TWO WIEN FILTER SPIN FLIPPER*

J. Grames#, P. Adderley, J. Benesch, J. Clark, J. Hansknecht, R. Kazimi, D. Machie, M. Poelker, M. Stutzman, R. Suleiman, Y. Zhang, Jefferson Lab, Newport News, VA 23606, U.S.A.

Abstract

A new electron beam 4π spin manipulator composed of two orthogonal Wien filters separated by two solenoids has been installed and successfully used at the Continuous Electron Beam Accelerator Facility (CEBAF).

INTRODUCTION

Precision parity-violation experiments like those performed at Jefferson Lab regularly reverse, or flip, the direction of the electron beam spin direction at the experiment target in order to measure and/or cancel helicity-correlated systematic "backgrounds" from the true physics asymmetry.

At CEBAF the polarized electron beam is produced by photoemission from GaAs in a DC high voltage photogun using circularly polarized laser light [1]. The laser beam helicity (and thus electron beam spin direction) is rapidly reversed to extract a spin-dependent physics asymmetry. This fast reversal is done using an electro-optic Pockels cell which flips polarity at repetition rates up to 1000 Hz. Unintended or uncontrolled systematic effects correlated with the fast helicity reversal may be revealed by performing a "slow" reversal of the spin direction. At CEBAF this is achieved by reversing the laser helicity with a λ/2 wave-plate ~ once per day. Similarly, one may reverse the *electron* helicity with the added benefit of suppressing potentially *immeasurable* effects the laser wave-plate reversal does not address. Electron polarization reversal can be achieved by introducing an accelerator energy-based spin flip, but requiring the experiment to run at different beam energies [2]. At CEBAF this technique is not practical because of the modest beam energies used (1 – 6 GeV). This paper describes a new injector-based electron beam spin flipper composed of two orthogonal Wien filters and two solenoid magnets.

4! MOTIVATION

A 4π "Z" spin manipulator [3], so-called because of its shape was originally conceived at Mainz, and then implemented at CEBAF in the mid-90's. However, its operational complexity was eventually superseded by a simpler single-axis Wien filter spin rotator. A single Wien filter operating with modest fields can easily rotate the spin direction of low energy (<150 keV) electron beam by ±π/2 which is sufficient to compensate for the in-plane precession of spin direction resulting from beam transport through the CEBAF arcs and end station transport lines, thus ensuring longitudinal polarization at the experimental target. This approach has been satisfactory for over a decade. Recently, however, increasingly demanding parity-violation experiments [4,5] have identified the need to introduce a "slow" reversal of the electron beam spin direction, apart from the spin flip obtained with the laser wave-plate. These same experiments also require out-of-plane spin polarization. Both of these requirements fall outside the capability of the single-axis Wien filter. To address these issues, a new 4π spin manipulator has been installed and successfully commissioned at CEBAF. It is compatible with ultra-high vacuum ($<10^{-10}$ Torr), effectively transports high beam current (>200 μA), operates over a range of photogun voltage (<140 kV) and maintains "parity quality" beam independent of *electron* reversal. It consists of two Wien filters and two intervening solenoid magnets, with components described below.

Wien Filter Spin Rotator

A Wien filter [6] consists of static electric and magnetic fields that are orthogonal to one another and to the particle momentum (see Fig. 1). Although invented as a low-energy velocity selector (electrons satisfying $v/c=E/B$ pass undeflected) the large magnetic field integral (> 2000 G-cm) makes it an excellent candidate as a spin rotator, where the electron polarization is precessed about the magnetic field axis by ⊥ / 2 . In addition, it is ultra-high vacuum compatible, compact (15 inches), and a straight element. Wien filters are astigmatic, but this may be corrected with quadrupole magnets. A thorough account may be found here [7].

