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Strangeness production in Au(1.23A GeV)+Au collisions

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Abstract

We present first data on centrality dependent K^+, K^- and ϕ production in Au+Au collisions at a kinetic beam energy of 1.23A GeV measured with HADES. We observe no significant increase of the K^+/K^- and ϕ/K^- multiplicity ratios with centrality of the collision. The measured ϕ/K^- ratio is found to be larger than results at higher energies. The significant ϕ feed-down contribution to the K^- yield substantially softens the measured transverse mass spectrum of K^-, explaining its lower observed effective temperature in comparison to the one of K^+.

Keywords: strangeness, sub-threshold, centrality dependence, Kaons, ϕ feed-down, effective temperature

1. Introduction

The production of strange hadrons below their respective nucleon-nucleon threshold energy is a suitable probe for the high-density phase of a heavy-ion collision. As they can not be produced in binary NN collisions, the energy to produce these particles has to be provided by the system. In the framework of transport model calculations the necessary energy is accumulated in multi-step processes via intermediate resonances. The first data on sub-threshold K^- production in heavy-ion collisions obtained by the KaoS collaboration revealed that the K^- and K^+ multiplicities show, despite their different NN threshold energies[1], a similar increase with collision centrality, whereas the transverse mass spectra of K^- are significantly softer compared to the ones of K^+ (for a review of the data see [1]). These two observations were explained within transport model calculations when assuming the strangeness exchange reaction $\Lambda\pi \rightarrow NK^-$ to be the dominant production channel for K^- below threshold [2]. This reaction couples the production of K^- to K^+, explaining their similar centrality dependence and the later decoupling of K^-, which explains the softer spectra. However, recent data on strangeness production in smaller collision systems indicate that ϕ feed-down decays constitute also a sizeable source for K^- production below the threshold [3, 4, 5], which was not taken into account in transport models. The measurement of a close-to-complete set of strange hadrons in Au+Au collisions at a kinetic beam energy of 1.23A GeV will help to differentiate between the effects of resonant production vs. strangeness exchange reactions.

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[1]The threshold for $NN \rightarrow N\Lambda K^+$ is $\sqrt{s}_{thr}$ = 2.55 GeV, and for $NN \rightarrow NNK^+K^-$: $\sqrt{s}_{thr}$ = 2.86 GeV

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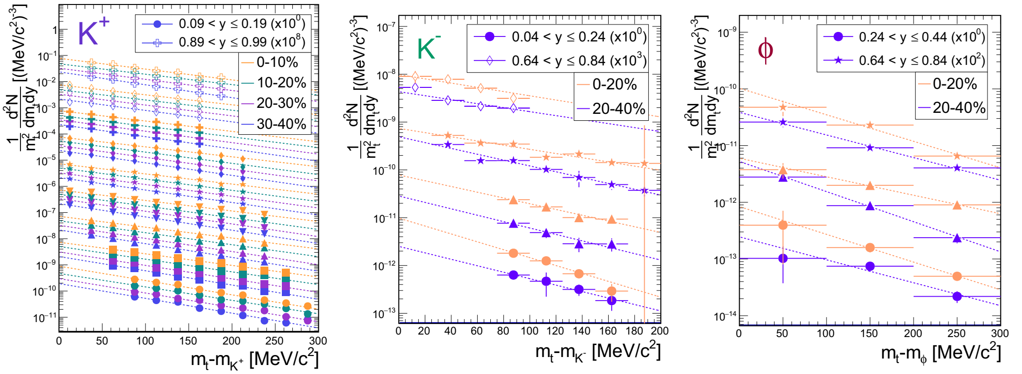

Fig. 1. Efficiency and acceptance corrected transverse mass spectra of K^+ (left), K^- (middle) and ϕ (right) for all analyzed rapidity (scaled for clearer display) and centrality intervals. The spectra are described by Boltzmann functions see Eq. 1 (dashed lines).

2. Experimental setup and data analysis

HADES is located at the SIS18 accelerator of the GSI Helmholtz center for heavy-ion research in Darmstadt, Germany. The detector is built out of six identical sectors, surrounding the beam axis and covering almost the full azimuthal and polar angles between 18 and 85°. For a detailed description of the spectrometer and its components see [6]. The track and momentum reconstruction are performed with a magnet spectrometer consisting of two Mini Drift Chambers (MDC) in front of and two behind a superconducting magnet. In combination with the time-of-flight determination via a scintillator hodoscope (TOF) and a Resistive Plate Chamber (RPC) at the end of the setup, particles can be identified. In order to reduce the contribution of protons and pions to the signal of the rarely produced kaons, the energy loss signal in the drift chambers and the TOF detector can be employed. The background is described using a third order polynomial function and is subtracted in an iterative fitting procedure. Unstable neutral hadrons are identified via their decay into charged particles ($\Lambda \to p\pi^-$, $K^0_S \to \pi^+\pi^-$, $\phi \to K^+K^-$). In order to increase the signal-to-background ratio and to reduce the amount of uncorrelated pairs, cuts on the specific decay topology of the weakly decaying Λ and K^0_S are applied. The remaining background is subtracted using the mixed-event technique. In total 2.1×10^9 Au+Au events are used in the analysis, corresponding to the 40% most central events, corresponding to $\langle A_{part} \rangle = 191 \pm 11$, as has been estimated with Glauber model calculations [7, 8]. The analysis is performed in small cells in reduced transverse mass $m_t - m_0$ and rapidity y and in four for K^+, or two for K^- and ϕ, centrality bins. The raw signal count rates are corrected in each phase space cell for acceptance and efficiency based on detailed simulations of the detector response. As input for the simulations the particles are generated with a thermal distribution and embedded into UrQMD events [9], which serve as realistic background. For a detailed description of the reconstruction of strange hadrons see [10, 11, 12].

