

## Contribution of three nucleon force investigated in deuteron-proton breakup reaction

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**Abstract.** The elastic scattering and deuteron breakup data were collected in the experiment performed at KVI (Groningen) with use of unpolarized deuteron beam with energy of 80 MeV per nucleon, impinging on hydrogen target. The procedure applied to determine total integrated luminosity is presented. The result will be used for normalization of the differential cross section for the deuteron-proton breakup reaction.

### 1 Introduction

3NF, Coulomb interactions [1] or relativistic component [2]. All effects reveal in different parts of the phase space with different magnitude what can be noticed in the observables.

Investigation of three-nucleon system dynamics provides basis for understanding interaction between nucleons, going also beyond simple pairwise nucleon-nucleon (NN) forces. Such additional dynamics is called three-nucleon force (3NF). It arises in the meson exchange picture as an intermediate excitation of a nucleon to a  $\Delta$ -isobar or it appears in a certain order of expansion from Chiral Effective Field Theory [1]. Modern models of 3NF, like Tucson-Melbourn 99 [2] or Urbana IX [3], are combined with the adequate realistic NN potential. Alternatively, the  $\Delta$ -isobar can be included explicitly in the coupled channel framework [4]. Precise measurement of observables like the cross-section in three-nucleon system is the way to validate these models.

### 2 Experimental set-up

The experiment was performed with the use of the deuteron beam provided by AGOR cyclotron at Kernfysisch Versneller Instituut in Groningen (the Netherlands). Unpolarized deuteron beam of

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160 MeV energy impinged on 3.3 mm thick liquid hydrogen target. Charged products of the reaction were detected by the BINA detection system (Big Instrument for Nuclear Analysis). BINA apparatus has been specially designed to investigate few-nucleon systems in the range of intermediate energies. It covers almost  $4\pi$  geometry and is composed of two main parts: forward Wall ( $\vartheta$ :  $13^\circ$ -  $40^\circ$ ) and backward Ball ( $\vartheta$ :  $40^\circ$ - $165^\circ$ ). In the forward Wall particles are registered in three detectors. At first, they are detected in the multi-wire proportional chamber (for reconstruction of angles of the scattered charged particles), next – in one of 12 vertical thin plastic scintillators (stripes) and finally, in the hodoscope made of 10 horizontal thick plastic scintillator (slabs). The plastic stripes and slabs form 240 telescopes for the  $\Delta E$ -E method of particle identification. Ball is made up of 149 triangular detector elements working in a phoswich mode. The Ball at the same time plays the role of the reaction chamber as well as the detector. Detailed description of the detector can be found in [5].

### 3 Data analysis

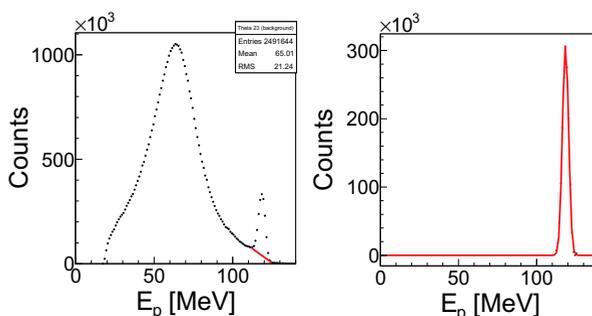
The analysis presented in this report focuses on the particles scattered forward from the reaction point and being detected in the WALL part of the detector. The details of the most basic steps of the data analysis including energy calibration, particle identification (PID) and detector efficiency calculation were described in previous publications [6–9]. To perform reliable PID the linearization method was applied. The  $\Delta E$ -E spectra were transformed to the new energy dependent variable as described in [7]. Differential cross-section distributions for the deuteron breakup reaction has been calculated as:

$$\sigma(\vartheta_1, \vartheta_2, \varphi_{12}, S) = \frac{N_{pp}(\vartheta_1, \vartheta_2, \varphi_{12}, S)}{L \Delta\Omega_1 \Delta\Omega_2 \Delta S \epsilon^{\vartheta_1 \vartheta_2 \varphi_{12}}} \quad (1)$$

