UNIVERSITY OF TORONTO

The ATLAS tracker strip detector for HL-LHC

Kyle Cormier on behalf of the ATLAS collaboration

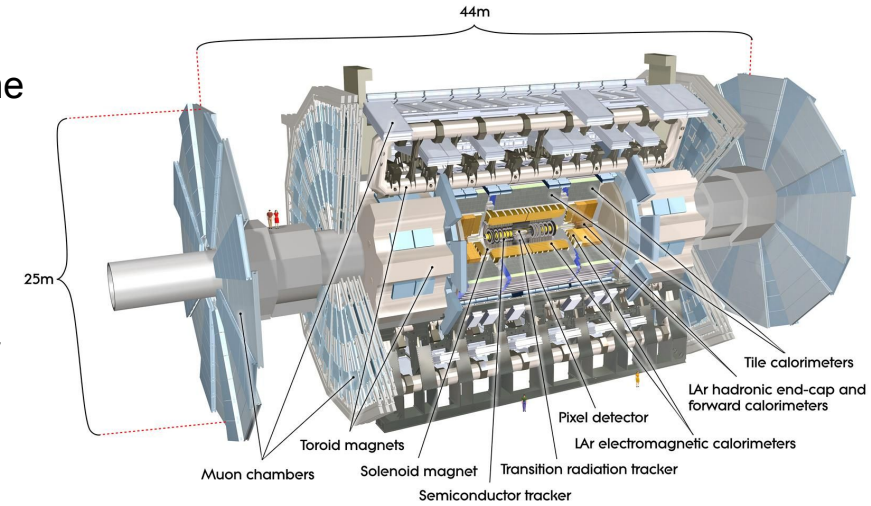
Vertex 2016

WHAT?

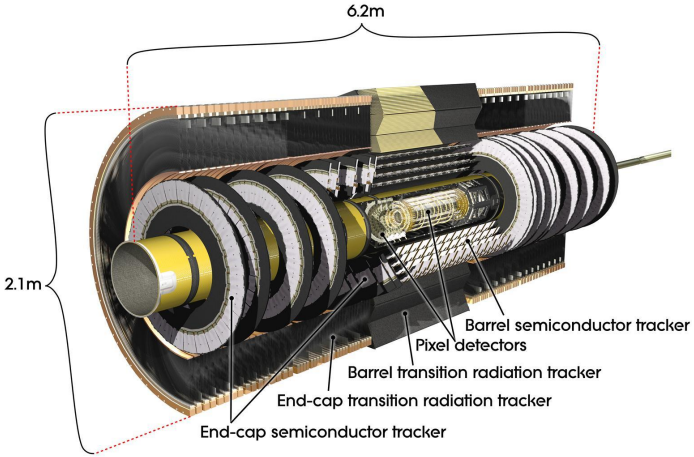
Introduction: ATLAS ITk Strips

The ATLAS ITk strip detector will be the strip portion of the ATLAS Inner Detector for the High Luminosity-LHC (HL-LHC).

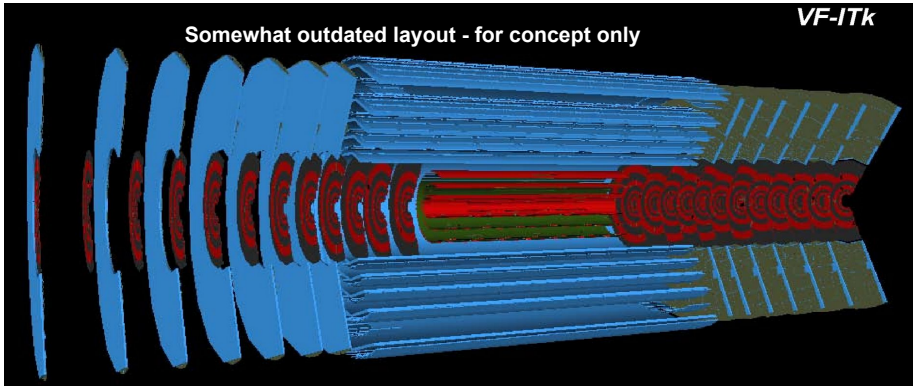
- Analogous functionality to the ATLAS SCT
- Extending to the largest radius portions of the Inner Detector, occupying space currently used by the Transition Radiation Tracker (TRT)



Current Inner Detector

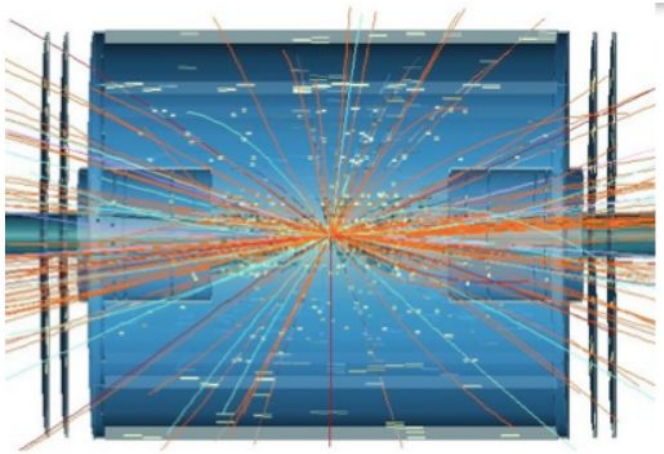


ITk Layout concept

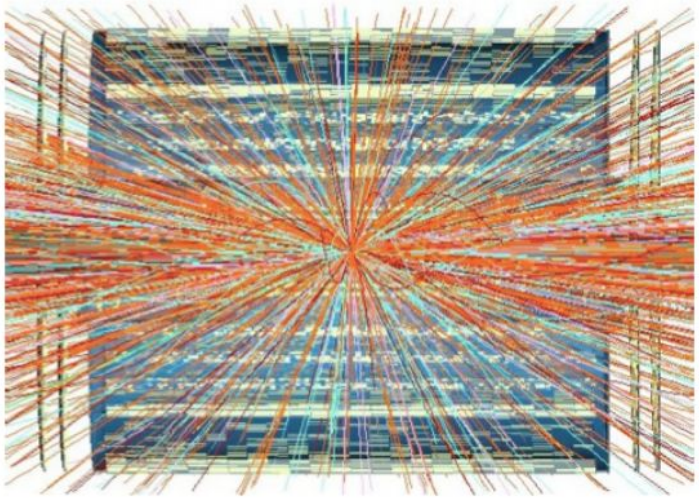


WHY?

Introduction: Motivation



LHC 300 fb^{-1}



HL-LHC 3000 fb^{-1}

Current Inner Detector not designed for such a high density environment or total lifetime ↦ Precision physics at HL-LHC requires new tracker.

Challenges to be addressed

Granularity → need to balance low occupancy requirements for reliable tracking with bandwidth considerations
Read out → need to meet higher ATLAS trigger rates while maintaining good granularity and low material budget
Radiation Damage → Components need to be hard against instantaneous radiation issues and lifetime damage

HOW?

