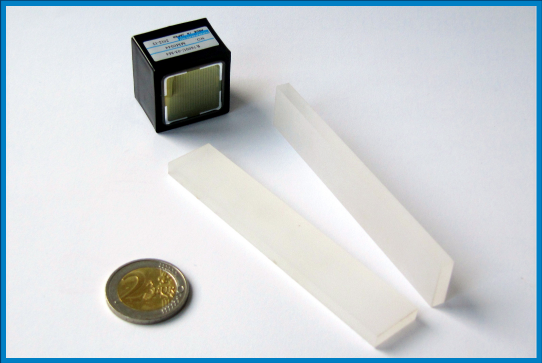
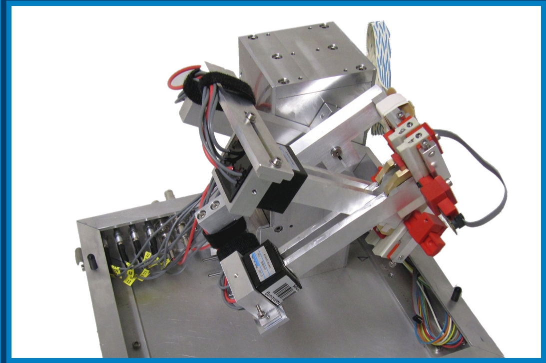
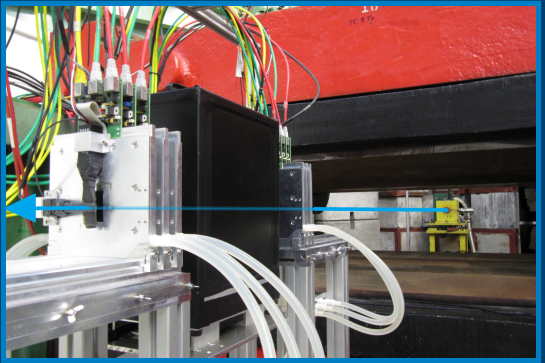
A Quartz Cherenkov Detector for Polarimetry at the ILC.

Jenny List, Annika Vauth

Mainz, 13.02.2014







Spin-Optimierung polarisierter Leptonstrahlen an Beschleunigern
(BMBF-Verbundforschungsprojekt mit UHH, Mainz, Bonn)

Teil-Projekt "Spin-Umsetzung":
Erreichbare Genauigkeit von Compton-Polarimetern

Bundesministerium
für Bildung
und Forschung

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

DESY

ilc

Polarimetry at the ILC

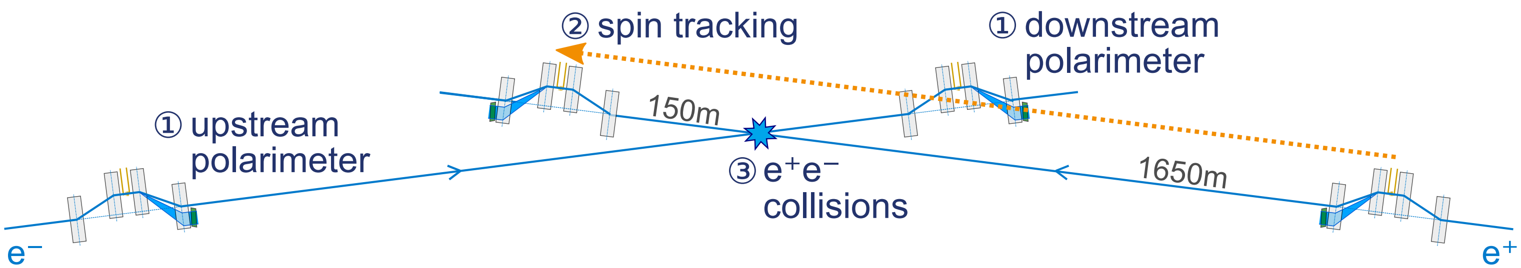
Quarz detector design

Detector application

Summary and Outlook

Polarimetry at the ILC.

Polarisation at the ILC: $P(e^+) \gtrsim 30\%$, $P(e^-) \approx 80\%$
Goal for ILC polarimetry: per mille level precision by combining



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

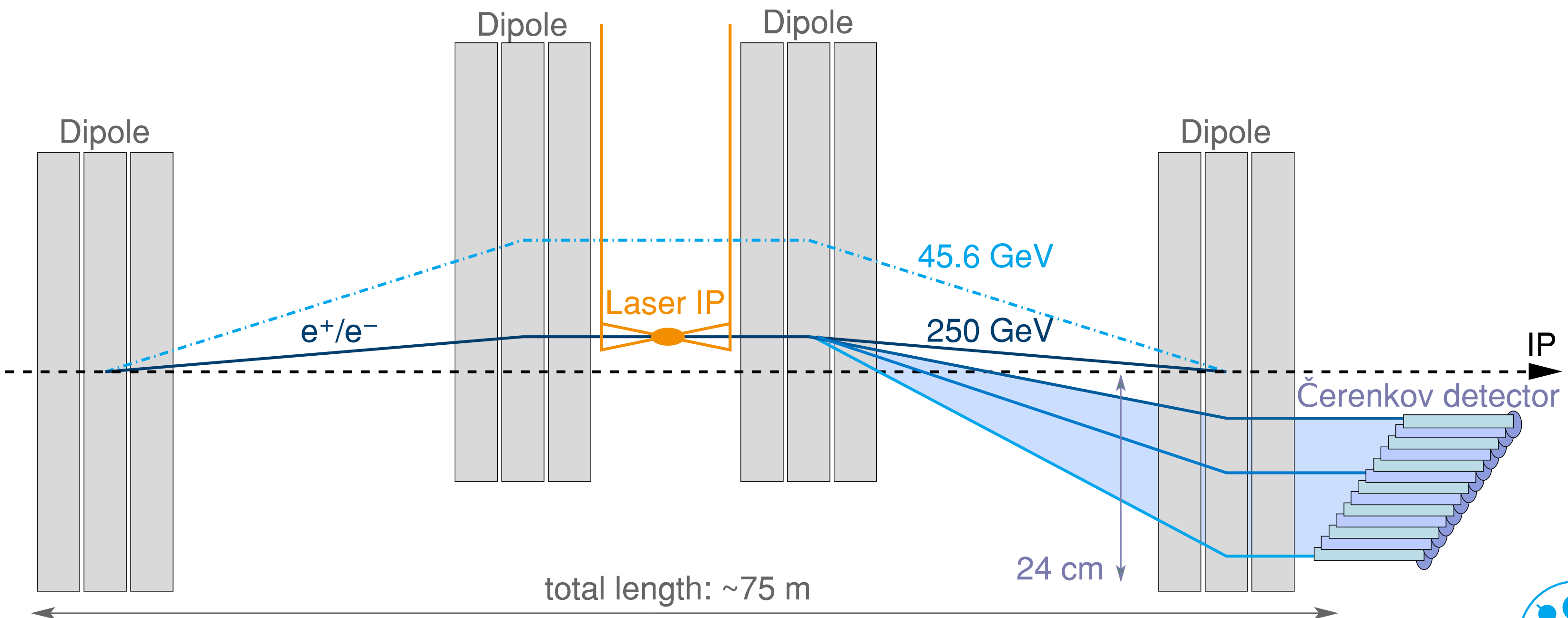
② Spin tracking studies to relate these measurements to the polarization at the e^+e^- interaction point

③ Long-term average determined from e^+e^- collision data as absolute scale calibration

Compton polarimeters.

