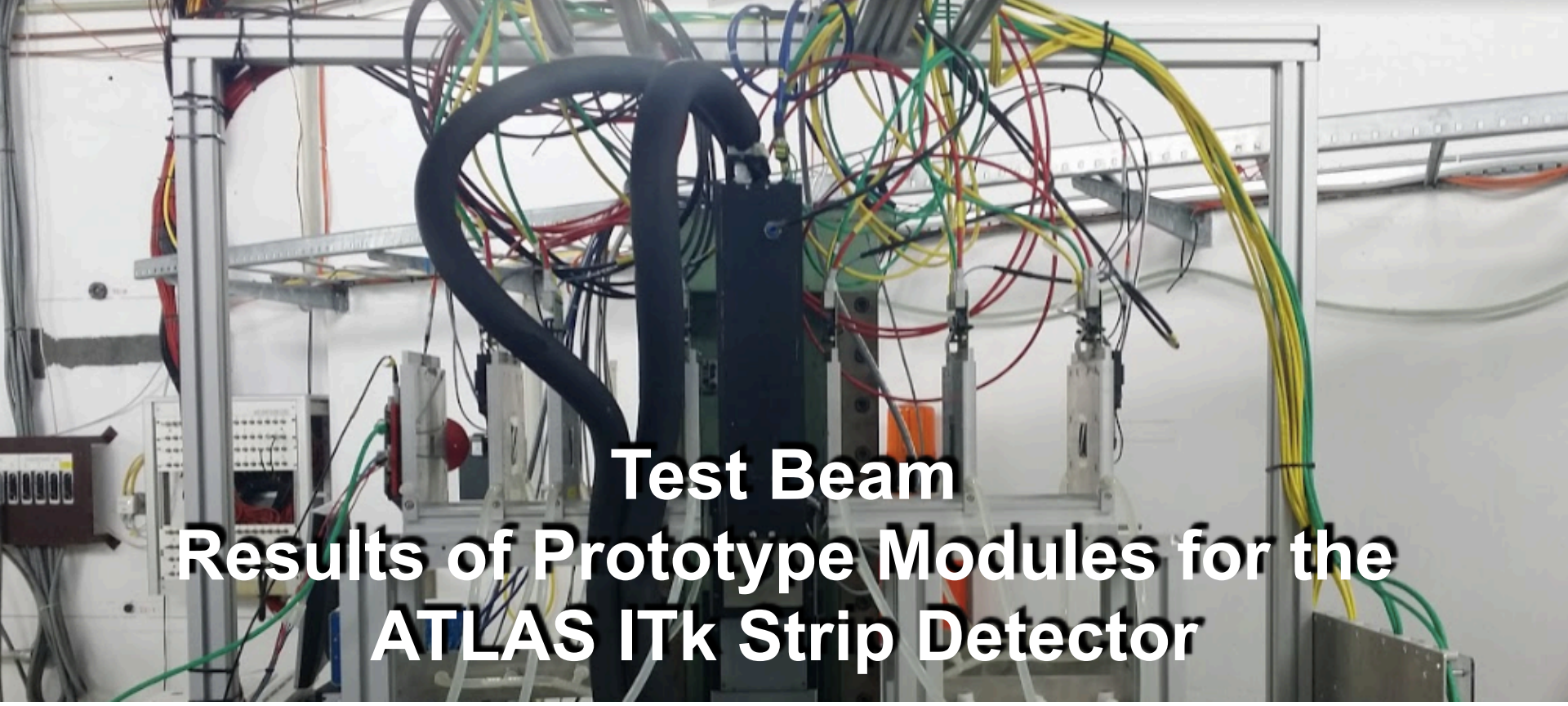


Test Beam
Results of Prototype Modules for the ATLAS ITk Strip Detector

Frederik Rühr, on behalf of the ATLAS ITk Strip Collaboration

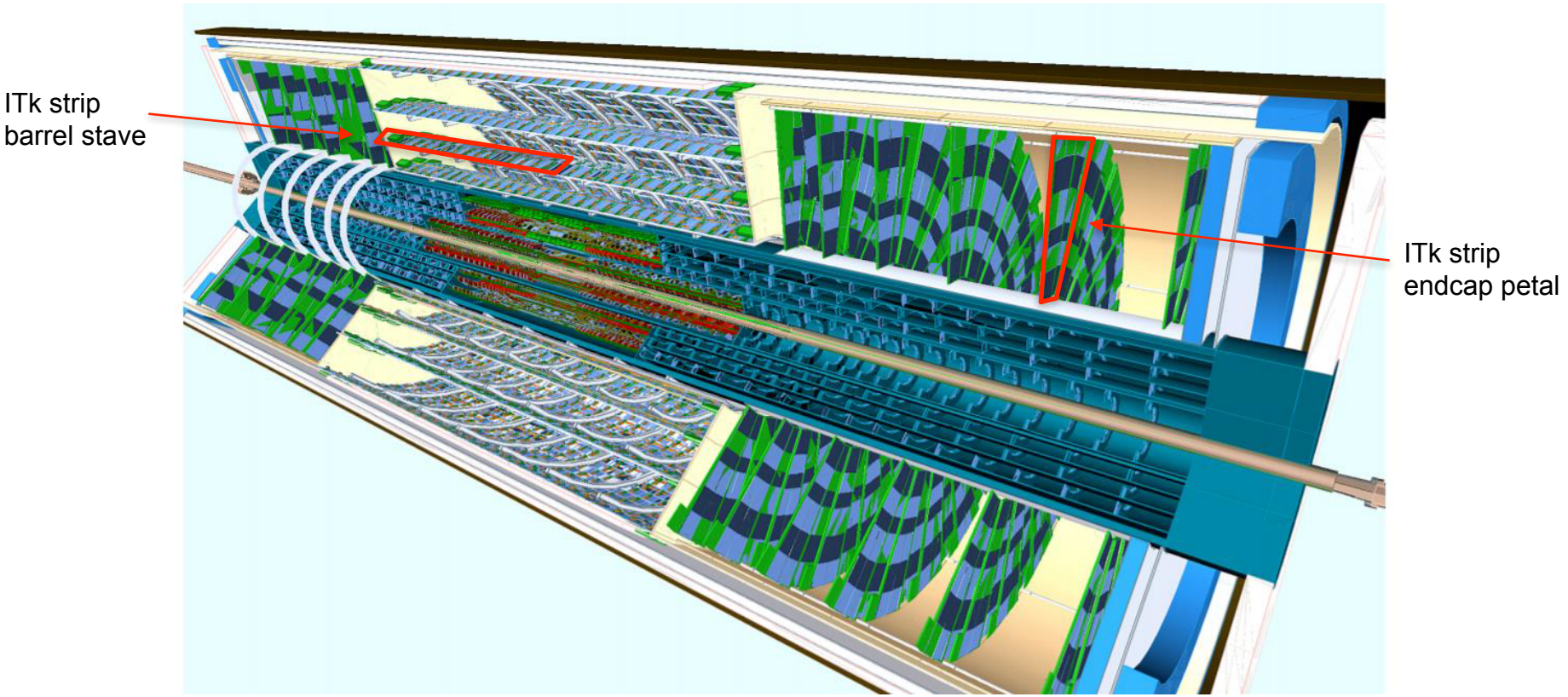
BTTB7, CERN, January 2019

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 654168

ATLAS Tracker Upgrade

- High Luminosity LHC (HL-LHC):
  - Integrated luminosity up to 4000 fb^{-1} -> High radiation hardness required
  - High instantaneous luminosity -> High granularity needed

