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Studies on η meson production in dp collisions at the ANKE spectrometer

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Abstract. Current investigations at the internal fixed target experiment ANKE at the storage ring COSY, located at the Forschungszentrum Jülich in Germany, focus on the behaviour of the η meson production process as well as on the study of angular distributions in the reactions $d+p \to {}^3\mathrm{He}+\eta$ and $p+d \to d+\eta+p_{\mathrm{sp}}$. The recent analysis status for both reactions will be presented and discussed.

1 Introduction

Investigations on the total cross sections of the reaction $d + p \to {}^3\mathrm{He} + \eta$ are of special interest since they differ strongly from a pure phase space behaviour near threshold (cf. Figure 1 (left)) [1–5].

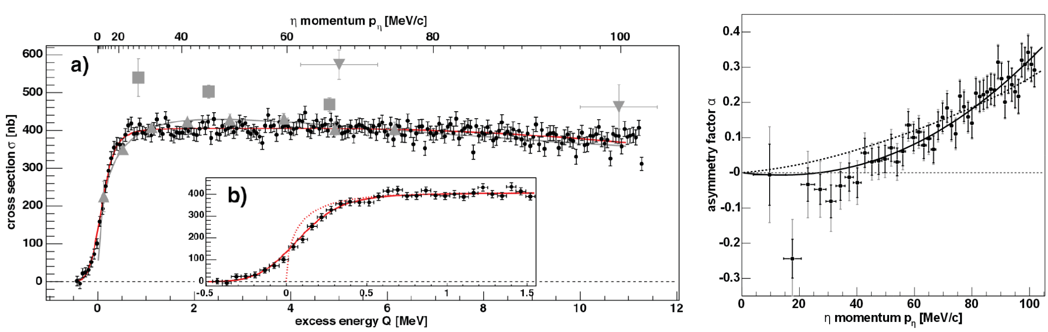

Figure 1. Left: a) Overview of the obtained total cross section of the reaction $d+p \to {}^3\mathrm{He}+\eta$. The red solid line shows a fit to the ANKE data set from threshold up to an excess energy of $Q = 11$ MeV, which is represented by the black filled circles [1]. **b)** Enlargement of the near threshold region. The red dotted line shows the FSI ansatz corrected for the beam momentum spread. **Right:** Variation of the asymmetry factor α with the η momentum p_η. The solid line is a fit to the ANKE data [1] with regard to s- and p-wave interference and the dashed line without s- and p-wave interference.

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Furthermore, analyses of the asymmetry factor α [6] of the differential cross sections (cf. Figure 1 (right)) show a distinct effect of s- and p-wave interference with the η momentum p_η, which can be explained by a rapid variation of the phase. These effects are an indication for an unexpected strong final state interaction (FSI) between η mesons and ^{3}He nuclei which could lead to a quasi bound state of the η^3He-system [6]. New high precision data from the ANKE spectrometer enable the extraction of additional total and differential cross sections for the η production up to an excess energy of $Q = 15\,\mathrm{MeV}$ with improved accuracy, which will clarify the behaviour of the asymmetry factor α with less uncertainties.
Assuming the FSI ansatz to be appropriate, the non pure phase space behaviour of the total cross section near threshold should be seen also in other production channels. This has been tested by different facilities [7–9]. Nevertheless, none of these measurements could clearly prove whether the η-nucleus system is in a bound or virtual state. In order to investigate this in more detail, studies on the properties of η-mesic nuclei with the reaction $p + d \to d + \eta + p_{\text{spec}}$ are in progress. The behaviour of the total cross sections near threshold will allow the determination of the scattering length $a_{d\eta}$ to gain new insights on the possible formation of η-mesic nuclei.

2 The ANKE spectrometer

The magnetic spectrometer **ANKE** ("**A**pparatus for Studies of **N**ucleon and **K**aon **E**jectiles") is an internal fixed target experiment at the accelerator and storage ring **COSY** ("**CO**oler **SY**nchrotron"), located at the Forschungszentrum Jülich in Germany, to study the properties and interaction of hadrons in a medium energy regime. For this purpose, COSY provides (un)polarized deuteron and proton beams with momenta between 0.3 GeV/c and 3.7 GeV/c. With its polarized storage-cell target and unpolarized cluster-jet target, the ANKE experiment focusses on the investigation of pp-, pd- and dd-collisions. The magnet spectrometer ANKE (cf. Figure 2) consists of three dipole magnets (D1 -

