Cherenkov Det. Prototype
Testbeam 2009

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1. Polarimetry at the ILC
   - Basics & Overall Concept
   - Up- and Downstream Chicanes
2. Prototyp Design & Simulation
   - ILC Layout → Prototype Requirements
   - Prototype Simulation & Construction
3. Testbeam 2009
   - Prototype Setup @ ELSA Accelerator
   - Alignment & First Signals
   - Comparison of Data & Simulation
4. Conclusions

Polarimetry Basics
Overall Concept

Compton Polarimetry Basics

- **ILC:** will use polarised beams $\rightarrow$ need precise knowledge
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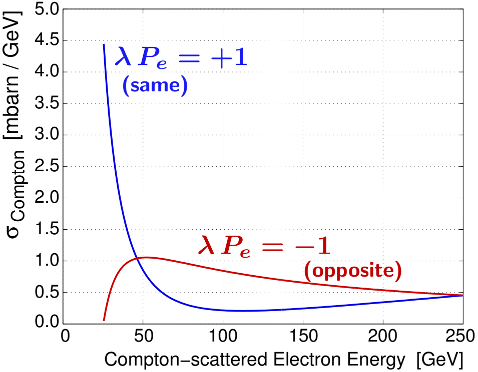
- Measure Compton event rate w.r.t. (known) laser helicity
  ⇒ **resulting asymmetry directly prop. to beam polarisation !**

Compton Process Dependencies



Differential Compton cross section vs. the energy of scatterd electrons for **same / opposite helicity config's** of photon- and electron spins: λP_e

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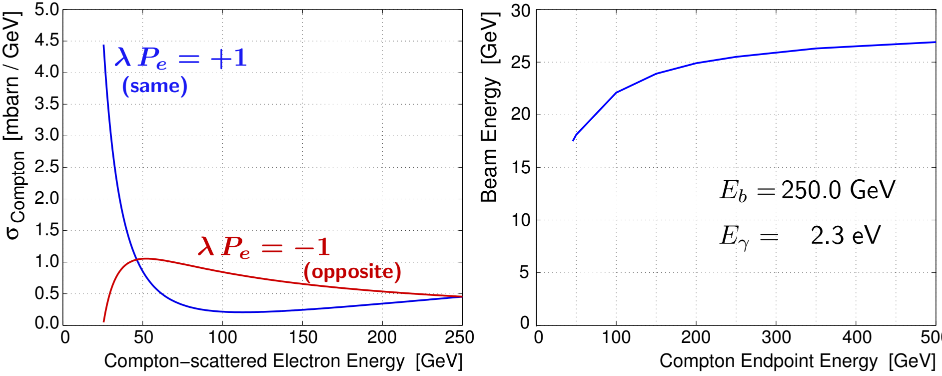
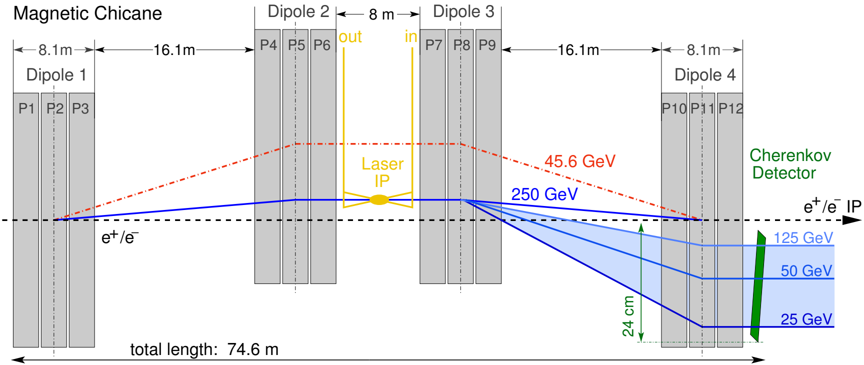


Differential Compton cross section vs. the energy of scatterd electrons for **same / opposite helicity config's** of photon- and electron spins: λP_e

Compton edge energy does hardly depend on the beam energy E_b

Upstream Chicane (original design)



- fast: $\mathcal{O}(10^3)$ Compton scatterings/bunch: energie- $\longrightarrow$ position distr.
- constant B-field: Compton edge position indep. of E_b (beam energy) and there are no E_b-dep. distortions of the energy spectrum
- laser moves $\approx 10\,\text{cm}$ horizontally $\leftrightarrow$ same frequency usable for all E_b
  (vacuum chamber & laser optics designed accordingly)

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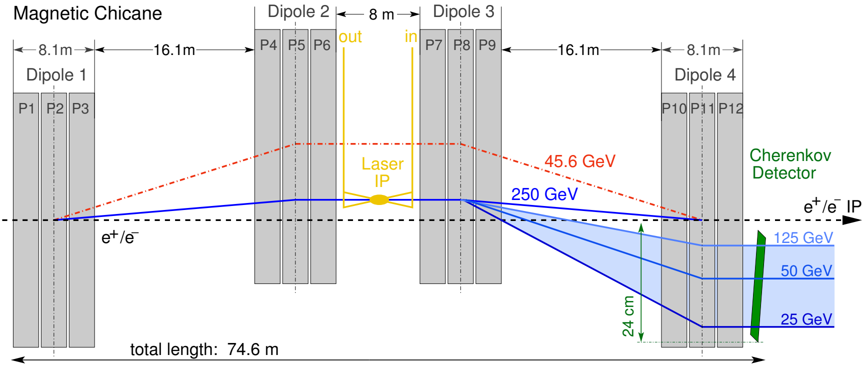
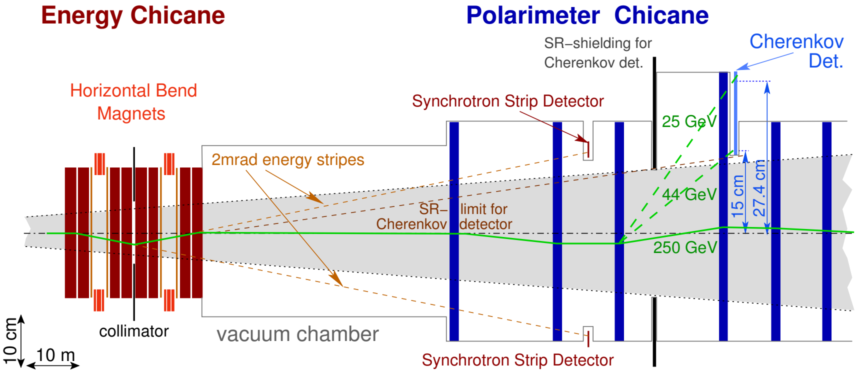


- any design changes of the upstream polarimeter chicane have serious consequences for the obtainable measurement precision
- integration of emittance diagnostics a/o MPS collimator not possible

$\Rightarrow$ **Polarimetry needs were fully acknowledged by GDE and BDS !**

Downstream Chicane (K. Moffeit, E. Torrence)



- Same principle as upstream polarisation meas., but more difficult disrupted beam & large SR background → need high-power laser
- Access to luminosity weighted polarisation (measure w/o collisions)

⇒ **Successfully integrates SR strip detectors to measure E_b !**

Overall Concept

- **Upstream: "cleanest" measurement, highest time resolution**
  can measure individual electron bunches → machine feedback!
  ⇒ correlations, left-right differences, time dependencies

ILC-NOTE-2008-047, arXiv:0808.1638v1 [physics.acc-ph]

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- **Annihilations data: very long-term → average polarisation**
  - ▷ determines absolute calibration scale for polarimeters
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⇒ **Complimentarity, Redundancy, Reduction of syst. errors !**

