MECHANICAL MODEL OF THE MDI

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under the European Union's Horizon 2020 research and innovation programme under grant agreement No 951754

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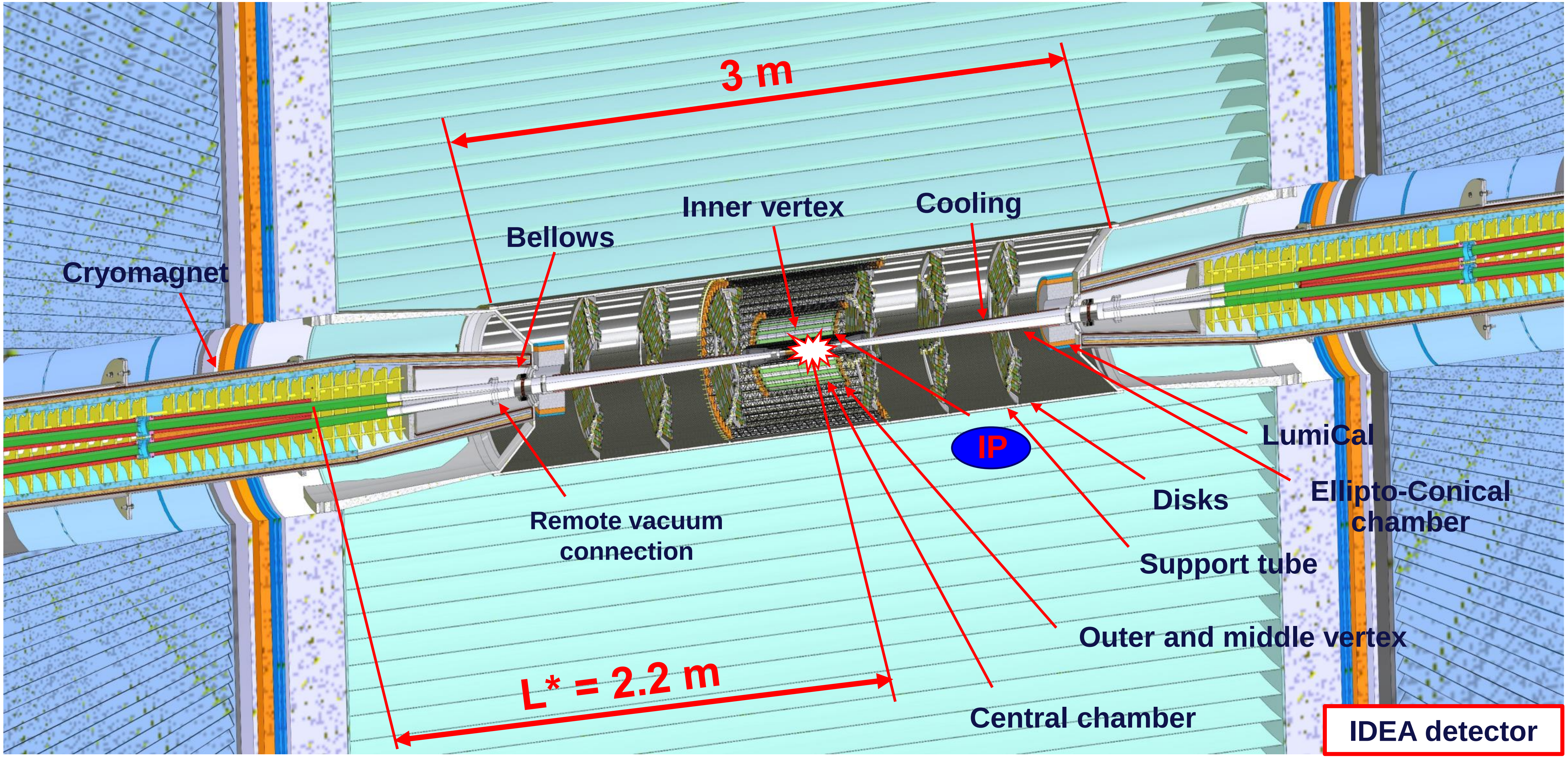
Introduction

Since the FCC week 2023 there have been progresses on:

- The **modification** of the **central chamber** design according to the **LumiCal requirement**.
- The complete re-**design** of the **trapezoidal chamber** and its cooling according to the LumiCal requirements. → **Ellipto-conical chamber**
- The **work in-progress design** of the **bellows with the HOM absorber.**
- The **in-progress design of the remote vacuum connection.**
- The **mock-up**.

