Meson Production in p+d Reactions

GEM Collaboration
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Abstract. Pion and η production on the deuteron are studied at energies in the vicinity of the absolute threshold. The data are expected to be sensitive to high momentum components in the deuteron wavefunction as well as to two step processes.

The study of meson production on the deuteron is the first step towards an understanding of meson production on nuclei and the related in-medium effects. In a first approximation, the reaction can be assumed to be mainly a nucleon–nucleon reaction with the second nucleon in the deuteron being a mere spectator [1]. However, the struck nucleon has a Fermi motion and thus an effective mass. In addition rescattering on the spectator nucleon may take place. All these processes

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do not take place reactions on the nucleon.

Here we will concentrate on \( \pi \) and \( \eta \) meson production, i.e., the reactions

\[
\begin{align*}
p + d &\rightarrow ^3\text{He} + \pi^0, \quad (1) \\
p + d &\rightarrow ^3\text{He} + \eta. \quad (2)
\end{align*}
\]

The underlying elementary process for both reactions is the \( p + n \rightarrow d + \text{meson} \) reaction. In both reactions, resonances play an important role: in case of the \( \eta \) it is the \( N^*(1535) \) which is an s-wave, while in the \( \pi \) channel it is the \( \Delta(1232) \), a p-wave. From a comparison of both reactions, one may therefore learn how different boundary conditions influence the reaction mechanism. In the experiments for reaction 1, the isospin related \( p + d \rightarrow ^3\text{H} + \pi^+ \) (3) was simultaneously measured. The experiment was performed at the external pro-

![Diagram](image_url)

FIGURE 1. The detector system "germanium wall". In the present measurement, detector E2 was removed.

ton beam of the COSY accelerator. Because of its storage mode, one can extract the beam by a stochastic method in time periods over several seconds, thus avoiding pile-up as well as dead time. The beam was focused to the center of a target cell, containing liquid deuterium with dimensions 6 mm in diameter and thicknesses from 2 to 6.5 mm in the different runs, respectively. Recoiling baryons were detected in an angular range in the laboratory system between 30 to 250 mrad by a high purity germanium stack detector called the germanium wall (see Fig. 1). Particles emitted into smaller angles were identified with a magnetic spectrograph. This setup has full acceptance for threshold measurements in the center of mass system.
The first detector has 40000 pixels formed by 200 Archimedes' spirals bent to the left and right on the front and rear side, respectively. The calorimeter detectors which follow have structures of 32 wedges on one side. More details on the detector can be found elsewhere [3]. Due to its high granularity, the germanium wall is well suited for high luminosities. However, in the early runs for reaction 2, a large halo prevented making use of this feature. The halo has now been reduced to the 1% level with the beam not cooled. Such were the conditions for the measurements of the 1 and 3 reactions. data were taken at beam momenta ranging from 750 MeV/c up to 1050 MeV/c in steps of 50 MeV/c, thus covering the full range of the Δ-excitation. For η production a momentum of 1673 MeV/c was chosen which corresponds to the pole position of the $N^*$ resonance. The information deduced from the germanium wall are energy, emission vertex and particle type. The energy information for a given exit channel can be transformed into the emission angle in the centre of mass system without making use of the additional measured quantities. However, possible background can not be subtracted by this method. Therefore, the missing mass of the unobserved pion is extracted by making use of all measurements together with the knowledge of the initial state and applying

\[ T = 330 \text{ MeV} \]

**FIGURE 2.** Angular distribution for pion from the two reactions. The presently obtained cross sections are compared with previous data for approximately the same beam energy ([4–6]), or deduced from pion absorption employing detailed balance (Ref. [7]). For the data from Dutty et al. [8] charge symmetry is assumed.
conservation of momentum, energy, charge and baryon number.

The measured differential cross sections in the centre of mass system for pion production at a beam momentum of 850 MeV/c are shown in Fig. 2, together with earlier measurements close to that beam momentum. The angular distributions for both reactions show a backward peaking of the $A = 3$ nuclei which corresponds to a forward peaking of the pion. This is also found in the other data to which the present results are compared with. The flat part seen in the range $\cos(\theta) \leq 0$ is not found in the time-reversed and isospin-related data from Källne et al. [7]. It is again this region for the $^3He + \pi^+$ channel where the data from Ref. [5] do not agree with the present results. The enhancement is predicted by a two-step process [11,12], where the resultant pion scatters on the spectator nucleon. It is obvious that none of the earlier measurements has the good statistics of the present results. We have fitted Legendre polynomials to the angular distributions. Polynomials up to 4th order were found necessary to achieve reasonable $\chi^2$ values.

FIGURE 3. Angular distribution of the reaction $p + d \rightarrow ^3He + \eta$. Added are two points from Ref’s [9,10]. A Legendre polynomial fit is shown as solid curve.

In Fig. 3 are the results for the $\eta$ production shown. Results from two different runs agree nicely with each other. Two data points for backward emission from Ref.’s [9,10] are added. The total cross section is extracted from a 2. order Legendre polynomial fit, also shown in the Figure. It should be mentioned that this measurement is still subthreshold in the nucleon–nucleon system, although quite far above the absolute threshold. The large momentum transfer of $\Delta p = 706$ MeV/c, which is nearly double than in the pion reaction, corresponds to a distance of only 0.27 fm. The reaction is, therefore, extremely sensitive to the high momentum

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components in the deuteron wave function.

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