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Measurement of the deuteron beam polarization at internal target at Nuclotron for DSS experiment

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Abstract. The current deuteron beam polarimetry at Nuclotron is provided by the Internal Target polarimeter based on the use of the asymmetry in *dp*- elastic scattering at large angles in the cms at 270 MeV. The upgraded deuteron beam polarimeter has been used obtain the vector and tensor polarization during 2016/2017 runs for the DSS experimental program. The polarimeter has been used also for tuning of the polarized ion source parameters for 6 different spin modes.

1. Introduction

The study of the spin structure of two-nucleon and three-nucleon short-range correlations via the measurements of the polarization observables in the deuteron induced reactions is main goal of the DSS project at Nuclotron[1, 2, 3]. The high precision polarimetry of the deuteron and proton beams is important for these investigations.

The goal of the present article is to report new results on the measurements of the vector and tensor beam polarizations using upgraded polarimeter based on the asymmetry measurements in *dp*- elastic scattering at 270 MeV [4] at the Internal Target Station (ITS) at Nuclotron. These measurements were performed during the DSS experiment on the study of the vector A_y, tensor A_{yy} and A_{xx} analyzing powers in *dp*- elastic scattering at large transverse momenta [5].

2. Deuteron polarimeter at ITS

Efficient polarimetry can be achieved even at relatively low beam intensity with using a thin solid target inside the inner ring of the accelerator. The luminosity can be increased significantly due to multiple beam passage through the interaction point and the use of a correctly configured internal target trajectory. Therefore, the internal beam polarimeter with a very thin target may have approximately the same efficiency as the extracted beams polarimeters.

The polarimeter based on the use of *dp*- elastic scattering at large angles ($\theta_{\rm cm} \geq 60^\circ$) at 270 MeV [4], where precise data on analyzing powers [6]-[8] exist, has been developed at internal target station (ITS) at Nuclotron[9]. The accuracy of the determination of the deuteron beam polarization achieved with this method is better than 2% because of the values of the analyzing powers were obtained for the polarized deuteron beam, which absolute polarization had been calibrated via the $^{12}{\rm C}(d,\alpha)^{10}{\rm B}^*[2^+]$ reaction[8].

Deuteron beam polarimeter [4] is placed in the Nuclotron ring. It consists of a spherical scattering chamber and system change targets that can be set six different targets. A detector support with 39 mounted plastic scintillation counters is placed downstream the ITS spherical chamber. Each plastic scintillation counter was coupled to a photo-multiplier tube Hamamatsu H7416MOD. Eight proton detectors were installed for left , as well as for right and up, but due to space limitation – only four for down. The angular span of one proton detector was 2° in the laboratory frame, which corresponds to $\sim 4^\circ$ in the cms. Three deuteron detectors are placed at scattering angles of deuterons coinciding kinematically with the protons. Only one deuteron detector can cover the solid angle corresponding to four proton detectors placed down. In addition, one pair of detectors is placed to register two protons from quasi-elastic $p-p$ scattering at θ_{pp}=90° in the cms in the horizontal plane. The scattered deuterons and recoil protons at 270 MeV were detected in kinematic coincidence over the cms angular range of 65–135° at eight different angles, defined by the positions of the proton detectors.

The VME (Versa Module Eurocard) based data acquisition system is used for the data taking from scintillation detectors [10]. The signals from the detectors are fed in 16-channel TQDC-16 charge-time-digital converters via commutator bar. TQDC-16 module allows to measure the amplitude and time appearance of the signal simultaneously. The hardware of the DSS VME system consists of 4 TQDC-16 modules, trigger module TTCM and VME controller. There is a possibility to tune the first-level trigger using logic of trigger and TQDC-16 modules. This system has been significantly upgraded recently [11].

Newly developed multichannel high-voltage power supply system (Wiener MPod) [12] is used to provide the power for about 70 scintillation detectors based on Hamamatsu photomultipliers.

3. Experiment at ITS

The internal target station (ITS) setup is well suited for study of the energy dependence of polarization observables for the deuteron-proton elastic scattering and deuteron breakup reaction with the detection of two protons at large scattering angles. For these purposes the CH_2-target of 10 μm thick is used for the measurements. The yield from carbon content of the CH_2-target is estimated in separate measurements using several twisted 8μm carbon wires. The measurements were performed using internal target station at Nuclotron [9] with new control and data acquisition system [13].

New source of polarized ions (SPI) [14] has been used to provide polarized deuteron beam. In the current experiment the spin modes with the maximal ideal values of (P_z,P_{zz})= (0,0), (-1/3,-1) and (-1/3, +1) were used. The deuteron beam polarization has been measured at 270 MeV [4].

The DSS data taking was separated on 3 parts: November 2016, December 2016 and February 2017. The deuteron beam polarization measurements were performed at 270 MeV before each energy studied in the range of 400-1800 MeV [5]. The beam polarization measurements were performed also in the end of each part of the experiment. The polarimeter [4] has been used to tune other spin modes of SPI.

