FAIR next generation scientists - 7th Edition Workshop

Monday 23 May 2022 - Friday 27 May 2022

Hotel & Spa Mediterranean Village, Paralia (Pieria, Greece)

Book of Abstracts

Contents

Registration / 79

Registration

80

Registration

81

Welcome

82

Precision Physics with Stored Exotic Ions

Corresponding Author: y.litvinov@gsi.de

The storage of freshly produced radioactive particles in a storage ring is a straightforward way to achieve the most efficient use of such rare species as it allows for using the same rare ion multiple times. Employing storage rings for precision physics experiments with highly-charged ions (HCI) at the intersection of atomic, nuclear, plasma and astrophysics is a rapidly developing field of research. Until very recently, there were only two accelerator laboratories, GSI Helmholtz Center in Darmstadt, Germany (GSI) and Institute of Modern Physics in Lanzhou, China (IMP), operating heavy-ion storage rings coupled to radioactive-ion production facilities. The experimental storage ring ESR at GSI and the experimental cooler-storage ring CSRe at IMP offer beams at energies of several hundred A MeV. The ESR is capable to slow down ion beams to as low as 4 A MeV (beta=0.1). Beam manipulations like deceleration, bunching, accumulation, and especially the efficient beam cooling as well as the sophisticated experimental equipment make rings versatile instruments. The number of physics cases is enormous. The focus here will be on the most recent highlight results achieved within FAIR-Phase 0 research program at the ESR.

83

Testing QED with spectroscopy of Highly charged ions from medium Z to high Z

Corresponding Author: louis.duval@lkb.upmc.fr

Spectroscopy of few electron highly-charged ions from medium to high atomic number Z allows to probe Quantum Electrodynamics (QED) effects in strong Coulomb fields. For such systems, theory can provide high-accuracy predictions, but experiments struggle to attain comparable precision. We present here two new measurements aimed at highest precision transition energy measurements in the X-ray regime to test strong field QED effects. The first measurement is on boron-like Argon, performed in Paris with an Electron Cyclotron Resonance Ion Source and a double crystal spectrometer. This is an absolute energy measurement with an accuracy of a few parts per million. Another experiment, recently performed at the ESR at GSI, Darmstadt, focused on the measurement of an intra-shell transition of heliumlike Uranium (two electrons present only), and achieved an accuracy of 35 parts per million. I will present these two results, and their impact on our understanding of bound-state QED in the strong field regime.

84

Compton Polarimetry on Rayleigh scattered hard x-rays

Corresponding Author: wilko.middents@uni-jena.de

Elastic scattering of hard x-rays on atoms is the fundamental photon-atom interaction process where both the incident and scattered photon carry the same energy. It is usually described as a coherent sum of different scattering processes depending on the scattering partner. Rayleigh scattering, being the 2nd order QED process of elastic scattering from bound electrons is the dominant scattering process from a few keV up to the MeV range, while at higher photon energies also other scattering processes as the scattering from vacuum fluctuations (Delbrück scattering) and nuclear scattering become important. In such a scattering scenario, the polarization transfer between incident and scattered photon is a highly sensitive observable allowing for a more stringent test of the underlying theory than conventional cross section measurements. For a sensitive polarization analysis both a brilliant, highly polarized hard x-ray source as provided by third generation synchrotrons and an efficient polarimeter for the hard x-ray regime are necessary. Such a detector is realized by a state-of-the-art 2D sensitive strip detector serving as highly efficient Compton polarimeters in the hard x-ray regime. In an experiment at the synchrotron facility PETRA III @ DESY, Hamburg we combined both technologies, scattering a highly linearly polarized synchrotron beam with a photon energy of 175 keV on a thin gold foil. In this experiment we were for the first time able to both determine the polarization of the incident synchrotron beam by cross section measurements as well as analyze the polarization of the elastically scattered radiation within and out of the polarization plane of the incident synchrotron beam with the help of a Compton polarimeter.

85

High Resolution X-ray Spectroscopy at the Electron Cooler of CRYRING@ESR

Corresponding Author: p.pfaefflein@gsi.de

Recent develpoments regarding metallic microcalorimeters (MMCs) have resulted in a new class of detectors for precision X-ray spectroscopy, for example the maXs detectors [1] (cryogenic micro-calorimeter arrays for high resolution X-ray spectroscopy), which have been developed within the SPARC collaboration. Outstanding features of MMCs are the combination of a very high energy resolution (1.7 eV FWHM at 6 keV [2]) comparable to crystal spectrometers with the broad band-width acceptance of semiconductor detectors (0.1 – 100 keV) [3]. These detectors are based on the following measurement principle: The energy deposition of an incident X-ray phtoton leads to a measurable temperature rise of an absorber. At operation temperatures below 50 mK this leads to a change in the magnetisation of a paramagnetic sensor which can be measured by a superconducting quantum interference device (SQUID) [4]. In this contribution we present the first application of maXs-type detectors for high resolution x-ray spectroscopy at CRYRING@ESR. Within the experiment, X-ray radiation emitted as a result of recombination events between the electron cooler electrons and a stored beam of U91+ ions was studied. For this purpose, two maXs detectors were positioned at the electron cooler under observation angles of 0° and 180° with respect to the ion beam axis. We will focus on details of the experimental setup and its integration into the storage ring environment. Noteworthy aspects are a quasi-continuous energy calibration, as well as the first usage of the time resolution of the maXs detectors to achieve a coincidence measurement with a particle detector. References: [1] C. Pies et al., J. Low Temp. Phys. 167, 269–279 (2012) [2] J.-P. Porst et al., J. Low Temp. Phys. 176, 617–623 (2014) [3] S. Kempf et al., https://edms.cern.ch/ui/file/2059592/1/TDR_maXs_public_2016_02_11.pdf, (2016) [4] D. Hengstler et al., Phys. Scr. T166, 014054 (2015)

86

X-ray emission study performed for H-like lead at the electron cooler of CRYRING@ESR

Corresponding Author: binghui.zhu@uni-jena.de

The study of x-ray emission associated with Radiative Recombination (RR) at "cold" temperature conditions, as it prevails at electron cooler devices at ion storage rings, allows for a stringent test of atomic structure and the subsequent x-ray emission characteristics. In particular, for heavy, highly charged ions at high-Z it enables to investigate in detail the prevailing cascade decay dynamics and provides detailed insight into the final state population of the recombination process itself. We report on an experiment where bare lead ions were decelerated down to 10 MeV/u in the ESR storage ring at GSI, Darmstadt and injected into CRYRING@ESR and, subsequently, the x-ray emission of H-like lead associated with RR were studied at the electron cooler. For this purpose, at the electron cooler dedicated vacuum chambers were used, equipped with beryllium view ports allowing for x-ray detection under 0° and 180° with respect to the ion beam axis. The x-ray detection was accomplished by using two standard high-purity germanium x-ray detectors. In order to suppress the dominant background, stemming from x-ray emission by the electron beam (bremsstrahlung) and the natural background, an ion detector (channel electron multiplier) was operated downstream to the cooler, enabling to record x-rays in coincidence with down-charged Pb81+ ions from electron cooler section. In this experiment, we observed for the very first time for stored ions the full x-ray emission spectrum associated with RR under electron cooling conditions. Most remarkably, no line distortion effect due to delayed emission are present in the well resolved spectra, spanning over a wide range of x-ray energies (from about 5 to 100 keV) which enable to identify fine-structure resolved Lyman, Balmer as well as Paschen x-ray lines along with the RR transitions into the K-, L- and M-shell of the ions. To compare with theory, an elaborate theoretical model has been applied. By considering the relativistic atomic structure of Pb81+, this model is based on a sophisticated computation of the initial population distribution via RR for all atomic levels up to Rydberg states with principal quantum number n = 165 in combination with cascade calculations based on time-dependent rate equations. Most notably, this comparison sheds light on the contribution of prompt and delayed x-ray emission to the observed x-ray spectra, originating in particular from Yrast transitions into inner shells.

