The ATLAS ITk Strip Detector System for the Phase-II LHC Upgrade

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On behalf of the ATLAS ITk Strip Collaboration

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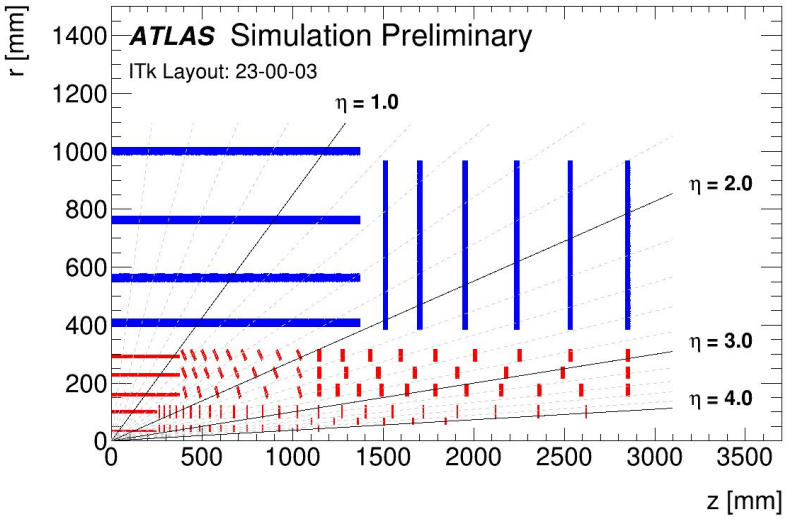
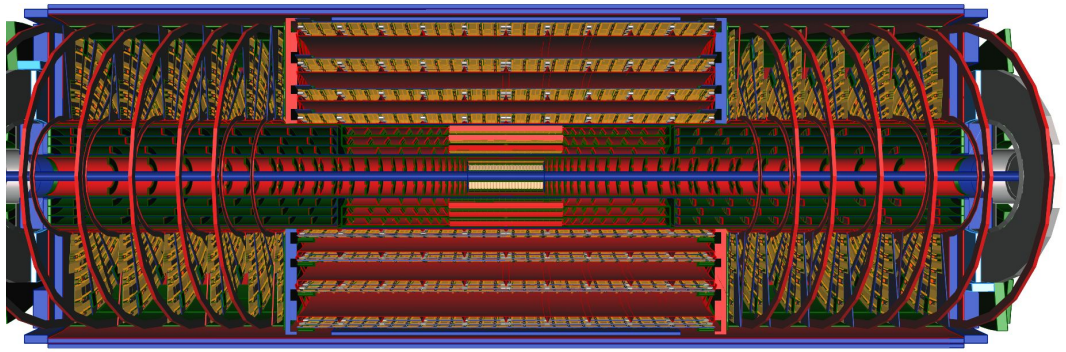
Introduction

- ★ Long Shutdown 3 from 2026 to 2029 will bring major upgrades to LHC and the experiments.
- ★ HL-LHC significantly improves upon LHC and top priority is an exploitation of its full physics potential.
- ★ **Complete replacement of Inner Detector with all-Silicon Inner Tracker.**
- ★ **Highly optimized new tracker layout to minimize the amount of material and maximize the number of hits per charged particle track.**





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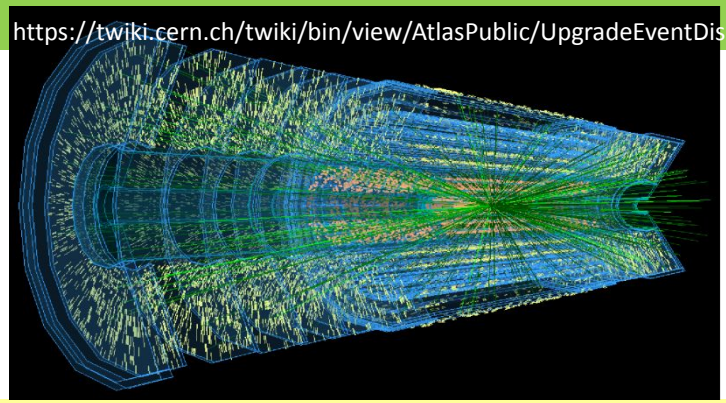
Detector challenges



HL-LHC expected performance:

- Centre of mass energy: $\sqrt{s} = 14$ TeV
- Instantaneous $L = 5.0 \times 10^{34}$ cm^{-2} s^{-1}
  - Ultimate $L = 7.5 \times 10^{34}$ cm^{-2} s^{-1}
- Integrated L 3000 fb^{-1}
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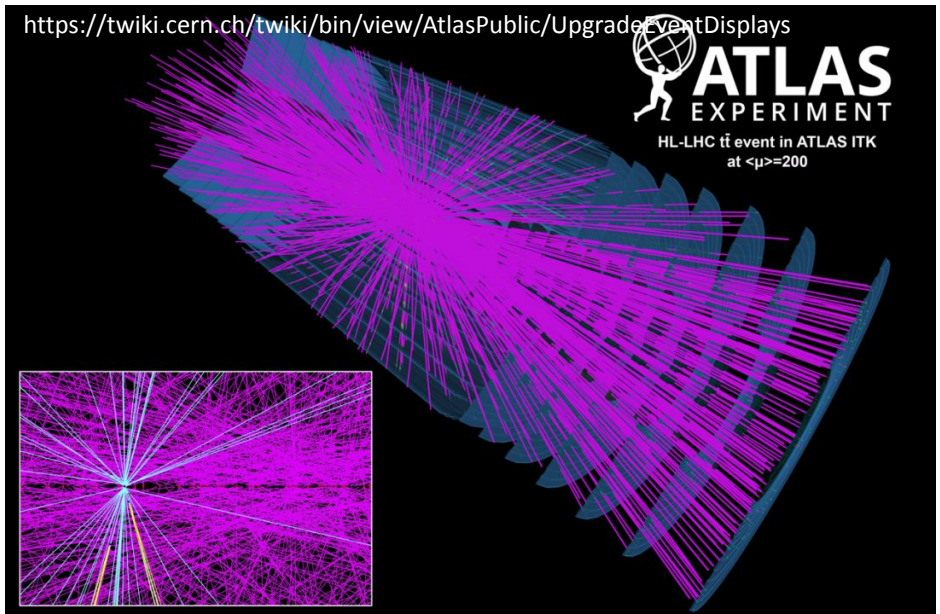
- Average interactions per bunch crossing: $\langle\mu\rangle = 200$



Detector challenges:

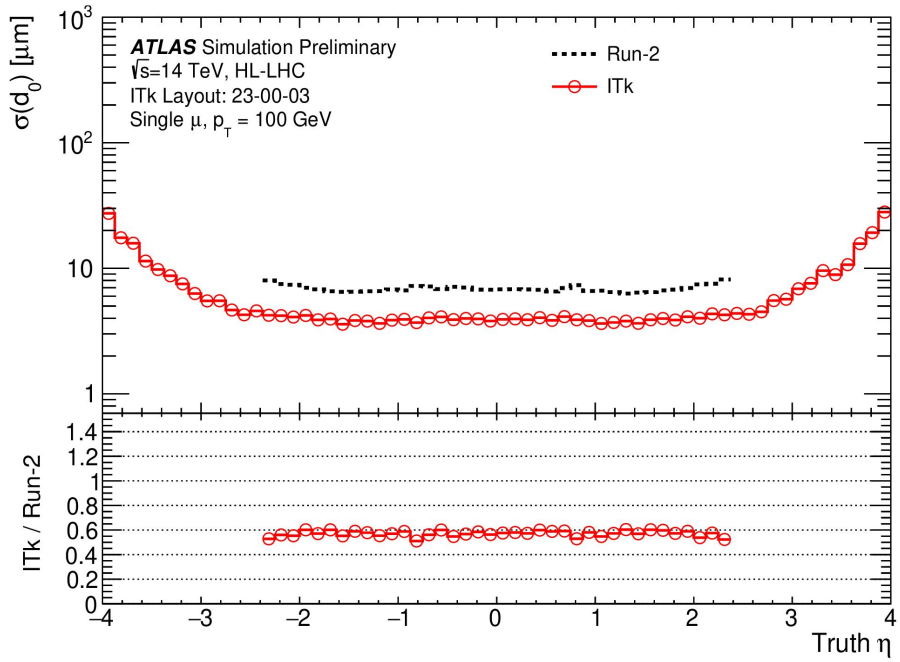
- Higher particle fluxes, larger event sizes, higher trigger rate
  - ⇒ trigger challenge
- Higher detector occupancy
  - ⇒ readout limitations
  - ⇒ increasing reconstruction complexity
- Increasing fluences, up to 10^{16} 1MeV n_{eq} cm^{-2} close to beam pipe
  - ⇒ increased radiation damage
  - ⇒ increased activation of materials

