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Linear Collider Collaboration Tech Notes

Spin Rotation Schemes at the ILC for Two Interaction Regions and Positron Polarization with Both Helicities

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Abstract: This note describes a spin rotation scheme for the ILC that allows the polarization spin vector of the electron and positron beams to be tuned independently for two Interaction Regions (IR). The correct spin direction for a particular IR can be selected by directing the beam into one of two parallel spin rotation beam lines located between the damping ring and the linac. With suitable fast kicker magnets, it is possible to rapidly switch between these parallel beam lines, so that polarized beams can be delivered to two IRs on a pulse train by pulse train basis. A similar scheme can be employed in the insertion beam line to the positron damping ring, to allow rapid helicity switching for polarized positrons. ¤

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Abstract

This note describes a spin rotation scheme for the ILC that allows the polarization spin vector of the electron and positron beams to be tuned independently for two Interaction Regions (IR). The correct spin direction for a particular IR can be selected by directing the beam into one of two parallel spin rotation beam lines located between the damping ring and the linac. With suitable fast kicker magnets, it is possible to rapidly switch between these parallel beam lines, so that polarized beams can be delivered to two IRs on a pulse train by pulse train basis. A similar scheme can be employed in the insertion beam line to the positron damping ring, to allow rapid helicity switching for polarized positrons.

1. Introduction

Two Interaction Regions (IR) are planned for the ILC. A possible configuration is to have one IR with a crossing angle of 20 mrad and one with 2 mrad, as shown in Figure 1 [1]. It may be desired to run both experiments concurrently, switching pulse train to pulse train between the two IRs. At the ILC, the electron beam will be polarized with polarization expected to be greater than 80%. The positrons may be polarized with polarization >40%. Both experiments will want to run with the beams fully longitudinally polarized at their IR.

At the ILC, the direction of the longitudinally polarized positrons may not be changed easily from right- to left-handed longitudinally polarized positrons at the source. For example, the helicity of an undulator-based polarized positron source is fixed by the winding sense of the helical undulator [2, 3]. A system to randomly flip the spin direction of the positrons is described.

A flat-beam spin rotation system was proposed in reference [4]. The detailed design included half solenoids with a reflector beam line between them to eliminate cross plane coupling and focusing elements to remove the focusing effects of the solenoid.

The beams will point in different directions at the two IRs. The BMT spin precession [5] with respect to the electron momentum vector is given by:

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

The spin direction of the beams at the two IRs will be different at all energies, except for multiples of $0.44065 \cdot \pi / \theta_{bend}$. For an angle of 11 mrad between the two IRs, this corresponds to 125.85 GeV.

Physics will dictate at what energy we run the ILC. This may not correspond to these magic energies. We want to design spin rotation systems to have optimum polarization at both IRs at any energy. Polarization direction can be tuned for each IR by introducing separate spin rotation systems for the two IRs at the exit of the damping rings and switch the beams to the different spin rotation systems between pulse trains. A scheme to do this at the ILC is described below. Furthermore, it also may be desirable to conduct experiments with transverse spin orientations [6].

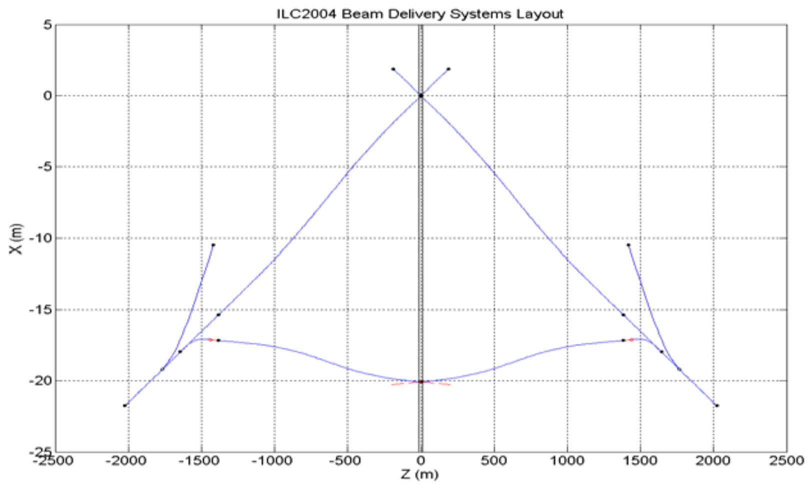

Figure 1: Proposal for two IRs at the ILC. The electron and positron beams enter the final focus systems from the lower left and right. The IR at the top of the figure has the beams crossing at 20 mrad; the one at the bottom of the figure crosses at 2 mrad.

