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SEARCH FOR THE ^{3}He − η BOUND STATE AT COSY-11

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FOR THE COSY-11 COLLABORATION

We have measured excitation function for $dp \to ppp\pi^-$ reaction near the η production threshold. We observe an enhancement of the counting rate above the threshold which can originate from the production of the η meson in the reaction $dp \to {}^3\mathrm{He}\,\eta$ and its subsequent absorption on neutron in the ^{3}He nucleus leading to creation of the $p\pi^-$ pair.

Keywords: Meson production; eta-mesic nucleus; final state interaction.

1. Introduction

Observation of a bound state of the η meson and atomic nucleus would be very interesting for studies of the $\eta - N$ interaction and for investigation of $N^*(1535)$ properties in nuclear matter. Existence of such states was postulated by Haider and Liu[1], however, up to now no firm experimental evidence for eta-mesic matter was found. Encouraged by the recent data from MAMI showing some indications for photoproduction of $\eta -^3$ He bound state[2], we performed a search for this state in the $d-p$ collisions. The measurements reported here were carried out with the COSY-11 detector[3] using a slowly ramped internal deuteron beam of the COSY accelerator[4] scattered on a proton target[5]. The momentum of the deuteron beam was varied continuously within each acceleration cycle from 3.095 GeV/c to 3.180 GeV/c, crossing the kinematical threshold for the η production in the $dp \to {}^3\mathrm{He}\,\eta$ reaction at 3.141 GeV/c[6]. A signature of existence of the $\eta - {}^3$He bound state would be an observation of a resonance-like structure with the center lying below the η production threshold in excitation curves for chosen decay channels. As decay modes we registered $^3\mathrm{He}\,\pi^0$, $ppp\pi^-$ and pd channel.

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We measured also the total and differential cross sections for the η production in the $dp \to {}^3\mathrm{He}\,\eta$ reaction. The cross sections from our measurements[6] and from similar measurements of the ANKE collaboration[7] indicate a presence of a bound or virtual state in the $\eta - {}^3\mathrm{He}$ system[8]. In turns, the excitation function for the $dp \to {}^3\mathrm{He}\,\pi^0$ process registered in the present experiment does not show any structure which could originate from the decay of $\eta - {}^3\mathrm{He}$ bound state[9]. However, this does not exclude existence of such state since its signal can lie below the sensitivity of the present experiment due to small production cross section and/or due to low probability of decay in the registered ${}^3\mathrm{He}\,\pi^0$ channel[9]. We expect that $ppp\pi^-$ can be a much more favorable decay channel since it is produced in a one step process via absorption of the η meson on the neutron inside the ${}^3\mathrm{He}$ nucleus leading to the creation of the $p\pi^-$ pair in the reaction $\eta n \to N^*(1535) \to p\pi^-$. In the ηn center-of-mass frame, the pion and the proton are emitted back-to-back with momenta of about 431 MeV/c. In the reaction center-of-mass system these momenta are smeared due to the Fermi motion of the neutron inside the ${}^3\mathrm{He}$ nucleus. However, they are significantly larger than the momenta of the two remaining protons in the ${}^3\mathrm{He}$ nucleus which play a role of "spectators" moving with the Fermi momenta which are in the order of 100 MeV/c. In the next chapter we present recent results of analysis of the $dp \to ppp\pi^-$ data collected in our experiment.

2. Excitation Function for the $dp \to ppp\pi^-$ Reaction

The protons originating from the $dp \to ppp\pi^-$ reaction were momentum analyzed in the COSY-11 dipole magnet and their trajectories were registered with a pair of drift chambers. A detailed description of the detection system can be found e.g. in articles[3]. The experimental trigger required at least three charged tracks in the scintillation hodoscope S1 standing in a distance of about 3 m from the target, and additionally at least two tracks in the hodoscope S3 placed 9 m behind S1. The momentum acceptance defined by the S1-S3 pair covered the momenta expected for the spectator protons. The time of flight measured between S1 and S3 combined with the momentum measurement was used for identification of the outgoing protons (see Fig. 1). For identification of protons registered in the S1 but not reaching the S3 hodoscope, the time of flight between the target and S1 was used. The pions were identified using the missing mass method (see Fig. 2).

Left panel of Fig. 3 shows distribution of the transversal vs. longitudinal momentum components of registered protons from the $dp \to ppp\pi^-$ reaction. This distribution is dominated by events of quasi-free π^- production in the process $np \to pp\pi^-$ where the neutron projectiles originate from the deuteron beam. The corresponding spectator protons from the deuteron beam are visible as a group of counts on the right hand side of Fig. 3(left). In the further analysis we rejected the quasi-free π^- production by setting an upper limit for the longitudinal proton momenta equal to 0.18 GeV/c in the c.m. system, represented by the dashed line in Fig. 3(left).

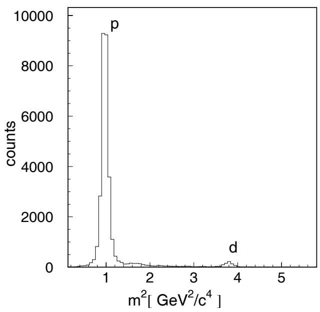

Fig. 1. Invariant mass squared determined on the basis of the time of flight between the S1 and S3 hodoscope.

