Study of the ^{3}He $-\eta$ system in $d-p$ collisions

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We have measured excitation functions for the $dp \to {}^3\mathrm{He}\, X$, $(X = \pi^0, \eta)$ channels near the η production threshold. The data were taken during a slow ramping of the COSY internal deuteron beam scattered on a proton target. 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 ^{3}He $-\eta$ bound state. We measured also the threshold excitation curve for the $dp \to {}^3\mathrm{He}\, X$ process, however, contrary to the SATURNE results, we observe no cusp near the η threshold.

1. INTRODUCTION

Study of the interaction between the η meson and the ^{3}He nucleus is of high interest due to the possible existence of a bound state [1, 2] and because of the potentiality of a strict description of this system within the four body scattering theory [3]. The $d-p$ collision is very well suited for the creation of a ^{3}He $-\eta$ pair since the corresponding production cross section (about 0.4 μb) is relatively high close to threshold. Investigations can be conducted both: above threshold, where the absolute value of the scattering length can be determined on the basis of FSI effects [4], and below threshold, where one should search for resonance-like structures in the excitation functions of decays from the eventual ^{3}He$-\eta$ bound state in various possible reaction channels like e.g. in the ^{3}He π^0 channel [5]. In order to study these topics we performed measurements of the exciatation functions for the $dp \to {}^3\mathrm{He}\, X$, $(X = \pi^0, \eta)$ reactions near the η production threshold.

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2. EXPERIMENT

The experiment was performed at the COoler SYnchrotron COSY in Jülich with the use of the COSY-11 detection facility [6] shown schematically in Fig. 1. The internal deuteron beam of COSY was scattered on a hydrogen cluster target installed in front of a COSY accelerator dipole magnet. The outgoing ^{3}He-ions from the $dp \to {}^3\mathrm{He}\,X$ reactions were momentum analyzed in the dipole magnet and their trajectories were registered with two drift chambers D1 and D2. Identification of the ^{3}He-ions was based on the energy loss in the scintillation hodoscope S1 and, independently, on the time of flight on a path of 9 m between the scintillation hodoscope S1 and S3.

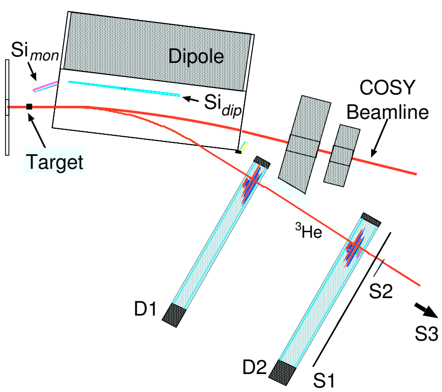

Figure 1. Scheme of the COSY-11 detection system.

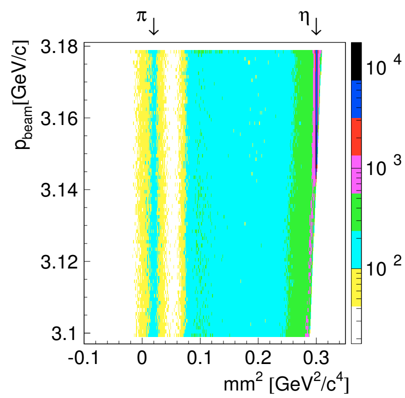

Figure 2. Missing mass (x-axis) as a function of beam momentum (y-axis).

The momentum of the deuteron beam was varied continuously within each cycle from 3.095 GeV/c to 3.180 GeV/c, crossing the threshold for the $dp \to {}^3\mathrm{He}\,\eta$ reaction at 3.141 GeV/c. In the missing mass spectrum determined as a function of the beam momentum (see Fig. 2) a clear signals from the η meson production as well as from the single π^0 production are visible. The present nominal beam momenta in the range around 3.1 GeV/c, calculated from the synchrotron frequency and the beam orbit length, are know at COSY with accuracy of 3 MeV/c. We determined the beam momentum more precisely using the dependence of the ^{3}He c.m. momentum squared (p^2_{cm}) on of the beam momentum for the $dp \to {}^3\mathrm{He}\eta$ reaction. The solid line in Fig. 3 represents a fit to the experimental points and the dashed line represents relation based on the two-body kinematics. The threshold beam momenta determined for these two cases, corresponding to $p_{cm} = 0$ MeV/c, differ by $\Delta p = (-2.0 \pm 0.4$ MeV/c. This difference was taken as a correction to the nominal beam momentum. The indicated error is dominated by contribution due to the uncertainty of the mass of the η meson (547.75 ± 0.12) MeV [7] which influences the present result via the threshold energy.

The luminosity was determined by comparing differential counting rates for simultaneously registered elastic $d-p$ scattering with corresponding cross sections taken from literature and parametrized as a function of the four-momentum transfer (see Fig. 4).

