# IHEP Polarized Proton Beam

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*Abstract*

The IHEP polarized proton beam with momentum up to 40 GeV/c from the decay of lambda hyperons is described. The measured characteristics of the beam are compared with the calculated ones.

## I. INTRODUCTION

The availability of a polarized proton beam may push further the development of the IHEP experiments devoted to the study of hadron interactions with polarized targets and production of high $p_t$ charged hadron (single and pair) in pp and pA collisions. In connection with this the existing multipurpose beam line №22 [1] which used to produce high intensity beams of protons, pions and electrons for two experimental facilities has been modernized. The existance of two working experimental facilities, each with its own requirements for the beam parameters, makes our task more difficult. During the modernization we should be led by following requirements:

- All the possibilities to form particle beams, that the beam line has before the modernization, should be conserved;
- Beam parameters at experimental facility targets should be also conserved;
- The necessary alterations should be minimized;
- The transversely polarized proton beam should have as high intensity $I_p$ and "polarization quality" $I_p\eta^2$ ($\eta$ - the average particle polarization) as it possible;
- The background contamination in the polarized proton beam should be minimized.

To produce a polarized proton beam, we, similar to [2], used parity-nonconserving decays of $\Lambda$ hyperons: $\Lambda \Rightarrow p + \pi^-$ [3]. The intensity of $\Lambda$ hyperons has been maximized by centering the beam line acceptance at $0^0$ production angle. Lambda hyperons are produced when 70-GeV/c protons from the IHEP accelerator strike an Al production target. The $\Lambda$ hyperons then decay into protons that are polarized along the proton direction of motion, as viewed in the $\Lambda$ rest frame. In these frame, the decay $\Lambda \Rightarrow p + \pi^-$ occurs isotropically and the decay-proton polarization is 64% [4]. A transversally polarized proton beam is produced by selecting a portion of these $\Lambda$ decays.

## II. POLARIZED PROTON BEAM DESCRIPTION

The incoming 70-GeV/c primary proton beam with intensity up to $10^{13}$ ppp is extracted from the accelerator with the pulse spill $t \sim 0.5 \div 1.5$ sec and focused on the production target into a spot with dimensions $4 \times 2.5$ mm$^2$ (H $\times$ V). The target (see fig. 1) with dimension of its working part $10 \times 3 \times 300$ mm$^3$ (H $\times$ V $\times$ L) is placed at the clearing magnet yoke entrance.

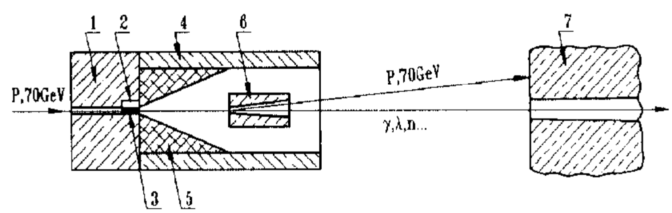


Figure 1. The layout of the head part of beam line №22 (plain view). 1 – local shield; 2 – target chamber; 3 – target; 4 – clearing magnet; 5 – shield in the magnet; 6 – safeguard collimator; 7 – beam absorber P1.

A clearing magnet with radiation resistant coil was designed and manufactured at IHEP [5]. It is 3 m long, its gap is 50 mm and magnetic field strength is 1.8 T. This magnet eliminates unwanted charged particles from the beam. Noninteracting primary beam protons are deflected downward into a beam dump P1. Charged particles produced at the target are bent from the beam line acceptance. Also, the charged particles from $\Lambda$ decay occurring too close to the production target are swept from the beam. In the second part of the magnet in its aperture there is a brass insert with an expanding hole, which acts as a collimator for the neutral particles. This collimator reduces the number of neutron interactions downstream that could simulate $\Lambda$ decays. It terminates $\sim$ 50 cm from the end of the magnet so that charged particles produced within the collimator can be deflected away from the beam line acceptance. The primary beam dump P1 starts 11.6 m downstream of the target. This absorber 5 m long has an expanding hole for the beam passage as well as for neutral particle beam. The neutral particles which passed through the holes in the safeguard collimator and in absorber P1 are transported without losses to the absorber P2, located just after the magnet MH2 $\sim$ 35 m downstream of the production target (see fig.2). At the beam line entrance the proton beam is limited in vertical and horizontal directions by two remotely controlled collimators K1 and K2. The vacuum system of the beam line starts at the exit of the clearing magnet to minimize the number of interactions that the beam has with air.



