A Quartz Cherenkov Detector for Polarimetry at the ILC

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ECFA Linear Collider Workshop 2013

DESY

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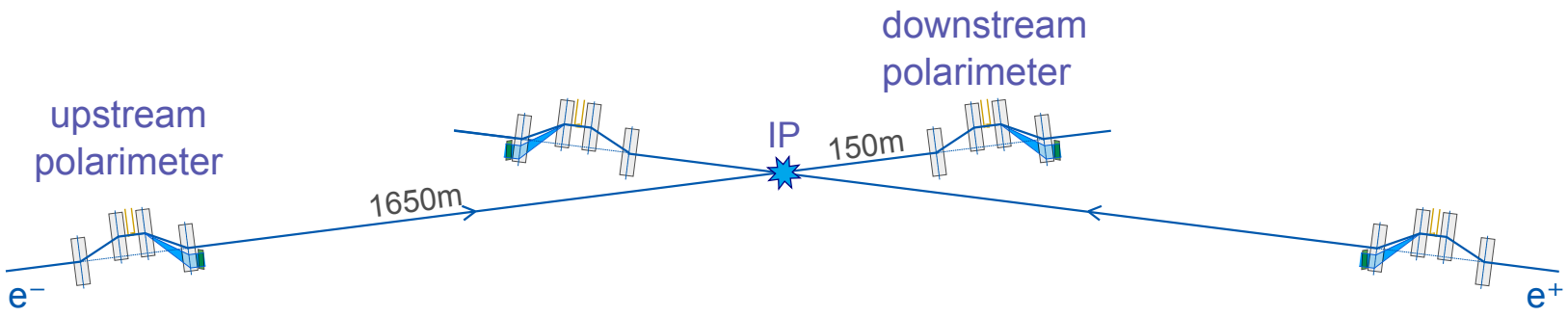
für Bildung
und Forschung

Polarimetry at the ILC

Polarimetry at the ILC

Polarisation at the ILC:

- $P(e^+) \gtrsim 30\%$, $P(e^-) \approx 80\%$
- (B)SM crosssections depend on polarisation.
  $\rightarrow$ To fully exploit the physics potential: precision polarimetry!
- Compton polarimeters for each beam, before and after the IP

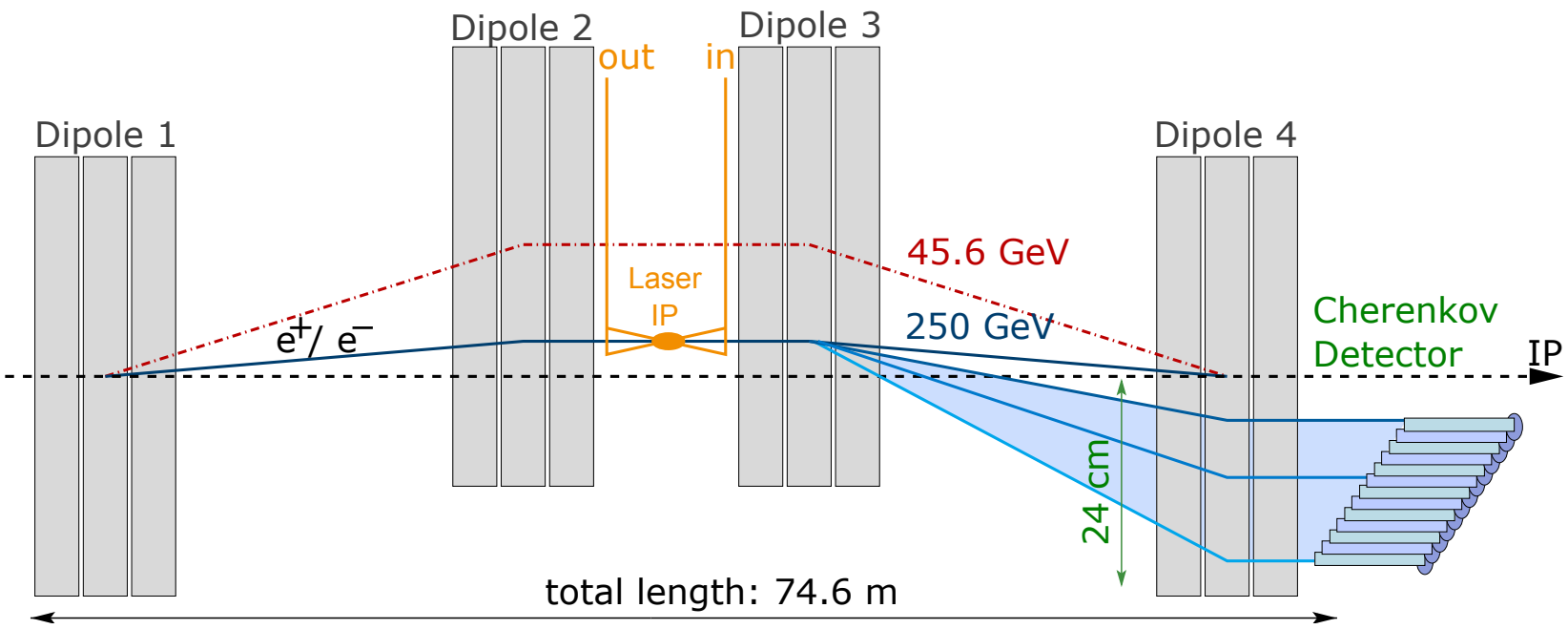


Goal for polarimetry at the ILC:

measure polarisation with precision $\Delta P/P \approx 0.25\%$

Polarimetry at the ILC

- $\mathcal{O}(10^3)$ Compton scatterings/bunch
- Energy spectrum of scattered e^+/e^- depends on polarisation
- Magnetic chicane: energy distibution $\rightarrow$ position distribution
- Measure number of e^+/e^- per detector channel



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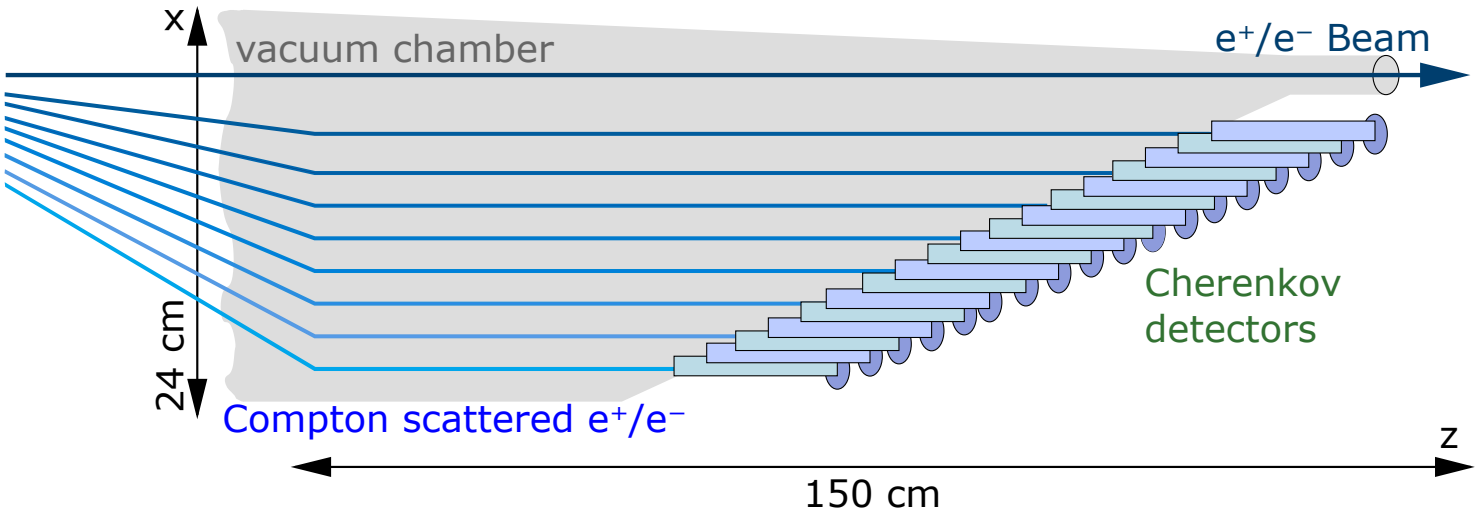
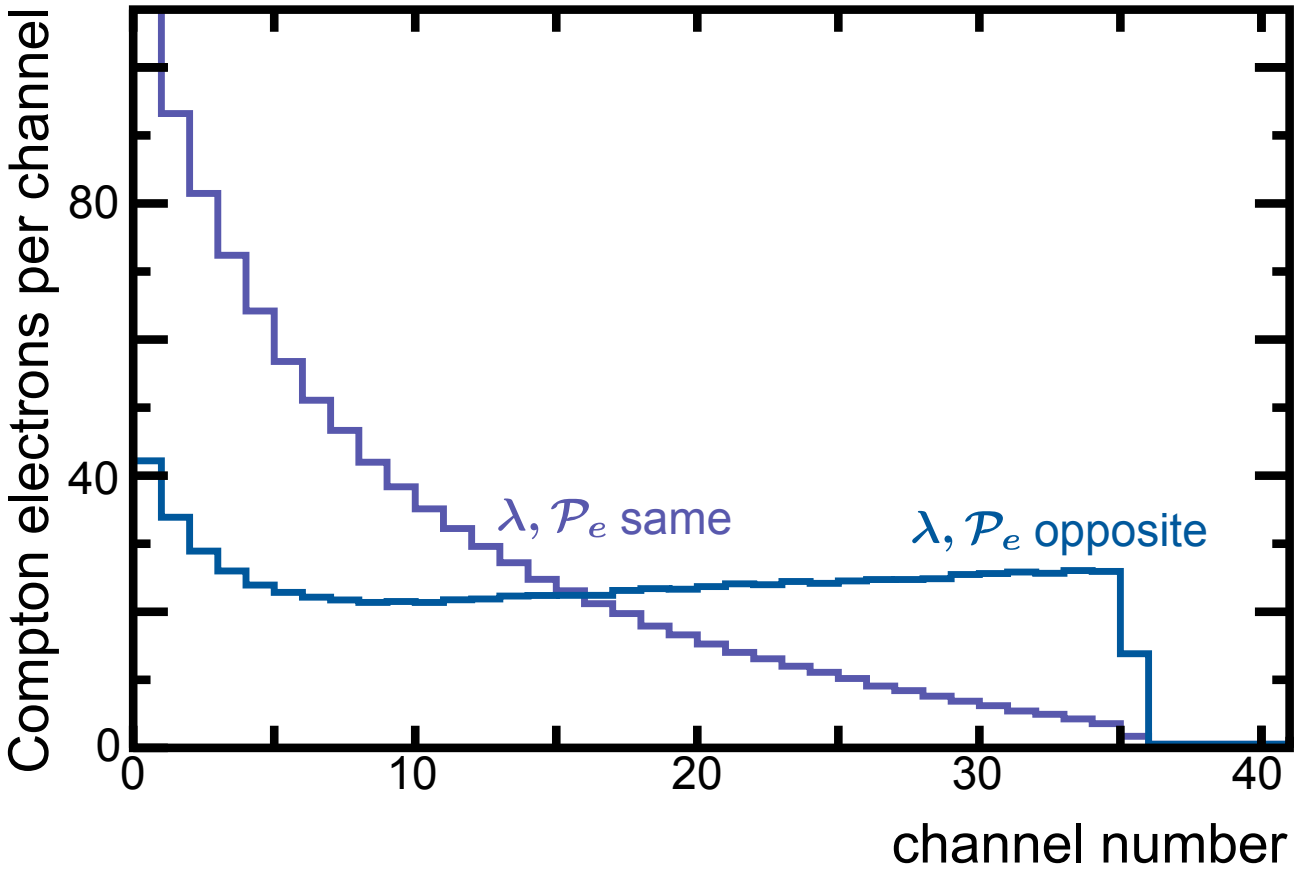


Polarisation Measurement

Compton rate asymmetry is proportional to the beam polarisation.
Expected number of Compton electons in 5 mm wide channels:



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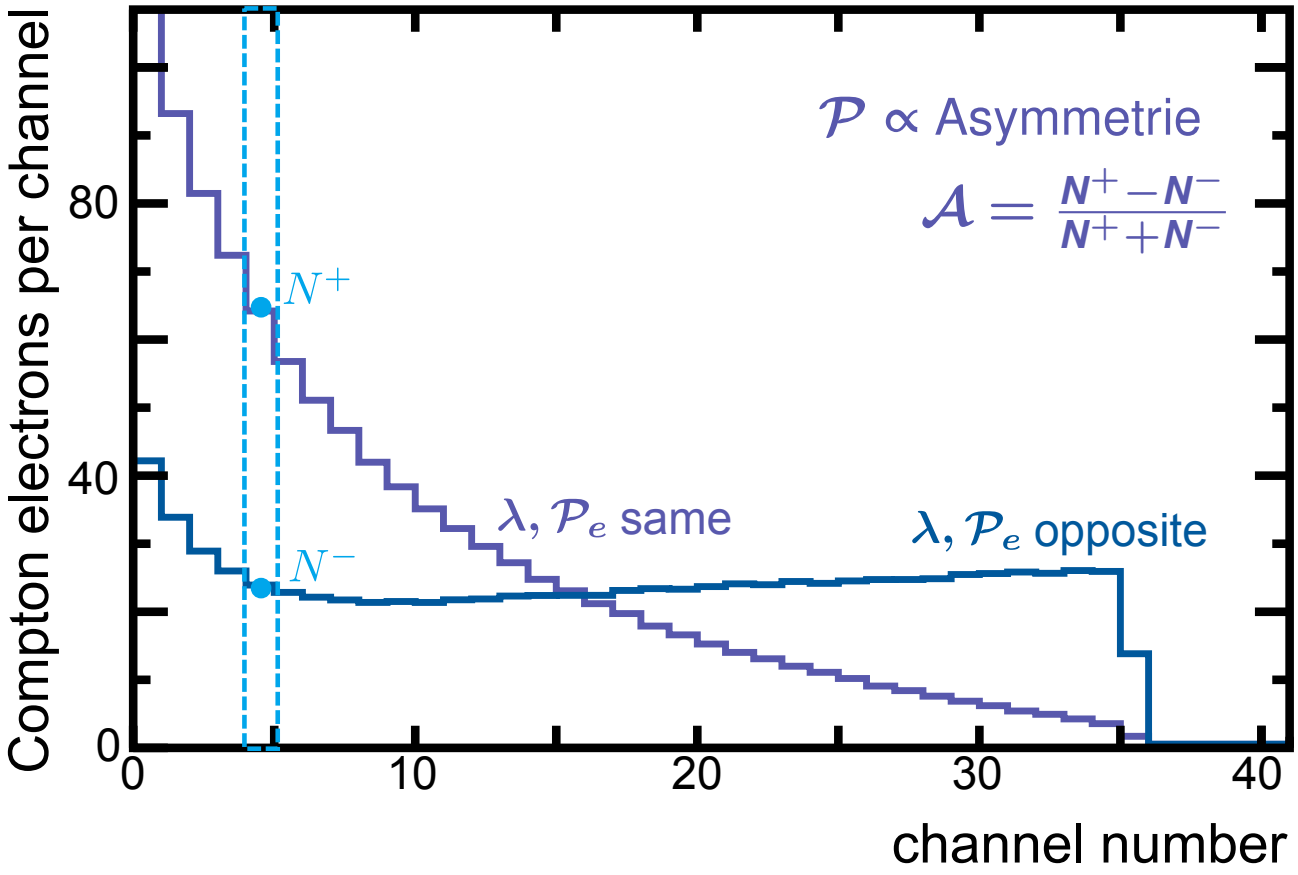
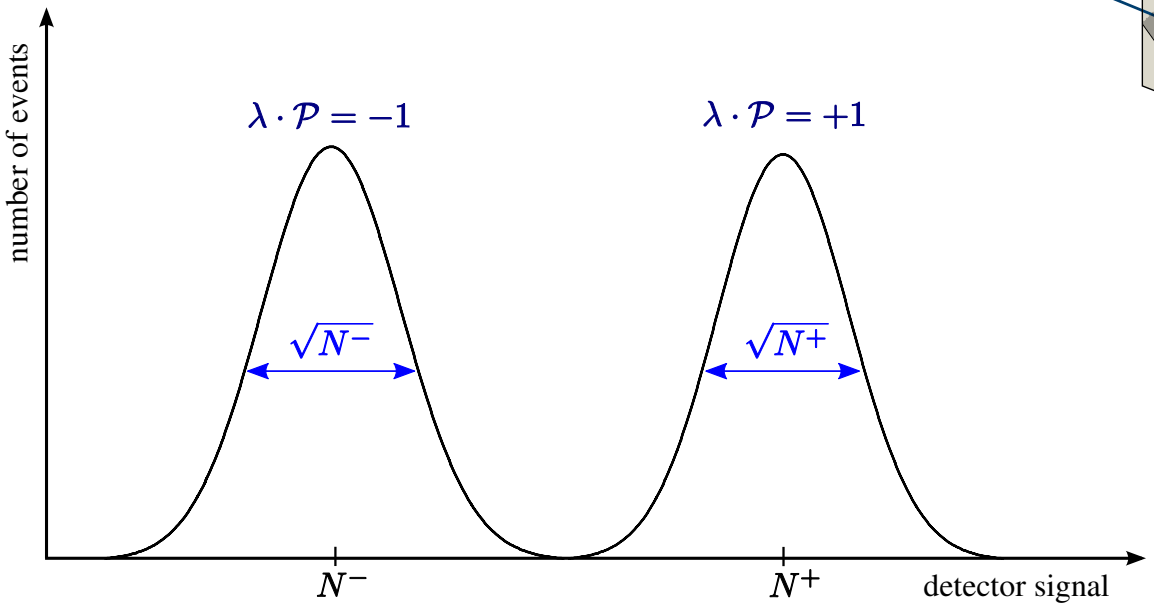
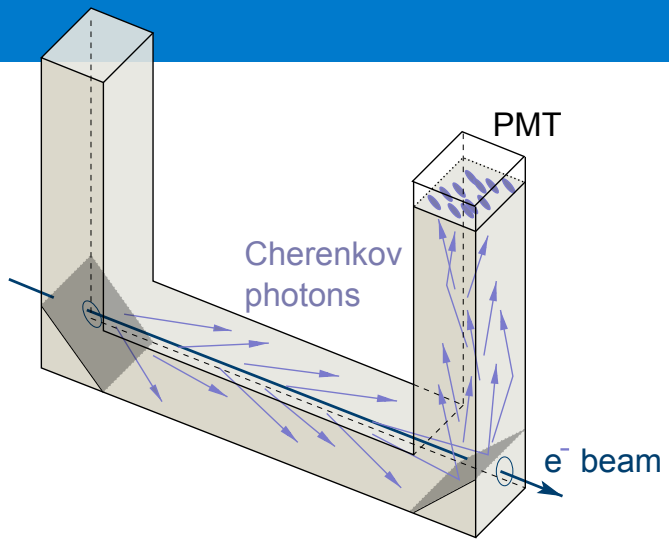


Polarisation Measurement

Detector channel after measurements at both laser configurations:





$$\mathcal{P} \propto \mathcal{A} = \frac{N^+ - N^-}{N^+ + N^-}$$

Polarisation Measurement

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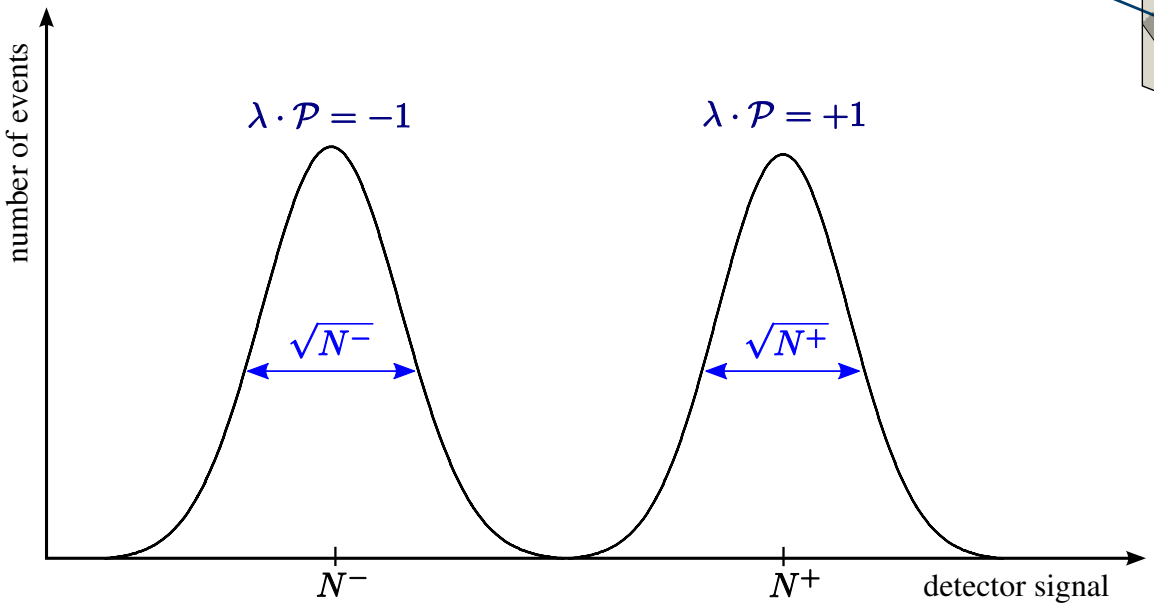
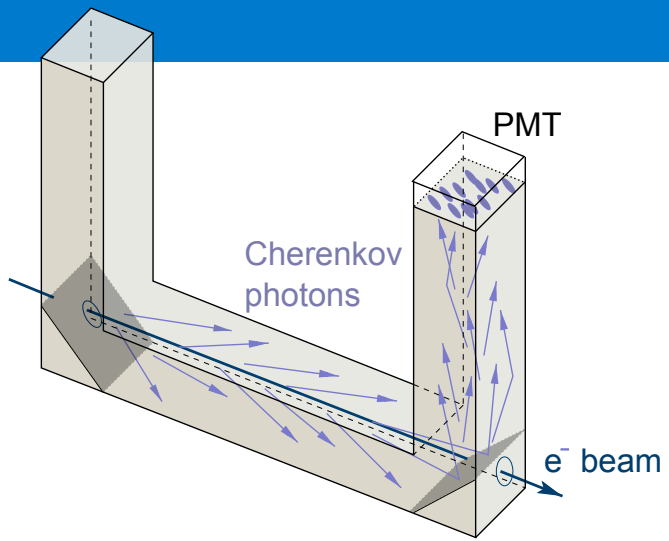




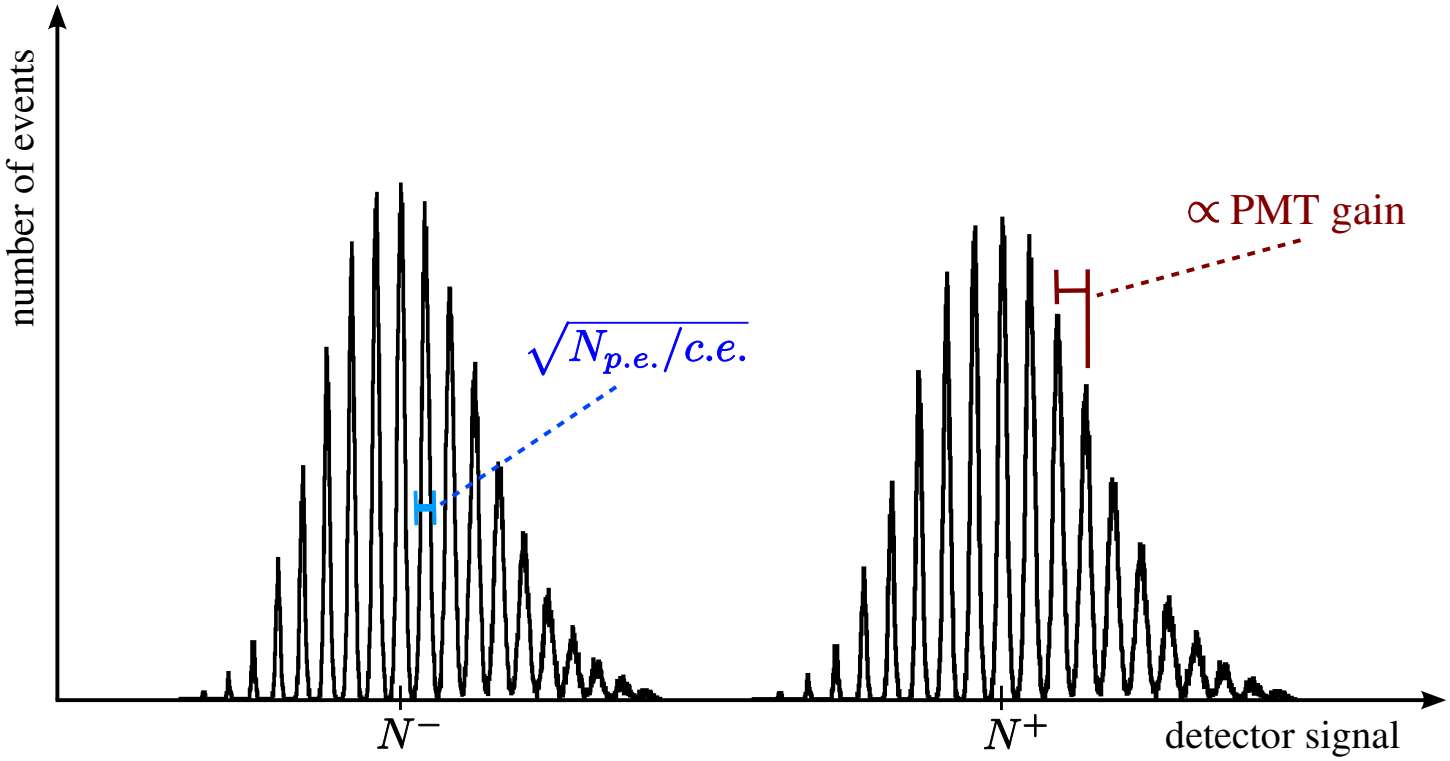
Goal: total uncertrainty $\Delta P / P \approx 0.25\%$, of which

- analysing power (i.e. asymmetry at $\mathcal{P} = 1$): 0.2%
- laser: 0.1%
- detector linearity: 0.1% $\longrightarrow$ calibration essential!

SELF-CALIBRATIONG DETECTOR

For a large enough number of photons per Compton electron, e.g. for 20 e^- per detector channel: $\gtrsim$ 800 photons per e^-

resolution of single peaks possible $\Rightarrow$ self-calibration!



