A hybrid-less micro strip telescope for the DESY II Test Beam Facility

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

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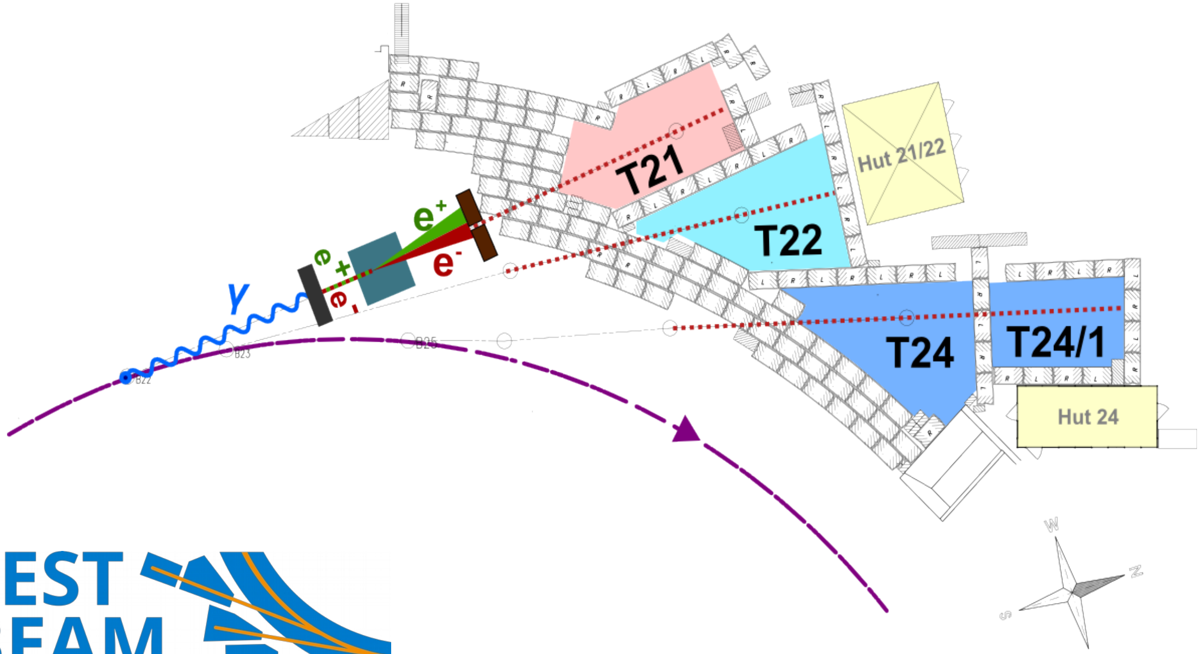
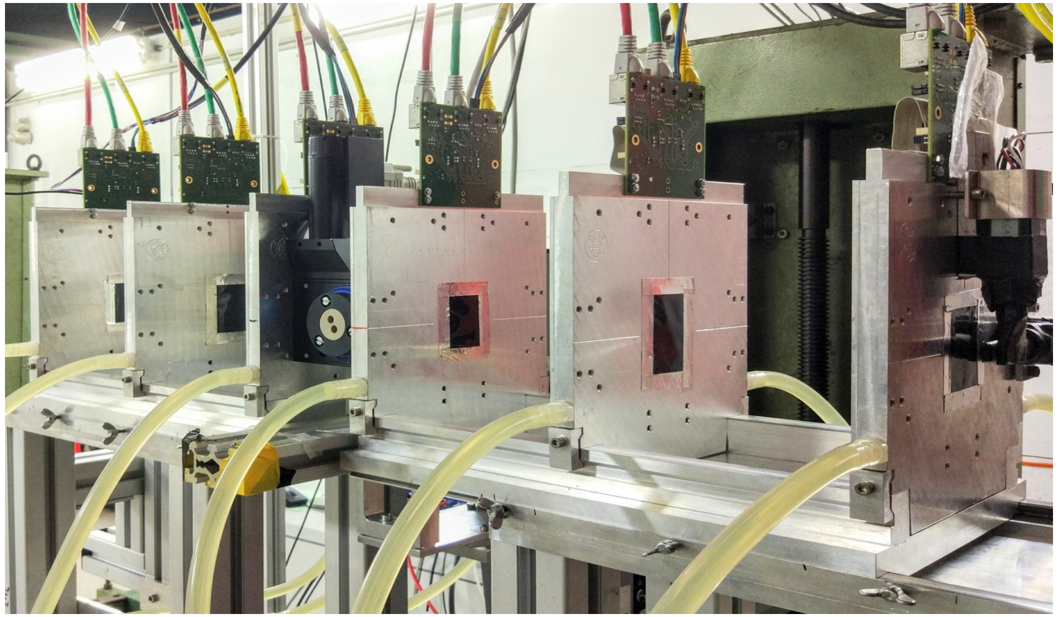
The DESY II Test Beam Facility

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





DESY TEST BEAM.

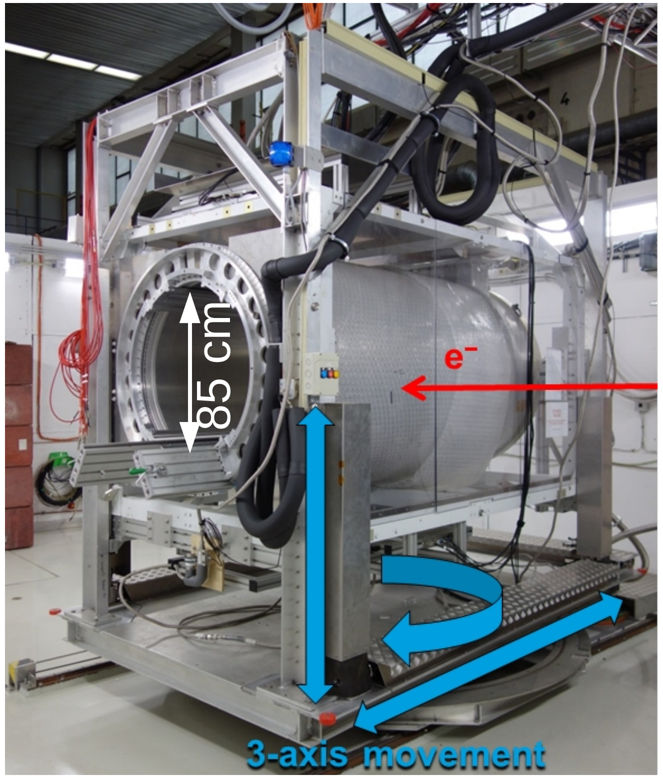
DESY.

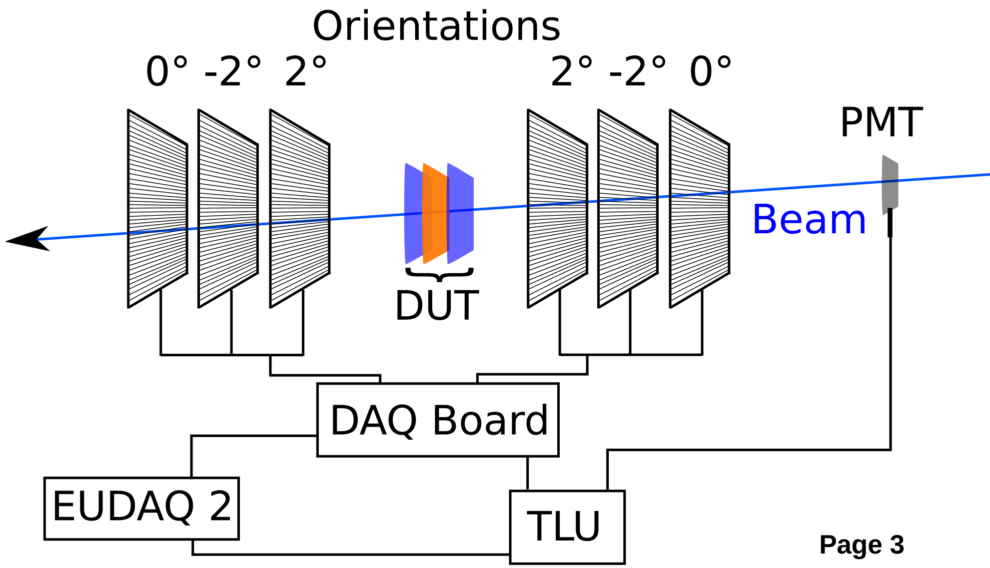
The Lycoris Telescope

An AIDA[2020] project

- A new large area strip telescope within the Test Beam Area 24/1 solenoid:
  - Wall thickness of 20% X_0.
  - Magnetic field strength of up to 1T.

- Telescope demands complementary to existing EUDET Telescopes and user demands:
  - Larger area ~10x10 cm².
  - Less than 3.5 cm of space per telescope module.
  - Spatial resolution requirements better than:
    - σ_{Bend} = ~10 µm.
    - $\sigma_{opening}$ = ~1 mm.
  - Higher time resolution (< 100 µs).





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 are being 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.

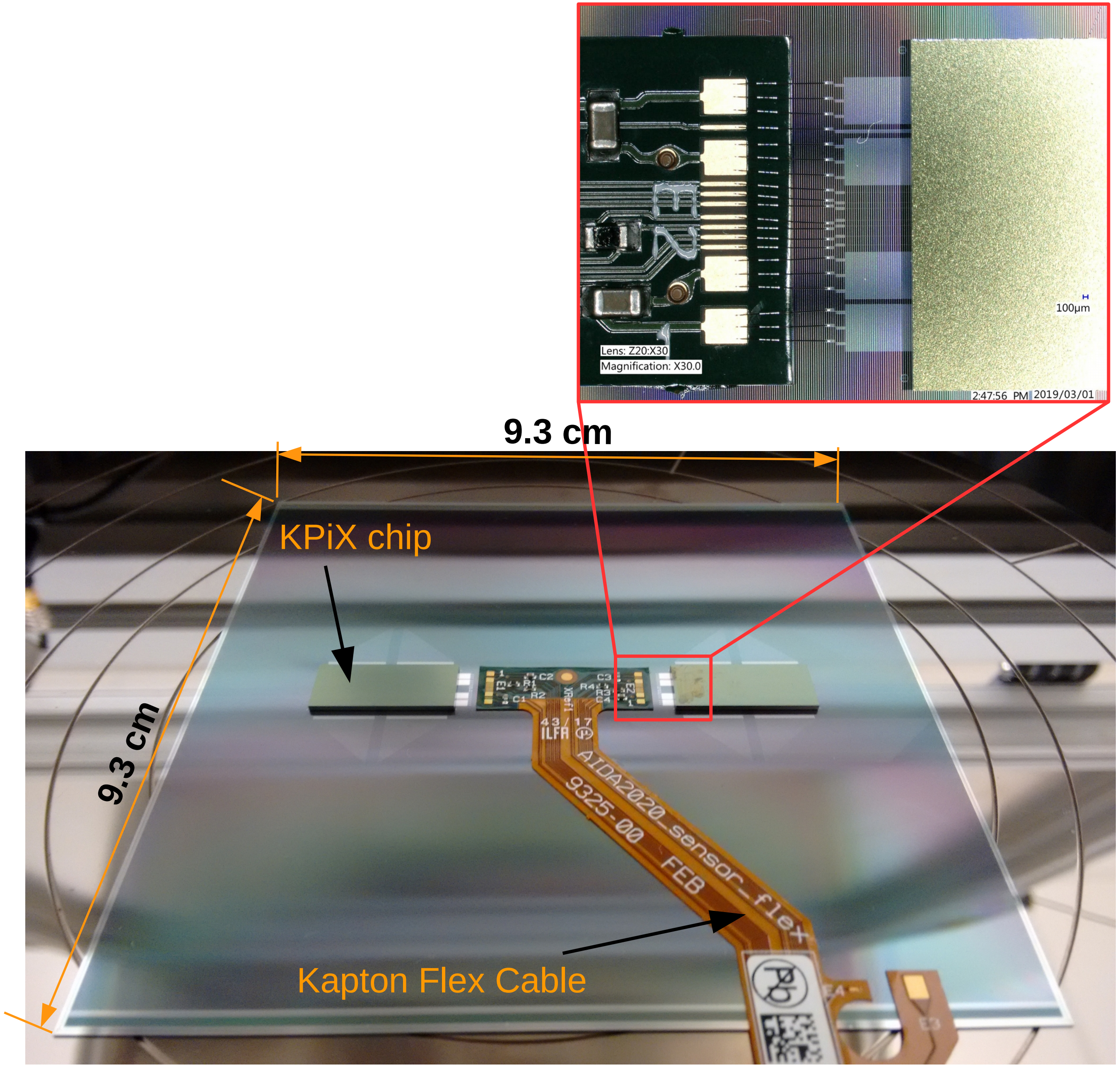


Fig.: Assembled Tracker Module

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 time frame.
- Length of the opening period depends on timing resolution.

