Test beam simulations of the ATLAS ITk Strip End-cap detectors

4th Allpix^2 User Workshop

Radek Privara

Palacky University Olomouc;
Institute of Physics, Czech Academy of Sciences

(radek.privara@cern.ch)

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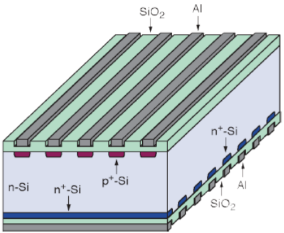
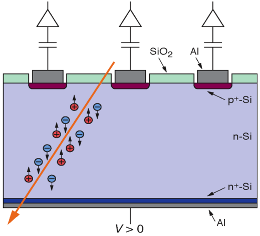
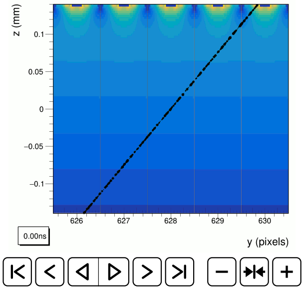
ATLAS ITk Strip detectors

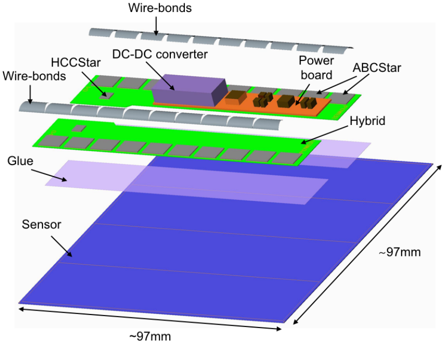
- Strip sensor based on multiple P-N junctions with applied high reverse-bias voltage.
- Passage of a charged particle creates free charge carriers.
- Carriers propagate to electrodes according to the applied voltage.
- Monitoring of charge collected on electrodes → position of the particle.



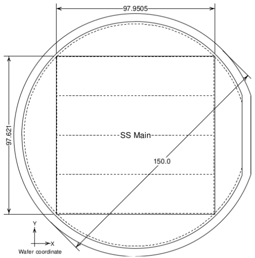


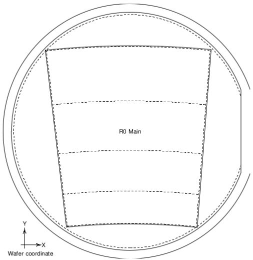


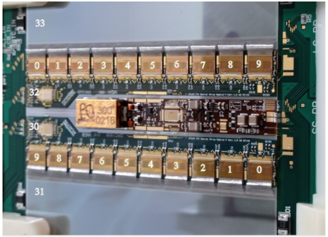
- An ITk strip module has a number of components:
  - silicon strip sensor,
  - read-out ASICs, wirebonded to strips,
  - Hybrid Controller Chips (HCC),
  - power board: low-voltage DC-DC converter, high-voltage circuit,
  - Autonomous Monitor and Control (AMAC) chip.



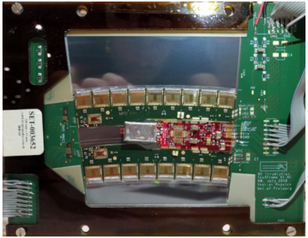
- Two module types: Barrel and End-cap.
- Same component groups, but different shape, dimensions and layout.
- Beneficial to work in cartesian coordinates for Barrel and in polar coordinates for End-cap detectors.





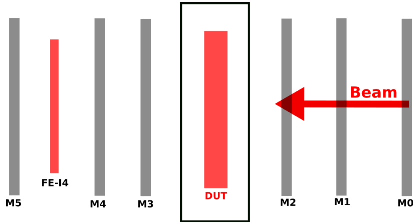


ITk Barrel strip modules.

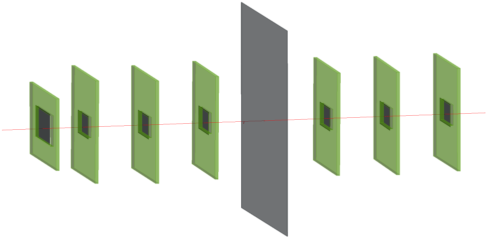


ITk End-cap strip modules.

