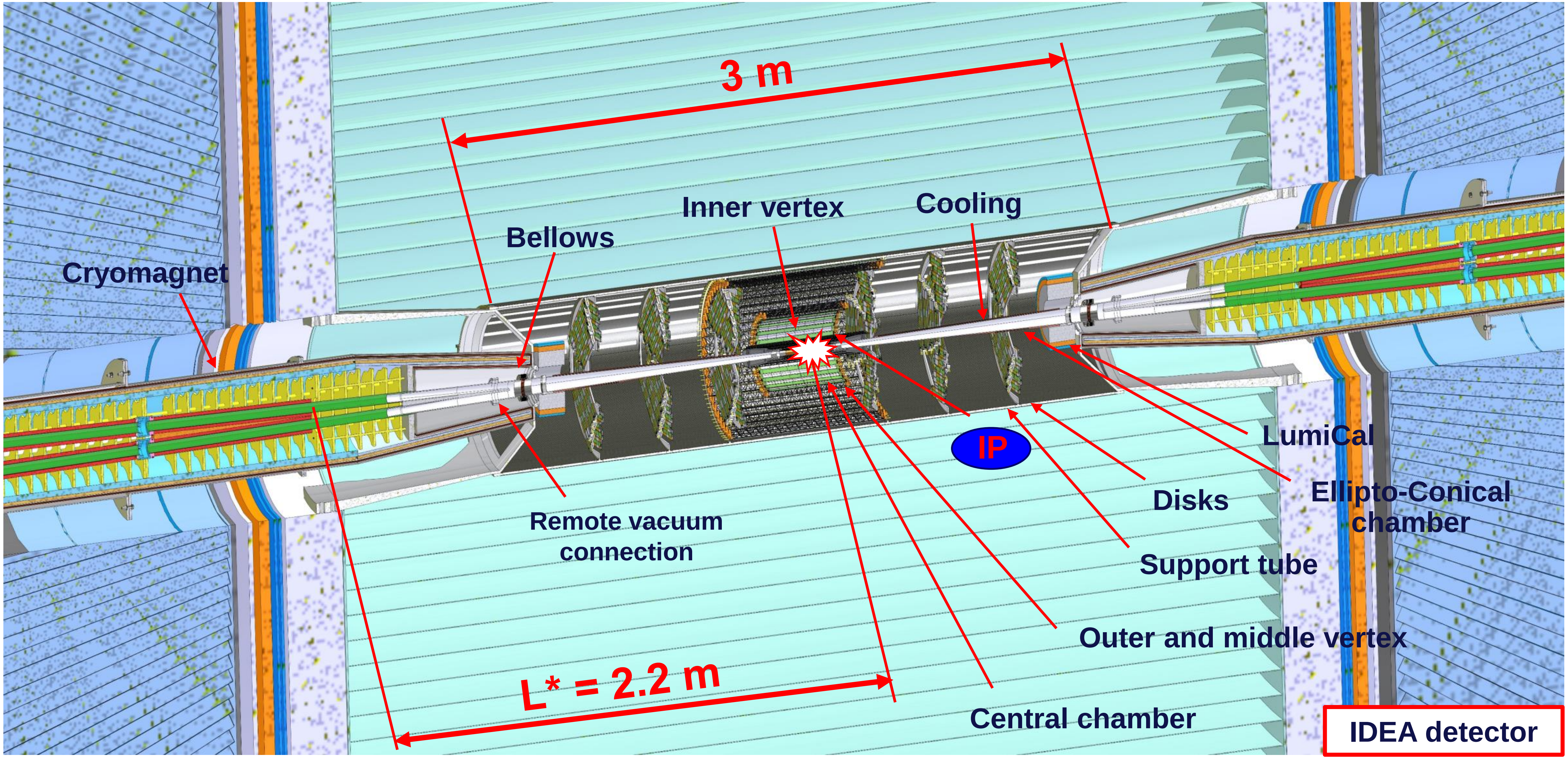
IR BEAM PIPES

Speaker: Francesco Fransesini

On behalf of the MDI study group

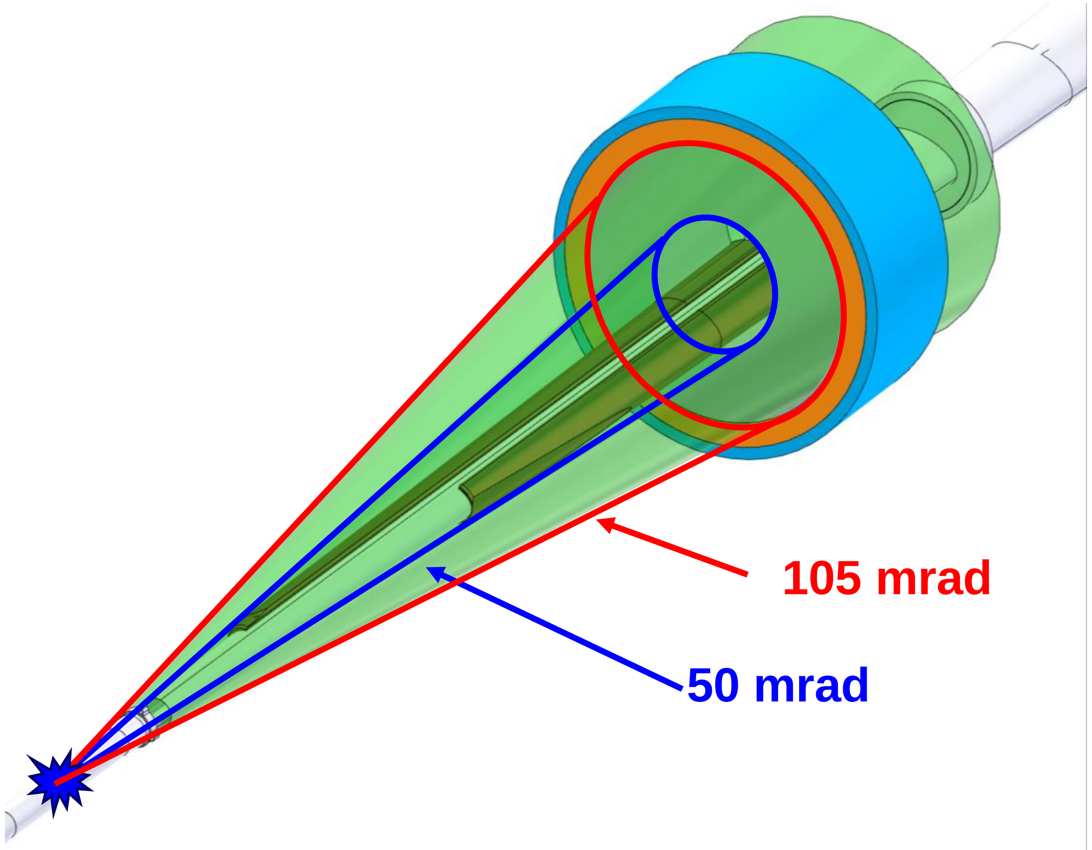
MDI mechanical model

This design is based on the **IDEA detector** concept.

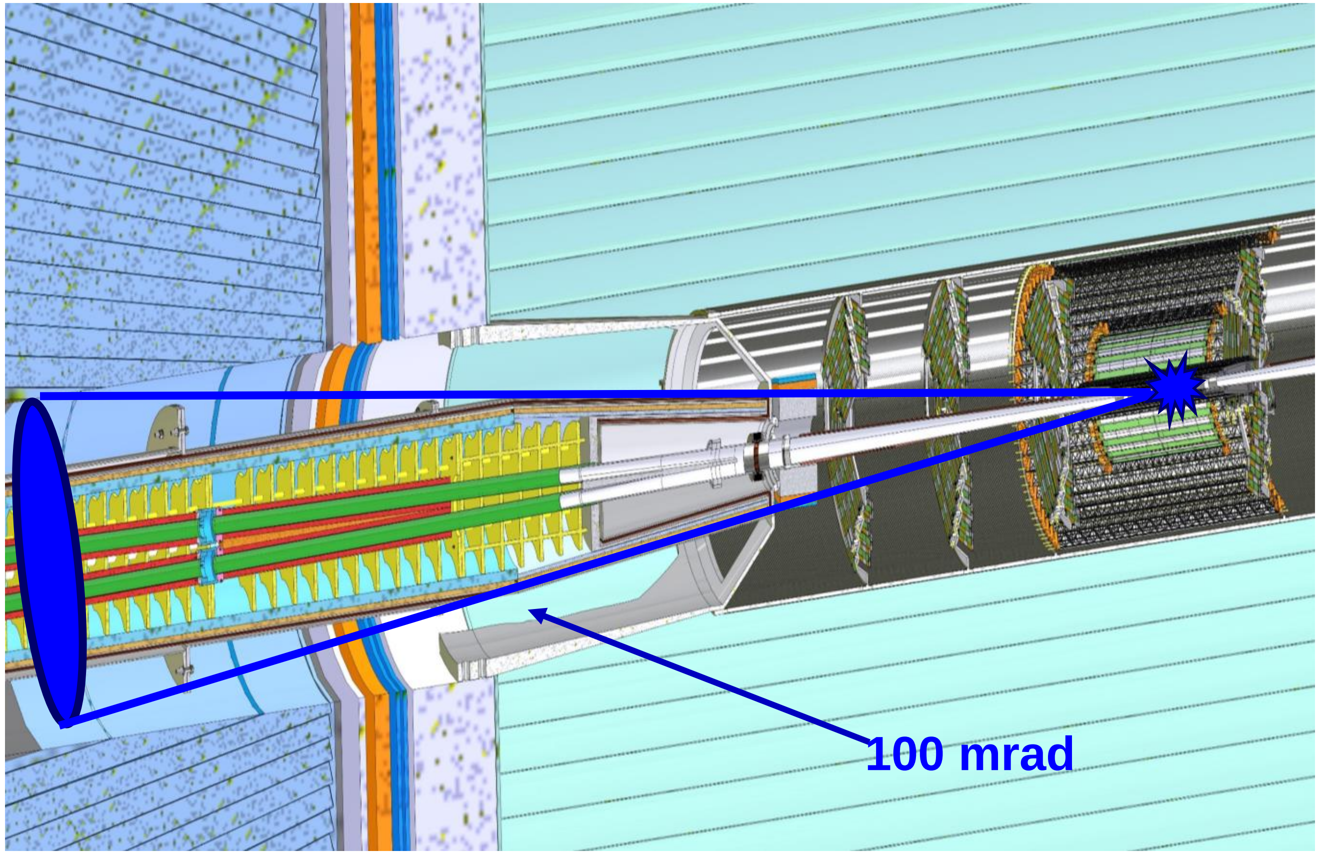


Spatial constraints

To achieve the required performance, it is necessary to have **low material budget** within the LumiCal acceptance (between **50 mrad** and **105 mrad** centered on the outgoing beam pipe).

