Depolarization Effects At The ILC

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Abstract. Spin polarization will play an important role in the International Linear Collider (ILC) physics program. The 'heLiCal' collaboration aims to provide a full analysis of all depolarization effects at the ILC As expected intuitively, the depolarization in damping rings with carefully corrected orbits is shown to be negligible. No noticeable depolarization is observed in the beam delivery system. The major depolarization effects are expected from the beam-beam interaction. These effects have been evaluated by the 'heLiCal' collaboration for a range of ILC parameter sets.

Keywords: ILC, polarized beams, spin transport, beam-beam interactions, depolarization.
PACS: 13.88+e, 29.17.Hj, 29.17.+w, 29.25.-t, 52.59.f

OVERVIEW

The physics examples presented in [1] have demonstrated that the full physics potential of the ILC could be realized only with polarized e^- and e^+. The baseline undulator based positron source [2], [3], [4] can be easily upgraded to provide beams with a polarization of about 60%. To fulfill the physics goals, it is important to ensure that no significant polarization is lost during the transport of e^- and e^+ beams from the sources to the interaction region(s). Therefore all transport elements which can contribute to a loss of polarization, i.e. the initial accelerating structures, the damping rings, the spin rotators, the main linac and the high energy beam delivery system have to be analyzed. As discussed below, the largest depolarizing effect is expected to result from the collision of the two beams at the interaction point(s).

DAMPING RINGS

There are two effects associated with spin motion in electric and magnetic fields, namely spin precession and spin flip via synchrotron radiation. Spin precession is described by the Thomas-Bargmann-Michel-Telegdi (T-BMT) equation. On the design orbit of a perfectly aligned ring the spins only experience the vertical dipole fields and with respect to the orbit, the spins precess around this field by an angle: $a\gamma \times$the angle of orbit deflection, where a is the electron gyromagnetic anomaly and $\gamma = E / m_e c^2$. In [5] it has been shown that at energies corresponding to spin–orbit resonances the beam can lose polarization after injection into a damping ring (DR). The synchrotron radiation, enhanced by the wigglers in DR, also has the potential to cause depolarization. Therefore further detailed studies have been made.

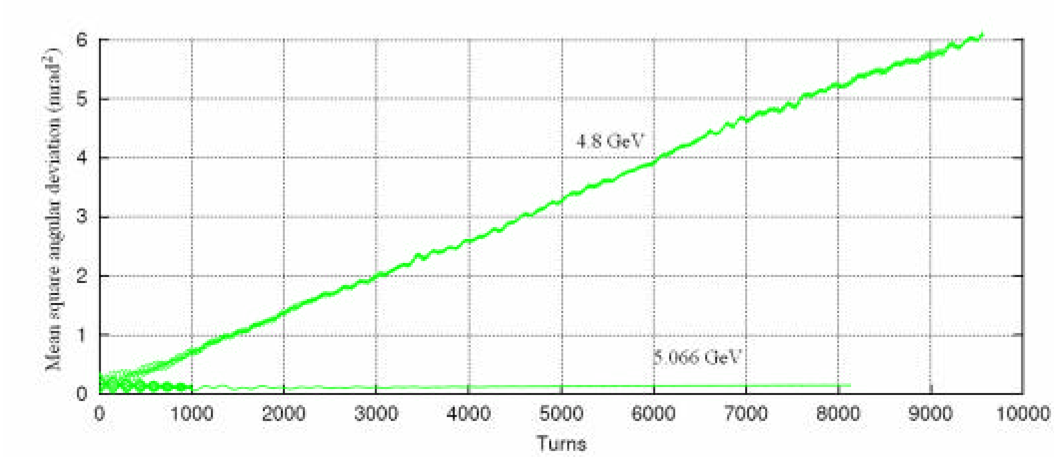

FIGURE 1. The mean square angular deviation (mrad^2) from the equilibrium direction in the ILC damping ring (OCS lattice) for two energies: 4.8 GeV (upperplot) and at 5.066 GeV (lower plot).

In damping rings the Sokolov-Ternov (S-T) effect can be neglected as the time to build up polarization via spin flip is very large compared to the typical time that the beam stays in the ring. However, the stochastic nature of the emission of radiation causes spin diffusion. Since the beam is not at equilibrium, analytical calculations of depolarization are not applicable, so that the code SLICKTRACK [6] which embeds the formalism of SLICK in a Monte-Carlo simulation of photon emission was used.

