ISSN 1063-7788, Physics of Atomic Nuclei, 2023, Vol. 86, No. 6, pp. 1173–1177. © Pleiades Publishing, Ltd., 2023.
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ELEMENTARY PARTICLES AND FIELDS
Experiment

Deuteron Beam Vector Polarization Measurement Using Proton–Proton Quasielastic Scattering at the Energies of 500 and 650 MeV/nucleon

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Received June 18, 2023; revised June 18, 2023; accepted June 18, 2023

Abstract—The deuteron beam vector polarization is obtained at the Nuclotron Internal Target Station using quasielastic proton–proton scattering on the polyethylene target. The selection of useful events is performed using the time and amplitude information from scintillation counters. The asymmetry on the hydrogen is obtained by the subtraction of the carbon background. The values of vector polarization are obtained at the beam energies of 500 and 650 MeV/nucleon. The obtained values are compared with the data obtained in the deuteron–proton elastic scattering at the beam energy of 135 MeV/nucleon.

DOI: 10.1134/S1063778823060066

1. INTRODUCTION

In modern nuclear physics the experiments on studying the deuteron–proton and proton–proton elastic scattering are fundamental for understanding nucleon–nucleon interactions. A large database of cross sections and polarization observable quantities was obtained for energies below 1 GeV, which allowed performing partial-wave analysis [1]. Modern phenomenological potential models of nucleon interaction provide well description of the data up to the threshold of pion production.

Extension of the meson exchange model for high energies requires including the contributions of inelastic channels due to excitation of baryon resonances. Elastic *dp* and *pp* scattering well suits to investigate the short-term part of nucleon–nucleon interactions. Accurate values of the analyzing power at energies above the threshold of pion production allow refining the contribution of spin-orbital forces sensitive to exchange of heavy mesons. Measurement of beam polarization also is an important part of these studies, which creates the need to develop new methods for investigating the polarization and the analyzing power.

In this work the values of vector polarization of deuteron beam were obtained at energies of 500 and 650 MeV/nucleon using the data obtained using the proton–proton quasielastic scattering.

2. SCHEME OF EXPERIMENT

The experiment was carried out at the Internal Target Station of the superconducting synchrotron Nuclotron, which is placed at the Laboratory of High-Energy Physics of the Joint Institute for Nuclear Research. The deuteron beam for this experiment was provided by a source of polarized ions [2], accelerated by RFQ and a linear accelerator, after which it was injected to the ring of the Nuclotron. As we reached the necessary energy, the disk with targets positioned inside the ring of the accelerator, were rotated putting the necessary target to the trajectory of deuteron motion. Registration of particles obtained in the course of interaction between the beam and target was conducted by means of scintillation detectors.

The Internal Target Station is a spherical vacuum chamber with a system of target replacement [3]. The chamber is fixed on a ion tube of the accelerator using a flange coupling. The disk with various targets (CH_2, C, W, Cu, etc.) is clamped inside the chamber at the axis of the stepper motor, which is used to rotate the disk and put the needed target to the beam trajectory. For the experiment we used the targets made of polyethylene film 10 μm in thickness and carbon fibers 8 μm in thickness. To obtain the effect on hydrogen, the procedure of subtracting the carbon

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Table 1. Averaged values of deuteron beam polarization obtained using deuteron–proton elastic scattering at an energy of 135 MeV/nucleon [9]

Component	p_z	Δp_z
(+1/3, +1)	−0.231	0.008
(+1/3, −1)	−0.245	0.006

background was performed. The signal of the target position sensor was used to assign the interaction point to the ion tube center.

The scintillation detectors placed around the scattering chamber in the beam direction recorded particles produced in the course of interaction between the beam and target. These counters detected the products of the proton–proton quasielastic scattering reaction. To register the protons scattered to the left and right, 22 detectors placed symmetrically with respect to the ion conductor axis were used. Two separate detectors were used to monitor the beam intensity and mounted at an angle of 90° in the center-of-mass system to provide insensitivity to vector polarization of the beam. The data on angular dependence of the analyzing power of the proton–proton quasielastic scattering were obtained at energies of 500 and 650 MeV/nucleon on polyethylene and carbon targets.

3. DATA ANALYSIS

Useful events were discriminated using the criteria for the time-of-flight difference in the pair of scintillation counters, for correlation of energy losses for signals of kinematically coupled counters, and target position, which was recorded for each event in the course of the experiment.