1. Design
    a. Layout
    b. Staves and Petals
    c. Electronics Architecture
    d. Modules
    e. Sensors
    f. ASICs
2. Status
    a. Testing
    b. Production

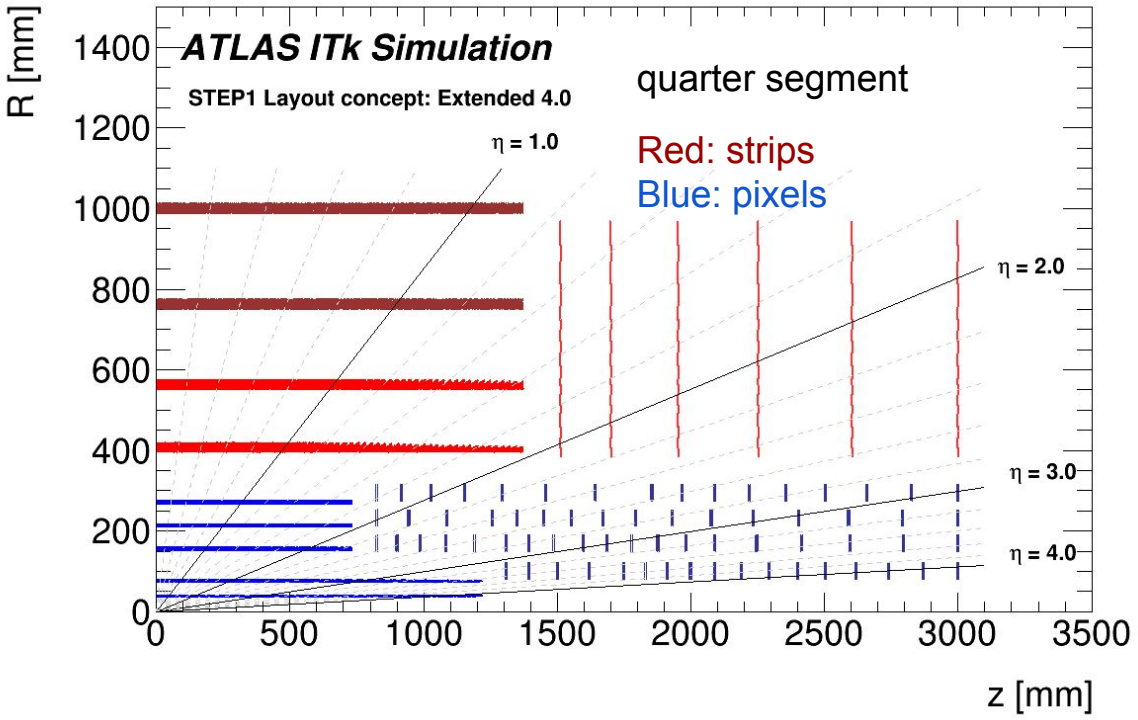
Design: Layout

ITk strips will occupy the large radius portion of the ATLAS inner cylinder including the region currently used by the Transition Radiation Tracker, providing faster readout and better granularity

Large radius → Occupancy, granularity and radiation damage alleviated. But lots of data to read out, large production, lots of pieces.

- Central Barrel Segment
  - 4 barrel layers
  - covers R = 405 - 1000mm
  - covers z = ±1400mm
  - short inner-layer strips
  - longer outer-layer strips
- Outer Endcaps on each side
  - 6 end cap disks on each side
  - Covers up to η = 2.5
  - Covers out to z = ± 3m
  - Disks made of 6 rings
  - Strip lengths and pitches vary to accommodate geometry and occupancy

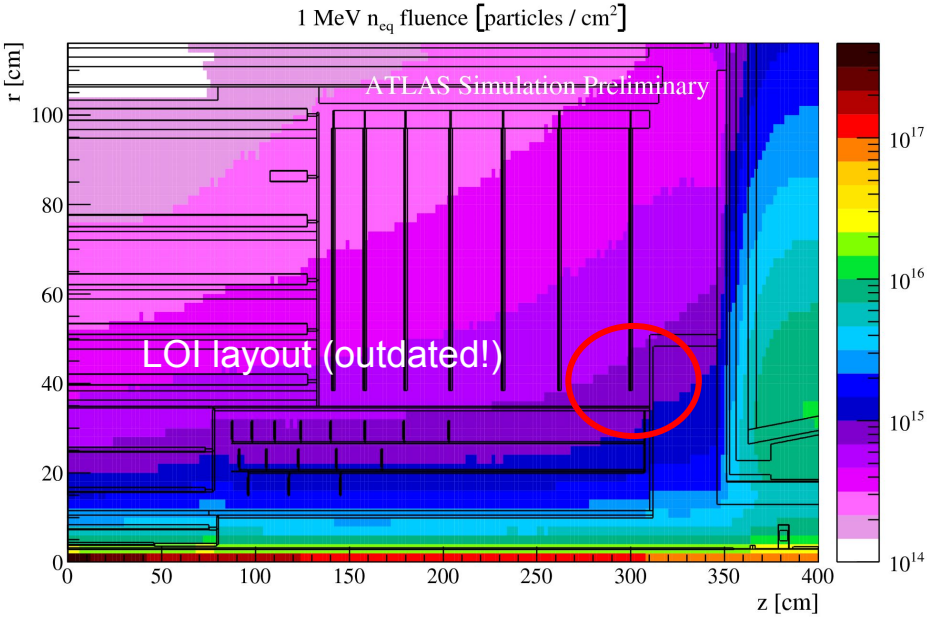
One of several layouts being considered



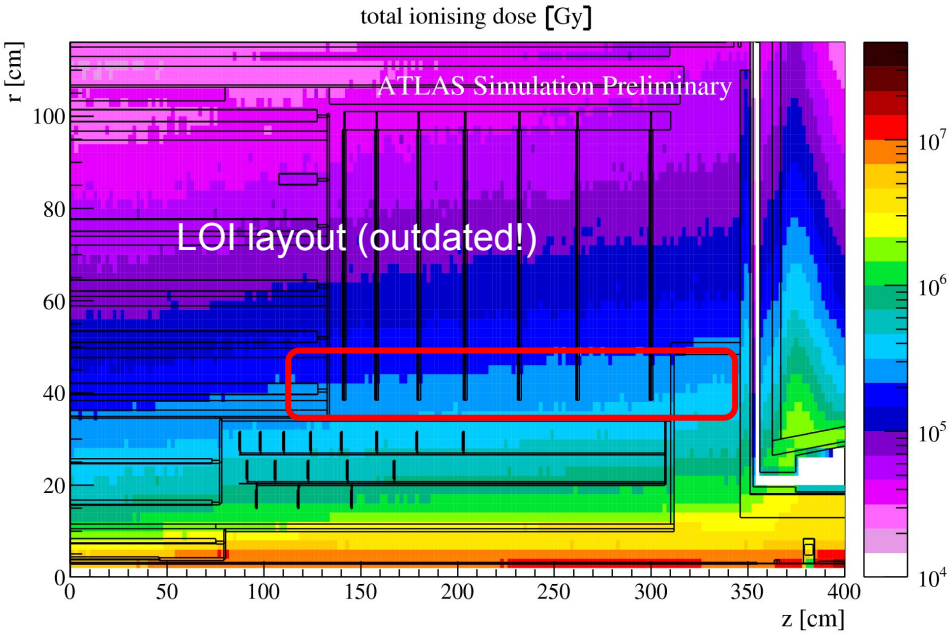
ATLAS Collaboration (2016) Step1 ITk Layouts. ITK-2016-001

Design: Layout 2

1 MeV Neutron Equivalent Flux



Total Ionizing Dose



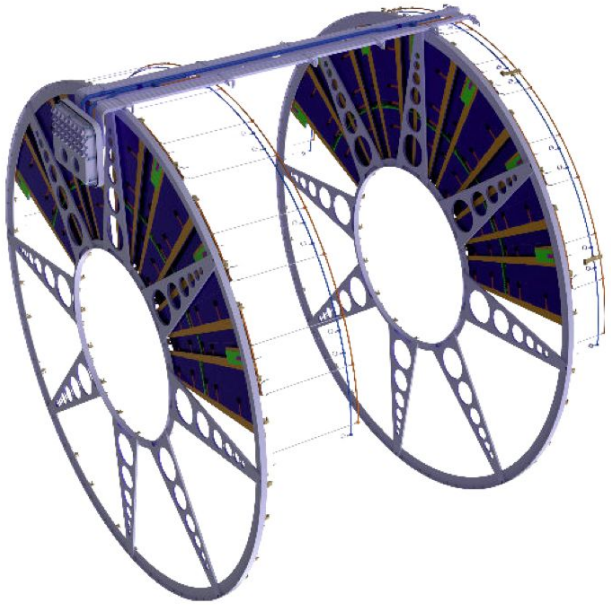
ATLAS Collaboration (2012) Letter of Intent for Phase-II Upgrade of the ATLAS Experiment. CERN-LHCC-2012-022

