Precision polarimetry for the International Linear Collider.

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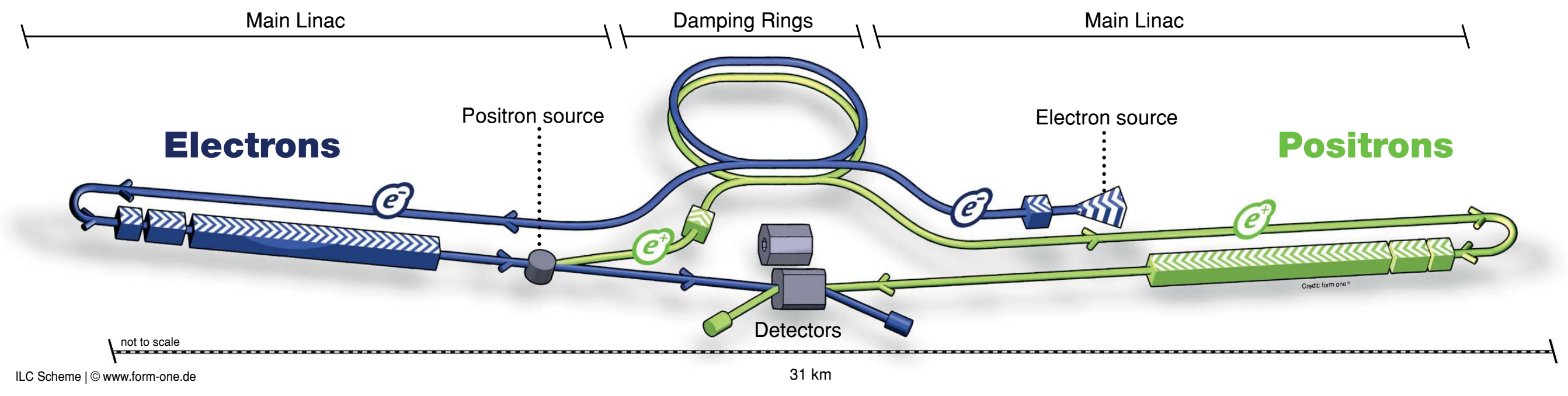
International Linear Collider (ILC)

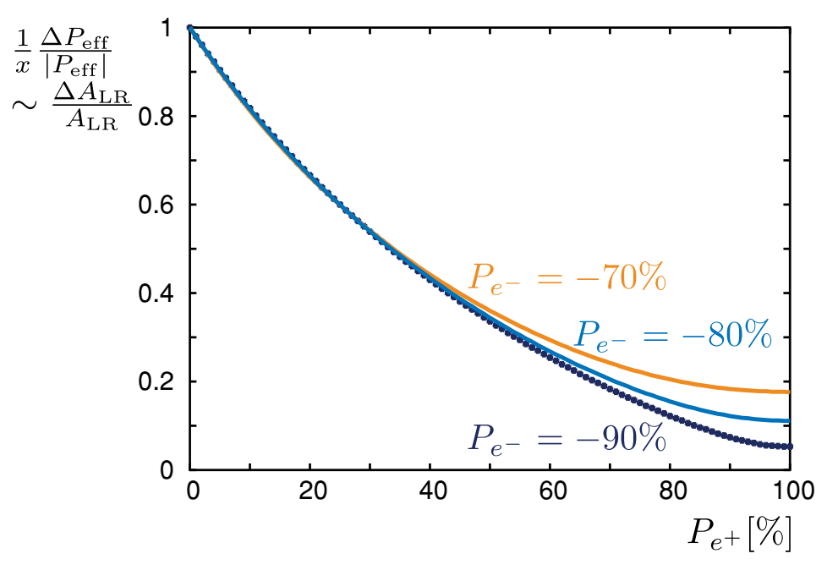
The International Linear Collider is a planned electron-positron collider with tunable center-of-mass energy of up to $\sqrt{s} = 500$ GeV (with the possibility to upgrade to 1 TeV).
It is foreseen to use polarized beams with a beam polarization of $P(e^-) \geqq 80\,\%$ for the electron beam and $P(e^+) \geqq 30\,\%$ for the positron beam.



Schematic layout of the International Linear Collider.

