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First measurements of the analyzing powers of the proton-deuteron break-up reaction at large proton scattering angles

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Summary. — A measurement of the analyzing powers for the $^2\mathrm{H}(\vec{p}, pp)n$ break-up reaction was carried out at KVI exploiting a polarized-proton beam at 135 MeV. In this work, we extended the earlier measurements that were done for kinematical configurations at small proton scattering angles to large angles. The results are compared with theoretical calculations based on a two-nucleon (NN) potential alone or combined with a three-nucleon (3N) potential. The theoretical calculations describe the main features of the measured distributions, but none of them can reproduce the details. This indicates the need for further development of the 3N force models.

The underlying dynamics of three-nucleon forces (3NF) is mainly investigated by the measurements of differential cross sections and polarization observables (vector and tensor analyzing powers, spin-correlation coefficients and polarization transfer coefficients) in elastic Nd scattering and break-up of the deuteron in its collision with a nucleon. In the past three decades, many measurements have been carried out at KVI and at other laboratories to obtain high-precision and rich data sets. An overview of the results can be found in [1-3]. As a conclusion for Nd elastic scattering measurements at intermediate energies, the importance of 3NFs to describe the differential cross section at angles corresponding to the smallest cross section is notable and the effect of the 3NF grows with increasing bombarding energy [4-8]. For the polarization observables, the discrepancy between the measured data and theory predictions with currently available 3NF

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models demonstrate that spin-dependent parts of the 3NFs are not completely understood [4-7, 9, 10]. For the description of the cross section for the breakup reactions we can draw similar conclusions as for the elastic scattering. However, a number of cases were observed in which discrepancies between the data and the theoretical calculations remain even after the inclusion of a 3NF in the calculations [8, 11, 12].

Based on these observations, and considering the rich phase space in the break-up reaction, it was decided to extend the analysis of the data taken in 2006 at KVI. These measurements were performed with the use of a Big Instrument for Nuclear-polarization Analysis (BINA). In this work, we extended the earlier measurements [2] that were done for kinematical configurations in small proton scattering angles by analyzing configurations at which one of the final-state protons scatters to the backward part of BINA.

BINA is composed of two parts: The Wall (forward) and the Ball (backward). The Wall consists of a Multi-Wire Proportional Chamber (MWPC) for the determination of the scattering angles and a segmented hodoscope of thin (2 mm) and thicker (12 cm) scintillators for determination of the energy of the charged reaction products. The Wall covers the polar angles θ between 10° and 35°, and the full range of the azimuthal angle ϕ. The Ball has 149 phoswich scintillator elements, covering polar angles between 40° to 160° and are glued together to operate as the scattering chamber. A beam of polarized protons produced in an atomic-beam type polarized ion source from the AGOR accelerator impinged on liquid-deuterium target with a thickness of 3.85 ± 0.2 mm which was mounted in the center of the backward part of BINA. The beam current was typically 15 pA and monitored during the experiment via a Faraday cup at the end of the beam line. The current meter was calibrated using a precision current source with an uncertainty of 2%.

In this work, break-up events were selected in which one of the final-state protons was detected in the Wall and the second one in the Ball. For each configuration θ_1, θ_2, $\phi_{12} = \phi_1 - \phi_2$ of the two outgoing protons, the kinematical spectra E_1 versus E_2 were built. The angular bins for events were chosen to be $\Delta\theta_1 = 20°$, $\Delta\theta_2 = 4°$ and $\Delta\phi_{12} = 20°$. The bin size along the kinematical S-curve is set to be ~ 10 MeV. The background of accidental coincidences and the hadronic contribution, which originates from hadronic interactions inside the detector or in the material between the target and the detector are considered as a background and are subtracted in the procedure. Also, in some configurations (close to the elastic kinematics), there was a background from the elastic channel which was not considered for further analysis. The experimental results for two analyzing powers, A_x and A_y for some configurations are presented in Fig. 1.

In Fig. 1, the error bars represent the statistical uncertainties only. The statistical uncertainties arise mainly from the number of counts for the break-up coincidences. The systematic error for the measured analyzing powers stems primarily from the uncertainty in the measurement of the beam polarization via the proton-deuteron elastic-scattering and the corresponding values were ∼3% and ∼6% for up and down polarizations, respectively. Altogether, by adding the systematic uncertainties in quadrature, the maximum systematic uncertainty for analyzing powers was less than 7%. The theoretical predictions obtained based on the realistic charge-dependent (CD) Bonn potential only (red dash-dotted lines) and within the coupled-channel framework with the CD Bonn + Δ potential without (green dashed lines) and with (black solid lines) Coulomb force are also shown after the effect of the finite solid angle has been folded with the theoretical calculations for these configurations. The experimental results for A_x show in general good agreement with the theoretical calculations where the effects of the 3NF are also shown to be small. For A_y, however, there are sizable discrepancies for small ϕ_{12} and

