ATLAS ITk

University of Glasgow

Frontier Detectors for Frontier Physics
16th Pisa Meeting on Advanced Detectors
La Biodola • Isola d'Elba • Italy
26 May - 1 June, 2024

Status of the ATLAS ITk Pixel Project

Craig Buttar
On behalf of the ATLAS ITk Pixel Collaboration

16th Pisa meeting on advanced detectors

Elbe May 2024

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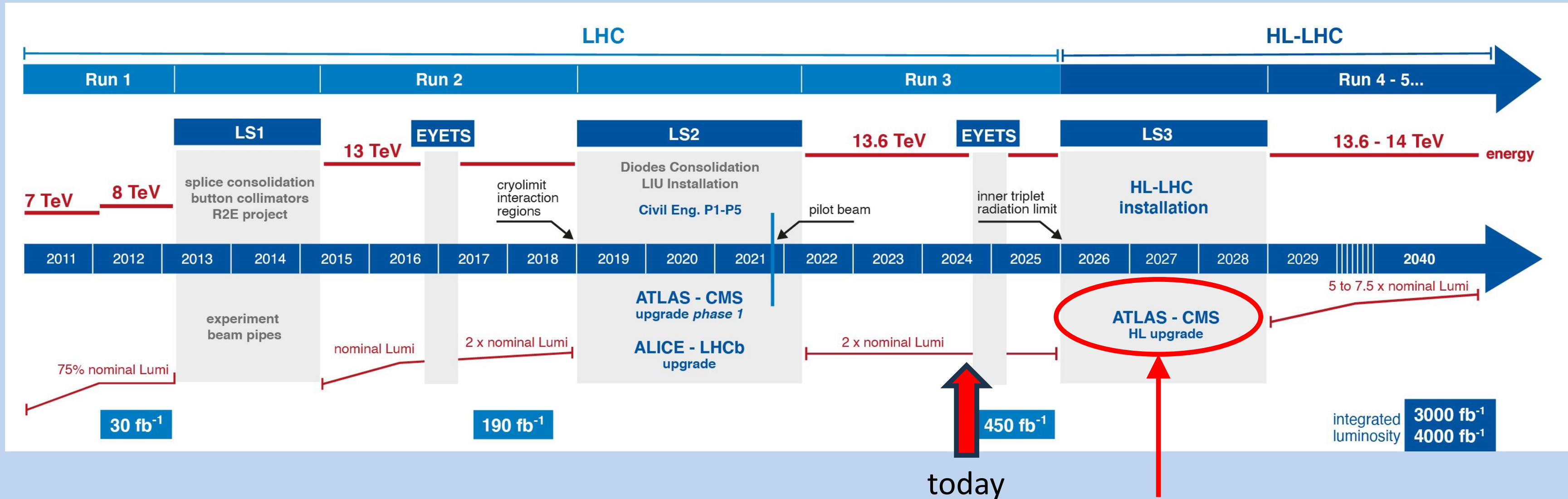
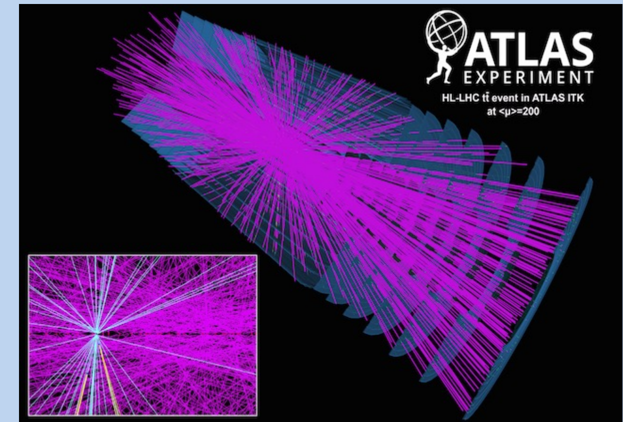
LHC timeline



- HL-LHC luminosity ~7x10^{34}cm^{-2}s^{-1} integrated ~3000fb^{-1}
  - ~3.5 times Run-2 peak luminosity
  - ~x5 times integrated luminosity at end of Run-3
- Increased luminosity → Increased pile-up:
  - Up to 200 pile-up events expected at the HL-LHC compared to ~48 in current Run-3 data
  - Increased pile-up compromises pattern recognition and requires higher readout rates
- Increased luminosity → Increased radiation damage
  - Damage scales approximately linearly with luminosity ~x10 increase

