ILC Cherenkov Detector:

Prototype Design & Testbeam Measurements

C. Bartels, A. Hartin, C. Helebrant, D. Käfer, J. List
daniela.kaefer@desy.de

Linear Collider Workshop of the Americas 2009 (ALCPG'09)
Albuquerque – Sep.29 - Oct.03, 2009

1. Design & Simulation
   - Conceptual design & requirements
   - Reflectivity measurements
   - Detailed simulation studies
2. Construction
   - CAD design & technical drawings
   - Photodetector Mountings
3. Testbeam Measurements
   - General setup @ELSA in Bonn
   - Detector alignment using x- and y-scans
   - Asymmetries in data & simulation
4. Summary & Outlook

ILC Polarimetry Concept

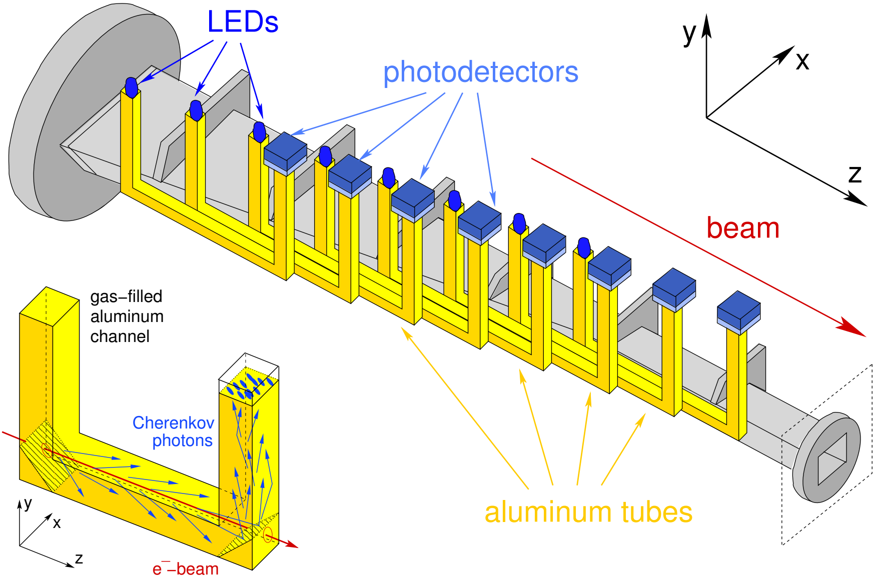
Two Compton polarimeters per beam are forseen in the BDS system.
One upstream & one downstream of the collider e^+e^- IP.

Reminder: We want to do precision physics
Thus, we **need** precise measurements of the beam polarisation.

Hoping to achieve: $\frac{d\mathcal{P}}{\mathcal{P}} = 0.25\%$ **per polarimeter**

Together with the polarisation measurement from annihilation data (which will be much slower), the polarimeters will provide the necessary redundancy and complimentarity!

Cherenkov Detector for ILC Polarimetry



Design & Simulation

Cherenkov Detector Requirements

- **Beam stay clear** (upstream: 2 cm; downstream: 15 cm)
- **Tapered beam pipe** & thin exit-window to avoid wake fields
- **Homogenous light response** to the flux of Compton-scattered e$^-$
  Cher.Rad. is independent of e$^-$ energy (for relativistic e$^-$ with $\beta \approx 1$)

$$dN^\gamma = 2\pi\alpha \left(1 - \frac{1}{n^2\beta^2}\right) \frac{d\lambda}{\lambda^2}\, d\ell\,,$$

N^γ : number of photons
ℓ : radiator length
α : fine structure constant

Thus: $\boldsymbol{N^\gamma \propto N(e^-)}$ per det. channel $\Rightarrow$ $\boldsymbol{N^\gamma \propto \ell}$ (U-basis)

- ▷ high reflectivity in a wide wavelength range ($1/\lambda^2$ spectrum), especially at low wavelengths: $\lambda \approx 200 - 350$ nm
- ▷ smooth and planar inner surfaces
- ▷ channel geometry $\leftrightarrow$ illuminate photodetector homogeneously

- **Gas- and light-tightness** of the entire detector system

Cherenkov Detector Requirements (cont'd)

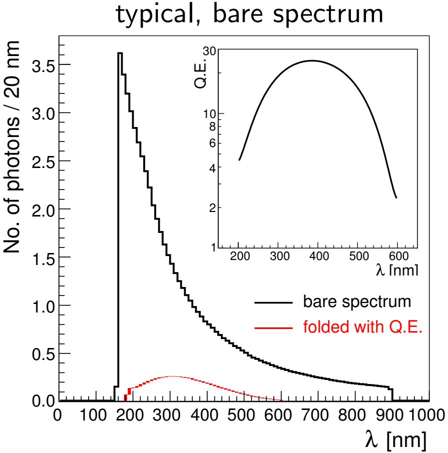
- **Robustness** with respect to backgrounds
  avoid Cher.Rad. from low energetic e^- (beam gas/halo, SR-pairs)
  $\longrightarrow$ radiator gas with high Cherenkov threshold (MeV-regime)
  place PDs well outside the (x, z)-plane (SR-fan) $\longrightarrow$ detector layout