Self-calibrationg detector

For a large enough number of photons per Compton electron,
e.g. for 20 e^- per detector channel: $\gtrsim$ 800 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

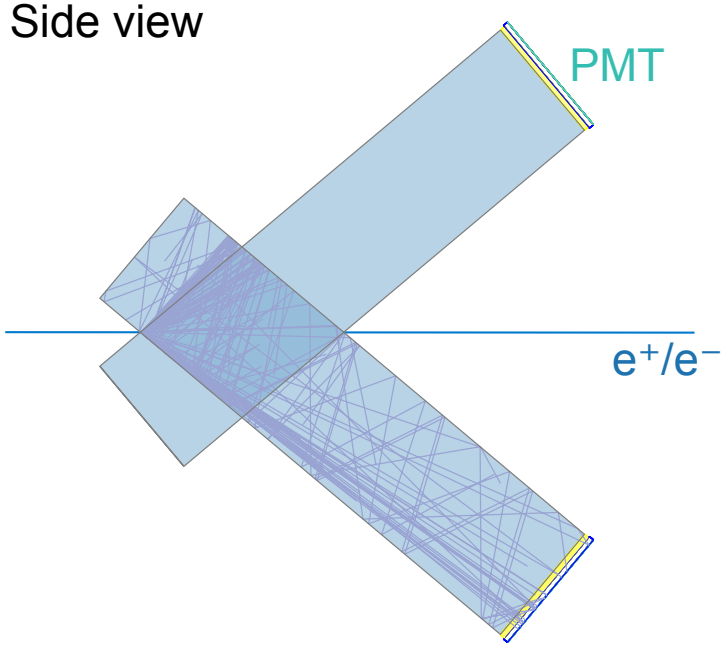
Properties of fused silica

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

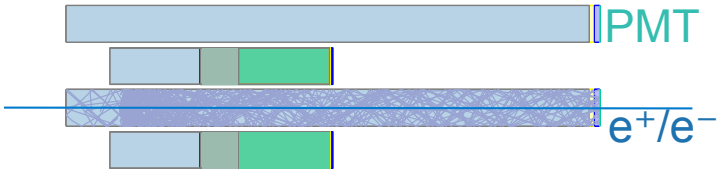
GEANT4 SIMULATION

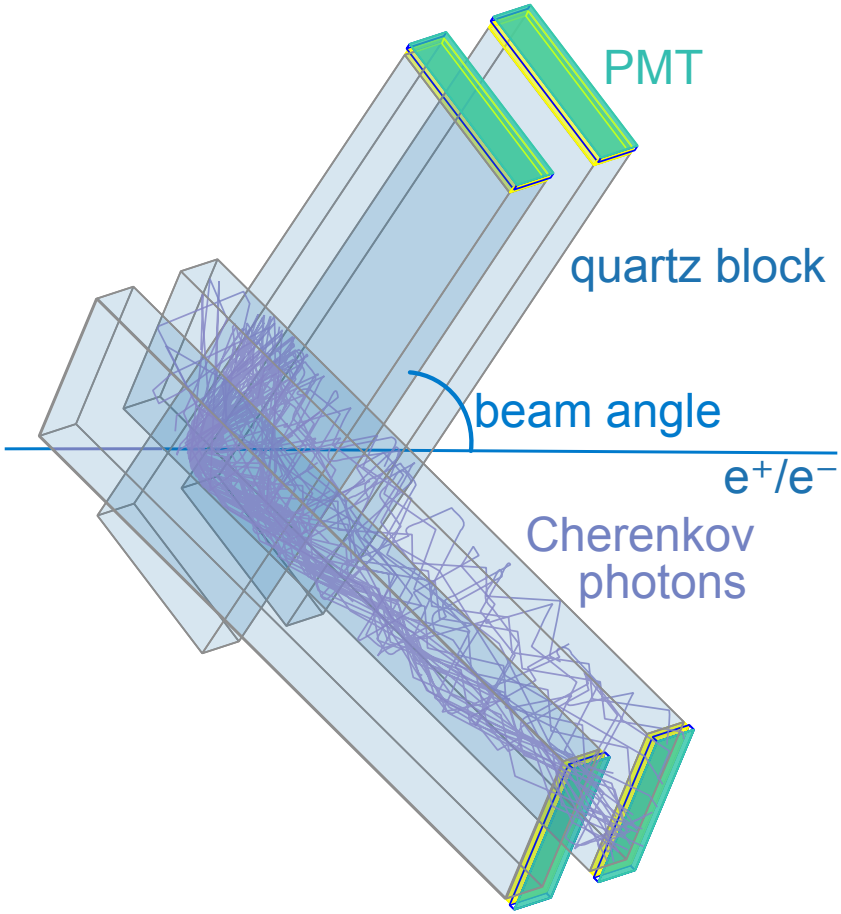
Multiple quartz bars / channels
(rotated → more space for photomultipliers and read-out)

Side view



top view



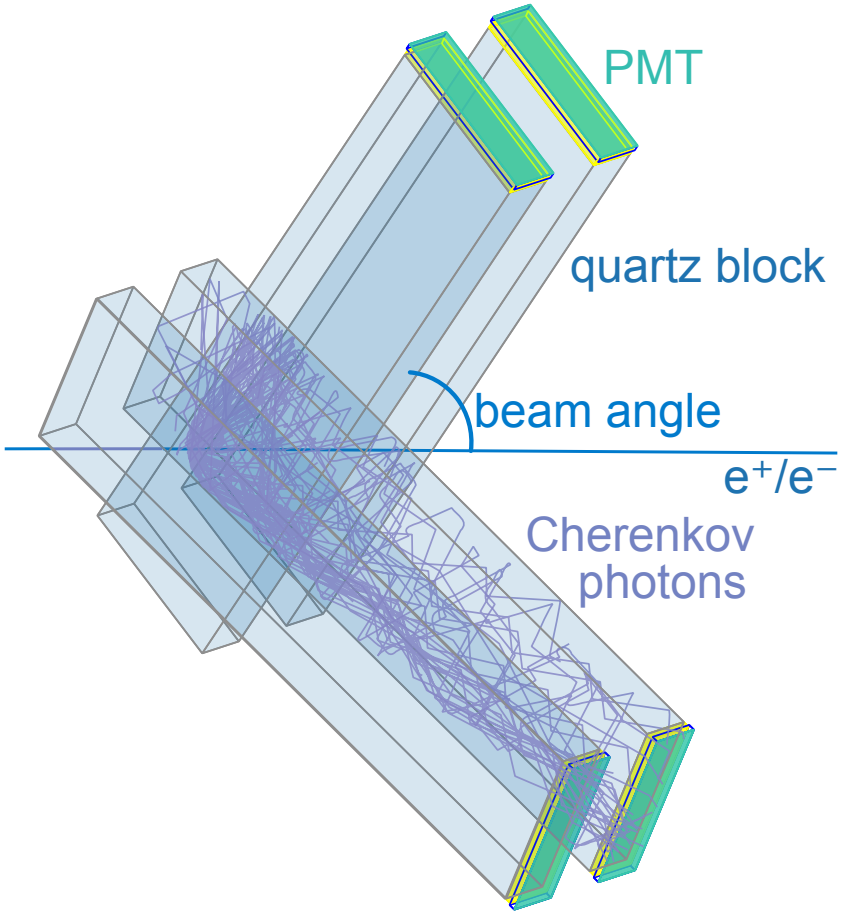


GEANT4 Simulation

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

Implementation in GEANT4:

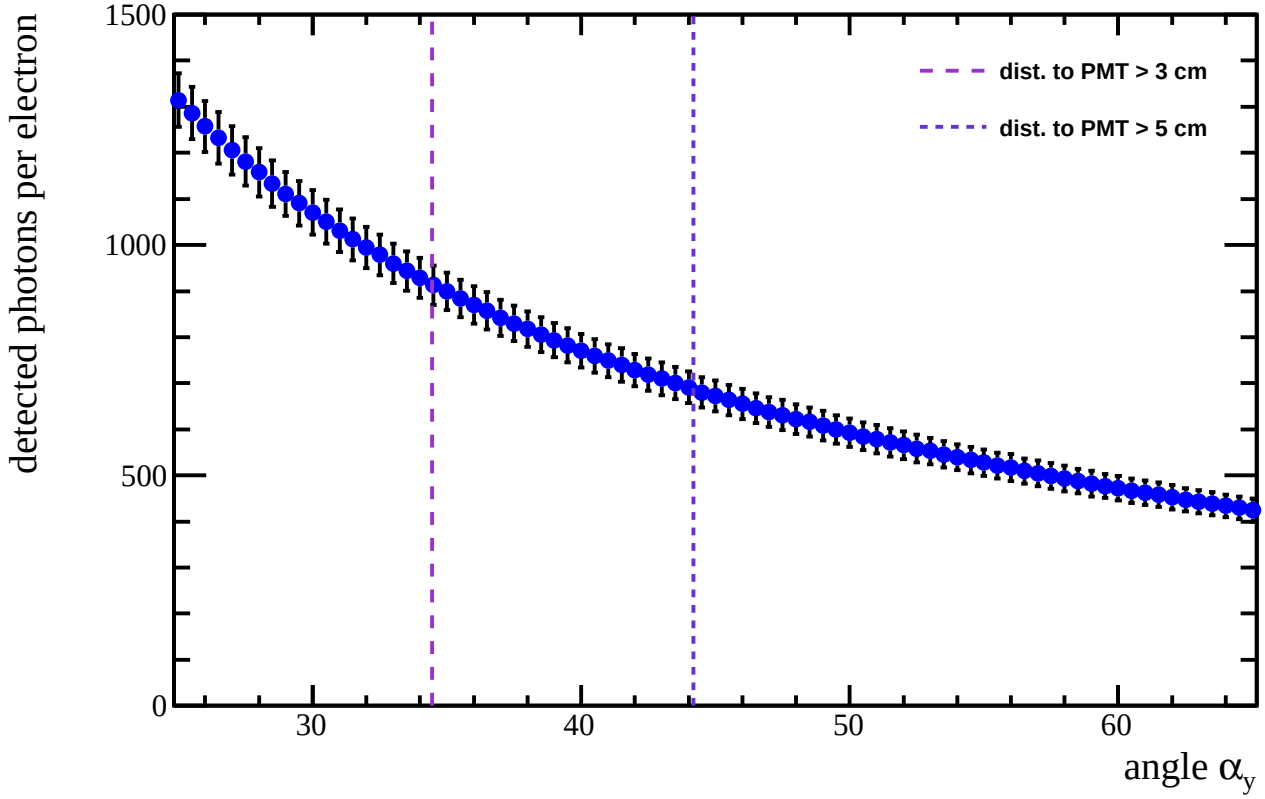
- Fused silica blocks
- photomultiplier (PMT) window and cathode
- coupled with optical grease
- different surface properties



DETECTOR GEOMETRY

Simulation of different incident angles, channel dimensions, ...
→ chose channels with 100mm length and 18mm height

Number of detected photons with this detector configuration:

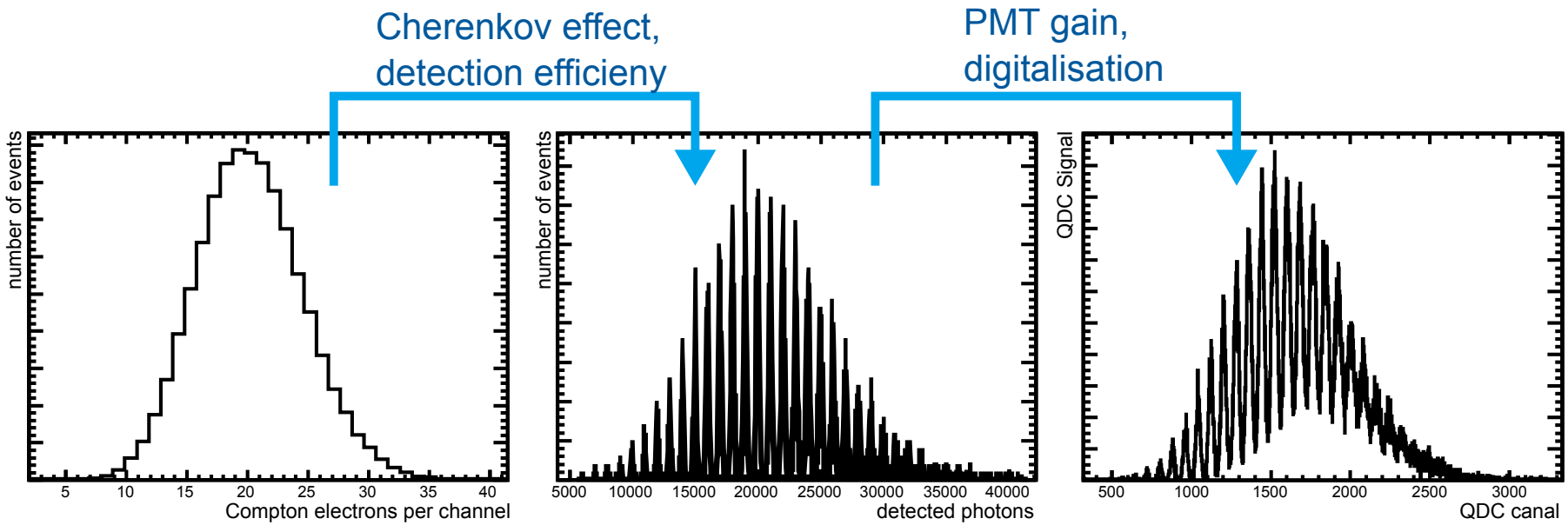


Number of Compton electrons

How many Compton electrons per channel would be possible?

