FUTURE CIRCULAR COLLIDER

INFN LNF Istituto Nazionale di Fisica Nucleare

FCC-EE DETECTOR BEAM PIPE

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for the IR mockup team

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FCC-ee Vertex Detector Workshop, Pisa

Interaction region layout

- **Beam pipes in AlBeMet (62% Be, 38% Al) up to LumiCal**
- **Central beam pipe 1 cm internal radius**
  - Internally 5 µm gold coated to reduce impedance and shield of sync. rad. photons.
- **Actively cooled due to impedance heat load**
  - Liquid paraffin for the central one (~60 W) and water for the lateral ones (~130 W).
- **Minimised material budget**
  - Central beam pipe double wall AlBeMet, paraffin and Au (0.68% X_0)
  - Lateral beam pipes minimised within LumiCal acceptance: (mostly 7% X_0, few regions up to 50% of X_0). Shaped to minimise showers off manifolds

[FSR Vol. 1, Fig. 82, p. 122]

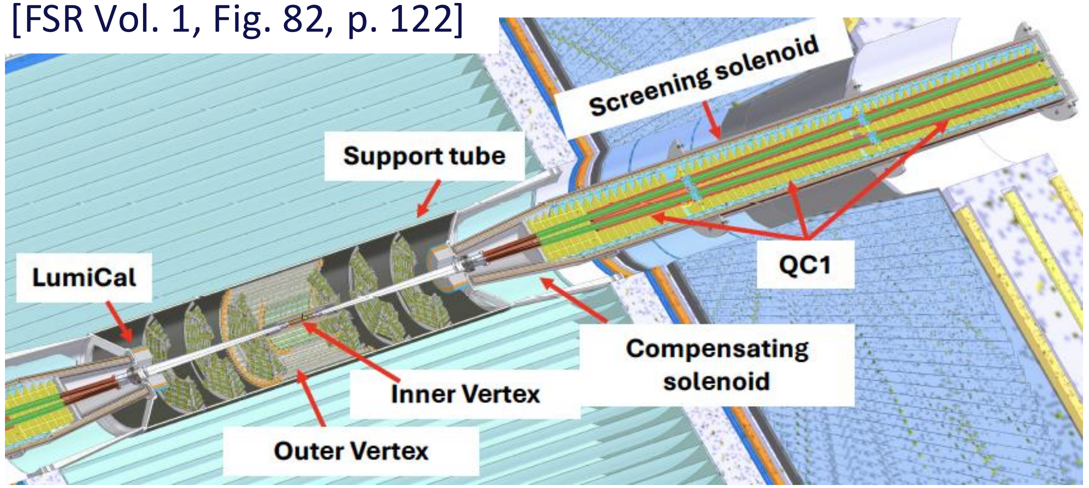


Fig. 48: Central chamber in AlBeMet162 including cooling inlets and outlets (left); cross-section view and zoom of the structure of the cooling channel for the paraffin flow.

Fig. 49: Ellipto-conical vacuum chamber.

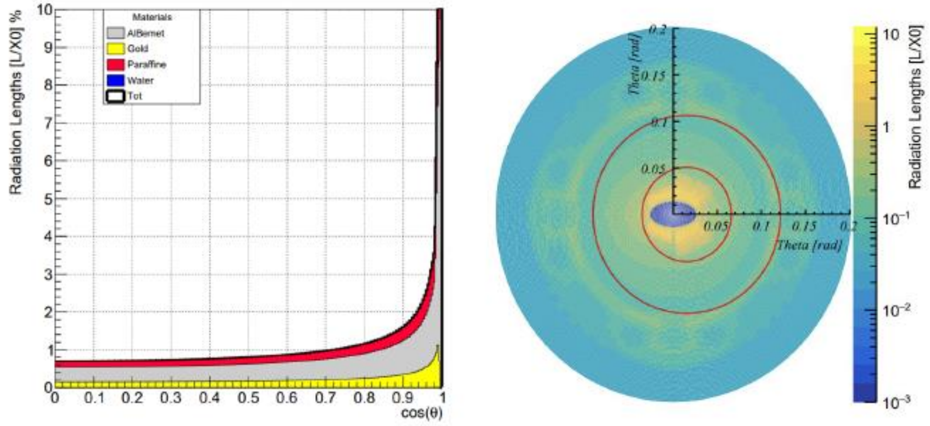
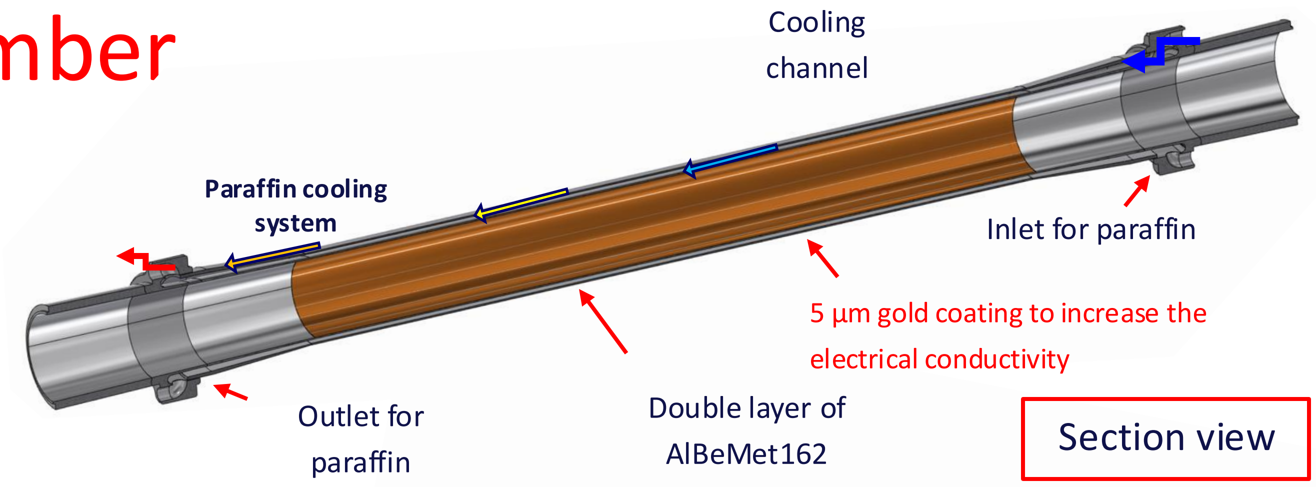


Fig. 50: Material budget of the beam pipe as a function of the polar angle (left) and in front of the LumiCal (right) in the region $\theta \in [0, 0.2]$ rad. The red lines represent the LumiCal acceptance, i.e. the 50 mrad and 105 mrad cones.

FCC-ee IR central chamber

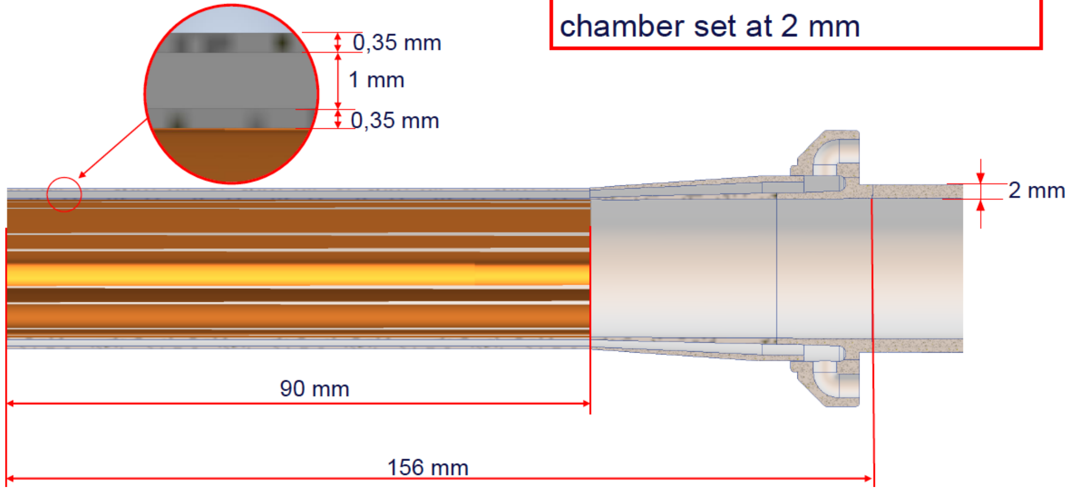
- AlBeMet 162 (62% Be, 38% Al)
- 180 mm long centered at the IP

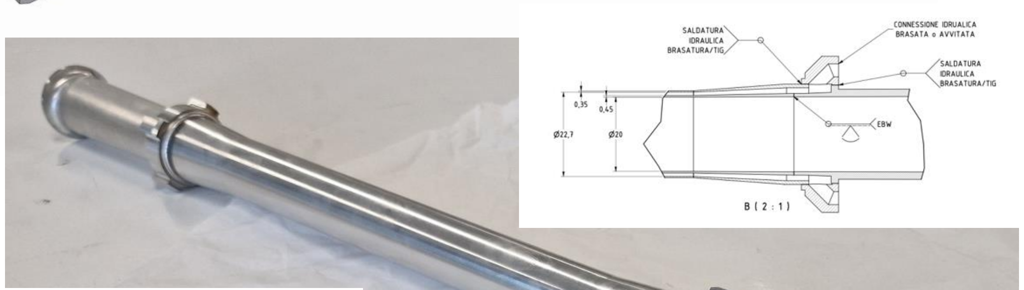
- **0.35 mm** outer radius AlBeMet162
- **1 mm gap** for paraffin
- **0.35 mm** inner radius AlBeMet162