Polarimeter Locations in the BDS

Spintracking (calc./sim.) **is very difficult:**

need cross checks / measurements

⇒ **measure before & after the** e^+e^- **IP !**

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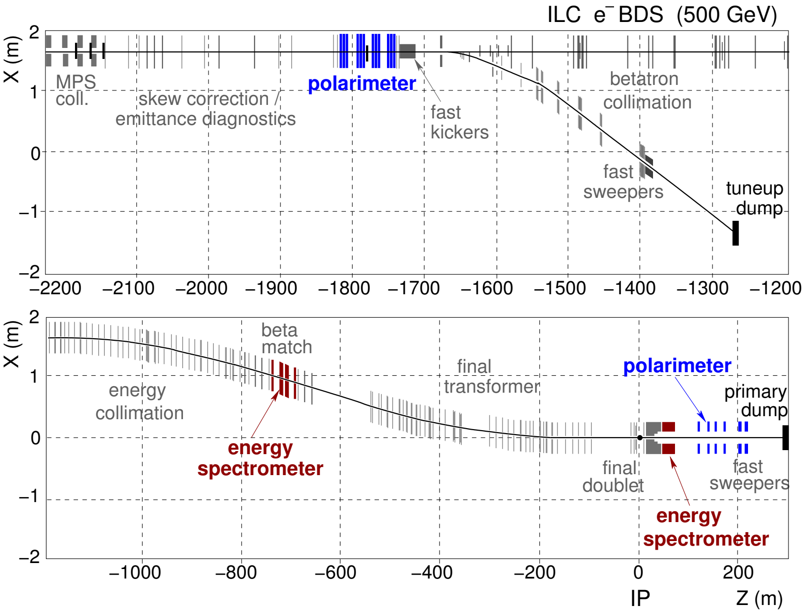
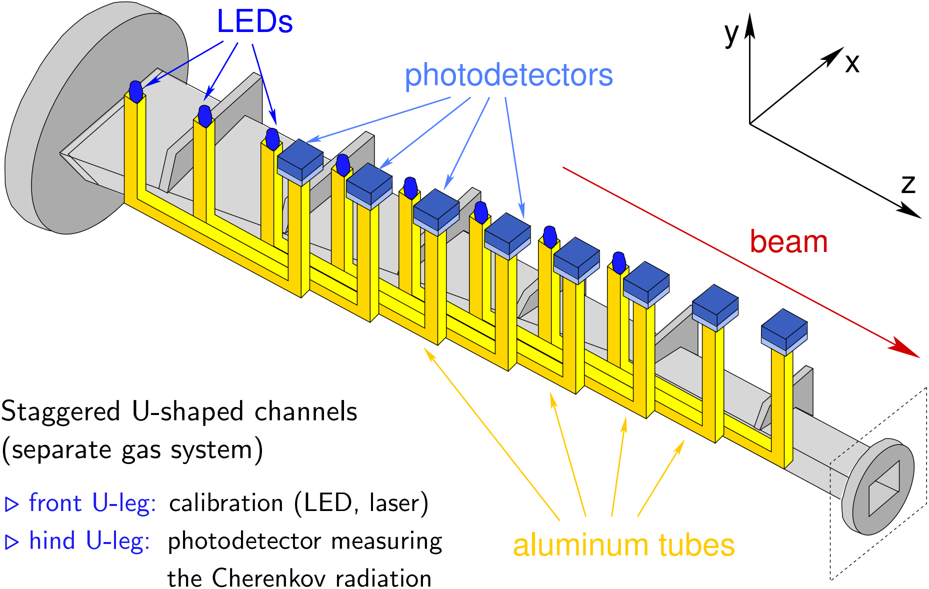


Prototyp Design
Simulation Studies

ILC Cherenkov Detector Layout



Staggered U-shaped channels
(separate gas system)

- ▷ front U-leg: calibration (LED, laser)
- ▷ hind U-leg: photodetector measuring the Cherenkov radiation

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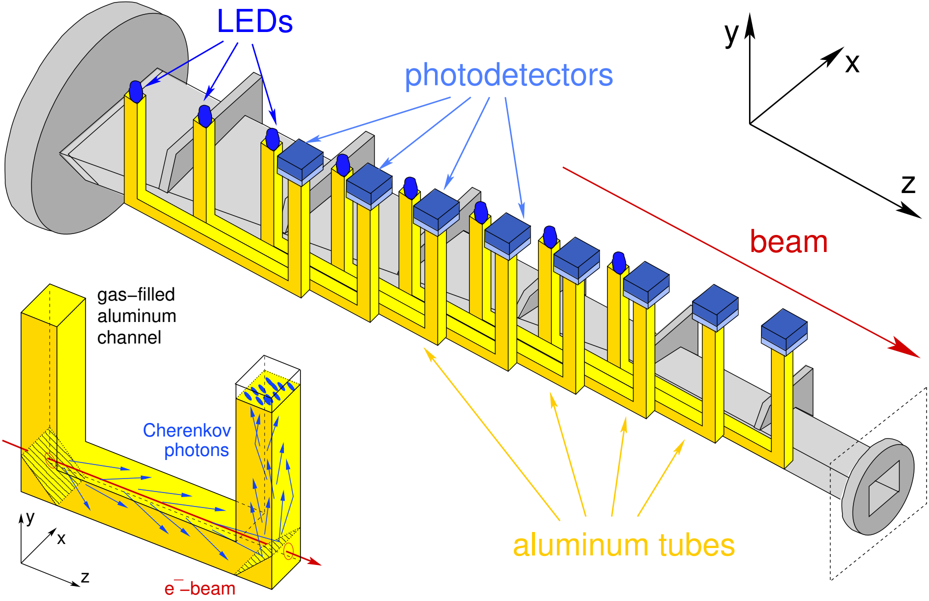
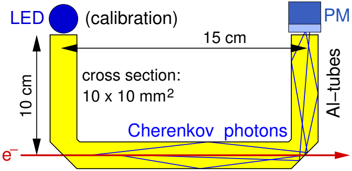


Prototype Requirements

Linearity: controllable / measurable with permille level precision !
→ need a stable detector response, also on macroscopic time scales

- **U-shape** protects PDs & calibr. system
  - ▷ outside of SR-fan & direct electrons
  - ▷ few reflections → little light loss
- **Gas- & light-tightness**



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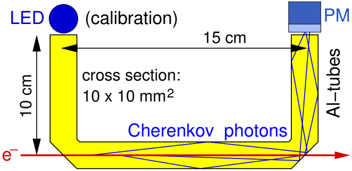
  - ▷ peak intensity in blue-ultraviol. range → need good reflectivity at small λ
  - ▷ smooth & planar inner surfaces → uniform channel illumination



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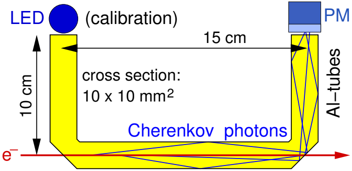
  gas: high Cherenkov threshold (MeV) → few photons due to low-energy electrons



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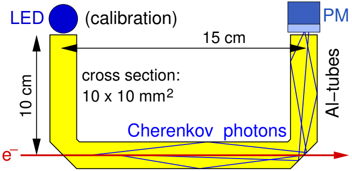

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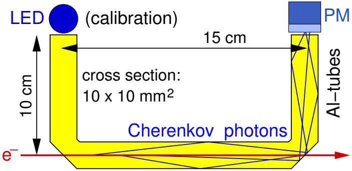

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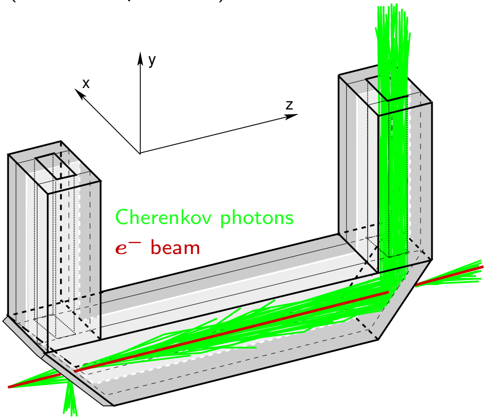
  possibility to control photodetector response (linearity) independent of beam
- **Thin wall(s)** between channels ⇒ go for a **Two-channel Prototype!**

Optical Simulation (GEANT4)

Goal: find characteristics like photon-yield per electron, average number of reflections, asymmetry effects due to geometry a/o material

Two-channel prototype

($T = 20°C$, $p = 1$ atm)



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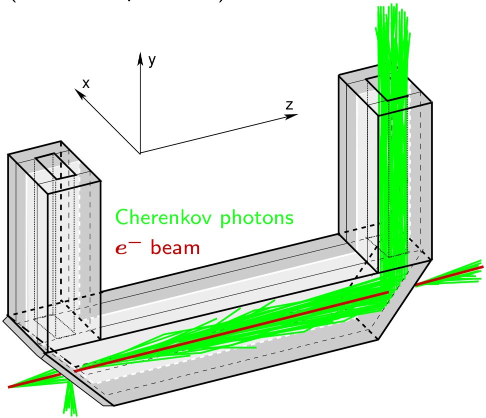

