Precision Polarimetry for Future e^+e^- Linear Colliders

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on behalf of the Linear Collider Physics & Detector Study

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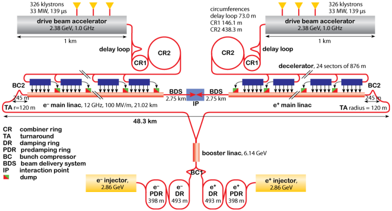
Two Linear Collider Concepts

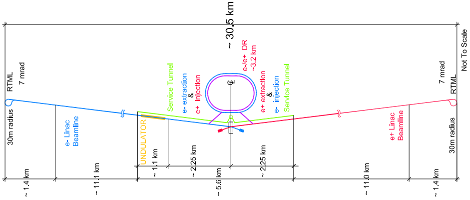
CLIC

- $\sqrt{s} = 0.5, 1.4, 3$ TeV
- technology under development
- $P(e^-) = 80\%$,
  $P(e^+) = 0$ (x%)
- beam energy spread: 0.3%
- energy loss (Beamstrahlung): 28%

ILC

- $\sqrt{s} = 90, 200 ... 500$ GeV (...1 TeV)
- technology proven (FLASH, ...)
- $P(e^-) \geq 80\%$,
  $P(e^+) \simeq 30\% (60\%)$
- beam energy spread: 0.1%
- energy loss (BS): 4.5%





Polarimetry Concept

Wanted:

- long-term luminosity weighted polarisation average

$$\langle P \rangle = \frac{\int P \cdot \mathcal{L} dt}{\int \mathcal{L} dt} \quad (1)$$

- for each data set, to per mille level precision!

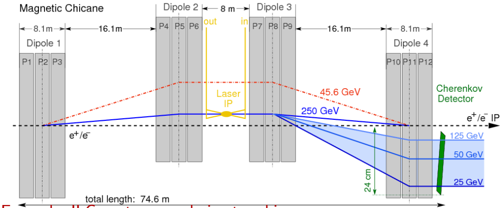
Tool Kit:

- Compton polarimeters upstream (& downstream) of e^+e^- IP
- Spin tracking between polarimeters and IP
- Cross-check with e^+e^- collision data

Working Principle

Laser Compton scattering:

- $\mathcal{O}(10^3)$ events / bunch
- $\frac{d\sigma}{dE}$ depends on P_z
- $\frac{d^2\sigma}{dEd\phi}$ depends on $P_{x,y}$
- asymmetry w.r.t. to laser helicity $\sim P_z$ $(P_{x,y})$



Example: ILC upstream polarimeter chicane

Magnetic Chicane:

- deflects scattered $e^\pm$ away from beam
- transforms $E \rightarrow x \Rightarrow$ measure dN/dx
- 4 magnet design:
  - restores unscattered beam
  - renders position on detector independent of E_{beam}

Polarimeter Uncertainties & Detector Requirements

Polarimeter Uncertainties

- laser polarisation: $\leq 0.1\%$
- alignment w.r.t. beam: 0.1...0.2%
  - lateral position ("Compton edge"): need $\mathcal{O}(0.1\ \mathrm{mm})$) for $\leq 0.1\%$
  - tilts: typ. 0.05%/ mrad
- detector linearity: aim for 0.1...0.2%

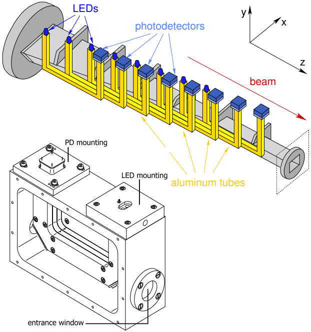
$\Rightarrow$ detector design with excellent possibilities to monitor alignment and linearity mandatory!

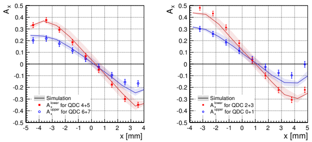
Detector Requirements

- alignment & linearity
- excellent monitoring, if possible online
- homogeneous response
- robustness against backgrounds (beam gas, beam halo, e^+e^- pairs, muons, synchrotron rad.) esp. at downstream location
- dynamic range: factor $\mathcal{O}(10^2)$ near Compton edge

Gas Cherenkov Detector [JINST **7**, P01019 (2012)]

- used in so far most precise Compton polarimeter (0.5..1% at SLD)
- robust against background via high Cherenkov threshold (10 MeV for e^- in C_4F_{10})
- in-situ monitoring improvements:
  - non-linearity to few per mille level → use LED between trains
  - angular alignment based on multi-anode photon detectors
- testbeam operation of 2-channel prototype
  → achieved tilt alignment of 0.1°