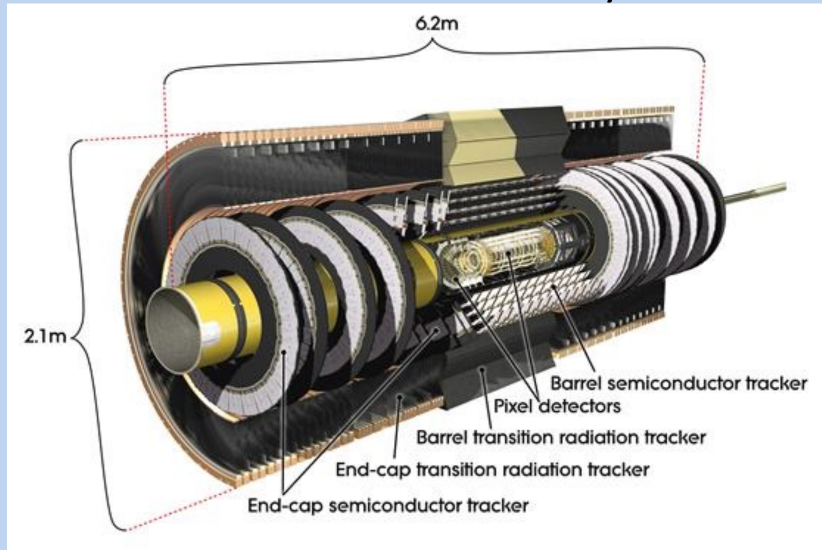
“Phase-II” upgrade of ATLAS in ~2027



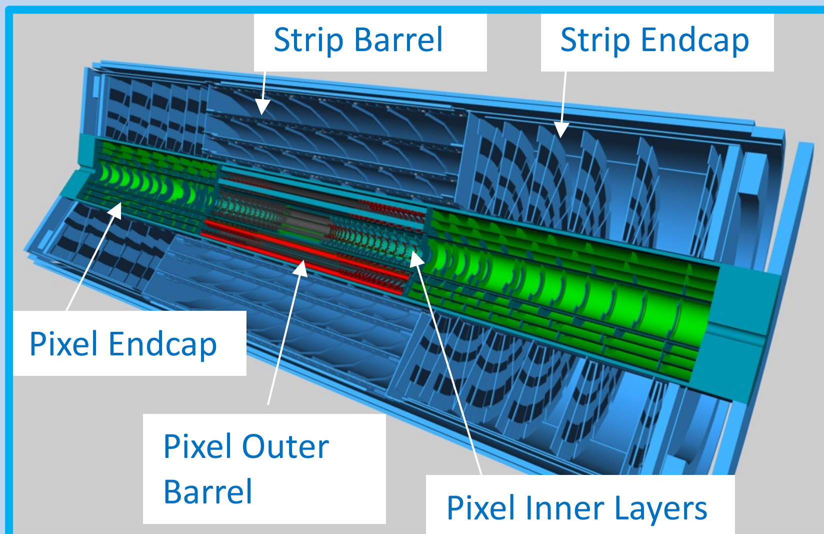
Simulated ttbar events with 200 pileup ATLAS public plot

ATLAS Inner Tracker (ITk)

Current Inner Detector System



Phase-II Inner Tracker (ITk)



The current inner detector system will be replaced with a new all-silicon tracking system -- ITk

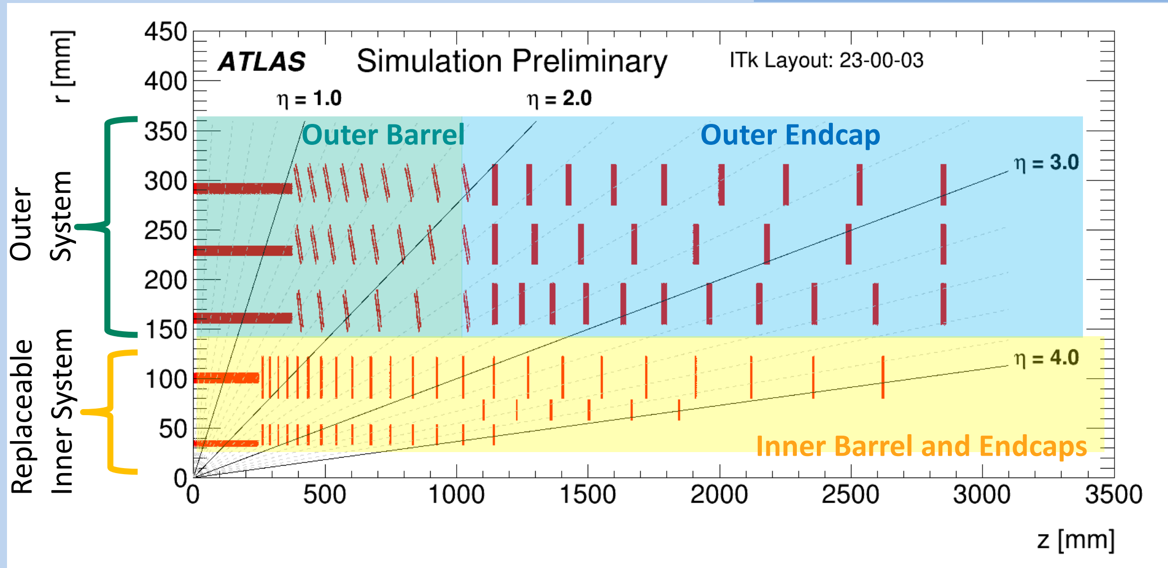
- New tracker
  - Targeting the same or better performance than current Inner Detector
  - Increased granularity to maintain occupancy <1%
  - Low mass mechanics, cooling and serial powering to minimize material
  - Increased radiation hardness

See talk "The ATLAS ITk strip detector system for the Phase-II LHC Upgrade " presented by Carles Solaz

ITk Pixel detector layout

Outer Barrel:
3 layers of flat staves and inclined rings
Si n-in-p planar quad modules
4472 quad modules, $6.94m^2$
$2.3x10^{15}n/cm^{-2}$ 1.7MGy @$4000fb^{-1}$

Endcap:
3 layers of rings
Si n-in-p planar quad modules
2344 modules, $3.64m^2$
$3.1x10^{15}n/cm^{-2}$ 3.5MGy @$4000fb^{-1}$



