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Preliminary results on the transverse flow of charged K mesons emitted from Ag+Ag collisions at beam energy of 1.58 GeV/nucleon measured with HADES

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Abstract. In this contribution, preliminary results on the flow of charged K mesons emitted from semicentral Ag+Ag collisions at a beam kinetic energy of 1.58 GeV/nucleon measured with HADES are presented as $v_{1,2}$ coefficients mapped in the scaled rapidity – transverse momentum phase space. The coefficients, extracted by fitting a Fourier series to the azimuthal angle distributions, are corrected for the finite resolution of the event plane reconstruction, but not yet for inefficiencies related to the local track density in the detector. The $K^{\pm}$ flow is compared to the corresponding distributions for protons emitted from the same system. These comparisons suggest a repulsive potential between the K^{+} and nuclear matter, while conclusions for the K^{-} are not possible to be drawn at this point, due to high statistical uncertainties.

1 Introduction and motivation

Heavy-ion collisions at energies of few *A*GeV allow the study of nuclear matter at extreme temperatures, pressures and densities [1, 2] by analysing the kinematic distributions of particles emitted from collisions and deducing the nature of the hot and dense nuclear matter via model comparisons. In this work, transverse flow is understood as anisotropies of emission in the azimuthal angle (with respect to the beam axis), sensitive to multiple properties of nuclear matter, like the Equation of State or partial restoration of chiral symmetry [3, 4].

For K mesons, an important open question is their interaction with nucleons, as well as with the $q\bar{q}$ condensate, in the expanding fireball. It was predicted in Ref. [5] that the potential of the kaon-nucleon (KN) interaction should be repulsive for the K^{+} and attractive for the K^{-}. The consequence of this interaction should be the changing of kaon mass and decay constant in dense nuclear matter [3]. Results on charged kaon flow in Ni+Ni collisions at a beam kinetic energy of 1.91*A* GeV published by the FOPI Collaboration [6] appear to support this hypothesis, although no final statement can be made as of now, in part due to limited statistics in the samples analysed therein.

The Ag+Ag collisions at beam energy of 1.58 GeV/nucleon, measured by the HADES spectrometer, may be essential in answering these open questions, due to the acceptance and precision of HADES, as well as the large statistics collected during the Ag+Ag run. By studying the transverse flow of $K^{\pm}$ mesons with unprecedentedly low uncertainties and a large coverage of the phase space, we hope to significantly further our understanding of this effect.

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2 The HADES spectrometer

HADES [7], standing for High-Acceptance Di-Electron Spectrometer, is a fixed-target experiment measuring mainly products of relativistic heavy-ion collisions, although some experiments with elementary beams were also conducted. A sketch of the setup is presented in Figure 1 and a short overview is provided in this section.

An essential component of the spectrometer are the four Multiwire Drift Chamber (MDC) planes separated by the superconducting magnet. This allows a momentum measurement based on the deflection of tracks in the known magnetic field. The relative precision of momentum reconstruction is 4 % [7], when using the Runge-Kutta method to solve the differential equations of motion of a charged particle in the known magnetic field.

By extrapolating the tracks to a common vertex in the target and to the detectors of the META system (Time Of Flight and Resistive Plate Chamber) one can obtain a path length for each track. This extrapolation can be matched to the nearest signal in TOF/RPC, and the event time from the START detector. Thus, the path length and the travel time within the detector can be obtained: two components of the velocity ($\vec{v}$). In combination with the reconstructed momentum ($\vec{p}$), this can be used to calculate the mass (m) for each track, based on the relativistic formula $\vec{p} = \gamma m\vec{v}$. The HADES detectors and track reconstruction methods are described in detail in Ref. [7].

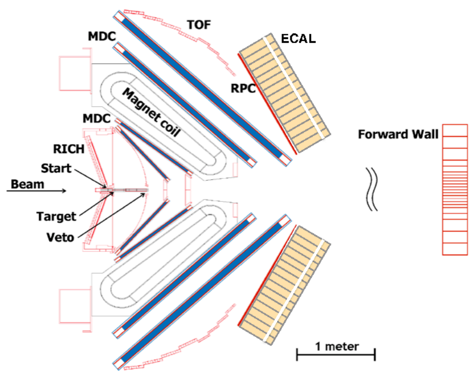

Figure 1. A schematic view of the HADES spectrometer as it was used for the Ag+Ag beamtime in March 2019. The distance between the main body and the Forward Wall detector is not to scale [7].

3 The flow extraction method

The $K^{\pm}$ mesons signal is extracted by modelling the signal and background in experimental mass distributions within cells of the momentum space in the scaled rapidity y_0[1], transverse momentum p_t and the azimuthal angle with respect to the event plane $\Delta\phi$. From these, a $\Delta\phi$ distribution can be obtained for every point in (y_0, p_t) and modelled with a cosine Fourier series:

$$\frac{dN}{d\Delta\phi} = \mathcal{N}\left(1 + 2\sum_n v_n \cos(n\Delta\phi)\right), \tag{1}$$

[1]Scaled rapidity is defined as $y_0 = \frac{y - y_{CM}}{y_{CM}}$, where y is the rapidity of a track and y_{CM} is the center-of-mass rapidity, both calculated in the Laboratory frame.

yielding maps of v_1 and v_2, describing the directed and elliptic flow, respectively, as functions of transverse momentum and scaled rapidity.

