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CONFIGURATION EFFICIENCY FOR DEUTERON BREAKUP REACTION INVESTIGATION*

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The elastic scattering and deuteron breakup data were collected in the experiment performed at KVI with the use of unpolarized deuteron beam of 80 MeV per nucleon, impinging on hydrogen target. The aim of the analysis is to obtain absolute values of the differential cross section for deuteron breakup reaction. Precise determination of the detection efficiency is indispensable for that purpose. This report explains the efficiency correction introduced to account for the detector granulation and geometry.

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1. Introduction

Understanding the interaction between nucleons in the few-nucleon systems is driven by dynamics beyond pairwise nucleon–nucleon (NN) forces. Such additional dynamics is called a three-nucleon force (3NF). It originates from the meson exchange picture as an intermediate excitation of a nucleon to a Δ-isobar or it appears at the certain expansion order of Chiral Effective Field Theory [1]. Modern models of 3NF, such as Tucson–Melbourne 99 [2] or Urbana IX [3], are combined with the adequate realistic NN potentials. Alternative approach — the coupled channel framework — includes the Δ-isobar explicitly [4]. The database of observables for three-nucleon systems has to be further expanded with precise measurements to validate models.

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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. Unpolarized deuteron beam of 160 MeV was impinged on 3.3 mm thick liquid hydrogen target. Charged products of the reaction were detected by the BINA (Big Instrument for Nuclear Analysis) detection system [5]. BINA apparatus has been specially designed to investigate few-nucleon systems in the range of intermediate energies. It covers almost 4π geometry and is composed of two main parts: forward Wall (ϑ: 13°–40°) and backward Ball (ϑ: 40°–165°). In the forward Wall, particles are registered in three detectors. At first, they are detected in the MWPC (multi-wire proportional chamber for reconstruction of angles), next, in one of twenty four, 2 mm thin plastic scintillator stripes (for energy loss information) and finally, in the hodoscope made of ten, 10 cm thick, plastic scintillators. Superposition of vertically oriented ΔE stripes and horizontal elements of E hodoscope forms 240 rectangular ΔE–E telescopes, used further for the particle identification. The Ball is made up of 149 triangular detector elements working in a phoswich mode. At the same time, it plays the role of a reaction chamber.

3. Data analysis

The analysis focuses on the particles scattered forward from the reaction point and being detected in the forward Wall. The details of the main steps of the data analysis including energy calibration, particle identification (PID) and detector hardware efficiency calculation were described in previous publications [6–8]. To perform reliable PID, the linearization method was applied to the ΔE–E spectra, as described in [9]. Values of the differential cross section for the deuteron breakup reaction at a chosen kinematic configuration are calculated in a following way:

$$\sigma\left(\vartheta_1,\vartheta_2,\varphi_{12}=\varphi_1-\varphi_2,S\right) = \frac{N_{pp}\left(\vartheta_1,\vartheta_2,\varphi_{12},S\right)}{L\Delta\Omega_1\Delta\Omega_2\Delta S\varepsilon(\vartheta_1,\vartheta_2,\varphi_{12})}\,, \tag{1}$$

where $N_{pp}\left(\vartheta_1,\vartheta_2,\varphi_{1,2},S\right)$ is a number of proton–proton pairs, registered within a bin of 1° for polar angles $(\vartheta_1,\vartheta_2)$, of 10° for relative azimuthal angle (φ_{12}) and of 8 MeV for the S variable, which is defined as the arc-length along the corresponding kinematical curve. L is the total integrated luminosity; $\varepsilon(\vartheta_1\vartheta_2\varphi_{12})$ represents the position-dependent detection efficiency for a proton pair; $\Delta\Omega_{1,2}$ — the corresponding solid angles. The total efficiency of registering a pair of protons from the breakup reaction is given by

$$\begin{aligned}\varepsilon\left(\vartheta_1,\vartheta_2,\varphi_{12}\right) &= \left(\varepsilon^{\mathrm{MWPC}}(\vartheta_1,\varphi_1)\varepsilon^{\Delta E}\left(\vartheta_1,\varphi_1\right)\right)\\ &\quad\times\left(\varepsilon^{\mathrm{MWPC}}\left(\vartheta_2,\varphi_2\right)\ \varepsilon^{\Delta E}\left(\vartheta_2,\varphi_2\right)\right)\varepsilon^{\mathrm{conf}}(\vartheta_1,\vartheta_2,\varphi_{12})\,,\end{aligned} \tag{2}$$

