STUDIES OF FEW-NUCLEON SYSTEM DYNAMICS VIA DEUTERON BREAKUP WITH THE WASA DETECTOR*

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Relativistic treatment of the few-nucleon theoretical models has been recently developed for the deuteron breakup reaction. This ingredient can be quantitatively verified with the use of the deuteron breakup reaction at the intermediate energy region. The interplay of relativistic and three-nucleon force (3NF) effects can also be studied. For this purpose, an experiment investigating the $^1\mathrm{H}(d,pp)n$ breakup cross section was performed in FZ-Jülich. The unpolarized deuteron beam of energies of 170, 190 and 200 MeV per nucleon was impinging on the hydrogen pellet target and the reaction products were registered with the use of the Wide Angle Shower Apparatus (WASA) detection system. Its almost 4π geometrical acceptance gives unique possibility to study a variety of kinematic configurations. The main steps of the analysis, including PID, efficiency studies and normalization, and the preliminary results of the cross section are discussed.

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1. Introduction

Investigation of few-nucleon systems is important for testing nuclear potentials. Observables calculated with the use of the Faddeev equations can be compared with the results of precise measurements and quantitatively verified. Modern realistic nucleon–nucleon (NN) potentials describe well two-nucleon systems but successfully predict observables of the deuteron–proton breakup reaction in the wide range of phase space only if combined with additional elements of the dynamics like the three-nucleon force (3NF).

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The modern calculations for few-nucleon systems include, besides NN potentials and 3NF contribution, additional elements of the dynamics like the Coulomb interactions [1] or relativistic effects [2]. These effects influence observables with different magnitude and in various parts of phase space of the breakup reaction, which can be verified by comparison with experimental data. Influence of the Coulomb force can be studied in the configurations with small relative angles of outgoing protons, on the other hand, the survey for the relativistic effects requires relatively high energies, but still below the pion production threshold. Experiments aiming to study nuclear dynamics by measurement of the ${}^{1}\mathrm{H}(d,pp)n$ breakup reaction were carried out at KVI Groningen [3, 4] and FZ-Jülich [5, 6] with the deuteron beam at the energies between 150 and 200 MeV/nucleon. This work focuses on the analysis steps including the particle identification method, the reconstruction efficiency and the normalization based on the elastic scattering process.

2. Experimental setup

The experiment dedicated to study the few-nucleon system dynamics via the ${}^{1}\mathrm{H}(d,pp)n$ breakup reaction was performed at FZ-Jülich. In the experiment, an unpolarized deuteron beam was impinging on the pellet target of hydrogen and proton–proton or deuteron–proton coincidences were registered in the WASA detector. The WASA setup consists of three main parts: the Forward Detector, the Central Detector and the pellet target system. The deuteron–proton reactions occur in the middle of the Central Detector in the intersection of the COSY beam with the vertical line formed by pellets. The interaction region is surrounded by the multi-layer cylindrical drift chamber (MDC), immersed in the axial magnetic field produced by the superconducting solenoid, and by one layer of 2 mm scintillators plastic bar-

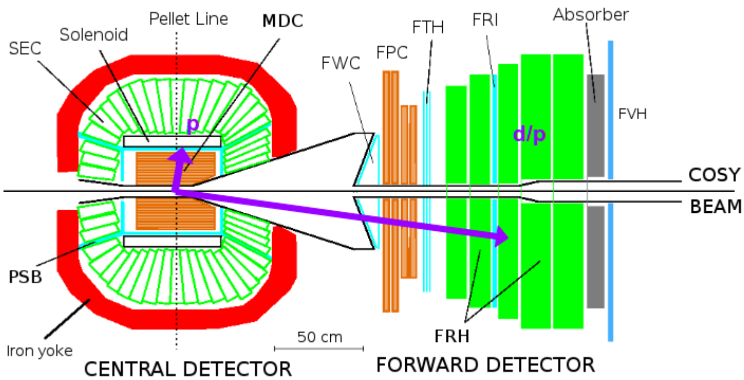

Fig. 1. Cross-sectional view of the WASA detector system.

rel (PSB). The Forward part consists of a proportional chamber and several layers of plastic scintillators, as shown in Fig. 1. The acceptance of the Forward and Central Detector is 3°–18° and 20°–169°, respectively. The beam was delivered by the Cooler Synchrotron COSY working in a super-cycle mode at three energies of 170, 190 and 200 MeV/A.

