VERTEX DETECTOR DESIGN AND INTEGRATION

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FCC Week 2024
San Francisco – California (USA)
10 – 14 June 2024

Outline

Progress on the layout since FCC week 2023

- New mechanical model for inner vertex Layer 3 and supports
- Lighter supports for Middle and Outer vertex

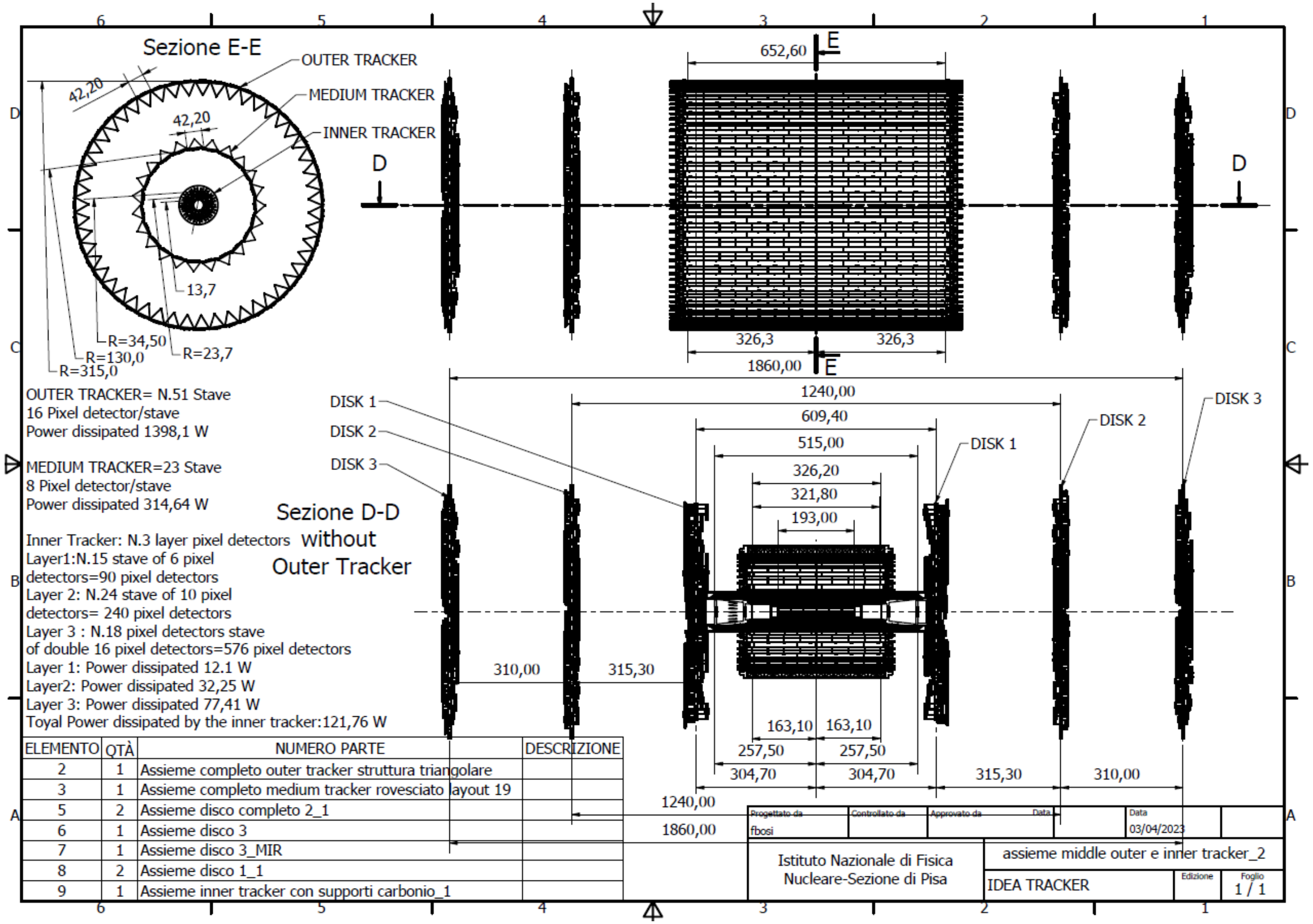
Ongoing efforts

- Integration of air cooling structures
- Air cooling studies
- Curved sensors layout studies

Conclusions

See also Armin Ilg talk on Tuesday PED session

Mid-term feasibility study vertex detector layout



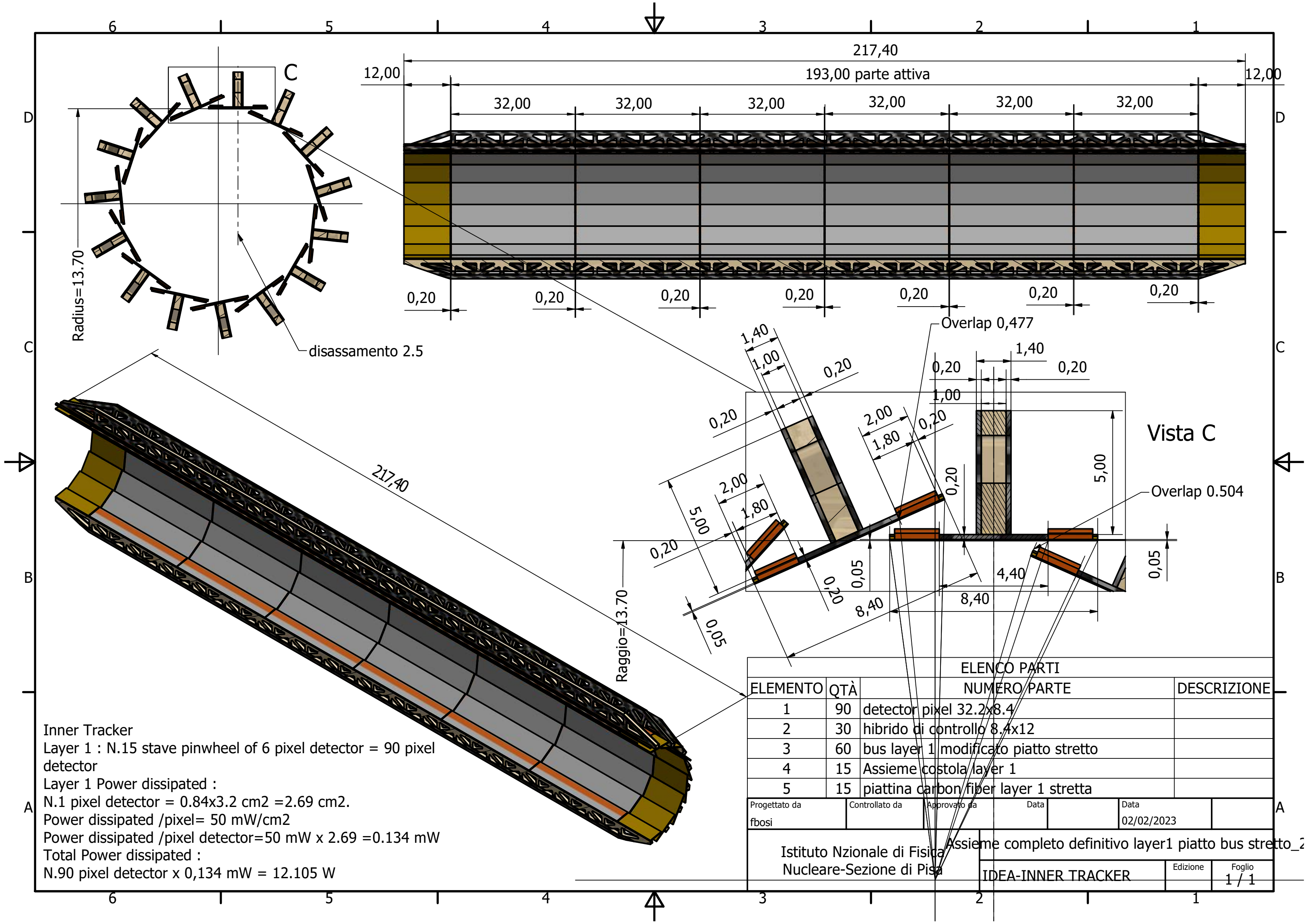
Outer vertex tracker:
ATLASPix3 based

Modules of $50 \times 150\ \mu m^2$ pixel size
- Intermediate barrel at 13 cm radius
- Outer barrel at 31.5 cm radius
- 3 disks per side

Inner Vertex detector:
ARCADIA based

Modules of $25 \times 25\ \mu m^2$ pixel size

3 barrel layers at
- 13.7, 23.7 and 34/35.6 mm radius



Layer 1

15 overlapping staves of 6 modules each

Overlap to allow alignment ~500 µm

Pinwheel geometry: all modules at the same (smallest) radius

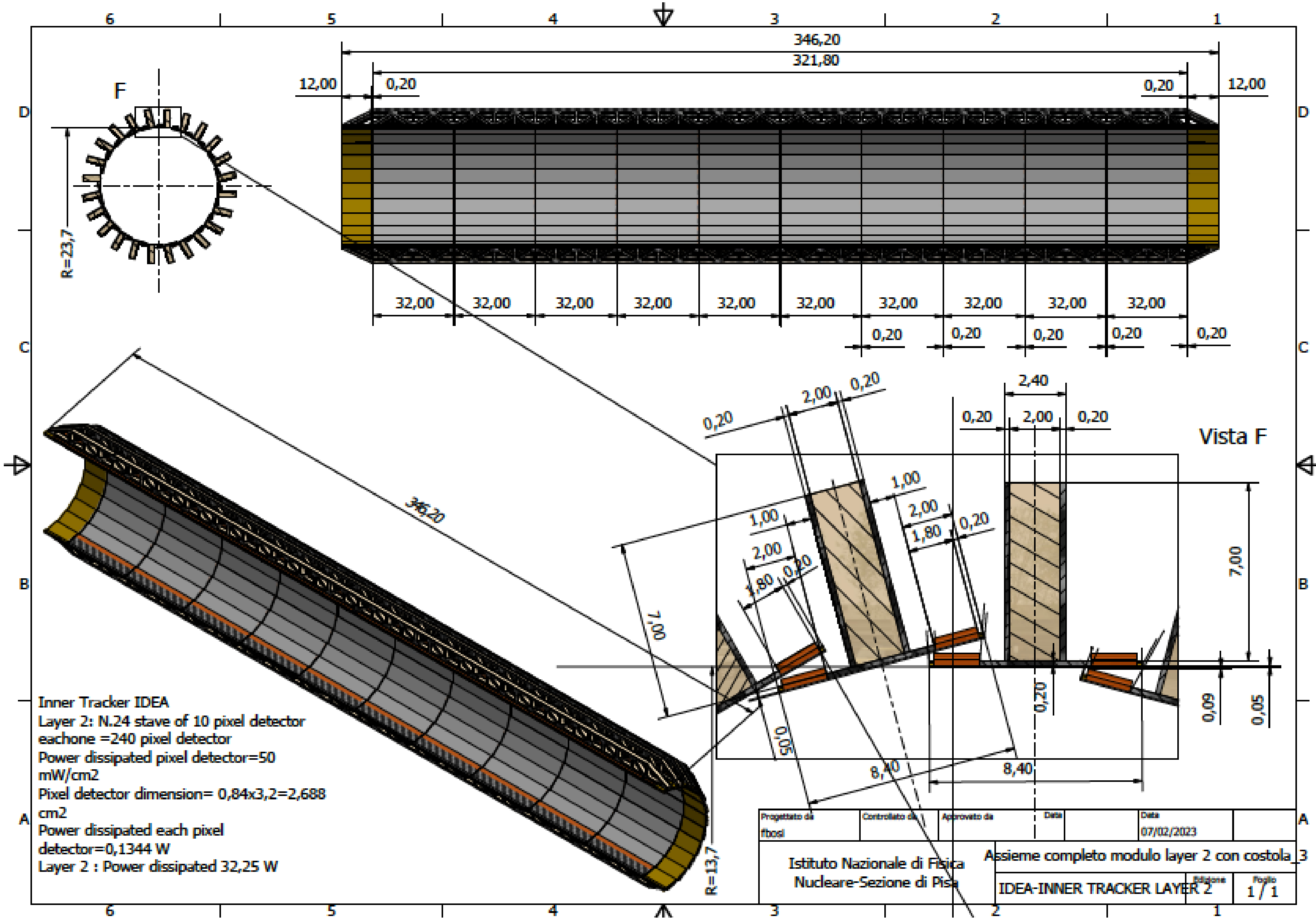
Power budget ~12 W

Total weight ~22 grams

Total thickness 0.25% X_0

Silicon: 0.053% X_0

Power and readout bus: 0.056% X_0



Layer 2

24 overlapping staves of 10 modules each

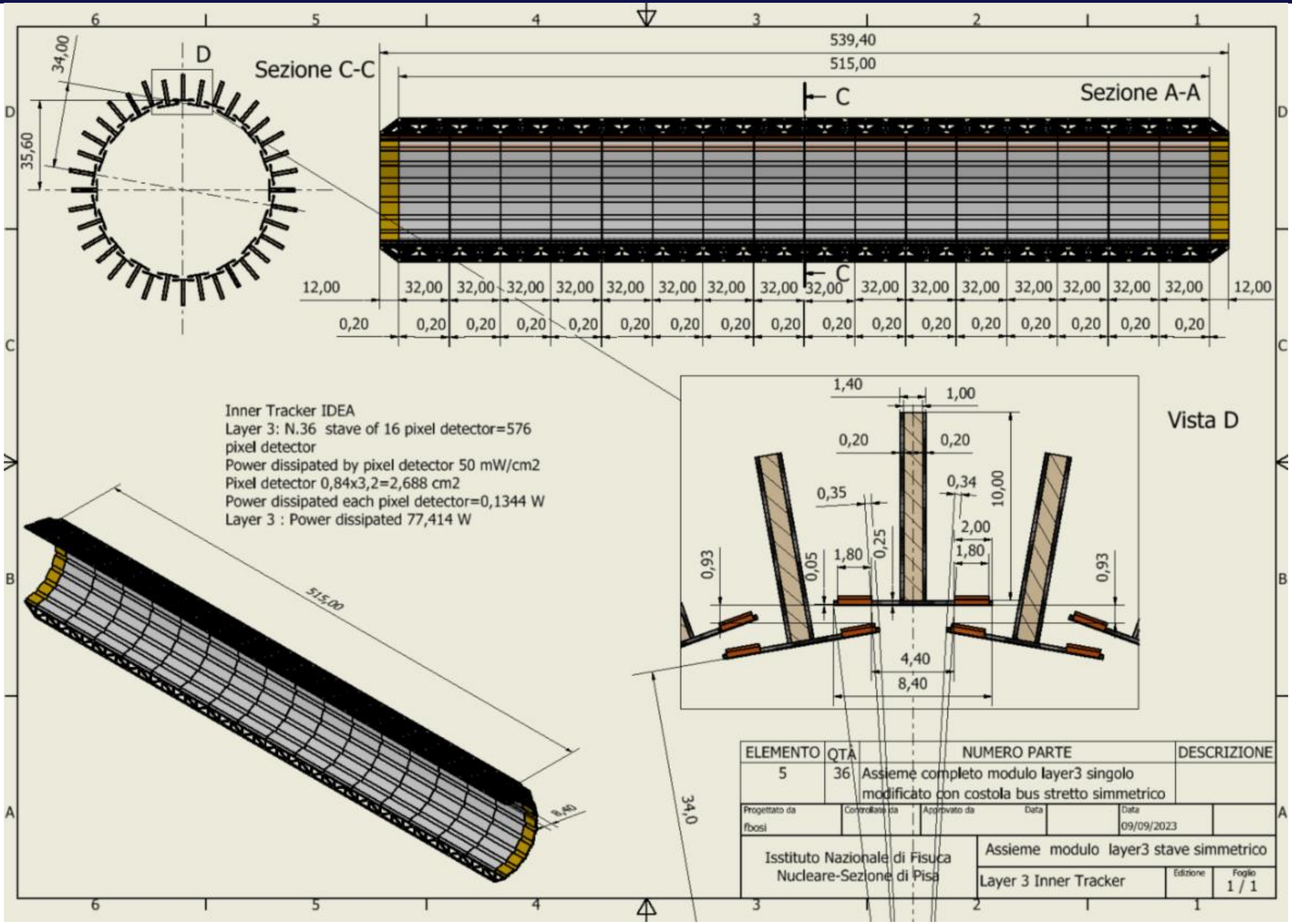
Pinwheel geometry

Counter-rotated wrt layer 1 to mitigate charge-asymmetry effects in track reconstruction

Power budget
~32 W

Total weight ~63 grams

Total thickness 0.25% X_0



New since FCC week 2023

Layer 3
36 staves of 16 modules each

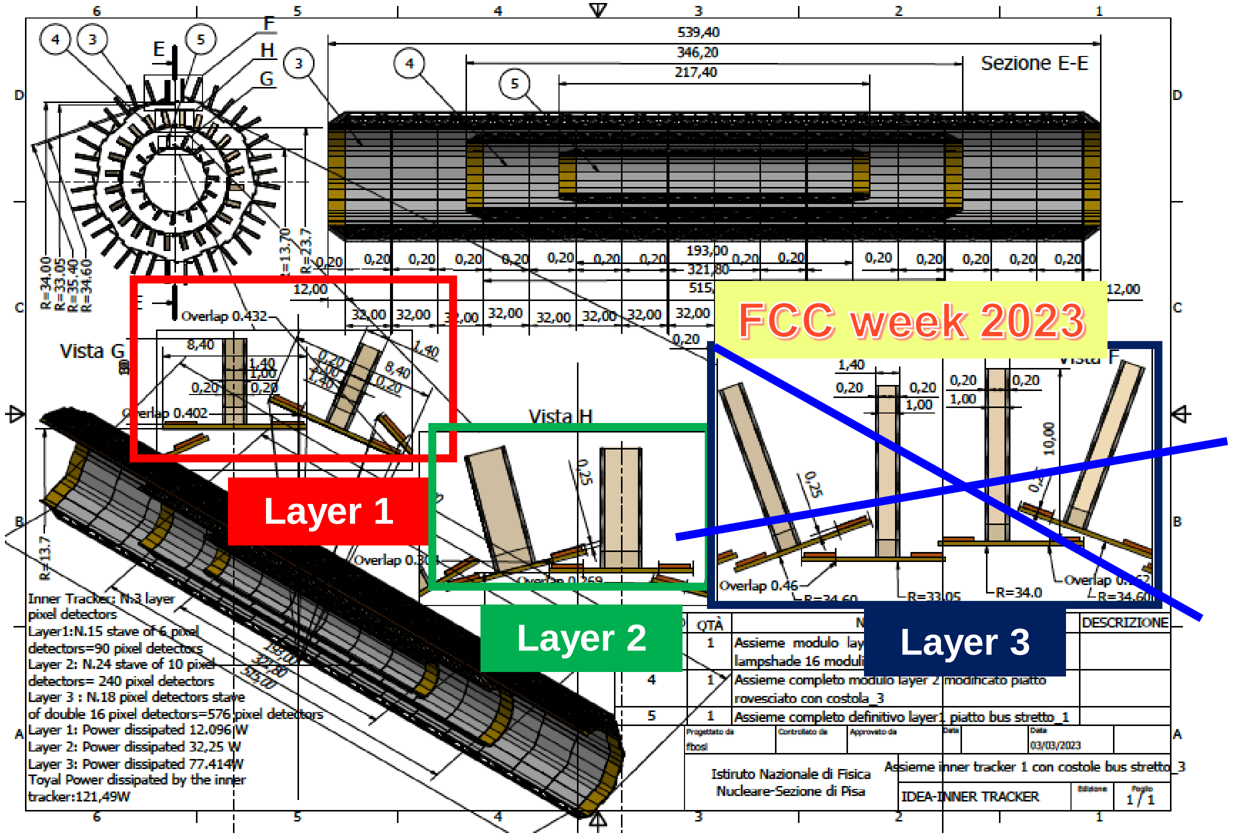
Lampshade geometry.
Charge symmetric track reconstruction

Total weight ~150 grams

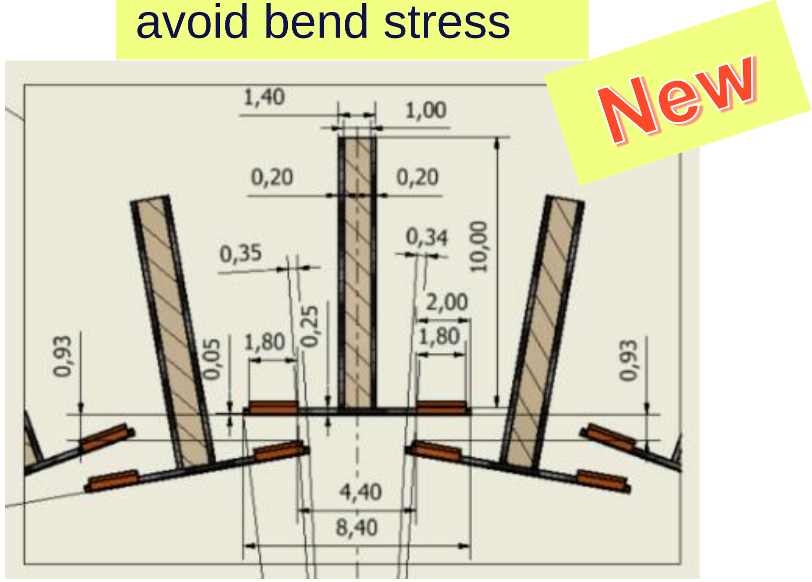
Total thickness 0.25% X_0

Power budget ~77 W

Overall Inner Vertex – FCC week 2023 vs 2024



Symmetric beam to avoid bend stress



Layer 1

- Overlap to allow alignment ~500 µm
- Pinwheel geometry
- Total weight ~22 grams
- *Power 12 Watt*

