

Polarized proton and antiproton beams for the SPASCHARM experiment at U-70 accelerator

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Abstract. The design and parameters of the polarized-beam facility at U-70 proton synchrotron of IHEP, Protvino, are presented. The polarized proton and antiproton beam line 24A is currently under development at IHEP. It will serve as a main playground for carrying out the rich program of the SPASCHARM experiment for comprehensive studies of spin phenomena in a wide variety of hadronic reactions in the beam energy range of ~ 10 –45 GeV.

1. Introduction

The anticipated upgrade of the U-70 synchrotron of IHEP, Protvino, Russia, to the higher intensity in the ring of up to $(2\text{--}3)\cdot 10^{13}$ of accelerated protons opens the new horizons for the next-generation experiments for comprehensive studies in high energy physics. This requires, in turn, building the more sophisticated next-generation facilities for delivering to the experiments the whole spectrum of primary and secondary particles at the highest achievable intensities in the beams of the best quality. The higher beam intensities bring new challenges to the beam-line designs. As a pilot project, two new beams, 24A and 24B, for the SPASCHARM and VES experiments are to be built. These two beams will operate from a single external primary target exposed to the slowly-extracted 60 GeV primary beam at the intensity of up to $2\cdot 10^{13}$ protons per 9–10 second cycle. The approach with more than one beam line operating from the same primary target [1] would significantly improve an utilization efficiency of the full intensity of accelerated in U-70 protons.

This report is focused on the design and properties of one of the mentioned above two beams, the beam line 24A for the SPASCHARM experiment. The rich program of SPASCHARM experiment [2] predominantly concentrates on systematic and comprehensive studies of spin phenomena in hadronic reactions in the U-70's energy range. It requires hadronic beams of various species as well as electron and/or positron beams for detector calibrations. But, first of all, the core SPASCHARM program relies on utilization of polarized proton and antiproton beams formed and transported to the experiment by the beam line 24A as well as on the usage of polarized targets [3].



2. The primary target station

The schematic view of the target station is shown in figure 1. With the help of dipole magnets MT1 and MT2, the primary proton beam from U-70 is directed through the target toward the center of magnet MT3 at a certain pointing angle φ to the MT1-MT3's center line¹. Then, the dipole MT3 distributes fractions of the secondary particle flow produced in the target T toward the beam lines 24A and 24B. Two parameters: angle φ and MT3's bending power are adjusted so as the secondaries of desirable charges and momenta, produced at zero angle², being directed toward the acceptances of channels 24A and 24B³. First time such a 'three-magnet' scheme has been used at CERN SPS [1] for operating two and three beams from a single primary target.

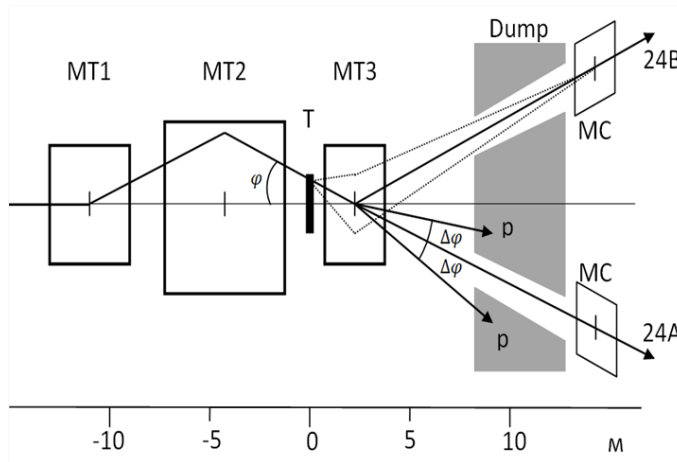


Figure 1. Schematic view in horizontal plane of the primary target station for the beam facility 24A/24B. The notation **T** is for the primary target; **MT1-MT3** are the dipole magnets; **MC** are the magnets-correctors; **Dump** is for the absorber of the beam halo and remnants of the primary proton beam. In the shown configuration, neutral secondaries go straight toward the 24A beam line, while charged ones of a desirable sign are bent toward 24B. Some trajectories of charged particles produced in the target **T** and within 24B channels acceptance are shown with the dashed-lines.