87

Kilonova emission from realistic neutron star merger simulations

Corresponding Author: c.collins@gsi.de

The detection of GW170817 and its electromagnetic counterpart AT2017gfo confirmed the expectation that a kilonova would accompany the merging of binary neutron stars, and subsequently there has been much interest in simulating kilonova emission to better understand the observations of AT2017gfo, including confirming that these are the primary production site of r-process material. The majority of models considered when predicting kilonova emission have been 1D, or even idealised toy models. Few simulations have been based on realistic merger simulations, and fewer have carried out full 3D simulations of the merger and subsequent kilonova emission. We present 3D radiative transfer simulations based on the dynamical ejecta from 3D smoothed-particle hydrodynamics neutron star merger simulations, including a sophisticated neutrino treatment. Nucleosynthesis calculations following the SPH trajectories provide the energy released due to radioactive decays of r-process material. We discuss the predicted light curves in different lines of sight, as well as the influence of the assumptions we make on the light curve evolution. This includes our assumption of opacities based on the electron fraction of the material, which is predominantly responsible for the distribution of r-process elements synthesised. We find that the light curves do not show a strong viewing angle dependence, despite the asymmetrical ejecta.

88

Electromagnetic Counterparts of Neutron Star Mergers: Signatures of Heavy r-Process Nucleosynthesis

Corresponding Author: a.floers@gsi.de

It has long since been established that observable actinides in the universe originate from the r-process. In 2017, the electromagnetic counterpart to the gravitational wave detection of two merging neutron stars was observed. From the light curve alone it was possible to characterize two ejecta components: one that contains low-Y⍰ material such as lanthanides and possibly actinides, and a high-Y⍰ component with low lanthanide abundances. The dividing characteristic between the two components is the opacity of the material: lanthanides have a ~100 times higher opacity than iron-group material. The opacity of actinides is expected to be on a similar level as that of the lanthanides, or, possibly, even higher. To identify specific elements, spectroscopic information is required. However, so far no clear detection of individual lanthanides or actinides has been made in the only observed neutron star merger. A great challenge for spectroscopic modeling of kilonovae using radiative transfer codes is the almost non-existent atomic data currently available for lanthanides and actinides. I will present how converged lanthanide and actinide opacities affect the kilonova spectrum compared to iron-group or light r-process elements. I will then use this collection of atomic data to show how we can use radiative transfer simulations to identify signatures or place constraints on the amount of heavy r-process material synthesized in kilonovae.

89

Monte Carlo radiative transfer for neutron star merger simulations

Corresponding Author: luke.shingles@gmail.com

The kilonova AT 2017gfo that resulted from the merger of two neutron stars has provided new insights into the rapid neutron capture process that is responsible for producing many of the elements heavier than iron. As with supernovae, progress in understanding kilonova spectra can made both by using simple models to connect spectral features to particular elements, as well as by attempting to construct detailed simulations that attempt to capture all of the relevant physics and initial conditions. In the forward modelling approach, we require a theoretical simulations of the merger and ejection physics, r-process nucleosynthesis, radioactive energy deposition, and radiative transfer in order to produce synthetic spectra that can be compared with observations. We plan to calculate synthetic spectra for a three-dimensional merger and r-process nucleosynthesis model using the ARTIS Monte Carlo radiative transfer code. I will describe current progress in extending the code to handle energy deposition from beta- and alpha-decay particles, and the new atomic data required to produce spectral features from transiron elements. I will also discuss challenges around modelling the ionisation state for ejecta in which non-thermal processes are important, which is the case for

Type Ia supernovae in their nebular phase, and likely also applies to kilonovae at a few days after the merger.

90

Discussion

91

Convergence of Atomic Data for Kilonova Modeling

Corresponding Author: g.leck@gsi.de

In recent years a lot of work has been dedicated to the analysis of multi-messenger signals from binary neutron star mergers. The electromagnetic signal, known as a kilonova, is powered by the radioactive decay of synthesized r-process nuclei and provides a unique opportunity to probe the in-situ operation of the r-process. Kilonova spectra are modeled with the aim of identifying spectral signatures of particular elements, confirming their formation during the r-process in the merger ejecta.\ In this talk, I will present a set of detailed atomic data obtained from structure calculations for all elements up to uranium which we intend to use to model kilonova spectra. I will show the convergence behaviour of the atomic data and to determine its impact on quantities which are relevant for the spectral modeling such as partition functions and opacities. By this we obtain a measure for the accuracy of the data required for kilonova spectral modeling.

92

Neutrinos and their impact on the nucleosynthesis in binary neutron star mergers

Corresponding Author: v.vijayan@gsi.de

Recent measurements of gravitational waves and kilonova observations show that neutron star mergers are an important source of r-process elements. In fact, this astrophysical scenario is by now the first and only confirmed site of r-process element production. A reliable modelling of neutrino transport plays a key role in determining the ejecta composition and the resulting nucleosynthesis. In this talk, I will give an overview on neutron star mergers as sources of heavy elements and discuss different neutrino transport models and in specific, the newly presented leakage scheme ILEAS (Ardevol-Pulpillo et al. 2019) that is used in our neutron star merger simulations.

93

Black-hole formation in mergers of spinning neutron stars

Corresponding Author: j.helbich@gsi.de

The mergers of neutron star binary systems are of great scientific interest as they can be used to explore and constrain the incompletely known Equation of State (EoS) at very high densities. Especially the formation of a black-hole due to a gravitational collapse is of interest. For a sufficiently high total binary mass the collapse occurs immediately after merging. This is called a prompt collapse and occurs if the mass exceeds a so called threshold mass. The threshold mass depends on the EoS and parameters of the binary system like the mass ratio and intrinsic spin. Quantifying those influences is therefore of interest considering unknown properties of neutron stars, constraining the EoS and mass ejection. Neutron stars in merging binary systems are assumed to be mostly irrotational but some have been observed to rotate rapidly with a spin period of a few tens of ms. The shortest spin period observed in a neutron star binary system so far has been 17ms. The intrinsic rotation of the neutron stars changes the total angular momentum in the system depending on its orientation relative to the orbital angular momentum. A high spin period could therefore have a noticeable impact on total angular momentum and thus effect the threshold mass. To systematically investigate this influence we discuss simulations with a relativistic hydrodynamical code considering various spin configurations for different mass ratios and EoS. We will describe the impact of orientation and magnitude of intrinsic spin as well as one or two rotating neutron stars.

94

Further probing the neutron star equation of state via frequency deviations in universal relations

Corresponding Author: g.lioutas@gsi.de

In this talk we focus on empirical relations between the gravitational wave frequencies produced by fluid oscillations in neutron stars and macroscopic characteristics like the radius and tidal deformability. Such relations can be employed to constrain the stellar properties, and in turn the underlying equation of state, from gravitational wave observations of neutron star systems. We focus on empirical relations describing two very distinct systems. In particular the quadrupolar mode in isolated, cold, non-rotating neutron stars and the dominant postmerger fluid oscillation in binary neutron star merger remnants. We examine the exact way in which individual models distribute with respect to the corresponding fits to all models and identify a systematic behavior in the way points scatter. We relate the scatter to the underlying equation of state and in particular the tidal Love number. Finally, we discuss how these deviations can lead to stricter equation of state constraints from future gravitational wave observations.

95

Core-Collapse Simulations of Very Massive Star: Gravitational Collapse, Black-hole Formation, and Beyond

Corresponding Author: n.rahman@gsi.de

We investigate the final collapse of rotating and non-rotating pulsational pair-instability supernova progenitors with zero-age-main-sequence masses of 60, 80, and 115Msun and iron cores between 2.37Msun and 2.72Msun by 2D hydrodynamics simulations. Using the general relativistic NADA-FLD code with energy-dependent three-flavor neutrino transport by flux-limited diffusion allows us to follow the evolution beyond the moment when the transiently forming neutron star (NS) collapses to a black hole (BH), which happens within 350-580 ms after bounce in all cases. Because of high neutrino luminosities and mean energies, neutrino heating leads to shock revival within ~250 ms post bounce in all cases except the rapidly rotating 60Msun model. In the latter case, centrifugal effects support a 10% higher NS mass but reduce the radiated neutrino luminosities and mean energies by ~20% and ~10%, respectively, and the neutrino-heating rate by roughly a factor of two compared to the non-rotating counterpart. After BH formation, the neutrino luminosities drop steeply but continue on a 1-2 orders of magnitude lower level for several 100 ms because of aspherical accretion

of neutrino and shock-heated matter, before the ultimately spherical collapse of the outer progenitor shells suppresses the neutrino emission to negligible values. In all shock-reviving models BH accretion swallows the entire neutrino-heated matter and the explosion energies decrease from maxima around 1.5e51 erg to zero within a few seconds latest. Nevertheless, the shock or a sonic pulse moves outward and may trigger mass loss, which we estimate by long-time simulations with the PROMETHEUS code. We also provide gravitational-wave signals.

