Overview on current state of the art Pixel Mechanics for the upgrade tracking detectors at the ATLAS and CMS experiments

Pixel2022: The Tenth International Workshop on
Semiconductor Pixel Detectors for Particles and Imaging

Santa Fe, New Mexico

Owen Shea
University of Edinburgh
On behalf of the ATLAS and CMS collaborations
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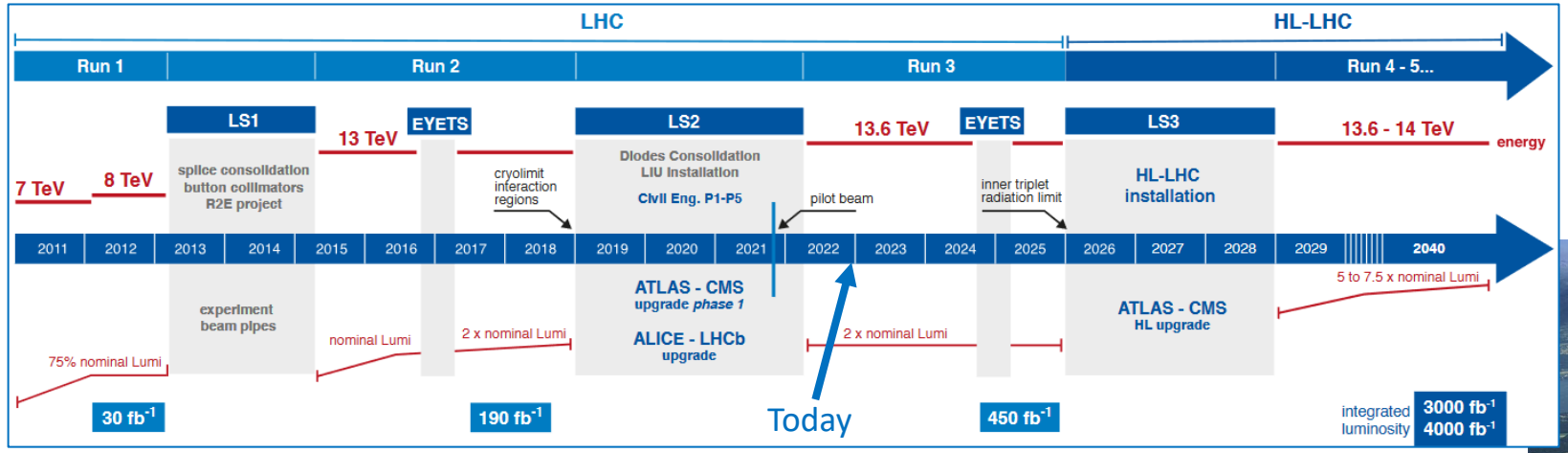
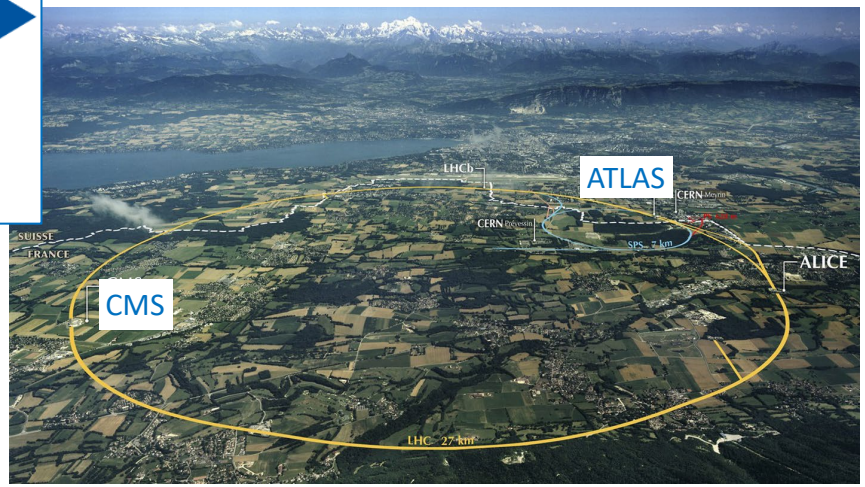
LHC Background

- The Large Hadron Collider is 27km in circumference, and collides protons and heavy ions in 4 experiments
- LHC will be shut down in December 2025 for a period of 36 months (LS3)
- Upgrades will be made to the ATLAS and CMS detectors in preparation for high-luminosity operation of the LHC from 2029 onwards
  - Higher radiation levels → Improve radiation hardness
  - Increased particle density → Greater detector granularity, reduction of material
- The tracking detectors at both ATLAS and CMS will be fully replaced



HL-LHC Upgrade Timeline

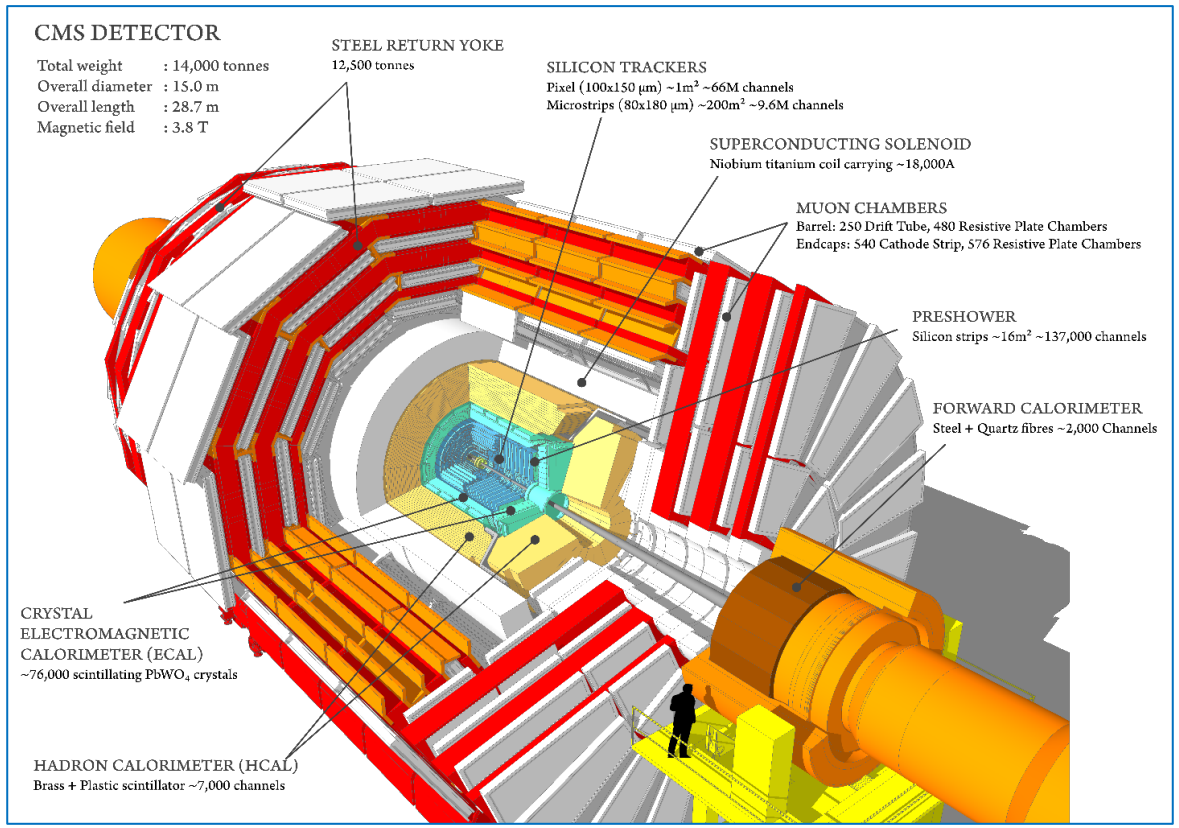
LHC on the France-Switzerland Border



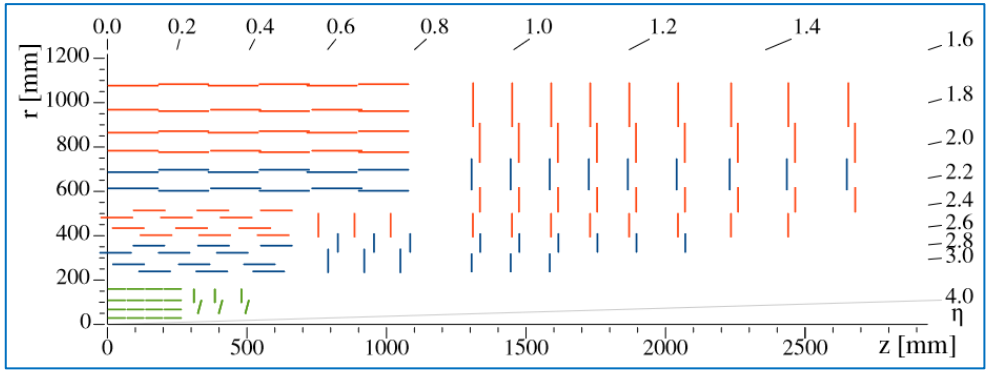
CMS Tracker Upgrade Background

- CMS (compact muon solenoid) is a general-purpose detector
- The upgraded tracker will consist of an Inner Tracker (IT) and Outer Tracker (OT)
  - OT consists of 3 sections which utilize different types of strip sensors

See the talk from Anna Macchiolo earlier this week!

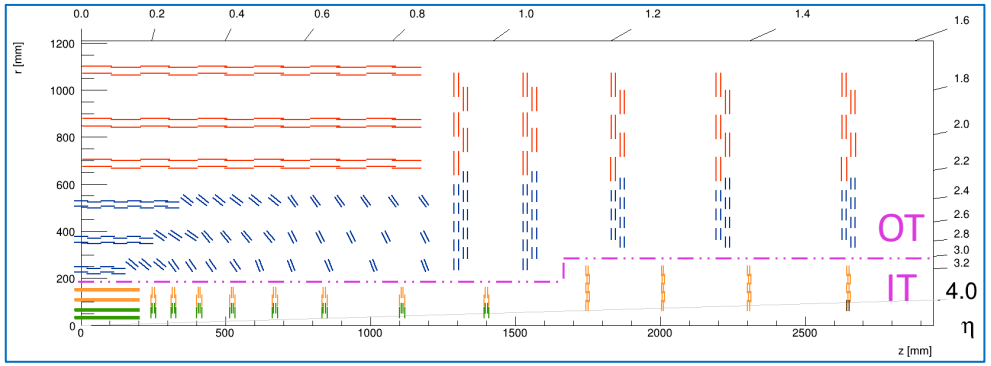


Overview of CMS



Pixel sensor area: ~1.9m²

Upgrade!

