INVESTIGATION OF SUBTHRESHOLD K^+ PRODUCTION IN P+A REACTIONS WITH THE 0° FACILITY AT COSY-JÜLICH

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ABSTRACT

A universal facility is in preparation for the study of particle production in proton-nucleus reactions at COSY-Jülich. The device will be located at the internal target position and will consist of three dipole magnets. This 0° Facility will separate ejectiles from the circulating COSY beam and allow momentum and angle analysis both for positively and negatively charged particles. A major goal of the experimental program is the investigation of the K^+-meson production at projectile energies far below the NN threshold ($T_{NN} = 1.58$ GeV). The measurement of double-differential K^+-production cross sections is planned in order to obtain information on the reaction mechanism. In particular, the observation of a peak in the momentum distribution of correlated deuterons would be a clear signal for a two-step mechanism. It is further planned to measure the production of π and η mesons in p+^{12}C reactions in order to investigate the influence of the nuclear medium on the properties of the Δ and $N^\star$ resonances.

1. Introduction

The study of the production of heavy mesons in proton-nucleus collisions at bombarding energies far below the free NN threshold allows the investigation of the influence of the nuclear medium on elementary-particle reactions. One hopes to learn either about cooperative nuclear phenomena or about high-momentum components of the nuclear-wave function[1]. Subthreshold K^+ production is especially well suited for

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Figure 1: Comparison of the calculated[5] total K^+-cross sections with the experimental data from Koptev et al.[3]. The dotted and dashed lines show the results for the first-collision model (FCM) with and without a high-momentum component of the nucleon-wave function, respectively. The solid lines represent the results of the two-step model (TSM) for the $p + N \rightarrow N + N + \pi$ (**a**) and $p + N \rightarrow d + \pi$ (**b**) channels.

the study of such effects since the mean free path of the K^+ mesons in nuclear matter is large and the information about their formation in the nuclear interior will not be disturbed by final-state interaction. Furthermore, the K^+ mass and consequently the "missing" energy is large at subthreshold energies. Internal momenta up to ~ 1 GeV/c are needed—especially for projectile energies close to the absolute threshold—if the kaon is produced in a single interaction of the impinging proton and a nucleon[2]. In the case of pion production only momenta close to the Fermi edge ($p_F \sim 270$ MeV/c) are involved.

It is well known, in the case of subthreshold K^+ production, that the kaons can stem from two-step processes where in a first collision an intermediate pion is produced[3-6]. In a subsequent reaction of this pion with a second nucleon the $K^+\Lambda$ pair is formed. Since the internal momentum of the nucleons can enter twice the minimum momentum is smaller than in the case of one-step production. It is obvious that, in order to extract information on the high-momentum components of the nucleon-wave function, one has to disentangle the different production mechanisms. So far, only the total K^+-production cross sections have been measured[3] far below the NN threshold. The data for carbon nuclei are shown in Fig.1. It can be seen that the cross sections are extremely small (in the range 1–100 nb) which makes such studies difficult. Knowledge of the total cross sections alone does not allow to distinguish between the different production mechanisms. We have made model calculations in order to analyze the dynamics of kaon production and to make suggestions for experimental studies which can unambiguously determine the reaction mechanism. In the next chapter we show the results of the calculations and then present the proposed experimental setup at the 0° Facility in COSY-Jülich.

2. Results of model calculations

In the framework of the First Collision Model (FCM) [7-9] the kaon is produced in a single collision of the incident proton with a nucleon due to the internal nuclear motion

$$\mathrm{p} + \mathrm{N} \rightarrow \mathrm{K}^+ + \Lambda + \mathrm{N} \tag{1}$$

In our calculations two different types of nucleon-momentum distributions were used. The standard approach is to represent the internal motion with the Fermi-gas model where a uniform distribution of the nucleon momenta inside a momentum sphere with radius p_F is chosen. However, at deep subthreshold energies the influence of the high-momentum component of the many-body nuclear wave function is very important to take into account. We use a double-gaussian function suggested by Geaga et al.[10]. Fig.1 shows the results of our calculations in comparison with the experimental data. It can be seen that only less than 10% of all kaons are produced in the FCM even if the high-momentum components are taken into account.

