MESON PRODUCTION IN $p + d$ REACTIONS*

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Differential cross sections of the $pd \to {}^3\mathrm{H}\,\pi^+/{}^3\mathrm{He}\,\pi^0$ reactions were measured simultaneously at three beam momenta: 750 MeV/c, 800 MeV/c and 850 MeV/c. The differential cross section of the $pd \to {}^3\mathrm{He}\,\eta$ was measured at 1675 MeV/c beam momentum. All measurements cover a wide angular range in the CM system. The experiments were performed at the COSY accelerator in Jülich, Germany, by means of high purity Germanium Wall detector together with the magnetic spectrometer BIG KARL. Estimated cross sections were compared with the predictions of simple theoretical models. In case of isospin symmetric $pd \to {}^3\mathrm{H}\,\pi^+/{}^3\mathrm{He}\,\pi^0$ reactions, the average cross section ratio was estimated.

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1. Introduction

The differential cross sections of

$$
\begin{aligned}
pd &\to {}^3\mathrm{H}\,\pi^+\,,\\
pd &\to {}^3\mathrm{He}\,\pi^0\,,\\
pd &\to {}^3\mathrm{He}\,\eta\,,
\end{aligned}
\tag{1}
$$

reactions allows to study the reaction mechanisms. In a simple impulse approximation above processes are dominated by the underlying elementary meson productions in *pp* or *pn* collisions. On the other hand the measured cross sections are influenced by Fermi momentum distribution in a deuteron.

Most of available theoretical approaches concerning pion production on deuteron target is based on impulse approximations [1, 2]. However, they can differ in the treatment of the bound state wave functions, additional interactions, distortions, inclusion of the deuteron D-state and so on. One of those approaches is the model of Locher and Weber [3]. However, fitted to the $pd \to {}^3\mathrm{He}\,\pi^0$ data in the Δ-resonance region it disagrees with measurements very close to threshold, where the shape of the excitation function is consistent with Germond and Wilkin model predictions [4]. However, the latter cannot be succesfully extrapolated to higher beam energies to describe experimental data near the Δ-resonance bump. Hence, for the $pd \to {}^3\mathrm{He}\,\pi^0$ measurement we chose three beam momenta to fill the gap in the experimental data in the mentioned intermediate region.

The η-meson production in *pd* collision gives an opportunity to investigate the interaction of the lightest isoscalar meson with the nucleus. According to Haider and Liu [7, 8] the attractive η—N potential can lead to the formation of η-mesic nuclei with mass number $A \geq 10$ or even with mass number $A \geq 2$ as reported by Rakityansky *et al.* [9]. It is not clear yet if the quasi-bound η—^{3}He states can be created in the $pd \to {}^3\mathrm{He}\,\eta$ process. Some theoretical works report on this topic [10–12].

2. Experiment

Accelarated proton beam from COSY[1] synchrotron was focused on a 6.4 ± 0.2 mm thick target cell filled with liquid deuterium. Depending on the emission angle reaction products could be detected by the Germanium Wall detector or in the magnetic spectrometer BIG KARL. Both Germanium Wall and BIG KARL spectrometer allowed to reconstruct all three components of the particle momentum at the target point.

[1] COoler SYnchrotron, Forschungszentrum Jülich, Germany.

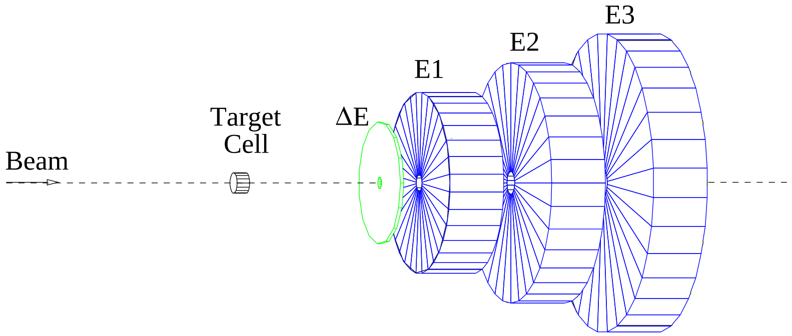

Fig. 1. Schematic view of Germanium Wall detector. All the set-up has a radial symmetry. The first element denoted by ΔE has a structure of 200 Archimedes spirals with right or left orientation depending on the detector side. Other elements denoted by E consist of 32 wedges.

