Collider Experiments Mechanical Support, Vertex Detectors

Walter Sondheim, P-25, LANL

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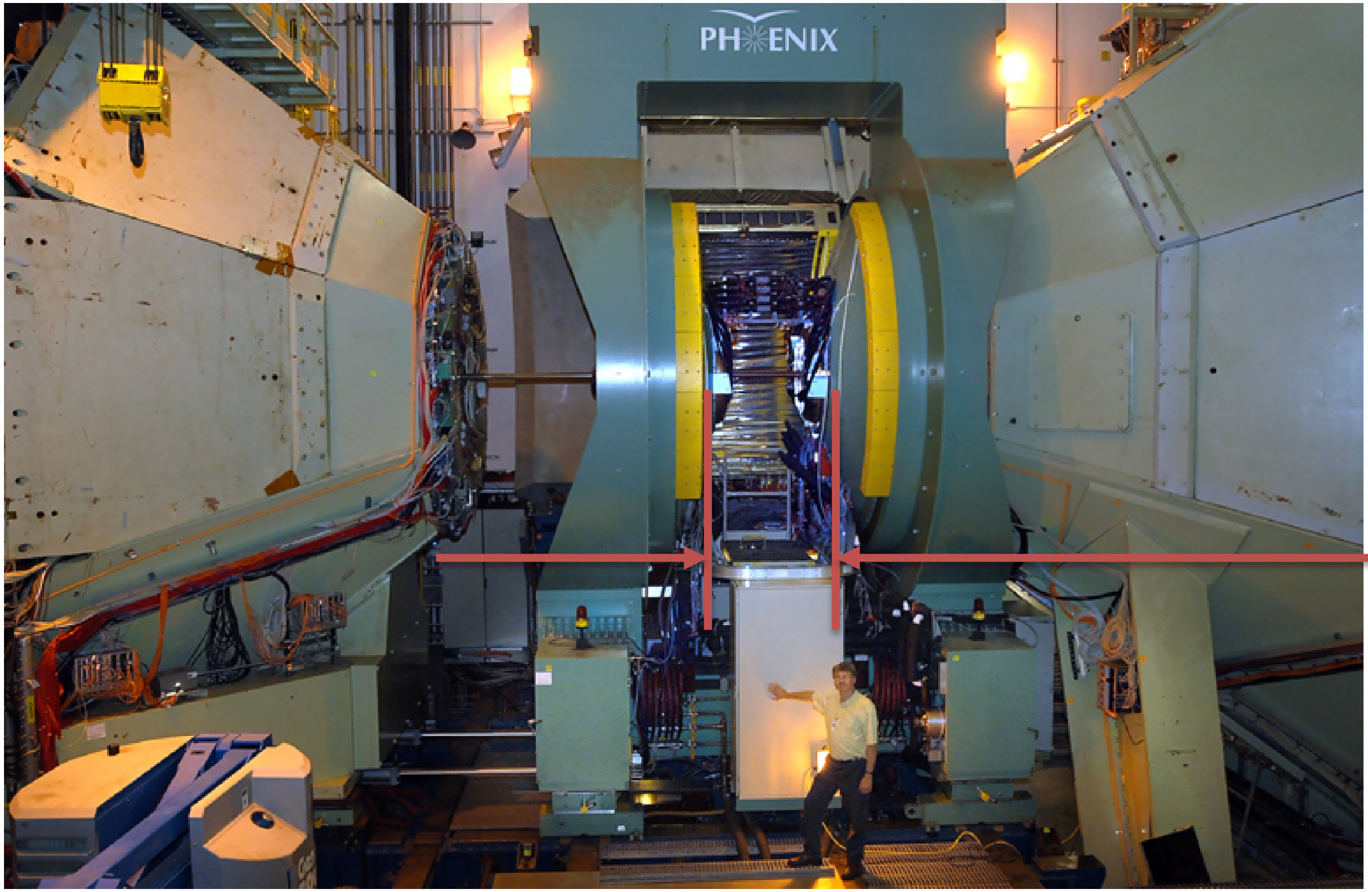
History; a few vertex detectors – in a collider environment;

- **RHIC** detectors;
  - PHEINX; VTX & FVTX
  - STAR; HFT
  - sPHENIX; MVTX
- **LHC** detectors; upgrades needed to cope with increasing luminosity
  - ATLAS; ITk
  - CMS
  - ALICE; ITS

General design parameters;

- Physics design requirements – rapidity coverage
- Radiation length – keep at a minimum
- Detector type(s) - silicon
- Power dissipation
- Services – routing
- Cooling – liquid, gas
- Survey and alignment – fixtures - access
- Support tie off points
- Integration

RHIC; PHENIX

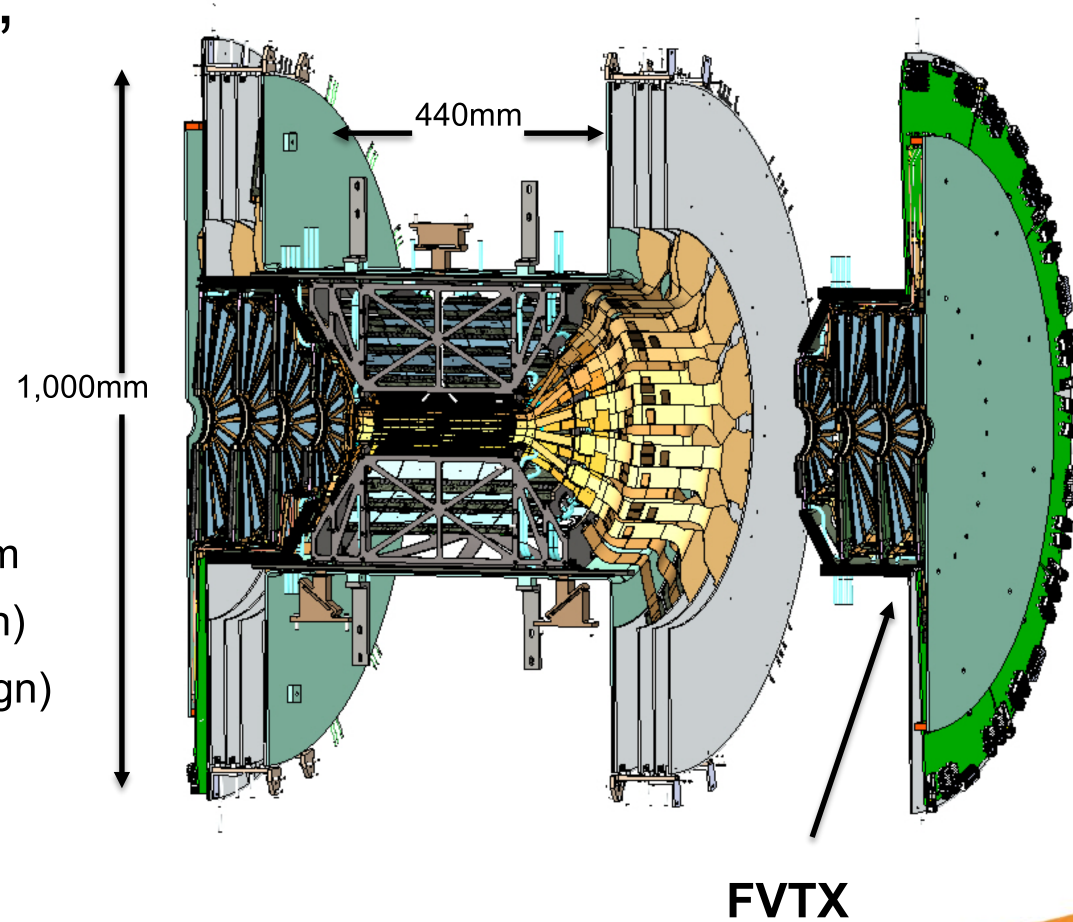


Available space for a vertex detector 800.0 mm between central magnet pole tips, beryllium beam pipe outer diameter 41.53 mm

RHIC; PHENIX Vertex &Forward Vertex Detector

- Design parameters;

- VTX barrel region;
  - 4 layers; 2 pixels, 2 strips
- FVTX assembly;
  - 4 tracking stations (Disks)
    - $1.2 < |\eta| < 2.4$
    - Φ acceptance = 2π
    - Silicon mini-strips, 2.8 – 11.2mm
    - 75. micron pitch (radial direction)
    - FPHX readout chip (FNAL design)
    - ~1.1M channels of readout



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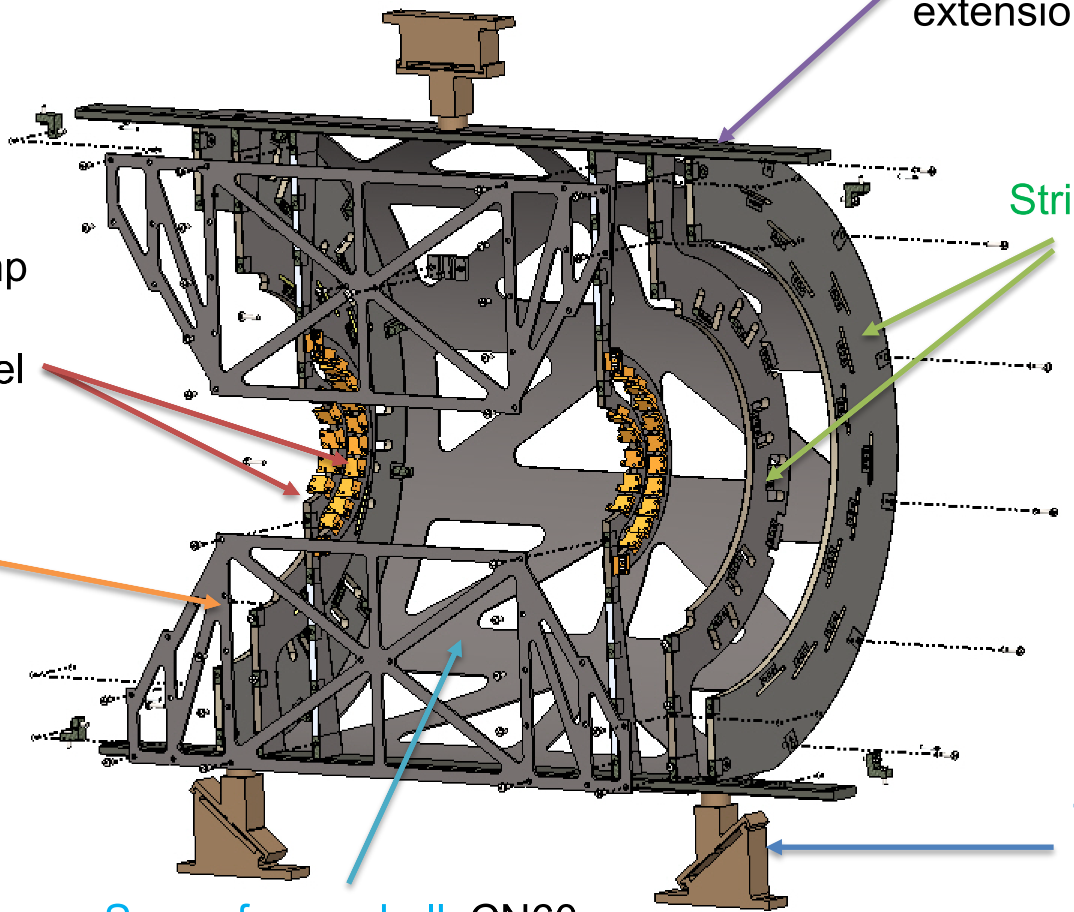
RHIC; PHENIX Vertex detector structural support

Main beam (2), POCO Graphite, extension attaches FVTX detector

Pixel layer 1 & 2 barrel mounts, M55J and Allcomp K3 Carbon foam, 3.6mm thick panel assembly

Stripixel layer 3 & 4 barrel mounts, M55J and Allcomp K3 Carbon foam, 6.3mm thick panel assembly