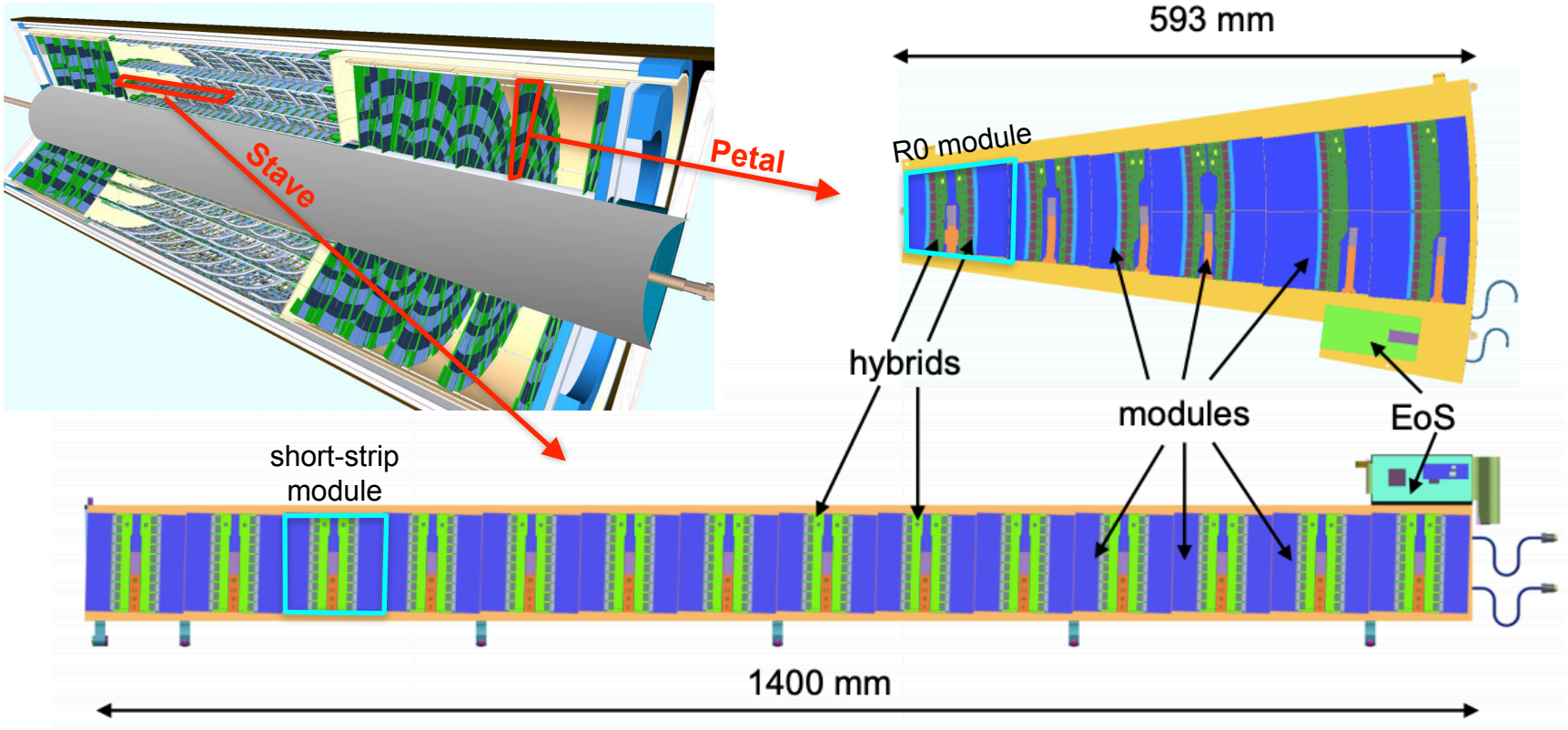
- Replace current Inner Detector with new all-silicon **I**nner **T**rac**k**er (ITk)



ATLAS ITk Strips

- ITk strip detector:
  - Four barrel layers of short-strip (inner two) or long-strip (outer two) “staves”
  - Two end-caps of six disks each, tiled with “petals”

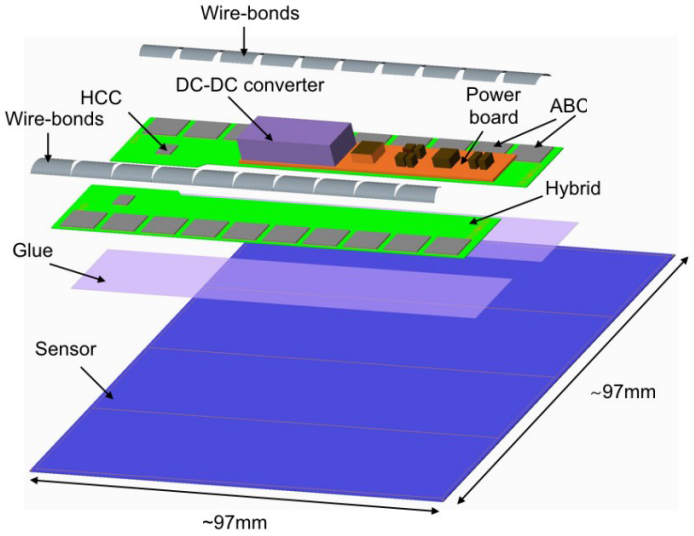
  - Populated by modules on both sides
  - Modules conceptually similar, same chipsets

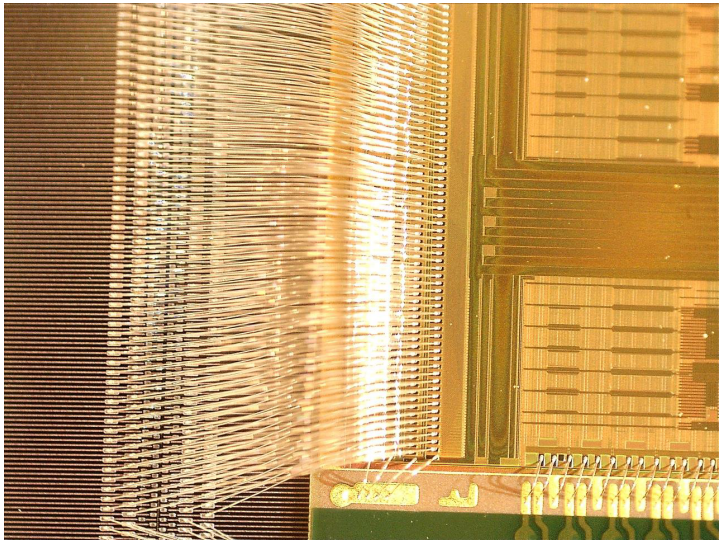


ITk Strip Detector

- n^+-in-p float zone silicon sensors
  - 300 µm thick
- Hybrids glued directly to sensors
- ATLAS Binary Readout Chip (ABC) and Hybrid Controller Chip glued to hybrid
  - wire-bonded to hybrid and sensor
- Power board for powering and monitoring of the module
- Module production expected to start in 2020
  - **Assessment of performance of current prototypes is critical!**

