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Investigation of three nucleon force effects in deuteron-proton breakup reaction

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Abstract. Experimental study of the deuteron-proton breakup process was perfomed in KVI Groningen. In this paper current status of the collected data analysis is presented, including preliminary results of the cross section for the sample kinematical configuration.

1 Introduction

Investigation of three-nucleon systems provides basis for the understanding of effective nucleon-nucleon (NN) potential and dynamics beyond such pairwise interactions. Quantitatively, this can be done by comparing observables calculated with the use of Faddeev equations with results of precise measurements. Modern realistic NN interaction models describe well systems composed of two nucleons. Calculations based on these models could correctly predict observables for $3N$ systems only if combined with additional component of the dynamics – the three nucleon force ($3NF$) [1]. Three-nucleon interaction can also be introduced within the coupled-channel (CC) framework by an explicit treatment of the Δ-isobar excitation [2]. Alternatively, contribution of NN and $3NF$ to the potential energy of a $3N$ system can be calculated within Chiral Perturbation Theory [3]. Here, the many-body interactions appear naturally at higher orders (non-vanishing $3NF$ at next-to-next- to leading order). Modern calculations include also other ingredients of few nucleon dynamics such as Coulomb interactions [4] or relativistic effects [5]. Predicted effects in differential cross section appear in different parts of the phase space of the deuteron-proton breakup reaction with different magnitude. Existing experimental data (see e.g. [6], [7], [8]) demonstrate quite sizable $3NF$ and Coulomb effects in, and confirm their importance for correct description of observables for the breakup reaction at medium energies. Such studies are continued at different energies in order to create the systematic database for testing models of the $3N$ system dynamics.

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2 Experimental setup

The experiment was performed at KVI Groningen with the use of the BINA detection system [7], dedicated to investigate few-body system dynamics in an almost 4π geometry. BINA was installed on the beamline of AGOR with a beam energy of 160 MeV impinging on hydrogen target. Charged products originating from elastic scattering and ^{1}H(d, pp)n breakup reaction channels were detected simultaneously. The backward part of the system (BALL), made of 2×149 plastic scintillators working in a phoswich mode, covers a range of polar angles between 40° and 165° and a full range of azimuthal angles. The forward part (WALL) consists of the Multi–Wire Proportional Chamber (MWPC) and two layers of plastic scintillator hodoscopes: one 12 cm thick, for total energy reconstruction (E) and one thin (2 mm), for energy loss information (ΔE). The WALL part accepts particles within the polar angles from 13° to 40°. The MWPC provides resolution of 0.4° in polar and 0.6° − 2.0° in azimuthal angles, depending on polar angle.

3 Data analysis

The collected data were preliminary sorted by removing those measured in periods characterized by unstable beam current or affected by malfunctions of the system elements. Next, the energy calibration and particle identification were performed [9]. For a better control of systematic effects two methods of setting particle identification (PID) cuts were proposed. Both are based on $\Delta E - E$ technique applied to each virtual telescope (an overlap of a ΔE stripe with an E slab) separately. In the first approach, bands corresponding to protons and deuterons in a given $\Delta E - E$ spectrum were defined manually (so–called graphical cuts were applied), whereas in the second case a semi-automatic linearization method [10] was used (see Fig. 1 and Fig. 2). For the discrimination of elastic scattering events from the breakup events, beside the particle identification, the coplanarity condition ($|\phi_1 - \phi_2| \sim 180°$) and cut on an energy (selection of the peak of protons originating from the elastic scattering) were used.

The aim of the experiment is to obtain differential cross section for the breakup reaction for a large set of angular configurations on systematic grid defined by polar angles of the two protons

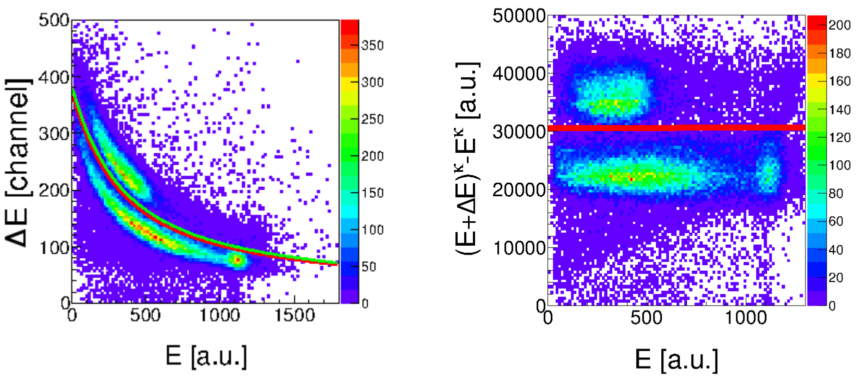

Figure 1. Data from deuteron-proton and deuteron-deuteron reactions registered in the sample $\Delta E - E$ telescope before (left panel) and after applying of the linearization function $(E + \Delta E)^{\kappa} - E^{\kappa}$ (*right panel*).

