IL NUOVO CIMENTO **42 C** (2019) 131
DOI 10.1393/ncc/i2019-19131-9

Colloquia: EuNPC 2018

Nuclear force studies in the proton-deuteron break-up channel at 135 MeV

H. Tavakoli-Zaniani(1)(2), M. T. Bayat(1), M. Eslami-Kalantari(2),
N. Kalantar-Nayestanaki(1), St. Kistryn(3), A. Kozela(4),
J. G. Messchendorp(1), M. Mohammadi-Dadkan(1)(5),
R. Ramazani-Sharifabadi(1)(6) and E. Stephan(7)

(1) *KVI-CART, University of Groningen - Groningen, The Netherlands*
(2) *Department of Physics, School of Science, Yazd University - Yazd, Iran*
(3) *Institute of Physics, Jagiellonian University - Kraków, Poland*
(4) *Institute of Nuclear Physics, PAN - Kraków, Poland*
(5) *Department of Physics, University of Sistan and Baluchestan - Zahedan, Iran*
(6) *Department of Physics, University of Tehran - Tehran, Iran*
(7) *Institute of Physics, University of Silesia - Chorzow, Poland*

received 5 February 2019

Summary. — In this contribution, vector analyzing powers, A_x and A_y, are presented for the proton-deuteron break-up reaction studied using a polarised-proton beam at 135 MeV impinging on a liquid-deuterium target. For the experiment we used the Big Instrument for Nuclear-polarisation Analysis (BINA) at KVI, the Netherlands. With this setup, we expanded our measurements of analyzing powers compared to earlier published result (Kalantar-Nayestanaki N. *et al.*, Rep. Prog. Phys. **75** (2012)). In particular, we determined, for the first time, A_x for a large range in the kinematical S, polar and azimuthal angles of the two outgoing protons. Analyzing power data are compared to predictions from Faddeev calculations. Our data are reasonably well described by calculations for kinematical configurations at which the three-nucleon force effect is predicted to be small. However, striking discrepancies are observed at specific configurations, in particular in cases where the relative azimuthal angle between the two protons becomes small. In this contribution, some of these configurations along with the analysis techniques will be presented.

1. – Introduction and experimental setup

A detailed description of nuclear forces is essential for understanding the properties of nuclei and the dynamics in few-nucleon scattering processes. The need for an additional three-nucleon potential became evident when comparing three-body scattering observables and light-nuclei binding energies with state-of-the-art calculations [2]. The aim is to significantly extend the world database in the three-nucleon scattering system as a benchmark to eventually have a better understanding of the structure of the three-nucleon interaction. The reaction of interest is studied with the Big Instrument for Nuclear-polarization Analysis (BINA). The detector system BINA is composed of two main parts: the forward wall which can measure the energy, the position, and the type of the particle at scattering angles between 10°-35°. It has three parts, namely E-scintillators, ΔE-scintillators, and a Multi-Wire Proportional Chamber (MWPC). Scattered particles with enough energy traverse from the target to the scintillators. They pass through the MWPC and as a result, their coordinates are recorded. Subsequently, particles pass through the ΔE-scintillators in which a small fraction of their energy is deposited. Finally, the particle is stopped (for protons with an energy less than 140 MeV) inside the E-scintillators and its deposited energy is measured. A combination of E and ΔE allows us to identify the type of particle detected, e.g. proton, deuteron, etc.. The backward ball has 149 detectors. It is the scattering chamber and a detector at the same time. The incoming beam hits the target which is placed at the center of the ball. The forward-going particles are detected by the forward wall, which is placed outside the vacuum, and particles scattering to angles larger than 35° up to 165° are detected by the ball [3, 4]. The two parts together, therefore, cover almost the entire kinematical phase space of the elastic and break-up reactions. Fig. (1) shows the BINA experimental setup.

2. – Data analysis

To obtain the analyzing power as a function of the proton energy or, equivalently, as a function of the arc-length, S, along the kinematical-correlation curve, an energy calibration is required in the range where the reaction is being investigated.