In the framework of the Two Step Model (TSM) the production of kaons in the collision of secondary pions with the nucleons is considered

$$\mathrm{p} + \mathrm{N}_1 \rightarrow \mathrm{N} + \mathrm{N} + \pi \tag{2}$$

$$\pi + \mathrm{N}_2 \rightarrow \Lambda + \mathrm{K}^+ \tag{3}$$

The dominant contribution from the pion-nucleon reaction channel was discussed by Koptev et al.[3] and also evinced by the calculations of Cassing et al.[4]. The resultant cross section for K^+ production is shown in Fig.1 by a solid line (curve a).

We also take into consideration the K^+-meson production via the particular two-step mechanism

$$\mathrm{p} + \mathrm{N}_1 \rightarrow \mathrm{d} + \pi \tag{4}$$

$$\pi + \mathrm{N}_2 \rightarrow \Lambda + \mathrm{K}^+ \tag{5}$$

with the formation of a deuteron in the first step. The result of the calculations is also shown in Fig.1 (curve b). It can be seen that the experimental K^+-production cross section is well reproduced by the two-step reaction channels since the sum of the curves a and b matches the data.

Unfortunately, the measurement of the total K^+-production cross section does not supply sufficient information to extract the contributions from the different reaction channels. Therefore, we have analyzed the momentum and angular spectra of kaons as well as of correlated particles produced via the different mechanisms. In Fig.2a we show the FCM and TSM results on K^+ angular and momentum spectra calculated for p+^{12}C collisions at 1 GeV, in Fig.2b the calculated angular and momentum spectra of protons which leave the target nucleus in correlation with the K^+ mesons. In case of the FCM only one proton is produced together with the kaon via reaction (1) whereas in the case of the TSM two protons from reaction (2) can be detected. As in the case of the kaon distributions the protons are forward peaked in the laboratory frame. From an inspection of the spectra shown in Fig.2 we conclude that the measurement of double-differential cross sections of K^+-mesons and correlated protons at forward angles might allow to study the different reaction mechanisms of subthreshold K^+ production, in agreement with the studies in Ref.[6, 11].

