CONF-790327--102

MASTER

A 1-12 GeV/c BEAM TRANSPORT FOR TRANSVERSE OR LONGITUDINALLY POLARIZED PROTONS

by

Eugene P. Colton

Prepared for

1979 Particle Accelerator Confernece

San Francisco, California

March 12-15, 1979

U of C-AUA-USDOE

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

Operated under Contract W-31-109-Eng-38 for the

U. S. DEPARTMENT OF ENERGY

The facilities of Argonne National Laboratory are owned by the United States Government. Under the terms of a contract (W-31-109-Eng-38) between the U. S. Department of Energy, Argonne Universities Association and The University of Chicago, the University employs the staff and operates the Laboratory in accordance with policies and programs formulated, approved and reviewed by the Association.

A 1-12 GeV/c BEAM TRANSPORT FOR TRANSVERSE OR LONGITUDINALLY POLARIZED PROTONS*

Eugene P. Colton÷

Abstract

A two-stage beam transport for polarized protons has been constructed and operated at the Argonne ZGS. The first stage delivers vertically polarized protons (N-type) to an elastic scattering polarimeter consisting of a 10 cm long LH_2 target and two moveable sets of forward and recoil scintillation counters. The unscattered protons transported through the beam's second stage are focused onto the polarized proton target PPT-III; this target utilizes a 2.5 T "R and A" magnet to produce target polarizations in the horizontal plane, either in the beam direction (L-type) or transverse to it (S-type). The second stage of the beam is equipped with a combination of superconducting solenoids and dipole magnets; thus the beam polarization can also be rotated to point in the L or S direction. The entire system has been operated successfully over the momentum range 1.0 - 11.75 GeV/c with NS, LS, SS, and LL beam target spin directions.

I. Introduction

The Argonne Polarized Proton Target (PPT) group has carried out a number of experiments utilizing the ZGS polarized proton beam.[1] Studies using polarized proton and deuteron targets have been performed with the PPT-III target; this target is polarized with the aid of a 2.5 T "R and A" magnet whose central field lies in the horizontal plane. This magnet can be rotated about a vertical axis to produce target polarizations along (or antiparallel to) the beam direction, or transverse to it ($\hat{S} = \hat{N} \times \hat{L}$).

We have constructed a special beam transport from the ZGS EPB to PPT-III in order to exploit the physics potential afforded by variable energy polarized proton beams from the ZGS. This transport covers the momentum range of 1.0 - 11.75 GeV/c, possesses its own elastic scattering polarimeter and can, in principle, deliver protons with an arbitrarily chosen spin direction. Particles with an initial half-divergence angle of $\sim$ 3.0 mrad are passed by the system, representing a beam acceptance of $\sim$ 30 μsr; thus, the full ZGS emittance of 4 π cm-mrad can be transmitted for an initial "source" of 2.5 cm diameter. Shielding considerations preclude use of higher intensities than 2 x 10^7 protons/pulse, however. The present transport represents an improvement over the earlier design which could reach 6 GeV/c and did not possess a polarimeter;[2] in that case, the initial polarization was inferred from upstream readings of the 50 MeV and CERN polarimeters. The heart of the transport is two superconducting solenoids which can be energized in order to precess the spin of the incoming protons about the beam direction from N-type to S-type; a downstream dipole is used to rotate the beam spin into the L direction, if desired.

II. Beam Layout and Optics

Figure 1 shows the two stages of the beam. The pulsed septum magnet SB1 splits the EPB with a 12 mrad beam right (BR) deflection; further separation is achieved with SB2 and SB3. The dipoles B1 and B2 steer the beam through the symmetric quadrupole triplet Q1-Q4 to the LH_2 polarimeter target. These quadrupoles place vertical and horizontal foci 75.0 cm