The left panel in Fig. (2) shows the energy correlation between two forward scattered protons after the energy calibration procedure. The data correspond to a specific kinematical configuration. The right panel depicts the projection of events for one slice

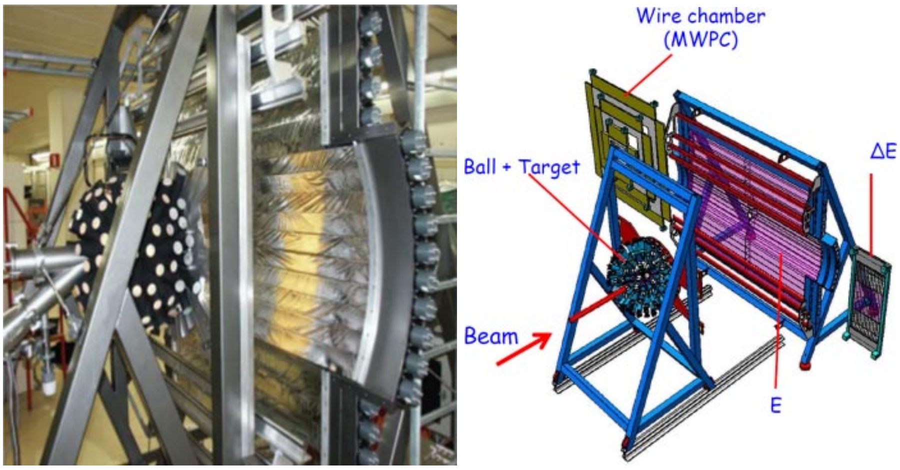

Fig. 1. – Left: side view of BINA. Right: technical sketch of the various detector components of BINA including the forward wall, backward ball, the target position, and the beam direction.

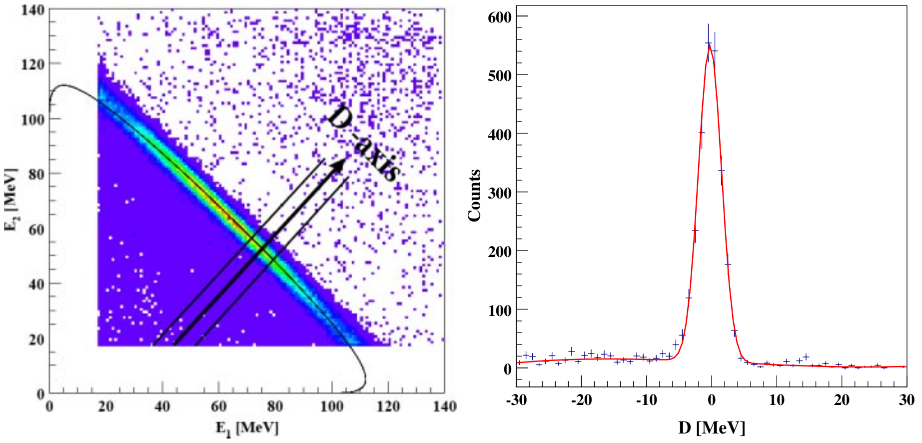

Fig. 2. – The left panel shows E_1 versus E_2, energy of the two protons at (θ_1, θ_2, ϕ_{12})=(28°±2, 28°±2, 180°±5). The solid line shows the kinematical curve calculated for the central values of the experimental angular ranges. The right panel is the projection of events along D-axis for one slice.

along the D-axis taken perpendicular to the S-curve. The number of break-up events for each polarization state in a certain configuration are recorded. To extract the vector analyzing powers A_y and A_x, we made use of the following equation [5]:

$$N(\xi,\phi) = N^0(\xi,\phi)(1 + p_z A_y \cos\phi - p_z A_x \sin\phi). \tag{1}$$

Eq. (1) shows the relation between the number of events for a polarized beam, N^s, and the number of events for an unpolarized beam, N^0. The vector polarization of the beam is given by p_Z and the vector analyzing powers are indicated by A_y and A_x. Here ϕ is the angle between quantization axis for the polarization and the normal to the scattering plane in the laboratory frame of reference. ξ defines a kinematical point (θ_1,θ_2,ϕ_{12},S).