3. Data analysis

3.1. Selection of events

Data were first preselected, according to the Central–Forward trigger condition. The particles registered in the Forward part were identified via the ΔE–E method. Sample spectra are presented in Fig. 2. In the next steps of the analysis, the energy calibration of the Forward Range Hodoscope (FRH) was performed and the identification cuts were defined. The energy at the reaction point was obtained based on the energy loses in different layers of

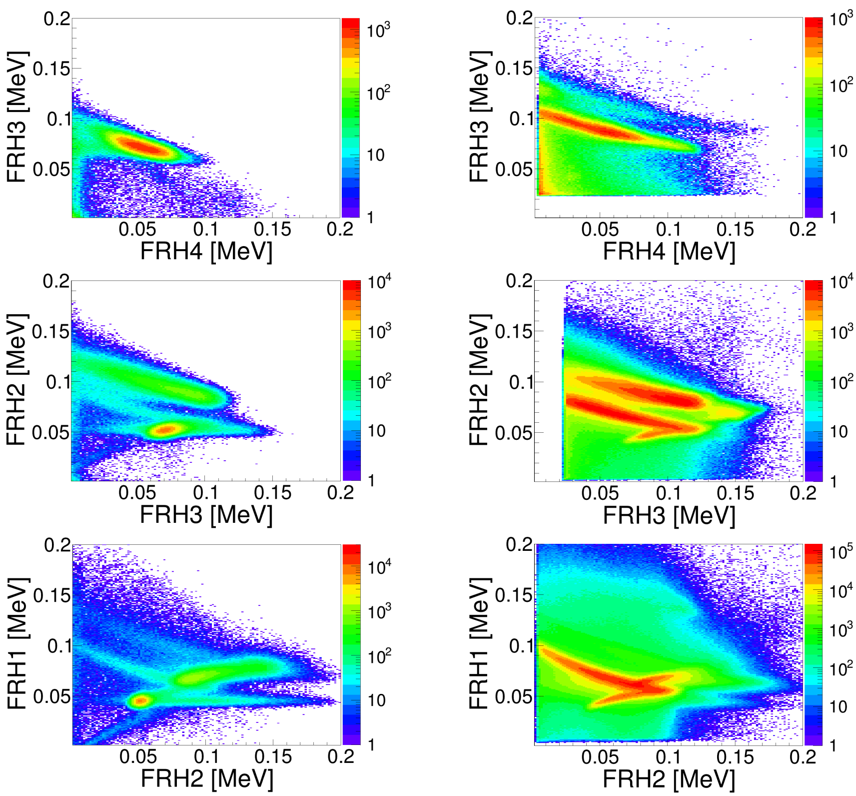

Fig. 2. ΔE–E spectra of particles stopped in FRH4 (top), FRH3 (middle) and in FRH2 (bottom panels).

FRH. Elastic scattering and deuteron breakup channels were selected. Both processes were simulated in the PLUTO generator and processed through the WASA Monte Carlo (WMC) to investigate the reconstruction efficiency.

3.2. Normalization factor

To obtain absolute values of the deuteron breakup cross section, the luminosity integrated over the measurement time was calculated. It corresponds to the number of elastically scattered events (N^{dp}). In order to select the elastic events, the coplanarity condition ($\Delta\varphi \sim 180^\circ$) was imposed. The integrated luminosity was calculated as a function of scattering angle ($\vartheta^{\rm CM}$), according to the following formula:

$$L\left(\vartheta^{\rm CM}\right) = \frac{N^{dp}\left(\vartheta^{\rm CM}\right)}{\Delta\Omega\left(\vartheta^{\rm CM}\right)\sigma^{dp}\left(\vartheta^{\rm CM}\right)\varepsilon^{dp}\left(\vartheta^{\rm CM}\right)}\,, \tag{1}$$

where $\sigma^{dp}(\vartheta^{\rm CM})$ represents the measured cross section [7], $\Delta\Omega(\vartheta^{\rm CM})$ is the solid angle and $\varepsilon^{dp}(\vartheta^{\rm CM})$ corresponds to the reconstruction efficiency. The efficiency was determined as a ratio of the coincidences reconstructed at a given $\vartheta^{\rm CM}$ obtained with WMC and those calculated from the PLUTO generator. Figure 3 shows the distribution of $\varepsilon^{dp}(\vartheta^{\rm CM})$ and the luminosity $L(\vartheta^{\rm CM})$ is presented in Fig. 4.

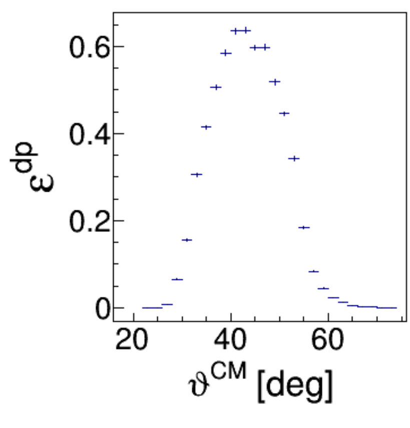

Fig. 3. Reconstruction efficiency for the forward–central coincidences from the elastic channel as a function of the polar scattering angle in the center-of-mass system $\vartheta^{\rm CM}$.

