Challenges for Polarimetry at the ILC

Spin Tracking Studies

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DESY - FLC

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DER FORSCHUNG | DER LEHRE | DER BILDUNG

DESY

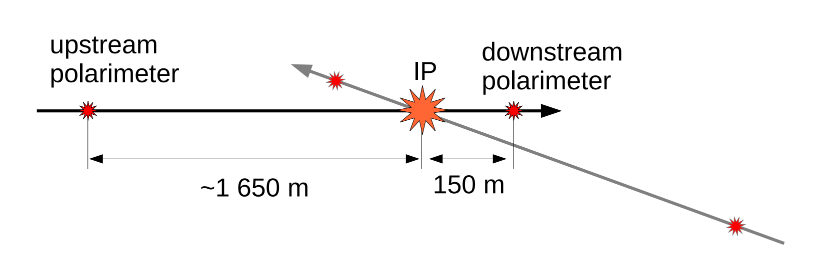
Bundesministerium für Bildung und Forschung

Emmy Noether-Programm
Deutsche Forschungsgemeinschaft DFG

Introduction: Polarimetry at the ILC

- **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)

Introduction: Polarimetry at the ILC



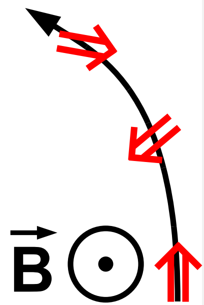
- **What happens between the polarimeters and the e^+-e^- IP? $\rightarrow$ simulation**
- Must understand spin diffusion/depolarization to 0.1 %

T-BMT Precession

- Spin transport through electromagnetic fields is described by T-BMT equation (**semi-classical**)

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

$$\vartheta_{\text{spin}} = \underbrace{\left(\frac{\mathbf{g-2}}{\mathbf{2}} \cdot \gamma + \mathbf{1}\right)}_{\approx 568 \text{ @ } 250\,\text{GeV}} \cdot \vartheta_{\text{orbit}}$$



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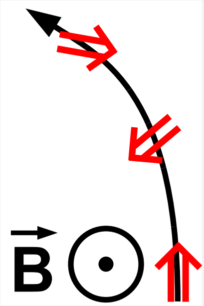
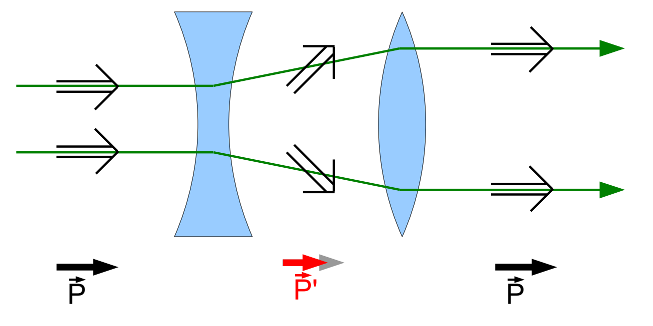


- Polarization vector $\vec{P} = \begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix}$ with polarization $|\vec{P}|$
- In this talk: **only longitudinal polarization P_z**

Spin Fan-Out in Quadrupole Magnets



- Different precession angles
  $\Rightarrow$ (not only longitudinal!) polarization "lost"
- Recoverable by second quadrupole, unlike for stochastic processes (radiative depolarization)

Particle / Spin Transport

- 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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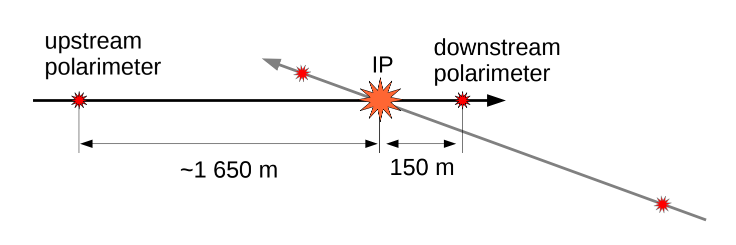
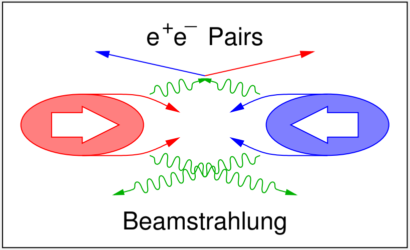