Thickness of the chamber

Uniform thickness of the conical chamber set at 2 mm



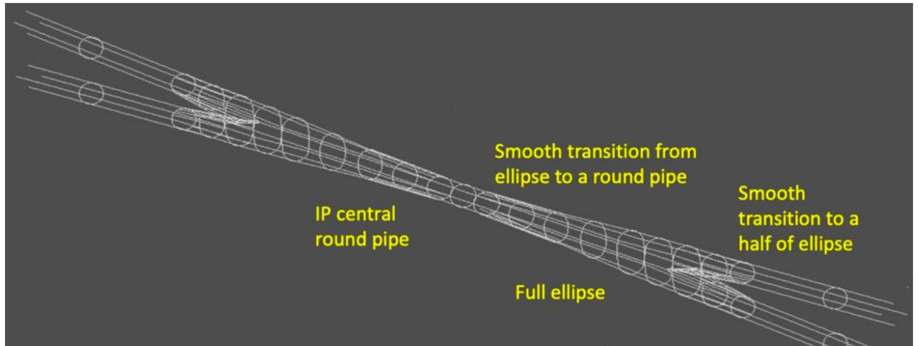


The prototype is in aluminium:

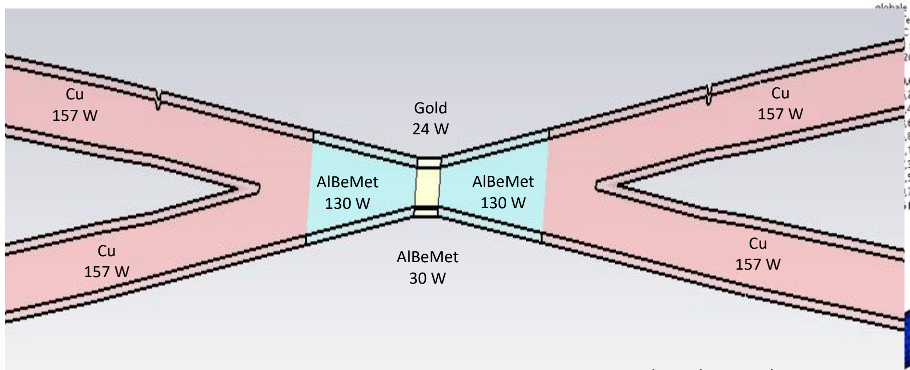
- **0.35 mm** outer radius
- **0.9 mm gap** for paraffin
- **0.45 mm** inner radius

Leveraging Belle-II beam pipe design (0.4 mm Be +0.6 mm Be + 1mm paraffin)

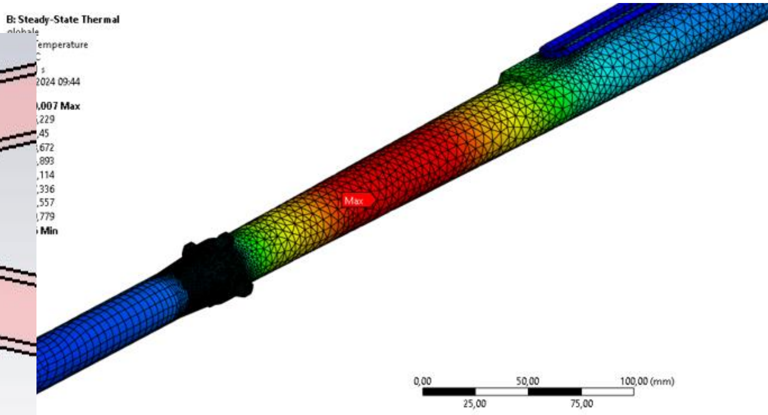
FCC-ee low-impedance IR vacuum chamber



Smooth transition in IR

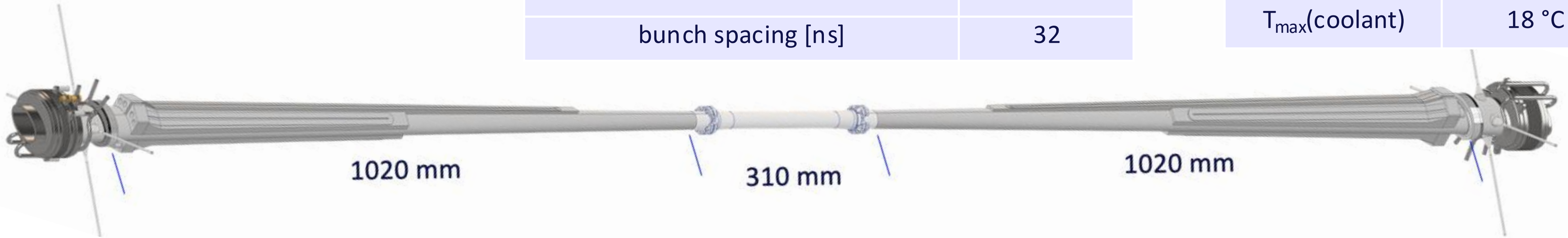


Scale is distorted



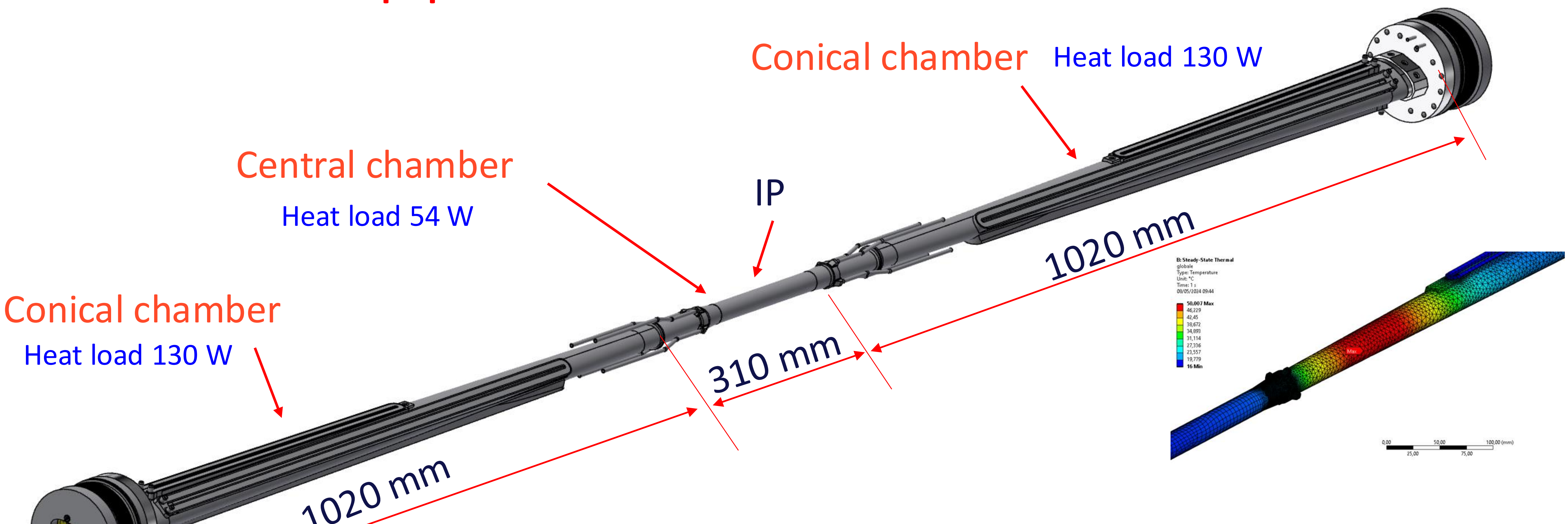
beam energy [GeV]	45
beam current [mA]	1280
number bunches/beam	1000
rms bunch length with SR / BS [mm]	4.38 / 14.5
bunch spacing [ns]	32

	conical chamber	central chamber
coolant	water	paraffin
T_{max} (chamber)	50°C	29°C
T_{max}(coolant)	18 °C	20 °C



Study and optimization of the material budget for the beam pipe has been performed and is in progress. LumiCal requirements and material budget minimization considered, also comparing Be with AlbeMet.

