IPBI TN-2008-3

Spin Rotation before the Damping Ring

Ken Moffeit

SLAC

Presented at the
Workshop on Polarization and Energy measurements at the ILC
9-11 April 2008
DESY, Zeuthen

The spin rotation systems for the ILC is described along with a new proposal to rotate the spin vector of the electron and positron beams into the direction normal to the plane of the damping ring (vertical) at a lower energy than the damping ring. Rotating the spin vector into the vertical direction at lower energy will reduce costs and performance requirements. A system proposed in 2005 to randomly select the helicity of the positrons at the e+e- interaction region is described, and is important to minimize systematic errors in the measurement of polarization asymmetries. At 400 MeV the parallel beam lines and kicker magnets needed for selecting the positron helicity between bunch trains will be much simpler than at 5 GeV.

Spin Rotation Systems

The baseline ILC machine described in the Reference Design Report has spin rotation systems located in the Linac-to-Ring, LTR, and Ring to Linac, RTL, of the positron and election beam lines before and after the damping rings operating at 5 GeV [1]. The BMT spin precession [2] with respect to the electron momentum vector is given by:

$$\theta_{spin} = \gamma \frac{g-2}{2} \cdot \theta_{bend} = \frac{E(GeV)}{0.44065} \cdot \theta_{bend} \tag{1}$$

A purely transverse electron spin is rotated about the longitudinal axis of a solenoid magnet by

$$\varphi^{spin} = \frac{e}{m\gamma\beta c}\left(1+\frac{g-2}{2}\right)\int B_z dz\ , \tag{2}$$

where B_z is the axial magnetic field in the solenoid. For electrons and positrons $\left(\frac{g-2}{2}\right) \approx 1.16 * 10^{-3}$ is the anomalous magnetic moment and can be ignored. Each spin rotation system at beam energy 5 GeV uses a small bend of 7.9317^o coupled with two superconducting solenoids of 13.1 Tesla-meters [3].

The concept for the LTR and RTL spin rotation systems are shown in Figure 1. The RTL spin rotation system is after a long transport line and turnaround as shown in Figures 1 and 2. The LTR spin rotation system rotates the incoming longitudinal spin to the vertical, while the RTL system has two spin rotation systems to convert the incoming vertical polarization to any arbitrary spin direction (e.g. transverse or longitudinal as shown in the figure 1).

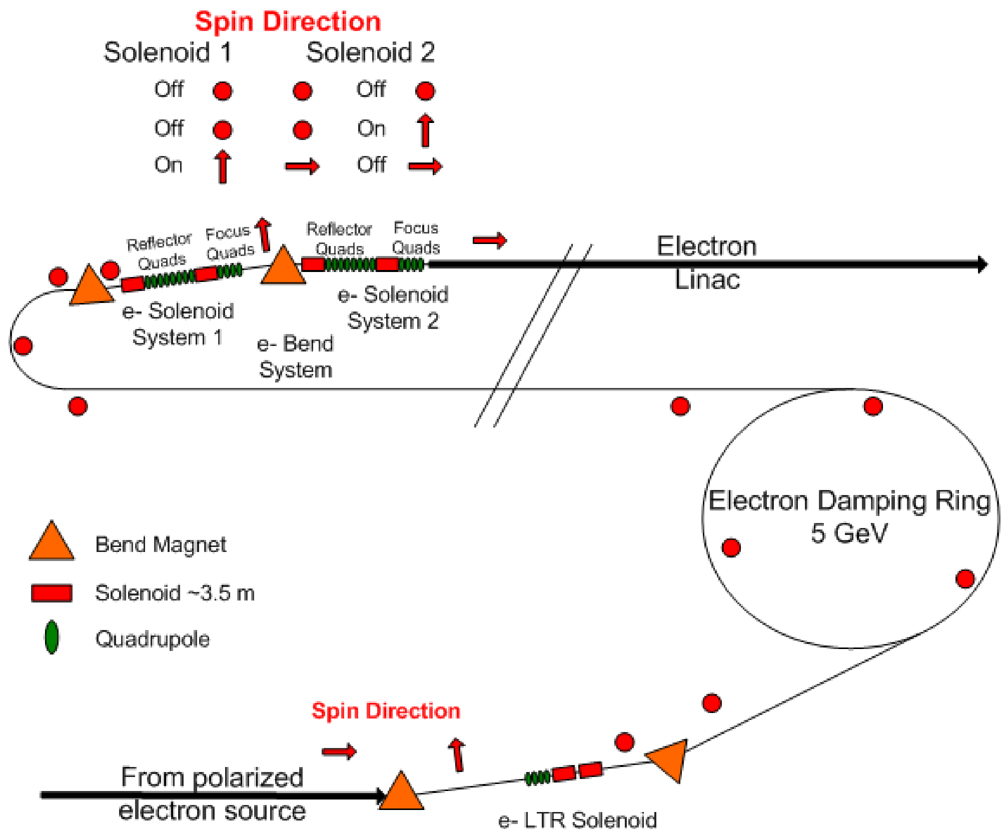

Figure 1: Layout of electron damping ring system showing the spin rotation solenoids.