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  L=15 cm, ⌀=8.5×8.5 mm^2
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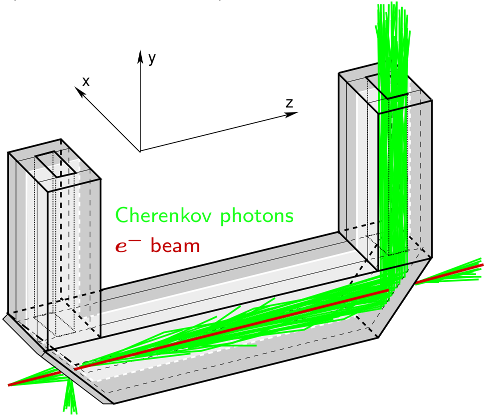

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  - diamant-milled: $R \approx 85\%$
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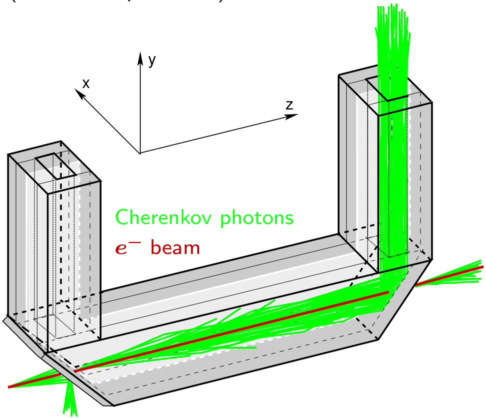

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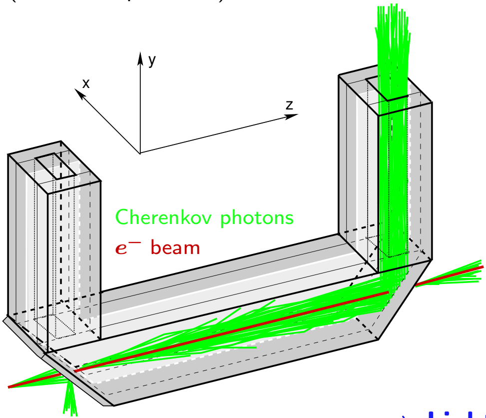

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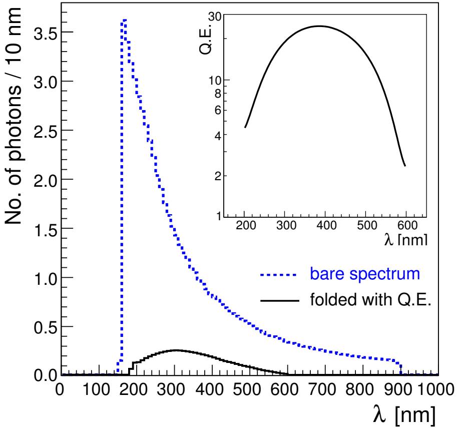
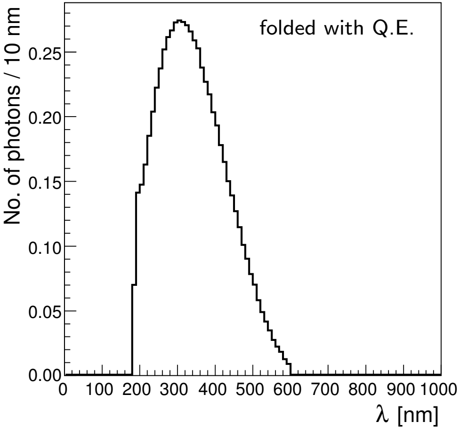
⇒ **Light distribution at photo cathode!**

Cherenkov Spectra & Quantum Efficiency

Density distribution of the Cherenkov radiation from a single electron after the optical simulation → at the photo cathode surface





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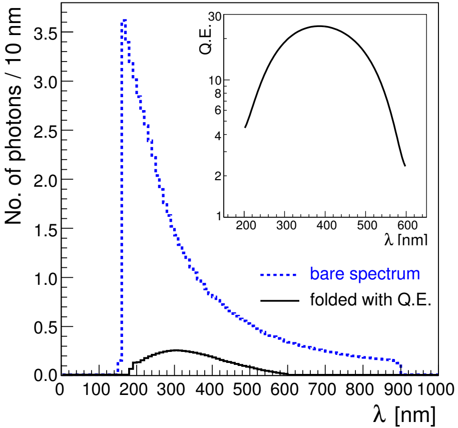
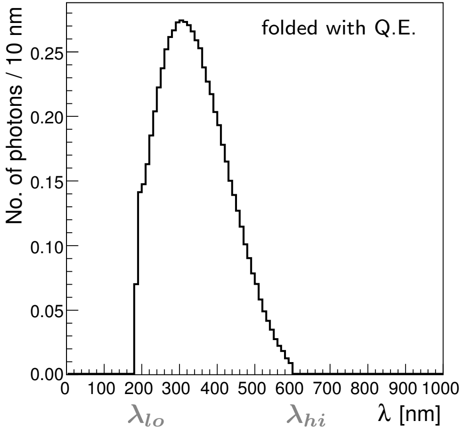
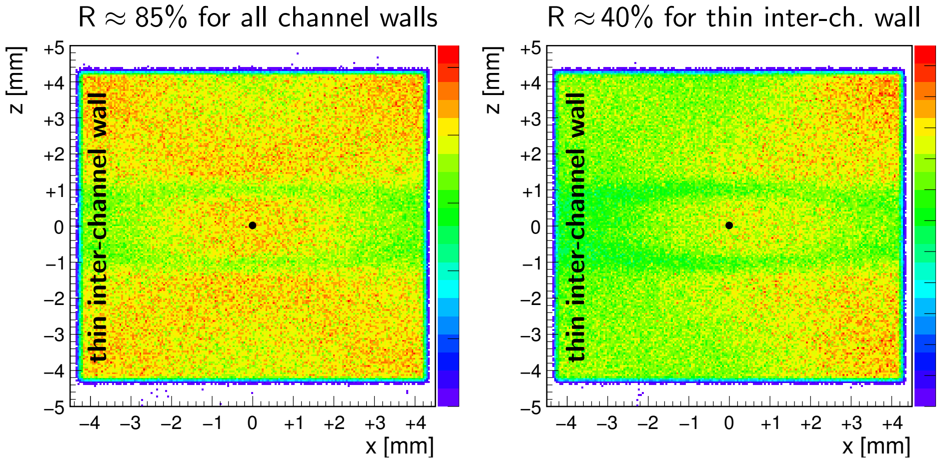




Steep decrease ($1/\lambda^2$-dep) ⇒ need blue/ultraviol. sensitive PDs

λ_{lo} : gas refractive index, λ_{hi} : photodet. dynamic range (hard-coded in simualtion)

Light Intensity at Photo Cathode

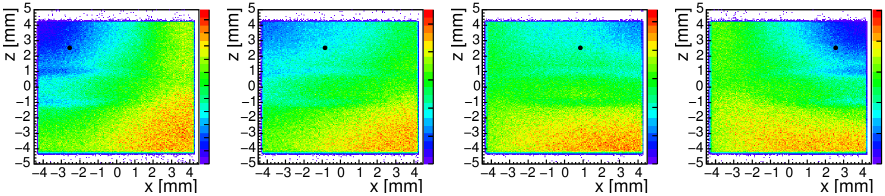


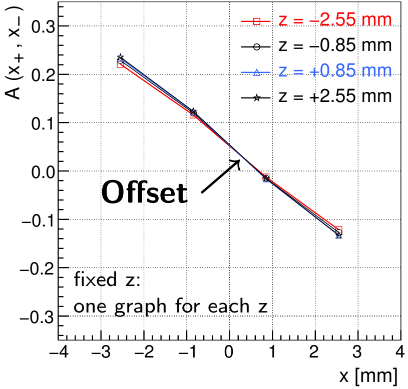
Intensity is highest opposite the inter-channel wall with worse reflectivity

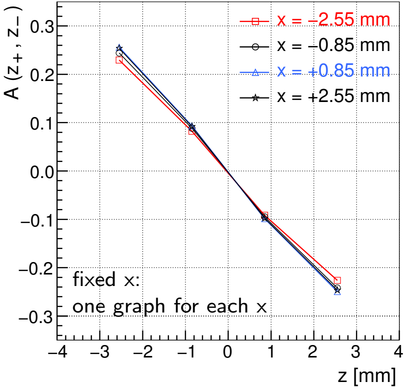
Sim. $\Rightarrow$ on average only one reflection under 'glancing angle' !

beam profil: 2-dim. Gauss ($\sigma_x = \sigma_y = 1.5$ mm), statistics: 100.000 e^-/pt., $E(e) = 2$ GeV

Asymmetries in Light Distribution



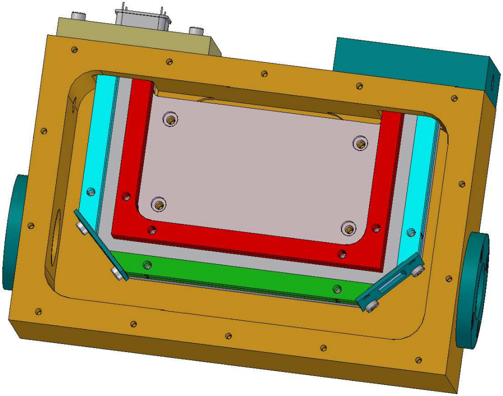




CAD & Technical Drawings (Univ. Hamburg)

Outer dimensions of the inner channel structure:

L×W×H : $178.5 \times 37 \times 114.25$ mm, base Cherenkov length: L=15 cm



CAD illustration of the inner channel structure located inside the box base body:

- ground plate,
- inner boundary walls,
- outer side boundary walls,
- and outer base wall.