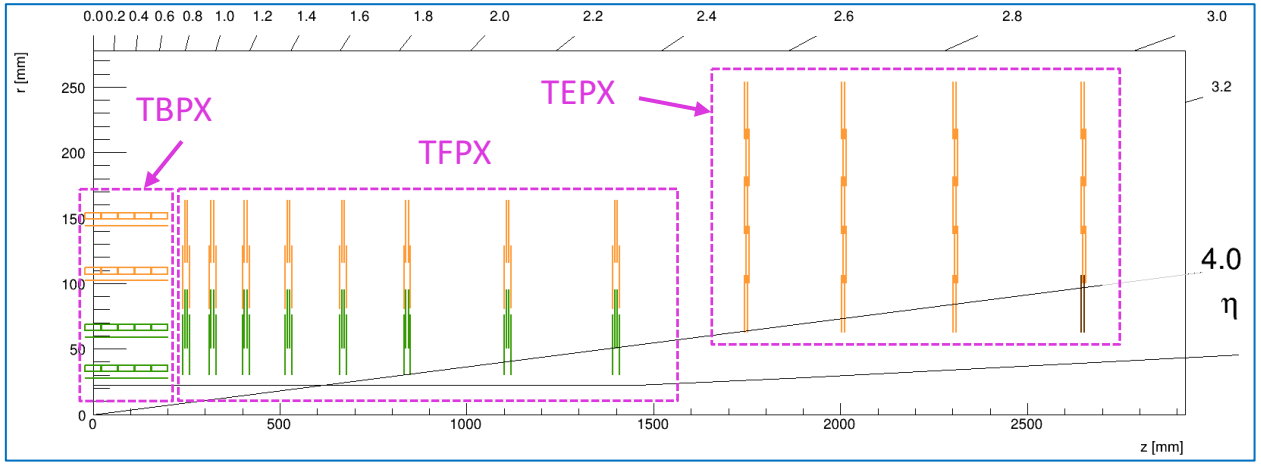


Pixel sensor area: ~4.9m²

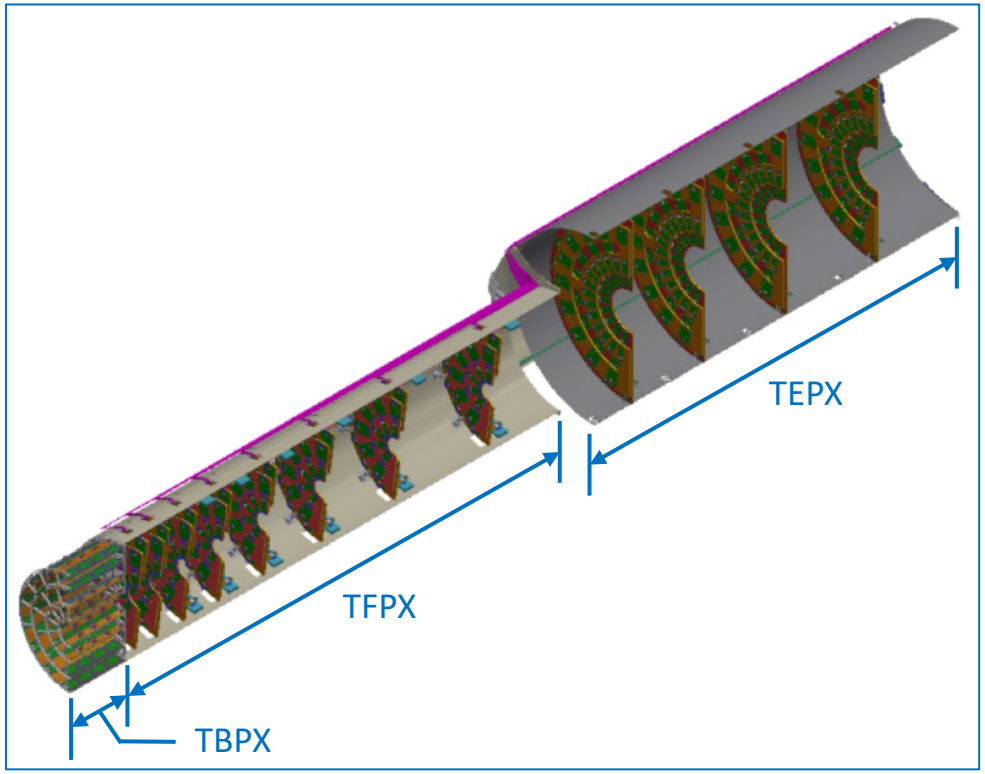
Schematic views of the current tracker (top) and phase-2 tracker upgrade (bottom). Red and blue denote strip sensors, yellow and green are pixels

CMS Inner Tracker

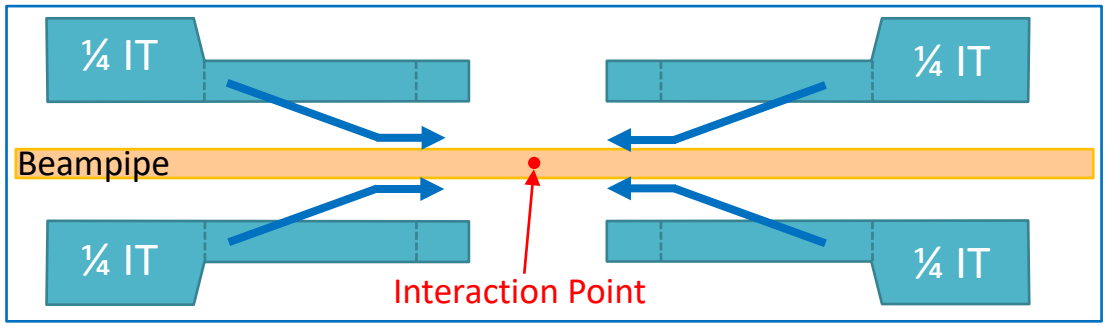
- The Inner Tracker is split into three distinct sections
  - Tracker Barrel Pixel (TBPX)
    - Modules mounted on ladder structures in 4 layers
  - Tracker Forward Pixel (TFPX)
    - Modules mounted on the faces of 8 small Ds
  - Tracker Extended Pixel (TEPX)
    - Modules mounted on the faces of 4 large Ds
- These structures are held by half-cylindrical support shells, which also support the electrical, cooling, and data transmission services
- The IT is designed to be inserted in quarters in situ – after the OT and beampipe are in place (different method from ATLAS)



Inner Tracker pixel sensors. Green represents modules with two (1x2) readout chips, yellow represents modules with four (2x2)



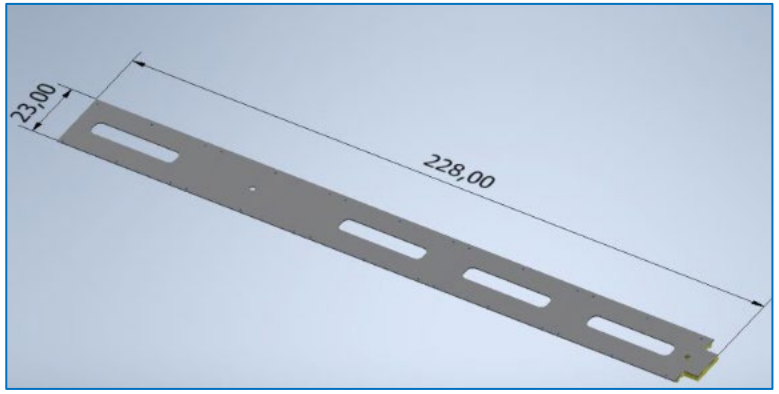
3D view of ¼ of the Inner Tracker (modules shown in green)



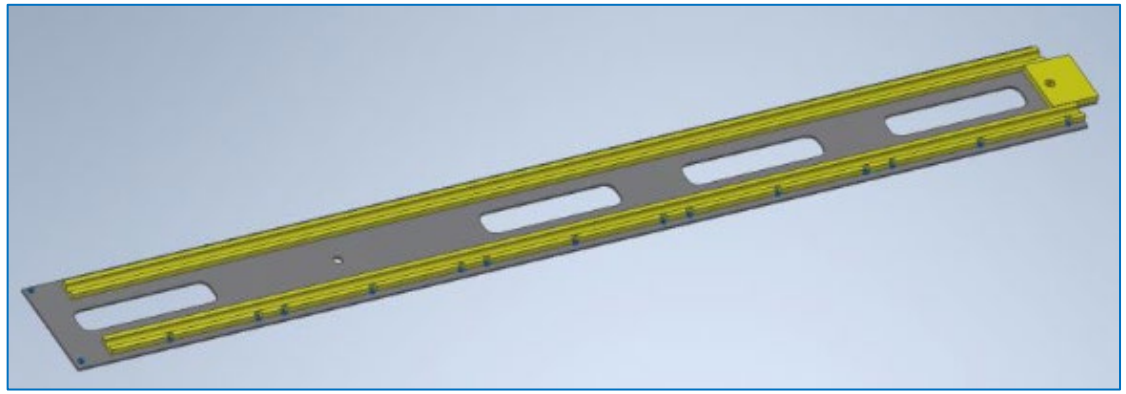
Schematic top-down view of 4 quarters of the IT joining around the beampipe (OT not shown)

TBPX Mechanics

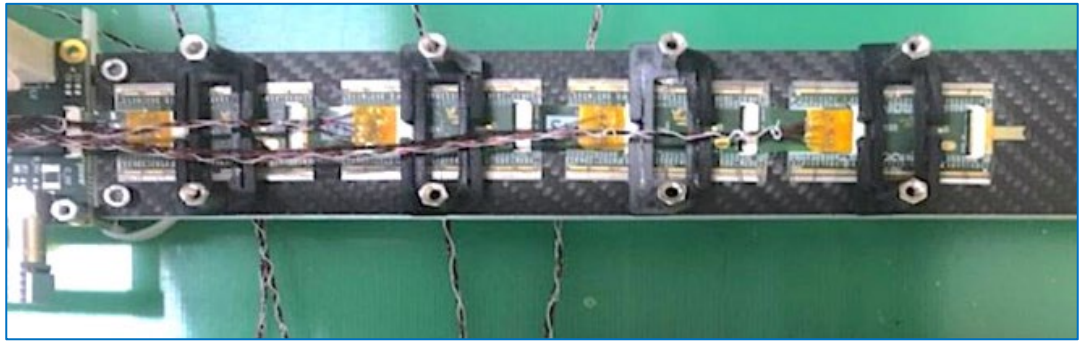
- The base unit of each layer is a ladder structure constructed from:
  - Ladder support (4-ply carbon fibre)
  - Pipe housing ribs (carbon foam)
  - Mounting bushings
- There are different flavours of ladder depending on layer, internal/external position, or edge position



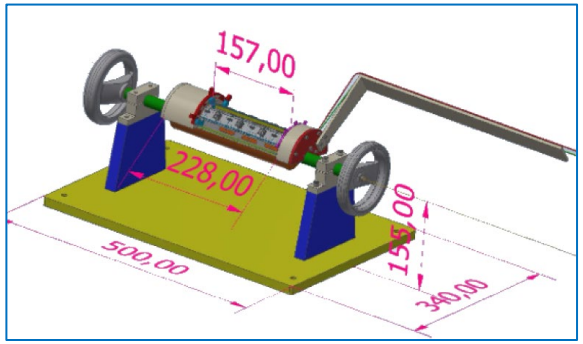
CF ladder support



Assembled ladder structure



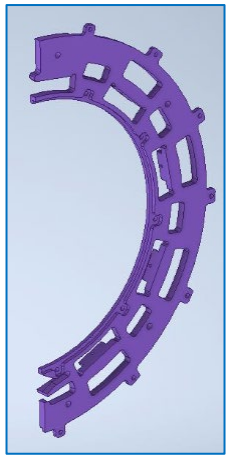
Prototype ladder



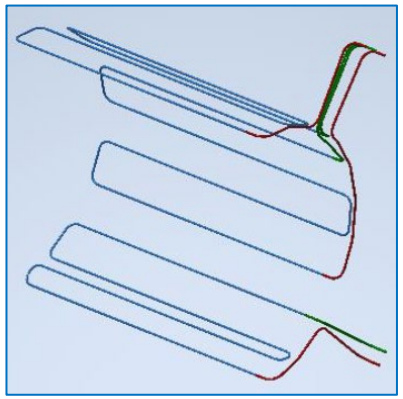
L1 assembly tool

TBPX Mechanics

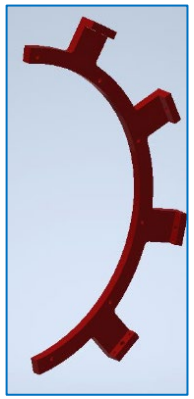
- Each of the 4 layers is constructed from:
  - Different ladder flavours
  - Cooling pipes
  - End Flange
  - Pillars
  - Internal Ring
- At one end, the End Flanges provide connection between layers – pillars and internal ring do so at the other
- The 4 layers of the TBPX are constructed separately then joined together, starting from the external support shell (higher r)
- Modules are staggered in each layer so that there is no gap at z=0
- The services from the TBPX run on the outside of the support cylinders



