Forum on Tracking Detector Mechanics – BONN, Germany

Developments on the mechanics and cooling for the CLIC tracking detector

Szymon Krzysztof Sroka, on behalf of the CLICdp collaboration

Outline

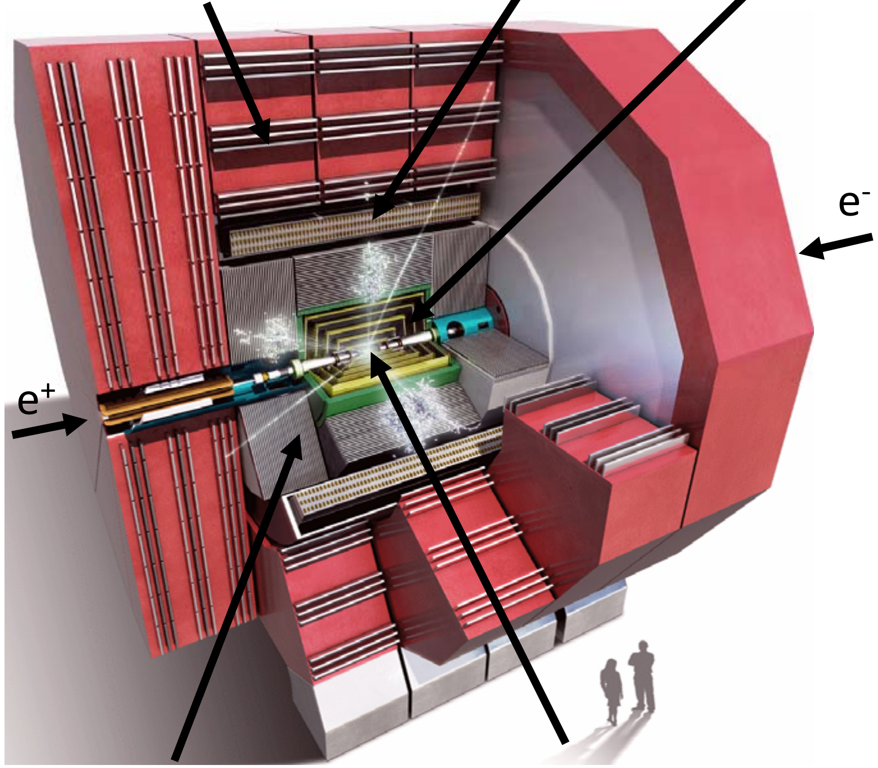
- **Introduction**
- **Vertex Detector**
  - Lightweight support structure development
  - Cooling & Vibrations
- **Tracker Detector**
  - Barrel & Disks support structures
  - Support Tube & Beam Pipe
  - Assembly sequence
- **Summary**

CLIC project

Return yoke with instrumentation for muon ID

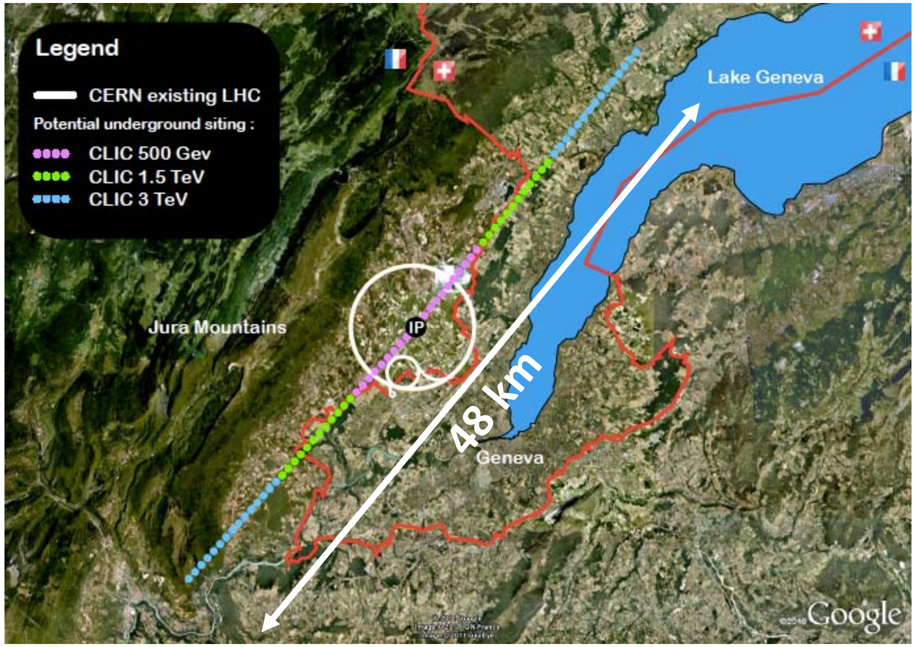
4T solenoid

All-silicon main tracker



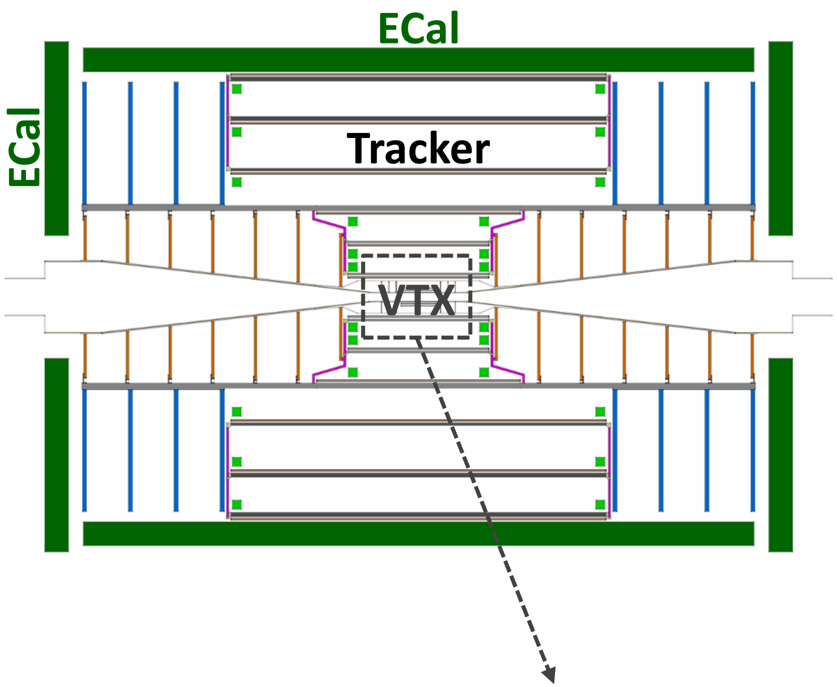
Fine grained (PFA) calorimetry, $1+7.5\lambda_i$

Low-mass vertex detector with ~25 µm pixels



Detector tracking system

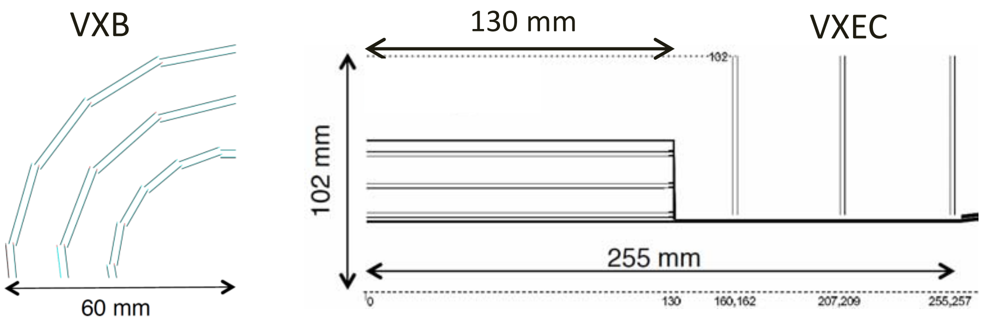
Vertex



- ~25×25 µm pixel size (~2 Giga-pixels);
- Radiation level <10^{11} $n_{eq}cm^{-2}year^{-1}$;

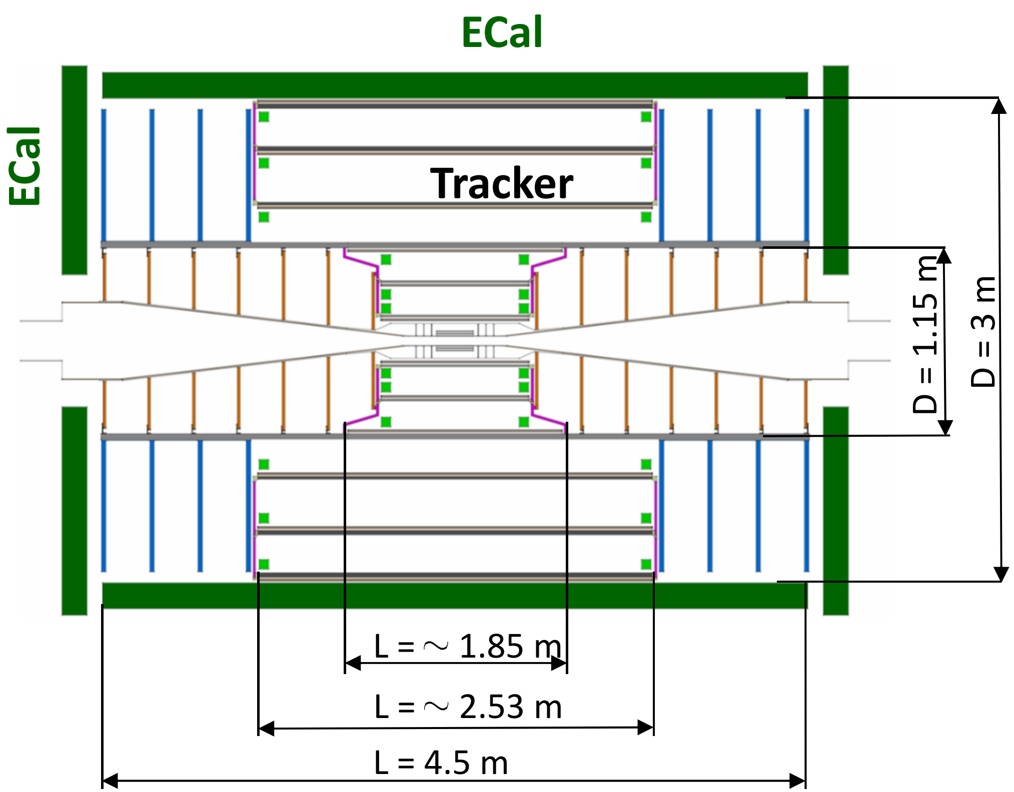
(10^4 times lower than LHC);

- Room-temperature operation;
- 0.2% X_0 material per layer:
  - Very thin materials/sensors ;
  - Low-power design, power pulsing, air cooling (goal – 50 mW/cm^2);



Detector tracking system

Tracker



- Silicon Strips:
  - Strips length from 1 to 10 mm;
- Occupancy less than 10^{-3};???
- Number of layers:
  - 3 Inner & 3 Outer Barrel;
  - 7 Inner & 4 Outer Disks;
  - Room-temperature operation;
- ~1-2% X_0 material per layer
  - Thin sensors ;
  - Power pulsing;

Requirements and objectives

Low material budget

- 0.2% X_0 per layer in the vertex detector (including 0.11% for silicon)
  - Low-mass support structures (~0.05% X_0);
  - Air (dry) cooling strategy (500 W; $T_{operation}$<40 ^{o}C);
- ~1-2% X_0 per layer in the tracker

Short term objectives

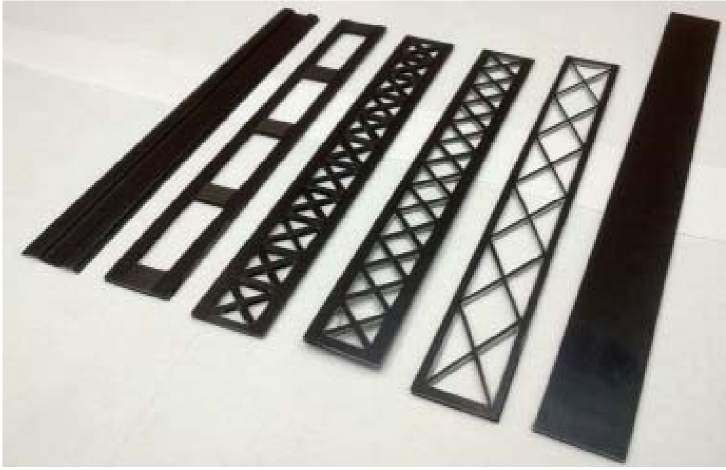
- Layout definition of the tracking system;
- Conceptual design of the support structures;
- Prototyping of low mass support structures;
- Evaluation of the feasibility of forced convection air cooling for the vertex detector (thermal + vibrations).

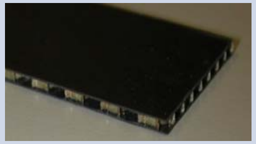
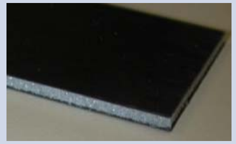
Vertex detector

Stave support structure

Designs

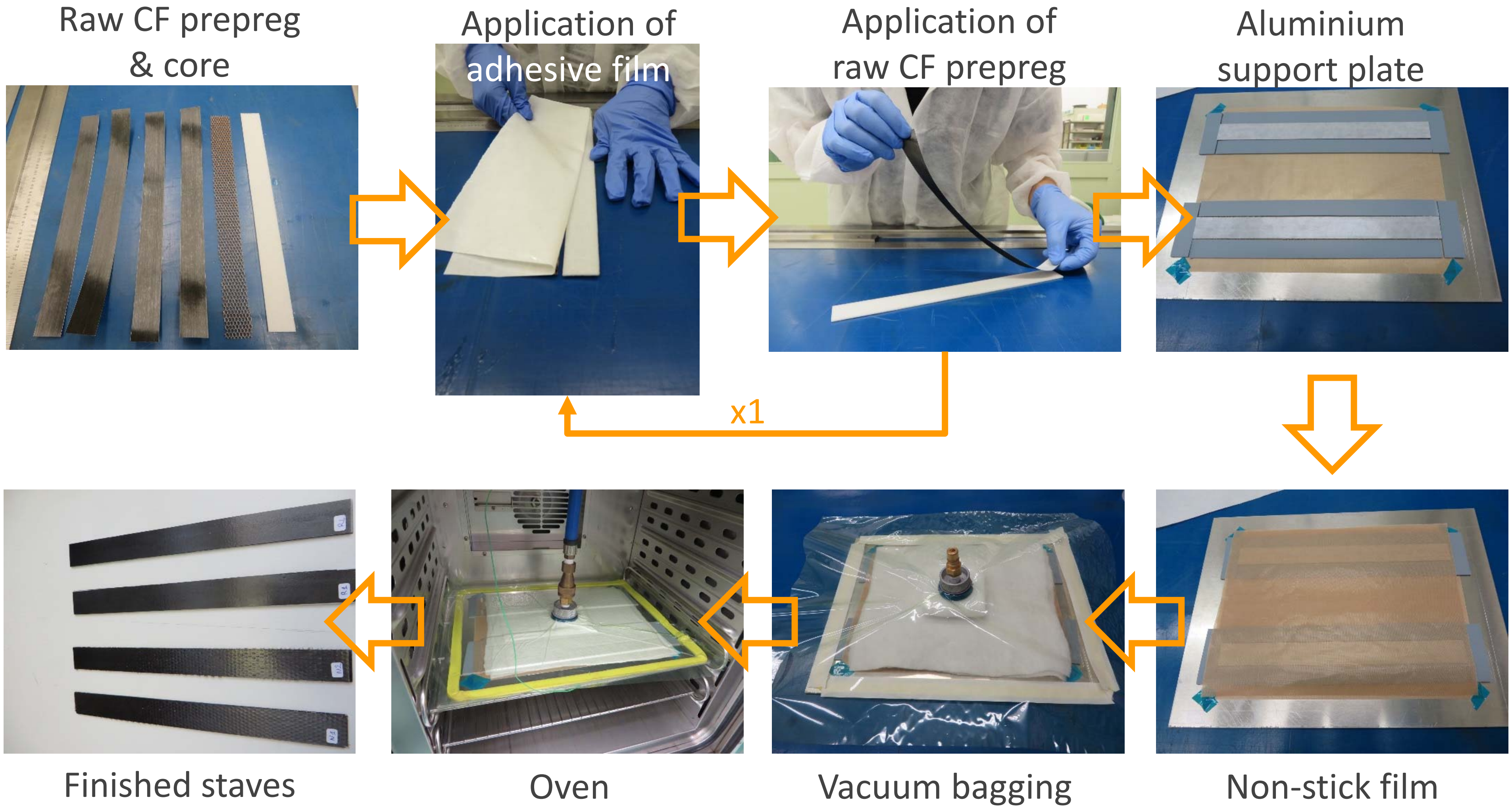
- Development of support structures that fulfil the 0.05% X_0 of radiation length (1.8x26x280mm^3);
- 2 designs currently being pursued (full sandwich & cross bracing);
- Using thin prepregs and glue films from NTPT (30 gm/m^2).



