Testbeam studies of irradiated modules for the ATLAS ITk Strip upgrade

10th Beam Telescopes and Test Beams Workshop

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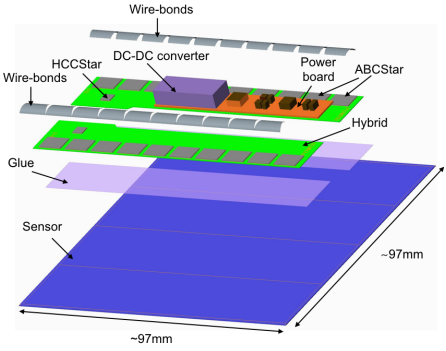
1. ATLAS detector upgrade
2. Test beam setup (DESY-II)
3. Test beam campaigns
4. Summary

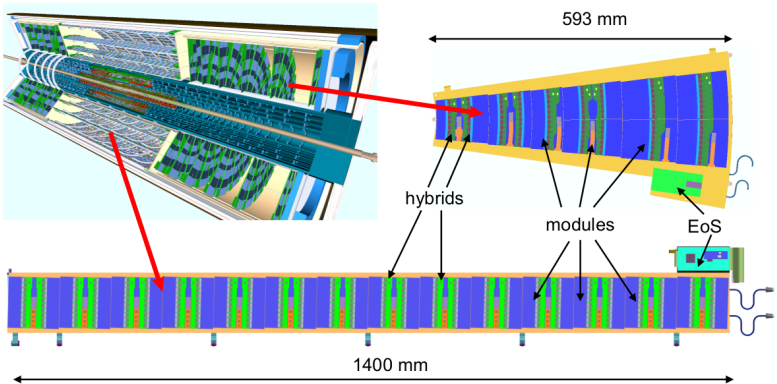
ATLAS detector upgrade

- Strip module components:
  - 320 μm-thick n^+-in-p silicon sensor with AC coupled strips.
  - PCB hybrids glued to the sensor.
  - Hybrid Controller Chips (HCC).
  - Read-out ASICs (ABCStar).
  - Power board: low-voltage DC-DC converter, high-voltage circuit.



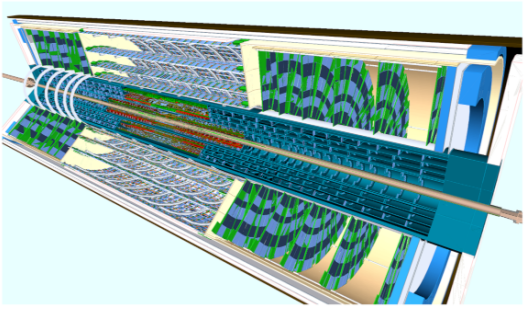
A barrel strip module layout with components.

- Strip modules come in two types - barrel and end-cap. Difference is 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."

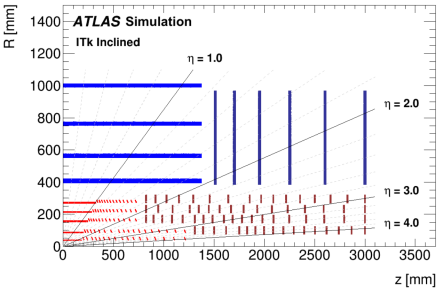


Barrel and end-cap regions of the ITk. Barrel modules on a stave, end-cap modules on a petal.

- ATLAS Inner Tracker (ITk) will be the innermost part of the ATLAS Detector.
- Critical for particle track and vertex reconstruction.
- Divided into two regions – barrel and end-cap.
- Utilizes two types of detectors – ITk Pixel and ITk Strip segments.



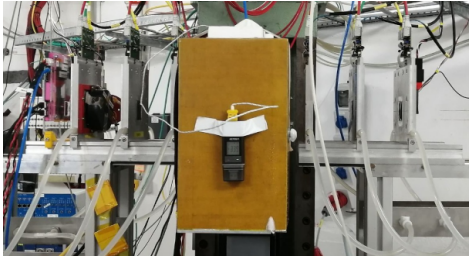
ATLAS ITk visualization.