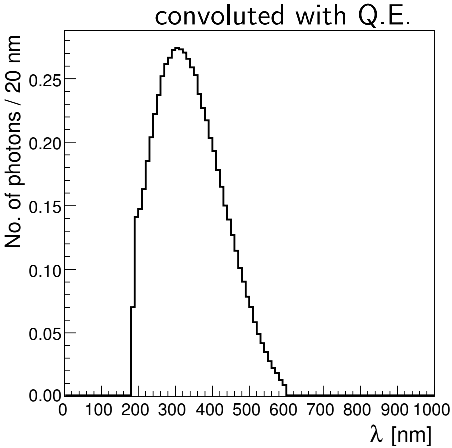
- **Calibration system** on the front U-leg
  use LEDs (or laser light?) to cross-check/control the photodetector linearity independent of e^--beam

- **Thin walls** between channels
  Polarisation measurement relies on detecting a spatial distribution
  $\longrightarrow$ need closely spaced channels with small cross sectional area
  $\longrightarrow$ thin inter-channel walls

- **Adjustable detector position** with respect to the e^--beam
  $\longrightarrow$ moveable along the x and y-axis; tiltable about all three axis

Cherenkov Spectra



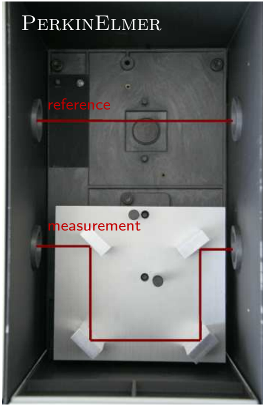


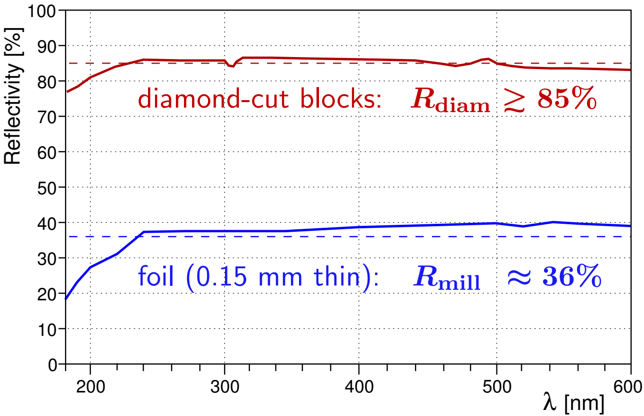
Cutoffs: $R_{\text{gas}} < 1 \;\rightarrow$ no photons emitted below: $\lambda_{\text{low}} \lesssim 160$ nm

PM constr. range [160...600 nm] $\rightarrow$ choose: $\lambda_{\text{high}} = 900$ nm

Need PMs sensitive to blue – even ultraviolet ($\lambda < 300$ nm) – light!

Reflectivity Measurement (IExpP Univ. Hamburg)





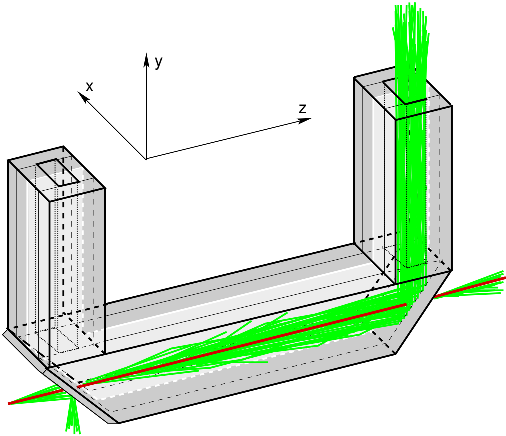
Reflectivities were measured using a modified transmission spectrometer.
4 blocks of diamond-cut aluminium (from IExpP, Univ. Hamburg),
and a 0.15 mm thin piece of milled aluminium foil (from GOODFELLOW).

Optical Simulation 1 (GEANT4)

- Length of the U-basis: 150 mm
- Height of both U-legs: 100 mm
- Two aluminum channels made of diff. Al-qualities:

  3 outer ch.-walls: $R \gtrsim 85\%$

  1 dividing wall: $R \gtrsim 36\%$
- Surrounding box is also filled with Cher.-gas C_4F_{10}



Find key figures: photon yield/electron, average number of reflections, possible asymmetries (due to geometry or used materials)

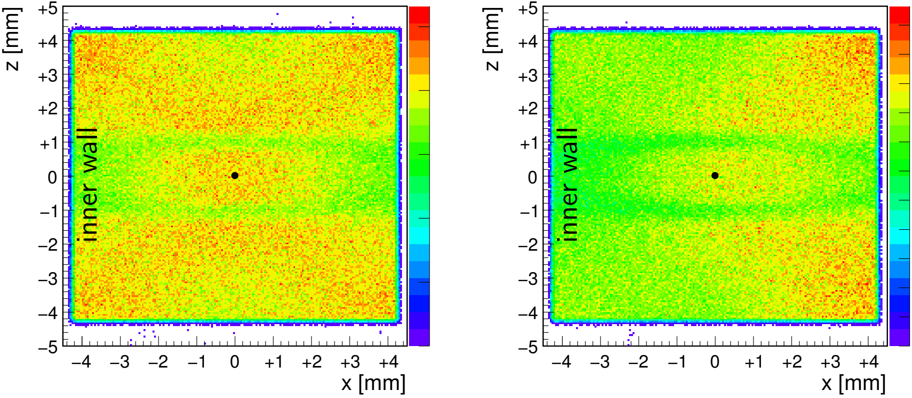
Optical Simulation 2 (GEANT4)