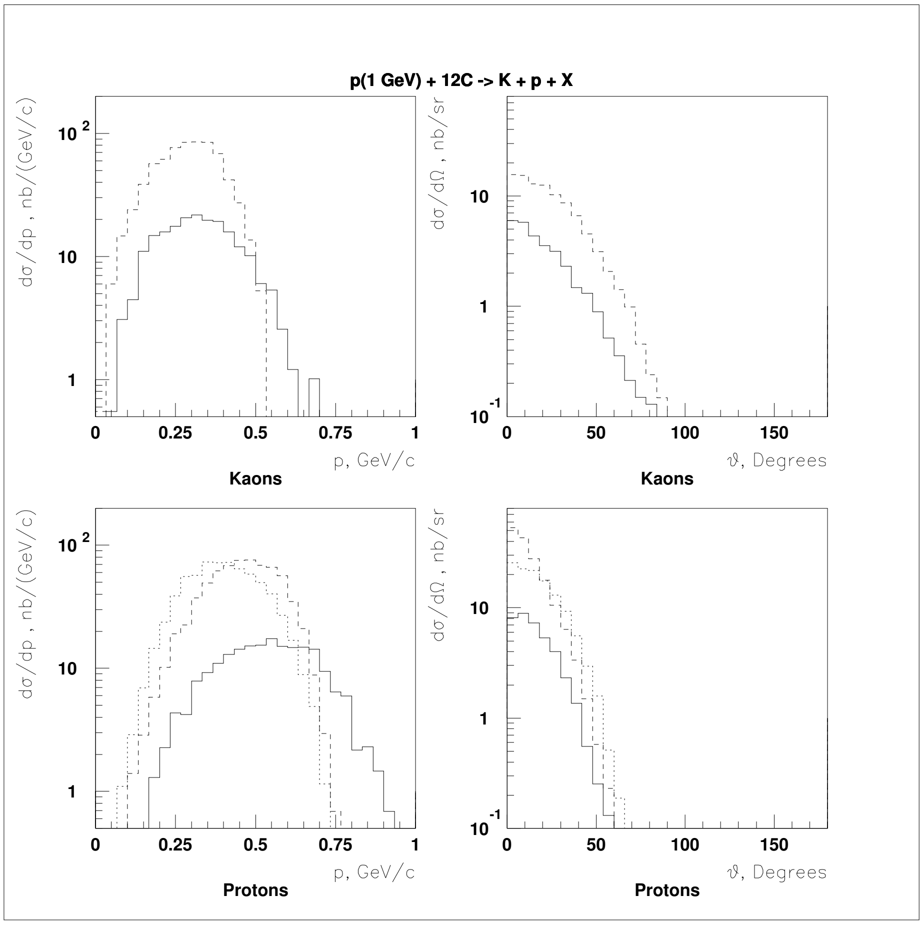

Figure 2: Calculated angular and momentum distributions of K^+ mesons (**a**) and correlated protons (**b**) in the first-collision model (FCM, solid line) and from two-step processes (TSM, dashed and dottes lines) for a projectile energy T_P = 1.0 GeV. Protons from Λ decay are not shown in the figure.

One of the possible ways to unambiguously identify the K^+-production channel with an intermediate pion and deuteron (reactions (4) and (5)) is to measure the deuteron-momentum spectrum in coincidence with the K^+. In Fig.3 the dotted curve

Figure 3: Calculated momentum spectra for deuterons in correlation with K^+ mesons[5]. The dotted and solid lines denote the original deuteron distribution and the one expected after rescattering in the target nucleus, respectively. The dashed curve shows the expected momentum distribution of fast deuterons from the same nucleus which are not directly related to the K^+-formation process.

shows the original deuteron-momentum spectrum calculated with the TSM for $p+^{12}C$ collisions at 1.0 GeV. All deuterons are produced at angles less than 30° due to the two-body kinematics of reaction (4). Our calculations show that the peak still stands out of the background of fast deuterons if rescattering of the deuterons in the target nucleus is taken into account. The hope is that the measurement of the deuteron-momentum spectrum shown in Fig.3 will allow to indentify the two-step mechanism.

3. Proposed measurements at the 0° Facility

Fig.4 shows the principal layout of the 0° Facility[2] which is being built by an international collaboration with members from KFA Jülich, JINR Dubna, PNPI Gatchina, CERN Geneva, ITEP Moscow, FZ Rossendorf and the Universities of Bonn, Cracow, Gießen, Moscow, Münster and Tbilisi. It will be located at an internal target position in one of the straight sections of the COSY ring and consist of three dipole magnets. The smaller outer dipoles D1 and D3 guide the circulating beam which is deflected in the central C-shaped spectrometer dipole D2. The latter will have a large gap of 20 cm which will allow coincidence studies even at small cross sections. It can be seen from the figure that ejectiles in the momentum range $p \approx 150 \ldots 450$ MeV/c leave the magnet through the side edge. They can be detected in the side-detection system which will consist of two wire chambers MWC1/2 for track reconstruction, a TOF-start detector wall with 23 scintillation counters and 13 telescopes which include the TOF-stop, ΔE, Čerenkov and veto counters. These side detectors have been optimized using the program package GEANT in order to identify K^+ mesons out of a $\sim 10^6$ times higher background consisting mainly of pions and protons and to give a kaon-momentum resolution of better than 2%. Correlated protons in the momentum range $p_p \approx 200 \ldots 800$ MeV can also be detected in the side detectors and in an additional "side wall" consisting of 6 scintillation counters for TOF-measurements, see Fig.4. The correlated deuterons will partially also hit this wall ($p_d < 700$ MeV). For the higher deuteron momenta a forward-detection system will be used consisting of wire chambers (MWC3/4) and scintillation counters.

