R&D for vertex tracker

Fabrizio Palla on behalf of the IDEA Silicon group

INFN Pisa

IDEA Study group

17June 2025

Summary

- **Inner vertex air-cooling test**
- **Vertex services integration and assembly test**
- **Development of a stave for the Silicon Wrapper with serial power and low mass mechanics**

- **Expression of interests submitted to European Strategy Update**

Expression of Interest for a
lightweight vertex detector for FCC-ee

Involved Laboratories:
Italy: INFN - Genova, Frascati, Milano, Padova, Perugia, Pisa, Torino, Trieste-Udine
Switzerland: ETH Zurich, Paul Scherrer Institute, University of Zurich
United States of America: Brown University, BNL, FNAL, LBNL, MIT, SLAC, Stony Brook University

Expression of Interest for the development of modules for
Vertex detector and Silicon Wrapper with combined tracking
and timing capability in LFoundry 110nm technology

Involved Laboratories:
Italy: INFN - Bologna, Milano, Padova, Pavia, Perugia, Pisa, Torino, TIFPA
United States: FNAL

- **Depleted Monolithic Active Pixel Detectors (DMAPS)**
- **Very thin sensors and curved geometries**
- **Layout optimization**
- **Low power architectures: air cooling**
- **Integration with the machine**

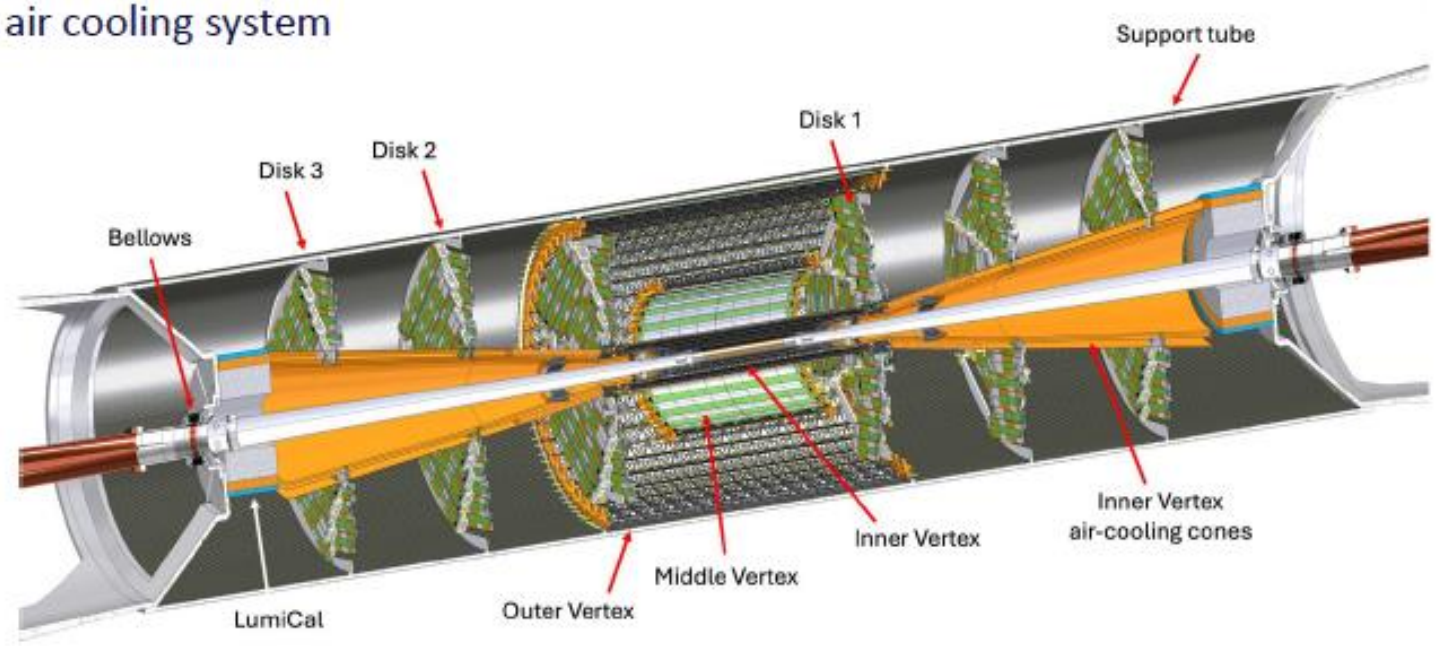
Report on ARCADIA tests and perspectives by M. Mandurrino at the 6th IDEA meeting

https://agenda.infn.it/event/46076/contributions/263027/attachments/134772/201700/2025Mandurrino_RDFCC.pdf

Services integration is instrumental also for the mockup of the interaction region being carried out at INFN-LNF

See M. Boscolo presentation at 2nd IDEA meeting
https://agenda.infn.it/event/43761/contributions/247869/attachments/128381/190149/241119_MDI_Mboscolo_IDEA%20MEETING.pdf

- Central vacuum chamber with cooling system
- Conical vacuum chamber with cooling system
- Bellows
- Inner vertex detector with air cooling system
- Outer tracker
- Support tube
- Luminosity calorimeter



Current vertex layout

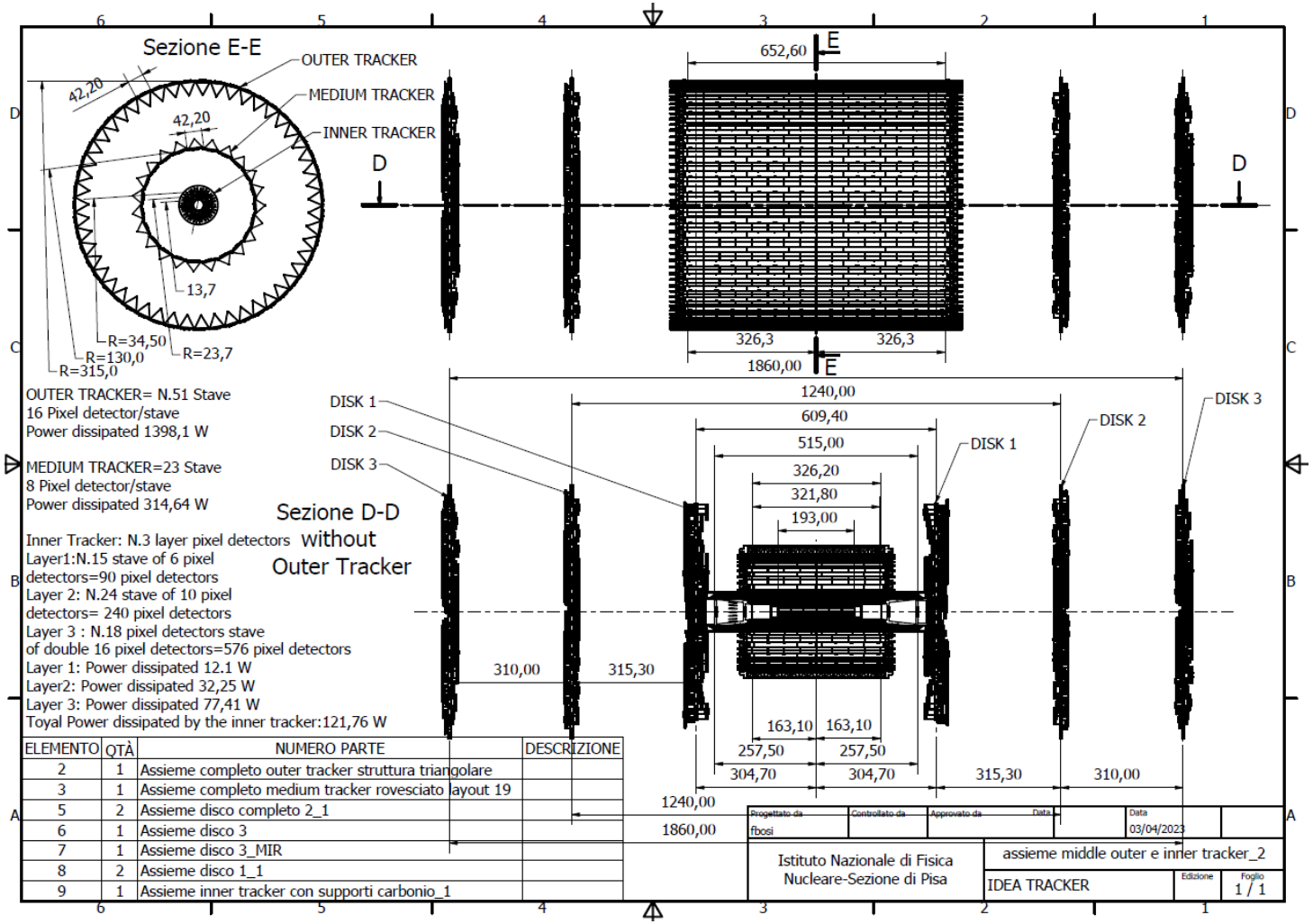
Outer vertex tracker:
ATLASPix3 based

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

Inner Vertex detector:
ARCADIA based

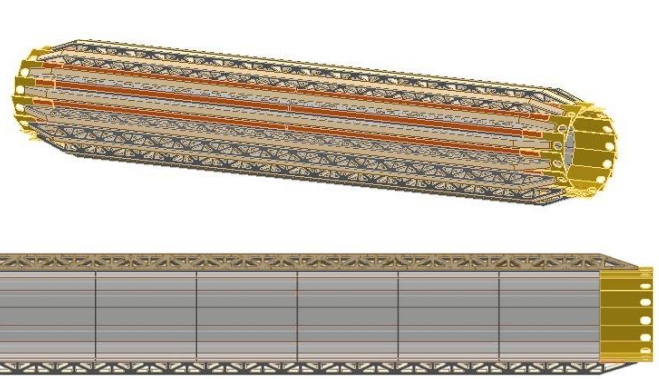
Modules of $25 \times 25\ \mu m^2$ pixel size

