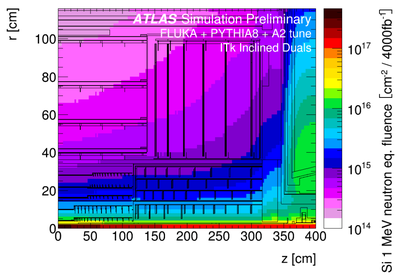
Test Beam Characterization of Prototype Modules for the ATLAS Inner Tracker Strip Detector.

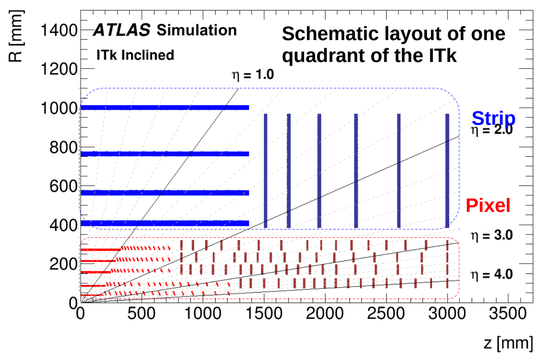
Edoardo Rossi on behalf of the ATLAS ITk Collaboration

ATLAS Inner Tracker and Strip Detector

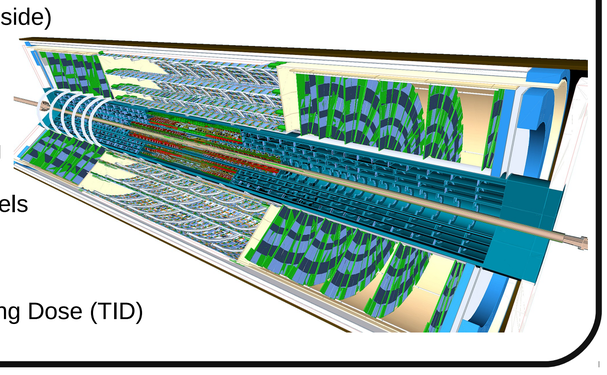
In order to cope with the high radiation levels and pile-up expected in the High-Luminosity LHC (HL-LHC), the ATLAS experiment will replace the current tracking system with an all silicon detector, the Inner Tracker (ITk)



Simulation of the NIEL (Non-Ionizing Energy Loss) dose expected in the ITk at the end-of-lifetime of the HL-LHC



The ITk will be an all silicon detector consisting of:
- **Pixel**: five barrels and multiple forward layers
- **Strip**: four barrel layers and twelve end cap disks (six on each side)



• A solenoid magnet provides a uniform magnetic field of 2T, that bends the tracks of charged particles, thus allowing to determine their momentum

• Low radiation length materials are used to minimize the multiple scattering

•The ITk Strip detector will have a silicon area of ~165m^2 and ~165M channels

• It will be ~6m long and with a radius of ~1m

• It will be subject to radiation levels up to 1.1x10^{15}n$_{eq}$/cm^2 and a Total Ionizing Dose (TID) up to 45MRad

Silicon Strip Modules

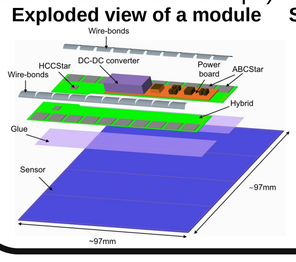
• n$^+$-in-p float zone silicon sensors with active area ≈10x10cm^2, 300-320μm thickness and 75.5μm strip pitch:
- rectangular strips in the barrel, with lengths 2.4 and 4.8cm
- radial strips in the end-caps, with lengths from 1.9 to 6cm

• The read-out ASICs (the ATLAS Binary Chips, ABC) and the Hybrid Controller Chips (HCC) are glued on the hybrid PCB, which is glued directly on the silicon sensor. Each read-out chip is wire-bonded to 256 strips

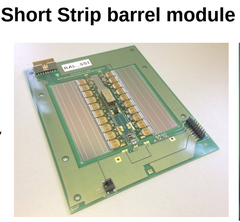
• The power board includes:
- A DC-DC converter to power the front-end read-out ASICs, which receives 11 V and supplies the hybrids with 1.5 V
- High-Voltage switch to disconnect non-operating modules
- Autonomous Monitor and Control Chip (AMAC) which monitors the current, voltage and temperature, controls the HV switch and provides interlock functionalities

• Total of **17888** modules in the ITk Strip Detector (10976 in the barrel and 6912 in the end-caps)