3. Results and discussion

The efficiency and acceptance corrected transverse mass spectra of K^+ (left), K^- (middle) and ϕ (right) are shown in Fig. 1 for all analyzed rapidity intervals and centrality classes[2]. HADES has a large phase space coverage down to lowest transverse mass covering mid-rapidity for all particles. The spectra are parameterized by Boltzmann functions of the following form:

$$\frac{1}{m_t^2}\frac{d^2N}{dm_t dmy} = c(y) \cdot \exp - \frac{(m_t - m_0)}{T_B(y)}, \quad (1)$$

with a rapidity dependent normalization $c(y)$ and the slope parameter $T_B(y)$, in order to extrapolate to unmeasured transverse mass regions. The resulting rapidity density distributions are shown in the upper row of

[2]For results from the inclusive measurement in 0-40% most central collisions see [10].

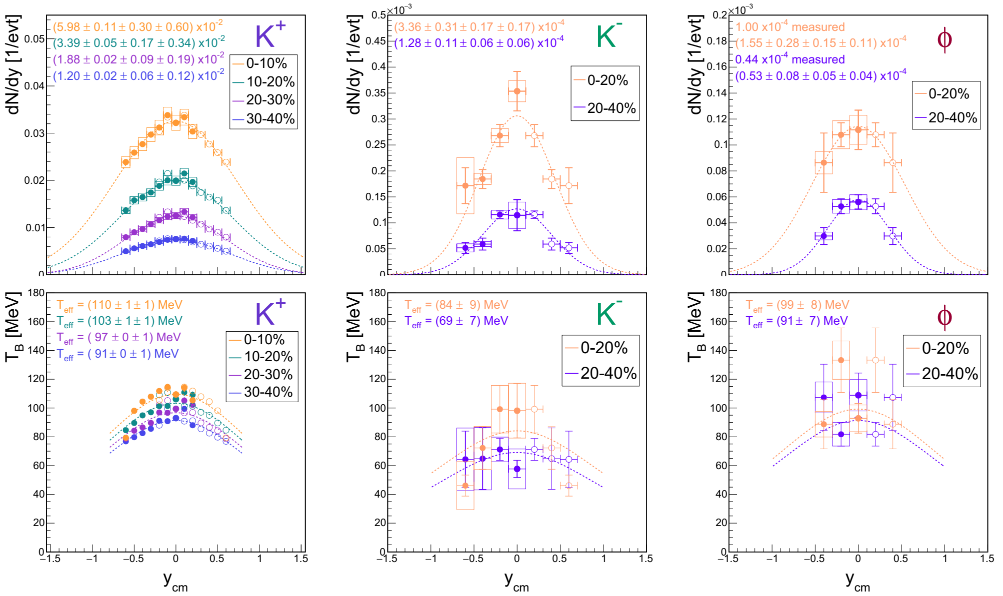

Fig. 2. Measured (full symbols) and reflected (open symbols) rapidity density (upper row) and slope parameter distributions (lower row) of K^+ (left), K^- (middle) and ϕ (right). The rapidity density distributions are fitted with Gaussians to extract the multiplicities stated in the plot. The inverse slope parameter distributions are described by $T_B(y) = T_{eff}/\cosh(y_{cm})$ to extract the effective temperature T_{eff} quoted in the plot. For details see text.

	$K^-/K^+ \times 10^{-3}$	ϕ/K^-
0 - 40%	6.45 ± 0.9	0.52 ± 0.16
0 - 20%	7.17 ± 1.1	0.46 ± 0.12
20 - 40%	8.31 ± 1.3	0.44 ± 0.10

Table 1. Charged kaon and ϕ multiplicity ratios.[2] Given errors correspond to the quadratic sum of the statistical and systematic errors.

Fig. 2. Gaussian functions are used to extrapolate to rapidity regions not covered by HADES to extract the total multiplicities of the particles, which are quoted in the plot. The first error corresponds to the statistical uncertainty. The systematic uncertainty, given as second error, is dominated by the following contributions: particle identification, averaging over the six different sectors of the spectrometer, input for the Monte-Carlo simulation and extrapolation to unmeasured m_t regions. These sources add up quadratically to 5% for kaons and to 10% for ϕ. The third contribution to the uncertainty on the multiplicity is due to the extrapolation to unmeasured rapidity regions and is obtained by comparing the relative contribution of extrapolations using the Gaussians to transport model calculations [2, 9]. The resulting multiplicity ratios are summarized in Tab. 1. The given errors correspond to the quadratic sum of the single error sources.

