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Experimental study of Three-Nucleon Dynamics in the dp breakup reaction

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Abstract.
An experiment to investigate the ^{1}H(*d,pp*)n breakup reaction using a deuteron beam of 340, 380 and 400 MeV and the WASA detector has been performed at the Cooler Synchrotron COSY-Jülich. The main goal was a detailed study of various aspects of few-nucleon dynamics like the three nucleon force (3NF), the long-range Coulomb interaction or relativistic effects in the medium energy region. The relativistic effects and their interplay with 3NF become more important with increasing available energy in the three nucleon system. The almost 4π geometry of the WASA detector provides an unique possibility to study various aspects of dynamics.
The studies of the 3N system dynamics in the breakup reaction with BINA detector are continued in the Cyclotron Center Bronowice.

1 Introduction

Few-nucleon system is ideal laboratory to study nuclear forces. The system composed of three nucleons (3N) is the simplest nontrivial environment, in which various models of the nucleon-nucleon (NN) interaction can be tested. Three-nucleon system dynamics can be investigated quantitatively by comparing observables calculated with the use of Faddeev equations with precise measurements. The breakup observables can be predicted using modern realistic pairwise nucleon-nucleon NN interactions, combined with model of 3N forces [1]. Moreover, the two- and three-nucleon interactions can be modeled within the coupled-channel (CC) framework by an explicit treatment of the Δ-isobar [2]. Alternatively, the dynamics is generated by the Chiral Perturbation Theory (ChPT), so far at the next-to-next-to-leading order with all relevant NN and 3N contributions taken into account [3]. The modern theoretical calculations include different pieces of nucleon-nucleon dynamics like the above mentioned three nucleon force but also the long-range Coulomb interaction or relativistic effects. Differential cross section in the region of medium energies is very sensitive to all these effects which reveal their influence in different regions of the phase space. In recent years the relativistic treatment of the breakup reaction in the 3N system has been developed using the NN potential [4]

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and this approach has also been extended for calculations including 3NF [5]. It was shown that in some particular regions of the breakup phase space, relativistic effects can increase or decrease the calculated breakup cross sections by up to 60%. At the same time the effects of 3NF may change certain observables by a similar factor. The relativistic effects and their interplay with 3NF become more important with increasing available energy in the three nucleon system. Therefore the energy range of interest is possibly to close pion production threshold (0.4 GeV for dp breakup reaction). We measured the differential cross section of the ^{1}H*(d,pp)n* breakup reaction at energies of 340, 380 and 400 MeV. The investigations will enable to study the evolution of the relativistic and 3NF effects in this energy range. This study will put strong constraints on the theoretical calculations.

2 Experiment

The experiment using the $^1\mathrm{H}(\vec{d}, pp)n$ breakup reaction at 340 MeV, 380 MeV and 400 MeV deuteron beam energy has been performed in January 2013 at the Cooler Synchrotron COSY-Jülich with the WASA-at-COSY detector [6], [7]. The WASA (Wide Angle Shower Apparatus) detector, covering almost full solid angle, consists of four main components: Central Detector (CD), Forward Detector (FD), Pellet Target Device and the Scattering Chamber (see Figure 1). Such a geometry of WASA gives an unique possibility to study various aspects of dynamics of the three nucleon system, which influence the differential cross section in different phase space regions.

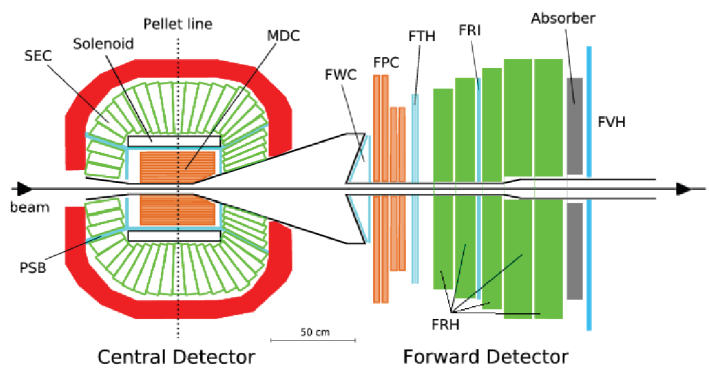

Figure 1. Schematic view of the detection system

The target components are situated on top of the platform of the CD. The target provides a narrow stream of frozen hydrogen or deuteron pellets with diameters of about 20μm. The CD surrounds the interaction region and covers the region of the polar angles from 20° to 169°. It consists of four elements: Mini Drift Chamber (MDC), Plastic Scintillator Barrel (PSB), Scintillator Electromagnetic Calorimeter (SEC) and Super Conduction Solenoid (SCS). The FD covers the region of the polar angles from deuterons of 3° to 18°. It consists of a set of plastic scintillators for the identification of charged hadrons and track reconstruction: Forward Window Counter (FWC), Forward Proportional Chamber (FPC), Forward Trigger Hodoscope (FTH), The Forward Range Hodoscope (FRH) and Forward Veto Hodoscope (FVH).