Design: Staves and Petals

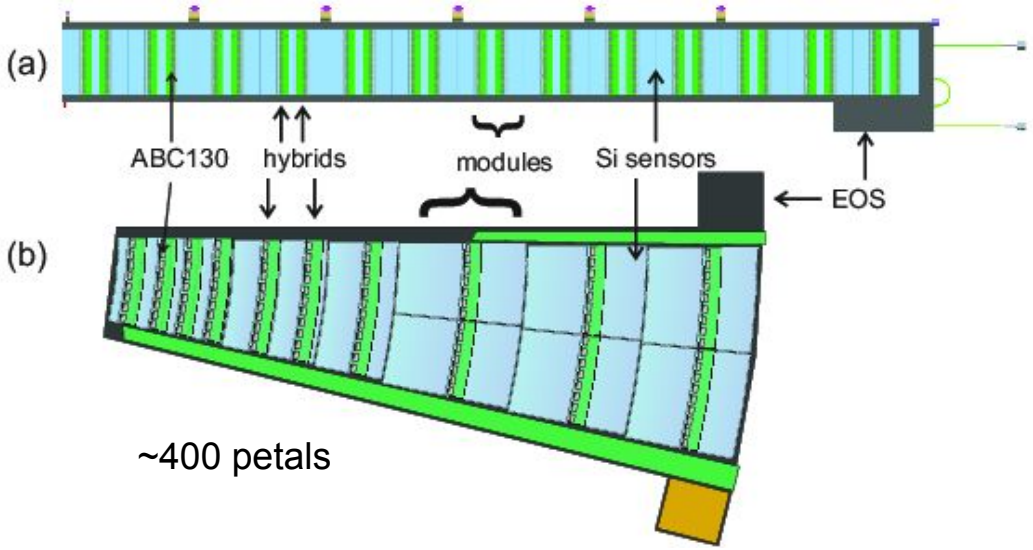
Overlapping Staves (Petals) tiled to build each Barrel Layer (Disk).

Staves/Petals form individual functional units providing **mechanical support, cooling, powering and readout** capabilities.

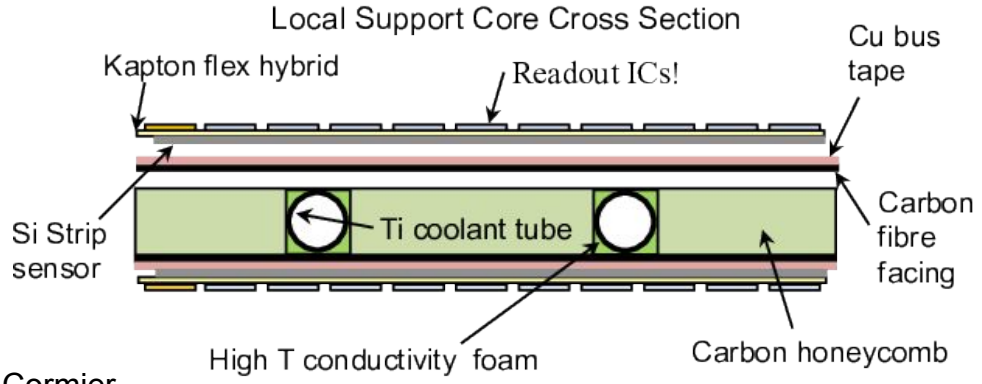
Required to provide support and services to active modules with minimal material budget for good performance



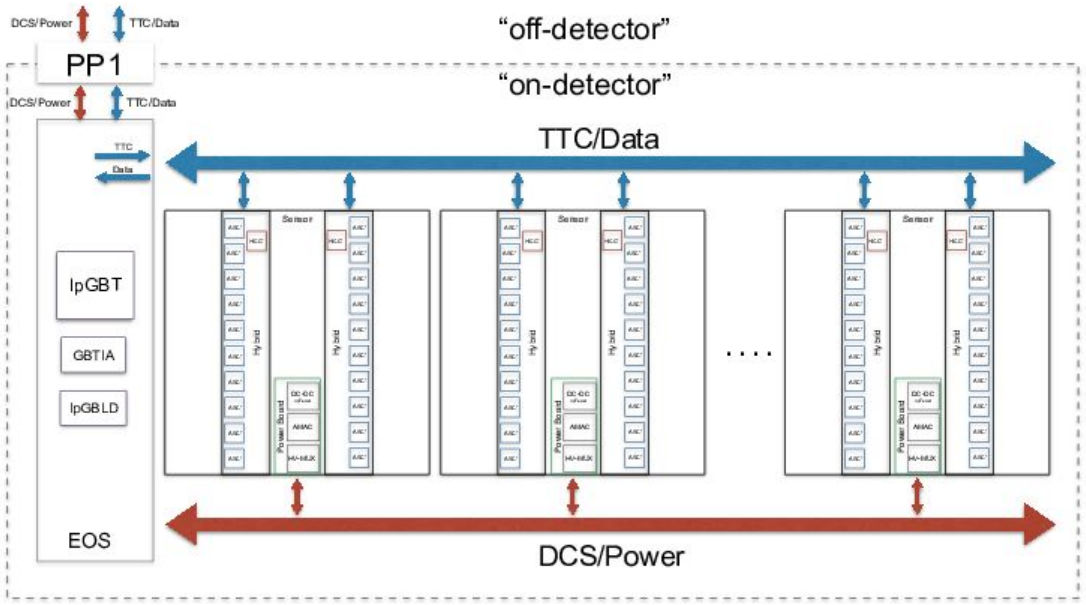
~400 Staves



~400 petals

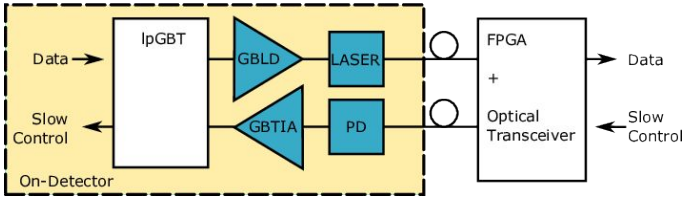


Design: Electronics Architecture



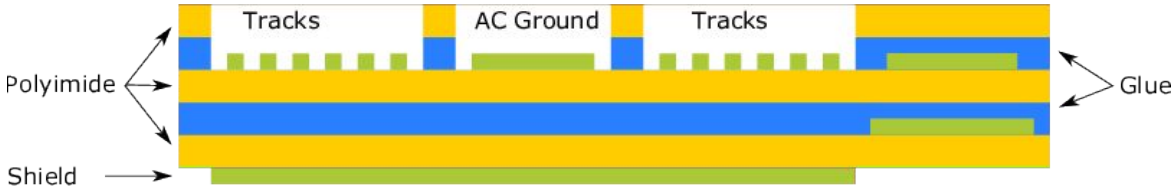
End of Substructure Cards:
Interface on-detector and off-detector electronics

- 2 lpGBTx for high-speed radiation hard multiplexing and de-multipllexing
- Versatile Link+ (VTRx) for optical communications off-detector



Bus Tapes:
Lightweight on-stave signalling and power

- Copper lines (17μm) with polyimide insulation (25 μm) connected with aluminum wire bonding
- Copper grounding plane in contact with carbon fibre skins and EOS card.
- AC and DC module ground lines

