MECHANICAL INTEGRATION OF THE IDEA VERTEX DETECTOR IN THE FCC-EE INTERACTION REGION

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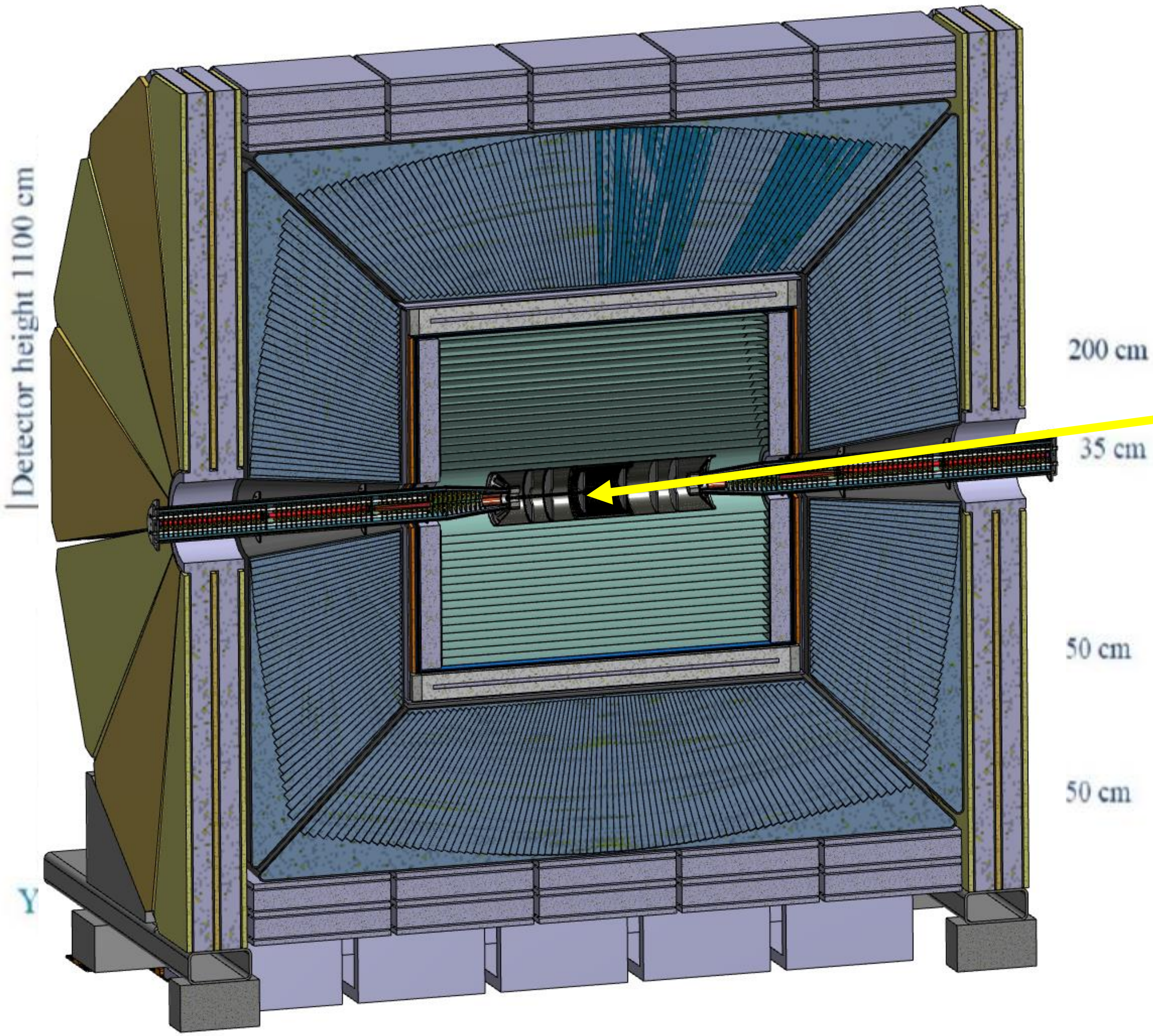
FCC-Week
London, 5-9 June 2023



- 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

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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 and the outer tracker must be done inside the support tube
- Minimize the radiation lengths

Inner and outer vertex trackers

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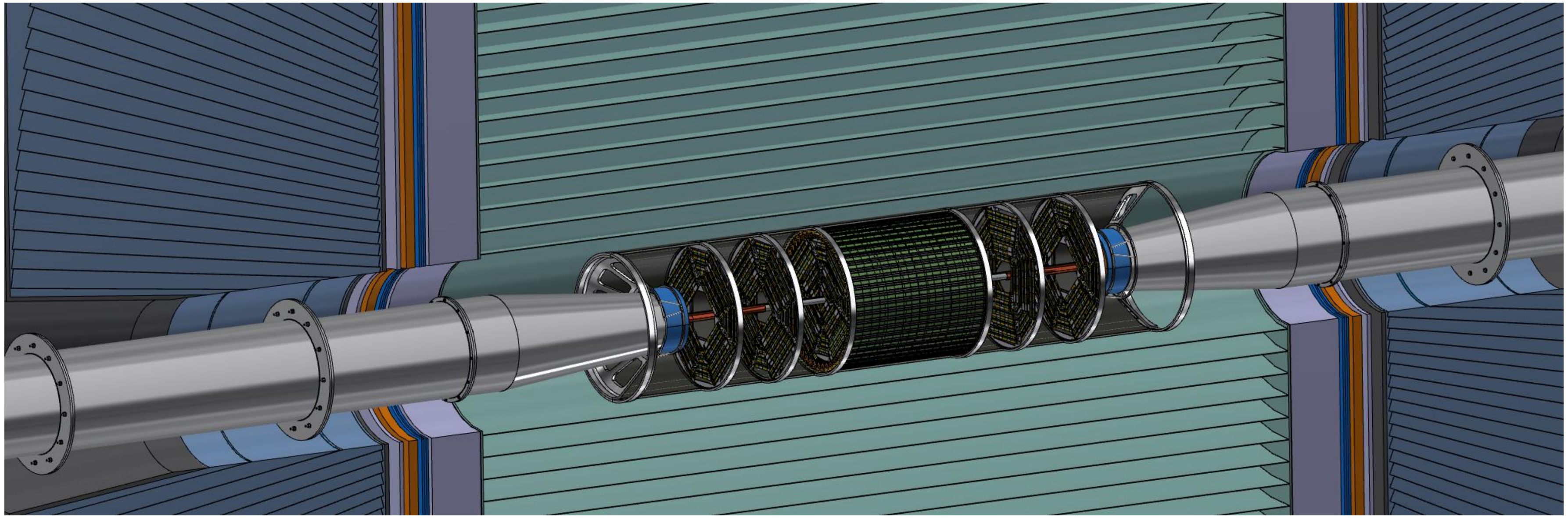
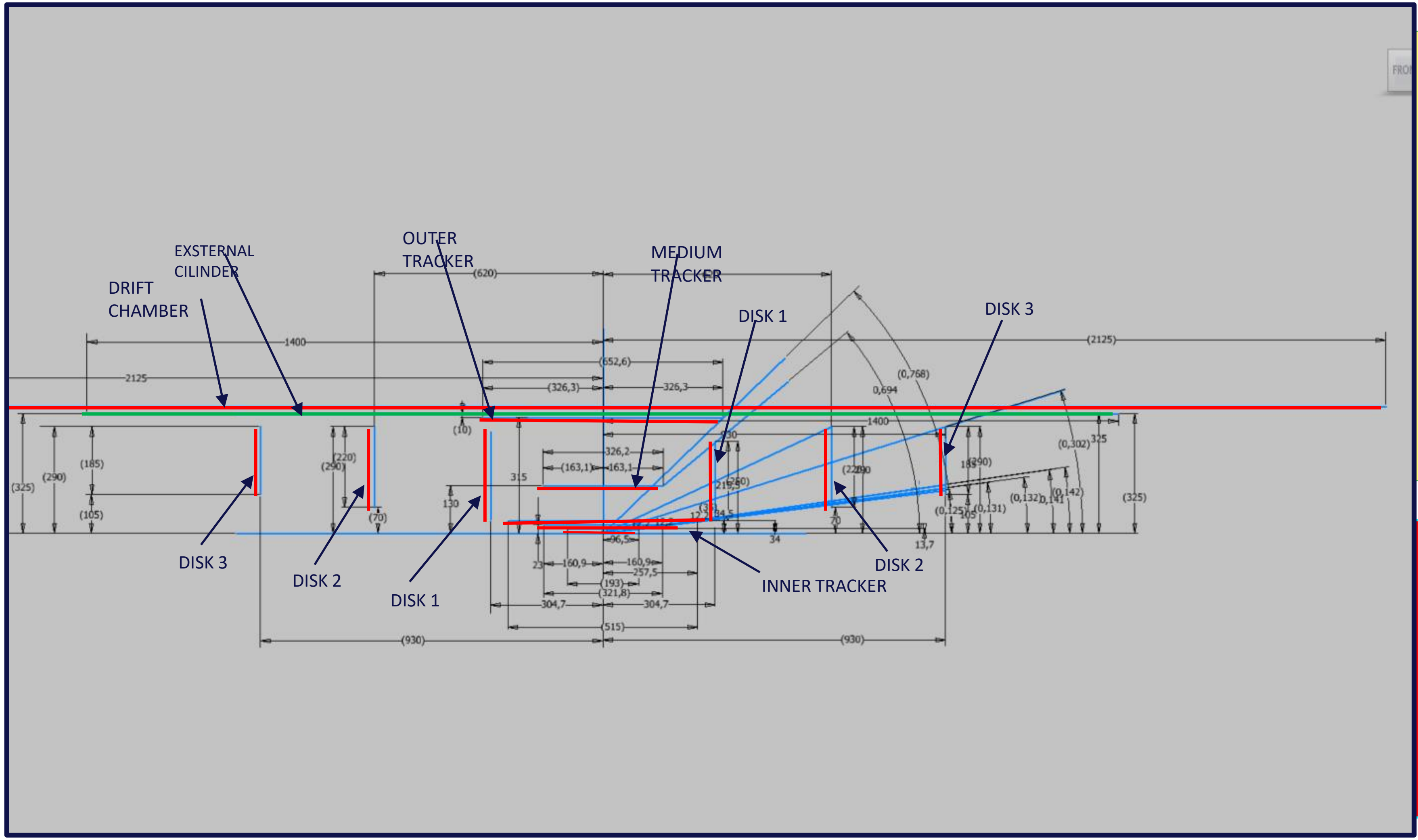


See talk by F. Fransesini for the interaction region layout

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



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

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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.

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

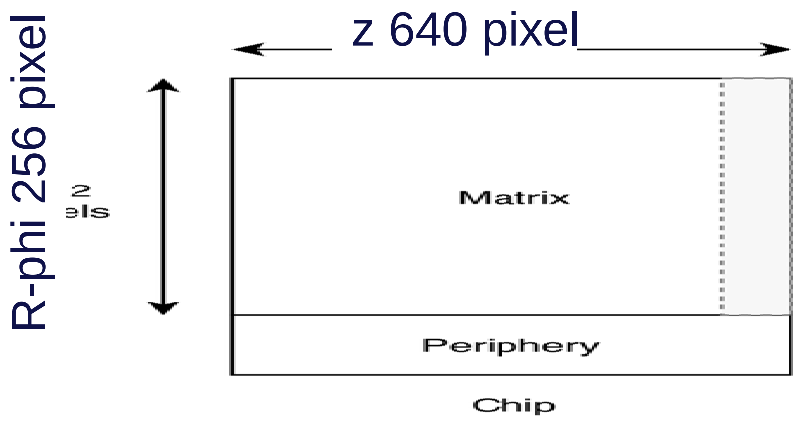
- Active area 640 pixel (16 mm) in z and 256 pixels (6.4 mm) in $r - \varphi$
- Chip periphery plus an inactive zone: total of 2 mm in $r - \varphi$
- Chips are side-abuttable in z (to be demonstrated)

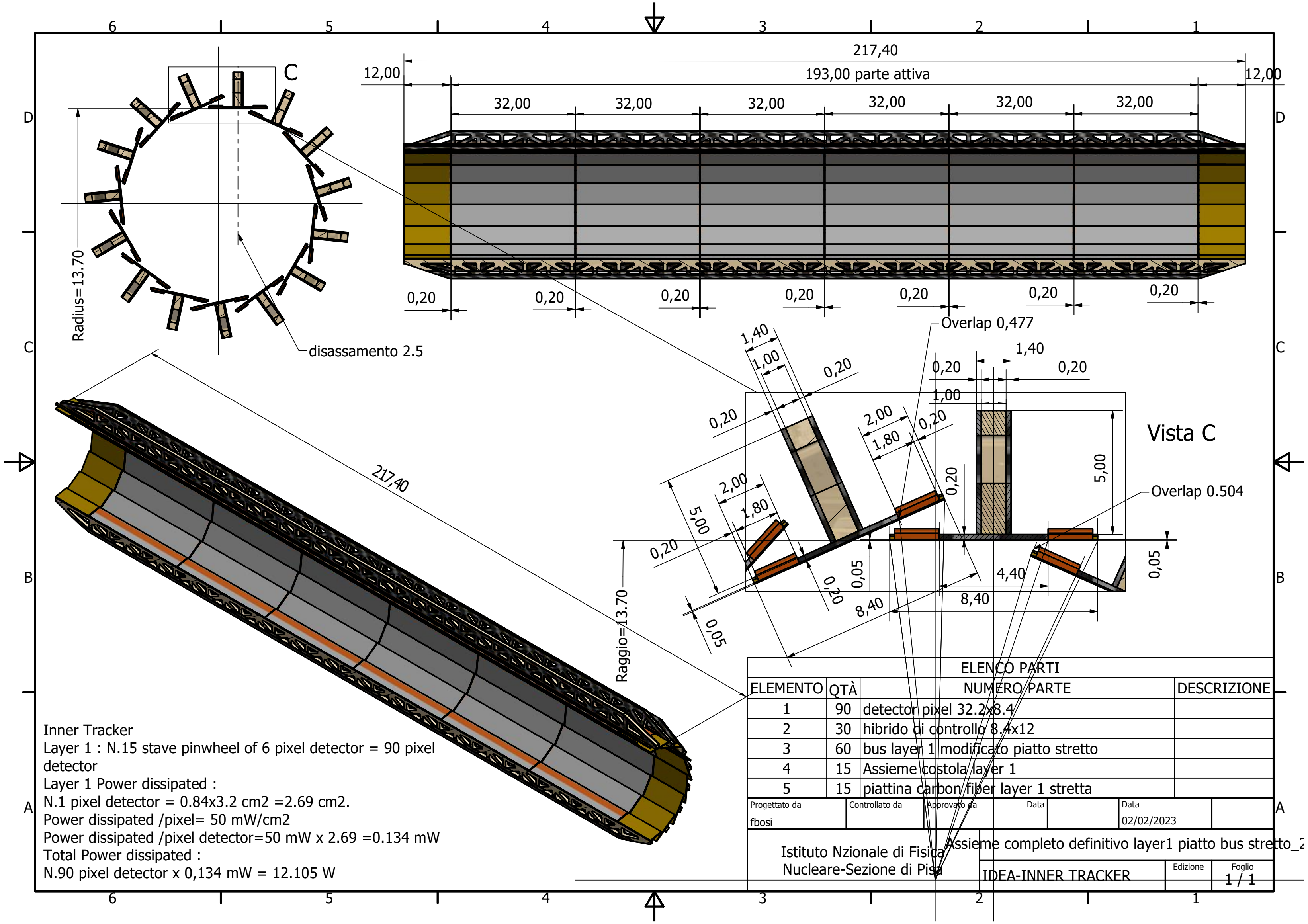
Modules composed of 2 sensors: total of 8.4 mm $(r - \varphi) \times$ 32 mm (z)

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

Breaking news from ARCADIA!

