

Polarized antiproton beam at U-70 accelerator of IHEP

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Abstract. The polarized proton and antiproton beam channel is currently under development at the U-70 accelerator of IHEP, Protvino, Russia. An availability of the both, polarized protons and antiprotons provides an exciting opportunity for the comparative studies of spin effects induced by polarized protons and antiprotons in a variety of hadronic reactions. While the proton and antiproton beams are formed by essentially the same method, there is the specific in the antiproton beam shaping and properties compared to protons. In this report, we address some technical details of forming the polarized antiproton beam and describe its main properties.

1. Introduction

The new experimental program SPASCHARM [1] for the 70 GeV proton synchrotron U-70 is currently under development at the Institute for High Energy Physics (IHEP), Protvino, Russia. The main physics motivation for the SPASCHARM experiment is the systematic study of spin phenomena for a wide range of inclusive and exclusive reactions. Spin asymmetries will be studied in inclusive and exclusive reactions in the beam fragmentation region with polarized beam or target as well as the hyperon and vector mesons polarization and depolarization phenomena. At the first stage, the measurements of single-spin asymmetries are carried out at the existing unpolarized beams, using the polarized target. At the second stage, the special polarized proton and antiproton channel 24A will be constructed. This will create the opportunity for studying the double-spin asymmetries as well as bring the new quality into the measurements of single-spin effects. The ultimate goal is to get the capabilities and reach the sensitivity to the longitudinal double-spin asymmetry A_{LL} in charmonium production in order to explore the gluon polarization $\Delta G/G(x)$ at large x_F . The SPASCHARM physics program and the experimental setup have been presented in details a number of times elsewhere [1–2].

The channel 24A is a part of a pair of two linked new channels, operating from the same slowly extracted to the external target U-70 primary proton beam (see figure 1). The bottom beam-line 24B shown in red in figure 1 delivers the beam to the spectroscopy experiment. The top red beam-line designates the polarized proton and antiproton beam channel 24A. The maximum allowed intensity of



the primary beam is $2 \cdot 10^{13}$ protons/cycle, and it is limited by the radiation safety requirements. The secondary beam from the primary target is split between these two channels by the first after the target, so called, ‘sweeping’ magnet. It directs charged particles to the channel 24B while the neutrals go straight to the channel 24A. The required bending power of this magnet is up to 4.7 Tm. The magnetic field achievable in a conventional ‘warm’ magnet is ~ 1.8 T. Thus, the sweeping magnet length must be at least 2.6 m.

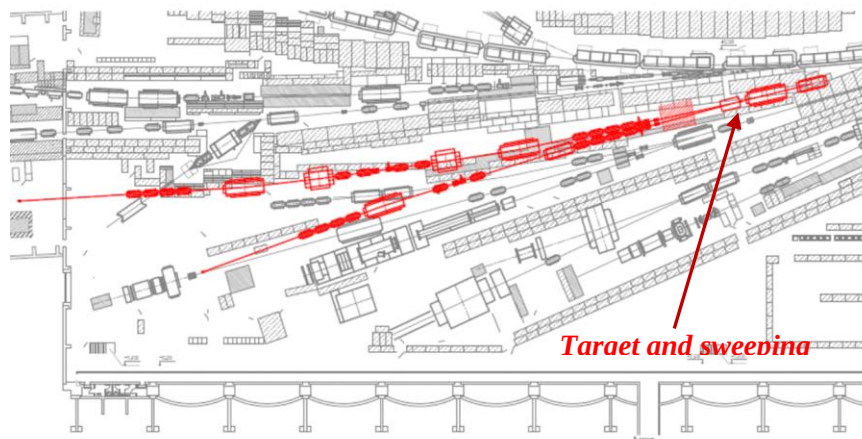


Figure 1. The layout of the new beam channels 24A and 24B in the U70 experimental hall.

2. Polarized beam

The polarization will be created from Λ -decay using standard technique. The idea of such method was suggested almost 50 years ago by O.E. Overseth and J.Sandweiss [3]. It has been successfully used in E-704 (FNAL) [4] and FODS (IHEP, Protvino) [5] experiments. In the Λ - hyperons rest frame, the decay protons or antiprotons are longitudinally polarized. After the Lorentz boost to the laboratory frame, they become transversely polarized, and this polarization depends on their emission angle in Λ -decay. By the appropriately designed channel's magnetic optics, the initial proton distribution over the decay angle is transformed to the spatial distribution at the plane of the so called ‘intermediate focus’. There the beam is sorted out into the samples of a certain transverse polarization either by each beam trajectory tagging with fast tracking detectors (hodoscopes) [4], or by a collimation [5]. The beam tagging provides the opportunity for potentially having beam samples of the opposite polarization at the experimental target simultaneously. This is equivalent to potential doubling the beam intensity compared to the collimation with the beam samples of the opposite polarization delivered to the experiment target alternately in time. Moreover, the tagging allows the much finer trajectory sorting over the phase space and over the momentum which is measured at the accuracy of better than 1% [7]. This reduces the effects of polarization smearing by the spread of the beam parameters and, as a result, allows to increase the effective average sample polarization. The verification and confirmation of operation of tagging system is done by the independent polarimetry which is discussed elsewhere [8].