- Used physics processes:

electrons ($e^{\pm}$):	multiple scattering, ionisation, bremsstrahlung, annihilation
muons ($\mu^{\pm}$):	multiple scattering, ionisation, bremsstrahlung, pair production
photons (γ):	Cherenkov radiation, scintillation, Optical absorption, optical boundary processes, and Rayleigh scattering
others particles:	multiple scattering, hadron ionisation

- Optical processes: relevant for $\lambda \gg d_{\text{atoms}}$ of the surface material
- Boundary processes: take place at surfaces betw. different materials $\rightarrow$ causing reflection, refraction, and absorption of photons

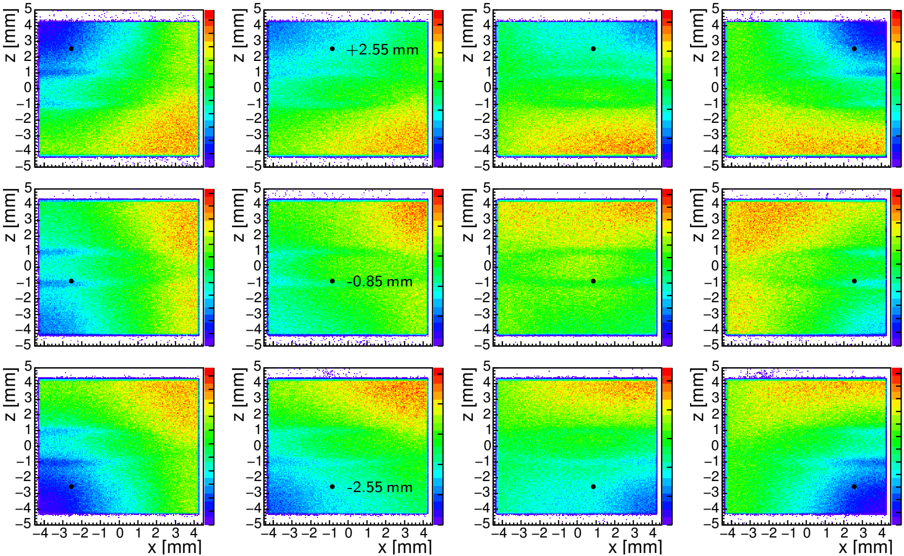
Channel Illumination (right-hand side)



$\langle N^\gamma \rangle \approx 64.7$ $\sigma^\gamma \approx 8.5$	average number of photons on photocathode per primary e^-	$\langle N^\gamma \rangle \approx 52.1$ $\sigma^\gamma \approx 7.8$
all equal $R \approx 80\%$	wall reflectivities	inner wall $R \approx 40\%$

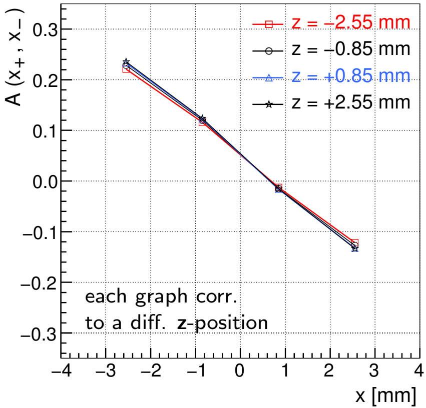
On average only one reflection under ‘glancing angle’ on the walls!

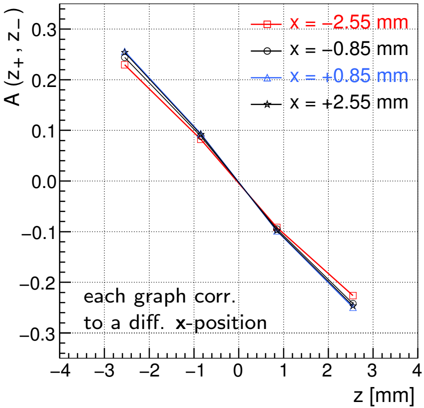
Light Intensity at PD cathode (Sim.)



