STRANGENESS PRODUCTION USING A π^- BEAM AT 1.15 GeV/c WITH FOPI*

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Pion-induced reactions were studied with the FOPI detector at an incident momentum of 1.15 GeV/c. Data were taken for five different targets: C, Al, Cu, Sn and Pb. A preliminary comparison of the phase-space distribution of the reconstructed $K^0_{\rm S}$ to the results of the IQMD transport-model calculations, as well as the preliminary study of the scaling behavior of the inclusive $\pi^- A \rightarrow K^0 X$ cross–section as a function of the mass of the target nucleus is reported. A preliminary estimate of the elementary $\pi^- p \rightarrow K^0 Y$ cross section in the presence of the surrounding nuclear medium is discussed.

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1. Introduction

Kaon condensation in dense nuclear matter was for the first time predicted by Nelson and Kaplan [1], who initiated a new direction in nuclear physics. Afterwards, kaon condensation was investigated in order to study the evolution of neutron stars [2]. According to recent model calculations based on chiral perturbation theory [3] or coupled channel dynamics [4], anti-kaons feel a strongly attractive force in the nuclear medium, whereas the in-medium kaon-nucleon potential is expected to be slightly repulsive [5].

Kaon production in heavy-ion reactions at intermediate energies (1–2 AGeV) is related to their properties (mass shift and modifications of KN interactions) in a dense nuclear medium. At SIS energies, kaons and anti-kaons are produced in various elementary processes. One of the important channels, of which the cross section in the nuclear medium is poorly

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known, is $\pi^- N \rightarrow K\, Y$. The relevant cross sections were calculated theoretically, by Tsushima *et al.* [6] in free space ($\rho = 0$), at the normal nuclear matter density ($\rho = \rho_0$) and at twice the normal nuclear matter density ($\rho = 2\rho_0$). The parameters of the calculation have been adjusted to the measured values in free space resulting in a definite prediction for the case of nuclear matter.

In August 2004, for the first time, a π^- beam was delivered to the site of the FOPI detector [7] at the GSI facility. The aim of the experiment was to study the reaction $\pi^- A \rightarrow Y K^0$ in order to extract the exclusive cross section of the elementary process $\pi^- p \rightarrow \Lambda K^0$ inside the nucleus and to compare it to theoretical predictions.

During 15 days of the beamtime, altogether about 40 million events were collected for five targets: Carbon, Aluminum, Copper, Tin and Lead. The momentum of the beam particles was 1.15 GeV/c with about 1% momentum spread. The beam intensity was about $10^4\ \pi^-/s$.

2. Results

2.1. The $K^0_{\rm S}$ invariant mass spectrum

The angular distribution of the elementary reaction $\pi^- p \rightarrow \Lambda K^0$ is non-isotropic [6]. This means that the K^0 and the Λ populate different regions of the phase space. Here, we focus only on the $K^0_{\rm S}$. With the FOPI detector, we can only reconstruct the $K^0_{\rm S}$ which decays into ($\pi^-\pi^+$) pairs with a branching ratio of 68 % (the $K^0_{\rm L}$ cannot be detected in FOPI due to its decay properties). Only the decay products of the $K^0_{\rm S}$ in the CDC acceptance are considered in the present work, *i.e.* pions emitted within a polar angular range between 33° and 130° with respect to the beam axis. Pions in the CDC are identified by the curvature of their tracks and their energy loss. Only tracks with at least 20 hits and a transverse momentum larger than 80 MeV/c have been selected. In addition we select pions with a transverse distance to the primary vertex between 0 cm and 10 cm, and a longitudinal distance to the primary vertex between −50 cm and +50 cm.

The resulting invariant mass spectrum of the reconstructed $K^0_{\rm S}$ candidates is shown with a solid line in the upper plot of Fig. 1. The dashed line represents the background evaluated by the event-mixing method. In the lower panel, the background-subtracted invariant mass spectrum is presented. The integral of the peak corresponding to $K^0_{\rm S}$ mesons amounts to about 17400 reconstructed particles. The width of the peak is about 21.5 MeV/c^2.

