PLANNED MESON-PRODUCTION STUDIES WITH ANKE AT COSY

M.Büscher

Institut für Kernphysik, Forschungszentrum Jülich, Postfach 1913, D-52425 Jülich, Germany

for the ANKE collaboration

Inst. für Hadronen- und Kernphysik, Forschungszentrum Rossendorf, D-01474 Dresden, Germany
Inst. für Strahlen- und Kernphysik, Univ. Bonn, Nußallee 14, D-53115 Bonn, Germany
Physikalisches Inst. II, Univ. Erlangen-Nürnberg, E.-Rommel-Str. 1, D-91058 Erlangen, Germany
Inst. für Theoretische Physik, Univ. Gießen, H.-Buff-Ring 16, D-35392 Gießen, Germany
Inst. für Kernphysik, Univ. Köln, Zülpicher Str. 77, D-50937 Köln, Germany
Inst. für Kernphysik, Univ. Münster, W.-Klemm-Str. 9, D-48149 Münster, Germany
Inst. of Physics, Jagellonian Univ., Reymonta 4, PL-30059 Cracow, Poland
Soltan Inst. for Nuclear Studies, PL-05400 Swierk, Poland
Laboratory of Nuclear Problems, Joint Inst. for Nuclear Research, 141980 Dubna, Russia
Dubna Branch of the Moscow State Univ., 141980 Dubna, Russia
High Energy Physics Department, Petersburg Nuclear Physics Inst. 188350 Gatchina, Russia
Inst. for Theoretical and Experimental Physics, Cheremushkinskaya 25, 117259 Moscow, Russia
High Energy Physics Inst., Tbilisi State Univ., Univ. Str. 9, 380 086 Tbilisi, Georgia

Abstract

A major goal of the experimental program with the 0° Facility "ANKE" at COSY-Jülich is the investigation of the influence of the nuclear medium on elementary particles and their reactions. In particular, it is planned to study the production of K^+, K^- and Φ mesons in proton-nucleus interactions close to and below the NN thresholds.

1 Introduction

The study of the production of heavy mesons in proton-nucleus collisions at bombarding energies around the free NN thresholds 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 the final-state interaction of mesons in the nuclear medium [1, 2, 3, 4].

The 0° Facility "ANKE" [2, 5, 6, 7] which is planned to start operation in the middle of 1997 will be located at the internal target position TPA of the cooler synchrotron COSY-Jülich. It consists of three dipole magnets — two smaller ones to guide the circulating COSY beam and a large C-shaped spectrometer magnet which will allow to analyze ejectiles at emission angles $\vartheta < 10°$ with a high angular acceptance of $\Omega \approx 50$ msr and an extremely large momentum acceptance. Furthermore, the flight path of the ejectiles between target and detectors is very short so that e.g. charged kaons can be detected with an efficiency of ~ 30 %. Thus, studies of reactions with extremely small cross sections will be possible, in particular, subthreshold kaon production where the produced ejectiles leave the target under forward angles. Detectors which are optimized for the identification of K^+ mesons in the momentum range $p_{K^+} \approx 140 \ldots 600$ MeV/c, of fast positively charged fragments (p, d, ^{3}He, ...) with larger momenta $p > 600$ MeV/c and of K^- mesons with $p_{K^-} \approx 170 \ldots 1000$ MeV/c are currently being built.

One major goal of the planned measurements at ANKE is the study of proton-induced strangeness production in the nuclear medium which, in principle, is also related with the strangeness content of the nucleon. Due to strangeness conservation in strong interactions charged kaon production in the COSY-energy regime can either take place in associated production $pA \to K^+\Lambda(\Sigma)X$ or in pair production $pA \to K^+K^-X$. The latter reaction may also be resonant e.g. via the production of a $\Phi(1020)$ meson.