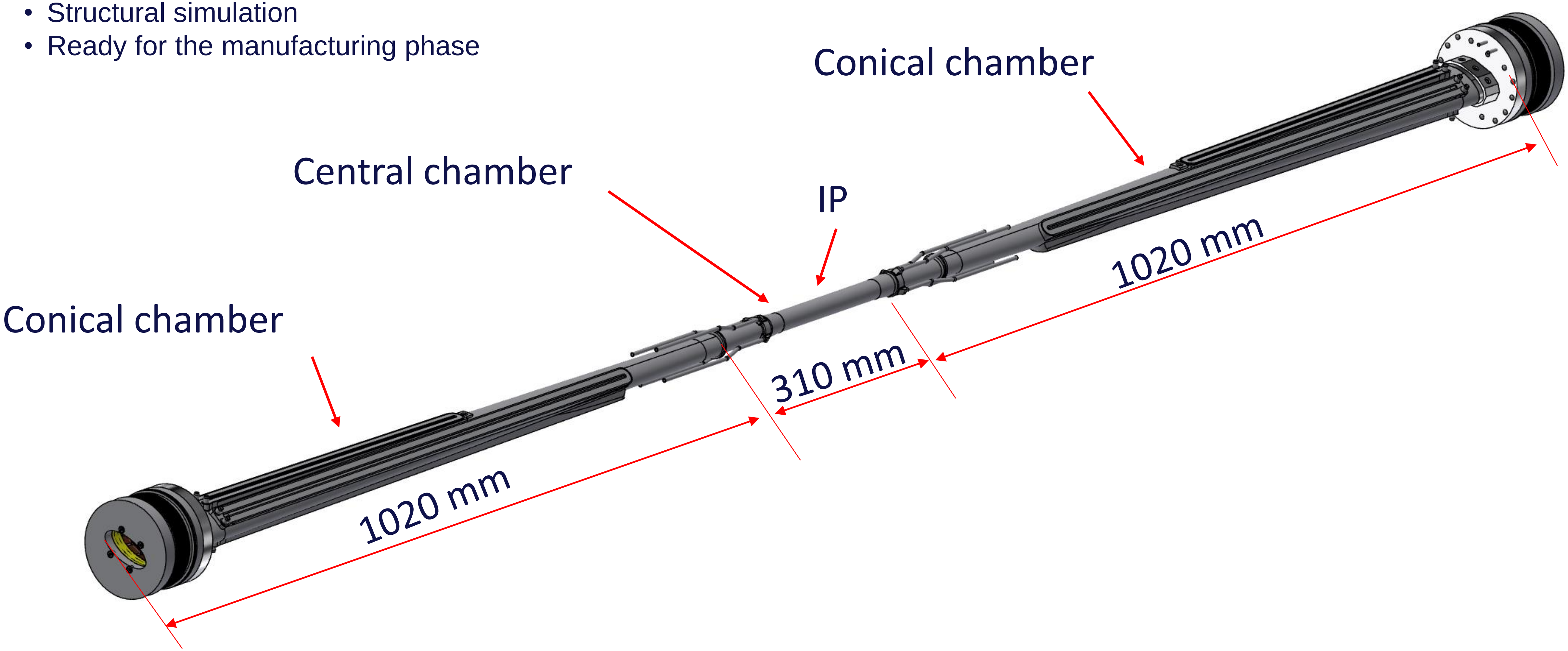


Every component of the MDI must stay inside the **100 mrad detector acceptance** cone.



Engineered Chambers

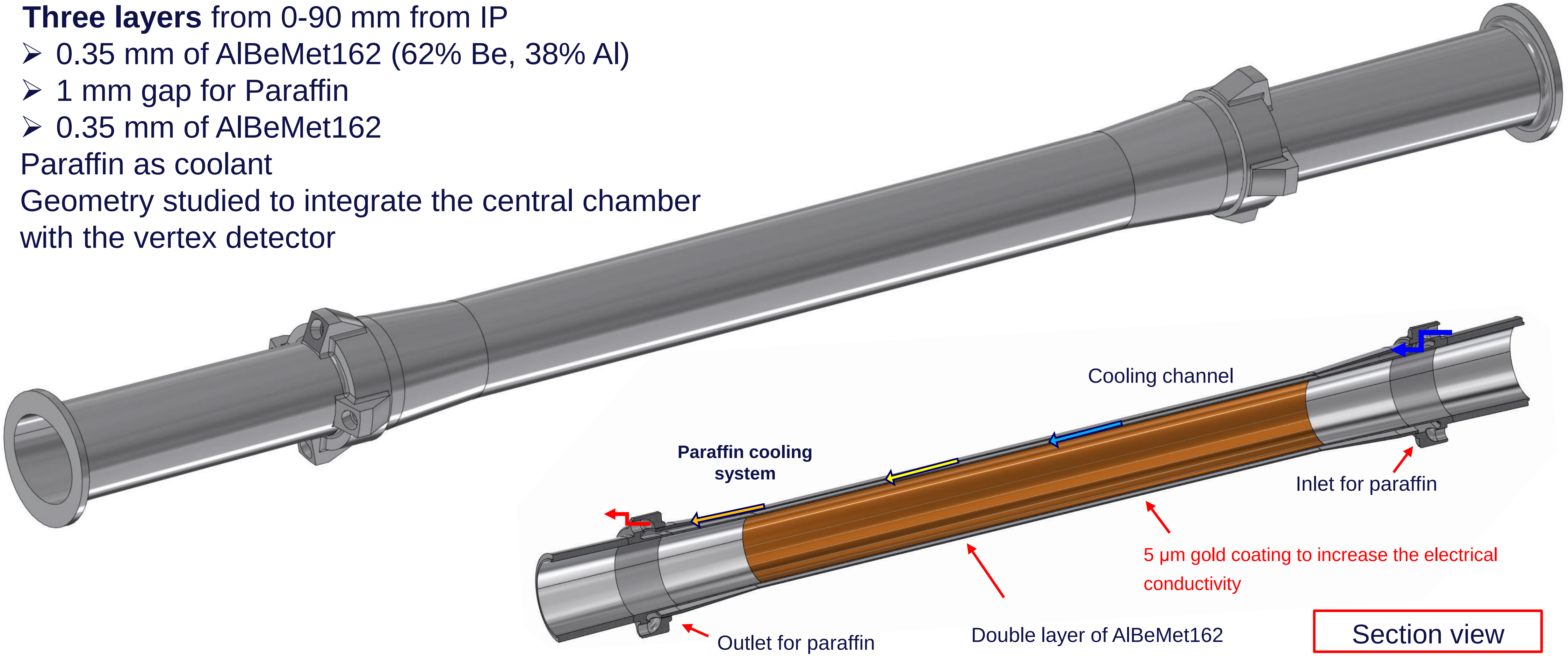
- Engineered design
- Thermal simulation
- Structural simulation
- Ready for the manufacturing phase



Central chamber

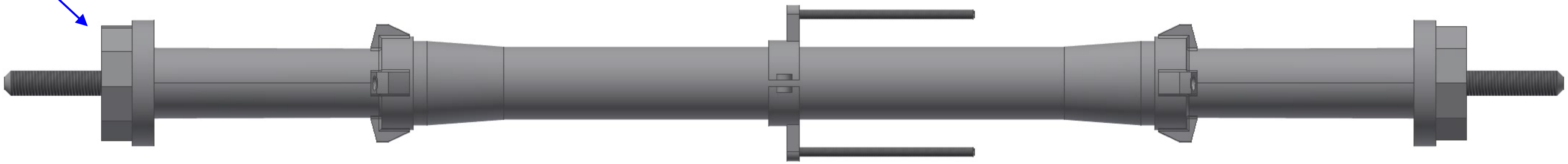
The main characteristics:

- **AlBeMet 162** as main material
- **Three layers** from 0-90 mm from IP
    - ➢ 0.35 mm of AlBeMet162 (62% Be, 38% Al)
    - ➢ 1 mm gap for Paraffin
    - ➢ 0.35 mm of AlBeMet162
- Paraffin as coolant
- Geometry studied to integrate the central chamber with the vertex detector