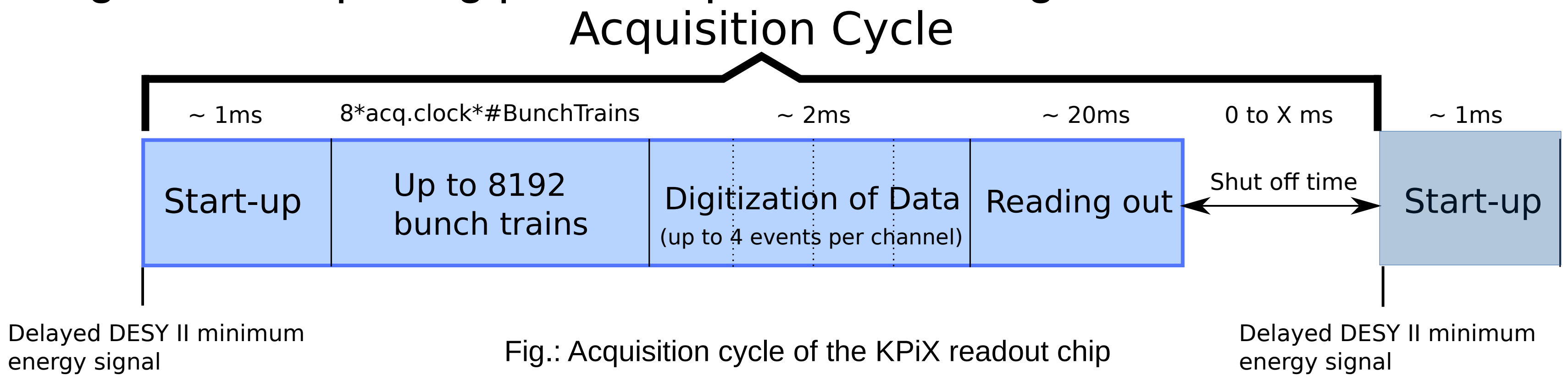


Fig.: Acquisition cycle of the KPiX readout chip

- 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

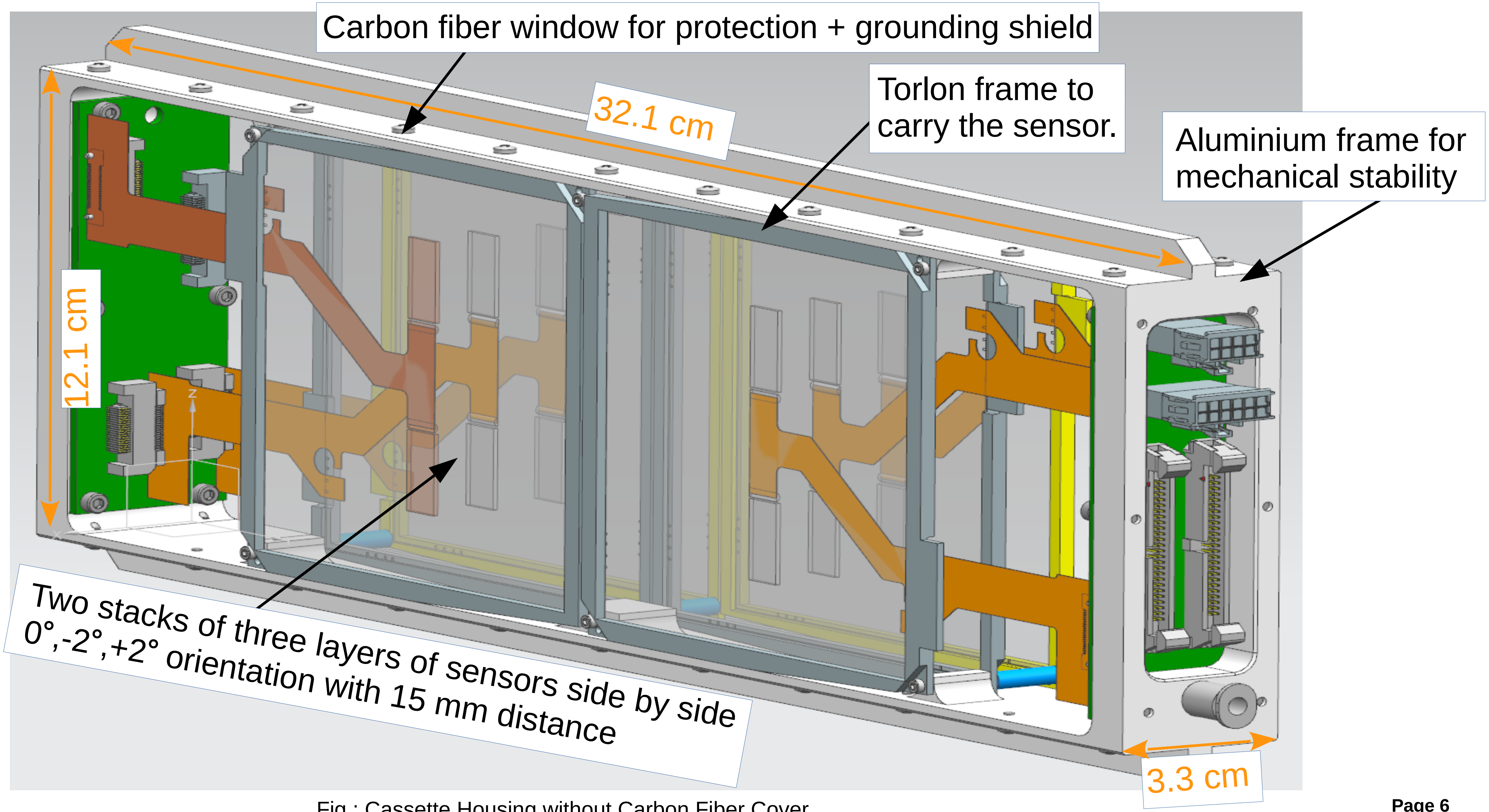


Fig.: Cassette Housing without Carbon Fiber Cover

The final system: The rail structure

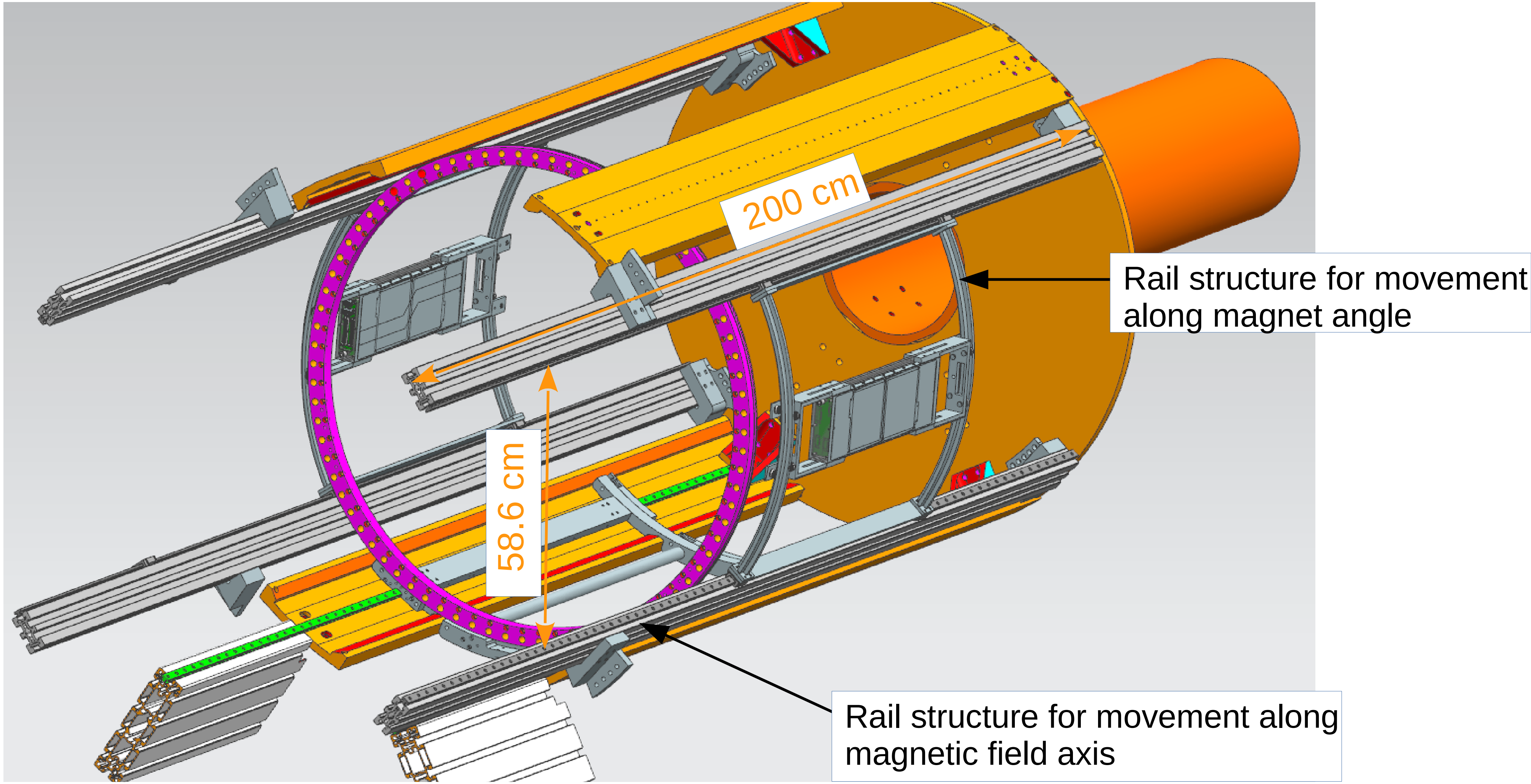


Fig.: T24/1 Solenoid with Telescope

System overview: Mechanics

- All mechanical components have been assembled.
- Functionality has been shown in first tests with dummies.
- Sensors were installed in the Cassette for first test beam.
- Average radiation length in beam path per cassette = ~1% X_0.
  - Carbon Fiber windows = ~0.1% X_0.
  - Araldite2011 = ~0.03% X_0.
  - Aluminium foil = ~0.015% X_0.
  - Silicon Sensors = ~0.7% X_0.

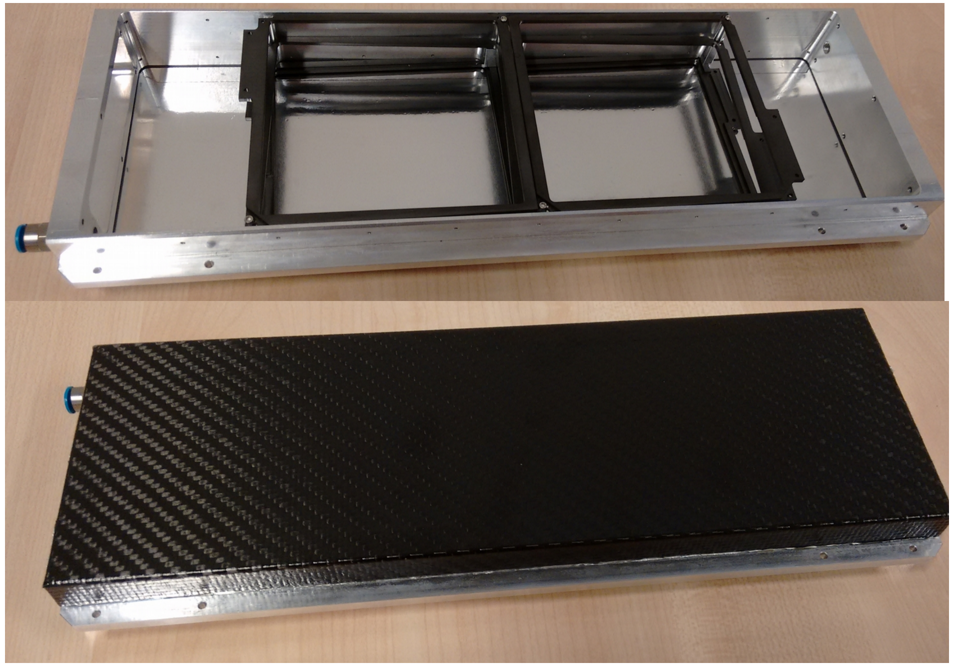


Fig.: Cassette Housing with Carbon Fiber Cover

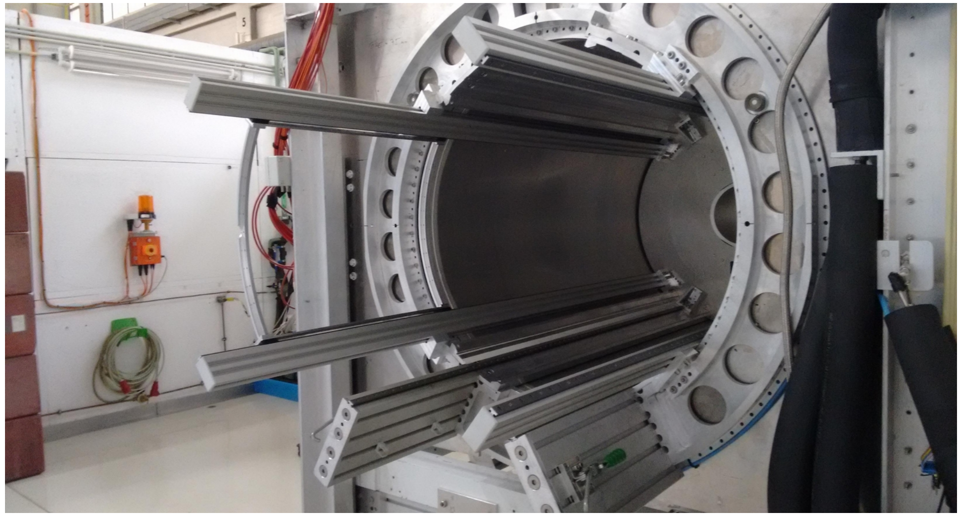


Fig.: PCMAG with cassette rails

System Overview: New Electronics

- All new electronic components are at DESY and currently under test.
- <u>AIDA trigger logic unit (TLU):</u>
  - Needed for synchronized data readout of DUT and telescope.
  - Can provide a common clock to all devices.
- <u>New data acquisition (DAQ) board:</u>
  - Provides necessary interfaces between new electronics and AIDA TLU.
  - Hardware/Firmware improvements compared to old system.
- <u>Cassette boards:</u>
  - Interface between the inside and outside of the cassette.
  - Provides on board power distribution and noise filtering
  - Ensures inside of the cassette needs not be touched during normal operation

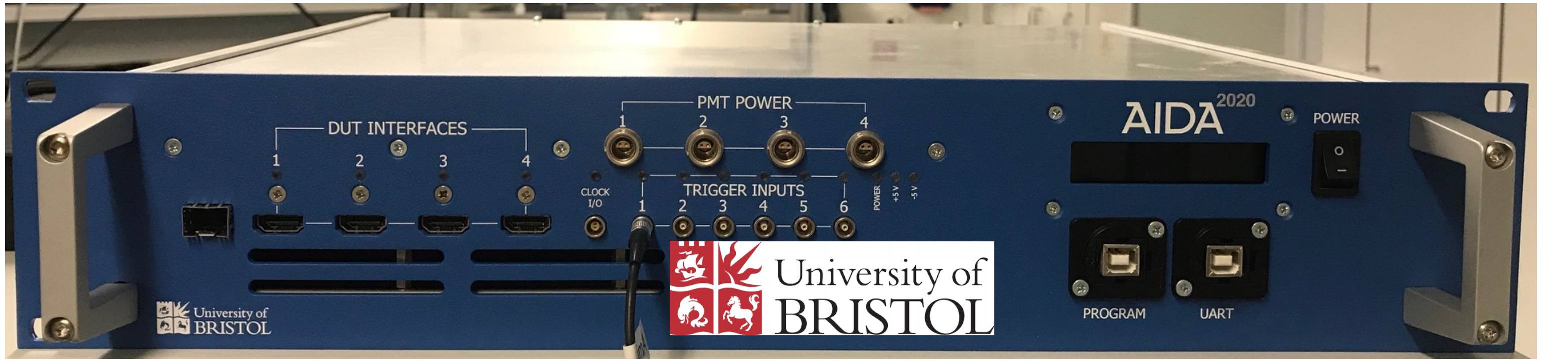


Fig.: AIDA TLU

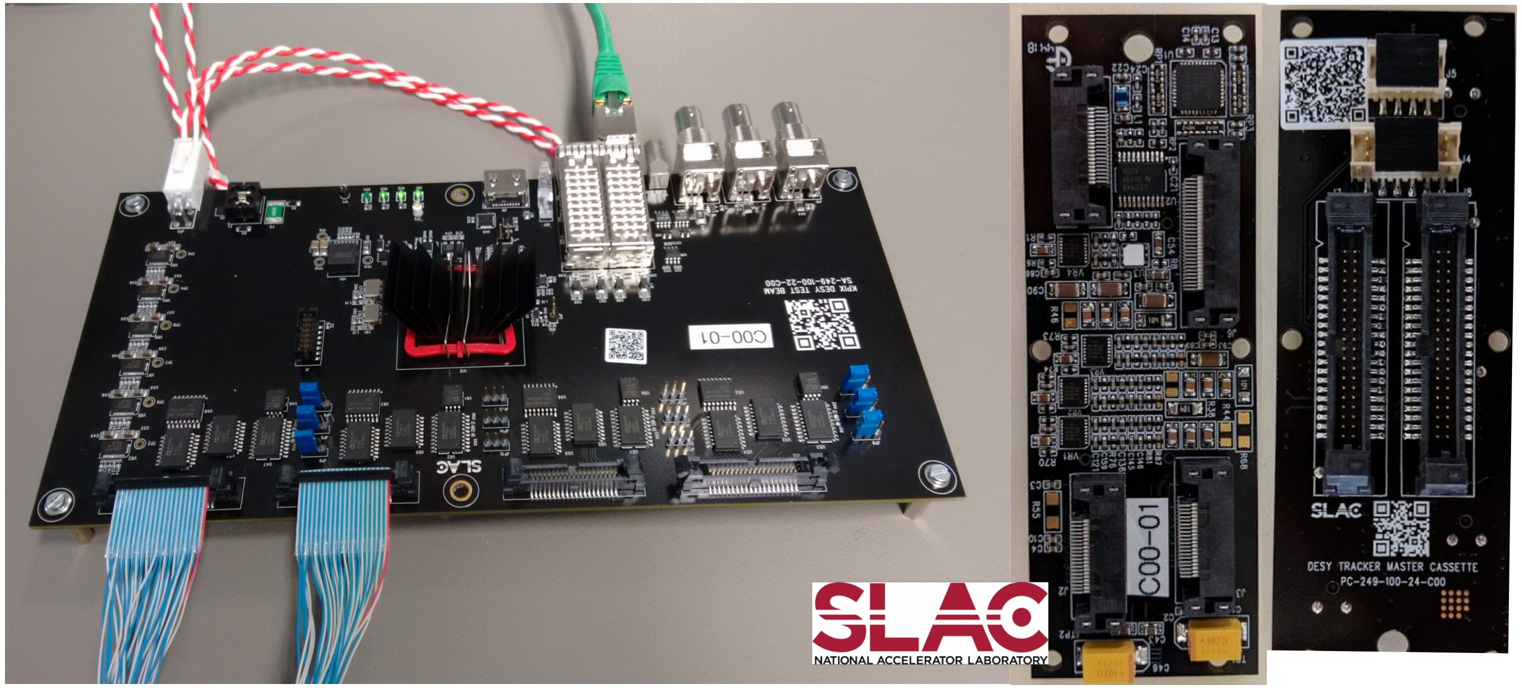


Fig.: New DAQ board with front and backside of cassette board.

