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Spin Rotation at lower energy than the damping ring

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Abstract

This note proposes a spin rotation scheme for the ILC that rotates 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. Two options are discussed for the electron spin rotation. The first option has the beginning accelerator section for the electron beam at an angle of 23.33^o with respect to the main accelerator sections. The spin rotation uses the bend of 23.33^o and a solenoid of integrated field 8.908 Tesla-meters to rotate the spin to the vertical at 1.7 GeV. The second option uses a dedicated horizontal chicane containing a pre-accelerator increasing the energy of the electron beam from 140 keV to 400 MeV. The spin rotation is done with a bend of 99.146^o and a solenoid with integrated field of 2.096 Tesla-meters at 400 MeV. The transverse spin direction remains in the vertical during the remaining acceleration and transport to the damping ring (5 GeV). The positron spin rotation system is proposed to be done at 400 MeV directly after the positron pre-accelerator. Similar to the second option for electrons the rotation would be done with a bend of 99.146^o and a solenoid with integrated field of 2.096 Tesla-meters. For the positrons we also propose parallel spin rotation beam lines with suitable fast kicker magnets to rapidly switch between solenoids with opposite fields to allow rapid helicity switching for polarized positrons.

1. Introduction

The electron and positron sources in the ILC RDR [1] produce longitudinally polarized beams. A spin rotation system at 5 GeV is used to rotate the beam polarization to be perpendicular to the plane of the damping ring to avoid depolarizing effects during the damping ring storage time.

The ILC design for the electron beam injection to the damping ring is shown in Figure 1. The electrons from the polarized source are accelerated to 76 MeV and bunched. Then they are accelerated in two sections to 5 GeV. In the first section, the electron beam is accelerated from 76 MeV to 1.7 GeV in cryomodules with one quadrupole per module. In the second section, the electron beam is accelerated to the final 5 GeV in cryomodules with one quadrupole every other module.The linac-to-ring (LTR) transfer line rotates the spin vector to be perpendicular to the plane of the damping ring (vertical), using 2 superconducting solenoid magnets (each with a field integral of 13.1 T-m) and dipole bend magnets.

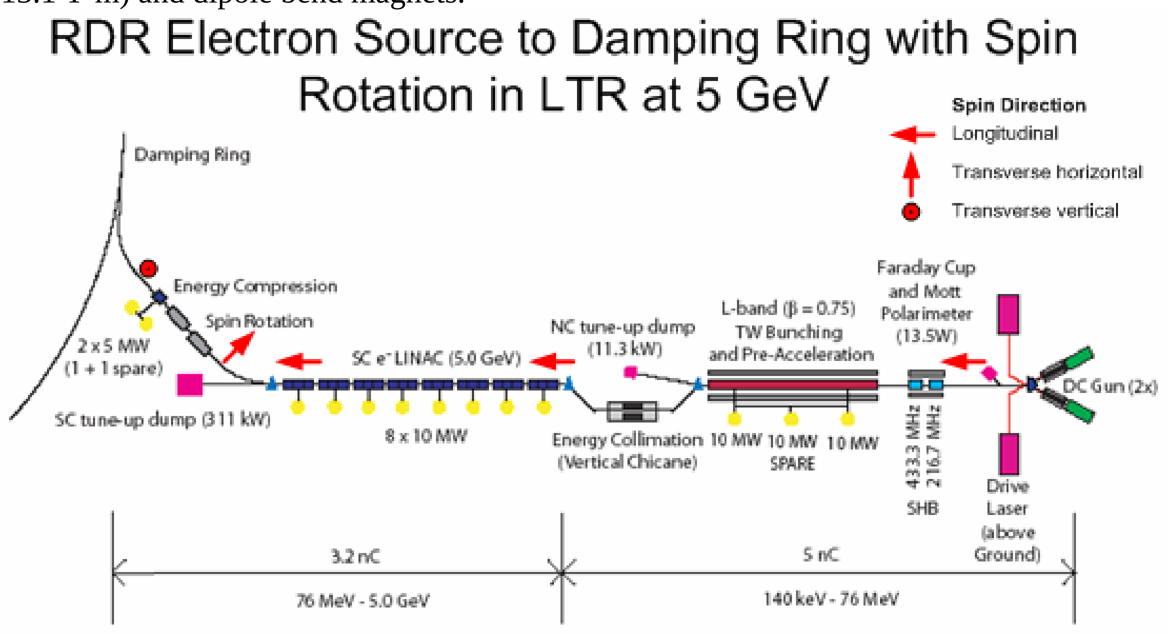

Figure 1: Schematic view of the polarized electron source from the RDR.