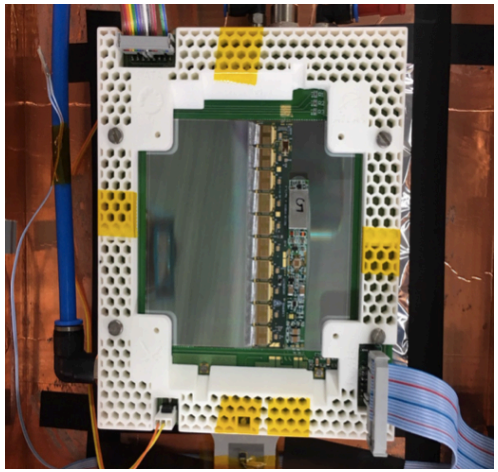
Exploded view of short-strip module

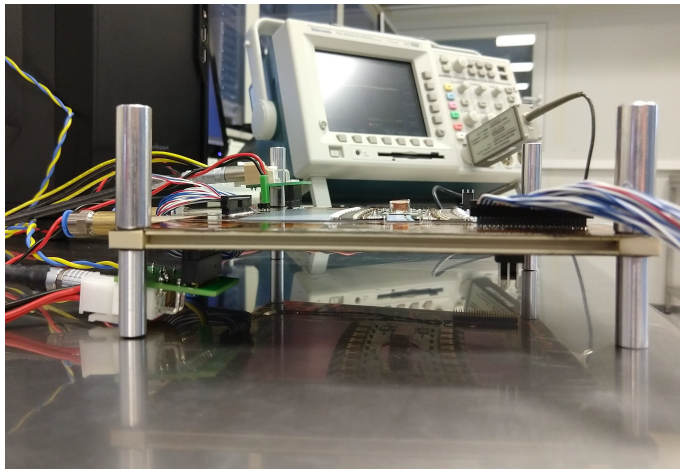


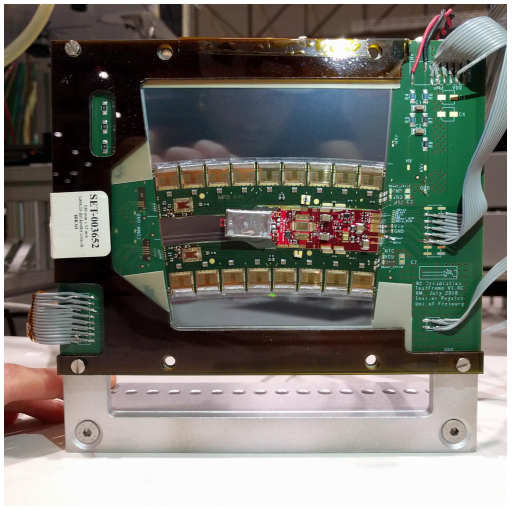


Modules and Beam Tests

- Two ITk strip testbeam campaigns in 2018 - about 3500 runs of data-taking
  - At DESY-II (Beamline 22) in June, using 4 GeV electrons
    - Two long-strip barrel modules
    - Double-sided R0 end-cap module
  - At CERN SPS north site (beam area H6A) in November, using 120 GeV pions
    - Test of irradiated R0 module
      - proton irradiated to 1.63×10^{15} neq/cm^2 at CERN IRRAD facility



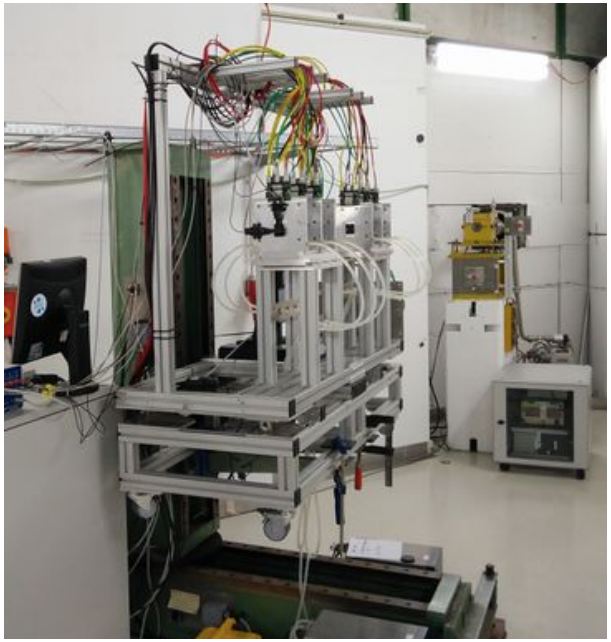


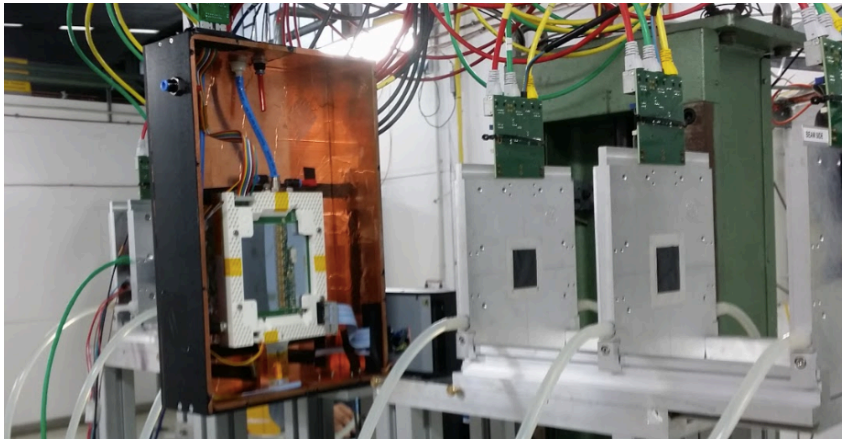


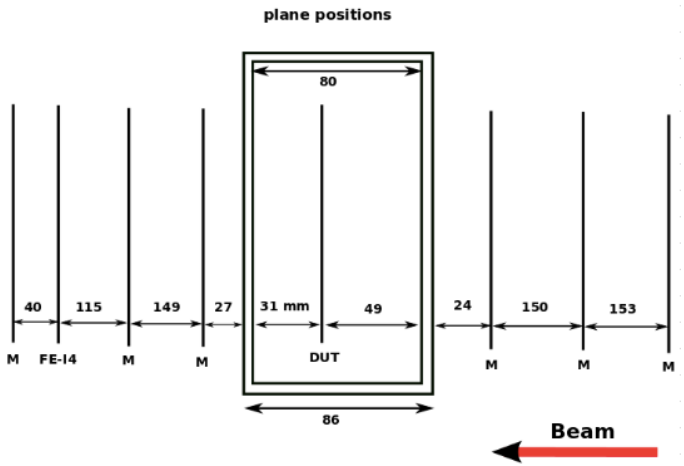
Modules and Beam Tests

- In both cases EUDET-type beam telescopes comprised of six Mimosa planes and one FE-I4 timing plane
  - DURANTA at DESY
  - ACONITE at CERN

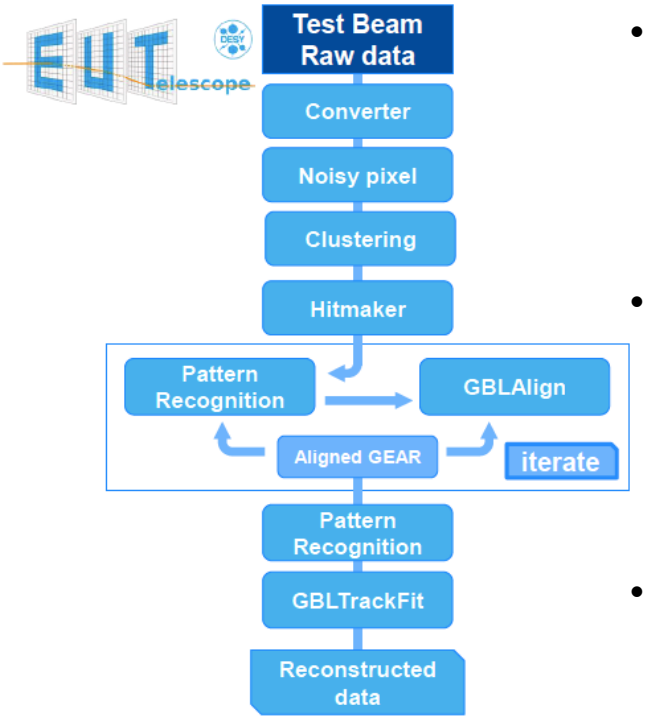
- Telescope and device under test (DUT) controlled and read-out using EUDAQ2





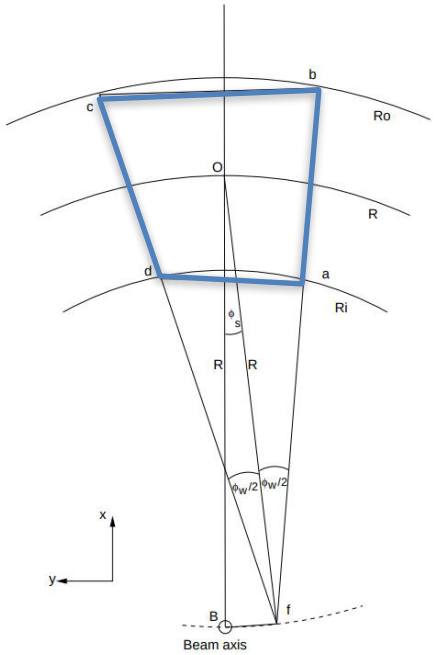


Data Reconstruction and Analysis



- Track reconstruction by EUTelescope software using General Broken Lines algorithm
  - DUT positions in beam differ between sets of runs
    - requires (re)alignment using tracks during reconstruction
- For analysis: select tracks with
  - trigger to read-out delay close to optimal
  - matching hit on FE-I4 plane
  - good track chi²/NDF
- Hit efficiency defined as