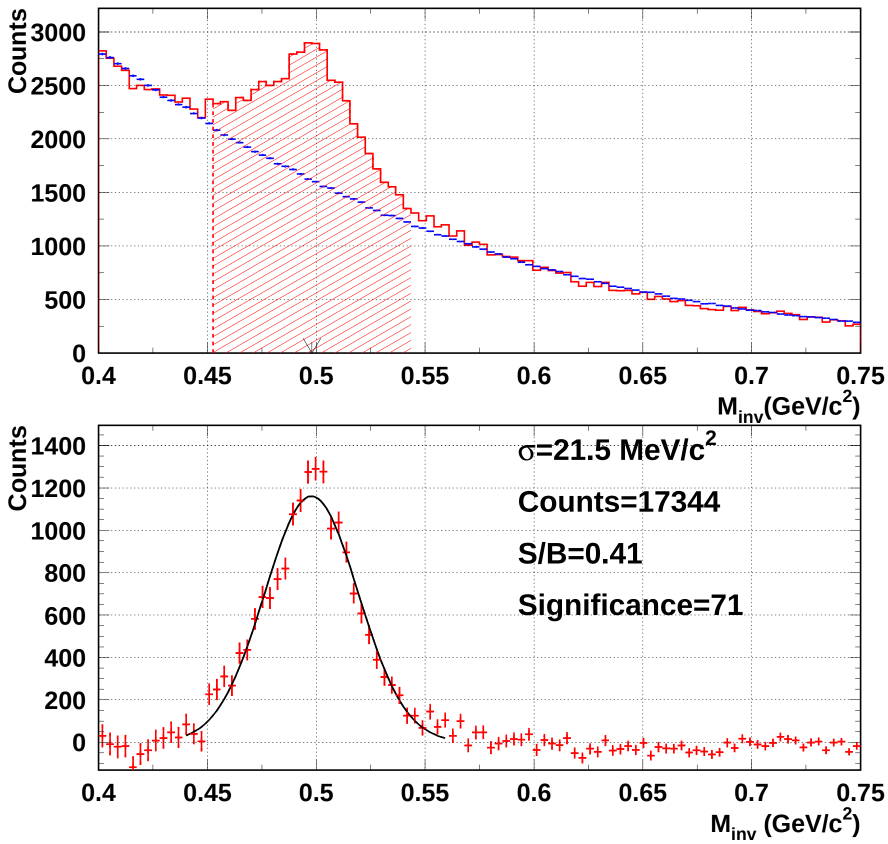

Fig. 1. The invariant mass spectrum of the K^0_S mesons for the Pb target. Upper plot: Invariant mass spectrum of $\pi^-\pi^+$ pairs (solid line) and mixed-events background (dashed line). Lower plot: Background-subtracted spectrum.

2.2. Phase-space distribution of the K^0

The goal of this experiment was to determine the exclusive cross section of the reaction $\pi^- p \rightarrow \Lambda K^0$ in the nuclear medium. A first step is to determine the K^0 inclusive reaction cross section in nuclear matter. In order to extrapolate the measured (acceptance and detection efficiency biased) yield to the primary 4π yield, the detector efficiency has to be considered. The estimation of the acceptance-bias is model dependent. In order to gain some confidence in it, it is hence mandatory to compare the measured phase-space distribution inside the acceptance to the distribution resulting from the model which was used for deducing the acceptance corrections. The

