PROGRESS ON AIR COOLING OF THE VERTEX DETECTOR

7th FCC Physics Workshop

Laboratoire d'Annecy de physique des particules, 29 January 2024 - 2 February 2024

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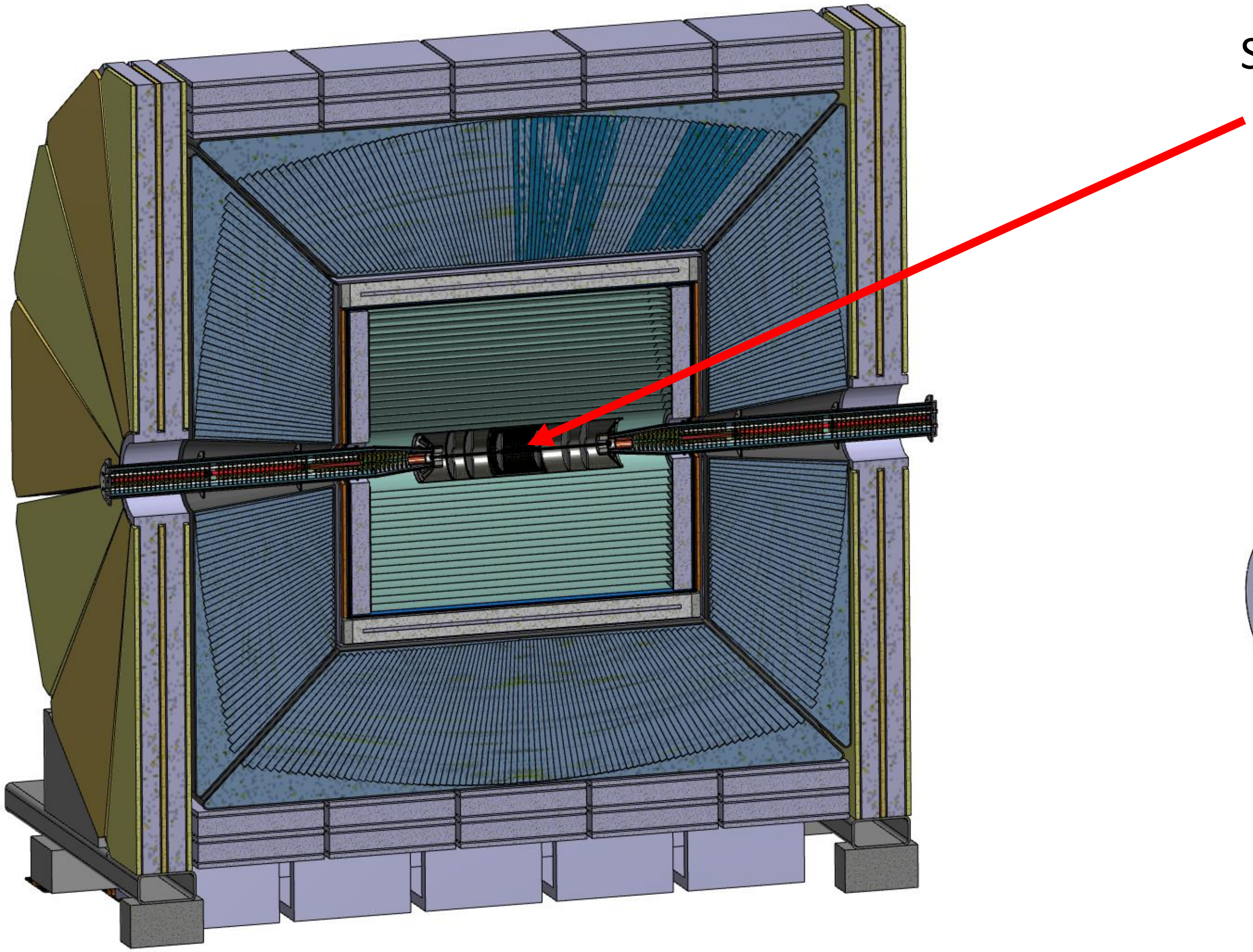
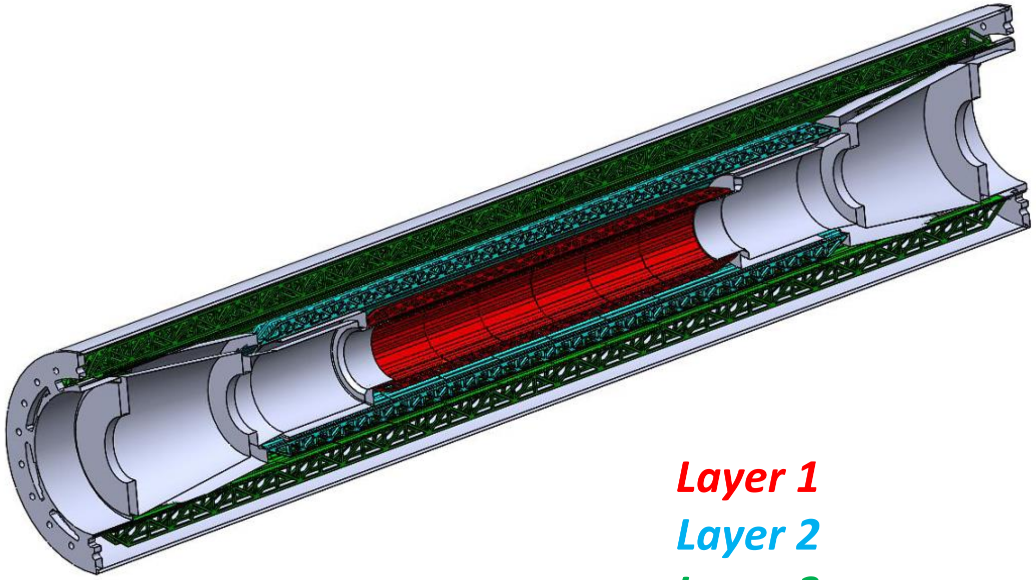
THE IDEA CONCEPT



Silicon detectors for precision measurements (vertex detector, silicon internal tracker)

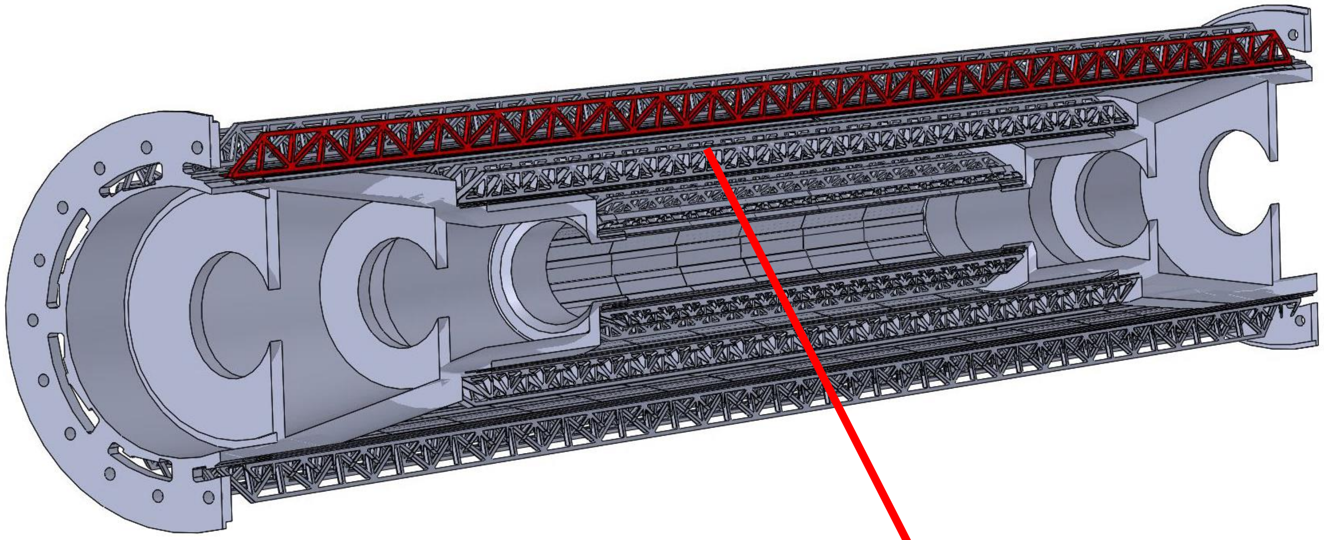


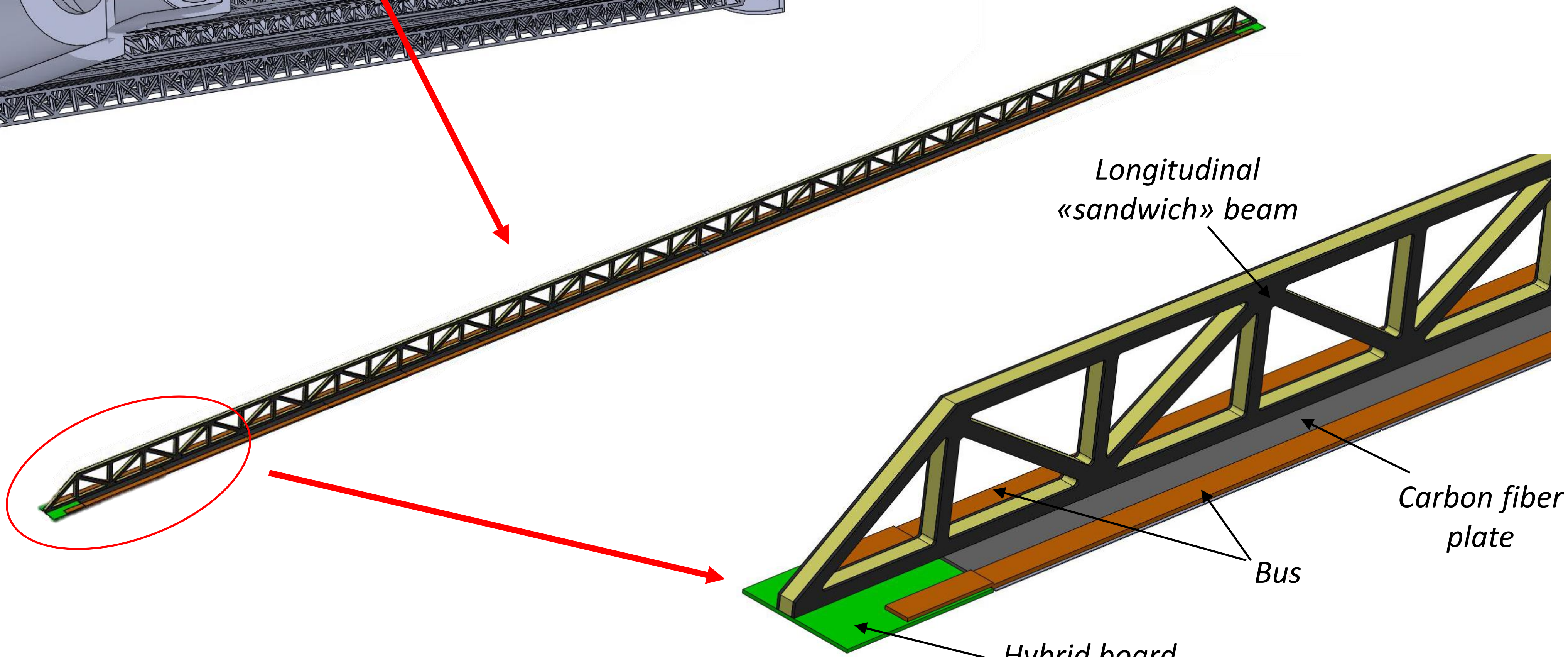
Sensors arranged in three concentric layers

