



Recent testbeam studies of ATLAS ITk pixel modules

VERTEX 2025 - Knoxville, Tennessee, 28/08/2025

Matías Mantiñan on behalf of ATLAS ITk Testbeam collaboration

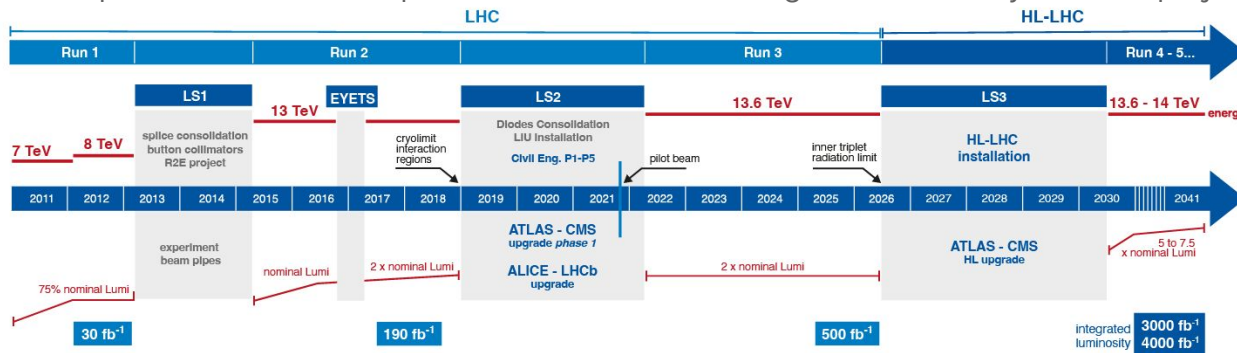
The University of Chicago

Content



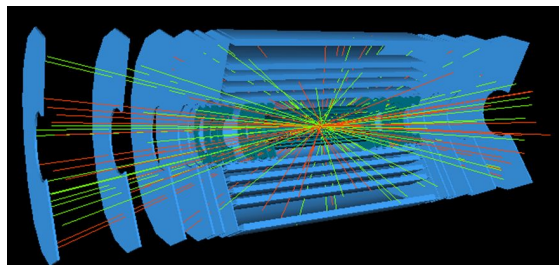
- HL-LHC Program
- ITk pixel modules
- Radiation hardness
- ITk testbeam setup
- Reconstruction
- Results

In the HL-LHC era, starting around 2030, the LHC will run at unprecedented luminosity, significantly increasing the number of simultaneous proton–proton collisions—or pile-up—in each event. The target instantaneous luminosity will be $5\text{--}7.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, enabling the experiments to record up to $3000\text{--}4000 \text{ fb}^{-1}$ of integrated luminosity over the project's lifetime.

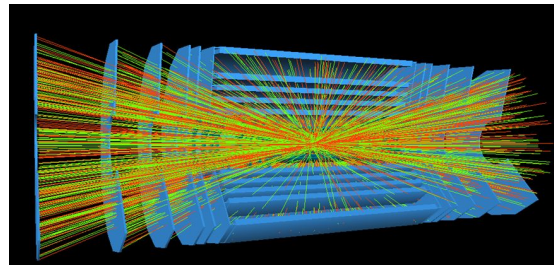


HL-LHC-WEB

pile up ≈ 50



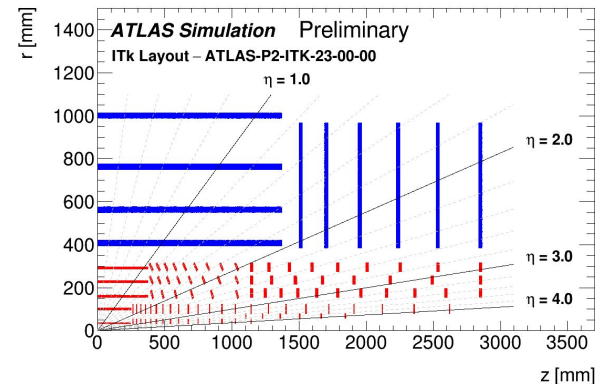
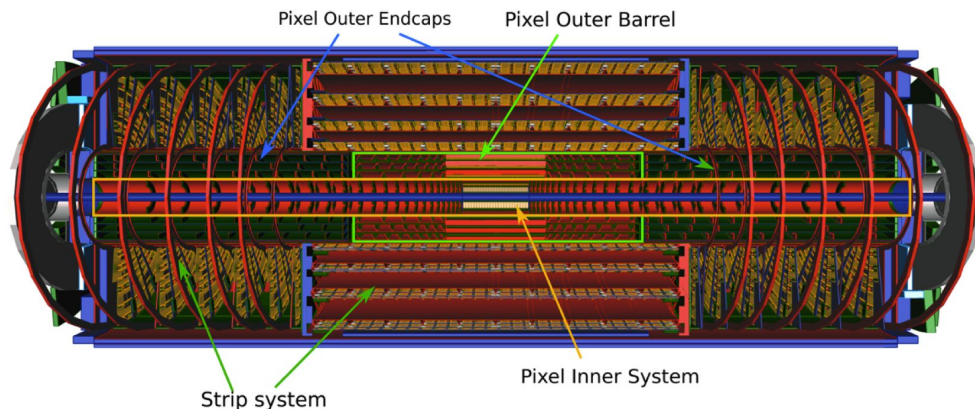
pile up ≈ 200



The Inner Tracker



The Inner Tracker (ITk) will replace the current ID with a fully silicon detector.



CERN-LHCC-2017-021

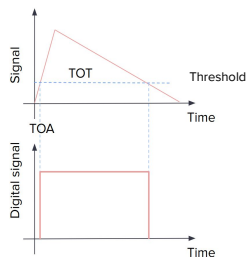
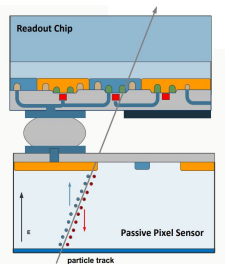
- All-silicon
- Coverage $|\eta| < 4$
- Pixel: 8000 modules covering 13 m^2

See more in [Catherina's Talk](#)

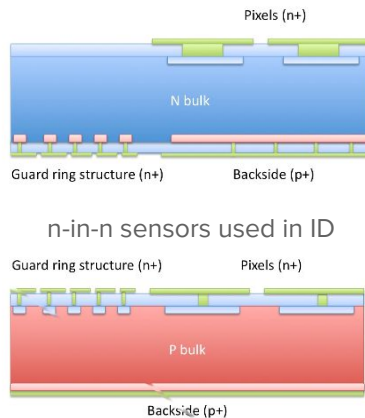
Silicon Detector



When ionizing particles pass through the sensor, they leave a trace of electron-hole pairs. The e-h pairs go to the surface where they leave a signal that is then sampled and processed.