Simulation with 800 detected photons per Compton electron

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



→ for $\leq$30 electrons majority of single peaks can be separated

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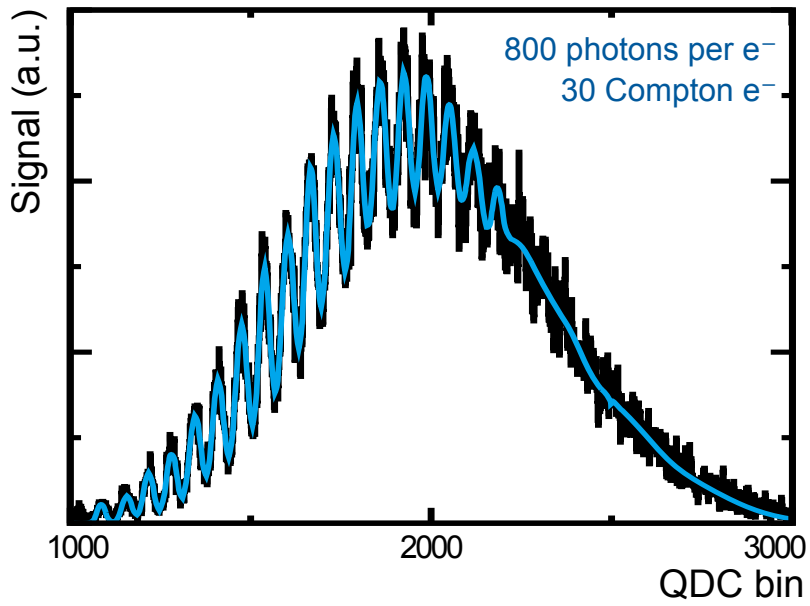
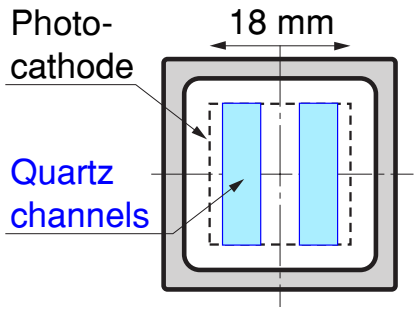


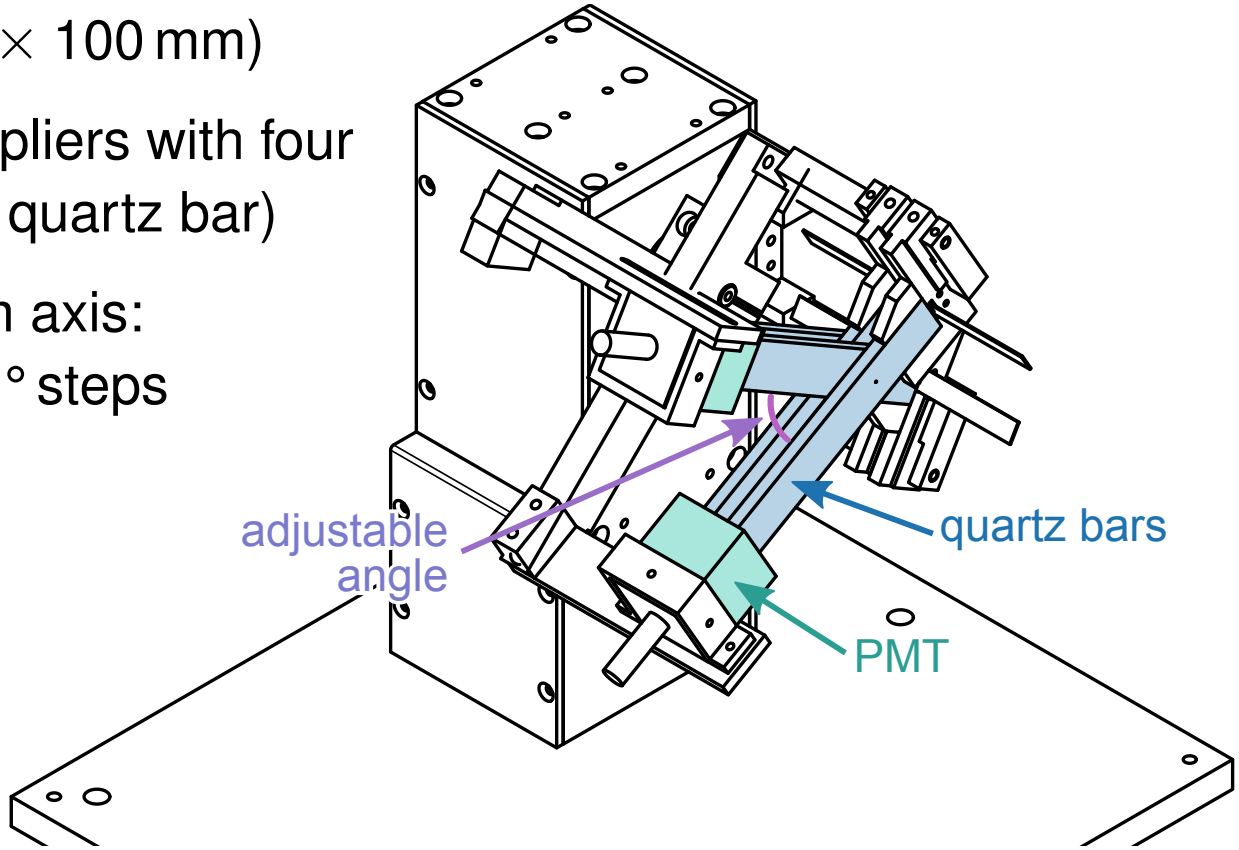
→ for ≤30 electrons majority of single peaks can be separated

Quartz prototype

Quartz prototype with four channels:

- channels: quartz bars ($5\,\mathrm{mm} \times 18\,\mathrm{mm} \times 100\,\mathrm{mm}$)
- using photomultipliers with four anodes (two per quartz bar)
- angle w.r.t. beam axis: adjustable in $0.5\,^{\circ}$ steps





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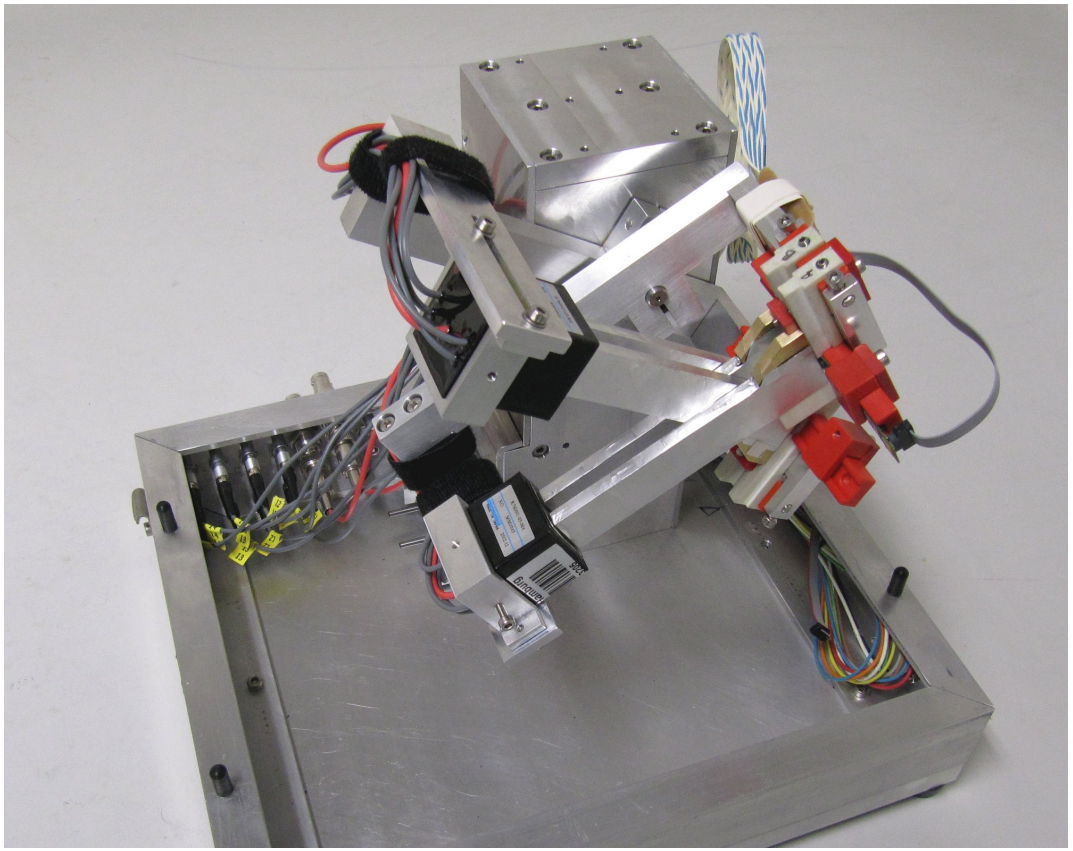


⇒ *Testbeam 22.04. - 05.05.2013*

Testbeam 2013

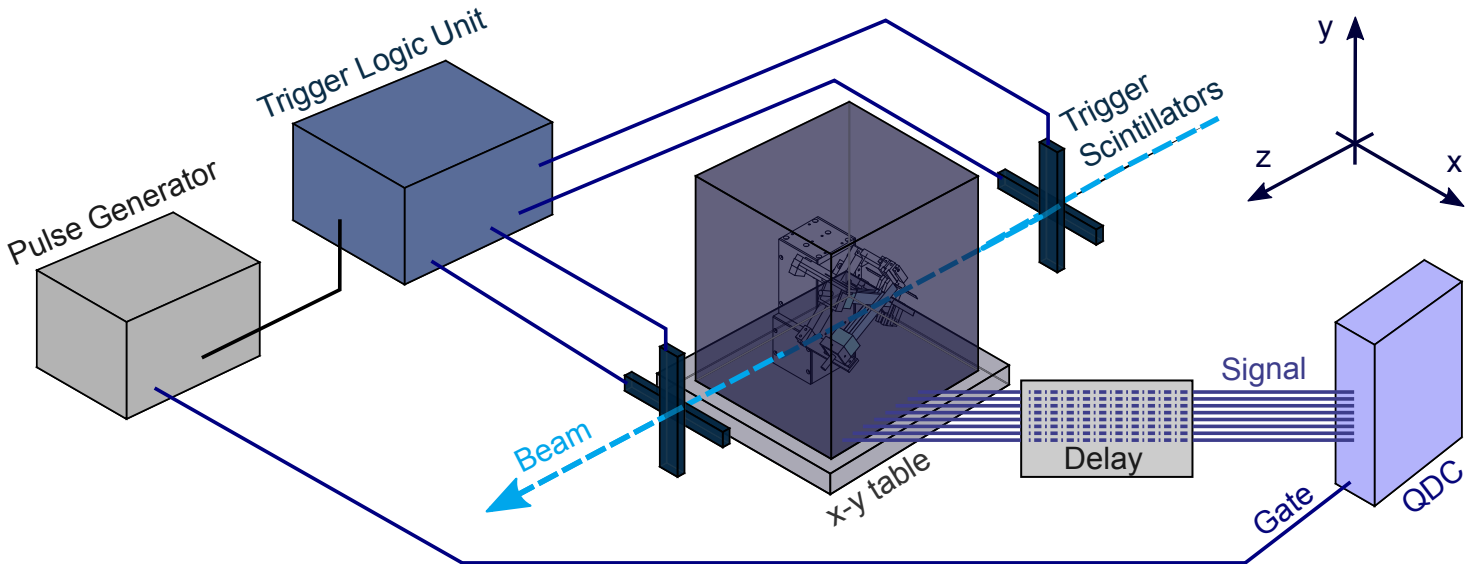
Goals for the testbeam:

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

→ Testbeam at DESY area T21, 22.04. - 05.05.2013

Testbeam Setup

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

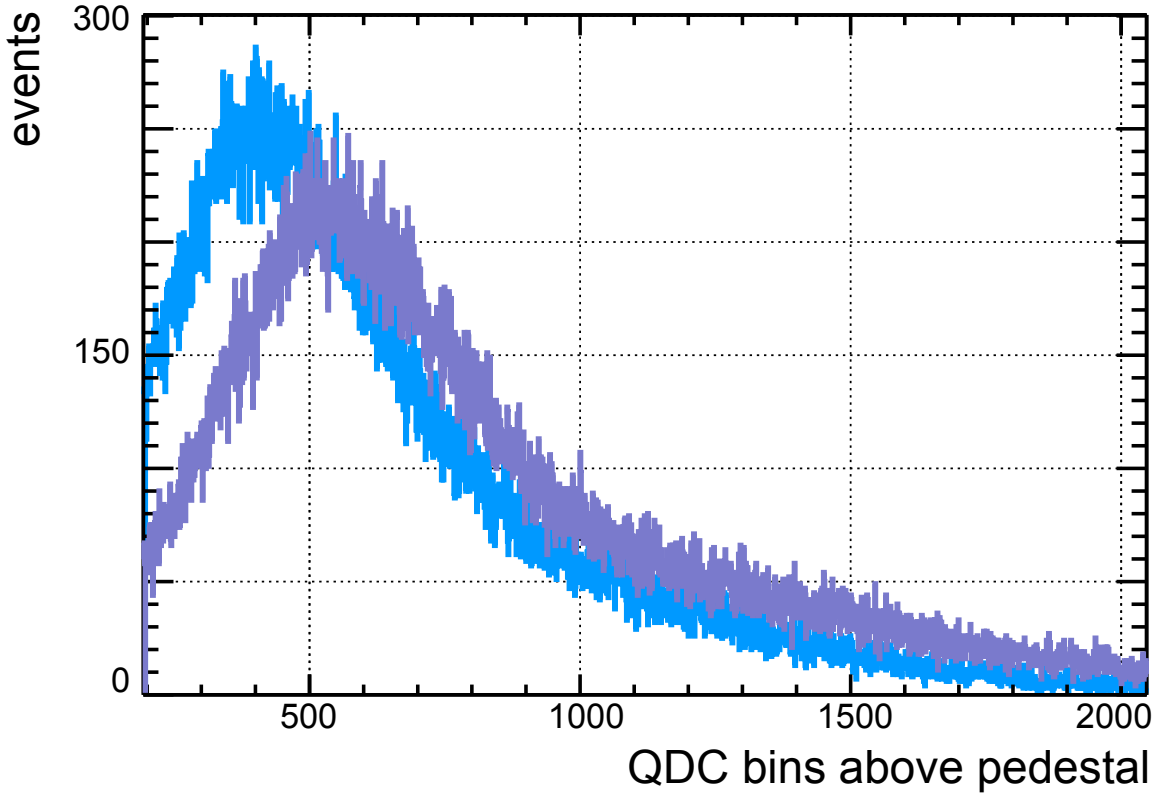


- Trigger: coincidence of four scintillators
- Generate QDC (charge digitizer) gate on trigger signal
- Delay photomultiplier signal long enough to fall inside gate

