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Experimental Investigation of Few-Nucleon Dynamics at Medium Energies

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An experiment, with unpolarized deuteron beam of 160 MeV impinging on liquid hydrogen and liquid deuterium targets, was carried out using BINA detector at KVI, in Groningen, the Netherlands. Data were collected for the purpose of obtaining high precision differential cross-section for the deuteron break-up reaction. The elastic scattering data were also collected alongside. We present here the methods applied in analysis of data collected in the backward part of the detector.

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1. Introduction

Experimental studies of three-nucleon dynamics has been the focus of few-body research in recent decades. Among them the nucleon–deuteron (Nd) scattering was the most common candidate for the study. Experiments at KVI in Groningen, at KUTL/RIKEN/RCNP in Japan, and at IUCF in USA have provided large sets of high-precision data [1] (and references therein), not only for the cross-sections but also for the polarization observables. Tremendous progress have been made to understand the 3N dynamics. With the new high-precision data, covering a large phase-space, it has become possible to pin-down the effects as subtle as three-nucleon forces (3NF) [2, 3]. The experimental program at KVI has been carried out to extent those studies to the breakup reaction. It used initially the SALAD detector [4] which finally has been upgraded to the BINA detector setup [5], covering even a larger phase-space and with better detection capabilities. The experiments with SALAD and BINA alone filled up a large gap in the 3N data-base, not only Nd elastic scattering but also breakup reaction. The next step for the experimental program was to move forward in the sector of four-nucleon (4N) system, where the knowledge is scarce in both the theoretical as well as the experimental part [6]. The 3NF effect is expected to be enhanced in 4N system, which makes the study of 4N even more attractive. The work presented here is based on the experiment performed at KVI in Groningen, the Netherlands, with BINA detector, where an unpolarized beam of deuterons with an energy of 160 MeV was provided from AGOR cyclotron and was impinged on liquid hydrogen and liquid deuterium targets.

2. Experiment

BINA is a 4π detection system designed for few nucleon scattering experiments at intermediate energies. It is divided into two main parts, forward Wall (θ: 9°–37°) and backward Ball (θ: 37°–165°). The forward Wall consists of (a) multi-wire proportional chamber (for reconstruction of angles of the scattered charged particles), (b) 12 vertical, 2 mm thin plastic scintillator "strips" for energy loss information and (c) 10 horizontal, 12 cm thick plastic scintillator "slabs" for total energy reconstruction. The plastic stripes and slabs form ΔE–E telescopes for particle identification. The backward Ball is shaped as a part of a sphere, axially symmetric, made up of 149 triangular phoswich detector elements arranged into a football-like geometrical structure. The Ball at the same time plays the role of a scattering chamber.

3. Data analysis and results

Data were collected and a preliminary presorting was performed. Parts of runs characterized with unstable beam current or problems in functioning of any system elements were carefully removed. The analysis of data collected in the forward part of the detectors, which included geometry cross-check, calibration, particle identification, event selection etc., were presented in our previous papers [7, 8]. Most recent step in the analysis, which are presented here, was to make energy calibration of the Ball scintillators. Since the Ball elements are covering polar angles above 37°, it was necessary to take Wall–Ball coincidences for registering the dd elastic scattering and therefore Ball calibration is needed. Important to note here that the lack of light tightness for the Ball elements results in additional signals in the

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neighboring crystals, and therefore, to reconstruct a complete event, one has to take into account a cluster instead of one detector. We chose Wall–Ball coincidences characterized with combination of polar angles corresponding to dp (and similarly dd) elastic scattering, imposing also the co-planarity condition of $|\Delta\phi - 180°| < 10°$. Then further cut on this selection was made by taking the elastically-scattered deuterons in the Wall, which ensures that the second particle detected in Ball from this reaction is proton (in case of experiment with a hydrogen target) or deuteron (in case of measurement with a deuteron target). Knowing the precise angular and energy information of the deuterons in the Wall and with the help of calculated elastic kinematics, it was possible to transform the channel (pulse height) into energy.

Figure 1 shows the energy relations between Wall–Ball coincident particles from the elastic scattering. Although the energy resolution in Ball is not as high as it is for the Wall, the calibration of Ball have improved the cluster based angular resolution where the weighted average of angles of a cluster is calculated according to the following formulae:

$$\theta_{\rm c} = \frac{\sum\limits_{i=1}^{n} \theta_i E_i}{\sum\limits_{i=1}^{n} E_i}\,, \quad \phi_{\rm c} = \frac{\sum\limits_{i=1}^{n} \phi_i E_i}{\sum\limits_{i=1}^{n} E_i} \quad \text{and} \quad E_{\rm c} = \sum_{i=1}^{n} E_i\,, \tag{1}$$

where n is the number of elements in a cluster, θ_i (ϕ_i) is the polar (azimuthal) angle of the i-th element in a cluster, $\theta_{\rm c}$ ($\phi_{\rm c}$) is the polar (azimuthal) angle of the cluster, E_i is the energy of the i-th element in a cluster and $E_{\rm c}$ is the energy of a cluster. Inclusion of the Ball detector in the analysis has also allowed to make cross-check of the quality of the particle identification (of elastically-scattered deuterons) in the Wall.

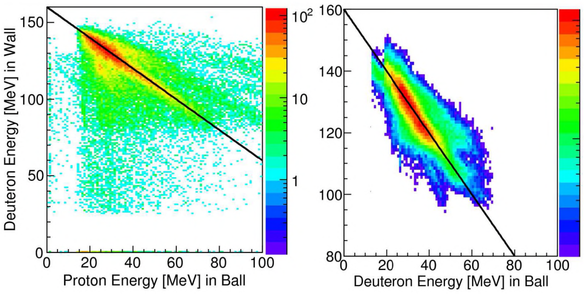

Fig. 1. The Wall-Ball energy correlation for dp elastic scattering (left part), and dd elastic scattering (right part). The black line is calculated kinematics for specified elastic scattering.

4. Conclusion and outlook

We presented a first attempt to precise data analysis of events registered in the Ball part of the BINA detector. Next step of the analysis will be to evaluate the detection efficiency of the Ball detector. The final goal of this work is to study the 3N and 4N dynamics. The obtained precise experimental data in a wide phase–space region can serve as valid tool for verification of rigorous theoretical calculations which have been and are being developed. Before the rigorous calculation become available for the 4N system, the specific configurations, corresponding to quasi-free dp scattering, with neutron as a spectator, can be compared with the predictions obtained for 3N system [9].

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