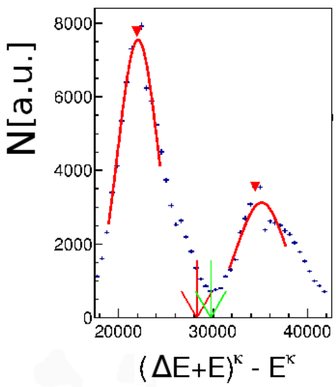

Figure 2. The κ parameter value was calculated for each telescope individually to obtain best separation of proton and deuteron peaks, seen in y-axis projection, approximated with two gaussian distributions. Position of the peaks (red triangles) defines the protons and deuterons bounds in linearized $\Delta E - E$ spectrum (see Fig. 1), right panel

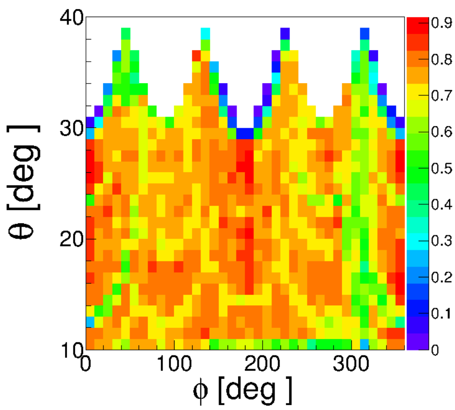

Figure 3. Efficiency map for protons detection as a product of Multi-Wire Proportional Chamber efficiency (ϵ^{p}_{MWPC}) and ΔE detector efficiency ($\epsilon^{p}_{\Delta E}$).

(θ_1, θ_2) and their relative azimuthal angle $(\Delta\phi)$. For each configuration the cross-section is obtained as a function of the arc-length S along a theoretical kinematical curve corresponding to the point-like, central geometry. To obtain this function, the data accumulated in the 2-dimensional kinematical spectra were projected onto the calculated kinematical curve (Fig. 4, left panel).

The active part of MWPC contains three measuring planes: one with vertical wires, one with horizontal wires and one with wires inclined by 45°. Position sensitive efficiency of each plane was obtained using the information from the remaining two others. In order to avoid ambiguities, only events with a single detected particle (confirmed by corresponding E and ΔE scintillators) were used. Position sensitive efficiency of ΔE detector was calculated in the similar way but using particles seen in all three planes of the MWPC and E detectors. Since ΔE detector is used for particle identification, in order to obtain its efficiency for a specific particle (protons or deuterons) one has to use only events identified as elastic scattering, ignoring information from ΔE detector for one particle. Fig. 3 presents the combined efficiency map of MWPC and ΔE for protons (left panel) and a sample of unnormalized differential cross section accounting for particle dependent efficiency correction (Fig. 4 right panel). The data points were scaled to the predictions obtained with the CD-Bonn NN-potential combined with TM99 $3NF$.

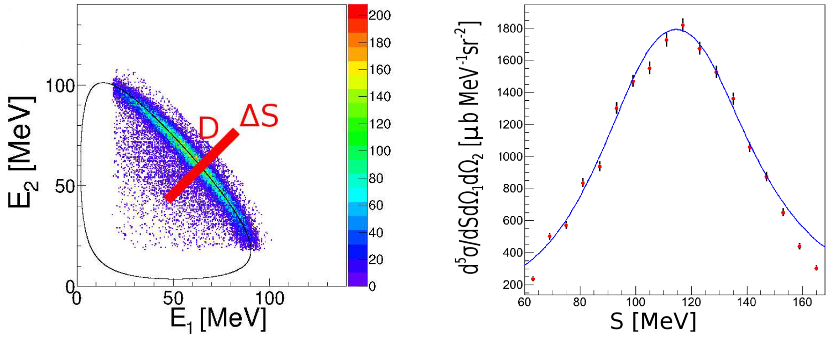

Figure 4. Left panel: Energy versus energy for two protons originating from the breakup reaction with $\theta_1 = 25°$, $\theta_2 = 15°$, $\Delta\phi = 80°$. Right panel: Unnormalised cross section data (red points)compared to the CD-Bonn + TM99 absolute predictions (solid line), for the given configuration.

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