Assembly procedure

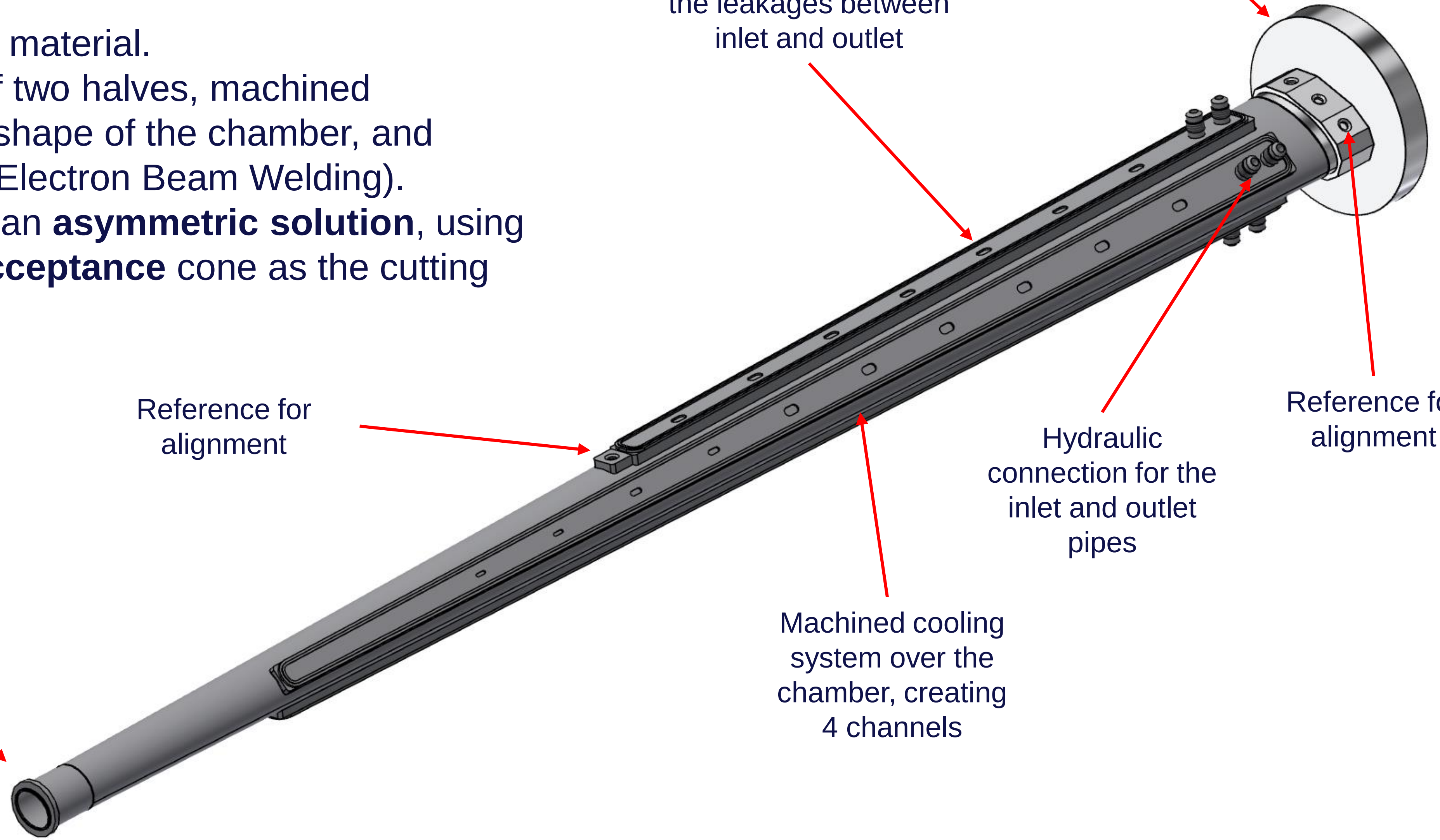
Tool for welding

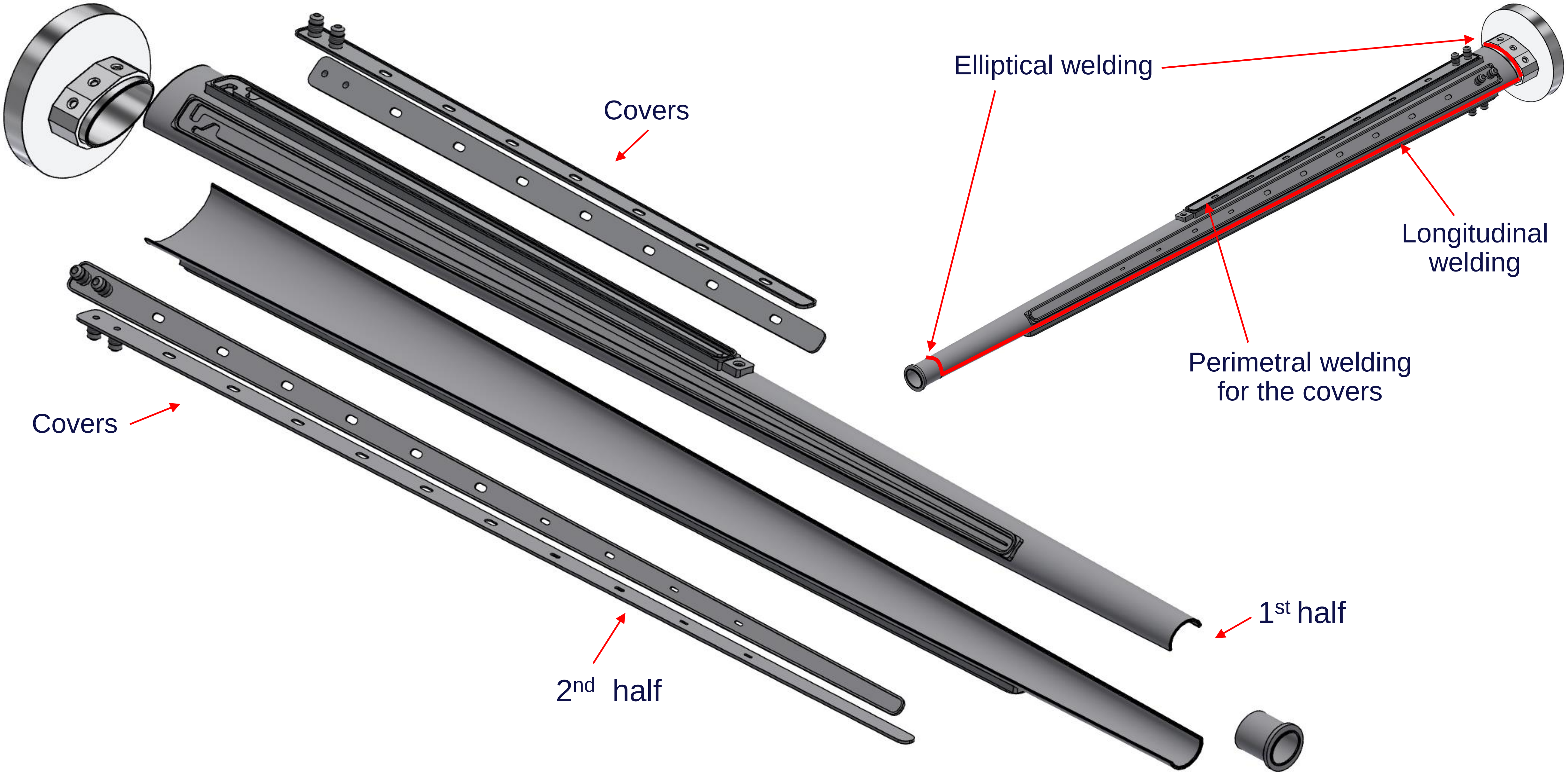


Ellipto-Conical chamber

Main characteristics:

- **AlBeMet162** is the main material.
- The chamber consists of two halves, machined considering the internal shape of the chamber, and assembled using EBW (Electron Beam Welding).
- The cooling is based on an **asymmetric solution**, using the **50 mrad Lumical acceptance** cone as the cutting profile.




Covers
Elliptical welding
Longitudinal welding
Perimetral welding for the covers
Covers
1st half
2nd half

Thermo-structural analysis

From CST calculations (**Alexander Novokhatski (SLAC)**)

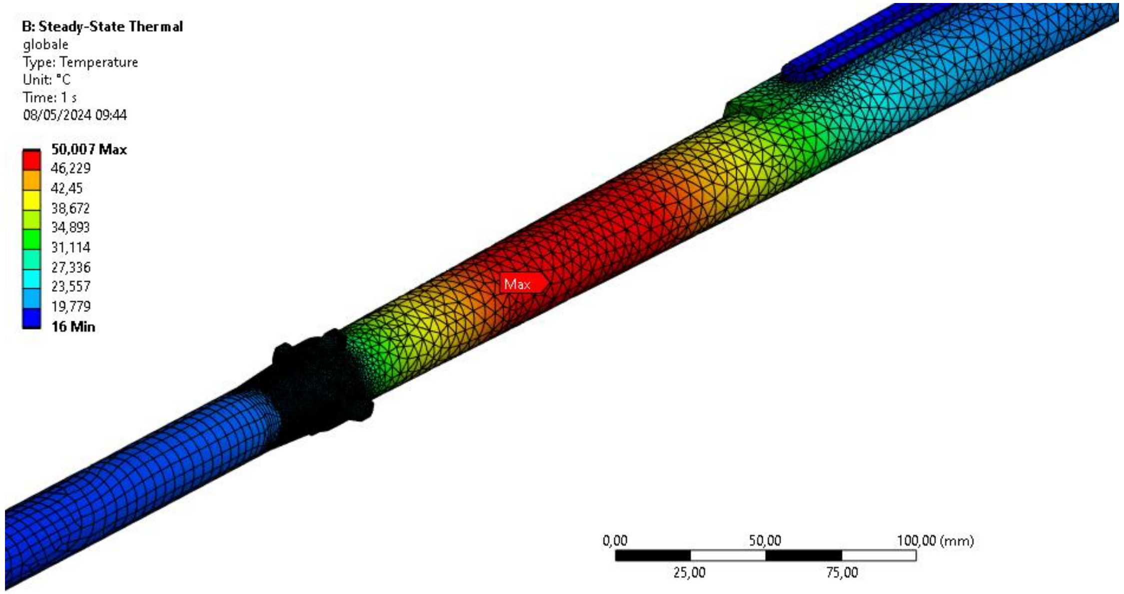
- **Paraffin flow (central chamber)**
  - Flow rate: 0,015 kg/s
  - Section:68,17 mm^2
  - Velocity: 0,3 m/s
  - Inlet temperature: 18°C
  - Convective coefficient: 900 W/m^2K

- **Water flow (Ellipto-Conical chamber)**
  - Flow rate: 0,01 kg/s (4 channels per side)
  - Total flow rate per side: 0,04 kg/s
  - Section: 12,25 mm^2
  - Velocity: 1 m/s
  - Inlet temperature: 16°C
  - Convective coefficient: 1200 W/m^2K

+

Chamber design (until the bellows)

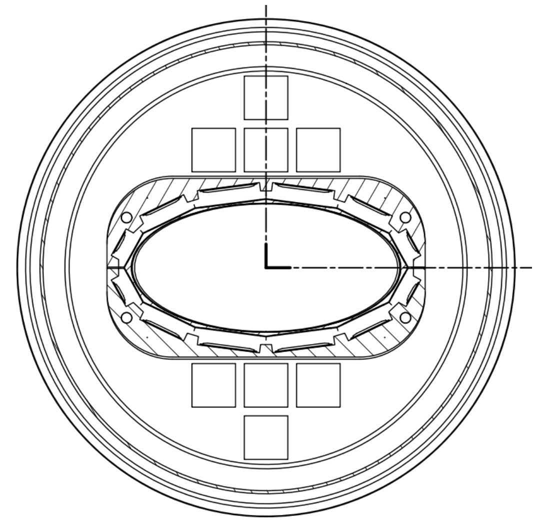
- **Heat load**
  - 54 W central
  - 130 W AlBeMet162 for each part
- **Weight**
  - chamber
  - Inner Vertex first layer
- **Constraint**
  - Cantilevered, simply supported configuration



	Conical chamber	Central chamber
Coolant	Water	Paraffin
Maximum chamber temperature [°C]	50	29
T_out coolant [°C]	18	20.5

