



Performance of ATLAS ITk strip detectors in test beams and simulations

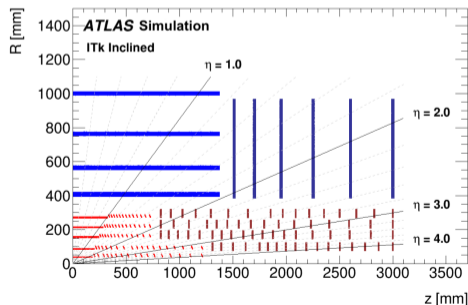
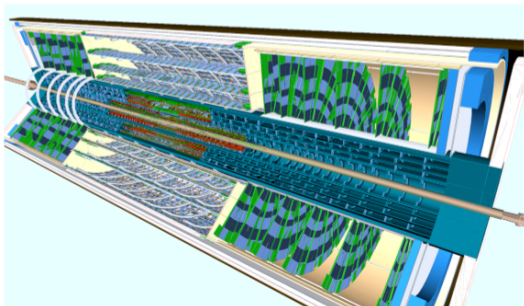
5th Allpix Squared User Workshop, Oxford, UK

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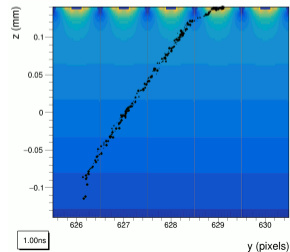
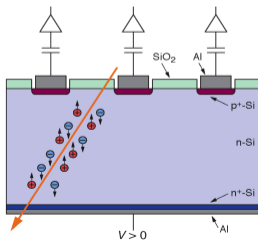
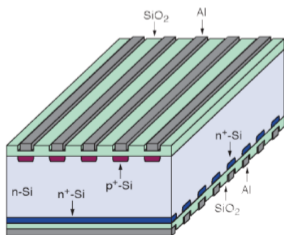
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ATLAS ITk strip detectors

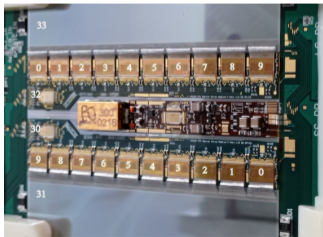
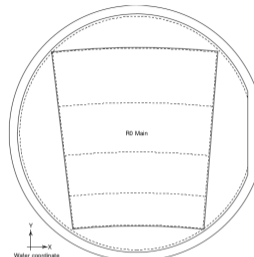
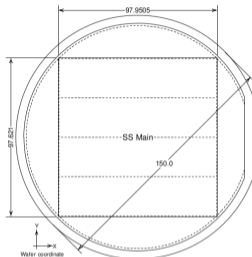
- ATLAS Inner Tracker (ITk) will be the innermost part of ATLAS, designed for High-Luminosity LHC runs (exp. 2029).
 - up to 200 interactions per 25ns bunch crossing (now 40)
- Critical for particle track and vertex reconstruction.
- Utilizes two types of detectors – ITk pixel and ITk strip modules.
 - barrel and end-cap regions
 - strips will cover 165 m² with ~ 18000 modules and 60M channels



- Strip sensor based on multiple discrete $p-n$ junctions with applied high reverse-bias voltage.
- Passage of a charged particle creates free charge carriers.
- Carriers propagate to electrodes according to the applied voltage.
- Monitoring of charge collected on electrodes \rightarrow position of the particle.
- ATLAS ITk strips: n^+ -in- p .
- Binary read-out mode (charge threshold, bools from strips).



- Two module types: barrel and end-cap.
- Same component groups, but different shape, dimensions and layout.
- Beneficial to work in cartesian coordinates for barrel and in polar coordinates for end-cap detectors.
- In Allpix², description using `PixelDetectorModel` and `RadialStripDetectorModel`.

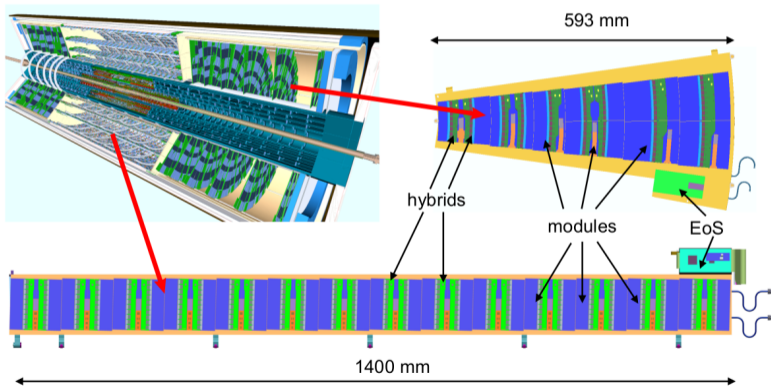


ITk barrel strip modules.