96

Analytic models of gravitational waves from neutron star merger remnants

Corresponding Author: th.soultanis@gmail.com

We present a new analytic model describing gravitational wave emission in the post-merger phase of binary neutron star mergers. The model is described by a number of physical parameters that are related to various oscillation modes, quasi-linear combination tones or non-linear features that appear in the post-merger phase. The time evolution of the main post-merger frequency peak is taken into account and it is described by a two-segment linear expression. Such type of models are critical for gravitational wave data analysis and thus the detection and parameter estimation of neutron star merger events. The performance of the model is evaluated along a sequence of equal-mass simulations of varying mass. We find that all parameters of the analytic model correlate with the total binary mass of the system. We can thus model the post-merger gravitational-wave emission with an analytic model that achieves high fitting factors for a wide range of total binary masses. For high masses, we identify new spectral features originating from the non-linear coupling between the quasi-radial oscillation and the antipodal tidal deformation. Our model can be used for the detection and parameter estimation of the post-merger phase in upcoming searches with upgraded second-generation detectors, such as aLIGO+ and aVirgo+, with future, third-generation detectors (Einstein Telescope and Cosmic Explorer) or with dedicated, high-frequency detectors.

97

Studying neutron stars with gravitational waves

Corresponding Author: kchatziioannou@caltech.edu

In this talk I will discuss how we can observe mergers of neutron stars with gravitational waves and how we can use them to extract information about neutron star macroscopic and microscopic properties.

98

Equation of state of hot hyperonic neutron star core

Corresponding Author: hriskoch@fqa.ub.edu

A study of the composition and properties of neutron stars and proto-neutron stars is presented, based on a relativistic mean-field model. The baryonic matter equation of state (EoS) at zero and finite temperatures is computed within the FSU2H model, which has been updated according to the recent analysis on Xi baryon potential. The finite temperature EoS and composition of matter are

computed at both constant temperature and constant entropy per baryon, in order to account for the different conditions of density and temperature that can be found in proto-neutron star, binary mergers remnants and supernova explosions. We find that high temperatures significantly change the composition and the EoS, especially for densities close to nuclear saturation density. This can have a strong impact on several astrophysical observables, such as the mass, radius and tidal deformability of the star.

99

Merging the thermodynamics of heavy-ion collisions and astrophysics

Corresponding Author: niels-uwe@bastian.science

In this talk I will present the recent progress in development of a thermodynamical model, which would be applicable for both astrophysics and heavy-ion collisions. To motivate this endeavor, the common aspects of both fields will be covered, as well as crucial details of each, which need to be taken into account within the development of a unified model. Main approach is a cluster-virial expansion which incorporates hadronic liquid and quark-gluon plasma. Relativistic density functionals are used to model interactions of the particles with their medium. This method has already shown success in astrophysical applications and is now applied to vanishing baryon densities. The prospects of the final model, which can describe the thermodynamics of astrophysics and heavy-ion collisions (at zero and finite temperature), as well as include the basis for future studies (e.g., of the possibility of a critical endpoint), will be outlined.

100

Reconstructing the neutron star equation of state from observational data via automatic differentiation

Corresponding Author: soma@fias.uni-frankfurt.de

Neutron stars harbor extreme conditions unattainable in terrestrial laboratories, making them ideal candidates to study the equation of state (EoS) of strongly interacting matter. Advancements in the measurements of neutron star masses, radii and tidal deformabilities through electromagnetic and gravitational wave observations have made it feasible to add further constraints on the EoS. In this work, we present a novel method that exploits deep learning techniques to reconstruct the neutron star EoS from mass-radius (MR) observations. Our approach makes use of an unsupervised learning procedure in the Automatic Differentiation framework to optimize the EoS. Using limited mock data, we demonstrate that our proposed method has the ability to successfully reconstruct a model-independent EoS while accounting for large observational errors. We further deploy our deep learning methodology on existing MR observations, including the latest data from NICER, to infer the neutron star EoS. The reconstructed EoS band is proven consistent with conventional nuclear EoS models. Lastly, we test our results against the bounds on tidal deformability obtained from the gravitational wave event, GW170817.

101

The soup that is not too hot

Corresponding Author: maria.stefaniak@pw.edu.pl

102

Charged pion emission in Ag+Ag collisions at \sqrt{s_{NN}}=2.55 GeV measured with HADES

Corresponding Author: m.nabroth@gsi.de

At the HADES (High-Acceptance-DiElectron-Spectrometer) experiment, located at the GSI, Darmstadt, the reaction products of relativistic heavy-ion collisions are investigated. The goal is to probe strongly interacting QCD matter that exhibits extreme densities as assumed to be found in merging neutron stars [1].\ In this contribution, results on charged pion emission in the collisions system Ag+Ag at sNN−−−−√=2.55 GeV, measured in March 2019, are presented. Due to the high statics available charged pions enable the investigation of the Coulomb effect, which can be used to estimate the baryon density at the point of kinematic freeze-out. Moreover, the focus is put on the azimuthal anisotropic flow. The reconstruction of the harmonics v1, v2 and v3 is explained and the results are inspected multi-differentially as a function of transverse momentum and rapidity. A special emphasis is put on the observation of triangular flow. \ [1] Adamczewski-Musch, J., Arnold, O., Behnke, C. et al. Probing dense baryon-rich matter with virtual photons. Nat. Phys. 15, 1040–1045 (2019), doi:10.1038/s41567-019-0583-8

103

Production of Charged Kaons and φ(1020) in Ag+Ag Collisions at sNN = 2.55 GeV

Corresponding Author: m.kohls@gsi.de

Heavy-ion collisions in the few GeV energy regimes probe similar temperatures and densities as created in neutron star mergers and provide a tool to probe cosmic matter in earthly laboratories \text{[1]}.\ In March 2019, the HADES collaboration recorded 13.7·109 Ag(1.58A~GeV)+Ag events as part of the FAIR Phase-0 program. Within this talk, we present preliminary results for yields and kinematic distributions of K+, K− and ϕ(1020).\ The presented strange hadrons are produced below the free nucleon-nucleon production threshold and thusly are a good probe for in-medium effects due to their steep excitation function. In this presentation, the relative yields of strange particles with different excitation energies are compared and their consistency with theoretical models and recent results of other experiments is reviewed. Especially comparing the ϕ(1020) with the Ξ− provides further insight into the accuracy of particle production yield calculations in statistical models. Furthermore, the system size dependence of strangeness production is tested by comparing central and peripheral collisions.\ \text{[1]} Adamczewski-Musch, J., Arnold, O., Behnke, C. et al. \textit{Probing dense baryon-rich matter with virtual photons}. Nat. Phys. 15, 1040–1045 (2019), doi:10.1038/s41567-019-0583-8

