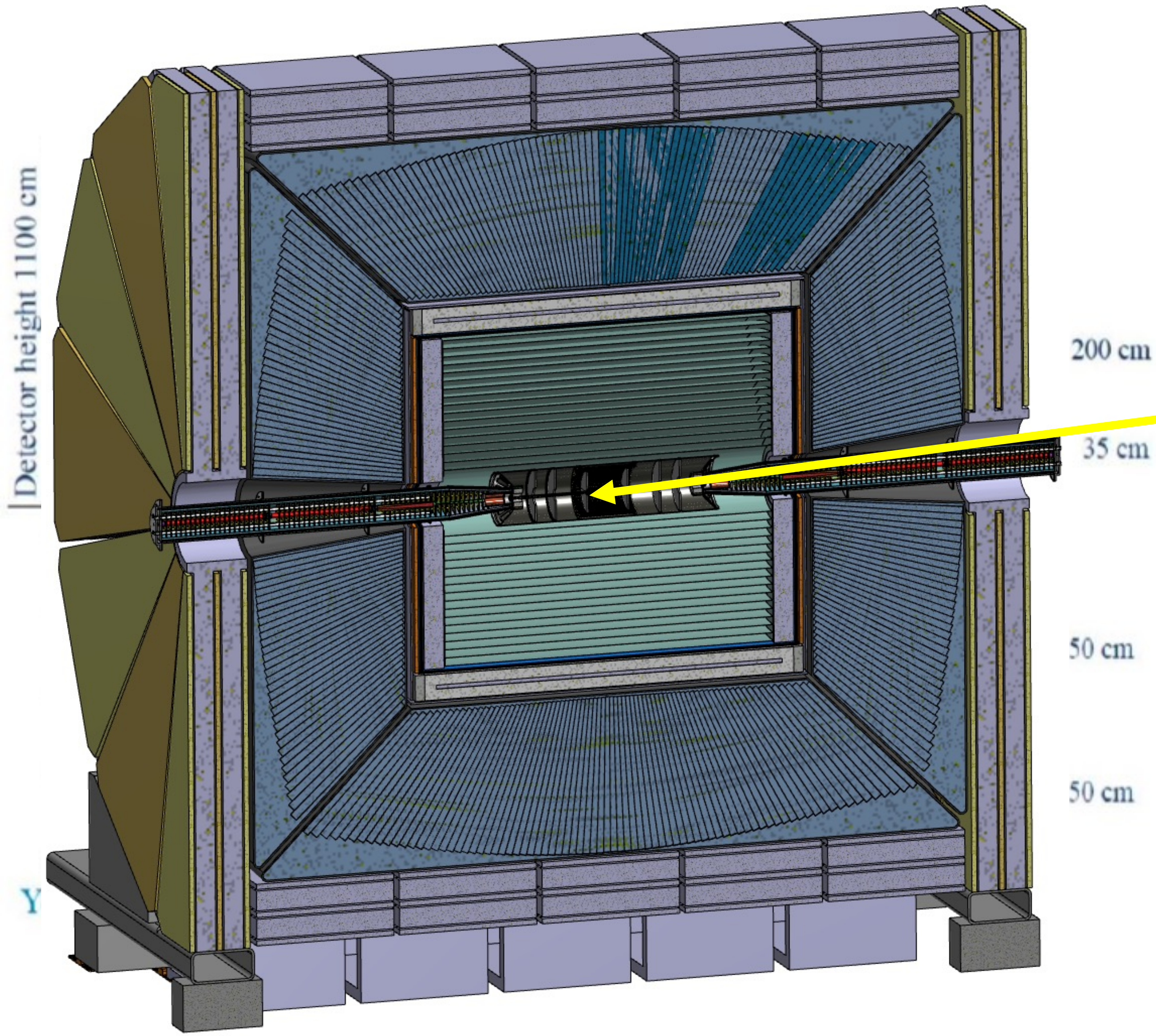
THE IDEA VERTEX DETECTOR AND ITS INTEGRATION INTHE FCC-EE INTERACTION REGION

Fabrizio Palla[1]

Manuela Boscolo [2], Filippo Bosi [1], Francesco Fransesini [2], Stefano Lauciani [2]

[1]INFN Sezione di Pisa, Italy
[2]INFN Laboratori Nazionali di Frascati (RM), Italy

Second ECFA workshop on e+e- Higgs/EW/Top Factories,
Paestum (Italy)
12 October 2023



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- Central tracking device:
  - light Drift CHamber
- **Silicon detectors for precision measurements**
  - vertex detector
  - silicon internal tracker
  - silicon wrapper
- Thin solenoid with 2T field (according to MDI limits)
- Dual readout calorimeter
  - supplemented by a pre-shower detector
- Muon chambers in the solenoid return yoke

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

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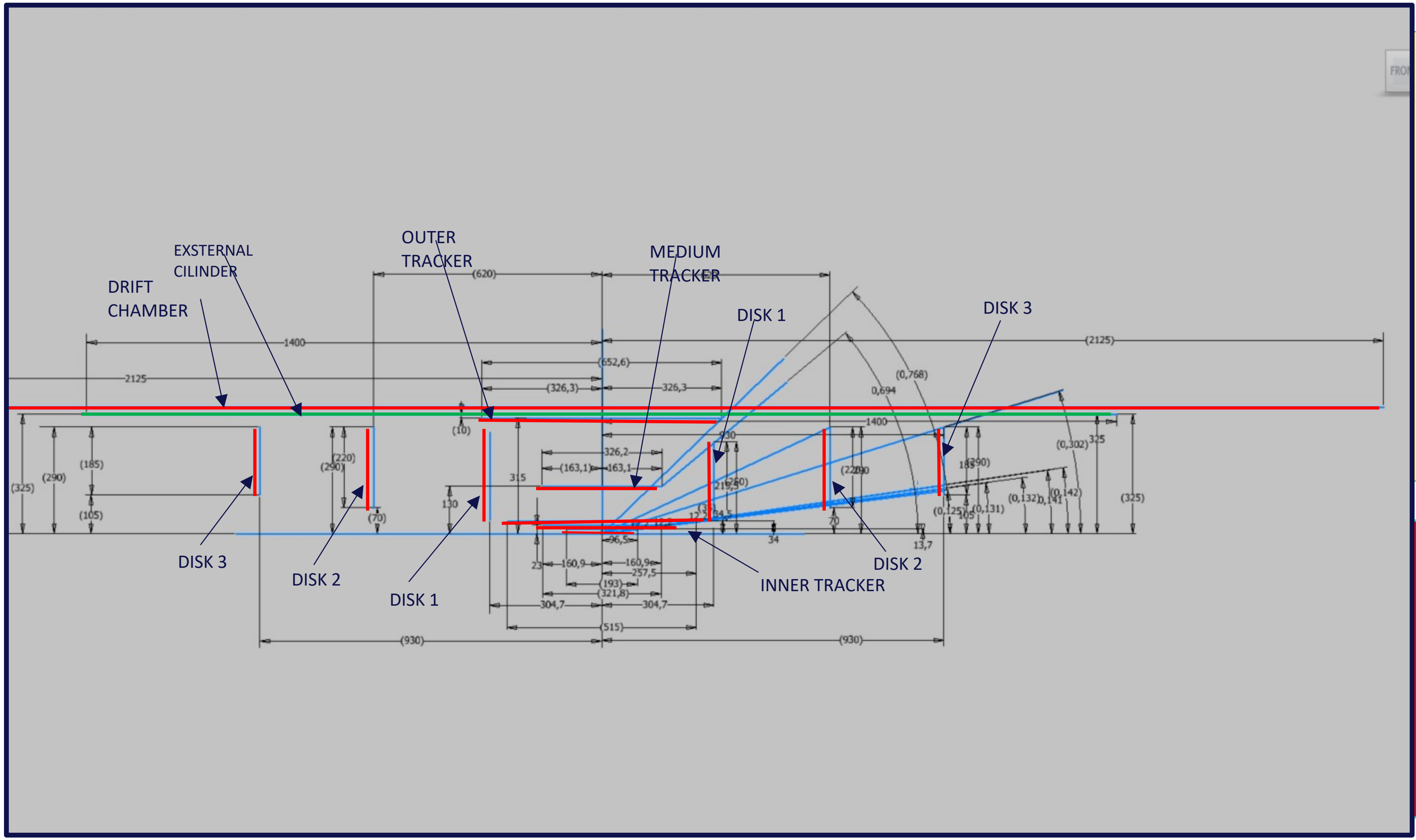

Outer vertex tracker:

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 33 mm radius

Inner vertex detector modules

Based on ARCADIA INFN R&D

"Fully Depleted MAPS in 110-nm CMOS Process With 100–300-μm Active Substrate," in IEEE Transactions on Electron Devices, June 2020, doi: 10.1109/TED.2020.2985639.

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Depleted Monolithic Active Pixel Detectors (DMAPS)
Technology: LF11is 110 nm CMOS node, high-resistivity bulk
Pixel size 25x25 μm^2 , 50 μm thick

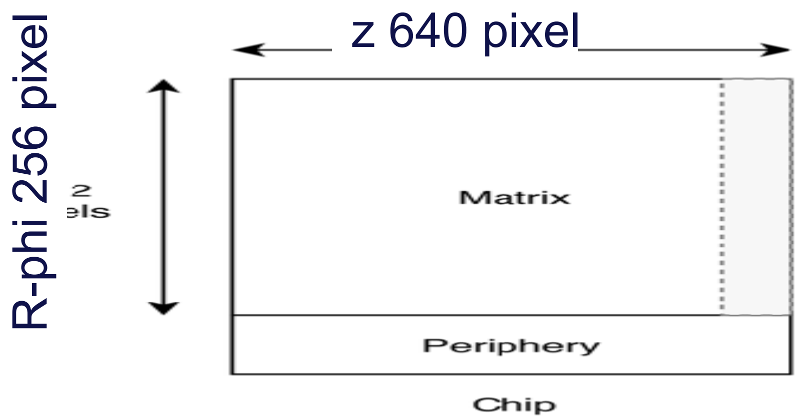
See talk by A. Andreazza

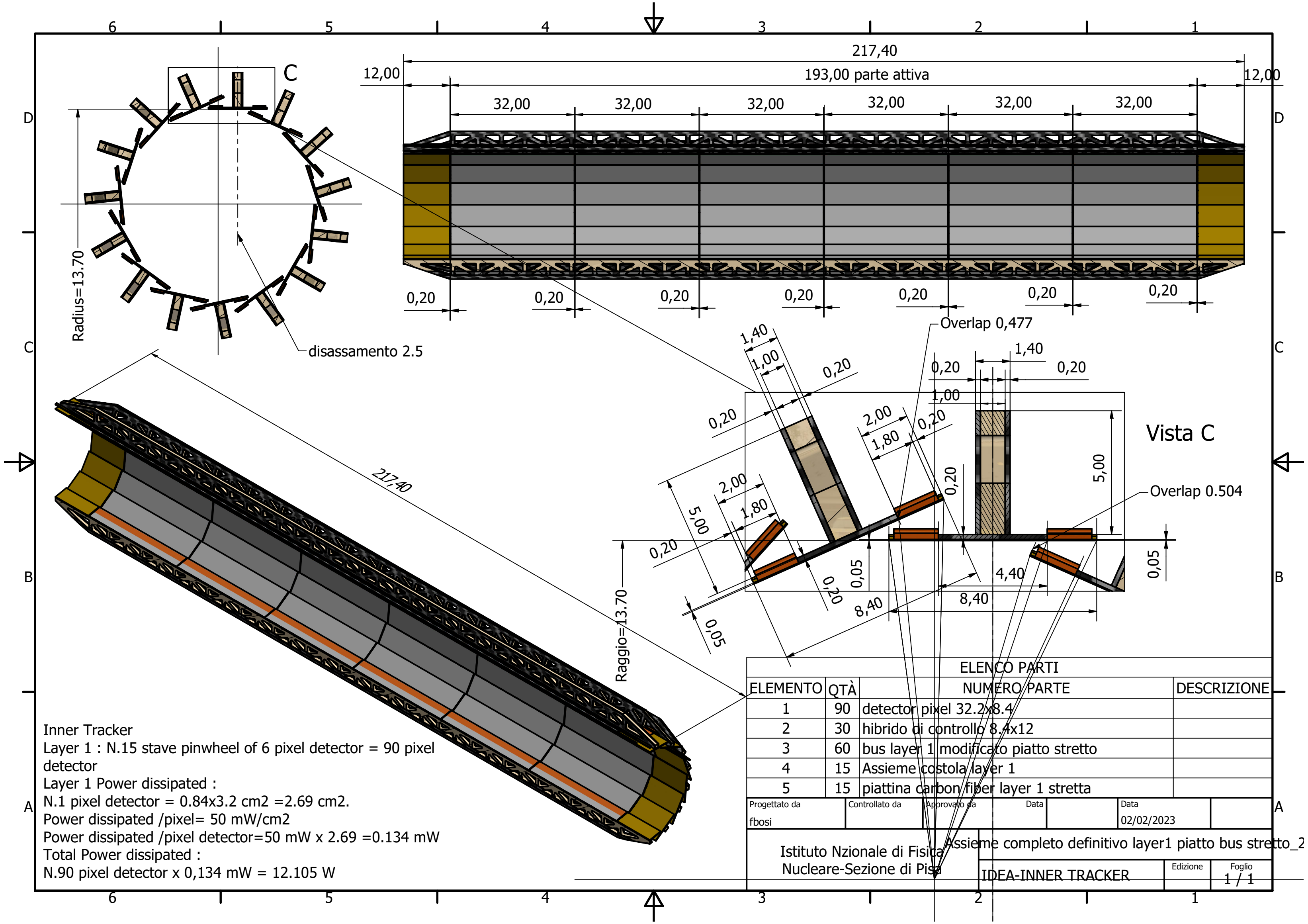
High rate capability (100 MHz/cm2) architecture on a scalable 512x512 pixel matrix (25μm pitch) MD3 Main Demonstrator chip: **measured** 30 mW/cm^2 at full-speed

Active area 640 pixel (16 mm) in z and 256 pixels (6.4 mm) in $r-\varphi$
Chip periphery plus an inactive zone: total of 2 mm in $r-\varphi$
Chips are side-abuttable in z

Modules composed of 2 sensors: total of 8.4 mm $(r-\varphi)\times$ 32 mm (z)

Power budget: assume $50\ \mathrm{mW/cm^2}$ - including power and readout buses





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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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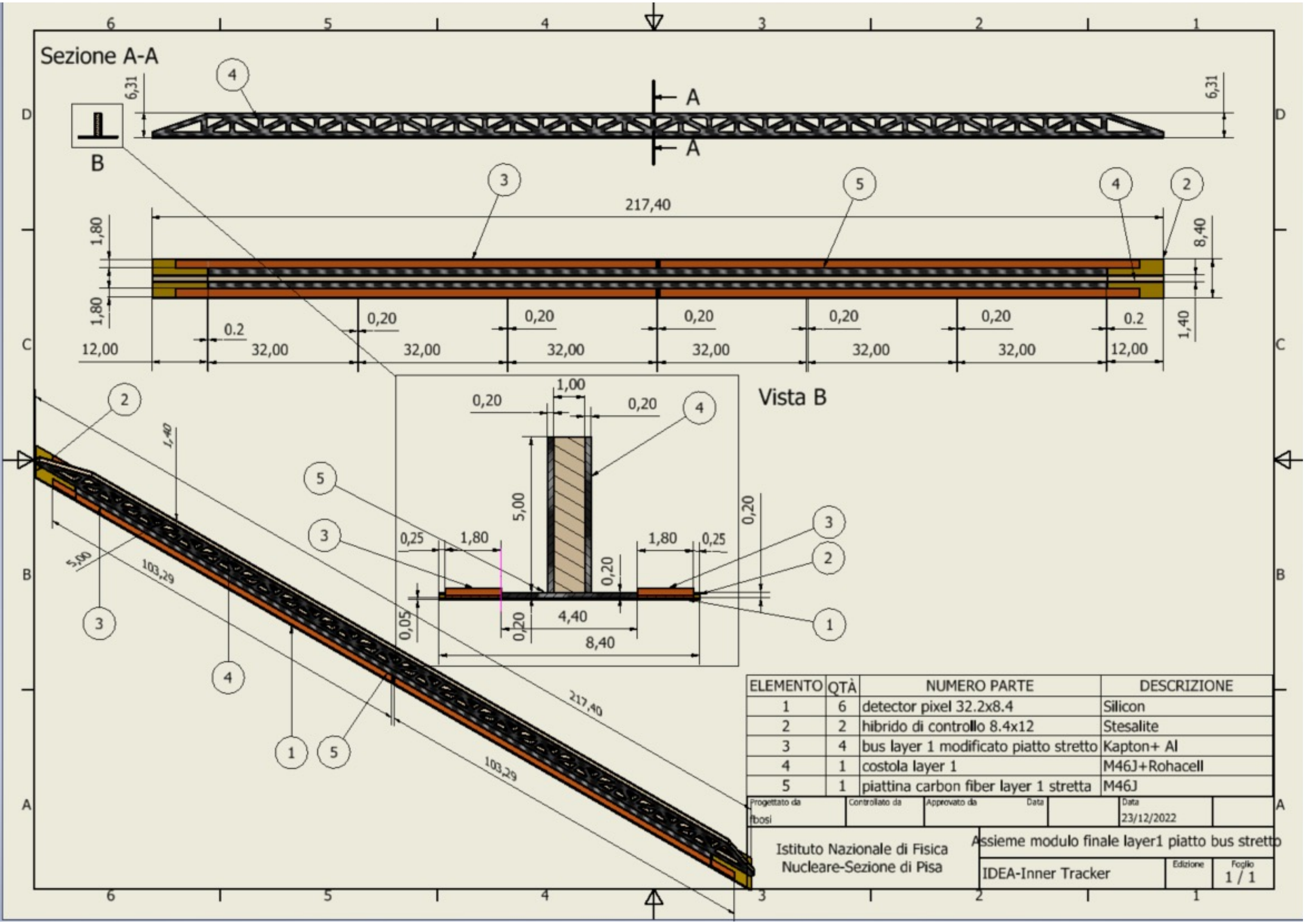