$$\epsilon = \frac{N_{tracks}^{DUT+FEI4}}{N_{tracks}^{FEI4}}$$

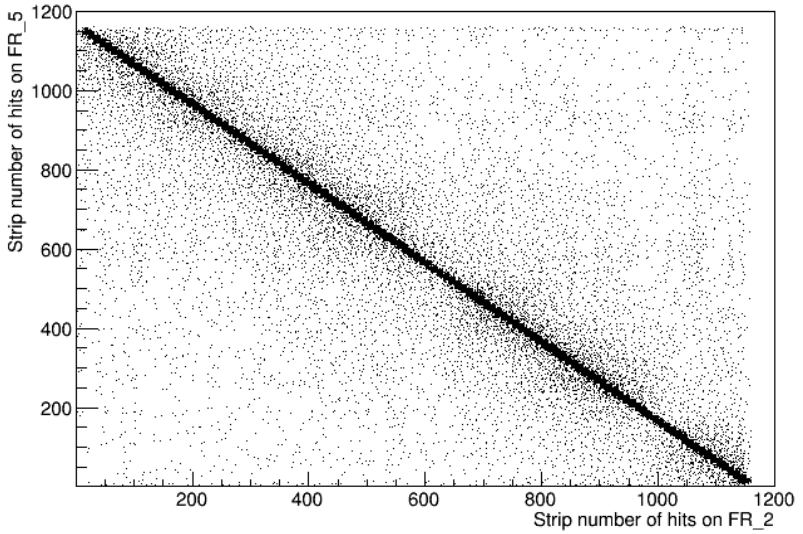


- R0 modules have (complex) radial geometry
  - accounted for by custom EUTelescope modifications
  - residuals of hit to track calculated in µrad instead of µm

Double-sided R0 module

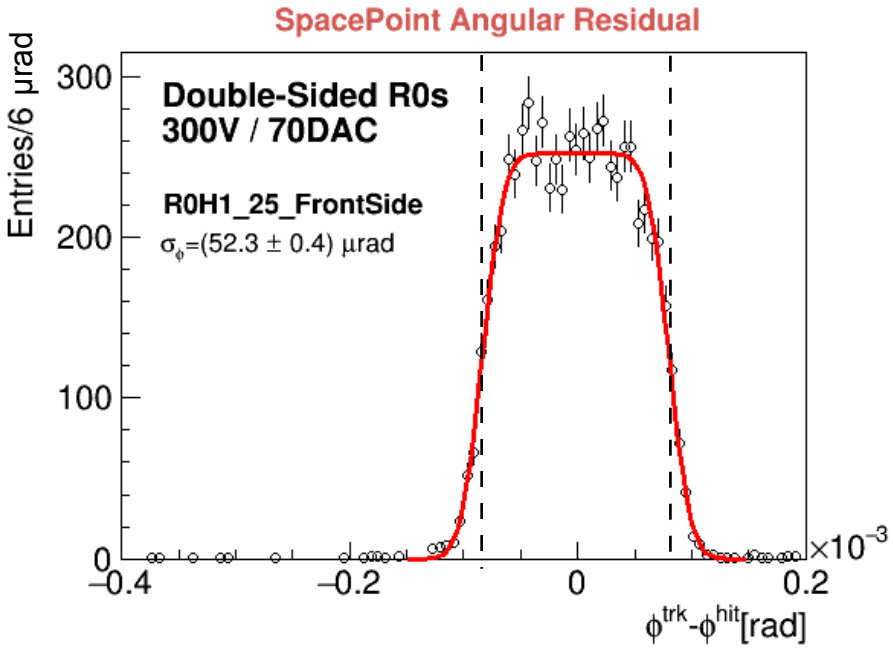
- First double-sided ITk strip end-cap module - successfully built and tested in the lab
  - Two modules glued onto a small “petal-like” core including services

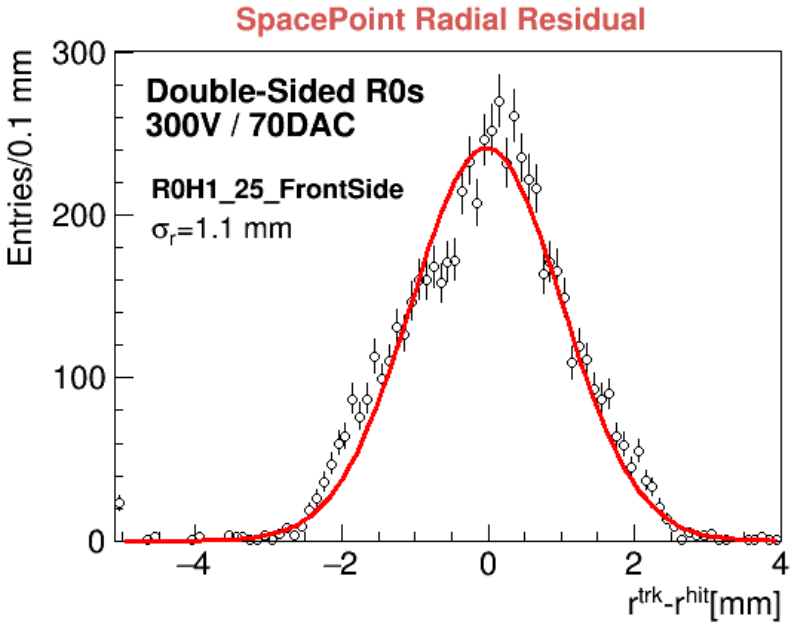
- Modules are “back-to-back” in the beam
  - Right: Per event for each hit on one module, all hits on other module plotted



Double-sided R0 module

- Stereo angle allows reconstruction of space points

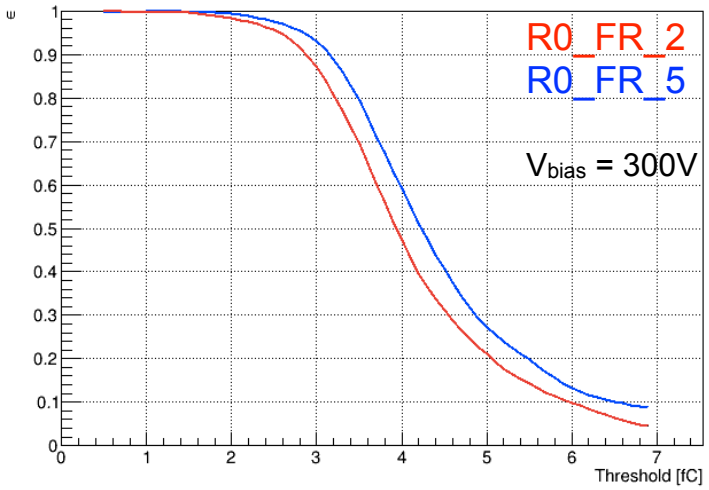


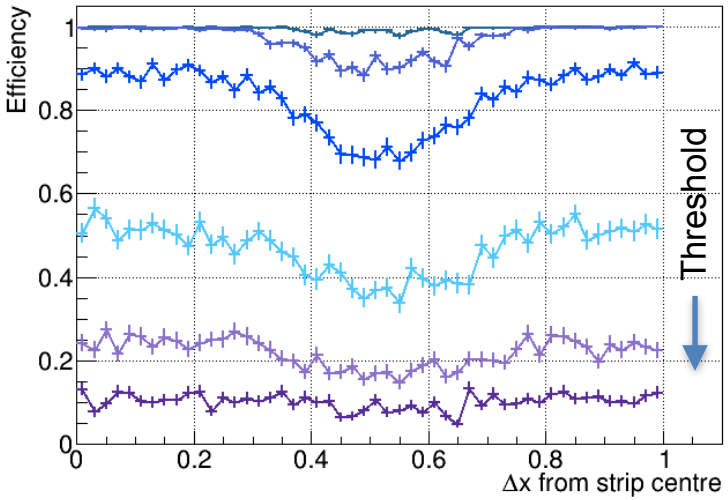


- Track reconstruction works reliably - angular resolution as expected ($\sigma = \frac{d}{\sqrt{12}}$)
- Preliminary study of r-reconstruction and resolution

