems are characterized by the presence of very intense electromagnetic fields, which attain their maximal strength in the early stage and interplay with the strong vorticity induced in the plasma by the large angular momentum of the colliding nuclei. A promising observable influenced by these phenomena is the particle directed flow v_1. We discuss the v_1 of light hadrons and heavy mesons in large and small colliding systems by means of relativistic transport simulations. We show that in HICs the magnitude of the v_1 of light particles keeps trace of the vorticity in the system, whereas the very large v_1 of neutral D mesons is due to the longitudinal asymmetry between bulk matter and charm quarks and to the large non-perturbative interaction of heavy quarks in QGP. The splitting of v_1 for D^0 and $\overline{D}^0$ is also much larger than the one observed for light particles, mainly due the early formation time of heavy quarks. However, standard electromagnetic profile with constant conductivity is not able to account for the huge splitting observed at LHC energy. In proton-nucleus collisions the generated electric field is comparable to the magnetic field since the beginning, due to the different number of protons in the colliding nuclei. Moreover, the particle rapidity distributions are strongly asymmetric inside the overlap region due to the different size of the incoming nuclei. We present our results on p+Au collisions at top RHIC energy, showing how the electromagnetic field leads to a sizeable splitting in the v_1 of pions and kaons and that this is mainly generated in the deconfined phase.

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Properties and production of hypernuclei in relativistic ion reactions.

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The study of hypernuclei and their production mechanisms open new opportunities for nuclear/particle physics and astrophysics. The hyperons influence many nuclear properties in finite nuclei and in neutron stars (infinite nuclear matter). We review the main processes leading to the production of hypernuclei in nuclear reactions including relativistic ion collisions. Such deep-inelastic high-energy interactions do lead to fragmentation and multifragmentation of nuclear matter, and hyper-fragments can be abundantly produced [1,2]. The binding energies of hyperons influence the hypernuclei formation [3,4] and this gives a chance to evaluate experimentally the hyperon effects in nuclear matter. The most promising process for such a hypernuclear research is a disintegration of large excited hyper-nuclear residues produced in peripheral relativistic nucleus-nucleus collisions. Besides, there is a coalescence-like mechanism responsible for combining hyperons and other baryons into light clusters. The primary coalescent nuclear clusters can be formed at the subnuclear densities and be excited. Their subsequent decay is able to explain new phenomena observed in central heavy-ion collisions. Also this process can be used to get information on unstable hypernuclear states. We use the transport, coalescence and statistical models to describe the whole process, and demonstrate the important regularities of the hypernuclei formation and the advantages of such reactions over the traditional hypernuclear methods: A broad distribution of predicted hypernuclei in masses and isospin allows for investigating properties of exotic hypernuclei. We point at the abundant production of multi-strange nuclei that will give an access to multi-hyperon systems and strange nuclear matter. The realistic estimates of hypernuclei yields in various collisions are presented.

[1] A.S. Botvina, et al., Phys. Rev. C95, 014902 (2017).
[2] A.S. Botvina, et al., Phys. Rev. C94, 054615 (2016).
[3] N. Buyukcizmeci, et al., Phys. Rev. C98, 064603 (2018).
[4] N. Buyukcizmeci, et al., Eur. Phys. J. A56, 210 (2020).

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Collective flow of light nuclei in Au+Au reactions at 1.23 A GeV

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We explore the rapidity and transverse momentum dependence and mass number scaling of collective flow harmonics of light nuclei in Au + Au reactions at a beam energy of 1.23 AGeV within the UrQMD approach. These investigations are of direct relevance for the high acceptance di electron spectrometer (HADES) experiment at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany, that has recently presented first data on the flow of light clusters in Au + Au collisions at 1.23 AGeV. To address the flow of light nuclei, UrQMD has been extended by a phase-space coalescence approach. We find that this ansatz provides a very good description of the measured deuteron and proton flow data, if a hard equation of state is used for the simulation. The results show a strong impact of cluster formation on the observable collective flow and agree well with the data obtained by the HADES collaboration.

