VERTEX DETECTOR AT FCC-EE

LAYOUT UPDATES AND POSSIBLE IMPROVEMENTS

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Annecy (France)
29 January – 2 February 2024

Outline

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- ❑ **Mid-Term Feasibility Vertex layout**
    - ❑ Updated Inner and Outer vertex mechanical description
    - ❑ Study of the services routings
- ❑ **Toward material budget reduction**
    - ❑ Some critical issues using curved sensors
- ❑ **Conclusions**

Requirements

Interaction region detectors must be integrated with the beam pipe

- The vertex detector innermost radius should profit of the reduced beam pipe diameter (2 cm) and should cover $|cos\theta| < 0.99$
- Must not interefere with the Luminosity Calorimeter (clearance of ~120 mrad)
- The mounting of the vertex tracker must be done inside the support tube
- Minimize the radiation lengths

Mid-term review vertex detector overall layout

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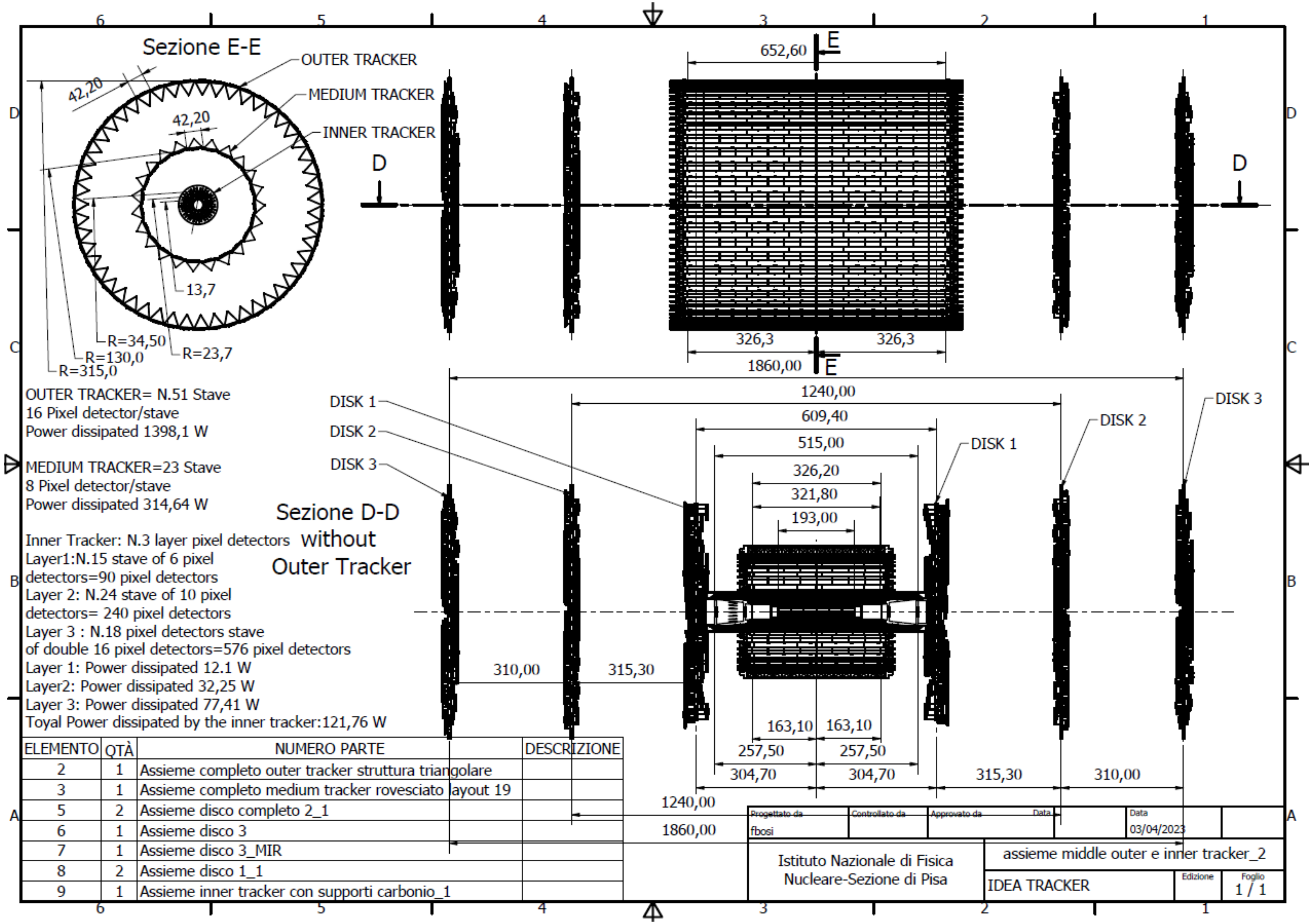

Outer vertex tracker:

Modules of $50 \times 150\ \mu m^2$ pixel size

- Intermediate barrel at 13 cm radius (improved reconstruction for $p_T > 40$ MeV tracks)
- Outer barrel at 31.5 cm radius
- 3 disks per side

Inner Vertex detector:

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

3 barrel layers at

- 13.7, 22.7 and 34.8 mm radius

Sensors technology and dimensions

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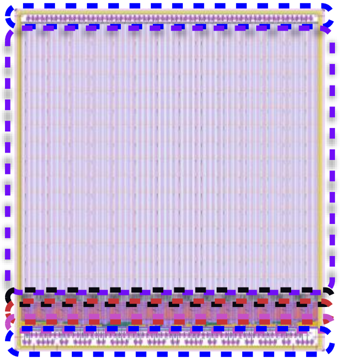
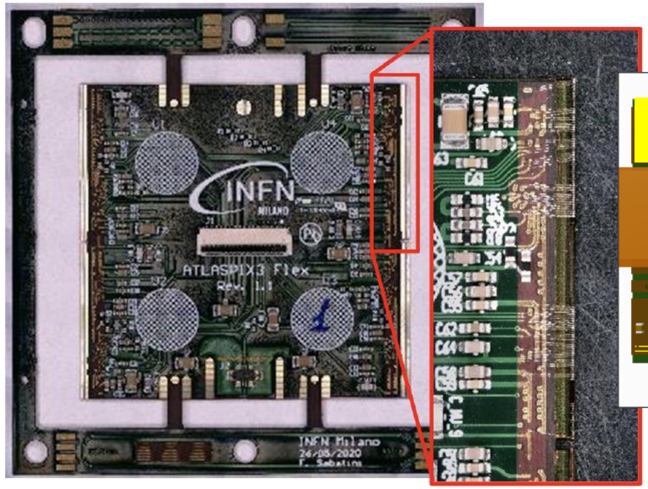
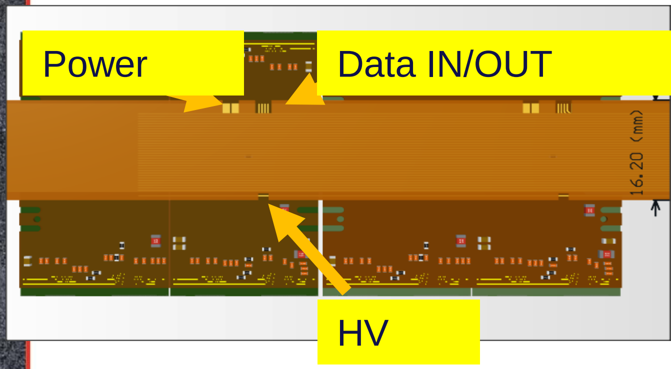
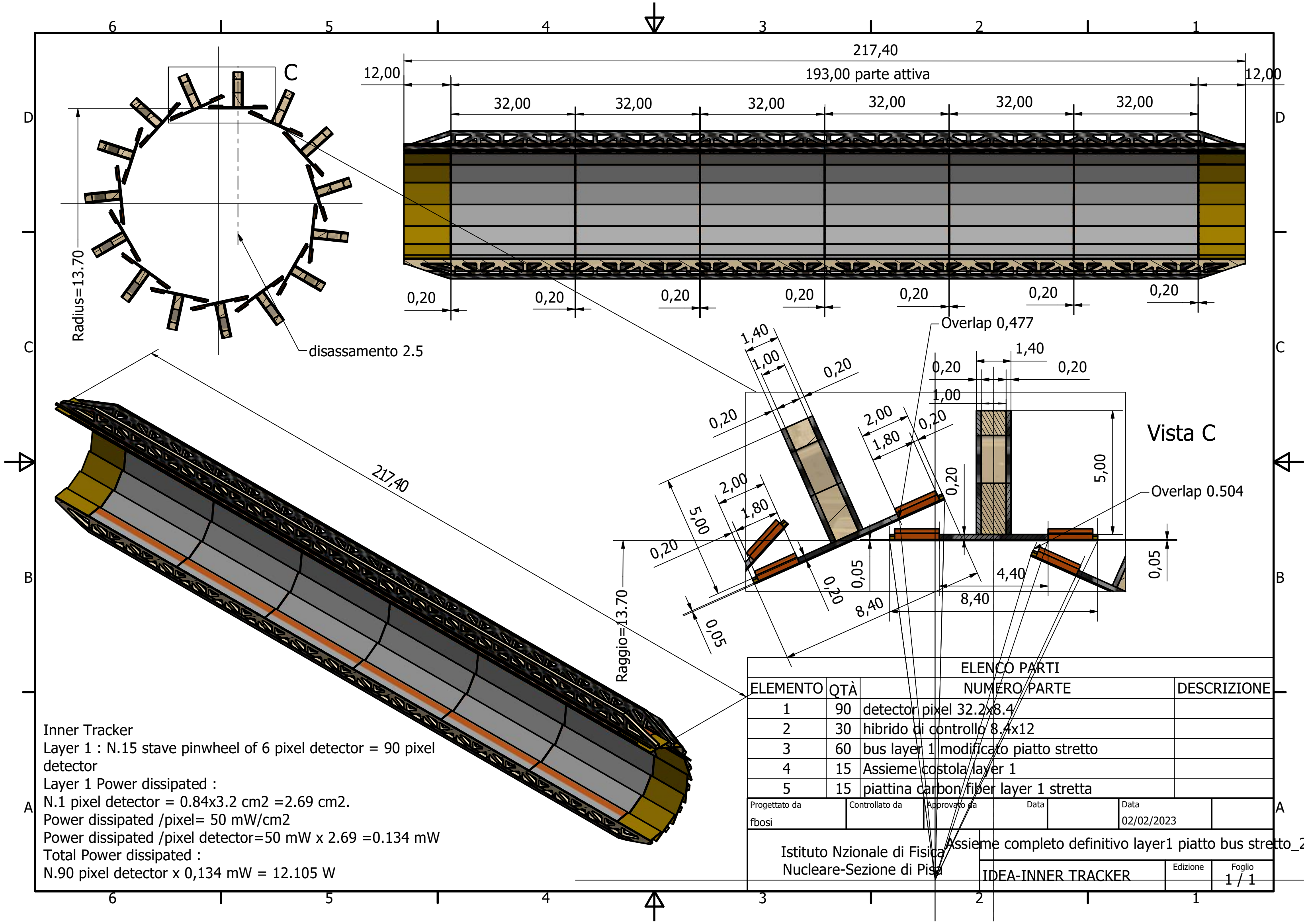
Depleted Monolithic Active Pixel Detectors

- **Inner Vertex (ARCADIA based):**
  - Lfoundry 110 nm process
  - *50 µm thick*
  - Dimensions: $8.4 \times 32\ mm^2$
  - Power density $50\ mW/cm^2$
  - **100 MHz/cm²**
- **Outer Vertex and disks (ATLASPIX3 base**
  - TSI 180 nm process
  - *50 µm thick*
  - Module dimensions: $42.2 \times 40.6\ mm^2$
  - Power density $100\ mW/cm^2$
  - **Up to 1.28 Gb/s downlink**









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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

