Joint MDI and detectors: Beam pipe, vertex detectors, LumiCa

Vertex detector cooling simulations

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8th FCC Physics Workshop - CERN

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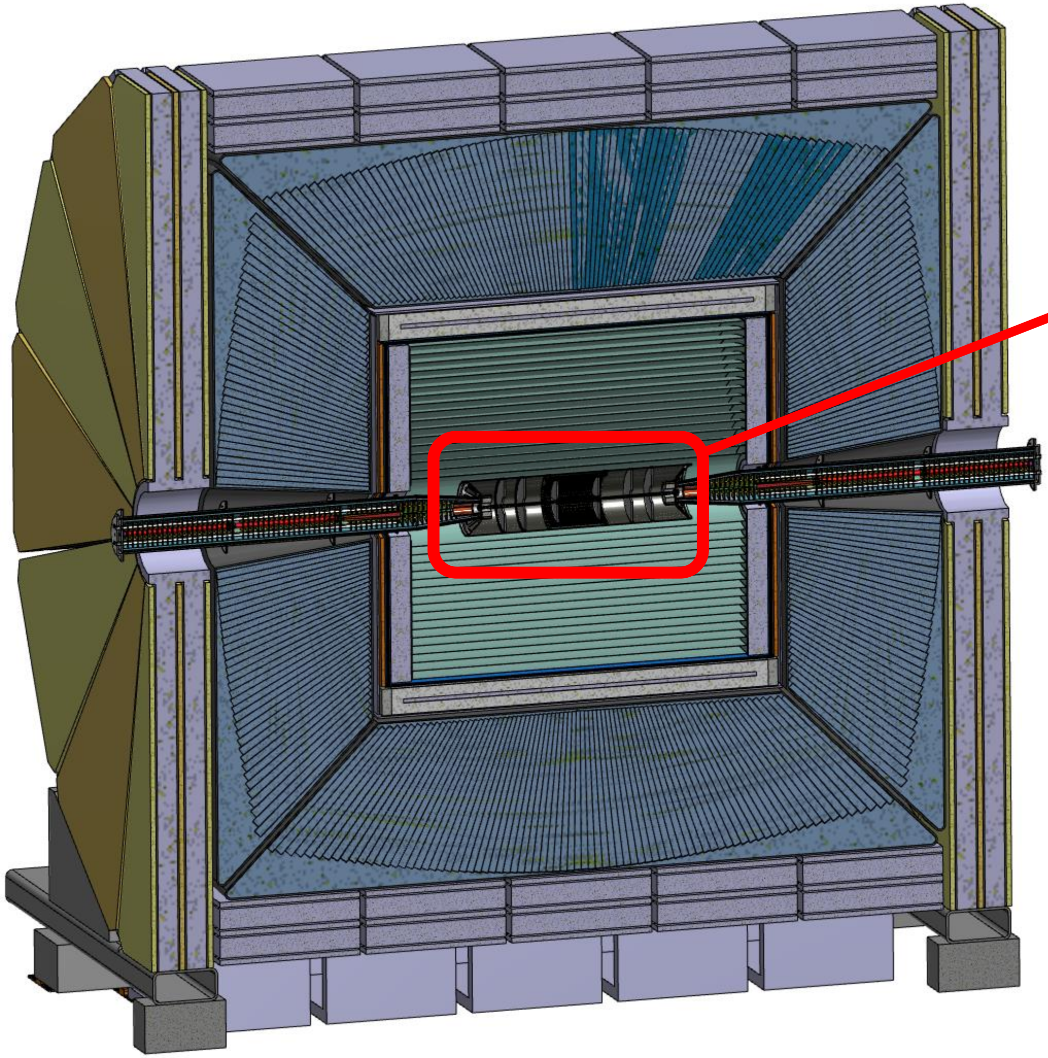
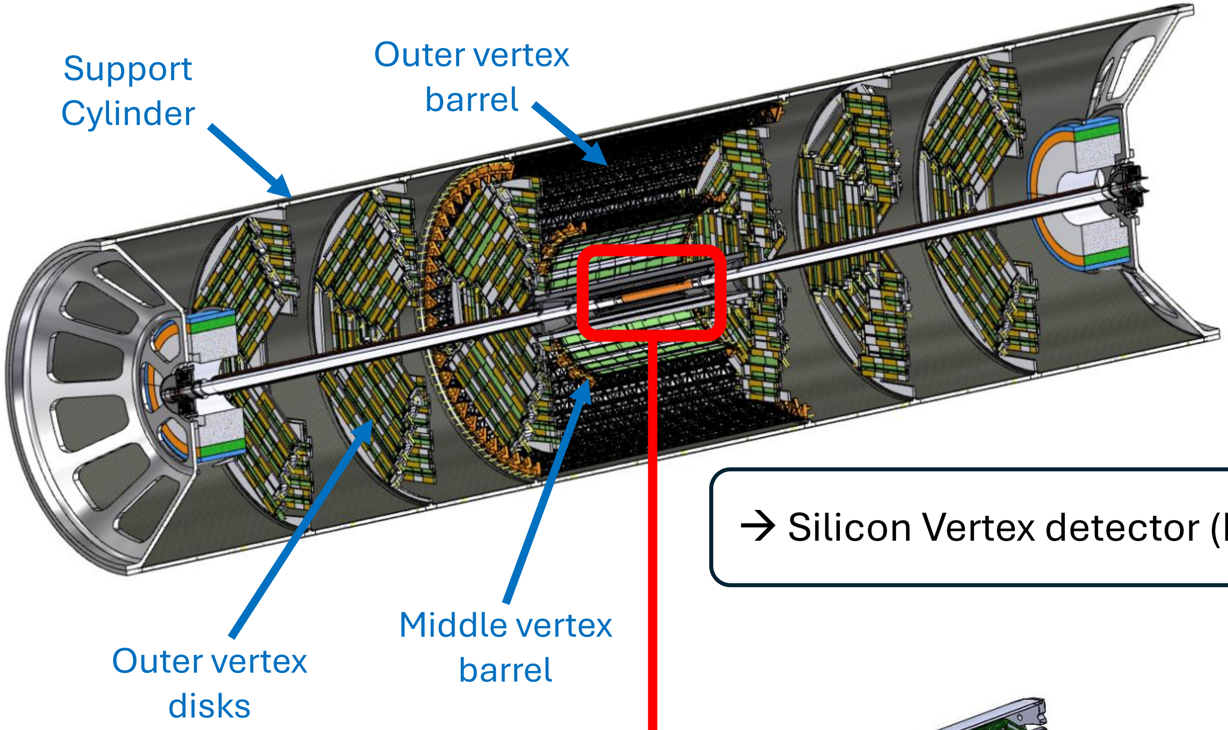
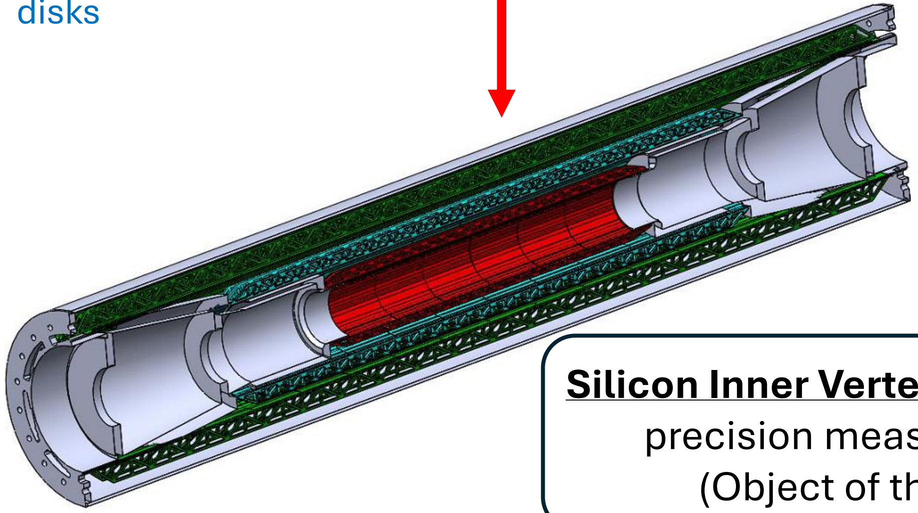
THE IDEA DETECTOR CONCEPT





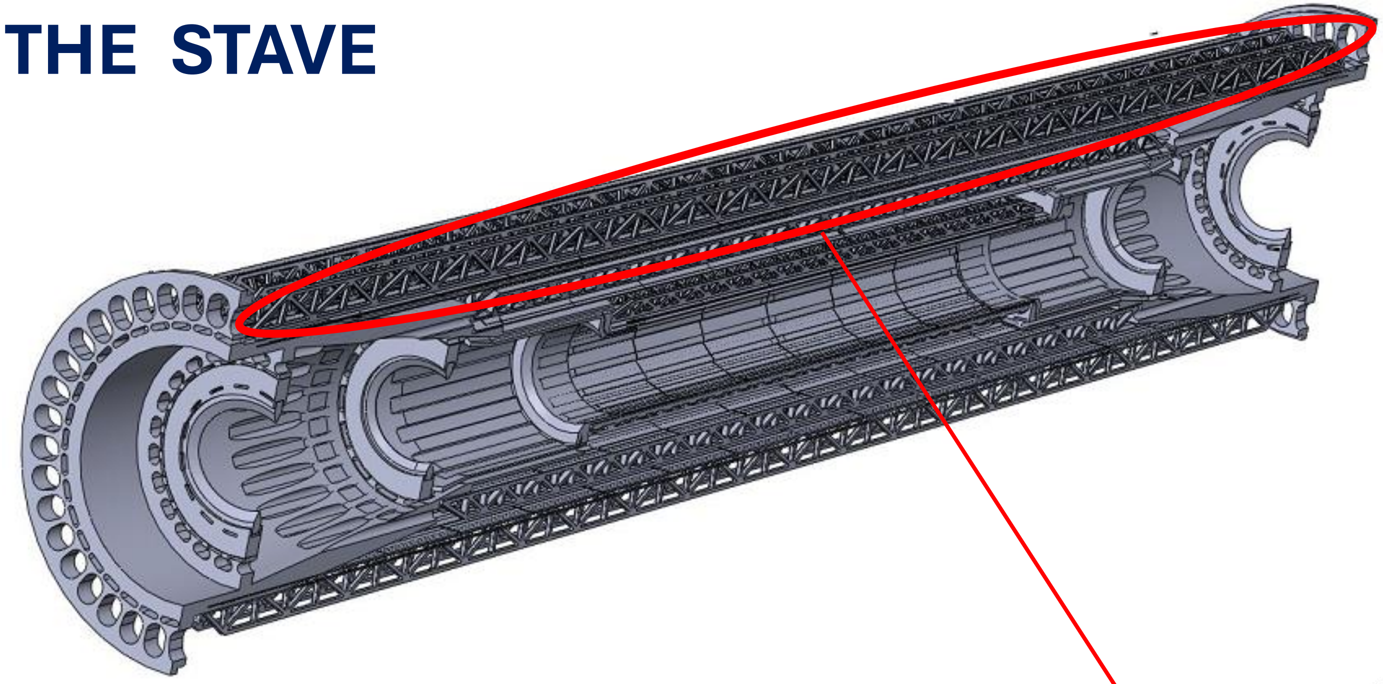
→ Silicon Vertex detector (MAPS)



<u>Silicon Inner Vertex Detector</u> for precision measurements (Object of this talk)

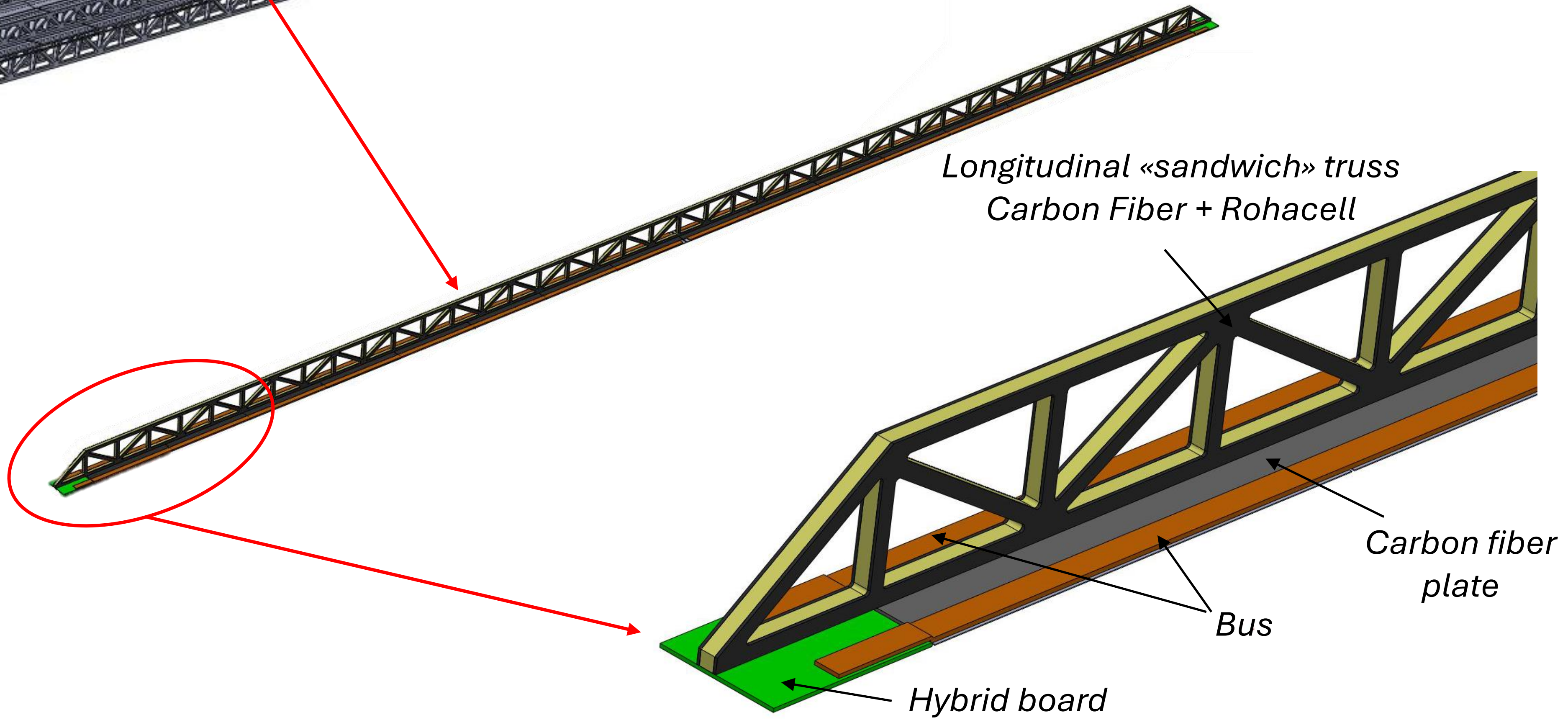
For more info: *Boscolo, M., Palla, F., Bosi, F. et al. Mechanical model for the FCC-ee interaction region. EPJ Techn Instrum 10, 16 (2023).* https://doi.org/10.1140/epjti/s40485-023-00103-7