Detector beam pipes



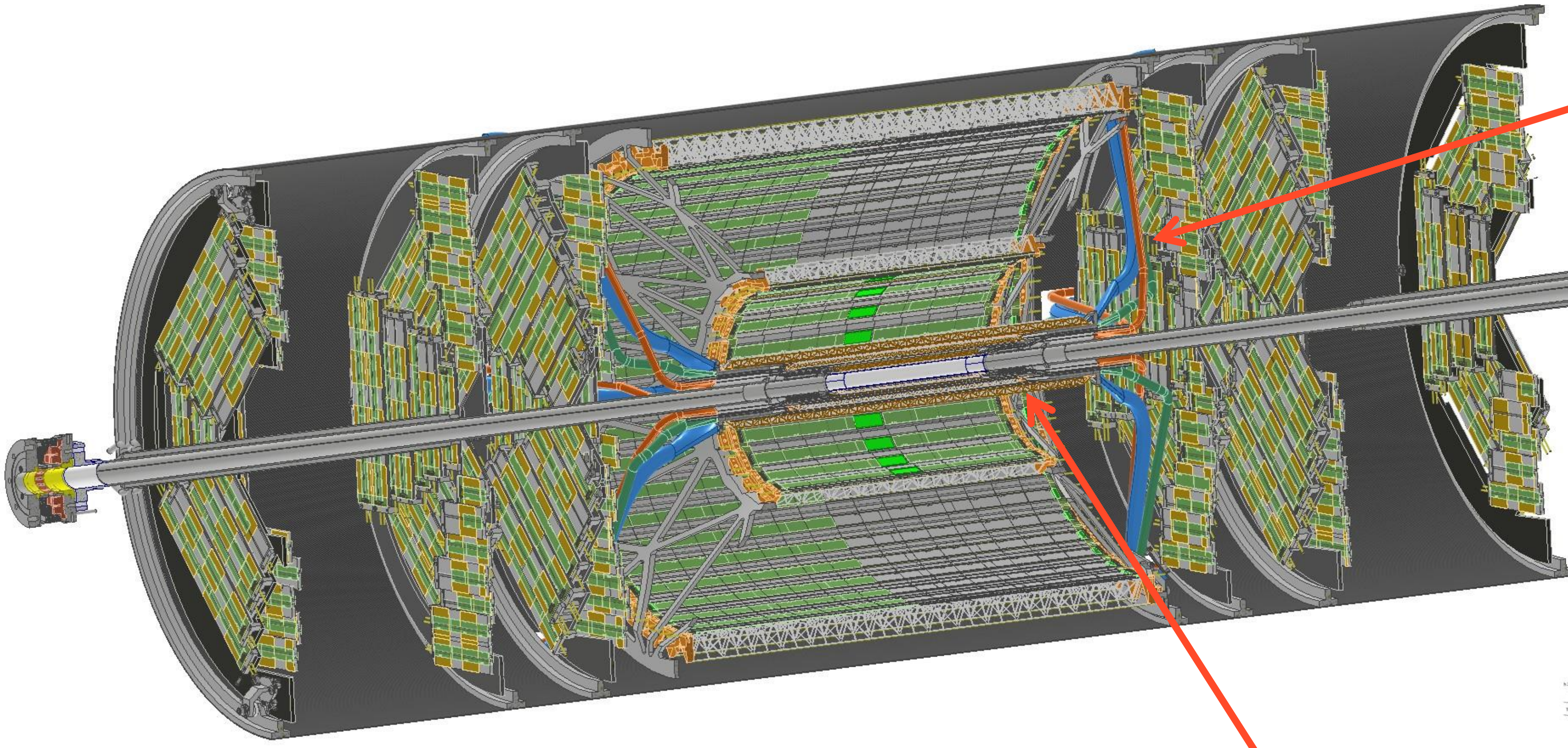
Paraffin flow (central chamber)

- 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)

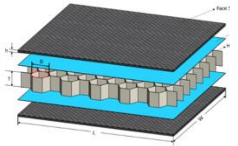
- Flow rate: 0,01 kg/s (4 channels per side)
- Total flow rate per side: 0,04 kg/s
- Section: 12,25 mm^2
- Velocity: 1 m/s
- Inlet temperature: 16°C
- Convective coefficient: 1200 W/m^{2}K

FCC-ee engineered Interaction Region



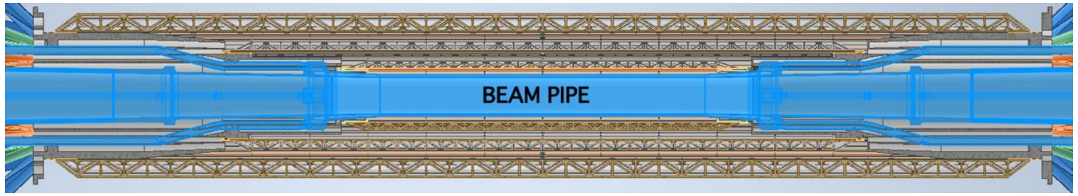
Alternative (better) option for air ducts instead of air-cooling cones

Support tube provides integration of beam pipes, vertex and LumiCal



Support tube material
1mm CF + 4mm HC + 1mm CF

Beam pipe cooling services and innermost vertex detector layer ones need to be carefully integrated



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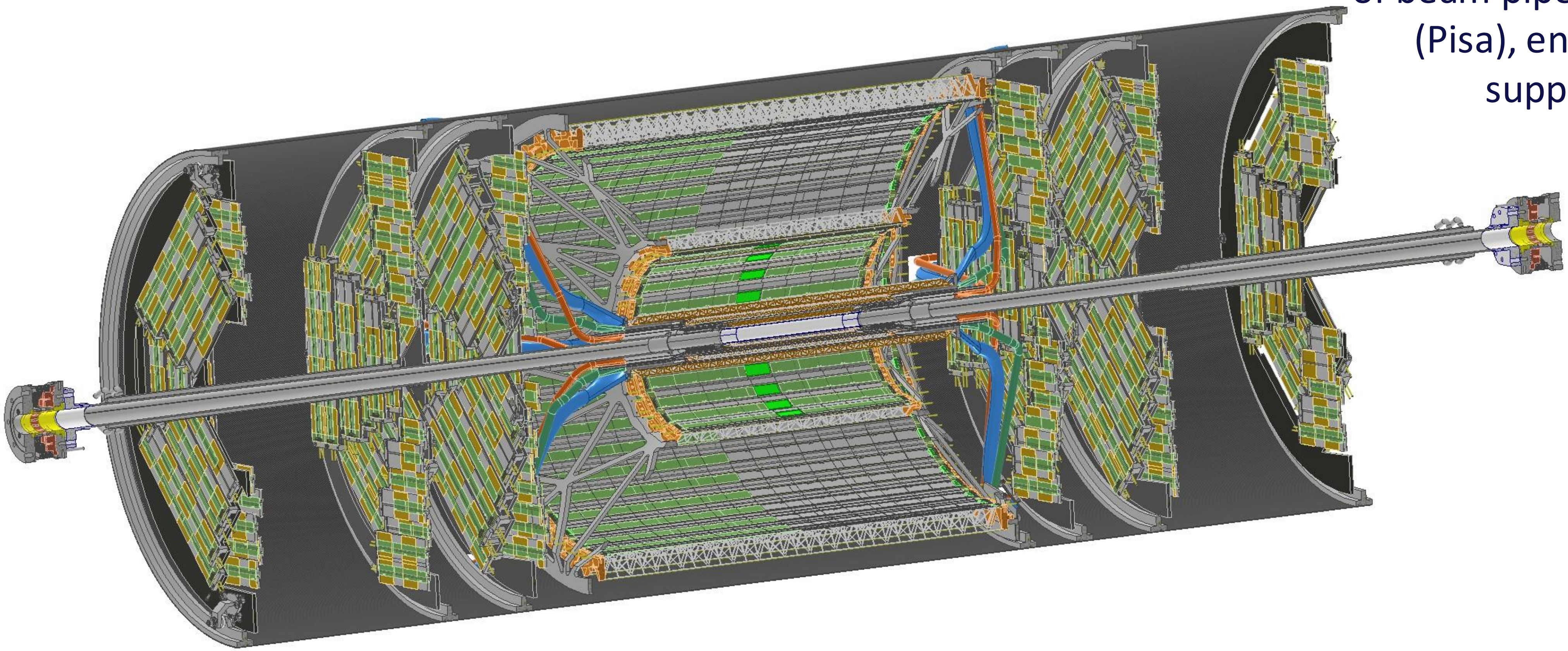
FCC-ee engineered Interaction Region

Support tube provides integration of beam pipes, vertex and LumiCal (Pisa), endcaps and lumical supports (Frascati)



Funded project INFN & CERN to realise in Frascati a full-scale mockup of this layout

Goal: design validation, buckling test, assembly and cooling/services test

Central Chamber

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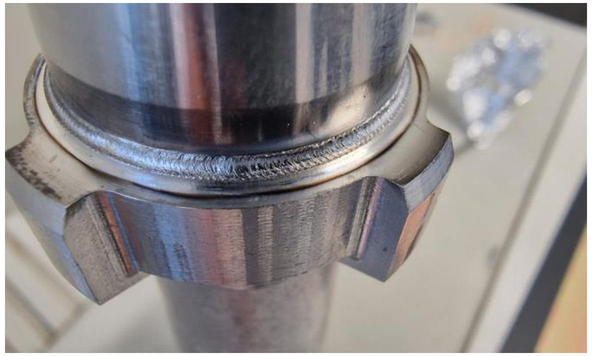
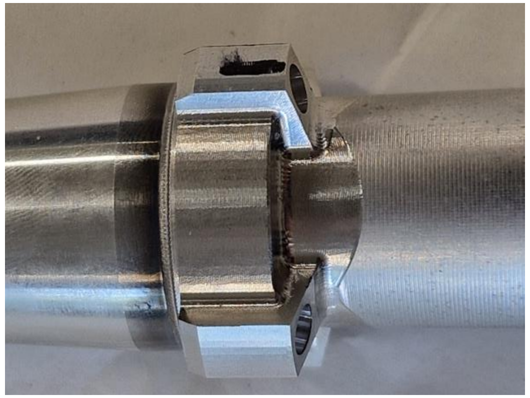
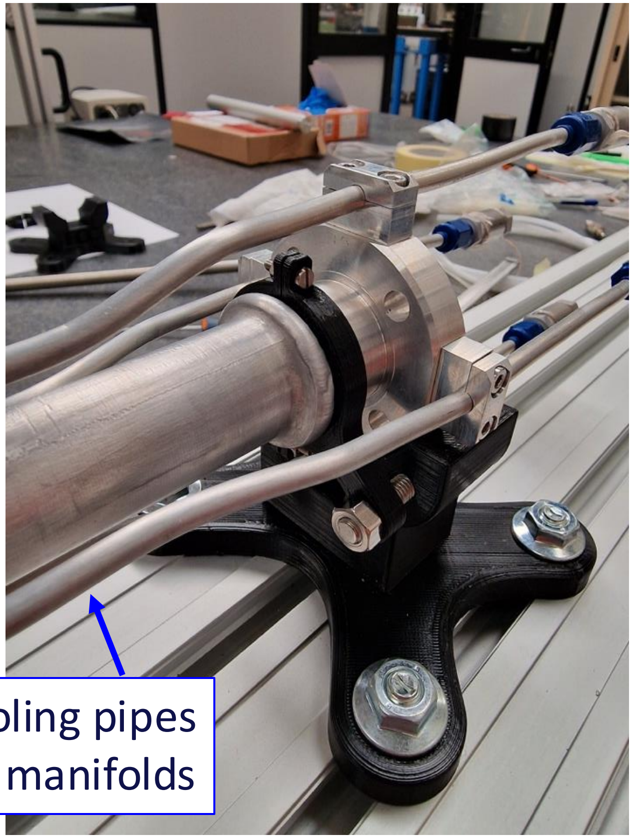






