Challenges for Polarimetry at the ILC
Spin Tracking Studies

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DESY - FLC

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• **Laser-Compton-Polarimeters** for 45-500 GeV beam energy in the beam delivery system (BDS)

• Polarimeters measure with **0.25 % systematic uncertainty** (goal)

• Additionally: calibration with average polarization from $e^+e^-$ collision data (e. g. $W^+W^-$ cross section)
What happens between the polarimeters and the $e^+ - e^-$ IP? → simulation

Must understand spin diffusion/depolarization to 0.1%
Spin transport through electromagnetic fields is described by T-BMT equation (semi-classical).

Approximation ($\vec{B}_\perp$ only) spin precession

\[ \vartheta_{\text{spin}} = \left( \frac{g-2}{2} \cdot \gamma + 1 \right) \cdot \vartheta_{\text{orbit}} \approx 568 \text{ @ 250 GeV} \]
Spin transport through electromagnetic fields is described by T-BMT equation (semi-classical).

Approximation ($\vec{B}_\perp$ only) spin precession

$$\mathcal{V}_{\text{spin}} = \left( \frac{g-2}{2} \cdot \gamma + 1 \right) \cdot \mathcal{V}_{\text{orbit}}$$

$$\approx 568 \, @ \, 250 \, \text{GeV}$$

Polarization vector $\vec{P} = \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix}$ with polarization $|\vec{P}|$

In this talk: **only longitudinal polarization** $P_z$
Spin Fan-Out in Quadrupole Magnets

- Different precession angles
  ⇒ (not only longitudinal!) polarization “lost”
- Recoverable by second quadrupole, unlike for stochastic processes (radiative depolarization)
• Simulation of particle and spin transport (incl. complete lattice): Bmad (www.lepp.cornell.edu/~dcs/bmad)
• 40,000 macroparticles per bunch, 1000 runs with randomly generated bunches
• RDR beam parameters (2007)
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40,000 macroparticles per bunch, 1000 runs with randomly generated bunches

RDR beam parameters (2007)

In the following: **collision effects** (incl. crossing angle) and **spin transport behind the IP**

Previous studies: spin transport up to the IP unproblematic, \( \Delta P_z \ll 0.1\% \)
Beam-Beam Collision Effects

- **T-BMT precession**: deflection from colliding bunch ($\sim 10^{-4}$ rad)
- Sokolov-Ternov: **spin flip** by emission of **beamstrahlung**

- Simulation with Guinea-Pig++
- Directly connected to transport simulation

A. Vogel
Results
Spin Transport without Collision

- Without collision with the $e^+$ beam
- Longitudinal polarization hardly differs between IP and downstream polarimeter

DP: downstream-polarimeter
Spin Transport after Collision

DP: downstream-polarimeter

- Different spin transport after collision with the $e^+$ beam due to larger angular divergence / energy spread
- Large spin fan-out in extraction line quadrupoles
- Measurable := within the laser spot of the polarimeter
Downstream Measurement

- Polarization measured in vertical chicane ⇒ dispersion

- **Laser spot size** at Compton-IP only $\sim 0.1 - 1\,\text{mm}$
  Limited by requesting large intensity and high-frequency pulses

- But: low-energy tail not welcome in Compton interaction
  No desire to redesign polarimeter chicane, have to live with consequences
Downstream Measurement

- Beamstrahlung correlates energy loss and depolarization
  ⇒ Polarization correlated with particle position
  ⇒ **Selective measurement, measurement bias**

- Detailed simulation of laser-bunch interaction at the downstream polarimeter required
- For now: limited to *measurable* polarization
Spin Transport for Different Scenarios

- w/o collisions
- with collisions

- UP
- before collision
- luminosity-weighted
- after collision
- DP
- DP measurable (0.1/0.2/0.5/1.0 mm)

- Beamstrahlung not taken into account, only T-BMT
- Selective measurement: DP measurable (0.1/0.2/0.5/1.0 mm)