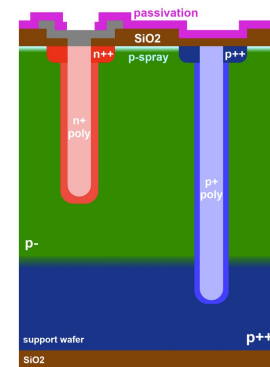


Silicon sensors principle



n-in-p sensors used in ITk

Planar Sensors

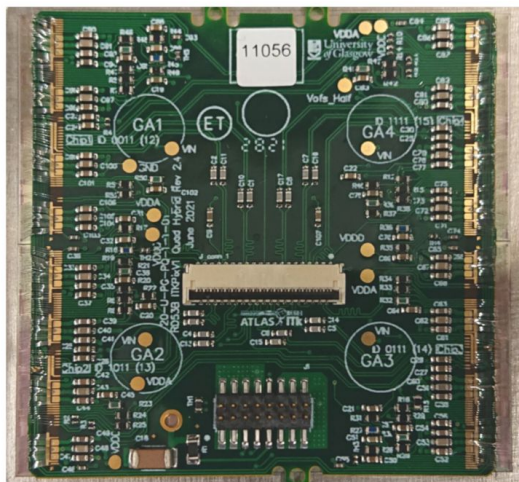


3D Sensors

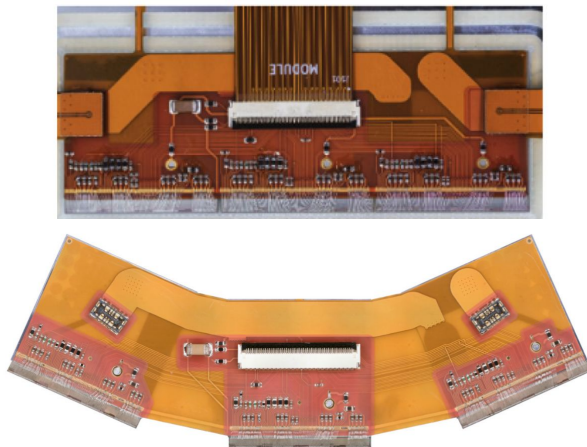
ITk will contain n-in-p sensors, allowing for single-sided processing. 3D sensors have a smaller drift distance, improving radiation hardness, they will be used in the first layer.

ITk pixel modules

The ITk pixel system will be built from larger modules, including quads with four readout chips and triplets with three. For development and characterization, we also use single-chip cards. These are not intended for installation in the detector, but they are very useful for testing and calibration studies.



Quad module



Two flavors of triplet modules



SCC (single chip card) used only for testing

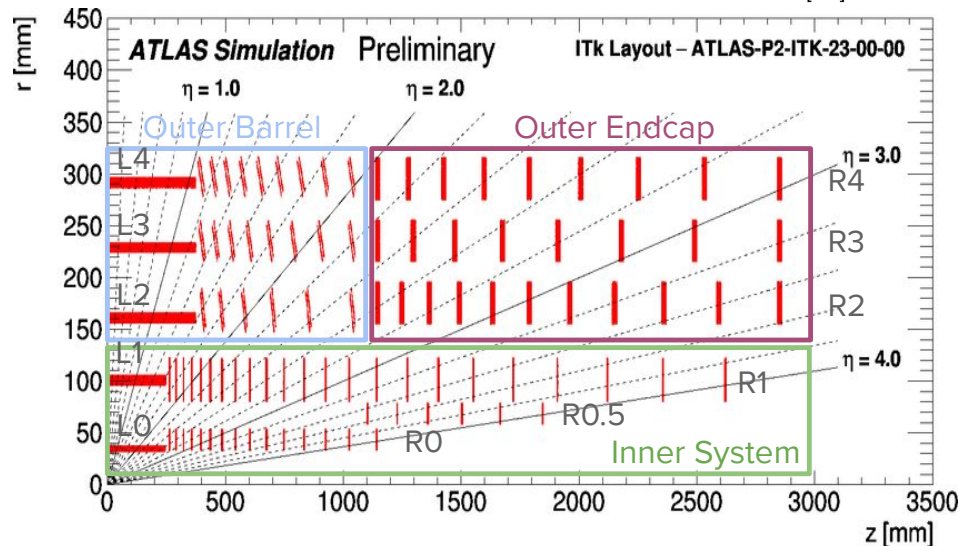
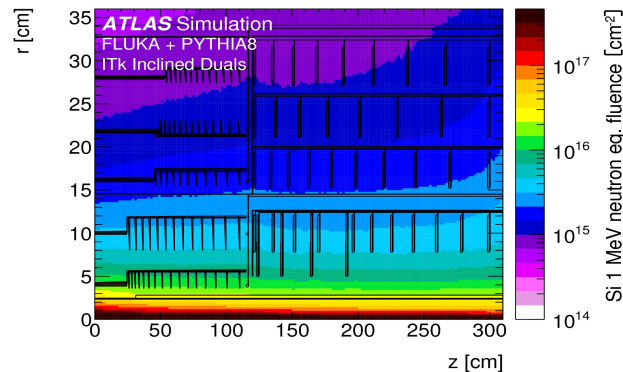
Radiation hardness



At HL-LHC the detectors will be exposed to high doses of radiation.

- L0, R0, and R0.5
 - 3D sensors $250\ \mu\text{m}$
 - $\approx 1.6 \times 10^{16}\ n_{\text{eq}}/\text{cm}^2$
 - Vendors: SINTEF, FBK
- L1 and R1
 - Planar $100\ \mu\text{m}$ and $150\ \mu\text{m}$
 - $\approx 4.0 \times 10^{15}\ n_{\text{eq}}/\text{cm}^2$
 - Vendors: HPK, Micron, FBK
- L2, L3, and L4: Planar $150\ \mu\text{m}$

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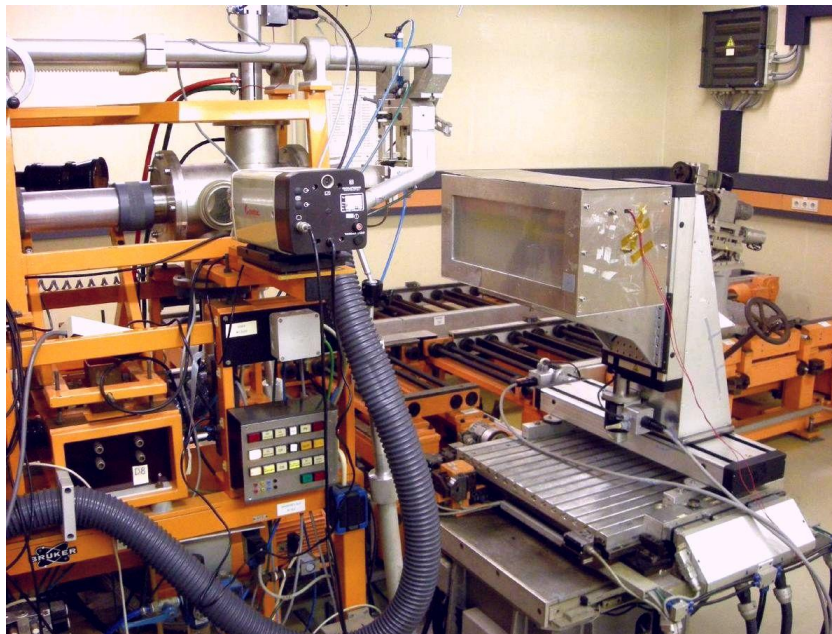
Irradiation facilities



To ensure the modules will withstand the HL-LHC environment, we irradiate them at dedicated facilities such as KIT. After irradiation, the modules are characterized to study their performance under realistic conditions.

Proton irradiation setup in front of beam pipe. Samples are placed in box, which can be cooled by cold nitrogen gas. The box is being scanned during irradiation to cover the whole target area.