4×4 equidistant points/channel and 10 000 e^- per beam entry point

Derived Asymmetries in x and z





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

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

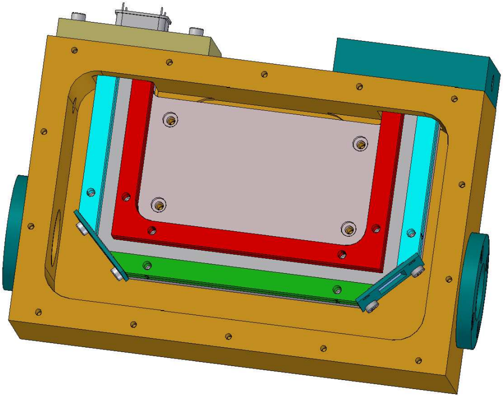
$I_{x,z}^+$ ($I_{x,z}^-$): Light intensity in the left/upper and (right/lower) channel half

Construction Phase

Design & Technical Drawings (IExpP Univ. Hamburg)

Outer dimensions of the inner channel structure:

L×W×H : 178.5 mm $\times$ 37 mm $\times$ 114.25 mm



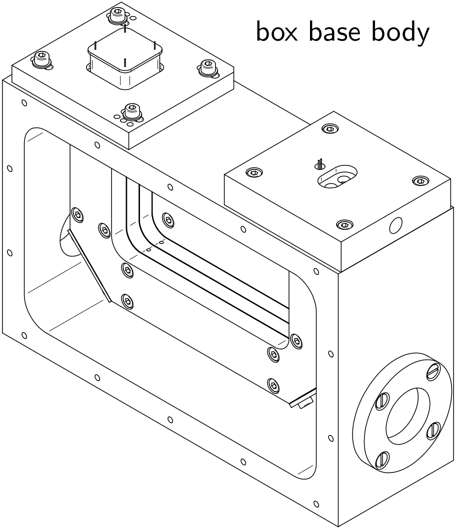
CAD illustration of the inner channel structure located inside the box base body:

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

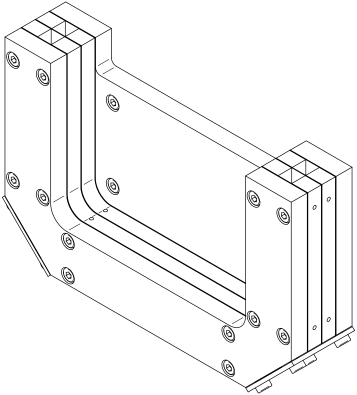
Design & Technical Drawings (IExpP Univ. Hamburg)

Technical drawing for the assembly of the prototype box:

box base body



inner structure:
2 parallel U-shaped channels



The Construction Process

(IExpP Univ. Hamburg)

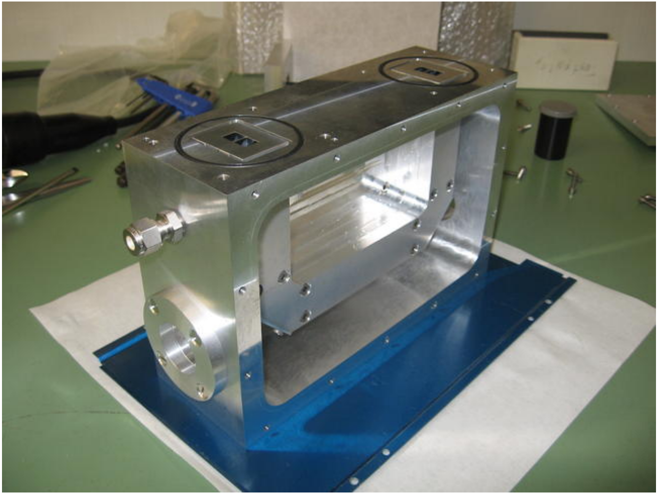
- **Box base body:** cut from a solid aluminum block L×W×H : 230 mm $\times$ 90 mm $\times$ 150 mm, to easily accomodate the inner channel structure (with 178.5 mm $\times$ 37 mm $\times$ 114.25 mm)

- **Inner structure:** manufactured from high-purity aluminum The Al-slabs/-bars are diamond-cut to ensure good reflectivity of at least three inner walls/ch. with: $R \gtrsim 85\%$, while milled foil (GoodFellow) makes up the thin middle wall: $R \gtrsim 36\%$.
  (see: reflectivity measurements)

- **Assembly I:** inner channel structure is placed inside the box base body and fixated by various screws

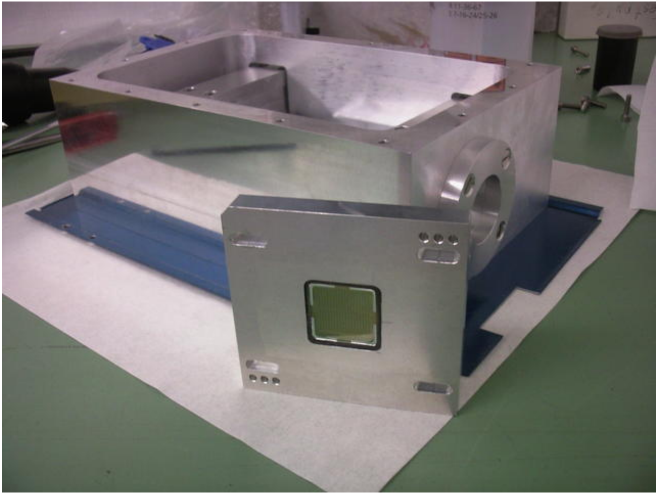
- **Assembly II:** a solid aluminum lid (with pressure gauge attached) is screwed to the box base body to ensure gas-tightness

Prototype: Construction Photos (IExpP Univ. Hamburg)