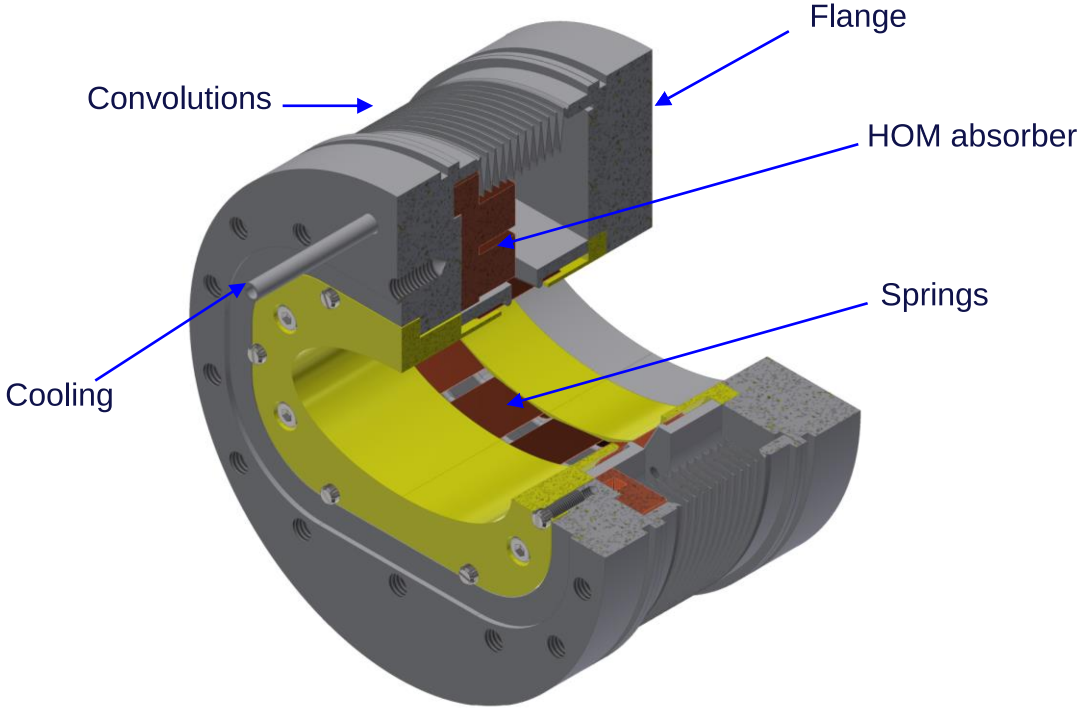
	Conical chamber	Central chamber
Maximum Von Mises stress	16 MPa	20 MPa
Maximum displacement	0.45 mm	0.5 mm

Bellows with HOM absorber



The **bellows is needed to**:
- **Protect the central chamber** during the assembly procedure.
- **Support properly the chamber** bellows-to-bellows, containing the deformation.
- **Allow the thermal deformation** without compromising the chamber.
- The high order mode (**HOM**) **absorber have been inserted** on the bellows and a prototype will be manufactured and tested at INFN-LNF.
- The **cooling** has been designed and included in the design.
- The HOM absorber currently are an envelope included as space holder: the number and the shape will be defined after dedicated simulation.

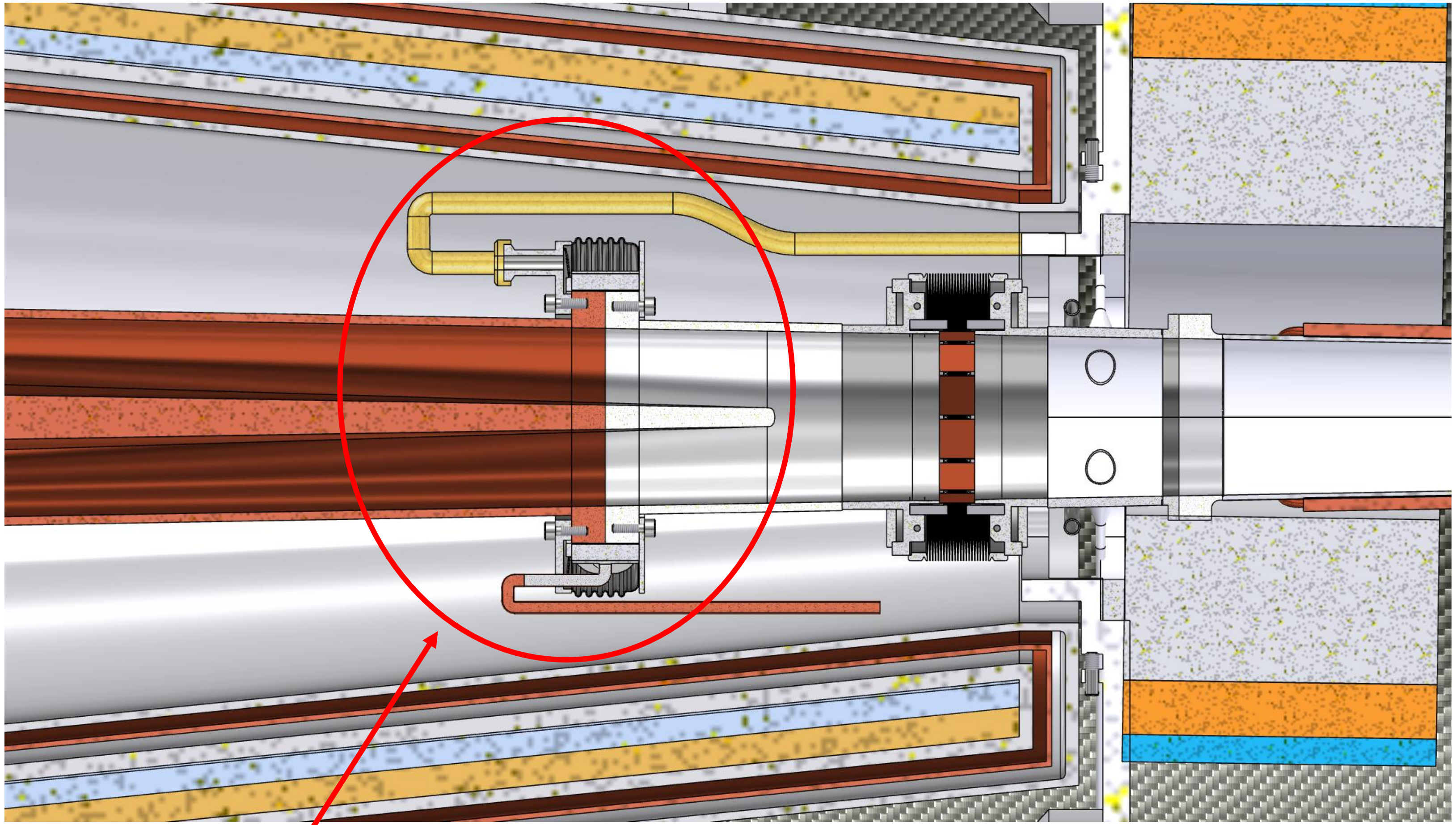
Main characteristics:
- **Cylindrical envelope**, to find the space for the HOM absorber.
- **Dismountable flanges**: to simplify the assembly procedure.
- The distribution of the springs can be modified according to the simulation.



Convolutions details:
- internal diameter: 90.3 mm
- external diameter: 110.3 mm
- free length: 23.21 mm
- compressed length: 7.26 mm
- extended length: 35.1 mm
- material: AISI 316l
- thickness: 0.15 mm

Stroke:
- axial stroke: 27.83 mm
- compression stroke: 15.95 mm
- extension stroke: 11.88 mm
- maximum angle: 14.45°
- radial offset: 1.33 mm
- spring rate: 4-8 n/mm

Remote vacuum connection



Remote vacuum connection

The remote vacuum connection it is necessary for the assembly procedure.

- The vacuum chamber mounted on the Support Tube has to be **connected to the vacuum chamber** from the cryomagnetic system.
- The **connection has to be remote**, indeed it is not possible to reach the inner part of the detector to connect the flanges.

Two options

Mechanical connection (as designed by DESY for SuperKEKB)

Shape memory alloy connection (SMA)

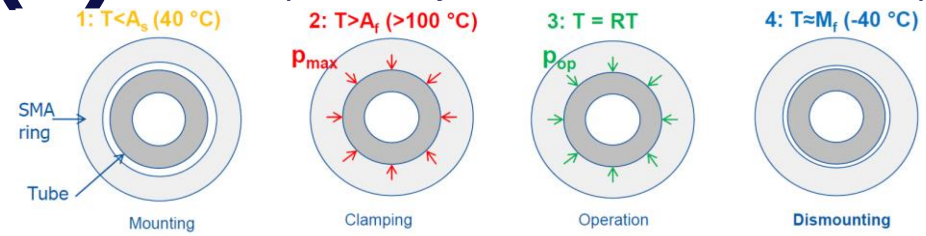
- CERN-TE/VSC
- University of Calabria, Italy

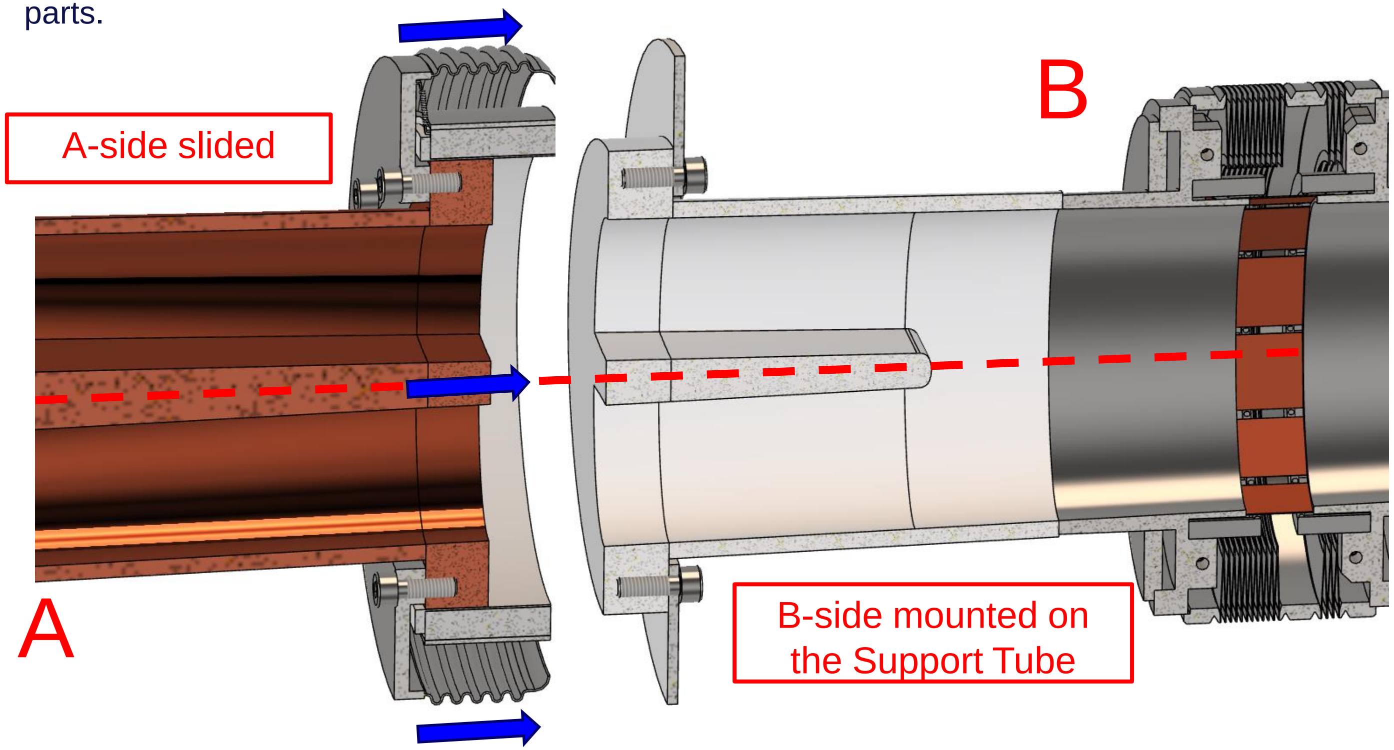
More Compact and compatible with the space available