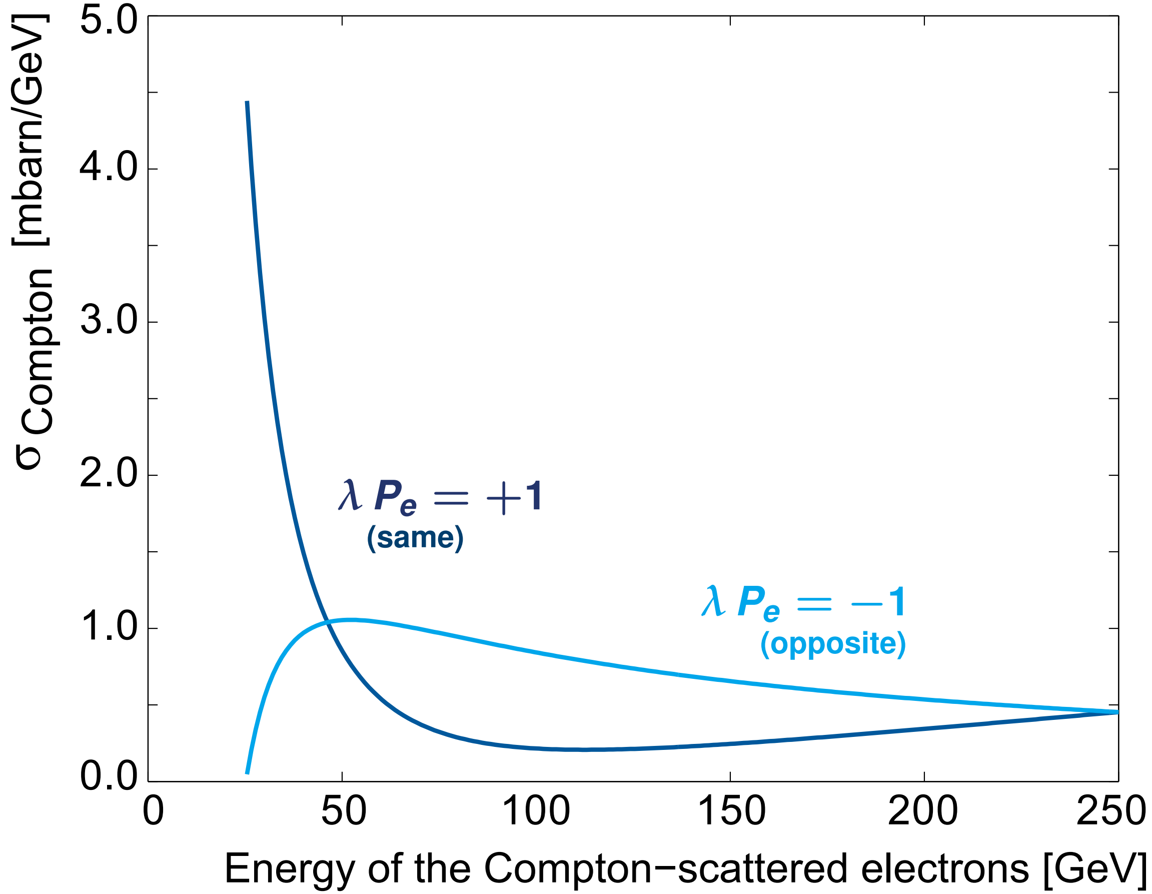
- $\mathcal{O}(10^3)$ Compton scatterings/bunch
- Energy spectrum of scattered e^+/e^- depends on polarisation
- Magnetic chicane:
  energy distibution $\longrightarrow$ spacial distribution ($\sim$ 20 cm wide)

$\Rightarrow$ Measure number of e^+/e^- per detector channel



Measurement principle.

Compton rate asymmetry is proportional to the beam polarisation:



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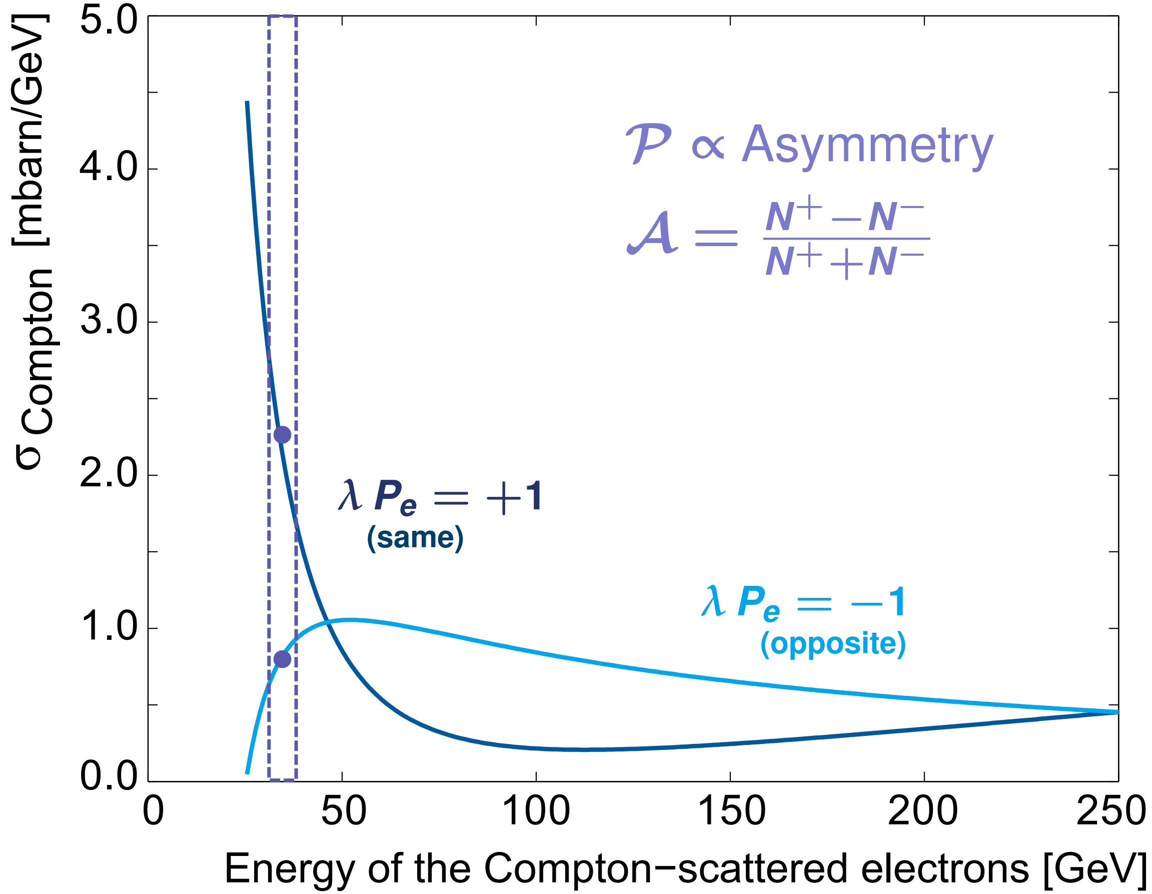


Detector requirements.

Requirements for the Compton electron detector behind the magnetic chicane:

- read out signals of 1000-2000 Compton electrons (25-250 GeV) every bunch crossing
- either very linear response or “counting“ electrons
- alignment to $\sim$ 100 µm and $\sim$ 1 mrad
- suppression of background from low energetic particles

Simple, robust, fast: Cherenkov detectors

- Cherenkov light emission proportional to number of electrons
- independent of electron energy (once relativistic)
- successfully used in best polarimeter so far at SLC

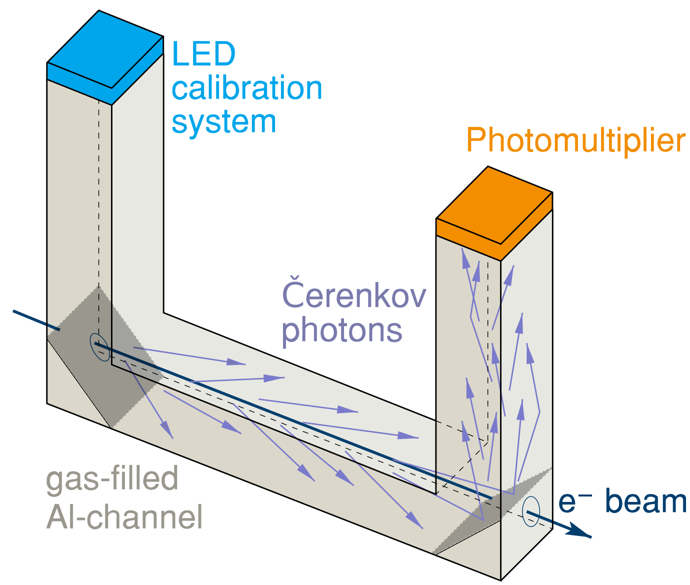
Detector options.

Goal: total uncertainty $\Delta P / P \approx 0.25\,\%$, of which

- laser: 0.1 %
- analysing power (i.e. asymmetry at $\mathcal{P} = 1$): 0.2 %
  $\Rightarrow$ Cherenkov detector design
- detector linearity: 0.1 % $\Rightarrow$ photodetector calibration

Gas Cherenkov detector

2-channel prototype:
tilt alignment of 0.1 ° reached
[JINST 7, P01019 (2012)]



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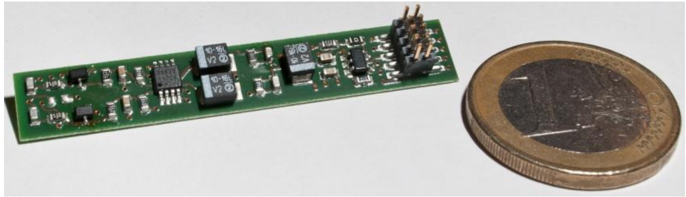
LED driver developed for
differential calibration method

$\longrightarrow$ fulfils requirements
[thesis B. Vormwald]