MECHANICAL DESIGN

The detector consists of lightweight longitudinal units supported by endcaps at the ends:

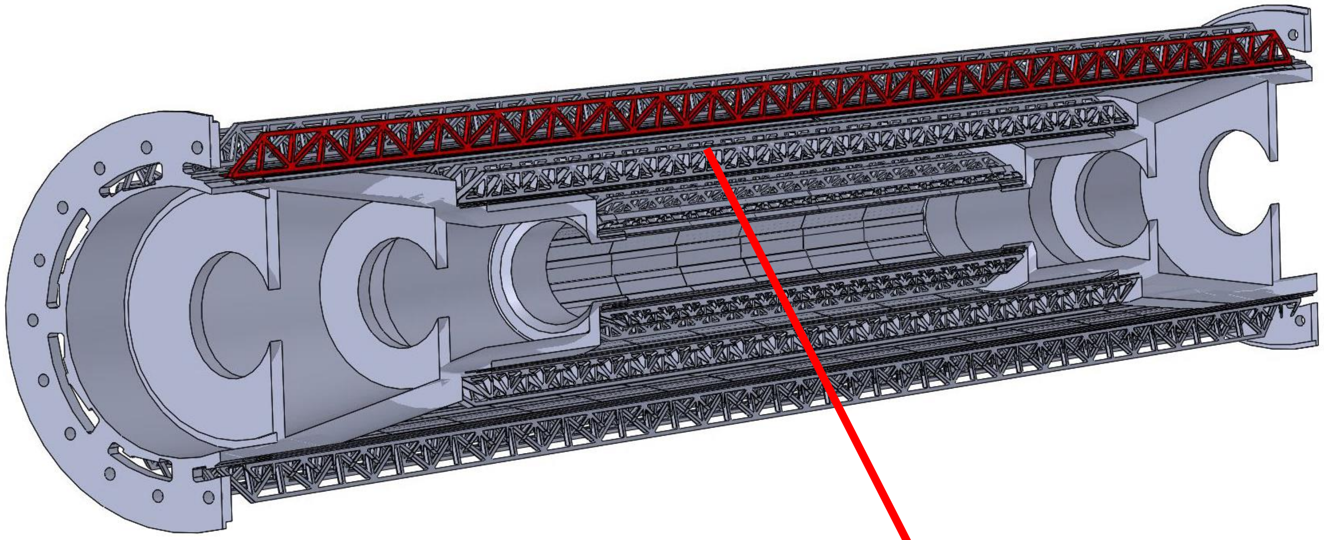
- 36 staves in layer 3, L = 540mm
- 24 staves in layer 2, L = 340mm
- 15 staves in layer 1, L = 220mm





Mechanical drawing kindly provided by INFN- Sezione di Pisa

HEAT LOADS



The detector consists of lightweight longitudinal units supported by endcaps at the ends:

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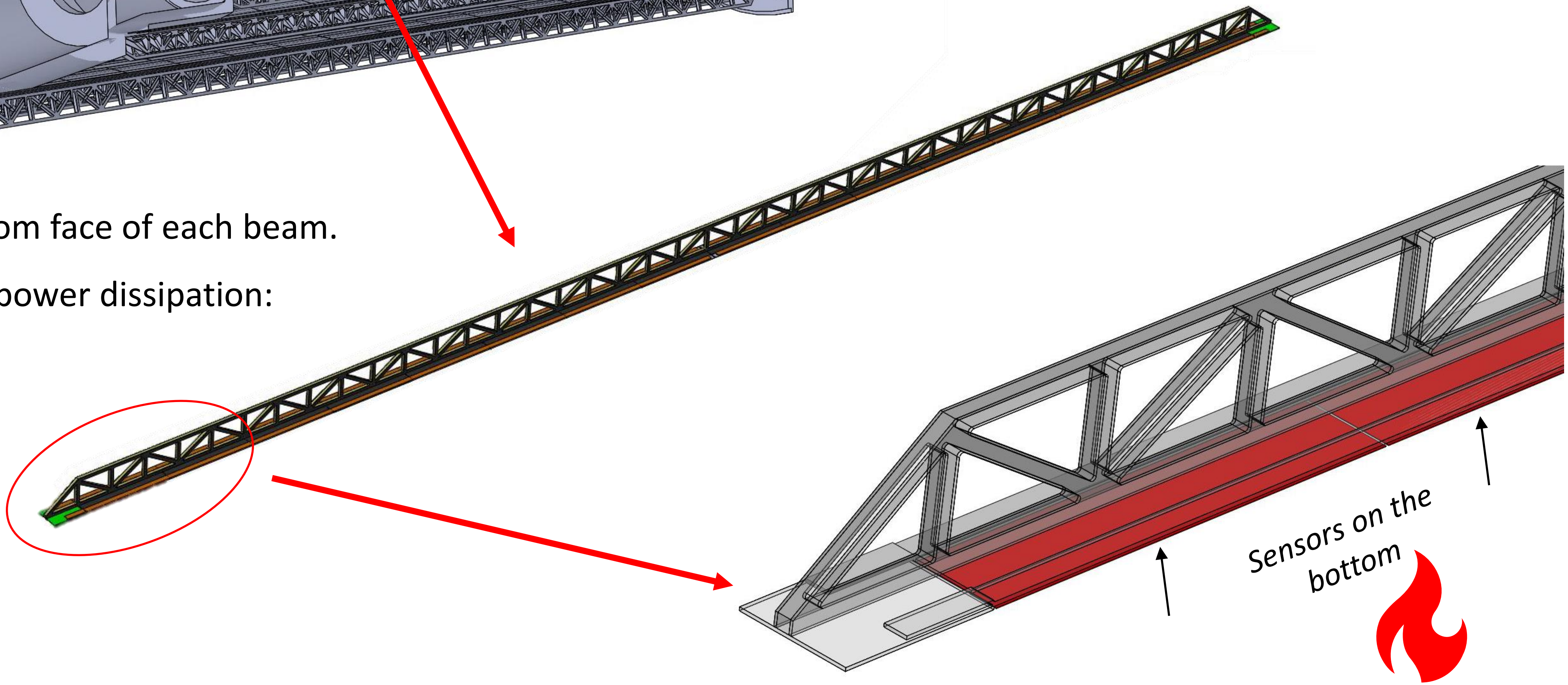
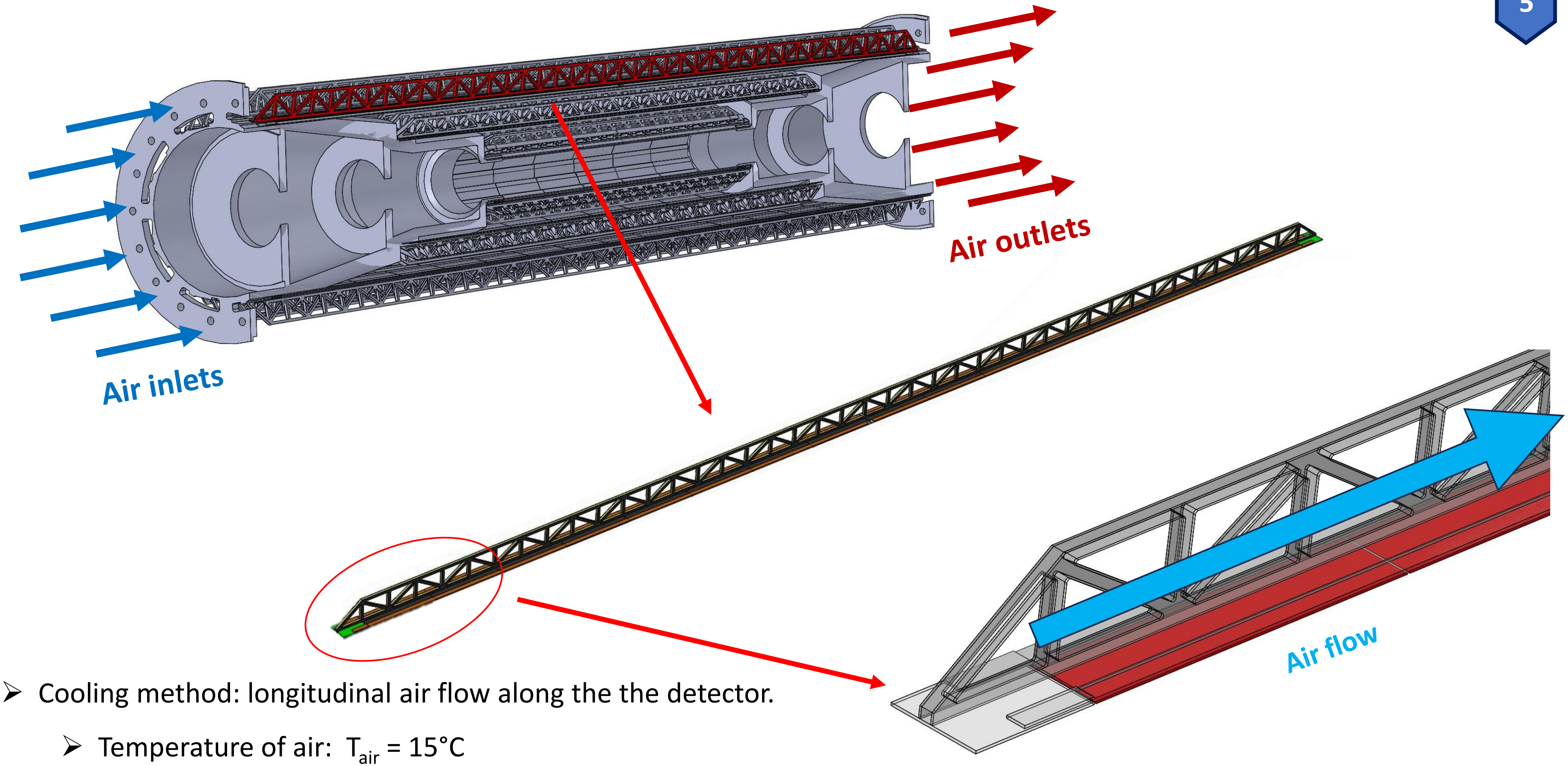


Sensors are in the bottom face of each beam.