The Germanium Wall is a high purity germanium detector having conical acceptance with an opening angle of ± 287.5 mrad, see Fig. 1 [5]. It allows to measure particle energy losses and to determine particle emission angle. The Germanium Wall consists of up to four segmented elements: the first one is 1.7 mm thick and has a structure of 200 Archimedes spirals with right or left orientation depending on the detector side. It defines approximately 40000 possible crossing points thus allowing good position and track reconstruction. Another three (or two, depending on experimental needs) elements are approximately ten times thicker (15 mm) and consist of 32 radial wedges[2]. The central hole in the detector with the opening angle of ± 28 mrad is foreseen for the beam to pass through to the beam dump. The reaction products emitted with small angles go through the hole as well and can be detected in BIG KARL.

BIG KARL consists of five active magnetic elements: three quadrupoles and two dipoles, see Fig. 2 [6]. It was used in a mode with point to point imaging in horizontal and point to parallel imaging in vertical direction. The focal plane detection set-up consisted of a two layer plastic scintillator hodoscope and two stacks of multi-wire drift chambers. The energy losses in 4 mm thick scintillators and time of flight between the layers were used for the particle identification. Signals delivered by the drift chambers were used to reconstruct the particle momentum at the target point.

Outside the scattering chamber few scintillator luminosity counters were mounted and used to determine the beam intensity.

[2] For the experiments described here only two such segments were mounted.

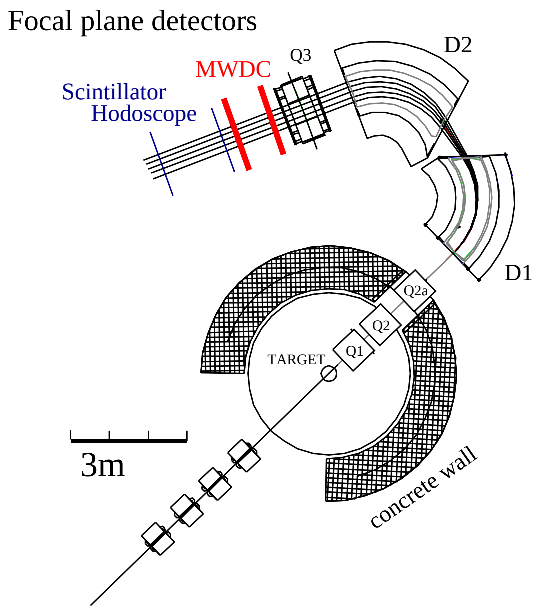

Fig. 2. Schematic view of BIG KARL magnetic spectrometer consisting of three quadrupoles Q1, Q2 and Q2a and two dipoles D1 and D2. The quadrupole Q3 was not used. The particles could be measured by means of the detectors at the focal plane: two layers of scintillator hodoscope and two stacks of Multi-Wire Drift Chambers (MWDC).

3. Results

3.1. $pd \to {}^3\mathrm{H}\,\pi^+/{}^3\mathrm{He}\,\pi^0$

The evaluated differential cross sections as functions of triton or helium $\cos(\vartheta)$ in centre of mass system for three measured beam momenta 750 MeV/c, 800 MeV/c and 850 MeV/c are shown in Fig. 3. A strong forward–backward assymetry is observed. For the lowest beam momentum the dependence fall off exponentially. For two higher beam momenta an additional component to the exponential decrease at forward angles appears. The presented experimental data are compared with predictions of Locher–Weber model and with calculations of Canton and Ueda. The models cannot reproduce the absolute yield of pion production and they are able to predict the shape of the distributions only at backward angles. The differential cross sections were fitted with analytical functions in order to evaluate the total cross sections for $pd \to {}^3\mathrm{H}\,\pi^+/{}^3\mathrm{He}\,\pi^0$ reactions. Legendre polynomials were found to yield the smallest χ^2/degree of freedom. The results are presented in Table I.