System Status: Sensors

- Multiple sensor modules assembled:
  - Shown the functionality of overall principle.
  - Sensor depletes through wire bonds and shows sensitivity to light and radioactive sources.
  - Functionality of sensors confirmed through calibration, pedestal data taking as well as multiple test beam campaigns.

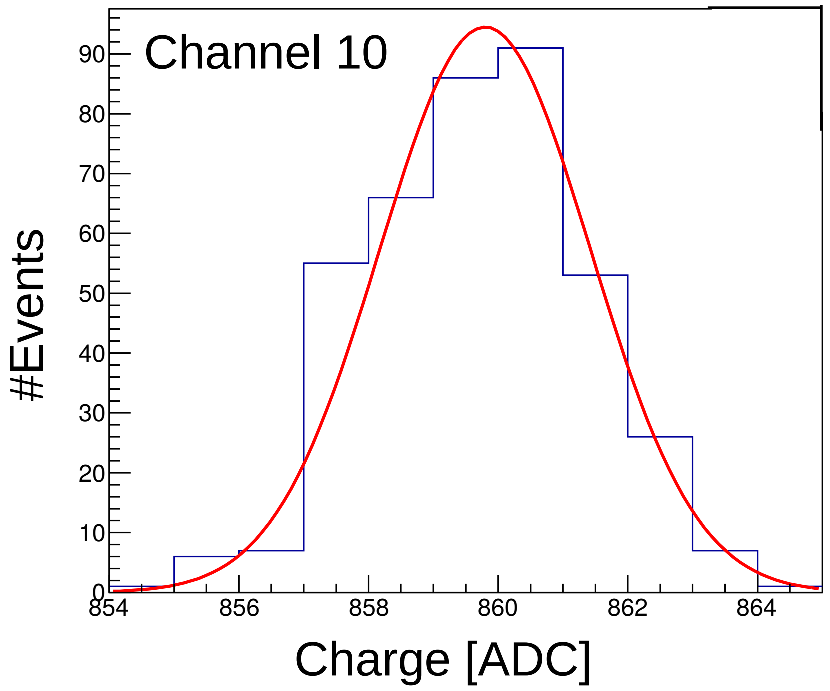


Fig.: Pedestal distribution of a single channel

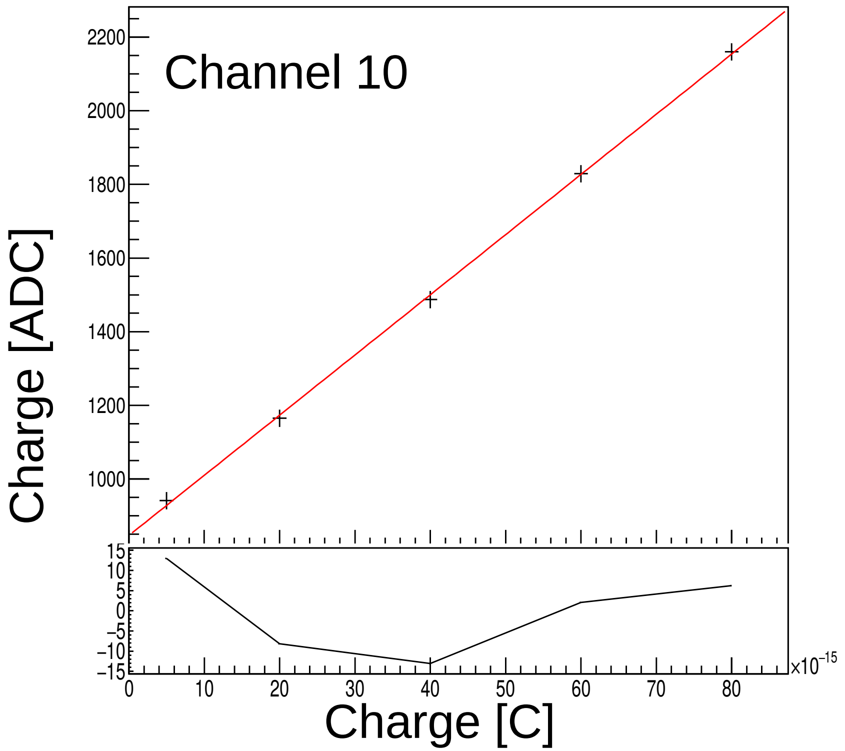


Fig.: ADC response to input charge during calibration

System Status: Sensors

Self triggering operation

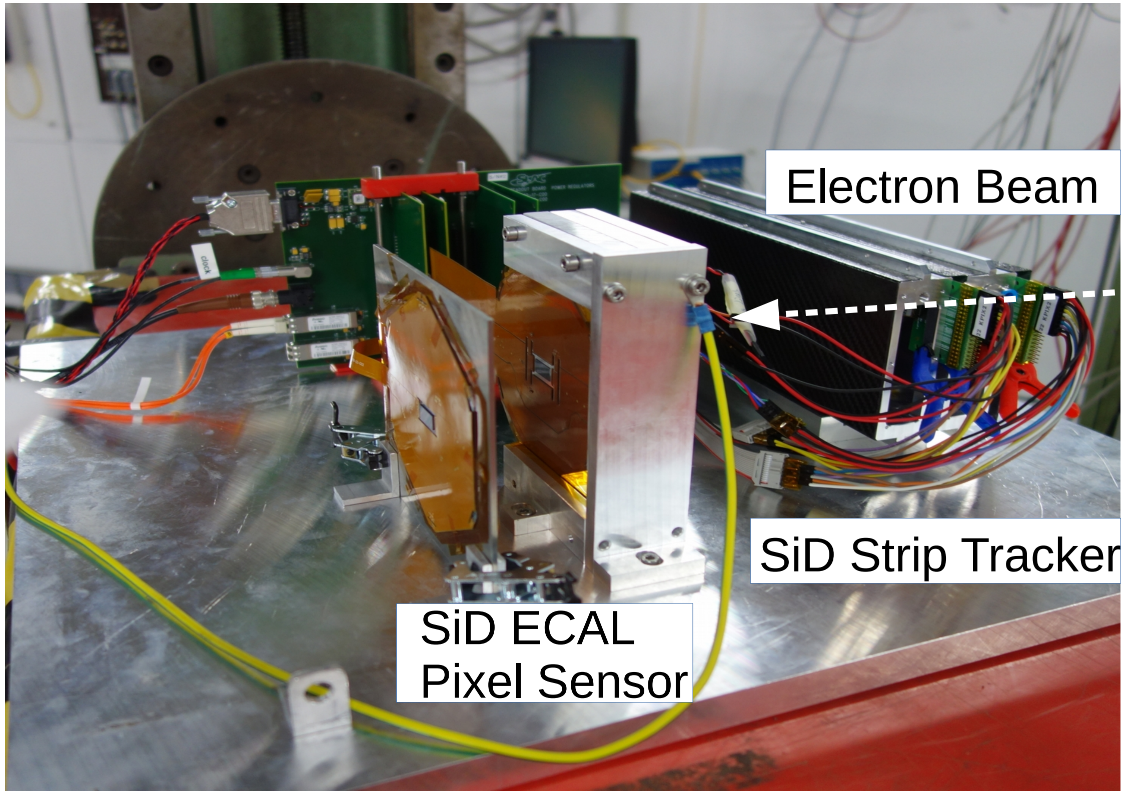
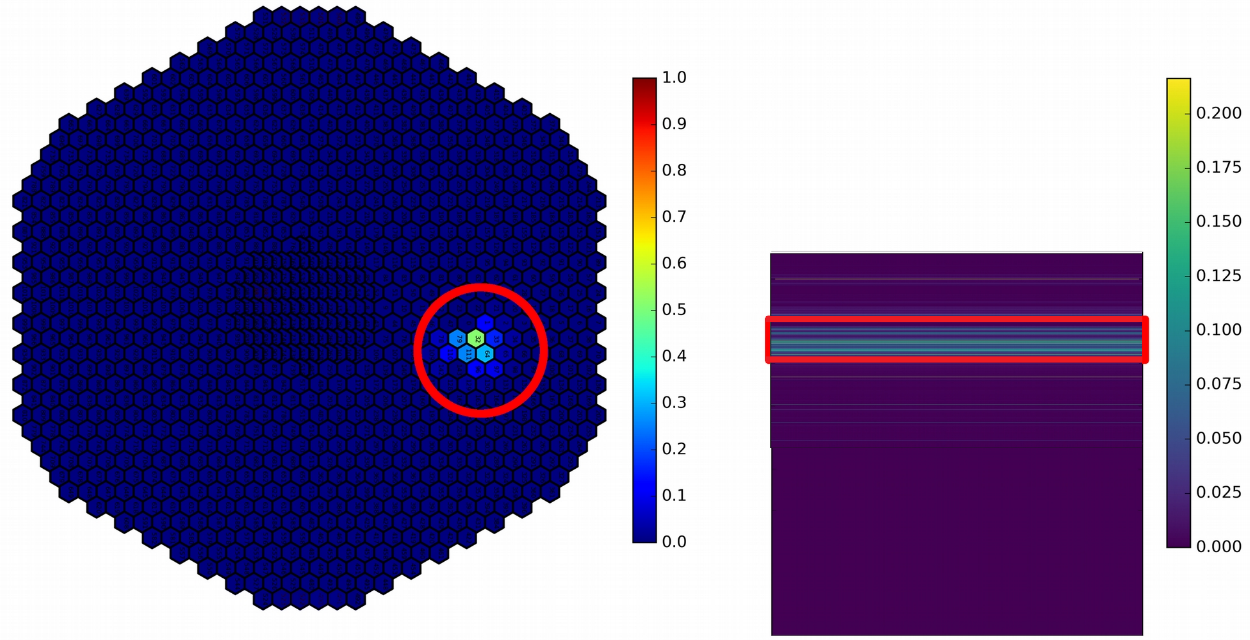


Fig.: Testbeam setup with the tracker in front and ECAL in the back.

- Just completed very successful testbeam campaign using multiple tracker and ECAL sensors.
- Recorded ~ 600.000 beam spills, split between different running modes, positions, angles, bias voltages etc.



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

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

System Status: Sensors

External triggering operation

- Final running operation with many DUT is going to be in external triggering
  - Current system noise is ~0.19 fC*
  - ~3 fC expected signal charge in 320 micron silicon
    - → **S/N = ~15***