Estimation for sensors power dissipation:

- Layer 3: Q ~ 77 W
- Layer 2: Q ~ 32 W
- Layer 1: Q ~ 12 W

AIR COOLING CONCEPT

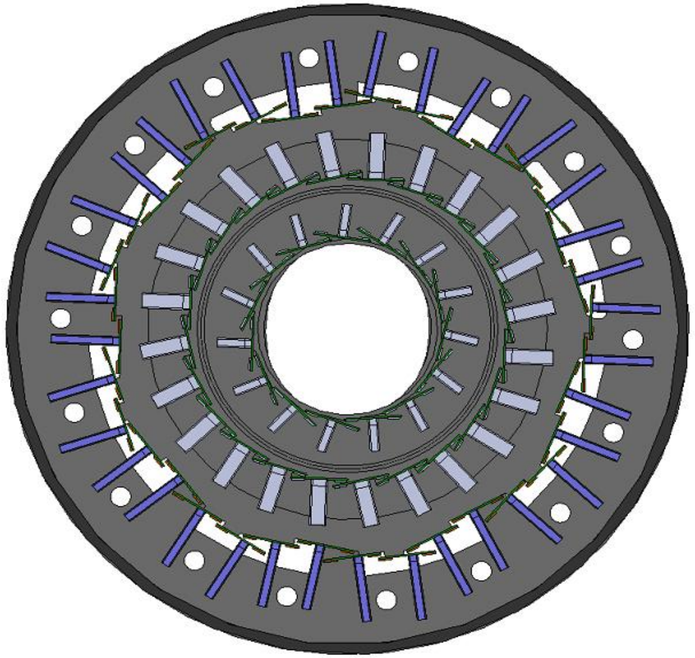


- Cooling method: longitudinal air flow along the the detector.
  - Temperature of air: T_{air} = 15°C

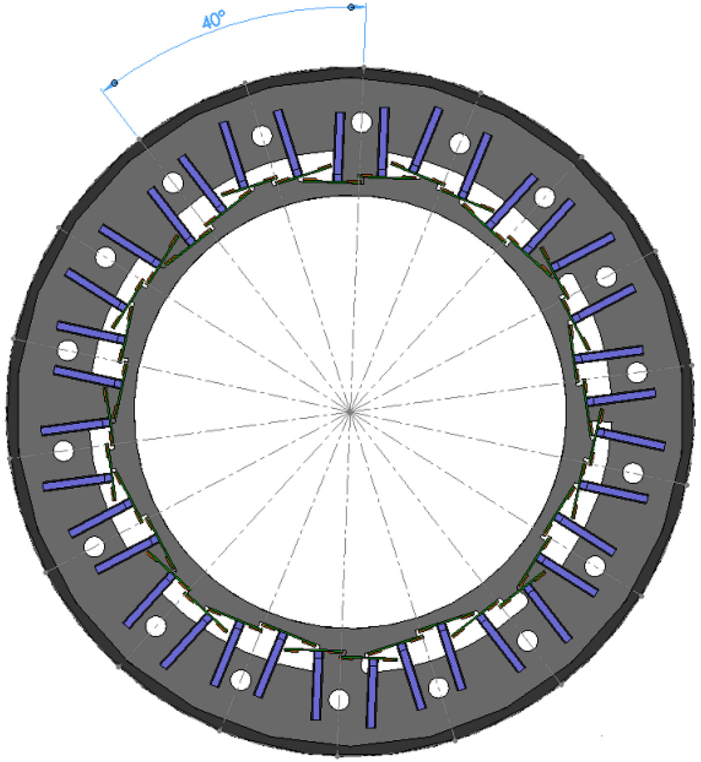
EVALUATING THERMAL PERFORMANCE

Ansys

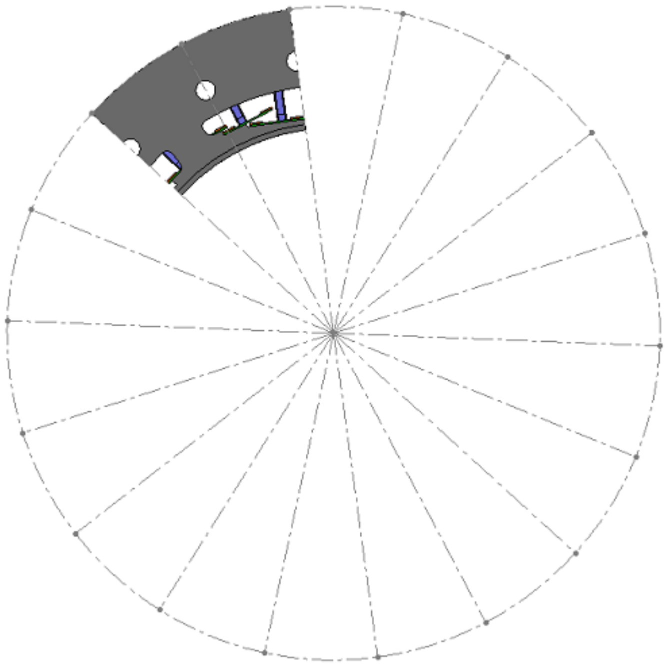
- Tool for thermal analysis: finite volume method (Ansys Fluent).
- Challange: <u>create the calculation grid for such a complex geometry</u>.
- Simplification of the geometry is needed. As first approach:



Full geometry



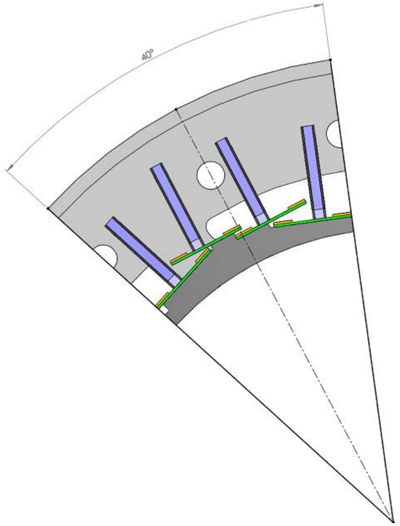
Removing
layer 1 and 2



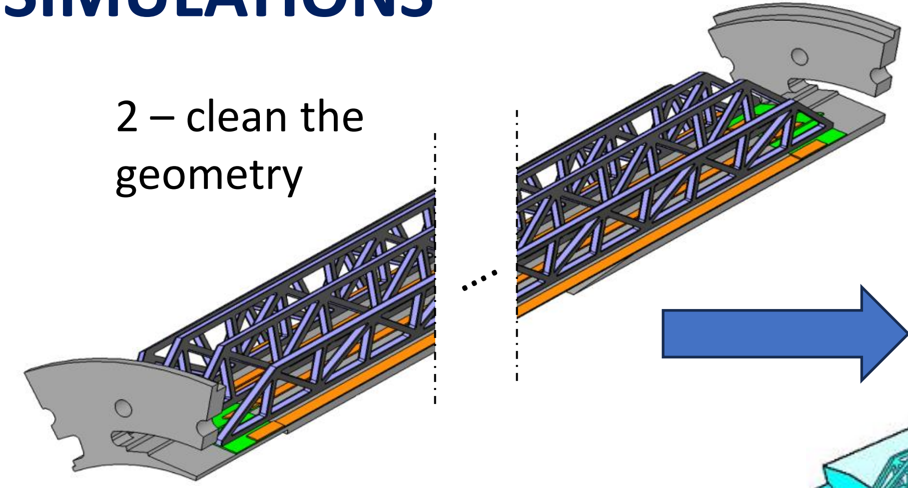
Focus on one sector
(40° circular symmetry)

STEPS FOR THERMAL SIMULATIONS

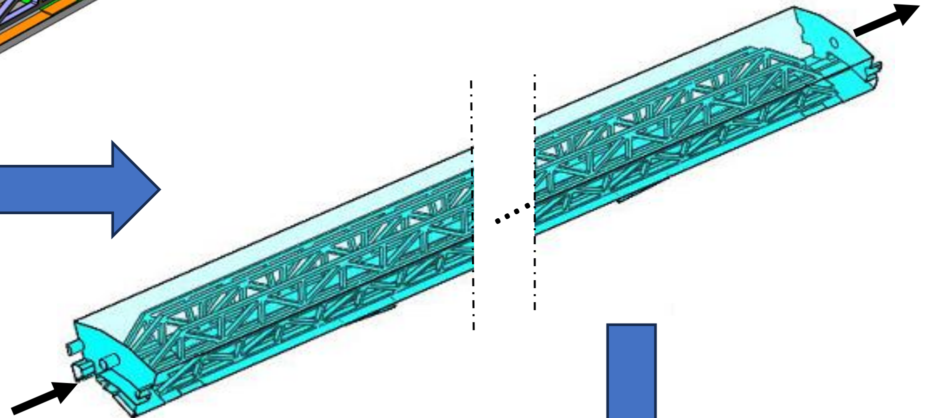
1 - Simplify the model



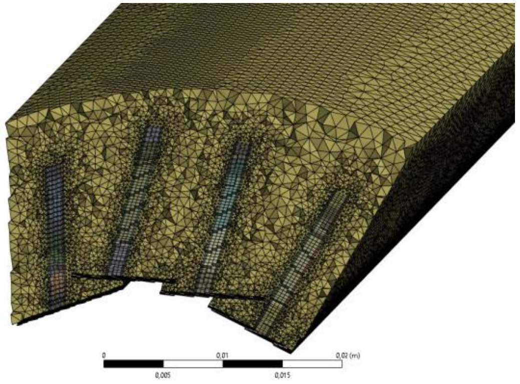
2 – clean the geometry



3 - Adding the volume of fluid

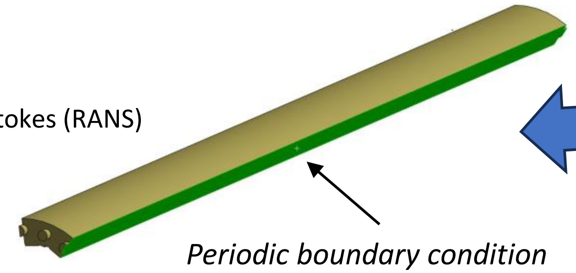


4 – Creating the grid



5 – Setting up the model

- ✓ Steady state conditions
- ✓ Turbulent flow
- ✓ Reynolds Average Navier Stokes (RANS)
- ✓ Viscous model k-ω SST
- ✓ Pressure based solver
- ✓ No radiation heat exchange