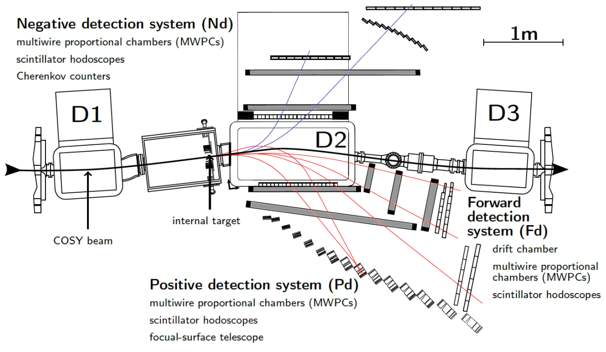

Figure 2. Schematic representation of the magnatic spectrometer ANKE consisting of three dipole magnets (D1 - D3), the internal target, and three detection systems (Nd-, Pd-, and Fd-system). The blue (red) lines illustrate negatively (positively) charged particles, which will be deflect by the second dipole magnet D2 into the Nd(Pd or Fd)-system.

D3), an internal target, and three detection systems (Nd-, Pd-, and Fd-system). Negatively (positively) charged ejectiles will be deflected by the second dipole magnet D2 into the Nd(Pd)-system. In addition to the Pd-system, the Fd-system was designed for heavy (^{3}He) or fast (p or d) positively charged ejectiles, which will be deflected by D2 under small laboratory scattering angles due to the large Lorentz boost in beam direction close to the beam pipe. The Fd-system is composed of one multiwire drift chamber and two multiwire proportional chambers used for track reconstruction and two layers of scintillator hodoscopes for energy loss and time-of-flight measurements. A special feature of the ANKE detector is its movable D2 magnet to optimize the detector acceptance for each reaction which will be investigated. The design of the ANKE spectrometer setup with its three dipole magnets is very well suited for the detection and reconstruction of charged particles generated even at small laboratory scattering angles in reactions, e.g. $d + p \rightarrow {}^3\mathrm{He} + \eta$, close to threshold.

3 The η production channel $d + p \rightarrow {}^3\mathrm{He} + \eta$

New data from the ANKE spectrometer allowed to determine the η meson mass with high precision using the $d+p \rightarrow {}^3\mathrm{He}+\eta$ reaction [10] and to study the two pion production using $d+p \rightarrow {}^3\mathrm{He}+\pi^+ +\pi^-$ [11]. In order to determine the η mass, data has been analysed at 18 deuteron beam momenta in a range between 3120.17 MeV$/c \leq p_d \leq$ 3204.16 MeV$/c$ which could be extracted very accurately via the resonant depolarisation technique with a precision of $\Delta p_d/p_d < 6 \times 10^{-5}$ [10, 12]. Moreover, due to the high statistics of $> 10^5$ ${}^3\mathrm{He}\eta$ events per energy in combination with full angle coverage these high precision ANKE data allow to investigate the total and differential cross sections of the reaction $d + p \rightarrow {}^3\mathrm{He} + \eta$. Such data can be used to investigate the behaviour of the asymmetry factor α especially in the near threshold region (cf. Figure 1 (right)). To extract total and differential cross section values a careful luminosity determination was performed for each of the 18 beam momenta of the beam time via dp-elastic scattering with high precision, i.e. $\Delta L_{\mathrm{stat}} = 1\%$ and $\Delta L_{\mathrm{sys}} = 6\%$, which corresponds to an improvement by at least a factor of two compared to previous measurements. The identification of the reaction $d + p \rightarrow {}^3\mathrm{He} + \eta$ is ensured by detecting the ^{3}He nucleus in the Fd-system. As shown in Figure 3 (left), it is straightforward to separate the reaction of interest from other reactions, e.g. pion production channels. Due to the fully reconstructed four momentum of the ^{3}He nuclei the usage of the missing mass method (cf. Figure 3 (right)) is feasible. A smooth model independent background description was realized by data taken below the η production threshold ($d + p \rightarrow {}^3\mathrm{He} + \eta$) at a beam momentum of p_d = 3120 MeV$/c$ which, after boosting them to the energy above threshold, perfectly fits the data. By this, a clean η signal remains, so that first results on total and differential cross sections will be available soon.

