First Results on the Subthreshold K$^+$ Meson Production at ANKE*

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The magnetic spectrometer ANKE (Fig.1) has been installed in the COSY–ring in May 1998. One primary goal was to investigate K$^+$-meson production in proton-nucleus interactions close to and far below the free nucleon–nucleon threshold at 1.58 GeV.

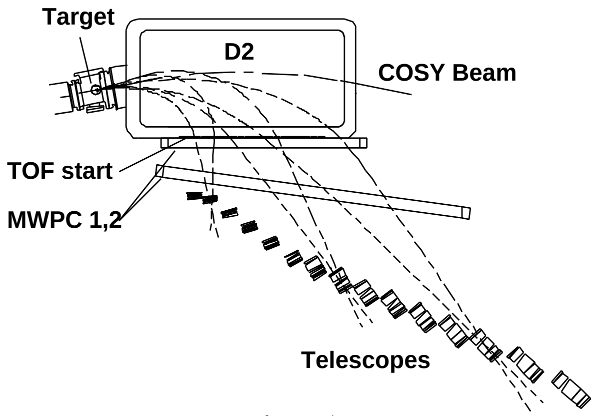

Figure 1: Top view of the ANKE spectrometer.

Measurements of inclusive kaon momentum spectra in the forward direction for C, Cu, Au targets have been performed in a proton energy range 1.0÷2.3 GeV. Ejectiles, leaving the strip target with angles $-12° < \Theta < +12°$ and momenta in the range 110÷525 MeV/c are bent by the dipole D2 to the detection system comprising 23 start counters (TOF start), multiwire proportional chambers (MWPC 1 and 2) and 15 range telescopes along the focal surface of D2(Fig.2). K$^+$-mesons were selected from a

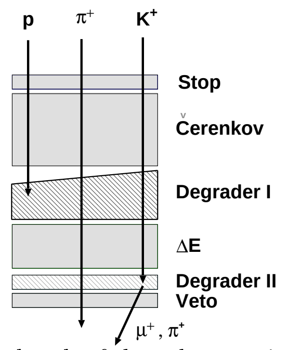

Figure 2: The sketch of the telescope in K$^+$ detection system.

huge background of mostly pions and protons by using time-of-flight and energy-loss criteria in start and stop counters, a reconstruction of the trajectories of ejectiles, by exploiting the range differences of the particles hitting individual telescopes and by detecting delayed muons or pions from the decaying kaons stopped in front of the veto counters.

The detailed description of ANKE–spectrometer and of the K$^+$–identification can be found in refs. [1, 2]. The complete analysis of all the data is still in progress. Here we present first results of the cross-section ratios for different targets and the values of the absolute cross sections obtained at the lowest proton energy of 1.0 GeV.

The double differential cross sections for K$^+$ production in pC collisions with momentum p_{K} were obtained from the number of kaons $N_{\mathrm{C}}^{\mathrm{K}}$ identified in each telescope (i) relative to the number of pions detected by the stop counters N_C^π of the corresponding telescope. The ratio of counts was corrected by the detection efficiencies ϵ and normalized to the corresponding proton beam fluxes M_c^π and M_c^K and to the cross sections of π^+–meson production in pC interactions in forward direction at 1.0 GeV known from the literature [3, 4, 5]. Thus, the cross section is given by:

$$\frac{d^2\sigma_C^K}{d\Omega dp} = \frac{d^2\sigma_C^\pi}{d\Omega dp}\frac{(N_C^K)_{tel(i)}}{(N_C^\pi)_{So(i)}}\frac{M_C^\pi}{M_C^K}\frac{1}{\epsilon}$$

$$\epsilon = \frac{\epsilon^K_{tel(i)}\cdot\epsilon^K_{det(i)}\cdot\epsilon^K_{MWPC(i)}\cdot\epsilon^K_{decay}}{\epsilon^\pi_{det(i)}\cdot\epsilon^\pi_{MWPC(i)}\cdot\epsilon^\pi_{decay}}$$

where $\epsilon^K_{tel(i)}$ is the intrinsic efficiency of the telescope (i) (corresponding to a certain momentum range), which takes into account the geometry and the detection probability of the decay muons and pions delayed by at least 2.5 ns in the veto counter with respect to the signals from the stopped kaons. $\epsilon^K_{det(i)}$ is the efficiency with which the kaons reaching the detectors are observed.