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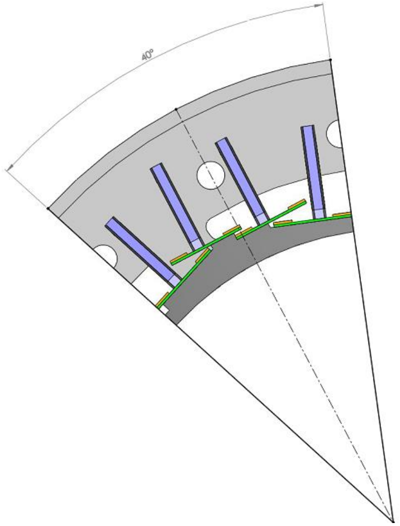

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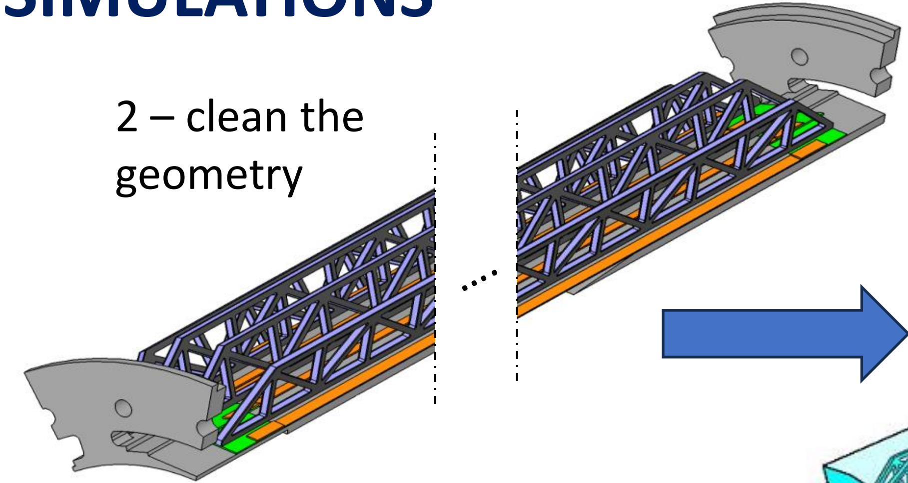
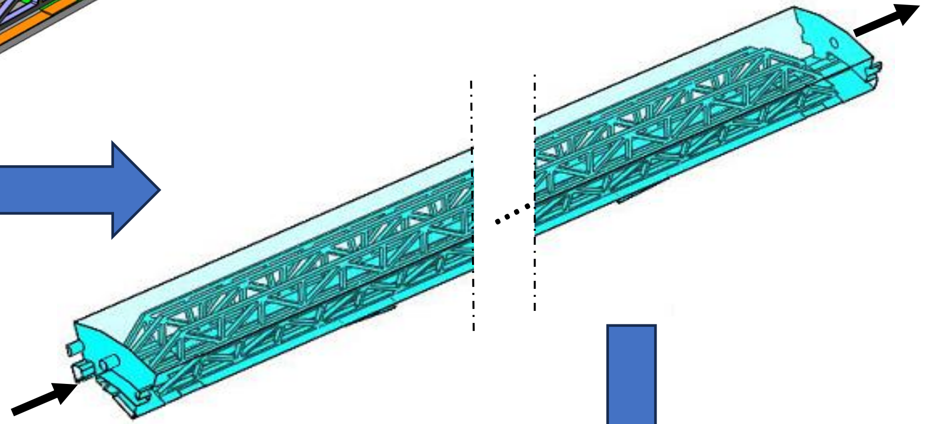


3 - Adding the volume of fluid



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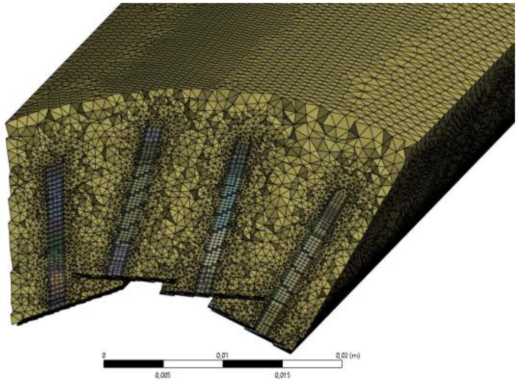

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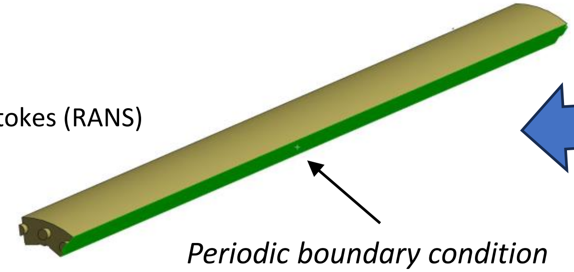
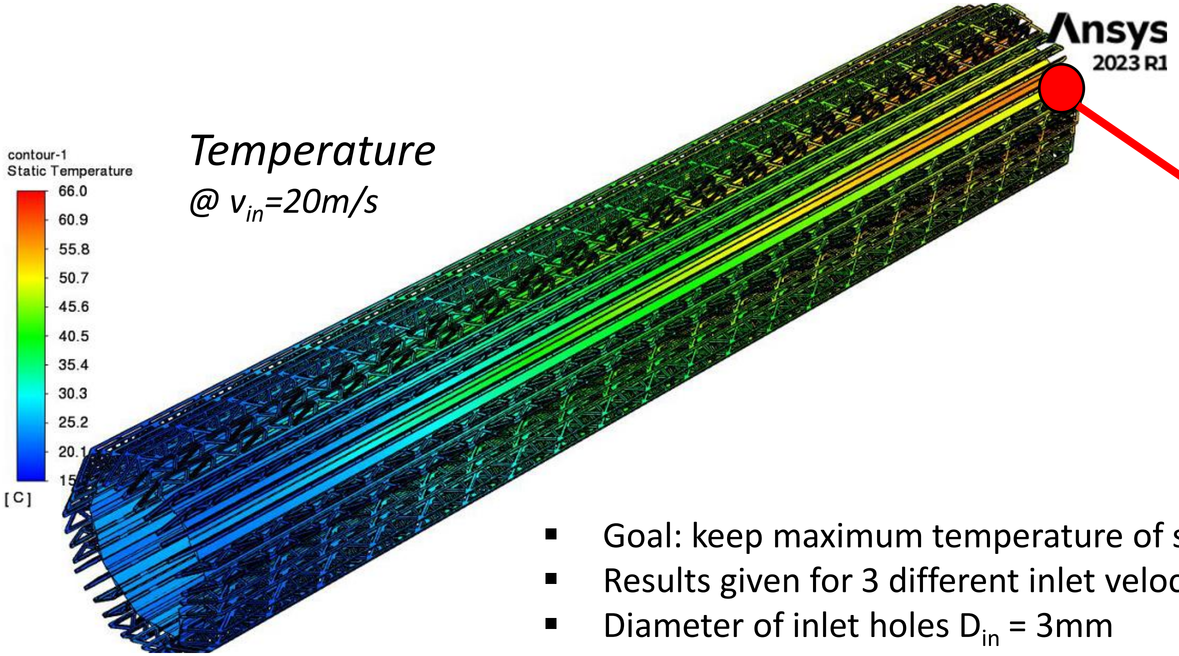