- In the following: **collision effects** (incl. crossing angle) and **spin transport behind the IP**
- Previous studies: spin transport up to the IP unproblematic, $\Delta P_z \ll 0.1\,\%$

Beam-Beam Collision Effects

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

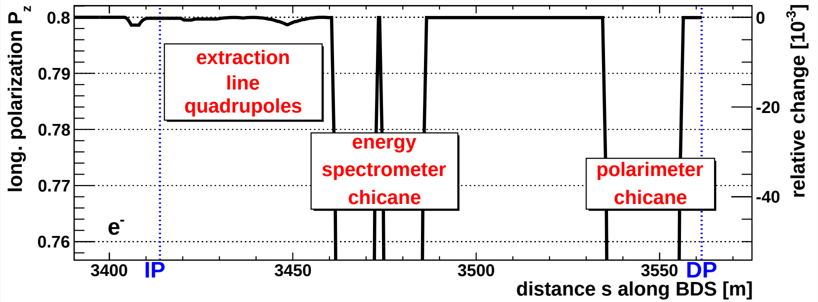


A. Vogel

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

Results

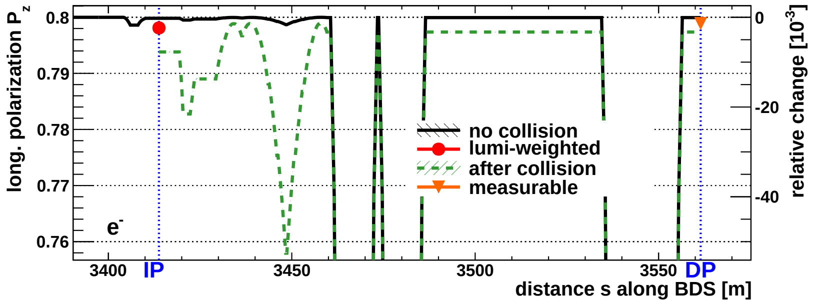
Spin Transport without Collision



DP: downstream-polarimeter

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

Spin Transport after Collision



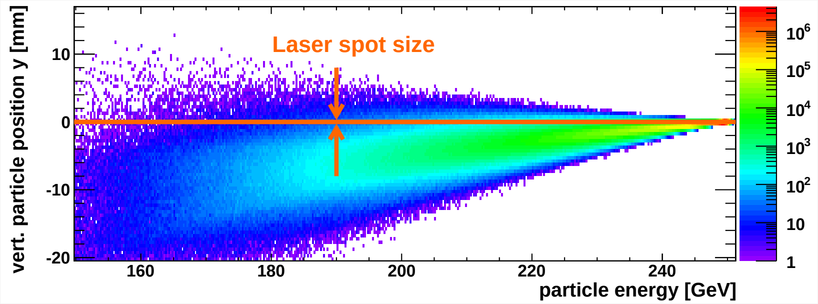
DP: downstream-polarimeter

- 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

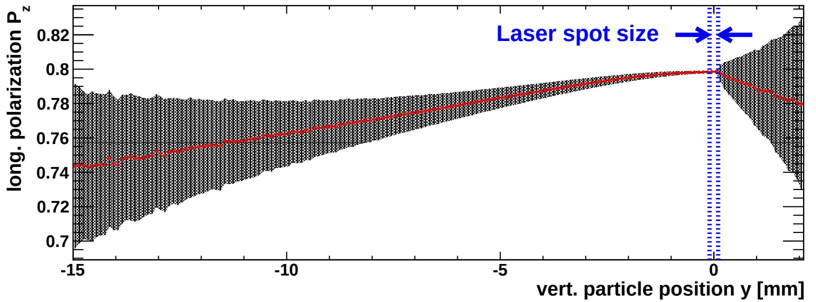
- Polarization measured in vertical chicane ⇒ **dispersion**

- **Laser spot size** at Compton-IP only ∼ **0.1 - 1 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



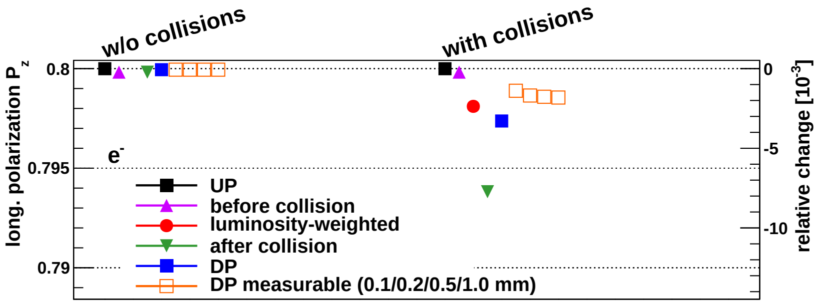
Downstream Measurement

- Beamstrahlung correlates energy loss and depolarization
  $\Rightarrow$ Polarization correlated with particle position
  $\Rightarrow$ **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



