Polarisation and Beam Energy Measurements at the ILC

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LCWS 2008 Chicago

Introduction
Polarisation
Beam Energy Measurements
From Z pole to 1 TeV
Conclusions & Recommendations

Emmy
Noether-
Programm

Deutsche
Forschungsgemeinschaft
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Introduction

What I'll try do to here:

- ▶ give an overview of E&P measurements at the ILC
- ▶ introduce the methods
- ▶ discuss the systems in the RDR
- ▶ present developments since RDR

Basis of this talk

- ▶ *Workshop on Polarisation and Beam Energy Measurements at the ILC*, DESY Zeuthen, April 14-16 2008
  http:www-zeuthen.desy.de/ILC/EPWS/
- ▶ „Executive Summary" arXiv:0808.1638 [physics.acc-ph]
- ▶ has been sent to GDE, Reseach Director, Detector Concepts

Polarisation and Beam Energies at the ILC

Polarisation:

- ▶ $P(e^-) = 80...90\%$, $P(e^+) = 0$ or $30...45\%$, later up to 60%
- ▶ polarimeter goal: $\delta P/P = 0.25\%$ (c.f. SLD $\delta P/P = 0.5\%$)
- ▶ physics requires $\delta P/P \leq 0.1\%$ (electroweak)
- ▶ $\Rightarrow$ needs cross calibration with annihilation data

Beam Energy:

- ▶ calibration at $E_{CM} = 91.2$ GeV
- ▶ physics at $E_{CM} = 200...500$ GeV, upgrade up to $E_{CM} = 1$ TeV
- ▶ $\delta E/E = 1..2 \cdot 10^{-4} \simeq$ LEP II
  (LEP I: $2 \cdot 10^{-5}$ with resonant depolarisation)

Sources, Low Energy Polarimetry and Spin Rotation

current baseline design:

Electrons

- ▶ photocathode gun, $P = 80..90\%$
- ▶ fast (train by train) helicity flip via laser
- ▶ Mott polarimeter near source

Positrons

- ▶ current baseline: (short) helical undulator $\rightarrow P = 30...45\%$
- ▶ helicity flip: polarity change of superconducting magnets $\rightarrow$ **slow!**
- ▶ no polarimeter near source (but R&D ongoing)

still two possibilities for positron polarisation:
destroy or do physics!

Overall Polarimetry Scheme

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, and again cross check!

Tools

▶ fast → polarimeters

▶ 2 locations → polarimeters

▶ non-colliding → polarimeters

▶ „fast" → polarimeters

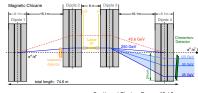▶ annihilation data

▶ annihilation data

▶ polarimeters and annihilation data
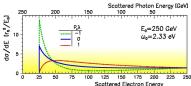
Polarimeters: Compton-Scattering $e^- \gamma \to e^- \gamma$

Concept:

- circularly polarised laser
- energy spectrum of scattered e^- depends on P
- want high statistics $\to$ many scatterings per bunch
- magnetic chicane $E \to x$
- Cherenkov hodoscope detector
- asymmetry w.r.t. laser helicity:
  $P(e) = \frac{1}{P_\lambda \cdot AP} \frac{N_L(x) - N_R(x)}{N_L(x) + N_R(x)}$
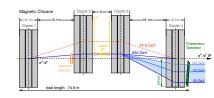

dominant systematics:
Analysing Power AP (0.2%), detector linearity (0.1%)

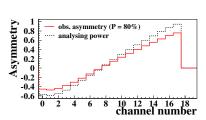# Polarimeters: Compton-Scattering $e^- \gamma \rightarrow e^- \gamma$

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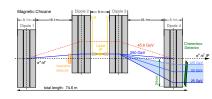**Analysing Power AP (0.2%), detector linearity (0.1%)**

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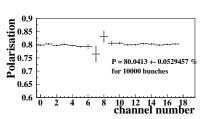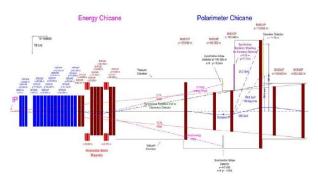**Analysing Power AP (0.2%), detector linearity (0.1%)**

The Downstream Polarimeter

- ▶ more complex to due fierce environment of spent beam!
- ▶ better background separation with 6 magnet chicane
- ▶ allows to run magnets 3 & 4 at higher fields

Complementarity of Up- and Downstream Polarimetry

Upstream Polarimeter

- ▶ 1.8 km upstream of IP
- ▶ clean environment
- ▶ stat. error 1% after 6 μs
- ▶ machine tuning (upstream of tune-up dump)

Downstream Polarimeter

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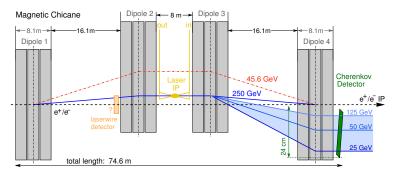- ▶ stat. error 1% after $\simeq$ 1 min
- ▶ access to depolarisation at IP

Combination

- ▶ without collisions: spin transport in Beam Delivery System
- ▶ with collisions: depolarisation at IP
- ▶ cross check each other![1]

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[1]c.f. „Spin Dance" Exp., Phys. Rev. ST Accel. Beams **7** 042802 (2004)

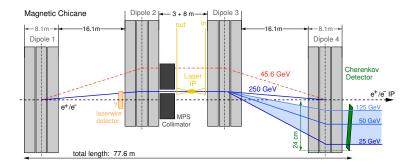## Upstream Polarimeter Issues
Why a 4-Dipole-Chicane?

