Study of the $^3\mathrm{He}-\eta$ interaction

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Abstract. We present a summary of measurements of the $dp \to {}^3\mathrm{He}X, (X = \pi^0, \eta)$ reactions performed with the COSY-11 facility. Our results for the $dp \to {}^3\mathrm{He}\eta$ total cross sections confirm a strong enhancement observed in previous experiments close to the kinematical threshold. The forward-backward asymmetries of the differential cross sections deviate clearly from zero for center of mass momenta above 50 MeV/c indicating the presence of higher partial waves in the final state. The excitation function for the reaction $dp \to {}^3\mathrm{He}\pi^0$ does not show any structure which could originate from the decay of the $^3\mathrm{He}-\eta$ bound state. Our measurements do not confirm the cusp structure observed in the threshold excitation curve measured with the SPES-4 spectrometer in the vicinity of the η production threshold.

Keywords: Meson production; Final state interaction; Eta-mesic nucleus
PACS: 13.60.Le; 14.40.-n; 21.45.+v; 25.45.-z

INTRODUCTION

The strong interaction in the $^3\mathrm{He}-\eta$ system leads to many interesting phenomena such as the enhancement of the production amplitude for the $pd \to {}^3\mathrm{He}\eta$ reaction observed for the first time in measurements performed at SATURNE [1, 2] and confirmed recently by the COSY-11 [3] and ANKE groups [4]. This enhancement can be used for determination of the $^3\mathrm{He}-\eta$ low energy scattering parameters. Another spectacular effect was predicted by C. Wilkin [5] who pointed out that the strong η-nucleus interaction may give rise to significant isospin-violation in pion production via $\pi^0-\eta$ mixing. In the $pd \to {}^3\mathrm{He}\pi^0$ process it should manifest itself as a cusp in the cross sections at beam energies close to the η production threshold. Magiera and Machner estimated this effect for the ratio R of differential cross sections in $pd \to {}^3\mathrm{H}\pi^+/{}^3\mathrm{He}\pi^0$ reactions using a simple model based on experimental amplitudes for π^0 and η production [6]. The predicted cusp is largest for small deuteron-pion relative angle in the center of mass system (c.m.) $\theta^{cm}_{d-\pi} = 0^\circ$ where it reaches the value of about 10% and for $\theta^{cm}_{d-\pi} = 180^\circ$ it is of about 1%. A rapid variation of the $pd \to {}^3\mathrm{He}\pi^0$ cross section in the vicinity of the η production threshold can be also caused by decay of $^3\mathrm{He}-\eta$ bound state in the $^3\mathrm{He}\pi^0$ channel. In this case one can expect to observe in the energy dependence of the cross sections a resonance-like structure with the center below the η threshold.

To study these effects we performed measurements of the $dp \to {}^3\mathrm{He}X, (X = \pi^0, \eta)$ reactions close to the η production threshold.

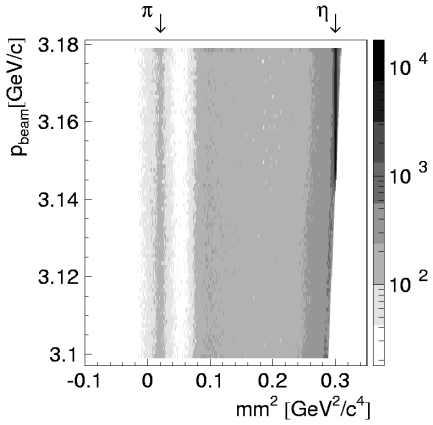

FIGURE 1. Missing mass (x-axis) as a function of beam momentum (y-axis).

EXPERIMENT

The measurements were done at the Cooler Synchrotron COSY with the COSY-11 facility [7]. The internal deuteron beam of COSY was scattered on the COSY-11 proton target of the cluster jet type. The nominal momentum of the deuteron beam was varied continuously within each acceleration cycle from 3.099 GeV/c to 3.179 GeV/c, crossing the threshold for the $dp \rightarrow {}^3\mathrm{He}\eta$ reaction at 3.140 GeV/c. The outgoing ^{3}He-ions from the $dp \rightarrow {}^3\mathrm{He}X$ reactions were momentum analyzed in the dipole magnet and their trajectories were registered with two drift chambers. Identification of the ^{3}He-ions was based on the energy loss in scintillation counters and, independently, on the time-of-flight measured on a path of 9 m between two scintillation hodoscopes. In the missing mass spectrum determined as a function of the beam momentum (see Fig. 1) clear signals from the η meson production as well as from the single π^0 production are visible.

Due to the rapid variation of the near-threshold cross section for the $dp \rightarrow {}^3\mathrm{He}\eta$ process as a function of the ^{3}He c.m. momentum - p_{cm}, a high precision knowledge of p_{cm} was extremely crucial. The nominal beam momentum in the range around 3.1 GeV/c calculated from the synchrotron frequency and the beam orbit length was known with an accuracy of 3 MeV/c only. The resulting uncertainty for p_{cm} = 32 MeV/c was about $\Delta p_{cm} = \pm 12$ MeV/c. A much improved precision of p_{cm} was reached on the basis of the extension of the ^{3}He kinematical ellipses measured via the momentum analysis in the magnetic field of the COSY-11 dipole magnet. Detailed description of this method is given in Ref. [8]. The real beam momentum calculated from p_{cm} was by $\Delta p_{beam} = 3.0 \pm 0.2 \pm 0.8$ MeV/c smaller than the nominal beam momentum, which was in line with results from previous experiments at COSY. The indicated errors correspond to the uncertainty of p_{cm} and of the η mass (547.51 ± 0.18 MeV/c^2 [9]), respectively.