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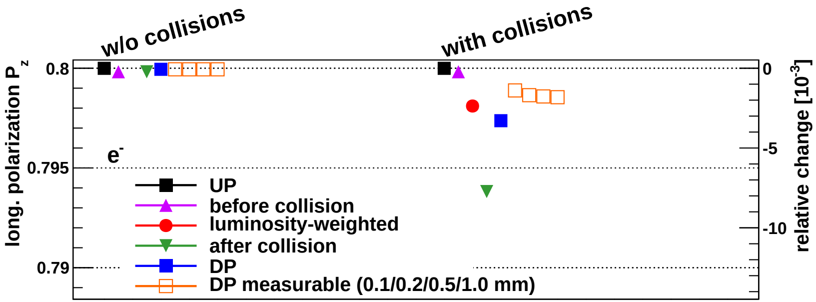
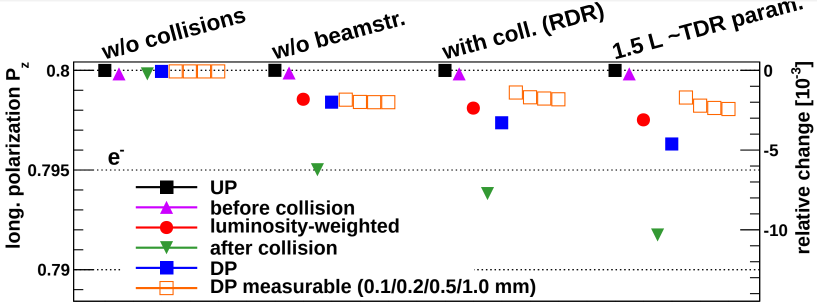


- ■ − ● = 0.24 %   (A. Hartin, LCWS 08: 0.22 %)
- Lattice designed such that **ideally** ● = ■(= □)
  (luminosity-weighted P_z should equal P_z at the DP)
- **Beamstrahlung not taken into account**, only T-BMT
  ⇒ ● − ■ = 0.1 % relative deviation
- Selective measurement: □ − ■ = 0.2 %

Spin Transport for Different Scenarios



- Simulation **without beamstrahlung**: ● = ■ = □
  ■ − ● = 0.18 %   (A. Hartin, LCWS 08: 0.17 %)
- TDR bunch-bunch luminosity (**1.5 L**):
  More beamstrahlung: ● − ■ = 0.15 %
  Growing bias: □ − ■ = 0.2 to 0.3 %
  ⇒ **Crucial to know laser spot size and position**

Conclusion (1)

- 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!

Thanks for support and useful discussions to:

- Daniel Schulte (CERN)
- David Sagan (Cornell University)
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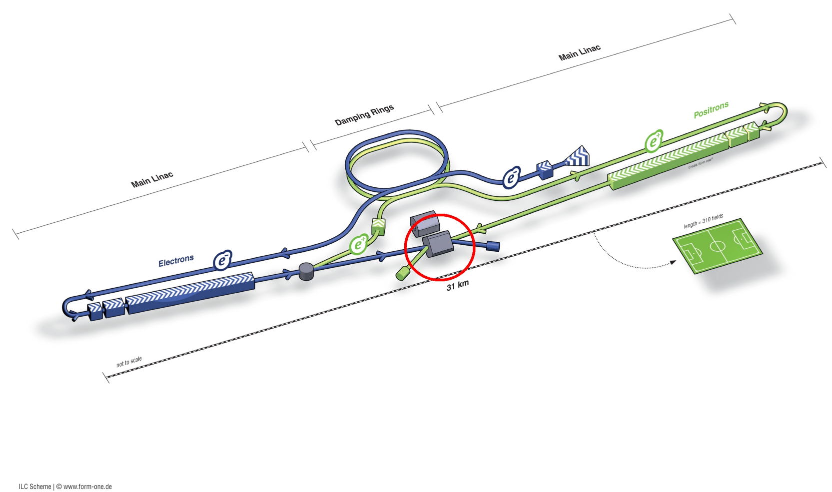
- Gudrid Moortgat-Pick (Hamburg University)
- Andrei Seryi (JAI)
- Kenneth Moffeit, Yuri Nosochkov, Michael Woods (SLAC)
- Jeff Smith (formerly SLAC)
- und many others...

