Polarimeters and Energy Spectrometers for the ILC Beam Delivery System

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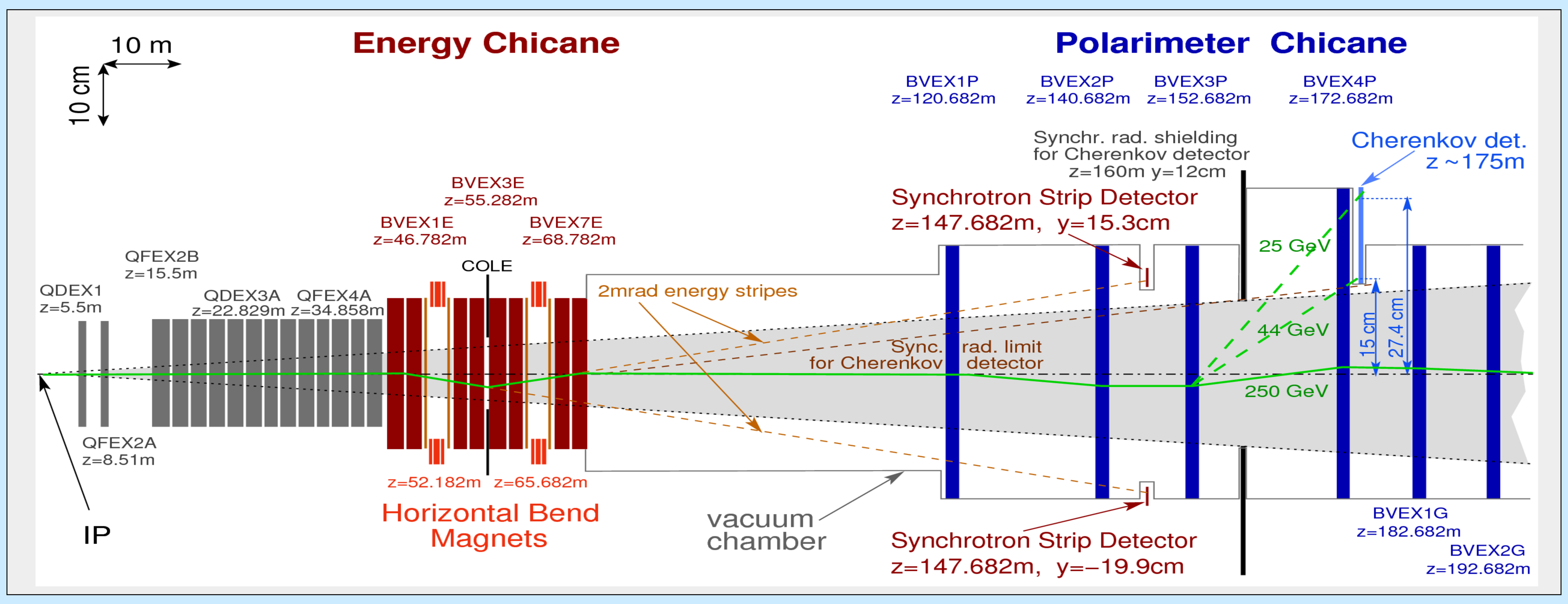
Motivation

