PROCEEDINGS OF SCIENCE

Reconstruction of Charged Kaons and $\phi(1020)$ from Ag+Ag Collisions at $\sqrt{s_{NN}} = 2.55$ GeV

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The **H**igh **A**cceptance **D**i**E**lectron **S**pectrometer (HADES) is a fixed target experiment located at the GSI accelerator facility in Darmstadt, Germany. The typical heavy-ion beam energies of 1-2 GeV, provided by the SIS18 synchrotron, provide an earthly laboratory for probing similar regions of the QCD phase diagram as present in binary neutron star mergers.

In March 2019, the HADES collaboration recorded $13.7 \cdot 10^9$ Ag(1.58A GeV)+Ag events within this facility as part of the FAIR Phase-0 program. The strange hadrons emerging from these collisions are produced below the free nucleon-nucleon production threshold. Due to their steep excitation function, this makes them a suitable probe for in-medium effects. In total 1.34×10^7 K^+, 1.21×10^5 K^- and 5.67×10^3 ϕ-mesons have been reconstructed in the scope of this work. Within this proceeding, we focus on the analysis steps performed and the resulting coverage in the transverse mass ($m_t - m_0$) vs. rapidity (y) plane for the three hadrons.

FAIR next generation scientists - 7th Edition Workshop,
23 - 27 May 2022,
Paralia (Pieria, Greece)

*Speaker

PoS(FAIRness2022)028

1. Heavy Ion Collisions in the few GeV Regime

Heavy Ion Collisions (HICs) can be used to investigate the properties of strongly interacting matter under extreme conditions. At high energies, the strongly Lorentz-contracted nuclei pass through each other nearly undisturbed. This results in a strongly interacting medium of high temperature and low net-baryon density. At low collision energies, the nuclei are partly or entirely stopped. The resulting systems have lower temperatures but higher net-baryon densities. Most emerging particles are protons and neutrons previously present within the nuclei. Below a center of mass collision energy of 2.55 GeV, individual nucleon-nucleon interactions do not provide enough energy for flavours heavier than u and d quarks to emerge.
The energetically most favourable process for strange hadron production is the nucleon-nucleon reaction $NN \rightarrow N\Lambda K$ with an energy threshold of 2.55 GeV, leading to the production of a K^+ or K^0 and a Λ^0. Together with other strangeness production channels, they are observed to occur well below their free NN production thresholds [1]. Therefore, at the investigated collision energy of $\sqrt{s_{\mathrm{NN}}} = 2.55$ GeV, the production of strange hadrons with energetic production thresholds beyond this value (e.g. K^- and ϕ) is driven by collective effects of the created medium rather than isolated NN collisions.
Furthermore, the comparison of density distributions within simulations of neutron star mergers and heavy ion collisions shows comparable values [2]. Figure 1 shows this direct density comparison for different points in time. Consequently, investigating heavy ion collisions at low energies and high

