Polarimetry

Testbeam Results, PD Linearity, and Prototype Design

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1. Testbeam Results
   - SLD Cherenkov detector in DESY testbeam
   - What have we learned?
2. Detailed Photodetector Measurements
   - Electronics (non)-linearity
   - Development of linearity methods: INL, DNL
3. Prototype Design
   - How should it look like in the end?
   - Design & Construction
   - Simulation & Testing
4. Summary & Outlook

Precision, Precision, Precision

Reminder: We want to do precision physics
→ **need** precise measurement of beam polarisation

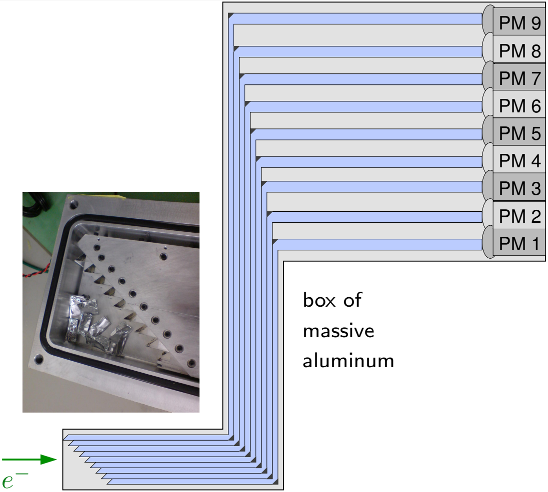
Hoping to achieve: $\frac{d\mathcal{P}}{\mathcal{P}} = 0.25\%$ **per beam.**

whereas - from a physics point of view - it would clearly be better to measure even more precisely.

Different areas of work/development:
⟹ testbeam data analyses, linearity measurements of photodetectors (PDs) and readout electronics, prototype design & construction

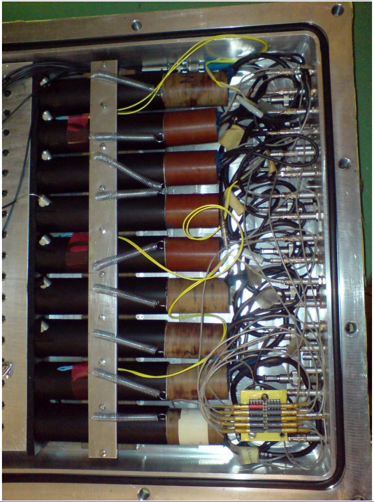
Testbeam Results:
SLD Cherenkov Detector

SLD Cherenkov Detector

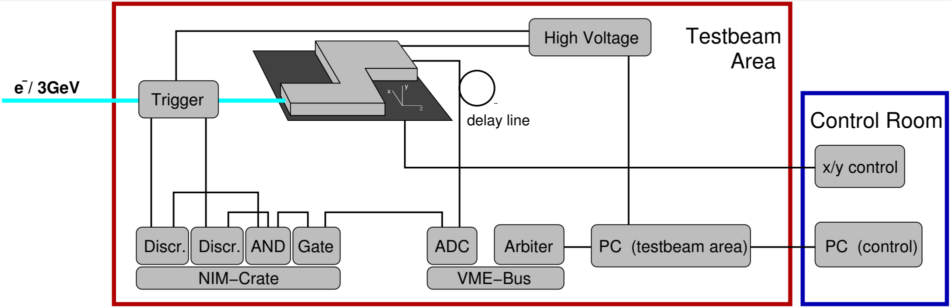


Cherenkov Detector:

has 9 channels made of polished aluminum & photomultipliers (R1398) for readout.



Setup in the Testbeam Area



November 2007

15 days: first time setup & tests

- unchanged; old PMTs
- ch.3 dead, ch.1+2 bad

December 2007

4 days right before christmas

- exchanged some PDs MAPMs(1,2,3) & SiPMs(6,8)

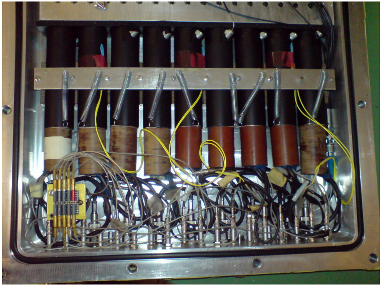
Both periods: using fast VME electronics for readout, especially:
a 12-bit QDC with two ranges: 200 fC and 25 fC LSB ("least significant bit")
Caveat: need to know QDC linearity very precisely to use its potential

SLD Cherenkov Detector Setup in DESY-II Testbeam

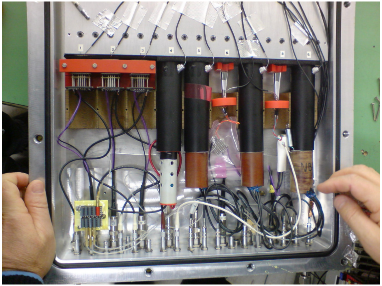
- detector mounted on moveable stage
- pressure gauge for monitoring purpose

Testbeam with SLD Cherenkov Detector

- November 2007:
  no changes done to the original SLD Cherenkov Detector using old PMTs, but our DAQ



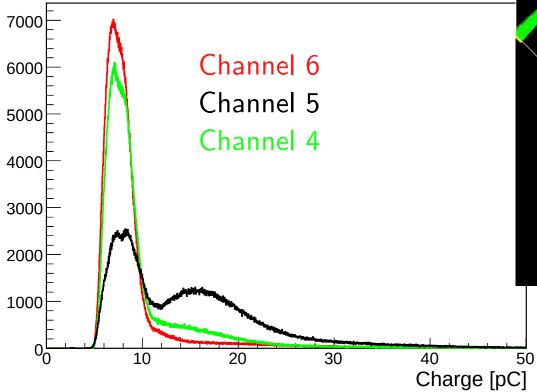
- December 2007:
  exchanged some photodetectors (PDs)
  ▷ Multi-anode PDs: 1, 2, 3 to study different DAQ-modes
  ▷ SiPMs: 6, 8 (smaller, faster → better?)
- study: reflectivity, crosstalk, and linearity (0° vs. 90° setup) etc.

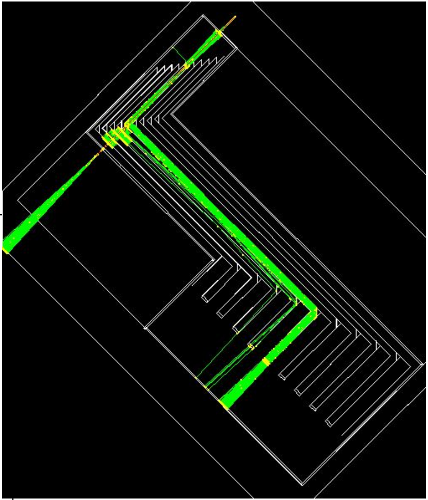


What we learned: Crosstalk

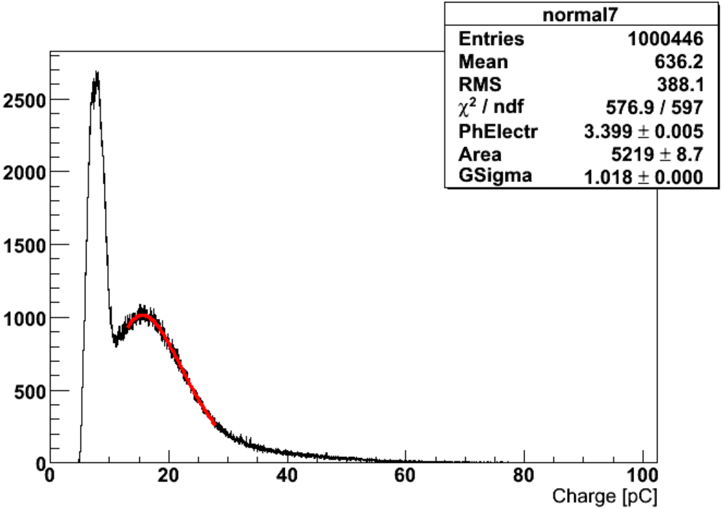
Crosstalk is asymmetric:

more in Channels to the left (4),
less in Channels to the right (6)
of the one with beam on (5).