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

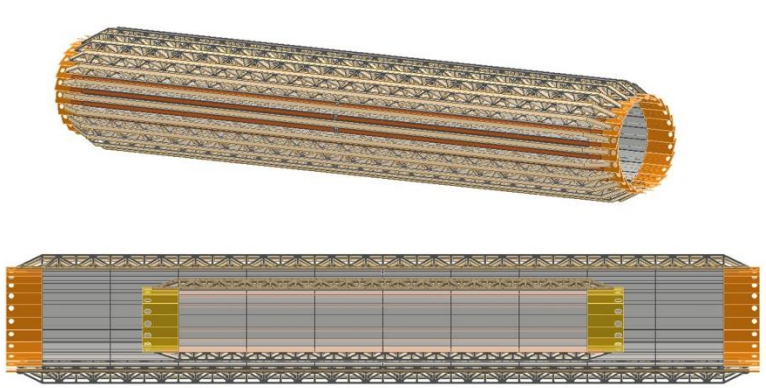


Inner vertex

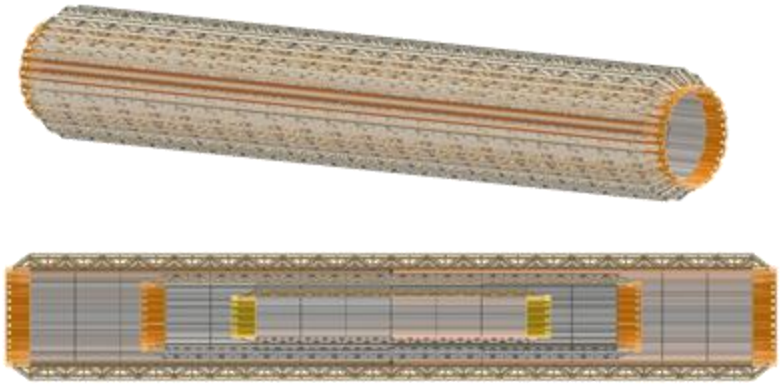
Layer 1:
15 staves of 6 modules
Power budget ≈ 12 W



Layer 2:
24 staves of 10 modules
Power budget ≈ 32 W



Layer 3:
36 staves of 16 modules
Power budget ≈ 77 W



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**

AIR INLET SUPPORT

Air cooling system to keep at a stable and uniform manageable temperature the silicon detectors

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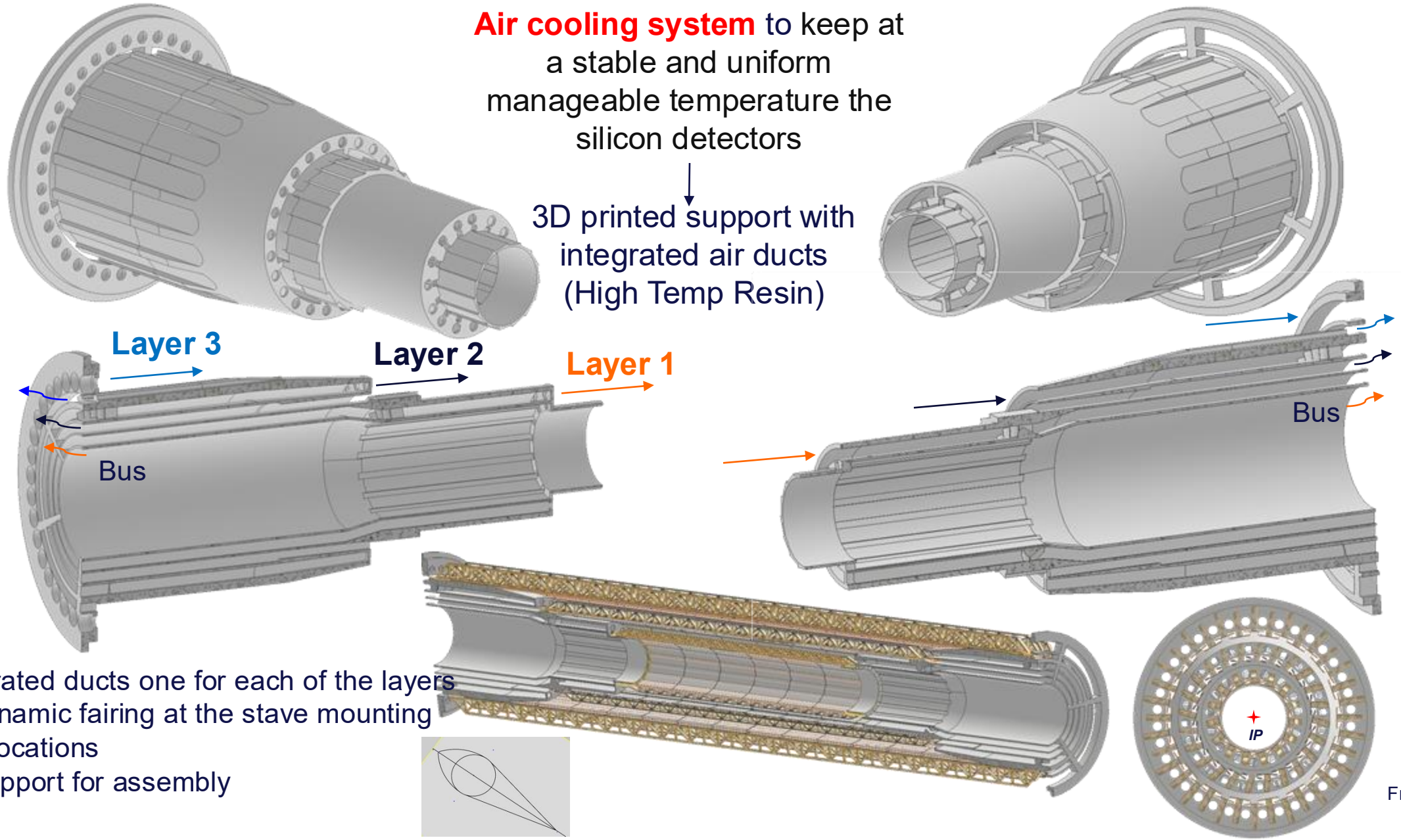
3D printed support with integrated air ducts (High Temp Resin)

AIR OUTLET SUPPORT



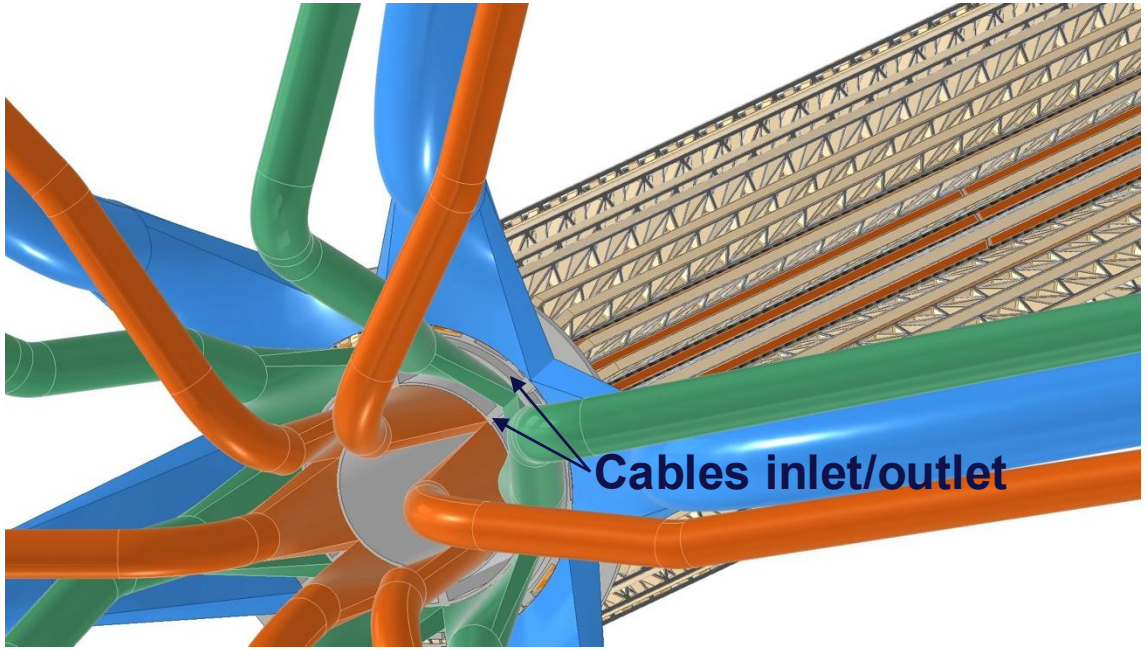
- 3 separated ducts one for each of the layers
- Aerodynamic fairing at the stave mounting screw locations
- Split support for assembly