Current pixel system
~92M pixels
~2000 modules
~$1.9m^2$ active area

ITk Pixel System
~5G pixels
~9,400 modules
~$13m^2$ active area

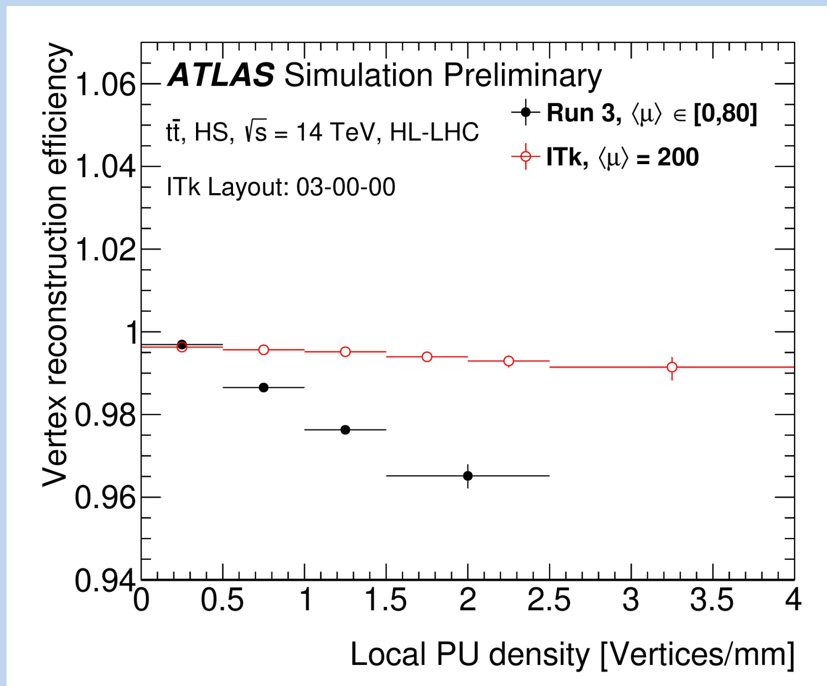
Inner System *Replaced after about* $1500fb^{-1}$
2 layers of flat staves and rings
L0: 396 3D Si triplet modules and 1160 L1: n-in-p planar quad modules, $2.4m^2$
$9.2x10^{15}ncm^{-2}$ 7.3MGy @$2000fb^{-1}$

Layout described in
ATL-PHYS-PUB-2021-024

Simulation studies of performance

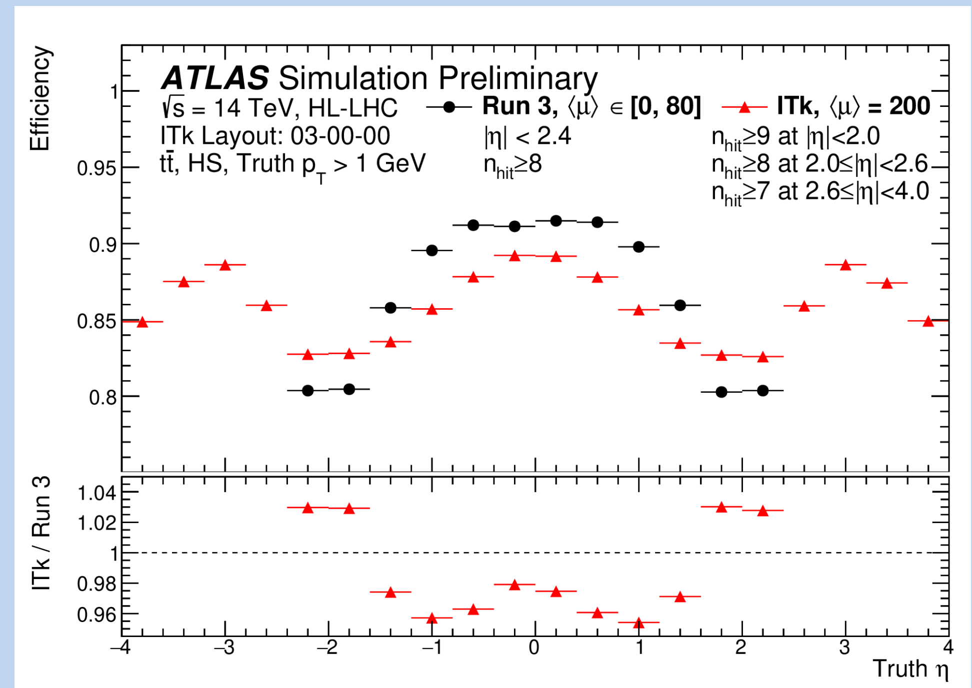
Aim for a performance as good as or better than the current inner tracker