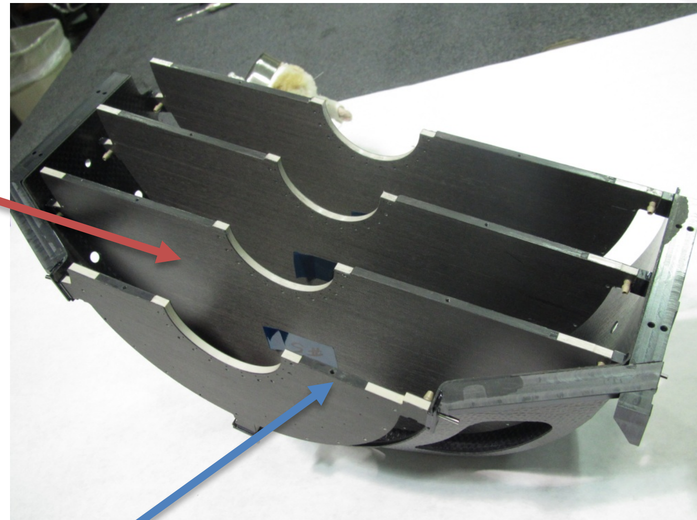
Center gussets CN60 cloth, 2.mm thick

Three point kinematic mount system

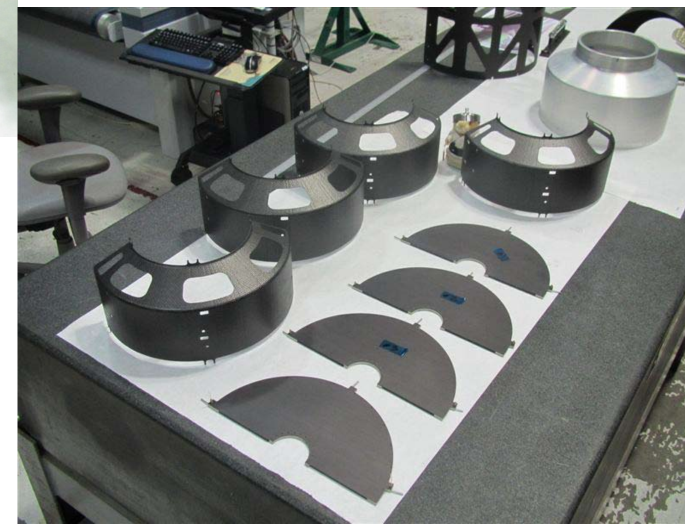
Space frame shell, CN60 cloth with EX1515 resin, 1.5mm thick

RHIC; PHEINX FVTX composite pieces

K13C2U uni-fiber face sheets, .40mm thick



Carbon loaded PEEK pieces along the panel edges, includes cooling channel.
Coolant for VTX & FVTX 3M NOVEC



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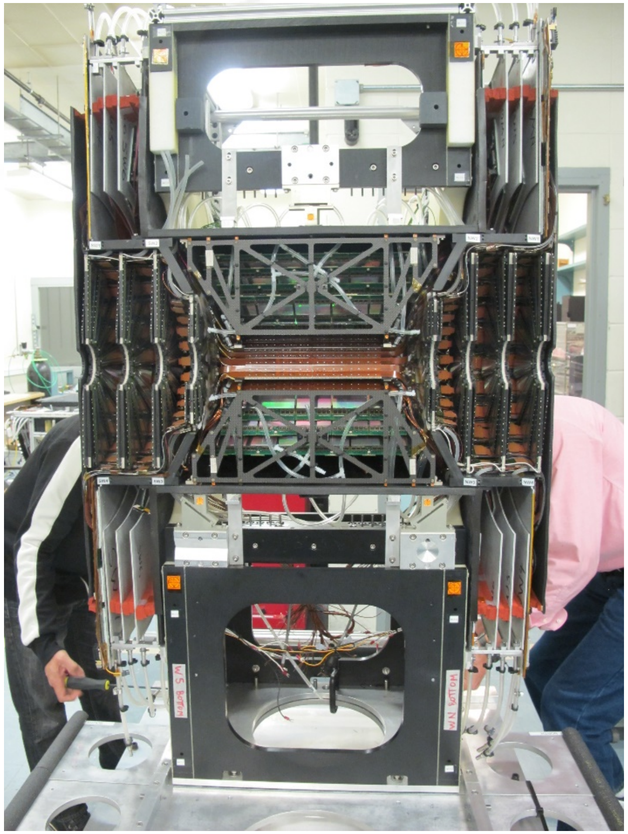
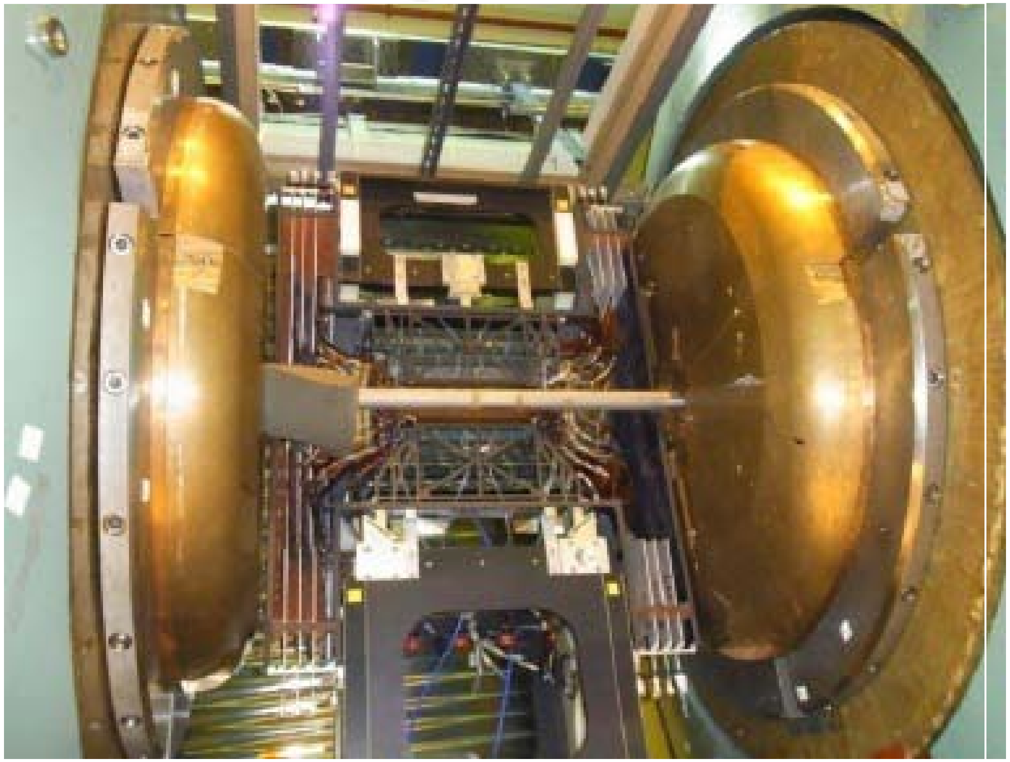
RHIC; PHENIX vertex detectors completed, aluminum super structure



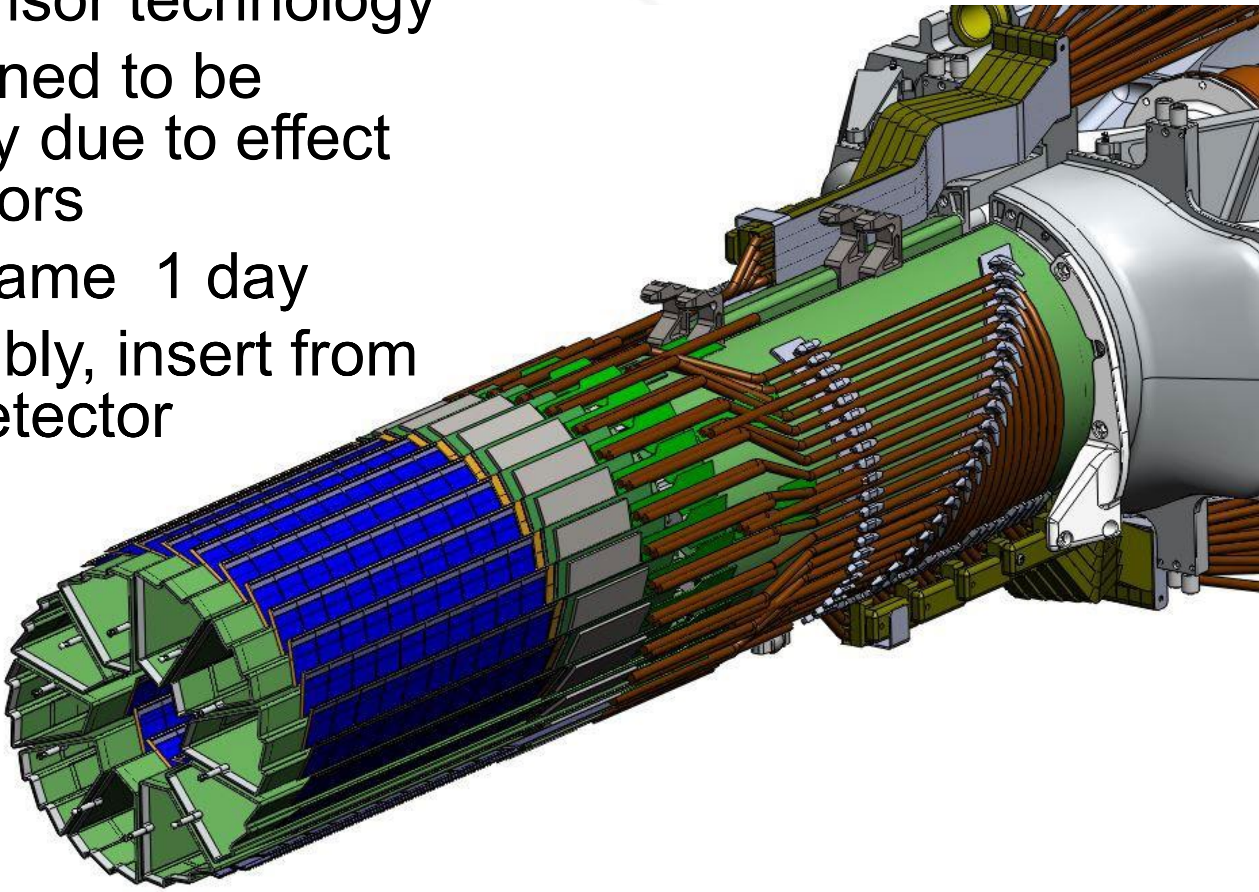
Assembled VTX & FVTX, one half weight ~ 200 pounds, support structure aluminum



Half assembly installed between PHENIX central magnet poles. Elevating platform with rails

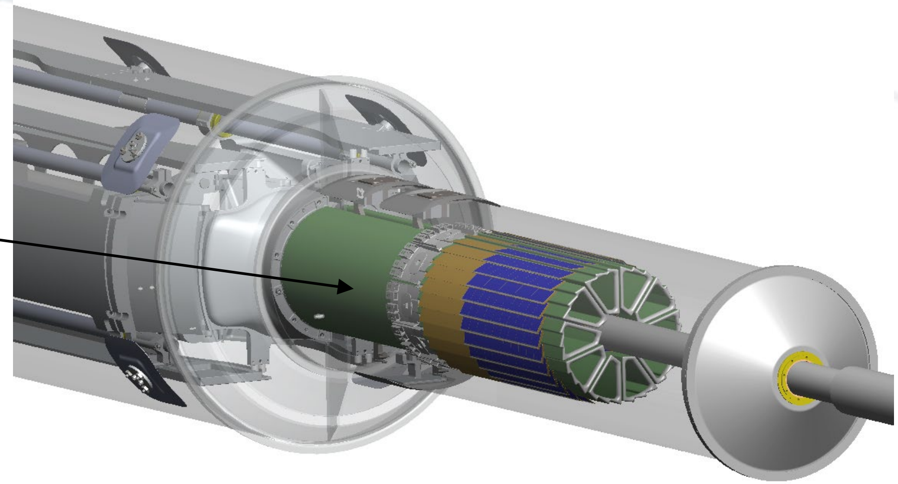
RHIC; STAR HFT vertex detector -

- First operational vertex detector based on MAPS sensor technology
- Pixel detector designed to be replaced periodically due to effect of radiation on sensors
- Replacement timeframe 1 day
- Cantilevered assembly, insert from one end of STAR detector

