First results on the measurements of the proton beam polarization at internal target at Nuclotron[1]

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Abstract. The spin program at NICA using SPD and MPD requires high intensity polarized proton beam with high value of the beam polarization. First results on the measurements of the proton beam polarization performed at internal target at Nuclotron are reported. The polarization of the proton beam provided by new source of polarized ions has been measured at 500 MeV using quasielastic proton-proton scattering and DSS setup at internal target. The obtained value of the vertical polarization of ∼35% is consistent with the calculations taking into account the current magnetic optics of the Nuclotron injection line.

1. Introduction

The availability of the polarized proton beam is required by the spin program at NICA [1]. The main part of the physics program with SPD detector consists of the measurements of asymmetries in the lepton pair (Drell-Yan) production in collisions of non-polarized, longitudinally and transversally polarized protons and deuterons beams. These measurements can provide an access to all leading twist collinear and Transverse-Momentum Dependent ditsribution functions of quarks and anti-quarks in nucleons. The measurements of asymmetries in production of $J\Psi$ and direct photons, which supply complimentary information on the nucleon structure, will be performed simultaneously with Drell-Yan data using dedicated triggers. The set of these measurements permits to tests the quark-parton model of nucleons at the QCD twist-2 level with minimal systematic errors [2, 3]. This program can be extended by the measurements of the single and double spin asymmetries in the pion, kaon, proton inclusive production, vector

[1] Dedicated to the memory of Prof. L.S.Zolin

mesons and hyperon production in polarized proton-proton collisions etc. Moreover, polarized proton beam is needed for the spin studies with fixed target, namely, measurements of spin observables proton-proton, proton-neutron and proton-deuteron elastic scattering., investigation of the spin structure of the short-range nucleon correlations and three nucleon forces [4]. The realization of this program requires good knowledge of the proton beam polarization.

In this paper we report first results of the proton beam polarization measurements performed using upgraded polarimeter [5] at the Nuclotron internal target station.

2. Experiment at ITS

The polarimeter based on the use of *dp*- elastic scattering at large angles ($\theta_{\rm cm} \geq 60^\circ$) at 270 MeV[5], where precise data on analyzing powers [6, 7, 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}C$(d,\alpha)^{10}$B$^*[2^+]$ reaction[8].

The use of large amount of the scintillation counters allowed to cover wide angular range. The measurement of the beam polarization has been performed at 270 MeV where the precise data on the tensor and vector analyzing powers based on the absolute calibration of the beam polarization exist [8]. These measurements were performed using internal target station at Nuclotron [9] with new control and data acquisition system [10]. The polarimeter has been upgraded [5] by new VME based DAQ [11], new MPod based high voltage system [12, 13], new system of monitors etc.

The same setup has been used to measure the vector A_y and tensor A_{yy} and A_{xx} analyzing powers in *dp*- elastic scattering between 400 MeV and 1800 MeV [14] using polarized deuteron beam from new source of polarized ions (SPI) developed at LHEP-JINR [15]. The setup has been also adopted for the measurements of the proton beam polarization at 500 MeV.

3. Measurements of the analyzing power for *pp*- elastic scattering

The classical method to measure the proton beam polarization at intermediate and high energies is the use of the left-right *pp*- elastic or quasi-elastic scattering (see, for instance, [16] and references therein). The maximal value of the analyzing power at the energies below 1000 MeV is close to $\sim 40^\circ$ in cms [17], that corresponds roughly 14-15° in the laboratory. Unfortunately, this angle is inaccessible due to design of ITS and detector support.

This method has been modified to increase the polarimeter figure of merit. For this purpose the measurements of the proton beam polarization using several pairs of the detectors placed in the kinematic coincidences corresponding to *pp*- elastic scattering in the horizontal plane (orbit plane of Nuclotron) have been proposed. The similar method has been used at COSY using EDDA setup [18, 19]. The feasibility of the proposed method at ITS has been checked in November 2016 run at Nuclotron using polarized deuteron beam with the energy of 500 MeV/nucleon.

New SPI [15] 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 [5]. 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 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. They were measured as (P_z,P_{zz})= (-0.232±0.018,+0.595±0.013) and (-0.243±0.013,-0.736±0.011) for spin modes "2-6" and "3-5", respectively.

After deuteron beam polarization measurements at 270 MeV, the beam has been accelerated up to 1000 MeV (or 500 MeV/nucleon). Eight pairs of the scintillation detectors were positioned in the horizontal plane covering angular range 55°-125° in the cms for *pp*- elastic scattering at 500 MeV on the left. Since analyzing power is antisymmetric with respect to θ^*=90°, the scattering in the backward hemisphere on the left at the angle $\pi - \theta$ can be considered as the scattering in the forward hemisphere on the right at the angle θ [20].