IDTR-2023-05



Vertex reconstruction efficiency vs pileup density

IDTR-2023-05

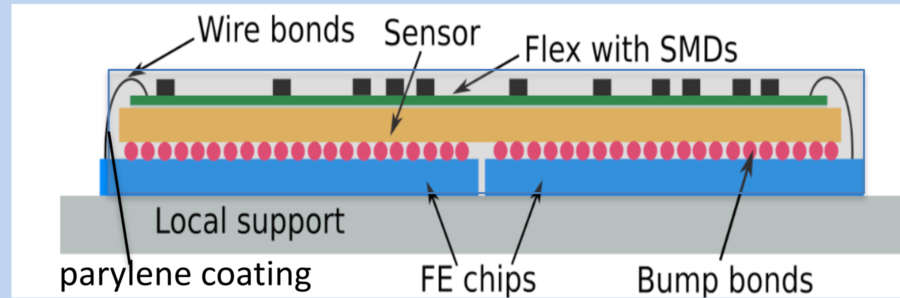


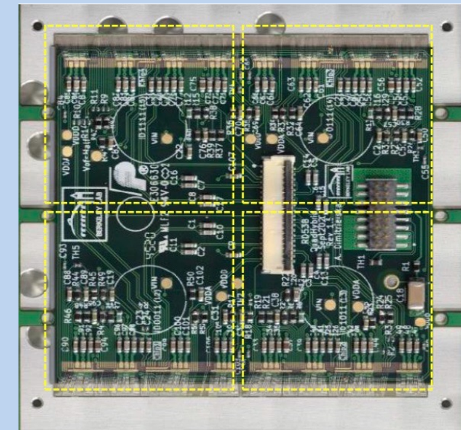
Track efficiency in ttbar events

Modules

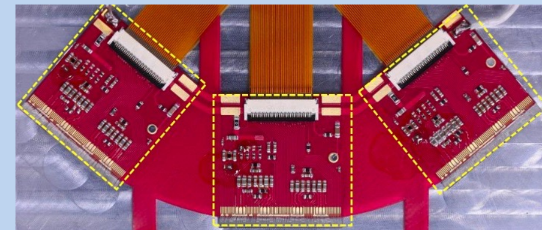
- 1 or 4 FE chips bump-bonded to sensor
  - Quad modules: 4 FE-chips bonded to 1 sensor
  - Triplet module: 1 FE-chip bonded to 1 sensor
- Cu-Kapton flex hybrid glued to sensor
  - Flex provides connections for power, DCS and data
- Mix of materials with different coefficients of thermal expansion make the module design challenging
  - Modules assembled at. +20°C, but lowest module temperature can be -45°C in the experiments
  - Difference in CTE between Cu and Si leads to thermal stress on the bumps
  - Amount of Cu needs to be carefully balanced between low power requirements and thermal stress on the bumps
  - Qualify bump-strength of solder based bumps after 100 thermal cycles (-55 → +60°C) for different vendors
  - Good results from qualification, being followed up in the pre-production
  - Indium bumps need further evaluation

See poster "Italian cluster technical solutions for the Quality Control tests to the modules of the ITk detector " presented by Giuseppe Carratta





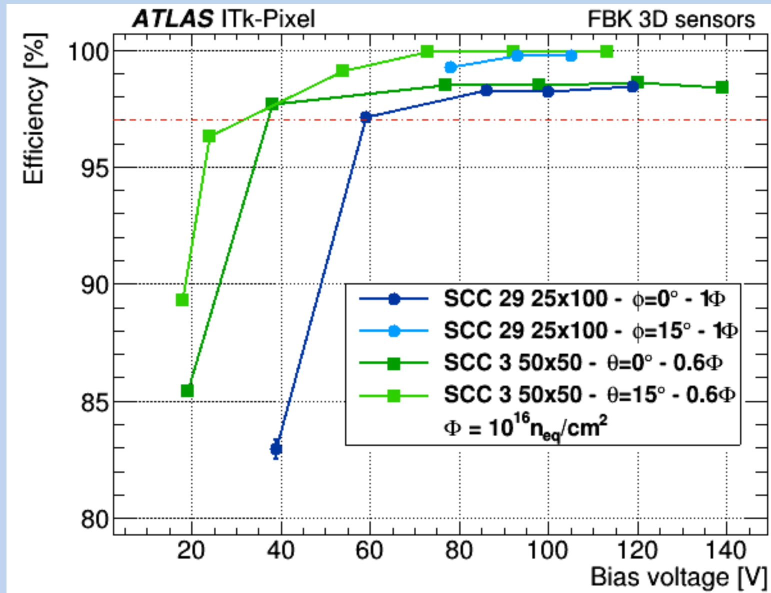
Quad module



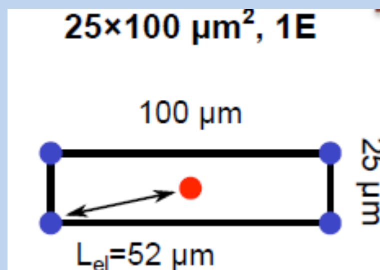
Triplet module

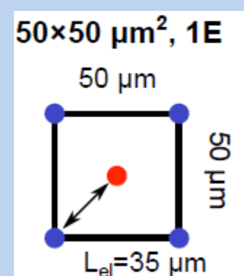
Sensors

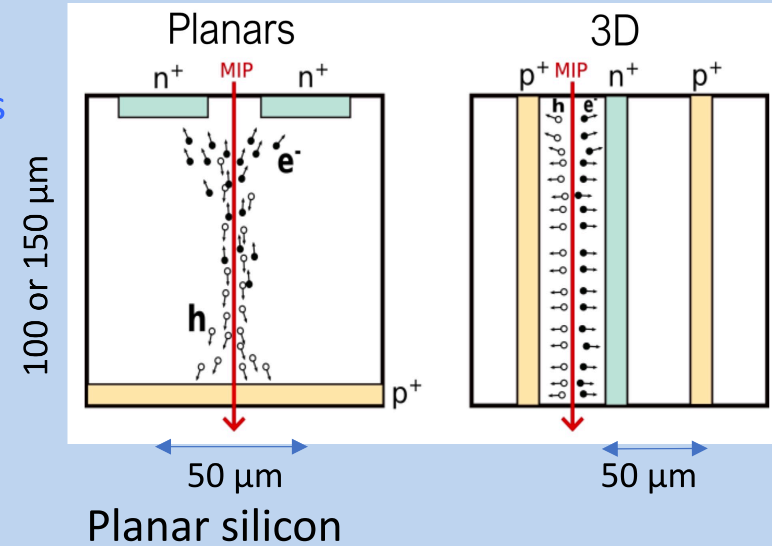
- Improve radiation hardness by:
  - Using thin planar sensor 100+150μm thickness
  - Use 3D sensors in inner layer