The beam optic of the channel 24A is schematically shown in figure 2. It is comprised of 12 quadrupole lenses and four bending magnets. The total beam rotation angle in horizontal plane is equal to ~ 160 mrad. The total beam-line length from a primary target to the experiment target is 120 m. The high-intensity polarized beams of momenta from ~ 10 to 45 GeV/c is delivered to the experiment target. The momentum analysis occurs in the horizontal plane, and sorting the beam trajectories over the transverse vertical polarization takes place around the intermediate focus in vertical plane. The one important feature of the channel 24A beam optic is its ‘unity’. This means that it transfers the phase space from the primary target plane to the target of experiment without distortions either in the spatial

or angular dimension. Such an optic is chosen so as to eliminate the beam depolarization effects in the chain of quadrupole lenses.

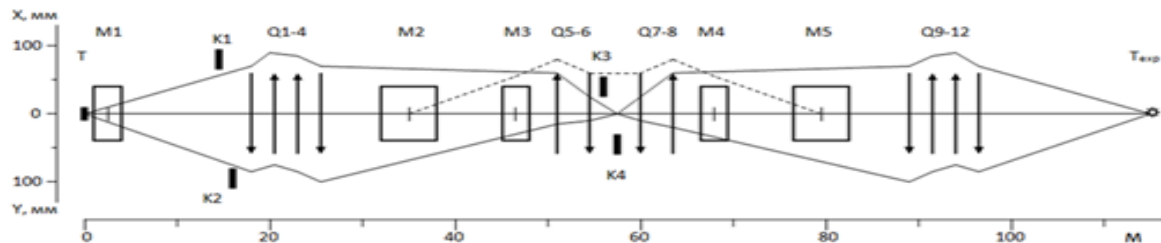


Figure 2. The optics of the polarized beam channel 24A: T – external target, $M1$ – sweeping magnet, $Q1$ - $Q12$ – quadrupole lenses, $M2$ - $M5$ – bending magnets, $K1$ - $K4$ – collimators, T_{exp} – the target of the experiment.

The intrinsic property of the (anti)proton beam from Λ -decays is that it always includes two approximately equal samples of the same intensity and of equal but of opposite signs transverse polarizations. This property is extremely valuable for reduction the systematic errors by directing to the experiment target the samples of opposite polarizations either simultaneously, using the tagging, or alternatingly in time. The further reduction of systematic errors is achieved by inverting (flipping) the polarization of the entire beam every few tens of minutes. The spin-flip for the entire beam will be performed by the special superconducting helical magnet [6], positions downstream of the last quadrupole lens $Q12$. Spin-flipper is also has the capability to convert the transverse polarization into the longitudinal without modifications of the spatial or angular properties of a trajectory.

The results of simulation of the beam properties are presented in table 1. The achievable intensity of the polarized proton beam satisfies all requirements of the experiment. However, the intensity of the polarized antiproton beam is not as high as desired.

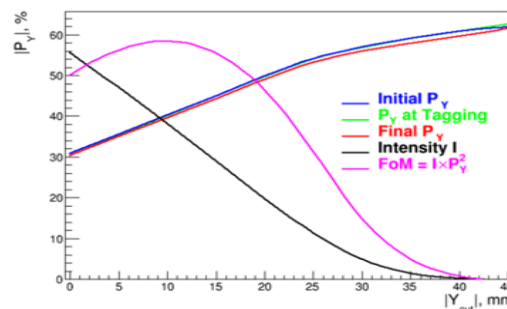
Table 1. Calculation of the polarized beam properties

	proton beam		antiproton beam	
	min	max	min	max
Momentum collimator position				
Polarized beam energy	45		14	
Momentum spread $\Delta p/p$, %	± 4.5	11.0	± 5.5	12.0
	($\sigma=2.1$)	($\sigma=5.3$)	($\sigma=2.3$)	($\sigma=5.6$)
Beam size, $\sigma_x \times \sigma_y$, mm	13×11	17×14	18×19	20×19
Beam divergence $\sigma_x \times \sigma_y$, mrad	1.6×2.0	1.5×1.9	1.6×1.9	1.5×2.0
Full intensity for 10^{13} protons in the target at 60 GeV	4.9×10^7	1.3×10^8	1.4×10^5	3.9×10^5

3. Polarized antiproton beam

This report is devoted mainly to the issues of forming a polarized antiproton beam.