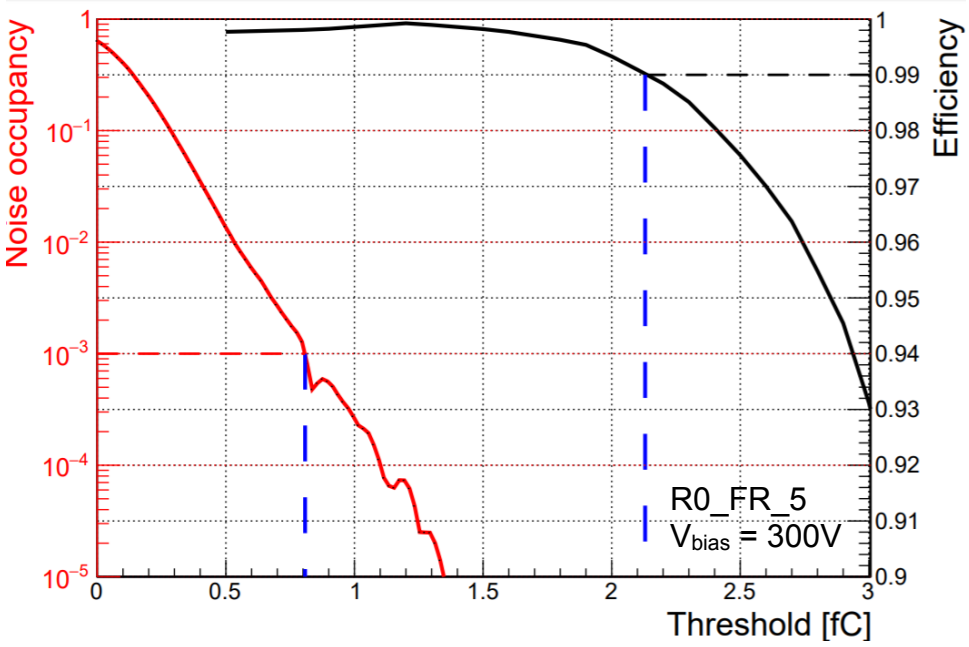
DSR0 Efficiency curves

$$\epsilon = \frac{N_{tracks}^{DUT+FEI4}}{N_{tracks}^{FEI4}}$$

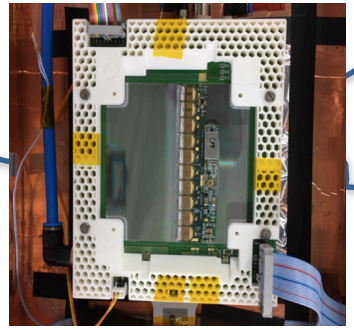




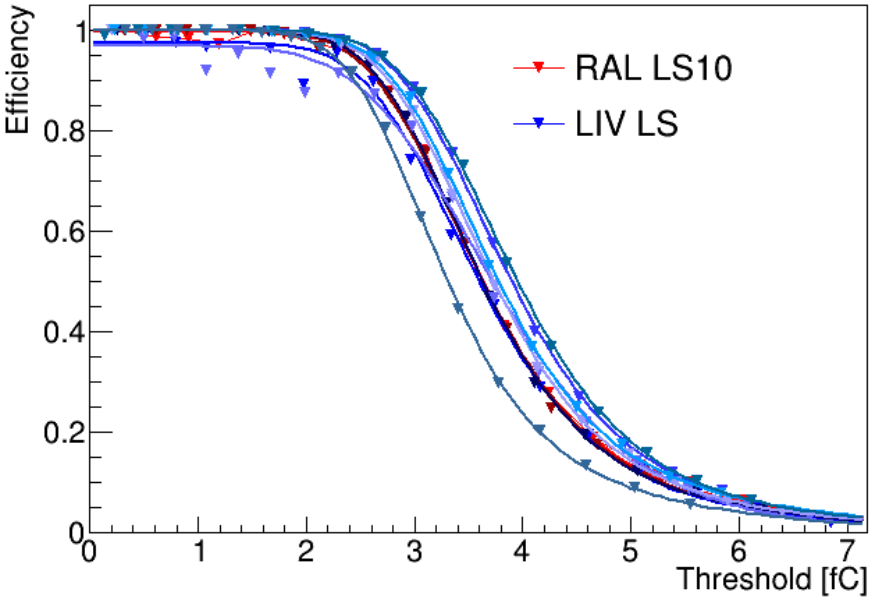
- Efficiencies match expectation
  - median charge ~ 4 fC @300V
- Differences among ASICs and modules mainly due to calibration
- Comparisons of hit efficiencies and noise occupancies indicate sufficiently wide operational corridor

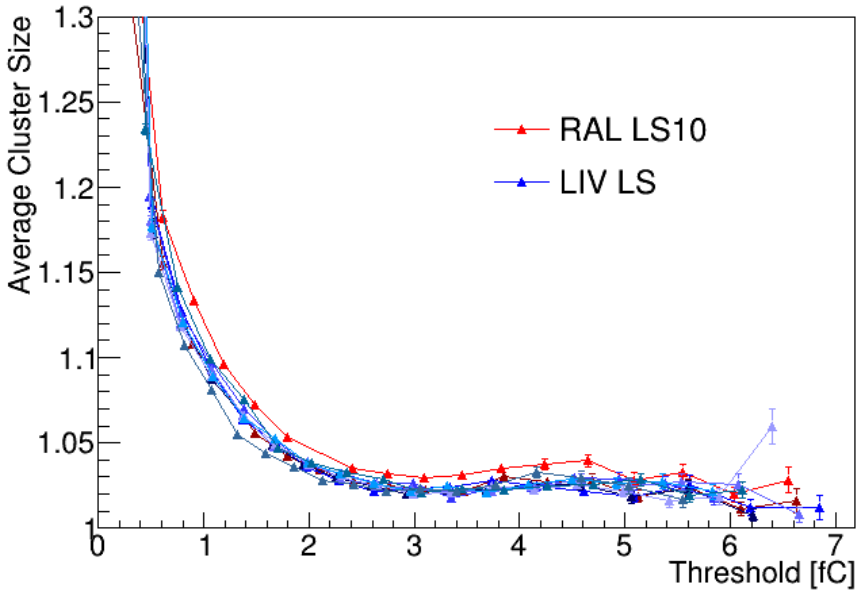


Results: Long-strip Modules



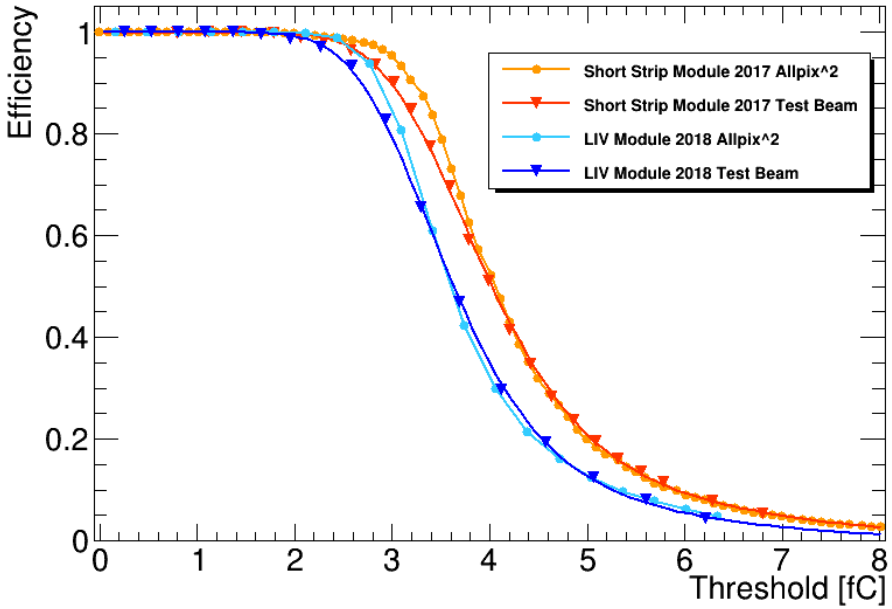
- Two modules tested, named RAL and LIV
  - First test of modules using long strip sensors
- Efficiencies and cluster sizes as function of threshold match expectation