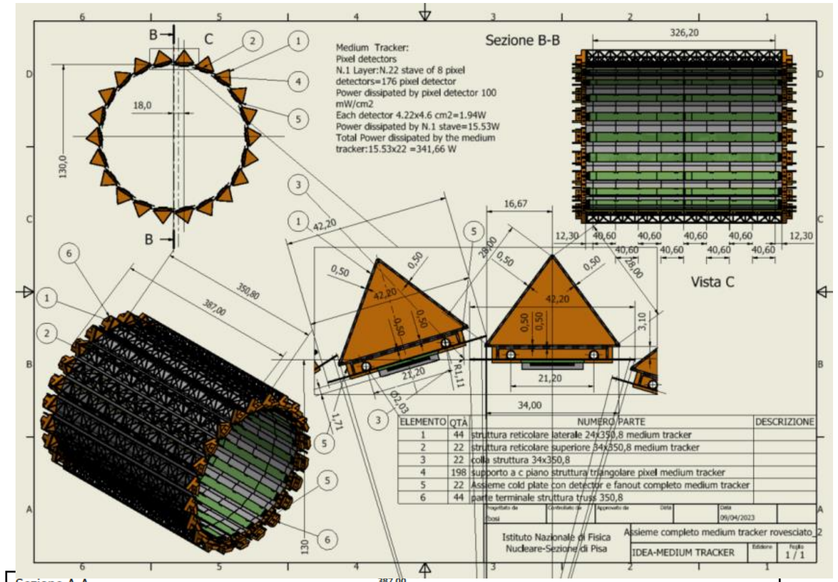
Layer 2

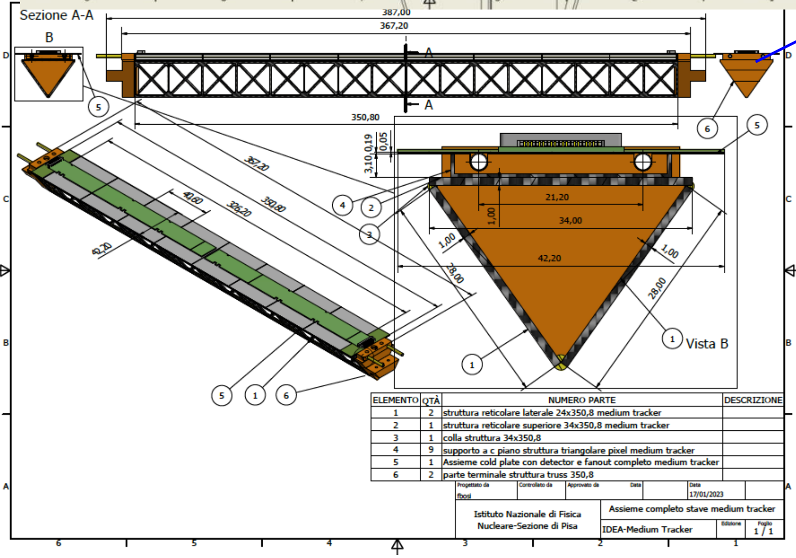
- Pinwheel geometry
- Counter-rotated wrt layer 1
- Total weight ~63 grams
- *Power 32 Watt*

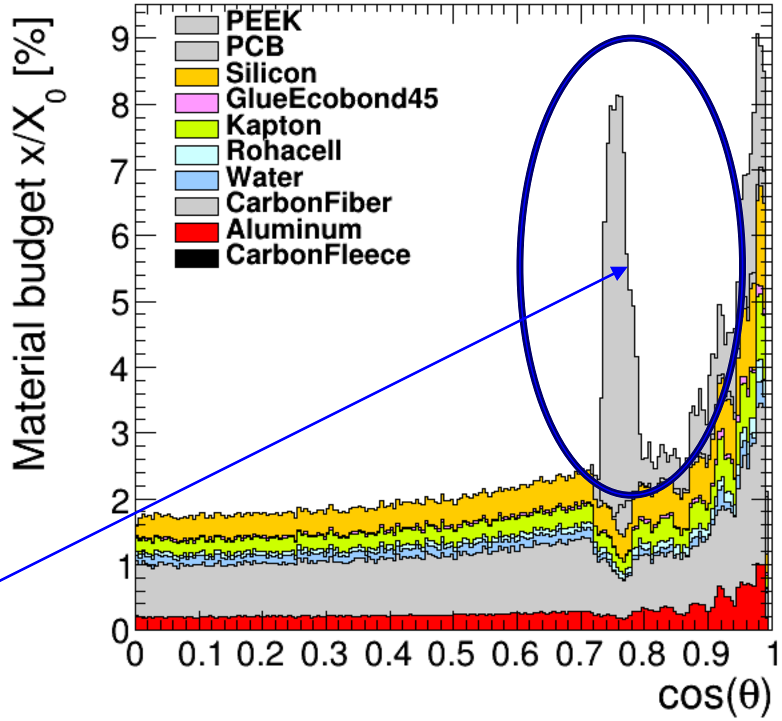
Layer 3

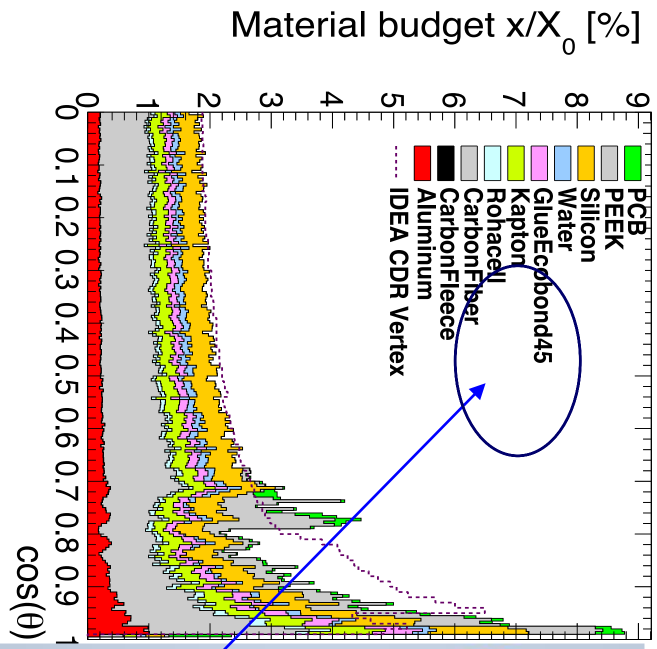
- Lampshade geometry.
- Total weight ~150 grams
- *Power 77 Watt*

Middle/outer vertex supports optimisation

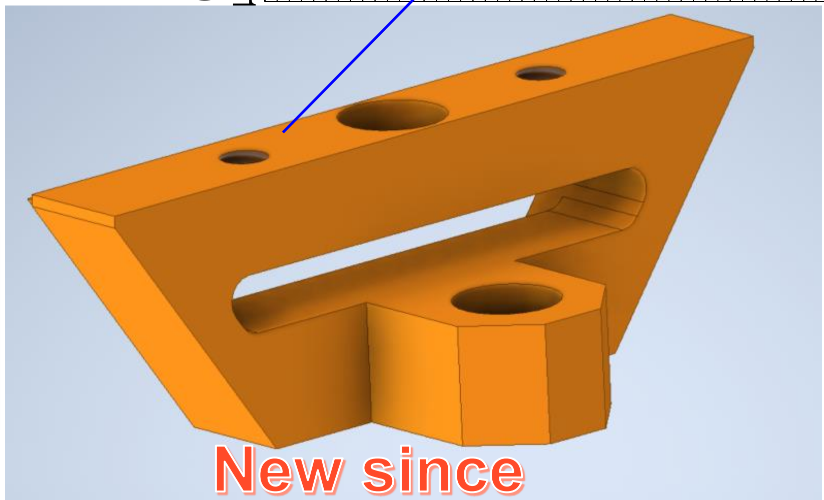






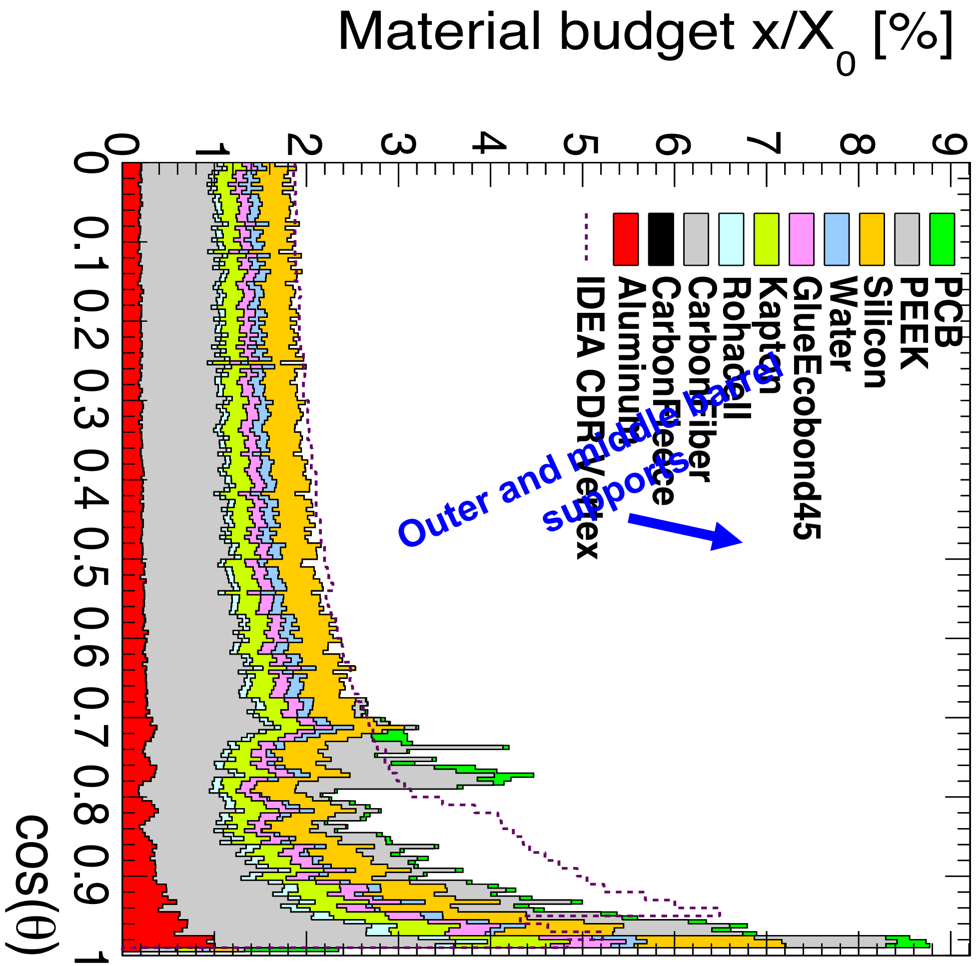


Shaped to minimize material at the end of the stave



New since FCC week 2023

Simulated material budget

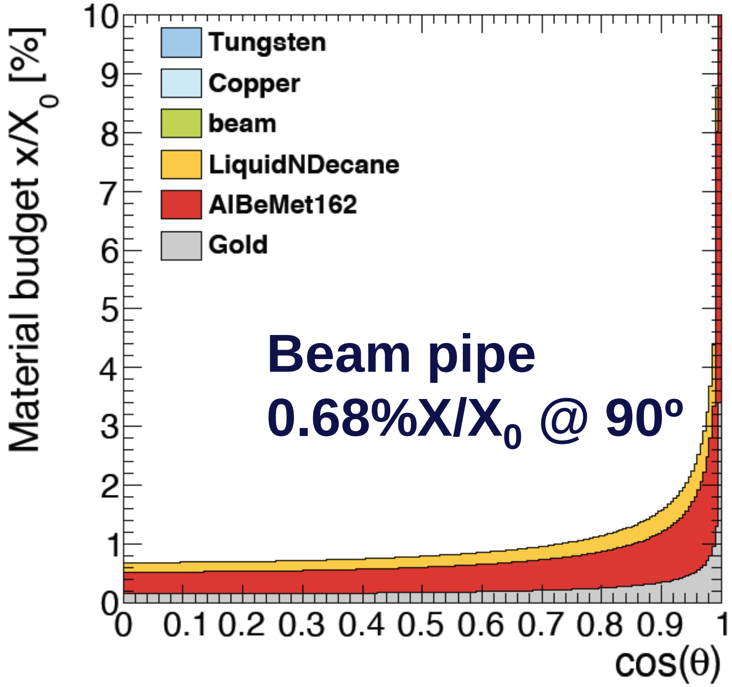


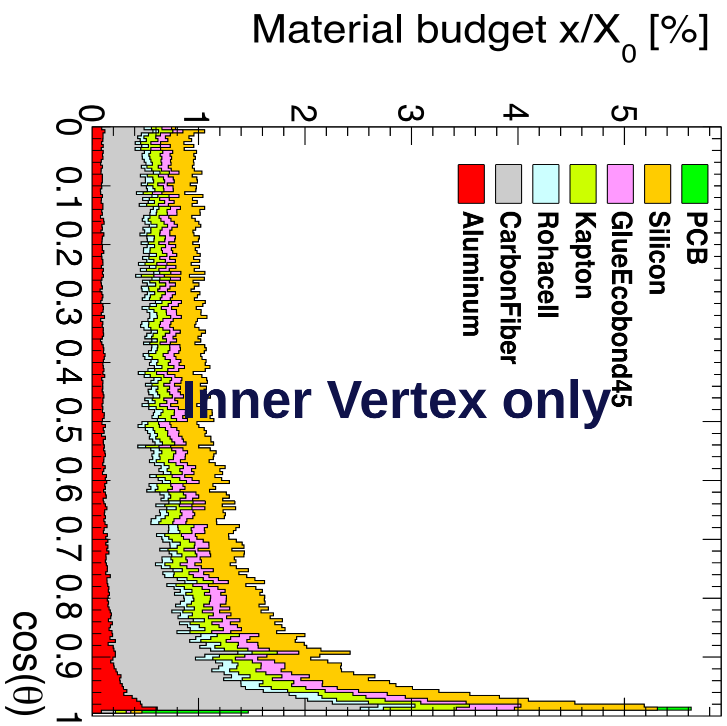
New since FCC week 2023

In agreement with CAD estimates

Smaller X/X_0 wrt IDEA CDR estimates even including power and readout cables in the sensitive region

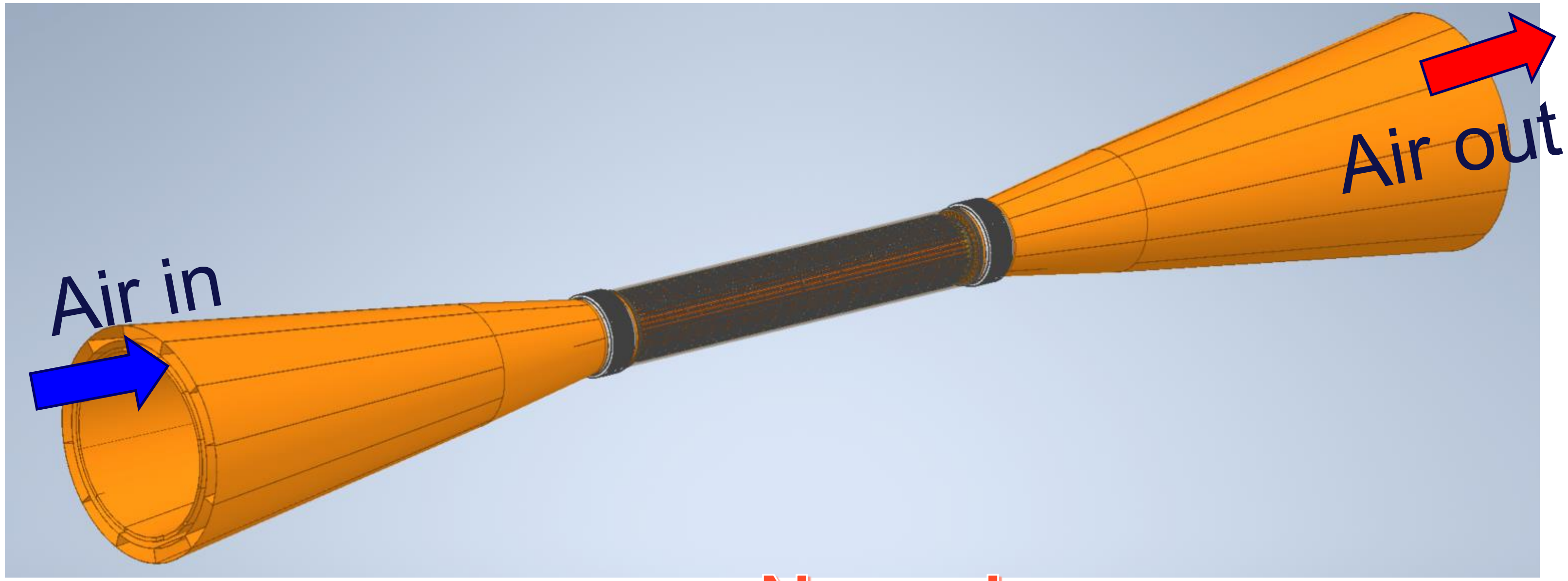
Silicon only ~15% of the total



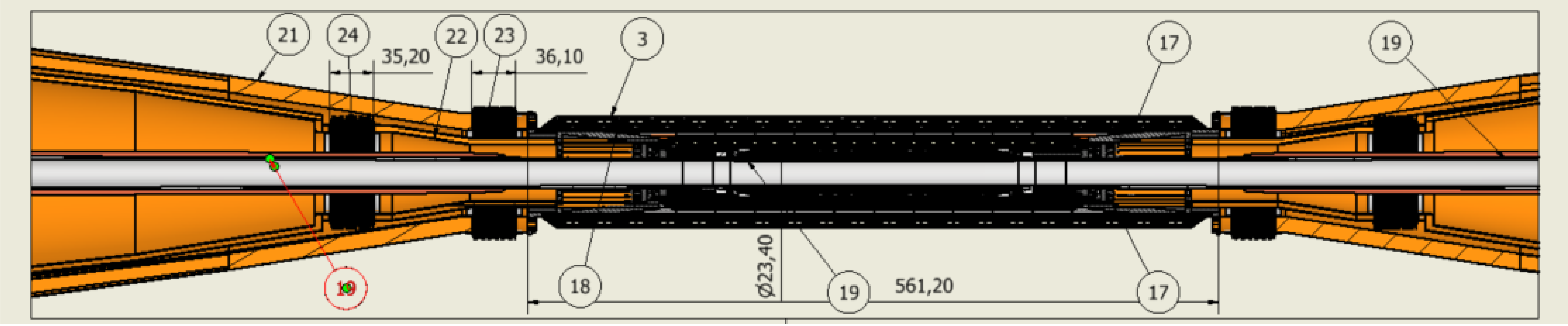


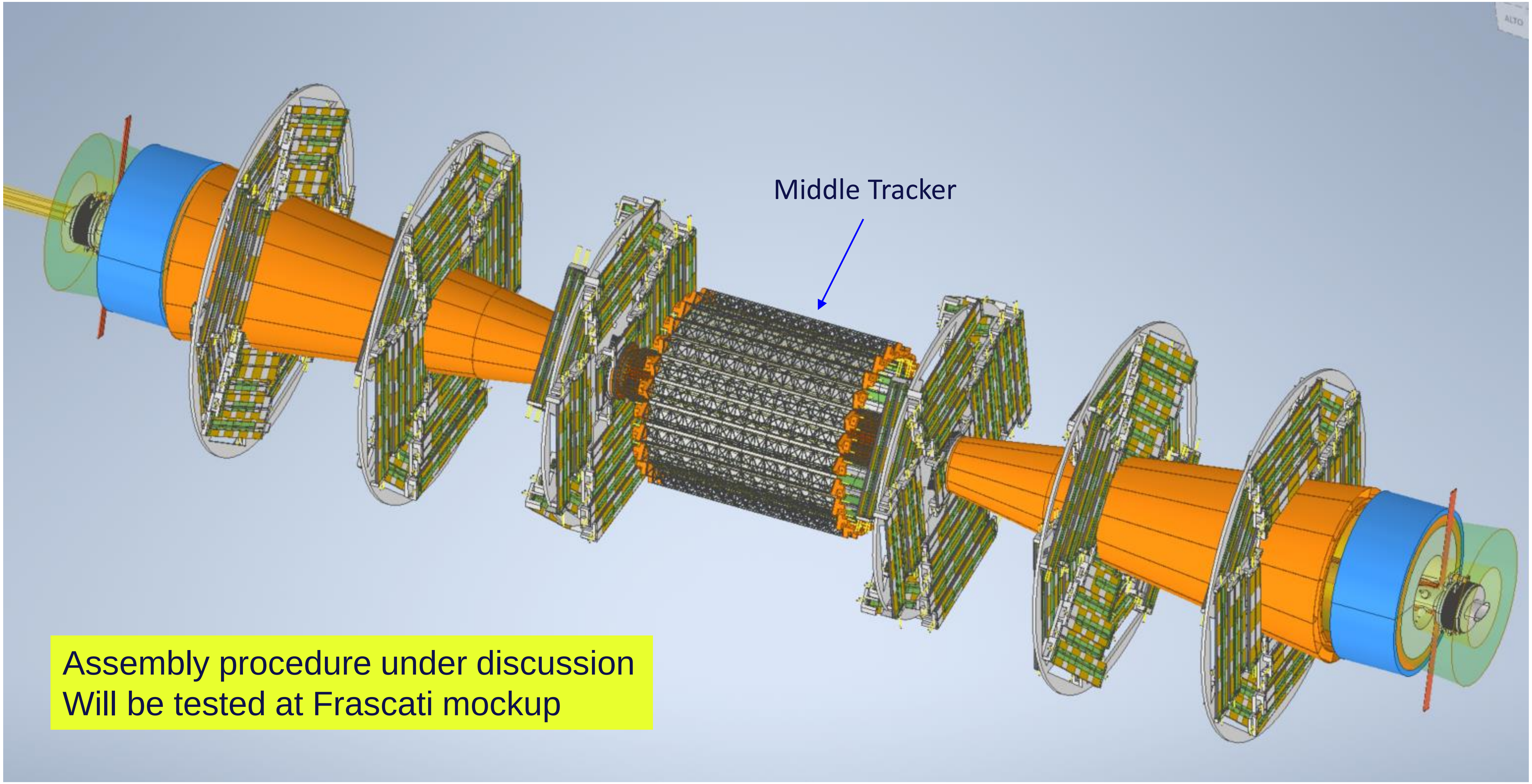
Air cooling + Cables cones

Elastically joined with bellows to the inner vertex to avoid stress.