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





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Layer 1

15 overlapping staves of 6 modules each

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

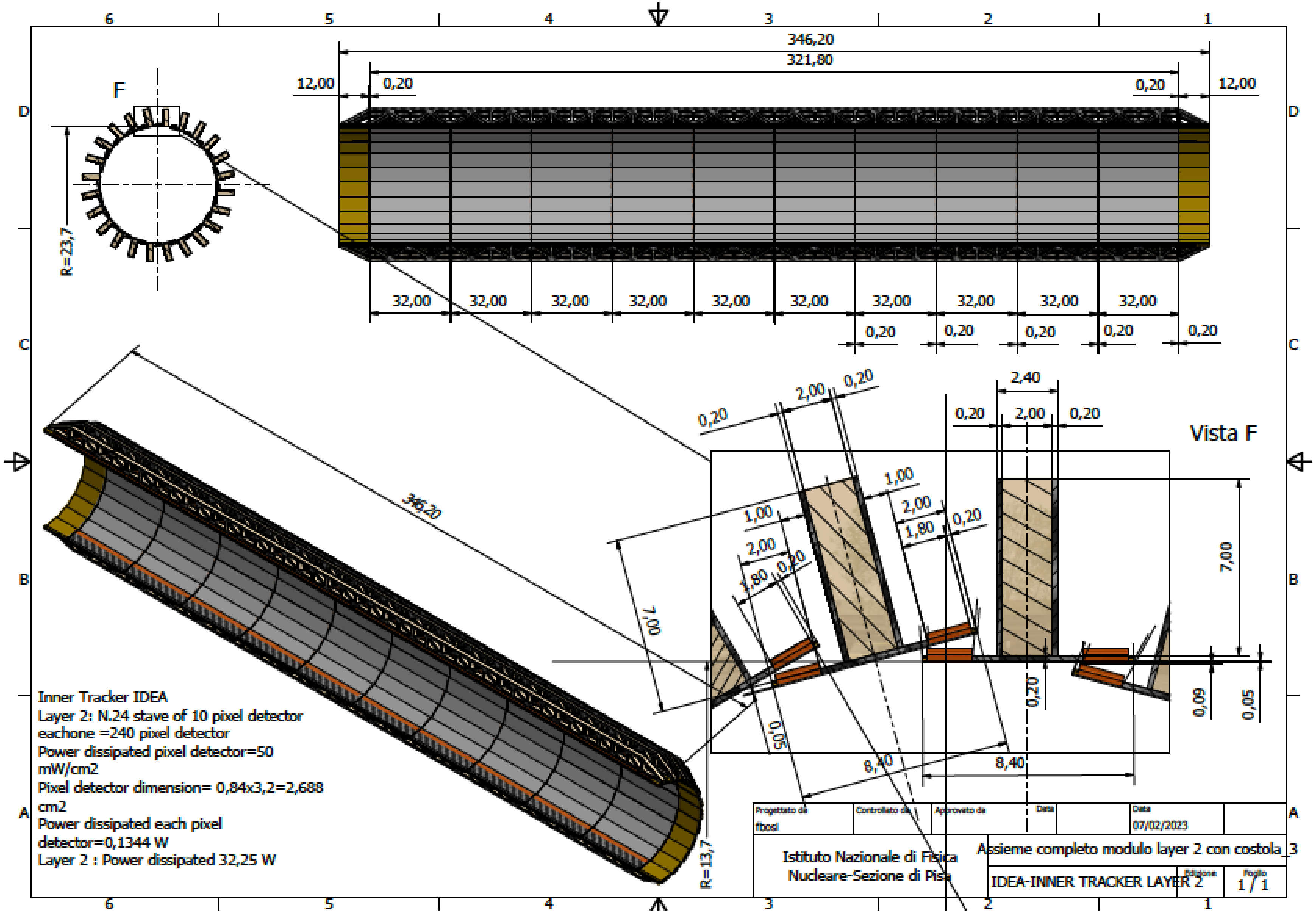
Power budget ~12 W

Total weight ~22 grams

Total thickness 0.25% X_0

Silicon: 0.053% X_0

Power and readout bus: 0.056% X_0



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Layer 2

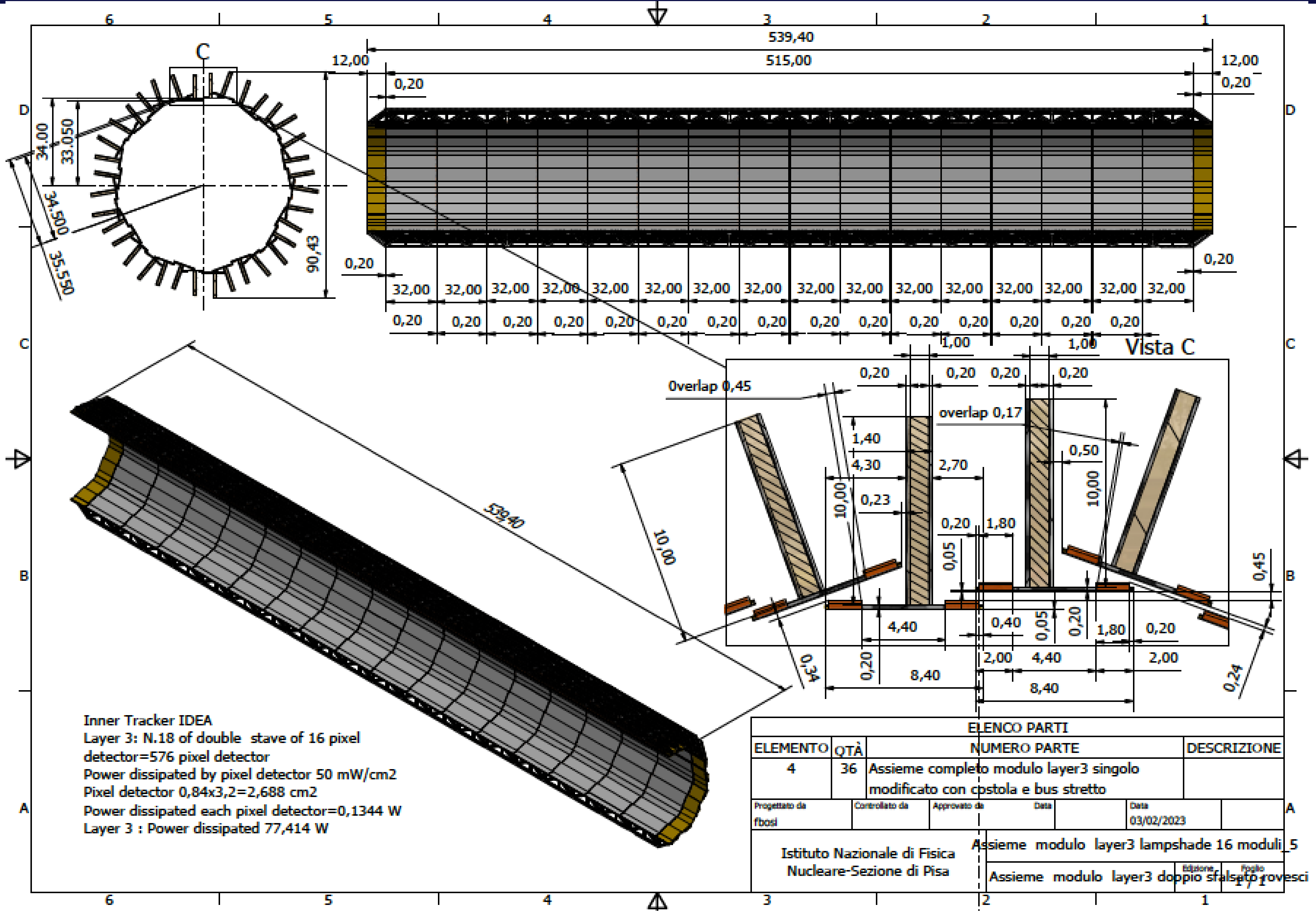
24 overlapping staves of 10 modules each

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

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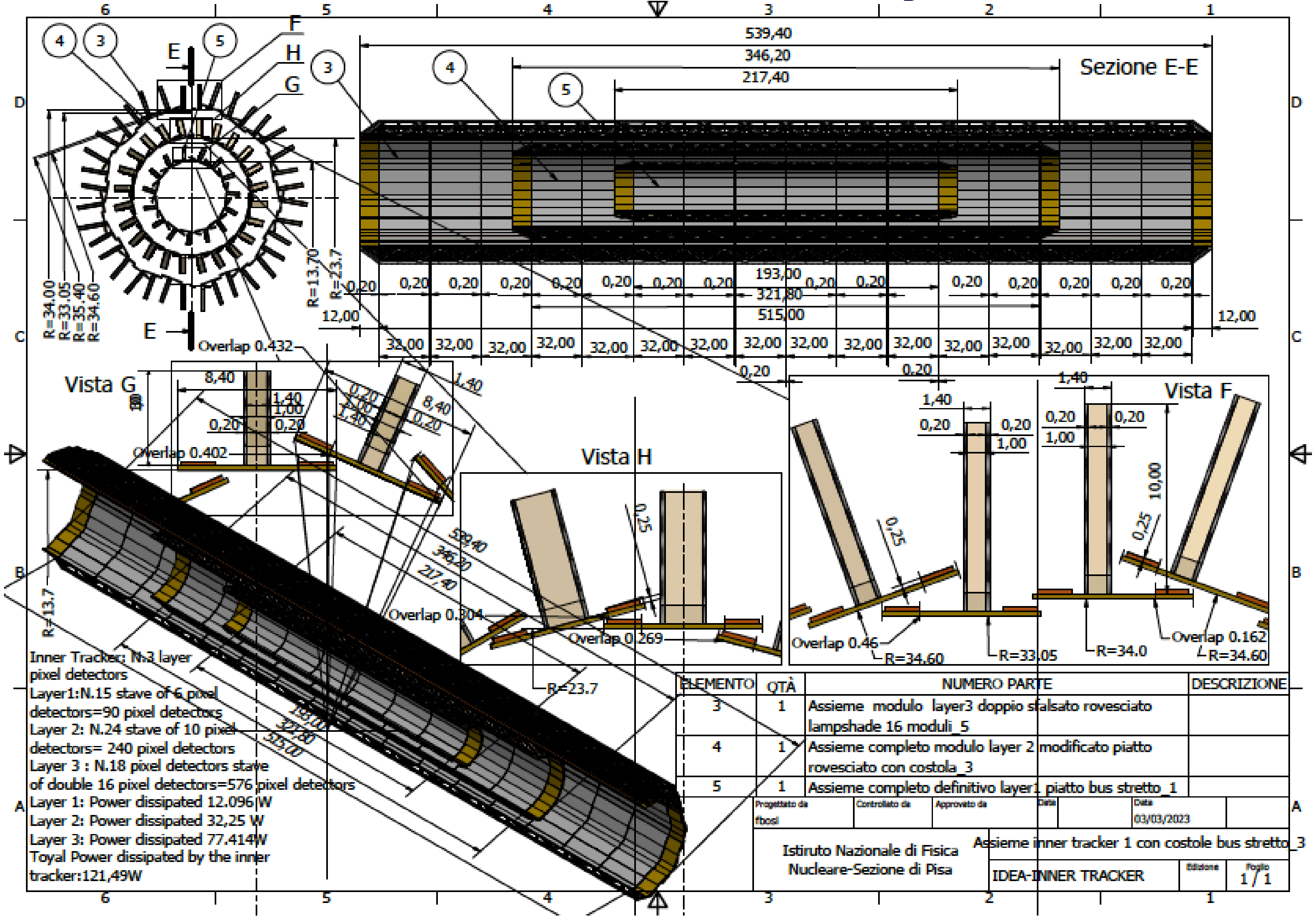
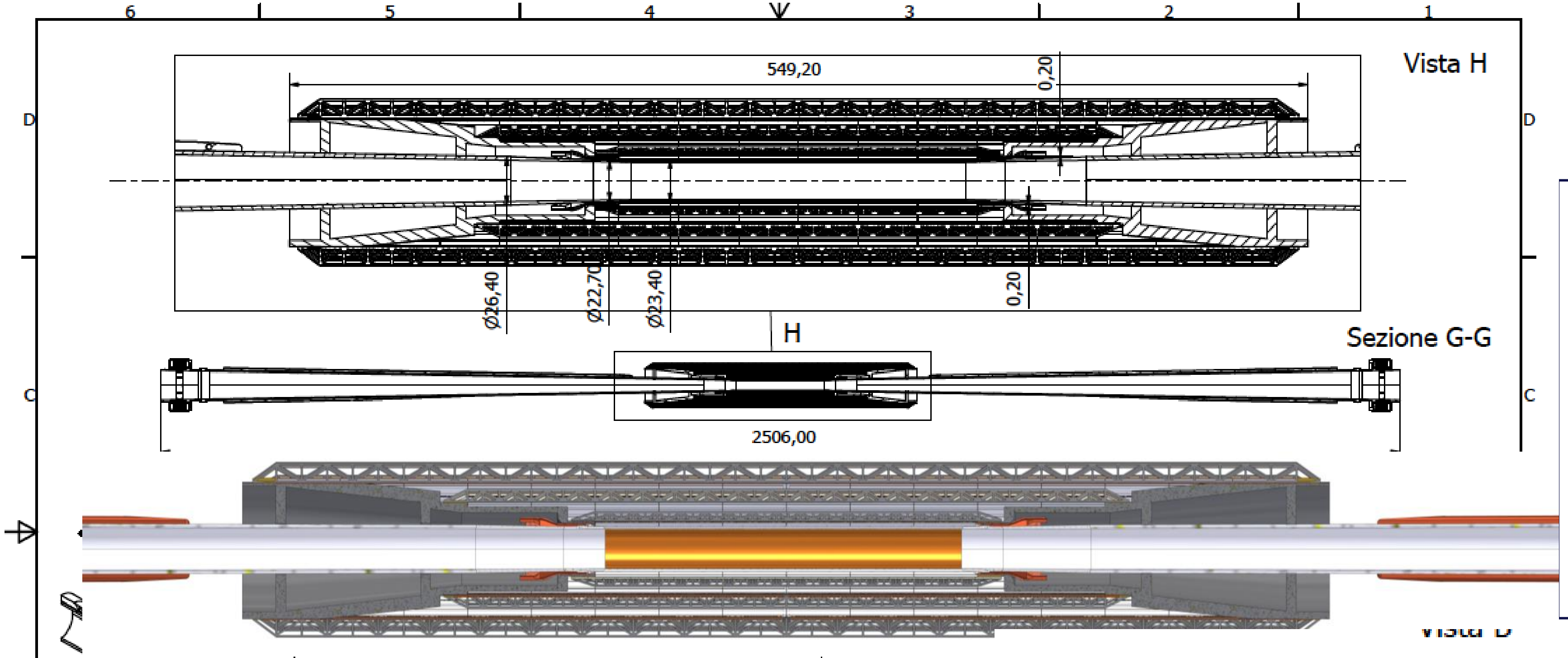


Total power ~120 W

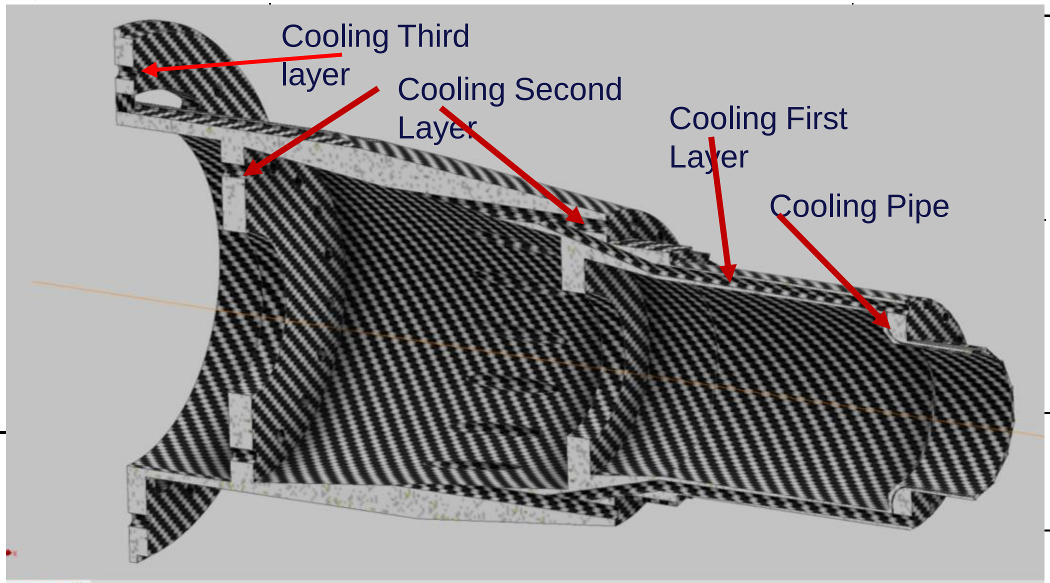
Total weight ~230 grams

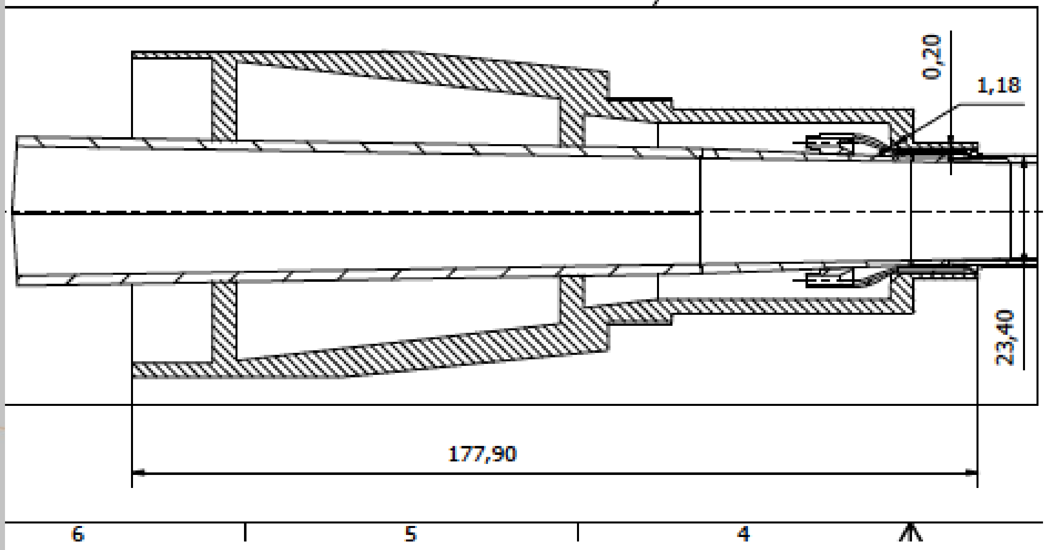
Air cooling studies have started!



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

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





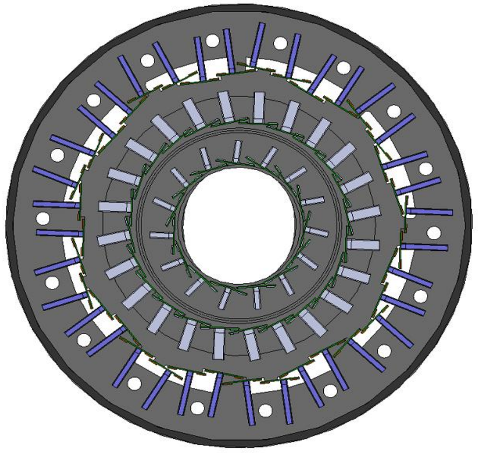
Thermal simulation started

INFN Perugia

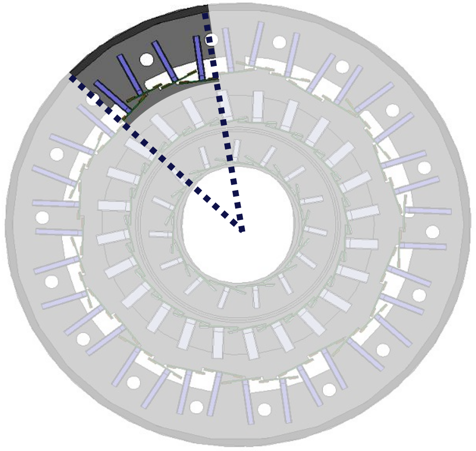
G. Baldinelli, F. Bianchi, C. Turrioni

Start from a radial sector of layer 3 (relying on periodic symmetry) and import in ANSYS FEA. Then move to all other layers.