The standard dipole magnets SP-129 and SP-7 from the equipment pool of U-70 complex are to be used for MT1 and MT2. However, the MT3 magnet is specially designed to sustain the high radiation loads from the high intensity flux of secondary particles emerging from the target T. Its coil is lifted up from the aperture [4] and placed behind the upper pole's steel as well as the concrete shield that fills the space between the poles and iron yoke. The simulations of radiation loads using the MARS computer code [5] have shown that, for such a design, the coil life-time would be about 2600 days at the average primary beam intensity of $\sim 1 \cdot 10^{13}$ protons per cycle. The MT3's aperture is $H \times V = 24 \times 5 \text{ cm}^2$, length 2.6 m, maximum field 1.9 T.

3. The optical scheme of the beam line 24A

The polarized proton and antiproton beams for the SPASCHARM experiment are to be formed by the method first suggested by O. Overseth and J. Sandweiss [6]. So far, this method has been twice successfully realized in practice: for the E704 experiment at Tevatron of Fermilab [7], and then for the FODS experiment at U-70 of IHEP [8]. The new beam transport system 24A at U-70 is optimized so as to obtain the both, polarized proton and antiproton beams with the highest achievable intensities and the best characteristics. The optical scheme of the beam line 24A is shown in figure 2. Its minimum (maximum) momentum acceptance $\Delta p/p$ varies from $\pm 4.5\%$ ($\pm 11.0\%$) at $p = 15 \text{ GeV}/c$ to $\pm 3.0\%$ ($\pm 9.5\%$) at $p = 45 \text{ GeV}/c$.

The method [6–8] relies on the parity-violating decays of Λ - and $\bar{\Lambda}$ -hyperons (figure 3, left frame). In the $\Lambda(\bar{\Lambda})$ -hyperon's rest frame, the decay protons or antiprotons are longitudinally

¹ The maximum angle $\varphi_{max} = 27 \text{ mrad}$.

² To the direction of incident primary protons.

³ In the configuration shown in figure 1, the neutral secondaries go straight to the 24A beam line. This is exactly the case for forming downstream a polarized proton or antiproton beam from $\Lambda(\bar{\Lambda})$ -decays as well as an electron or positron beam from γ -conversions.

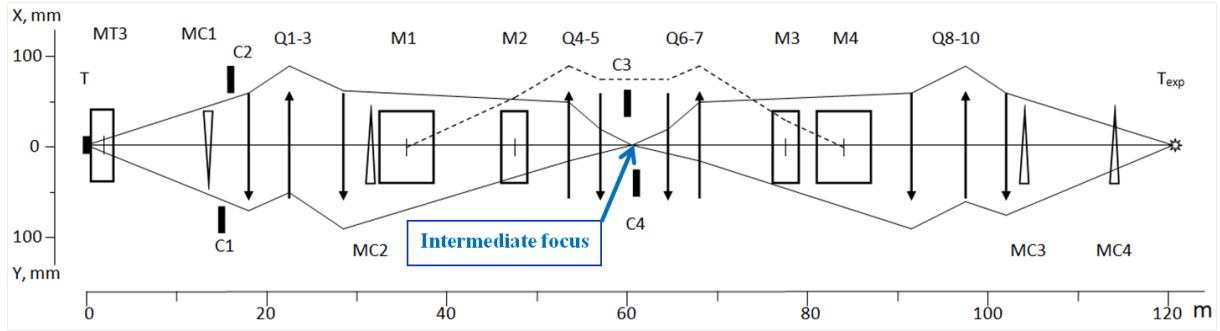


Figure 2. The optics of the polarized beam channel 24A: **T** is the primary target; **MT3** is the sweeping magnet; **Q1-Q10** are quadrupole lenses; **M1-M4** are bending magnets; **C1-C4** are beam collimators; **MC1-MC4** are vertical magnets-correctors; **T_{exp}** is the experiment's target. The spatial beam envelopes for the both planes are shown with the solid lines. The beam momentum dispersion in horizontal plane is shown with the dashed line for the momentum spread $\Delta p/p=10\%$.