When the deuteron beam interacts with a polyethylene target, carbon background inevitably appears in the data. The contribution of the carbon to the data from the CH_2 target was estimated from individual measurements in which we used a carbon target. It was assumed that the shape of the carbon spectrum was the same at scattering on both polyethylene and carbon targets. The procedure of subtracting the carbon background consisted in determining the coefficient which should be used to multiply the data obtained on carbon in order to approximate the carbon background in the data obtained on polyethylene. To conduct the subtracting procedure, use was made of the formula

$$N_p = N_{\mathrm{CH_2}} - kN_{\mathrm{C}}, \tag{1}$$

where N_p is the number of events on protons, $N_{\mathrm{CH_2}}$ is the number of events on polyethylene, N_{C} is the number of events on carbon, and k is the sought coefficient.

The coefficient k was found as follows: in the data from the kinematically coupled sensors, at scattering on the polyethylene target the region of useful events corresponding to the proton–proton scattering was separated. This criterion was also transferred to histograms of energy losses for the carbon target. Taking into account just the data appearing outside the criterion, the carbon spectrum was approximated to the polyethylene spectrum using the least-squares method. As a result, the coefficient k by which we should multiply the carbon spectrum to obtain a spectrum maximally close to the carbon background in data on polyethylene was obtained.

The values of analyzing power of the pp quasielastic scattering were computed using the data obtained using subtraction of carbon background from the data on polyethylene target. Figures 1 and 2 show the values of analyzing powers of proton–proton quasielastic scattering at beam energies of 500 and 650 MeV/nucleon. These values were obtained using polarization given in Table 1. The obtained values of analyzing power indicate that the pp quasielastic scattering can be used to compute the vector polarization of the deuteron beam.

To compute the vector beam polarization, we used the following formulas derived from [10] for the case described in this work:

$$N_L = 1 + P_z A_y, \tag{2}$$

$$N_R = 1 - P_z A_y, \tag{3}$$

where N_{L} and N_{R} are the reaction yields, P_z is the value of vector polarization, and A_y is the value of the vector analyzing power of scattering. We applied the following formulas for computing the vector analyzing power of the pp quasielastic scattering:

$$P_z^+ = \frac{\dfrac{N_L^+ M^0}{N_L^0 M^+} - \dfrac{N_R^+ M^0}{N_R^0 M^+}}{2A_y}, \tag{4}$$

$$P_z^- = \frac{\dfrac{N_L^- M^0}{N_L^0 M^-} - \dfrac{N_R^- M^0}{N_R^0 M^-}}{2A_y}, \tag{5}$$

where P_z^+ and P_z^- are vector polarizations for the corresponding polarization mode; N_{L}^+ and N_{L}^-, and N_{L}^0 are the numbers of events for a specific angle to the left for two polarization modes and nonpolarized mode, respectively; N_{R}^+, N_{R}^-, and N_{R}^0 are the numbers of events for a specific angle to the right for two polarization modes and nonpolarized mode, respectively; M^+, M^-, and M^0 are the numbers of events