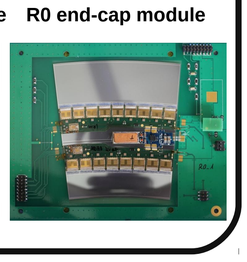
Exploded view of a module



Short Strip barrel module



R0 end-cap module



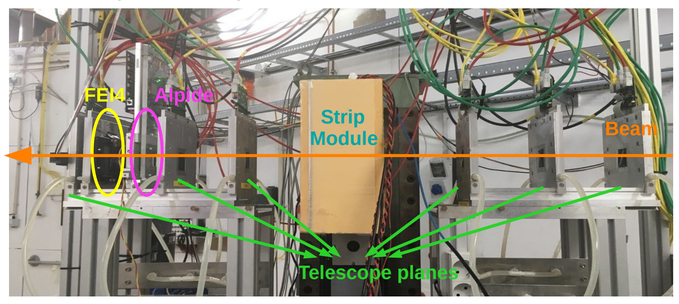
Test Beam Set-Up

• Electron beam with energy up to 6GeV at DESY, pions up to 170GeV at CERN SPS

• EUDET-type telescope provides tracks with resolution of 5-10μm at DESY, and 2-5μm at CERN SPS

• FEI4 pixel plane as a time reference plane (Alpide pixel plane used in latest test beams)

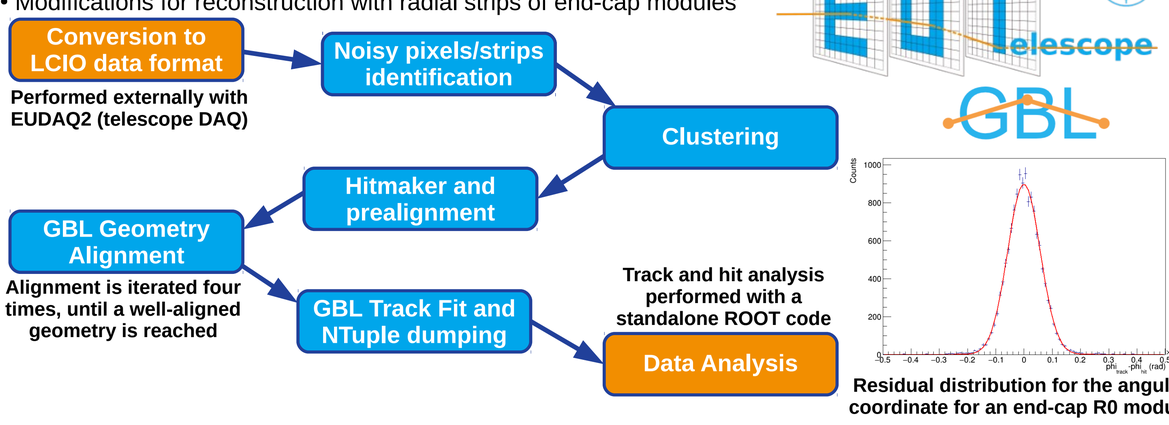
• Module cooled with dry ice in a styrofoam cold box



Track Reconstruction and Data Analysis

• Track reconstruction and data analysis performed with the EUTelescope reconstruction framework using the General Broken Lines (GBL) track fitting algorithm

• Modifications for reconstruction with radial strips of end-cap modules

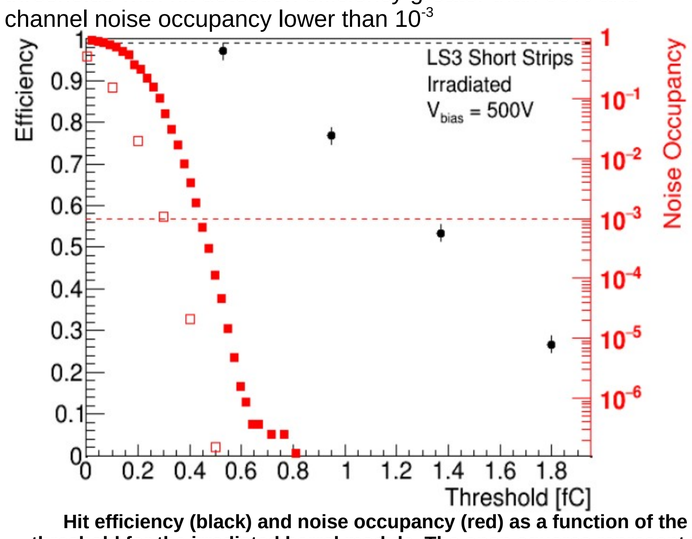


Irradiated Barrel Module

• A Short Strip barrel module was built at the Rutherford Appleton Laboratory (RAL) in 2016 and irradiated at the CERN PS to a NIEL dose of 8x10^{14}n$_{eq}$/cm^2 (maximum fluence expected at the end-of-lifetime of the HL-LHC for short strip modules, **including a safety factor 1.4**). The sensor was not annealed. The module was tested in a test beam at CERN SPS in July 2016