IQMD transport model, which was used in the case of this work [8], adopts the nucleon–nucleon and the π^--nucleon free cross sections and, to certain extend, takes into account the mass modifications of hadrons in the nuclear medium via potentials. It also includes the rescattering of strange particles inside the nuclear medium. IQMD events (π^- on carbon and on lead at 1.15GeV/c momentum) were filtered through the GEANT–FOPI environment apropriate for the π^- beam experiment (*i.e.* taking into account the spot of the π^- beam, the dimensions and the material of the targets). In this way, the response of the simulated detector was evaluated. In Fig. 2, the measured K^0_{S} rapidity distribution in comparison to IQMD model calculations [8] is shown. In general, within the statistical errors the experimental- and model-distributions agree. This satisfactory agreement justifies the usage of the IQMD model for estimation of the detector efficiency. The total efficiency is given by the ratio of the reconstructed K^0 mesons to the number of initially generated ones. In the case of the carbon and lead targets the total K^0 reconstruction efficiency was found to be about 9%.

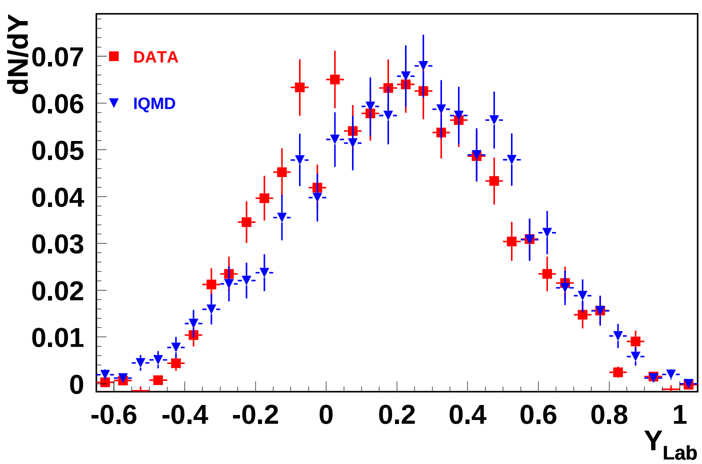

Fig. 2. The phase space distribution of the K^0_{S} from the lead target, the square points are from data, triangle points are from IQMD calculations.

2.3. K^0 inclusive cross section

In order to study the scaling behavior of the $\pi^- A \;\rightarrow\; K^0 X$ reaction cross section as a function of the mass of the target nucleus, five different targets were used. Two possibilities were considered in order to compare the elementary $\pi^- p \rightarrow\; K^0 X$ reaction cross section deduced from the reactions

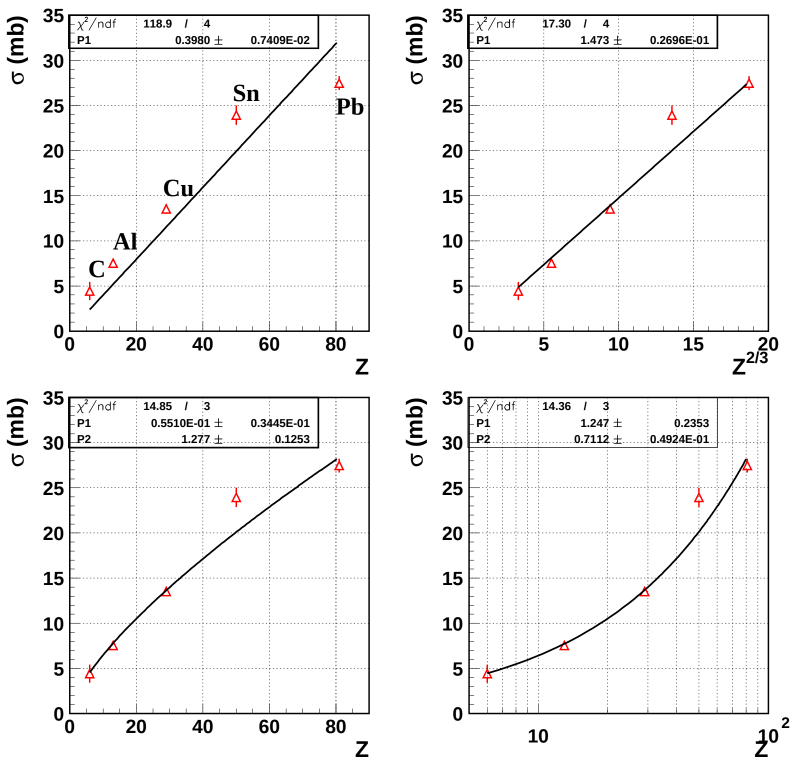

Fig. 3. Comparison of different K^0 inclusive cross section scaling methods.