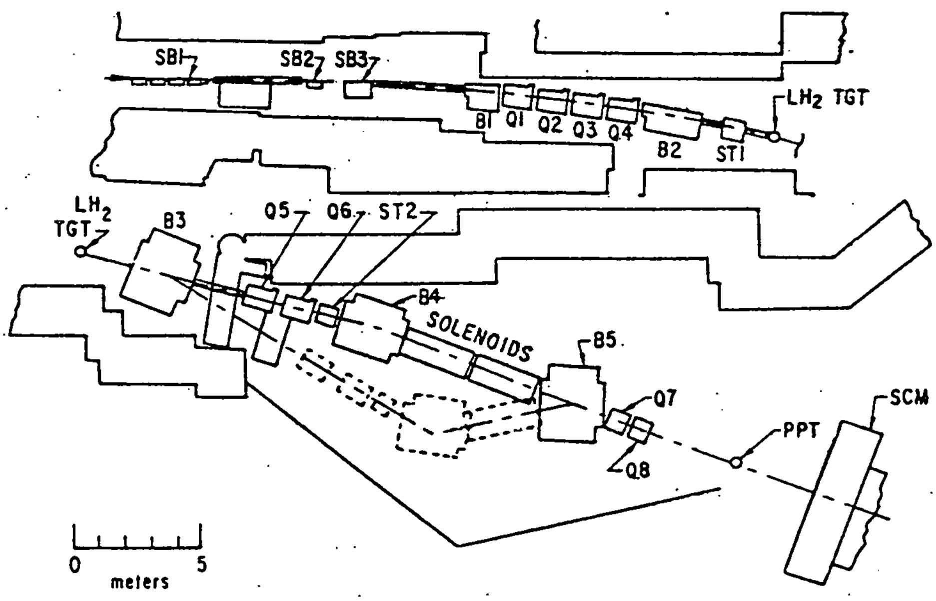

Fig. 1 Physical Layout of Polarized Proton Transport Line

Top half shows first stage from "source" to LH_2 target of polarimeter. The lower section displays the beam's second stage for transport of an N- or S-type beam with B5 off; also shown (dashed) is the configuration utilized for a low-energy ($\leq$ 6 GeV/c) L-type beam with B5 energized.

* Work supported by the U.S. Department of Energy.
÷ Argonne National Laboratory, Argonne, Ill.60439 USA

A 1-12 GeV/c BEAM TRANSPORT FOR TRANSVERSE OR LONGITUDINALLY POLARIZED PROTONS*

Eugene P. Colton†

Abstract

A two-stage beam transport for polarized protons has been constructed and operated at the Argonne ZGS. The first stage delivers vertically polarized protons (N-type) to an elastic scattering polarimeter consisting of a 10 cm long LH_2 target and two moveable sets of forward and recoil scintillation counters. The unscattered protons transported through the beam's second stage are focused onto the polarized proton target PPT-III; this target utilizes a 2.5 T "R and A" magnet to produce target polarizations in the horizontal plane, either in the beam direction (L-type) or transverse to it (S-type). The second stage of the beam is equipped with a combination of superconducting solenoids and dipole magnets; thus the beam polarization can also be rotated to point in the L or S direction. The entire system has been operated successfully over the momentum range 1.0 - 11.75 GeV/c with NS, LS, SS, and LL beam target spin directions.

I. Introduction

The Argonne Polarized Proton Target (PPT) group has carried out a number of experiments utilizing the ZGS polarized proton beam.[1] Studies using polarized proton and deuteron targets have been performed with the PPT-III target; this target is polarized with the aid of a 2.5 T "R and A" magnet whose central field lies in the horizontal plane. This magnet can be rotated about a vertical axis to produce target polarizations along (or antiparallel to) the beam direction, or transverse to it ($\hat{S} = \hat{N} \times \hat{L}$).

We have constructed a special beam transport from the ZGS EPB to PPT-III in order to exploit the physics potential afforded by variable energy polarized proton beams from the ZGS. This transport covers the momentum range of 1.0 - 11.75 GeV/c, possesses its own elastic scattering polarimeter and can, in principle, deliver protons with an arbitrarily chosen spin direction. Particles with an initial half-divergence angle of $\sim$ 3.0 mrad are passed by the system, representing a beam acceptance of $\sim$ 30 μsr; thus, the full ZGS emittance of 4 π cm-mrad can be transmitted for an initial "source" of 2.5 cm diameter. Shielding considerations preclude use of higher intensities than 2×10^7 protons/pulse, however. The present transport represents an improvement over the earlier design which could reach 6 GeV/c and did not possess a polarimeter;[2] in that case, the initial polarization was inferred from upstream readings of the 50 MeV and CERN polarimeters. The heart of the transport is two superconducting solenoids which can be energized in order to precess the spin of the incoming protons about the beam direction from N-type to S-type; a downstream dipole is used to rotate the beam spin into the L direction, if desired.