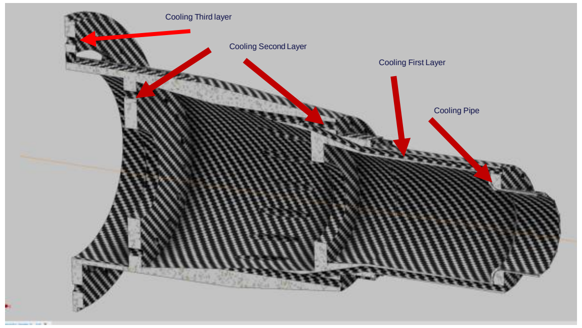
New since FCC week 2023

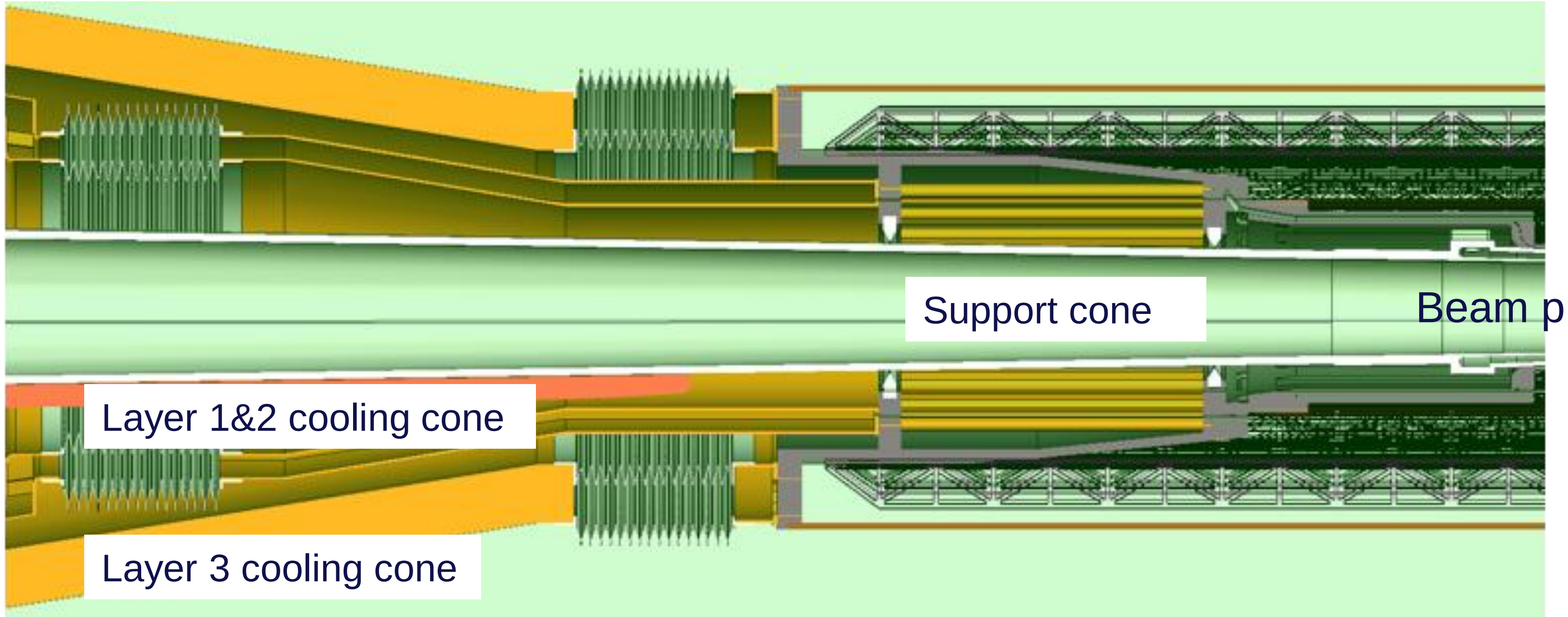




Assembly procedure under discussion
Will be tested at Frascati mockup

Inner vertex support and cooling cones

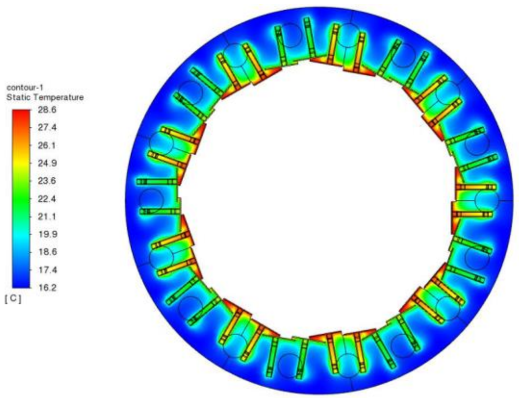




New since FCC week 2023

- Anchored to the conical chamber
- Air cooled
- Thermally isolated from the beam pipe during bakeout (150 ºC), by peek supports

Air cooling simulations

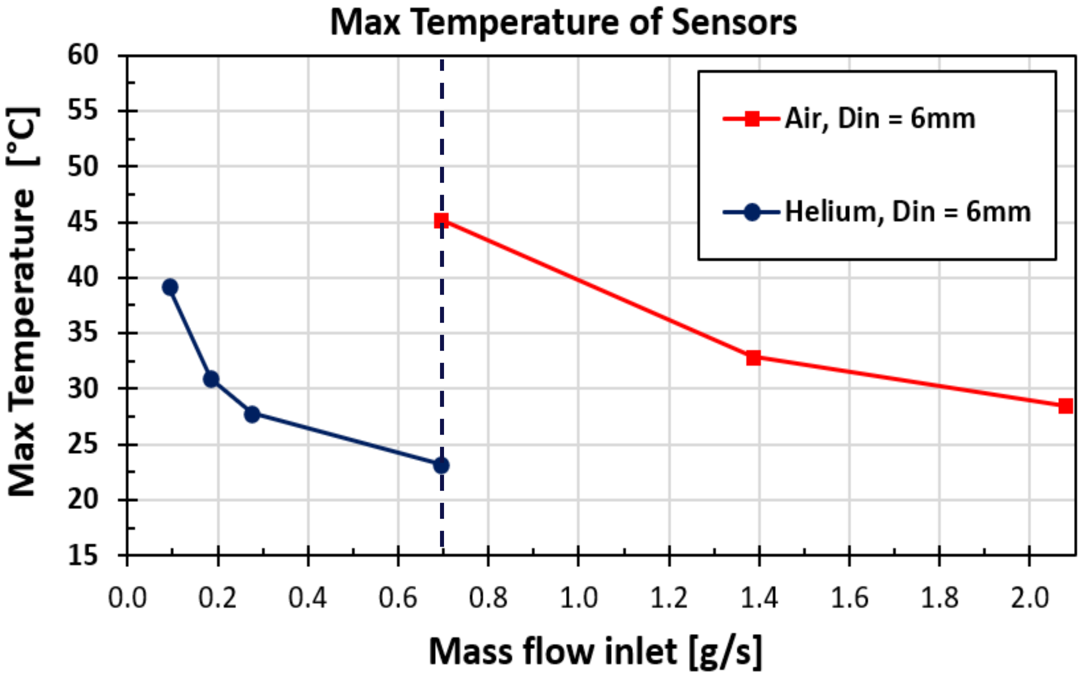


Layer 3 – largest power dissipation: 77 W

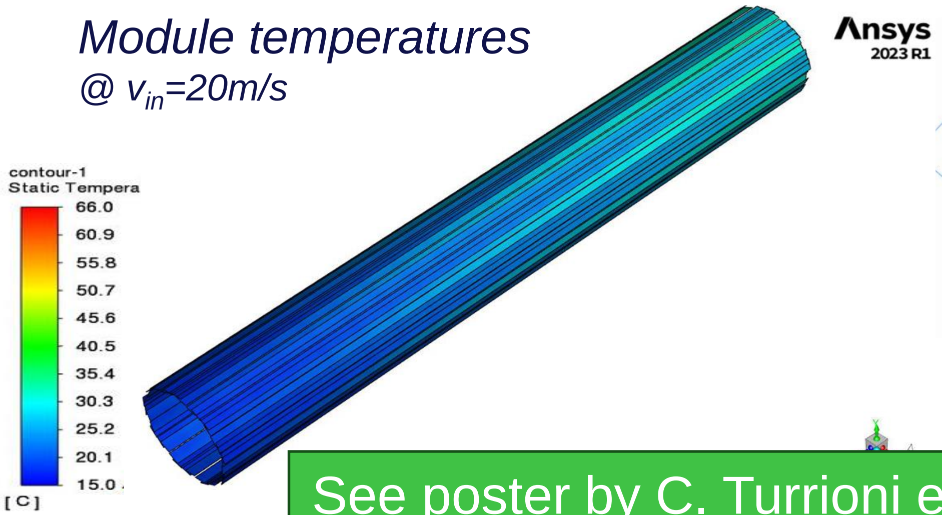
Optimization of flow rate

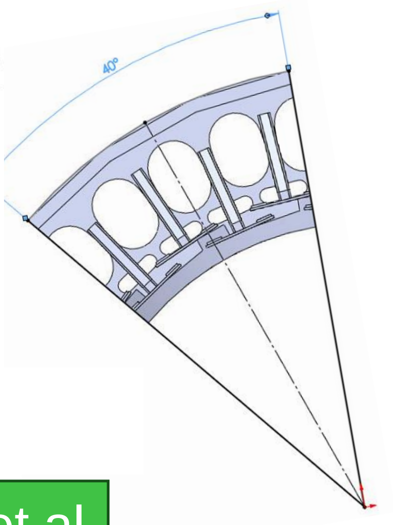
Compare Air with Helium

Max $\Delta T < 10^{\circ}\mathrm{C}$ achievable

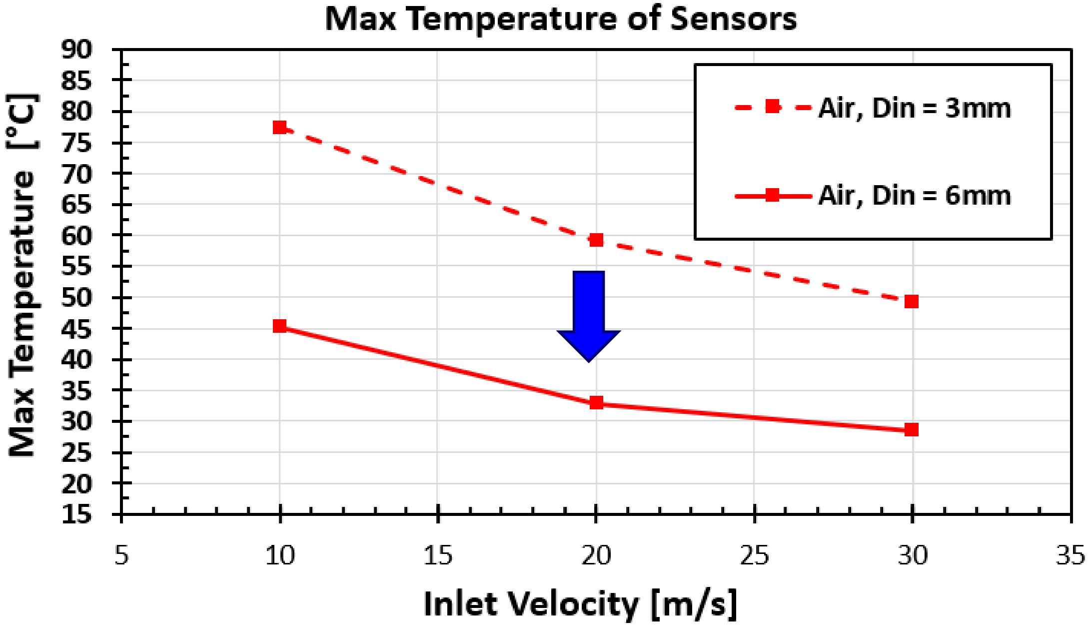


Module temperatures
@ v_{in}=20m/s

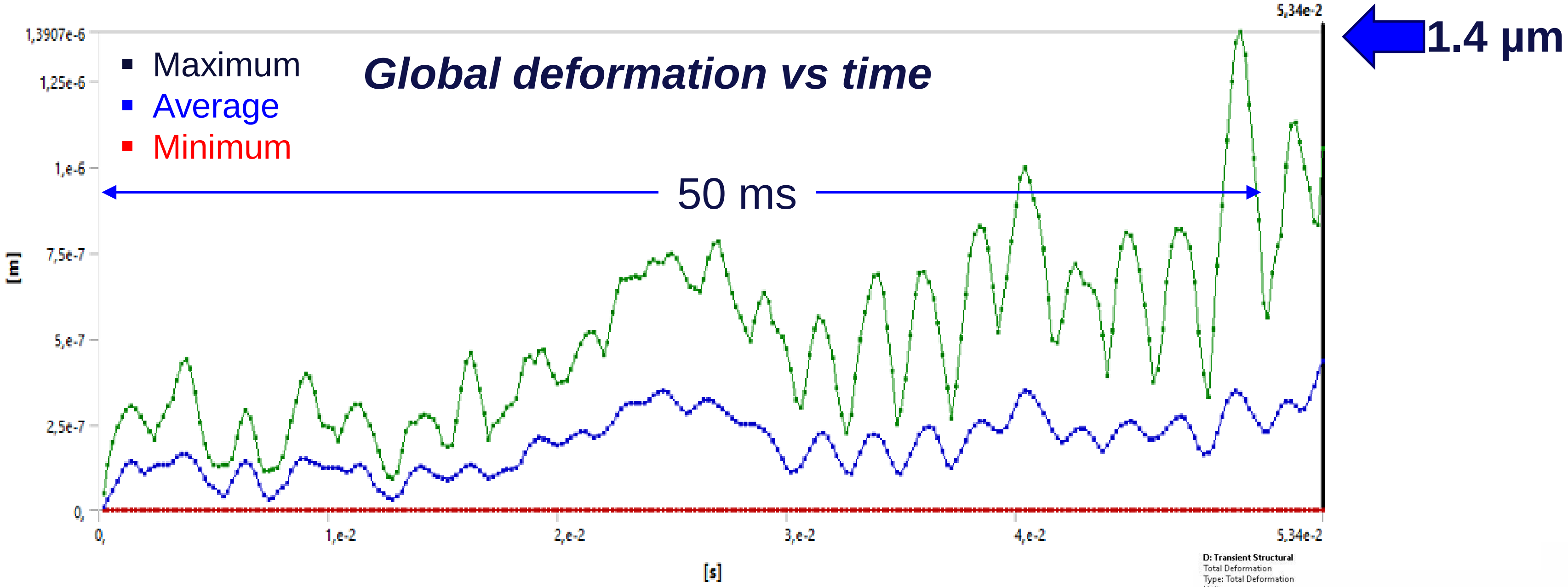


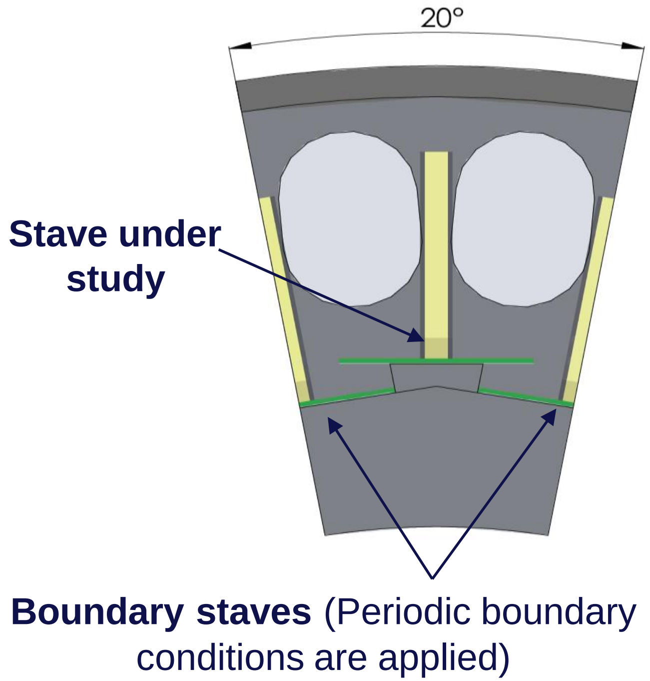


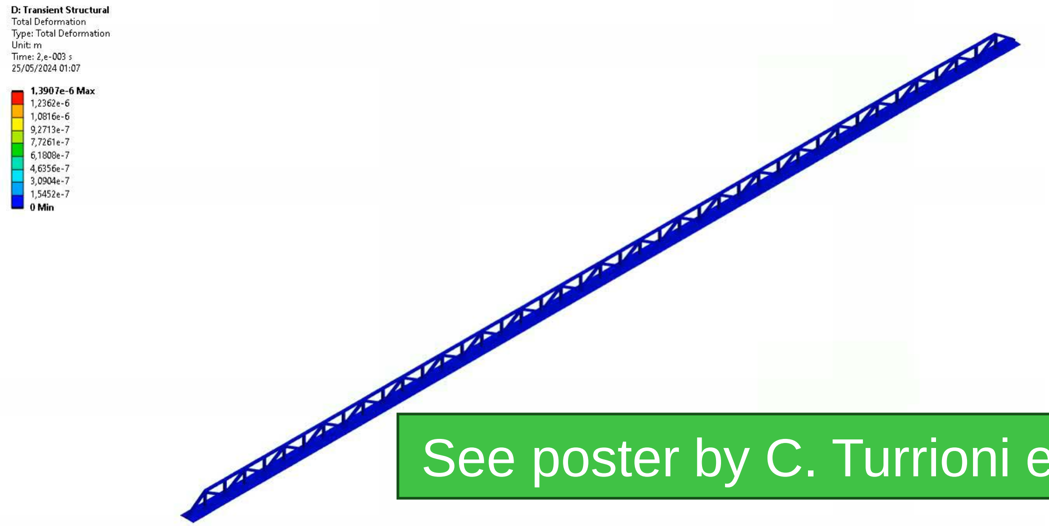
See poster by C. Turrioni et al



Transient mechanical analysis





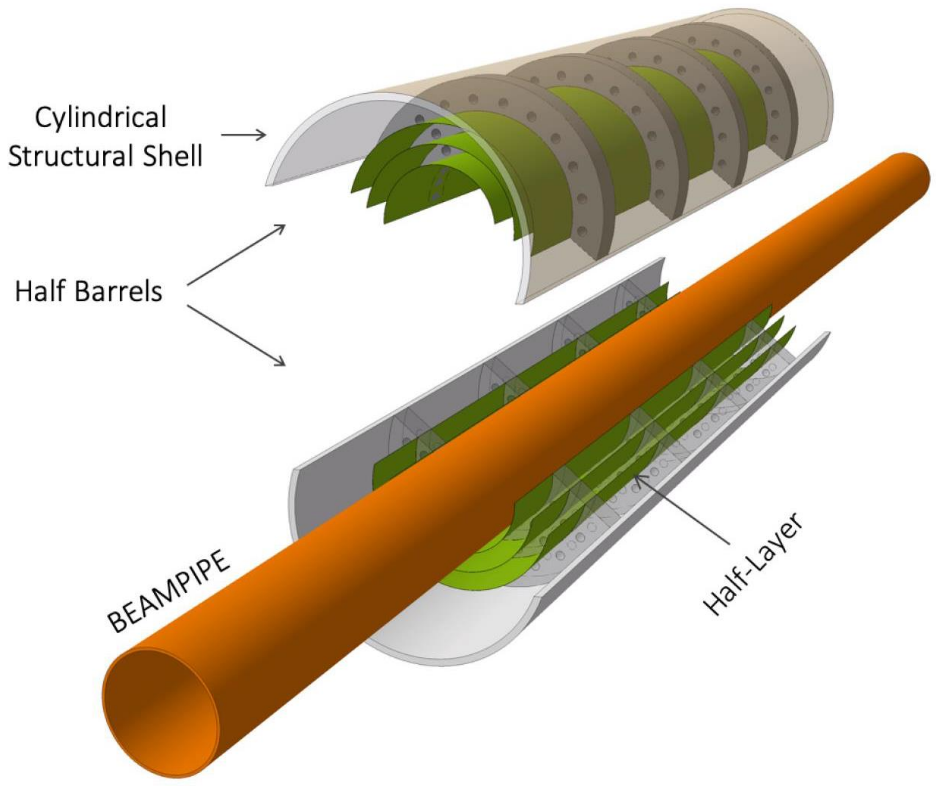


Maximum displacement ~ 1.5 µm @ v_{in} = 10 m/s due to first flapping mode – can be easily mitigated by redesign the supporting cone envelope.

More simulations ongoing changing boundary conditions.

