Up-to-date test beam results of ATLAS ITk Pixel sensors and modules

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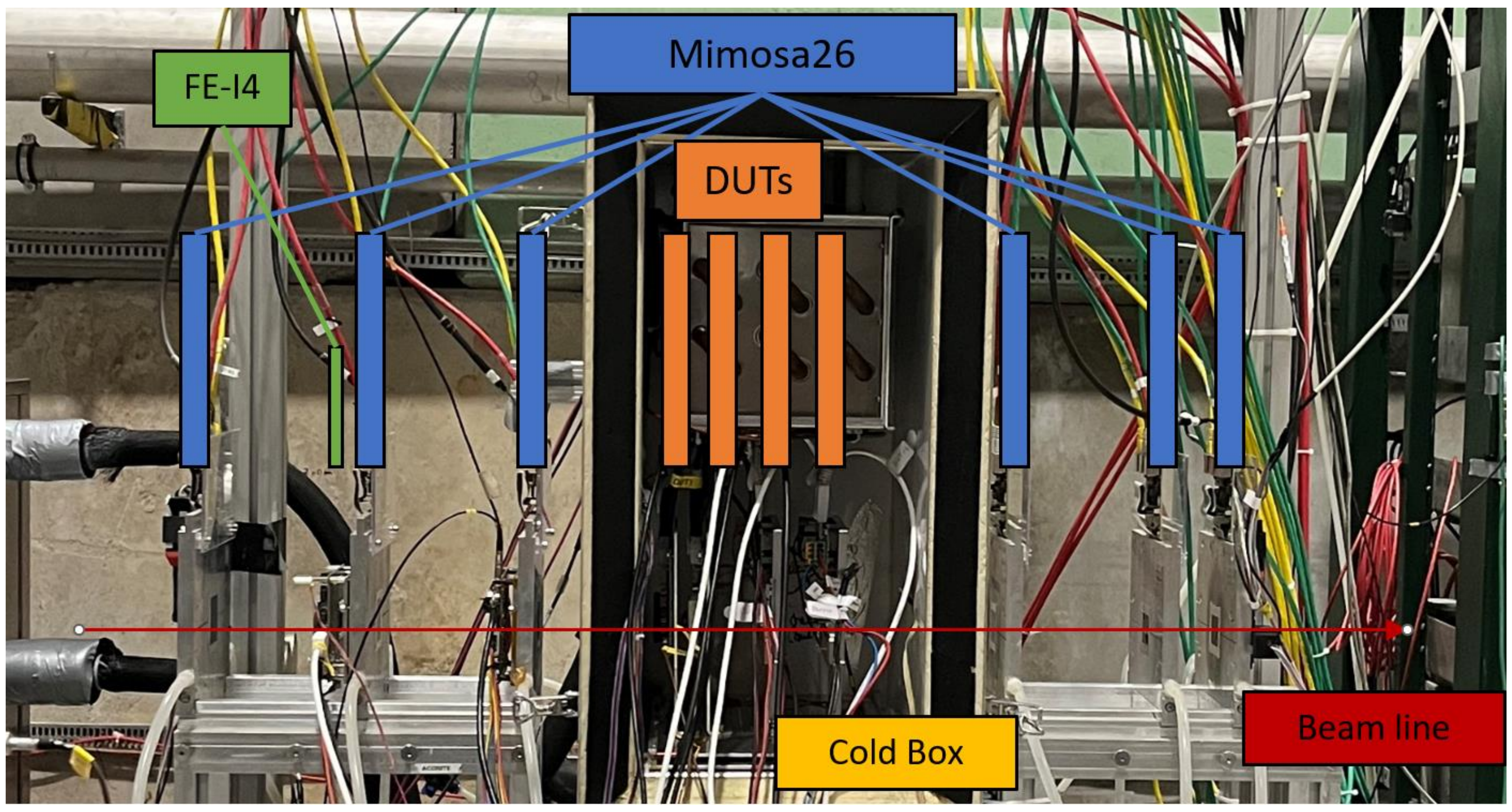
Introduction