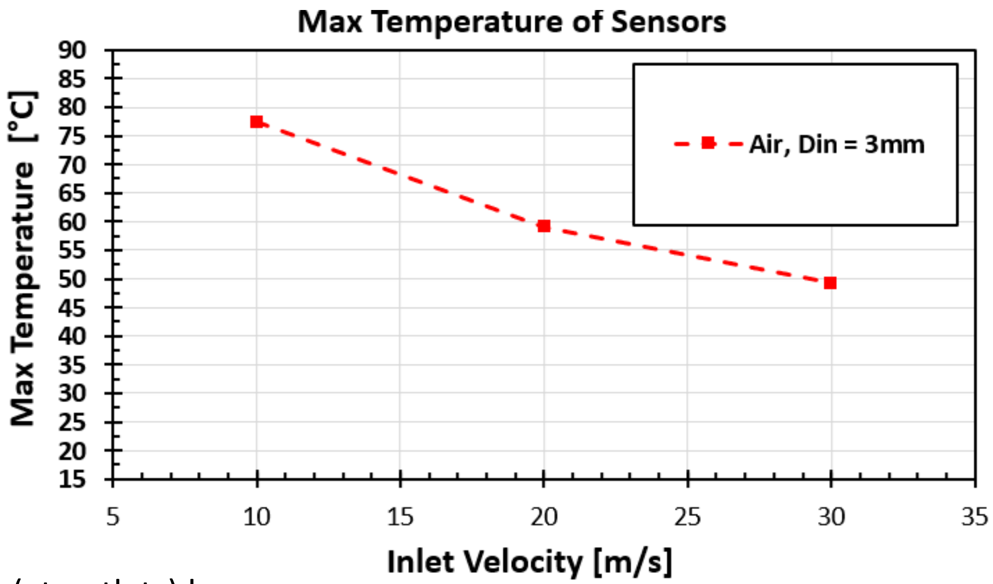
6 – Run calculations

ANALYSIS OF RESULTS

Temperature

@ v_{in}=20m/s

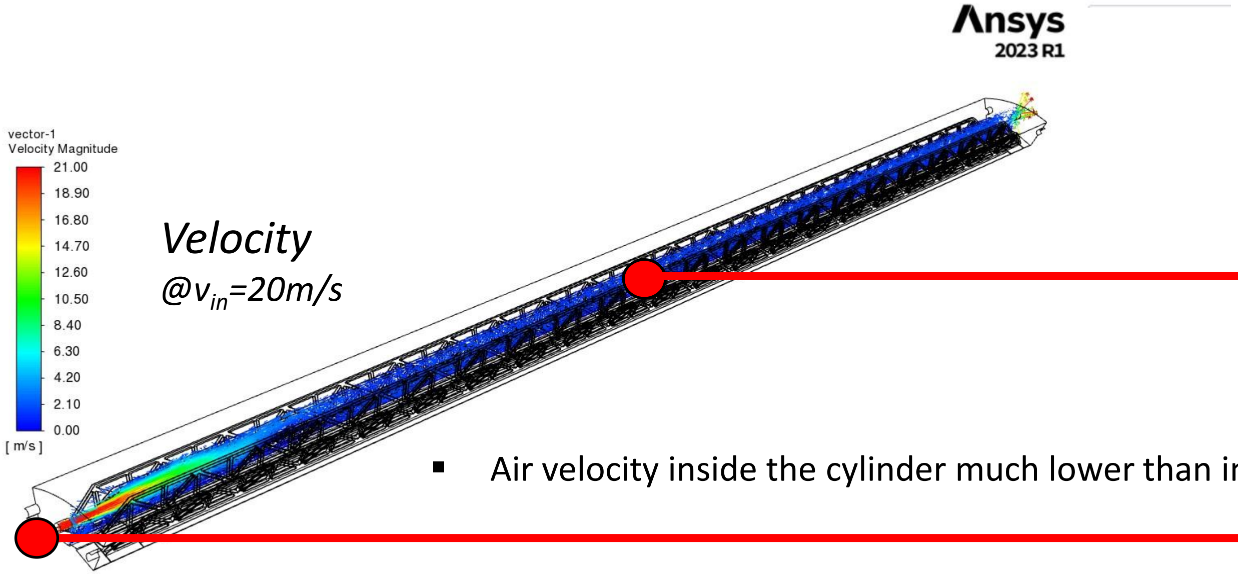


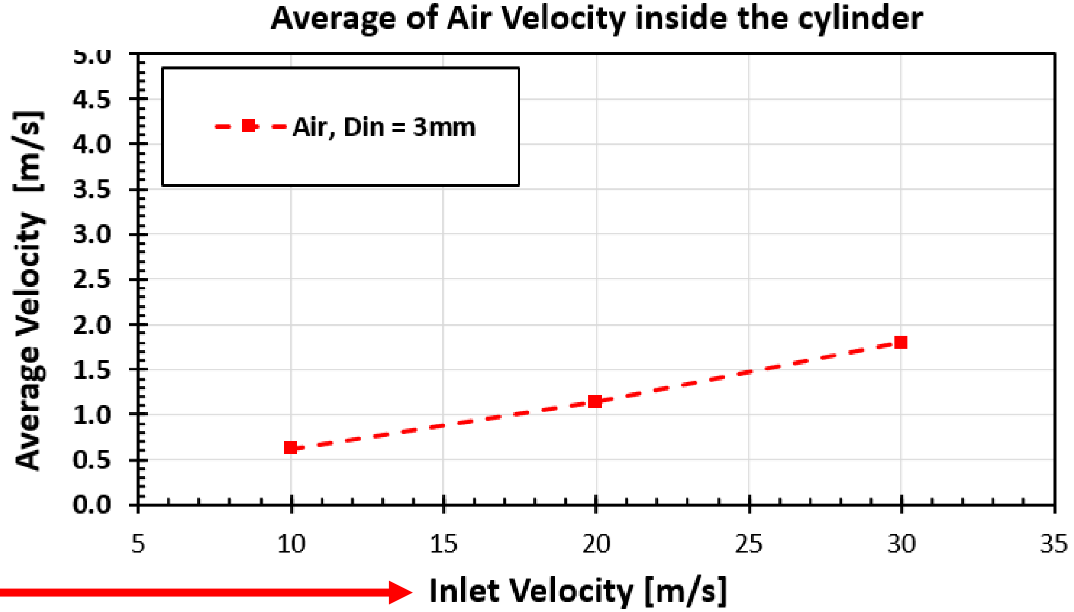


- Goal: keep maximum temperature of sensors (at outlets) low
- Results given for 3 different inlet velocity of air
- Diameter of inlet holes D_{in} = 3mm

Velocity

@v_{in}=20m/s

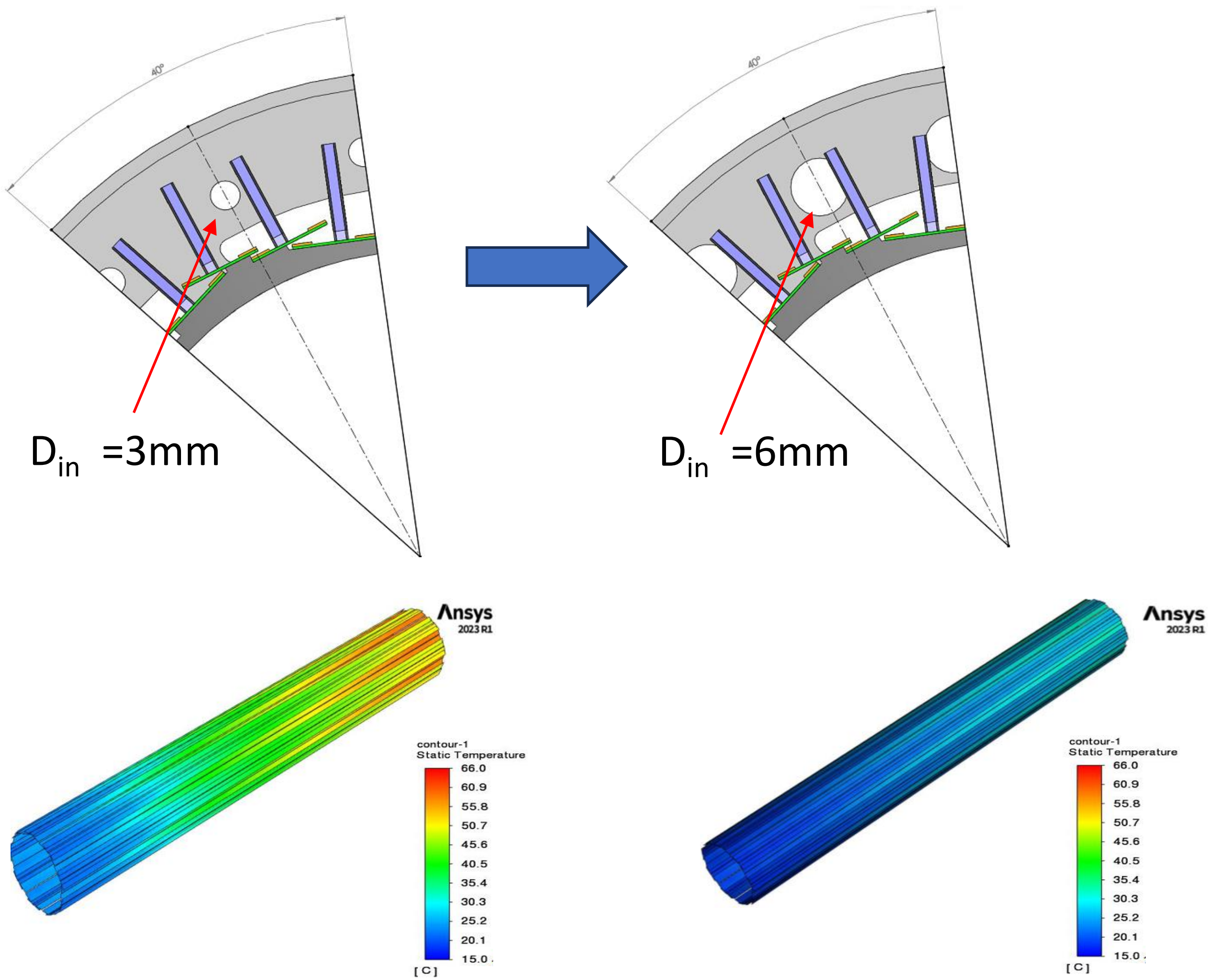


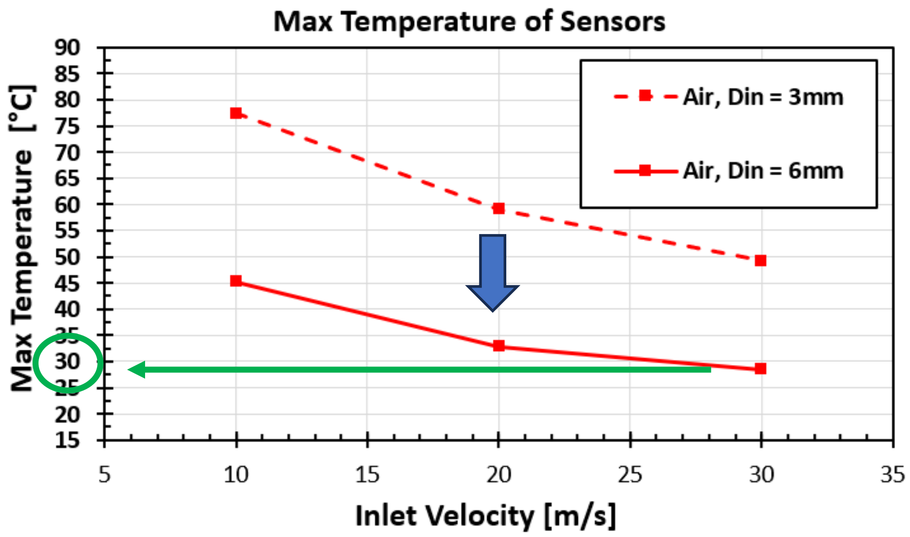


- Air velocity inside the cylinder much lower than inlets.