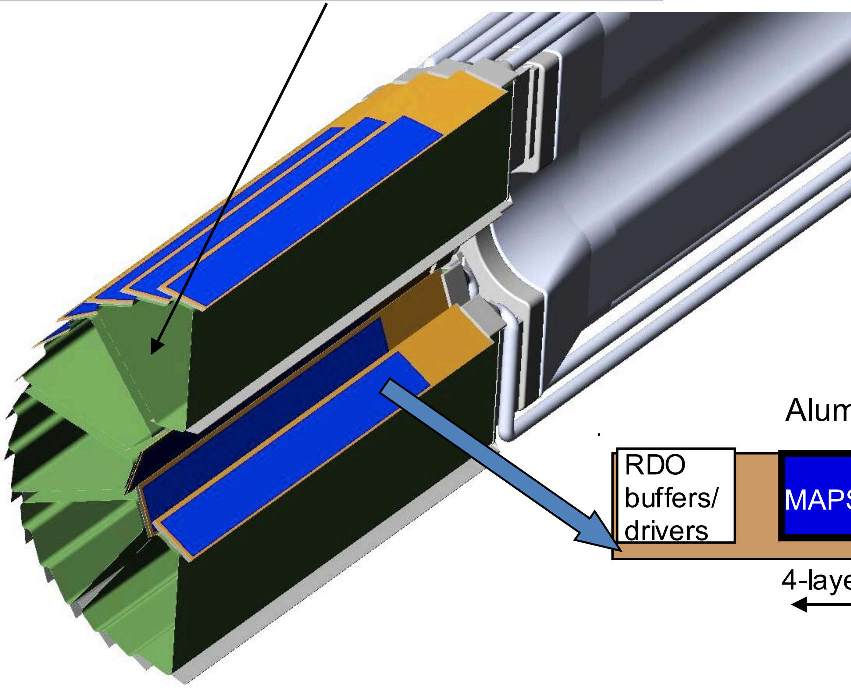


HFT - PXL Detector Mechanical Design;

Mechanical support with kinematic mounts (insertion side)

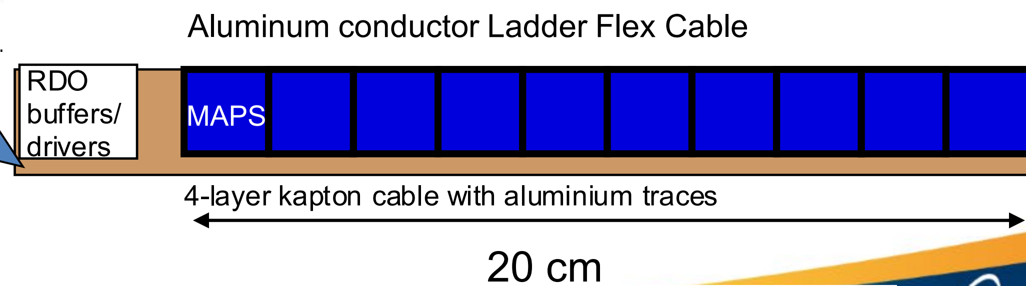


carbon fibre sector tubes (~ 200μm thick), air cooling



Insertion from one side
2 layers
5 sectors / half (10 sectors total)
4 ladders / sector

Ladder with 10 MAPS sensors (~ 2×2 cm each)



RHIC; STAR half HFT assembly

Carbon composite support tube with air cooling channel, Air flow velocity 9 – 10 m/sec, Delta T - 11°C

Estimate power dissipation 240 watts Si + drivers

RHIC; STAR HFT insertion mechanism

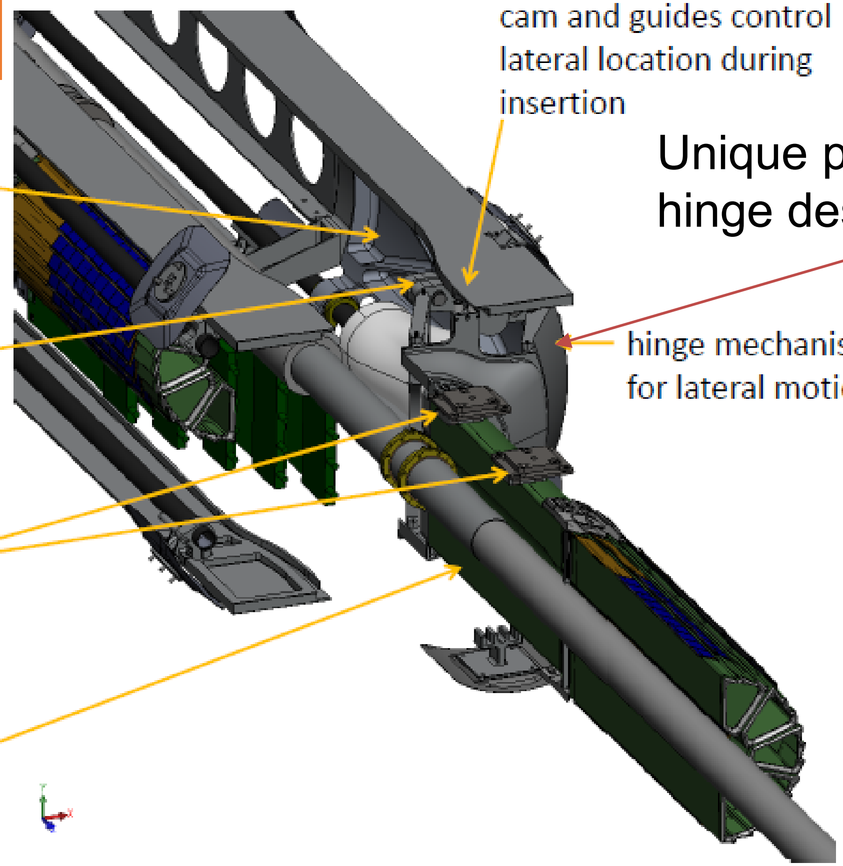
System for rapid PXL installation (internal mechanics)

STAR HFT

cam and guides control lateral location during insertion

Unique pneumatic hinge design

carriage rides on support rails



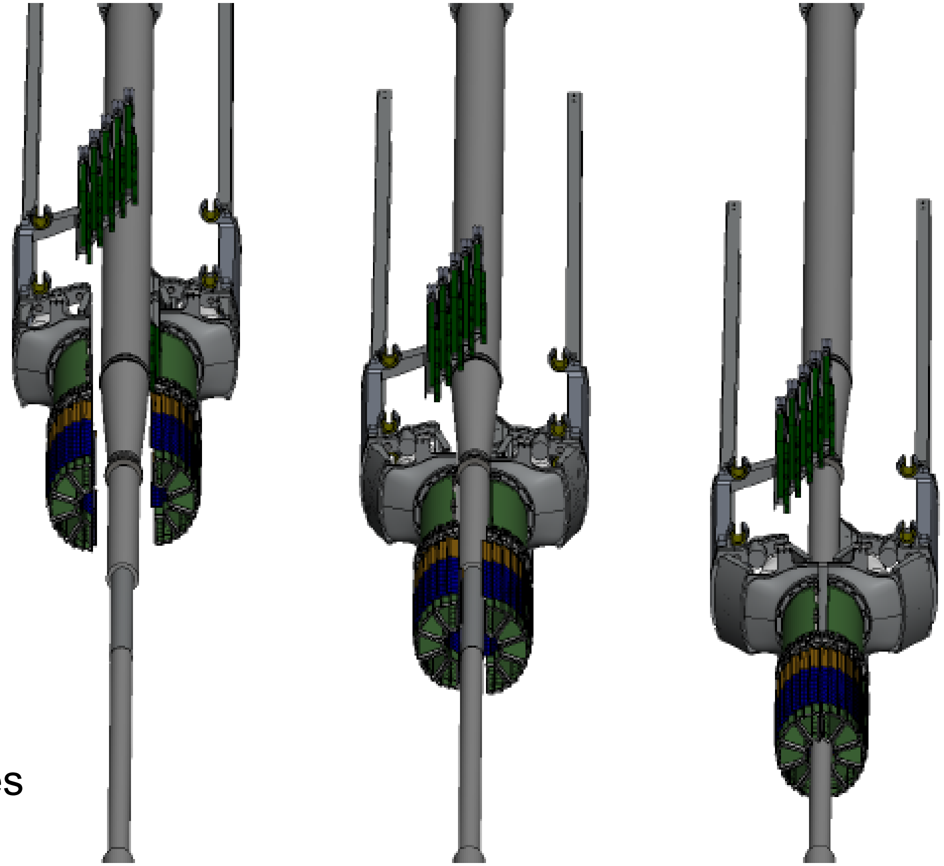
hinge mechanism for lateral motion

mechanical release to transfer load to kinematic mounts

kinematic mounts engage at home position

thin carbon half tube for PXL support and cooling air duct

RHIC; STAR HFT insertion around existing beam-pipe.



Open to clear beam-pipe flanges

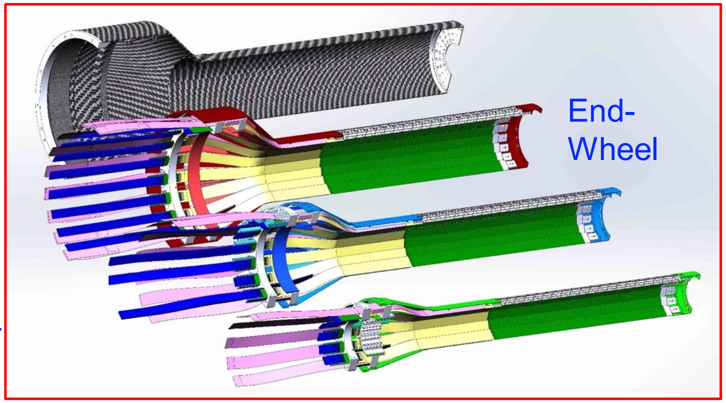
Closing down

Fully inserted to IP and locked in kinematic mounts

RHIC; sPHENIX - MVTX Detector

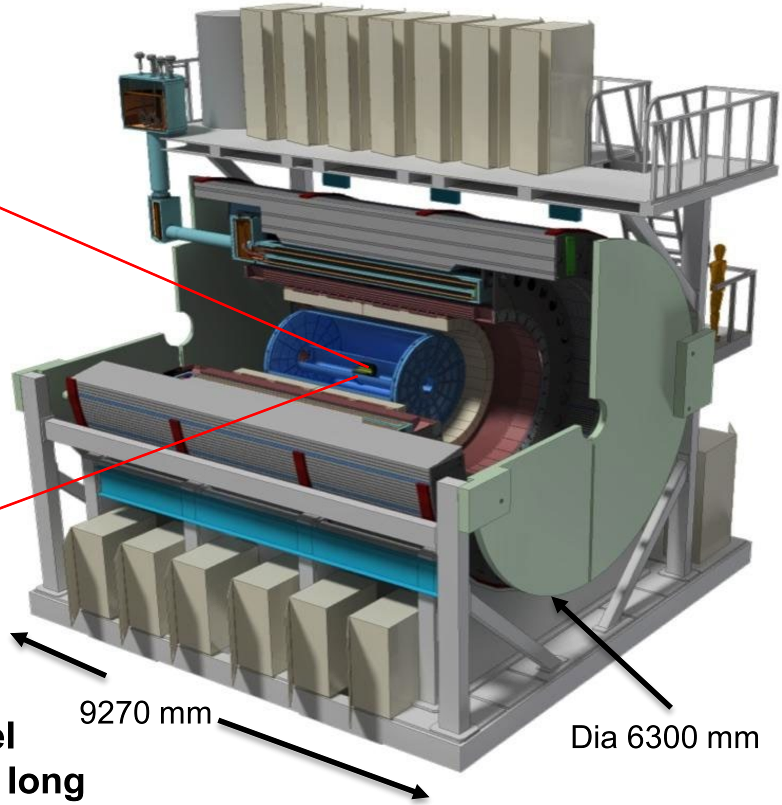
MVTX Detector volume modelled after the ALICE ITS inner detector