Stave label #	CERN #5	CD #7	CD #8	NTPT #5
Material	M55J + Rohacell 51 	T800 [0°; 90°; 0°] + Rohacell 51 	T800 [0°; 90°; 0°] + Nomex 	M55JB [0°] + Rohacell 51 
Flexural stiffness (Span=180mm)	2.23 N/mm	*2.12 N/mm*	*2.17 N/mm*	-
Flexural stiffness (Span=260mm)	-	*0.781 N/mm*	*0.776 N/mm*	*1.22 N/mm*
Mass (280mm long)	1.76g	3.17 g	3.45 g	2.07 g
X/X0	0.051%	0.104 %	0.112 %	0.064 %
Manufacturing difficulty	☹	☺	☺	😐

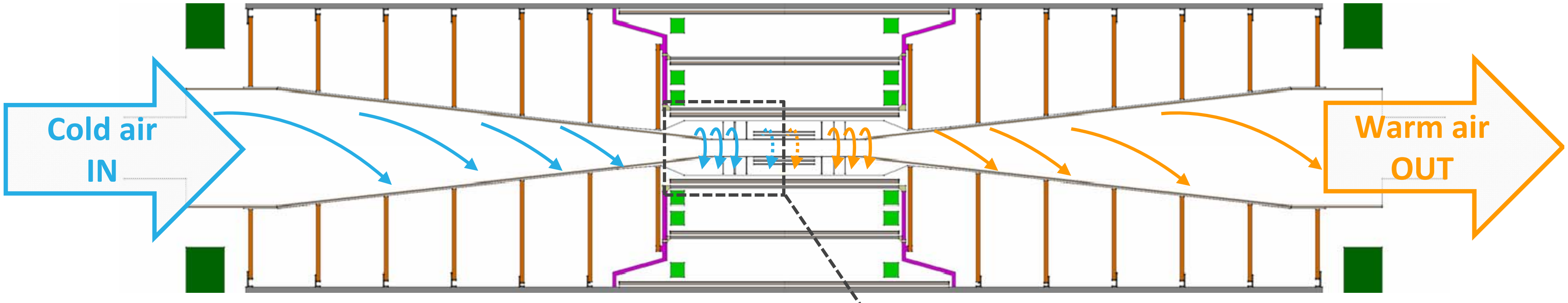
Stave support structure

Prototyping at CERN

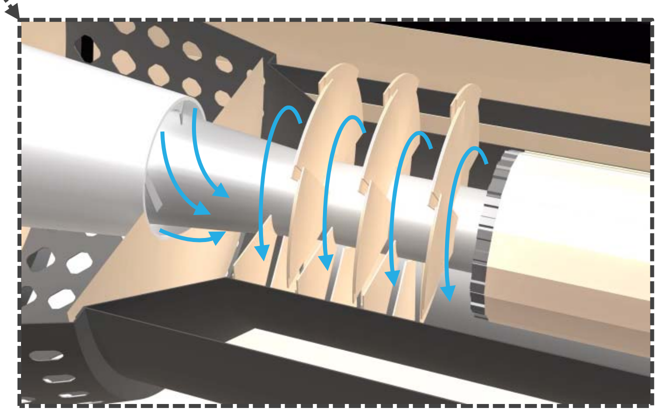


Air cooling

Concept

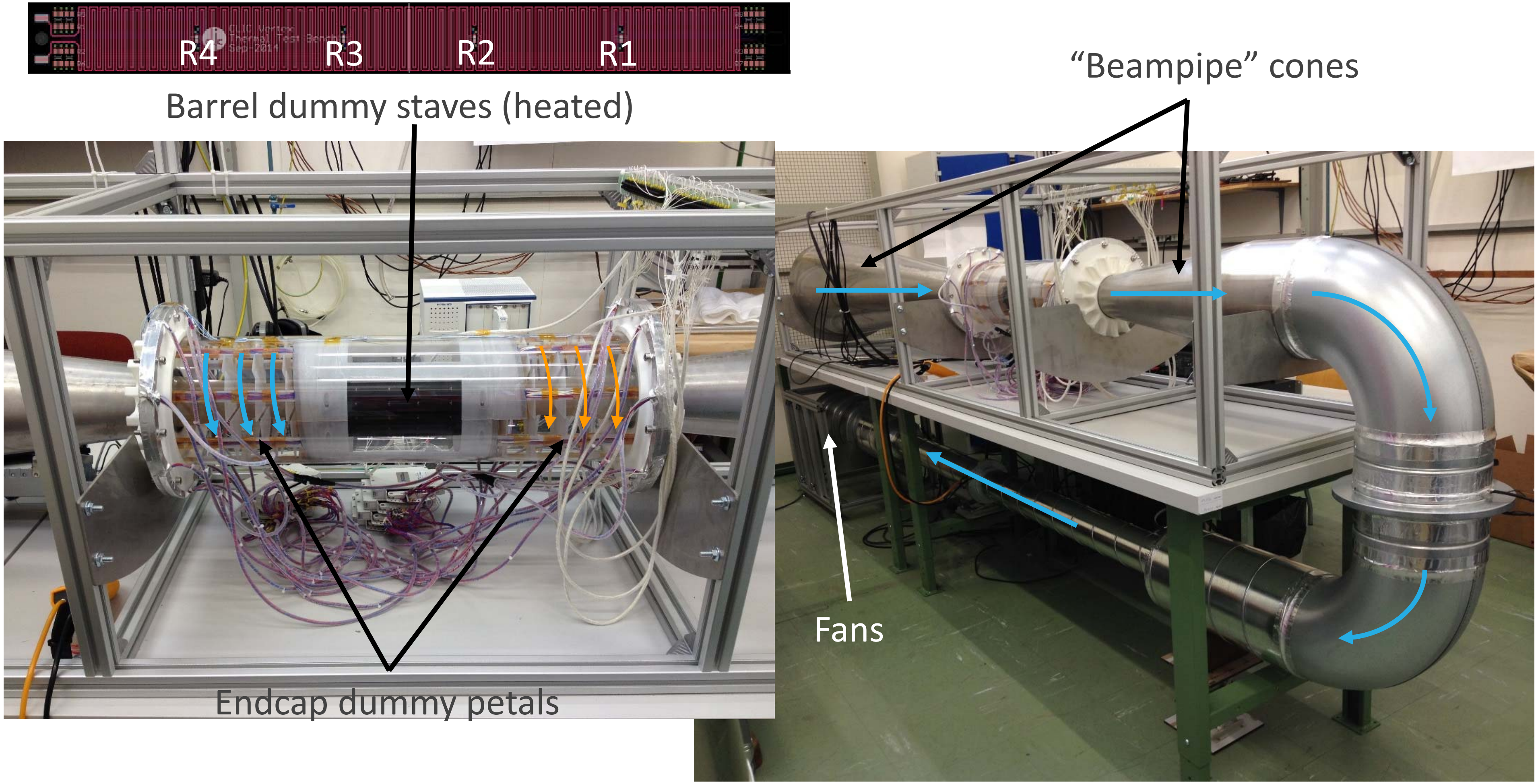


- Moderate velocity forced convection;
- Dry air delivered/extracted through channel between beam pipe and CFRP shell;
- Helical shaped flow;
- Forward petals placed to minimize disturbances.



Air cooling

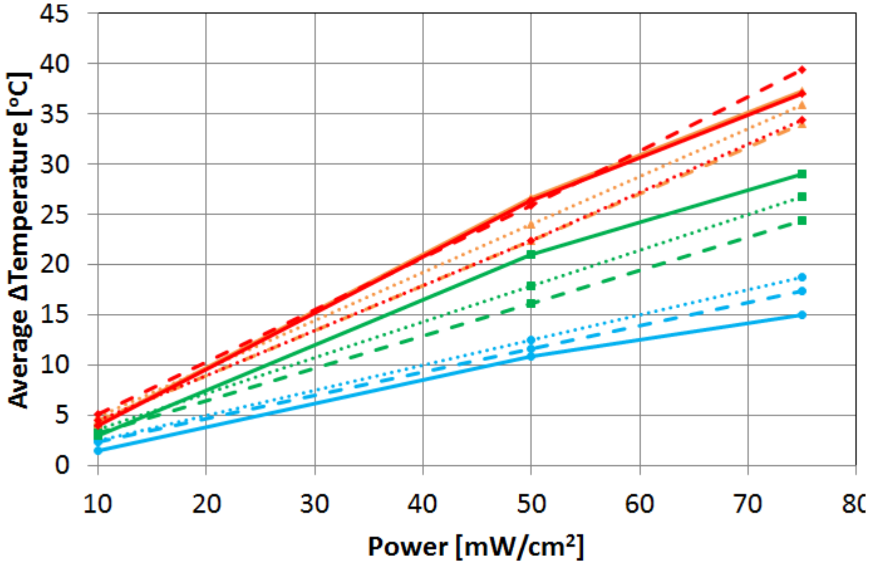
Mock-up



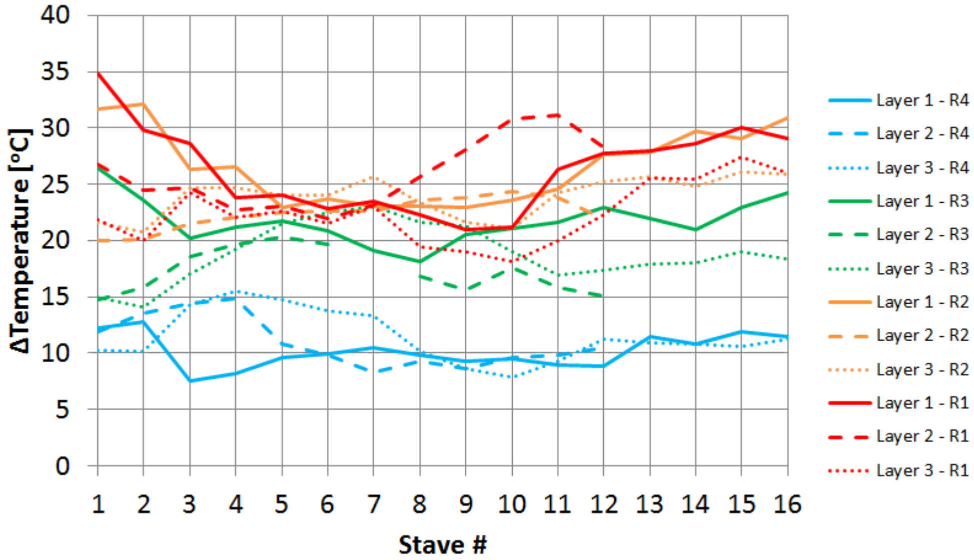
Air cooling

Performance

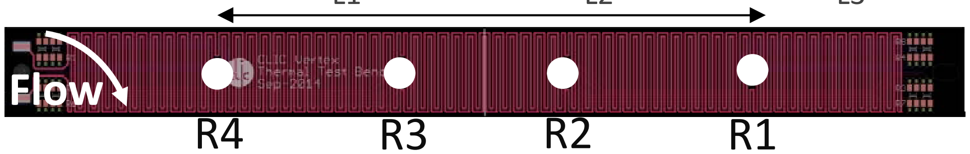
Temperature vs. Power (for 17 l/s)

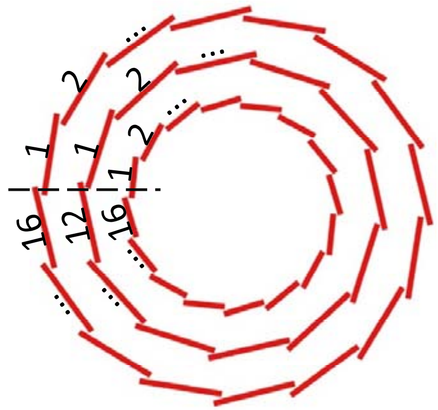


Temperature distribution along φ



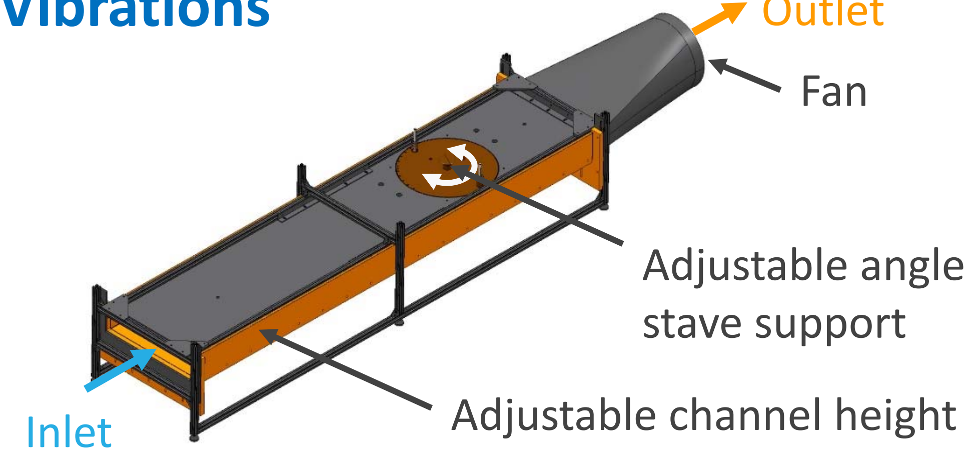
@ 50 mW/cm^2: $\Delta T_{L1} \approx 15$ ^oC; $\Delta T_{L2} \approx 14$ ^oC; $\Delta T_{L3} \approx 10$ ^oC





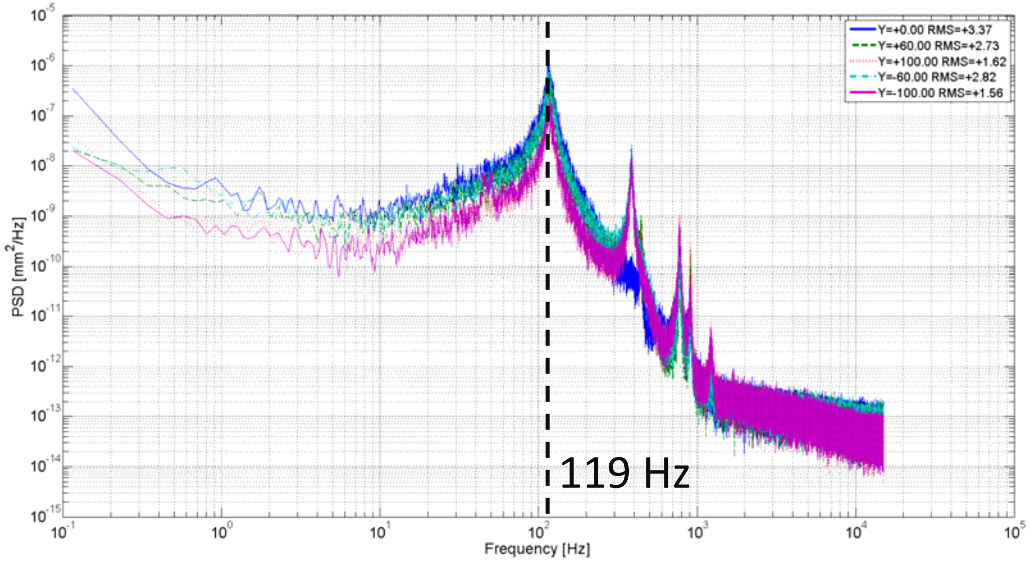
Air cooling

Vibrations

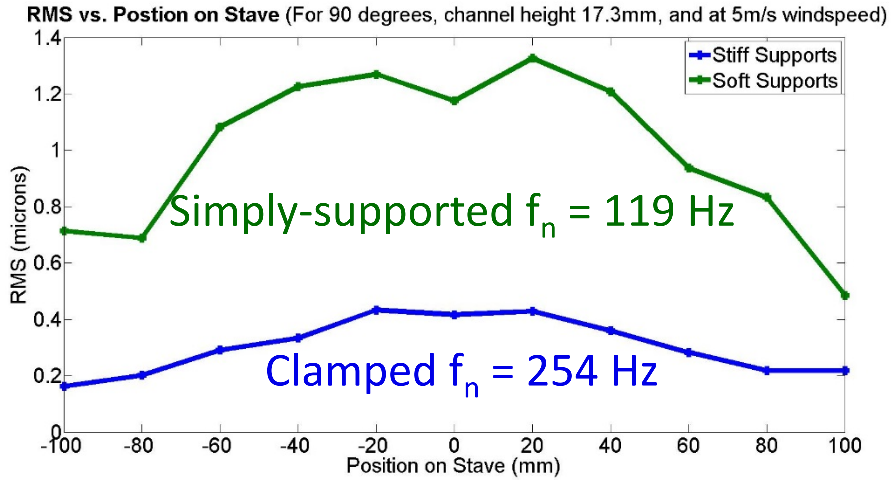


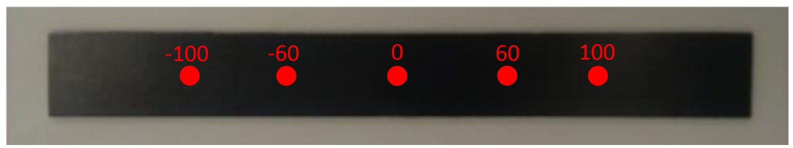
At 5m/s, the out-of-plane vibrations are below 2.5 µm (3.5 µm @ 7.5 m/s) sim supr !!!!!

PSD (simply-supported)



Amplitude (RMS)

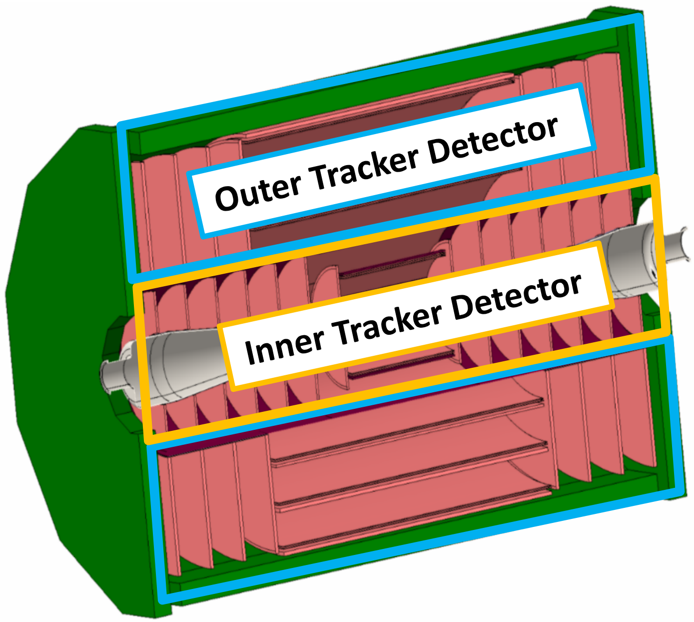


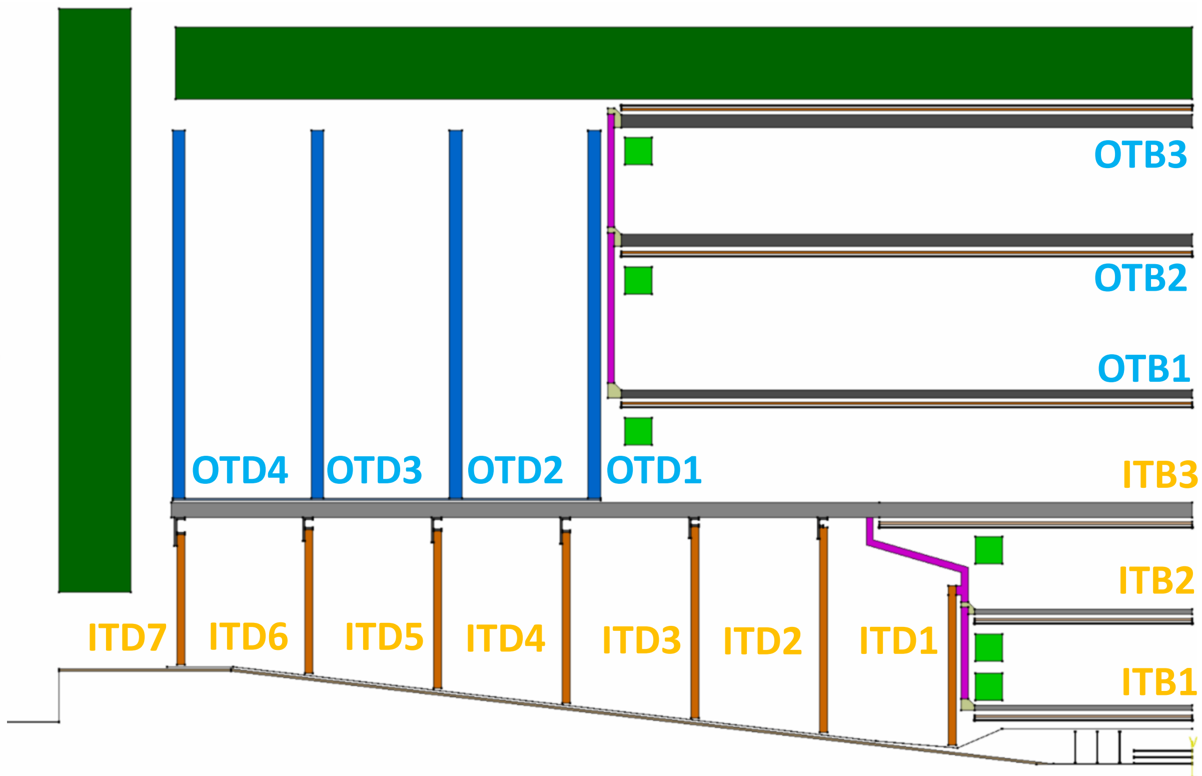


Tracker detector

Inner and Outer Tracker

Detector Sub-Systems





Inner Tracker:

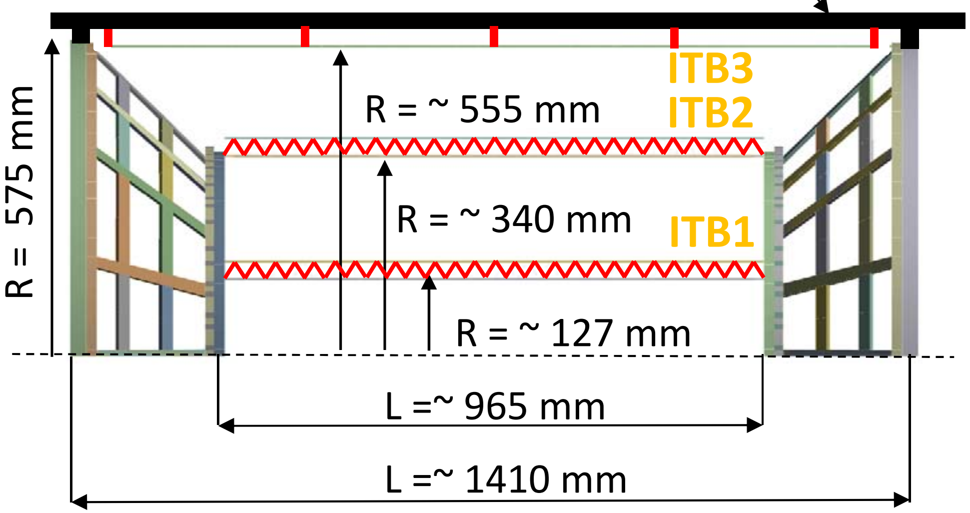
- 7 Tracker Disks
- 3 Barrel Layers

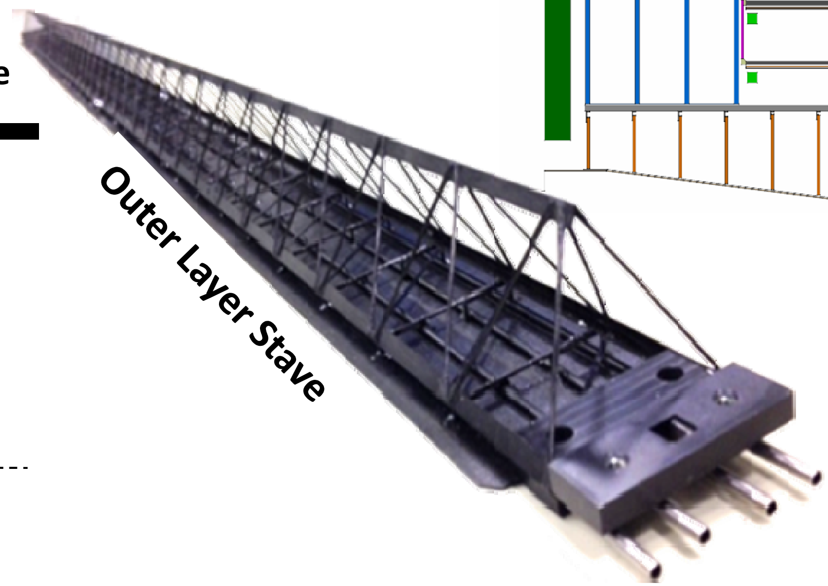
Outer Tracker:

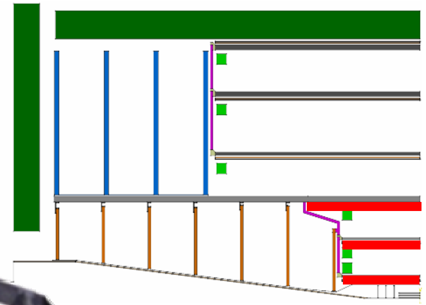
- 4 Tracker Disks
- 3 Barrel Layers

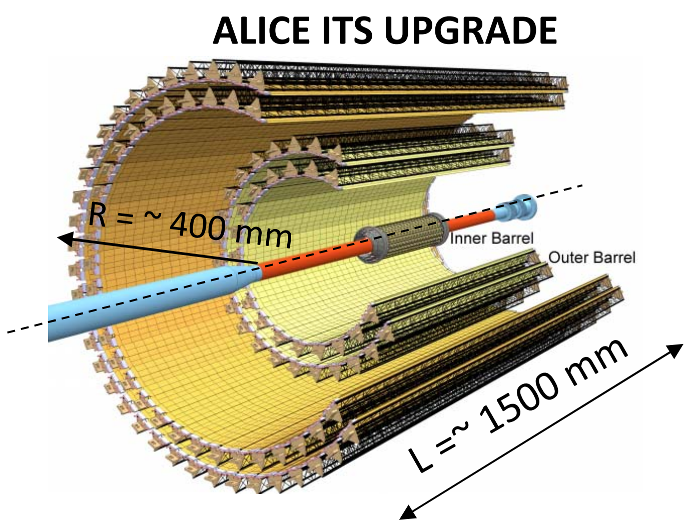
Inner Barrel

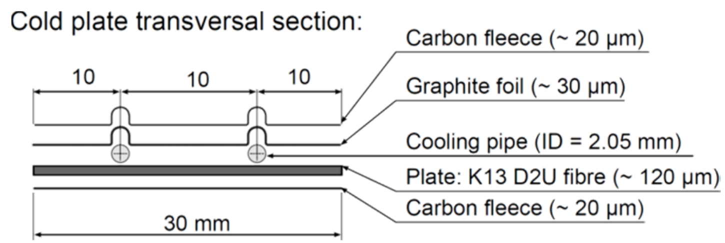
Support Structure concept







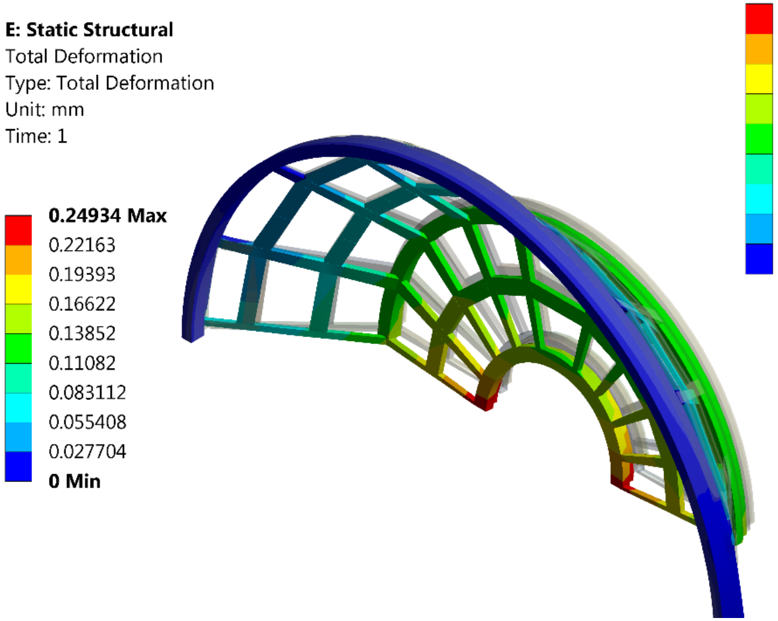


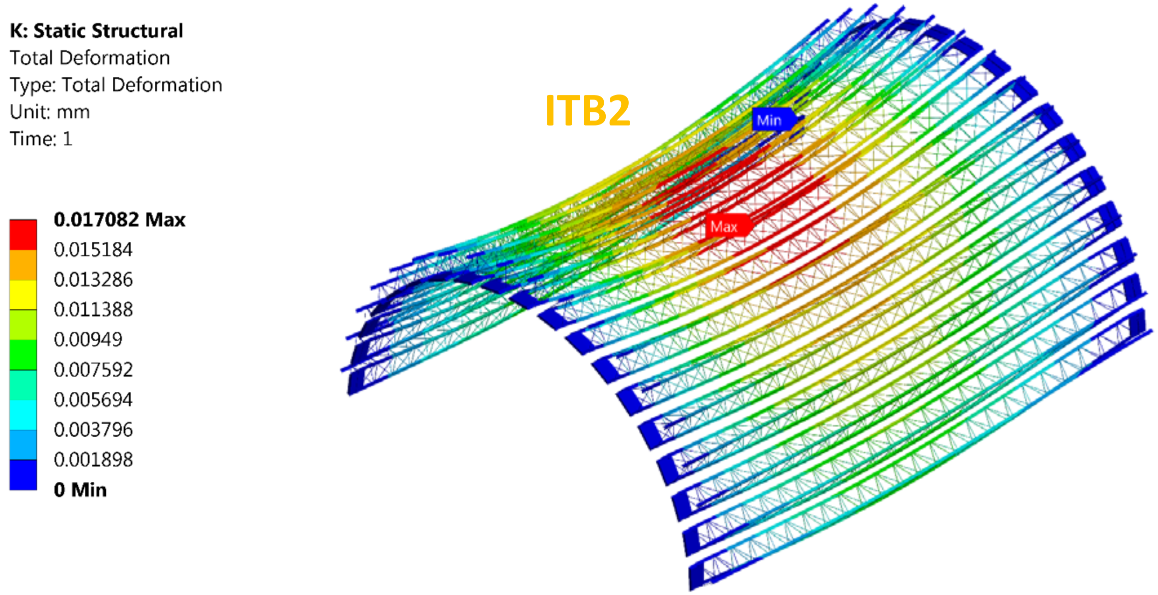


- Radiation length: ~1% X_0
- Room - operational temperature
- Max. sag < 100 μm

Inner Barrel

FEA simulations





First iteration:

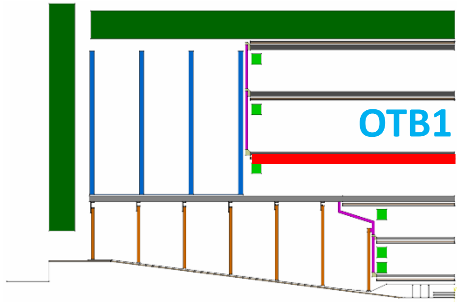
- Sandwich structure
- Material proposal:
  CFRP skins + CORE
  (HoneyComb/Rohacell IG-51)

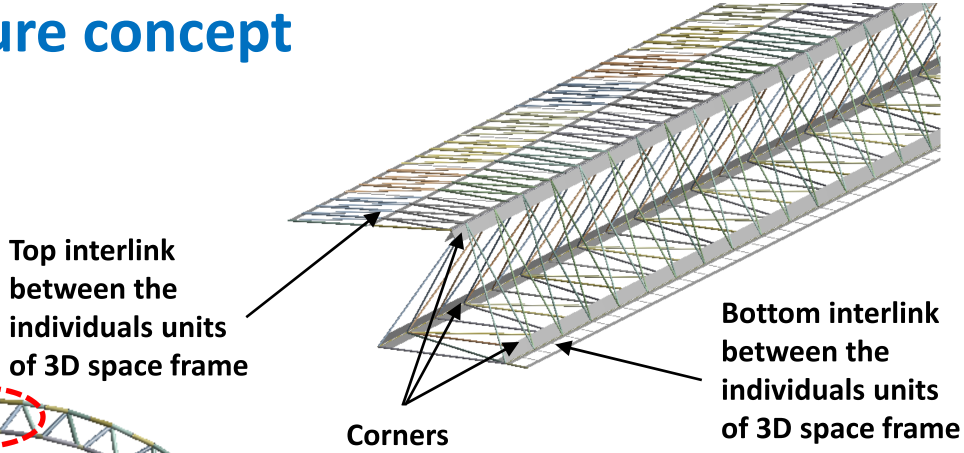
FEA Layup - Staves

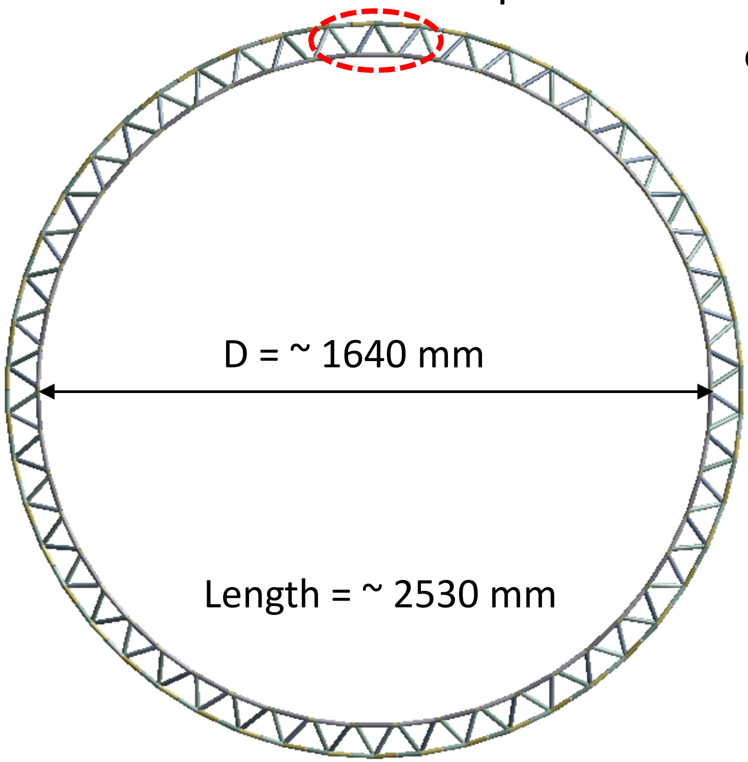
	Material	Thickness of layer [μm]	Radius [mm]	Cross-section area [mm²]
Corners (thin shell elements)	UD prepreg M55J 4 Layers	100	-	-
Cross member beams on both sides	3 impregnated thread M55J	-	0.45	~0.63
Cross member beams on bottom (nearby to cold plate)	4 impregnated thread M55J		0.5	~0.78