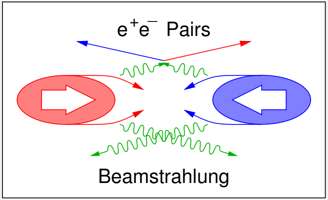
Backup Slides

Spin Transport behind the IP

No net bending angle in extraction line



Lattice Design for Downstream Polarimeter



Spin fan-out due to T-BMT precession:

$$\mathbf{\Delta P_z} \propto \quad \boldsymbol{\theta_x} \quad ^{\mathbf{2}}$$

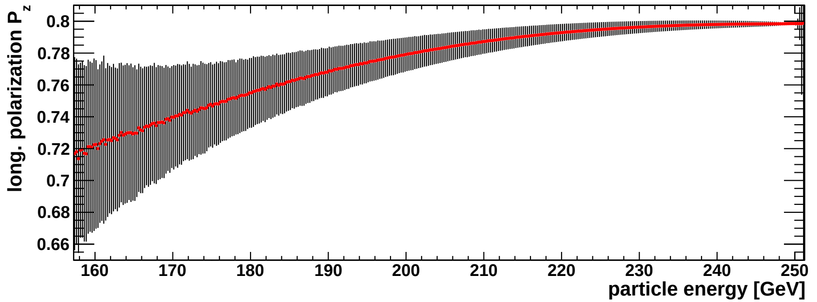
$$\mathbf{\Delta P_z^{lum}} \approx \frac{1}{4} \Delta P_z \propto \left(\frac{\boldsymbol{\theta_x}}{\mathbf{2}} \right)^{\mathbf{2}}$$

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

Idea: $|\mathbf{R_{22}(IP \longrightarrow DP)}| = \mathbf{0.5} \quad \Rightarrow \quad \mathbf{P_z^{lum} = P_z^{DP}}$

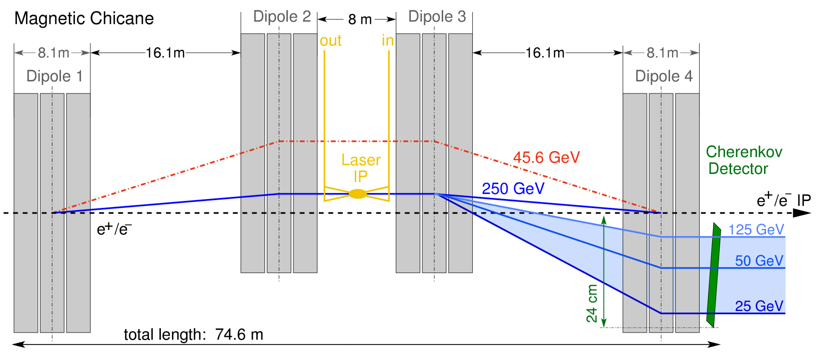
Downstream Measurement

Longitudinal polarization vs. energy at the downstream polarimeter, after collision



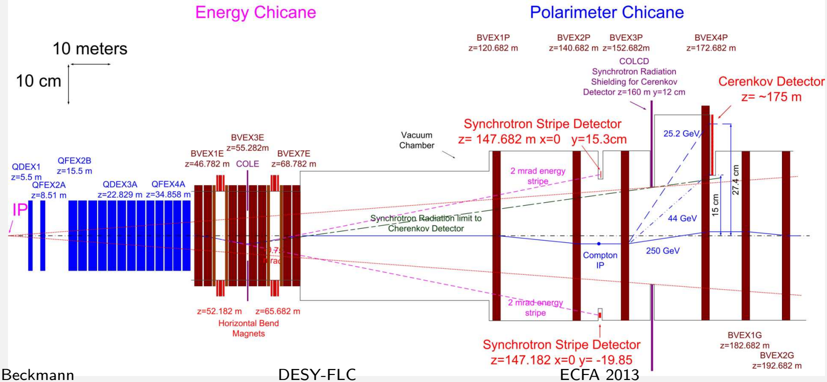
Polarimeter Chicane (upstream)

- 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 → 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*