CYSS: Cylindrical Shell Structure



Extended power FPC

sPHENIX solenoid magnet and detector carriage



MVTX parameters

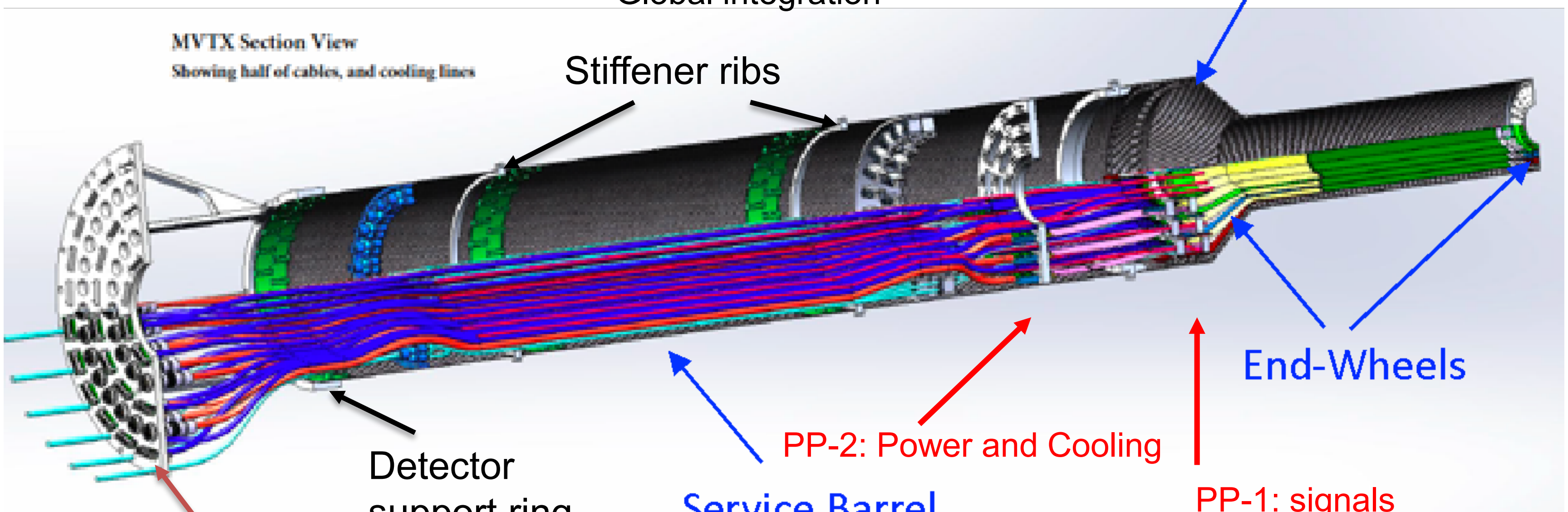
	R_min (mm)
Layer 0	24.61
Layer 1	31.98
Layer 2	39.93

3-layer sensor barrel
- **48 staves, 27.1cm long**
- **432 ALPIDE chips**

RHIC; sPHENIX MVTX half assembly with service barrel;

CAD 3-D Model developed:
- Detector
- Service Barrel
- Global integration

CYSS: Cylindrical Shell Structure



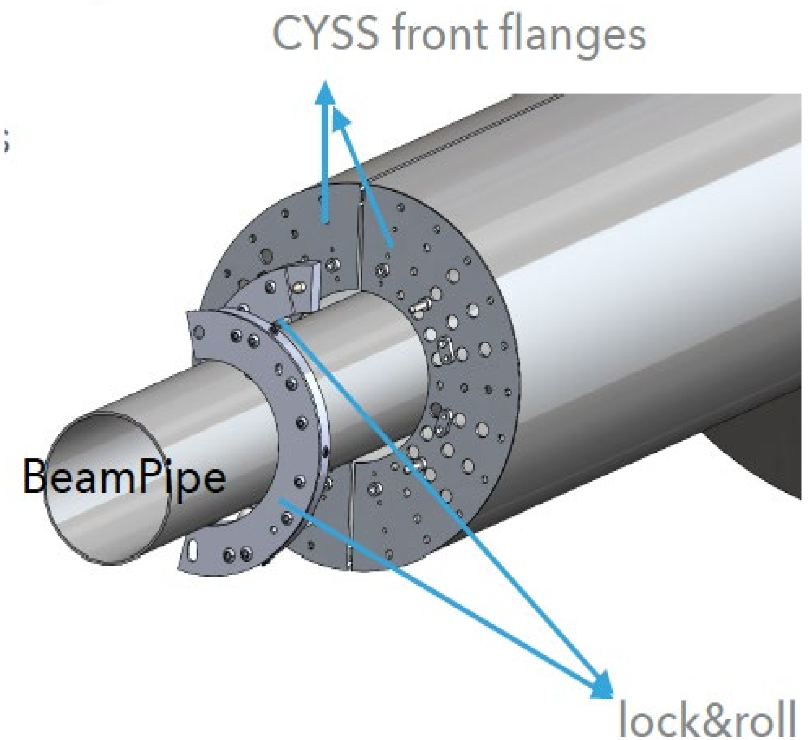
PP-3: External world

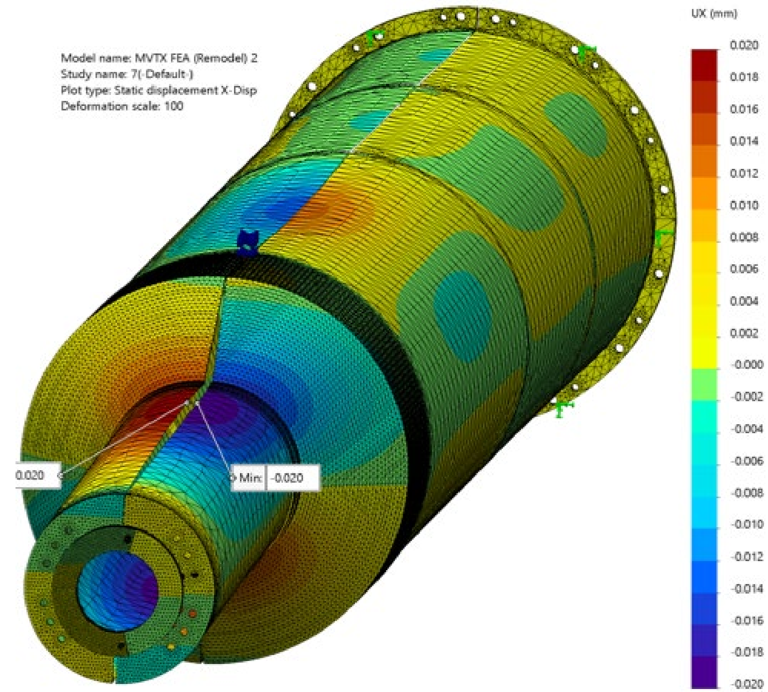
~1,000 mm length
R 107.5 mm

RHIC; sPHENIX – MVTX, FEA study

MVTX detector will be installed after the beam-pipe, intermediate silicon strip detector and TPC have been installed. This restricted the radial volume for the MVTX

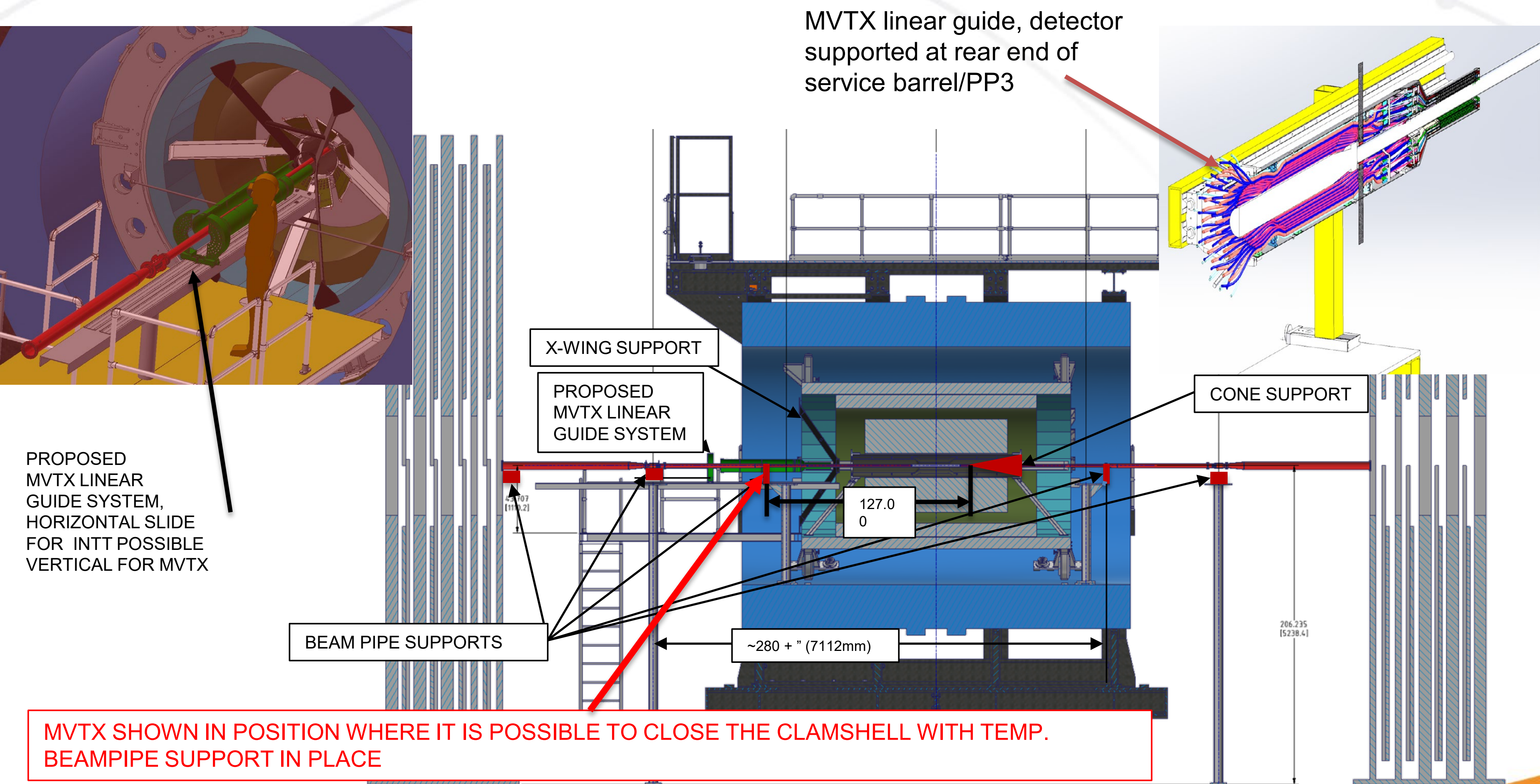
FEA analysis for cantilevered detector assembly gave a deflection of .283 mm with M55J, .218 mm using CN80





Total mass of detector plus service barrel 21.45 kgms

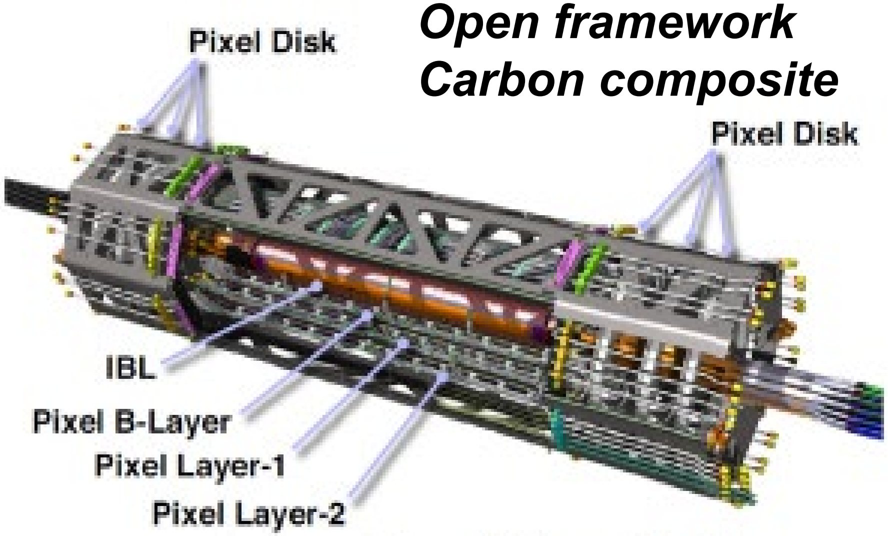
RHIC; sPHENIX – Beam-pipe – MVTX installation & support structure