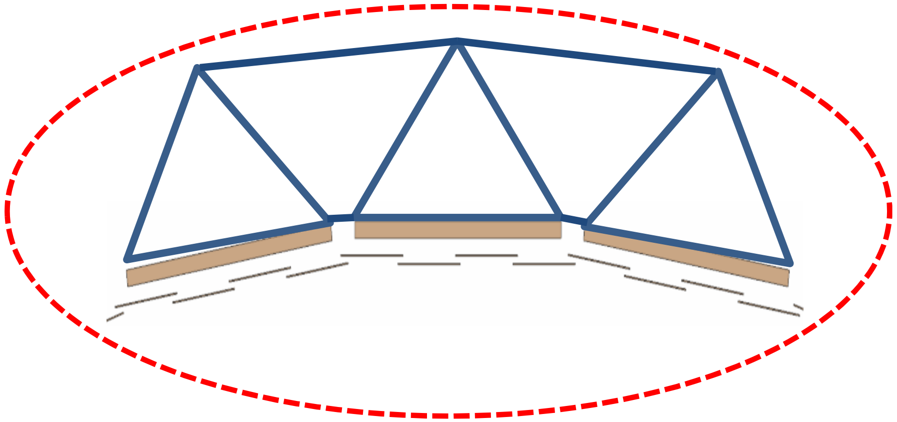
Innermost layer of Outer Barrel

Support Structure concept





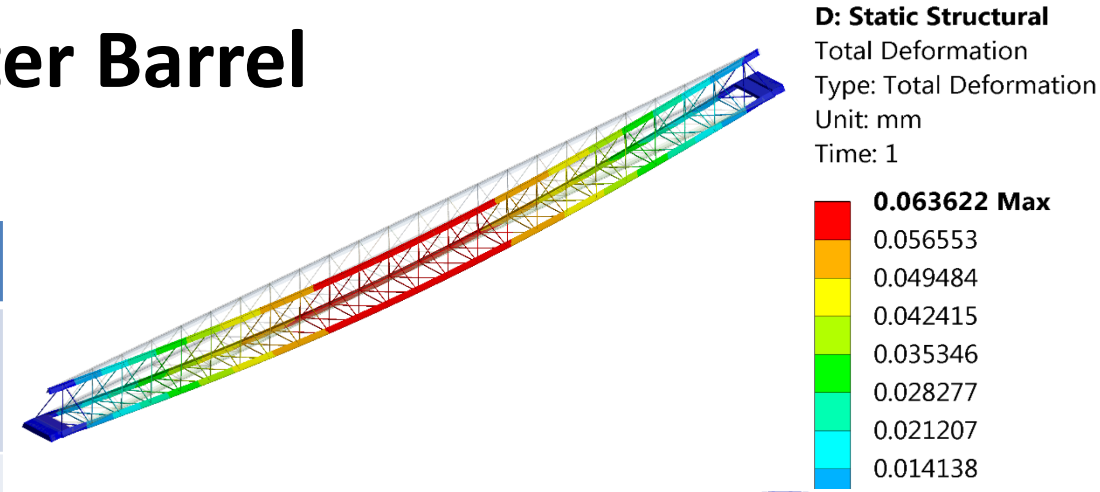


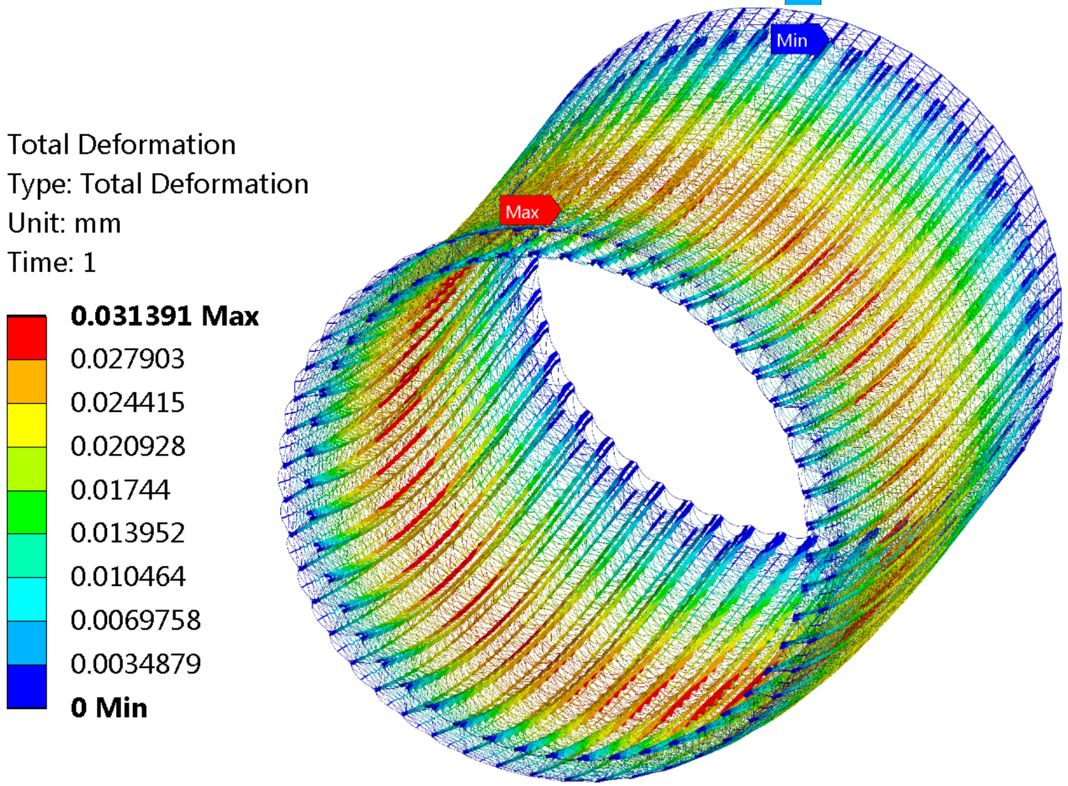


Innermost layer of Outer Barrel

FEA simulations

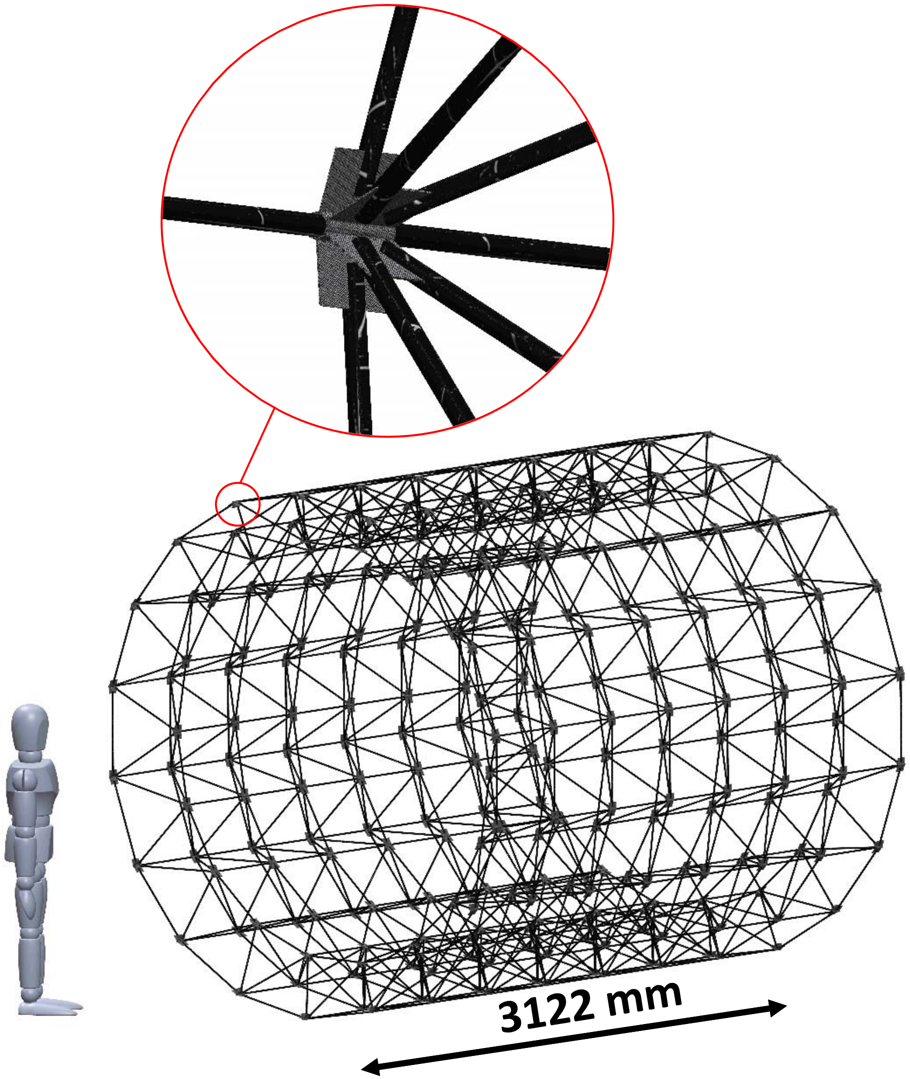
Layup - Preliminary			
	Nb. of Layers and Material	Thickness of layer [µm]	Radius [mm]
Top interlink	4 Layers Toray M55J	200	-
Bottom interlink	4 Layers Toray M55J	200	-
Corners	4 Layers Toray M55J	150	-
Frame Members	Toray M55J	-	0.5
CFR along the corners	Toray M55J	-	0.6

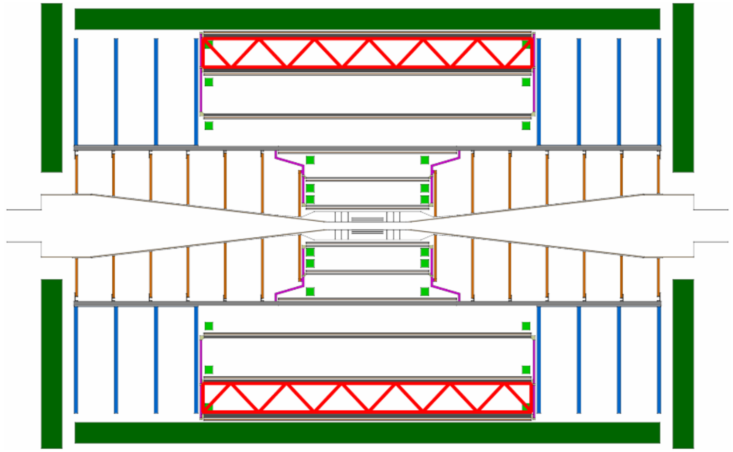


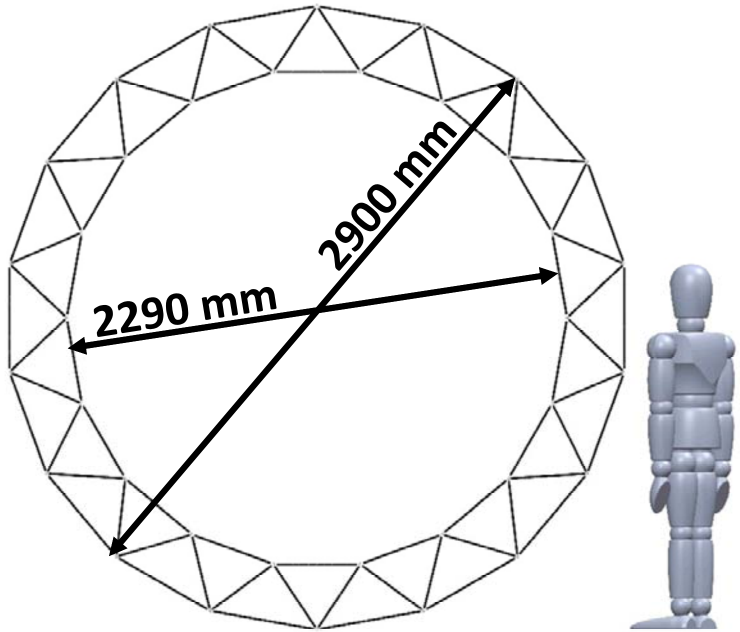


Outermost layers: OTB2 & OTB3

Support Structure concept

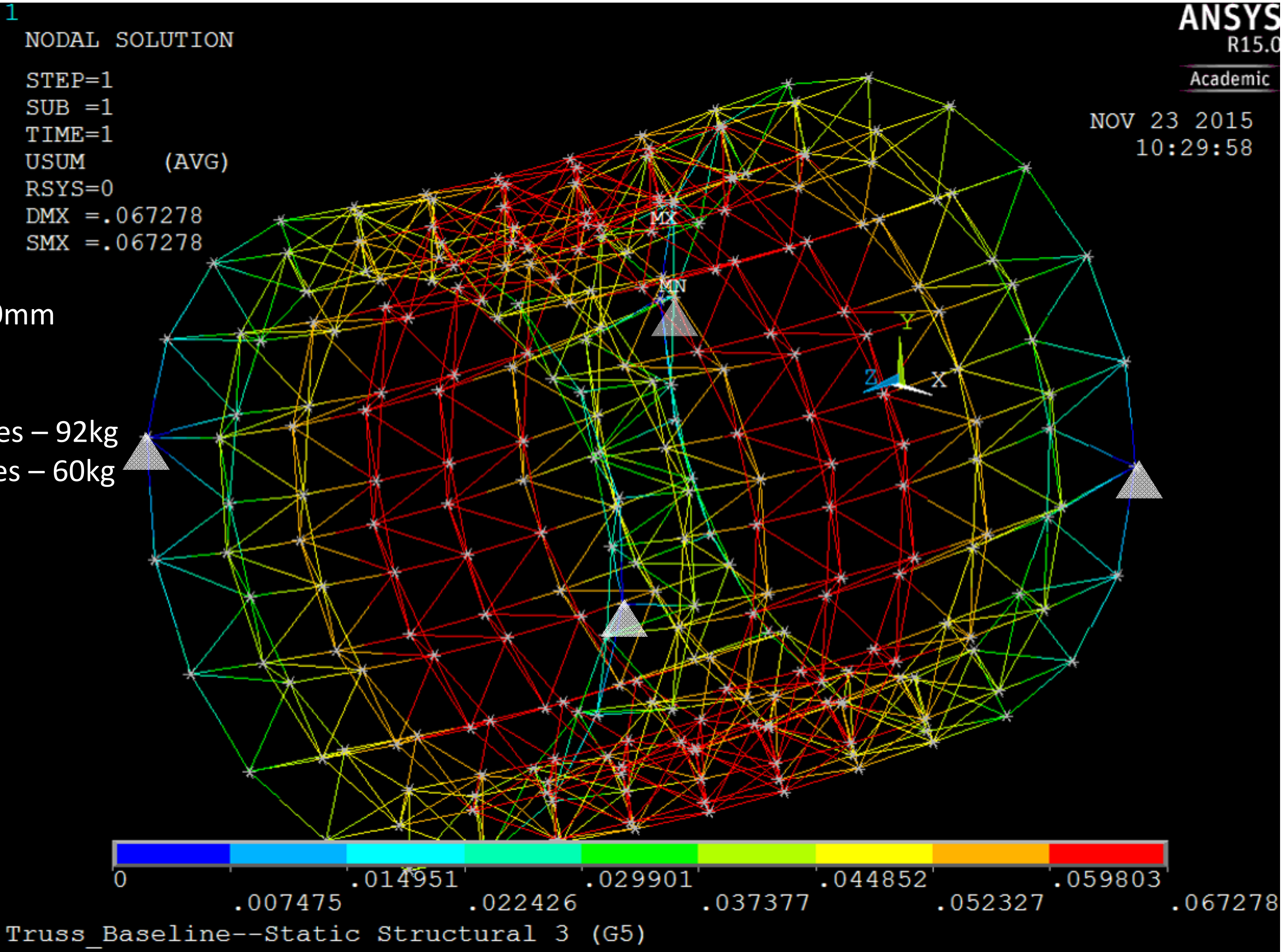






Outermost layers: OTB2 & OTB3

FEA simulation

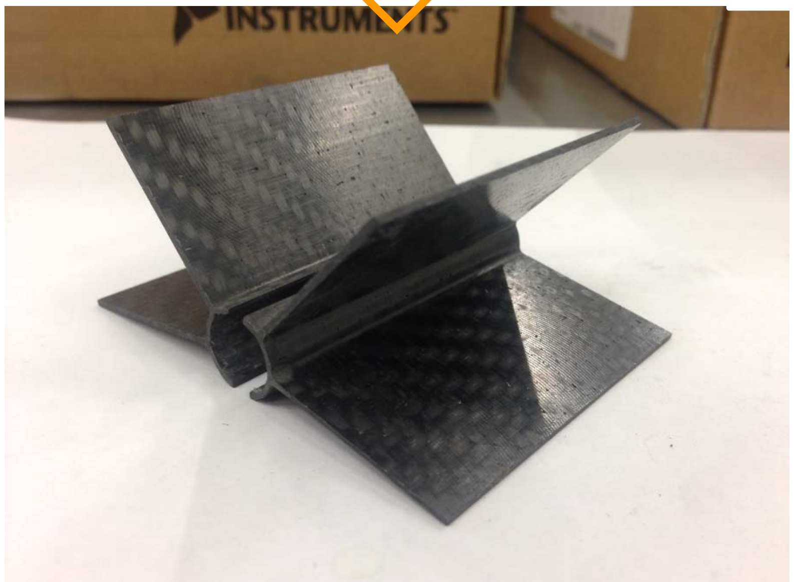


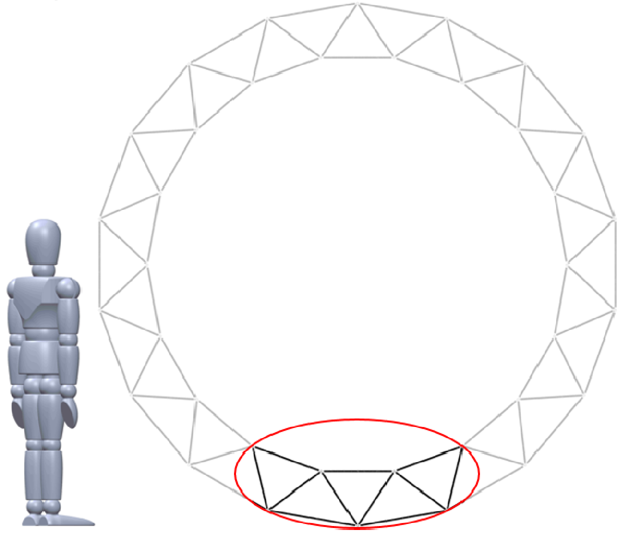
Outer diameter of tube – 10mm
Thickness of tube – 0.5mm
Node mass – 14gm
Mass of outer radius modules – 92kg
Mass of inner radius modules – 60kg
M55J fibers

