# Lycoris: Large Area Telescope

## LYCORIS Telescope: Large Area x-Y Coverage Readout Integrated Strip Telescope

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BTTB 7, 16th of January 2019

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

SLAC NATIONAL ACCELERATOR LABORATORY

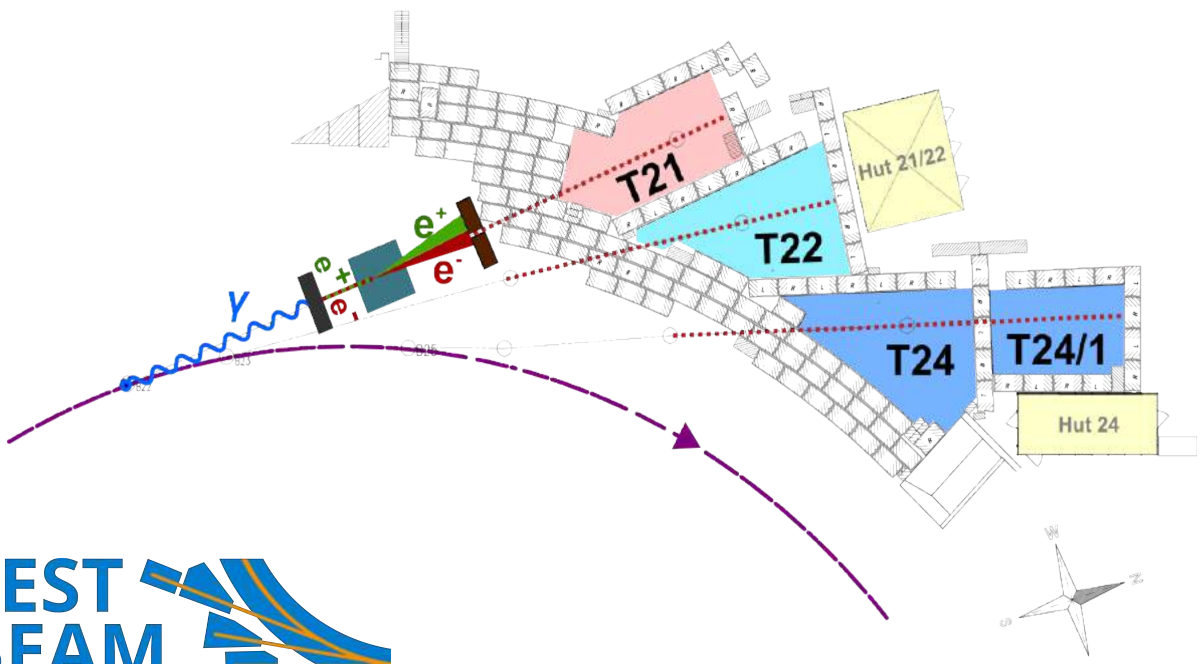
AIDA 2020

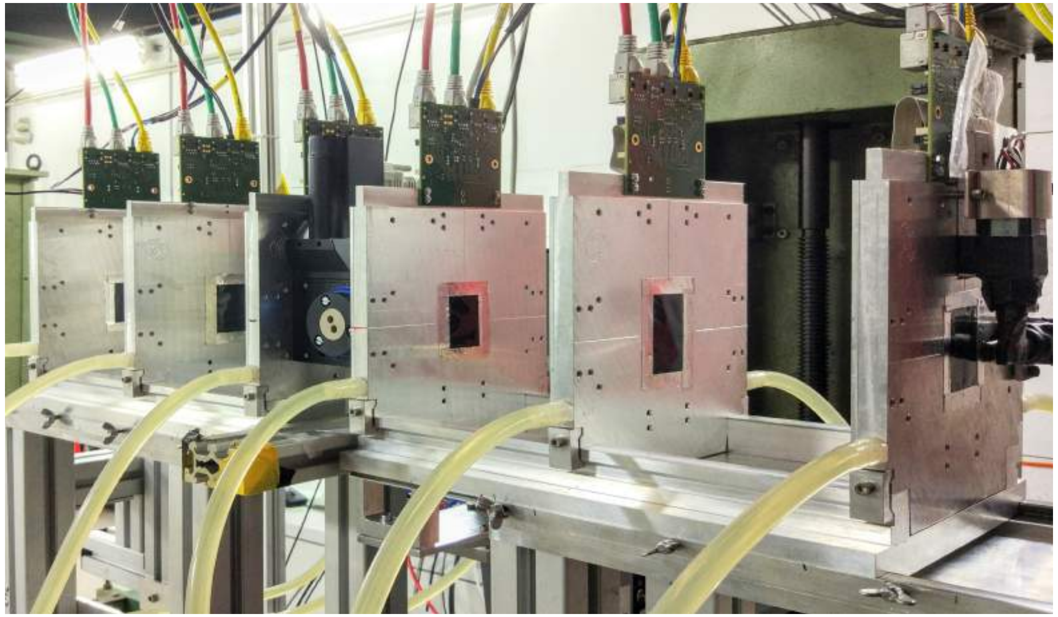
DESY TEST BEAM.

DESY.

# The DESY II Test Beam Facility

- Electron beam provided by DESY II synchrotron
- $e^+/e^-$ particles with energy up to 6 GeV
- 1.2 T Dipole magnet in T21
- Two silicon pixel Telescopes (Datura/Duranta), based on Mimosa 26, in T21 and T22
- 1 T Superconducting solenoid (PCMAG) in T24/1



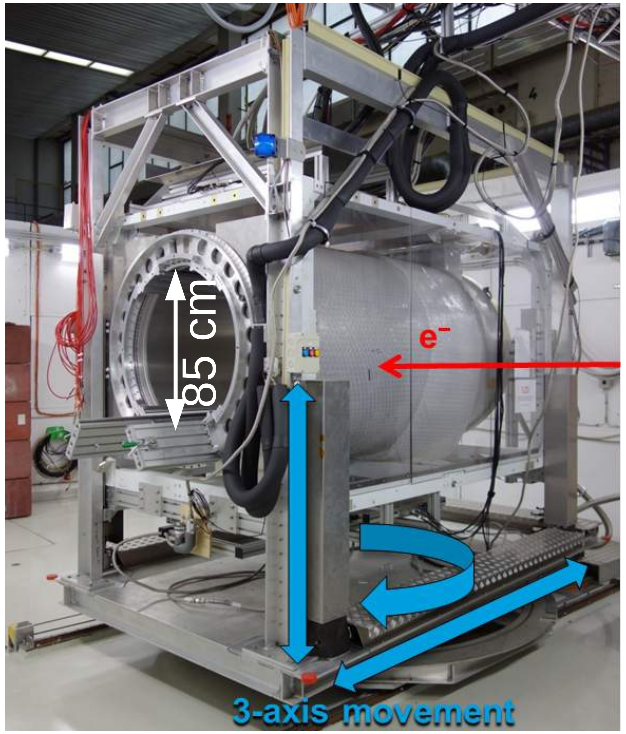



DESY TEST BEAM.

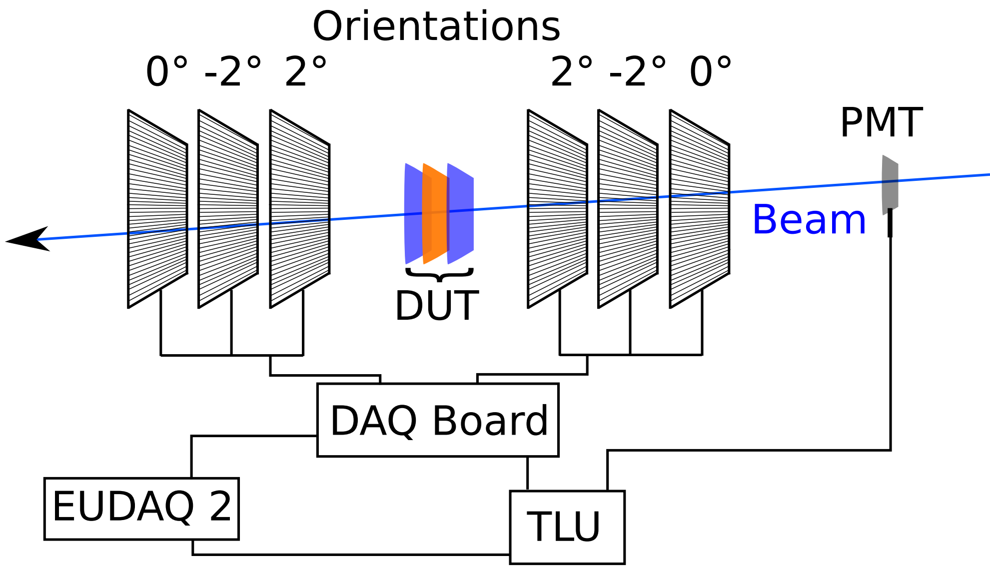
# The Lycoris Telescope

An AIDA 2020 project

- A new large area strip telescope within the Test Beam Area 24/1 solenoid
- The solenoid has:
  - Wall thickness of 20% $X_0$
  - Mounted on a stage to be able to move/rotate along 3 axes
  - Magnetic field strength of up to 1T




- Telescope demands defined by use case:
  - Coverage area of ~10x10 $cm^2$
  - Less than 3.5 cm of space per telescope module.
  - Spatial resolution requirements better than:
    - $\sigma_y$= ~10 µm
    - $\sigma_z$= ~1 mm



# The SiD Silicon Strip Sensor

Hybrid-Less silicon strip sensor designed by SLAC NATIONAL ACCELERATOR LABORATORY for the ILC :

- A strip pitch of 25 µm
- ~7 micron tracking resolution
- Alternate strips will be read out
- An integrated pitch adapter and digital readout (KPiX)
  - → Directly bump bonded to sensor surface
- Thickness of 320 µm
- Material budget of 0.3% $X_0$

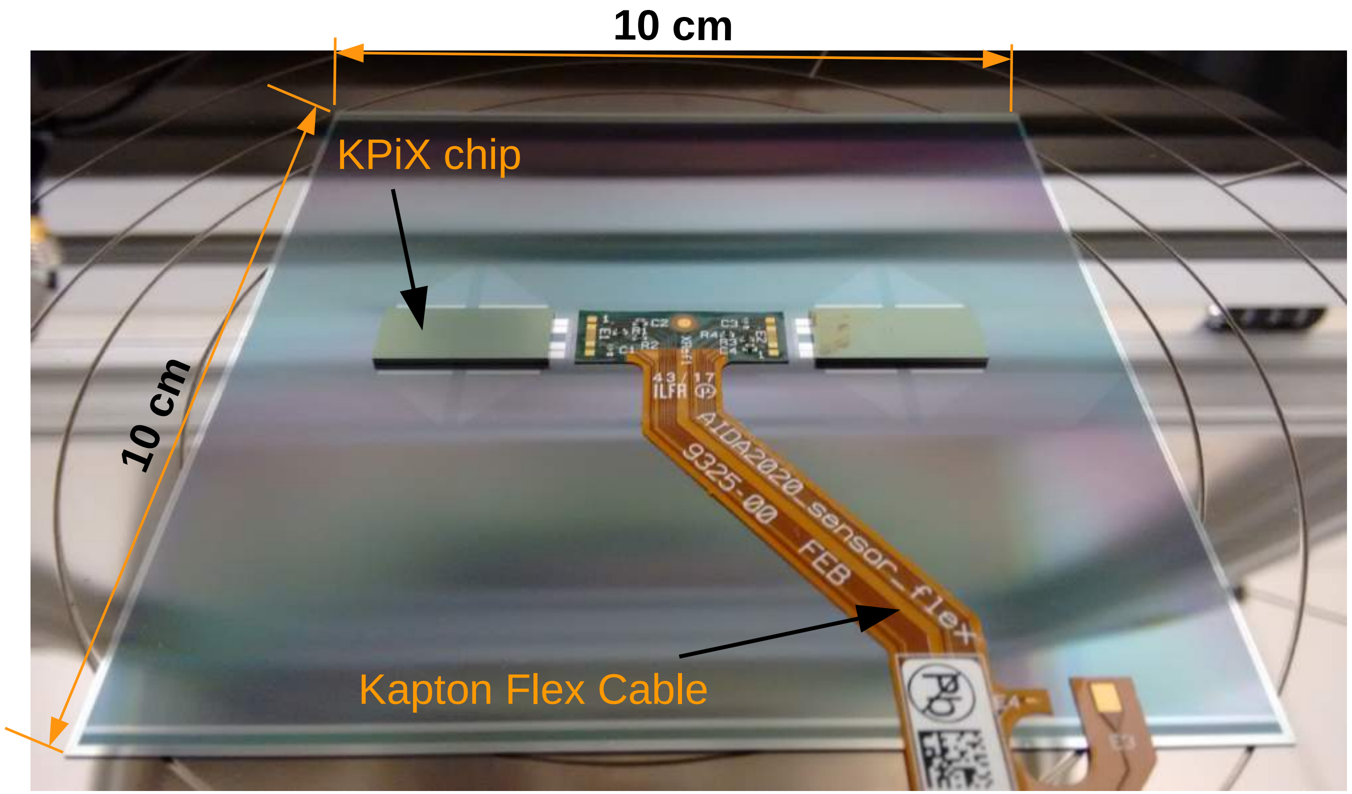
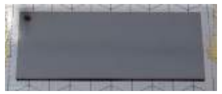



Fig.: Assembled Tracker Module

# KPiX readout chip  

- 1024 channel fully digital readout with 13 bit resolution (8192 ADC)
- 100 MHz clock → 10 ns flexible acq. Clock period
- Can work in two modes:
  - Self/Internal trigger =  4 events per channel per cycle stored
  - External trigger = 4 events per cycle stored
- Power pulsing operation → Only open for a short timeframe
- Length of the opening period depends on timing resolution

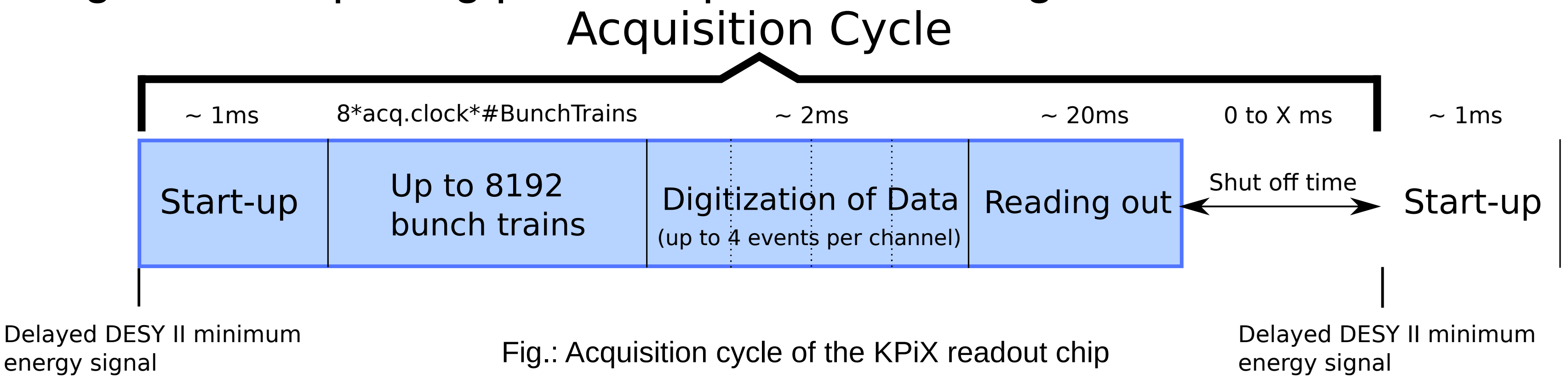



Fig.: Acquisition cycle of the KPiX readout chip

- Only open for a maximum time of 8192*8*acq.clock
  →For example with a 320 ns acq.clock = 20.97 ms