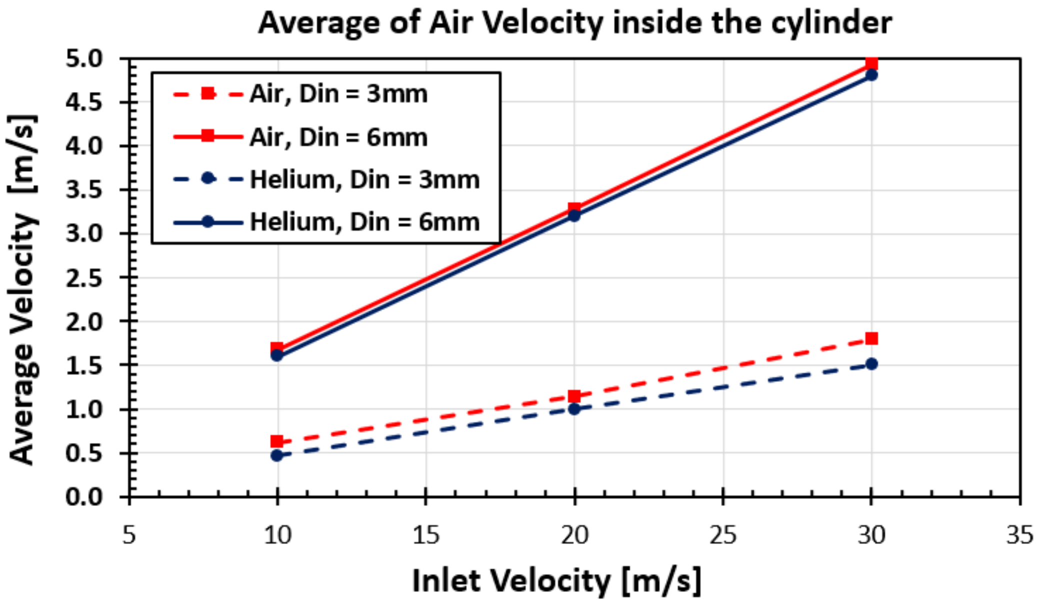
DESIGN OPTIMIZATION

- Increase the diameter for inlets holes.
  - Mass flow rate increase as well (for same v_{in})





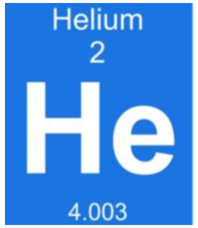
➢ Max temperature decrease about 30°C !

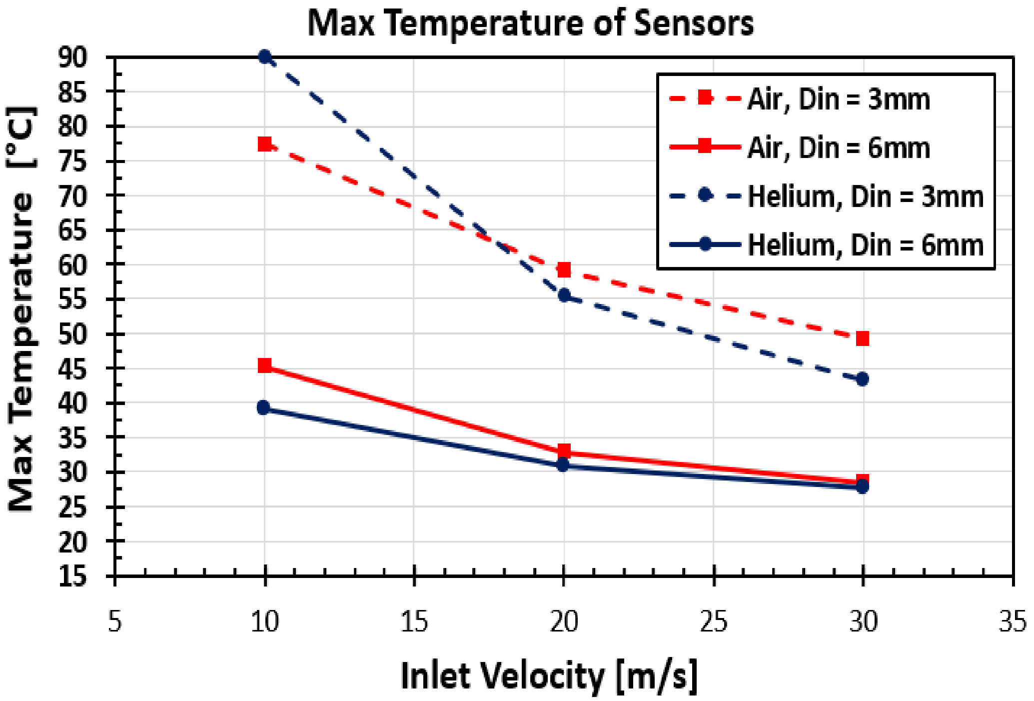


CHANGING THE FLUID PROPERTIES

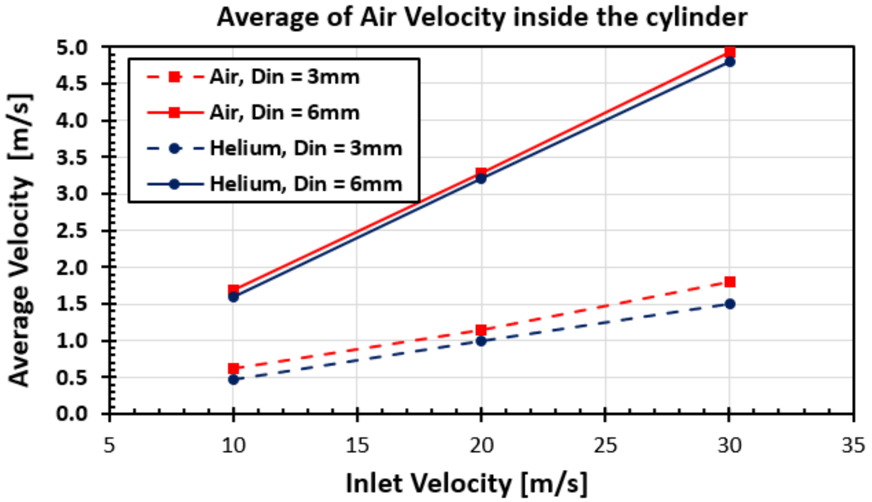
- The **use of helium** as a fluid instead of air was investigated.

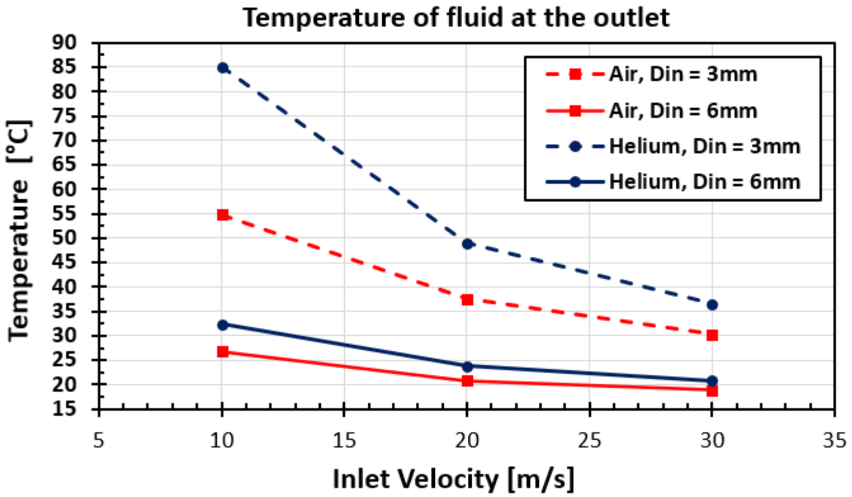
- Properties of helium taken from Ansys libraries:
  - Lower density than air.
  - Higher thermal conductivity than air.





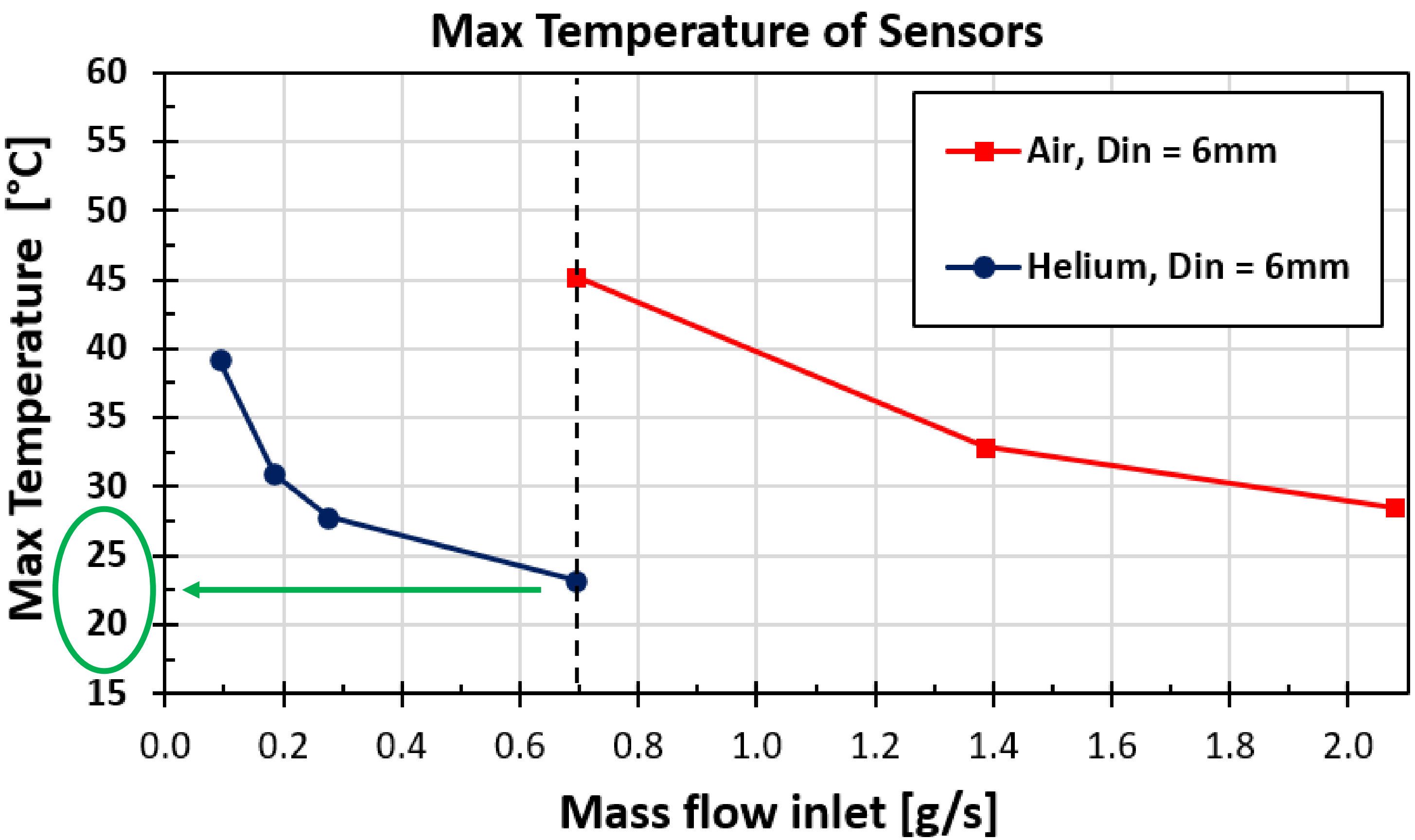
	Air	Helium
Density [kg/m^3]	1.225	0.1625
Specific Heat [J/(kg K)]	1’006	5’193
Thermal Conductivity [W/(m K)]	0.024	0.152
Viscosity [kg/(m s)]	1.79e-05	1.99e-05





