PRECISION MEASUREMENTS OF THE EFFECTS OF ENERGY AND INTENSITY MODULATION OF AN OPTICALLY-PUMPED POLARIZED ION SOURCE

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Changes in proton beam properties were measured at the parts per million level when energy and intensity modulations were introduced to an optically pumped polarized ion source and injection system. The injection energy was modulated by varying the electron cyclotron resonance source extraction voltage, and then the 300 kV extraction column voltage. The 200 nA intensity was varied by photo-neutralization of the H^- beam. The resulting post-accelerator intensity, position and shape modulations were studied with hydrogen-filled transverse field ion chambers and vacuum secondary emission monitors. The synchronously detected signals were amplified and digitized.

1 Introduction

In a precision measurement of parity non-conservation at TRIUMF, the sensitivity of the apparatus to beam variations was measured. Parity violation is indicated by a non zero measurement of a longitudinal analyzing power. In preliminary work it was necessary to measure the maximum contribution of each source of instrumental or systematic non-zero values. To do this the 223.4 MeV proton beam was deliberately disturbed. These disturbances and their effects will be discussed here.

Of significance is the sensitivity with which the effects were measured by the transverse field ion chambers.[1,2] Two ion chambers were used: one immediately either side of the target. The transmission measurement is based on accurate measurement of the incoming and outgoing currents, which are too large for event-by-event counting. The current from the downstream ion chamber is carefully subtracted from that upstream, and the difference signal monitored.

The present ion chamber design consists of two plates separated vertically by two stacks of side electrodes which run the length of the 100cm plates. The cross-section of the ion chamber gap is close to a 10cm square. This size was chosen as it was thought to preclude beam halo interaction with anything but the immersion gas - hydrogen.

A negative high voltage was applied to the upper plate (corona shield). A uniform resistor chain between the side electrodes ran to the lower, grounded plate. The ground plate had a rectangular section removed. The hole was filled by a close-fitting but electrically isolated electron collection plate from which a current was drained. The goal was a uniform electric field throughout the region above the signal plate. If the beam halo is small and the homogenous region large, the signal is insensitive to variations in the beam.

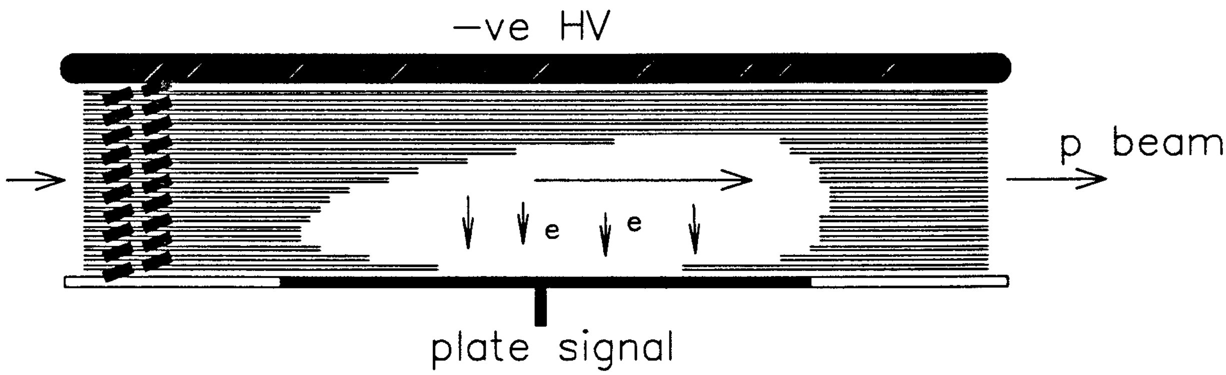

Figure 1: Side view of a transverse field ion chamber. Beam protons ionize the gas; the electrons are collected on the signal plate embedded in the ground plate.

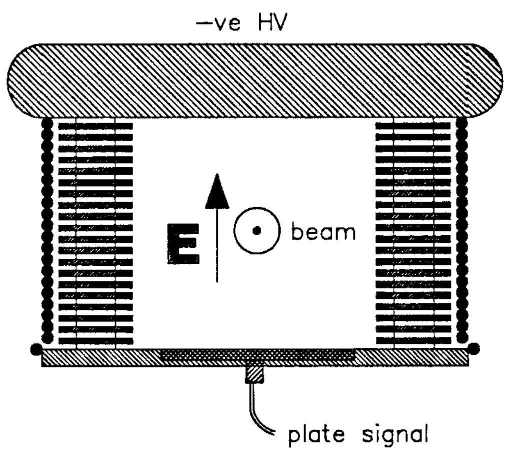

Figure 2: Cross-sectional view through a transverse field ion chamber. Electrodes and ceramic spacers form the side stacks. Resistors across the spacers are mounted on the outside.

2 Modulations

Variations in the beam which were considered, include those in beam position, diameter and intensity. Upstream bending magnets prevent protons of varying energy from being transmitted without changes in position. There are a number of ways to produce these variations, and sometimes a combination was produced. Here we cover the effects of changes at the ion source.