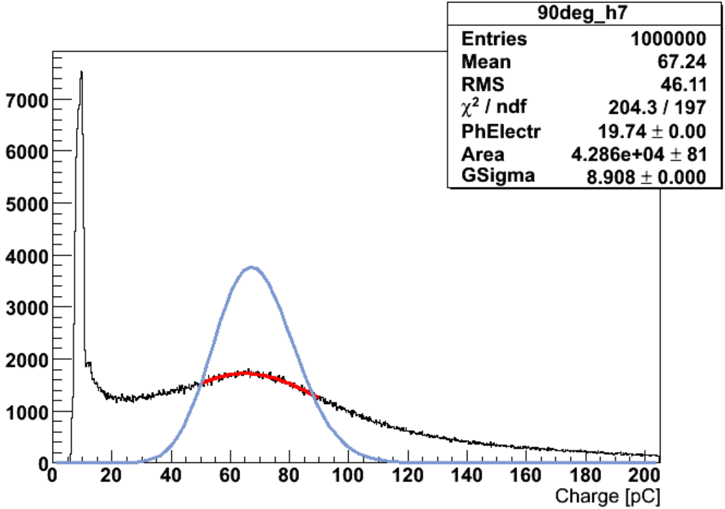


What we learned: Reflectivity & Linearity



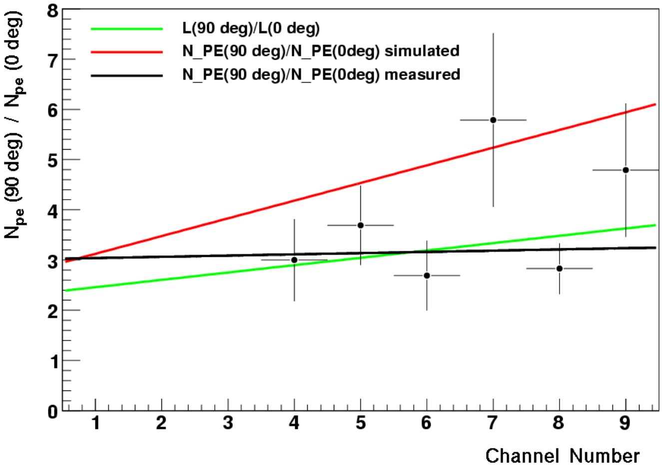
Beam incident at 0° w.r.t. SLD Cherenkov channels.

What we learned: Reflectivity & Linearity



Beam incident at 90° w.r.t. SLD Cherenkov channels.

What we learned: Reflectivity & Linearity



Compare $N_{pe}(90^\circ)/N_{pe}(0^\circ)$ with simulation (94% reflectivity) taking different channel lengths into account. → Data prefer even flatter slope!

Compressed Testbeam Results

What have we learned from the two testbeam periods:

- Crosstalk probability should be kept as small as possible!
  ⇒ Room for improvement!

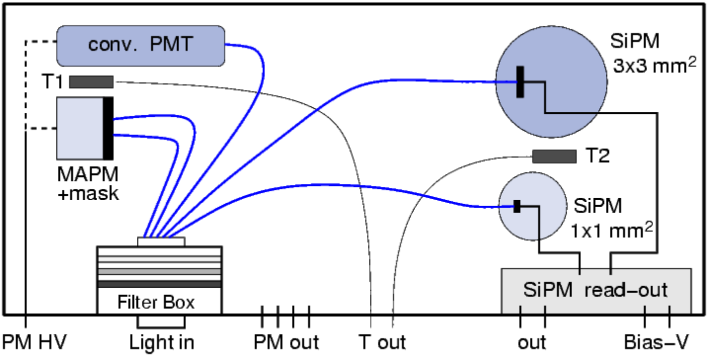
- Reflectivity of old SLD Cherenkov detector still surprisingly high!
  ...otherwise we would not have seen the small single electron signals from the DESY-II testbeam.
  (might not be as important as thought before...)

- Much more important is the linearity of the device:
  - not just for the channels (guiding Cherenkov photons towards the PDs)
  - but also the PDs themselves and the entire readout chain, where thorough testing is still ongoing!

- Dark current should be narrow and NOT have a peculiar shape (had originally been optimized for high rates)

Photodetectors:
Linearity Measurements

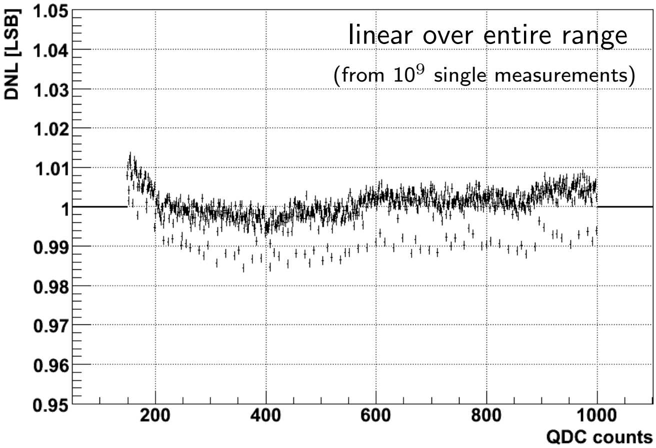
Test Bench for PD & Electronics Studies



- Light-tight box: fibers, filters, photodetectors (MAPMs, SiPMs)
- Blue LED ($\lambda = 470$ nm), controlled via a function generator
- DAQ: high resolution double range 12-bit QDC: 200 fC and 25 fC wide least significant bit (LSB) $\rightarrow$ allows diff. readout modes!