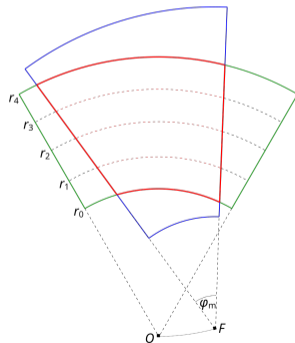
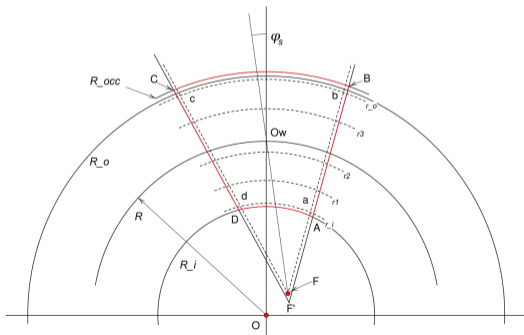


ITk end-cap strip modules.

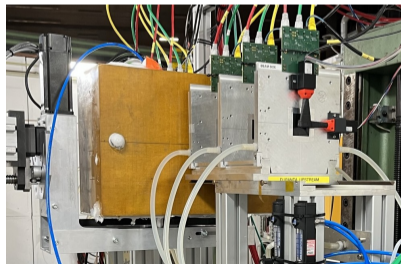
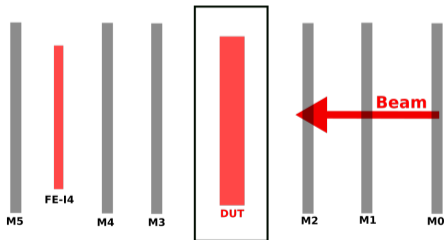
- Strip modules placed on local support structures – provides mechanical and electrical support, cooling.
 - Rectangular barrel modules of 2 types placed on "staves."
 - Trapezoidal end-cap modules of 6 types fit onto a "petal."



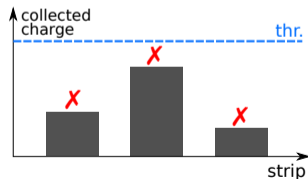
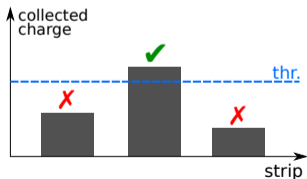
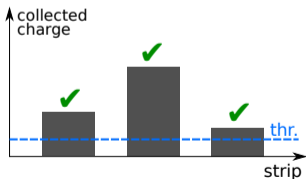
- ATLAS ITk end-cap sensors feature the stereo angle:
Strips do not point to the sensor origin O , but to a focus F .
- Critical for tracking performance of double-sided modules.
- Stereo angle is 20 mrad (1.15°) for every ITk strip end-cap sensor.



- Pre-production module prototypes characterized using test beam measurements.
- DUT placed in a polystyrene box for dry-ice cooling ($< 40^{\circ}\text{C}$).
- EUDET-type beam telescopes – six Mimosa planes and FE-I4 timing plane.
- Control and read-out of the telescope and device-under-test (DUT) using EUDAQ2.
- Data reconstruction and analysis using Corryvreckan.

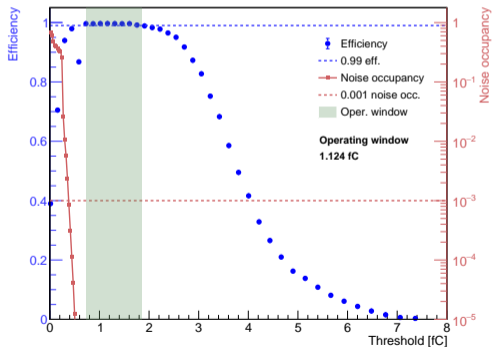


- Module characterization by performing threshold scans:
 - Systematically varying the DUT charge threshold (for a hit to be called).
 - Observing several parameters as a function of the threshold.
- At low thresholds, noise creates a lot of false hits.
- At high thresholds, real hits are ignored.
- Requirement: window of thresholds with $> 99\%$ efficiency and $< 0.1\%$ noise occupancy.

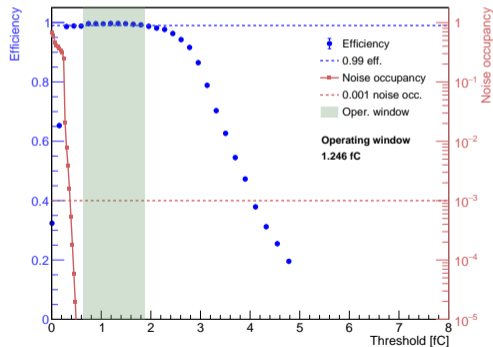


- Test beam results of an ITk R2 end-cap module measured at DESY Hamburg.
- Wide operating window found for multiple all module segments.