- Pre-production modules characterized using test beam measurements.
- 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.
- Outputs of interest:
  - detection efficiency and noise occupancy (ATLAS ITk Collaboration performance requirement),
  - residuals,
  - cluster sizes,
  - effect of non-perpendicular beam incidence on the above.

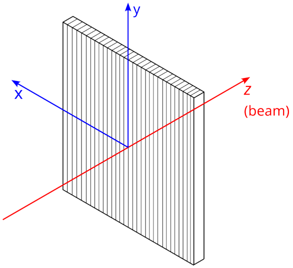


Telescope layout.

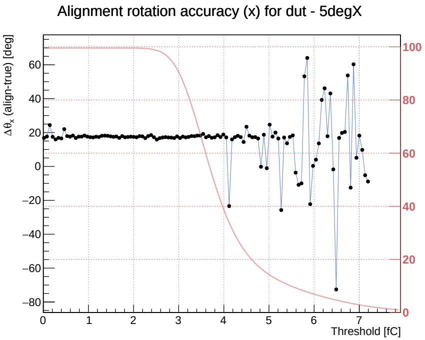

Telescope layout in Allpix^2 simulations.

Alignment studies

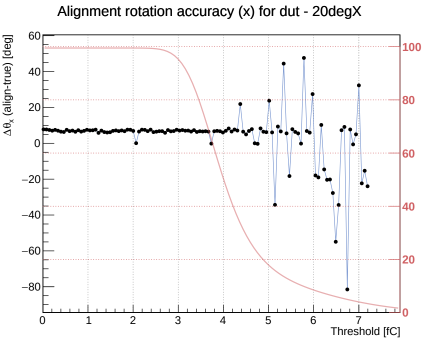
- **Motivation:** issues in the past with alignment of strip detectors with non-perpendicular incidence angles.
- Which angles can be aligned safely and accurately?
  - Can't answer using test beams as we don't accurately know the true DUT orientation.
- In simulations, positions and orientations are absolute $\rightarrow$ comparison to results after running alignment.
  - Starting angle for alignment was very close to the true angle.
  - Primary output: difference between the aligned and true angle.
- Exploring the effect of misalignment.
  - Corresponds to inaccurately measured angles during a test beam.



- Alignment of the x-axis angle is:
  - Stable at low and middle thresholds but consistently wrong.
  - Unstable at higher thresholds.
  - ⇒ Not recommended.



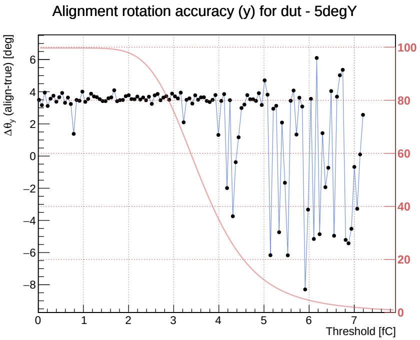
DUT rotated by 5 degrees around x-axis.



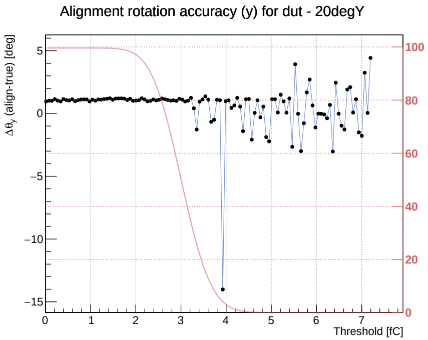
DUT rotated by 20 degrees around x-axis.

- Alignment of the *y*-axis angle is:
  - Stable at low and middle thresholds but consistently wrong.
  - Unstable at higher thresholds.

  ⇒ Not recommended.

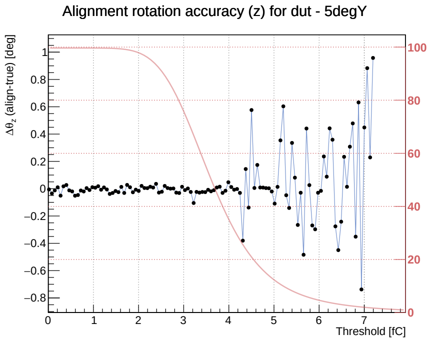


DUT rotated by 5 degrees around *y*-axis.

