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

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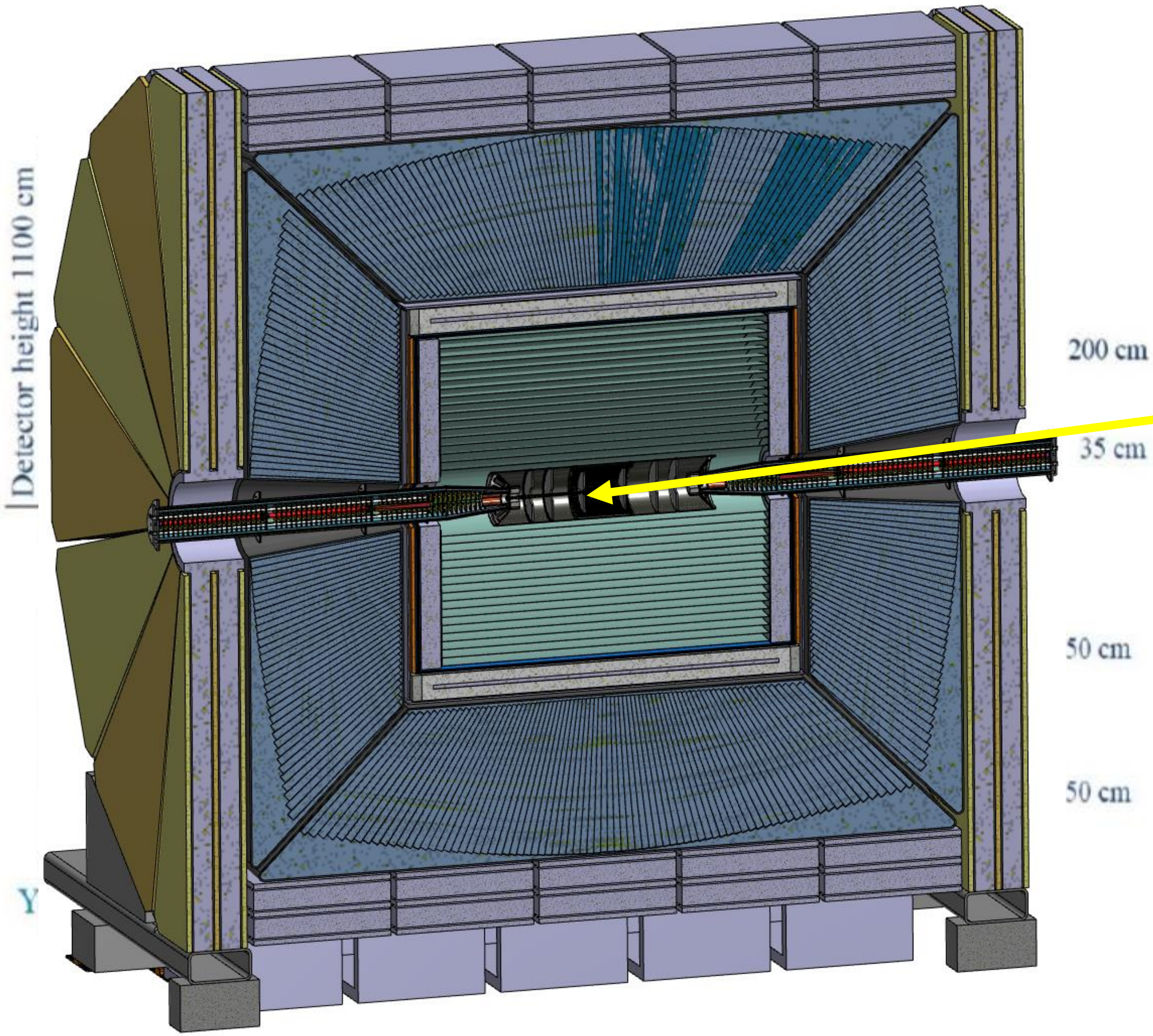
Joint DC & SW meeting
31 July 2023



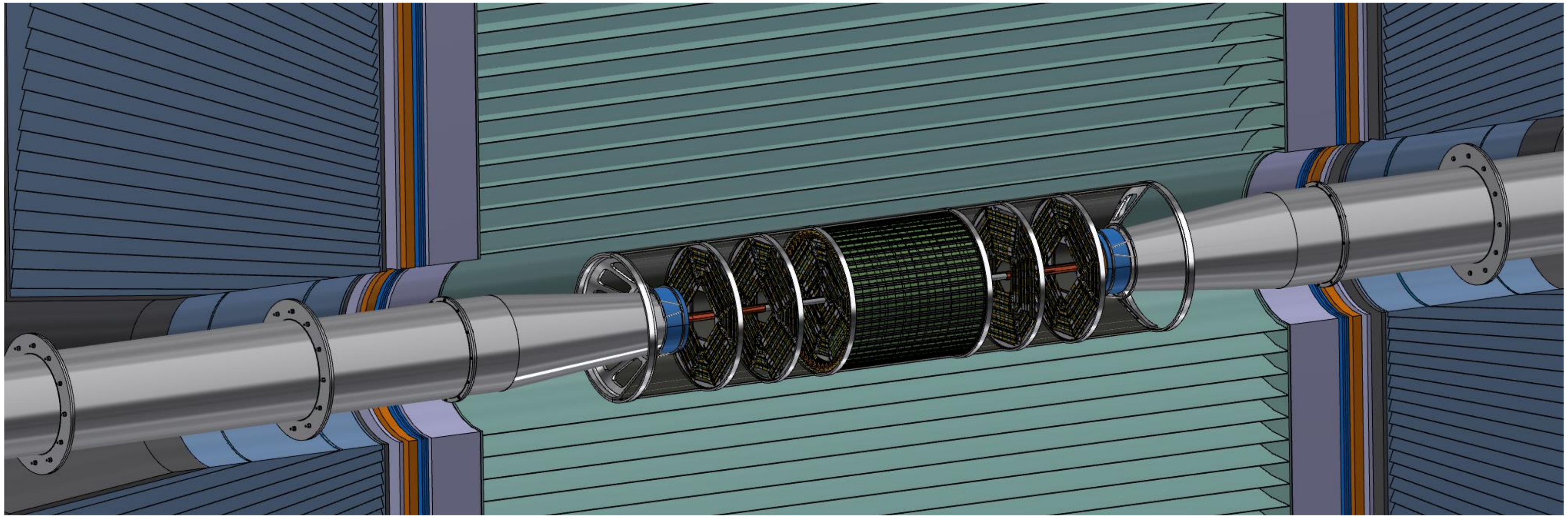
- Central tracking device:
  - light Drift CHamber
- **Silicon detectors for precision measurements**
  - vertex detector
  - silicon internal tracker
  - silicon wrapper
- Thin solenoid with 2T field (according to MDI limits)
- Dual readout calorimeter
  - supplemented by a pre-shower detector
- Muon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

Inner and outer vertex trackers



Inside the same volume of the support tube that holds also the LumiCal

Inner vertex detector supported by the beam pipe

Outer vertex detector (2 barrel and 6 disks) fixed to the support tube

Minimal number of detector module variants

One module type only for the Vertex

One module type only for the Outer barrel and disks

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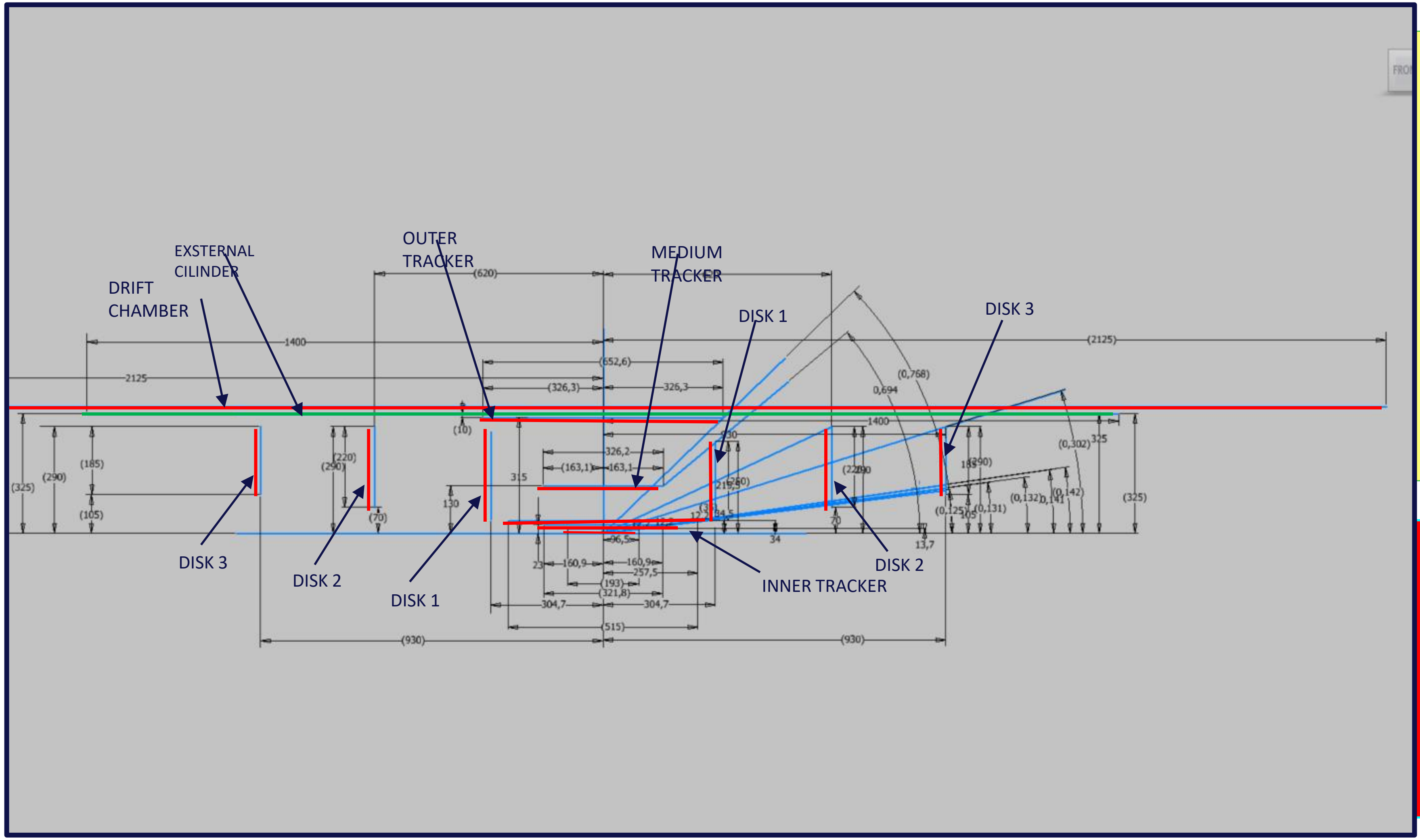


Outer vertex tracker:

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

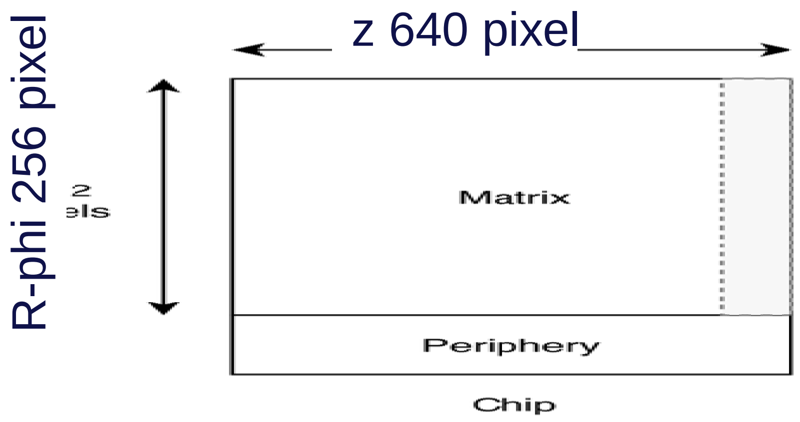
Based on ARCADIA INFN R&D

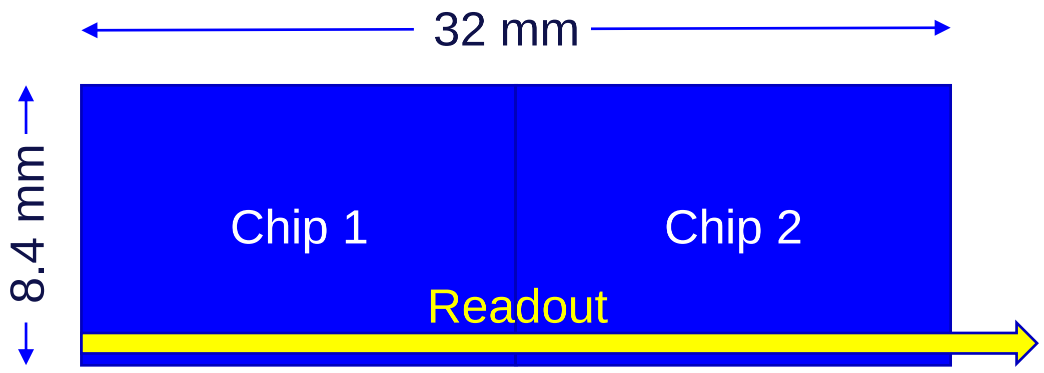
Depleted Monolithic Active Pixel Detectors (DMAPS)
Technology: LF11is 110 nm CMOS node, high-resistivity bulk
Pixel size 25x25 µm^2 , 50 µm thick

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



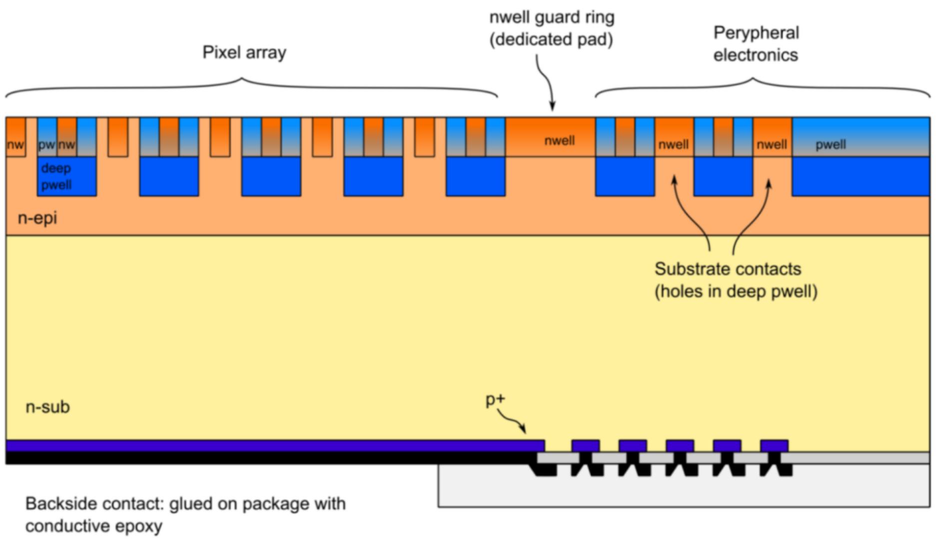


ARCADIA DMAPS R&D at INFN

Advanced Readout CMOS Architectures with Depleted Integrated sensor Arrays

Fully Depleted Monolithic Active Pixel CMOS sensor technology platform allowing for:

- Active sensor thickness in the range 50 µm to 500 µm or more;
- Operation in full depletion with fast charge collection by drift, small collecting electrode for optimal signal-to-noise ratio;
- Scalable readout architecture with ultra-low power capability (O(10 mW/cm2));
- Compatibility with standard CMOS fabrication processes
- Technology: LF11is 110nm CMOS node (quad-well, both PMOS and NMOS), high-resistivity bulk
- Custom patterned backside, patented process developed in collaboration with LFoundry



ARCADIA

"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.

ARCADIA R&D

- Sensor R&D and Technology, CMOS IP Design and Chip Integration, Data Acquisition and Characterisation
- 3 engineering runs with full-scale FD-DMAPS and sensor R&D (monolithic FD-strips and readout, fast sensors with gain layer)
- High rate capability (100 MHz/cm2) architecture on a scalable 512x512 pixel matrix (25um pitch) MD3 Main Demonstrator chip:
  - ***measured* 30 mW/cm²** at full-speed (16 data Tx active) and 10 mW/cm² on low-rate mode (1 data Tx active)