cooling pipes manifolds

Vacuum chambers manufactured by COMEB s.r.l. (Italy)

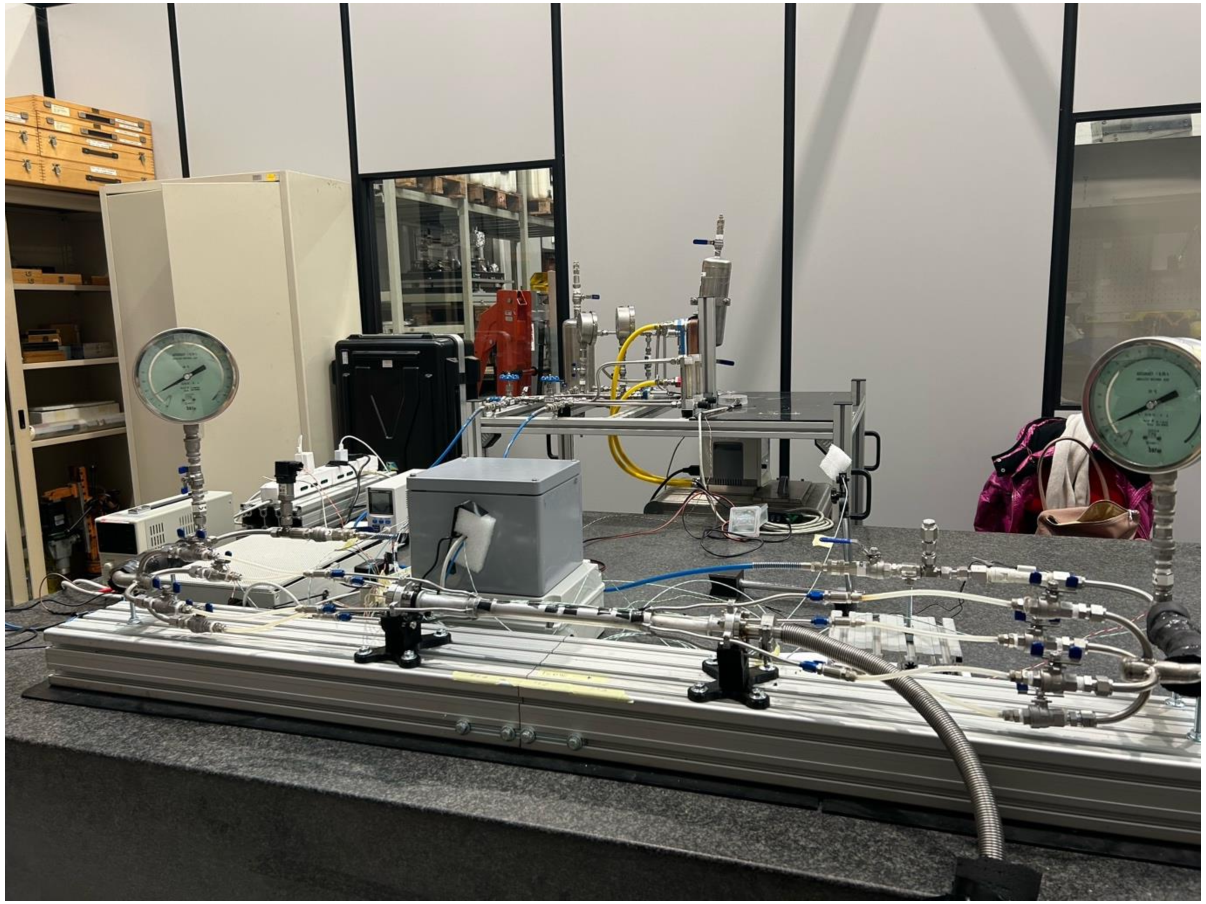
http://www.comeb.it/

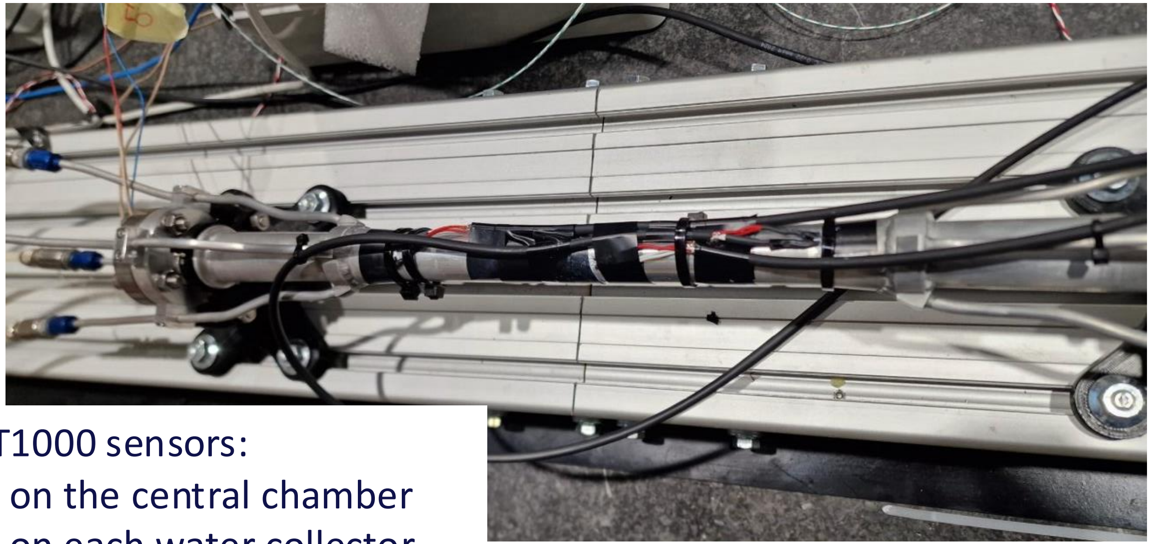
RAVENS COURT

Electron Beam Welding (EBW) by Ravenscourt Eng. Limited (UK)

https://ravenscourtengineering.co.uk/

Measurement set-up



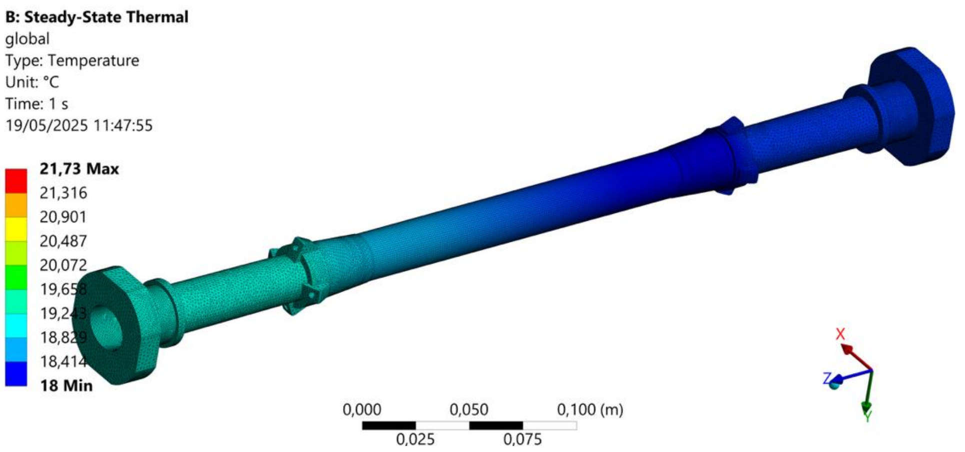


PT1000 sensors:
- 3 on the central chamber
- 1 on each water collector
- 1 environment

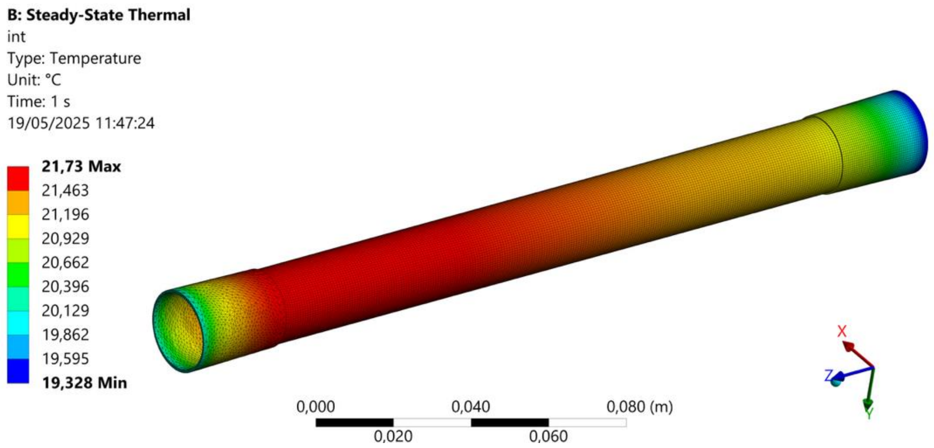
An internal ohmic heater inside the vacuum chamber simulates the beam heat load on the pipe during the beam passage.
A variable power supply controls the power deposited on the chamber.