*Preliminary as this was measured with the old electronics

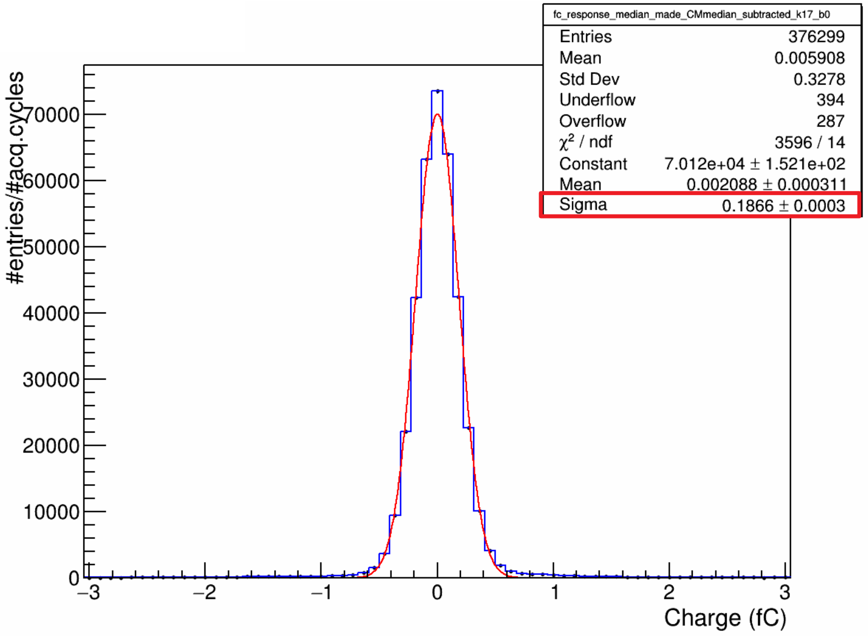


Fig.: Pedestal distribution for Tracker sensor

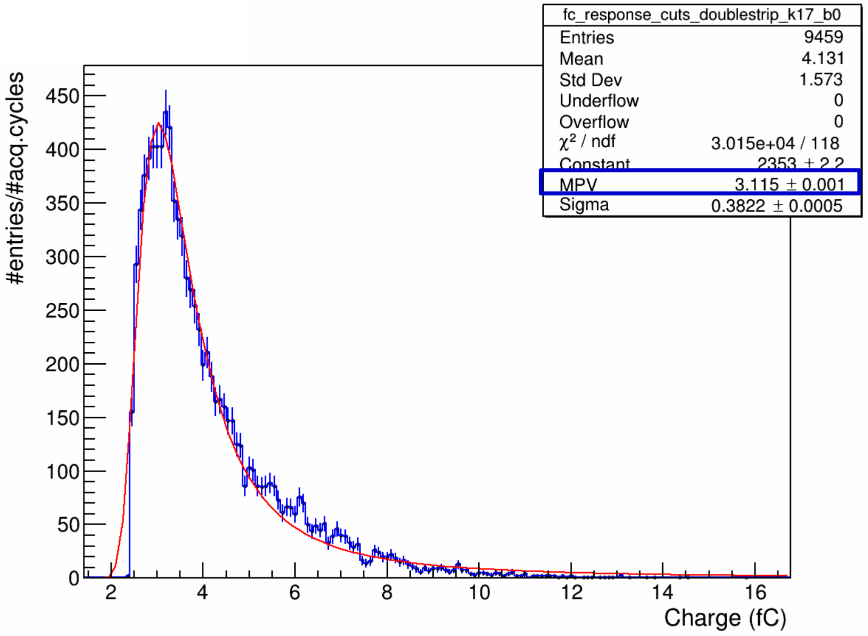
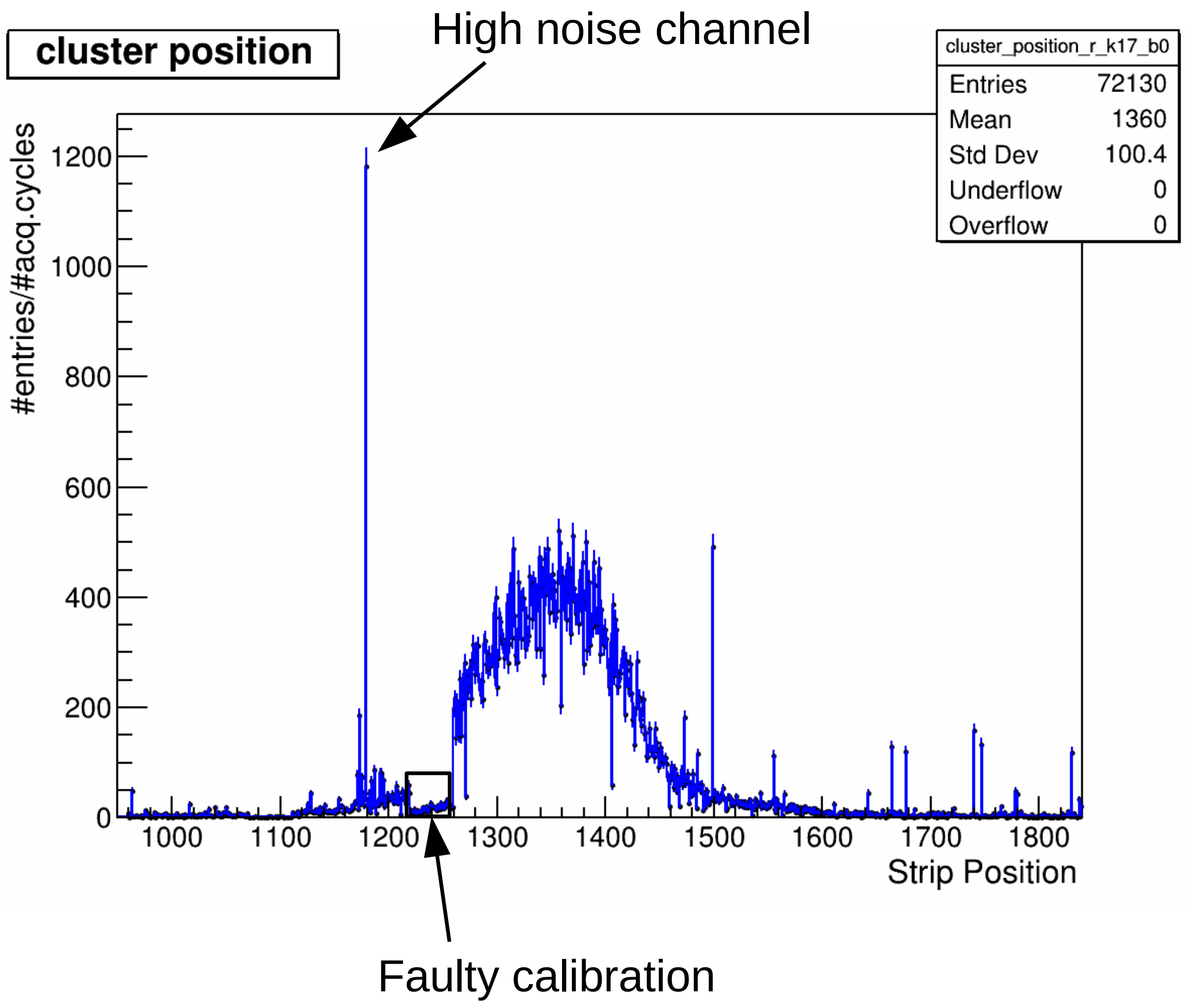


Fig.: Charge distribution of hit candidates.

System Status: Reconstruction

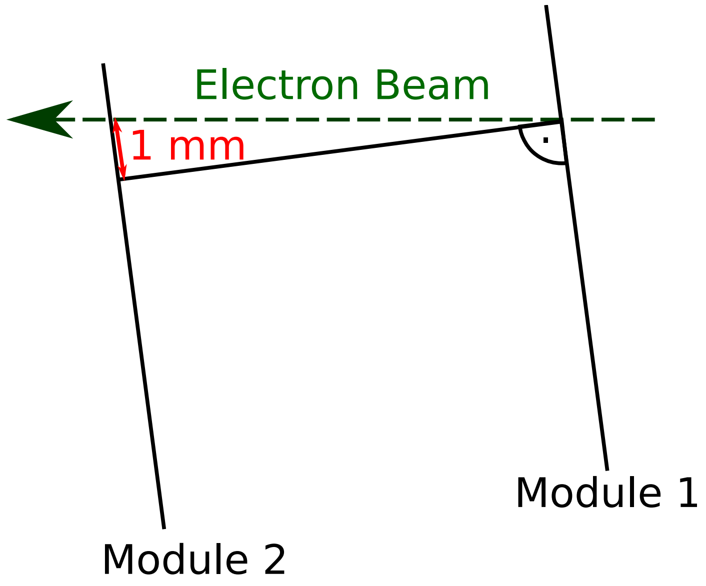
External triggering operation

- Very early steps into cluster reconstruction shows promising results but:
  - Current clustering is very sensitive to single high charge channels
    → Need to mask noisy channels
  - As a result of floating strips there are two cases, one of which the current clustering does not take into account correctly:
    - ✔ Case 1: Readout strip hit = high amounts of charge in a single strip
      → Ideal starting candidate for clustering
    - ✗ Case 2: Floating strip hit = 40% of charge gets transferred to adjacent strips
      → No single strip with very high charge

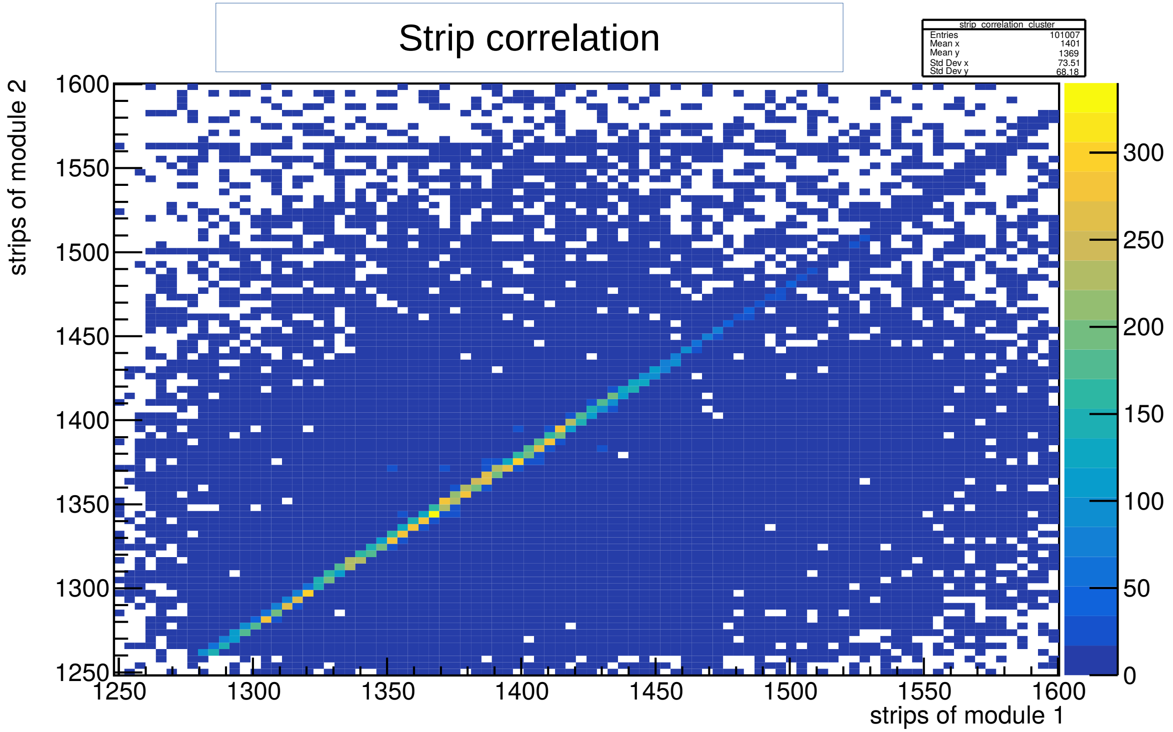


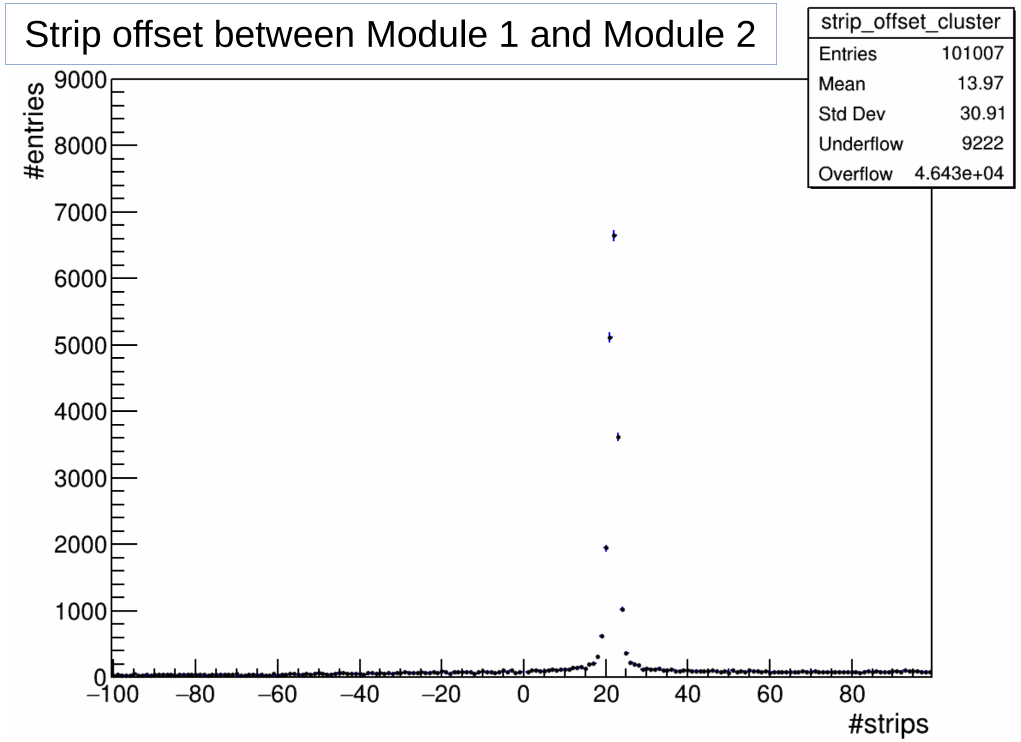
System Status: Reconstruction

External triggering operation



- Clearly visible strip correlation between two modules.
- Offset between Module 1 and Module 2 of roughly 20 strips = 1 mm.
  - Agreement with tilt of modules to the electron beam as a result of stage tilt.





Summary and Outlook

- New telescope based on hybrid-less silicon sensors is nearing completion.
- Works well to complement the current EUDET-type telescopes in operational features.
- The components of the new telescope system are all in place.
- Assembled the first telescope modules.
  - Successful communication with and calibration of both chips.
  - Completed multiple tests of the sensor in the laboratory and at the DESY II Test Beam Facility.
  - Shown capability of track finding with multiple tracker sensors.

- Next steps towards system completion:
  - Test campaign with full 6 sensor layers.
  - Use newly arrived electronics.
  - Further development of reconstruction and analysis software.
  - Write Documentation.

- Testbeam of LYCORIS within T24/1 solenoid with EUDET telescope as reference, scheduled for **04/2019.**