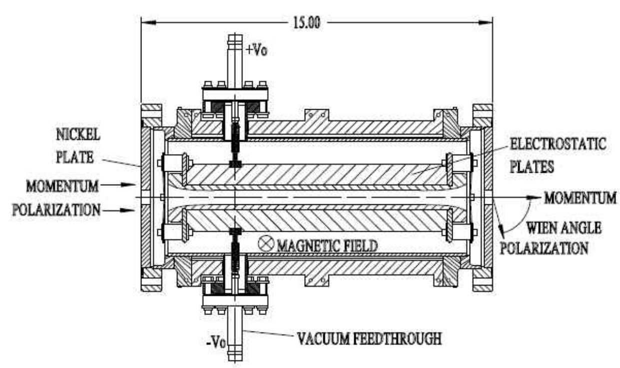

Figure 1: Diagram of Wien filter indicates the static fields and net effect on the beam in the precession plane.

Solenoid Spin Rotator

A solenoid magnetic field provides the most effective focussing of a low momentum (0.1 – 1 MeV/c) electron beam, where the focal length is inversely proportional to the integral of the square of the magnetic field, given in

*Work supported by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177. The U.S. Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce this manuscript for U.S. Government purposes.
#grames@jlab.org

the para-axial approximation by 1/ = /2 2 [8]. A solenoid is similarly well suited to rotate the spin of a low energy electron beam by an amount /2 , with the spin rotated about the longitudinal magnetic field. It is common to use two solenoids in series in order to simultaneously set both the optical focusing and spin rotation. A further benefit is the capability to achieve various net spin rotations, for example, x + x, x - x, -x - x, without changing the overall focussing. In order to optimize the relative amount of focussing and spin precession one can design low (high) peak field with long (short) effective length.

For CEBAF, two 5.91 inch long solenoids (identical) were fabricated (see Fig. 2) and spaced 24.3 cm apart to ensure the field overlap was small (<2 %). Measurements of the axial magnetic field are shown in Fig. 3 and demonstrate the capability of various coil excitations.

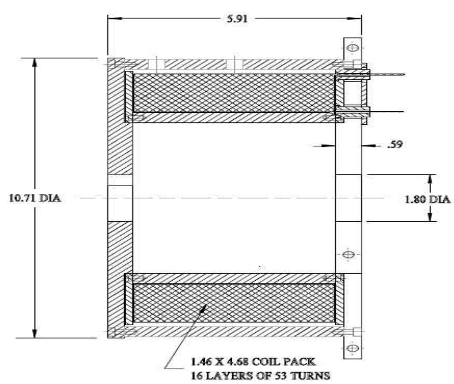

Figure 2: Diagram of the solenoid magnet fabricated.

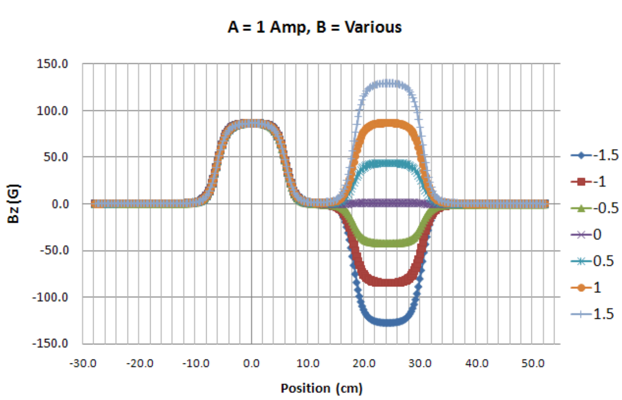

Figure 3: Measurements of the axial magnetic field for two solenoids with the first excited at 1 ampere and the second over a range of currents to add, zero or buck the net magnetic field integral (net spin rotation).

TWO WIEN FILTER SPIN FLIPPER

The CEBAF polarized photoinjector with 4π spin manipulator was installed during Summer 2010 (see Fig. 5 layout). This was the result of a year-long design, modelling and fabrication effort followed by a 10 week installation and commissioning period. To accomplish a “slow” spin flip, the first Wien filter is oriented to rotate the spin polarization out of the plane of the accelerator, in the vertical direction. The downstream solenoids can then be set to rotate the polarization “left” or “right”, while keeping the focusing and beam envelope constant. Typically, the solenoids are set to orient the spin in the horizontal plane, and with the spin vector orthogonal to the beam direction. The second Wien filter is oriented in the horizontal plane and adjusted to “cancel out” the spin precession introduced by the CEBAF transport magnets. To obtain the slow spin flip, one simply changes the sign of the field direction of the solenoid magnets.