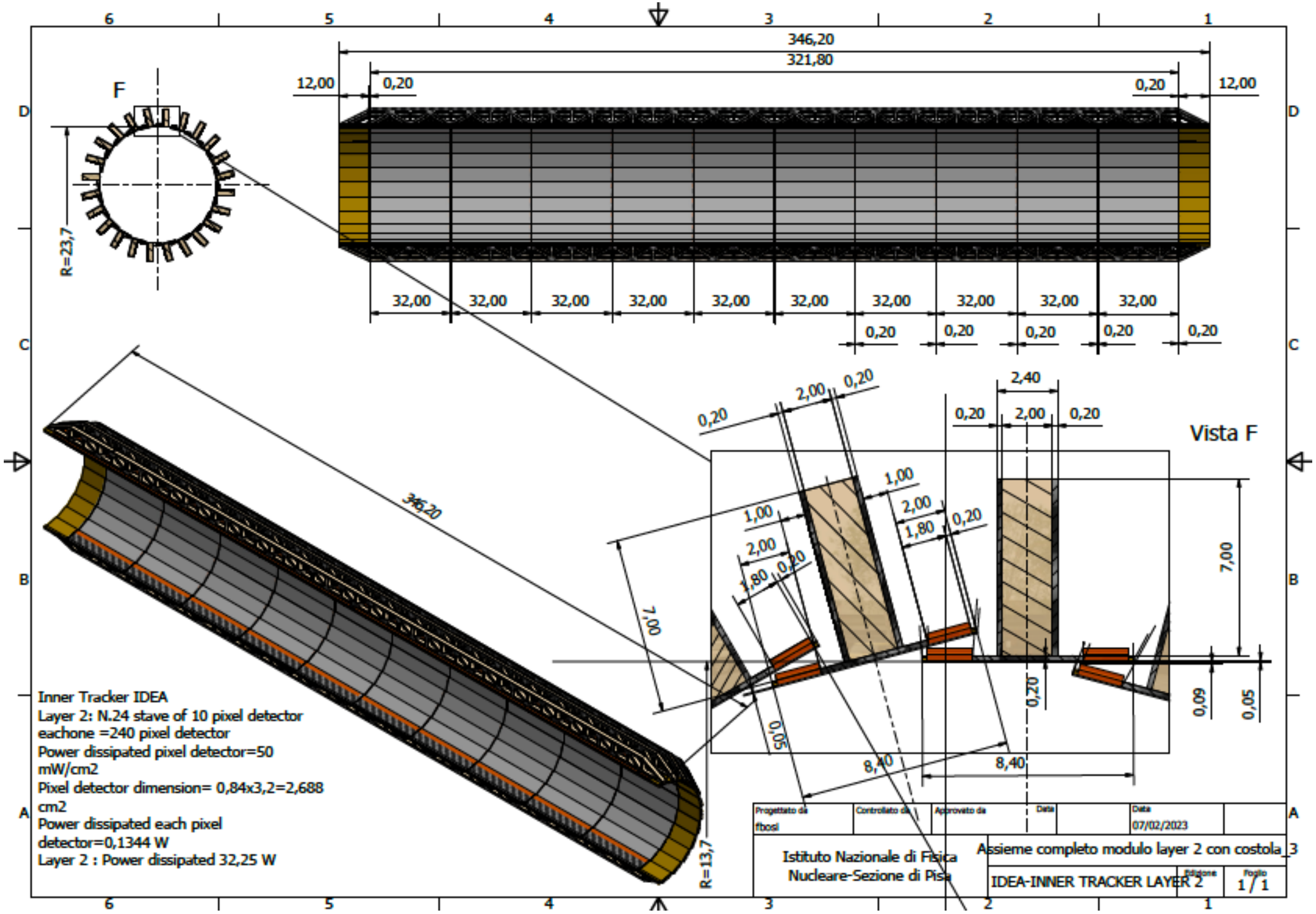
Reticular lightweight support to provide stiffness

- 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

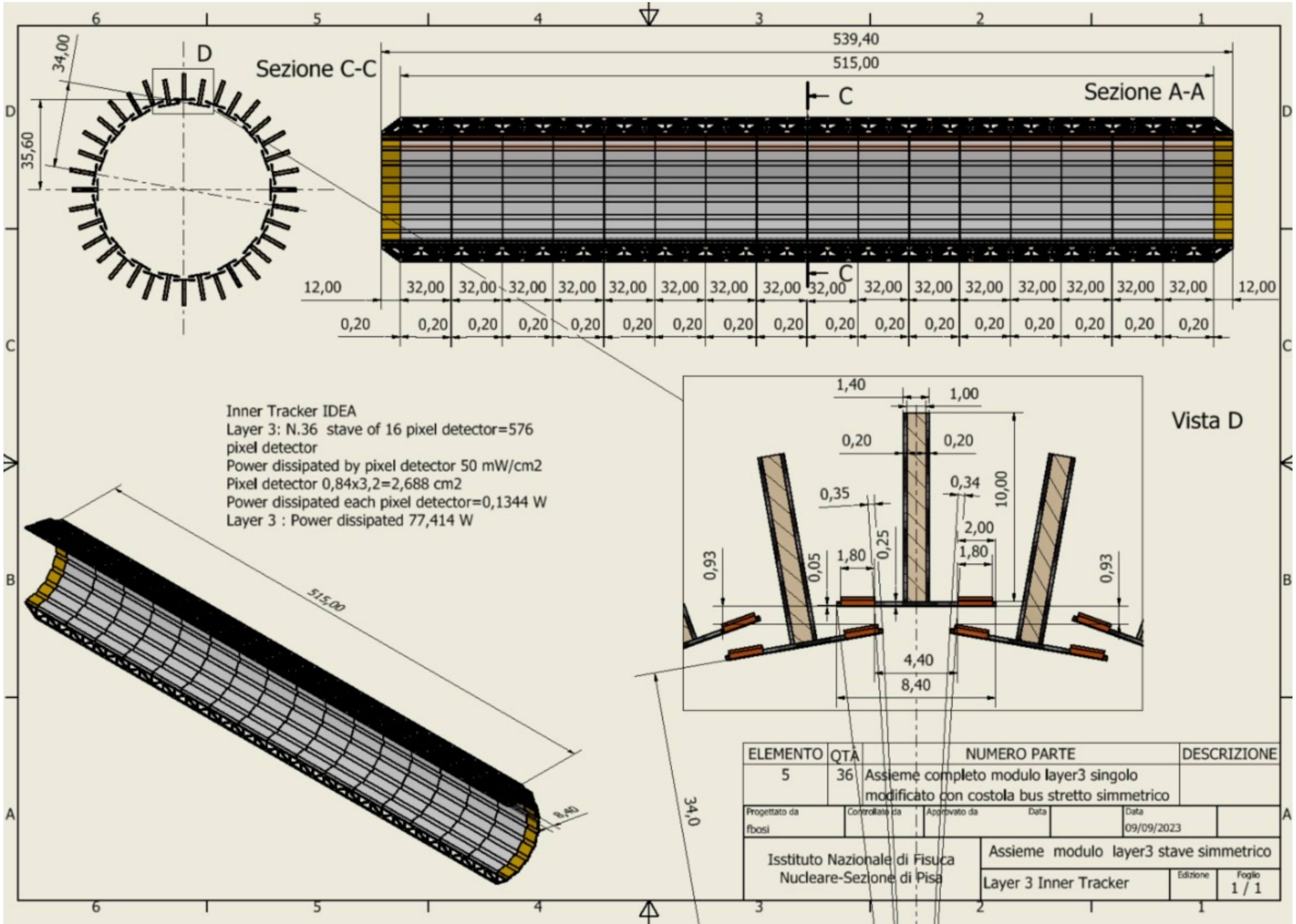
Pinwheel geometry

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



NEW

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Layer 3

36 staves of 16 modules each

Lampshade geometry.

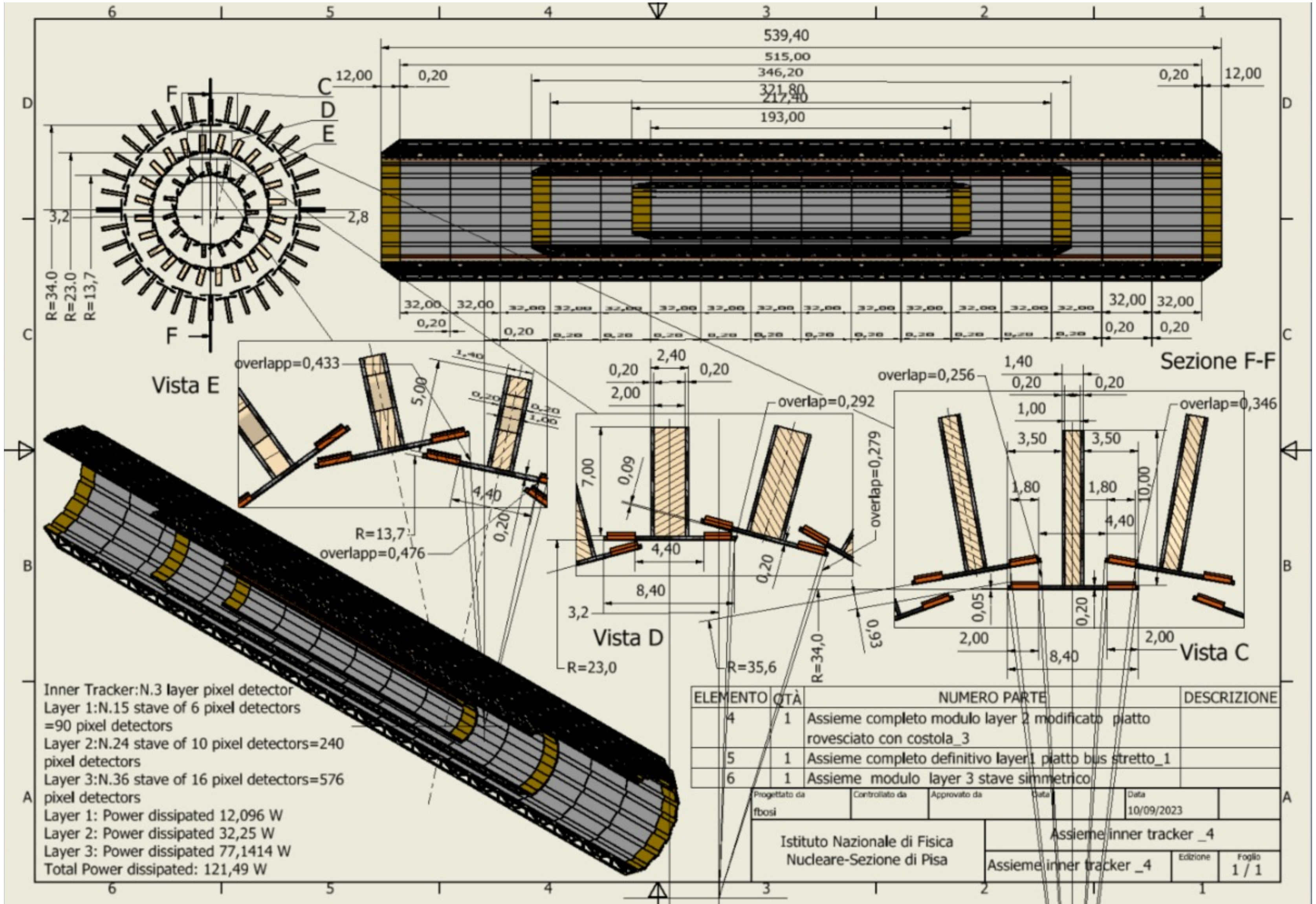
Charge symmetric track reconstruction

Total weight ~150 grams

Total thickness 0.25% X_0

Power budget ~77 W

Overall Inner Vertex layout



NEW

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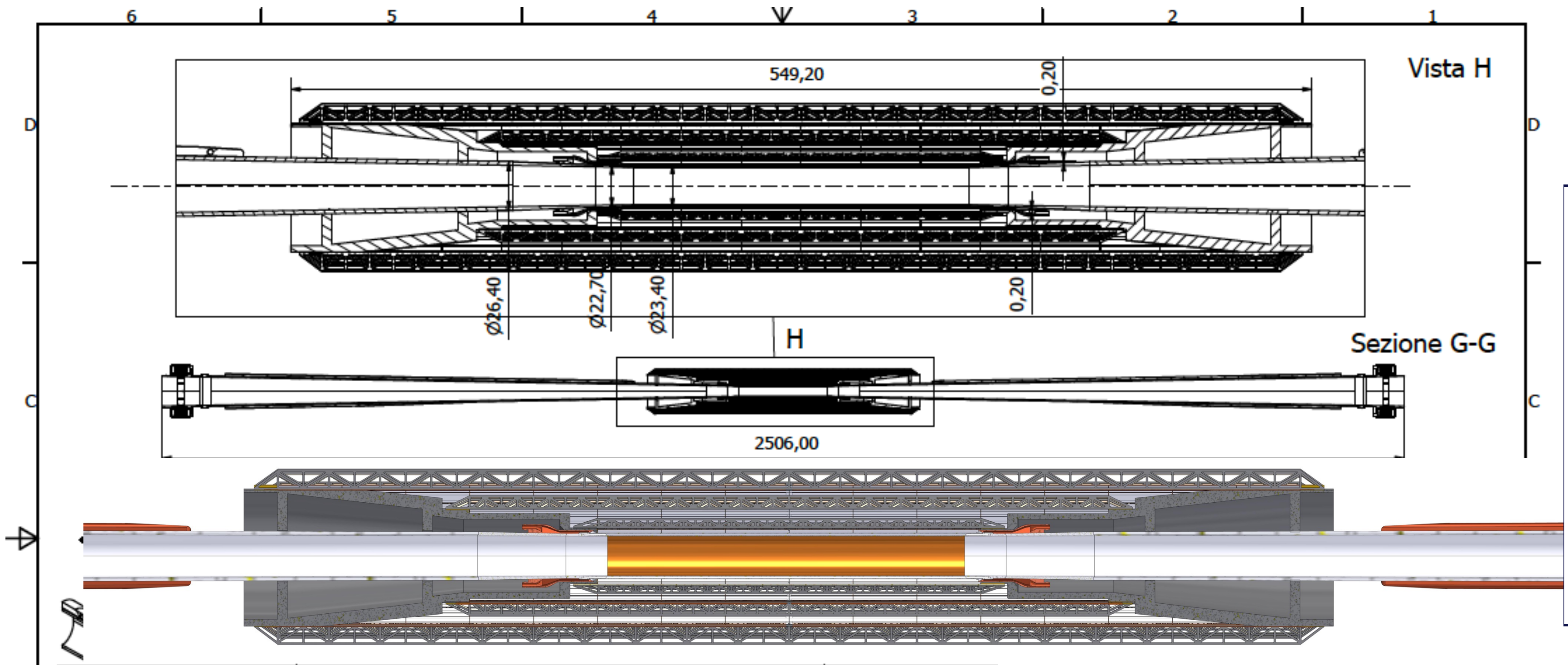
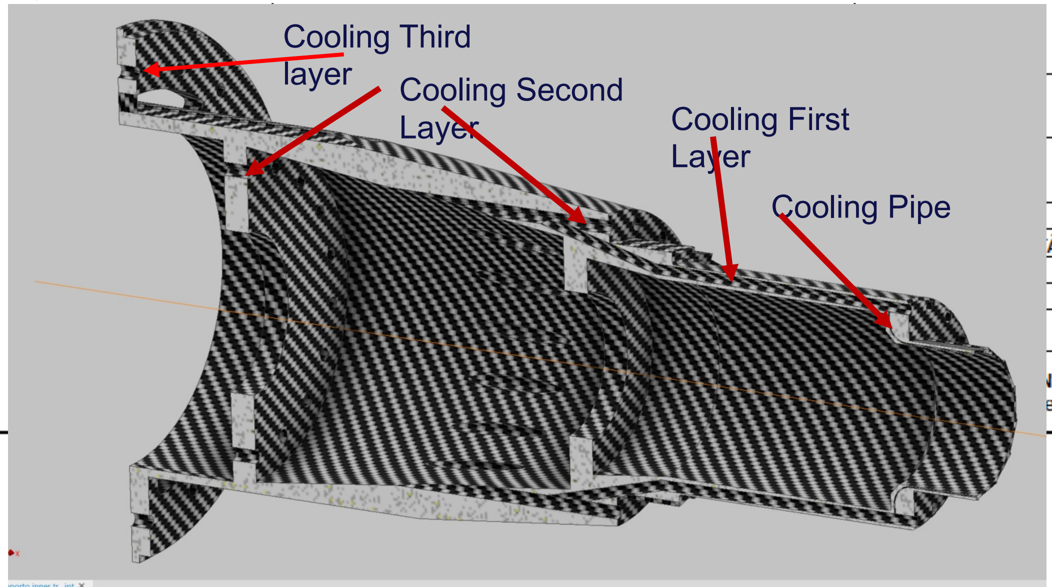
Total power ~120 W

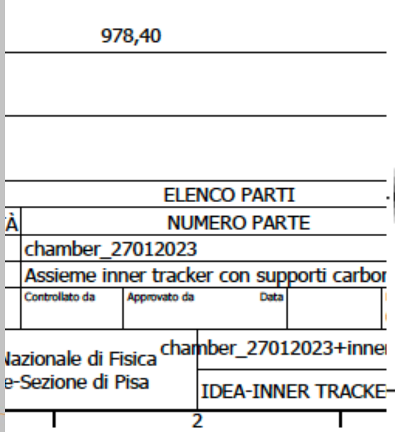
Total weight ~230 grams

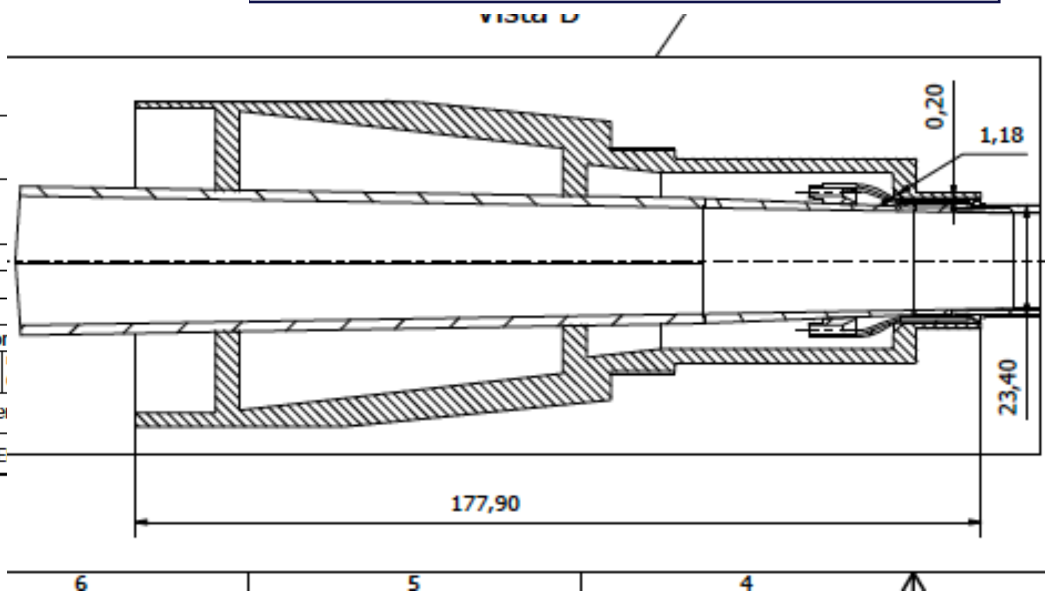


Inner vertex detector supporting conical structures on elliptical chamber
~450 grams

