MEASUREMENT OF THE EXTRACTED DEUTERON BEAM VECTOR POLARIZATION AT NUCLotron

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Abstract

The results of the measurements of the vector polarization of the extracted deuteron beam at Nuclotron are presented. The intensity of the polarized deuteron beam during the measurements was $\sim 2.5 \cdot 10^7$ particles/spill. The measurements were made at the initial deuteron momenta of 5 and 3.5 GeV/c. The averaged polarizations of the beam were 0.606 ± 0.014 and 0.540 ± 0.019, respectively.

The investigation has been performed at LHE and LNP JINR.
1 Introduction

The experimental spin program proposed for Nuclotron (LHE-JINR) requires good knowledge of the polarization of the primary deuteron beam and/or a continuous monitoring of the vector polarization stability during the experiment. Such experiments are, for example, Ayy [1], PIKASO [2], PHe3 [3], DELTA – SIGMA [4], SMS – MGU [5], STRELA and other, which are planned to be performed at Nuclotron.

For these purposes the new version of the polarimeter [8, 9] based on the measurement of the asymmetry of quasi-elastic $pp$ scattering on hydrogen in $CH_2$ target has been installed at the focal point $F3$ in the LHE experimental hall.

The aim of this paper is to present the results of the vector polarization measurements during first extraction of the polarized deuteron beam from Nuclotron in December 2002.

A brief description of the new version of on-line beam polarimeter is given in Section 2. The results of the deuteron beam vector polarization measurements are given in Section 3. The effect of the trigger is discussed in Section 4. The conclusions are drawn in the last section.

2 Polarimeter

The measurements of the left-right asymmetry of quasi-elastic $pp$ scattering is the classical method to obtain the value of nucleon beam polarization at intermediate energies. It has been used earlier at SATURNE II [6]. The comparison of the elastic and quasi-elastic $pp$ analyzing powers shows no difference between these quantities in a very large energy range [7]. Using this property, the LHE polarimeter [8, 9] measures $\vec{P}_B(d)$ of deuterons provided by the ion source POLARIS [10]. The polarizations of protons and neutrons produced by the deuteron breakup reaction in the forward direction are equal to each other; they are related to the vector polarization of the deuteron beam.

The polarimeter for the measurement of the deuteron beam vector polarization was installed close to the focal point $F3$ of the extraction beam line of Nuclotron at LHE, JINR. The details of the polarimeter
were discussed in ref. [8, 9]. Here we refer briefly the main changes made for new version of the polarimeter.

The layout of the polarimeter is given in Fig. 1. Here $S_{1-12}$ are the scintillation counters, $IC$ is an ionization chamber, $T$ is the target.

The polarimeter measures the left-right (L-R) asymmetry of $pp$ quasi-elastic scattering, detecting both scattered and recoil particles in coincidence. It consists of two pairs of arms in the horizontal plane installed at the angles corresponding to $pp$ - elastic scattering kinematics. Each arm is equipped by three scintillation counters. The six-fold (instead of four-fold in the previous version [8, 9]) coincidence of counter signals from each pair of conjugated arms $S_1$ to $S_6$ and $S_7$ to $S_{12}$ define L or R scattering events, respectively. The increasing of the level of coincidence reduces significantly the number of random coincidences. Also the ionization chamber $IC$ used as beam intensity monitor is installed just in front of the polarimeter target $T$.

The sizes of plastic scintillators and the distance of the counters $S_1 - S_{12}$ from the target point are given in Table 1. The solid angles of the forward and recoil arms are defined by the sizes and positions of the $S_1$, $S_8$ and $S_5$, $S_{11}$ counters, respectively. The solid angle for $pp$ - elastic scattering is defined by the acceptances of the forward arms, while the recoil arms have larger acceptance. The size of the forward arms determining counters ($S_1$ and $S_8$) is $40 \times 40 \text{ mm}^2$ and their distance from the target center is $1720 \text{ mm}$. Therefore the scattering angle acceptance and solid angle subtended by the L or R counters are $\Delta \theta = \pm 0.67^\circ$ and $\Delta \Omega = 5.4 \cdot 10^{-4} \text{ sr}$, respectively. The solid angle for the recoil particles is $\Delta \Omega_{rec} = 9 \cdot 10^{-3} \text{ sr}$. Such an angle allows to detect the recoil protons from $pp$ - elastic scattering without losses of the statistics and with insignificant magnification of the admixture of the quasi-elastic events from the carbon content of $CH_2$ target.