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Understanding the energy dependence of B_2 in heavy ion collisions: Interplay of volume and space-momentum correlations

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The deuteron coalescence parameter B_2 in proton+proton and nucleus+nucleus collisions in the energy range of $\sqrt{s_{NN}}$ = 900 - 7000 GeV for proton+proton and $\sqrt{s_{NN}}$ = 2 - 2760 GeV for nucleus+nucleus collisions is analyzed with the Ultrarelativistic Quantum Molecular Dynamics (UrQMD) transport model, supplemented by an event-by-event phase space coalescence model for deuteron and anti-deuteron production. The results are compared to data by the E866, E877, PHENIX, STAR and ALICE experiments. The B_2 values are calculated from the final spectra of protons and deuterons. At lower energies, $\sqrt{s_{NN}} \leq$ 20 GeV, B_2 drops drastically with increasing energy. The calculations confirm that this is due to the increasing freeze-out volume reflected in $B_2 \sim 1/V$. At higher energies, $\sqrt{s_{NN}} \geq$ 20 GeV, B_2 saturates at a constant level. This qualitative change and the vanishing of the volume suppression is shown to be due to the development of strong radial flow with increasing energy. The flow leads to strong space-momentum correlations which counteract the volume effect.

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Kinetic and chemical freeze-out parameters from resonance reconstruction

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The hadronic transport simulation UrQMD is used to pin down the chemical freeze-out space-time point of each final state pion. In combination with a coarse-grained collision evolution, the local temperature T and the local baryo-chemical potential μ_{B} are estimated up to the top RHIC energies. The results match thermal model estimates of experimental data with high accuracy. However, here the chemical freeze-out is linked to the space and time dependent relation between the expansion and the scattering rate and not to the onset of deconfinement. Moreover, typical freeze-out criteria proposed in the literature are investigated on the reconstructed chemical freeze-out hyper-surface. The average energy per particle criterion $\langle E\rangle/\langle N\rangle = 1$ is confirmed within the whole energy range with deviations up to 20% depending on the meson/baryon content of the colliding system. The entropy per baryon criterion $s/T^3 = 7$ and the total baryon density criterion $n_{\mathrm{B}} + n_{\bar{\mathrm{B}}} = 0.12$ fm^{-3} are confirmed above 7 and 20 GeV, respectively. Finally, the combined UrQMD + coarse-graining model is used to constrain the space and time dependence of the shear viscosity to entropy density ratio η/s in central Au+Au collisions at a beam energy of 1.23 AGeV. The results indicate an intricate sensitivity to the different stages of the collision at this energy, i.e. the compression phase and expansion phase.

1

Chiral hydrodynamics of plasma in strong magnetic fields & quantum criticality

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In this presentation I will motivate and construct the hydrodynamic description of a chiral plasma subject to a strong magnetic field. Such a description can be applied to the quark gluon plasma or astrophysical plasma. Kubo formulae are computed which relate 22 transport coefficients to particular correlation functions. Among those transport coefficients, 8 are novel. Known transport coefficients, such as the Hall viscosity and Hall conductivity, are now splitting into two each, one longitudinal and one transverse to the magnetic field. We provide a successful validity check by computing all transport coefficients in a specific holographic model. In this holographic dual, at large chemical potential, a quantum critical point emerges. We compute the entanglement entropy and conjecture a c-function near this critical point, aiming eventually at a theoretical description of quantum critical transport. An experimentally accessible system from condensed matter physics displaying these featurs are Weyl semimetals.

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Quantum vacuum ferromagnetism and jets

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Quantum vacuum in large fields of the order of twice or greater than the critical Schwinger field 2Bc shows strong anisotropic properties: virtual photons as well as electrons and positrons tend to propagate in a parallel direction to the magnetic field. In order to overcome this anisotropic behavior, we propose an heuristic model based on fermion pairing of boson-vacuum in the form of virtual para-positronium, a chiral noninvariant electron-positron bound state leading to a ferromagnetic quantum phase transition of the vacuum for fields of order of twice the critical Schwinger field 2Bc. Our aim is to suggest a possible quantum relativistic self-magnetized jet model.