The dependence of the beam properties on the collimator position ($K4$) in the intermediate focus is shown on figure 2.

Figure 2. Polarization, intensity and FOM for the polarized beam

The coordinate Y means the selection of the particles with coordinate greater than $|Y|$. Intensity and Figure of Merit ($FOM=I \cdot P_y^2$) are presented in arbitrary units. The maximum value of FOM is achieved at $|Y| > 10$ mm with the average polarization $\pm 39.6\%$. Beam depolarization is in the range of (0.5-1.3)%. The beam profiles on the target are presented on figure 3.

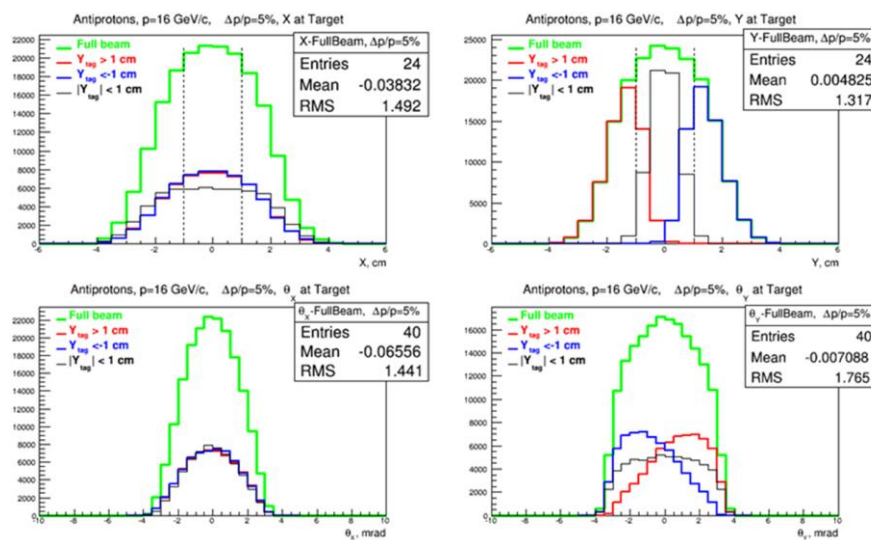


Figure 3. Polarized antiproton Beam at the experiment target.

Dashed line is the size of the polarized frozen target. One can observe that the beam size is larger than the size of available polarized target. This means that the desire of having at the target simultaneously the sample of the both polarizations, sorted by tagging, leads to an ineffective usage of the beam intensity. The solution for the case of this small in diameter target is the alternating in time steering to the target of a sample of only one sign polarization, using the vertical magnet-correctors (not shown in figure 1).

The simulations of the polarized beam and background have been done at the following conditions:

- All numbers for intensities of polarized beams are for the cases when only one part of the polarized beam (positive or negative) has been steered onto the experiment target through the collimator K4 with the slit width of 2 cm.
- For the unpolarized beam is selected the central part of the total beam passed through the collimator K4 of the same slit width 2 cm with the magnets-correctors off.

The intensity of the polarized beams defined above are presented in table 2.

Table 2. Intensities of polarized beams of various energies and of average polarization 40%.

Beam Momentum (GeV/c)	antiproton beam		proton beam	
	In target plane	At 2 cm target ¹	In target plane	At 2 cm target
16	$7,34 \times 10^4$	$2,41 \times 10^4$	$1,84 \times 10^6$	$6,90 \times 10^5$
20	$5,70 \times 10^4$	$2,20 \times 10^4$	$4,08 \times 10^6$	$1,56 \times 10^6$
30	$1,60 \times 10^4$	$7,66 \times 10^3$	$1,10 \times 10^7$	$5,63 \times 10^6$
40	$2,71 \times 10^3$	$1,52 \times 10^3$	$1,43 \times 10^7$	$8,04 \times 10^6$

¹Number of particles hitting the polarized target of the diameter 2 cm

The results of background simulations from two main sources are presented in the table 3. The comparison of energies 14 and 16 GeV demonstrate the effect of sharp drop of negative pions from Λ -decays which is forbidden by kinematics at and above 16 GeV. This, unfortunately, is not valid for the pion background from K^0 -decays.

Table 3. Background estimates

		P=14 GeV/c		P=16 GeV/c	
		In target plane	At 2 cm target	In target plane	At 2 cm target
Polarized part	$\pi^-(K^0)$	$1,75 \times 10^5$	$1,81 \times 10^4$	$1,88 \times 10^5$	$2,89 \times 10^4$
	$\pi^-(\Lambda^0)$	$1,35 \times 10^5$	$6,28 \times 10^4$	0	0
Unpolarized part	$\pi^-(K^0)$	$1,50 \times 10^5$	$1,79 \times 10^4$	$2,15 \times 10^5$	$2,76 \times 10^4$
	$\pi^-(\Lambda^0)$	$4,19 \times 10^5$	$2,00 \times 10^5$	0	0

One can observe that the expected pion background, while usually higher than the antiproton intensity, it does not exceed the capabilities of its significant suppression by the beam Cherenkov threshold counter.

