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THE 200 nA VARIABLE ENERGY POLARIZED PROTON BEAM AT TRIUMF

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ABSTRACT

A Lamb-shift type polarized H^- source has been recently upgraded to produce a 1 μA beam current within a normalized emittance of about 0.3π mm-mrad. The polarization, enhanced through a diabatic field reversal, is approximately 80%. The 500 eV ions are accelerated and focused via a 5 kV gap lens to match the acceptance of a 300 kV acceleration tube. At 300 keV, at the entrance of a 45 m long electrostatic transport line, the spin is rotated via a Wien filter to compensate for the precession caused by the cyclotron's stray magnetic field along the line. Spin aberrations along the injection path, including the electrostatic spiral inflector, have been calculated to be less than a few degrees. A slight loss in polarization has been measured in the cyclotron between 200 MeV and 520 MeV; however, the polarization of the 200 nA extracted beam is greater than 70% at all energies. The extracted beam is delivered primarily to two beam lines in one experimental area. One is equipped with a ~500 keV magnetic spectrometer. The other, with a liquid deuterium target, can produce a 50-65% polarized neutron beam with a flux of the order of 10^6 n/sec through a 5 cm diam collimator. An additional beam line is being installed to utilize the capability of extracting two beams simultaneously.

INTRODUCTION

The layout of the TRIUMF facility is given in Fig. 1. The polarized source was installed adjacent to the high intensity H^- source

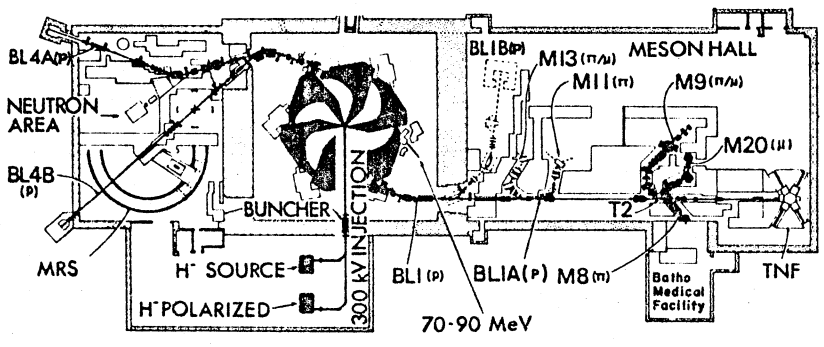

Fig. 1. Layout of the TRIUMF facility.

during the fall of 1975. By March 1976 a polarized beam had been transported at ~300 keV along the 45 m long injection line, accelerated to 520 MeV in the cyclotron, and extracted. Experiments requiring polarized protons were located, in the proton hall, along both beam line 4A (BL4A) and beam line 4B (BL4B) and, in the meson hall, at the first target position in beam line 1A (BL1A). During 1976 the polarized current extracted from the cyclotron varied from 10 to 30 nA. Higher intensities were required by experiments utilizing a polarized neutron beam produced from a liquid deuterium target in beam line 4A. A program to upgrade the source was begun in 1977 with the result that by April 1978 a maximum current of 1 μA of polarized H^- was produced by the source, with the required emittance, and 200 nA were extracted at 500 MeV.

SOURCE

The polarized source, shown schematically in Fig. 2, is of the Lamb-shift type[1] and uses the diabatic field reversal technique of Sona[2] to enhance the polarization. Through the use of a close-coupled geometry the overall length from the duoplasmatron to the entrance of the 300 kV acceleration tube has been kept to 1.5 m. Helmholtz coils, not shown, are used to reduce the cyclotron's fringe field in the zero-cross region between solenoids 1 and 2. The spin direction can be altered, in about 2 sec, by reversing the field in all three solenoids simultaneously, either manually or automatically through the cyclotron computer.