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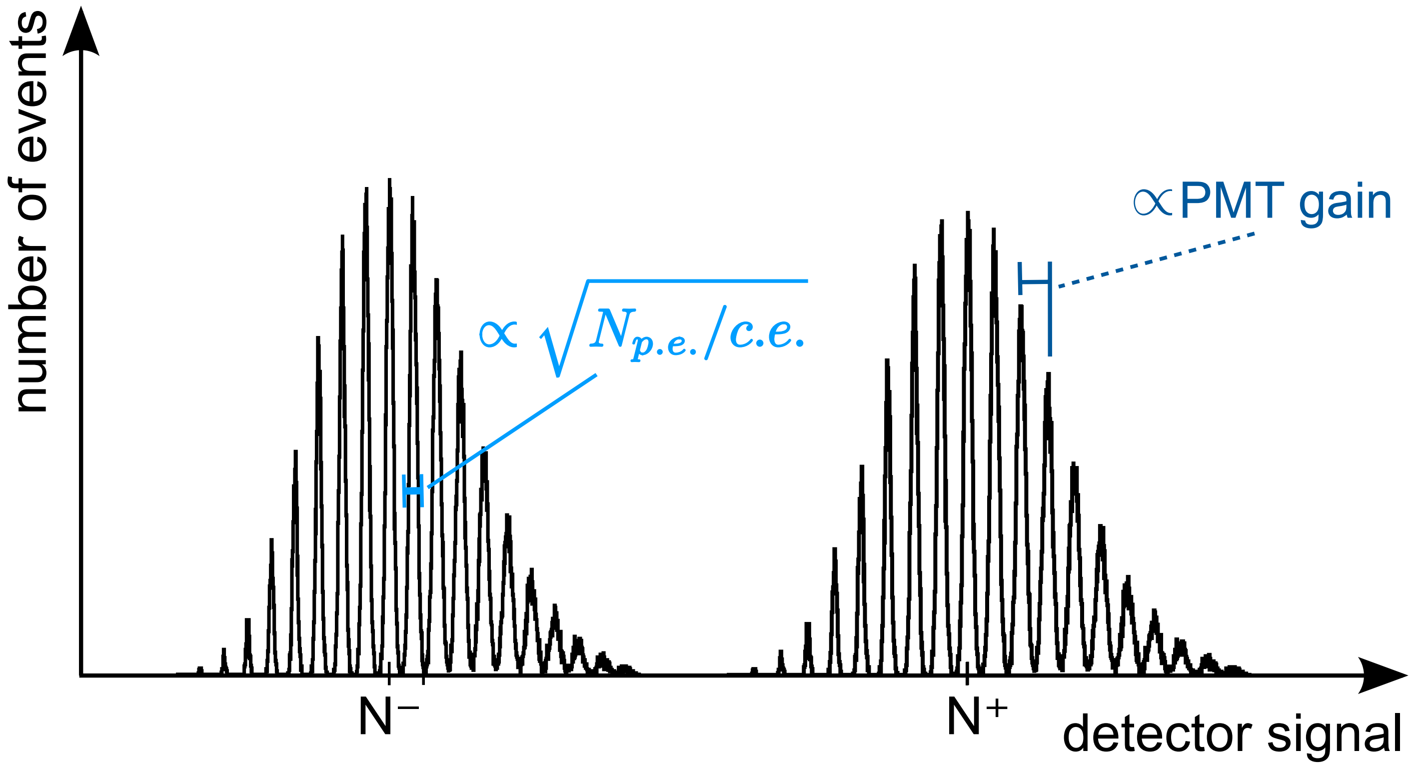
In the scope of the BMBF spin optimisation project:

Alternate detector concept studied:
Quartz as Cherenkov material.

Why quartz? Self-calibrationg detector.

For a large enough number of photons per Compton electron,
e.g. for 15 e^- per detector channel: $\gtrsim$ 200 photons per e^-
resolution of single peaks possible $\Rightarrow$ self-calibration!



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For a large enough number of photons per Compton electron,
e.g. for 15 e^- per detector channel: $\gtrsim$ 200 photons per e^-
resolution of single peaks possible $\Rightarrow$ self-calibration!

a) less Compton electrons: smaller channels
b) higher light yield: quartz as Cherenkov material

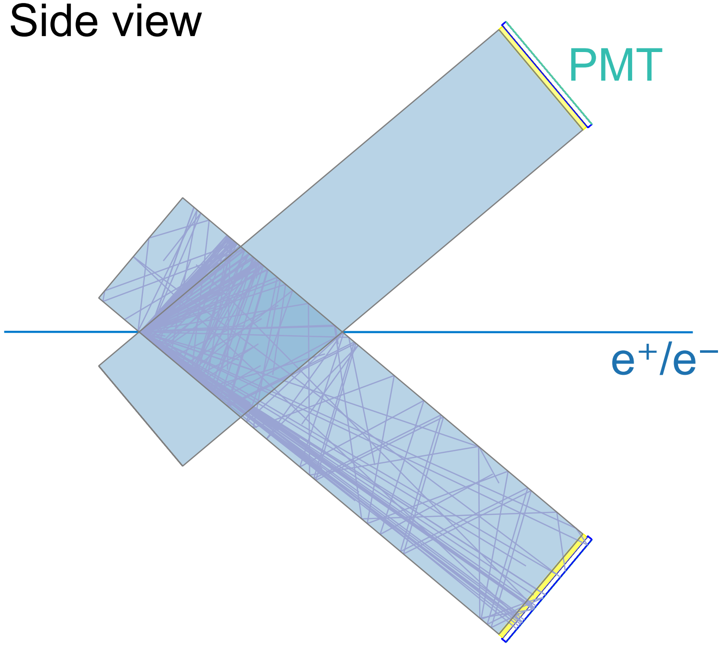
Properties of fused silica

- refractive index n≈1.45 (for comparision: $n(C_4F_{10}) = 1.0014$)
- Cherenkov angle $\theta_c \approx 46^\circ$
- Cherenkov threshold $E_{thr} \approx 0.9\,\text{MeV}$

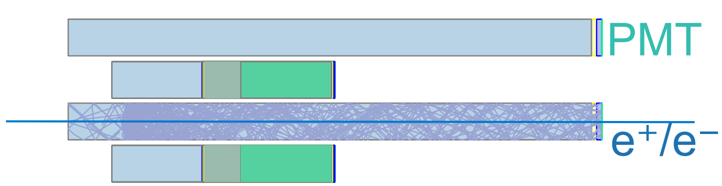
GEANT4 Simulation.

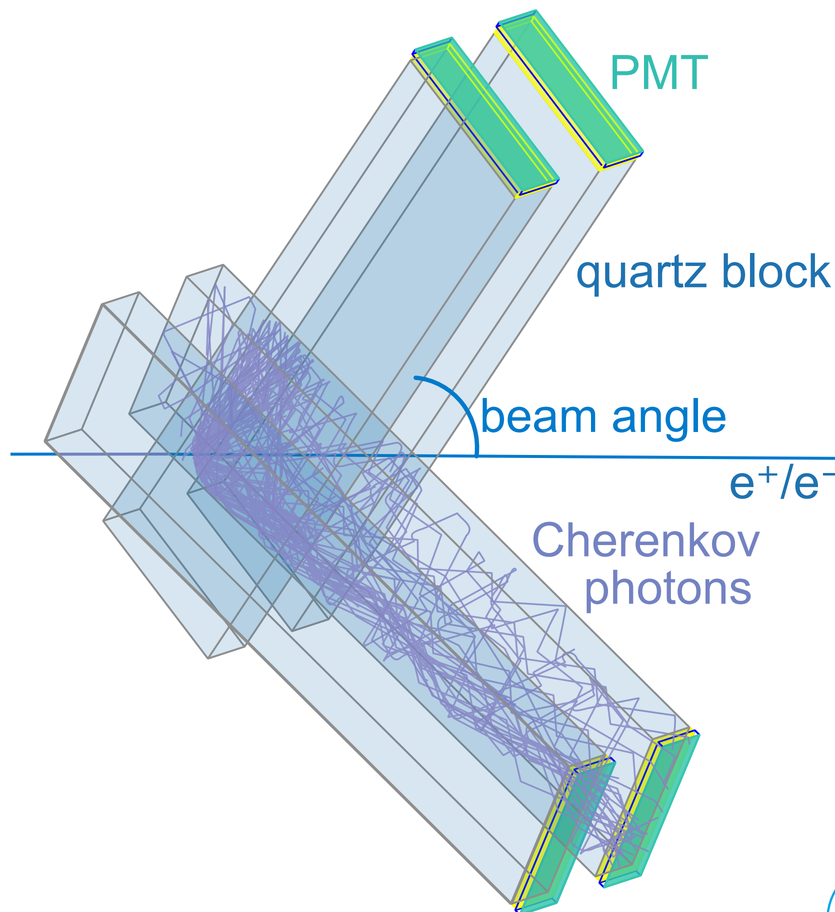
Multiple quartz bars / channels
(rotated → more space for photomultipliers and read-out)