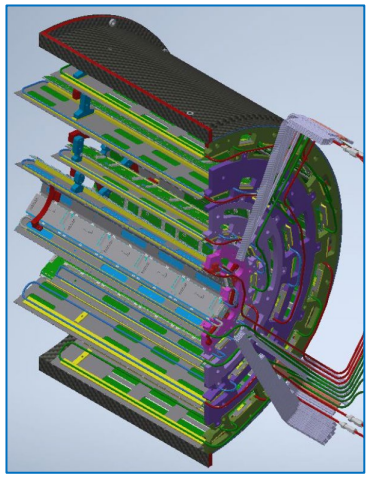
End Flange



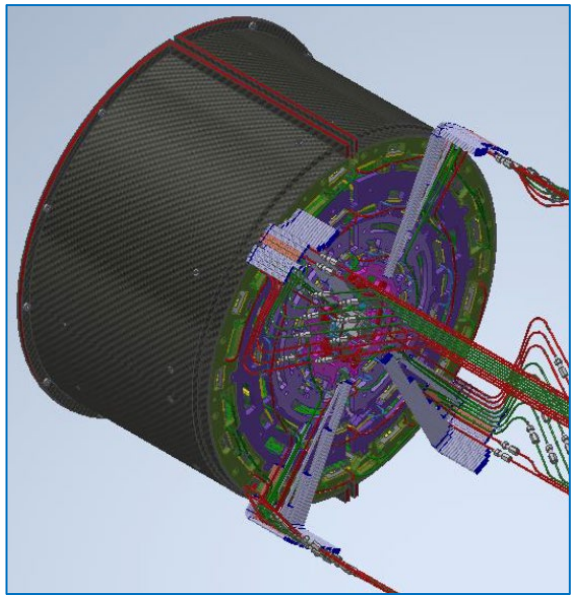
Cooling Pipes



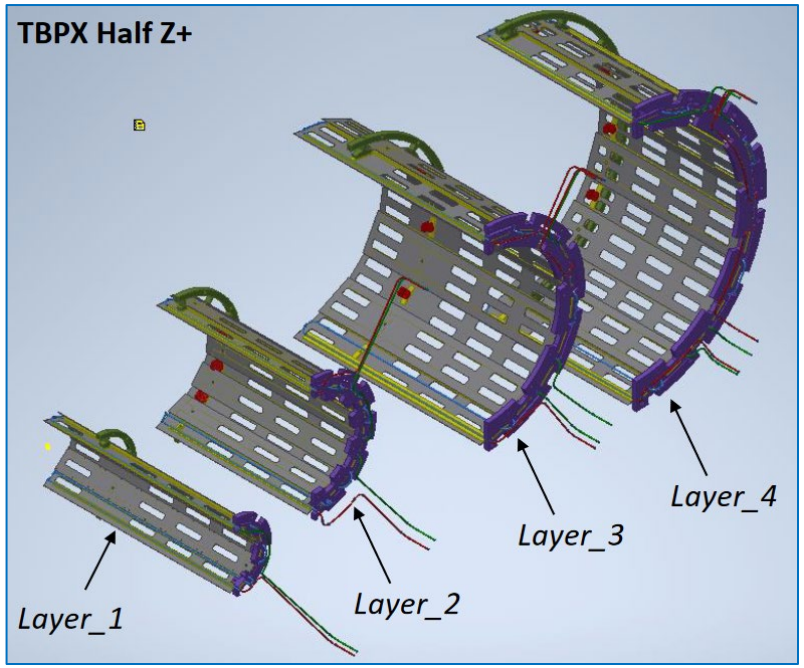
Internal Ring



¼ of the TBPX



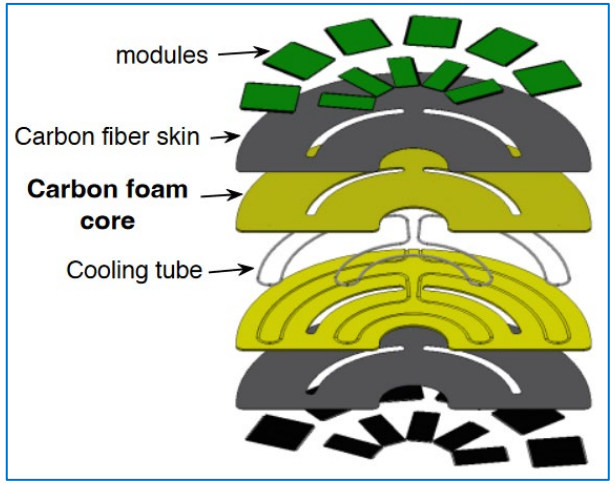
½ of the TBPX



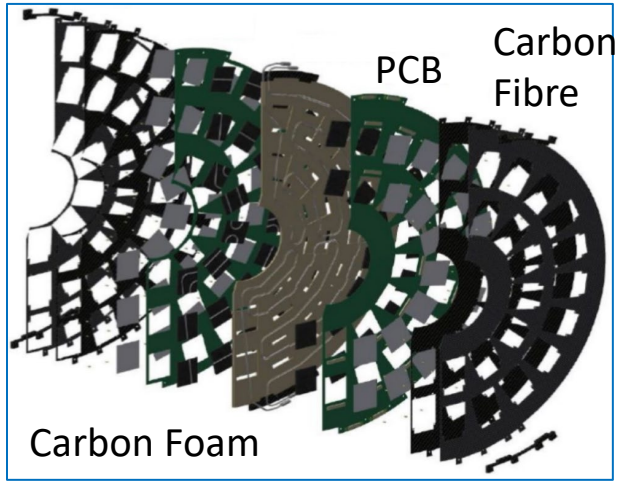
TBPX Layers (no modules)

TFPX and TEPX Mechanics

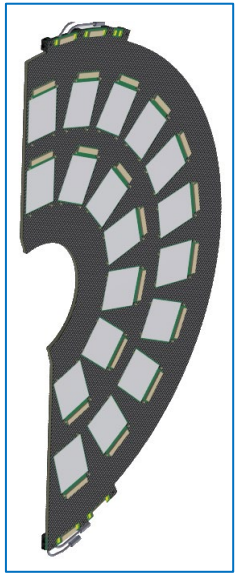
- In the TFPX and TEPX, sensors are mounted on the faces of support discs
  - Each disc consists of dees
  - Dees are made from carbon foam sandwiched between carbon fibre skins, with cooling pipes in the centre
  - In TFPX, dees are supported by cartridges which also hold port cards used to transmit data from the modules
    - Cartridges are loaded into the service cylinder
  - Due to space constraints in TBPX, its port cards are also mounted within the TFPX services cylinder



