

Elastic scattering polarimeter for a polarized antiproton beam at U-70 accelerator of IHEP

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Abstract. The absolute polarimeter based on the elastic $\bar{p}p$ -scattering in the diffraction kinematic regions with the total momentum transfer squared coverage of $0.1 < -t < 0.3 \text{ (GeV/c)}^2$ is proposed for the polarized antiproton beam at the U-70 proton synchrotron of IHEP. It is shown that it would take $\sim 200\text{--}400$ hours for measuring the beam polarization at the statistical errors of $\Delta P_B/P_B \simeq 10\text{--}15\%$. These time estimates include also the time which is necessary for the measurements of an analyzing power A_N , using a polarized target. Besides the measurements of beam polarizations, the proposed polarimeter provides an opportunity for carrying out the experimental studies of the small momentum transfers physics which would be a valuable enrichment of the SPASCHARM experiment capabilities and its physics program.

1. Introduction

The polarized proton and antiproton beam-channel 24A for the SPASCHARM experiment [1] is to be built at the 70 GeV accelerator of IHEP, Protvino, Russia. The method of forming these polarized beams and their characteristics have been described in details elsewhere [1–3]. The beam protons and antiprotons originate from the parity-violating decays of Λ -hyperons. The transversely polarized portions of the total beam are selected, using the particle's trajectory tagging or collimation. An independent beam polarimetry is an important part of the beam-channel setup which serves the purposes of verification and confirmation of operation of the beam forming system. For the case of protons, it has been discussed in a number of publications and presentations¹.

The polarimetry for an antiproton beam has two additional complications. The intensity of antiprotons will be much lower compared to the proton beam. Moreover, the currently available data on spin analyzing power for antiprotons are very scarce and of a noticeably worse experimental accuracy than for protons. For the momentum transfers of interest here, we are aware of only two publications on measurements of analyzing power A_N in elastic $\bar{p}p$ -scattering:

¹ See, for example, Refs. [3–6].



Ref. [7] is devoted to the measurements at low momenta of 0.1–0.2 GeV/c, and Ref. [8] describes the experiment at the large beam momentum of 40 GeV/c. The similar A_N measurements have been carried out at 45 GeV/c in the experiment [9], but only for proton-proton elastic scattering. The bottom line from the written above is that, an antiproton polarimeter at SPASCHARM must be capable to measure first an analyzing power for the process of antiproton scattering, using a polarized target, in order to use then the results for measuring an antiproton beam polarization.

A number of physics processes have been considered for the polarimetry at SPASCHARM experiment. Among them are elastic pp - and $\bar{p}p$ -scatterings in Coulomb-Nuclear Interference [3, 10] and diffraction [3] kinematic regions, polarimetry with inclusive neutral [4] and charged [6] pions as well as with inclusive photons [5]. In this report, we discuss the antiproton polarimetry based on $\bar{p}p$ elastic scattering in diffraction kinematic region.

2. Elastic scattering polarimeter in the diffraction kinematic region

The layout of the proposed SPASCHARM diffraction elastic scattering polarimeter is shown in figure 1. It consists of the beam counters and hodoscopes upstream the target, of two forward arms for detection of forward-scattered antiprotons as well as two recoil arms for detection of recoil protons. The detector acceptance for elastic pp - and $\bar{p}p$ -events in momentum transfer squared is $0.1 < -t < 0.3$ (GeV/c)² for the beam momenta from ~ 10 to 45 GeV/c. The acceptance in azimuth is limited by the combined acceptance $\Delta\phi$ of two recoil arms which is equal to $2 \times 0.05 \times 2\pi = 0.1 \times 2\pi$ rad. The trigger for pp and $\bar{p}p$ elastic scattering would be a coincidence of signals from a forward and recoil arm.

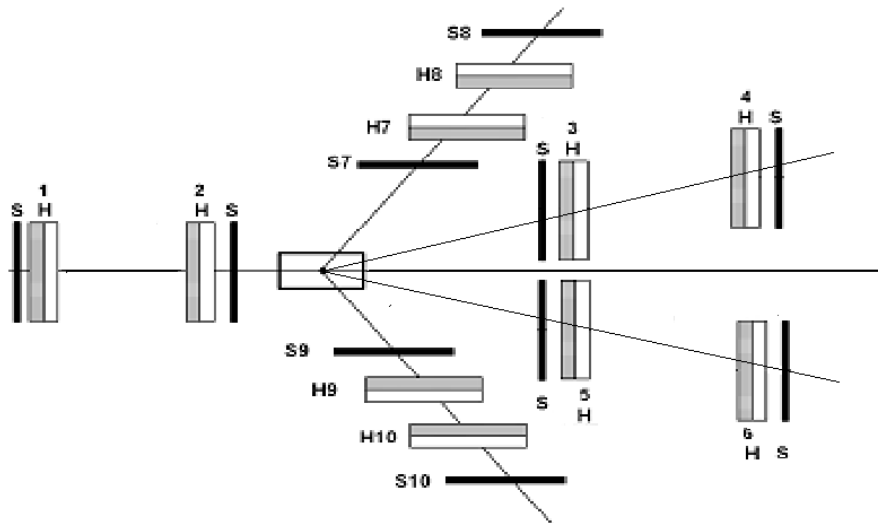


Figure 1. The layout of the SPASCHARM diffraction elastic scattering polarimeter. S_1 – S_{10} are the scintillator counters for measuring total particle fluxes; H_1 and H_2 are the beam hodoscopes; H_3 – H_6 are the hodoscopes of the forward arms, and H_7 – H_{10} are the hodoscopes of the recoil arms.