We propose that the spin rotation before the damping ring be made at a lower energy than the damping ring energy. Transverse polarized electrons with spin vector normal to the damping ring plane can then be transported to the damping ring without depolarization provided bends are only made in the plane of the damping ring. This will reduce the cost and performance requirements for the beam line magnets, solenoids and kickers. Similarly, spin rotation for the positron beam can also be done at an energy lower than 5 GeV, also reducing cost and easing performance requirements for the magnets.

2. Proposed Spin Rotation System for Electron Beam

The first option discussed is to rotate the spin vector to the vertical after the first accelerator section where the beam is 1.7 GeV (see figure 2). The BMT spin precession [2] with respect to the electron momentum vector is given by:

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

At 1.7 GeV the electron spin component in the plane normal to an applied magnetic field will precess 90 degrees in that plane for every 23.33^o of rotation of the momentum vector. An axial solenoidal field integral of 8.908 Tesla-meters is then needed to rotate the spin parallel to the field of the damping ring (vertical); i.e. by 90 degrees. A solenoid of 2.31 meters in length with maximum field strength of $\pm 38.5 \cdot kGauss$ is needed. The design of the superconducting solenoids used in the RTL could be used. However, the maximum field integral is larger than required (13.1 Tesla-meters with length 3.5 meters).