But the device is very versatile and can be operated in many ways, by providing 3 orthogonal rotations in series: about the horizontal, longitudinal and vertical axes, respectively. Each element can provide ±π/2 rotation at beam energies up to ~ 140 keV. Some typical configurations used to set the beam polarization orientation at the end station targets are list in Table 1.

Table 1: Examples of how various polarization orientations are obtained at the target are shown. In particular “slow reversal” cases are indicated by “±π/2”.

Orientation At Target	Spin Flipper	V-Wien R(x)	Solenoids R(z)	H-Wien R(y)
P_x or P_z	Off	0	0	< ±π/2
P_x or P_z	On	π/2	±π/2	< ±π/2
P_y	Off	π/2	0	0
P_y	On	±π/2	0	0

The optical design approach was performed in two stages. In the first stage PARMELA [9] was used (with space charge) to optimize solenoid focusing and buncher location in order to attain high transmission at the transverse and longitudinal emittance filters for high current (>100 µA) cw-beam. In the second stage ELEGANT [10] was used to optimize the transverse optics and evaluate the spin dependent astigmatism due to each Wien filter.

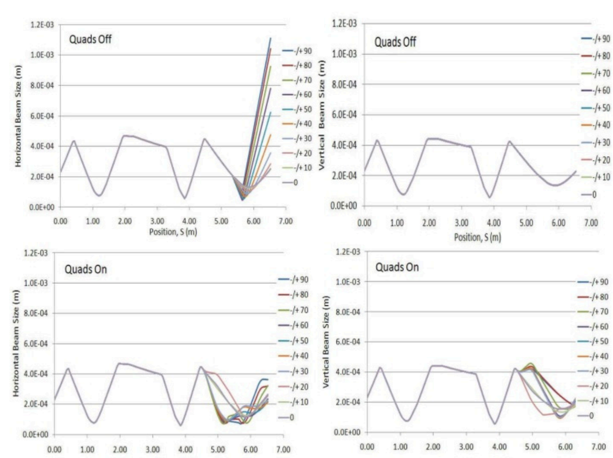

Figure 4: RMS beam size (horizontal/vertical) vs. Wien filter spin angle (±90° in 10° increments) without (upper) and with (lower) quadrupole correction.

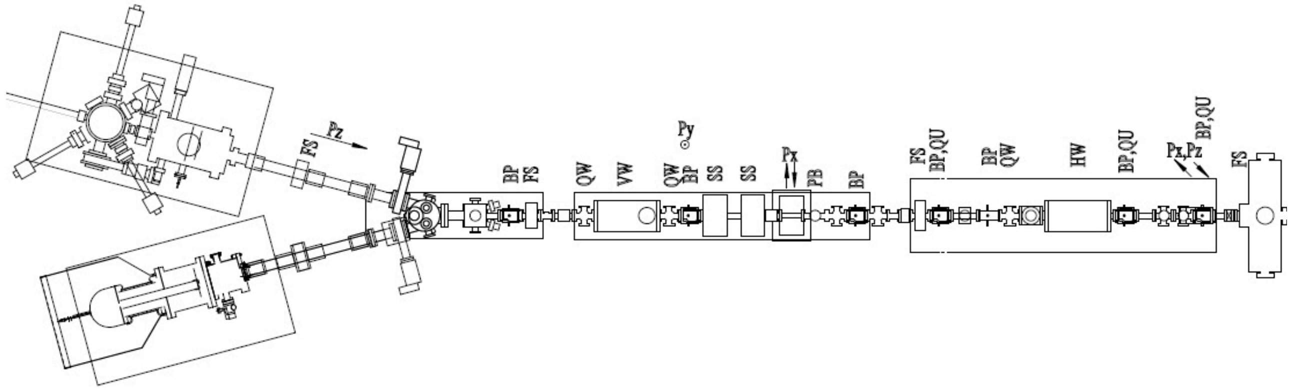

Figure 5: The CEBAF figure shows the load-lock inverted photogun (top) and horizontal photogun (bottom) followed by the new electron beam line composed of focussing (FS) and spin solenoids (SS), Vertical (VW) and Horizontal (HW) Wien filters, quads (QW, QU), a buncher (PB) and beam position monitors (BP). The electron polarization exits the photogun longitudinally (Pz), may then be rotated vertically (Py) and then for slow reversal either "left" or "right" (Px). The second Wien filter rotates the polarization in-plane to compensate precession of CEBAF transport magnets.