polarized. After the Lorentz boost into the laboratory frame, they become transversely polarized, and the polarization degree depends on their emission angle in Λ -decay. By the appropriately designed magnetic optics, the initial proton distribution over the decay angle is transformed into the spatial distribution in the plane of the so called 'intermediate focus' (see figures 2 and 3, right frame). There, the trajectories are sorted out into the beam samples of a certain nonzero average transverse polarization either by each beam trajectory tagging with the fast tracking detectors [7], or by the collimation [8], i.e. by cutting out a polarized sample using the magnet-corrector MC1 and collimator C4 and then centering the sample at the experiment target with the correctors MC2 and MC3. The sign of polarization of the beam at the experiment target is inverted from cycle to cycle by reversing the currents in the correctors in between cycles. In the optics of 24A beam, the horizontal plane is used for momentum analysis while sorting out over the transverse vertical polarization takes place in the vertical plane.

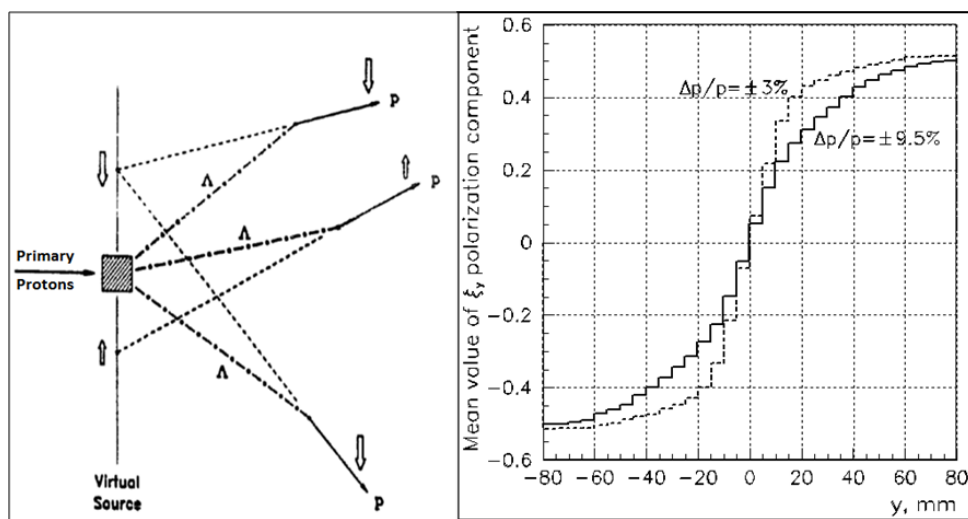


Figure 3. Proton polarization in Λ -decays (left frame) and the correlations of the proton vertical polarization component ζ_y to the vertical position of proton trajectory at the intermediate focus (right frame).

The beam tagging provides an opportunity for having beam samples of the opposite polarizations at the experimental target simultaneously. This is equivalent to effective doubling the beam intensity compared to the collimation with which the beam samples of the opposite polarizations are delivered to the experiment target alternately in time. Moreover, with the tagging, there is no polarization smearing over the beam momentum spread. The tagging also provides the flexibility for selecting appropriate beam samples at the analysis stage. On the other hand, with the collimation, the beam position at the target is virtually independent of the polarization sign, and the beam is generally smaller compared to the full beam without collimation. At operational time of the beam 24A, the both approaches will be used together or separately depending on the real needs of experiment.

4. Parameters of polarized beam at the experiment target

The expected from simulations⁴ parameters of polarized proton beam at the experiment target are shown in table 1 for three momenta p and for two momentum spreads $\sigma_{\Delta p/p}$ per each momentum value. In this table, σ_x and σ_y are for the horizontal and vertical spatial beam sizes, respectively; $\sigma_{x'}$ and $\sigma_{y'}$ are for the widths of angular distributions; and I_p is the full beam intensity before sorting out over polarization. The full intensity is almost evenly distributed between three sub-samples with the average sample polarizations $\langle \zeta_y \rangle$ of -40% , 0 , and $+40\%$.