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







Thermal simulation in progress

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G. Baldinelli, F. Bianchi, C. Turrioni

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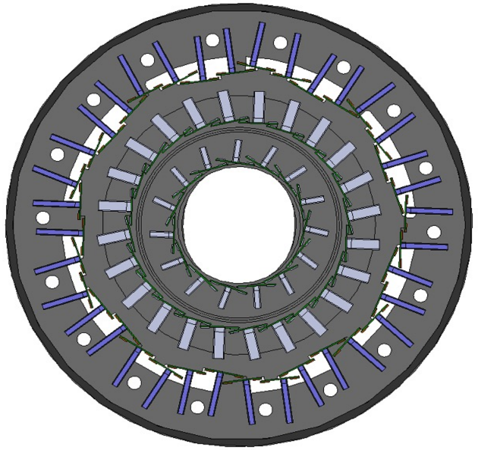
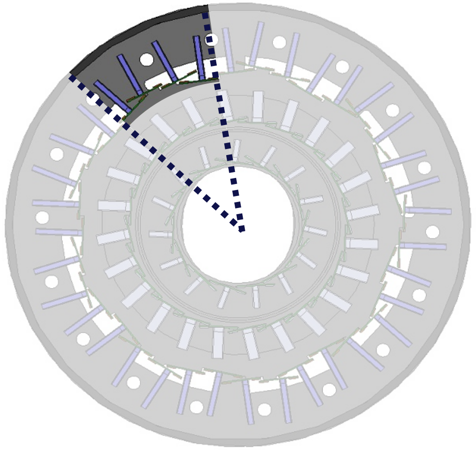
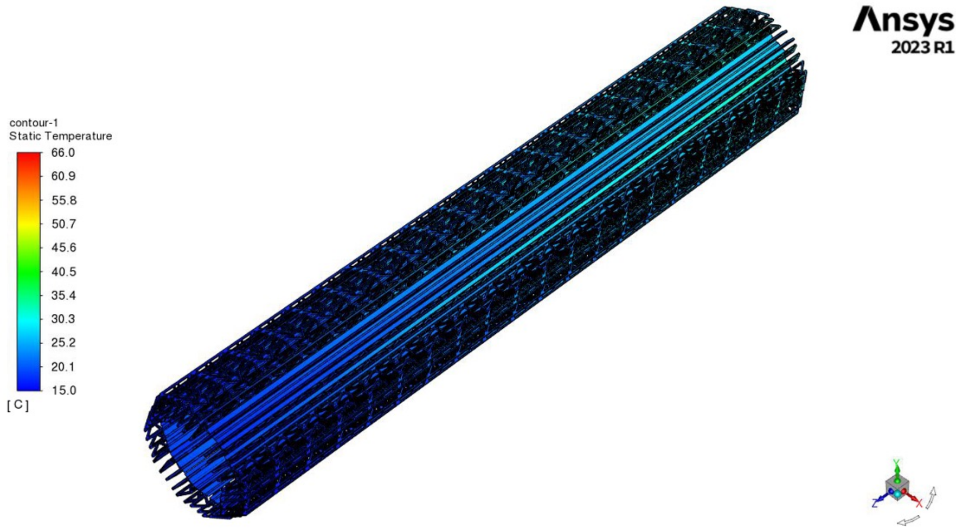
Start from a radial sector of layer 3 (relying on periodic symmetry) and import in ANSYS FEA. Then move to all other layers
Layer 3 is the toughest in power dissipation and length



Full model



Extraction of a radial sector for layer 3



- ❑ Optimisation of the system ongoing: (speed and T of air, direction of the inlet flow, connection with the other layers, etc…)
- ❑ A mechanical vibrational analysis will be performed
- ❑ Experimental validation of the simulations foreseen

Outer vertex layers modules

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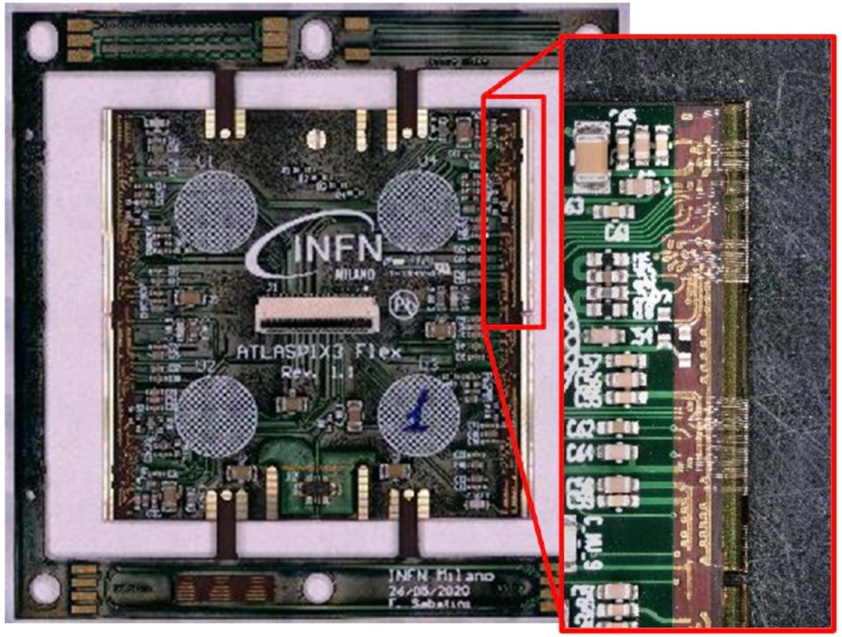
Based on ATLASPIX3 R&D

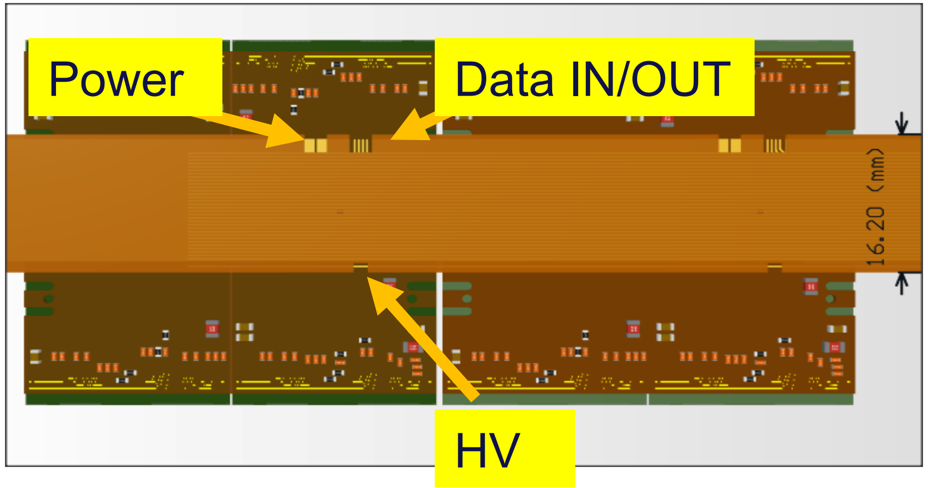
- DMAPS
- 50 x 150 μm^2
- Up to 1.28 Gb/s downlink
- TSI 180 nm process
- 132 columns of 372 pixels

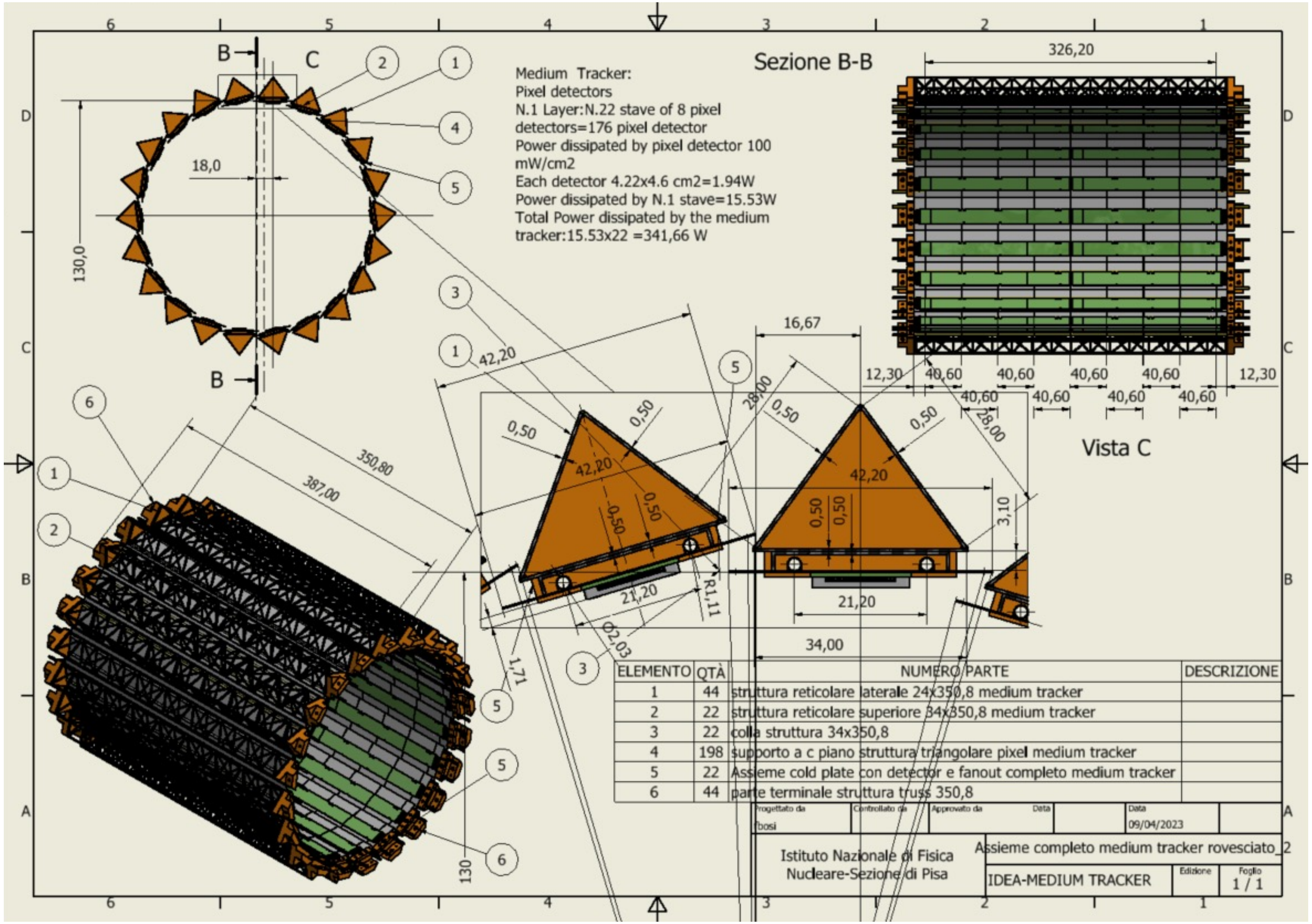
- Active (total) length (r-phi x z)
  - 18.6 (21) mm x 19.8 (20.2) mm
- Module is made of 2x2 chips – total length:
  - size 42.2 mm x 40.6 mm

- Power budget not established yet: assume $100\ \mathrm{mW/cm^2}$

For details see A. Andreazza talk







ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
1	44	struttura reticolare laterale 24x350,8 medium tracker	
2	22	struttura reticolare superiore 34x350,8 medium tracker	
3	22	colla struttura 34x350,8	
4	198	supporto a c piano struttura triangolare pixel medium tracker	
5	22	Assieme cold plate con detector e fanout completo medium tracker	
6	44	parte terminale struttura truss 350,8	

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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)

MIDDLE TRACKER

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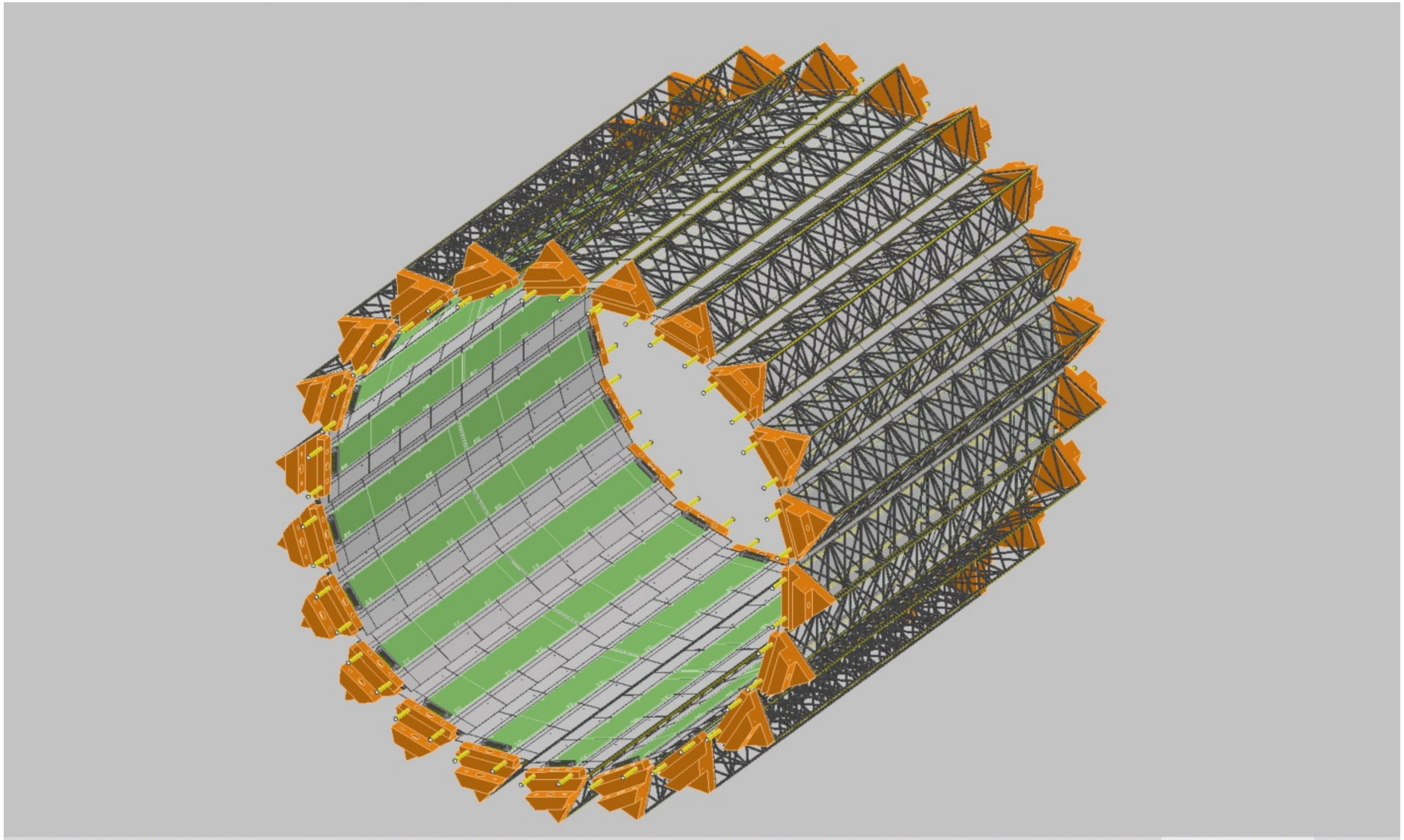