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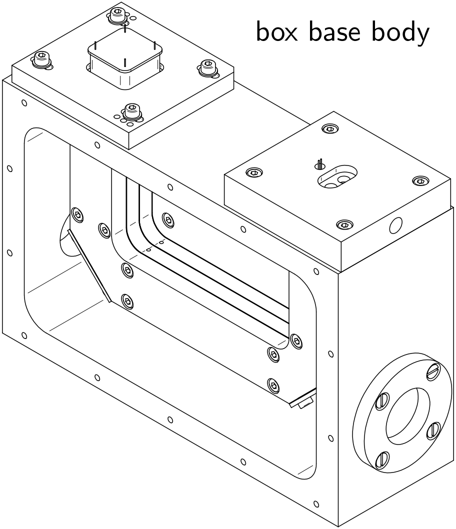
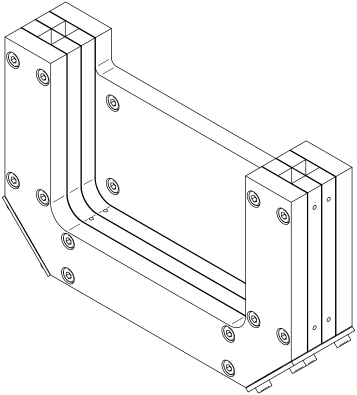
Technical drawing for the assembly of the prototype box:

box base body



inner structure:
2 parallel U-shaped channels



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- **Inner structure:** all slabs/bars/tiles are diamond-milled
  - ▷ ensure good reflectivity ($R \approx 85\%$) of all inner surfaces
  - ▷ exception: thin inter-channel foil with $R \approx 40\%$ (from GoodFellow)

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- **Box base body:** cut from a solid aluminum block
  - ▷ ensure gas- & light-tightness of the entire structure
  - ▷ allow enough room to easily accomodate the inner structure (outer box: $230 \times 90 \times 150$ mm ↔ inner dim.: $178.5 \times 37 \times 114.25$ mm)

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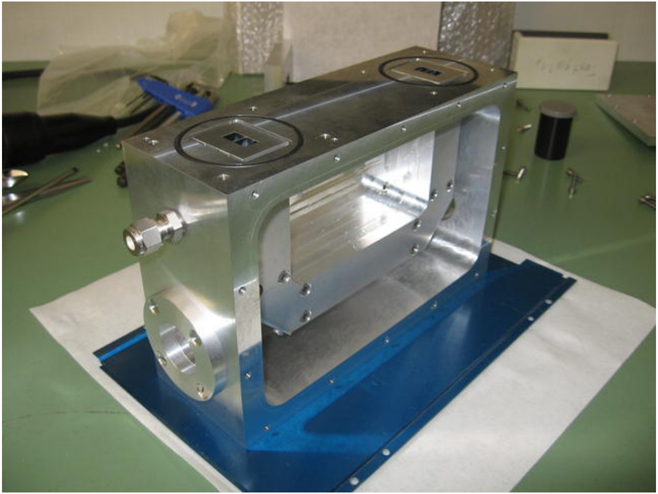
- **Assembly:**
  - ▷ assemble the complete inner channel structure
  - ▷ place inside base box & close the solid aluminum lid
  - ▷ add photodetector & calibration modules (LED only)

Some Construction Photos (Univ. Hamburg)



Open prototype box (standing), without LED- or PM-mountings

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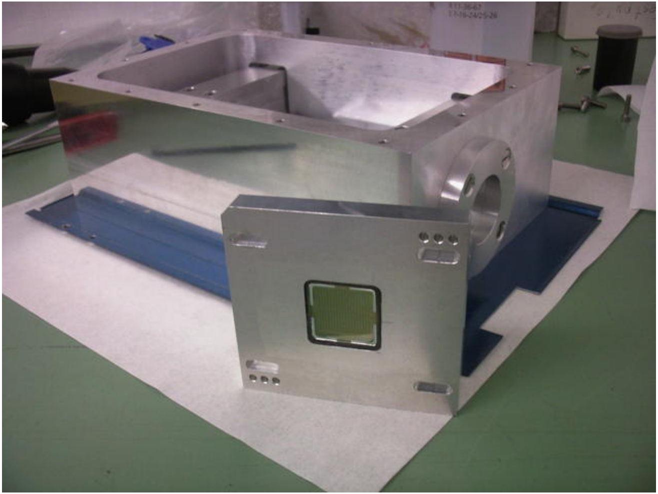

Open prototype box (lying), with PM-mounting in foreground

Testbeam 2009
(at ELSA in Bonn)

ELSA Fill Structure ↔ Readout

ELektronen-**S**tretcher-**A**nlage:[b] a three stage electron accelerator

- energy (injection/extraction) in testbeam mode: 1.2 GeV / 2.0 GeV
- variable extraction current $\approx$10 pA . . . 220 pA
- beam spot: focusable to $\approx$1...2 mm

[b] W. Hillert, Eur. Phys. J. A **28S1** (2006) 139

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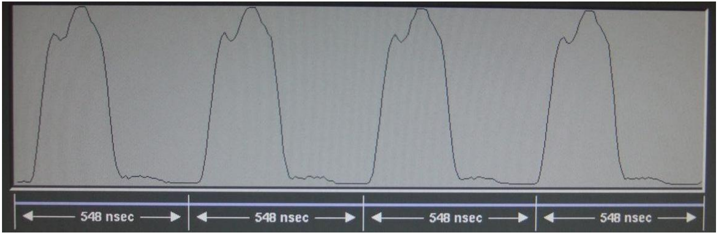

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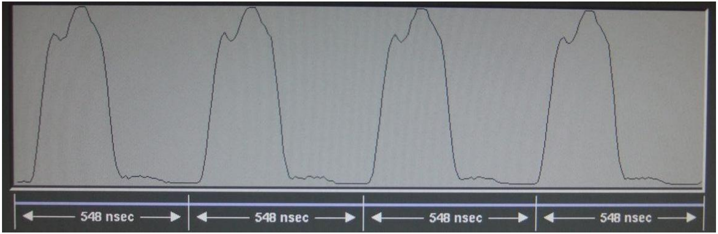


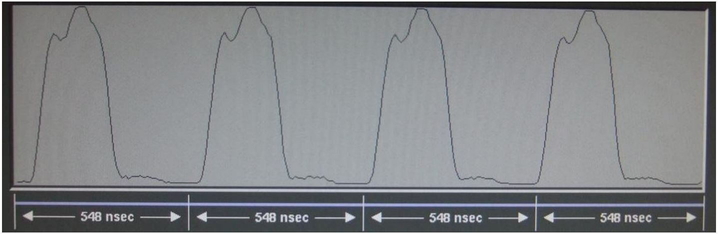
- no trigger: gate for readout electronics via "beam clock + pulse generator"
  length: detector integrates over all e^- bunches of an entire turn ($<$ 548 ns)