HL-LHC

- ATLAS experiment undergoing major transformation for the HL-LHC upgrade
- Fully replacing the Inner Detector
  - New system: all-silicon Inner Tracker (ITk)
- Upgrade needed for measurements at the high-radiation and high-occupancy environment of the LH-LHC

ITk

- Innermost layer (L0) will use 3D sensor technology
  - Radiation fluence up to 2×10^{16} neq/cm²
- Outer layers (L1–L4) will use n-in-p planar hybrid modules
  - Sensor thicknesses 100 μm and 150 μm



EUDAT telescope setup at CERN SPS H6 test beam facility

- 120 GeV pions
- EUDAQV2 as DAQ
- DUTs in a cooling box
- Six Mimosa26 tracking planes
- planar FBK reference pixel module FE-I4

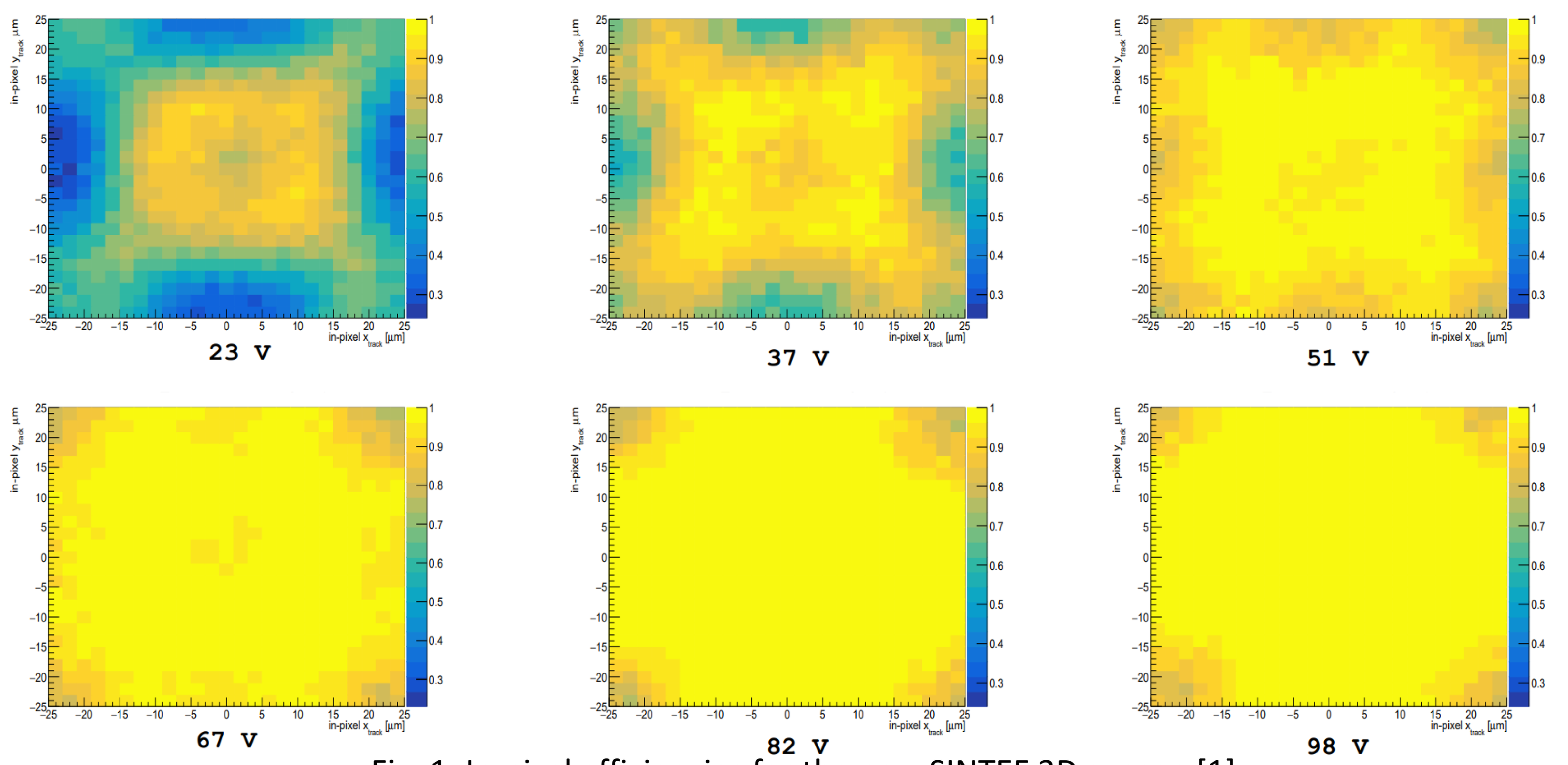


Fig. 1: In-pixel efficiencies for the new SINTEF 3D sensor. [1]

3D Sensors

- SINTEF 3D sensors fabricated using DRIE to form p+ and n+ columns using optimized final passivation layer with a new PECVD Si_3N_4 pass to reduce sensor warping and pixel disconnections in sensor corners