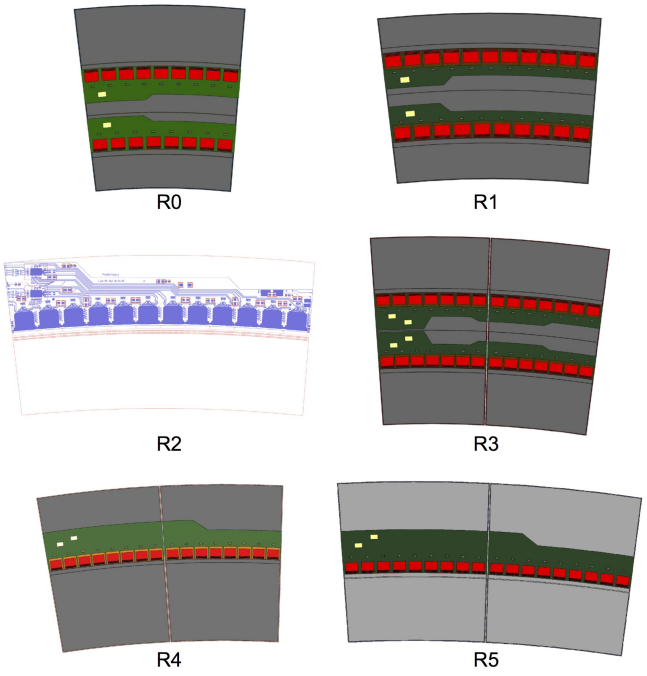


Module Power Boards
Per Module powering

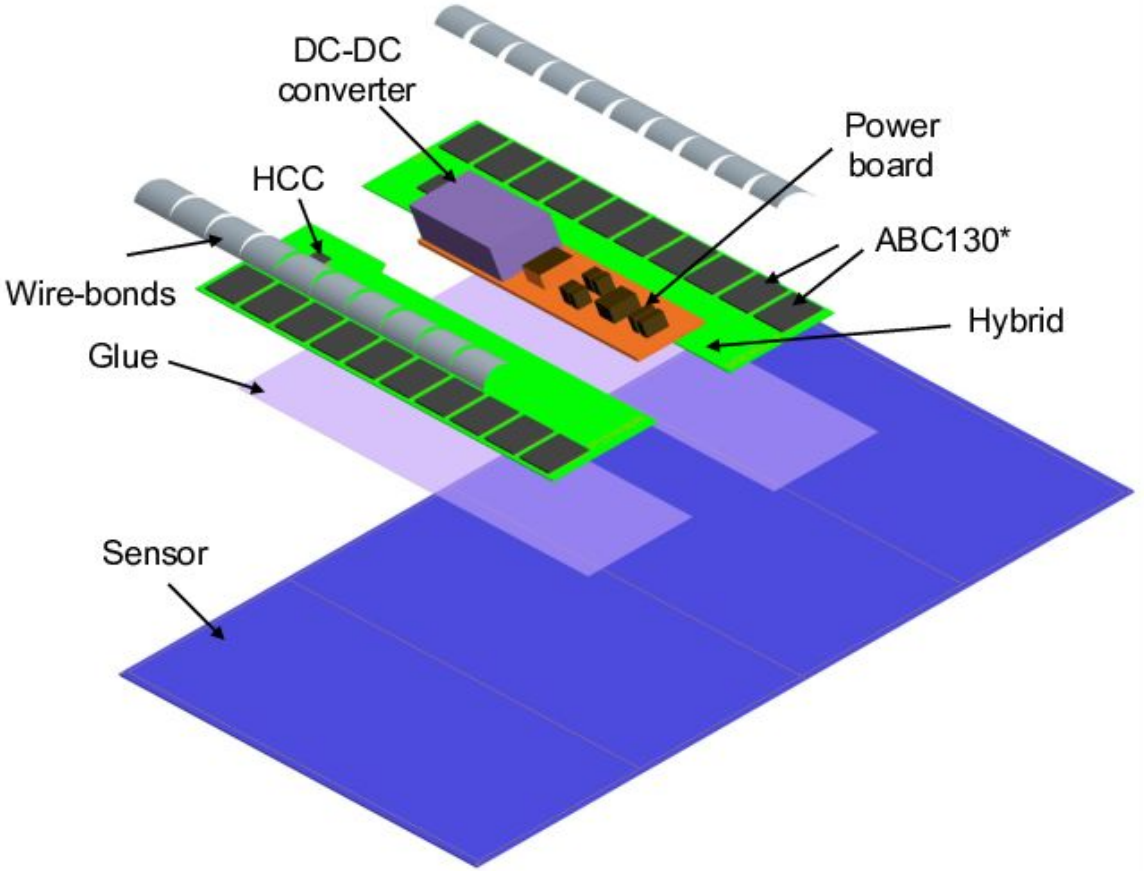
- Rad hard DC-DC converters
- HV switch
- Autonomous monitoring for DCS

Design: Modules

Functional building blocks which make up staves/petals.