THE STAVE



- The detector is made of lightweight longitudinal elements (“staves”) supported by endcaps at the ends:

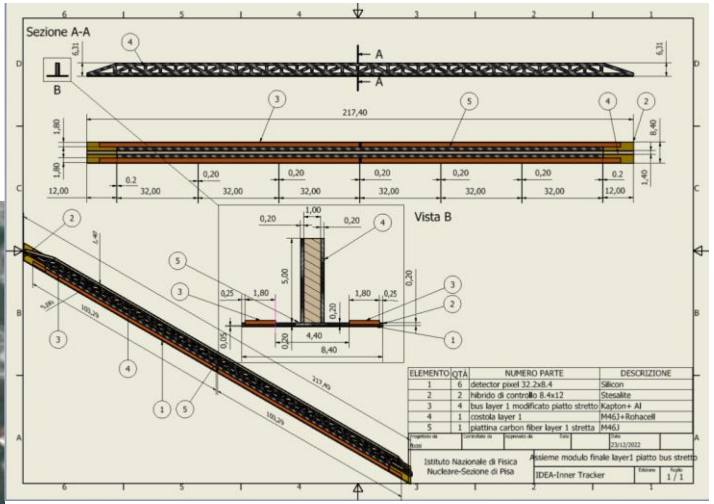
  - 36 staves in layer 3, 16 Modules each, L = 540mm
  - 24 staves in layer 2, 10 Modules each, L = 340mm
  - 15 staves in layer 1, 6 Modules each, L = 220mm



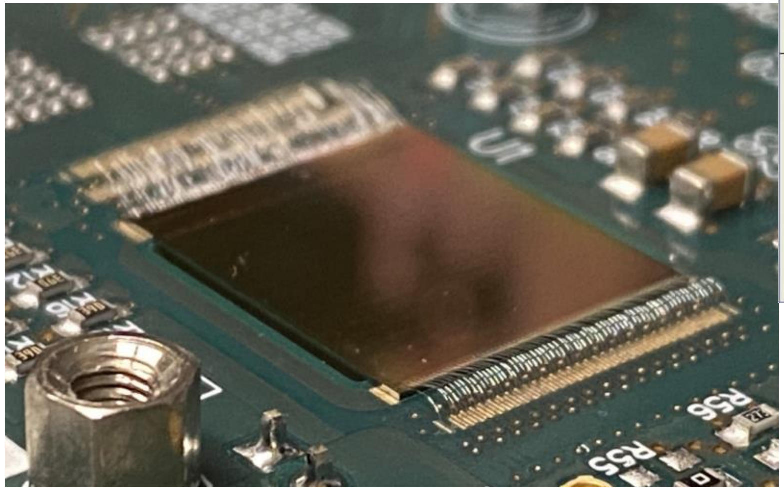
- Reticular lightweight support to provide stiffness.
- Thin carbon fiber walls interleaved with Rohacell.
- 2 buses (data and power).
- 1.8 mm wide and 250 μm thick (50 μm Al, 200 μm kapton) per side.
- Inspired to low mass hybrid R&D.
- Sensors facing interaction point w/o any other material in front.
- Readout chips either sides.

SENSORS

- Sensors are postioned in the bottom face of each stave.

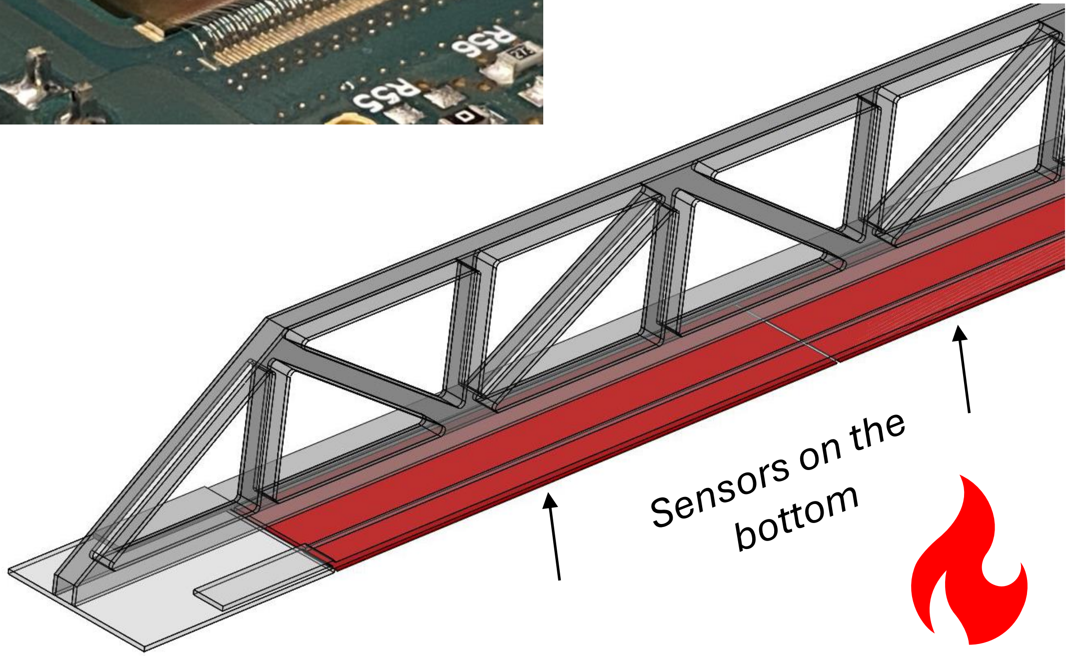


Modules of 25 $\times$ 25 μm^2 pixel size

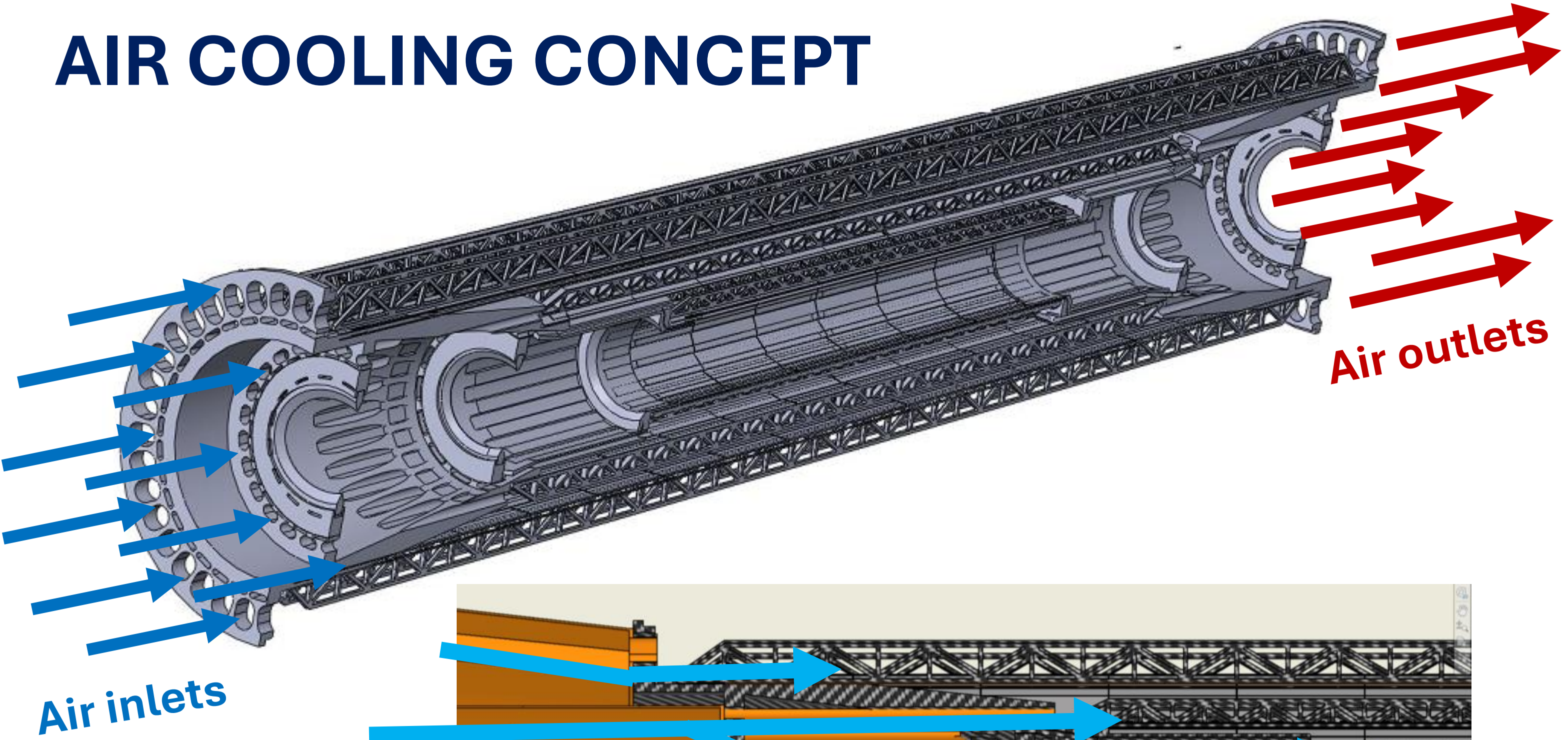


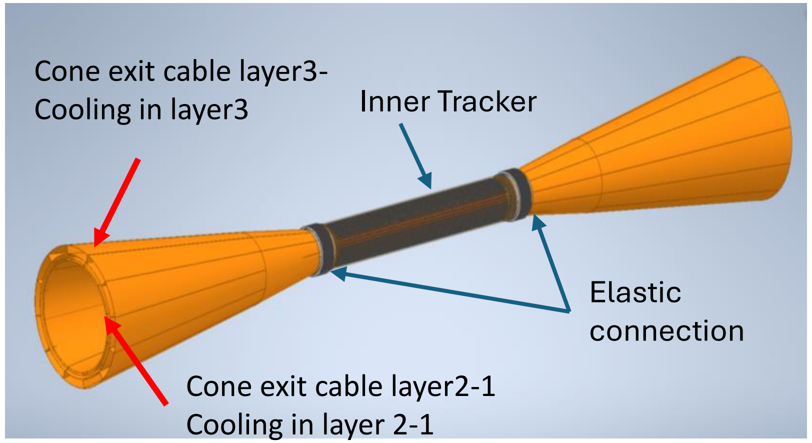
- **Inner Vertex (ARCADIA based):**
  - Lfoundry 110 nm process
  - *50 μm thick*
  - Module Dimensions: $8.4 \times 32\ mm^2$
  - Power density 50 mW/cm^2
  - **100 MHz/cm²**

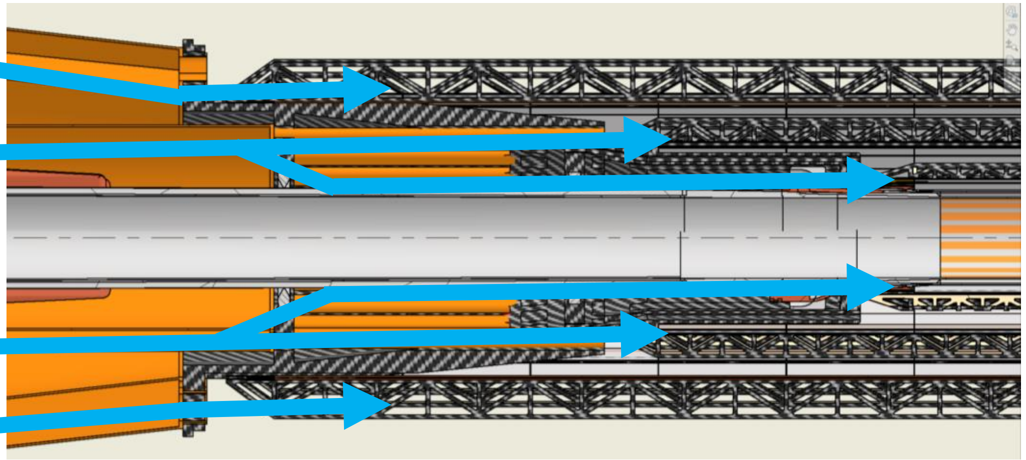
- Estimation for sensors power dissipation:
  - Layer 3: $\dot{Q}$ **~ 77 W** (total)
  - Layer 2: $\dot{Q}$ **~ 32 W** (total)
  - Layer 1: $\dot{Q}$ **~ 12 W** (total)