- Sensor irradiated at KIT facility to a fluence of 1.7×10^{16} neq/cm² and tested during test beams
- In-pixel efficiency increases with bias voltage - central inefficiency vanishes by V_{bias} of 51V, corner inefficiencies persist
  - Caused by p+ etched columns - expected from the sensor design
  - Expected for 3D sensors at perpendicular incidence – 15° tilt in ITk
- The ITk requires an efficiency of 96% for irradiated 3D sensors mounted perpendicularly – achieved at V_{bias} of 67V
- Compared to the original design, the new version performs equivalently and matches the efficiency at higher voltages
- SINTEF 3D sensors with new passivation process meet ATLAS specifications

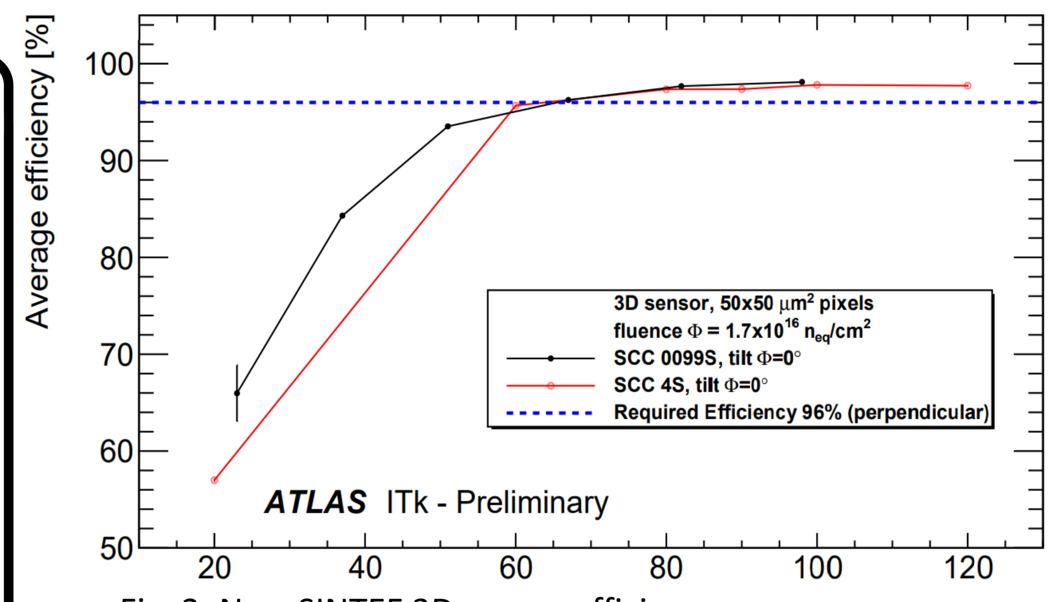


Fig. 2: New SINTEF 3D sensor efficiency compared to the original design (red). [1]