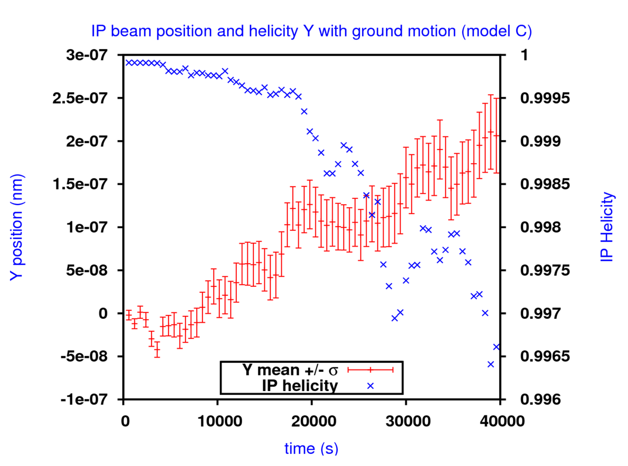
Any future high energy e+e- linear collider aims at precision measurements of Standard Model quantities as well as of new, not yet discovered phenomena. In order to pursue this physics programme, excellent detectors at the interaction region have to be complemented by beam diagnostics of unprecedented precision. Of central importance is precise knowledge of the beam energy and polarisation at collision. A combination of upstream and downstream polarimeters and energy spectrometers is required. For the International Linear Collider these have been designed to fulfill the precision goals at a large range of beam energies from 45.6 GeV at the Z pole up to 250 GeV or, as an upgrade, up to 500 GeV. Different beam conditions have led to different layouts for the upstream diagnostic systems compared to the respective downstream ones. [1]



Schematic of the downstream diagnostics for the energy spectrometer and the Compton Polarimeter. The Extraction Line Spectrometer (XLS) measures the distance (which is proportional to the beam energy) between two synchrotron stripes created by the energy chicane. The downstream polarimeter chicane incorporates the energy spectrometer detector. The Compton IP for this polarimeter is 150m downstream of the collider Interaction Point. In order for the downstream Cherenkov detector to avoid the synchrotron radiation fan from the IP (illustrated in grey) the dipole magnets are relatively larger with much higher fields.

Spin tracking in the BDS

In order to relate the measurements of the polarimeters to the polarization measured at the actual collider IP, the depolarisation along the accelerator and during the collisions has to be modelled in theory and simulations. In the Beam Delivery System (BDS), depolarisation can occur due to ground motion induced misalignments.



Simulation of the depolarisation of a charge bunch initially with helicity +1 due to ground motion (from a noisy site). The bunch dimension σ_y starting on axis and with nominal value of 5 nm disperses and drifts of axis as the polarisation deteriorates

Depolarisation at the Interaction Point

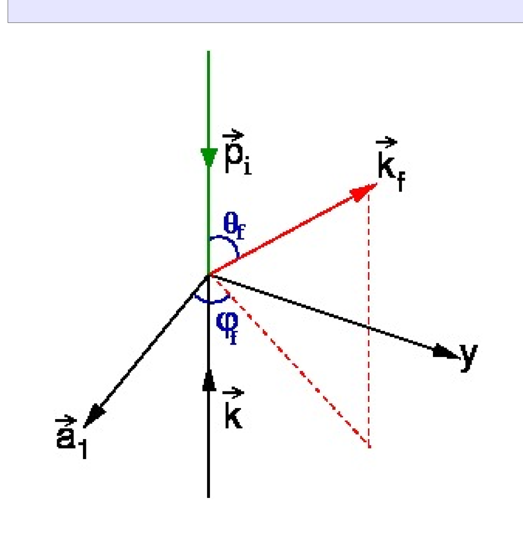
There are two processes that lead to depolarisation during the beam-beam collision, classical spin precession described by the T-BMT equation and the quantum Beamstrahlung (Sokolov-Ternov) process. Both have been simulated in the CAIN program for ILC and CLIC beam parameters. [2]

Parameter Set	ILC 100/100	ILC 80/30	CLIC 3TeV
T-BMT	0.17%	0.14%	0.10%
Sok-Tern	0.05%	0.03%	3.40%
incoherent	0.00%	0.00%	0.06%
coherent	0.00%	0.00%	1.30%
total	0.22%	0.17%	4.80%

Simulation results for depolarisation ($\Delta P/P$) from various processes due to beam-beam effects at the ILC with 100%/100% and 80%/30% polarised e-e+ beams and for the CLIC 3TeV parameters (2008)