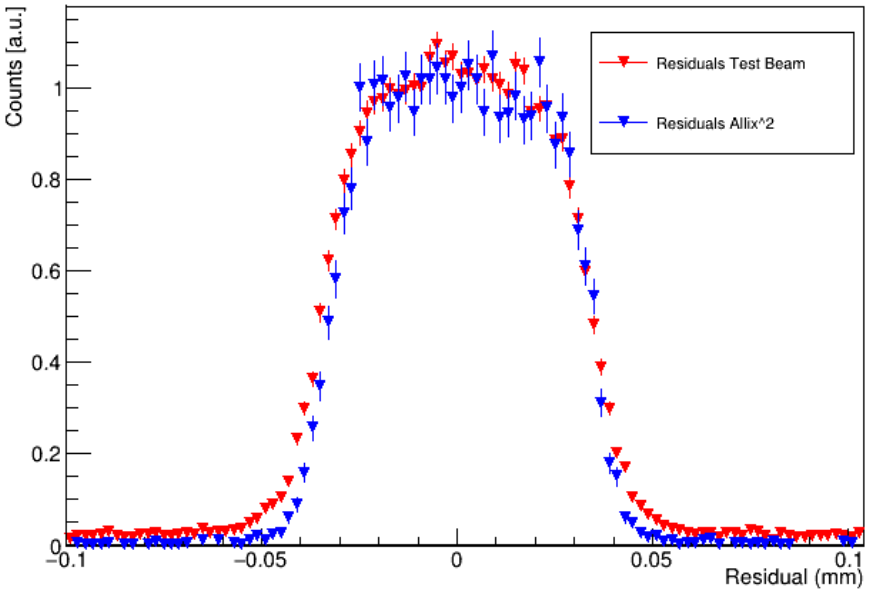




- Differences in S-curve among ASICs again mainly due to calibration
- Periods of desynchronisation between telescope and DUT readout observed, not masked yet -> efficiencies can be below 1 in figures even for low thresholds

Long-strip Modules - Simulation



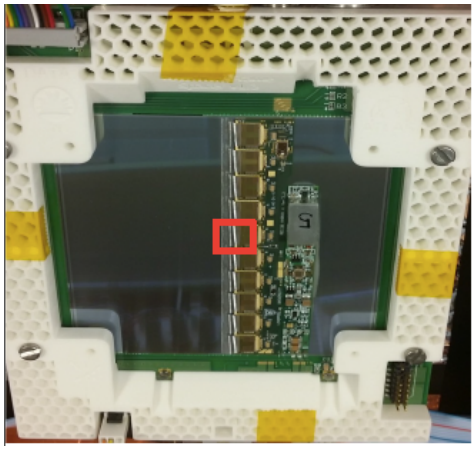


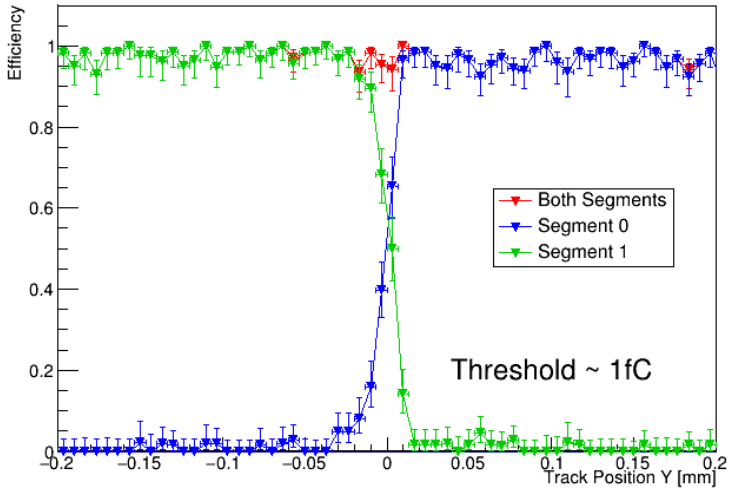
- Simulation with Allpix2 using TCAD electric field maps
  - Matches well with efficiency S-curves at centre of strips
  - Inter-strip region under study

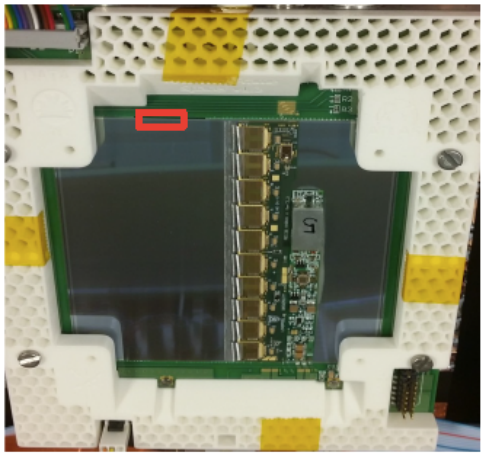
- First tracking results - performing simulation of the full telescope

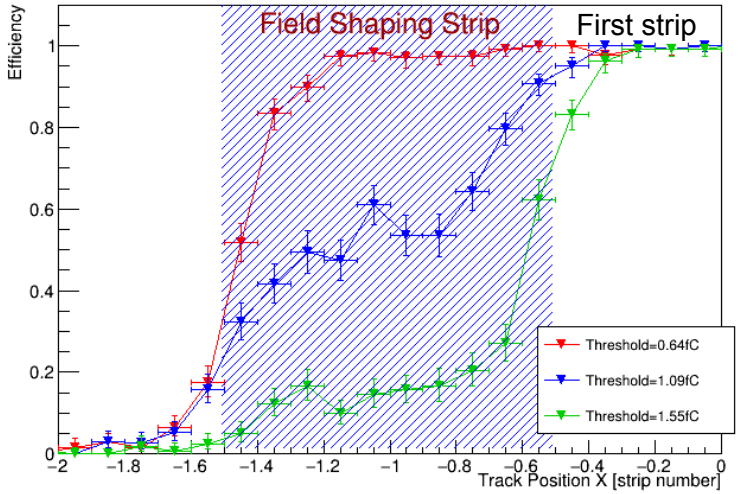
Results: Long-strip Modules

- A number of (high statistics) runs targeted sensor edges and region between sensor segments