Front view

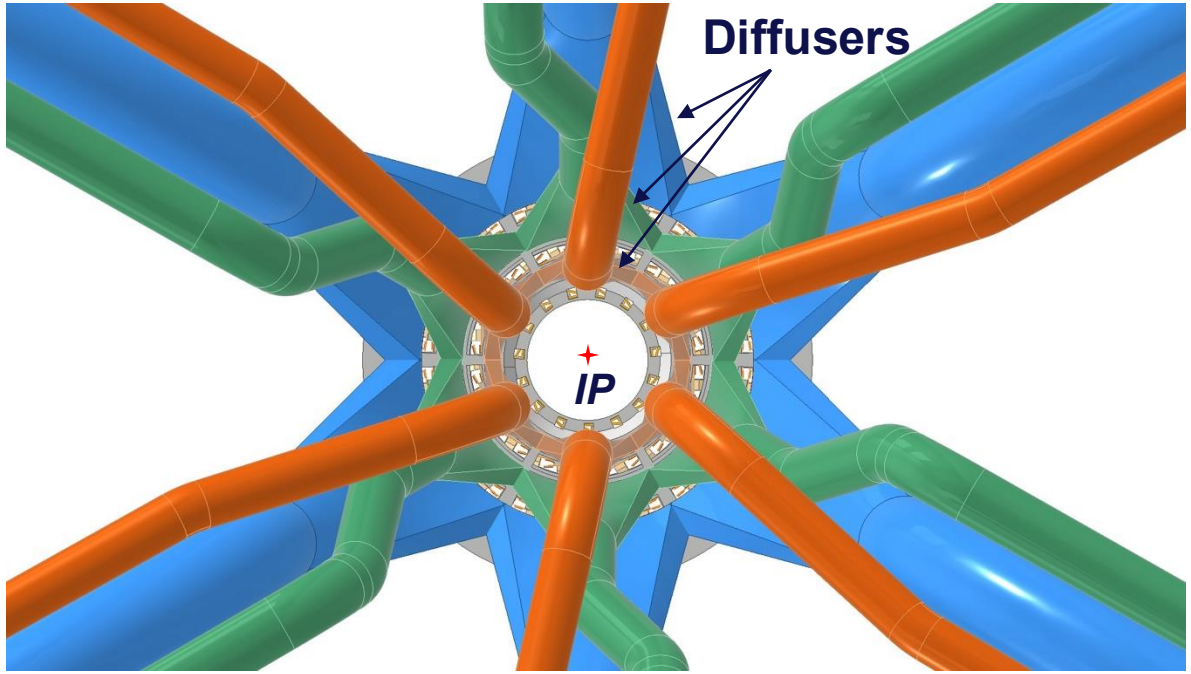
Study of the services

- **Inner vertex**
  - Air cooled

- **Outer vertex and disks**
  - Water cooled

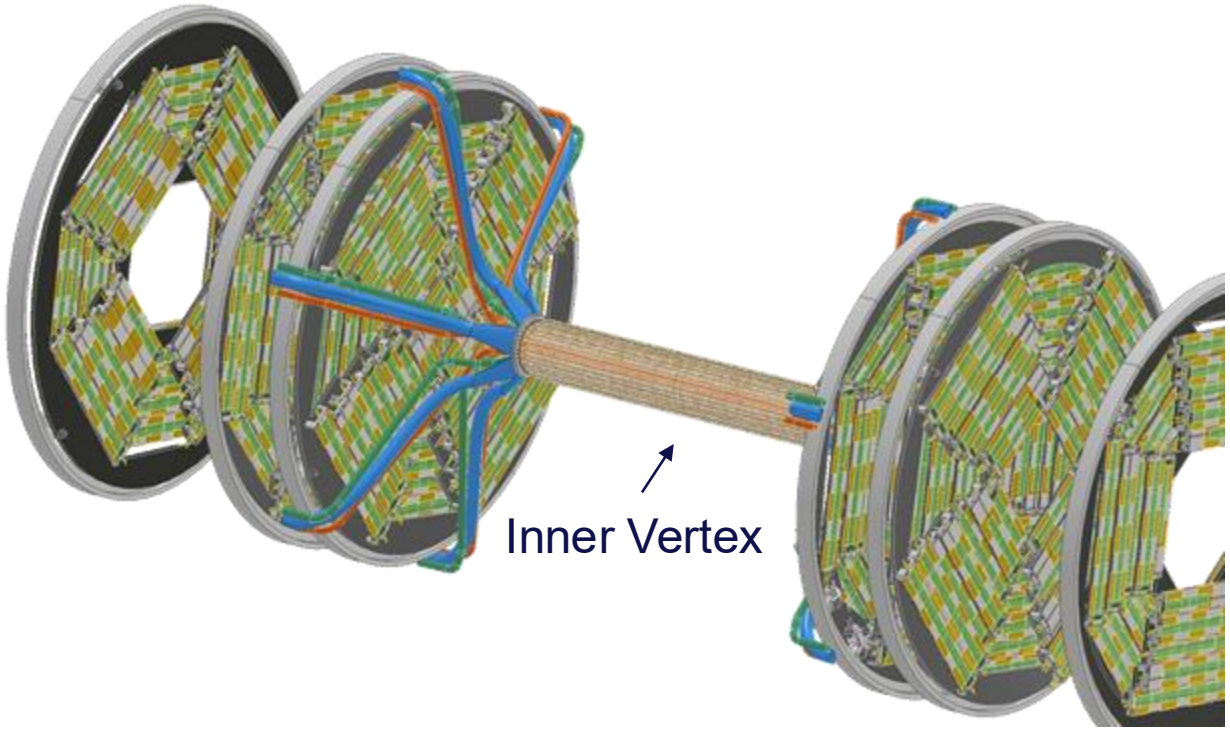


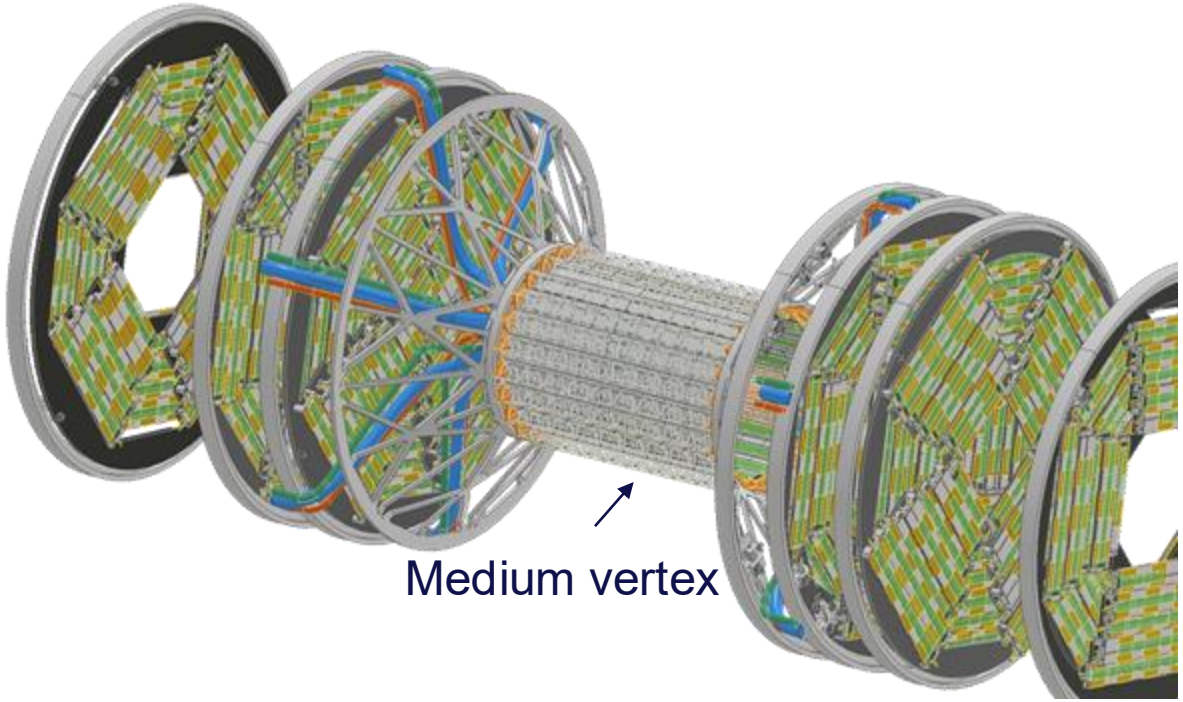
— Layer 3 ducts
— Layer 2 ducts
— Layer 1 ducts



Rear view

<u>6 sectors of 60° for each of the three indipendently powered layers</u> → Diffusers included in the 3D printed support with hose connection → Need to be optimized in terms of length and pitch angle to allow for easy cables routing