FIRST STEPS

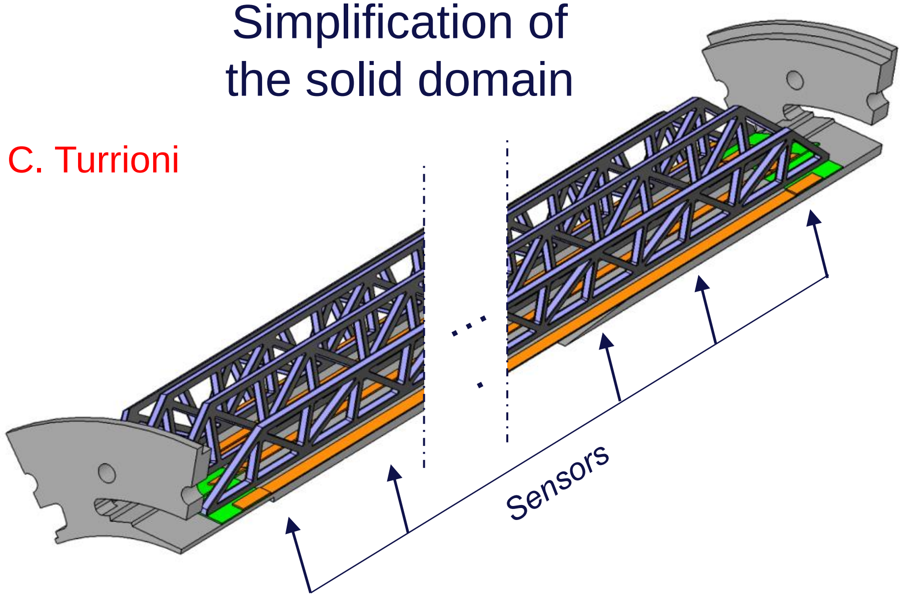


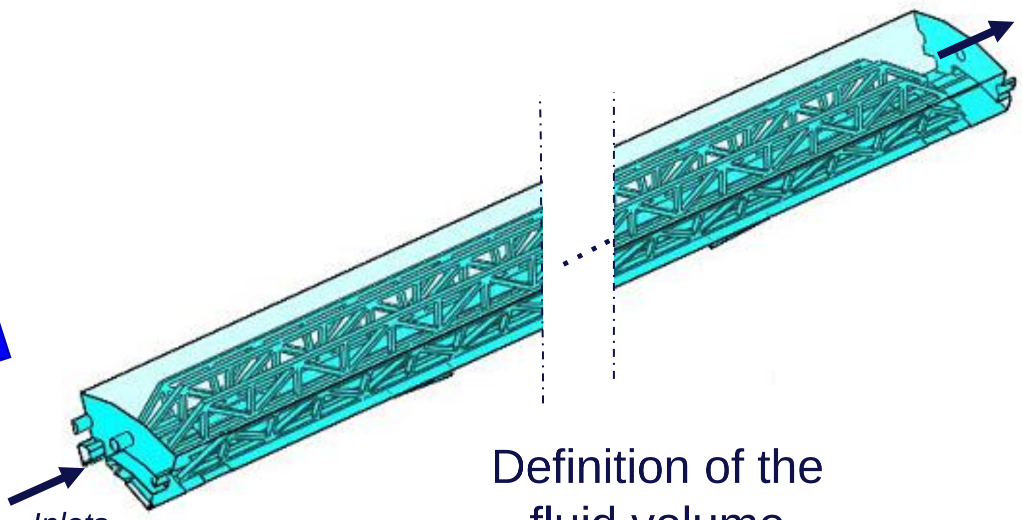
Full model



Extraction of a radial sector for layer 3

Simplification of the solid domain





Definition of the fluid volume

Outer vertex layers modules

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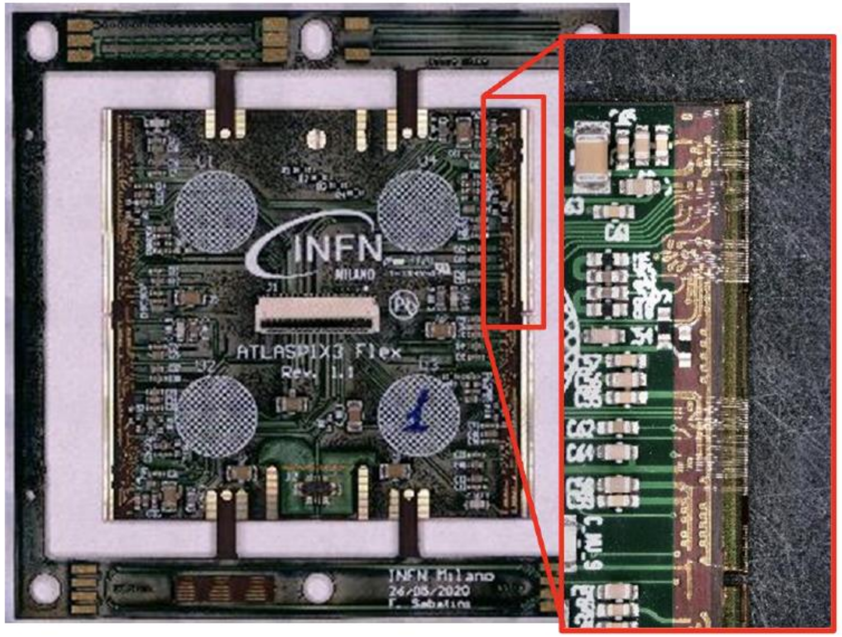
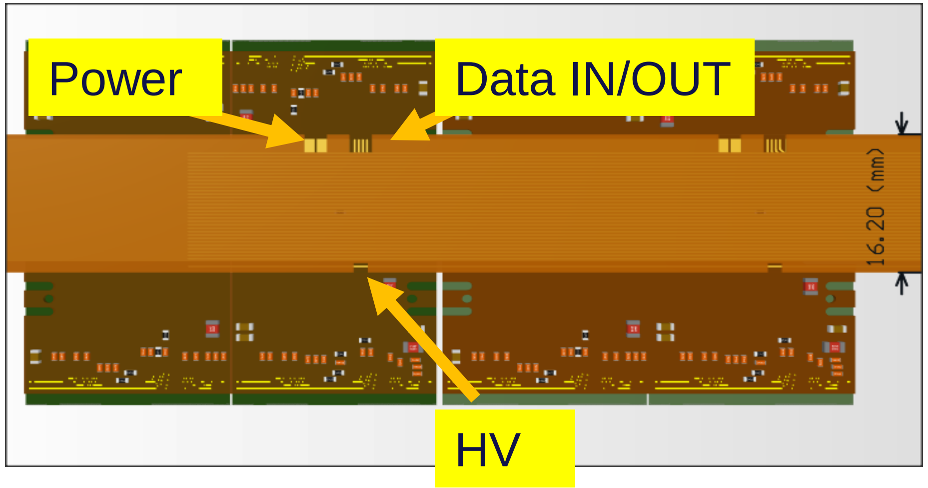
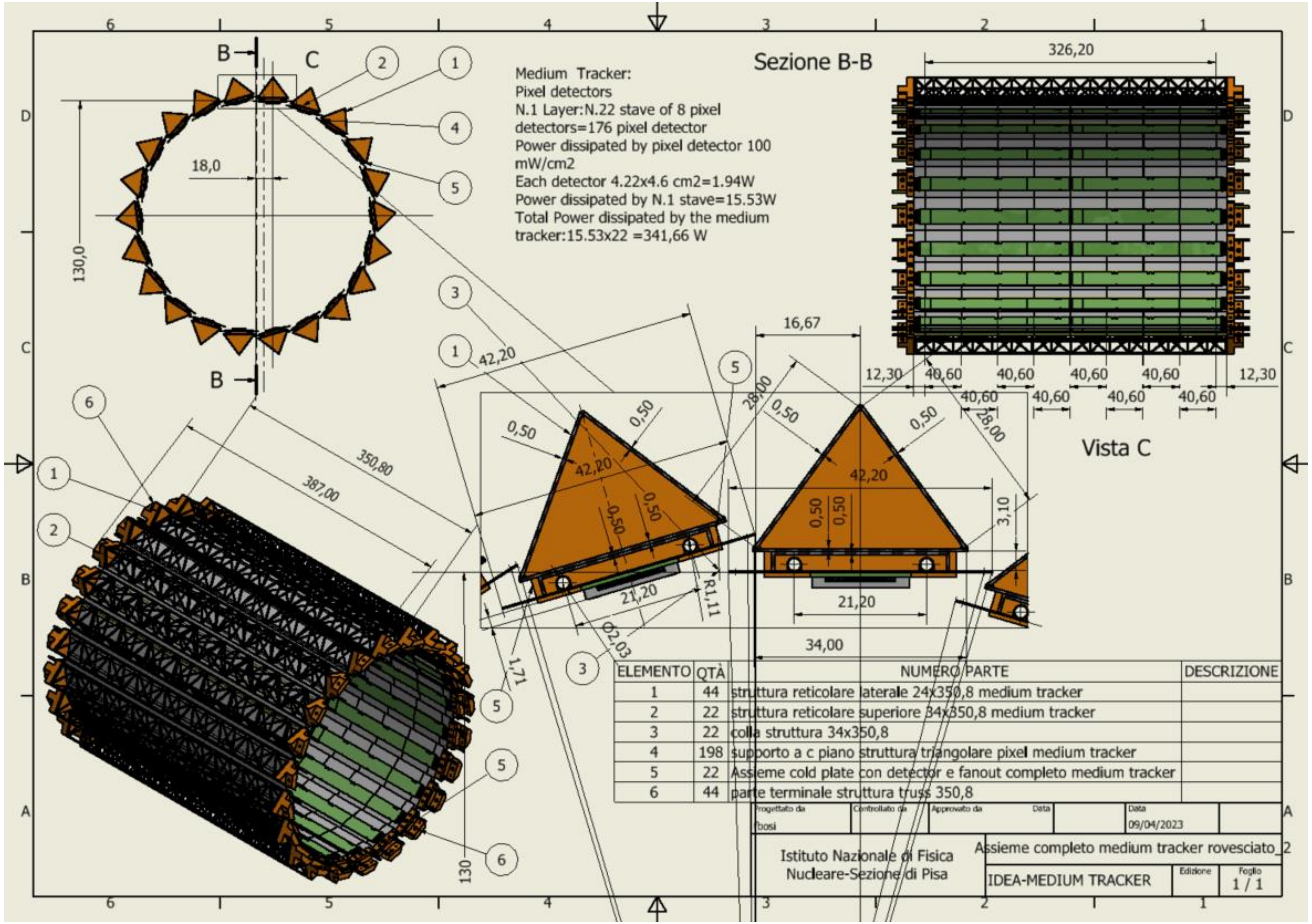
Based on ATLASPIX3 R&D
- DMAPS
- 50 x 150 µm^2
- Up to 1.28 Gb/s downlink
- TSI 180 nm process
- 132 columns of 372 pixels

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







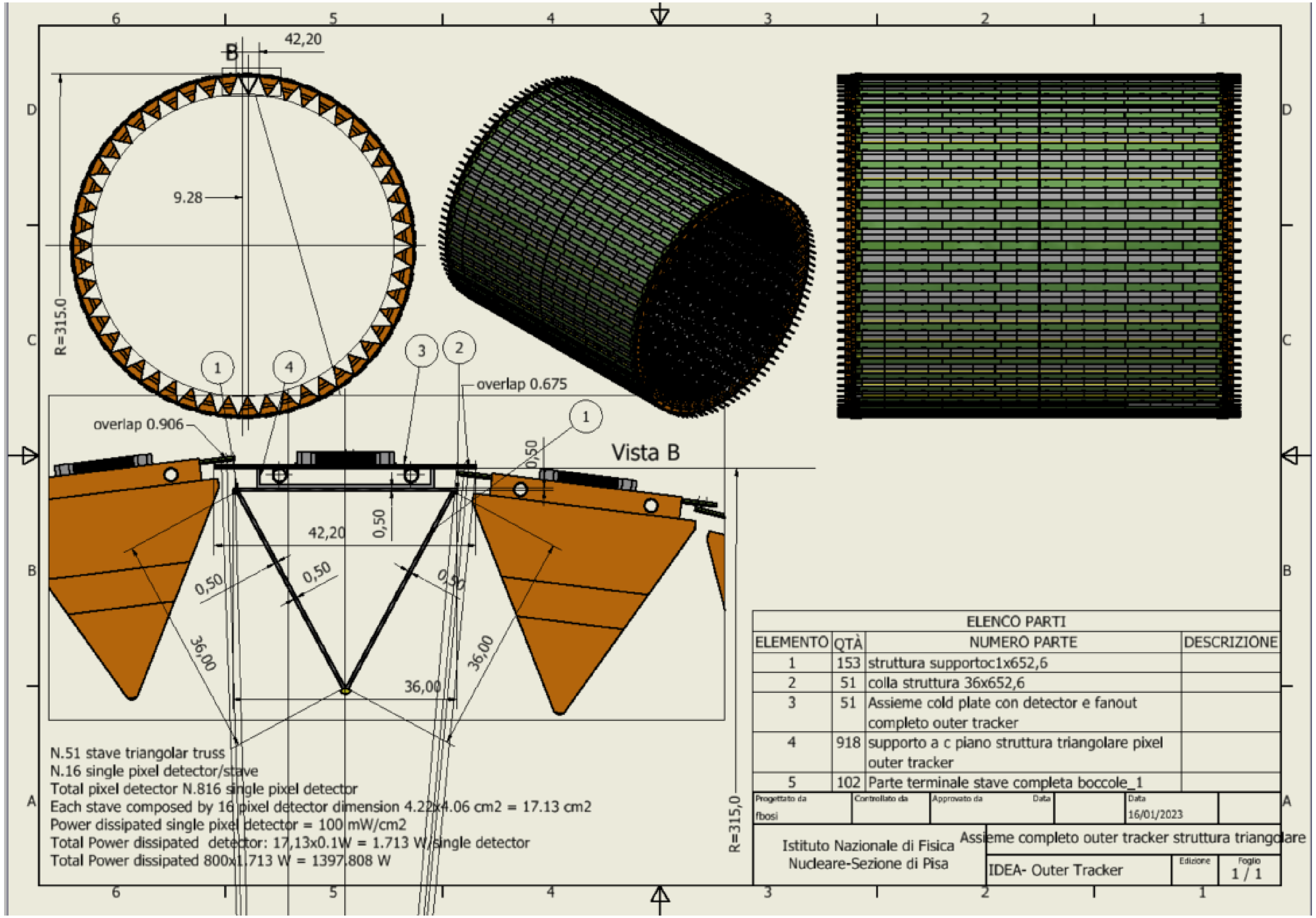
Middle Vertex Barrel
At 13 cm radius

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)



ELENCO PARTI

ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
1	153	struttura supportoc1x652,6	
2	51	colla struttura 36x652,6	
3	51	Assieme cold plate con detector e fanout completo outer tracker	
4	918	supporto a c piano struttura triangolare pixel outer tracker	
5	102	Parte terminale stave completa boccole_1	

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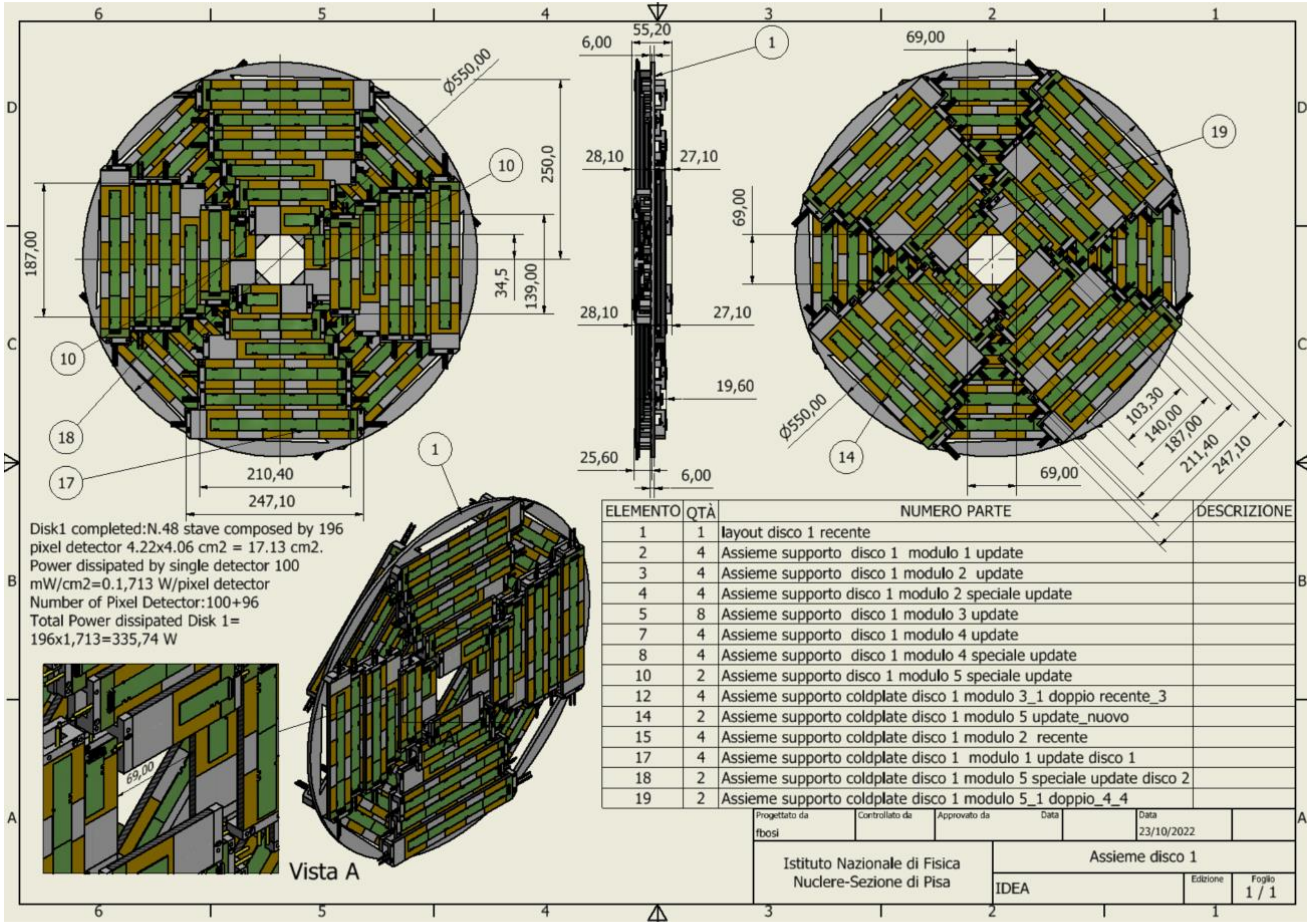
Outer Vertex Tracker Barrel
At 31.5 cm radius