Motivation for polarized beams

Many physics processes depend on the longitudinal polarization of the interacting particles. Polarizing the beams can enhance rates and cross sections and suppress background processes. Both measurements of standard model parameters as well as searches for new physics can profit from this.
An example for a standard model measurement which profits from polarized beams is probing the couplings of the top quark to the electroweak gauge bosons, where the left-right asymmetry A_{LR} has to be measured with high accuracy.
In searches for new physics, the use of polarized beams can not only help in the suppression of standard model background such as WW-pairs, but also to test the quantum numbers of new particles.



Relative uncertainty on the effective polarization (normalized to the relative polarimeter precision x) as a function of positron polarization. [hep-ph/0607173]

Polarized beams at past colliders

At **SLC** (SLAC Linear Collider), an electron beam with $\mathcal{P}_{e^-} = 75\,\%$ was used. The beam polarization was measured by a Compton polarimeter, with a systematic uncertainty of $\Delta P/P \sim 0.5\,\%$.
Utilizing the polarized beam provided an improvement in the statistical power of observables such as the left-right asymmetry, which allowed a very high precision measurement of $sin^2\theta_{eff}$.

At **HERA** (Hadron-Elektron Ring-Anlage), a maximum polarization of $\mathcal{P}_{e^\pm} = 76\,\%$ was achieved in the first period of running. In the second run period, the typical polarization was $\mathcal{P}_{e^\pm} = 40$ to $50\,\%$, measured with a systematic uncertainty of $\Delta P/P \sim 2\,\%$. One application of the polarization was in a study which set a lower limit on the mass of a hypothetical right-handed W-boson.

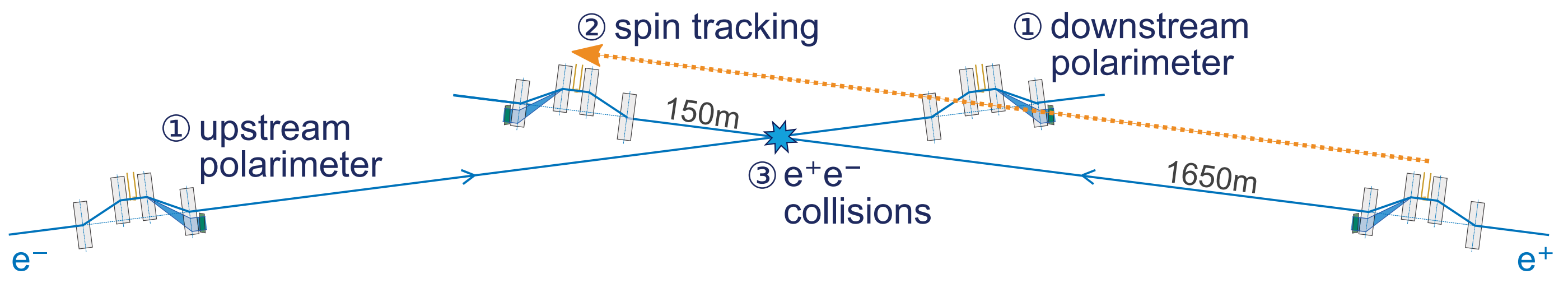
Polarimetry at the ILC

The decisive quantity for the experiments is the luminosity weighted polarization average $\langle P\rangle = \frac{\int P\cdot\mathcal{L}dt}{\mathcal{L}dt}$ for each data set. For the ILC, the goal is to measure this with per mille level precision. To do this, the polarization will be determined by combining

① Compton polarimeter measurements upstream and downstream of the e^+e^- interaction point

② Spin tracking studies to relate these measurements to the polarization at the e^+e^- interaction point