[b] W. Hillert, Eur. Phys. J. A **28S1** (2006) 139

ELSA Fill Structure ↔ Readout

ELektronen-**S**tretcher-**A**nlage:[b] a three stage electron accelerator

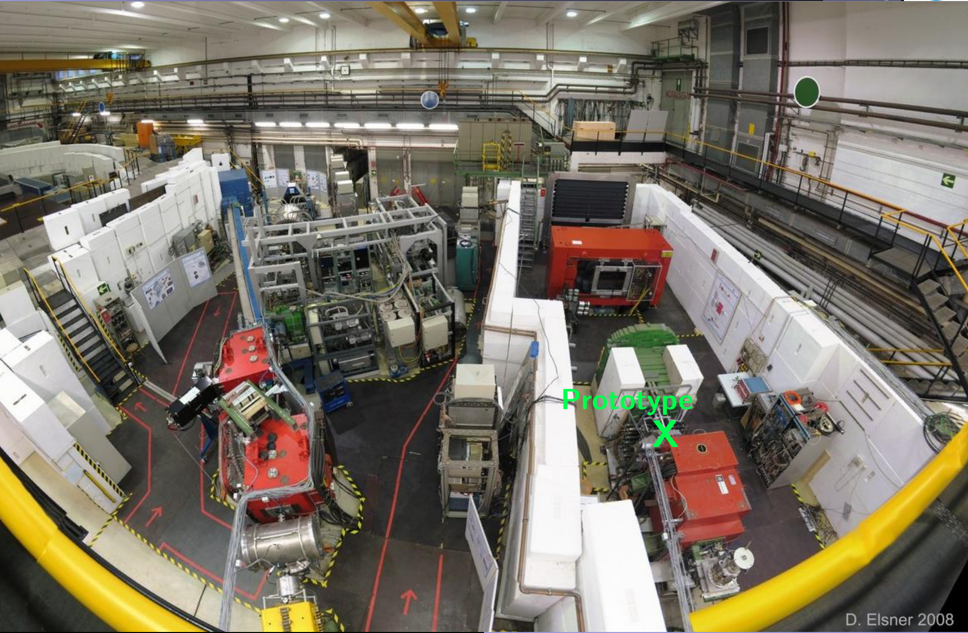
- energy (injection/extraction) in testbeam mode: 1.2 GeV / 2.0 GeV
- variable extraction current ≈10 pA . . . 220 pA
- beam spot: focusable to ≈1...2 mm
- variable fill structure: maximal 274 bunches in 2 ns intervals



- no trigger: gate for readout electronics via "beam clock + pulse generator"
  length: detector integrates over all e^- bunches of an entire turn (<548 ns)
- extraction: 4.0 s, injection/accel..: 1.1 s ⟶ ratio ≈ 4:1

[b] W. Hillert, Eur. Phys. J. A **28S1** (2006) 139

Prototype Location @ ELSA



Prototype Location @ ELSA

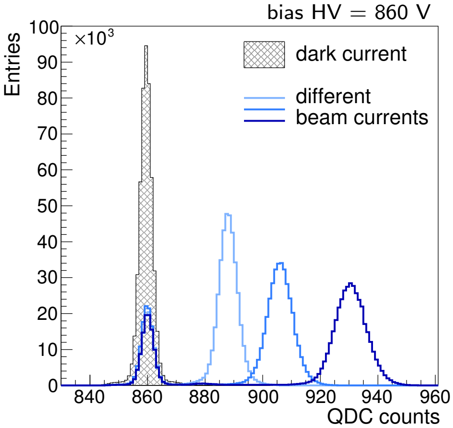
Setup in external ELSA beam line:

- directly behind a dipole magnet (dumping the electron beam)
- fixated to a translation stage: movable in x and y
- tilted in: $\alpha_x \approx 7.5° ... 7.8°$
- mounted on a base plate turnable in α_y
- $\alpha_z \approx 0°$ adjusted using a spirit level

First Cherenkov Signals

Cherenkov signals correspond to variation of the extraction beam current!

- Stable pedestal (pos. & width)
  → **constant DC rate**
  (see also: ≈ 4:1 ratio)



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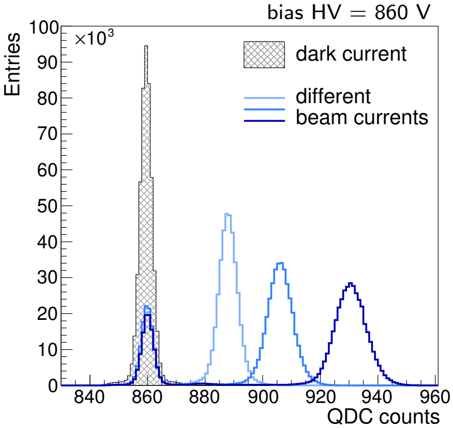

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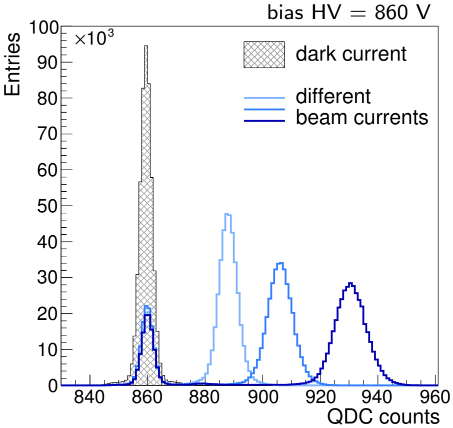

⇒ No effect seen due to changes in temperature / beam conditions!

Alignment via Cherenkov Data: α_y

Previously: align detector in x/y-direction using coarse scans, then:
several x-scans for different **tilt angles: $\alpha_y = 0, \pm1, \pm2, +3$**

Approach might be helpful regarding the alignment of real ILC pol. Cherenkov detectors

- **N photons $\propto$ channel length**

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  $\rightarrow$ **less light !**

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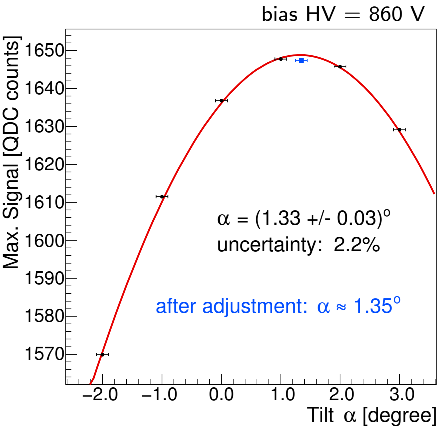

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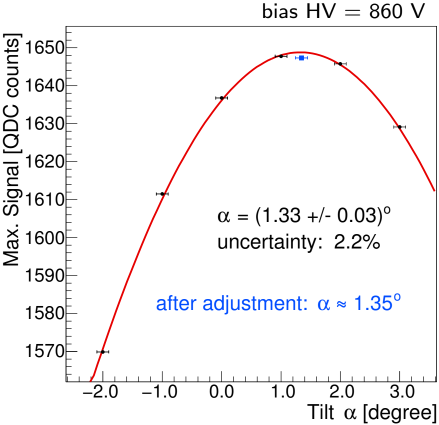
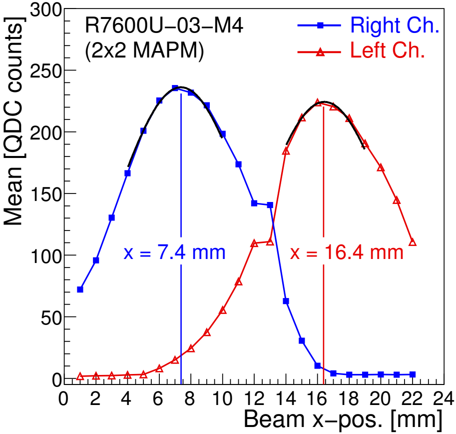


$\Rightarrow$ **Accuracy improved from $\Delta\alpha_y \approx 3^\circ$ (before) to $\lesssim 0.1^\circ$ (after)**

Different Photodetectors

absolute x-values denote the table position w.r.t. the electron beam → meaningless



Ch. distance: $\Delta x = (9.0 \pm 0.2)$ mm

nominal value: 8.8 mm

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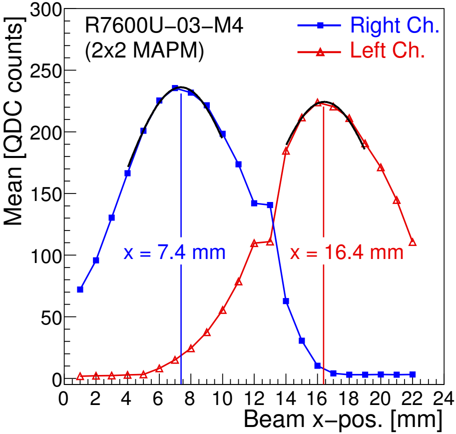

