K^+-meson Production in Subthreshold pA Collisions with ANKE [1]

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Abstract. The production of K^+-mesons in proton-nucleus interactions at projectile energies far below and above the free nucleon-nucleon-threshold of 1.58 GeV has been investigated using the ANKE spectrometer at COSY-Jülich. Double differential cross sections of K^+ production have been obtained for diamond, copper and gold strip targets and beam energies $T_p = 1.0...2.3$ GeV. At $T_p = 1.0$ GeV the complete momentum spectrum of kaons emitted at forward angles ($\theta \leq 12°$) has been measured. The analysis of the target-mass dependence of the cross sections does not allow unambiguous conclusions about the underlying reaction mechanisms. Therefore, further measurements at forward emission angles, in particular of coincident K^+p and K^+d pairs, are needed.

A central topic of hadron physics is the influence of the nuclear medium on elementary processes. The investigation of positively charged K^+-meson production is particularly well suited since this meson is relatively heavy so that its production requires strong medium effects. Due to strangeness conservation, kaons with relatively low momenta which are considered in this work, are not absorbed in nuclear matter after their creation and can carry away the information about the production mechanism. Also quasi-elastic scattering of K^+-mesons in nuclei is substantially suppressed leading to a large mean free path of $\lambda_{K^+} \sim 5$ fm. In this context the production of K^+-mesons in proton-nucleus interactions at projectile energies far below and above the free nucleon-nucleon-threshold of 1.58 GeV has been investigated using the large acceptance ANKE spectrometer [1] at an internal target position of the accelerator COSY-Jülich [2].

The spectrometer, including its detectors and the data-acquisition system (DAQ), is optimized to study K^+ spectra at different beam energies. The main experimental challenge is that at low energies the background (of mostly pions and protons) is approximately factor of 10^6 more intense than the signal (kaons). The detection system of ANKE allows to suppress this huge background and to detect rare K^+-mesons in the momentum range $p \approx 200...500$ MeV/c. Combining hardware and software criteria such as time-of-flight, information from the wire chambers and delayed signals from the K^+-decay gives us a unique possibility to identify kaons. The detectors and corresponding data-analysis procedures for K^+ identification are described in detail in [3].

The measured double differential cross sections for K^+ production in pC interactions

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[2] For a complete collaboration list see: `http://www.fz-juelich.de/ikp/anke`

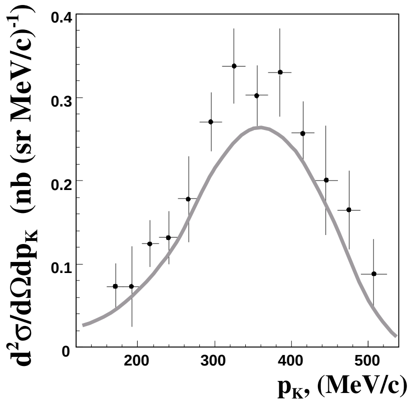

FIGURE 1. Double differential K^+-production cross section for the $p(1.0GeV)^{12}C \to K^+X$ reaction as a function of the K^+ momentum. The solid line is the result of a calculation within the folding model assuming the two-step production mechanism (*E.Ya.Paryev, private communication*).

at the lowest beam energy are shown in Fig. 1. This is the first complete coverage of the momentum spectrum at deep subthreshold energies. The cross sections were calculated by a normalization to known pion-production cross sections measured in similar kinematical conditions [5, 6].

In addition to the direct production on a single target nucleon the K^+-mesons can also be produced in two-step processes with intermediate pion production, i.e a $pN_1 \to \pi X$ reaction, followed by $\pi N_2 \to K^+X$ on a second target nucleon. Depending on the beam energy, K^+-production may be due to both the direct and two-step reaction mechanisms. At low beam energies the two-step process is energetically favorable since the intrinsic nucleon motion can be utilized twice. Based on folding calculation of two-step kaon production a reasonable description of the measured cross section was obtained (see Fig. 1).

The analysis of the target-mass dependence aims to deduce the exponent α by fitting the cross sections measured with different target nuclei with an A^α dependence. We have analyzed available data on K^+-production in pA collisions at beam energies $T_p \leq$ 2.9 GeV [7]. One expects that the K^+-production cross section is proportional to $\simeq A^{0.7}$ if the kaons are dominantly produced via the direct production mechanism. Since two nucleons are needed for the two-step kaon production, a stronger A dependence for two-step production as compared with direct kaon production is expected.

Total K^+-production cross sections σ_{tot} in proton-nucleus collisions at $T_p \leq 1.0$ GeV for *Be*, *C*, *Cu*, *Sn* and *Pb* as target nuclei have been measured by Koptev et al. [8] at the Petersburg Nuclear Physics Institute (PNPI). The data can well be described by a constant value $\alpha = 1.04 \pm 0.01$ independent of the beam energy T_p. The strong A dependence of the total K^+-production cross section has been interpreted [8, 9, 10] as an indication for the dominance of non-direct K^+-meson production in pA collisions at energies far below the free nucleon-nucleon threshold.