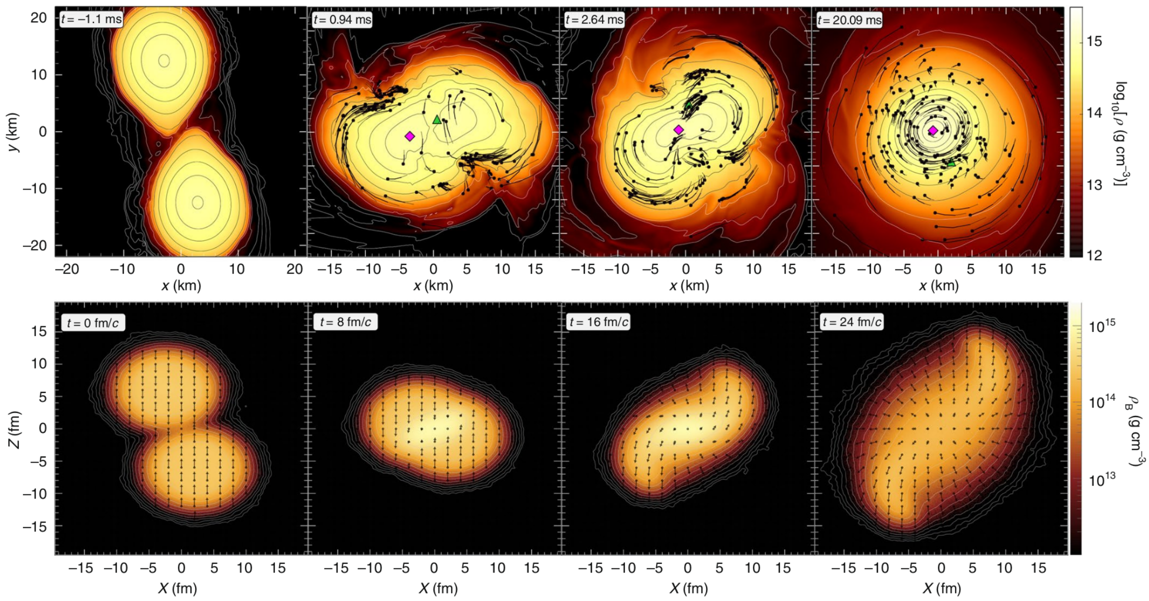

Figure 1: Density profile in units of nuclear density ρ_0 as a function of time for a neutron star merger system (top) in comparison to the collision of two Au nuclei at 2.4 GeV [2].

baryochemical potentials offers an earthly probe for otherwise astronomical events. In particular, it allows the investigation of the microscopic composition of dense nuclear matter, which is hardly possible in astronomical observations. The observed steep rise of their excitation function makes the $K^{\pm}$ and ϕ yield a sensitive probe for the properties of the created medium.

2. HADES

The spectrometer setup during the measurement of Ag+Ag collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.55 GeV is depicted in Figure 2. Due to the forward boost of secondary particles resulting from the fixed target configuration, the detectors are all situated in the forward direction in the laboratory frame of reference. In the azimuthal direction, the detector setup reaches a nearly total 360° coverage. A

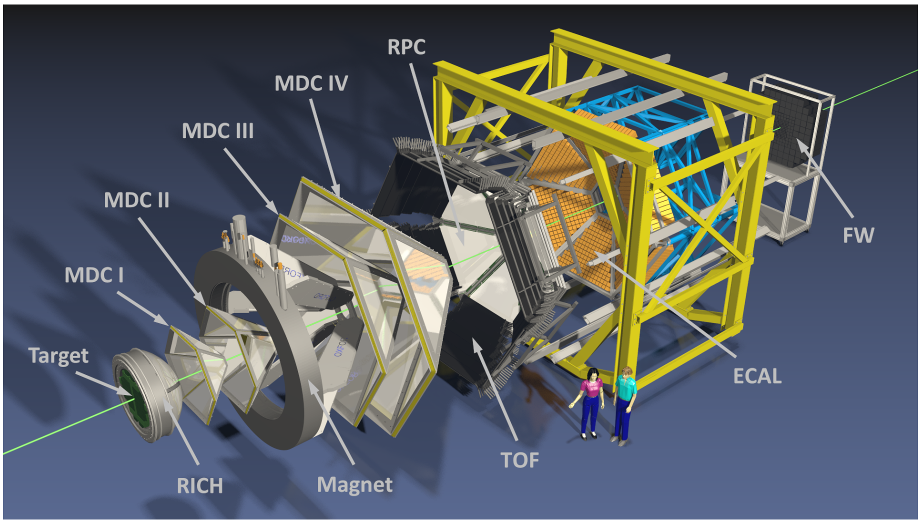

Figure 2: Cross section of the HADES experimental setup in an exploded view.