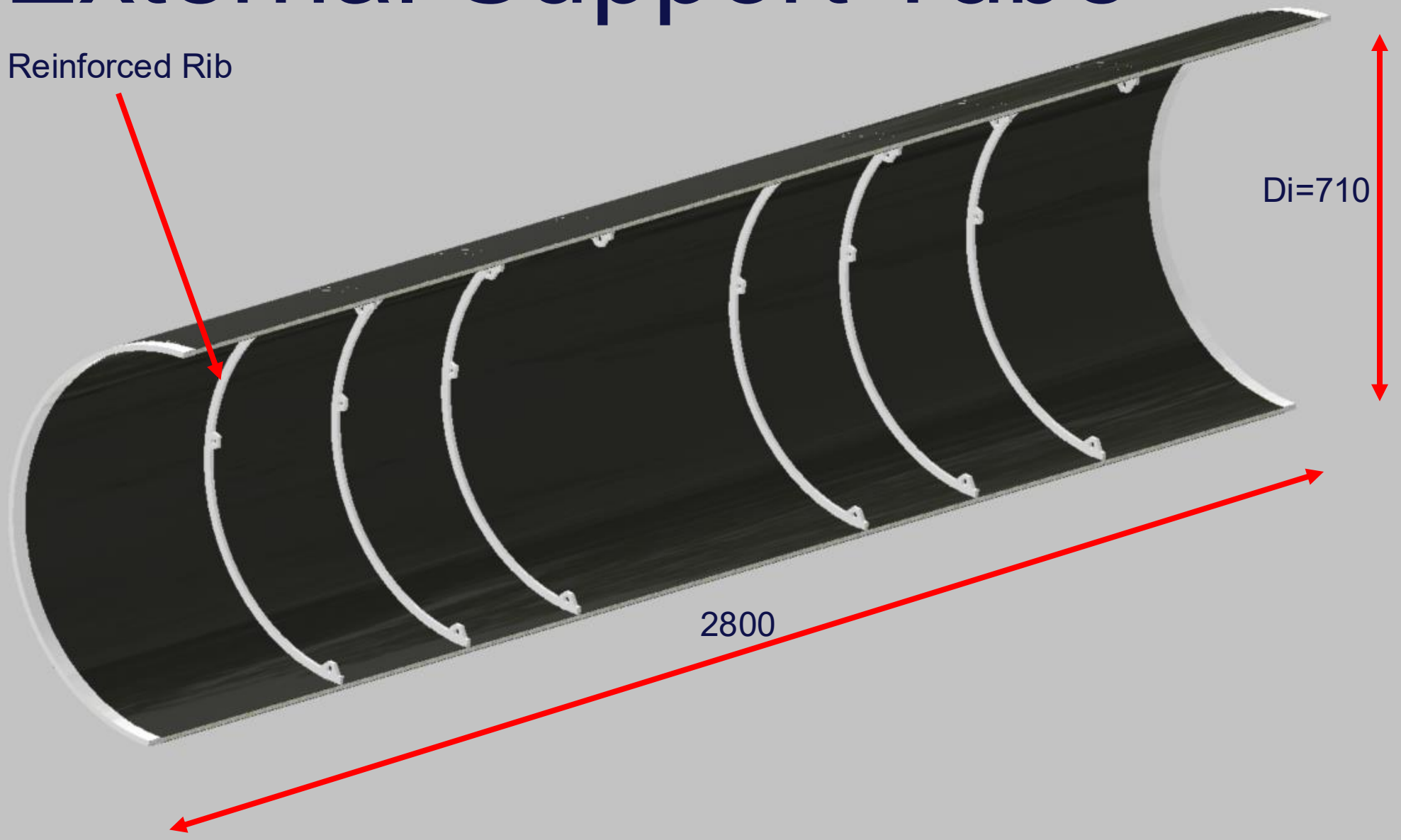


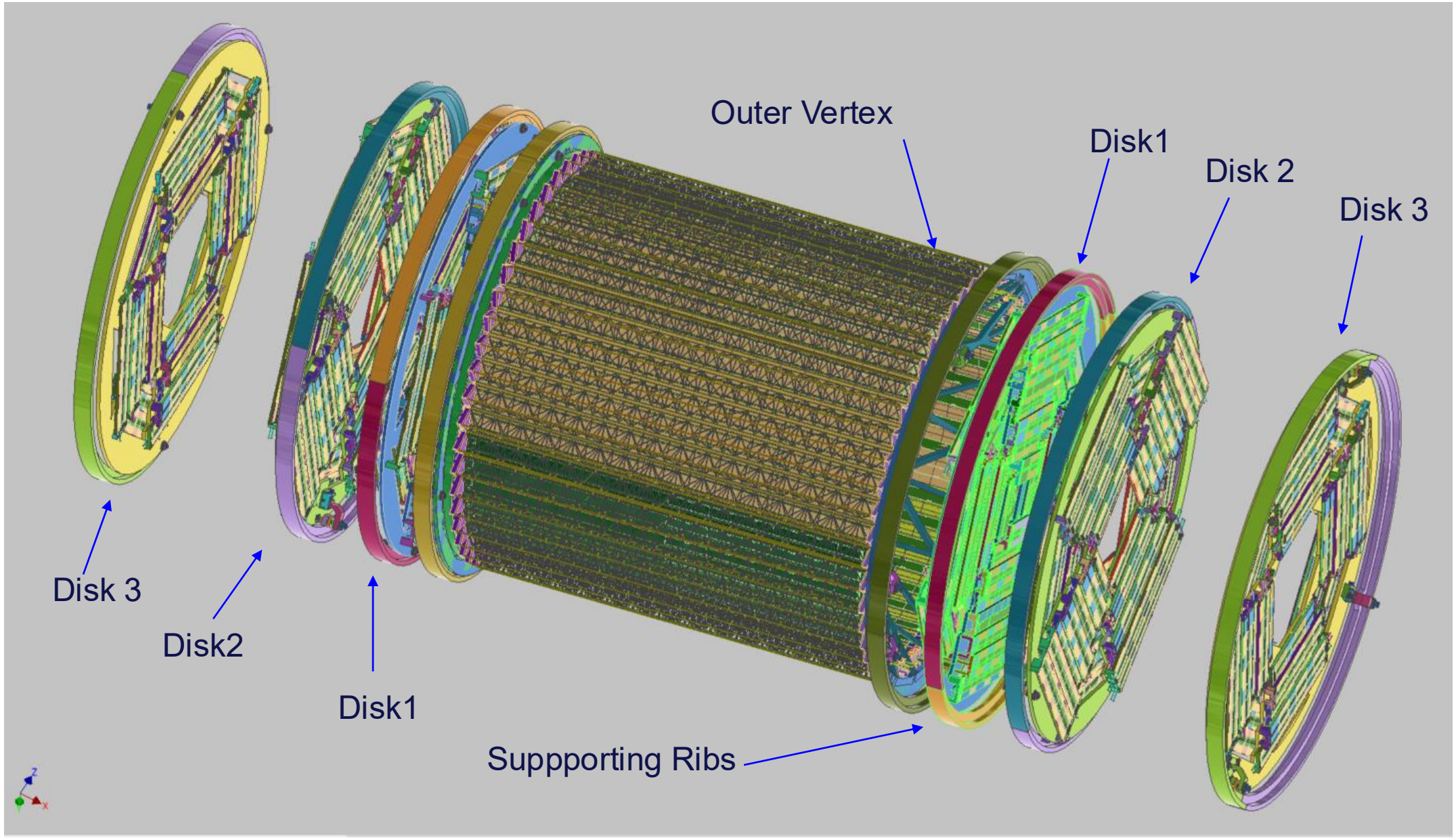


Pipe system that wraps around the innermost disk:

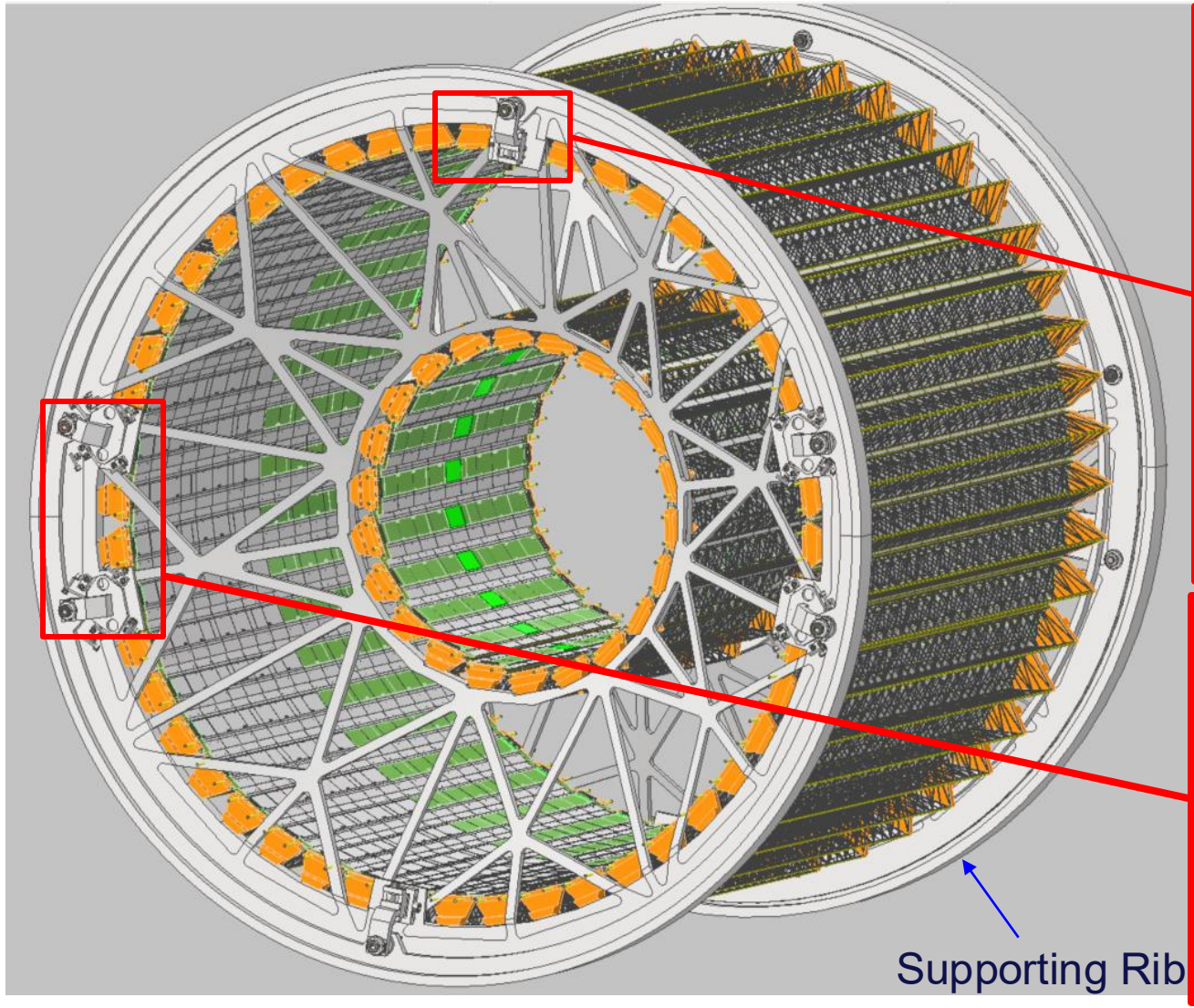
- Minimize the effect on the others
- Necessity of an adequate assembly procedure