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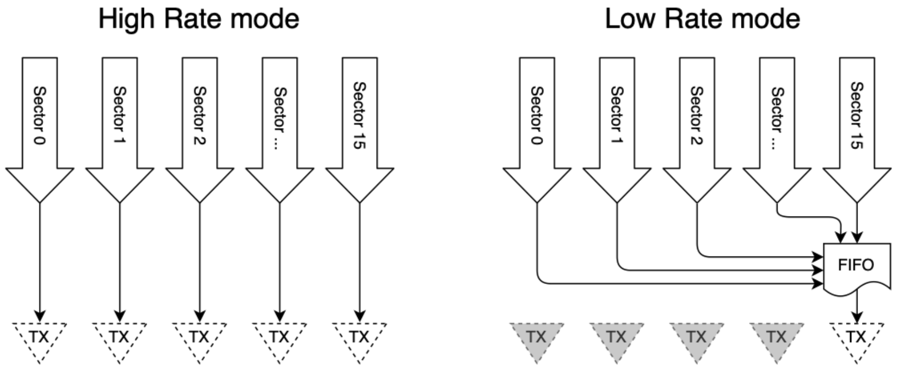
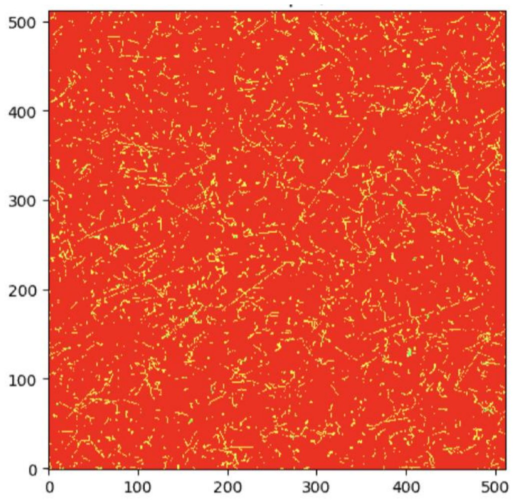
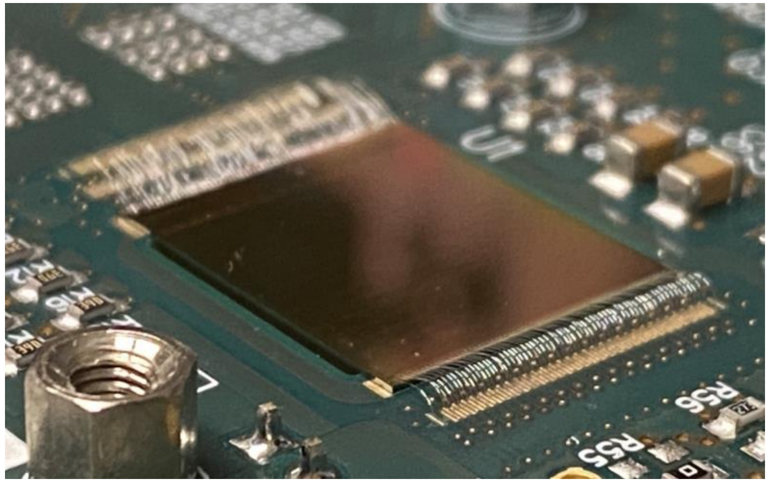
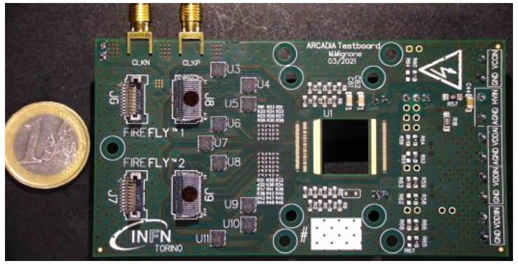
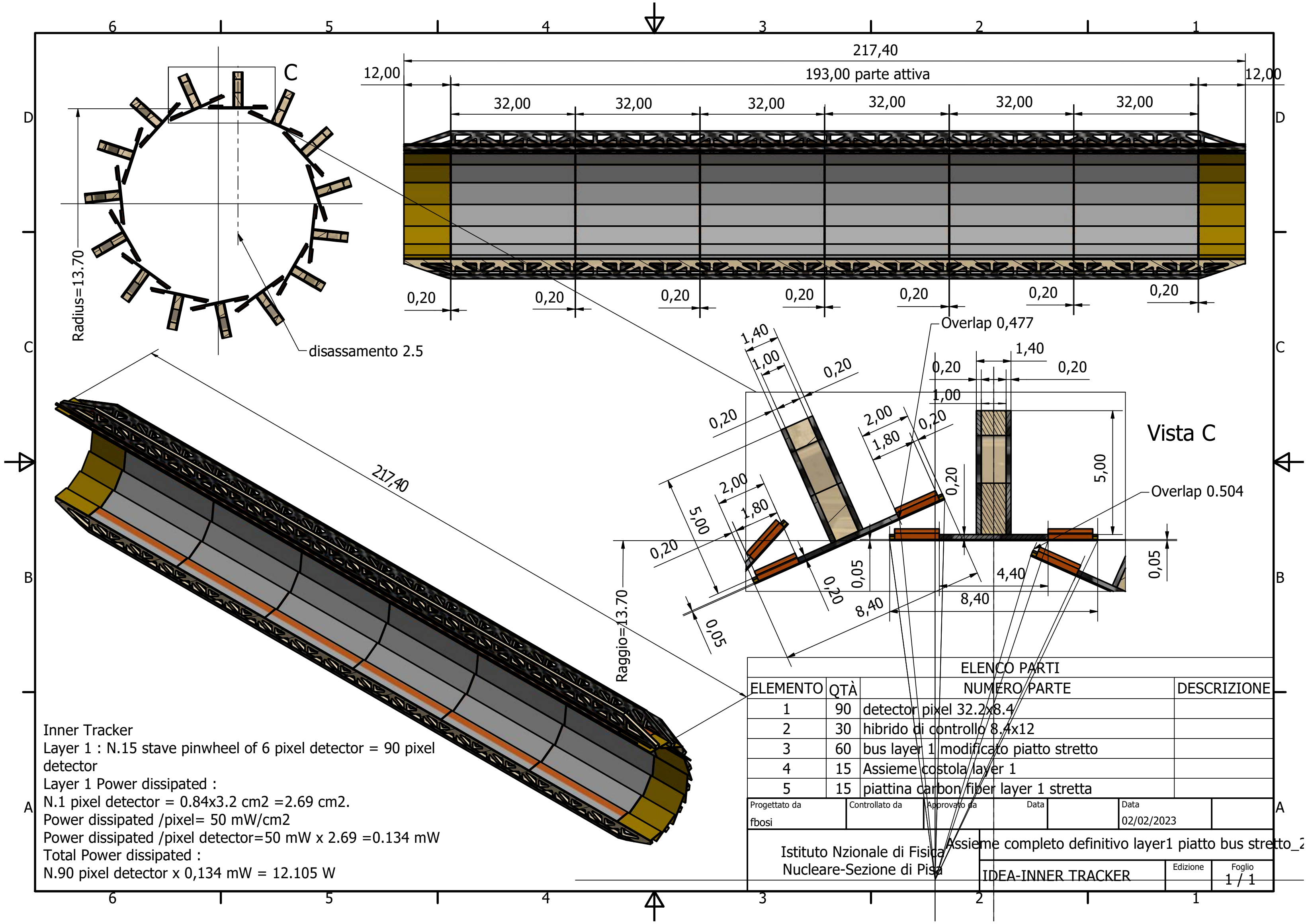




Cosmic ray data







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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

Half-ladder layout – layer 1

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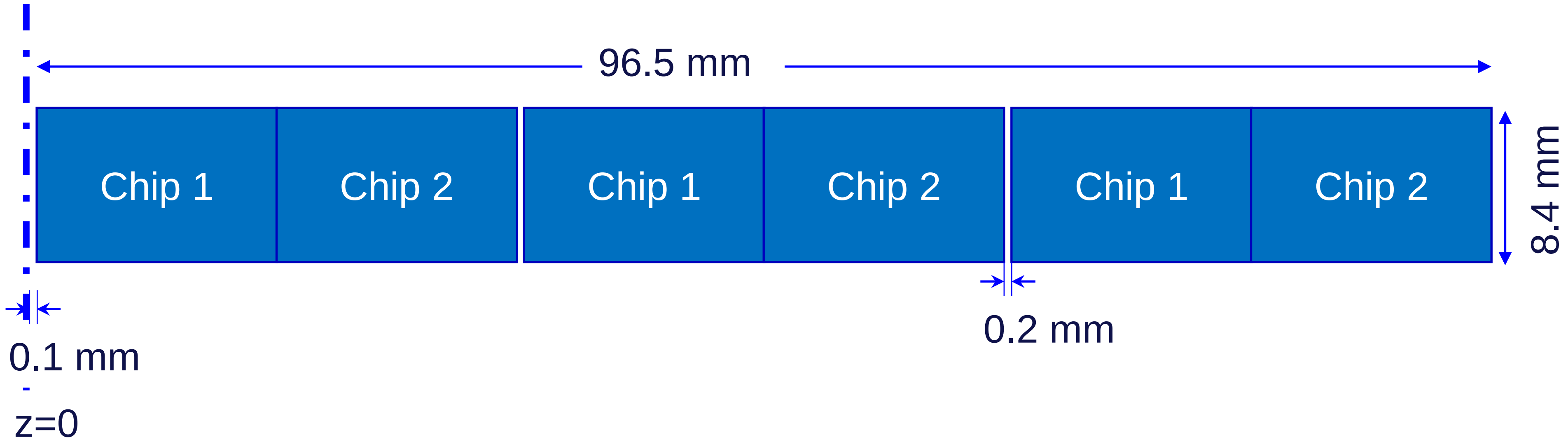
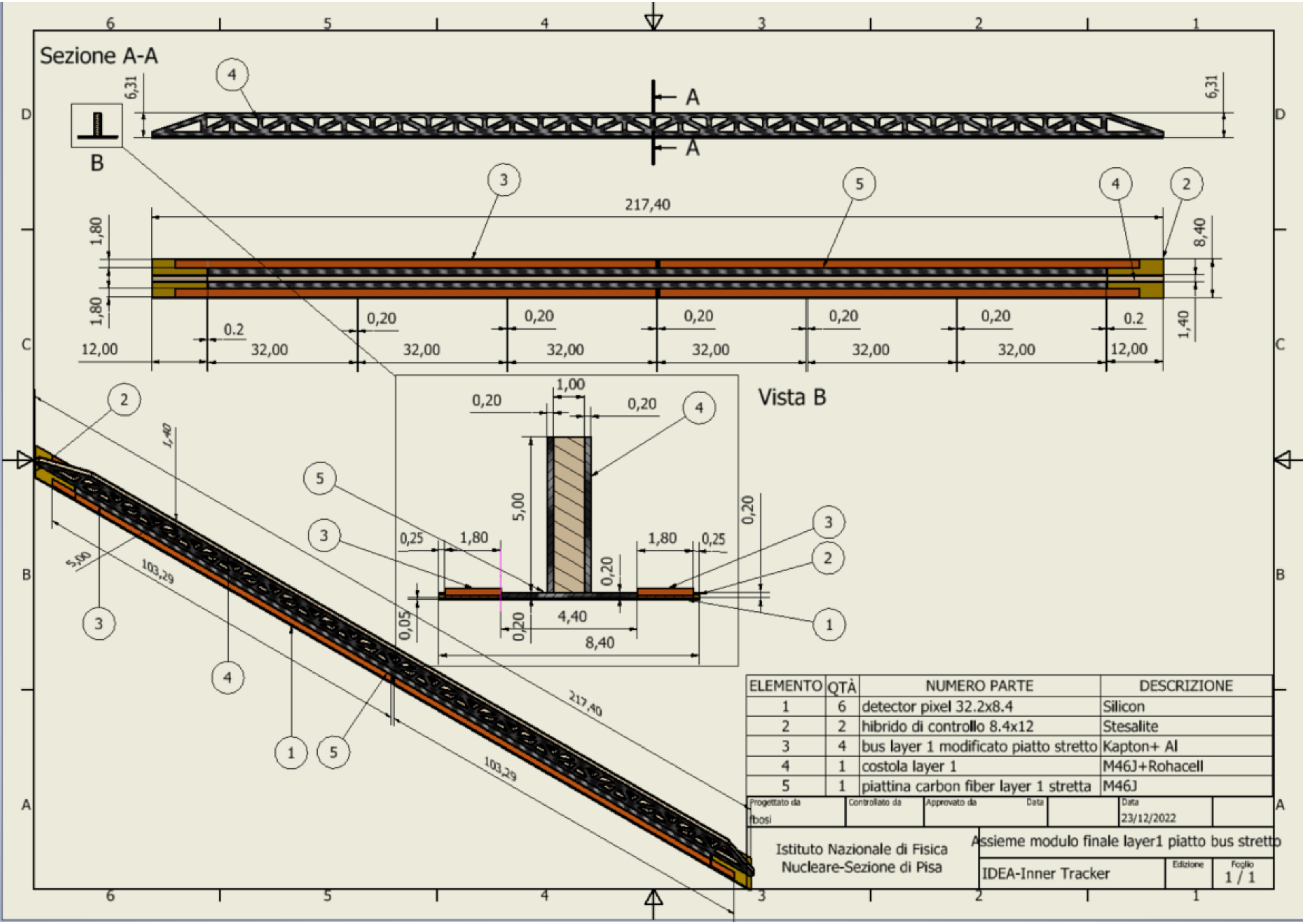


Layer 1 ladders are placed at 13.7 mm radius

Layer 1 stave detail



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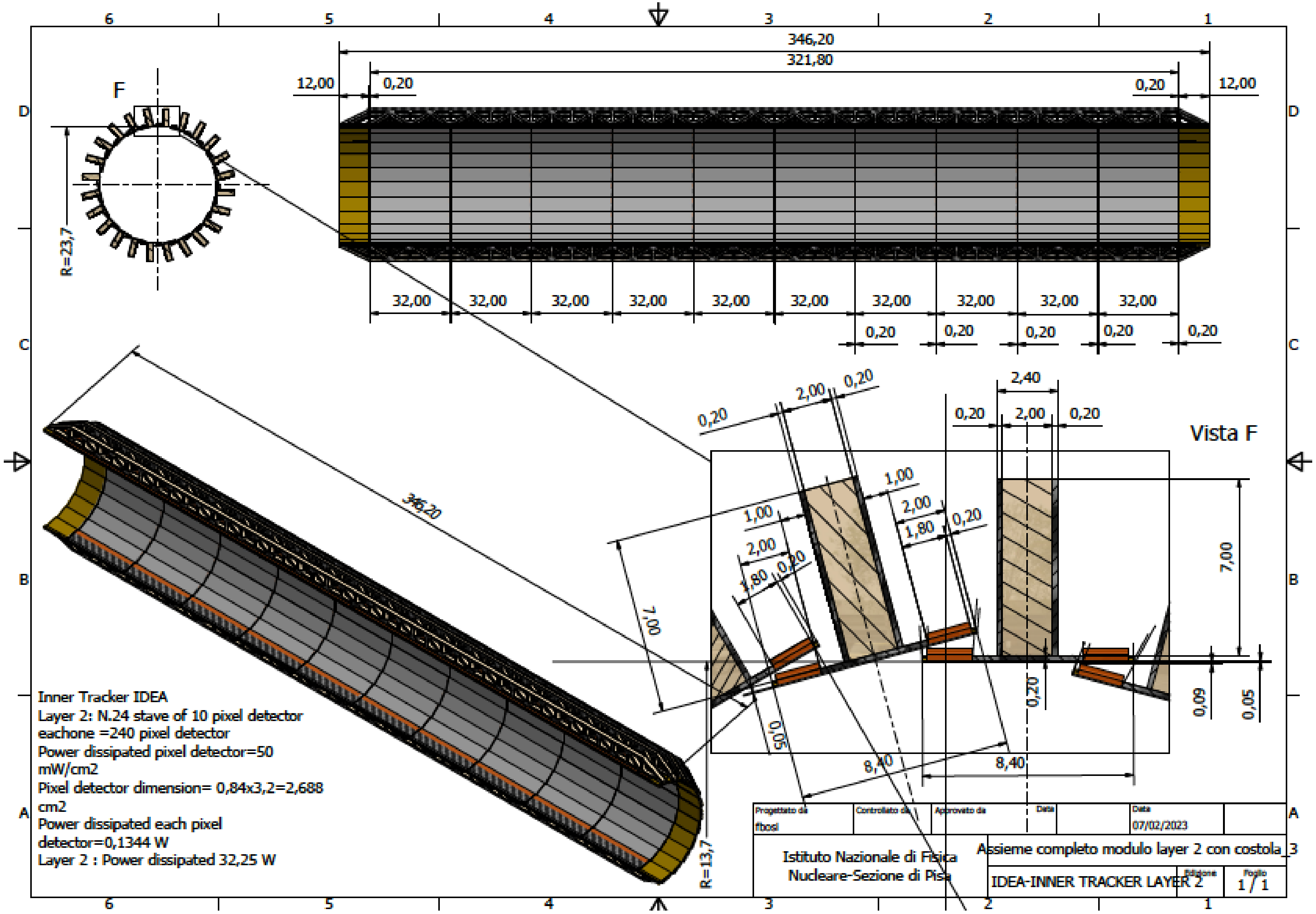
Reticular lightweight support to provide stiffness

- 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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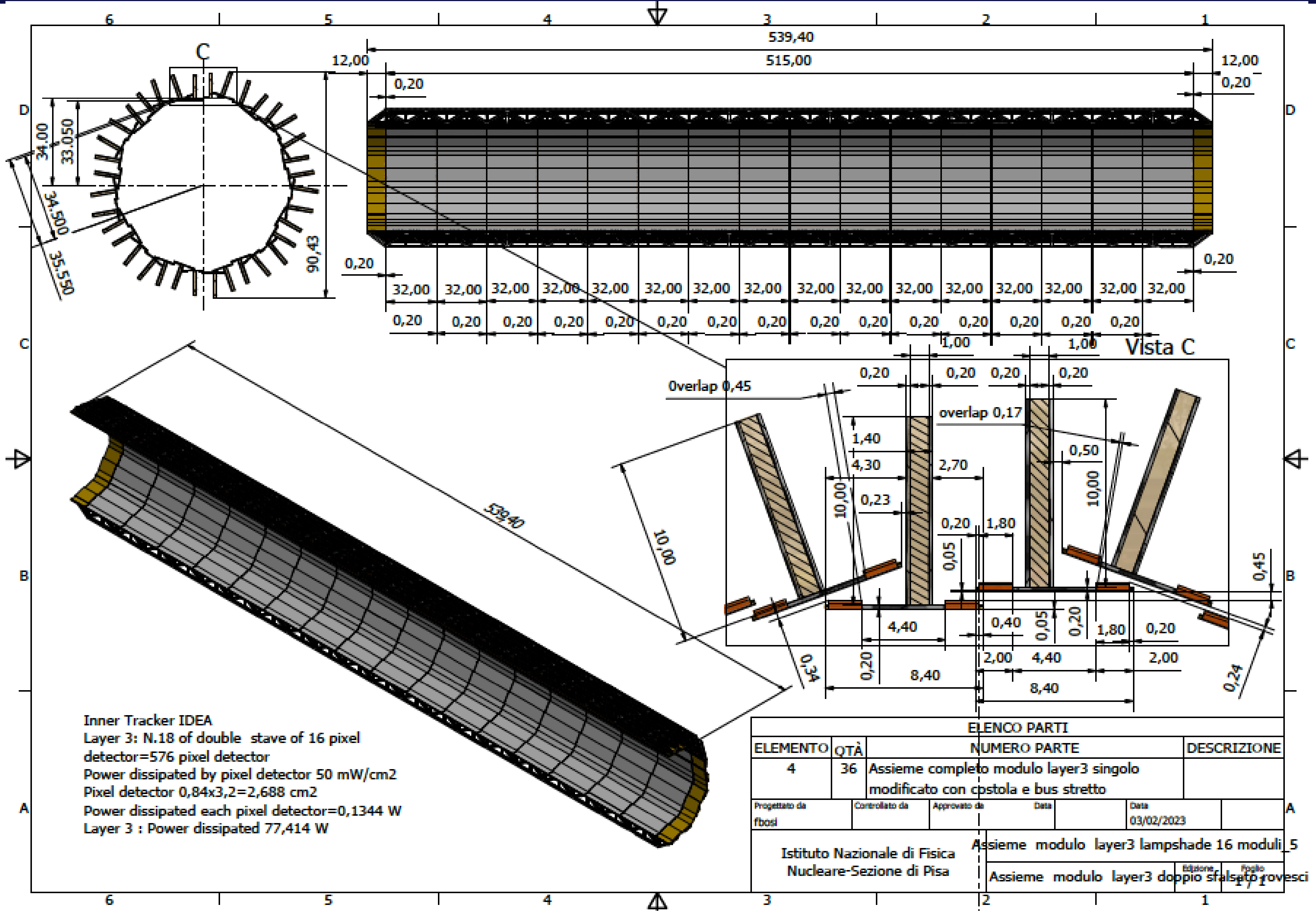
Layer 2
24 overlapping staves of 10 modules each

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

18 overlapping staves of double 16 modules each

Lampshade geometry.