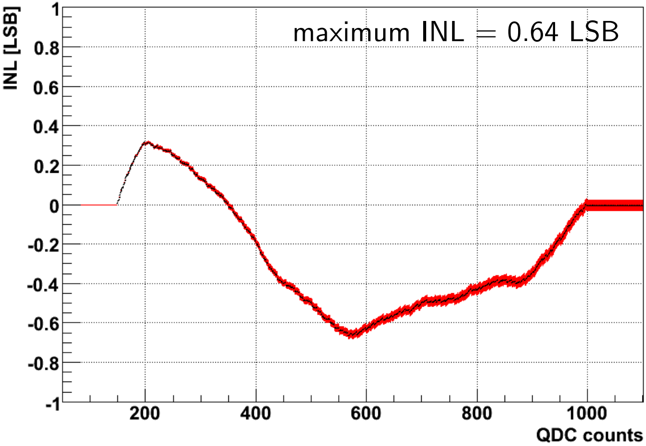
Aim: measure & control the photodetector linearity to an order of 0.1%

QDC: Differential & Integral Non-Linearity



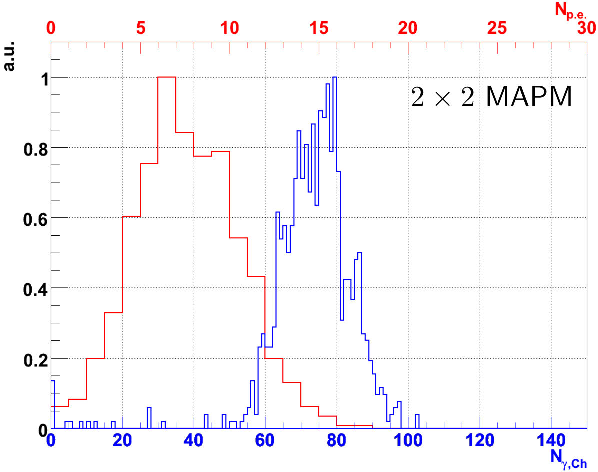
- Ramp @ 10 Hz with random read-out @ about 22 kHz (gate: 50 ns)
- Ratio of measured and uniform ideal distribution gives the DNL
- Differential Non-Linearity (DNL): deviation from ideal bin width

QDC: Differential & Integral Non-Linearity

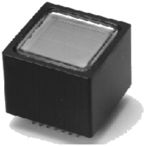


Integral non-linearity (INL): summing up DNLs to the bin of interest

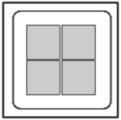
Simulating the Photodetector Response



photo



anode structure



- 5 million single events per measurement (not limited by systematics)
- Fit PD spectrum with a modified Poisson function → number of photoelectrons $N_{p.e.}$ (The reduced χ^2-values are generally very good.)

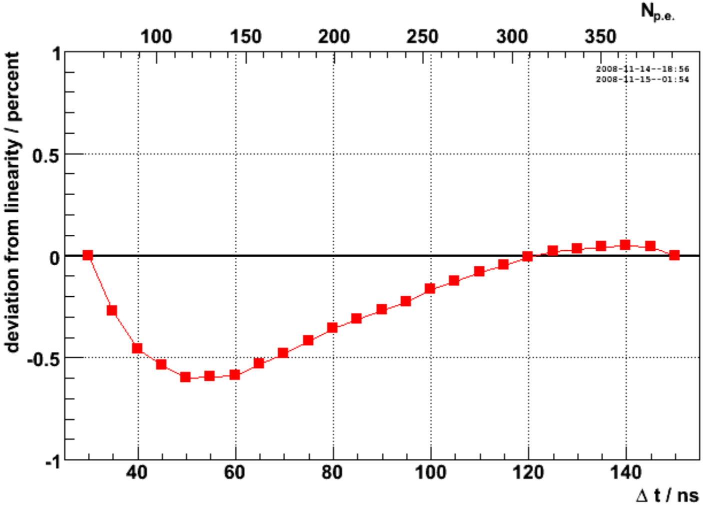
PD: Integral Non-Linearity (INL)

Use two different methods to measure the PD Integral Non-Linearity:

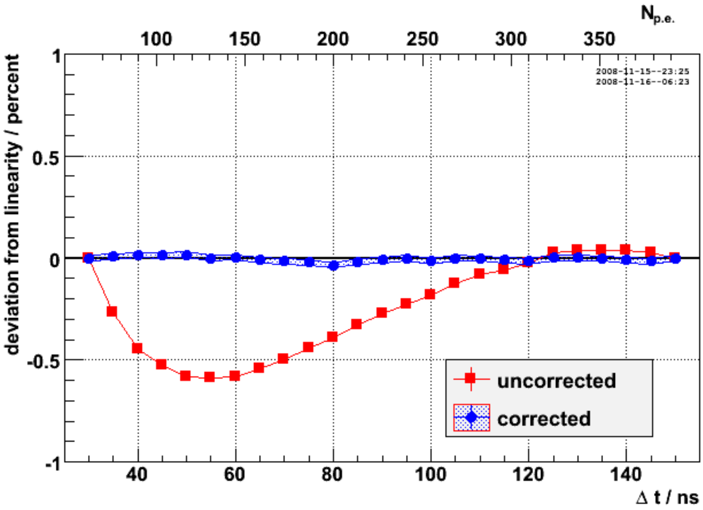
Optical Filters: LED light is attenuated by 3 optical filters
$\rightarrow$ 8 series of measurements, but: large errors due to insufficient knowledge of the filter transmittance
The filters have been recalibrated recently!

Pulse Length: linear variation of LED light (on photo cathode) is achieved by varying the length of a rectangular LED pulse (5 ns steps from 30 ns to 100 ns)
$\Rightarrow$ most promising method so far!

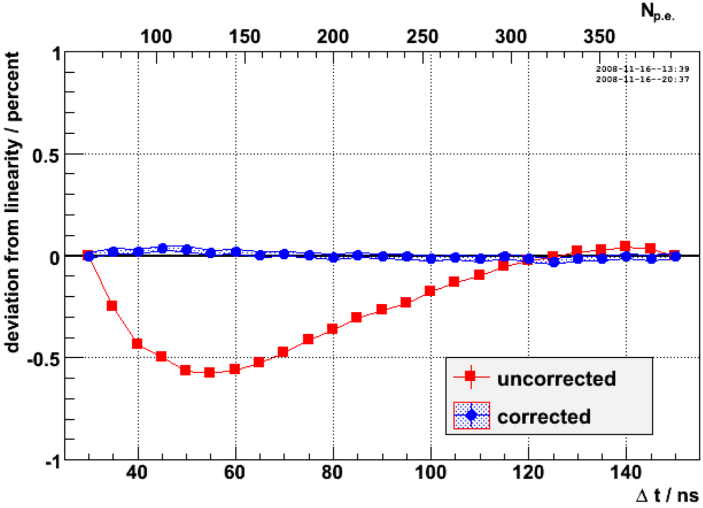
Allows to measure (control) the PD non-linearity at permille level!



This measurement is used as a reference for further measurements taken with the “pulse-length” method in the following days.



After correction with the reference measurement, the non-linearity can be controled to below permille level precision: **NL** $\ll 0.1\%$.