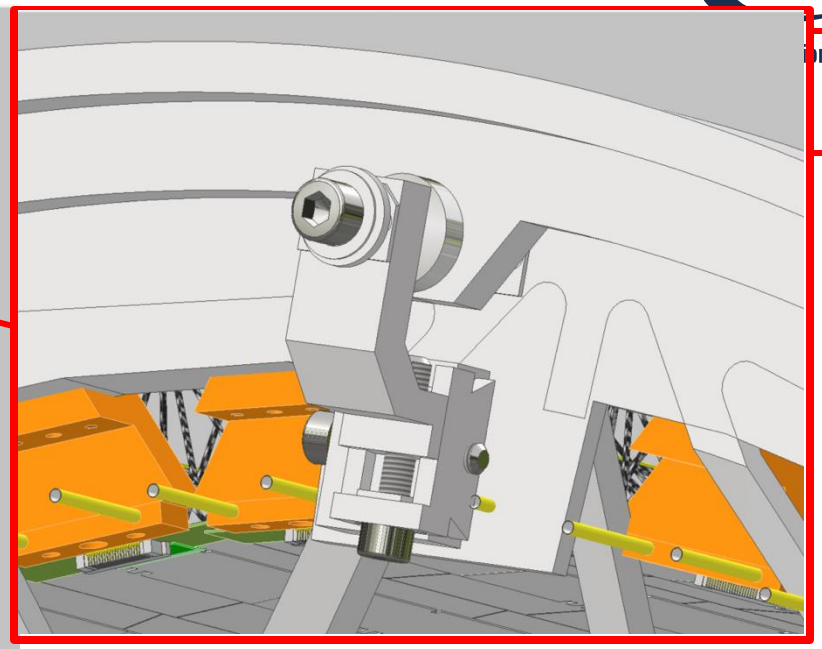
External Support Tube



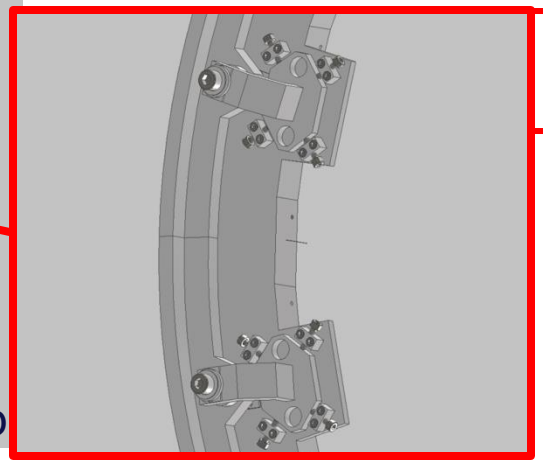

Outer Vertex
Disk1
Disk 2
Disk 3
Disk 3
Disk2
Disk1
Suppporting Ribs

Positioning of the Inner and Outer Vertex



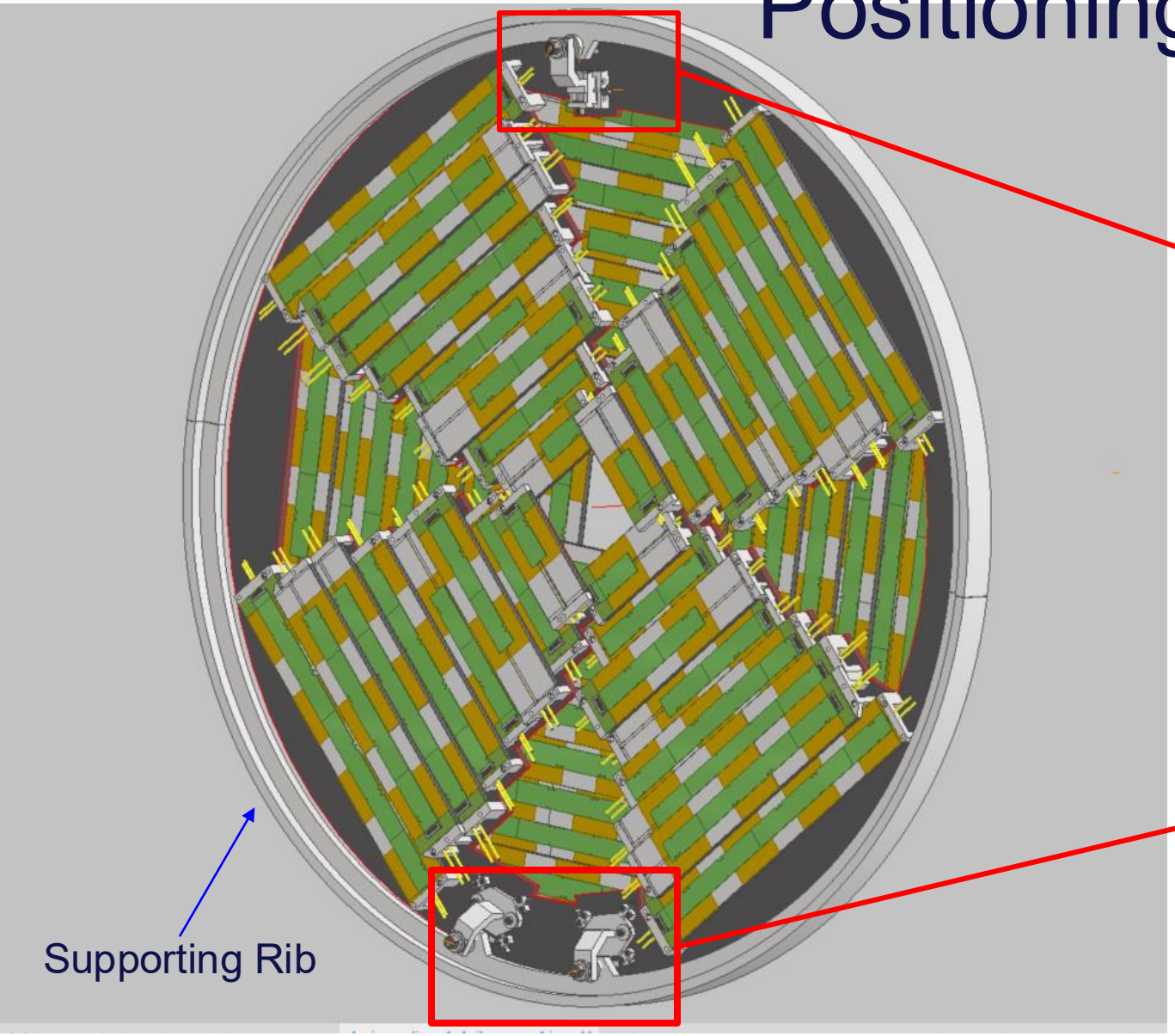


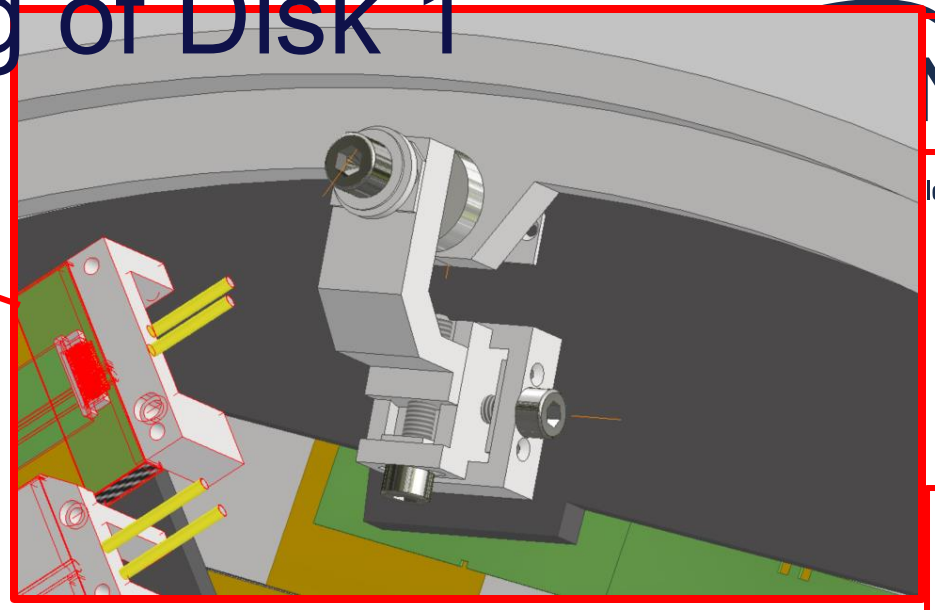
X,Y,Z setting



Angular,Z setting

Positioning of Disk 1





X,Y,Z setting

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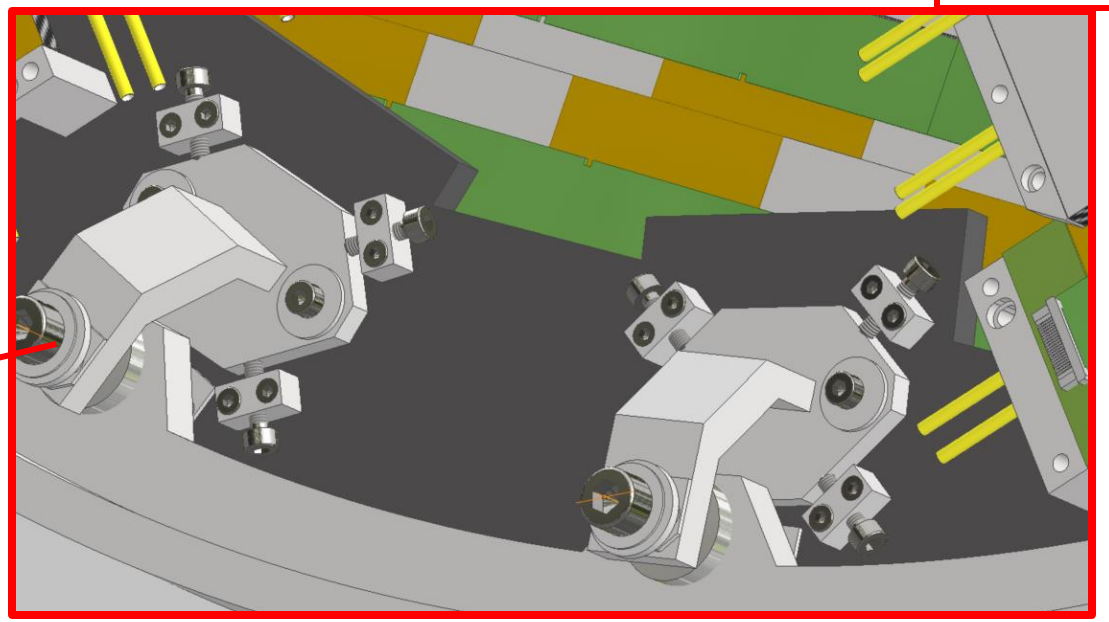
Angular, Z setting