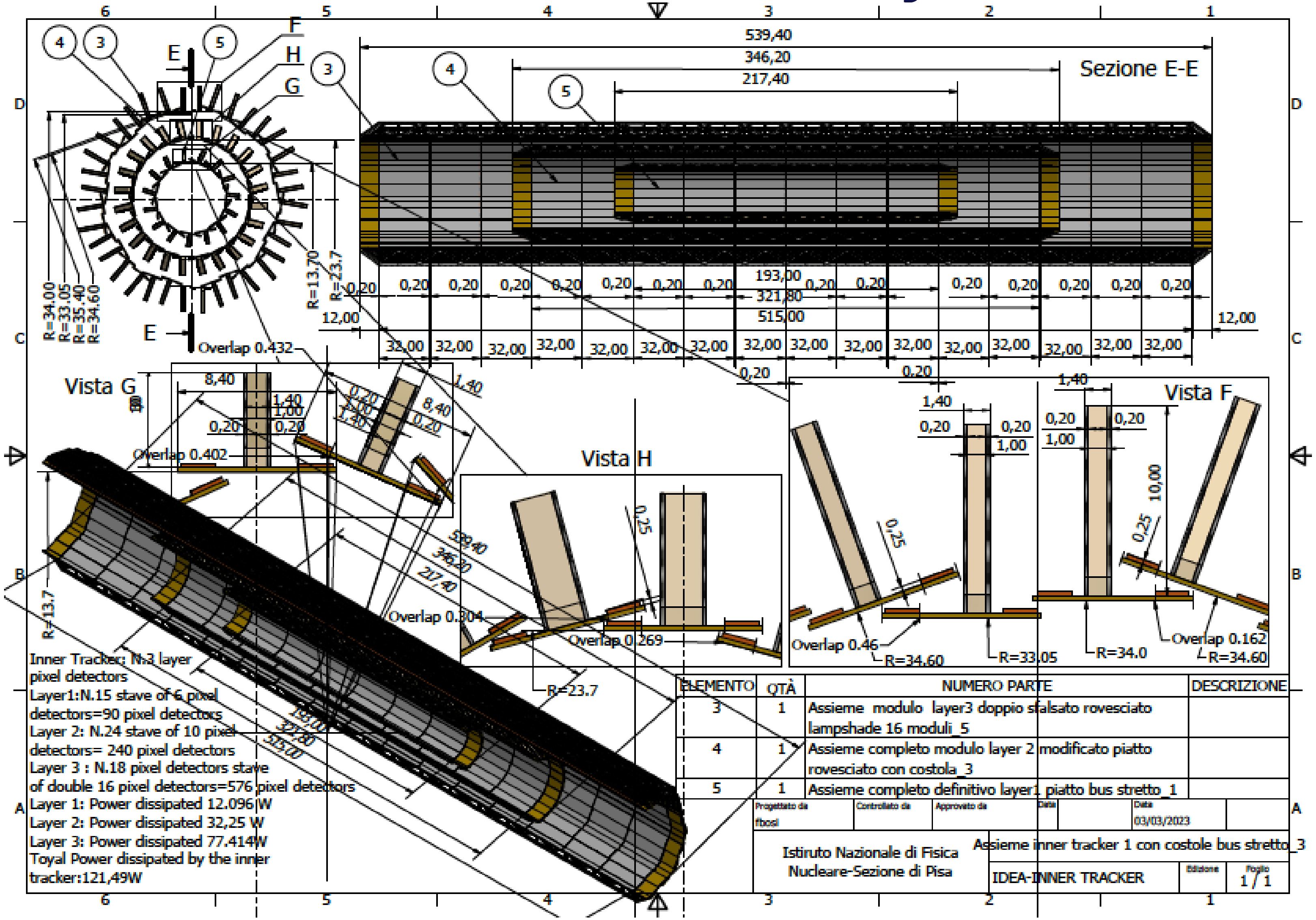
Charge symmetric track reconstruction

Total weight ~150 grams

Total thickness 0.25% X_0

Power budget ~77 W

Overall Inner Vertex layout



Total power ~120 W

Total weight ~230 grams

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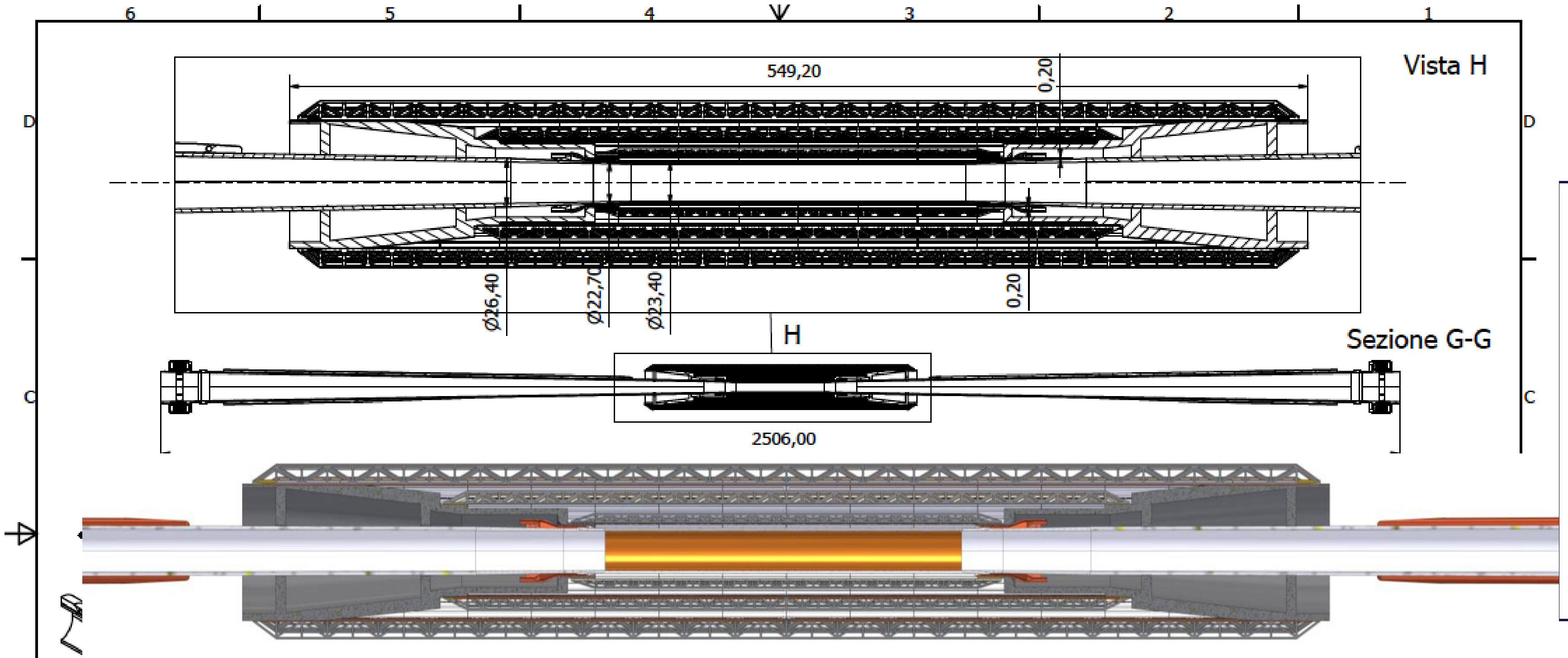
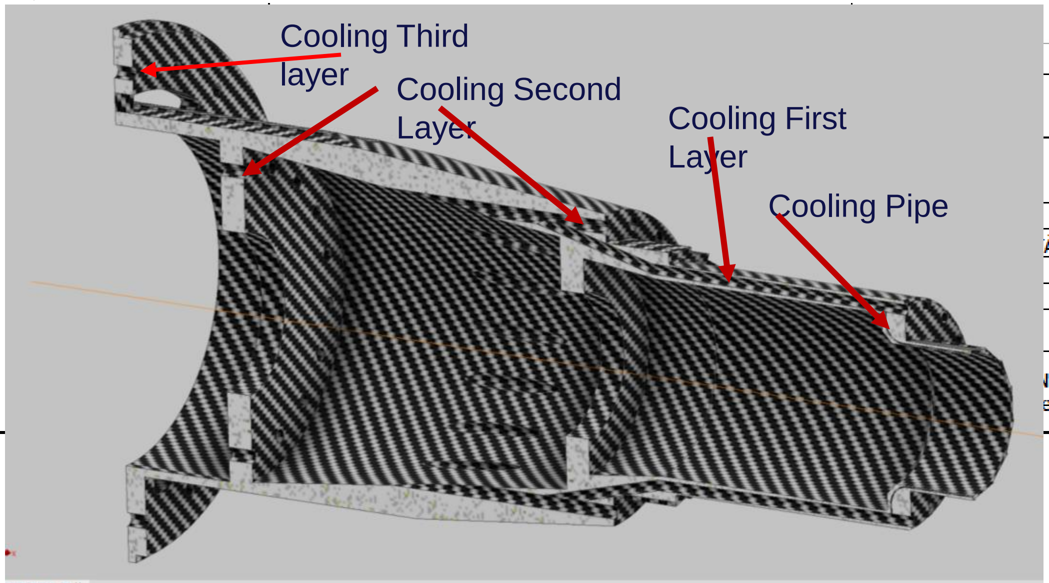
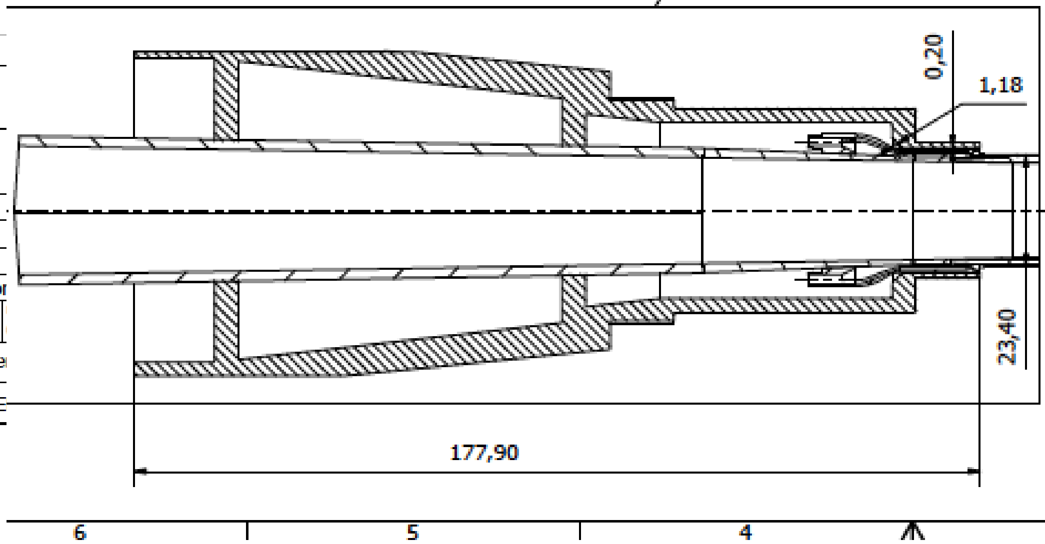






Inner vertex detector supporting conical structures on elliptical chamber
~450 grams

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

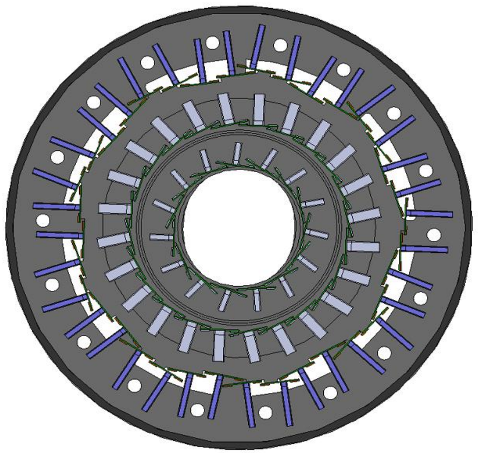
Thermal simulation started

INFN Perugia

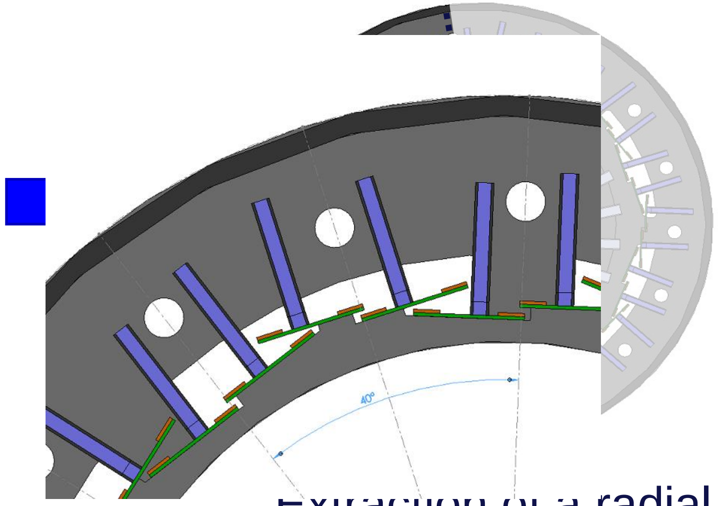
G. Baldinelli, F. Bianchi, C. Turrioni

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

FIRST STEPS

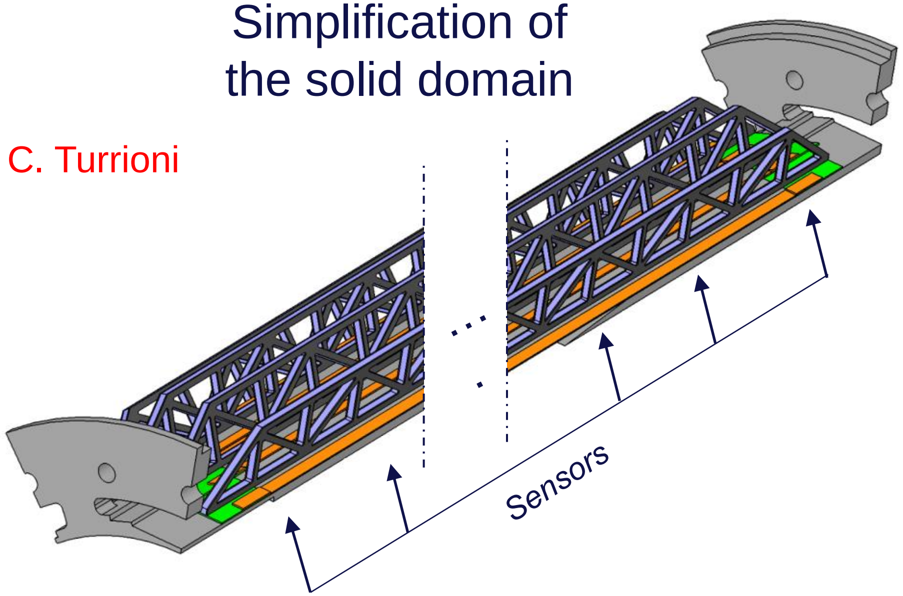


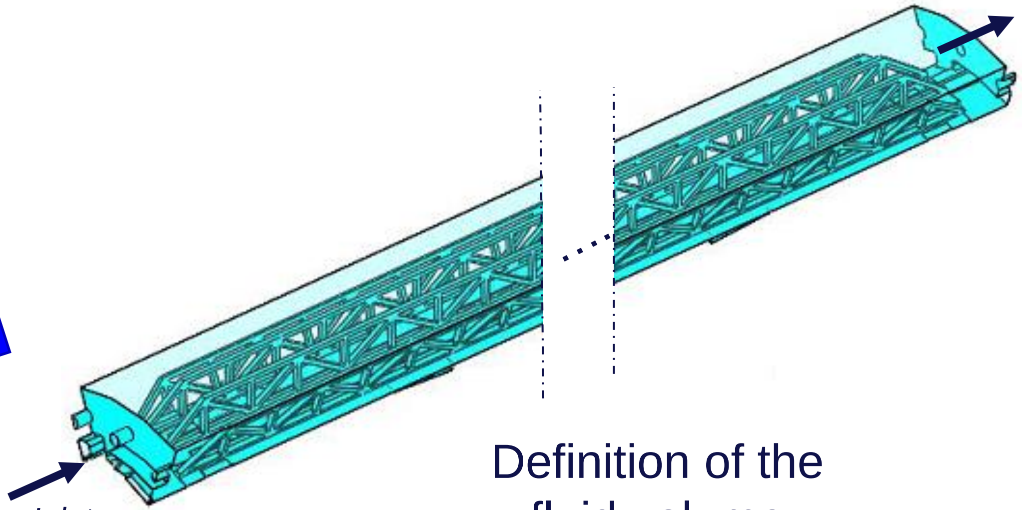
Full model



Extraction of a radial sector for layer 3

Simplification of the solid domain

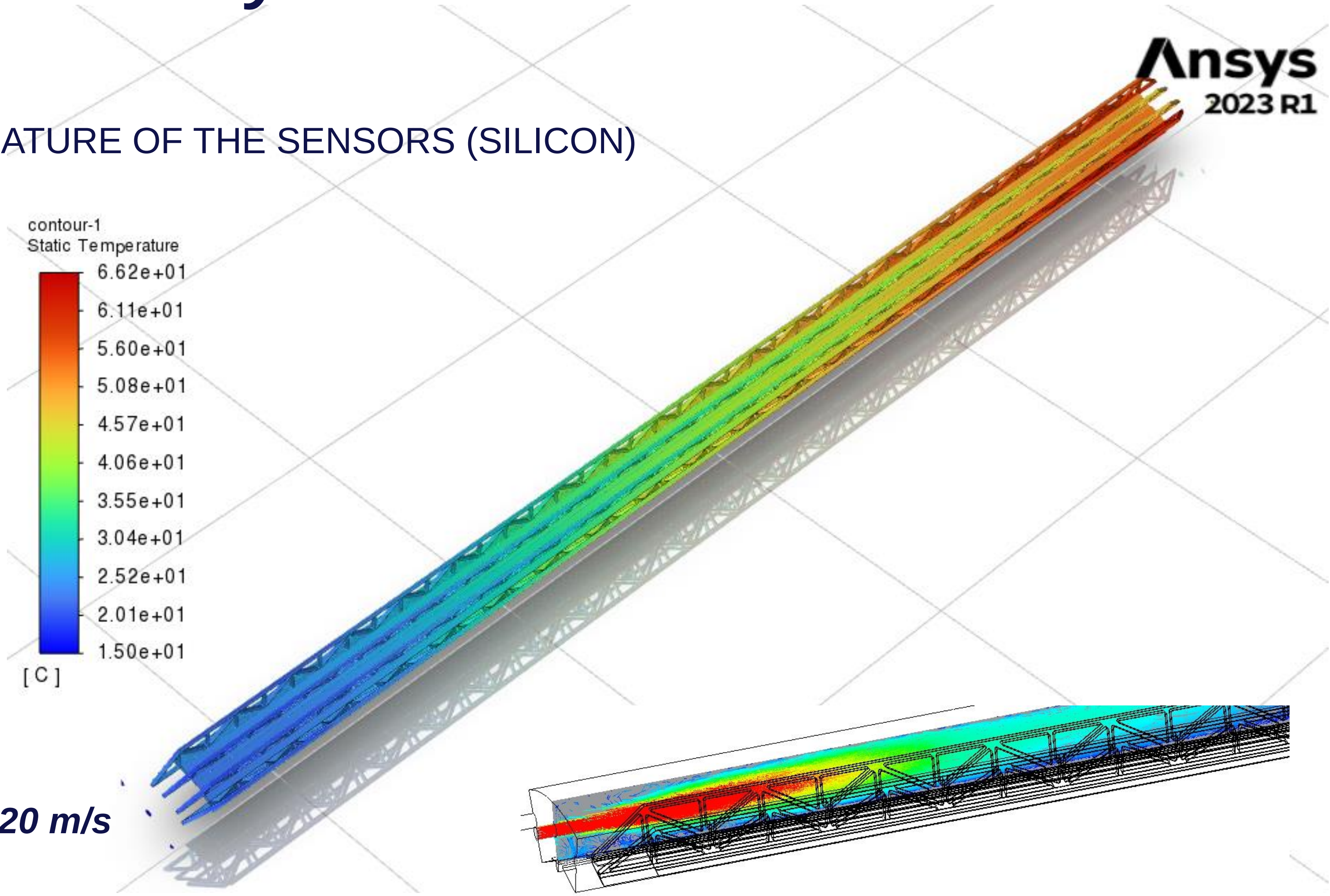




Definition of the fluid volume

Preliminary results – simulations

TEMPERATURE OF THE SENSORS (SILICON)



Air at 15°C – 20 m/s

Maximum temperature = +66°C

Air velocity drops to 10 m/s inside (from 20 m/s)

Thermal figure of merit:
66-15 = 51°C

Linear behaviour

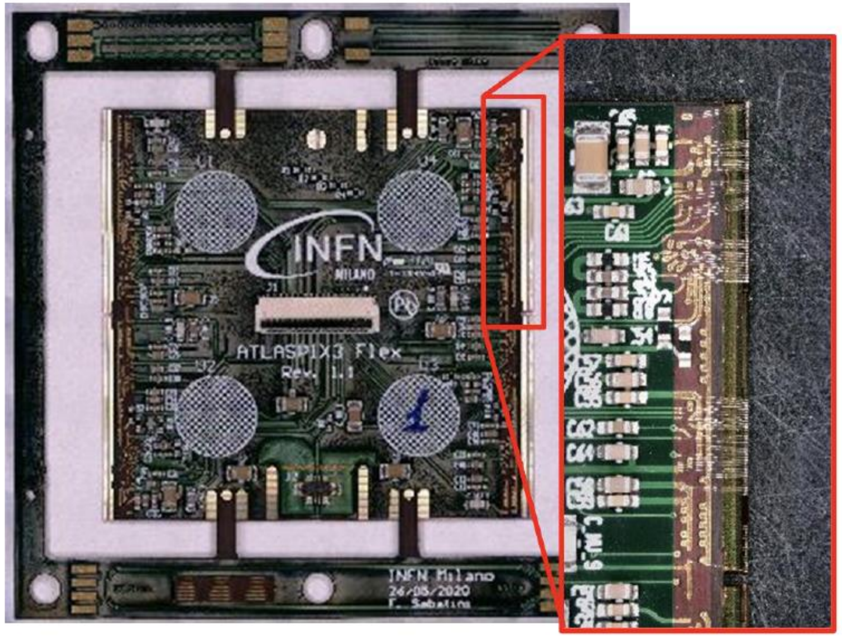
Feeding holes diameter is 2.5 mm too small → next try 6 mm (>5x flux increase)