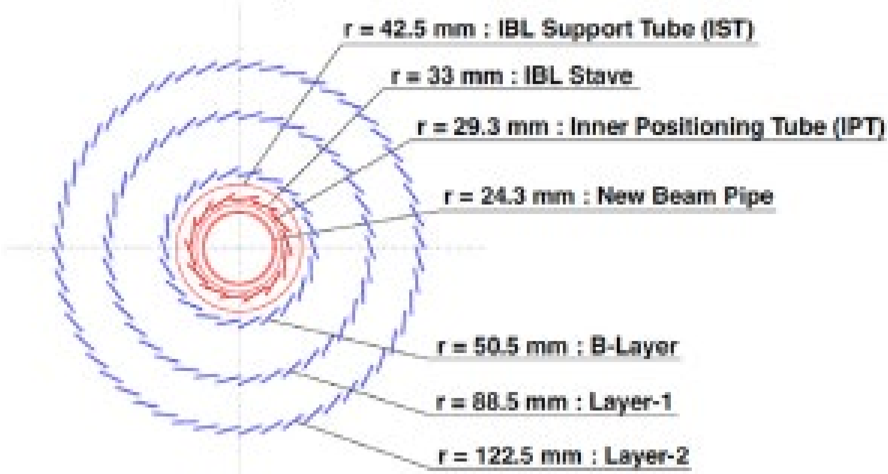


LHC; ATLAS pixel upgrade for Run 4, ITk

Original inner pixel detector, L 1442 mm, diameter 430 mm

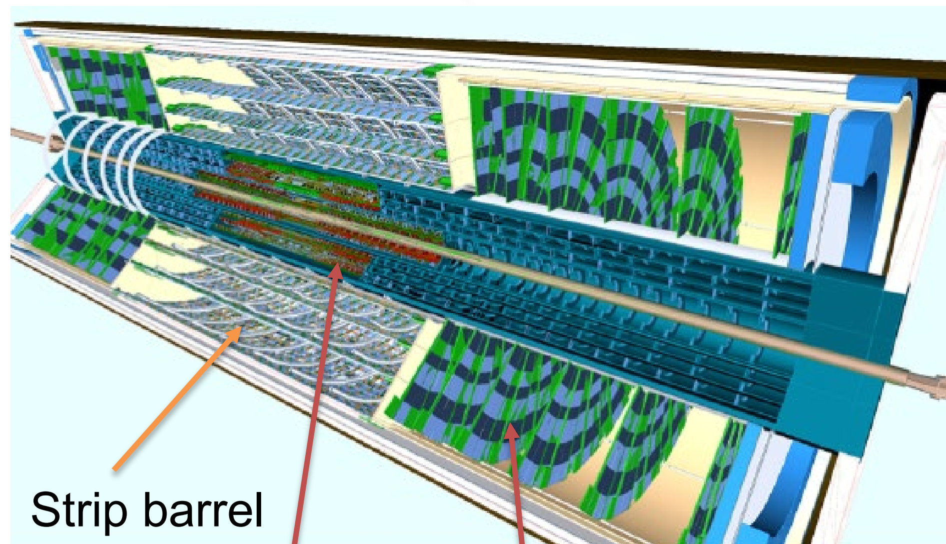
Open framework
Carbon composite





Closed set of cylinders

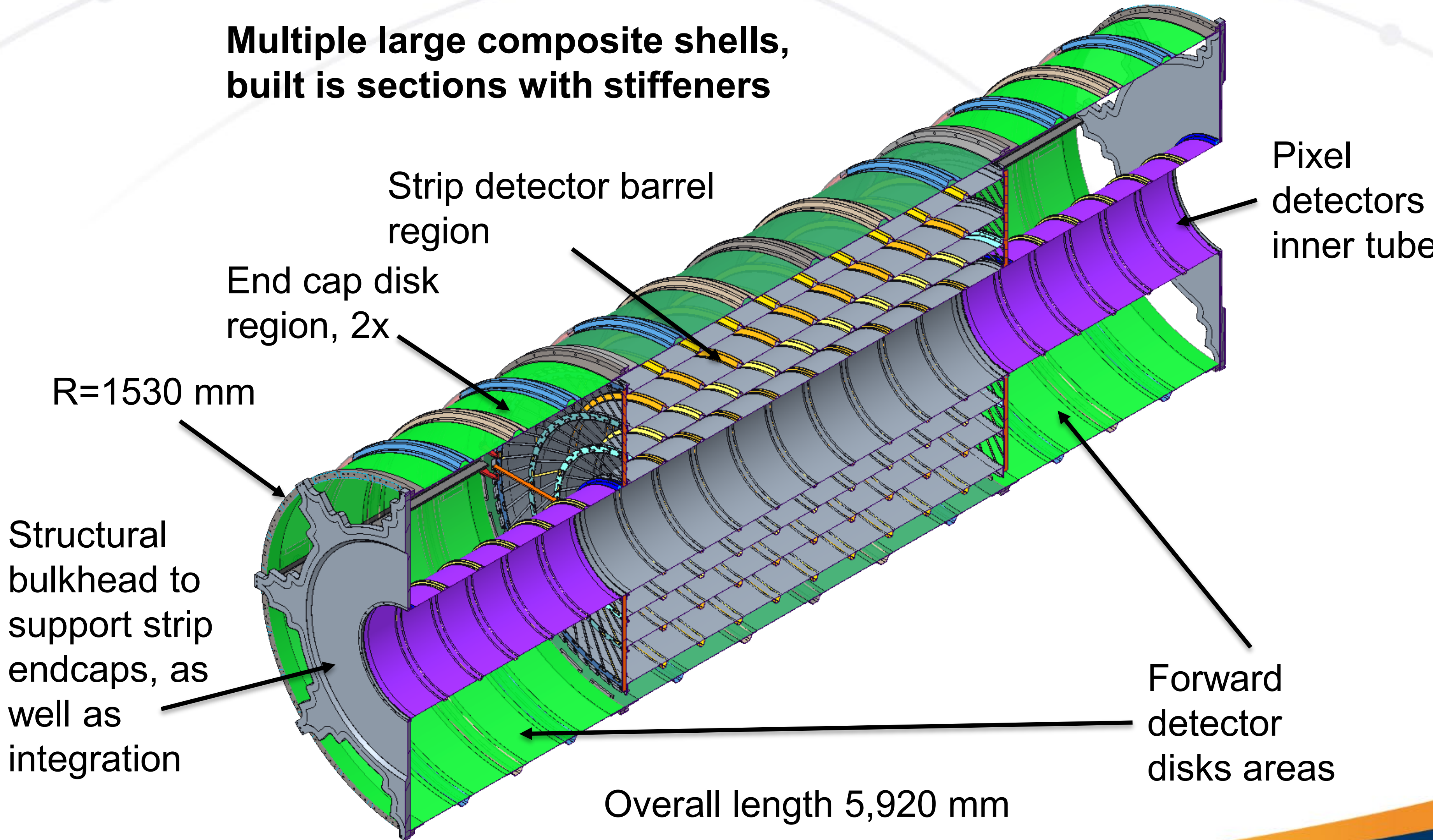
New ITk inner tracker for ATLAS



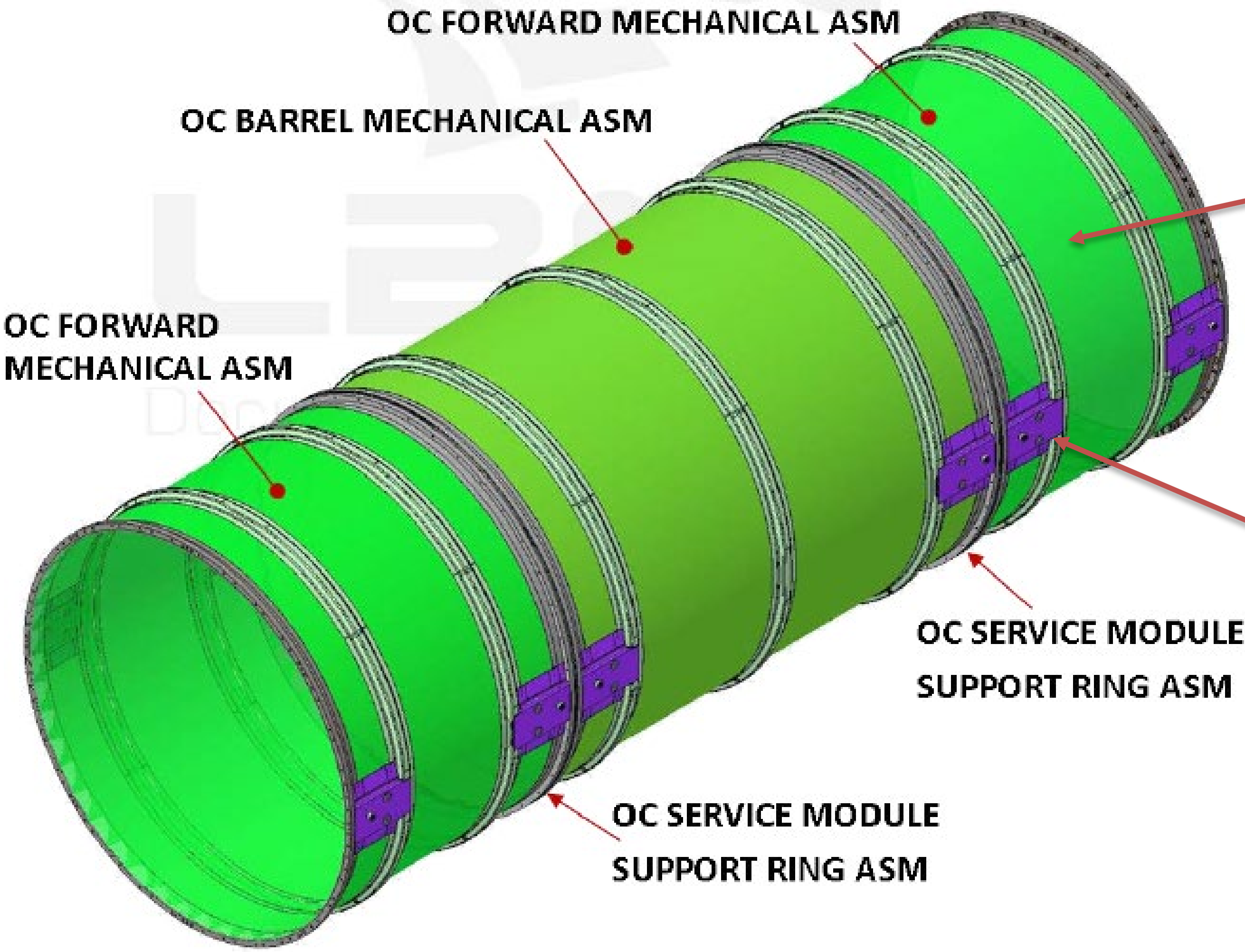
Installation planned for 2024 - 2026

ITk Global Mechanical Structure

Multiple large composite shells, built is sections with stiffeners



Itk outer cylinder assembly, three sections

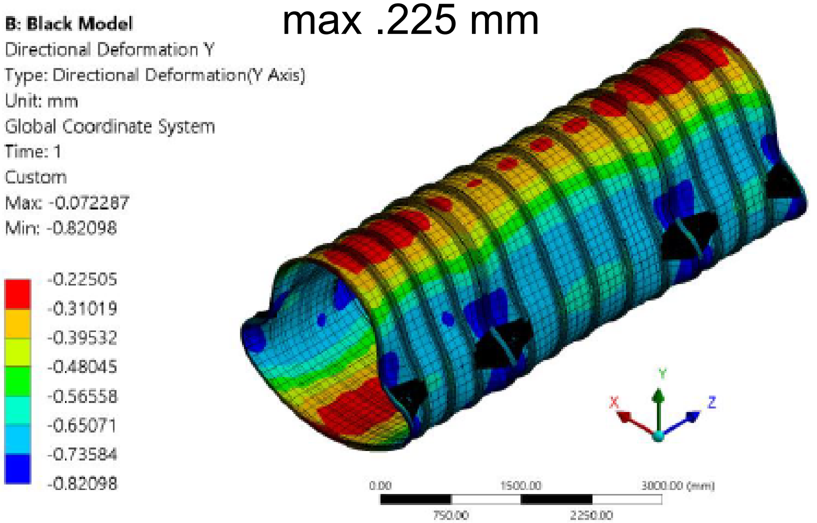


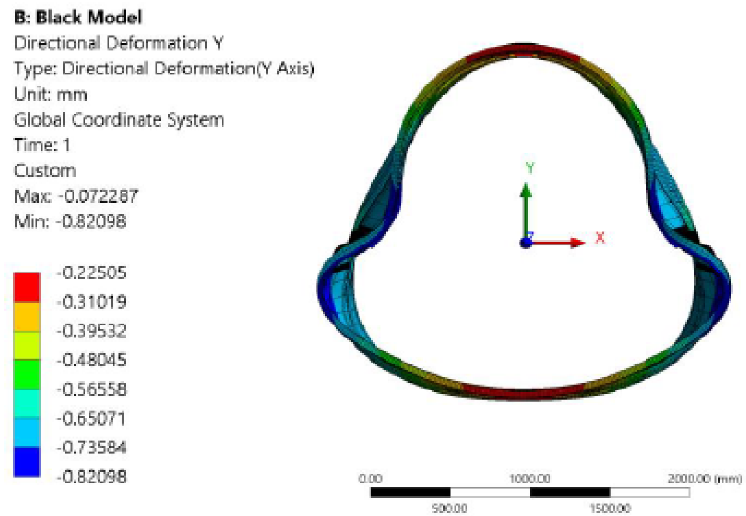
Shells made up from 10 layers of CN60 with cyanate ester resin, a 1oz copper foil layer for shielding