# The Final System: The Cassette

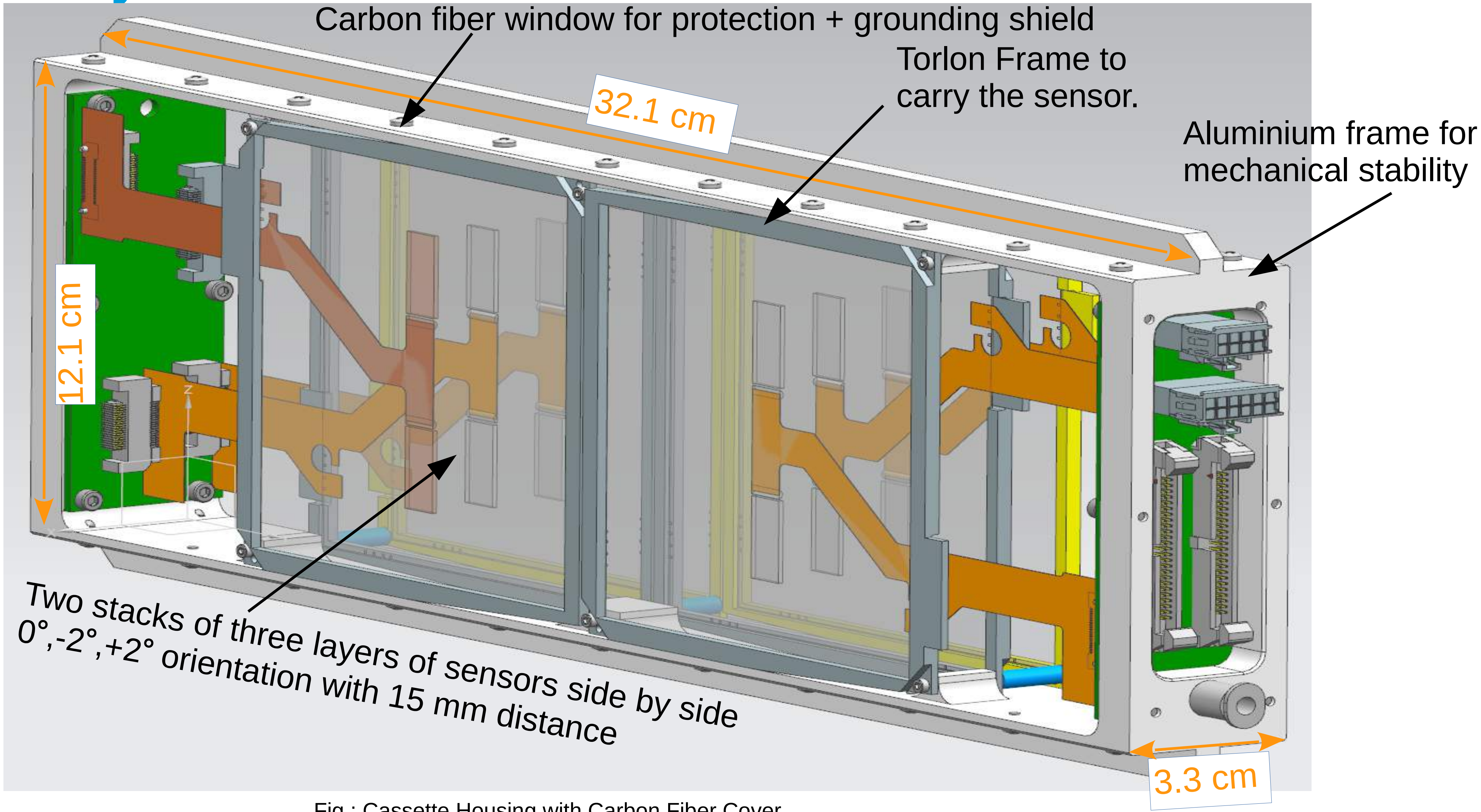



Fig.: Cassette Housing with Carbon Fiber Cover

# The Final System: The rail system

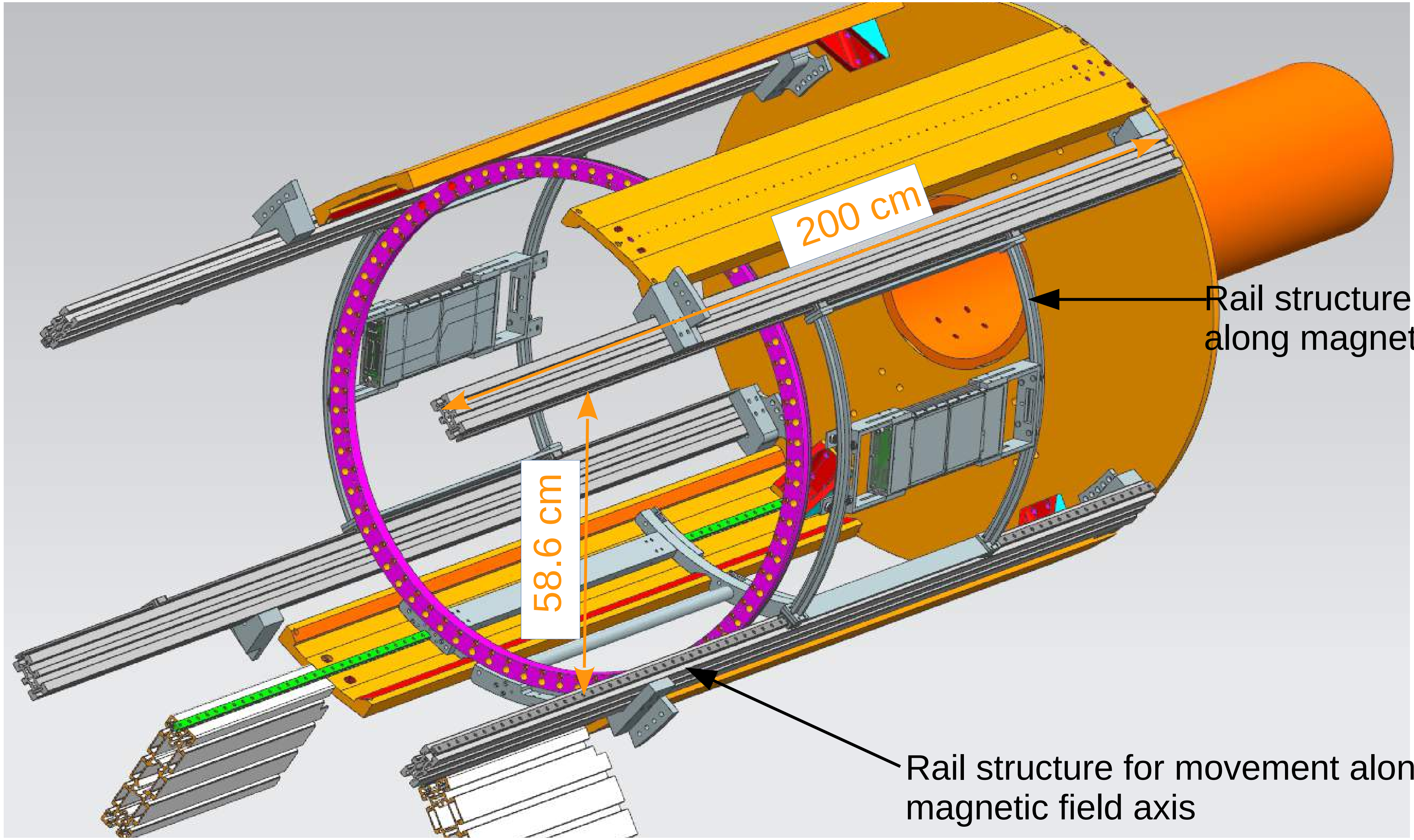



Fig.: PCMAG with cassette rails

# System Status: Mechanics

- All mechanical components have been produced
- A first test of the rail system shows the overall functionality
- Dummies and one sensor were already installed in the Cassette for first test beam
- Radiation length in beam path per cassette ~ 1% $X_0$

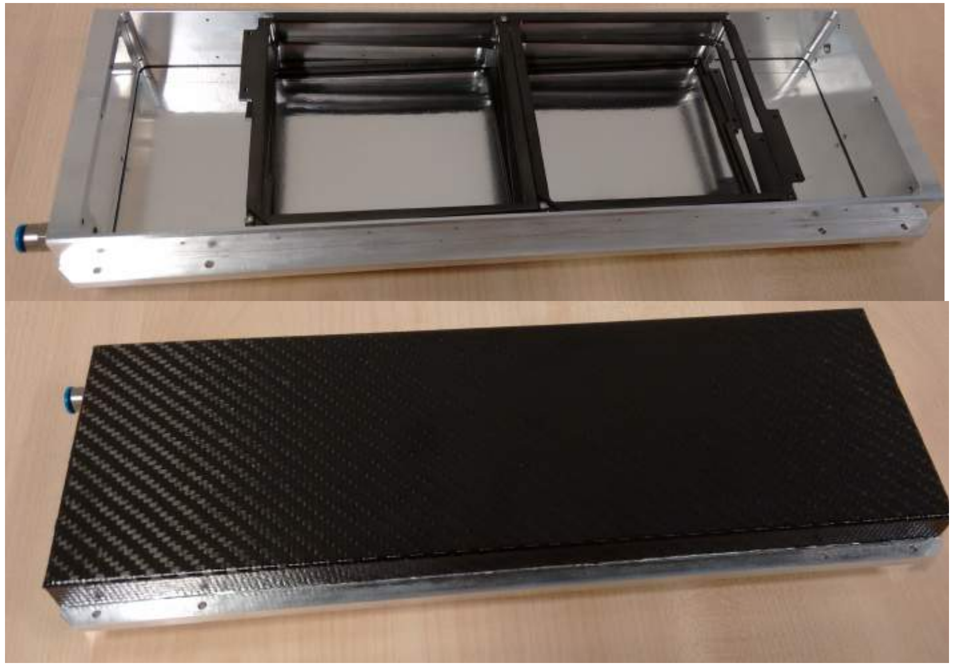


Fig.: Cassette Housing with Carbon Fiber Cover

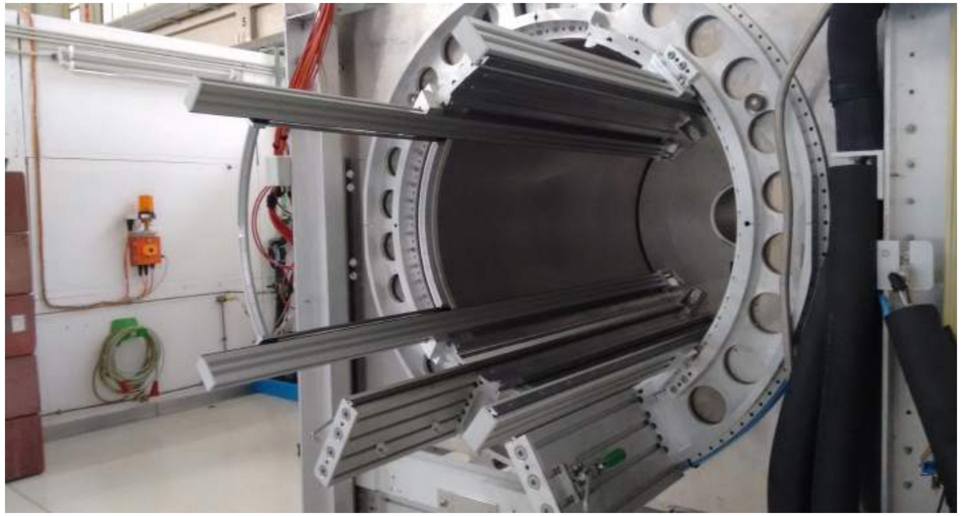


Fig.: PCMAG with cassette rails

# System Status: Electronics

- AIDA TLU
  - Needed for Synchronized data readout of DUT and telescope
  - Arrived July of 2018

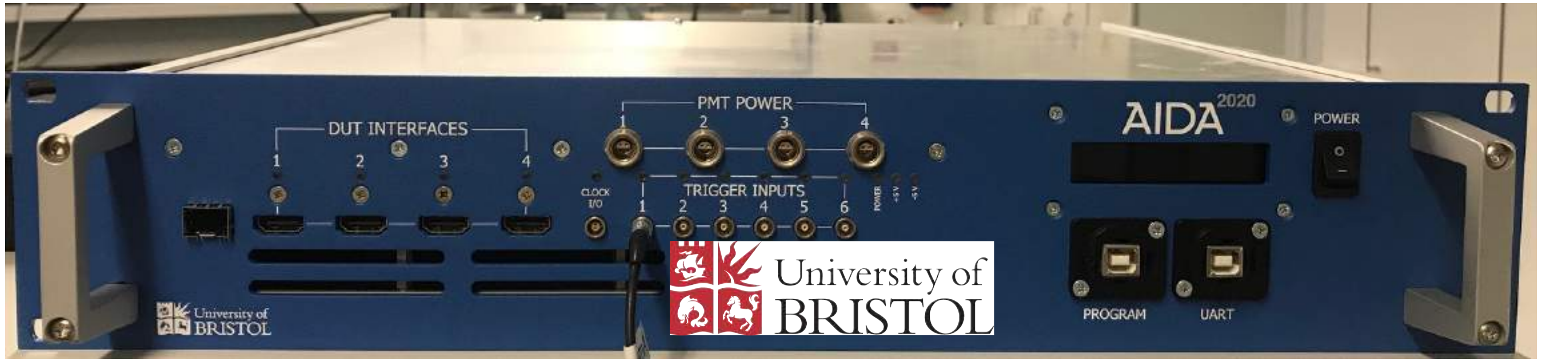


Fig.: AIDA TLU

- New DAQ board
  - Provide necessary connections
  - Hardware/Firmware improvement compared to old sytem
  - Arrived October of 2018
- Cassette boards
  - connecting electronics within the cassette to outside world.
  - In transit to DESY