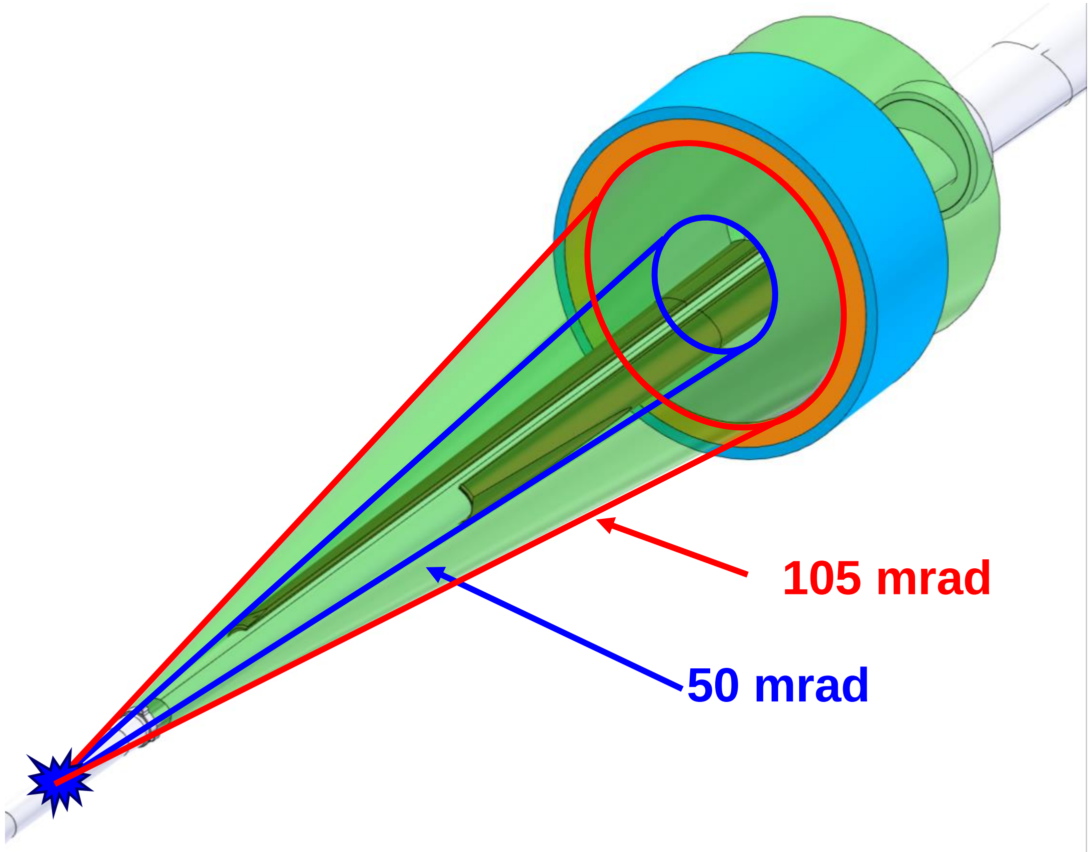
MDI mechanical model

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

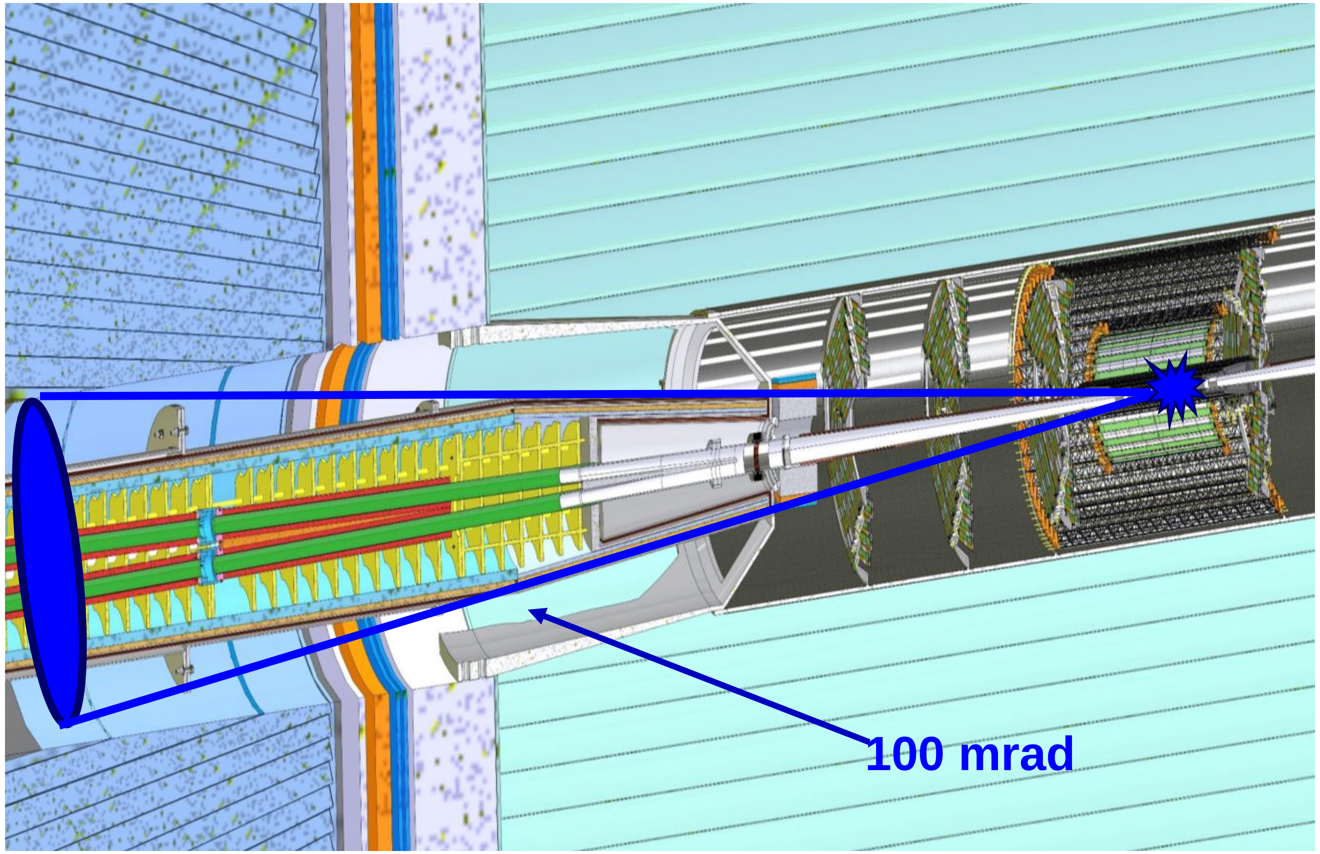


Spatial constraints

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.



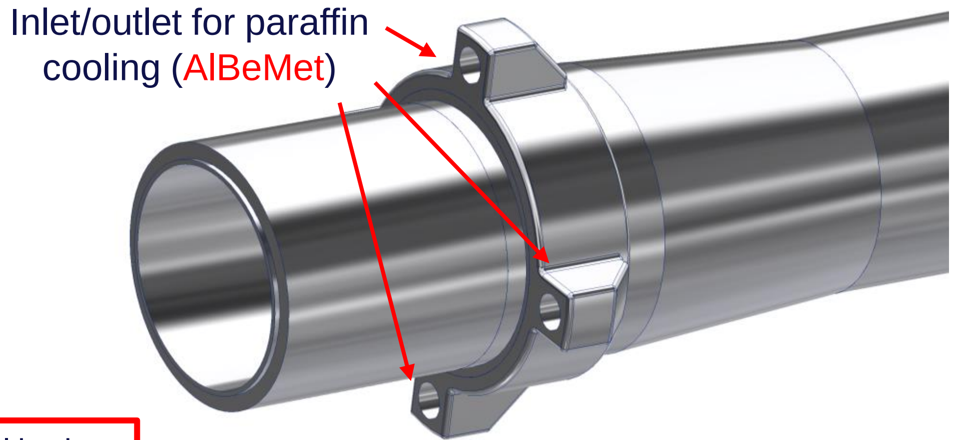
Central chamber – change of the design

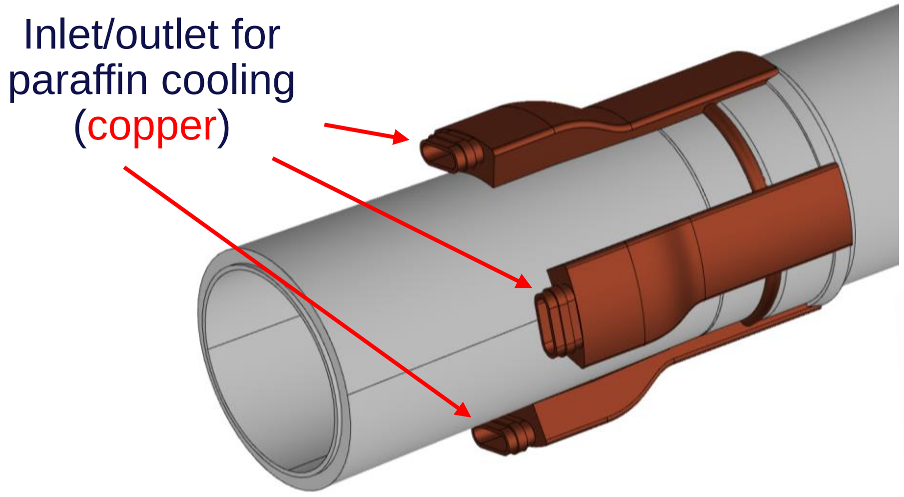
The main characteristics are maintained:

- 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

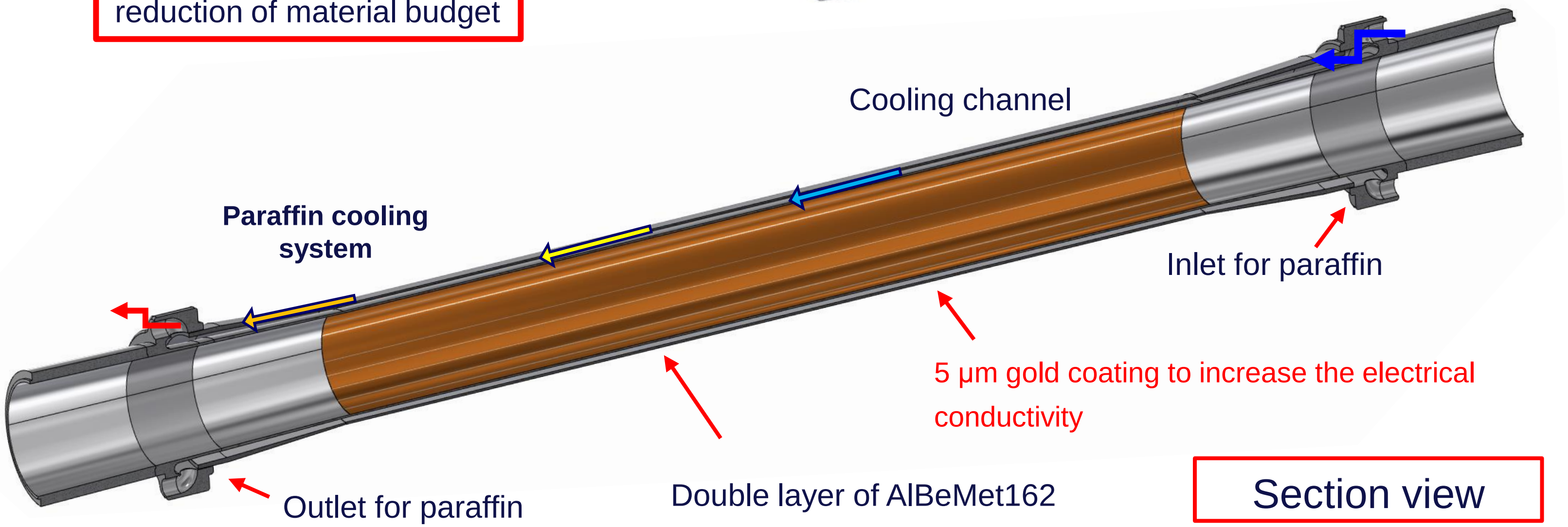
Change of the inlet and outlet material

- Reduction of the material budget, avoiding any manifold in copper





reduction of material budget

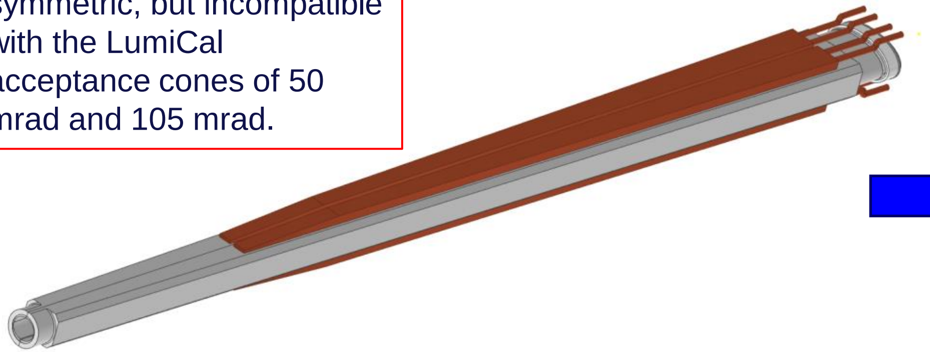


Section view

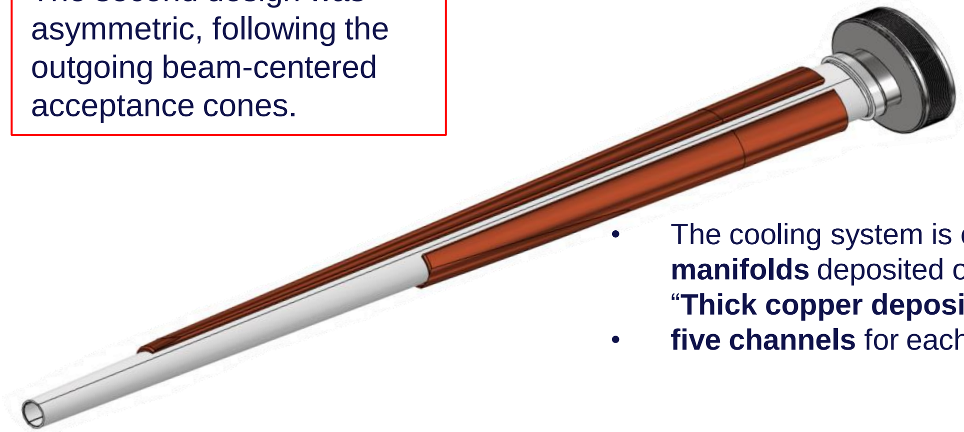
Trapezoidal chamber → Ellipto conical chamber

During these years, the design of the chamber starting at 90 mm until the bellows has been changed few times to match the requirements of the LumiCal.

The first design was symmetric, but incompatible with the LumiCal acceptance cones of 50 mrad and 105 mrad.

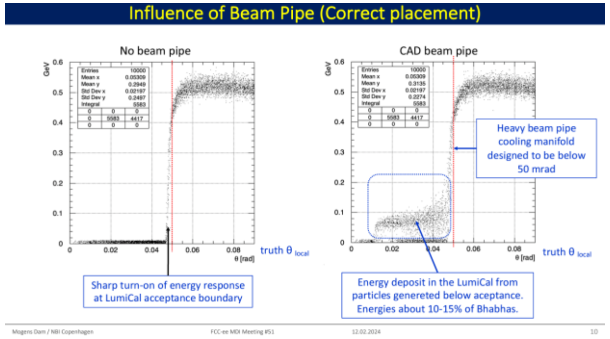


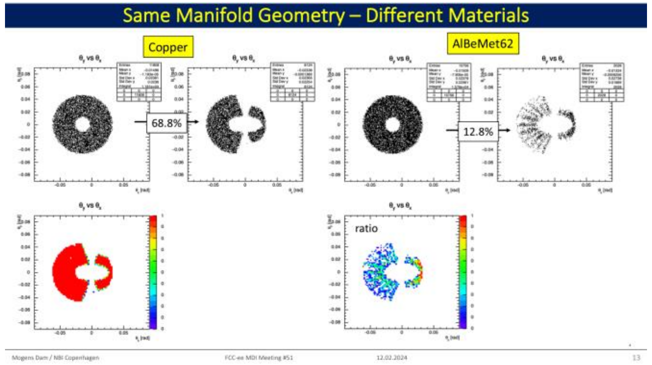
The second design was asymmetric, following the outgoing beam-centered acceptance cones.



- The cooling system is created using **copper manifolds** deposited over the chamber using the "**Thick copper deposition**" technique.
- **five channels** for each side

Mogens Dam during the 7th FCC Physics Workshop, 29 January 2024 to 2 February 2024, LAPP



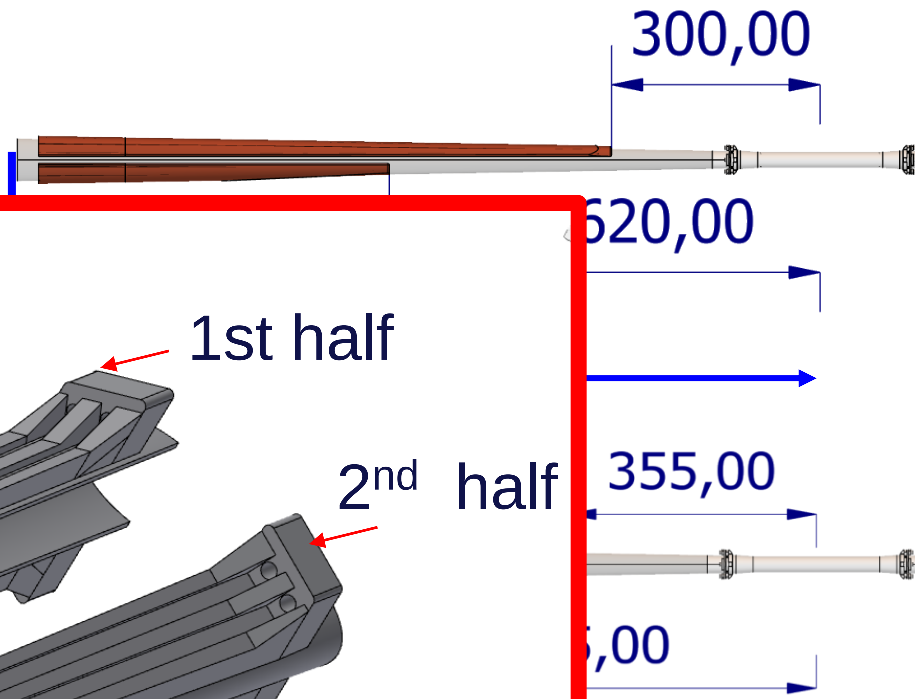


During the workshop in Annecy, Mogens Dam highlights the weakness of the ellipto-conical chamber design with the copper cooling.

Energy deposit in the LumiCal from particles generated below the acceptance.