Other irradiation centers are Irrad and RARis



Irradiation Center at KIT

Testbeam studies



Testbeam studies are crucial to test modules and their capabilities:

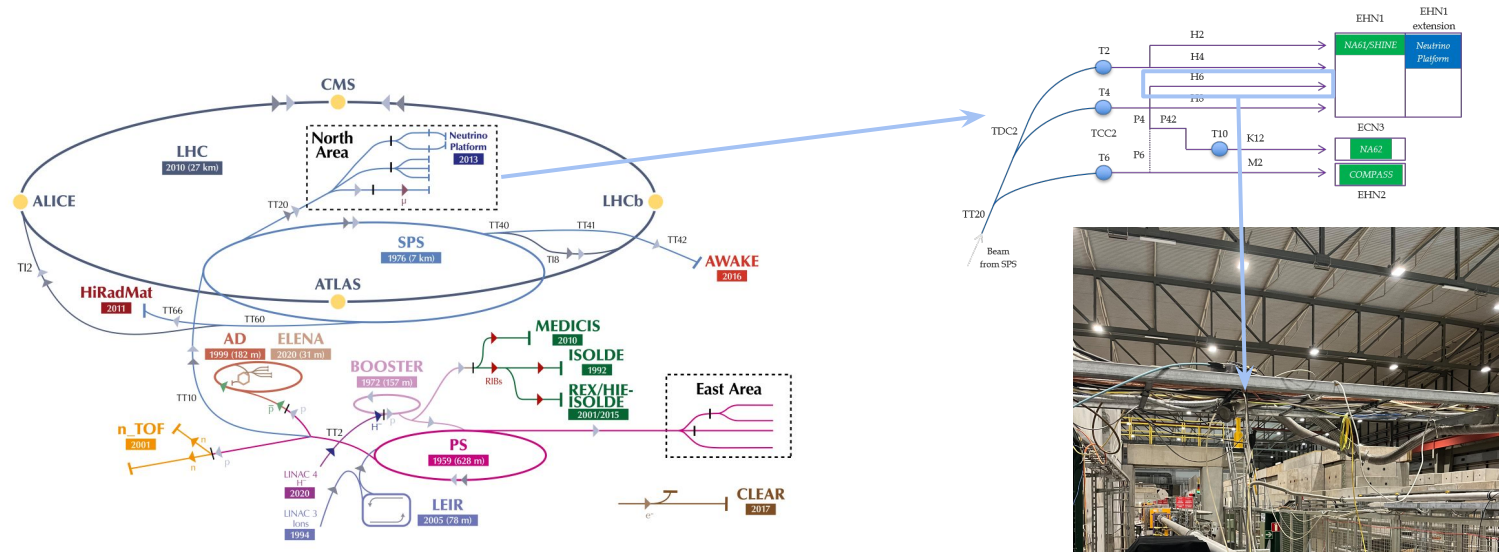
- A test beam is the closest we can get to a collision environment.
- Test spatial resolution
- Efficiency measurements



The North Area of SPS



The North Area is at the end of the Super Proton Synchrotron (SPS), located at the Preveessin Site of CERN.

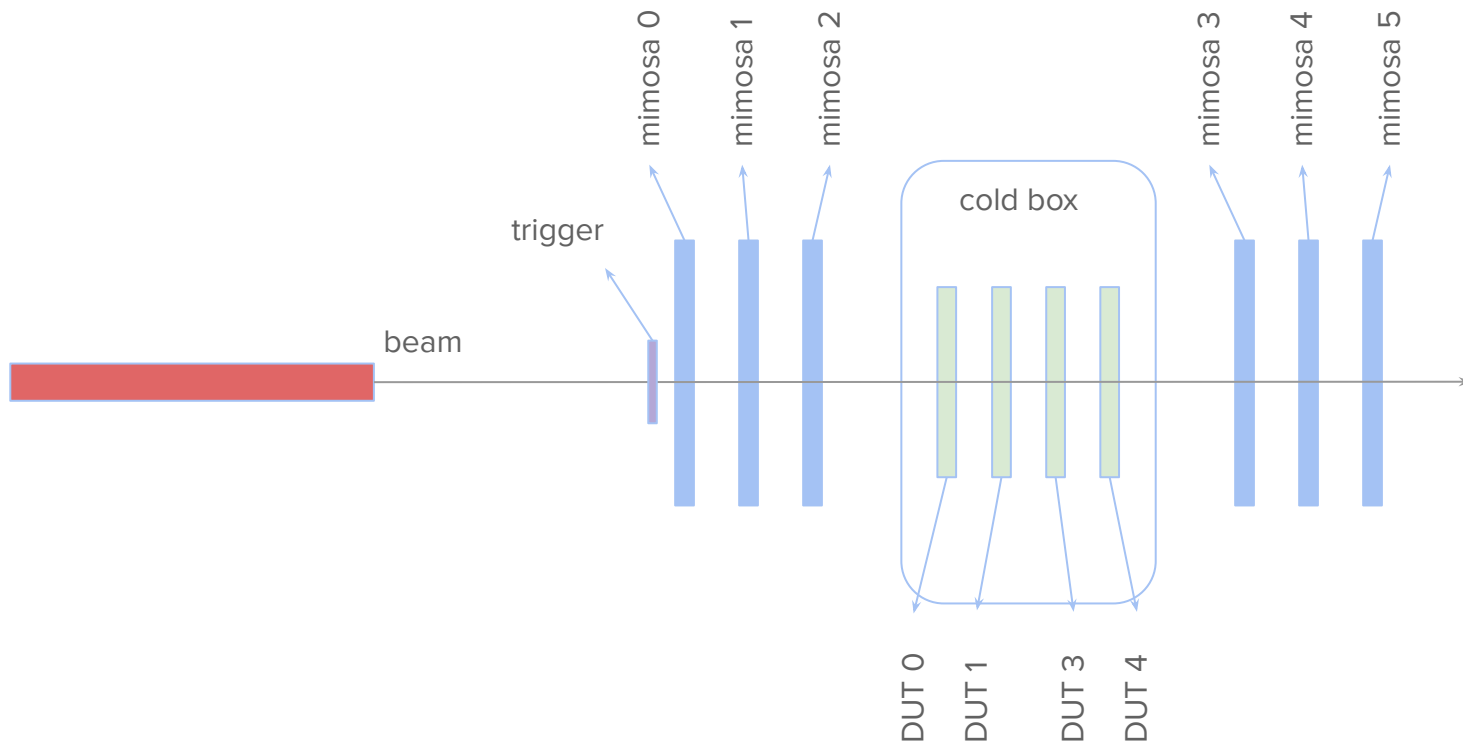


The beam outputs pions of 120 GeV.