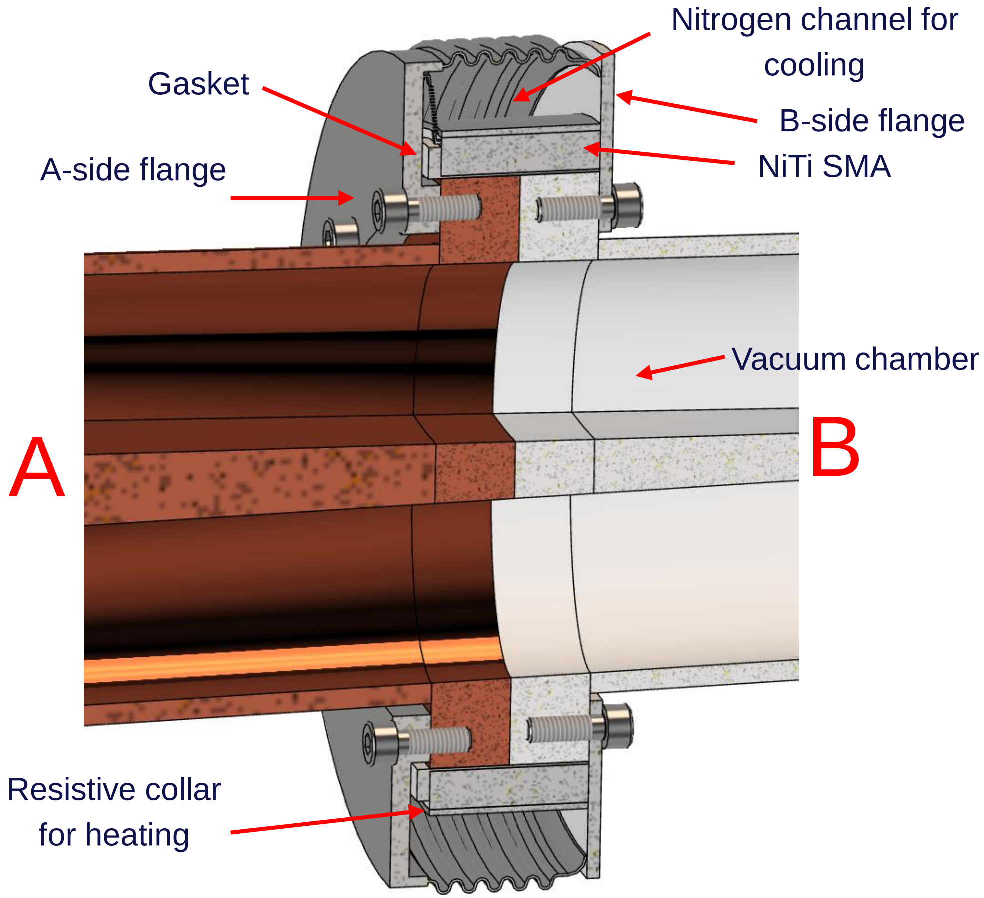
Remote vacuum connection (1)

Work made with **Fabrizio Niccoli** (University of Calabria, CERN-TE/VSC)

A **shape memory alloy** (SMA) is a material that can recover a large pseudoplastic deformation through heating. This process can be **reversable using two-way shape memory alloy**, this material can switch between **two different shape simply by heating and cooling**. In this way is possible to create a connection dismountable between two parts.







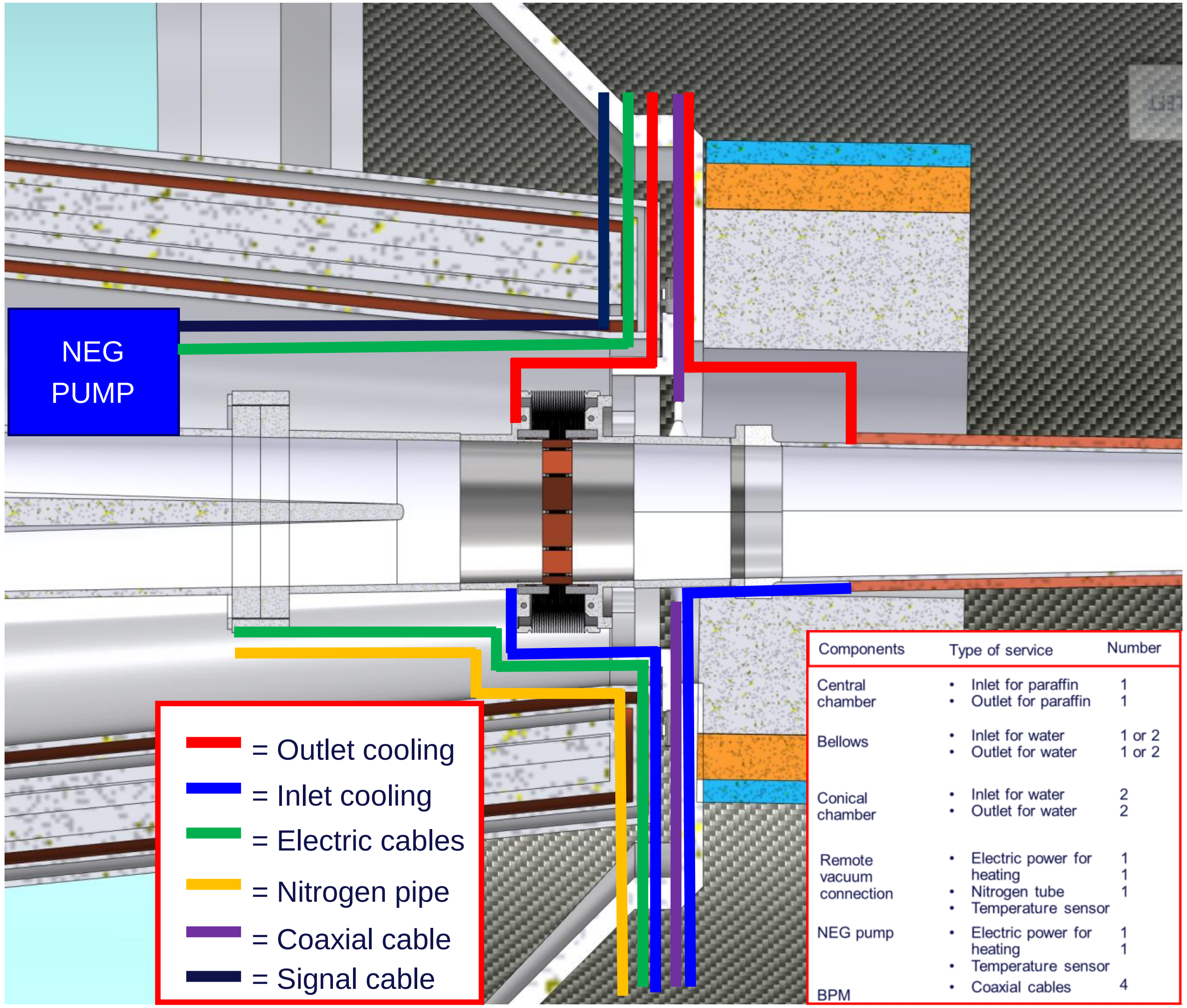
In progress:

- **Positioning system design** (in order to reach the tolerances needed for the gasket mounting)
- **Dismounting system** (cooling system for SMA ring expansion + easy gasket removal)
- Evaluation of the possibility to use a **bellows flange as the B-side flange**, in order to reduce the space needed for the connection

[1] Niccoli, Fabrizio & Garion, Cedric & Maletta, Carmine & Chiggiato, Paolo. (2017). Shape-memory alloy rings as tight couplers between ultrahigh-vacuum pipes: Design and experimental assessment. Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films. 35. 10.1116/1.4978044.

[2] F. Niccoli, C. Garion, C. Maletta, E. Sgambitterra, F. Furgiuele, P. Chiggiato, Beam-pipe coupling in particle accelerators by shape memory alloy rings, Materials & Design, Volume 114, 2017, Pages 603-611, ISSN 0264-1275, https://doi.org/10.1016/j.matdes.2016.11.101.