Thank you for your attention

Fig.: Datura

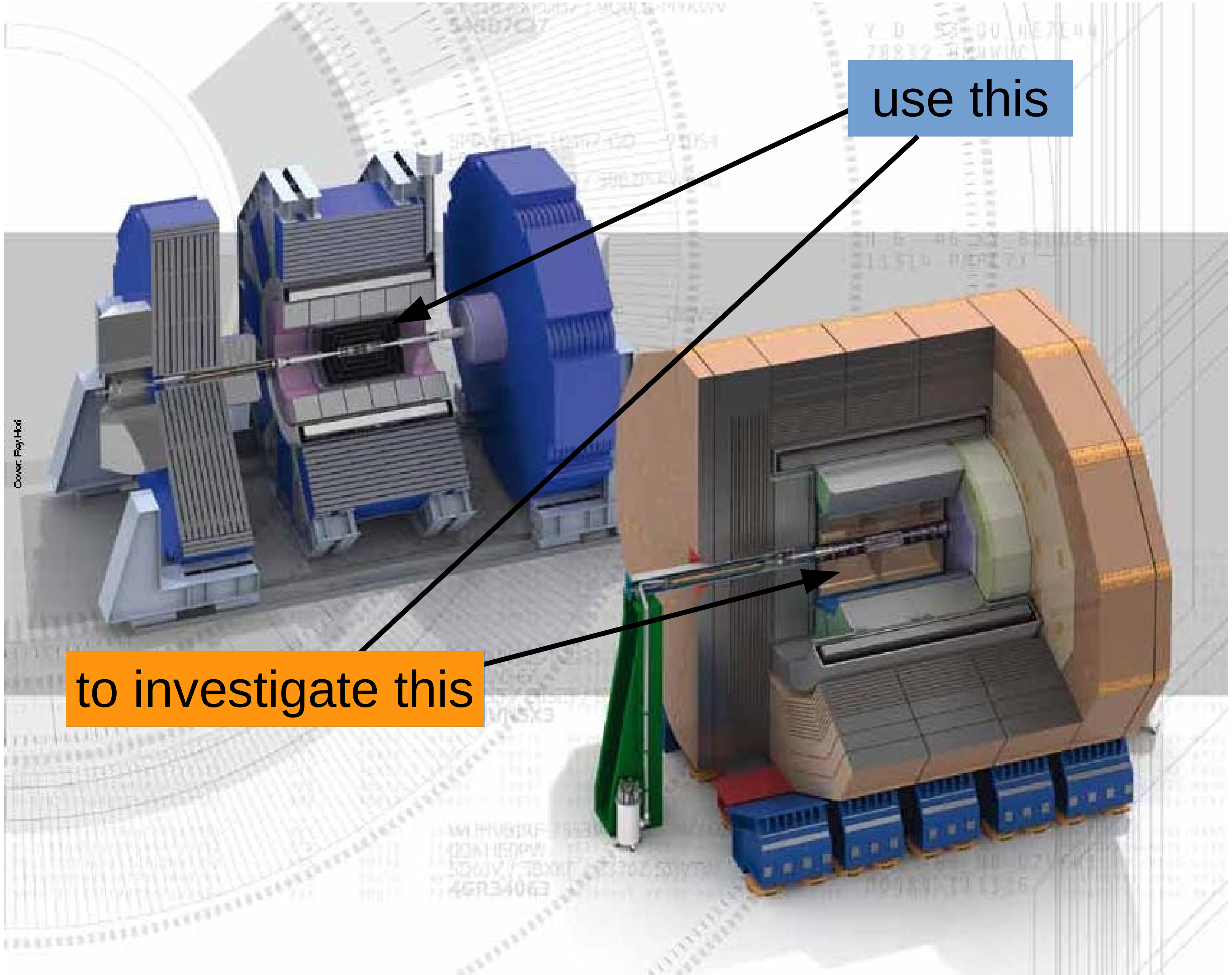
Fig.: Duranta

Fig.: Azalea

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

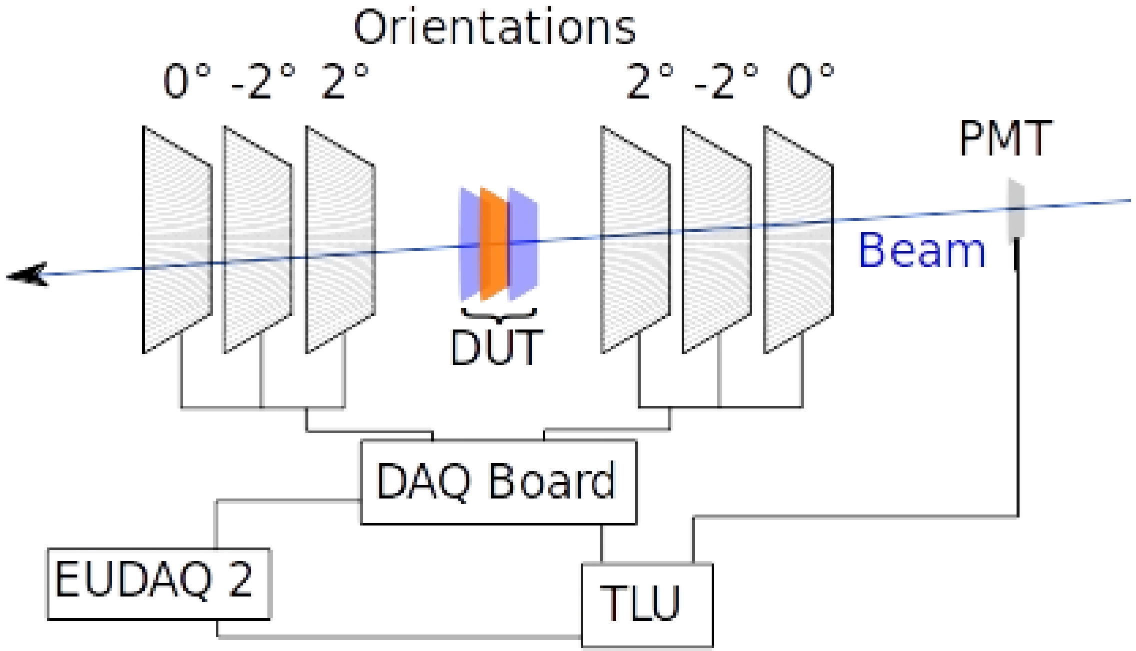


Fig.: External strip tracker sketch

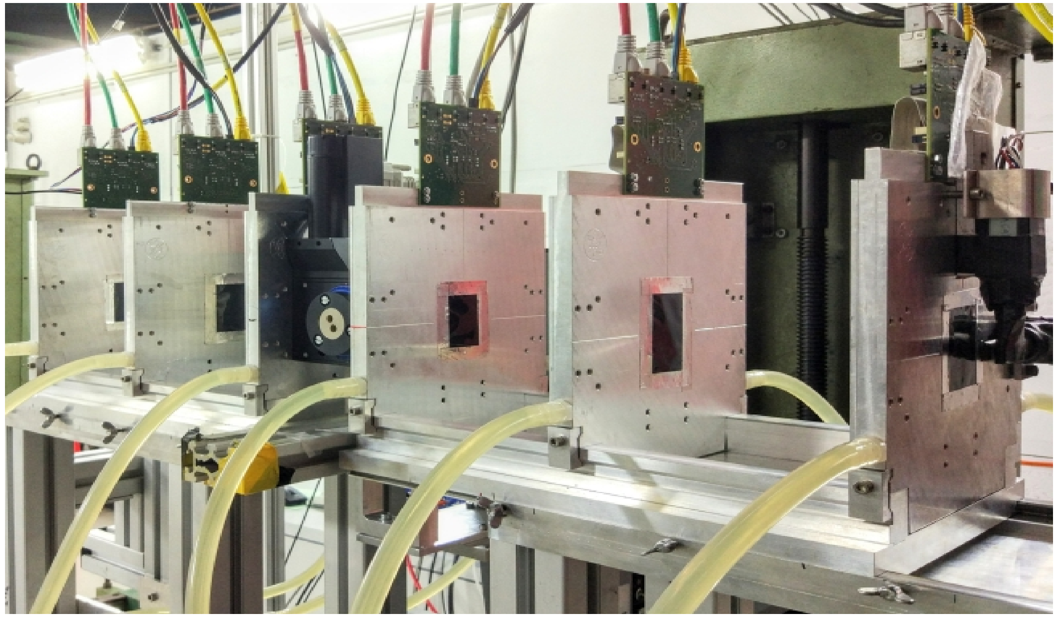


Fig.: EUDET Type Telescopes at DESY II Test Beam Facility

Case for an External Reference Tracker

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

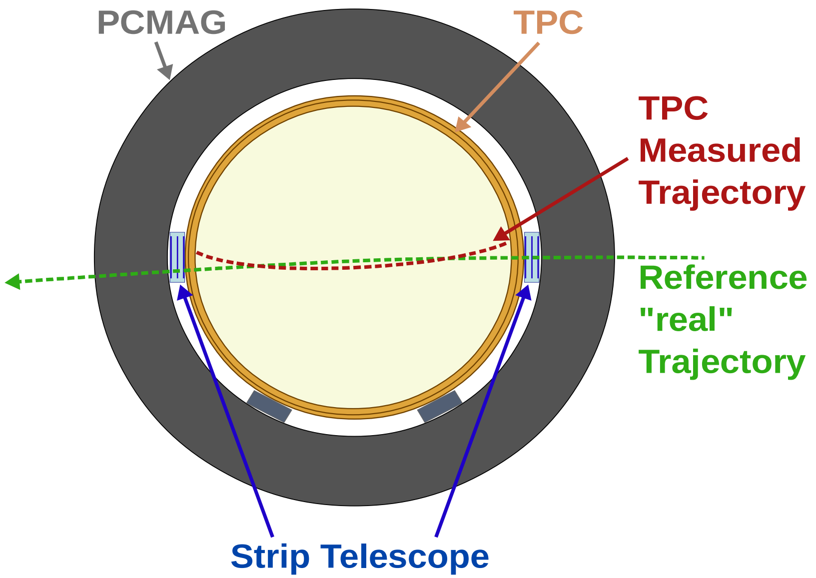


Fig.: Sketch explanation for the need of a reference trajectory

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

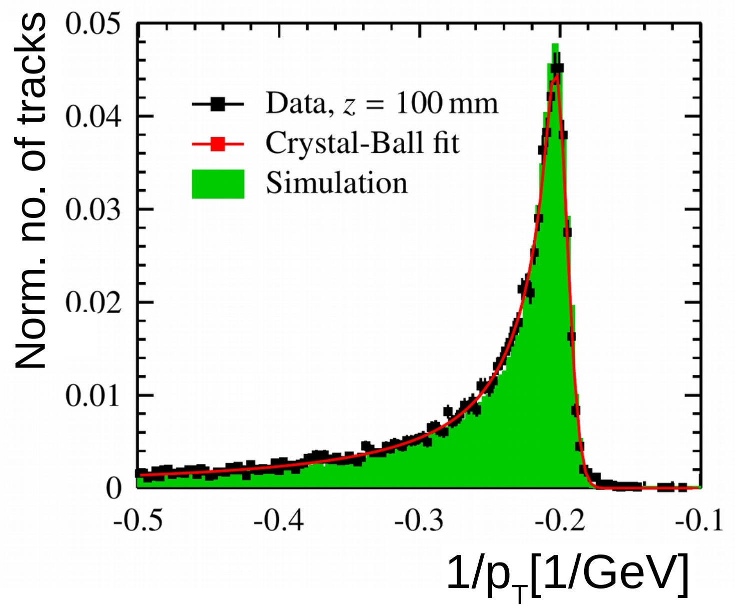


Fig.: Momentum distribution after interaction with the PCMAG wall (Felix Müller | DOI: 10.3204/PUBDB-2016-02659)

