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IHEP POLARIZED PROTON BEAM

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Abstract

Galyaev N.A. et al. IHEP Polarized Proton Beam: IHEP Preprint 92-159. – Protvino, 1992. – p. 9, figs. 5, refs.: 16.

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.

Аннотация

Галяев Н.А. и др. Пучок поляризованных протонов на ускорителе ИФВЭ : Препринт ИФВЭ 92-159. – Протвино, 1992. – 9 с., 5 рис., библиогр.: 16.

Дается описание пучка поляризованных протонов с импульсом до 40 ГэВ/с от распада Λ-гиперонов. Проводится сравнение измеренных характеристик пучка с расчетными.

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CONCLUSION

At the IHEP accelerator there was constructed a polarized proton (antiproton) beam at 40 GeV/c based on the nonconserving parity Λ ($\bar{\Lambda}$) decay. Multifunctional beam line N22 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:

1. high intensity (up to $3.5 \cdot 10^7$ppp) for $\sim 40\%$ average proton polarization;
2. low level of background ($\sim 1 \div 1.5\%$);
3. the use of a collimator to reverse the polarization direction;
4. automatic positioning of the beam on the beam line axis (and onto the facility 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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INTRODUCTION

The availability of a polarized proton beam may push further the development of the experiments at IHEP devoted to the study of hadron interactions with polarized targets and to production of high p_t charged hadron (single and pair) in pp and pA collisions. In connection with this, IHEP, since the beginning of the 70-s, elaborated different techniques of polarized particle beam production from external targets as well as the problems of beam transport, formation and construction of polarimeters based on coulomb - nuclear interference [1-5]. IHEP physicists repeatedly proposed projects of polarized proton beam construction at the Serpukhov accelerator (see, for example, [6]) which unfortunately were not realized due to different reasons. We did manage to solve this problem by modernizing the existing multipurpose beam line N22 [7] used to produce high intensity beams of protons, pions and electrons (positrons) for FODS-2 and special beams for SVD. The natural requirement was to preserve all resources to form particle beams that existed before the modernization and to minimize the necessary alteration. In this paper modernized beam line N22 and its possibilities to form a transversely polarized proton beam is described, the calculated beam parameters are compared with the measured ones.

1. PRODUCTION OF POLARIZED PROTONS

A promising way to produce a polarized proton beam is Λ-hyperon decay [8]. In this case due to nonconservation of space parity the decay protons in the Λ rest frame (no matter what the initial Λ-hyperon polarization is) are polarized along their momentum direction. In the rest frame of the hyperon the decay $\Lambda \Rightarrow p\pi^-$ occurs isotropically and the maximum polarization of the decay protons is $\approx 65\%$ [9]. If the decay proton trajectory is traced back to the plane

of the production target center (perpendicular to the primary proton beam axis) then on this plane a virtual source with dimensions which are much larger than those of the primary proton beam is produced. The salient feature of the virtual source is the correlation of the value and direction of the transverse spin component of the decay proton with its space position in the virtual source. In particular, each part of the virtual source phase space corresponds to a definite value of average polarization, growing from the center to periphery. Besides, the transverse spin component is directed to the center of the source. Due to the axial symmetry the beam, as a whole, is unpolarized, but one can obtain a beam with transverse polarization selecting with the collimator a small part of the beam [6] which has a large transverse polarization, or tagging such protons [10]. Λ-hyperons emitted at 0° relative the primary proton beam must be selected to obtain maximal flux of the polarized protons. Such method was used to obtain polarized proton (antiproton) beam at FNAL [11].

2. POLARIZED PROTON BEAM DESCRIPTION

The incoming 70-GeV/c primary proton beam with intensity up to 10^{13} ppp is extracted with pulse spill $t \sim 0.5 \div 1.5$ sec from the accelerator and focused on the production target into a spot with dimensions 4×2.5 mm^2 (H $\times$ V). The target (see fig. 1) is placed in the target chamber of the local radiation shield made in the form of parallelepiped with dimensions $1.0 \times 1.0 \times 1.25$ m^3 (H $\times$ V $\times$ L). The first (along the beam) part of the shield 1 m long is made of steel, the last 0.25 m is made of brass. In the center of the steel shield there is a 50 mm diameter hole for the primary proton beam passage. At the opposite side of the shield this hole ends in the target chamber with dimensions $100 \times 50 \times 350$ mm^3 (H $\times$ V $\times$ L). The brass part of the local shield is rigidly fasten to the clearing magnet yoke and makes a single piece with it. The working part of the target is an Al plate with dimensions $10 \times 3 \times 300$ mm^3 (H $\times$ V $\times$ L). The design provides for remote control of target lead-in and lead-out in the beam.