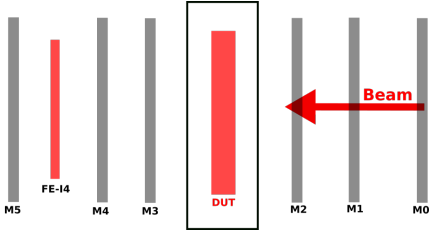
ATLAS ITk layout: pixel modules in red, strip modules in blue.

Test beam setup (DESY-II)

- Six Mimosa26 planes and an additional FE-I4 timing plane (with USBPix read-out).
- EUDAQ2 used for control and read-out of the telescope and the DUT.
- Tracking resolution of 5–10 μm.
- DUT placed in a cold box and operated at -500V bias voltage.



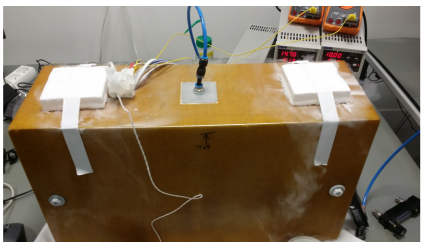
DURANTA Telescope at DESY-II, DUT cold box in the center.

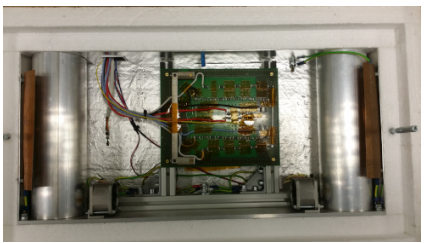


Telescope layout.

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).

- Polystyrene cold box with an adjustable module holder.
- Cooling towers for dry ice, fans for air circulation in the box.
- Air temperature in the box well below -40 °C.
- Dry ice refilled every ∼2 hours.
- The box moves as dry ice is refilled ⇒ re-alignment between runs required during reconstruction.

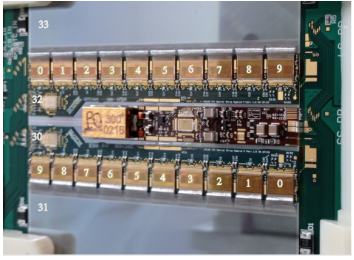




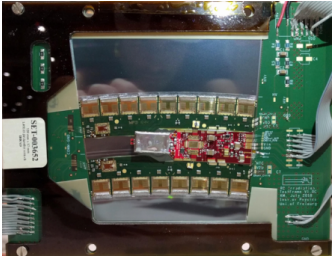
- Reconstruction of data using EUTelescope and Corryvreckan frameworks.
  - Efforts to move all our reconstruction flows to Corryvreckan due to higher speed and better support and functionality.
- Reconstruction and analysis done separately for each hybrid on a module.
- Tracking performed with the General Broken Lines (GBL) algorithm.
- For efficiency calculation, tracks are considered matched if there is a cluster on the DUT within 110 μm.
- Collected charge evaluation done only using tracks passing close to strip center.

Test beam campaigns

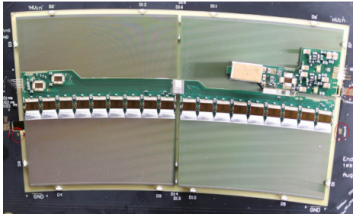
- Past year: 4.5 weeks of beam time during 3 campaigns.
  - This year: 7 weeks of beam time during 4 campaigns.
- Barrel short-strip (SS) and end-cap R0 and R5 modules tested.
  - Modules assembled from irradiated components (pre-production A).
- Currently testing an irradiated R1 and an unirradiated R2 module at DESY-II.
- Plans to measure SS and R0 modules (irradiated at CERN IRRAD) at CERN SPS.
- Potentially testing of the remaining irradiated end-cap modules throughout the year (R2, R3, R4).