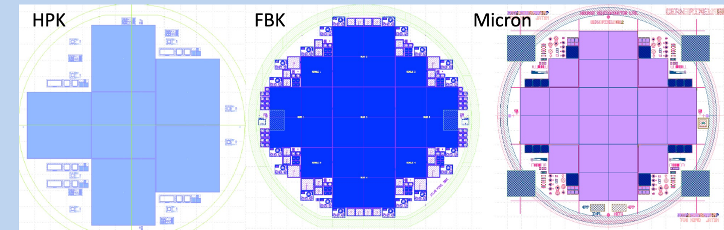
Irradiated 3D 25x100mm^2 & 50x50μm^2 module with ITkPixV1.1 readout irradiated to $1\times10^{16} n_{eq}cm^{-2}$



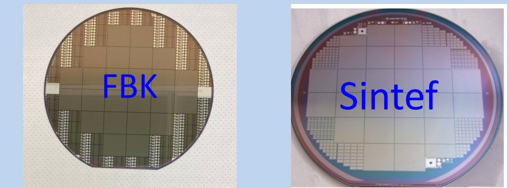




Planar silicon



3D sensors

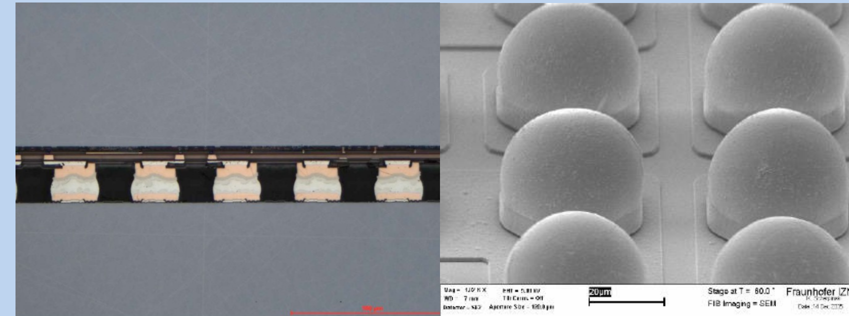


Planar preproduction complete and 3D close to completion

See poster "Qualification of pre-production 3D sensors for the new ATLAS ITk detector with test beams" presented by Thibaud Carcone

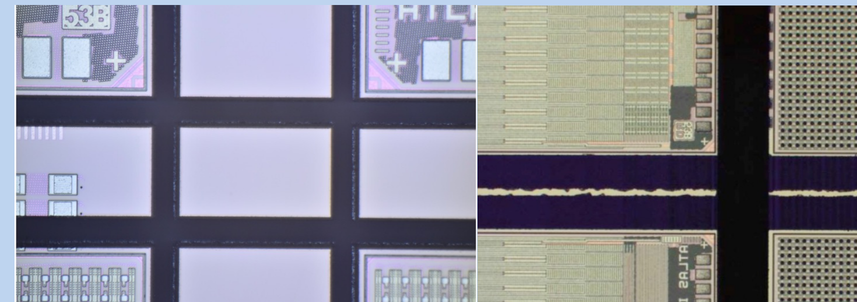
Hybridisation

- Number of modules requires 4 hybridization vendors to meet the needed capacity
- Technical issues
  - Dicing of FE-chips can lead to chipping and debris
  - flip-chip of multiple FE-chips to a sensorhas caused problems for some vendors
  - Handling the bow of sensors during flip-chip
- Currently, approximately 380 quad modules and 100 3D single modules delivered for technical evaluation and module pre-production