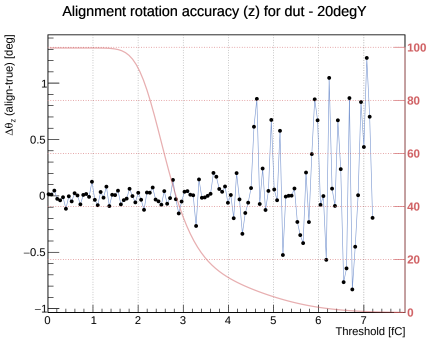


DUT rotated by 20 degrees around *y*-axis.

- Alignment of the *z*-axis angle is:
  - Accurate at low and middle thresholds
  - Less accurate at higher thresholds, but still perfectly acceptable.
  - ⇒ Recommended.

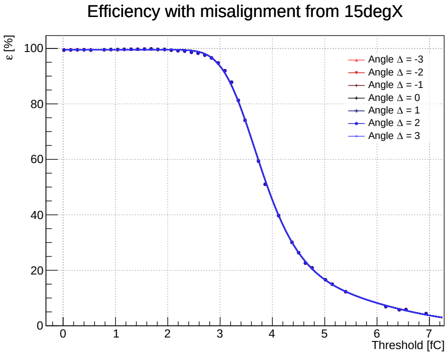


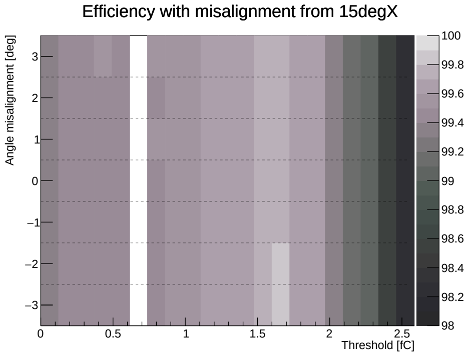
DUT rotated by 5 degrees around *y*-axis.



DUT rotated by 20 degrees around *y*-axis.

- Since we don't align *x*- and *y*-axis angles, what if we measure them wrong during a test beam?
- Reconstruction process is given an incorrect starting angle and is not allowed to align it.
  - Shifts from -3° to 3° from the true angle.
- Comparison of efficiencies obtained when misaligned, with focus on low threshold.
- Small effect on the efficiency if incorrect *x*-axis angle is provided.





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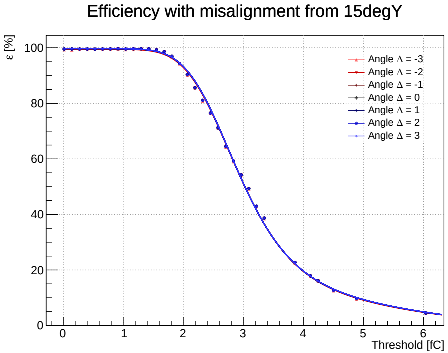
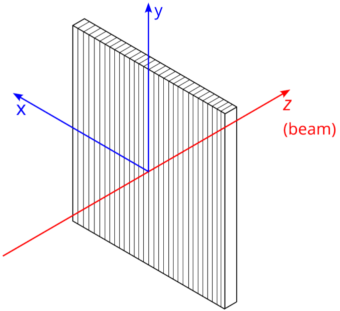
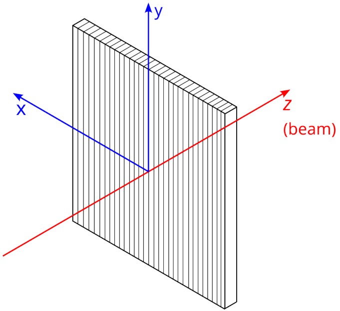


- In the context of strip detectors, alignment of:
  - × *x*-axis angle is not recommended,
  - × *y*-axis angle is not recommended,
  - ✓ *z*-axis angle is recommended.
- Fortunately, slightly inaccurate measurement of *x*- and *y*-axis angles doesn't affect the reconstructed efficiency.