The RTL systems for the electron and positron beams are identical and include the return line, turnaround and spin rotation solenoids as shown in figure 2. The beam polarization in the damping rings is vertical, and this polarization is transported with negligible loss or precession to the end of the Turnaround [1]. After the Turnaround the two spin rotation systems described above are located.

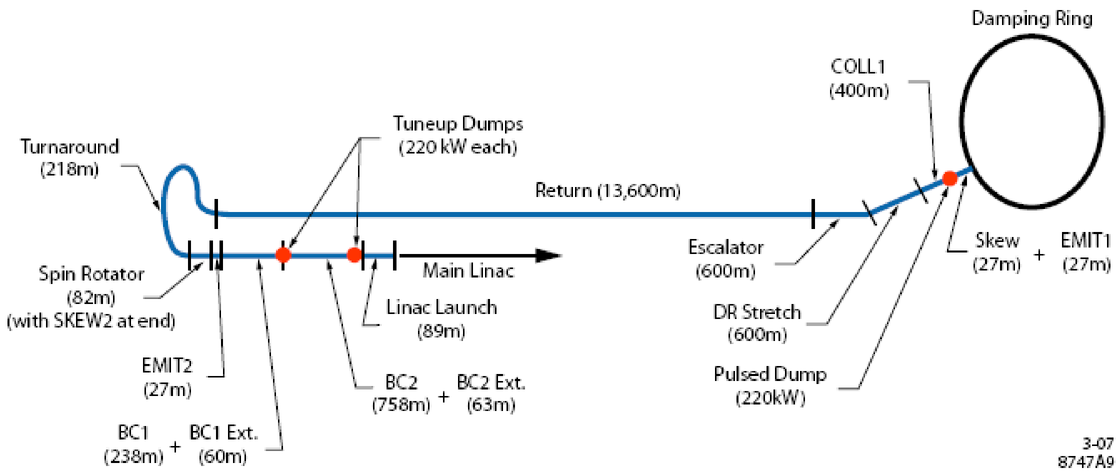

Figure 2: Layout of damping Ring to Linac showing the return line, turnaround and spin rotation solenoids (figure taken from reference 1).

Spin rotation system for polarized positron beam at low energy

The major elements of the ILC positron source are shown in Figure 3. The source uses photoproduction to generate positrons [1]. After acceleration to 150 GeV, the electron beam is diverted into an offset beam line, transported through a 150-meter helical undulator, and returned to the electron linac. Circularly polarized high-energy (~10 MeV) photons from the undulator are directed onto a rotating 0.4 radiation-length Ti-alloy target ~500 meters downstream, producing a beam of electron and positron pairs. Longitudinally polarized positrons are generated in the target from the circularly polarized photons. This beam is then matched using an optical matching device into a normal conducting L-band RF and solenoidal-focusing capture system and accelerated to 125 MeV. The electrons and remaining photons are separated from the positrons and dumped. The positrons are accelerated to 400 MeV in a normal conducting L-band linac with solenoidal focusing. The beam is transported 5 km through the rest of the electron main linac tunnel, brought to the central injector complex, and accelerated to 5 GeV using superconducting L-band RF. Before injection into the damping ring, superconducting solenoids rotate the spin vector into the vertical, and a separate superconducting RF structure is used for energy compression.