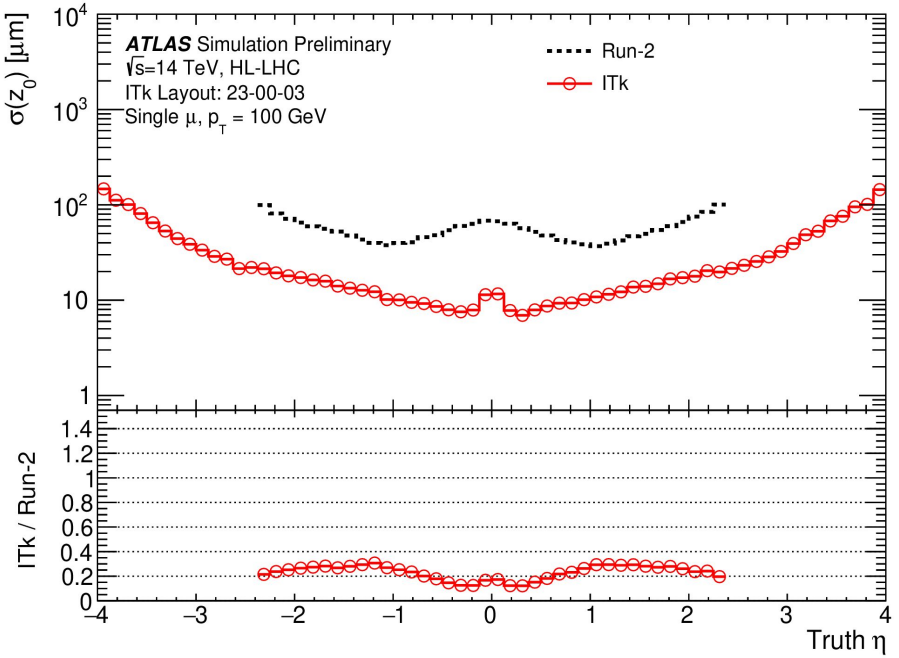
Inner Tracker Performance

CERN-LHCC-2017-021

The ITk is expected to have a superior transverse impact parameter

Transverse and longitudinal impact parameter resolution



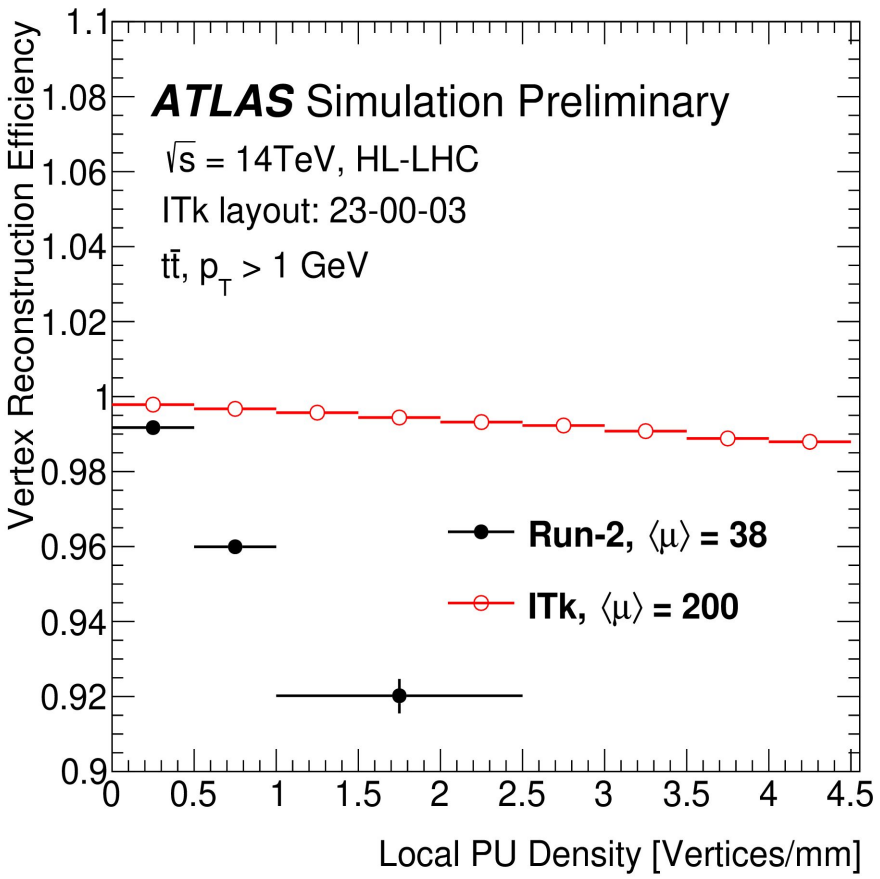


https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2021-024/

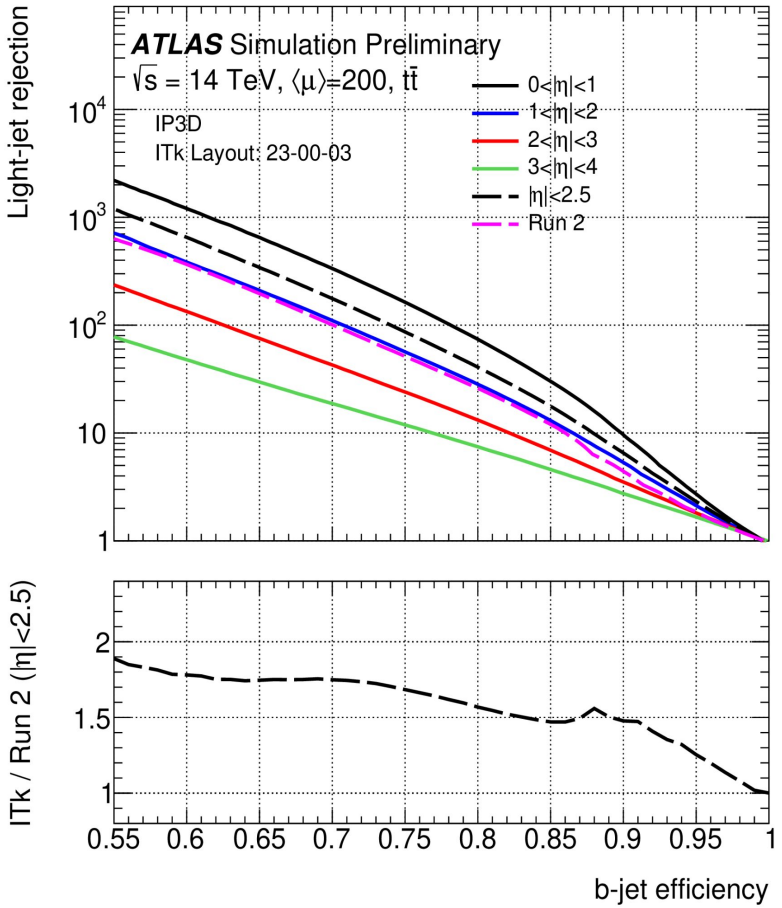
Inner Tracker Performance

CERN-LHCC-2017-021

vertexing



b-tagging



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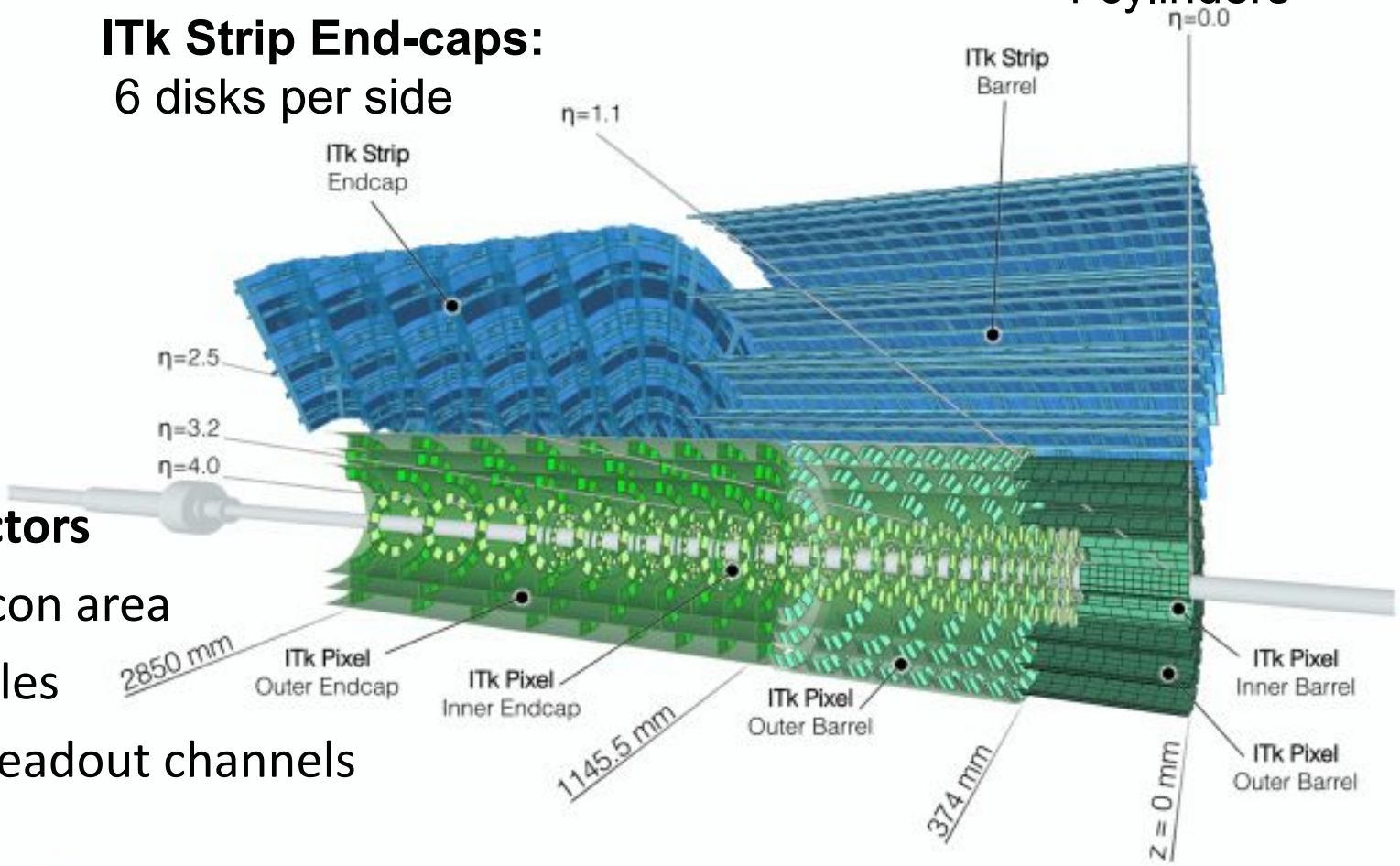
Inner Tracker Strips

ITk Strip Barrel:
4 cylinders

ITk Strip End-caps:
6 disks per side



ITk Strip detectors

- ~165 m2 silicon area
- 17888 modules
- ~60 million readout channels

ATLAS EXPERIMENT

ATLAS-PHOTO-2024-044

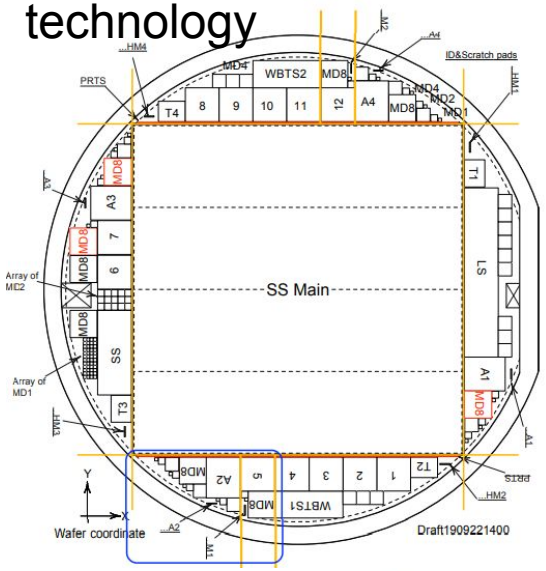
Inner **T**rac**k**er Strips