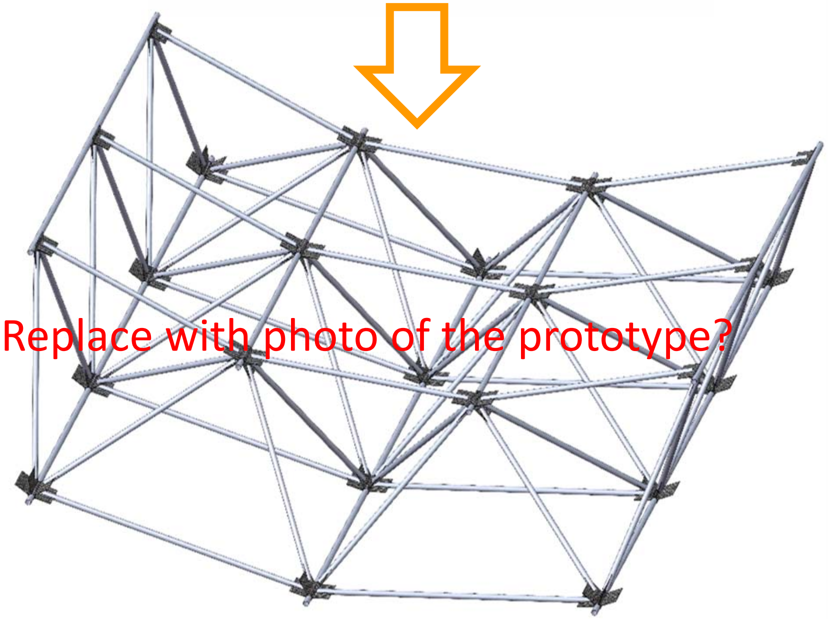
X/X0 ≈ 0.125%
δ=67 µm

Outermost layers: OTB2 & OTB3

Prototyping activities

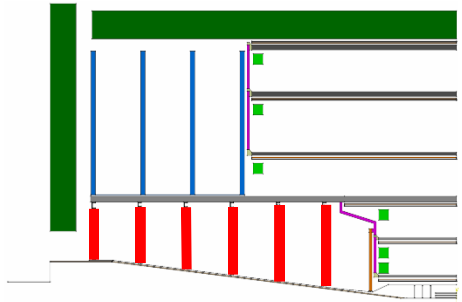


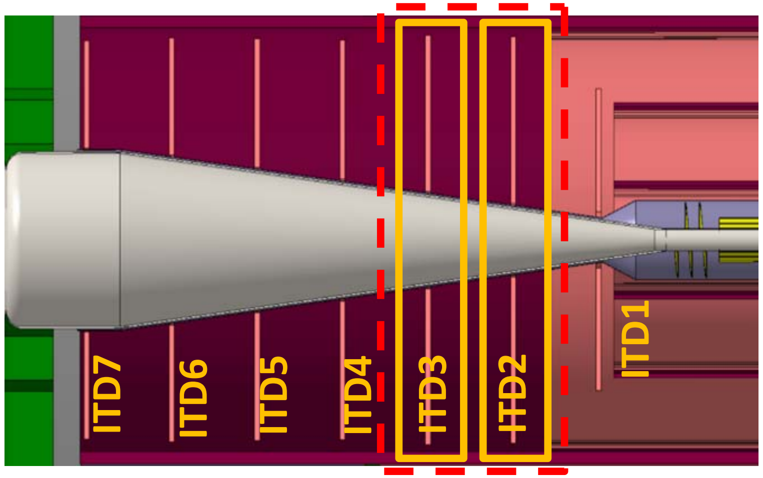


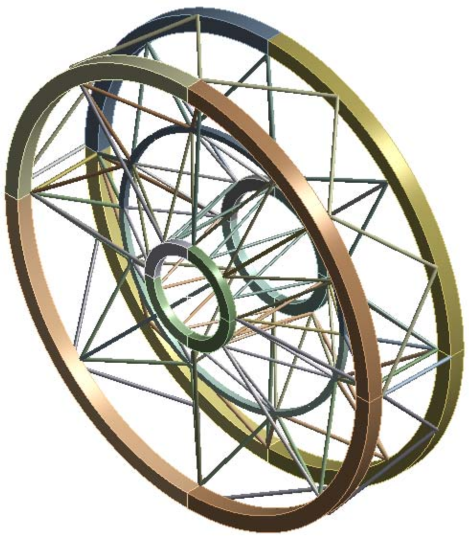


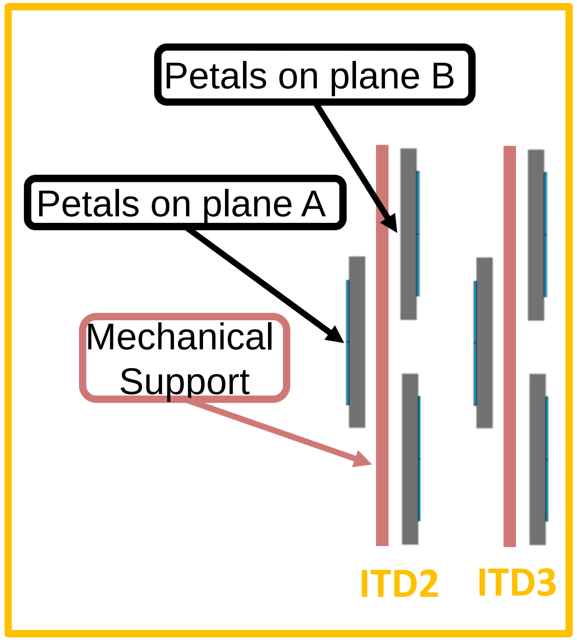
Inner Tracker Disks

Support Structure concept

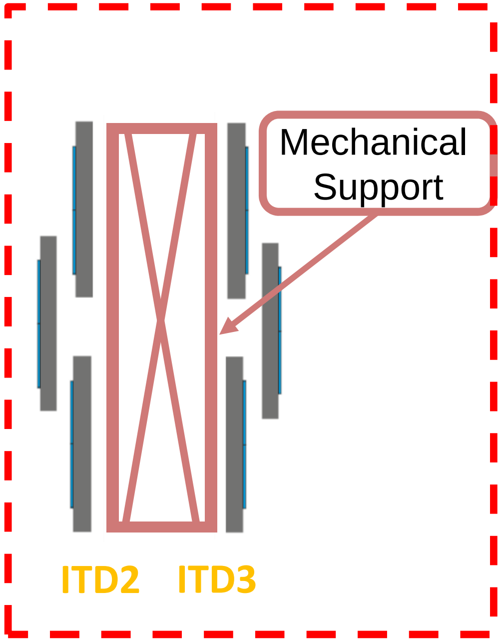








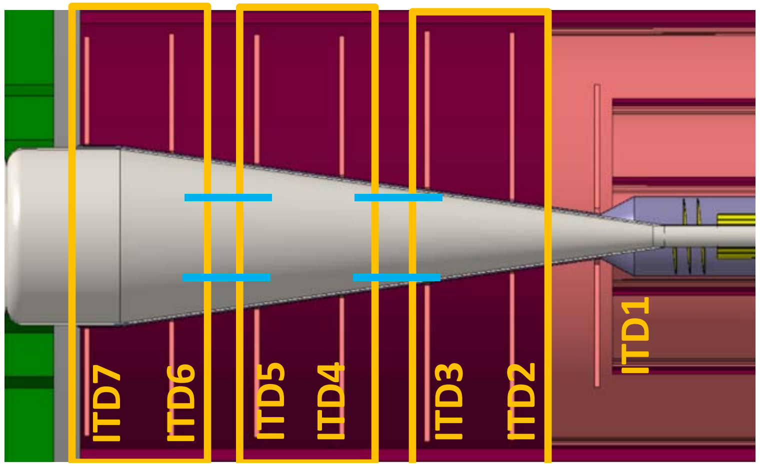
Conventional design

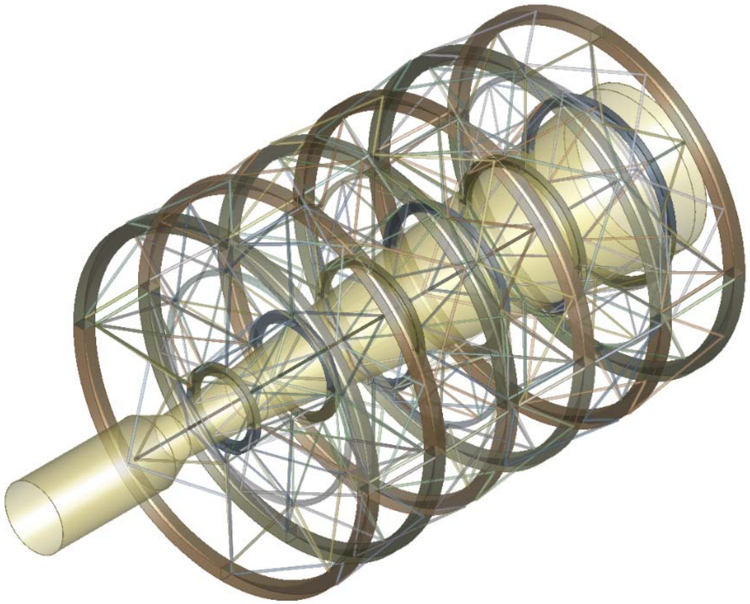


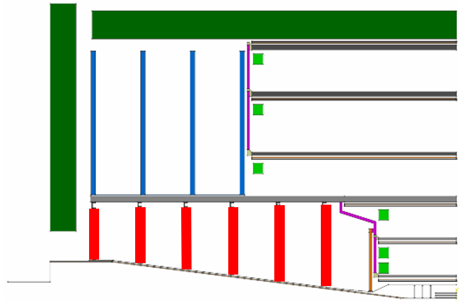
Design Proposal for CLIC

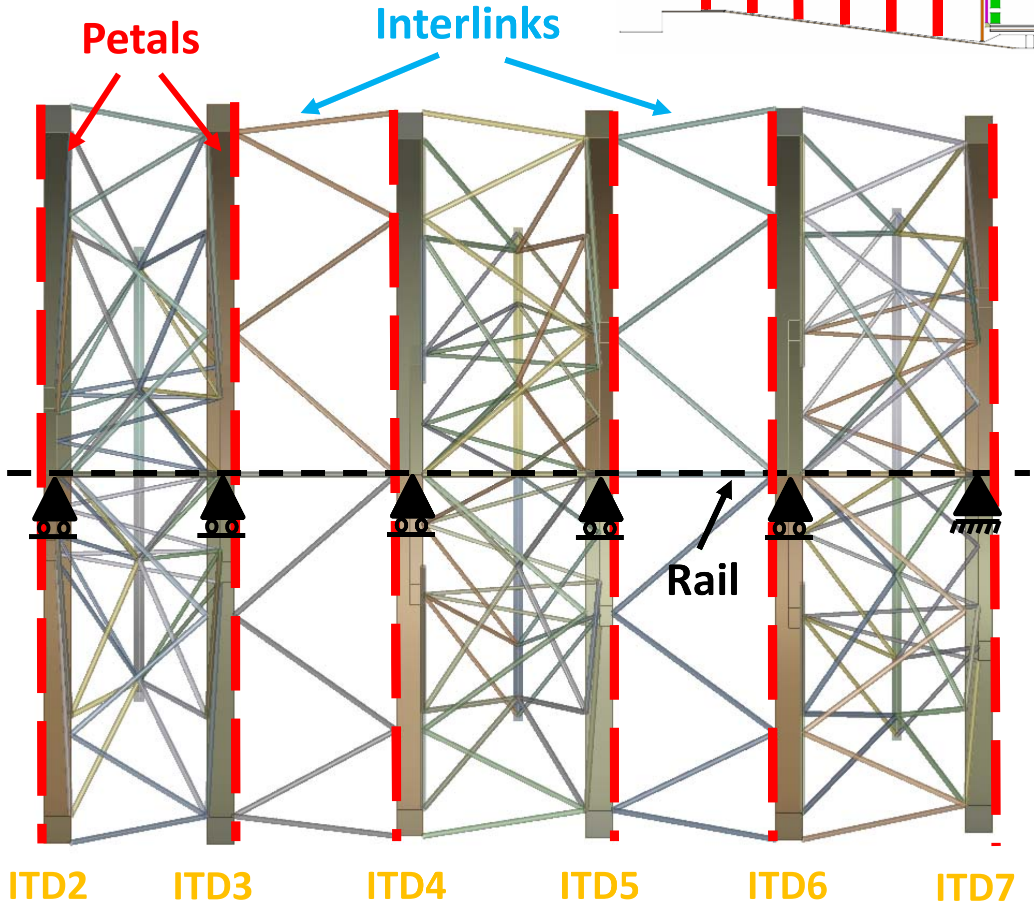
Inner Tracker Disks

Support Structure concept



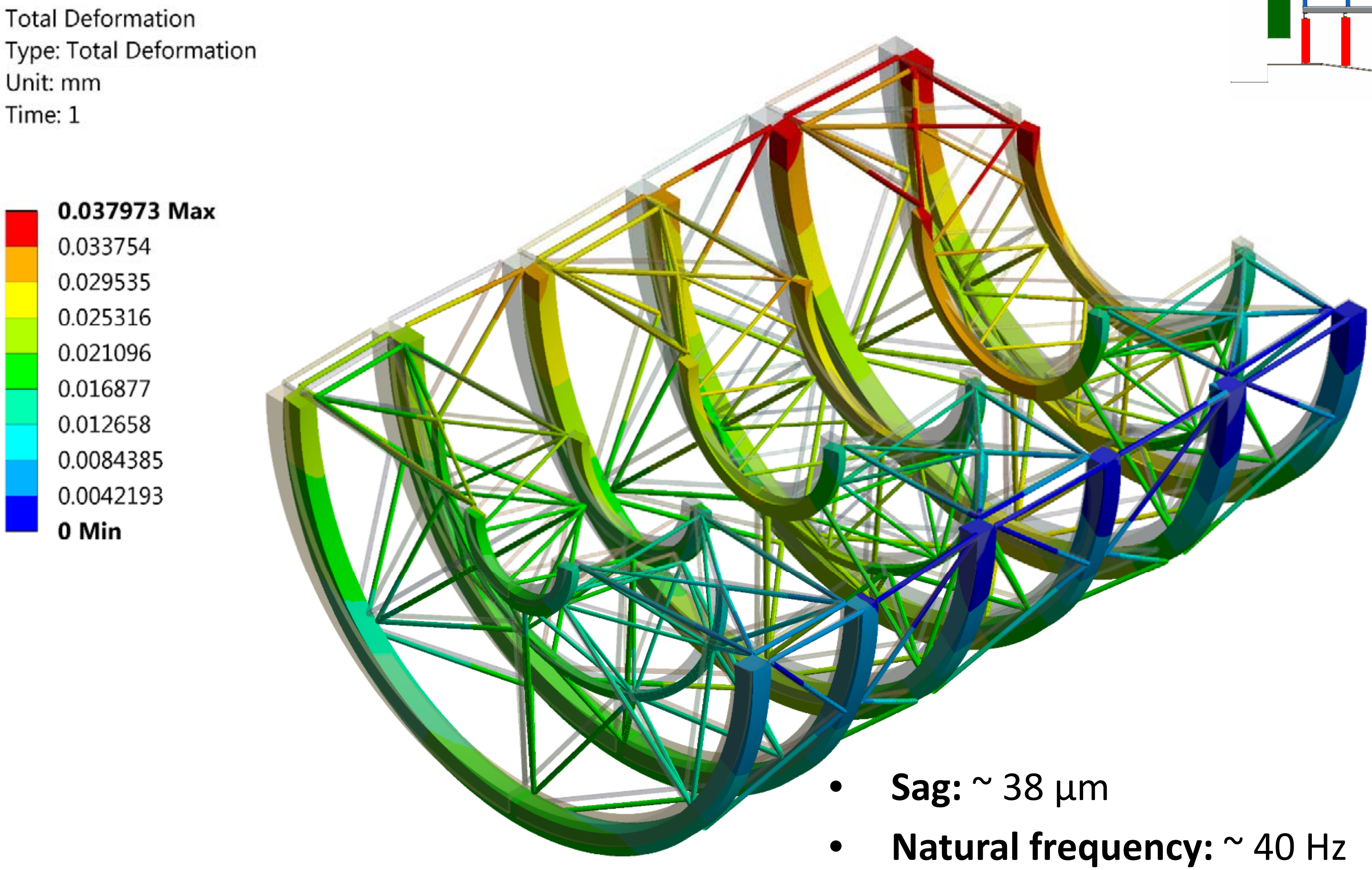


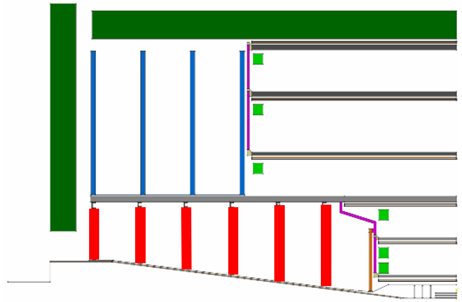




Inner Tracker Disks

FEA simulation

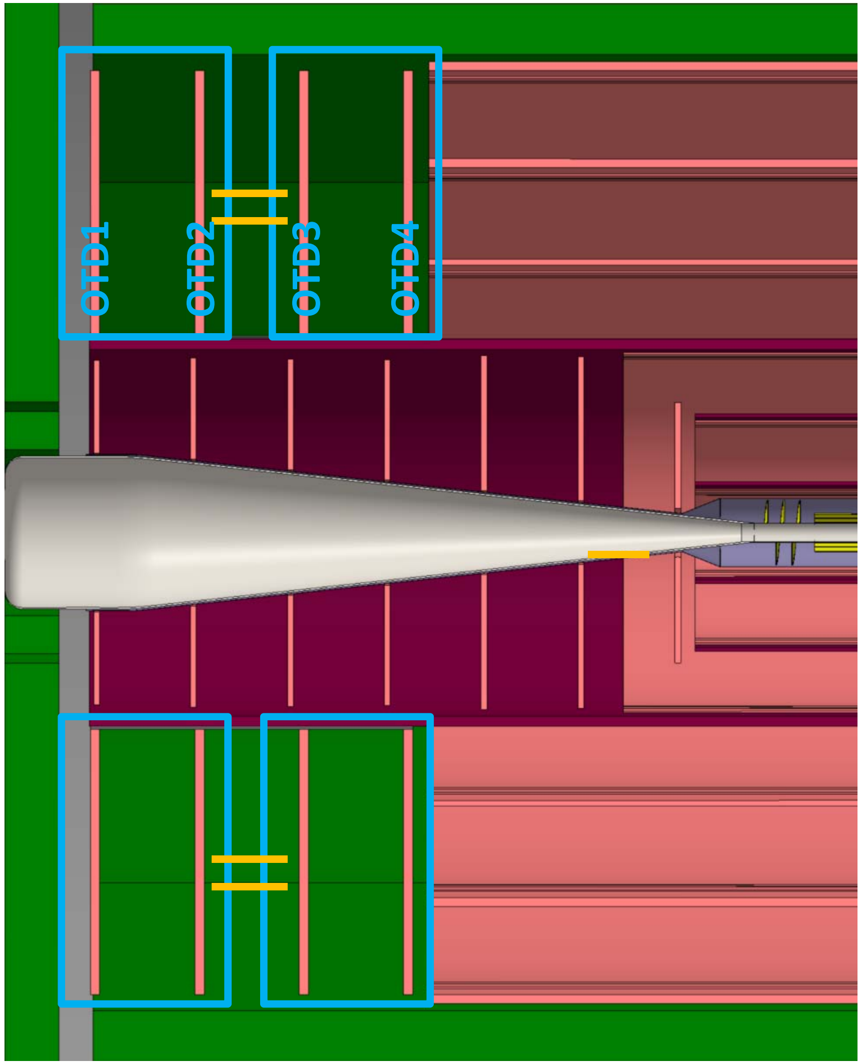


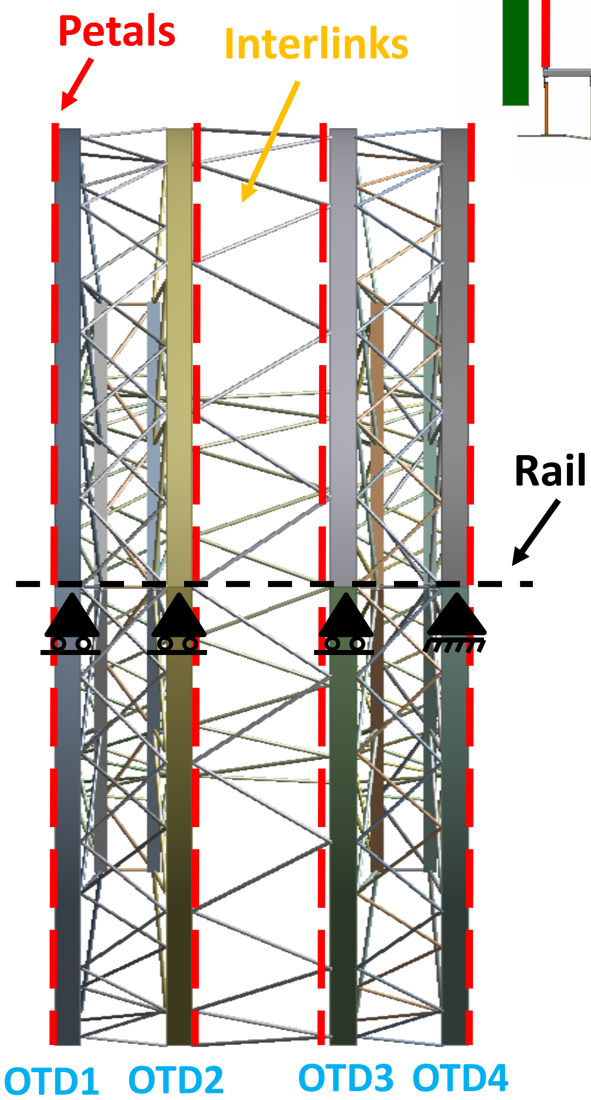


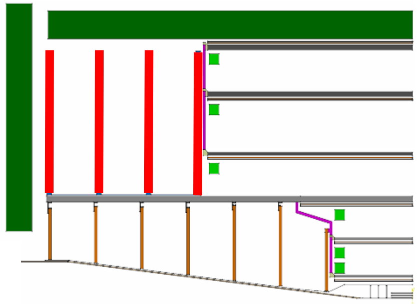
- **Sag:** ~ 38 µm
- **Natural frequency:** ~ 40 Hz
- **Estimated Radiation Length:** ~0.235 % X0