Cross-section of sensor & FE-chip voninnection

Solder bumps



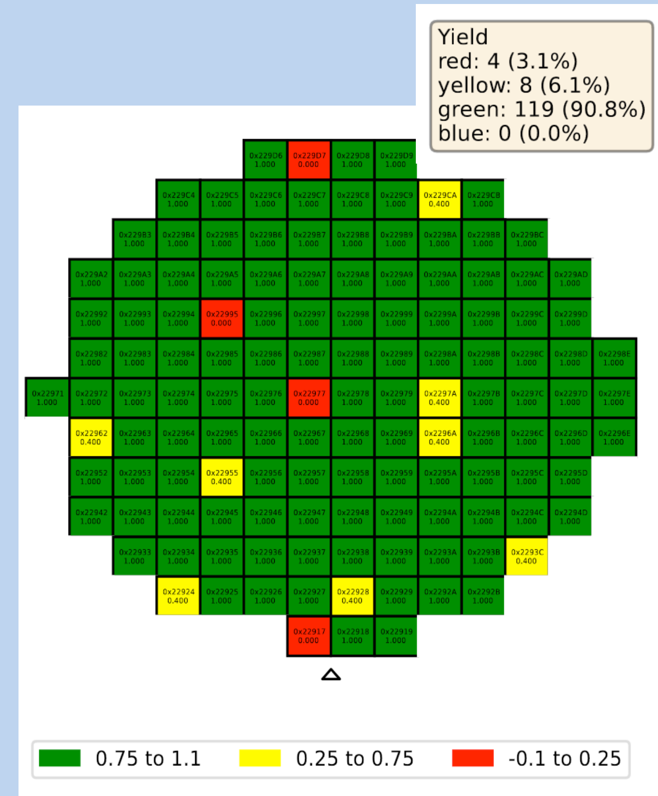
laser pre-grooving and dicing

blade dicing

FE-chip: ITkPixV2

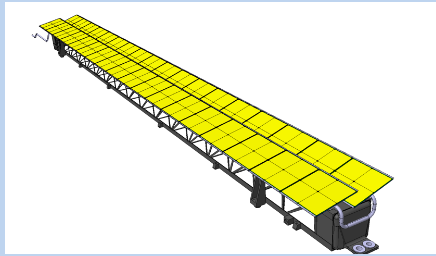
- RD53 Collaboration: joint R&D for ATLAS and CMS ASIC in TSMC 65nm
- Main features for ATLAS
  - 65nm technology, 152800 pixels per chip, 50x50 μm^2 pitch, total area 2x2cm^2
  - Tracking in dense environments
    - Low threshold operation
    - Cluster charge readout using Time over Threshold
  - Radiation environment
    - Sensor leakage current compensation
    - SEE hardening
  - 1.28Gb/s data rates
    - 4 data links per chip at 1.28 Gb/s
    - data compression
  - Optimisation of services
    - Merging of chip data in module
    - Integrated shuntLDO regulator for serial powering
- Final chip ITkPixV2 submitted March 2023
  - Wafer probing yield around 90% based on first 100 wafers

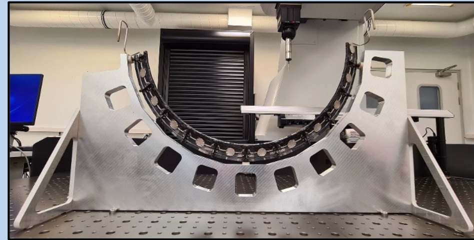
Wafer probing yield map

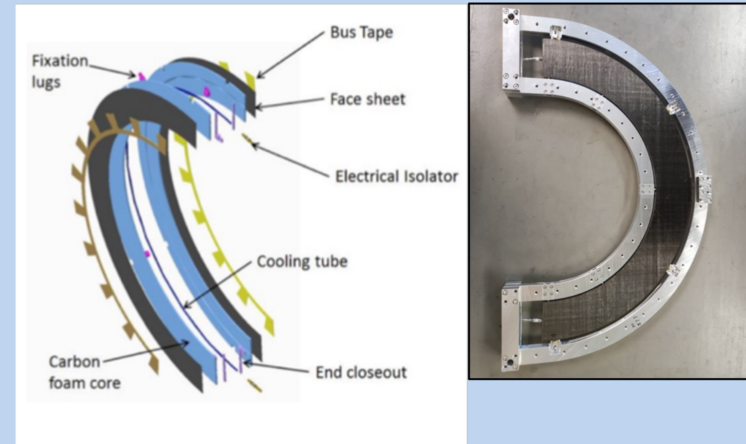


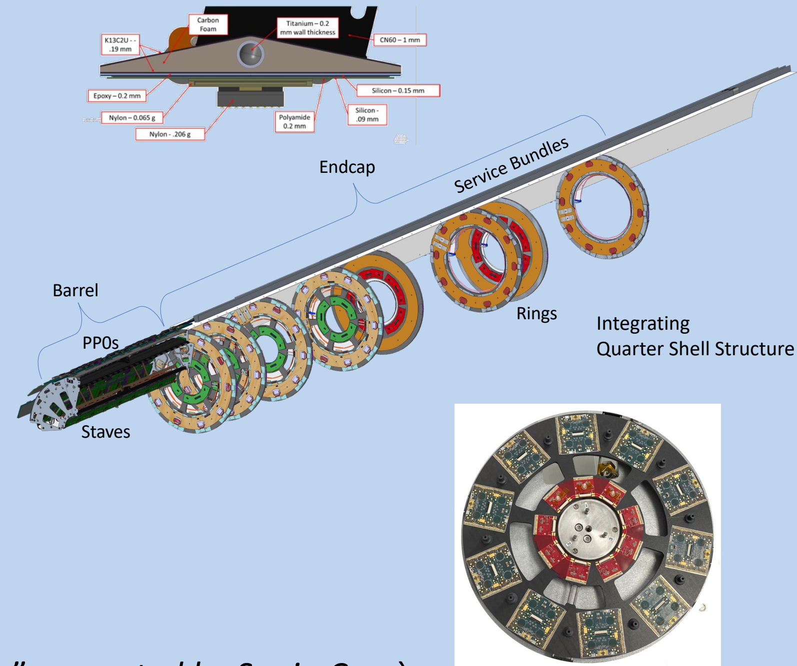
131 chips per wafer
Probing of full wafer takes about 24hrs
Yield map based on test of power, digital and analog functionality