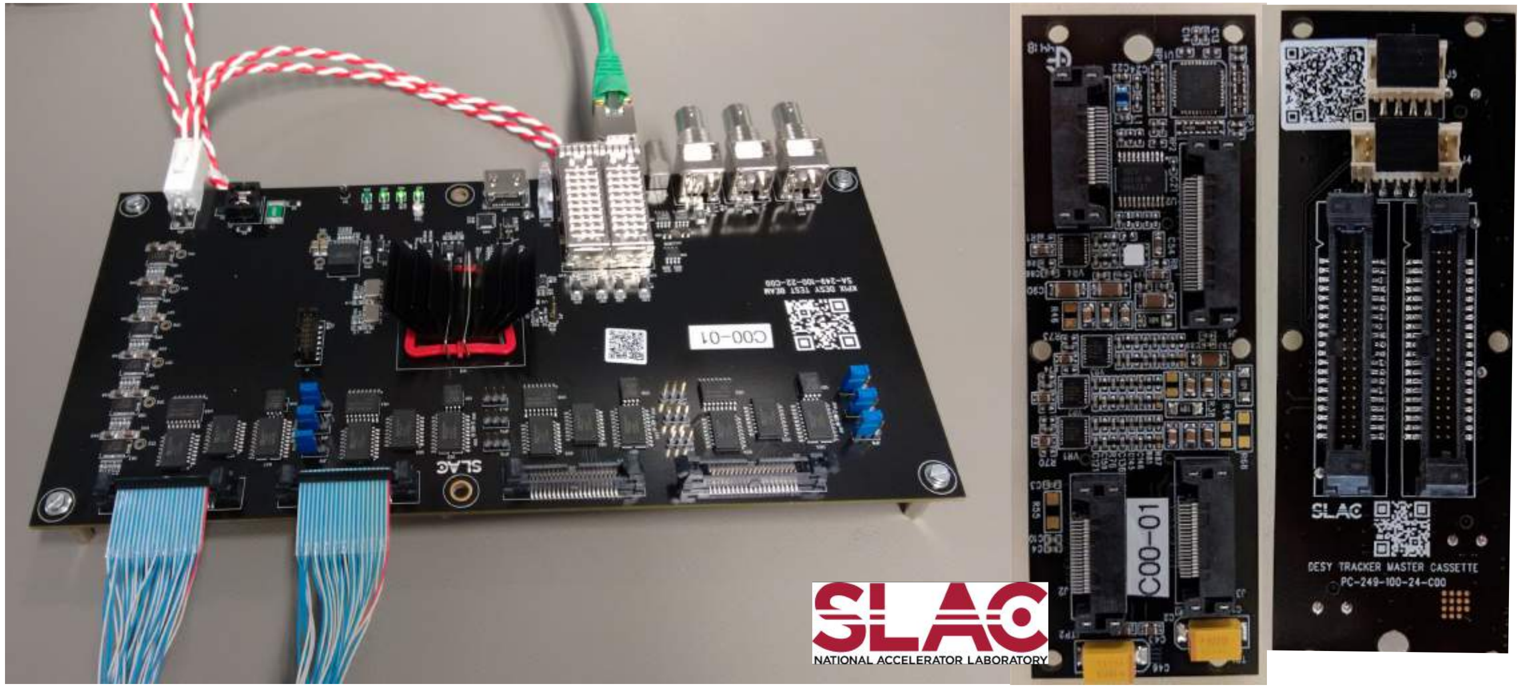
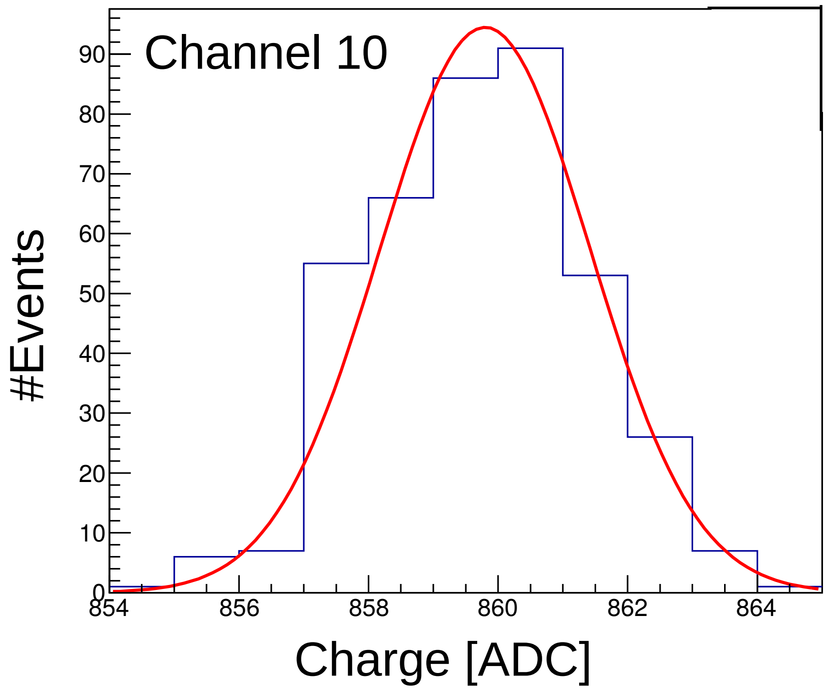
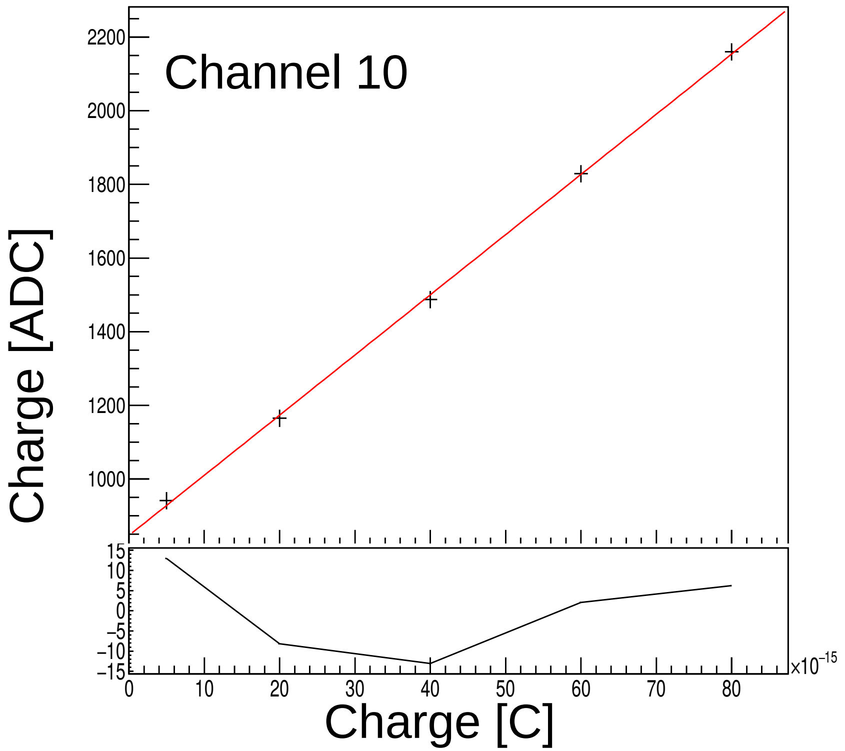


Fig.: New DAQ board with front and backside of cassette board.

# System Status: Sensors

- First sensors assembled and tests on the first sensors are nearing completion:
  - Both readout chips can be talked to.
  - Sensor depletes through wire bonds and shows sensitivity to light
  - Functionality of sensors confirmed through calibration, pedestal data taking as well as a test beam campaign.



# System Status: Sensors

## Self triggering operation

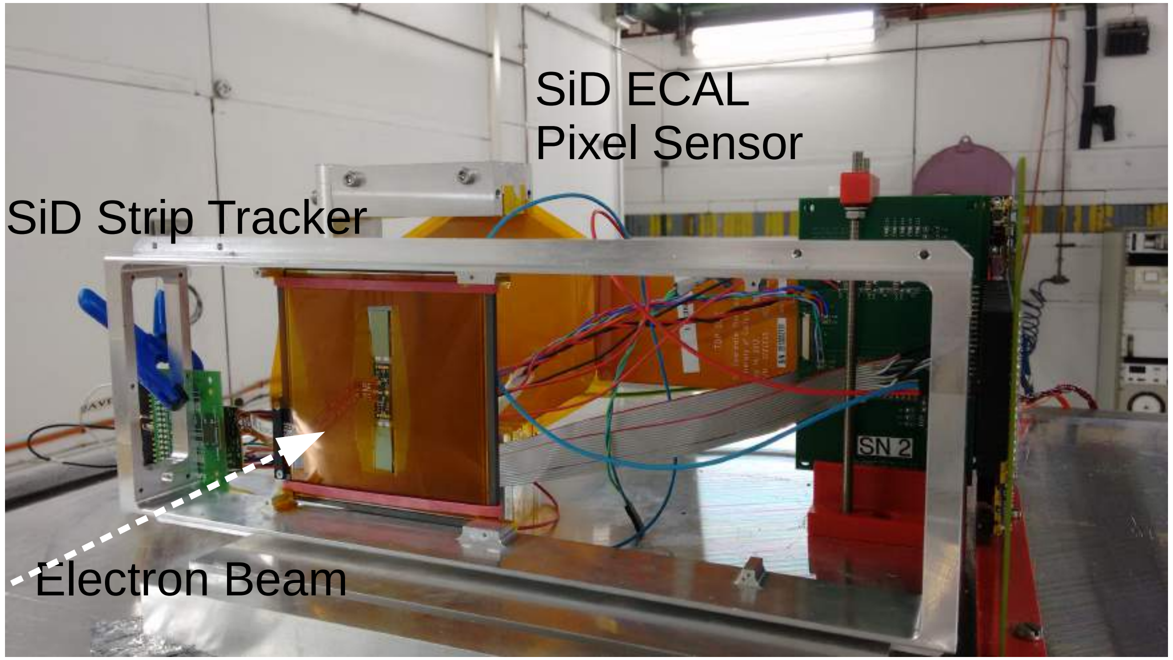



Fig.: Testbeam setup with the tracker in front and ECAL in the back.

- Recently completed first Testbeam with the new tracker sensor
- ~ 2 Million Events recorded, split between different running modes.
- Test of both internal triggering and external triggering functionality.

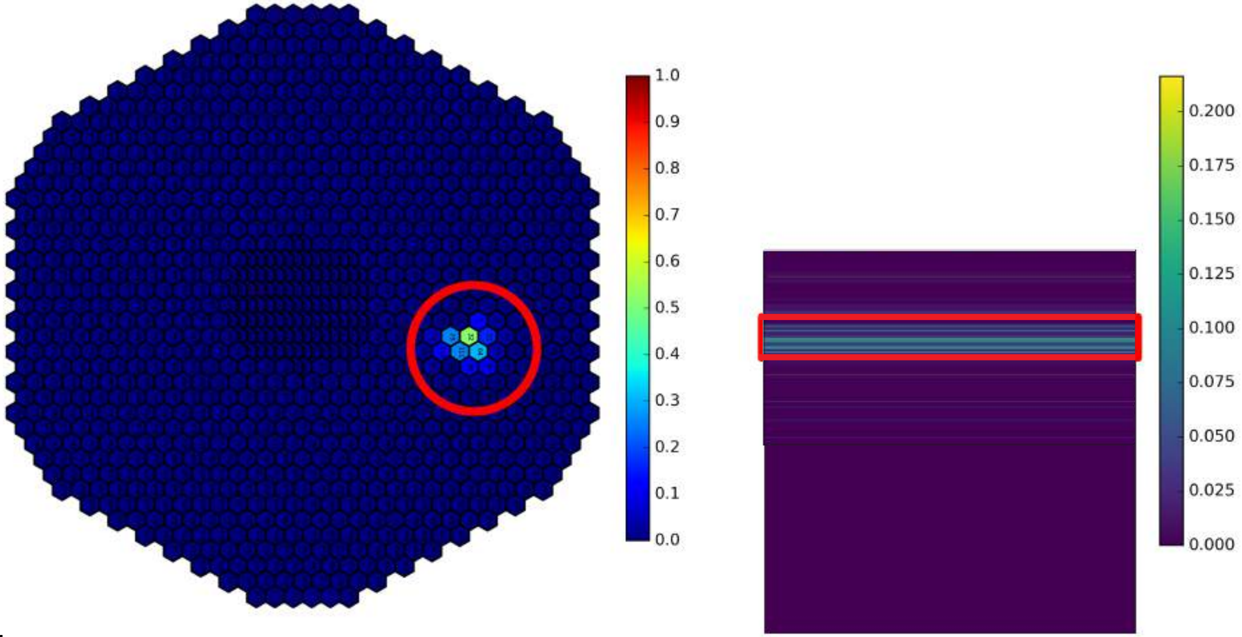



Fig.: Mapping of trigger hits to ECAL (left) and tracker (right)

- Full coincidence:
  - SiD Strip Tracker ↔ SiD ECAL Pixel Sensor ↔ Beam Scintillators.

# System Status: Sensors

## Self triggering operation

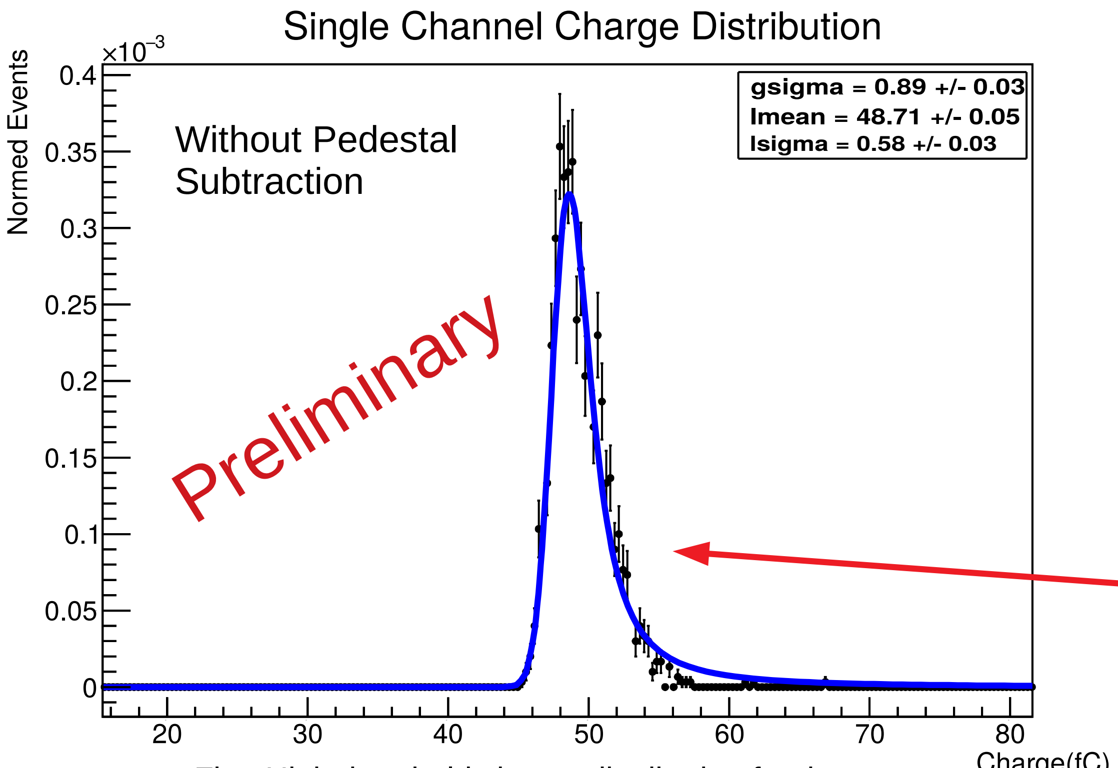



Fig.: High threshold charge distribution for the tracker with landau gauss convolution fit

- Recently completed first Testbeam with the new tracker sensor
- ~ 2 Million Events recorded, split between different running modes.
- Test of both internal triggering and external triggering functionality.

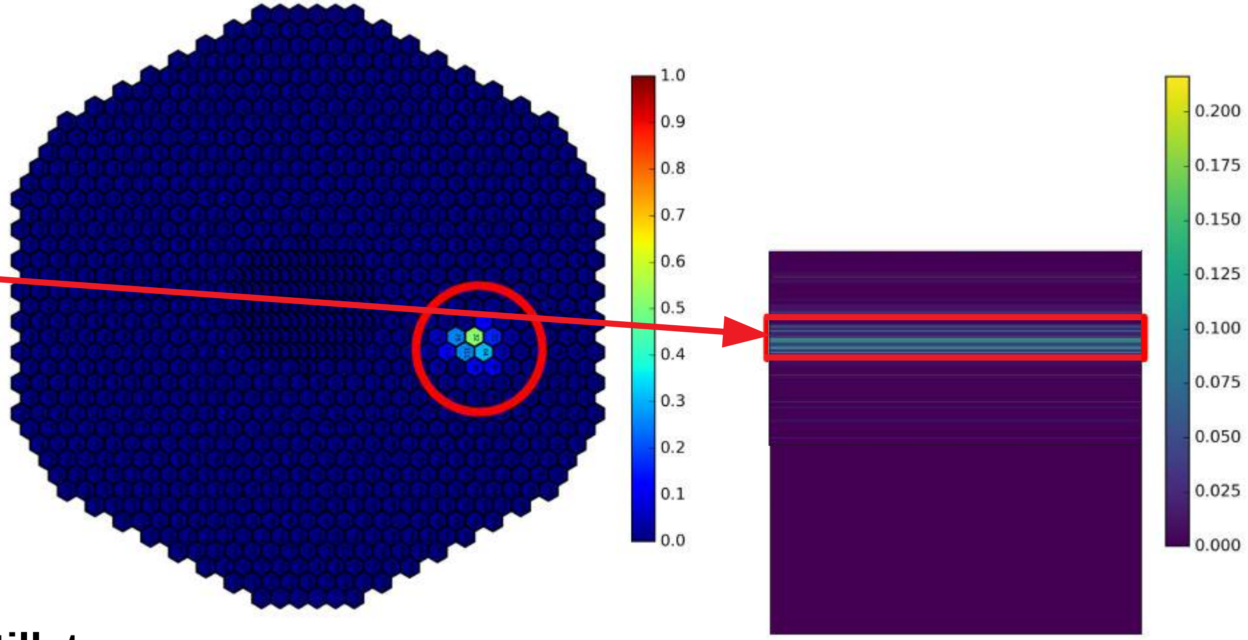



Fig.: Mapping of trigger hits to ECAL (left) and tracker (right)

- **Full coincidence:**
  - **SiD Strip Tracker ↔ SiD ECAL Pixel Sensor ↔ Beam Scintillators.**

# System Status: Sensors

## External triggering operation

- Final running operation with many DUT is going to be in external triggering
  - System noise was lowered to 0.28 fC (Tracker) and 0.32 fc (ECAL)
  - ~3 fC excpected signal charge in 320 micron silicon
    - → S/N = ~10*