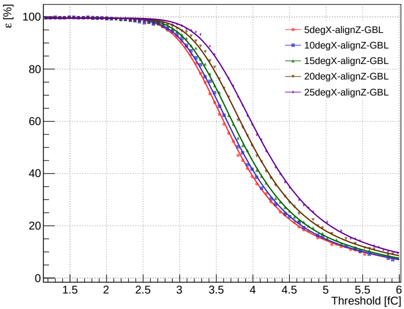


Test beam simulations

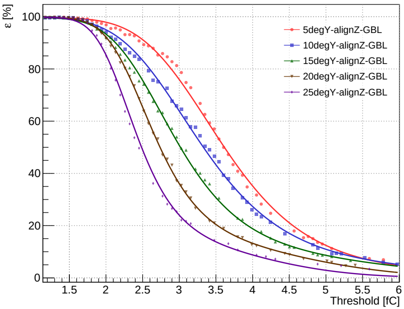
- **Goal:** Provide reference results to compare against reconstructed test beam data.
- DUT rotated around x- and y-axis by 5°, 10°, 15°, 20° and 25°.
- Rotation effects:
  - x-axis: effectively shortens the strips and increases the sensor thickness.
  - y-axis: effectively narrows the strips, overlaps them and increases the sensor thickness.
- Primary outputs are efficiency, mean cluster size and residual distributions.
- Test beam data reconstruction is ongoing.



- *x*-axis: larger angles lead to a slight increase in efficiency as more charge is deposited and collected.
- *y*-axis: larger angles lead to efficiency dropping sooner as deposited charge is shared among multiple strips.

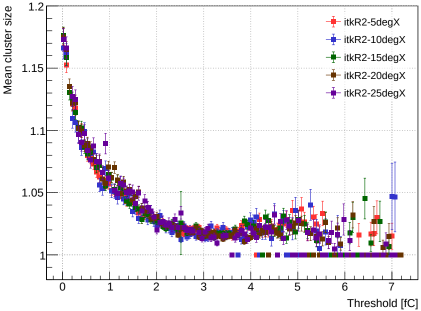


DUT rotated around *x*-axis.

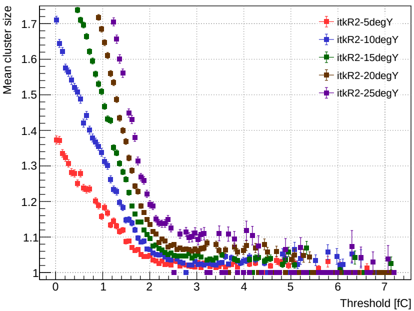


DUT rotated around *y*-axis.

- *x*-axis: larger angles have a negligible effect.
- *y*-axis: larger angles significantly increase charge sharing among strips.

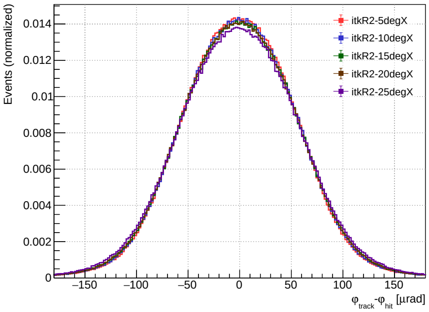


DUT rotated around *x*-axis.

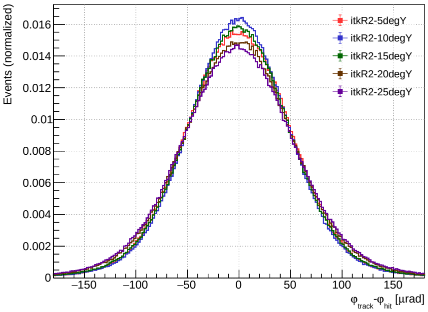


DUT rotated around *y*-axis.

- Residuals in polar coordinates (r, φ) instead of cartesian (x, y) due to End-cap sensor geometry.
- Very small effect of either rotation on φ-residuals distribution.



DUT rotated around x-axis.



DUT rotated around y-axis.

- Allpix^2 has been used for performance studies of ATLAS ITk strip modules.
- Simulations used to explore alignment accuracy of strip sensors.
  - → Recommendations which angles should or shouldn't be aligned.
  - → Effect of a mismeasured angle is fairly small.
- Reference results from test beam simulations obtained for comparison to actual data.
  - Data reconstruction ongoing.