104

Production and decays of hyperons in p+p reactions measured with HADES

Corresponding Author: konrad.sumara@doctoral.uj.edu.pl

The exact structure and inner workings of nucleons are debated, since the existence of quarks was postulated. Since then, a lot of experimental evidence has been gathered, indicating that nucleons and their excited states are not simple static quark states but are significantly influenced by the dynamics of baryon-meson interactions. In this context it is interesting to extend studies to hyperons where one light quark in a nucleon is replaced by a heavier strange quark, e.g. Σ-(1385) or excited Λ(1520), Λ(1405) states. Many models controversially describe the internal structure of these hyperons, including those based on the dynamical state generation. In order to determine which of the models are close to nature, it is helpful to measure radiative decays (with emission of a photon or e+e- pairs) and hadronic decays, e.g. Λ (1520)->Σ-(1385) π+ , Λ(1405)->Σ π. These decays are largely unexplored at present and are the motivation for the project presented in this talk. The goal of this project is to study the production of Sigma Σ- (1385) and Lambda Λ (1520), Λ(1405) hyperons produced in proton-proton at beam energies ranging from 3.5 GeV to 4.5 GeV with HADES detector at FAIR [1]. The analysis performed on data obtained from p + p at 3.5 GeV and first look into newly collected data from measurements in February 2022 will be presented. [1] J. Adamczewski-Musch et. al. (HADES Collaboration); Production and electromagnetic decay of hyperons: a feasibility study with HADES as a phase-0 experiment at FAIR; Eur. Phys. J. A (2021) 57: 138

105

Charged pion production in few-GeV heavy-ion collisions measured with HADES

Corresponding Author: j.orlinski@gsi.de

Experiments carried out with HADES (High Acceptance DiElectron Spectrometer) measure products of heavy-ion collisions in the beam energy regime of few GeV per nucleon. Its large geometric acceptance and reconstruction efficiency give insight into the extremely hot and dense nuclear matter produced in such reactions. The focal point of this contribution is the production of charged pions in Ag+Ag collisions at √s_{NN} = 2.4 GeV. Since these hadrons are the lightest particles formed in nuclear collisions, they are produced abundantly and provide a good probe for investigating the nature of nuclear matter in such extreme conditions. Transverse momentum/mass and rapidity distributions were obtained in four centrality classes spanning 40% of most central events and then used to reconstruct the total yield of pions per event. Several systematic aspects are also discussed, including different approaches to spectra extrapolation. The results are compared with state-of-art transport model calculations and other results from the HADES Collaboration. The latter comparison was used to obtain systematics of pion yield as a function of participating nucleons. This research project was financially supported by the GET_INvolved ERASMUS+ Programme of GSI/FAIR, HADES and the University of Warsaw.

106

Characterising the hot and dense fireball with virtual photons at HADES

Corresponding Author: n.schild@gsi.de

Electromagnetic particles offer a unique opportunity to study the conditions in heavy-ion collisions throughout their whole evolution. Once created, these probes can travel largely unhindered through the strongly interacting medium and bring direct information from their origins to a detector. Virtual photons, decaying into lepton pairs, serve as particularly interesting because they also carry additional information in their invariant mass. In this contribution, measurements of such dileptons are presented. Based on high statistics experiments of Au+Au and Ag+Ag collisions, collected at the High-Acceptance-DiElectron-Spectrometer (HADES), at sNN−−−−√=2.42 GeV and sNN−−−−√=2.55

GeV respectively, various dilepton observables have been extracted. This includes the invariant mass spectra, which also allow a determination of the fireball temperature, as well as the overall dilepton yield, which can be connected to the lifetime of the fireball. Furthermore, first results on the dilepton anisotropy and anisotropy coefficients are presented, giving more insights into the collective properties of the hot and dense medium.

107

Reconstruction of neutral mesons via photon conversion method in Ag-Ag collisions at 1.58A GeV with HADES

Corresponding Author: povartetiana@gmail.com

The physics program of the HADES (High Acceptance DiElectron Spectrometer) experiment is focused on investigating properties of strongly interacting matter at moderate temperatures and large baryo-chemical potential. One of the important observables is the study of virtual photons and their decays into electron pairs (e−+e+) in hadron and heavy-ion collisions. As leptons are not affected by final-state interactions, the electrons and positrons offer the possibility to look into the dense nuclear medium in the first stage of collisions. The major background in the dilepton spectrum at the low invariant masses region are Dalitz-decays of light neutral mesons, so that precise knowledge about neutral meson production is mandatory for the dilepton analyses. In HADES, these mesons can be reconstructed via their dominant γ,γ decays utilizing double photon detection in the electromagnetic calorimeter (ECAL) or via double external pair conversion γmaterial⟶e++e− in target or detector material with subsequent electron/positron identification. In this contribution, main emphasis will be put on most recent results from π0 and η-reconstruction via conversion method in Ag+Ag collisions at 1.58A GeV.

108

Neutral mesons flow and yields in AgAg@1.58 AGev at HADES

Corresponding Author: prozorov@ujf.cas.cz

The Dielectron Spectrometer HADES operated at the SIS18 synchrotron, GSI Darmstadt recently provided new intriguing results on production of electron pairs and of strangeness from nucleus-nucleus collisions, as well as from elementary reactions, in energy region of 1−2~A~GeV. In 2019 the spectrometer was complemented by an electromagnetic calorimeter based on lead-glass modules, which allows us to measure photons, thus study production of the π0 and η mesons via their two-photon decay. The knowledge of the neutral meson production is a mandatory prerequisite for the interpretation of dielectron data and at the same time almost no respective data about their production in nucleus-nucleus collisions are presently available for this energy range.\par Particularly, directed and elliptic flow of neutral mesons will be shown with respect to transverse momentum and rapidity for different centrality classes in Ag + Ag collisions at 1.58~A~GeV. Results of analysis corresponding to 14×109 events will be confronted with results of other experiments and with up-to-date model calculations.

109

Investigation of hadronic exit channels of the π−+C reaction at

an incident momentum of 0.7 GeV/c

Corresponding Author: fatima.hojeij@ijclab.in2p3.fr

The pion-nucleus reaction is an important source of information about hadronic matter. At incident momenta below 2 GeV/c, it gives access in a very unique way to the properties of baryonic resonances in the nuclear medium. While the region of the Δ(1232) resonance, corresponding to incident pion beam momenta of about 300 MeV/c, was studied in detail in the past, only very scarce measurements were provided at higher energies, e.g. in the second resonance region (N(1440), N(1520), N(1535),..). Such information is needed in the context of dense hadronic matter studies for the description of heavy-ion reactions at a few GeV, where pion-nucleus dynamics plays a crucial role. More general, measurements of proton and pion differential spectra are needed to validate transport models or hadronic cascades used in GEANT4 for various applications involving pion detection. This talk will focus on the analysis of π^-+C reactions performed with HADES [1], using the GSI pion beam at an incident pion momentum of 0.7 GeV/c. Pion and proton differential spectra measured in various exit channel topologies (inclusive, $p\pi^-$, $p\pi^+$, pp, $\pi^+\pi^-$,…, $\pi\pi pp$) are compared to predictions of the INCL++ cascade [2] and of transport models (SMASH [3,4], rQMD [5], GIBUU [6],…). The results test selectively the capacity of the models to describe the various mechanisms (quasi-elastic scattering, multipion production, re-scattering and pion absorption). The sensitivity of the data measured in the quasi-elastic channel to short range correlations is also investigated. [1] G. Agakishiev et al. (HADES collaboration), Eur. Phys. J. A41, 243-277 (2009). [2] S. Leray et al. J. Phys. Conf. Series 420 (2013) 012065. [3] J. Weil et al., Phys. Rev., C 94, 054905 (2016). [4] H. Petersen, Nuclear Physics A, 1 (2018). [5] H. Sorge, Phys. Rev. C 52, 3291 (1995). [6] J. Weil et al., Eur. Phys. J., A 48, 111 (2012).