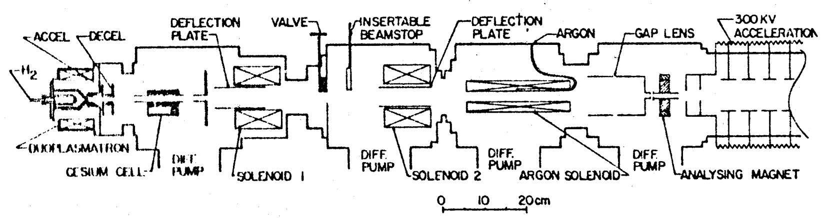

Fig. 2. Schematic diagram of the Lamb-shift source.

An anode aperture of approximately 0.4 mm minimizes the spill on the accel lens without significantly affecting the current through the lens. The 90° present expansion cup cone angle is not critical as found from tests of various expansion cup designs.

A momentum analyzing magnet, located immediately prior to the acceleration tube, can be used to bend the 500 eV beam through 90° onto a Faraday cup. The current reading from this cup is used to align the accel-decel lens system as well as to optimize the duoplasmatron parameters and accel voltage. The positions of the accel-decel lenses are adjusted only transverse to the beam direction, during the beam optimization process.

Matching of the source to the 300 kV acceleration tube and the beam line acceptance is achieved by a system of two lenses. A 5 kV gap lens focuses the H^- beam through a 3 mm aperture. This is followed by a second gap lens, at approximately 0.1 kV, which is used to make small adjustments to the virtual position of the focus.

Alignment of the ground cylinder of the 5 kV lens is crucial. Mechanical alignment has not been adequate, and the final position has been determined using the beam. Horizontal and vertical steering prior to the acceleration tube is achieved by the analyzing magnet and by voltages applied to insulated plates on the pole faces.

The beam emittance has been measured, at the Wien filter location, 40 cm downstream of the acceleration tube. The vertical emittance, shown in Fig. 3, is 10π mm-mrad at 300 keV ($\sim 0.3\pi$ mm-mrad normalized). The theoretically expected emittance ellipse is also shown and indicates that the emittance orientation is much as expected. Since the system has axial symmetry, the horizontal emittance has not been measured and it has been assumed to be as calculated. The beam centroid changes slightly with spin direction; however, the beam line can be tuned to accept this larger effective emittance.

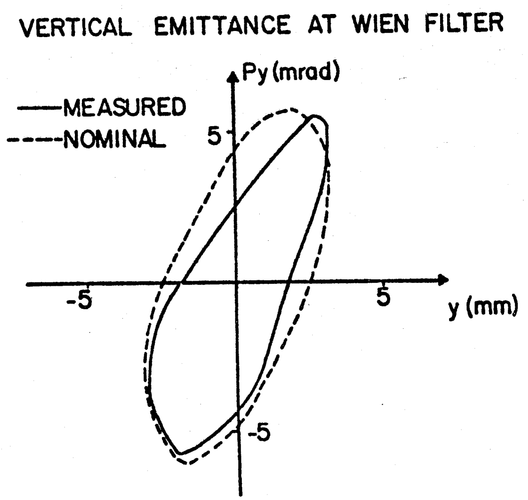

Fig. 3. The vertical emittance, as measured (solid curve), and as theoretically expected (dashed curve).

INJECTION LINE

A 45 m long injection line, shown in Fig. 4, transports the 300 keV H^- beam from the source into the cyclotron. The beam enters the cyclotron axially and is bent into the median plane by a spiral inflector. The line contains 90 electrostatic quadrupoles, 66 electrostatic steering plates, a Wien filter, and three RF devices, namely, a beam buncher, a 1:5 selector and a beam chopper.

