

ELEMENTARY PARTICLES AND FIELDS

Experiment

Vector Polarization of the Deuteron Beam at Nuclotron at the Energies from 200 to 650 MeV/Nucleon

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Abstract—The deuteron beam vector polarization was obtained at the Nuclotron Internal Target Station using the proton–proton quasielastic scattering on the polyethylene target at the beam energies of 200, 500, 550, and 650 MeV/nucleon. The selection of useful events was performed using the time and amplitude information from the scintillation counters. The asymmetry on hydrogen was obtained by the subtraction of the carbon background. The obtained values are compared with the data obtained using the deuteron–proton elastic scattering at the beam energy of 135 MeV/nucleon.

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1. INTRODUCTION

Experiments to study proton–proton (pp) and deuteron–proton (dp) scattering are fundamental for understanding of the nucleon–nucleon interaction [1]. At the same time, the study of spin effects at accelerators requires continuous monitoring of the beam polarization during the experiments. For this purpose, the polarimeter based on the asymmetry measurement of the deuteron–proton elastic scattering has been developed and installed at the Nuclotron Internal Target Station [2]. This polarimeter is designed to measure vector and tensor polarization of a deuteron beam using polyethylene and carbon targets.

The part of the detectors of this polarimeter was used to carry out tests of another classical method of the beam polarization measurement, which uses the asymmetry of quasielastic proton–proton scattering [3]. A comparison of the analyzing power of the elastic and quasi-elastic pp -scattering shows that they are the same within achieved experimental accuracy over a large energy range [4]. This allows one to measure

both the polarization of the proton beam and the vector polarization of the deuteron beam, since the counters were installed in accordance with pp -elastic scattering kinematics.

The purpose of this article is to present the data on the measurements of the vector polarization of the deuteron beam at various energies using the asymmetry of the proton–proton quasi-elastic scattering.

2. EXPERIMENT AND SEPARATING OF USEFUL DATA

The beam of polarized deuterons was provided by the source of polarized ions (SPI) [5, 6]. In the experiment three spin modes of the source were used: unpolarized, “2–6” and “3–5”, with maximum theoretical values $(p_z, p_{zz}) = (0, 0)$, $(+1/3, +1)$, and $(+1/3, -1)$, respectively. The spin modes of the source were changed one by one from cycle to cycle. The polarization quantization axis was perpendicular to the plane of the Nuclotron ring. Polarization of the beam was measured using deuteron–proton elastic scattering at the beam energy of 135 MeV/nucleon [7]. This procedure was performed regularly during the experiment, alternating with the measurements at other energies. Polarized deuterons were accelerated by the linear accelerator, and then injected into the Nuclotron ring for the further acceleration.

The internal target station is a spherical vacuum chamber with the target changing system [8]. The chamber is fixed to the accelerator ion tube using a flange connection. The disk with various targets

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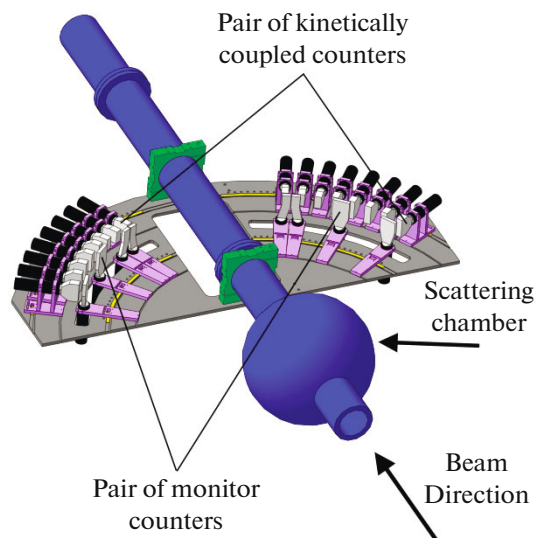


Fig. 1. Detector setup for the proton polarimetry at the Nuclotron internal target station. The pp -elastic scattering kinematics were used. The setup for 500 MeV/nucleon is shown as an example.

(CH₂, C, W, Cu, etc.) is fixed inside the chamber on the axis of the stepper motor. The targets are mounted between the hub and rim of the disk. During beam acceleration, the disk was turned with an empty slot, and upon reaching the required energy, the disk has been rotated, bringing out the desired target into the ion tube [9]. For the experiment, the polyethylene film with a thickness of 10 μm was used. To evaluate the background from carbon contained in polyethylene, the target consisting of 10 twisted carbon filaments, each 8 μm thick, was used.

