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Spin Dynamics: Status and Plans

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on behalf of

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Introduction

Aim of our studies

To ensure optimum use is made of polarised beams at the ILC. We are developing the theory and software tools needed to fully understand the ILC spin dynamics.

The uncertainty on the luminosity-weighted polarisation at the IP needs to be 0.1% or less for high-precision measurements.

Where does this work belong in the framework of the ILC EDR phase?

Would like to see it form a work package of the simulations group.

Summary of Past Work

- **Updated SLICKTRACK software package to include full non-commuting spin rotations**
- **Simulated spin dynamics in ILC damping rings**
- **Simulated spin dynamics in ILC beam delivery system**
- **Simulated spin dynamics through main linac**
- **Evaluated theoretical uncertainties in beam-beam interactions at the ILC**
- **Introduced fully-polarised pair-production cross-sections into CAIN**

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Motivation

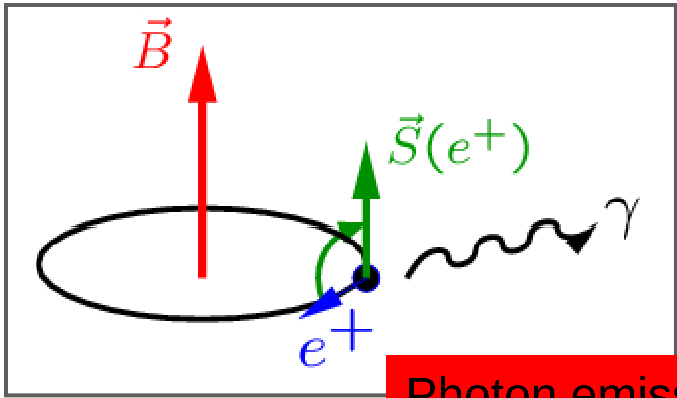
Our motivation is to ensure optimum use is made of polarised beams at the ILC which give increased effective luminosity, access to precision physics and new physics. This means evaluating both spin precession and depolarisation effects throughout the ILC.

Both stochastic spin diffusion through photon emission and classical spin precession in inhomogeneous magnetic fields can lead to depolarisation.

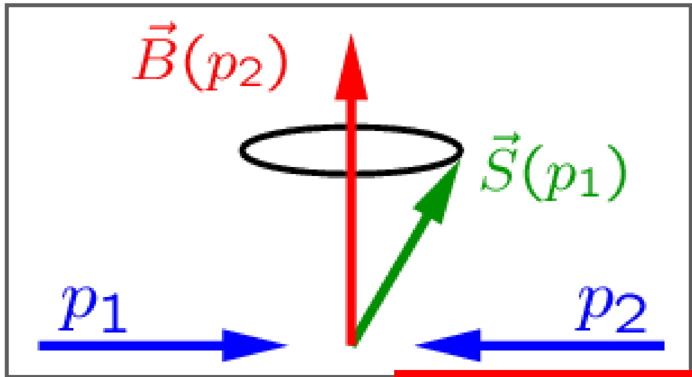
$$\delta\theta_{spin} \propto \frac{(g-2)}{2}\gamma\delta\theta_{orbit}$$

1 mrad orbital deflection $\Rightarrow$ 30° spin precession at 250GeV.

Largest depolarisation effects are expected at the Interaction Points, but cumulative effects from other accelerator sections may be important too.



Photon emission



Spin precession

Software Tools

	Undulator	Collimator / Target	Capture Optics
Physics Process	Electrodynamics	Standard Model	T-BMT (spin spread)
Packages	SPECTRA, URGENT	GEANT4, FLUKA	(ASTRA)

e^+ source

	Damping ring	Main Linac / BDS	Interaction Region
Physics Process	T-BMT (spin diffusion)	T-BMT	Bunch-Bunch
Packages	SLICKTRACK, (Merlin)	SLICKTRACK (Merlin)	CAIN2.35 (Guinea-Pig)

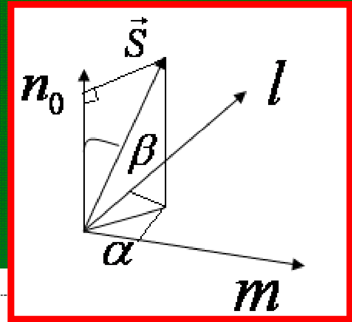
Packages in parentheses will be evaluated at a later date.