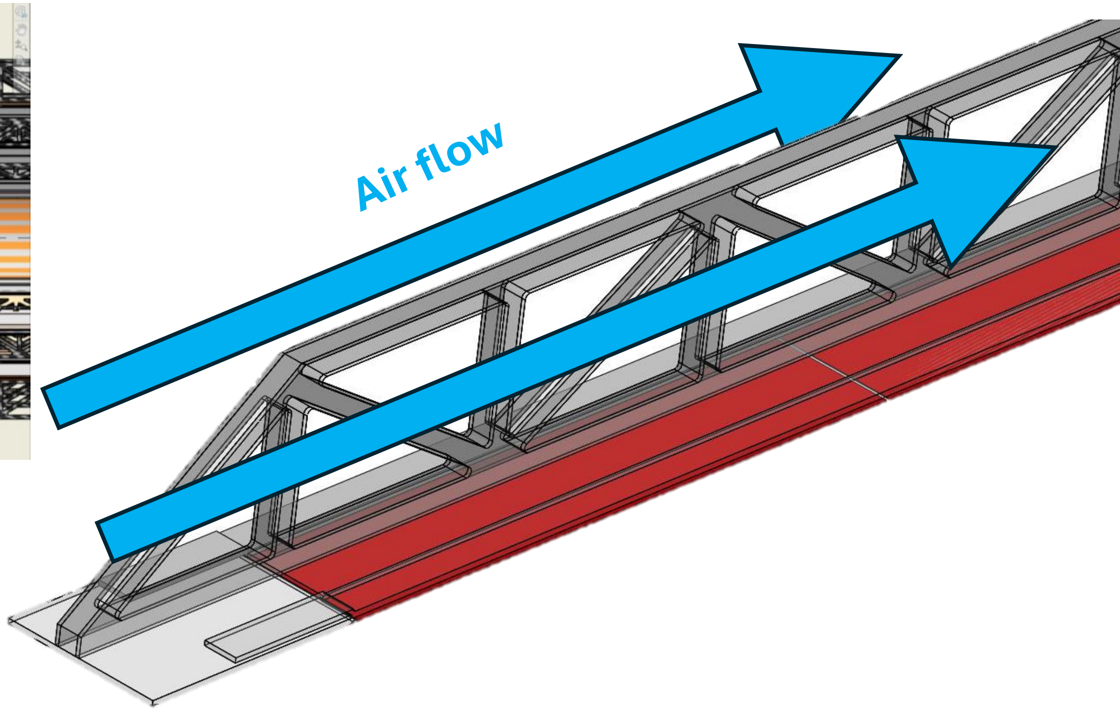


AIR COOLING CONCEPT





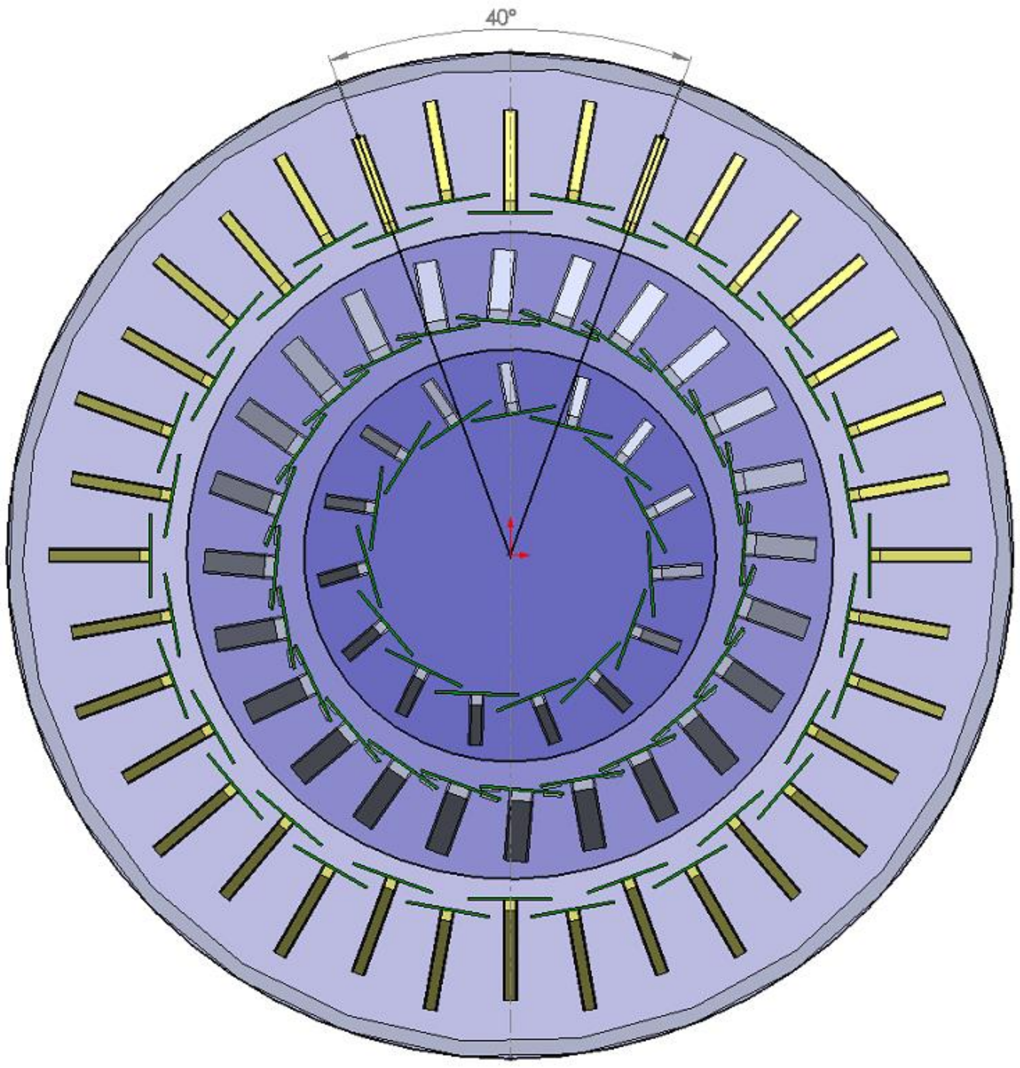


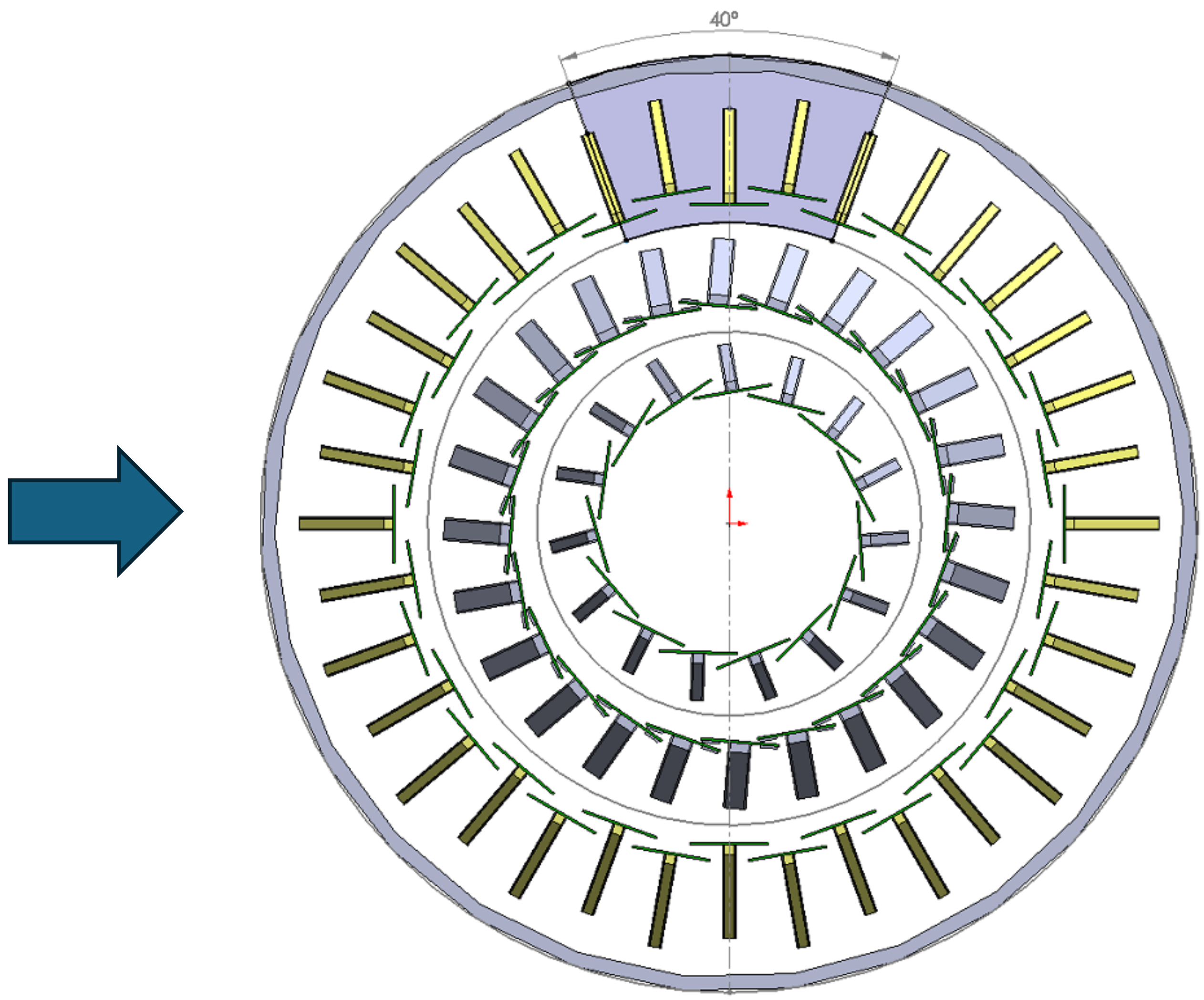


- Cooling method: longitudinal air flow along the the detector.
  - Temperature of air at the inlet: T_{air} = 15°C
  - The air flow has the same direction for all the layers

HISTORY - FIRST ATTEMPT: FOCUS ON LAYER 3

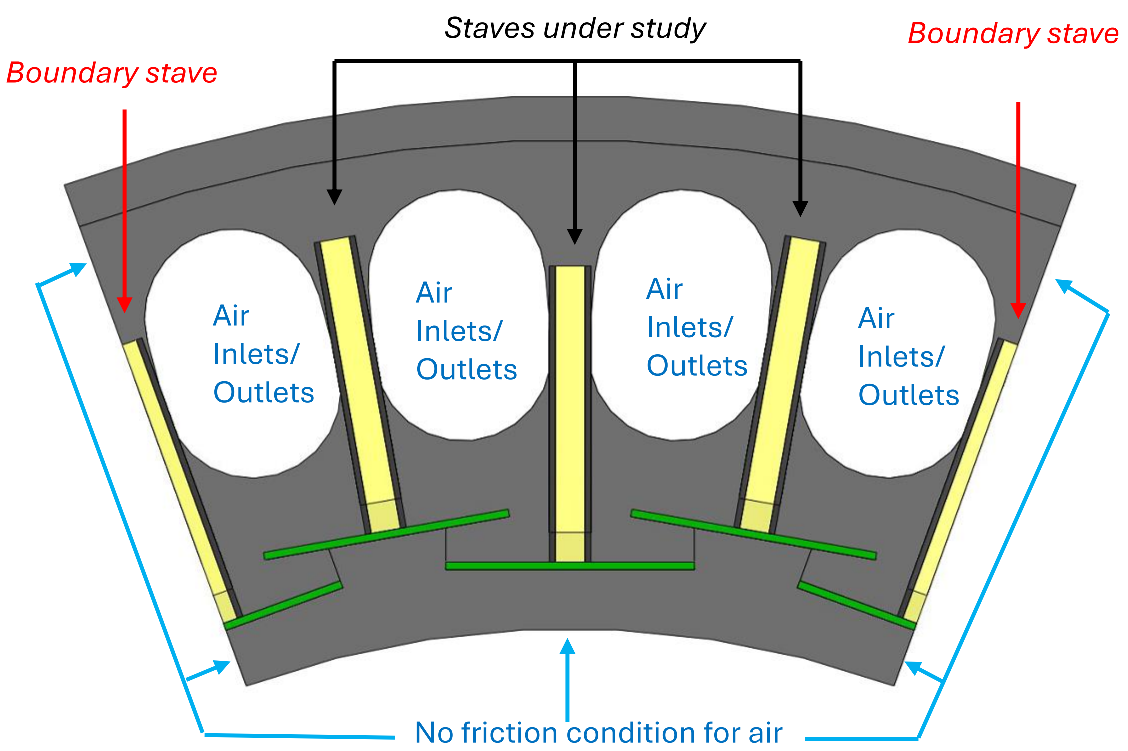
- Layer 3 has the max. lenght and power dissipation





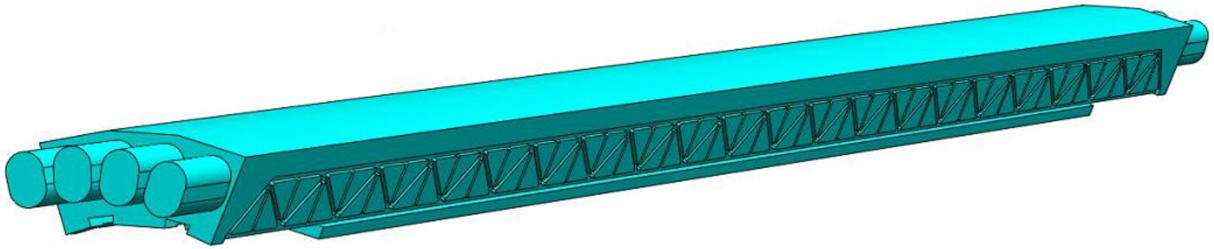
- Given the complexity of geometry, only a 40° sector of layer 3 was simulated.
- In the last model, the section plane passes exactly on the center of the staves.

HISTORY - FIRST ATTEMPT: FOCUS ON LAYER 3

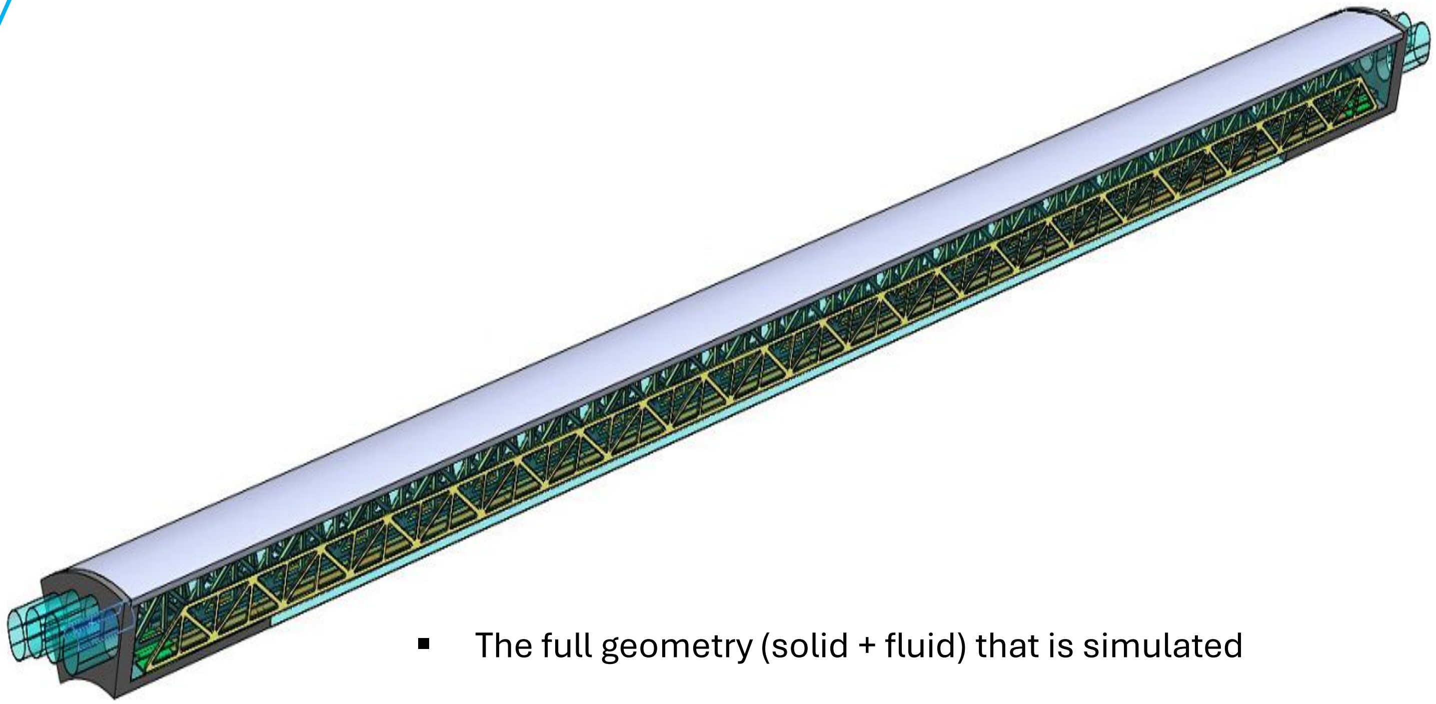


- ✓ Steady state conditions
- ✓ Turbulent flow: Reynolds Average Navier Stokes (RANS)
- ✓ Viscous model k-ω SST
- ✓ Pressure based solver
- ✓ No radiation heat exchange
- ✓ Volumetric constant power source on sensors volume

- Both the solid and fluid domains are simulated at the same time (Conjugate heat transfer). The fluid volume is so modeled and added to the geometry.