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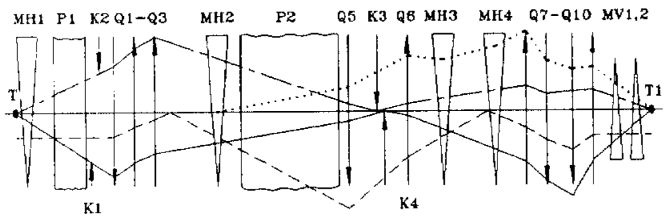


Figure 2. Structure and optical scheme of the beam line. T, T1 – production target and target of experimental facility; P1, P2 – absorbers of charged and neutral particles; K – collimators; Q – quadrupole lenses; MH, MV – bending and correcting magnets; $X/X'_o$, $Y/Y'_o$, $Y/Y_o$, $X/\delta p$ – matrix coefficients: solid line – $Y/Y'_o$, dotted line – $Y/Y_o$, dot-dash line – $X/X'_o$, dots – $X/\delta p$.

## III. POLARIZED PROTON BEAM OPTICS

Unfortunately the optical scheme of beam line №22 cannot fulfil all requirements, that usually are imposed on such systems [2,3,6,7,8]. The corresponding modernization of the beam line is impossible due to limited space and other restrictions. Nevertheless, we managed to satisfy basic, undoubtedly essential requirements. The quadrupole lenses Q1, Q2, Q3, Q5 (their polarity is clear from Fig.2) provide the beam focusing in the horizontal plane in the center of the momentum collimator K3, and in the vertical plane they form an intermediate image in the center of the collimator K4. The spatial vertical magnification at the intermediate focus −2.68 is sufficient for reliable selection of the beam part with required degree of polarization. The linear beam dispersion at the momentum slit is 15.6 mm/1% Δp/p, that provides fairly good momentum analysis of the beam. The quadrupole lenses Q6-Q10 form the beam on the experimental facility target, providing strictly unity first-order transfer matrix in the vertical plane. The linear beam dispersion on the experimental facility target turns out to be practically fully compensated. The main calculated beam parameters of the transversely polarized protons at 40 GeV/c momentum are presented in the table. The calculations of the beam line parameters were carried out with a program TRANSPORT [9], more detailed calculations were based on a modified program TURTLE [10].

Table
Calculated Parameters of the Polarized Beam at 40 GeV/c.

| № | Parameter | Value |
|---|---|---|
| 1. | Beam dispersion at momentum slit | 15.6 mm/1%Δp/p |
| 2. | Space magnification at intermediate focus (collimator K4) | −2.68 |
| 3. | Beam profile at final focus: Horizontal<br>Vertical | $\sigma_x = 10.6$ mm<br>$\sigma_y = 8.1$ mm |
| 4. | Angular divergence at final focus: Horizontal<br>Vertical | ±6.5 mrad (max)<br>±6.0 mrad (max) |
| 5. | Momentum band | ±4.5% Δp/p |
| 6. | Total intensity of polarized protons at final focus, with incident flux of $10^{13}$ppp | $8.1 \cdot 10^7$ |
| 7. | Intensity of polarized protons with average polarization ~40% | $2.6 \cdot 10^7$ |
| 8. | $\pi^+$-meson background from decay $K^o_s \Rightarrow \pi^+\pi^-$ | 0.8% |

## IV. EXPERIMENTAL RESULTS AND COMPARISON WITH CALCULATION

The first run on beam line № 22 with polarized protons was in December 1990. Transversely polarized protons were formed at momentum 40 GeV/c and expected degree of average polarization $\sim \pm 40\%$. The beam tuning was made with the well known method of focal coefficients and consisted in accurate beam steering along the beam line axis, correcting the beam focuses in both transverse planes and choosing the corresponding opening of the collimators. The operation regims of the beam elements practically coincide with the calculated ones. The intensity of the primary proton beam was about $\sim 4.4 \cdot 10^{12}$ppp, the total intensity of the beam (unpolarized in a whole) was $\sim 3.75 \cdot 10^7$, and polarized proton intensity was $\sim 1.5 \cdot 10^7$. The background level measured by threshold Cherenkov counters was $\sim 1.4\%$. The selection of the beam with the required direction and degree of polarization was realized by collimator K4. Fig.3 shows the calculated dependence of the average beam polarization $\eta$ (line 1), the intensity of polarized beam $I_p$ corresponding to this polarization(line 2), and the "polarization quality" $I_p\eta^2$ (line 3) versus collimator K4 opening. The lower jaw of the collimator is set on the coordinate Y = −60 mm, the upper jaw is moving from −60 mm to +60 mm.The value $I_p$ is normalized to the intensity of the primary beam $10^{13}$ ppp.