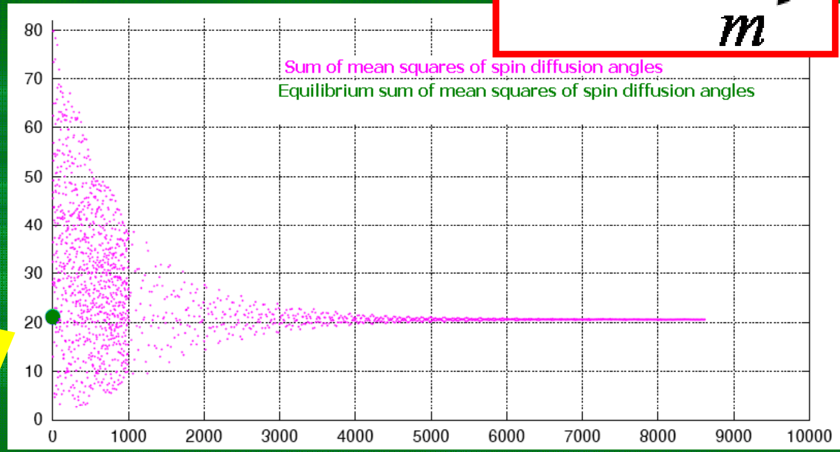
LC-ABD1 Highlights(1)

Spin Transport Simulations

- Developed Monte Carlo spin dynamics simulation with full non-commuting spin rotations.
- Simulated spin precession and depolarisation effects in the ILC damping rings (DR), main linac and BDS.
- Contributed to ILC DR lattice design study.
  - Variance of transverse spin component distribution in electron damping ring < 0.1mrad^2
  - Variance of transverse spin component distribution in positron damping ring < 20mrad^2
- Demonstrated that longitudinal components of spin vectors may not fully decohere in the ILC damping rings. Impact on ILC design.
  - 2 spin rotators needed per DR even for baseline positron source

Example of SLICKTRACK output showing depolarisation in ILC damping rings will be negligible.





The mean square angle of tilt away from vertical in units of square miliradians as a function of the number of turns around a damping ring. The OCS6 damping ring at 5.0 GeV (expected operating energy) with +/- 25 MeV injected energy spread as expected for the ILC positron source.

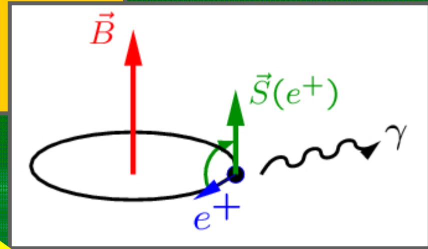
LC-ABD1 Highlights (2)

Beam-Beam Simulations

- **Applied CAIN beam-beam simulation to the ILC interaction point for a range of possible beam parameters. Depolarisation dominated by spin precession** *(see table on right).*
- **Derived strong-field approximation of the anomalous magnetic moment and validated form used by CAIN in T-BMT equation.**
- **Investigated validity of equivalent photon approximation used in pair-production processes in CAIN and showed approximation is NOT valid in all cases.**
- **Included fully polarised cross-sections for incoherent pair-production processes into CAIN. Landau-Lifshitz process investigated (ongoing) using GRC4F event generator (includes helicity amplitudes)**

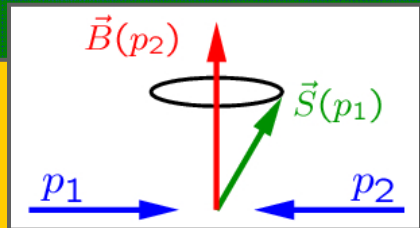
Depolarisation at the IP

Stochastic spin diffusion from photon emission: Sokolov-Ternov effect, etc.



Parameter set	Depolarization ΔP_{lw}		
	T-BMT	S-T	total
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%

Classical spin precession in inhomogeneous external fields: T-BMT equation.



LC-ABD1 Highlights (3)