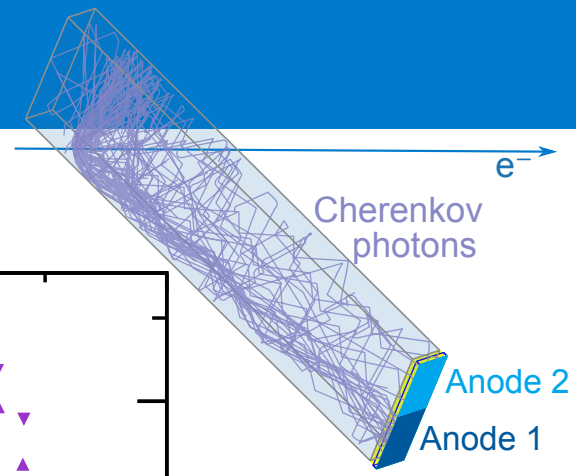
Number of photons

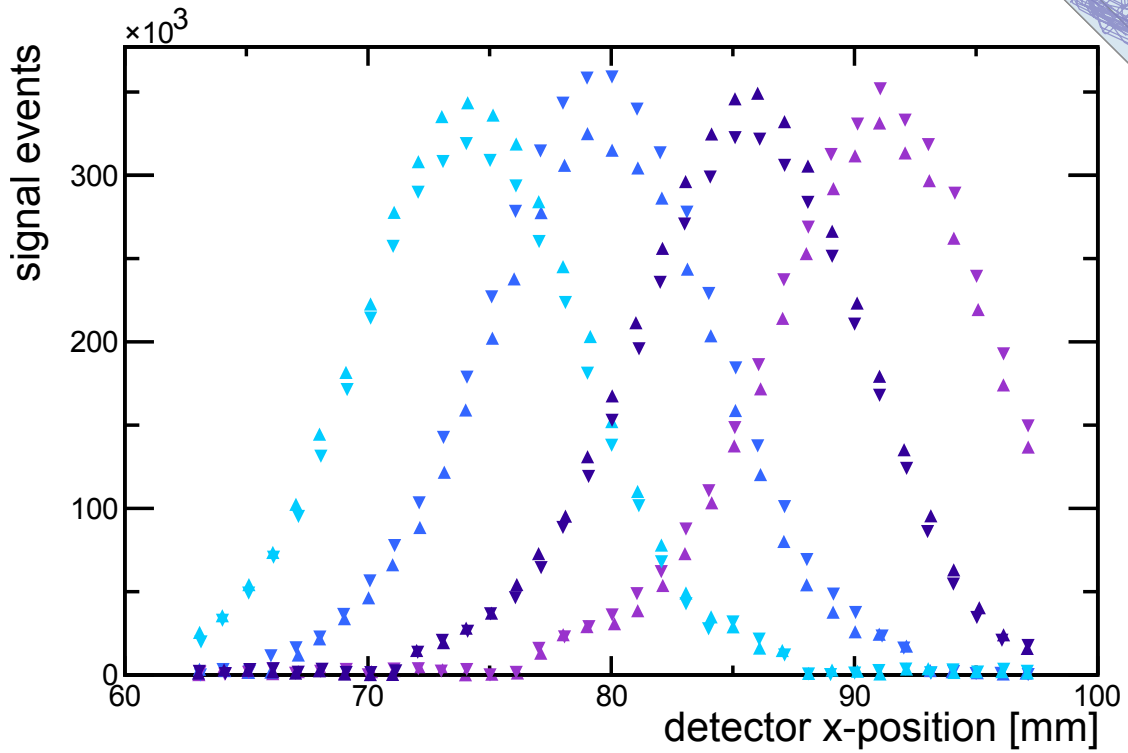
With the gain / HV settings used: 1 photon $\approx$ 10 QDC bins
Predicted by simulation: $\geq$ 250 photons per anode

Example: signal for both anodes on a channel



X-POSITION SCAN

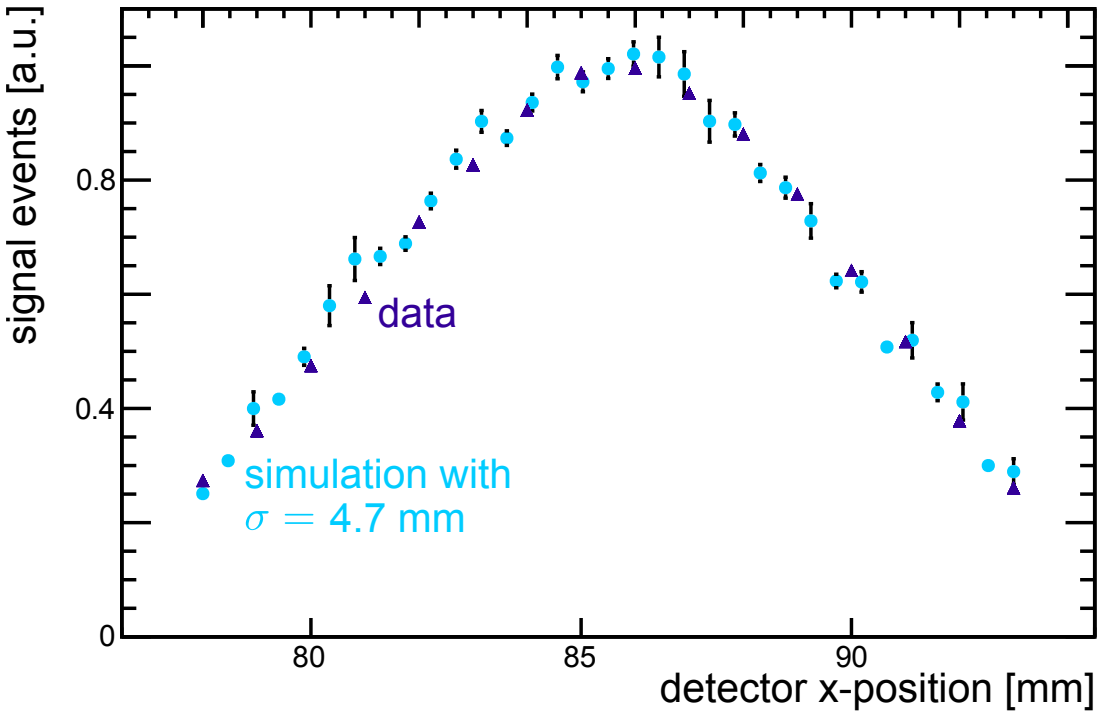




- x=5 mm wide channels
- scan across x-direction: they appear wider
  → due to beam spot size

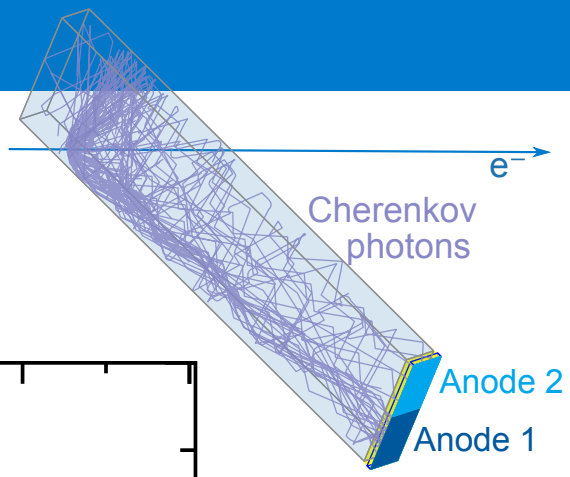
Beamspot size

Comparision with simulation:

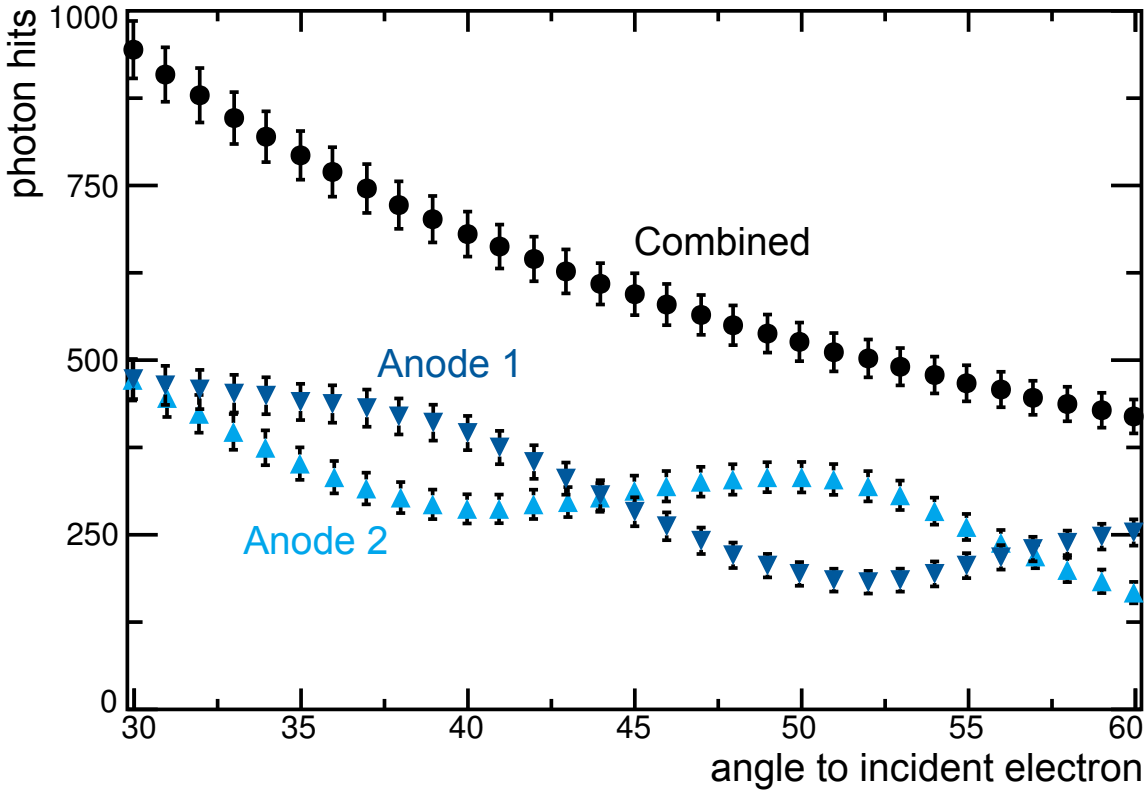


$\rightarrow$ determined beamspot spot size to be $\sigma \approx 4.7$ mm

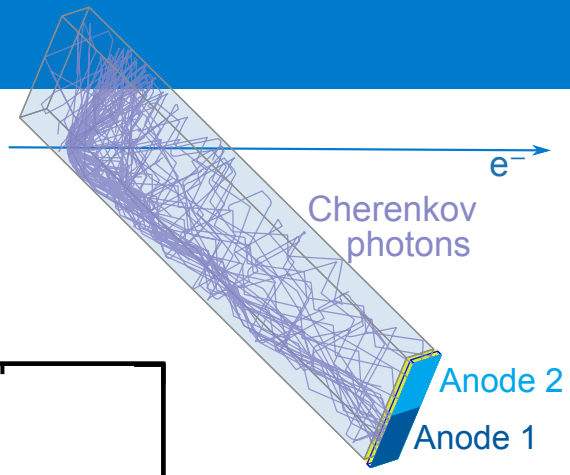
Angle scan (Simulation)



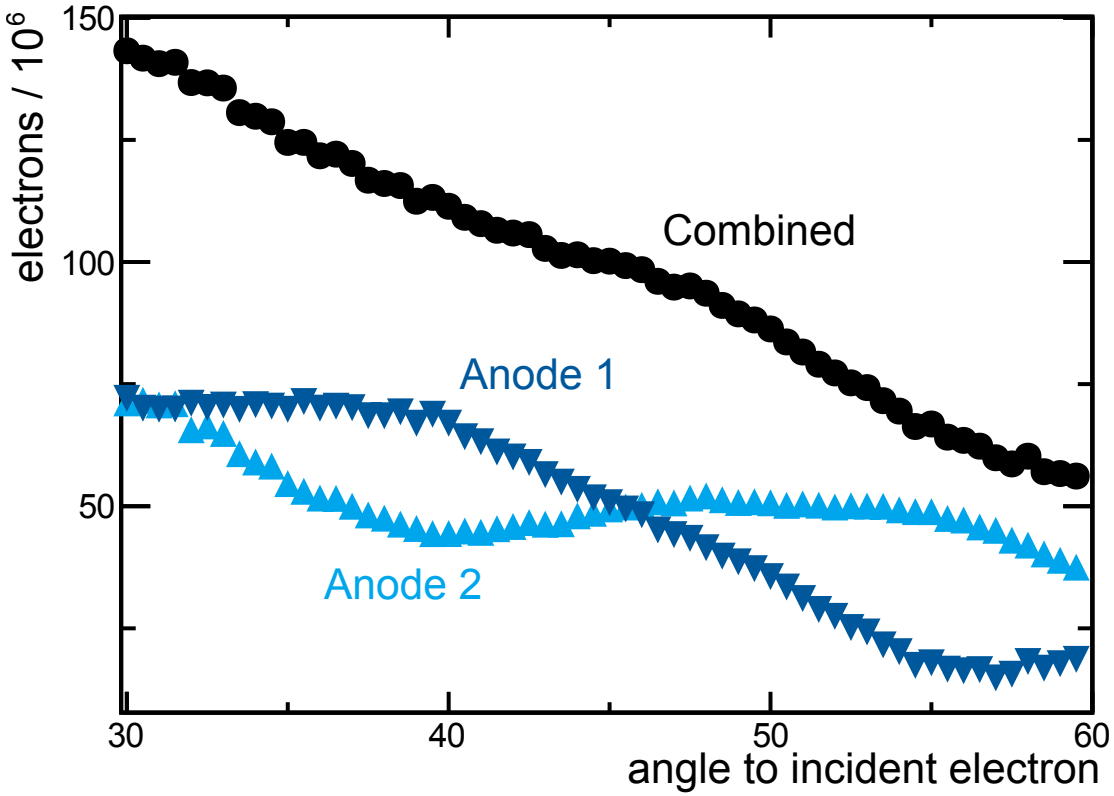
Simulation:



Angle scan (Data)



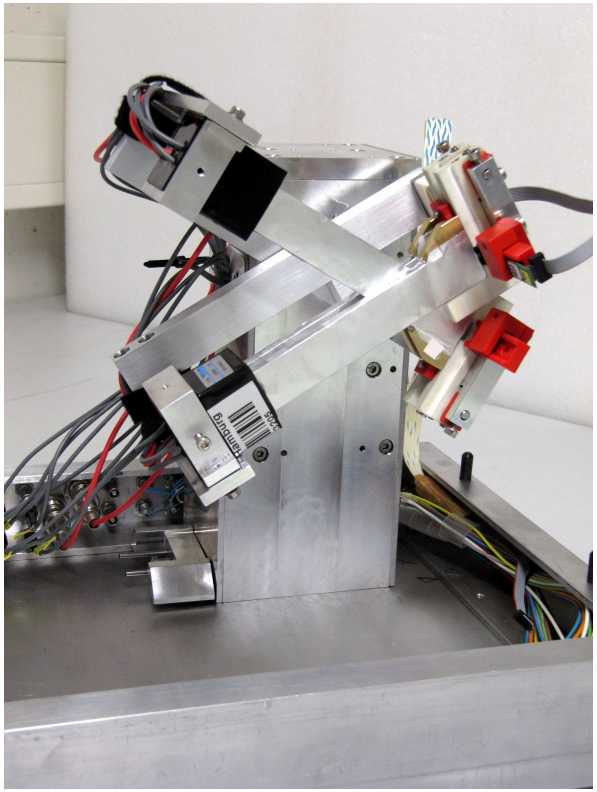
Measurement shows similar behaviour:



Summary and Outlook

Summary:

- Possible option for upstream polarimeter: quartz detector
- After simulation studies: design chosen that promises to allow self-calibration
  → syst. uncertainty due to PMT-nonlinearity reduceable
- Detector prototype completed and tested at DESY II testbeam
  → it works ☺

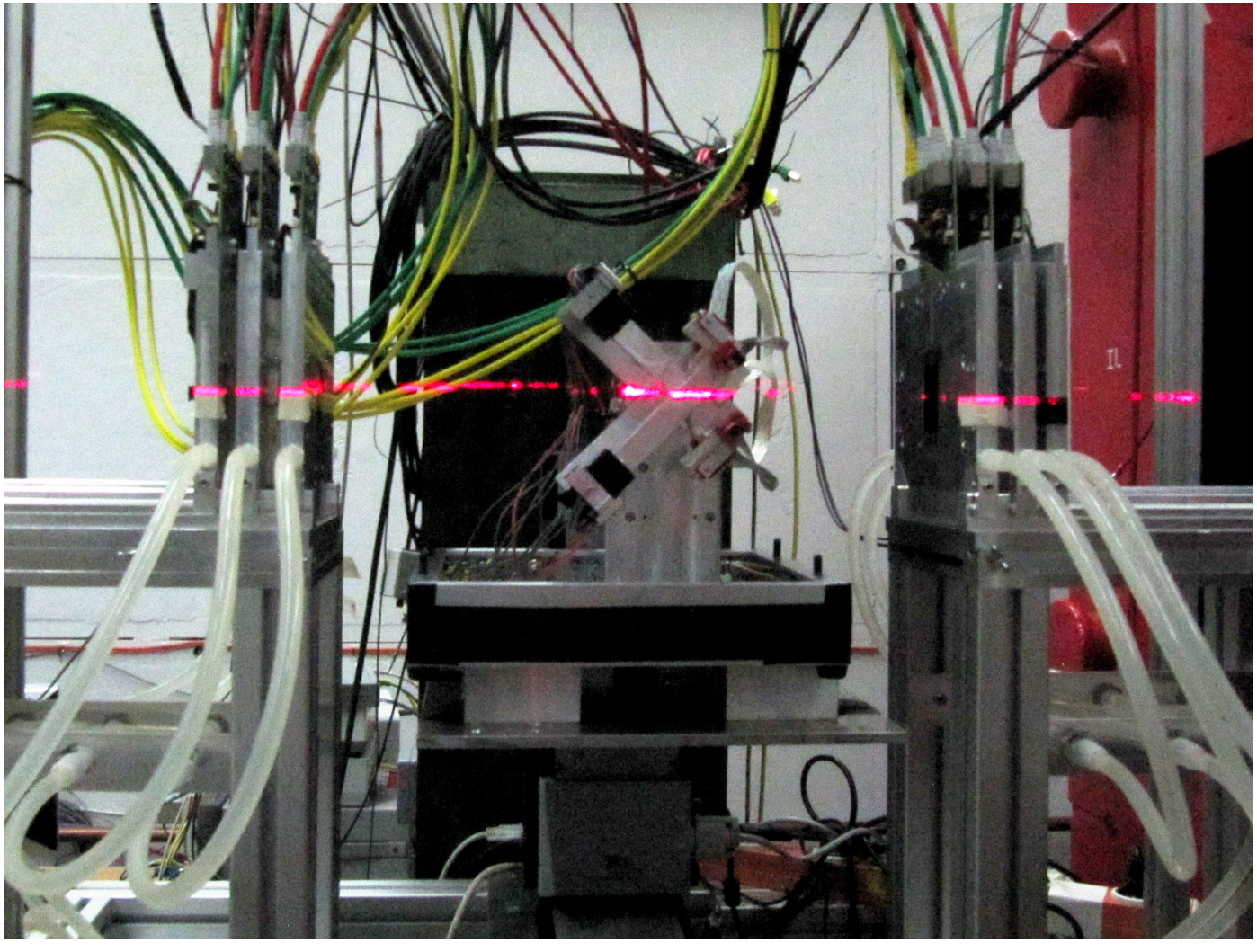


Outlook:

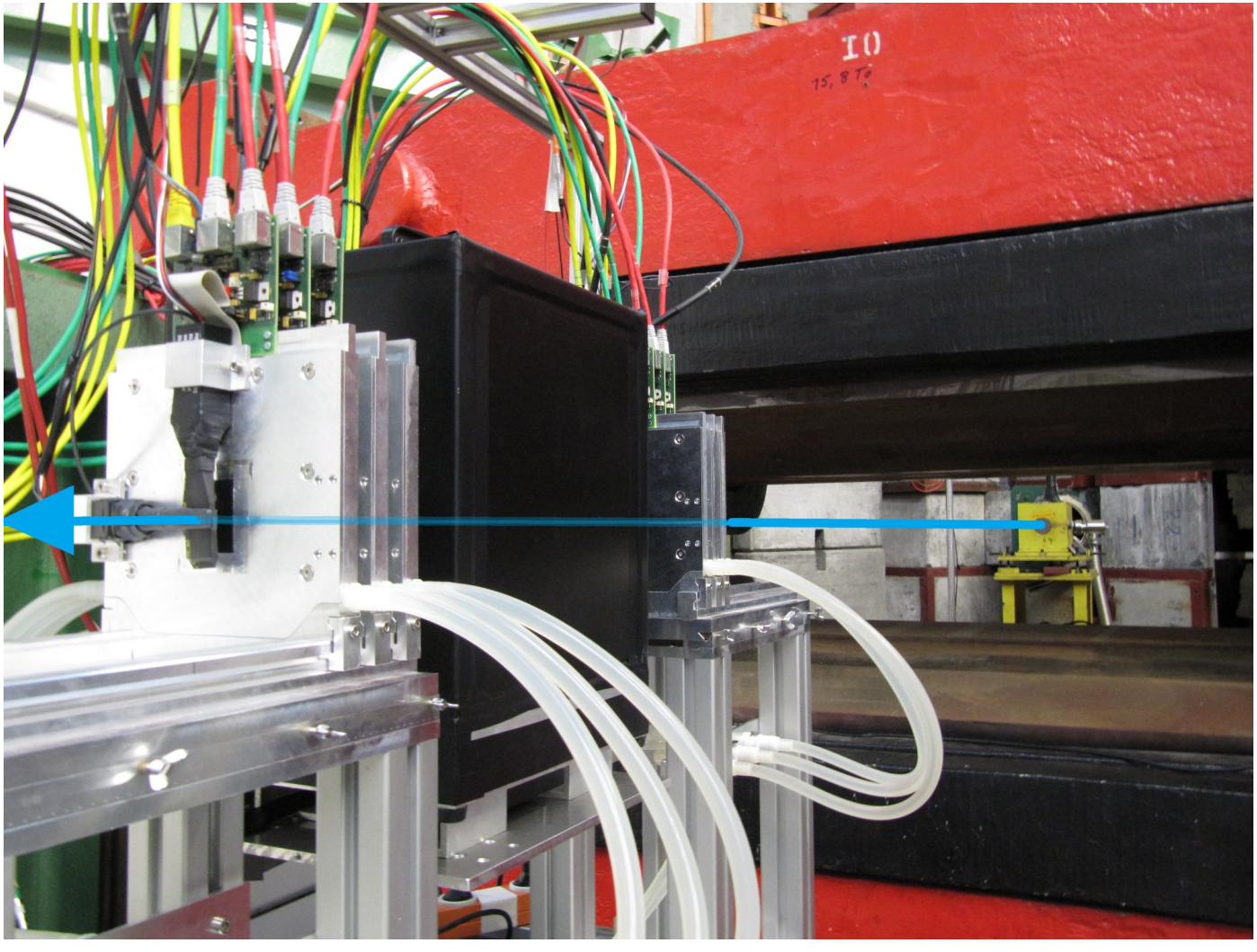
- Detailed analysis of the data...