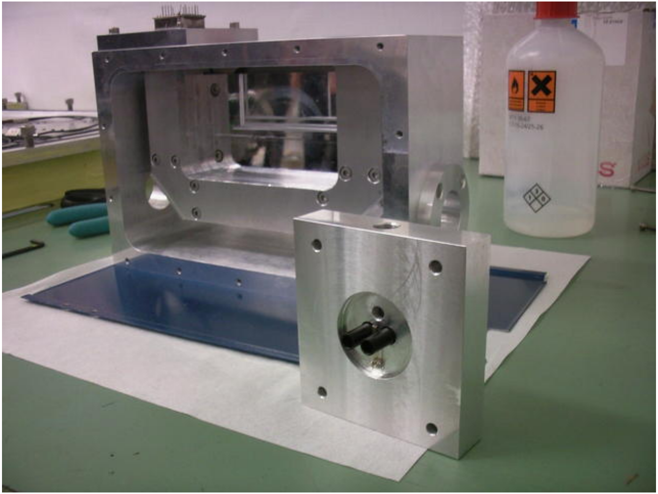
Open prototype box (standing), without LED- or PM-mountings

Prototype: Construction Photos (IExpP Univ. Hamburg)



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

Prototype: Construction Photos (IExpP Univ. Hamburg)

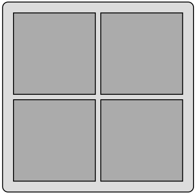


Open prototype box (standing), with LED-mounting in foreground

Prototype: Construction Photos (IExpP Univ. Hamburg)

Closed prototype box, including the LED- & PM-mountings and a pressure gauge (left-hand side)

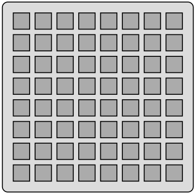
Photodetectors & Mountings (IExpP Univ. Hamburg)



M4: 2×2 pads

18.0×18.0 mm^2

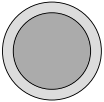
$\lambda = 185..600$ nm



M64: 8×8 pads

18.1×18.1 mm^2

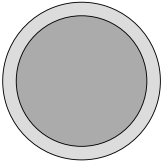
$\lambda = 300..600$ nm



R7400U-06

$\varnothing = 8$ mm

$\lambda = 160..600$ nm

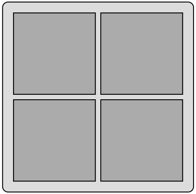


XP1911/UV

$\varnothing = 15$ mm

$\lambda = 200..600$ nm

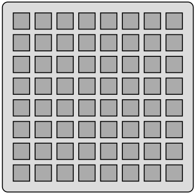
Photodetectors & Mountings (IExpP Univ. Hamburg)



M4: 2×2 pads

18.0×18.0 mm^2

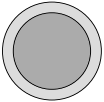
$\lambda = 185..600$ nm



M64: 8×8 pads

18.1×18.1 mm^2

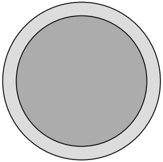
$\lambda = 300..600$ nm



R7400U-06

$\varnothing = 8$ mm

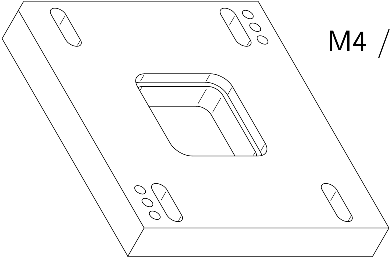
$\lambda = 160..600$ nm



XP1911/UV

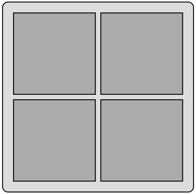
$\varnothing = 15$ mm

$\lambda = 200..600$ nm



M4 / M64 mounting

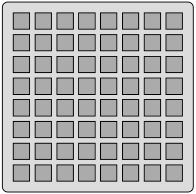
Photodetectors & Mountings (IExpP Univ. Hamburg)



M4: 2×2 pads

18.0×18.0 mm^2

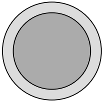
$\lambda = 185..600$ nm



M64: 8×8 pads

18.1×18.1 mm^2

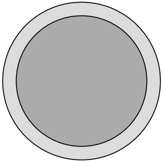
$\lambda = 300..600$ nm



R7400U-06

$\varnothing = 8$ mm

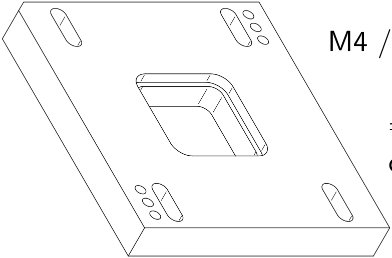
$\lambda = 160..600$ nm



XP1911/UV

$\varnothing = 15$ mm

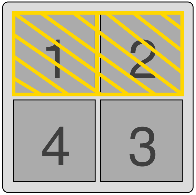
$\lambda = 200..600$ nm



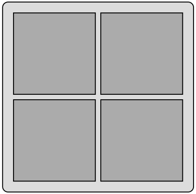
M4 / M64 mounting

$\Rightarrow$ cross-talk studies

channels vs. PD-anodes



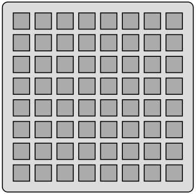
Photodetectors & Mountings (IExpP Univ. Hamburg)