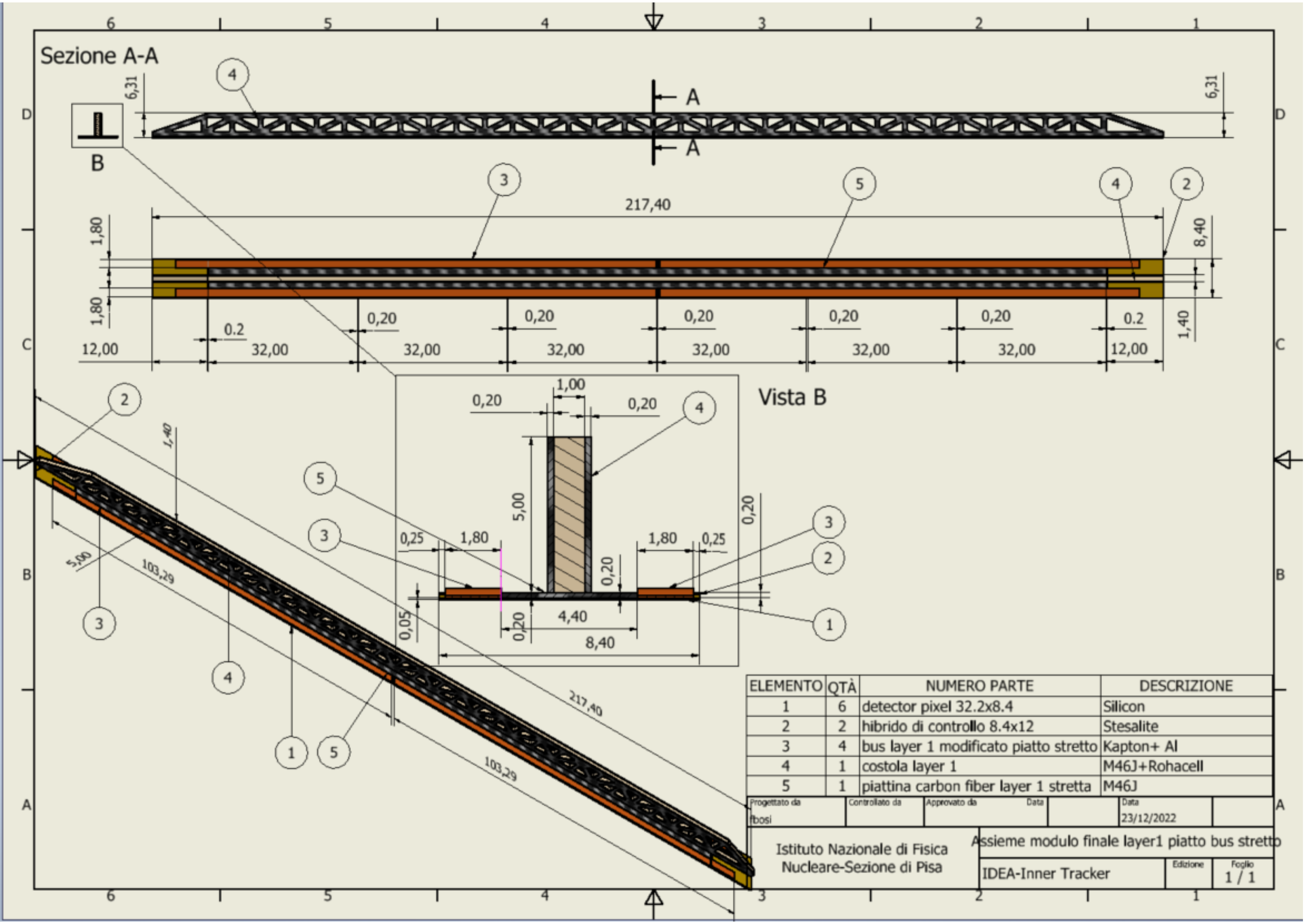
Total weight ~22 grams

Total thickness 0.25% X_0

Silicon: 0.053% X_0

Power and readout bus: 0.056% X_0

Layer 1 stave detail



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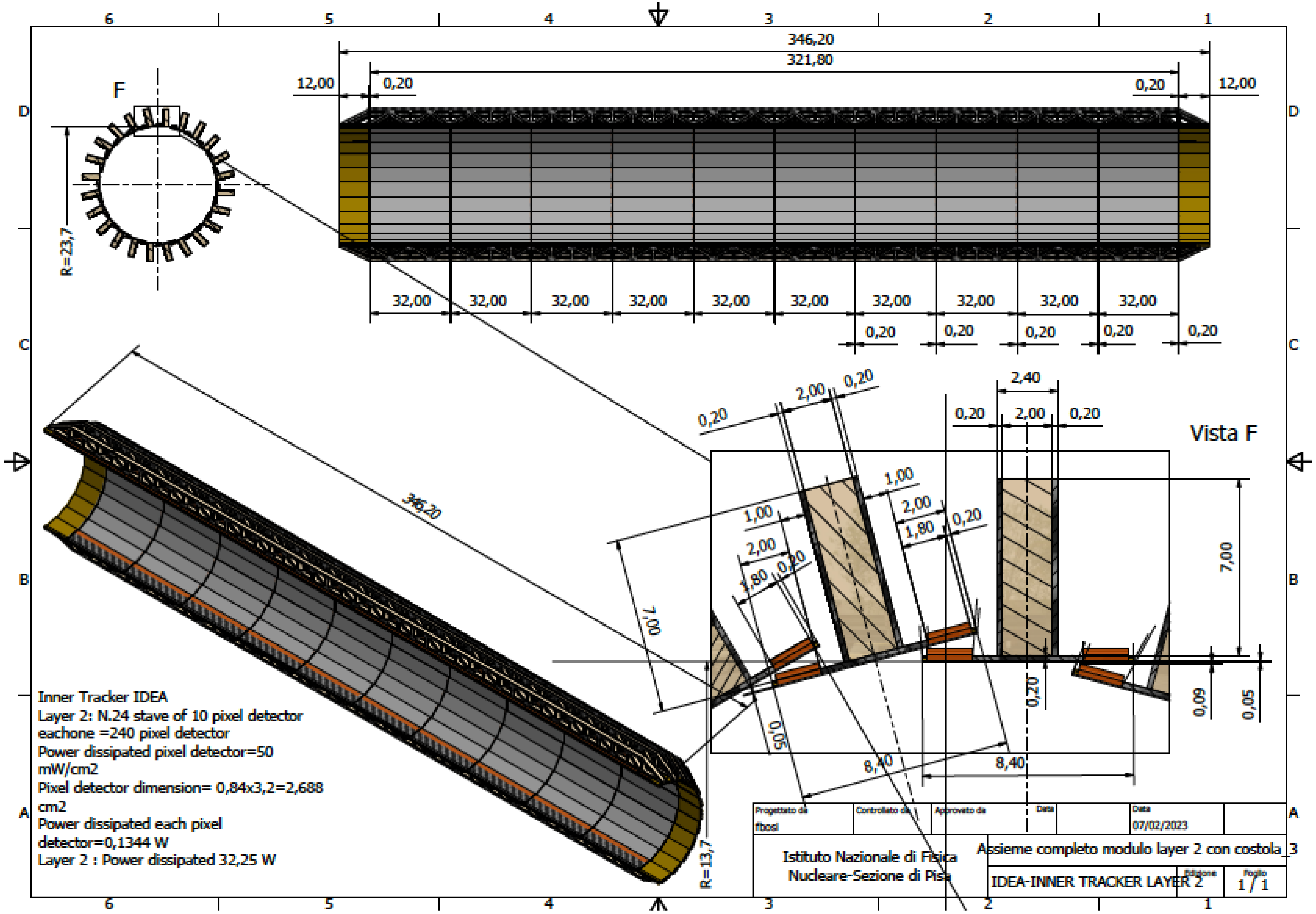
Reticular lightweight support to provide stiffness

- 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



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Layer 2

24 overlapping staves of 10 modules each

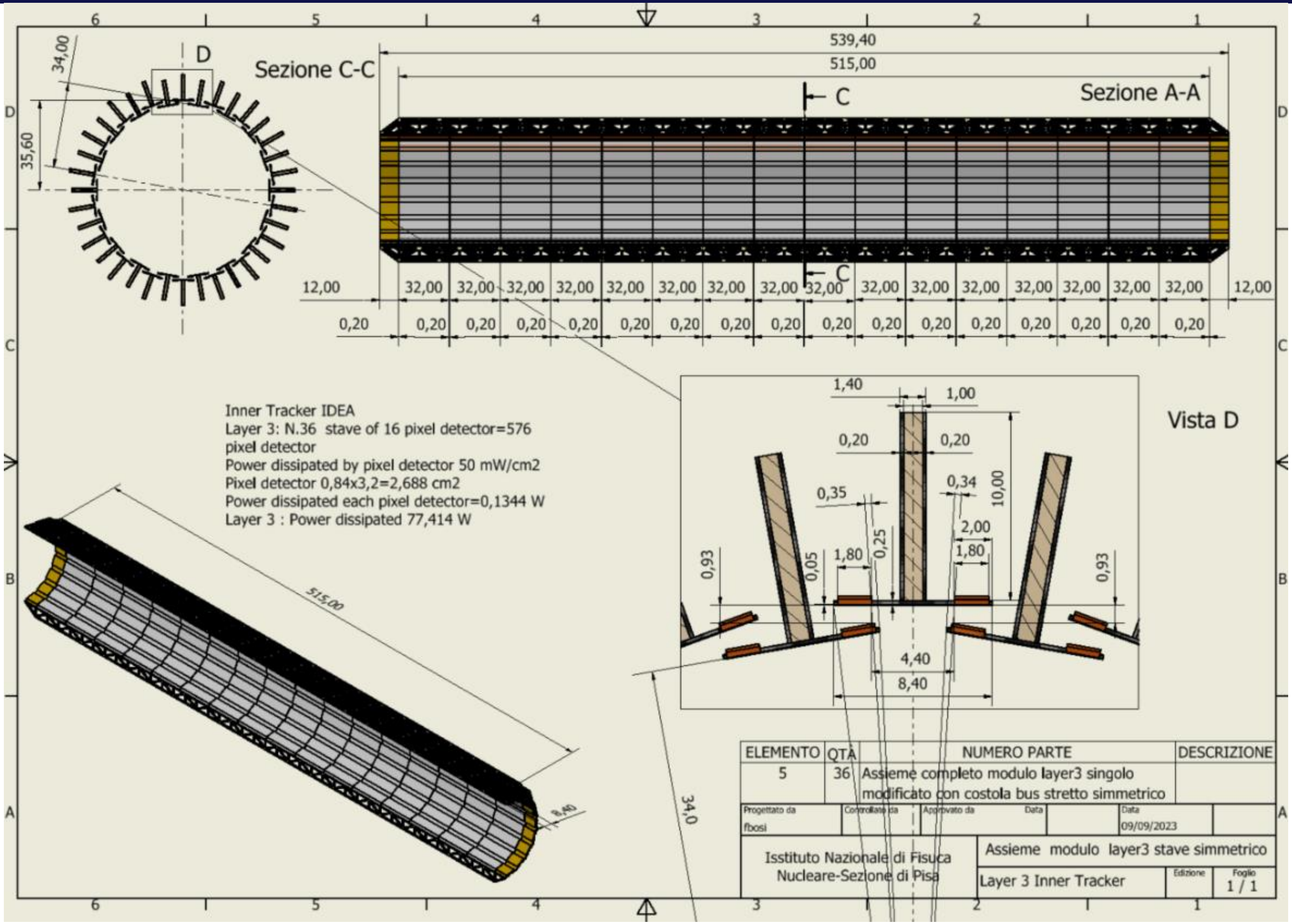
Pinwheel geometry

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



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Layer 3

36 staves of 16 modules each

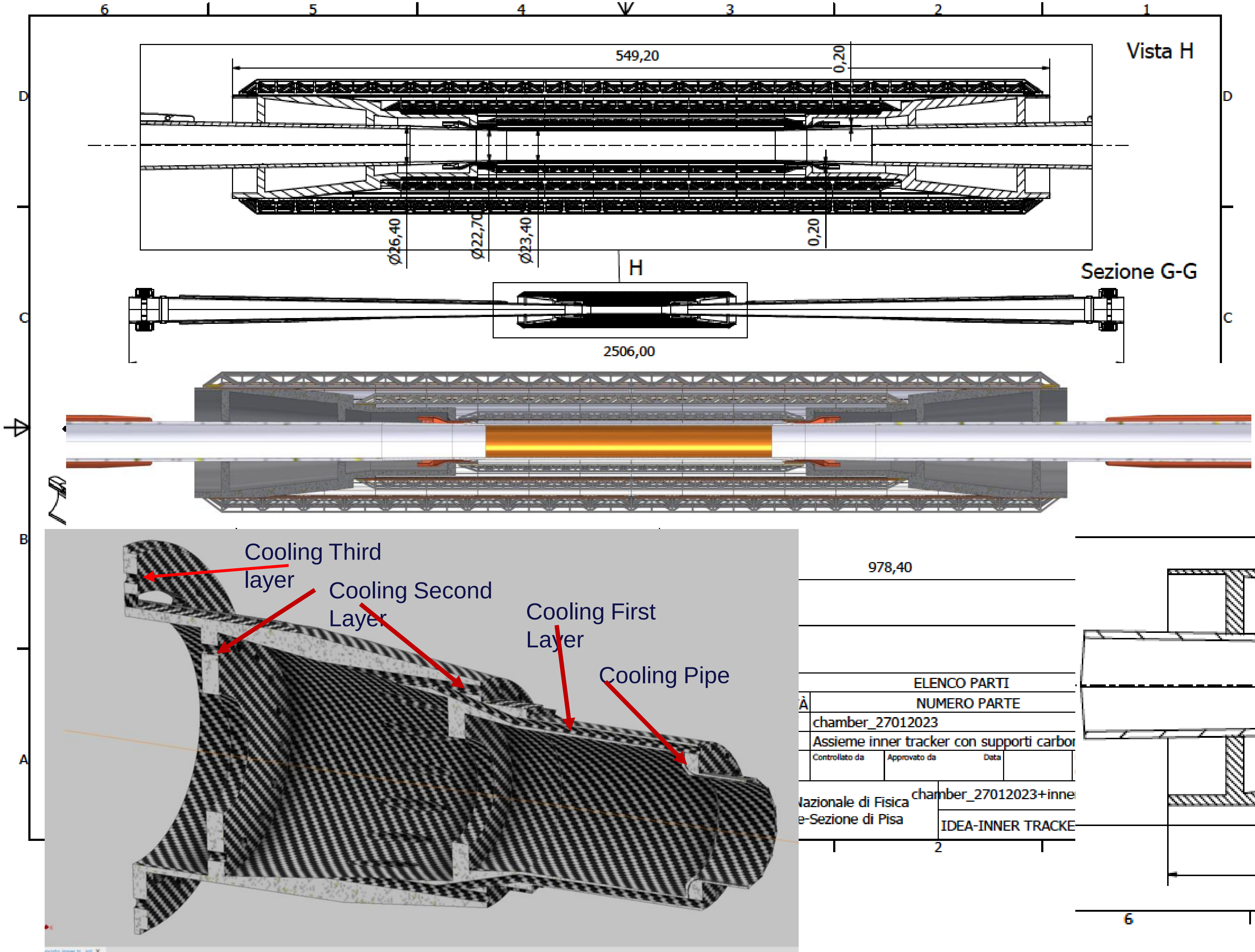
Lampshade geometry.

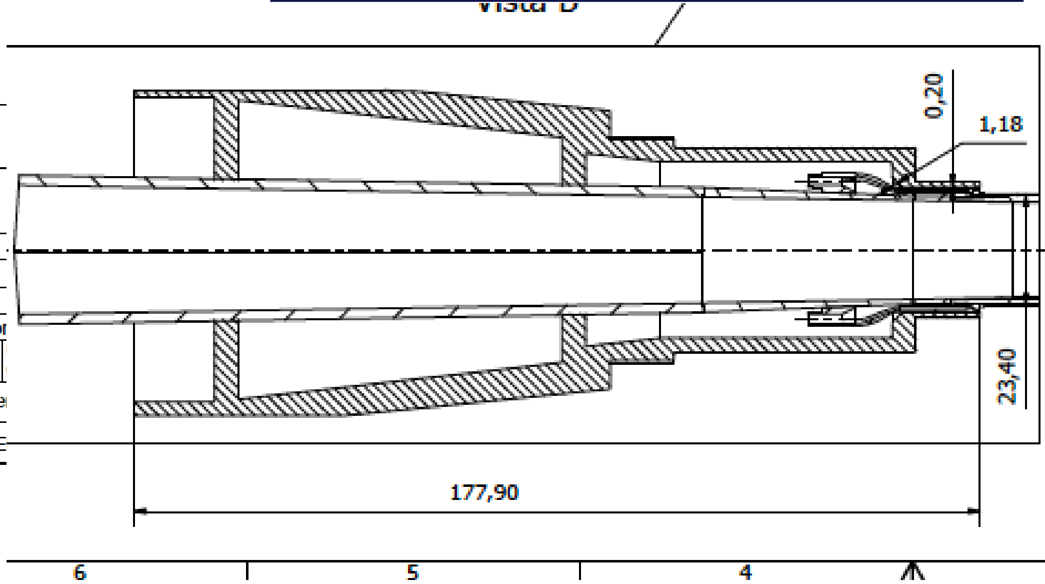
Charge symmetric track reconstruction

Total weight ~150 grams

Total thickness 0.25% X_0

Power budget ~77 W

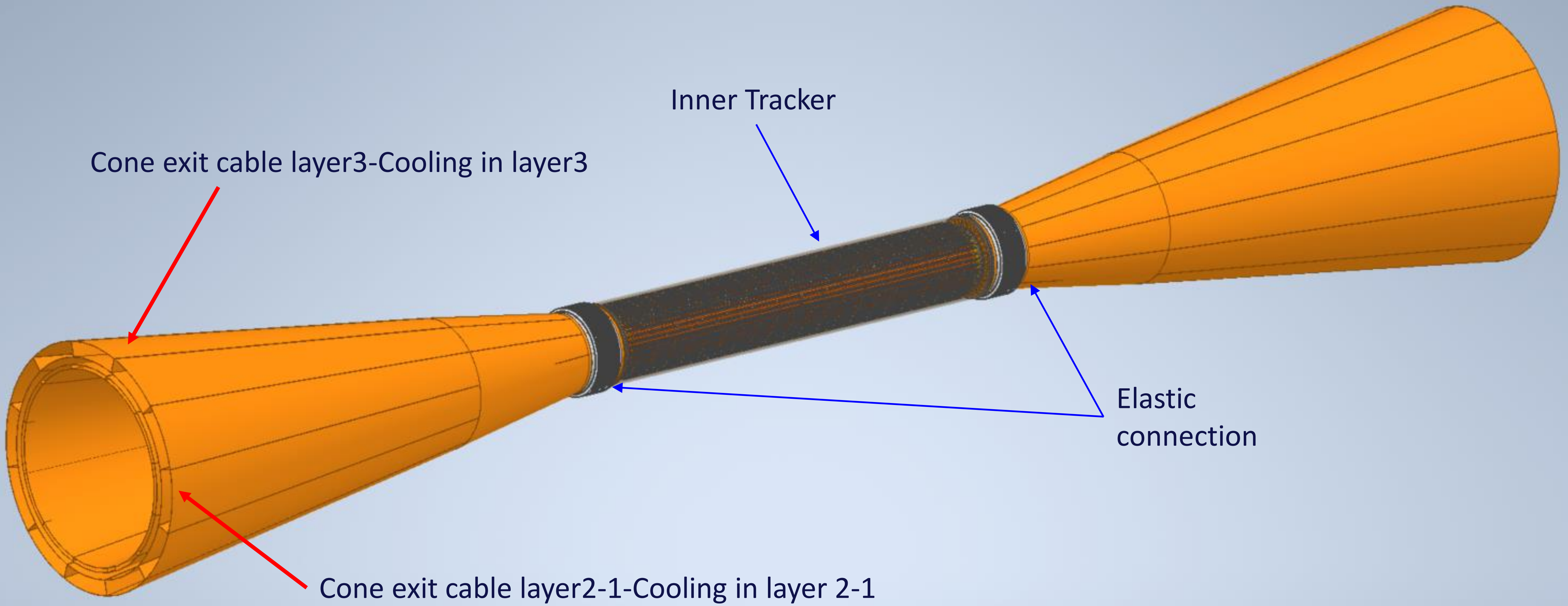




Inner vertex detector supporting conical structures on elliptical chamber
~450 grams