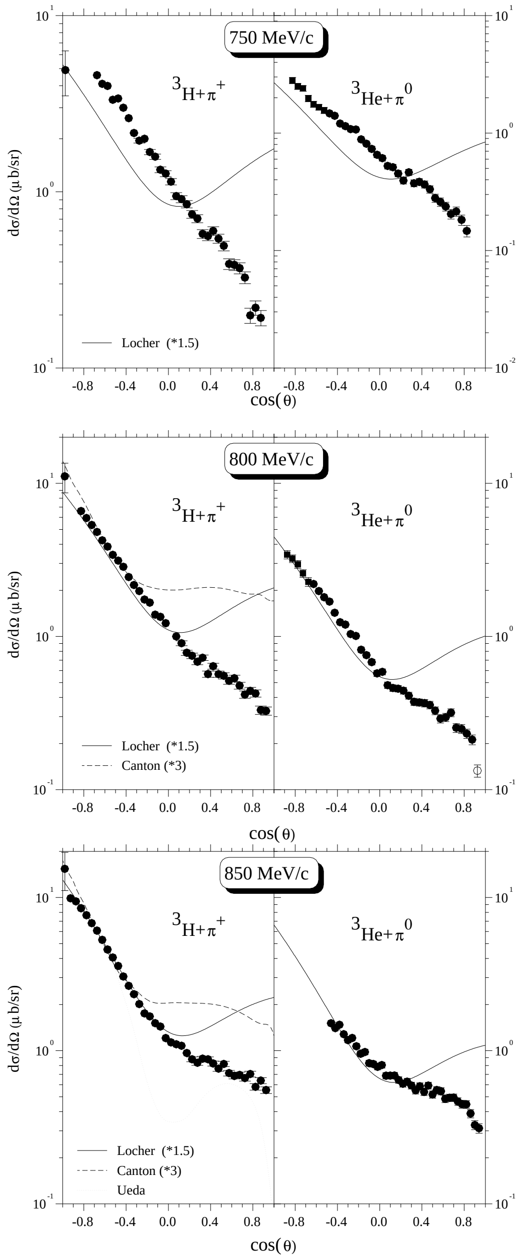

Fig. 3. Differential cross sections for $pd \to {}^3\mathrm{H}\,\pi^+/{}^3\mathrm{He}\,\pi^0$ reaction. Measured data are shown with full dots. Scaled theoretical calculations according to models of Locher–Weber, Canton and Ueda are presented as well.

TABLE I

Total cross sections evaluated for $pd \to {}^3\mathrm{H}\,\pi^+/{}^3\mathrm{He}\,\pi^0$ reactions. Only statistical errors are given here.

Momentum [MeV/c]	$\sigma(pd \to {}^3\mathrm{He}\,\pi^0)$ [μb]	$\sigma(pd \to {}^3\mathrm{H}\,\pi^+)$ [μb]
750	12.48 ± 0.17	26.72 ± 0.37
800	14.43 ± 0.13	28.05 ± 0.18
850	15.54 ± 0.30	34.90 ± 0.23

Since both reactions were measured simultaneously the obtained results could be used to estimate the cross section ratio — the parameter often used is isospin symmetry breaking studies. In a very naive model, if one neglects the Coulomb interaction, the tritons are expected to be produced twice often as helium particles. We evaluated the cross section ratio of both processes at the same η values[3] to 1.905 ± 0.034 at $\eta = 0.807$ and 2.145 ± 0.013 at $\eta = 1.014$.