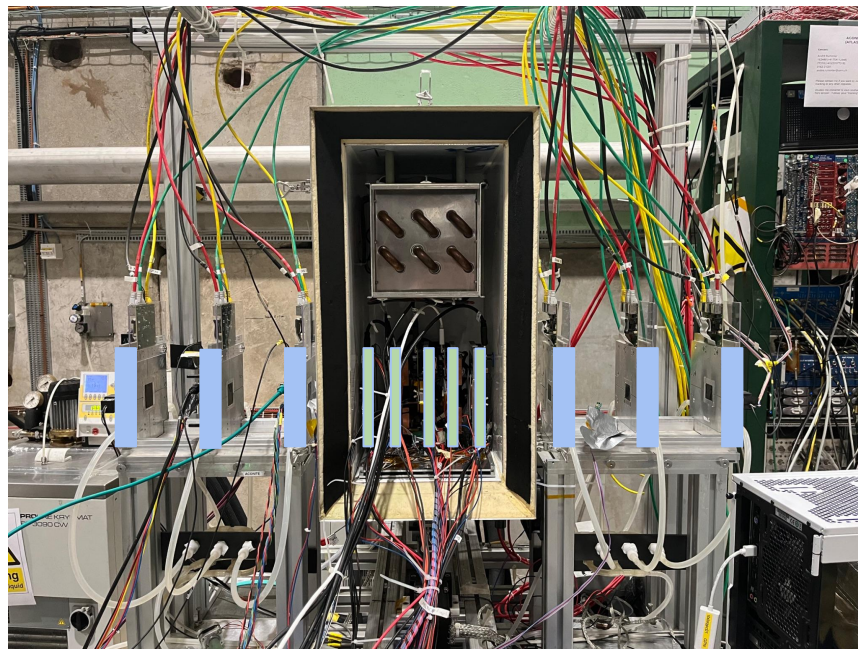
The experimental setup



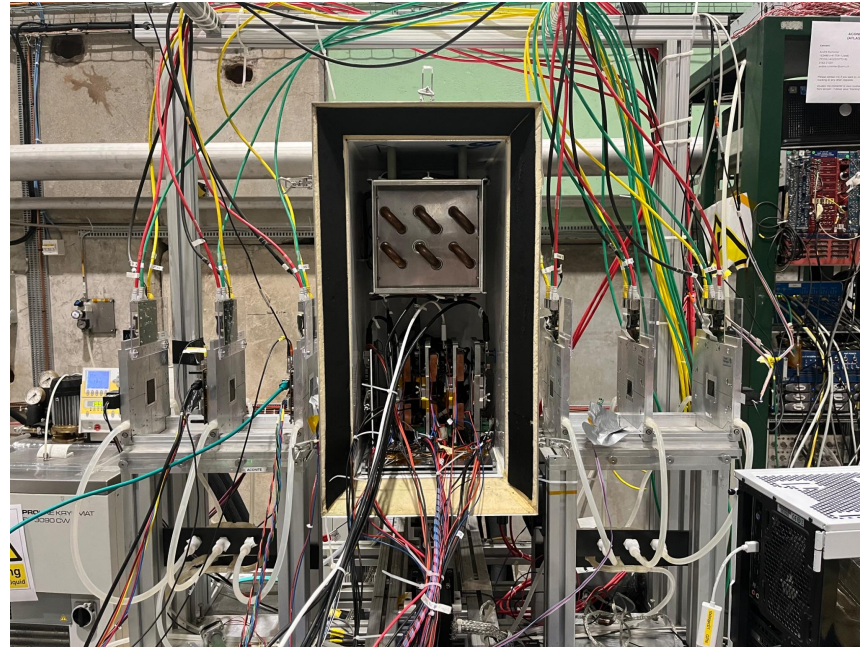
The telescope consists of a trigger, 6 pixel planes used for reconstruction and the DUTs.



The experimental setup



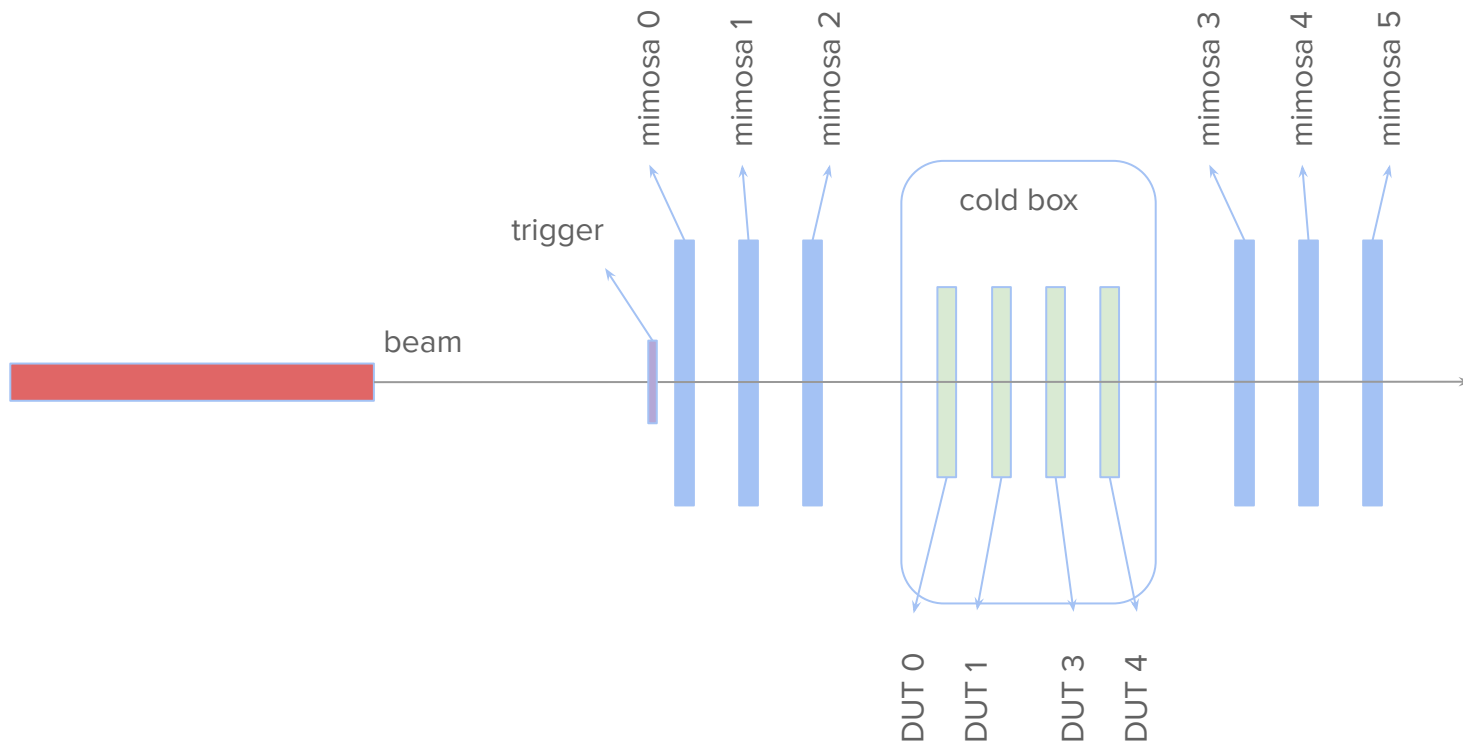
The experimental setup



The experimental setup



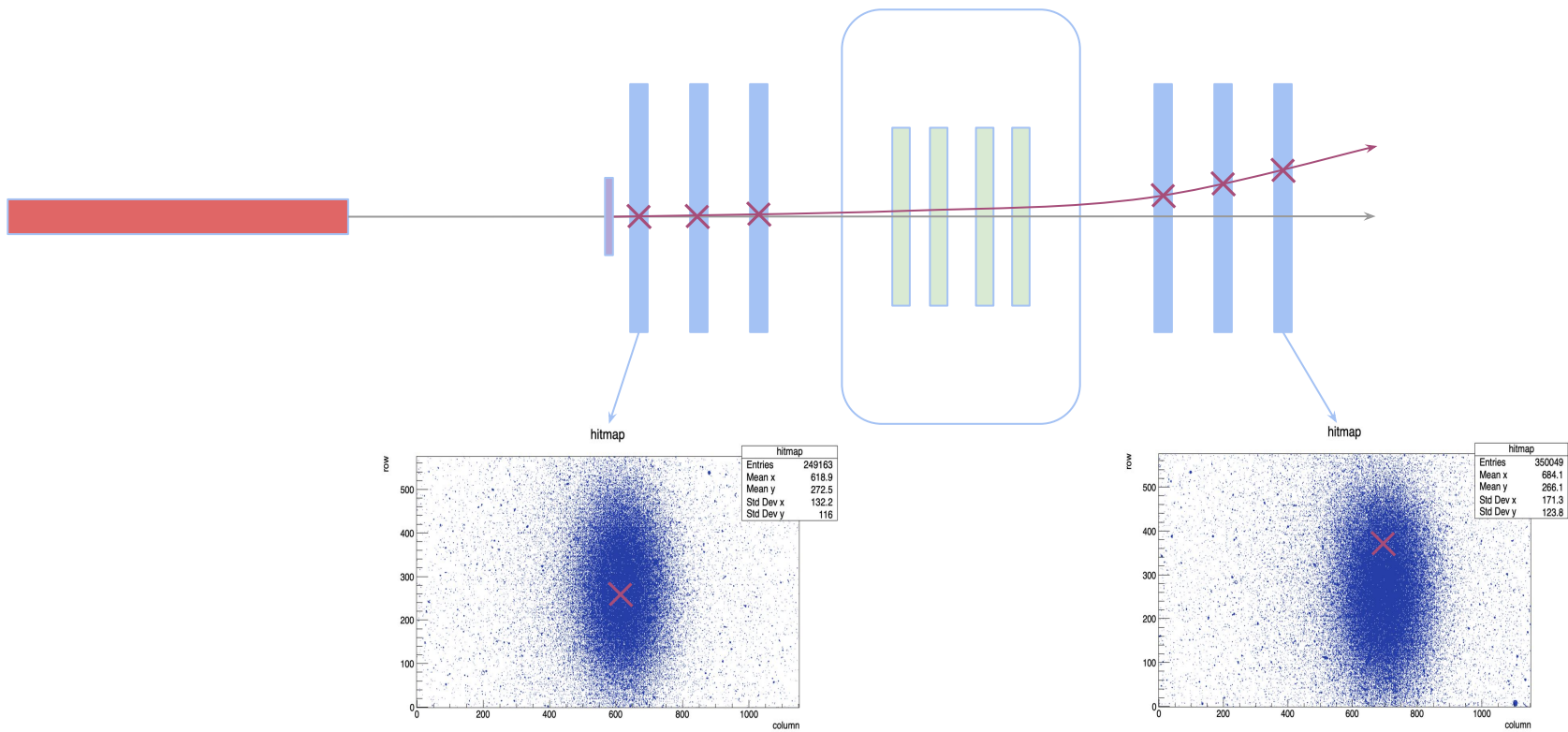
The telescope consists of a trigger, 6 pixel planes used for reconstruction and the DUTs.



