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K^0 production in pp and pNb reactions

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The kaon nucleus (KN) interaction in nuclear matter is predicted to be repulsive and dependent from the density. However, values for this potential extracted by comparing the K^0_S/K^+ measurements for different reactions with transport models are not yet consistent with each other. We analyze K^0_S mesons identified with the HADES detector in p+p and p+^{93}Nb collisions at 3.5 GeV kinetic beam energy. To determine the KN potential at normal nuclear density we propose to compare the K^0_S differential distributions in p+^{93}Nb and p+p collisions. The high statistics collected for low p_t-kaons ($p_t < 100$ MeV/c) ensure the sensitivity of our measurements to nuclear matter effects. We present the data analysis method and first results on the transverse momentum, angular and rapidity density distributions in comparison to simulations.

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1. Introduction

The modification of kaon properties in nuclear medium is a subject of permanent interest in related theoretical and experimental research [1]. In particular it is important to extract the in-medium KN potential as a function of density, which can be studied at normal nuclear density employing γ, π or proton induced reactions [2]. Theory predicts a slightly repulsive potential, which can be observed in yields and kinematical distributions. One may conclude from theoretical model predictions that momentum distributions, in particular in the low momentum region, are sensitive to the influence of the KN potential. Moreover, it is favorable to analyze neutral kaons as they are not distorted by the Coulomb interaction.

In different experiments this aspect has been studied at normal nuclear densities with pion and proton induced reactions and at higher densities by means of heavy ion collisions. The results are not consistent: the data obtained in pion/proton induced reactions are best described by models employing $U_{KN}(\rho_0) \approx +20$ MeV [3, 4], whereas heavy ion collisions are reproduced with $U_{KN}(\rho_0) \approx +40$ MeV [5].

This discrepancy motivates us to remeasure the K^0's in cold nuclear matter with the HADES setup [6]. The advantage of our experiment is a high acceptance for low p_t-kaons (fig. 1). Around $4 \cdot 10^9$ events were collected for the p+^{93}Nb and $1.2 \cdot 10^9$ for the p+p reaction, both at a kinetic beam energy of 3.5 GeV. As no effect from the finite nuclear density is expected in the p+p system, a direct indication for the KN potential can be deduced from the ratio $\sigma(pNb)/\sigma(pp)$ in the momentum distribution. The quantitative strength can then be extracted by a comparison to theoretical models. Due to a larger data sample than reported in [5], the uncertainty of our measurement is expected to be smaller.

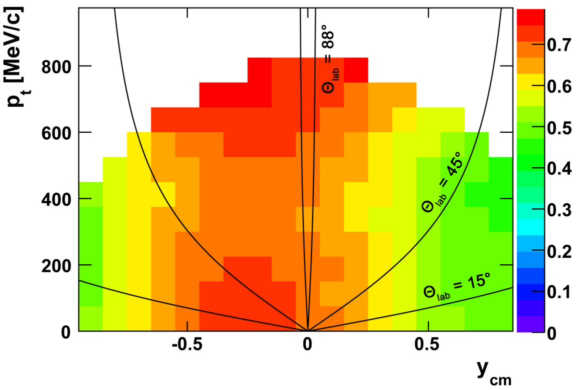

Figure 1: Acceptance for the K^0_S production in p+p at $E_{kin} = 3.5$ GeV.

2. The HADES experiment

The **H**igh-**A**cceptance **D**i-**E**lectron **S**pectrometer (HADES) is a versatile experiment operating at the SIS18 heavy ion synchrotron at the GSI Helmholtzzentrum in Darmstadt, Germany. It is originally constructed for measurements of dileptons with pion, proton and heavy ion beams of

1-3 AGeV kinetic beam energy. However, the spectrometer is also suited for hadron physics. The most important components for this study are the MDCs (multi wire drift chambers) - two planes in front of the superconducting magnet (toroidal field) and two planes behind for charged particle tracking - and the Time-Of-Flight wall for the trigger settings. In the present experiment the first level trigger (LVL1) condition required three hits in the Time-Of-Flight wall to reduce contributions from the p+p elastic scattering. For more details see [6].