The luminosity was monitored using coincident measurement of the elastic $d-p$ scattering and, independently, of the $p-p$ quasi-free scattering.

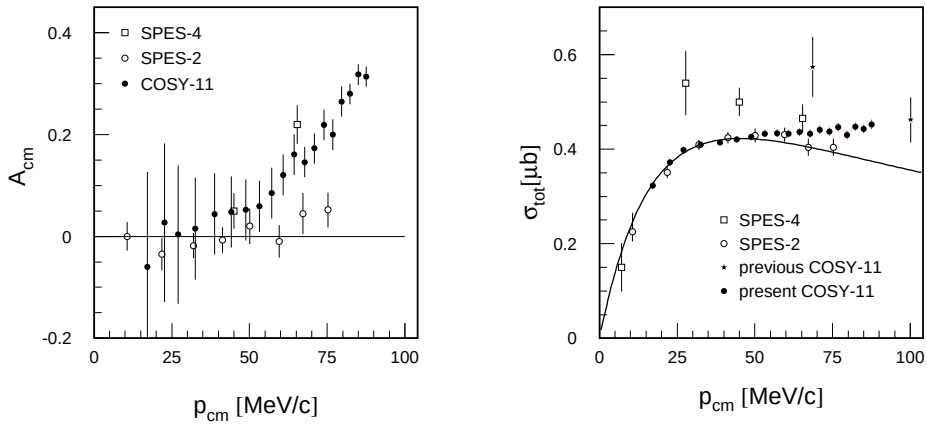

FIGURE 2. Left: Forward-backward asymmetries in the c.m. system. **Right:** Total cross section as a function of the ^{3}He c.m. momentum. The solid line represents the scattering length fit to the present data in the c.m. momentum range below 50 MeV/c.

ETA MESON PRODUCTION

Numbers of $^3\mathrm{He}-\eta$ events corrected for the COSY-11 acceptance and normalized according to the integrated luminosity were used for the determination of the angular distributions. These distributions can be well described by the linear function:

$$\frac{d\sigma}{d\Omega_{cm}} = \frac{\sigma_{tot}}{4\pi}[1 + A_{cm}cos(\theta_{cm})], \tag{1}$$

where σ_{tot} is the total cross section and A_{cm} is the forward-backward asymmetry.

Our results on the forward-backward asymmetries are consistent with the points from SPES-4 measurements [1] and, at lower momenta, also with the SPES-2 data [2], however, at higher momenta, they disagree with the SPES-2 results (see Fig. 2 left). They deviate clearly from zero for momenta above 50 MeV/c. This effect has been confirmed by the most recent results from the ANKE experiment [4] and it indicates a presence of higher partial waves in the final state. It can result from the S- and P-wave interference.

The present data for the total cross section (see Fig. 2 right) confirm the strong near-threshold enhancement observed in the previous measurements [1, 2, 3, 4] interpreted as a result of the final state interaction. We used this enhancement to determine the complex $^3\mathrm{He}-\eta$ scattering length [8]. A scattering length fit to the points for $p_{cm} <$ 50 MeV/c, where the S-wave production dominates gives: $|Re(a)| = 2.9 \pm 0.6$ fm and $Im(a) = 3.2 \pm 0.4$ fm at χ^2/n_{free} = 0.5 in agreement with results from Ref. [2] of $|Re(a)| = 3.8 \pm 0.6$ fm and $Im(a) = 1.6 \pm 1.1$ fm. Further analysis of the data in the full momentum range including contribution from the P-wave is in progress.

PION PRODUCTION AT THE ETA-THRESHOLD

For a search of a cusp or of a resonance like structure originating from decays of the $^3\mathrm{He}-\eta$ bound state, we investigated the $dp \rightarrow {}^3\mathrm{He}\pi^0$ differential cross sections for the forward pion angles ($\Theta^{cm}_{d-\pi} = 0^\circ$). This choice is dictated by the fact that the $dp \rightarrow {}^3\mathrm{He}\pi^0$ cross section is up to two orders of magnitude smaller at the forward angles than at the most backward angles [10]. Assuming that the searched structure is produced isotropically, one can expect that it can be best seen just at the forward angles since it appears on the level of small "non-resonant" cross section. Except of statistical fluctuations no structure can be seen in the excitation curve for the forward cross section presented in Ref. [11].

Data collected in the present experiment were also used to investigate the cusp observed in the threshold excitation curve for the $dp \rightarrow {}^3\mathrm{He}X$ process which was measured with the SPES-4 spectrometer at SATURNE [12]. The cusp was visible at the η threshold and, as suggested by Wilkin [13], it can be caused by an interference between an intermediate state including the η meson and the non-resonant background corresponding to the multi-pion production. Our data presented in Ref. [14] do not confirm the cups measured at the SPES-4 spectrometer.

ACKNOWLEDGMENTS

We acknowledge the support of the European Community-Research Infrastructure Activity under FP6 programme (Hadron Physics, N4:EtaMesonNet, RII3-CT-2004-506078), the support of the Polish Ministry of Science and Higher Education under the grants No. PB1060/P03/2004/26, 3240/H03/2006/31 and 1202/DFG/2007/03, and the support of the German Research Foundation (DFG) under the grant No. GZ: 436 POL 113/117/0-1.

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