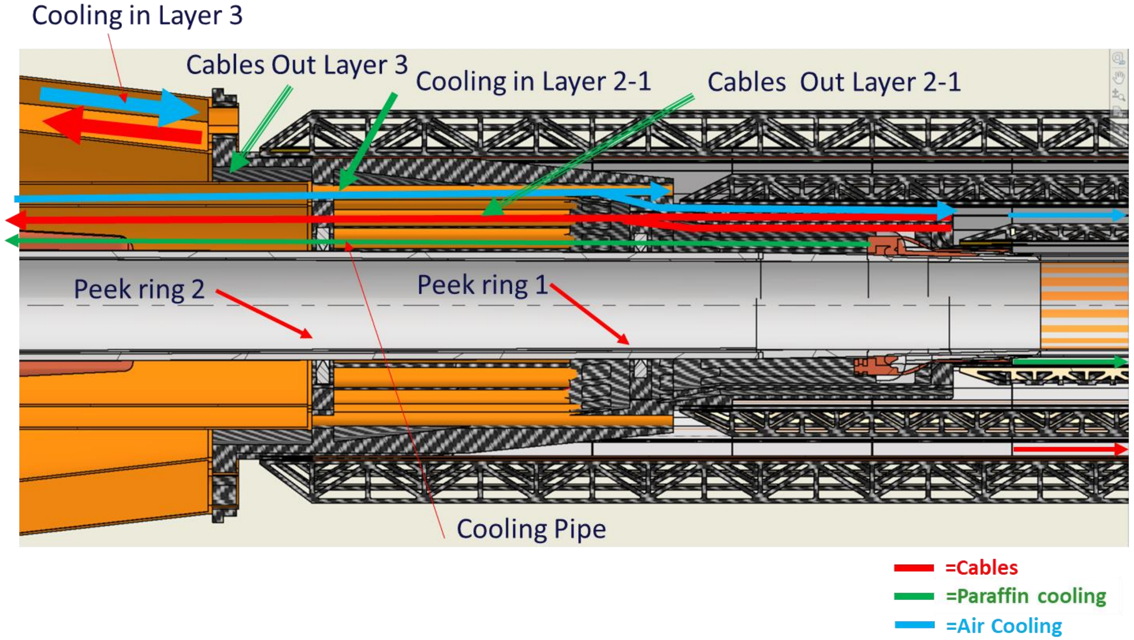
Services integration challenges

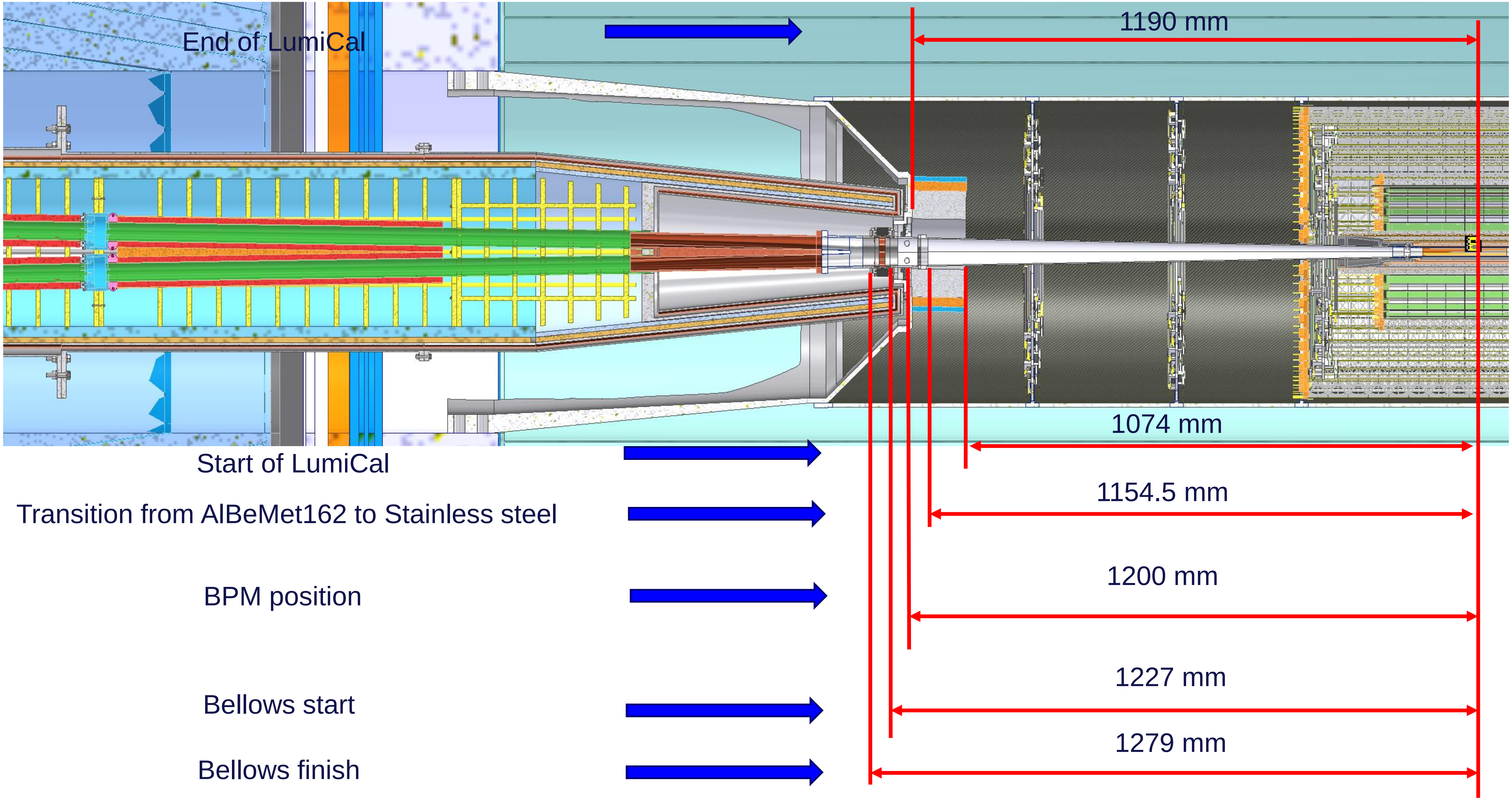


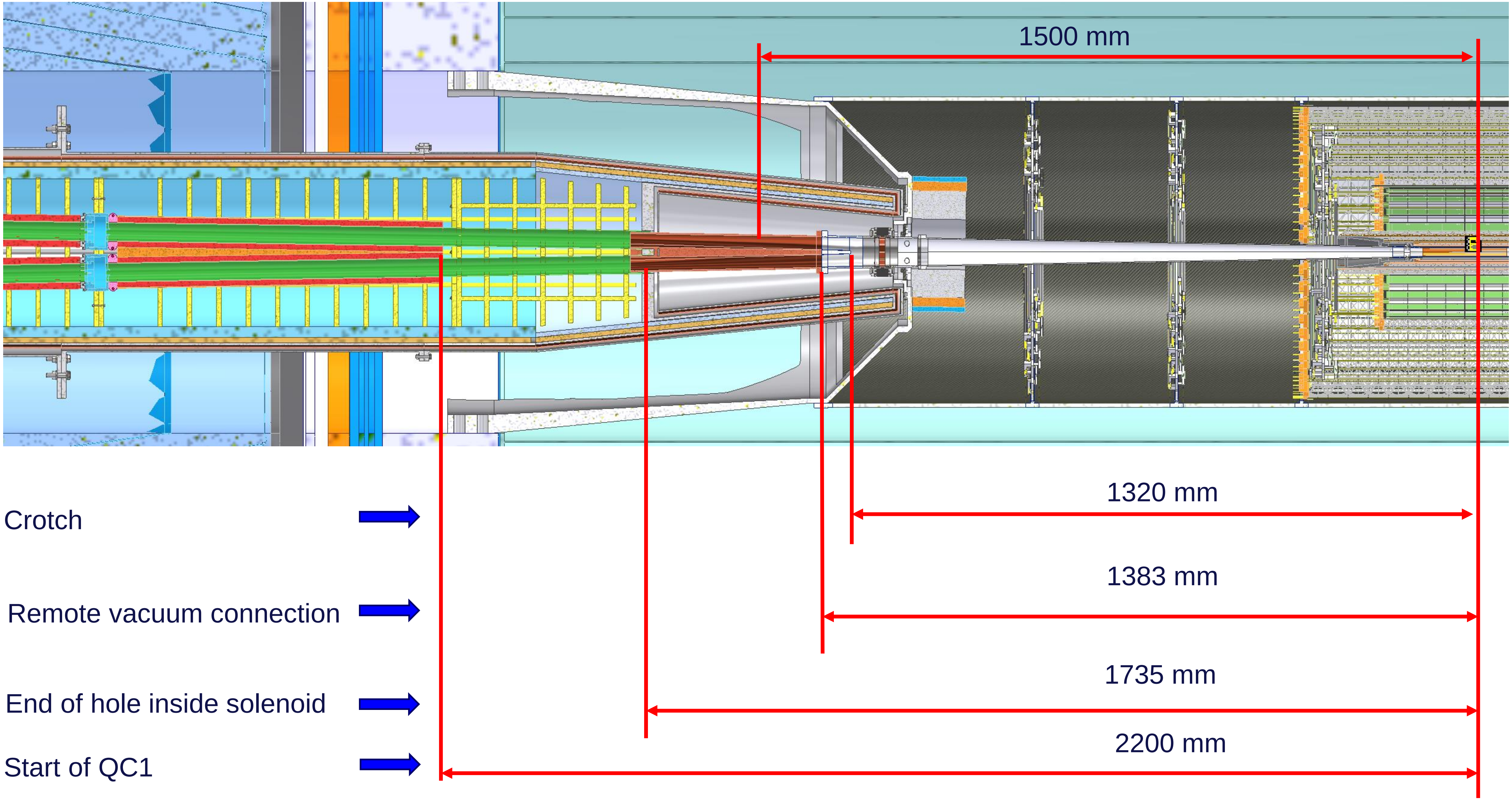
Components	Type of service	Number
Central chamber	• Inlet for paraffin • Outlet for paraffin	1 1
Bellows	• Inlet for water • Outlet for water	1 or 2 1 or 2
Conical chamber	• Inlet for water • Outlet for water	2 2
Remote vacuum connection	• Electric power for heating • Nitrogen tube • Temperature sensor	1 1 1
NEG pump	• Electric power for heating • Temperature sensor	1 1
BPM	• Coaxial cables	4