Building blocks

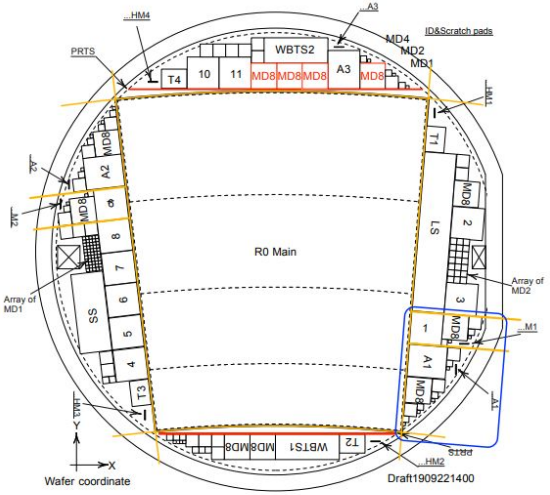
Sensors

Silicon sensors ⟶ **n+ -in-p float-zone (FZ)**

- ❖ collects electrons: more & faster signal, less trapping
- ❖ no radiation-induced type inversion
- ❖ single-sided process ⇒ easy production

Design based on 6-inch wafer technology





Sensor shape and strip pitch to maintain hit occupancy below 1 % :

Two types of barrel sensors:

- Inner 2 layers Short-Strip (2.4 cm)
- Outer 2 layers Long-Strip (4.8 cm)
- Active area of 9.7×9.7cm^2 (75.5μm pitch)

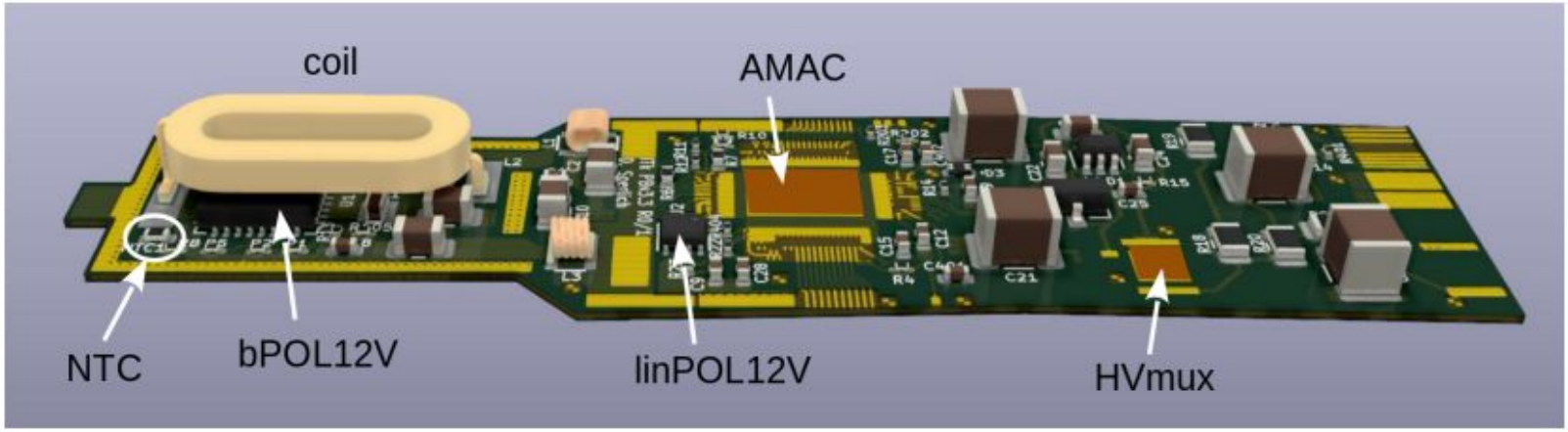
Six end-cap sensor geometries:

- 1.5-6cm strip length
- 70 − 80 μm pitch

Hybrids & Power boards

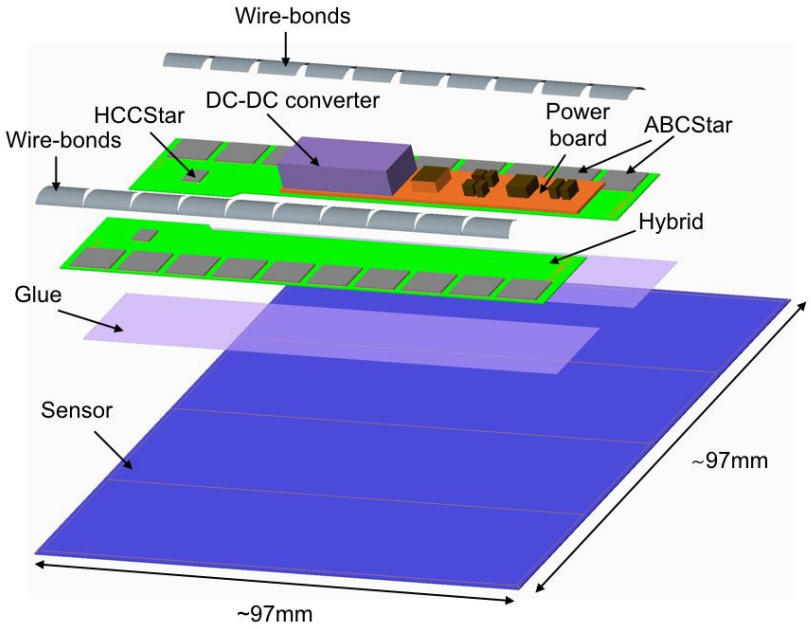
Hybrids: Hosts Binary readout chip ABCStar, Hybrid controller chip HCCStar. 13 (EC) + 2 (Barrel) designs.