The software for data analysis was developed using the ROOT package in C++. The *dp*-elastic scattering events at 270 MeV were selected using correlation of the energy losses and time-of-flight difference for deuteron and proton detectors. The measurements were performed using CH_2 target only. The carbon contamination was measured to be less than 0.5%.

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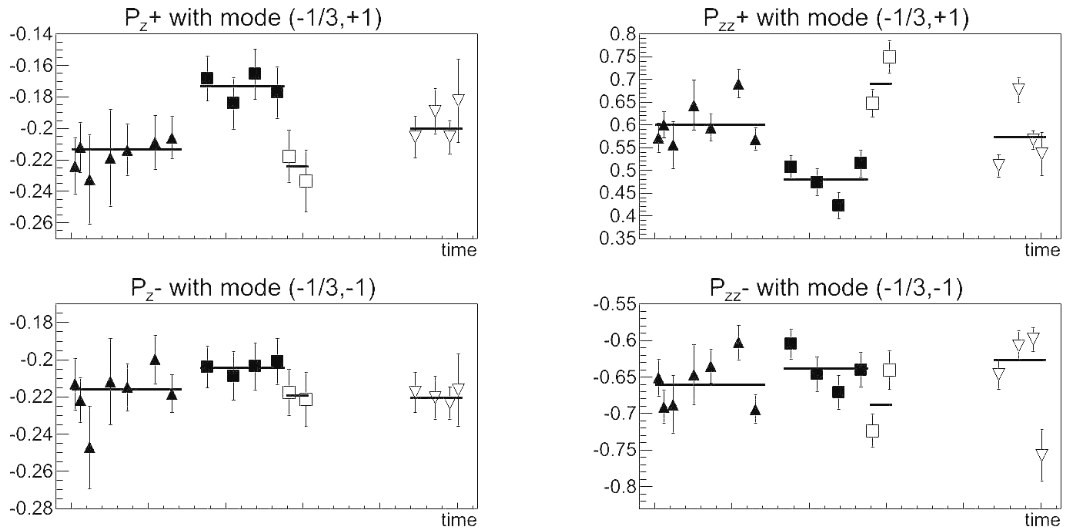

Figure 1. Polarizations values P_z and P_{zz} for spin modes (P_z,P_{zz})= (-1/3,-1) and (-1/3, +1) during the runs in 2016 — 2017 yy.

The precise data on the deuteron analyzing powers at 270 MeV [6]-[8] were used to get the polarization values at several angles [4]. Assuming that the Y-axis is a symmetry axis (β=90°, φ =0°) one can calculate P_z and P_{zz} using the normalized dp-elastic scattering events and analyzing powers known [4]. The values of the beam polarization for different spin have been obtained as weighted averages for 8 scattering angles for dp- elastic scattering in the horizontal plane only. The typical values of the beam polarization were ∼65-75% from the ideal values.

4. The results of the polarization measurements

The vector and tensor polarizations were measured seven, six and four times in the parts at November-2016, at December-2016 and at February-2017, respectively. The values have small statistical and systematics errors. They are rather stable within each part of the experiment. The exception is the December-2016 part, when the physics program was separated on two parts by the tuning of the SPI for pure tensor modes (P_z,P_{zz})= (0,-2) and (0,+1) during 8 hours. This is the reason why December-2016 part is divided by sets of the measurements. The polarization values were approximated by the constants for all four sets of the data. The results of the measurements and approximation are presented in Fig. 1. All the results are within two standard deviations from these constants. One can see that the beam polarization values are quite stable within more than 200 hour of the SPI operation. On the other hand, SPI demonstrates good reproducibility of the polarization values for different sets of the data after long interruptions. The typical values of the vector and tensor components of the beam polarization for the spin modes (-1/3,-1) and (-1/3,+1) are given in the table 1.

The polarimeter [4] has been used also to tune the SPI [14] operation for pure tensor spin modes (0,-2) and (0,+1), for pure vector spin mode (+2/3,0) and for the spin mode (-2/3,+1) with both vector and tensor components. The preliminary results are presented in table 1. One can see, that the typical values of the beam polarization were ∼65-75% from the ideal values for all 6 spin modes of SPI.

Table 1. The vector and tensor polarization for different spin modes of SPI [14].

Spin mode(P_z, P_{zz})	P_z	dP_z	P_{zz}	dP_{zz}
(-1/3,+1)	-0.254	0.022	0.637	0.039
(-1/3,-1)	-0.223	0.017	-0.621	0.030
(-2/3,+1)	-0.489	0.026	0.631	0.045
(+2/3,0)	0.427	0.021	0.061	0.037
(0,+1)	0.030	0.027	0.880	0.049
(0,-2)	0.046	0.015	-1.469	0.031

5. Conclusion

The upgraded version of the 270 MeV deuteron beam polarimeter has been used to obtain the vector and tensor polarization during 2016/2017 runs.

The long-term stability of the vector and tensor components of the beam polarization has been demonstrated for the spin modes (-1/3,+1) and (-1/3,-1) of SPI.

The polarimeter has been used for tuning of the polarized ion source parameters for 6 different spin modes.

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