Testbeam studies of irradiated sensors for the ITk strip detector

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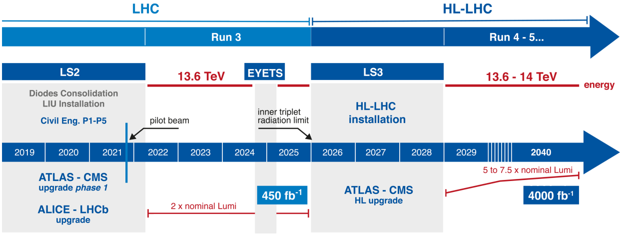
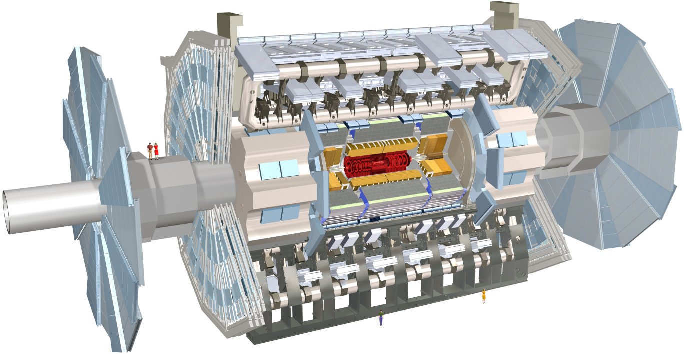
The HL-LHC

- High-Luminosity LHC: upgrade during LS3 (2026 - 2028)
  - more collisions $\rightarrow$ higher stats
  - better study/search for rare processes
- High-luminosity beam poses experimental challenges
  - collision rate saturates detectors and readout
  - radiation environment damages semiconductors



The ATLAS Detector

- ATLAS: large general-purpose detector for observing results of proton-proton collisions in the LHC
  - central Inner Detector (ID) module shown in red

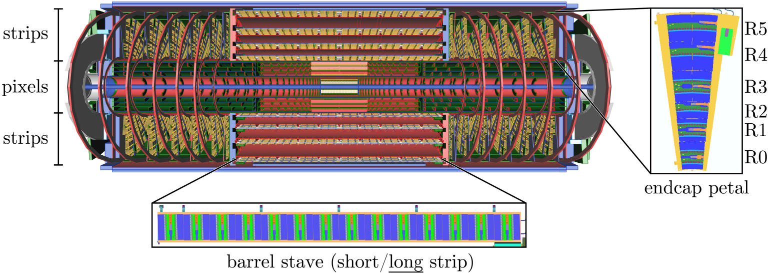


The ITk

- Inner Detector (ID): high-resolution ionization detector
  - uses layers of silicon and gas sub-detectors to track collision products near the interaction point
  - will be unable to keep up with increased luminosity
- Planned successor: Inner Tracker (ITk)
  - higher-resolution, radiation-hard, all-silicon design will provide increased performance necessary for HL-LHC

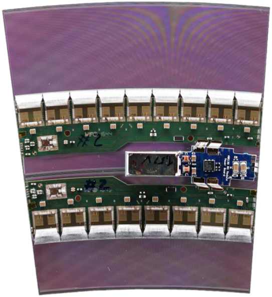
The ITk strip detector

- The ITk will consist of pixel and strip sub-detectors
  - inner layers: pixel sensors for highest tracking performance
  - outer layers: crossed strip sensors to manage channel count
- Strip sensors are held on “stave” and “petal” supports



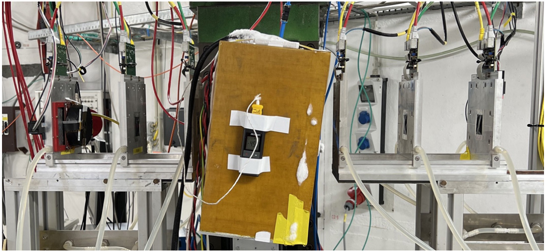
ITk strip sensors

- The ITk strip detector consists of ∼20k silicon sensors
  - sensors are ∼10x10 cm and 320 µm thick
  - strips are ∼80 µm wide and 2 - 6 cm long
- Barrel sensors are rectangular
- Endcap sensors (R0 shown) use a radial layout centered on beam
  - strips radiate from common point
- Readout and power electronics are bonded to each sensor



