ILC: Spins Running the Gauntlet

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Abstract

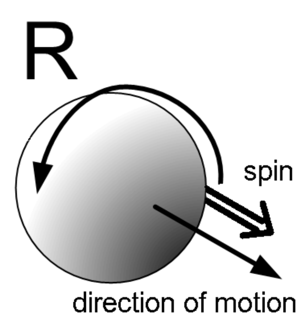
At the planned International Linear Collider (ILC), the longitudinal polarization of the beams is going to be measured with a systematic uncertainty of 0.25%. As the polarimeters are placed 1.6 km in front of the interaction point (IP) and 150 m behind it, the question arises how precise the actual polarization at the IP is known from these measurements.

For my PhD thesis, a beamline simulation of the beam delivery system (BDS) is set up in order to answer this question. This involves investigations of the effects of misalignments and collision effects at the IP.

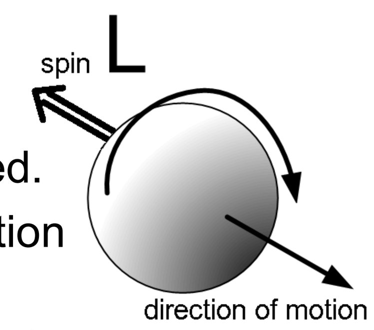
The measurements in the Compton polarimeters are simulated and confronted with testbeam data from a polarimeter prototype.

What is Polarization?

Polarization is a measure for the ordering of spins in a ensemble of particles. If the spin orientation relative to the direction of motion is measured, the *longitudinal polarization* is defined as the probability to find a right-handed particle (R, see picture) minus the probability to find a left-handed particle (L): $P_z = R - L$ where $R + L = 1$



Example: 90% L (and thus 10% R) give a longitudinal polarization of -80%

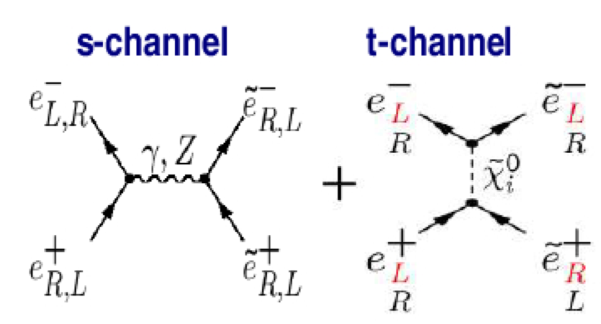


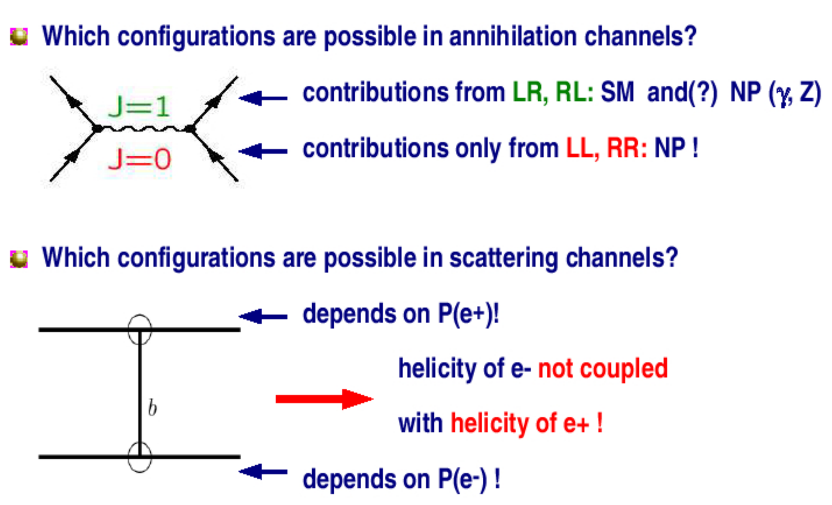
Likewise, the transversal polarizations P_x and P_y are defined. The total polarization P is given by the norm of the polarization vector $(P_x, P_y, P_z)^T$. According to the second law of thermodynamics, polarization does not increase by itself, as it describes the degree of spin ordering.

What is Polarization good for?

> As the cross-section of electroweak processes depends on the longitudinal polarization, it is crucial for lepton colliders to know it precisely.