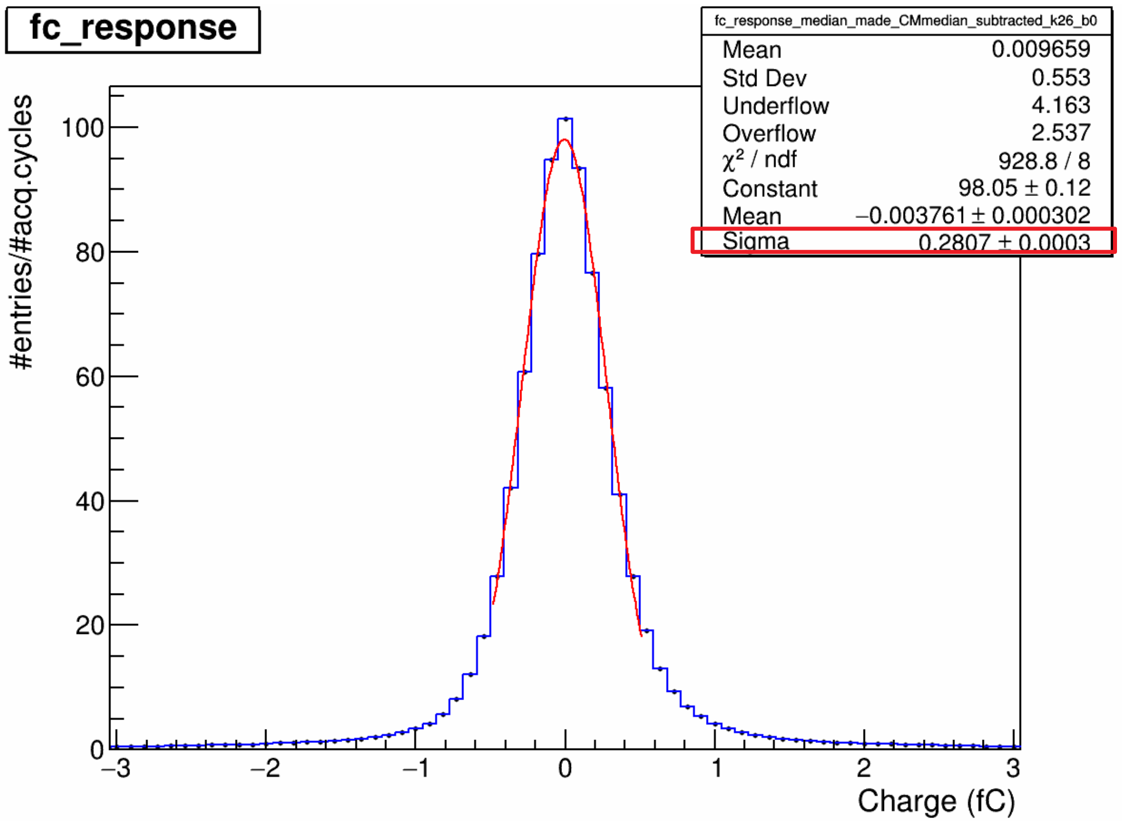


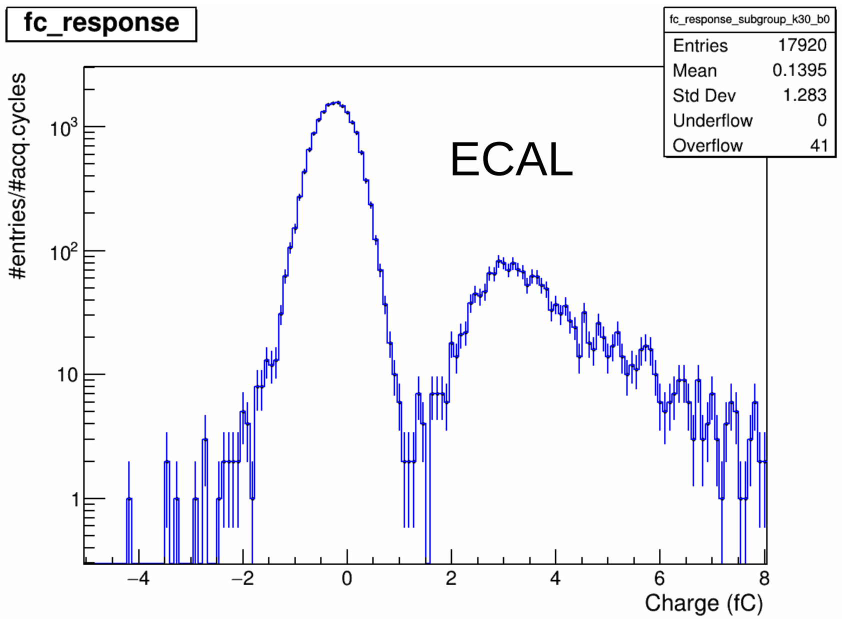

Fig.: Pedestal distribution for Tracker sensor

*Preliminary as this was done with the old electronics

# System Status: Sensors

## External triggering operation

- Needs more detailed analysis for the tracker than for the ECAL
  - ECAL:
    - ~4x4 mm$^2$ pads
      → ~10 pads in beam
      → effectively no charge sharing
  - Tracker:
    - 25 µm strip pitch + alternating readout and floating strips
      → ~ 400 strips in beam (200 readout strips)
      → significant charge sharing and multiple different hit profiles



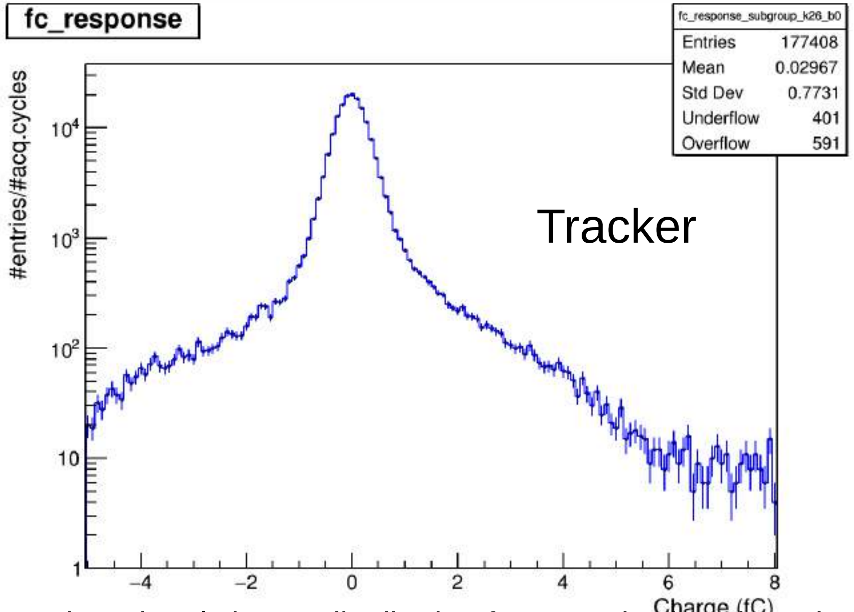




Fig.: Signal charge distribution for ECAL(top) and Tracker (bottom) sensor with channel preselection

# System Status: Sensors

## External triggering operation

- Need deeper look into hit profile candidates for analysis.
- We expect 1 particle per trigger within the sensor with multiple cases depending on where/what it hits
  - Case 1: readout strip → look for 1 single channel per trigger with ~3 fC
  - Case 2: floating strip → look for 1 single cluster candidate of adjacent strips per trigger each with charge ~1.2 fC
  - ...

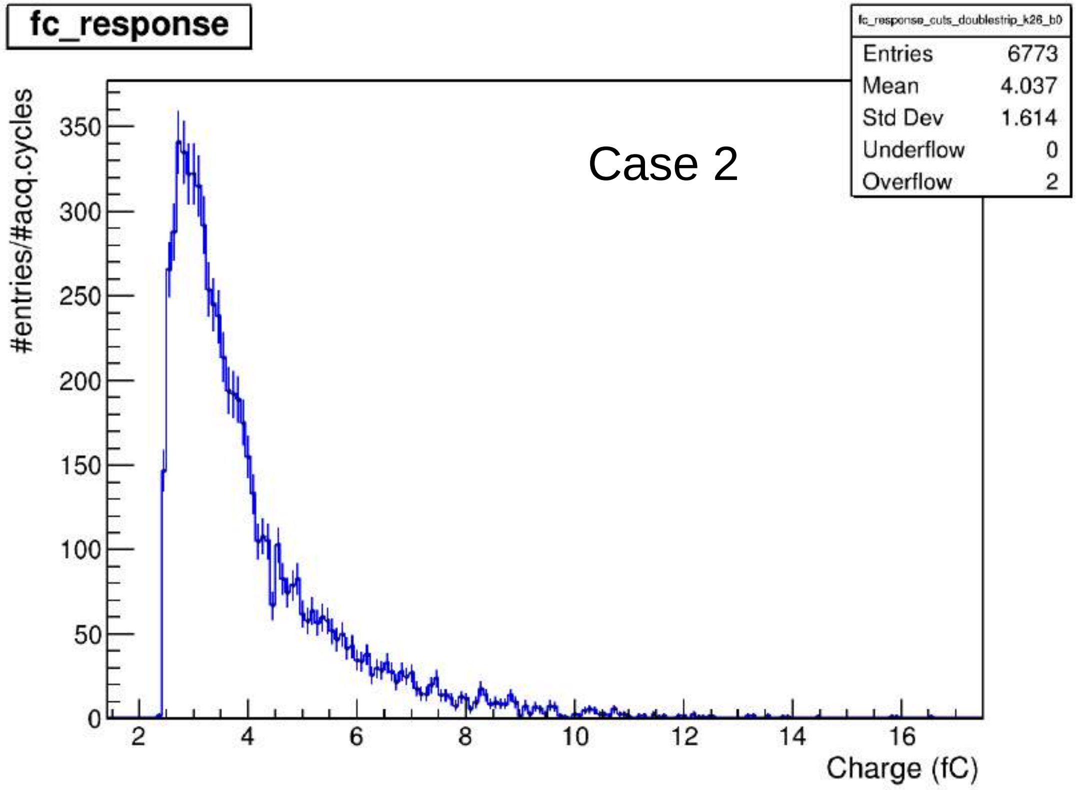



Fig.: Charge distribution after floating strip hit candidate filtering

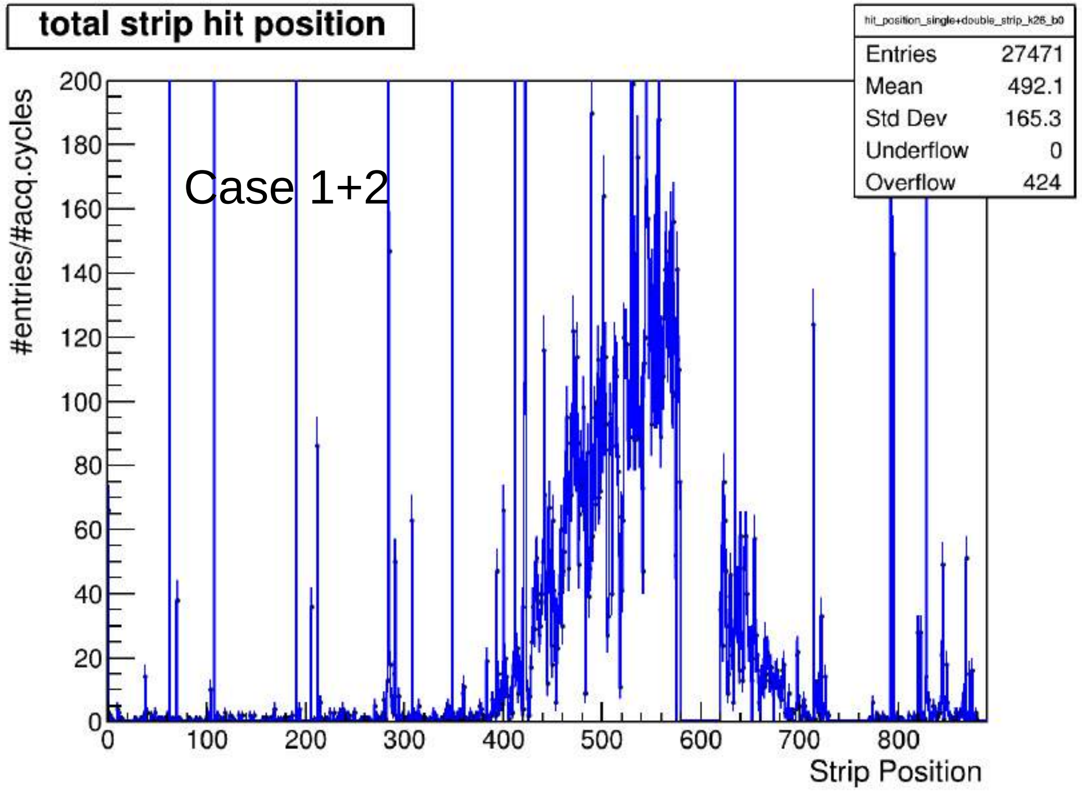



Fig.: Hit position after floating strip + single strip hit candidate filtering

# Summary and Outlook

- Receiving last missing components for the system.
  - Mechanical structure fully assembled and sensor+dummies tested within the structure
  - New DAQ board recently finished
    → First tests of the new firmware and hardware successful.
  - Cassette electronics in transit

- Assembled the first telescope module.
  - Successful communication and calibration with both chips
  - Completed multiple tests of the sensor in the lab and at the DESY II Test Beam Facility
  - Moving to assembly of remaining sensors with new tool.
  - Challenges from the assembly and component lifetime going to be conquered within a few weeks.
    → Assembly of the sensors in the coming week(s)

- Work is ongoing on the analysis of the data including clustering algorithms and tracking.
- Testbeam with multiple modules in the cassette and a mimosa telescope scheduled for **02/2019**
- Testbeam of LYCORIS within PCMAG, potentially with a DUT, scheduled for **04/2019**

# Thank you for your attention

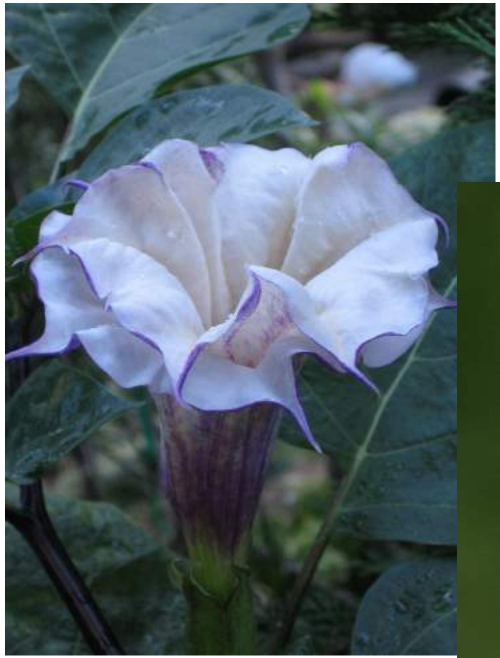


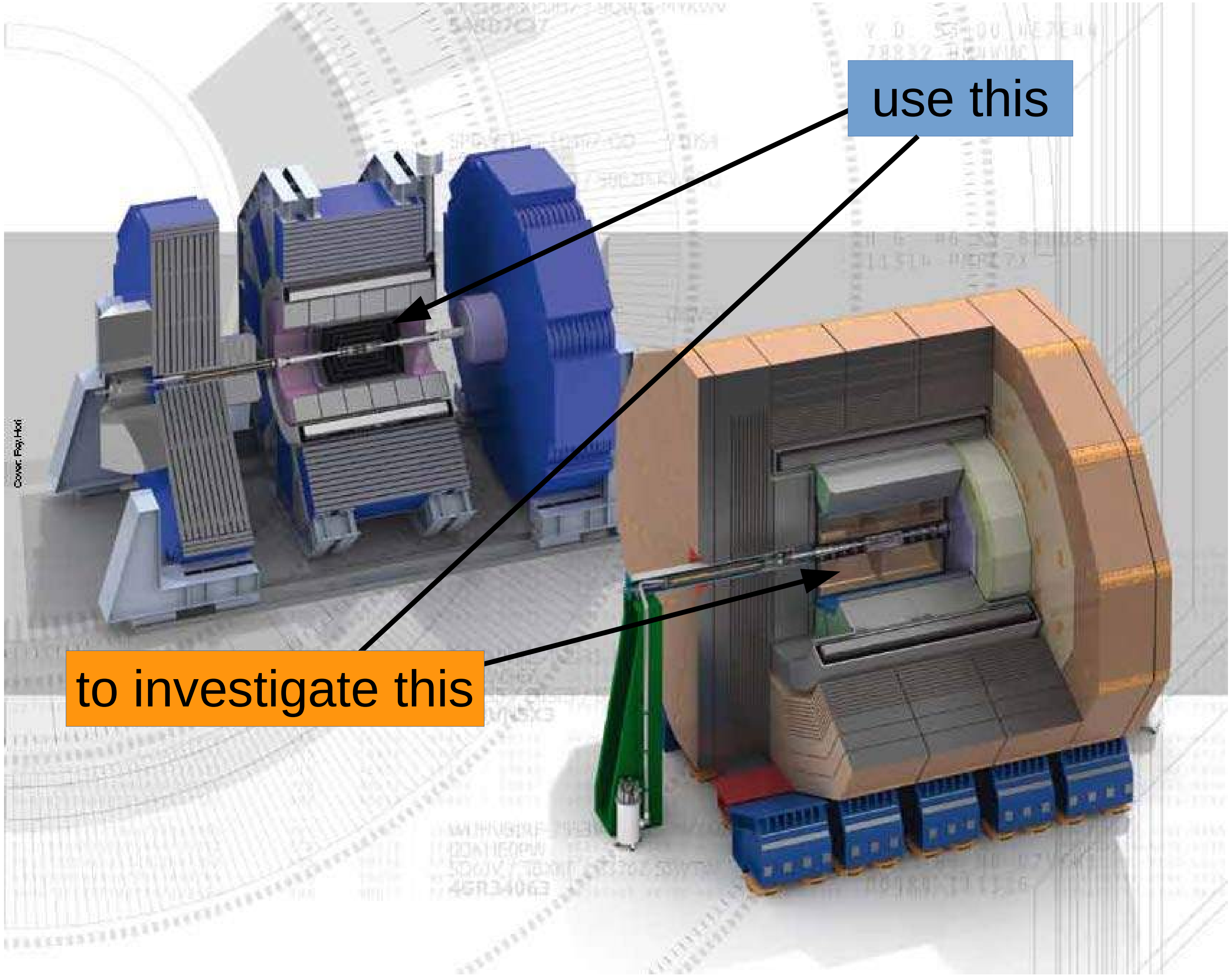
Fig.: Datura

Fig.: Duranta

Fig.: Lycoris

# BACKUP

# The LYCORIS Project In the Context of ILC



# Silicon Telescopes

- High precision silicon trackers
- Used to provide reference measurements of particle track
- Multiple layers placed before and after the Device Under Test (DUT)