Alternative Detectors

Quartz Cherenkov Detector

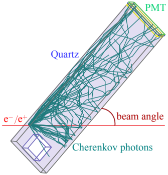
[A. Vauth]

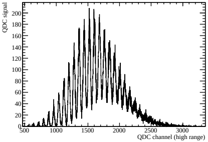
- high photon yield: $\sim 10^3$ photo e^- per Compton e^-
- can resolve Compton e^- peaks in photoelectron (QDC) spectrum
- $\rightarrow$ "self=calibrating"
- optimised geometry based on Geant4 simulation

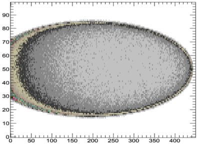
Silicon Pixel Detector

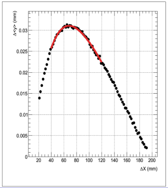
[G. Alexander, I. Ben Mordechai]

- option for transverse polarimetry
- standard LHC style pixel detector ok in terms of rad. hardness and occupancy (ILC upstream)
- simulation result based on ILC upstream chicane: can get $dP_y/P_y = 0.2\%$









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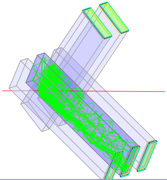
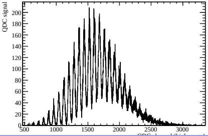
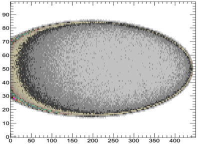
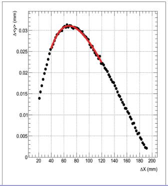








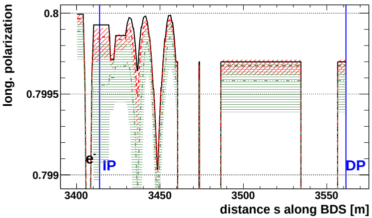
Spin Tracking in Beam Delivery System

[M. Beckmann]

From upstream via IP to downstream

- using BMAD, based on full T-BMT equation
- for $B_\perp$ only: $\theta_{spin} = (\frac{g-2}{2} \cdot \gamma + 1) \cdot \theta_{orbit} \simeq 568 \cdot \theta_{orbit}$
- start with $P_z = 80\%$, show median $\pm 1\sigma$ band from 1000 runs

- perfect lattice
- 5(10) μm random misaligments (& corr. kickers, fast-feedback)
- + detector solenoid, anti-DID, crab cavities
- + collisions (500 GeV, w.s.)



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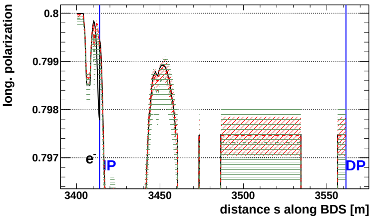

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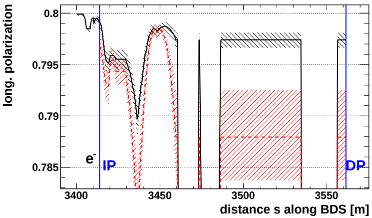
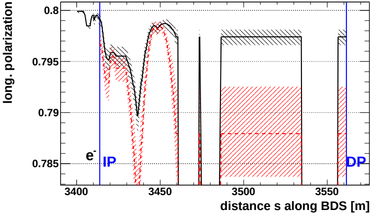
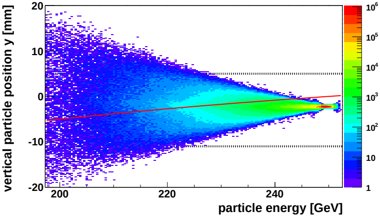


Measuring the Depolarisation

- collision effect at IP $\simeq 0.2\%$
- upstream measurement very close to $\langle P \rangle$
- P_z drops another $1.2\% \pm \mathbf{0.5}\%$ from IP to downstream pol.
- dominated by energy spread after collision and extraction line quad's
- correlation with y position:
- reduce effect by small laser spot?

$\Rightarrow$ complement polarimeters with longterm $\langle P \rangle$ from collision data





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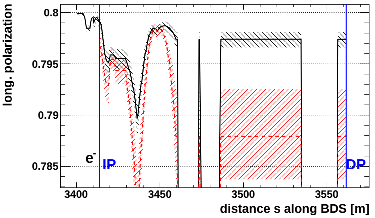