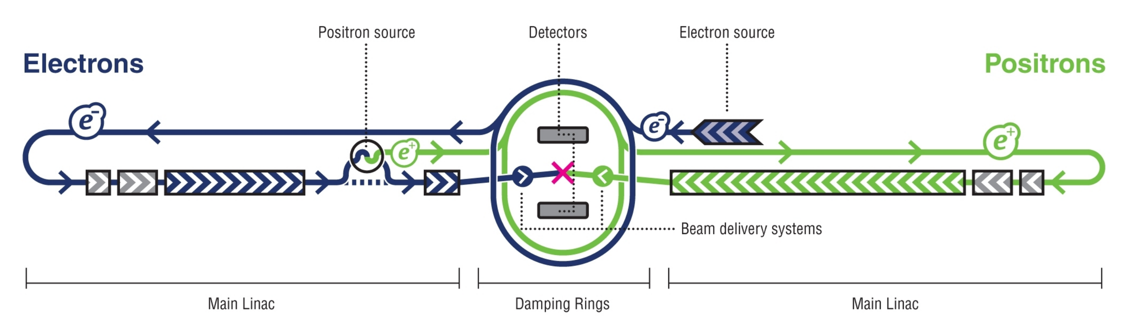
> Weak processes sensitive to helicity
→ suppress / enhance processes
→ chirality tests (L/R-selectrons)





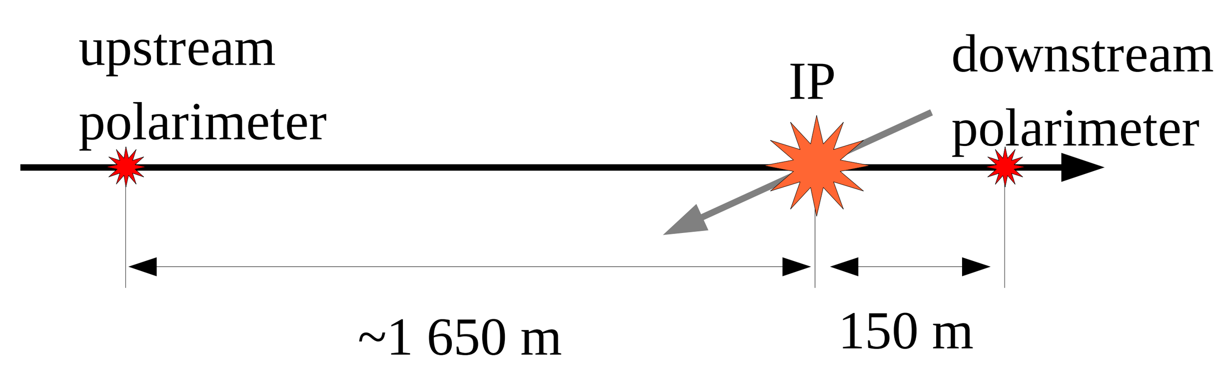
The International Linear Collider (ILC)

> e^+e^- collider, 500 GeV c.o.m. energy, extension to 1 TeV possible
> $P_z(e^-)$=80%, $P_z(e^+)$≥30%
> Yet unequaled goal for measurement precision: $DP_z/P_z \approx 0.25\%$



High-Precision Polarization Measurement

> Two Compton polarimeters measure polarization with envisaged uncertainty of 0.25 %
> Long-run average polarization can be determined from collision data with down to 0.1 % uncertainty → cross-calibration of polarimeters
> **Question**: **What happens between polarimeters and IP?** EM fields on the way affect spins and might cause significant depolarization
> Detailed spin tracking study needs to quantify depolarizing effects down to 0.1 %



Spins in Electromagnetic Fields

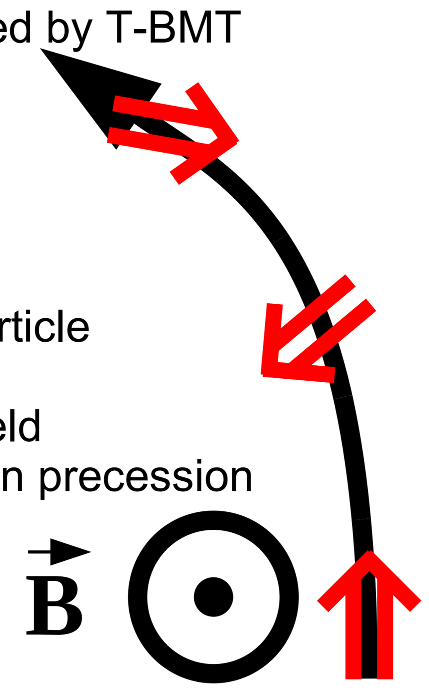
> Spin propagation in electromagnetic fields is described by T-BMT equation:

$$\frac{d}{dt}\vec{s} = \vec{\Omega}\left(\vec{E}(\vec{r},t),\, \vec{B}(\vec{r},t),\, \vec{p},\, m,\, a\right) \times \vec{s}$$

E, B: electric / magnetic field in lab frame
s, p, m: spin / momentum / mass of particle
a = (g-2)/2: anomalous gyro-magnetic moment of particle