110

Upgrade and commissioning of the ALICE muon spectrometer

Corresponding Author: livia.terlizzi@cern.ch

ALICE (A Large Ion Collider Experiment) at the CERN Large Hadron Collider (LHC) is designed to study proton-proton and heavy-ion collisions at ultra-relativistic energies. The main goal of the experiment is to assess the properties of quark gluon plasma, a state of matter where quarks and gluons are de-confined, reached in extreme conditions of temperature and energy density. During the ongoing long shutdown 2 of LHC, ALICE is undergoing a major upgrade of its apparatus, in view of the LHC Run 3, scheduled to start in 2022. The upgrade will allow a new ambitious programme of high-precision measurements to be deployed. Moreover, the detectors will have to cope with an increased collision rate, which will go up to 50 kHz in Pb-Pb collisions. For the muon spectrometer ALICE is implementing new hardware and software solutions. The installation of a new vertex tracker, the Muon Forward Tracker (MFT), in the acceptance of the muon spectrometer will improve present measurements and enable new ones. It will allow one to separate, for the first time in ALICE in the forward-rapidity region, the prompt and non-prompt contributions to the cross-sections of charmonia. The matching of the muon tracks reconstructed in the MFT with those in the muon spectrometer will add vertexing capabilities covering a broad range of transverse momenta down to p T = 0 and will improve significantly the invariant mass resolution, allowing for a better separation of the J/ψ and ψ(2S) states. In addition, the front-end and readout electronics of the muon tracking system (cathode pad chambers) and of the muon identification system (resistive plate chambers) will be upgraded, in order to optimize the detector performance in the new running conditions. A detailed description of the muon spectrometer upgrades, together with the results from the commissioning with cosmic rays and the first LHC beams, will be presented in this talk.

111

The new Forward Tracker System for the HADES FAIR Phase-0 experiment

Corresponding Author: gabriela.perezandrade@fair-center.eu

As part of the FAIR phase-0, the HADES experiment underwent a hardware upgrade that included updating existing components, data-acquisition systems, and the integration of new detectors. In particular, the new Straw Tracking Stations (STS) enlarge the HADES acceptance to low polar angles, crucial for the FAIR phase-0 physics program, including hyperon reconstruction. The STS stations have four double layers of staws arranged in four azimuthal orientations for a full 3D track reconstruction and resolving ambiguities in multi-track events. Pre-commissioning tests showed a spatial resolution of 0.13 mm for MIPs. The STS system was installed at HADES in 2020 and tested during a dedicated commissioning beamtime in February 2021. The collected data was used to develop the calibration and track reconstruction methods. The STS is one of the PANDA systems in early operation during the FAIR Phase-0, and will become part of the PANDA FT at the start of FAIR Phase-1. A description of the STS system and a summary of the results from the beamtime will be presented.

112

Secondary Track Finding for PANDA

Corresponding Author: a.scholl@fz-juelich.de

Track reconstruction is essential for a meaningful physics analysis of data from complex detectors such as PANDA. For hyperon detection this task is even more challenging because hyperons typically fly several centimeters before they decay. Therefore, a secondary track finder for PANDA's barrel part will be presented. This algorithm, the ApolloniusTripletTrackFinder, is the only algorithm currently available at PANDA designed to find tracks not coming from the interaction point. Therefore, the finding rate for secondary particles is much higher (about 20 \%-points) than for the currently existing algorithms. Combining this algorithm with a primary track finder promises to improve the reconstruction rate for hyperon decays. The performance of this algorithm for simple test cases and simulated physics processes will be presented.

113

Extraction of global event features at the CBM experiment using PointNet

Corresponding Author: manjunath@fias.uni-frankfurt.de

The upcoming Compressed Baryonic Matter (CBM) experiment will explore the phase diagram of QCD matter at the highest baryon densities. The experiment is expected to run at an unprecedented event rate of up to 10 MHz, resulting in about 1 TB/s of free-streaming raw data. This demands the development of novel analysis techniques to quickly identify the event characteristics and select interesting events for permanent storage. In this talk, we show that PointNet based Deep Learning (DL) models can be used for online event characterisation at the CBM experiment. These models make use of the inherent point cloud structure of detector output, thus enabling the models to work directly on experimental output. We demonstrate that PointNet based models can accurately extract several global features of the collisions at CBM such as the impact parameter [1, 2] of the collision or the nature of QCD transition [3]. The PointNet based models accurately determine the impact parameter of collisions at CBM directly from the hits/ tracks of particles from the detector planes. The models have their mean error varying from -0.33 to 0.22 fm for impact parameters 2-14 fm

and outperform conventional methods based on a single observable such as track multiplicity. The DL models also distinguish a first order phase transition from a crossover transition at CBM using the reconstructed tracks of charged particles with an accuracy of up to 99.8%. The models are also shown to outperform methods relying on conventional mean observables. References: [1] Omana Kuttan, M., Steinheimer, J., Zhou, K., Redelbach, A., & Stoecker, H. (2020). A fast centrality-meter for heavy-ion collisions at the CBM experiment. Physics Letters B, 811, 135872 [2] Omana Kuttan, M., Steinheimer, J., Zhou, K., Redelbach, A., & Stoecker, H. (2021). Deep Learning Based Impact Parameter Determination for the CBM Experiment. Particles, 4(1), 47-52. [3] Omana Kuttan, M., Zhou, K., Steinheimer, J., Redelbach, A., & Stoecker, H. (2021). An equation-of-state-meter for CBM using PointNet. Journal of High Energy Physics, 2021(10), 1-25.

114

CBM performance for the measurement of strange hyperons' anisotropic flow in Au+Au collisions at FAIR SIS-100 energies

Corresponding Author: o.lubynets@gsi.de

The main goal of the CBM experiment is to study highly compressed baryonic matter produced in collisions of heavy ions. The SIS-100 accelerator at FAIR will enable investigation of the QCD matter at temperatures up to about 120 MeV and net baryon densities 5-6 times the normal nuclear density. Hyperons produced during the dense phase of a heavy-ion collision provide information about the equation of state of the QCD matter. The measurement of (multi)strange hyperons' anisotropic flow is important for understanding the dynamics and evolution of the QCD matter created in the collision. We will present the status of performance studies for strange hyperons anisotropic flow measurement for the CBM experiment at FAIR. Strange hyperons decay within the CBM detector volume and are reconstructed via their decay topology. The Particle-Finder Simple package, which provides an interface to the Kalman Filter Particle mathematics, is used to reconstruct decay kinematics and to optimize criteria for strange hyperons candidates selection. Anisotropic flow of strange hyperons is studied as a function of rapidity, transverse momentum and collision centrality. The effects due to non-uniformity of the CBM detector response in t

115

CBM performance for (multi-)strange hadron measurements using Machine Learning techniques

Corresponding Author: o.lavoryk@gsi.de

The Compressed Baryonic Matter (CBM) experiment at FAIR will investigate the QCD phase diagram at high net-baryon density (μB > 400 MeV) in the energy range of √sNN = 2.7−4.9 GeV. Precise determination of dense baryonic matter properties requires multi-differential measurements of strange hadron yields, both for most copiously produced kaons and Λ as well as for rare (multi-)strange hyperons and their anti-particles. In this presentation, the CBM performance for the multi-differential yield measurements of strange hadrons (Ks0, Λ and ⊠-) will be reported. The strange hadrons are reconstructed via their weak decay topology using the Kalman Filter algorithm. Machine Learning techniques, such as XGBoost, are used for non-linear multi-parameter selection of weak decay topology, resulting in high signal purity and efficient rejection of the combinatorial background. Yield extraction and extrapolation to unmeasured phase space is implemented as a multi-step fitting procedure, differentially in centrality, transverse momentum, and rapidity at different collision energies. Variation of the analysis parameters allows estimating systematic uncertainties. A novel approach to study feed-down contribution to the primary strange hadrons using Machine Learning algorithms will also be discussed.

116

Exploring the nucleon structure: fragmentation functions from e+e- annihilation experiment

Corresponding Author: isabella.garzia@unife.it

The understanding of the fundamental constituent of nucleons and the internal parton dynamics is one of main goal in modern physics. However, the description of the nucleon structure in the Quantum Chromodynamics (QCD) remains one of the most outstanding challenges in modern high energy and particle physics. Parton distribution and fragmentation functions are used to describe the distribution of partons in the nucleon and the formation of colourless hadrons starting from a coloured parsonic initial state, respectively. They are non-perturbative functions which cannot be derived from first principle but for which experimental input are needed. In the last decades, a strong interest has risen about the transverse momentum dependent (TMD) functions, which can be used as a tools to investigate the 3D-structure of nucleons. In this talk we will report a review of the existing data on fragmentation function related measurements form e+e- annihilation experiments used for the extraction of parton distributions functions. The aim is to highlight what are the actual limit, what is needed for a better understanding of nucleon structure and the possibilities offered by nucleon-nucleon experiments.