The ϕ/K^- multiplicity ratio for the 0-40% most central collisions [10] is shown on the left side of Fig. 3 in comparison to measurements at similar energies in lighter systems [3, 4, 5] as well as data at higher $\sqrt{s_{NN}}$ [13, 14, 15]. Whereas this ratio is flat at energies above $\sqrt{s_{NN}} \geq 4$ GeV with values of about 0.15, it is increasing for energies below the NN threshold. As a consequence ϕ feed-down becomes a sizeable source for K^- production below the threshold even in the large Au+Au system.

We find that the multiplicity ratios are constant within errors, indicating that all strange hadrons show, despite their different elementary production thresholds, a similar dependence on the centrality of the collision, as observed also at higher energies. Whereas the coupling of K^- to K^+ can be explained in a microscopic picture by strangeness exchange reactions, current transport models are not able to reproduce the large ϕ/K^- multiplicity ratio below the NN threshold and can not explain the centrality independence seen for ϕ production.

The distributions of the inverse slope parameters $T_B(y)$ are displayed in the lower row of Fig. 2. These

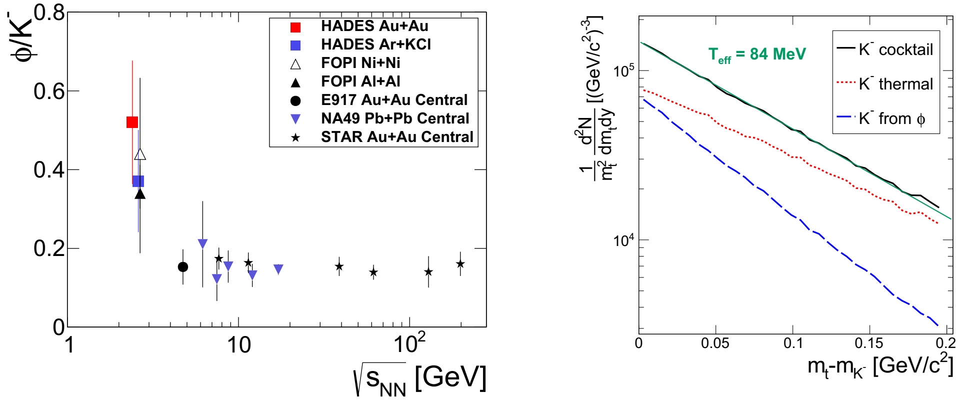

Fig. 3. Left: ϕ/K^- multiplicity ratio as a function of $\sqrt{s_{NN}}$ [10, 3, 4, 5, 13, 14, 15]. Right: Simulated transverse mass spectra of thermally produced K^- (dotted red), K^- from ϕ decays (dashed blue), and their sum, here denoted as cocktail (black), generated according to the effective temperatures measured for 0-40% most central collisions[2] (see text). The spectra can be described by Eq. 1 in order to extract the effective temperature T_{eff}.

can be described using $T_B(y) = T_{eff}/\cosh(y_{cm})$ in order to extract the effective temperature T_{eff} which is quoted in the plot. The systematic uncertainties are found to be well below the statistical uncertainty for K^- and ϕ and are therefore negligible. However, for the centrality dependent analysis of K^- an additional systematic uncertainty is shown for the data points, reflecting the smaller phase space coverage compared to the other strange hadrons. As observed at slightly higher energies [1], we find a systematic lower effective temperature for K^- than for K^+ and the other strange hadrons. However, when taking the 25% feed-down contribution to the K^- production from ϕ decays into account, we find that the K^- originating from these decays are significantly cooler than thermally produced kaons, and therefore result in an overall softer K^- spectrum. The effect can be seen on the right side of Fig. 3, where a simulated two-component cocktail of the K^- transverse mass spectrum around mid-rapidity is shown. To the 75% thermally produced K^- (dotted red), generated with the measured effective temperature of the K^+ in the 0-40% most central collisions [10] (T_{eff}^{K+} = (104 ± 1 ± 1) MeV), we add 25% K^- from ϕ decays (dashed blue), which have been generated according to the measured value of T_{eff} (T_{eff}^{ϕ} = (108 ± 7) MeV). As a consequence the obtained inverse slope parameter of the cocktail (solid black) is significantly lower for K^- than the one of K^+ (T_{eff}^{K-} = 84 MeV, obtained using Eq. 1), as observed in the experiment (measured T_{eff}^{K-} = (84 ± 6) MeV).

In conclusion, when simply taking into account the strong ϕ feed-down contribution, we find no indication for a sequential kaon freeze-out scenario, which has been suggested formerly by transport model calculations as an explanation for the significantly lower effective temperature of K^- compared to K^+.

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