Test Beam Studies of Prototype Modules for the ATLAS ITk Strip Detector

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High Luminosity-LHC

• The HL-LHC is an upgrade of the LHC expected to start operations in 2026

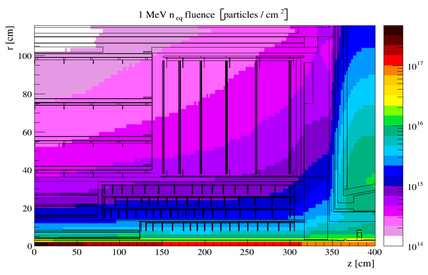
• Instantaneous luminosity up to $7.5 \times 10^{34} cm^{-2} s^{-1}$

• 200 inelastic proton-proton collisions per beam crossing

• Total integrated luminosity of $4000 fb^{-1}$

• Radiation level in the detectors one order of magnitude larger than with the LHC

• Needed upgrade of detectors to cope with increased pile-up and radiation

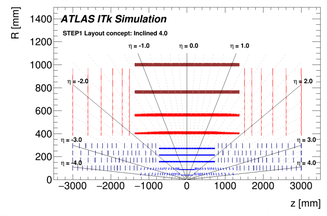


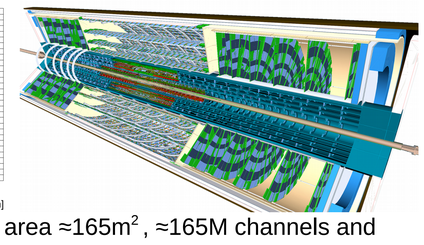
ATLAS ITk Strip Detector

• Replacement needed of the current ATLAS Inner Detector with a high granularity and more radiation-hard tracker

• The new ATLAS Inner Tracker (ITk) will be an all silicon detector with:
- Five central and multiple forward pixel layers
- Four barrel and six end-cap strip layers

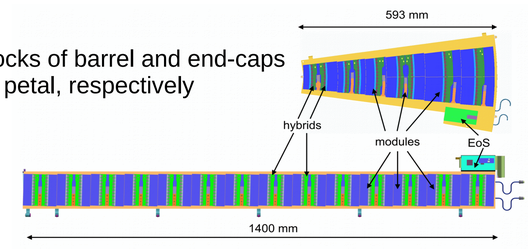
• 2T magnetic field, ≈6m long, ≈1m radius





• The strip detector has a silicon area ≈$165 m^2$, ≈165M channels and ≈18000 modules

• Basic building blocks of barrel and end-caps are the stave and petal, respectively



Silicon Strip Module

• n^+-in-p float zone silicon sensors, active area ≈10x10cm^2, 300µm thickness and 74.5µm strip pitch:
- square strips in the barrel, with lengths 2.5 and 5cm
- radial strips in the end-caps, with lengths from 2 to 5cm

• Hybrids glued directly to silicon sensors

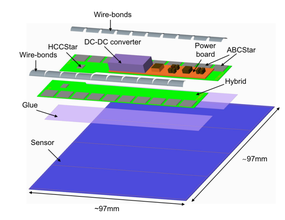
• ATLAS Binary read-out Chips (ABC) and Hybrid Controller Chips (HCC) are glued and wire-bonded to the hybrid

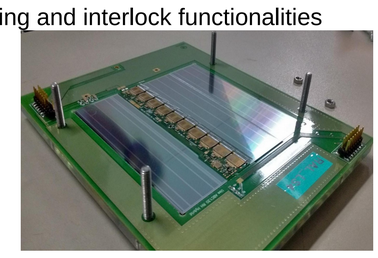
• Each read-out chip is connected to 256 strips with wire-bonds

• Threshold applied in discriminators in the ABC and binary output sampled every 25ns