As part of a study to determine the optimal damping ring configuration for the ILC, the depolarization for two damping ring designs, the 6 km OCS ring and the 17 km TESLA ring [7], have been studied. Realistic misalignments (1/3 mm misalignments and 1/3 mrad roll for quadrupoles) and closed orbit corrections were included. The transverse emittances of the injected beams were twice as large as those for the planned setup. Two energies have been studied, 4.8 GeV (close to a first order synchrotron resonance) and 5.066 GeV, see Fig.1. The curves show the mean squares of tilts of spins away from the direction of equilibrium polarization (10000 turns correspond to the store time of 200 ms). As expected, the loss of polarization is negligible for the time the beam stays in the damping ring.

SLICKTRACK shows that, if the incoming polarization vector is tilted from the vertical, there is little decoherence of the horizontal components of the spins during the damping process. The distribution of projections is in excellent agreement with a simple analytical model [8] which predicts that the width of distribution of the spin projections on horizontal plane should reach equilibrium with the value of about 24 degrees, whilst SLICKTRACK gives about 25 degrees.

Note that radiative depolarization is negligible even with injected beams that have transverse emittances ten times larger than those planned for the real setup.

BEAM DELIVERY SYSTEM

After acceleration up to 250 GeV for the first stage of the ILC, the beam must be brought into collision by the beam delivery system via bending and focusing magnets. For a 250 GeV e^- beam undergoing the total of 11mrad of bend, the spin precession is approximately 332 degrees. Calculations with SLICKTRACK running in the single pass mode indicate no significant loss of polarization, confirming earlier work[9].

BEAM-BEAM INTERACTIONS

In order to evaluate analytically the two sources of depolarization (T-BMT and S-T) during beam-beam interactions at the ILC, the program CAIN [10] has been used. A study of such depolarizing effects for NLC parameters has been made in [11], analyzing both sources of possible depolarization separately. The luminosity-weighted depolarization ΔP_{lw} was about 0.2% at $\sqrt{s}$ =500 GeV and up to 0.5% at $\sqrt{s}$ =1 TeV for various NLC sets.

In this study the depolarizing effects of the $e^{\pm}$ beams have been analyzed for various ILC parameter sets, see details in [2], [12]. The sum of T-BMT and S-T effects for the luminosity-weighted depolarization is in the range between 0.06% ('low Q') up to 0.24% ('low P'), see Table 1. The total depolarization is $\Delta P_{tot} \sim 0.273 \Delta P_{lw}$ [10]; that relation is valid in all our sets since the disruption parameter D_x is much less than one. For higher energy, e.g. $\sqrt{s}$ =1 TeV in the 'Nominal' as well as in the 'low P' schemes, the depolarization increases by about a factor 2; this is mainly due to the contribution from the S-T effect. The listed values have been derived for head-on collisions and 100% polarized beams. With partially polarized beams, namely the expected 90% (60%) polarization for the e^- (e^+) beam at the ILC, the absolute depolarization decreases correspondingly.

TABLE 1. Comparison of the luminosity-weighted depolarizing effects in beam-beam interactions at $\sqrt{s}$ =500 GeV for the ILC parameters sets.

Parameter set	Depolarization T-BMT	Depolarization (S-T)	Total depolarization
Nominal	0.08%	0.02%	0.10%
Low Q	0.04%	0.02%	0.06%
Large Y	0.17%	0.02%	0.19%
Low P	0.15%	0.09%	0.24%
TESLA	0.11%	0.03%	0.14%

CAIN includes coherent and incoherent pair production processes. For coherent processes, polarization effects are included, but for all ILC sets, production of coherent pairs is completely negligible. Full spin correlations are not yet included in the production of incoherent pairs and have been calculated in CAIN only in the equivalent photon approximation (EPA). However, for the bremsstrahlung process this approximation can only be applied for specific kinematic conditions [13]. For all ILC parameter sets the contribution of the bremsstrahlung to the incoherent processes is between 35% and 47%. Therefore, contributions to the depolarization by including the spins of the produced pairs and no EPA are expected. Studies of a fuller treatment of bremsstrahlung, and studies of the validity of T-BMT equation for strong fields are still ongoing and will lead to a corresponding update of the simulation code.

CONCLUSIONS

- The depolarization in damping rings with a carefully corrected orbit is negligible. Nevertheless, as a new lattice design is now under development, this rolling study to include extra effects will be continued.
- There is no noticeable depolarization in the BDS. However the effects of misalignment on the beam sizes will require careful further studies.
- Depolarizing effects in beam-beam interactions have been evaluated for various ILC parameter sets. The expected depolarization is at most about 0.2% and the smallest effects are <0.1% for the 'low Q' scenario. At higher energy $\sqrt{s} = 1$ TeV the effect will increase by about a factor 2.
- There are still theoretical uncertainties from the use of EPA for the incoherent processes; for strong fields the validity of the T-BMT equation must be checked.
- Using the results of this work, CAIN will be updated and a comparison with the simulation code Guinea-Pig [14] is foreseen.

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