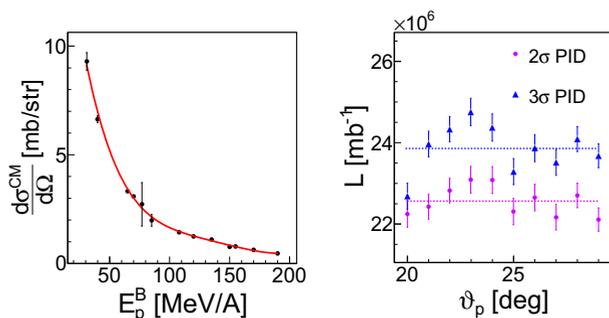
where:  $N_{pp}(\vartheta_1, \vartheta_2, \varphi_{12}, S)$  is the number of proton–proton pairs, registered within a bin of  $1^\circ$  for polar angles ( $\vartheta_1, \vartheta_2$ ), of  $10^\circ$  for relative azimuthal angle ( $\varphi_{12}$ ) and of 8 MeV for the  $S$  variable standing for length along the corresponding kinematical curve.  $L$  is the total integrated luminosity;  $\epsilon^{\vartheta_1 \vartheta_2 \varphi_{12}}$  represents the detection efficiency for a proton pair emitted at these angles;  $\Delta\Omega_{1,2}$  - the corresponding solid angles. The normalization factor  $L$  is obtained on the basis of elastic scattering data analyzed for each  $\Delta\vartheta = 1^\circ$  bin in the range ( $20^\circ, 29^\circ$ ). The final luminosity is taken as an average value of:

$$L(\vartheta_p) = \frac{N^{el}(\vartheta_p)}{\sigma^{el}(\vartheta_p) \Delta\Omega(\vartheta_p) \epsilon^{\vartheta_p, \varphi_p}} \quad (2)$$

Here  $\sigma^{el}(\vartheta_p)$  is cross-section for proton–deuteron elastic scattering,  $\epsilon^{\vartheta_p, \varphi_p}$  represents the efficiency of registering of a proton and  $\Delta\Omega(\vartheta_p)$  is the solid angle.  $N^{el}(\vartheta_p)$  is the number of elastically scattered protons registered at the  $\vartheta_p$  angle, after subtracting the background component (see Fig. 1) It is obtained by fitting the gaussian function and integrating within  $\pm 3\sigma$ . Since there is no experimental data for the cross-section for the elastic scattering at 80 MeV/A,  $\sigma^{el}(\vartheta_k)$  was obtained from the interpolation between all the data measured at energies in wide range 30–190 MeV/A. For each energy, polynomial was fitted to angular distribution of the data in the center of mass frame ( $\vartheta^{CM}$ ). Then, for each value of  $\vartheta^{CM}$  the polynomial was fitted to the energy distribution (see Fig. 2). Finally, the transformation of the interpolated values for 80 MeV/A to laboratory frame was done. The systematic uncertainty connected to particle identification procedure, mentioned earlier, is illustrated in Fig. 2. Since different particles tend to group around well defined particle kind specific values, one may use gaussian distribution to control the quality of particle type assignment. The systematical error was calculated as difference between values of luminosities obtained by accepting ranges of two and three  $\sigma$  around the proton peak in PID method. The error due to this cut was estimated to be about 7%.



**Figure 1.** *Left panel:* Energy distribution of protons registered with the minimum-bias trigger in chosen  $\vartheta_p = 23^\circ$  bin. Straight red line represents the background model. *Right panel:* Energy distribution of protons from elastic scattering channel obtained after the background subtraction.



**Figure 2.** *Left panel:* Polynomial fit to the elastic scattering cross-section data in function of the beam energy example for  $\vartheta^{CM} = 132^\circ$ . *Right panel:* Integrated luminosity obtained for each of the studied  $\vartheta_p$  angle. Horizontal lines represent weighted averages of the data points.

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