SS module; neutron irradiated sensor, X-ray irradiated ASICs and powerboard.

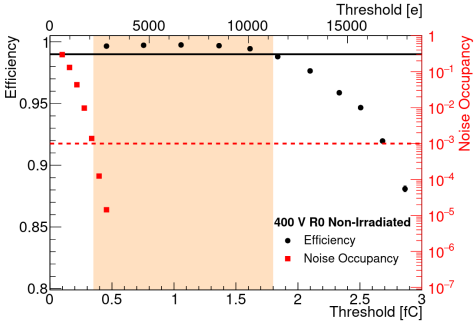


R0 module; neutron irradiated sensor, X-ray irradiated ASICs and powerboard.

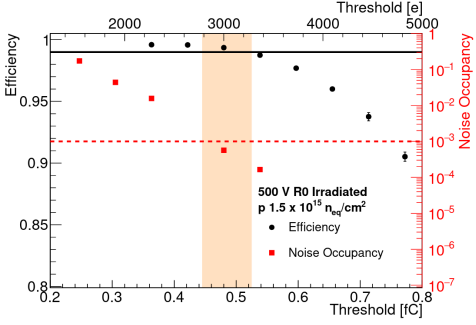


R5 module; neutron irradiated sensor.

- Official requirement for end-of-life modules: operating threshold window with S/N ratio > 10.
  - Equivalent to detection efficiency $> 99\%$ with noise occupancy $< 0.1\%$.
- Easy to satisfy for unirradiated modules, very difficult for irradiated modules:
  - Unirradiated: 1.40 fC wide window
  - Irrad. at $1.5 \times 10^{15} n_{eq}/cm^2$: 0.08 fC wide window



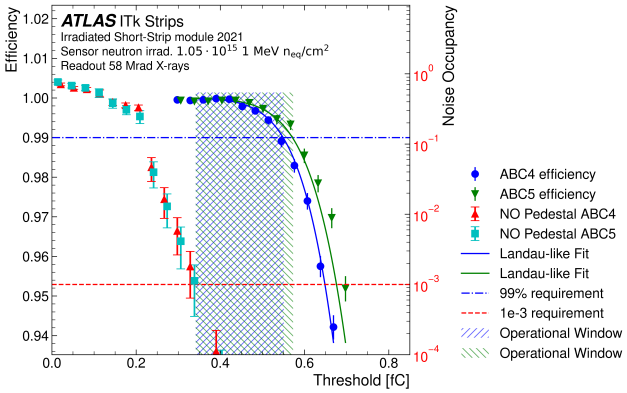
Operating window for an unirradiated module[1].



Operating window for an irradiated module[1].

[1] Edoardo Rossi's dissertation (http://cds.cern.ch/record/2743994)

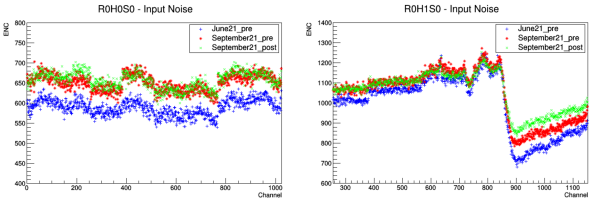
- ATLAS ITk Short-Strip module passed.
- An operating window (0.22 fC wide) with performance requirements met.
- S/N ratio of 16.9:
  - median signal: 1.52 fC,
  - median noise: 0.09 fC.

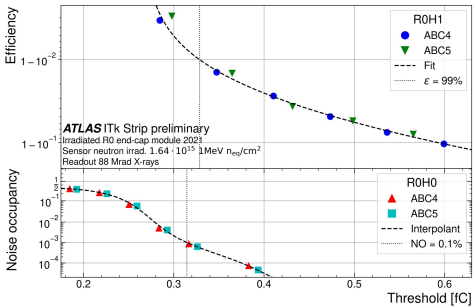


Operating window for the irradiated SS module[1].