An optically-pumped polarized ion source (OPPIS) was used.[3] The electron cyclotron resonance (ECR) extraction voltage was around 3kV. The column extraction voltage was 297 kV, producing over 100 μA of polarized 300keV protons. Injection beam energy variations were achieved by modulating both these voltages separately.

Energy variations in the injected beam become position and size modulations after passing through the array of bending (and necessarily momentum dispersive) magnets in the injection line to the cyclotron. A beam which normally fills the acceptance of the cyclotron would have some fraction pushed out during the modulation. This would produce an intensity modulation in the cyclotron and beyond. Modulating the column voltage had similar effects to changing the ECR voltage. Changing the ECR voltage altered both the intensity and the emittance of the injected beam, producing a breathing effect in the final beam.

The electron cyclotron resonance (ECR) voltage of the ion source was varied to produce an energy modulation. This varied the emittance going in to the cyclotron due to a momentum spread increase which is translated into a position spread by a dipole. This, in turn, produced an intensity modulation in the beamline.

Beam intensity modulations were produced by photo-neutralization. A bend in the injection beamline allowed along-axis access to the beam by the laser. The laser envelope was much larger than that of the beam so that uniform de-ionization occured across the ion beam. The electrically neutral hydrogen ions failed to bend in the next dipole and so were lost from the beam. The end effect of photo-neutralization was purely a reduction in beam intensity at the ion chambers.

To see the effect of these modulations ion chamber currents were measured in an alternating manner. The modulations were done at 40Hz with the modulation on (+) for 25ms then off (-). The sequence + - - + - + + - is repeated. By comparing + state with - state data one can deduce an artificial 'helicity' correlated effect resulting in a non-zero analysing power measurement. This choice of method for measuring modulations was chosen to best approximate data taking. Variations in the beam at the ion chambers were measured at the parts per million level.

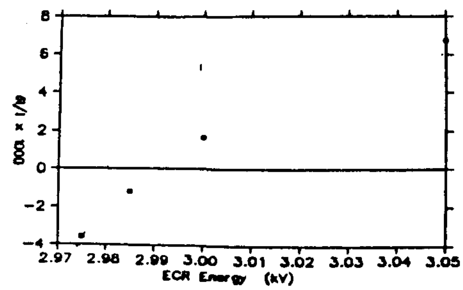

Figure 3: Fractional current change as a function of ECR energy.

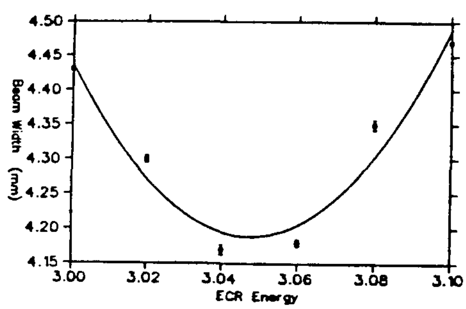

Figure 4: Beam width as a function of ECR energy.

3 Results

Modulating the ECR voltage produced changes in the current measured in the ion chambers. A 0.2% change in current was measured for a 0.3% ECR voltage modulation (10V). See Fig 3. This result is closely related to the observation of an asymmetry of 2×10^{-5}.

An ECR voltage was found which minimized the beam width (see Fig. 4). At V_{ECR}=3.00 kV a change in beam width of 6 - 40μm was observed for a 1% change in V_{ECR} (see Fig. 5 for the most sensitive case). The range in breathing noted here covers vertical and horizontal cases at the two different ion chamber locations. Changing the column voltage by 0.3% while modulating V_{ECR} (0.4V) typically produced 5μm changes in beam width.

Modulation of the column voltage (by 60V) produced a shift in beam position of roughly 5 to 10 μm. Reproducibility of data was a problem suggesting unrecorded changes of another beam property. The intensity fluctuations were similar to those produced by ECR modulation.

A 0.1% photo-neutralization modulation produced a proportional current variation in the beam line at all locations.

The ion chambers' sensitivity to these small changes

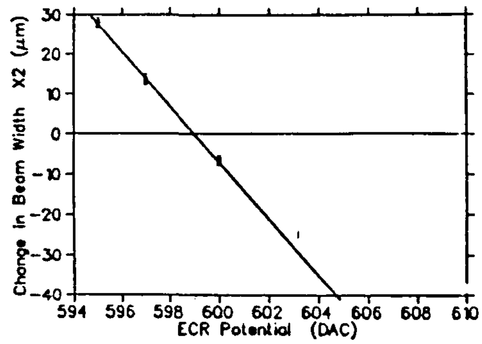

Figure 5: Change in beam width as a function of ECR energy (600=3kV).

in beam properties proved to be a good tool for beam diagnostics. However, the parity violation work prefers an insensitive (to beam breathing and shifts) current monitor and so at present larger gap (15cm) ion chambers are in use. The larger gap reduces the effects of beam halo tails interacting with the electrodes of the ion chamber, which is the interaction which made the smaller gap chambers sensitive beam diagnostic devices.

Acknowledgements

The authors wish to thank the Natural Science and Engineering Council of Canada for its support.

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