Change of the material from copper to AlBeMet 162

Ellipto-Conical chamber



Common main characteristics:
- **AlBeMe**
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- Machine
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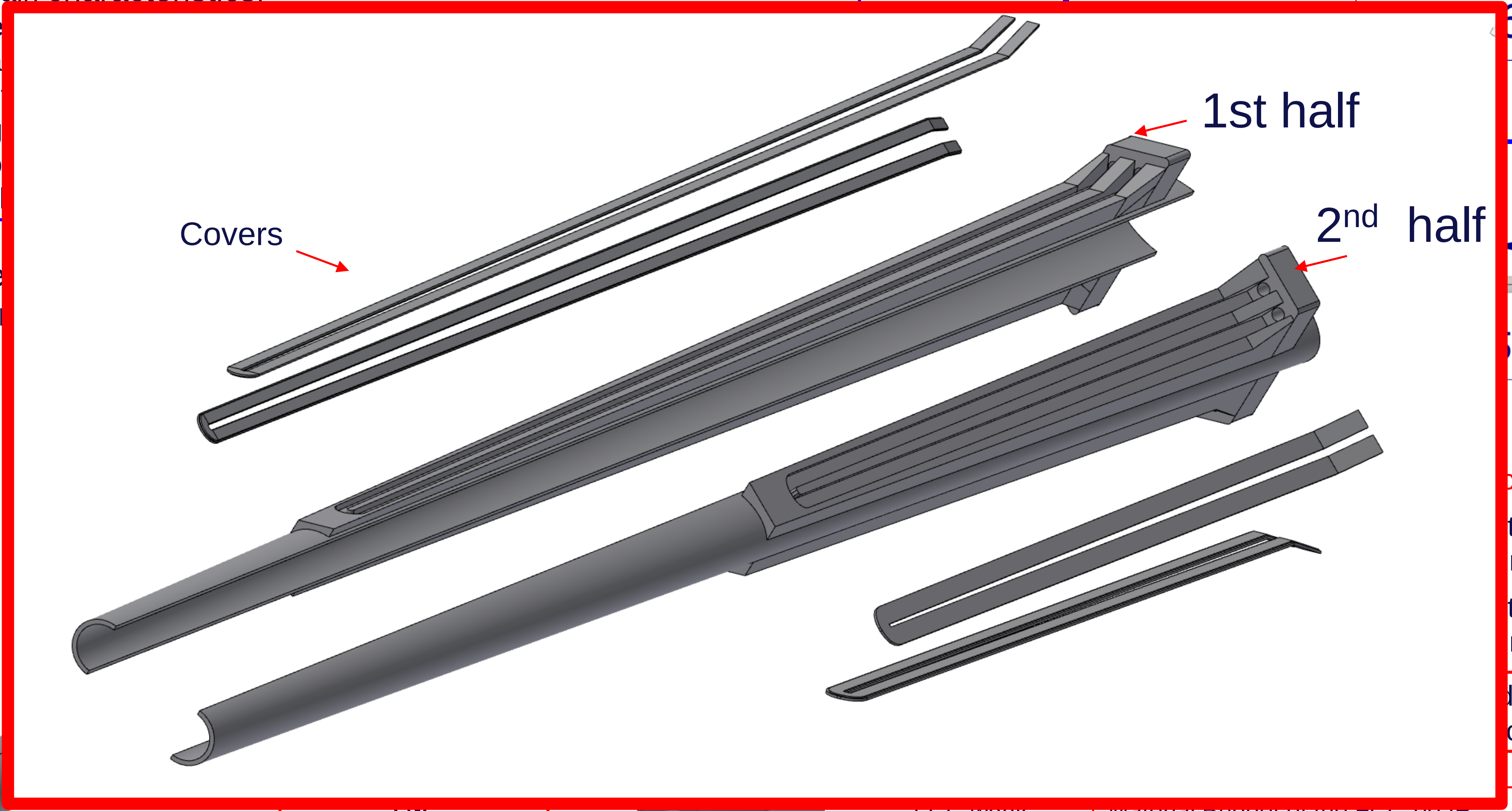

ces:
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- ter outgoing cooling nels

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LNF

FCC week poster session → Material Budget of the FCC-ee IR
G. Nigrelli, M. Boscolo, A. Ciarma, F. Fransesini, F. Palla

Thermo-structural analysis

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

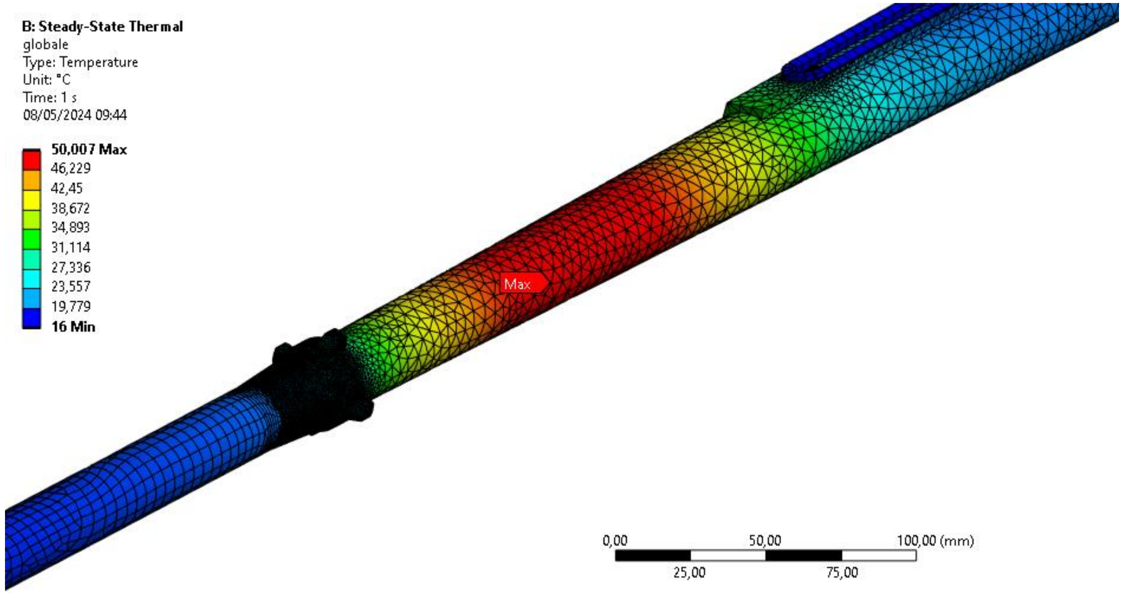
- **Paraffin flow (central chamber)**
  - Flow rate: 0,015 kg/s
  - Section:68,17 mm^2
  - Velocity: 0,3 m/s
  - Inlet temperature: 18°C
  - Convective coefficient: 900 W/m^{2}K

- **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^{2}K

+

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

Central chamber buckling analysis and comparison with Beryllium

The buckling analysis 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.

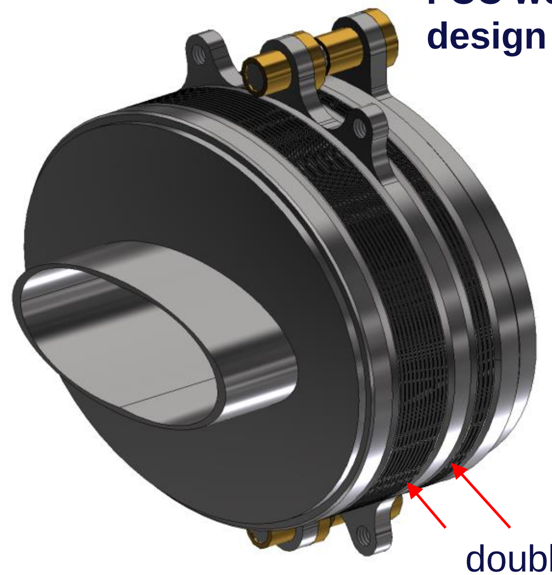
⬇

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

Bellows with HOM absorber

We are working to **insert** the high order mode (**HOM**) **absorber** on the bellows and a prototype will be manufactured and tested at INFN-LNF