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

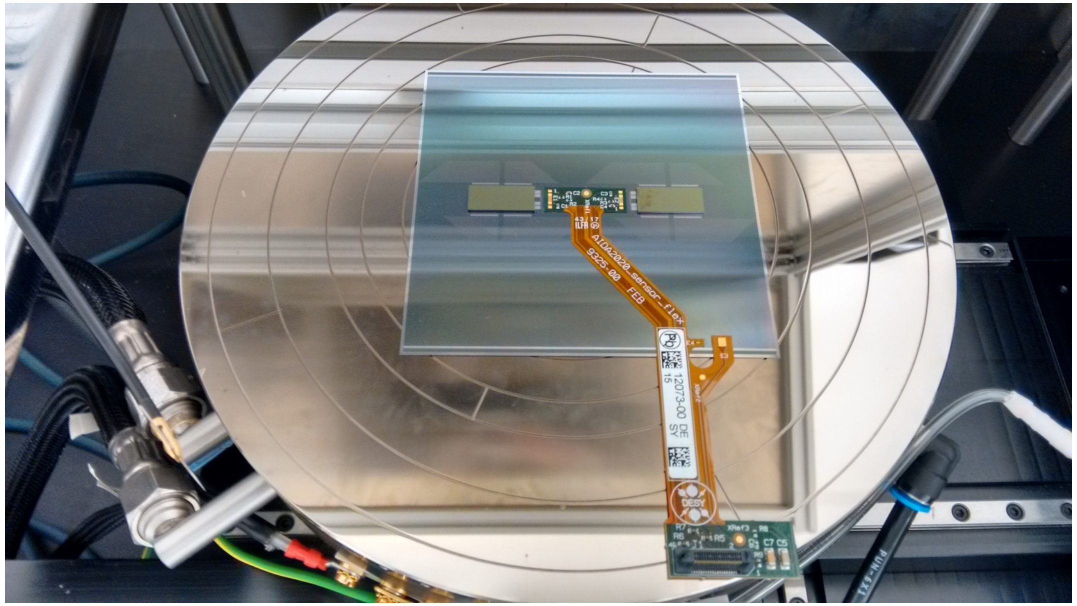


Fig.: Bump Bonded Sensor with flex cable on the probe station

60V operational voltage

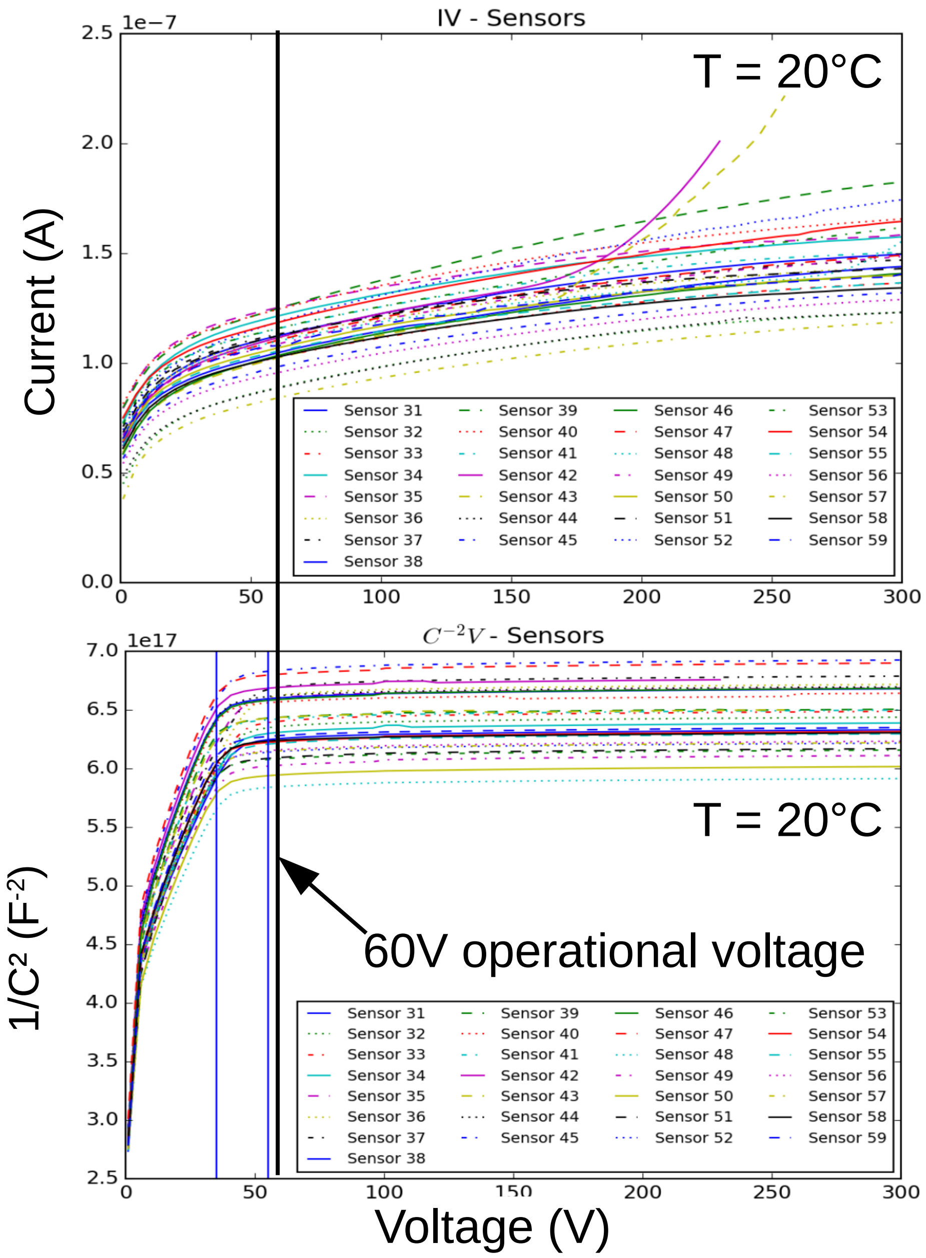


Fig.: IV (top) and CV (bottom) of the sensors

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

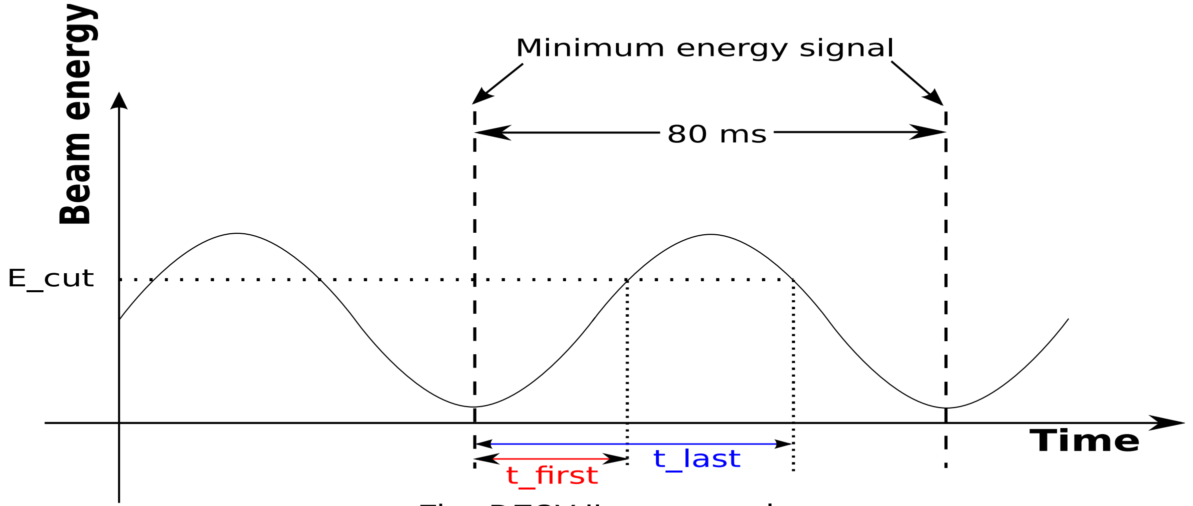


Fig.: DESY II energy cycle

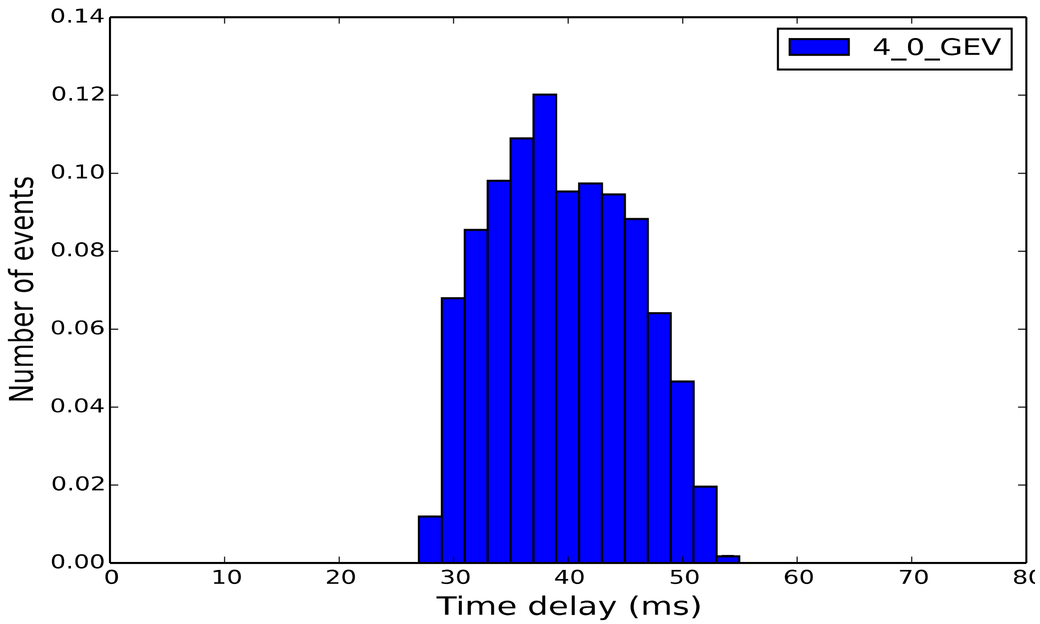


Fig.: Time difference from min. energy to trigger signal

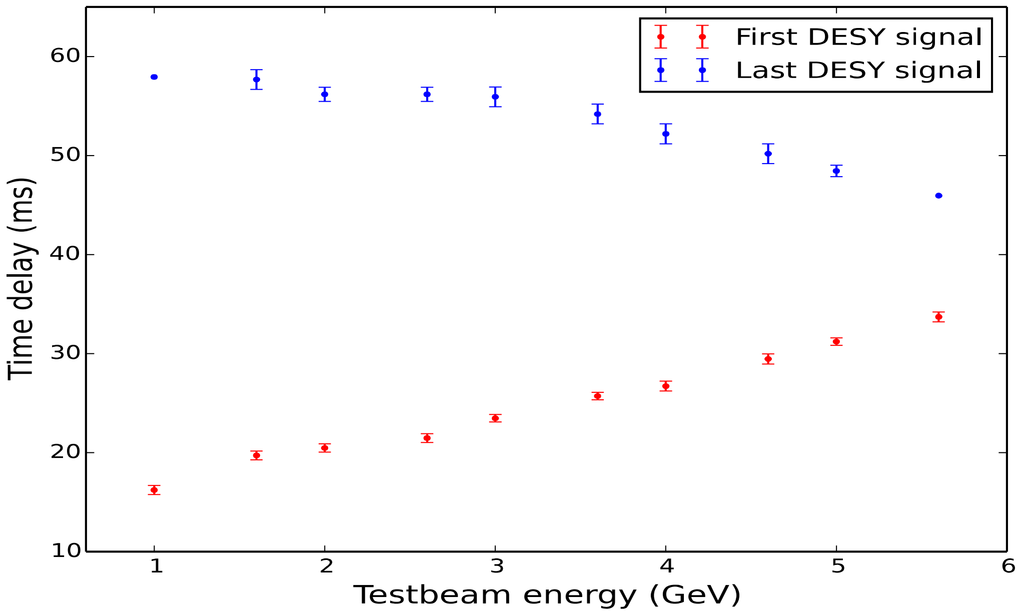


Fig.: First and last DESY signal in a cycle for different energies

System Status: Sensors

Self triggering operation

Without Pedestal Subtraction

SiD ECAL Pixel Sensor

Preliminary

Electron Beam

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

- Recently completed first Testbeam with multiple tracker sensors
- Recorded ~ 600.000 beam spills, split between different running modes, positions, angles, bias voltages...

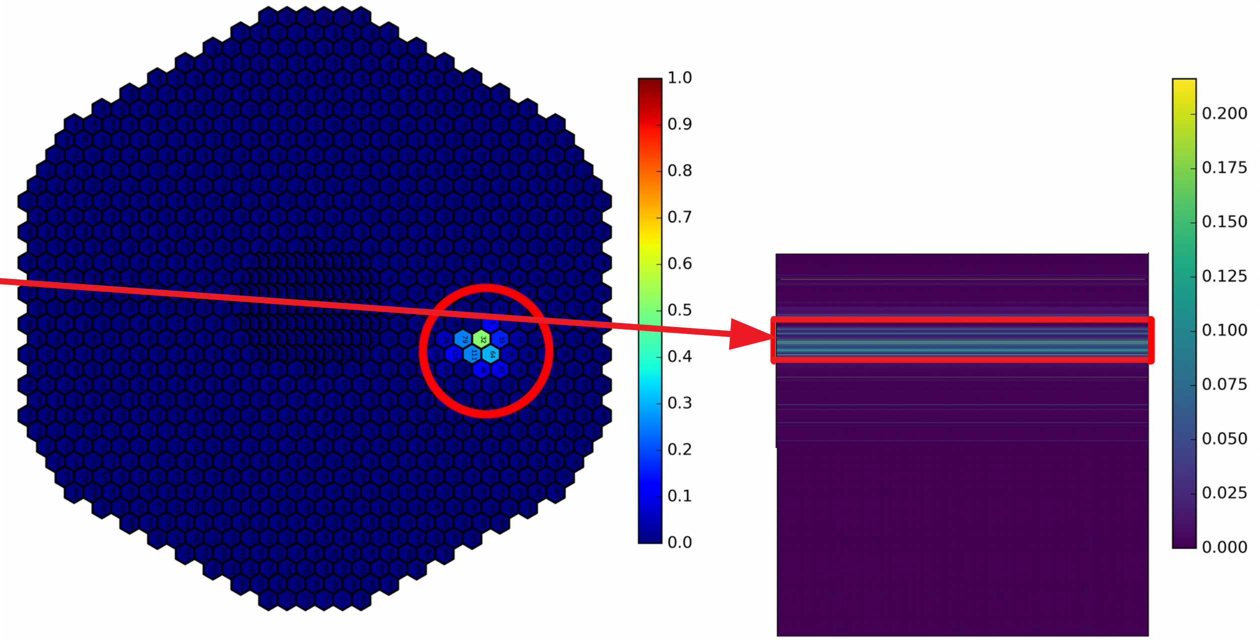


Fig.: Mapping of trigger hits to ECAL (left) and tracker (right)

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

System Status: Sensors

External triggering operation

- 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 candidate of 2 adjacent strips per trigger each with charge ~1.2 fC
  - ...

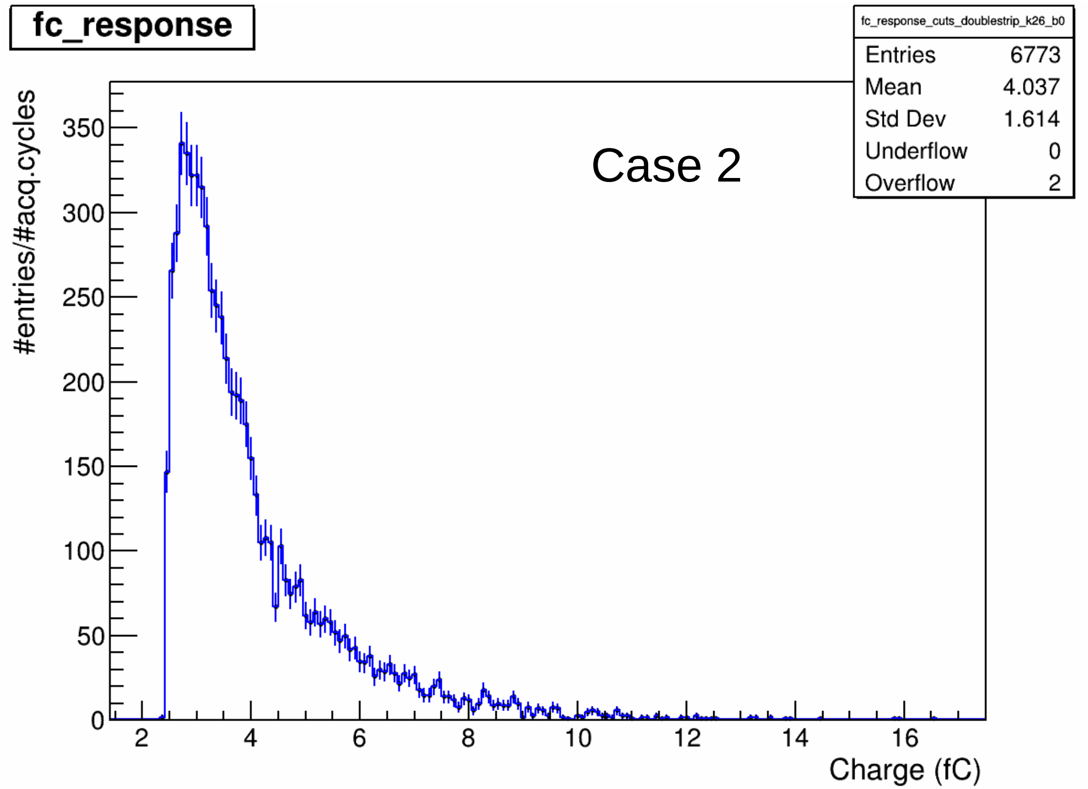


Fig.: Charge distribution after floating strip hit candidate filtering

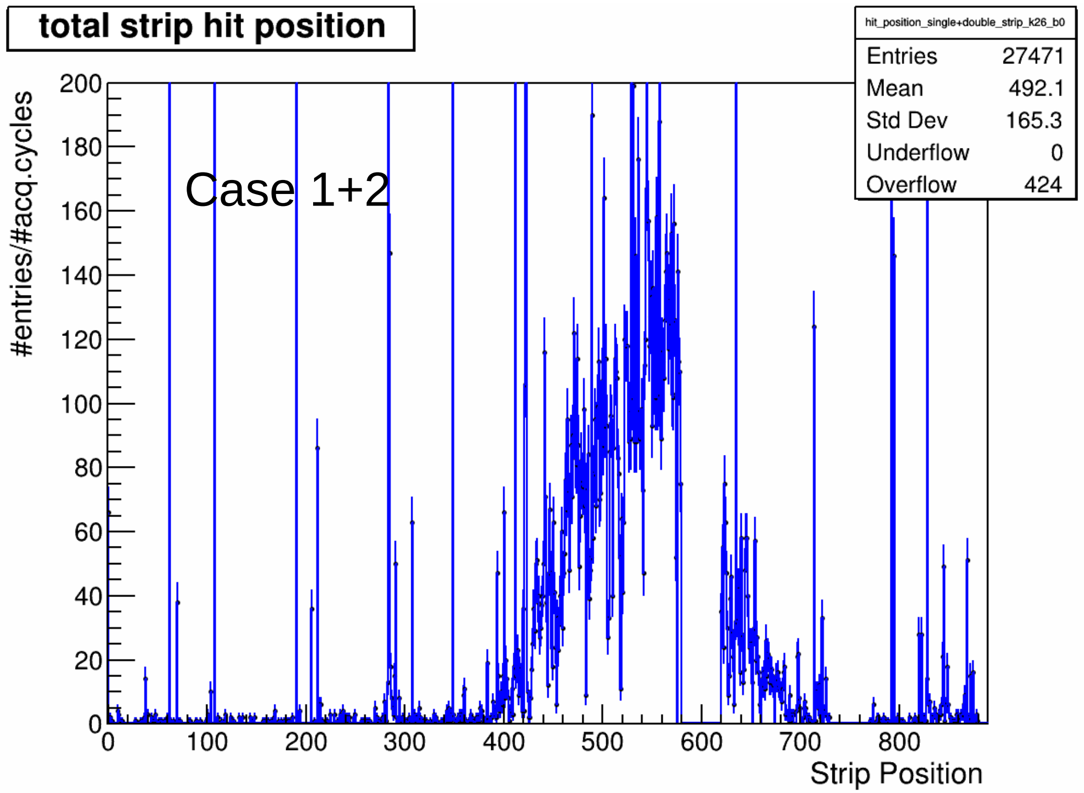


Fig.: Hit position after floating strip + single strip hit candidate filtering.

System Status: Sensors

External triggering operation

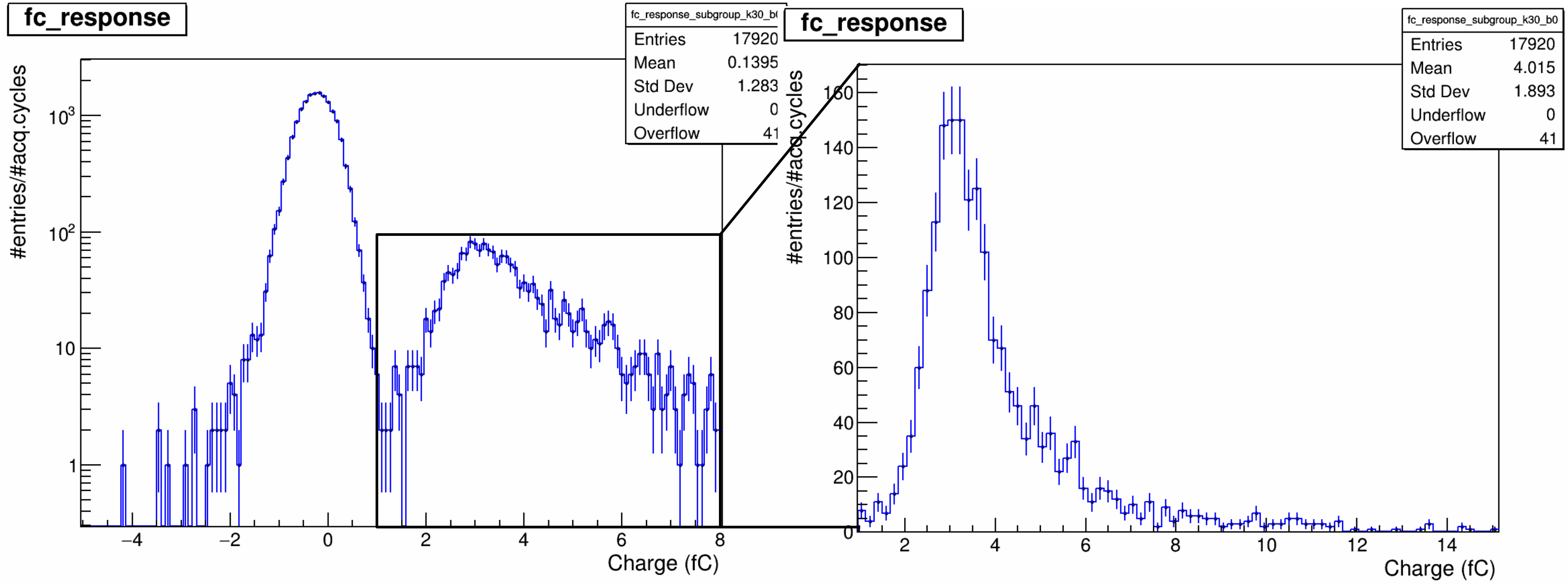
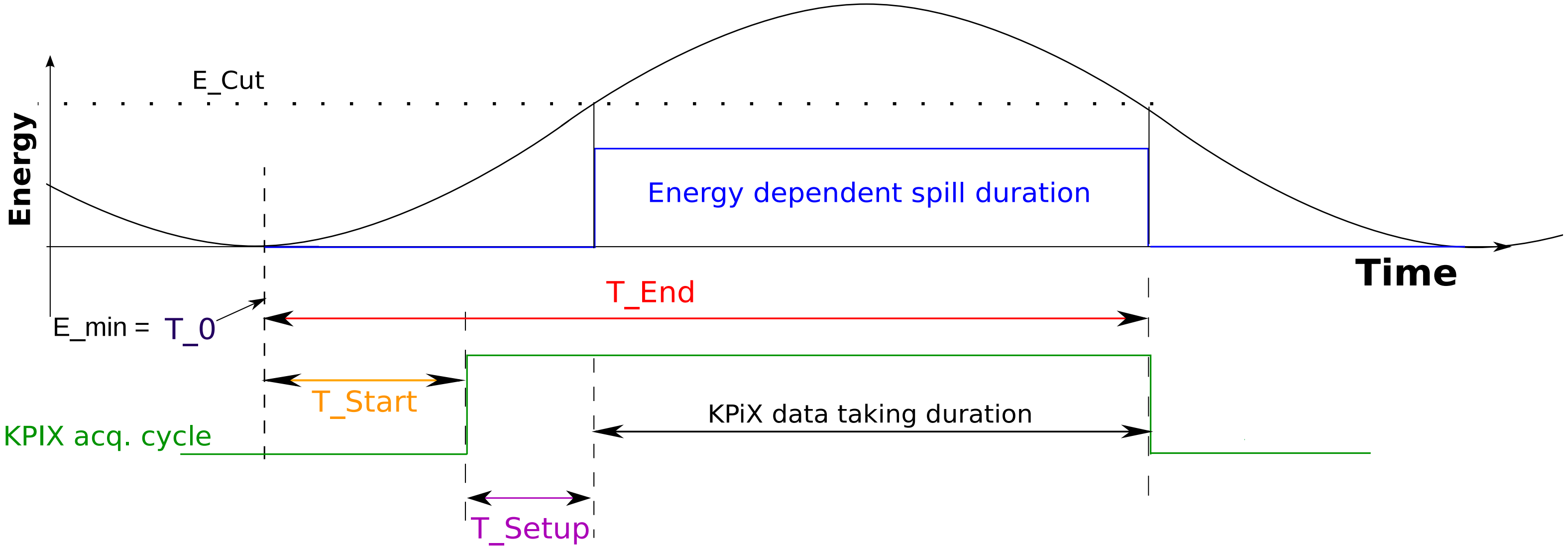