Few approaches have been explored for increasing the antiproton beam intensity within the fiducial area of the experiment target. Among them, was the attempt of compressing the transverse beam size at the target by some departure from the ‘unity’ channel optic which might potentially be harmful for the polarization conservation. In figure 4 are shown, the result of the respective simulations. It is apparent that the transverse dimensions of the beam are noticeably reduced, the vertical one by a factor of ~ 2 . This came at the price of widening of the angular distributions which was expected of course. It is amazing however, that the departure from the ‘unity’ optic did not damage much the beam polarization. It dropped down from 39.6% to only 38.9%. The FOM at the 2 cm diameter increased almost twice.

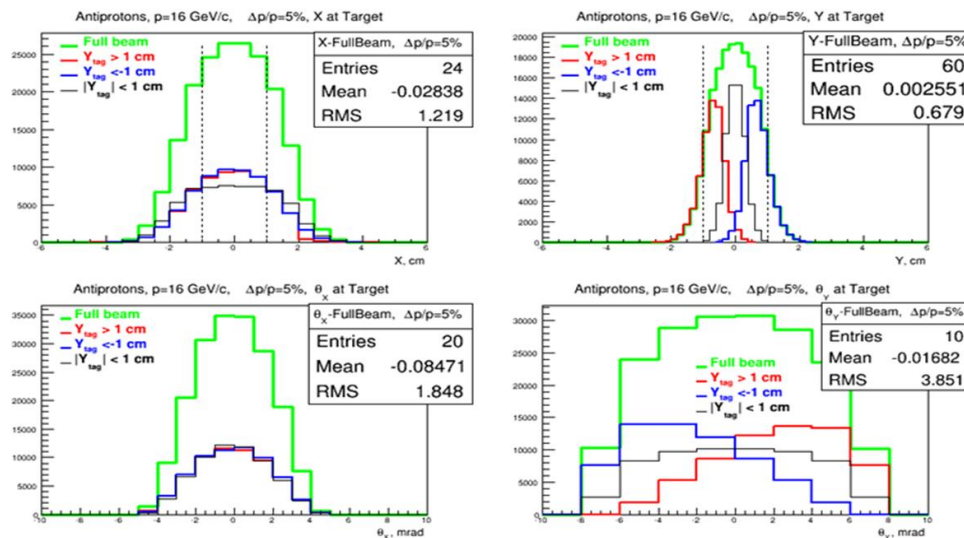


Figure 4. Narrow polarized antiproton Beam at the experiment target with asymmetric optics

Another possibility is to use the whole beam for the asymmetry measurements. The standard method is to select the ensemble of the particle sorted out by either vertical (Y) or horizontal (X) polarization component and to measure the asymmetry relative to the vertical or horizontal plane. But the SPASCHARM tagging system [7] allows reconstructing of the both components of each Λ -decay and thus assign to each (anti)proton in the beam the both transverse components of polarization. With such a more complete information, the spin asymmetry analysis could be done in respect to the specific plane which rotates from event to event. One can show that such an approach would provide an effective increase of a polarized beam intensity by factor ~ 1.5 .

The very effective way for increasing the beam intensity could be the shortening of the sweeping magnet just after the primary target. However, in order to conserve the bending power 4.7 Tm, the magnetic field must be increased above the achievable level for the conventional warm magnets. Currently, the possibility of using the existing at IHEP 1 m long superconducting magnet with the field of ~ 5 T is under the study. One more option currently at study is to place the channel 24A primary target inside the conventional sweeping magnet at its middle. The primary target for the channel 24B remains at its current place before the magnet. The expected intensity gain from this option is at about factor 3. However, there is a potential danger of worsening the background situation due to reduced magnet sweeping power downstream the primary target of the channel 24A.

4. Summary

The polarized beam channel for the second stage of the SPASCHARM experiment is under development at IHEP. It is designed so as to create a high-intensity polarized proton beam in a wide momentum range from ~ 10 to 45 GeV/c.

The polarized antiproton beam would be of an intensity $\sim 4 \cdot 10^5$ antiprotons per each 9 sec long accelerator cycle, and it is adequate for carrying out many single-spin measurements with low background from pions. It will be possible to do the measurements with polarized protons and antiprotons of the same energies in the range of 16-24 GeV with the same detector configurations.

There are under study a few the possibilities for increasing the antiproton beam intensity by factor of 3-5 which would be sufficient for meaningful double-spin asymmetry measurements, including the ones in the production of charmonia.

Acknowledgments

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