117

Data-driven dispersive analysis of the $\gamma\gamma \to D\bar{D}$ data

Corresponding Author: deineka@uni-mainz.de

We present a data-driven analysis of the $\gamma\gamma \to D^+D^-$ and $\gamma\gamma \to D^0\bar{D}^0$ reactions from threshold up to 4.0 GeV in the $D\bar{D}$ invariant mass. For the S-wave contribution, we adopt a partial-wave dispersive representation, which is solved using the N/D ansatz. The left-hand cuts are accounted for using the model-independent conformal expansion. The D-wave $\chi_{c2}(3930)$ state is described as a Breit-Wigner resonance. The resulting fits are consistent with the data on the invariant mass distribution of the $e^+e^- \to J/\psi D\bar{D}$ process. Performing an analytic continuation to the complex s-plane, we find no evidence of a pole corresponding to the broad resonance X(3860) reported by the Belle Collaboration. Instead, we find a clear bound state below the $D\bar{D}$ threshold at $\sqrt{s_B}=3695(4)$ MeV, confirming the previous phenomenological and lattice predictions. The existence of such state X(3695) may be tested in direct production at PANDA@FAIR.

118

Bottomonium results and prospects at Belle II

Corresponding Author: pangioni@to.infn.it

The Belle II experiment at the SuperKEKB energy-asymmetric ⊠+⊠− collider is a substantial upgrade of the B factory facility at KEK in Tsukuba, Japan. The experiment began operation in 2019 and has collected 267 fb-1 so far. Belle II is uniquely capable of studying the so-called "XYZ" particles: heavy exotic hadrons consisting of more than three quarks. Moreover the bottomonium sector offers an interesting doorway of the physics beyond the Standard Model such as lepton flavor violation, lepton flavor universality, dark matter and low mass Higgs bosons. We present recent results in new Belle II data, and the future prospects to explore both exotic and conventional bottomonium physics.

119

Low-energy charmonium, bottomonium and tetraquark production cross-sections from a statistical model

Corresponding Author: balassa.gabor@wigner.hu

Many proposed and on-going experiments require the preliminary knowledge of low-energy production cross-sections of different onium and/or exotic states in hadronic e.g. in proton-antiproton collisions, to be able to make estimates to the expected yields, momentum distributions etc. These are necessary ingredients to simulate the detector systems, and to plan the experiments. Here, we propose a statistical based model to estimate the low-energy cross-sections of some charmonium, bottomonium, and the X(3872) possible tetraquark state in proton-proton, pion-proton, and proton-antiproton collisions at a few GeV center-of-mass energies. The X(3872) cross-sections are calculated, using the assumption that it is a diquark-antidiquark bound state in the triplet-antitriplet representation, which gave a good match with the available high energy data in proton-proton collisions at 7 TeV. The estimated low-energy cross-sections can be used as inputs e.g. in transport simulations of heavy-ion collisions, which can be used as event generators to detector studies, which is an important task during the construction of the detector systems. In each case the calculated cross-sections are compared to the available measured data, giving a good match between the two.

120

Lattice QCD at finite temperature and density: present and future

Corresponding Author: paolo.parotto@gmail.com

In this talk I will provide an overview of the lattice formulation of Quantum Chromodynamics (QCD). I will discuss the methods and observables that play a major role in the study of QCD thermodynamics on the lattice. I will focus on results at finite temperature, and weigh in on the achievements and obstacles that the lattice community deals with at the moment. In particular, I will talk about the problem of extending calculations to finite chemical potentials, covering current methods, as well as promising new ones for future explorations of the QCD phase diagram towards higher densities.

121

Critical endpoint of QCD in a finite volume

Corresponding Author: julian.bernhardt@physik.uni-giessen.de

We summarize recent results on the volume dependence of the location of the critical endpoint in the QCD phase diagram. To this end, we employ a sophisticated combination of Lattice Yang-Mills theory and a (truncated) version of Dyson-Schwinger equations in Landau gauge for 2 + 1 quark flavors. We study this system at small and intermediate volumes and determine the dependence of the location of the critical endpoint on the boundary conditions and the volume of a three-dimensional cube with edge length L. We also discuss quark number fluctuations in this setup. Additionally, we report on the chiral limit of the light quarks for different strange quark masses at vanishing chemical potential.

122

QCD's equation of state from Dyson-Schwinger equations

Corresponding Author: philipp.isserstedt@posteo.de

We summarize a truncation-independent method to compute the equation of state within functional continuum approaches. First, its viability and reliability is demonstrated using a two-flavor Nambu-Jona-Lasinio model in mean-field approximation. Second, the method is applied to solutions obtained from a set of truncated Dyson-Schwinger equations for the nonperturbative quark and gluon propagators of (2+1)-flavor QCD to obtain the pressure, entropy density, energy density, and interaction measure across the phase diagram of QCD.

123

R3B at project ESCAPE; a case study to practice open science for FAIR/GSI experiments

Corresponding Author: m.mohammadi-dadkan@rug.nl

The open science movement aims at more open and collaborative research practices in which data, software, and other types of academic output are shared and made available for reuse leading to greater scientific and societal impact. Within the nuclear and particle physics communities, the complexity of the analysis codes and the volume of the collected data are the most common obstacles to making their scientific outcomes accessible and reusable. In the project ESCAPE, we tried to find solutions for challenges concerning implementation of the FAIR (Findable, Accessible, Interoperable, Reuseable) principles by taking the R3BRoot analysis software and the associated data obtained by the NeuLAND detector of the R3B experiment as a case study. In this presentation, we demonstrate how we can technically apply FAIR principles in the analysis workflows and data management of the FAIR/GSI experiments and provide them as a web service to the end-users.

124

The upper right corner of the Columbia plot with staggered fermions

Corresponding Author: rkara@uni-wuppertal.de

QCD with heavy dynamical quarks exhibits a first order thermal transition which is driven by the spontaneous breaking of the global Z_3 center symmetry. Decreasing the quark masses weakens the transition until the corresponding latent heat vanishes at the critical mass. We explore the heavy mass region with three flavors of staggered quarks and analyze the Polyakov loop and its moments in a finite volume scaling study. We calculate the heavy critical mass in the three flavor theory in the infinite volume limit for several temporal extensions.

125

Approaching the Continuum Limit of the Deconfinement Critical Point for Nf=2 Staggered Fermions

Corresponding Author: kaiser@itp.uni-frankfurt.de

Quenched QCD at zero baryonic chemical potential undergoes a first-order deconfinement phase transition at a critical temperature Tc, which is related to the spontaneous breaking of the global center symmetry. The center symmetry is broken explicitly by including dynamical quarks, which weaken the first-order phase transition for decreasing quark masses. At a certain critical quark mass, which corresponds to the Z2-critical point, the first-order phase transition turns into a smooth crossover. We investigate the Z2-critical quark mass for Nf=2 staggered fermions on Nt=8, 10 lattices, where larger Nt correspond to finer lattices. Monte-Carlo simulations are performed for several quark mass values and aspect ratios in order to extrapolate to the thermodynamic limit. We present final results for Nt=8 and preliminary results for Nt=10 for the critical mass, which are obtained from fitting to a kurtosis finite size scaling formula of the absolute value of the Polyakov loop. Similar to studies with Wilson fermions, our preliminary analysis shows a decrease of the critical quark mass with decreasing lattice spacing. Investigating QCD for heavy quark masses offers the opportunity to study the interplay between dynamical screening, which happens in vaccuum as well as in medium, and Debye screening, which only happens at finite temperature.

126

Nuclear structure calculations for astrophysics

Corresponding Author: c.robin@gsi.de

Nuclear physics is key to address fundamental questions related to the origin of the elements, the structure of matter, as well as fundamental symmetries of nature. The advent of new radioactive-beam facilities such as FAIR, together with the urgent need to interpret recent astrophysical observations, now make it essential to provide a predictive description of nuclear properties across the chart. In particular, precise and consistent calculations of masses, excitation energies, decay and reaction rates of a large range of nuclei, including those far from stability, are needed in order to advance our comprehension of the formation of the elements. Such a theoretical description is however still lacking and represents a formidable task for nuclear theory. In this talk I will discuss recent theoretical developments to address this challenge. In particular, I will highlight calculations of weak-interaction process.