Fig.: Signal charge distribution for ECAL sensor with channel preselection

- Operation works quite well for the ECAL

KPiX synchronisation, DUT and Beam



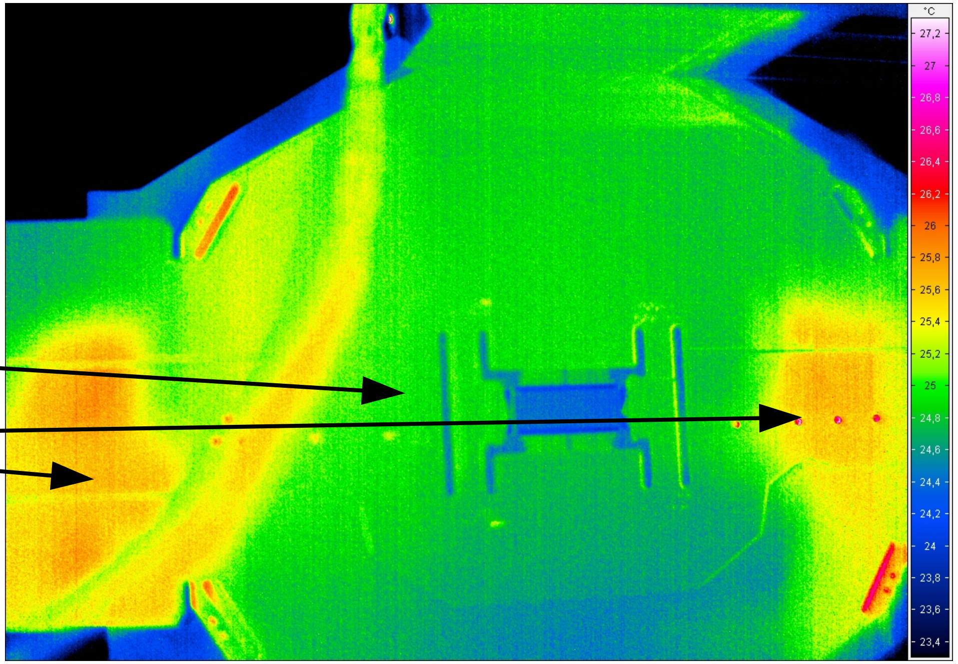
- KpiX needs to be synchronised to beam spill of the acceleerator and the DUT
  - T_0: Accelerator signal for synchronisation with beam spiull
  - T_Start: User adjustable delay between T_0 and KpiX switch on.
  - T_Setup: Setup time of KpiX. At the end of which KpiX can start the data taking
  - T_End: 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

KPiX Chip

Reflection of heat sources



- Overall power consumption and heat generation is negligible

  → No active cooling needed

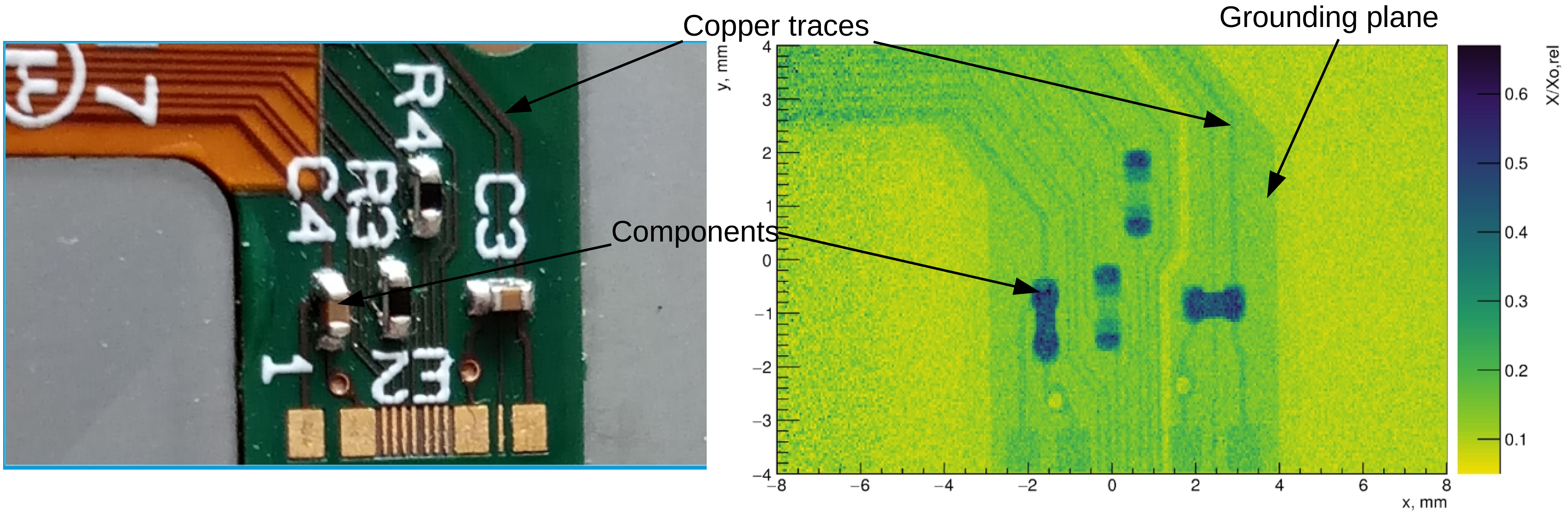
Radiation Length

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

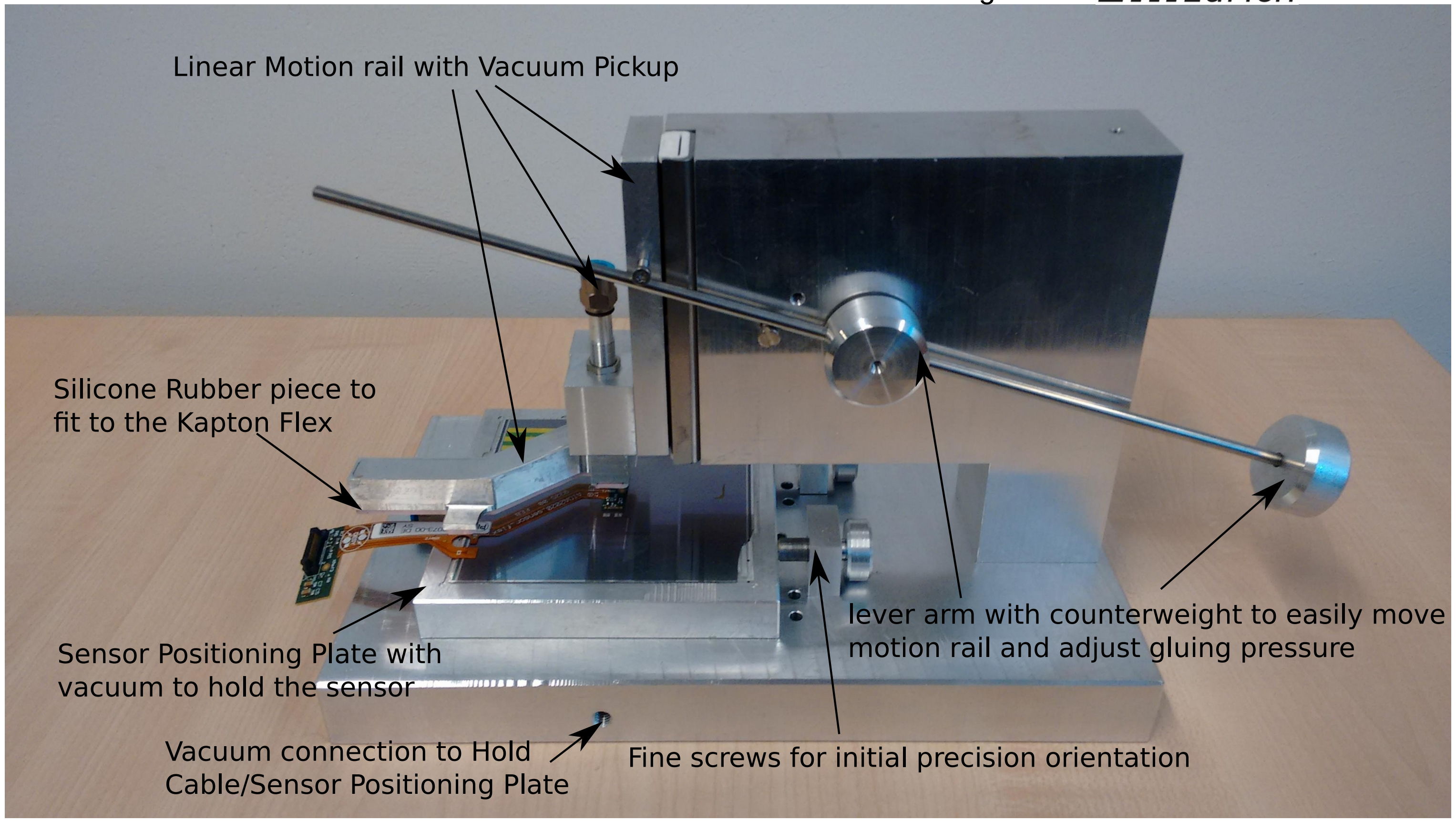
Radiation Length



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

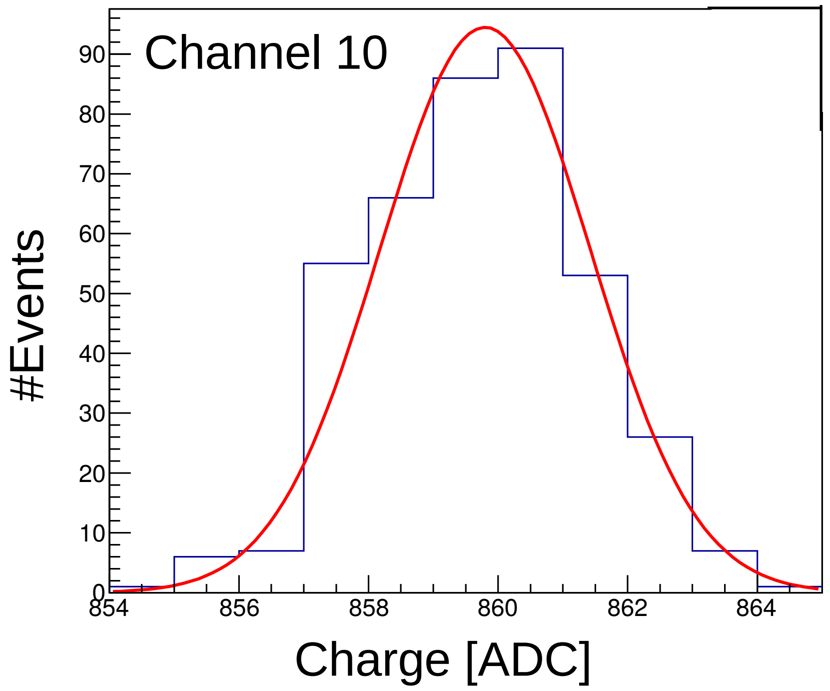
Based on a design from ETH zürich

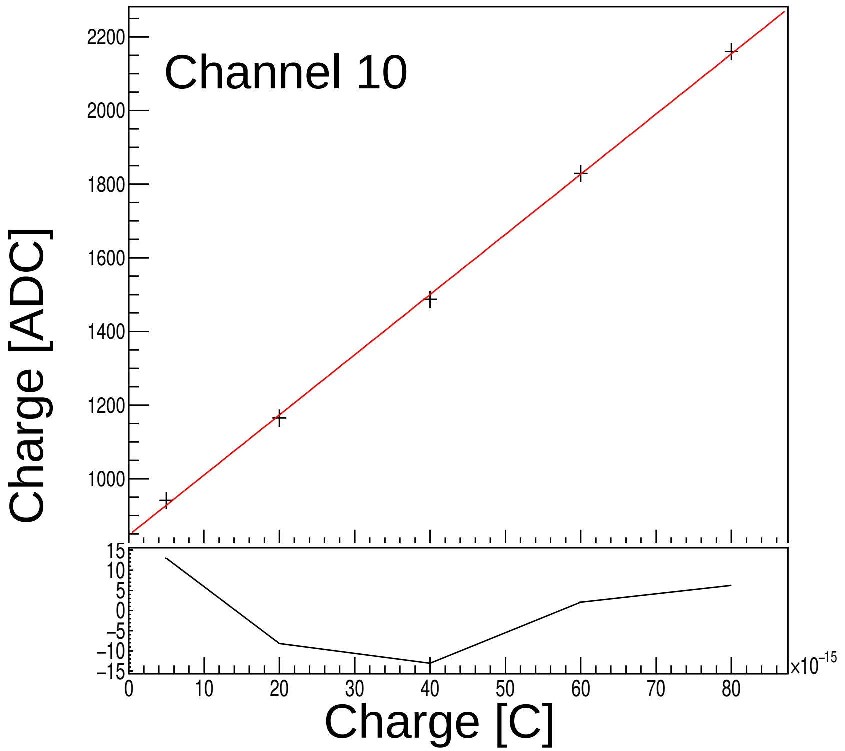


First assembly with new tool expected to start next week.