FCC week 2023 design



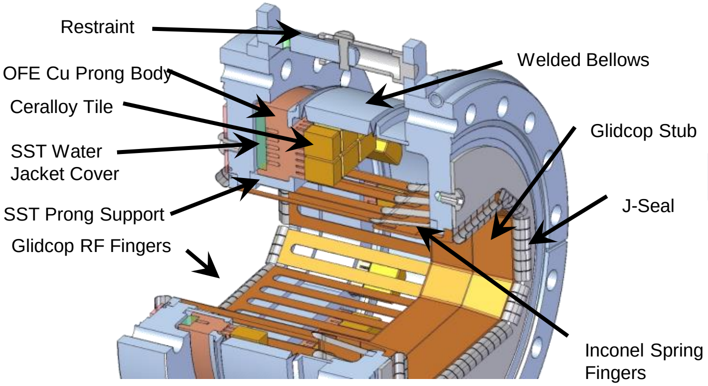
double series of convolution

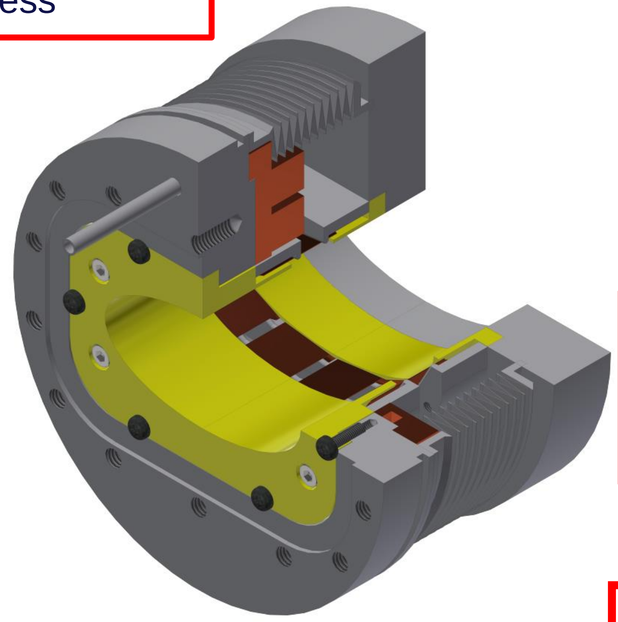
The previous design consisted of **two kind of bellows** in order to:

- **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.

Considering the design used at PEP-II, the design has been changed and is currently in progress

SLAC PEP-II



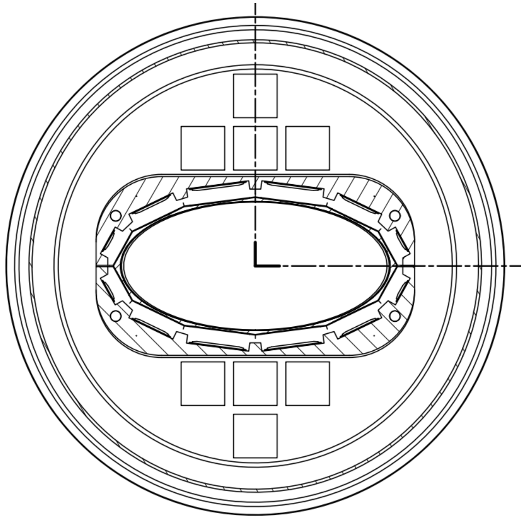


IN PROGRESS

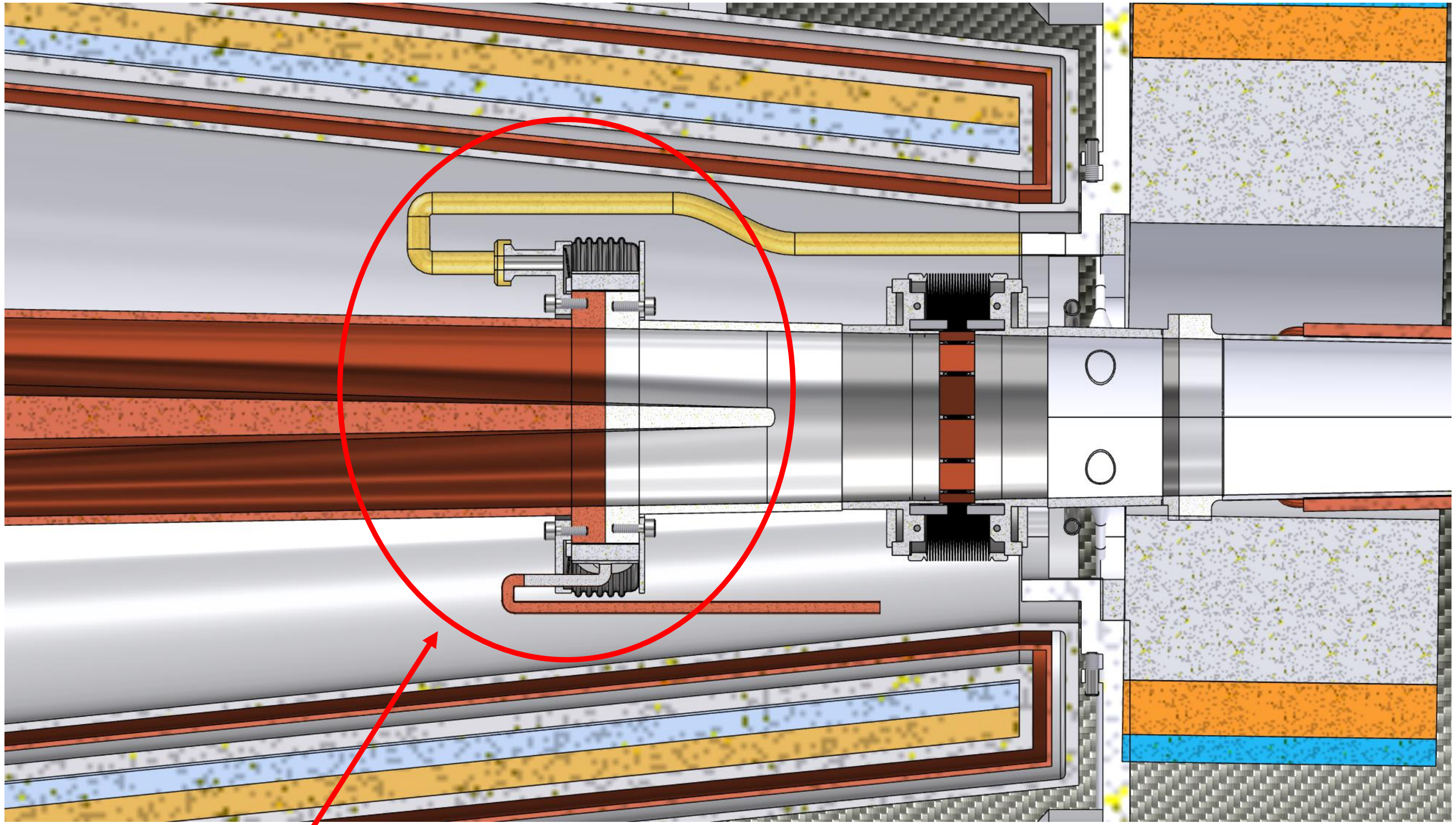
Main characteristics:

- Cylindrical envelope, to find the space for the HOM absorber.
- Dismountable flanges: to simplify the assembly procedure.
- Not enough space for the double series of convolution as the previous design.

It is necessary to change the chamber constraint-scheme.