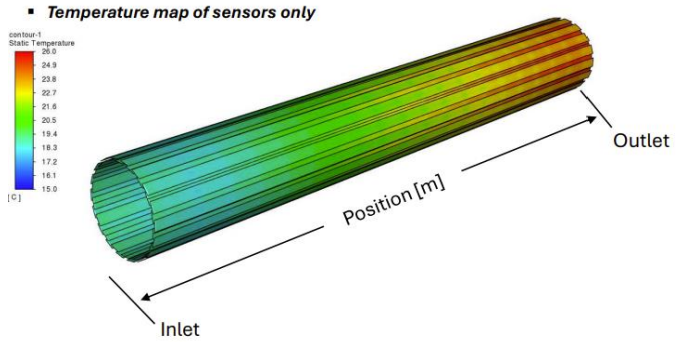
Study of the air cooling

Goal of the study

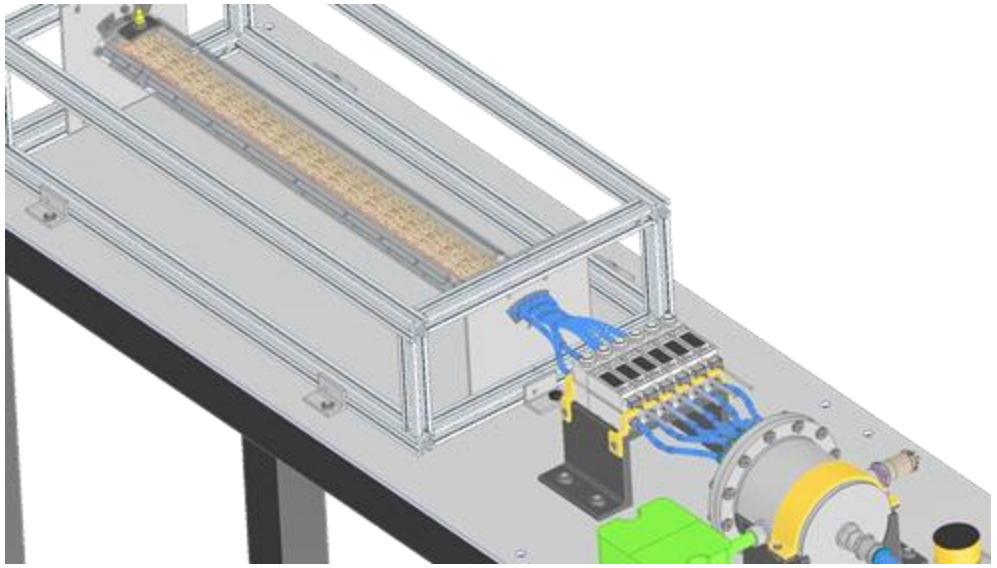
- **Reproduce simulation result**
- See
- https://indico.cern.ch/event/1439509/contributions/6289579/attachments/2995130/5276700/Baldinelli.pdf

- **Test turbulence, mechanical stress/vibrations**

- **Test interference with cables and beam-pipe services**



Experimental setup to evaluate the effectiveness of air cooling



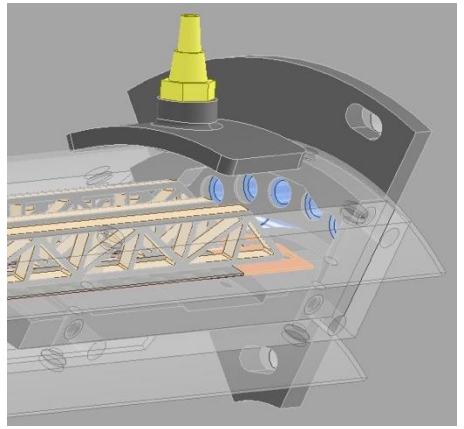
First test on a 60° circular sector of **layer 3** including five staves

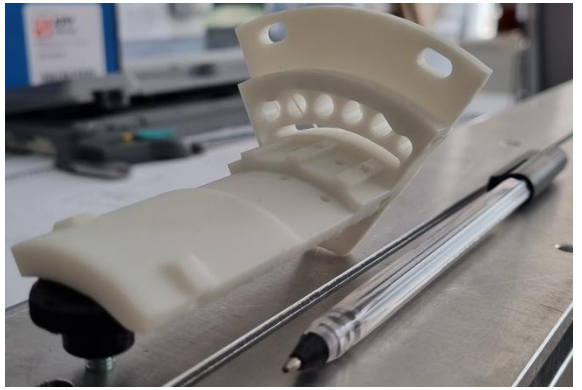
Next test on the same circular sector with all three layers

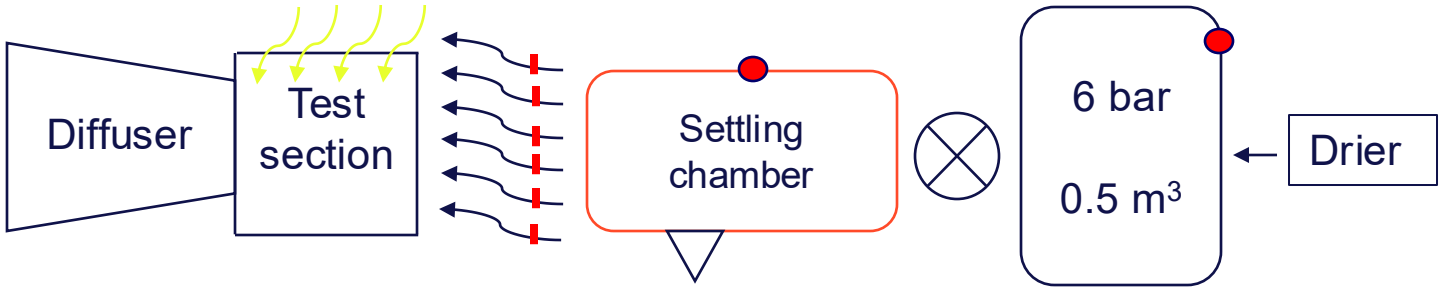
Compressed air system to define:

- **Flow rate** needed to cool the detectors
- **Pressure drop** in the central region
- **Temperature increase** between inlet and outlet