In order to make estimates of necessary beam exposition times for antiproton polarimetry, the knowledge of the cross section σ and analyzing power A_N is required. Unfortunately, as it has been already mentioned above, the reliable experimental data for $\bar{p}p$ -scattering are not currently available either on σ , or A_N for the energies and in the kinematic region of interest.

However, according to Ref. [11], the $\bar{p}p$ differential cross section is close to the one in pp -scattering. Using the results of measurements [11, 12], the elastic pp cross section integrated over the interval $0.1 < -t < 0.3$ (GeV/c)² could be estimated as $\sigma \approx 2.1$ mb. For the purpose of the considerations below, we will also assume the analyzing power in $\bar{p}p$ to be equal to the one in pp collisions. For pp , as it has been measured in Refs. [9, 13], the averaged over the t -interval above $A_N \approx 2.3\%$. We also assume here the intensity of the both, transversely polarized² and unpolarized antiproton beams $I \simeq 6 \times 10^4$ antiprotons/cycle of U-70 accelerator with the cycle repetition frequency of 0.11 Hz.

3. Measurement of analyzing power A_N in $\bar{p}p$ -collisions with polarized target

The measurements of analyzing power A_N will be carried out with an unpolarized antiproton beam striking a 'frozen' propan-diol ($C_3H_8O_2$) target. The clean samples of elastic $\bar{p}p$ events will be separated from $\bar{p}C$ and $\bar{p}O$ events by reconstruction of the collision kinematics for the forward and recoil charged particles. The parameters of a polarized target are taken as follows: the length $l = 20$ cm; the density of hydrogen nuclei in the target $\rho = 0.12$ g/cm³ (that corresponds to the proton density $n_p = 0.12 \times 6 \cdot 10^{23} = 7.2 \cdot 10^{22}$ protons/cm³); the proton polarization in the target $P_T \simeq 70\%$.

We require the relative statistical error for the measurements of analyzing power A_N to be: $\Delta A_N/A_N = \Delta\epsilon/\epsilon = 0.1$ where ϵ is the raw asymmetry as it is measured in the polarimeter:

$$\epsilon = A_N \times P_T = 0.023 \times 0.7 \simeq 0.0161 \quad (1)$$

Thus, the required statistical error in raw asymmetry is:

$$\Delta\epsilon = 0.1 \times 0.0161 \simeq 0.00161 = 1/\sqrt{N_{req}} \quad (2)$$

where $N_{req} \simeq 4 \times 10^5$ is the required number of events to accumulate in order to achieve the relative error $\Delta\epsilon/\epsilon = \Delta A_N/A_N = 10\%$. An expected number of events per U-70 cycle in the acceptance of $\Delta\phi/2\pi = 2 \times 0.05 = 0.1$ and $0.1 < -t < 0.3$ (GeV/c)² could be estimated as:

$$N_{cycle} \simeq I \times \sigma \times n_p \times l \times \frac{\Delta\phi}{2\pi} \simeq 6 \cdot 10^4 \times 2.1 \cdot 10^{-27} \times 7.2 \cdot 10^{22} \times 20 \times 0.1 \simeq 18 \text{ events/cycle} \quad (3)$$

The required number of events can be accumulated for $N_{req}/N_{cycle} = 4 \cdot 10^5/18 = 2.2 \cdot 10^4$ cycles. At the cycle repetition frequency of 0.11 Hz, this corresponds to $\sim 2 \cdot 10^5$ seconds ≈ 54 hours.

4. Time estimates for measuring an antiproton beam polarization, using the known analyzing power A_N

For these estimates, we assume the transverse beam polarization $P_B \simeq 40\%$ [2]. The cross section, the analyzing power A_N and the statistical error requirement $\Delta P_B/P_B = \Delta\epsilon/\epsilon = 0.1$ are assumed to be same as in Sec. 3.

The beam polarization measurements can be carried out as with a propan-diol target³ as well as with a liquid hydrogen target.

For the case of a propan-diol target, the only difference to the estimates of Sec. 3 is the beam polarization of 40% which is lower than the assumed above target polarization of 70%. Due to this difference, the raw asymmetry ϵ will be lower by a factor of $70/40=1.75$. As a result, for the antiproton beam polarization measurements with the requirements and at the assumptions above, it would take $54 \times 1.75^2 \simeq 165$ hours of data taking time.

² One sign of polarization.

³ Unpolarized though.

In the case of a liquid-hydrogen target of the same length 20 cm, the only difference from the propan-diol is the lower hydrogen density: 0.071 g/cm^3 . With this modification, the event rate would be lower by a factor of $0.12/0.071=1.7$ which would lead to prolongation of the required measurement time to $165 \times 1.7=280$ hours.

5. Conclusion

For the purpose of verification and confirmation of operation of the polarized antiproton beam forming system in the channel 24A at U-70 of IHEP, we propose to build the absolute polarimeter based on elastic $\bar{p}p$ -scattering in the diffraction kinematic regions of $0.1 < -t < 0.3 \text{ (GeV/c)}^2$. It is shown that the measurements of analyzing power A_N , using the polarized target, at the relative statistical errors of $\Delta A_N/A_N \simeq 10\%$ could be completed for $\sim 50\text{--}60$ hours. Then, it would take additional $\sim 150\text{--}300$ hours for measuring an antiproton beam polarization at the same relative statistical errors of $\Delta P_B/P_B \simeq 10\%$.

It worth mentioning that the discussed here beam polarimeter can also be used for the experimental studies of the small momentum transfers physics which would be a valuable enrichment of the SPASCHARM experiment capabilities and its physics program.

Acknowledgments

This work has been supported in part by the RFBR Grant No.15-02-1669.

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