A test setup will be made in Pisa and Perugia to validate the simulation

See poster by C. Turrioni et al



INFN
Istituto Nazionale di Fisica Nucleare

- A mini-workshop on vertex detector technologies (including system integration and mechanical aspects) will be held at CERN on July 1 and 2, with a lot of discussions:

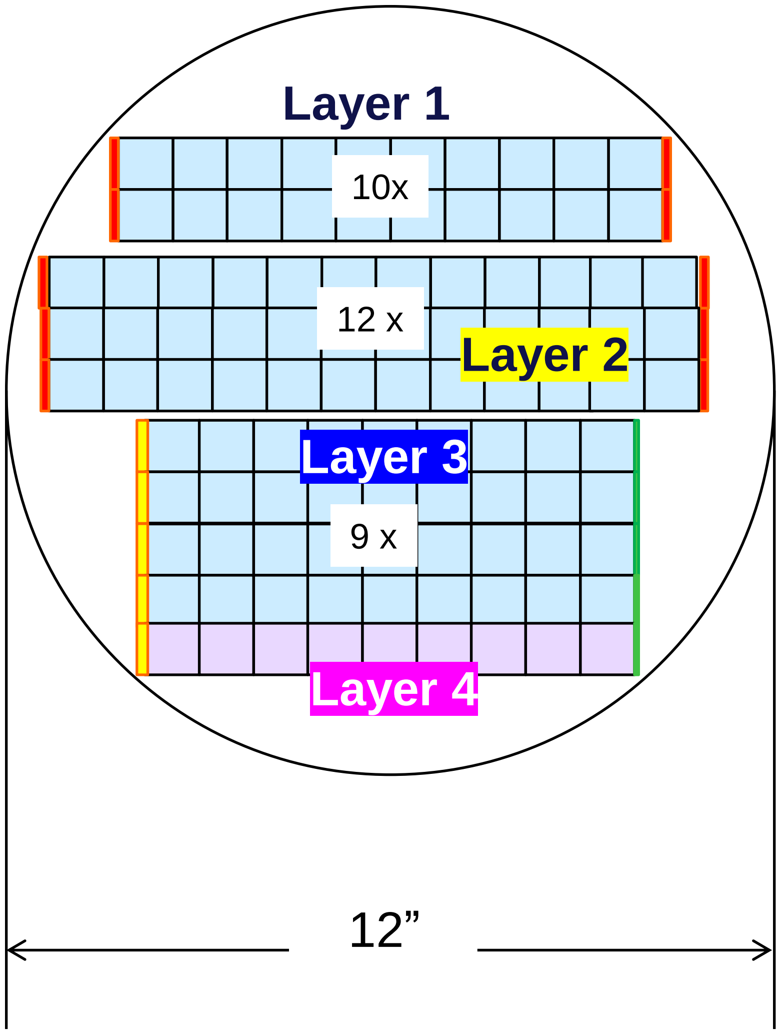
  https://indico.cern.ch/event/1417976/

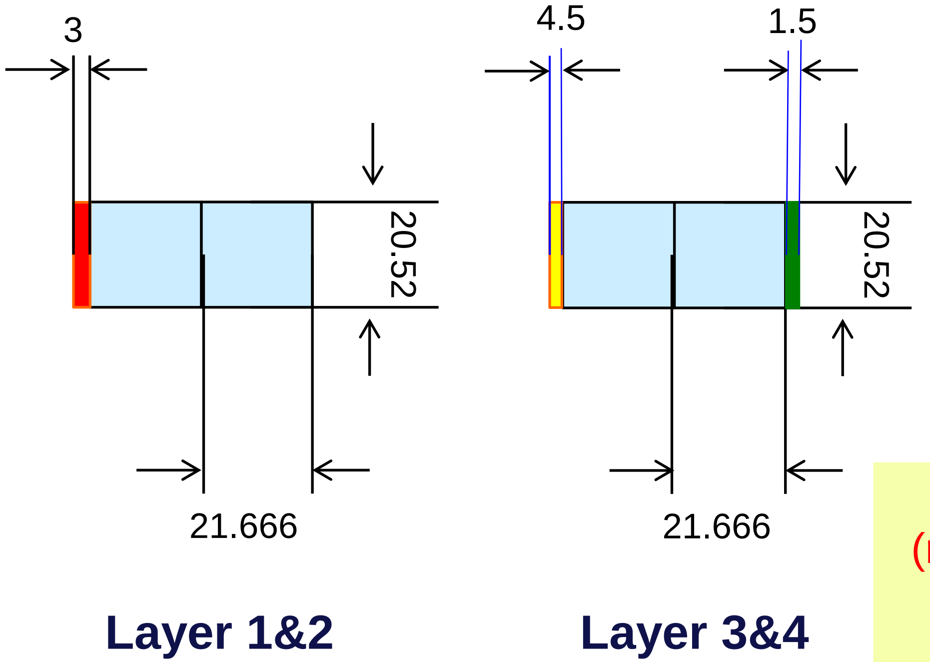
Lightweight layout using an ALICE ITS3 inspired design

($\sim 0.05\ \%\ X/X_0$ material budget per layer – 5 times less than the Mid-Term one)

*After fruitful discussions with **C. Gargiulo, A. Junique, G. Aglieri Rinella, W. Snoeys***

Same reticle for all layers





Layer	Radius (mm)
1	13.7
2	20.23
3	26.76
4	33.3

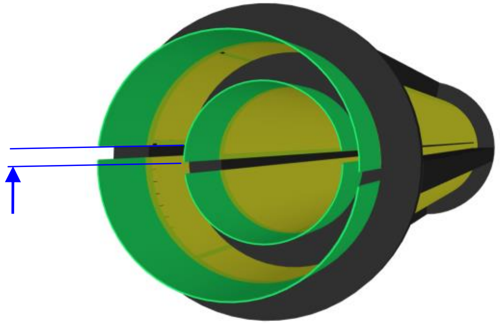
Power dissipation in ITS3
(not necessarily the same for FCC-ee)

- RSU~ 50 mW/cm^2 (depends on Temp.)
- LEC ~ 700 mW/cm^2

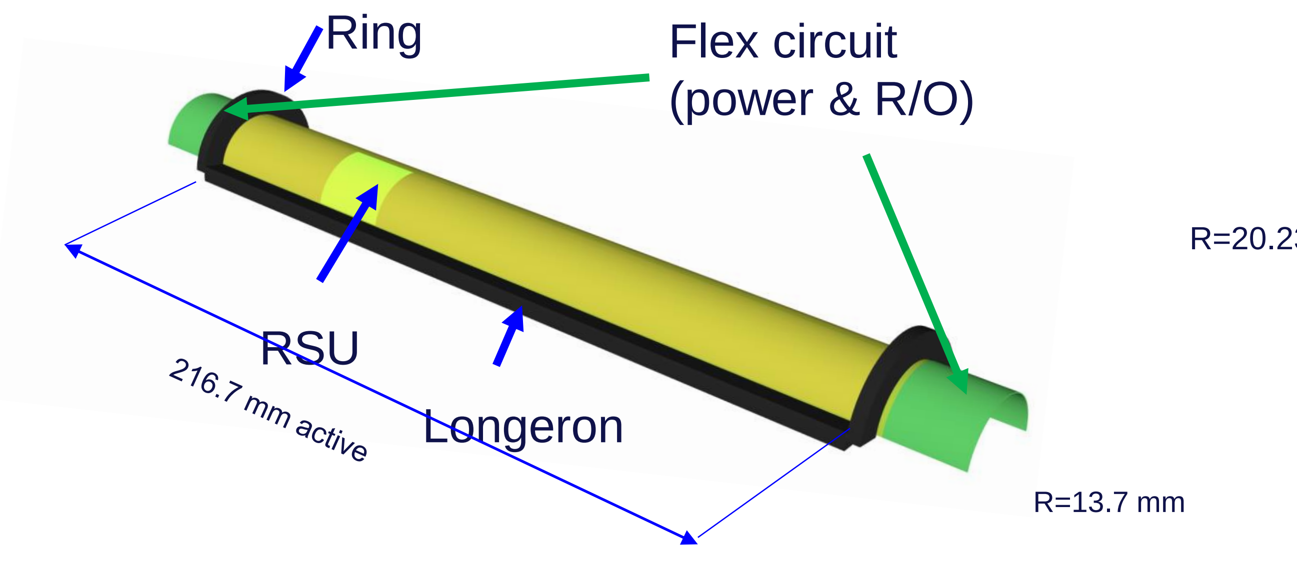
	Power density [$mW\,cm^{-2}$]		
	Expected 25 °C	Max 25 °C	Max 45 °C
Left End Cap (LEC)		791	
Active area (RSU)	28	44	62
Pixel matrix	15	32	51
Biasing	168	168	168
Readout peripheries	432	457	496
Data backbone	719	719	719

Active pixels <95% of covered area

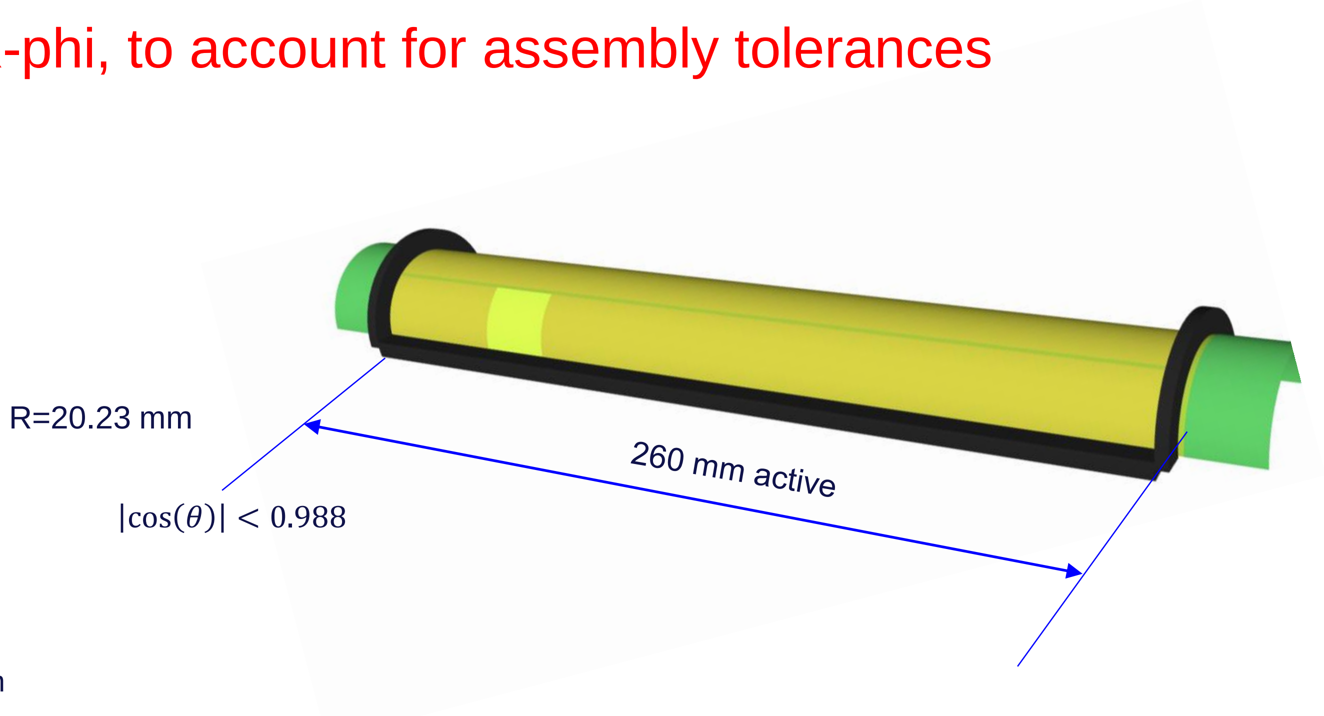
Layers 1 & 2



- Single stitched wafer
  - Readout and power from both sides (reduces transmission off-detector and limits power dissipation in the endcaps)
- Leaves ~1.25 mm* insensitive gap in R-phi, to account for assembly tolerances



Layer 1



Layer 2

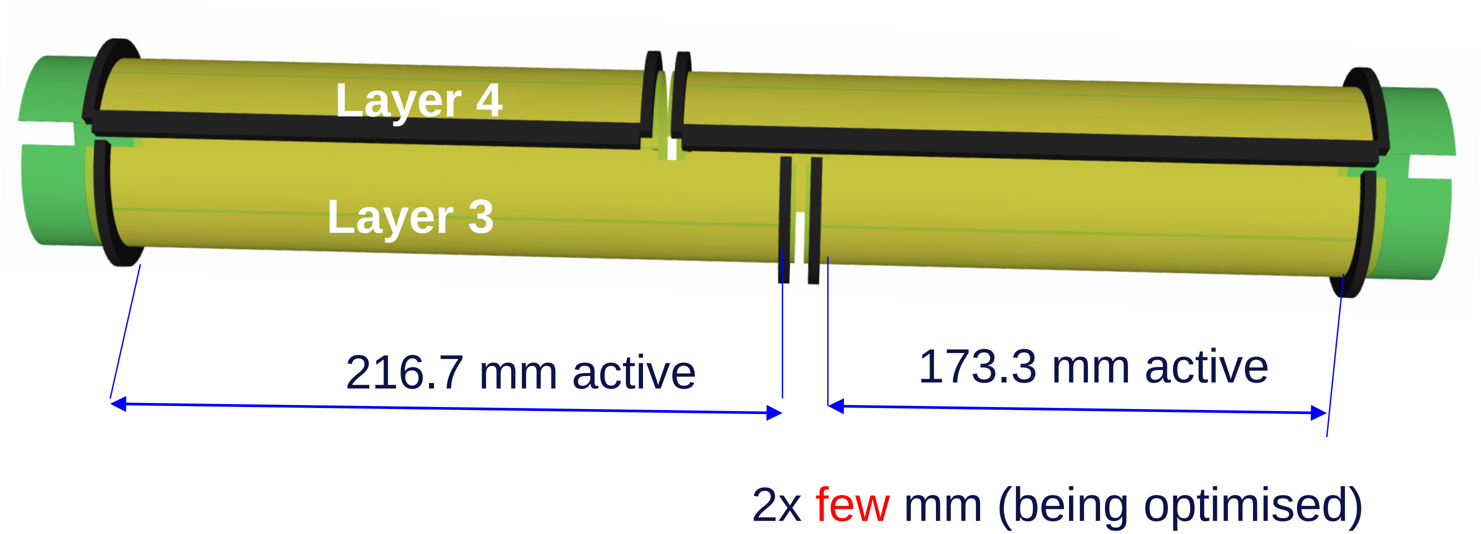
Layers 3 & 4

- Four “quarter” layers to allow ~same angular coverage for all layers and use 12” wafers
- Layer 4 has the same length of Layer 3 but higher radius
- Quarter readout only on one side, the other only for power (wire)
    - Gap of ~ 2xO(10 mm) at |z|~2.2 cm: **quarters with non-symmetric layout** (left quarter with 10 RSU and right one with 8 RSU, and swapped for L4)