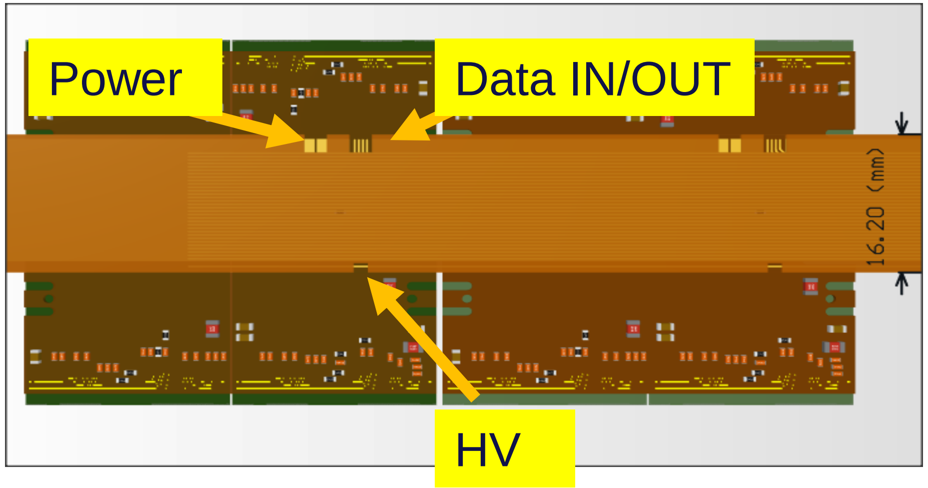
Outer vertex layers modules

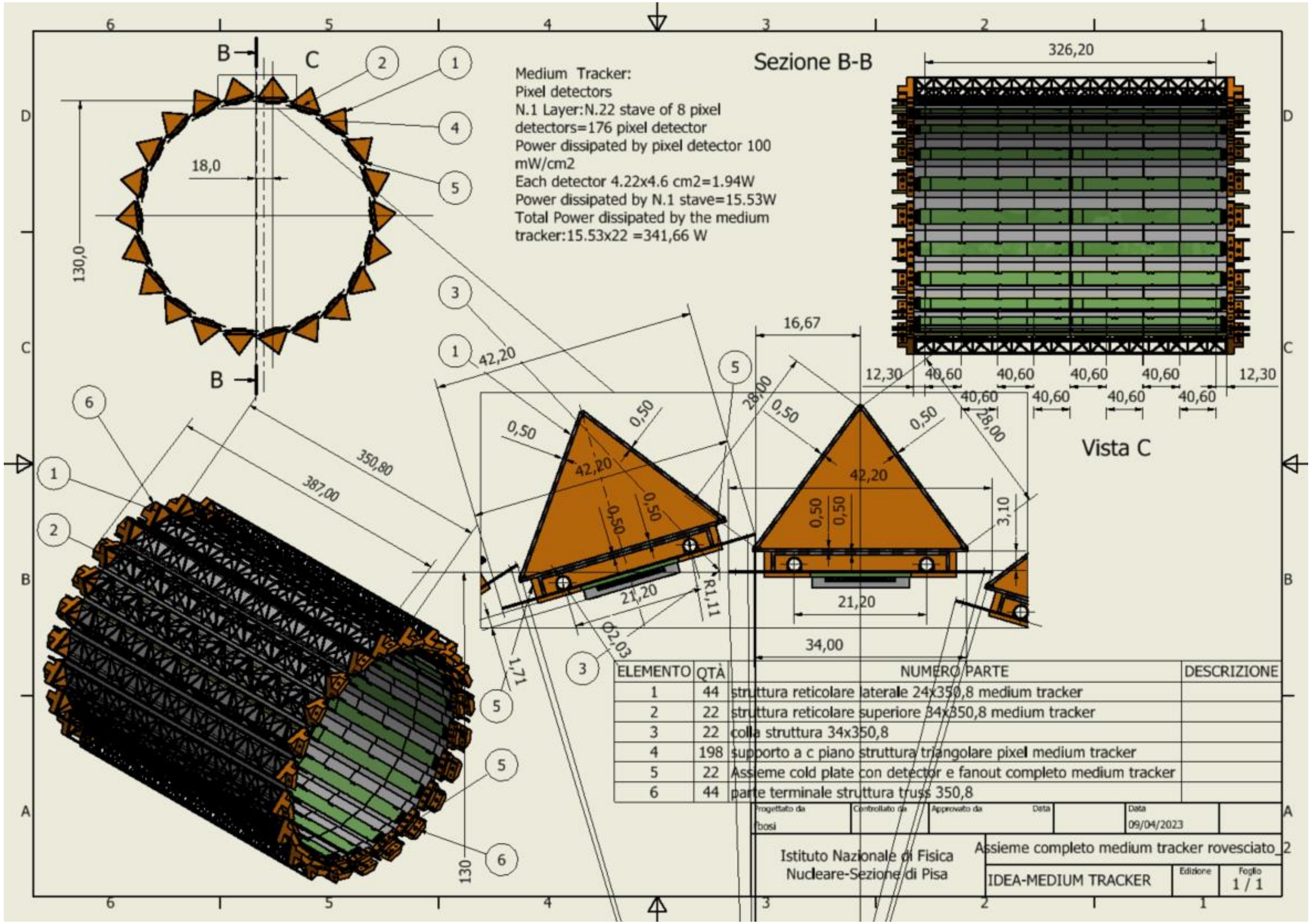
Based on ATLASPIX3 R&D
- DMAPS
- 50 x 150 μm^2
- Up to 1.28 Gb/s downlink
- TSI 180 nm process
- 132 columns of 372 pixels

- 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 $100\ \mathrm{mW/cm^2}$







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Middle Vertex Barrel
At 13 cm radius

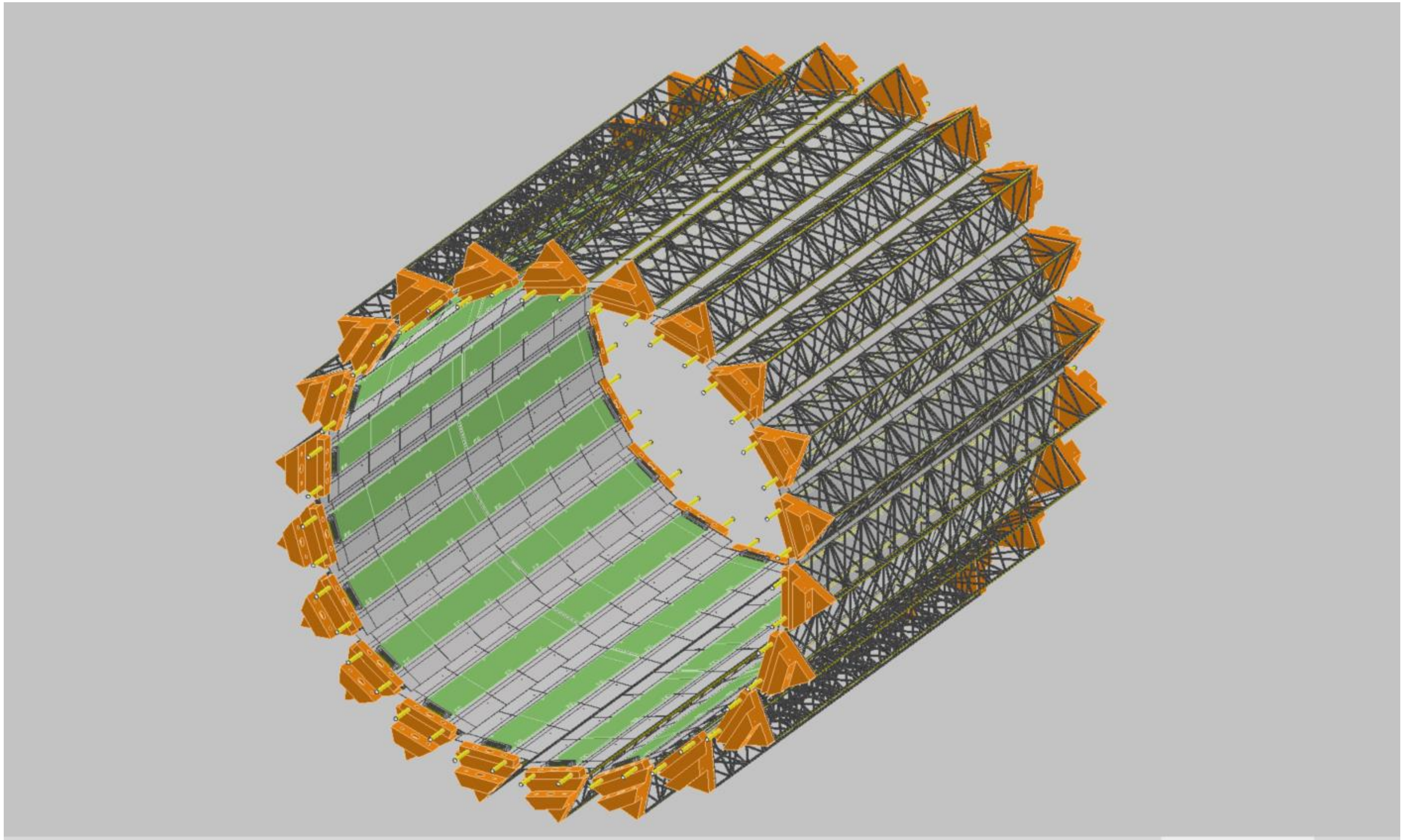
22 staves of 8 modules each.

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



Stave detail

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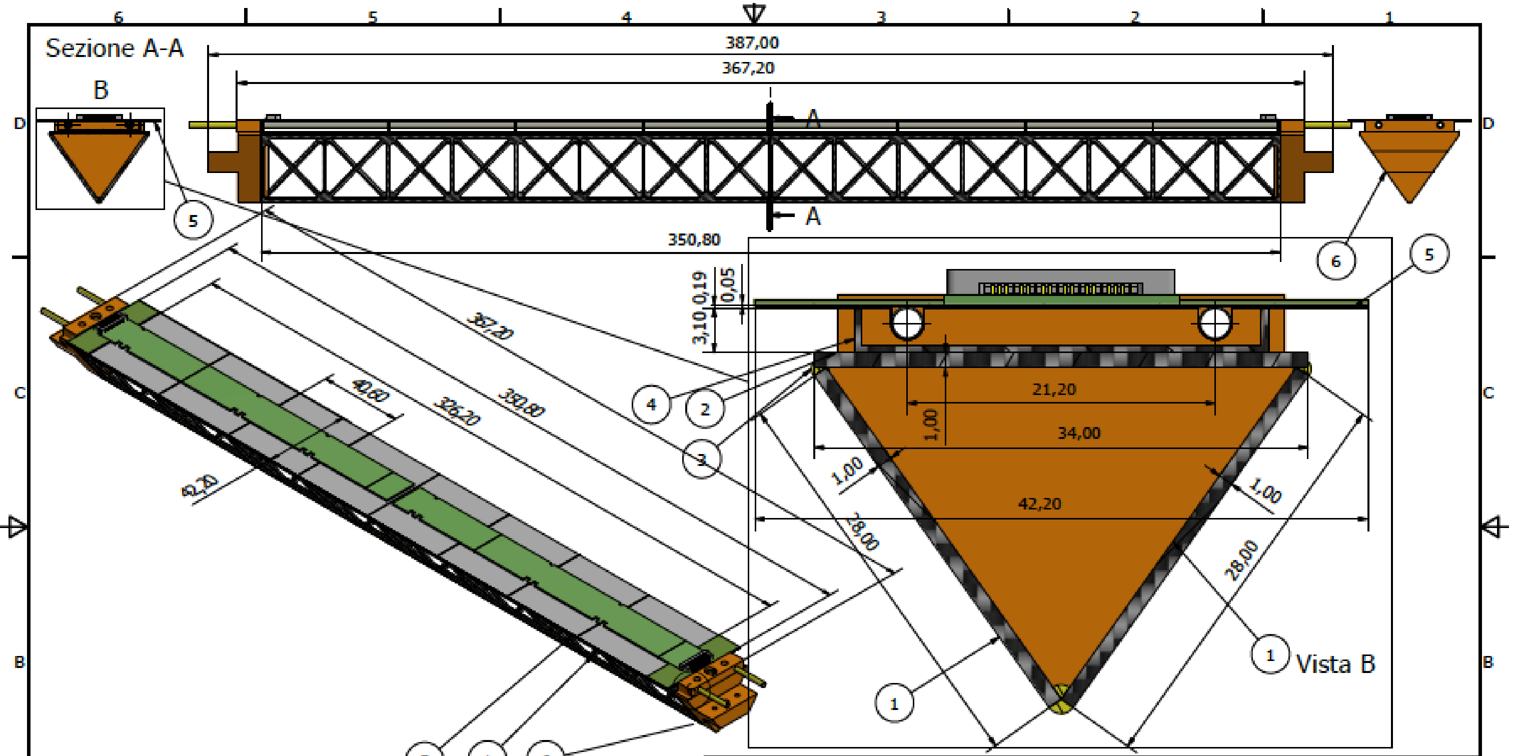


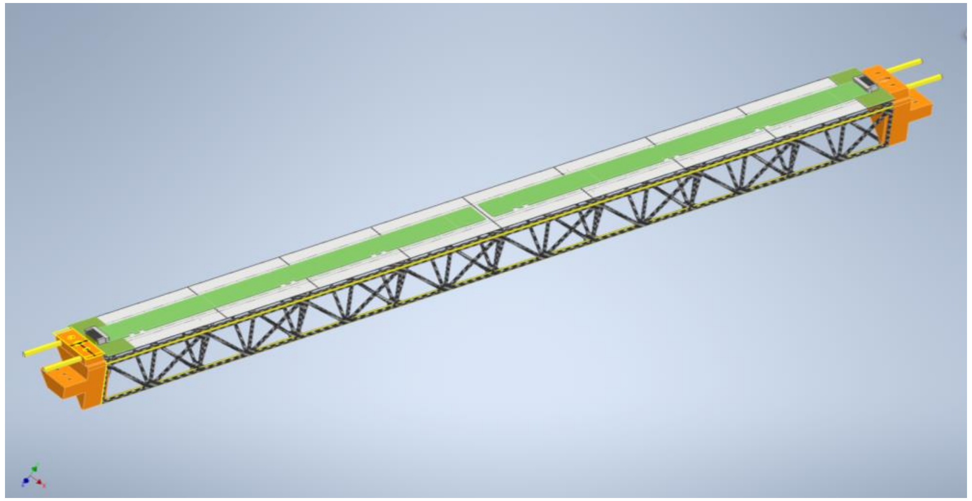
ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
1	2	struttura reticolare laterale 24x350,8 medium tracker	
2	1	struttura reticolare superiore 34x350,8 medium tracker	
3	1	colla struttura 34x350,8	
4	9	supporto a c piano struttura triangolare pixel medium tracker	
5	1	Assieme cold plate con detector e fanout completo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

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

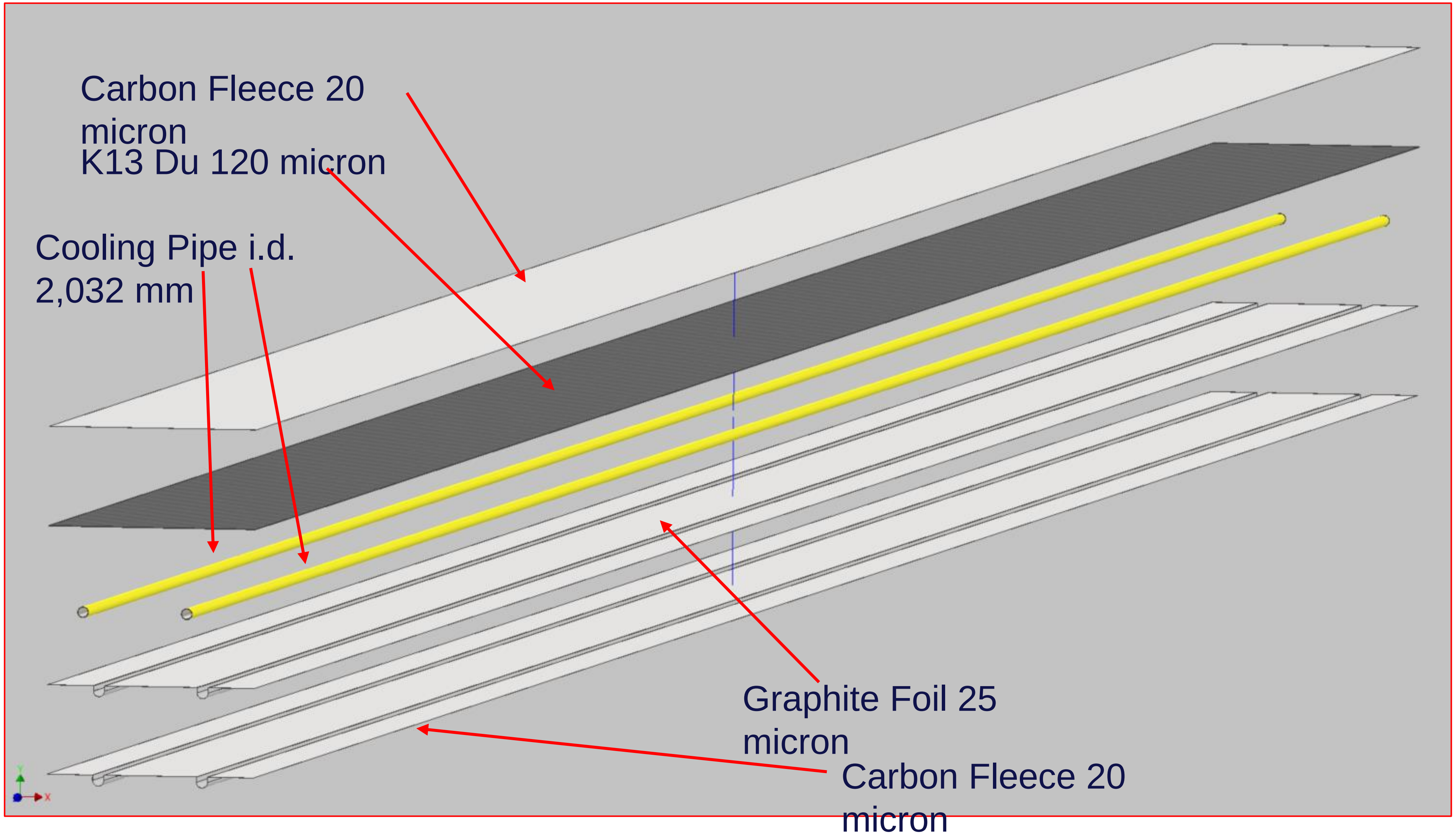
Istituto Nazionale di Fisica Nucleare-Sezione di Pisa