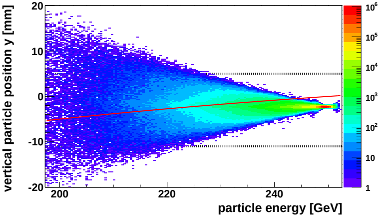

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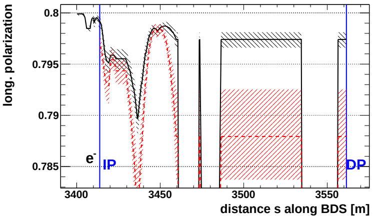
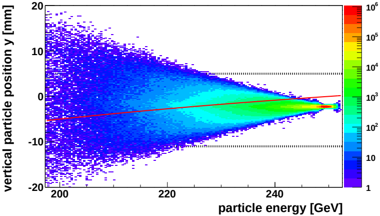
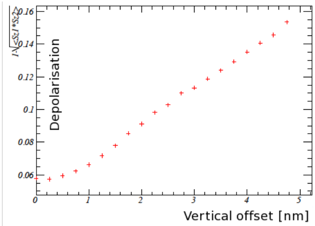
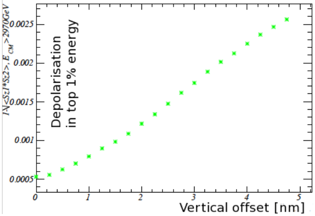




Depolarisation at CLIC [J. Esberg, D. Schulte *et al*]

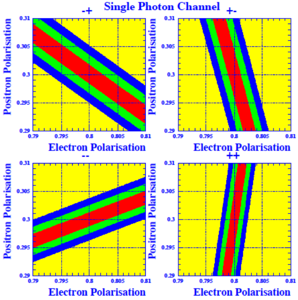
- higher energy, smaller bunches $\Rightarrow$ need strong field effects (c.f. talk by A. Hartin)!
- implemented in GuineaPig++
- studied depolarisation in collision as function of vertical offset of the beams ($\sigma_y = 1$ nm)
- total depolarisation: $\gtrsim 6\%$
- only in 1% of nominal $\sqrt{s}$: $\lesssim 0.1\%$
- a priori don't know actual $\sqrt{s'}$ on single event basis, e.g. for channels with missing 4-momentum





$\langle P \rangle$ from leptonic single W / Z and single γ [G. Wilson]

- dominated by $e^+e^- \to W^\pm e^\mp \nu_e$ and $e^+e^- \to \nu_e \bar{\nu}_e Z/\gamma$
- measure total 4 cross-sections for up to 9 possible polarisation configurations: $+-, -+, ++, --, -0, +0, 0-, 0+, 00$
- determine either $|P^L_{e^-}| = |P^R_{e^-}|$ and $|P^L_{e^+}| = |P^R_{e^+}|$ or additionally low small differences δ_- and δ_+

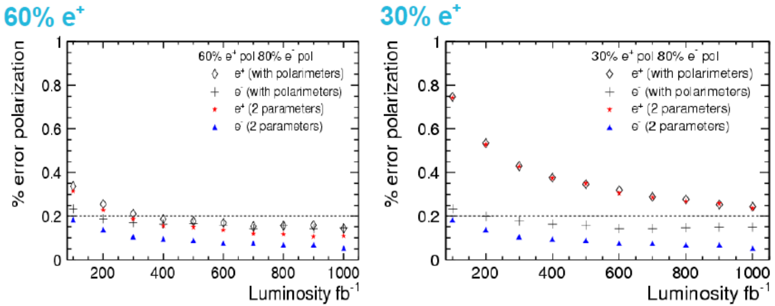


stat. sign. (500 fb^{-1} per hel. config.)

- assume 2 ab^{-1} at 3 TeV, 25% $+-$, 25% $-+$, 50% others
- δ's free:
  $\Delta|P_{e^+}|/|P_{e^+}| = 0.3\%$, $\Delta|P_{e^-}|/|P_{e^-}| = 0.16\%$, $\delta = 0 \pm 0.27\%$

$\langle P \rangle$ from $d\sigma(e^+e^- \to W^+W^-)/d\cos\theta$ [I. Marchesini]

- measure for 4 sign combinations $P = (+,-), P = (-,+), P = (+,+), P = (-,-)$
- fit for $|P(e^+)|$, $|P(e^-)|$ (and triple gauge couplings)
- optionally unequal $|P| \Rightarrow$ take differences from polarimeters
- can determine polarisations to 0.1...0.2% level with $\mathcal{O}(1\text{ab}^{-1})$
- systematically limited by polarimeters $\Rightarrow$ minimize difference by fast helicity reversal or need additional runs with one $P = 0$



Conclusions

- per mille level determination of the luminosity weighted polarisation average $\langle P \rangle$ needs
  - excellent Compton polarimetry
  - detailed understanding of spin transport between polarimeter(s) and IP
  - detailed understanding of collision effects
  - cross-check from collision data
- in all these aspects progress has been achieved
- measuring $\langle P \rangle$ to a few per mille seems achievable for ILC
- less studied so far, but probably also valid for CLIC