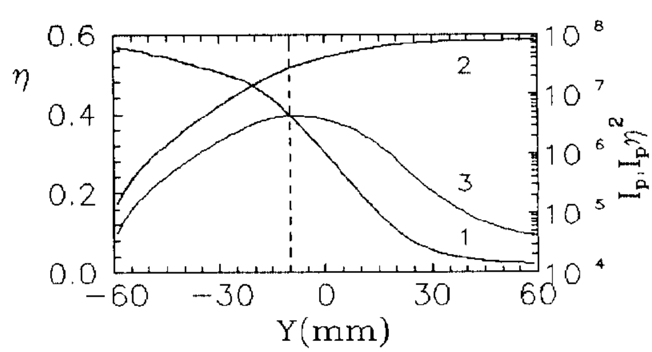


Figure 3. 1 – $\eta$, 2 – $I_p$, 3 – $I_p\eta^2$

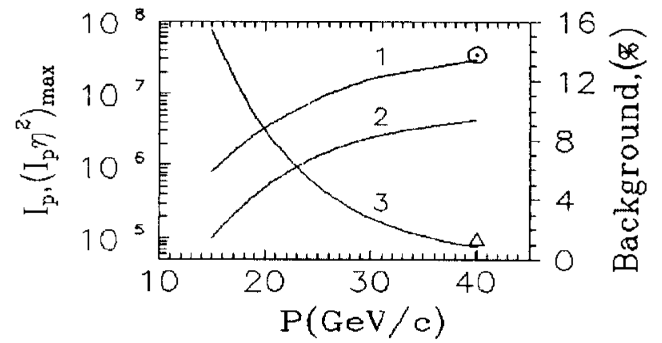


Figure 4. The potentiality of the beam line to form a polarized proton beams at different energies. 2 – the maximum value of the "polarization quality" $(I_p\eta^2)_{max}$; 1 – the corresponding to $(I_p\eta^2)_{max}$ intensity of the polarized beam; 3 – the $\pi^+$-meson background from decay $K^o_s \Rightarrow \pi^+\pi^-$; ⊙ – the measured (and normalized to primary beam of $10^{13}$ppp) intensity of the polarized beam at P=40 GeV/c; Δ – the measured background of positive particles.

The vertical dotted line on the figure is drawn through the selected operating position of the upper collimator jaw at Y = −10 mm where the value of "polarization quality" $I_p\eta^2$ is maximum and average polarization is ~ 40%. The revers of the beam polarization is achieved by changing the position of the K4 collimator jaws from −60 mm and −10 mm to +10 mm and +60 mm respectively. The use of the collimator for the selection of the beam fraction with the required direction and degree of polarization leads to the effect of vertical displacement of the beam symmetrically relative to the beam line axis. In our case it was ±10 mm for linear and ±0.46 mrad for angular displacement. These displacements make extremely difficult the experiments with polarized beams because lead to the apparatus asymmetry. To eliminate the displacements two vertical bending magnets are placed close to the experimental facility target. The selection of the beam fraction with the required direction of polarization vector (up or down) and shifting it on the beam line axis is made automatically now during 3 - 4 accelerator spills with the algorithm determined by an experimentators.

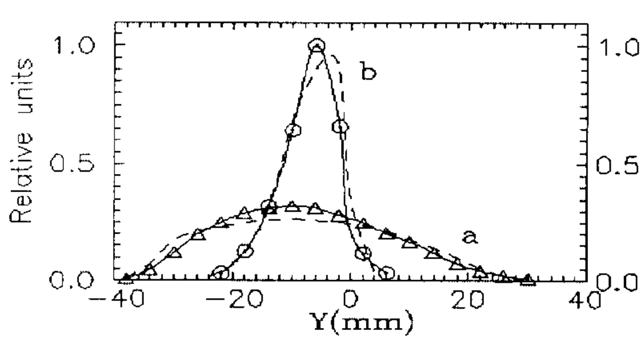


Figure 5.

The potentiality of the beam line to form transversely polarized protons at different energies are illustrated in Fig.4. Fig.5 presents the vertical beam distribution of the polarized protons at 40 GeV/c with expected average polarization about ~ 40% measured at ~ 5.5 m (a) and ~ 0.9 m (b) upstream of the experimental facility target. The dotted lines correspond to the calculated values. As one can see there is a good agreement between the calculated and measured values. This fact allows one to hope that the polarization degree of the formed beam will be close to the calculated one.

## V. CONCLUSION

At the IHEP accelerator there was constructed a polarized proton (antiproton) beam at 40 GeV/c based on the nonconserving parity $\Lambda$ ($\bar{\Lambda}$) decay. Multifunctional beam line №22 has been modernized to obtain the polarized beam. All potentialities of this beam line — high intensity proton, pion, and electron beams are preserved. The stable position of the beam on the target for reverse of the polarization is provided by two dipole magnets. The degree of average beam polarization is supposed to be measured by the coulomb - nuclear interference method, the rest parameters are close to the calculated ones. The salient features of the polarized proton beam production are:

- High intensity (up to $3.5 \cdot 10^7$ppp) for ~ 40% average proton polarization;
- Low level of background (~ $1 \div 1.5$%);
- Automatic positioning of the beam on the beam line axis (and onto the experimental target center) at the beam polarization reverse.

In conclusion the authors express their deep gratitude to the Institute colleagues who took part in the beam line modernization and the measurements of the beam characteristics.

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