A problem for the theory and simulation of precision spin tracking is that the Beamstrahlung transition rate contains a divergence for radiation in the backwards direction ($\cos\theta_f$ = 1) despite the experimental fact that radiation is emitted forwards in a $1/\gamma$ cone. [3]

$$dW \propto \frac{u}{(1+u)^2}\int_\xi^\infty K_{5/3}(y)\,dy - \frac{u^2}{(1+u)}K_{2/3}\quad,\quad \xi, u \propto w_f(1-\cos\theta_f)$$

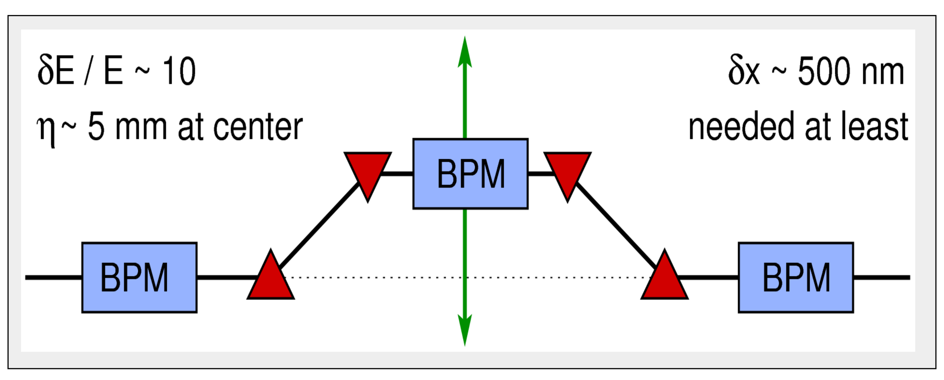


An incoming electron of momentum p_i is usually directed opposite to the field wave vector k of an oncoming charge bunch. The transition rate of the process is divergent when the radiated photon k_f is parallel to the field wave vector.

Beam Energy Measurements

The two primary methods planned for making precise beam energy measurements are a non-invasive spectrometer based on beam position monitors (BPMs), located upstream of the interaction point just after the energy collimators and a synchrotron imaging detector which is located downstream of the IP in the extraction line to the beam dump.

The upstream energy spectrometer's planned location is about 700 m upstream of the collider interaction point, just after the energy collimation system. The spectrometer consists of four dipoles which introduce a fixed dispersion of η=5mm at the centre. When operating the spectrometer with a fixed dispersion over the whole energy range, a BPM resolution of 0.5 μm is required. Cavity beam position monitors can achieve the required single shot accuracy, even significantly better accuracy of 20 nm has been achieved.



Schematic for the upstream energy spectrometer using Beam Position Monitors.

The planned ILC extraction line energy diagnostic [4] is based on the SLC Wire Imaging Synchrotron Radiation Detector. It consists of the Extraction Line Spectrometer (XLS) an analysing dipole to produce synchrotron stripes and is provided by a 4-magnet chicane 55 m downstream of the collider IP. With a total bend angle of 4 mrad, and a flight distance of nearly 100 m, the synchrotron stripes will have a vertical separation of 400 mm, which must be measured to a precision of 40 μm to achieve the target accuracy of $\Delta E/E = 10^{-4}$. In addition to the transverse separation of the synchrotron stripes, the integrated bending field of the analysing dipole also needs to be measured and monitored to a comparable precision of 10^{-4}. The XLS spectrometer is planned to consist of an array of radiation hard 100 μm quartz fibres to detect Cherenkov radiation from secondary electrons and MAPMs for readout.