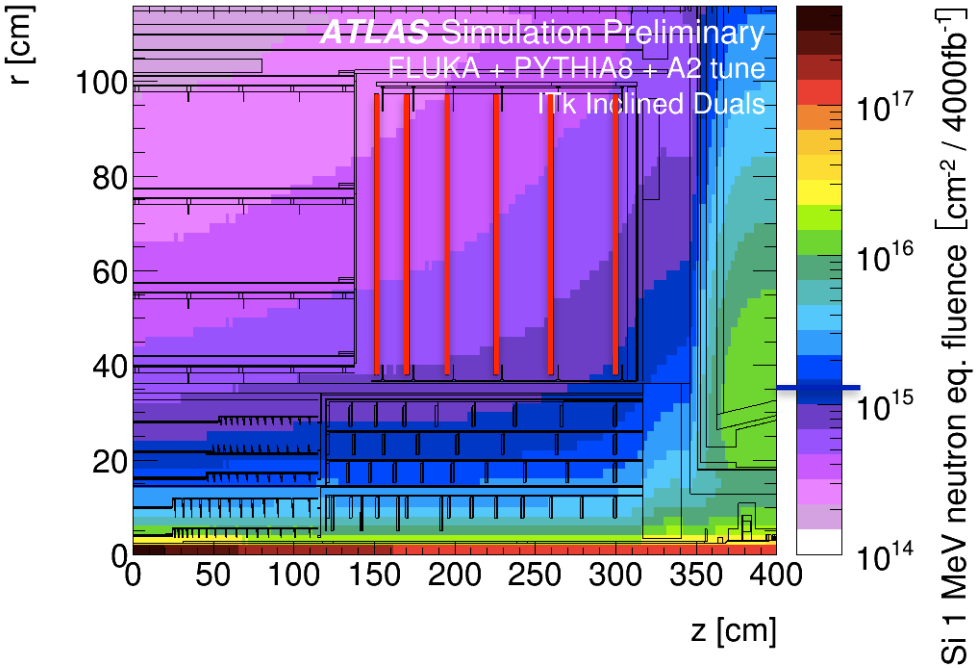


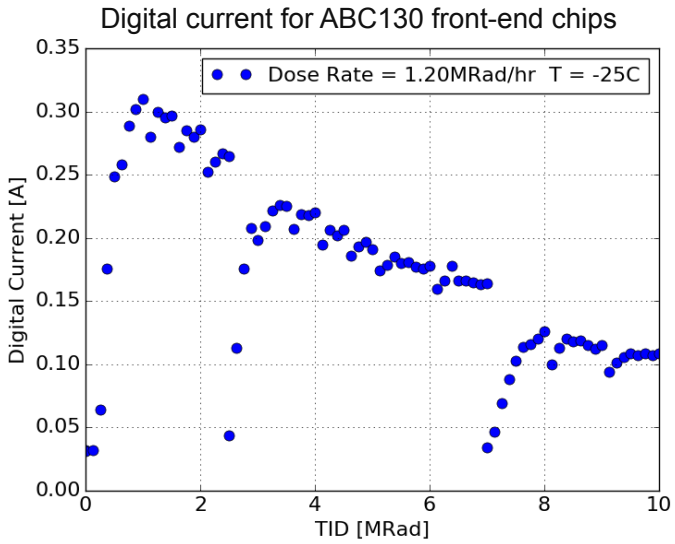






Irradiated R0 module



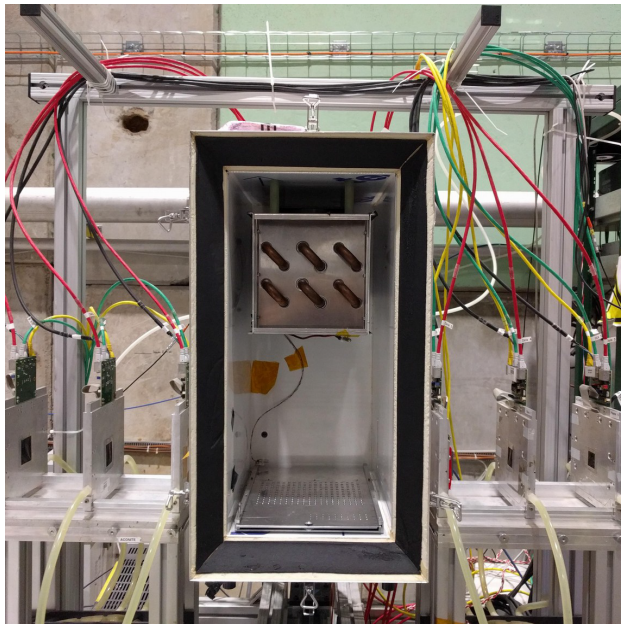


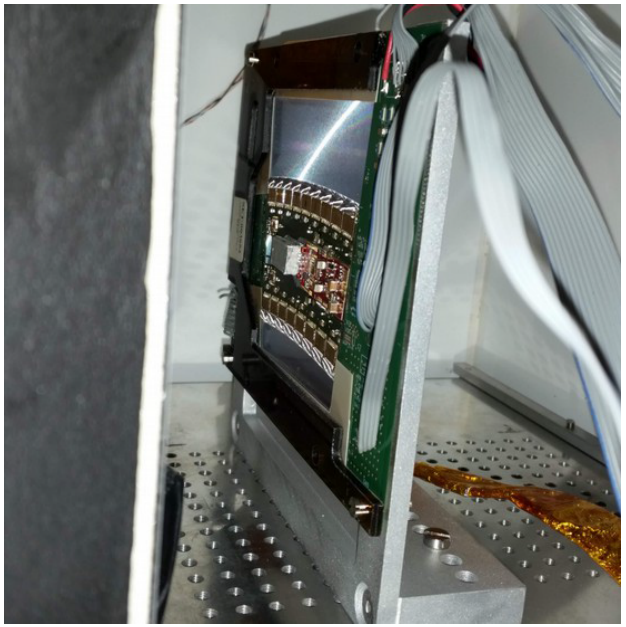
- Irradiated beyond lifetime dose within ~3 weeks - 75 MRad / 1.63x10^{15} neq/cm^2
  - Module powered and read out during irradiation
  - “Bump” in module current due dose happened during first night
  - Two out of 17 ABC chips dead, control chip AMACv2* in bistable state

* Autonomous Monitoring and Control ASIC version 2

Irradiated R0 module

- Goals of test beam:
  - **Establish module performance at (beyond) end of life**
  - **Confirm extrapolation from irradiated components to module**

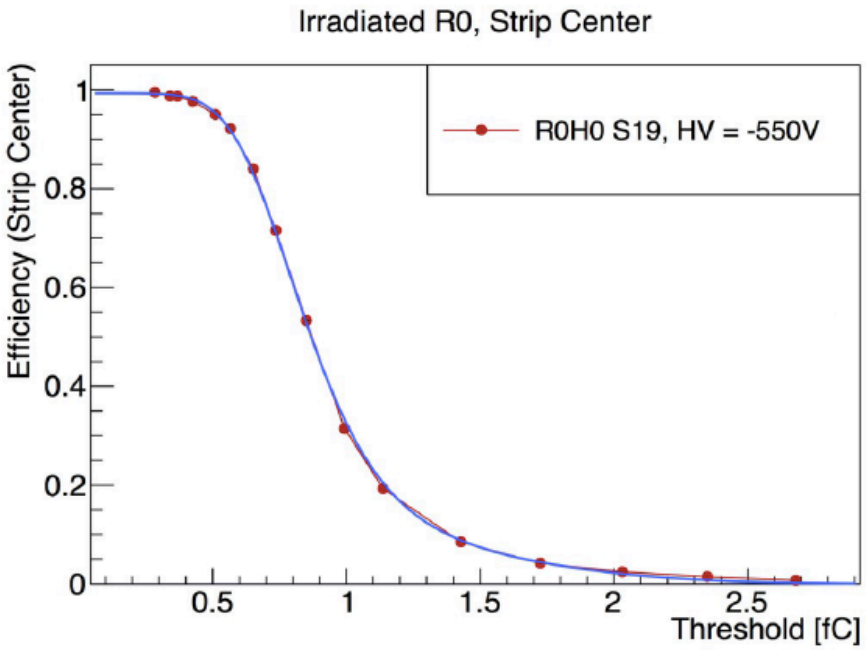


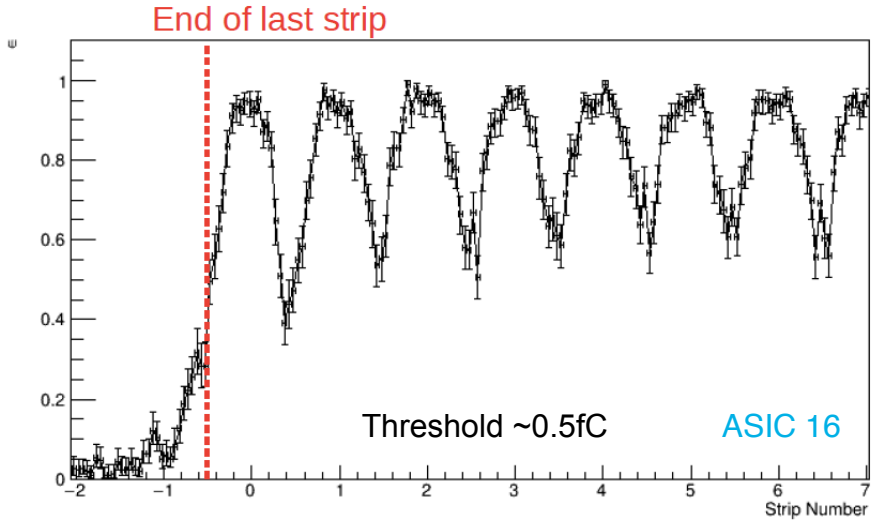


- Module mounted on test-jig inside cooling box
  - Air cooled to -50° C - no cooling pipes
  - Thermal runaway an issue - operated below optimal bias voltage
    - no full depletion

First Results: Irradiated R0 module

- **Data analysis just started, results are very preliminary**
- First results indicate lower signal than expected - under investigation





- Measurements at sensor edges were done
  - High statistics runs allow detailed study