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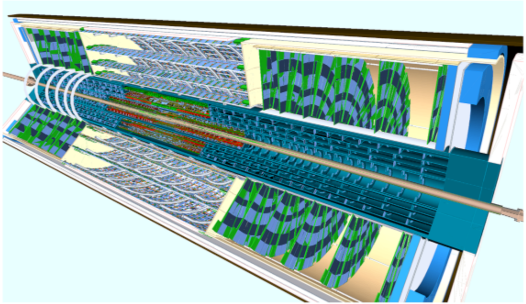
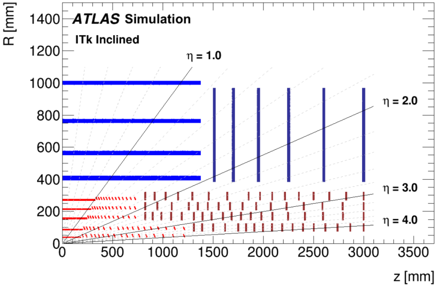
Backup

- ATLAS Inner Tracker (ITk) is the innermost (future) part of the ATLAS Detector.
- Critical for particle track and vertex reconstruction.
- Utilizes two types of detectors – ITk Pixel and ITk Strip segments.

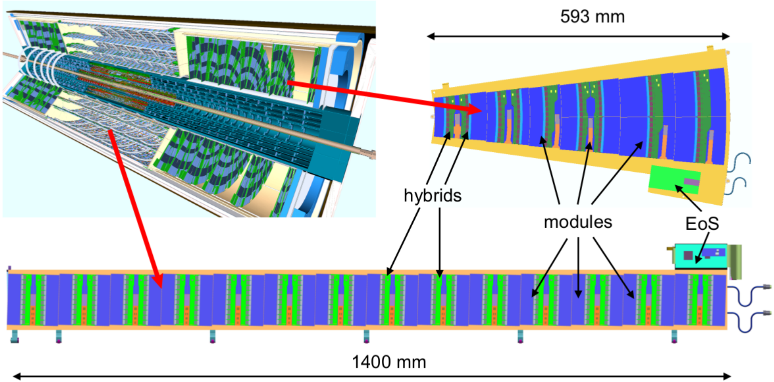


ATLAS ITk visualization.



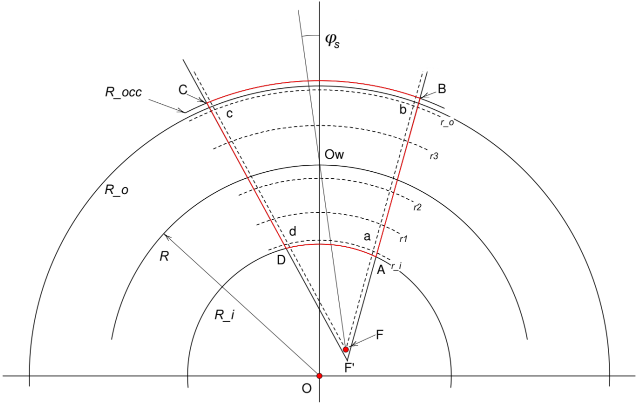
ATLAS ITk layout: pixel modules in red, strip modules in blue.

- Barrel and end-cap strip modules differ in size and shape.
  - Barrel modules are rectangular and placed on "staves."
  - End-cap modules are trapezoidal, have various shapes (R0–R5) to fit onto a "petal."

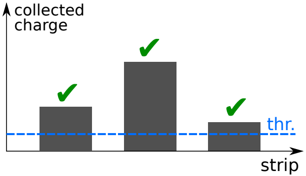


Barrel and end-cap regions of the ITk. Barrel modules on a stave, end-cap modules on a petal.

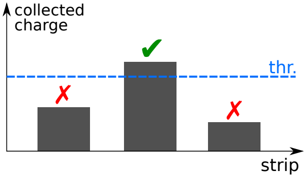
- ATLAS ITk end-cap sensors feature the stereo angle:
  Strips do not point to the sensor origin O, but to a focus F. Point F is obtained by rotating point O around the sensor center Ow by the stereo angle φ_s.
- Critical for tracking performance of double-sided modules.
- Stereo angle is 20 mrad (1.15°)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



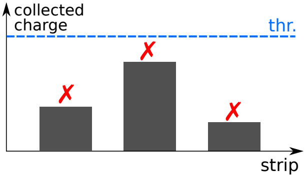
- Module characterization by performing threshold scans:
  - Systematically varying a charge threshold (for a hit to be called).
  - Observing several parameters as a function of the threshold.
- At low thresholds, noise creates a lot of false hits.
- At high thresholds, real hits are ignored.



Low thresholds are noisy.



Medium thresholds are fine.



High thresholds have no hits.