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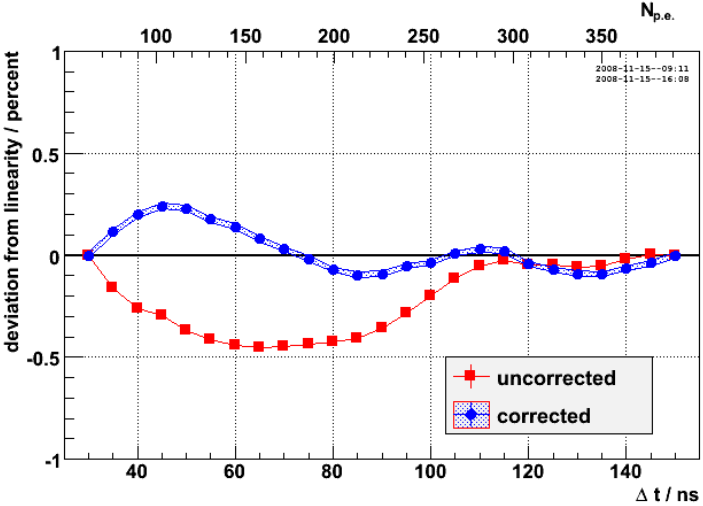
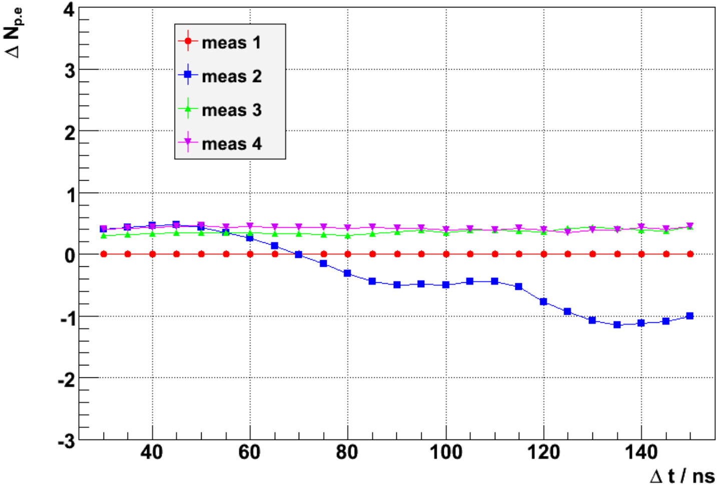


Interestingly the first measurement taken after the one used as a reference cannot be corrected satisfactorily: **NL** $\approx \mathbf{0.25\%}$.



Ordering (in time) in which the previously shown measurements have been taken.

PD: Differential Non-Linearity (DNL)

Two further methods have been developed to measure the PD Differential Non-Linearity:

Mask: apply a 4-hole mask to the 2×2 MAPM; measure the PD response to LED pulses through each hole and one pulse simultaneously through all four holes:
$\Rightarrow$ DNL $= (P_1 + P_2 + P_3 + P_4)/P_0 - 1$
However, the measurement has not yet been realized.

Double Pulse: Measure the PD response to two different LED pulses P_i and $P_i + p$ (where $P_i \gg p$); vary P_i to determine DNL over the entire range
$\Rightarrow$ analysis of measurements is ongoing, but early results look promising!

Cherenkov Detector Prototype Design

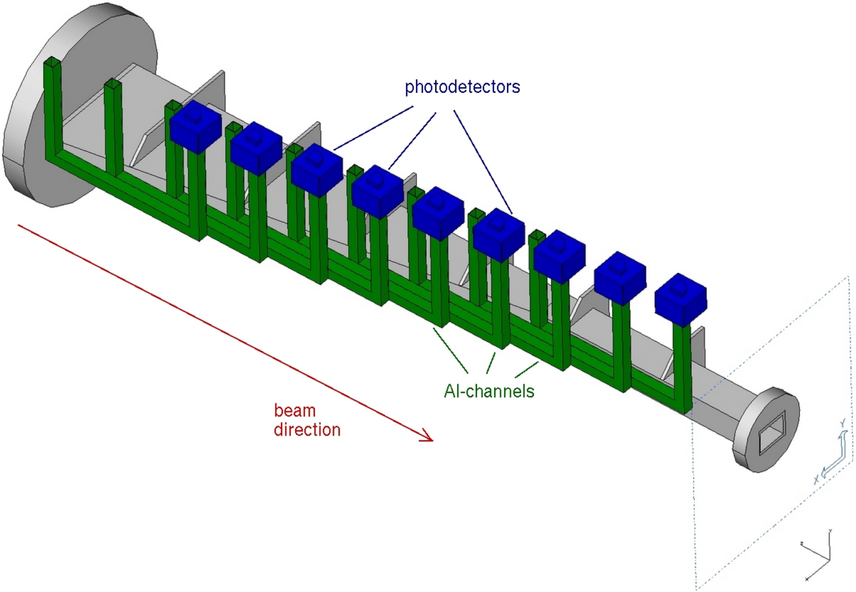
ILC Cherenkov Detector I

How it would look like in the ILC:

- beam stay clear of 2 cm of the beam pipe
- tapered beam pipe with thin exit-window to avoid the creation of wake fields as much as possible . . .
- staggered aluminum channels (U-shaped pipes)
  - ⋆ one end occupied by an LED for calibration purposes
  - ⋆ the other end equipped with a photodetector
- each aluminum channel equipped with its own gas system

  (still needs a lot of design & engineering work)

ILC Cherenkov Detector II

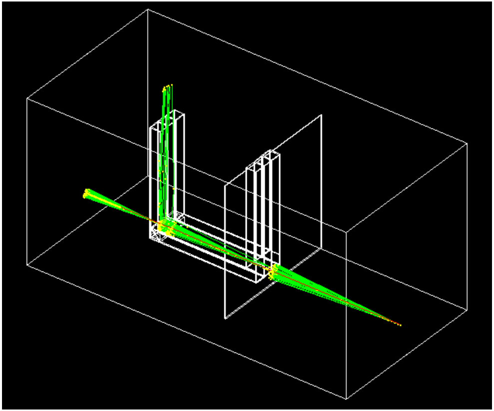


Testbox: Simulation Development

Simulation of the testbox:

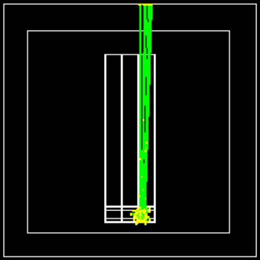
- 2 channels of polished aluminum
- thin entrance window (0.3 mm aluminum)
- the photodetectors are not simulated in GEANT;