Layer 3

R=26.76 mm

$|\cos(\theta)| < 0.992$

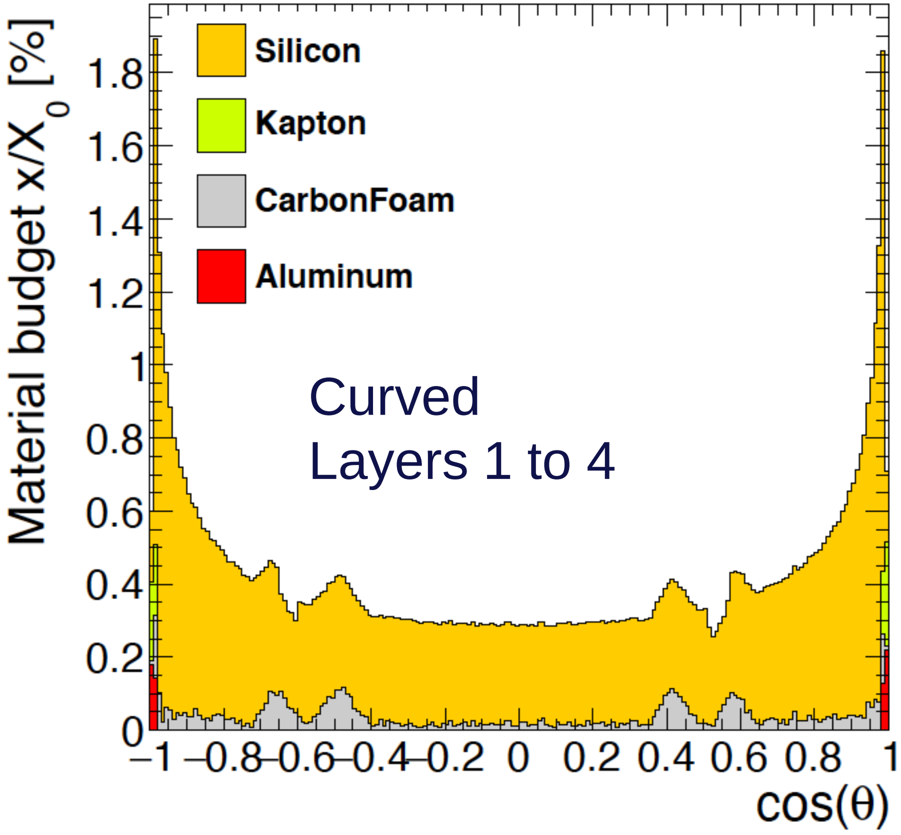


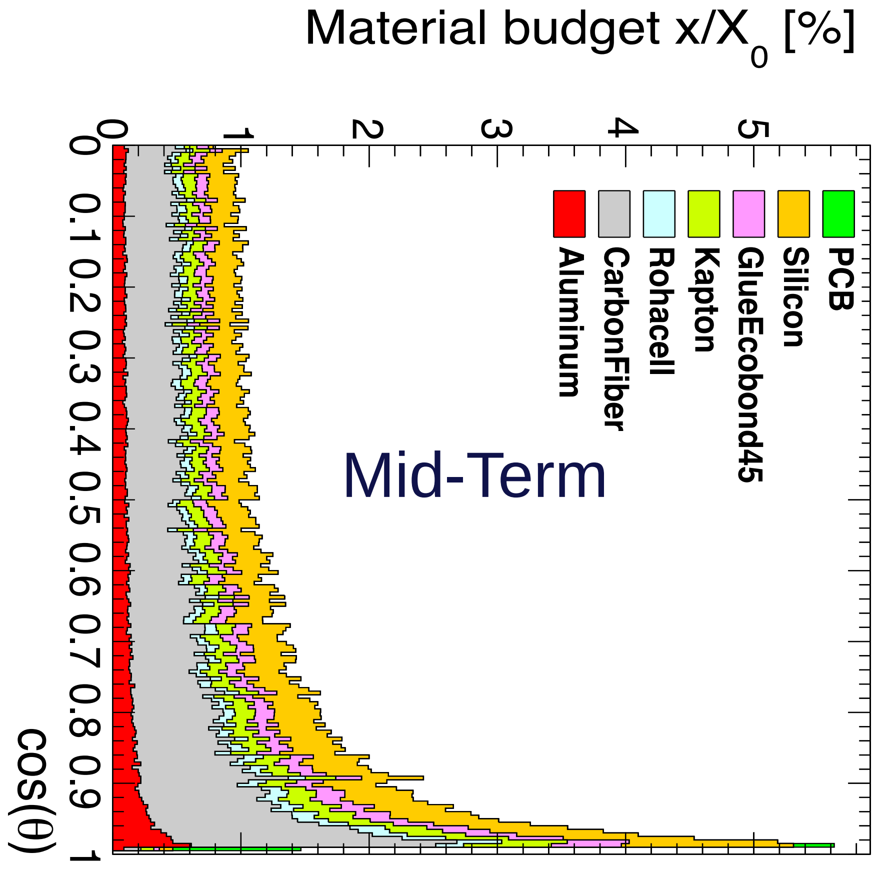
Layer 4

R=33.3 mm

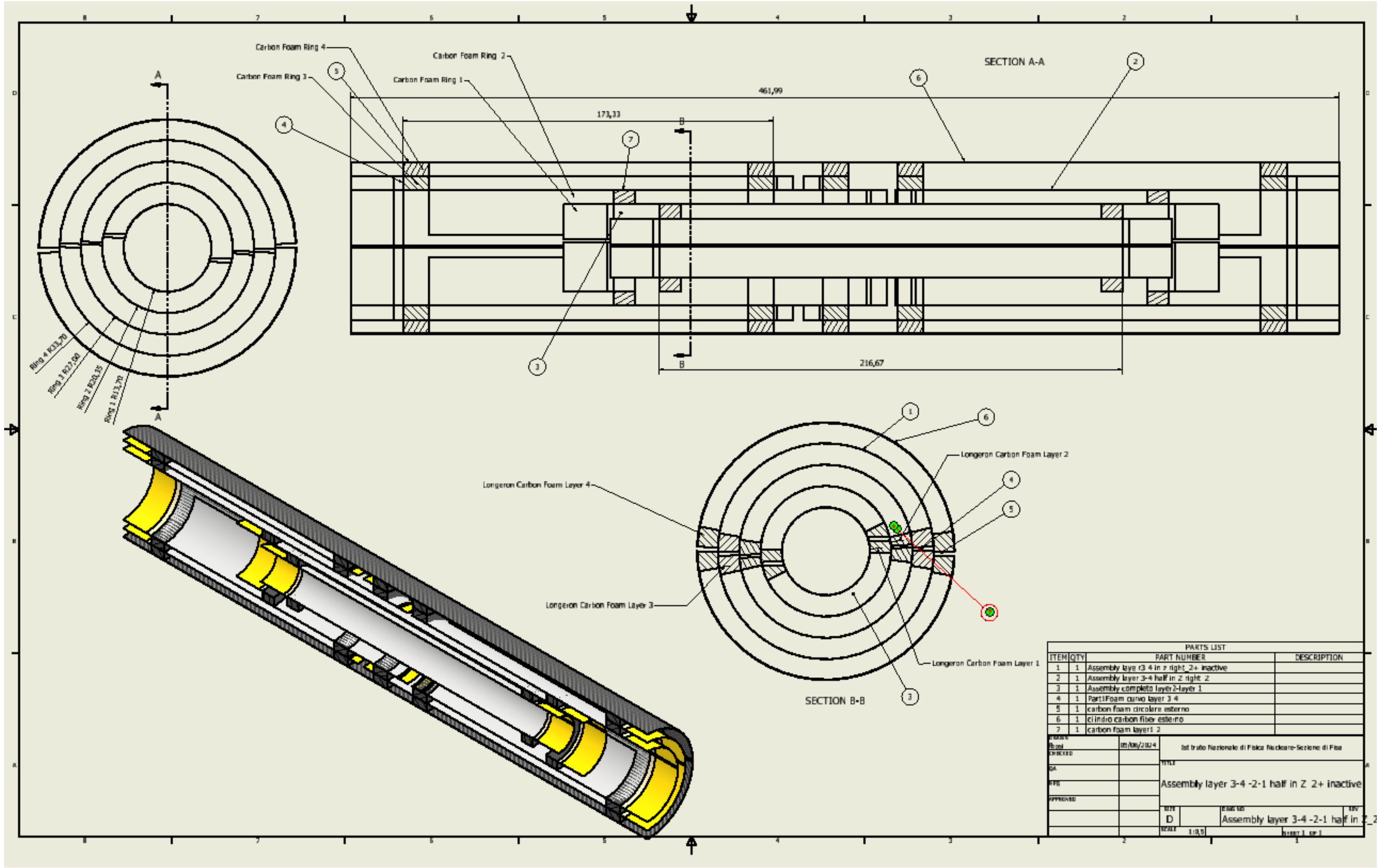
$|\cos(\theta)| < 0.987$

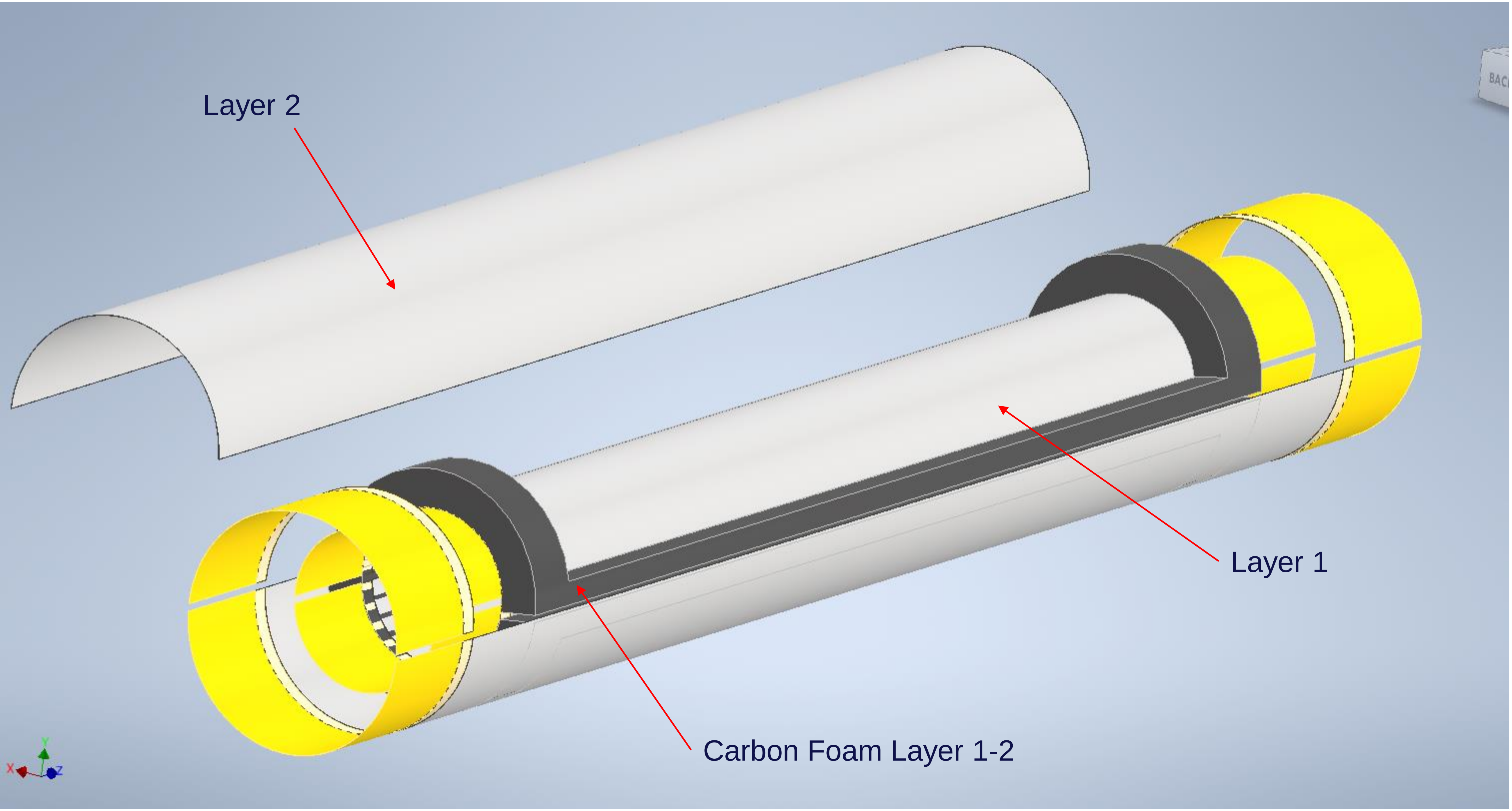
Material budget inner vertex

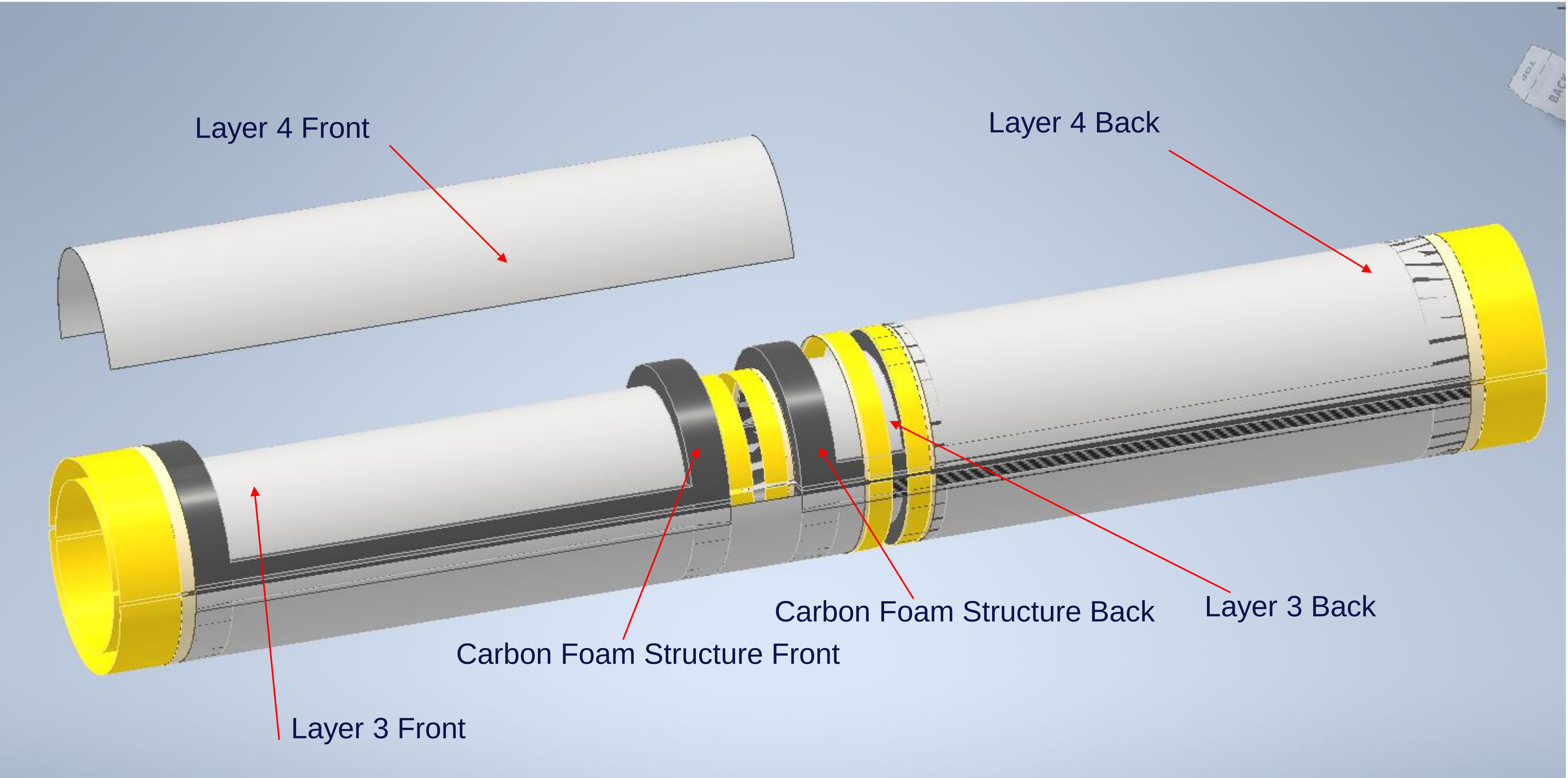




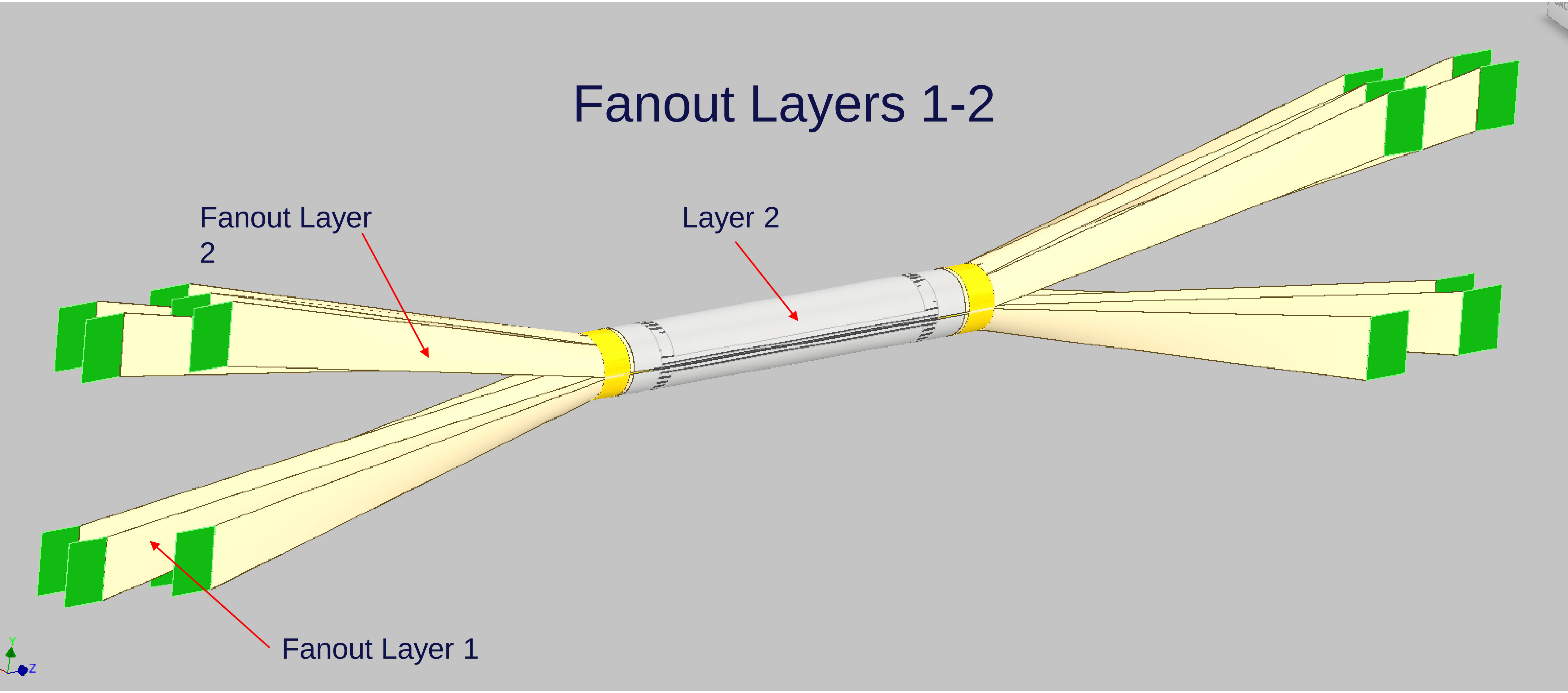
Starting engineering layout




Layer 2
Layer 1
Carbon Foam Layer 1-2


Layer 4 Front
Layer 4 Back
Carbon Foam Structure Back
Layer 3 Back
Carbon Foam Structure Front
Layer 3 Front

Fanout Layers 1-2



Conclusions and next steps

- **A Vertex Detector layout has been engineered**
  - Integration with the machine elements being developed
  - Services integration and cooling being finalised
    - Thermal and structural simulations look promising
    - A test setup is being constructed to validate simulations
  - Useful iterations between designers and simulations to keep material budget under control

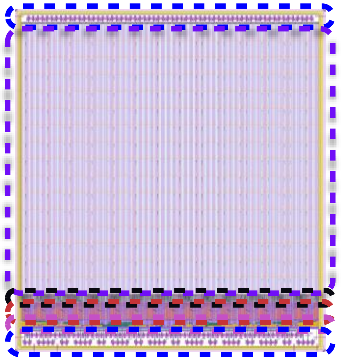
- **A lighter concept with curved and stitched MAPS is being engineered**
  - First layout done
  - Engineering drawings started, having in mind construction sequence
  - Cooling (air) and flex circuits routing will be addressed shortly

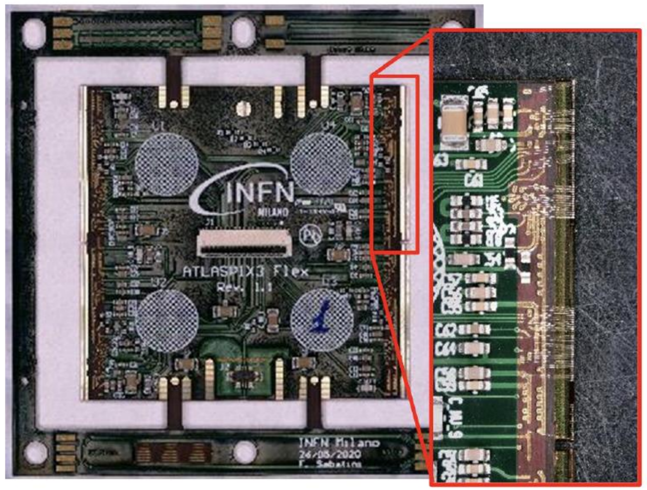
Thank you for your attention.

Sensors technology and dimensions

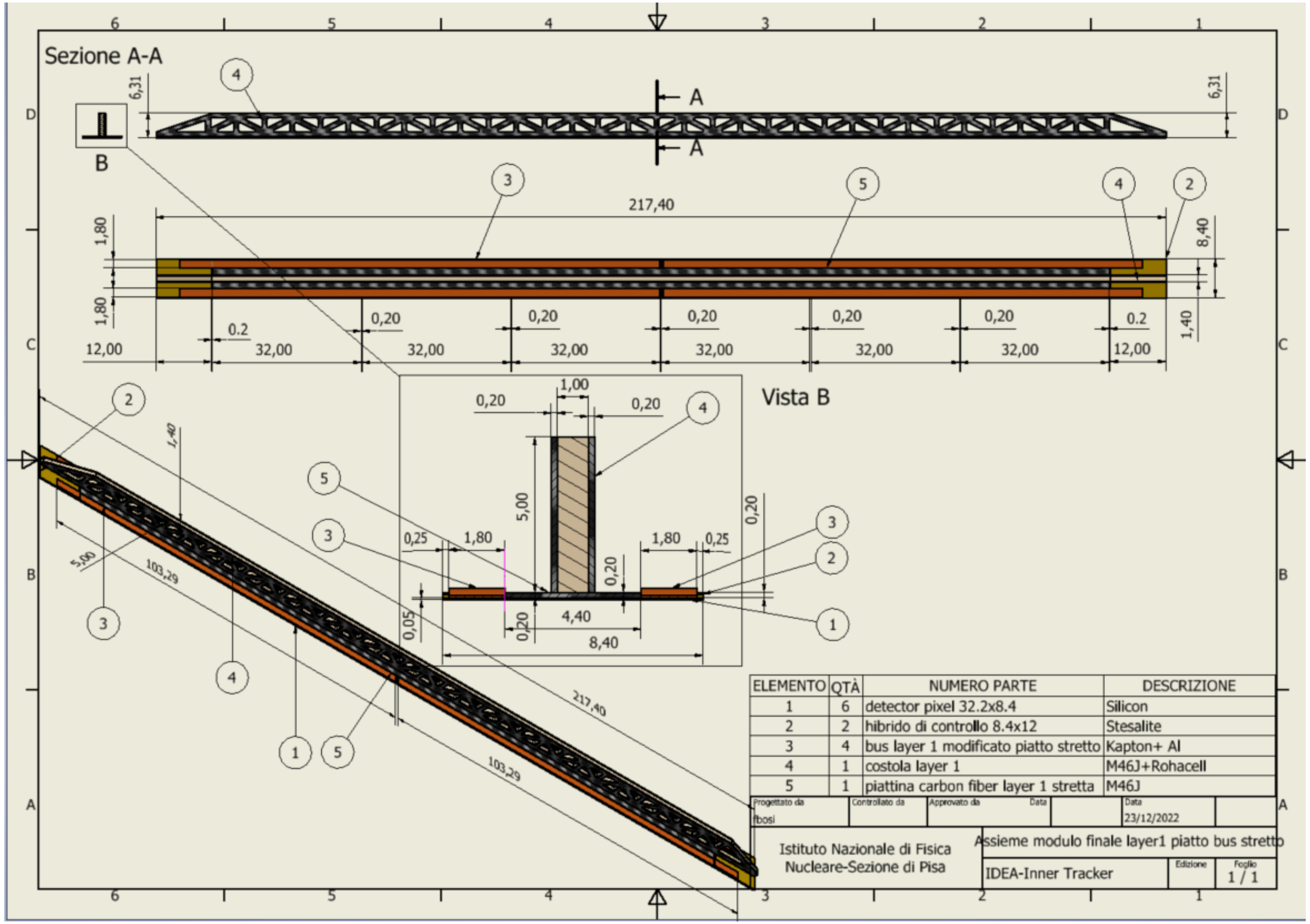
Depleted Monolithic Active Pixel Detectors

- **Inner Vertex (inspired to ARCADIA):**
  - Lfoundry 110 nm process
  - *50 μm thick, 25 μm x 25 μm*
  - Module dimensions: $8.4 \times 32\ mm^2$
  - Power density $50\ mW/cm^2$ (core $30\ mW/cm^2$)
  - **Current at 100 MHz/cm²**
- **Outer Vertex and disks (inspired to ATLASPIX3)**
  - TSI 180 nm process
  - *50 μm thick (50 μm x 150 μm)*
  - Module dimensions: $42.2 \times 40.6\ mm^2$
  - Power density: assume $100\ mW/cm^2$
  - **Up to 1.28 Gb/s downlink**





Layer 1 stave detail



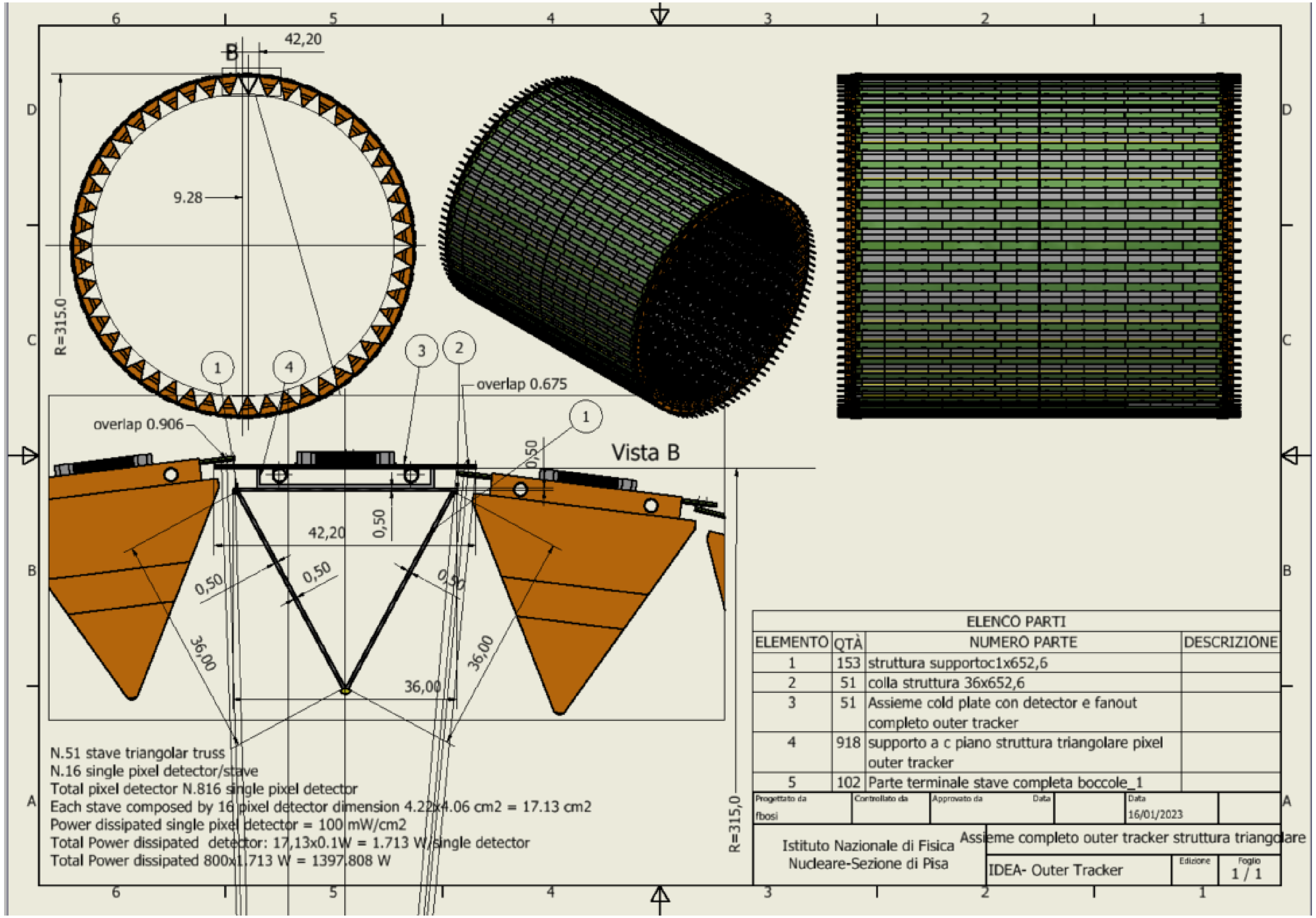
Reticular lightweight support to provide stiffness

- Thin carbon fiber walls interleaved with Rohacell
- 2 buses (data and power) 1.8 mm wide and 250 µm thick (50 µm Al, 200 µm kapton) per side
  - Inspired to low mass hybrid R&D

Sensors facing interaction point w/o any other material in front

Readout chips either sides

Air cooled



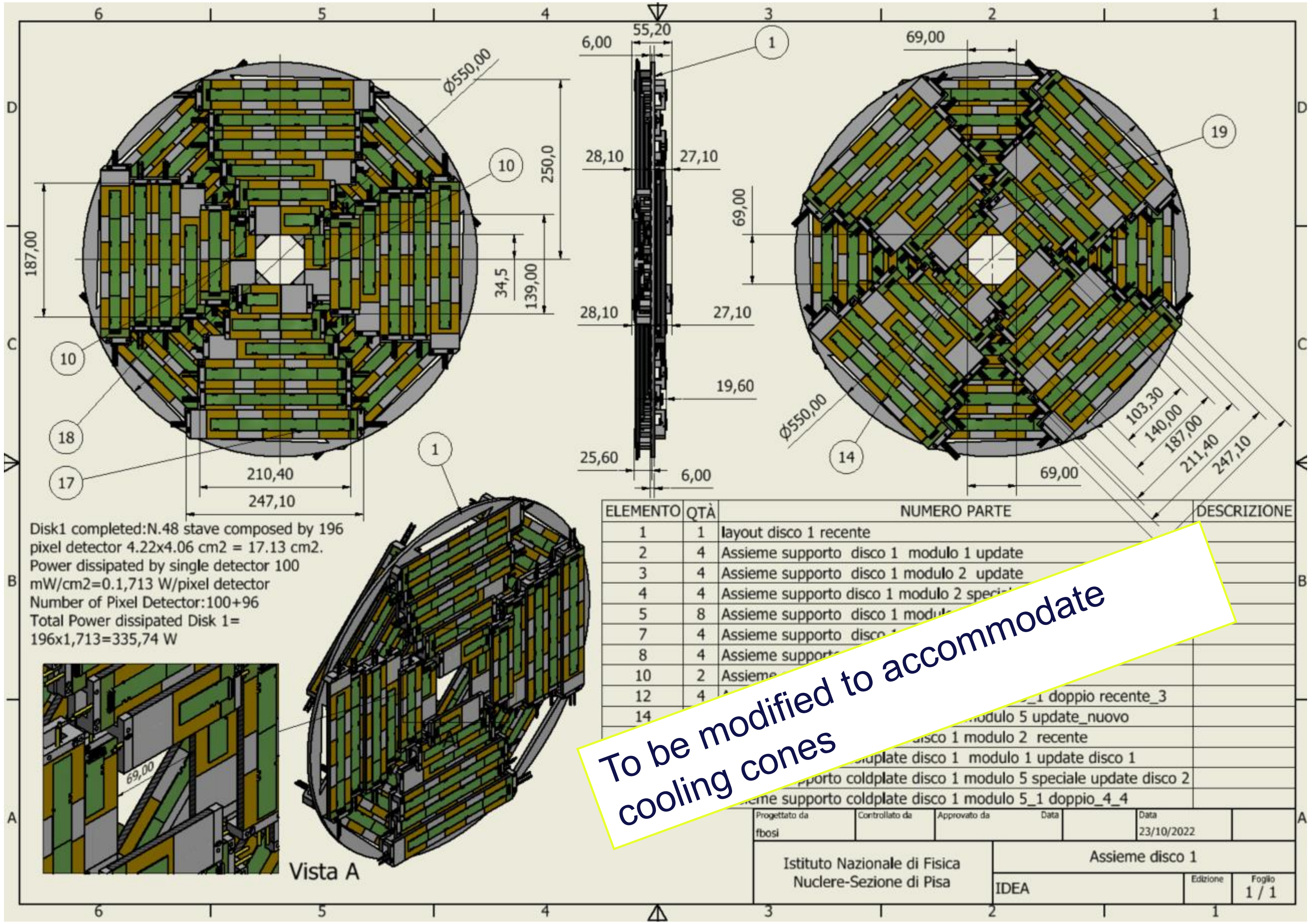
Outer Vertex Tracker Barrel
At 31.5 cm radius

51 staves of 16 modules each

Lightweight reticular support structure (ALICE/Belle-II like)

Total weight ~3.7 kg
Readout chips either side
Power budget
~1400 W

Water cooled (2 pipes of 2 mm diameter)



Outer Vertex Tracker Disk 1

2 sides (front and back) each with 4 petals.