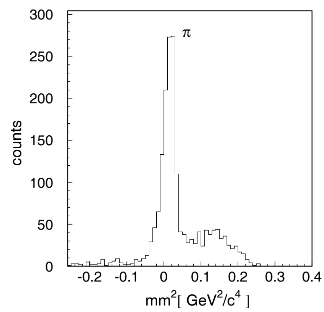

Fig. 2. Missing mass squared of the three protons system.

The distribution of the π^- momenta determined after application of this cut is centered at the value of about 430 MeV/c (see middle panel of Fig. 3) as expected for pions originating from decay of the $N^*(1535)$. Also the distribution of the c.m. angles between the pion momentum vector and the momentum vector of the proton with the highest absolute value of the c.m. momentum indicates for such decay since the angles are close to 180°(right panel of Fig. 3).

The counting rate of all identified $dp \to ppp\pi^-$ events including the quasi-free π^- production remains constant in the scanned range of the beam momentum (see Fig. 4a). However, after rejection of the quasi-free events, the number of $dp \to ppp\pi^-$ counts in the beam momentum interval above the η threshold is higher than the number of counts in the beam momentum interval of equal width below the threshold (see Fig. 4b). This difference is equal to $23 - 9 = 14$ and its statistical significance is of 2.5σ. This difference only slightly decreases to the value of $16 - 4 = 12$ after application of an additional requirement that two out

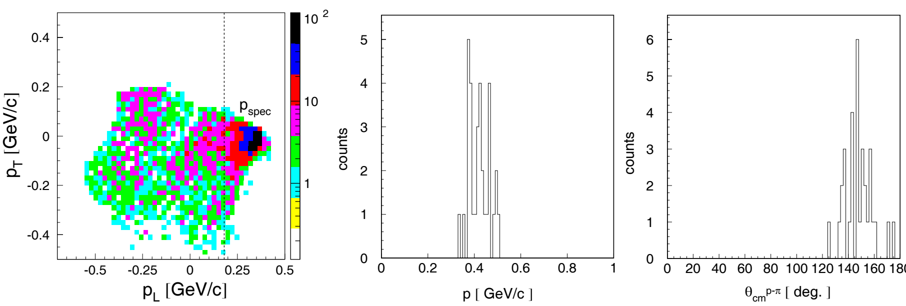

Fig. 3. (Left) Transversal vs. longitudinal momentum distribution of protons. The dashed vertical line represents the cut ($p_L < 0.18 GeV/c$) applied on the longitudinal proton momenta. The counts at $p_L > 0.18 GeV/c$ correspond predominantly to the spectator protons from the deuteron beam. (Middle) Distribution of pion momentum in the c.m. system. (Right) Angle between the pion momentum vector and momentum vector of the proton with the highest absolute value of c.m. momentum.

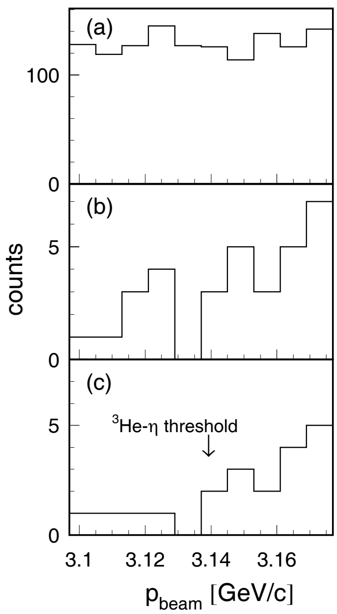

Fig. 4. Number of $dp \to ppp\pi^-$ events as a function of the beam momentum: without any cuts (a), after rejection of events corresponding to the quasi-free π^- production (b), and after additional cut on the momenta of the spectator protons - $p^{cm} < 200$ MeV/c (c).

of the three outgoing protons have the c.m. momenta smaller than 200 MeV/c as expected with high probability for the spectator protons (see Fig. 4c). As a possible reaction mechanism explaining the observed excitation function we consider production of the η meson in the reaction $dp \to {}^3\text{He}\,\eta$ which subsequently convert to π^- in the interaction with the neutron in the ^{3}He nucleus in the process $\eta n \to N^*(1535) \to p\pi^-$.

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References

1. Q. Haider, L.C. Liu, *Phys. Lett. B* **172**, 257 (1986).
2. M. Pfeiffer *et al.*, *Phys. Rev. Lett.* **92**, 252001 (2004).
3. S. Brauksiepe *et al.*, *Nucl. Instr. Meth. Phys. Res. Sect. A* **376**, 397 (1996);
   P. Klaja *et al.*, *AIP Conf. Proc.* **796**, 160 (2005);
   J. Smyrski *et al.*, *Nucl. Instr. Meth. Phys. Res. Sect. A* **541**, 574 (2005).
4. D. Prasuhn *et al.*, *Nucl. Instr. Meth. Phys. Res. Sect. A* **441**, 167 (2000).
5. H. Dombrowski *et al.*, *Nucl. Instr. Meth. Phys. Res. Sect. A* **386**, 228 (1997).
6. J. Smyrski *et al.*, *Phys. Lett. B* **649**, 258 (2007).

7. T. Mersmann *et al.*, *Phys. Rev. Lett.* **98**, 242301 (2007).
8. C. Wilkin *et al.*, *Phys. Lett. B* **654**, 92 (2007).
9. J. Smyrski *et al.*, *Nucl. Phys. A* **790**, 438 (2007);
   J. Smyrski *et al.*, *Acta Phys. Slovaca* **56**, 213 (2006).