  choose a modular setup to be able to quickly exchange different photodetectors

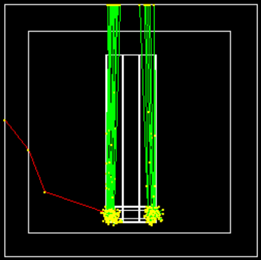


vacuum chamber filled with C_4F_{10}

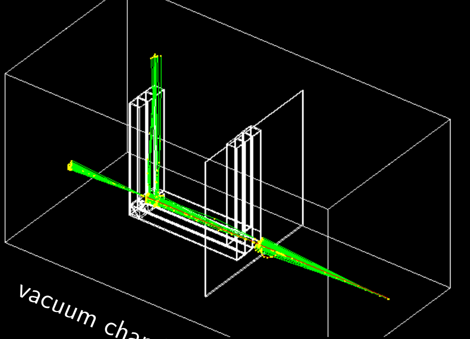
Some Simulated Events



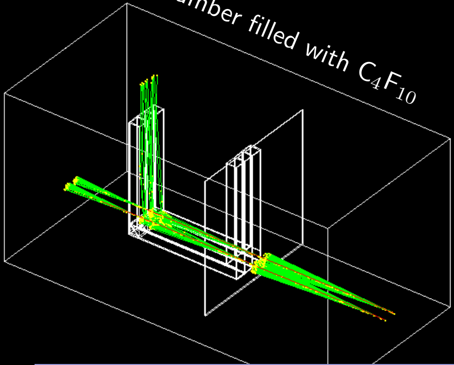
one e^- incident



two e^- incident

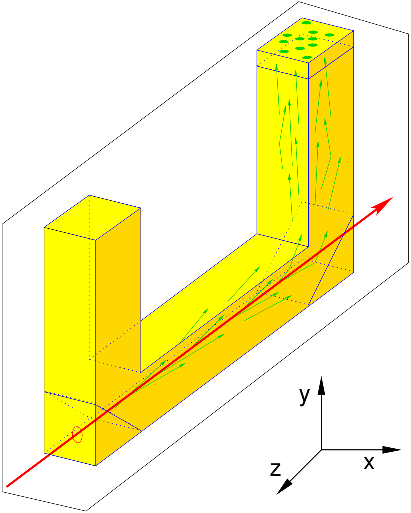


vacuum chamber filled with C_4F_{10}



Advantages of U-shaped Channels

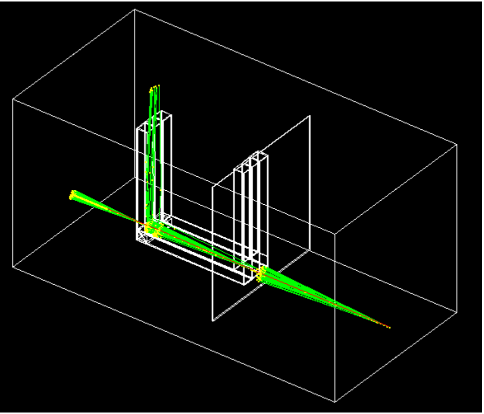
- no synchtroton radiation incident on the photodetectors
- no (or much less) crosstalk between different channels (compared to a layout in the x/z-plane)
- only ≈ 2-3 reflections
  → reflectivity does not have to be extremely good
  (e.g. ≈ 90% sufficient)

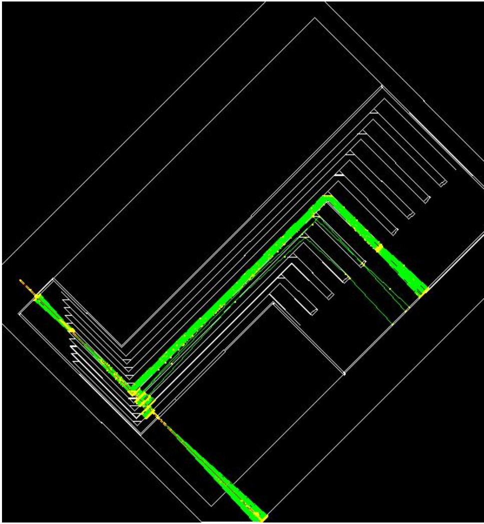


Crosstalk: SLD vs Prototype

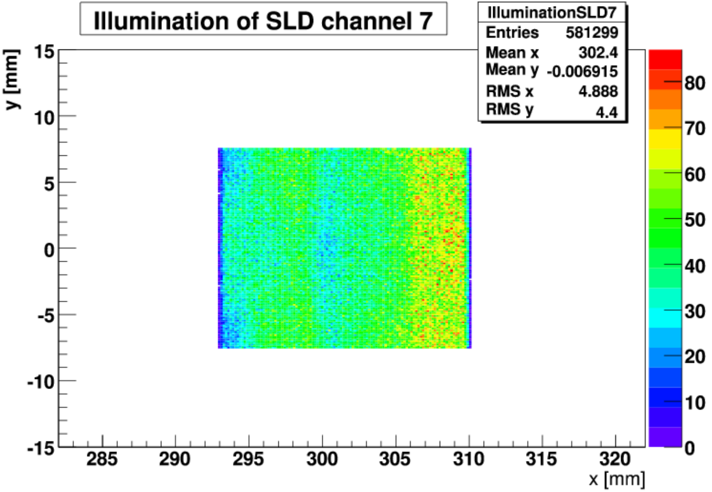
Comparison: U-shaped testbox versus planar SLD-layout

⇒ no, or at least, largely reduced crosstalk !





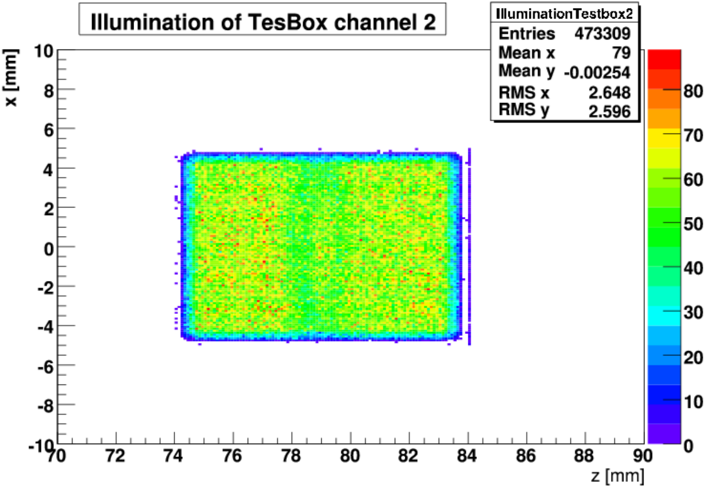
Crosstalk: SLD vs Prototype



Simulation: electrons incident in the middle of the channel

SLD: asymmetry clearly visible where a uniform distribution is expected

Crosstalk: SLD vs Prototype



Simulation: electrons incident in the middle of the channel

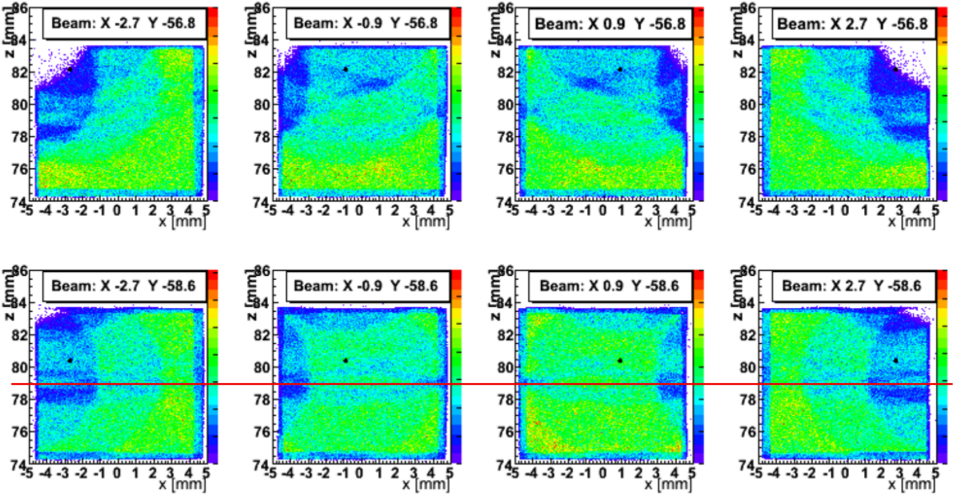
Prototype: no asymmetry observed for uniform illumination!