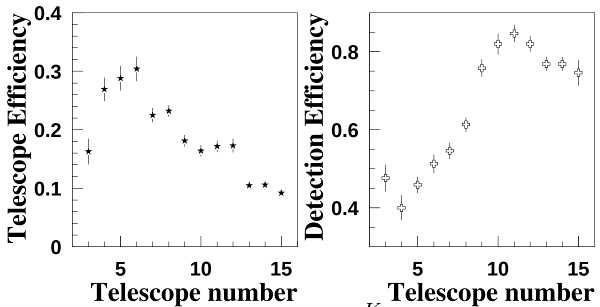

Figure 3: Telescope efficiency $\epsilon^K_{tel(i)}$ and kaon detection efficiency $\epsilon^K_{det(i)}$ as a function of the telescope number.

The $\epsilon^K_{tel(i)}$ were measured at 2.3 GeV (where the K$^+$ yield is rather high) as ratio between kaons detected by the proper start–stop combination and kaons detected by the telescope in coincidence with the same start counters (Fig.3). The start–stop measurements were done with low energy-loss thresholds in the start, stop, ΔE - counters and wide TOF–gates to provide the kaon detection efficiency $\epsilon^K_{det(i)}$ to be not less than 0.98. At 1.0 GeV the kaon data analysis was done with the higher thresholds and narrower TOF–gates in order to reduce the several orders of magnitude larger background which is present in this case. The kaon detection efficiency was reduced to $\epsilon^K_{det(i)} = 0.4 \div 0.8$ as was checked with measurements at 2.3 GeV, where analyses were performed with wide and narrow gates(Fig.3)

The pion detection efficiencies $\epsilon^\pi_{det(i)}$ on the average were equal to 0.98. MWPC efficiencies ϵ^K_{MWPC} and ϵ^π_{MWPC} were equal to 0.97÷0.99. The decay rates

between the target and the stop counters were determined as $\epsilon^K_{decay} = (0.30 \div 0.36)$ for kaons and $\epsilon^\pi_{decay} = (0.85 \div 0.88)$ for pions. Relative monitoring of the proton beam interacting with the target for different energies and nuclei (A) (M^K_A and M^π_A) was done with an accuracy of 2.0% using 4-fold coincidences of telescopes 2, 3, 4 and 5 (selection of ejectiles by-passing the spectrometer dipole D2).
The double differential cross sections of K^+ production in pC interactions at the energy of 1.0 GeV are presented in Fig.4. It shows that ANKE allows to measure the complete kaon spectra in forward direction for deep-subthreshold processes with cross sections as low as $10^{-34}\mathrm{cm}^2$ during several days of work at COSY. The analysis of data at other energies (1.2 GeV, 1.5 GeV, 2.0 GeV and 2.3 GeV) is in progress. Model calculations have been started. Final conclusions about the mechanism of the subthreshold kaon production are expected to be possible after the analysis is finished. But first conclusions can be drawn already from the measured cross section ratios for C, Cu, Au targets.

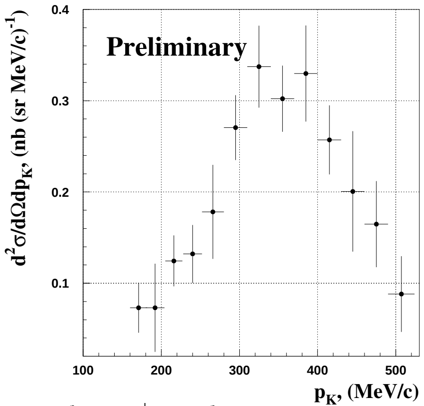

Figure 4: The K^+-production cross section for $p(1.0\mathrm{GeV})C \to K^+X$ as a function of kaon momentum.