Local Supports







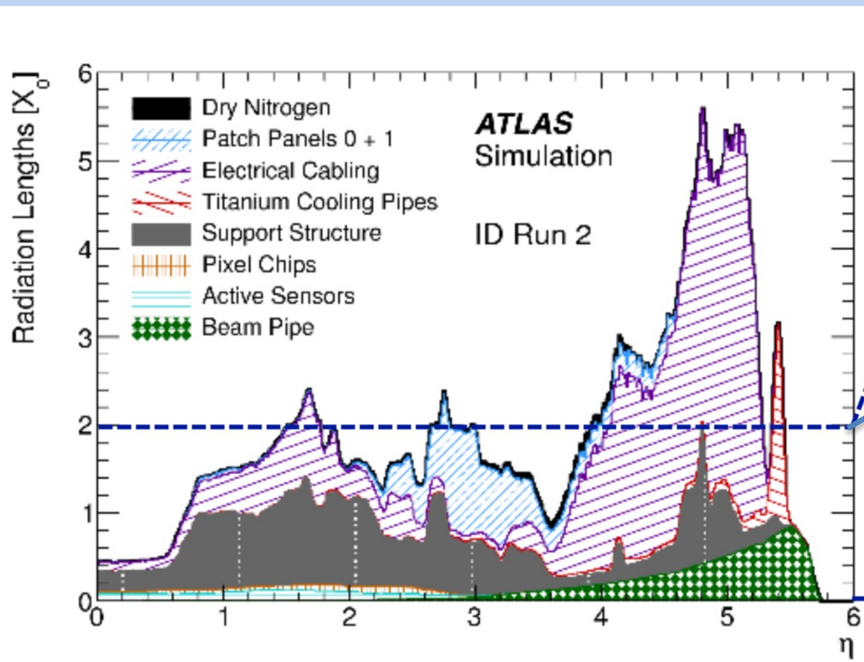


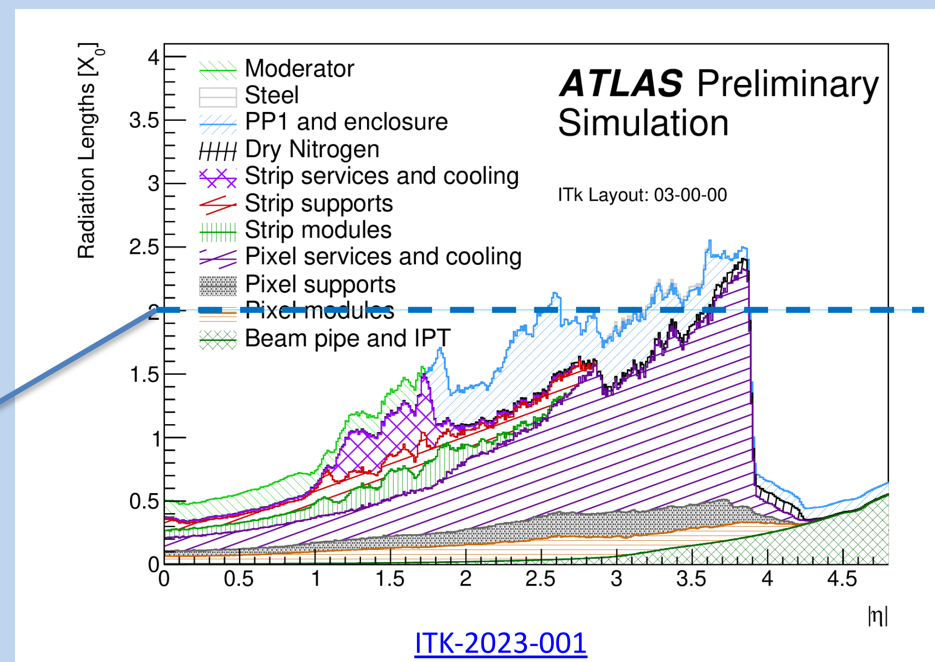
- Local supports provide stable low-mass supports for modules and services
- Critical element is interface between module and cooling pipes
- Production of parts underway

See poster “ATLAS ITk Pixel Outer Endcap CO2 cooling system prototype” presented by Sonia Carrà

Material

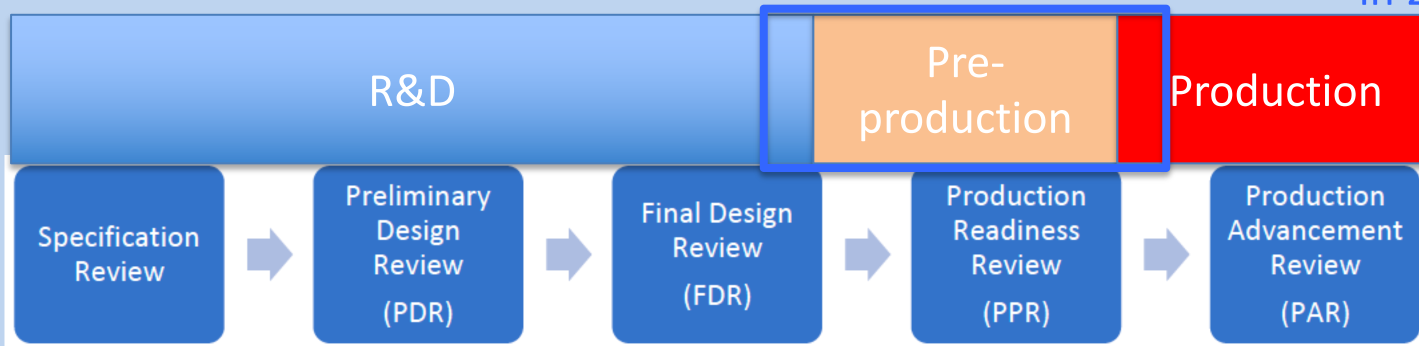
- Material impacts tracking, radiation levels, data rates and downstream detectors such as the calorimeter. It is important to minimize the material.
- Reduce material using
  - CO_2 cooling with thin titanium pipes
  - Modules with thin Si sensors (100-150μm) and FE-chips (150μm)
  - Serial powering of pixel modules to reduce cabling
  - Low-mass carbon structures for mechanical stability and mounting
  - Optimise number of readout cables using data link sharing





ITK-2023-001

Status of the project



Timeline
Not to scale!