Stave detail

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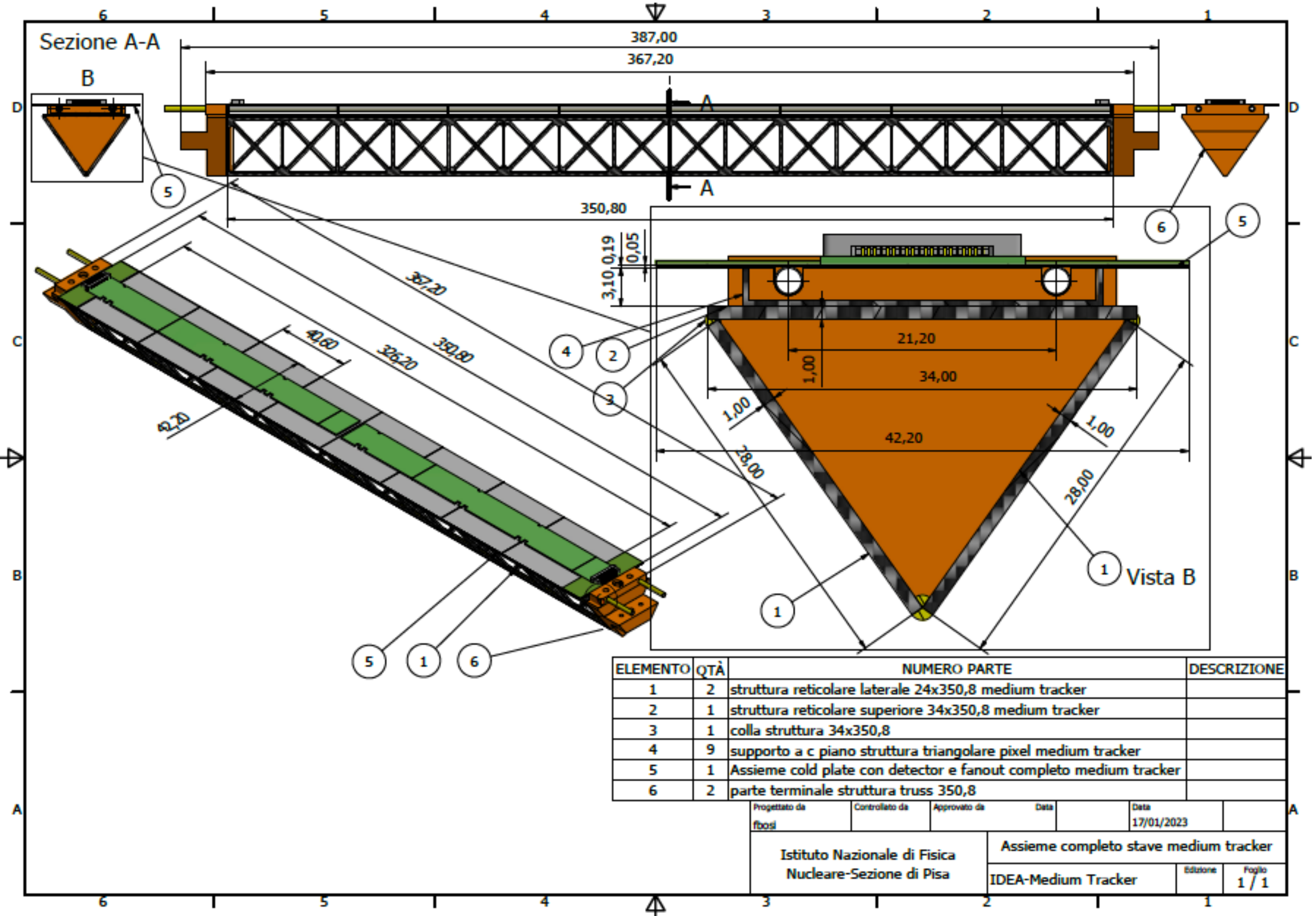
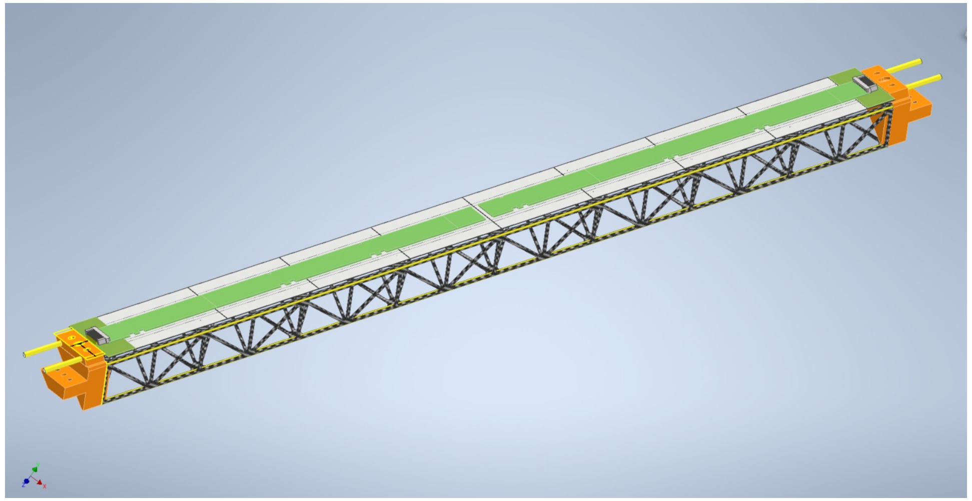
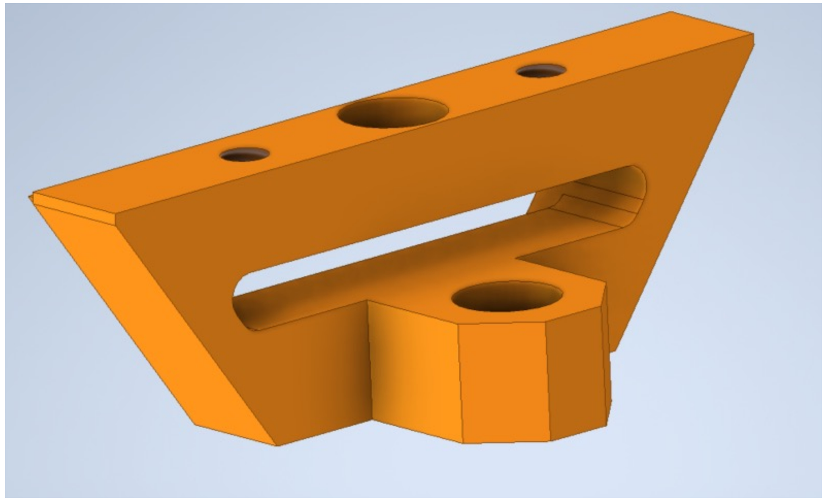


ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
1	2	struttura reticolare laterale 24x350,8 medium tracker	
2	1	struttura reticolare superiore 34x350,8 medium tracker	
3	1	colla struttura 34x350,8	
4	9	supporto a c piano struttura triangolare pixel medium tracker	
5	1	Assieme cold plate con detector e fanout completo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





Prototypes built for Belle II upgrade in Pisa

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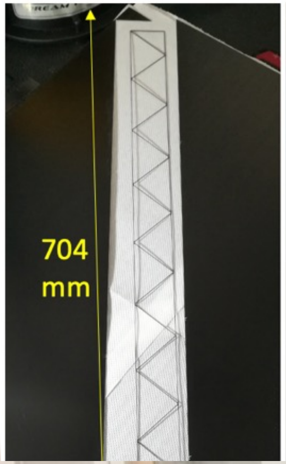
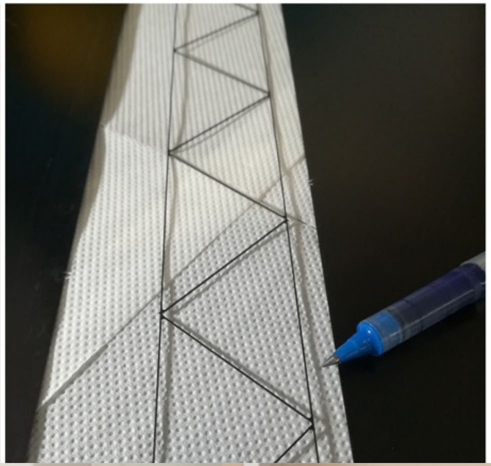
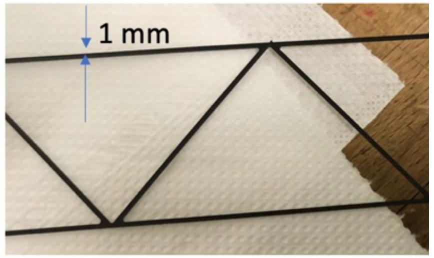
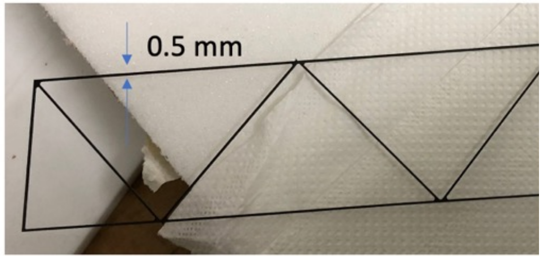
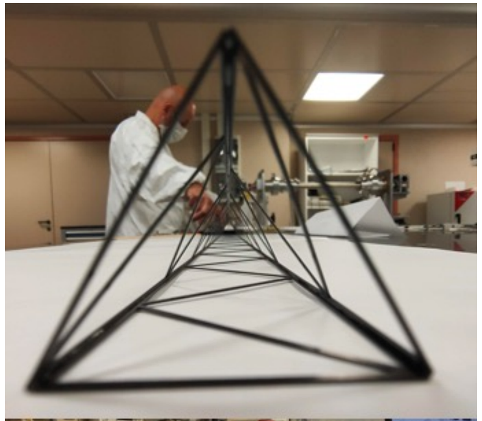
CF water-jet cut (by WatAJet Company)

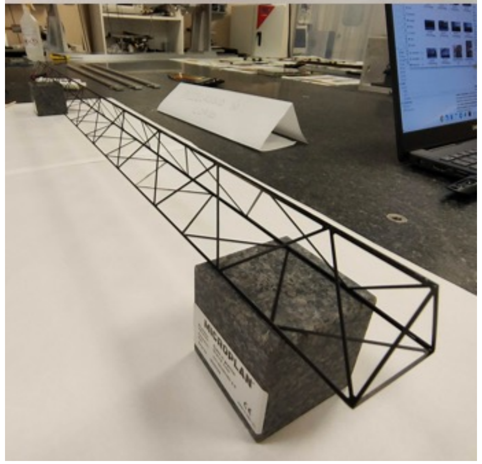


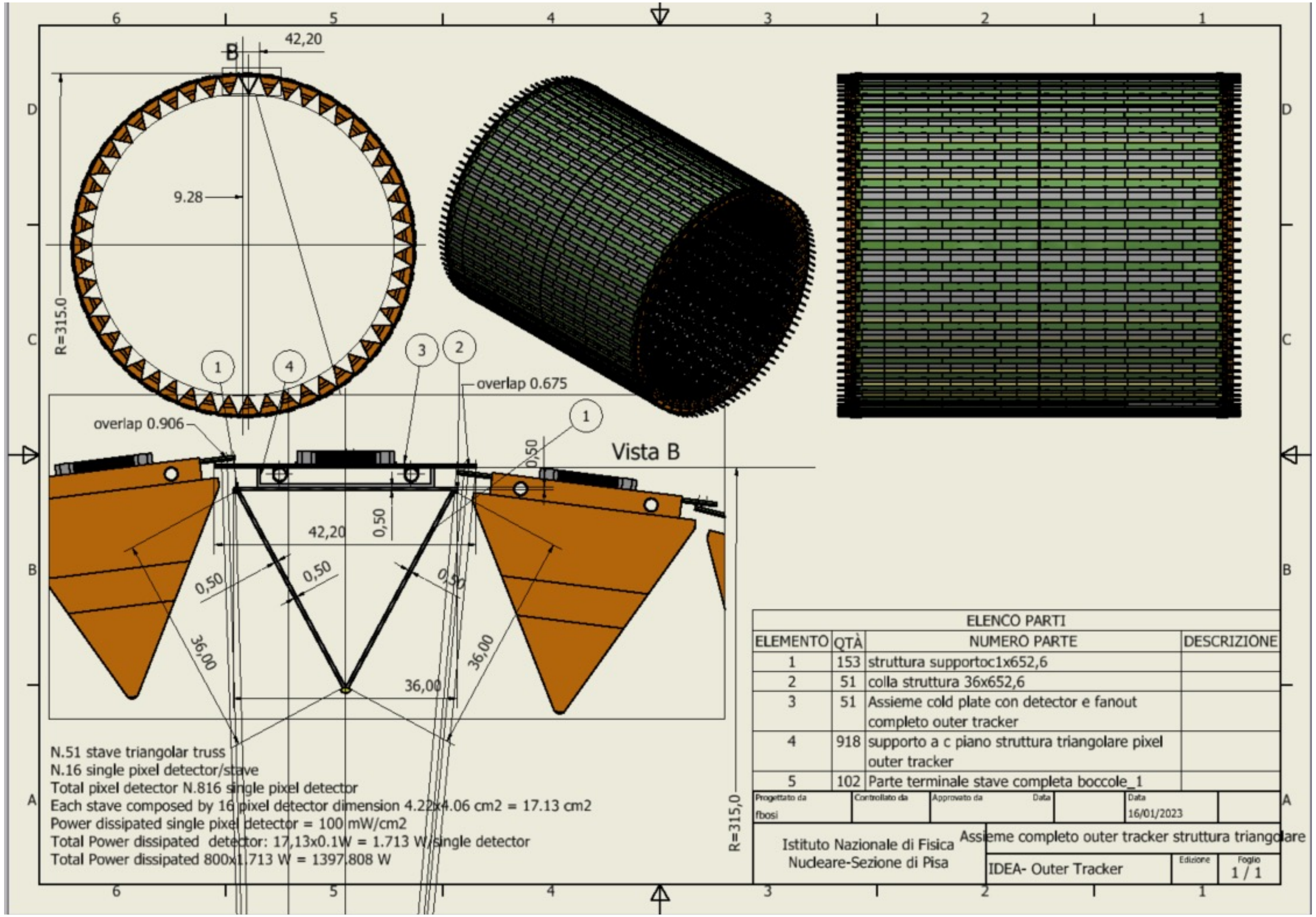












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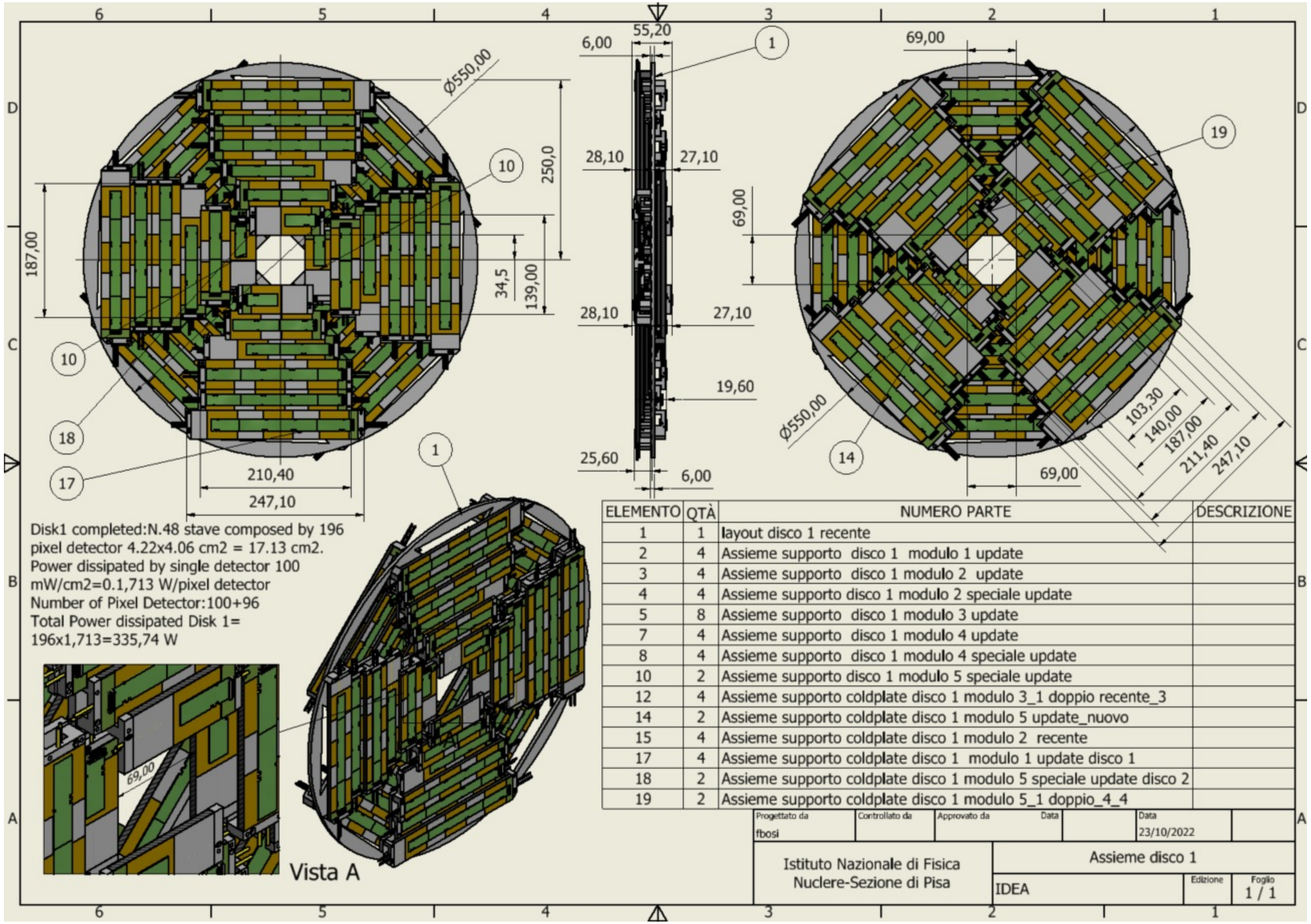
Outer Vertex Tracker Barrel
At 31.5 cm radius

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)



ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
1	1	layout disco 1 recente	
2	4	Assieme supporto disco 1 modulo 1 update	
3	4	Assieme supporto disco 1 modulo 2 update	
4	4	Assieme supporto disco 1 modulo 2 speciale update	
5	8	Assieme supporto disco 1 modulo 3 update	
7	4	Assieme supporto disco 1 modulo 4 update	
8	4	Assieme supporto disco 1 modulo 4 speciale update	
10	2	Assieme supporto disco 1 modulo 5 speciale update	
12	4	Assieme supporto coldplate disco 1 modulo 3_1 doppio recente_3	
14	2	Assieme supporto coldplate disco 1 modulo 5 update_nuovo	
15	4	Assieme supporto coldplate disco 1 modulo 2 recente	
17	4	Assieme supporto coldplate disco 1 modulo 1 update disco 1	
18	2	Assieme supporto coldplate disco 1 modulo 5 speciale update disco 2	
19	2	Assieme supporto coldplate disco 1 modulo 5_1 doppio_4_4	

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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