M4: 2×2 pads

18.0×18.0 mm^2

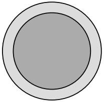
$\lambda = 185..600$ nm



M64: 8×8 pads

18.1×18.1 mm^2

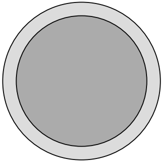
$\lambda = 300..600$ nm



R7400U-06

$\varnothing = 8$ mm

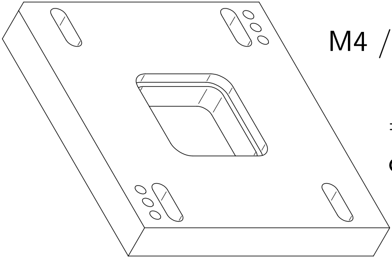
$\lambda = 160..600$ nm



XP1911/UV

$\varnothing = 15$ mm

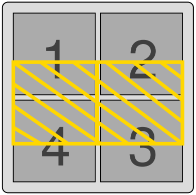
$\lambda = 200..600$ nm



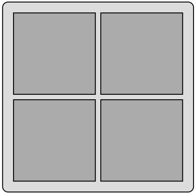
M4 / M64 mounting

⇒ cross-talk studies

channels vs. PD-anodes



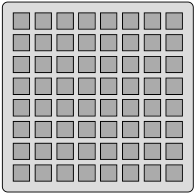
Photodetectors & Mountings (IExpP Univ. Hamburg)



M4: 2×2 pads

18.0×18.0 mm^2

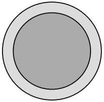
$\lambda = 185..600$ nm



M64: 8×8 pads

18.1×18.1 mm^2

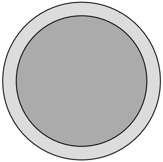
$\lambda = 300..600$ nm



R7400U-06

$\varnothing = 8$ mm

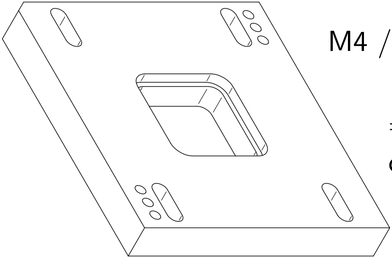
$\lambda = 160..600$ nm



XP1911/UV

$\varnothing = 15$ mm

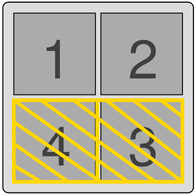
$\lambda = 200..600$ nm



M4 / M64 mounting

⇒ cross-talk studies

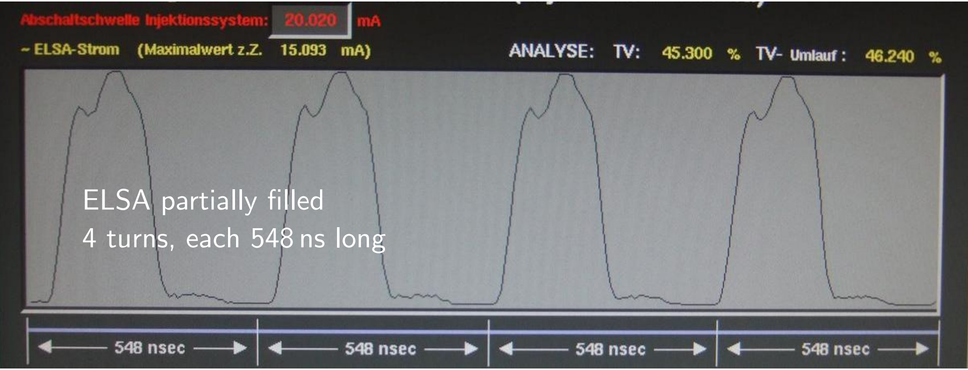
channels vs. PD-anodes



Testbeam Measurements

ELSA Specifications

ELektronen-Stretcher-Anlage



turn time: 548 ns, **beam structure**: 274 buckets, one every 2 ns
Continuous extraction over 4 s, (cycle time: 5.1 s, refill/acc: 1.1 s)

2 ns	bunch repetition rate	numerous e^- passing simult.
10..200 pA	adj. extraction current	through the detector U-basis
1..2 mm	beam spot size	⇒ **large Cherenkov signals!**

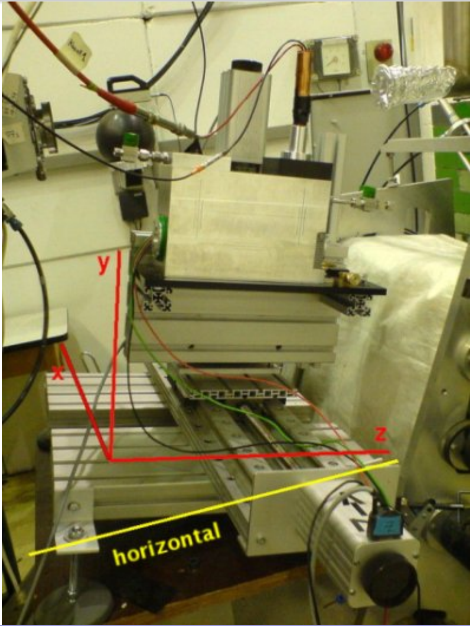
Detector Setup @ ELSA

- use beam clock to gate QDC, adjustable between 100..480 ns
  $\Rightarrow$ integrating over complete turn!
  (not resolving the 2 ns sub-structure)

Expected av. number of e^-/turn:
(extr. current $\times$ turn time / e)

10 pA	$\rightarrow$	$\approx$	30 e^-
200 pA	$\rightarrow$	$\approx$	680 e^-
at ILC	$\rightarrow$	$\approx$	200 e^-/ch.