II. Beam Layout and Optics

Figure 1 shows the two stages of the beam. The pulsed septum magnet SB1 splits the EPB with a 12 mrad beam right (BR) deflection; further separation is achieved with SB2 and SB3. The dipoles B1 and B2 steer the beam through the symmetric quadrupole triplet Q1-Q4 to the LH_2 polarimeter target. These quadrupoles place vertical and horizontal foci 75.0 cm

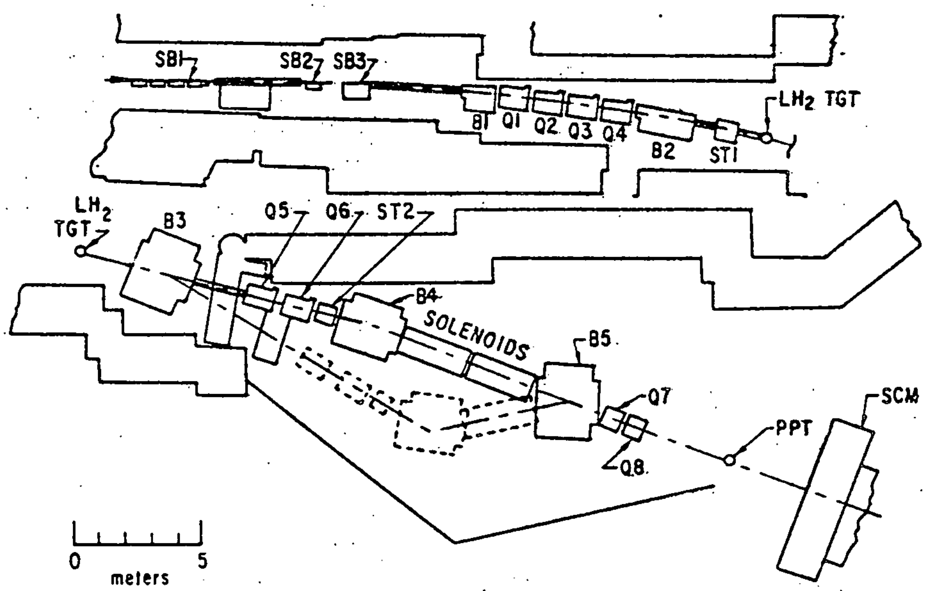

Fig. 1 Physical Layout of Polarized Proton Transport Line

Top half shows first stage from "source" to LH_2 target of polarimeter. The lower section displays the beam's second stage for transport of an N- or S-type beam with B5 off; also shown (dashed) is the configuration utilized for a low-energy ($\leq$ 6 GeV/c) L-type beam with B5 energized.

* Work supported by the U.S. Department of Energy.
† Argonne National Laboratory, Argonne, Ill.60439 USA

upstream, and 150.0 cm downstream of the target, respectively, with spatial magnifications near -0.58. The focal locations are so displaced in order to facilitate polarimeter operation at small four-momentum transfer ($\sqrt{t}$). However, the beam size is still less than 1.5 cm in diameter at the 5.0 cm diameter LH_2 target. Unscattered protons exiting the 10 cm of LH_2 are steered on axis through the solenoids by the dipoles B3 and B4 in the second stage of the beam (see lower half of Fig. 1); quadrupoles Q5-Q8 recapture the beam and produce final foci at the PPT with horizontal and vertical magnifications of 1.3 and 1.2, respectively. The pitching magnets ST1 and ST2 center the beam vertically level at the PPT center. We list the beam elements in Table I as arranged for 11.75 GeV/c final N- or S-type beam polarization; the quadrupole strengths listed were obtained using the first-order optimization procedure incorporated in the program TRANSPORT.[3] Note that in this case the dipole B5 is off; the dashed example shown in Fig. 1 represents a system yielding an L-type beam polarization. (See Sec. IV.) In this case, a physical move of Q5, Q6, ST2, B4, and solenoids is required for each energy change - this usually takes less than six hours.

The beam envelopes through the system listed in Table I are shown in Fig. 2; apertures, magnet locations, and horizontal plane optics are also indicated. The unlabeled arrows represent adjustable collimators which are used to control final flux, spot size and beam divergence. The final divergences are expressed as $X' = 2.75\ X_0 + 0.75\ X_0'$ and $Y' = 0.8\ Y_0'$ (using cm and mrad units); the 20.0 cm long brass collimator located between Q5 and Q6 effectively limits the maximum X_0' and Y_0' passed by the system, and so limits final divergence.