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

Overall layout and dimensions

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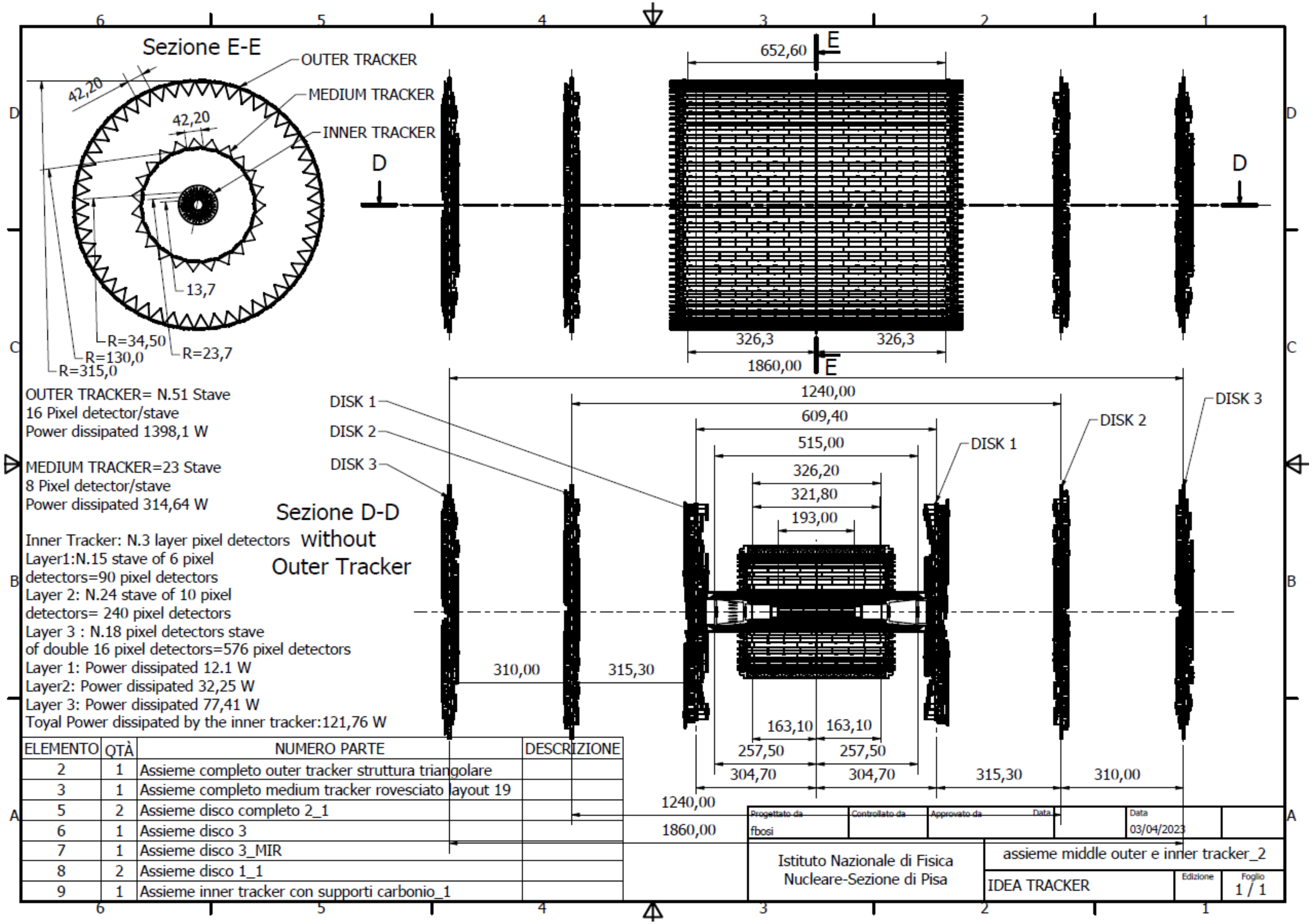
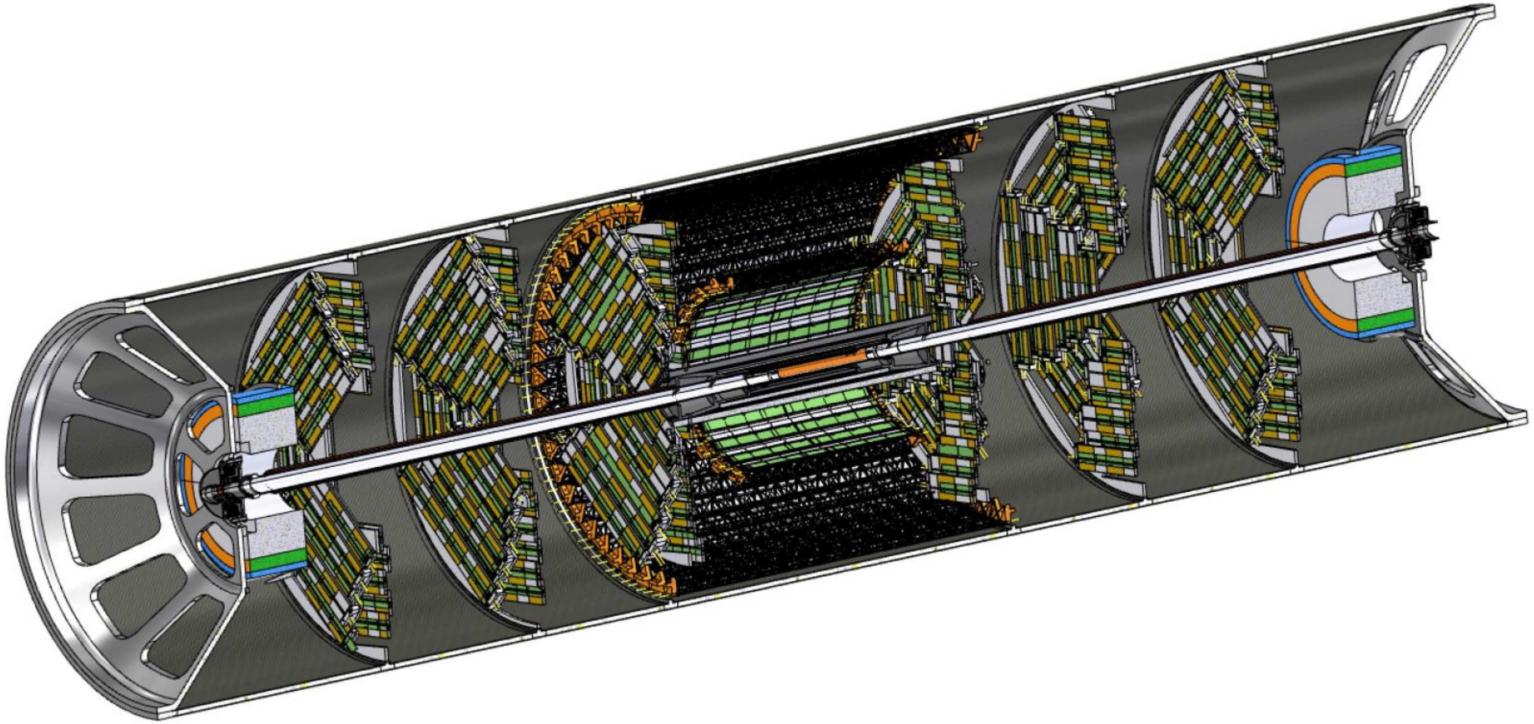


Support cylinder

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)



See F. Fransesini talk

LumiCal integration

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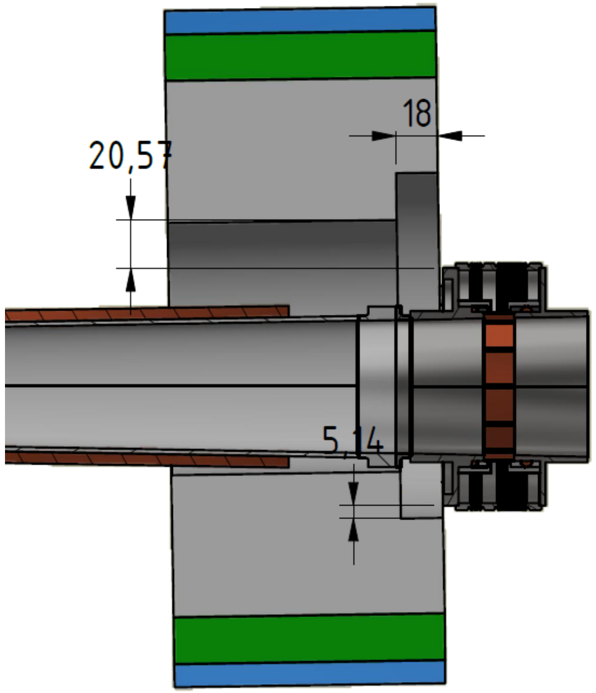
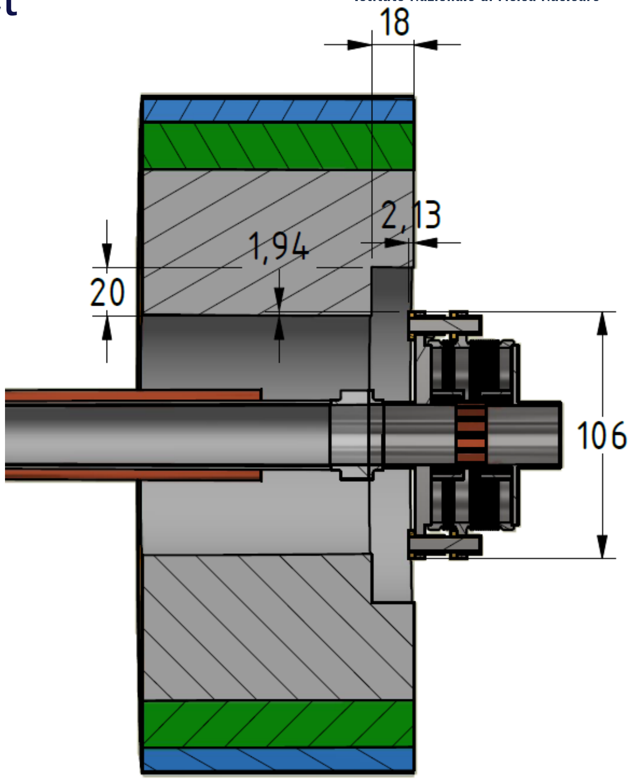
Currently under study the possibility to include LumiCal as a single object

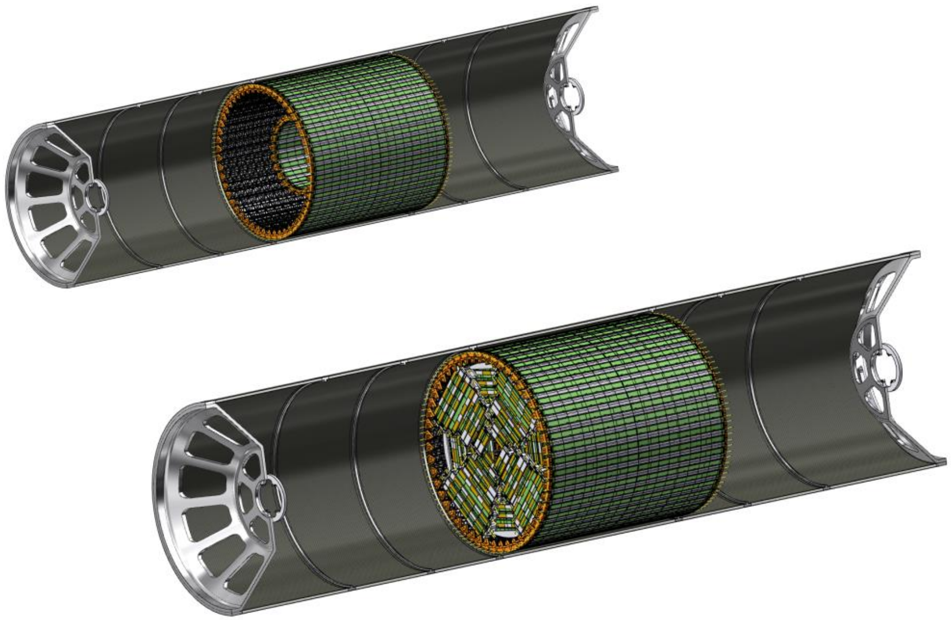
The main modification consists into the creation of an annulus:

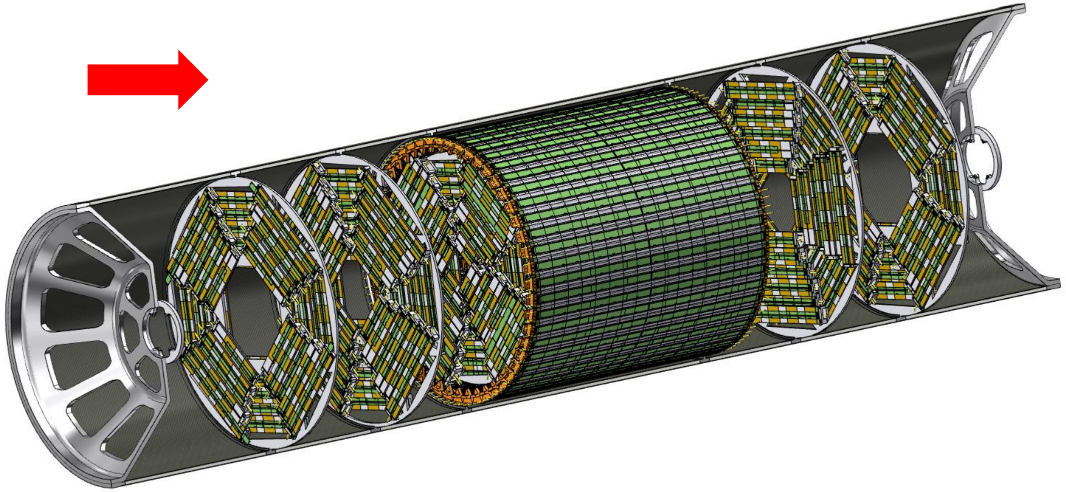
- 18 mm along z (a multiple of 3.5 mm W (1X0) + 1.0 mm gap for Si pads)
- 20 mm along the radius of the Lumical





Assembly procedure – I

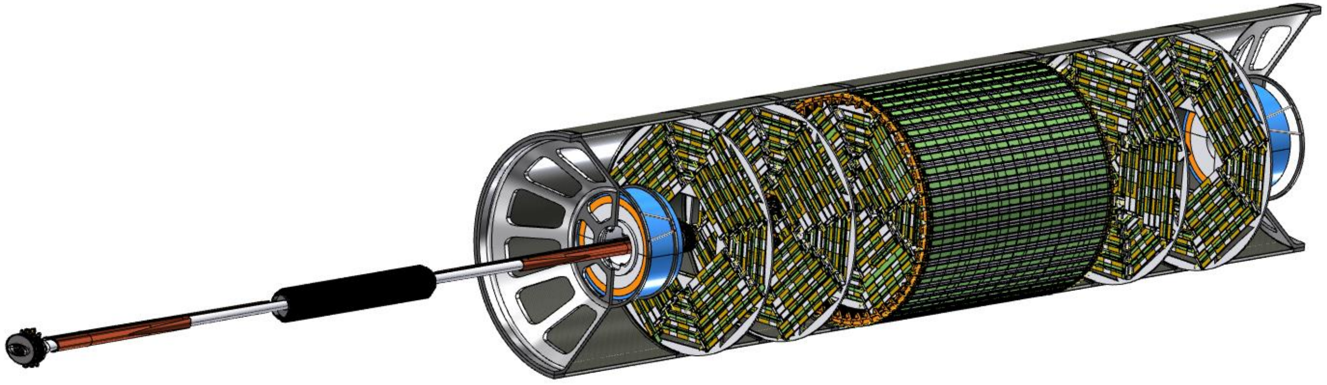


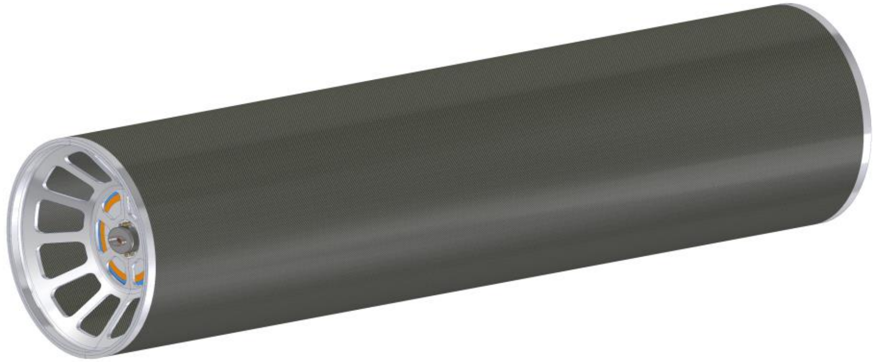


1) Outer vertx tracker, middle vertex tracker and disks 1 are installed as a rigid structure inside the support tube