→ Provide tracking through the DUT even in the case of multiple scattering

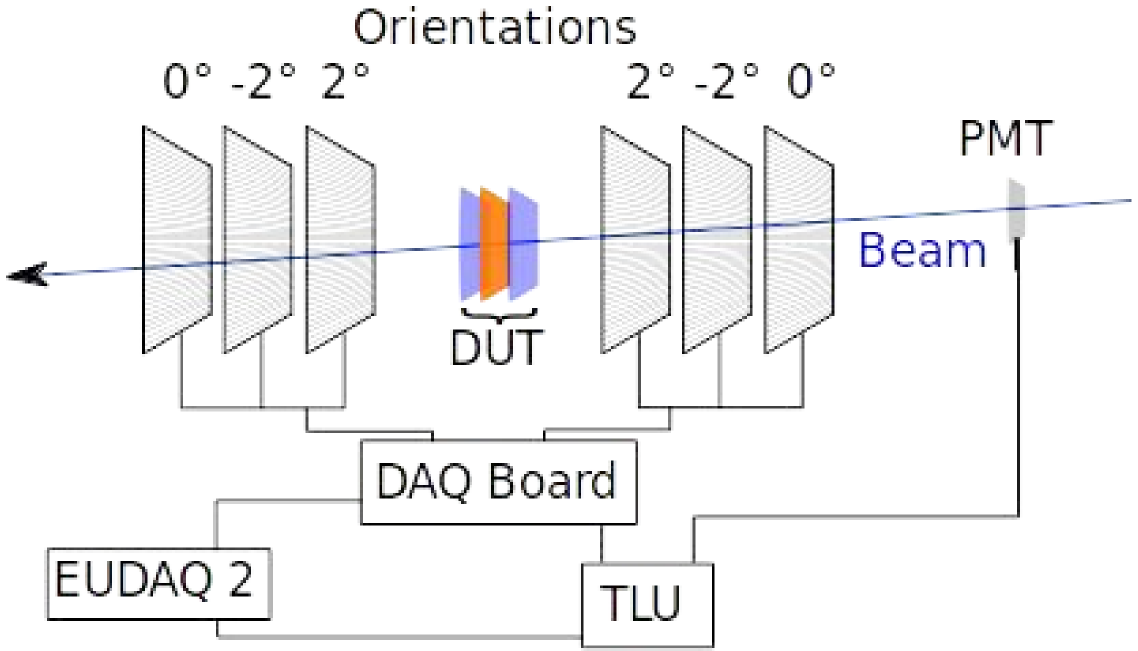



Fig.: External strip tracker sketch

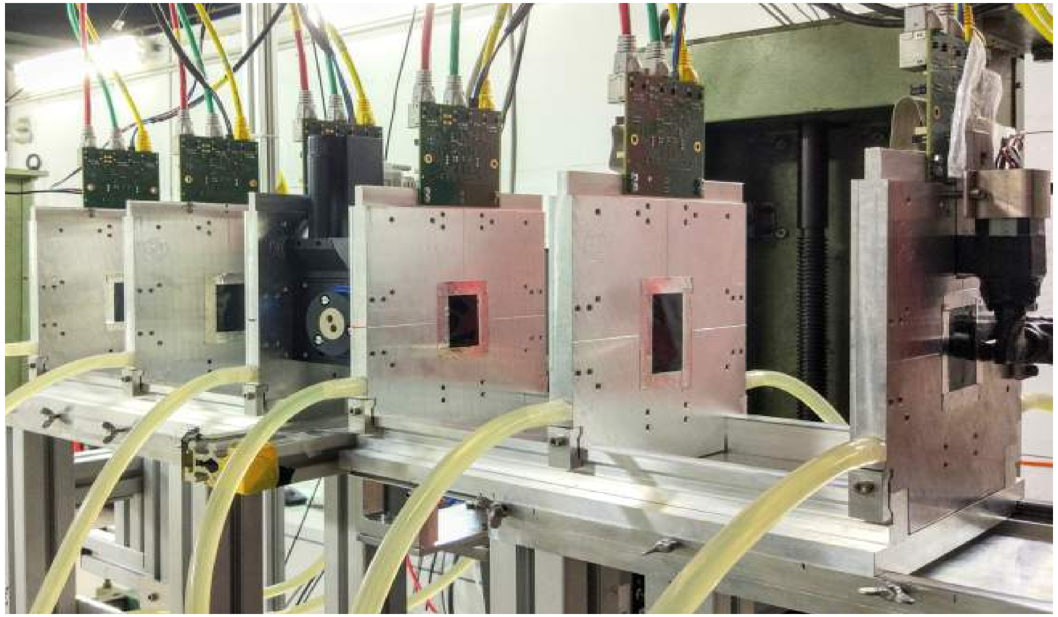


Fig.: EUDET Type Telescopes at DESY II Test Beam Facility

# Case for an External Reference Tracker

- **Challenge:** Distortion of particle trajectory as a result of multiple scattering or inhomogeneous electric fields
- **Solution:** Reference measurement of the particle position before and after the DUT

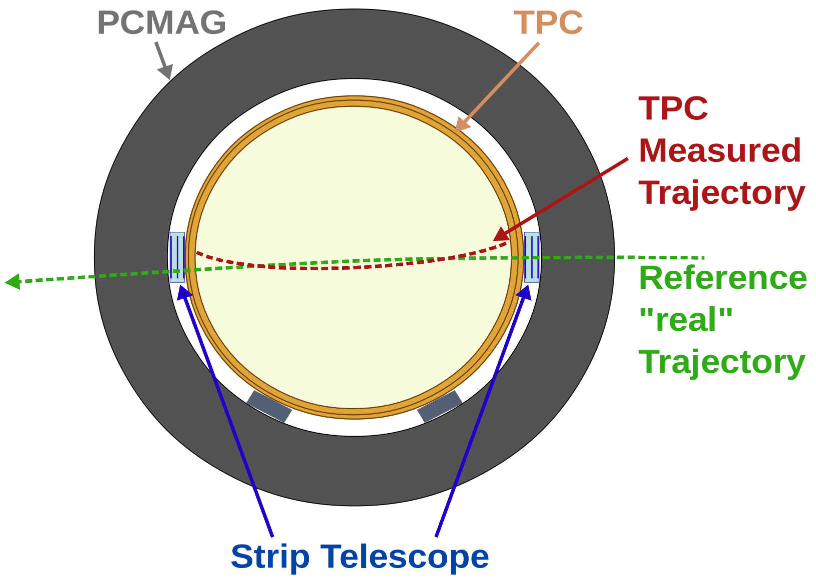



Fig.: Sketch explanation for the need of a reference trajectory

- **Challenge:** Smearing of particle momentum as a result of interactions with the magnet wall
- **Solution:** Accurate measurement of the momentum after magnet wall

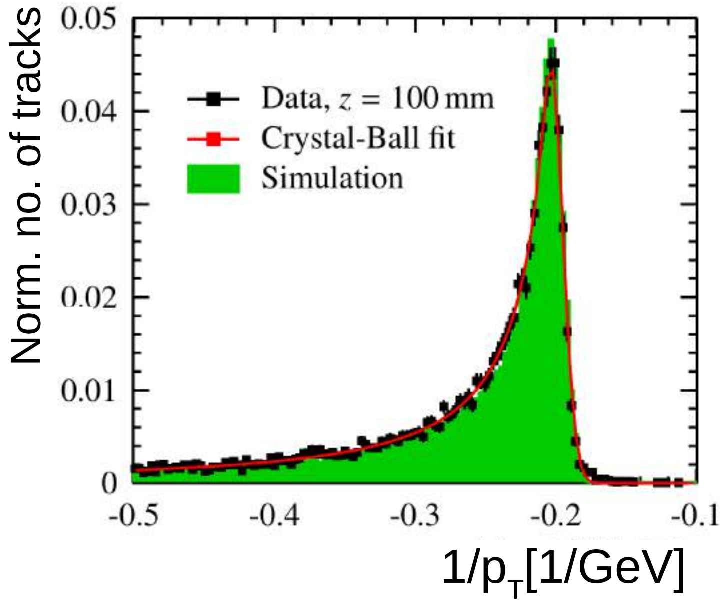



Fig.: Momentum distribution after interaction with the PCMAG wall (Felix Müller | DOI: 10.3204/PUBDB-2016-02659 )

# System Status: Sensors

- 27 Bump Bonded sensors tested:
  - Good behaviour:
    - ~ 100 nA currents, stable up to 300 V
    - Depletion voltage for all sensors at ~50 V
  - Two sensors show breakdown beginning at  280 V

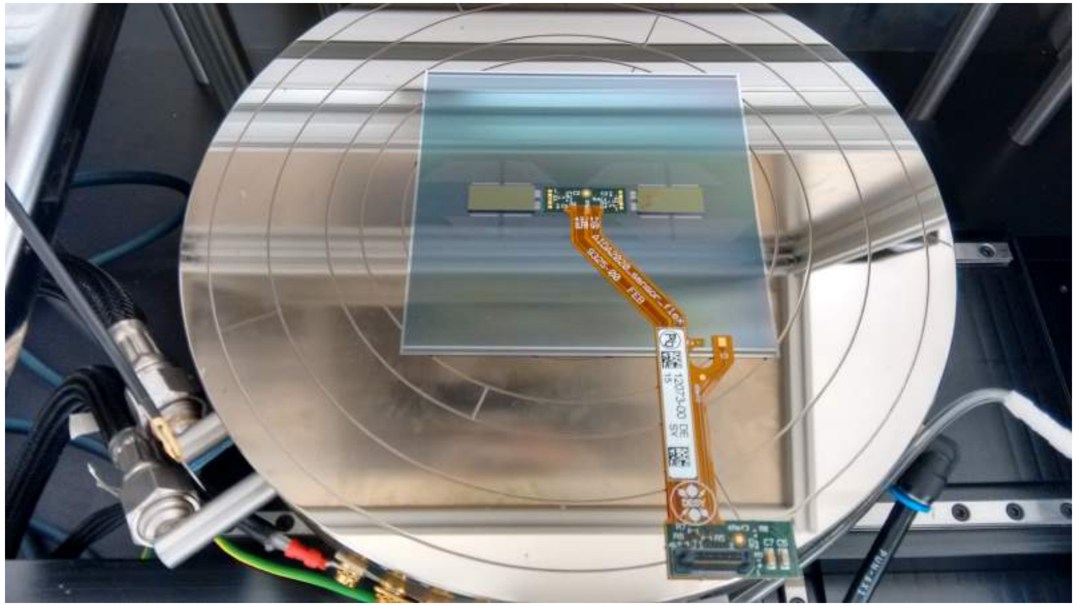


Fig.: Bump Bonded Sensor with flex cable on the probe station

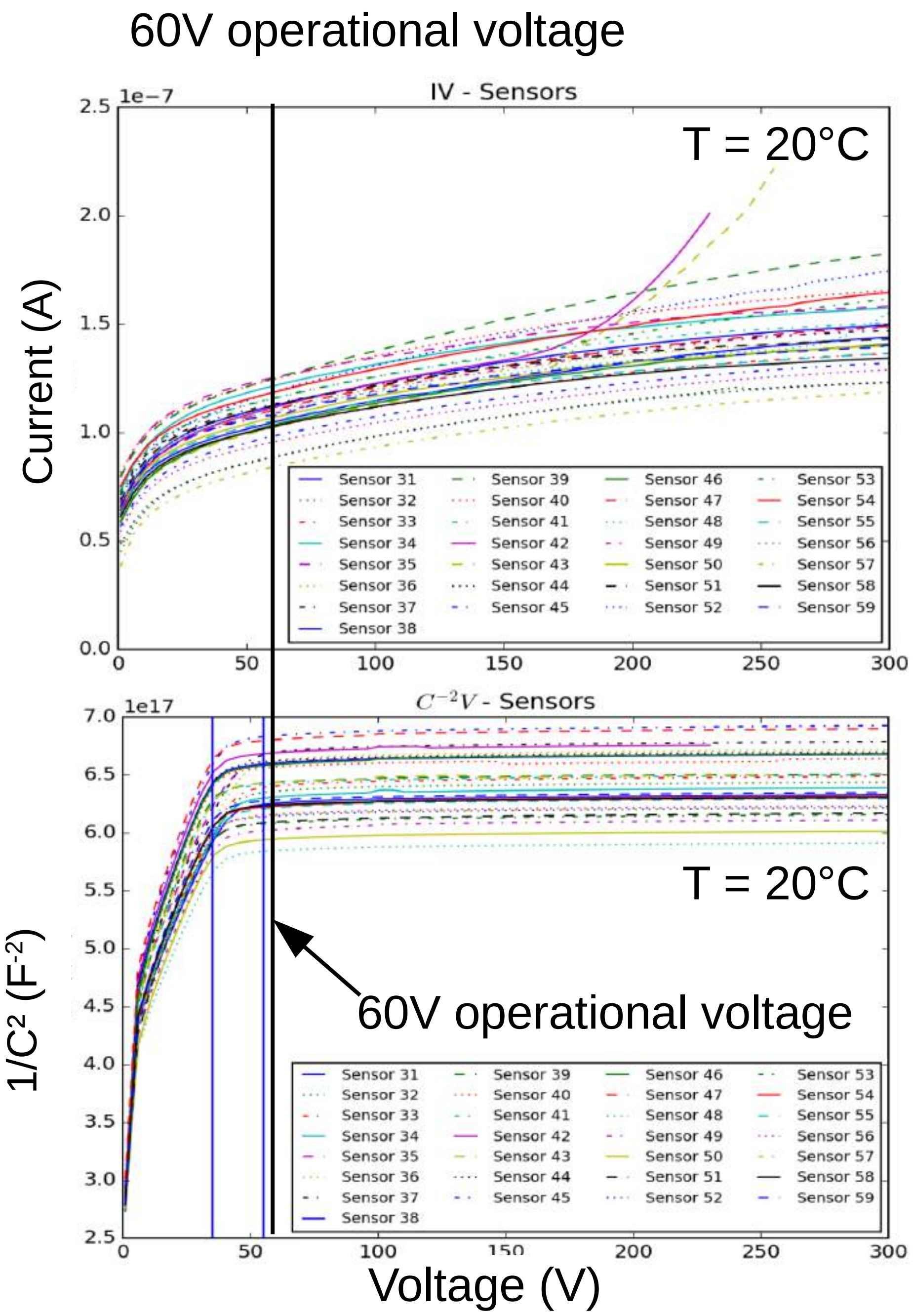



Fig.: IV (top) and CV (bottom) of the sensors

# The DESY II Energy Cycle

- DESY II energy cycle follows a sinoidal curve
- Time difference between minimal energy signal and signal in the test area is measured using scintillator triggers in the area