The experimental setup



Hits in the sensors are reconstructed into tracks using the mimosa planes



Hit efficiency



During their lifetime, ITk modules need to maintain high hit efficiency standards. So far, every ITk module tested meet the requirements.

- For non-irradiated modules: $\epsilon > 98.5\%$
- After irradiation the requirements are:
 - 3D sensors: $\epsilon > 96\%$ in normal incidence and $\epsilon > 97\%$ tilted (15°).
 - Planar sensors: $\epsilon > 97\%$ at maximum bias (-400 V for 100 μm sensors and -600 for 150 μm sensors)

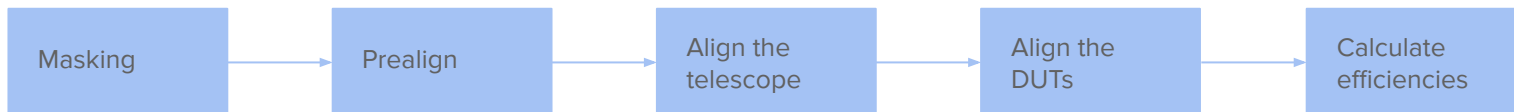
$$\epsilon = \frac{\text{Number of tracks with associated cluster on DUT}}{\text{Total Number of tracks intersecting DUT}}$$

We use the software Corryvreckan to do the reconstruction.

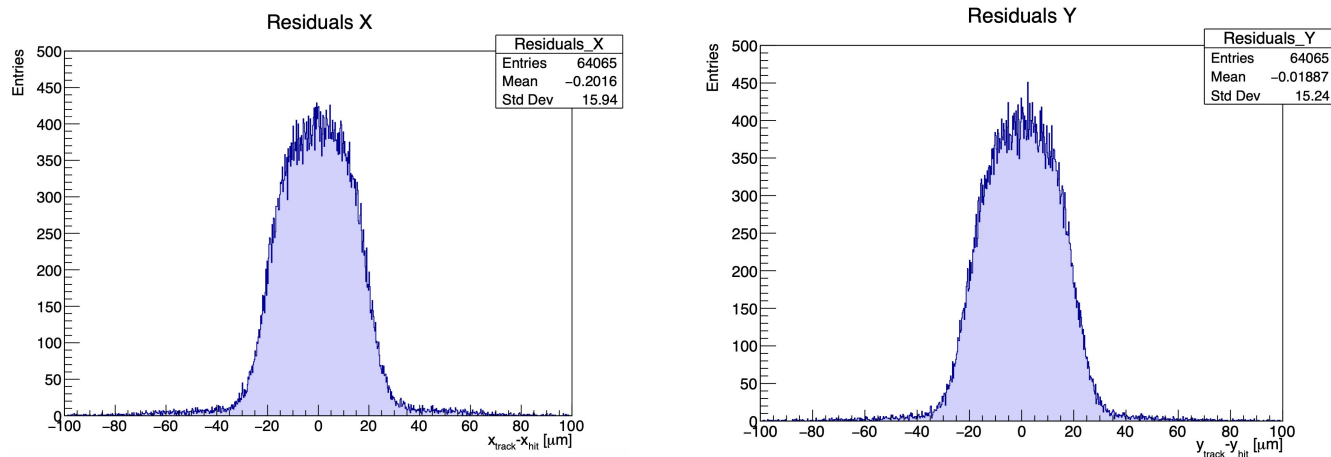
Efficiency measurement



The analysis flow is the following



The end result of the alignment is a

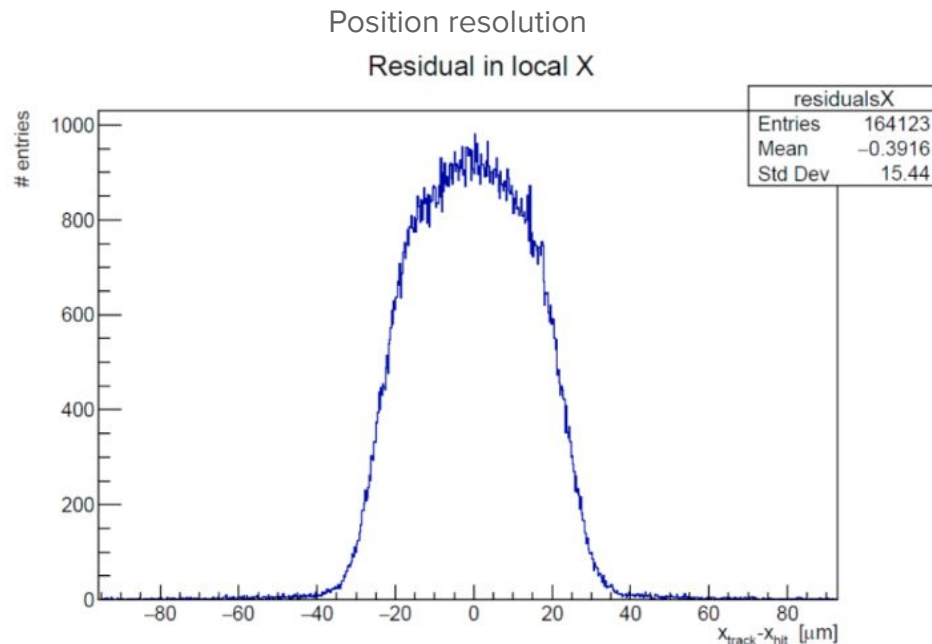
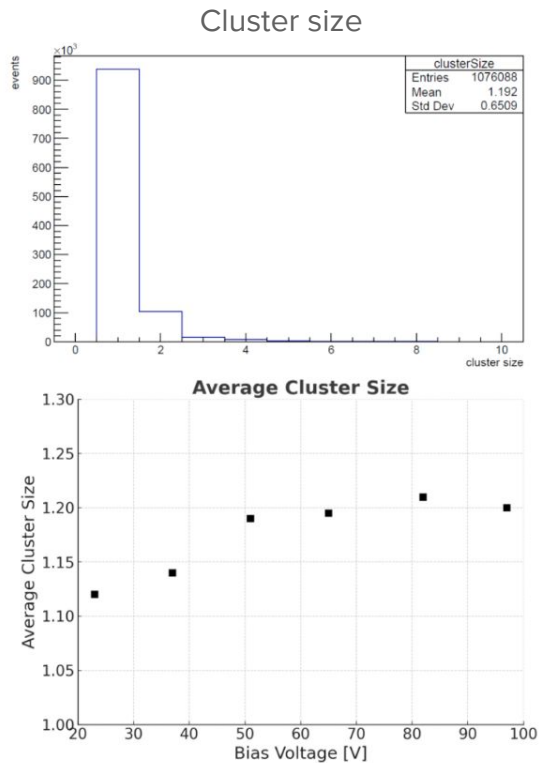