Side view



top view



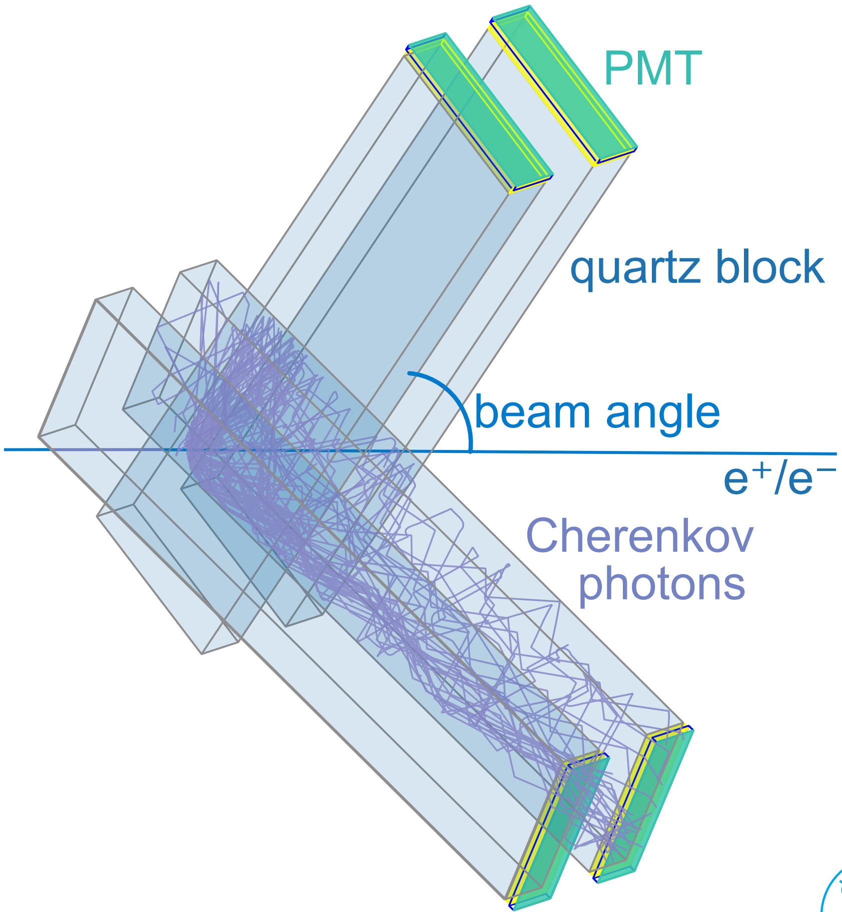


GEANT4 Simulation.

Multiple quartz bars / channels
(rotated $\longrightarrow$ more space for photomultipliers and read-out)

Implementation in GEANT4:

- Fused silica blocks
- photomultiplier (PMT) window and cathode
- coupled with optical grease
- different surface properties

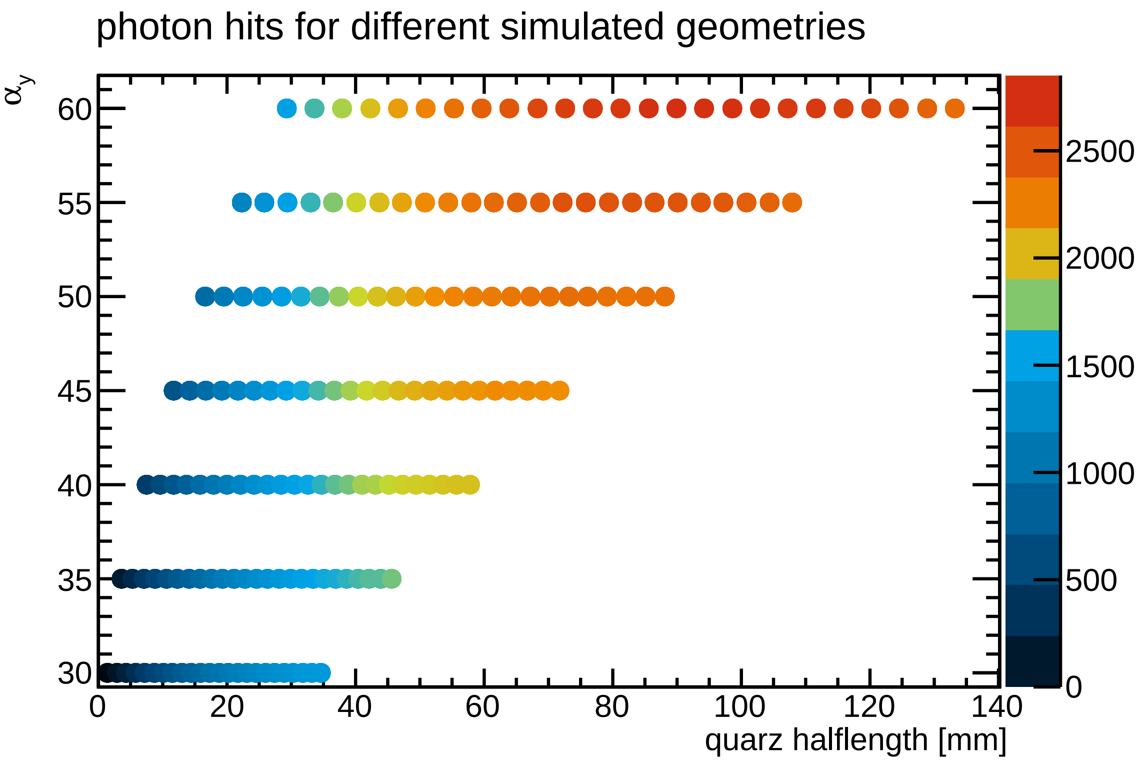


Detector geometry.

Simulation of different incident angles, channel dimensions, ...

Number of photon hits on PMT with different detector geometries

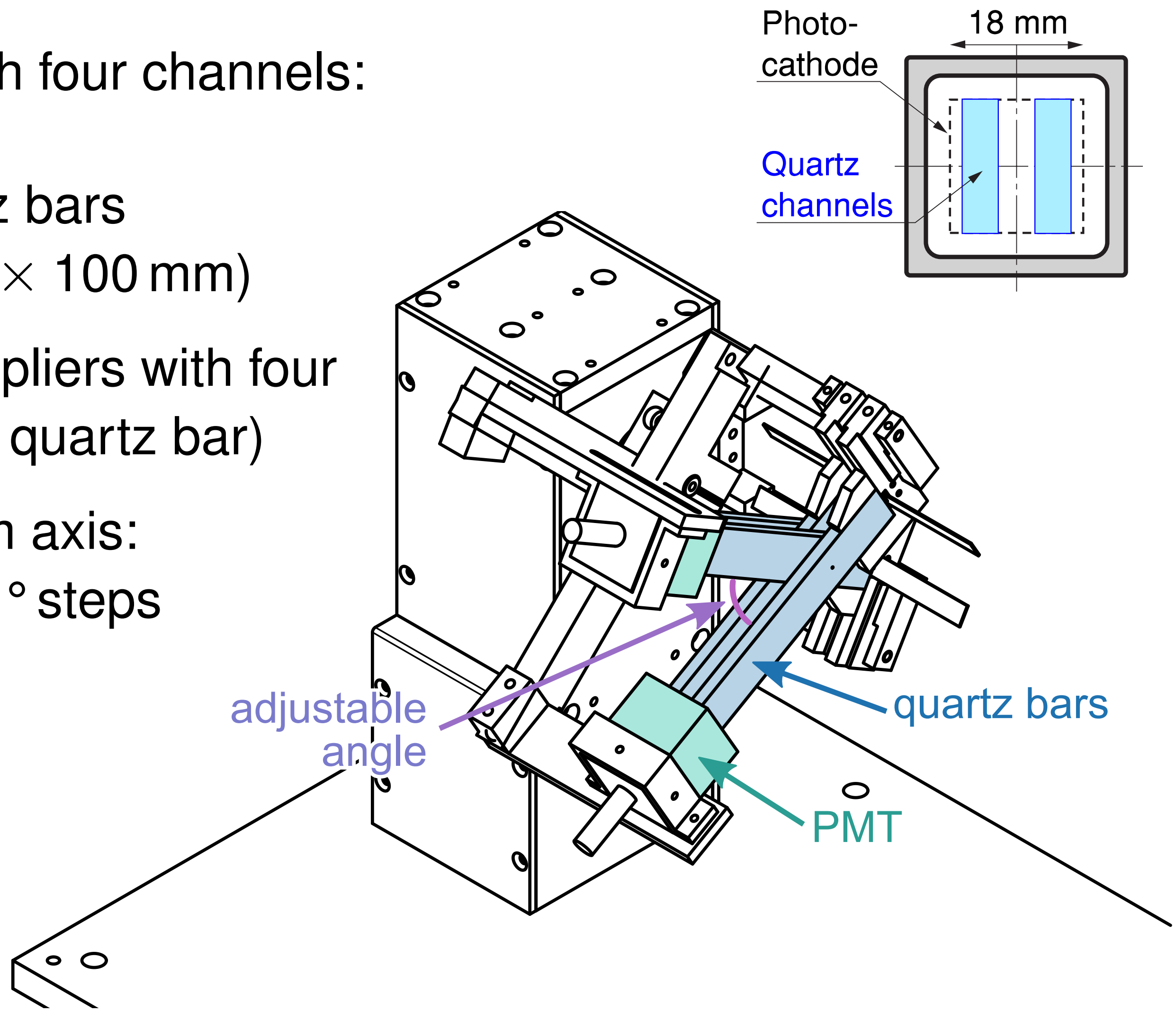
(length, height and angle chosen so that distance between electrons and PMT is 3 cm):



Quartz prototype.