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)

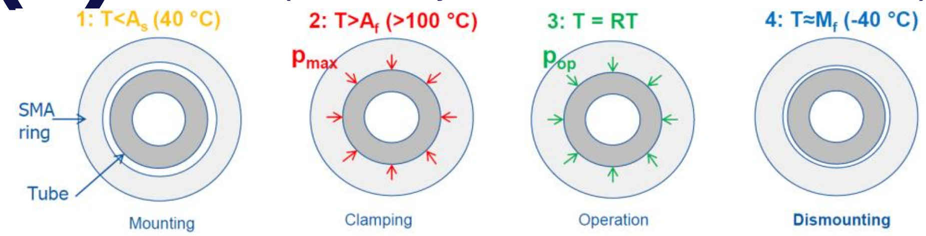
- CERN-TE/VSC
- University of Calabria, Italy

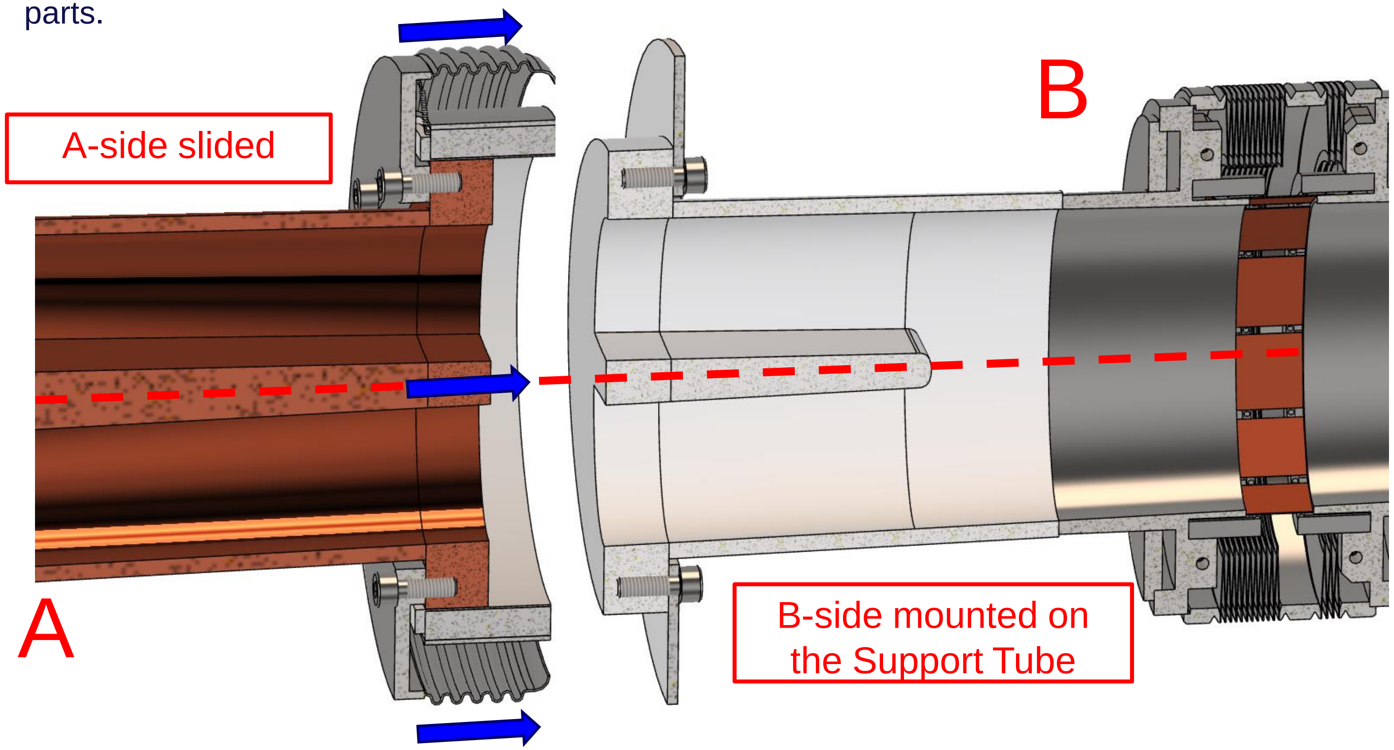
More Compact and compatible with the space available

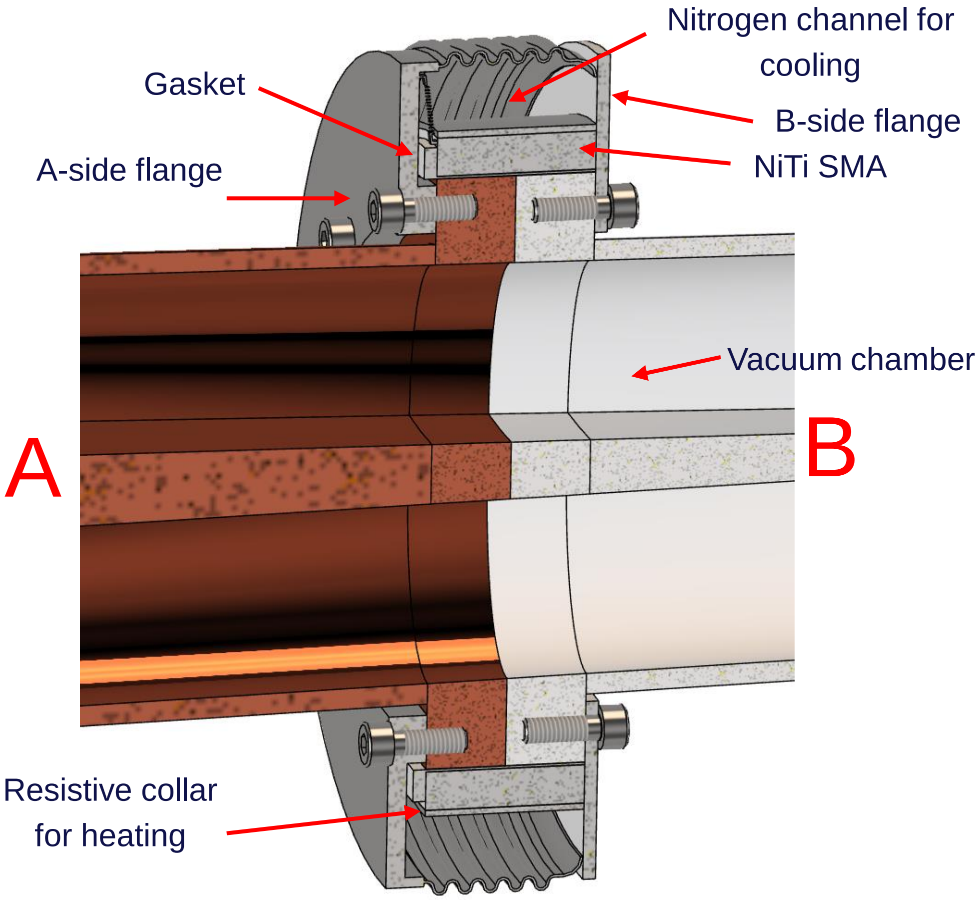
Remote vacuum connection (1)

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.