Overall layout and dimensions

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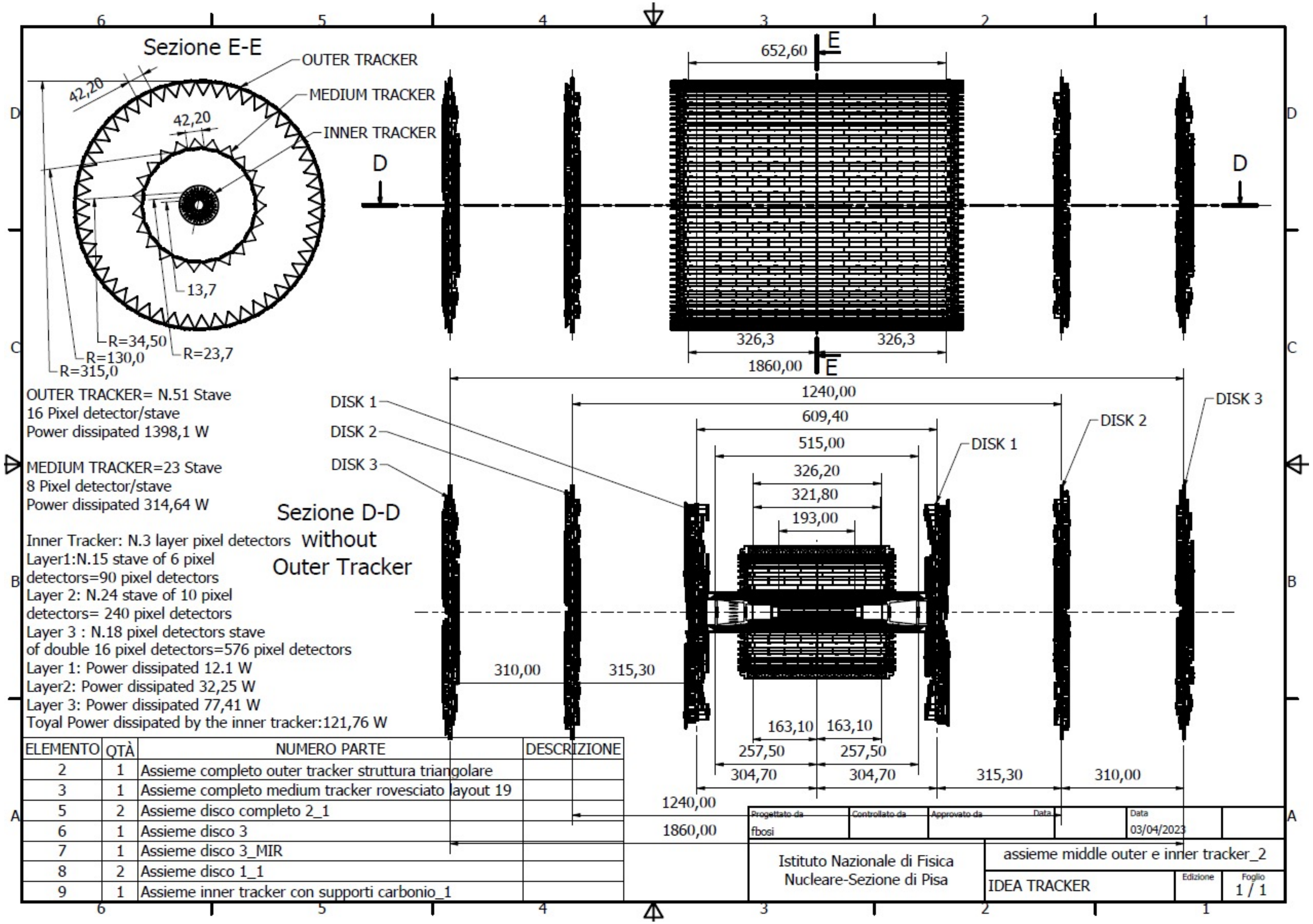
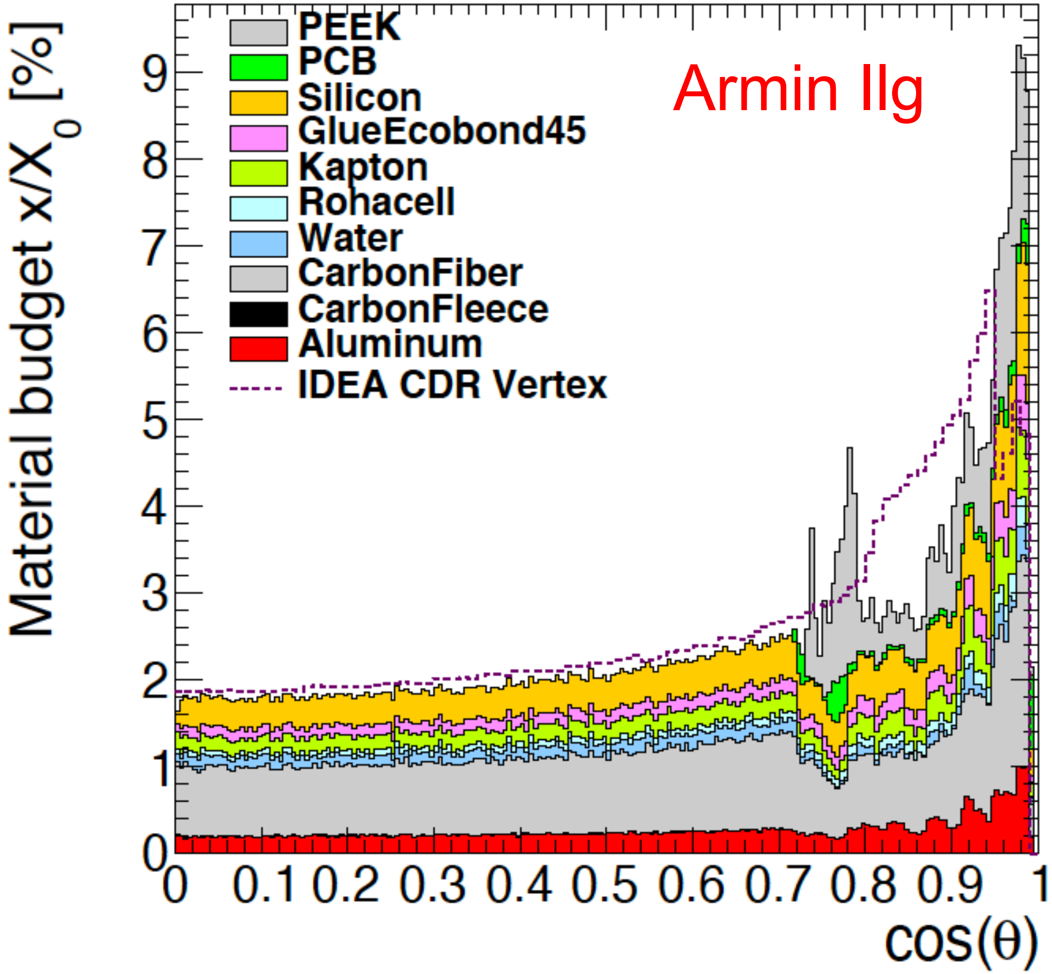


Simulated material budget



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

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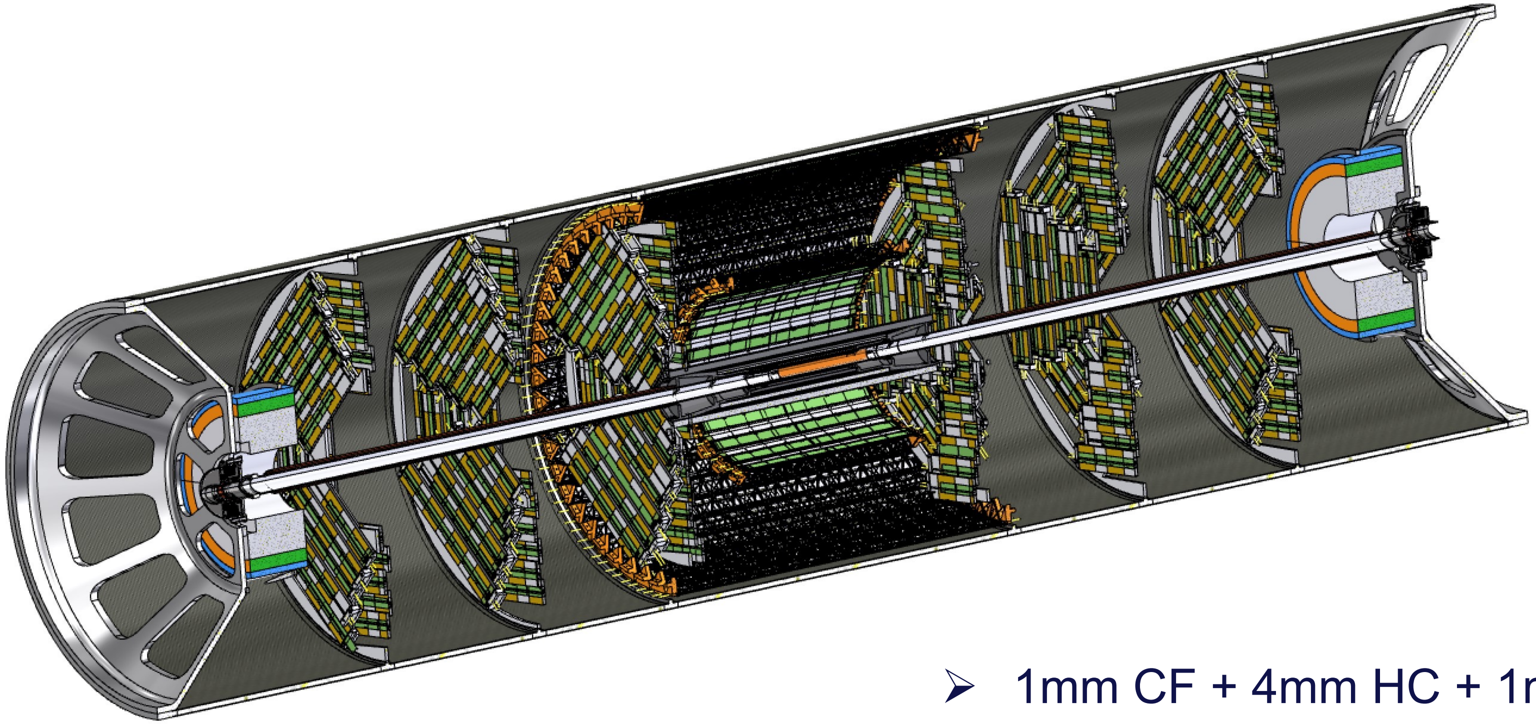
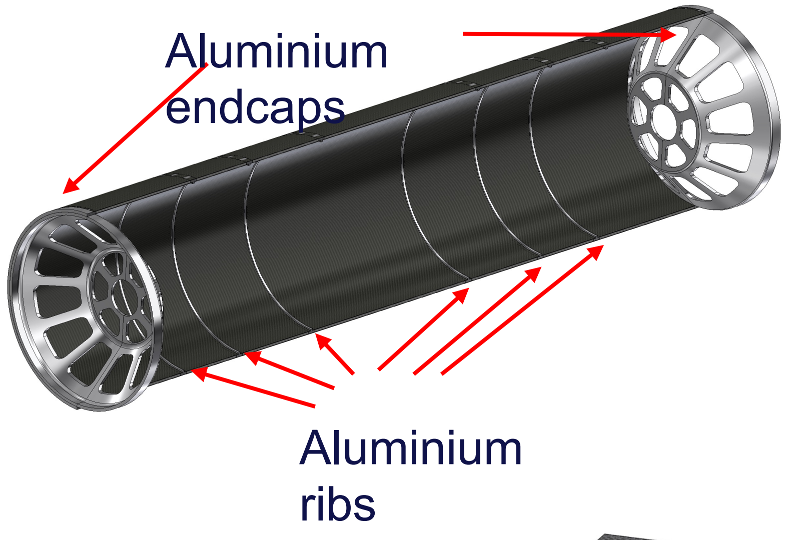
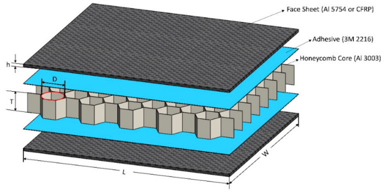
All elements in the interaction region (Vertex and LumiCal) are mounted rigidly on a support cylinder that guarantees mechanical stability and alignment

- Once the structure is assembled it is slided inside the rest of the detector
- Studies on-going where to anchor it (most likely to the Calorimeter)

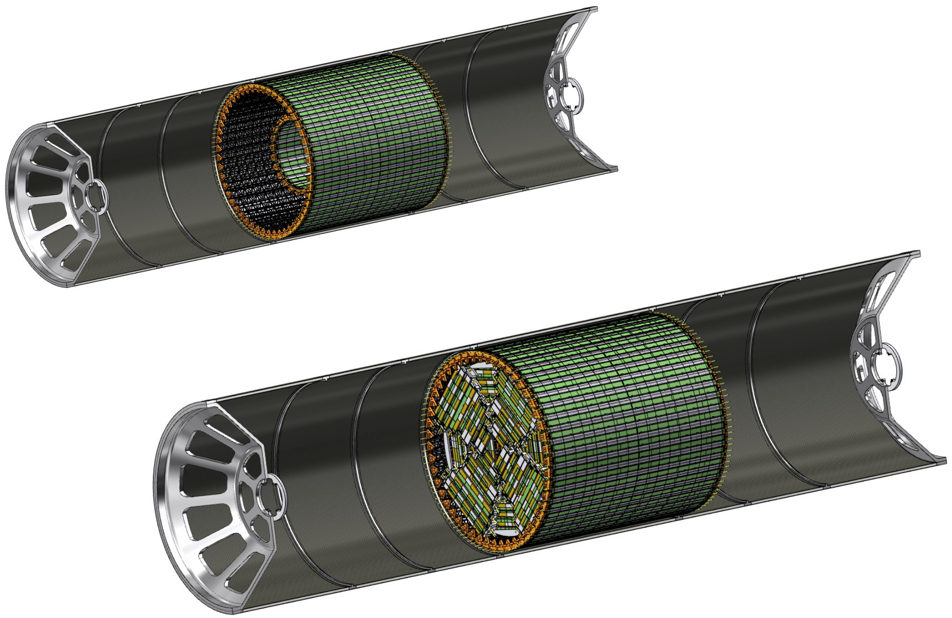


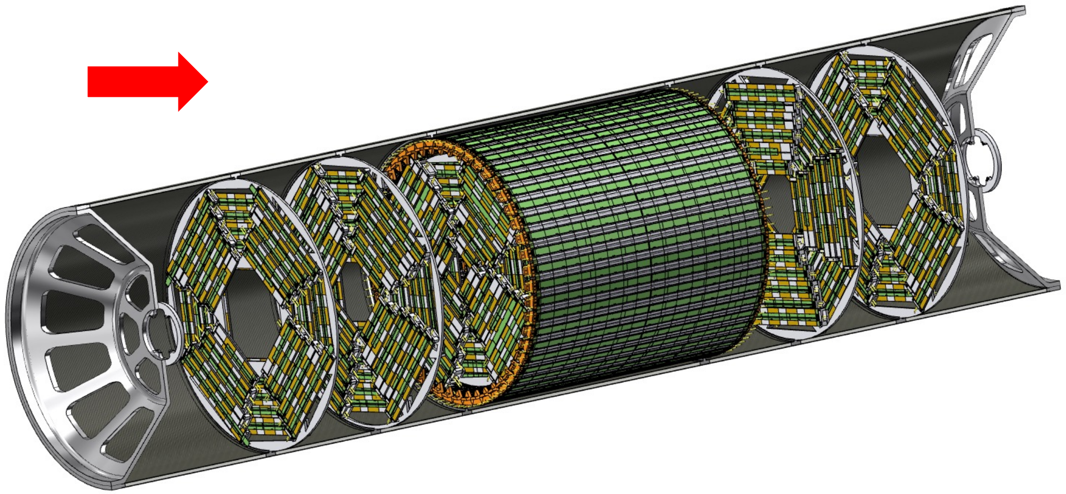


- 1mm CF + 4mm HC + 1mm CF



Assembly procedure – I

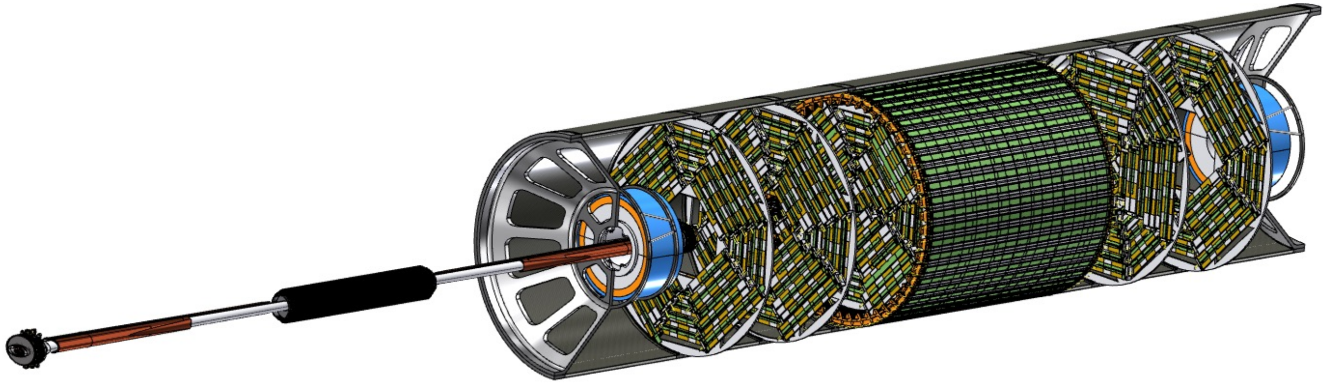


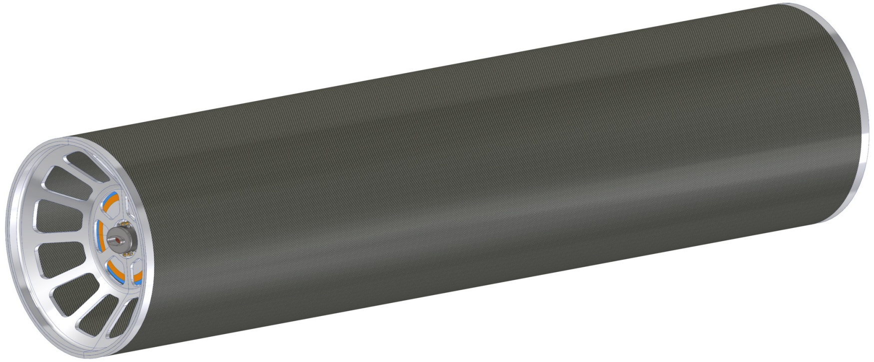


1) Outer vertx tracker, middle vertex tracker and disks 1 are installed as a rigid structure inside the support tube