Ansys simulation with the prototype of the central beam pipe

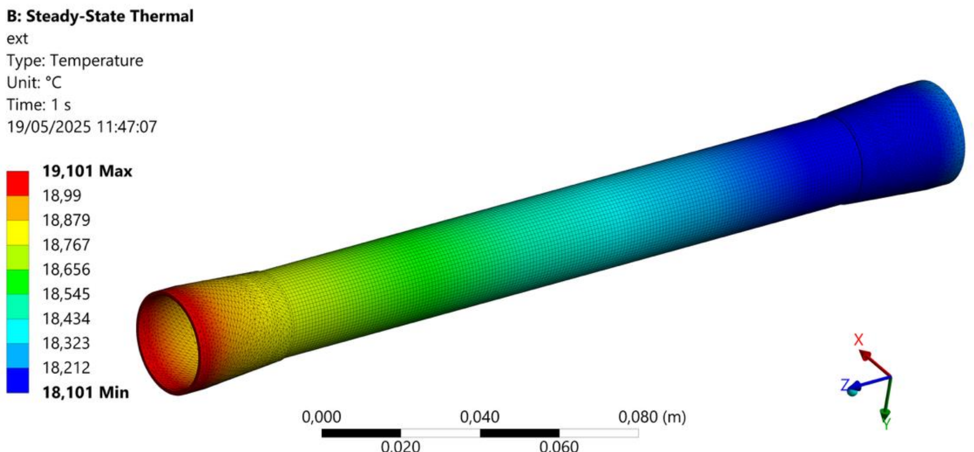
Water at 18 ºC, flow rate 1 l/min, and beam pipe at 54 W



Temperature of the external side of the the beam pipe



Temperature of the internal side of the the beam pipe



water temperature

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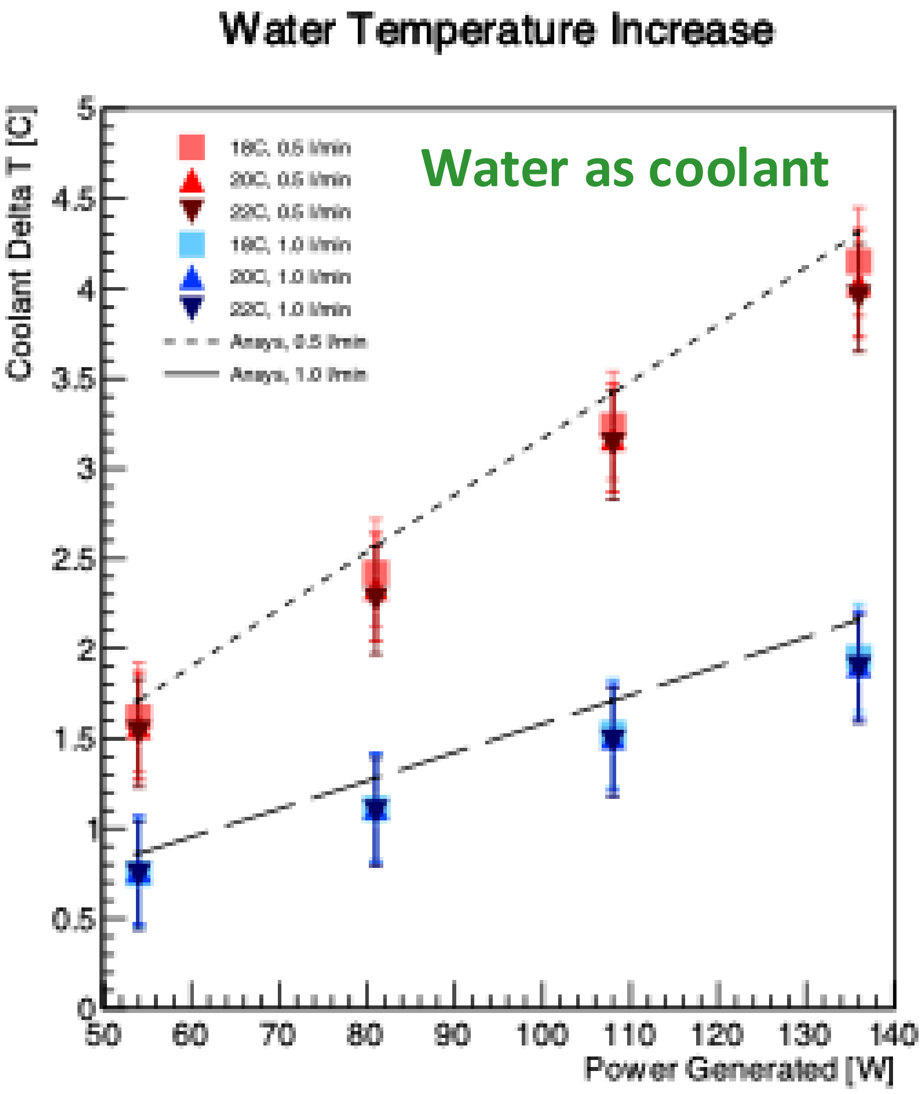
Measurements with the prototype of the central beam pipe



- **Each measurement corresponds to the water temperature increase for a given power on the beam pipe for a flow rate of 0.5 l/min and 1 l/min.**

- 54 W is the nominal beam heat load on the beam pipe.
- Measurements in good agreement with expectations.
- Linear behaviour as expected.

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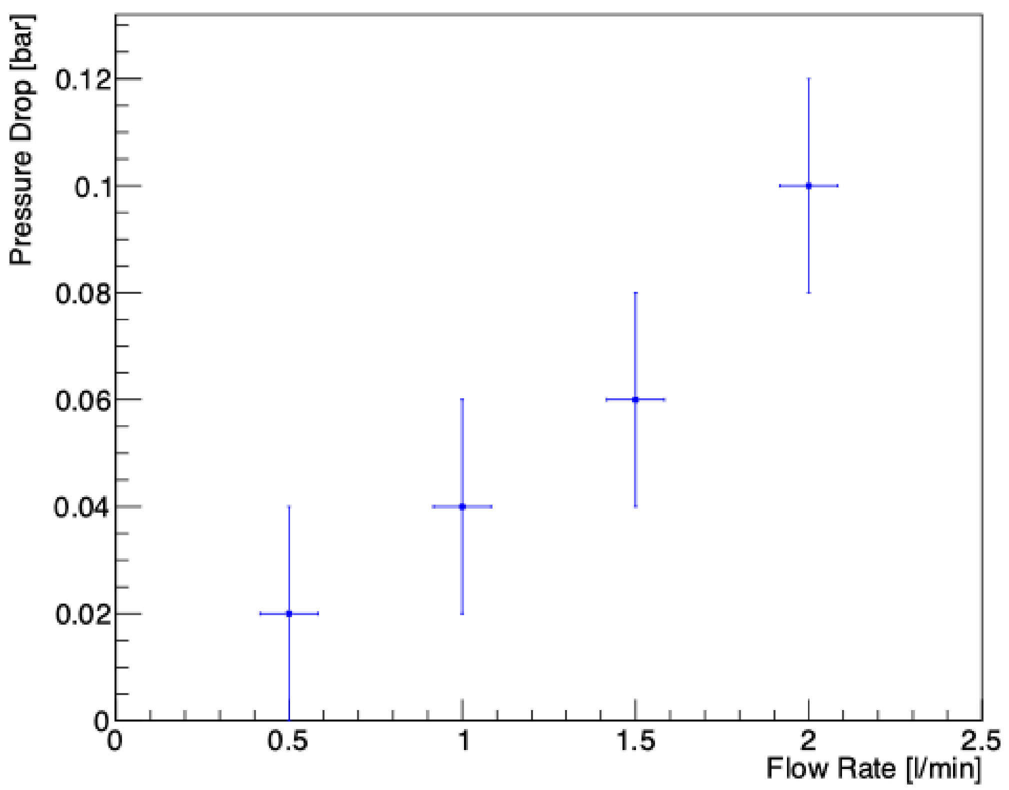
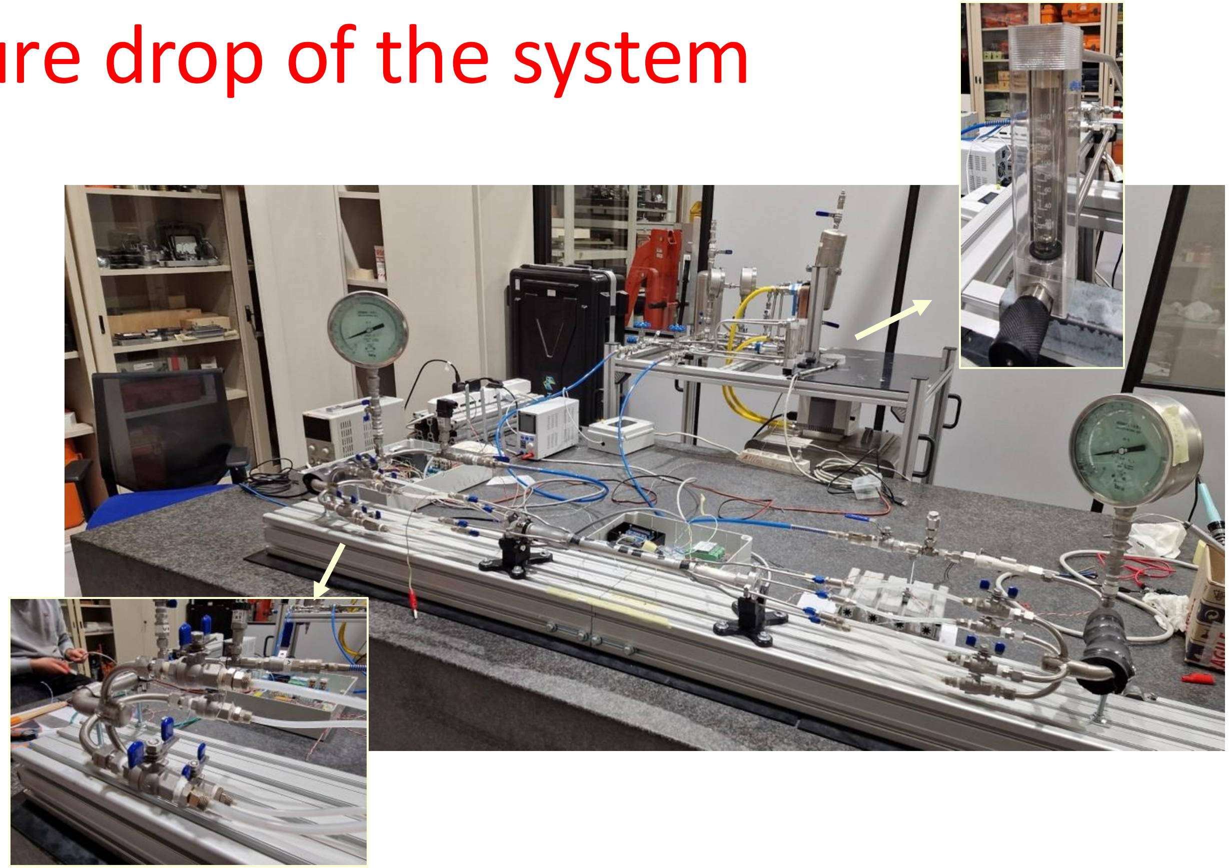
Measurements of the pressure drop of the system

