The silicon strips Inner Tracker (ITk) of the ATLAS Phase-II upgrade detector

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Outline

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  - ABCStar & HCCStar
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- Conclusions and future plan

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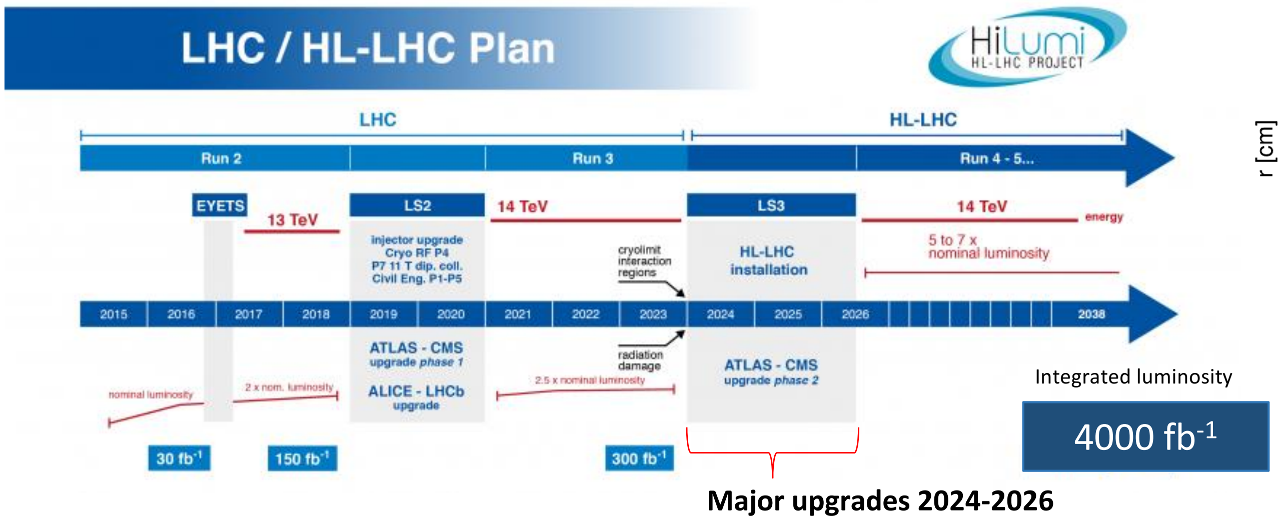
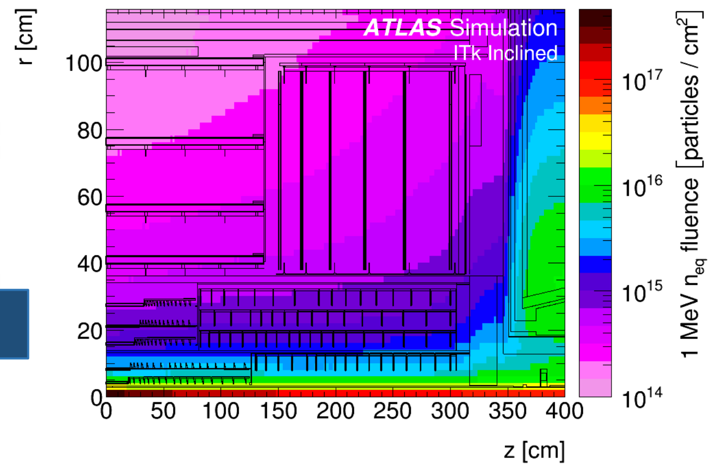
Introduction: HL-LHC

- HL-LHC is foreseen to start operations in 2026 → Instantaneous luminosity up to **7.5 x 10^{34} cm^{-2} s^{-1}**



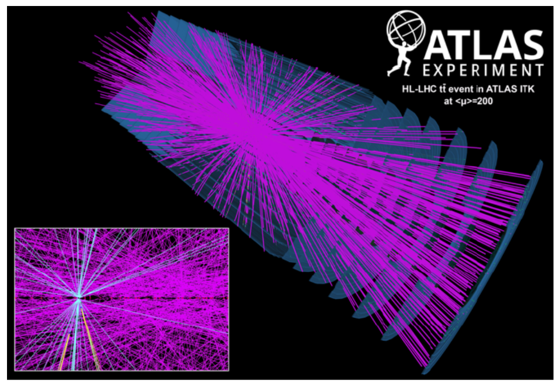
Fluence expected at the end-of-lifetime of HL-LHC



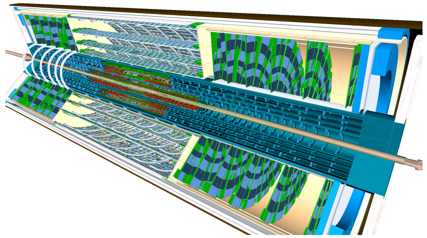
- Increase in pile-up → <μ> ≈ 200 (currently, <μ> ≈ 40)

A replacement of the present tracker detector is needed!!

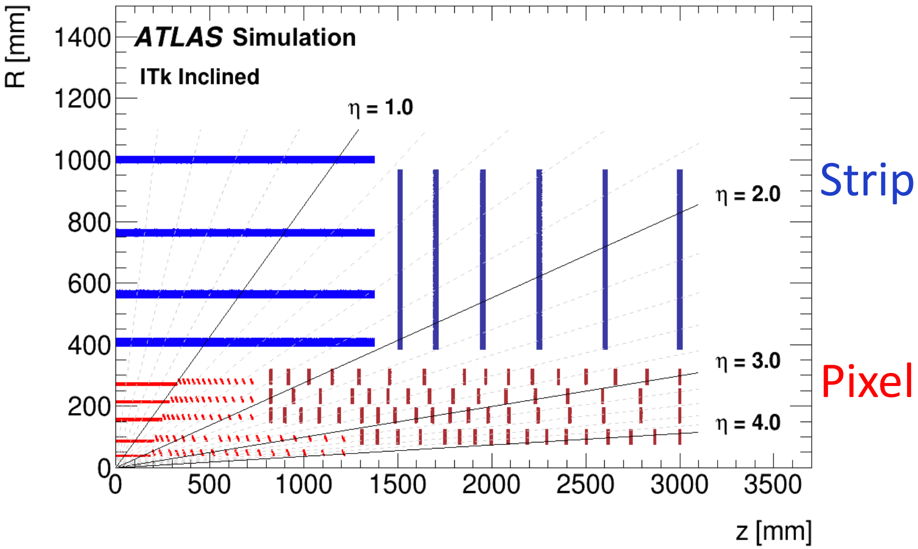
- Higher granularity to keep occupancies low, and to have more precise measurements
- New detector designs to cope with higher radiation environment
- While reducing power consumption and keeping low material