3. The K_S^0 analysis

Similar analyses were carried out for both data sets. The K_S^0 was reconstructed exploiting its decay into π^+ and π^- pairs (BR = 69.20 %), which were identified via graphical cuts on the energy loss versus momentum distribution. The contribution of $\bar{K}^0$ can be neglected, as the $\bar{K}^0/K^0$ ratio in both data samples is less than 4% (estimated from HSD [7] simulations).

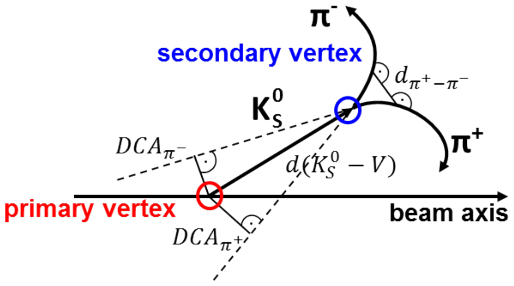

Figure 2: K_S^0 decay scheme with the applied secondary vertex cuts.

To increase the signal-to-background ratio (S/B), following secondary vertex cuts were applied (fig. 2): (1) distance between the two pion tracks ($d_{\pi^+-\pi^-} < 7$ mm), (2) distance between the primary reaction vertex and the secondary decay vertex ($d(K_S^0 - V) > 25$ mm), (3) distance of closest approach to the primary vertex for the two pion tracks ($\mathrm{DCA}_{\pi^+} > 7$ mm, $\mathrm{DCA}_{\pi^-} > 7$ mm). These cuts were optimized to maximize the ratio S^2/B. The resulting $\pi^+\pi^-$ invariant mass spectra for the p+p and p+^{93}Nb colliding systems are shown in figure 3. Both spectra are described by a fit of the signal (two Gaussians[1]) and the combinatorial background (Landau function and polynoms). High statistics allow differential analysis of the yield in rapidity ($\Delta y = 0.1$) and transverse momentum ($\Delta p_t = 75$ MeV/c).

For acceptance and efficiency corrections of the p+p reaction the Pluto [8] event generator was used to simulate 14 K^0 production channels. All of them were simulated with an isotropic angular distribution except for the reaction $p + p \rightarrow \Sigma^+ + p + K^0$. Here an angular anisotropic production was introduced as obtained from an exclusive study of this channel at $p_{beam} = 3059$ MeV/c [9]. Each channel was then weighted with its corresponding cross section and processed through the full analysis chain. The cross sections from the Landolt-Börnstein database were recalculated with updated experimental cross sections using a phase space fit from [10]. Three of the channels

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[1] Two Gaussians are needed to take multiple scattering effects into account.

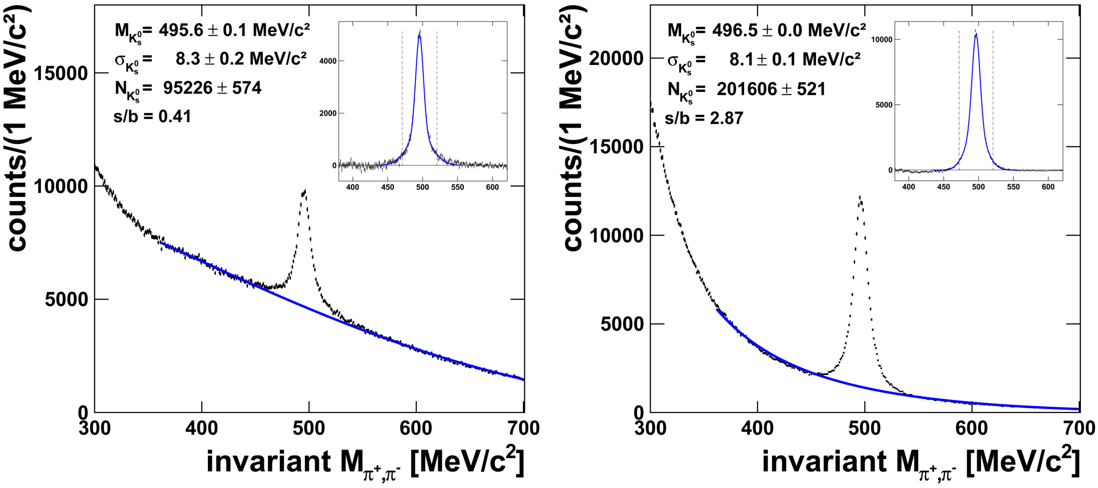

Figure 3: Invariant mass π^+ π^- for p+p (left) and p+^{93}Nb (right).