2) Disks 2 and 3 are installed inside the support tube

Assembly procedure – II

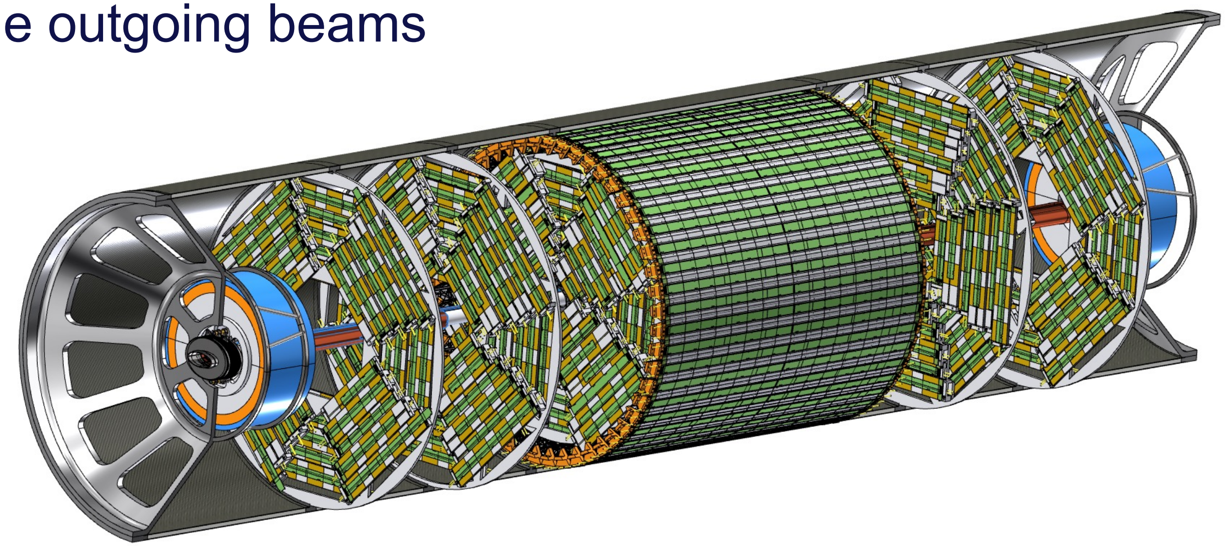




3) LumiCal is installed in centered position, then beam pipe with inner vertex detector is inserted with a dedicated tool inside disks and outer vertex tracker, then fixed to both endcaps

4) LumiCal can be aligned in the correct position on the outgoing beams

5) Support tube can be closed



General integration

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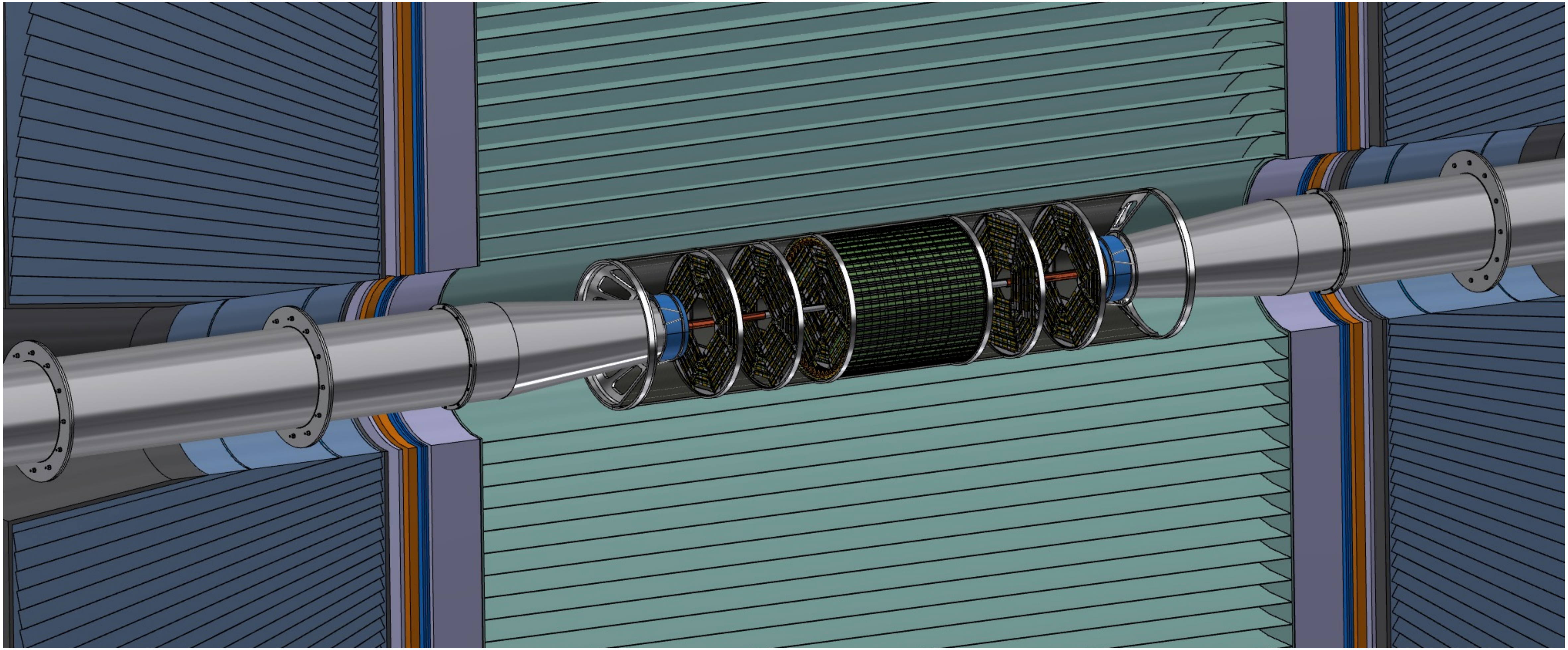
M. Boscolo, F. Palla, F. Fransesini, F. Bosi and S. Lauciani, Mechanical model for the FCC-ee MDI, *EPJ Techn Instrum* **10**, 16 (2023).
https://doi.org/10.1140/epjti/s40485-023-00103-7



Conclusions

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A layout of the interaction region with LumiCal and vertex trackers of the IDEA detector has been engineered

- Feasibility studies of integration successfully done including mounting sequence
- Documented in
  - *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

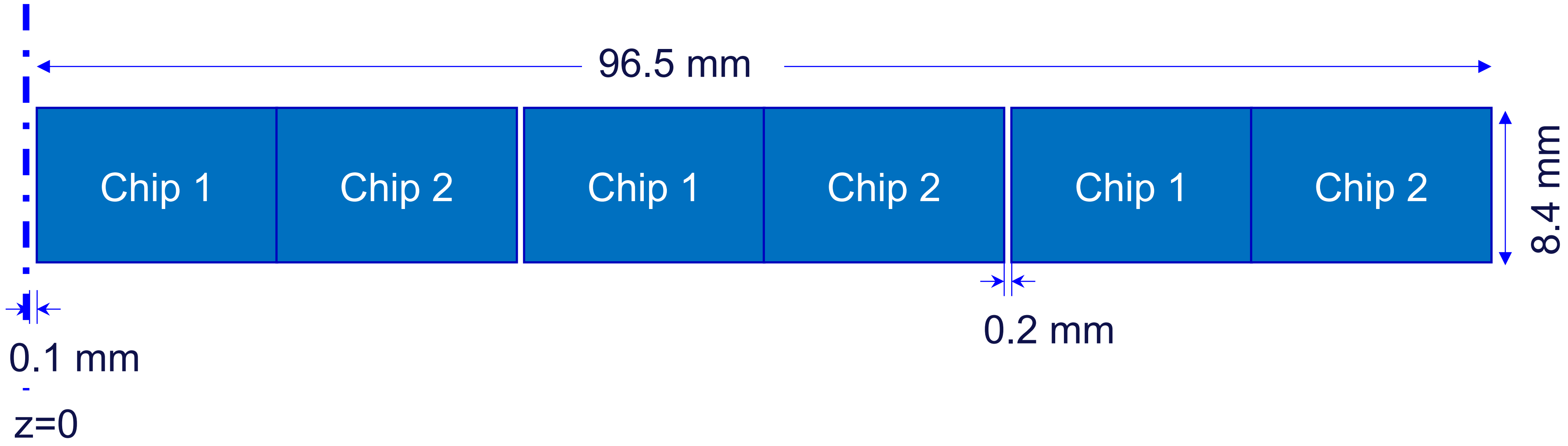
Next/ongoing steps:

- Inner Vertex detector
  - Study thermal isolation from the beampipe bakeout in progress
  - Study the routing of the services (readout and power cables) in progress
- Outer Vertex Tracker
  - Study the routing of the services (readout and power cables, cooling manifolds) in progress

Thank you for your attention.

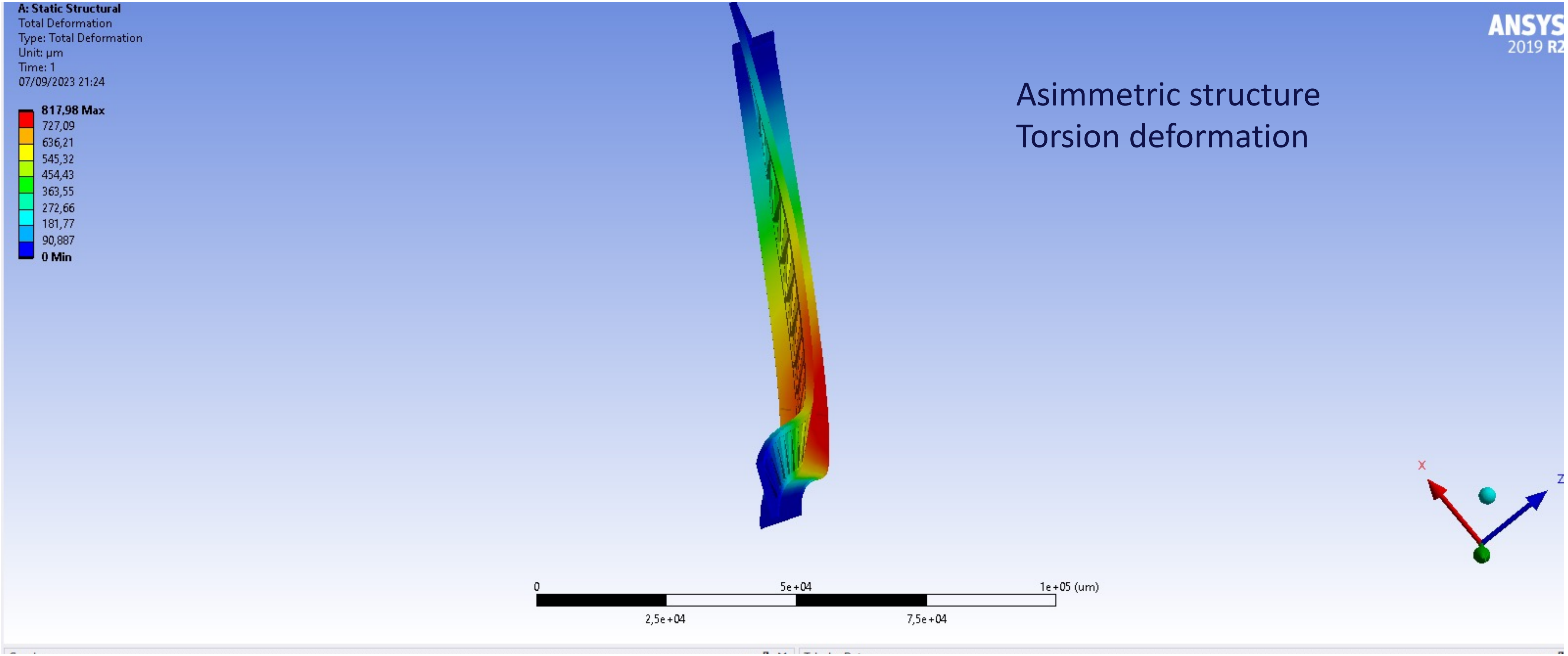
Backup

Half-ladder layout – layer 1



Layer 1 ladders are placed at 13.7 mm radius

Static Simulation old Layer 3



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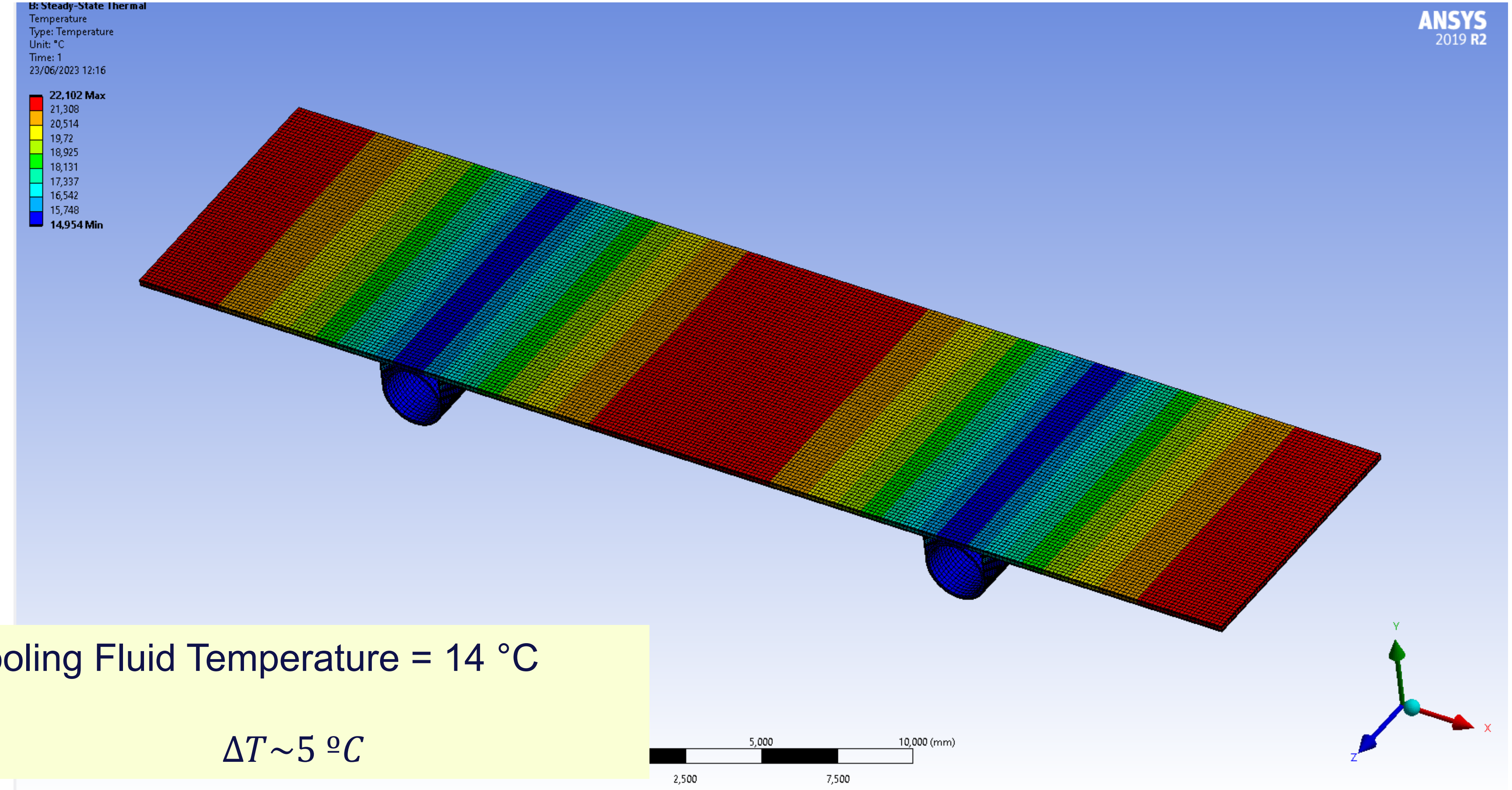
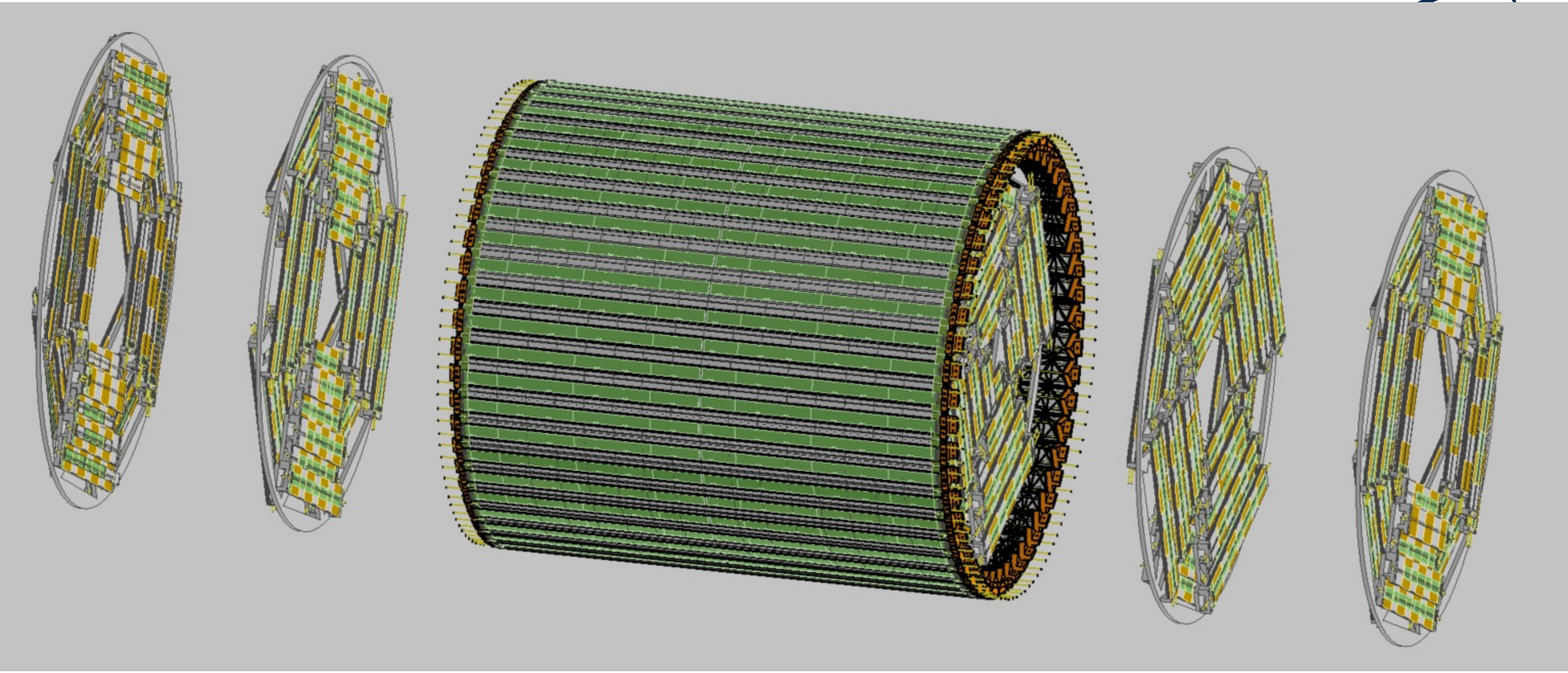
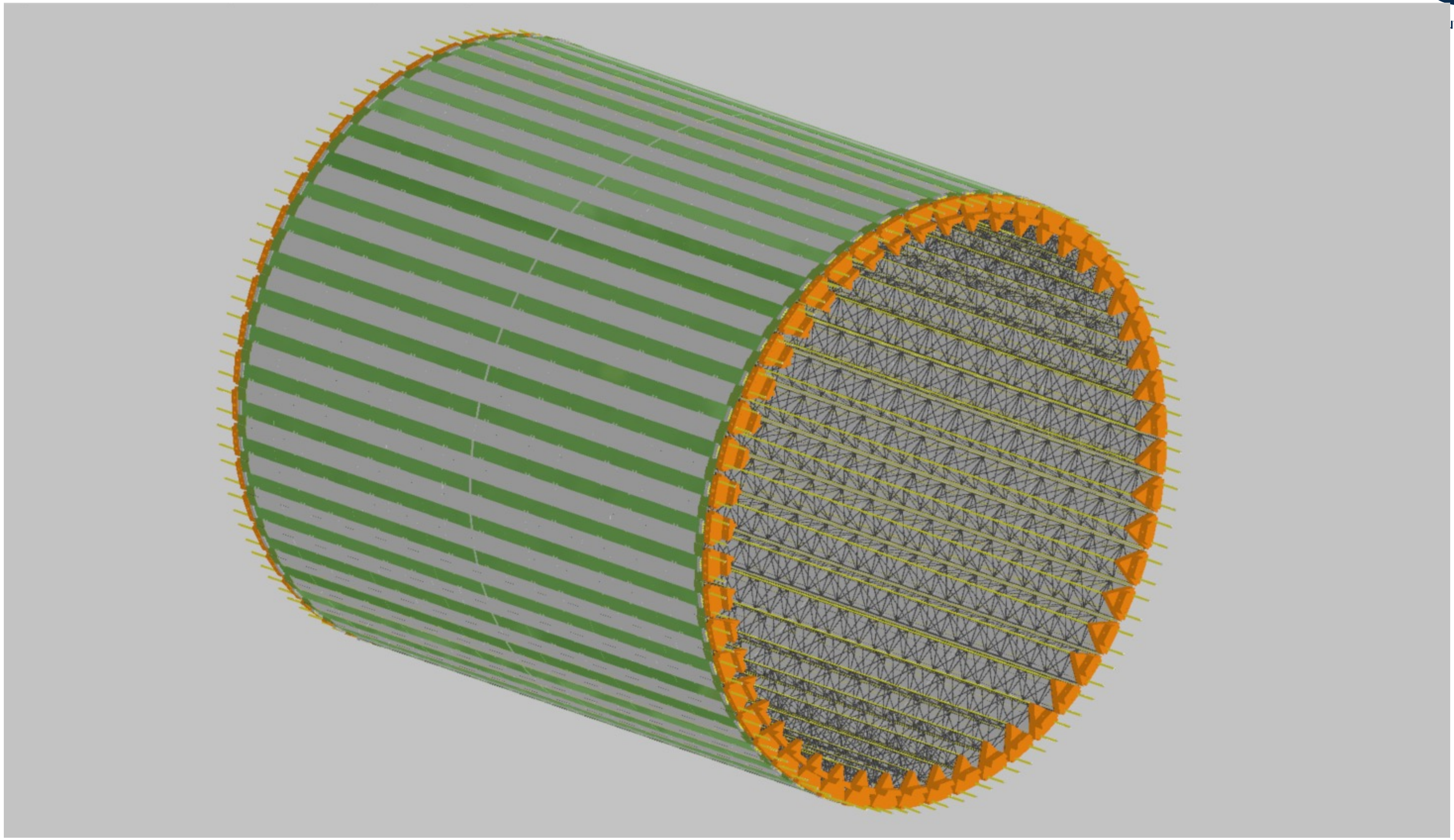