ATLAS Inner Tracker (ITk)



- The new ATLAS Tracker will be an all-silicon detector:
  - Pixel → 5 barrel layers and multiple forward disks
  - Strip → 4 barrel layers and 6x2 end-cap disks
  - With a solenoid magnet providing an uniform magnetic field of 2T
- Low radiation length materials are used to minimize the multiple scattering
  - The ITk material budget is around 30% lower in the region $|\eta|<4.0$
  - Most of the reduction comes from cables due to serial powering for pixel and DC-DC powering for strips



Radius ≈ 1m, length ≈ 6m

ITK Detector:

- Channels: Pixels ≈ 80M → 580M; Strips ≈ 6M → 60M
- Area: Pixels ≈ 13 cm^2 ; Strips ≈ 165 cm^2
- Expected radiation levels:
  - Pixels up to 3 x 10^{16} n_{eq}/cm^2
  - Strips up to 1.2 x 10^{15} n_{eq}/cm^2
- Total Ionizing Dose (TID) of 50MRad (Strips)

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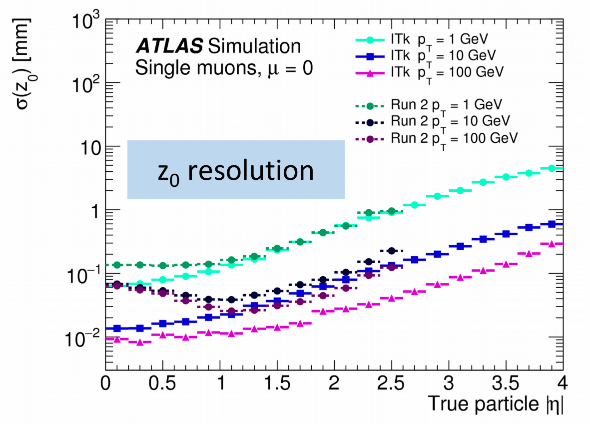
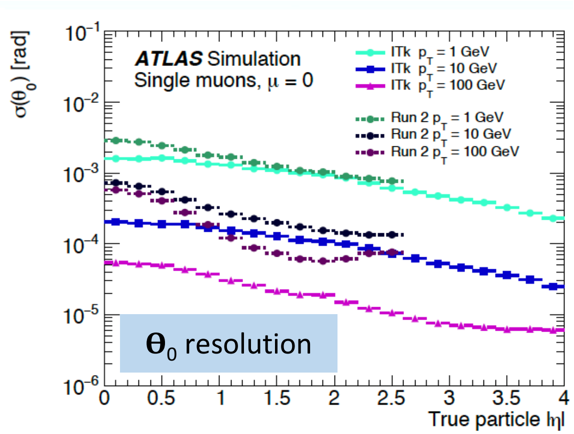
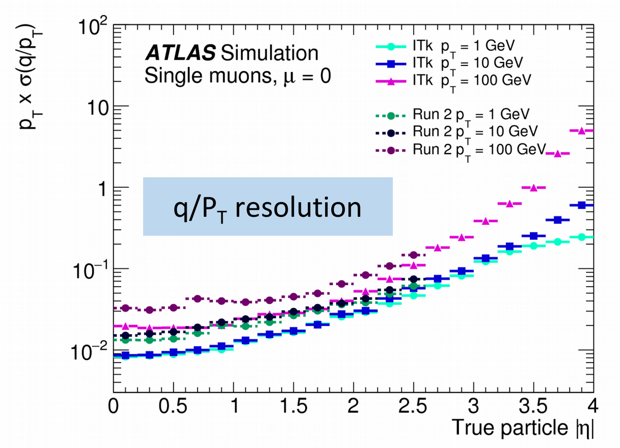
Performance studies

- In the ITk, the tracking parameter resolution is maintained or improved with respect to the current ATLAS inner detector during Run2 for the ITk Inclined layout