where $\varepsilon^{\mathrm{MWPC}}(\vartheta_i, \varphi_i)$ and $\varepsilon^{\Delta E}(\vartheta_i, \varphi_i)$ are the probabilities for a proton detection in a chosen angular bin in the multi-wire proportional chamber and thin scintillator respectively; $\varepsilon^{\mathrm{conf}}(\vartheta_1, \vartheta_2, \varphi_{12})$ is the configuration efficiency. It accounts for configuration-specific loss of coincident events due to the detector construction. For a correct reconstruction of the event, signals from two separate elements of E and ΔE detectors and two tracks reconstructed in MWPC are required. Due to the finite granulation of the detector, both particles may enter the same detector element and the event has to be rejected. Configuration efficiency is obtained from an analysis of the set of breakup events simulated with the use of Geant4 framework with Wall detector geometry included. Since the good statistical accuracy of such correction has been ensured, the only significant uncertainty may has originated from the applied model of simulated angular distribution. In the following, the uniform 3-body breakup phase space distribution has been used, which is well-justified in the case of narrow angular ranges applied in defining the configuration.

For both E and ΔE hodoscopes, the configuration efficiency for a given geometry $(\vartheta_1, \vartheta_2, \varphi_{12})$ is defined as the ratio of the number of events for which both particles were registered by separate detector elements to the number of all simulated events.

Due to a fine granularity of the MWPC (96 wires per measuring plane) as compared to the hodoscopes, the corresponding inefficiency is small. The event is rejected when the clusters produced by both particles overlap. In the simulation, the distribution of cluster sizes observed in the experiment was used. Because of serious contact problems at hardly accessible places, certain electronics channels of MWPC did not work. This resulted in additional inefficiency which, for the technical reasons, has been included into simulations and incorporated into the configuration efficiency. All other inefficiencies of MWPC are calculated from experimental data and included explicitly in Eq. (2).

Resulted values of the configuration efficiency show, in general, non-monotonic growth with increase of the relative azimuthal angle. Local minima are mainly due to E hodoscope segmentation. As expected, the efficiency decreases with decreasing φ_{12} (see Fig. 1 (left panel)).

Based on the same principle, the configuration efficiency for elastically scattered proton–deuteron pairs was introduced as a function of a proton polar angle (see Fig. 1 (middle panel)).

Figure 1 (right panel) shows the values of luminosity obtained from the analysis of $d + p$ elastic scattering data and the known cross section for the process (for details of interpolation, see [10]). After the configuration efficiency correction has been applied, the results obtained for various proton polar angles are consistent with each other.

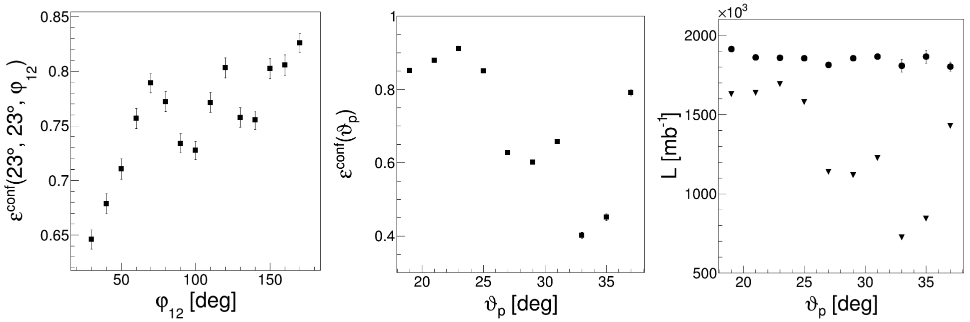

Fig. 1. Left panel: Configuration efficiencies for a set of selected angular configurations of the breakup reactions defined by polar angles ($\vartheta_1 = 23°, \vartheta_2 = 23°$) and various φ_{12} angles. Middle panel: Configuration efficiency for elastic scattering events. Right panel: Luminosity obtained before (triangles) and after (dots) correcting the elastic scattering data for the configuration efficiency.

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