Cooling Fluid Temperature = 14 °C

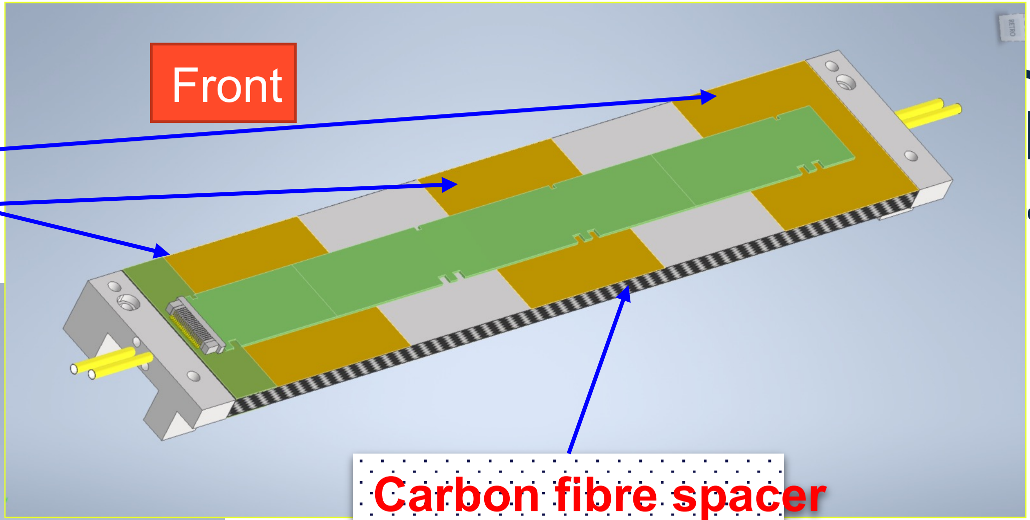
$\Delta T \sim 5\ ºC$

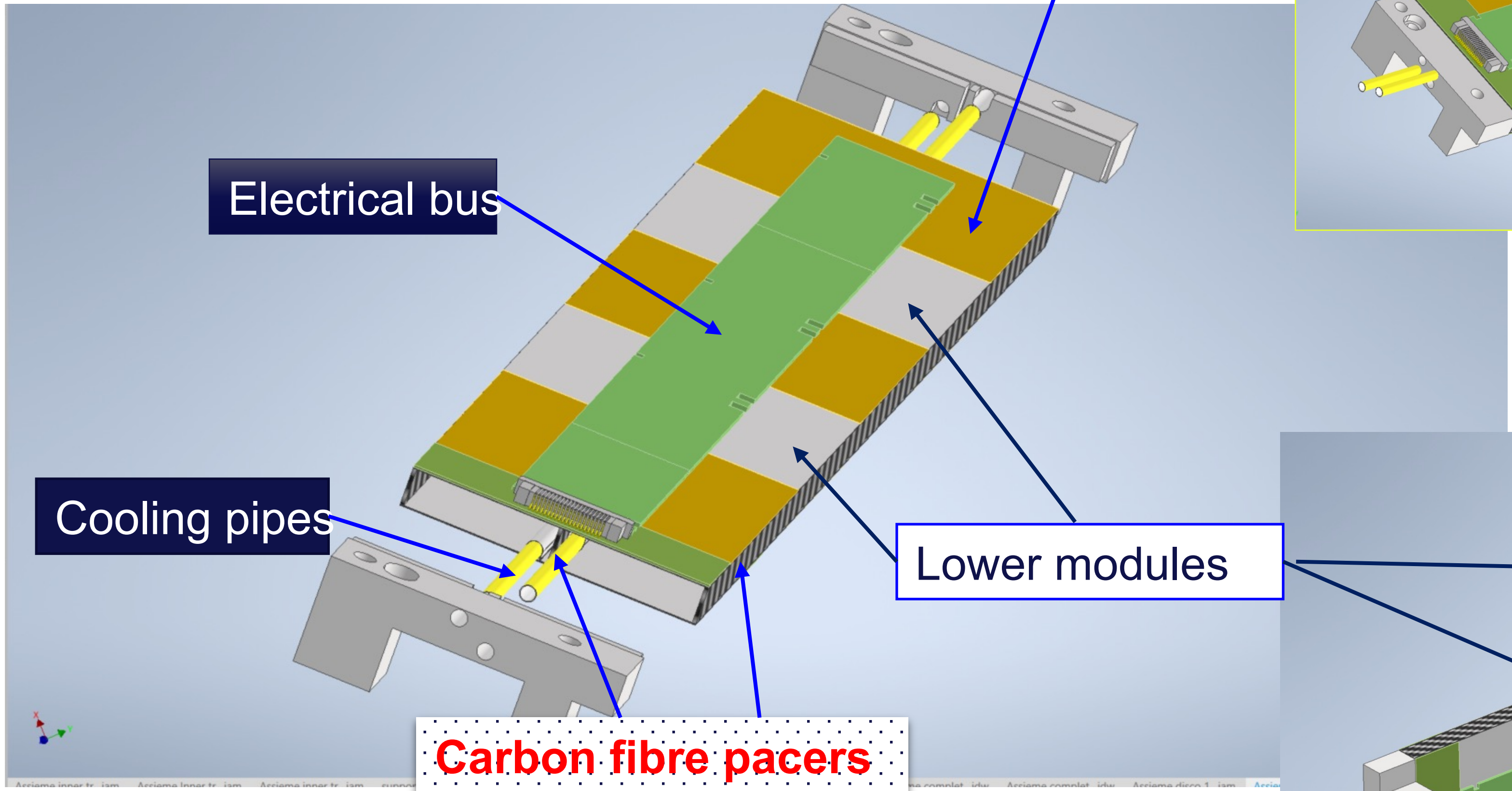


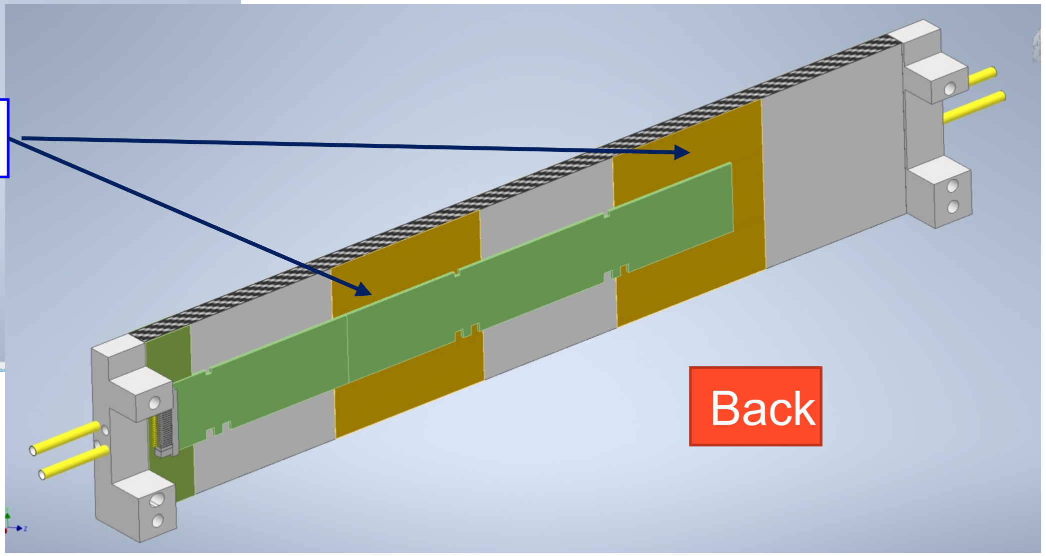
OUTER TRACKER



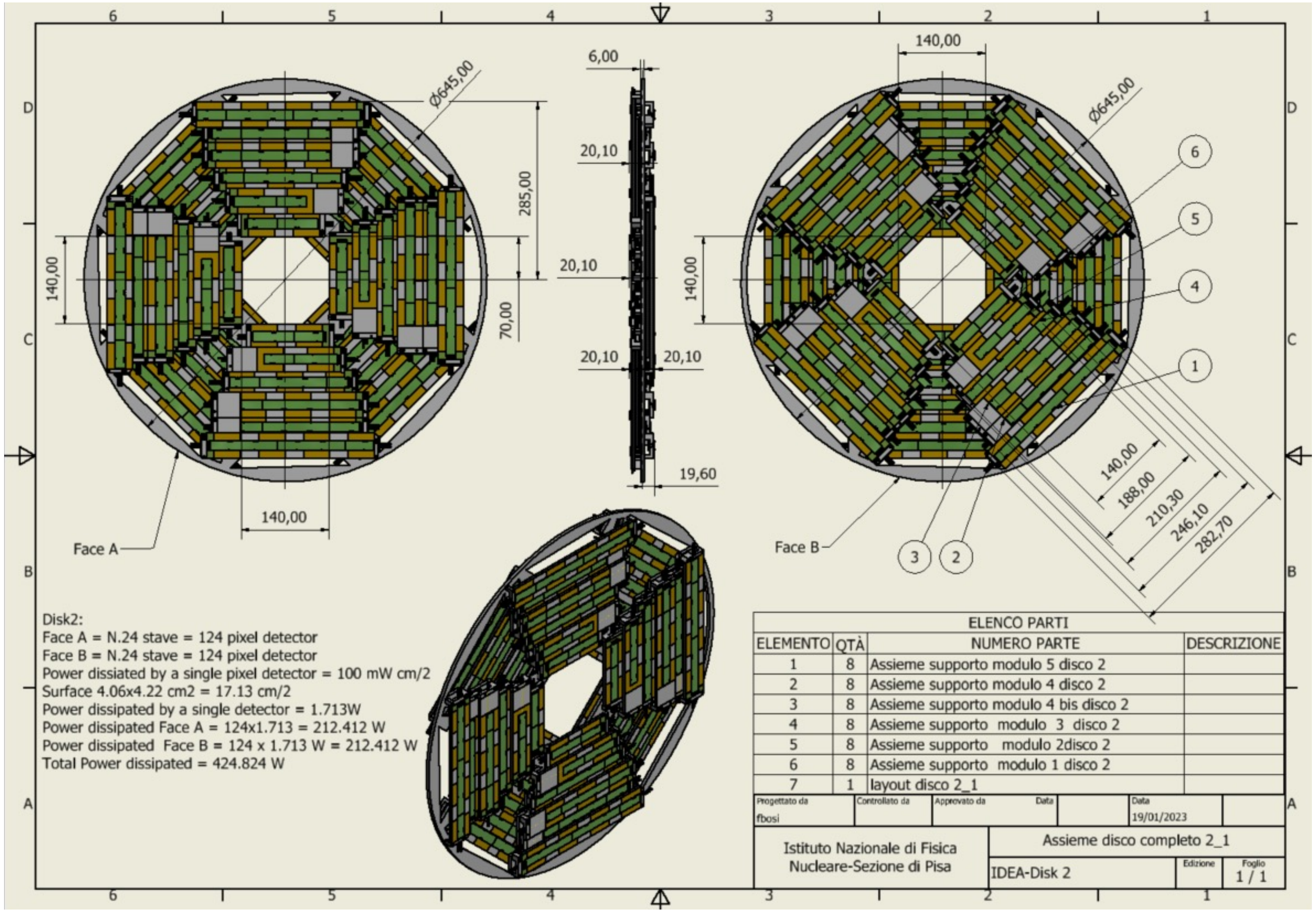
Typical disk module stave







DISK 2



ELENCO PARTI

ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
1	8	Assieme supporto modulo 5 disco 2	
2	8	Assieme supporto modulo 4 disco 2	
3	8	Assieme supporto modulo 4 bis disco 2	
4	8	Assieme supporto modulo 3 disco 2	
5	8	Assieme supporto modulo 2disco 2	
6	8	Assieme supporto modulo 1 disco 2	
7	1	layout disco 2_1	