The design of the 0° Facility has been optimized in order to allow a variety of further studies on nuclear-medium effects. One of these studies is the measurement of the π and η production in p+^{12}C reactions. It is well known that there is a substantial downward shift of the mass of the Δ resonance in nuclei compared to the free Δ mass of 1232 MeV. Part of this shift is caused by a coherent medium effect on the spin-longitudinal response function[12]. We want to study the coherent π production ^{12}C(^{3}He,tπ^+)^{12}C(g.s.) by measuring both the outgoing t and π^+ which are forward peaked. It will also be possible to investigate the coherent π production in processes which do not leave the participating nucleus in the ground state e.g. from a measurement of the reaction ^{12}C(^{3}He,tp$\prime$p$\prime\prime$)^{10}B. The two protons p$\prime$ and p$\prime\prime$ stem from the decay of the Δ resonance inside the target nucleus. Since they leave the target in a collinear geometry they can be measured with the 0° Facility at angles $\vartheta \sim 0°$ and $\sim 180°$, respectively, in coincidence with the forward peaked t. For the separation of the backward going ejectiles the dipole D1 will be utilized. It is further planned to extend the studies on coherent π production to the reaction ^{12}C(p,p$\prime\eta$)^{12}C(g.s.) where the outgoing proton as well as the two γ's from the η decay would have to be measured[13].

Finally, there is a proposal[14] for the study of the exclusive deuteron break-up reaction $\vec{\mathrm{p}} + \vec{\mathrm{d}} \rightarrow \mathrm{p}(0°) + \mathrm{p}(180°) + \mathrm{n}$ using a (1–2.5 GeV) polarized proton beam and a polarized deuterium gas target. Vector and tensor analyzing powers and also the spin-correlation asymmetry will be exclusively measured. For the momentum analysis of the slow proton emitted backward at $\sim 180°$ the small dipole D1 will be used and the fast proton emitted under $\sim 0°$ will be detected in the forward detection system.

References

1. W.Cassing et al., *Phys. Rep.* **188** (1990) 363.
2. M.Büscher et al., *Physica Scripta* **48** (1993) 50.
3. V.P.Koptev et al., *Sov. Phys. JETP* **67** (1988) 2177.
4. W.Cassing et al., *Phys.Lett.* **B238** (1990) 25.
5. A.A.Sibirtsev, M.Büscher, *Z.Phys.* **A347** (1994) 191.
6. B.Kamys, Proc. 105th Int. WE-Heraeus-Seminar, Bad Honnef, Germany, Feb.1–3, 1993, *Konferenzen der Forschungszentrums Jülich*, Vol.12, p, 215.
7. A.Shor et al., *Nucl.Phys.* **A514** (1990) 717.
8. W.Cassing et al., *Z.Phys.* **A340** (1991) 51.

9. A.A.Sibirtsev, *Yad.Fiz.* **56** (1993) 65.
10. J.V.Geaga et al., *Phys.Rev.Lett.* **45** (1980) 1993.
11. W.Cassing et al., *Z.Phys*, in print.
12. F.Osterfeld et al., *Physica Scripta* **48** (1993) 68.
13. H.Seyfarth et al., *COSY Proposal no. 23* (1991).
14. V.I.Komarov et al., *COSY Proposal no. 20* (1991).

Figure 4: Principle layout of the 0° Facility and the detectors used for the subthreshold K^+-experiment. Tracks of ejectiles with different momenta and emission angles are shown.