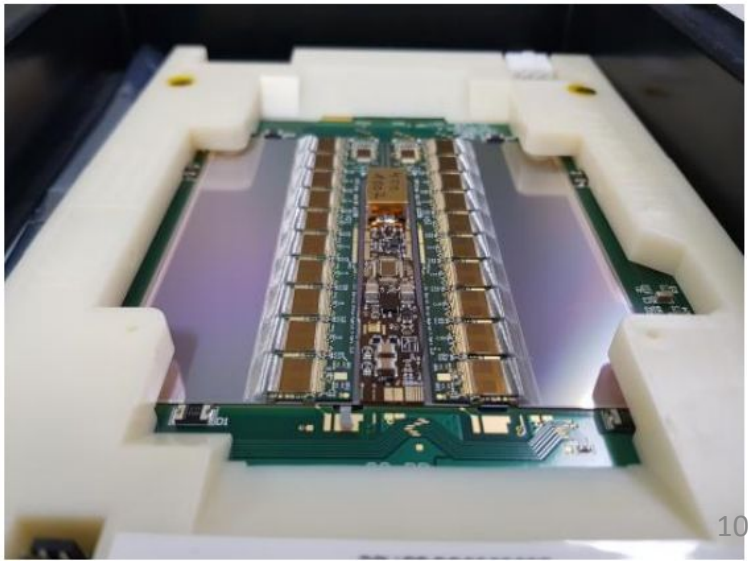
Power board: Hosts monitor and control AMACStar, DC-DC converter and HV filter and switch. 4 (EC) + 1 (Barrel) designs.



Modules

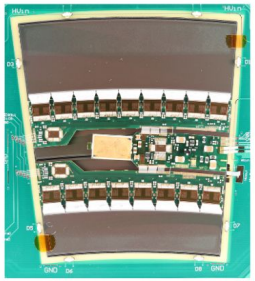
- ★ All modules have same electrical architecture but with different geometries :
  - 2 module variants in the barrel: Long strips and short strips
  - 6 module variants in the end-cap
- ★ New design:
  - low mass PCB's directly glued on sensor
  - Hosting readout electronics
  - Connection to strips by wire-bonds



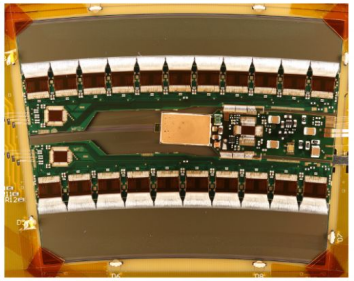


Modules

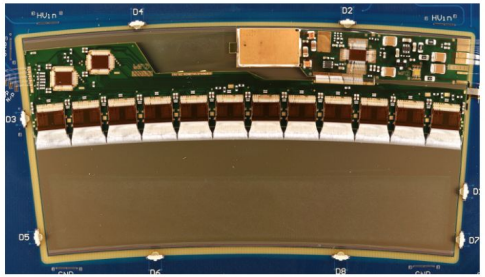
★ Six Enc-cap module geometries:
- Sensors for outer rings (R3, R4, R5) cannot be made from a single (6 inch) silicon wafer
- Modules made from two sensors utilising split hybrids
  - Retains basic architecture with data on LHS and power from RHS



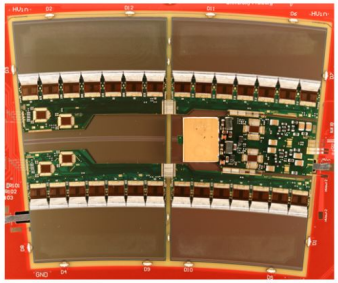
R0

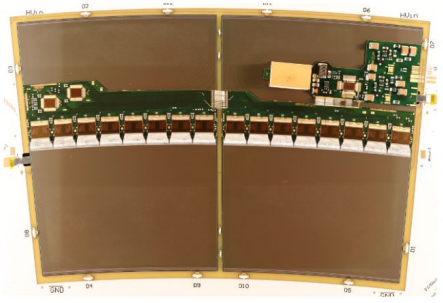


R1

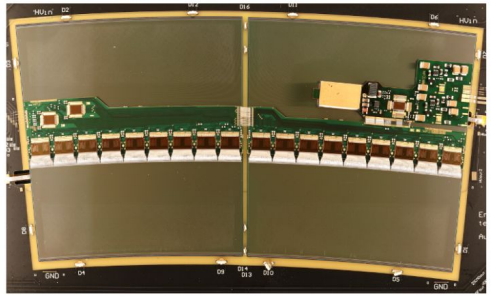


R2





R4

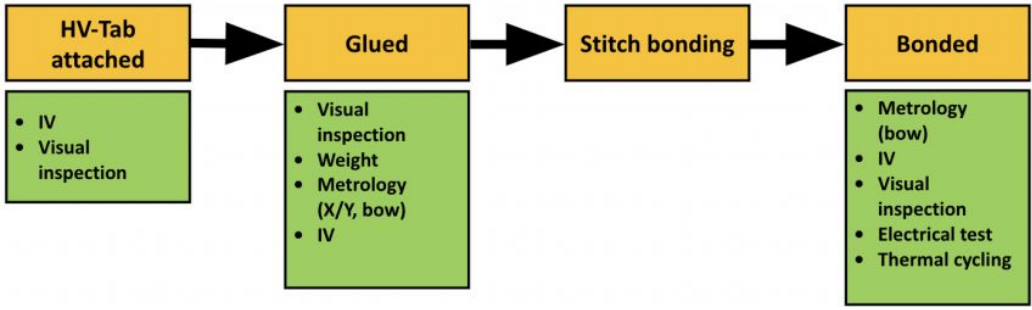


R5

10.1088/1748-0221/19/03/C03015

Module production

- ★ ~30 module assembly sites
  - Site qualification process based on a set of agreed-upon procedures
  - Dedicated high-precision tools for different module types
  - Precision assembly: from sensor positioning to glue thickness
- ★ Rigorous QC/QA procedures at every production stage:
  - Visual inspections and metrology
  - IV curves
  - Thermal cycling
  - Hybrid burn-in test
- ★ Nearly all (93%) module sites are now production ready
  - Two technical issues currently under investigation before production can start



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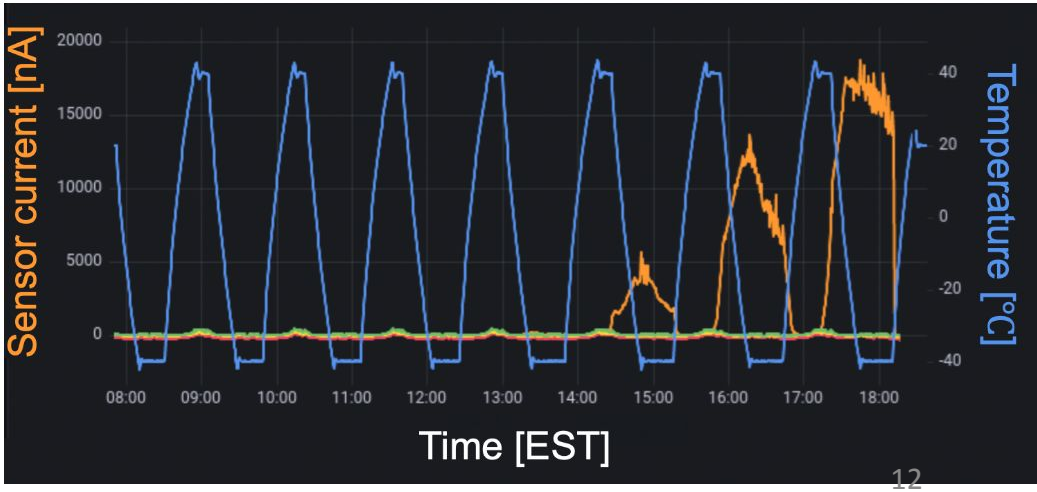
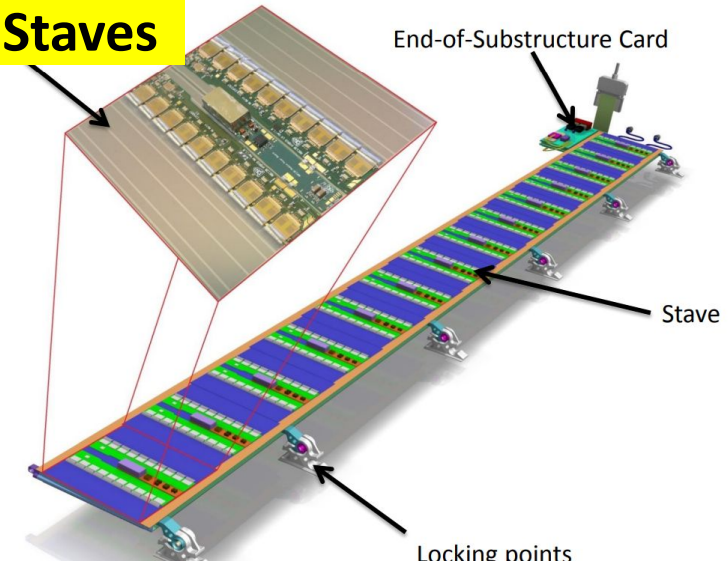