Pressure drop versus the water flow rate

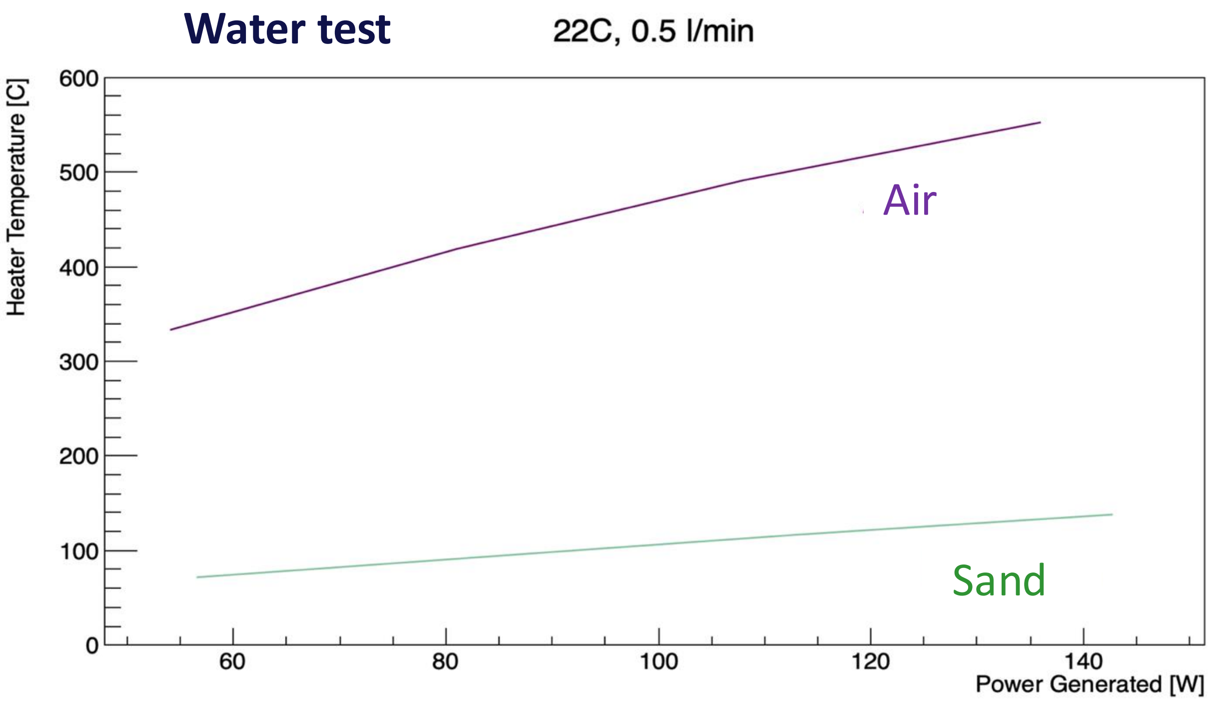


Behaviour as expected.



- Further measurements planned to characterise the system and to determine the pressure drop only at the beam pipe.
- Differential flowmeters would help to increase the accuracy.

Heating by conduction rather than radiation



Power on the beam pipe	Beam pipe max. temperature
54 W	44 °C
81 W	53 °C
104 W	63 °C
136 W	73 °C

Measurements of the cooling chamber with paraffin have just been performed this week.

- Internal beam pipe filled with sand reduces drastically the temperature of the resistance required to heat the pipe to the nominal 54 W
- Risk with paraffin greatly reduced

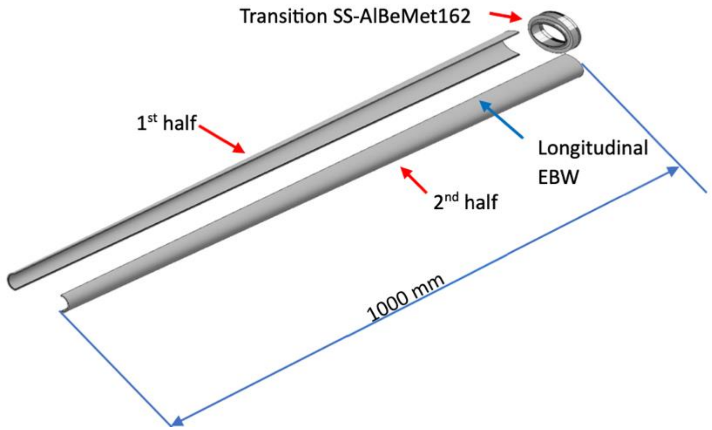
Liquid paraffin:

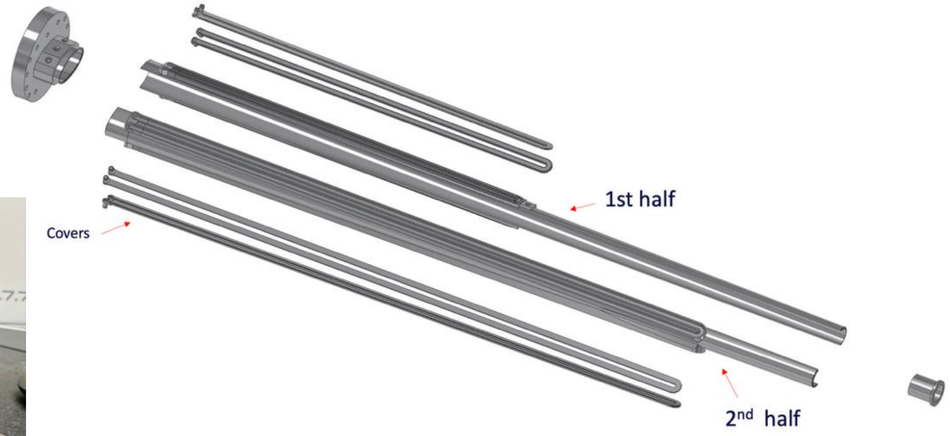
- Flash point 215 ºC
- Auto-ignition point between 245°C to 370°C

Conical Vacuum Chambers

Presently in UK for EBW

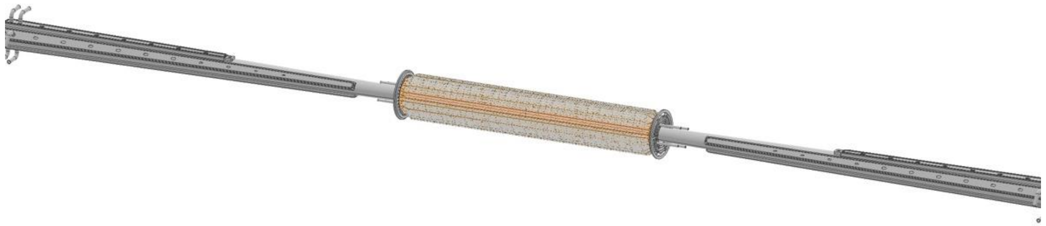
Prototype in aluminium.
Conical chambers are fabricated in two halves that need to be welded with EBW.
The cover part of the water cooling channels will be brazed on top.