The Wien filter, which has a 1.1 cm aperture between the electrostatic plates and an overall length of 64 cm, is used to precess the spin of the H^- beam from the axial orientation at the source to an orientation which will be vertical at the end of the injection line. The three RF devices are phase locked to the 23 MHz RF accelerating system in the cyclotron. The beam buncher is capable of

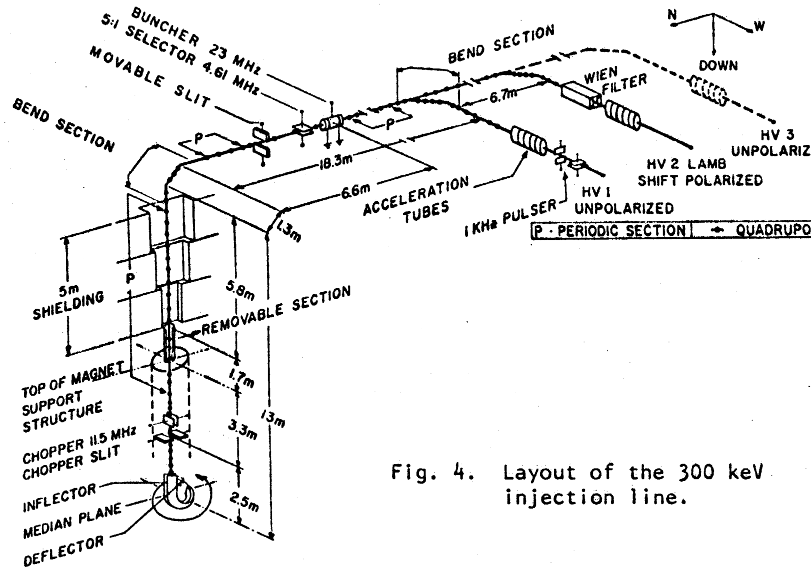

Fig. 4. Layout of the 300 keV injection line.

injecting 40% of the dc beam into the 45° wide cyclotron phase acceptance. The 1:5 selector eliminates four out of the five beam bunches being accelerated in the cyclotron, so that at extraction the time between beam bursts is 215 nsec rather than 43 nsec. The chopper can be used to reduce the width of each beam burst from approximately 4 to 1 nsec.

The fringe field from the cyclotron extends over the full length of the injection line varying from a few gauss to over 100 G in the horizontal section and from 100 to 3000 G along the vertical section. This field is essentially transverse to the beam line along the horizontal section and parallel along the vertical line. To minimize the effects of this field, mild steel cylindrical shields, 25 cm in diameter and 4 mm thick, were placed around the horizontal line wherever possible. Small ferrite dipoles were placed in these shields to compensate for the field in the unshielded regions. The total spin precession from the uncompensated stray magnetic field was calculated to be 63°, which compares well with the 73° inferred from the optimum settings for the Wien filter. Calculations indicate that the spin aberrations due to the uncompensated stray magnetic field is negligible along the horizontal line and that along the vertical line the depolarization due to aberrations should be less than 2%. It is estimated that the inflector could introduce spin aberrations of the order of 1°, which would produce negligible depolarization.

CYCLOTRON

The properties of the TRIUMF H^- accelerator, a six-sector, strong focusing cyclotron, have been described in a number of recent papers.[3,4] Two or more proton beams may be simultaneously extracted, over an energy range variable from 183 to 520 MeV, by inserting

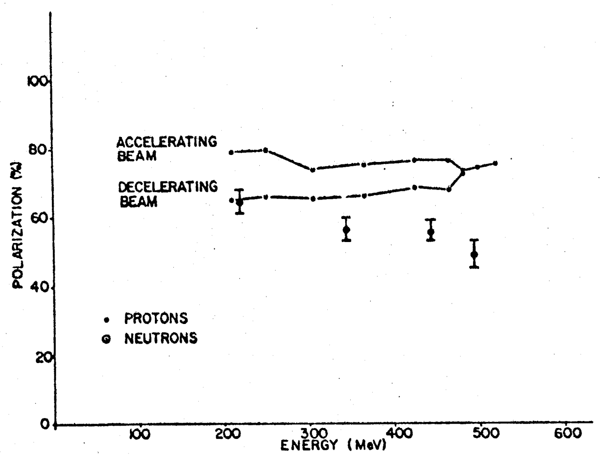

Fig. 5. The polarization of the proton beam (closed circles) and the beam line 4A neutron beam (open circles) as a function of energy.