2. Spin rotation system for polarized electron beam

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The electron beam is made longitudinally polarized and accelerated to 5GeV; then it enters a transport line (LTR) to the damping ring. The electrons are stored between pulse trains in the damping ring (see Figure 2). Only electron spin directions parallel or anti-parallel to the magnetic field—that is, transverse to the plane of the damping ring—will preserve their polarization in the damping ring. A spin rotation system, consisting of a combination of dipole and superconducting solenoid magnets, will orient the spin vector parallel (or anti-parallel) to the magnetic field of the damping ring as the electrons traverse the injection line to the ring.

The electron spin is rotated about the longitudinal axis of a solenoid magnet by

$$\varphi^{spin} = \left[1 - \left(\frac{g-2}{2}\right)\right] \frac{\int B_z \cdot dl}{B_0 \rho} \approx \frac{\int B_z \cdot dl}{B_0 \rho} = 2\varphi^{orbit}, \qquad (2)$$

where $B_0\rho$ is the magnetic rigidity. [4, 8] The damped flat beam is rolled through an angle φ^{orbit}. For electrons and positrons, $\left(\frac{g-2}{2}\right) \approx 1.16X10^{-3}$, is the anomalous magnetic moment and can be ignored. For example, if we need to rotate the spin direction by 90^0 after the damping ring, the flat beam will be rolled by 45^0.