Particles scattered from the interaction of the beam with the target were detected by the scintillation counters. The part of the detectors of the deuteron polarimeter, using the asymmetry of dp -elastic scattering at the energy of 135 MeV/nucleon [2], was used in the experiment. The scheme of the detectors setup is shown in Fig. 1. In the present experiment, 22 scintillation counters were used. Two additional counters, also called monitor counters, were settled at 90° in center-of-mass system (c.m.s.) to provide insensitivity to the vector polarization. The software part of the data acquisition system is described more detailed in [10].

To select events in the experiment, pairs of detectors were used, installed in accordance with the kinematics of pp -elastic scattering. Useful events were identified using criteria for the time-of-flight difference and the energy losses correlation in the kinematically coupled scintillation detectors, as well as taking into account the position of the interaction point (target position monitor) [11].

Since the deuteron beam interacted with the polyethylene target, a background inevitably appeared in the obtained data. The number of events from the interaction with carbon in the CH₂ target was estimated from the measurements using the carbon target. It was assumed that the shape of the carbon spectrum was the same for the events obtained on polyethylene and carbon targets. The procedure for subtracting the carbon background consisted of finding the coefficient by which it is necessary to multiply the data obtained on the carbon target in order to evaluate the background in the data obtained on the polyethylene target.

Figure 2 shows the result of the subtracting the carbon background from the data obtained on the polyethylene target. The ionization losses for the data obtained on the polyethylene and carbon targets are shown in the panel (a) by the solid black and red lines, respectively. The data on the carbon target was multiplied by the coefficient obtained using the least squares method. The result of the CH₂–C subtraction is shown in the panel (b). One can see that the data obtained on the carbon target are in good agreement with the background in the data obtained on polyethylene. The figure shows the data for the unpolarized mode of the ion source. The dashed lines are the cut for selecting useful events.

While the detectors were positioned symmetrically relative to the center of the ion tube, the resulting events were recorded with a shift arising when the beam did not pass the center of the ion tube. However, the angles at which the events were recorded can be corrected using the data on the position of the target at the moment of interaction with the beam. The simulation was proceeded to eliminate the appearance of the false asymmetry. The pp -elastic events for the simulation were generated using the Pluto library [12], which is a set of libraries for the ROOT software package, to estimate the effect of the beam shifting. The angular dependence of the pp -elastic scattering for the simulation was taken from the SP07 SAID solution [13].

3. RESULTS

The polarization values were calculated using the data on the asymmetry of proton–proton quasi-elastic scattering for each angle in the center-of-mass system separately, then weighted averaged to obtain the values for the given energy. Comparison of the presented polarization values, averaged over the angles, with the results obtained at the energy of 135 MeV/nucleon [7] is presented in Fig. 3. The results of the beam polarization measurements are shown in Table 1.

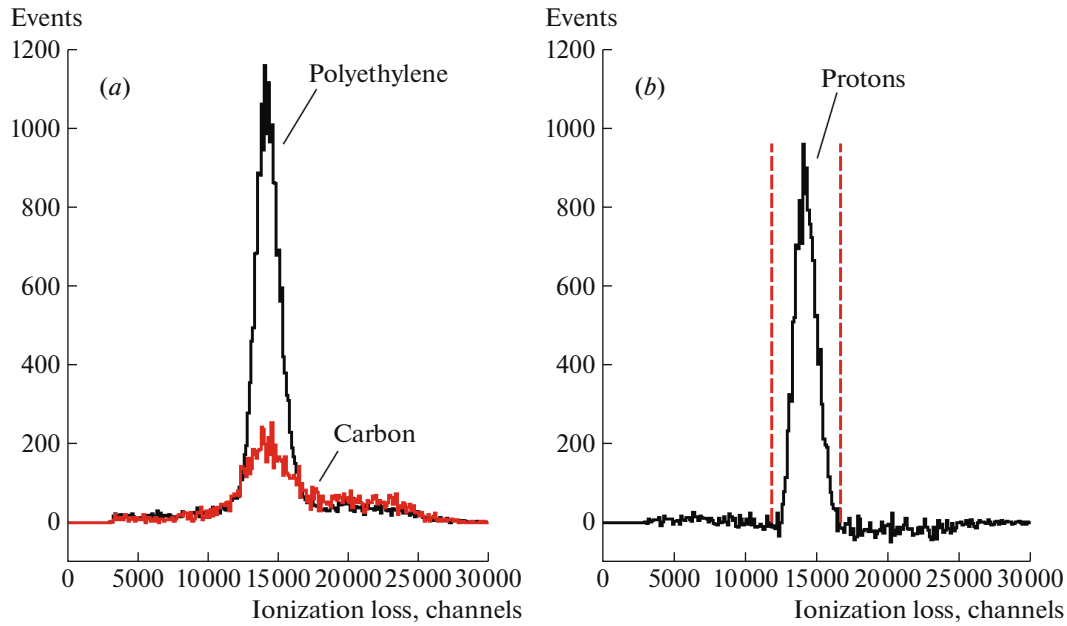


Fig. 2. The result of the carbon background subtraction procedure at the scattering angle of 85° in c.m.s. at the beam energy of 500 MeV/nucleon for the unpolarized mode of the ion source. The ionization losses for the data obtained on the polyethylene and carbon targets are shown in the panel (a) by the solid black and gray lines, respectively. The result of the $\text{CH}_2\text{-C}$ subtraction is shown in the panel (b). The dashed lines are the event selection cut.