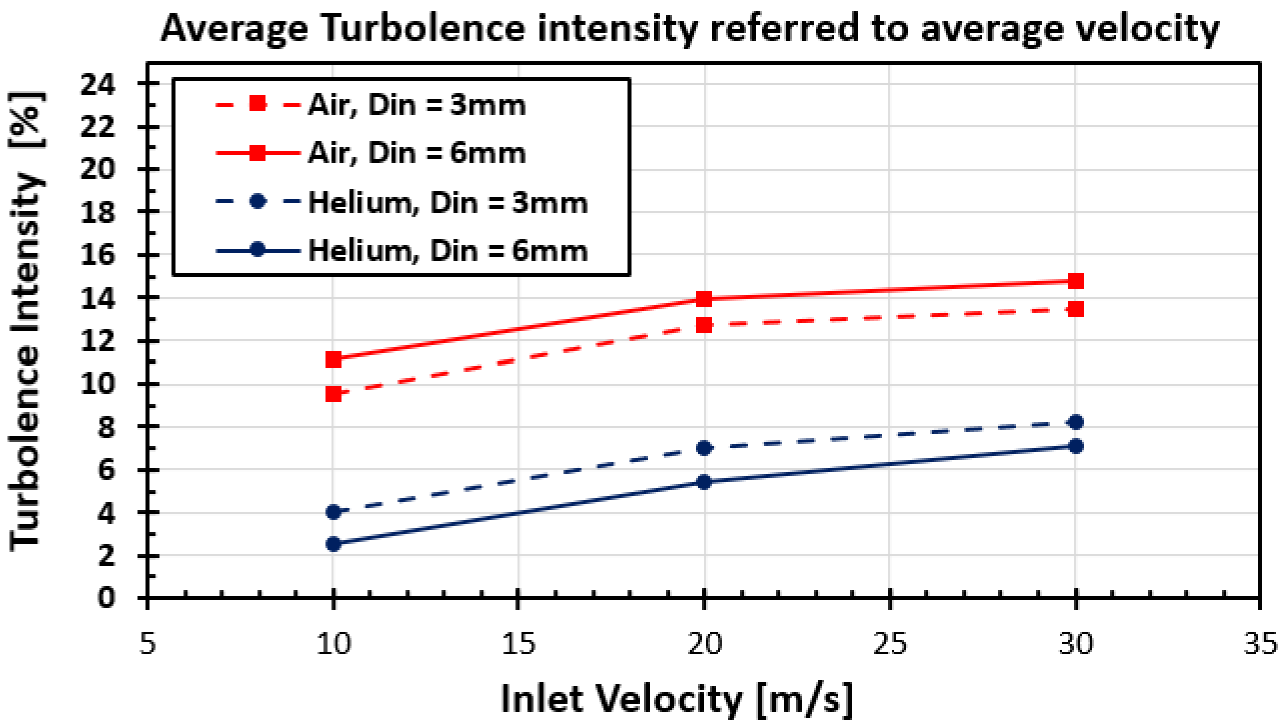
CHANGING THE FLUID PROPERTIES

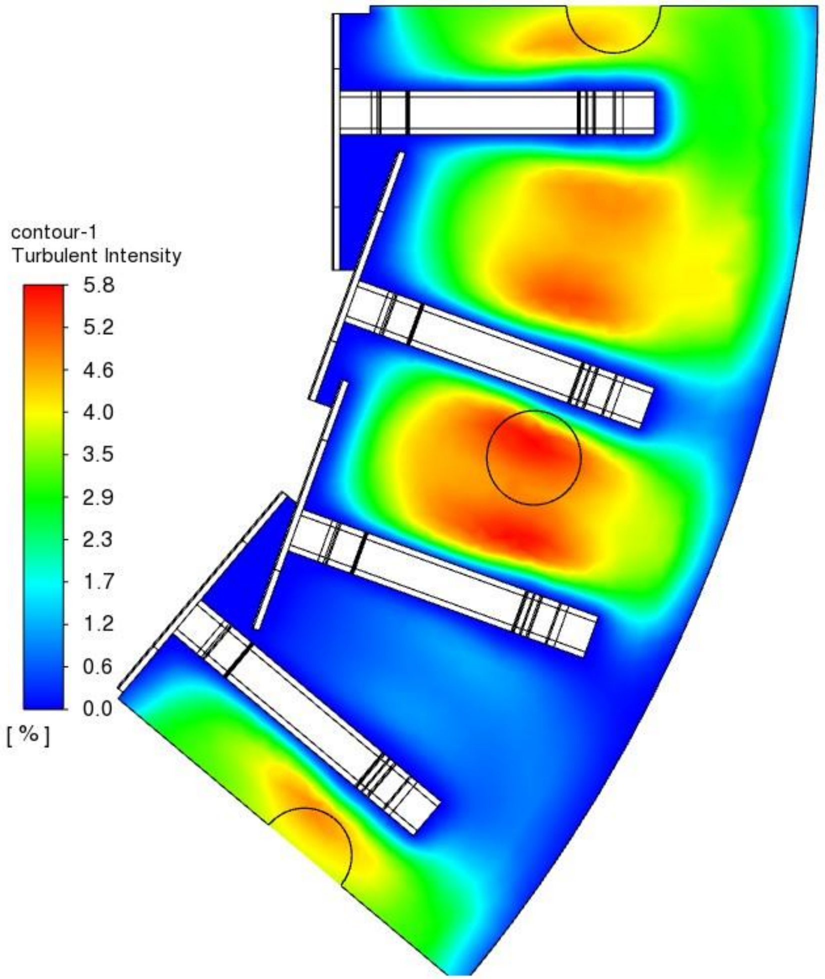
- Comparison is interestesting considering same mass flow rate instead of same inlet velocity.
- Helium offers much better cooling than air for same mass flow rate.



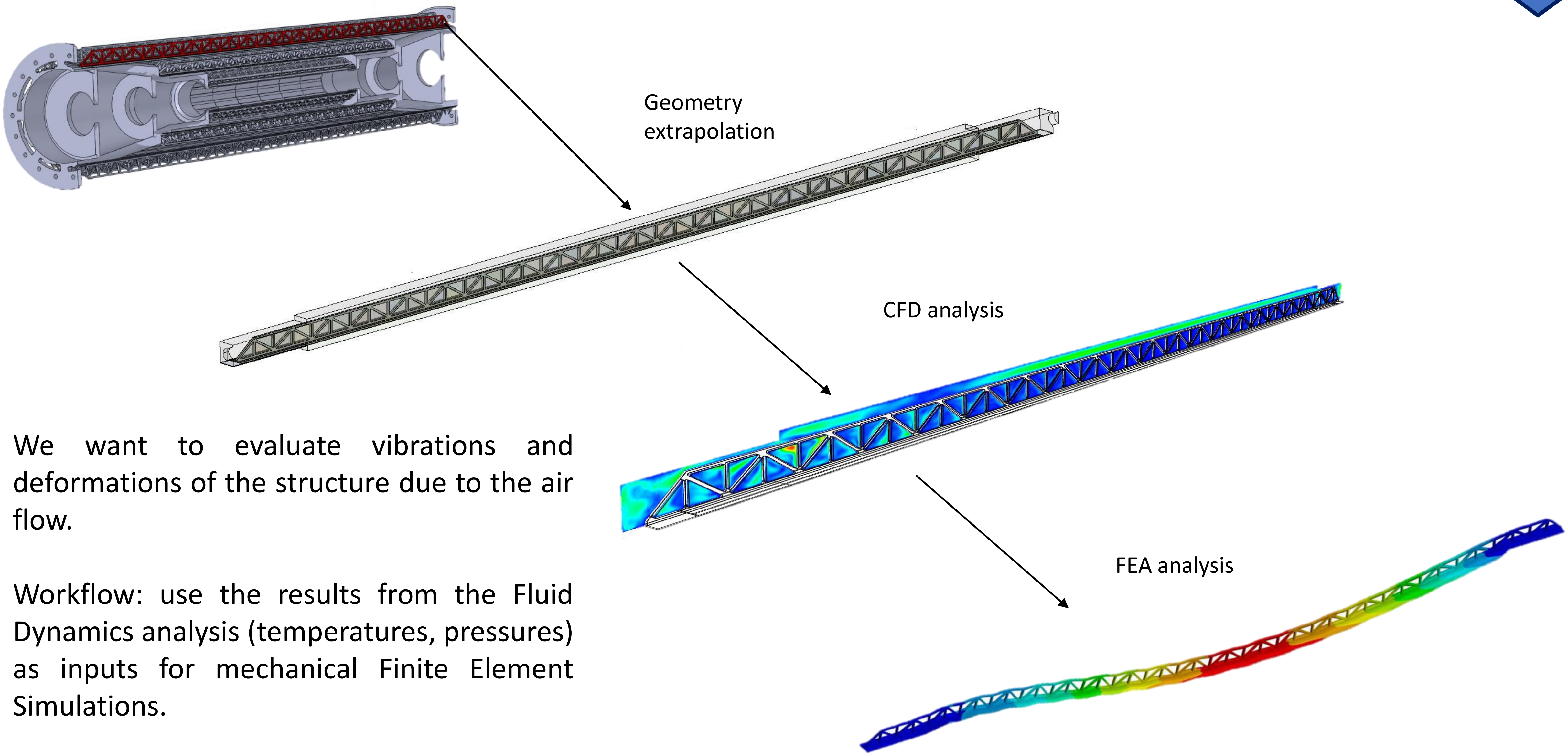
TURBOLENCE

- The turbulence generates a mixing of air which favors heat exchange
- But also induces vibrations on the lightweight structure.
- Need to study effect of turbolence to the structures for high flows.