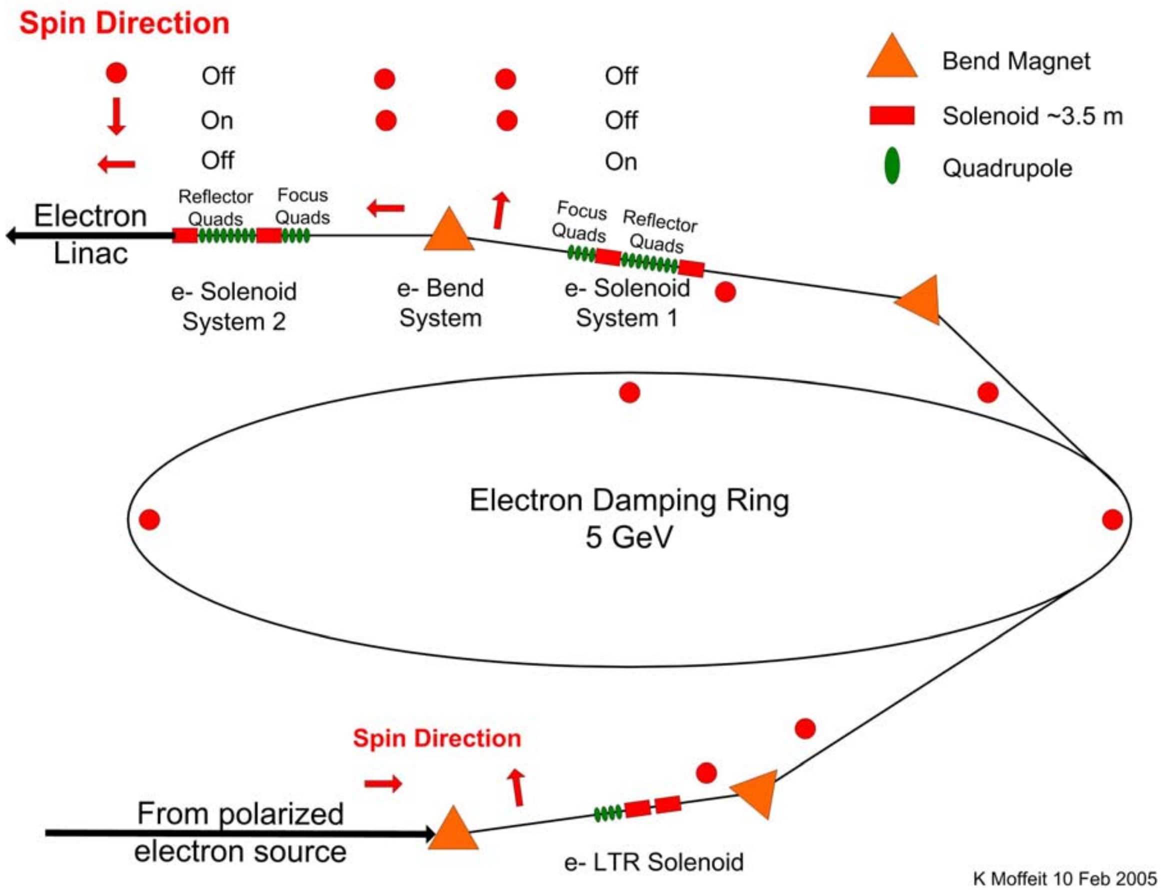

Figure 2: Layout of electron damping ring system showing the spin rotation solenoids.

The 5 GeV longitudinal polarized electrons are deflected in a bend system before they enter the solenoid system (see Figure 2). Using equation 1, we find the electron spin component in the plane normal to the applied magnetic field will precess 90^o in that plane for every 7.9317^o of rotation of the momentum vector at 5GeV. An axial solenoid field integral of 26.2 Tesla-meters will rotate the spin direction parallel to the field of the DR, i.e., by 90^o (see equation 2). Two half solenoids 3.5 meters in length with maximum field strength of $\pm 38.5 \cdot kGauss$ will be used; each will rotate the spin by 45^{o} at a beam energy of 5 GeV. In the linac-to-ring (LTR) transfer line, the paired solenoids will be located after a bend of $n \times 7.9312^o$, where n is an odd integer. Following the DR, two additional spin rotator systems are needed to achieve arbitrary spin orientation in the Linac or at the electron-positron interaction point. To establish longitudinal polarization after the damping ring, one solenoid pair will be installed in the ring-to-linac transfer line and the in-plane precession will be accomplished by a subsequent bend of 7.9317^o. Another solenoid pair is used to give arbitrary transverse polarization to the beam. To achieve full longitudinal polarization at the IR, and to compensate for the spin precession in the transport lines to the IR, requires all 3 sets of spin rotators.

Solenoid magnets used to rotate the electron spin about the longitudinal axis, as is planned for the ILC, focus the beam and introduce a roll about the beam axis (see equation 2). The roll about the beam axis would rotate the damped flat beam and would potentially destroy the vertical emittance. Inserting a reflector beam line [4] that consists of eight quadrupoles between half solenoids corrects for this effect; and the beam exiting maintains the small emittance in the vertical. The focusing dependence of the solenoid system can be compensated with matching quadrupoles. These reflector beam line and focusing elements are shown in Figure 2.

2a. Spin rotation system for polarized electron beam directed to two IRs

In order to achieve the ability to set the polarization at each IR, parallel spin rotation beam lines from the damping ring to the linac are introduced. A schematic of the scheme is shown in Figure 3. A pair of kicker magnets is used to deflect the beam into the IR2 chicane beam line and its set of spin rotation magnets. Normal bend magnets of opposite polarity deflect the beam into the chicane with the IR1 spin rotation magnets.

