Robust Spin Polarisation Status

I.R. Bailey[1,2], D.P. Barber[1,3], A. Hartin[4], L.I. Malysheva[1,2], G.A. Moortgat-Pick[1,5], E. Baynham[7], A. Birch[1,6], T. Bradshaw[7], A. Brummitt[7] ,S. Carr[7], J.A. Clarke[1,6], P. Cooke[2], J.B. Dainton[1,2], Y. Ivanyushenkov[7], L.J. Jenner[1,2,*], A. Lintern[7], O.B. Malyshev[1,6], J. Rochford[7], D.J. Scott[1,2,6], L. Zang[1,2]

[1] Cockcroft Institute, Daresbury Laboratory, Warrington, Cheshire WA4 4AD, U.K.
[2] Department of Physics, University of Liverpool, Oxford St., Liverpool, L69 7ZE, U.K.
[3] DESY, Deutsches Elektronen Synchrotron, Notkestraße 85, D-22607 Hamburg, Germany
[4] John Adams Institute, Oxford University Physics, Oxford OX1 3RH, U.K.
[5] Institute of Particle Physics Phenomenology, University of Durham, Durham DH1 3LE, U.K.
[6] STFC ASTeC Daresbury Laboratory, Daresbury, Warrington, Cheshire WA4 4AD, U.K.
[7] STFC Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire OX11 0QX, U.K.

The heLiCal collaboration has undertaken the task of creating a complete cradle to grave spin-tracking simulation of the positrons in the ILC. SLICKTRACK is the main software code being used for this purpose; it has been updated to include full non-commuting spin dynamics and will be upgraded to handle non-linear orbital motion. So far, spin dynamics have been simulated in the damping rings, beam delivery system and main linac. The theoretical uncertainties associated with beam-beam interactions at the ILC have been evaluated.

1 Introduction

The heLiCal collaboration is group of around 25 people from institutions mainly within the UK. The remit of the collaboration is to develop reliable software tools which will allow the ILC to be optimised for spin polarisation as well as luminosity via full cradle-to-grave simulations. This has been identified as high priority by the Global R&D board. As such, simulations of depolarising effects in the damping rings, beam delivery system, main linac and during bunch-bunch interactions have been carried out. In addition, simulations of spin transport through the entire positron source has been performed. This is to enable background reduction and unlock sensitivity to new physics.

2 Depolarisation

The spin state of particles within a bunch can change with respect to each other by photon emission or classical precession through inhomogeneous magnetic fields. This is described by the Thomas-Bargmann-Michel-Telegdi equation:

$$\delta\theta_{spin} \propto \frac{g-2}{2}\gamma\delta\theta_{orbit} \tag{1}$$

more commonly known as the T-BMT equation. Here depolarisation is a term used to describe the uniformity of spin directions within the bunch; the physical spin angles are usually not of concern.

*l.j.jenner@cockcroft.ac.uk

3 Beam-Beam Interactions

The program CAIN [2] analytically evaluates both sources of depolarisation that occurs during beam-beam interactions at the ILC. Normal perturbation theory cannot be used when very large fields are present, as is the case in these types of interactions. A quasi-classical approximation has been used which has been demonstrated to be valid in these conditions [2, 4, 5]. Modelling of both coherent and incoherent background pairs resulting from these interactions has been added into CAIN. Studies of the effect of polarisation on the Breit-Wheeler process show a decrease in the number of photons produced; this is because it is strongly dependent on the initial photons states. This was carried out for a number of ILC beam parameter sets.

4 Damping Rings

Previously [3] results have been presented showing that spin motion in the 6 km DR (OCS) of the ILC, including both spin precession and synchrotron radiation effects in the presence of realistic magnet misalignments (1/3 mm misalignments and 1/3 mrad roll for quadrupole), leads to negligible depolarisation both at the design energy of 5.066 GeV and close to a spin-orbit resonance at 4.8 GeV.