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

Service cones for cooling and cables



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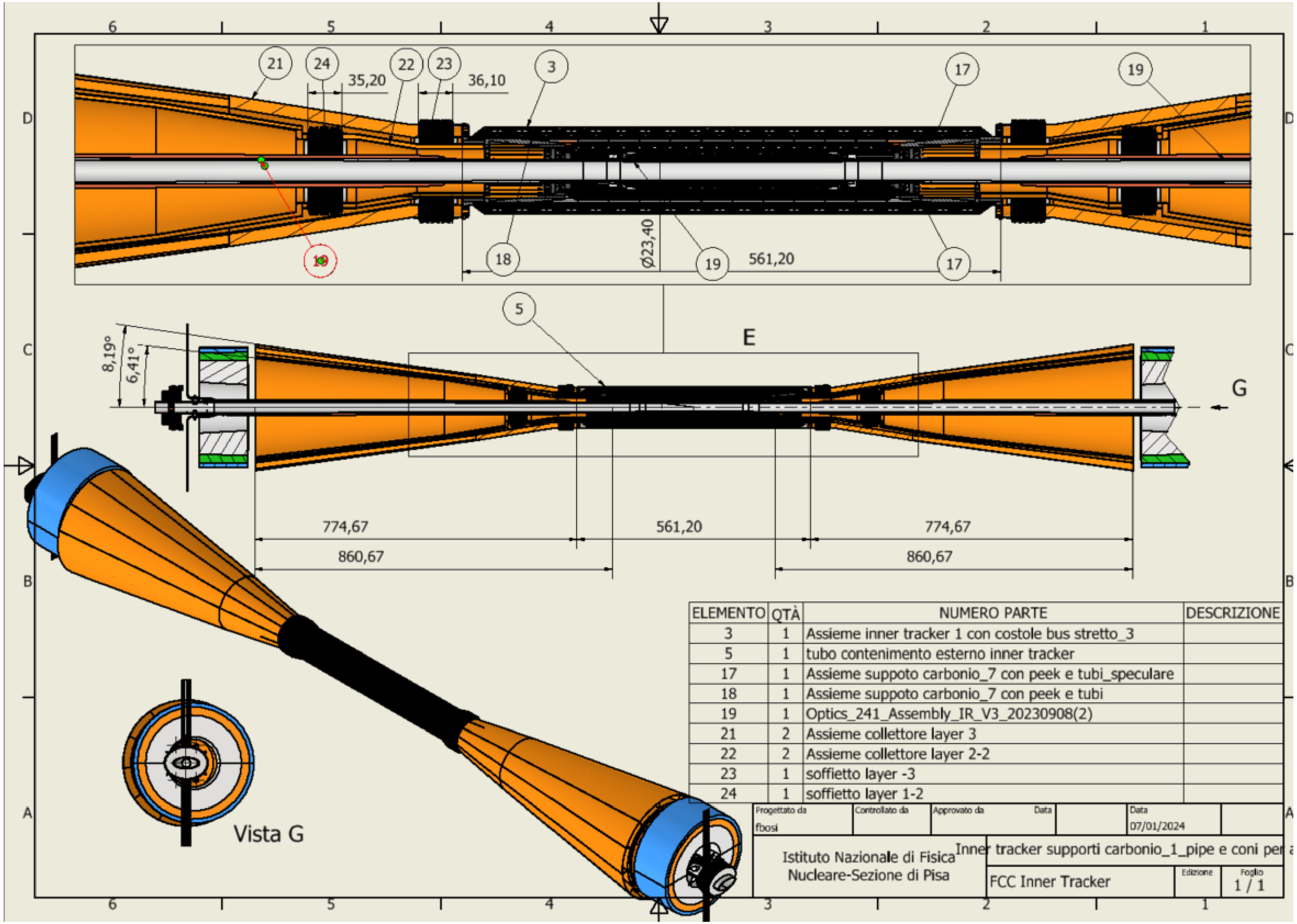

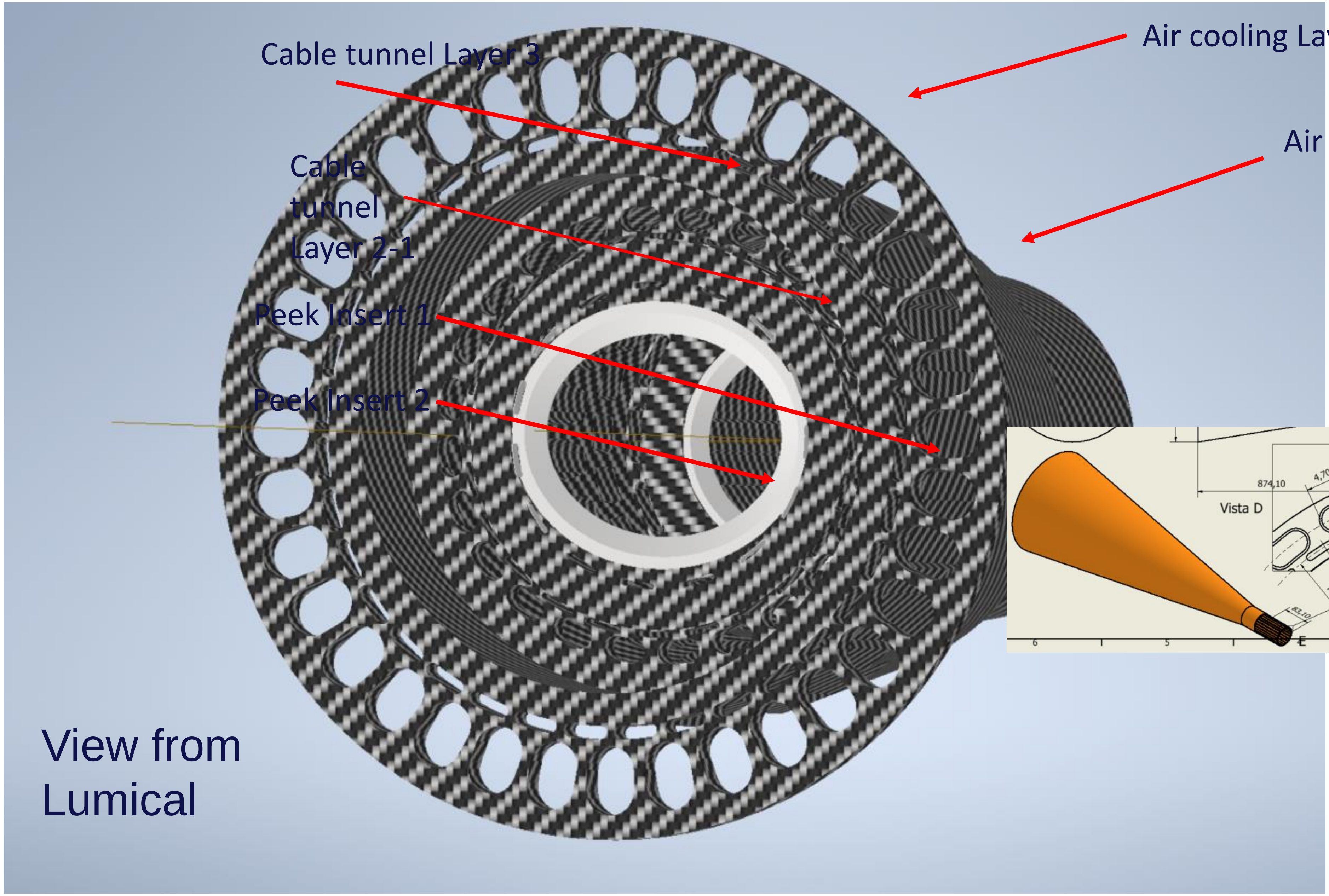

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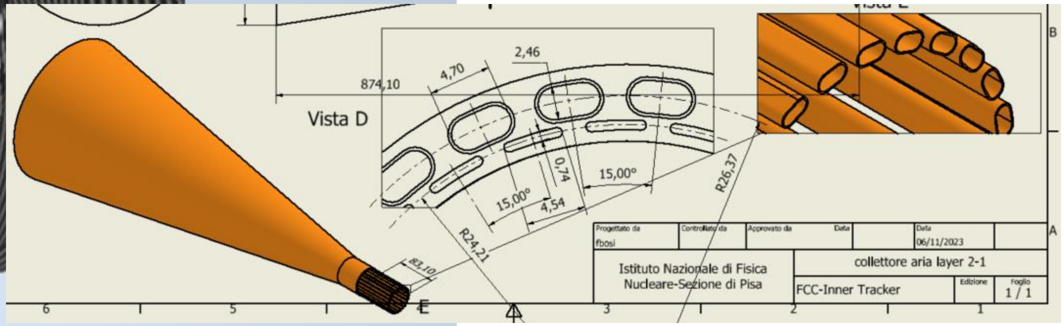
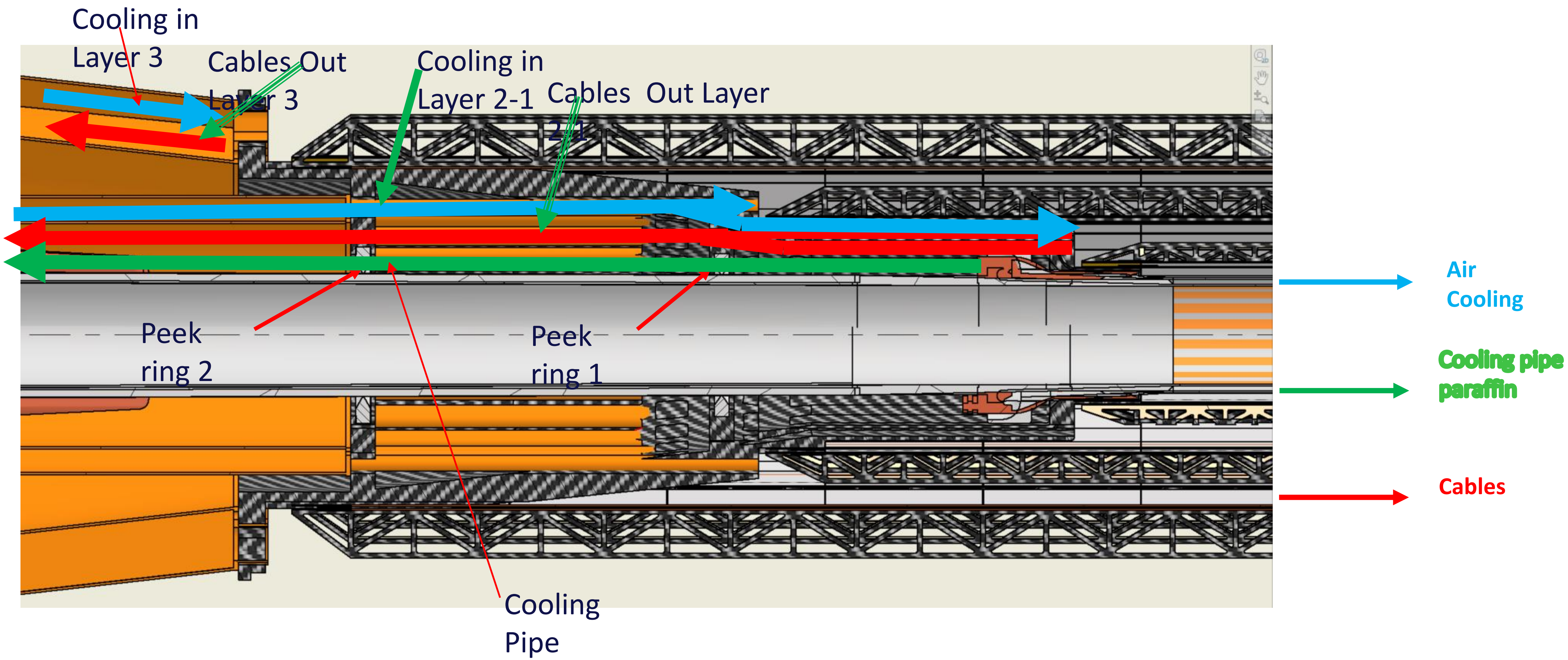
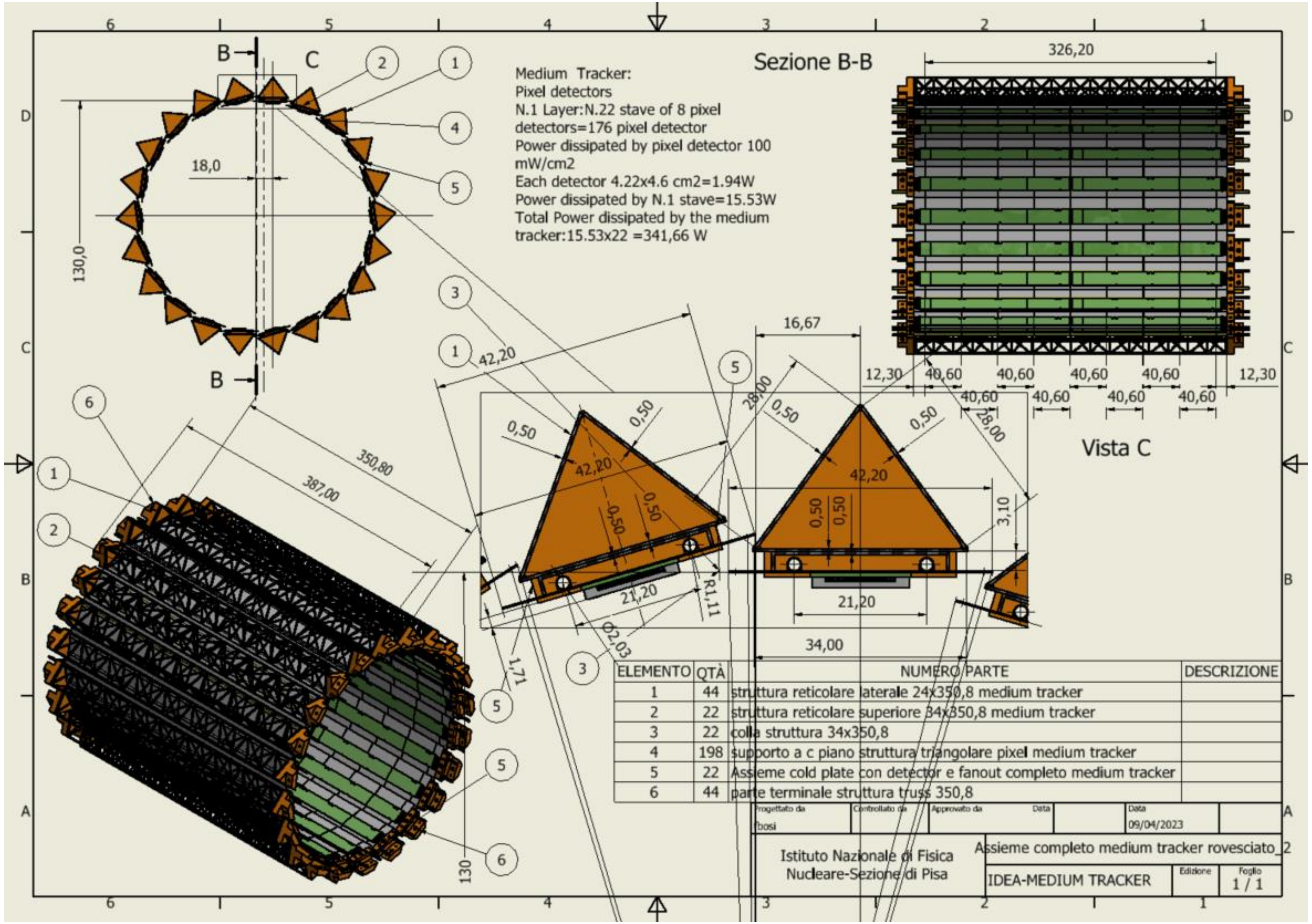


See C. Turrioni talk on Vertex Air cooling

Integration with beam pipe cooling manifold





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Middle Vertex Barrel
At 13 cm radius