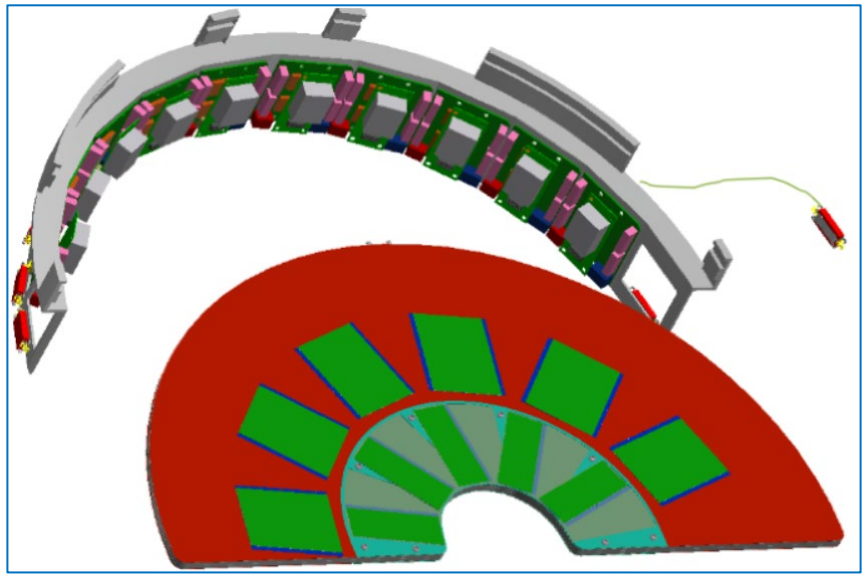
TFPX Dee support sandwich composition



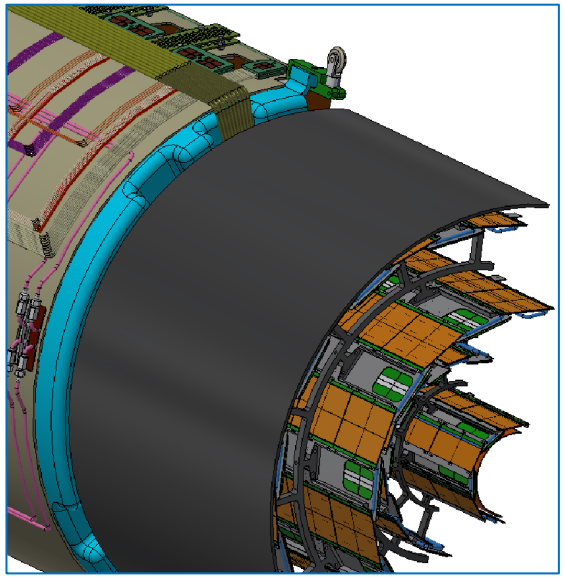
TEPX Dee support sandwich composition



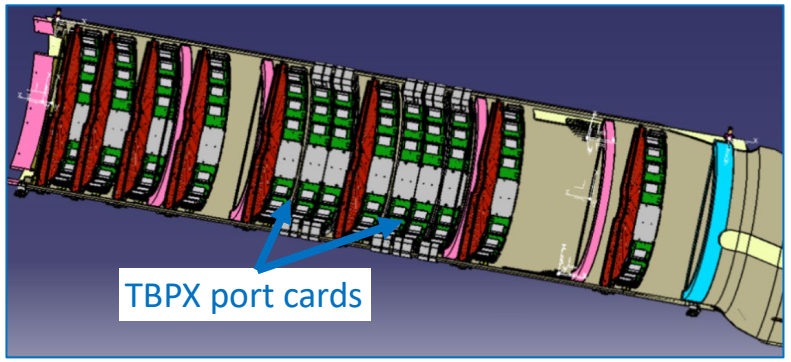
TEPX dee



Dee integration with cartridge chassis



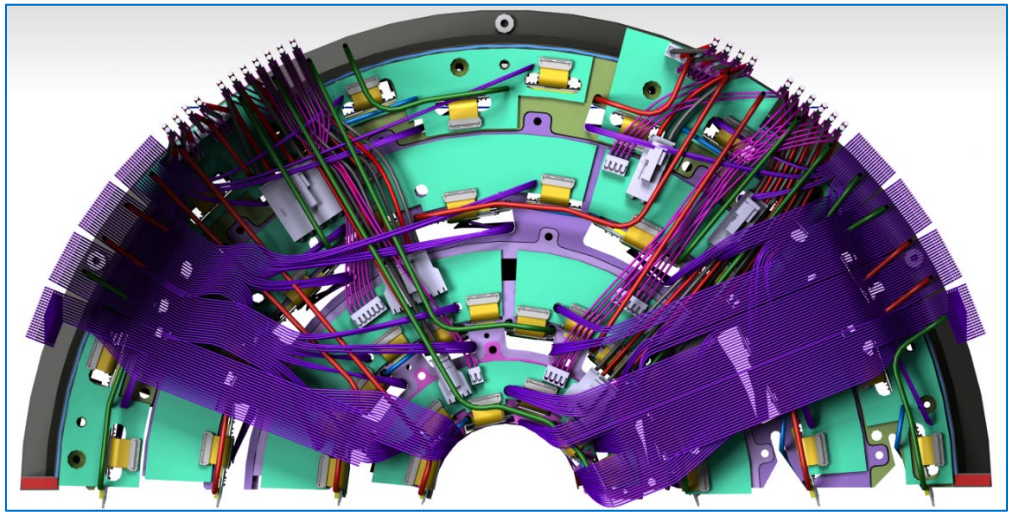
Interface between TBPX and TFPX



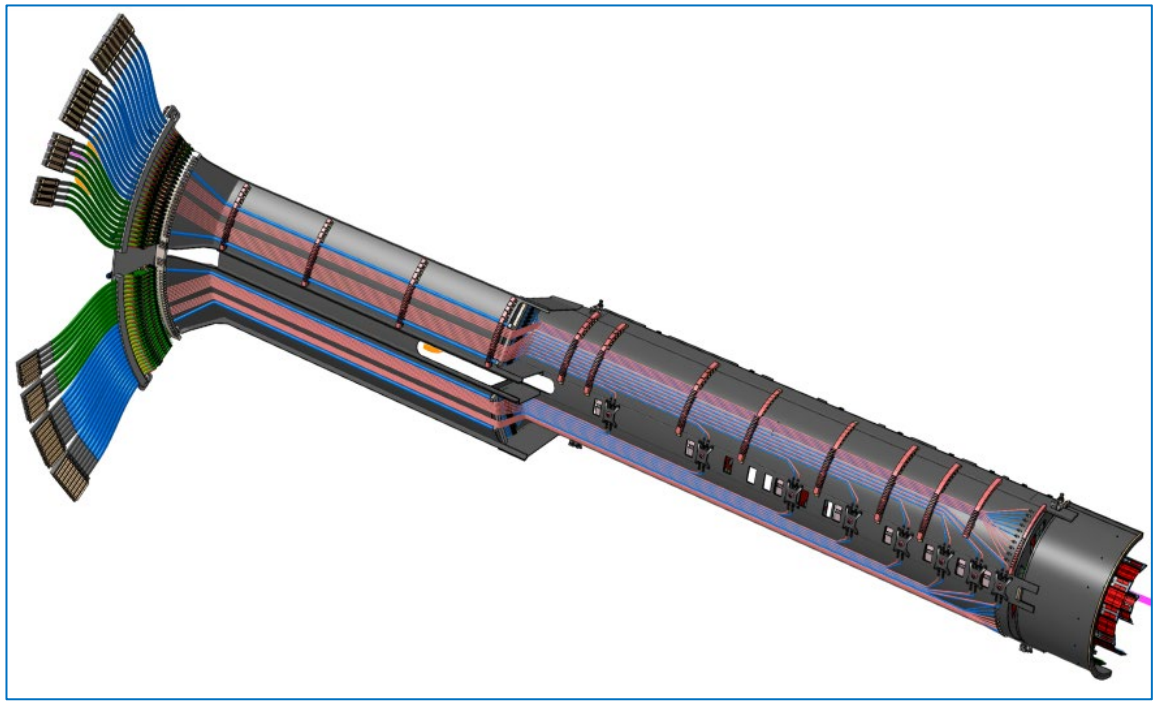
TBPX port cards within the TFPX half cylinder

CMS Inner Tracker Services

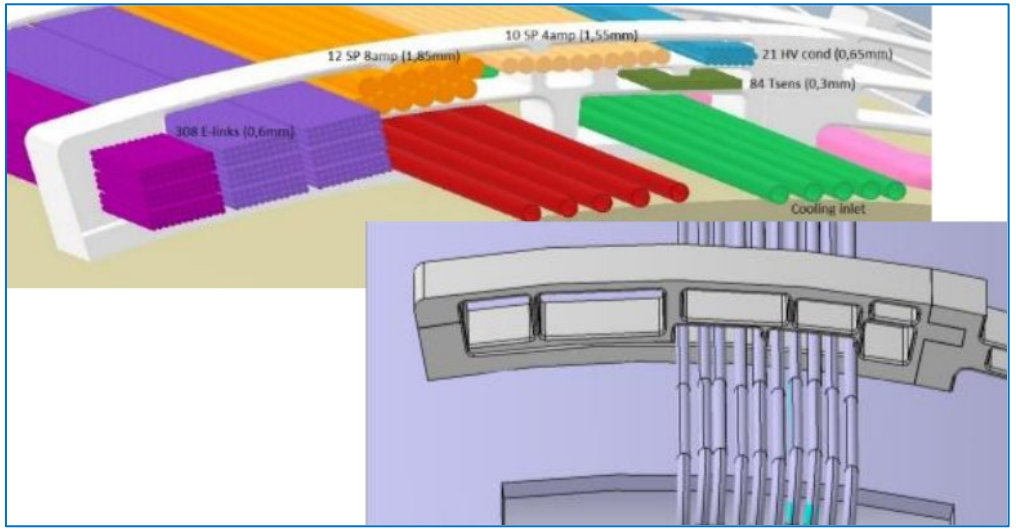
- Services are clamped to the outside of the shell along its length
  - The gap available for the services along the shell is approximately 13mm high
  - Careful routing required in regions of limited space



Services distribution at the TBPX flange



Services on shells

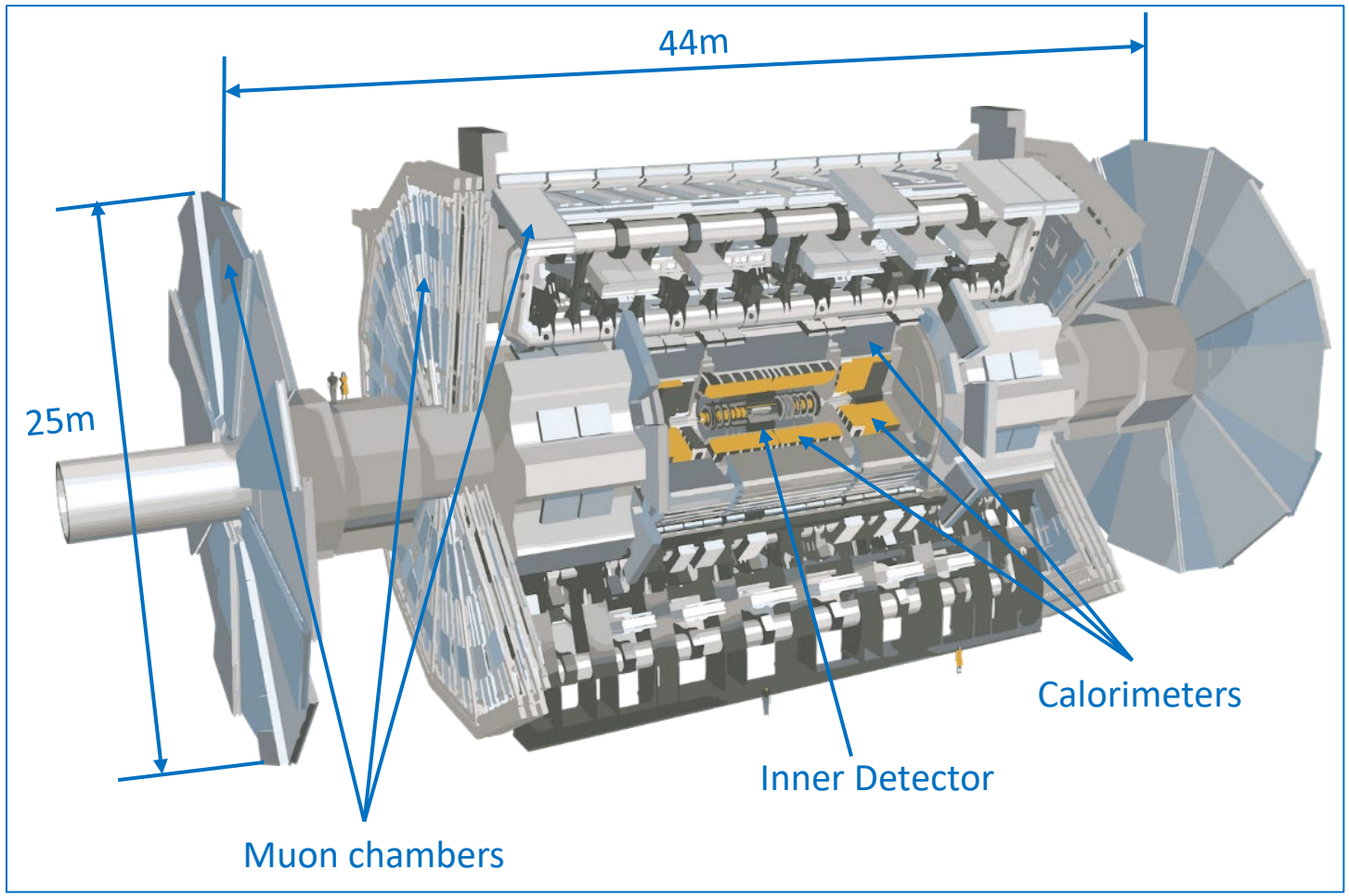


Clamps for services

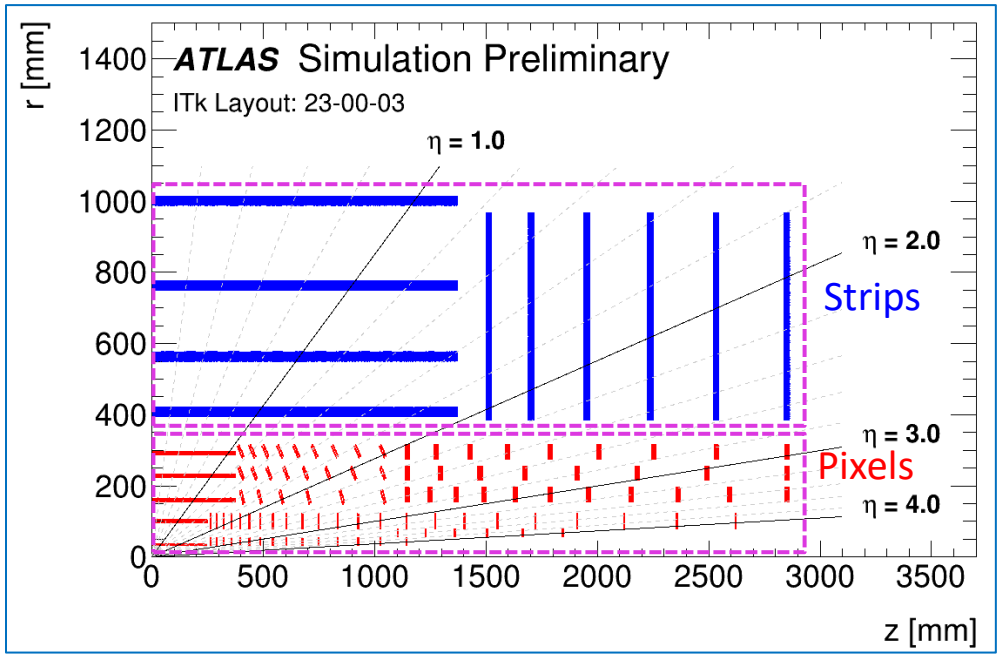
ATLAS Upgrade Background

- Inner Tracker (ITk) will have 10x the active area compared to the existing Inner Detector
- It consists of a strip and pixel section
  - Pixel sensor area will increase from ~1.9m^2 to ~13m^2

See the talk from Craig Buttar earlier this week!