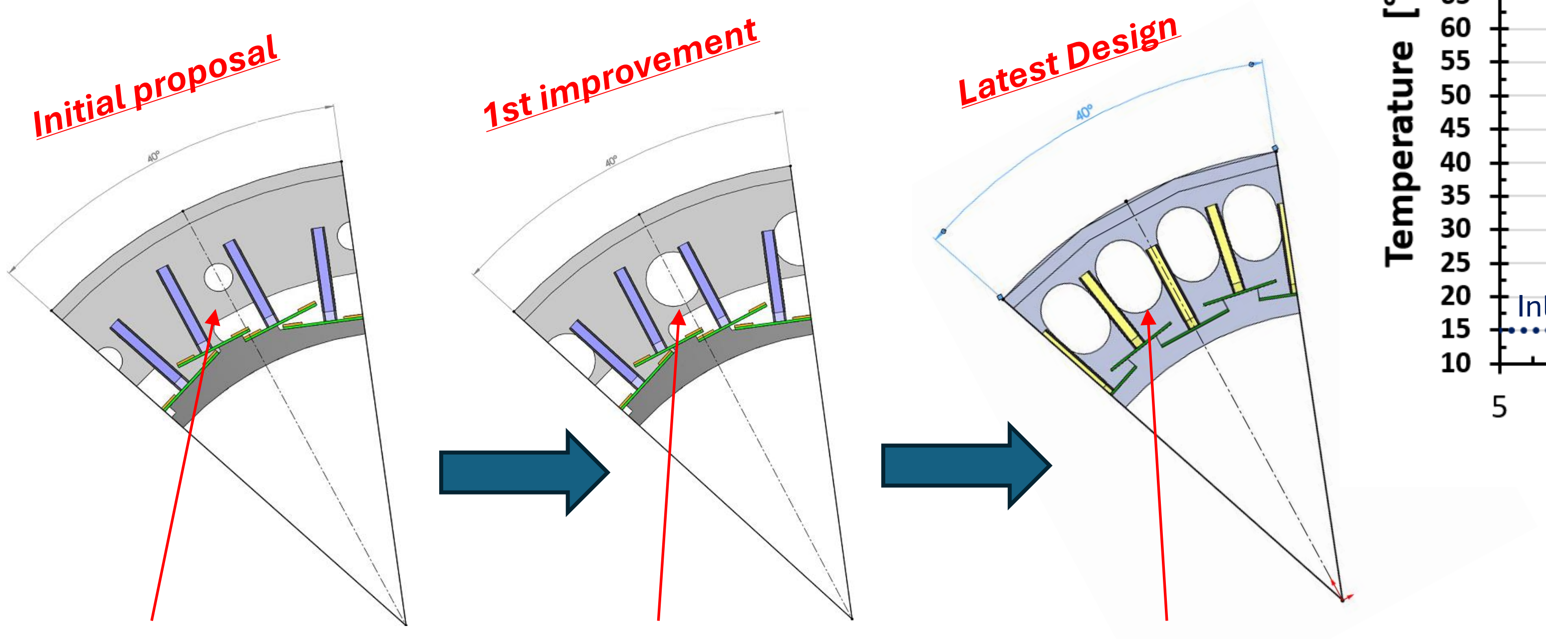
- Set 5% of turbulence at inlets (Ansys default value)



- The full geometry (solid + fluid) that is simulated

DESIGN OPTIMIZATION OF LAYER 3

- Some improvements in the last year in the layer 3 geometry
  - Increasing inlets section
  - Increasing number of inlets
  - Moving staves to a radial configuration



Inlets: hole Ø3mm

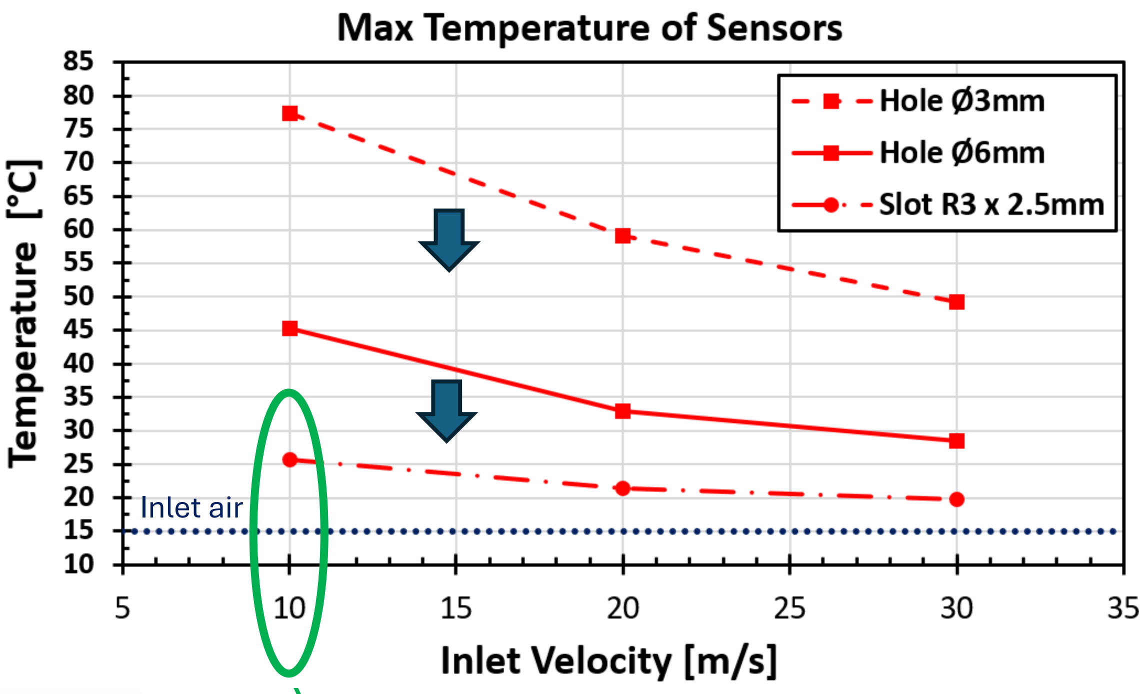
Section: 7 mm^2 per hole

Inlets: hole Ø6mm

Section: 28 mm^2 per hole

Inlets: slot R3 x 2.5mm

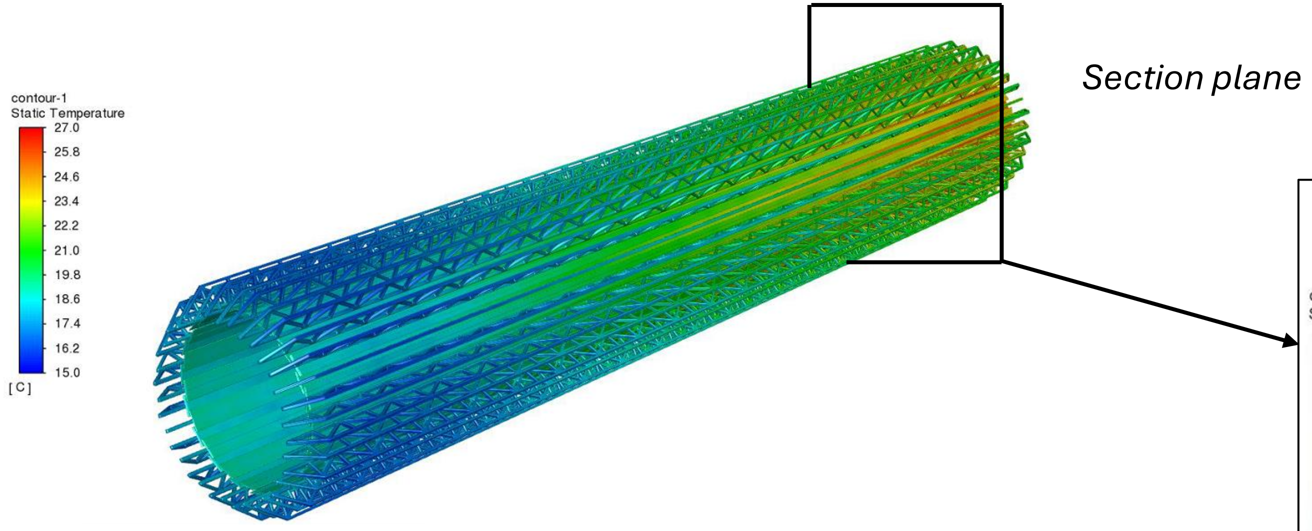
Section: 43 mm^2 per slot

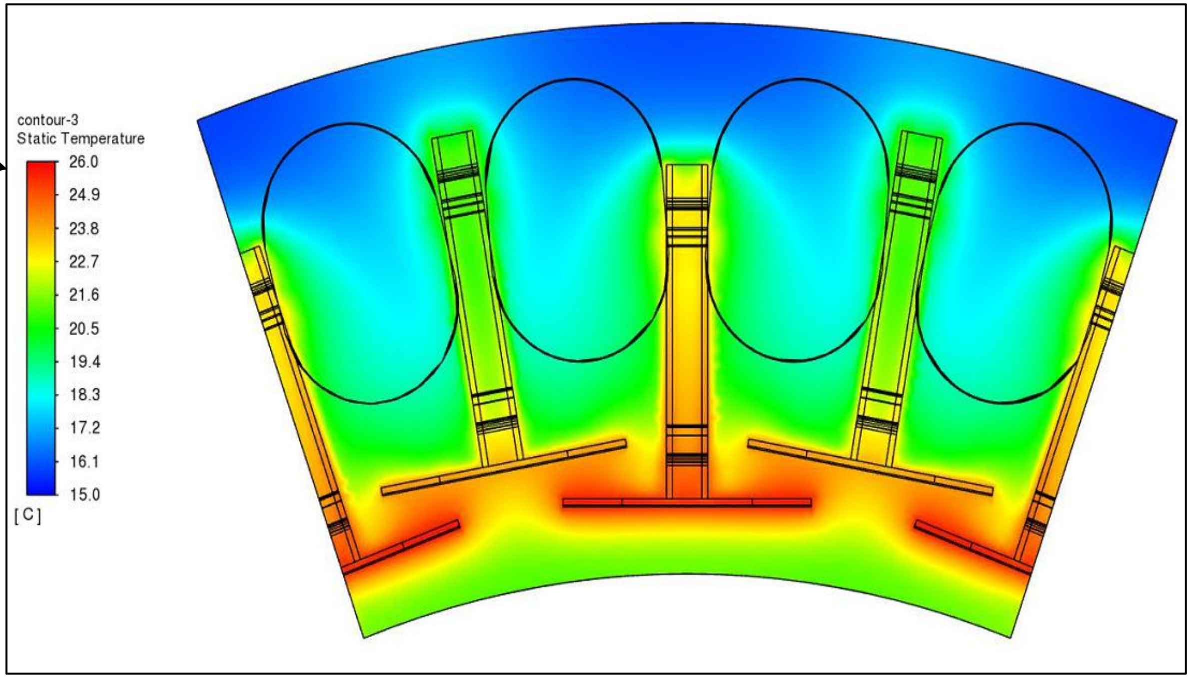


With current design, maximum temperature of **26°C** with V_{in} **= 10 m/s and 15°C** is reached.