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The photon time delay in strong magnetic field

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We calculate the time delay for photons propagating both in QED vacuum and in a charged electron-positron gas, in an external magnetic field. Our final aim is the study of this effect for photons in a neutron star magnetosphere like scenario.

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A stability analysis of the static EKG Boson Stars

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An analysis is realized on the stability of the recently proposed static solutions of Boson Stars. These solutions of Einstein-Klein-Gordon (EKG) equations arise from considering the interactions of a real scalar field with matter. We assumed that the inclusion of the scalar field in addition with matter, allows to justify that stability implies the total mass of the solution should grow when the initial condition for the density of matter at the origin is also increased. We uses a linear relation concerning to the source and the energy density as well as for this and the pressure, with this we found the relation between the scalar field in the origin and matter energy density in the same point. We also determine the behavior of the total mass with the matter energy density in the origin determining through this, and the weak energy condition, two possible ranges for stable solutions of static boson stars.

4

Reaction mechanisms for deuteron production in HICs within a transport approach

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We discuss about formation of deuterons in hadronic matter by means of a microscopic description of inelastic many-body scattering processes. The dominant reactions $dN \leftrightarrow NNN$ and $d\pi \leftrightarrow NN\pi$ which are characterized by measured cross sections $\sigma \simeq 200\,mb$, much larger than subdominant $d\pi \leftrightarrow NN$ process, have been fully implemented within a kinetic approach by solving the collision integral in terms of covariant scattering rate.
We adopt the theoretical formulation of baryon-antibaryon production by three-meson fusion and apply to the case of deuteron including also its weak-bound properties in terms of the quantum wave function of the proton-neutron pair interacting through effective nuclear potential.
We investigate the validity of detailed balance within a BUU-type model simulating deuteron reactions in infinite nuclear matter at equilibrium and using proper parametrization of hadronic cross sections on the experimental measurements.
After that, we implement the same mechanisms within the Parton–Hadron–String Dynamics (PHSD) transport approach to calculate multiplicity and transverse momentum spectra of deuterons at mid-rapidity in $Pb+Pb$ collisions at the energy range of SPS and compare to available experimental data.
Finally, we discuss about future development of our model to the novel Parton–Hadron–Quantum-Molecular Dynamics (PHQMD) framework to study the impact of different dynamical description and the use of clusterization algorithms.

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Collective flow measurements with HADES in Au+Au collisions at 1.23 AGeV

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Flow coefficients v_n of the orders $n = 1 - 6$ are measured with the High-Acceptance DiElectron Spectrometer (HADES) at GSI for protons, deuterons and tritons in Au+Au collisions at $\sqrt{s_{NN}} = 2.4$ GeV.
HADES provides a large acceptance combined with a high mass-resolution and therefore allows to study dielectron, hadron and light nuclei production in heavy-ion collisions with unprecedented precision. Here we present the multi-differential measurement of flow coefficients over a large region of phase space. We will discuss the scaling properties of the various flow harmonics as a function of transverse momentum p_t, rapidity and centrality for the three hydrogen isotopes.
Combining the information from the flow coefficients of all orders allows to construct for the first time, at collision energies of a few GeV, a full 3D-picture in momentum space of the angular emission pattern of these particles. It reflects the complicated interplay between the effect of a non-uniform fireball pressure gradient in azimuthal and longitudinal direction on the emission of particles and their subsequent interaction with spectator matter.
The high precision information on higher order flow coefficients puts strong constraints on the determination of the properties of dense baryonic matter, such as its viscosity and equation-of-state (EOS).