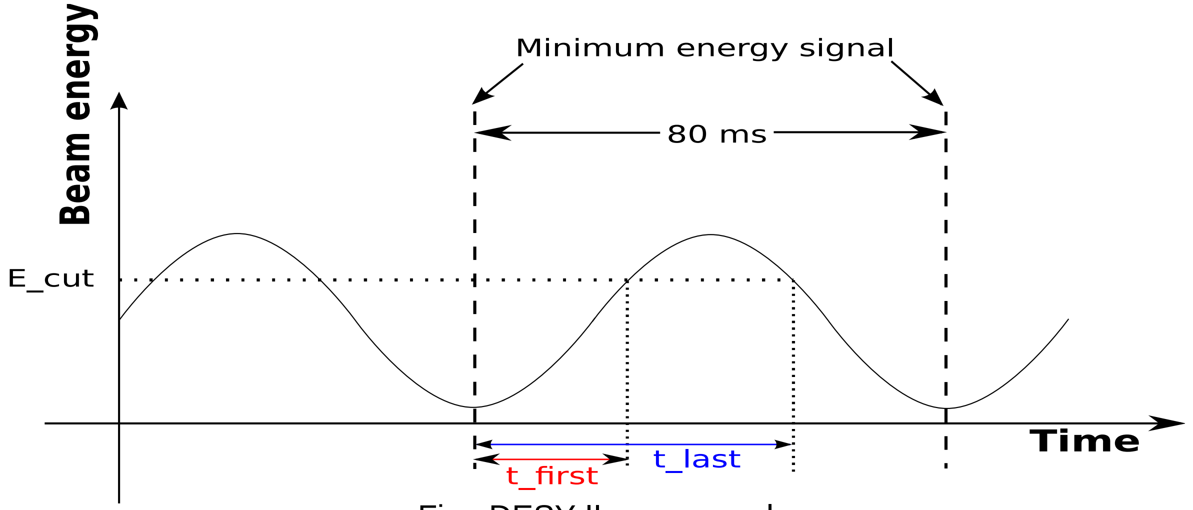



Fig.: DESY II energy cycle

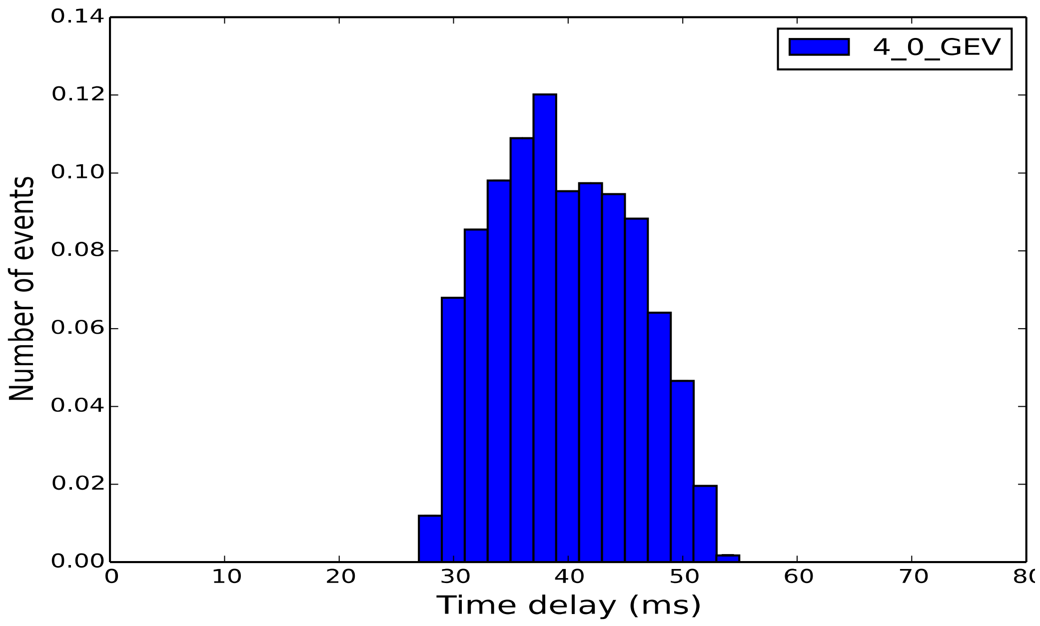



Fig.: Time difference from min. energy to trigger signal

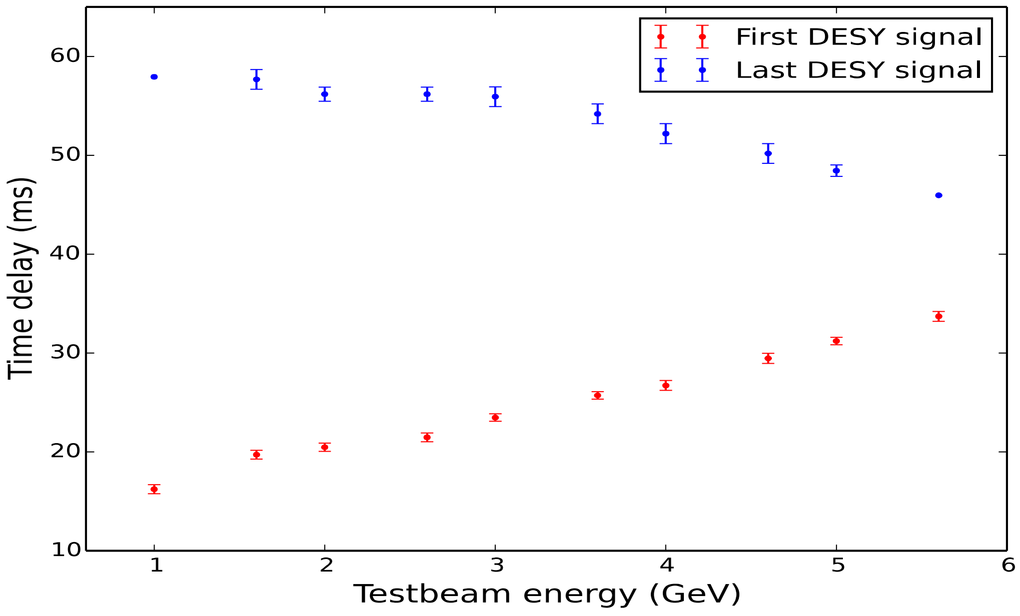



Fig.: First and last DESY signal in a cycle for different energies

# System Status: Sensors

## External triggering operation

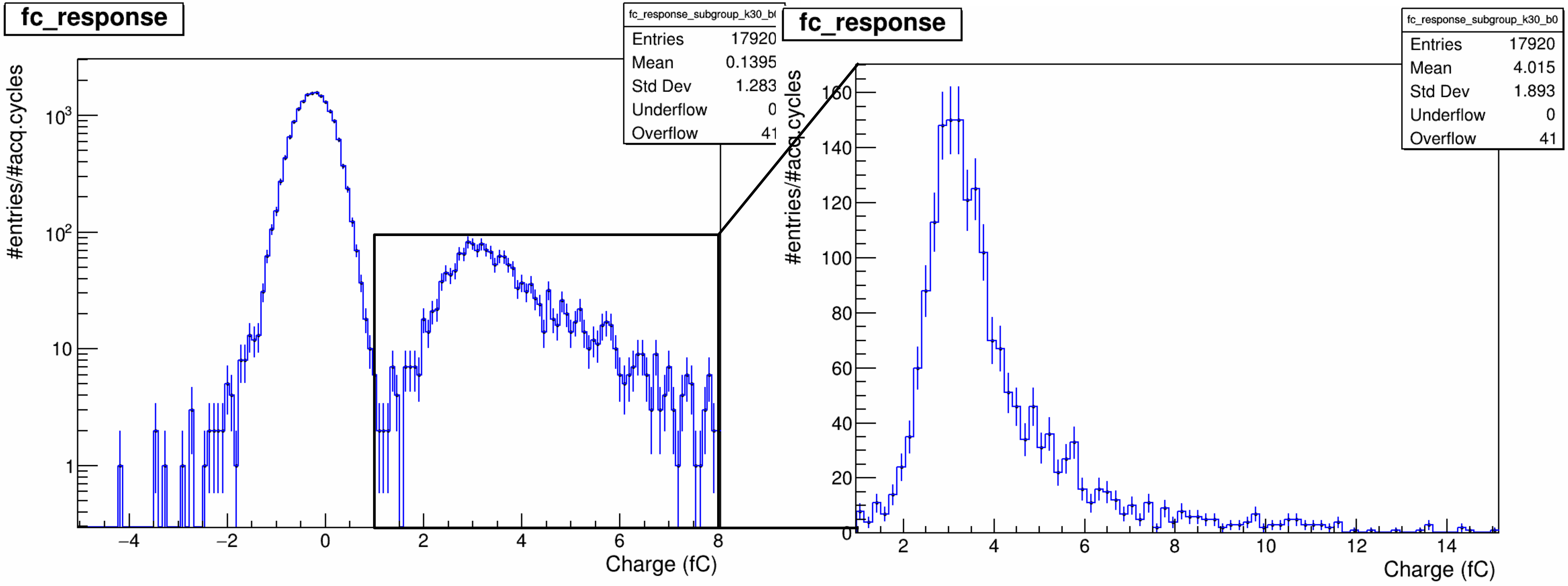
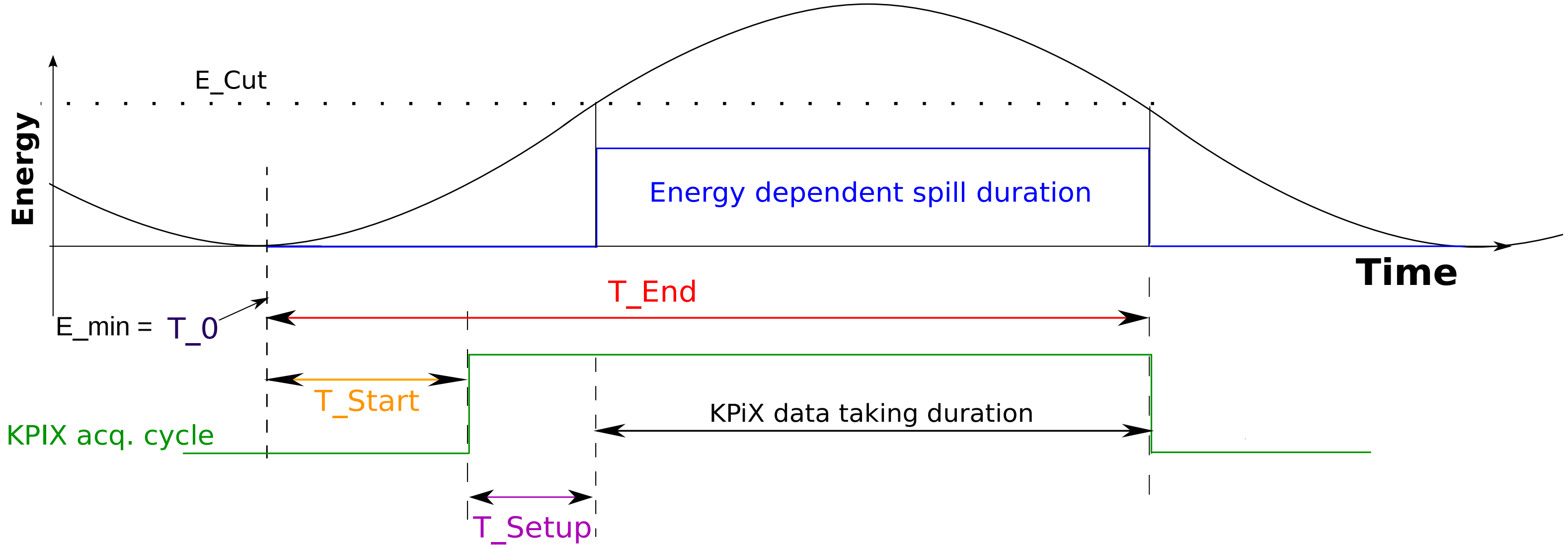



Fig.: Signal charge distribution for ECAL sensor with channel preselection

- Operation works quite well for the ECAL

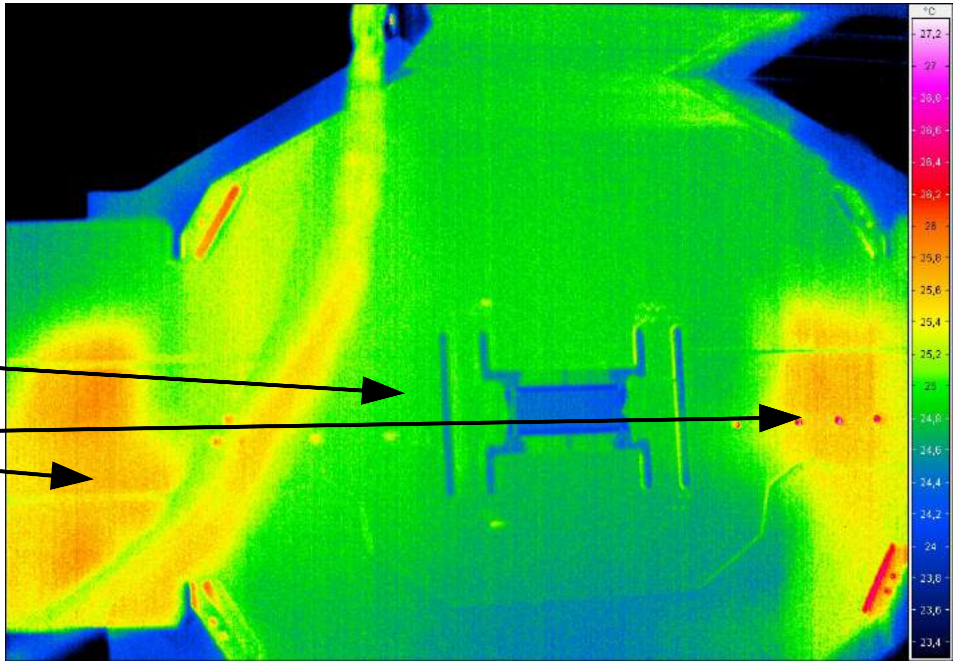
# KPiX synchronisation, DUT and Beam




- KpiX needs to be synchronised to beam spill of the acceleerator and the DUT
  - T_0: Accelerator signal for synchronisation with beam spiull
  - T_Start: User adjustable delay between T_0 and KpiX switch on.
  - T_Setup: Setup time of KpiX. At the end of which KpiX can start the data taking
  - T_End: User adjustable signal telling all devices that KpiX has stopped data taking
- New AIDA TLU (Trigger Logic Unit) will be able to provide these signals and distribute a common clock

# Heat production

- As a result of power pulsing and only 1024 channels, a low power Consumption is expected (40 mW in total)
- Measurement of heat production done via infrared camera