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

Assembly procedure – II

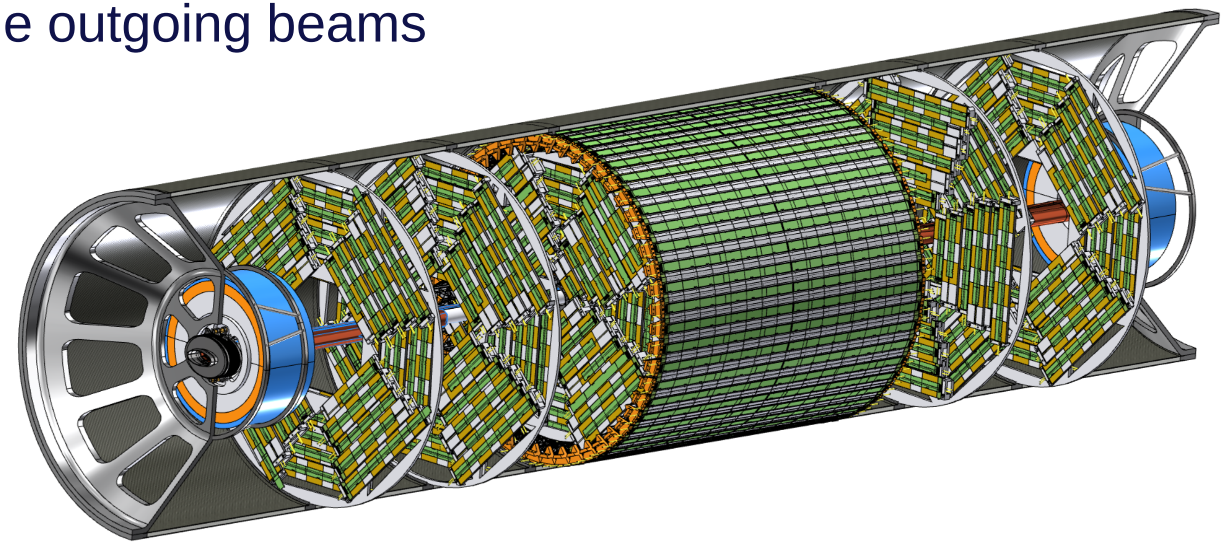




3) LumiCal is installed in centered position, then beam pipe with inner vertex detector is inserted with a dedicated tool inside disks and outer vertex tracker, then fixed to both endcaps

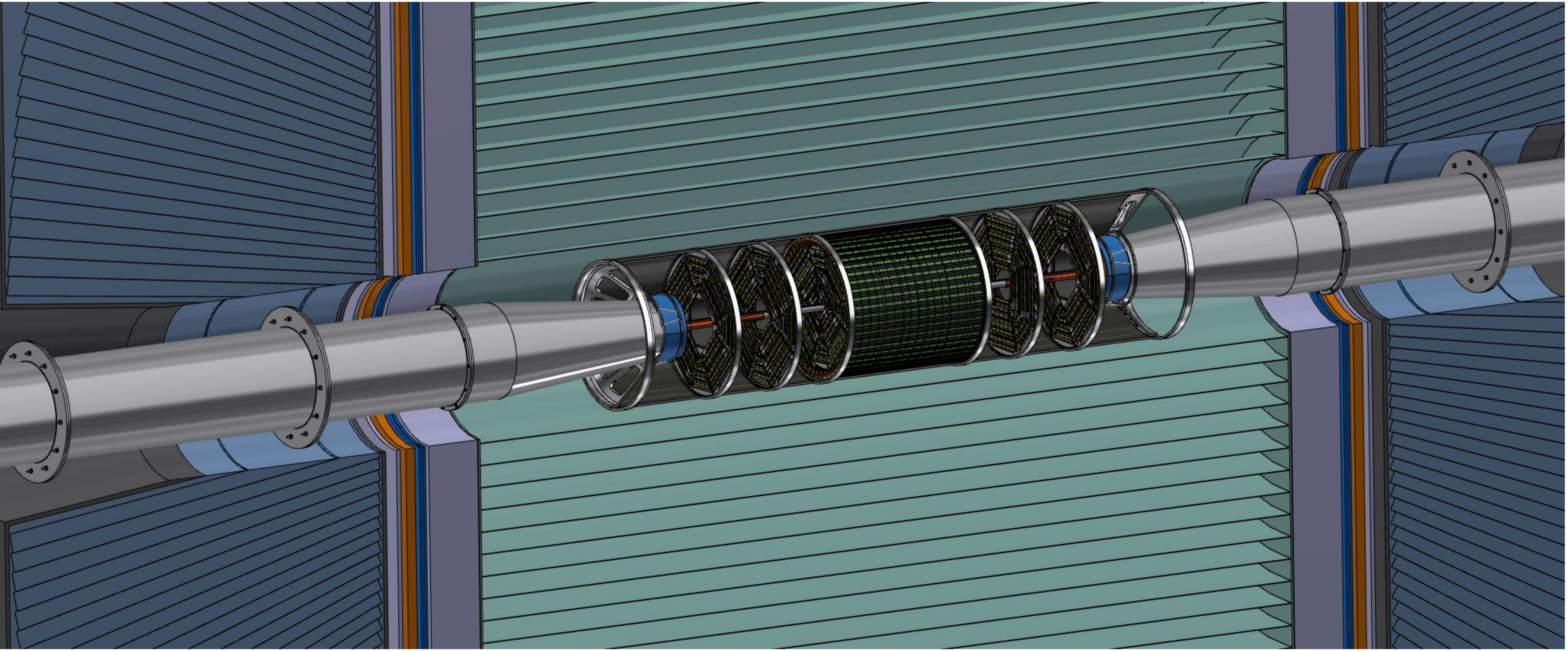
4) LumiCal can be aligned in the correct position on the outgoing beams

5) Support tube can be closed



General integration

M. Boscolo, F. Palla, F. Fransesini, F. Bosi and S. Lauciani, Mechanical model for the FCC-ee MDI, EPJ+ Techn. and Instr.



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 (accepted for publication)
  - *M. Boscolo, F. Palla, F. Fransesini, F. Bosi and S. Lauciani, Mechanical model for the FCC-ee MDI, EPJ+ Techn. and Instr.*

Next/ongoing steps:

- Inner Vertex detector
  - Dimensioning the air-cooling system has started
  - 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
- Lumical
  - Engineering and assembly to be done

Engineering layout imported in the simulation (see next talk by A. Ilg)

Thank you for your attention.

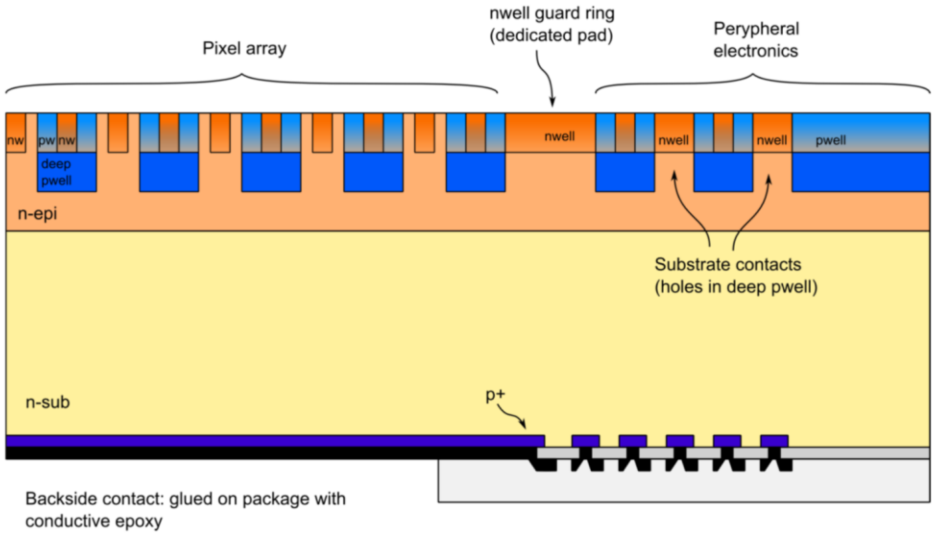
Backup

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

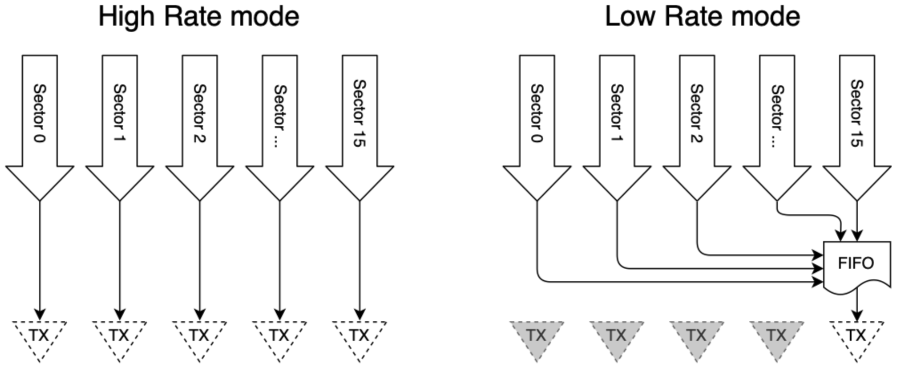


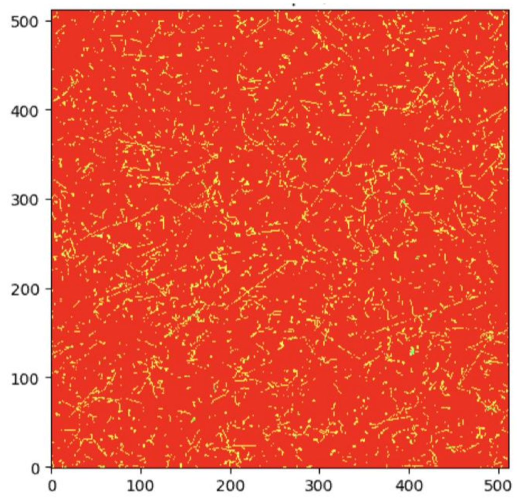
"Fully Depleted MAPS in 110-nm CMOS Process With 100–300-µm Active Substrate," in IEEE Transactions on Electron Devices, June 2020, doi: 10.1109/TED.2020.2985639.

ARCADIA DMAPS R&D at INFN

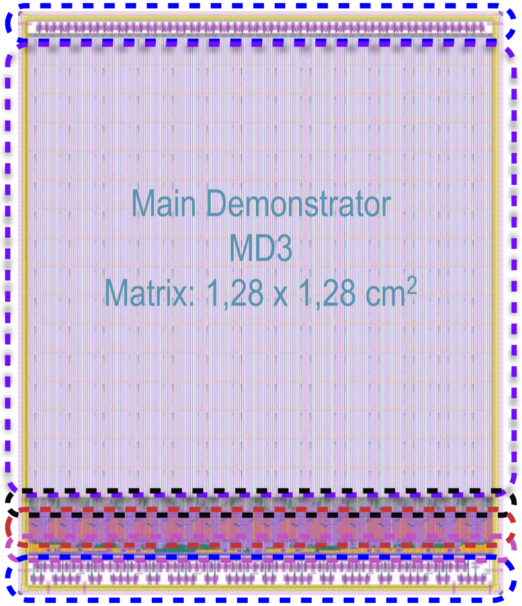
Advanced Readout CMOS Architectures with Depleted Integrated sensor Arrays

- 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)

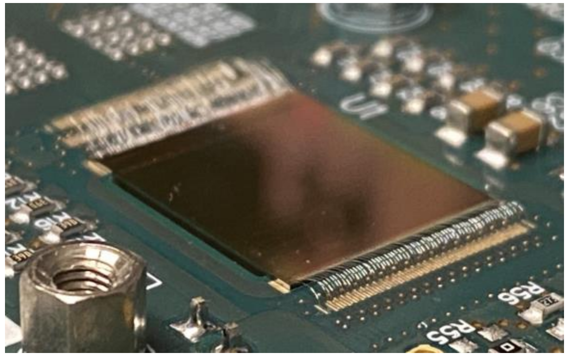


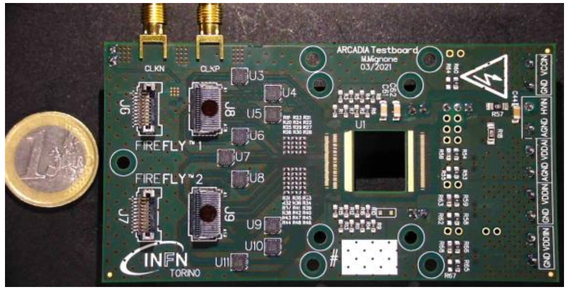


Cosmic ray data



ARCADIA INFN CSN5 Call Project





Half-ladder layout – layer 1

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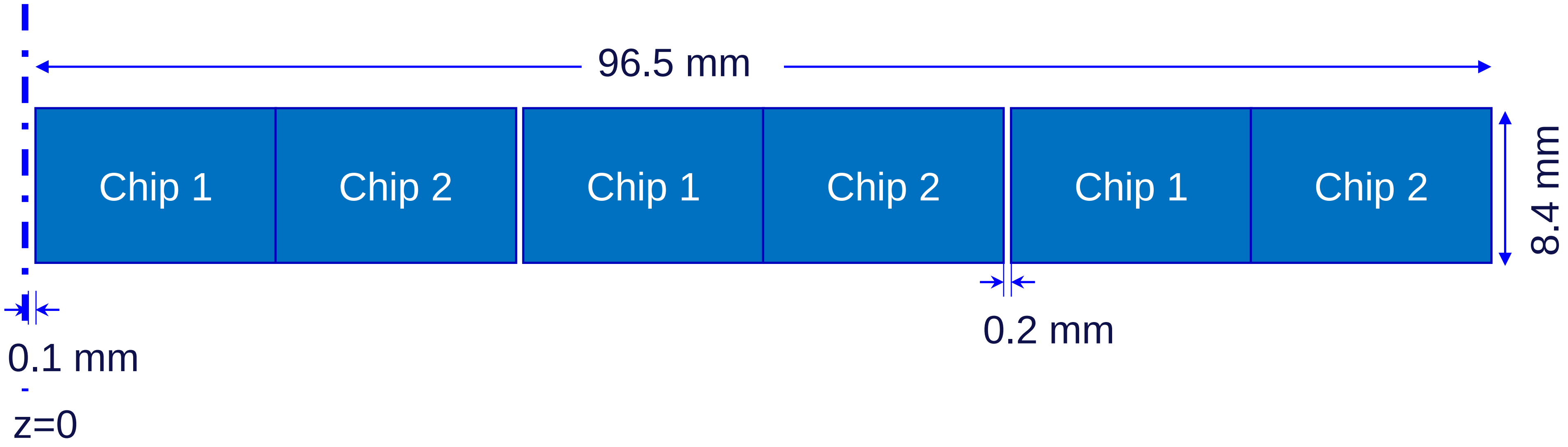
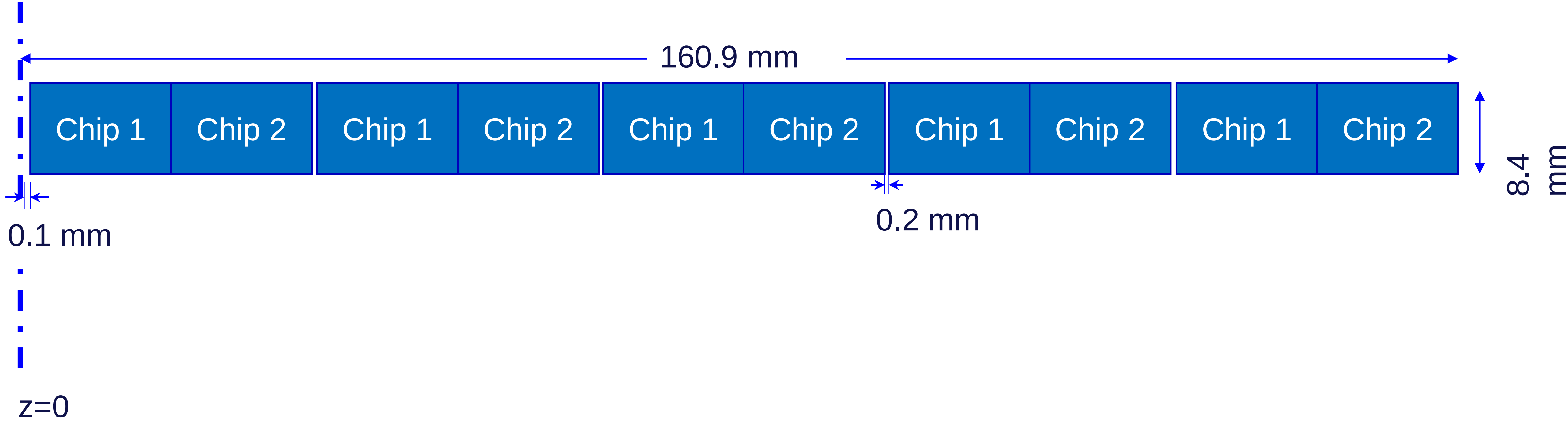