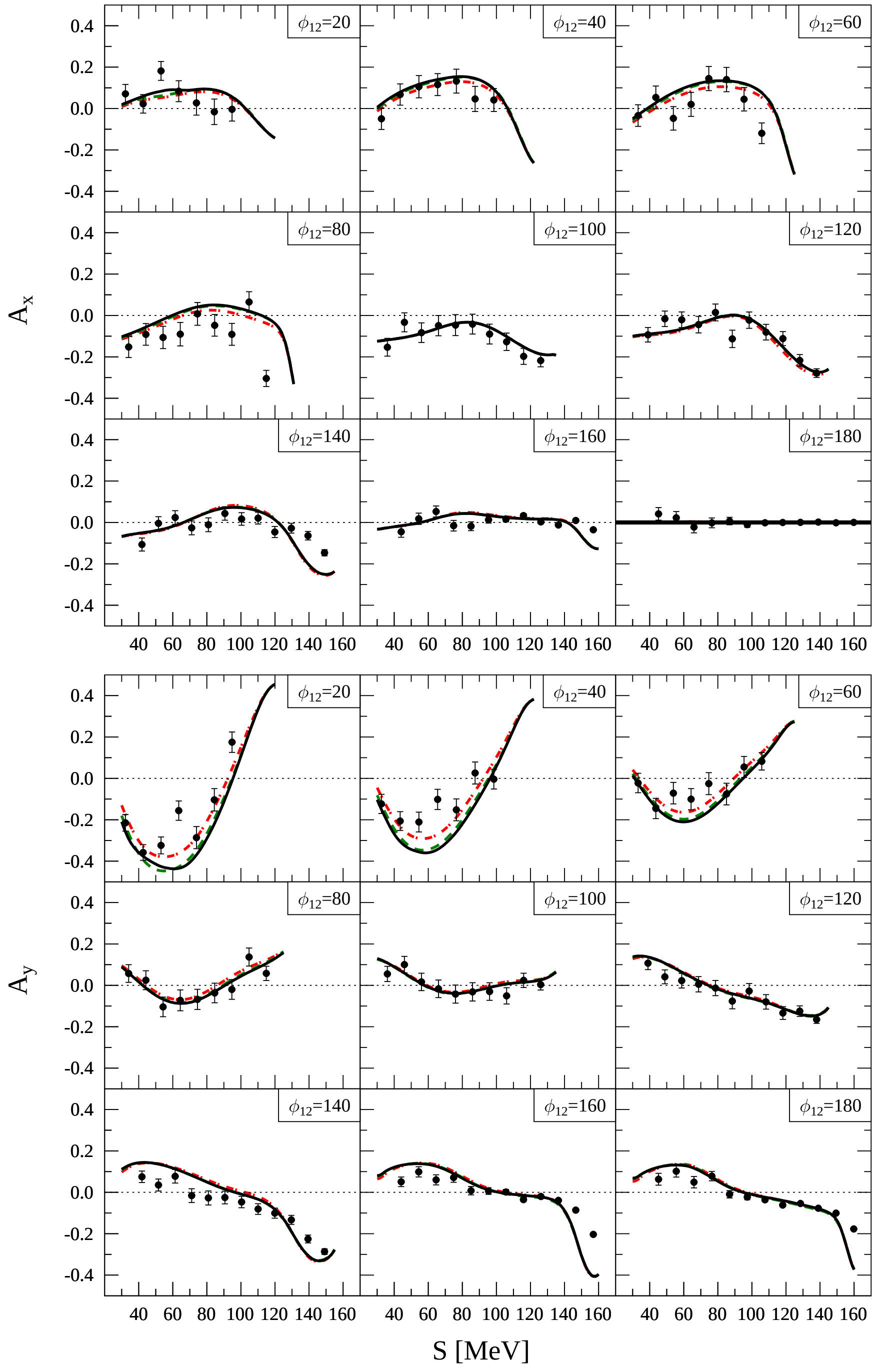

Fig. 1. – The analyzing powers at $(\theta_1, \theta_2) = (45^\circ, 28^\circ)$ as a function of S for different azimuthal opening angles. Error bars reflect only statistical uncertainties. The dash-dotted (red), dashed (green), solid (black) lines show predictions of Faddeev calculations using CDB (NN), CDB+Δ (3NF) and CDB+Δ+Coulomb calculations, respectively.

the inclusion of the 3NF makes the discrepancies even larger.

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