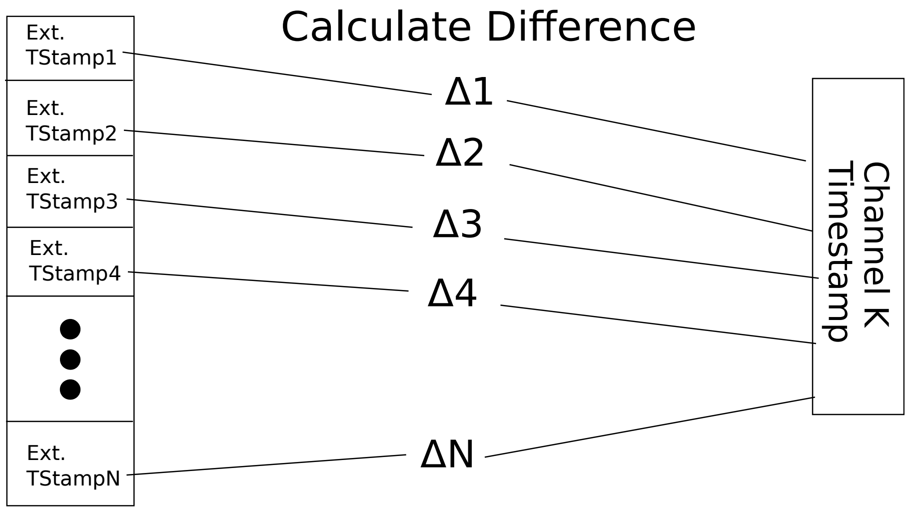
System Status: Sensors

- 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**

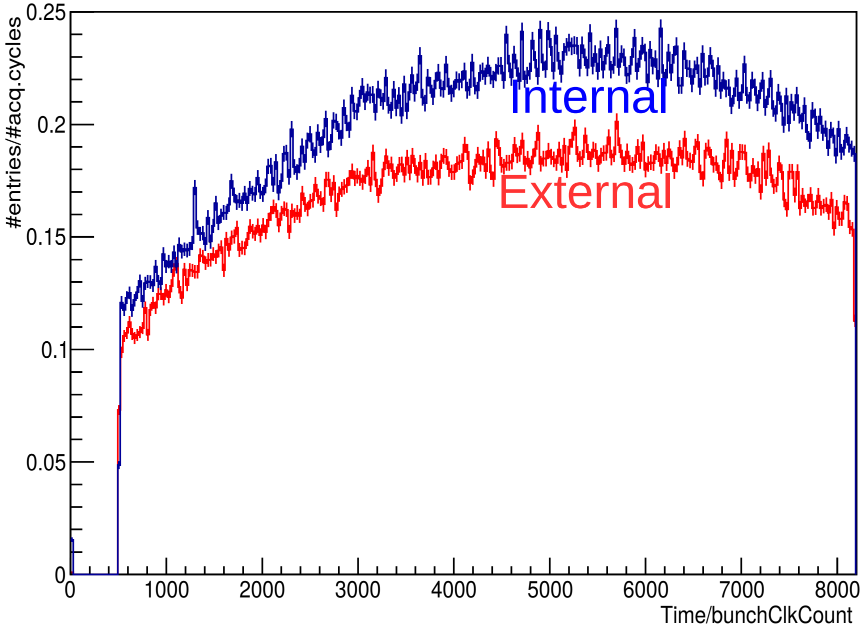


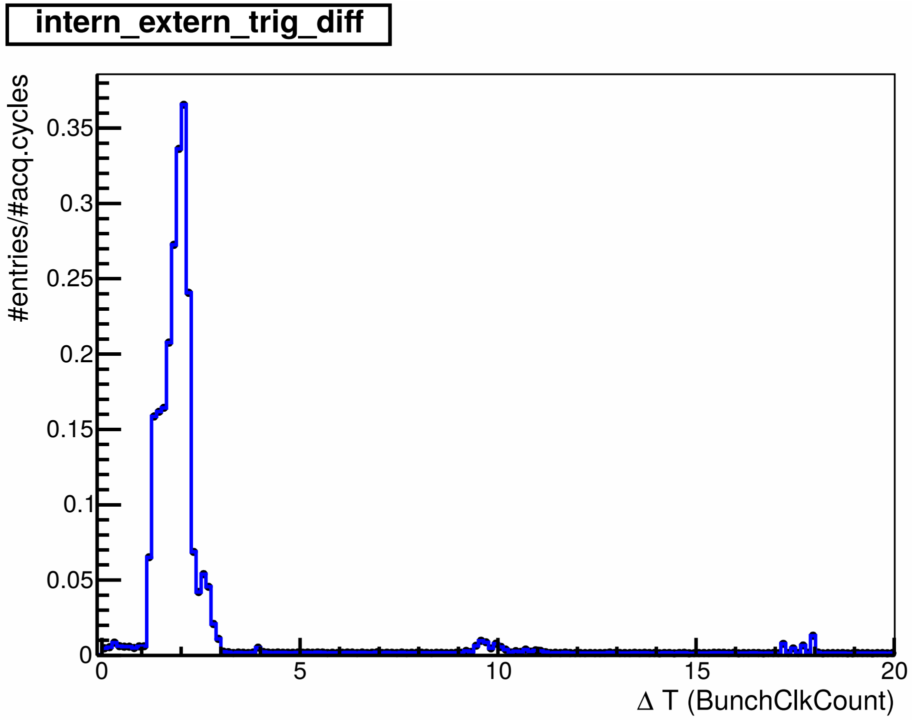


Time Coincidence



Δ4 < Δ3 < Δ2 < Δ1 < …. < ΔN
=> Δ4 = 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

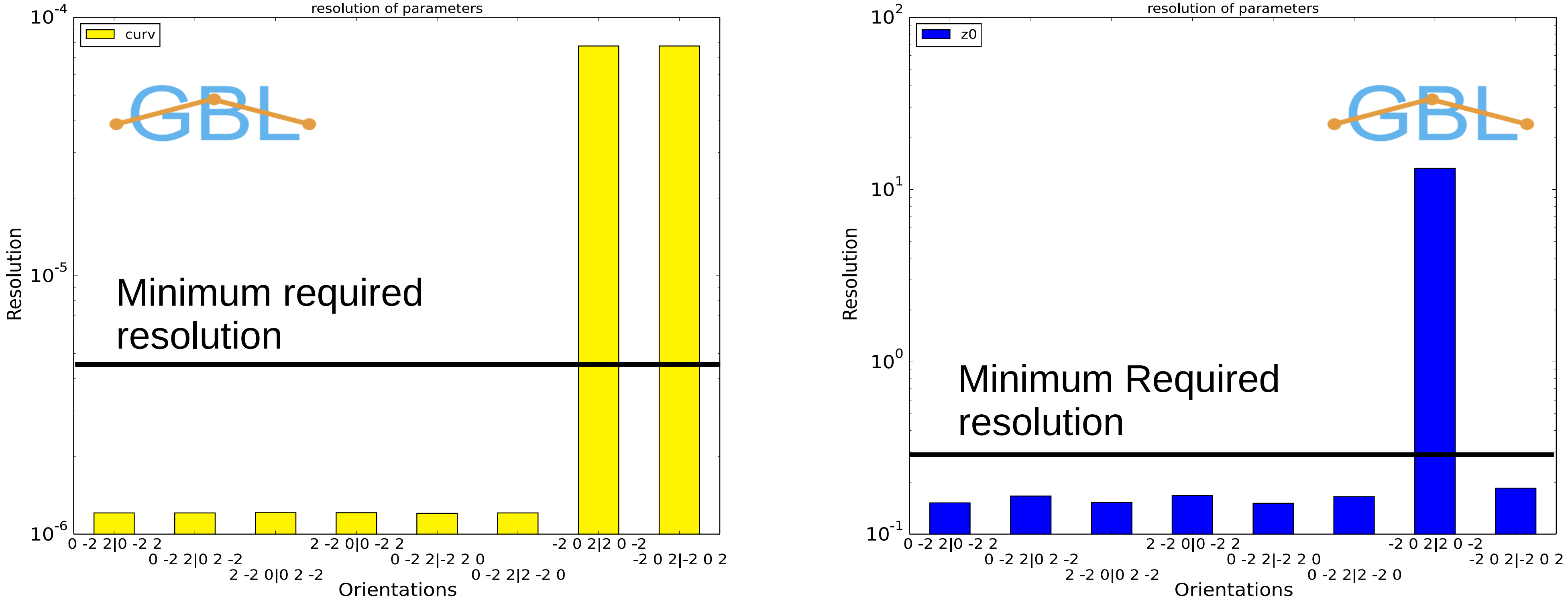
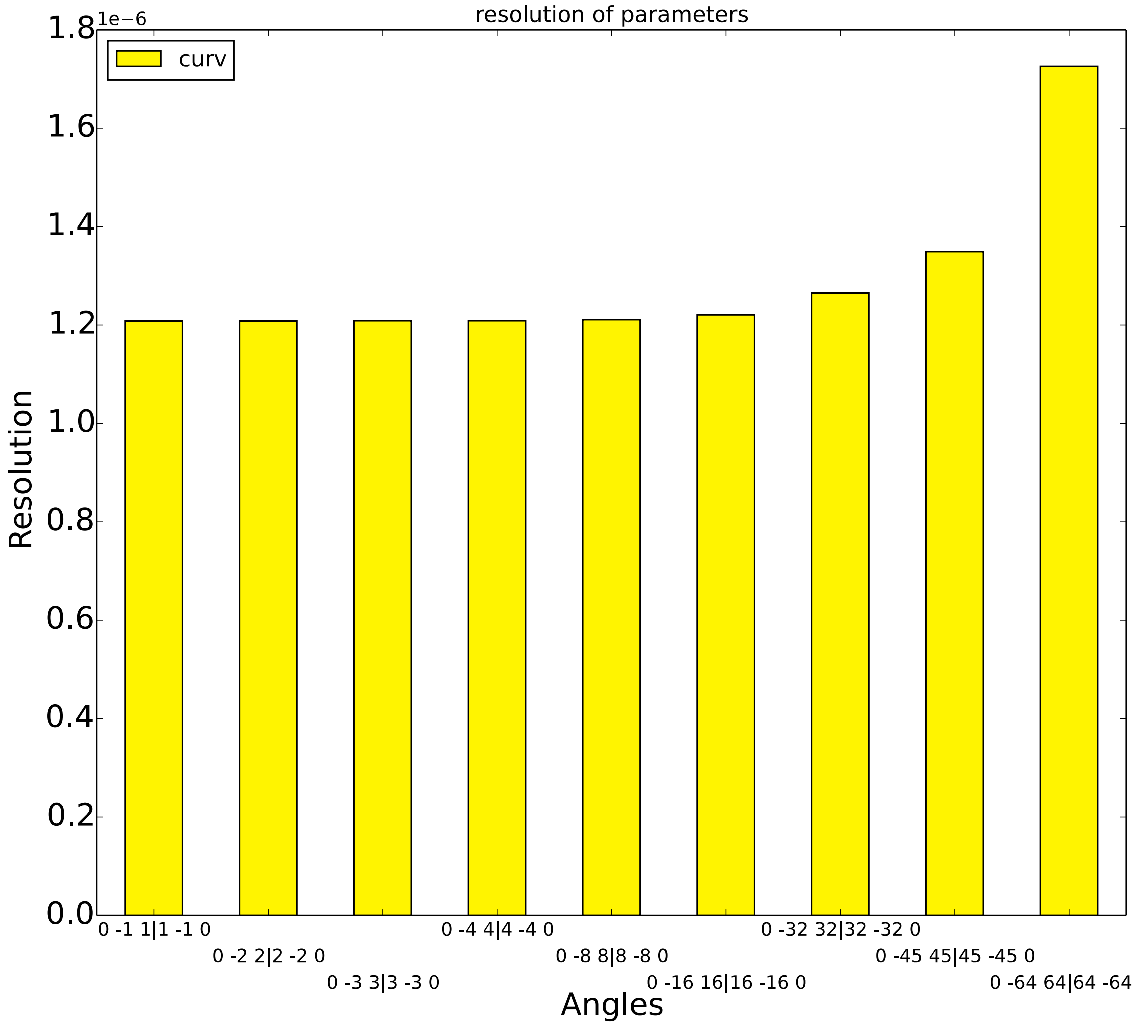
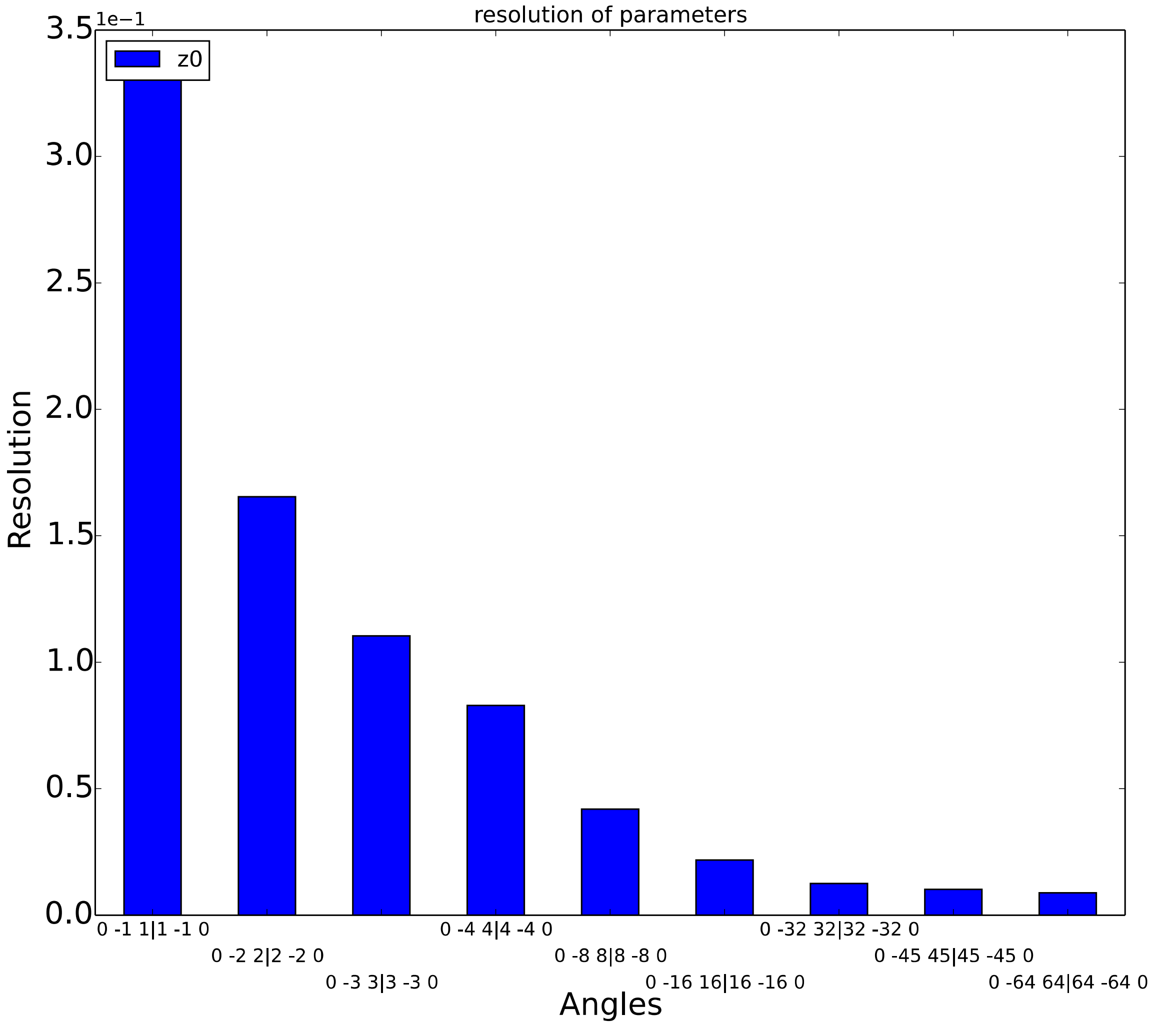


Fig.: Achievable curvature and z resolution of the telescope, with multiple scattering, depending on angular orientation

Stereo angle variation





Parameter correlation