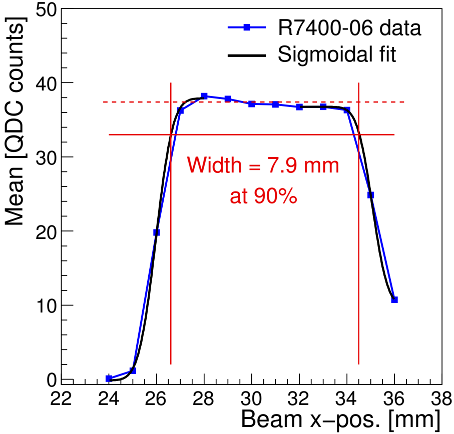

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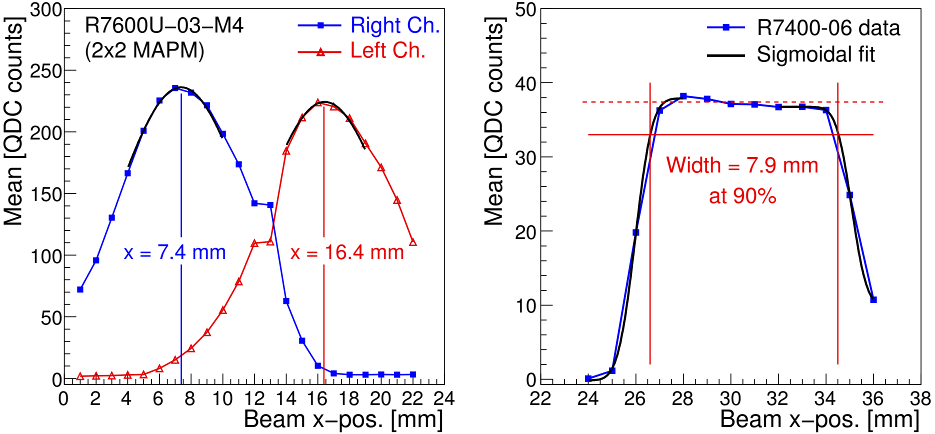

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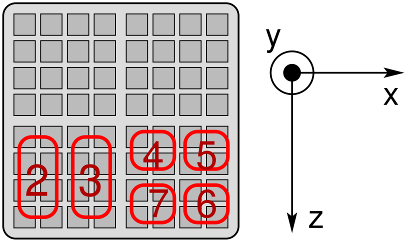
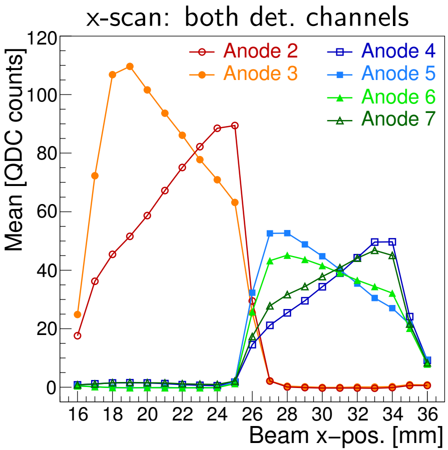
Not taken into account: non-perfect beam profile & any remaining misalignment

Multianode Photodetector (8×8)

anode readout configuration
for 8×8 MAPM, (bias HV = 500 V)





16 anodes/ch.: high position resol., but not enough readout channels

Distance: $\Delta x = (8.3 \pm 0.4)$ mm (8.8 mm) arithmetic mean from diff. methods

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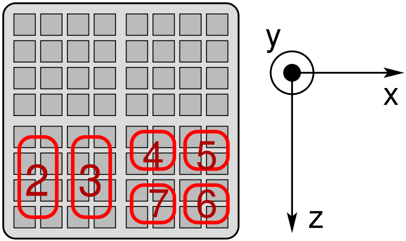
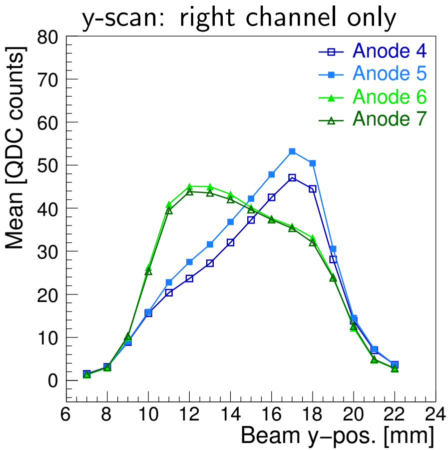


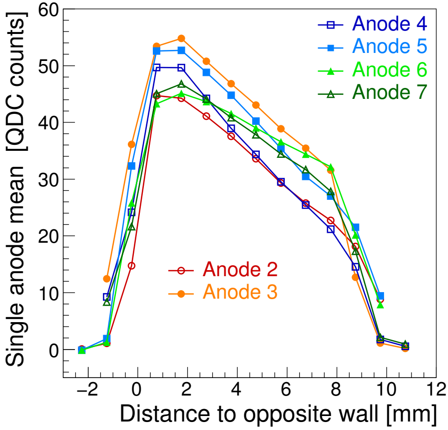


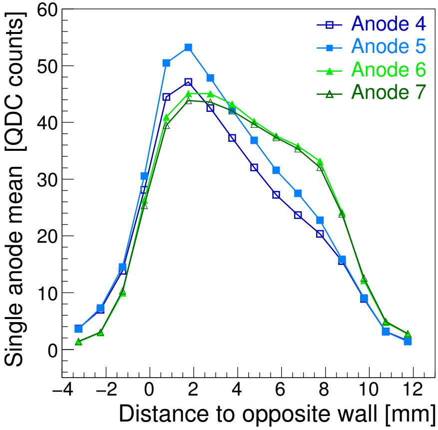
Both scans: **highest light intensity opposite the beam entry point !**

(Absolute x/y-values denote the table position w.r.t. the electron beam → meaningless!)

. . . more 8×8 MAPM

Account for: grouping of anodes & their respective distance from channel walls ⇒ same shapes! (measure distance: beam entry point ↔ opposite wall)





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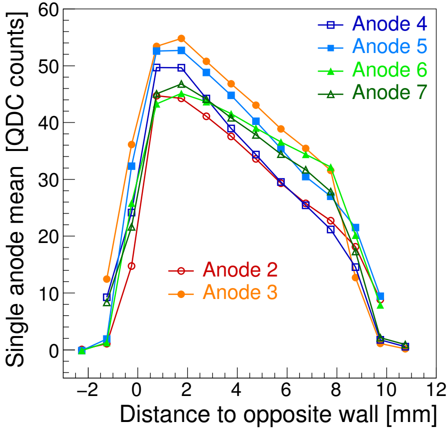
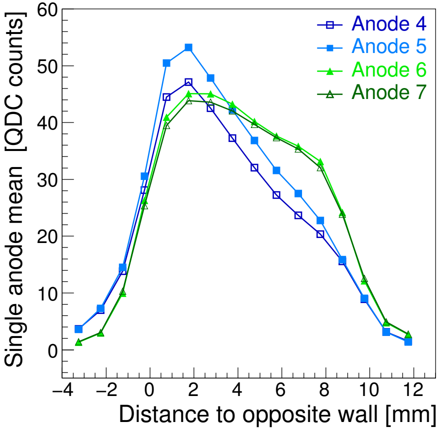
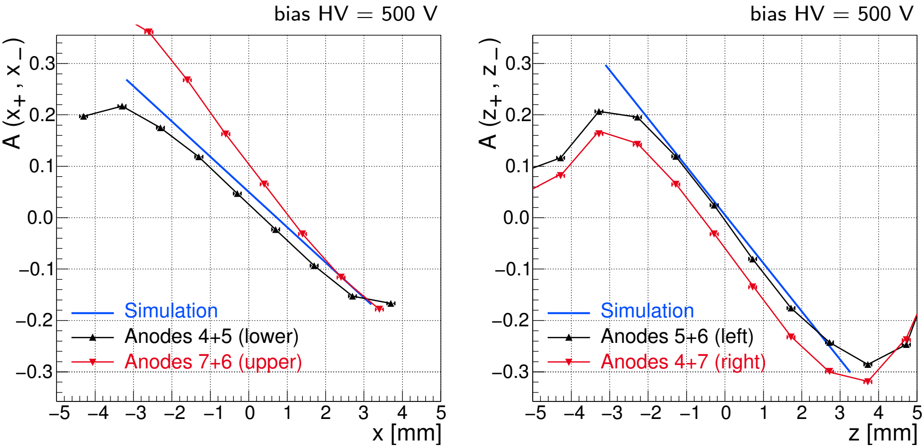




⇒ Data confirm Sim.: on average one 'glancing angle' reflection !

