

V^0 Reconstruction of Strange Hadrons in Au+Au Collisions at 1.23 AGeV with HADES

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Abstract. Preliminary results on the production of weakly decaying strange hadrons are reported for collisions of Au+Au at 1.23 AGeV beam energy studied with the HADES detector at GSI in Darmstadt. At this collision energy all strange particles are created below their elementary threshold. The reconstruction of the investigated particles (i.e. Λ and K_s^0) via the topology of their charged decay products (V^0 reconstruction) is presented in detail. From the corrected yields of Λ and K_s^0 the ratio K_s^0/Λ can be calculated and included into a statistical model fit.

1. Introduction

Hadrons containing strange quarks are well suited probes of the high density phase of nuclear matter created in heavy-ion collisions at SIS energies. For example, the investigations on sub or near threshold production of K^+ provided constraints on the nuclear equation of state at matter densities of about 2-3 ρ_0 [1, 2, 3], which are typical for the SIS energy regime. A rather consistent picture of in-medium K^+ potentials emerged and the resulting equation of state agrees fairly well with K^+ phase space distributions and flow patterns [4, 5, 6, 7].

Furthermore, as a consequence of strangeness conservation the kaon production is directly connected to the production of hyperons. Whereas the strangeness production is well understood in elementary collisions of nucleons, in heavy-ion collisions further mechanisms have to be taken into account i.e. effective in-medium potentials or multi-step processes involving baryon resonances or mesons. Strangeness exchange channels like $\pi\Lambda \rightarrow NK^-$ have been proposed to explain observed K^- yields [8, 9]. Additionally it was shown that the feed down from the Φ meson decaying into a $K^+ K^-$ pair gives a non-negligible contribution to the K^- yields [10, 11]. For a deeper understanding of strangeness production and propagation in a density dominated environment more information on all produced strange hadrons at these energies needs to be collected.

In this contribution, preliminary results on the production of the weakly decaying strange hadrons Λ and K_s^0 from Au+Au data at 1.23 AGeV incident beam energy collected with the HADES experiment are presented. At this energy all strange particles are produced below their free nucleon-nucleon threshold including the Λ and K_s^0 observed for the first time subthreshold. A special emphasis will be put on the analysis methods used to reconstruct these particles and to correct for acceptance and efficiency effects of the detector system. Finally the preliminary ratio of K_s^0 to Λ will be included into a statistical model fit.

2. Au+Au Data Sample

Au+Au data at 1.23 AGeV with a beam rate of $(1.2 - 1.5) \cdot 10^6$ ions/s was collected in April and May 2012 comprising in total 557 hours. In order to reduce the amount of data and select more central events a multiplicity trigger ($M > 20$ in the outer detector region selecting 0 – 40% most central collisions) was used, leading to an average data rate of 8 kHz and 200 MByte/s during the spills and a mean number of participating nucleons per reaction of $\langle A_{part} \rangle \approx 174$. In the selected data sample 7.3 billion events were recorded giving a total amount of 140×10^{12} bytes.

3. Particle Identification

The High Acceptance Di-Electron Spectrometer covers almost fully the azimuthal angle ϕ and largely the polar angle ($\theta = 18^\circ - 85^\circ$). With two planes of Multi-Wire Drift Chambers in front and two behind the superconducting toroidal magnet ILSE the tracks of charged particles can be reconstructed and their momenta determined. For this purpose a new algorithm for high track density environments has been developed. By additionally measuring the time of flight of the tracks with a Diamond-Start-Detector plus the two time-of-flight walls RPC and TOF (covering inner and outer polar angles) the particles can be identified. More details on the HADES detector can be found in [12].

4. V^0 Reconstruction of Λ and K_s^0

Λ and K_s^0 decay via the weak interaction which leads to relatively long life-times compared to strong decays. Both decay into two charged particles:

$$\Lambda \rightarrow \pi^- + p$$

$$K_s^0 \rightarrow \pi^- + \pi^+$$

These decay particles are then detected with HADES and from their reconstructed tracks the invariant mass can be calculated. Due to the fact that most of the pions and protons are produced thermally in the collision zone the obtained invariant mass spectra are mainly populated by uncorrelated pairs. Because of their long life-times the secondary decay vertex of Λ and K_s^0 can be separated from the primary collision vertex and therefore constraints on the decay topology can be set. The topology is shown in Fig. 2a exemplarily for the Λ decay. Applied conditions are: minimum distance of primary to secondary vertex (d_v), minimum distance of the daughter tracks to the primary vertex (d_2 , d_3), distance of closest approach for daughter tracks (d_t), distance of closest approach of mother track to primary vertex (d_1) and minimum opening angle of the daughter tracks ($\Delta\beta$).