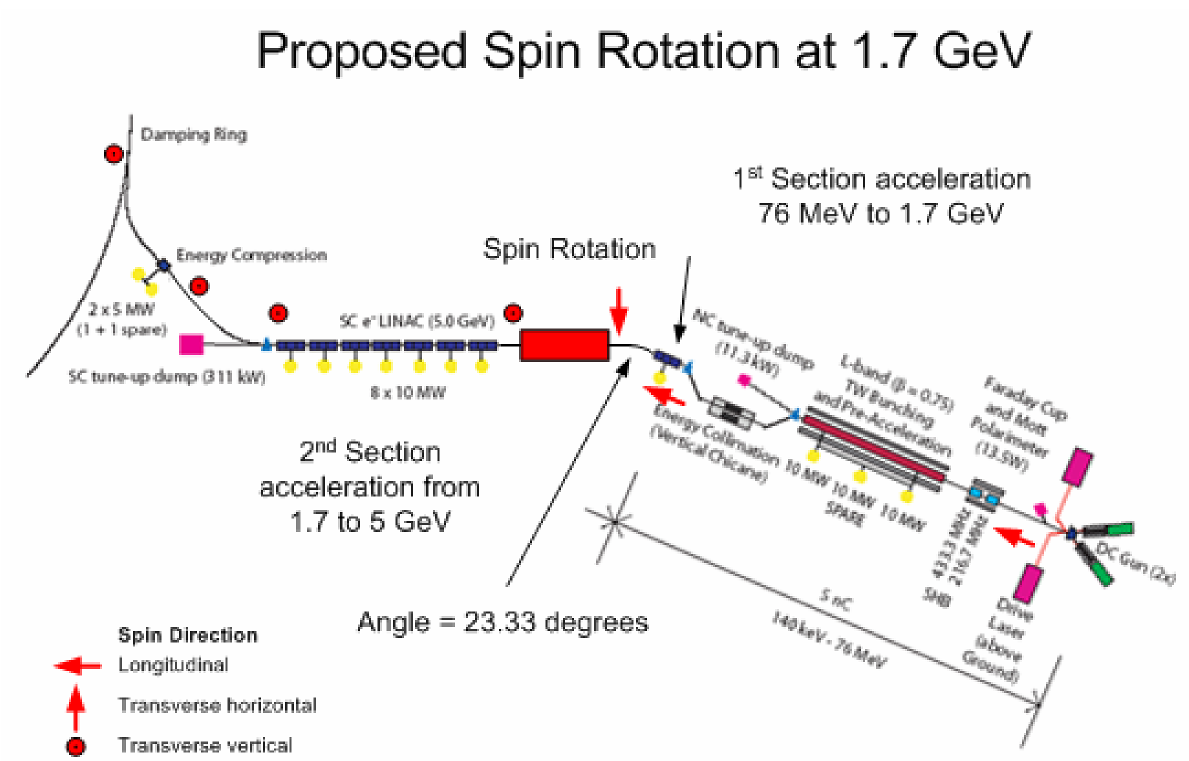

Figure 2: Schematic of proposed electron beam spin rotation occurring after the 1st section of acceleration to 1.7 GeV. Spin rotation system contains a bend of 23.33^o followed by a solenoid of 8.908 Tesla meters.

The bend angle of 23.33^o will require optics that corrects for the dispersion using additional quadrupole magnets.

A second option for the electron spin rotation system is illustrated in figure 3 with the spin rotation done at 400 MeV as proposed for the positron spin rotation system. After the energy collimation at 140 keV the electrons are deflected into a horizontal chicane with a pre-accelerator bringing the electron beam to 400 MeV. After acceleration the electron beam is deflected by 99.146^o where the spin vector precesses ahead by 90^o and enters a solenoid of integrated field strength of 2.096 Tesla-meters. See proposal for the positrons spin rotation system below for further discussion of spin rotation at 400 MeV. The spin vector is rotated into the vertical and then transported to the damping ring.

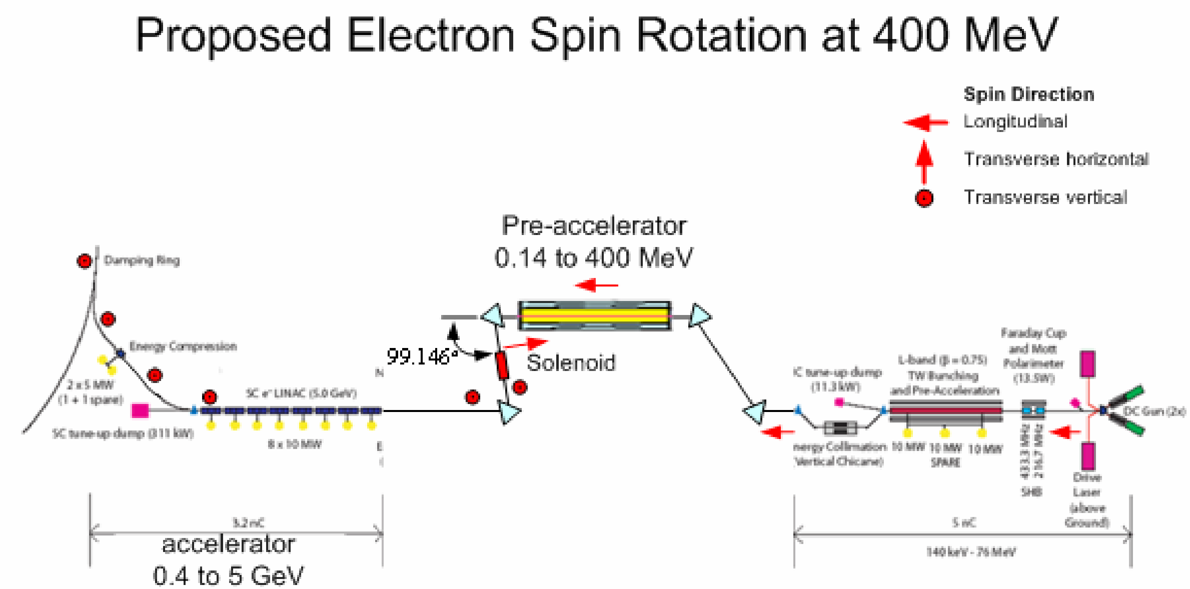

Figure 3: Schematic for 2nd option of proposed electron beam spin rotation occurring at 400 MeV. Spin rotation system contains a bend of 99.146^o followed by a solenoid of 2.096 Tesla-meters.