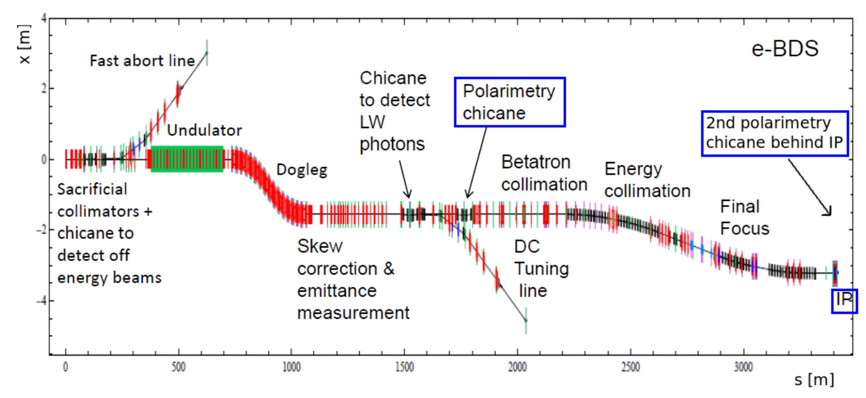
> Assuming no electric and no longitudinal magnetic field (as in most beamline magnets), this boils down to spin precession around the magnetic field lines:

$\theta_{Spin} = a{\cdot}\gamma{\cdot}\theta_{Orbit}$, $a{\cdot}\gamma = 2.27{\cdot}E/\mathrm{GeV}$ for $e^\pm$

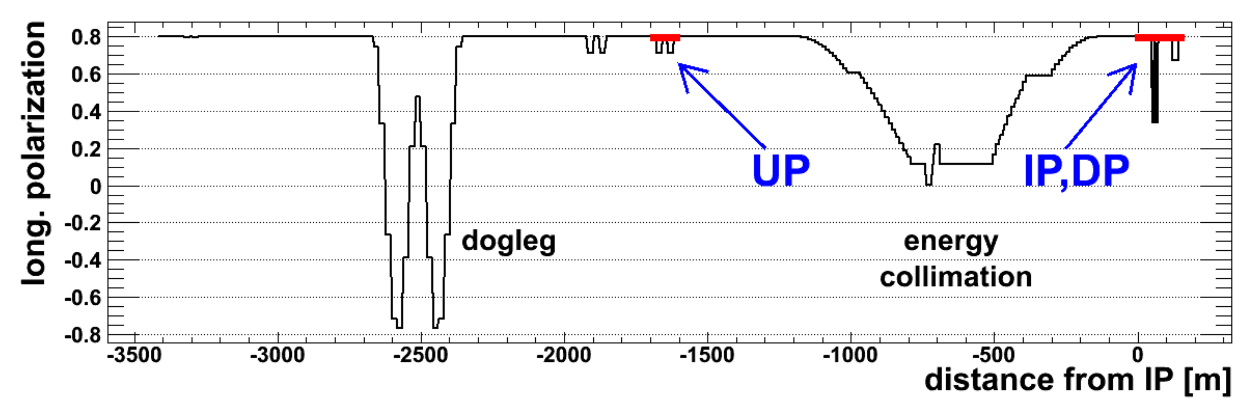


Will Misalignments Spoil It?

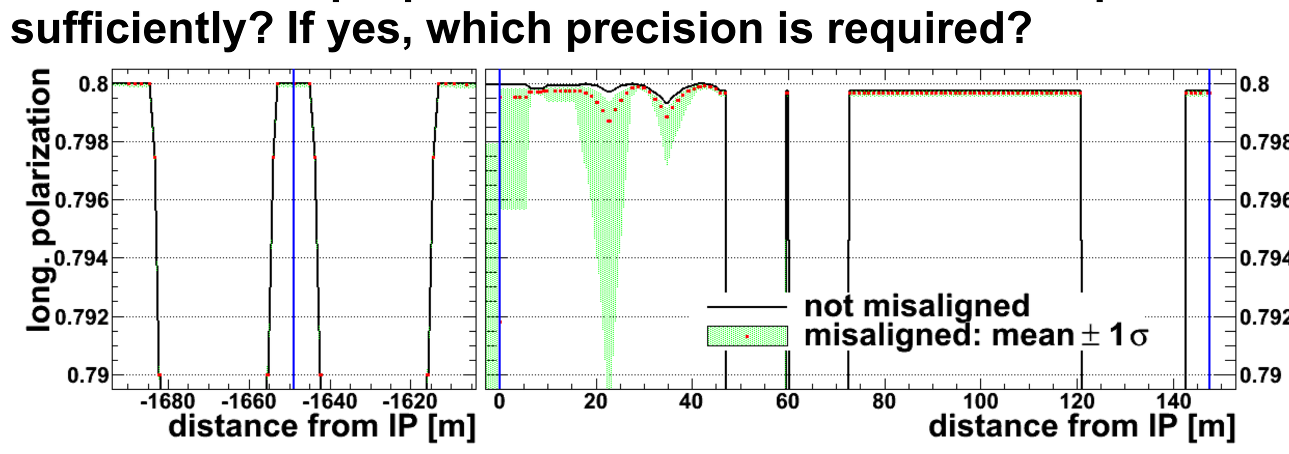
> Small curves in the beamline have large impact on longitudinal polarization at high energies (E=250 GeV in the plot below)