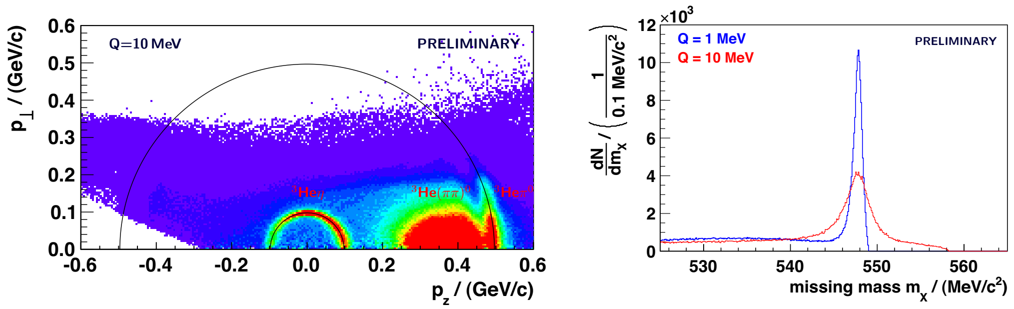

Figure 3. Left: The magnitude of the transverse momentum plotted against the longitudinal momentum in the center of mass system for Q = 10 MeV. The solid black lines represent the calculated kinematical loci of the reactions $d + p \rightarrow {}^3\mathrm{He} + \eta$ and $d + p \rightarrow {}^3\mathrm{He} + \pi^0$ **Right:** Missing mass distributions for two different excess energies (Q = 1 MeV and Q = 10 MeV).

4 The η production channel $p + d \rightarrow d + \eta + p_{\mathbf{sp}}$

An additional beam time was performed at ANKE to investigate the properties of η-mesic nuclei with the reaction $p + d \rightarrow d + \eta + p_{\mathrm{spec}}$, where the initial deuteron serves as an effective neutron target. The combination of two beam momenta p_1 = 2.09 GeV$/c$ and p_2 = 2.25 GeV$/c$ and the Fermi motion inside the deuteron allows to extract differential and total cross sections in a wide excess energy range between 0 – 100 MeV. Moreover, it enables the determination of the scattering length $\alpha_{d\eta}$ to validate the range of the s-wave FSI ansatz and the production of higher partial waves. For this purpose, the precise measurement and clear identification of both the spectator protons and the deuterons is necessary. The identification of the spectator protons is ensured via two Silicon Tracking Telescopes (acronym: "STT"), each consisting of three layers of segmented semiconductor for track reconstruction and energy loss measurements (cf. Figure 4 (left)). The reconstruction of the deuteron in the Fd-system is more challenging because of a similar energy loss of the huge proton background and the deuterons in this momentum range. Therefore, using a cut on the time-of-flight difference between pions in the Pd-system and particles in the Fd-system, energy loss cut conditions can be determined, so that the proton background can be suppressed and a clear deuteron band becomes visible, as shown in Figure 4 (right). With both charged ejectiles, i.e. spectator proton and deuteron, and an accurate calibration of the detection systems, the reaction can be identified via the missing mass technique. First results on the cross section will be available soon.

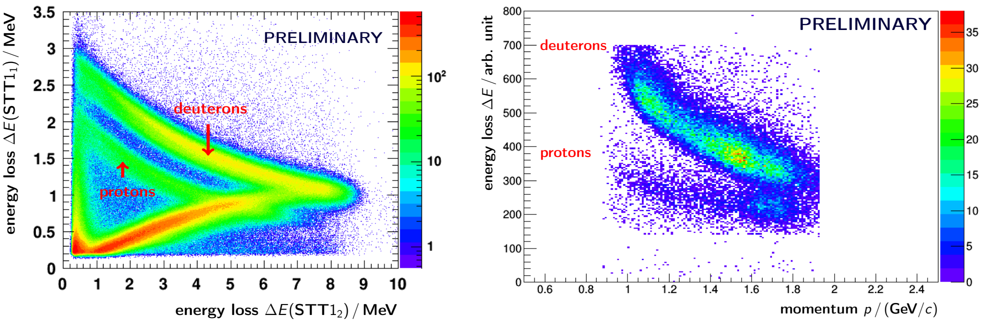

Figure 4. Left: Deposited energy of protons and deuterons in the first layer of one of the Silicon Tracking Telescopes plotted against the energy loss information of the second semiconductor layer of the same STT. **Right:** Energy loss measurements of particles detected in the Fd-system. By applying cuts on the time-of-flight difference between particles in the Fd-system and positively charged pions in the Pd-system, a clear deuteron band becomes visible.

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