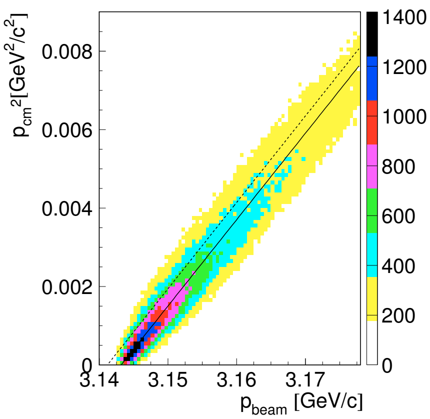

Figure 3. ^{3}He c.m. momentum squared as a function of the nominal beam momentum. Solid line corresponds to a fit to the experimental counts and dashed line represents kinematical relation based on known particle masses.

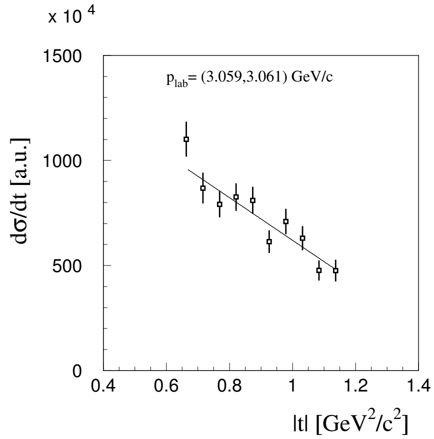

Figure 4. Experimental rate of elastic dp events corrected for the detector acceptance as a function of the four-momentum transfer. Solid line corresponds to parametrization of elastic dp cross sections.

3. EXCITATION FUNCTIONS

In our search 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 ($\Theta^{cm}_{d-\pi} = 0°$). 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 [8]. 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. Fig. 5 shows the pion production cross sections as a function of the beam momentum. Except of statistical fluctuations no structure can be seen in this curve. Assuming, that a 3σ deviation in this curve would be a signal of the $^3\mathrm{He}-\eta$ bound state formation and its subsequent decay in $^3\mathrm{He}\pi^0$ channel, we determined the upper limit for the corresponding cross section as equal to 70 nb. This limit appears not very restrictive at least under assumption that the cross sections for the $^3\mathrm{He}-\eta$ bound state formation are of the same order as the $dp \rightarrow {}^3\mathrm{He}\,\eta$ cross sections near threshold (0.4μb), and that other possible decay channels like $dp\pi^0$ are more favorable.

The analysis of the experimental data for the $dp \rightarrow {}^3\mathrm{He}\,\eta$ channel is not finished yet, however, the preliminary total cross sections for excess energies $Q < 4$ MeV are in agreement with the data of Mayer et al. [9] and confirm the strong enhancement observed near-threshold due to the $^3\mathrm{He}-\eta$ FSI.

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-IV spectrometer at SATURNE [10]. The cusp was visible at the η threshold and, as suggested by Wilkin [11], it can be caused by an interference between an intermediate

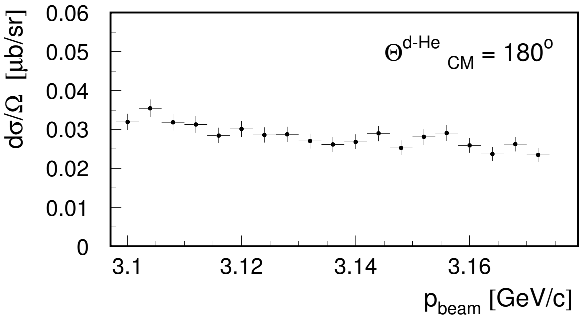

Figure 5. $dp \to {}^3\mathrm{He}\,\pi^0$ cross section for backward ^{3}He scattering as a function of beam momentum.

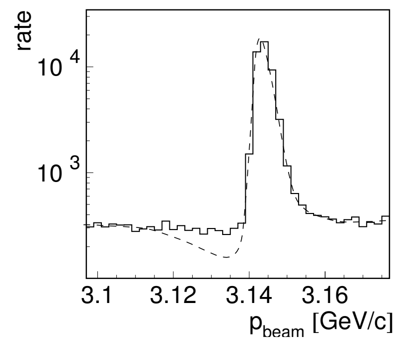

Figure 6. Threshold excitation curve for the $dp \to {}^3\mathrm{He}\,X$ reaction measured near the η threshold. Dashed line indicates shape of expected cusp.

state including the η meson and the non-resonant background corresponding to the multi-pion production. The threshold excitation curve was determined by varying the beam momentum and adjusting the setting of the SPES-IV spectrometer in such a way that only the ^{3}He associated with the maximum missing masses were registered. Since the COSY-11 momentum and angular acceptance is much larger than one of the SPES IV spectrometer, limitation of the acceptance was realized by means of corresponding cuts during the data analysis. More details concerning the data analysis and preliminary threshold excitation curve are given in Ref. [12]. Final threshold excitation curve based on the full collected statistics is shown in Fig. 6. The peak in the middle of the spectrum is associated with opening of the $dp \to {}^3\mathrm{He}\,\eta$ channel. Contrary to the SATURNE result we see no cusp near the η threshold.

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