June2022-unirradR2 (perpendicular), s31, ASICs 2,3

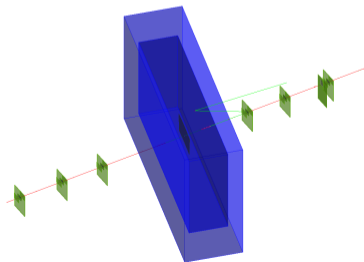
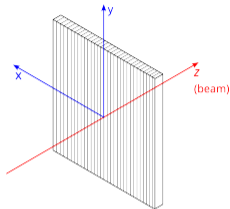


June2022-unirradR2 (perpendicular), s33, ASICs 2,3



Test beam simulations

- Full test beam simulation of an unirradiated end-cap ITk R2 module.
- DUT rotated around the y -axis by $5\text{--}25^\circ$.
- Comparison to reconstructed test beam measurements, using the same Corryvreckan build.
- Simulation parameters:
 - Accurate detector geometry, simple cooling box model.
 - Linear electric field model.
 - Electronics noise taken from module measurements.
 - Capacitance-based cross-talk model.
- Primary outputs are efficiency, mean cluster size and residual distributions.



- A cross-talk model based on inter-strip, strip-to-backplane, and coupling capacitances. From ATL-INDET-2003-011.

Charge to the FE channel:

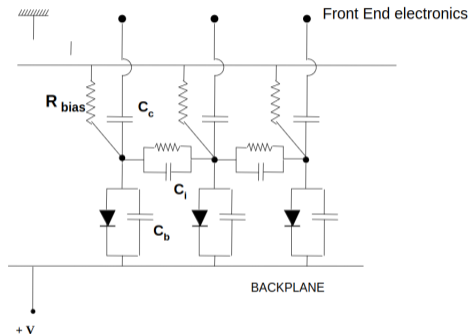
$$Q_{FE} = \frac{C_c}{C_i + C_b + C_c}$$

Charge to adjacent strips:

$$Q_s = \frac{C_i}{C_i + C_b + C_c}$$

Charge to the backplane:

$$Q_b = \frac{C_b}{C_i + C_b + C_c}$$

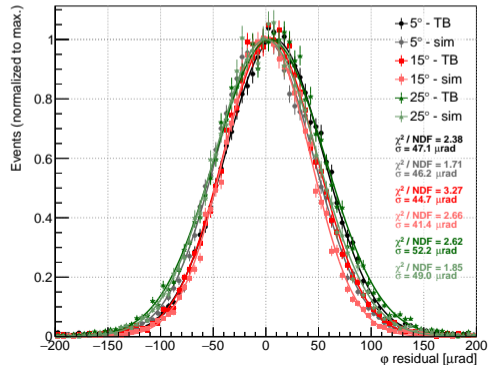
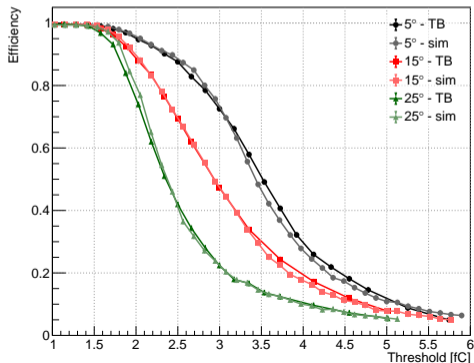


- In Allpix², cross-talk implemented in the CapacitiveTransfer module. User defines the coupling_matrix:

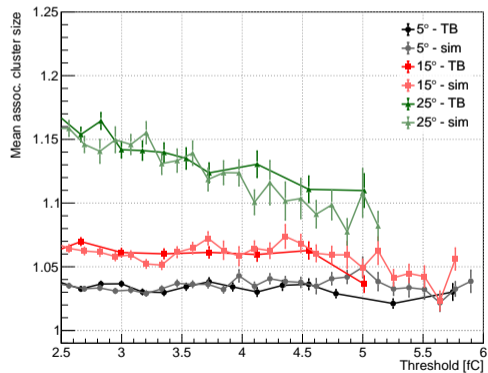
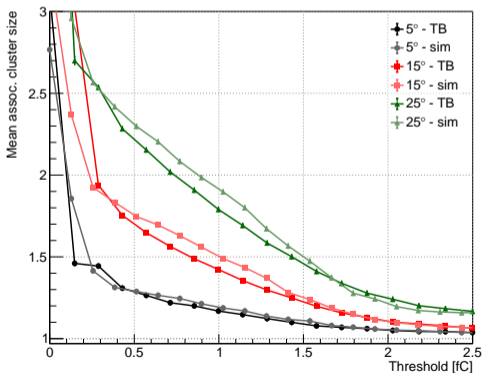
no crosstalk: $\begin{pmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$

1.4% to each adjacent strip, 1% lost to backplane: $\begin{pmatrix} 0 & 0 & 0 \\ 0.014 & 0.961 & 0.014 \\ 0 & 0 & 0 \end{pmatrix}$

- Efficiency generally in very good agreement between simulations and test beams.
 - Slope of the curves slightly different.
- Residual distributions mostly match, slightly better results in simulations:
 - angular resolution of 41.4–49.0 μrad in simulations,
 - angular resolution of 44.7–52.2 μrad in test beam measurements.



- Simulations give slightly higher cluster sizes at low thresholds.
- Good description at higher thresholds.



- The ATLAS Inner Detector will be replaced with the ITk to cope with HL-LHC conditions.
- Pre-production and testing of ITk strip modules is ongoing.
- Allpix² has been used for performance studies of ATLAS ITk strip modules.
- Comparison of simulations and test beams shows good agreement in key performance metrics.

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The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF).