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Spin-Correlated Position Modulations of a Polarized Proton Beam

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Modulations of the polarized proton beam position or intensity correlated with the spin flip may introduce serious systematic errors in the 50 MeV $\vec{p}$-p parity-violation experiment in progress at Texas A&M.[1] We have developed a pair of secondary electron emission monitors to measure these fluctuations. They have proven to be powerful diagnostic tools, not only to understand the coupling of the proton spin to other beam properties, but also to identify problems with the cyclotron and beam transport systems as well.

Each beam monitor consists of three 6.4 μm thick doubly aluminized mylar foils, separated from each other by 1.6 mm. The 50 MeV proton beam loses 30 keV and is multiply scattered through a mean angle of 0.9 mrad as it passes through these foils. The aluminum surfaces of the middle foil are separated into four quadrants (upper left, upper right, lower left, lower right). Each quadrant is connected to a separate current-to-voltage converter which provides a virtual ground. As the proton beam passes through this foil, secondary electrons are emitted. They are attracted to the outer foils by a +45 volt bias provided by a battery. At 50 MeV, the total secondary electron current is 30% of the proton current. The total electron current measures the beam intensity, while the relative contributions from the separate quadrants provide information about the beam centroid location. The voltage signals from the current-to-voltage converters are processed by a special control module that generates voltage levels proportional to the beam intensity and the relative horizontal and vertical coordinates of the beam centroid. In particular, it calculates the quantities:

$$\frac{I_L - I_R}{I_L + I_R} \quad \text{and} \quad \frac{I_D - I_U}{I_D + I_U}$$

where I_L, for example, is the sum of the currents from the upper and lower left quadrants. The control module also generates error signals, proportional to the difference between these levels and pre-determined set points, which may be used to drive a pair of fast steering magnets for feedback control if desired. Two independent beam centroid monitors are located in front of the target chamber, so that angular modulations of the beam may be measured in addition to position modulations. The absolute calibration of the monitors depends upon the size and shape of the beam spot. It is determined by comparing the relative centroid outputs to the true beam position, as measured by two scanning polarimeters located on the same beamline that are similar in design to those in Ref. 2.

It is known[3] that atomic beam, polarized proton sources have intensity modulations correlated with spin state at the level of $\approx 5 \times 10^{-5}$, but correlated position modulations have not been reported. We have measured the position modulations correlated with spin state with our centroid monitors. To measure these modulations, the (L-R)/(L+R) or the (D-U)/(D+U) output of the appropriate centroid monitor control module was input to a lock-in amplifier referenced to the spin flip frequency. The output of the lock-in amplifier was integrated for 8 seconds, digitized, and recorded on tape. When we pulsed the polarized ion source intermediate field transition unit at 26.3 Hz, while leaving the weak field transition unit off, we found correlated position modulations at our first centroid monitor of 50 ± 13 nm in the horizontal direction and 30 ± 10 nm in the vertical direction. This monitor is located 1.3 meters downstream from a 47.6° bending magnet. At this point the beam is approximately 2 cm square. The horizontal measurement required 15 minutes in the presence of the an 0.3 mm horizontal 60 Hz modulation produced by ripple in the cyclotron RF voltage. The vertical determination required 10 minutes in the presence of an 0.1 mm vertical 60 Hz modulation. When the weak and intermediate field transitions were alternated, the horizontal modulation at the first centroid monitor was reduced to 10 ± 10 nm, while it was 33 ± 20 nm at the second monitor. The second monitor is 0.9 m downstream from the first, and the beam spot is 1.5 cm (x) by 1.2 cm (y). Vertical modulations were <5 nm. It is not clear whether these modulations are due to correlated changes in the position, direction, or energy of the proton beam extracted from the cyclotron. Calculations of the beam optics seem to favor a change in the beam angle, but this has not yet been confirmed. These modulations represent only a small systematic error in the parity-violation experiment, unless they are related to changes in the beam energy. In the latter case, they would represent an error of $\approx 1 \times 10^{-7}$. It is also unclear what causes this effect. The most likely mechanism is that a very small spin-correlated shift in the average proton beam velocity in the axial injection line couples to the phase of the RF buncher. This could introduce a correlated change in the acceptance of the cyclotron.

We observed such an effect when we intentionally superimposed a small modulation on the buncher RF amplitude in order to investigate our sensitivity to beam intensity modulations. A 1% intensity modulation introduced a correlated horizontal modulation at the first centroid monitor of 1700 ± 100 nm. We found that we could reduce this effect a factor of 20 if we modulated the DC grid voltage of the dissociator RF tube to produce the intensity modulation instead. These position modulations are under further investigation at present.

References

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