Summary and Conclusions

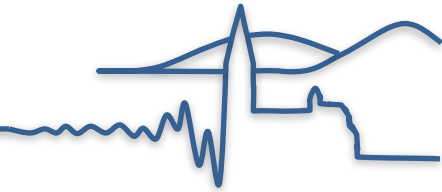
- Two ITk strip test beam campaigns in 2018 - about 3500 runs of data-taking
  - Tested double-sided R0 end-cap module, two barrel long-strip modules and irradiated R0 module

  - **Data taking very successful**
    - **Tremendous effort by ITK strip test beam group**

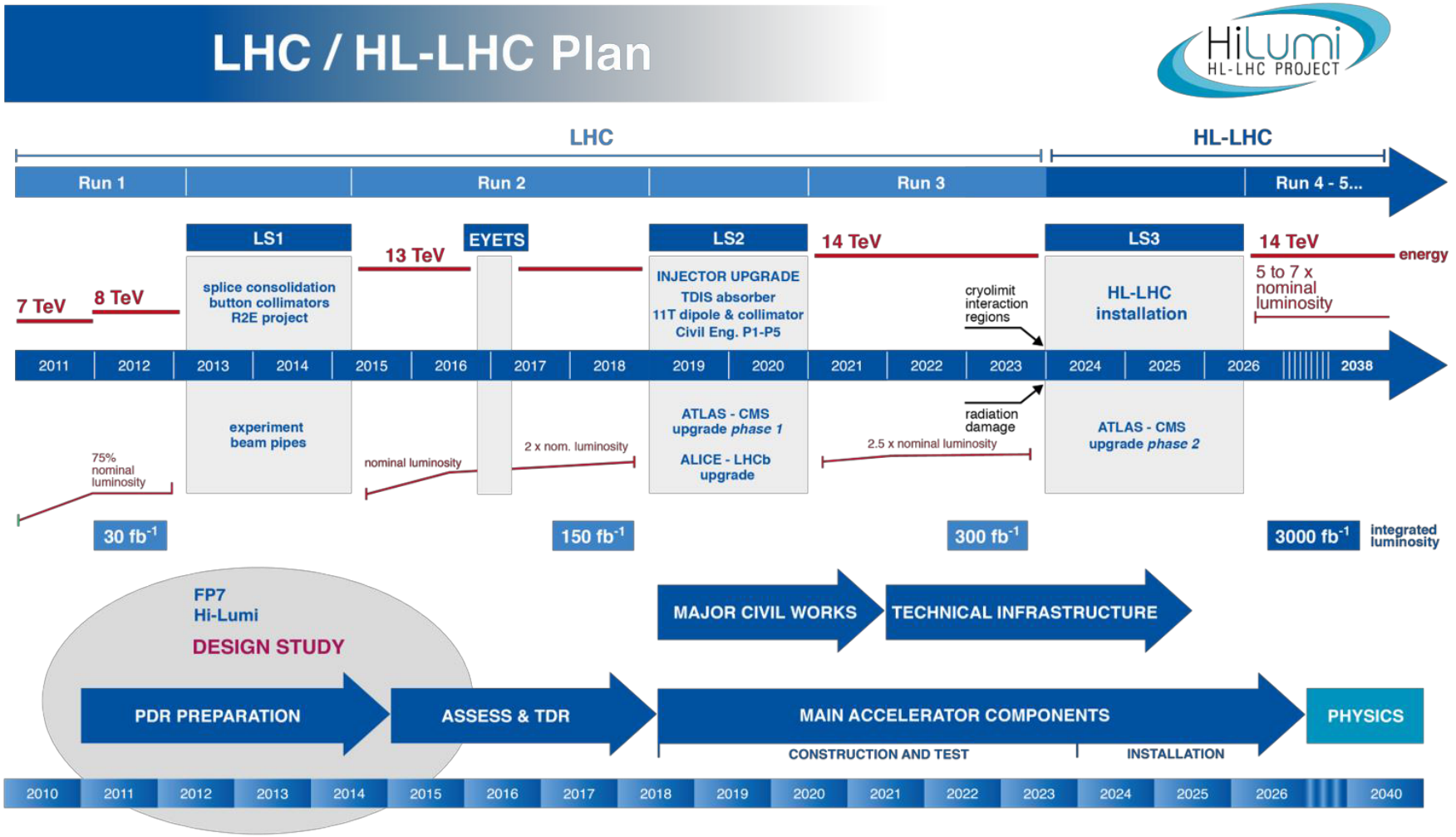
- In general resolution, cluster size, hit efficiencies and noise are within expectation and indicate sufficient performance for ATLAS operation
  - Data and performance of (over-)irradiated R0 module has to be investigated further

- **Main goal for 2019: testing of modules with production version of readout electronics**

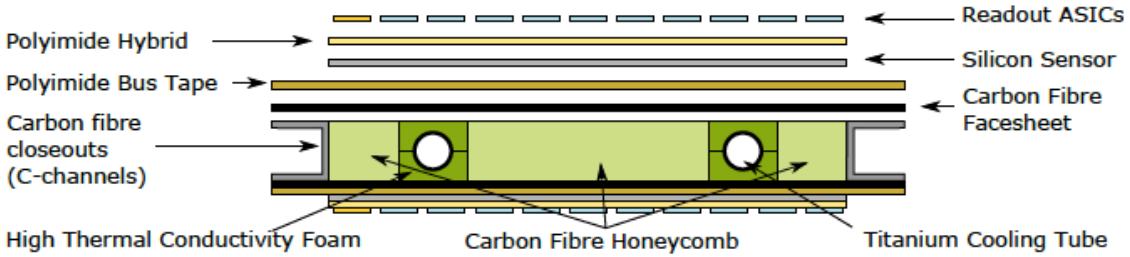
Backup Slides

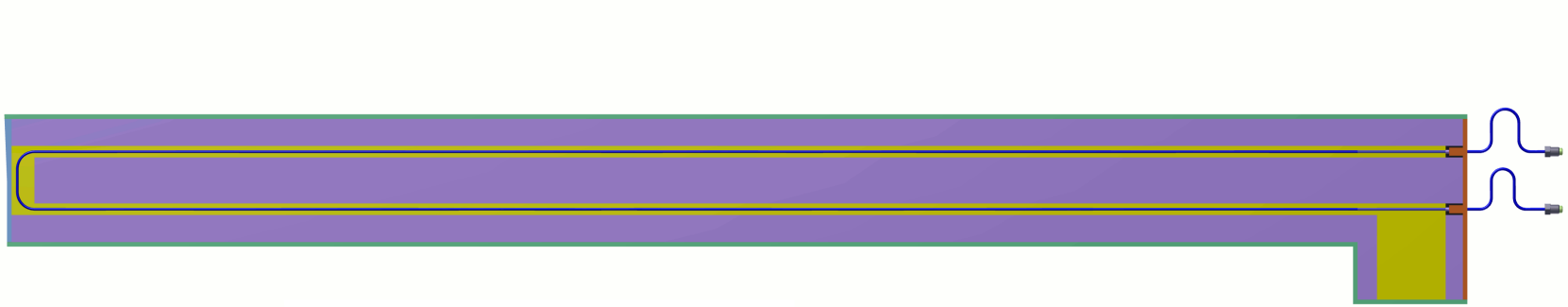


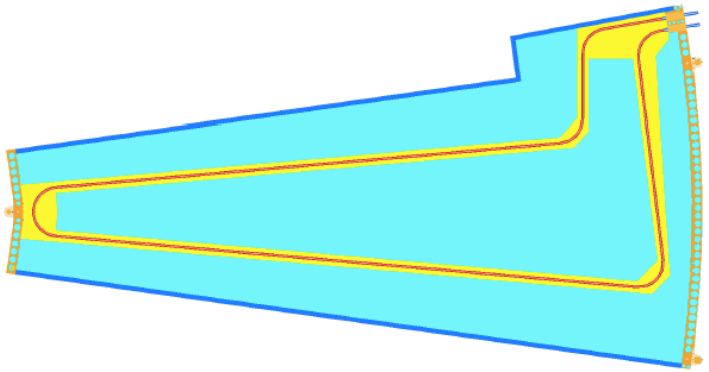
LHC Schedule



Petal and Stave Cooling







ITk strip electronics