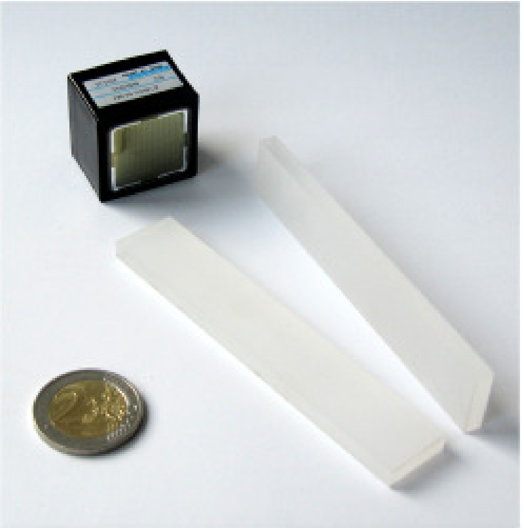
Quartz prototype with four channels:

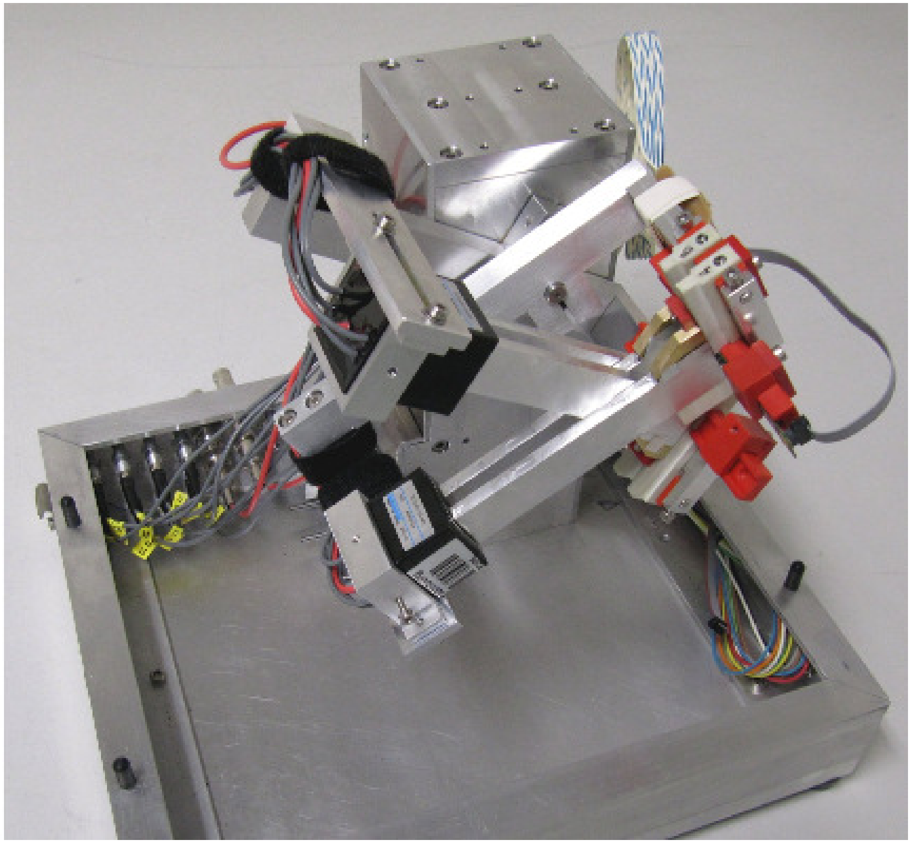
- channels: quartz bars (5 mm × 18 mm × 100 mm)
- using photomultipliers with four anodes (two per quartz bar)
- angle w.r.t. beam axis: adjustable in 0.5° steps



Quartz prototype.

Quartz prototype with four channels:





⇒ *DESY II Testbeam 22.04. - 05.05.2013*

Polarimetry at the ILC

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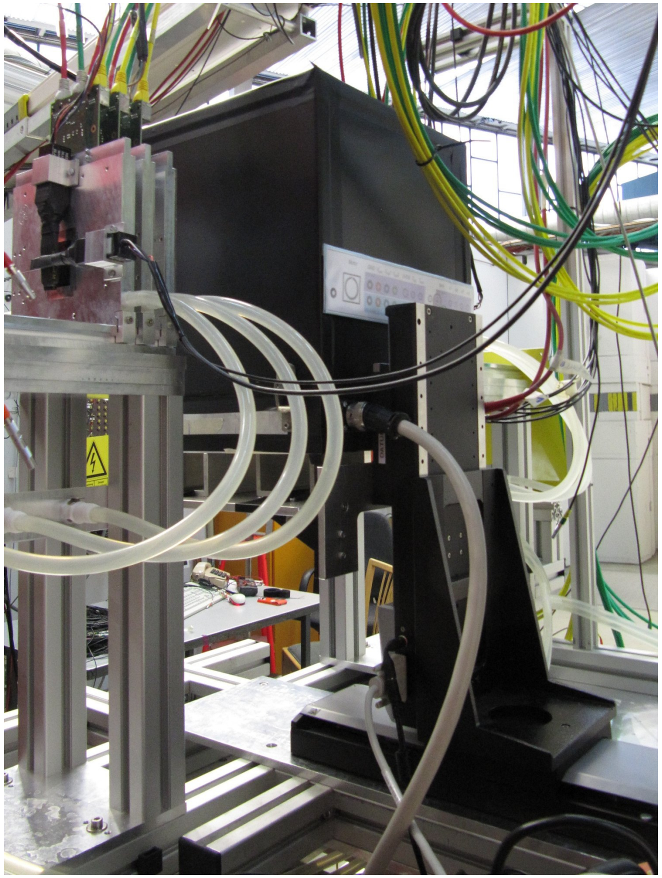
Summary and Outlook

DESY Testbeam 2013.

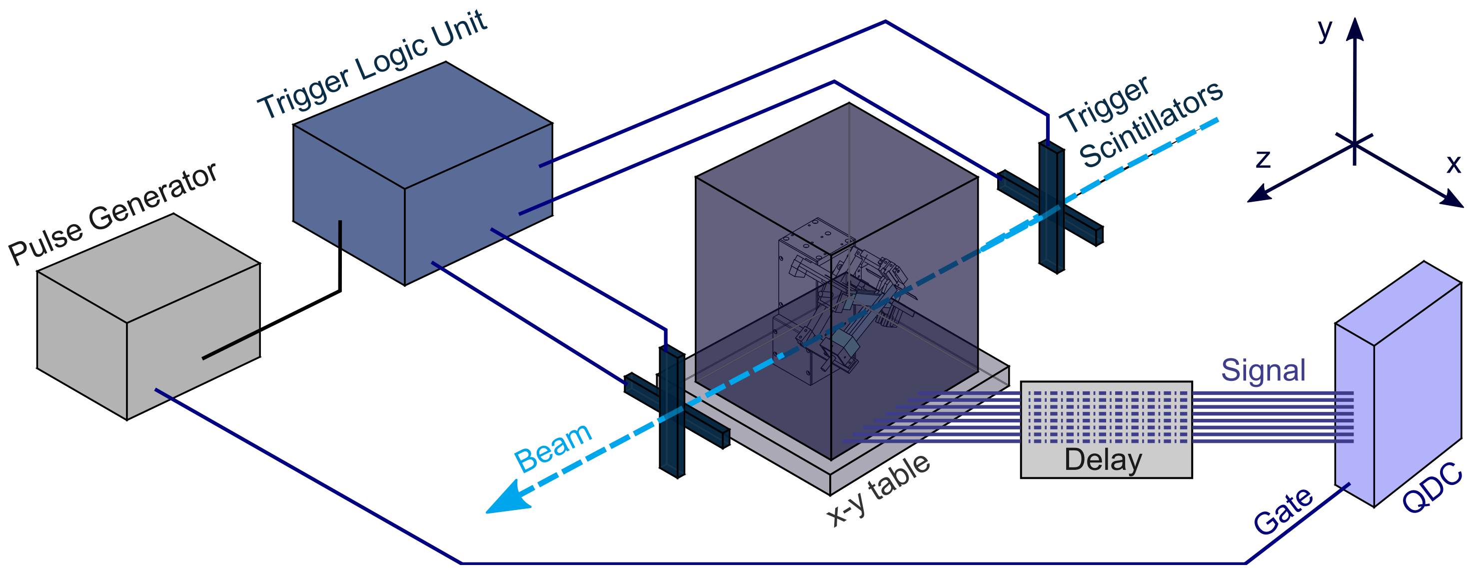
Goals for the testbeam:

- Test detector signal for single electrons
- Compare light output to expectations
- Study detector response for different angles and positions



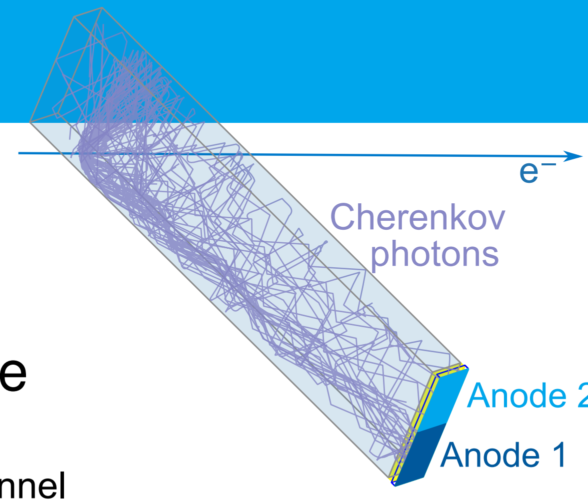
DESY Testbeam: Setup.