range between approximately 18° and 85° is covered in the polar angle direction.
Initially, right before the target, an incoming beam ion passes a diamond-based t_0 detector, which registers the start time for a reaction. The secondary particles, leaving the collision zone of the two ions, pass a series of subdetectors:
The **R**ing **I**maging **Ch**erenkov Detector (RICH) is used for lepton identification via Cherenkov light.
Multiwire **D**rift **C**hambers (MDCs) form four layers of Ar/CO_2 gas-filled detection volumes with six stereo layers of sensing wires each. With the toroidal magnet between layers II and III, the MDCs perform the charged particle tracking and energy loss measurement before and after the magnetic field.
TOF and **R**esistive **P**late **C**hamber (RPC) time of flight wall, usually referred to as **M**ultiplicity and **E**lectron **T**rigger **A**rray (META), detectors register the time of flight of particles through the detection system. META also functions as a trigger for the event multiplicity.
ECal - the **E**lectromagnetic **Cal**orimeter - detects and aids in identifying leptons, $\pi^{\pm}$ and photons.
The **F**orward **W**all (FW) in return registers the spectators (non-interacting nucleons) of the collision in order to determine the reaction plane.

More details on the setup can be found in [3]. With the META time of flight information and the bent trajectory reconstructed by the MDCs, the p/q of a particle can be determined. Together with the energy loss information, these are designated PID criteria used in this analysis.

3. Analysis

Particle multiplicities of charged Kaons and ϕ-mesons are orders of magnitude below those of protons, $\pi^{\pm}$ and light nuclei. As a consequence, track quality criteria and MDC and TOF energy loss constraints are applied to suppress the p and $\pi^{\pm}$ contributions in the $K^{\pm}$ mass spectra. In order to obtain the true signal from these spectra, the background is interpolated ($K^{\pm}$) below the peak or estimated by the event mixing technique (ϕ) and then subtracted. This is performed for all mass spectra in the corresponding $(m_t - m_0)$-y intervals, as indicated on the left side of Figure 3. This