Incoherent pair-production dominates at ILC energies

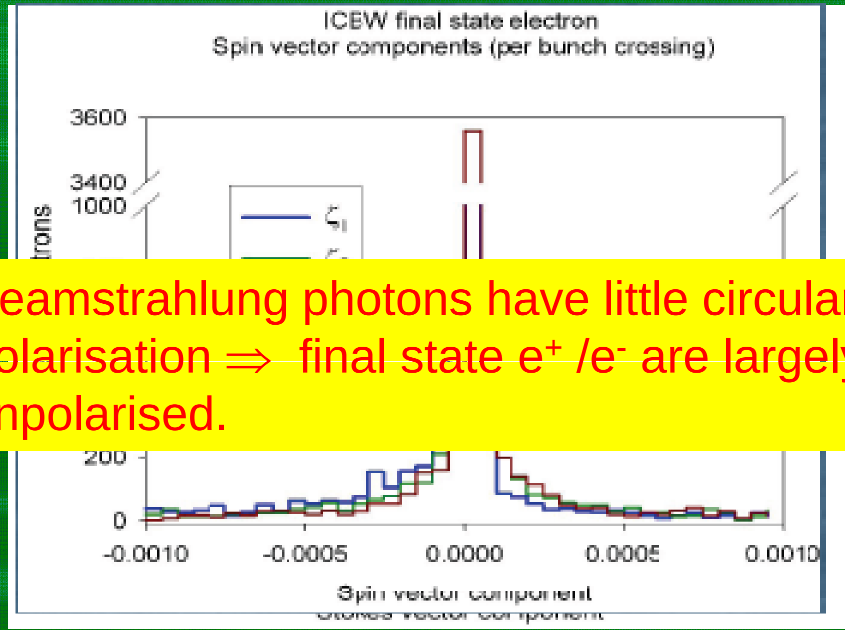
- Breit-Wheeler: $\gamma + \gamma \longrightarrow e^+ + e^-$ (real photons)
- Bethe-Heitler: $e^\pm + \gamma \longrightarrow e^\pm + e^+ + e^-$
  becomes in EPA: $\gamma^* + \gamma \longrightarrow e^+ + e^-$
- Landau-Lifshitz: $e^+ + e^- \longrightarrow e^+ + e^- + e^+ + e^-$
  becomes in EPA: $\gamma^* + \gamma^* \longrightarrow e^+ + e^-$
- Bremsstrahlung: $e^+ + e^- \longrightarrow e^+ + e^- + \gamma$
  becomes in EPA: $e^+ + \gamma^* \longrightarrow e^+ + \gamma$

•**Equivalent Photon Approximation requires proper treatment of initial and final state polarisation.**

•**Not valid in all cases (e.g. only applicable to Bremsstrahlung for specific kinematics).**

Polarised cross-sections for incoherent Breit-Wheeler pair production added to CAIN:

$$\frac{d\sigma}{d\cos(\theta)\,d\phi} = \frac{\alpha^2}{4s^2x^2y^2}\sum_{ii'jj'} F^{ii'}_{jj'}\,\xi_j\xi_{j'}\,\zeta_i\zeta_{i'}$$



Beamstrahlung photons have little circular polarisation ⇒ final state e^+ /e^- are largely unpolarised.

A. Hartin - EUROTeV-2007-040

Status by ILC Region

- Electron Source
  - Not aware of any spin transport simulations.
- Positron Source
  - Partial simulations exist (e.g. DESY, ANL) but not yet complete.
  - Currently deveoping realistic simulation of photon beam polarization.
  - Need to track electrons through undulator (all analytical calculations show the depolarization to be negligible).

- Damping Rings
  - Depolarization (e^-) ~5×10^{-5} %
  - Depolarization (e^+) ~1×10^{-3} %
  - Realistic injected bunches needed
- Main linac
  - Spin precession ~26°
  - Depolarization~5×10^{-7} %
- BDS
  - Spin precession ~332°
  - Depolarization~6×10^{-2} %
- IP
  - Depolarization ~0.1 %
- NB depolarization in the BDS is 60% of depolarization at the IP.

Goals of Spin Dynamics group

- **Future work motivated by**
  - **HEP community support for polarised beams to offset any reduction in ILC design luminosity**
  - **Precision physics requires uncertainty ≤0.1% on luminosity-weighted polarisation. We've shown depolarising effects also of order 0.1% (IP and BDS).**
  - **ILC compatability with upgrade to a 60% polarised positron beam has been identified as a critical R&D topic by the Global R&D board** *(see April 2007 report)*
- **Goals**
  - **Calculate spin rotator settings required to achieve longitudinal (or transverse) polarisation of electrons and positrons at IP.**
  - **Inclusion of non-linear transport maps in SLICKTRACK (modelling sextupoles, etc) and re-simulation of the BDS.**
  - **Development of positron source simulation including electron beam jitter, photon collimation effects, etc**
  - **Continued theoretical work on beam-beam interactions including second-order coherent pair-production processes, etc.**
  - **A continued rolling study of the whole machine to optimise use of polarisation as a tool for the ILC.**