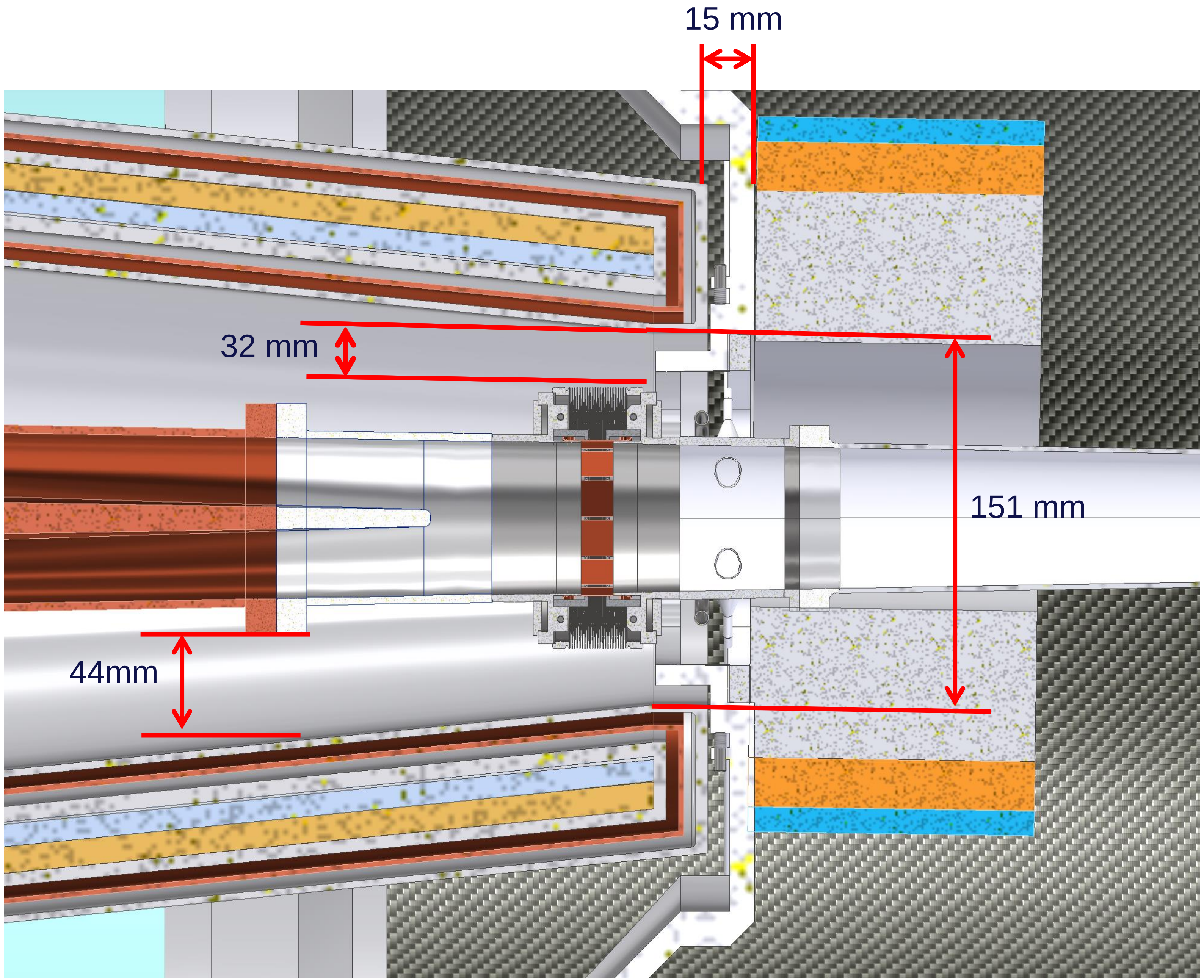
There are two problematic areas for the services integration:

- Interface with the cryomagnetic system.
- Interface between the vacuum chamber and the vertex detector.

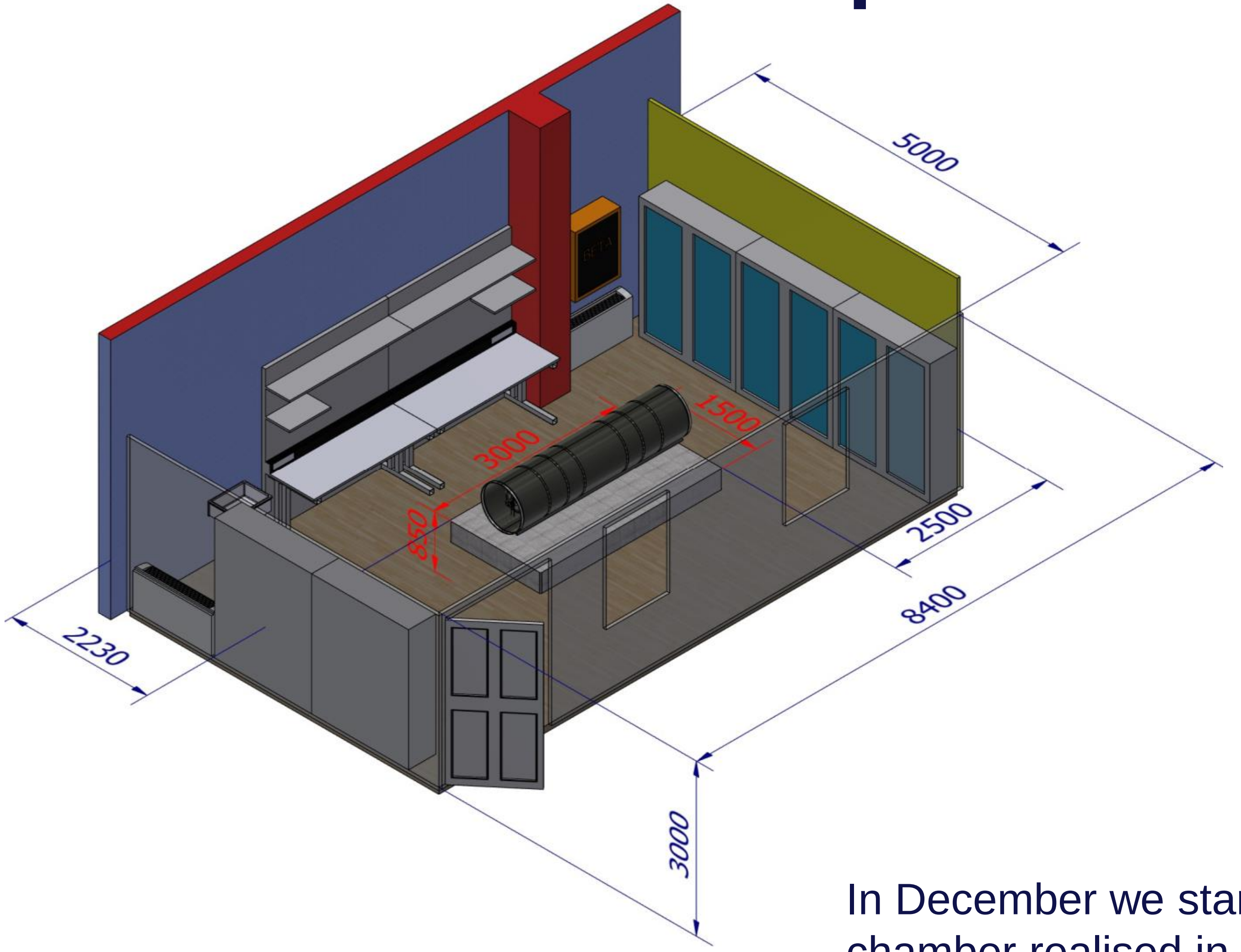



End of LumiCal
1190 mm
1074 mm
Start of LumiCal
1154.5 mm
Transition from AlBeMet162 to Stainless steel
1200 mm
BPM position
1227 mm
Bellows start
1279 mm
Bellows finish


1500 mm
1320 mm
1383 mm
1735 mm
2200 mm
Crotch
Remote vacuum connection
End of hole inside solenoid
Start of QC1


15 mm
32 mm
151 mm
44mm

MDI R&D IR Mockup



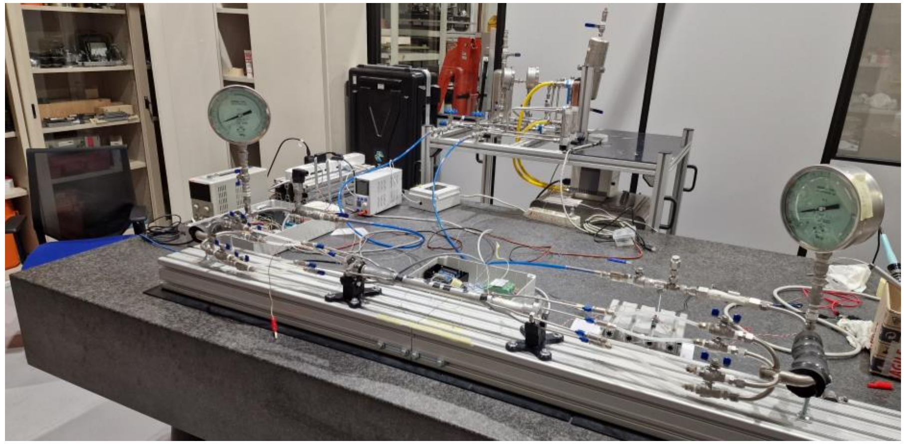
Activities started for FCC-ee IR mockup **to be built at INFN-LNF**.

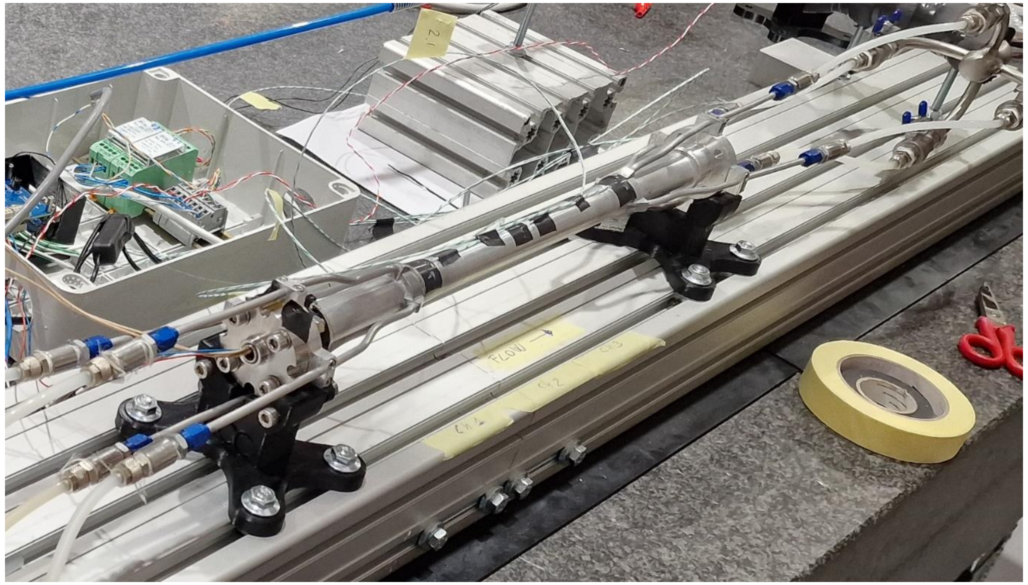
- Check **assembly strategy feasibility** for the single parts of the chamber (central, ellipto-conical) and of whole system (chamber, bellows, inner vertex, outer vertex, middle vertex, disks).
- Check the feasibility of the **Electron Beam Welding** along an **elliptical shape.**
- Test of the **cooling systems**.
- Test the **constraint schema** and the stiffness of bellows with CuBe blades.
- Study of cables and cooling pipes fitting.