The distance of the hits with the fitted tracks give us information of the spatial resolution of the detectors. The theoretical resolutions is $\text{pixel_pitch}/\sqrt{12} \approx 14.5 \mu\text{m}$



Results for 3D Sensors (SCCs)

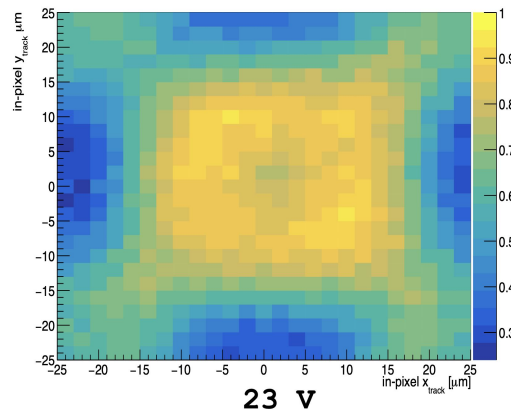
SINTEF 3D sensors $1.7 \times 10^{16} n_{eq}/cm^2$, cluster size and position resolution



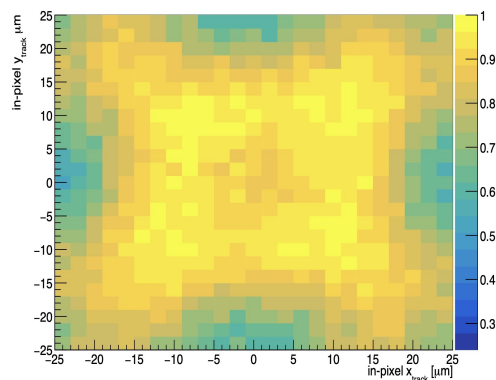
3D sensors



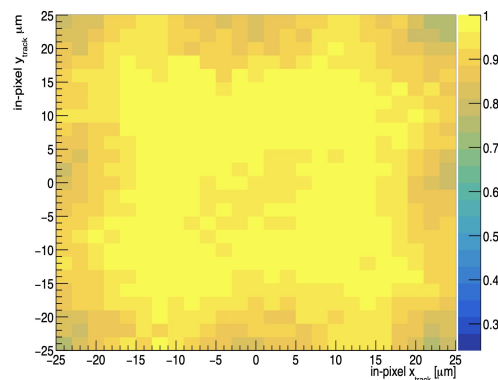
Irradiated SINTEF 3D sensors $1.7 \times 10^{16} n_{eq}/cm^2$



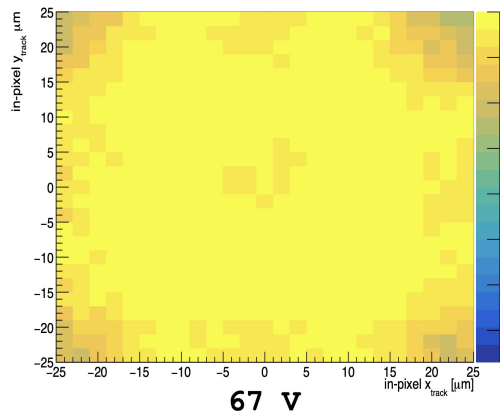
23 V



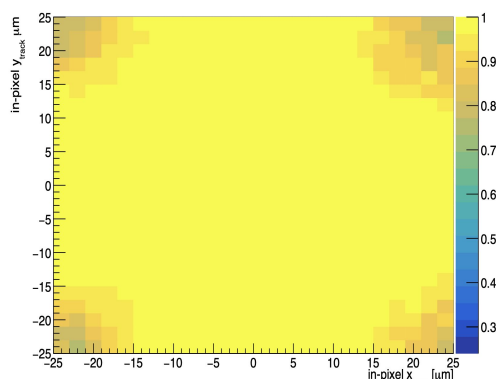
37 V



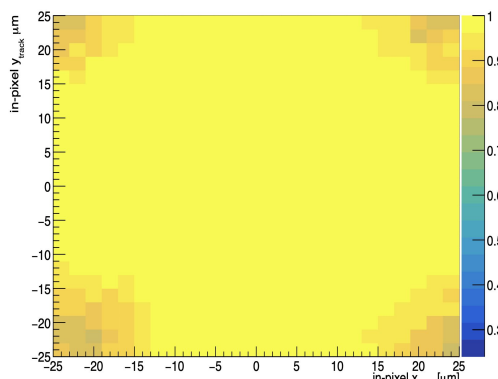
51 V



67 V



82 V

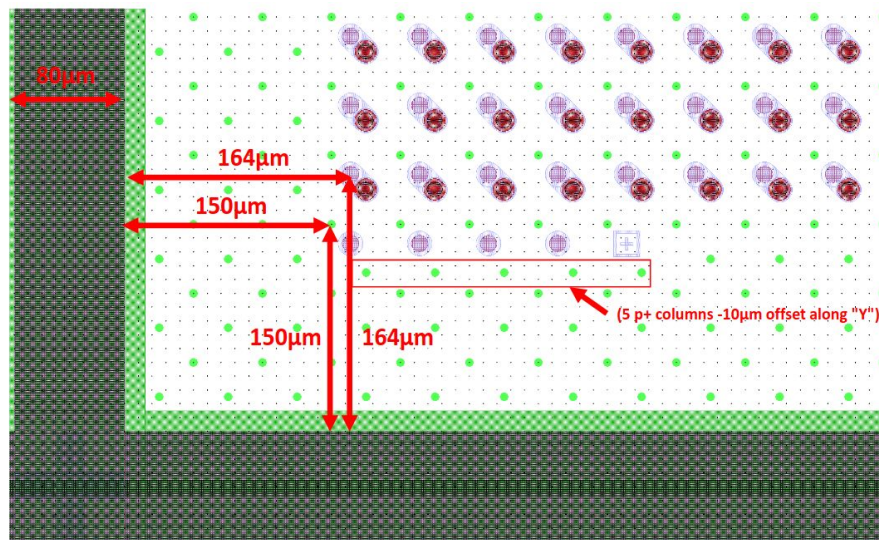
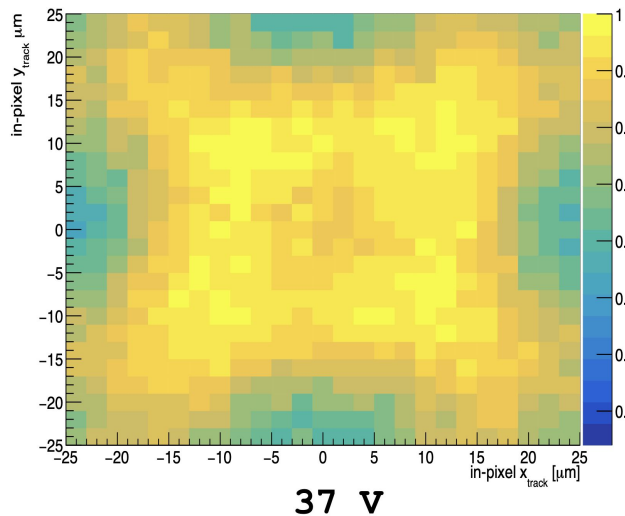