Due to its large mean free path ($\lambda \approx 6$ fm) in nuclear matter the K^+ meson is an ideal probe for reactions deep inside the nucleus. At ANKE it is planned to study the production of K^+ mesons far below the nucleon-nucleon threshold ($T_{\rm p}$ = 1.58 GeV) down to beam energies of $T_{\rm p} \approx 0.9$ GeV [2] where the total K$^+$-production cross section can be as low as $\sigma_{\rm K^+} \approx 10$ nb [8]. At these small energies one should be sensitive for medium effects like large internal momenta ($p > 300$ MeV/c) of the participating nucleons. Alternatively, it has been discussed that the energy needed for subthreshold K$^+$ production can be provided from the interaction of the impinging proton with a cluster consisting of several target nucleons [2]. It should be mentioned that in order to extract information about the above mentioned phenomena one first has to pin down the reaction mechanism for subthreshold K$^+$ production which should be possible with the envisaged measurements at ANKE, see below.

As in the case of near threshold K$^+$ production the mechanism of K$^+$K$^-$-pair production in pA collisions is largely unknown. Thus, a new method has been proposed [3] to measure the production of K$^+$K$^-$ mesons at energies $T_{\rm p} \approx 2.0 \ldots 2.5$ GeV in coincidence with fast fragments like p, d, ^{3}He, ... An analysis of the missing mass of the detected particles should help to identify the reaction mechanism [3]. The proposed K$^+$K$^-$ measurements are a natural extension of the subthreshold K$^+$ studies and particularly interesting for the following reasons: In contrast to the K$^+$ meson the K$^-$ strongly interacts with the surrounding nuclear matter and, thus, it is an interesting question if the degeneracy of the free K$^+$ and K$^-$ masses persists in the nuclear medium. The density dependence of the kaon masses in nuclei is investigated at GSI for densities $\rho > \rho_0$, and at ANKE information at normal densities can be obtained. Furthermore, from the observation of K$^+$K$^-$ pairs which are produced via the $\Phi(1020)$ meson one hopes to obtain information about the production and propagation of the Φ meson in nuclei. These studies will also be complementary to Φ production with electro-magnetic probes at electron accelerators. Since the elementary pp $\rightarrow$ ppΦ production has not been measured near threshold yet it has also been proposed [9] to study the reaction $\vec{\rm p}\vec{\rm p} \rightarrow {\rm pp}\Phi \rightarrow {\rm ppK^+K^-}$ at ANKE via a measurement of all outgoing particles.

2 Proposed measurements at ANKE

In the case of near-threshold K$^+$ production in proton-nucleus interactions, the kaons can stem from direct processes (pN $\rightarrow$ K$^+\Lambda$N) and from the two-step mechanism (pN$_1$ $\rightarrow$ NNπ , πN$_2$ $\rightarrow$ K$^+\Lambda$) [8, 11, 12]. So far, K$^+$ production in pA reactions has been measured at energies $T_{\rm p} \approx 0.8 \ldots 1.0$ GeV [8] (total cross sections), $T_{\rm p} = 1.2, 1.5, 2.5$ GeV [13], $T_{\rm p} = 2.1$ GeV [14] and $T_{\rm p} = 2.9$ GeV [15] (double differential cross sections) for various target masses A. The existing data seem to indicate a dominance of two-step mechanisms at $T_{\rm p} < 1.5$ GeV and of the direct K$^+$ production at energies above the NN threshold [11, 12, 16]. However, a recent analysis [15] of total K$^+$-production cross sections in the range $T_{\rm p} = 2.1 \ldots 2.9$ indicates that even at these higher energies collective processes (like the above mentioned two-step mechanism) might contribute significantly to the total cross sections. In [15] the total cross sections were extracted from the measured double differential ones [13, 14, 15] using a phase-space approach. Figure 1 shows the total K$^+$-production cross sections $\sigma_{\rm tot}$(pA) as calculated in [15] as a function of the target mass A. In the figure the values of $\sigma_{\rm tot}$(pA) have been normalized by the elementary K$^+$-production cross section σ(pp) [17] in order to eliminate the energy dependence of σ(pp). For comparison, we also show in the figure the normalized cross section as functions $\sigma_{\rm tot}({\rm pA})/\sigma({\rm pp}) = A^\alpha$ for slope parameters α in the range 0.6 ... 1.4. Values of α around 0.7 indicate one-step processes (pN$\rightarrow$K$^+\Lambda$N) whereas values above 1.2 might be due a collective behavior of the target nucleus [15]. It can be seen from the figure that the various data points favour different α values and no conclusions can be drawn about the dominant reaction mechanism.