To address the astigmatism two types of novel air-core quadrupole magnets were fabricated to save beam line space; bakeable "QW" quadrupoles captured to 6-way crosses and water-cooled large bore "QU" quads which encompass a beam position monitor and steering coils. Calculations using Elegant demonstrate (see Fig. 4) the effect of the Wien filter on beam size and the ability to control beam size and divergence at a match point.

PERFORMANCE

Calibration of the spin rotators were performed using the injector 5 MeV Mott polarimeter (see Fig. 6).

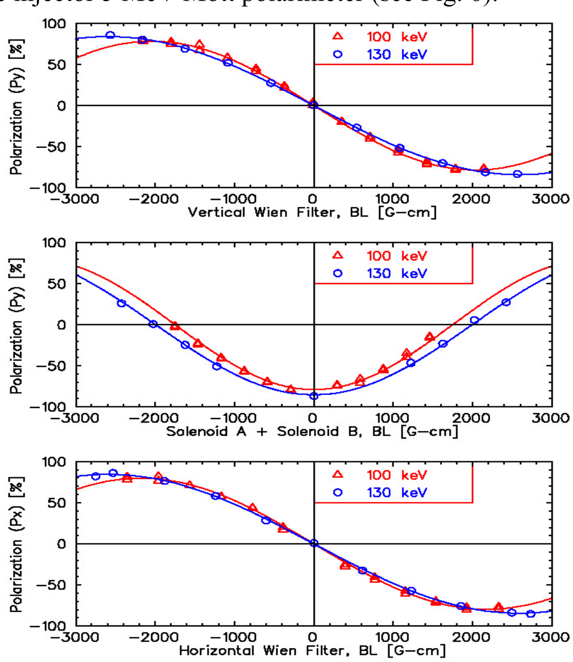

Figure 6: Variation of the electron polarization as a function of the magnetic integral for each spin rotator is shown. The two calibrations used different photocathodes, which explain the difference in maximum polarization.

The spin rotators have been used to provide longitudinal polarization, slow reversal and vertical polarization. In addition, the vertical polarization is controlled at the sub-percent level to better control systematic effects.

CONCLUSION

The new CEBAF polarized source beam line has been in operation for about one year and used with two parity violation experiments and during 3-hall operation. It has performed 4π spin rotations at two gun voltages, and with single-hall "parity quality" beam current up to 180 μA.

REFERENCES

[1] P. A. Adderley, J. Clark, J. Grames, J. Hansknecht, K. Surles-Law, D. Machie, M. Poelker, M. L. Stutzman, and R. Suleiman, Phys. Rev. ST Accel. Beams 13, 010101 (2010).

[2] P. L. Anthony et al. (SLAC E158 Collaboration), Phys. Rev. Lett. 95, 081601 (2005).

[3] D. A Engwall, B. M. Dunham, L. S. Cardman, D. P. Heddle, C. K. Sinclair, Nucl. Inst. and Meth. in Phys. Research A324 (1993) 409-420.

[4] C. J. Horowitz, S. J. Pollock, P. A. Souder and R. Michaels, Phys. Rev. C 63, 025501 (2001).

[5] R. D. Carlini et al. "The Qweak Experiment: A Search for New Physics at the TeV Scale via a Measurement of the Proton's Weak Charge", (2007), http://www.jlab.org/qweak/.

[6] M. Salomaa and H. A. Enge, Nucl. Inst. and Meth. 145 (1977) 279-282.

[7] V. Tioukine and K. Aulenbacher, Nucl. Inst. and Meth. A568 (2006) 537-542.

[8] J.D. Lawson, "The Physics of Charged Particle Beams", Oxford University Press, (1977).

[9] L. Young and J. Billen "The Particle Tracking Code PARMELA," PAC03, Portland, p. 3521 (2003).

[10] M. Borland, "A Self-Describing File Protocol for Simulation Integration and Shared Postprocessors," PAC95, Dallas, May 1995, p. 2184 (1996).