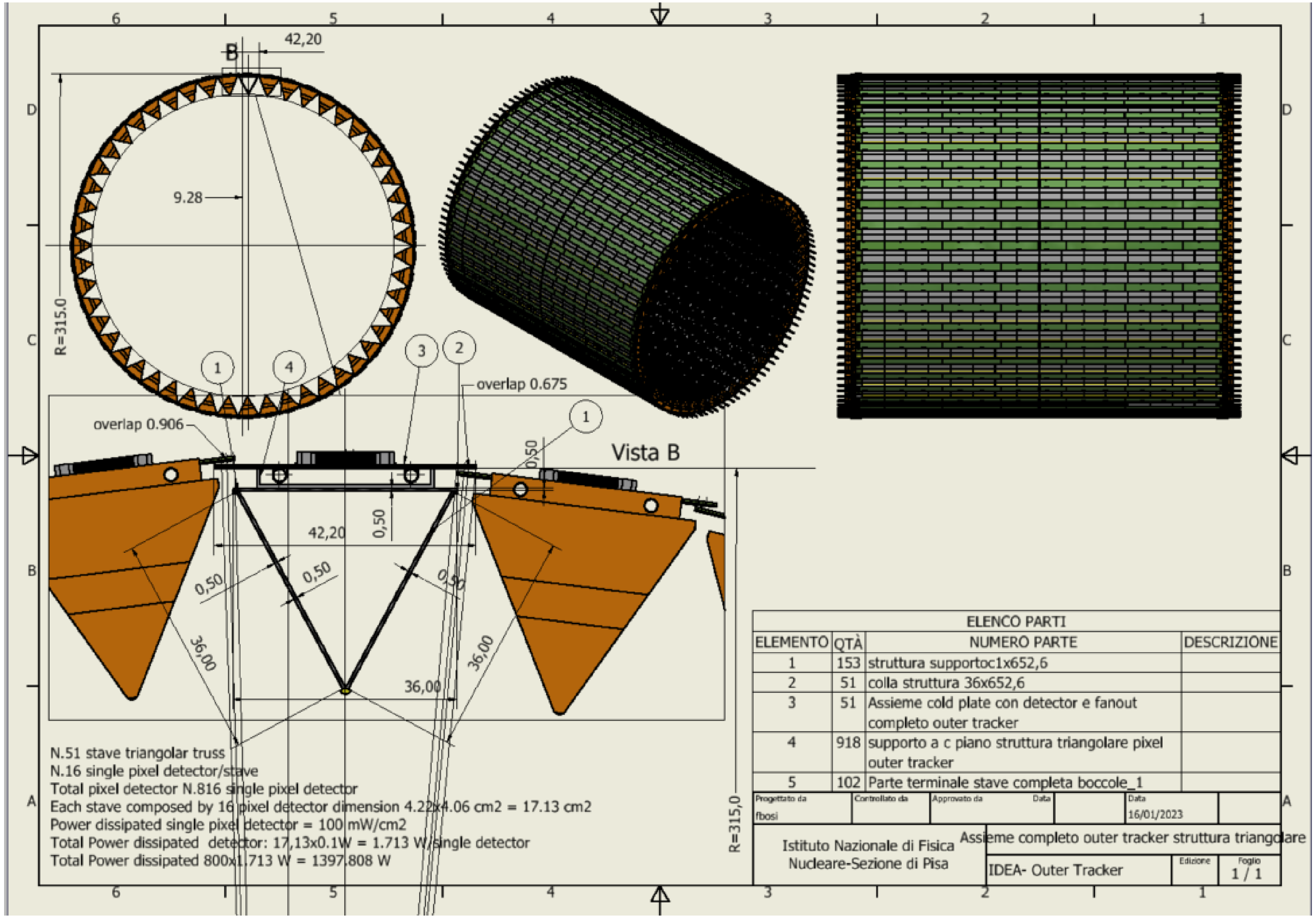
22 staves of 8 modules each.

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

Readout chips either side

Power budget
~342 W

Total weight ~1 kg
Water cooled (2 pipes of 2 mm diameter)



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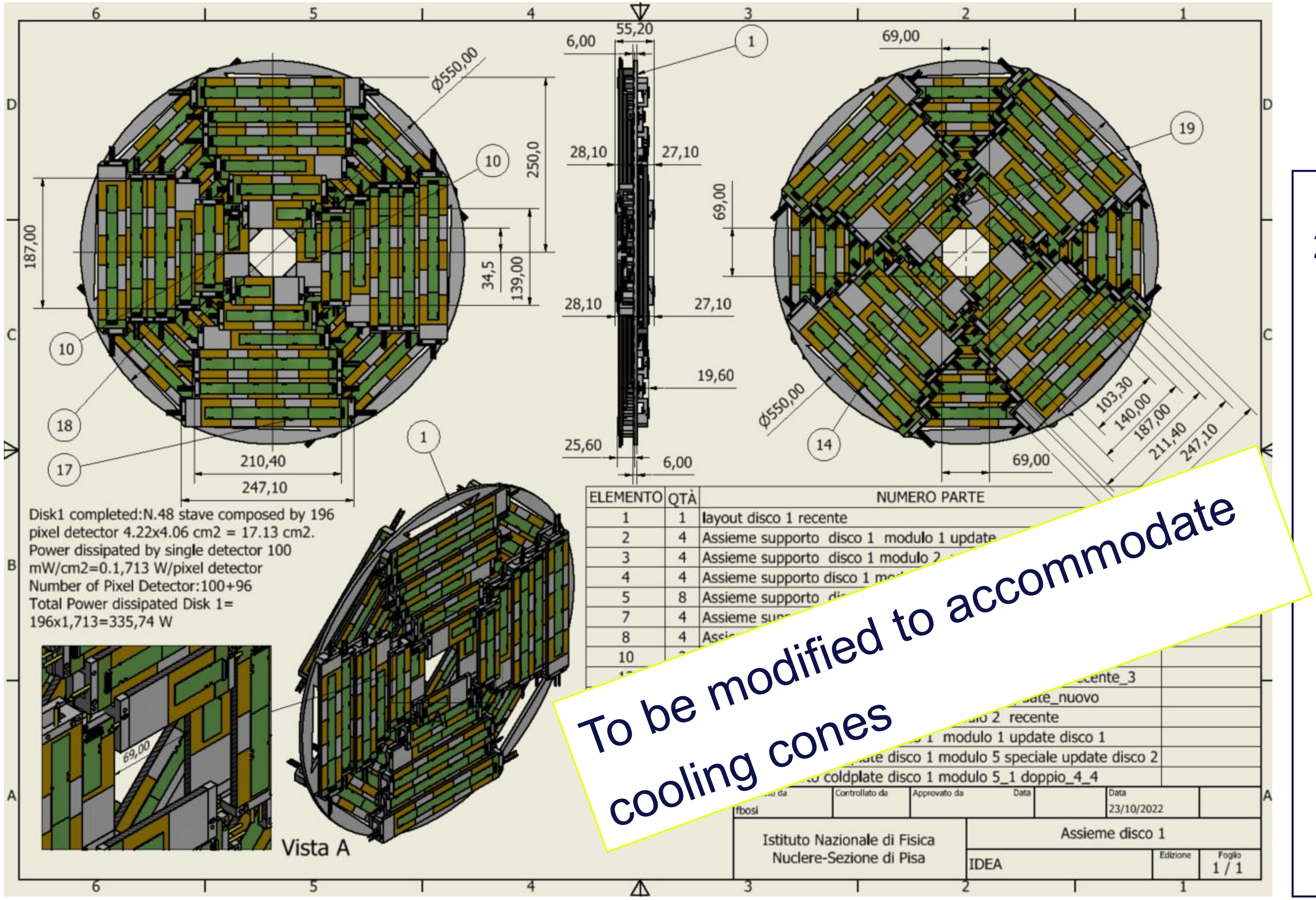
Outer Vertex Tracker Barrel
At 31.5 cm radius

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)



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Outer Vertex Tracker Disk 1

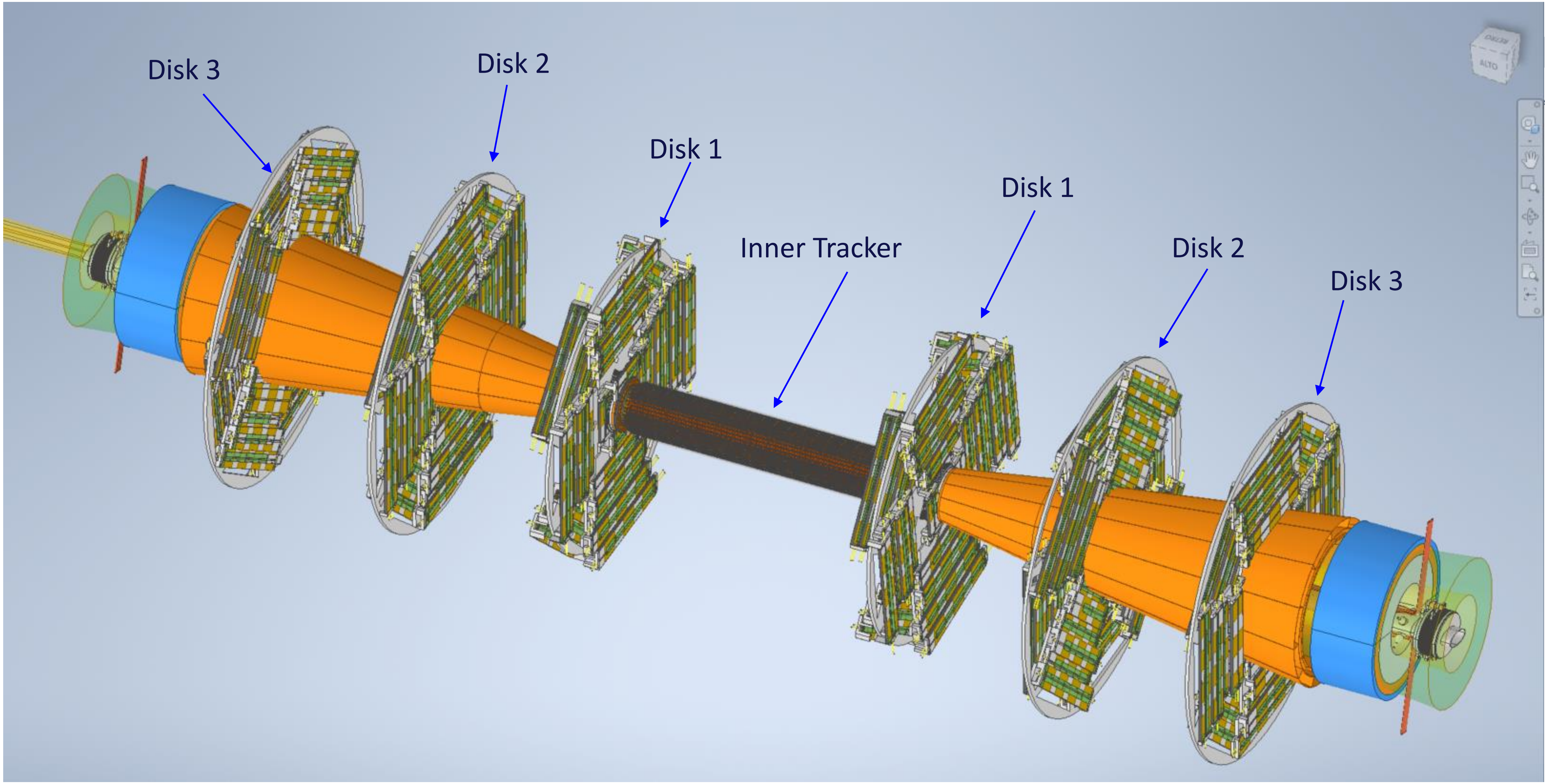
2 sides (front and back) each with 4 petals.

One petal is made of different staves of overlapping modules

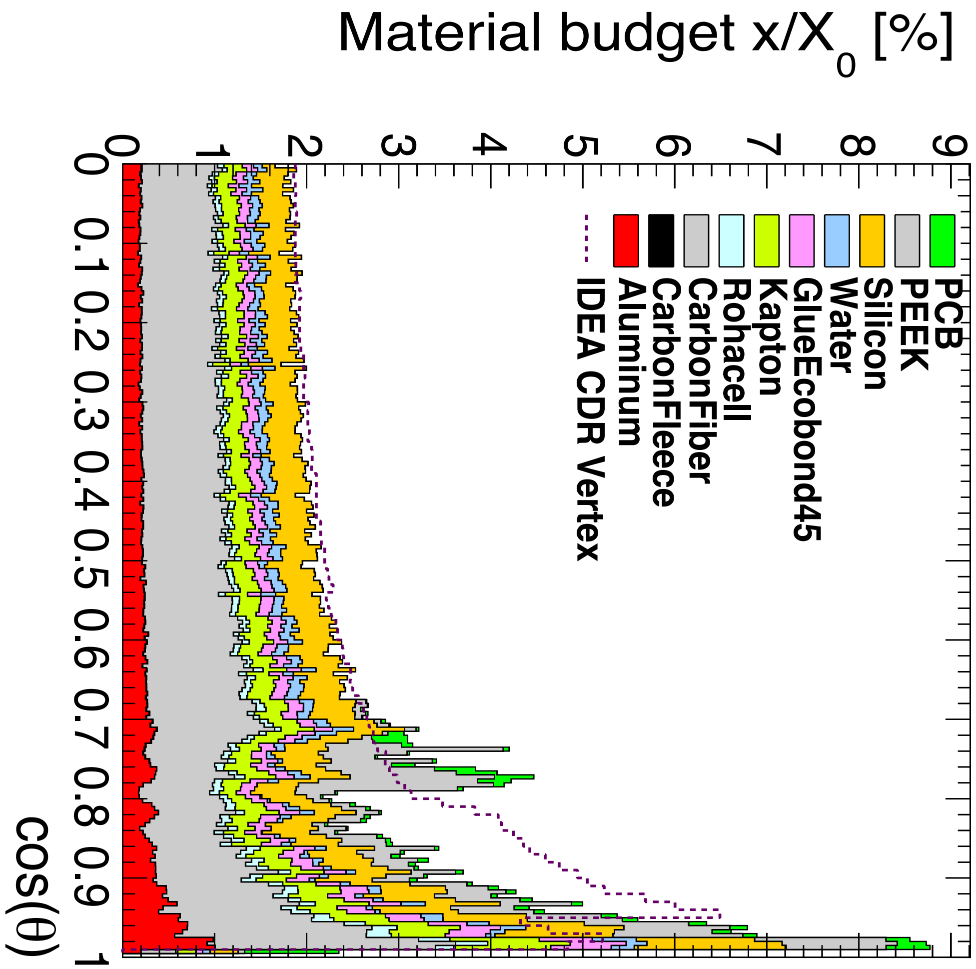
Total modules per disk: 196
Total weight ~850 grams
Power budget ~ 336 W

Cooling using 1 water pipe (2 mm diameter)