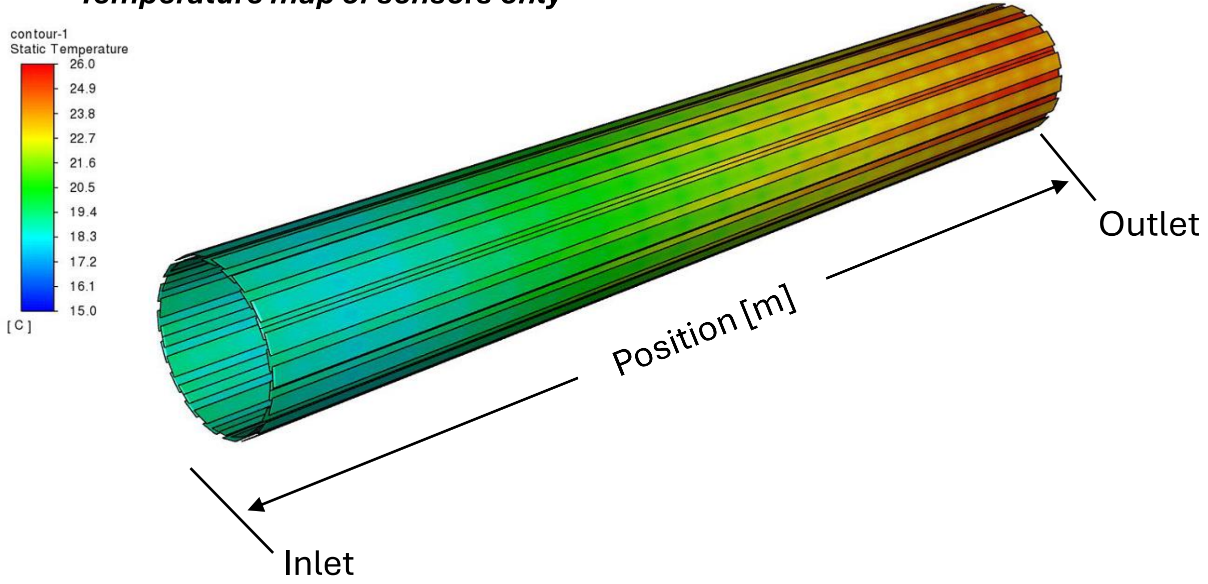
LAYER 3 - TEMPERATURE

- ***Temperature map of sensors + staves***



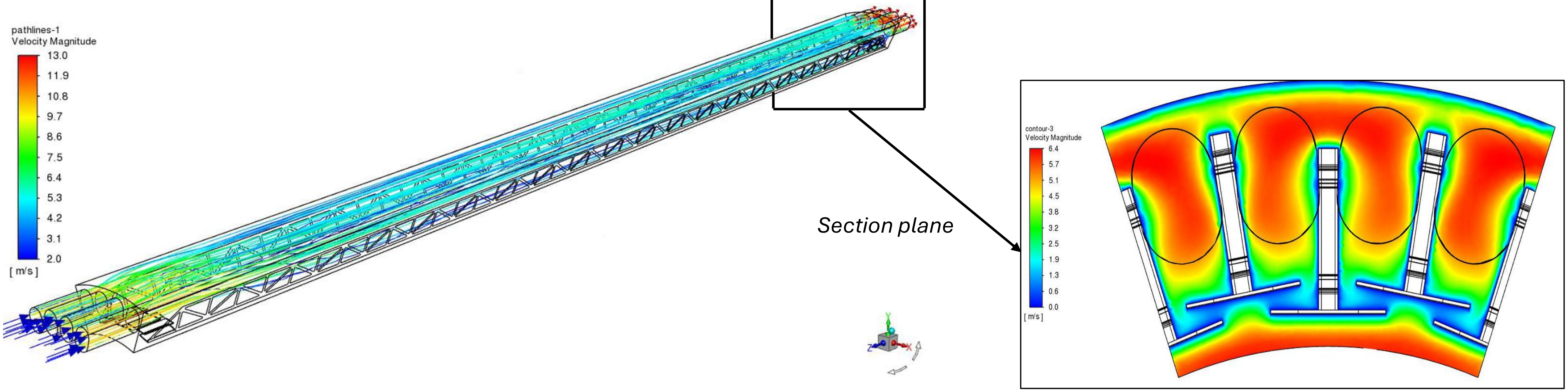


- ***Temperature map of sensors only***

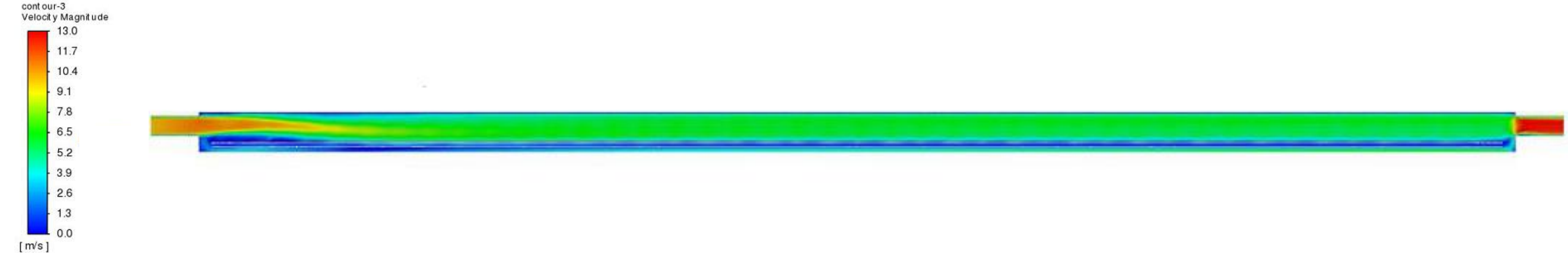


LAYER 3 - VELOCITY

- Average velocity around the sensors is 4.2 m/s, quite lower than the inlet velocity

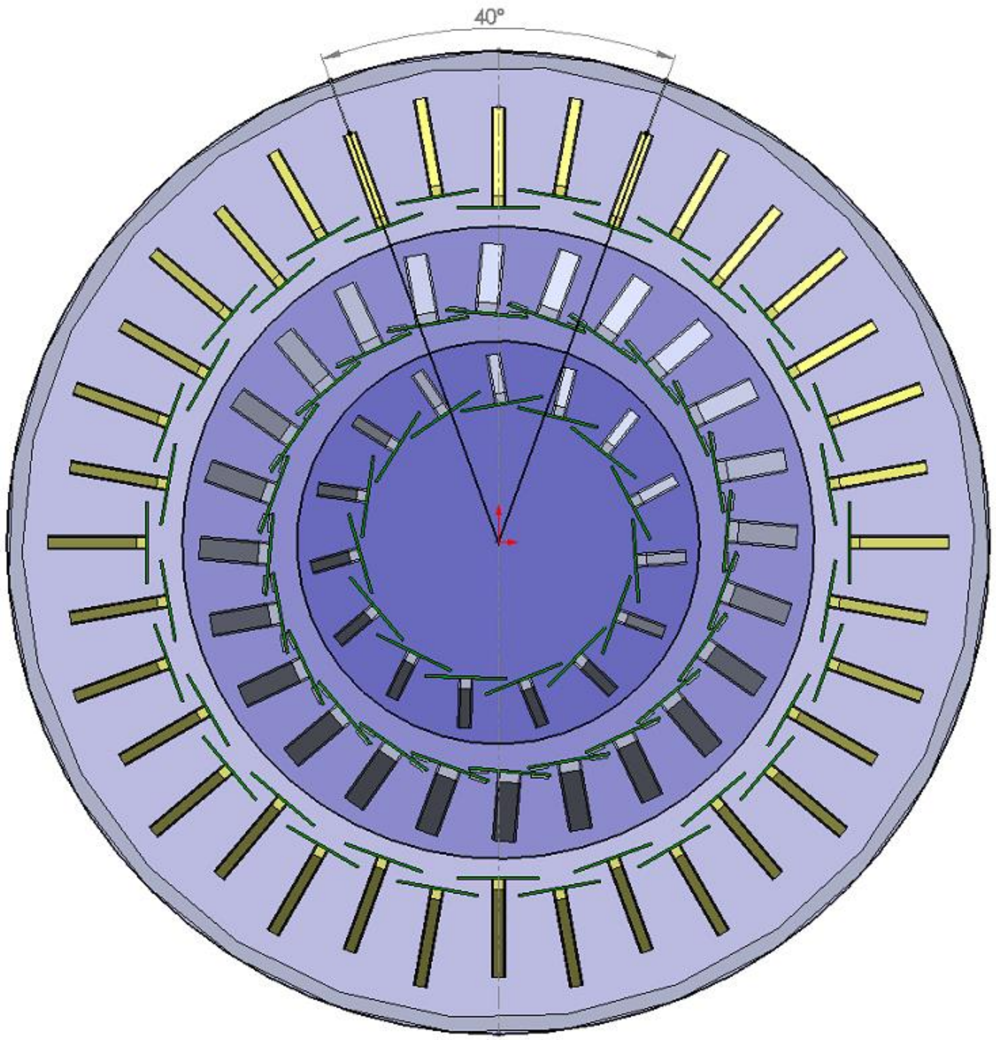


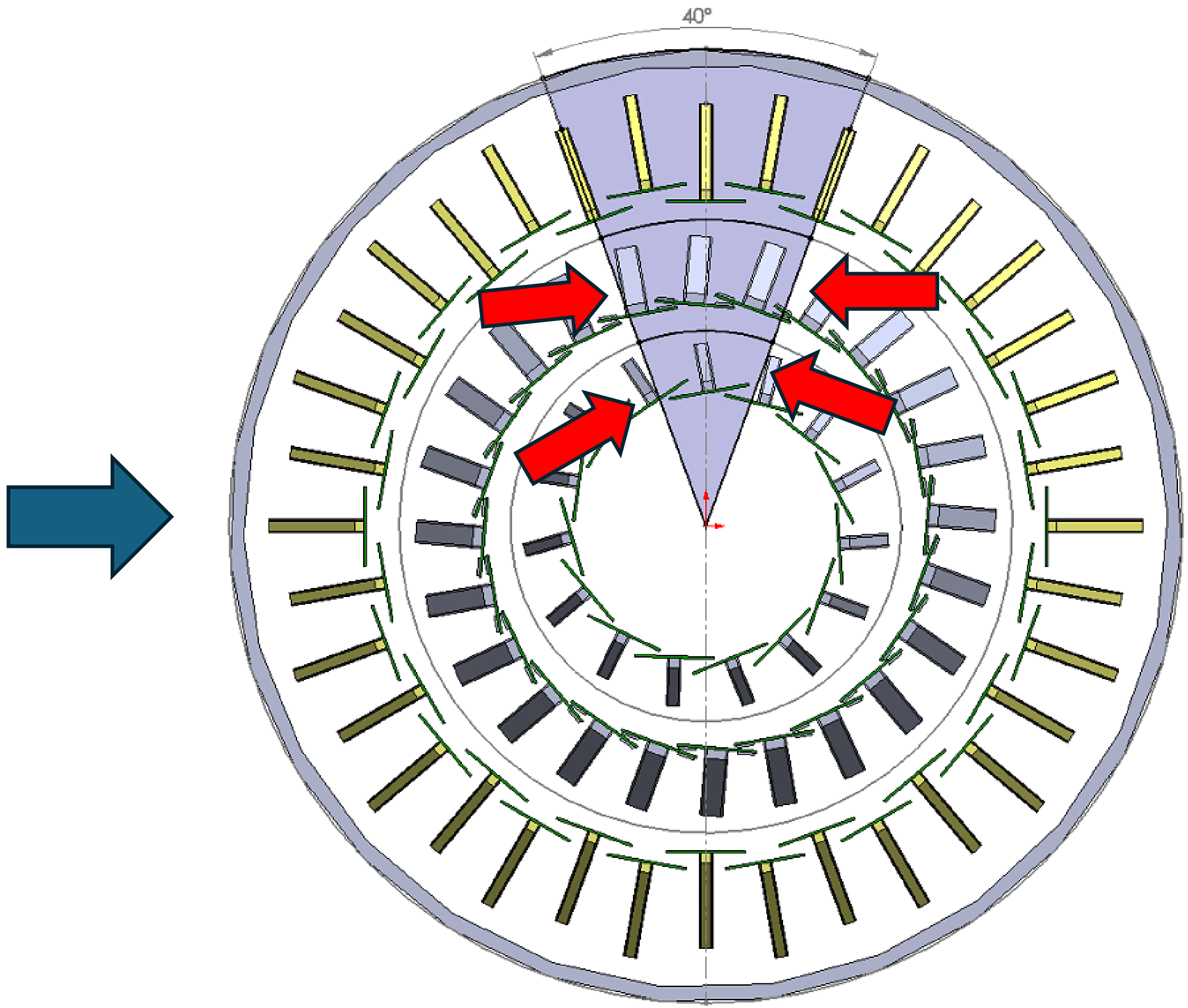
- Longitudinal section:



INCLUDING ALSO LAYER 2 AND LAYER 1

Challenge: layer 2 and layer 1 are rotated and any cutting plane does not fall on the middle of the stave of all layers