3. – Results

The analysis of the $\vec{p}$+d break-up reaction was measured with BINA using a polarized proton beam with an energy of 135 MeV on a liquid deuterium target. Analyzing powers have successfully been measured and are presented as a function of S for different combinations of (θ_1,θ_2,ϕ_{12}). In Fig. (3) the filled circles show the vector analyzing powers, A_y and A_x, measured for small, intermediate and large azimuthal opening angles between the two protons. The predictions of the Faddeev calculations based on a nucleon-nucleon (NN) potential and including a three-nucleon potential (3NF) are added to every panel with line colors and styles. The black (solid), the blue (dotted) and red (dash) lines correspond to calculations based on CDB (NN), CDB+Δ (3NF), and CDB+Δ+Coulomb calculations from the Hannover-Lisbon group [6], respectively. The effects of the Coulomb force are generally predicted to be very small for the analyzing power of these configurations as shown in Fig. (3).

At small azimuthal opening angles, the predictions based on a NN potential are closest to the data specially for the analyzing powers of A_y, although, the disagreement is still

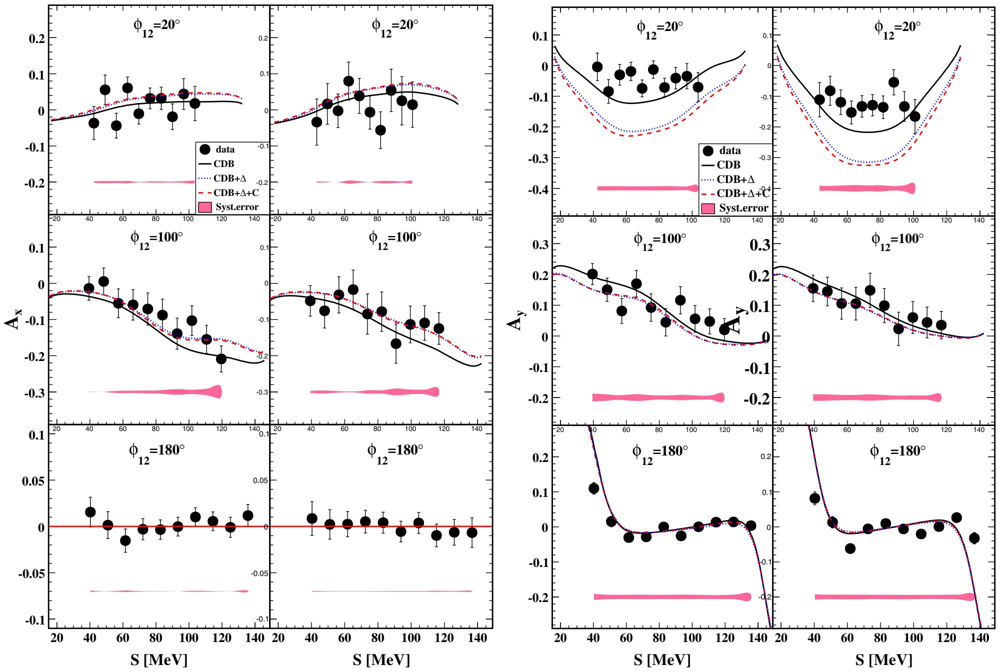

Fig. 3. – Analyzing powers A_x and A_y as a function of S. For each panel, the left column correspond to (θ_1, θ_2)=(28°, 24°) and the right column correspond to (θ_1, θ_2)=(28°, 28°) configurations.

significant. Therefore, the origin of this discrepancy must lie in the treatment of 3NF. Strikingly, the calculation with an additional 3NF results in an even larger discrepancy between data and theory. At intermediate azimuthal opening angles for A_x there is a better agreement between data and a 3NF calculation. For ϕ_{12}=180°, A_x is zero as expected due to parity arguments and the agreement between calculations and data for A_y is reasonably good.

In general, the state-of-the-art calculations describe reasonably well the experimental break-up data. Possibly, the modeling of short-range 3NF can be significantly improved.The present data would serve as a good test bench for the modifications of 3NF.

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