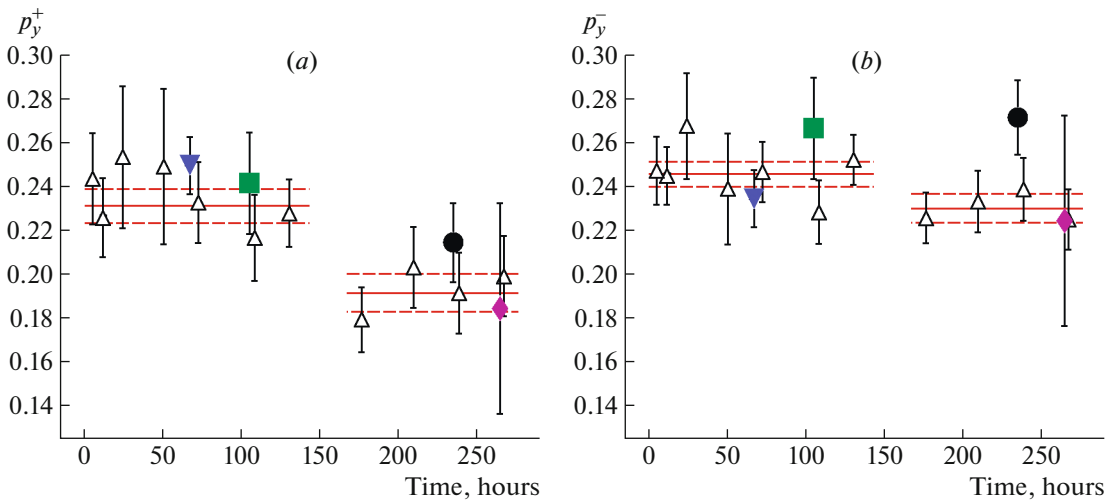


Fig. 3. Vector polarization values of the deuteron beam for the “2–6” and “3–5” spin modes of the source of polarized ions are shown in the panels (a) and (b), respectively. Values obtained in the present work are shown using the filled symbols. The polarization values obtained using dp -elastic scattering at the energy of 135 MeV/nucleon [7] are shown by the empty symbols. The lines and symbols are described in the text.

Vector polarization values of the deuteron beam for the “2–6” and “3–5” spin modes of the SPI [5, 6] are shown in Fig. 3. in the panels (a) and (b), respectively. Values obtained in the present work are shown by the filled symbols: $\blacktriangledown$ —500, $\blacksquare$ —650, $\square$ —550, $\square$ —200 MeV/nucleon. The polarization values obtained using dp -elastic scattering at the energy of

135 MeV/nucleon [7], which were approximated by a constant (solid line), are shown by empty markers. The dashed lines correspond to $\pm 1\sigma$ from the data obtained using dp -elastic scattering. Only statistical errors are indicated.

Polarization was calculated using the analyzing power values obtained by fitting the data from other

Table 1. The results of the deuteron beam polarization measurements at the different beam energies; + and – for the SPI modes “2–6” and “3–5”, respectively

Beam Energy, MeV/nucleon	p_y^+	Δp_y^+	p_y^-	Δp_y^-
200	0.184	0.048	0.224	0.048
500	0.249	0.013	0.234	0.013
550	0.214	0.018	0.271	0.017
650	0.241	0.023	0.266	0.023

experiments with a third degree polynomial. The events, that were used to calculate the asymmetry for the polarization, were selected taking into account criteria for the position of the target at the moment of interaction of the beam with the target, the time-of-flight difference, and the correlation of the ionization losses. The coefficient obtained using the least squares method was used for the subtraction of the carbon background.

4. CONCLUSIONS

The results obtained in the present work are in agreement with the polarization measured using the asymmetry of the dp -elastic scattering [7].

The experiment was carried out in 2016 at the internal target of the Nuclotron, superconducting synchrotron suited in JINR Laboratory of High Energy Physics. Quite a large statistical uncertainty at some energies was a consequence of the fact that the experiment was carried out in the test mode and did not have enough time to collect the data. In future studies with polarized beams of protons and deuterons, it is planned to improve the accuracy of measurements of the polarization and analyzing power by increasing the angular range of measurements and the statistics [14].

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CONFLICT OF INTEREST

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

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