Few-Body Syst
DOI 10.1007/s00601-016-1206-x

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Experimental Study of Three-Nucleon Dynamics in the Dp Breakup Collisions Using the WASA Detector

Received: 29 November 2016 / Accepted: 23 December 2016

Abstract Until recently, all calculations of breakup observables were carried out in a non-relativistic regime. The relativistic treatment of the breakup reaction in 3 N system is quite a new achievement. The detailed study of various aspects of few-nucleon system dynamics in medium energy region, with a particular emphasis on investigation of relativistic effects and their interplay with three nucleon force (3NF) becomes feasible with increasing available energy in the three nucleon system. Therefore an experiment to investigate the ^{1}H(d, pp)n breakup cross section using a deuteron beam of 300, 340, 380 and 400 MeV and the WASA detector has been performed at COSY-Jülich. The almost 4π geometry of the WASA detector gives an unique possibility to study variety of kinematic configurations, which reveal different sensitivity to aspects of dynamics of the three nucleon system. The main steps of the analysis, including energy calibration, PID, normalization and efficiency studies, and their impact on the final accuracy of the result, are discussed.

1 Introduction

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 calculated using modern realistic pairwise nucleon–nucleon NN interactions, combined with model of 3 N 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 [2,3]. Alternatively, the dynamics is generated by the chiral effective field theory (χEFT), so far at the next-to-next-to-leading order with all relevant NN and 3 N contributions taken into account [4]. The new, improved version of ChPT is currently being developed [5]. The modern theoretical

This article belongs to the Topical Collection "The 23rd European Conference on Few-Body Problems in Physics".

This work was partially supported by Polish National Science Center from Grant DEC-2012/05/B/ST2/02556 and by the European Commission within the Seventh Framework Programme through IA-ENSAR (Contract No. RII3-CT-2010-262010).

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Published online: 19 January 2017

calculations include also the long-range Coulomb interaction or relativistic effects. In the recent years the relativistic treatment of the breakup reaction in 3 N system was developed using NN potential in [6] and this approach has also been extended for calculations including 3NF in [7]. 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. We measured the differential cross section of the $^1H(d, pp)n$ breakup reaction at energies of 300, 340, 380 and 400 MeV. The investigations at this energy range will enable to study the evolution of the relativistic and 3NF effects, and will put strong constraints on the theoretical calculations.

2 Data Analysis

The experiment studying the ^{1}H($\mathbf{d}$, pp)n breakup reaction at beam energies 300, 340, 380 and 400 MeV has been performed at the Cooler Synchrotron COSY-Jülich with the WASA (Wide Angle Shower Apparatus) detector [8,9]. The detection system consists of four main components: Central Detector (CD), Forward Detector (FD), a pellet target device and a scattering chamber.

Currently, the data analysis is focused on the proton-proton coincidences registered in the Forward Detector with the aim to determine the differential cross section on dense angular grid of kinematical configurations defined by the emission angles of the two outgoing protons: two polar angles θ_1 and θ_2 (in the range between 4° and 18°) and the relative azimuthal angle ϕ_{12}. The first step of data analysis is the identification of interesting events, i.e. proton pairs from the breakup process and deuterons from the elastic scattering channel registered in the Forward Detector. The particle identification is based on the $\Delta E - E$ technique.

To obtain differential cross section, the luminosity should be determined on the basis of the number of the elastically-scattered deuterons at a given θ angle and the known cross section for elastic scattering at the studied energy [10]. Systematic scatter of the data in this energy region motivated normalization based on all the data sets from the range of energies (between 216 and 400 MeV) compared to theoretical calculations with the CDBonn potential and TM99 3NF. After selection of deuterons registered in the Forward Detector and energy calibration, the correct energy vs angle relation for elastically scattered deuterons was obtained, see Fig. 1, left panel. The values of the luminosity presented as function of the deuteron scattering polar angle is shown in Fig. 1, right panel. Luminosity as function of scattering angle was plotted as consistency check. The error bars represent statistical uncertainties only. The boxes represents systematic errors due to normalization either to calculated or measured cross section and/or uncertainty related to subtraction of the proton background. The number of deuterons was corrected by efficiency factors, determined on the basis of Monte Carlo simulation. Including detector acceptance and all cuts applied in the analysis, detector efficiency for registering and identifying elastically scattered deuterons is about 80 %.