The upstream section through the pre-accelerator could also be constructed at an angle of 99.146^o degrees with respect to the direction of the accelerator similar to Option 1 above. This variation of Option 2 only has one bend instead of four if a chicane is used.

Lastly, it may be possible to rotate the spin vector to the vertical at a very low energy near the polarized electron gun either before or after the sub-harmonic buncher. We recommend that this idea be investigated further.

3. Proposed spin rotation system for polarized positron beam

The major elements of the ILC positron source are shown in Figure 4. The source uses photoproduction to generate positrons. After acceleration to 150 GeV, the electron beam is diverted into an offset beamline, transported through a 150-meter helical undulator, and returned to the electron linac. The 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. This beam is then matched using an optical matching device into a normal conducting (NC) 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 NC 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.

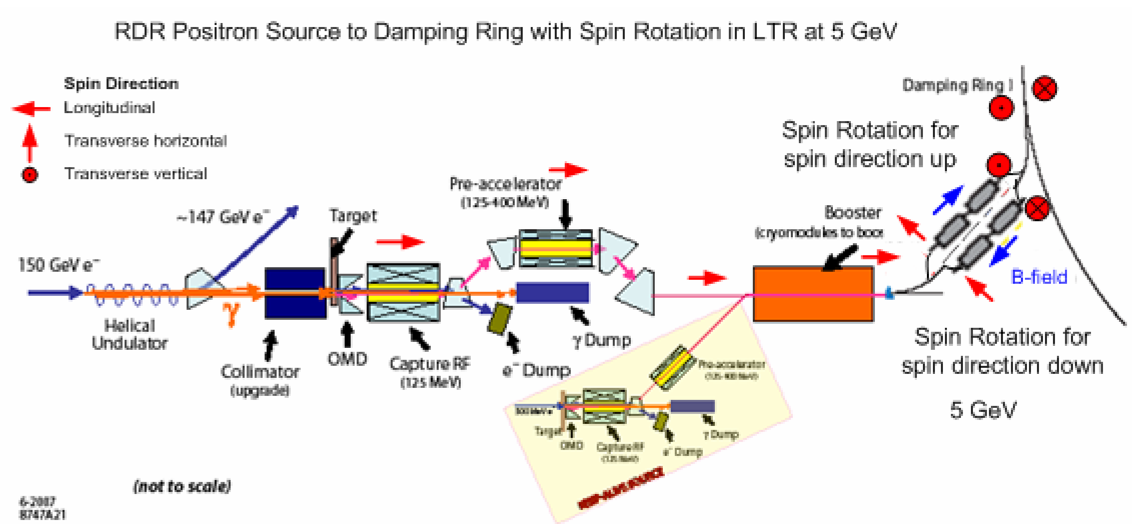

Figure 4: Overall layout of the positron source given in the RDR.

We propose to modify the positron injector system so the spin rotation is done after the pre-accelerator where the energy is 400 MeV. The proposed change to the pre-accelerator chicane section is shown in figure 5.