End-Cap module designs

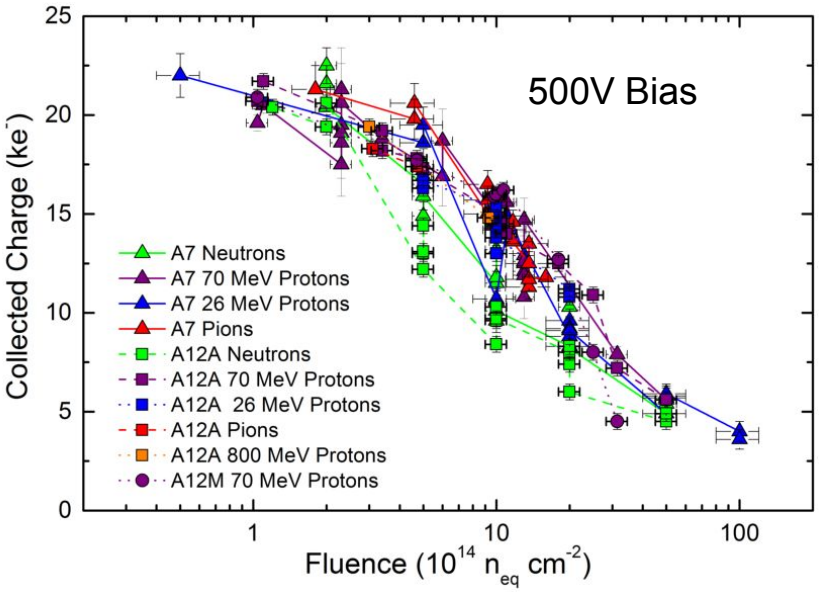


Design: Sensors

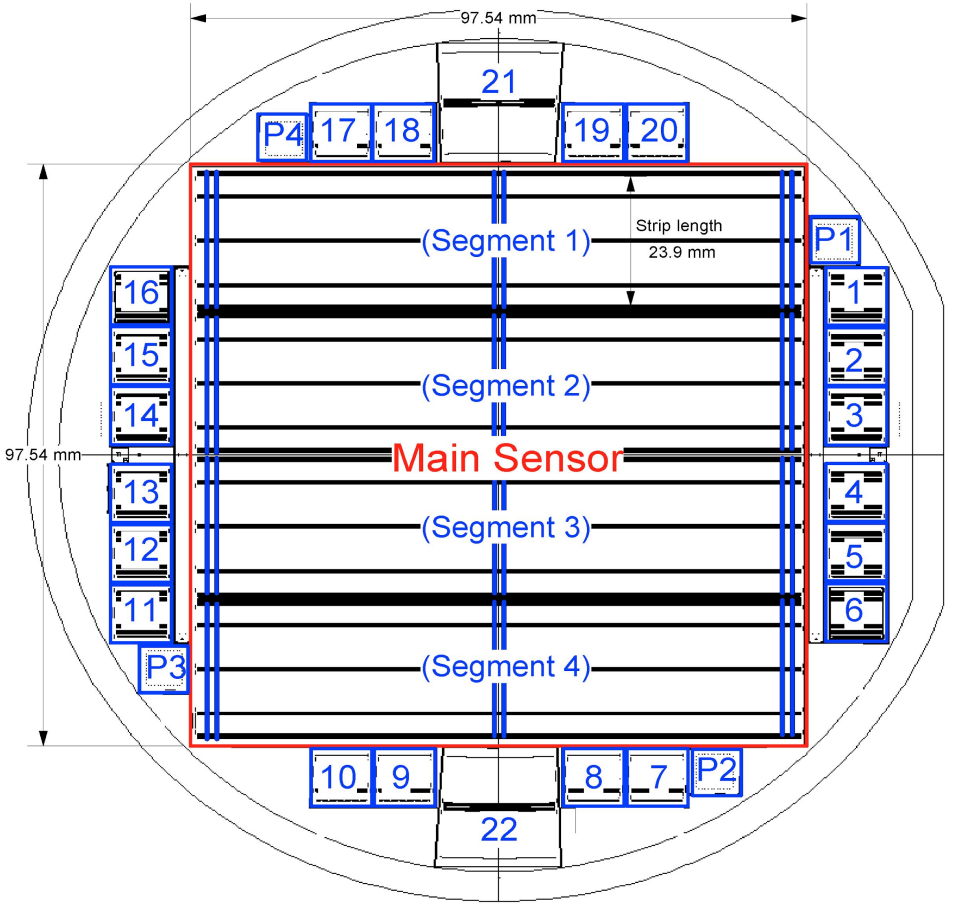
AC coupled n-type implants with p-type float zone up to 700V bias

- Collects electrons
- No type inversion, much better signal post-irradiation

Substrate Material	
Size	8-inch/200 mm or 6-inch/150 mm
Type	p-type FZ
Crystal orientation	<100>
Thickness (physical)	300-320 μm
Thickness (active)	>= 90% of physical thickness
Thickness tolerance	$\pm$ 5 %
Resistivity	> 3 kΩcm
Oxygen concentration	$1 \cdot 10^{16}$ to $7 \cdot 10^{17}$ cm^{-3}



K. Hara et al., NIM A DOI:10.1016/j.nima.2016.04.035
Y. Unno et al., NIM A 765 (2014) 80-90



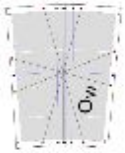
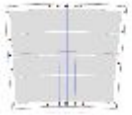
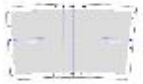
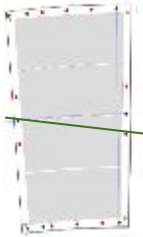
Design: Sensors 2

26 mrad strip rotation for barrel, 20 mrad built-in stereo angle for end-cap sensors

Quality Assurance tests from batch of 100 sensors has shown high quality results.

- Average 51 micron bow corner to centre
- Breakdown below 1kV only observed in 1 sensor
- 99.97% good strips

Short and long strips

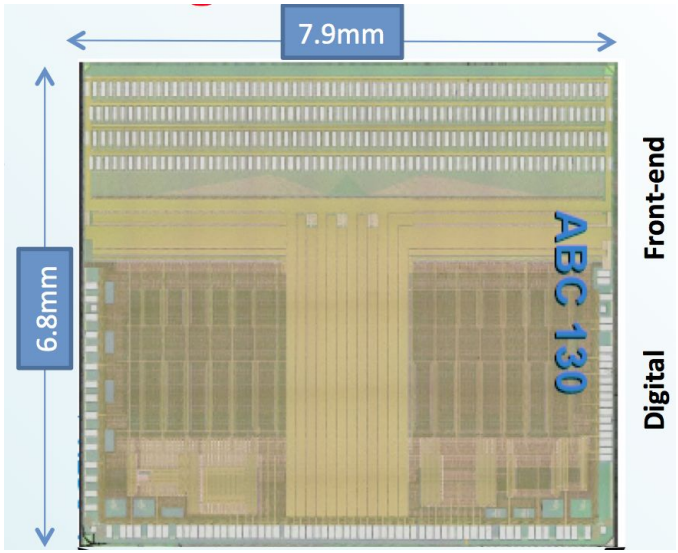
Sensor Type	Number of Sensors	Shape	Number of Columns	Channels per Sensor	Min/Max Pitch (μm)
Short Barrel	6000	Square	4	5128	74.5
Long Barrel	8000	Square	2	2564	74.5
EC Ring 0	1000		4	4360	73.5/84
EC Ring 1	1000		4	5640	69/81
EC Ring 2	1000		2	3076	73.5/84
EC Ring 3	2000		4	3592	70.6/83.5
EC Ring 4	2000		2	2052	73.4/83.9
EC Ring 5	2000		2	2308	74.8/83.6

Varying strip pitches in end cap

Design: ABC130

Front-End ASIC:

- Binary Read out
- 256 channels/chip



Analog Functionality

- Signal amplification and tunable discrimination
- Charge injection calibration circuits
- Enclosed Layout Transistors for maximum performance stability despite radiation damage

Digital Functionality

- Event compression and buffering
- Control and tuning registers
- Register triplication for data persistency in high radiation environment

Design: ABC130 continued

Next iteration: ABC130* (pronounced ABC130 Star)

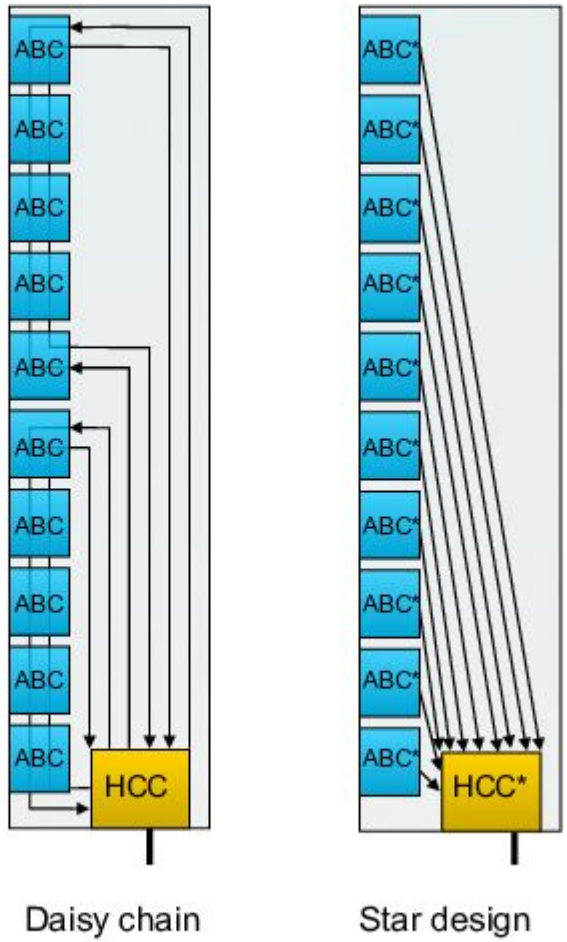
Many updates:

- New communication scheme with HCC
- Accommodate developing power, and readout schemes
- Employ more robust triggering techniques (L0 tag)
- Tests of ABC130

Recent specification review
Plan to submit chip in first half of 2017

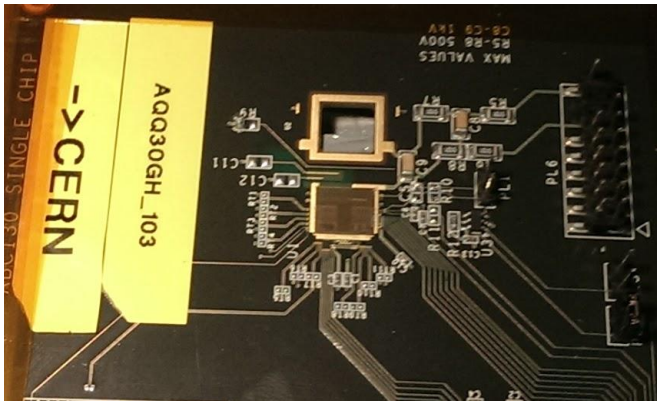
HCC130(*)

