

ANISOTROPIC FLOW OF STRANGE HADRONS IN RELATIVISTIC HEAVY-ION COLLISIONS MEASURED WITH HADES*

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In this contribution, the ongoing analysis of the anisotropic flow of strange hadrons (K^\pm , Λ) emitted from the Ag+Ag collisions at a beam kinetic energy of 1.58 GeV per nucleon is presented. The anisotropic flow is expressed with the Fourier coefficients of the 1st and 2nd order, corresponding to the directed and elliptic flow, respectively. However, only the v_1 distribution is shown due to statistical limitations. The directed flow of K^+ has a negative slope in the low- p_t region, opposite to protons, while the v_1 slope of Λ is similar to that of the protons regardless of momentum.

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1. Introduction

Relativistic Heavy Ion Collisions (RHIC) are experiments where two nuclei collide at relativistic energies up to hundreds of GeV per nucleon. At the lower boundary of this region lies the few-GeV energy regime, where nuclear matter is transformed into a very hot and dense state for a very short time of $\sim 10^{-22}$ s [1]. Particles emitted from the collision zone carry information about this high-density nuclear medium and about their interaction with it. A beam kinetic energy of 1.58 GeV/nucleon is the kinematic threshold for strangeness production in the energetically most favoured channel of $NN \rightarrow NK\Lambda$ [2]. Thus, strange hadrons are produced sparsely and act as probes of both the interaction between them and the nuclear medium, through which they first traverse.

It is expected that this interaction will be reflected in their momentum distributions and a proposed good probe of this effect is anisotropic flow [3], corresponding to anisotropies of particle emission around the azimuthal

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angle (around the beam axis). For charged kaons, it is predicted that their effective mass and decay constant should deviate from the vacuum values, when surrounded by dense nuclear matter [4, 5]. Additionally, the interaction between Λ baryons and nuclear matter is of interest to the astrophysics community, since the medium produced at these energies resembles Neutron Stars (NS) during their mergers [1]. Through measurements of the anisotropic flow of Λ baryons, we may resolve the tension between predictions of hyperons being present in Neutron Stars, effectively softening their equation of state, and observations of massive neutron stars (“hyperon puzzle”) [6].

2. Experimental setup

HADES (High Acceptance Di-Electron Spectrometer) [7] is an experiment installed at the SIS18 accelerator at GSI, Darmstadt measuring products of heavy, as well as elementary particle collisions at beam kinetic energies of a few GeV per nucleon. The setup measures four-momenta of emitted particles with high angular acceptance (polar angles 18° – 85° , full azimuthal angle) and momentum precision within a few %.

The spatial orientation of the colliding system (Event Plane) is determined with the Forward Wall detector located a few meters upstream from the main setup (7 m from the target). The momentum-to-charge ratio of hadrons and leptons is measured with two pairs of Multiwire Drift Chambers (MDC) separated by a superconducting, toroidal magnet. Timing is provided by the START detector located next to the target combined with the time-of-flight detectors TOF and RPC. A detailed overview of HADES is presented in the summary paper [7].

3. Particle identification

Particle identification is the set of procedures used to process all the measured particles and to obtain the measured multiplicity \mathcal{N} in the predefined ranges of transverse momentum p_t , reduced rapidity y_0 ¹, azimuthal angle $\Delta\phi$ ², and collision centrality C ³. For the case of K^\pm , this procedure is relatively straightforward, as the particles can be directly measured in the spectrometer. The signal can be then obtained by fitting the mass spectrum

¹ Rapidity is the Lorentz-additive expression of momentum along the beam axis, defined as $y = \tanh^{-1} \beta_z$. The reduced rapidity $y_0 = (y - y_{CM})/y_{CM}$ is preferred as it is anchored in the COM reference frame and normalized.

² The measured azimuthal angle ϕ corrected for the orientation of the colliding nuclei (so-called Event Plane), $\Delta\phi = \phi - \Psi_{EP}$.

³ Determined by relating measured multiplicities in the TOF+RPC detectors with participating nucleus via the GlauberMC model, see [8] for details.

around the mass of K^\pm with a Gaussian distribution combined with a function modelling the background in the mass distribution (polynomial for the K^+ and exponential for the K^-).