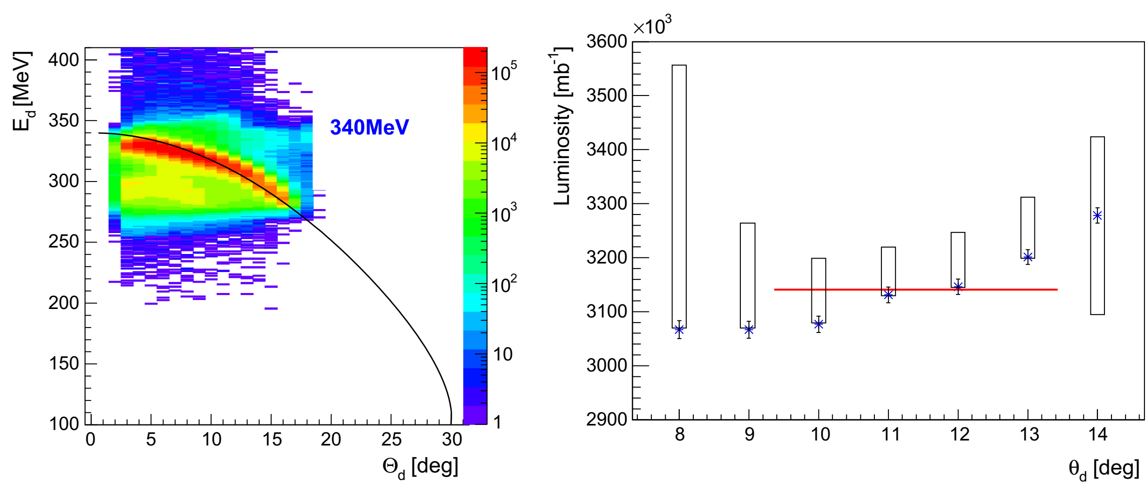

Fig. 1 Preliminary determination of luminosity. *Left panel* selection of deuterons registered in FD. *Solid curve* corresponds to kinematics for elastically scattered deuterons. *Right panel* the values of the luminosity presented as function of the deuteron scattering polar angle. The *solid line* corresponds to the weighted average of four results with the smallest systematic errors (shown as *boxes*). The *error bars* represent statistical uncertainties only

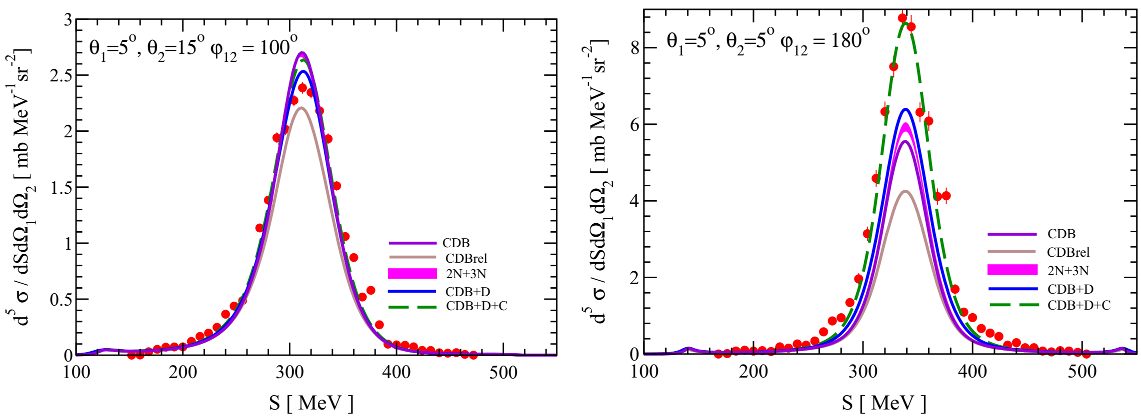

Fig. 2 Examples of the preliminary differential cross section of breakup reaction obtained for chosen kinematical configurations as a function of the S value at 340 MeV beam energy, *red dots*. *Magenta band* represents calculations based on realistic potentials: 2N complemented with the TM99 3NF and the realistic AV18 potential combined with the Urbana IX. The calculations within the coupled-channel approach with the CD Bonn + Δ potential without (CDB + D) and with (CDB + D + C) the Coulomb force included are represented by *blue solid line* and *green dashed line*, respectively. *Violet* and *brown solid lines* present theoretical calculations with CD Bonn potential in norelativistic (CDB) and relativistic (CDBrel) regime, respectively (color figure online)

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}, with defined integration limits: $\Delta\theta_1 = \Delta\theta_2 = 1\circ$ and $\Delta\phi_{12} = 5°$. The kinematical spectra E_1 vs E_2 are produced for each analyzed configuration.

Events belonging to the chosen configuration of interest 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 examples of the preliminary normalized experimental breakup event rate obtained for the chosen kinematical configurations at the energy of 340 MeV are presented in Fig. 2. In this figure the theoretical calculations [1–3] are also shown. The calculations in relativistic regime have recently been performed for the ^{1}H(*d, pp*)n breakup reaction at the beam energies of 340, 380 and 400 MeV [11], clearly demonstrating importance of relativistic description at these energies. The errors in this figure represent statistical errors with uncertainty of the detection efficiency, determined on the basis of Monte Carlo simulation. The result presented in the left panel indicates that the data confirm the importance of relativistic effect, which is partially compensated by an influence of the 3NF. The configuration shown in the right panel is very sensitive to Coulomb effects.

3 Summary and Outlook

The analysis is continued with the aim to determine the differential cross sections for the the deuteron breakup process for a large set of kinematical configurations covering a significant part of the reaction phase space. The data will be compared to the theoretical predictions for three nucleon systems with the aim to investigate relativistic effects. Currently, the analysis is focused on precise determination of efficiency of the detection system for proton–proton coincidences and its impact on final accuracy of the result. The calculations including relativistic effects with 3NFs [7] and studies of Coulomb effects are very important to draw definitive conclusions. The studies will be further extended to data collected at three other beam energies.

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