Similar geometry for the other two disks


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

Simulated material budget

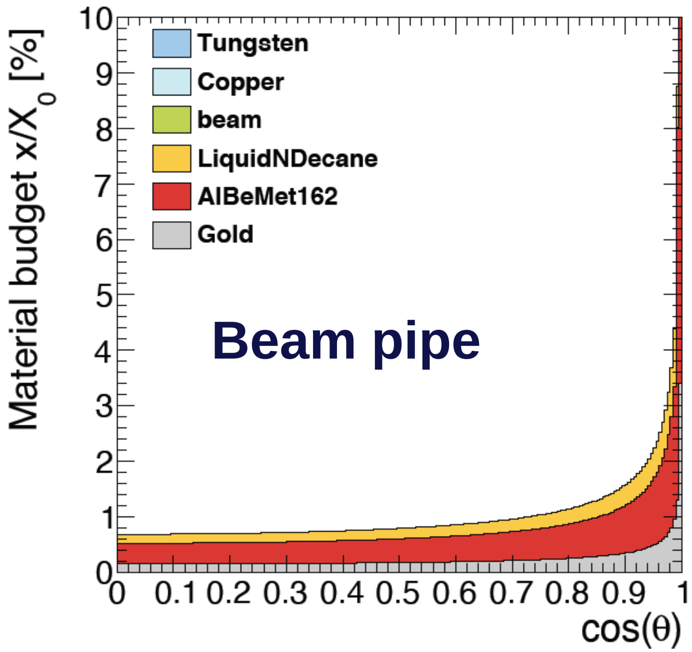


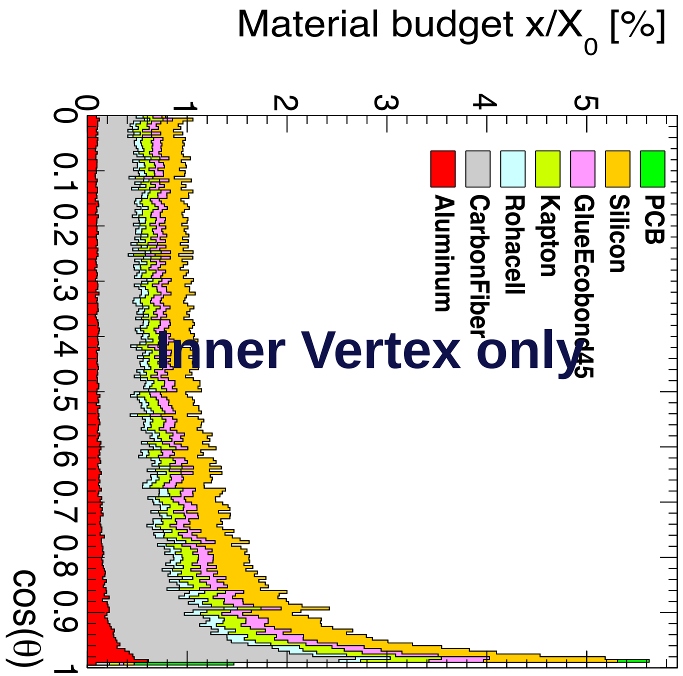
See A. Ilg talk

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





Support cylinder

See talk from F. Fransesini

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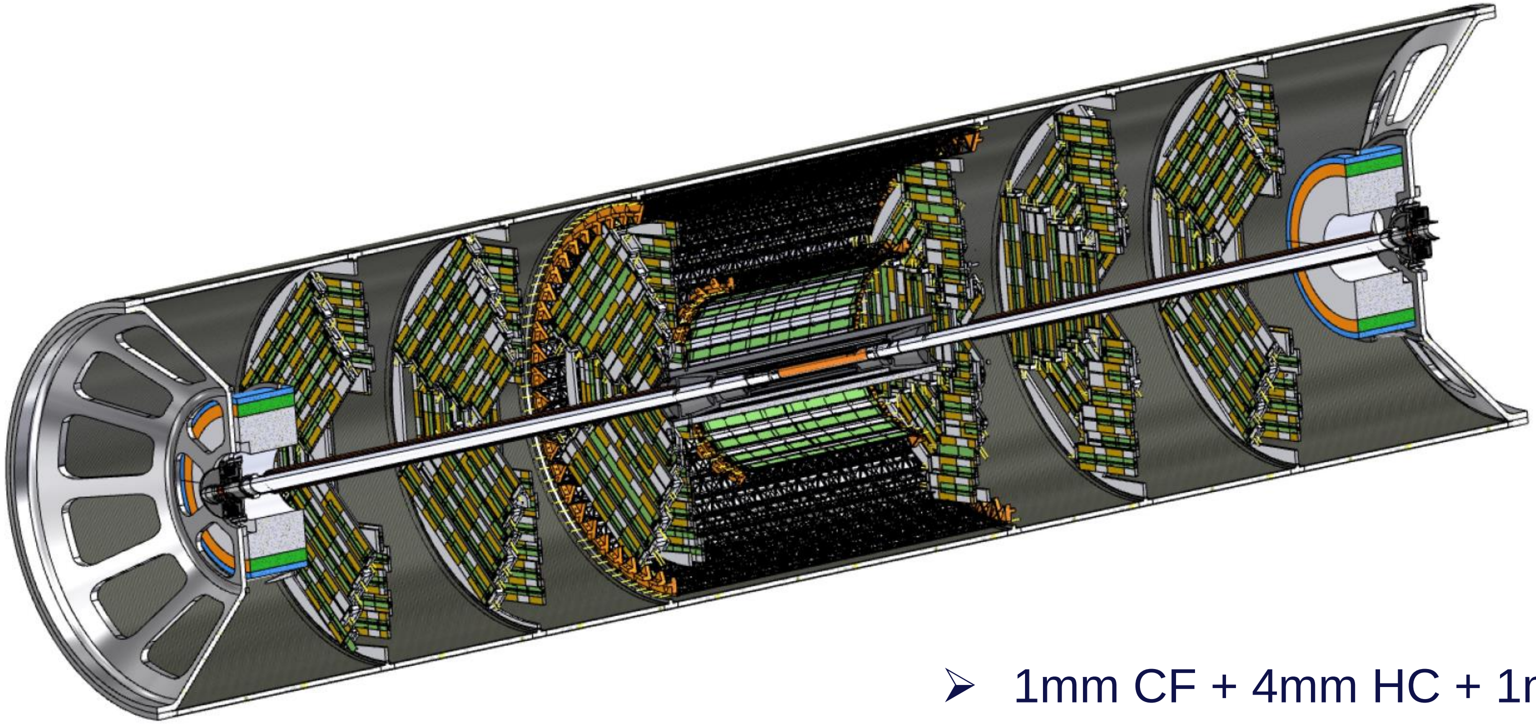
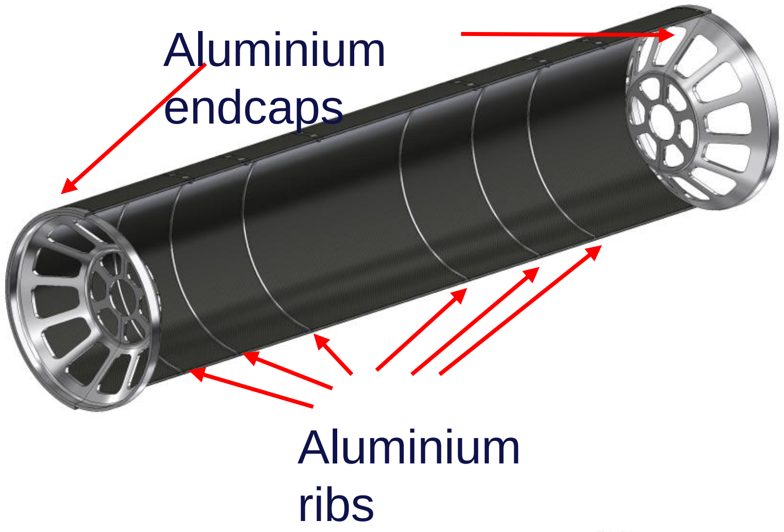
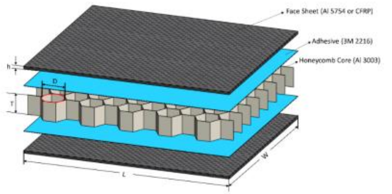
All elements in the interaction region (Vertex and LumiCal) are mounted rigidly on a support cylinder that guarantees mechanical stability and alignment

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





➢ 1mm CF + 4mm HC + 1mm CF



General integration

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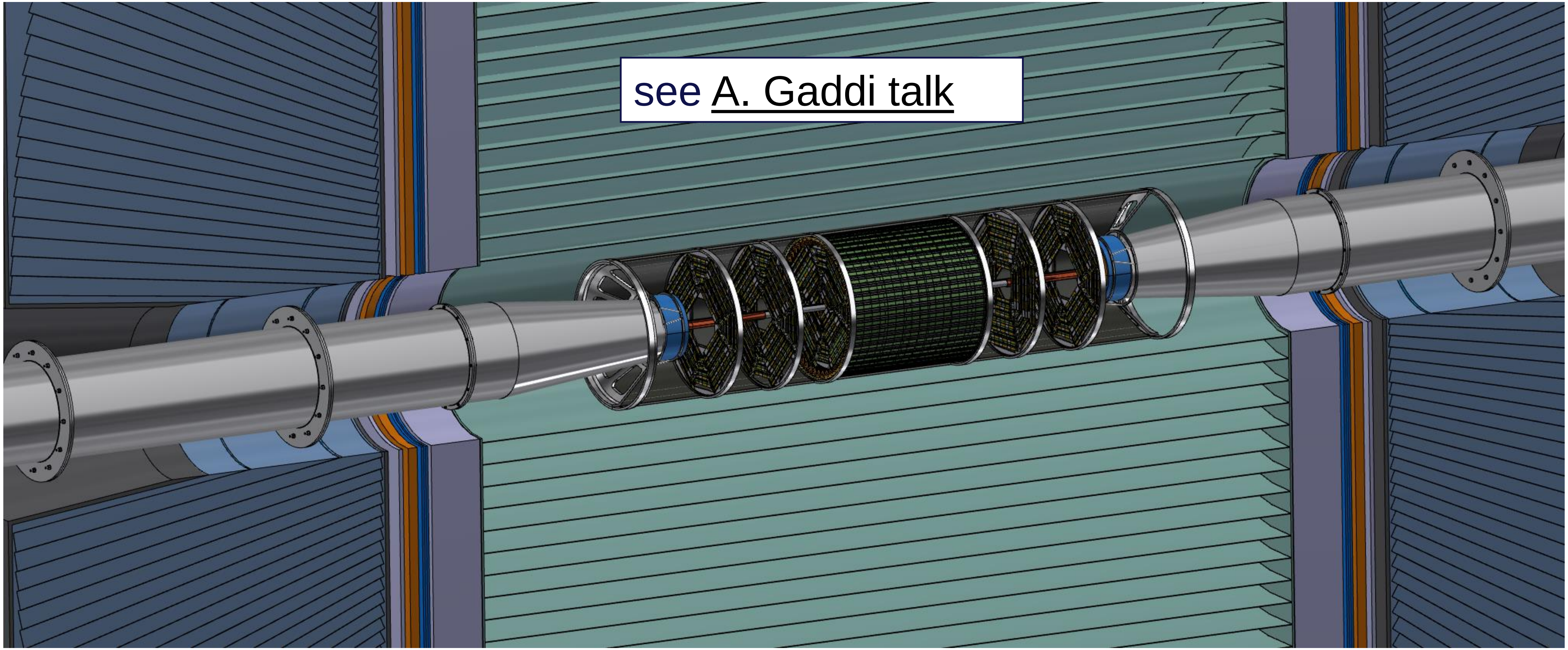
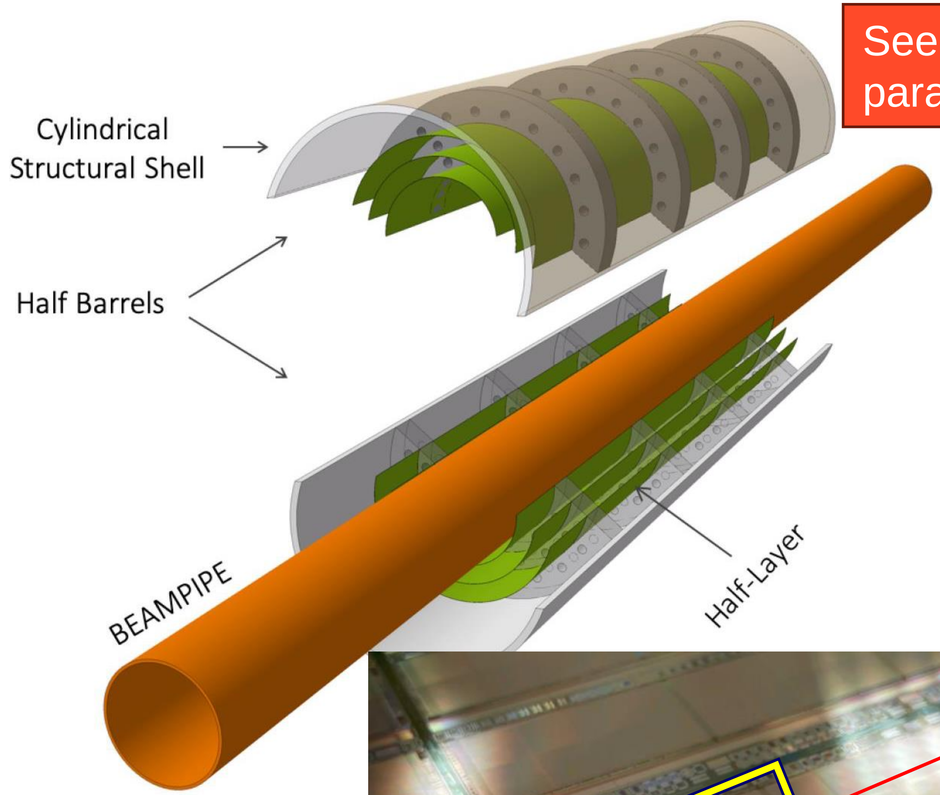
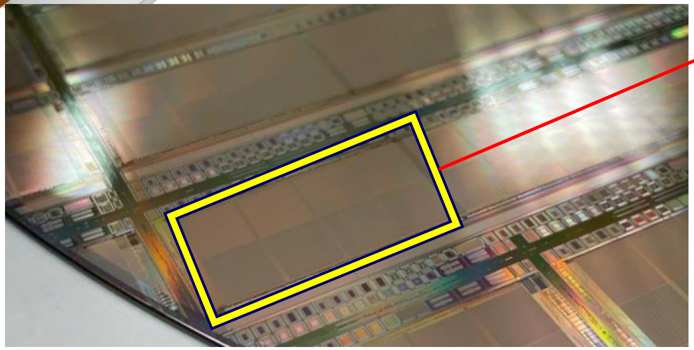
M. Boscolo, F. Palla, F. Fransesini, F. Bosi and S. Lauciani, Mechanical model for the FCC-ee MDI, *EPJ Techn Instrum* **10**, 16 (2023).
https://doi.org/10.1140/epjti/s40485-023-00103-7

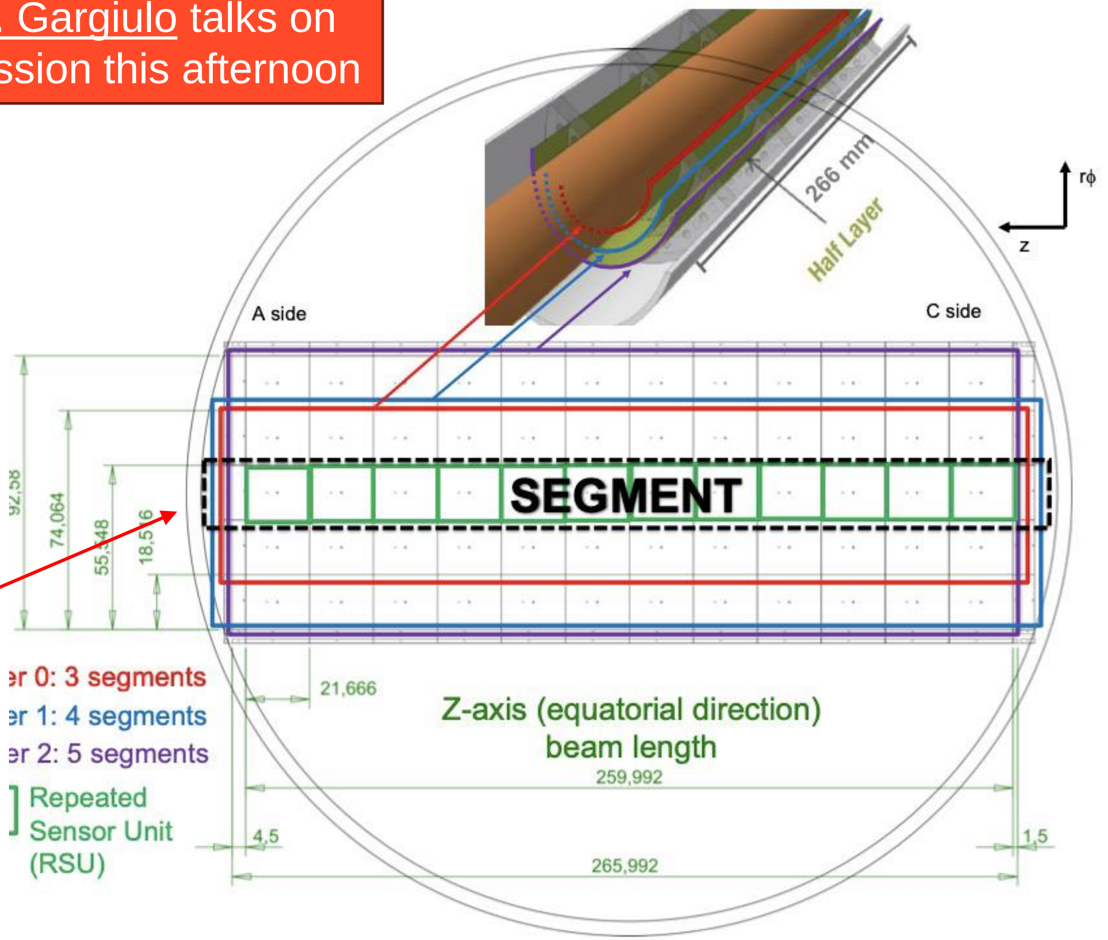


see A. Gaddi talk

See K. Gautam and C. Gargiulo talks on parallel 2 detectors session this afternoon