- Angle of the quartz bars: controlled with stepping motor
- Movement of the whole detector: used testbeam x-y table



- Trigger: coincidence of four scintillators
- Generate QDC (charge digitizer) gate on trigger signal
- Delay photomultiplier signal long enough to fall inside gate

Number of photons (data).

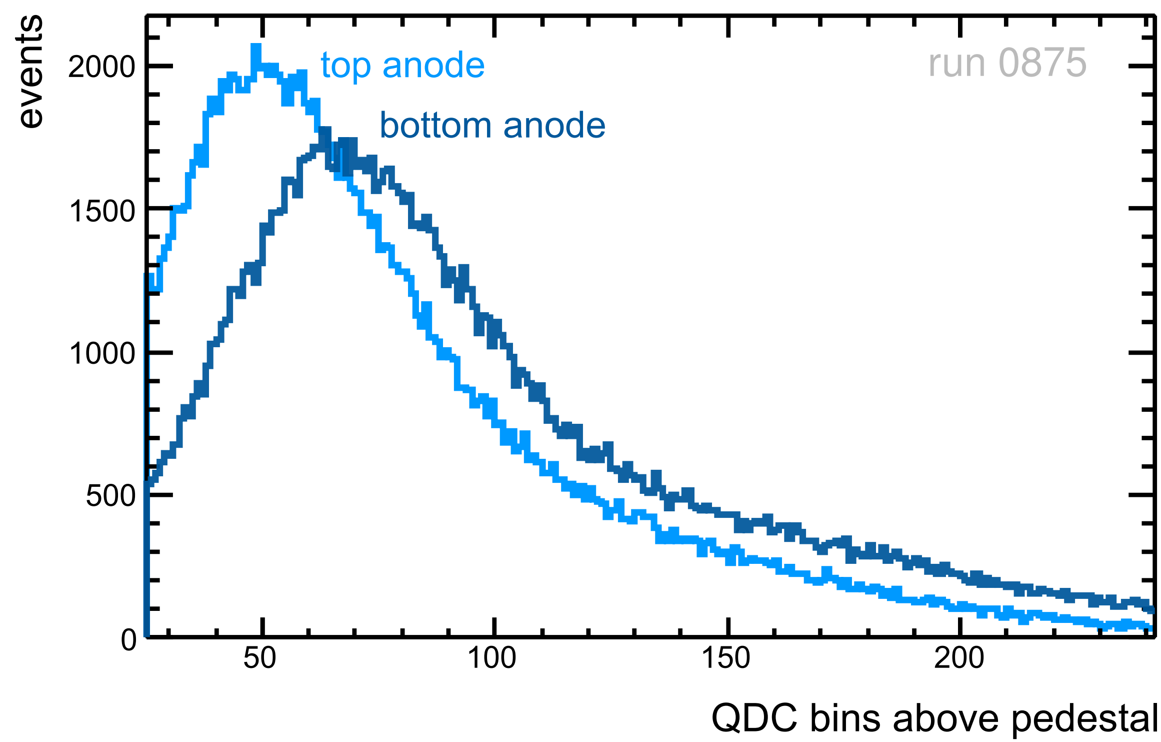


With the gain / HV settings used:

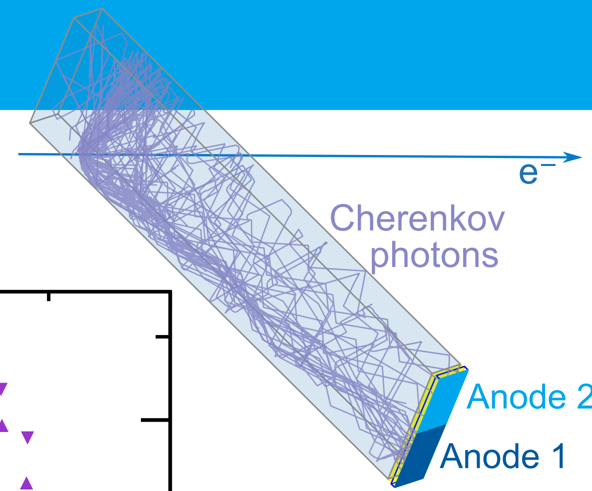
1 photon $\approx$ 1.5 QDC bins

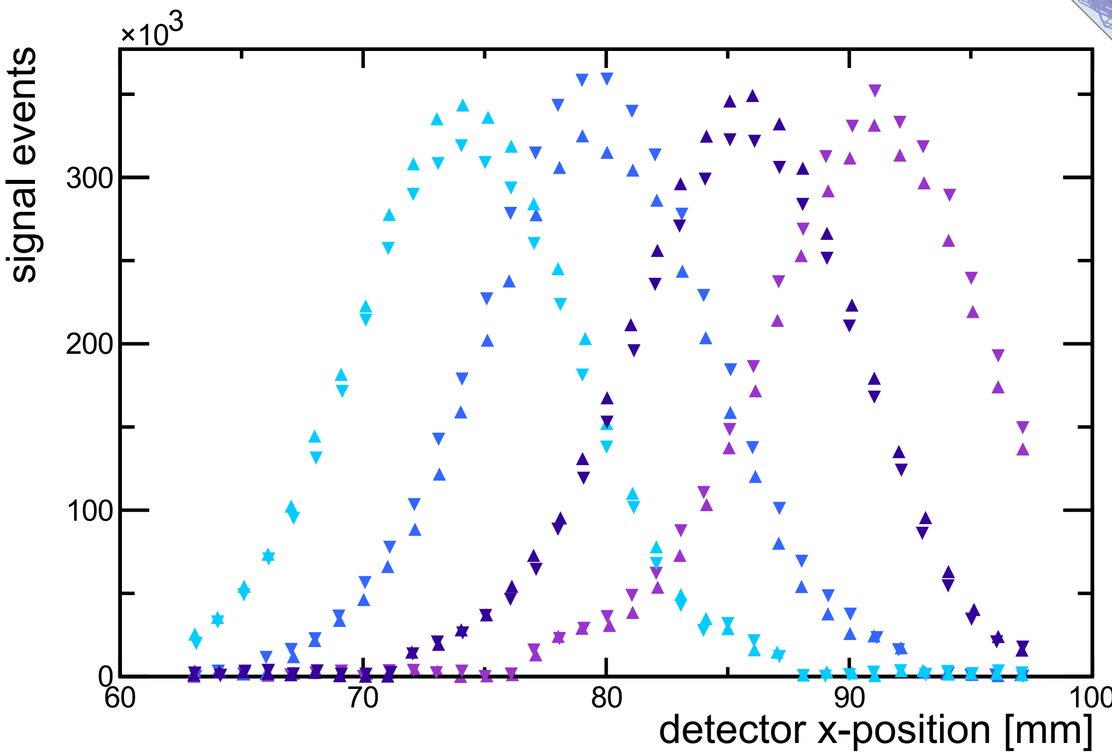
Predicted by simulation: $\sim$ 40 photons per anode

Example: QDC signal for both anodes on one quartz channel



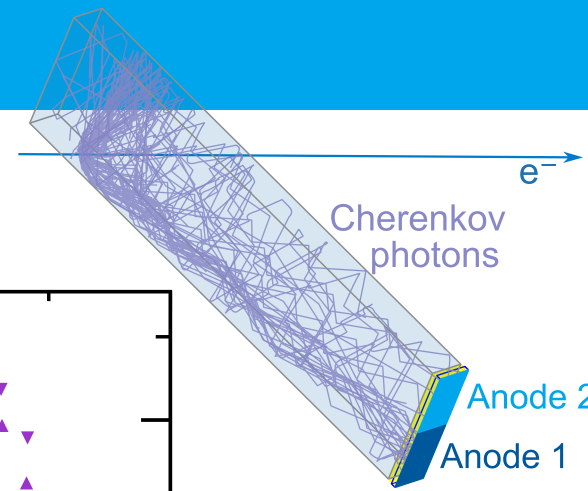
X-position scan (data).

