# Study of the $dp \to ppp\pi^-$ reaction near the $\eta$ production threshold with COSY-11

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The excitation function as well as differential distributions for the $dp \to ppp\pi^-$ reaction have been measured near the $\eta$ production threshold in a search for a signal from decays of $^3$He$-\eta$ bound state. The measurements were done at the Cooler Synchrotron COSY-Juelich with the COSY-11 detection system [1]. Fig. 1 shows the c.m. distribution of the transversal vs. the longitudinal momentum components of the registered protons from the $dp \to ppp\pi^-$ reaction. This distribution is dominated by events of quasi-free $\pi^-$ production in the process $np \to pp\pi^-$ where the neutron projectiles originate from the deuteron beam. The corresponding spectator protons from the deuteron (visible as a group of counts on the right hand side) were rejected in the further analysis 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. The counting rate of all identified

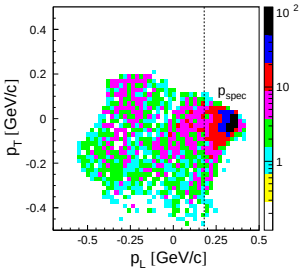


Fig. 1: Transversal vs. longitudinal momentum distribution of protons in the center of mass system.

$dp \to ppp\pi^-$ events including the quasi-free $\pi^-$ production remains constant in the scanned range of the beam momentum. However, after rejection of the quasi-free events, the number of $dp \to ppp\pi^-$ counts in a beam momentum interval above the $\eta$ threshold is higher than the number of counts in the beam momentum interval of equal width below the threshold.This difference is equal to $23-9=14$ and its statistical significance is of $2.5\sigma$. The observation of this effect we reported already in Ref. [3]. As a possible reaction mechanism –explaining the observed enhancement– we suggested the production of "on-shell" $\eta$ mesons in the reaction $dp \to {}^3\mathrm{He}\,\eta$ which subsequently convert to pions in the interaction with one of nucleons in the $^3$He nucleus via excitation of the N(1535) resonance. In order to estimate the counting rate of the $dp \to ppp\pi^-$ events originating from the $\eta$ absorption we assumed that the absorption cross section $\sigma_{abs}$ is equal to the cross section for the $dp \to {}^3\mathrm{He}\,\eta$ reaction. This assumption we justify by the observation that the real and imaginary part of the $^3$He$-\eta$ scattering length [2] have comparable values. The number $\Delta N$ of the $dp \to ppp\pi^-$ events corresponding to the momentum interval $\Delta p$ of the ramped beam was calculated using the following formula:

$$\Delta N = \frac{\delta L}{\delta p} A \frac{1}{3}\frac{2}{3}\sigma_{abs}\Delta p, \qquad (1)$$

where $\frac{\delta L}{\delta p}$ is the integrated luminosity per beam momentum unit which was equal to about 1.0 nb$^{-1}$/MeV/c. $A$ is the acceptance of the COSY-11 detection system for the $dp \to ppp\pi^-$ channel equal to 0.0005. It was calculated in computer simulations assuming that the two spectator protons have c.m. momenta described by the Fermi momentum distribution of protons in the $^3$He nucleus taken from Ref. [4]. For the proton-pion pair associated with the two spectator protons, an isotropic angular distribution in the c.m. system of this pair was assumed. The factor $\frac{1}{3}$ in the above formula represents the probability of absorption on the neutron being one of three nucleons in the $^3$He nucleus and the factor $\frac{2}{3}$ is the Clebsch-Gordan coefficient associated with the isospin coupling in the process $\eta n \to \pi^- p$.

The result of our estimation underestimates the experimental counts roughly by an order of magnitude and thus it does not corroborate the $\eta$ absorption hypothesis.

In the momentum distribution for the spectator protons the experiment and the simulations of the direct production give much higher momenta than the $\eta$ absorption. This indicates, that the dominant process in the observed $dp \to ppp\pi^-$ reaction is not associated with the $\eta$ absorption. This is also confirmed by the distribution of the c.m. angles between the pion momentum vector and the momentum vector of the leading proton which, in the case of simulations of the $\eta$ absorption, are close to $180^\circ$ and for the experiment lie around $160^\circ$. Contrary to the discussed momentum spectra, the experimental angular distribution does not agree with the results of simulations for the direct production. One can expect, that due to very similar kinematical conditions, absorption of $\eta$ mesons bound in the $^3$He nucleus is characterized by differential distributions which are very close to the ones predicted in our simulations for the absorption of "on-shell" $\eta$ mesons. In particular one can expect that the $\pi^- - p$ pairs originating from a decay of the $\eta$-mesic $^3$He are emitted at c.m. angles concentrated predominately in the range $150^\circ - 180^\circ$ as it is the case for the $\eta$ absorption. In this angular range, there are only two experimental counts. Assuming, that these two counts originate from decay of the $^3$He$-\eta$ bound state, we estimated the cross section for the production of such a state in the $d-p$ collisions close to the $\eta$ production threshold. The calculation was done using $\sigma_{abs}$ derived from formula 1. The resulting cross section of $0.27 \pm 0.19$ $\mu$b should be considered as an upper limit for the production cross section of the $^3$He$-\eta$ bound state since the observed two events might originate from other processes than the bound state decay. It is worthwhile to note that this limit is comparable with the near-threshold cross section for the $dp \to {}^3\mathrm{He}\,\eta$ reaction equal to about 0.4 $\mu$b.

**References:**

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