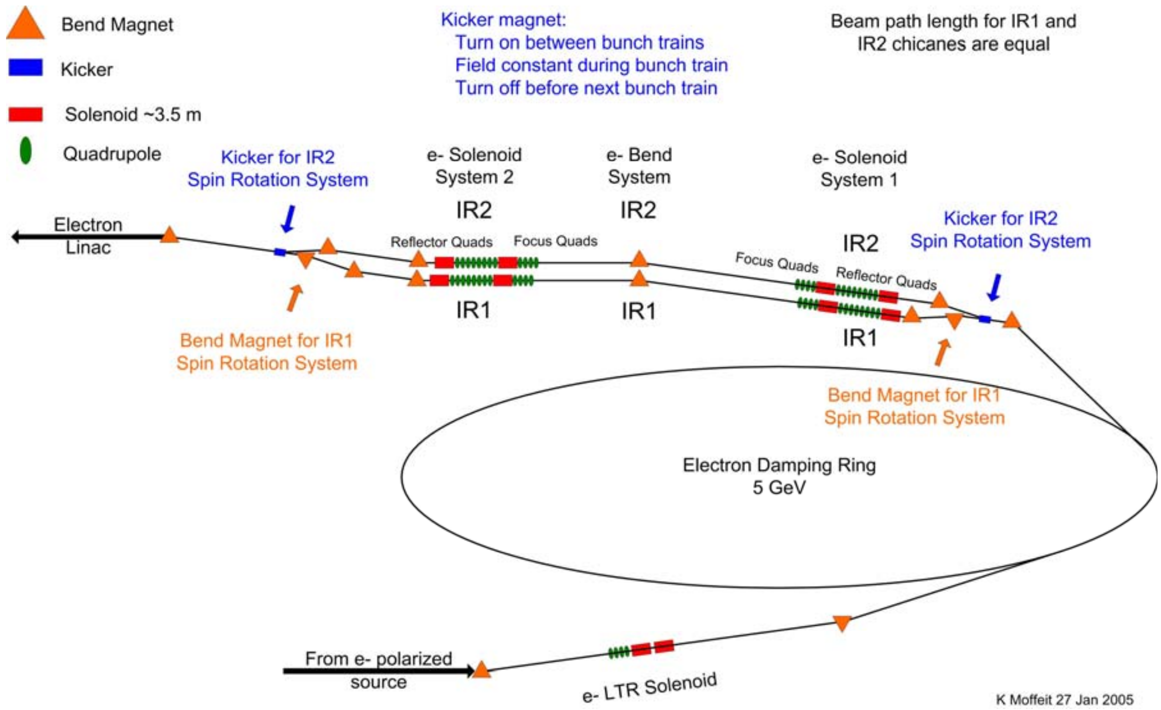

Figure 3: Layout of electron damping ring system showing the parallel spin rotation beam lines for IR1 and IR2. A pair of kicker magnets is turned on between pulse-trains to deflect the beam to the spin rotation solenoids for IR2.

Some considerations for the parallel beam lines are:

- The chicanes for the parallel beam lines are in the horizontal plane, so there are no bends in the vertical plane, since the beam emittance is critical in that dimension.
- Path lengths for the parallel beams need to be almost equal, with any difference small compared to the bunch length. Path length correction chicanes can be added to the parallel beam lines, if necessary.
- The pair of kicker magnet can be powered in series from the same current source to minimize beam jitter entering the linac.
- The double-solenoid spin rotator system is a small energy band-pass system. It must be located upstream of the RF used to compress the bunch length. The beam at the damping ring extraction has an rms relative energy spread of about 0.1%, rather than the 1-2% rms level in the bunch compressor. [4]

3. Spin rotation system for polarized positron beam

A promising method for generating polarized positrons at the ILC is to use a helical undulator to produce circularly polarized photons [2,3,6,7]. The longitudinally polarized positrons are generated in a target. 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.

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 (see Figure 4). 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.