98 V

3D sensors



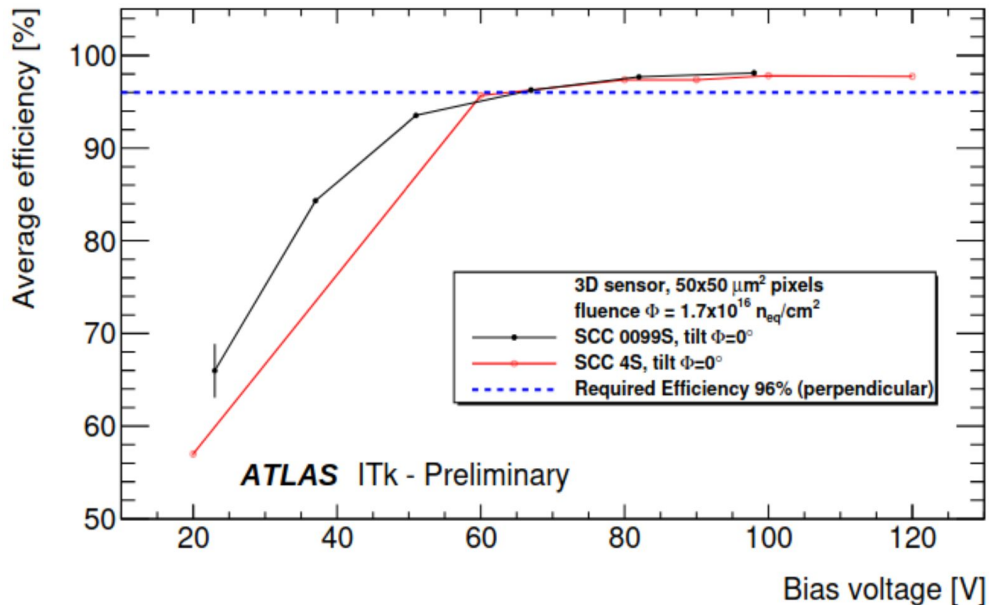
Irradiated SINTEF 3D sensors $1.7 \times 10^{16} n_{eq}/cm^2$. Inefficiency areas appear in the collecting columns of the 3D.



3D sensors



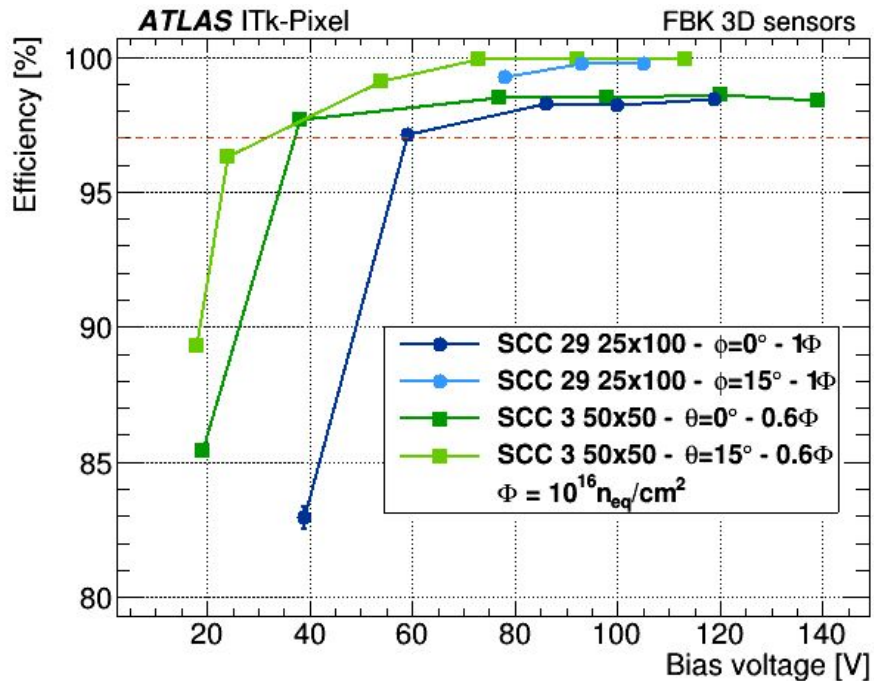
Efficiency of irradiated SINTEF 3D sensors $1.7 \times 10^{16} n_{eq}/cm^2$, both sensors meet the efficiency requirements



3D sensors



Efficiency of irradiated FBK 3D sensors $0.6 \times 10^{16} n_{eq}/cm^2$ and $1 \times 10^{16} n_{eq}/cm^2$, again they both meet the requirements.



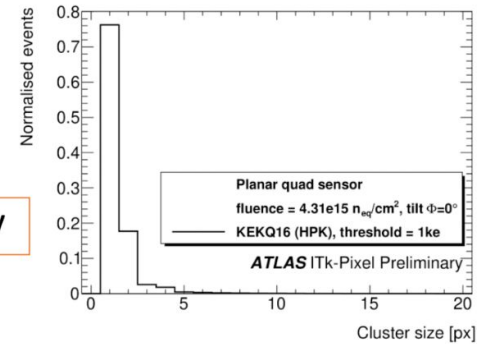
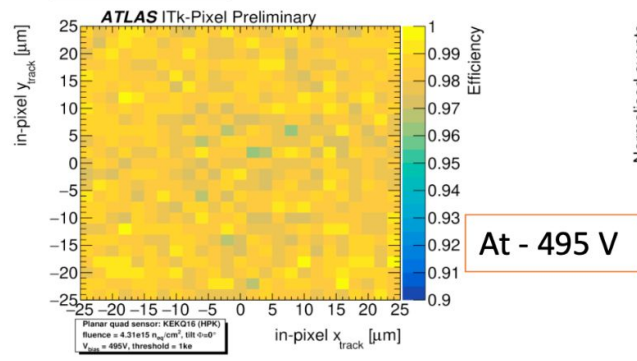
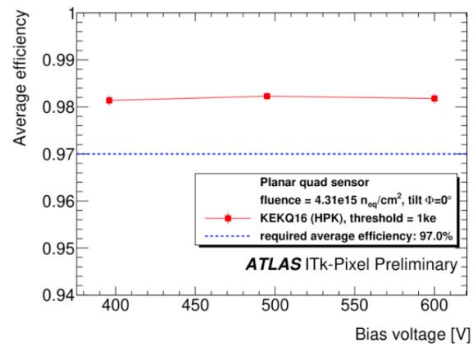
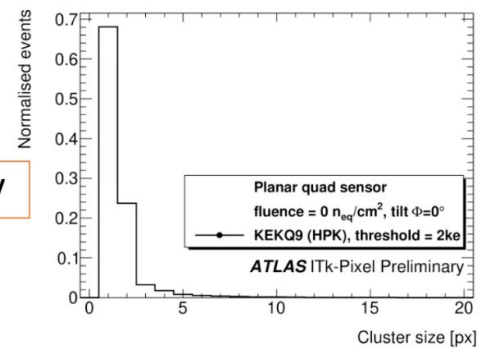
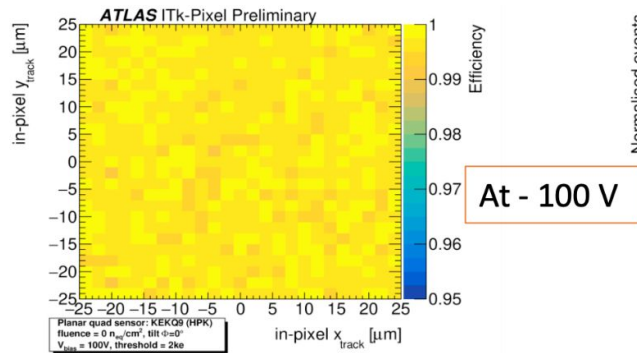
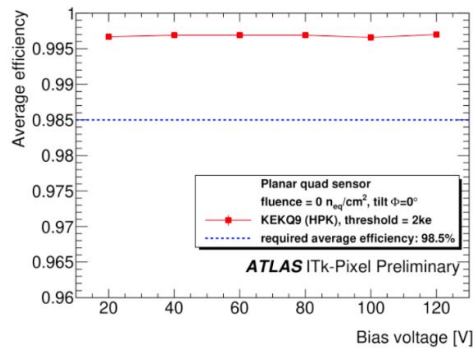


Results for Planar Sensors

Planar sensors

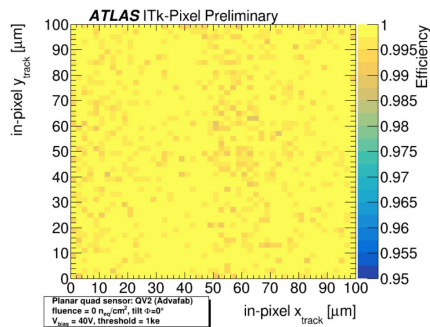


Two HPK planar sensors before and after irradiation, they both meet the efficiency requirements.

