SUBTHRESHOLD K^+ PRODUCTION IN PROTON-NUCLEUS COLLISIONS AND THE NUCLEAR SPECTRAL FUNCTION*

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K^+ production on carbon and lead was measured for proton beam kinetic energies from 1.2 up to 2.5 GeV. It was found that the high momentum tail of the kaon spectrum extends beyond the kinematical limit for the elementary reaction. The influence of the internal motion of nucleons on the particle production was studied within the folding model.

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In our experiments we studied K^+ production on carbon and lead targets. The proton beam kinetic energies were 1.2 and 1.5 GeV for the Pb target and 1.2, 1.5 and 2.5 GeV for the C target. The spectrometer was set at the laboratory angle of $\theta_{\rm lab} = 40°$ corresponding to particles emitted at midrapidity. The particles were identified by the time-of-flight.

For the beam energy above the free N–N threshold (1.58 GeV) the data measured on the nuclear target can be compared to elementary data $(p+p \to K^+ + X)$ [1]. Both data sets are shown in Fig. 1.
In order to compare the data sets directly we had to correct for the size of the carbon nucleus. This is done by multiplying the elementary cross section by the factor $\sigma_{\rm C}^{\rm inel}/\sigma_p^{\rm inel} = 7$. The comparison shows that above the

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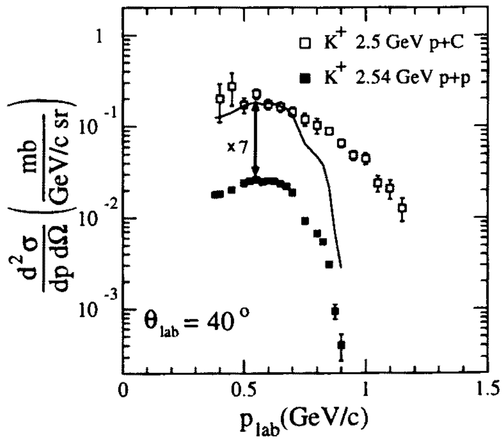

Fig. 1. Double differential cross section for K^+ production in $p+\mathrm{C}$ collision at 2.5 GeV bombarding energy in comparison with the elementary kaon cross section measured at 2.54 GeV beam energy at the same $\theta_{\mathrm{lab}} = 40°$. The data from $p+p$ collision are scaled by the factor $\sigma_C^{\mathrm{inel}}/\sigma_p^{\mathrm{inel}}$ corresponding to the size of both targets — see text.

threshold kaons are produced mainly in direct processes. However, the high momentum tail of the kaon spectrum extends beyond the kinematical limit for the elementary reaction. This indicates the presence of other complex K^+ production mechanisms in the nuclear medium. The additional energy to overcome the threshold can be taken from the Fermi motion of nucleons.

The influence of the internal motion of nucleons on the particle production can be studied quantitatively within the folding model. If we consider collisions of the beam proton with target nucleons with a given momentum distribution we can calculate the resulting cross section as an integral:

$$\sigma_{pA}^{K^+} = N \int d^3p \int dE^* \, S(p, E^*) \, \sigma_{pN}^{K^+}(\sqrt{s}) \,, \tag{1}$$

where $N = \sigma_A^{\mathrm{inel}}/\sigma_p^{\mathrm{inel}}$, p is the internal momentum of a nucleon and E^* the corresponding total energy of this nucleon. $S(p, E^*)$ is the nuclear spectral function giving the distribution of these variables [2] (see Fig. 2). $\sigma_{pN}^{K^+}(\sqrt{s})$ is the free elementary cross section for kaon production. It depends only on the total available CMS energy. A similar approach has been already presented (see *i.e.* [3]) but up to now nucleons were considered as on-shell particles. This can lead to problems with energy conservation in the system if a head-on collision with a nucleon with very high momentum is considered. The integral (1) takes already into account that nucleons in the nucleus are bound and thus are off-shell (they do not obey the vacuum formula $E^2 = p^2 + m_N^2$).