A clearing magnet with radiation resistant coil was designed and manufactured at IHEP [12]. 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. Non-interacting primary beam protons are deflected downward into a beam dump. Charged particles produced at the target are bent from the channel acceptance. Also, the charged particles from Λ 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 dimensions $70 \times 50 \times 1000$ mm^3 (H $\times$ V $\times$ L) which acts as a collimator for the neutral particles while allowing

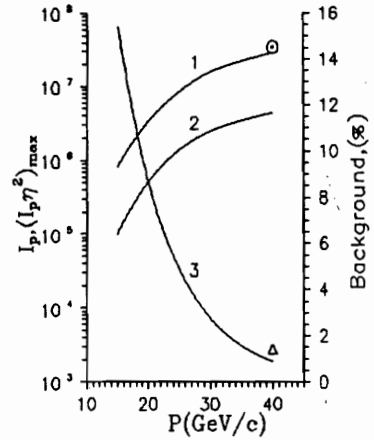

Figure 4. The potentiality of the beam line to form a polarized proton beam at different energies. 2 – the maximum value of the "polarization quality" $(I_p\eta^2)_{max}$; 1 – the corresponding to $(I_p\eta^2)_{max}$ intensity of the polarized beam; 3 – the π^+-meson background from decay $K_s^o \Rightarrow \pi^+\pi^-$; $\odot$ – 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.

corresponding intensity of the polarized beam I_p (line 1) and the contamination of the π^+-meson background (from the decay $K_s^o \Rightarrow \pi^+\pi^-$) (line 3) versus the beam momentum. There is also shown the measured (and normalized to the primary proton beam intensity 10^{13} ppp) value of the polarized beam intensity ($\odot$) and the measured value of the background containment (Δ).

Fig.5 presents the vertical beam distribution of the polarized protons at 40 GeV/c with expected average polarization about $\sim$ 40% measured at $\sim$ 5.5 m (a) and $\sim$ 0.9 m (b) upstream of the 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.

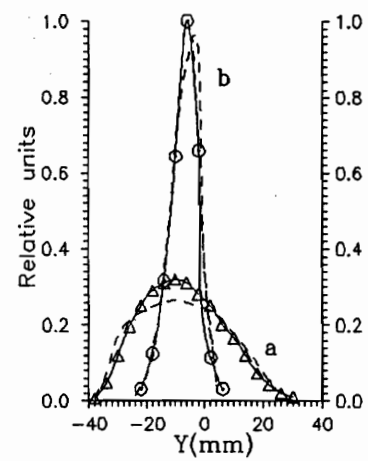

Figure 5. The vertical distribution of the polarized proton beam at 40 GeV/c. The solid line is the measured distributions at $\sim$ 5.5 m (a) and $\sim$ 0.9 m (b) upstream of the experimental target, the dotted lines correspond to the calculated values.

this polarization (line 2), and the "polarization quality" $I_p\eta^2$ (line 3) versus collimator K4 opening.

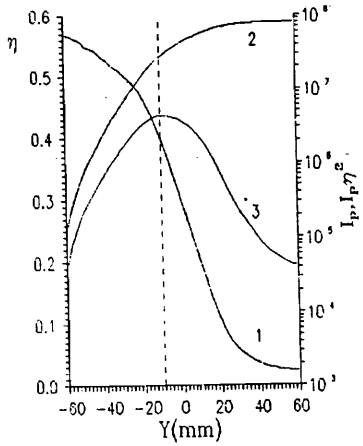

Figure 3. The calculated dependence of the average beam polarization η (line 1), intensity I_p (line 2), and the value of "polarization quality" $I_p\eta^2$ (line 3) of the beam with momentum 40 GeV/c versus the collimator K4 opening. The vertical dotted line corresponds to the operating opening of the collimator.

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. 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 reverse 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 on the target symmetrically relative to its center. 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 they 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 during 3 - 4 accelerator spills with the algorithm determined by an experimentators.

The potentiality of the beam line to form transversely polarized protons at different energies is illustrated in Fig.4. The figure shows the calculated dependence of the maximum value of "polarization quality" $I_p\eta^2_{max}$ (line 2).