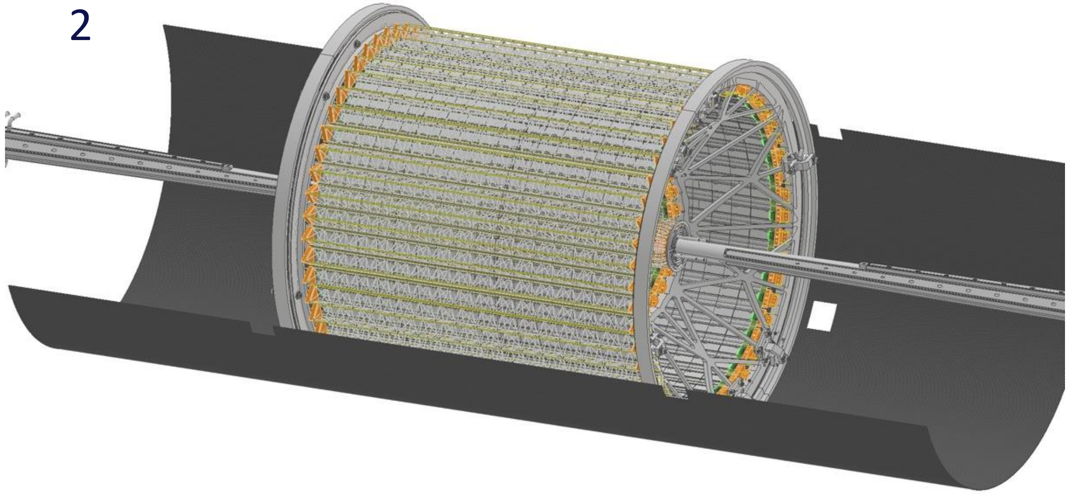
Possible assembly procedure

1



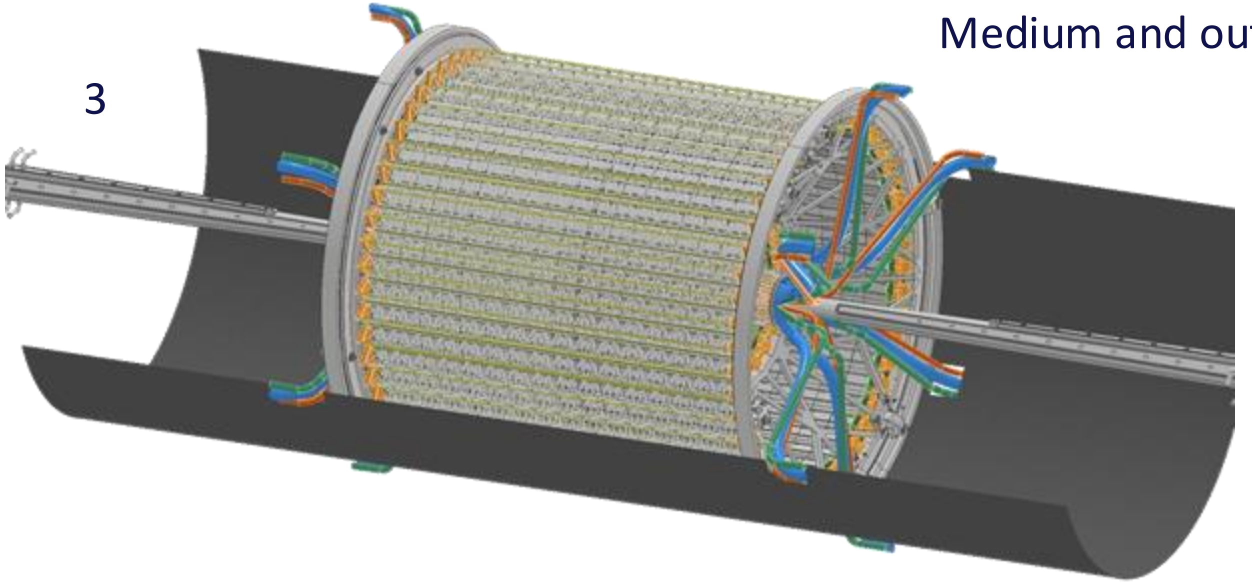
Beam pipe with inner vertex

2



Medium and outer vertex assembly

3

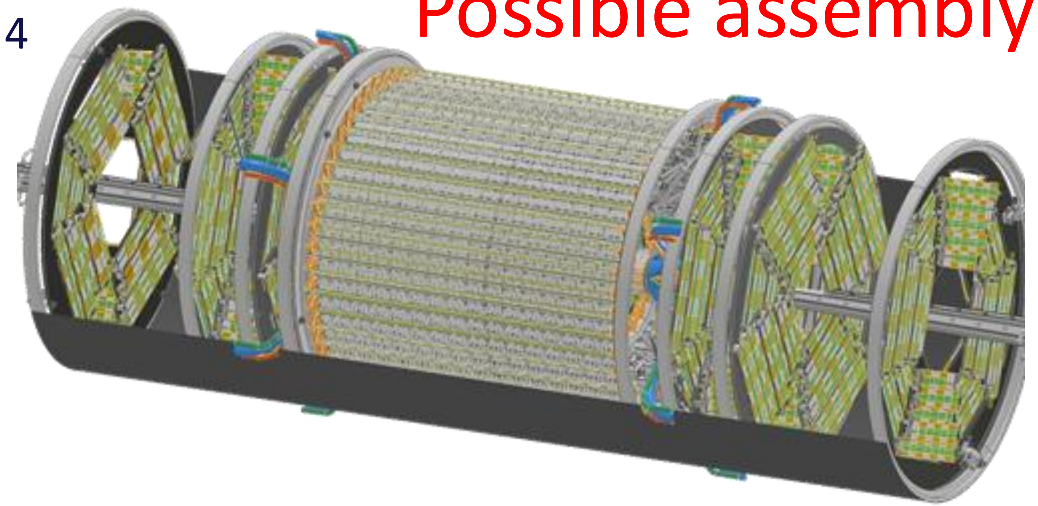


Layer 3 ducts
Layer 2 ducts
Layer 1 ducts

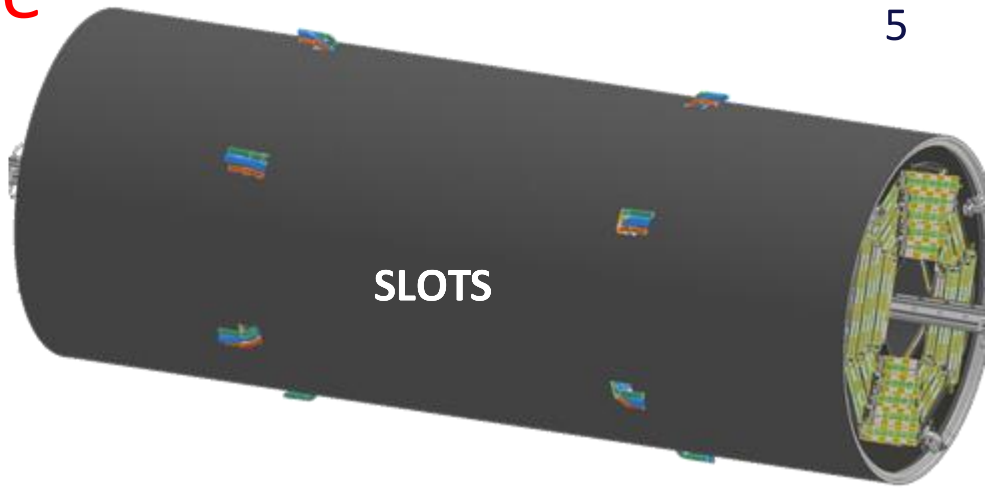
Inner vertex services assembly

Possible assembly procedure

4



5



Discs assembly

Slots are required on the support tube to allow ducts entry and exit

Support tube closure

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

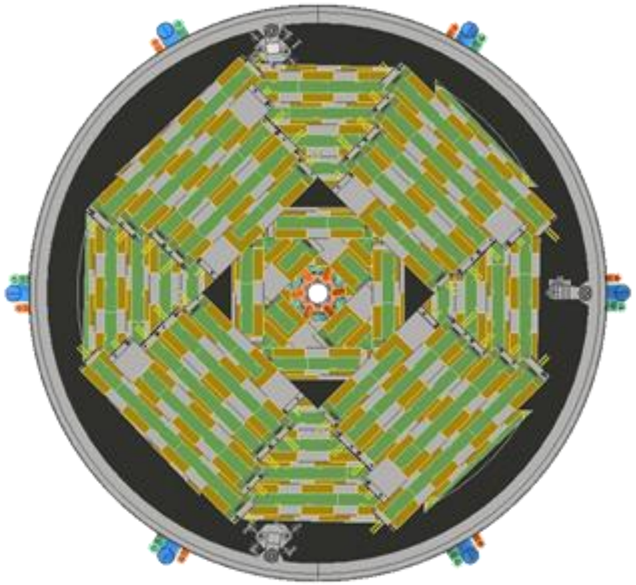
↓

The arrangement and shape of the slots must be studied to accomodate:

Air ducts of the three layers

Cooling water channels of discs, middle and outer barrels

Cables from the inner region



ADVANTAGES:

- Easier routing of services
- Full Discs

Future Perspectives on the detector beam pipes

- This activity is part of the **DRD8-WP1** collaboration.
- The current design is our baseline as reported in the FSR, and it has been prototyped in aluminium and measurements performed with water and paraffin as coolant.