Prototype: Illumination Scan I

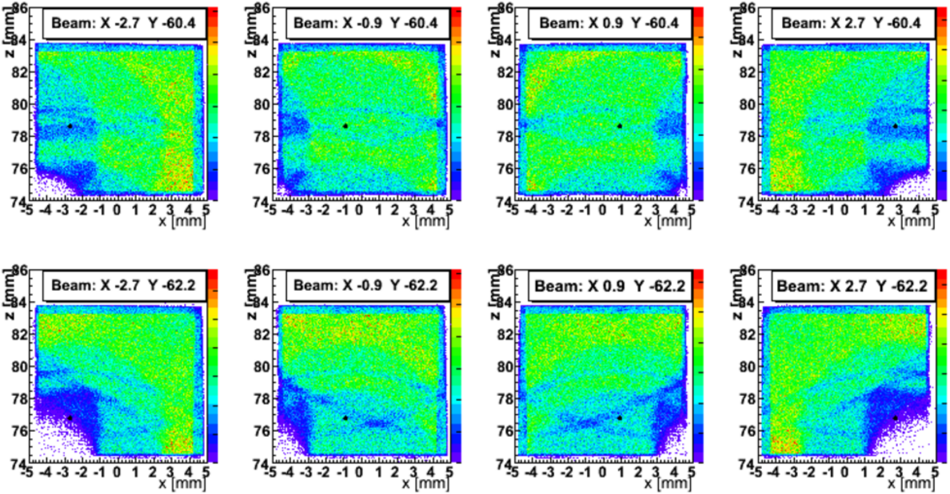
What effects could be observed from asymmetric illumination:

- define a grid of 4×4 points, where to shoot a very highly collimated electron beam (might be mimicked by laser photons)
- use 10,000 electrons per shot, no beam spread(!)
- calculate asymmetries from scans in x- and y-direction
  Note: (x,y)-plane from incident beam changes into (x,z)-plane for the photodetectors due to the U-shaped geometry of the channels.
- Asymmetry from asymmetric illumination is clearly visible in the data! $\Rightarrow$ Will try to make use of 2×2 MAPM and even a newly aquired 8×8 MAPM to resolve electron position (energy) spectra inside a channel!

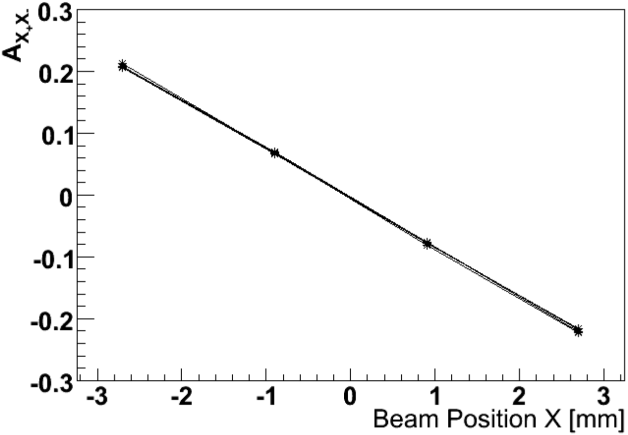
Prototype: Illumination Scan II



Prototype: Illumination Scan II



Intra-Channel Asymmetries (from Illumination Scan)



Maximum intensitiy moves from negative to positive x ⇒ Asymmetry!

$A_{x,x}$: 4 graphs for 4 different x-pos. (y fixed) ⇒ good linearity!

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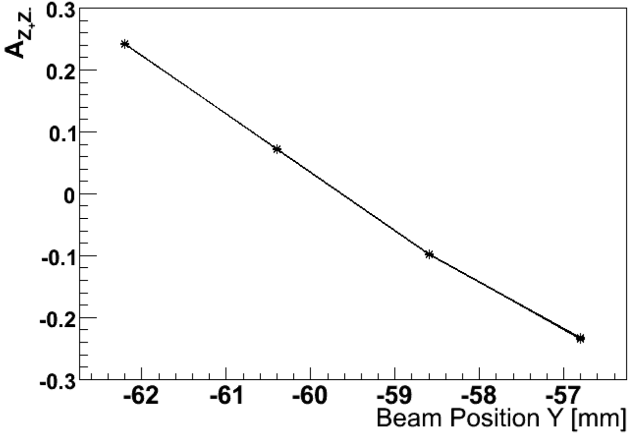


Maximum intensitiy moves from negative to positive z ⇒ Asymmetry!

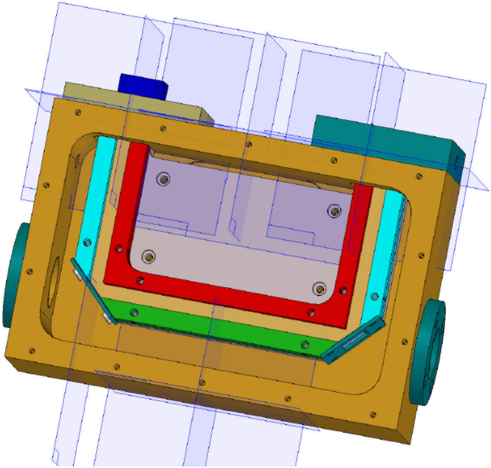
$A_{z,z}$: 4 graphs for 4 different y-pos. (x fixed) ⇒ good linearity!

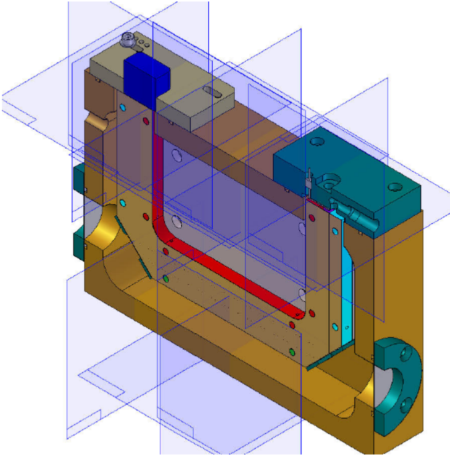
Prototype Design I

What do we want to study?

- different photodetectors at once
- crosstalk between channels
- different readout modes, depending on photodetectors, e.g. multianode photodetectors, SiPMs, etc.
- different calibration systems, i.e. either via LED- or laser-light (housing or thin throughput window)
- effect of wall thickness / beam spread . . .
- but, most importantly: the entire readout chain!