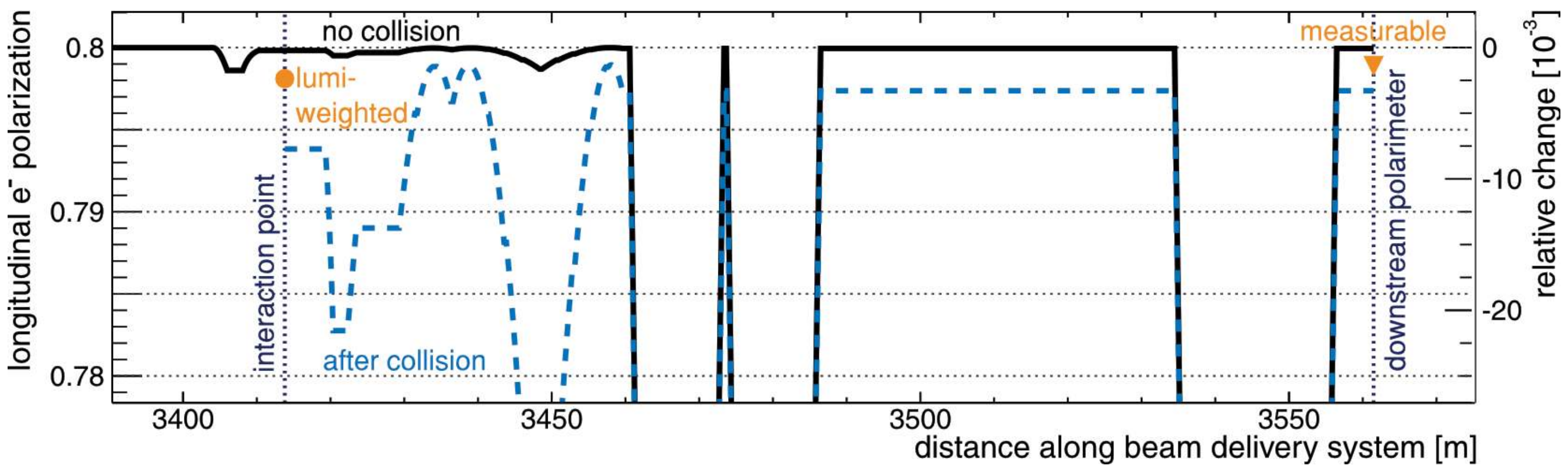
③ Long-term average determined from e^+e^- collision data as absolute scale calibration
[see talk by Jenny List, 20.07.13 @ 11:00 in the Top & EW session]



Components of the polarization measurement.

Spin tracking studies

The two Compton polarimeters are located 1.6 km upstream and 150 m downstream of the e^+e^- interaction point. The transport between the polarimeters and the interaction point can induce depolarization due to misalignment of the the beam delivery system's lattice elements. The e^+e^- collisions themselves also affect the polarization. To quantify these effects, the spin transport along the beam delivery system is simulated. The studies show that the spin transport between the upstream polarimeter and the interaction point is unproblematic, $\Delta P_z \ll 0.1\,\%$. In case of no or little beamstrahlung, the downstream polarimeter measures luminosity-weighted longitudinal polarization as foreseen by the lattice design.
For more beamstrahlung, a detailed analysis of the interaction between the downstream polarimeter laser and the particle bunch is required: At design luminosity, beamstrahlung effects can lead to a difference of $\Delta P_z \approx 0.2\,\%$ between luminosity-weighted polarization and downstream polarimeter measurement.