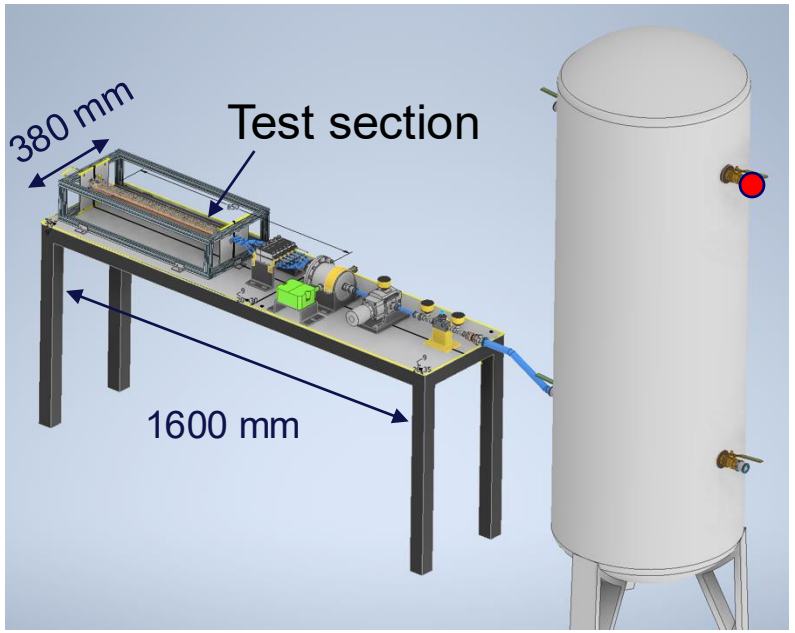
In progress →

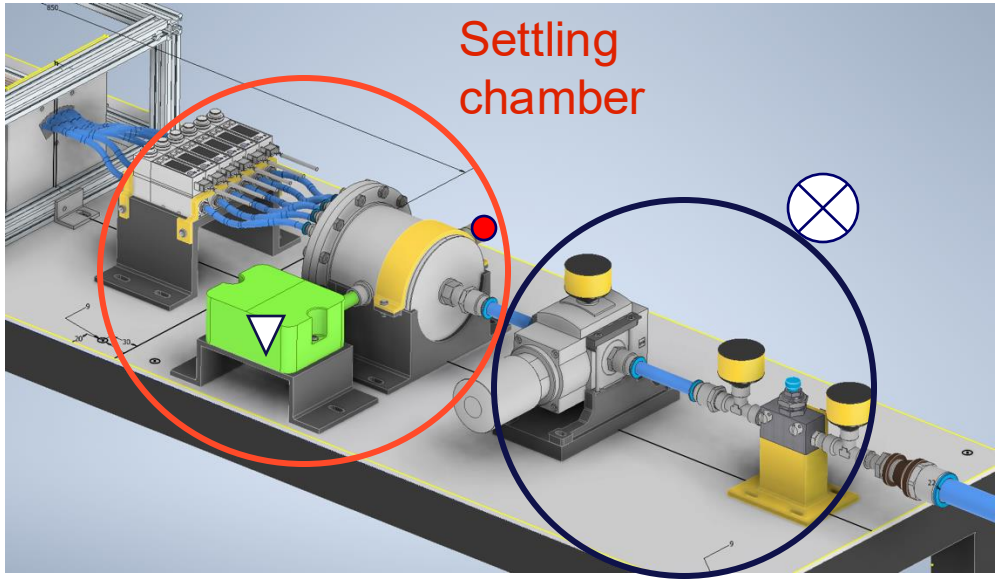


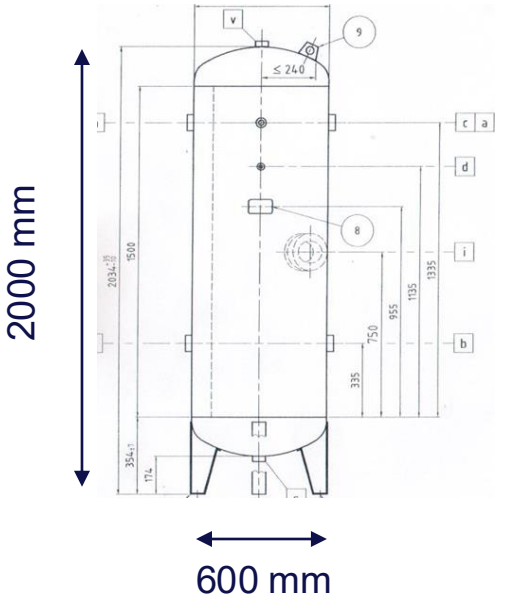




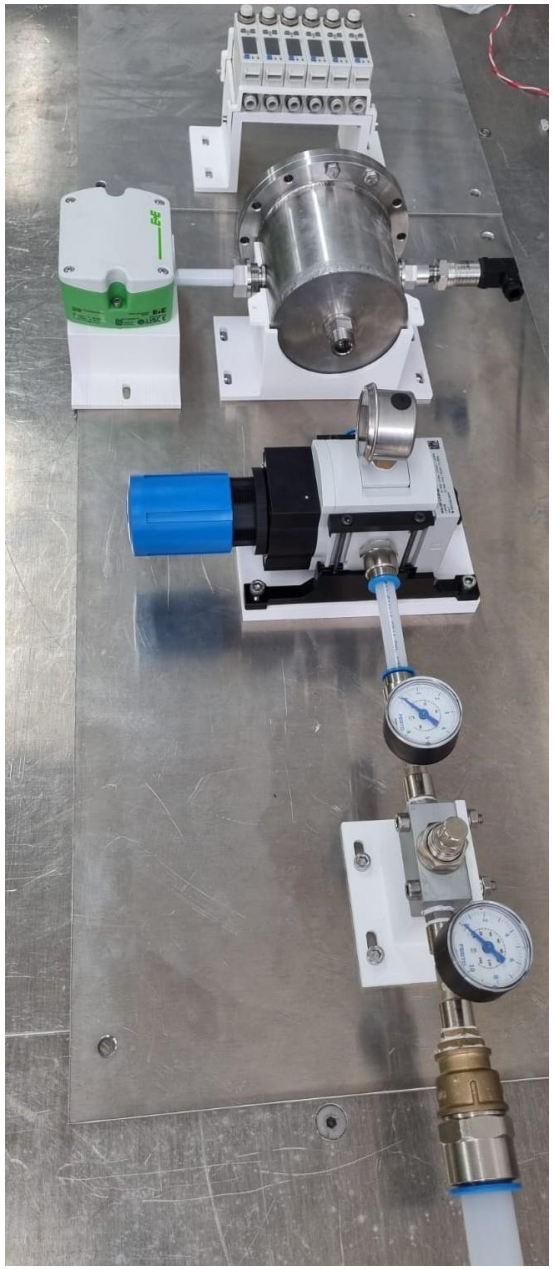
- Flowmeters
- Absolute Pressure sensor
- Temperature/Humidity sensor
- Valve group
- RTD







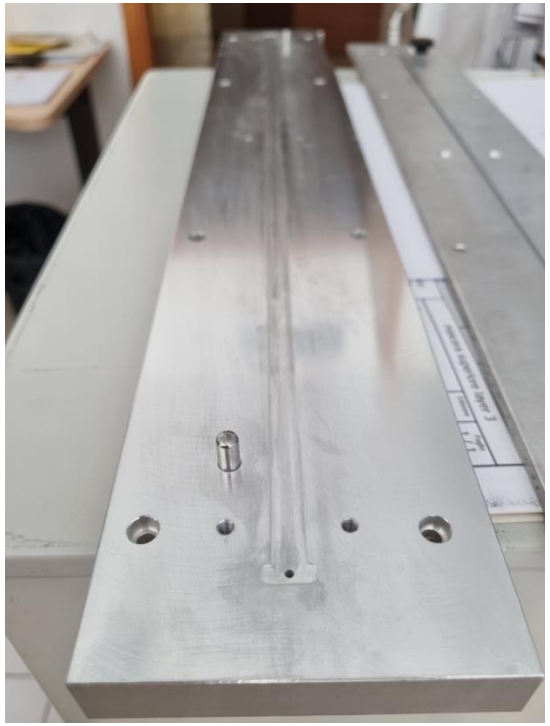
Compressed air system under installation in Pisa



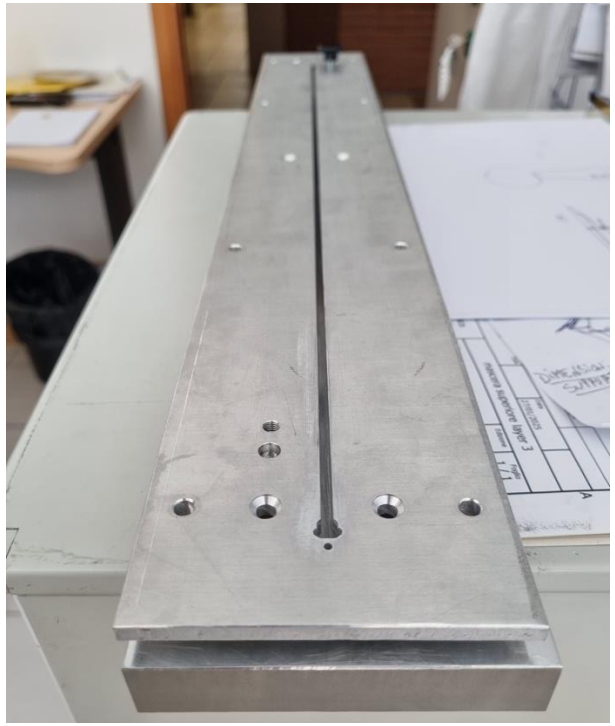
Designed to:

- Be **adaptable**
- Be **controlled**
- Allow **CFD result verification**

Bonding tool



Lower

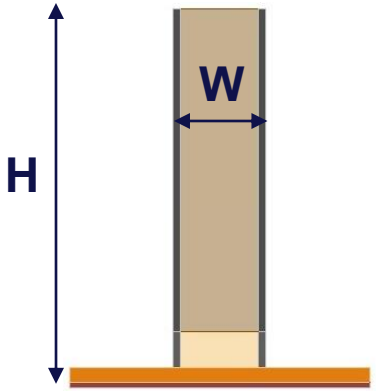


Upper

With stave

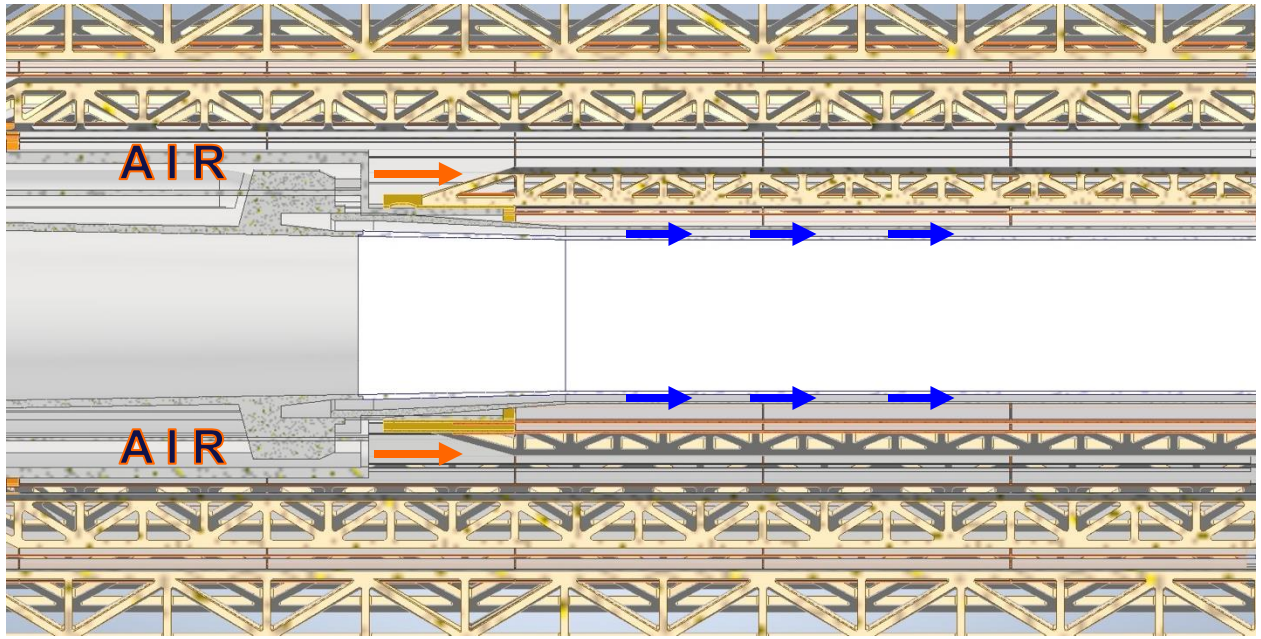
Stave dimensions (mm)		
	H	W
Design	10.25	1.4
Real	10.5	2.6*