> Since all particles are affected likewise by bending, the total polarization is not lost, but the polarization vector is rotated (reversible)

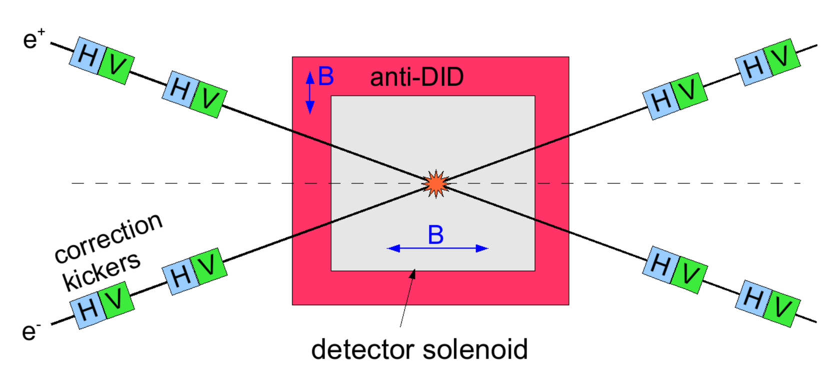


> Moderate misalignments of order 2 μm with coarse correction would already lead to uncertainty of ~0.3%
(implementation of more detailed orbit correction system in progress)
> **Question: Can proper orbit correction also correct polarization sufficiently? If yes, which precision is required?**



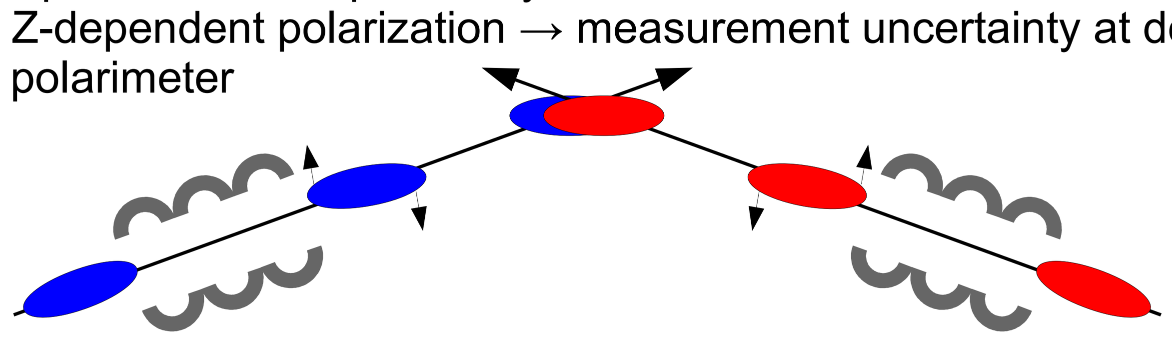
Detector Magnets

> Solenoid field for tracking devices tilted towards beams (7mrad)
> Anti-DiD (Detector-Integrated Dipole) to reduce background
> Additional correctors required to correct beam position



Side-Effects of Crab Cavities

> Bunches must collide head-on to reach maximum luminosity
> Crab cavities apply z-(position-)dependent kick to bunch → rotation
> Spins rotate z-dependently as well
> Z-dependent polarization → measurement uncertainty at downstream polarimeter



Outlook

> Implement orbit correction system (see above)
> Include effects from bunch collisions: mutual focussing (pinch-effect) and spin-flips due to emission of beamstrahlung
> Simulate measurement of Compton polarimeters: Compton scattering, tracking of scattered particles, response of Cherenkov detector

References

> S. Boogert et al., "Polarimeters and Energy Spectrometers for the ILC Beam Delivery System", JINST 4:P10015,2009, arXiv:0904.0122
> BMAD homepage: http://www.lns.cornell.edu/~dcs/bmad/
> M. Beckmann, J. List: "Spin tracking studies for polarimetry at the ILC", 2011 J. Phys.: Conf. Ser. 295 012134

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