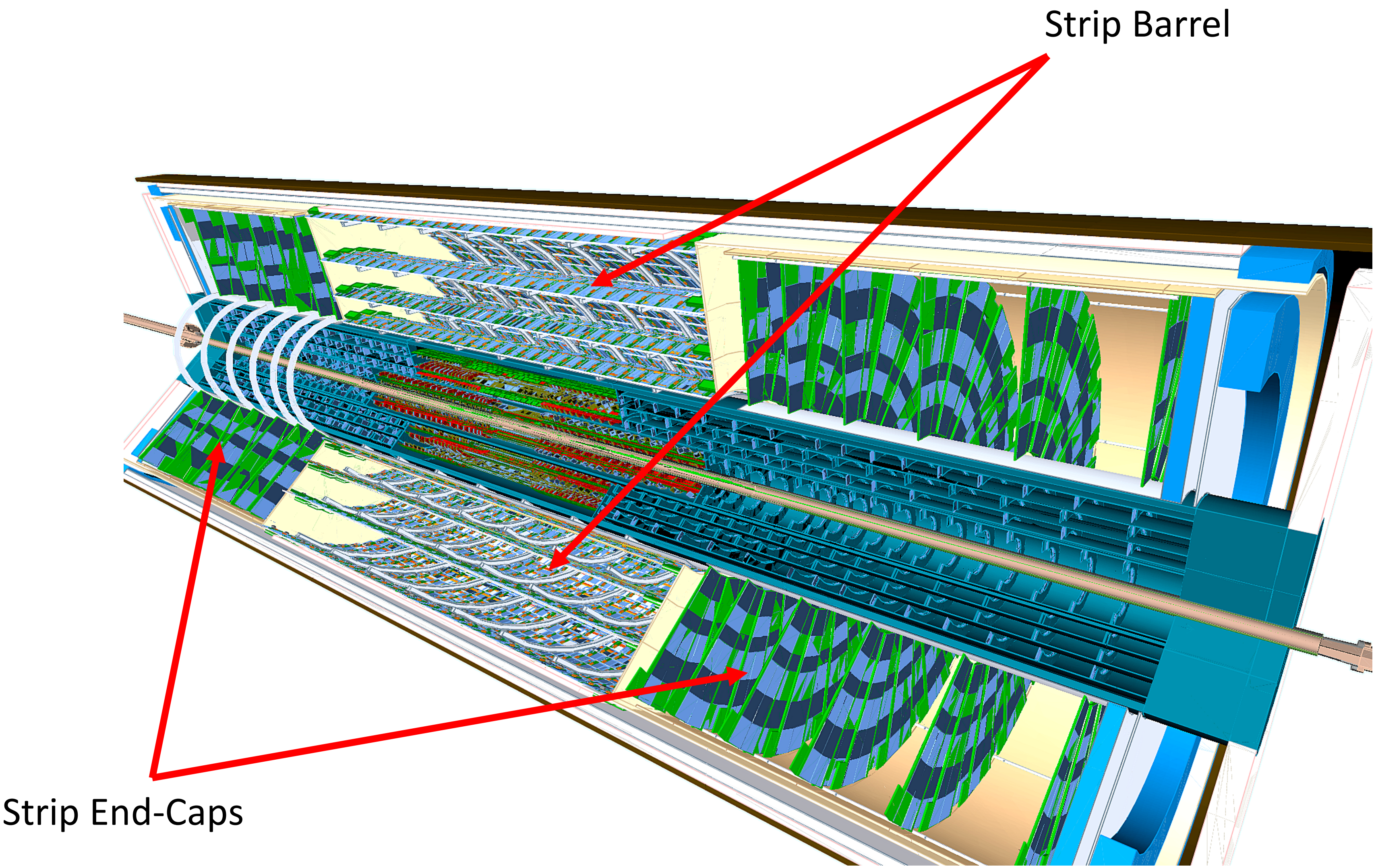






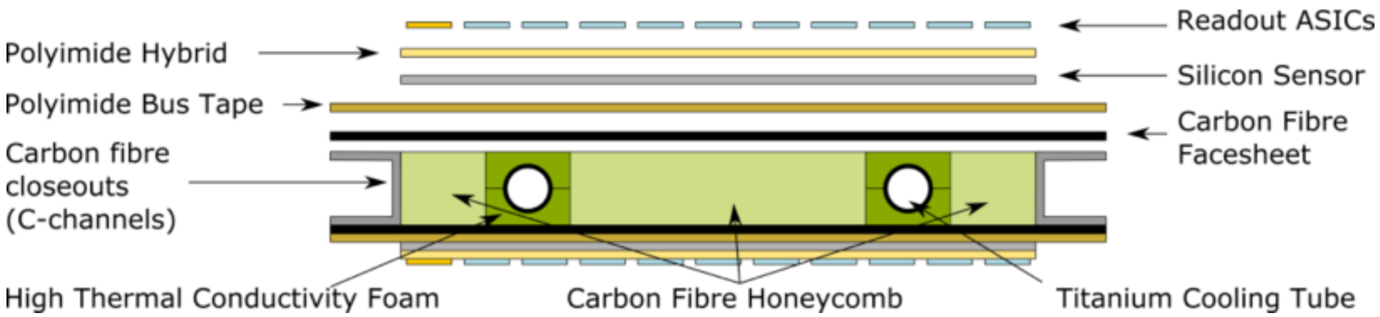
- Shorter **pixel** pitch in the longitudinal direction improves resolution in Z_0 and $\boldsymbol{\theta}_0$
- Due to reduced material and higher precision of the **ITk Strip Detector** with respect to the Transition Radiation Tracker (TRT) in the outer layers of the current Inner Detector → Improvement of the momentum resolution

ITk Strip Detector



ITk Strip Detector: Local Supports

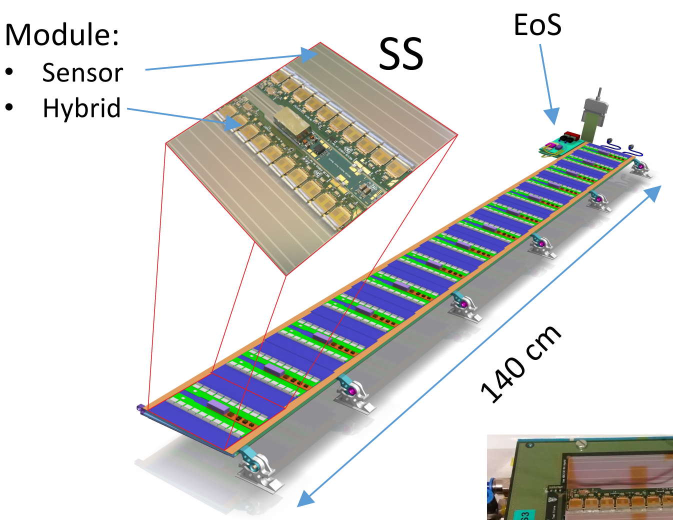
- Modules are glued on independent double-side local support structures: **Barrel Staves and End-cap petals**.
- Geometric stability with carbon fiber-based core
- Integrated titanium cooling tubes (2.3 mm outer diameter)
  - U-shaped bend at the small z side for the barrel and at the small radius of the petal
  - CO_2 evaporative system, allowing stable operations down to -35ºC
- Integrated bus tape per side on which modules are attached:
  - Copper lines between layers of polyimide
  - To provide electrical connections (power and data transfer)
- The End-Of-Substructure (EOS) card is the interface between the stave/petals and the off-detector electronics

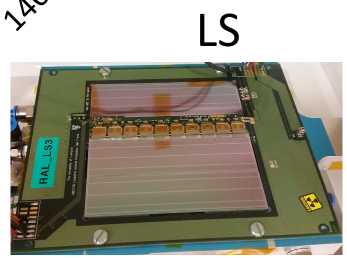


Internal structure of a module support

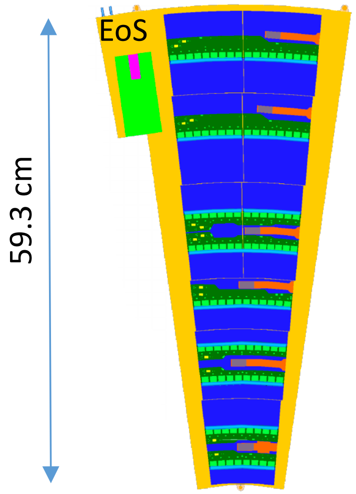
Strip Local Supports

- **Staves** for barrel
  - 2 layers with “Long Strip” modules (LS): strip length: 4.82 cm
  - 2 layers with “Short Strip” modules (SS): strip length: 2.41 cm
  - 14 modules per side
  - 10 read-out chips per hybrid





- **Petals** for end-cap disks
  - 9 flavours of modules(13 flavours of hybrids)
  - [7-12] read-out chips per hybrid
  - Different power/DAQ requirements