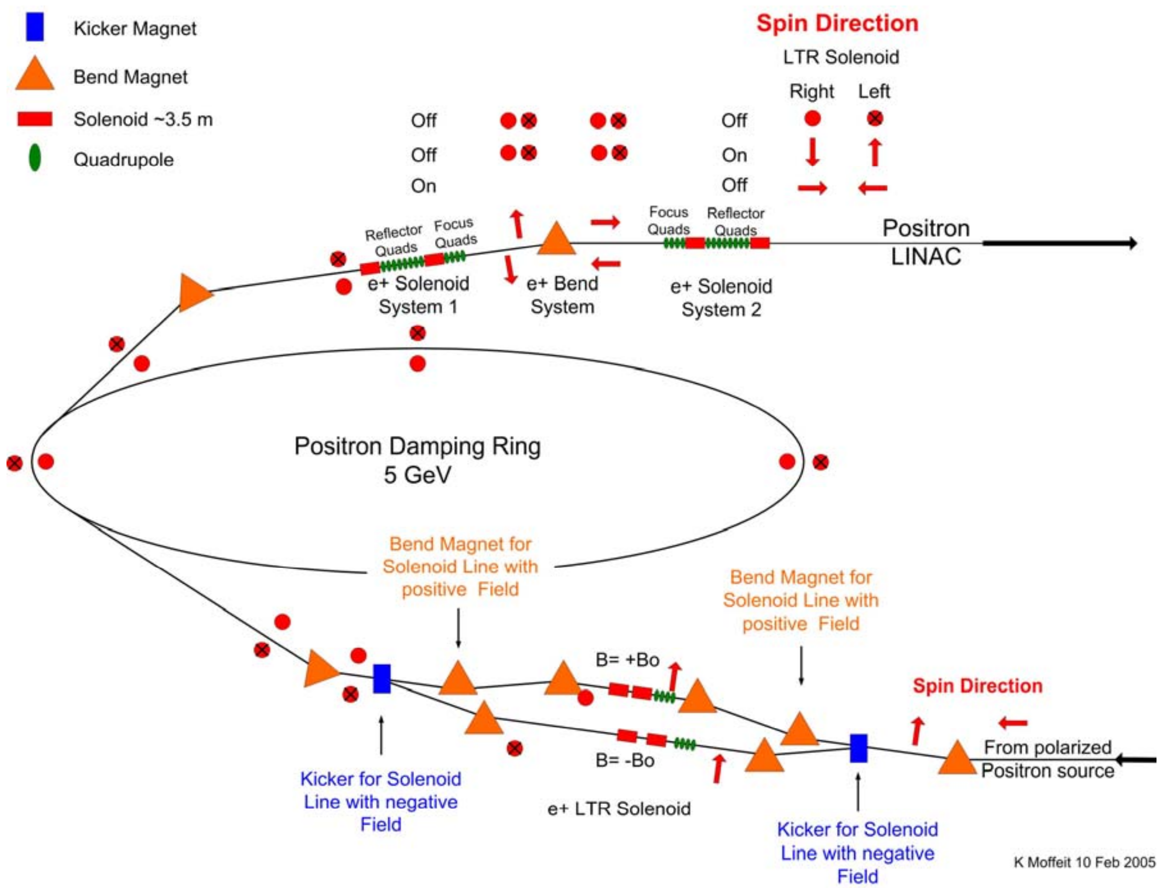

Figure 4: Layout of positron damping ring system showing the parallel spin rotation beam lines for randomly selecting positron polarization direction. A pair of kicker magnets is turned on between pulse-trains to deflect the beam to the spin rotation solenoids with negative B-field.

As already described for the electron beam, parallel spin rotation beam line systems can be introduced between the positron damping ring and the positron linac to achieve the desired polarization direction at IR1 and IR2 and be able to switch between IRs on a pulse-train basis (see Figure 5).