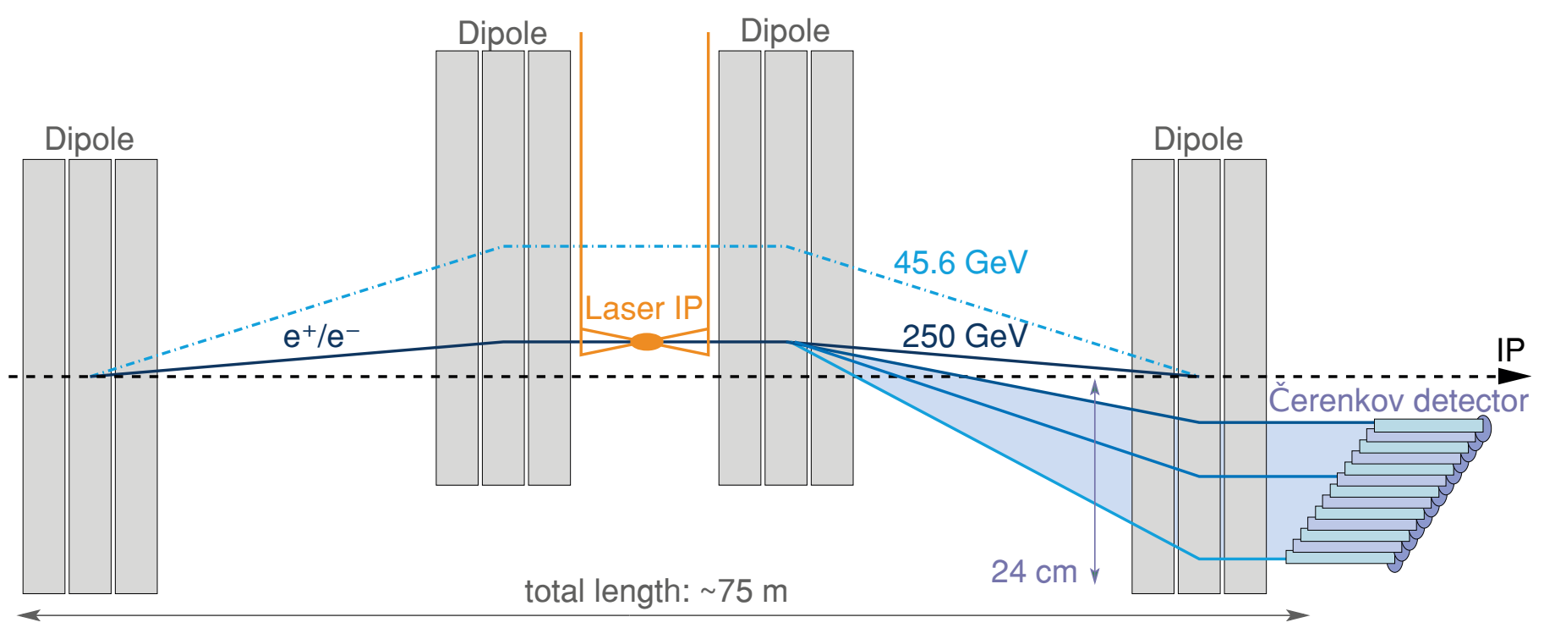


Spin transport simulation with collision effects.

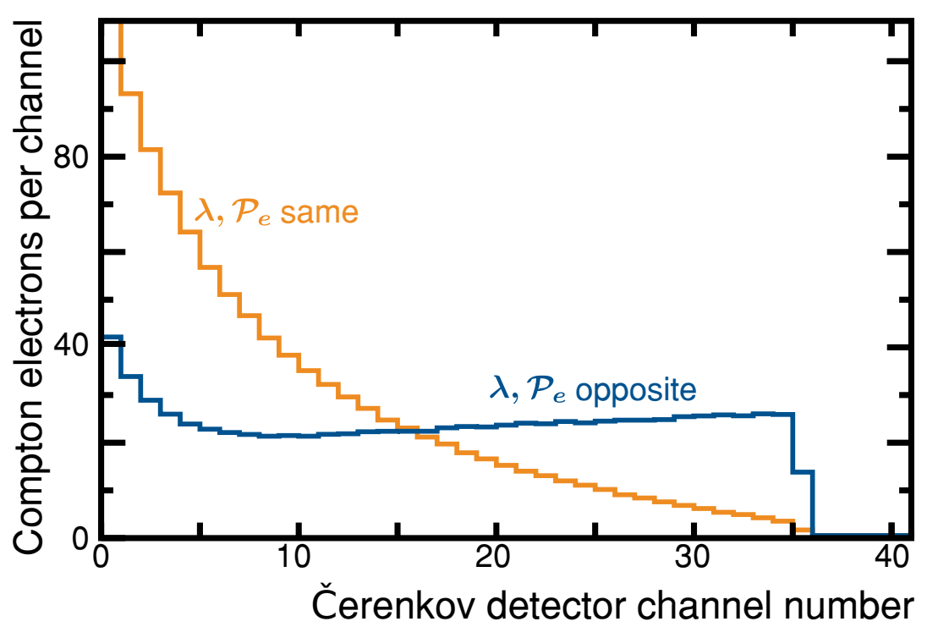
Compton polarimeters

While the annihilation data can yield the absolute polarization scale, two polarimeters per beam are foreseen to provide fast measurements which allow to track variations over time. These polarimeters rely on the polarization dependence of Compton scattering:

Circularly polarized laser light is shot under a small angle onto the individual bunches causing typically $\sim 10^3$ electrons or positrons per bunch to undergo Compton scattering. The energy spectrum of these scattered particles depends on the product of laser and beam polarizations. Inside a magnetic chicane, the energy distribution can be transformed into a spacial distribution. This distribution can be measured using a multi-channel Čerenkov detector. The rate asymmetry between measurements with two different laser helicities is directly proportional to the beam polarization.