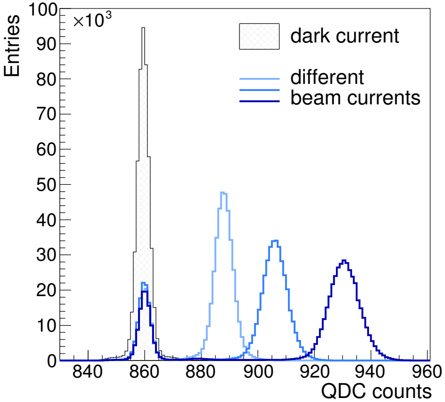
- prototype box installed on stage:
  - movable along x and y-axis
  - tiltable about all three axis, but
  - fine adjustment only about y-axis: for $|\alpha_y| < 3.0°$ in steps of $0.125°$
    (beam slope: $\alpha_x \approx 7.5° - 7.8°$)



Some Cherenkov Signals

- signals vary with e^- beam current
  low current $\rightarrow$ less γ^{Cher} (vice versa)
- dark current (DC) rate depends on integration time / gate width
- DC consists of electronics pedestal & PM thermal noise, depending
  - primarily on bias voltage
  - not (directly) on temperature
  - or on beam conditions...

  but: changes in beam conditions influence temp./beam backgr./etc.



$4 \times$ A(DC peak) $\approx$ A(right peak)
refill: 1.1 s extract: 4 s

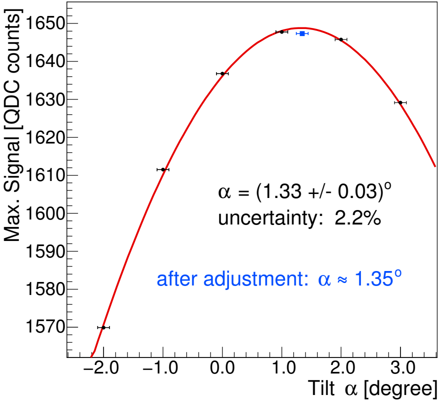
$\Rightarrow$ **Stable DC rate: none of these effects are discernible so far!**

Tilt Adjustment about y-axis

After PM exchange: adjust bias voltage $\rightarrow$ distinguish signal & DC peak

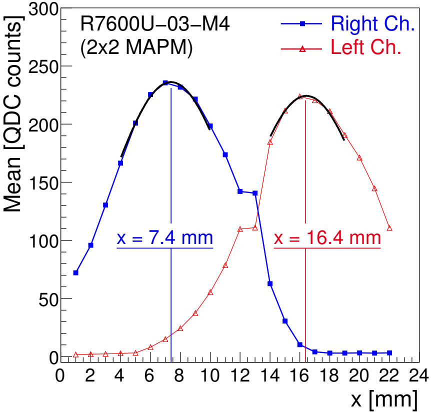
(even for low beam currents of ≈ 20 pA and keep linear response to higher beam currents.)

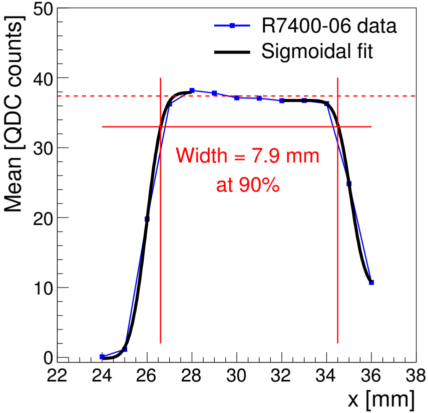
- using Cherenkov data itself
  ("fine" alignement of ILC-polarimeter will likely have to be done this way)
- adjust (x, y)-pos. roughly by doing coarse x- and y-scans
- adjust α_y (tilt about y-axis) doing various x-scans at different α_y
  - $N(\gamma^{\text{Cher}}) \propto \ell^{\text{ch}}$
  - tilt $\rightarrow$ diagonal beam path $\rightarrow$ less Cherenkov photons...



Turnable base plate + above method: $\boldsymbol{\Delta\alpha_y \gtrsim 3^\circ \rightarrow \Delta\alpha \lesssim 0.1^\circ}$

Scans in x for Different PMs





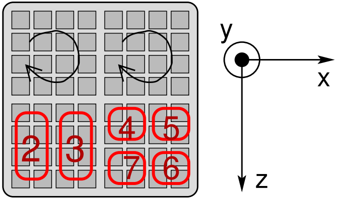
Gaussian fits:
$\Delta x \approx 9$ mm (nominal: 8.8 mm)

Sigmoidal fits:
$w_{\text{ch}} \approx 7.9$ mm (nom: 8.5 mm)

Channel distance & width agree well with the nominal values!