One petal is made of different staves of overlapping modules

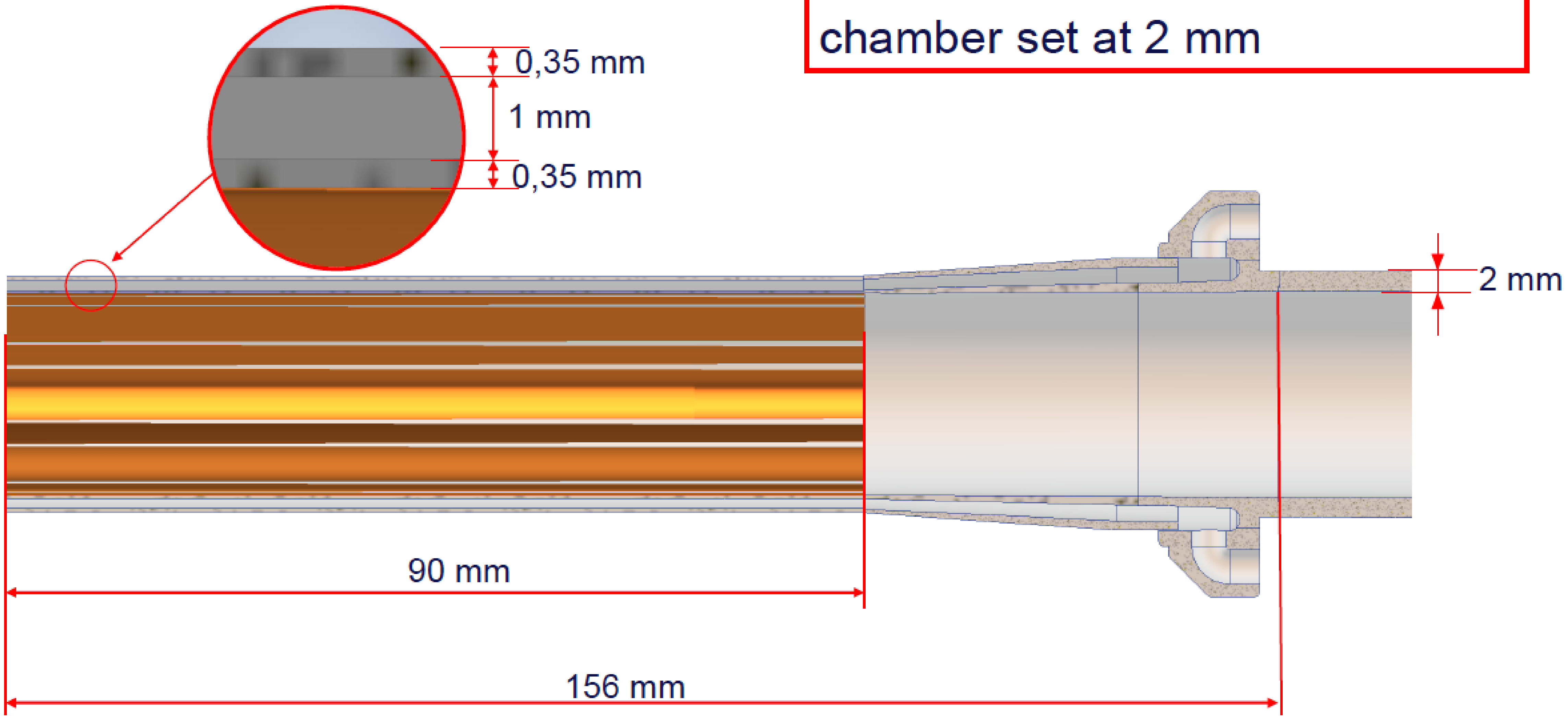
Total modules per disk: 196
Total weight ~850 grams
Power budget ~ 336 W

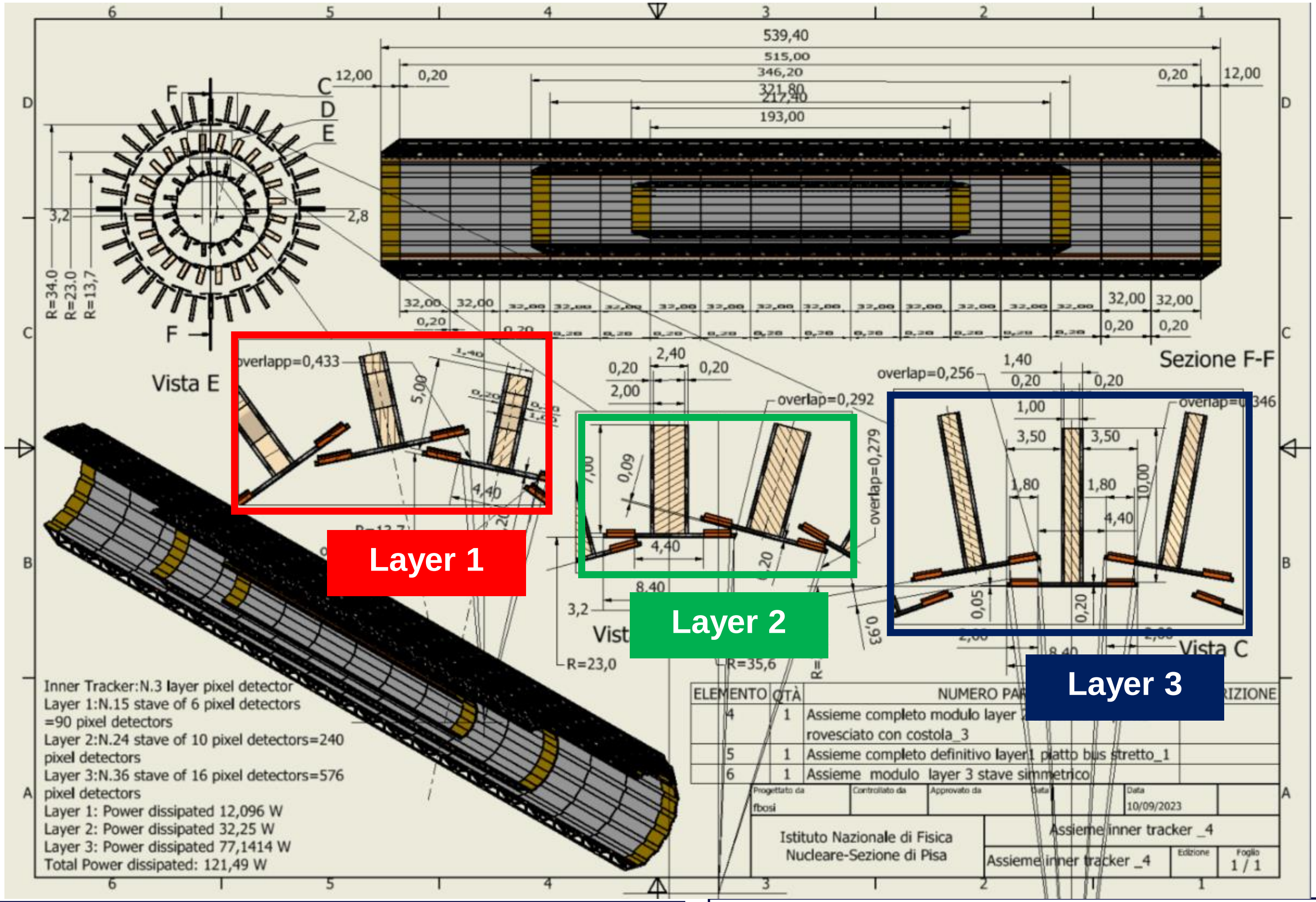
Cooling using 1 water pipe (2 mm diameter)

Similar geometry for the other two disks

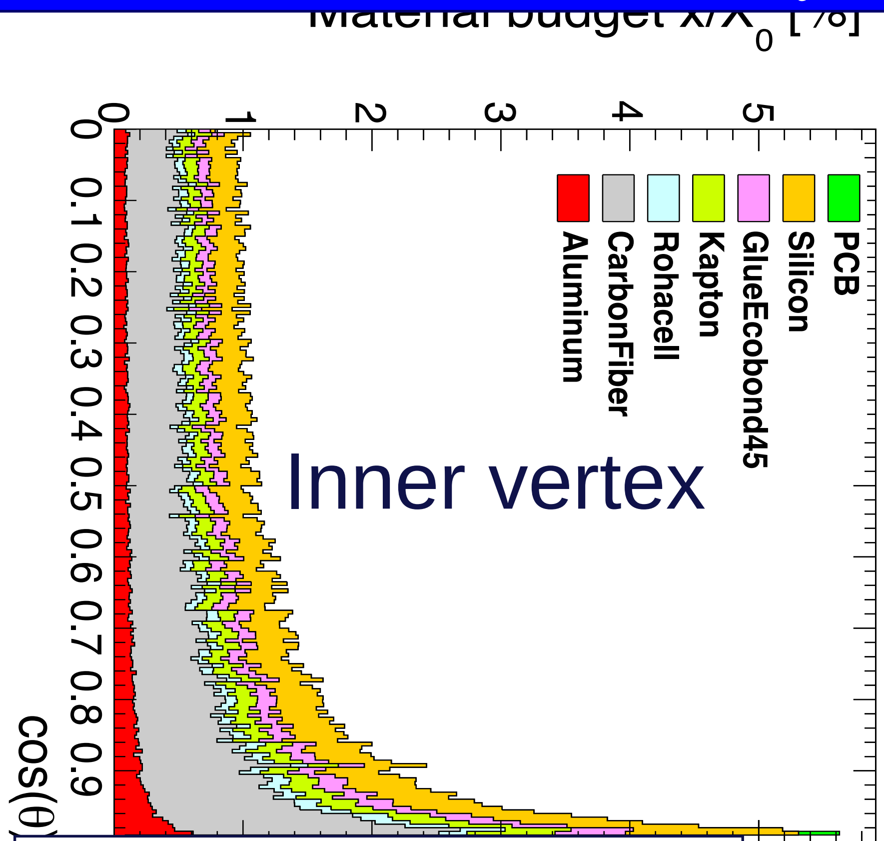
Thickness of the chamber

Uniform thickness of the conical chamber set at 2 mm





Total thickness 0.25% X_0 *per layer*
- *Silicon: 0.053% X_0,*
- *Power and readout bus: 0.056% X_0*

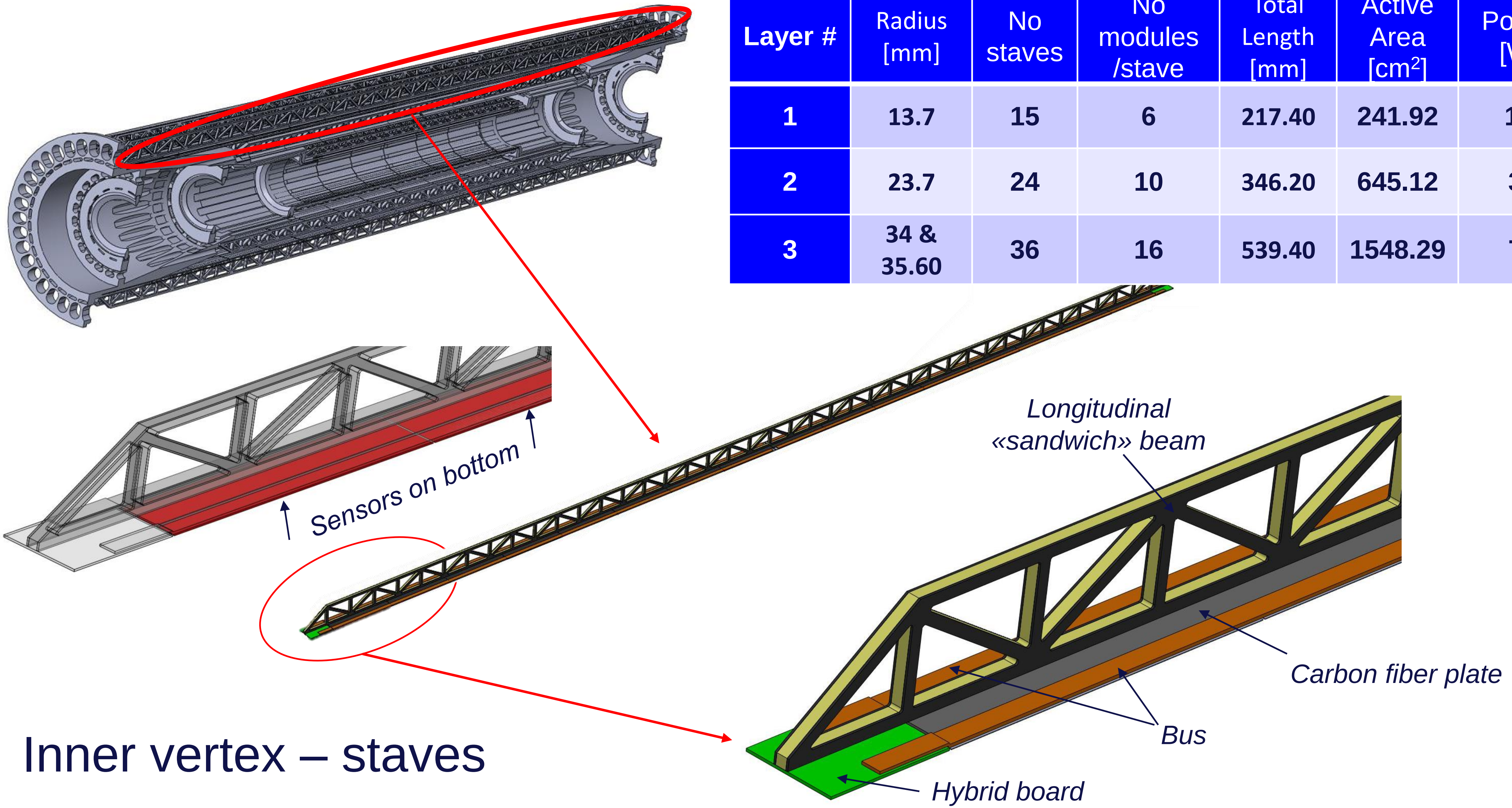


Layer 1
- Overlap to allow alignment ~500 μm
- Pinwheel geometry
- Total weight ~22 grams
- *Power 12 Watt*

Layer 2
- Pinwheel geometry
- Counter-rotated wrt layer 1
- Total weight ~63 grams
- *Power 32 Watt*

Layer 3
- Lampshade geometry.
- Total weight ~150 grams
- *Power 77 Watt*

Layer #	Radius [mm]	No staves	No modules /stave	Total Length [mm]	Active Area [cm^2]	Power [W]
1	13.7	15	6	217.40	241.92	12
2	23.7	24	10	346.20	645.12	32
3	34 & 35.60	36	16	539.40	1548.29	77



Inner vertex – staves

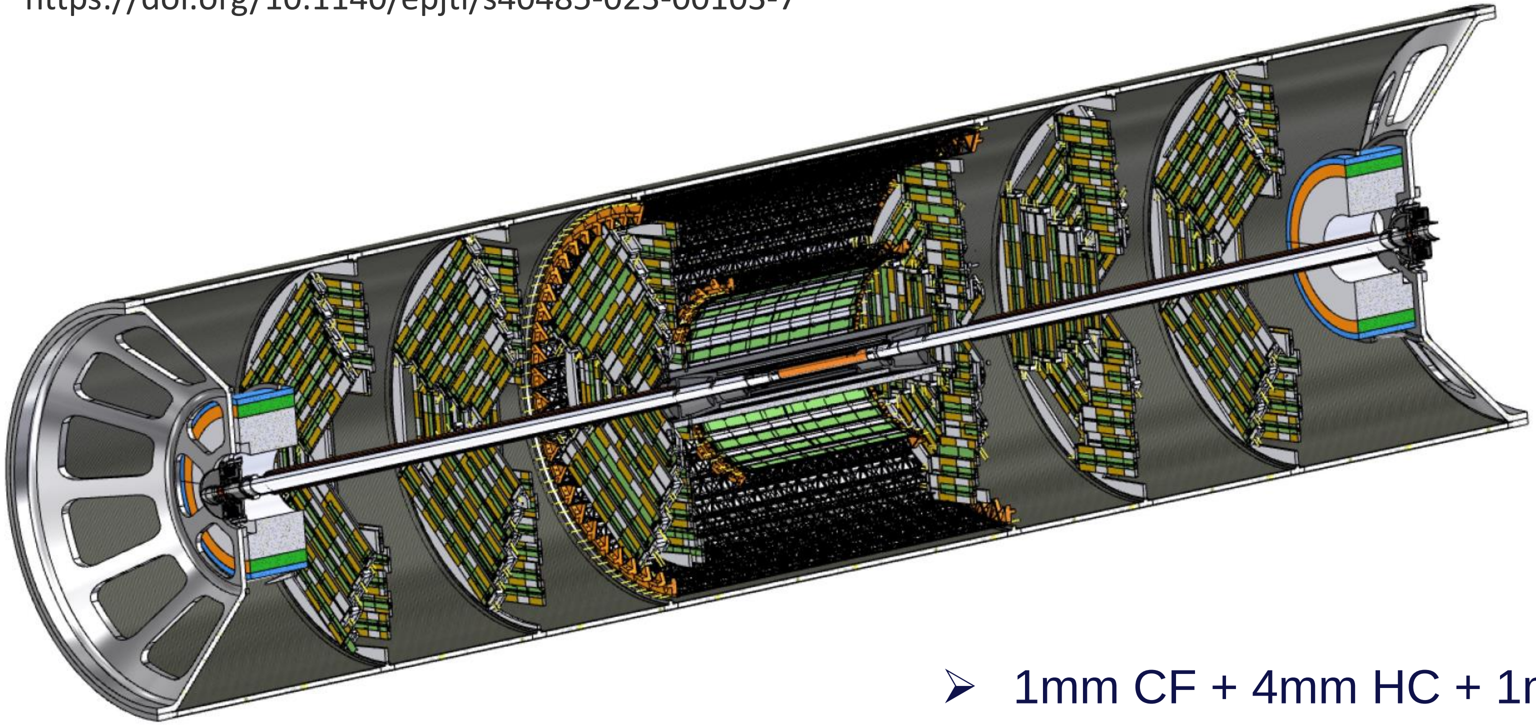
Support cylinder

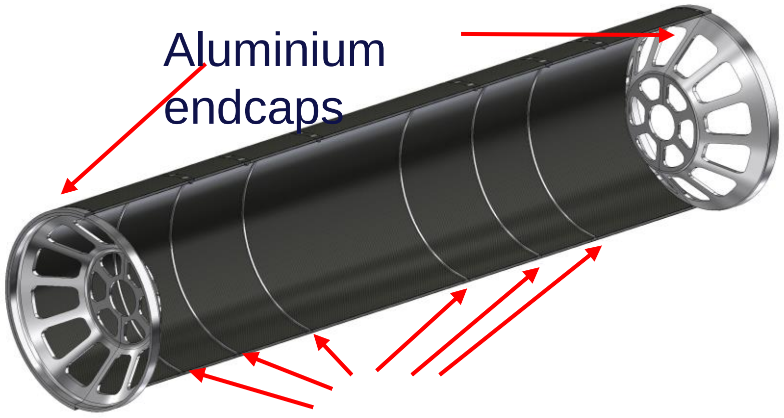
See F. Fransesini talk

All elements in the interaction region (Vertex and LumiCal) are mounted rigidly on a support cylinder that guarantees mechanical stability and alignment

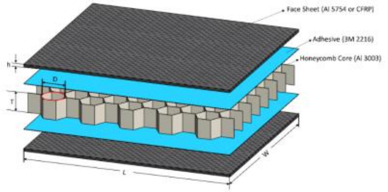
- Once the structure is assembled it is slided inside the rest of the detector