127

Fission isomer studies with the FRS

Corresponding Author: j.zhao@gsi.de

The 'island' of fission isomers identified in the actinide region (Z = 92 - 97, N = 141- 151) originates from the multi-humped fission barriers, which can be described as the result of superimposing microscopic shell corrections to the macroscopic liquid drop barrier. For the first time, fission isomers were studied using the fragmentation of 1 GeV/u 238U projectiles rather than light-particle induced reactions currently in use. The projectile fragmentation gives access to isotopes that are hard or impossible to reach by light particle reactions. In-flight separation with the FRS allows for studying fission isomers with short half-lives. Most importantly, it provides beams with high purity and enables the event-by-event identification. Furthermore, different detection methods such as decay and mass spectrometry have been used to identify the fission isomers within a half-live range from 50 ns to 50 ms. In this contribution, the experiment performed in FAIR Phase-0 and its first results of fission isomer studies with the FRS at GSI will be presented.

128

Exploring jet transport coefficients in the strongly interacting quark-gluon plasma

Corresponding Author: grishmanovsky.i@gmail.com

We study the interaction of leading jet partons in a strongly interacting quark-gluon plasma (sQGP) medium based on the effective dynamical quasi-particle model (DQPM). The DQPM describes the non-perturbative QCD nature of the sQGP at finite temperature T and baryon chemical potential μB based on a propagator representation in terms of massive off-shell partons (quarks and gluons) which properties (characterized by complex self-energies, i.e. masses and widths) are adjusted to reproduce the lQCD EoS for the QGP in thermodynamic equilibrium. We present the results for the jet transport coefficients such as q^, the transverse momentum transfer per unit length, the drag coefficient A as well as the energy loss per unit length ΔE=dE/dx, in the QGP and investigate its dependence on QGP properties such as medium temperature T and baryon chemical potential μB as well as on the jet properties such as leading jet parton momentum, mass, flavor, and the strong coupling constant. In this first study only elastic scattering processes of leading jet parton with the sQGP partons are explored discarding presently the radiative processes (such as gluon Bremsstrahlung) which are expected to be suppressed for the emission of massive gluons. We present a comparison of our results for the elastic energy loss in the sQGP medium with other theoretical approaches such as lattice QCD and the LO-HTL as well as with estimates of q^ by the JET and JETSCAPE collaborations based on a comparison of hydrodynamical calculations with the experimental heavy-ion data.

129

Nuclear fission studies in inverse kinematics with the R3B setup at GSI

Despite the recent experimental and theoretical progress in the investigation of the nuclear fission process, a complete description still represents a challenge in nuclear physics because it is a very complex dynamical process, whose description involves the coupling between intrinsic and collective degrees of freedom as well as different quantum-mechanical phenomena. Due to this complexity and the use of different reaction mechanisms to induce the fission process, as well as the definition of different fission observables which were often biased by the experimental conditions, many contradictory results and conclusions exist in literature. In the last decade, unprecedented fission experiments have been carried out at the GSI facility using the inverse kinematics technique in combination with state-of-the-art detectors especially designed to measure the fission products with high detection efficiency and acceptance. For the first time in the long-standing history of fission, it was possible to simultaneously measure and identify both fission fragments in mass and atomic numbers and obtain many correlations among them sensitive to the fission process dynamics and the nuclear structure at the scission point. Recently, these measurements have been improved by combining the previous experimental setup with the calorimeter CALIFA (CALorimeter for In-Flight detection of gamma-rays and high energy charged pArticles) and the neutron detector NeuLAND (New LArge Neutron Detector) developed by the R3B collaboration, which allow us to measure the gamma rays and light particles in coincidence with the fission fragments. In this talk I will show the results obtained in all these experiments, summarizing as well the new ideas for the future fission experiments at FAIR.

130

Coulomb Corrections to Delbrück scattering

Corresponding Author: j.sommerfeldt@tu-bs.de

Delbrück scattering is the process in which a photon is elastically scattered by an atomic nucleus via the production of virtual electron-positron pairs. It is one of the few non-linear quantum electrodynamical processes that can be observed experimentally and, hence, testing the respective theoretical predictions serves as an important test of QED in strong electromagnetic fields. Despite the strong motivation, most theoretical studies in the past have been limited to the lowest-order Born approximation in which all interactions with the Coulomb field beyond the lowest order are neglected. This assumption makes the predictions unreliable in the high-Z regime. Therefore, we present a new approach to evaluate Delbrück amplitudes without any approximation regarding the coupling to the nucleus (Phys. Rev. A 105, 022804).

131

Deep Learning for Inverse Problems in High Energy Nuclear Physics

Corresponding Author: zhou@fias.uni-frankfurt.de

We recently devised a methodology within automatic differentiation (AD) which integrates our physics-priors into the specific IPs and deep learning representation together to perform Bayesian inference on the IPs. We demonstrated the developed methodology in several IPs raised in high energy nuclear physics (can also be easily generalized to other physics areas as well). (1) We first deploy the above AD-based approach to reconstruct spectral functions from Euclidean correlation functions which has been proven ill-posed especially with limited and noisy measurements. In our method the spectral is represented by DNNs while the reconstruction turns out to be optimization within AD under natural regularization to fit the measured correlators. We demonstrated and proved that the network with weight regularization can provide non-local regulator for this IP. Compared to conventional maximum-entropy-method (MEM), our method achieved better performance in realistic large-noise situation. It's for the first time to introduce non-local regulator using DNNs for the problem and is an inherent advantage for the method, which can promisingly lead to substantial improvements in related problems and IPs. (2) We applied the method to reconstruct the fundamental QCD force – heavy-quark potential – from lQCD calculated bottomonium in-medium spectrum. Both the radius and temperature dependence of the interaction are well reconstructed via inverse the Schroedinger equation given limited and discretized bottomonium low-lying states mass and width. (3) We also demonstrated the method's ability to infer neutron star EoS from astrophysical observables, with exciting results on closure tests for reasonable EoS reconstruction based on finite noisy M-R observables. Compared to conventional approaches our method holds unbiased representation for the EoS and bare interpretable Bayesian picture for the reconstruction.

132

Lattice gauge theory computation of heavy quark potentials and prediction of quarkonium bound states

Corresponding Author: eichberg@itp.uni-frankfurt.de

We discuss recent lattice gauge theory results from an ongoing project concerned with the computation of spin and mass dependent heavy quark-antiquark potentials. These potentials are then used in a Schrödinger eq

133

Effective spectral function of vector mesons via lifetime analysis

Corresponding Author: hirayama@fias.uni-frankfurt.de

We reconstruct effective spectral functions of the ρ-meson in different scenarios via lifetime analysis using the hadronic transport SMASH (Simulating Many Accelerated Strongly-interacting Hadrons). The theoretical interest in the behavior of in-medium spectral functions lies in the expected restoration of chiral symmetry at high energy densities, which may be accessed experimentally by studying dilepton mass spectra in heavy-ion collisions. Within SMASH, the phase space of all particles is available at all times, as well as information on interactions, allowing for a direct assessment of particle lifetimes and the mass distributions. Our reconstruction of the spectral function consists in using the total width – considering both decays and collisions – as input for a Breit-Wigner ansatz. The broadening of the spectral function in a thermalized system is shown to be consistent with model calculations, and the dependence of total width on local hadron density is provided. This broadening develops dynamically, since SMASH relies only on vacuum properties of resonances as an input. On the other hand, we present the effective ρ-meson spectral function for the dynamical evolution of heavy-ion collisions, finding a clear correlation of broadening to system size. Furthermore, we discuss the difference in the results between the thermal system and full collision dynamics, which may point to out-of-equilibrium effects. The results shown in this work are of interest to distinguish dynamical broadening from additional genuine medium-modified spectral functions.