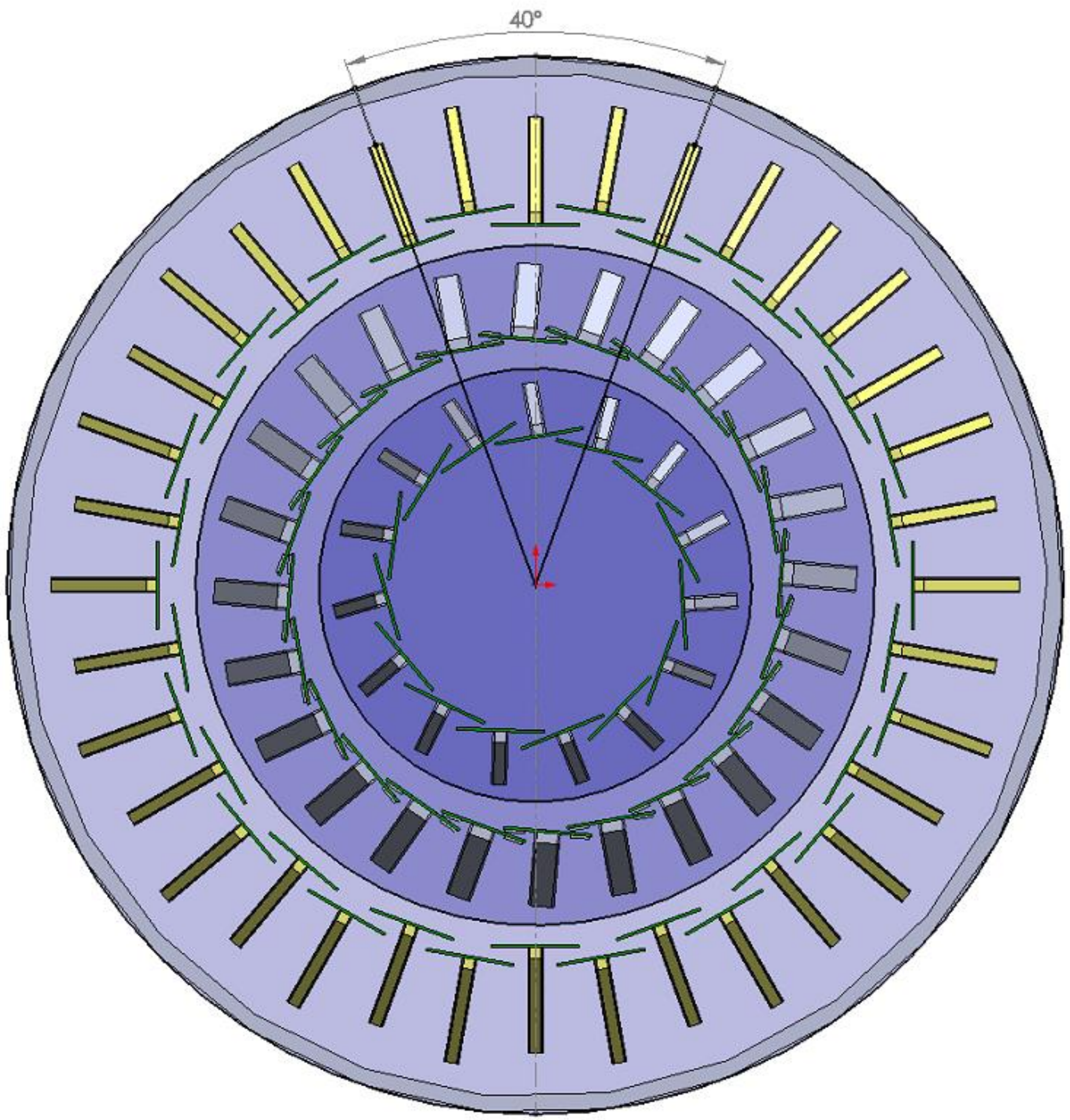


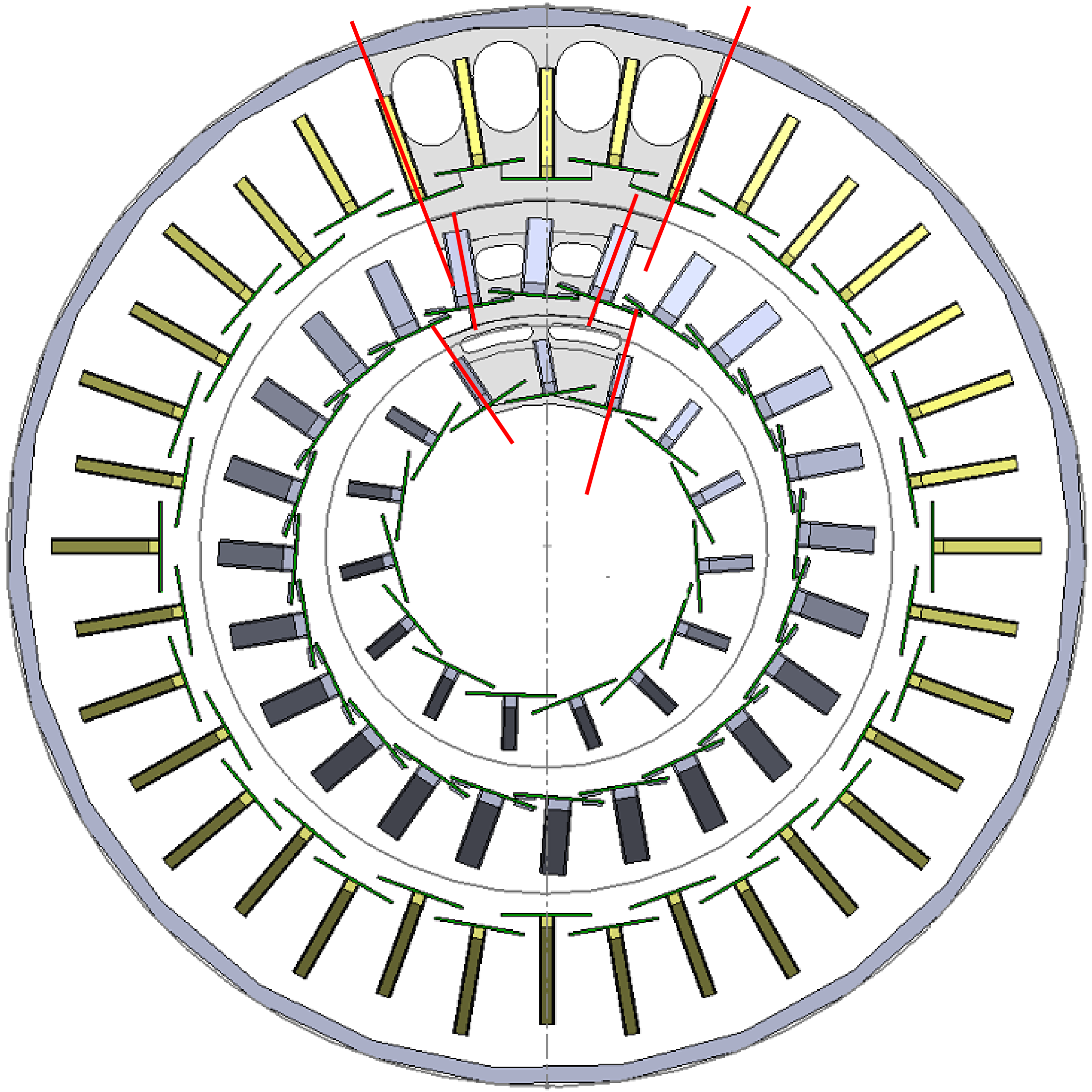


A straight cutting plane will brake the simmetry in the model, enhancing simulation complexity.

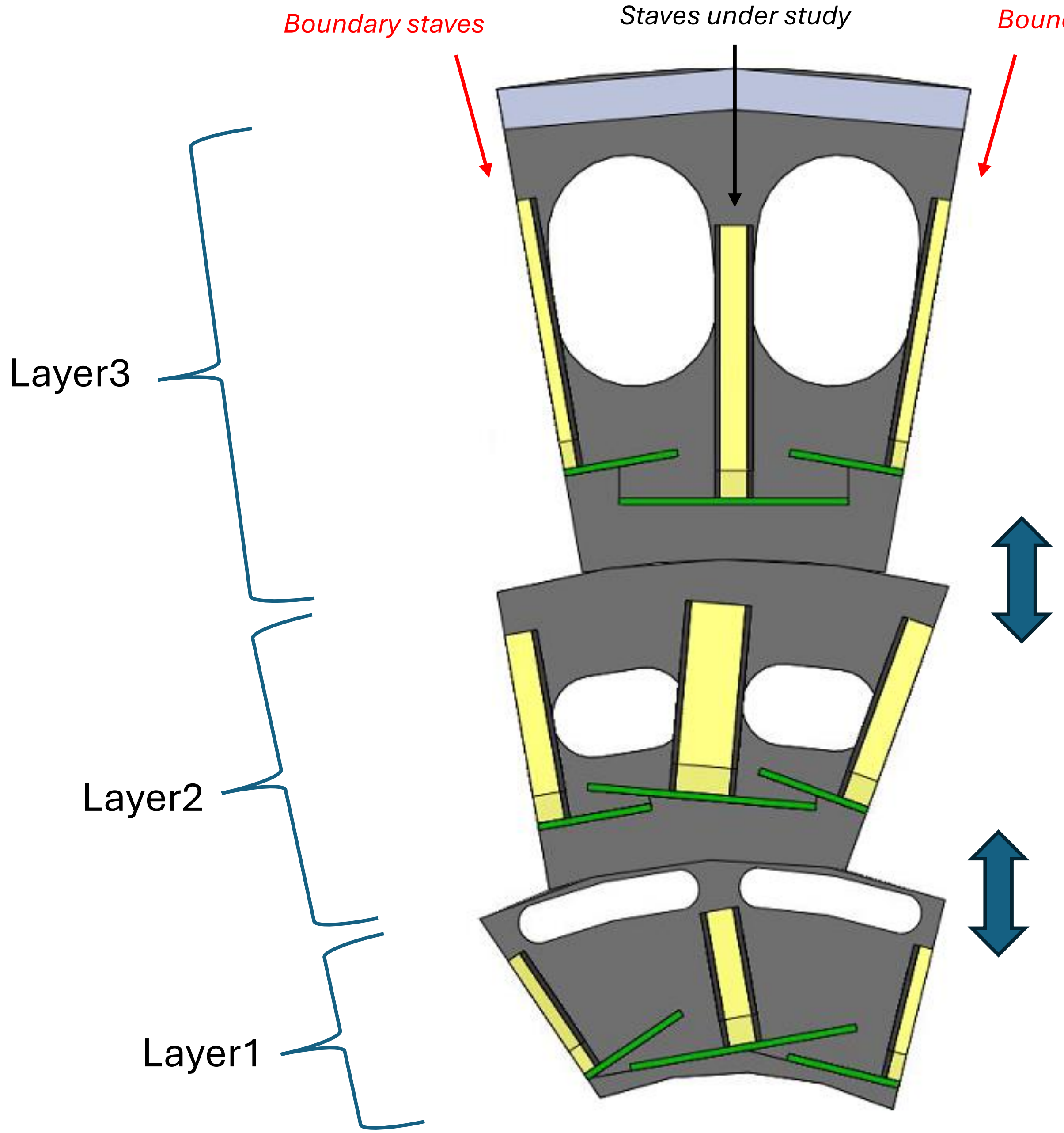
INCLUDING ALSO LAYER 2 AND LAYER 1

- It has been decided to preserve the cutting at the center of each stave, by introducing multiple cutting lines.





INCLUDING ALSO LAYER 2 AND LAYER 1 - DOMAIN ANALYSED

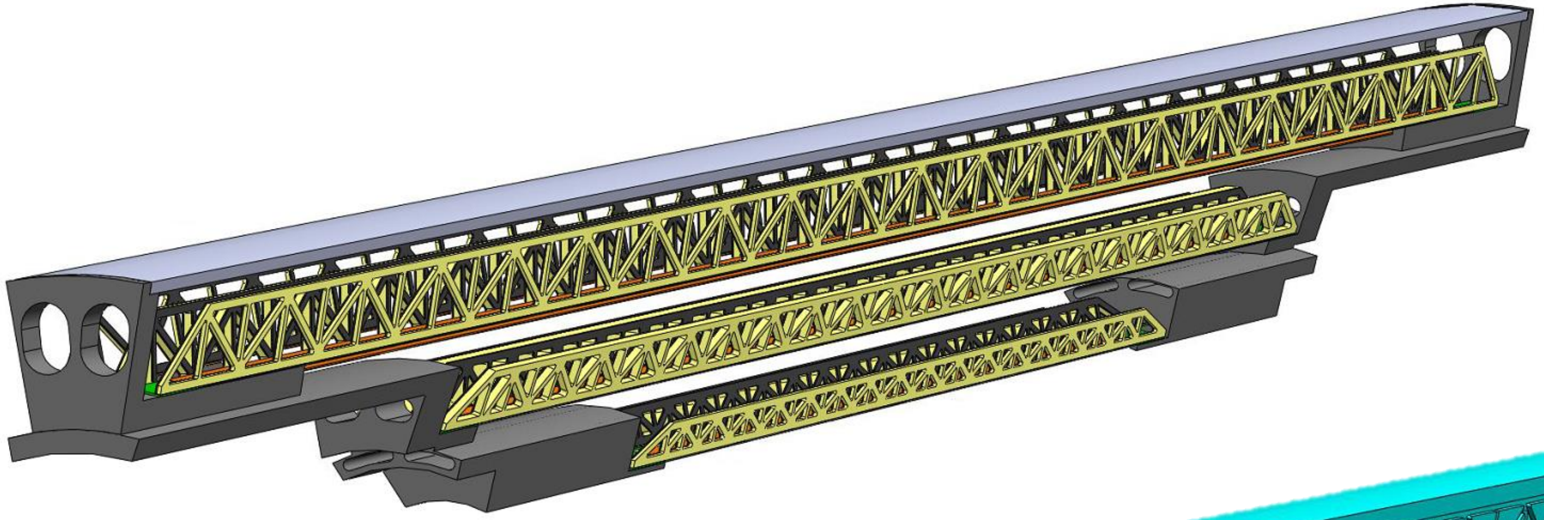


Exchange of mass and energy allowed through the layers.

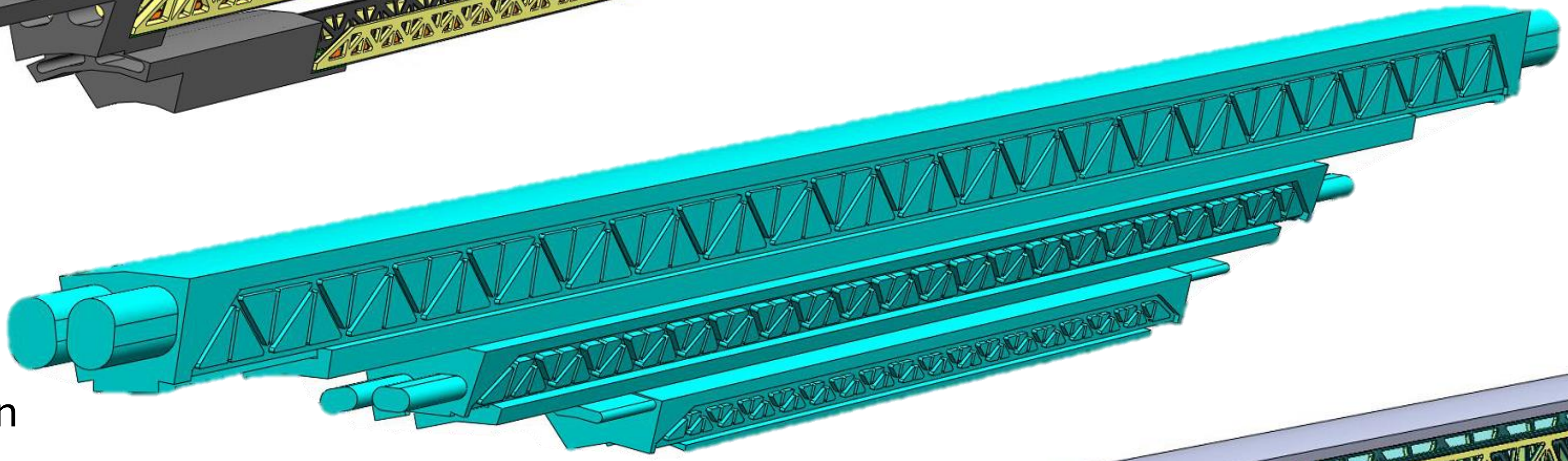
Inspired by Taipei tower 101

THE FULL GEOMETRY

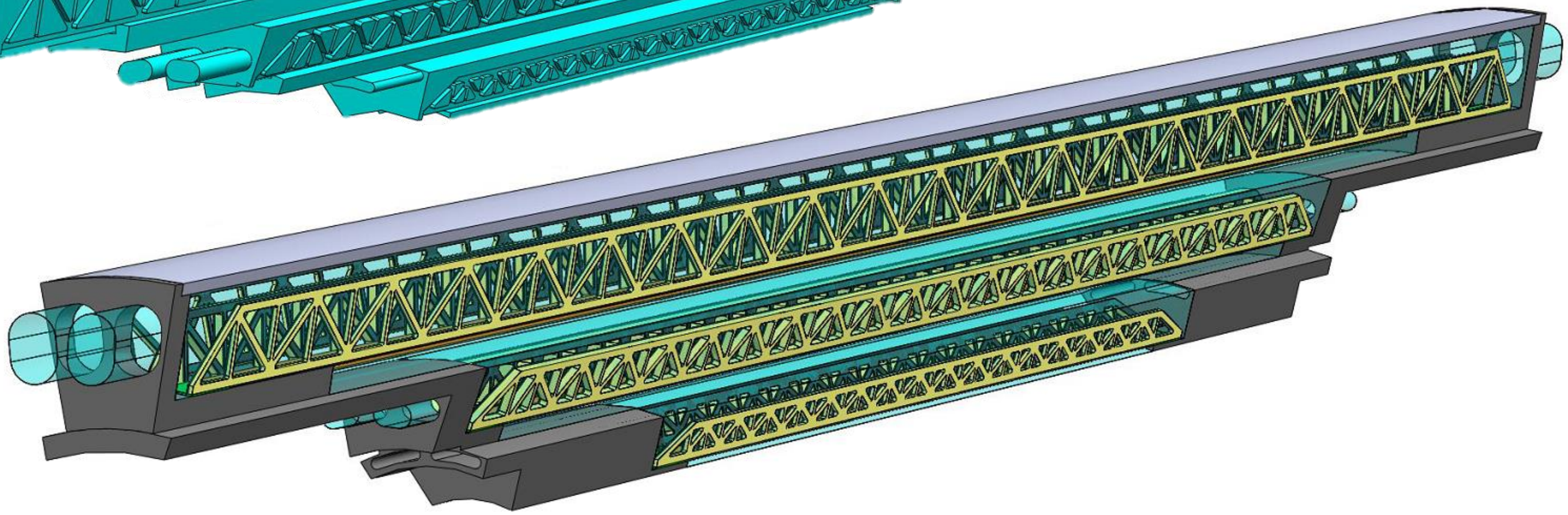
Meshing this model took about 30 Million of elements