ALICE ITS3 inner vertex inspired design – issues

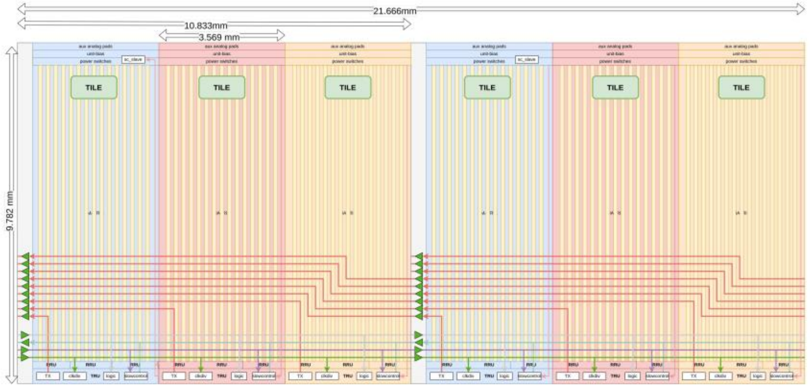
(0.2 % X/X_0 material budget – 5 times less than the Mid-Term one)

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

Issues – I

ALICE smaller radius will be 18 mm (beam pipe 16 mm)

- **Needs to demonstrate bent MAPS with 13.5 mm radius works electrically – mechanically OK**

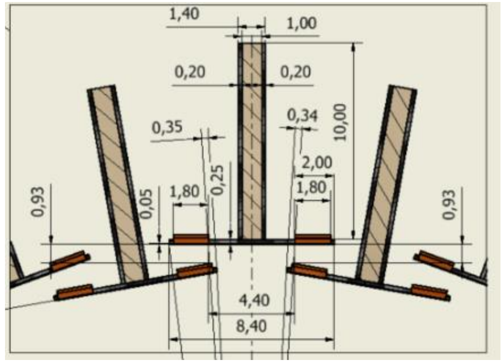


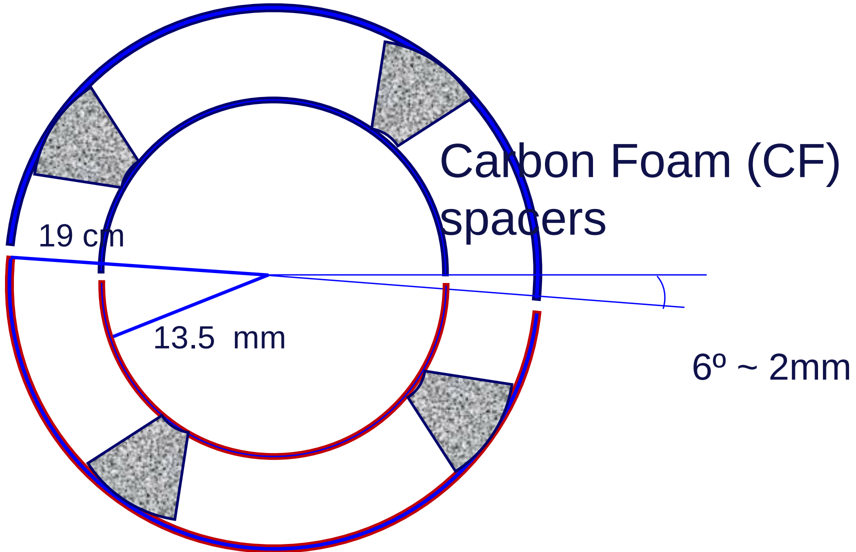
Active pixels 95% of covered area (chip service zones)

- **Which impact has on physics?**
- **Cannot overlap sensors as in "traditional" layouts in same layer**
- **Can be recovered in ϕ by rotating two layers at different radii**

If same angular coverage for all layers is seeked

- **Then needs to 2 stitched structures in z for outer layers**





ELECTRICAL UNITS

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MOSAIX - Top Integration Diagram

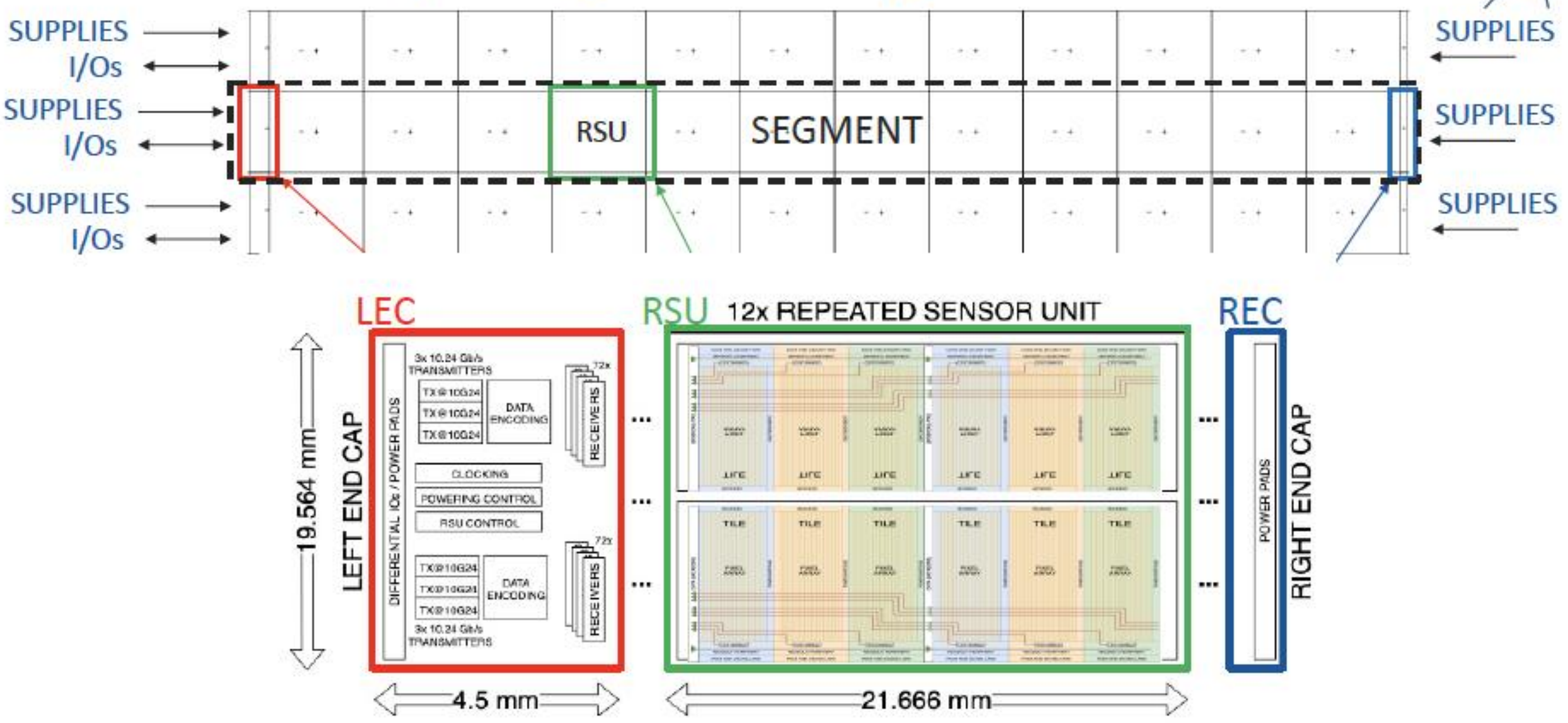
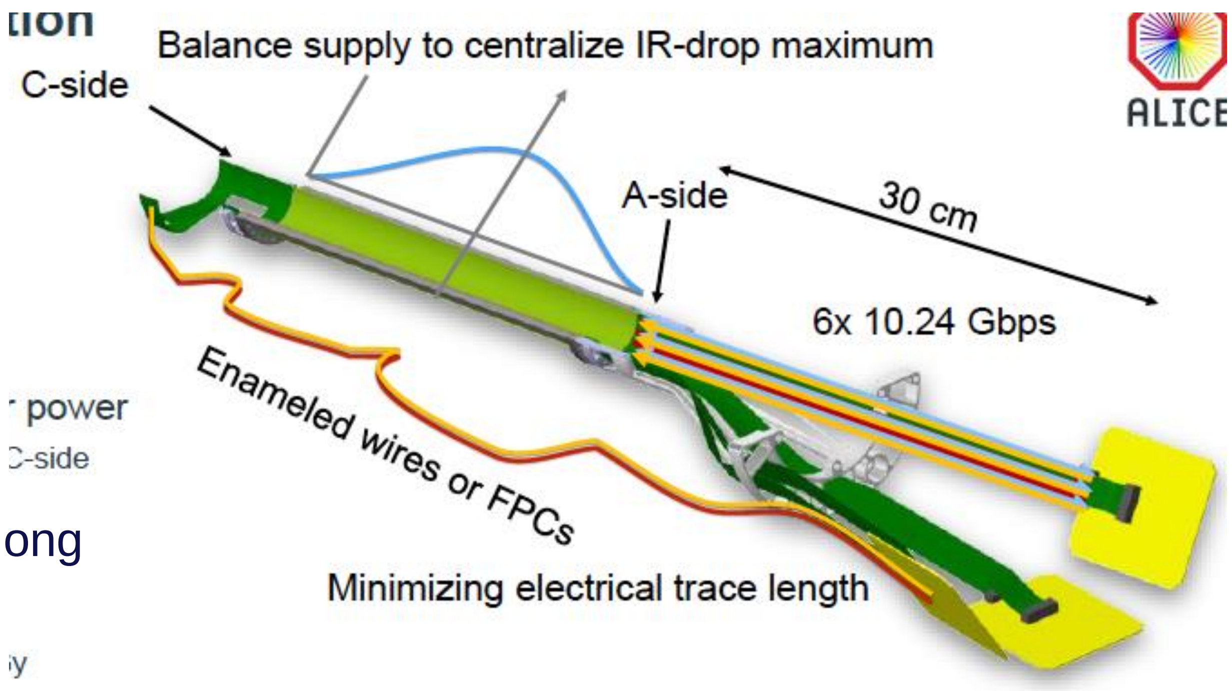
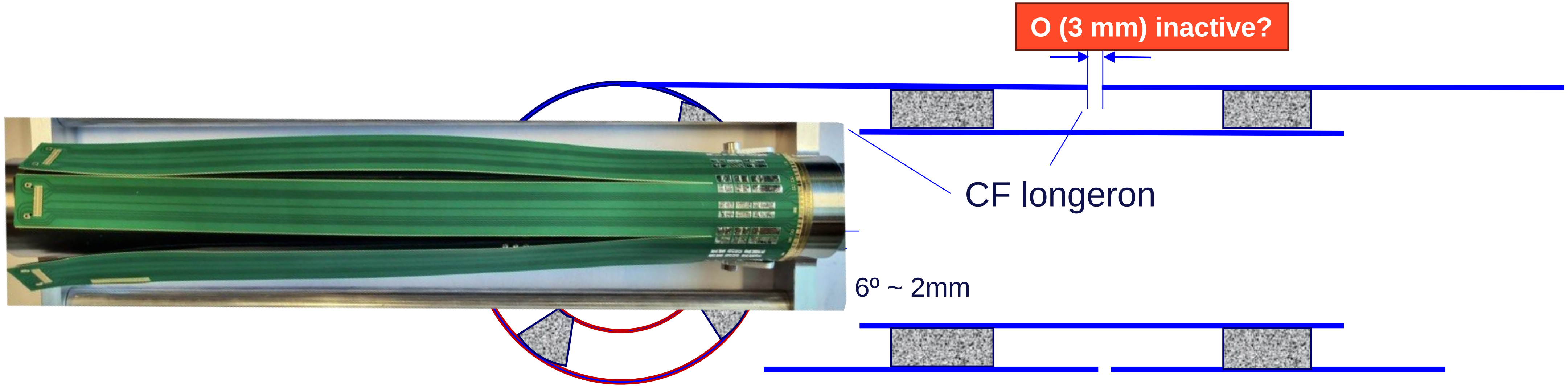


Figure 3.34: Block diagram of the sensor segment.

Issues – II

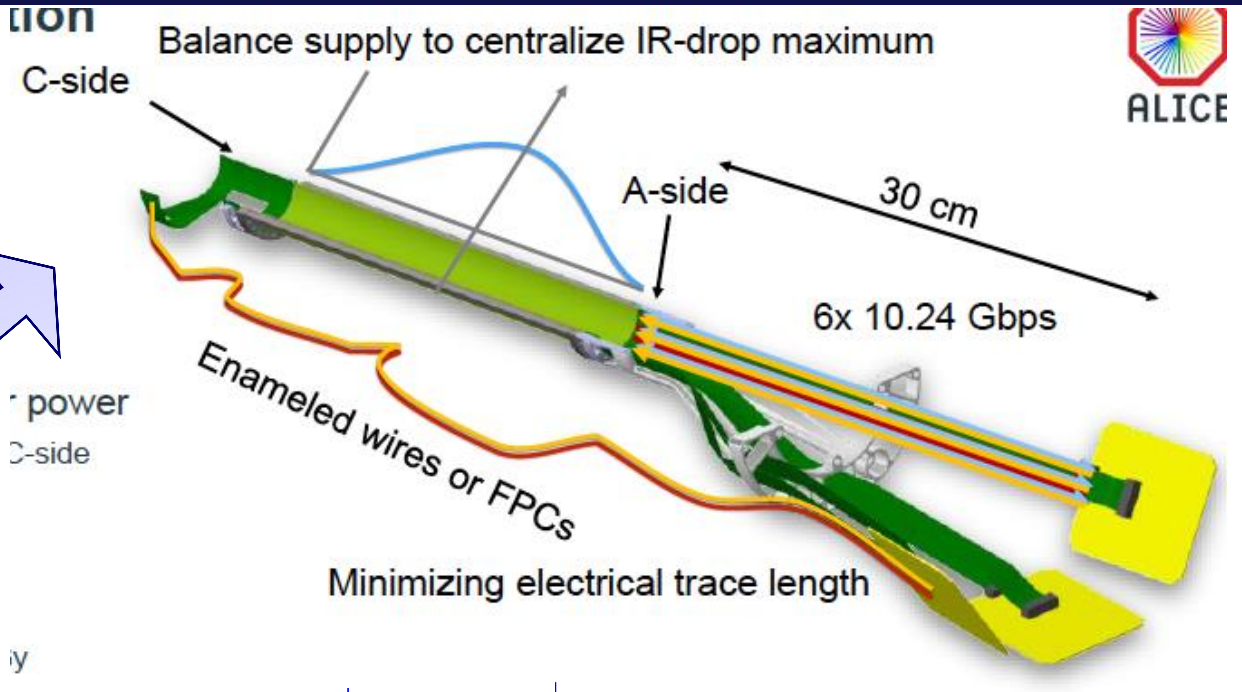


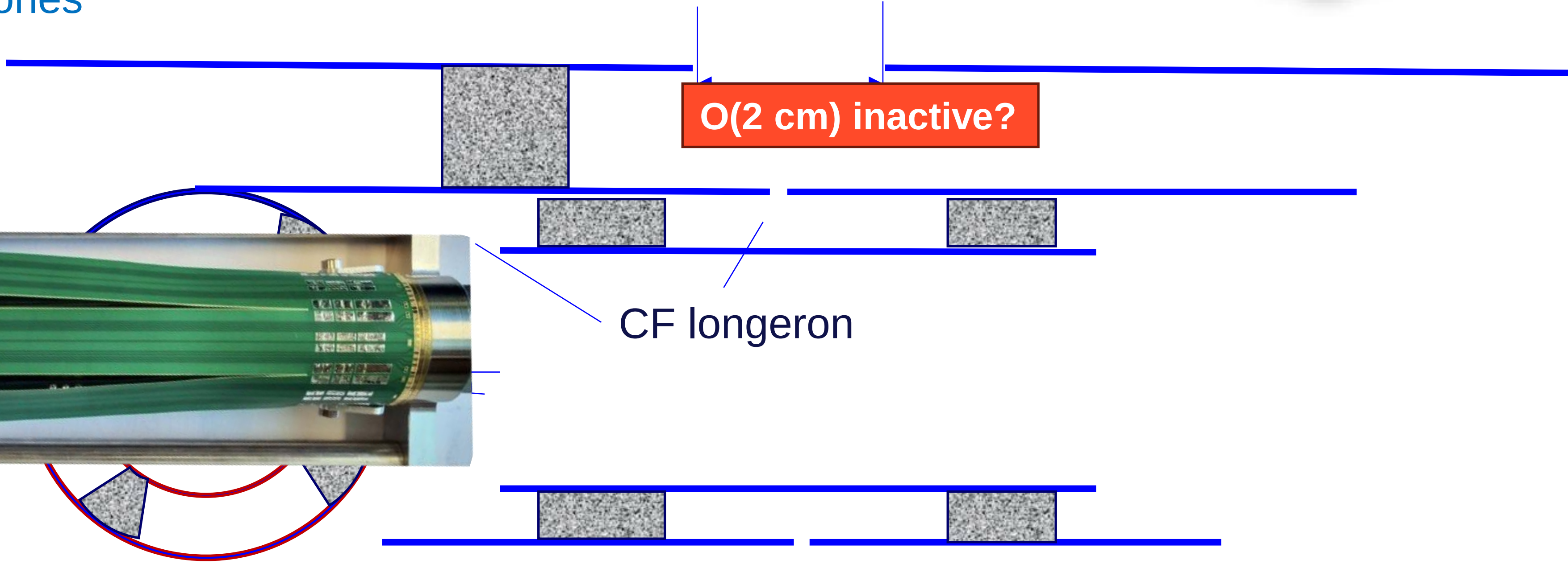
- **2nd layer @ higher radius**
  - Rotated to recover ϕ dead zones of 1st layer
  - 27 cm long in z → needs two stitched 13.5 cm long
  - Possible to power on one side only
  - Cannot overlay two stitched structures
    - Few mm inactive zones