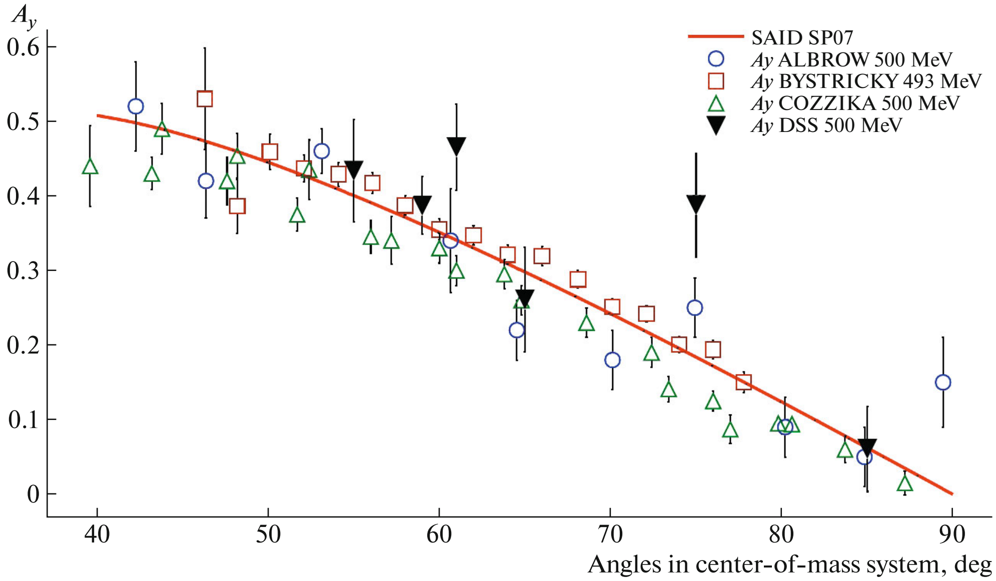

Fig. 1. Comparison of analyzing power in the *pp* quasielastic scattering reaction at an energy of 500 MeV/nucleon to the world data and results of SP07 solution of the partial-wave analysis SAID. The filled symbols are for the results of this experiment, while hollow symbols are for the world data [4–6]. The solid curve denotes the SAID predictions [1].

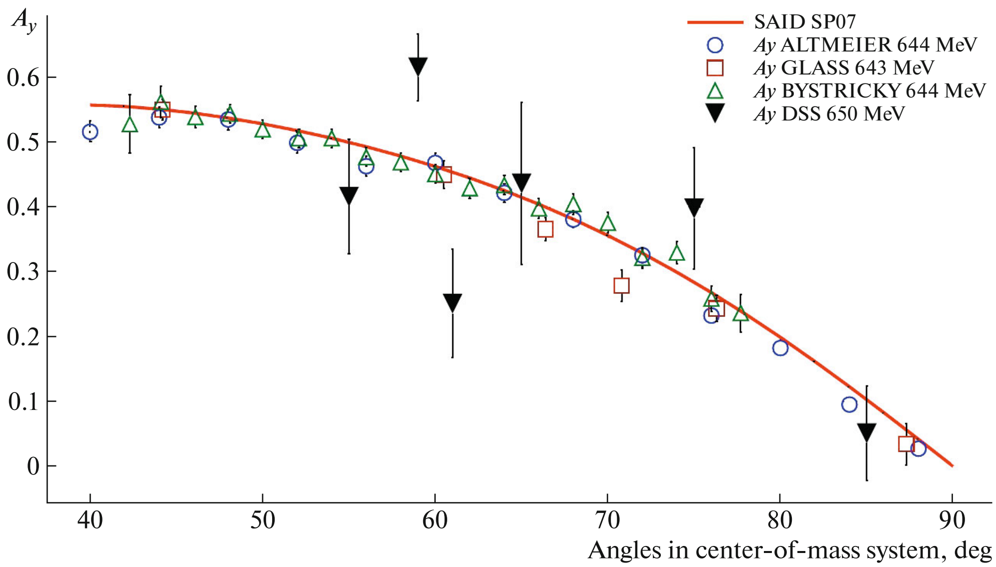

Fig. 2. Comparison of analyzing power in the *pp* quasielastic scattering reaction at an energy of 650 MeV/nucleon to the world data and results of SP07 solution of the partial-wave analysis SAID. The filled symbols are for the results of this experiment, while hollow symbols are for the world data [5, 7, 8]. The solid curve denotes the SAID predictions [1].

in the monitoring counters for the corresponding spin modes; and A_y are the values of the vector analyzing power for the corresponding angle in the center-of-mass system.

To determine the vector polarization, we used 13 different pairs of detectors: six pairs at particle scattering to the left, six pairs to the right, and one pair for scattering at an angle of 90° in the center-of-mass system. Further, we averaged the results for the corresponding angles using the weighted mean for two polarization modes separately.

The beam polarization was measured regularly in the course of experiment using the deuteron–proton elastic scattering at a beam energy of 135 MeV/nucleon [9]. In the experiment we used three spin modes of the source of polarized ions: nonpolarized and two mixed ones with ideal values (p_z, p_{zz}) equal to $(0, 0)$, $(+1/3, +1)$, and $(+1/3, -1)$, respectively.

