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Overview of recent results from HADES

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Abstract

HADES is a multi-purpose charged-particle detector operated at the SIS18 synchrotron located at the GSI Helmholtz Center for Heavy Ion Research in Darmstadt, Germany. The provided ion beam energies of 1-2 A GeV are the lowest of all currently running heavy-ion experiments and result in the highest baryo-chemical potentials at freeze-out in case of Au+Au collisions. At this Quark Matter conference we presented results from Au+Au collisions at $\sqrt{s_{NN}} = 2.4$ GeV. The created system exhibits a very clear hierarchy in hadron yields, with about 100 protons, 10 pions, 10^{-2} kaons and 10^{-4} antikaons per event. The HADES program focuses on four main observables: (subthreshold) strangeness production, particle flow and its anisotropies, virtual photon emission and net-proton number fluctuations.

Keywords: HADES, QCD-phase diagram, high μ_B, GSI, SIS18, subthreshold, strangeness, charged kaon freeze-out, flow anisotropies, virtual photon emission, net-proton fluctuations

1. HADES and the Baryon-Rich Side of the QCD Phase Diagram

The characterizations of physical properties of strongly interacting matter in its different phases is one of the challenges of modern physics. Especially, at high net-baryon densities properties of QCD matter are not well established. Due to the fermion determinant sign problem [1], ab-initio calculations can not be preformed in this regime. Thus, one has to rely on extrapolations or models based on effective Lagrangians, which need to be confronted with experimental data.

Heavy-ion collisions (HIC) provide a unique tool for this enterprise. As both, the inter-penetration time of the colliding nuclei decrease with increasing collision energy, and the amount of stopped nucleons in the collision zone decreases, resulting in a systematic increase of net-baryon density in the collision zone with decreasing energy. On a more quantitative level the extracted freeze-out parameters from statistical hadronization model (SHM) fits [2, 3, 4] to particle yields obtained at various energies show a striking regularity, lining up on a curve in the temperature - baryo-chemical potential plane, connecting smoothly data from the lowest energies at SIS18 up to the highest available energy at LHC [5, 6]. This offers a unique possibility of a systematic scan of the different phases of strongly interacting matter in the laboratory.

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HADES comprises a 6-coil toroidal magnet centered around the beam axis and six identical detection sections located between the coils, covering almost the full azimuthal angle. Each sector is equipped with a Ring-Imaging Cherenkov (RICH) detector followed by low-mass Mini-Drift Chambers (MDCs), two in front of and two behind the magnetic field, as well as a scintillator hodoscope (TOF) and a resistive plate chamber (RPC) at the end of the system. The RICH detector is used mainly for electron/positron identification, the MDCs are the main tracking detectors, while the TOF and RPC are used for time-of-flight measurements in combination with a diamond start detector located in front of a 15-folded segmented target. The setup is completed by a forward hodoscope used for event plane determination. A detailed description of the HADES detector is given in [7].

At this Quark Matter conference we presented results from Au+Au collisions at $\sqrt{s_{NN}}$ = 2.4 GeV. The created system exhibits a very clear hierarchy in hadron yields, with about 100 protons, 10 pions, 10^{-2} kaons and 10^{-4} antikaons per event. In order to accumulate sufficient statistics for a multi-differential analysis, even of the most rarely produced hadrons like antikaons, a fast data acquisition is mandatory. In total about 4×10^9 Au+Au events corresponding to the 40% most central events [8], have been collected in a four week measuring campaign with average trigger rates of 8 kHz and a 50% duty cycle. Particles are identified based on the correlation between the time-of-flight and the momentum measurement. Additional separation power is gained by the energy-loss information from the MDCs and the TOF detector and in case of electron/positron identification based on the information of the dedicated RICH and Pre-shower detectors.

The HADES program focuses on four main observables: (subthreshold) strangeness production, particle flow and its anisotropies, virtual photon emission and net-proton number fluctuations; they are discussed successively below.

2. (Subthreshold) Strangeness Production

Hadrons carrying strangeness are promising probes of the system created in HIC and have relevance for various astrophysical processes. As kaons contain an anti-strange quark, their coupling to baryons via formation of resonances is suppressed and they propagate in nuclear matter at ground state densities relatively free. One can estimate their mean free path in nuclear matter to $\lambda \approx 5$ fm by applying the low density approximation to the measured K^+-N cross-section, as implemented in microscopic transport models [9].

On the other hand, the spectral function of antikaons is complicated due to their coupling to baryon-resonances and have attracted much attention since the possibility of a $\overline{K}$ condensate in dense nuclear matter was first discussed in the eighties of last century by Kaplan and Nelson [10]. Various approaches based on chiral Lagrangians [11], one-boson-exchange models [12], the Nambu-Jona-Lasino model [13] or coupled-channel calculations [14, 15, 16] predict an overall attractive $\overline{K}$-nucleon potential.

Hyperons, in addition, are of particular interest as their behavior influences the properties of the surrounding matter, as well. It has long been realized that inside neutron stars the appearance of hyperons is possible via the weak interaction and it substantially softens the equation of state (EOS) [17, 18, 19, 20]. This leads to an upper limit for the maximum neutron star mass, what creates tension [21, 22] with the recent observations of two solar mass neutron stars [23, 24]. Whether the appearance of hyperons inside a neutron star is energetically favorable depends on the strength of the Λ-nucleon potential, which is known to be attractive at ground state densities from hypernuclei formation [25]. However, the density dependence of the potential is vague [26]. Calculations based on the quark model in combination with a non-linear $\omega - \sigma$ model predict an attractive potential for densities below three times nuclear ground density but a repulsive potential for higher densities [27]. HIC are the unique tool to study the potentials between nucleons and hadrons carrying strangeness at high densities. Hence, numerous works focused on kaons in this energy regime in the past.

One of the most notable is the attempt to extract the equation of state (EOS) at densities exceeding nuclear ground state, based on the comparison of K^+ multiplicity ratios from heavy (Au+Au) to light (C+C) collision systems to the same quantity obtained from microscopic transport models [28, 29, 30].

In addition, the K-N potential has been frequently in the focus of investigations. Most of the comparisons of experimental data to microscopic models are also in favor of a repulsive K-N potential [31, 32, 33, 34, 9, 35, 36]. However, no complete picture of one model being able to describe all kaon observables consistently emerged yet [37, 38]. Note, that in a recent work by the UrQMD group, the uncertainty of the kaon spectra