Backup Slides

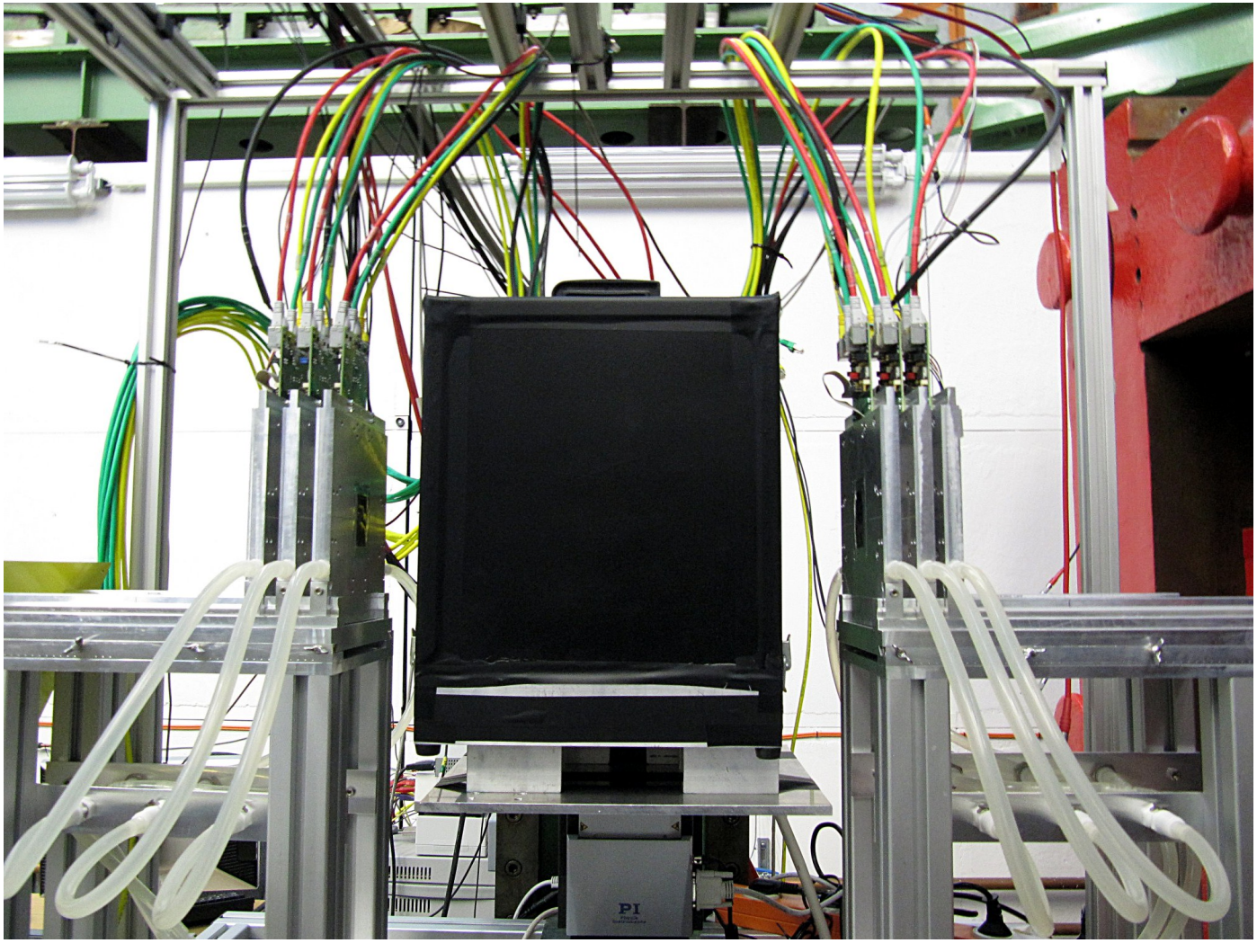
Alignment



Box and Trigger



Box between Telescope

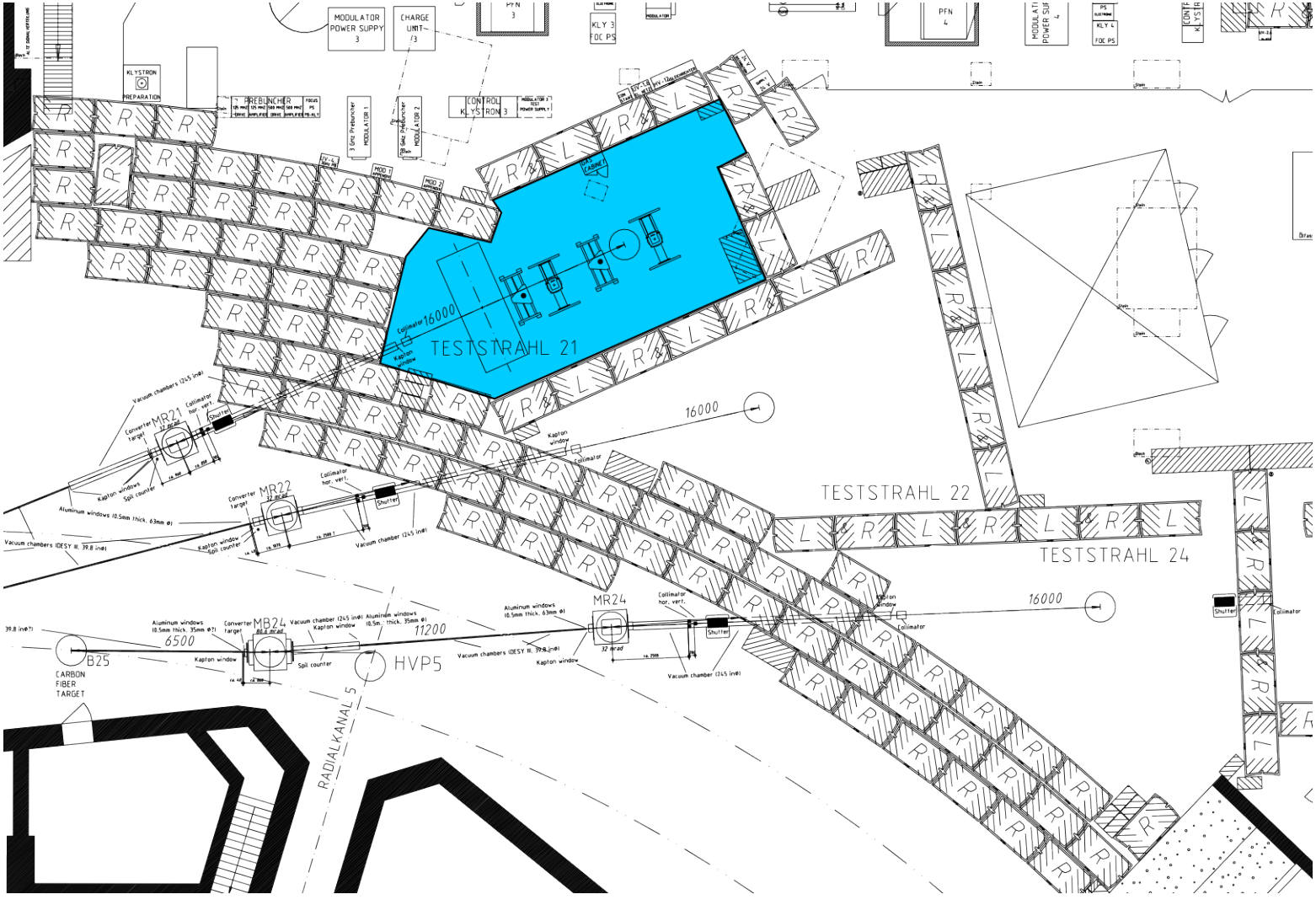


Collimator

STAGE

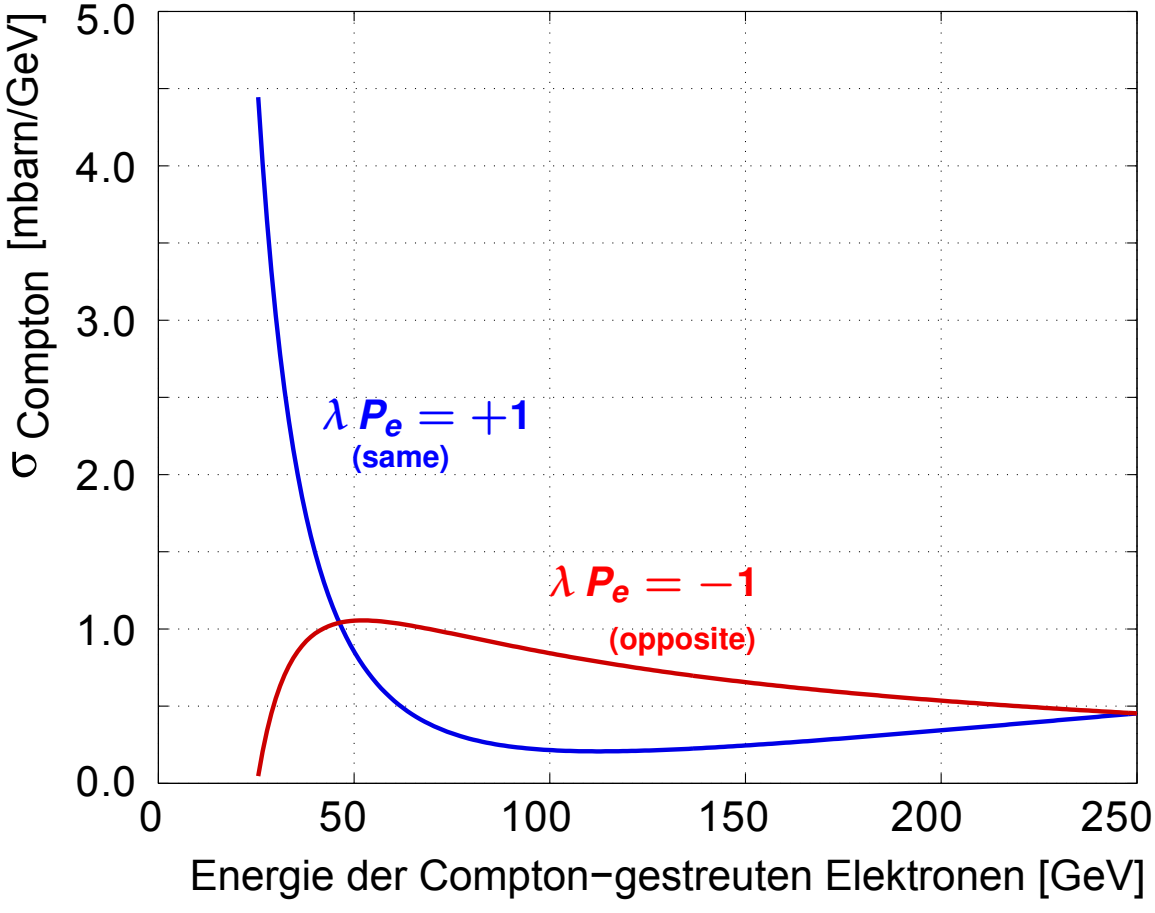
M-531.DD, M-521.DD und M-511.DD und M-505.2DG
Hochlast-Mikropositioniertische mit Kugelspindelantrieb (v. u. n. o.)

T21


TESTSTRAHL 21
TESTSTRAHL 22
TESTSTRAHL 24
16000
16000
16000
MR21
MR22
MR24
MB24
B25
HVP5
6500
11200
CARBON FIBER TARGET
RADIALKANAL 5
MODULATOR POWER SUPPY 3
CHARGE UNIT 3
KLYSTRON PREPARATION
PREBUNCHER
CONTROL KLYSTRON 3
PFN 3
PFN 4
KLY 3 FOC PS
KLY 4 FOC PS
Collimator
Shutter
Kapton window
Spill counter
Converter target
Vacuum chamber (245 inØ)
Aluminum windows (0.5mm thick, 63mm Ø)
Vacuum chambers (DESY R. 39.8 inØ)

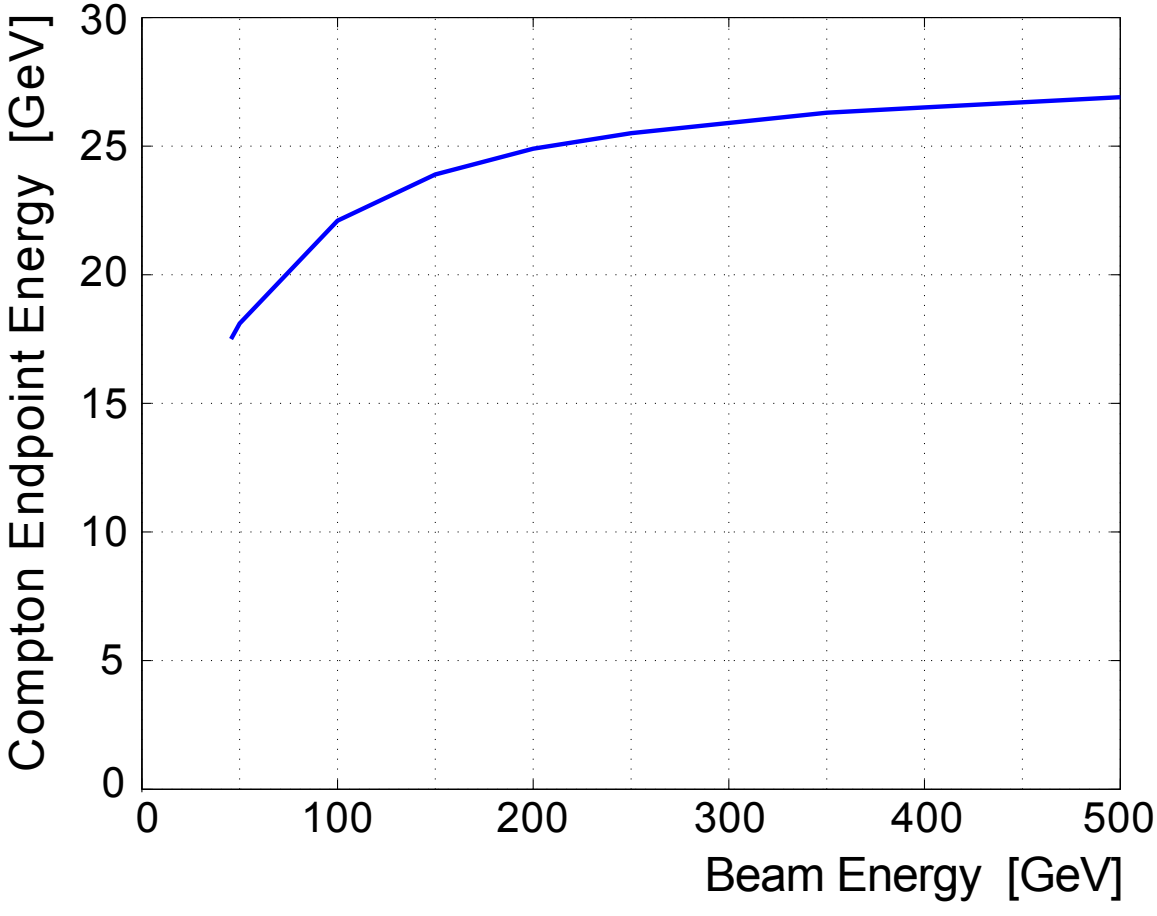
Compton Crosssection

Compton rate asymmetry is proportional to the beam polarisation

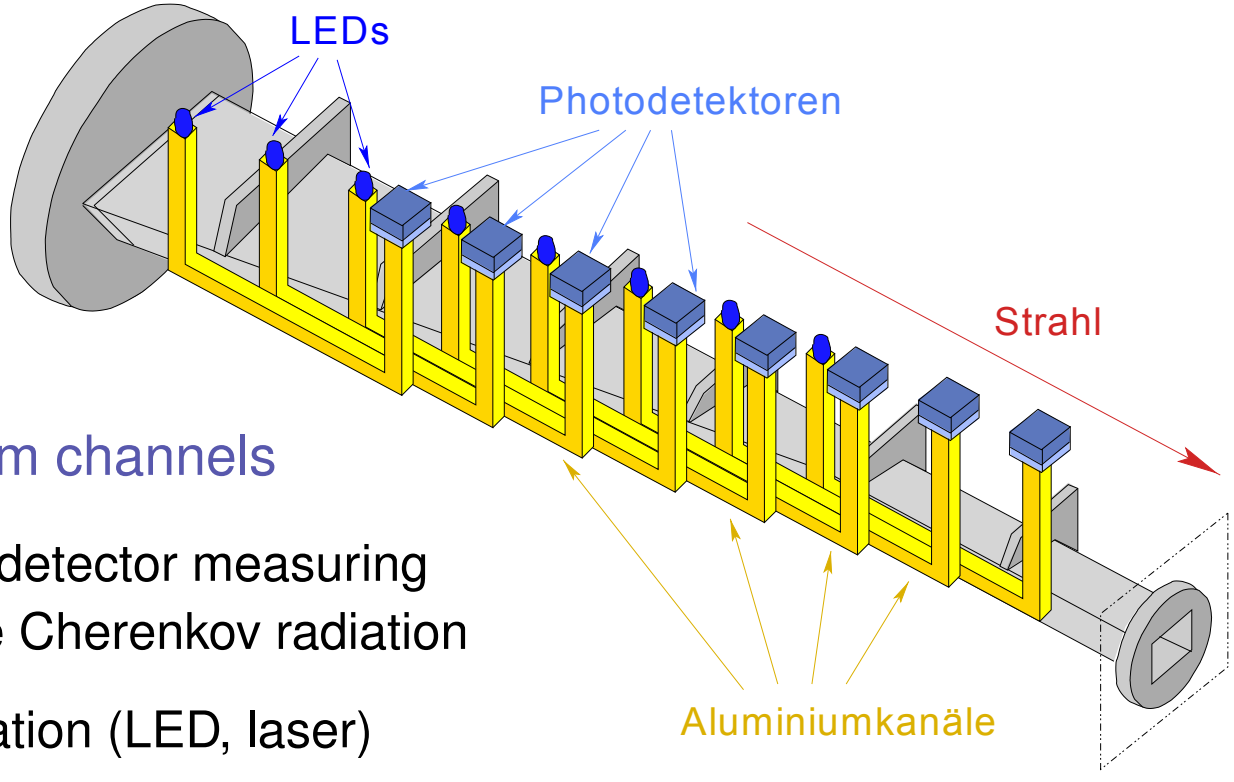


Compton edge

Compton edge position nearly independent of beam energy



Gas Cherenkov detector



Gas filled Aluminum channels

▷ hind U-leg: photodetector measuring the Cherenkov radiation

▷ front U-leg: calibration (LED, laser)