Planar Quad Sensors

- Four readout chips bump-bonded to one sensor
- Interchip region different pixel sizes
- ITk efficiency requirements: 98.5% for non-irradiated; 97% for irradiated
- HPK and Micron quads tested during test beams
- Efficiency requirement met at V_{bias} of 20V (non-irradiated) and 250V (irradiated)

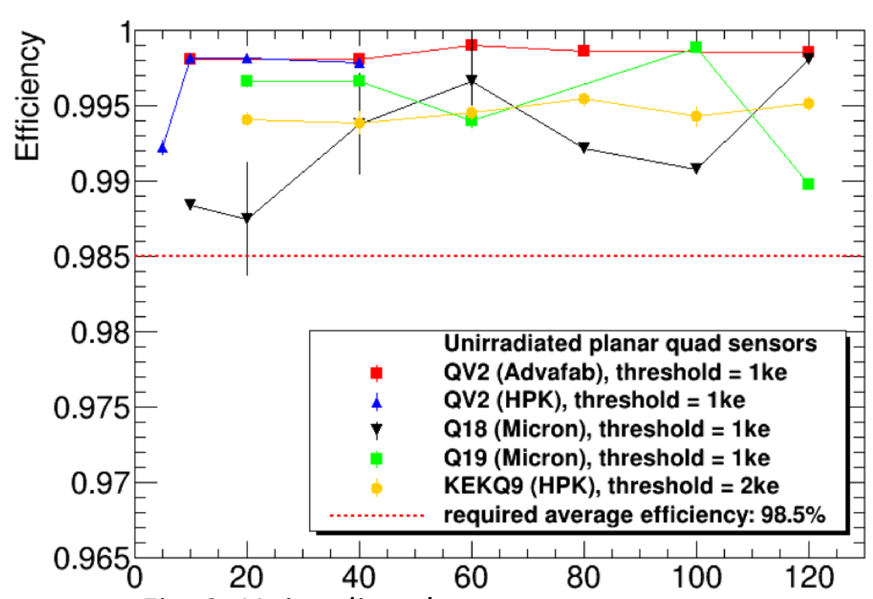


Fig. 3: Unirradiated sensor efficiencies. [2]

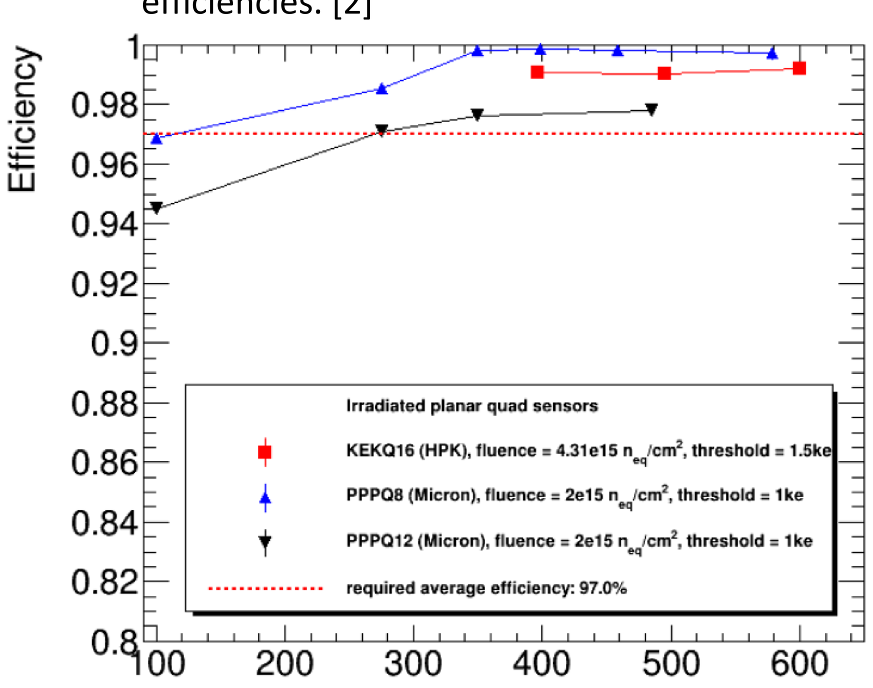


Fig. 4: Irradiated sensor efficiencies. [2]