Issues – III

- **Problems in z for 3rd layer**
  - 2x25 cm long in z
  - Need power on both sides
  - Flex circuit length ~ O(1 cm)
  - Cannot overlap the two sides
  - Large O(few cm) dead zones

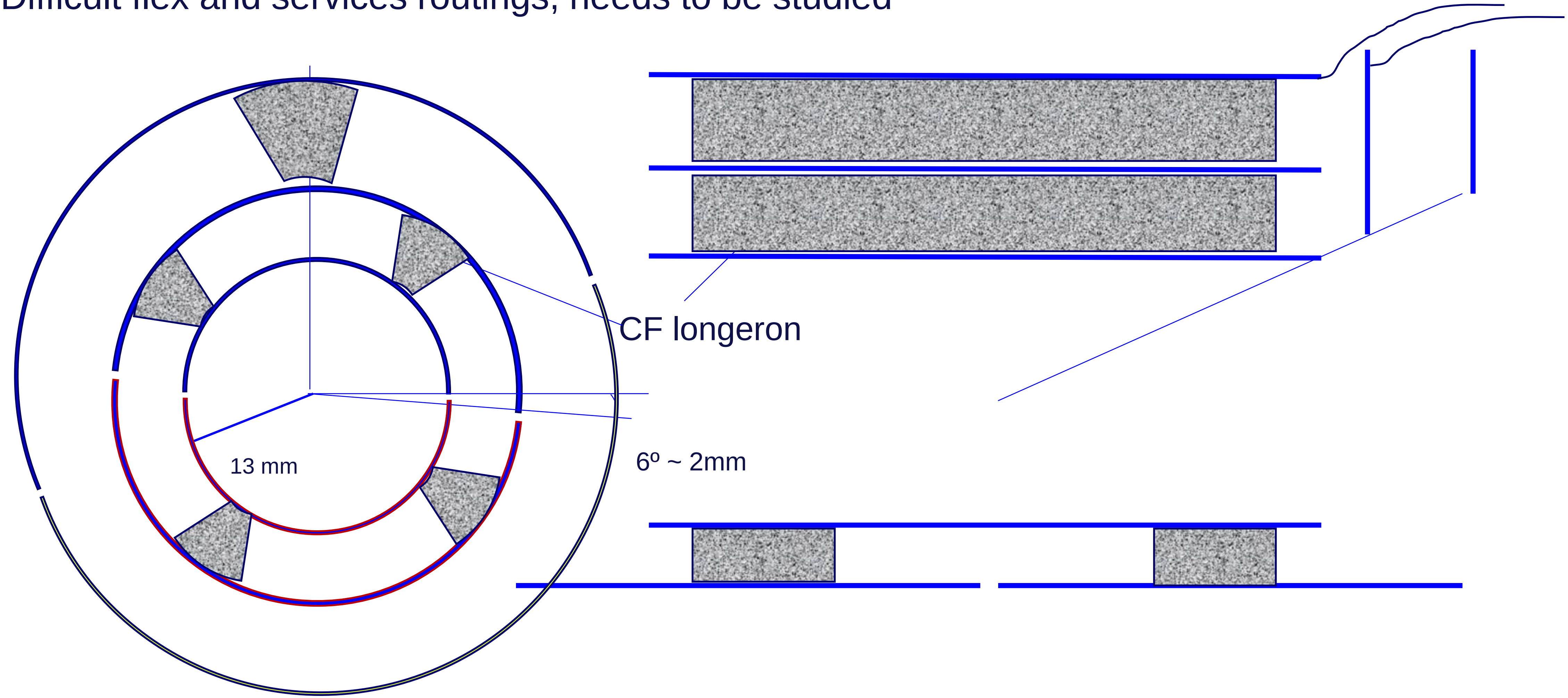




Issues – IV

Alternative layout using one same length barrel section plus disks?

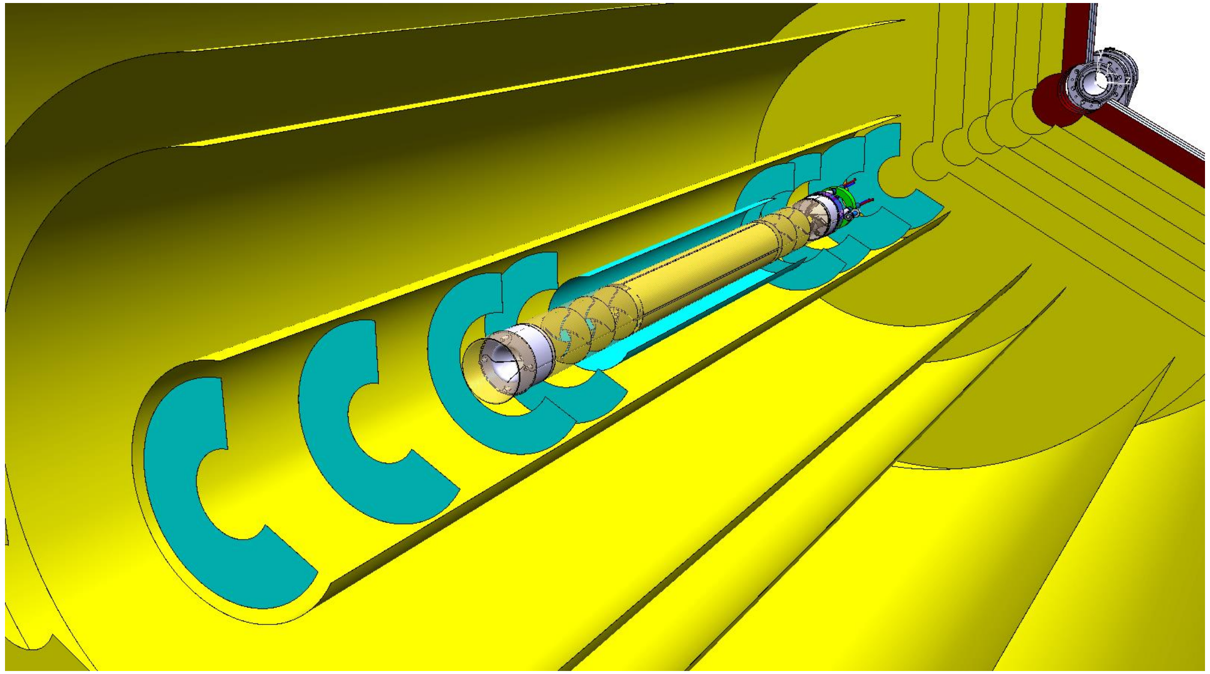
- Difficult flex and services routings, needs to be studied



Issues – V

Even more aggressive put everything in beam pipe with a secondary vacuum (ALICE IRIS) needs to address (and solve!) several other problems

- Beampipe aperture
- Vacuum
- Resistive wall effects (heating – O(60 Watt for 5 mm radius @ the Z) – and beam instability)
- Cooling and services routing
- …



Conclusions

- **A layout of the Vertex Detector of IDEA (and ALLEGRO) has been engineered**
  - Uses low power, thin (50 µm) MAPS technology
  - Integration with the machine detector elements developed
  - Services integration and cooling are being finalised
  - Material budget kept at the level of $0.3\ \%\ X/X_0$ per layer (Silicon only 15% of the total)
- **A much lighter concept with curved and stitched MAPS is starting**
  - Issues to be solved to gain full detector efficiency
  - Might be of interest for dedicated experiment for heavy flavours

Thank you for your attention.

Overall Inner Vertex layout

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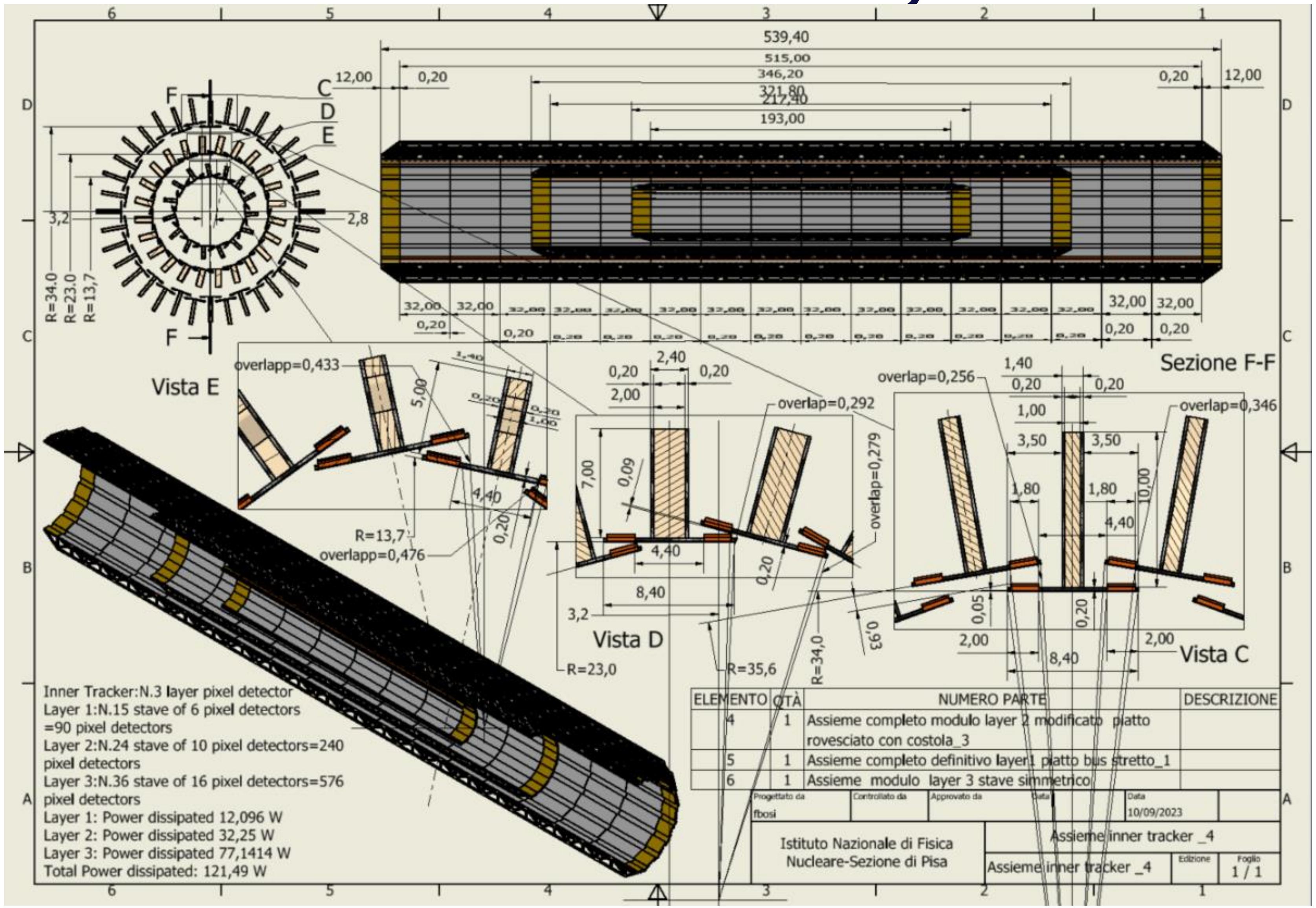

Total power ~120 W

Total weight ~230 grams

Stave detail

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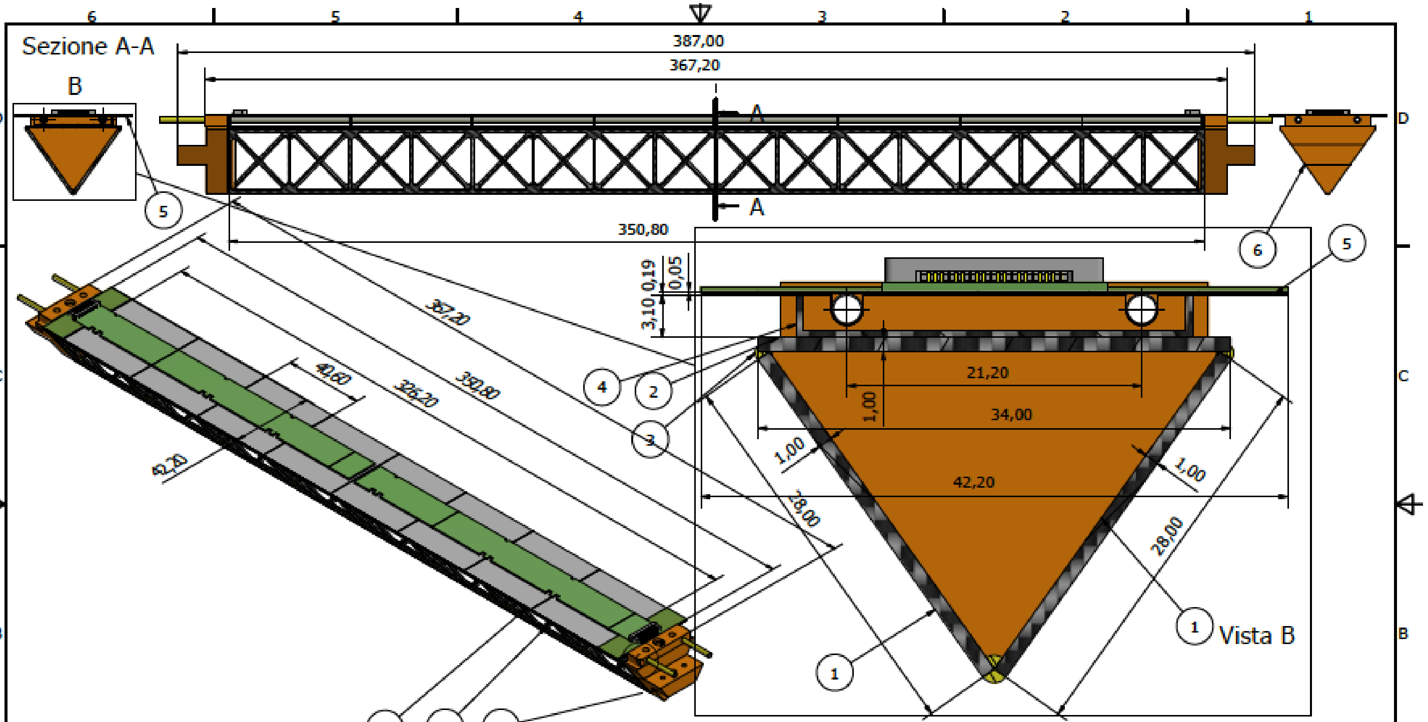