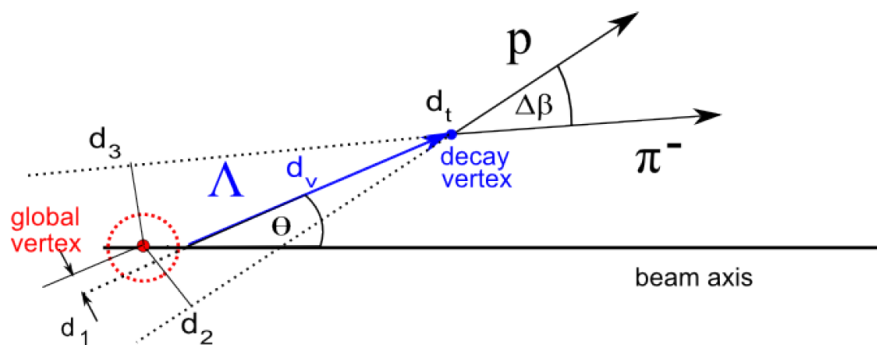


Figure 1: Topology of a Λ decay.

The background is estimated with the event-mixing technique. Here the invariant mass of the two decay particles is calculated under the condition that they come from different collisions. Hence the pairs are by definition uncorrelated and therefore their invariant mass spectrum reproduces the background of the same event spectrum. The events are mixed under the condition that they are close in centrality and have comparable detector performances as well as proximate reaction vertices.

The invariant mass spectra obtained after applying all topology cuts are shown in Fig. 2a and Fig. 2b. The corresponding cut values are listed in Table 1.

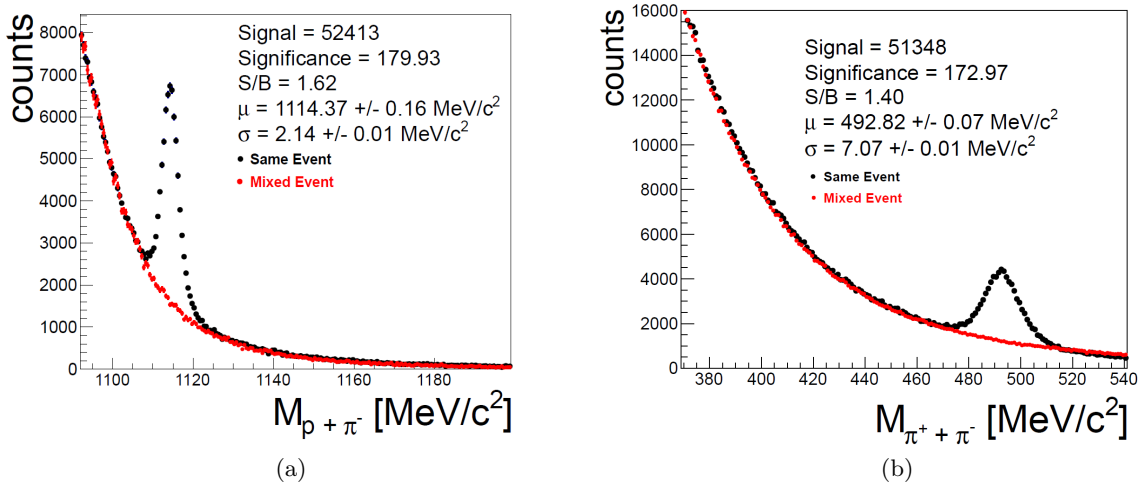


Figure 2: Invariant mass spectrum of negative pions plus (a) protons and (b) positive pions, respectively, coming from the same event (black) and different events (red). A highly significant peak is visible close to the expected mass for (a) Λ and (b) K_S^0 .

Cut		d_v [mm]	d_1 [mm]	d_2 [mm]	d_3 [mm]	d_t [mm]	$\Delta\beta$ [°]
Value	Λ	> 55	< 5	> 21	> 6	< 7	> 15
	K_S^0	> 20	< 10	> 8	> 8	< 10	> 15

Table 1: Values for the topological constraints chosen for the V^0 reconstruction

A clear peak emerging from the background close to the expected mass is visible showing a highly significant Λ and K_S^0 sample respectively. The significance is comparable to that obtained in Ar+KCl, the second largest collision system investigated with HADES [10]. The high statistics allow for a double differential analysis as a function of transverse mass and rapidity.

Furthermore, the reconstructed signal has to be corrected for the non-perfect acceptance and efficiency of the detector. For this purpose the strange hadrons are generated in a full Monte-Carlo simulation within the Pluto framework [13]. Then the simulated particles are subjected to a GEANT simulation [14] giving a realistic detector response of HADES. Finally they are propagated through the same analysis chain that was used for data leading to a correction factor for acceptance and efficiency effects. This factor is then applied on the reconstructed signal giving the yield of initially produced particles.