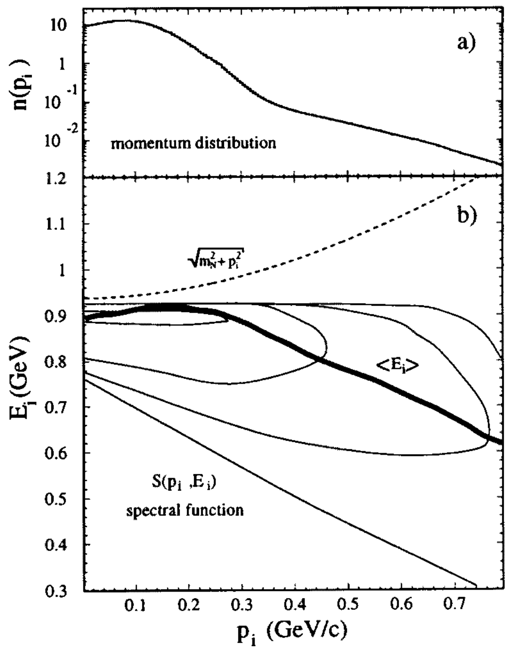

Fig. 2. Momentum distribution of nucleons in the nucleus (a) and the spectral function for the same nucleus (b), as calculated by Sick *et al.* [2]. The thick solid line is the ridge of the distribution. The dashed line correspond to the free space energy.

Above the threshold at 2.5 GeV beam energy the results are in fair agreement with the data. Below threshold the measured kaon yield cannot be reproduced by first chance collisions even if the Fermi motion of nucleons is taken into account (*c.f.* Fig. 3 — dashed lines). More complex processes like a two-step production mechanisms must be introduced. In the first step a pion is produced in the reaction $NN \to NN\pi$ and the pion can produce a kaon in the subsequent collision with another nucleon $\pi N \to K\Lambda(\Sigma)$. This process can also be calculated with the folding model. The distribution of pions produced in the first step is folded with the nuclear momentum distribution as in (1).

The results of the folding model calculation together with our data are shown in Fig. 3. Already at 1.5 GeV beam energy about 80% of kaons measured at $\theta_{\mathrm{lab}} = 40°$ are produced in two-step processes. At lower bombarding energies the contribution of kaons produced in first-chance collisions

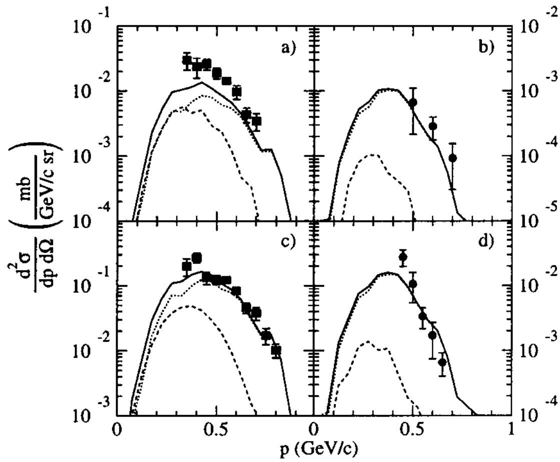

Fig. 3. Measured and calculated kaon production cross sections in proton–nucleus collisions. a) — $p+\mathrm{C}$ at 1.5 GeV, b) — $p+\mathrm{C}$ at 1.2 GeV, c) — $p+\mathrm{Pb}$ at 1.5 GeV and d) — $p+\mathrm{Pb}$ at 1.2 GeV. The dashed lines are kaons produced in first chance collisions, the dotted lines — kaons from $\pi N \to KY$ processes and the solid lines are summed both components.

is less than 10% at this angle. The introduction of the secondary processes with an intermediate pion leads to fair agreement with the data.

In the calculations the K^+ production with an intermediate Δ resonance ($NN \to N\Delta, \Delta N \to K^+YN$) has not been taken into account. This channel would lower the calculated spectra. The role of different processes contributing to subthreshold kaon production can be better understood if instead of proton heavier projectiles — deuteron and α would be used. The analysis of these data is in progress.

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