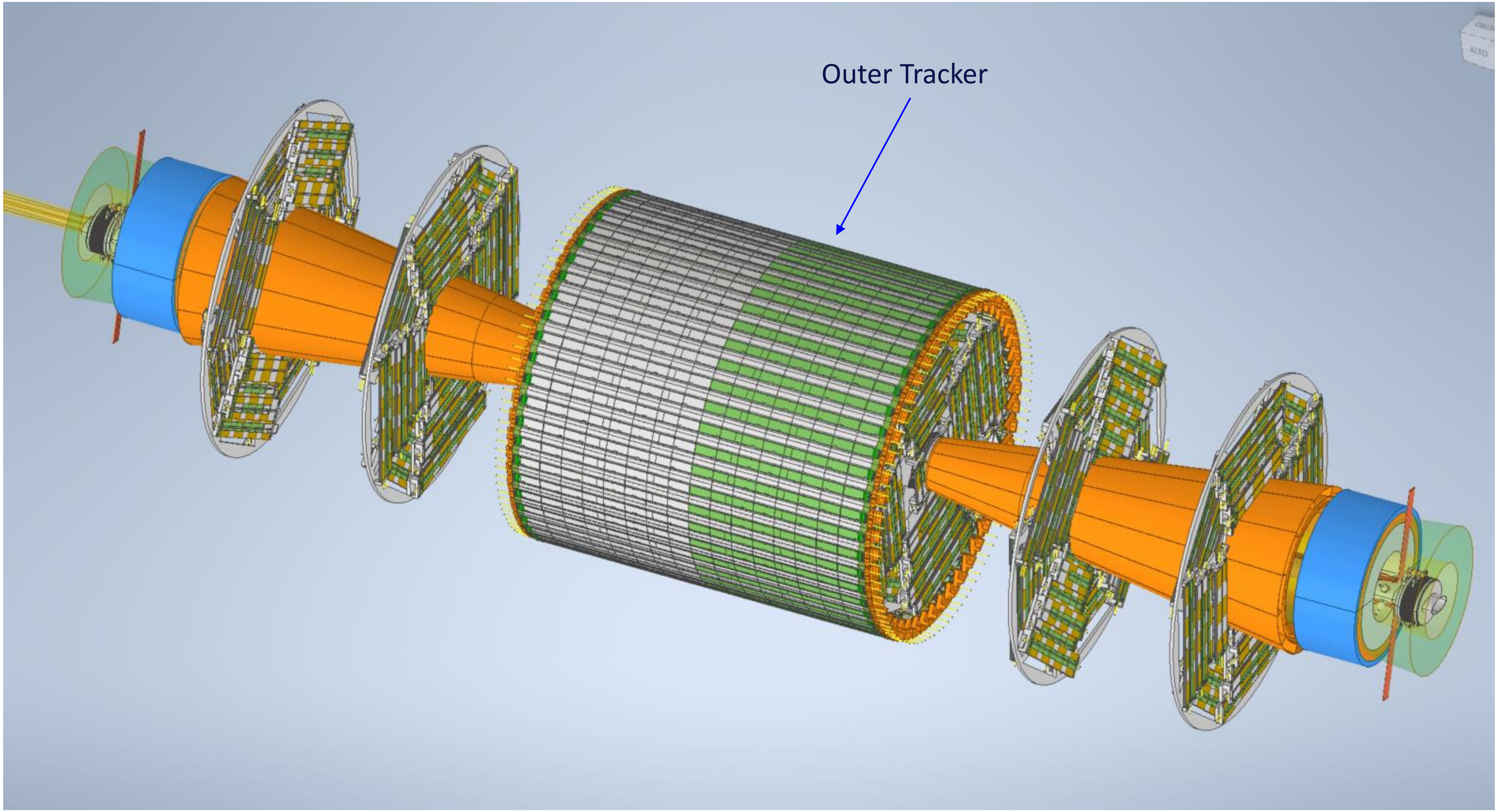
M. Boscolo, F. Palla, F. Fransesini, F. Bosi and S. Lauciani, Mechanical model for the FCC-ee MDI, EPJ Techn Instrum **10**, 16 (2023). https://doi.org/10.1140/epjti/s40485-023-00103-7

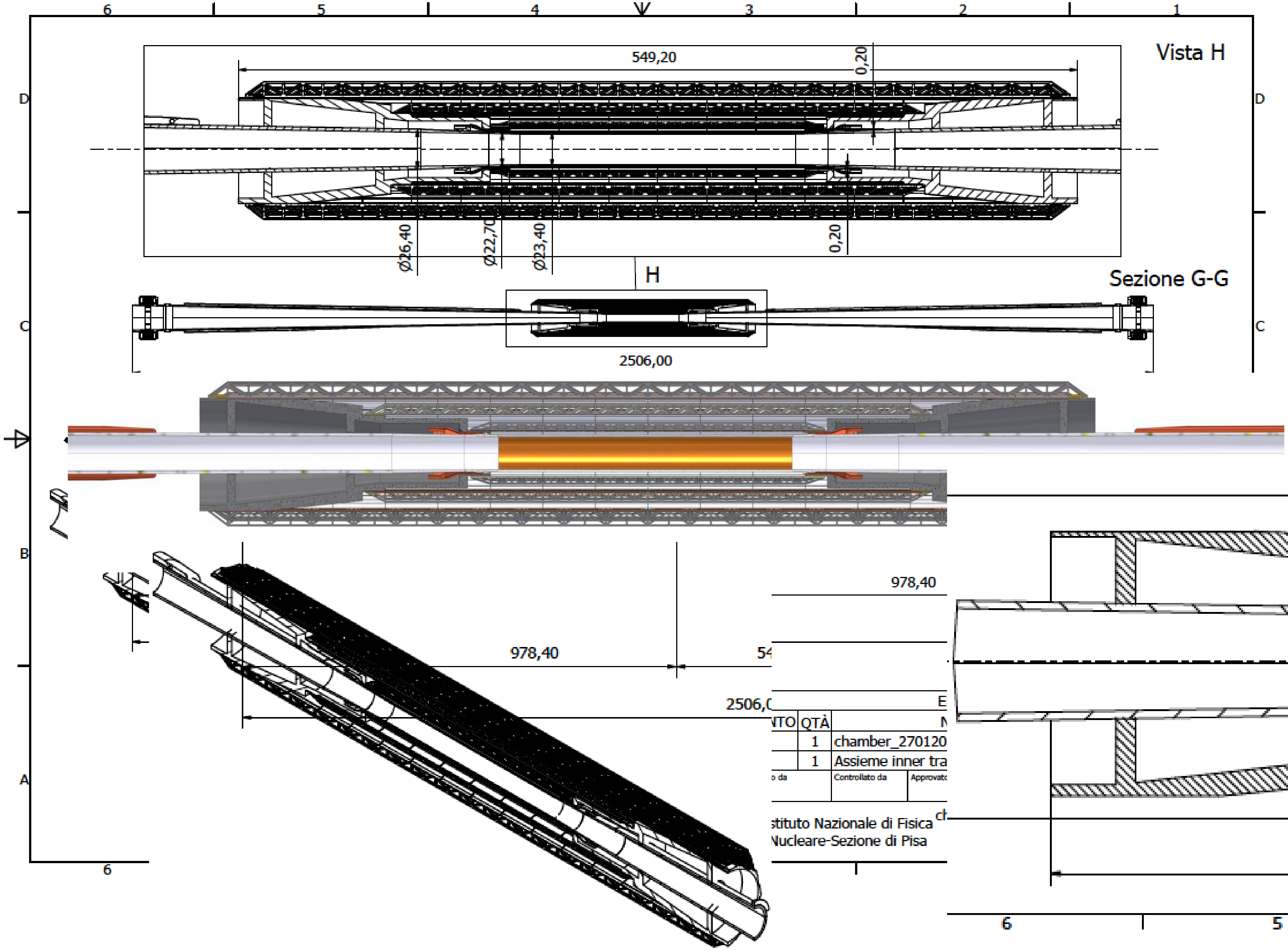




- 1mm CF + 4mm HC + 1mm CF

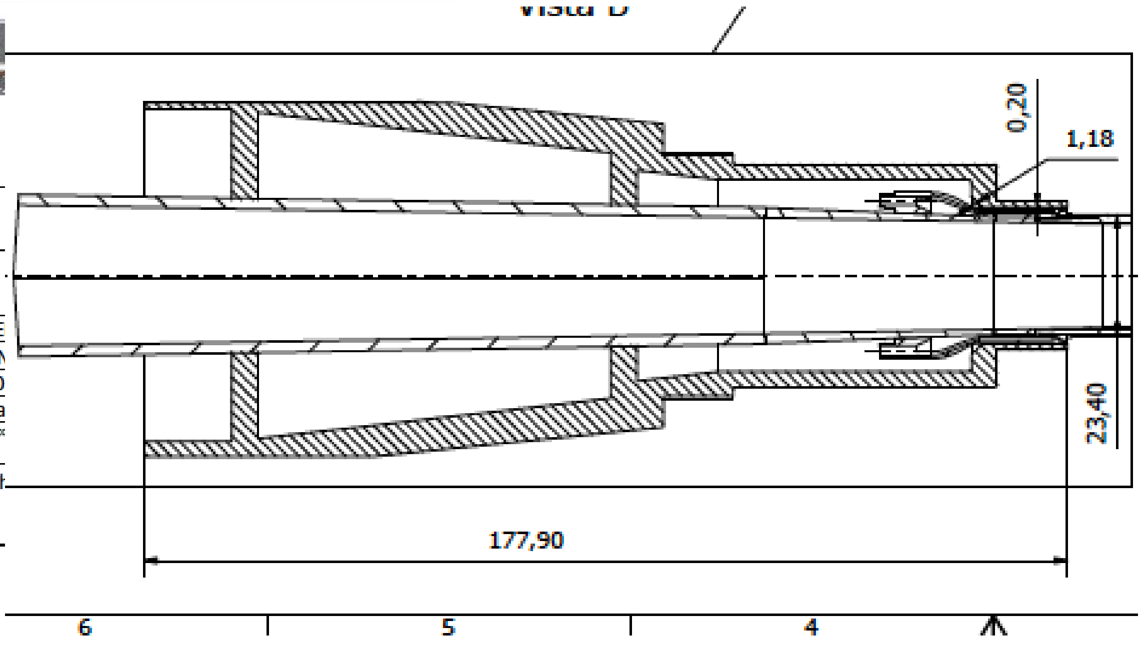


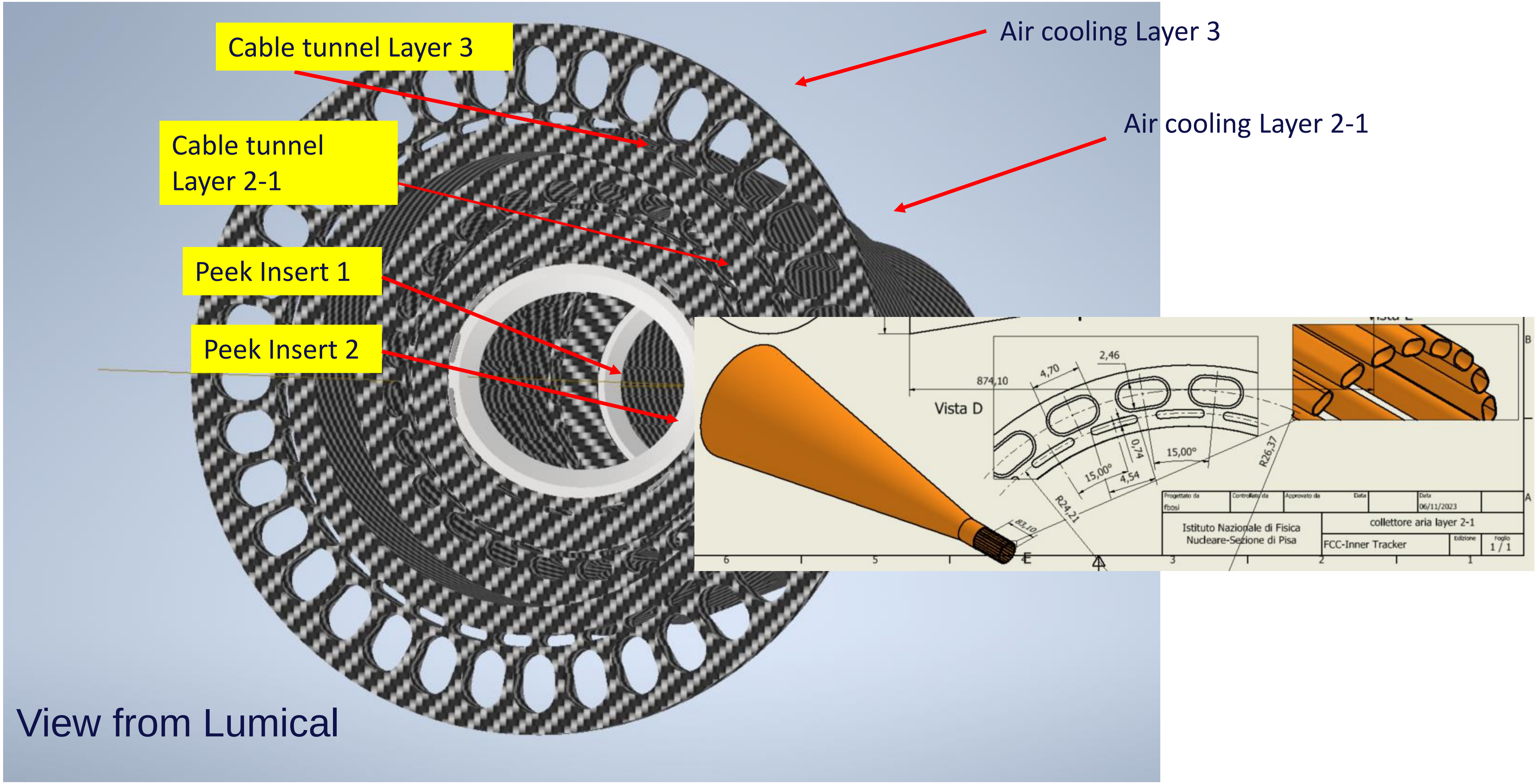

Outer Tracker



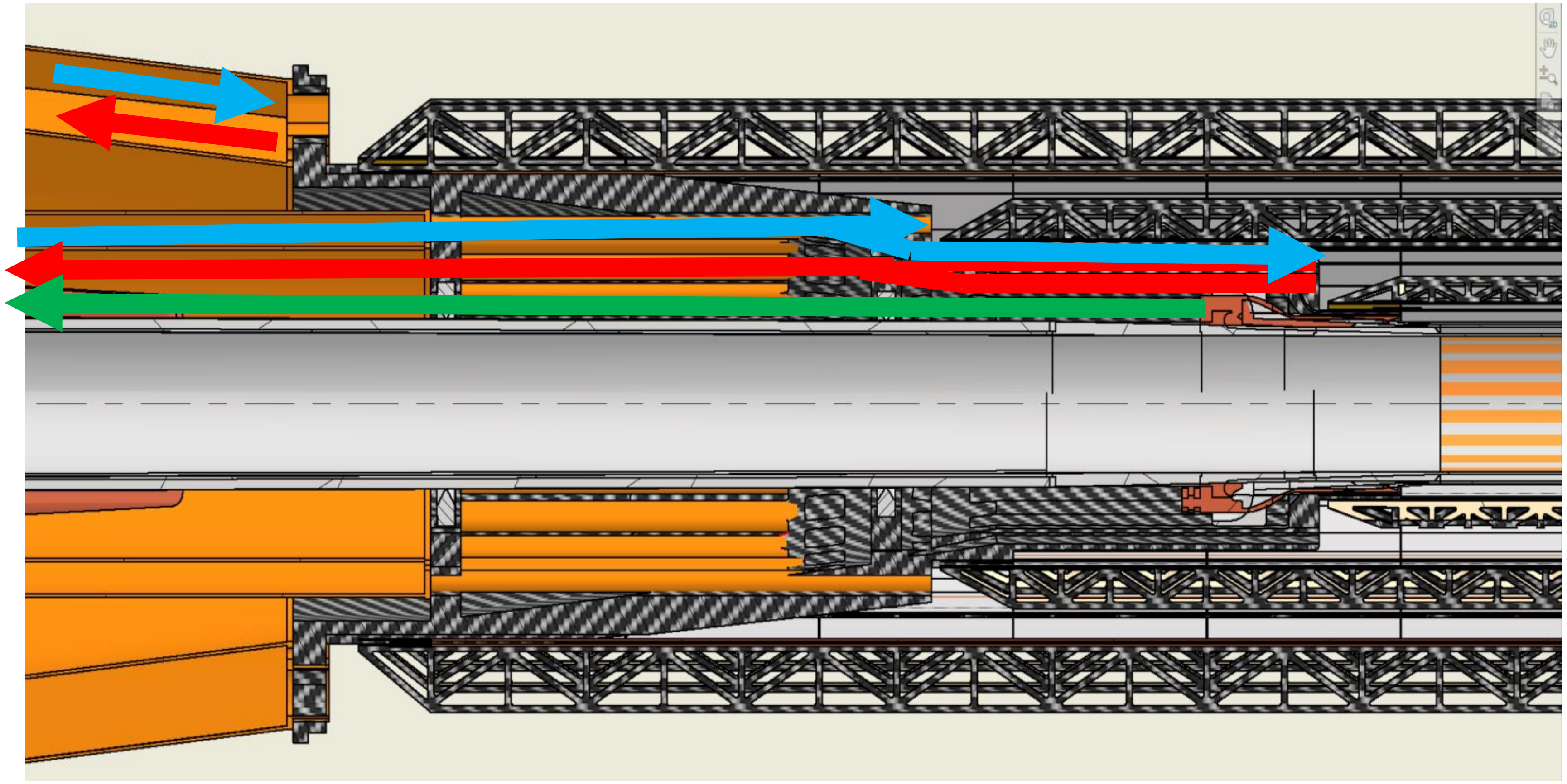
Inner vertex detector supporting conical structures on elliptical chamber
~450 grams

Engineered for air ducts and thermal isolation from the beam pipe during bakeout




Cable tunnel Layer 3
Cable tunnel Layer 2-1
Peek Insert 1
Peek Insert 2
Air cooling Layer 3
Air cooling Layer 2-1
View from Lumical
Vista D
874,10
4,70
2,46
0,74
15,00°
15,00°
4,54
R26,37
R24,21
Progettato da
fbosi
Controllato da
Approvato da
Data
Data
06/11/2023
Istituto Nazionale di Fisica
Nucleare-Sezione di Pisa
collettore aria layer 2-1
FCC-Inner Tracker
Edizione
Foglio
1 / 1

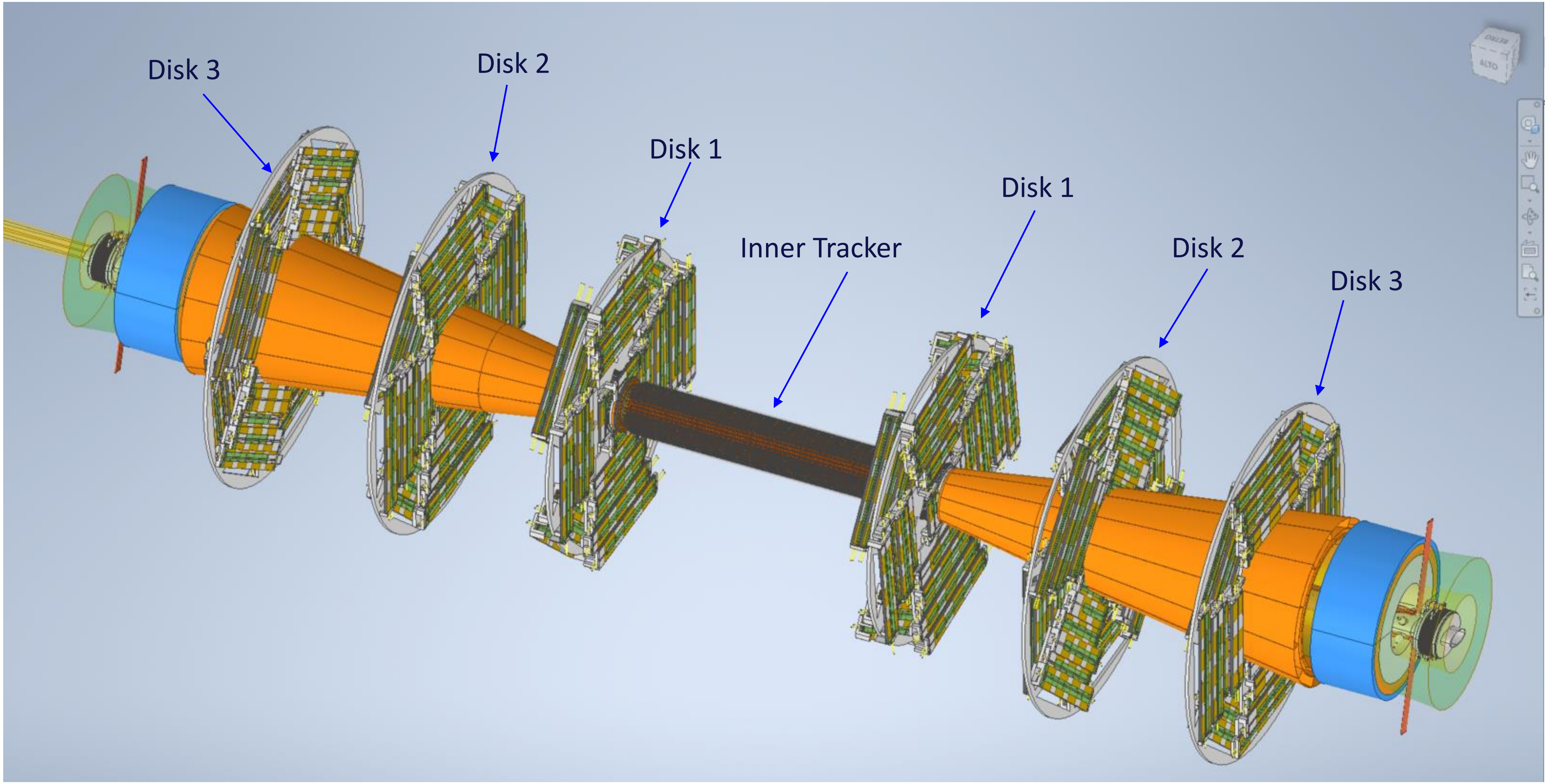
Integration with beam pipe cooling manifold