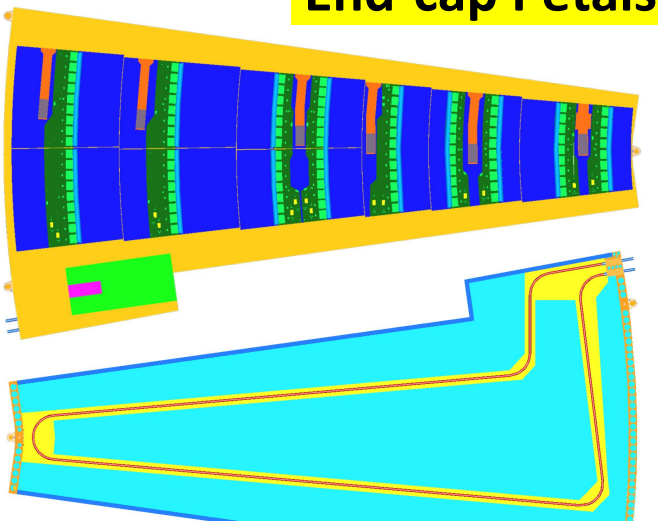
Local support

Detector assembled from intermediate local support objects:

Barrel Staves

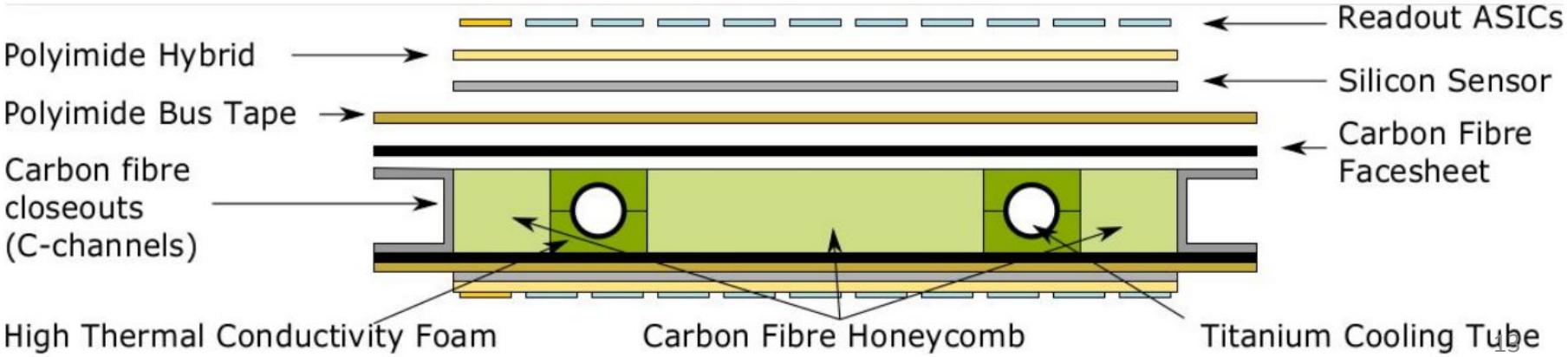


End-cap Petals



Cross section

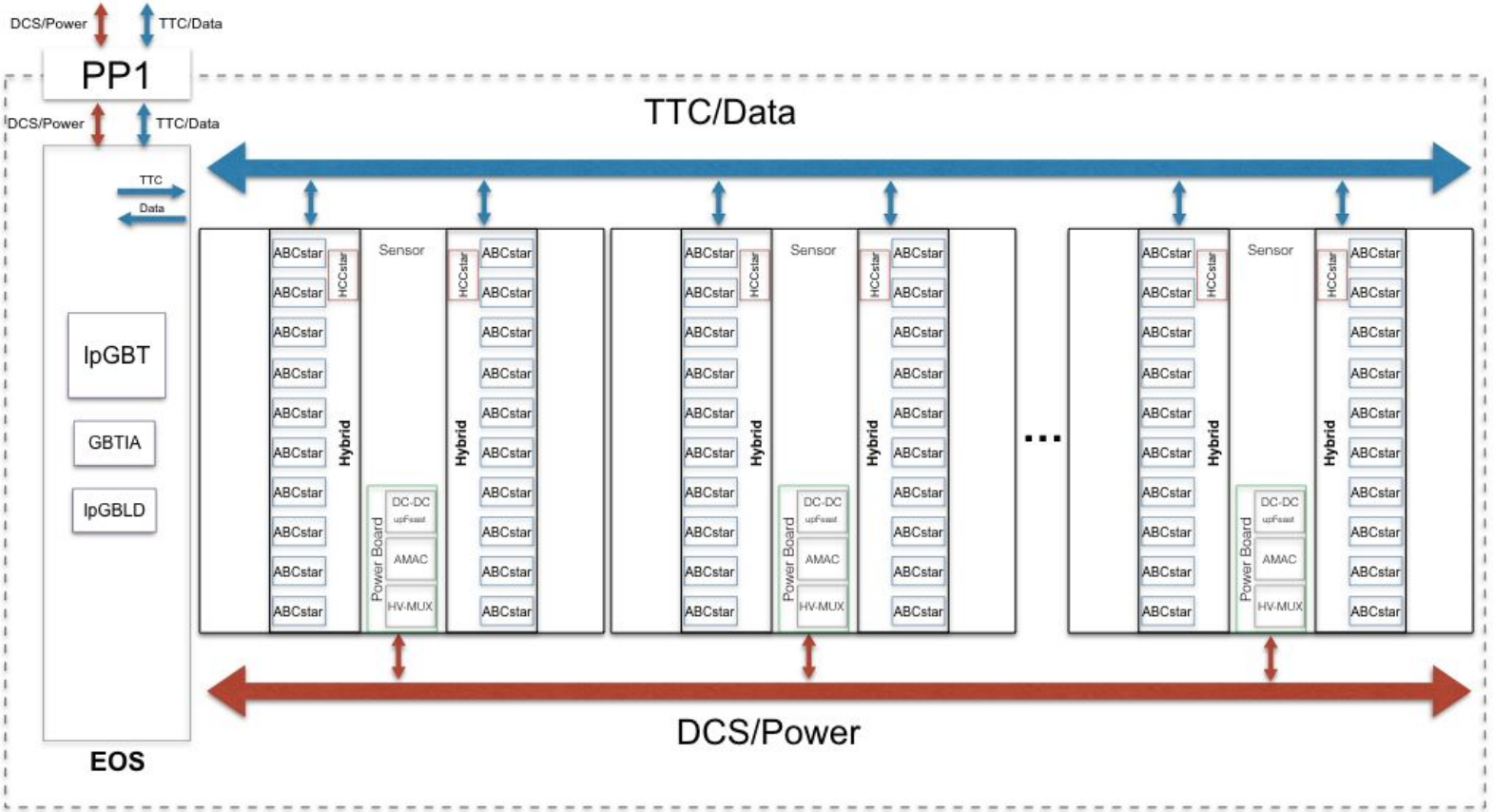
CERN-LHCC-2017-005



Signal and Power distribution

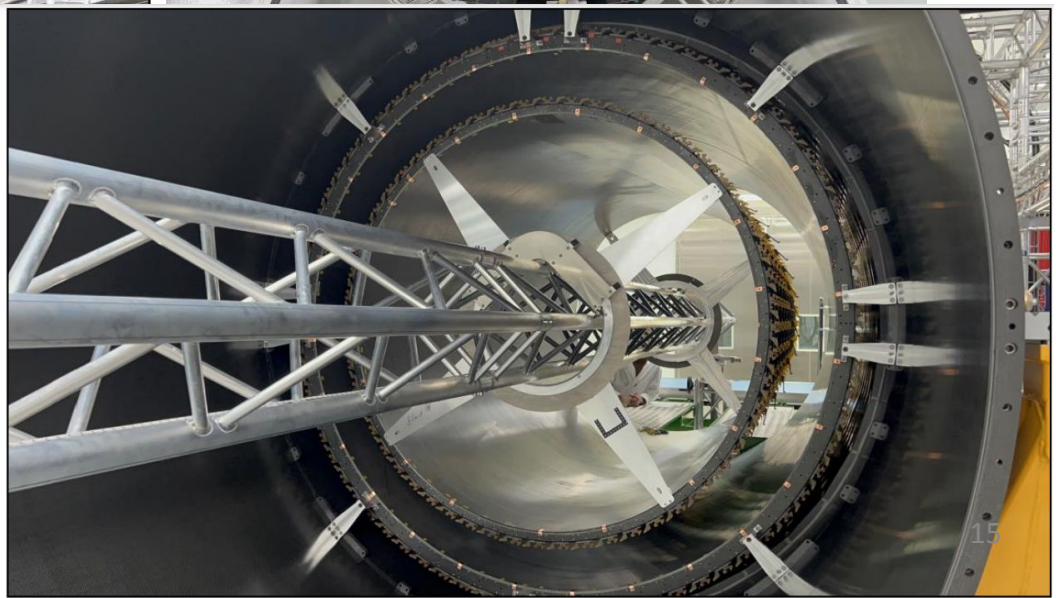
Each Stave/Petal is a standalone system level object providing:

- ★ Mechanical support and location control
- ★ Cooling; Power (LV & HV) ; Trigger, control, clock signals; CERN Low Power Signalling (CLPS) ; T, V, I monitoring; Data readout
- ★ Electrical-to-optical conversion at End-of Substructure (EoS)



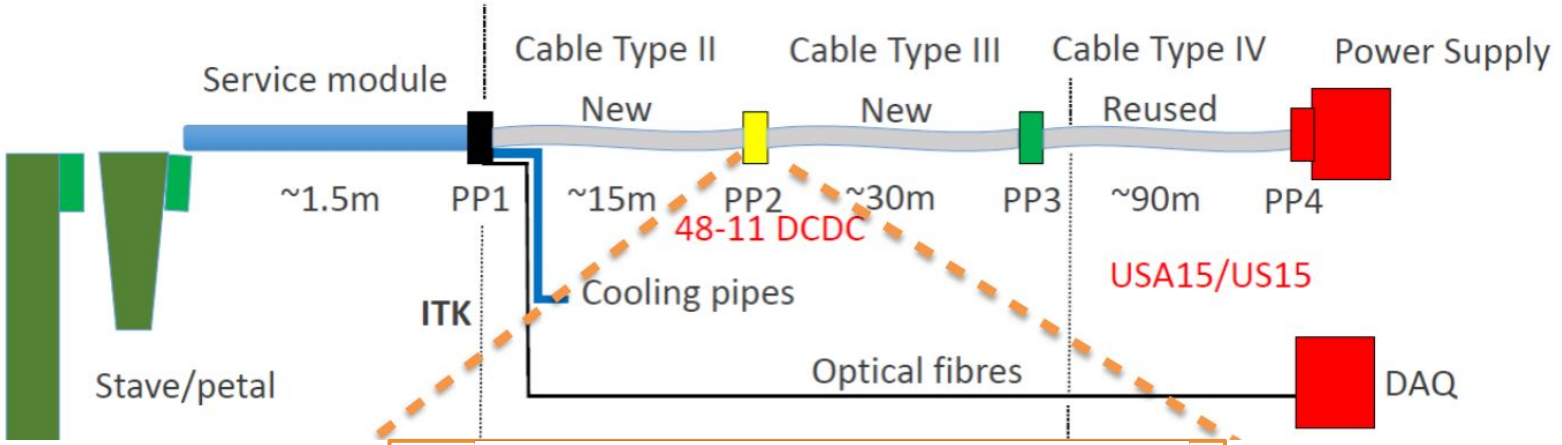
Global support

Global structures are mostly made out of carbon fiber-reinforced plastic (CFRP)



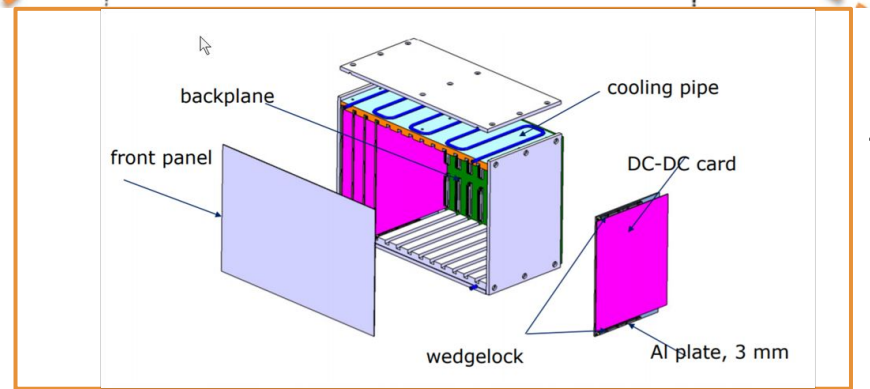
Powering & services

- ★ ~130 m long powering chain including two-stages DC-DC conversion
- ★ Cable plant partially re-used from current detector
- ★ Includes commercial power supplies and custom design electronic



Dedicated design

DC-DC step down converter system.

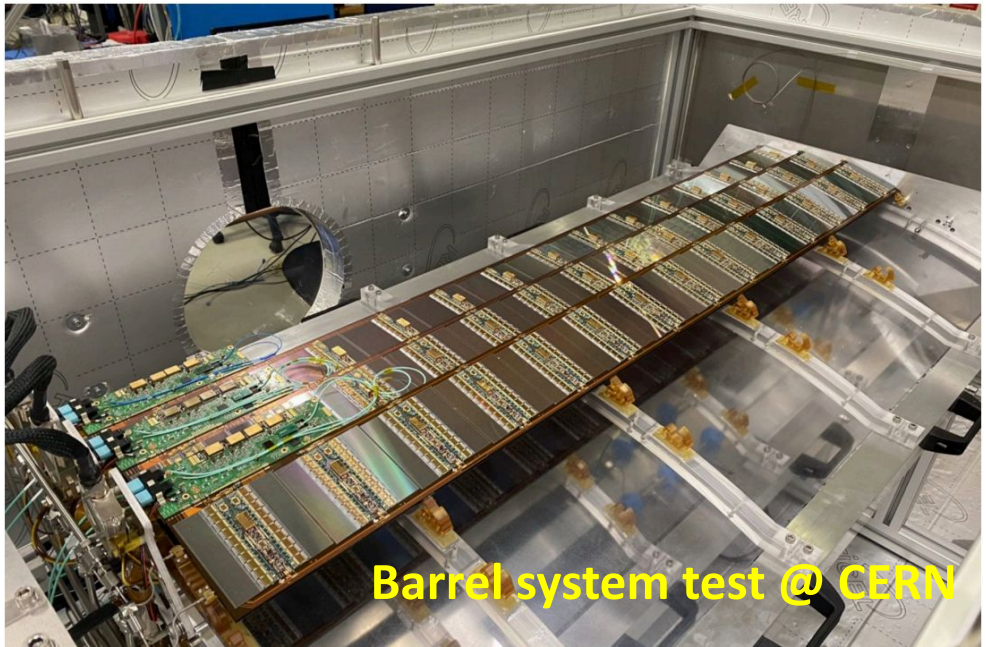


Tolerant to magnetic field (2T) and radiation

System test

Pre-production staves and petals in system tests to demonstrate full system performance with:

Full power chain • CO2 dual-phase cooling system • Thermal box providing dry air and environmental monitoring • Hardware interlock • Readout chain targeting the final DAQ system