TABLE I. Beam Elements for 11.75 GeV/c N,S Operation

Magnet	Use	Location (m)	Fld.(T) or Grad. (T/m)
SB1	12.0 mr BR	-1.0 - +1.0	0.231
SB2	14.0 mr BR	5.00 - 5.67	0.822
SB3	40.1 mr BR	6.30 - 7.42	1.398
B1	47.1 mr BR	10.83 -11.77	1.965
Q1	Hor. Defoc.	12.23 -13.18	16.99
Q2	Hor. Focus	13.53 -14.48	13.51
Q3	Hor. Focus	14.83 -15.78	13.51
Q4	Hor. Defoc.	16.13 -17.08	16.99
B2	104.7 mr BR	17.49 -19.34	2.214
ST1	Vert. Steer.(up)	20.46 -21.02	0.05
B3	34.4 mr BR	24.33 -26.21	0.718
Q5	Hor. Defoc.	28.62 -29.58	16.99
Q6	Hor. Focus	30.14 -31.09	16.16
ST2	Vert. Steer.(down)	31.43 -31.99	0.025
B4	122.2 mr BR	32.56 -34.44	2.546
SOLA	Spin Prec.	35.09 -37.22	6.5
SOLB	Spin Prec.	37.53 -39.66	6.5
B5	Off	40.31 -42.20	Zero
Q7	Hor. Defoc.	42.83 -43.30	11.02
Q8	Hor. Focus	43.67 -44.18	Zero

III. Beam Polarimeter

The incident beam polarization (N-type) is monitored with an elastic scattering polarimeter which uses the LH_2 target as a scatterer. Figure 3 shows a close-up view of the resident apparatus. The incoming proton flux is monitored by the ion chamber (IC) and the scintillation counter S_0; the segmented proportional ion chambers (SPIC's) provide horizontal beam profiles. Two sets of recoil and forward counter telescopes are used to identify elastic scattering events at $t = -0.15\ (GeV/c)^2$. Below 6 GeV/c no magnetic

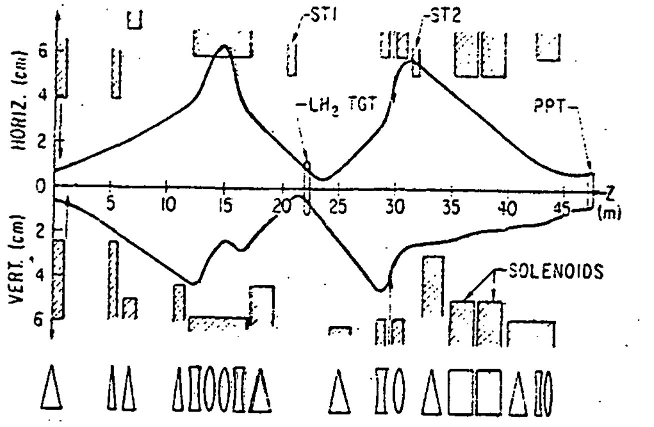

Fig. 2 TRANSPORT Beam Envelopes Through the 47.0 m Beam Line

Initial conditions are: horizontal half-width $X_0 = 0.625$ cm, horizontal half-divergence angle $X_0' = 3.0$ mrad, vertical half-height $Y_0 = 0.625$ cm, and vertical half-divergence angle $Y_0' = 3.5$ mrad.

analysis is performed and the LF_2 and RF_2 counters are placed just downstream of LF_1 and RF_1, respectively. In all cases, the acceptance of the system is based upon the solid angle subtended by the LF_2 and RF_2 counters. Each recoil arm contains two slabs of aluminum, the first to stop protons with initial kinetic energy less than 50 MeV [$t = -0.1\ (GeV/c)^2$], and the second to stop protons with less than 110 MeV [$t = -0.2\ (GeV/c)^2$] or pions with less than 45 MeV. The recoil coincidences, then, are $LR = LR_1 \cdot LR_2 \cdot \overline{LR}_3$ and $RR = RR_1 \cdot RR_2 \cdot RR_3$. The elastic triggers are defined by $L = S_0 \cdot L \cdot RF_1 \cdot RF_2$ and $R = S_0 \cdot RR \cdot LF_1 \cdot LF_2$. Data were accumulated over a period of 1-2 hours; this gives a typical polarization uncertainty of 3% with normal running conditions. The beam intensity is limited to less than 2×10^7 ppp at S_0 with a ZGS repetition rate of about 15 per minute. The beam polarization is given by

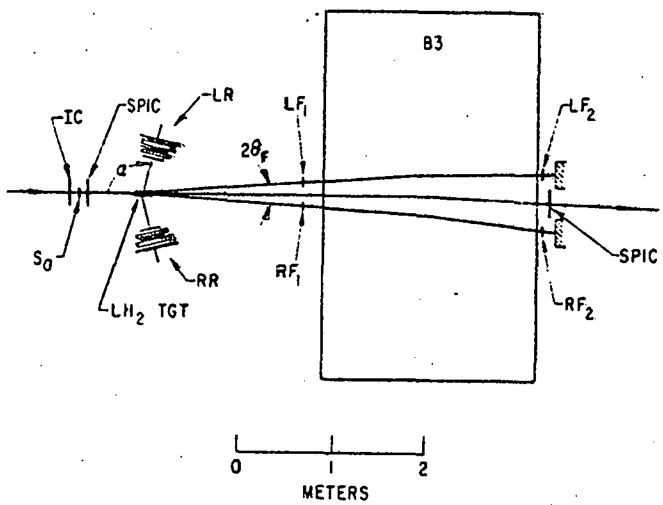

Fig. 3 Elastic Scattering Polarimeter; the recoil angle θ_R is given by $\pi-\alpha$ and θ_F is the angle between the incident beam trajectory and forward counter (LF1 or RF1).