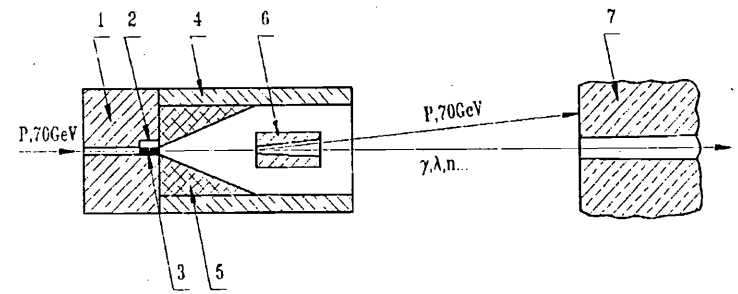

Figure 1. The layout of the head part of beam line N22 (plain view). 1 – local shield; 2 – target chamber; 3 – target; 4 – clearing magnet; 5 – shield in the magnet; 6 – safeguard collimator; 7 – beam absorber P1.

passage of the primary beam. This collimator, with an expanding hole, reduces the number of neutron interactions downstream that could simulate Λ decays. It terminates ∼ 50 cm from the end of the magnet so that charged particles produced within the collimator can be deflected away from the channel acceptance. The primary beam absorber 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 ∼ 35 m downstream of the production target (see fig.2). The beam line transports decay protons produced between 3 and 14 m behind the production target. 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. The vacuum minimizes the number of interactions that the beam has with air.

3. POLARIZED PROTON BEAM OPTICS

The known solutions of transversally polarized proton beam optics are [8,11,13,14]:

1. The first-order transfer matrix from the virtual source to the experimental facility target should be identity in both transversal planes. An identity transform in beam focusing gives spin transparency, or not spin precession.
2. The particle momentum analysis should be made on the base of lensless completely achromatic set of four bending magnets. Such a set of four

bending dipoles produces no net momentum dispersion or particle spin precession.

3. The spatial vertical magnification at the intermediate focus should be greater than unity. In this intermediate focus it is useful to place a collimator to select a part of the beam with the required value and direction of the polarization vector, or a corresponding tagging system.
4. A spin rotator "snake" should be used to periodically reverse the polarization direction so that experimental systematic errors are controlled, and to change the spin direction from vertical to longitudinal or horizontal for different experimental measurements.

Unfortunately the optical scheme of beam line N22 cannot fulfil all these requirements, the corresponding modernization is impossible due to limited space and other restrictions. Nevertheless under these conditions it turned out to be possible to satisfy basic undoubtedly essential requirements.

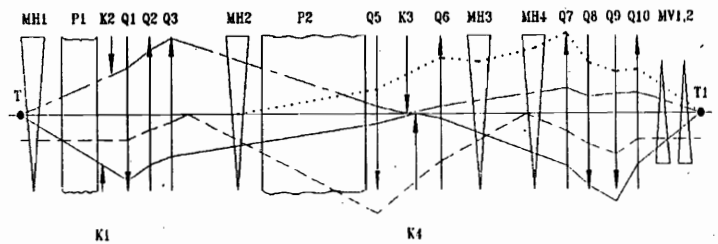

Figure 2. Structure and optical scheme of the beam line. T, T1 – production target and target of experimental facility; P1, P2 – absorbers of charged and neutral particles; K – collimators; Q – quadrupole lenses; MH, MV – bending and correcting magnets; X/X'_o, Y/Y'_o, Y/Y_o, $X/\delta p$ – matrix coefficients: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

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 beam linear dispersion in the center of the momentum collimator is 15.6 mm/1% $\Delta p/p$, 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 matrix of the vertical plane. The linear dispersion of the beam on the 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.

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

N	Parameter	Value
1.	Beam dispersion at momentum slit	15.6 mm/1%$\Delta p/p$
2.	Space magnification at intermediate focus (collimator K4)	-2.68
3.	Beam profile at final focus:	
	Horizontal	$\sigma_x = 10.6$ mm
	Vertical	$\sigma_y = 8.1$ mm
4.	Angular divergence at final focus	
	Horizontal	±6.5 mrad (max)
	Vertical	±6.0 mrad (max)
5.	Momentum band	±4.5% $\Delta p/p$
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.	π^+-meson background from decay $K^o_s \Rightarrow \pi^+\pi^-$	0.8%

The calculations of the beam line parameters were carried out with program TRANSPORT [15], more detailed calculations were based on a modified program TURTLE [16].

4. EXPERIMENTAL RESULTS AND COMPARISON WITH CALCULATION

The first run on beam line N22 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 use of 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 conditions 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 η (line 1), the intensity of polarized beam I_p corresponding to