- Overall power consumption and heat generation is negligible

  → No active cooling needed

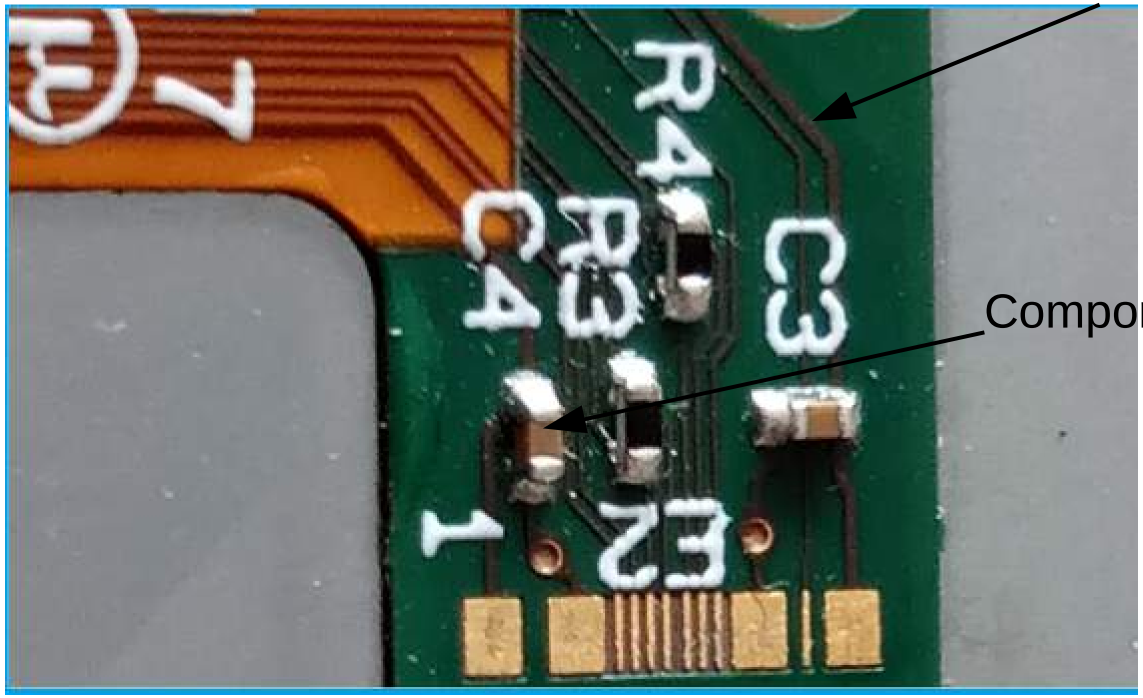
# Radiation Length

| Material | Thickness | General Radiation Length ( = 1 X0) | Final Radiation length (as multiples of X0) |
|---|---|---|---|
| Carbon Fiber Window | 0.03 cm | ~29 cm | 0.103% |
| Aluminium Foil (Al) | 0.0013 cm | 8.897 cm | 0.015% |
| Silicon Sensor (Si) | 0.032 cm | 9.37 cm | 0.342% |
| Kapton Cable (Cu) | maximum 0.025 cm | 1.436 cm | 1.74% (maximum) |
| Kapton Cable (Kapton) | maximum 0.025 cm | 57.6 cm | 0.043% (maximum) |
| KPiX (Si) | 0.032 cm | 9.37 cm | 0.342% |
| Araldite (2011) by ATLAS | ~0.01 cm | 33.5 cm | 0.030% |
| Araldite (2011) by calculation (C6 H6 O) | ~0.01 cm | 46.24 cm | 0.022% |

The materials in question are the following:

1. Carbon Fiber Window + Aluminium Sheet + Stycast
2. Master↔Slave Interboard Kapton Flex
3. **Sensor 1 (+Kapton Flex && Araldite2011 || +KPiX)**
4. **Sensor 2 (+Kapton Flex && Araldite2011 || +KPiX)**
5. **Sensor 3 (+Kapton Flex && Araldite2011 || +KPiX)**
6. **Carbon Fiber Window + Aluminium Sheet + Stycast**
7. DUT
8. **Carbon Fiber Window + Aluminium Sheet + Stycast**
9. **Sensor 4 (+Kapton Flex && Araldite2011 || +KPiX)**
10. **Sensor 5 (+Kapton Flex && Araldite2011 || +KPiX)**
11. **Sensor 6 (+Kapton Flex && Araldite2011 || +KPiX)**
12. Master↔Slave Interboard Kapton Flex
13. Carbon Fiber Window + Aluminium Sheet + Stycast

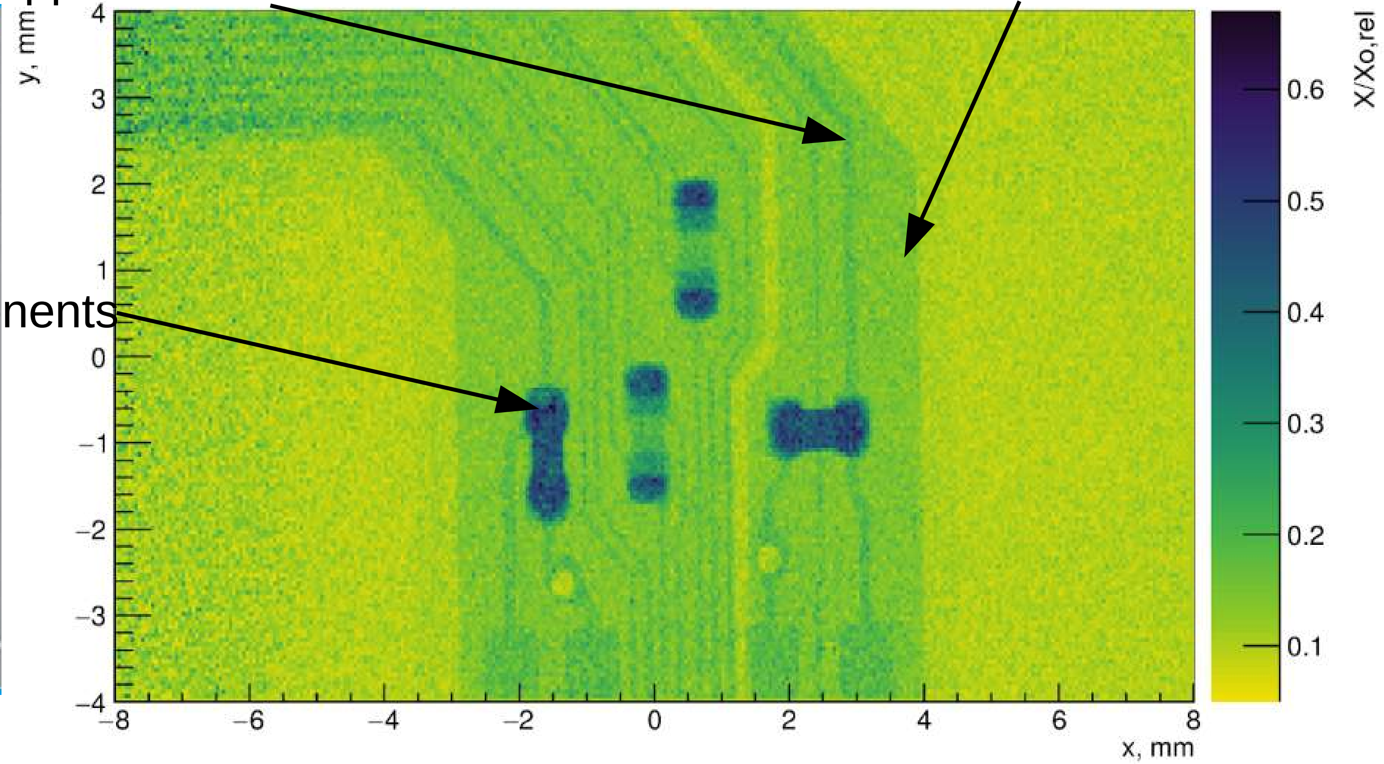
# Radiation Length




Copper traces

Grounding plane

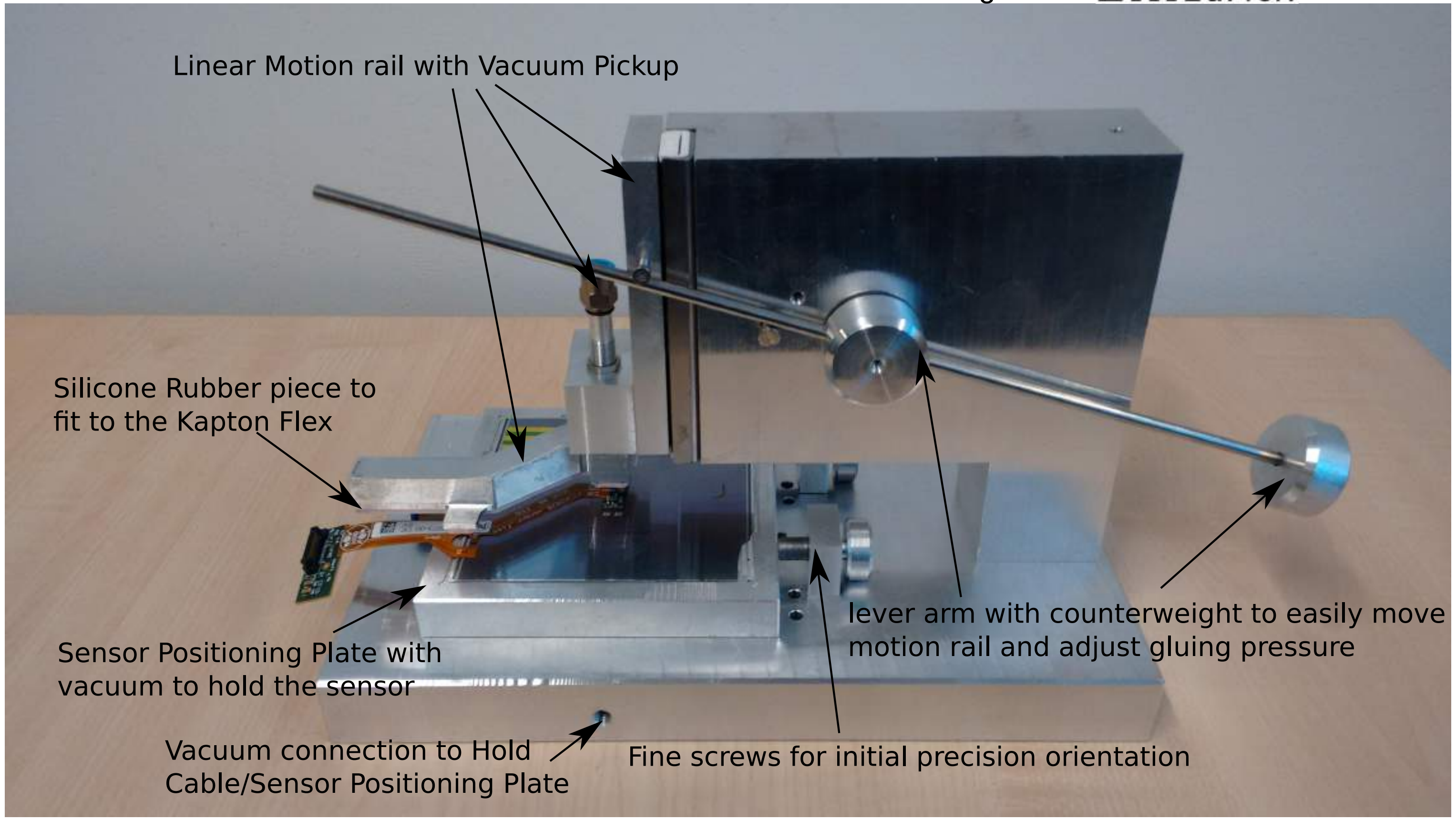
Components



# System Status: Mechanics

- After first manual assemblies, a new tool was designed and built to provide reproducible results through:
  - Controlled glue application
  - Fine adjustable gluing pressure
  - Precise cable positioning
- Able to be used for further assembly of sensors into Torlon frames

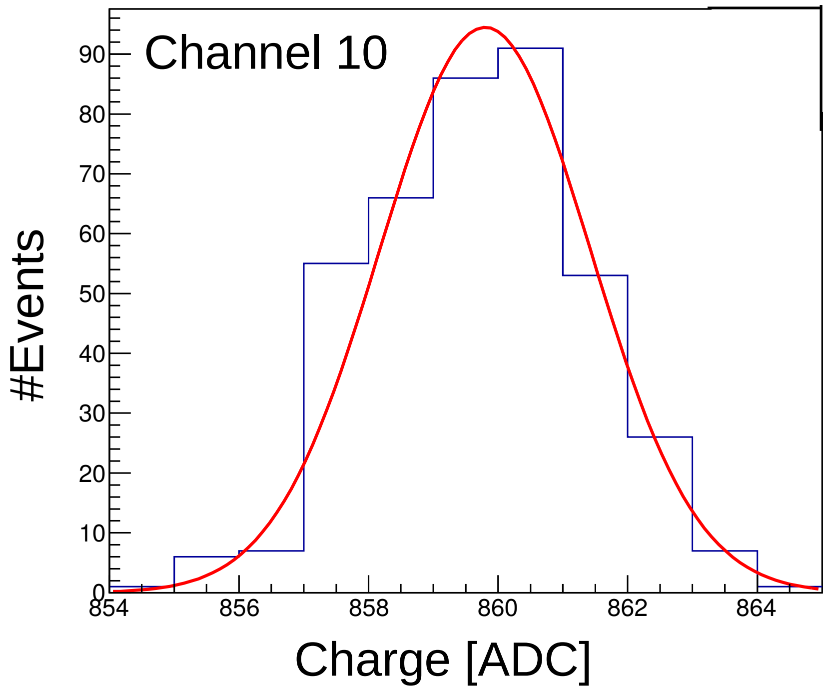
Based on a design from ETH zürich

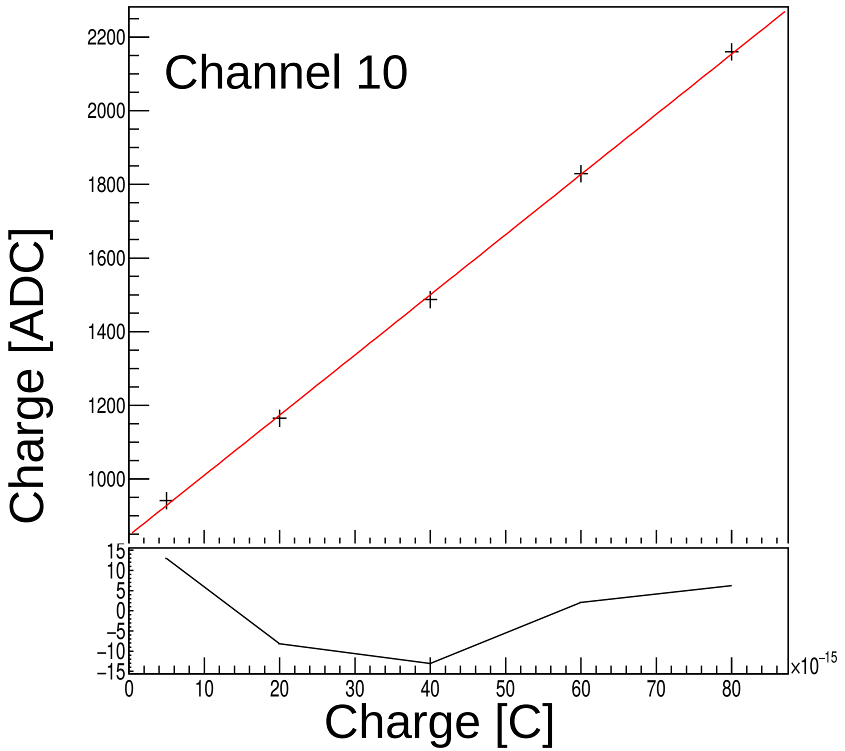



First assembly with new tool expected to start next week.