3 Data Analysis

The first step of data analysis is the identification of interesting events, *i.e.* two protons from the breakup process and deuteron-proton pairs from elastic scattering channel in the Forward Detector (range of the polar angles is from 3° to 18°). The particle identification is based on the ΔE-E technique.

After selection of the proton-proton coincidences and having performed the energy calibration, the differential cross section of the breakup reaction can be determined for a chosen kinematic configuration. The configuration is defined by the emission angles of the two outgoing protons: two polar angles θ_1 and θ_2 and the relative azimuthal angle ϕ_{12} (reconstructed from FPC in Forward Detector and MDC in Central Detector).

For a chosen configuration a kinematical spectrum (E_1 vs E_2) is built and the events are projected onto a kinematical curve in order to obtain the distribution as a function of the arc-length S measured along the kinematics. An example of the preliminary non-normalized experimental breakup rate (not corrected for efficiency and acceptance) obtained for the chosen kinematical configurations are presented in Fig. 2. In the right panel in this figure the theoretical calculations [1] [8] are also shown. In the studied angular region, close to FSI configuration of a proton pair (two protons flying close to each other), Coulomb force plays an important role, decreasing locally the cross section. Shape of the experimental distribution confirms that prediction. Although only 10% of collected data has been analysed, the statistical uncertainty per data point is already between 5%-10% in configuration registred in Forward Detector.

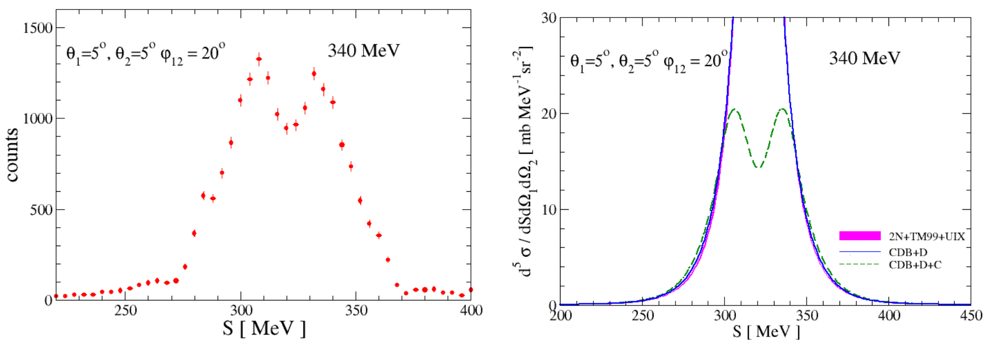

Figure 2. An example of the preliminary non-normalized experimental breakup event rate (not efficiency and acceptance corrected) obtained for chosen kinematical configurations as a function of the S value (left panel). Magenta bands represent calculations based on realistic potentials: 2N complemented with the TM99 3NF and the realistic AV18 potential combined with the Urbana IX. The calculations within the coupled-channel approach with the CD Bonn+ Δ potential without and with the Coulomb force included are represented by blue solid line and green dashed line, respectively (right panel).

4 Summary and outlook

The analysis is continued with the aim to determine the differential cross sections for the the deuteron breakup process in the $d+p$ system at energies of 340, 380 and 400 MeV. The theoretical calculations using modern realistic nucleon-nucleon (NN) interactions, combined with a suitable model of 3N forces [1] and to the calculations within the coupled-channel approach with the CD Bonn+Δ

potential and with the Coulomb force included [8] exist and can be compared with experimental data after normalization. The calculations including relativistic effects are also been prepared [10].

Currently, the analysis is focused on obtaining normalized experimental results of the cross sections for the different combinations of kinematical configurations of the polar angles θ_1 and θ_2 and the relative azimuthal angle ϕ_{12}. The luminosity will be determined using measured angular distribution of the elastically-scattered deuterons and the known cross section [9]. Preliminary selection of registered deuterons has been done.

The studies of the 3N system dynamics in the breakup reaction are continued with BINA detector in Cyclotron Center of Bronowice (CCB). The Proteus C-235 cyclotron at CCB provides proton beams with energy from 70 MeV to 230 MeV with energy spread ΔE/E <0.7% and beam current in the range of 500 nA to 0.1 nA. BINA detector has been instalated in CCB (adapted to beam line and infrastructure) and commissioned. First test run with all detectors using ZnS, CD_2 and CH_2 targets has been done. We plan the measurement of the cross sections of *p+d* elastic scattering for 108, 135 and 160 MeV and, subsequently, the differentional cross sections of *p+d* breakup reaction at 108 MeV.

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