Barrel system test @ CERN

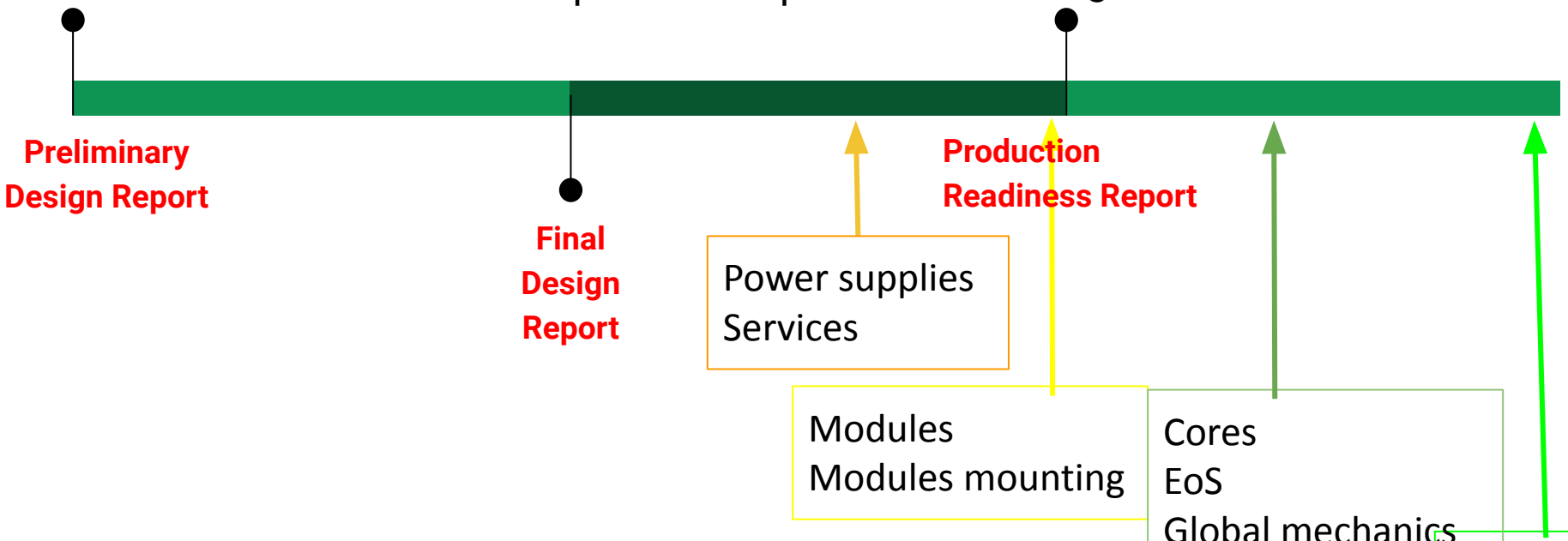

End-cap system test @ DESY

Towards full detector

Prototyping
To prove the design and performance of elements

Pre-production
used to build system test to validate full chain, prepare QC/QA, production processes

Production
Final full-scale production of the detector components. Integration of the detector segments

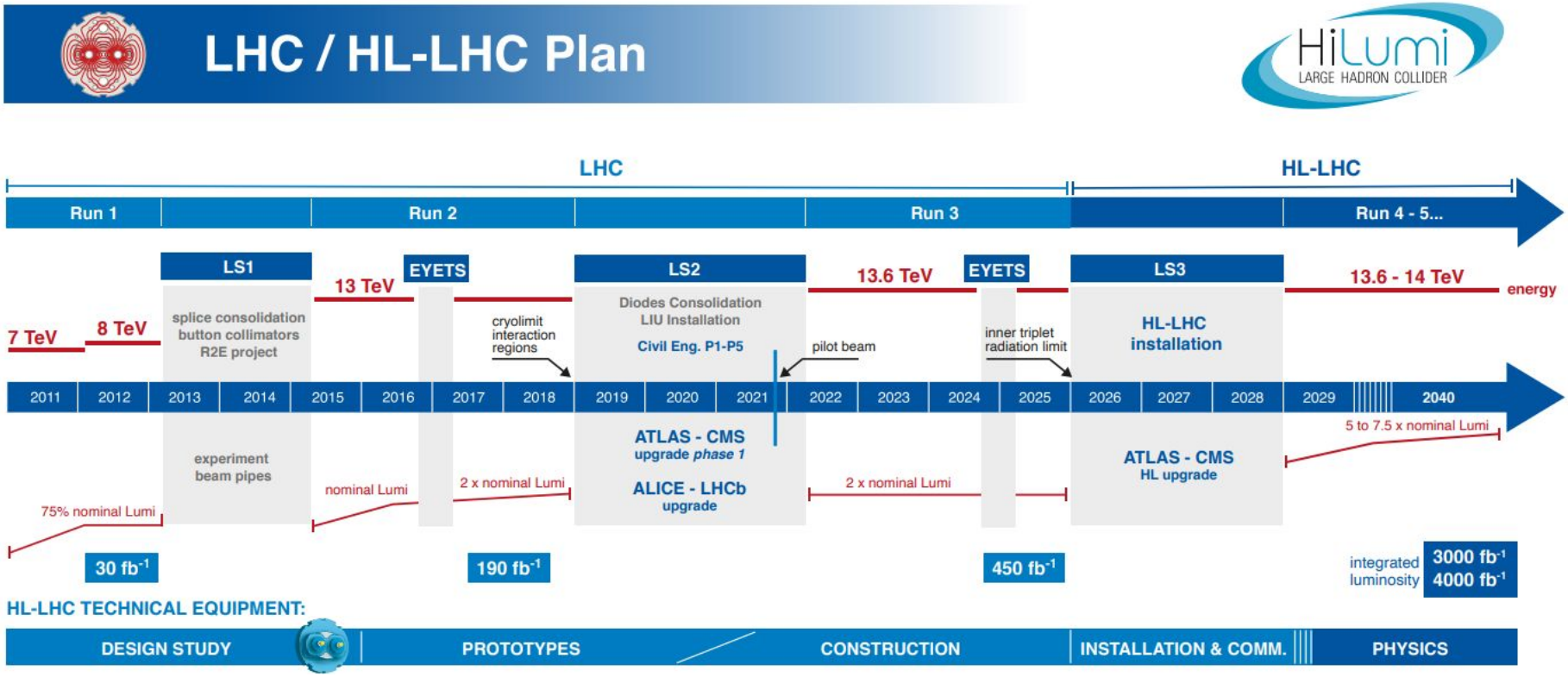


Summary

- ★ ITk Strip Detector will provide excellent particle tracking in the extremely high density HL-LHC environment, maintaining or improving performance of the present detector
- ★ The ITk Strip detector is in production phase
  - The production takes place in ~60 institutes in 14 countries all over the world
  - Most of the building blocks advancing toward finishing production
  - A couple of technical issues being wrapped up before starting module production
  - Services and Power Supplies pre-production ongoing to serve Integration tests

Backup

LHC and HL-LHC plans

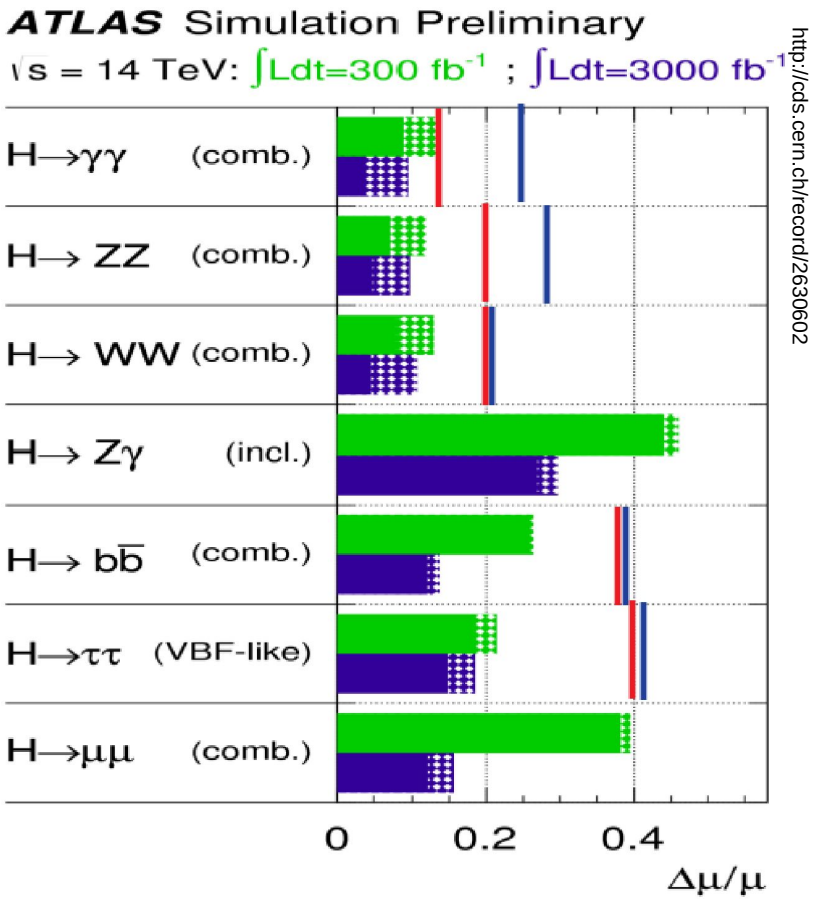


https://project-hl-lhc-industry.web.cern.ch/content/project-schedule

- Long Shutdown 3 from 2026 to 2029 will bring major upgrades to LHC and the experiments
- HL-LHC significantly improves upon LHC and top priority is an exploitation of its full potential

Physics prospects: SM and beyond

- **Precise SM and Higgs sector measurements**
  - Higgs boson μ values , access to rare Higgs processes
  - Higgs boson couplings will be measured with precision of 2-10%
  - Higgs self-coupling in SM accessible at HL-LHC
  - Weak boson scattering
- **Beyond Standard Model physics**
  - Searches for new massive states on HL-LHC will extend mass reach by ~20%
  - SUSY particles searches significantly extended
  - High mass gauge bosons, tt resonances, quark and lepton substructure, extra dimensions, dark matter candidate, …