R5: split sensor/hybrid, 9 chips/hybrid

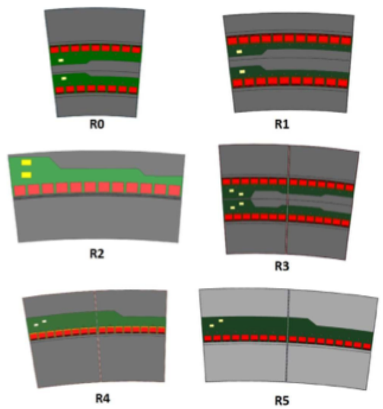
R4: split sensor/hybrid, 8 chips/hybrid

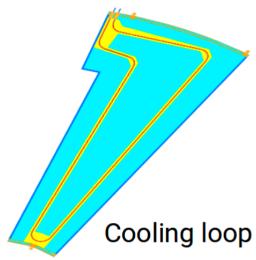
R3: split sensor/hybrid, 7 chips/hybrid

R2: 12 chips

R1: 10 and 11 chips

R0: 8 and 9 chips





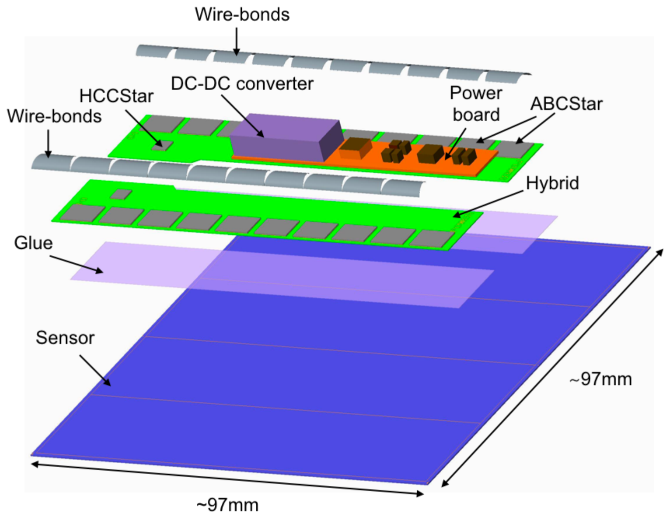
Silicon Strip Modules

- **n⁺-on-p FZ Silicon sensor** → No bulk type inversion
  - Bulk resistivity ~ 2.5K*Ω* cm (Depletion voltage 365V)
  - Rectangular strips in the barrel → length = 2.41 cm (**SS**) and 4.82 cm (**LS**)
  - Radial strips in the end-caps → length= [1.51 – 6.02] cm

Sensor:	
Active area (cm^2)	9.7x9.7
Thickness (µm)	300-320
Strip pitch (µm)	75.5 (Barrel) [69.9-80.7] (End-cap)

- Mechanical support and thermal management

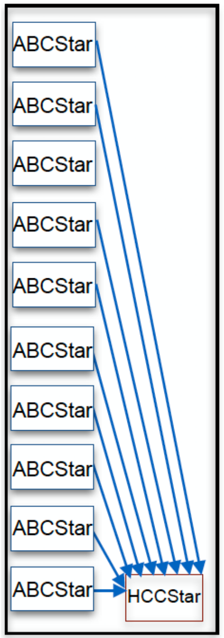
- **Power-board**
  - Integrated DC-DC LV Power block
  - HV multiplexer for sensor bias
  - Detector control system: AMAC (Autonomous Monitored and Control Chip) to control and monitoring of HV, LV currents and temperature
- **ATLAS Binary Chip ABCStar**
  - Read out 256 strips from a silicon sensor
  - Convert incoming charge from the strips to hit
  - Binary outputs sampled at 40MHz rate and store in a pipeline
- **Hybrid Control Chip (HCC)**
  - Interface between the read-out chips and the End-of-Substructure

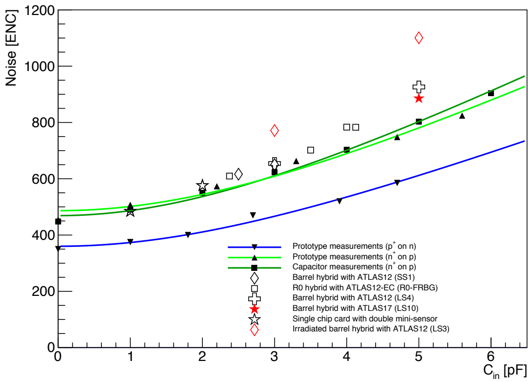


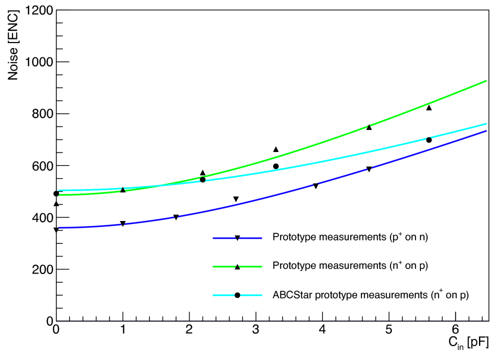
There will be **17888** modules in the Itk Strip Detector!!

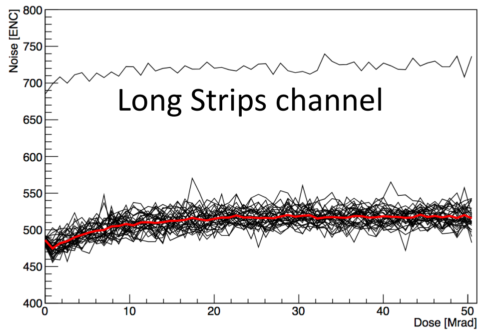
ABCStar and HCCStar

- Evolution of the ABC130 and HCC130 chips, 130nm process
- 12 wafers with the last read-out chip design already submitted to stablish the final design this year
- Change in the read-out architecture to point-to-point links between each ABCStar and the HCC Star
- Higher radiation tolerance









0.87 Mrad/h @RT

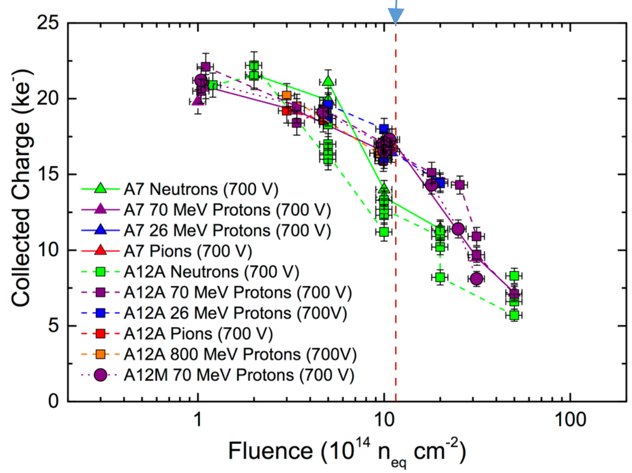
- Noise measurements for different input capacitances, ABC130 and ABCStar prototypes and ABC130 on different hybrids
- Lower noise with irradiation than ABC130

R&D: Components

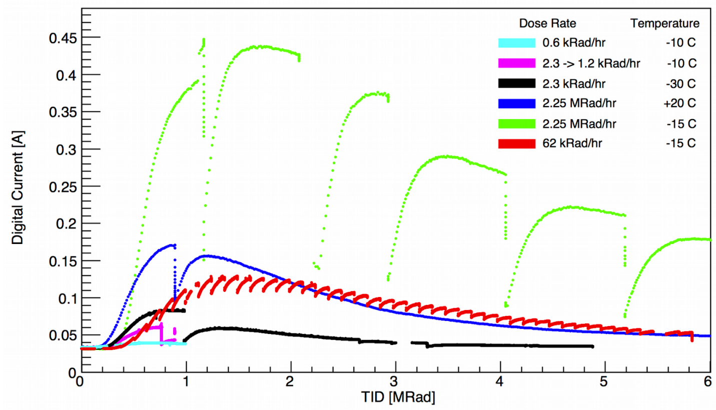
- Every component of the Itk Strip detector has passed through an extensive prototyping and testing phase.

