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High precision data on elastic $\vec{d}d$ scattering at 65 MeV/nucleon

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Summary. — We present the results of measurements of differential cross section and analyzing powers for the elastic $^2\mathrm{H}(\vec{d},d)d$ scattering process. The data were obtained using a 130 MeV polarized deuteron beam impinging a liquid-deuterium target. The experiments were conducted at the AGOR facility at KVI using the BINA 4π-detection system. Our measurements are compared to results of previous studies and to a different set of data taken with the BBS at KVI. The data are found to be in excellent agreement with each other. The results can be used to confront upcoming state-of-the-art calculations in the four-nucleon scattering domain, and will, thereby, provide further insights in the dynamics of three- and four-nucleon forces in few-nucleon systems.

1. – Introduction

Three-nucleon force (3NF) effects have been investigated through many nucleon-deuteron scattering experiments at various energies below pion-production threshold [1]-[13]. Even though the three-nucleon (3N) system is the cleanest system to study 3NF

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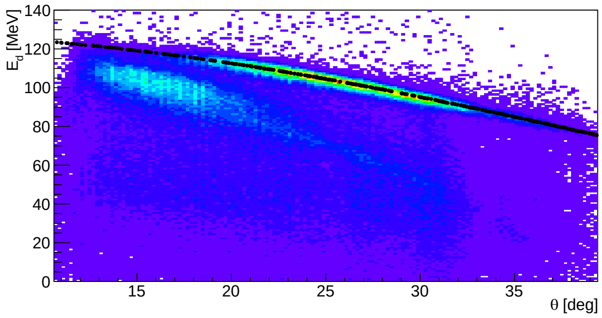

Fig. 1. – The correlation between the energy and scattering angle of reconstructed particles that were detected in the forward part of BINA with a coincidence requirement with the backward ball. The dotted line shows the kinematical loci for the elastic deuteron-deuteron scattering process. The other loci originates from the neutron-transfer channel.

effects since only NN and 3N forces can contribute and observables can be calculated ab-initio, the influence of 3NF effects are in general small in a 3N system aside from some selected kinematics. An alternative approach relies on investigation of the four-nucleon (4N) system in which 3NF effects could be significantly enhanced [14]. This paper presents measurements of the differential cross section and spin observables in the ^{2}H($\vec{d}, d$)d elastic scattering process for a deuteron-beam energy of 65 MeV/nucleon. The data were obtained by making use of a vector- and tensor-polarized deuteron beam that was provided by the AGOR facility at KVI in Groningen, the Netherlands.

2. – Data analysis method

For the event selection, cuts were applied to meet a relative opening angle of 83° (Based on relativistic point of view) and a coplanar configuration with respect to the azimuthal angles. After applying these angular cuts with a window of ±20°, a major reduction of backgrounds from other hadronic final states, such as breakup and nucleon-transfer reactions, was obtained. Figure 1 shows the correlation between energy and scattering angle of deuterons detected in the forward wall of the BINA detector after this event selection. Events that originate from elastically-scattered deuteron can easily be observed and distinguished from background channels. The dashed line represents the expected kinematical loci for elastic deuteron-deuteron scattering. The data below the elastic events reveal another clear correlation which has been identified as events belonging to the neutron-transfer channel, $d + d \rightarrow ^3$H+p.

Projection of the events on the energy axis generates the corresponding histogram in intervals of 2° of the scattering angle. Subsequently, the number of counts is extracted by integrating the number of events under the elastic peak after background subtraction. To obtain the cross section, the extracted number of counts is corrected by efficiencies of the system such as live-time of the acquisition (40%), MWPC efficiencies (99%), average hadronic interactions (84%), and down-scale factor that comes from trigger system.

For the extraction of analyzing powers, the cross section of elastic channel with po-

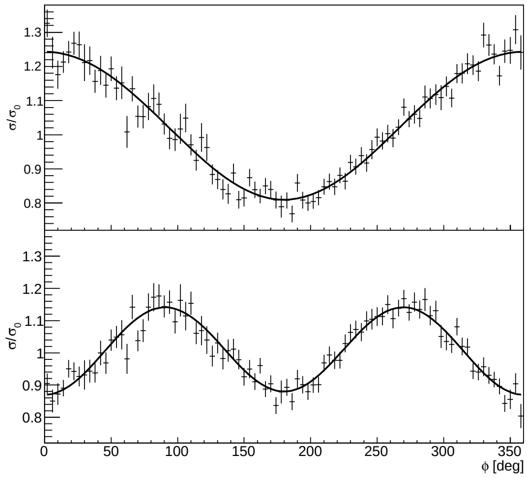

Fig. 2. – Asymmetry ratio of cross section for polarized over unpolarized beam as a function of ϕ for a pure vector-polarized beam (top panel) and pure tensor-polarized beam (bottom panel). The scattering angle of elastically scattered deuteron is $26 \pm 1^\circ$. The reduced χ^2 for the top (bottom) panel is 1.04 (0.97).