Kaon production induced by 2.1 GeV protons (i.e. above the free NN threshold) on NaF and Pb targets has been studied by Schnetzer et al. [11] at the Lawrence Berkley Laboratory (LBL). The mass dependence is rather weak ($\alpha = 0.56 \pm 0.05$) for $\theta_K = 15°$,

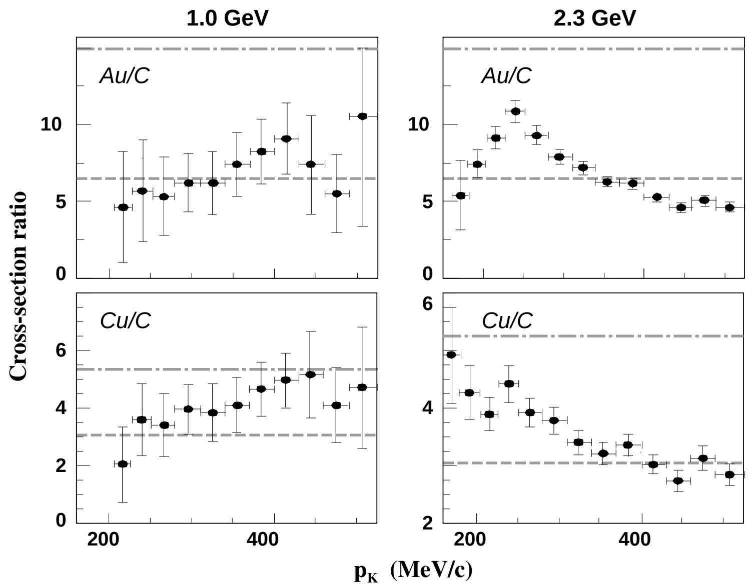

FIGURE 2. Ratios of the K^+-production cross sections for Cu/C (lower figures) and Au/C (upper figures) as a function of the kaon momentum. The left-hand figures correspond to the proton beam energy of 1.0 GeV, right-hand figures to $T_p = 2.3$ GeV. The lines illustrate the ratios if the cross sections scale like $A^{2/3}$ (dashed lines) and A^1 (dashed-dotted lines).

and increases to larger angles ($\alpha = 0.88 \pm 0.08$ for $\theta_K = 80°$). This might be explained by the fact that the contribution of the two-step mechanism becomes stronger with increasing production angle. The data measured by other groups [12, 13] in the beam energy range 1.2...1.5 GeV give a value of the exponent, which is very close to the expected $\alpha \approx 0.7$ indicating the dominance of one-step kaon production.

Fig. 2 shows the target-mass dependence of the K^+ lab-momentum evaluated from the ANKE data for two different energies. At the highest investigated energy of 2.3 GeV the average cross-section ratios are in a good agreement with an $A^{0.7}$ dependence. One observes a strong momentum dependence, possibly resulting from rescattering of the produced kaons in the nuclear environment.

A fit to the lowest beam energy data with a constant value gives $\alpha = 0.74 \pm 0.05$. A comparison with the values for α obtained from the total cross sections at the same beam energy [8] shows that the ANKE data have a much softer A dependence. The only difference between the PNPI and the ANKE measurements is that at ANKE the K^+-mesons were detected inside the forward cone $0° \leq \theta_K \leq 12°$, whereas at PNPI angular-integrated spectra were obtained. Therefore, the very soft A dependence may be attributed to some special features of K^+-production at forward angles. It can be speculated that at 1.0 GeV, α increases with increasing K^+-emission angle similar to the behavior that has been deduced from the LBL data. It could also be that two-step production combined with rescattering effects of the produced kaons may result in a weaker A dependence.

The analysis of the cross sections as well as their target-mass dependence does not yet allow an unambiguous conclusion about the underlying reaction mechanisms. Therefore,

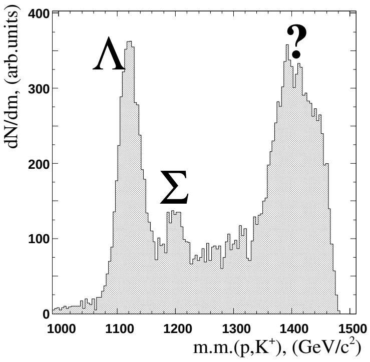

FIGURE 3. K^+p missing mass spectrum for the reaction $p(2.65GeV)p \to pK^+Y$.

it was proposed to investigate the production K^+ mesons correlated with protons and deuterons from one-step or two-step production mechanisms. The K^+d final state can only be observed in case of the two-step reaction, while K^+p pairs come both from the two-step and direct production mechanisms. In the latter case an analysis of more than two correlated particles will provide a recognition of the πN or pN channels [14].

The possibility of such a correlation experiment was tested during the last ANKE beam-time devoted to a_0^+ production in pp collisions at $T_p = 2.65$ GeV [15]. The missing mass spectrum of the K^+p final state is shown in Fig. 3. One can clearly see two peaks close to the Λ and Σ^+ masses. In addition, the broad peak on the right-hand side of the distribution can be attributed to the production of higher resonances like $\Sigma(1380)$ and $\Lambda(1405)$ [16]. Additional measurements at lower energy (1.2 GeV) should give us an answer whether we can directly measure the contributions of different mechanisms.

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