Overview of ATLAS

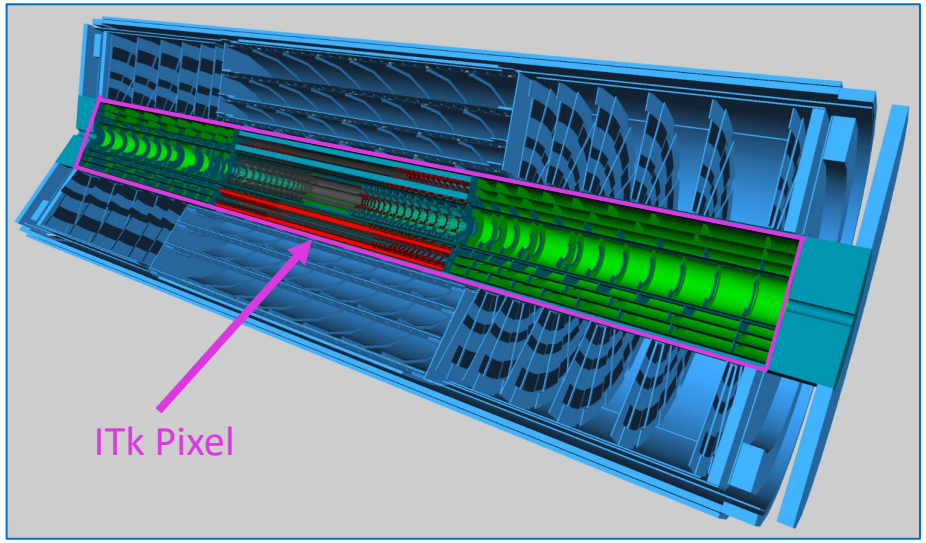


Schematic view of the upgraded ITk layout.
Blue represents strip sensors, red is for pixels

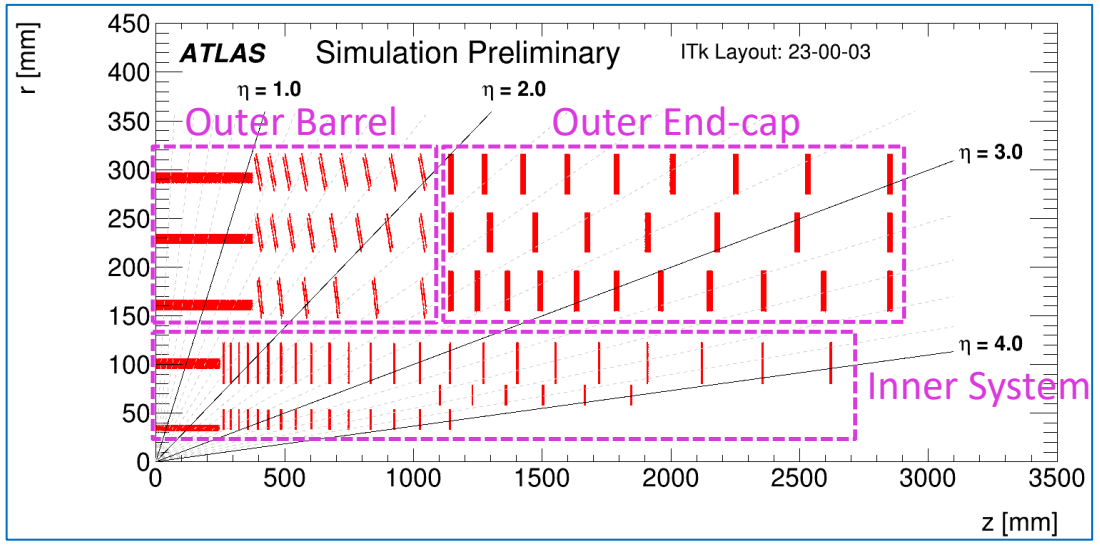
ITk Pixel Detector

- The ITk is split into 3 sections
  - Outer Barrel
    - Modules are mounted on longerons and inclined rings, organised in 3 layers
  - Outer End-cap
    - Modules are mounted on half-rings (perpendicular to beamline), organised in 3 layers
  - Inner System
    - Modules are mounted flat in the central barrel section and on rings further from the interaction point

More information on local supports in ITk Pixel is coming soon in Francisca Muñoz Sánchez's talk at 11:10!



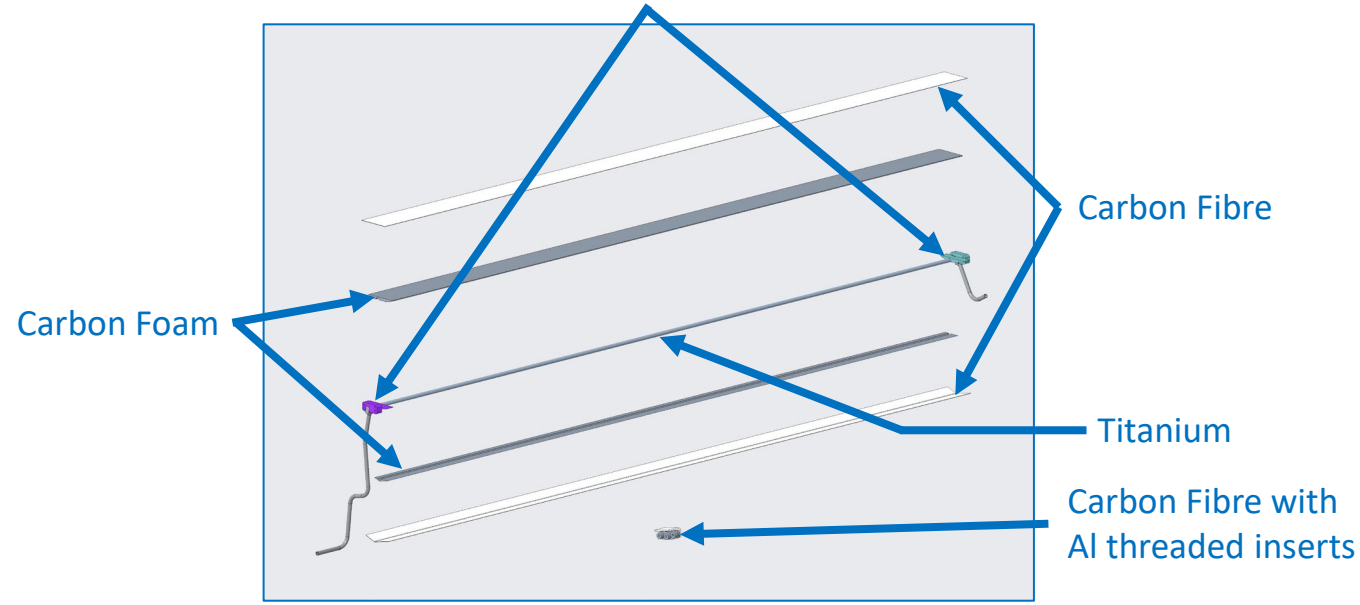
ITk Pixel Detector within the overall ITk



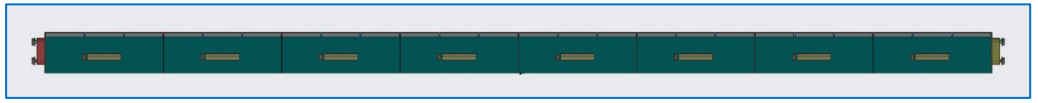
Schematic view of the ITk Pixel Detector and its subsystems

ITk Inner System Mechanics

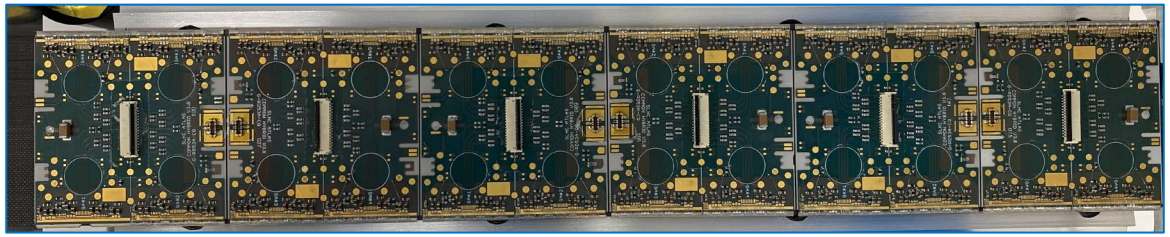
- The Inner System has a barrel section, where modules are mounted on staves
  - Staves are composed of:
    - Carbon Fibre
    - Carbon Foam
    - Carbon-filled PEEK
    - Aluminium threaded inserts
    - Cooling pipes (Ti)
  - 2 flavours of staves
    - For L0 – triplet (1x3) modules
    - For L1 – quad (2x2) modules



Inner System stave construction



L0 Stave

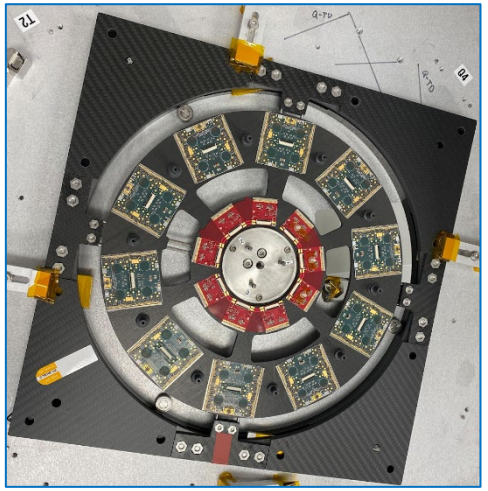


Prototype L1 Stave

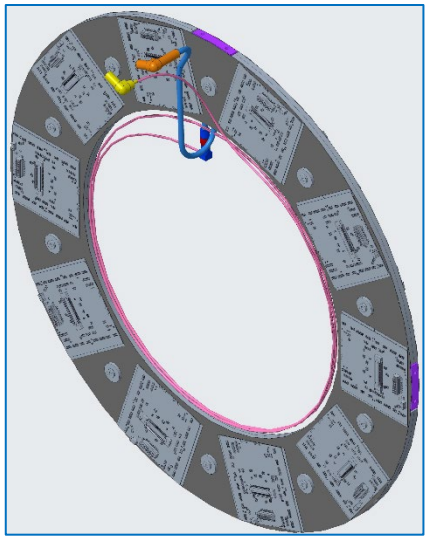
L1 Stave

ITk Inner System Mechanics

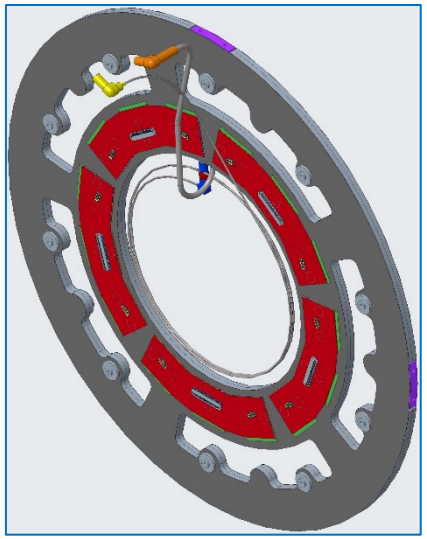
- The Inner System also has 3 flavours of rings which support modules in its endcap region
  - Rings are composed of:
    - Carbon fibre
    - Carbon foam
    - Ultem clips
    - Titanium cooling pipes
    - Carbon-filled PEEK