Assieme completo stave medium tracker

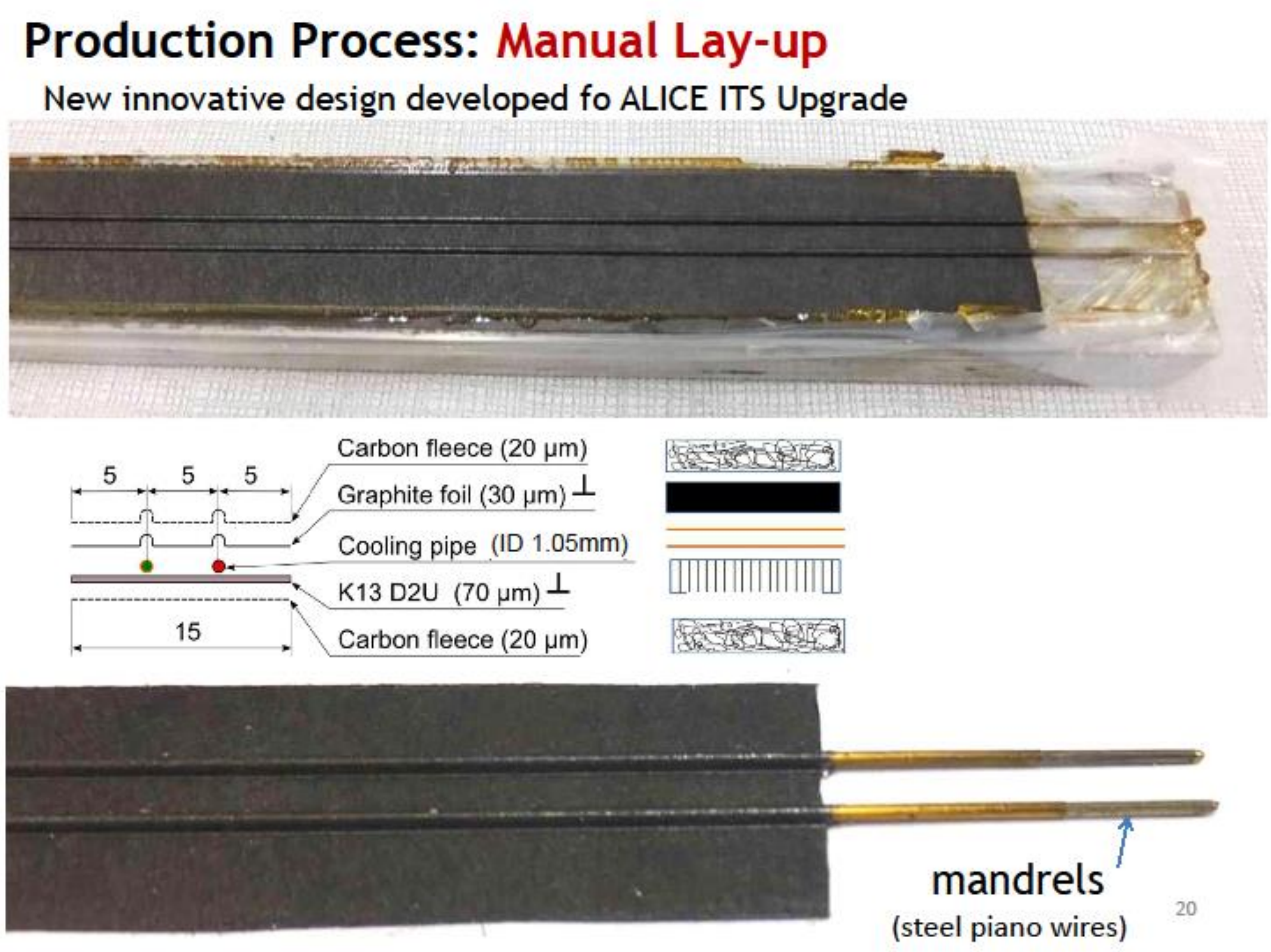
IDEA-Medium Tracker | Edizione | Foglio 1 / 1



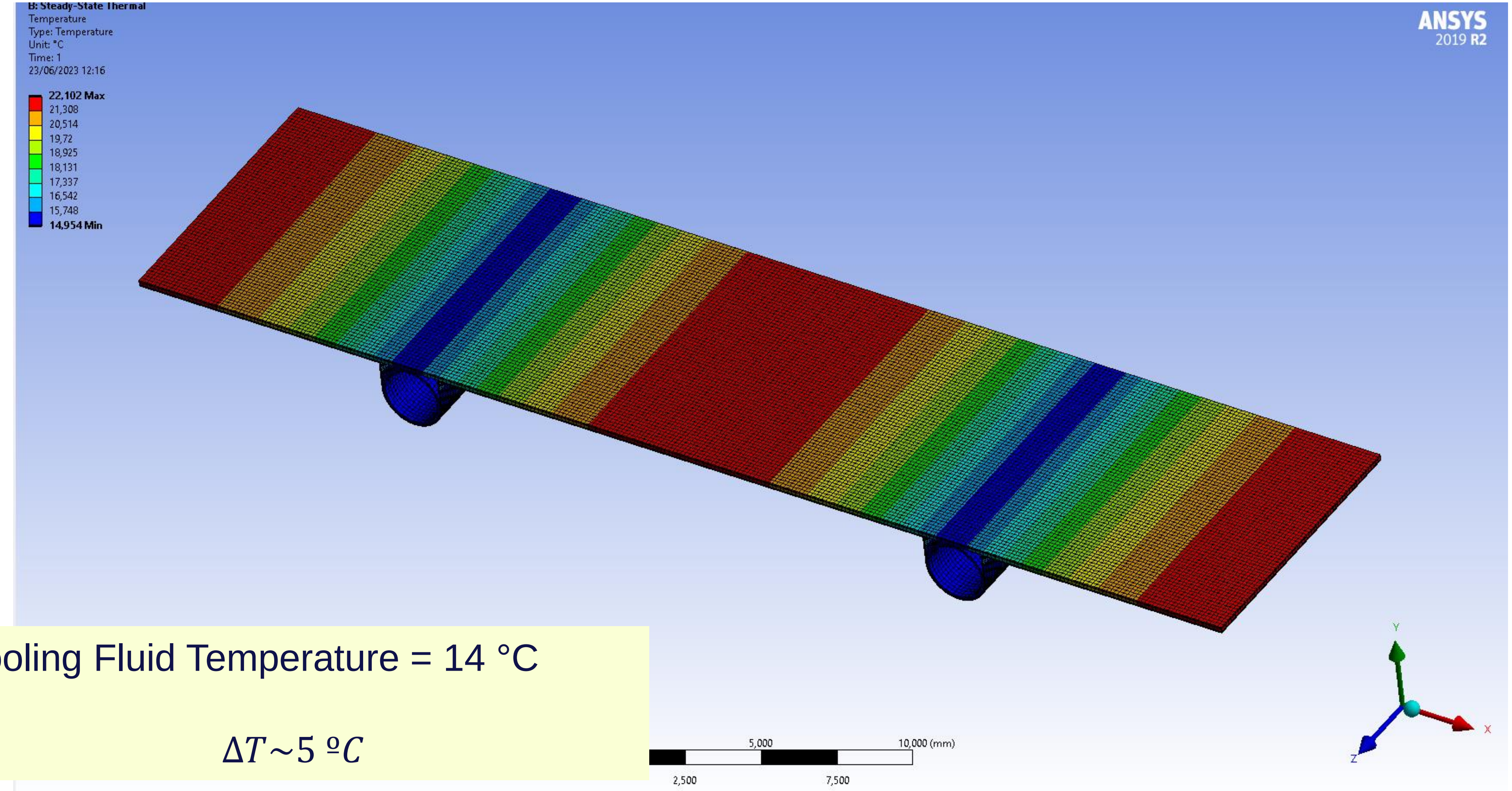
Detail of the cold plate



SINGLE STRUCTURE COLD PLATE



PROTOTYPE REALIZED BY ALICE



Cooling Fluid Temperature = 14 °C

$\Delta T \sim 5\ ºC$

Prototypes built for Belle II upgrade in Pisa

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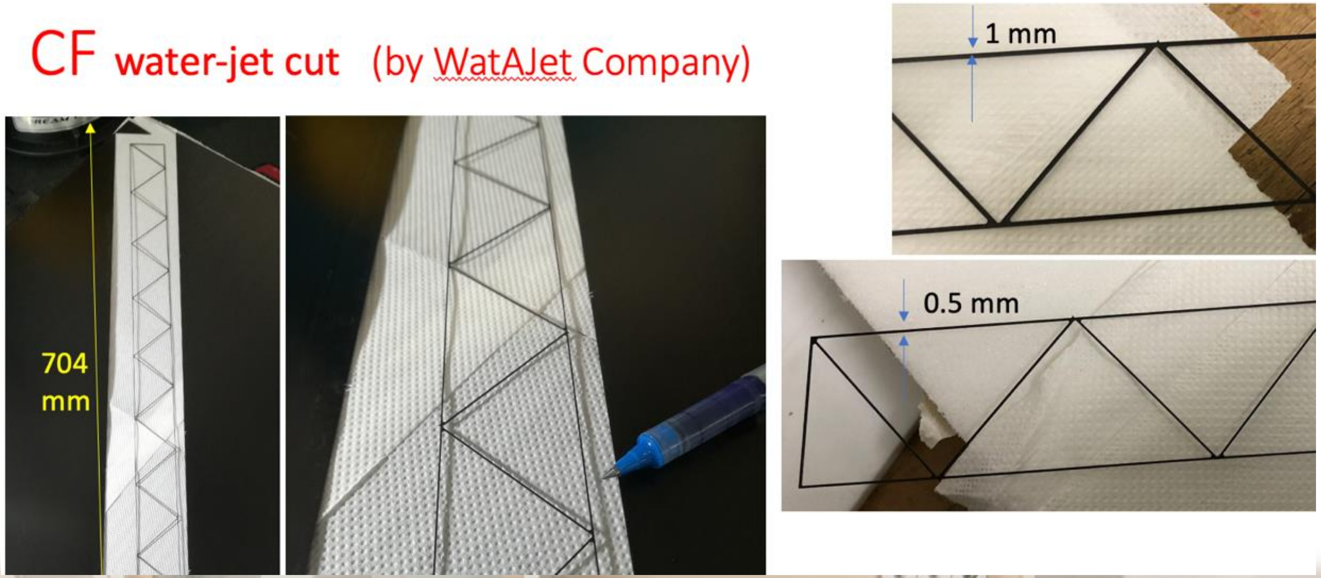

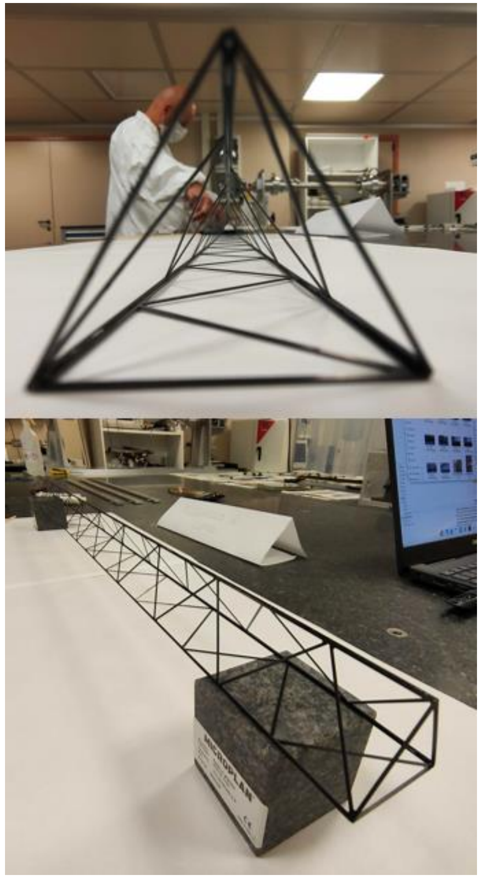

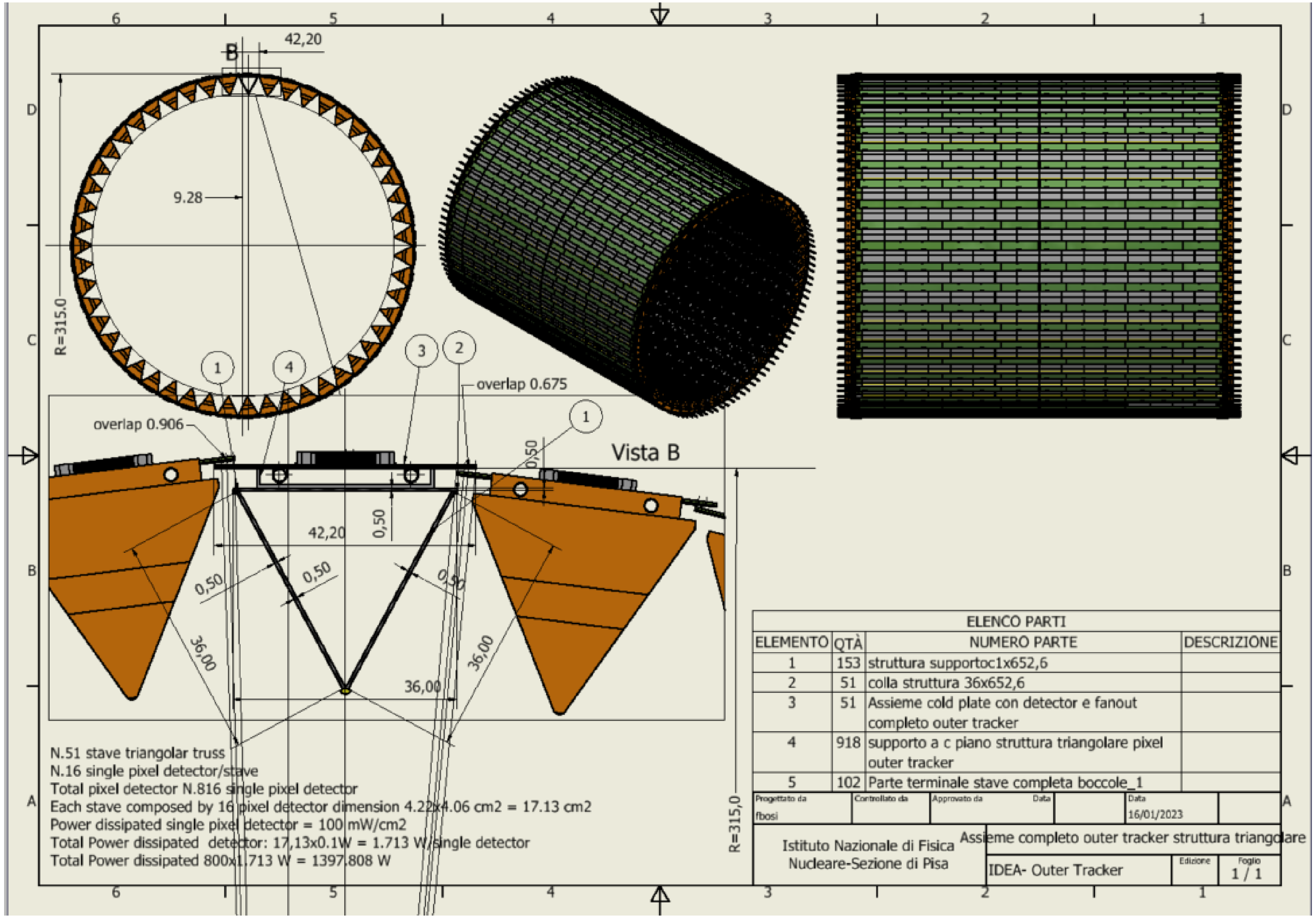

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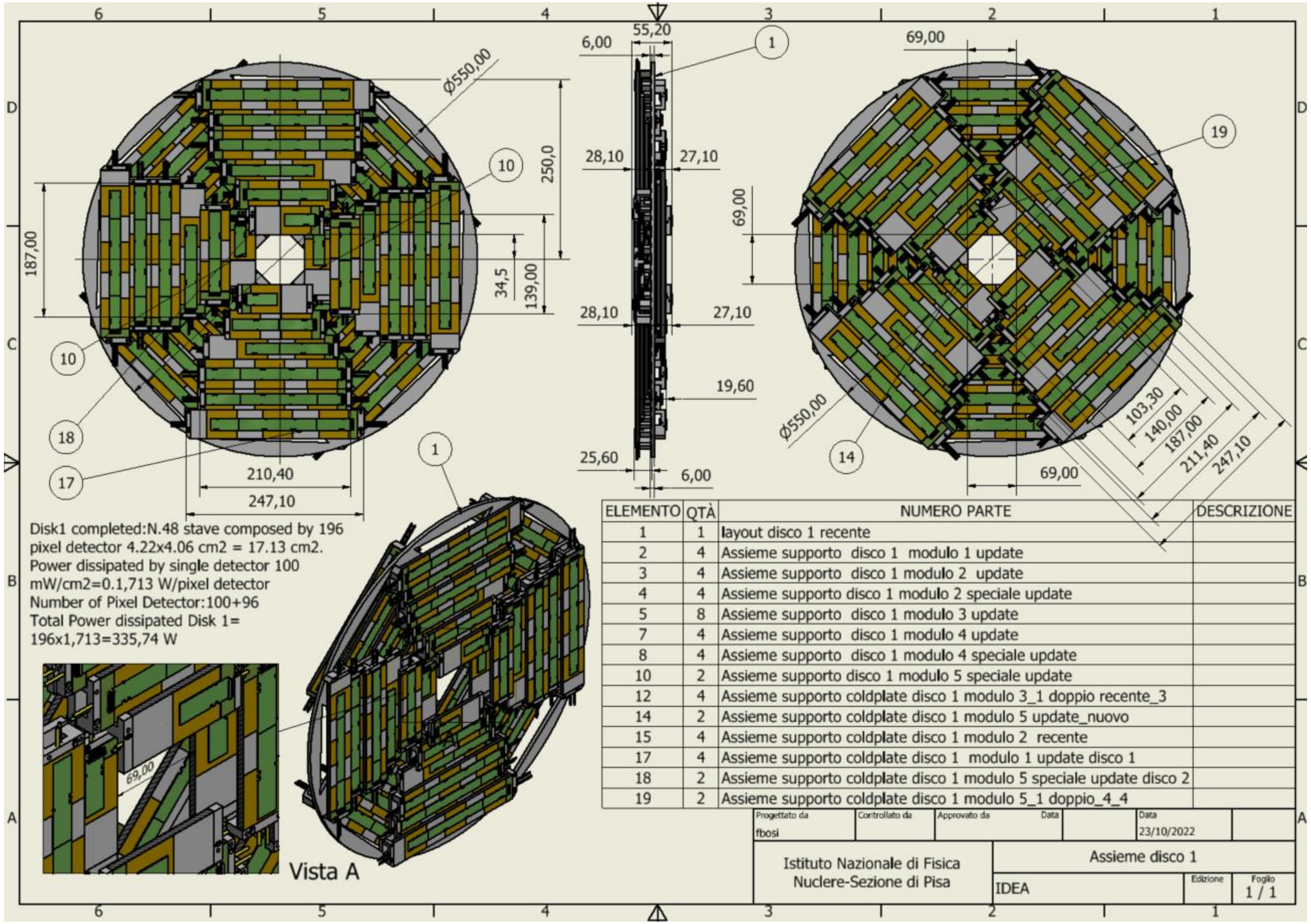
Outer Vertex Tracker Barrel
At 31.5 cm radius

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.