$1.2 \times 10^{15}\ n_{eq}/cm^2$ (includes a safety factor of 1.5)

- Collected charge by sensors biased at 700V for minimun ionising particles vs. Irradiation fluence expected in the ITk Strip detector
- From 11 to 17Ke⁻ at the end of lifetime ✓



- Digital current for ABC130 chips vs TID dose, for various X-ray irradiation rates and temperatures compatible with HL-LHC
- Increase in current by the digital portion of the chip around a TID of 1 MRad



- Considerations for cooling and powering requirements have been adjusted to take into account the increased power consumption of the chips at the TID bump

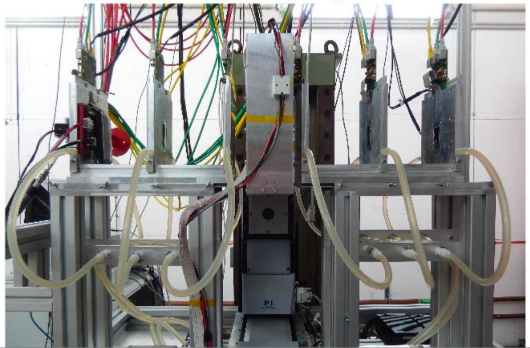
R&D on assemble and testing of strip modules

- Several full-size prototype modules have been tested, both before and after irradiation. The most critical parameters under study are noise, gain and hit efficiency.

- During 2016:

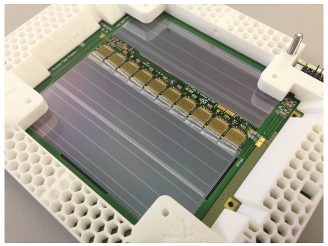
1. Testbeam at DESY with 4.8 GeV electrons
   - Non-irradiated barrel module (LS4) with short and long strip regions
2. Testbeam at CERN SPS with 120 GeV pions
   - Barrel module previously irradiated with 24GeV protons to 8 x 10^{14} n_{eq}/cm^2 and TID=37.2 Mrad (LS3)

@DESY

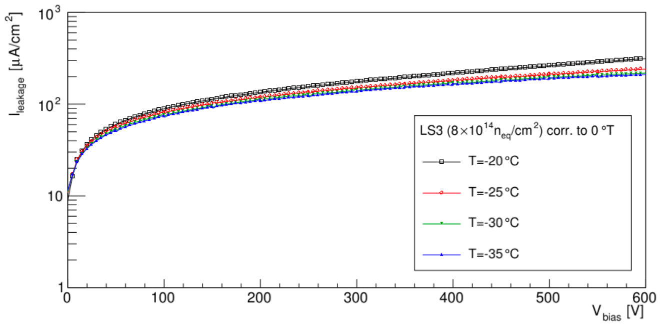


EUDET Telescope with 6 cooled Mimosa26 planes and FEI4

LS4

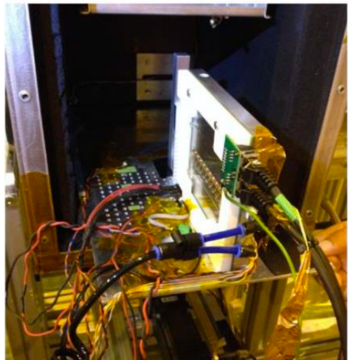


LS3



IV characteristics after irradiation

@CERN



Operated in coldbox at -35C (Sensor at -15C)

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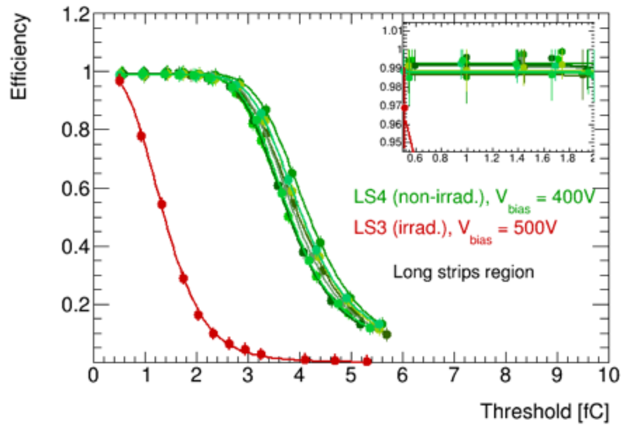
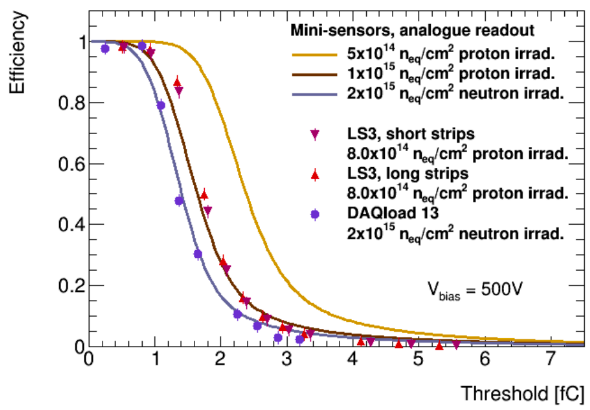
R&D on assemble and testing of strip modules

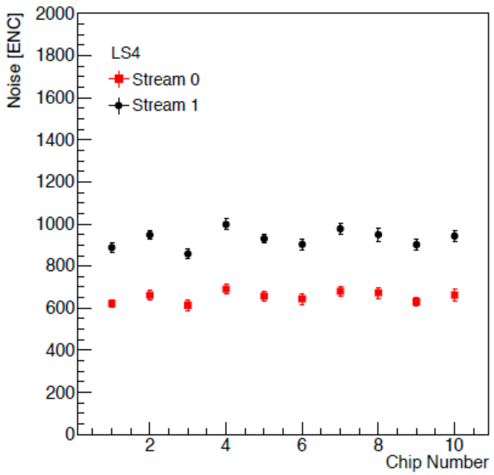
- Modules are required to have, for their entire lifetime of ITk, a range of thresholds with a hit detection efficiency greater than 99% and channel noise occupancy lower than 10^{-3}
- Results:
  - As expected, the signal efficiency is reduced significantly after irradiation