• The module was built with **previous iterations**, with respect to the current ones, for the front-end chips (ABC130 and HCC130) and for the sensor (ATLAS12)

• In order to satisfy the tracking specifications, the modules are required to have, for the entire lifetime of the ITk, a range of thresholds with hit detection efficiency greater than 99% and channel noise occupancy lower than 10^{-3}



Hit efficiency (black) and noise occupancy (red) as a function of the threshold for the irradiated barrel module. The open squares represent the noise occupancy expected at the time with the final front-end (ABCStar).

Satisfactory performance for a prototype module, but significant improvements were expected with the final front-end and sensors, and annealing of the sensor

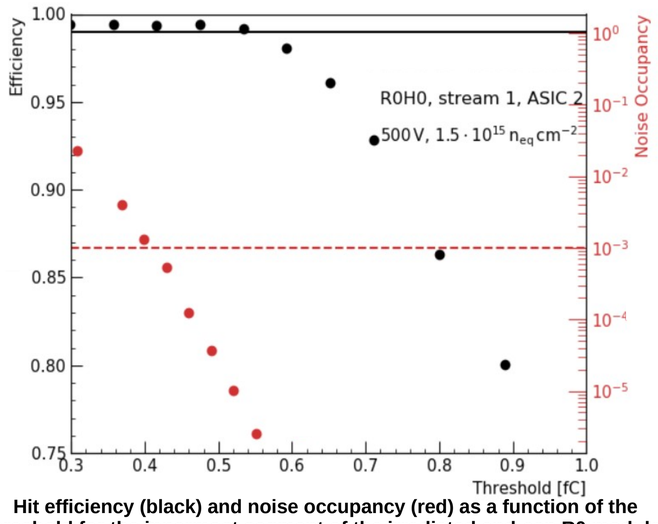
Irradiated End-Cap Module

• In 2019, an end-cap R0 (innermost ring) module was assembled in Freiburg with:

- ATLAS12EC sensor irradiated with 24 GeV protons at CERN PS to a NIEL dose of 1.5x10^{15}n$_{eq}$/cm^2 (maximum fluence expected at the end-of-lifetime of the HL-LHC in the ITk Strip, **including a safety factor 1.4**). The sensor was annealed at 60 for 80 minutes

- hybrids, hosting the latest front-end chips (ABCStar and HCCStar), and powerboard, both irradiated at RAL with x-rays with a TID up to 35MRad

• The module was tested in a test beam DESY in June 2019



Hit efficiency (black) and noise occupancy (red) as a function of the threshold for the innermost segment of the irradiated end-cap R0 module. Note: the saturation of the efficiency at about 99.4% is due to the use of Alpide pixel plane as time reference plane

A wide range of thresholds around 0.5fC satisfies both efficiency and noise occupancy requirements

Signal-to-Noise

• In previous test beams it has been proven that a signal-to-noise > 10 guarantees that a range of thresholds exists with both the efficiency and noise occupancy requirements satisfied

• The lowest signal-to-noise is expected for the innermost region (R0) of the end-caps, where at the end-of-lifetime of the HL-LHC (including a safety factor) a signal-to-noise of 12.2 is expected

• With the irradiated R0 tested at the test beam a signal-to-noise of 11.7 is measured. A range of thresholds satisfying the requirements is present

• The minimum signal-to-noise expected for the Short Strip region of the barrel at the end-of-lifetime of the HL-LHC is 15.8, while for the long strip region is 16.2

Conclusions and Outlook

• Test beam results prove that the current prototype modules would satisfy the performance requirements up to the end-of-lifetime of the High-Luminosity LHC

• A Long Strip module built with irradiated components has been tested in a test beam at DESY in September 2019 and the data analysis is on-going

• The test beam effort with prototype modules will continue after the reception of the production-grade sensors, expected in 2020

References

ATLAS Collaboration, Technical Design Report for the ATLAS Inner Tracker Strip Detector (2017), CERN-LHCC-2017-005; ATLAS-TDR-025
https://cds.cern.ch/record/2257755

28th International Workshop on Vertex Detectors
Lopud Island, Croatia, 13-18 October 2019