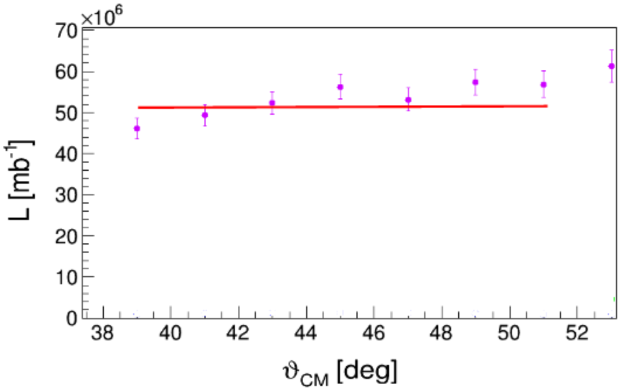

Fig. 4. The points represent the value of luminosity obtained as a function of the scattering angle. The straight line marks the average value of luminosity, being the normalisation factor for the breakup cross section.

3.3. Cross section for deuteron breakup

Values of the differential cross section for the deuteron breakup reaction for a chosen kinematical configuration defined by the $(\vartheta_1, \vartheta_2)$ polar angles of the two breakup protons and their relative azimuthal angle (φ_{12}) are calculated in the following way:

$$\sigma\left(\vartheta_1, \vartheta_2, \varphi_{12} = \varphi_1 - \varphi_2, S\right) = \frac{N_{pp}\left(\vartheta_1, \vartheta_2, \varphi_{12}, S\right)}{L \Delta\Omega_1 \Delta\Omega_2 \Delta S \varepsilon^{pp}(\vartheta_1, \vartheta_2, \varphi_{12})}, \qquad (2)$$

where $N_{pp}\left(\vartheta_1, \vartheta_2, \varphi_{1,2}, S\right)$ is the number of proton–proton coincidences, registered at polar angles $(\vartheta_1, \vartheta_2)$ with the bin size of $\Delta\vartheta = 1°$, $10°$ for the relative azimuthal angle φ_{12} and 8 MeV for the S variable, which is defined as the arc-length along the corresponding kinematical curve. L is the value of the luminosity, and $\Delta\Omega_{1,2}$ are the corresponding solid angles. Determination of the efficiency for the reconstruction $\varepsilon^{pp}(\vartheta_1, \vartheta_2, \varphi_{12})$ for the breakup events is still ongoing, therefore, in order to compare the data with the theories, the experimental distributions were scaled by an arbitrary factor. Sample distributions are presented in Fig. 5.

The shapes of the experimental distributions are well-reproduced by the theories, however their absolute normalization needs to be performed.

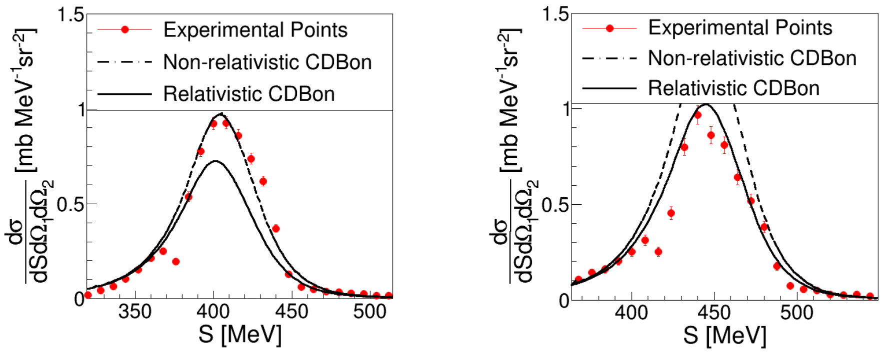

Fig. 5. A sample of the differential cross-section distribution for the selected geometrical configurations of the two breakup protons ($\vartheta_1 = 5^\circ$, $\vartheta_2 = 40^\circ$, $\varphi_{12} = 80^\circ$) (left panel) and ($\vartheta_1 = 5^\circ$, $\vartheta_2 = 40^\circ$, $\varphi_{12} = 180^\circ$) (right panel). Dashed (solid) lines represent non-relativistic (relativistic) calculations not including three-nucleon force effects [8].

4. Outlook

The analysis of the $^1\mathrm{H}(d,pp)n$ breakup at the beam energy of 170 MeV$/A$ is ongoing. The reconstruction efficiency and the absolute values of the differential cross section for the breakup reaction still need to be determined in order to test the validity of the different dynamical components included in the theoretical calculations.

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