• DC-DC powering based on FEAST chip

• AMAC chip for both monitoring and interlock functionalities

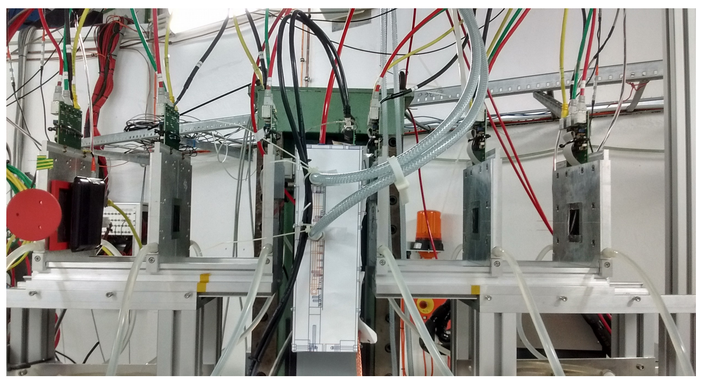


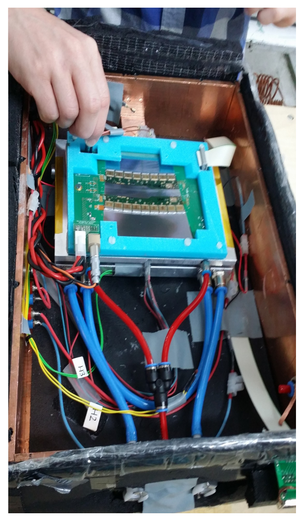


Test Beam and Telescope

• Five prototype modules and many mini-sensors tested at DESY (4.4GeV electrons) and CERN (120GeV pions)

• EUDET-type telescopes used for precise tracking:
- Six planes with MIMOSA26 chips with pitch 18.4µm
- Optimal tracking resolution ≈2µm (without device under test)
- FEI4 reference plane added for precise timing information (25ns)



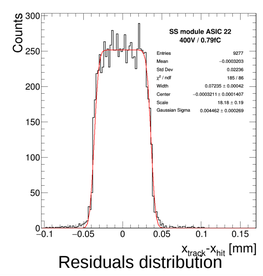


Track Reconstruction

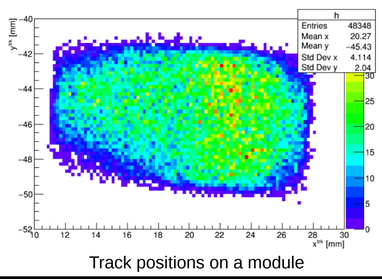
• Reconstruction performed with the software EUTelescope and the General Broken Lines (GBL) algorithm:
1) Conversion to lcio data format
2) Cluster identification and noisy channel masking
3) Creation of the initial geometry
4) Track pattern recognition
5) Geometry alignment
6) Track fitting

• Modifications to allow the reconstruction with a radial geometry

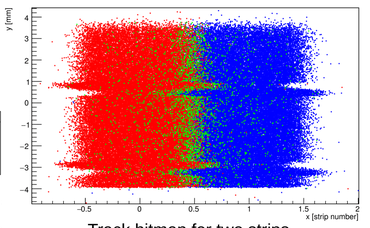
• Preliminary estimation of tracking resolution of our setup ≈6µm