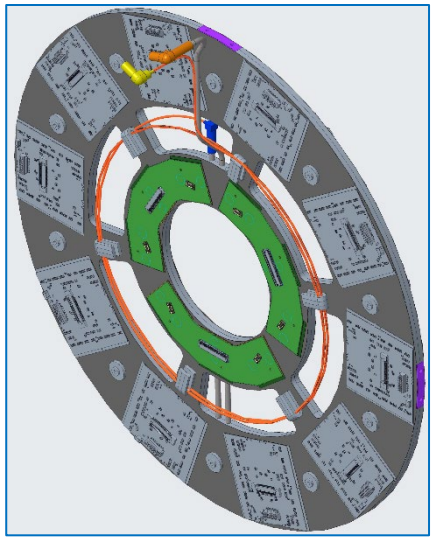
Prototype Inner System ring



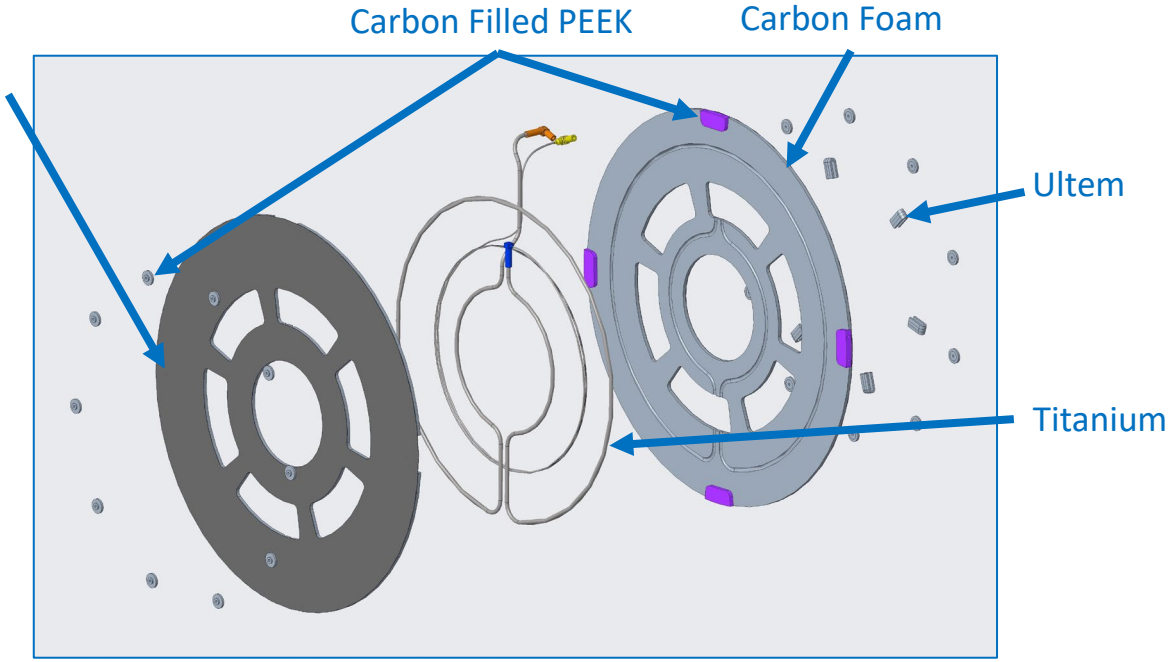
R1 Flavour



R0.5 Flavour



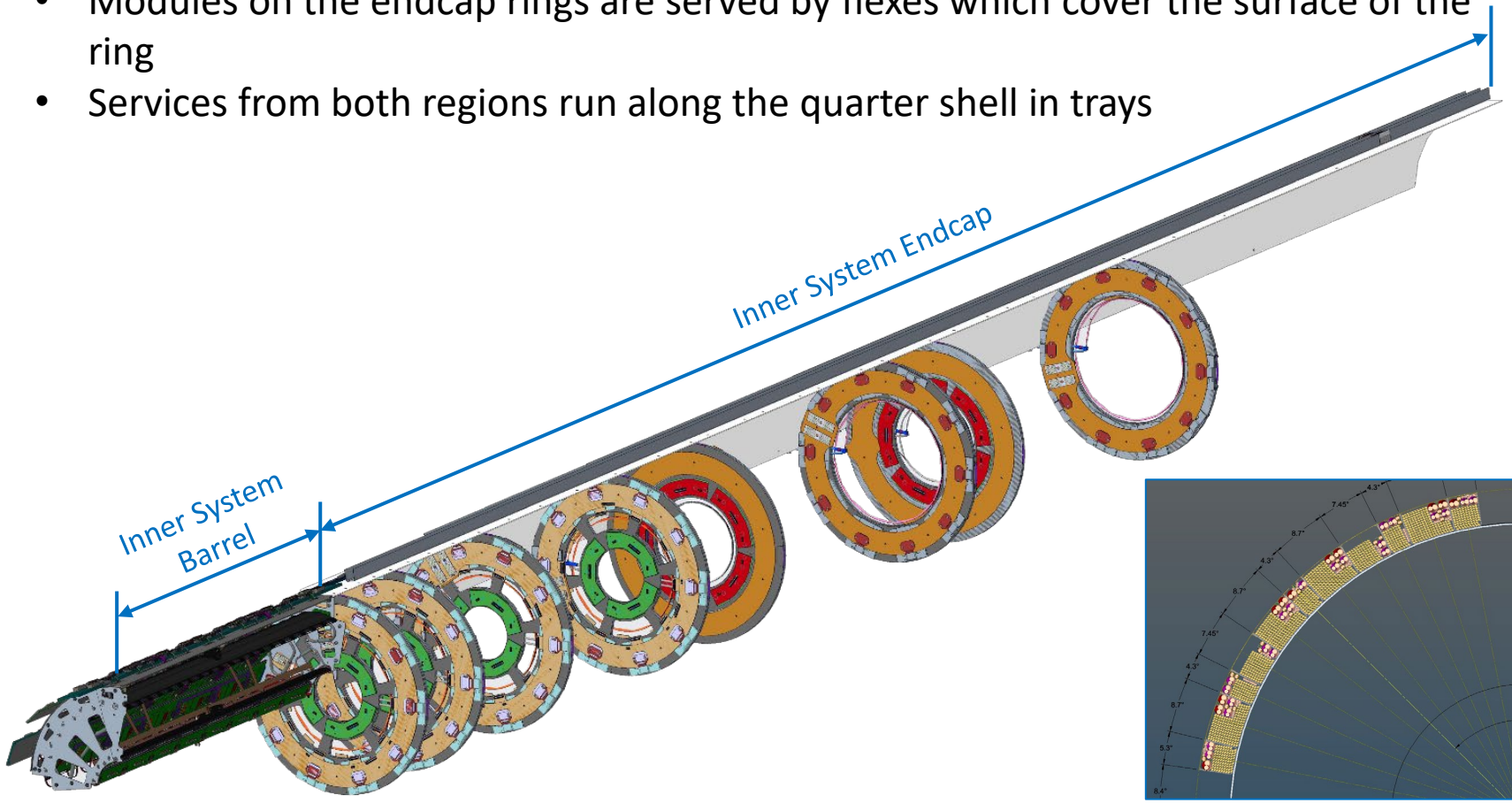
R0/R1 Flavour



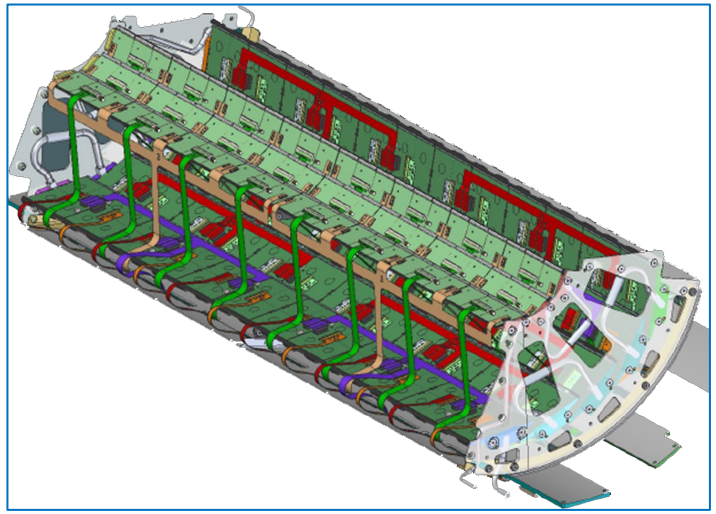
Inner System ring construction

ITk Inner System Mechanics

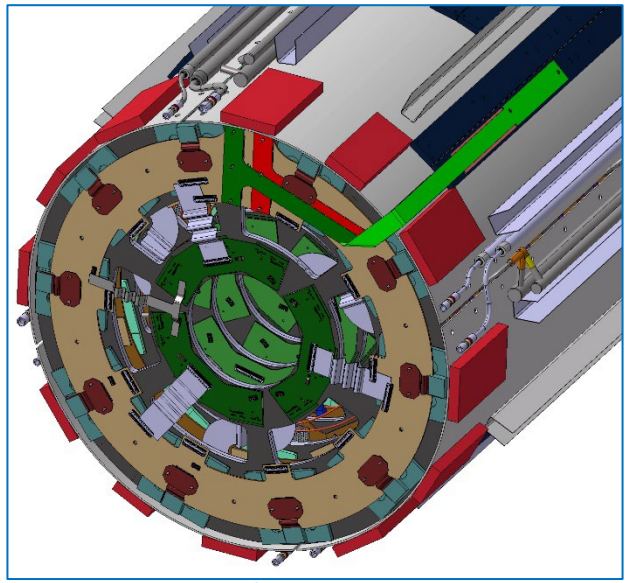
- The rings and staves of the Inner System are supported by quarter shells
  - Each quarter shell holds rings at different positions so that they fit together
- Barrel services connect to each module individually, and are run to the quarter shell exterior
- Modules on the endcap rings are served by flexes which cover the surface of the ring
- Services from both regions run along the quarter shell in trays



Inner System Service Tray



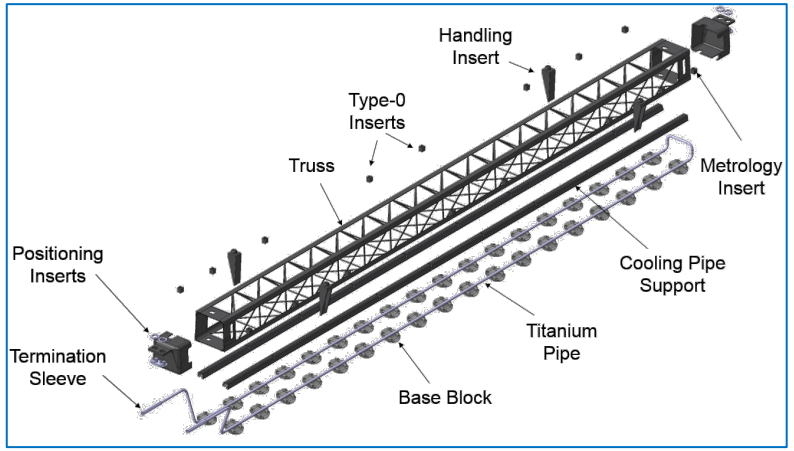
Barrel services running to the outside of the quarter shell



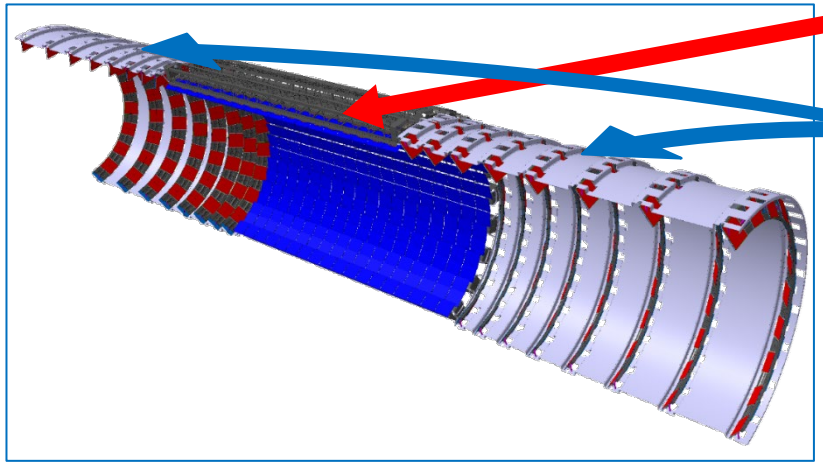
Endcap services

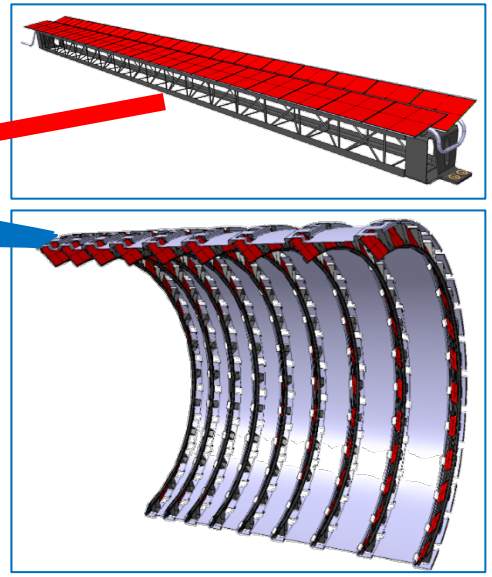
ITk Outer Barrel Mechanics

- In the Outer Barrel, modules are mounted on pyrolytic graphite tiles
  - These are then mounted on either:
    - Longerons, in the flat section
    - Inclined half rings, in the inclined section
    - Interface to cooling pipes is made via aluminum-graphite mounting block in both sections
  - Longerons and inclined half rings are made from carbon fibre
  - Support is provided by carbon fibre half-layer shells
  - Services run out of the shells and along its surface