Table 1. Polarized proton beam parameters at the experiment target.

p , GeV/c	15		30		45	
$\sigma_{\Delta p/p}$, %	2.0	4.5	1.4	4.4	1.2	4.1
$\sigma_x \times \sigma_y$, mm	17×14	19×16	14×10	17×11	11×8.7	16×9.0
$\sigma_{x'} \times \sigma_{y'}$, mrad	1.4×1.5	1.3×1.5	1.5×1.8	1.3×1.8	1.4×1.7	1.4×1.7
I_p per 10^{13} of primary protons	3.5×10^6	9.2×10^6	2.1×10^7	7.8×10^7	1.5×10^7	6.8×10^7

Due to much lower yield of $\bar{\Lambda}$ -hyperons compared to Λ , an intensity of a 15-16 GeV/c polarized antiproton beam is by a factor of 20-30 as low as of a proton beam. The difference becomes even more significant at higher momenta. An intensity of 16 GeV/c polarized antiproton beam with a wide momentum spread is estimated to be $\sim 4 \cdot 10^5$ per 10^{13} of primary protons. The momentum dependencies of polarized beam intensities, along with the background estimates, are shown in figure 4. The high pion background to antiprotons from $\Lambda \rightarrow p\pi^-$ decays might make it not feasible operating antiproton beam at momenta below 16 GeV/c. The background to antiprotons from $K_S^0 \rightarrow \pi^+\pi^-$ decays is expected to be suppressed by the beam Cherenkov counters.

5. Conclusion

The design and optimization of parameters of the 24A/24B beam facility for U-70 accelerator of IHEP, Protvino, is currently at its final stage. The new polarized proton and antiproton beam line 24A will provide an opportunity for unique systematic studies of spin phenomena for a wide range of inclusive and exclusive reactions in collisions of high-energy polarized hadrons in the QCD non-perturbative region with the multipurpose large acceptance SPASCHARM spectrometer.

⁴ Simulations are carried out using the DECAY TURTLE computer code [9]. The embedded code for Λ - and $\bar{\Lambda}$ -hyperon yields are based on the analysis of Ref. [10].

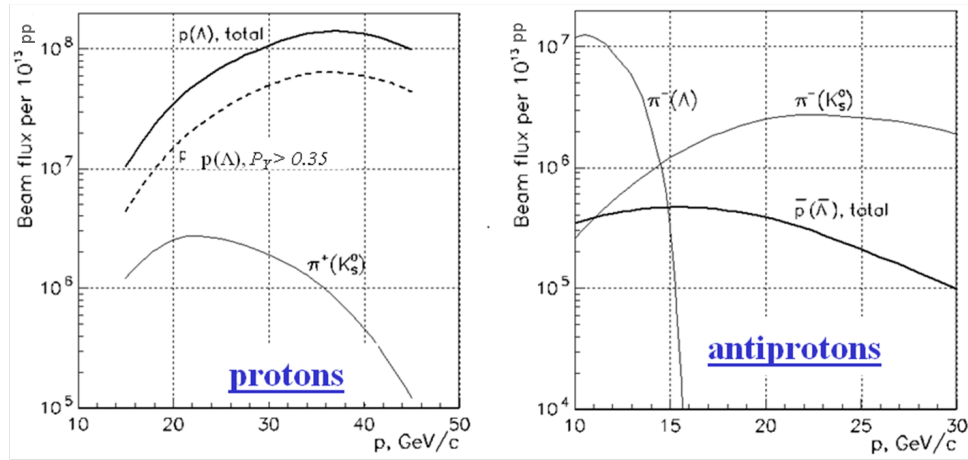


Figure 4. The intensity of polarized proton (left frame) and antiproton (right frame) beams with the maximum $\Delta p/p$ per 10^{13} of 60 GeV primary protons (pp), along with the estimated π -meson backgrounds from $K_S^0 \rightarrow \pi^+\pi^-$ and $\Lambda \rightarrow p\pi^-$ decays. In the left frame, the dashed line shows the intensity of proton samples with the cut $\zeta_y > 35\%$.

Acknowledgments

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