Reaction	$\sigma[\mu b]$
$p+p \rightarrow \Sigma^+ + p + K^0$	21.3
$p+p \rightarrow \Lambda + p + \pi^+ + K^0$	18.4
$p+p \rightarrow \Sigma^0 + p + \pi^+ + K^0$	12.4

Table 1: Three K^0 production channels with highest cross sections used as simulation input.

with the highest contributions are listed in table 1. In case of the p+^{93}Nb reaction UrQMD [11] simulations were used to correct the experimental data.

4. Preliminary results

Transverse momentum distributions at 13 raipdity bins ($\Delta y = 0.1$) obtained by the Pluto [8] event generator were compared to acceptance and efficiency corrected experimental data from p+p collisions. The spectra were normalized using a single scaling factor obtained at mid-rapidity. The particular p_t-spectrum at mid-rapidity is shown in figure 4. Overall an agreement within 10% deviation was observed. Moreover, the rapidity density distributions of experimental and simulated data were compared (fig. 4). To extract the yields, the measured points in the p_t-spectra were summed up in the region where measurements are available. A Boltzmann function was fitted to the tail of the p_t-spectra to extrapolate the yield to the not measured region. The experimental distribution is symmetric with respect to mid-rapidity, but favors a more anisotropic K^0 production in comparison to simulation.

In addition a double differential analysis in p_{cm} and $cos\Theta_{cm}$ of the p+p data was performed to study the angular distribution of the inclusive K^0 production. The integrated spectrum (0 MeV/c < p_{cm} < 800 MeV/c) is shown in figure 5 and it was fitted with a Legendre polynomial function (Eq. 4.1). The resulting ratio of the coefficients a_2/a_0 is found to be 0.270 ± 0.016 (stat.). This ratio is a measure for the anisotropy in the production.

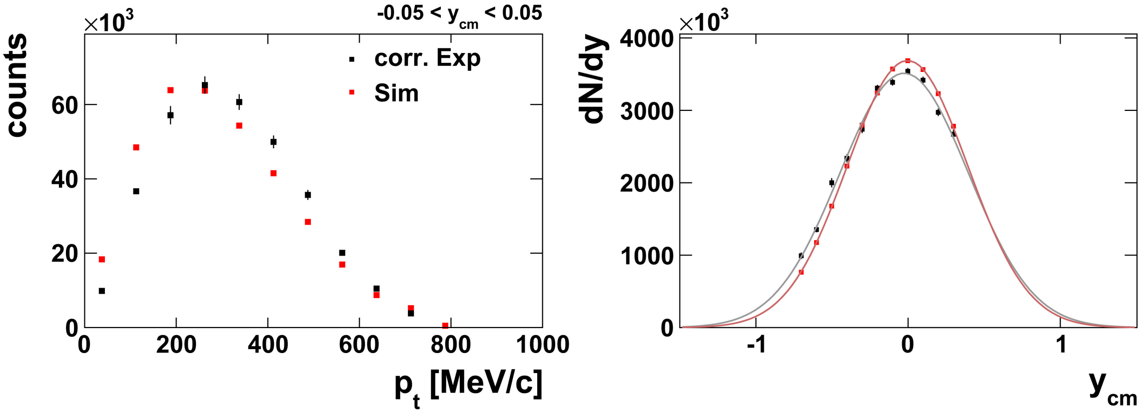

Figure 4: p+p: Corrected p_t distribution at mid-rapidity in comparison to simulated data (left). Comparison of the K^0_S rapidity density distribution of corrected experimental data and simulated data fitted with a Gaussian (μ_{exp} = -0.03 ± 0.01) (right).

$$\frac{dN}{dcos\Theta_{cm}} = a_0 + a_1 \cdot cos\Theta_{cm} + a_2 \cdot \frac{1}{2}(3cos\Theta^2_{cm} - 1). \tag{4.1}$$