Outer Tracker Disks

Support Structure concepts

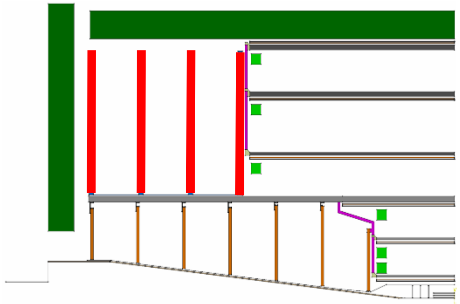


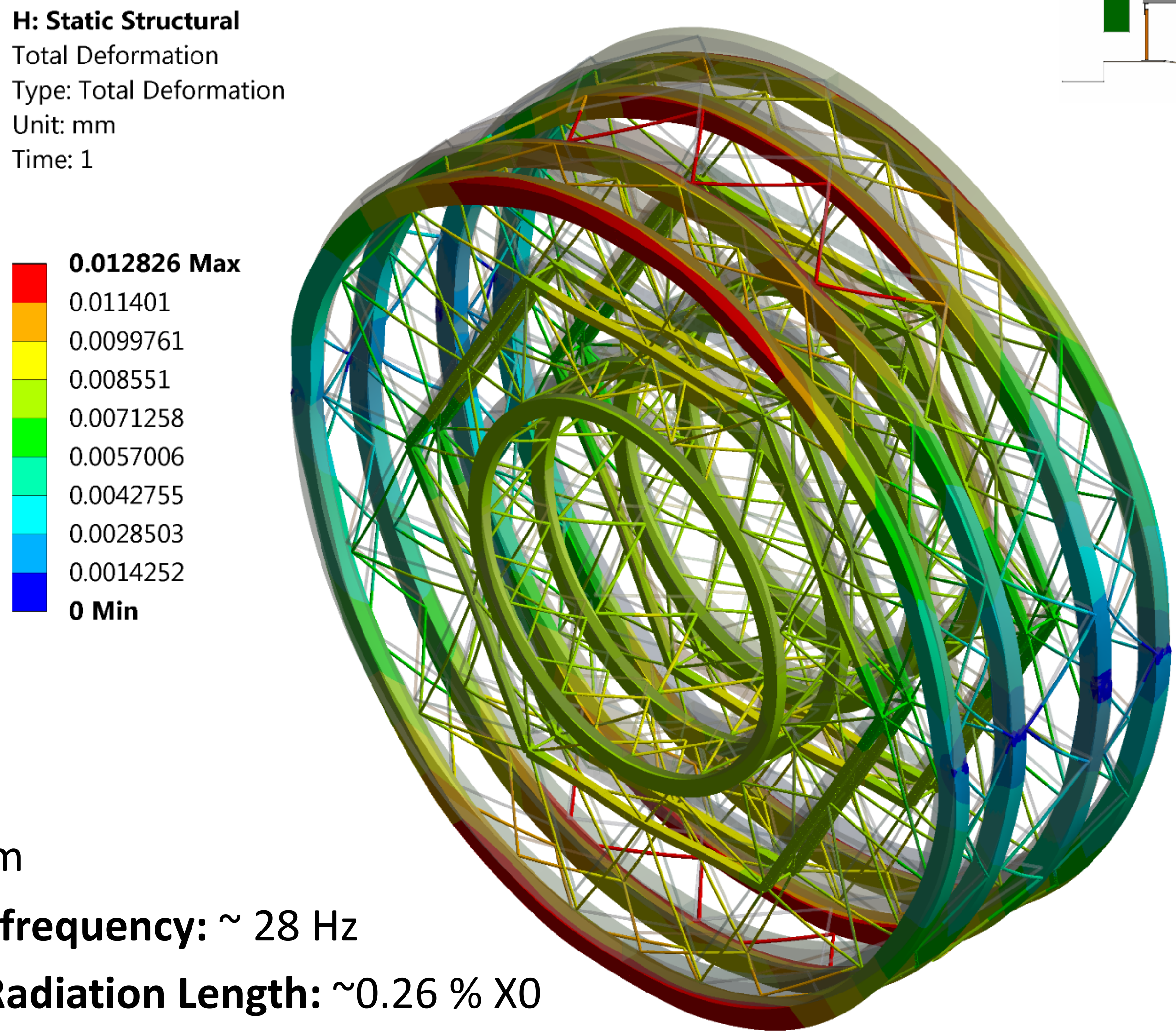




Outer Tracker Disks

FEA simulation

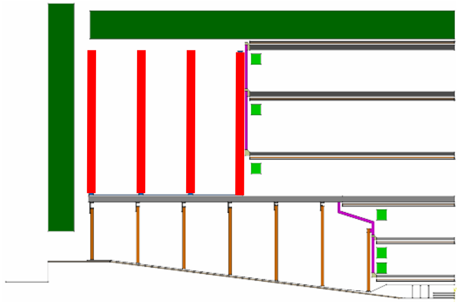


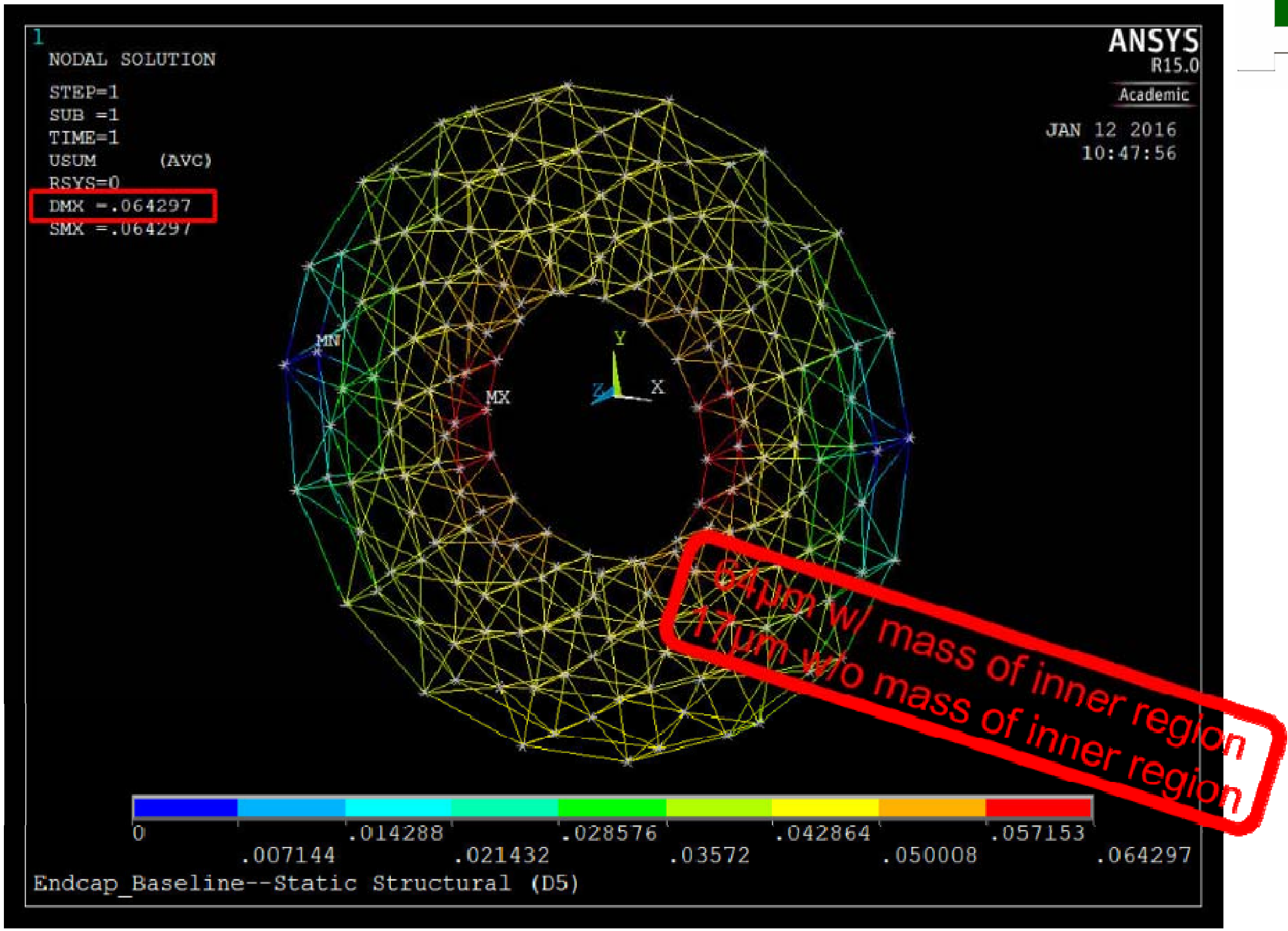


- **Sag:** ~ 13μm
- **1st Natural frequency:** ~ 28 Hz
- **Estimated Radiation Length:** ~0.26 % X0

Outer Tracker Disks

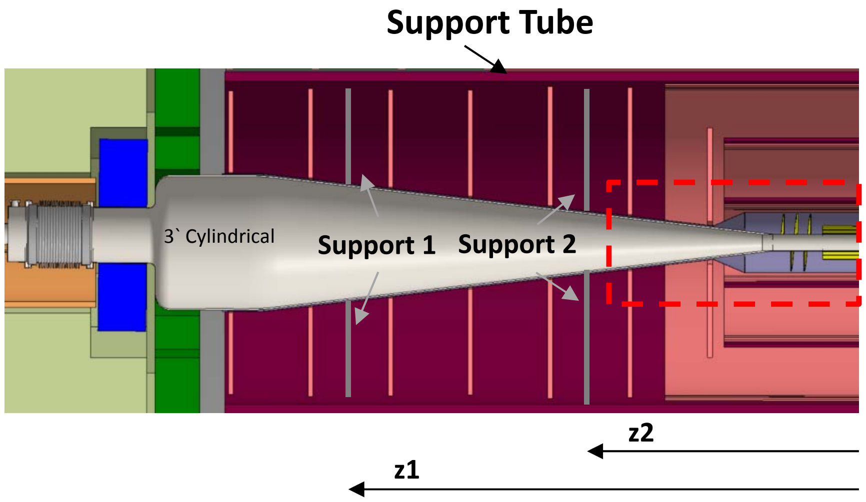
Support Structure concept

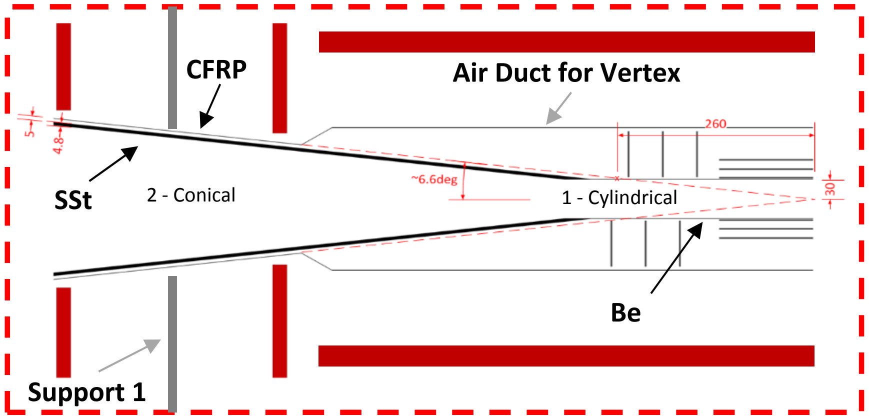


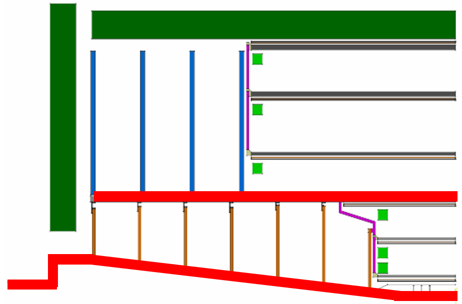


Support Tube & Beam Pipe

Concept





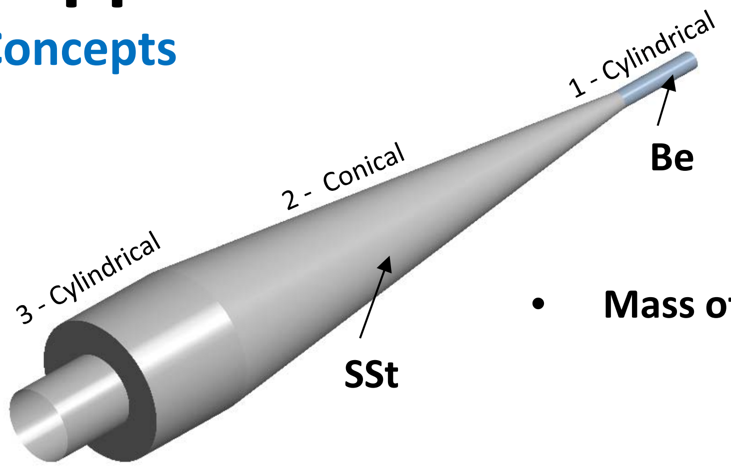


Design Objectives:

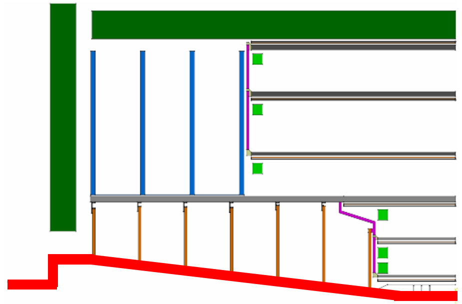
- Minimizing the stresses on the interface between the parts made of beryllium & stainless steel

Support Tube & Beam Pipe

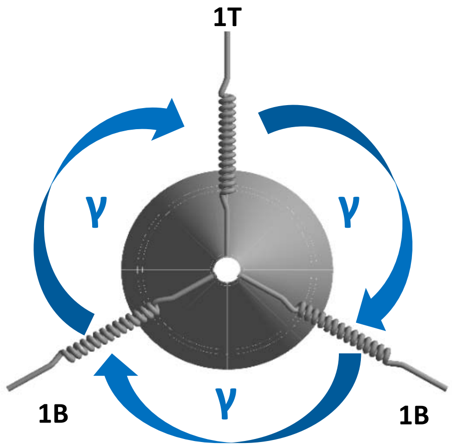
Concepts

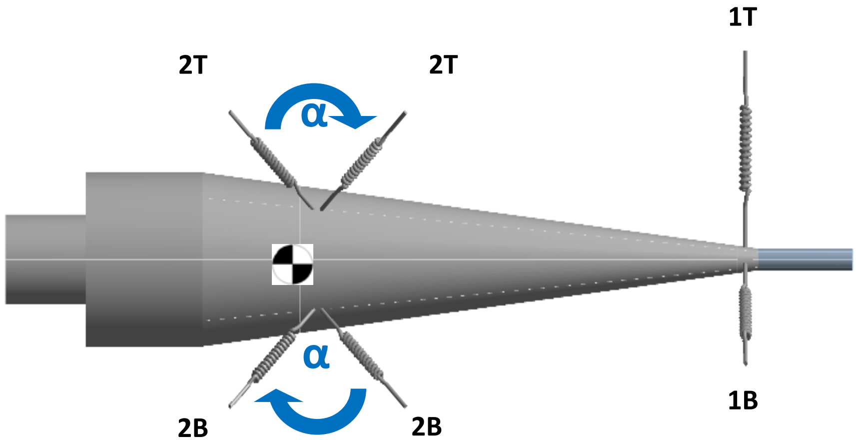


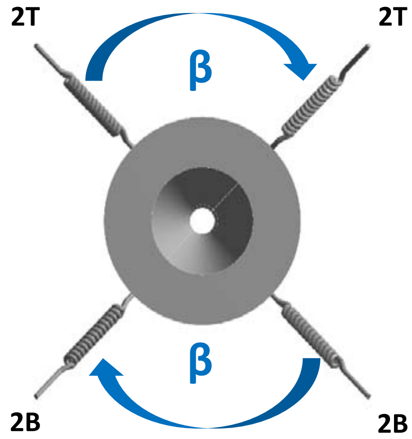
- **Mass of Beam Pipe:** ~180 kg



1 - Cylindrical: R1=30 [mm], L1= 308 [mm], T1= 0.6 [mm]
2 - Conical: R1=30 [mm], R2=240 [mm, L2= 1820 [mm], T2= 4.8 [mm]
3 - Cylindrical: R2=240 [mm], L3= 381 [mm], T3= 4.8 [mm]

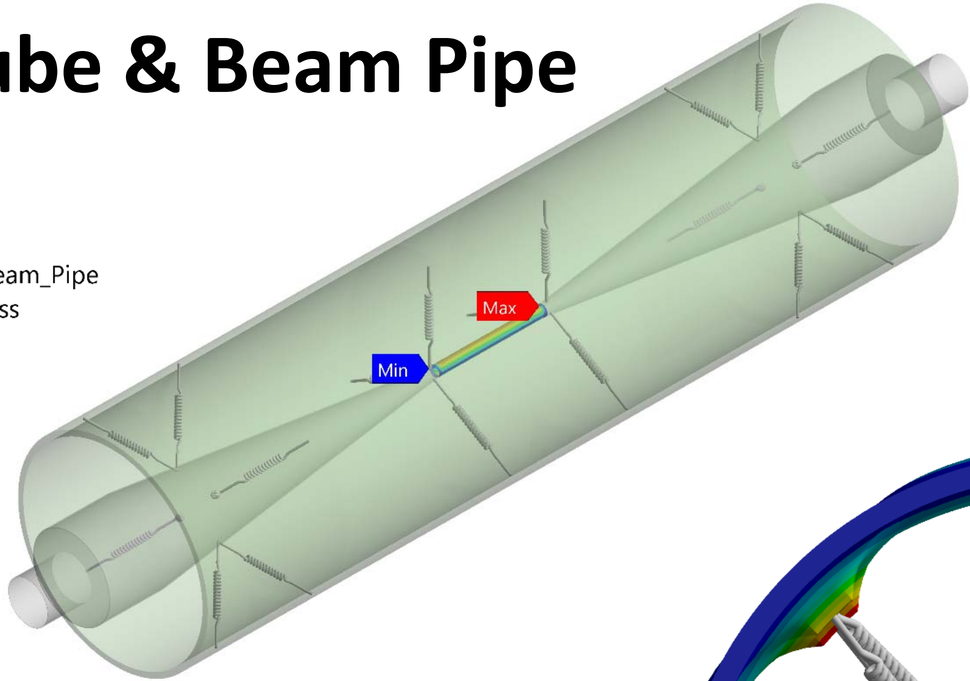






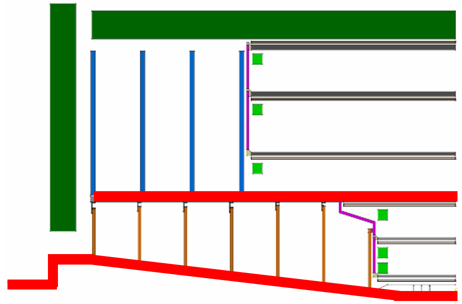
Support Tube & Beam Pipe

FEA simulations



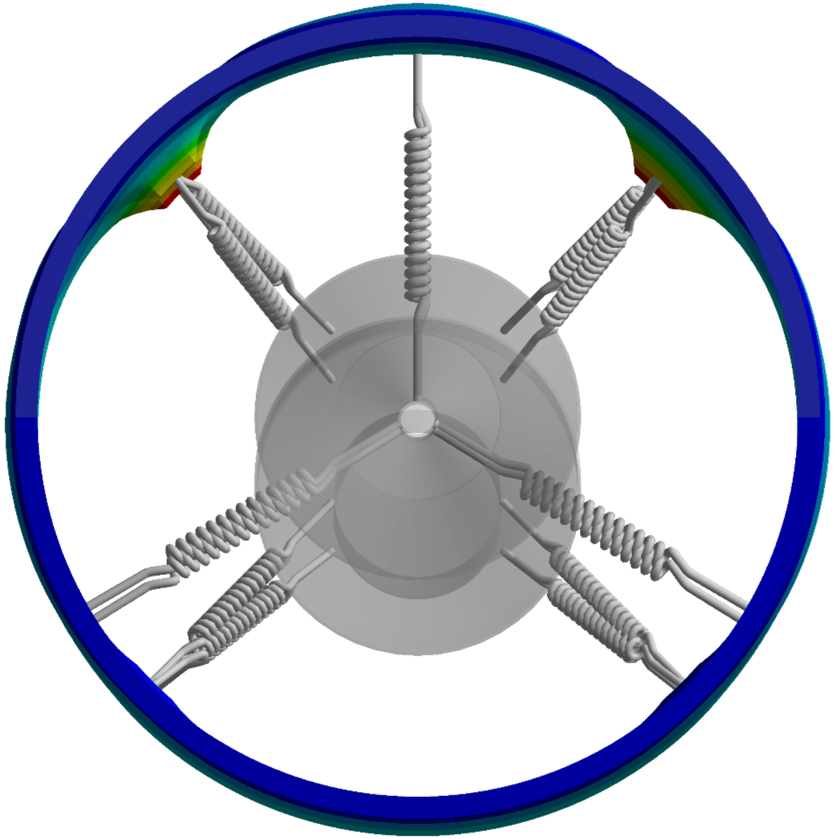
B: Copy of Static Structural
Equivalent (von-Mises) Stress - Beam_Pipe
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1