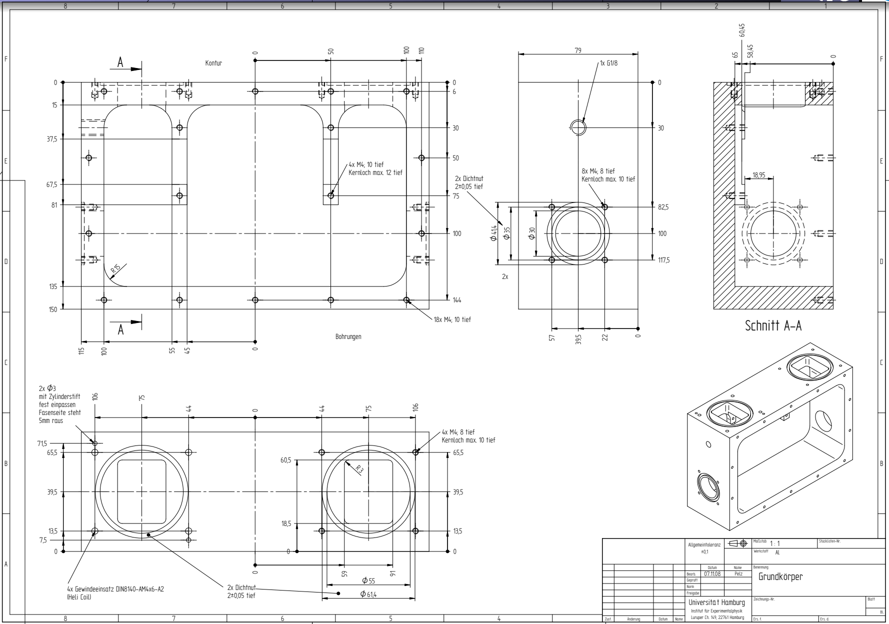
Prototype Design II





- Aluminum box with two channels & thin inter-channel wall (0.3 mm)
- flanges for a calibration system (LED-housing or laser) and for photodetector modules (quick & easy exchange)

Technical Drawing: Base Plate



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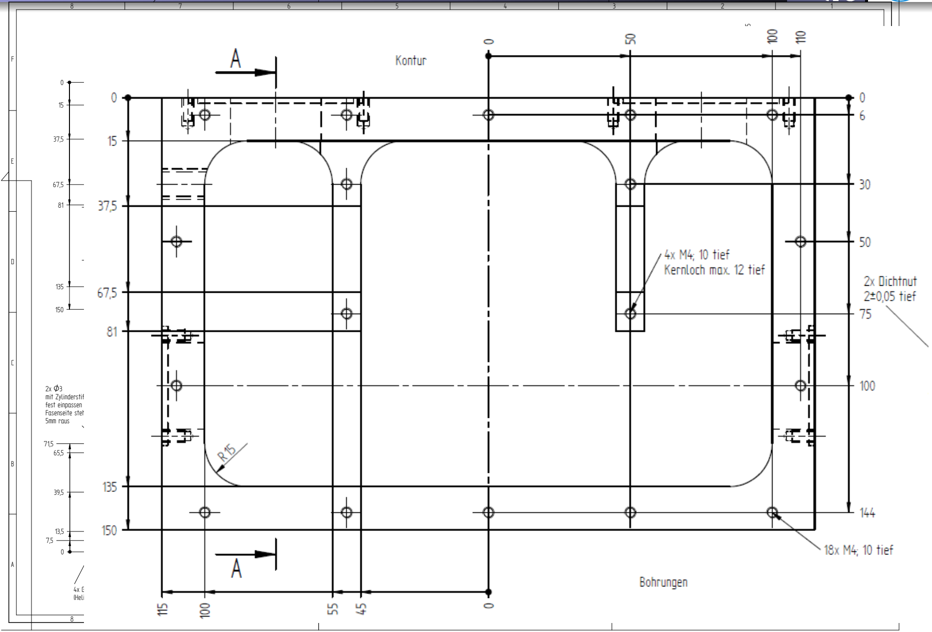

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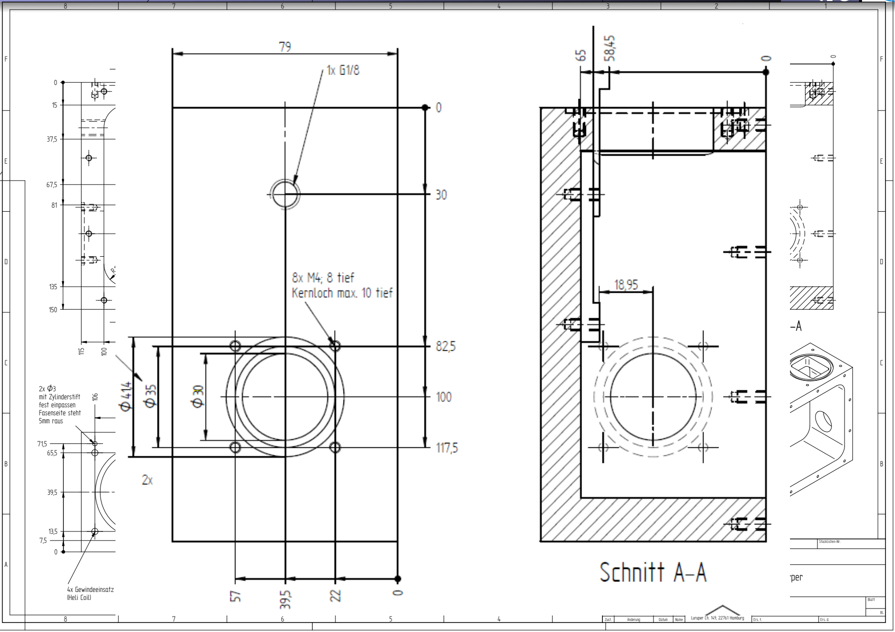

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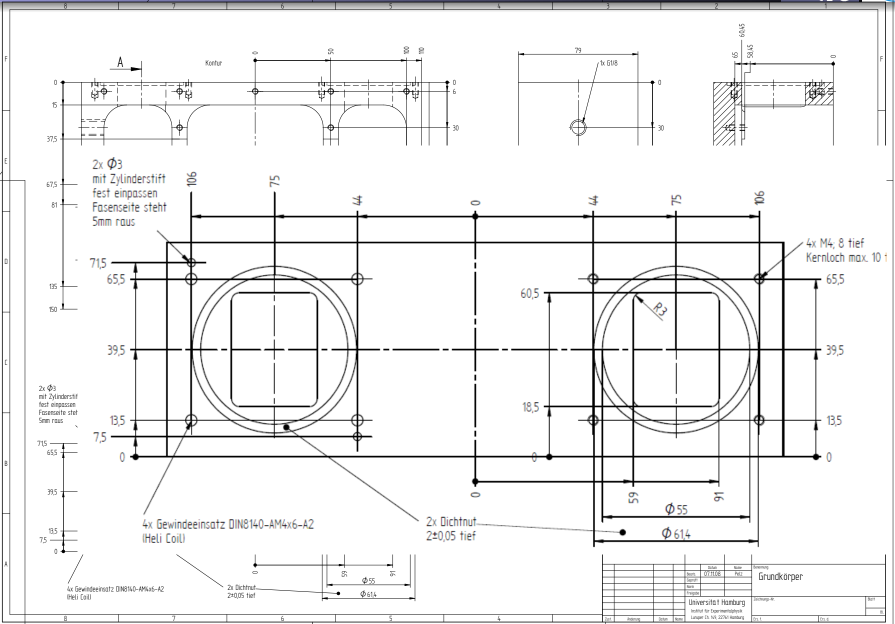
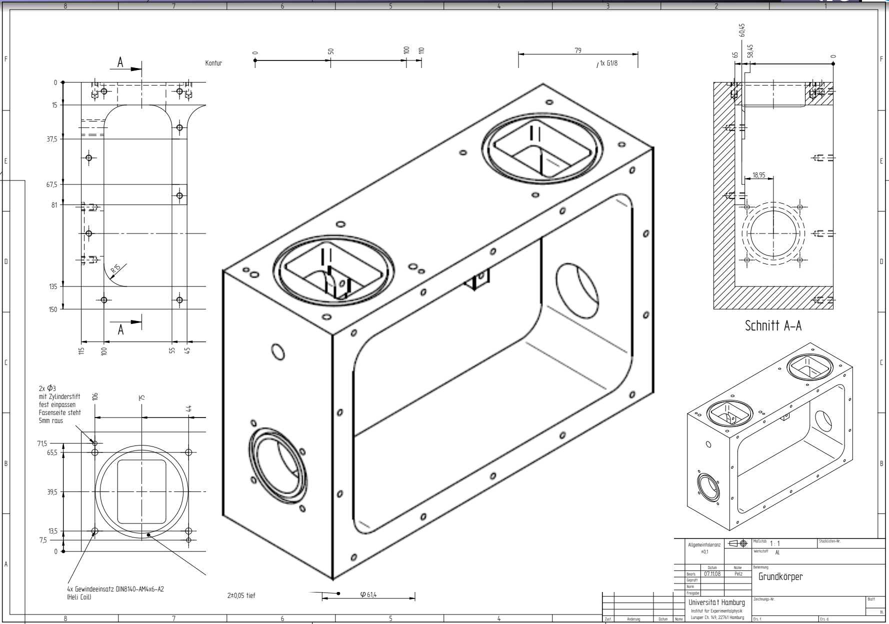