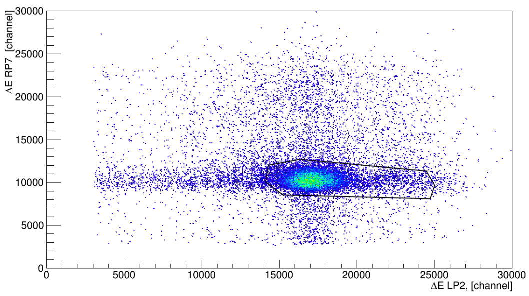

Figure 1. Correlation of the signal amplitudes in scintillation counters for proton-proton coincidences at 65° in cms. The solid line is a graphical cut to select *pp*- quasielastic scattering events.

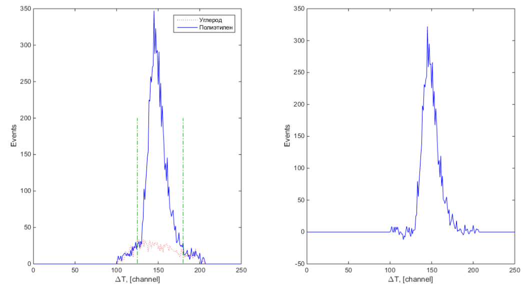

Figure 2. The time-of-flight difference between the signals from two proton detectors placed at 65° in cms. Left and right panels are the spectra obtained on CH_2 target and after carbon subtraction, respectively.

The main part of the measurements were performed using CH_2 target. Carbon target was used to estimate the background. The *pp*- quasielastic scattering events were selected using the energy losses and time-of-flight difference for two proton detectors placed in the kinematic coincidences. The correlation of the signal amplitudes in scintillation counters for proton-proton coincidences at 65° in cms is shown in Fig.1. The time-of-flight difference between the signals from two proton detectors placed at 65° in cms is presented in Fig.2. Left and right panels are the spectra obtained on CH_2 target and after CH_2-C subtraction, respectively.

The normalized numbers of *pp*-elastic scattering events for each spin mode were used to calculate the values of the analyzing power of *pp*- elastic scattering at 500 MeV. The obtained results were found to be in good agreement with the SP07 solution of SAID PWA [17], that proved the feasibility of the proposed method.

4. Results of the proton beam polarization measurement

The unpolarized and polarized proton beam provided by SPI [15] has been accelerated in March 2017 run up to 500 MeV. The typical intensity of the beam was $\sim$1.5·10^8 ppp and $\sim$2-3·10^7 ppp for unpolarized and polarized cases, respectively. SPI provided proton beam polarization using WFT 1$\to$3 with ideal value of the polarization P=-1. The polarization of the proton beam has been obtained using the data from eight pairs of the detectors placed in the kinematic coincidences. The values of the analyzing power for *pp* elastic scattering were taken from SAID PWA [17].

The weighted average values of the proton beam polarization were found as 0.017±0.021 and -0.354±0.022 for unpolarized and polarized cases, respectively. According to spin transport calculations taking into account the current magnetic option of the Nuclotron injection line [21] the polarization at the exit of SPI equals -0.90±0.06. The vertical component of the proton beam polarization at the ITS point can be increased up to this value by the installation of two solenoids at the exit of SPI and in to the Nuclotron injection line [21].

5. Conclusions

The ITS deuteron beam polarimeter [5] has been used to measure the proton beam polarization at 500 MeV using *pp*- quasi-elastic scattering.

The obtained value of the vertical proton polarization is -0.354±0.022. This value corresponds to polarization at the exit of SPI of -0.90±0.06 taking into account the current magnetic option of the Nuclotron injection line. Installation of two solenoids at the exit of SPI and in to the Nuclotron injection line will increase the vertical component of the proton beam polarization at the ITS point.

The current version of the ITS deuteron beam polarimeter can be applied for the proton beam polarization measurement at the energy range of 200-1000 MeV. The extension of the proton polarimetry at ITS to the higher energies (up to 3500 MeV) is possible by the enlargement of the angular span of the polarimeter using new detector support, new scintillation counters etc.

The availability of the polarized proton beam allows to extend the DSS physics program at ITS [4], namely, to perform the experiments on the measurements of the nucleon analyzing power A_y^p in *pd*- elastic scattering at 135-1000 MeV and in *pd*- nonmesonic breakup at the energies between 135-250 MeV for different kinematic configurations etc.

Acknowledgments

The authors thank the Nuclotron staff for providing good conditions of the experiment. They are grateful to Dr.V.A. Mikhaylov for the advise during acceleration of polarized protons. They thank V.B. Shutov and V.I. Maximenkova for the help during the preparation of the detector. The work has been supported in part by the RFBR under grant $N^0$16-02-00203a and JINR-Slovak Republic scientific cooperation program in 2016-2017.

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