Coincidence counts of the polarimeter arms and monitor informations were recorded for each beam polarization direction and stored by a PC data acquisition system after the end of each beam spill.

The polarization of the extracted beam was oriented along the vertical axis (perpendicularly to the beam momentum direction) and flipped every accelerator spill.

The method of the vector polarization measurement is based on the
detection of the particles scattered leftwards and rightwards. The left-right asymmetry for a certain sign of the beam polarization ($\pm$) can be calculated from the relation

$$\epsilon^\pm = \frac{n^\pm_L/n^\pm_R - n^0_L/n^0_R}{n^\pm_L/n^\pm_R + n^0_L/n^0_R},$$  

where $n^\pm_L$ and $n^\pm_R$ are the respective numbers of events scattered leftwards and rightwards for different spin states of polarization source normalized to the beam intensity.

If an effective analyzing power of the polarimeter $A$ is known, the beam polarization $P^\pm$ can be calculated according to

$$P^\pm = \frac{\epsilon^\pm}{A}. \tag{2}$$

3 Measurements of the beam polarization

The polarized deuterons were produced by the ion source POLARIS [10]. The extraction of the polarized deuteron beam from Nuclotron has been performed at 5.0 GeV/c and 3.5 GeV/c. The intensity of the beam was measured by the ionization chamber $IC$ placed in front of the polarimeter. The results of the intensity measurements versus time are shown in Fig.2.

The averaged beam intensity was only $\sim 2 - 3 \cdot 10^7$ particles per burst. Therefore, to have a reasonable counting rate for both left and right arms of the polarimeter the $CH_2$ target thickness was increased up to 5 cm, and the level of coincidences was decreased from 6 to 4 (or 3).

The results of the asymmetry measurements for the both signs of the beam polarization are shown in Fig.3. The measurements were made at the initial deuteron momenta 5.0 GeV/c and 3.5 GeV/c (last 3 points in Fig.3). The forward scattering angle was set 14° for the both momenta, while the angle for the recoil proton was set in accordance with the kinematics of elastic $pp$ scattering. At higher momentum the absolute value of the asymmetry is lower due to a fall in effective analyzing power of the polarimeter versus energy [8, 9].

Since the polarimeter was not calibrated at these both deuteron momenta, the values of the effective analyzing power $A(CH_2)$ were taken
from the parametrization. The results of the linear and quadratic proton momentum dependences of the analyzing power $A(CH_2)$ are presented in Fig. 4 by the dashed and solid lines, respectively.

The linear dependence of analyzing power on the proton momenta has the following form \cite{11}

$$A(CH_2)(p_p) = 0.6429 - 0.1628 \cdot p_p,$$ (3)

while the quadratic dependence is given as

$$A(CH_2)(p_p) = 0.5190 - 0.0456 \cdot p_p - 0.0262 \cdot p_p^2,$$ (4)

The values of the effective analyzing power $A(CH_2)$ at the proton momenta 1.75 GeV/c and 2.5 GeV/c were taken according relation (4) as 0.359 and 0.241, respectively. Note, that the values of analyzing power $A(CH_2)$ at 1.75 GeV/c obtained from expressions (3) and (4) agrees with the precision better than 0.5%.

The values of the deuteron beam vector polarization at the both deuteron momenta are presented in Table 2. The averaged over spin states values of polarization are 0.540 ± 0.019 and 0.606 ± 0.014 at 3.5 GeV/c and 5.0 GeV/c, respectively. Some difference in the polarization values at the both momenta can be due to uncertainty in the values of effective analyzing power $A(CH_2)$ used.