Mounting pads, points for greatest stress as seen in FEA work

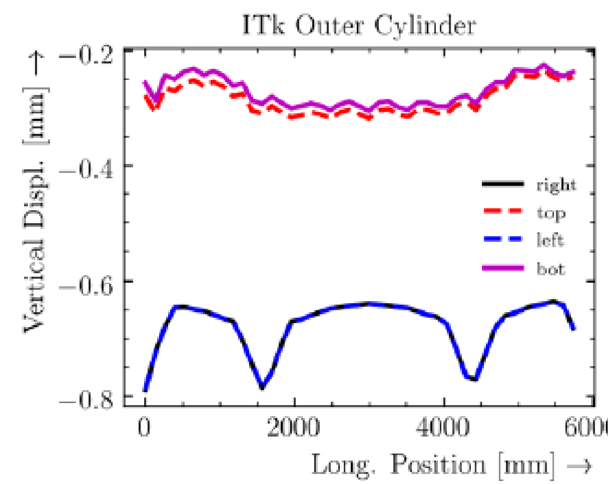
LHC; ATLAS – FEA of outer shell assembly

Y deformation
max .225 mm

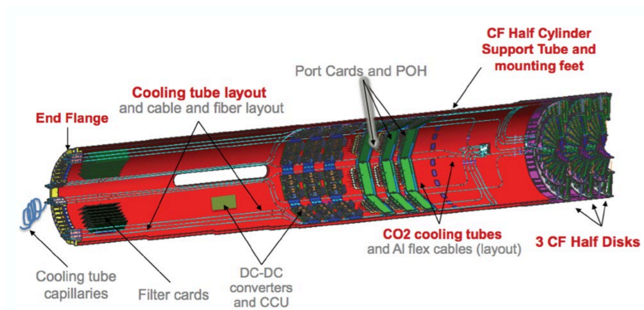




- Deformation **localized** around the Mount Pads
  - Non-negligible local **rotation**
- Negligible bending (along the length)
- Higher **vertical sag** on the shell **sides**
- Lower sag at the **top** and **bottom** surfaces



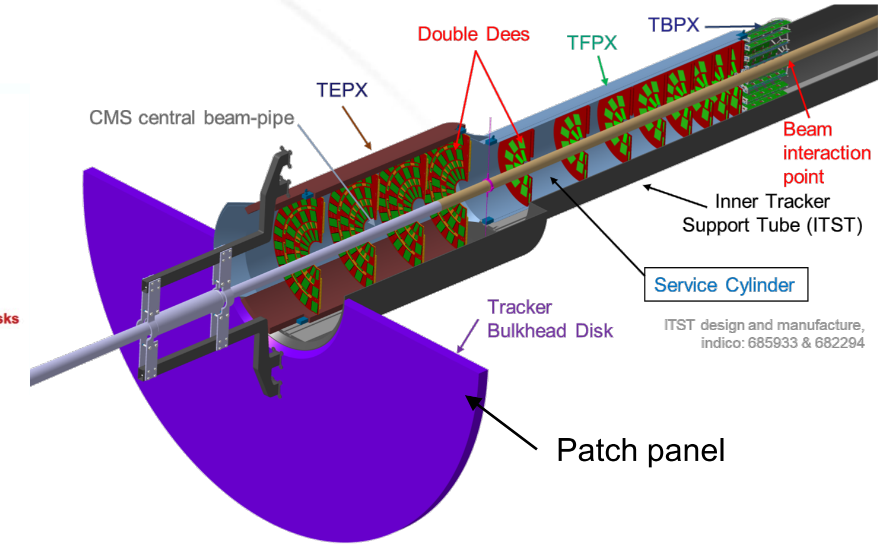
LHC; CMS vertex detector upgrade Comparison of Phase I & Phase II



CMS Phase I Service Cylinder design:

- Double-wall of Carbon Fiber (K13C2U)
- Stiff/Rigid structure with 12mm of "Wall thickness"

4 layers, 6 disks



→ CMS Phase II Service Cylinder constraints:

- ***A lot*** more space for services
- **Needs a design with < 1mm wall thickness**

4 layers, 24 disks

Scheduled installation 2024-2025

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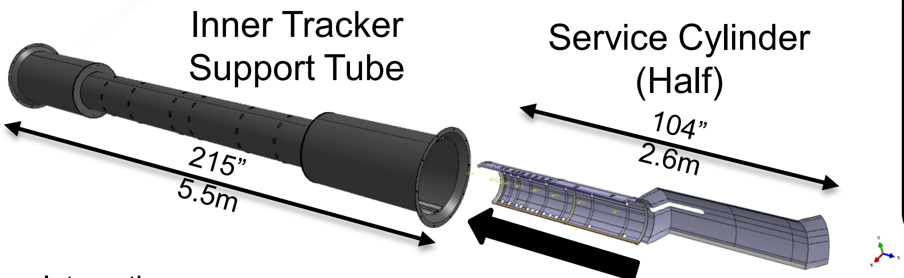
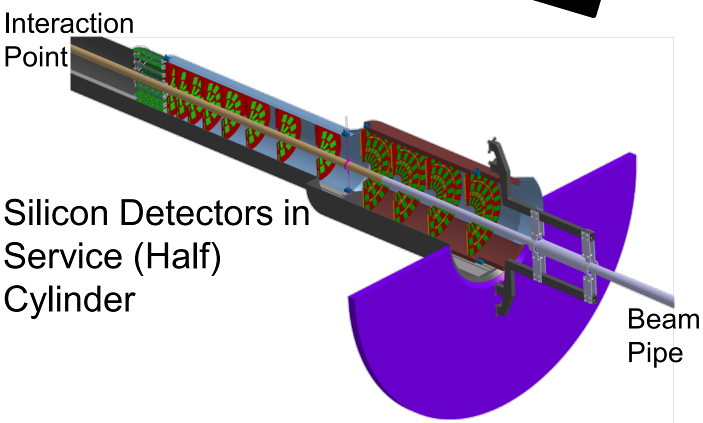
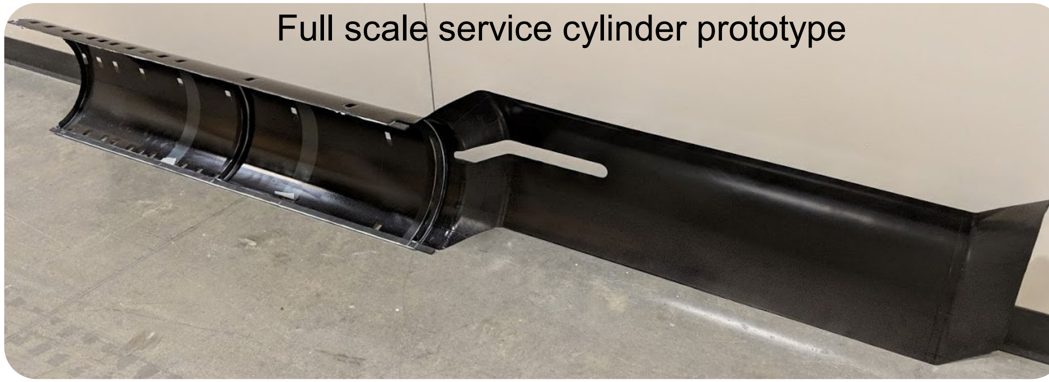
LHC; CMS Phase 2 inner tracker structure;



- Designed 3 kg composite structure to support ~25 kg* detector and services
- Fabricated prototype service cylinder
- Validated structural simulations

*Specified at time of design. Closer to 40kg in latest.





Cooling; 2 phase CO_2, operate sensors <-20°C

LHC; CMS FEA structural analysis of outer cylinder;

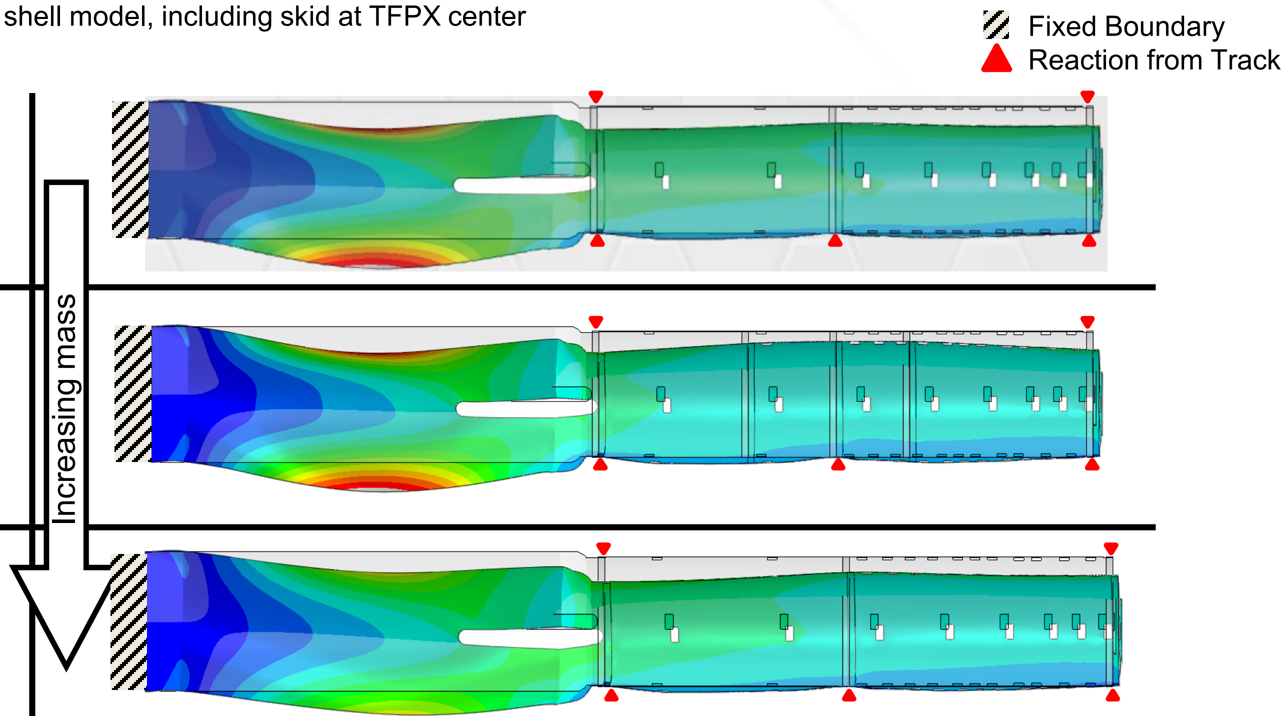
Tradeoff between structural stiffness and mass:

Using Abaqus composite shell model, including skid at TFPX center

Design 1:
$U_{max,TEPX}$ = 0.632 mm
$U_{max,TFPX}$ = 0.345 mm
M= 2.77 kg

Design 2:
$U_{max,TEPX}$ = 0.635 mm
$U_{max,TFPX}$ = 0.319 mm
M= 2.96 kg

Design 3:
$U_{max,TEPX}$ = 0.430 mm
$U_{max,TFPX}$ = 0.358 mm
M= 3.34 kg



200x scale factor

Contours show magnitude of the deflection.