MAPM: no plateau visible contrary to what is observed in SAPM-data → cause unkown
Assumption: ellipsoidal elongated beam profile → currently being investigated

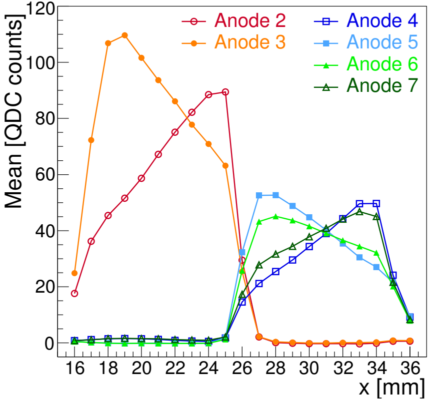
8 × 8 MAPM: x-Scan



fine segmented anode

64 anode pads: 16/channel

grouped together

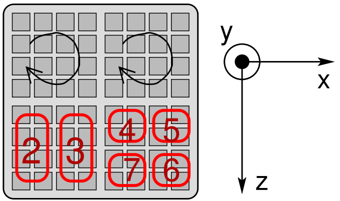


Channel distance & width, arithmetic mean (different methods):
$\Delta x \approx$ 8.6 mm (nominal: 8.8 mm) and $w_{ch} \approx$ 7.8 mm (nominal: 8.5 mm)

Data confirms Sim: highest light intesity opposite beam entry point!

Height difference: inter-ch. ↔ anode grouping; intra-ch. ↔ anode sensitivity?
Intersection points of same-side anodes (A4+7, A5+6) ↔ possibly residual tilt about y

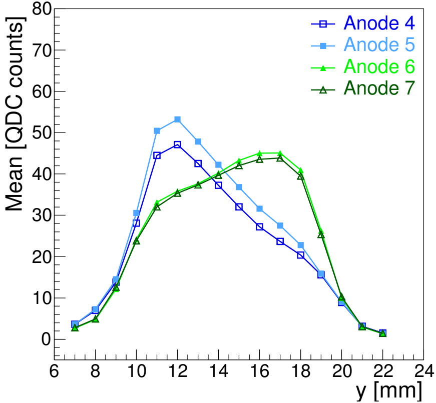
8×8 MAPM: y-Scan



fine segmented anode

64 anode pads: 16/channel

grouped together



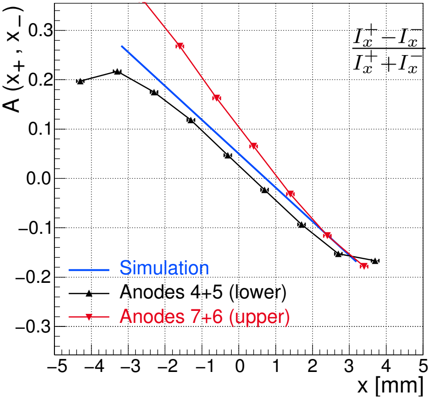
Channel height arithmetic mean: $w_{\mathrm{ch}} \approx 8.2$ mm (nominal: 8.5 mm)

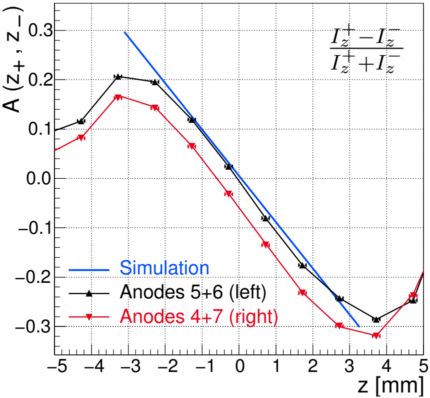
Data confirms Sim: highest light intesity opposite beam entry point!

Height difference: intra-ch. ↔ anode sensitivity? (as for x-scan data)

Intersection points of same-side anodes (A4+5, A7+6) ↔ possibly residual tilt about x, or z

Asymmetries: Data vs. Simulation





Both asymmetries are calculated in the exact same way as the simulated ones.

diff. slope ↔ residual tilt α_y, or α_z
both affect left-right symmetry

A4+7 offset ↔ residual tilt α_x,
or due to elongated beam profile

Data confirms Sim: important characteristics are very similar !

⇒ asymmetry data even usable as additional alignment information

Conclusions & Outlook

Conclusions & Outlook

- Prototype Cherenkov detector completed in February 2009
  (two testbeams @DESY, Hamburg (not shown), one @ELSA, Bonn)
- An optical simulation has been developed based on GEANT4
  (further tuning using recent testbeam data)
- Successful 2-week testbeam period @ELSA in Bonn
  - ▷ first analysis results are very promising
  - ▷ data shows a behaviour as expected from simulation
  - ▷ full-fledged analysis of all data is in progress . . .
    and expected to advance the understanding of the prototype detector,
    as well as improve the design of the ILC Cherenkov detector
- ILC Cherenkov detector needs more design & engineering work:
  - ▷ mechanical stability/robustness ↔ extremely thin inter-channel walls
  - ▷ gas system: separate for each channel ↔ one for all channels