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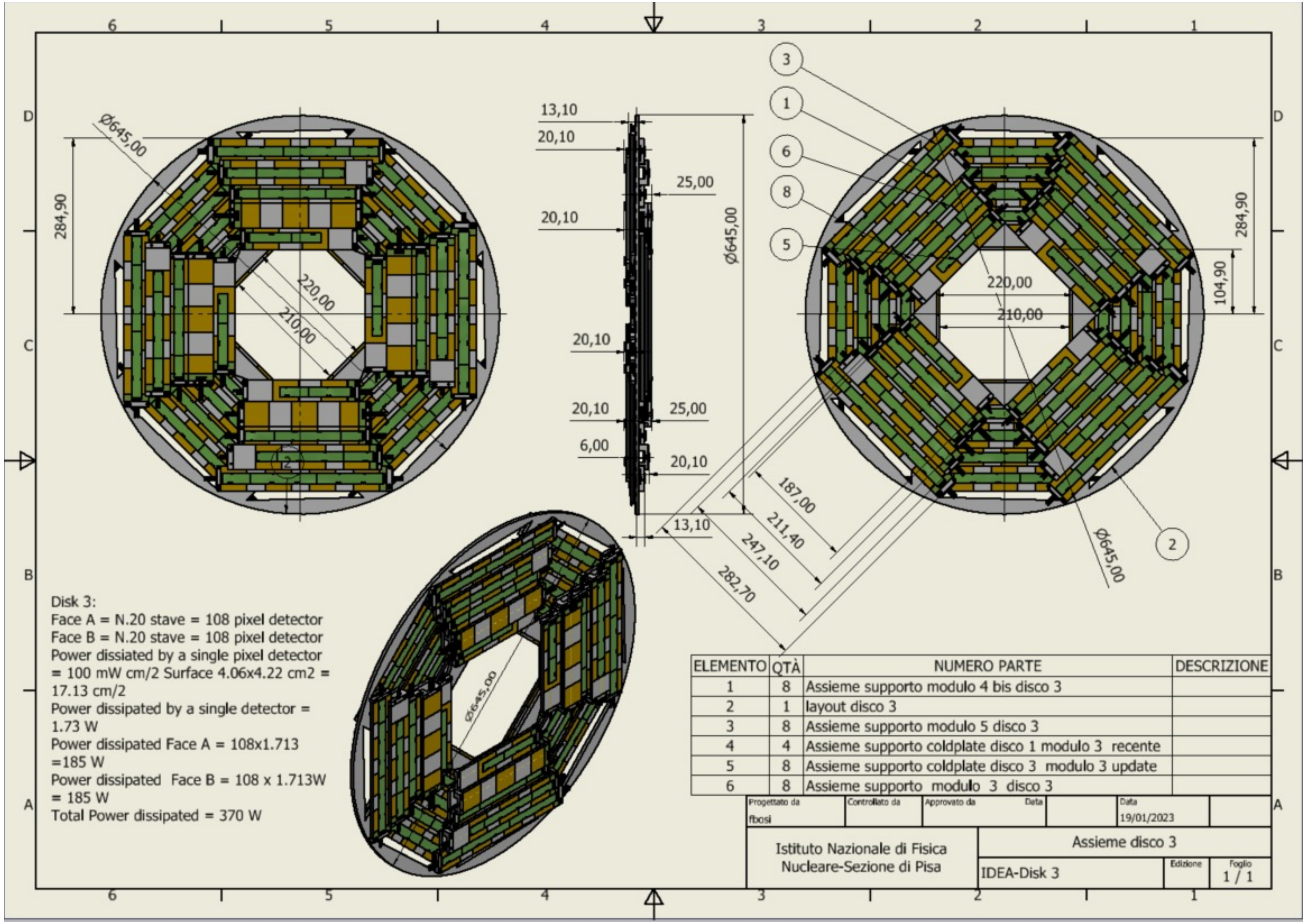
DISK 3



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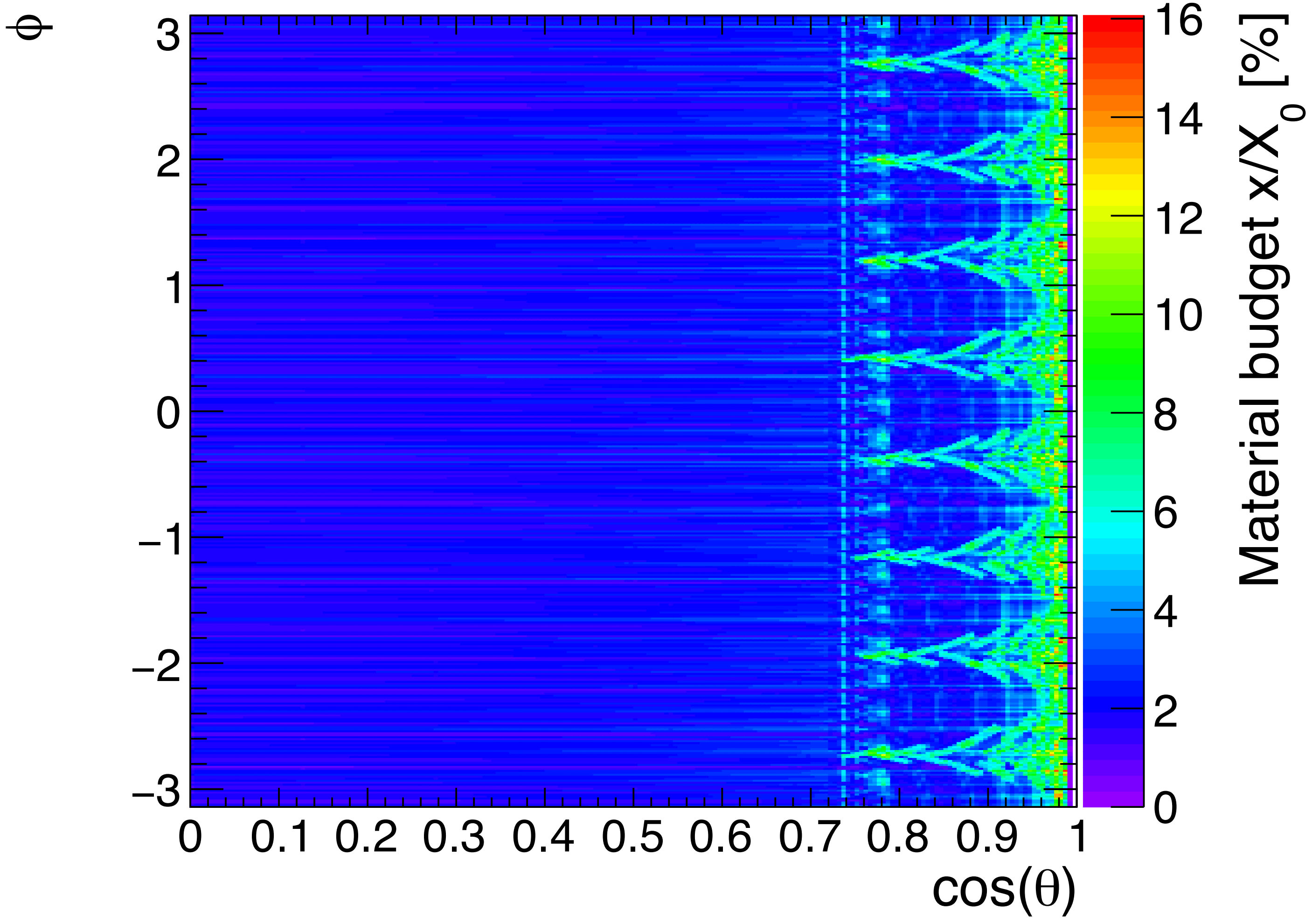
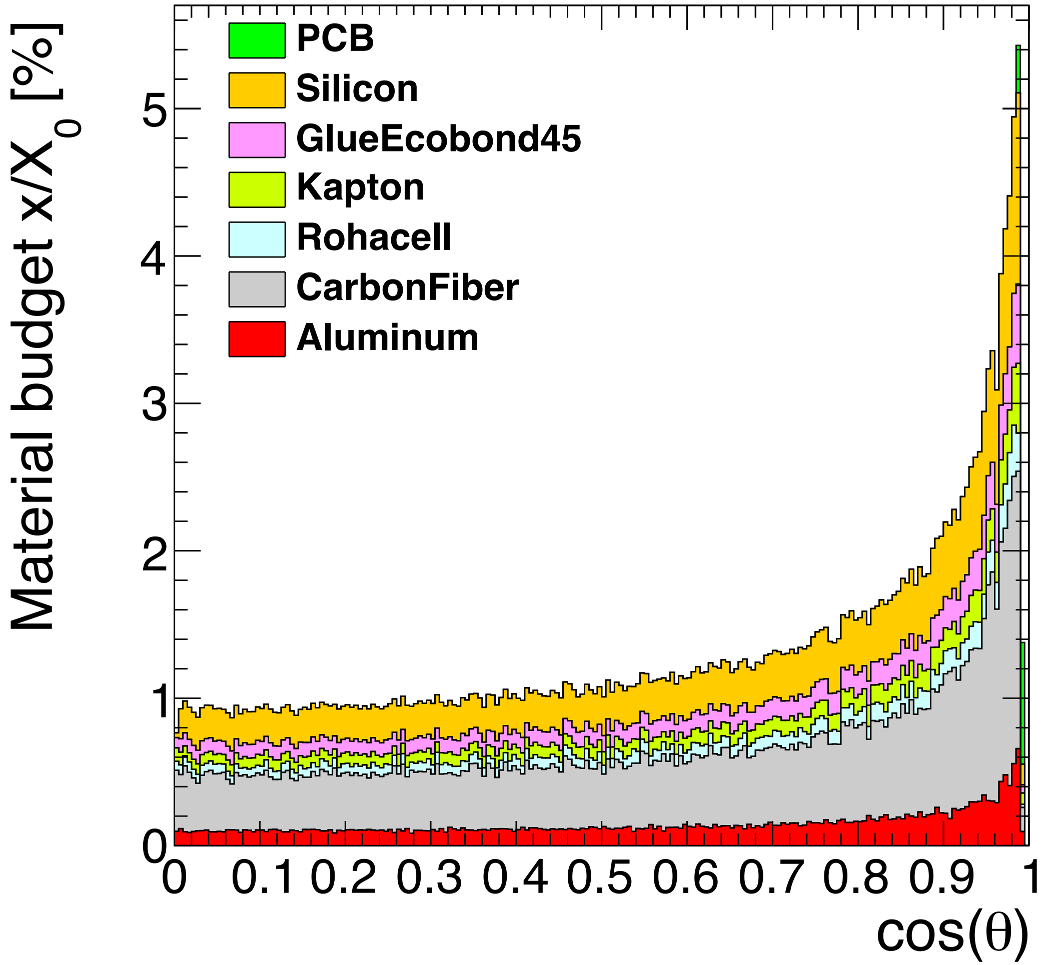


All Vertex

Inner vertex (all 3 layers)



A. Ilg

Middle and Outer vertex

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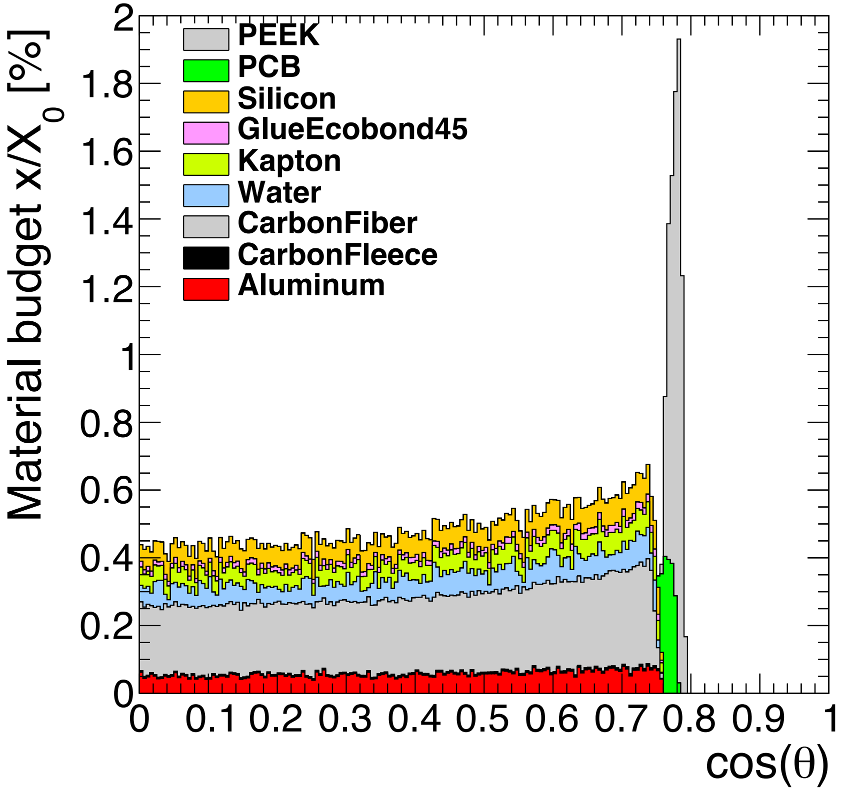
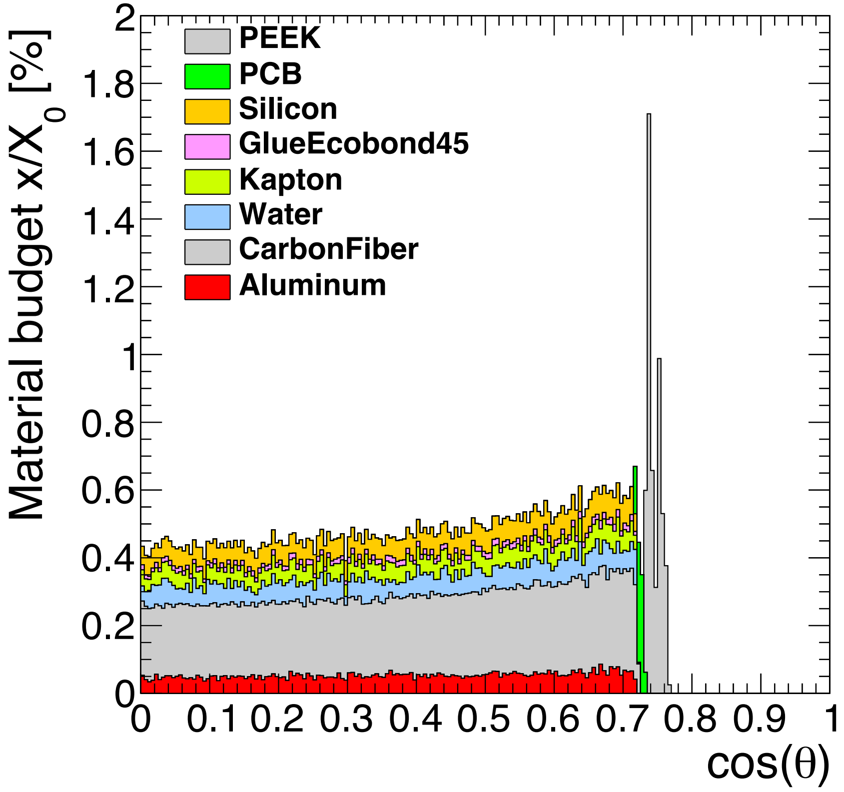
Middle



A. Ilg

Outer



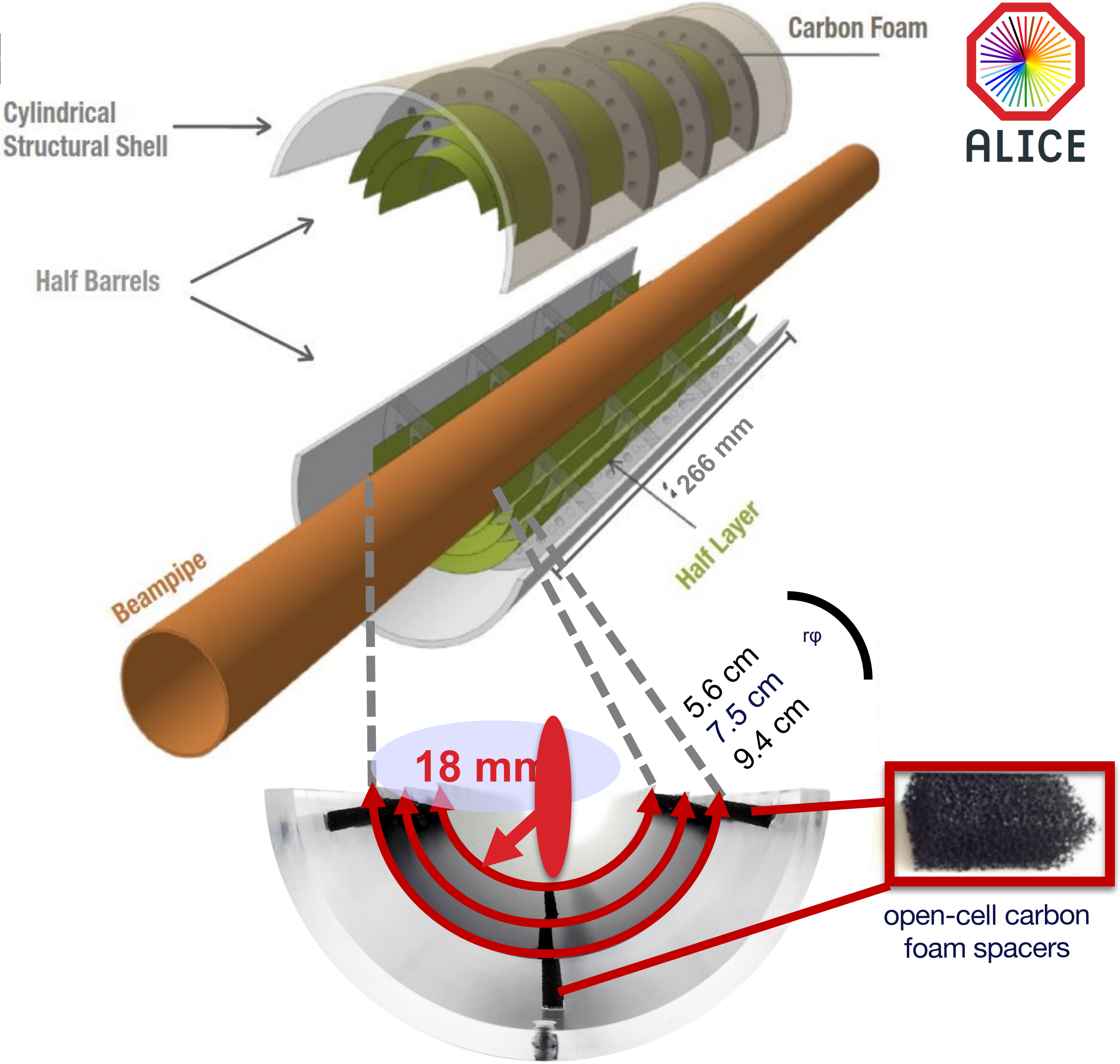
Inner Tracking System 3 (ALICE)

Detector Overview

- Wafer-scale sensor ASICs
- Fabricated with stitching
- All electrical signals and power routed on-chip
- Ultra-thin and bendable: 50 µm
- 266 mm (Z) x variable width* (rφ)
- CMOS MAPS
  - 65 nm technology
- Open-cell carbon foam spacers

Key benefits

- Extremely lightweight
  - Material budget: 0.35% X_0 => 0.05% X_0
- Uniformly distributed material
- Closer to interaction point
  - Beam pipe radius: 18.2 mm => 16 mm
  - Radial position: 24 mm => 18 mm



* The sensor width (rφ) varies with layer