Area	PDR	Prototyping	FDR	Preproduction	PRR	Production
Planar Si sensors	Complete	Complete	Complete	Complete	Ongoing	Ongoing
3D Si sensors	Complete	Complete	Complete	Complete	Ongoing	Ongoing
FE-ASIC	Complete	Complete	Complete	Complete	Complete	Complete
Hybridisation	Complete	Complete	Complete	Ongoing	Ongoing	Upcoming
Module assembly	Complete	Complete	Complete	Ongoing	Upcoming	Upcoming
On-detector services	Complete	Complete	Complete	Ongoing	Upcoming	Upcoming
Off-detector services	Complete	Complete	Complete	Ongoing	Upcoming	Upcoming
Data Transmission	Complete	Complete	Ongoing	Upcoming	Upcoming	Upcoming
Bare Local Supports	Complete	Complete	Complete	Ongoing	Ongoing	Ongoing
Loaded Local Supports	Complete	Complete	Complete	Upcoming	Upcoming	Upcoming
Global Mechanics	Complete	Complete	Ongoing	Upcoming	Upcoming	Upcoming
Integration	Complete	Complete	Ongoing	Upcoming	Upcoming	Upcoming
Power supplies	Complete	Complete	Complete	Ongoing	Upcoming	Upcoming

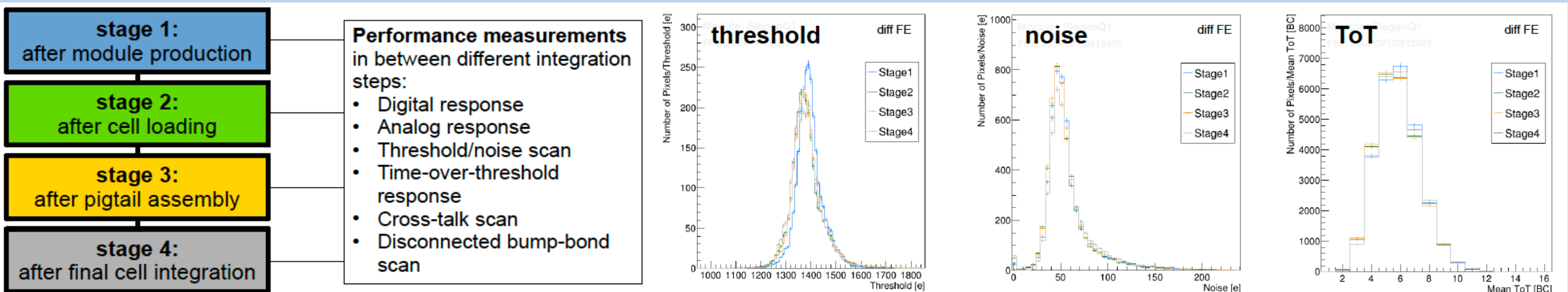
Complete / Ongoing / Upcoming

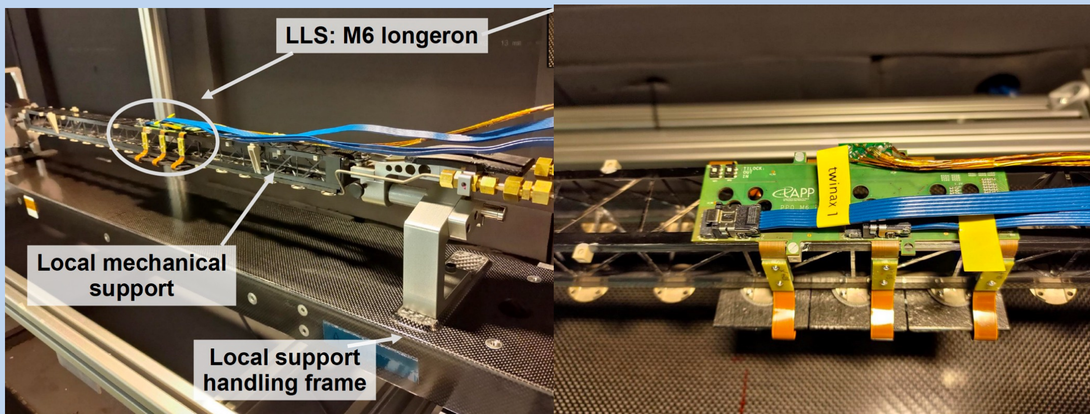
Tenders for major components complete and contracts in place for major components:

- Planar sensors
- 3D sensors
- FE chips
- Module hybridisation
- Power supplies

Loaded Local Supports and System test

- Outer barrel module loading and system tests
  - RD53 prototype modules loaded on to cells and thermally tested mounted onto local supoerts system test
  - Performance of modules monitored through the loading process
  - Work on system tests preproduction items in progress





Summary

- The ATLAS ITk Pixel detector has been designed to operate in the challenging HL-LHC environment and maintain the performance of the current tracking system
  - Increased radiation hardness
  - Maintain pixel hit occupancy at 1% by increasing granularity
  - Low mass achieved using carbon based mechanics, serial powering and data merging
- The project is now in pre-production
  - Large scale production brings a new set of problems as more sensitive to rare problems
- Moving from development of individual items system level tests
  - Loaded local support system tests are underway, excellent testbed for integration issues

Backup