The distributions are then corrected for the finite resolution of the event-plane reconstruction. The event plane in HADES is reconstructed based on charged hits from the collision spectators in the Forward Wall detector located a few meters downstream from the main setup (see Fig. 1). This is done only with some limited resolution and the random smearing in this reconstruction dampens the measured anisotropies. Correction factors for the strength of each harmonic are calculated according to the method described by J.-Y. Ollitrault in Ref. [8].

The presented distributions are not yet corrected for relative efficiency losses in areas of large local track density, which causes a lack of symmetry with respect to mid-rapidity, which would be expected from the system's geometry. Other efficiency effects are negligible, since they are dependent on p_t and y_0, and no integrated distributions are shown herein.

4 Results and discussion

In Figure 2 the experimentally found v_1 coefficient is shown for the K^+ (left panel) and the K^- (right panel). The distributions are shown as functions of scaled rapidity, for consecutive bins of p_t. The distributions are superimposed onto the proton flow measured in the p_t interval of 500-600 MeV/c. As the distributions are not corrected for the aforementioned occupancy effects (expected to affect more the y_0>0 region), and thus not symmetrical, it is currently hard to draw any physical conclusions. This is complicated further by the lack of systematic uncertainties in the analysis. However, the behaviour of K^+ mesons in comparison to that of the protons, could be seen as an indication of the so-called *antiflow* effect, where the studied particles have an inverse slope of $v_1(y_0)$ than that of the bulk matter. The appearance of this effect, within the statistical uncertainties, seems to be p_t-dependent. For the K^-, current statistical uncertainties themselves make any speculation difficult.

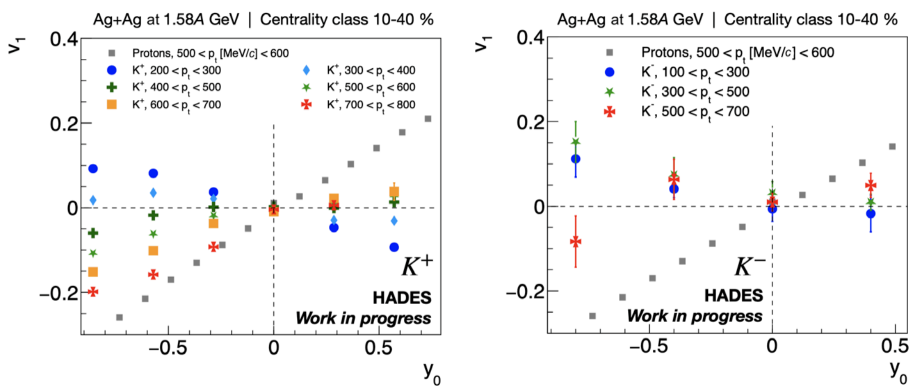

Figure 2. Distribution of v_1 coefficients describing the directed flow of K^+ mesons (left panel) and K^- (right) as function of scaled rapidity y_0 and in different p_t ranges. The flow of protons with $500 < p_t$ [MeV/c] < 600 emitted from the same system is shown in grey. For many points the statistical uncertainties are smaller than the markers; systematic uncertainties are not evaluated as of yet.

In Figure 3, the v_2 profiles are shown for both charges (K^+ on the left, K^- – right) as a function of transverse momentum, for different y_0 bins. The mid-rapidity proton flow is superimposed onto the plot. Here, the occupancy corrections were also not applied and the systematics were not evaluated. Moreover, the statistical uncertainties are higher for the v_2 coefficient, than for v_1. Thus, it is impossible to draw firm physical conclusions as of yet.

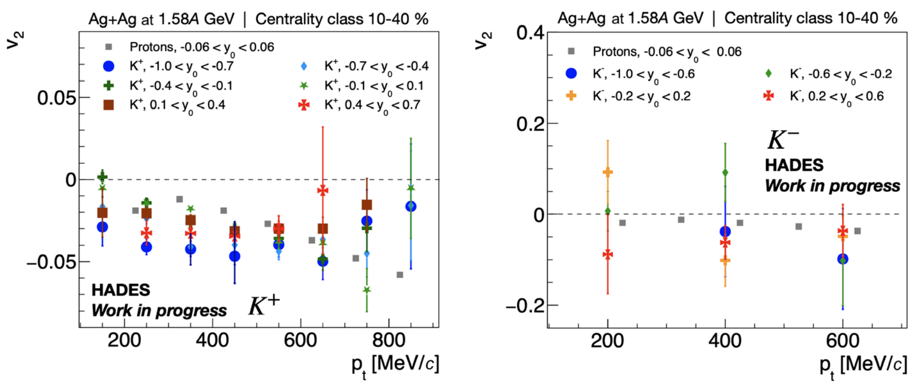

Figure 3. Distribution of v_2 coefficients describing the elliptic flow of K^+ mesons (left panel) and K^- (right) as function of transverse momentum p_t and in different y_0 ranges. The flow of protons emitted from the same system at midrapidity is also shown in grey. Systematic uncertainties are not evaulated as of yet.

5 Summary and outlook

The unprecedented precision of the HADES experiment for Ag+Ag collisions at a beam kinetic energy of 1.58 GeV/nucleon may significantly advance our understanding of the KN interaction in hot and dense nuclear matter, by measuring the transverse flow of charged K mesons. In this contribution, the work-in-progress results of this measurement for Ag+Ag collisions at beam energy of 1.58 GeV/nucleon are shown. The results still require efficiency corrections and an evaluation of systematic uncertainties, however the achieved precision and coverage are already promising. The results allow us to speculate, that – once they are finalized – they will provide valuable insight into the interaction of K mesons with nuclear matter.

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