- Parallel development with ABC130(*)
- Responsible for distributing communications to/from ABC130s
- More involved serialization/de-serialization, packet building for star layout
- Autonomous Monitoring block



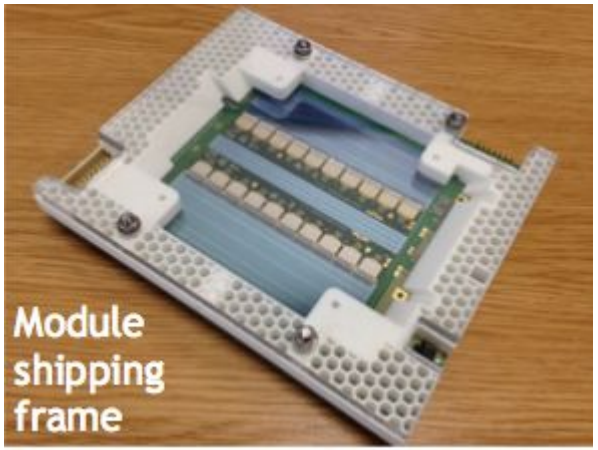
Daisy chain Star design

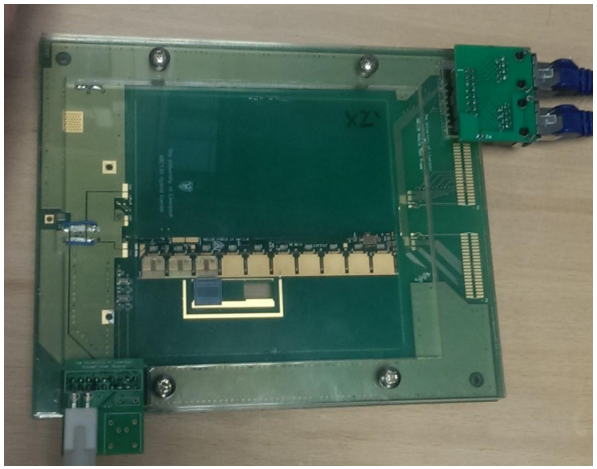
Testing: ABC130 continued



Tests of ABC130

- Table-top front end characteristics tests
- Test beams with sensors
- Single Event Effects tests
- TID tests with various sources





Testing: ABC130 continued

Single Event Effects

- Observed importance in current LHC and Detector electronics
- Can be problematic with low power small structures
- Mitigation built in to ABC130 design

Design Features

- Critical Register Triplication
- SEU monitoring register
- Room for inclusion of Error Correcting Code in ABC130*

SEE effects tested with proton irradiation at CERN PS facility:

- Bit flip rates in pipeline and registers
  - Bit flip cross section measured, in agreement with expectations
- Register triplication
  - Reduced overall rate of logical errors ~50, likely dependent on register positioning
- Effect of voltage
  - Observable change in SEU rate with input voltage
  - Not expected to be of operational concern
- TID influence
  - No observed change with dose

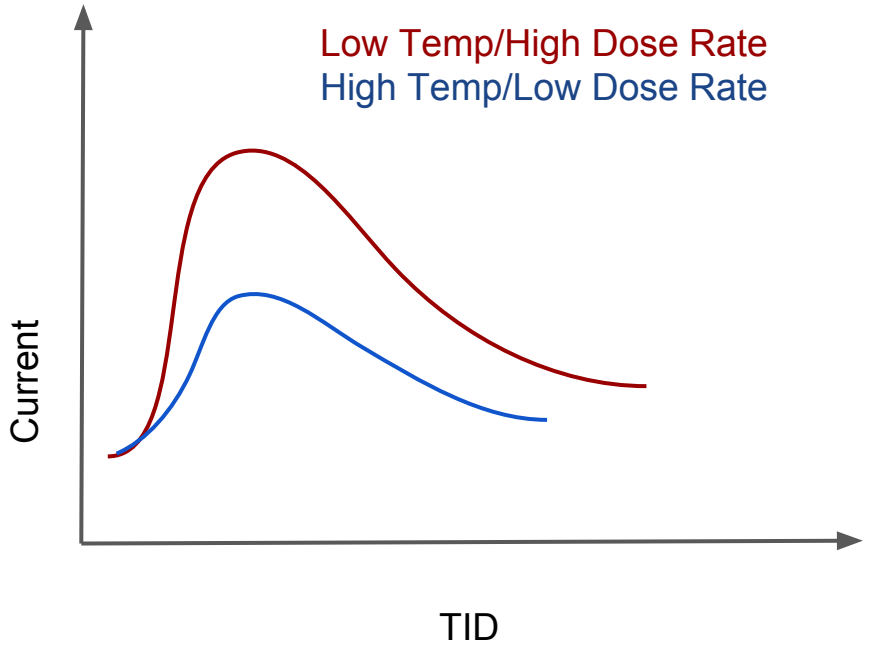
Testing: ABC130 continued

Total Ionising Dose

- Can affect front end performance
- Can cause changes in power consumption
- Analog functionality protected by Enclosed Layout Transistors

TID in 130 CMOS

- Measured, described by F. Faccio et. al.[1,2]
- Partial model
- Not ubiquitous 130nm feature



Tests performed at various facilities with different dose types, rates and environmental conditions

- Increase in noise
- Small O(2%) decrease in gain recovering at high doses
- Current increase “TID Bump” around 1 Mrad

Number of tests to characterize “TID Bump” and understand its effects at realistic temperatures and rates. Recent tests performed at O(krad/h) and T~-30

1.F.Faccio, G.Cervelli, “Radiation-induced edge effects in deep submicron CMOS transistors”, IEEE Trans. Nucl. Science, Vol.52, No.6, December 2005, pp.2413-2420

2.F.Faccio et al., “Total ionizing dose effects in shallow trench isolation oxides”, Microelectronics Reliability 48 (2008) 1000-1007

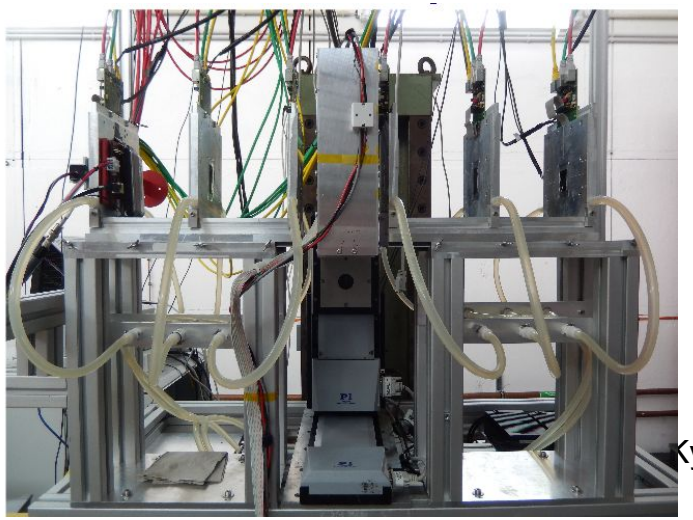
Testing: Test Beams

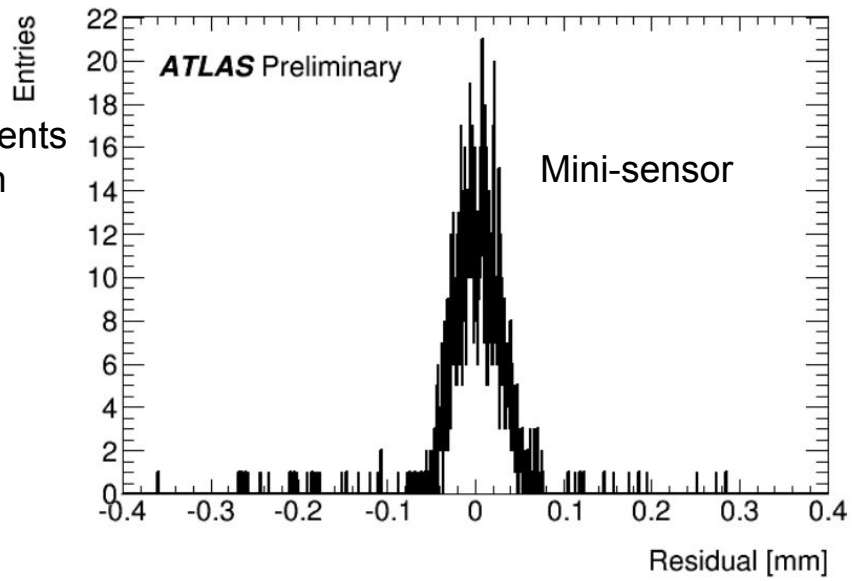
Several test beam campaigns focusing on measurements of many aspects of project including recent tests of an irradiated module