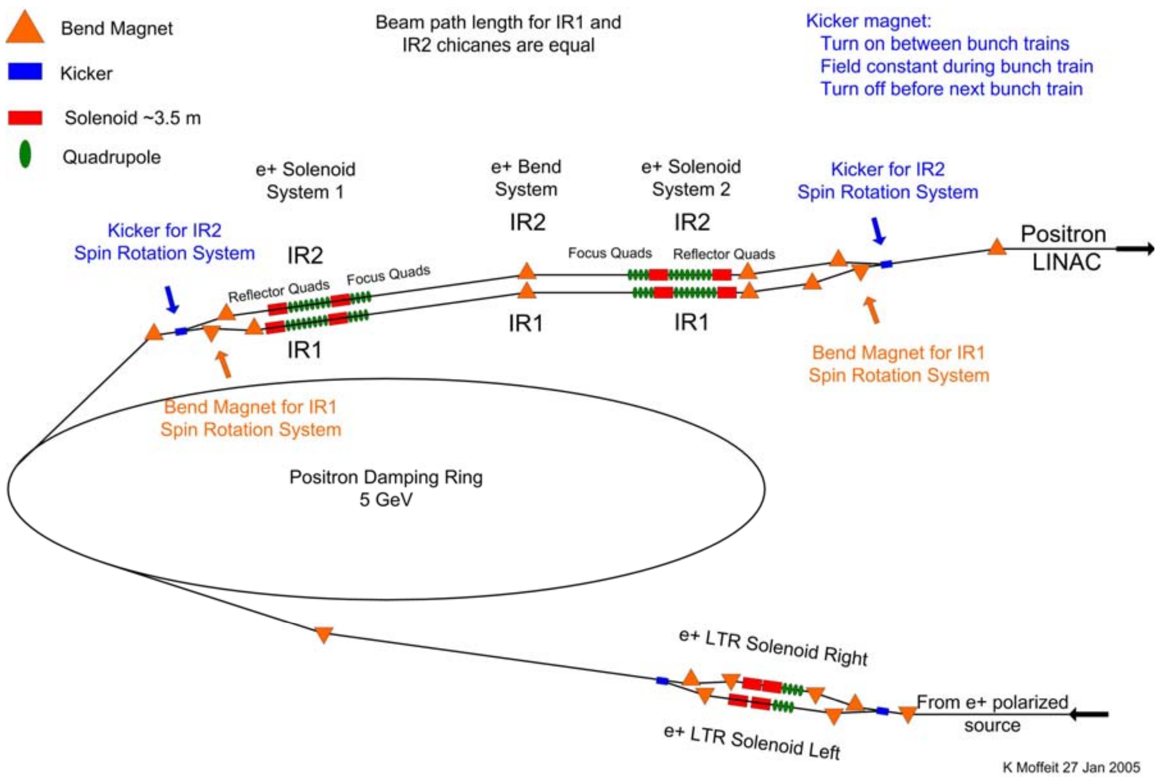

Figure 5: Layout of positron damping ring system showing the parallel spin rotation beam lines for IR1 and IR2. A pair of kicker magnets is turned on between pulse-trains to deflect the beam to the spin rotation solenoids for IR2. The parallel beam lines before the positron damping ring in the LTR can be used to randomly select the direction (+ or -) of the vector at the electron-positron interaction point.

The ILC plans also to have the option to study e-e- interactions. In this option, polarized electrons replace the positrons. The parallel spin rotation beam line system after the damping ring described here for polarized positrons, will work for a polarized electron beam.

4. Conclusions

A spin rotation system that would have optimum polarization at both IRs at any energy is feasible. Polarization direction can be tuned for each IR by introducing separate spin rotation systems for the two IRs at the exit of the damping rings. A pair of kicker magnets is used to switch the beams to the different spin rotation systems between pulse trains.

A system to randomly select the direction of the polarization vector of the positrons at the e+e- IR is feasible. Such a scheme is important to minimize systematic errors in the measurement of polarization asymmetries.

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

References

[1] Workshop on Machine-Detector Interface at the International Linear Collider, Andrei Seryi et al., Crossing Angle Session, see http://www-conf.slac.stanford.edu/mdi/, talk by R. Appleby, talk by Y. Nosochkov, figure 1 from Mark Woodley.

[2] V.E. Balakin and A.A. Mikhailichenko, Conversion system for obtaining highly polarized electrons and positrons, Preprint INP 79-85, Novosibirsk 1979.

[3] SLAC proposal E166, Undulator-based production of polarized positrons, June 2003, SLAC-TN-04-018.

[4] P. Emma, A Spin Rotator System for the NLC, NLC Note 7, SLAC, December 1994.

[5] 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.

[6] G. Moortgat-Pick, et al, The Case for Positron Polarization at the Linear Collider, DCPT-04-100, IPPP-04-50,2005.

[7] TESLA Technical Design Report, Volume II, Section 4.3.7, Potential upgrade to a polarized positron source, March 2001.

[8] Workshop on Machine-Detector Interface at the International Linear Collider, Polarization Session, see http://www-conf.slac.stanford.edu/mdi/, talk by K. Peter Schuler.