3.2. $pd \to {}^3\mathrm{He}\,\eta$

The evaluated differential cross section for $pd \to {}^3\mathrm{He}\,\eta$ reaction measured at 1675 MeV/c beam momentum is presented in Fig. 4. Two separate runs were performed at different experimental times. They seem to be consistent within statistical errors. The measured points together with one

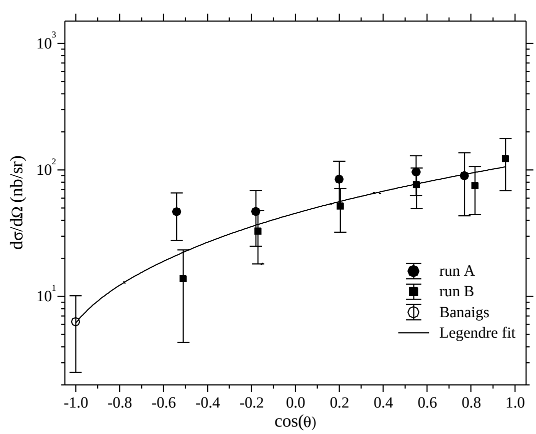

Fig. 4. Differential cross section for $pd \to {}^3\mathrm{He}\,\eta$ reaction. Present data are marked with full dots and full squares. The Legendre polynomial fit was made to the data points including the one of Banaigs [13].

[3] The η parameter is defined as pion momentum in CM system divided by its mass.

measured in Saclay were fitted with Legendre polynomial in order to evaluate the total cross section resulting with 622 ± 91nb. In a similar way the experimental data from Banaigs *et al.* [13], Loireleux [14] and Kirchner [15] were treated. Together with the data from Mayer [16] indicating the narrow maximum near threshold, the total cross section data as a function of proton beam momentum are shown in Fig. 5. The experimental data are compared with two-step model of Kilian and Nann [17]. It assumes that the pion from elementary $pp \to d\pi^+$ reaction produces η-meson in rescattering process. However, the present data exclude this model as the main reaction mechanism. The scaled calculation employing the matrix element from photoproduction is represented by the solid line in the figure giving the overall trend of the excitation function.

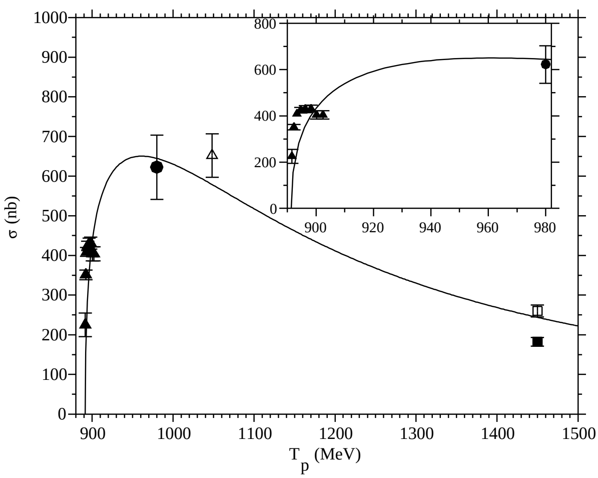

Fig. 5. Total cross section for $pd \to {}^3\mathrm{He}\,\eta$ reaction as function of beam kinetic energy. The present data point is marked with full dot. Near threshold data from Mayer [16] indicate some enhancement of the the cross section above the solid line — calculation employing the matrix element from photoproduction on the proton. The insert shows the near threshold region.

4. Summary

The pion and η-meson production was studied in *pd* reactions. We measured the differential cross sections over a wide angular range in CM system. The beam momenta were chosen to fill the gap in the available experimental information.

For the pion production comparison with a few theoretical models was made showing their weakness especially for forward angles in CM system. All calculation had to be scaled to match the measured production yield.

The simultaneous measurement of both neutral and charged pion production was a test for isospin symmetry breaking. The average cross section ratio considered at the same η-value was evaluated to 2.11 ± 0.08 for the beam momenta between 750 MeV/c and 850 MeV/c. This ratio is consistent with result of [18] but is smaller than the one given by [19].

A good agreement of the data for $pd \rightarrow {}^3\mathrm{He}\,\eta$ reaction with the calculation based on $N^*(1535)$-resonance excitation is an indication that this is the dominant reaction mechanism. However, the enhancement of the data in near threshold region relative to the mentioned calculation can be caused by strong final state interaction not included in the model, see the insert in Fig 5.

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