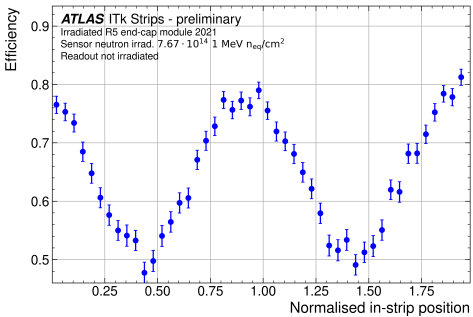
[1] ATL-COM-ITK-2021-049 (https://cds.cern.ch/record/2798394)

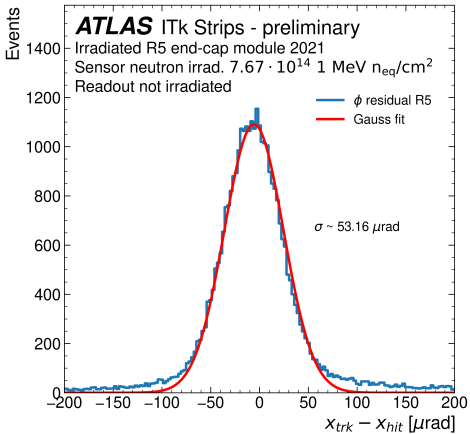
- Data from H0 not yet fully reconstructed due to desynchronization issues ⇒ poor efficiency, no operating window found yet.
- Noise on H1 unexpectedly high (even after annealing), but data reconstructed and efficiency obtained ⇒ no operating window found on H1.
- Small operating window (0.09 fC) when combining efficiency of H1 and noise of H0.





- Data analysis still in progress.
- Desync issues, the cause is not well understood.
- Analysis of synced data is promising.





Summary

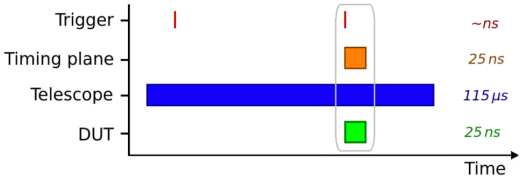
- Prototype strip modules are tested to verify their suitability for deployment in the ATLAS Inner Tracker.
  - Assessment based primarily on the S/N ratio of fully irradiated modules.
- Desynchronization issues prevent full reconstruction of measured data.
  - The cause is being investigated.
- 3 modules measured during 4.5 weeks of beam time in the past year.
  - SS: Good results, large operating window found.
  - R0: Currently no operating window due to high noise and desync issues.
  - R5: Analysis in progress; desync issues but preliminary results are promising.
- Plans to measure 7 modules during 7 weeks of beam time this year.

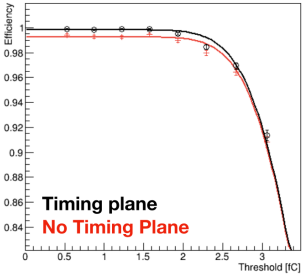
Thanks for your attention!

Backup

- Telescope integration time is long (115 μs), reconstructed tracks in this window do not carry finer timestamps $\Rightarrow$ Track association to DUT events is problematic.
- Timing plane adds fine timestamps to tracks, ensuring they can be matched to DUT events.
- Used for efficiency measurements:

$$\epsilon = \frac{N_{\text{tracks}}^{\text{FE-I4+DUT}}}{N_{\text{tracks}}^{\text{FE-I4}}}$$





- Test beam data is written into containers sequentially.
- If a data source encounters errors, a packet can be lost leading to unsynced events.
- Resynchronization is in principle possible using readout system clock.

- Incoming data stream with a lost packet from one data source:

1	2	3	4	5	6	7	8	9
1	2	LOST	4	5	6	7	8	9

- Written data:

1	2	3	4	5	6	7	8	9
1	2	4	5	6	7	8	9	10