Updated simulations using SLICKTRACK [7]with the "OCS6" damping ring lattice at 5.0 GeV show that the sum of the mean squares of the angles of tilts of spins away from the direction of the equilibrium polarisation (approximately vertical) to be less than 0.1 mrad^2, even after 8000 turns (8 damping times). At 4.8 GeV the sum of the mean squares of the angles was shown to reach approximately 40 mrad^2 after 8000 turns, which still represents a negligible degree of depolarisation. I.e. the ratio of final to initial polarisations in this case is $\cos(\sqrt{40}\ \text{mrad}) \approx 0.99998$. These simulations were carried out assuming the narrow energy spread ($\pm$45 keV) expected for injected electron bunches. Similar simulations have also been carried out for the OCS6 damping ring lattice at 5 GeV assuming an initial energy spread of $\pm$25 MeV, much greater than the natural energy spread of the damping ring, as expected for positrons coming from the ILC baseline positron source. In this case the sum of the mean squares of the spin angles after 8000 turns was found to be approximately 20mrad^2 which is once again negligible. It was also shown that in this case, as in the previous simulations, the horizontal projections of the spin vectors of an electron or positron bunch do not fully decohere after 8000 turns, i.e. if the spins are tilted from the vertical at injection then their projections do not fan out uniformly in the horizontal plane during damping, even if the initial energy spread is large. In further work, the effect of the length of the injected positron bunches on this conclusion will be investigated.

5 Beam Delivery System

SLICKTRACK has been modified to include a "single pass" mode and then applied to the 2 mrad crossing-angle arm of the older design of the ILC BDS. Realistic misalignments were included as in the damping ring analysis. Simulations showed a total spin precession of approximately 332 degrees and an absolute decrease in the polarisation of 0.06% or less. These figures are consistent with those obtained by Smith et al using the BMAD computer program [1]. Our work will be repeated using updated versions of the BDS lattice consistent with the RDR.

6 Main Linac

The SLICKTRACK computer code has also been modified to include acceleration effects and then applied to the ILC main linac. Spin precession of approximately 26 degrees is expected in the Earth-following linac, and SLICKTRACK simulations of the spin motion show the ratio of the final to initial polarisations of particle bunches travelling through the linac is approximately $\cos(10^{-4}\text{rad})$.

7 CONCLUSIONS AND OUTLOOK

Possible depolarisation effects at the ILC have been studied for the damping ring, main linac, beam delivery system and during the beam-beam interactions for a range of ILC parameters as part of an ongoing rolling study.

•An analysis of depolarisation processes during ILC beam-beam interactions was carried out. The current CAIN implementation of depolarisation through spin precession has been shown to be valid for ILC energies.

•The polarisation dependence of coherent and incoherent pair production at the interaction point has been studied, and these effects are currently being incorporated into CAIN. This work is ongoing, but initial results from CAIN indicate a substantial decrease in low energy incoherent pair production when polarisation effects are included.

•The SLICKTRACK software package has been extended to simulate the spin dynamics through the ILC BDS and main linac. All simulations show very small amounts of depolarisation, as expected.

•Additional SLICKTRACK simulations of the ILC damping ring lattices support our earlier results showing that the horizontal projections of the spin vectors of the electron and positron bunches injected into the damping rings do not rapidly decohere. It is therefore very important that the vectors be properly aligned prior to injection.

•SLICKTRACK is being extended to include non-linear orbital motion, allowing a detailed study of spin motion in non-linear elements such as sextupoles and wigglers.

References

[1] ILC-Note-2007-012, J.C. Smith, *Depolarisation Study in the International Linear Collider.*

[2] K. Yokoya, P. Chen, SLAC-PUB-4692, 1988; K. Yokoya, 'User's Manual of CAIN', Version 2.35, April 2003.

[3] EuroTeV-Report-2006-037, G. Moortgat-Pick et al., *Spin Tracking at the ILC.*

[4] V. N. Baier and V. M. Katkov, Phys. Lett. A **280** (2001) 275; V. N. Baier and V. M. Katkov, Phys. Rept. **409** (2005) 261.

[5] G. Moortgat-Pick et al., Cockcroft-07-22 (in preparation).

[6] V.N. Baier, A.G. Grozin, hep-ph/0209361.

[7] D.P. Barber, et al., Cockcroft-04-01.