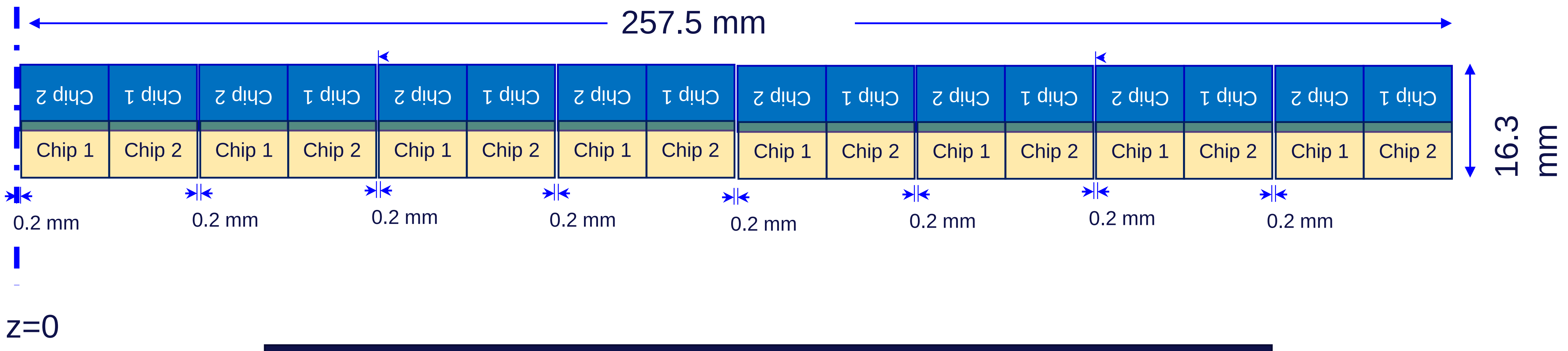
Layer 1 ladders are placed at 13.7 mm radius

Half-ladder layout – layer 2



Layer 2 ladders are placed at 23.7 mm radius

Half ladder layout – layer 3

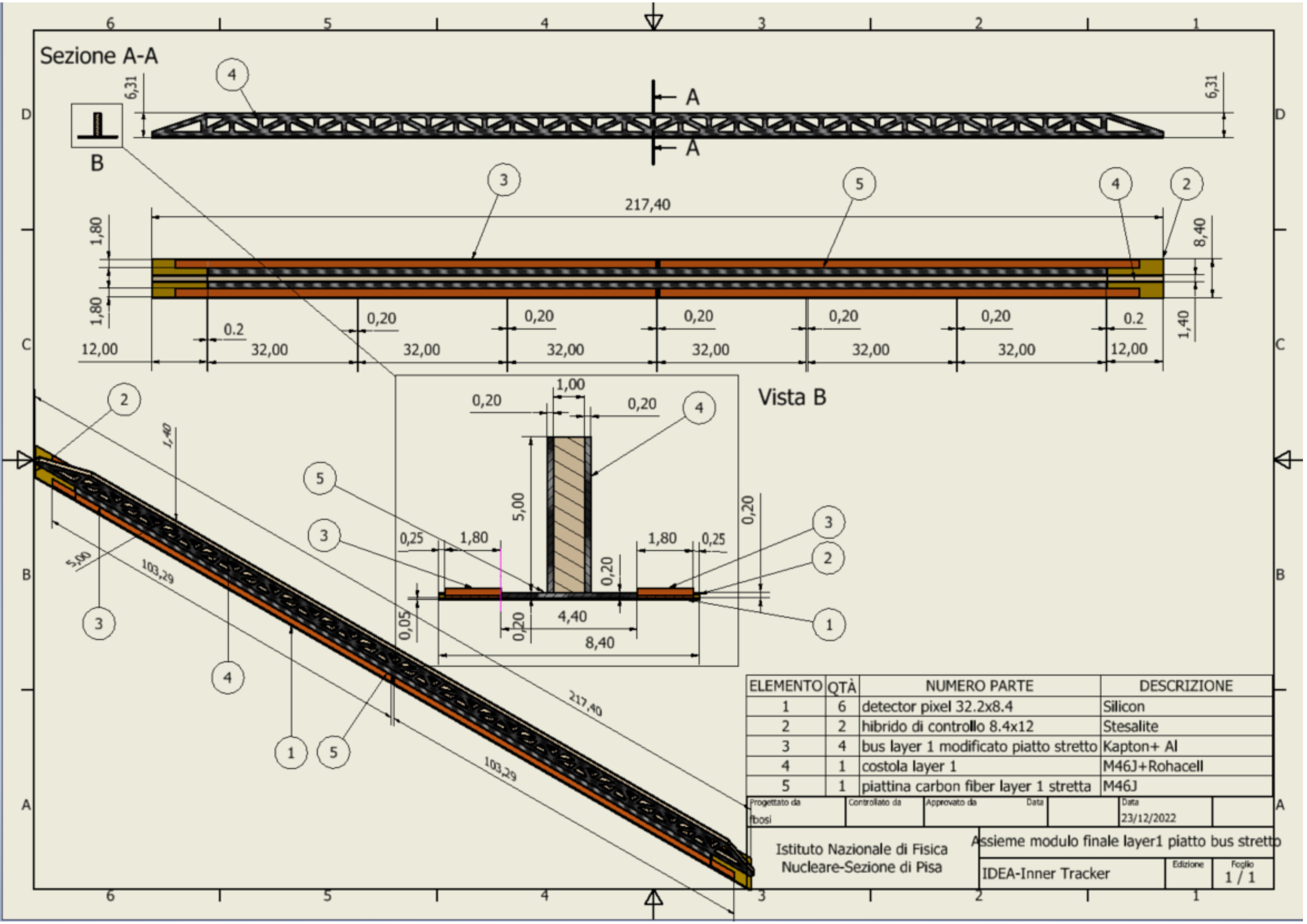


Overlapping in $r-\varphi$:2 parallel ladders separated by 500 µm - see engineering drawings later

Passive parts on the sides

Layer 3 ladders are placed between 30.5 and 35.55 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

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

Readout chips either sides

Air cooled

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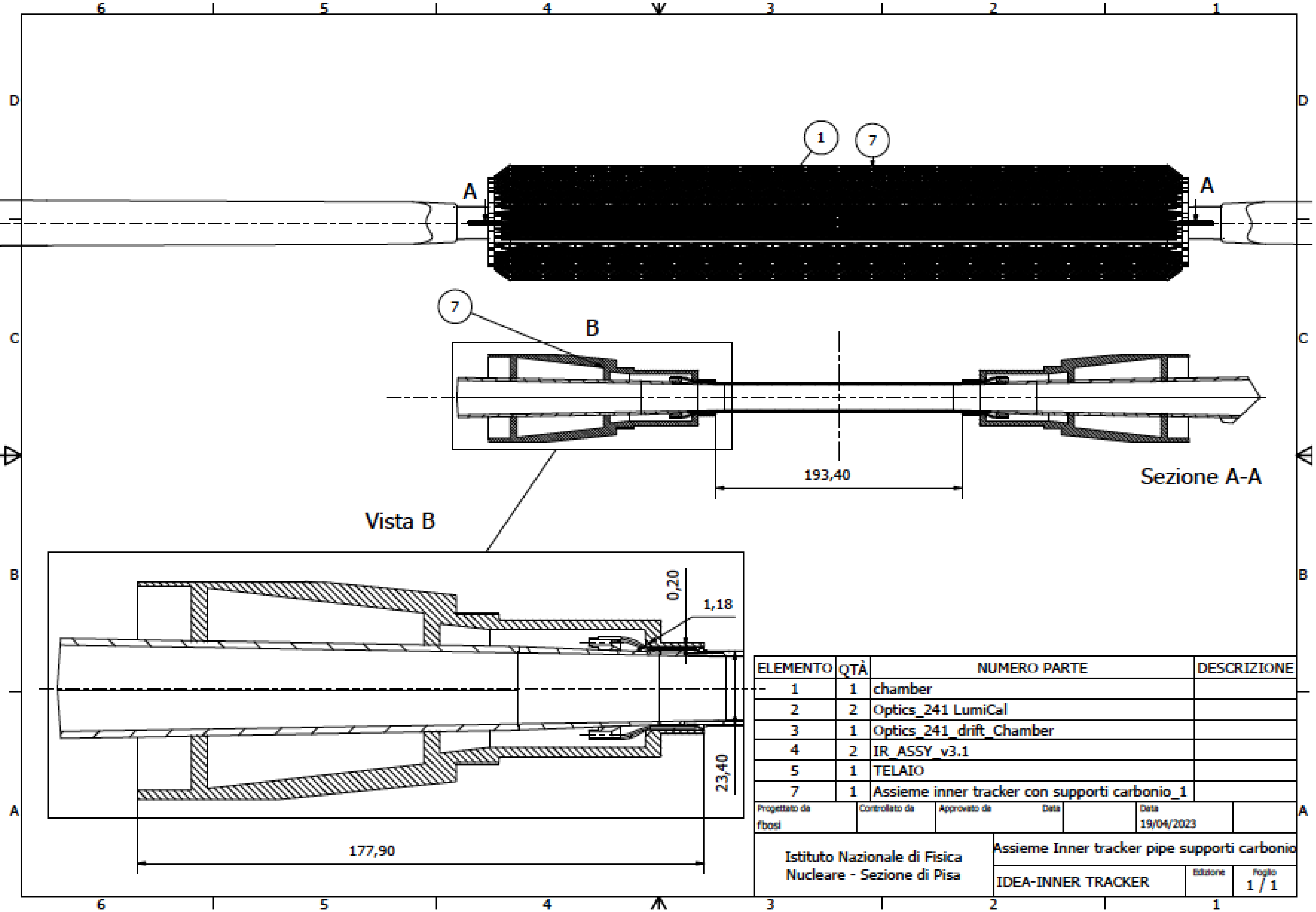

ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
1	1	chamber	
2	2	Optics_241 LumiCal	
3	1	Optics_241_drift_Chamber	
4	2	IR_ASSY_v3.1	
5	1	TELAIO	
7	1	Assieme inner tracker con supporti carbonio_1	

Progettato da	Controllato da	Approvato da	Data	Data
fbosi				19/04/2023

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Assieme Inner tracker pipe supporti carbonio

IDEA-INNER TRACKER — Edizione — Foglio 1 / 1

Vertex on the beam-pipe

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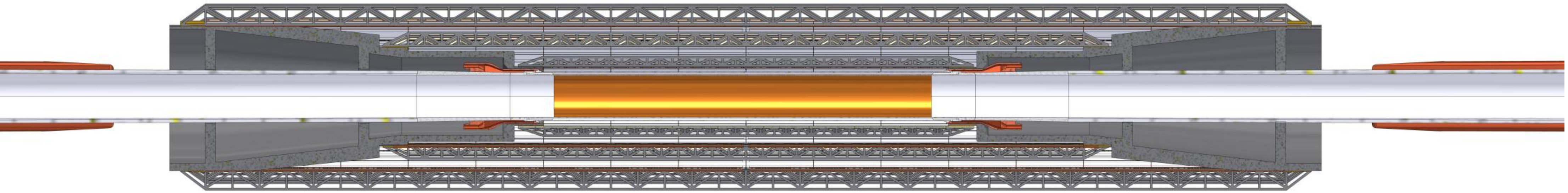

Air cooling for Belle-II upgrade

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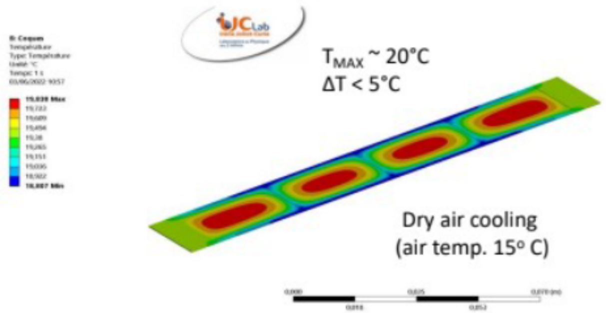
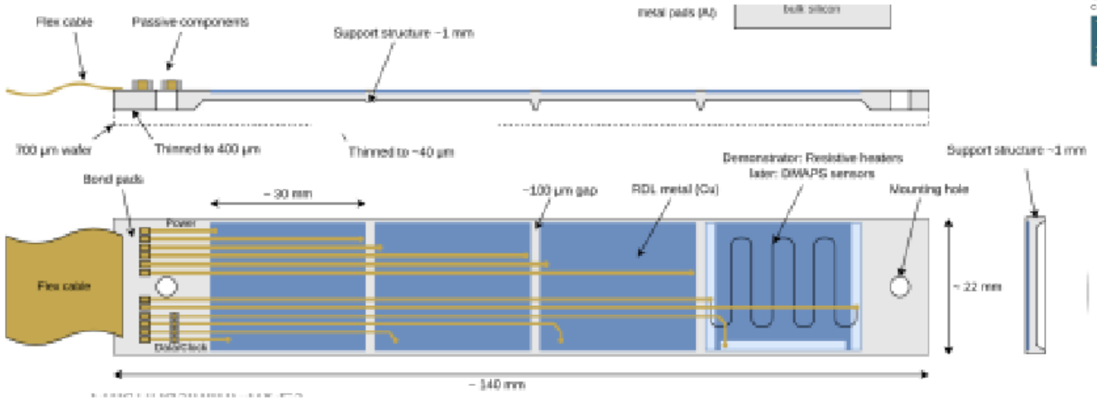
AIDA innova

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



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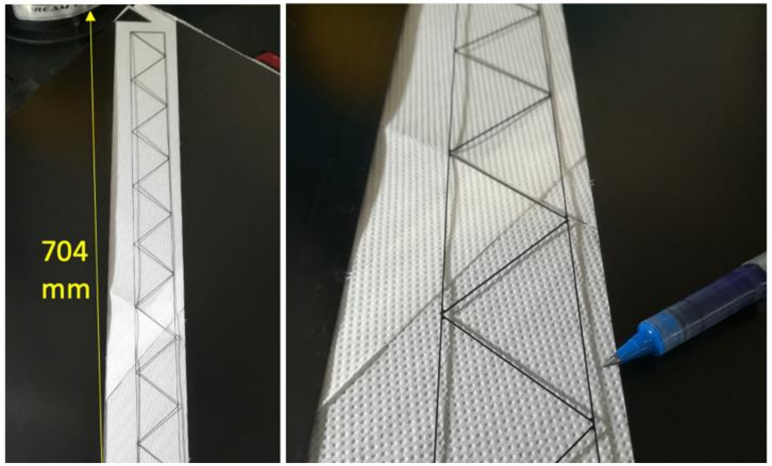
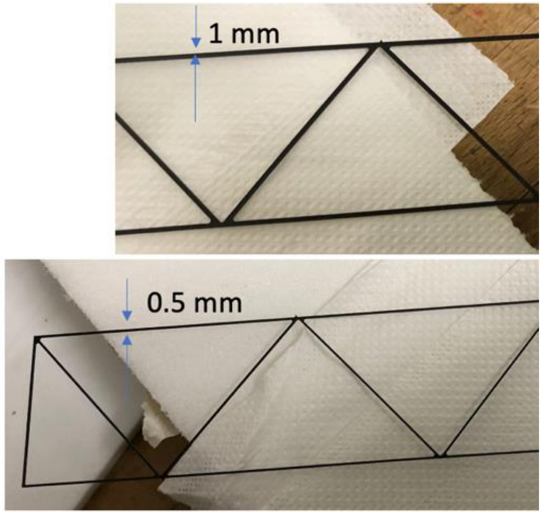
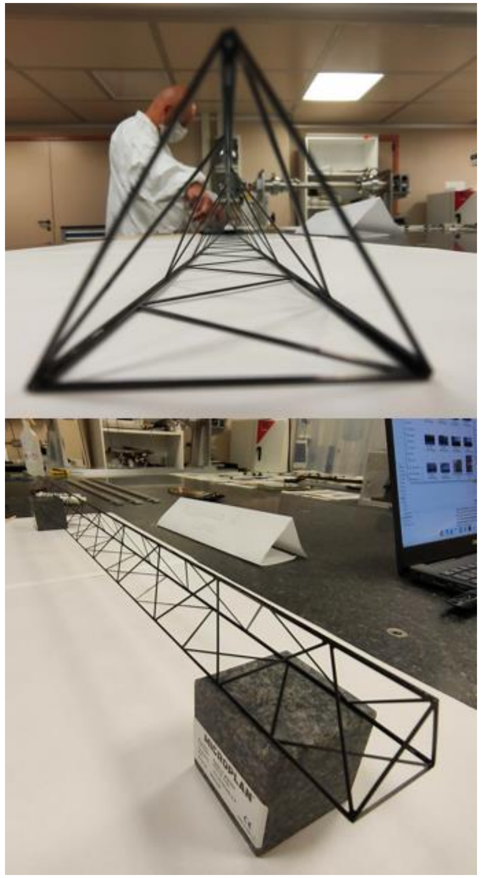
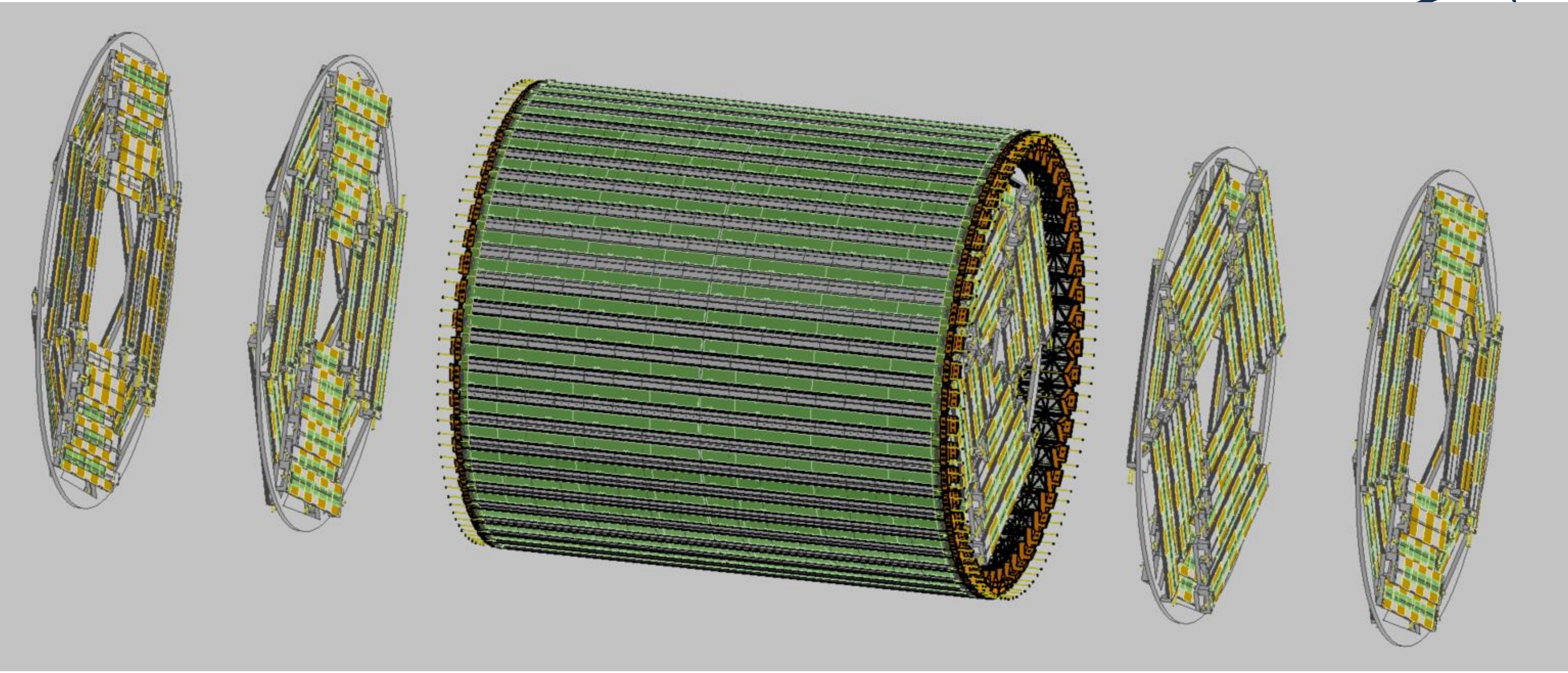
CF water-jet cut (by WatAJet Company)