▶ Compton edge position (least energetic $e^{\pm}$) at detector independent of E_{beam} if B-field constant

▶ price to pay: Compton IP moves laterally with E_{beam}
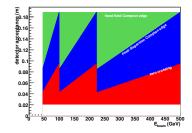
Upstream Polarimeter Issues
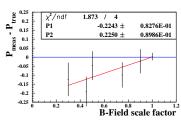
Scaled field operation?

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

Scaled vs Fixed Field Operation

- detector acceptance varies with E_{beam}
  $\Rightarrow$ inhomogeneous quality of polarisation measurement

- calibration of polarimeter: Compton edge position w.r.t. main beam

- simulation study for 1cm channels:
  - fixed field:
    $\delta\mathcal{P}/\mathcal{P} = 0.1\% \Leftrightarrow \delta x = 0.4$ mm
  - scaled field:
    $\delta\mathcal{P}/\mathcal{P} = 0.1\% \Leftrightarrow \delta x = 0.2$ mm
  - $\Rightarrow$ systematic deviations for large scale factors

- not compatible with extreme precision requirements c.f. ILC-NOTE-2008-047

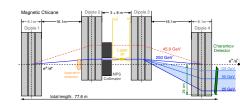## More Upstream Polarimeter Issues

Include MPS collimator?

- ▶ wakefields?!
- ▶ complicated & expensive in fixed field operation
- ▶ creates potentially serious backgrounds

Include laser wire emittance diagnostics?

- ▶ create HUGE backgrounds, about 70% of Compton signal
- ▶ → alternate bunches?
- ▶ incompatible with polarimetry at Z pole (polarimeter calibration!)

Polarimetry with Annihilation Data

if no positron polarisation

- $\sigma = \sigma_0[1 - P(e^-)A_{LR}]$
- $\Rightarrow \frac{\delta A_{LR}}{A_{LR}} = \frac{\delta P}{P}$
- scale uncertainty enters directly
- polarimeter calibration: at Z pole w.r.t. to SLD measurement of A_{LR}[2]

---

[2]remember $\sin \theta_{\mathrm{eff}}$ from A_{LR} and $A_{\mathrm{FB}^{\mathrm{had}}}$ inconsistent!

Polarimetry with Annihilation Data

if positron polarisation

- $\sigma = \sigma_0[1 - P(e^+) \cdot P(e^-) + (P(e^+) - P(e^-))A_{LR}]$
- $\Rightarrow$ correlations matter!
- can calibrate polarimeters with modified Blondel Scheme:
  $|P(e^\pm)| = \sqrt{\frac{(\sigma_{LR}+\sigma_{RL}-\sigma_{LL}-\sigma_{RR})\cdot(\pm\sigma_{LR}\mp\sigma_{RL}+\sigma_{LL}-\sigma_{RR})}{(\sigma_{LR}+\sigma_{RL}+\sigma_{LL}+\sigma_{RR})\cdot(\pm\sigma_{LR}\mp\sigma_{RL}-\sigma_{LL}+\sigma_{RR})}}$
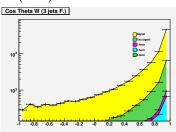- **if $P_L = P_R$ (for each beam)**
- if not: corrections $\simeq$ uncorrelated polarimeter error on $P_L - P_R$
- advantage: model independent!
- need to spend substancial amount of running time on LL and RR $\rightarrow$ expensive!

$e^+ e^- \rightarrow W^+ W^-$

preliminary results from full simulation (ILD)

- Blondel scheme for 100 fb^{-1} for each helicity state:
  $\delta P(e^-)/P(e^-) = 0.1\%$,
  $\delta P(e^+)/P(e^+) = 0.2\%$

- from $\frac{d\sigma}{d\cos\theta}$: large $\cos\theta$
  t-channel domianted, P
  changes relative contribution of
  t-channel

- contribution of new physics?
  $\Rightarrow$ common determination with
  triple gauge couplings

Cos Theta W (3 jets F.)

fit yields for 20 fb^{-1}:
$P(e^-) = 80.17 \pm 0.15$,
$P(e^+) = 60.10 \pm 0.20$
(no backgrounds yet)

Polarimetry: putting it all together

requirements

- ▶ beam trajectories at upstream, IP and downstream aligned to better than 50μrad
- ▶ controle by BPM measurements in chicanes
- ▶ understand
    - ▶ spin transport (ground motion, feedback loop)
      $\rightarrow$ by Tony Hartin in BDS session Wednesday 13:30
    - ▶ depolarisation in collisions $\rightarrow$ dito
    - ▶ influence of DID/ anti-DID
    - ▶ influence of crab-crossing?