Longeron components

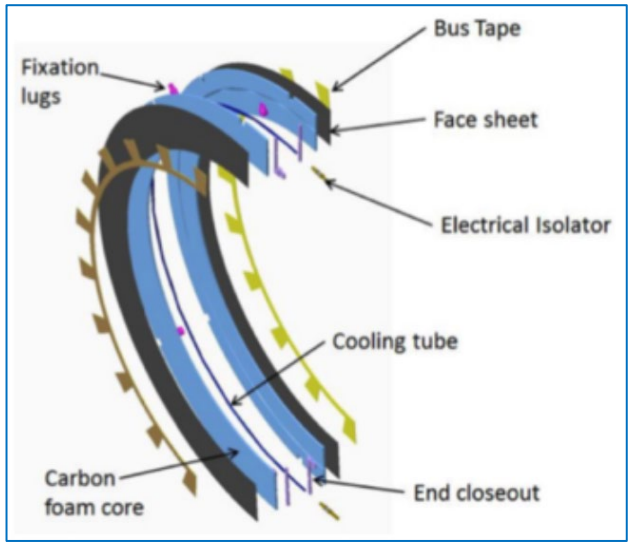

Completed half layer – longerons + 2 inclined units


Loaded longerons (top) and inclined half rings mounted on half-layer shell (bottom)

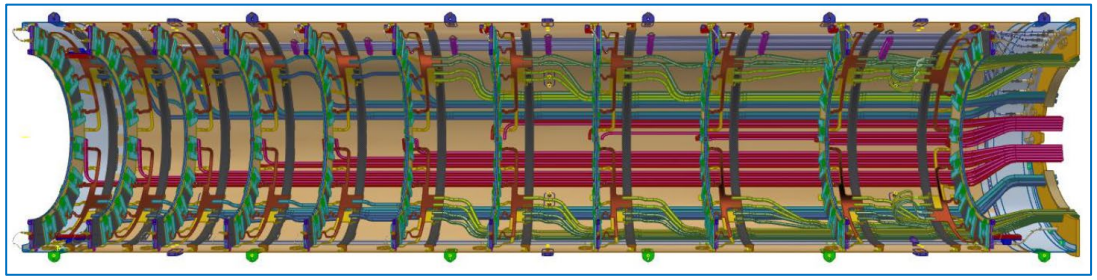

Prototypes of longeron (top) and inclined half ring (bottom)

ITk Outer End-cap Mechanics

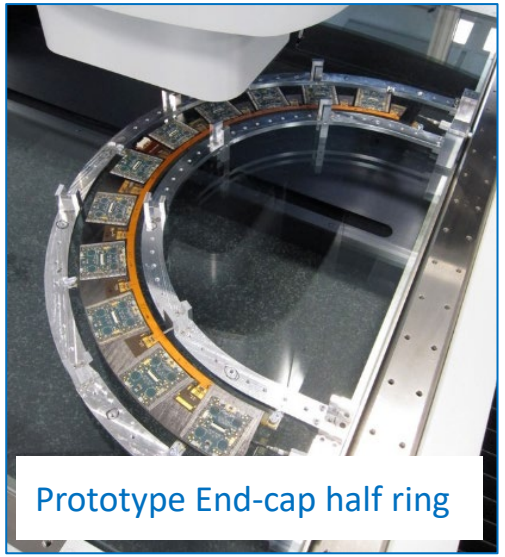
- In the Outer End-cap, modules are mounted on half rings constructed from a carbon foam/carbon fibre sandwich, with cooling embedded in the middle
- Split into 3 layers, with carbon fibre half-cylinder shells between them
- Half rings are mounted on these shells
  - They also support the cooling and electrical services, which run on the interior surface, between the shell and rings
    - Electrical services are guided by support rings mounted on the inside of the shells (gap of 6.6 or 7.6mm)
- The smallest layer (L2) is built into a full cylinder, then layers 3 and 4 are added on top
  - Layers are joined together at both ends



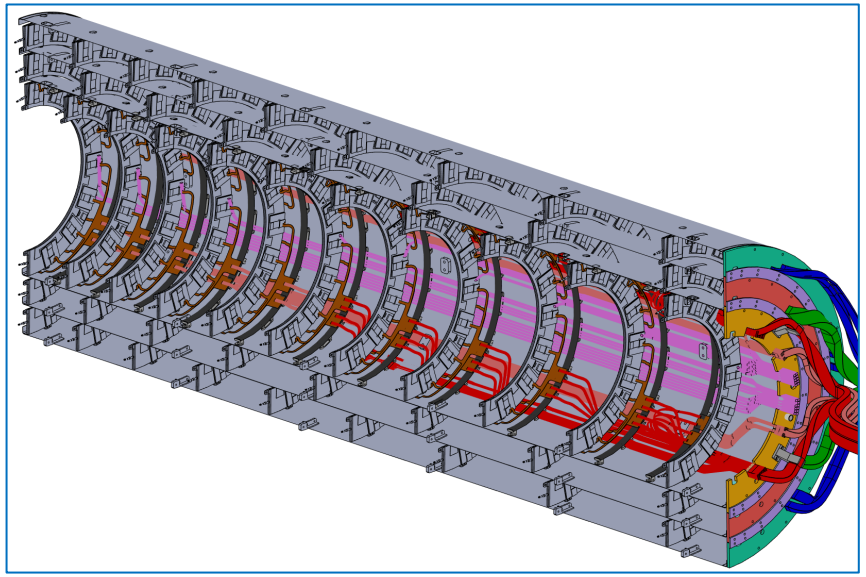
Half ring composition



Layer 2 of the Outer End-cap with services routing shown



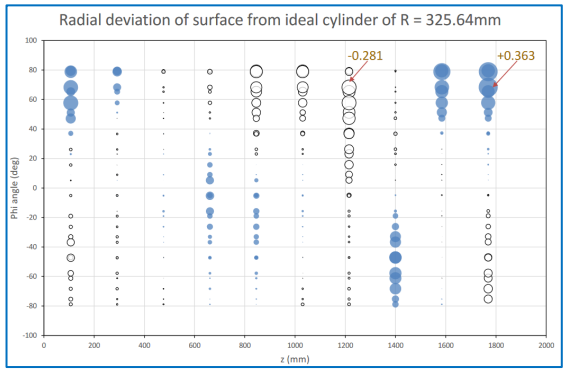
Prototype End-cap half ring



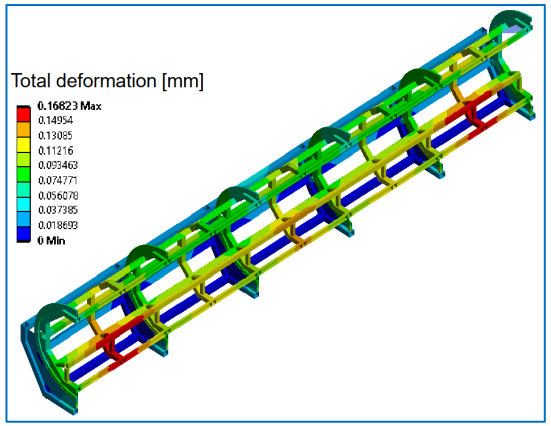
½ Outer End-cap

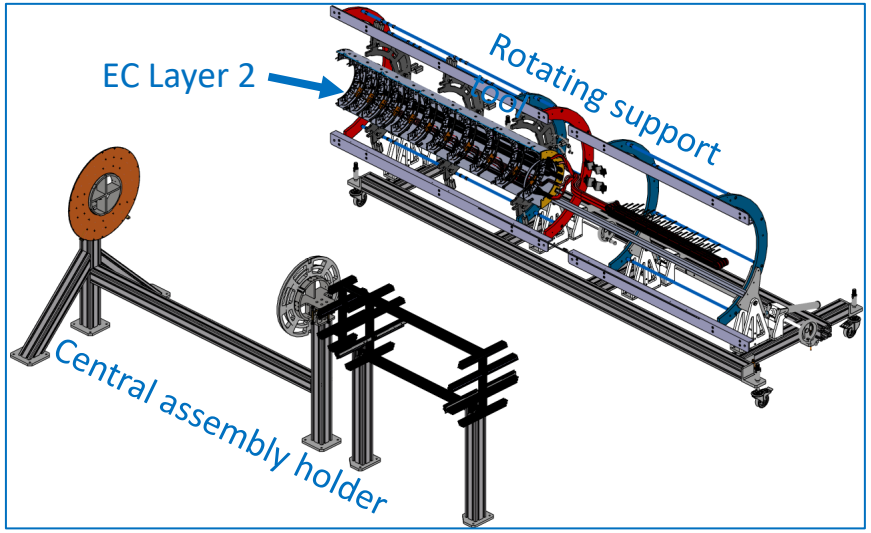
ITk Pixel Assembly Tools

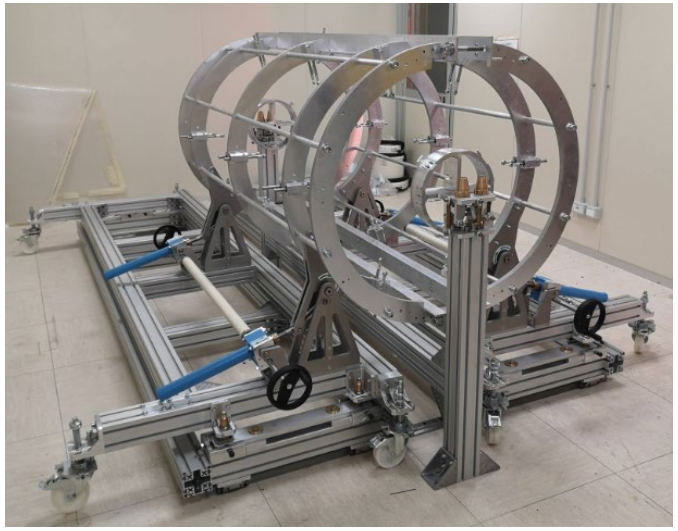
- The assembly of the ITk Pixel detector requires a wide range of tools in order to ensure components fit together correctly, and ultimately, that the sensors are positioned where they ought to be
  - Everything from the moulds for carbon fibre supports to large integration cradles which support the entire detector