Solid domain



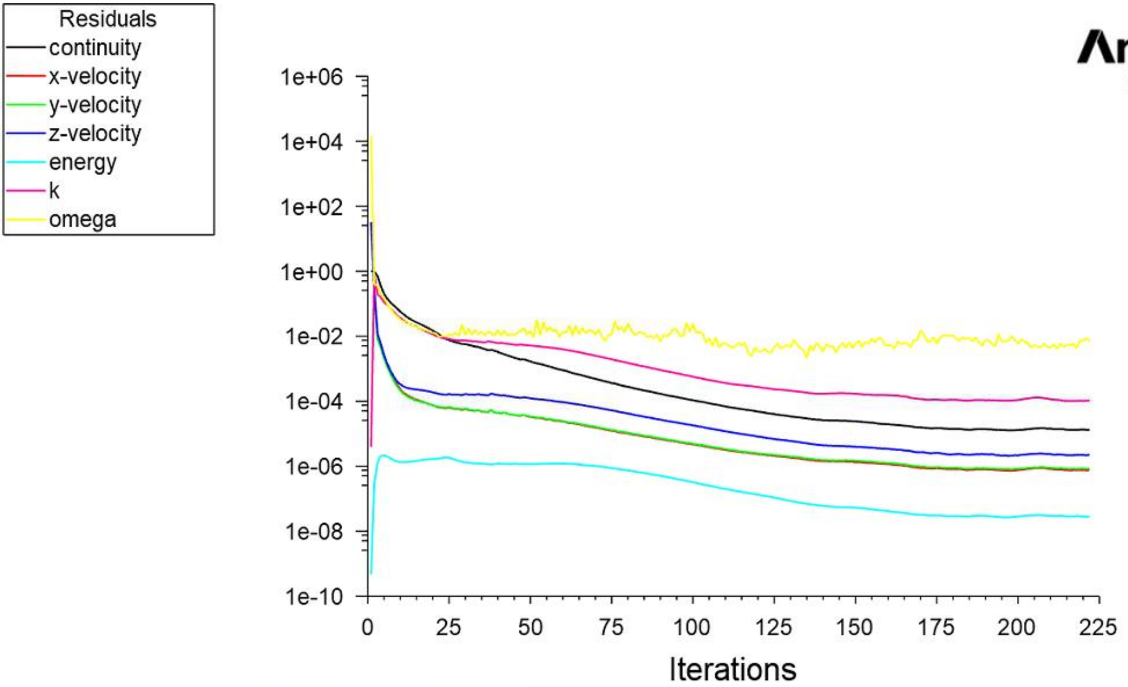
Fluid domain

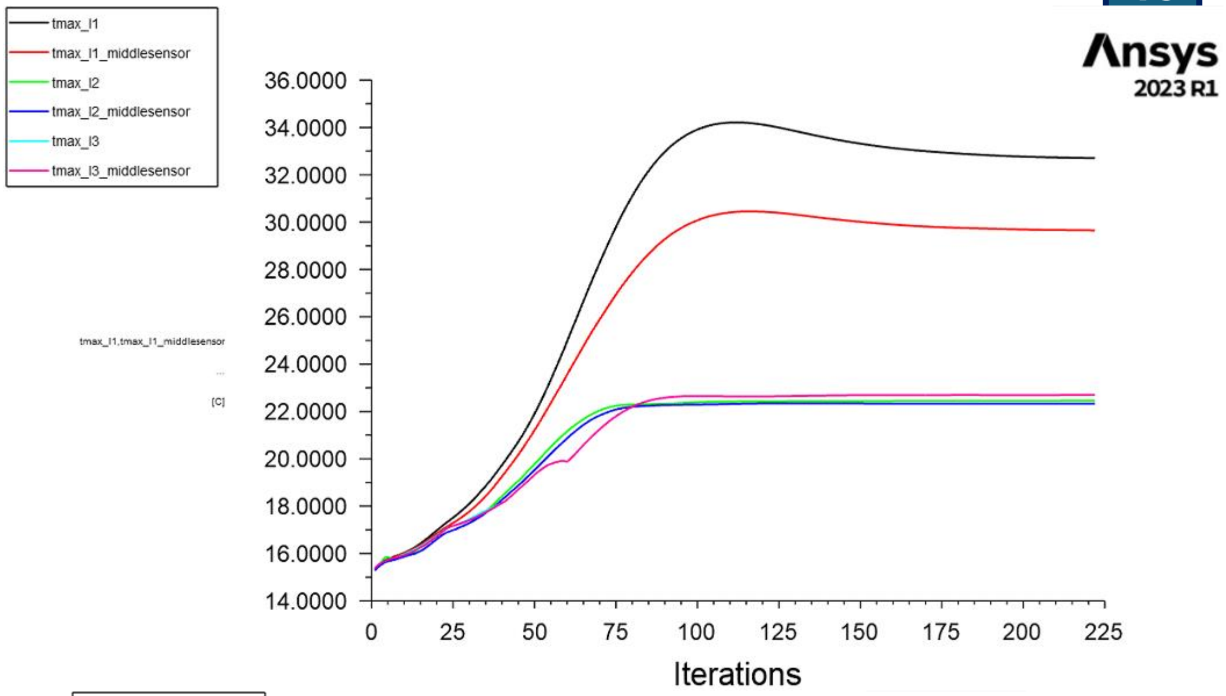


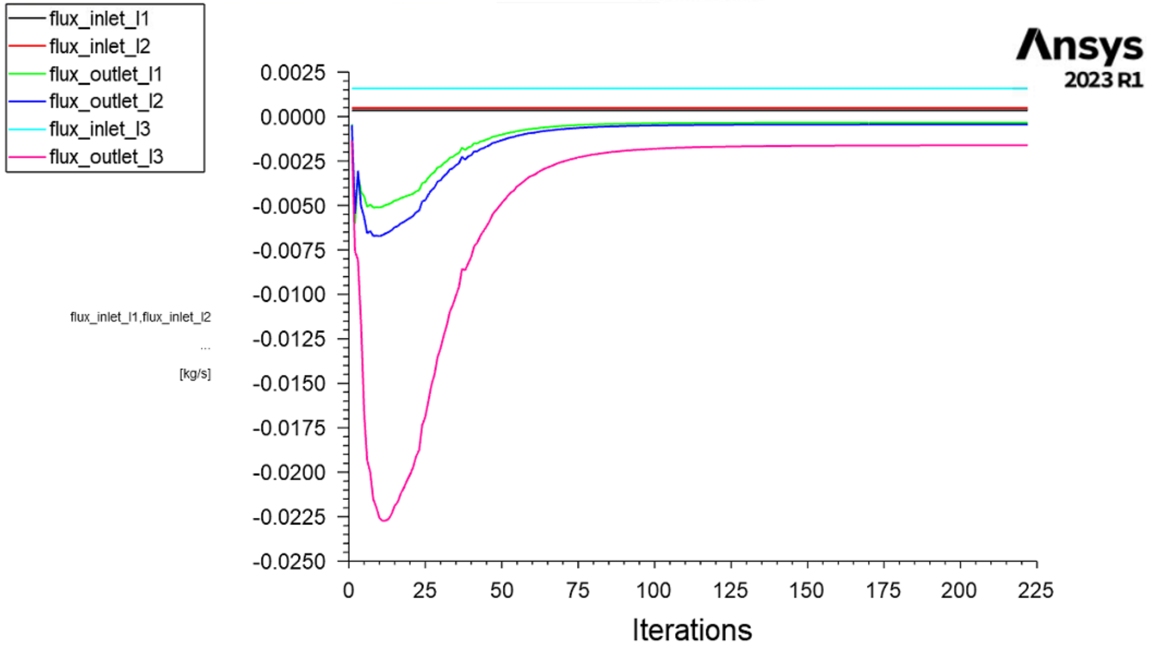
Both solid and fluid

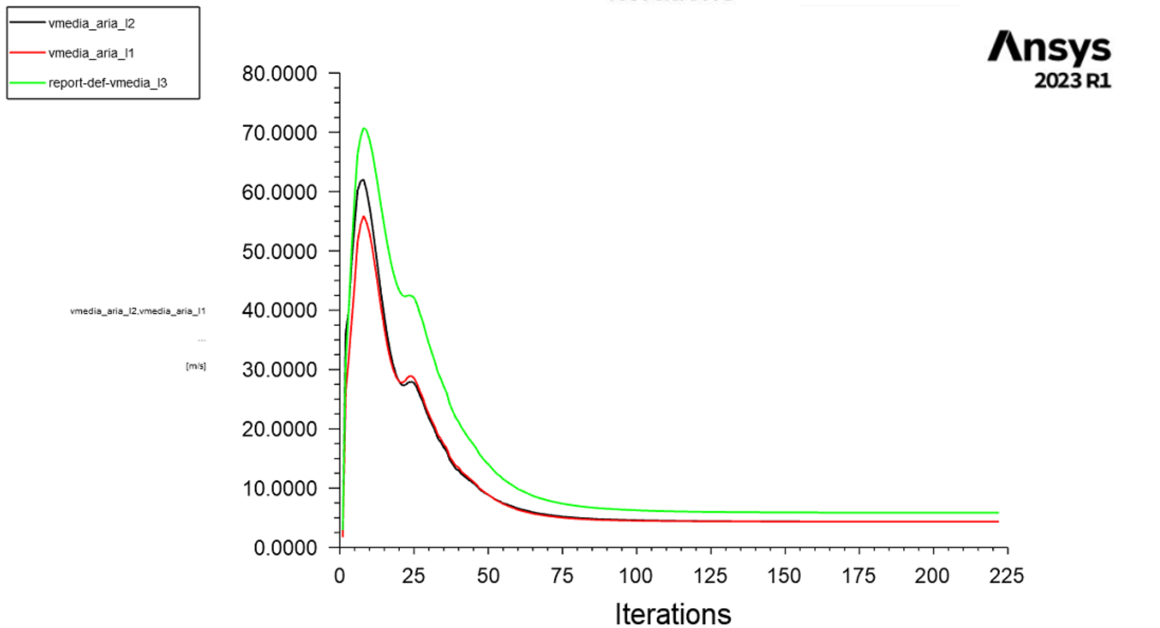
LAYER 1 + LAYER 2 + LAYER 3 residulas

- 8-10 hours for convergence





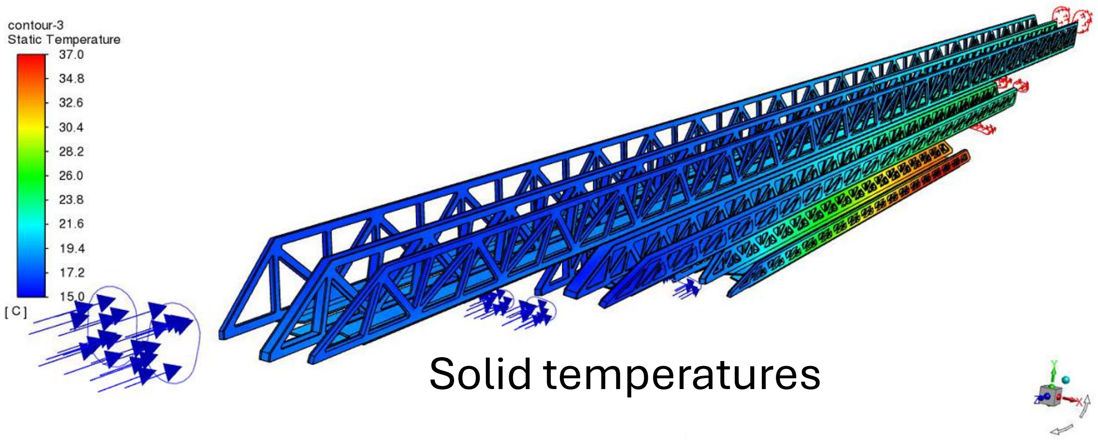




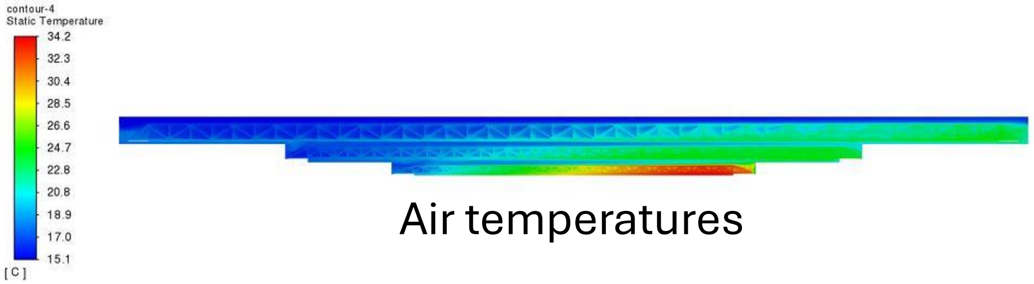
RESULTS

INPUTS	
V_{in}(layer1)	10 [m/s]
V_{in}(layer2)	10 [m/s]
V_{in}(layer3)	10 [m/s]
A_{in}(layer1)	2x9.50E-6 [m^2]
A_{in}(layer2)	2x1.31E-5 [m^2]
A_{in}(layer3)	2x4.33E-5 [m^2]
Q_{TOT}(layer1)	1.6 [W]
Q_{TOT}(layer2)	2.7 [W]
Q_{TOT}(layer3)	4.3 [W]
T_{air_in}	15 [°C]

Sensors in layer 1 are the warmest (lower air mass flow)

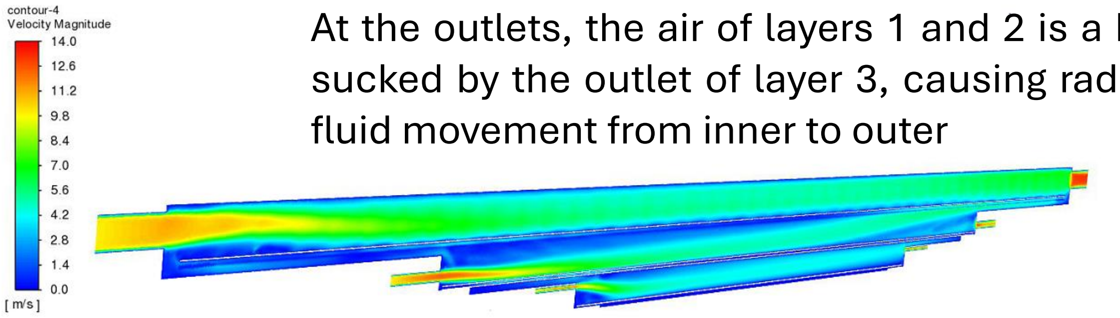


Solid temperatures



Air temperatures

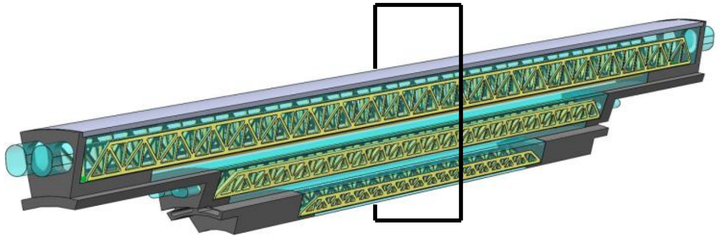
At the outlets, the air of layers 1 and 2 is a bit sucked by the outlet of layer 3, causing radial fluid movement from inner to outer