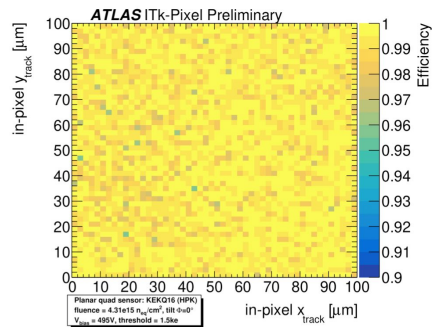


Inefficiency zones may appear depending on the layout of the chips

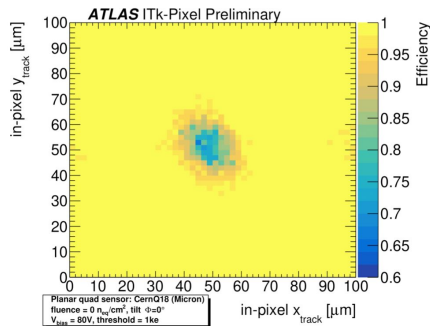
Advafab V2, 40 V, no irradi



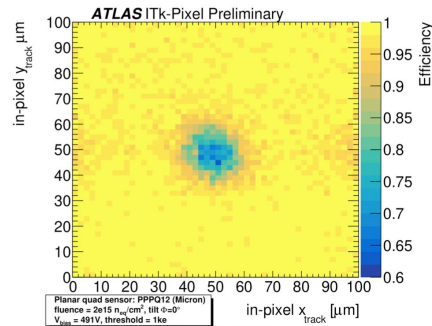
HPK, 495 V, irradiated



Micron, 80 V, no irradi

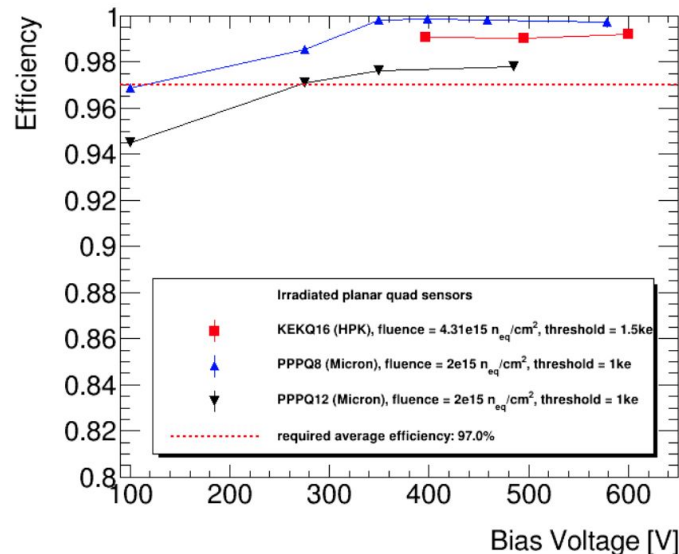
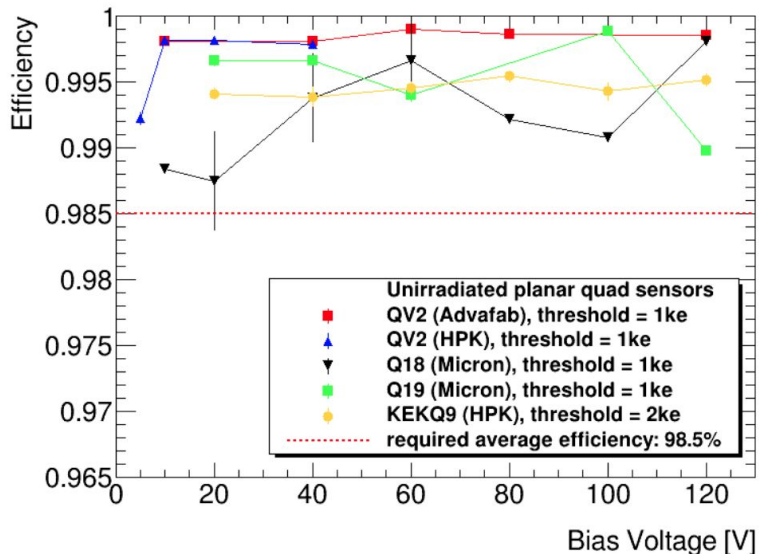


Micron, 491 V, irradiated



Planar sensors

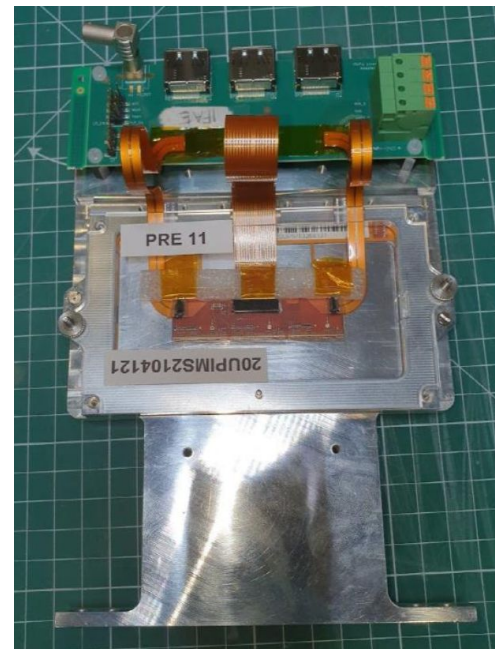
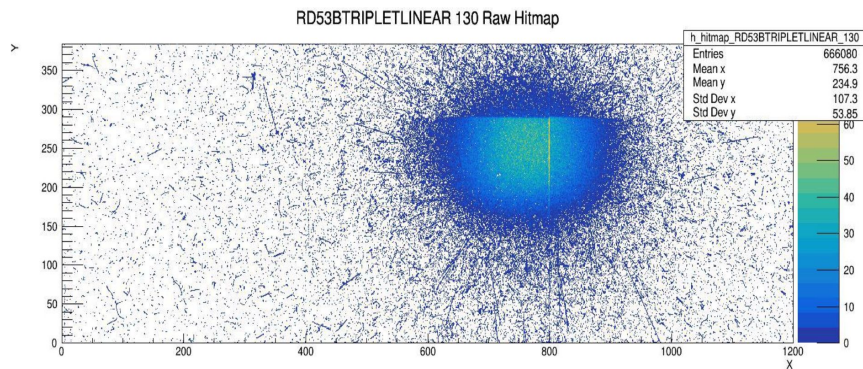
All tested planar sensors meet the efficiency requirements before and after irradiation



Triplet modules



In the 2025 testbeam campaigns a new holder was developed to test linear triplet modules.



The reconstruction is ongoing. We already tested two V1.1 triplets and we are irradiating a V2

Summary



- Unirradiated planar sensors: Advafab V2, HPK V2, two Micron and an HPK V1.1
- Irradiated planars: Two Micron and an HPK
- 3D sensors: Two SINTEF and two FBK modules
- All sensors meet efficiency requirements
- Local inefficiencies from bump bonds and electrode columns
- Triplet analysis ongoing