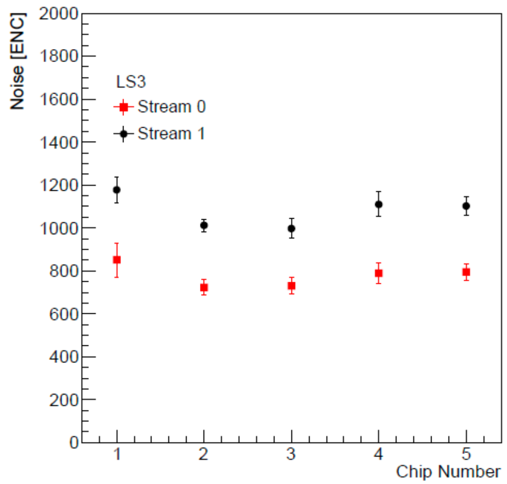




* The performance will be further improved with the new front-end chip and with production-grade silicon technology

- Input noise averaged per read-out chip for the non-irradiated module (LS4) and the irradiated module (LS3)
- Using the internal calibration circuit of the ABC130
- Increased noise for the irradiated module in agreement with previous ABC130 chip irradiations and strip length





- V_{bias} = 600V

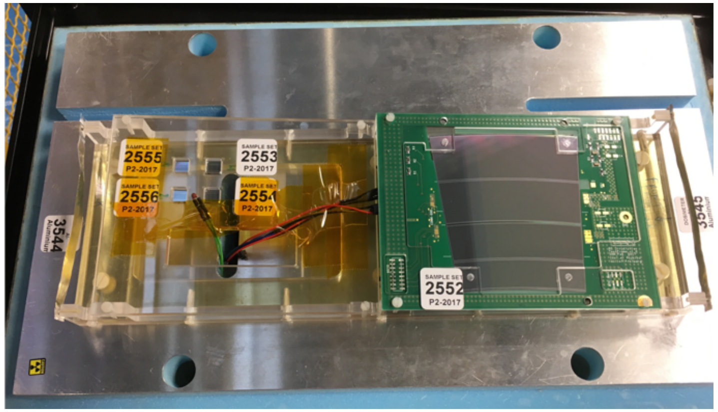
Long Strips

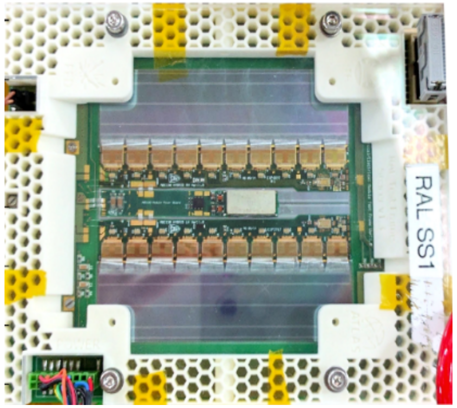
Short Strips

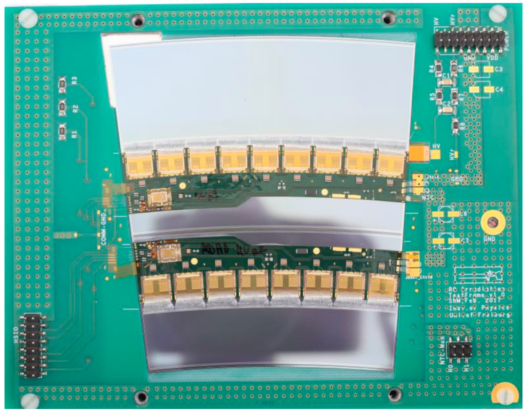
R&D on assemble and testing of strip modules

- During 2017:

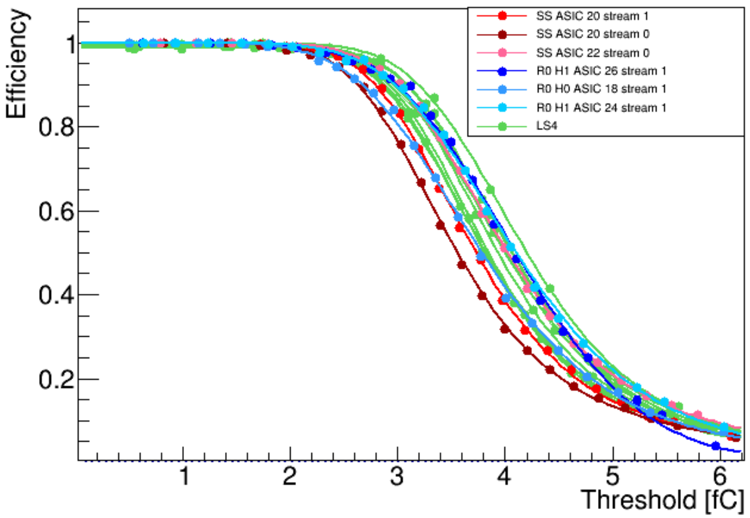
1. First batch of R0 sensors (radial strip sensors)
   - Long-term electrical characterization under evaluation
   - R0 sensor irradiated to a total fluence of 1.5 x $10^{15} n_{eq}/cm^2$
   - Under testing
2. Testbeam at DESY with 4.4 GeV electrons
   - First non-irradiated R0 module (End-cap)
   - Non-irradiated SS1 module (Barrel) with power board







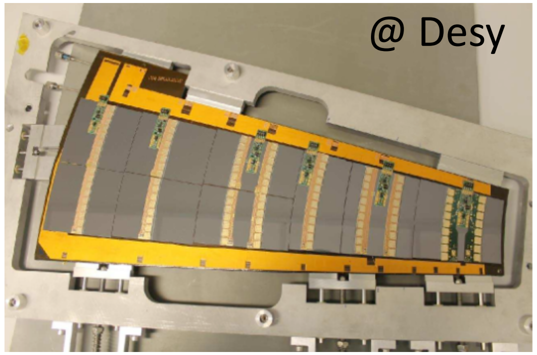
Noise and gain are consistent with previous barrel protoptypes

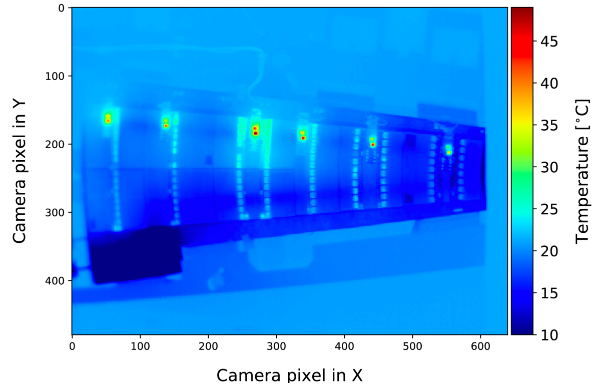


Petal/Stave Tests

Thermal tests:

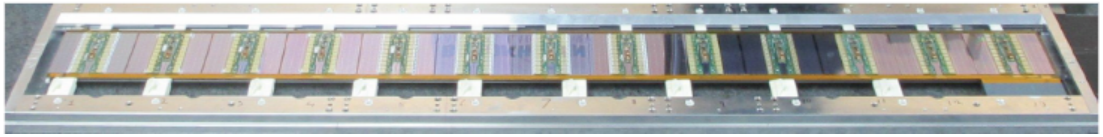
- Thermal performance proven in all subsystems
- Thermo-mechanical petal/stave inspected by IR thermography techniques

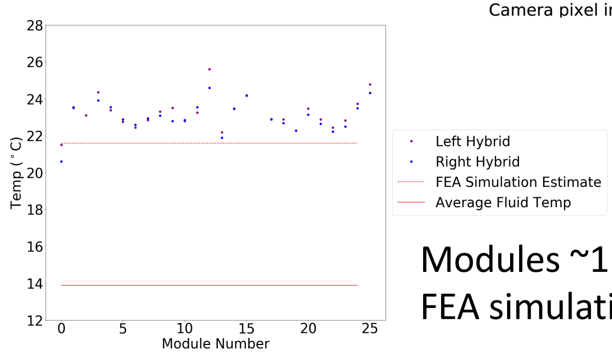




@ US

3 NTCs/module x 13 modules/side

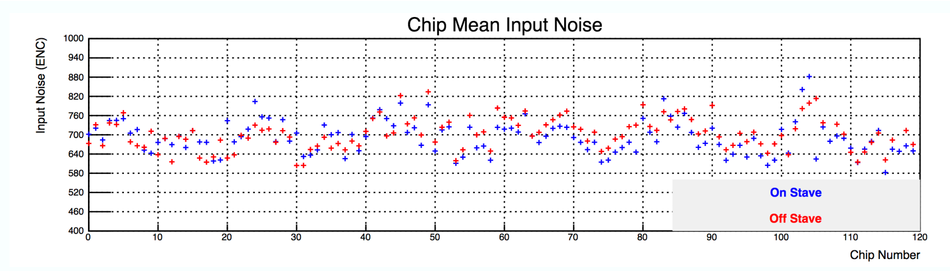


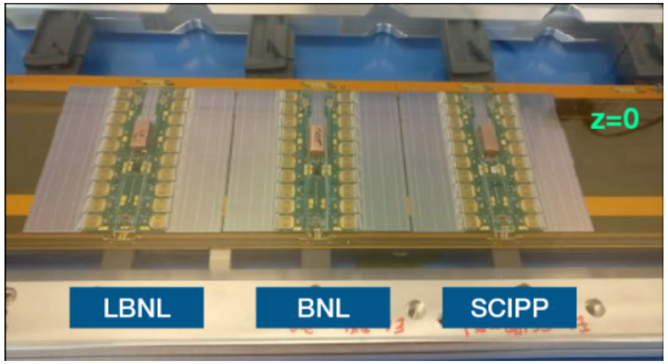


Modules ~1.6^{o}C above FEA simulations

Electrical tests:

- 3-Module Stavelet built at US
- Operating well

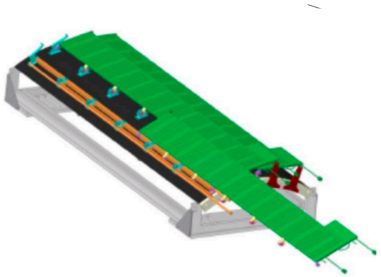


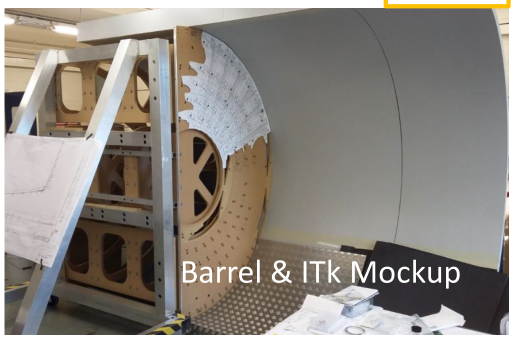


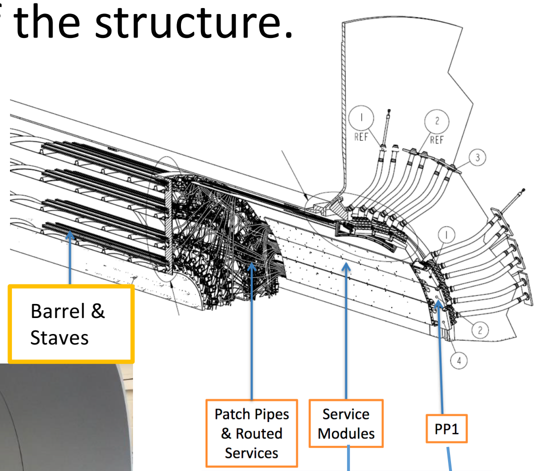
More electrical staves/petals to be prepared by the collaboration sites during this year

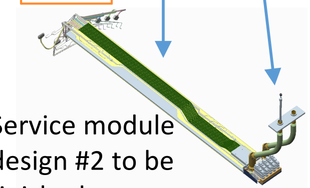
Integration into global structures

- Staves and Petals are mounted on global support structures, largely made of carbon-fibre
- Barrel Staves are inserted into the fully assembled cylinder structure from the ends, using temporary rails. The barrel consists of 4 concentric cylinders connected together at the ends by interlinks. Services are routed by trays overtop of the endcap services.
- Endcap petals are mounted onto wheel structures, forming a disk, with 32 petals per wheel. One endcap contains 6 disks and services are routed to the large radius side of the structure.