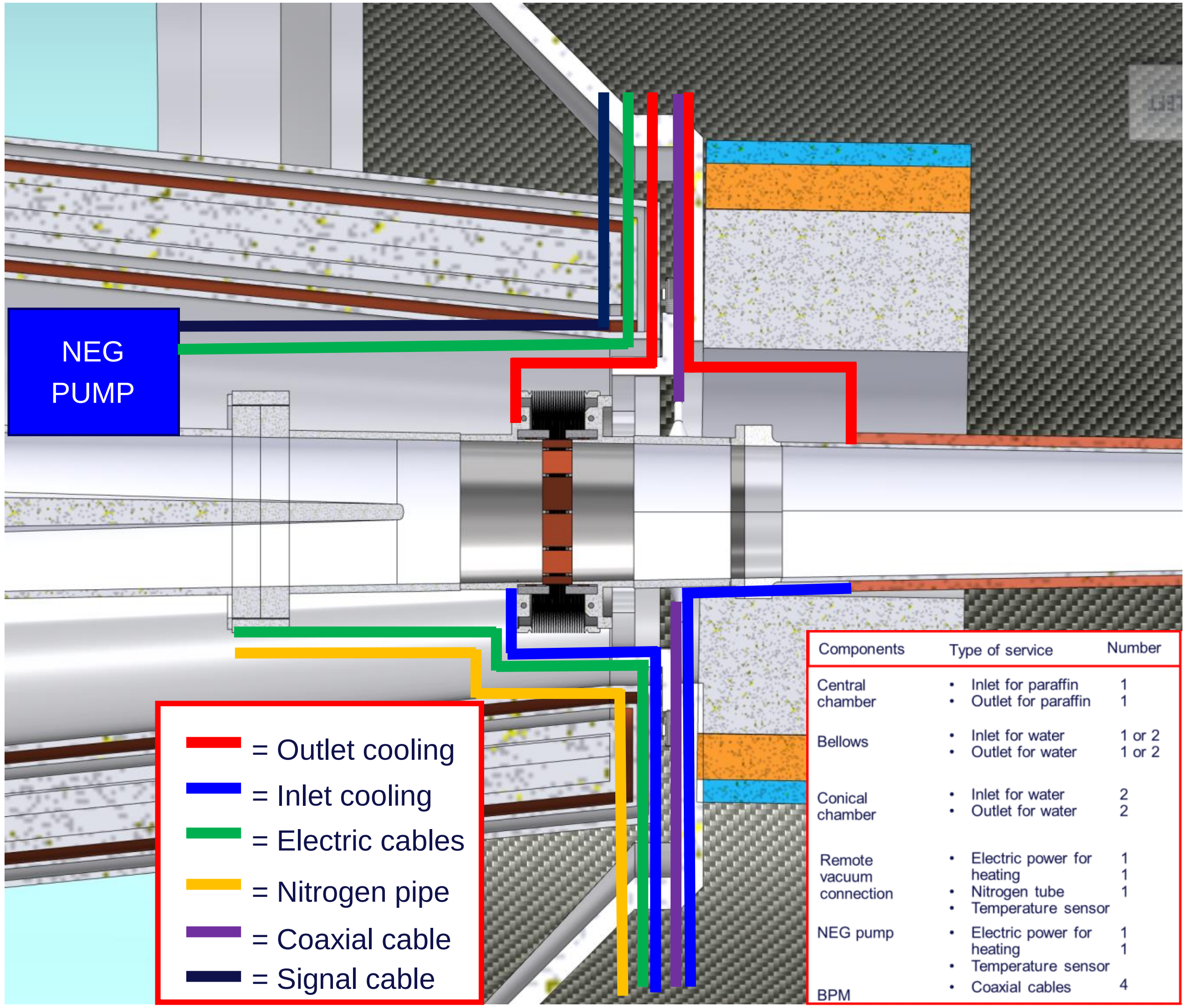


In progress:

- **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.

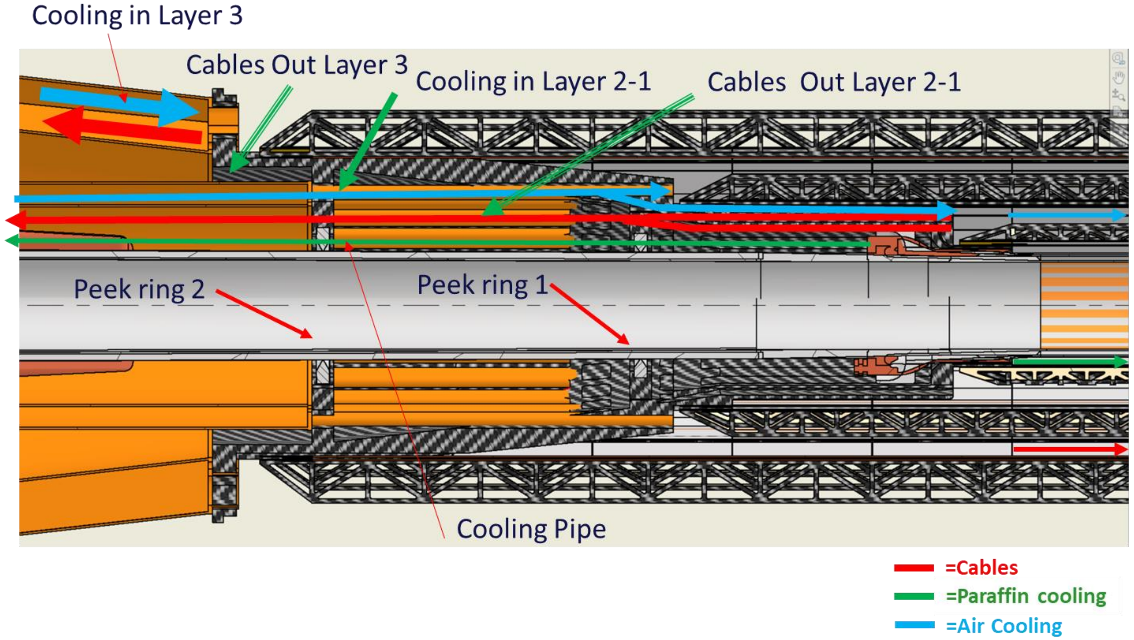
Services integration challenges



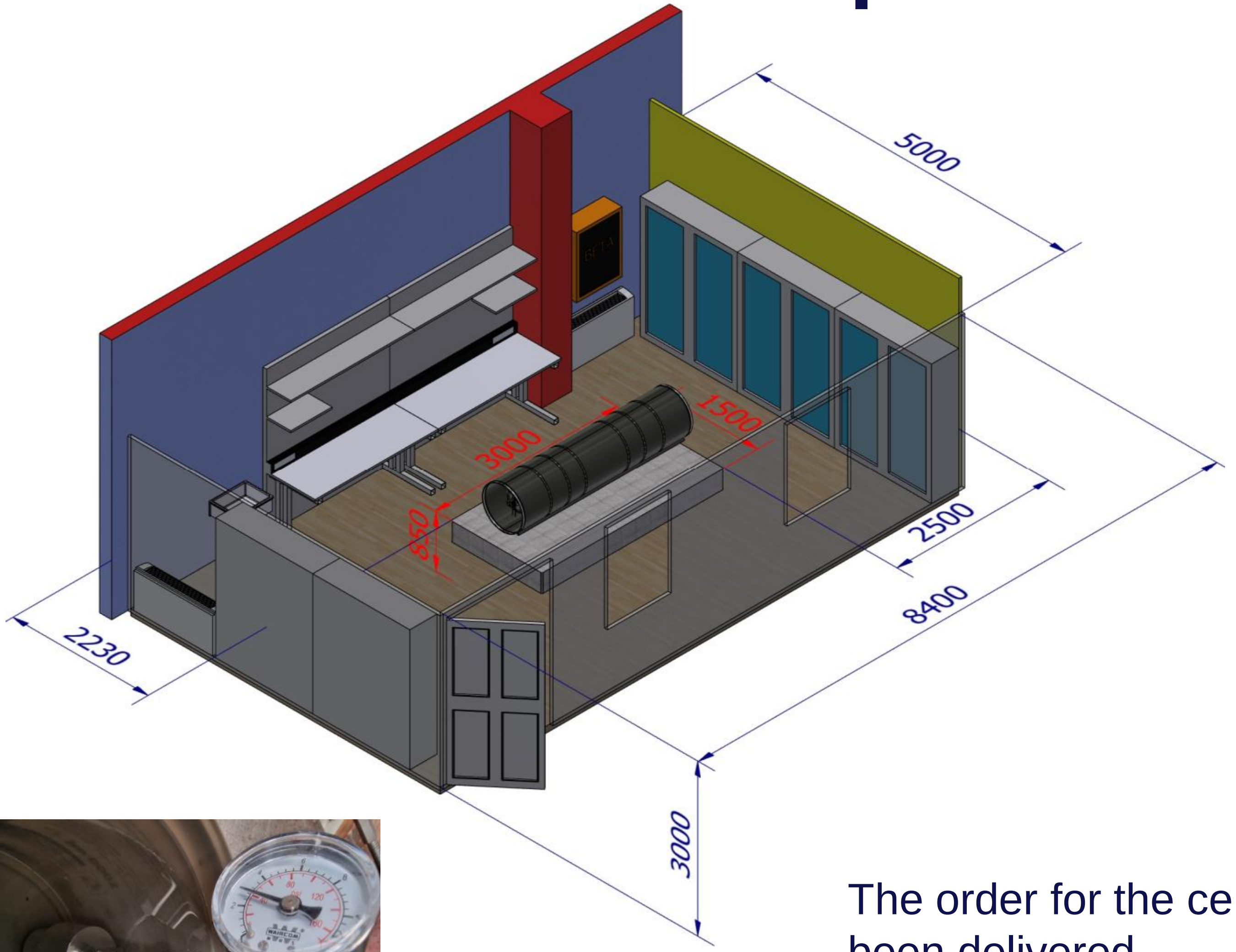
Components	Type of service	Number
Central chamber	• Inlet for paraffin	1
	• Outlet for paraffin	1
Bellows	• Inlet for water	1 or 2
	• Outlet for water	1 or 2
Conical chamber	• Inlet for water	2
	• Outlet for water	2
Remote vacuum connection	• Electric power for heating	1 1
	• Nitrogen tube	1
	• Temperature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



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 **AlBeMet162-Stainless Steel transition**
- Test the **constraint schema** and the stiffness of bellows with CuBe blades.
- Study of cables and cooling pipes fitting.