The procedure is more complex for the Λ baryon, which is electrically neutral and decays weakly with a mean free path of a few centimetres⁴. Therefore, it cannot be directly measured within the acceptance of HADES. Its dominant decay channel is the $\Lambda \rightarrow \pi^- + p$ process⁵, where both daughter particles are electrically charged. By using momentum and energy conservation, the Λ baryon four-momentum can be deduced from the kinematic properties of the decay daughters. In particular, the rest mass of the decaying particle equals the invariant mass of that system. One can then obtain the Λ signal by subtracting the normalized Mixed-Event distribution (which reproduces the combinatorial background of uncorrelated (p, π^-) pairs) from the Same-Event distribution (where a significant fraction of pairs come from Λ decay).

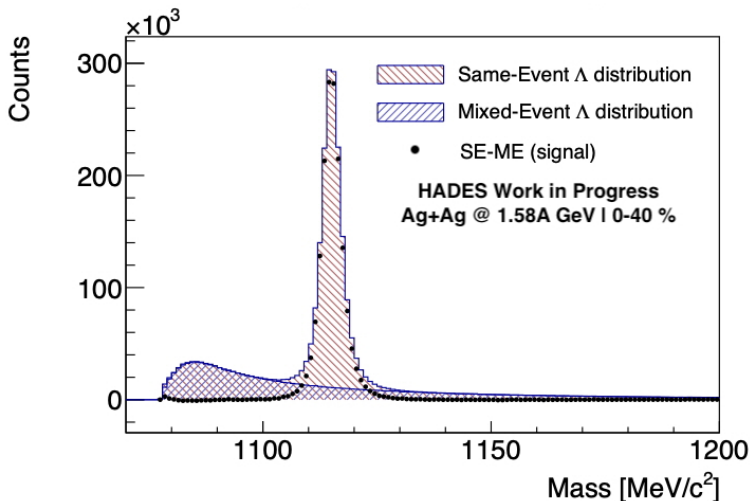


Fig. 1. (Colour online) Distribution of the invariant mass of (p, π^-) pairs emitted from Ag+Ag collisions at a beam kinetic energy of 1.6 GeV per nucleon. The distribution resulting from the Same-Event sample is shown as the red area and that of pairs coming from mixed events with comparable properties in blue; the signal is extracted as the difference between these two distributions and is shown as black markers.

The statistical significance of the Λ peak is optimized with filters on variables inspired by the geometry of the Λ decay (*e.g.* the distance of closest approach between the assumed daughter particles or the distance

⁴ Mean lifetime of the Λ baryon in its own reference frame is $\tau \approx 2.6 \times 10^{-10}$ s [9].

⁵ BR \approx 64% [9].

between the reconstructed Λ decay vertex and the target). The Same-Event and Mixed-Event distributions, together with the obtained signal, are shown in Fig. 1 for a combined sample of the 40% most central collisions.

4. Fourier decomposition

Once the signal distribution $\mathcal{N}(y_0, p_t, \Delta\phi)$ is obtained, it is subject to a Fourier decomposition, using

$$\frac{d^3N}{dp^3} = \mathcal{N}(p_t, y_0) \left(1 + 2 \sum_n v_n(p_t, y_0) \cos(n\Delta\phi) \right), \quad (1)$$

where $\mathcal{N}(p_t, y_0)$ is the two-dimensional momentum distribution, which is the basis of multiplicity measurements [10]. The v_n coefficients describe respective harmonics in the Fourier decomposition of the angular distribution. In this work, n is limited to 2 due to statistical limitations. We have obtained the distributions of v_1 and v_2 coefficients, corresponding to directed and elliptic flow, respectively. However, the values of v_2 are prone to fluctuations and we omitted them for clarity. The distributions of the directed flow for the charged kaons and the Λ baryons are shown in Fig. 2 and Fig. 3, respectively. The v_1 distributions are corrected for the finite resolution of the Event-Plane orientation measurement, which contributes to smearing of observed anisotropies, according to the method described in Ref. [11]. The observed v_1 distributions may also be influenced by decreases of the efficiency under local overpopulation of tracks. Track density is a global parameter,