OUTER TRACKER

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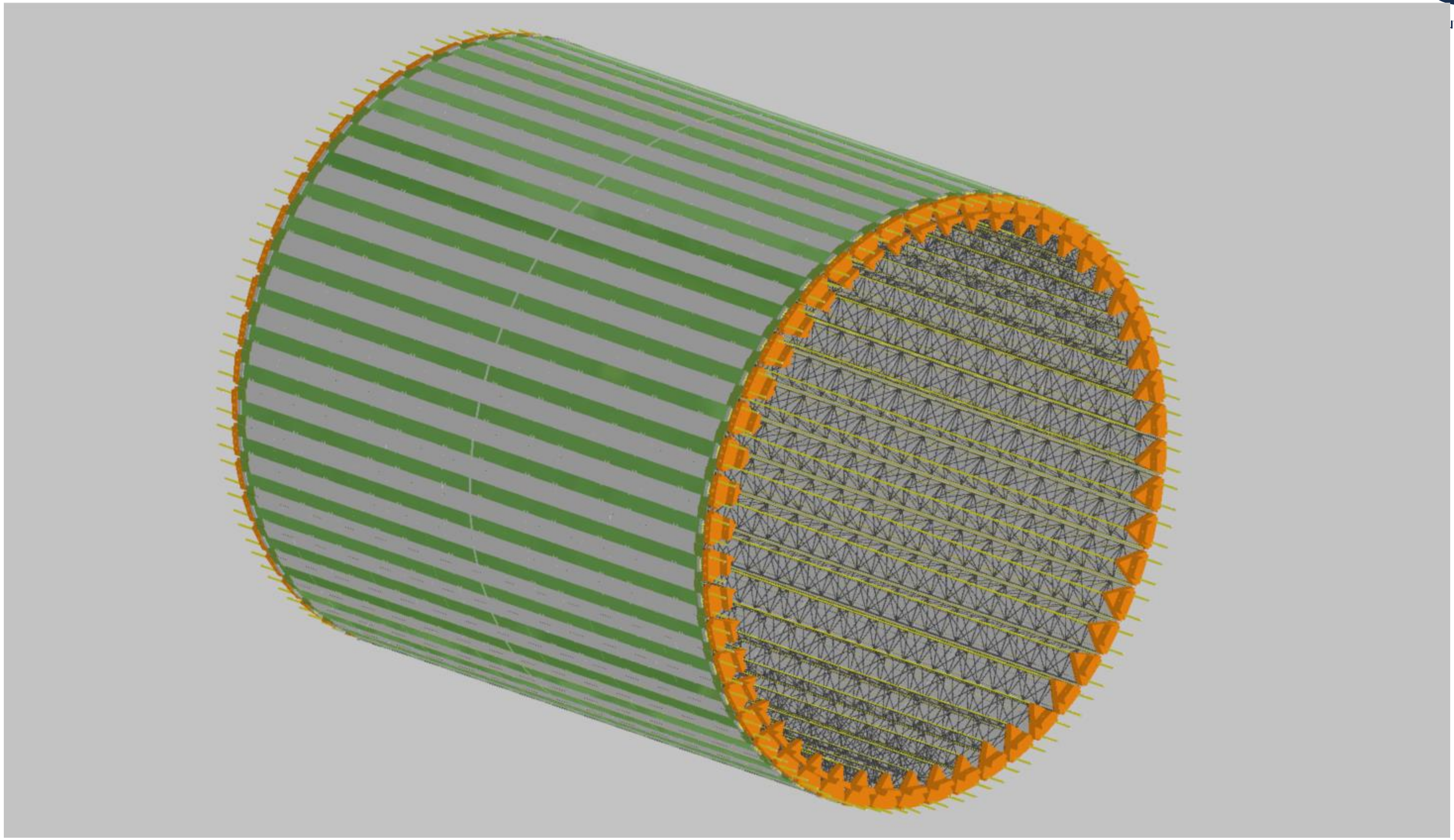
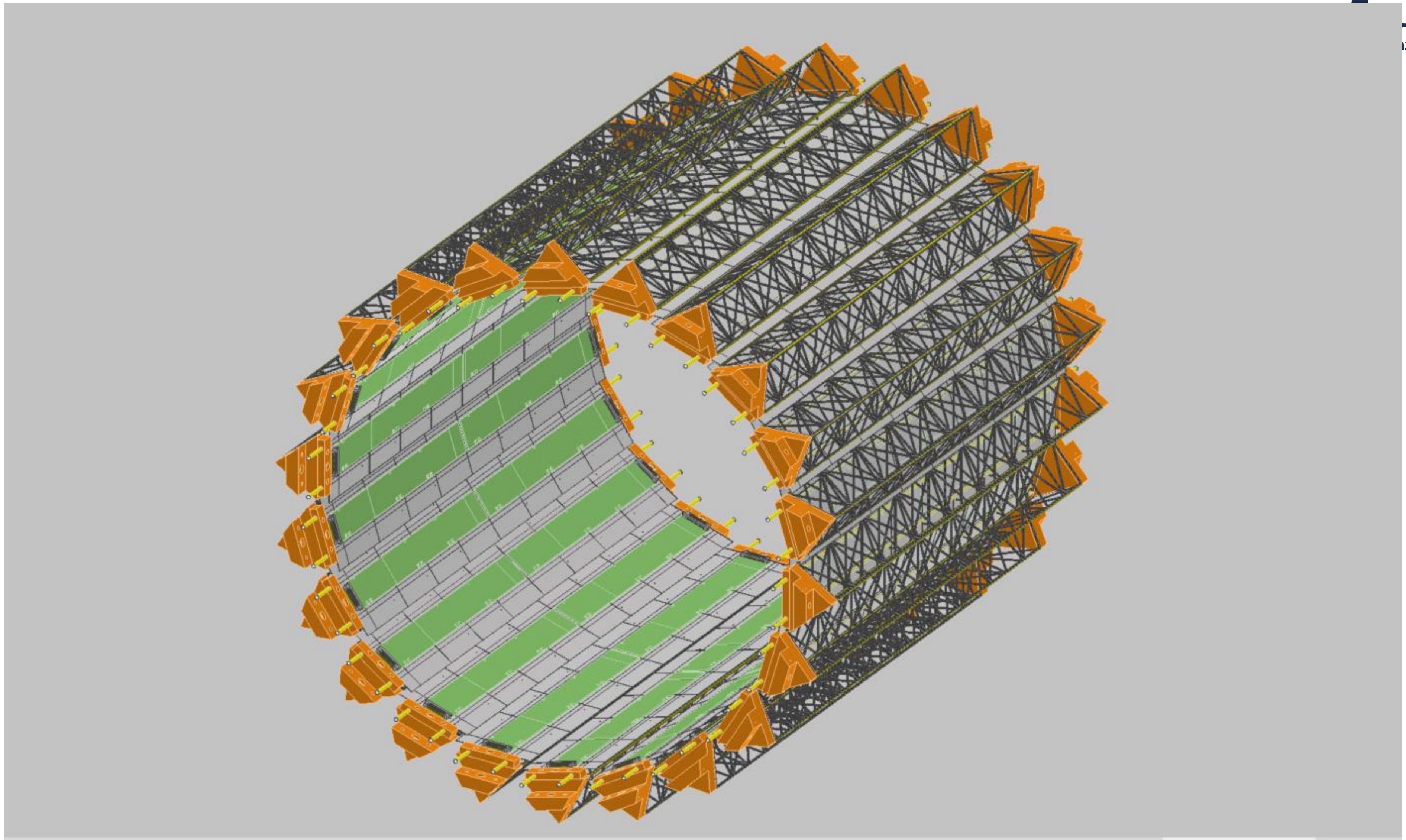


MIDDLE TRACKER



Stave detail

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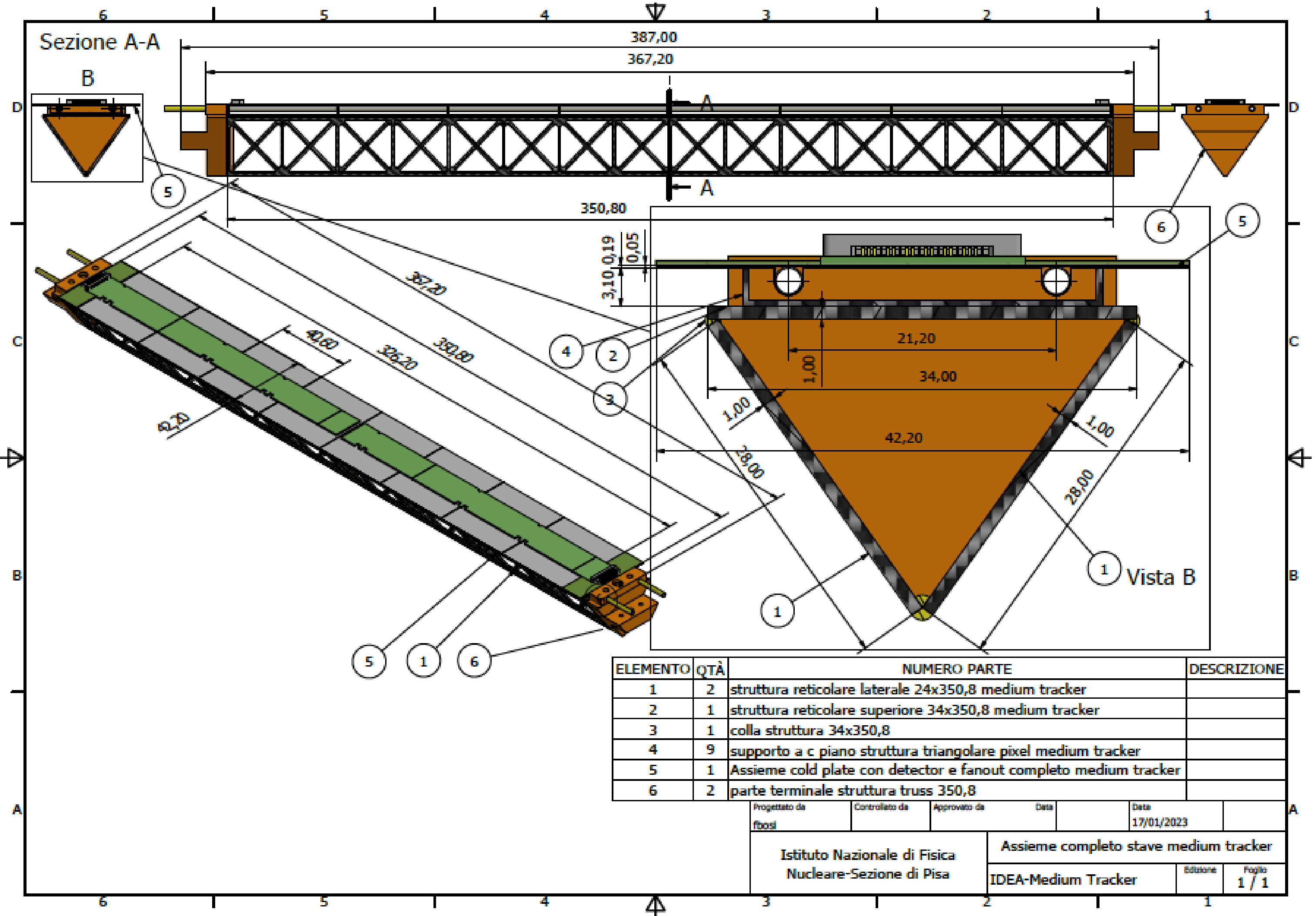
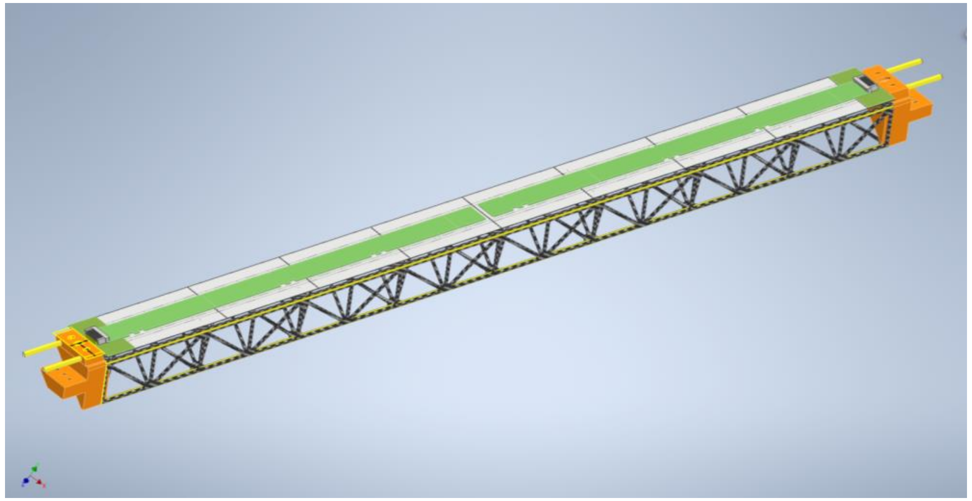
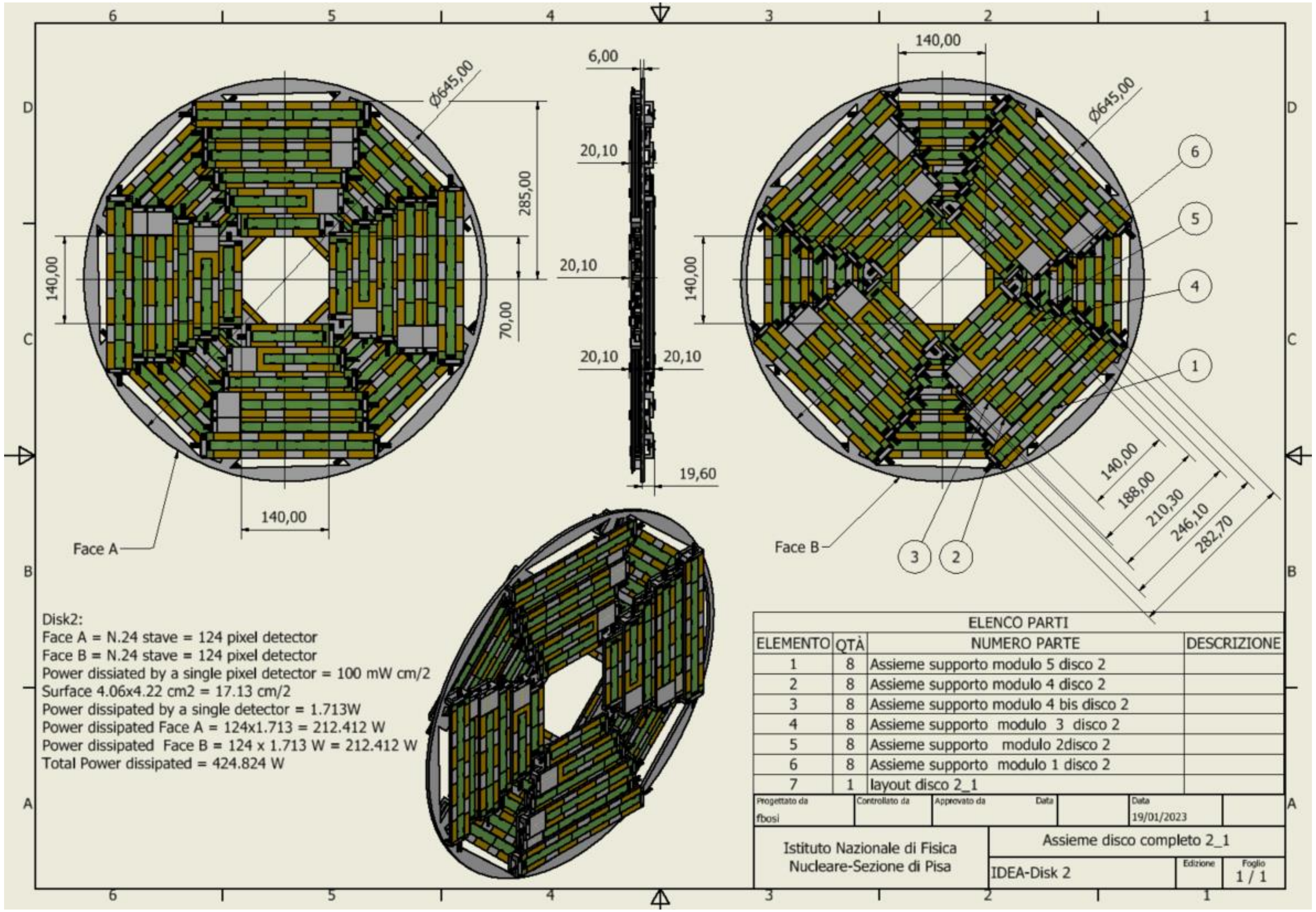