Schematic view of the magnetic chicane for the ILC upstream polarimeter.



Simulated measurement with both helicities.

Polarimeter requirements

In order to reach the target precision of the polarimeters, $\Delta P/P \approx 0.25\%$, the design limits for the individual contributions to the systematic uncertainty of the measurement are

- 0.1% for the laser polarization,
- 0.2% for the analyzing power (asymmetry at $\mathcal{P} = 1$, i.e. alignment),
- 0.1% for the detector linearity, which corresponds to a detector non-linearity $< 0.5\,\%$.

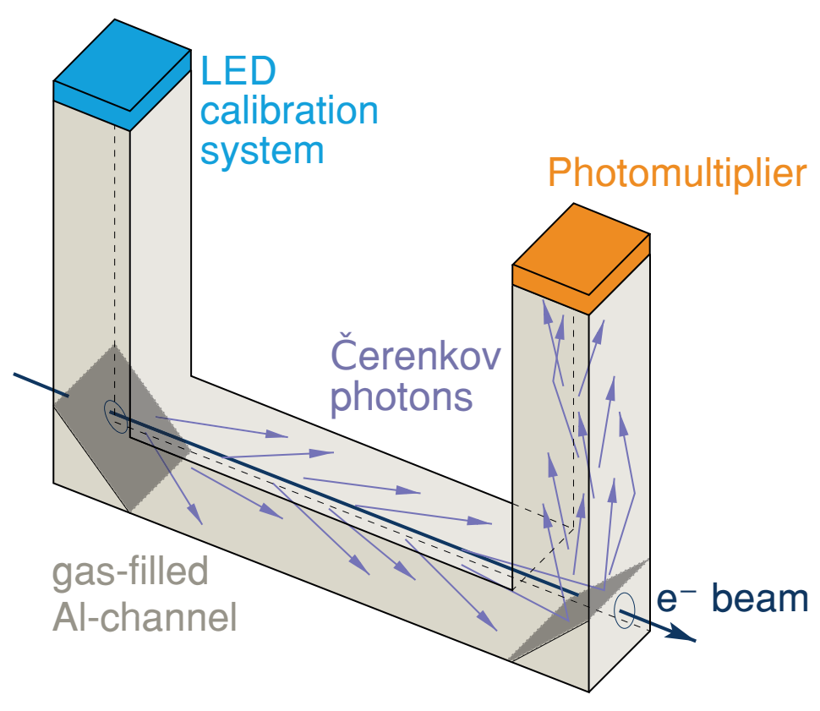
This makes the design of the Čerenkov detector a crucial issue for reaching the desired precision.

Čerenkov detector development

In order to fulfill the precision requirements, different Čerenkov detector concepts and calibration systems are investigated.

Gas Čerenkov detector

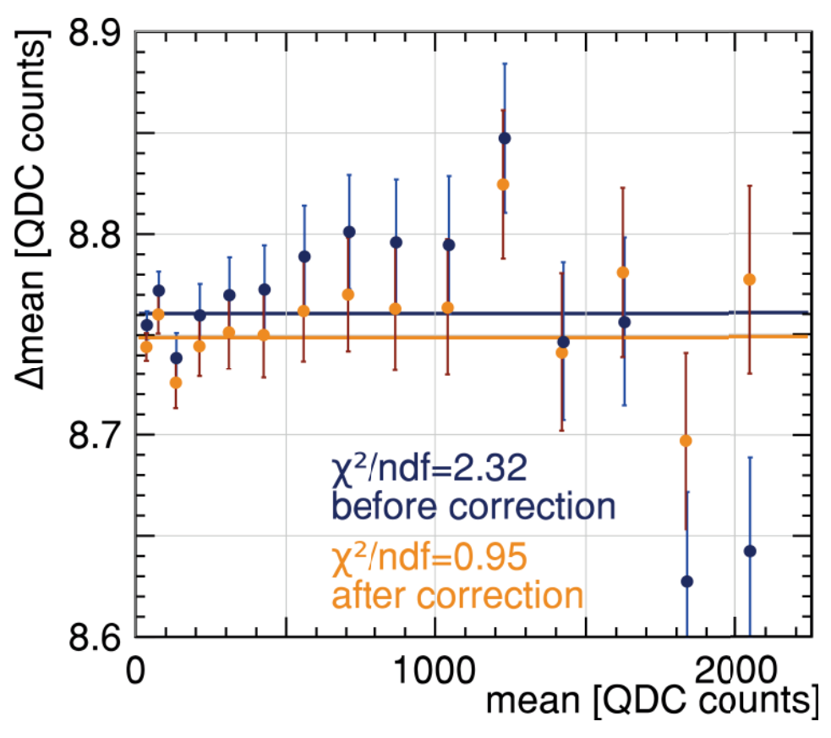
In the most precise Compton polarimeter so far (at SLD), a gas-filled Čerenkov detector was used. A design to use such a detector at the ILC has been developed, comprising U-shaped aluminum channels with an LED-calibration system on one leg and a photomultiplier tube for photon detection on the other.
The angular alignment of such a detector can be improved using multi-anode photon detectors. In the testbeam operation of a 2-channel prototype, it was possible to reach a tilt alignment of 0.1° with the determination of the asymmetry between the photodetector anodes [JINST 7, P01019 (2012)] .
This fulfills the alignment requirements within 20 % and could possibly allow to calibrate the detector position without need for dedicated beam-time.