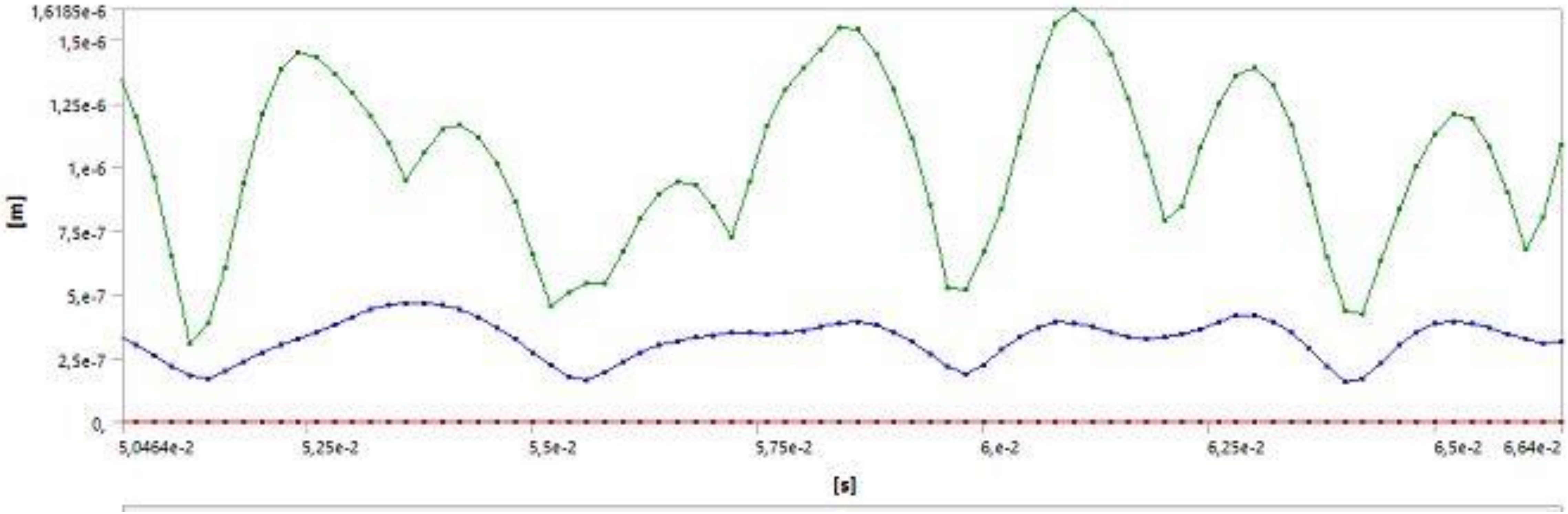


Air Cooling

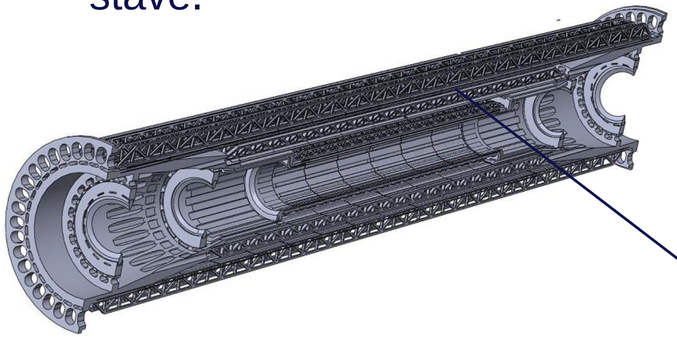
Cooling pipe paraffin

Cables


Disk 3
Disk 2
Disk 1
Inner Tracker
Disk 1
Disk 2
Disk 3


1,6185e-6
1,5e-6
1,25e-6
1,e-6
7,5e-7
5,e-7
2,5e-7
0,
[m]
5,0464e-2
5,25e-2
5,5e-2
5,75e-2
6,e-2
6,25e-2
6,5e-2
6,64e-2
[s]

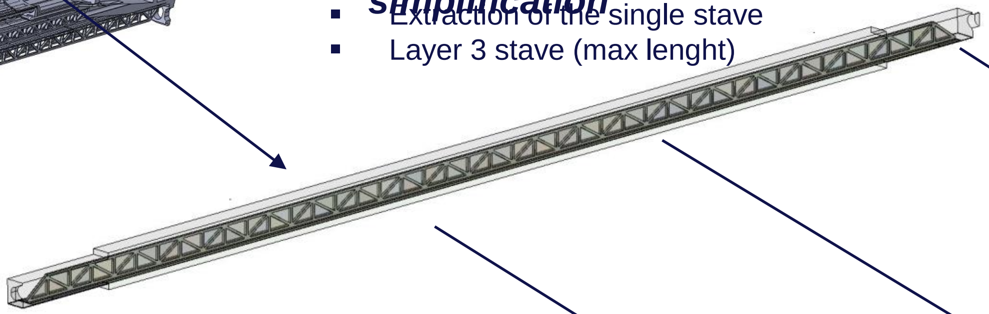
- Define a tool to evaluate whether the air flow necessary to remove the heat generates excessive vibrations on the stave.

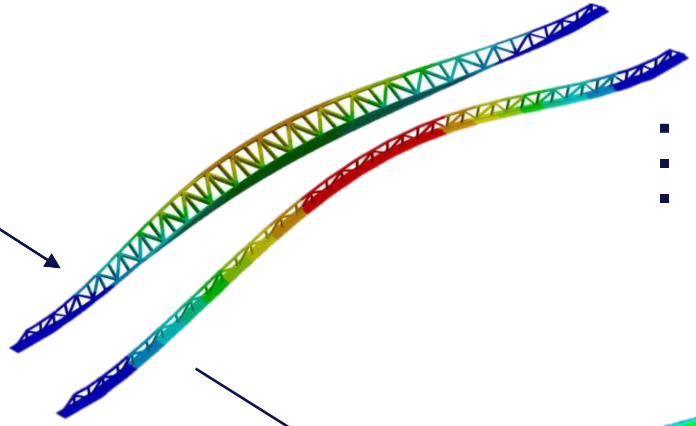


CAD Model

Geometry simplification

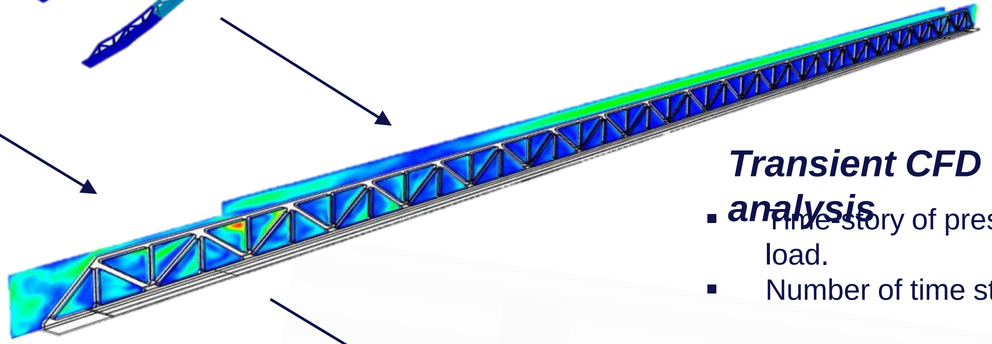
- Extraction of the single stave
- Layer 3 stave (max lenght)





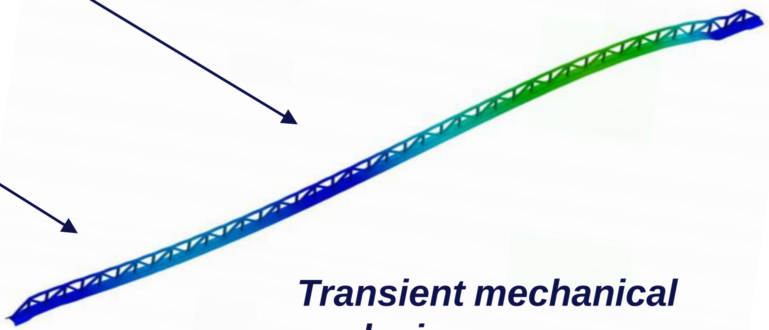
Modal analysis

- Participation factors.
- Natural frequencies.
- Duration of time step.



Transient CFD analysis

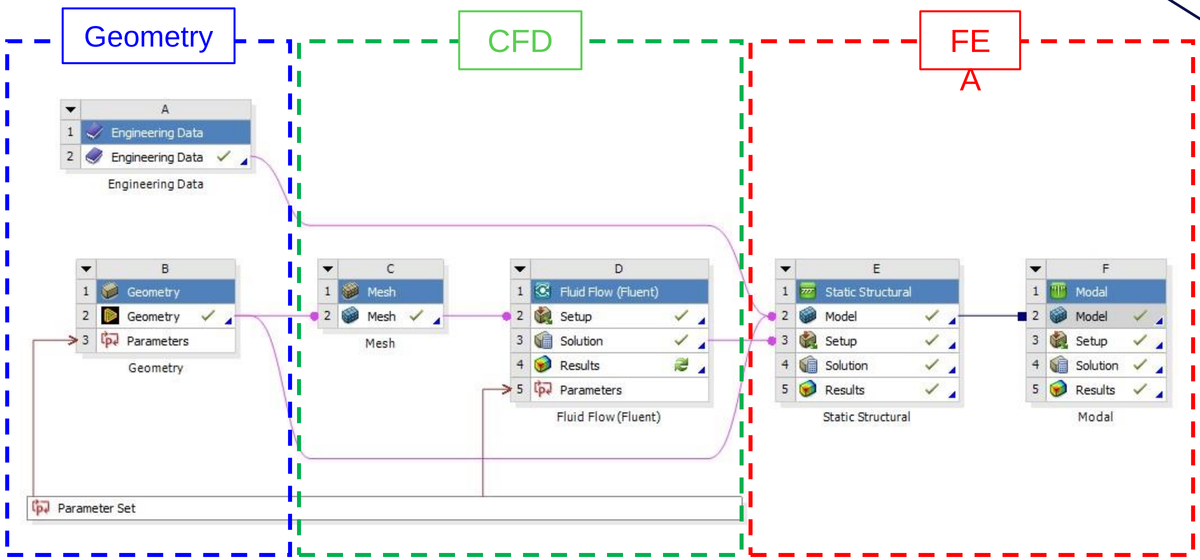
- Time-story of pressure load.
- Number of time steps.



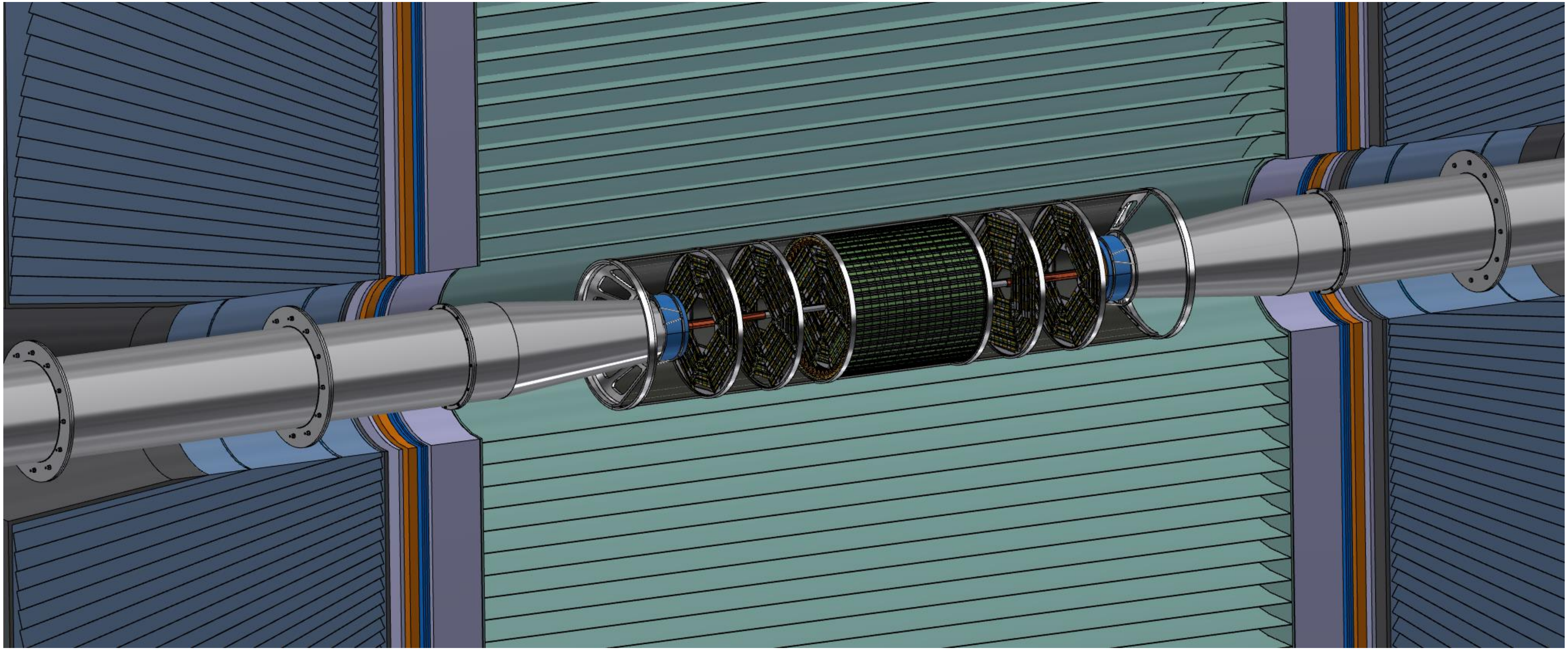
Transient mechanical analysis

- Dynamic displacement

- Flow of data managed by Ansys Workbech



General integration



ELECTRICAL UNITS

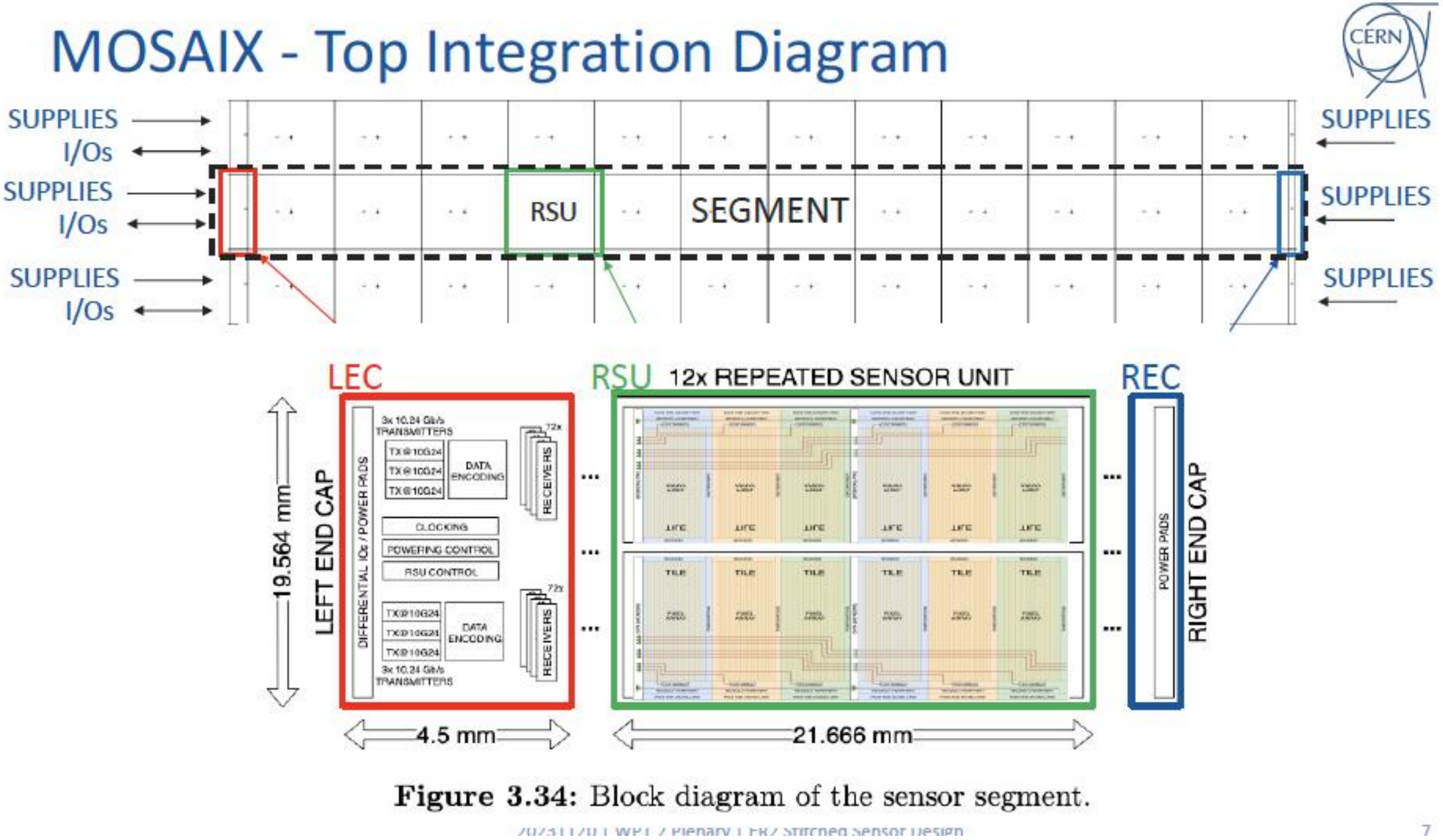
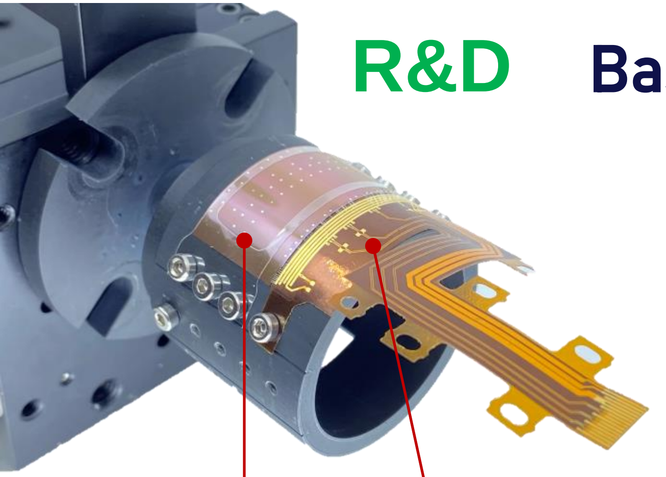


Figure 3.34: Block diagram of the sensor segment.

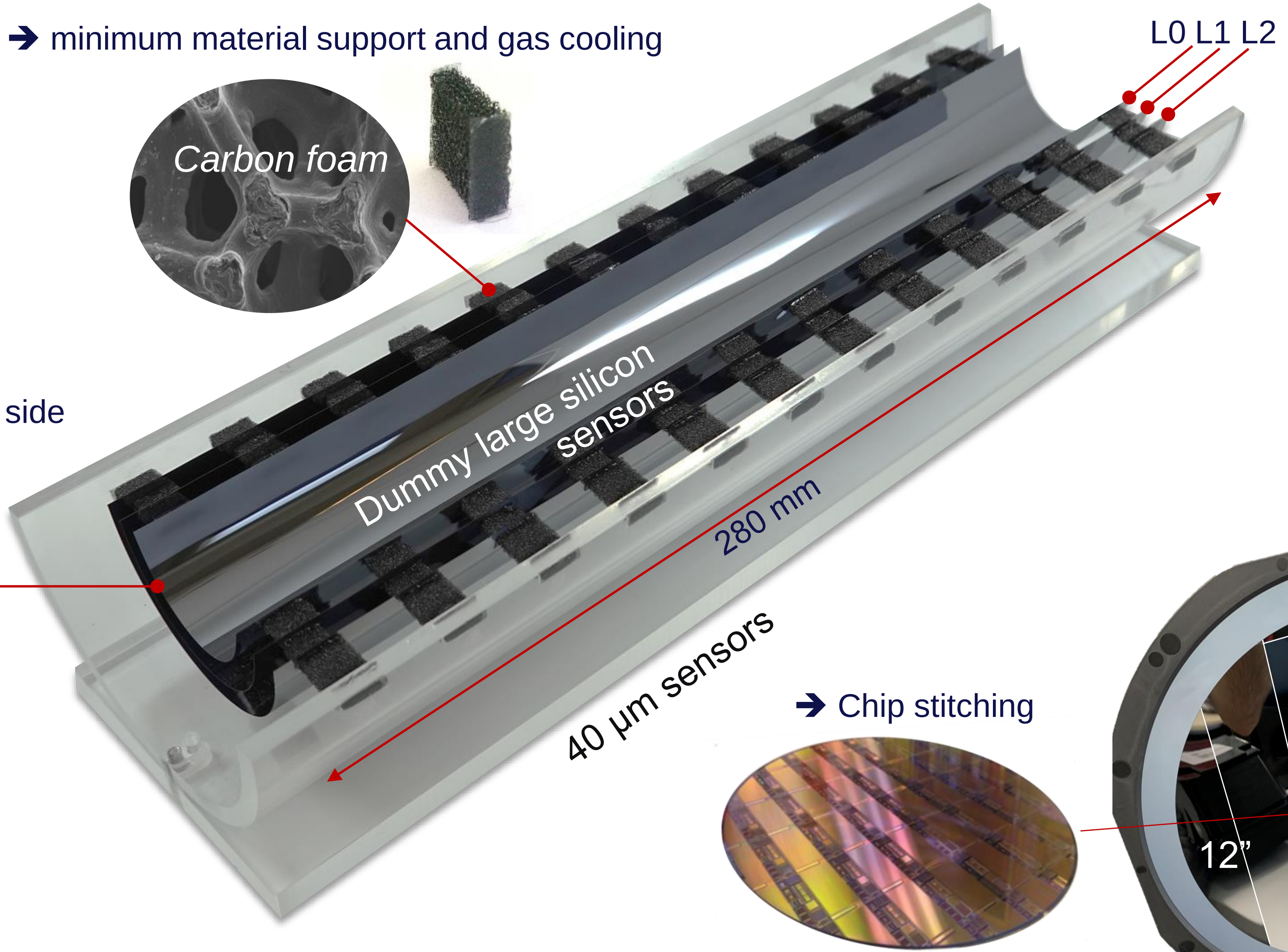
A column driven approach reaches higher bandwidth, but needs low power consumption

ALICE

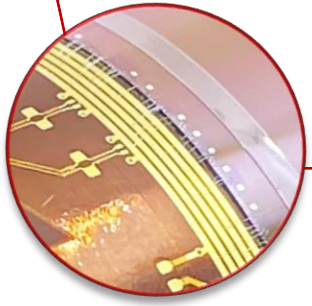
R&D Based on present effort in the design of the ITS3 (RUN4 –LS3)



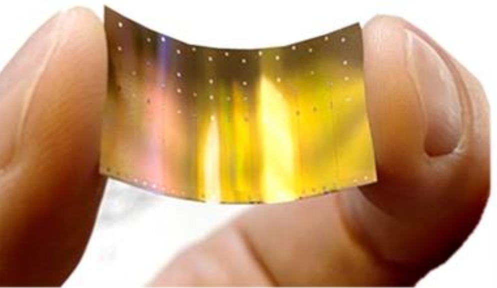
→ minimum material support and gas cooling



→ Wire bonding at the edge side



→Curved Silicon sensors



→ Chip stitching