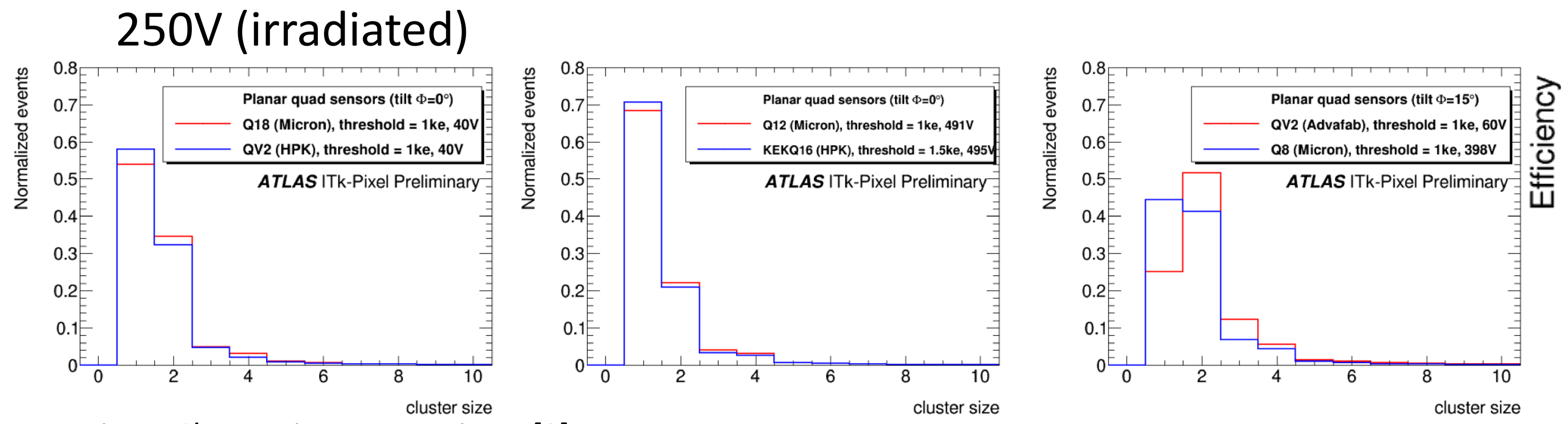


Fig. 5: Cluster sizes comparison. [2]

- Irradiation reduced charge collection efficiency
  - The frequency of cluster sizes > 1 decreased
- Tilting the sensors increased the frequency of larger cluster sizes – irradiation effects remain visible

Conclusions

- Recent test beam results of ATLAS ITk Pixel sensors and modules are showcased, sensors achieve required efficiencies
- Data analysis and further testing of the new triplet-configured 3D sensors and quad-configured planar sensors from the 2025 test beam still ongoing

[1] Huiberts, Simon Kristian. "Test Beam Results of SINTEF 3D Pixel Sensors for the ATLAS Phase II Upgrade." Presented at the 13th Beam Telescopes and Test Beams Workshop, ADEIT – Fundación Universidad-Empresa de la Universitat de València, Valencia, Spain, May 19–23, 2025

[2] Krause, Christopher. "Up-to-date Test Beam Results of ATLAS ITk Pixel Sensors and Modules." Presented at the 20th Anniversary "Trento" Workshop on Advanced Silicon Radiation Detectors, Trento, Italy, February 4, 2025.

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