on different target nuclei. Depending on how far the pions can penetrate the nucleus before undergoing a reaction, the total $\pi^- A \rightarrow K^0 X$ cross section can scale *(i)* volume-like, *i.e.* as a function of the number of protons in the target nucleus, or *(ii)* surface-like, or *(iii)* according to a combination of the surface and the volume. In addition, one can try to parametrize the cross section according to a power law. Fig. 3 shows how these different hypotheses were tested. In the upper left plot, the inclusive production cross section of K^0 is plotted as a function of the number of protons Z of the target nucleus. The data points were fitted with a linear function $\sigma = a\,Z$. The error bars of the cross sections are statistical only. One can see that the straight line does not fit the data, which is confirmed by the quality of the fit, *i.e.*, the χ^2. The inclusive cross section apparently does not scale volume-like, which means that most of the pions probably do not reach the inner part of the nucleus. In the upper right plot, the inclusive production cross section of K^0 is plotted as function of $Z^{2/3}$, which is proportional to the number of protons at the surface of the nucleus. It is rather obvious that this function fits the data better. Another possibility is to combine the surface and volume terms. In the lower right plot, the data points were fitted with the function $\sigma = a\,Z + b\ \ Z^{2/3}$. From the parameters of the fit one can see that the surface contribution dominates over that of the volume. Finally, the power law scaling $\sigma = a\,Z^b$ can be tested (see the lower right plot in Fig. 3). In this case, the data points are aligned very well around the fitted function, which gives an independent confirmation for the scaling of the inclusive cross section. The fact that the fit parameter b is about 0.71, suggests that the K^0 inclusive production cross section does not scale exactly as a surface, but comes very close to it.

Taking into account these results, it can be concluded at this point that the effective inclusive K^0-meson production cross section per charge unit is dominated by the surface. This result was expected, since the mean free path of a π^- meson with momentum of about 1.15 GeV/c in the nuclear matter at the normal density is about 0.98 fm [9]. Furthermore, from the parameters of the fit, one can deduce that the cross section of the elementary process, $\pi^- p \ \rightarrow\ K^0\,Y$, in the presence of the surrounding nuclear medium amounts effectively to about 1.25 ± 0.24 mb (see the lower right plot in Fig. 3). The volume contribution to the reaction cross section cannot be fully excluded, since the probability that π^- reach the inner part of the nucleus is obviously not zero. By comparing the fit parameters corresponding to the combined surface– and volume–terms (*i.e.* $a\ \ \ Z + b\ \ \ Z^{2/3}$) to the fit parameters of the power law (*i.e.* $a\,Z^b$), one can deduce that the difference in the reaction cross section is about 0.03 mb. The relative contribution of the volume-like scaling to the reaction cross section is about 4 %.

3. Summary

The inclusive K^0 production cross section of the elementary reaction, $\pi^- p \rightarrow K^0 X$, in the presence of the surrounding nuclear medium, has been extracted from the measurement of the K^0_{S} production in the reactions of 1.15 GeV/c momentum π^--mesons on nuclear targets. The cross section was found to be dominated by the contribution of the nuclear surface and to amount effectively to about 1.25 ± 0.24 mb. The phase space distribution of the K^0_{S} was found to be in good agreement with the predictions of the IQMD model.

The next step in the analysis will be to further disentangle various exclusive channels and to compare them to model predictions. $\Lambda\,K^0$ correlations could also give further insights into the strangeness production mechanism.

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