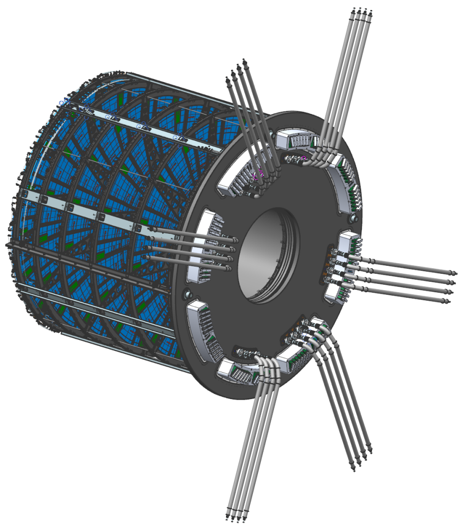








Service module design #2 to be finished



Recently, Prototype insertion tool of Petal to EC tested successfully

Wheel mockup @Nikhef

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Conclusions and future plan

- A new ATLAS tracker detector is being developed for working under the HL-LHC conditions
  - Extended η coverage, low mass, radiation harder

- All the baseline components of the ITk Strip detectors are defined and available for the collaboration
- New Front-end is almost finished
- Barrel modules show good end-of-life performance
- End-cap modules consistent with barrel prototypes
- Multi-module structures are being built and tested by the collaboration
- In the global supports/service area
  - Thermodynamics, radiation tests, robustness tests… on going
  - Service routing is being optimized

- Extensive irradiation campaign (proton, gamma, neutron) planned for new sensor deliveries (full-size and mini sensors) is under going. Testbeam campaign at Desy carried out this June and planned at CERN later this year.
- QA/QC procedures are under preparation
- Pre-production expected for Q2-2019 and then, Production at 2020! Planning 3.5 years module production
- Distributed production model:
  - Sites specialize in producing one or more components and/or building processes
  - Barrel assembly and integration at CERN
  - Endcap assembly at DESY and NIKHEF and shipped to CERN

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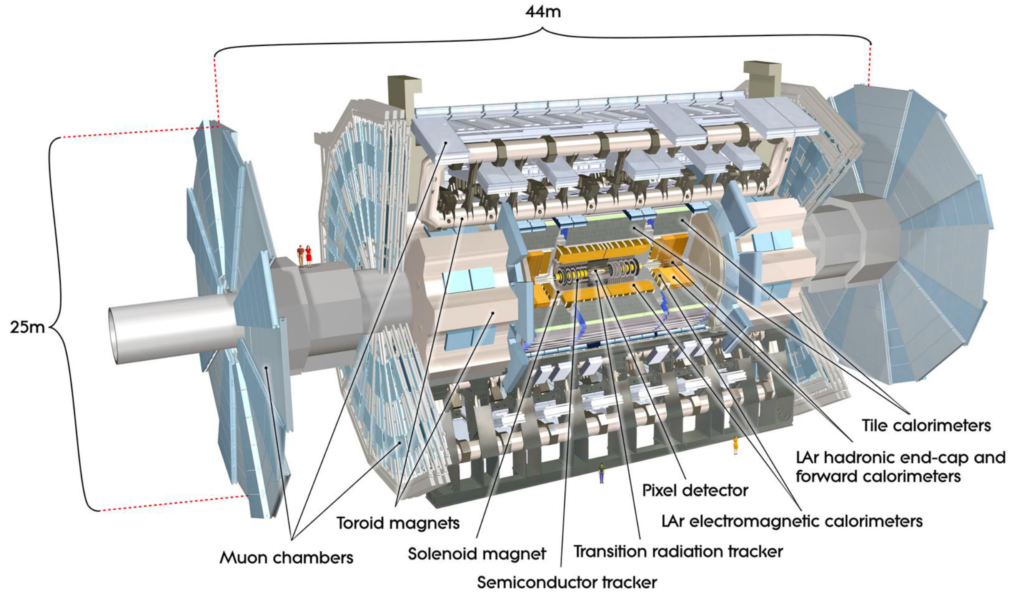
Back-up

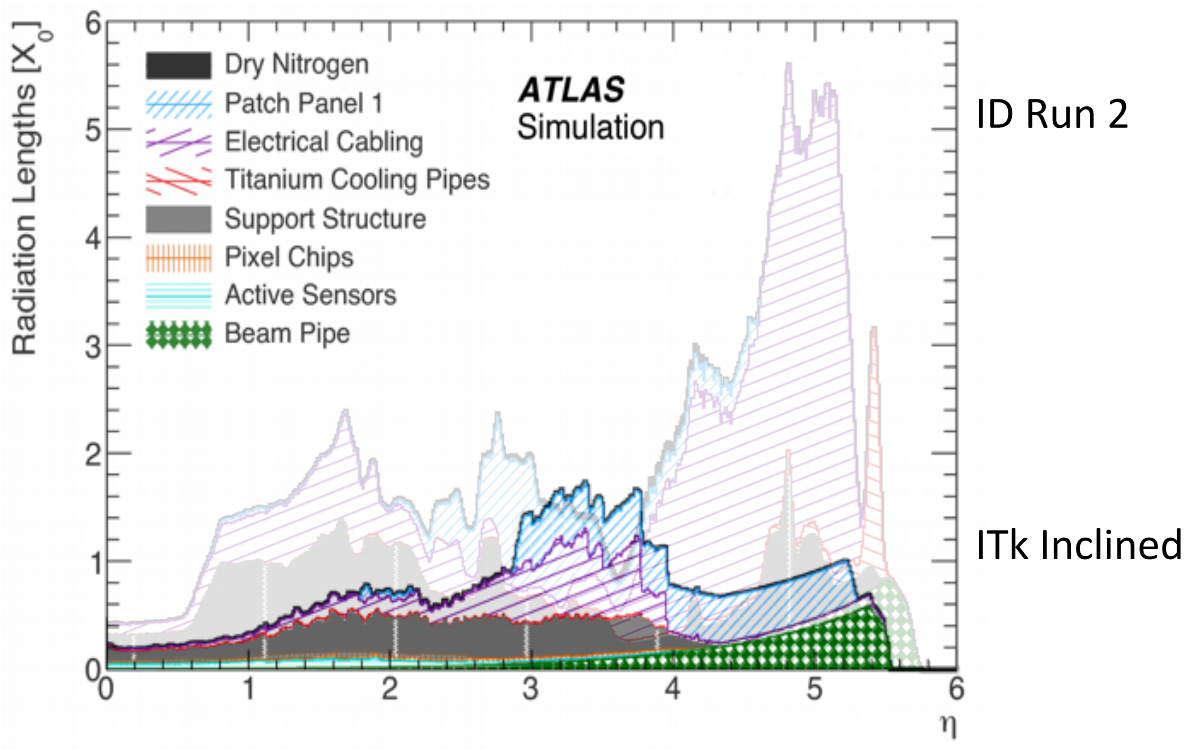
Current ATLAS Detector

- ATLAS is a general purpose experiment at the LHC
- It consists of:
  - Tracker (Inner Detector), built with a silicon pixel detector, silicon strip detector (SCT) and a Transition Radiation Tracker (TRT)
  - Electromagnetic and hadronic calorimeter
  - Muon chambers

Designed for μ = 25 at 25ns bunch crossings



Material Budget



In comparison to the current ID, the ITk material budget is around 30% lower in the region |η|<4.0. At the highest |η|, an even larger reduction is achieved.

References

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