References

[1] S.Boogert et al., *Polarimeters and Energy Spectrometers for the ILC BDS*, Jinst **4** P10015 (2009)

[2] I.R.Bailey et al., *Depolarisation and Beam-beam effects at Linear Colliders*, EUROTev-Report-2008-026

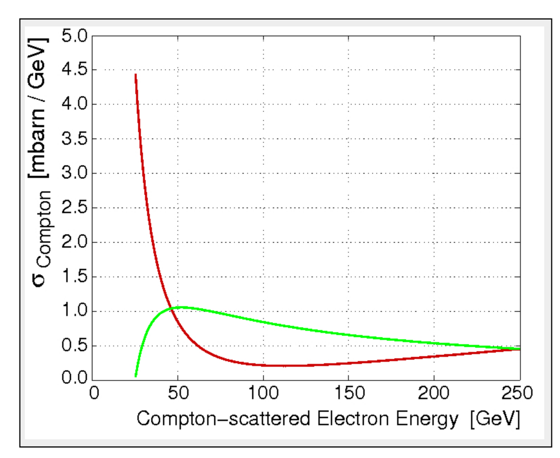
[3] A.F.Hartin, J Phys Conf Ser **198** 012004 (2009)

[4] E.Torrence, *Downstream Synchrotron Radiation stripe Spectrometer Status*, indico.desy.de ConfId 585

[5] J.List and D.Käfer, *Improvements to the ILC Upstream Polarimeter*, arXiv:0902.1516

Beam Polarisation Measurements

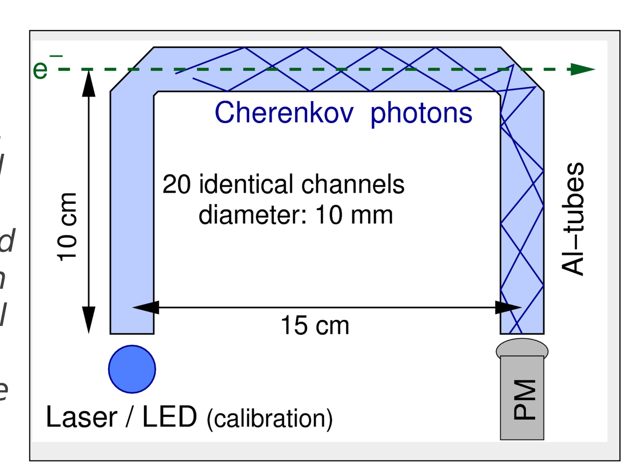
Both upstream and downstream polarimeters will use Compton scattering of high power lasers with the polarized beams. The large difference between the Compton edge energy and the beam energy, and the large asymmetry of the cross-section for different helicity configurations allows precise polarimeter measurements. It is expected that a systematic precision of $\Delta P/P$ =0.25% can be achieved, the main limitations being the analyzing power calibration and the detector linearity, both of which are in the range of 0.1% to 0.2%. [5]



Compton differential cross-section versus scattered electron energy for same (red curve) and opposite (green curve) helicity configuration of laser photon and electron. Electron energy is 250 GeV and the laser photon energy 2.3 eV

The polarimeter chicanes have been designed to spread the Compton spectrum horizontally over about 20 cm with a low dispersion of 20 mm at the mid-chicane point leading to a stable position distribution of fixed shape and location at the surface of the Cherenkov detector. Different detector options are being studied. One uses gas tubes for the radiator with the Cherenkov light detected by conventional photomultipliers. Another option utilises silicon-based photomultipliers coupled to quartz fibers as radiator.

Novel U-shaped Cherenkov channel for the Polarimeter detector. The channels are rotated out of the plane of beam synchrotron radiation and can be calibrated with an LED on the extra channel arm. The channels are filled with C_4F_{10} and have a square 1cm cross-section



The upstream Compton polarimeter is located at the beginning of the BDS where the design helicity and the beam direction matches those at the collider IP. The polarimeter laser can have the same pulse structure as the beam allowing measurements of every bunch, permitting fast recognition of polarisation variations within each bunch train as well as time-dependent effects that vary train-by-train. The statistical precision of the polarisation measurement is estimated to be 3% for any two bunches with opposite helicity, The average over two entire bunch trains with opposite helicity will have a statistical error of $\Delta P/P$=0.1%.

The downstream polarimeter is located 150 m from the collider IP in the extraction line and can measure the beam polarization both with and without collisions, thereby testing the calculated depolarisation due to beam-beam effects.