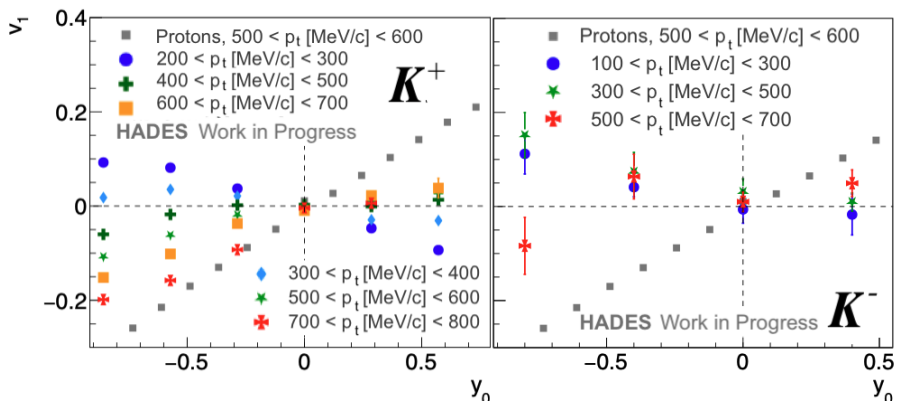


Fig. 2. (Colour online) Distributions of the $v_1(p_t, y_0)$ coefficients of charged kaons emitted from 10–40% most central Ag+Ag collisions at a beam kinetic energy of 1.58 GeV/nucleon. The data is shown as a function of y_0 for consecutive range of p_t . The left panel corresponds to K^+ and the right to K^- . The distribution for protons is superimposed in small grey squares.

driven mostly by the highly abundant protons, pions, and light nuclei, but it affects all measured particles, including the rare strange hadrons. Drops of efficiency caused by particles with different kinematic properties distort the expected symmetry of the angular distribution. There are data-driven approaches that reproduce the desired symmetries [12]. Further studies are ongoing to apply these corrections in this study.

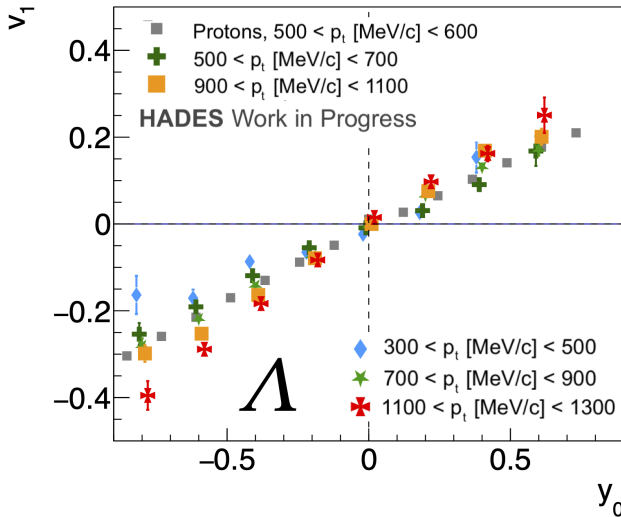


Fig. 3. (Colour online) Distributions of the $v_1(p_t, y_0)$ coefficient of Λ baryons emitted from 10–40% most central Ag+Ag collisions at a beam kinetic energy of 1.58 GeV/nucleon. The data is shown as a function of y_0 for consecutive ranges of p_t . The distribution for protons is superimposed in small gray squares.

Assuming the current state of the v_1 distributions, the directed flow of charged K^+ , as shown in Fig. 2, exhibits an interesting behaviour. While the v_1 slope is positive for high p_t , it shifts to a reversed slope in the low- p_t region. Since this negative slope is opposite to that of the protons, it is referred to as “antiflow”. The $v_1(y_0)$ of Λ appears to exhibit nearly a linear rise, and the slope rises with the p_t range. It aligns itself with the directed flow of the protons for all considered momenta. It is worth noting that the symmetry (v_1 is expected to be an odd function) of directed flow for all particle species is already quite consistent with expectations. In particular, $v_1(0)$ appears to be consistent with 0 within statistical uncertainties.

5. Summary and outlook

In this work, we have presented the preliminary results of the directed flow of strange hadrons (K^\pm , Λ) emitted from Ag+Ag collisions at a beam

kinetic energy of 1.58 GeV/nucleon measured with the HADES experiment. The preliminary distributions of v_1 in the two-dimensional (p_t, y_0) momentum space are already corrected for the finite resolution of event-plane reconstruction. An application of a density-based efficiency correction, as well as an evaluation of systematic uncertainties is currently being developed. Calculations of transport model predictions are also underway. The slope of the directed flow of K^+ mesons varies with p_t : it is positive (as for protons) in the high- p_t region and opposite for low transverse momenta. The directed flow of Λ baryons appears to behave proton-like regardless of momentum. It is difficult to make any definite observations about the K^- as its burdened with high statistical uncertainties. The results are consistent with reports on strangeness flow by the FOPI Collaboration [3, 13] and the Λ flow results from STAR, which occupy slightly larger beam energies [14].

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