- Lattice designed such that ideally = 0
- % (A. Hartin, LCWS 08: 0.22 %)
- % relative deviation

- 24 % (A. Hartin, LCWS 08: 0.22 %)

- Relative change [10^3]

- z long. polarization P
- 0.79
- 0.795
- 0.8

- -3
- -10
- -5
Spin Transport for Different Scenarios

- $\text{UP} - \text{DP} = 0.24\%$ (A. Hartin, LCWS 08: 0.22\%)

- Lattice designed such that ideally $\bullet = \Box(= \square)$
  (luminosity-weighted $P_z$ should equal $P_z$ at the DP)

- Beamstrahlung not taken into account, only T-BMT
  $\Rightarrow \bullet - \square = 0.1\%$ relative deviation

- Selective measurement: $\square - \Box = 0.2\%$
Spin Transport for Different Scenarios

- Simulation without beamstrahlung: $\bullet = \square = \Box$
  - $\blacksquare - \bullet = 0.18\%$ (A. Hartin, LCWS 08: 0.17%)

- TDR bunch-bunch luminosity ($1.5\,L$):
  - More beamstrahlung: $\bullet - \blacksquare = 0.15\%$
  - Growing bias: $\Box - \blacksquare = 0.2$ to $0.3\%$
  - Crucial to know laser spot size and position
In **absence of beamstrahlung**: downstream polarimeter measures luminosity-weighted longitudinal polarization as foreseen by the lattice design ✓

In **presence of beamstrahlung**, the measurement of polarization after collision already difficult assuming **ideal conditions**: $\approx 0.1\%$ relative deviation $\rightarrow$ subtract (✓)

**Worse for higher luminosities** (TDR): 0.05 to 0.15% relative deviation, precision limited by knowledge of laser spot size? **Possible problem**, further examination necessary
Conclusion (2) and Outlook

• Need one polarimeter each in front of / behind the IP

Downstream polarimeter:
• Assess collision effects
• Direct access to luminosity-weighted longitudinal polarization at least for small luminosities (little beamstrahlung)
• Achievable precision for TDR beam parameters (stronger beamstrahlung)?

Upstream polarimeter:
• Measurement without interference from collision effects
• Cross-check for downstream measurement

• Not in this talk: detector magnets, misalignments of magnets/ground motion
Thanks for your attention!

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- Jeff Smith (formerly SLAC)
- und many others...
Backup Slides
Spin Transport behind the IP

No net bending angle in extraction line
Spin fan-out due to T-BMT precession:

\[ \Delta P_z \propto \theta_x^2 \]

\[ \Delta P_z^{\text{lum}} \approx \frac{1}{4} \Delta P_z \propto \left( \frac{\theta_x}{2} \right)^2 \]

(SLAC-PUB-4692, SLAC-PUB-8397, \( \theta_x \gg \theta_y \))

Idea: \( |R_{22}(\text{IP} \rightarrow \text{DP})| = 0.5 \implies P_z^{\text{lum}} = P_z^{\text{DP}} \)
Longitudinal polarization vs. energy at the downstream polarimeter, after collision
Polarimeter Chicane (upstream)

- Constant magnetic field
- Dispersion (depending on beam energy): 1-11 cm
- Measures every bunch per bunch train
- Energy spectrum is polarization-dependent
- Energy distribution → spatial distribution
- Cherenkov gas detector counts electrons per channel
Polarimeter Chicane (downstream)

- Constant magnetic field
- Dispersion (depending on beam energy): 1-11 cm
- Measures 3 bunches per bunch train
- Energy spectrum is polarization-dependent
- Energy distribution $\rightarrow$ spatial distribution
- Cherenkov gas detector counts electrons per channel
Bunch Rotation at the IP

- Collision under crossing angle of 14 mrad
- Maximize luminosity: rotate bunches using *crab cavities*