- In the next pre-TDR phase we will perform an optimisation of this design in terms of **material budget and integration with the vertex detector.**
- We plan to design & prototype a double layer central beam pipe with the **internal layer in AlBeMet and the external one in Carbon-fibre.**
- We plan to investigate alternatives to paraffin cooling, such as **CO2 supercritical.**
- We need to design the **anchoring of the VXD to the beam pipe**, considering the beam pipe vibrations, to be studied.

Additional material

Status of measurements and validations

- **Verify liquid cooling system efficiency of beam pipes (Frascati)**
  - ✓ **Central chamber: measurement with water as liquid coolant** **Q2-Q3 2025**
  - ✓ Central chamber: measurement with liquid **paraffin – test in preparation** **Q3-Q4 2025**
  - ✓ Conical chambers: measurements with water – chambers fabricated, ready for EBW
  - ✓ Bellows in fabrication

- **Verify air-cooling efficiency for inner vertex detector (Pisa)**
  - ✓ **Staves fabricated** **Q3-Q4 2025**
  - ✓ **Wind tunnel assembled, measurements started** **Q3 2025**

After the cooling tests: **(Frascati)**

- **Support tube fabrication (at company)**
- **Assembly all components and vertex services to the support tube**
- **Assembly and integration tests**

Targeting Q2-Q4 2026

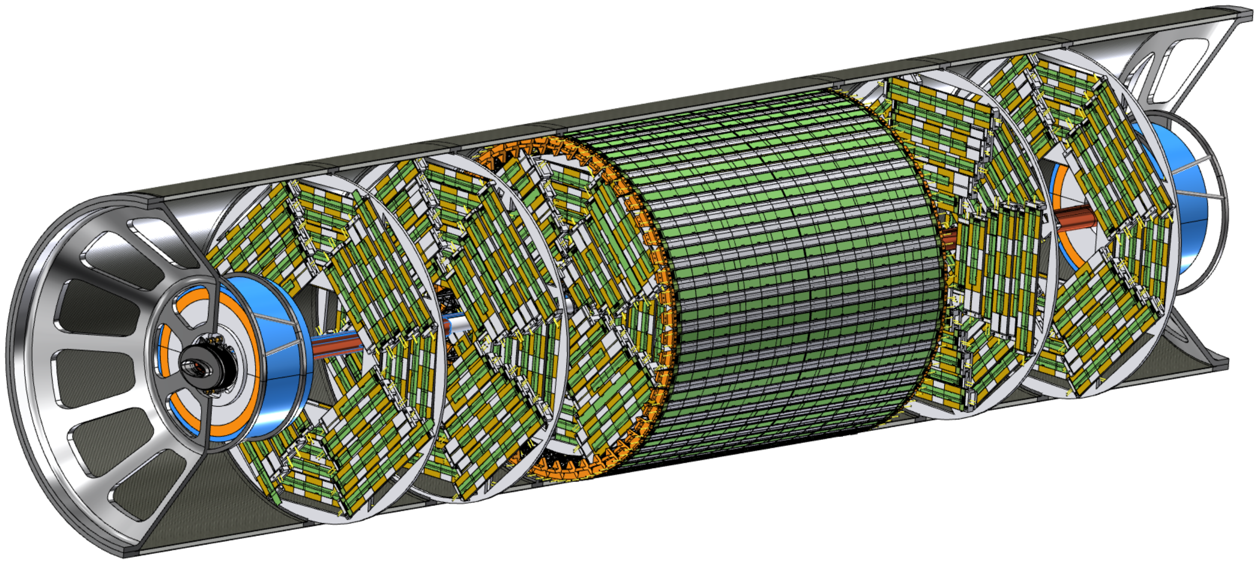
FCC-ee IR full-scale mock-up

Main Components

- Actively cooled detector beam pipes in aluminium
- Bellows
- Air-cooled inner vertex in carbon fibre and kapton heaters (no MAPS)
- Outer vertex and disks in aluminium
- Vertex services integration
- Support tube in carbon fibre and honeycomb
- Lumical in lead

Deliverables:

- ✓ Construction of central chamber
- ✓ Construction of conical chambers
- • Construction of bellows prototype
- ✓ Assembly of inner vertex
- ✓ Construction of wind tunnel
- • Construction of outer vertex
- • Construction of support tube



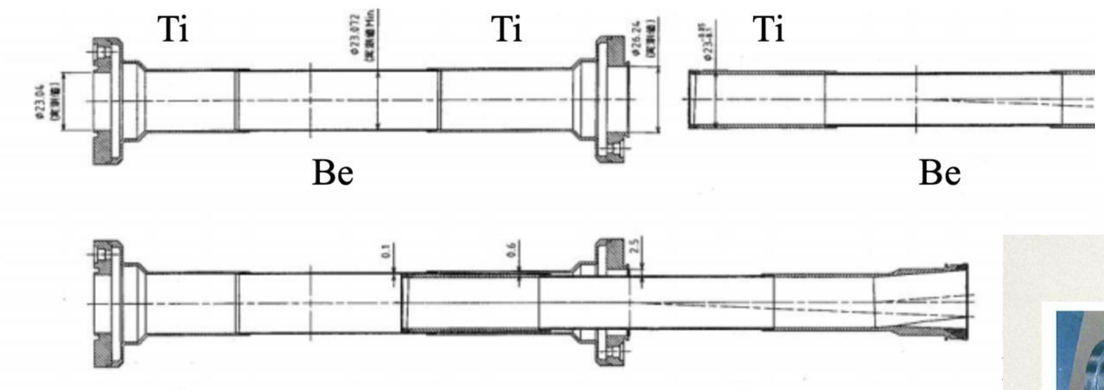
Milestones:

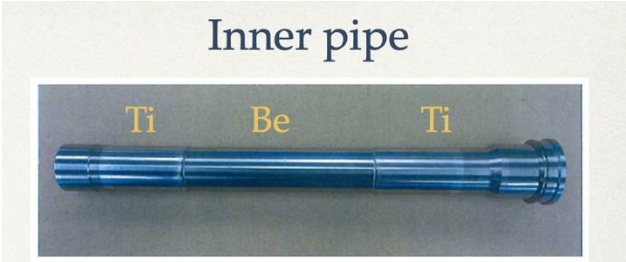
- ✓ Verification of assembled chamber cooling system
- ✓ Validation of inner vertex cooling system
- • Validation assembly sequence
- • Structural integrity tests

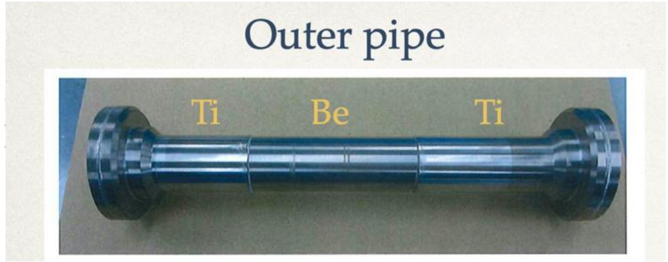
Activity in WP1-DRD8 https://drd8.web.cern.ch/
Mechanics & Cooling of Future Vertex and Tracking Systems

SuperKEKB Beryllium beam pipe at IP

- The beam pipe at the IP is a double pipe, each consists of middle (Be) and side (Ti) parts, brazed to each other.
- The inside of inner pipe is Au coated (10 μm thickness via 0.3 μmTi) by magnetonsputtering
- Paraffin runs between them

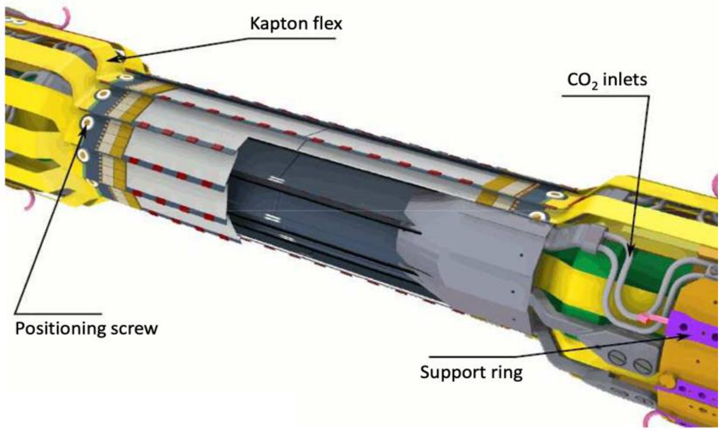






- Outer Be: 0.4 mm thick
- Inner Be: 0.6 mm thick
- Gap: 1 mm

K. Kanazawa



Light material (Be) inside detector acceptance
Paraffin ($C_{10}H_{22}$) flow to remove heat from image charge (~80 W)
Gold plating on inner wall protects detectors

- Low material budget cooling
  - Massive structures outside the acceptance to cool down the readout chips
  - The center of the ladder rely on cold air