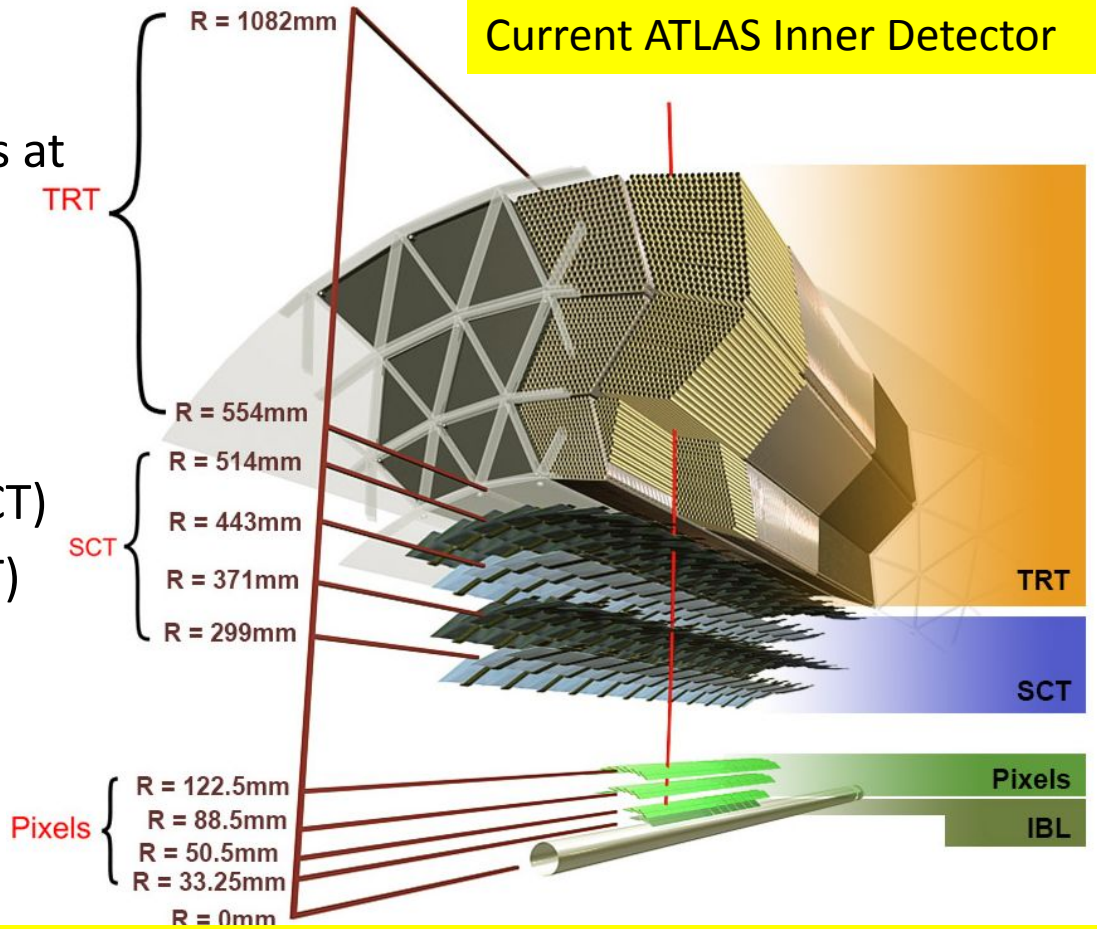
http://cds.cern.ch/record/2630602

Inner Tracker (ITk) Overview

- Current ATLAS Inner Detector designed to operate for 10 years at $L=1x10^{34}$ cm^{-2} s^{-1} with $<\mu>=23$, @25ns, L1=100kHz

Limiting factors at HL-LHC

- Bandwidth saturation (Pixels, SCT)
- Increased occupancies (TRT, SCT)
- Radiation damage (Pixels (SCT) designed for 400 (700) fb^{-1})



Complete replacement of Inner Detector with all-Silicon Inner Tracker

Inner Tracker Overview

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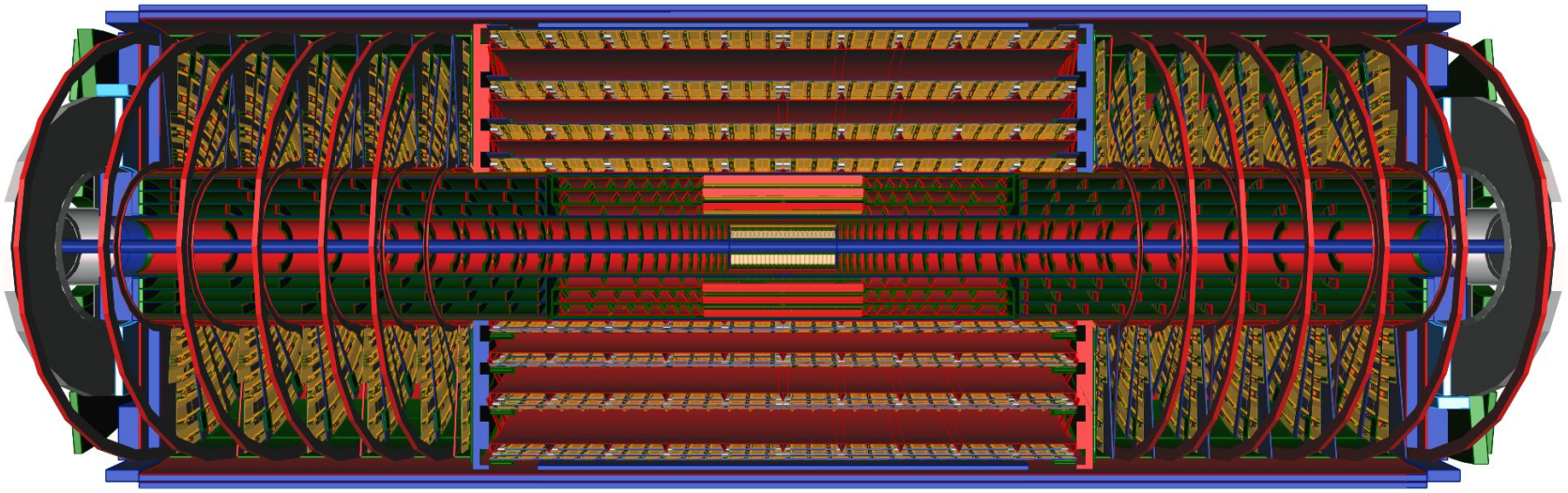

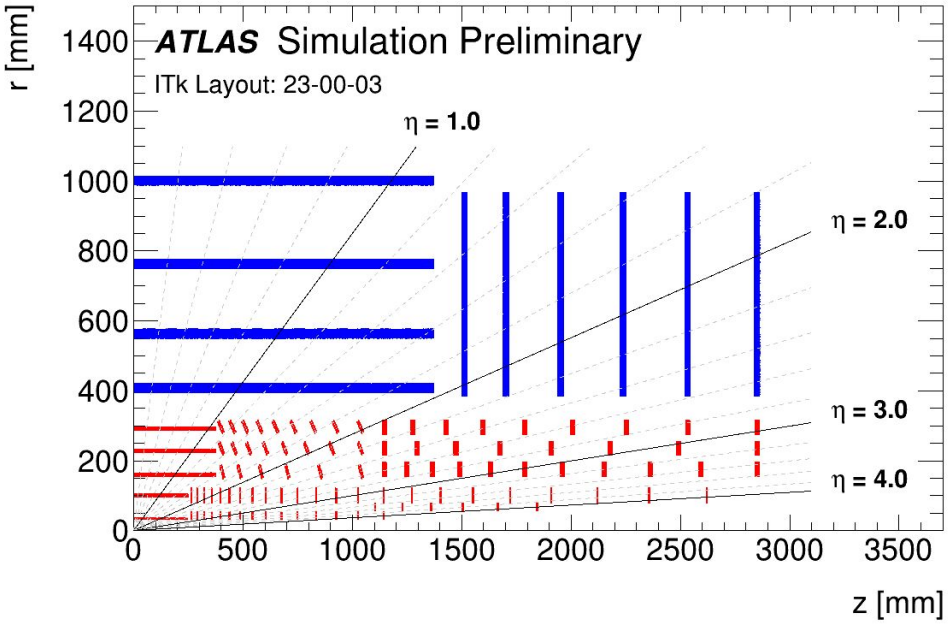

- Acceptance extended
  from $|\eta|<2.5$ to $|\eta|<4.0$
- Number of hits in barrel ~ 13
  (2 hits/strip module)
  In forward regions at least 9 pixel hits
- Minimizes silicon area and material.