Residuals distribution



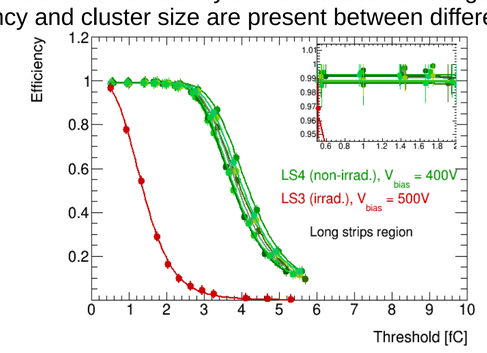
Track positions on a module

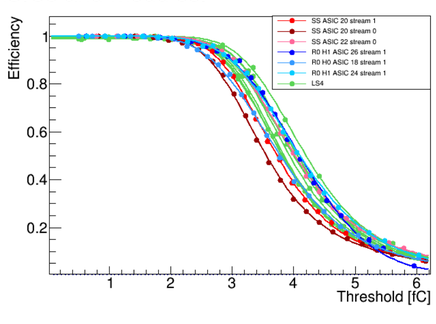


Track hitmap for two strips.
In green hits with signal on both strips

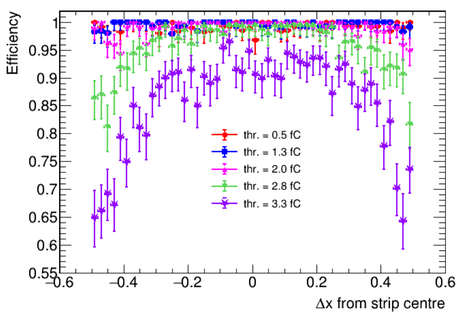
Efficiency and Cluster Size

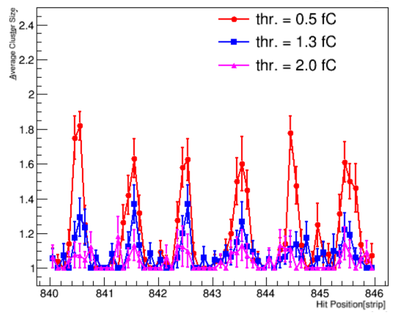
• The hit detection efficiency and the collected charge are decreased after irradiation. Small differences of efficiency and cluster size are present between different ASICs and modules.



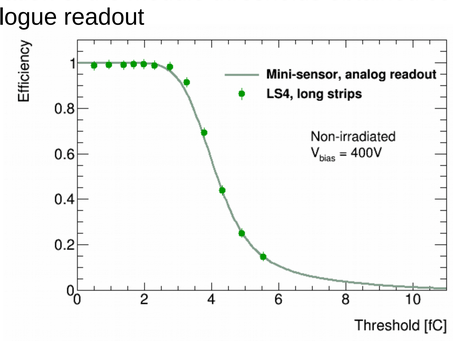


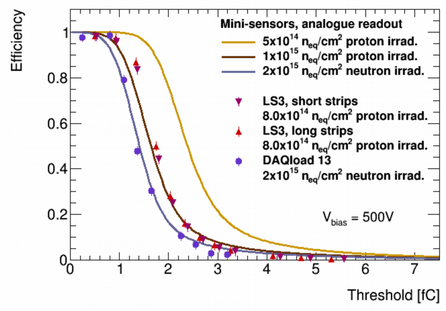
• Efficiency is decreased in the inter-strip region and cluster size is increased, because of a larger charge sharing.





• Calibration of the module thresholds obtained comparing the test beam results with source measurements with an analogue readout

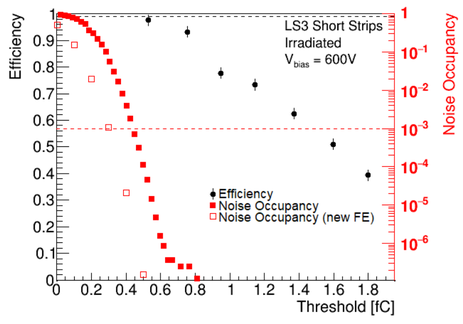


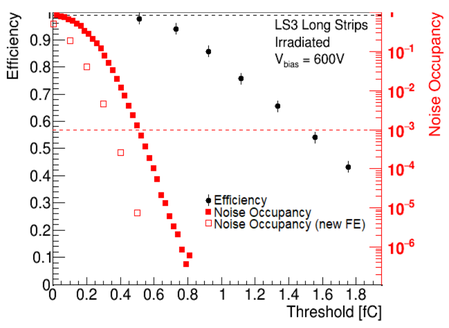


End-of-lifetime Performance

• A module has been fully irradiated with with 24GeV protons at the CERN Proton Irradiation Facility to a NIEL dose of $8 \times 10^{14} n_{eq}/cm^2$ (the maximum NIEL dose expected in the barrel)

• The modules are required to have a threshold with:
- Efficiency > 99%
- Noise occupancy < 0.1%





• Satisfactory performance for a prototype module

• Performance in the final modules will be improved thanks to lower noise in the new front-end chip and higher resistivity silicon

Future Plans

• Test beams played a crucial role in understanding the current prototype modules

• In the near future, evaluation of the performance of new prototypes, pre and post irradiation

• Test of more complex objects, as double-sided objects, staves and petals

• Test beams will be very important in the next ATLAS ITk Strip phases:
- During pre-production focus on understanding the devices and their performance
- During production focus on quality control

ATLAS EXPERIMENT

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

ITk Strip Test beam group

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University of Glasgow
Science & Technology Facilities Council, Rutherford Appleton Laboratory
University of Cape Town
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Humboldt-Universität zu Berlin
The Czech Academy of Sciences
University of Birmingham
Charles University
Carleton University
Nikhef
Uni Freiburg
TRIUMF
University of Cambridge

XIV ICFA School on Instrumentation in Elementary Particle Physics