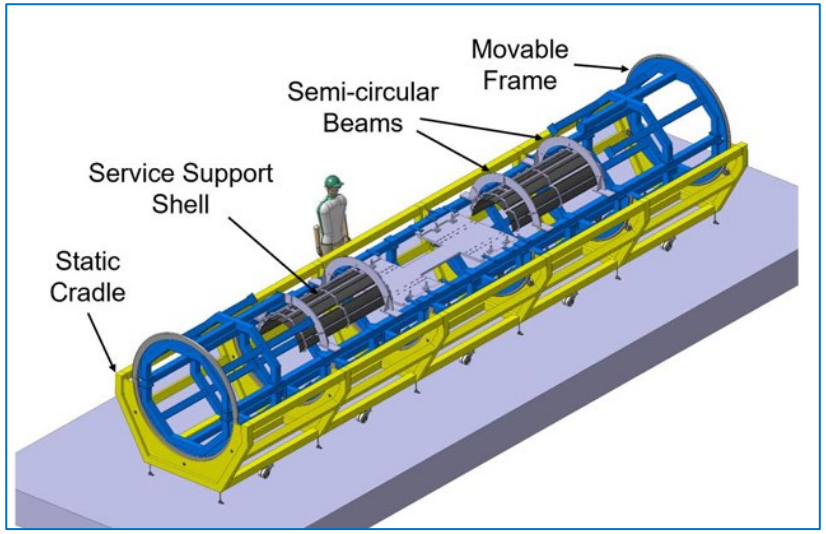
Prototype Outer End-cap shell and associated metrology results







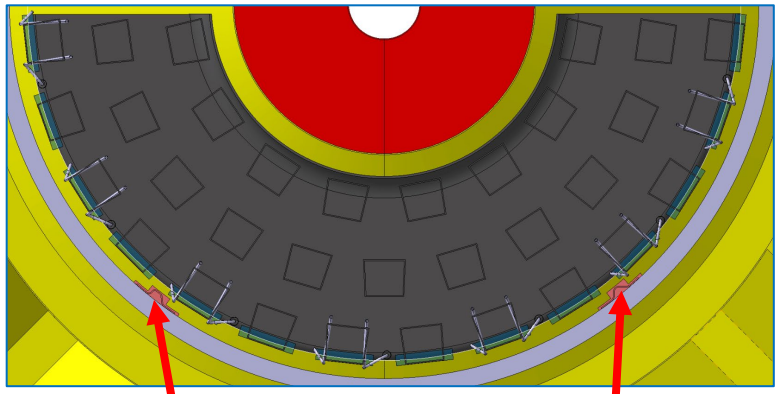
Outer end-cap integration tool model (left) and prototype (right)

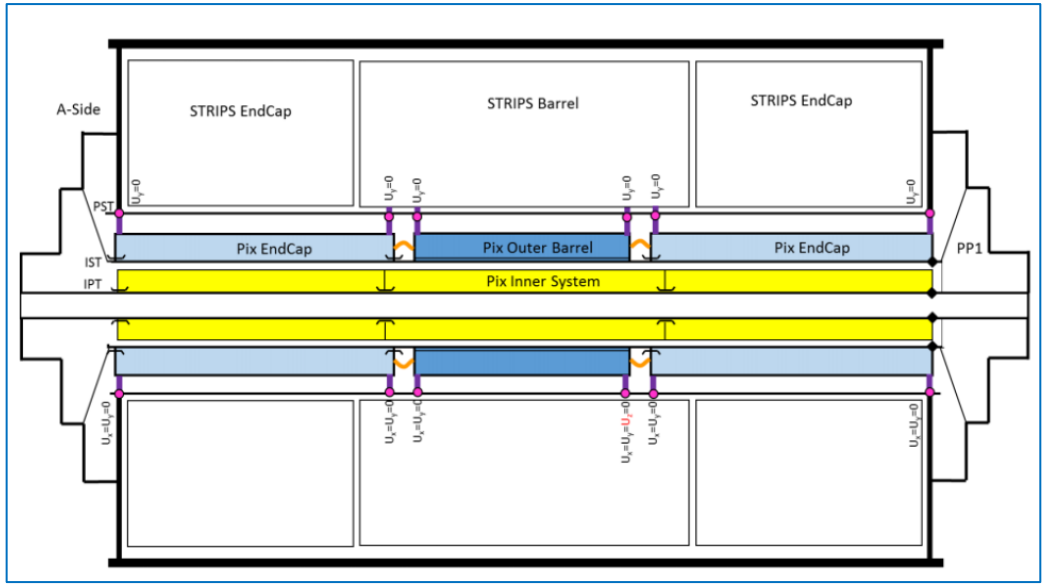


Outer Barrel integration tool (bottom) and example FEA deformation results (top)

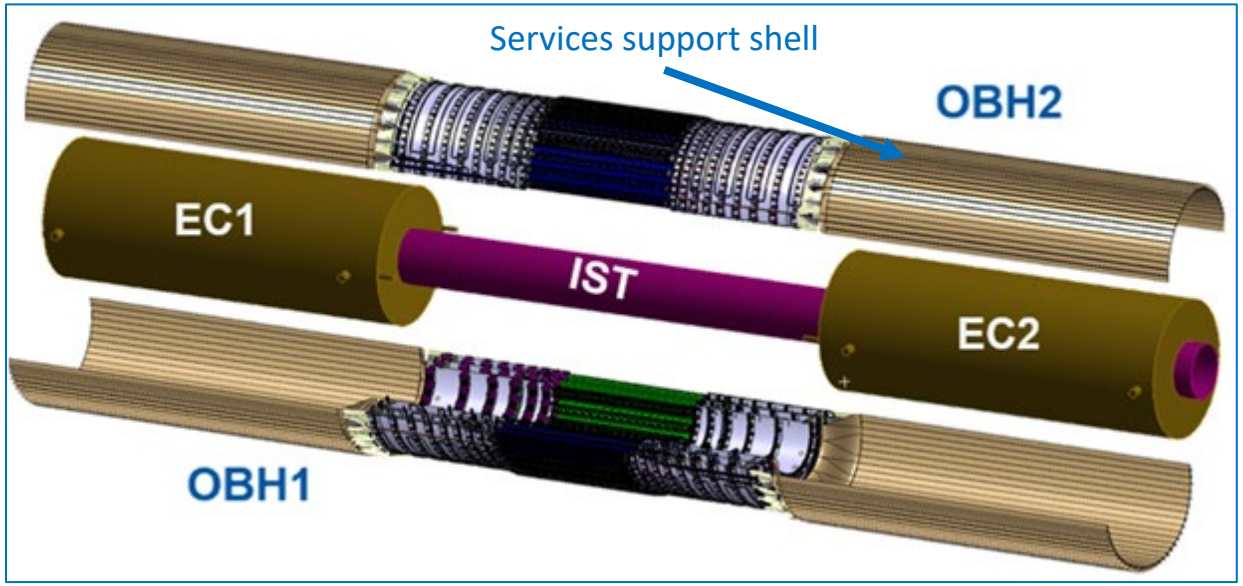
ITk Pixel Mechanics

- The Outer Barrel and Outer End-cap are joined together prior to final installation
  - They run along rails which are supported by the carbon fibre pixel support tube (PST)
  - The outer barrel services are supported around the end-cap on a thin shell
- The Inner System is supported within the outer system by the inner support tube (IST), also made from carbon fibre
  - The inner system is planned to be replaced during the period of high-luminosity operation





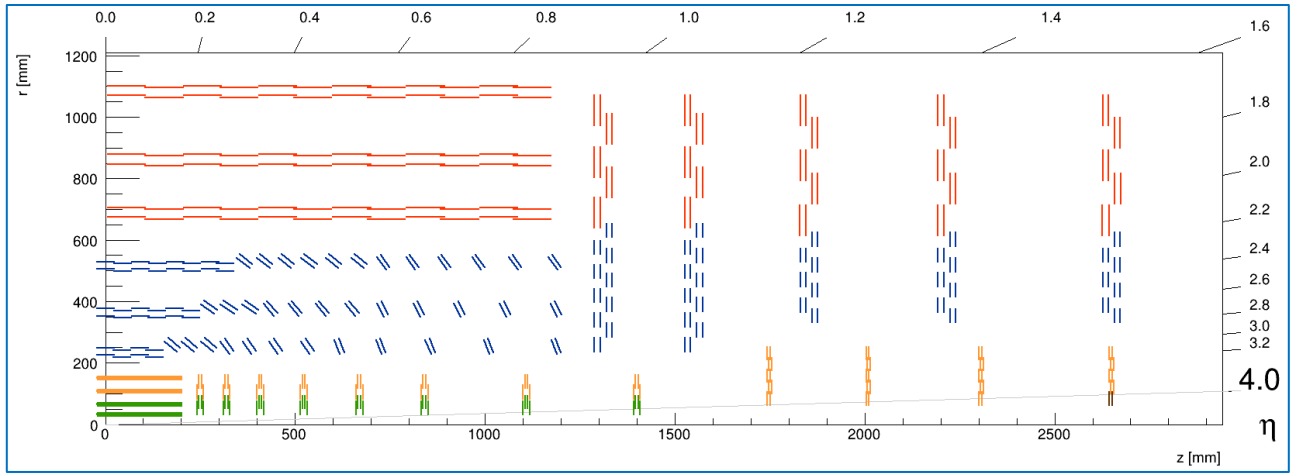
Schematic View of the ITk Pixel detector showing PST and IST



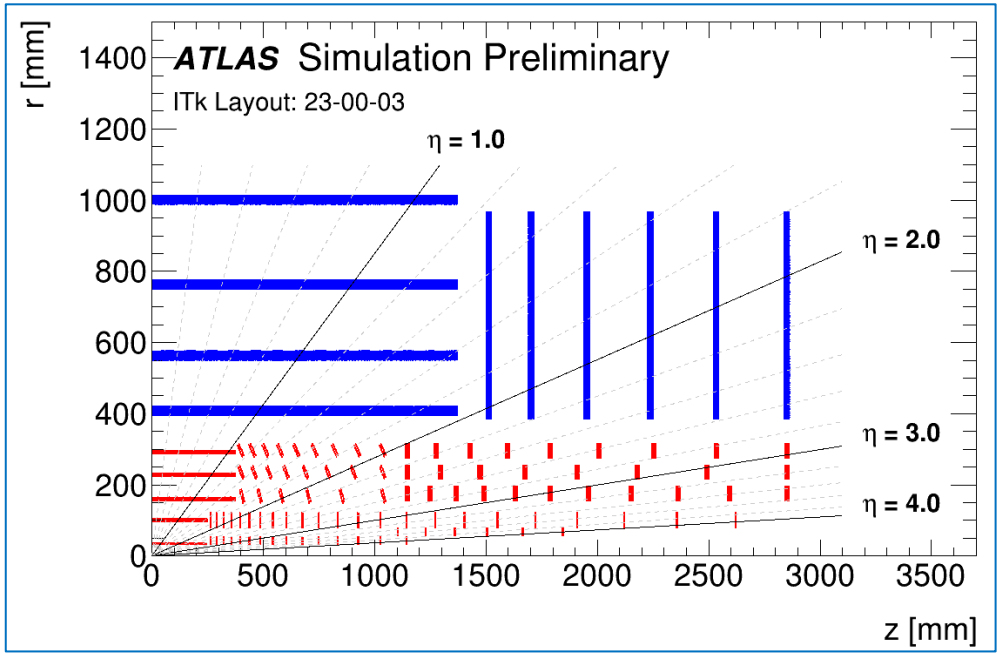
Integrated outer system (exploded view) showing the outer barrel services support shells

Summary

- Significant upgrades to the pixel detectors in ATLAS and CMS are on due to be installed while the LHC is turned off for 3 years in 2025
  - ITk Pixel On-detector services FDR – Dec 2022
  - ITk Pixel Inner System local supports FDR – Nov 2022
  - ITk Pixel Outer System loaded local supports FDR – Early 2023
  - ITk Pixel Global mechanics FDR – Q1/Q2 2023
- In ATLAS and CMS, sensor surface area will increase significantly, but with the same (or lesser) material usage
- ATLAS and CMS have adopted similar (but distinct) solutions to similar problems



CMS



ATLAS

Thanks for Listening

Any Questions?