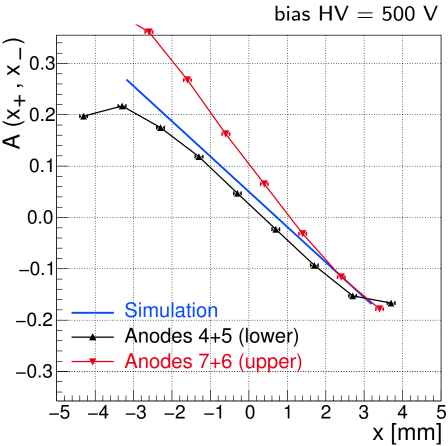
Asymmetries: Data & Simulation

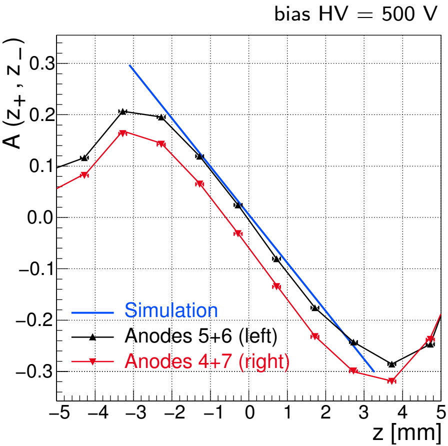


$$A(+,-) = \frac{I^+ - I^-}{I^+ + I^-}$$

light intensity in left (upper) channel half minus the one in right (lower) channel half

Asymmetries: Data & Simulation





Reduced inter-ch.wall reflectivity ⇒ **x-asym. not point-symmetric!**

data deviate slightly from simulation results → hints to remaining misalignment, non-perfect beam profile, different anode sensitivities . . .

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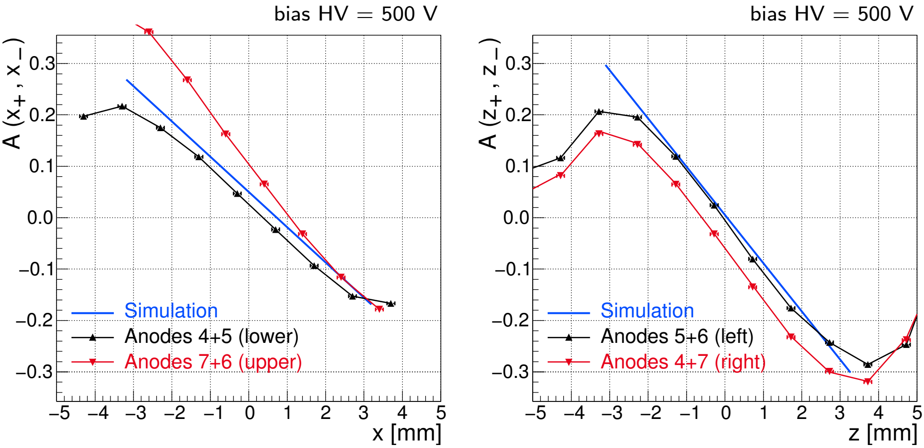
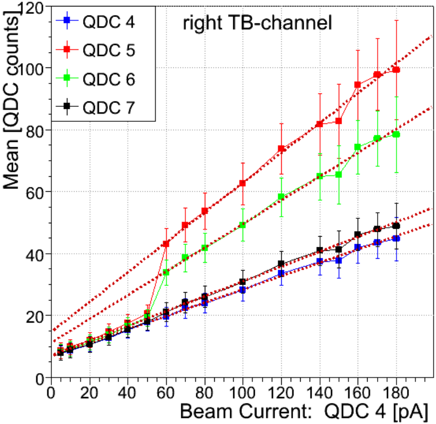
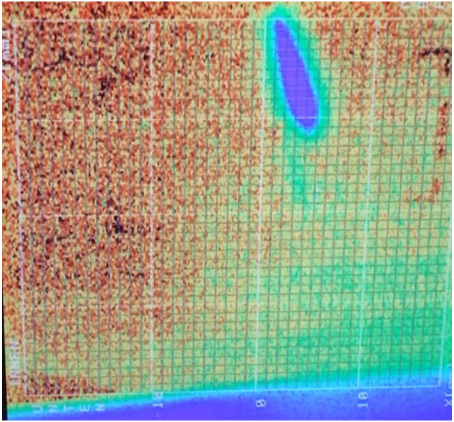


However: data & simulation agree rather well, overall !

Linearity Measurement (via beam current)





extraction current measurement rather imprecise: errors up to 10. . . 15%
→ no gain for the determination of the detector linearity

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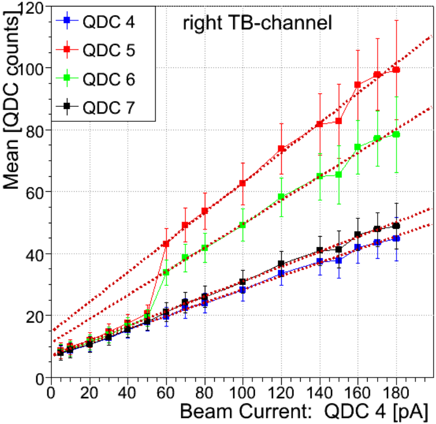

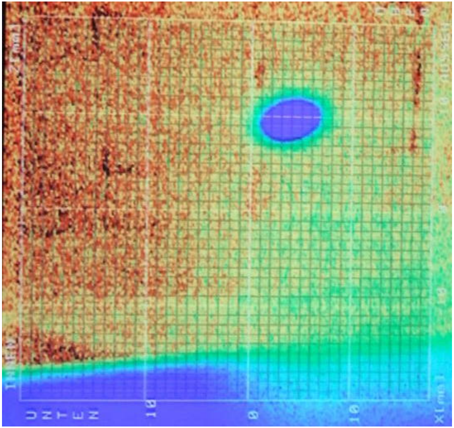

slight machine problems → troubleshooting also improves beam profile

⇒ **run simulation with non-perfect (elongated) beam profile !**

Conclusions
& Perspectives

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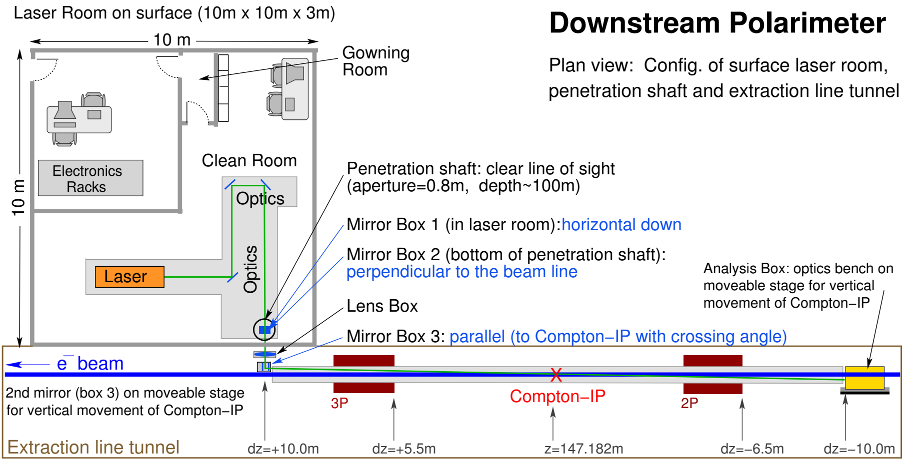
Thank you for your attention!