0.025 mm thick carbon foils into the median plane of the cyclotron to strip the two electrons from the circulating H^- ions. The energy resolution of the extracted beam is normally about 1 MeV FWHM. With the use of internal slits this can be reduced to 0.5 MeV and is expected to reach 0.1 MeV with the advent of third harmonic RF flat-topping which will permit separated turn operation up to full energy. Approximately 25% of the current injected into the cyclotron can be accelerated to 520 MeV. Transmission through the injection line is typically about 80% (1/2 of the loss is due to gas stripping). Consequently, with 1 μA at the source it was possible to extract 200 nA at 500 MeV.

The polarization of the extracted beam has been measured as a function of energy. The H^- beam was accelerated up to 520 MeV and decelerated back towards the machine centre. A narrow foil was used to partially strip both the accelerating and the decelerating beams. The polarization of the two beams was measured and the results are shown by the closed circles in Fig. 5. There is a slight loss in polarization (~3%) in the region 460 to 480 MeV and (~6%) in the region 250 to 300 MeV. The reason for this loss in polarization is not understood and a program to investigate possible causes is planned.

EXPERIMENTAL AREAS

Along beam line 4A (Fig. 1), a 10 cm long deuterium target can produce a monoenergetic polarized neutron beam with a neutron flux of approximately 2×10^6 neutron/sec through a 5 cm aperture for the 200 nA proton beam. A superconducting solenoid, capable of precessing the spin of 500 MeV protons through 270°, can be located in front of this target. The measured neutron polarization, from 50 to 65%, is shown at four neutron energies as open circles in Fig. 5. This polarized neutron beam has been used to do $\vec{n}p$ scattering in order to measure the Wolfenstein polarization transfer parameters.

Beam line 4B is a low intensity line designed for currents less than 100 nA. This line has two experimental stations. The first is a general purpose station with four movable arms for detection apparatus. The second station has a medium resolution (~0.5 MeV) magnetic spectrometer. Experiments using the polarized beam have examined elastic scattering on helium and deuterium, quasi-free scattering on calcium and oxygen, and inclusive scattering on helium. In all experiments the beam polarization is continuously monitored by polarimeters measuring the $\vec{p}p$ scattering asymmetry. These polarimeters have been calibrated to an accuracy of about 1% by two double scattering experiments, one of which involved polarization pumping from the $\vec{p}\,^4\vec{He}$ reaction.

An experiment, studying $\vec{p}\pi$ reactions on various targets using a 65 cm Browne-Buechner magnetic spectrograph to measure the angular dependence of spin-dependent effects, has until recently been located in beam line 1A. The increase in unpolarized proton beam intensity, with the associated increase in residual activity, has eliminated experimental stations using polarized beam along BL1A. This experiment, with an upgraded spectrograph, is moving to a low intensity (≲10 nA) beam line 1B, which is being constructed so that two polarized proton experiments can, once again, run simultaneously.

FUTURE IMPROVEMENTS

An improved beam bunching system is presently being considered which should be able to improve the overall beam transmission by about 20%. Considerable work has gone into matching the beam from the unpolarized source to the cyclotron with the result that the beam transmission from this source to extraction has exceeded 30%. With a comparable effort, a 50% increase in the overall transmission and extracted intensity can be expected for the polarized beam. New extraction ports have been installed in the cyclotron which can extend the variable energy range down to 65 MeV. Proton beams from these ports could be transported to the beam line 1B target position. In addition, preliminary studies have been made of a post-accelerator complex which could raise the energy of a beam from the TRIUMF cyclotron to a few GeV.

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