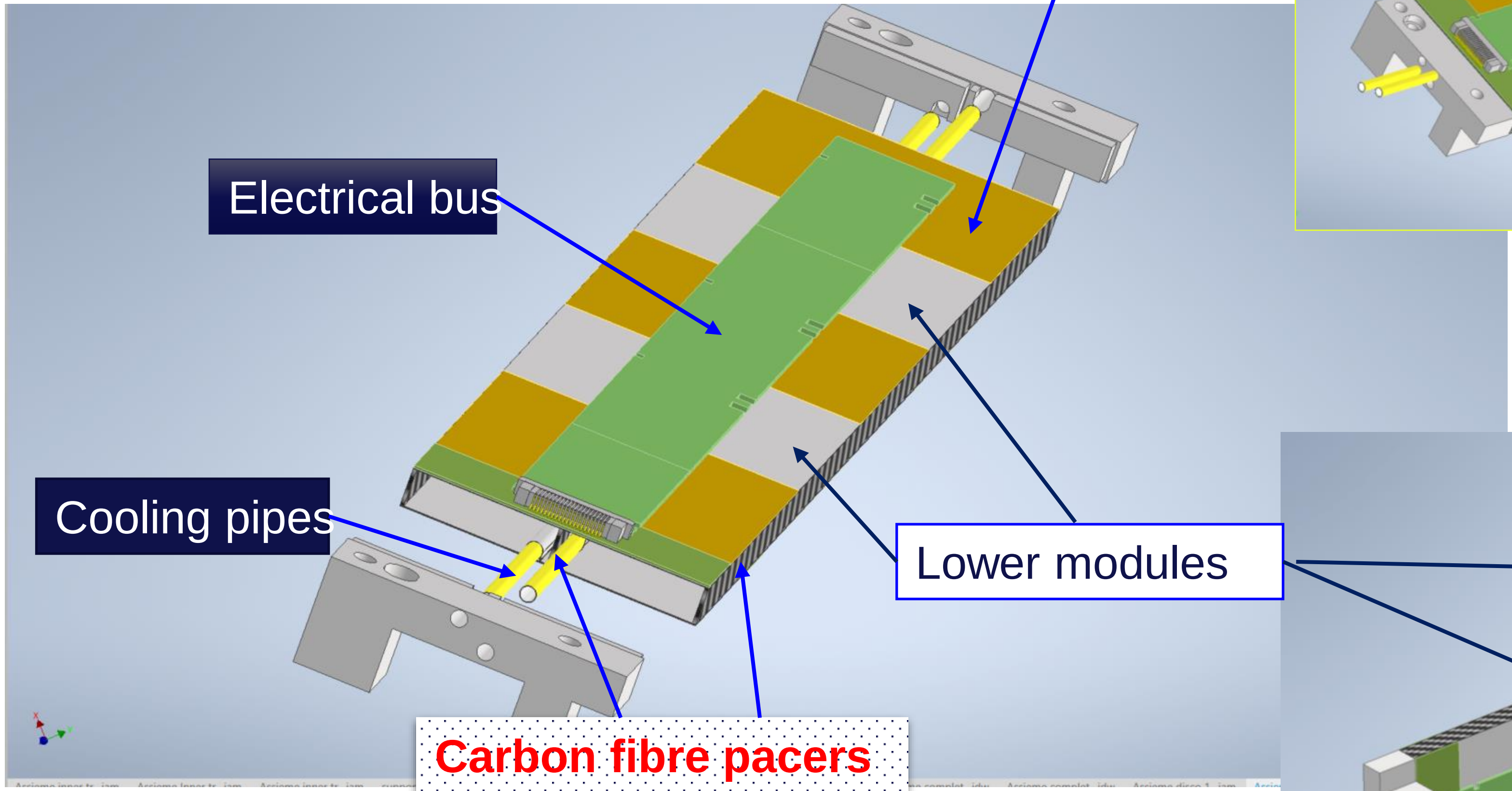
One petal is made of different staves of overlapping modules

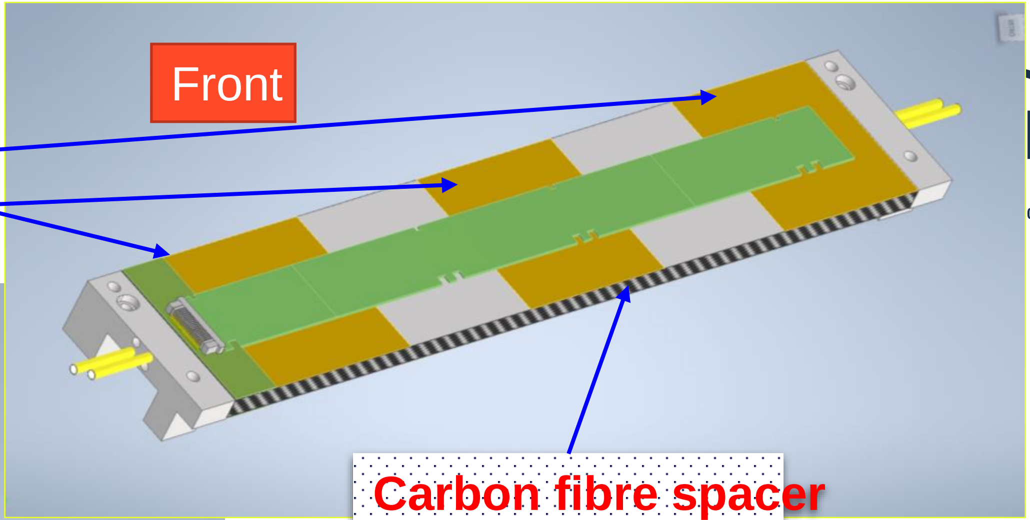
Total modules per disk: 196
Total weight ~850 grams
Power budget ~ 336 W

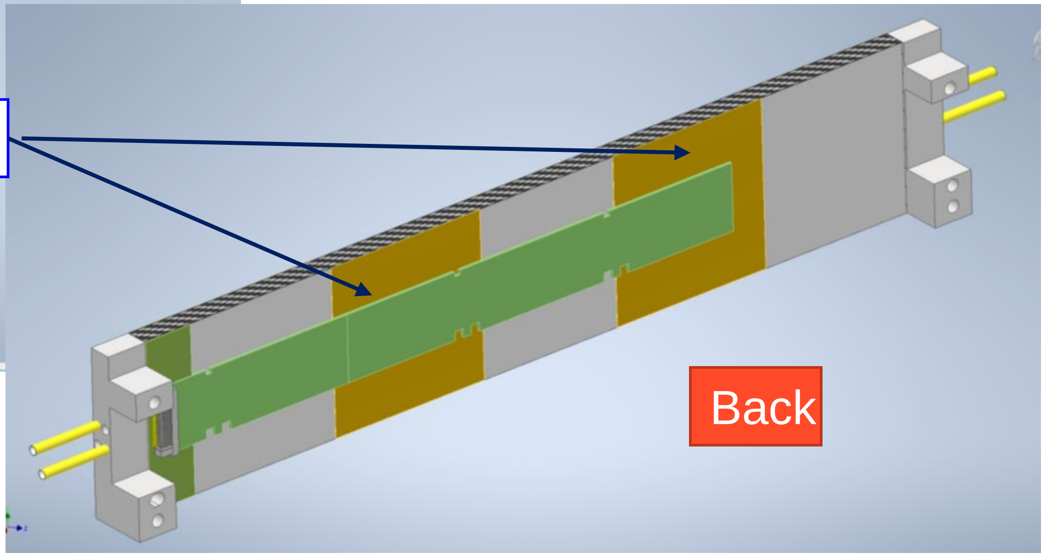
Cooling using 1 water pipe (2 mm diameter)

Similar geometry for the other two disks

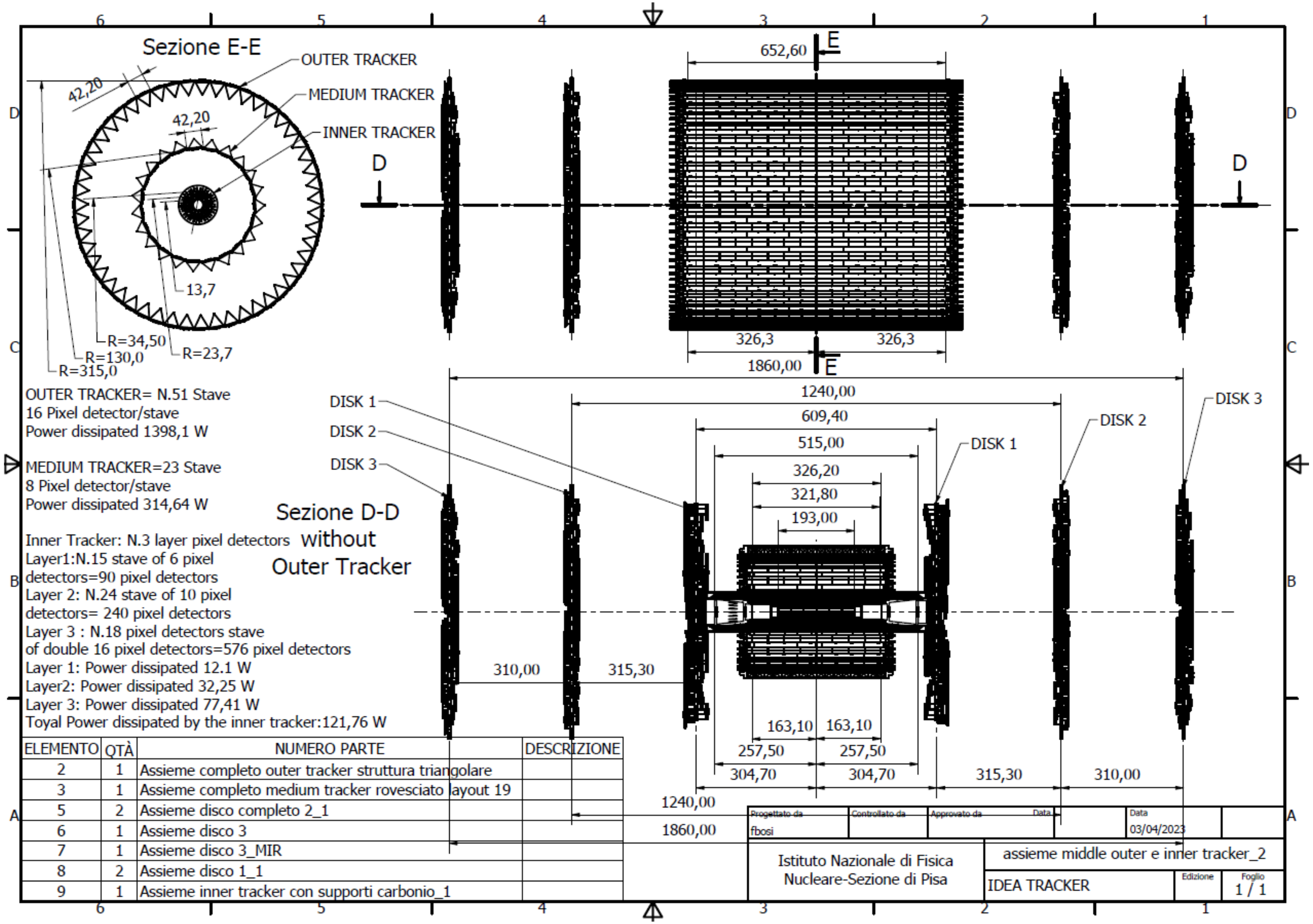
Typical disk module stave







Overall layout and dimensions



ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
2	1	Assieme completo outer tracker struttura triangolare	
3	1	Assieme completo medium tracker rovesciato layout 19	
5	2	Assieme disco completo 2_1	
6	1	Assieme disco 3	
7	1	Assieme disco 3_MIR	
8	2	Assieme disco 1_1	
9	1	Assieme inner tracker con supporti carbonio_1	

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Material budget estimate

- Detailed table with materials from the CAD drawings
- Material smeared over the surface of the ladder

	COMPONENT	QUANTITY	STAVE QUANTITY	VOLUME from CAD mm3	TOTAL STAVE VOLUME mm3	DENSITY g/cm3	SINGLE STAVE WEIGHT g	TOTAL WEIGHT g	SURFACE TO SPREAD THE VOLUME cm2	THICKNESS EQUIVALENT cm	MATERIAL RADIATION LENGHT	EQUIVALENT RADIATION LENGTH
Layer 1	BUS KAPTON	4	15	34,668	138,672	1,42	0,197	2,954	15,826	0,00876229	28,41	0,031
	BUS ALUMINUM	4	15	8,667	34,668	2,7	0,094	1,404	15,826	0,002190572	8,90	0,025
	COSTOLA CARBON FIBER	2	15	144	288,000	1,85	0,533	7,992	15,826	0,018197902	26,00	0,070
	COSTOLA ROHACELL	1	15	720,425	720,425	0,071	0,051	0,767	15,826	0,04552161	563,00	0,008
	LAMINA APPOGGIO CARBON FIBER	1	15	169,84	169,840	1,85	0,314	4,713	15,826	0,010731707	26,00	0,041
	DETECTORS	6	15	13,44	80,640	2,33	0,188	2,818	15,826	0,005095413	9,70	0,053
	GLUE	1	15	113,484	113,484	1,12	0,127	1,907	15,826	0,007170732	33,50	0,021
	TOTAL SINGLE STAVE LAYER 1						1,504					0,249
	TOTAL LAYER 1		12					17,832				

Material budget estimate from CAD

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- Detailed table with materials from the CAD drawings
- Material smeared over the surface of the ladder

- **Inner vertex 0.25% radiation length per ladder**:
  - Due to ~40% overlap between two staves, the average material budget per layer increases to 0.35%
- **Outer vertex**
  - 0.71 % middle
  - 0.58% outer

➢ Needs inputs from Physics if middle vertex at 13 cm is needed for low momentum tracks or not

Simulated material budget

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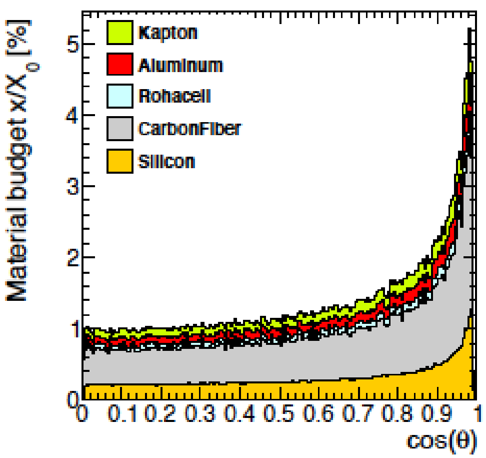
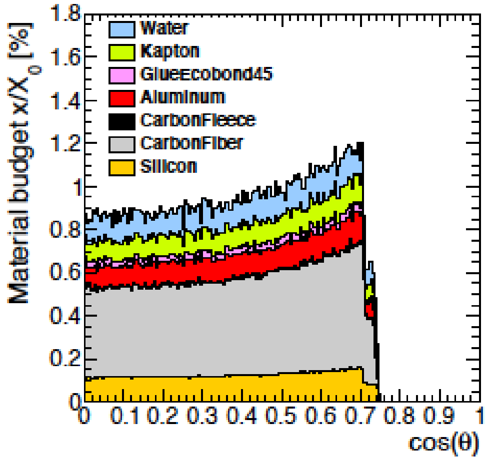
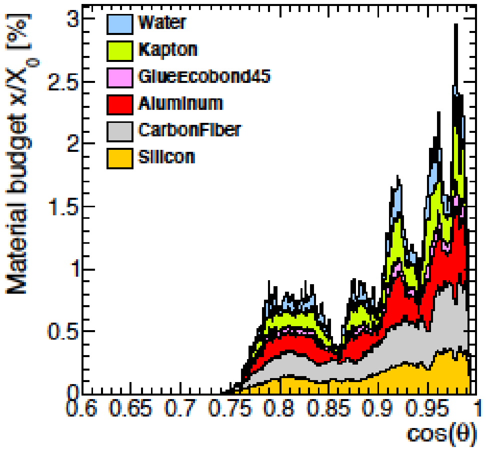


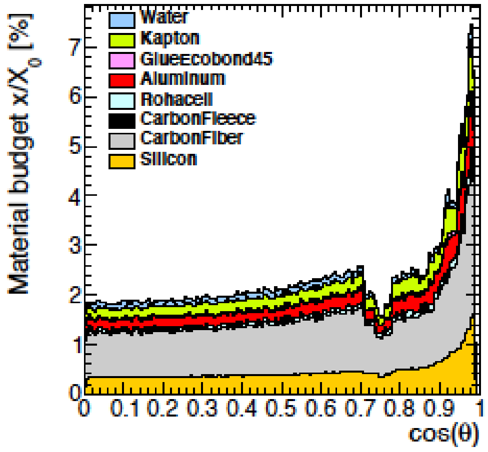
(a) Vertex inner barrel



(b) Vertex outer barrel



(c) Vertex disks



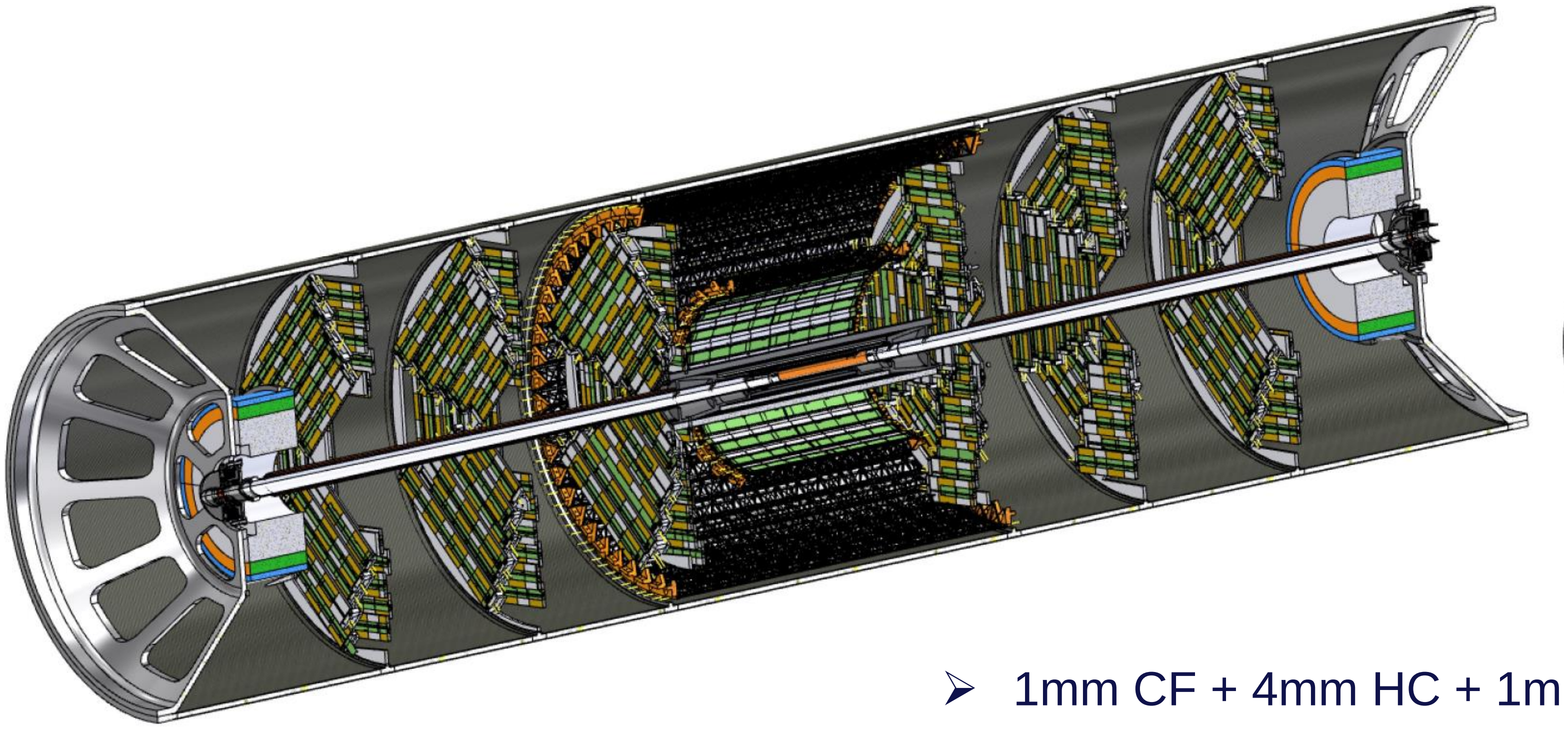
(d) Whole vertex detector

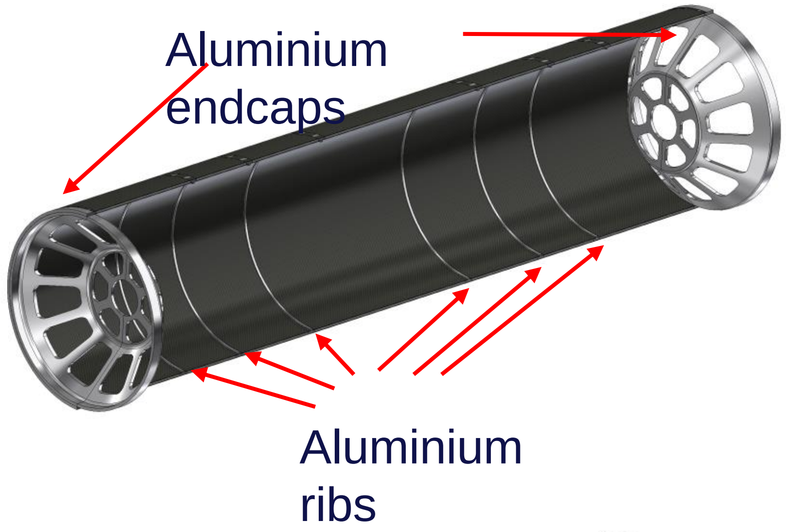
See talk from A. Ilg

Support cylinder

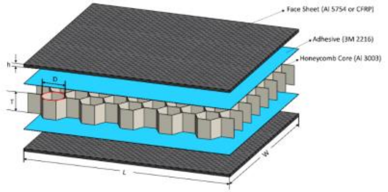
All elements in the interaction region (Vertex and LumiCal) are mounted rigidly on a support cylinder that guarantees mechanical stability and alignment