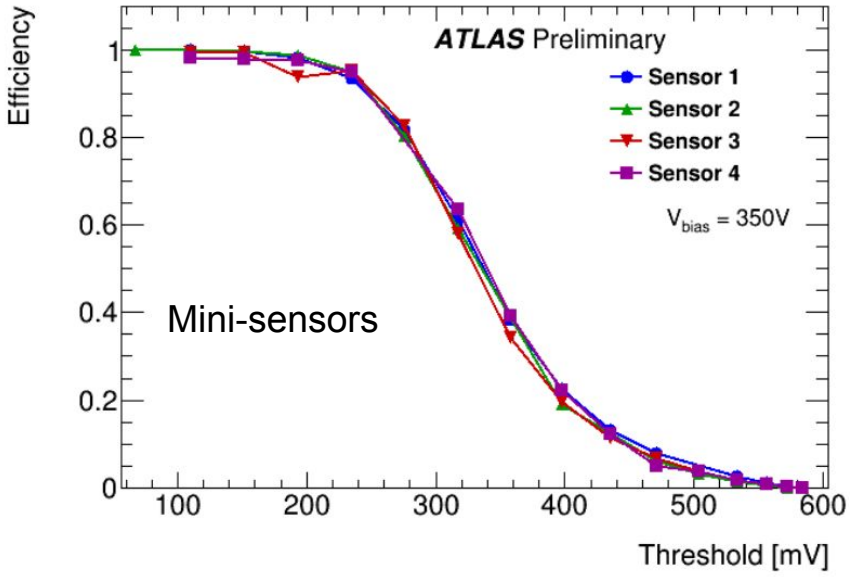
Sensor and ASIC front end tests in environment similar to real operating conditions

Tests of:

- Signal to noise
- Charge sharing
- Sensor biasing
- Efficiencies
- Various sensor types



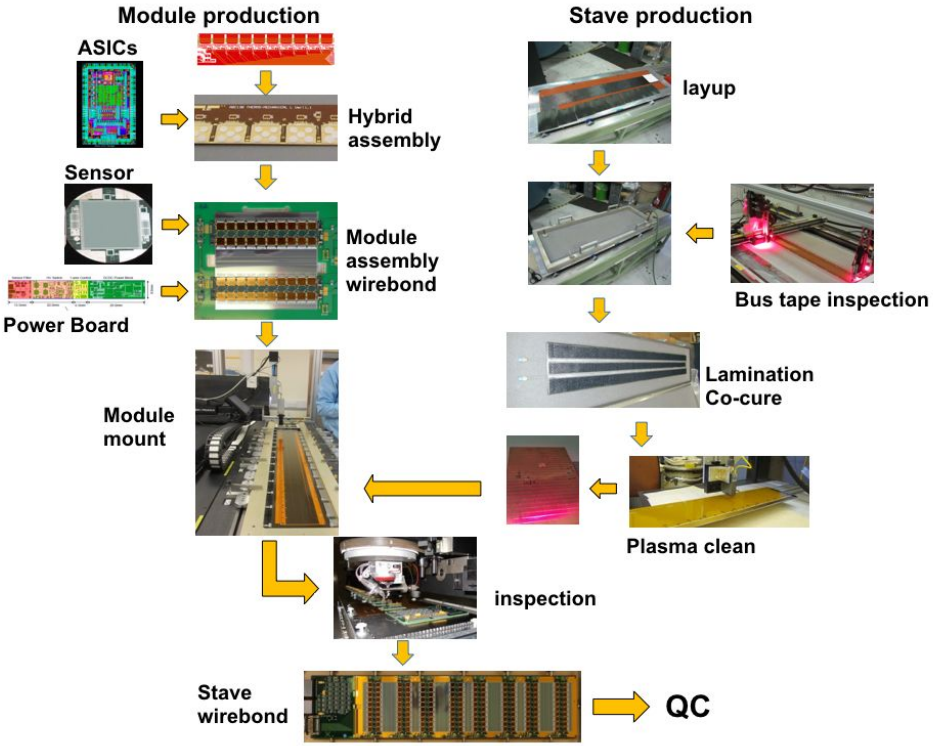


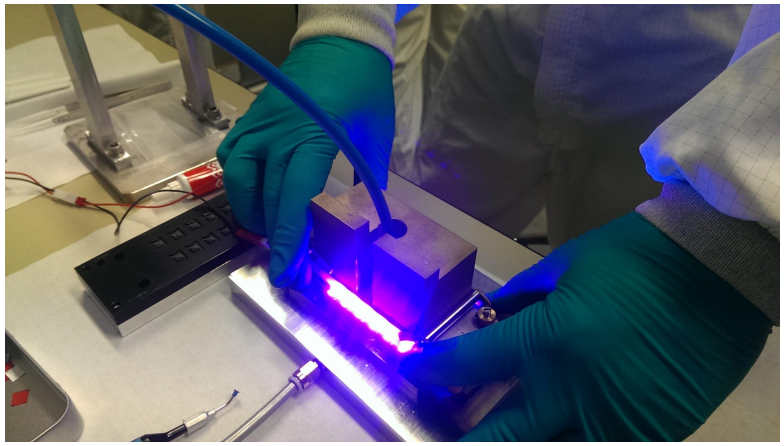


Kuehn, Suzanne (2016) first test beam results of prototype modules for the upgrade of the ATLAS strip tracking detector. ATL-ITK-SLIDE-2016-445

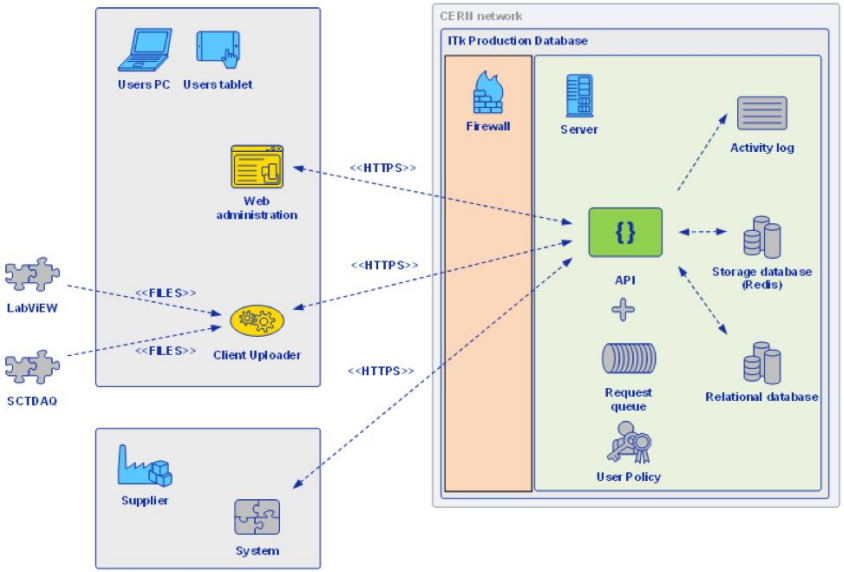
Production

Distributed module production with standardized production and testing capabilities





Database for tracking parts/components as they flow through the production chain being established



Summary

The ATLAS strip detector for the HL-LHC is being designed to meet the high performance requirements in a challenging environment

Large project:

- ~165m^2 silicon
- ~18k modules
- ~230k front end ASICs
- ~60M channels

- ➢ Mature Design and Testing stage
- ➢ Technical Design Report to be submitted later this year
- ➢ Expertise being built at many institutions
- ➢ Production coming quickly

Many specifics are not covered in this talk, right down to lowering into the ATLAS cavern and insertion into the detector

BACKUP

Design: Mechanical Support and Cooling

Good mechanical stability required in changing conditions for tracking.