CMS - Preliminary results

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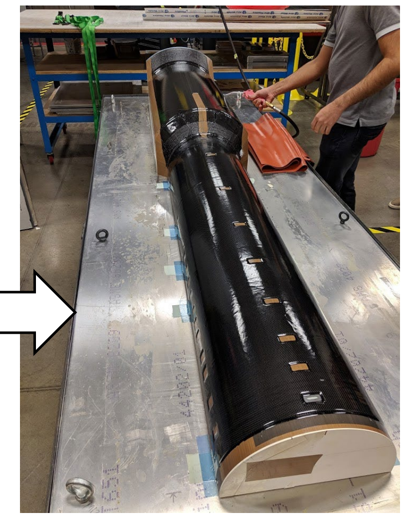
CMS prototype service cylinder shell layup;

- Plies cut to shape, including services windows
- Hand layup onto tool with silicone caul sheet, breather, vacuum bag
- Part cured on cart in walk-in oven at CMSC

Hand layup

Vacuum bagging



Cured part

Material used in prototype layup;
Plain weave; AS4 fibers, NB321 resin, 356gsm
Unidirectional, continuous fiber tape: TR50S fibers, NB321 resin, 232gsm

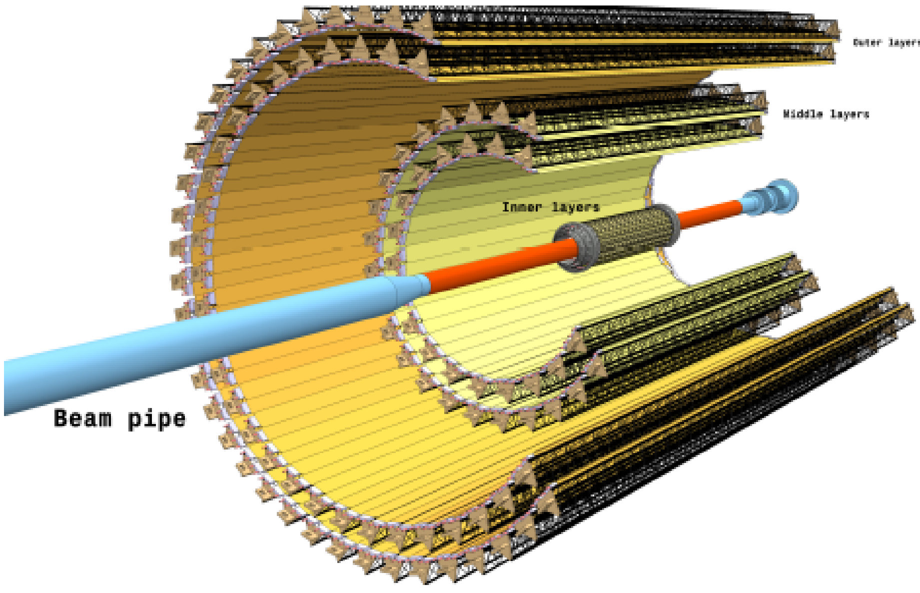
LHC: ALICE ITS upgrade vertex detector

The ITS upgrade

ALICE

Improve physics reach for low-mass dilectrons and rare probes at low p_T e.g.: B meson, D meson, λ_c baryon by improving vertex resolution, tracking efficiency and readout rate.

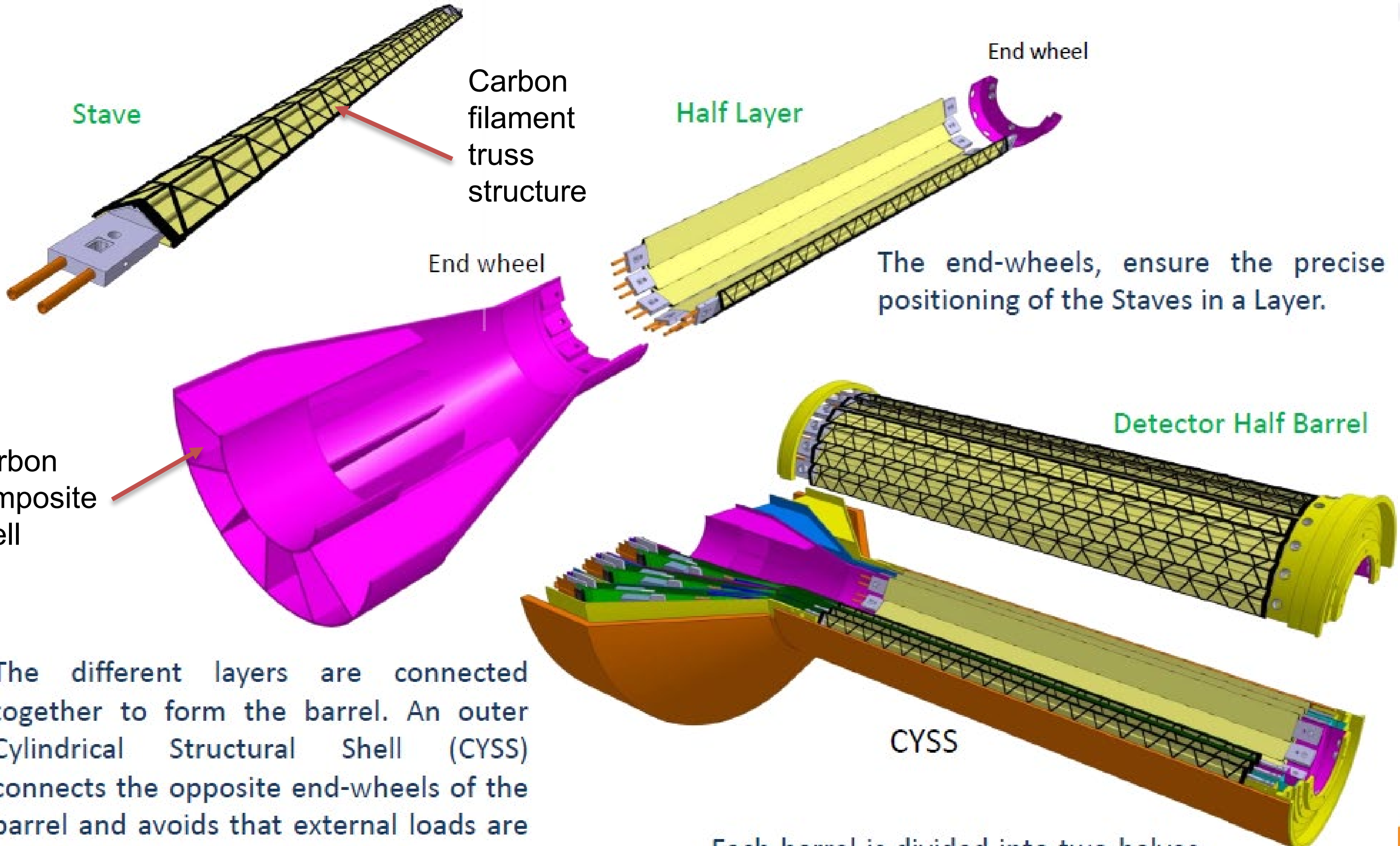
- 7 cylindrical layers covering $10m^2$
- increase the readout rate to 100kHz
- reduce pixel size to $27\mu m \times 29\mu m$
- reduce the radius of the innermost layer from 39mm to 23mm
- Material budget:
  - Inner Barrel: material budget of 0.35% X_0/layer
  - Outer Barrel: material budget: 1.1% X_0/layer



Total 12.5G pixels

7 layers of MAPS sensors, neg-pressure water cooled staves, room temperature

LHC; ALICE ITS inner detector barrel

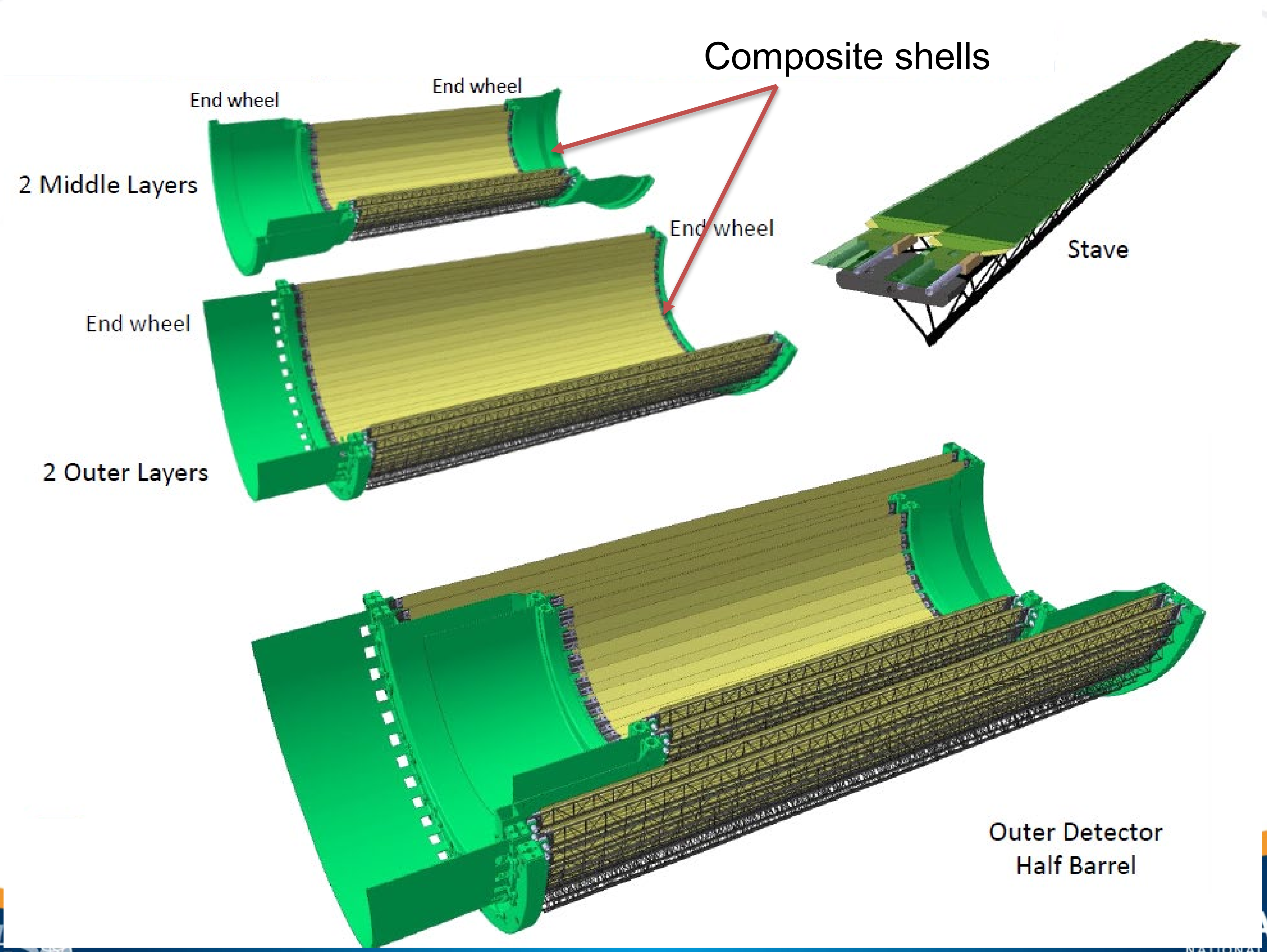


The end-wheels, ensure the precise positioning of the Staves in a Layer.

The different layers are connected together to form the barrel. An outer Cylindrical Structural Shell (CYSS) connects the opposite end-wheels of the barrel and avoids that external loads are transferred directly to the Staves.

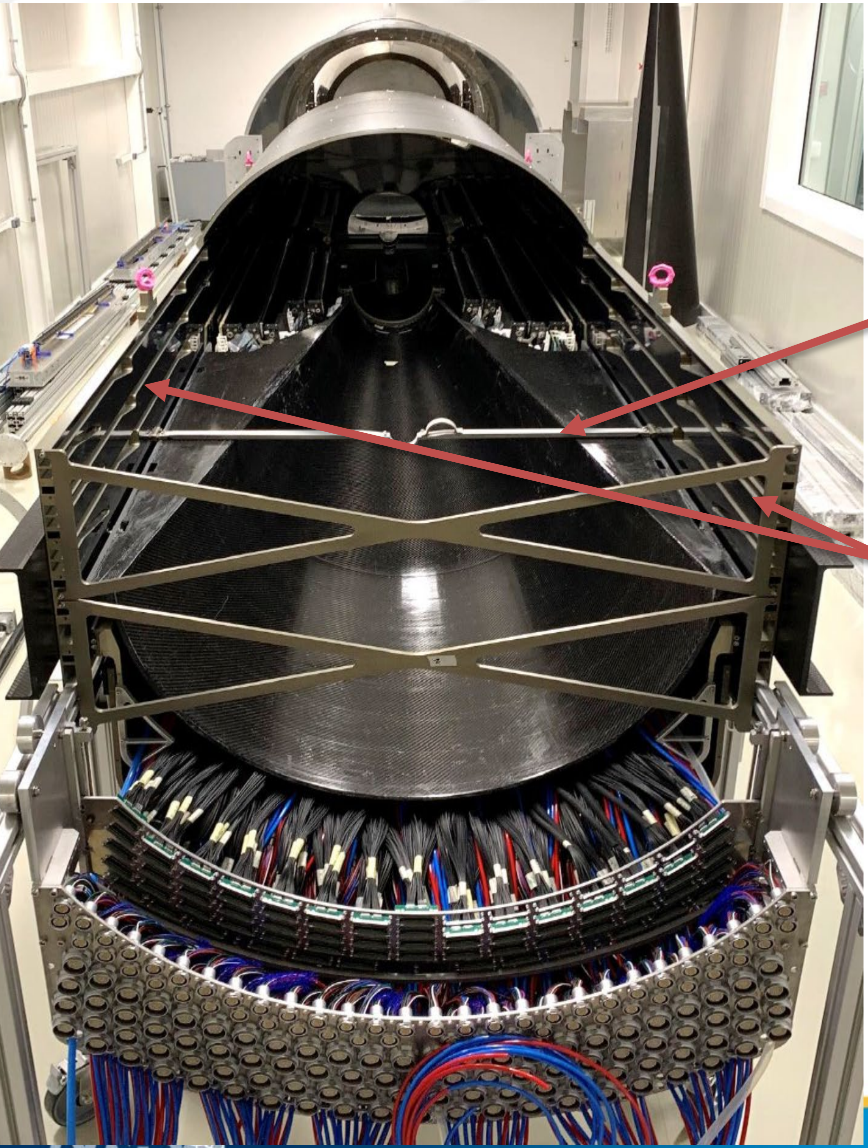
Each barrel is divided into two halves, top and bottom, which are mounted separately around the beam pipe.