ELEMENTO	QTÀ	NUMERO PARTE	DESCRIZIONE
1	2	struttura reticolare laterale 24x350,8 medium tracker	
2	1	struttura reticolare superiore 34x350,8 medium tracker	
3	1	colla struttura 34x350,8	
4	9	supporto a c piano struttura triangolare pixel medium tracker	
5	1	Assieme cold plate con detector e fanout completo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



DISK 2



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DISK 3

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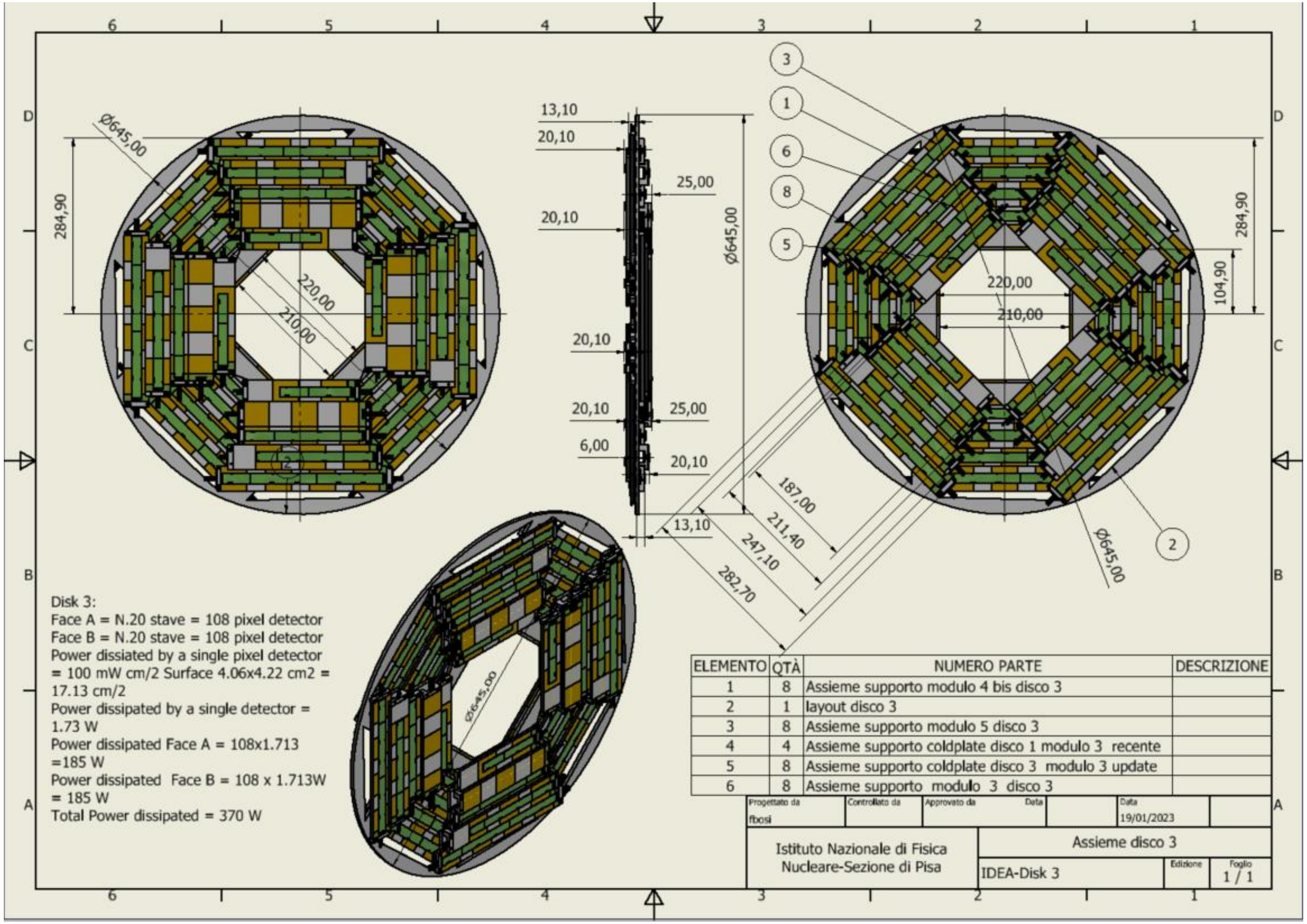
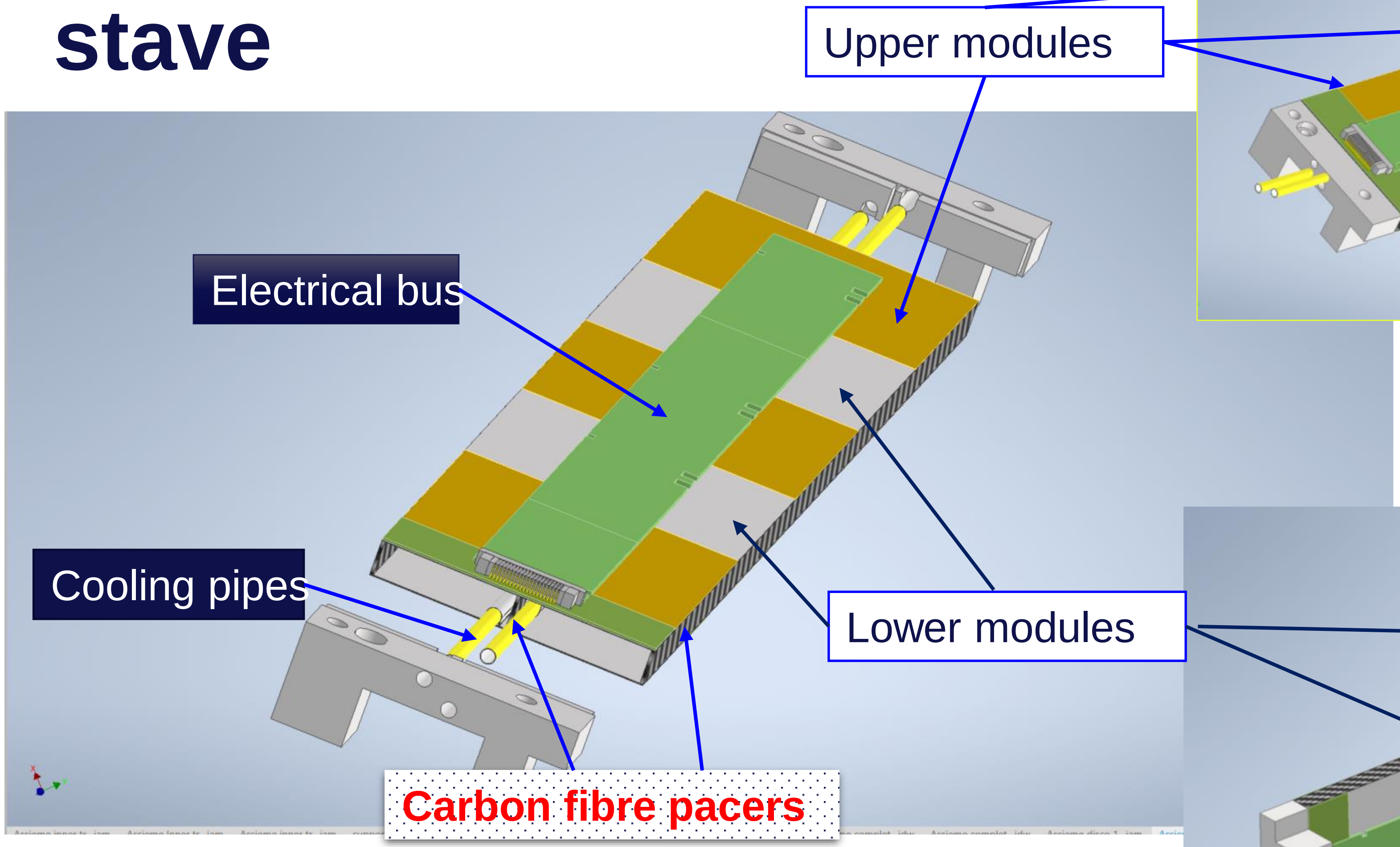
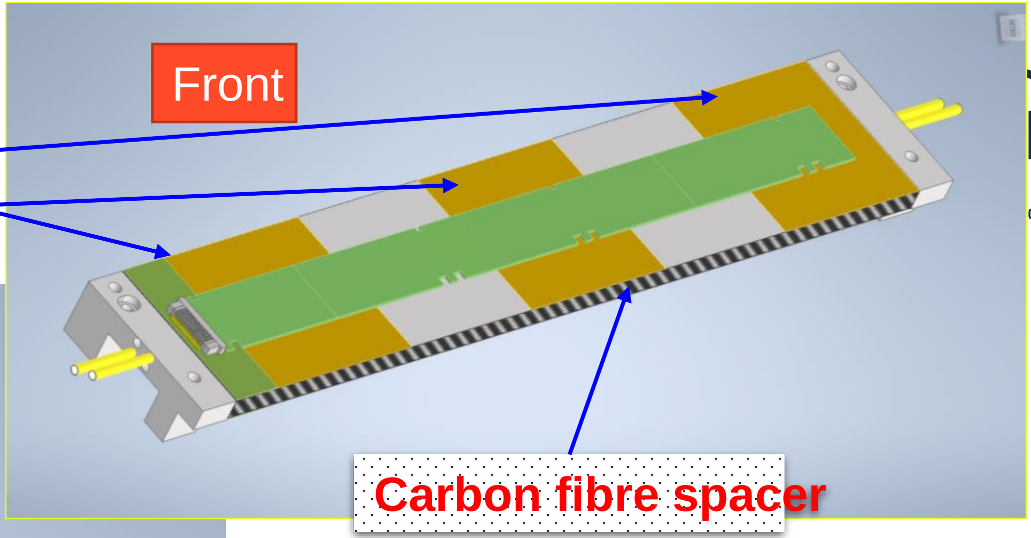
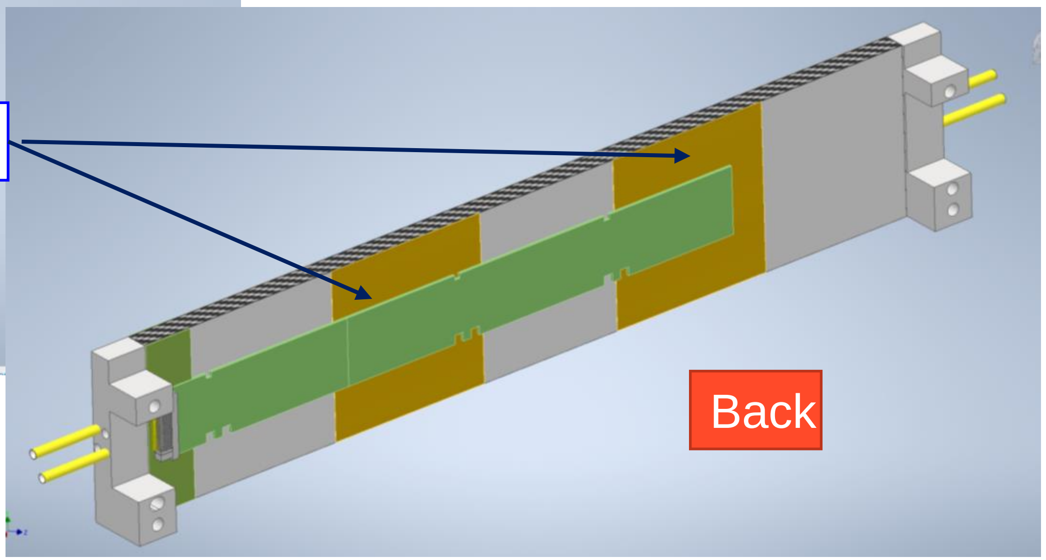


Typical disk module stave

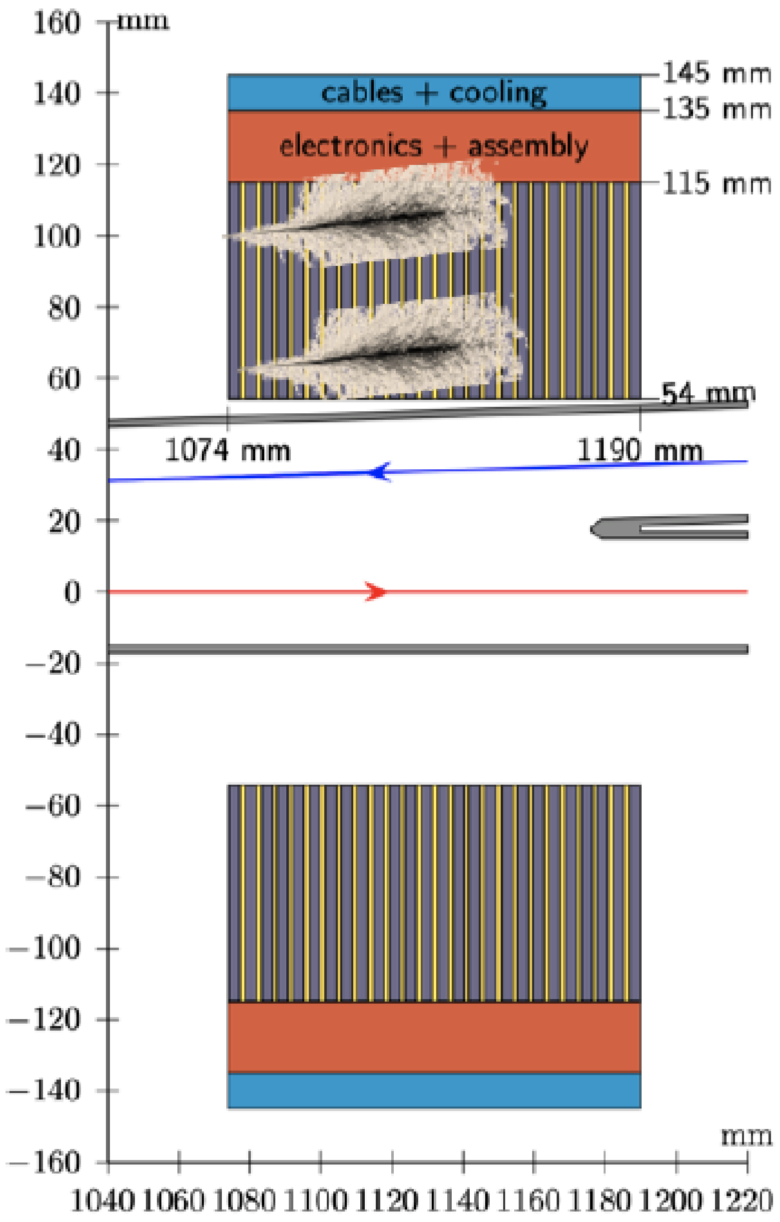






Acceptance and tolerances

- Effective Moliere radius of W-Si sandwich: **~15 mm**
- Stay 1 Moliere radius away from both inner radius and somewhat more at outer radius
    - To be optimised
- => **Wide acceptance:** **62 – 88 mrad**
- Slightly smaller **narrow acceptance**: **64 – 86 mrad**
    - **Bhabha cross section: 14 nb**
        - Compared to 30 nb multihadronic Z decays at peak
- Geometrical tolerances for shift in acceptance of 10^{-4}:
    - **Inner border:** $\delta\Theta_{min}$ **= ± 1.3 µrad ;** δR_{min} **= ± 1.5 µm**
    - **Outer border:** $\delta\Theta_{max}$ **= ± 3.0 µrad ;** δR_{max} **= ± 3.3 µm**
    - **Half distance between two calorimeters:** δZ **= ± 55 µm**



CDR LumiCal Design

Design considerations:

- Need to control geometry to a precision of $\mathcal{O}$(1 µm)
  - Keep geometry as simple as at all possible

  Multilayer barrels where all layes have identical circular geometry

- 25 layer SiW sandwich
  - 3.5 mm W (1 X_0) + 1.0 mm gap for Si pads
- Physical dimensions
  - Sensitive region: r = 54-115 mm
  - Region for "services": 115-145 mm
  - Calorimeter face at x = 1074 mm
- Proposed segmentation
  - 32x32 pads/layer (1.9 x 10-22 mm² pads)
  - 25,600 channels per LumiCal
- Weight
  - About 65 kg per LumiCal