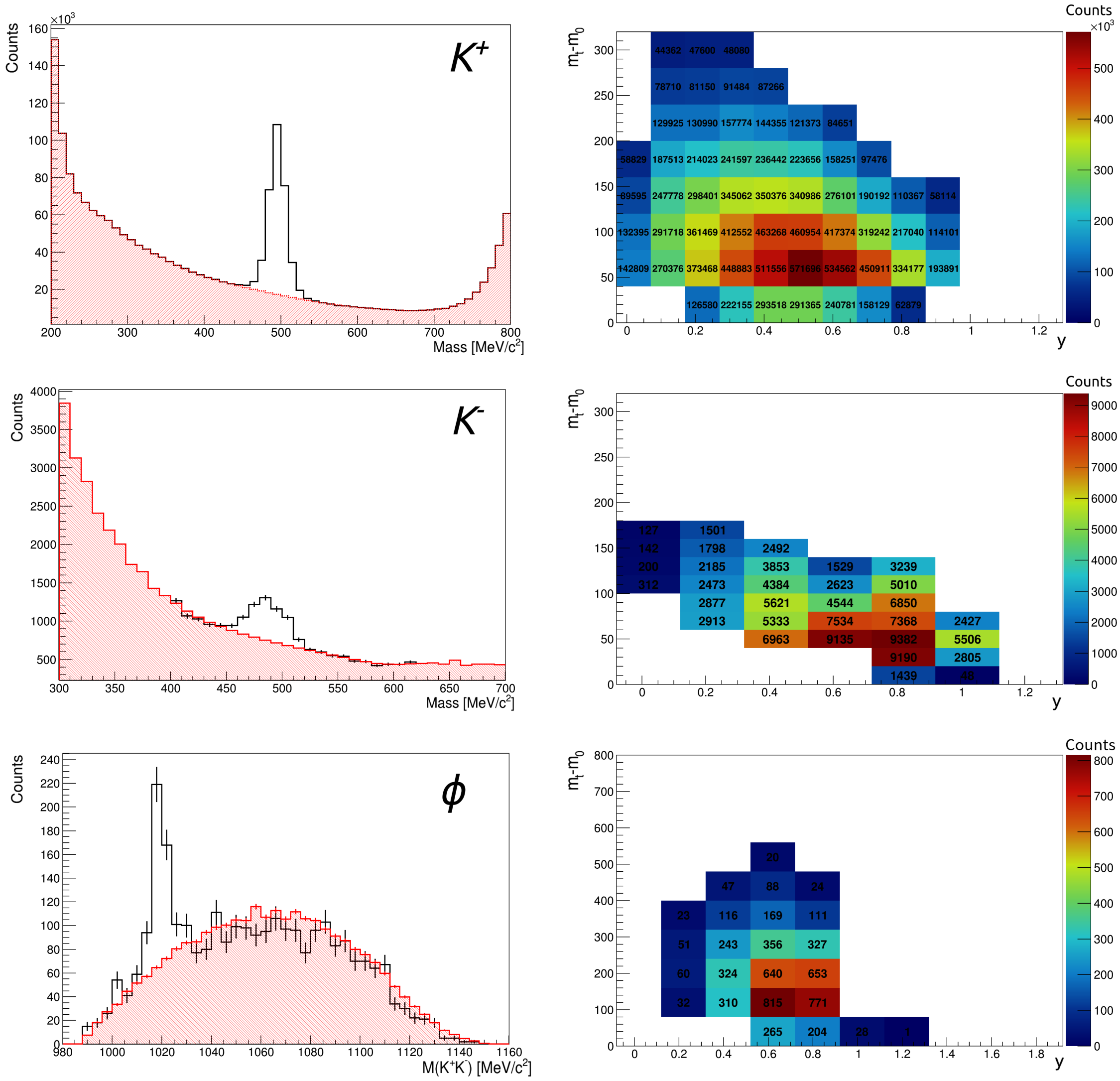

Figure 3: Exemplary differential mass spectra for K^+ , K^- and ϕ (left) and the resulting reconstructed phase space (right) in 0 – 30% centrality. The full collection of spectra can be found in [3].

results in a measured (raw) yield map of the particles' phase space, as displayed on the right side of Figure 3. In these two-dimensional projections, the coloured areas represent the phase space reconstructed from the data. The numbers within the intervals represent the number of counts extracted within this region, coded by the underlying colour. In total 1.34×10^7 K^+, 1.21×10^5 K^-

and 5.67×10^3 ϕ-mesons are used in the analysis. The multiplicity distributions are corrected for loss in geometrical acceptance and tracking as well as identification efficiency. For this, UrQMD [4] generated events are transported through a GEANT representation of the HADES detector setup to obtain the relative loss due to those effects. Then, the relative loss is used to correct the reconstructed yield in each phase space bin, resulting in the final $(m_t - m_0)$ spectra for each rapidity interval. More details on the procedure can be found in [3]. The extracted statistics allow for a multi-differential analysis of all three hadron species not only in the presented $(m_t - m_0) - y$ grid but also in three classes of collision centralities ranging from $0 - 10\%$, $10 - 20\%$ and $20 - 30\%$ most central events.

4. Outlook

The analysis aims to investigate the steep energy excitation function of strange hadrons in the few GeV regime. The high statistics of the data sample allow for a high precision comparison between the obtained yields of K^+, K^- and ϕ with the existing data as well as hadronic transport and thermal models.

Furthermore, we aim to investigate previous intriguing results on particle ratios like the observed rise of the ϕ/K^- [1][5][6], and the ϕ/Ξ^- [7] ratio towards low collision energies. Another goal is to check the universal scaling of strange hadron production yields according to $\mathrm{Mult}/\langle \mathrm{A_{part}} \rangle \propto \langle \mathrm{A_{part}} \rangle^{\alpha}$ as observed in [6][7]. It is of particular interest, as the ϕ-meson possesses no net-strangeness and should consequently not be suppressed compared to the K^-. In [1] and [5], it is found as well that the lower T_{Eff} for the K^- can be explained by feed-down from the $\phi \to K^+K^-$ channel, depriving the strangeness exchange hypothesis of its leading role in the K^- production. Thus, it is important to use the data to check this observation as well.

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