2.2435 Max
1.9947
1.7459
1.4971
1.2483
0.99948
0.75068
0.50188
0.25308
0.0042767 Min



B: Static Structural
Total Deformation - Support_Tube
Type: Total Deformation
Unit: mm
Time: 1

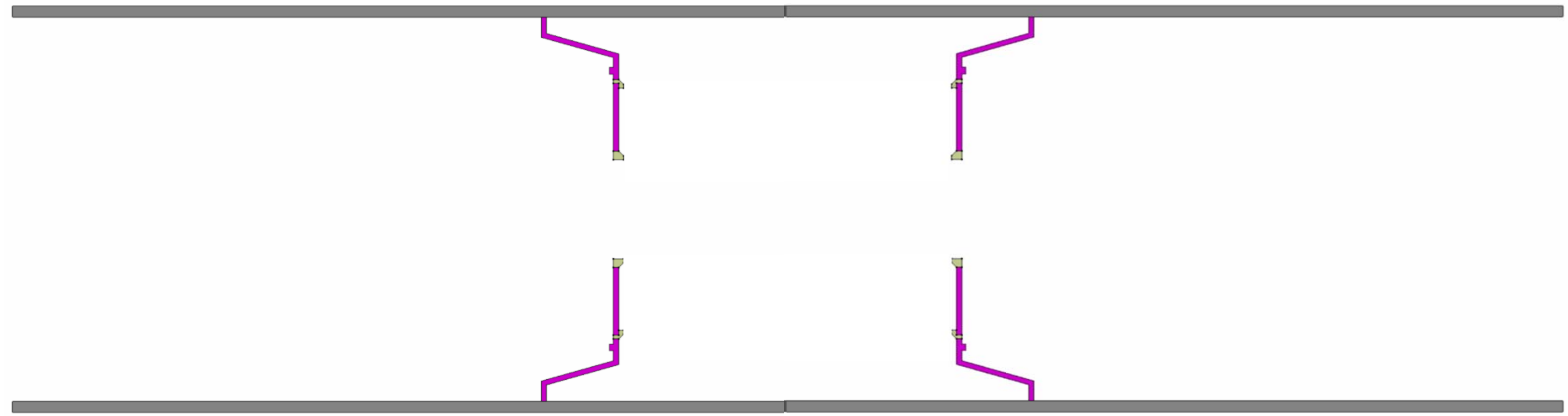
0.11847 Max
0.1053
0.092141
0.078978
0.065815
0.052652
0.039489
0.026326
0.013163
0 Min



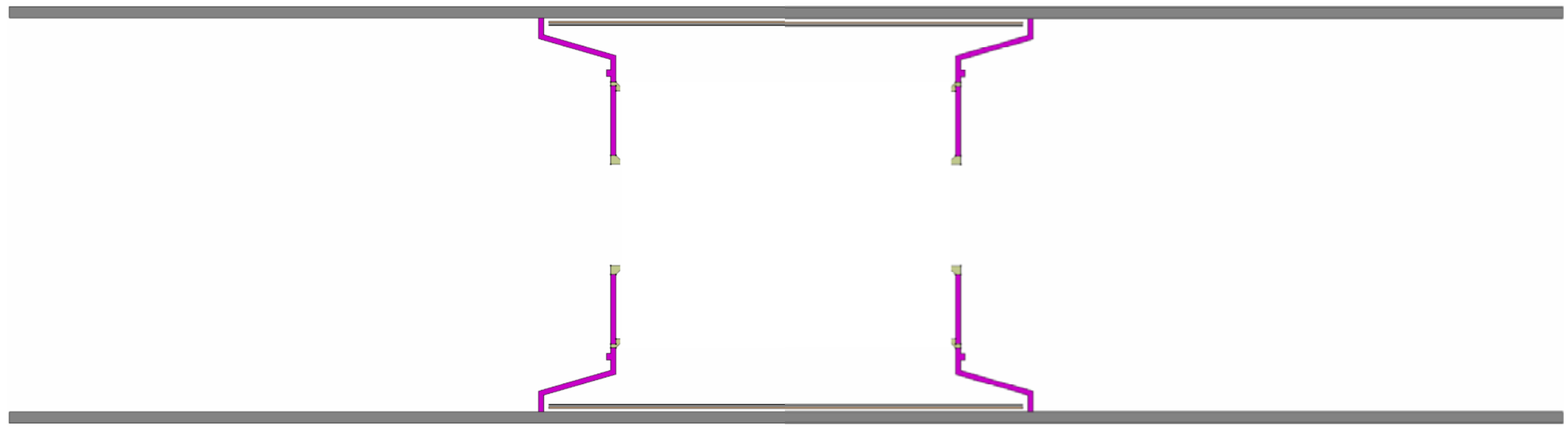
Assembly Sequence

Inner Tracker - Barrel

1)



2)

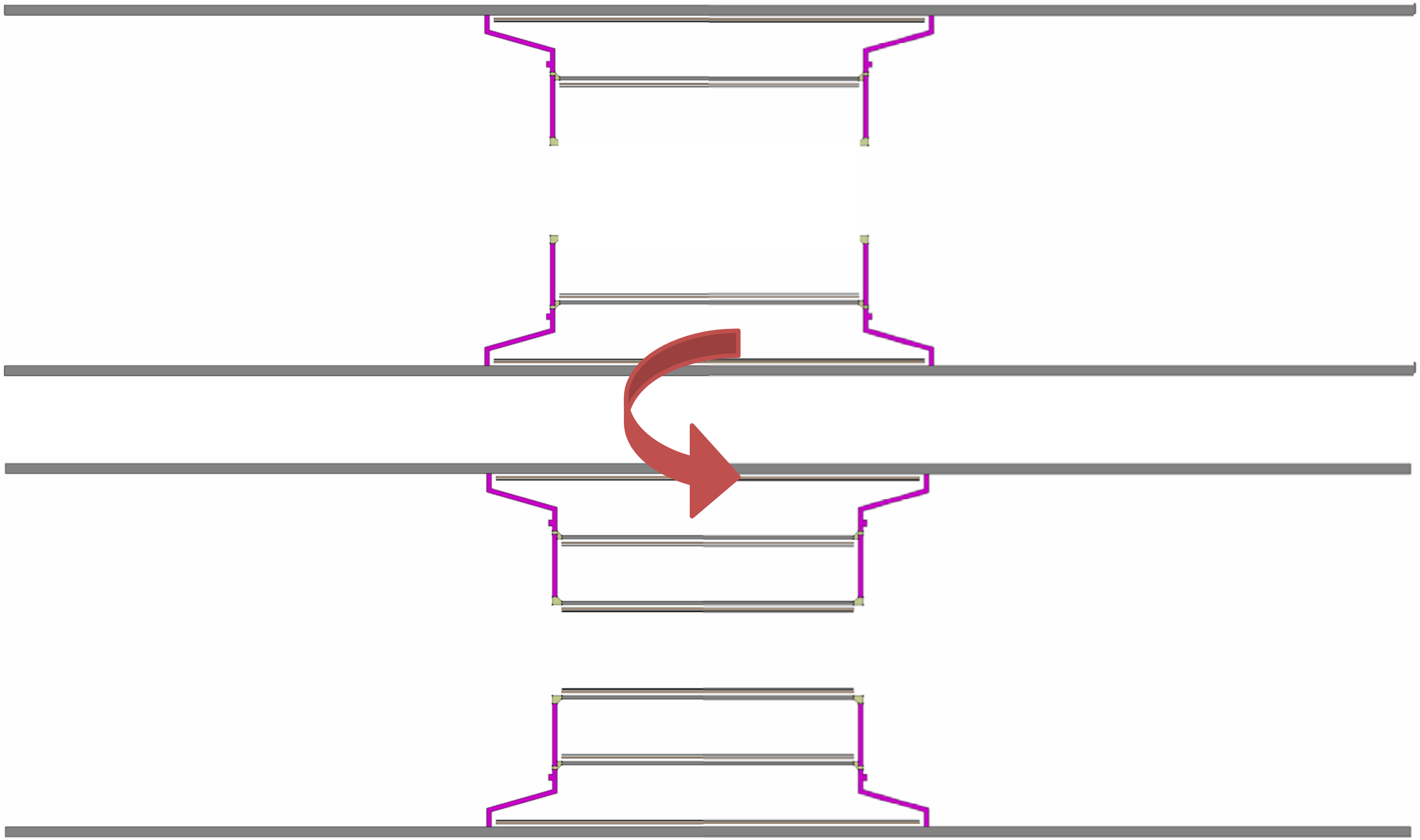


Assembly Sequence

Inner Tracker - Barrel

3)

4)

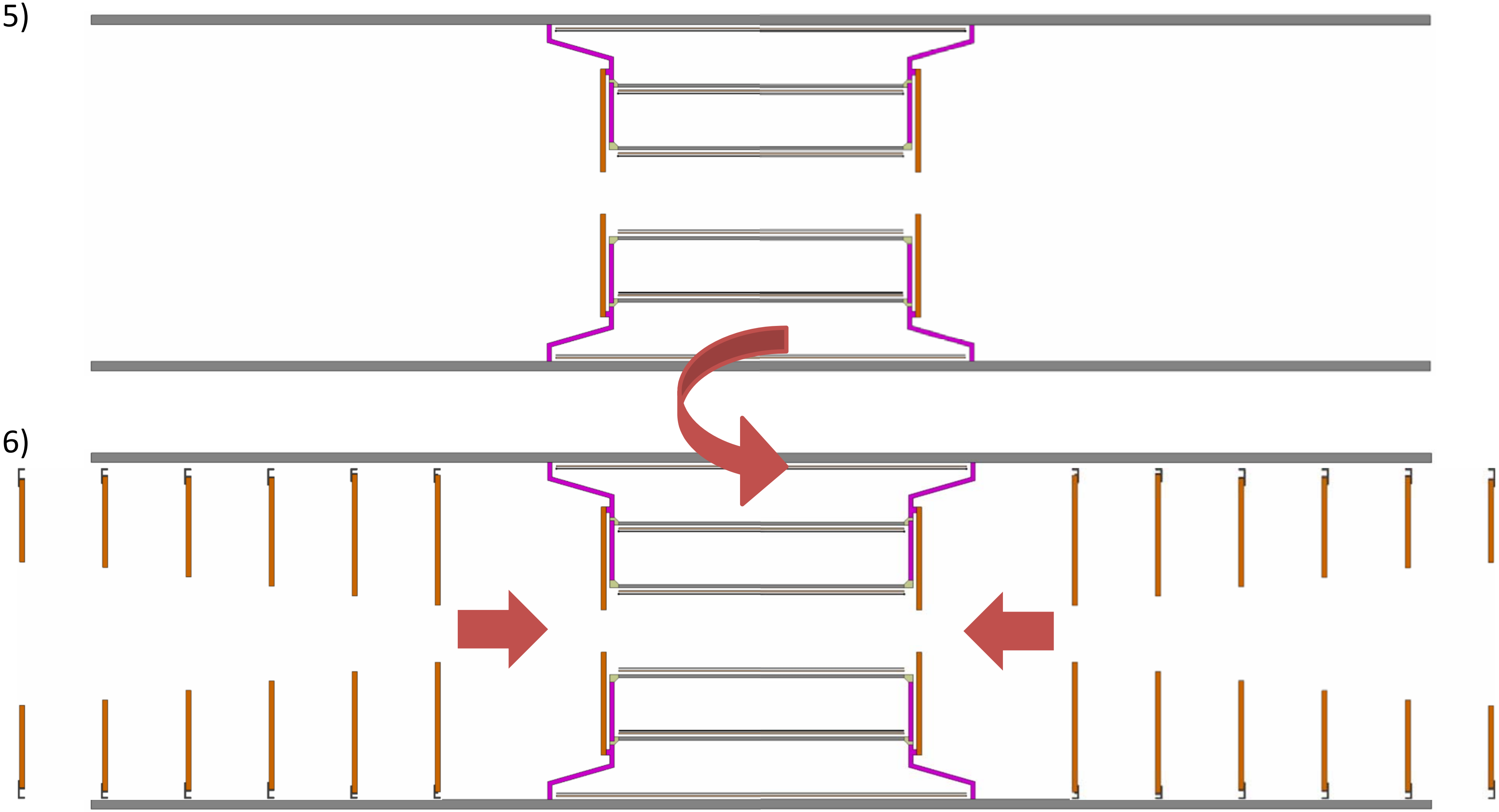


Assembly Sequence

Inner Tracker - Barrel & Tracker Disks

5)

6)

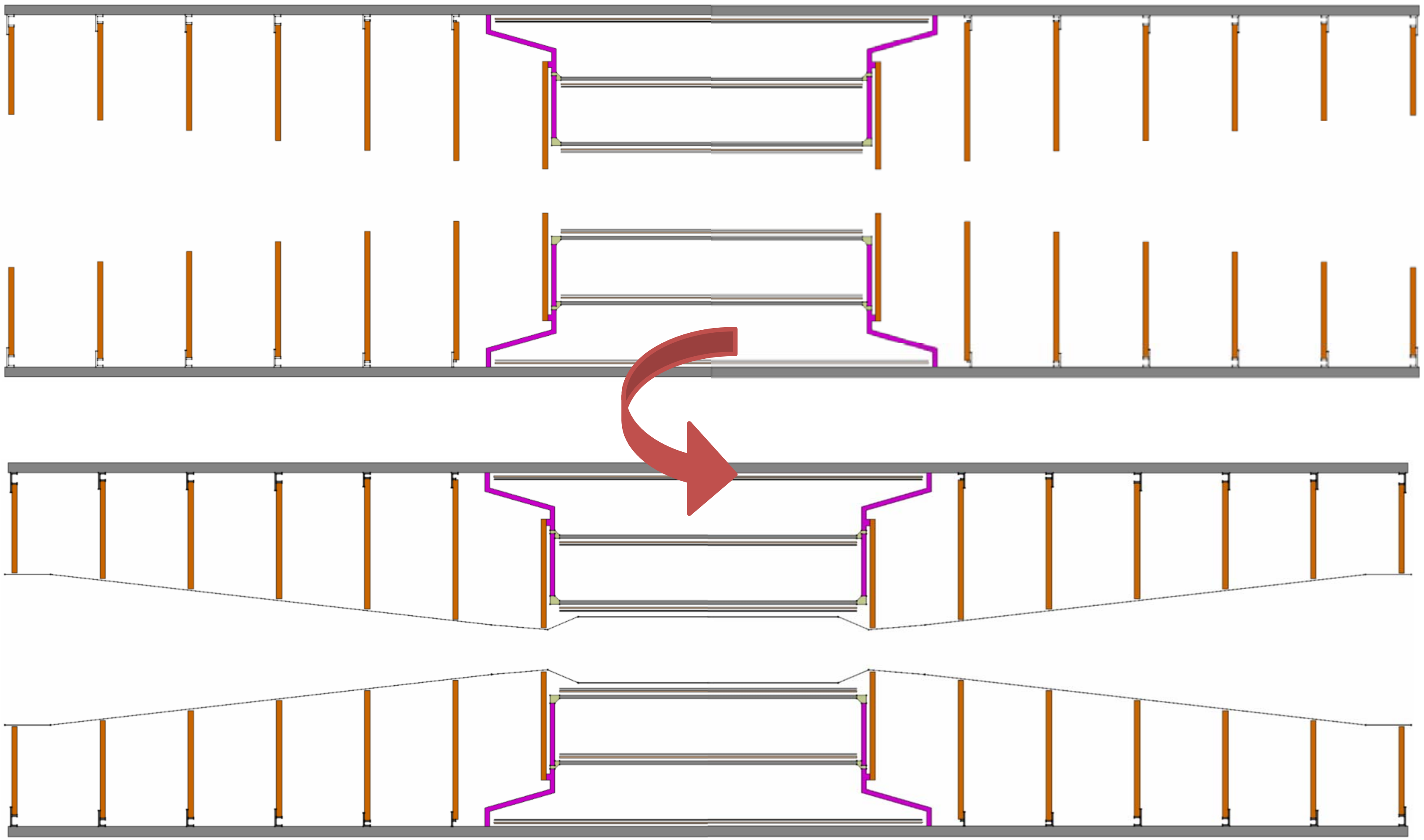


Assembly Sequence

Inner Tracker - Tracker Disks & Air Duct

7)

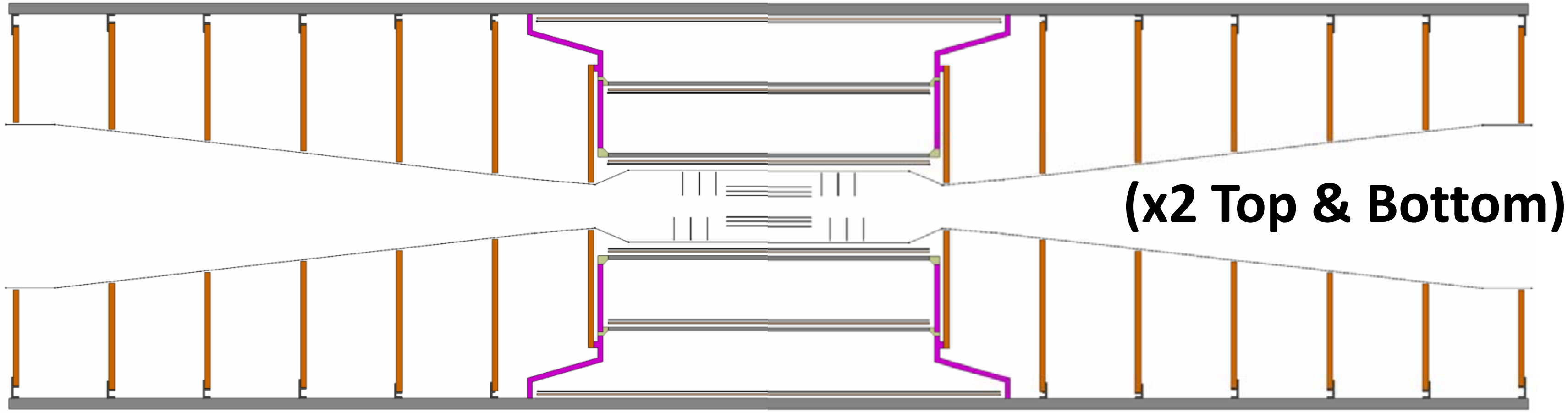
8)