Technical Drawing: Base Plate

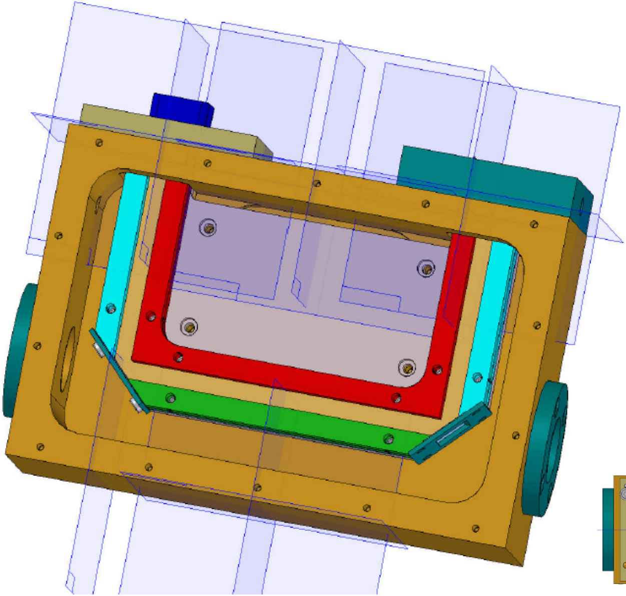


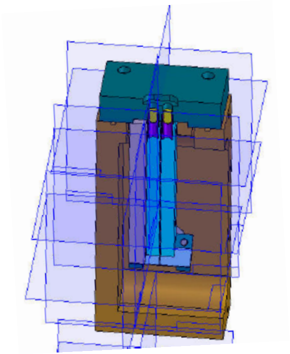
Summary
& Outlook

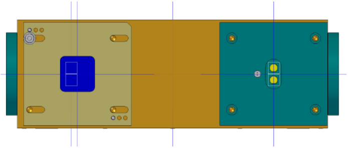
Summary & Outlook

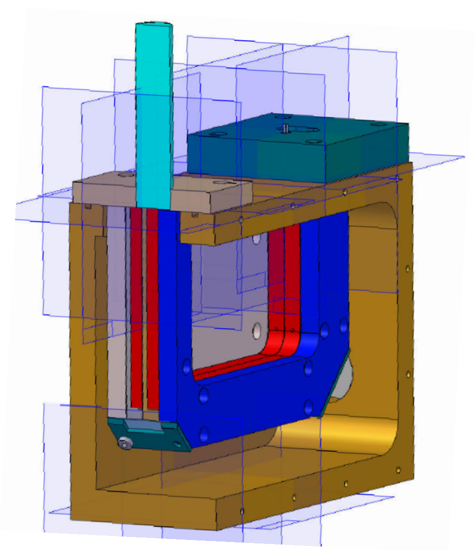
- First testbeam period with the SLD Cherenkov detector has been very useful → reflectivity, crosstalk!
- Electronics & photodetector measurements are ongoing different methods to measure the PD linearity (INL, DNL) have been developed and show promising results
- Linearity measurements challenging due to many dependencies (temperature ↔ HV-heating, inherent QDC non-linearity, etc.) But: desired precision is achievable!)
- Design of the prototype (testbox) is complete as of Nov.10 now, construction is ongoing (using resources @ Univ. of Hamburg)
- Prototype simulation has been developed & studies are ongoing. First results show possibilities for further measurements

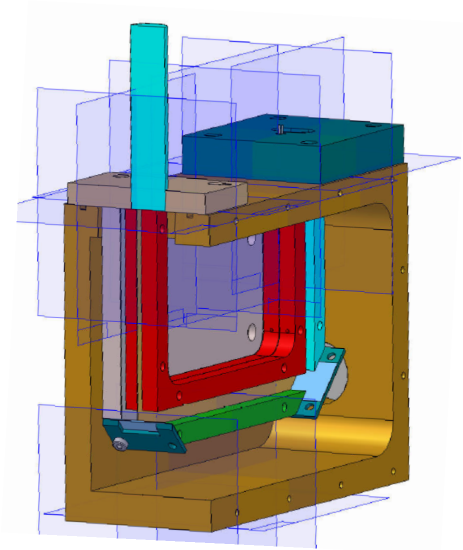
Colorful 3D-Model Technical Drawings

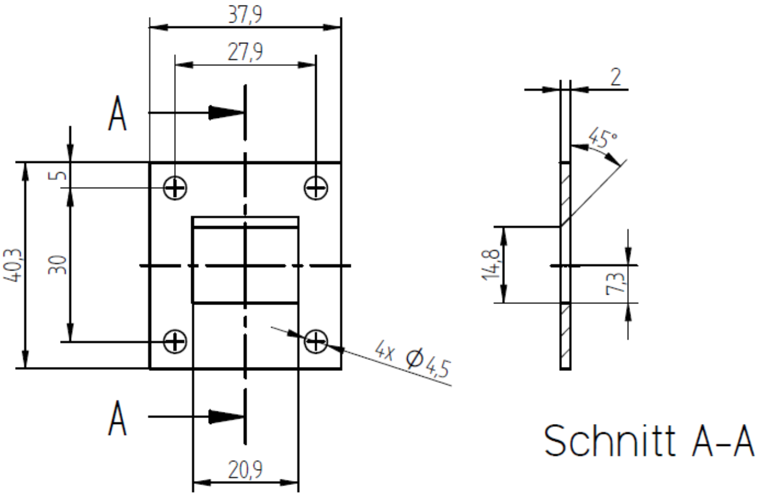











37,9
27,9
A
5
40,3
30
4x Ø4,5
A
20,9
2
45°
14,8
7,3
Schnitt A-A

Technical Drawing: Mounting for LEDs