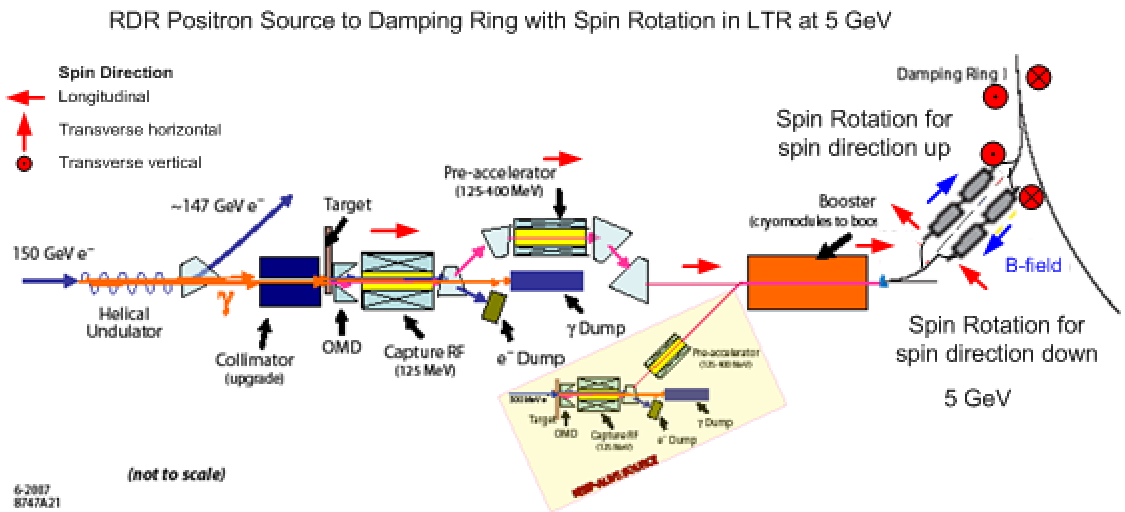

Figure 3: Overall layout of the positron source. The parallel beam lines for helicity selection of the positrons are not included in the Reference Design Report.

The direction of the longitudinally polarized positrons will not easily be changed from right- to left-handed longitudinally polarized positrons at the source. However, randomly selecting the direction of the polarization vector of the positrons at the e+e- IR is important to minimizing systematic errors in the measurement of polarization asymmetries. The Reference Design Report doesn't include the ability to flip the direction of the positrons before the damping ring.

Selecting the direction of the spin vector can be accomplished in the input line to the damping ring by introducing parallel positron LTR spin rotation solenoid beam lines as shown in figure 3. The axial solenoid fields are equal but opposite directions in the two lines. A pair of kicker magnets is used to deflect the positrons into the beam line, with the B-field in the superconducting solenoids having opposite polarity. This proposal has been presented to the management of the ILC [4].

The spin rotation systems in the LTR before the damping ring are costly. Flipping the helicity of the positrons at 5 GeV will require tunnel length and special magnets to separate the parallel paths. At lower energy the parallel beam lines and kicker magnets will be much simpler than at 5 GeV. The axial solenoid field required at lower energy is not as large and may be produced with copper wound magnets. A proposal to modify the positron injector system so the spin rotation is done after the pre-accelerator where the energy is 400 MeV has been presented [5]. The proposed change to the positron pre-accelerator chicane section is shown in figure 4.

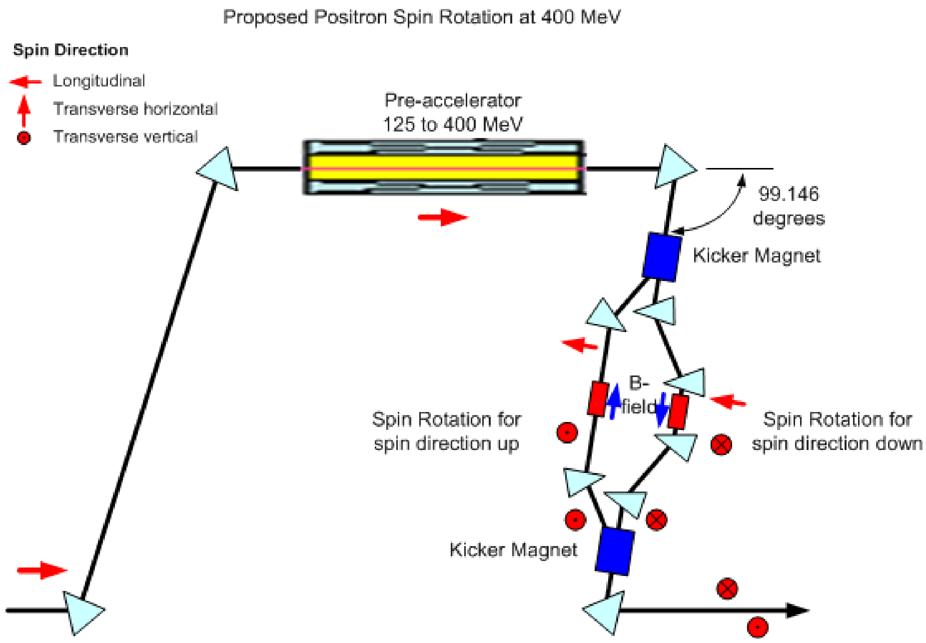

Figure 4: Layout of proposed positron spin rotation systems in the Chicane for the Pre-accelerator. Kicker magnets and parallel spin rotator beam lines allow fast polarization reversals for the positron beam.