## 4 Trigger effect

The level of coincidences of scintillation counter signal was reduced because of a low intensity of the beam during polarization measurements. In this case the effective solid angle of the polarimeter changes due to finite size of the beam and target. Therefore, the effective analyzing power of the polarimeter could also change due to possible different yield from carbon content of the target.

The special study to test such an effect was performed using unpolarized deuteron beam with the momentum of 3.5 GeV/c at Nuclotron run in June 2003.

The idea of these studies is based on the following assumption. Let us suppose that an effective analyzing power of polarimeter $A$ may be
represented as
\[ A = (1 - k) \cdot A_{pp} + k \cdot A_{pC}, \] (5)
where \( A_{pp} \) and \( A_{pC} \) are the analyzing powers of \( pp \) elastic scattering and \( pC \rightarrow ppX \) reaction, respectively, and \( k \) is a coefficient proportional to the carbon content of \( CH_2 \) target. If the effective solid angle changes, the fraction of events from carbon also may change, and new value of an effective analyzing power \( \bar{A} \) can be written as:
\[ \bar{A} = (1 - \bar{k}) \cdot A_{pp} + \bar{k} \cdot A_{pC}, \] (6)
where \( \bar{k} \) is some new coefficient. If \( A_{pp}, A, k \) and \( \bar{k} \) are known, a corrected value of the effective analyzing power \( \bar{A} \) may be found from
\[ \bar{A} = \frac{\bar{k}}{k} \cdot A + (1 - \frac{\bar{k}}{k}) \cdot A_{pp}. \] (7)

The value of \( A_{pp} = 0.418 \) is known from the fit to the world \( pp \)-data for the scattering at an angle of 14° (see Fig. 5), \( A = 0.359 \) can be taken from the previous calibration of polarimeter at the deuteron momentum of 3.5 GeV/c, and \( k \) and \( \bar{k} \) have been obtained from direct measurements in a special run at Nuclotron in June 2003.

The results of these measurements are presented in Fig.6 for 2 configurations of the polarimeter trigger: Trigger 1 is 6-fold coincidences, while Trigger 2 is 4(3)-fold coincidences. The counting rates normalized for the beam intensity and target thickness for the \( CH_2 \) (open symbols) and carbon (filled symbols) are shown versus recoil particle scattering angle. The solid lines are the results of the fit of the \( CH_2 \) and carbon yield.

Since the carbon content, in general, can be different for the left and right arms, both of them were considered as the separate polarimeters with their own effective analyzing powers. The polarization of the beam was calculated for the left and right arms of the polarimeter and weighted averaged for each sign of the polarized ion source.

Two methods to estimate possible trigger effect were used. The first method (Method 1) is based on the subtraction of the direct measurements of the event rates from \( CH_2 \) and carbon targets normalized to the beam intensity and number of nuclei in the targets. The second one (Method 2) uses the values obtained from the parameters of the fit for
the $CH_2$ and carbon. The results are given in Table 3. The first line contain the polarization values obtained without corrections, while the second and the third ones give the values obtained with the corrections using Method 1 and Method 2, respectively. It is seen that the values of polarization corrected with our methods agree in limits of error bars with those obtained initially.

Fig.7 demonstrates the normalized yield of the events from the hydrogen content of the $CH_2$ target obtained by the $CH_2 - C$ subtraction. The cleanness of the subtraction, especially, for the 6-fold coincidences allows to obtain the values of the polarization by the use the data on the analyzing power of $pp$ elastic scattering only, as it is proposed in ref. [11]. Such a procedure can be applied in future on polarized deuteron beam at Nuclotron.

5 Conclusions

The results of this work can be summarized as following.

The intensity of the firstly extracted polarized deuteron beam at Nuclotron during the measurements was $\sim 2.5 \cdot 10^7$ particles/spill.

The polarimeter placed at focal point $F3$ measured significant asymmetry at 5 GeV/c and 3.5 GeV/c for the vector polarized deuteron beam. The polarization of the extracted deuteron beam averaged over the spin states was $0.606 \pm 0.014$ and $0.540 \pm 0.019$ at 5 GeV/c and 3.5 GeV/c, respectively.