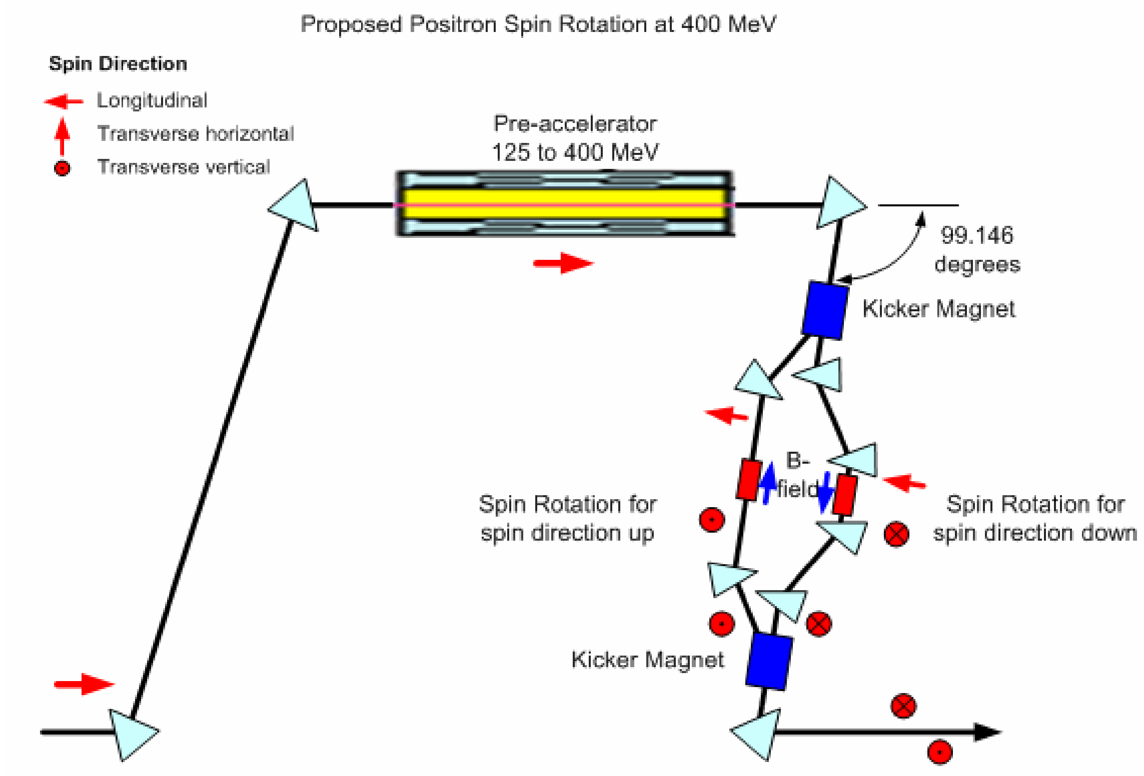

Figure 5: Layout of proposed positron spin rotation systems in the Chicane for the Pre-accelerator. Kicker magnets and parallel spin rotator beamlines allow fast polarization reversals for the positron beam.

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. At 400 MeV the spin precesses ahead of the directional vector by 90 degree 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). [3] An axial solenoid of field integral 2.096 Tesla-meters rotates the spin vector to the vertical. A copper wound solenoid of length 2.2 meters with an axial field of 9.53 kilogauss and a bore of 2 inch 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 or figure 4. The B-field in the superconducting solenoids in the parallel beam lines have opposite polarity to allow fast flipping of the positron beam helicity at the e+e- collision point by selecting the beam path through this spin rotation system . The kicker magnets that select this beam path are designed to turn on and off for a single pulse train.

The lowest positron energy the spin vertor could be rotated into the vertical is after the RF capture section at 125 MeV. At this energy the positron spin precesses 90^o ahead of the momentum for a bend of 317.267^o, and would require solenoids of integral field strength of only 0.655 Tesla-meters. Spin rotation to the vertical for the positrons should also be considered at 125 MeV.

5. 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 at 400 MeV can be used. 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 alignments 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 and for the polarized positrons after the capture section at 125 MeV.

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

References

[1] INTERNATIONAL LINEAR COLLIDER REFERENCE DESIGN REPORT ILC Global Design Effort and World Wide Study AUGUST, 2007. The description and figures used in this paper for the RDR design are taken directly from this report.

[2] V. Bargmann, L. Michel, and V.L. Telegdi, Precession of the polarization of particles moving in a homogeneous electro-magnetic field. Phys. Rev. Lett. 2(10):435-436, 1959.

[3] LCC-159. ***Spin Rotation Schemes at the ILC for Two Interaction Regions and Positron Polarization with both Helicities,*** K. Moffeit, P. Bambade, K. Moenig, P. Schuler, M. Woods, February 2005.