- 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)

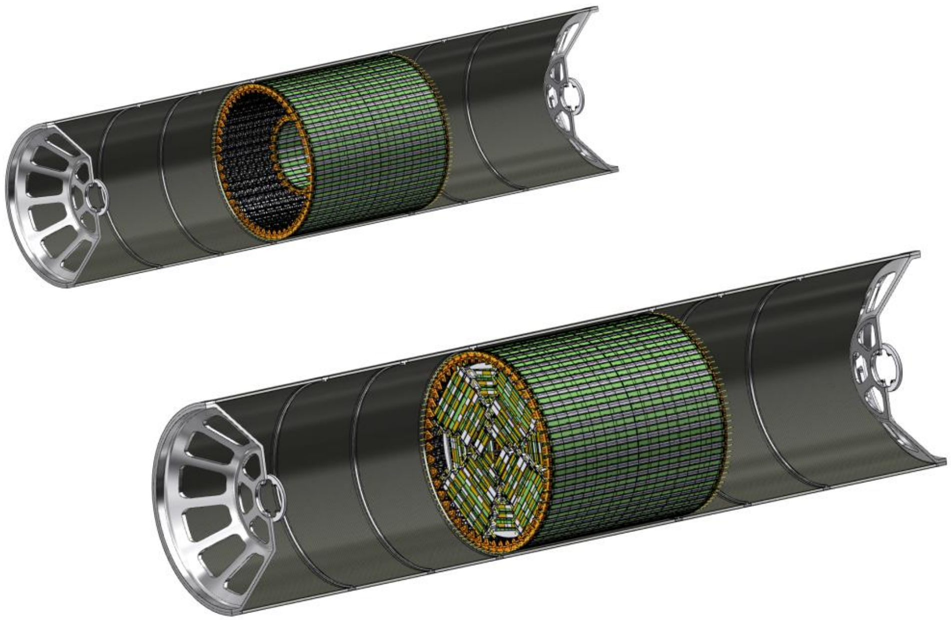


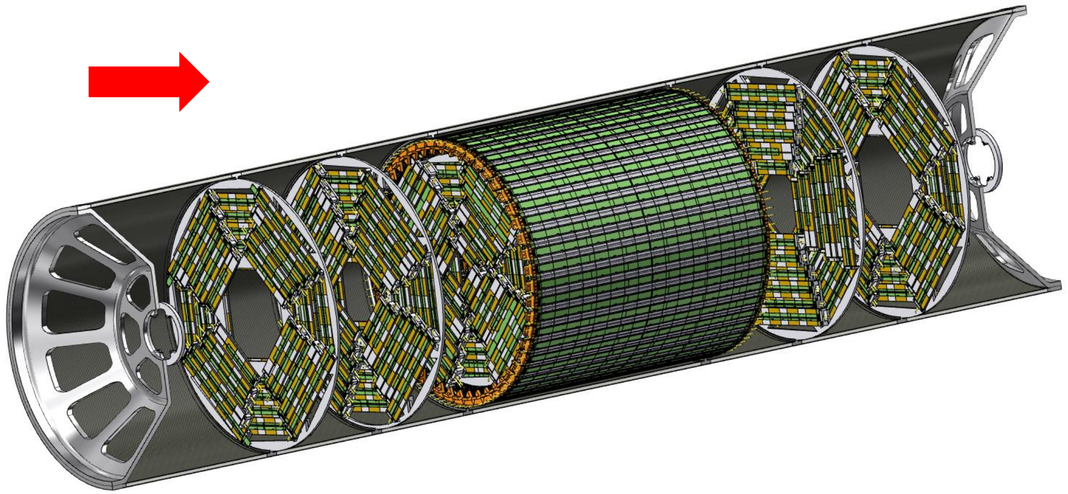


- 1mm CF + 4mm HC + 1mm CF



Assembly procedure – I

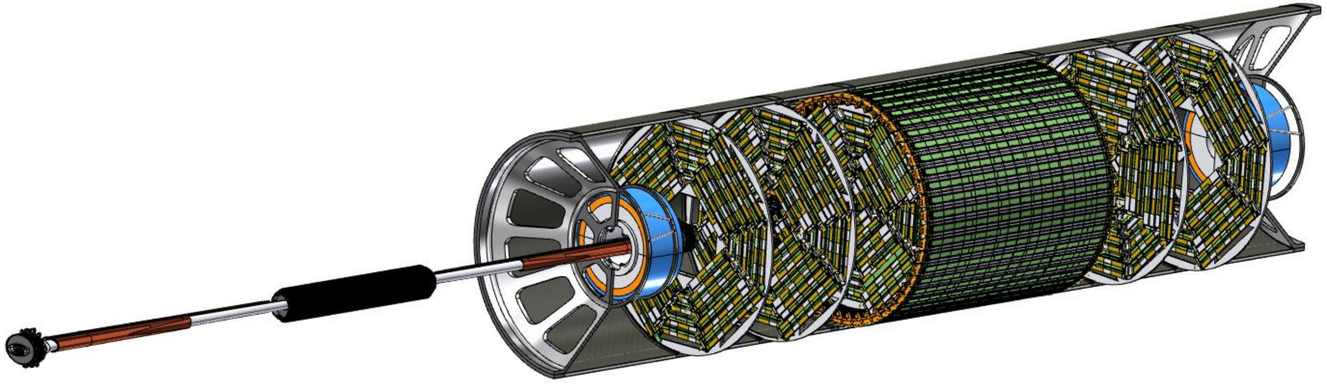


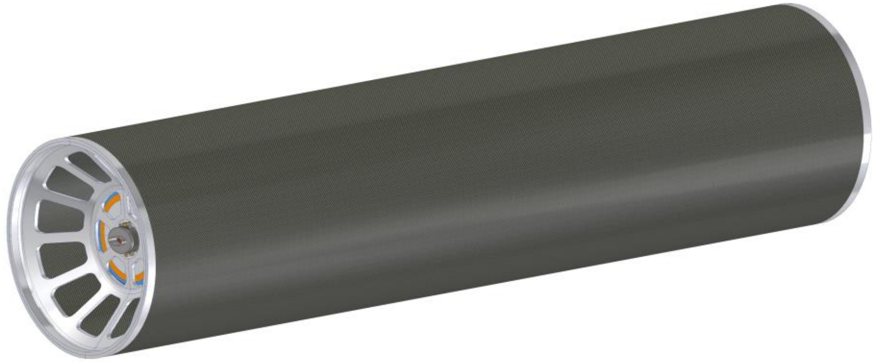


1) Outer vertx tracker, middle vertex tracker and disks 1 are installed as a rigid structure inside the support tube

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

Assembly procedure – II

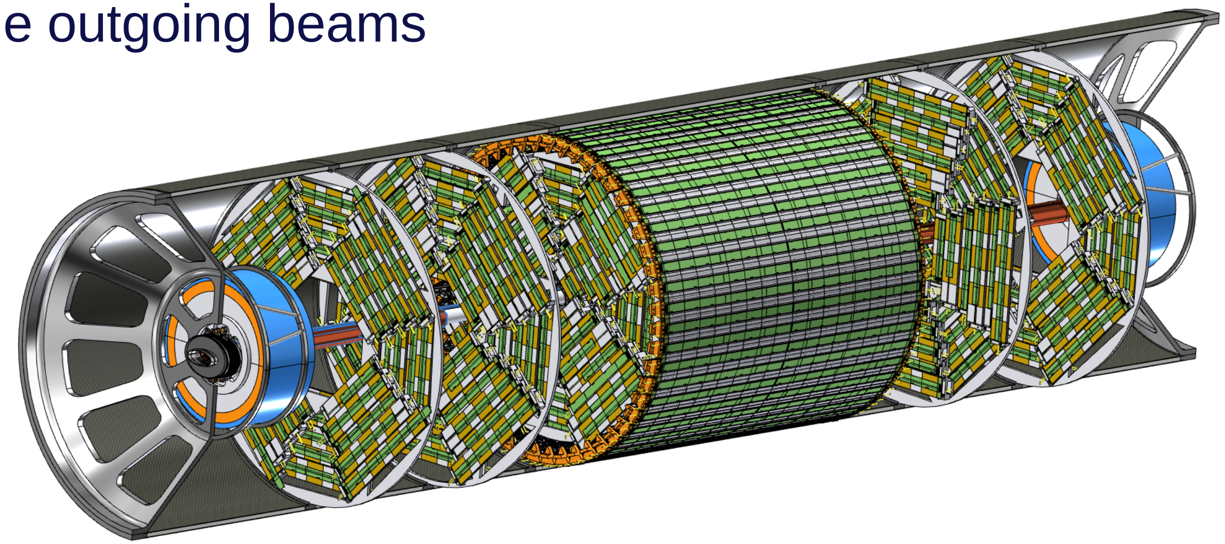




3) LumiCal is installed in centered position, then beam pipe with inner vertex detector is inserted with a dedicated tool inside disks and outer vertex tracker, then fixed to both endcaps

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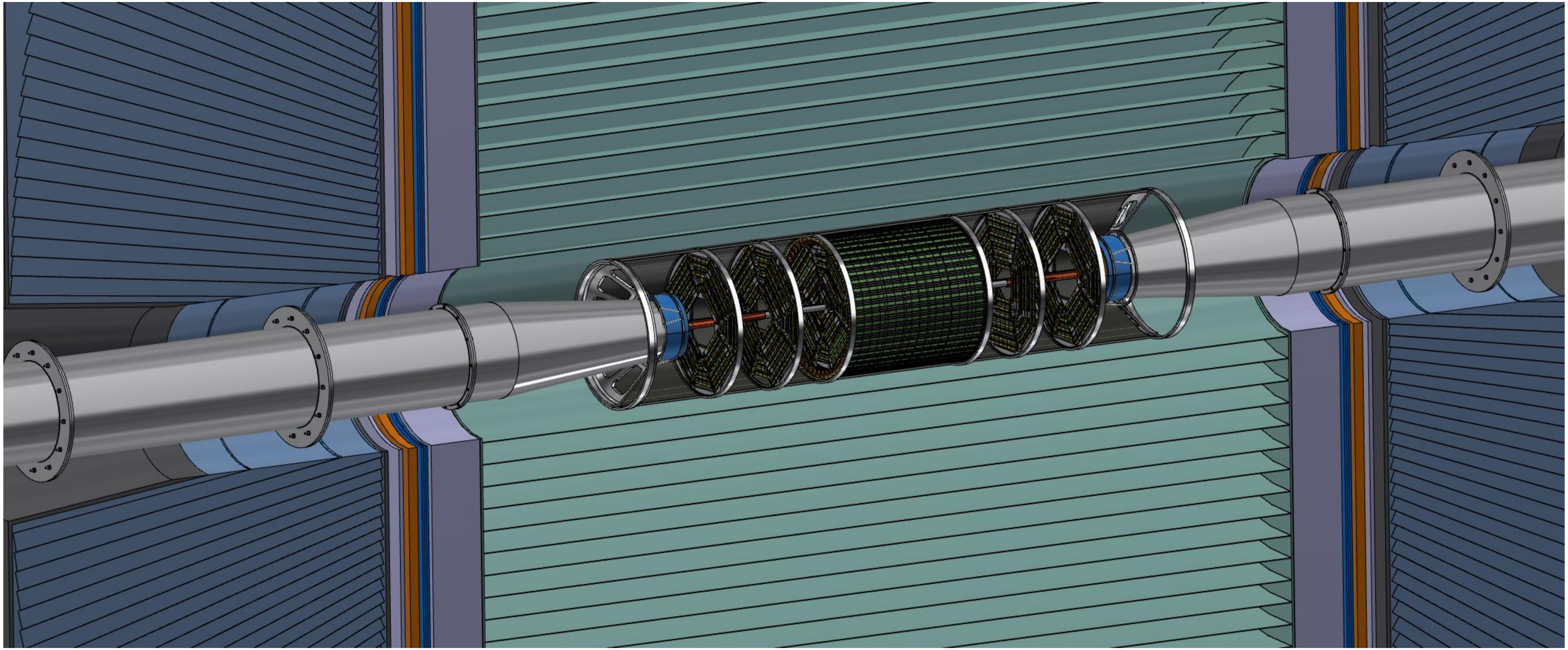
M. Boscolo, F. Palla, F. Fransesini, F. Bosi and S. Lauciani, Mechanical model for the FCC-ee MDI, EPJ Techn Instrum **10**, 16 (2023).
https://doi.org/10.1140/epjti/s40485-023-00103-7



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
  - *MDI Note for mid-term review (Version 1)* https://cernbox.cern.ch/s/FQEHOkF9kTeBsBh

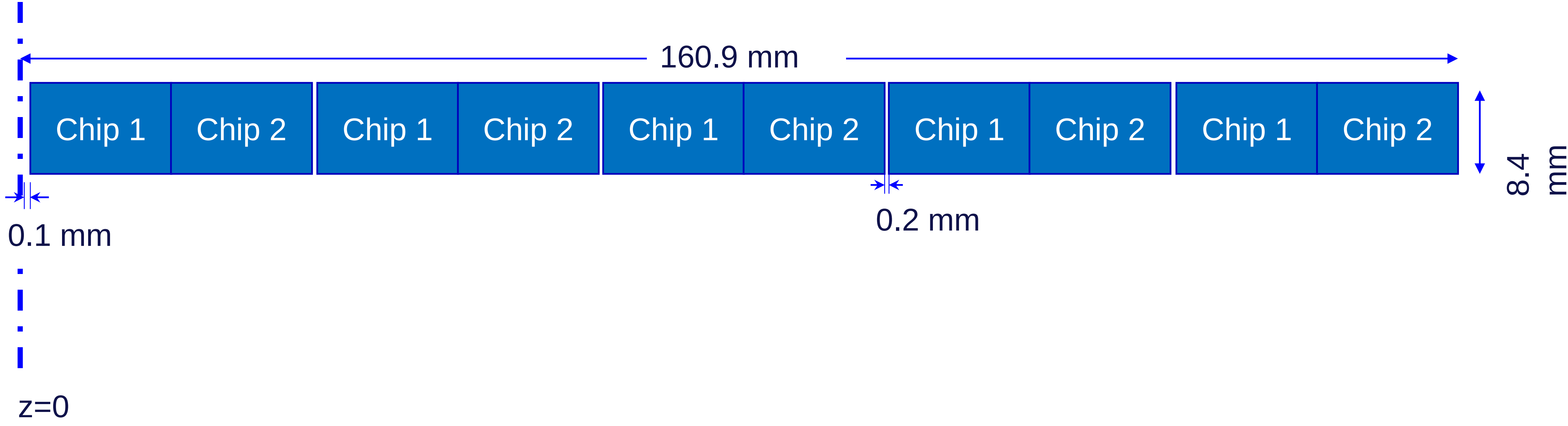
Next/ongoing steps:

- 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 2



Half ladder layout – layer 3

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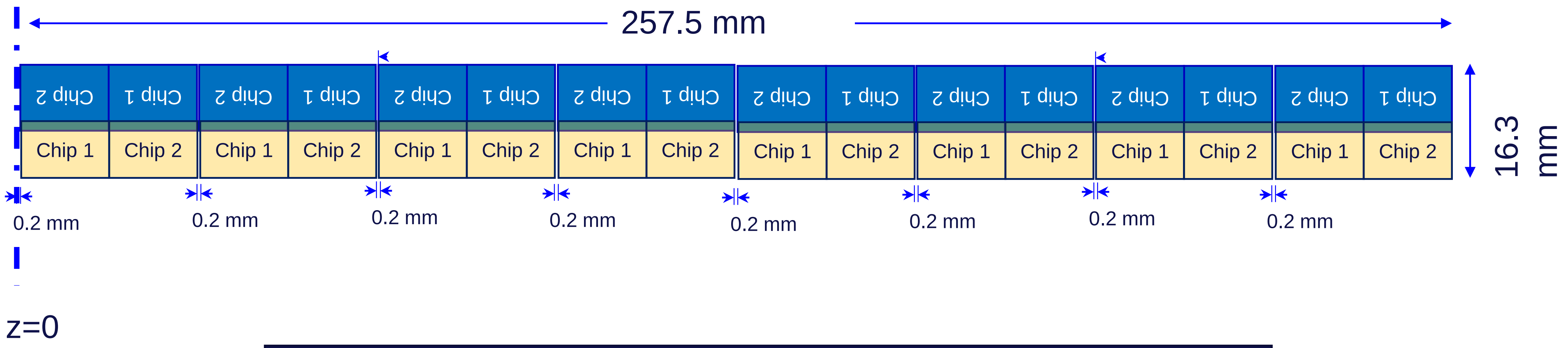

Overlapping in $r-\varphi$:2 parallel ladders separated by 500 µm - see engineering drawings later

Passive parts on the sides

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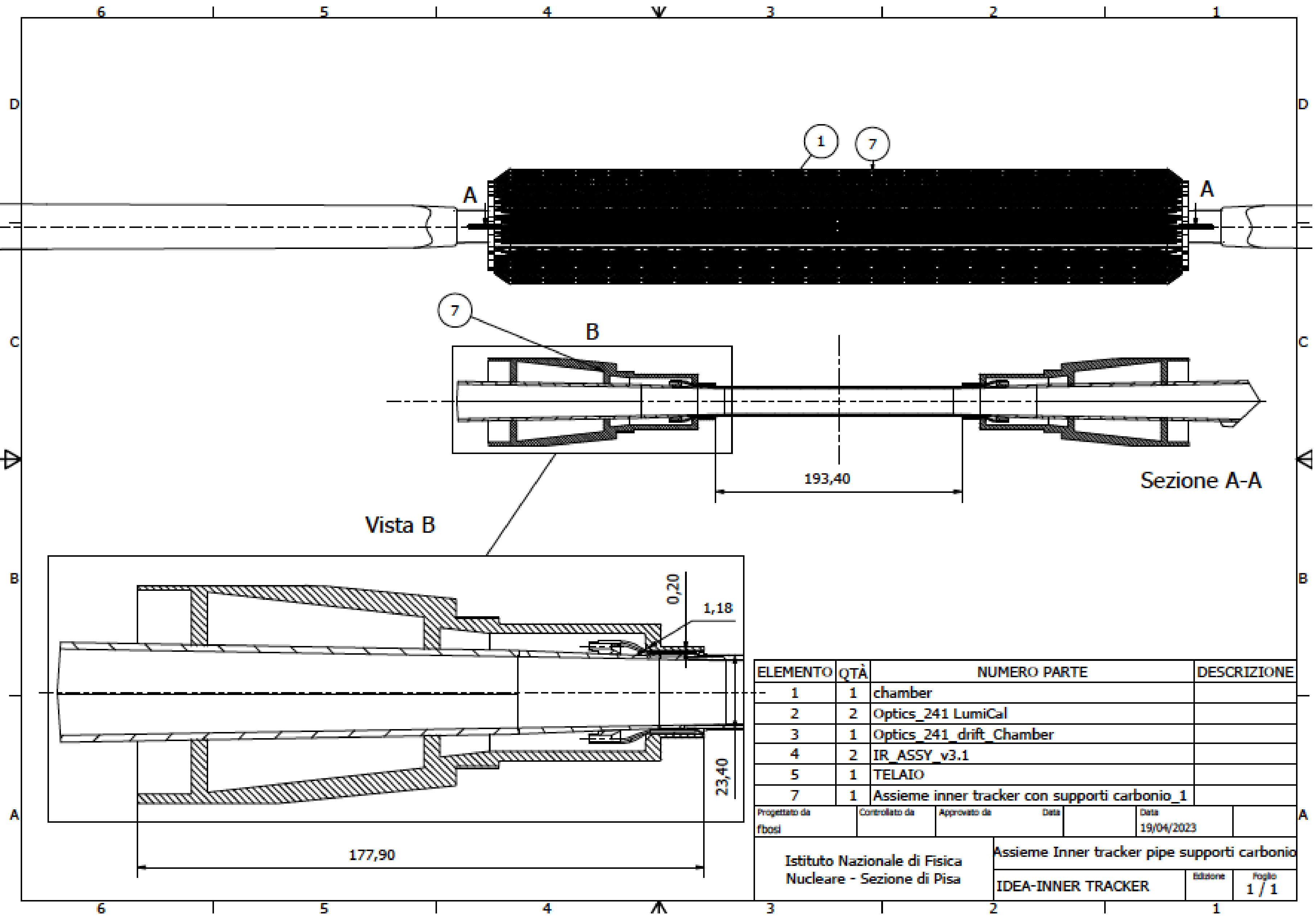

ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
1	1	chamber	
2	2	Optics_241 LumiCal	
3	1	Optics_241_drift_Chamber	
4	2	IR_ASSY_v3.1	
5	1	TELAIO	
7	1	Assieme inner tracker con supporti carbonio_1	

Vertex on the beam-pipe

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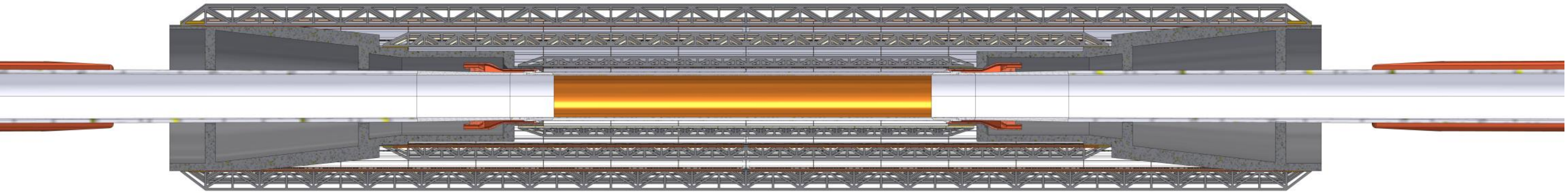

Air cooling for Belle-II upgrade

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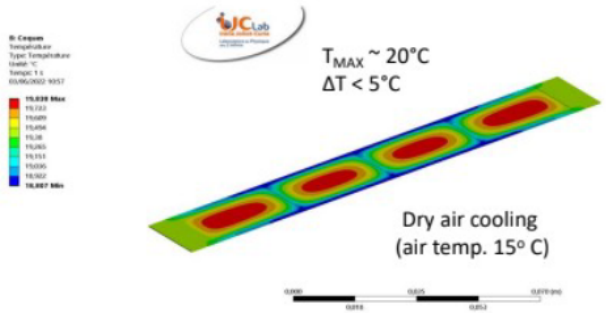
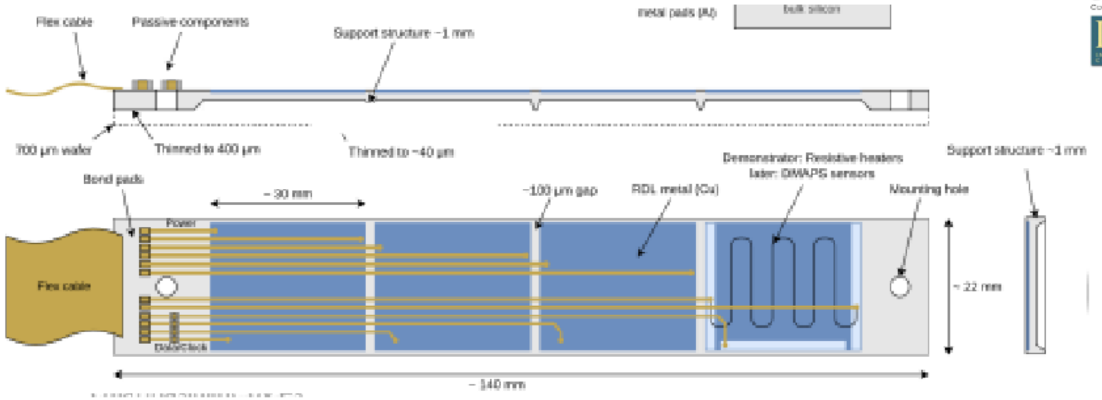
AIDA innova

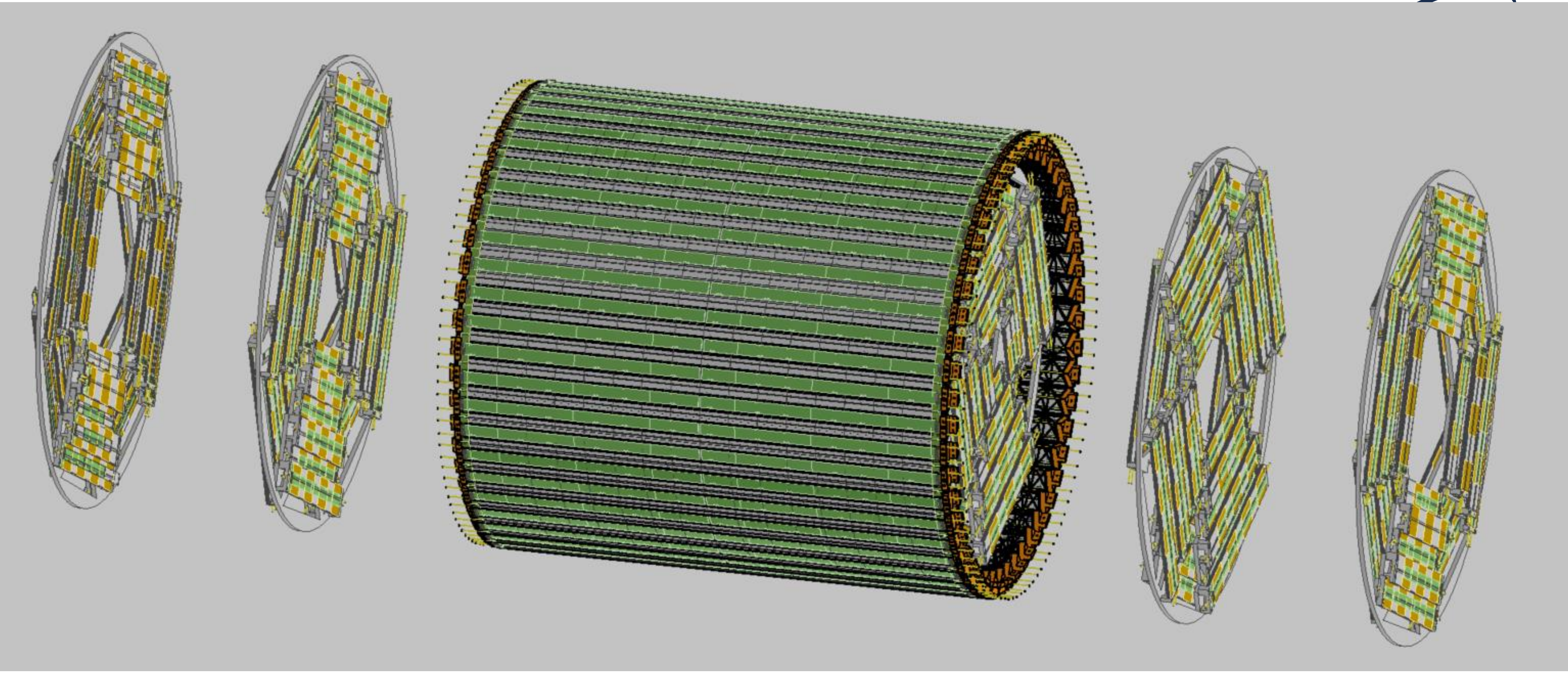
WP10.2
Integrated micro-channels

Thin multi-CMOS-chip Silicon structures for Belle 2 upgrade
Thermo-mechanical demonstrator submitted to IZM by Valencia and Bonn, thermal simulations in IJCLab Paris



CSIC
IFIC cnm





OUTER TRACKER

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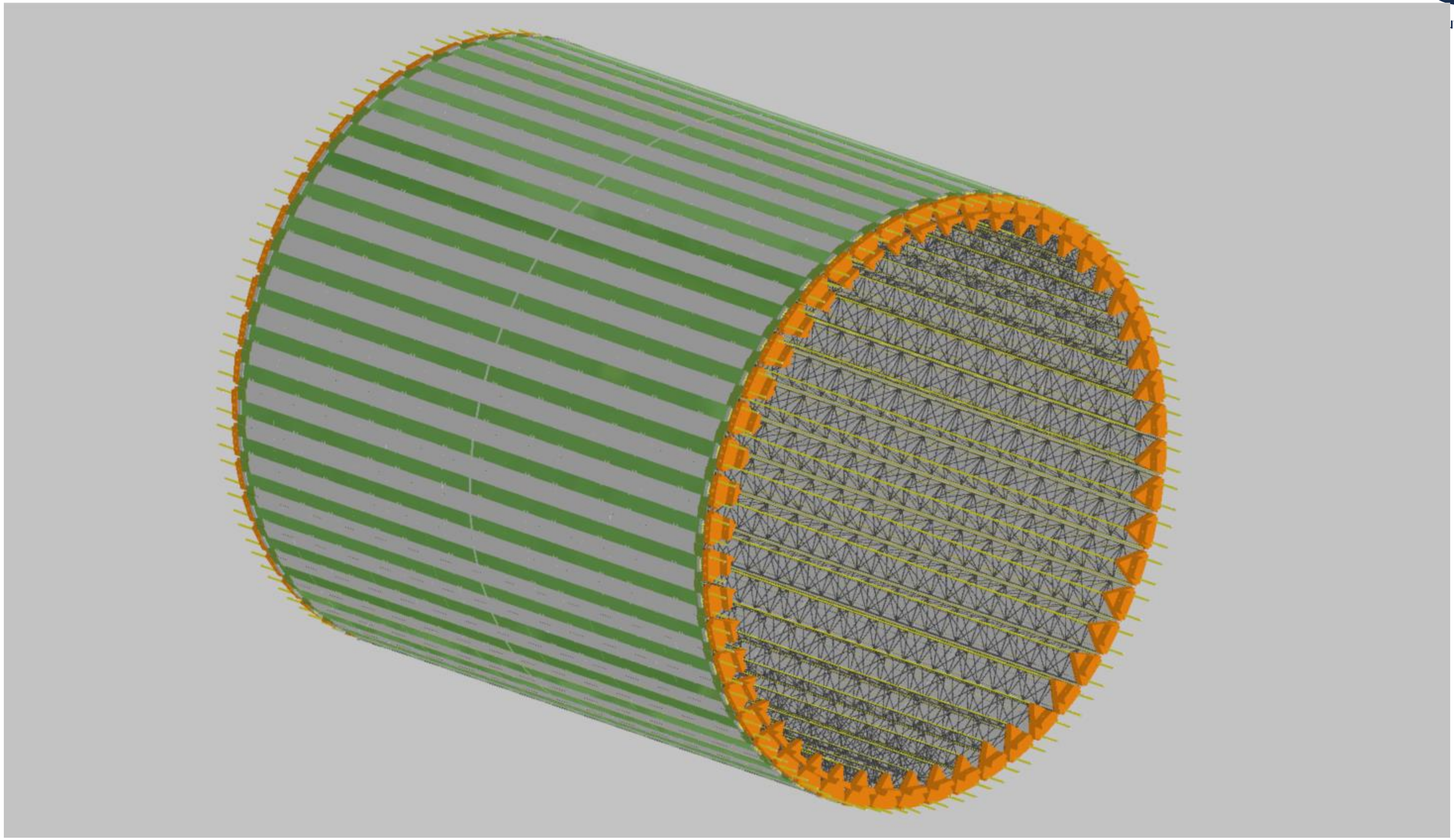
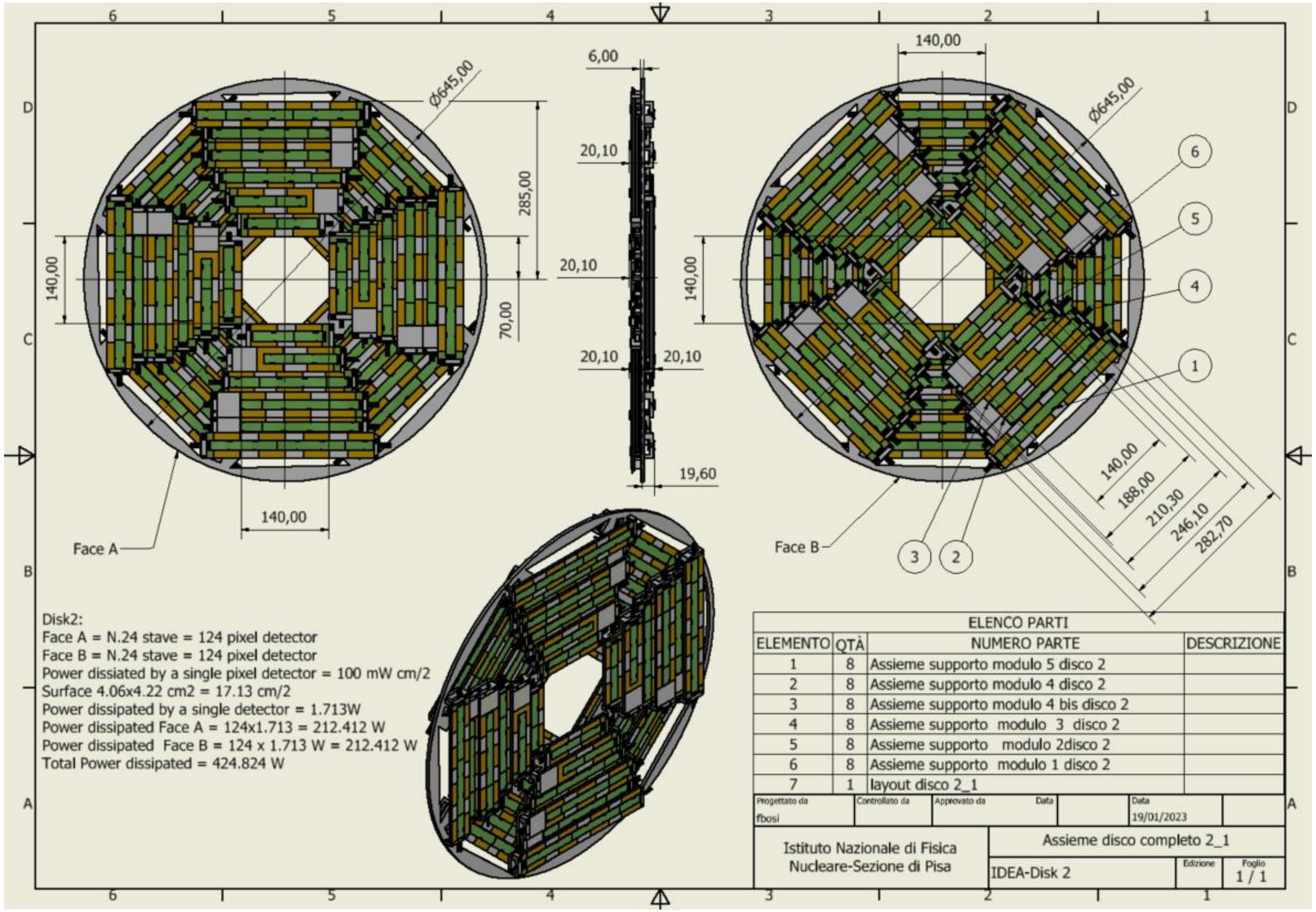


DISK 2



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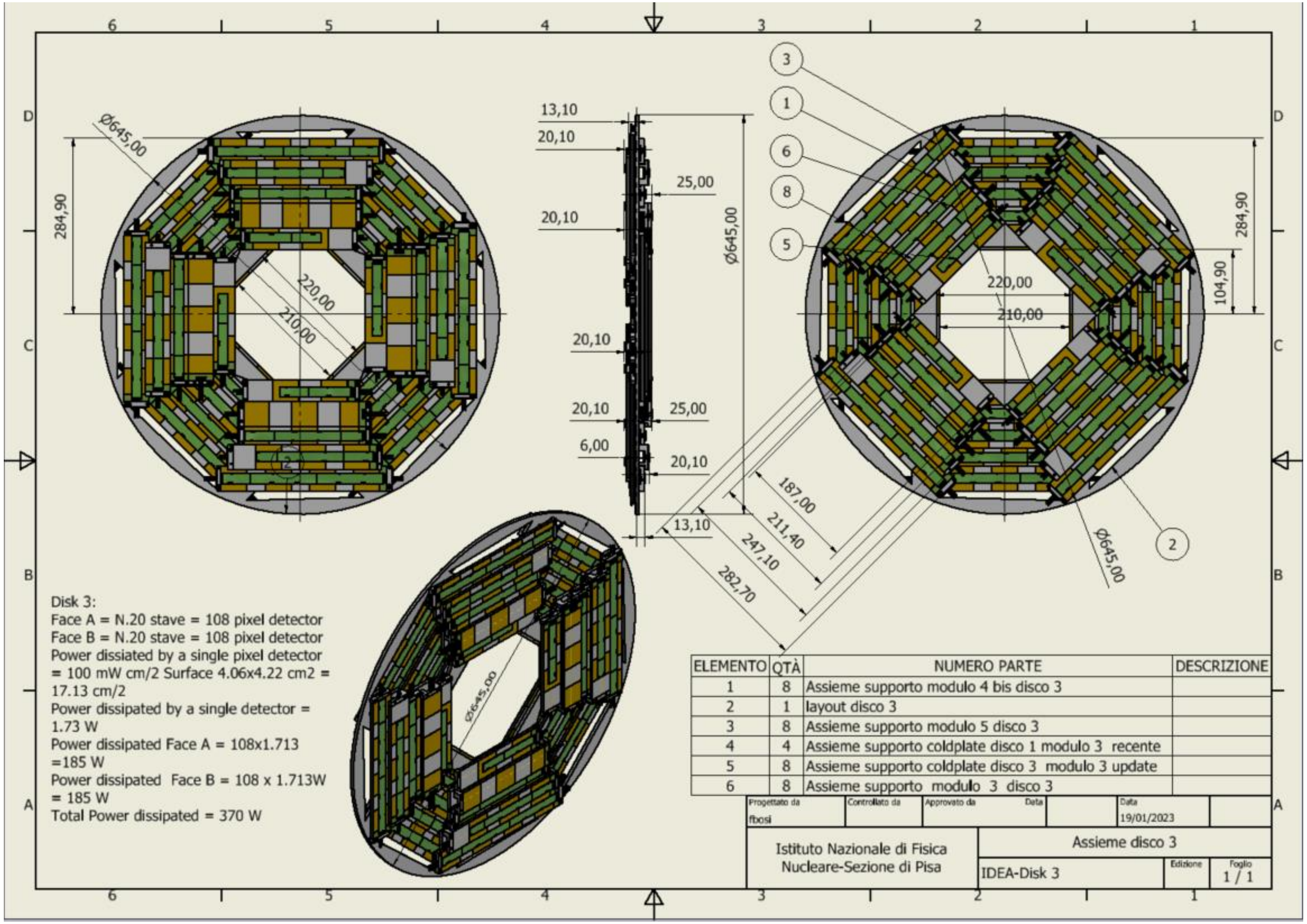
DISK 3



ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
1	8	Assieme supporto modulo 4 bis disco 3	
2	1	layout disco 3	
3	8	Assieme supporto modulo 5 disco 3	
4	4	Assieme supporto coldplate disco 1 modulo 3 recente	
5	8	Assieme supporto coldplate disco 3 modulo 3 update	
6	8	Assieme supporto modulo 3 disco 3	

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