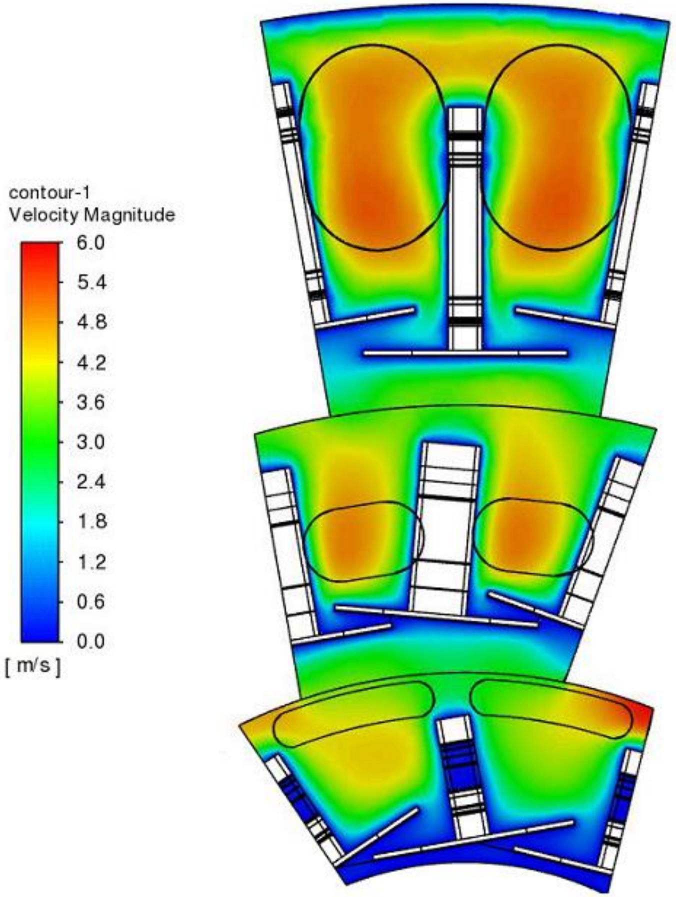
OUTPUTS	
T_{sens_max}(layer1)	**34.4 [°C]**
T_{sens_max}(layer2)	**25.0 [°C]**
T_{sens_max}(layer3)	**25.3 [°C]**
T_{air_outlet}(layer1)	22.3 [°C]
T_{air_outlet}(layer2)	22.5 [°C]
T_{air_outlet}(layer3)	19.4 [°C]
V_{media_aria}(layer1)	2.8 [m/s]
V_{media_aria}(layer2)	2.9 [m/s]
V_{media_aria}(layer3)	3.9 [m/s]
M_{outlet}(layer1)	0.00022 [Kg/s]
M_{outlet}(layer2)	0.00029[Kg/s]
M_{outlet}(layer3)	0.00109[Kg/s]

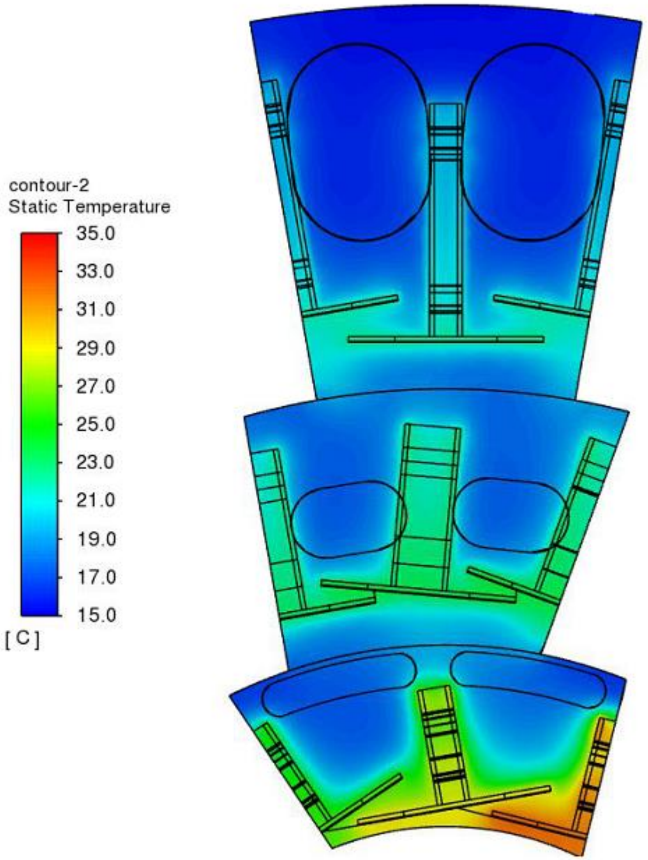
- There is no significant difference in temperature on layer 3 compared to the single layer model (26°C).

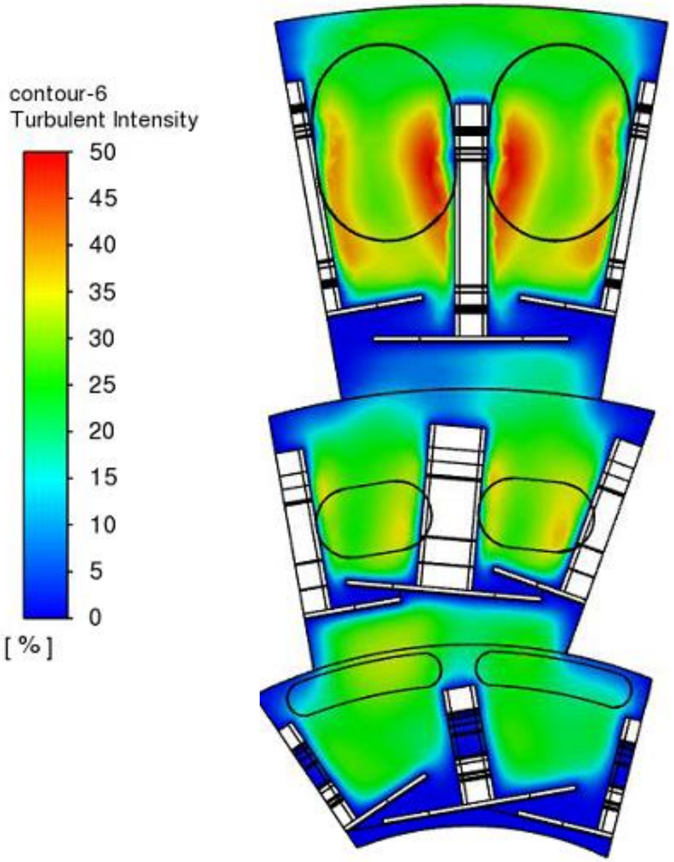
RESULTS



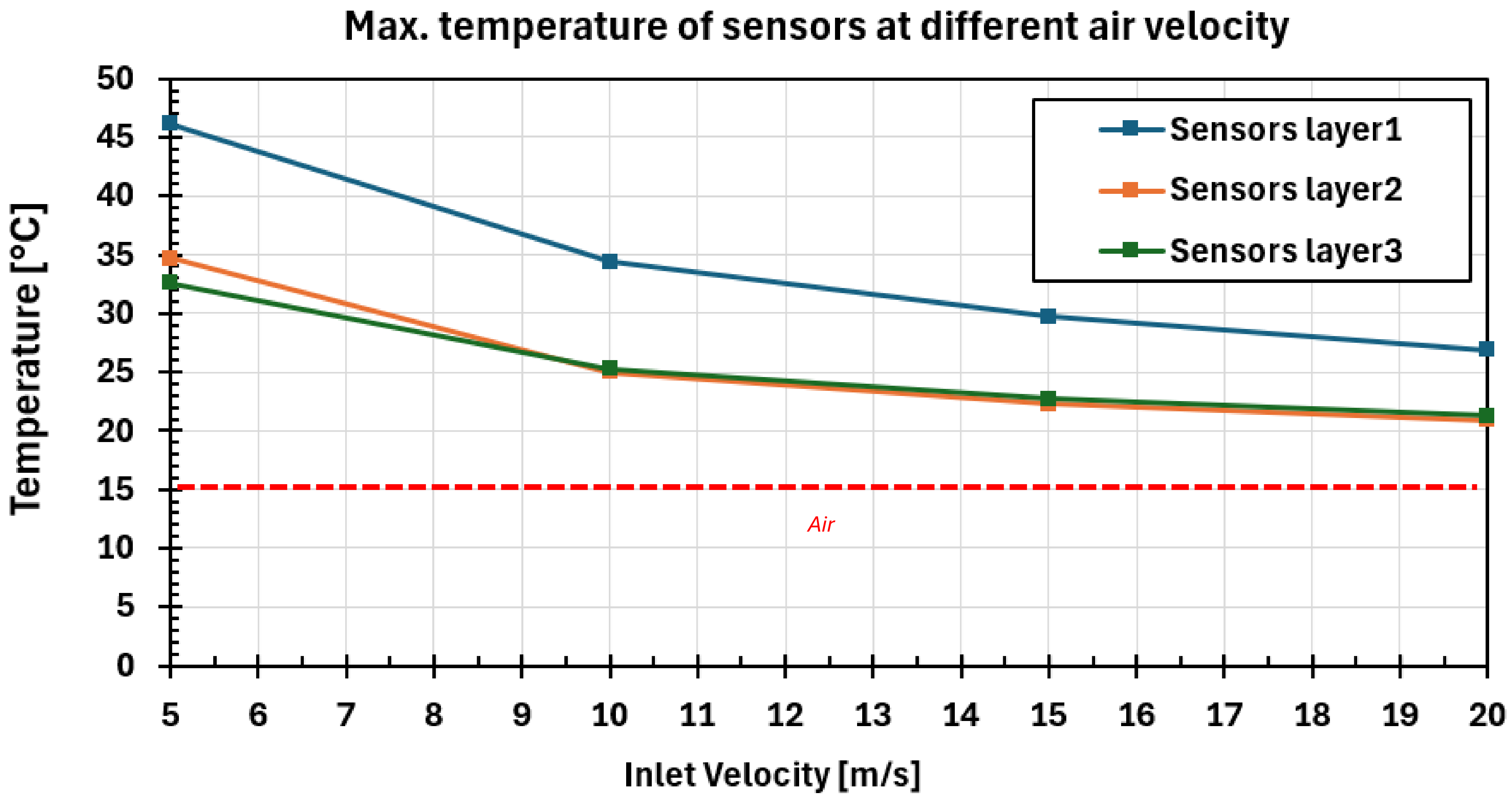
Section plane







RESULTS



$T_{air} = 15°C$

CONCLUSIONS

- The feasibility of a model that simultaneously simulates the 3 layers of the Silicon Inner Vertex Detector is shown.

- **Max. ΔT between air and sensors about 10°C for layer 3 and 2, and 20°C for layer 1**, for air inlet at 10 m/s.

  - Encouraging results for the feasibility study.

  - Inlets for layer 1 and 2 are not yet engineered (low flow in layer 1).

  - Some cross-talk found between air flow of different layers, not changing significantly the results respect to the layer-by-layer simulations.

- Next steps: it is crucial to study manifold and routings of air channels.

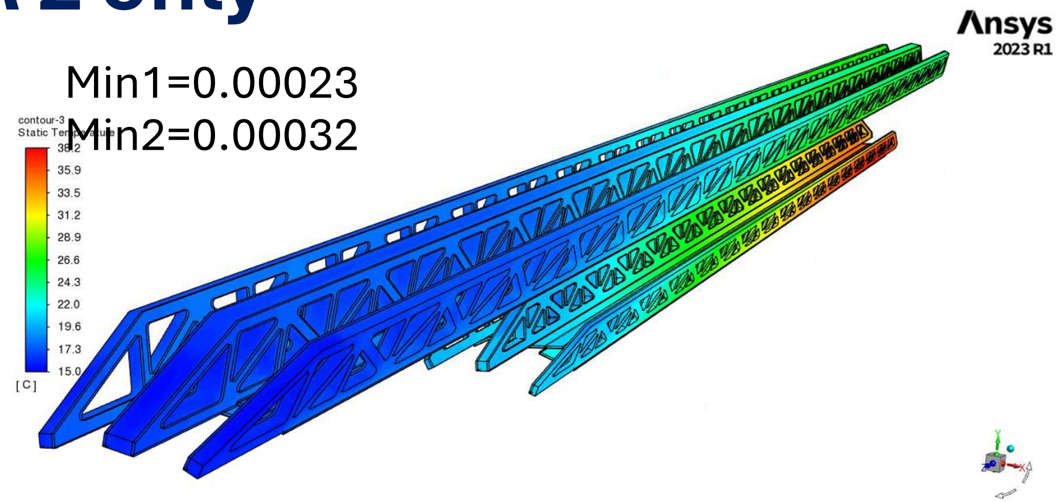
  - **The air has the potential to cool the vertex, without significant mechanical displacements**, see a previous talk on the argument:
    https://indico.cern.ch/event/1336746/contributions/5922977/attachments/2867651/5019790/FTDM_2024_Turrioni.pdf
  - The most influential current boundary condition is that the average velocity at each inlet hole is 10 m/s: in real conditions the speed in the openings will change according to the pressure drop and the overall geometry.
  - The main issue is the fluid dynamic optimisation of the air route, more than its thermal capability of dissipating the heat.

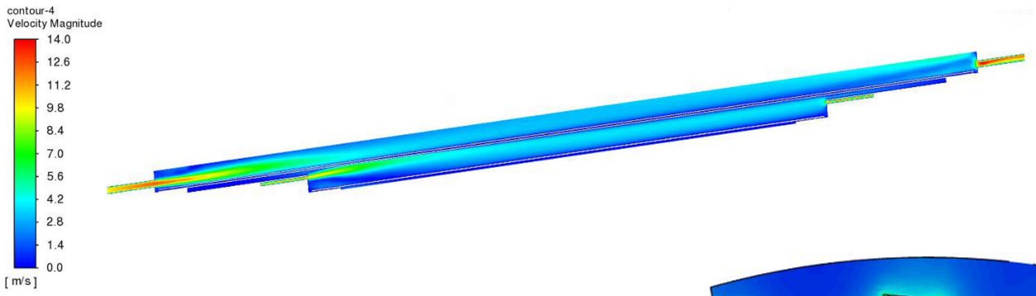
BACKUP

LAYER 1 + LAYER 2 only

INPUT	
V_{in}(layer1)	10 [m/s]
V_{in}(layer2)	10 [m/s]
A_{in}(layer1)	2x9.5E-6 [m^2]
A_{in}(layer2)	2x1.31E-5 [m^2]
Q_{in}(layer1)	1.6 [W]
Q_{in}(layer2)	2.66 [W]
T_{air_in}	15 [°C]

MATERIALS [K]	
Silicon	148 [W/mK]
Flex circuit	0.3 [W/mK]
CF through	2 [W/mK]
CF in-plane	180 [W/mK]
Rohacell	0.03 W/mK]





OUTPUT 2 layer	
T_{sens_max}(layer1)	35.5 [°C]
T_{sens_max}(layer2)	27.8 [°C]
T_{air_outlet}(layer1)	22.9 [°C]
T_{air_outlet}(layer2)	22.6 [°C]
V_{media_aria}(layer1)	2.4 [m/s]
V_{media_aria}(layer2)	2.3 [m/s]
M_{outlet}(layer1)	0.00023 [Kg/s]
M_{outlet}(layer2)	0.00032[Kg/s]