The bend angles of the chicane magnets after the pre-accelerator are set to 99.146^o degrees. The positrons leave the pre-accelerator with a momentum of 400 MeV. Using equation (1) at 400 MeV the spin precesses ahead of the directional vector by 90^o for every 99.146^o the momentum vector is rotated. After the bend the spin vector is transverse to the momentum direction. Selecting the direction of the spin vector can be accomplished after the 99.146^o bend by introducing parallel positron spin rotation solenoid beam lines (see Figure 4). A (+ or – in the parallel beam lines) axial solenoid of field integral 2.096 Tesla-meters rotates the spin vector to the vertical (up or down). Copper wound solenoids of length 2.2 meters with an axial field of 9.53 kilogauss and a bore of 2 inches in diameter can be used. A pair of kicker magnets is used to deflect the positrons into the parallel beam lines on the left or right allowing fast flipping of the positron beam helicity at the e+e- collision. The kicker magnets that select this beam path are designed to turn on and off for a single pulse train. The cost of the kicker magnets and parallel beam lines at 400 MeV is much reduced over that at 5 GeV.

The tolerance on the spin alignment is ~ 3 degrees resulting in a depolarization of 0.1%.

There are two concerns in locating the positron spin rotation system after the pre-accelerator that are related to the large energy spread of the positrons at 400 MeV, which may be as large as $\pm 25 MeV$ [6]. A momentum spread of less than 3% for the positron beam at 400 MeV will give a negligible contribution to the depolarization of the positron beam due to the spin rotation system before the damping ring, however, an energy spread as large as 6% will result in spin diffusion and depolarization. Figure 5 shows the angle of spin rotation after a positron beam of energy $400 \pm 25 MeV$ traverses the spin rotation solenoid tuned for 90 degree rotation at 400 MeV. Also shown in figure 5 is the spin projection for the positrons leaving the spin rotation solenoid. The spin diffusion results in a loss of polarization with the positrons having 99.48% of their original polarization.

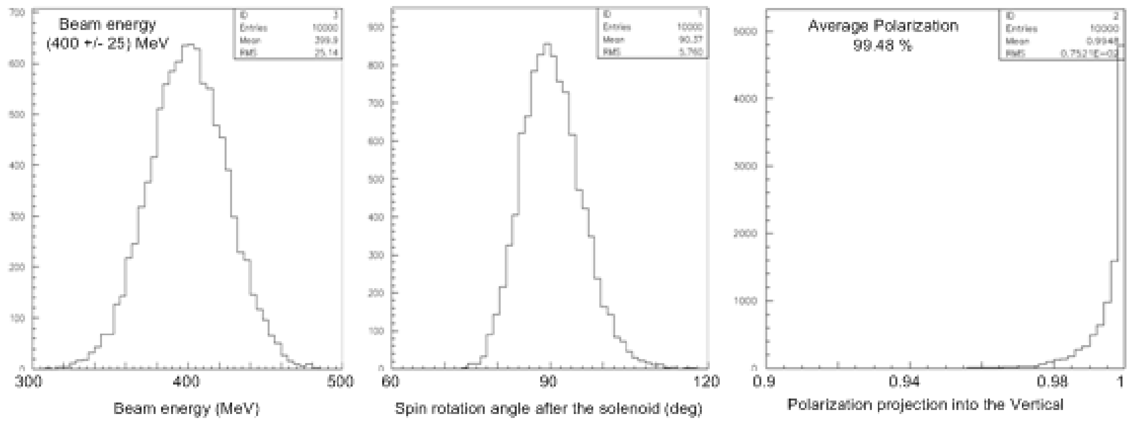

Figure 5: Beam energy, spin rotation angle and polarization projection on the vertical for a beam with energy $E = 400 \pm 25 MeV$. Figure from Takashi Maruyama.

The other concern is to transport the beam through the two 99.146^{o} bends and the optics of the parallel beam lines without significant positron beam losses.

Spin rotation system for polarized electron beam near the polarized electron source
The electron spin direction can be rotated to the vertical near the polarized electron source where the beam energy is less than a few MeV using a Wien filter [7] (see figure 6). This method was used at the Jefferson Laboratory as part of their spin rotation system [8]. Since rotation of the spin vector to the vertical before the damping ring is needed at the ILC only the Wien filter is required.