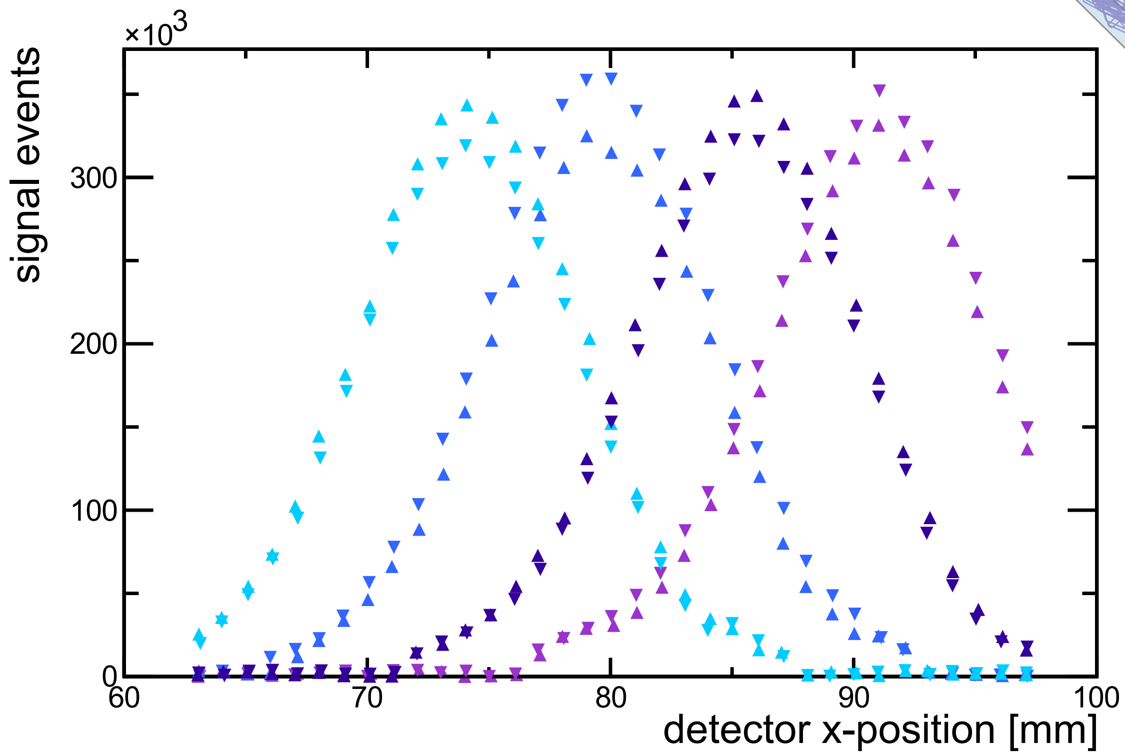




- x=5 mm wide channels
- scan across x-direction → determine beam spot size

X-position scan (data).

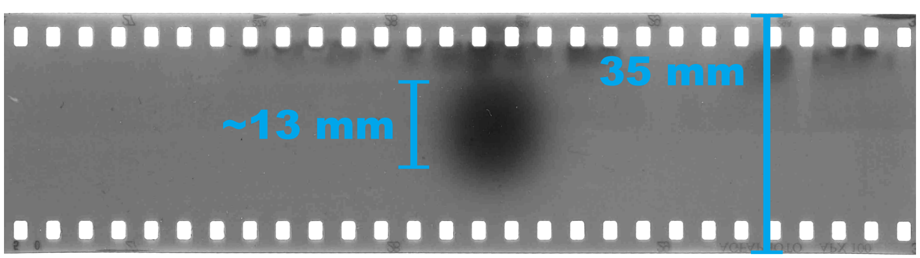




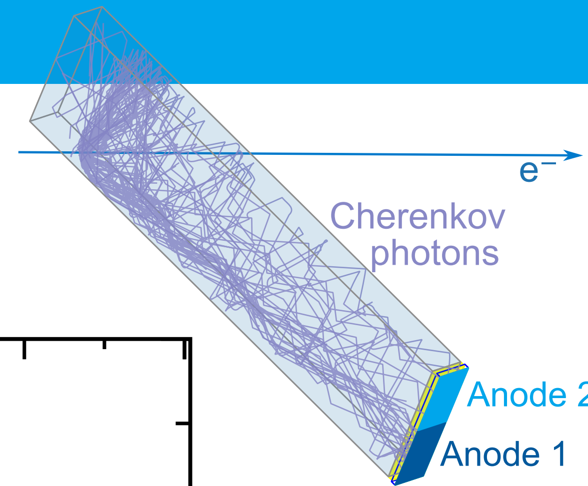
varied in simulation:

$\longrightarrow$ beam profile with

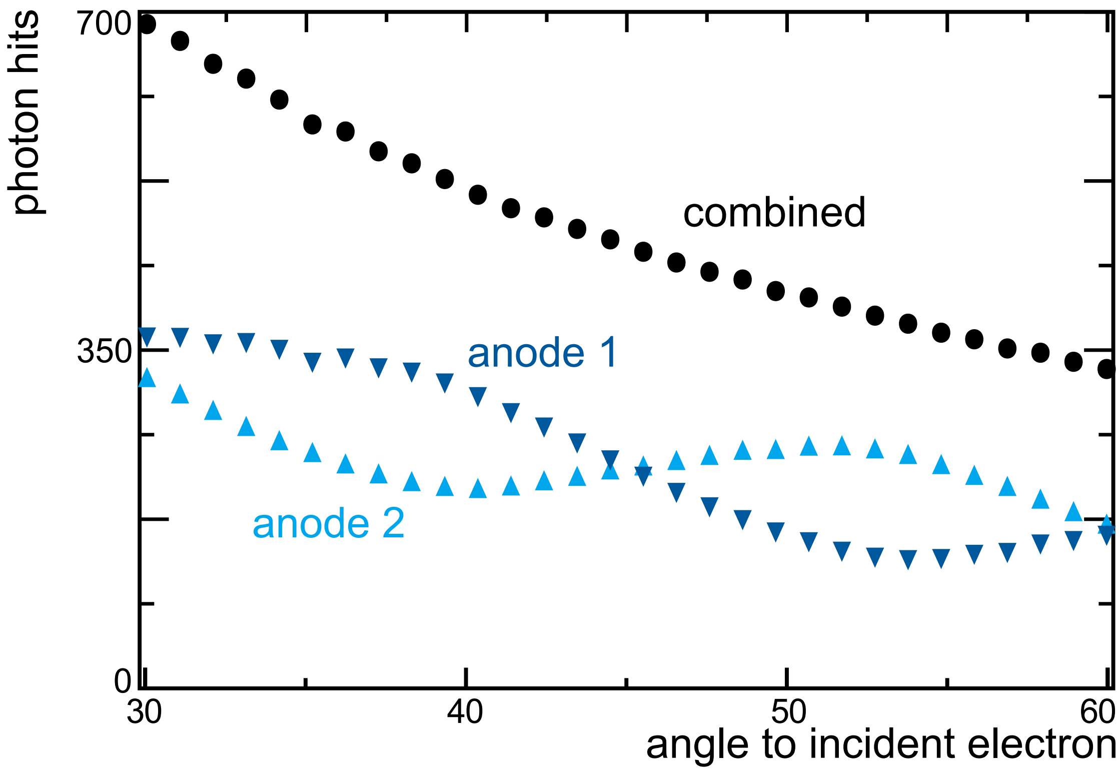
$\sigma \approx 4.7\,\mathrm{mm}$



Angle scan (simulation).

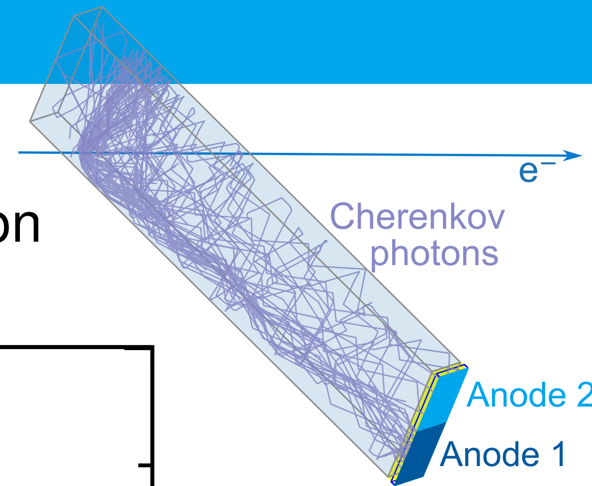


Use two anodes per channel for alignment?

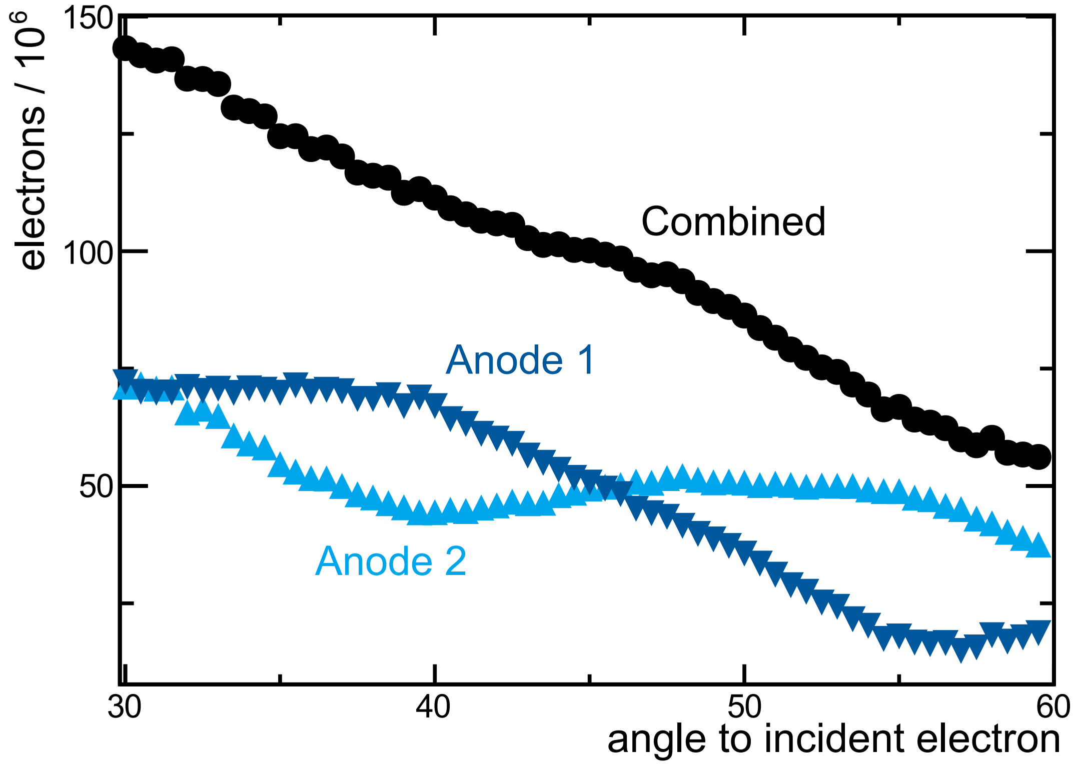


Ratio between anodes of a channel angle dependent

Angle scan (data).