$$P = \frac{1}{A_{pp}} \frac{\sqrt{L^+R^-} - \sqrt{L^-R^+}}{\sqrt{L^+R^-} + \sqrt{L^-R^+}} \qquad (3.1)$$

with an uncertainty of

$$\Delta P = \frac{1}{A_{pp}} \left[L^+ + L^- + R^+ + R^-\right]^{-\frac{1}{2}} \qquad (3.2)$$

where the +/- sign represents the initial spin up/down from the ZGS and A_{pp} is the analyzing power in pp scattering. The spins are flipped on alternate pulses.

IV. Spin Precession

Allowing for the small depolarizations due to, e.g., vertical steering magnets, quadrupoles and other inhomogeneties, the beam incident to the solenoid(s) is vertically polarized (N-type). The spin direction of these protons will be precessed by the solenoid fields and following dipole B5 if they are powered, and by the "R and A" magnetic field. The angle of precession θ_{s1} (in the NS plane) due to the axial solenoid field B_s is given by $g\int B_s dl/(2B\rho)$ where $B\rho$ is the magnetic rigidity of the beam and g/2 is the proton magnetic moment (≡ 2.7928 nm).[4] The spin precession angle θ_{s2} (in the SL plane) due to B5 is given by $(g/2-1)\gamma\theta_5$ where θ_5 is the physical bend angle due to B5; the system is constrained so $\theta_3 + \theta_4 + \theta_5 = 156.59$ mrad BR. Magnet locations and bend angles can be calculated using the examples in Reference 2. Finally, the "R and A" magnet also precesses the beam spin by an angle θ_{s3} - in the NL plane for an S-type target polarization and in the NS plane for an L-type target polarization. In the latter case θ_{s3} is calculated just as θ_{s1} (see above), but assuming an axial field integral of 0.5 T-m; then the spin direction at the PPT is given by

$$\text{spin} = \hat{L} \sin\theta_{s1} \sin\theta_{s2} + V\left\{\hat{S}\cos(\alpha-\theta_{s3}) + \hat{N}\sin(\alpha\ \theta_{s3})\right\} \qquad (4.1)$$

where $\alpha = \tan^{-1}\left[\cot\theta_{s1}/\cos\theta_{s2}\right]$ and $V = \left[\cos^2\theta_{s1} + \sin^2\theta_{s1}\cos^2\theta_{s2}\right]^{\frac{1}{2}}$

Careful beam steering is required in order to maintain proper spin rotations in the solenoid(s) and B5. SPIC's are mounted at the upstream and downstream ends of the solenoid(s) as well as 1 m upstream of the PPT. Thus, we keep the beam centered on-axis at the SPIC positions. The $\int Bdl$ of B5 is known to 0.1% from Hall probe and wire-orbit measurements, and the solenoid and "R and A" field integrals are also well known. Undesireable spin components are kept below the 5% level in all cases. This technique was worked well over the full momentum range of 1.0 - 11.75 GeV/c for the spin configuration NS, LS, SS, and LL.

Acknowledgements

The personnel of the Accelerator Research Facilities and High Energy Physics Divisions are to be commended for carrying out a successful installation and maintenance of the beam line and target. Drs. H. Halpern, D. Underwood and N. Tamura, and J. Dawson are responsible for the successful design and operation of the polarimeter. Finally, my colleagues in the PPT Group are to be cited.

References

1. See e.g., I. P. Auer, et al., Physics Letters 67B, 43 (1977), ibid 70B, 475 (1977). See also e.g., I. P. Auer, et al., Physical Review Letters 41, 354, (1978), ibid 41, 1436 (1978).
2. E. Colton, et al., Nuclear Instruments and Methods, 151, 85 (1978).
3. K. L. Brown, D. C. Carey, Ch. Iselin, and F. Rothacker, CERN 73-16 (1973).
4. See e.g., A. P. Banford, "The Transport of Charged Particle Beams" Section 7.4, and F. N. Spon Limited (London, 1966).