134

Impact of hadronic interactions and conservation laws on cumulants of conserved charges in a dynamical model

Corresponding Author: hammelmann@fias.uni-frankfurt.de

Understanding the phase diagram of QCD by measuring fluctuations of conserved charges in heavy-ion collision is one of the main goals of the beam energy scan program at RHIC. For a precise measurement of the cumulants it is necessary to grasp the role of charge conservation in heavy-ion collision measurements. Within this work, we calculate the role of hadronic interactions and momentum cuts on cumulants of conserved charges up to fourth order in a system in equilibrium within a hadronic transport approach (SMASH). In our model the net-baryon, net-charge and net-strangeness is perfectly conserved on an event-by-event basis and the cumulants are calculated as a function of subvolume sizes and compared to analytic expectations. This reflects the experimental situation in which e.g. the net-baryon number is conserved in a heavy-ion collision and the results depend on the rapidity window. We find a modification of the kurtosis due to charge annihilation processes in systems with simplified degrees of freedom. Furthermore the result of the full SMASH hadron gas for the net-baryon and net-proton number fluctuations is presented for systems with zero and finite values of baryochemical potential. Additionally the problem of mapping between the net-proton and net-baryon fluctuations is addressed and we find that due to dynamical correlations the cumulants of the net-baryon number cannot be recovered from the net-protons. Finally the influence of deuteron cluster formation on the net-proton and net-baryon fluctuations in simplified system is shown. This analysis is important to better understand the relation between measurements of fluctuations in heavy-ion collisions and theoretical calculation which are often performed in a grand canonical ensemble.

135

Application of the Three-fluid Hydrodynamics-based Generator THESEUS to CBM. Proton rapidity- transverse mass spectra reconstruction and correction

Corresponding Author: e.volkova@gsi.de

The Compressed Baryonic Matter experiment (CBM) aims to study the area of the QCD phase diagram at high net baryon densities and moderate temperatures. It is predicted by Three-fluid Hydrodynamics-based Event Simulator (THESEUS) that one of the signatures of phase transition is a change in shape of the mid-rapidity curvature and yield. In this contribution we will present CBM performance for proton rapidity- transverse mass spectra. The results are obtained for Au+Au collisions at (√sNN) = 2.7 - 4.9 GeV/c produced by THESEUS model. CBM detector response is simulated with the GEANT3 engine and reconstruction is done using the CbmRoot framework. Protons are identified with Time-of-Flight technique using 2 different approaches. Obtained spectra are corrected for detector biases using the UrQMD event generator. Results are compared with simulated values and sources of systematic biases are discussed.

136

Performance studies of strangeness production in central Pb-Pb collisions at sNN = 8.8 GeV with the NA60+ experiment at the CERN SPS

Corresponding Author: giacomo.alocco@cern.ch

The NA60+ experiment is designed to study the phase diagram of strongly interacting matter by measuring thermal dimuons, charm, and strange particles produced in ultra-relativistic heavy-ion collisions. NA60+ will be installed at the CERN SPS, allowing an energy scan in the range sNN−−−−√~5−17 GeV and studying a region of high baryonic density little explored so far. The apparatus will be formed by a vertex telescope and a muon spectrometer. The vertex telescope will consist of layers of large area and ultra-thin state-of-the-art Monolithic Active Pixel Sensors (MAPS), which offer excellent spatial resolution with a low material budget. The vertex telescope will allow the production of strange particles, such as ϕ, K0S, (anti-)Λ0, Ξ±, and Ω± to be studied through exclusive reconstruction of hadronic decay channels. The enhancement of strangeness production is a direct probe of the quark-gluon plasma formation in ultra-relativistic heavy-ion collisions. The ϕ, Ξ±, and Ω± are composed respectively of ss¯, d¯s¯s¯ (dss) , and s¯s¯s¯ (sss) quarks. Therefore, they are ideal probes to study strangeness production. Moreover, previous measurements of ϕ production performed by the NA49 and NA50 experiments at the SPS, respectively in the K+K− and μ+μ− decay channels, showed a large discrepancy. NA60+ could measure both decay channels, shedding light on this puzzle. The K0S and (anti-)Λ0 are also a probe for the study of strangeness production. Since they are more abundantly produced in Pb-Pb collisions compared to other hyperons, they can also be used to test the baryon production models by measuring their yield ratios. In this talk, I will present the expected performances for the measurement of the ϕ, K0S, (anti-)Λ0, Ξ±, and Ω± production in central Pb-Pb collisions at sNN−−−−√=8.8 GeV, using the vertex spectrometer to reconstruct their hadronic decays respectively into K+K−, π+π−, pπ− + c.c., Λ0(pπ−)π− + c.c, and Λ0(pπ−)K− + c.c.

137

(Anti)(hyper)nuclei production in small collision systems measured with ALICE at the LHC

Corresponding Author: chiara.pinto@cern.ch

The production mechanism of (anti)nuclei in ultrarelativistic hadronic collisions is under intense debate in the scientific community. The description of the experimental measurements is currently based on two competing phenomenological models: the statistical hadronisation model and the coalescence approach. Light (anti)(hyper)nuclei have been extensively measured in small collision systems with ALICE at the LHC. In this contribution, the (anti)deuteron production in pp collisions at several centre-of-mass energies is presented. For the first time, the deuteron production is measured both in jets and in the underlying event and discussed in the context of phenomenological models. New insights on the nucleosynthesis process can be obtained from (anti)hypertriton measurements in small collision systems. Recent ALICE results on the hypertriton production in pp and p—Pb collisions are also discussed in this contribution.

138

pp Scattering from Standard to the Unknown with PANDA@HADES

Corresponding Author: j.rieger@gsi.de

One of the most challenging questions about the smallest constituents of visible matter is how hadrons are build from quarks. This means we do not yet understand the structure of one of the most abundant particles of our world, the nucleon. But what if we change the nucleon a little bit? Would that extend our picture? Hyperons are similar to nucleons but contain one or several strange quarks. By studying the decays of the unstable hyperons, we can gather valuable information about their inner structure. This inner structure is quantified by electromagnetic form factors. Especially by studying hyperon Dalitz decays, where a hyperon decays into a lighter hyperon and a virtual photon that produces an electron-positron pair, basic particle quantities as magnetic dipole moments become accessible. The FAIR Phase-0 project PANDA@HADES with this spring's beam time dedicated to hyperons enables such studies. In this framework the HADES spectrometer was complemented by the PANDA forward tracking system and the forward Resistant Plate Chambers which extend the acceptance for protons in the forward direction. pp elastic scattering with known cross section is used for commissioning of the new detectors as well as for an absolute luminosity measurement. I will present the application of pp elastic scattering for luminosity monitoring purposes as well as first efforts of measuring the Σ^0 Dalitz decay in the experiment recently performed.

139

4-quark states from functional methods

Corresponding Author: joshua.hoffer@theo.physik.uni-giessen.de

Since the discovery of tetraquarks, there has been a lot of excitement around this topic from the theoretical as well as the experimental side. To study the poperties of these 4-quark states we use a functional framework which combines (truncated) Dyson-Schwinger and Bethe-Salpeter equations in Landau gauge. This approach allows us to extract qualitative results for mass spectra, decay widths and wavefunctions of tetraquark candidates. Furthermore, we can investigate the possible internal structure of such states. We report on recent developments and results using this functional framework and give an overview about the current status as well as future developments.

140

R3B at project ESCAPE; a case study to practice open science for FAIR/GSI experiments

Corresponding Author: m.mohammadi-dadkan@rug.nl

The open science movement aims at more open and collaborative research practices in which data, software, and other types of academic output are shared and made available for reuse leading to greater scientific and societal impact. Within the nuclear and particle physics communities, the complexity of the analysis codes and the volume of the collected data are the most common obstacles to making their scientific outcomes accessible and reusable. In the project ESCAPE, we tried to find solutions for challenges concerning implementation of the FAIR (Findable, Accessible, Interoperable, Reuseable) principles by taking the R3BRoot analysis software and the associated data obtained by the NeuLAND detector of the R3B experiment as a case study. In this presentation, we demonstrate how we can technically apply FAIR principles in the analysis workflows and data management of the FAIR/GSI experiments and provide them as a web service to the end-users.

141

Information Proceedings

142

Close out