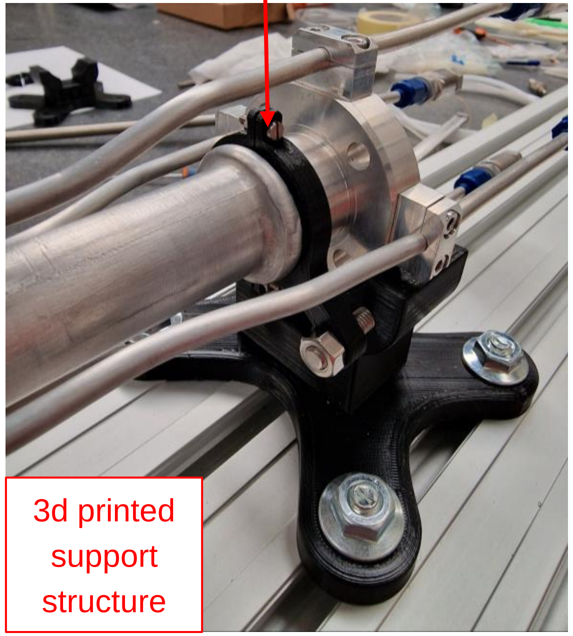
In December we started the cooling test with the paraffin on the central chamber realised in Al6082.

Mockup activities for central chamber

- A first prototype has been realized.
- The central chamber is now connected to an hydraulic circuit to test the thermal behaviour of the chamber under thermal load.





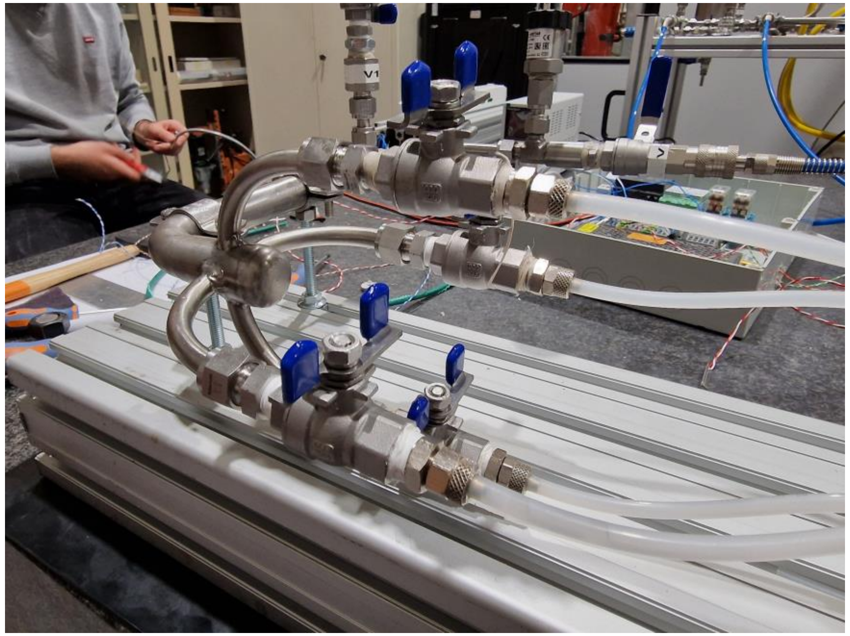


3d printed support structure

We set up the system for the thermal test.

- Four thermocouples are mounted (3 on the chamber and 1 for the environment).
- The thermocouples have been calibrated using a mixture of ice and water, to recreate the 0°C condition.
- The thermocouples are managed using a Raspberry pi 4 with 8GB RAM and the acquisition is made using a Python script.

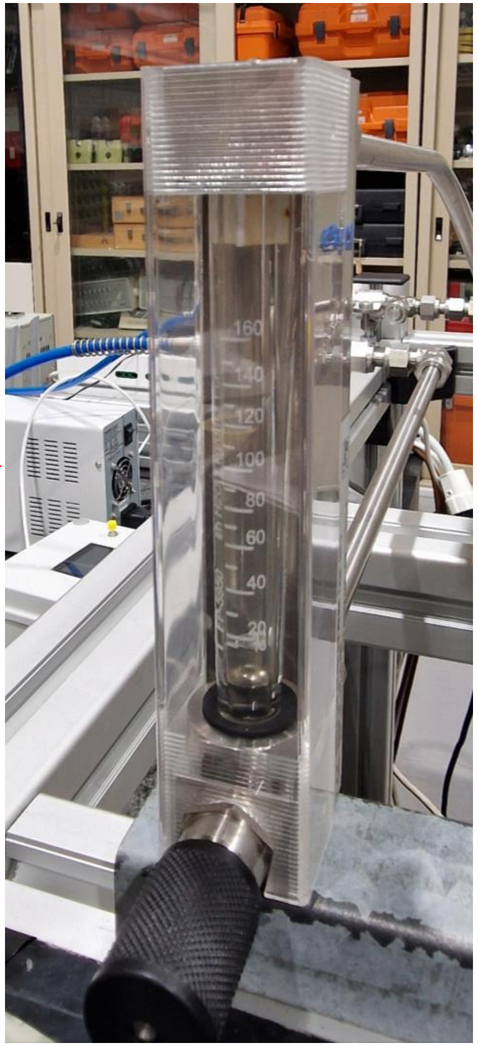
After the tuning, the thermocouple have been mounted using a thermal paste, in order to optimize the thermal contact between the chamber and the thermocouple.

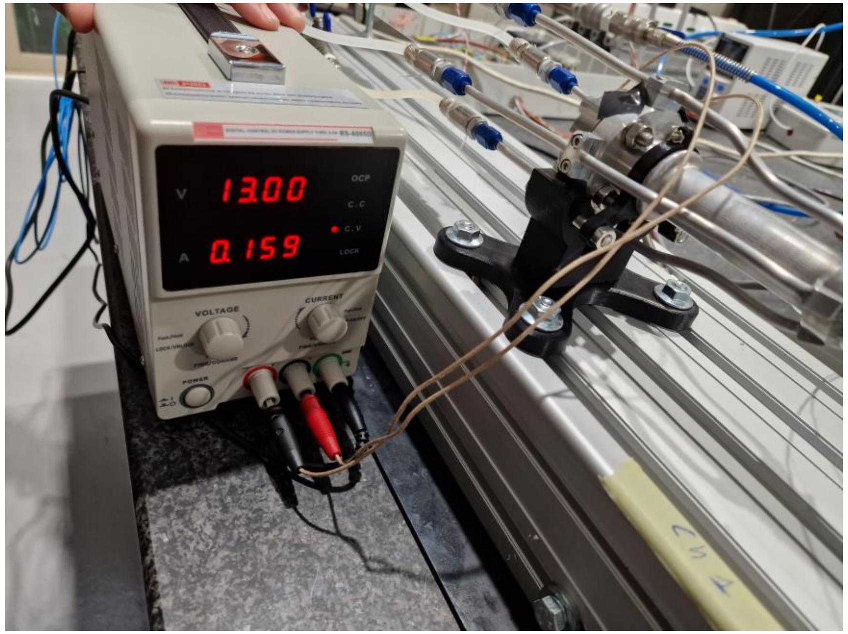


The central chamber is connected to the hydraulic circuit using a handmade connector, in order to distribute properly the coolant.

In this system are controlled the inlet temperature, the flow rate and the pressure of the coolant.

The coolant outlet temperature, the chamber temperature, the pressure drop and the flow rate are precisely measured.





An electrical heater is used to simulate the heat load.
The power is controlled using a variable power supply.

Conclusions

- The engineered design of the chambers has been presented. The current design is the result of iterations with the company, in order to optimise the fabricating process.
- We received the central chamber manufactured in Al 6068, and we are working on the ellipto-conical chamber realisation.
- The engineered design of the bellows has been presented, showing the insertion of HOM absorber and cooling. We have just started the procedure for the procurement, working in parallel with the company that will make the flanges.
- The mock-up activities are started in the central chamber; before the Christmas holyday, we tested different scenarios and we are now analysing data.

Future steps

- As soon as we receive the ellipto-conical chamber, the mockup will be extended, including the two ellitpo-conical chambers with the cooling system.
- We continue the test data analysis and the same will be done using the test results after the ellipto-conical chamber mounting.
- The bellows simulation will be done in order to finalize the design with the HOM absorber.

THANK YOU FOR YOUR ATTENTION

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BACKUP SLIDES

Speaker: Francesco Fransesini

Central chamber buckling analysis and comparison with Beryllium

The buckling analysis of the thin internal cylinder has been performed using the analytic formulation and Finite Element Analysis.

The critical pressure for the collapse of the thin wall cylinder under external pressure can be calculated with the following simplified formula:

$$P_{critic} = \frac{E}{4(1-\nu^2)}\left(\frac{t}{r}\right)^3$$

$E = Young's\ Modulus$

$\nu = Poisson's\ ratio$

$r = medium\ radius$

$t = cylinder's\ thickness$

Properties	AlBeMet162 (AMS 7911)	Beryllium S200F (AMS 7906)
Density [g/cm³]	2.10	1.85
Composition	Al-62 wt% Be	Be
Modulus [GPa]	193	290
Poisson's Ratio	0.17	0.18
CTE @ 25°C [ppm/˚C]	13.9	11.4
Yield strength [MPa]	193	241
Radiation length [cm]	19.1	35.24
Thermal Conductivity [W/mK]	210	216

$P_{critic} \propto E$ $\quad P_{critic} \propto 1/\nu$ $\quad P_{critic} \propto t$ $\quad P_{critic} \propto 1/r$

Material independent

Material		Analytic model	FEM	Difference
AlBeMet162	Critical pressure	20 bar	18 bar	11 %
	Maximal pressure allowable (S.F. =5)	4 bar	3.6 bar	
Beryllium S200F	Critical pressure	30 bar	28 bar	7 %
	Maximal pressure allowable (S.F. =5)	6 bar	5.6 bar	

In order to reduce the material budget of the central chamber we are considering to use Beryllium as the main material.

$$E_{Be} > E_{AlBeMet162} \rightarrow \mathrm{P}_{\mathrm{critic}_{\mathrm{Be}}} > \mathrm{P}_{\mathrm{critic}_{\mathrm{AlBeMet162}}}$$

Considering the better performance in mechanical resistance, the low coefficient of thermal expansion and the higher radiation length, the beryllium is the best candidate material for the chamber fabrication.

The feasibility of the Beryllium design in terms manufacturability technique has to be checked.