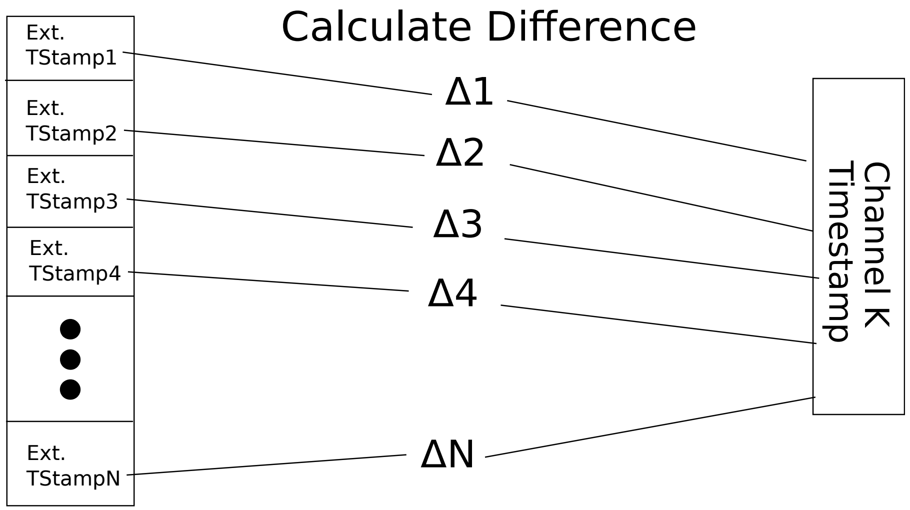
# System Status: Sensors

- First sensors assembled and tests on the first sensors are nearing completion:
  - Both readout chips can be talked to.
  - Sensor depletes through wire bonds and shows sensitivity to light
  - First pedestal data taking and calibration measurements **completed**



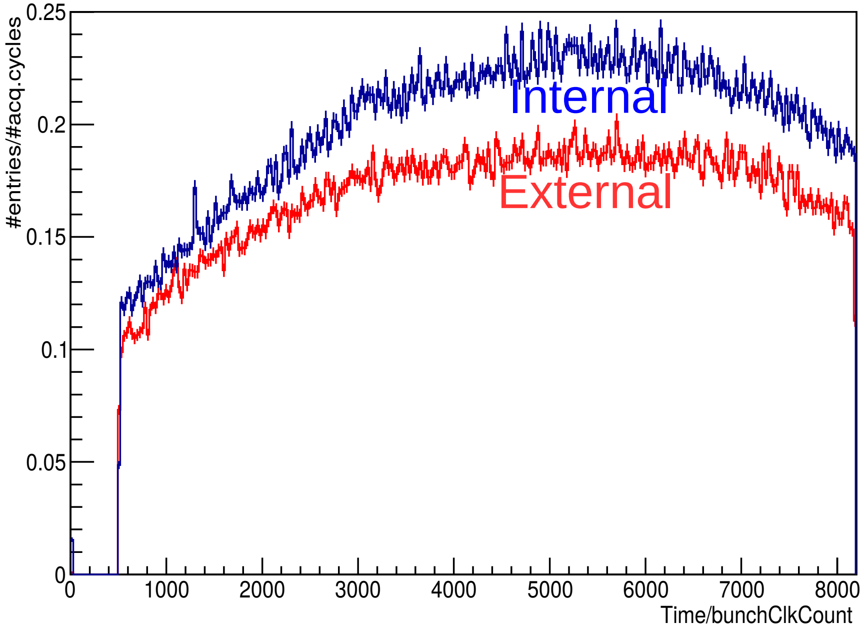



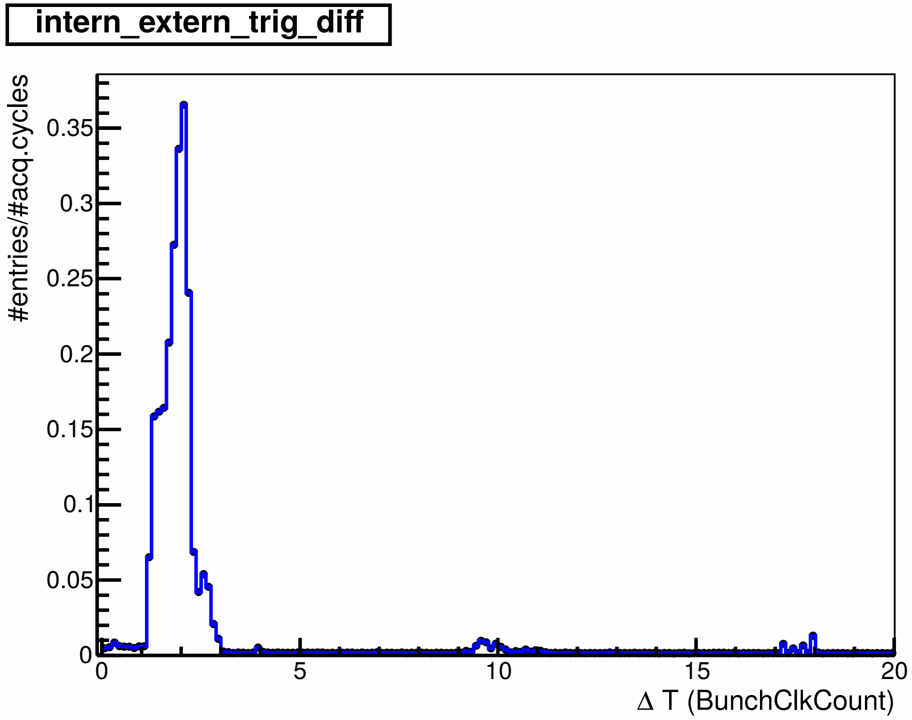
# Time Coincidence




$\Delta 4 < \Delta 3 < \Delta 2 < \Delta 1 < .... < \Delta N$

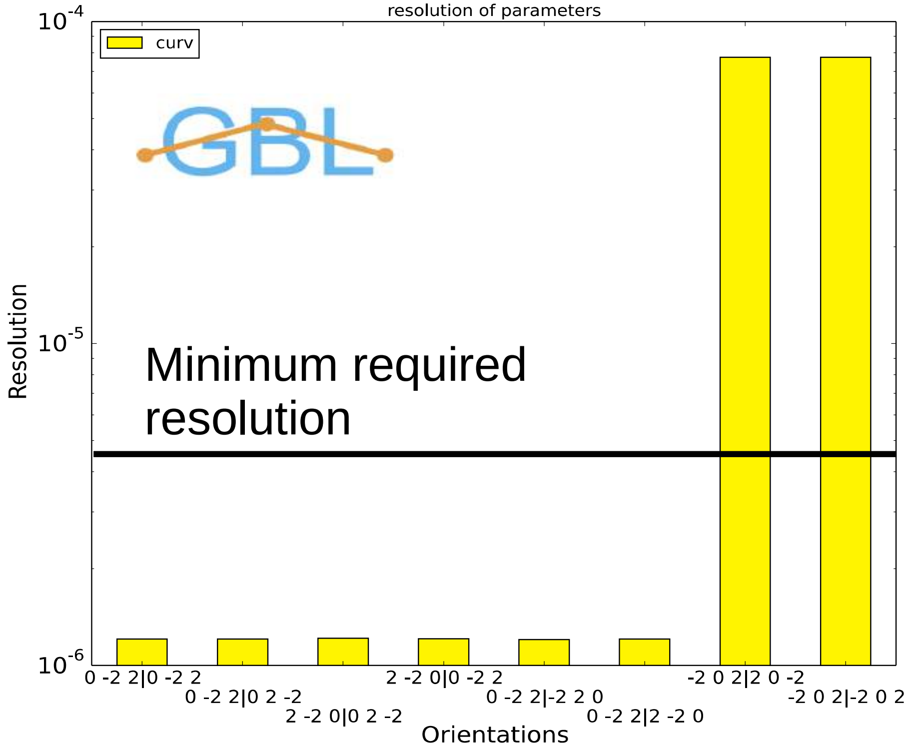
=> $\Delta 4$ = Time difference for channel K



# The expected resolution

- Analytical calculations using GeneralBrokenLines (GBL) by Claus Kleinwort with a 25 µm pitch strip sensor.
- Depending on the orientations, correlations between planes severely limit the resolution



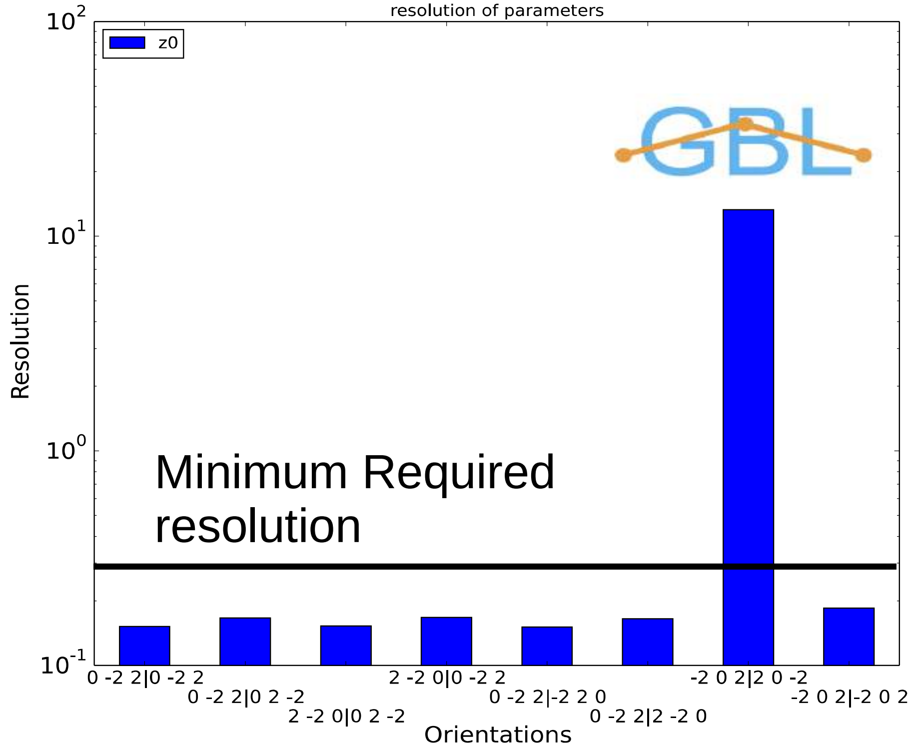
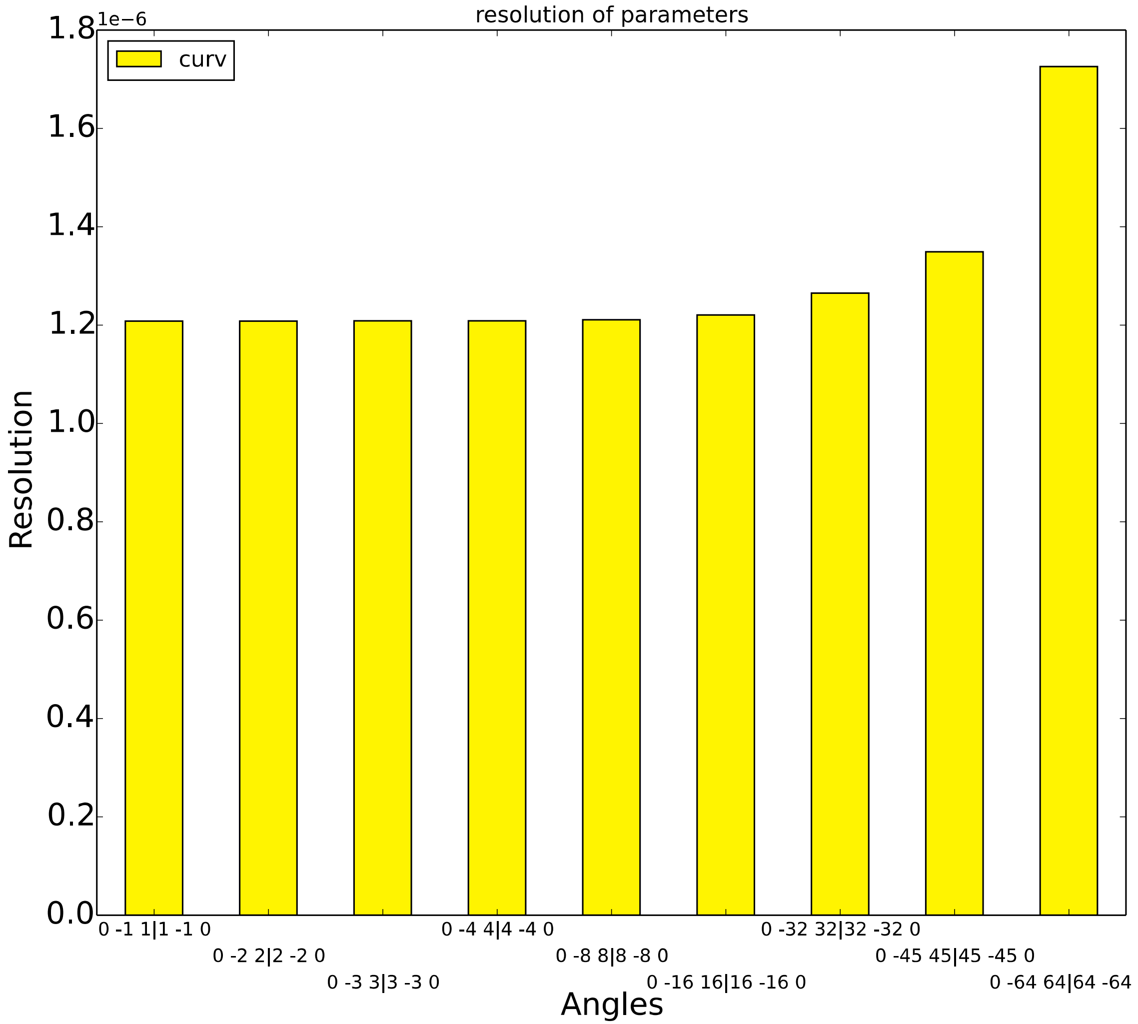
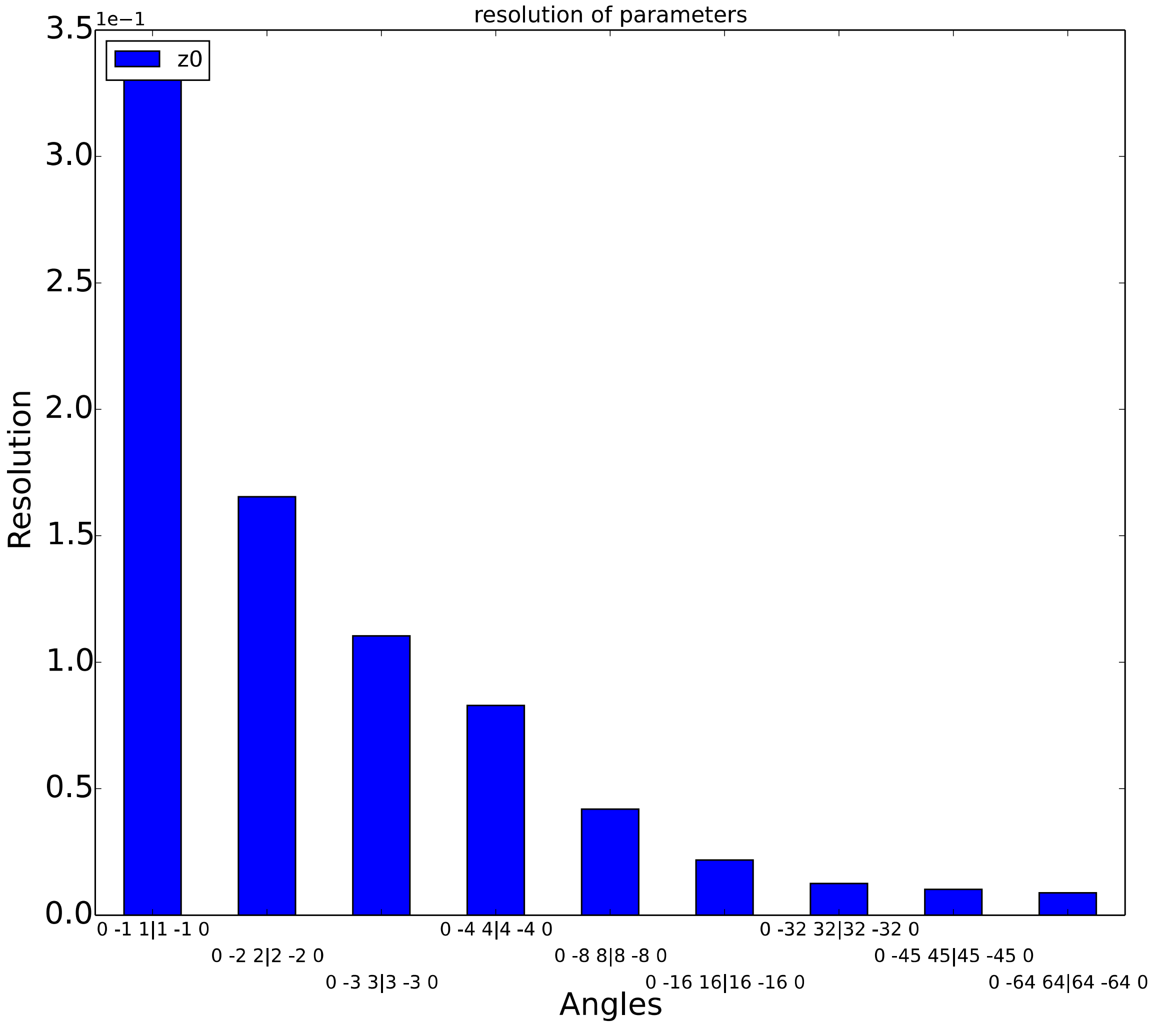




Fig.: Achievable curvature and z resolution of the telescope, with multiple scattering, depending on angular orientation

# Stereo angle variation



# Parameter correlation