LHC; ALICE middle and outer barrels



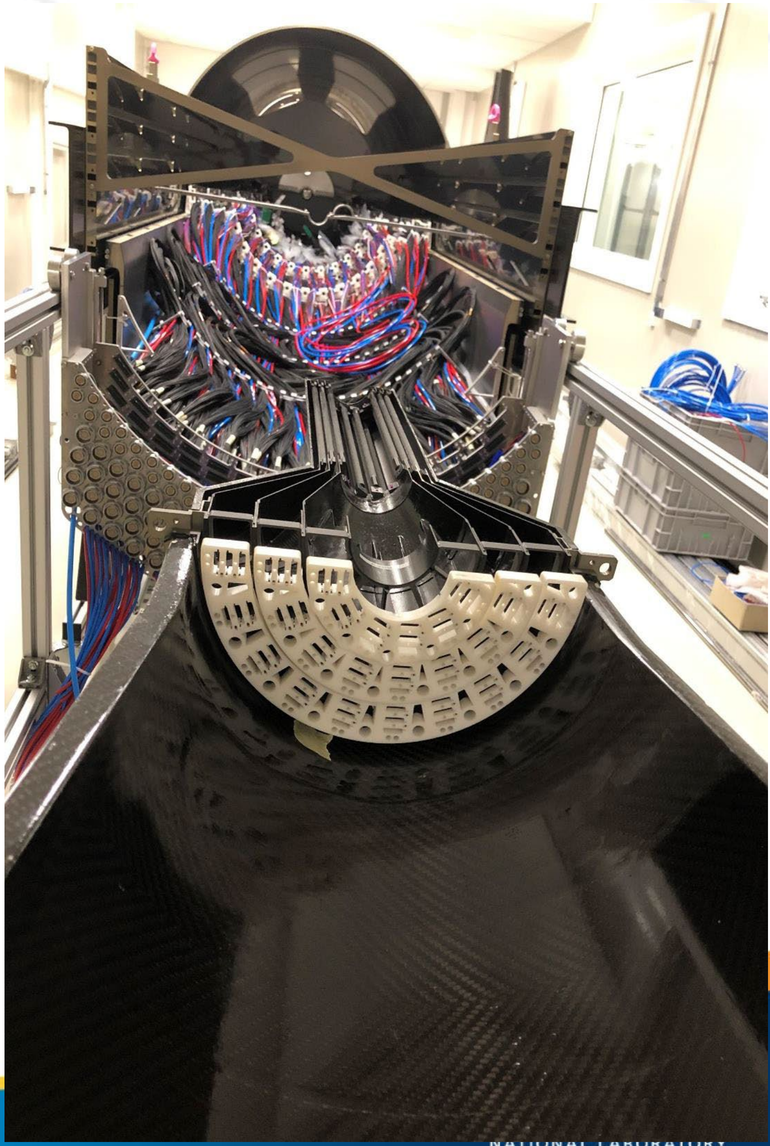
Middle and outer layers mounted in insertion tube with rails, carbon composite shells, aluminum tracks

Inner detector layer shell assembly being added to middle and outer layers



Beam-pipe support

Layer insertion tracks



EIC; possible, concerns, issues

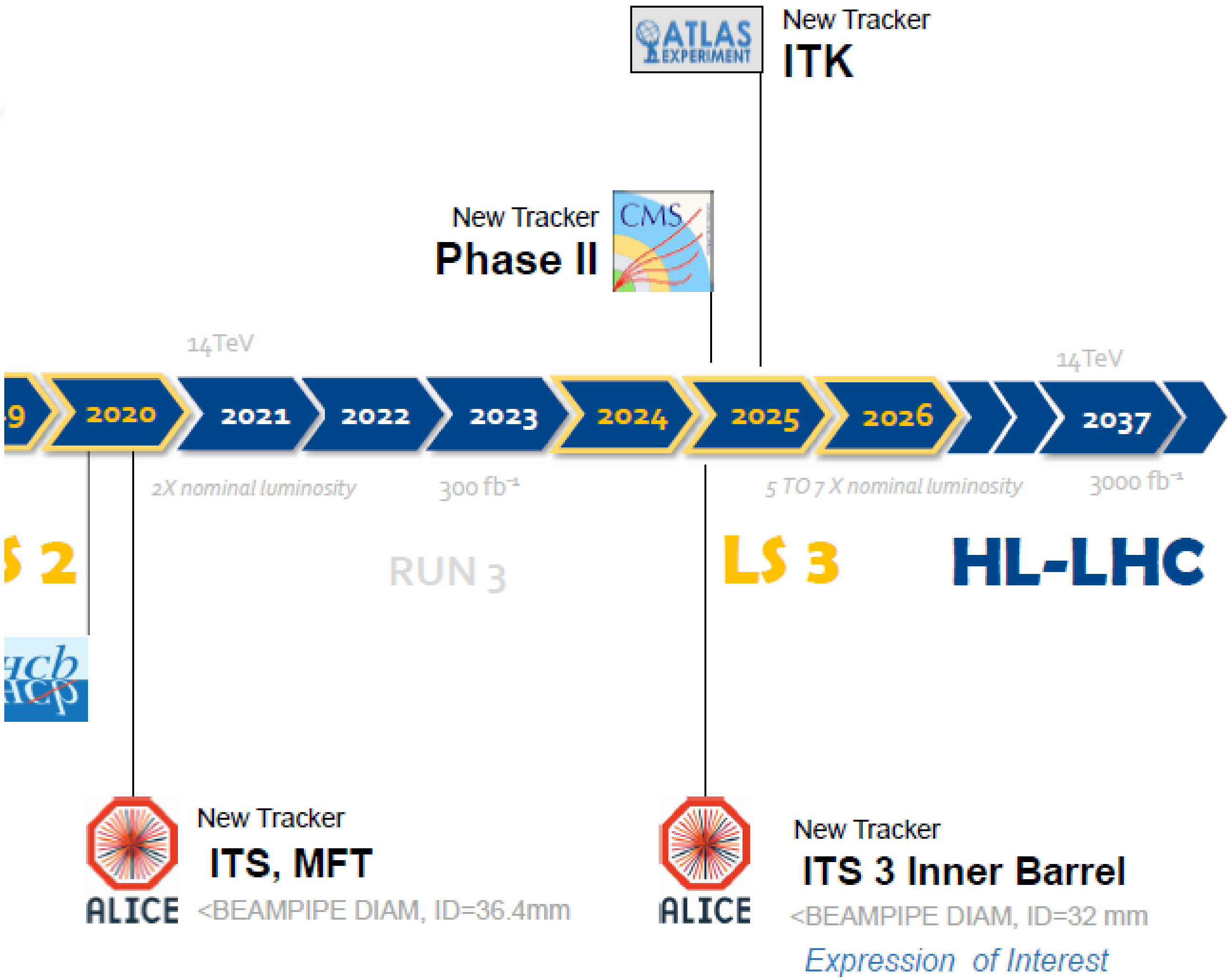
- Best configuration, singular assembly or split
  - A single barrel assembly
  - An open framework cage assembly
- Environment
  - Magnetic field
  - Shielding
  - Temperature, cooling
  - Grounding
- Beam-pipe
  - Existing or later installed
  - Bake-out, neg-coating
  - Alignment
- R & D activities
  - WP-4 mechanics group at CERN

Thank you for your attention:

Back up slides:

- Suggested references:
  - https://indico.cern.ch/event/696066/
    - See Corrado Gargiulo and Antti Onnela's talk
  - https://indico.cern.ch/event/775863/timetable/?view=standard
    - Forum on tracking detector mechanics
- Acknowledgement
  - I would like to thank many authors who have published articles on these detectors, from which I have taken information that has become part of this presentation

LHC Projected timeline for upgrade installation;



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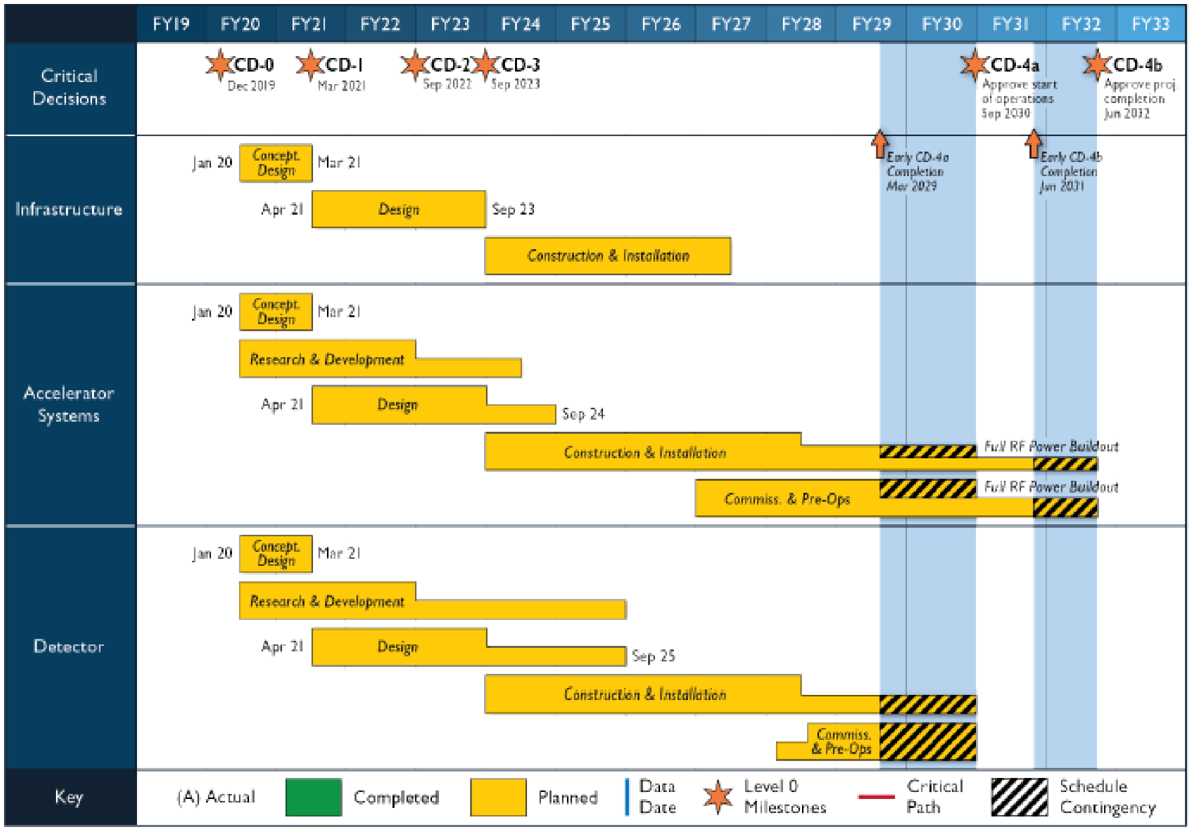
Projected EIC timeline from a talk given on 8-28-2020 by Thomas Ullrich at CERN

EIC Project Planning



DOE's outlines a series of staged project approvals, referred to as a "Critical Decision (CD)

Aggressive Time Schedule:

CD-1: March 2021
Alternative and Cost Range

CD-2: September 2022
Performance baseline

CD-3: September 2023
Start construction

CD-4a: September 2029
Start operation

CD-4b: September 2031
Full RF Power Installed