Testbeam overview

- Testbeam strategy: place device under test (DUT) in beam, with tracking detectors (a "telescope") on either side
  - telescope measures tracks of particles passing through DUT
  - compare tracks with DUT hits to measure performance
- Most ITk strip testbeams are done at DESY-II synchrotron
  - telescope: 6 Mimosa26 pixel sensors for tracking, 1 FEI-4 pixel sensor for added timing precision, scintillator trigger



Testbeam reconstruction

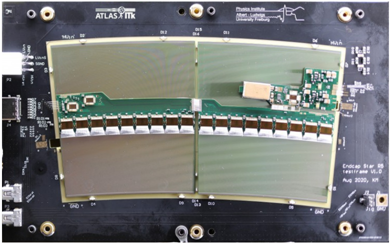
- Key testbeam challenge: telescope "alignment"
  - want ∼10 µm precision on detector positions, but telescope detectors can only be positioned within ∼1 mm
- Solution: work out alignment using tracks in data
  - fit tracks to sensor hits based on known scattering behaviour
  - vary detector geometry in analysis for best track likelihood

Efficiency and noise

- Detection performance with binary readout: efficiency
  - fraction of particles (i.e. telescope tracks) detected by DUT
  - ITk requirement: efficiency $> 99\%$
- Noise performance: occupancy
  - fraction of DUT strips firing in a given trigger with beam off
  - ITk requirement: occupancy $< 0.1\%$
- Goal: find threshold setting that meets both requirements
  - motivated by tracking simulation

Irradiated R5 tests

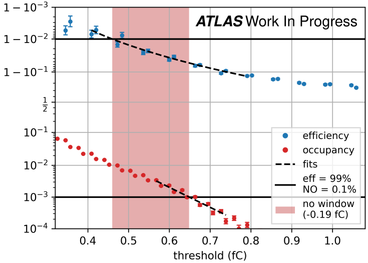
- Results on following slides: irradiated R5 DUT
  - outermost endcap sensor, longest strips → highest noise
  - irradiated to 1.5x expected lifetime fluence to simulate end-of-life performance in HL-LHC
- R5 was tested in 2021 and showed abnormally high noise
  - excess noise later traced to power electronics
  - module re-tested in 2022 with redesigned powerboard



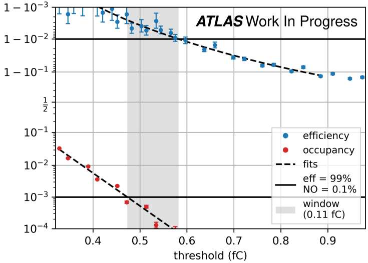
Irradiated R5 results

- Module failed efficiency/noise spec when tested in 2021
  - all thresholds show either low efficiency or high noise
- Passed when re-tested in 2022 with new powerboard
  - window of thresholds with high efficiency and low noise

2021



2022



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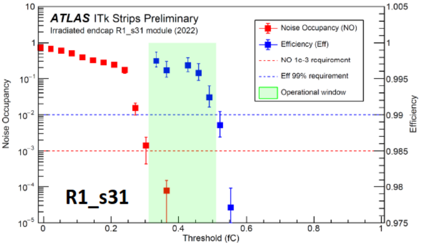
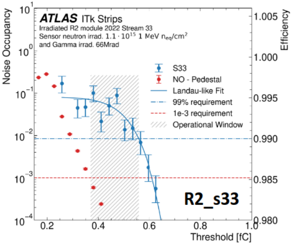
ATLAS ITk

Other testbeam results

- Most other module types have been irradiated, measured at testbeam, and found to meet efficiency/noise requirement
  - LS, SS, R0, R1, R2, R5 passed
  - irradiated R4 measured last week, positive initial results
  - irradiated R3 to be measured this fall





(BTTB 2023)

Outlook

- Upcoming testbeam campaigns in August and September
  - test final sensor type (R3)
  - test sensors irradiated after module assembly (R0, R1)
- New analyses also possible with existing data
  - how does performance change near sensor edge?
  - how does performance change with angle of incidence?
  - how much charge is produced by hits and noise?
- Testbeam studies have given confidence that the ITk strip detector will provide efficient tracking throughout its lifetime