Test of homemade hydraulic fitting

The order for the central chamber and the inner vertex realization has just been delivered.
In September we will start the cooling test with the paraffin.

Conclusion

- The **central chamber** design is compatible with the **LumiCal Requirement**.
- The design of **ellipto-conical chamber** is compatible with **LumiCal requirements**.
- The central chamber and the **ellipto-conical chamber** provide **low material and side effects to the LumiCal.**
- The preliminary design of **remote vacuum connection** has been proposed.
- The activities related to the **mock-up are ongoing**.

Future steps

- Refinement of the remote vacuum connection design.
- Refinement of the bellows design considering the impedance simulation.
- Services implementation and material budget evaluation.

THANK YOU FOR YOUR ATTENTION

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BACK-UP

Contact: francesco.fransesini@lnf.infn.it

Support tube

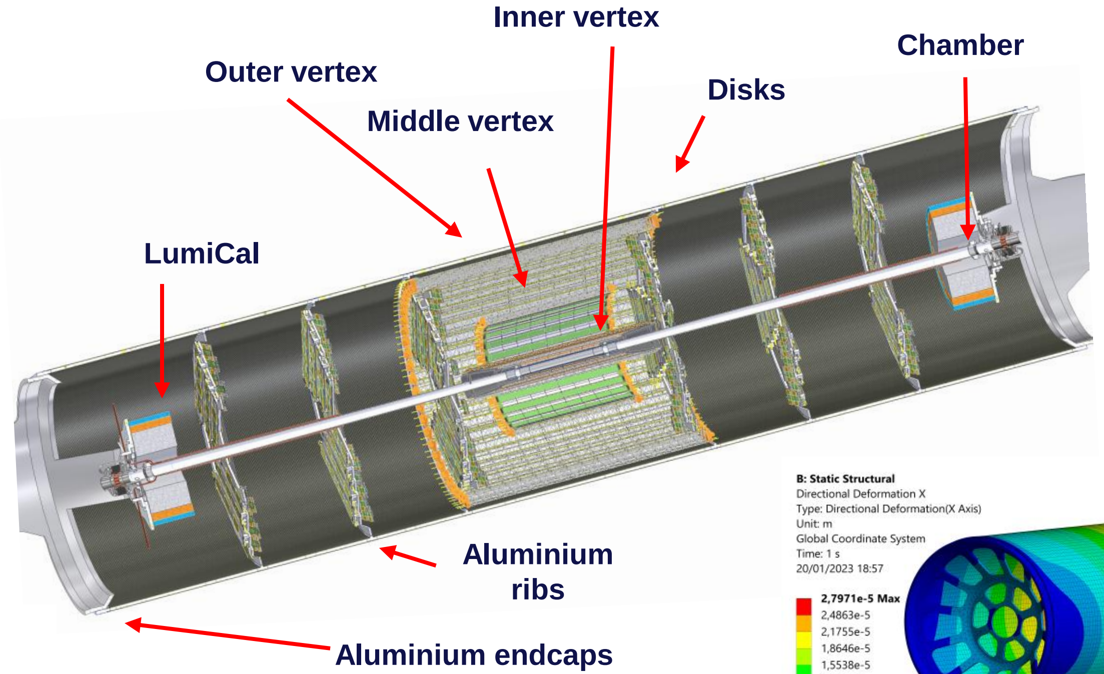
The support tube aims to :

- Provide a **cantilevered support for the pipe**
- **Avoid loads on thin-walled central chamber** during assembly or due to its own weight
- **Support LumiCal**
- **Support** the outer vertex and disks

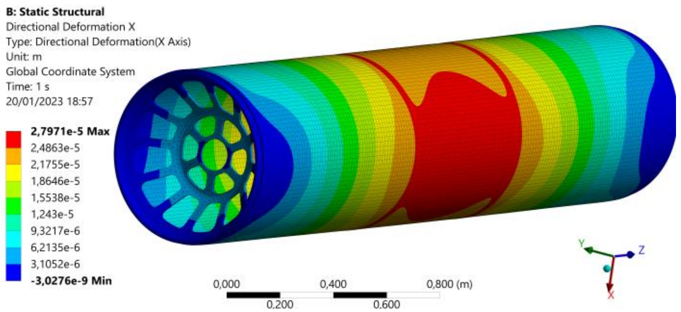
The structure is made with a **multiple layer structure**:

- ➢ 1mm CF + 4mm HC + 1mm CF

- To allow the support of the disks are necessary **6 reinforcement ribs.**
- The cylinder is split in **two halves** to simplify the assembly procedure
- The Aluminium endcaps support the LumiCal and the beampipe



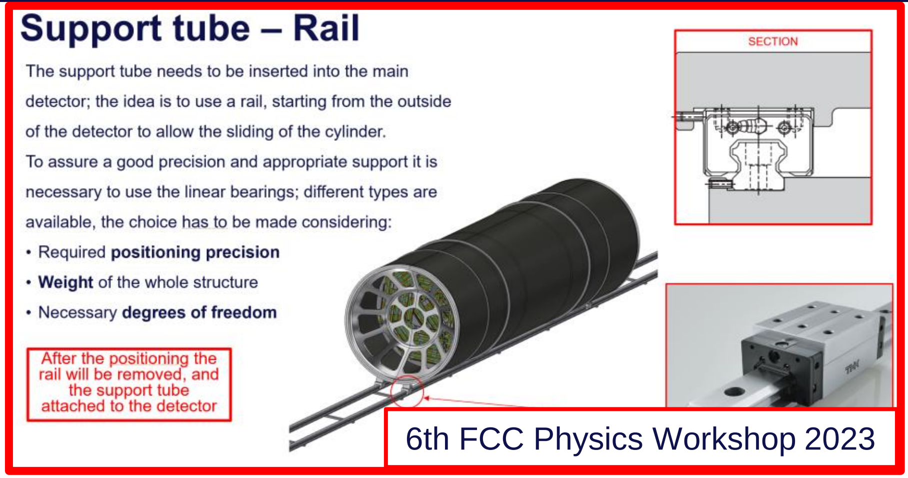
CF=carbon fibre
HC=honeycomb



Chamber	50 kg
LumiCal	70 kg + 70 kg
Vertex Disks	6*10 kg
Outer Vertex	15 kg
Medium Vertex	7 kg
First guess loads (overestimated)	

	Maximum stress [MPa]
Aluminium flanges	2.08
Aluminium ribs	0.20
Honeycomb	0.02
Carbon fiber	0.60
	Maximum displacement X [mm]
Aluminium flanges	1.34 e-2
Aluminium ribs	2.62 e-2
Composite	2.80 e-2

Support tube – How to insert it



6th FCC Physics Workshop 2023

After a discussion with Andrea Gaddi, a new idea came out.

- The idea presented during the *6th FCC Physics Workshop* consists of a rail, mounted only the sliding procedure, then removed. In this way the Support Tube should have been attached to the detector in order to remove the rail, a supplemental operation.
- The new idea is based on the creation of a Carbon Fiber rail embedded on the support tube, and placing some guides in the detector, to allow the sliding.

Understudy:
- Rail support
- Rail anchoring
- Rails length
- Geometry of the rail section
- Linear bearing type
- Positioning system

To continue the design, it is necessary to know:
- **Allowable anchoring** point from detector side
- **Allowable space** (internal detector diameter and geometry)