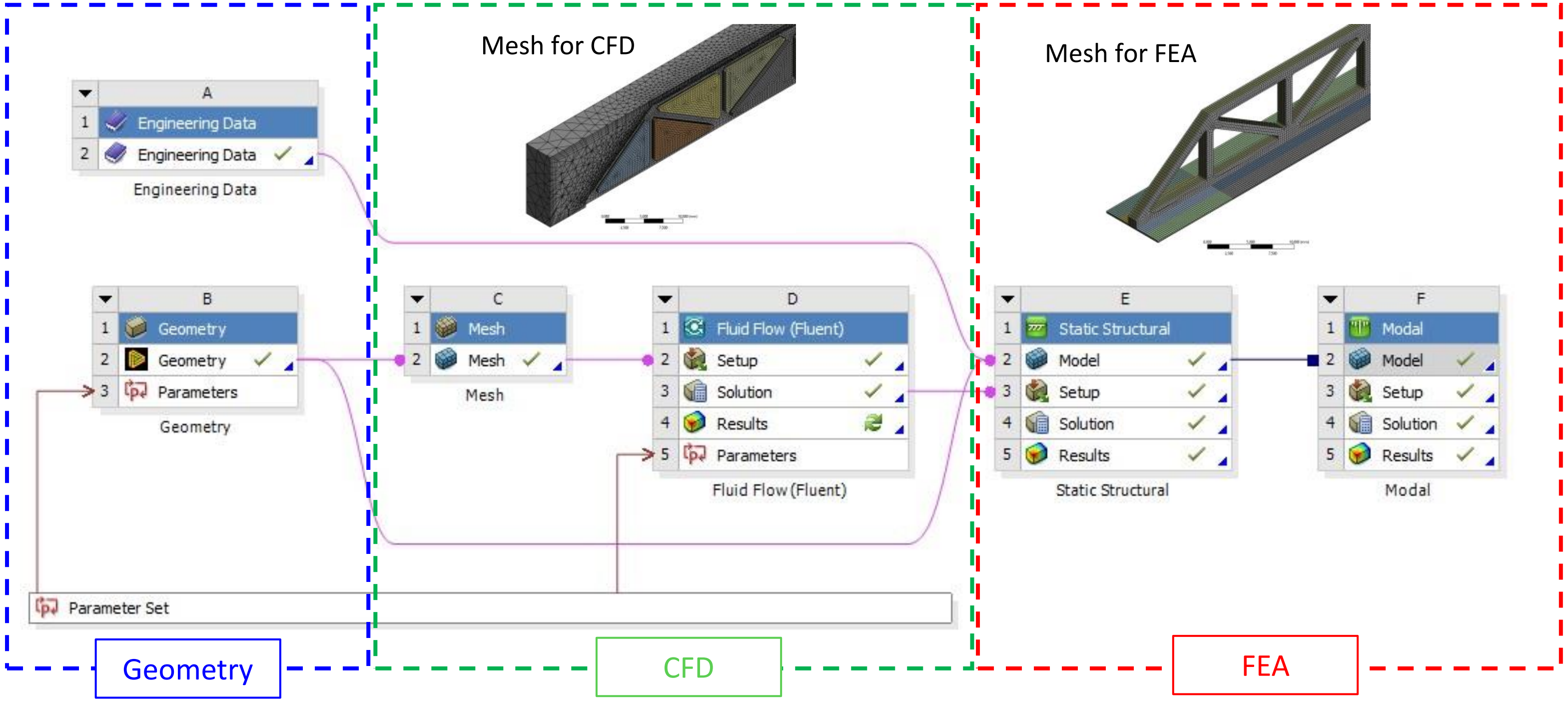
A MULTIPHYSICS MODEL FOR THE EVALUATION OF MECHANICAL STRESS



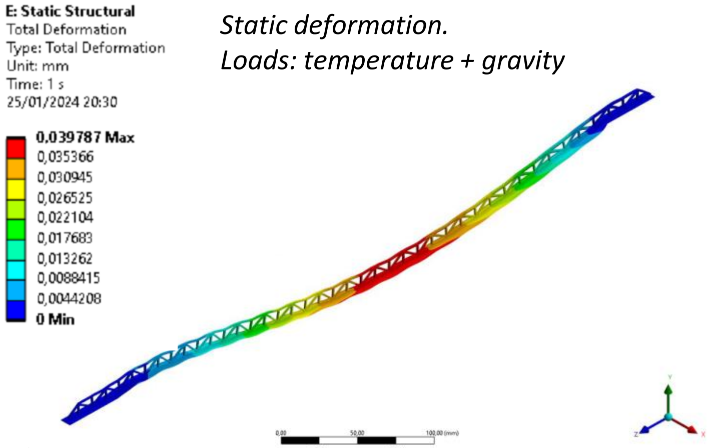
- We want to evaluate vibrations and deformations of the structure due to the air flow.

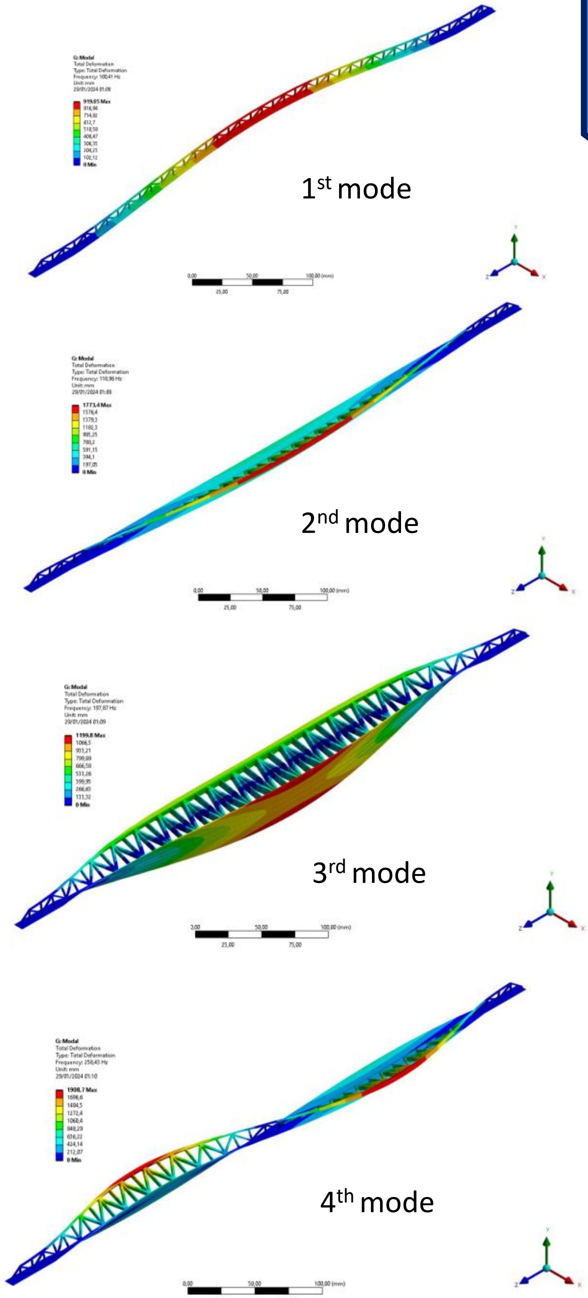
- Workflow: use the results from the Fluid Dynamics analysis (temperatures, pressures) as inputs for mechanical Finite Element Simulations.

FEA SIMULATIONS



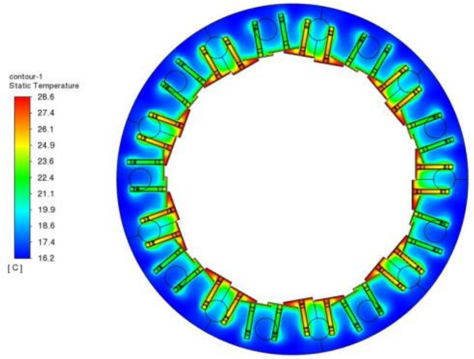
- Workflow of data through Ansys Workbench platform.
- Static analysis already set.
- Model is still work-in progress:
  - Implementing fluid pressures in dynamic regime.
- Building an experimental mockup for validating results is crucial.
- Modal analysis executed on the old geometry: to be updated with the new design !

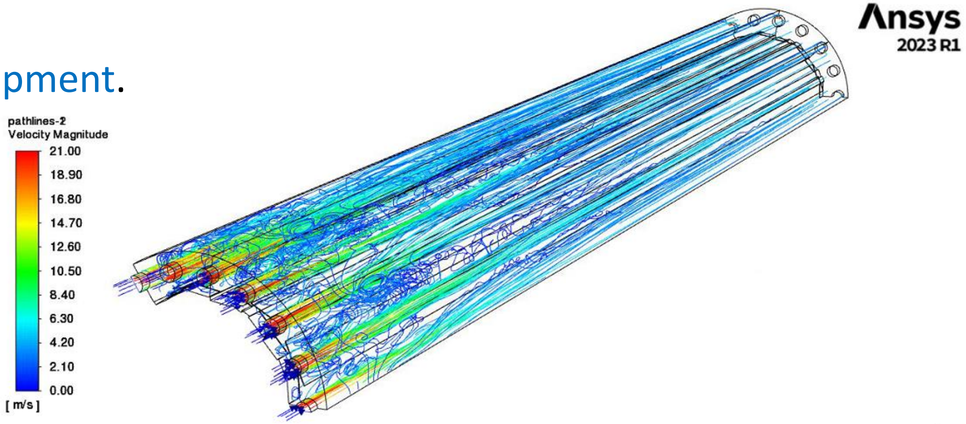




SUMMARY & OUTLOOK

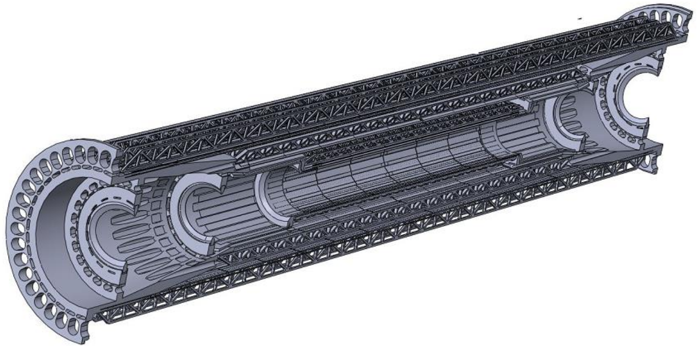
- A CFD model for the evaluation of thermal performance of layer 3 has been made.
    - The model reproduces both the solid part of the detector and the air that circulates inside it.
- Already in use to evaluate different geometry choices and different operating fluids.
- The model provides some promising design points with the gas cooling concept.
- The presence of slender structures and high flows makes necessary a careful analysis of vibrations.
    - A computational model for studying fluid-structure interactions is in development.
    - Coupling between CFD and FEA via Ansys Workbench.





➢ NEXT STEPS:

- Improve the stability of the model (mesh refinement in the fluid part).
- Update the geometry with the new design (already available !)
- Try to include in one single model all the three layers together.
- Validate with tests on mock-ups.



Thanks for your attention