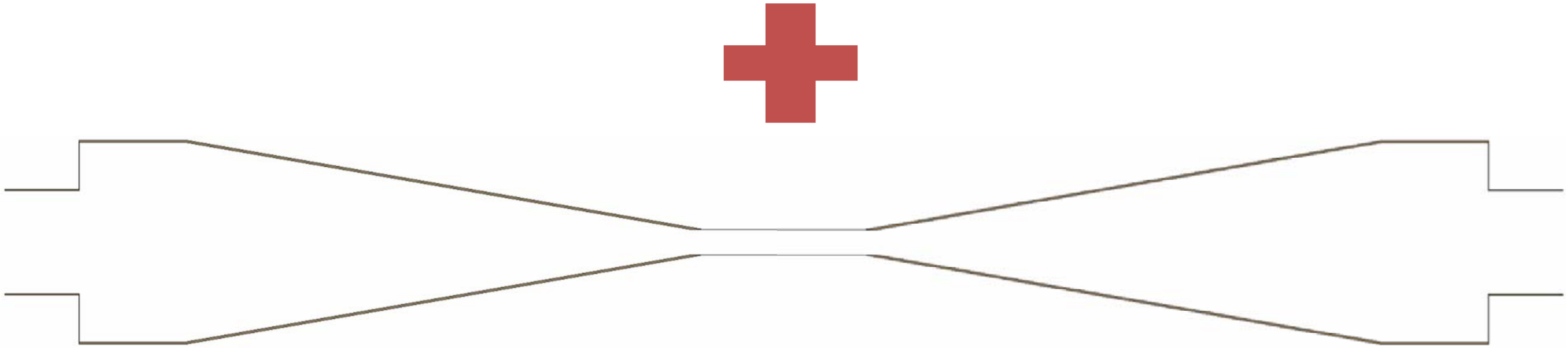
Assembly Sequence

Integration of Inner Tracker with Beam Pipe

9)



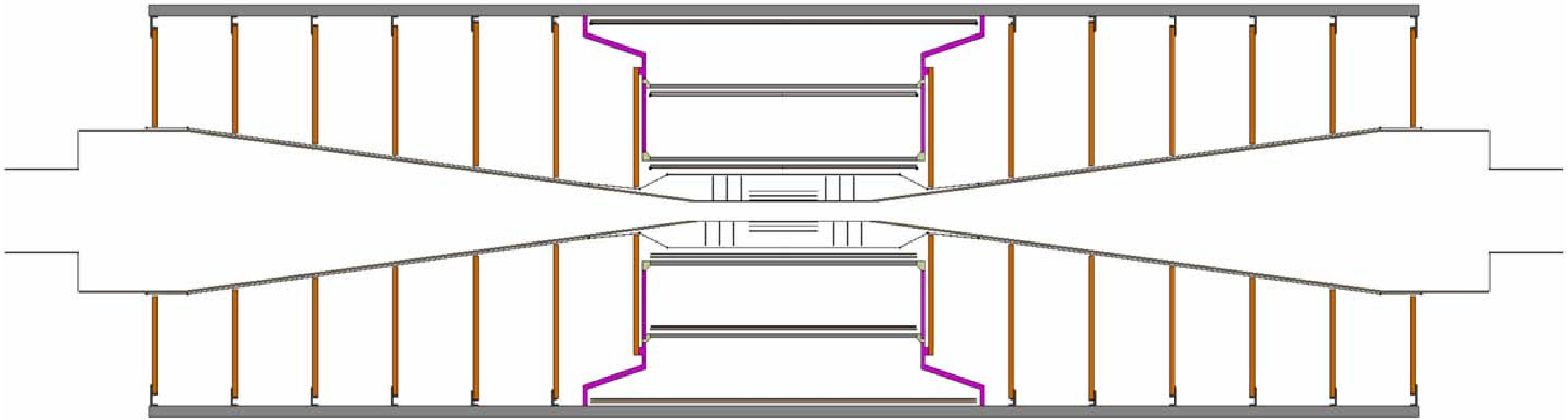
10)



Assembly Sequence

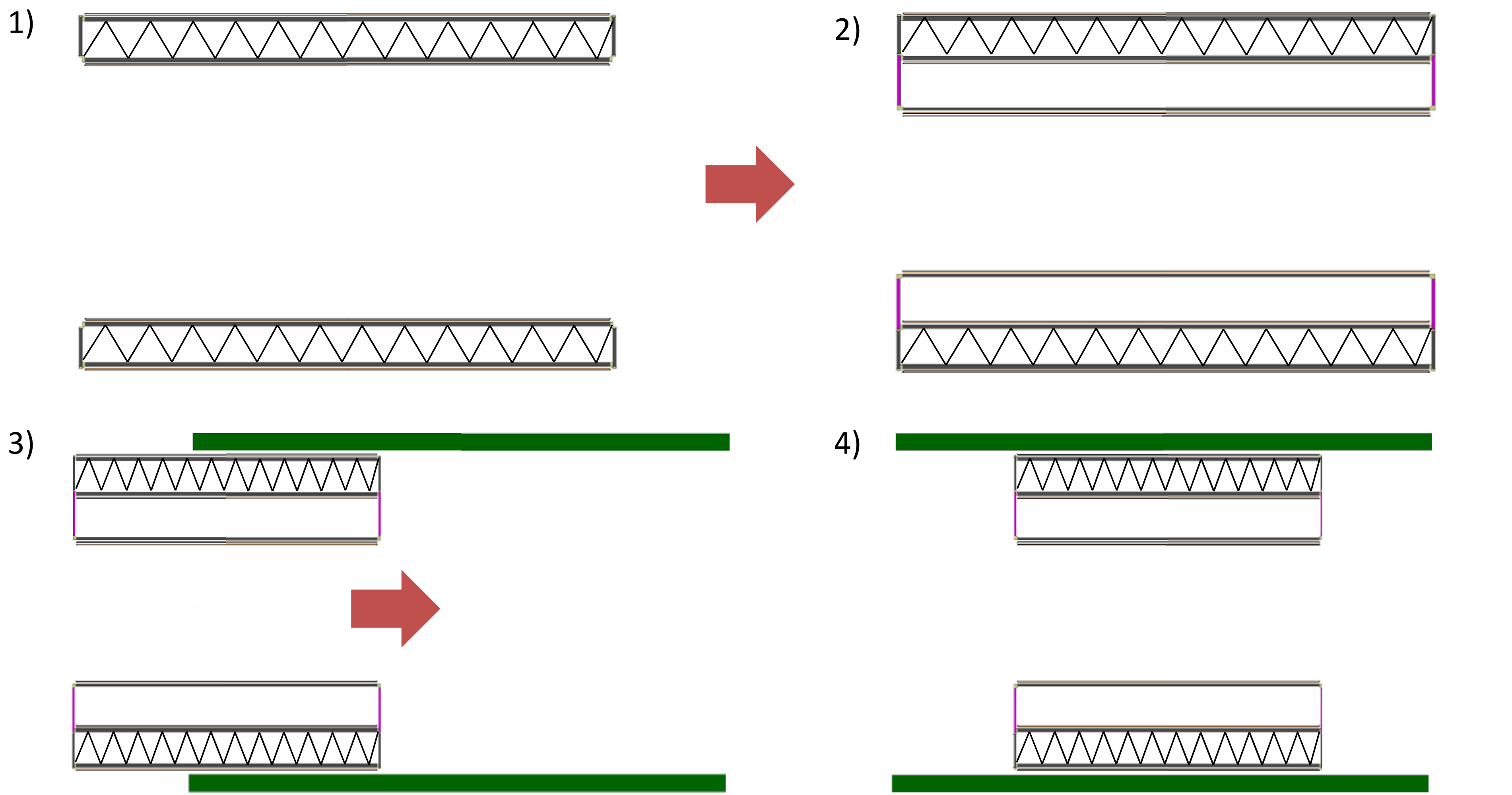
Completed assembly of Inner Tracker

11)



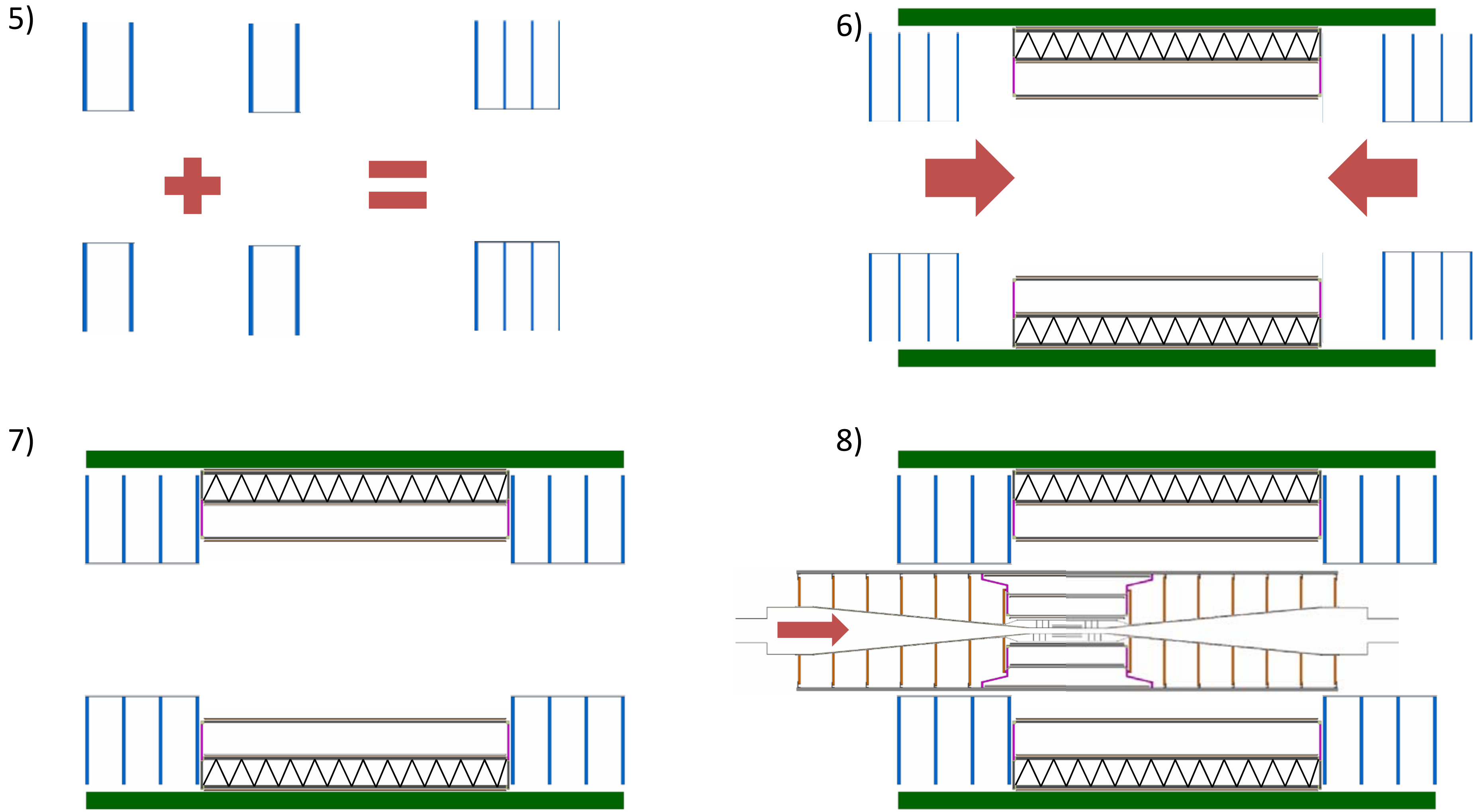
Assembly Sequence

Outer Tracker - Barrel



Assembly Sequence

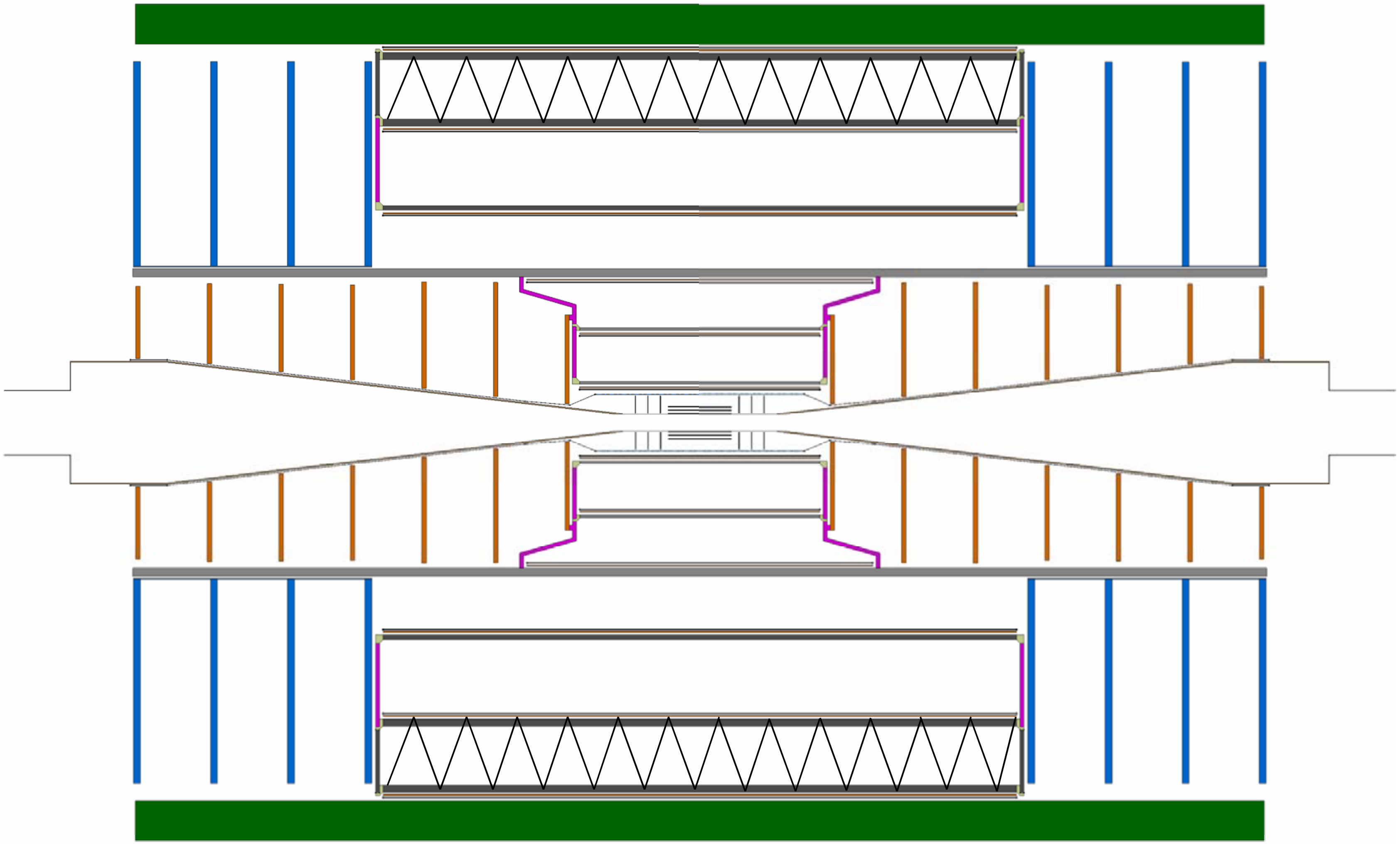
Outer Tracker - Tracker Disks



Assembly Sequence

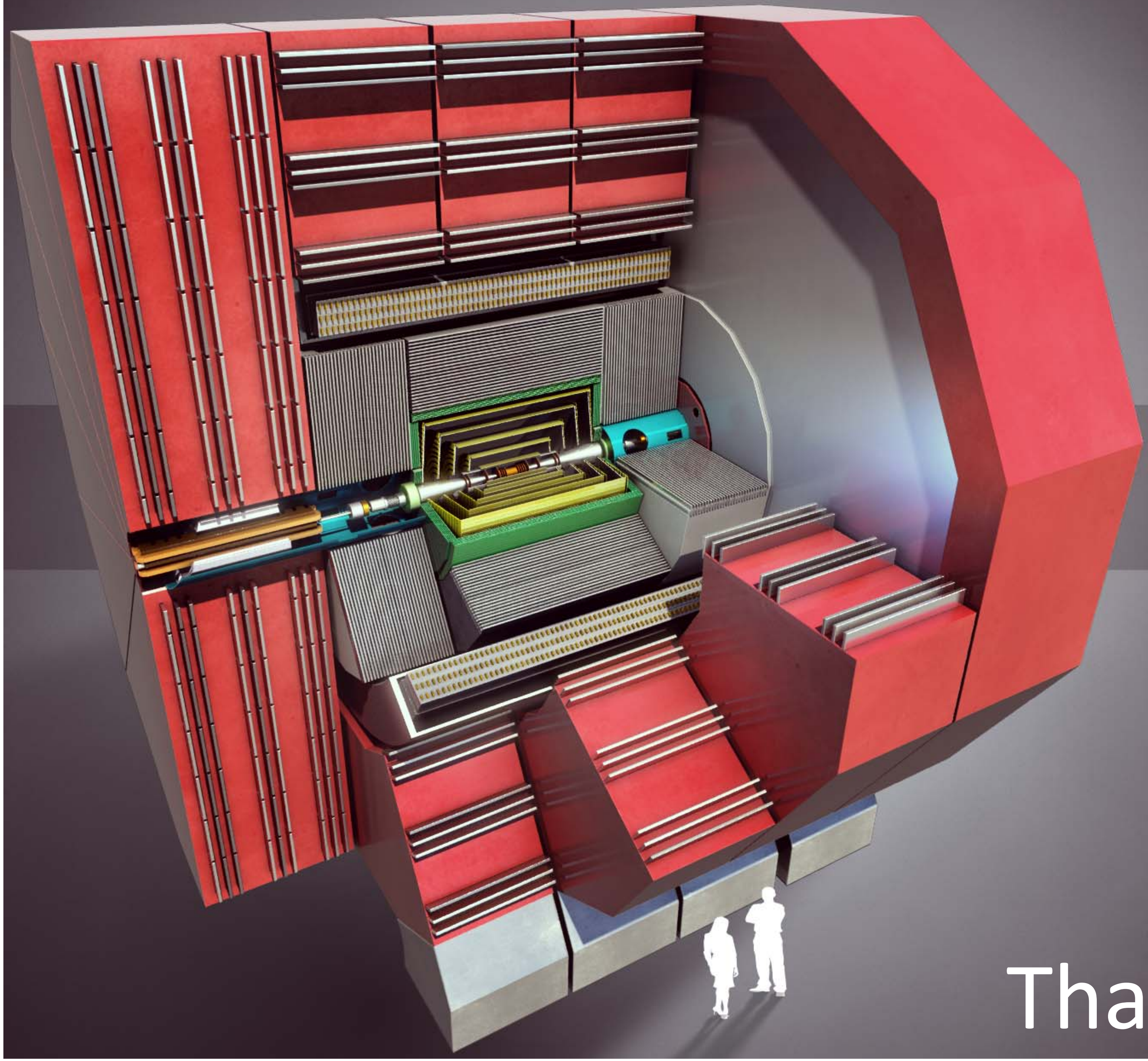
Completed assembly of Detector

9)



Summary:

- An air cooling strategy for the inner region of the CLIC detector is currently being investigated and developed
- Tests indicate that it will be possible to maintain sensor temperatures <40^{o}C for a nominal heat load of 50 mW/cm2;
- Lightweight support structure concepts for the inner & outer tracker layers (barrel & endcaps) have been shown
- Work is ongoing towards the prototyping of nodes and assembly of a portion of the outermost barrel space frame.



CLIC Detector

Thank you