Measurements with different targets were performed with the same geometry of ANKE spectrometer and its detection system and the same settings of the proton beam. Therefore ratios of the kaon production cross sections for various nuclei as a function of kaon momentum $\frac{\sigma^{K^+}_A}{\sigma^{K^+}_C}(p_{K^+})$ are equal to the corresponding ratios of kaon count rates in the individual telescopes normalized to pion production cross section ratio at a momentum of 507±17 MeV/c detected in telescope 15:

$$\left(\frac{\sigma^K_A}{\sigma^K_C}\right)_{(i)} = \left(\frac{N^K_A}{N^K_C}\right)_{(i)} \frac{M^K_C}{M^K_A} \left(\frac{N^\pi_C}{N^\pi_A}\right)_{(15)} \frac{M^\pi_A}{M^\pi_C} \left(\frac{\sigma^\pi_A}{\sigma^\pi_C}\right)_{(15)}.$$

Pion-production cross sections ratios in pA collisions with a momenta of 500 MeV/c in forward direction were measured by several groups [3, 4, 5] in the proton energy range 0.73÷4.2 GeV and are known with an accuracy better than 10% [6]. Fig. 5 shows the deduced K^+ production cross section ratios at $T_\mathrm{p} = 2.3\,\mathrm{GeV}$, i.e. above the N–N threshold.
The momentum integrated cross-section ratios are:

$$\mathrm{R} = 3.23 \pm 0.35 \ \text{ for } \ \mathrm{Cu/C}$$

$$\mathrm{R} = 6.29 \pm 0.70 \ \text{ for } \ \mathrm{Au/C}.$$

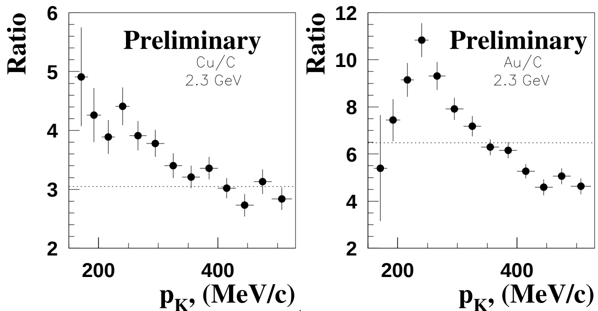

Figure 5: Ratios of the K^+ production cross sections for Cu/C and Au/C as a function of the kaon momentum for $T_\mathrm{p} = 2.3\,\mathrm{GeV}$. The dotted line indicates an $A^{2/3}$ dependence of the cross section.

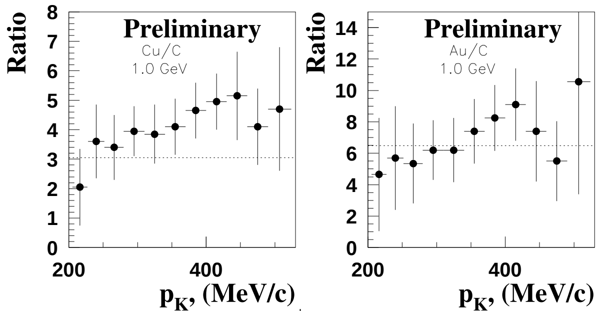

Figure 6: Ratios of the K^+ production cross sections for Cu/C and Au/C as a function of the kaon momentum for $T_\mathrm{p} = 1.0\,\mathrm{GeV}$. The dotted line indicates an is $A^{2/3}$ dependence of the cross section.

These ratios are in a good agreement with an $A^{2/3}$ dependence of the total cross section, which is expected if the kaons are produced via one-step mechanism. One observes a strong momentum dependence, possibly resulting from a rescattering of the produced kaons in the nuclear environment.
Fig. 6 shows the ratios at $T_\mathrm{p} = 1.0\,\mathrm{GeV}$. The momentum integrated cross-section ratios are:

$$\mathrm{R} = 3.9 \pm 0.4 \ \text{ for } \ \mathrm{Cu/C}$$

$$\mathrm{R} = 6.6 \pm 0.8 \ \text{ for } \ \mathrm{Au/C}.$$

Unexpectedly, these ratios are also close to an $A^{2/3}$ dependence of the total cross section, but the momentum dependence is quite different from what was observed for the ratios at $T_\mathrm{p} = 2.3\,\mathrm{GeV}$.

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