larized deuteron beam is obtained from the following equation:

$$\begin{aligned}\sigma(\theta,\phi) = \sigma_0(\theta)[1 + \frac{3}{2}p_z A_y(\theta)\cos(\phi) \\ - \frac{1}{4}p_{zz}A_{zz}(\theta) + \frac{1}{4}p_{zz}(A_{zz}(\theta) + 2A_{yy}(\theta))\cos(2\phi)],\end{aligned} \tag{1}$$

where $\mathrm{A_y}$ is vector analyzing power, while $\mathrm{A_{zz}}$ and $\mathrm{A_{yy}}$ are tensor analyzing powers. The asymmetry ratio of $\frac{\sigma}{\sigma_0}$ represents a $\cos\phi$ shape if a pure vector-polarized deuteron beam is used and a $\cos 2\phi$ shape when a tensor-polarized deutron beam is used, see Fig. 2. It is, therefore, $\mathrm{A_y}$ is extracted from the amplitude of $\cos\phi$ and $\mathrm{A_{zz}}$ and $\mathrm{A_{yy}}$ are extracted from the offset and amplitude of the $\cos 2\phi$ term, respectively.

3. – Experimental Results

The resulting differential cross section after efficiency corrections and analyzing powers for the $^2\mathrm{H}(\vec{d},d)d$ elastic deuteron-deuteron scattering are shown in fig. 3. The systematic uncertainties are shown as a gray band in each panel. The results are compared with previous existing data for this channel that were obtained at KVI, with the BBS setup. Our results are shown as filled circles, while the results of previous analysis of KVI data are presented by the open rectangles [16]. Also, the results of previously data analysis from the BBS setup is shown as open circles. The total systematic uncertainty is 7% for the differential cross section and 5% for the analyzing power. The solid line comes from an approximation based on the lowest-order terms in the Born series expansion of the Alt-Grassberger-Sandhas equation for four nucleons interaction using CD-Bonn+Δ potential [15,19]. These data clearly show the need for new and more precise calculations for the four-body system.

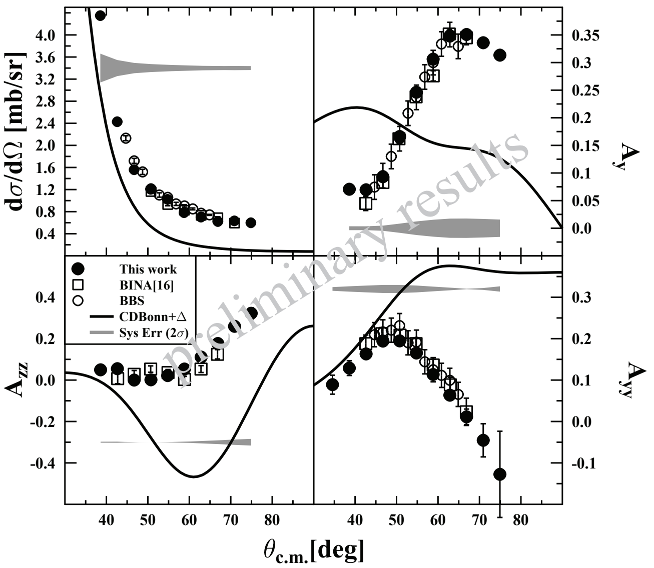

Fig. 3. – Differential cross section and analyzing powers of elastic channel of reaction $^2\mathrm{H}(\vec{d},d)d$ are shown along with statistical errors for each point. The total systematic uncertainty is shown with a gray band for each panel. The results of this work are shown as filled circles. The results are compared with results from a previous analysis of the KVI data (open rectangles) [16] and data taken with the BBS setup at KVI (open circles). The solid line is a calculation based on the lowest-order terms in the Born series expansion of the Alt-Grassberger-Sandhas equation for four nucleons using the CD-Bonn+Δ potential [15, 19]. The total systematic uncertainty is 7% for the differential cross section and 5% for the analyzing power.

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