BACKUP



Downstream Polarimeter

Plan view: Config. of surface laser room, penetration shaft and extraction line tunnel

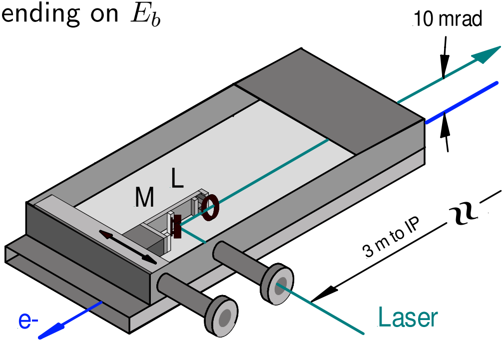
Setup for upstream laser facilities is very similar:
surface buildings, penetration shaft, laser path & moveable mirror box

Fixed field operation:

e^+/e^- beam moves laterally depending on E_b (dispersion changes)

moveable stage / mirror box:

ensure that the laser hits the e^+/e^- bunche for all available beam energies



Setup for upstream laser facilities is very similar:
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Laser choice for the upstream polarimeter:

- use same laser as for TTF/Flash injector gun
  in routine operation for many years!
- operates @ nominal pulse & bunch pattern of TESLA
  $\rightarrow$ can hit every bunch!
- pulse length: ≈ 8 ps   ($\rightarrow$ most of the laser power is available for collisions)
  - ▷ after only 20 trains (4 s) $\rightarrow$ average prec. of 1% for each bunch
  - ▷ average over two entire trains: $d\mathcal{P}/\mathcal{P} \approx 0.1\,\%$ at 50 W

S.Schreiber et al., NIM A 445 (2000) 427

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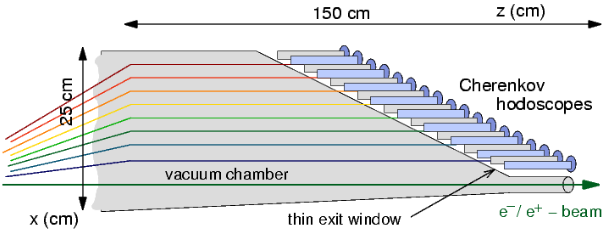
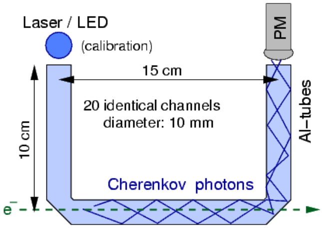
S.Schreiber et al., NIM A 445 (2000) 427

Laser choice for the downstream polarimeter:

- use frequency doubled Nd:YAG laser $\rightarrow$ slow (only hits one bunch/train)
- need to employ 3 lasers to hit 3 bunches/train
- pulse length: ≈ 6 ns $\rightarrow$ after 1 minute:
  average of the 3 measured bunches: $d\mathcal{P}/\mathcal{P} \approx 1\,\%$/min. at 50 W

Messung der Energie-/Ortsverteilung mittels Cherenkov-Detektoren





Compton-Elektronen $\rightarrow$ Cherenkov-Strahlung $\rightarrow$ Photo-Elektronen

Cherenkov-Effekt: $N_\gamma^{\mathrm{Ch}} = \varepsilon^{\mathrm{Ch}} N_e^{\mathrm{Co}}$ $\leftrightarrow$ Länge/Br.index/Reflektivität

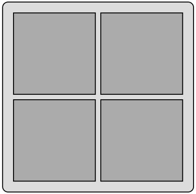
Photo-Elektronen: $N_e^{\mathrm{Ph}} = \varepsilon^{\mathrm{PM}} \varepsilon^{\mathrm{Att}} N_\gamma^{\mathrm{Ch}}$ $\leftrightarrow$ Photodetektor Typ!

$\rightarrow$ Linearität extrem wichtig!

(Größe/Form evt. Nichtlinearitäten genau messen & gegebenenfalls korrigieren.)

Photodetectors & Mountings

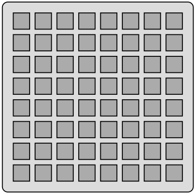
(IExpP Univ. Hamburg)



M4: 2×2 pads

18.0×18.0 mm^2

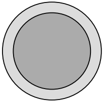
$\lambda = 185..600$ nm



M64: 8×8 pads

18.1×18.1 mm^2

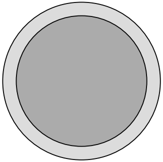
$\lambda = 300..600$ nm



R7400U-06

$\varnothing = 8$ mm

$\lambda = 160..600$ nm



XP1911/UV

$\varnothing = 15$ mm

$\lambda = 200..600$ nm

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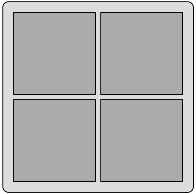

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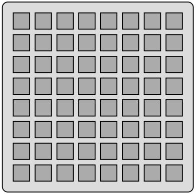

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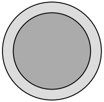

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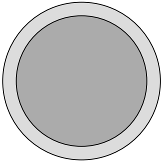

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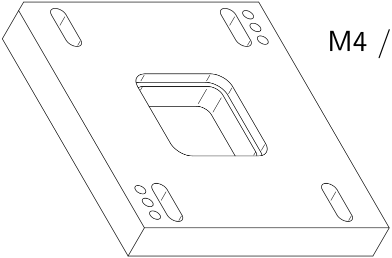
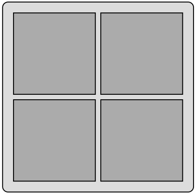


M4 / M64 mounting



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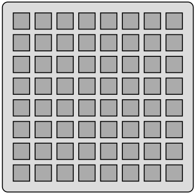

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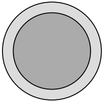

R7400U-06

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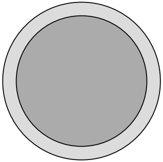
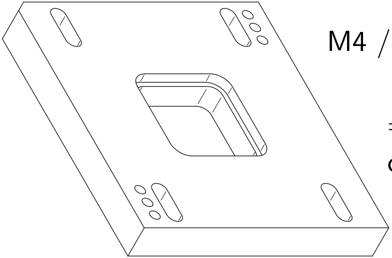
$\lambda = 160..600$ nm



XP1911/UV

$\varnothing = 15$ mm

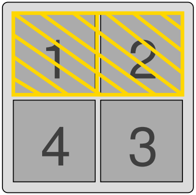
$\lambda = 200..600$ nm



M4 / M64 mounting

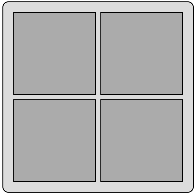
$\Rightarrow$ cross-talk studies

channels vs. PD-anodes



Photodetectors & Mountings

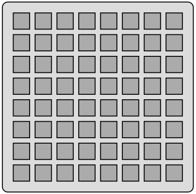
(IExpP Univ. Hamburg)



M4: 2×2 pads

18.0×18.0 mm^2

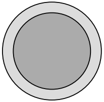
$\lambda = 185..600$ nm



M64: 8×8 pads

18.1×18.1 mm^2

$\lambda = 300..600$ nm



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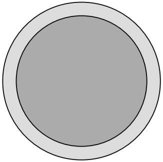

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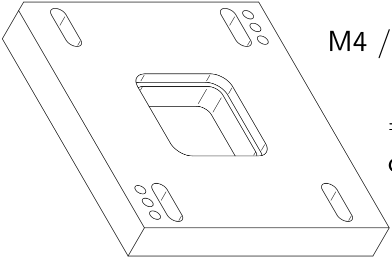

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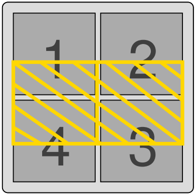

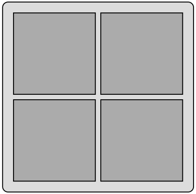

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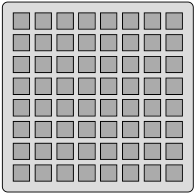

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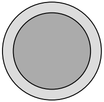

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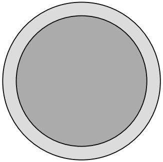

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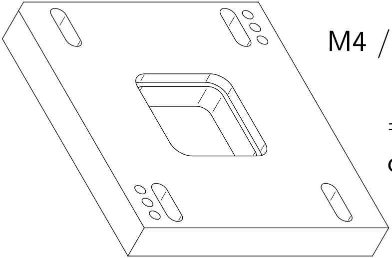

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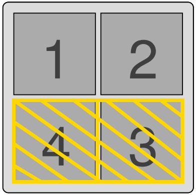

Recommendations (from 2008 EP-Workshop)

1. Separate the functions of the upstream polarimeter chicane. Do not include an MPS energy collimator or laser-wire emittance diagnostics; use instead a separate (dog-leg) setup for these two.

2. Modify the extraction line polarimeter chicane from a 4-magnet chicane to a 6-magnet chicane to allow the Compton electrons to be deflected further from the disrupted beam line.

3. Include precise polarisation and beam energy measurements for Z-pole calibration runs into the baseline configuration.

4. Keep the initial positron polarisation of 30-45% for physics.

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Recommendations cont'd (from 2008 EP-Workshop)

5. Implement parallel spin rotator beamlines with a kicker system before the damping ring to provide rapid helicity flipping of the positron spin.

6. Move pre-DR positron spin rotator system from 5 GeV to 400 MeV. This eliminates expensive superconducting magnets and reduces costs.

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