Qualitatively similar behaviour as in the simulation



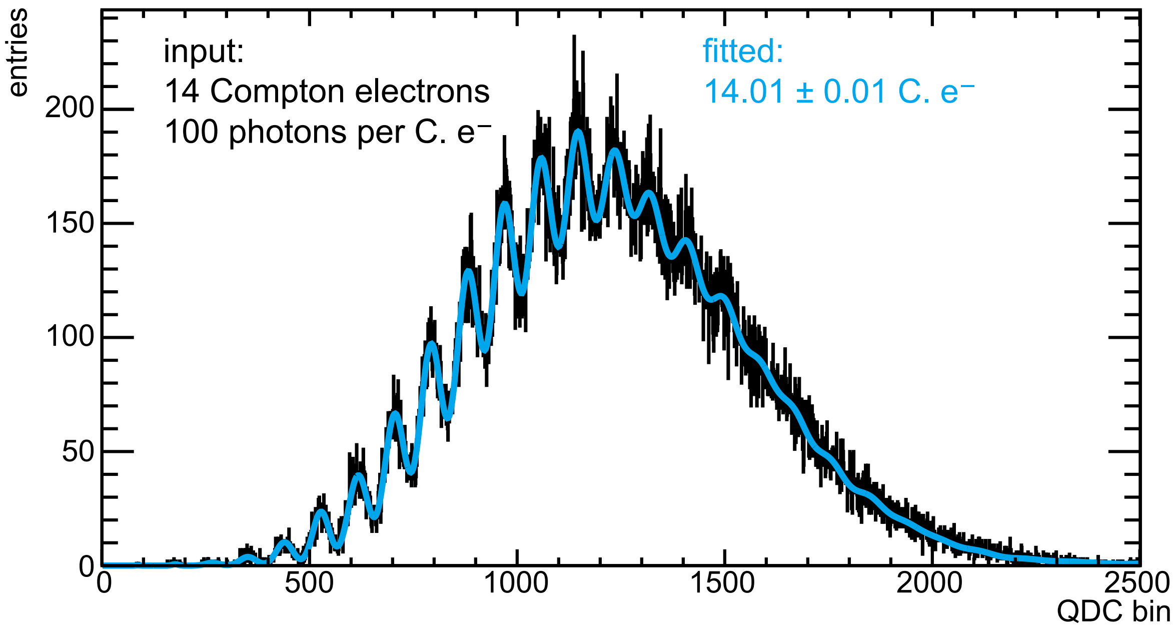
→ Comparison with simulation to determine tilts/shifts of detector: work in progress

Multi-electron spectra (simulation).

How many Compton electrons per channel would be possible?

Simulation with 200 detected photons per Compton electron

(from Compton electrons to spectrum at the charge-to-digital converter (QDC))

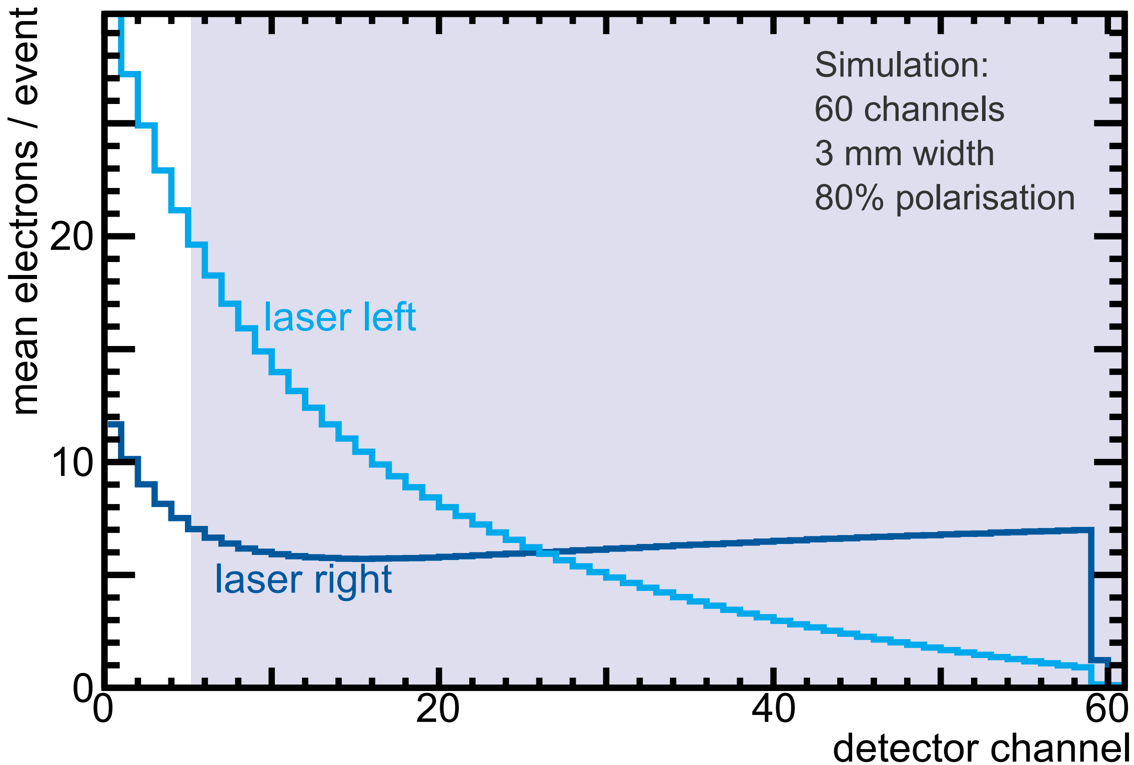


→ for ≤20 electrons majority of single peaks can be separated

Comparison to requirements (simulation).

Simulated polarisation measurement:

(80 % polarsation, 3 mm wide detector channels)



→ nearly all channels ≤20 electrons.

Polarimetry at the ILC

Quarz detector design

Detector application

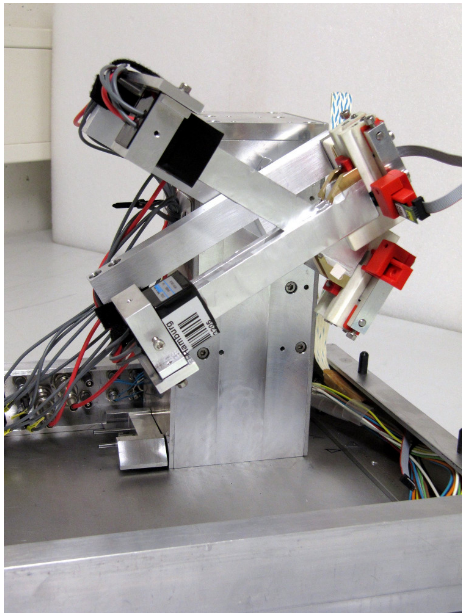
Summary and Outlook

Summary and Outlook (1).

Quartz detector:

- Option for polarimeter detector: quartz as Cherenkov medium
- Prototype designed, constructed & and tested at DESY II testbeam:
  - Test detector signal for single electrons ☑
  - Compare light output to expectations (☑)
  - Study detector response for different angles and positions (☑)

    Qualitative agreement with simulation, more detailed alignment work in progress



Outlook:

- Study application on full polarisation measurement

Summary and Outlook (2).

Compton polarimetry at ILC:

Precision goal for ILC polarimetry: $\Delta P/P \approx 0.25\%$

Needs combination of:

- scale calibration from e^+e^- collision data
- spin tracking and understanding of collision effects
- upstream (UP) and downstream (DP) polarimeters
  - **UP**: time resolution
  - **DP**: collision effects
  - **combined**: cross-check, lumi-weighted polarisation @ IP

Outlook:

- site specific studies
- detectors: prototypes $\longrightarrow$ full-scale, DAQ, ...