**only with all three complementary tools
— upstream, downstream, annihilation data —
permille precision can be reached**
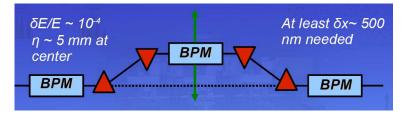
Beam Energy Measurements

Overall Scheme

- ▶ redundant beam-based measurements, $\delta E/E = 10^{-4}$
- ▶ real time diagnostics
- ▶ additional: physics reference $e^+e^- \to \mu^+\mu^-\gamma + M_Z$
- ▶ BPM spectrometer a la LEP II upstream
- ▶ synchrotron radiation imaging detector a la SLD downstream
- ▶ both devices run testbeam experiments, goals achievable

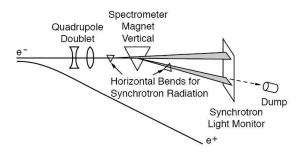## The Upstream Energy Spectrometer

- ▶ prototype set-up T-474 experiment at Endstation A at SLAC
- ▶ resolutions of $\simeq 1\mu$m achieved
- ▶ to watch: drifts....

The Downstream Energy Spectrometer

- ▶ detector test at T-475 experiment at Endstation A at SLAC
- ▶ chicane provides 2mrad vertical bend + wigglers
- ▶ secondary focus 150 m downstream of IP (polarimeter!)
- ▶ array 100 μm quartz fibers detects Cherekov light
- ▶ read out by multi-anode PMTs

Alternative Methods

R & D on three further methods

- ▶ Compton scattering:
  - ▶ measure edge position (10μm) relative to photons (1μm) and beam electrons (0.5μm)
  - ▶ proof-of-principle in preparation in Novosibirsk
- ▶ use synchrotron radiation from upstream energy spectrometer chicane
- ▶ resonant absorption of laser light
- ▶ see for example Zeuthen workshop for more details

From Z pole to 1 TeV

Z pole calibration data

- ▶ calibration of polarimeters against physics data
- ▶ calibration of energy spectrometers against M_Z
- ▶ do also real physics with these calibration data?
- ▶ improve $\sin\theta_{\mathrm{eff}}$ substancially without GigaZ option!
- ▶ $\rightarrow$ talk by Gudrid Moortgat-Pick in Higgs/EW Tuesday 16:00!

1 TeV upgrade

- ▶ polarimetry: scaled field option limited by emittance blow up
- ▶ MPS collimator left with ± 1 mm aperture (3m length)
- ▶ practically impossible to operate ?!

Conclusions

Beam Energy

- ▶ up- and downstream instrumentation in RDR o.k., important to keep both!
- ▶ R & D for LEP II / SLD methods well advanced
- ▶ in addition: many ideas for complementary methods
- ▶ overall on a good way to reach $\delta E/E = 10^{-4}$

Polarisation

- ▶ situation more critical
- ▶ RDR description of upstream polarimeter not acceptable
- ▶ precision aim only feasible with optimal polarimeters plus annihilation data
- ▶ still many details to be studied in spin transport
- ▶ positron polarisation still needs your support!

Recommendations to GDE and Research Director

1. Separate the functions of the upstream polarimeter chicane. Do not include an MPS energy collimator or laser-wire emittance diagnostics; use instead a separate setup for these two.

2. Modify the extraction line polarimeter chicane from a 4-magnet chicane to a 6-magnet chicane to allow the Compton electrons to be deflected further from the disrupted beam line.

3. Include precise polarisation and beam energy measurements for **Z**-pole calibration runs into the baseline configuration.

4. Keep the initial positron polarisation of 30-45% for physics (baseline).

5. Implement parallel spin rotator beamlines with a kicker system before the damping ring to provide rapid helicity flipping of the positron spin.

6. Move the pre-DR positron spin rotator system from 5 GeV to 400 MeV. This eliminates expensive superconducting magnets and reduces costs.

7. Move the pre-DR electron spin rotator system to the source area. This eliminates expensive superconducting magnets and reduces costs.

Outlook

- ▶ BDS/MDI session devoted to the issues presented here: Wednesday 13:30, incl. discussion
- ▶ plenary talk by Sabine Riemann Wednesday 16:00

Special thanks to those who contributed to the material of this talk and to all the discussions in the last year(s):

Klaus Mönig, Wolfgang Lorenzon, Sabine Riemann, Gudrid Moortgat-Pick, Peter Schüler, Eric Torrence, Ken Moffeit, Mike Woods, Daniela Käfer, Ivan Marchesini and all participants of the EPWS in Zeuthen!

BACKUP