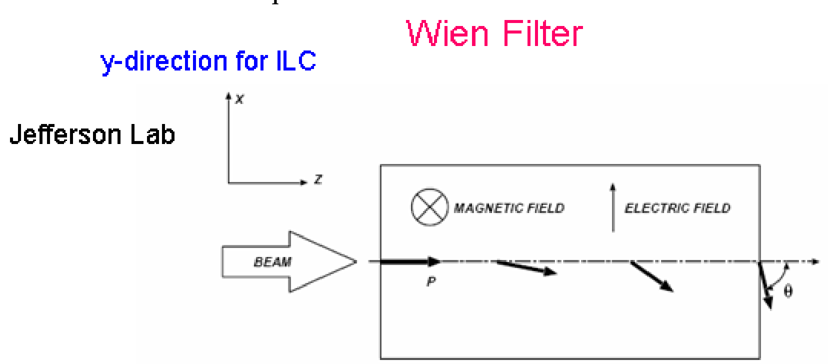

Figure 6: Diagram of a Wien filter indication the rotation of the beam polarization relative to the beam direction in crossed magnetic and electric fields $\beta = E/B$ (figure taken from reference 8).

Placing the Wien filter in the main electron beam line will rotate the spin direction to the vertical without changing the momentum direction as shown in figure 7. The spin direction remains in the vertical direction while the electron beam is accelerated and transported to the electron damping ring. The Reference Design Report already has a Wien filter for rotating longitudinal electrons to the transverse direction for a Mott polarimeter near the polarized electron source.

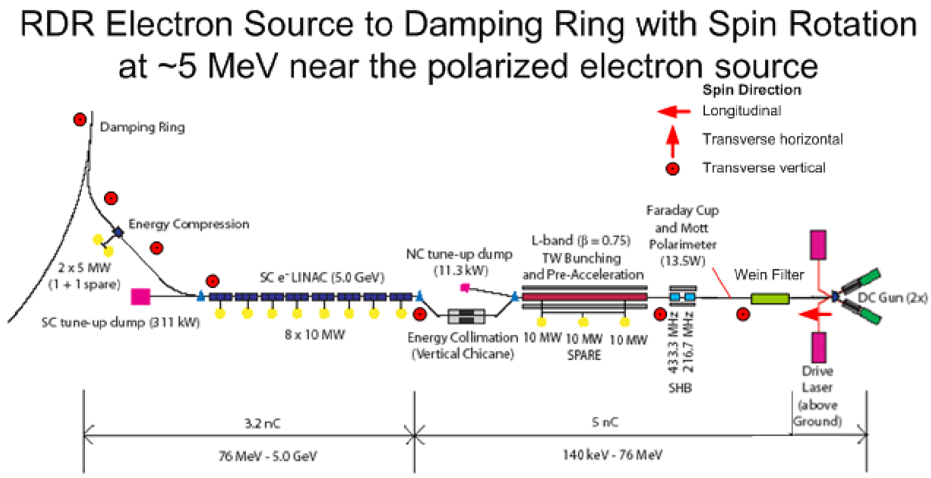

Figure 7: Diagram of the electron spin rotation system using a Wien filter near the polarized electron source.

Conclusions

The costs and performance requirements for the spin rotation systems will be less demanding at lower energy than at the damping ring energy of 5 GeV. Warm copper-wound solenoids for the spin rotation system for the positron beam at 400 MeV can be used. The positron energy spread may be as large as $400 \pm 25 MeV$. The spin diffusion results in a loss of polarization with the positrons having 99.48% of their original polarization. There may be positron beam losses as the beam traverses the spin rotation system with such a large energy spread.

It is required to make all momentum directional changes for the spin rotation systems in the plane of the damping ring. The angle the beam leaves the spin rotation system is required to be in the plane of the damping ring. The tolerance on the angle alignment is ~ 3^o resulting in a depolarization of 0.1%.

A system to randomly select the helicity of the positrons at the e+e- IR is given. Such a scheme is important to minimize systematic errors in the measurement of polarization asymmetries. At 400 MeV the parallel beam lines and kicker magnets will be much simpler than at 5 GeV.

It may be possible to rotate the spin vector to the vertical at very low energy for the electrons near the polarized gun.

The spin rotations systems presented here are conceptual designs. A more detailed optics design, including simulating performance and overall operation, will be needed.

References

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