Figure 1: Figure 1: Target-mass dependence of the total cross section for the production of K$^+$ mesons in pA collisions in the energy range $T_{\rm p} = 2.1 \ldots 2.9$ GeV [13, 14, 15] normalized by the elementary pp$\rightarrow$K$^+$X cross section [17]. The lines show the expected A dependences for various slope parameters α, see text.

In order to clarify the K$^+$-production mechanism *below* the NN threshold it is planned to measure at ANKE double differential K$^+$ spectra at emission angles $\vartheta < 10°$. From the shape of the K$^+$ spectra and also from those of correlated protons one hopes to get insight into the production mechanism [5, 16]. From model calculations it is expected that the K$^+$ spectra peak in the range $p_{K^+} \approx 150 \ldots 500$ MeV/c [1, 5, 11, 12, 16]. One attractive way to unambiguously identify the two-step K^+ production far below the NN threshold at $T_p = 1.0$ GeV seems to be the measurement of deuterons which can be produced in the particular two-step mechanism ($pN_1 \to d\pi$, $\pi N_2 \to K^+\Lambda$)[2, 5, 12] in coincidence with the K^+ mesons. These deuterons are produced at angles less than 30° and are peaked at $p_d \sim 800$ MeV/c with a width of ~ 200 MeV/c. Our calculations showed [12] that the peak still stands out of the background of fast deuterons even if rescattering in the target nucleus is taken into account. If such a deuteron-momentum spectrum is observed in coincidence with K^+ mesons it will be a clear evidence for the two-step mechanism.

As mentioned above, a missing-mass analysis of K^+K^- pairs measured at ANKE in coincidence with correlated fast fragments should allow to determine the reaction mechanism in case of near-threshold K^+K^- production. This is one prerequisite for extraction of medium effects from the observed kaon spectra. Besides of that the experimental setup should offer sufficiently high counting rates in order to perform the measurements in a reasonable time and — in case of the Φ meson — the momentum resolution for the K^+K^- should be high enough (in order of a few percent) to reconstruct the invariant K^+K^- mass in the Φ region with an accuracy comparable with the natural Φ width ($\Gamma_\Phi \approx 4.4$ MeV). From our GEANT simulation calculations [3] it follows that at $T_p = 2.0$ GeV one can expect a few thousand detected K^+K^- pairs per day. Figure 2 shows the reconstructed invariant mass spectra of the detected kaons in the vicinity of the Φ meson. For comparison the spectrum for kaons emitted at the target calculated with the Rossendorf Collision (ROC) model [4, 19] is also shown. A peak around 1.02 GeV stemming from Φ mesons is clearly visible. A selection of K^+K^- pairs which lie inside/outside the Φ-meson peak will allow to analyze those events where a Φ meson has been formed and propagated through the nucleus or those where the K^+K^- pair has been produced directly in the target nucleus. Thus a study of medium effects on K^+, K^- and Φ mesons can be performed at ANKE.

Figure 2: Figure 2: Invariant mass of K^+K^- pairs produced in $p^{12}C$ collisions under emission angles $\vartheta < 10°$ calculated with the ROC model [4, 19] (solid line). After detection of the kaons at ANKE the peak around the Φ mass is clearly visible (dashed line).

It should be noted that the experimental program on the investigation of nuclear-medium effects at the 0° Facility outlined here is only part of the envisaged studies. Measurements of π and η production in $p^{12}C$ reactions [5, 20] and of the proton induced deuteron breakup [21, 22] are also foreseen.

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