Towards Precision Polarimetry at the ILC: Concepts, Simulations, Testbeam Results

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The International Linear Collider

the goals:

- Unveil the nature of physics beyond the Standard Model
- precision measurements of known and new particles

the tools:

- Electron - positron collisions at $\sqrt{s} = 90$ GeV up to 1 TeV
- Polarisation: $P_e^- = 80-90\%$, $P_e^+ = 30-60\%$

the challenge:

- determine luminosity weighted average polarisation at the collision point to $\delta P/P = 0.1\%$
- ... and in some cases even to $\delta P/P = 0.01\%$
Compton Polarimetry at the ILC

- Compton scattering off laser beam:
  - hit $O(10^3)$ $e^\pm$ per bunch of $10^{10}$
  - $\mathcal{P}$ proportional to energy asymmetry
  - scattered $e^\pm$ colimated within 10 $\mu$rad
  - $\Rightarrow$ spectrometer magnets: energy $\rightarrow$ position
- achieved (SLD): $\delta\mathcal{P}/\mathcal{P} = 0.5\%$, ILC: $\delta\mathcal{P}/\mathcal{P} = 0.25\%$ (syst.)
- not possible at $e^+e^-\text{IP}$, but upstream and downstream
- typical timescales: few bunches / trains

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Polarimetry with Annihilation Data

\[ e^+ e^- \rightarrow W^+ W^- \]

- from total cross-section or \( \frac{d\sigma}{d \cos \theta} \)
- contribution of new physics?
  \( \Rightarrow \) common determination with triple gauge couplings
- longterm (\( \mathcal{O} \) (years)) absolute scale to \( \delta P/P = 0.1\% \)

\[ c.f. \text{LC-PHSM-2001-022, update underway} \]

Blondel Scheme

- needs \( P_{e^+} \neq 0 \) and all four \( e^\pm \) helicity combinations
- determines \( P_{\text{eff}} = \frac{|P_{e^-}| + |P_{e^+}|}{1 + |P_{e^-}| + |P_{e^+}|} \) to \( \delta P_{\text{eff}}/P_{\text{eff}} = 0.01\% \)

\[ c.f. \text{K. Mönig, LCWS S2004} \]
## Complementarity of Polarimeters and Annihilation Data

### Tasks
- tune spin rotators, monitor time dependence and correlations
- determine spin transport effects
- depolarisation due to collisions
- analysis of first years’ data
- direct access to luminosity weighted average polarisation
- ultimate calibration of absolute polarisation scale
- cross check, cross check, cross check!

### Tools
- fast → polarimeters
- 2 locations → polarimeters
- non-colliding → polarimeters
- „fast“ → polarimeters
- annihilation data
- polarimeters and annihilation data

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Complementarity of Up- and Downstream Polarimetry

Upstream Polarimeter

- 1.8 km upstream of IP

Downstream Polarimeter

- 140 m downstream of IP

Combination

- without collisions: spin transport in Beam Delivery System
- with collisions: depolarisation at IP
- cross check each other!


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Complementarity of Up- and Downstream Polarimetry

Upstream Polarimeter

- 1.8 km upstream of IP
- clean environment
- stat. error 1% after 6 $\mu$s
- machine tuning (upstream of tune-up dump)

Downstream Polarimeter

- 140 m downstream of IP
- high backgrounds
- stat. error 1% after $\approx 1$ min
- access to depolarisation at IP

Combination

- without collisions: spin transport in Beam Delivery System
- with collisions: depolarisation at IP
- cross check each other!\(^1\)

Design of the Upstream Polarimeter Chicane

Why a 4-Dipole-Chicane?

- Compton edge position (least energetic $e^\pm$) at detector independent of $E_{\text{beam}}$ if $B$-field constant
- price to pay: Compton IP moves laterally with $E_{\text{beam}}$
Design of the Upstream Polarimeter Chicane

Scaled field operation?

- fixed Compton IP position
- facilitates energy collimation, emittance diagnostics

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Scaled vs Fixed Field Operation

- detector acceptance varies with $E_{\text{beam}}$ ⇒ inhomogeneous quality of polarisation measurement
- calibration of polarimeter: Compton edge position w.r.t. main beam
- simulation study for 1cm channels:
  - fixed field: 
    $$\delta P/P = 0.1\% \Leftrightarrow \delta x 0.4 \text{ mm}$$
  - scaled field: 
    $$\delta P/P = 0.1\% \Leftrightarrow \delta x 0.2 \text{ mm}$$
  - ⇒ systematic deviations for large scale factors
- not compatible with extreme precision requirements c.f. ILC-NOTE-2008-047
The Cherenkov Detector of the SLD Polarimeter

LED & DESY Testbeam

- Cherenkov gas \( \text{C}_4\text{F}_{10}, n = 1.0014 \), 10 MeV threshold
- 3 GeV single \( e^- \) at DESY II

9 channels of Al–coated Cherenkov gas tubes and photomultipliers
Single Electron Response
Channel 5, Data & Simulation

Channel 7, 0° & 90°

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0° / 90° ratio vs channel number

- channels’ „middle“ sections longer ⇒ more light yield
- length of middle sections scales with channel number
- less reflections to PMT for 90° orientation
- goal: determine reflectivity, tune simulation (red line: \( R = 0.94\% \))
Results: Crosstalk & Channel Geometry

- observation: neighboring channels on the *outside* of the first bend observe part of signal
Results: Crosstalk & Channel Geometry

- observation: neighboring channels on the outside of the first bend observe part of signal
- explanation: cross-talk if $e^{-}$ traverses neighboring channel close to mirror!
Results: Crosstalk & Channel Geometry

- observation: neighboring channels on the outside of the first bend observe part of signal
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- ILC solution: use U-shaped channels, bend in 3rd dimension!
Spatial Distribution of Light in Channel

- SLD: inhomogenous light yield due to widening of channels
- avoid in ILC design!

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Summary

- precision goals of ILC require combination of upstream and downstream polarimeters as well as annihilation data
- best design for upstream polarimeter is a four-magnet chicane with fixed field operation at all beam energies
- polarimeters should improve by factor of 2 w.r.t. SLD
- Cherenkov detector of SLD has been operated in testbeam
- good agreement with simulation
- several improvements for ILC design identified
Outlook

- ILC-like prototype under construction
- various photodetectors under test (c.f. poster session)
- testbeam measurements with multiple electron events at ELSA in spring 2009
Introduction

The Overall Polarimetry Concept

Simulation Studies

Testbeam

Summary & Outlook

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Synchrotron Radiation

Synchrotron Radiation Geometry

Dipole 1: 8.1 m
Dipole 2: 16.1 m
Dipole 3: 8 m
Dipole 4: 16.1 m
Dipole 5: 8.1 m

Total length: 74.6 m

Laser

IP

Cherenkov Detector

$e^+ / e^-$ IP

$24 \text{ cm}$

$2 \text{ mm}$

$a = 0.837 \text{ mrad}$

$250 \text{ GeV}$

$45.6 \text{ GeV}$

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