In plane stability
Days timescale: < 2μm
Month timescale: < 5μm

- Modules adhesively attached to local supports
- Local supports attached to global supports with locking points

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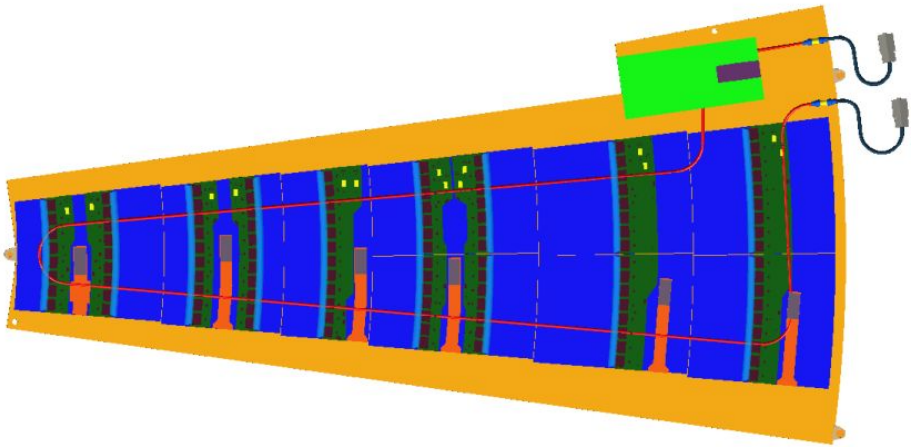
Services all provided on one end (z=1.4m for barrel, R =1.0 , for end caps)

Cooling pipe temperatures of -35 C and good thermal contact with sensors

Symmetric cooling pipe design to divide structure into 4 segments of equal length.

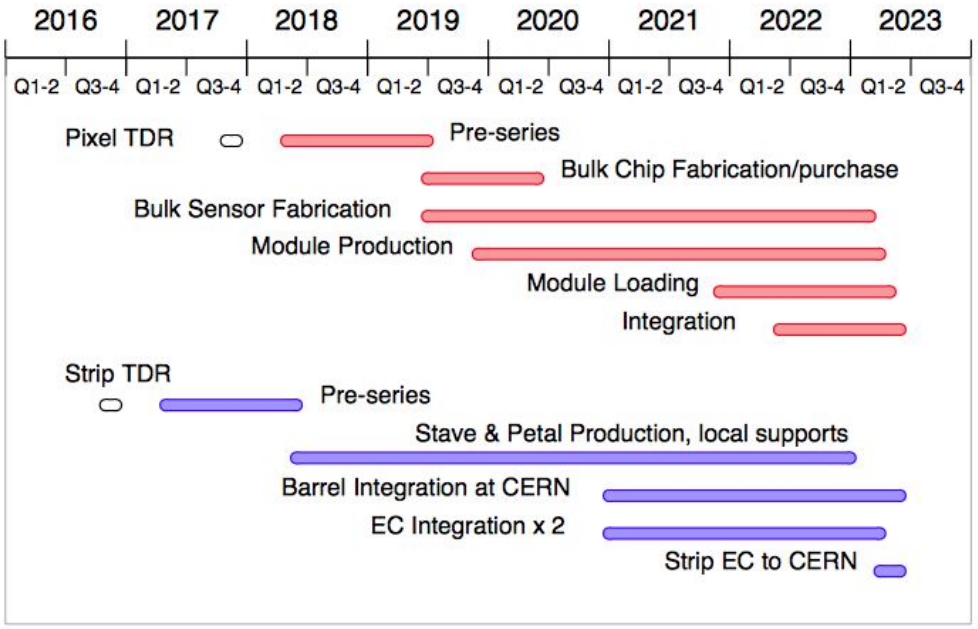
Ceramic insulating breaks near connectors for electrical isolation.

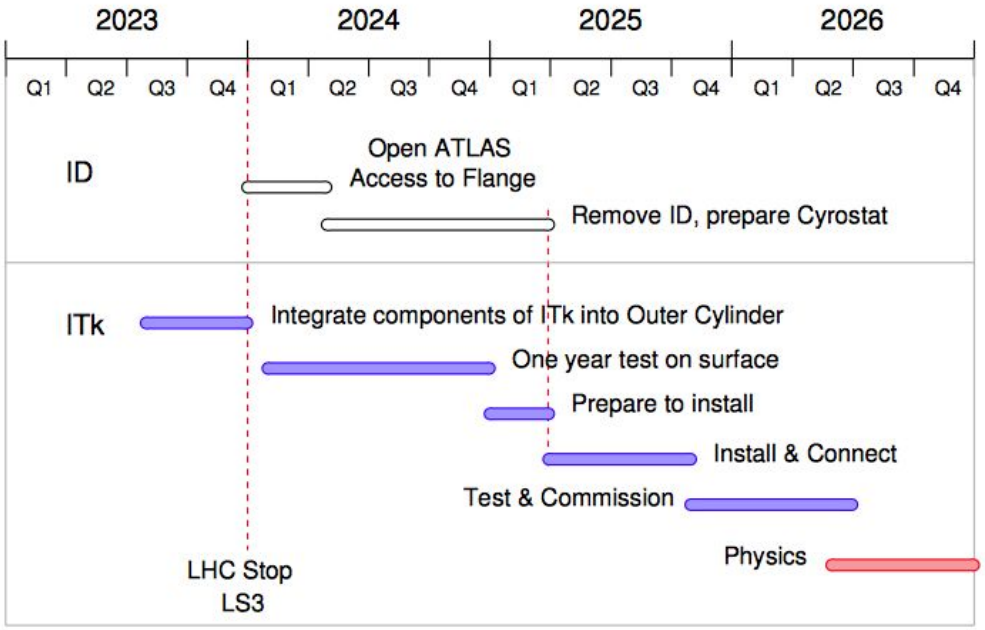
Required to deal with changing environment due to powering changes as radiation effects on-detector electronics



Finite Element Analysis simulations performed to estimate temperatures at both ‘TID bump’ and end of life.

Schedule


2016
2017
2018
2019
2020
2021
2022
2023
Q1-2 Q3-4 Q1-2 Q3-4 Q1-2 Q3-4 Q1-2 Q3-4 Q1-2 Q3-4 Q1-2 Q3-4 Q1-2 Q3-4 Q1-2 Q3-4
Pixel TDR
Pre-series
Bulk Chip Fabrication/purchase
Bulk Sensor Fabrication
Module Production
Module Loading
Integration
Strip TDR
Pre-series
Stave & Petal Production, local supports
Barrel Integration at CERN
EC Integration x 2
Strip EC to CERN


2023
2024
2025
2026
Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
ID
Open ATLAS
Access to Flange
Remove ID, prepare Cyrostat
ITk
Integrate components of ITk into Outer Cylinder
One year test on surface
Prepare to install
Install & Connect
Test & Commission
Physics
LHC Stop
LS3