Sketch of one gas-detector channel.

LED calibration system

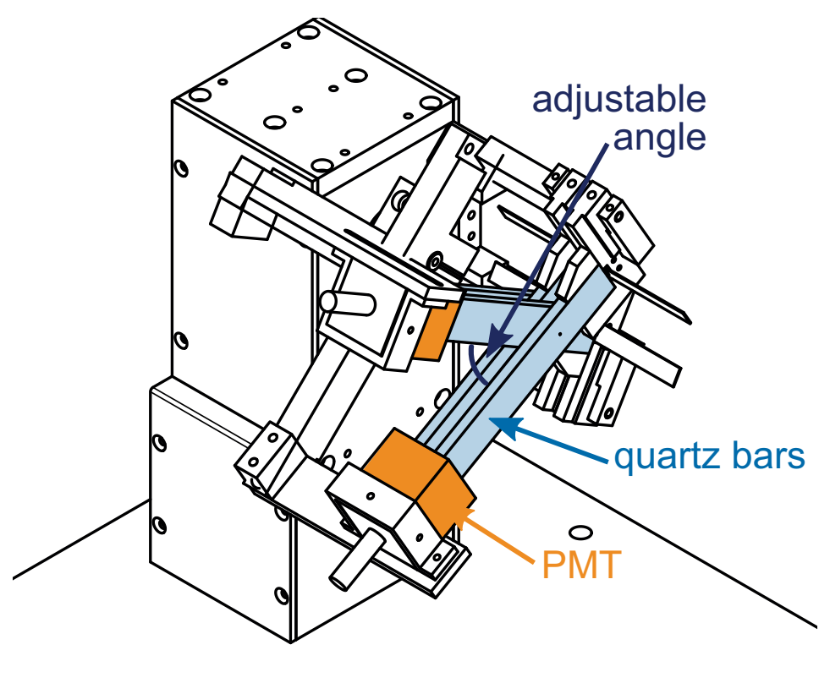
To reach the desired detector linearity, a system to measure the differential non-linearity (DNL) of the photodetectors has been designed. The system is base on an electronic circuit with two LEDs. The base LED pulse can be tuned to cover the entire dynamic range of the polarimeter. The DNL is determined by measuring the difference in the detector output with and without a small additional pulse. This allows to derive a correction function for the non-linearity. Monte Carlo studies of this method show that corrections of non-linearities up to 4 % are possible. In a test setup, one of the photomultipliers used with the gas detector prototype (Hamamatsu M5900 M4) was characterized.
A non-linearity $< 0.2\,\%$ in the expected dynamic range of the polarimeter has been reached.



Differential non-linearity correction.

Quartz Čerenkov detector

Alternatively, the use of a quartz as Čerenkov material for the upstream polarimeter is currently investigated. The higher refractive index of quartz compared to the common gas detector results in a higher photon yield. This could allow to resolve individual Compton e^- peaks in the photoelectron spectrum. In that case, an online calibration of the photomultiplier gain would be possible.
The possible detector design has been optimized in detailed simulations, in which the single peak resolution has been achieved.
A four channel prototype of such a quartz detector has been operated in a first testbeam campaign at the DESY II testbeam this year.



Sketch of the quartz detector prototype.

http://www-flc.desy.de/polarimetry

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