Special study was performed to estimate the possible systematics due to trigger effect using unpolarized deuteron beam. It was shown that the modification of the polarization values at 3.5 GeV/c due to this effect is small and does not exceed the statistical and systematic errors.

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Figures caption

**Fig.1.** New version of the beam polarimeter at focal point F3. IC is the ionization chamber, T is the CH$_2$ (or C) target, $S_1 - S_{12}$ are the scintillation counters.

**Fig.2.** Intensity of the extracted polarized deuteron beam at Nuclotron in December 2002 run versus time.

**Fig.3.** Asymmetry of the extracted polarized deuteron beam at Nuclotron in 2002 December run at 5.0 and 3.5 GeV/c (last 3 points) versus time.

**Fig.4.** The fit of the energy dependence of the effective analyzing power $A(CH_2)$ at 14° [9, 11]. The dashed and solid lines are the results of the parametrization by the linear and quadratic dependences on the proton momentum, respectively.

**Fig.5.** The fit of the energy dependence of the $A_{pp}$ analyzing power at 14°.

**Fig.6.** The normalized counting rate for the CH$_2$ (open symbols) and carbon (filled symbols) targets for different configurations of the trigger versus recoil particle scattering angle. Figures a) and b) correspond to the 6 fold coincidences for the left and right arms, while figures c) and d) correspond to the 4(3) fold coincidences, respectively.

**Fig.7.** The normalized counting rate for the hydrogen content of the CH$_2$ target for different configurations of the trigger versus recoil particle scattering angle. Figures a) and b) correspond to the 6 fold coincidences for the left and right arms, while figures c) and d) correspond to the 4(3) fold coincidences, respectively.
Table 1. Dimensions of plastic scintillators ($x \times y \times z$), where $x$ and $y$ are the sizes in the horizontal and vertical planes, respectively, and $z$ is the thickness) and their distance from the target center.

| Arm   | Counter | Dimensions, $mm^3$ | Distance from the target, $mm$ |
|-------|---------|--------------------|--------------------------------|
| Forward | $S_1$, $S_8$ | $40 \times 40 \times 5$ | 1720 |
|       | $S_3$, $S_9$ | $40 \times 40 \times 5$ | 1260 |
|       | $S_2$, $S_7$ | $35 \times 35 \times 5$ | 835  |
| Recoil | $S_5$, $S_{11}$ | $50 \times 160 \times 8$ | 940  |
|       | $S_6$, $S_{12}$ | $45 \times 145 \times 8$ | 690  |
|       | $S_4$, $S_{10}$ | $40 \times 130 \times 8$ | 460  |
Table 2. Vector polarization of the extracted deuteron beam at incident momenta 3.5 and 5.0 GeV/c.

| $P_d$, GeV/c | $P^+ \pm \Delta P^+$ | $P^- \pm \Delta P^-$ | $P \pm \Delta P$ |
|--------------|---------------------|---------------------|------------------|
| 3.5          | 0.531 ± 0.026       | −0.548 ± 0.027      | 0.540 ± 0.019    |
| 5.0          | 0.633 ± 0.019       | −0.578 ± 0.020      | 0.606 ± 0.014    |
**Table 3.** The beam polarization for the both spin states of the polarized ion source without and with the correction for the trigger effect.

| Method                  | $P^+ \pm \Delta P^+$ | $P^- \pm \Delta P^-$ | $P \pm \Delta P$  |
|-------------------------|-----------------------|-----------------------|-------------------|
| Without corrections     | 0.531 ± 0.026         | -0.552 ± 0.027        | 0.541 ± 0.019     |
| Method 1                | 0.540 ± 0.027         | -0.552 ± 0.027        | 0.546 ± 0.019     |
| Method 2                | 0.563 ± 0.028         | -0.564 ± 0.028        | 0.563 ± 0.020     |
Fig. 1
Fig. 2
Fig. 4
Fig. 5

A of elastic $p-p$ scattering at $\Theta = 14^\circ$

$a$

$b$

$T_p$, GeV
Fig. 6
Fig. 7