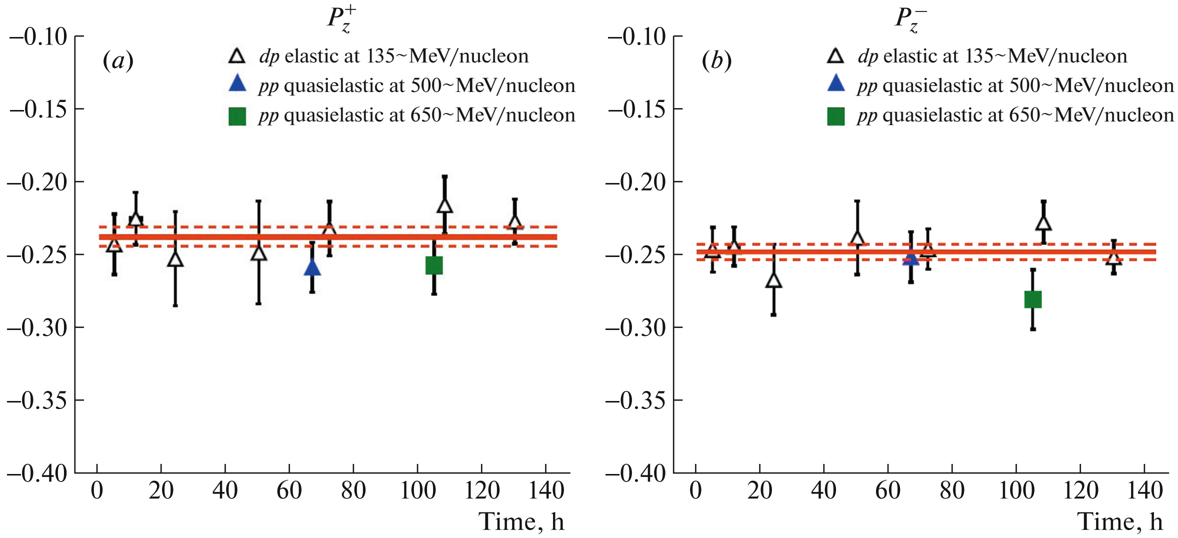

Fig. 3. Comparison of vector polarization values of the deuteron beam obtained at energies of 500 and 650 MeV/nucleon to the polarization values obtained using deuteron–proton scattering at an energy of 135 MeV/nucleon [9]. (a) For polarization mode (+1/3, +1) and (b) for polarization mode (+1/3, −1).

The obtained values of the vector polarization at deuteron beam energies of 500 and 650 MeV/nucleon can be compared with the data obtained at an energy of 135 MeV/nucleon.

4. RESULTS

Figures 1 and 2 present the angular dependences of the vector analyzing power A_y in the proton–proton quasielastic scattering at beam energies of 500 and 650 MeV/nucleon, respectively. The filled symbols are the results of this experiment carried out at the Internal Target Station of the Nuclotron. The hollow symbols are the data obtained in other experiments [4–8]. The values of the analyzing power are also compared with the predictions of the partial-wave analysis SP07 SAID [1]. We see well agreement of the data at the Nuclotron with the results obtained earlier and with the SAID SP07 solution. Consequently, it is possible to perform measurement of the deuteron beam polarization using the proton–proton quasielastic scattering.

The polarization values of the deuteron beam at energies of 500 and 650 MeV/nucleon are given in Fig. 3. The filled symbols represent the results of this experiment, while hollow symbols are the data on polarization obtained at a beam energy of 135 MeV/nucleon. The solid line is the weighted mean value of polarization over all points, and the dashed line is the weighted mean error of measurements. We see well agreement of the polarization values presented in this work with the values obtained at another energy [9].

5. CONCLUSIONS

At the Internal Target Station of the Nuclotron, Joint Institute for Nuclear Research, the vector polarization of the deuteron beam was obtained. For this purpose, the data obtained in the *pp* quasielastic kinematics for energies of 500 and 650 MeV/nucleon were used. Polarization of the deuteron beam was first measured at the Nuclotron using the proton–proton quasielastic scattering.

The polarization results were compared with the data obtained using the deuteron–proton elastic scattering at an energy of 135 MeV/nucleon. Comparison showed that the results well correspond to the polarization obtained by another method [9].

We conducted our experiment in the test mode. We plan to improve the measurement accuracy of polarizations and analyzing power in the future studies with polarized proton and deuteron beams.

FUNDING

This work was supported by ongoing institutional funding. No additional grants to carry out or direct this particular research were obtained.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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Translated by E. Oborin