After correcting the yields as a function of transverse mass and rapidity the transverse mass spectra can be fitted with a Boltzmann function in order to extrapolate to the unmeasured phase space. By integrating each fit and plotting each yield as a function of the center of mass rapidity one obtains the corrected rapidity distribution. This distribution can be fitted with a gaussian

function and by integration the total multiplicity can be determined. For minimization of the systematic errors only the values at mid-rapidity are considered here.

Moreover, statistics are sufficient to do this analysis for different centrality classes.

5. Results and Discussion

Following this procedure a preliminary ratio for the yields of Λ and K_S^0 can be calculated:

$$\frac{N(K_S^0)}{N(\Lambda)} = 0.26 \pm 0.11.$$

The error of this ratio includes statistical and systematic uncertainties. At this point of our analysis this error is yet dominated by systematics.

As a tool to describe hadron yields measured in heavy-ion collisions statistical models have been quite successful in the past [15, 16]. Combined with further determined preliminary results on multiplicities in this collision system a simultaneous statistical hadronization fit can be applied using the volume V , temperature T and baryochemical potential μ_B of the system as free parameters. In order to account for strangeness suppression a (strangeness-)canonical ensemble is used where the strangeness quantum number needs to be conserved exactly within a subvolume V_c with radius R_c . The freely available statistical model THERMUS [17] was used to simultaneously fit the K_S^0/Λ ratio together with π^-/p , K^-/K^+ and the ϕ/K^- , where all values were taken at mid-rapidity. Details for the fitting procedure and constraints on the parameters are described in [18]. The fit of the statistical model to the data points is shown in Fig. 3a. From this we find the baryochemical potential and the temperature to be $\mu_B = 799 \pm 34$ MeV and $T_{chem} = (47 \pm 5)$ MeV respectively. The ratio of the radius of the subvolume to the radius of the overall volume of the system is determined to be $R_C/R = 0.3 \pm 0.2$ whereas the $\chi^2/d.o.f.$ of the fit is equal to 1.2. In Fig. 3b the corresponding point of freeze-out in the $T - \mu_B$ plane is plotted showing a good agreement with systematics of other experiments [10, 15, 19].

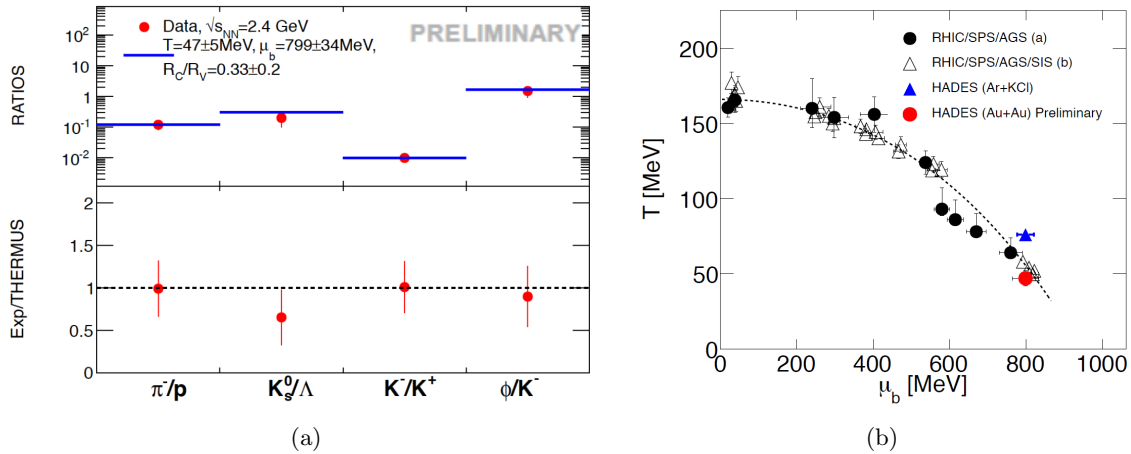


Figure 3: (a) Comparison between data and statistical model for ratios of particle yields at mid-rapidity together with the parameter values obtained from the statistical model fit. (b) Corresponding freeze-out point in the $T - \mu_B$ plane together with a collection of points from other experiments [10, 15, 19].

6. Conclusion

In summary, preliminary results on the production of the uncharged strange hadrons Λ and K_S^0 in the Au+Au collision system at incident beam energy of 1.23 AGeV with HADES have been presented. The particles have been reconstructed via the topology of their charged decay products. The corrected transverse mass spectra have been determined in order to calculate the total production yield. The preliminary ratio of the yields at mid-rapidity $K_S^0/\Lambda = 0.26 \pm 0.11$ – together with further hadron ratios – was compared to a statistical model resulting in an overall good agreement.

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