Alignment: locate Compton edge in the spectrometer

Segmented photodetectors: → maybe online-monitoring of Compton edge position without dedicated calibrati

Cherenkov effect

Intensity: Frank-Tamm equation

$$dE = \frac{\mu(\omega)q^2}{4\pi}\omega\left(1 - \frac{c^2}{n^2 v^2(\omega)}\right)dxd\omega$$

Cherenkov angle: $cos\,\theta_c = \frac{1}{n\beta}$

quartz (fused silica):

- n_q = 1.53836 at 210 nm $\Rightarrow \theta_c = 49.46^\circ$
- n_q = 1.46233 at 500 nm $\Rightarrow \theta_c = 46.84^\circ$
- n_q = 1.45332 at 800 nm $\Rightarrow \theta_c = 46.52^\circ$

Cherenkov threshold:

$$E_{thr} = \gamma_{thr} mc^2 \ , \ \gamma_{thr} = \frac{1}{\sqrt{1-\beta_{thr}^2}} = \frac{1}{\sqrt{1-\frac{1}{n^2}}}$$

quartz (fused silica) (for e^+/e^-):

- n_q = 1.53836 at 210 nm $\Rightarrow E_{thr}$ = 0.864 MeV
- n_q = 1.46233 at 500 nm $\Rightarrow E_{thr}$ = 0.909MeV
- n_q = 1.45332 at 800 nm $\Rightarrow E_{thr}$ = 0.915MeV

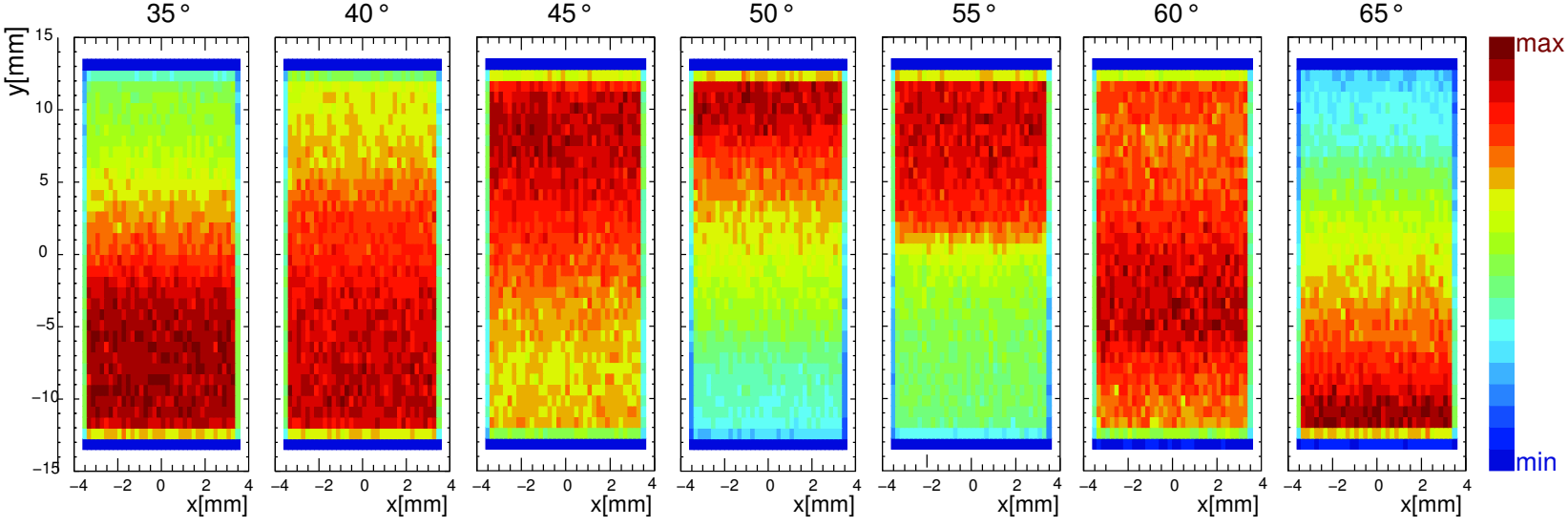
LCPolMC - channel width

relative statistical error on polarisation measurement
in percent (after 141000 bunches):

	30% Polarisation	**80% Polarisation**
20 channels, 10 mm	0.064	0.020
40 channels, 5 mm	0.065	0.021
20 channels, 4 mm	0.085	0.025

LIGHT DISTRIBUTION

Light distribution on the photo cathode depends on angle of incident electrons:



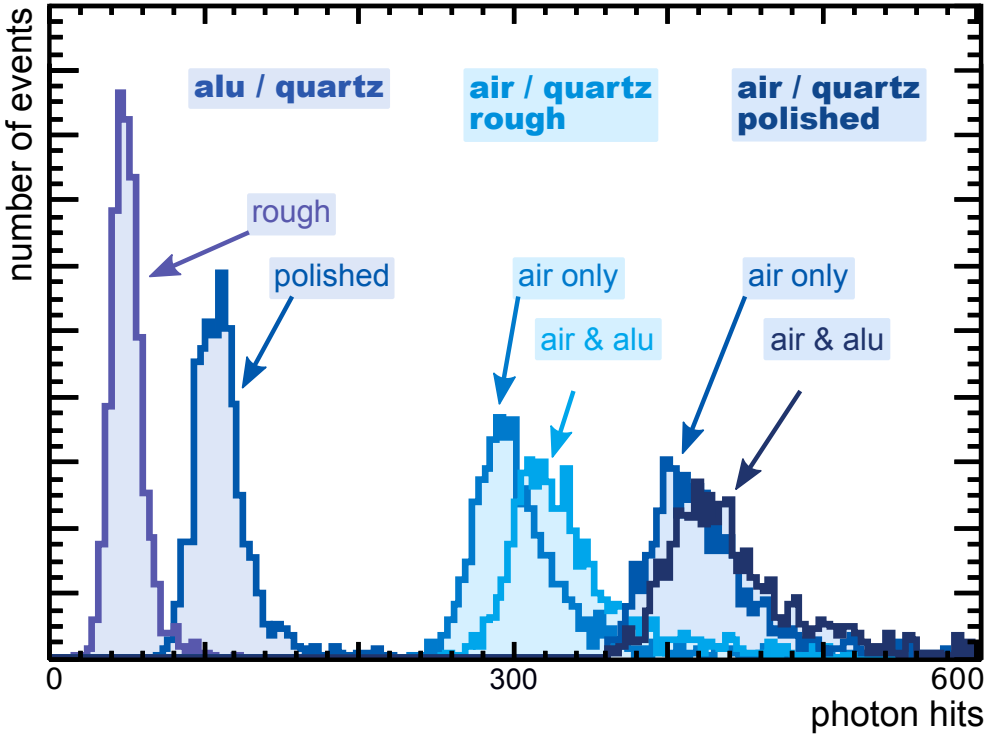
$\longrightarrow$ use for detector alignment?

Number of photons

Less photons measured than predicted by simulaton.

- Coupling quartz / PMT ?
- Surface roughness ?
- ...

Reason still to be determined.

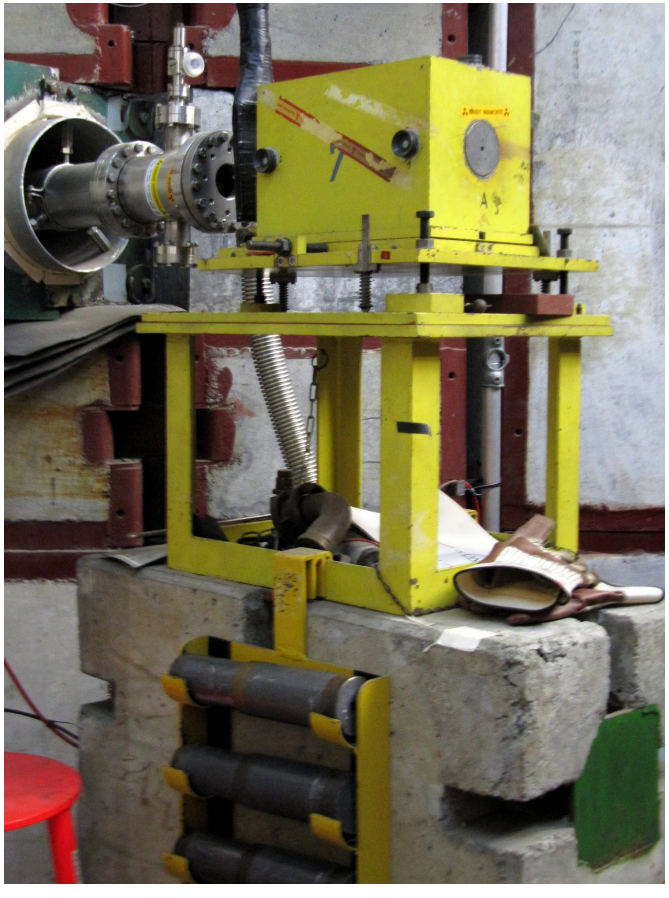


Collimator

Different area collimators available.
Smaller collimator: smaller beamspot, but also lower rate...

Tested three different sizes:

- 2 mm × 2 mm
- 5 mm × 5 mm
- 15 mm × 15 mm



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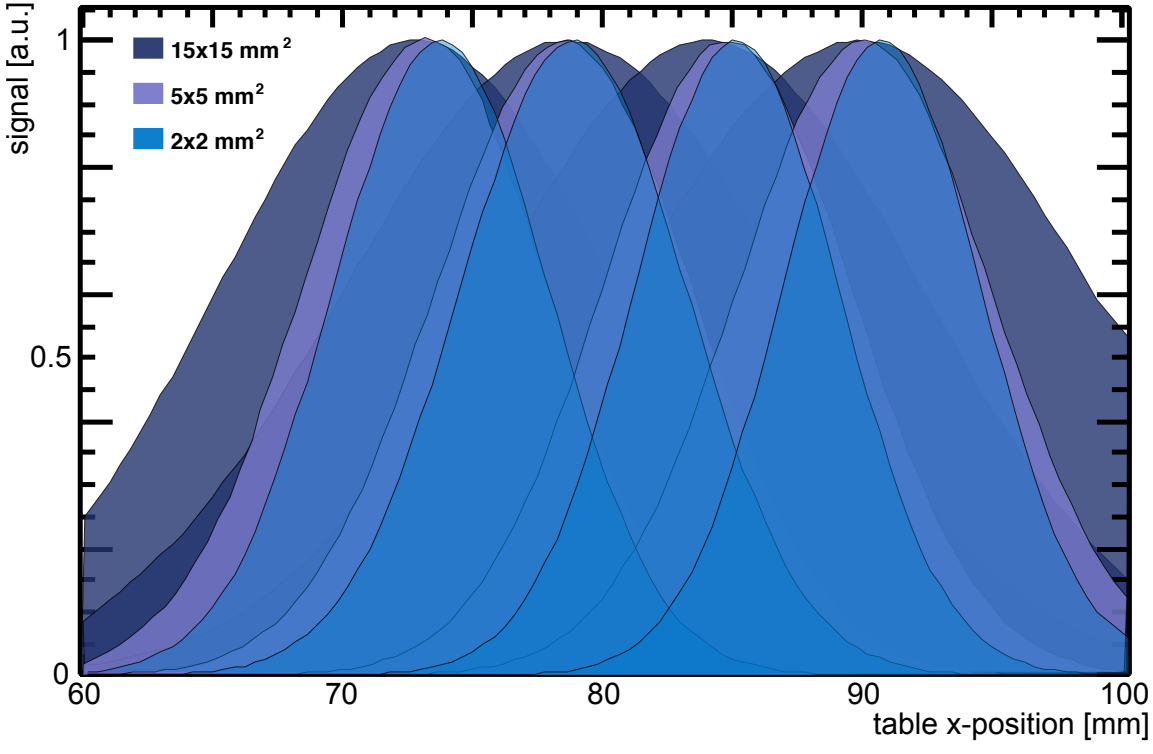

Picked 5 mm $\times$ 5 mm collimator for most measurements.