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Introduction to Holography and its Application to Heavy-Ion Physics

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Holography, also known as AdS/CFT correspondence, lies at the intersection of gravitational physics and quantum field theory. It is a duality which maps the physics of a strongly coupled quantum field configuration onto the physics of a weakly curved model spacetime. It has been successfully applied to describe a variety of systems in gravitational terms–from condensed matter to quantum information theory. In the context of heavy-ion collisions, holography contributes to the understanding of jet quenching, quarkonium yields, and elliptic flow.
After an introduction to holography, this talk focuses on the calculation of hydrodynamic transport coefficients of the quark-gluon plasma. We will show how the specific shear viscosity, η/s, in the near-equilibrium regime can be derived from a nearly static black hole configuration. Next, the definitions of entropy density and shear viscosity will be properly generalized to the far-from equilibrium regime. We will construct a strongly time-dependent spacetime and find that the specific shear viscosity is decreased by more than 60% in the initial phase of a heavy-ion collision. These corrections impact the simulation of heavy-ion collisions and the extraction of viscosity from experimental data. Such a sharpened analysis paves the way towards a deeper understanding of the quark-gluon plasma.

3

Transport properties and evolution of the QGP in HICs

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We study the influence of the baryon chemical potential μB on the dynamical properties of the Quark–Gluon–Plasma (QGP) in- and out-of equilibrium. The description of the QGP in equilibrium is based on the effective propagators and couplings from the Dynamical QuasiParticle Model (DQPM)that is matched to reproduce the equation-of-state of the partonic system above the deconfinement temperature Tc from lattice Quantum Chromodynamics (lQCD).
We study the transport coefficients such as the ratio of the shear and bulk viscosities to the entropy density, i.e. η/s and ζ/s, the electric conductivity σ0/T as well as the baryon diffusion coefficient κB and compare to related approaches from the literature(non-conformal holographic model, lattice QCD, NJL). We find that the ratios η/s and ζ/s, as well as σ0/T, are in accord with the results from lattice QCD at μB=0. Furthermore, we have considered the shear viscosity and the electric conductivity of strongly interacting quark matter within the extended Nf=3 Polyakov Nambu-Jona-Lasinio (PNJL) model along with the crossover transition line for moderate values of baryon chemical potential 0≤μB≤0.9 GeV as well as in the vicinity of the critical end point (CEP) and at large baryon chemical potential μB=1.2 GeV, where the first-order phase transition takes place.
We explore how the nature of the degrees-of-freedom affects the transport properties of the QGP. Moreover, we study the possible influence of the presence of a CEP and of a 1st order phase transition at high baryon chemical potential.
The out-of-equilibrium study of the QGP is performed within the Parton–Hadron–String Dynamics (PHSD) transport approach extended in the partonic sector by explicitly calculating the total and differential partonic scattering cross sections based on the DQPM and the evaluated at actual temperature T and baryon chemical potential μB in each individual space-time cell where partonic scattering takes place. The traces of their μB dependencies are investigated in different observables for symmetric Au + Au and asymmetric Cu + Au collisions such as rapidity and m_T-distributions and directed and elliptic flow coefficients v1, v2 in the energy range (s_NN)^(1/2) from 7.7 GeV to 200 GeV.

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Charmonium production with Remler generalized coalescence model

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Two of the most important observables for understanding Quark-Gluon Plasma (QGP) physics are quarkonia suppression and the energy loss process. Although quarkonia are compound objects, it is usually advocated that their production at intermediate ⊠T follows a behavior similar to the one of single particles, like for instance D mesons. Ultimately, this kind of study will bring more information about the way in which the QGP thermalize the energy during the hadronization process. We will be focus in explore the production of charmonia employing a relativistic phase space coalescence model born from the Remler formalism, to track the production probability time evolution at mid-rapidity in central collision for lead-lead and proton-proton cases. The model allows as to compute and study the several observables likes (⊠T, flow coefficient, and RAA), through their relationship with the charmonium formation probability. Those observables are quite susceptible to suppression and energy loss of charmonium in the medium.