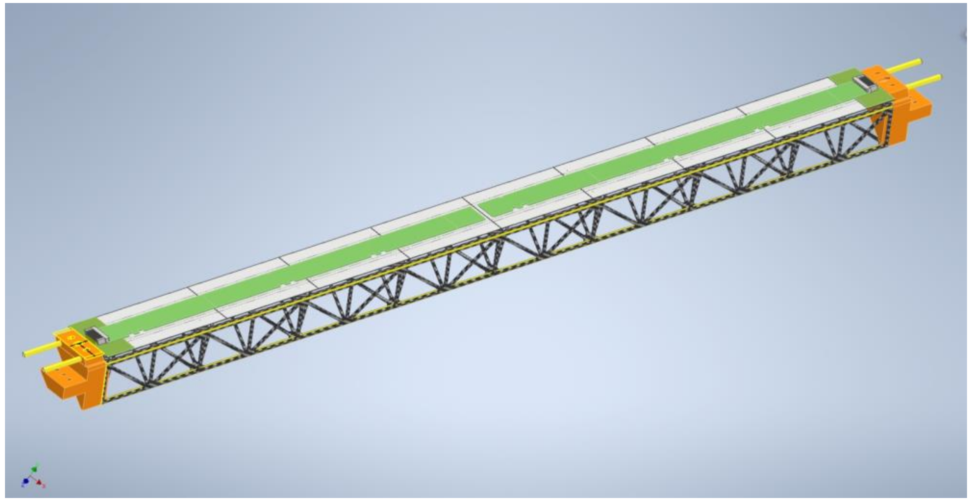
ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
1	2	struttura reticolare laterale 24x350,8 medium tracker	
2	1	struttura reticolare superiore 34x350,8 medium tracker	
3	1	colla struttura 34x350,8	
4	9	supporto a c piano struttura triangolare pixel medium tracker	
5	1	Assieme cold plate con detector e fanout completo medium tracker	
6	2	parte terminale struttura truss 350,8	

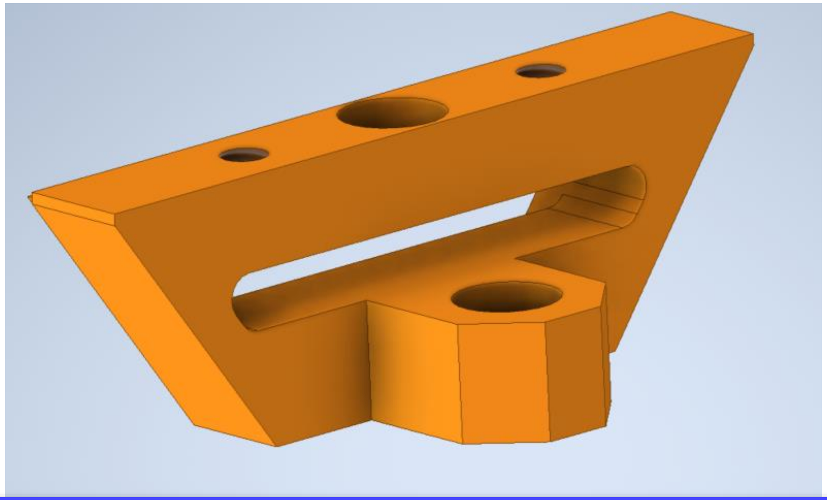
Progettato da fbosi | Controllato da | Approvato da | Data | Data 17/01/2023

Istituto Nazionale di Fisica Nucleare-Sezione di Pisa

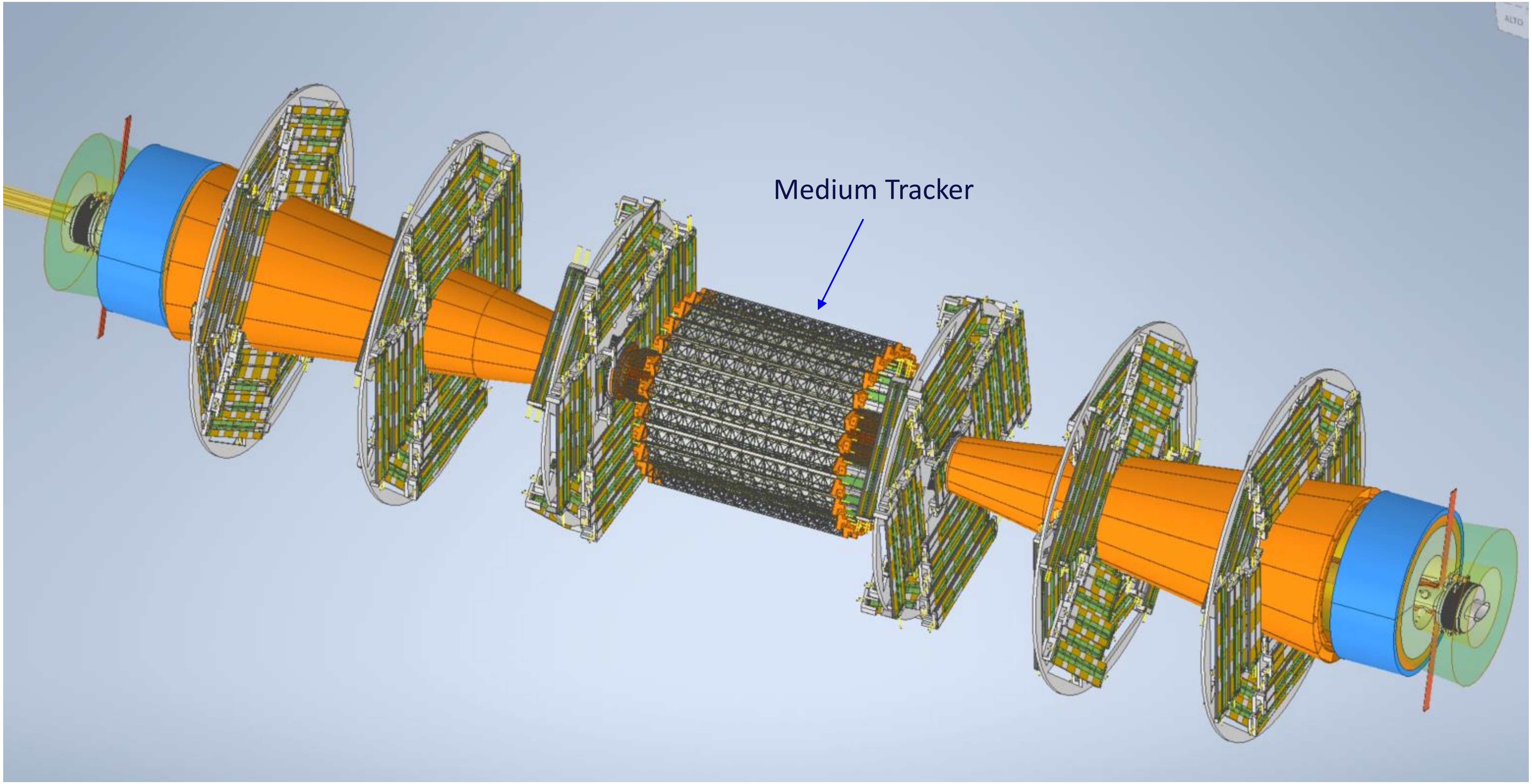
Assieme completo stave medium tracker

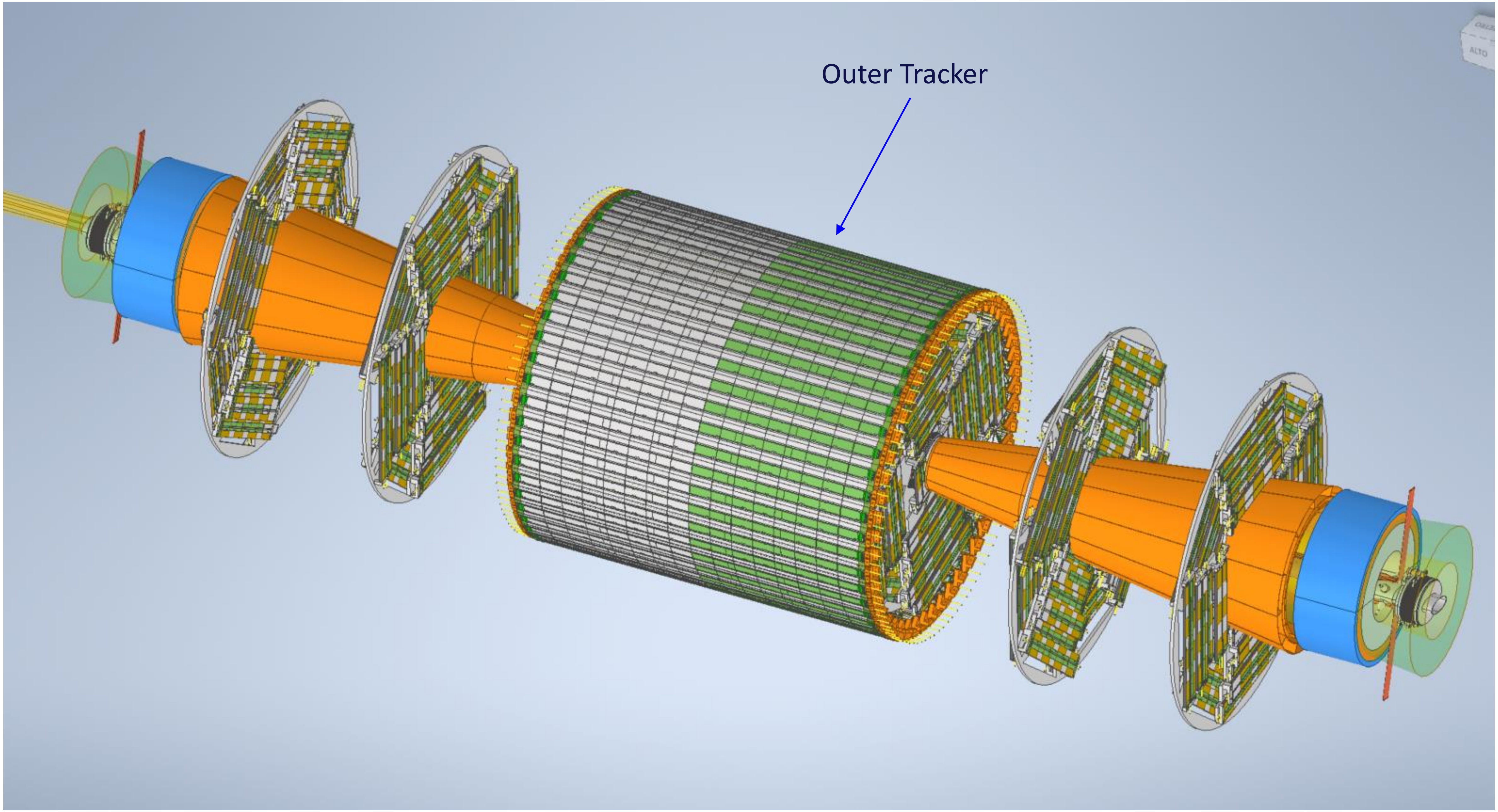
IDEA-Medium Tracker | Edizione | Foglio 1 / 1





Shaped to minimize material at the end of the stave


Medium Tracker

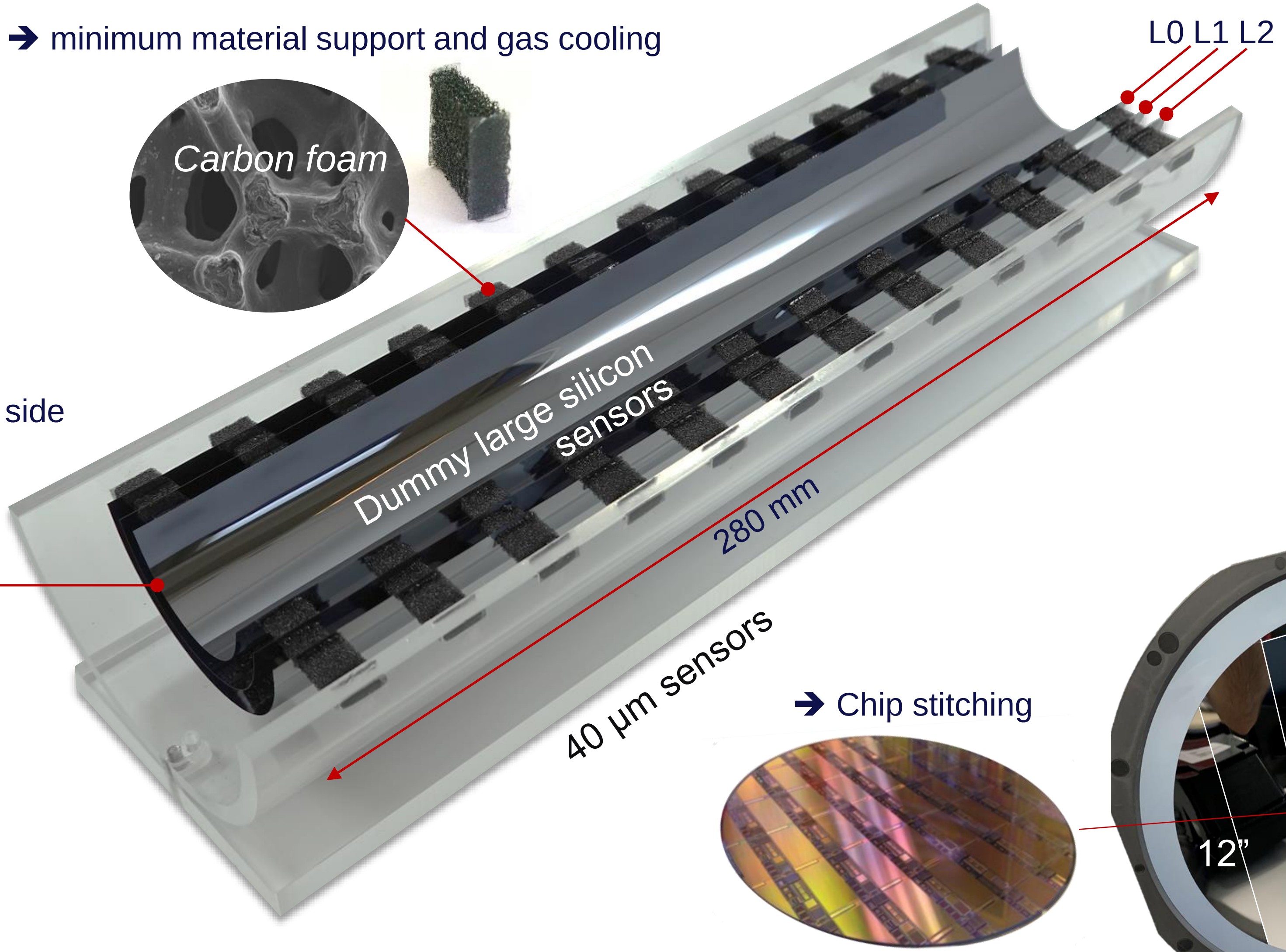

Outer Tracker

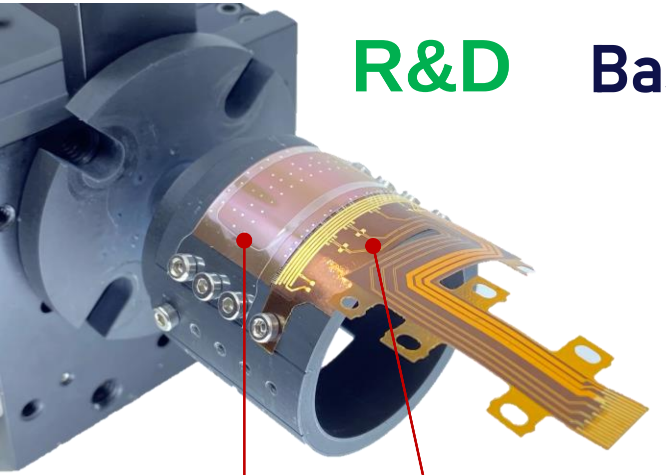
R&D Based on present effort in the design of the ITS3 (RUN4 –LS3)

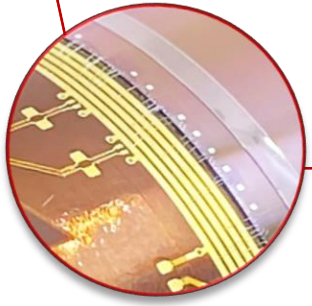
➔ minimum material support and gas cooling

➔ Wire bonding at the edge side

➔ Chip stitching







➔Curved Silicon sensors