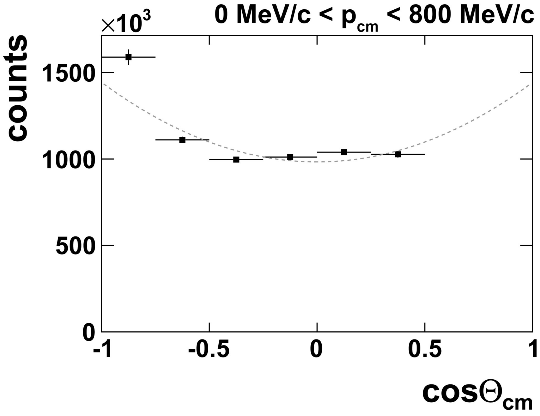

Figure 5: p+p: K^0 angular distribution integrated from p_{cm} = 0 MeV/c to p_{cm} = 800 MeV/c and fitted with a Legendre polynomial function (a_2/a_0 = 0.270 ± 0.016 (stat.)).

Furthermore the p_t distributions from p+^{93}Nb collisions have been studied and checked against the transport models HSD [7] and GiBUU [12] - both simulated with zero KN potential. Again a single scaling factor was used to normalize the spectra of 13 rapidity bins. From figure 6 a rather good agreement with HSD at the nucleon nucleon mid-rapidity can be seen, while GiBUU shows an overshoot in the low transverse momentum region.

A comparison of the rapidity density distributions was carried out to both models as well (fig. 6). In contrast to the p+p case a shift of the distribution towards backward rapidities was observed for the experimental data. This shift is expected, as the colliding system is not symmetric. One can see, that HSD shows a rather symmetric distribution with respect to the nucleon nucleon mid-rapidty, whereas GiBUU follows the trend of the experimental data. From deeper studies of the GiBUU model it is known, that the observed shift of the dN/dy distribution is mainly caused by scattering, whereas in the transverse momentum distributions scattering plays a minor role.

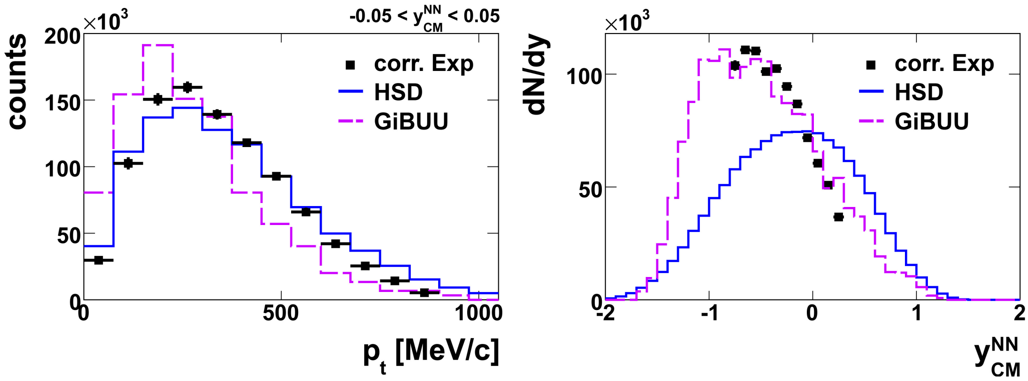

Figure 6: p+^{93}Nb: Corrected K^0_S p_t distribution at nucleon nucleon mid-rapidity (left) and rapidity density distribution (right) in comparison to transport models HSD [7] and GiBUU [12].

5. Summary and outlook

We have reported on the ongoing analysis of the K^0 production in p+p and p+^{93}Nb reactions at 3.5 GeV kinetic beam energy measured with the HADES setup. Corrected p_t distributions were shown for both data samples as well as corrected rapidity density distributions. The comparisons of the p+p data to the Pluto [8] simulation are in rather good agreement showing, that the experimental data favors a stronger anisotropic production. To understand furthermore the K^0 production in p+p, we plan to study the channel $p+p \rightarrow \Sigma^+ + p + K^0$ exclusively, as it has the highest contribution to the inclusive K^0 sample. That way we can also determine the angular anisotropy of this reaction at our beam energy. As presented the transport models HSD [7] and GiBUU [12] are not describing the p+^{93}Nb data satisfactorily as they are not yet tuned. This has to be done on the p+p data first to obtain reliable results for p+^{93}Nb. Finally the goal will be to determine absolutely normalized yields and the in-medium KN potential from the ratio $\sigma(pNb)/\sigma(pp)$ as well as by a comparison to the tuned transport models with KN potential switched on.

6. Acknowledgement

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