* increase in thickness of Rohacell

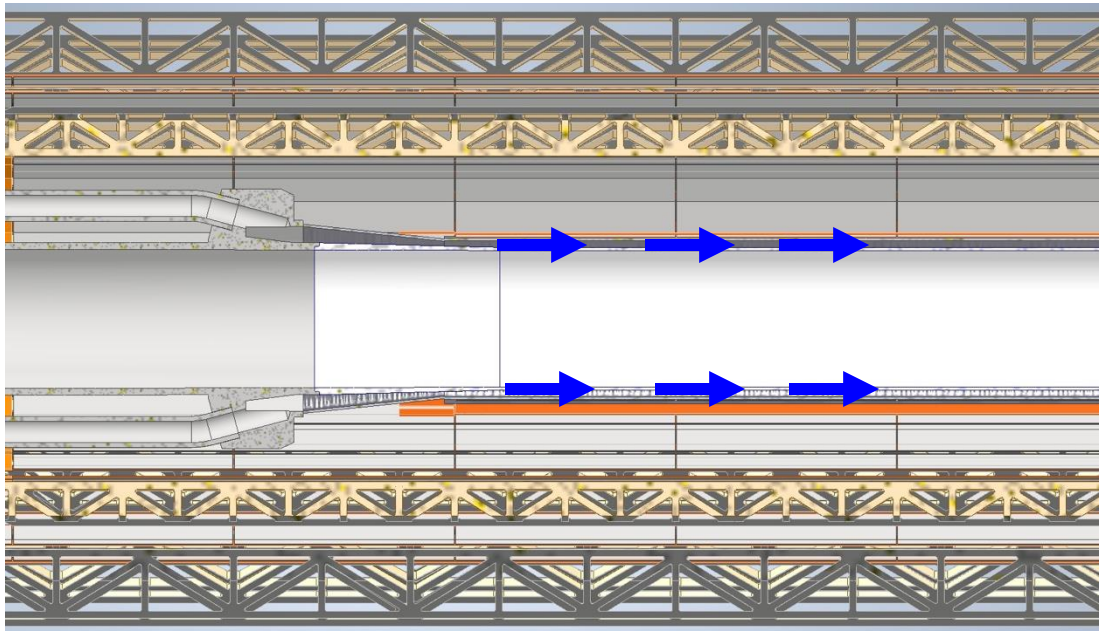


RESULT

Air-cooled Layer 1



Integrated design



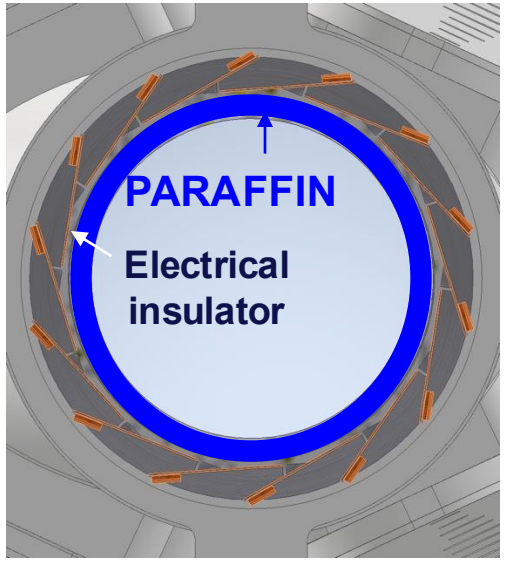
With the **integrated design** solution:

ADVANTAGES:

1. Layer 1 stiffeners are **eliminated**
2. Layer 1 air ducts are **eliminated**
3. Small additional heat load (12 W compatible with the paraffin system performance)
4. Layer 1 is ~2 mm closer to the interaction point
5. Easier integration of cooling systems

Contact between the detectors and the outer jacket mediated by a layer of electrical insulator:

- Kapton
- Ceramics



Need for a rigid support for the sensors:

- **Bonding**
- **Centering**
- **Assembly**

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Design under study

HV-CMOS demonstrator with serial powering

Birmingham, Bristol, Edinburgh, FBK, Heidelberg, Hochschule RheinMain, IHEP, KIT, Lancaster, Milano, Pisa, Torino, Trento

- **P.I. Attilio Andreazza (Milan), Yanyan Gao (Edinburgh)**
- **See presentation by A. Andreazza at the DRD3 week in Amsterdam https://indico.cern.ch/event/1507215/contributions/6540418/**
- **Project goals**

- *Demonstrate the operation of a CMOS based multi-chip module SP chain in realistic environment*
- *Explore high density* low mass *aluminium flex PCB production and innovative interconnections, to reduce*
- **Case study: long staves for the Silicon Wrapper**

Distribution of power and data signals along the local supports

- **serial powering** to reduce dissipation on the distribution lines
- **minimize** the number of connections

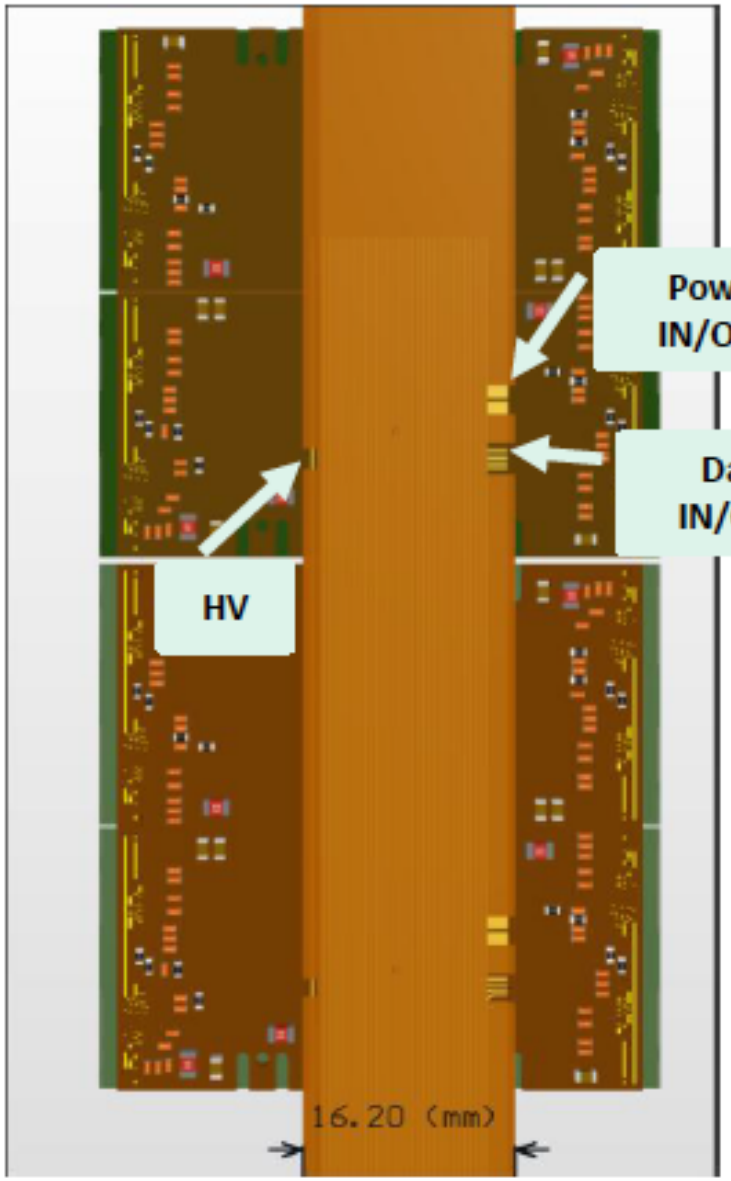
Read-out units are:

- **multi-chip modules** (example 2x2 quad modules)
- (or large stitched detectors)

Minimal I/O connection on chip requires:

- Serial powering chain: all biases generated internally by shunt-LDO regulators
  - 1 LV and 1 HV line per "stave"
- chip-to-chip data transmissions: local data aggregation on module
  - 1 data-out per "module"
- LVDS module configuration with clock data recovery
  - 1 data-in per module
- **No current detector providing all these features**

Reducing material by developing PCB with Al as conductor

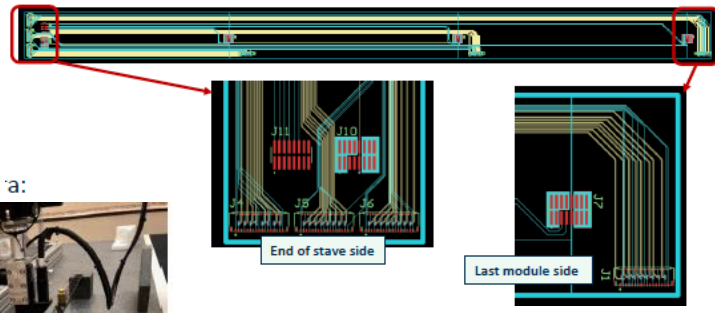


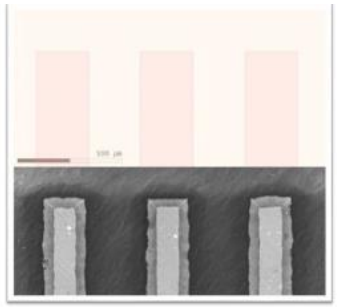
Steps

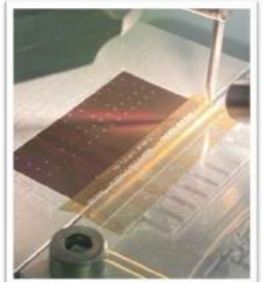
- **Assemble 3 modules with ATLASPix3.1 on a bus to test serial powering**
- Mount and power modules on a long (1330 mm) stave fabricated in Pisa

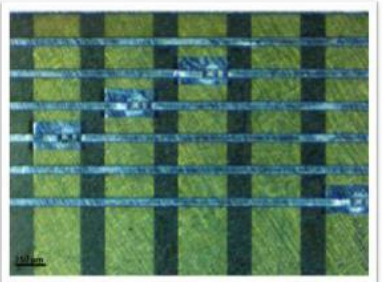
- **Produce a second larger (2 or 4 cm2) in Lfoundry 150 nm with suitable components not available or not tested on ATLASPix**
- clock data recovery , chip-to-chip data handling

- **Develop low-mas Aluminium (20 μm)-Kapton(25 μm) PCBs**
- Mount and power modules on a long stave









Time line

Deliverable	Timeline
Multi-chip module construction and readout (ATLASPix3.1)	06/2025
Al-flex production for ATLASPix3.1 power bus	09/2025
ATLASPix-based SP chain prototype construction and characterisation	03/2026
Submission and production of new CMOS sensors (LF)	07/2025-03/2026
Multi-chip readout flex submission for the LF CMOS sensors	12/2026
Multi-chip LF module construction and readout	03/2027
Al-flex production for the LF CMOS sensors	09/2027
LF sensors based SP chain prototype construction	01/2028
LF sensors based SP chain prototype evaluation	03/2028

Conclusions and perspectives

- **Vertex design activities ongoing**
- **First study of the services**
- **R&D launched for a serial powering and flex demonstrator**