MECHANICAL DESIGN OF THE MDI

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Outline

The presentation concerns:

- the **preliminary assembly** of the MDI, including the vacuum chamber, quadrupoles and solenoids
- the **mechanical study** examines the structural behaviour of the chamber at different thickness values, using FEA techniques.
- the preliminary **heat transfer study** is intended to determine the feasibility of using paraffin to remove the heat load from the central part of the vacuum chamber, accounting for the annular gap available and the pressure head allowance.

This preliminary assembly sets the starting point of the 3D engineered mechanical model

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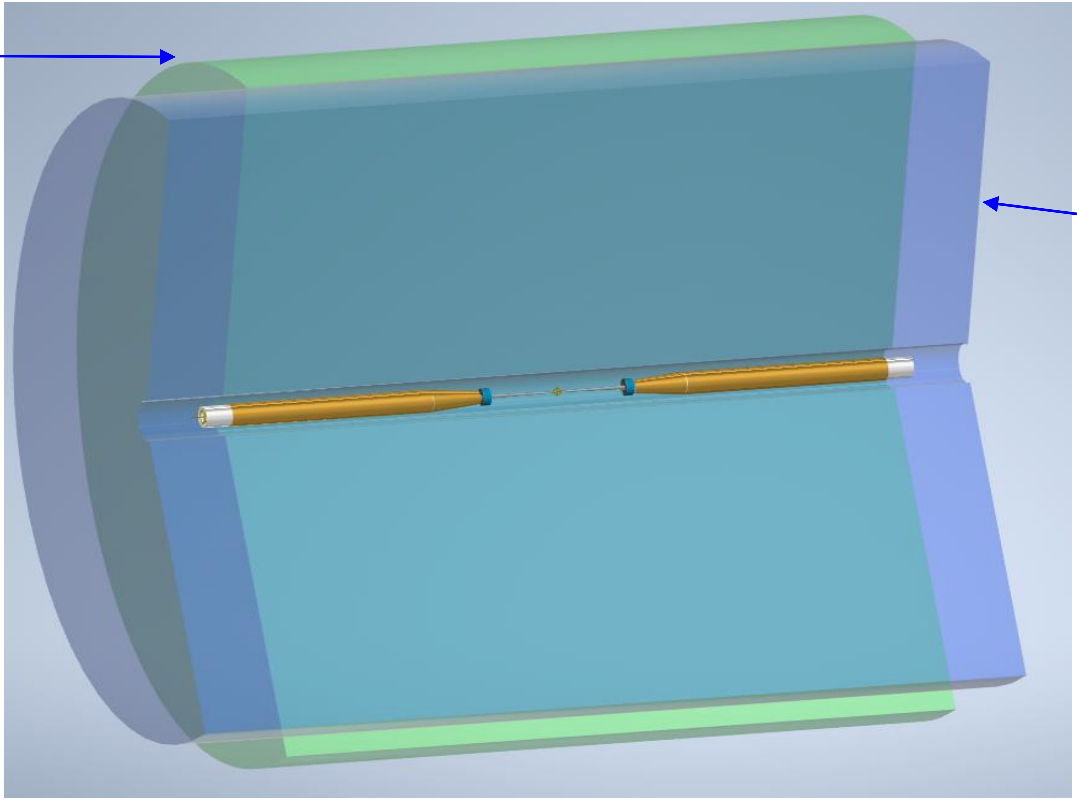
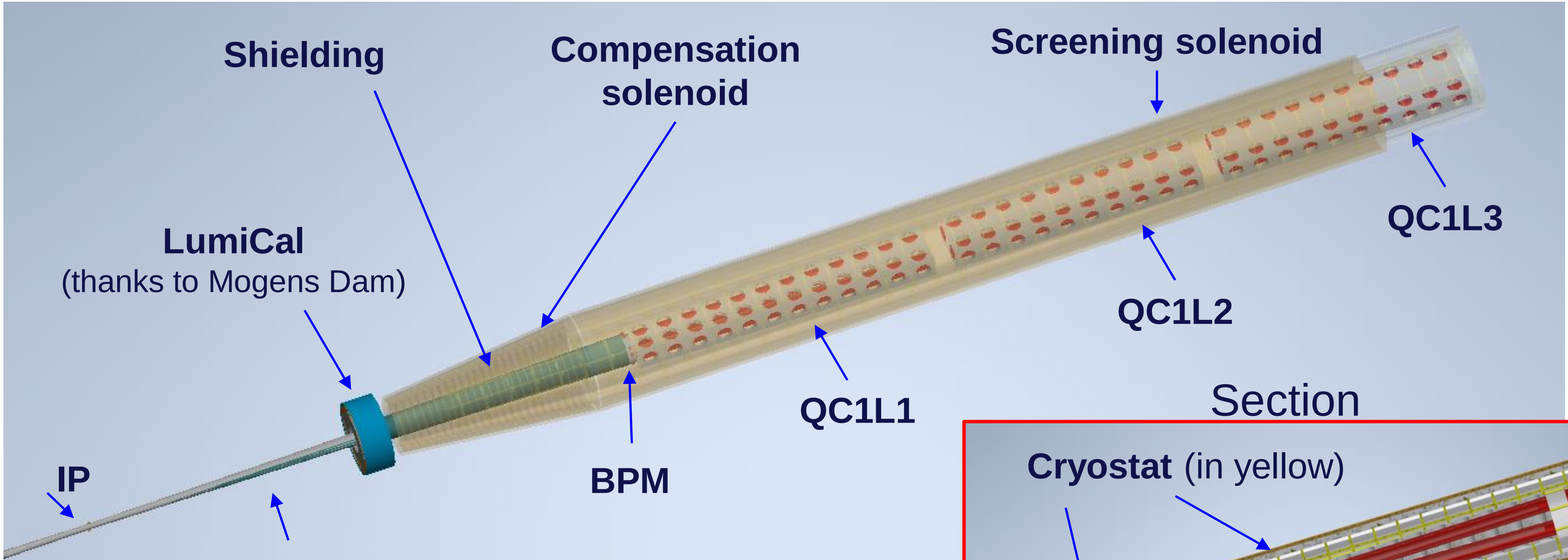


IDEA

Preliminary assembly of the MDI



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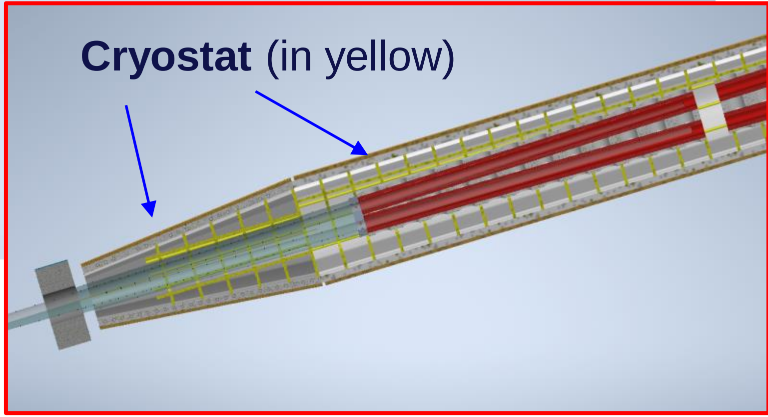

Thanks to M. Koratzinos for the magnets and cryostat

Preliminary assembly of the MDI

Coordinates for the assembly elements (optics v241):

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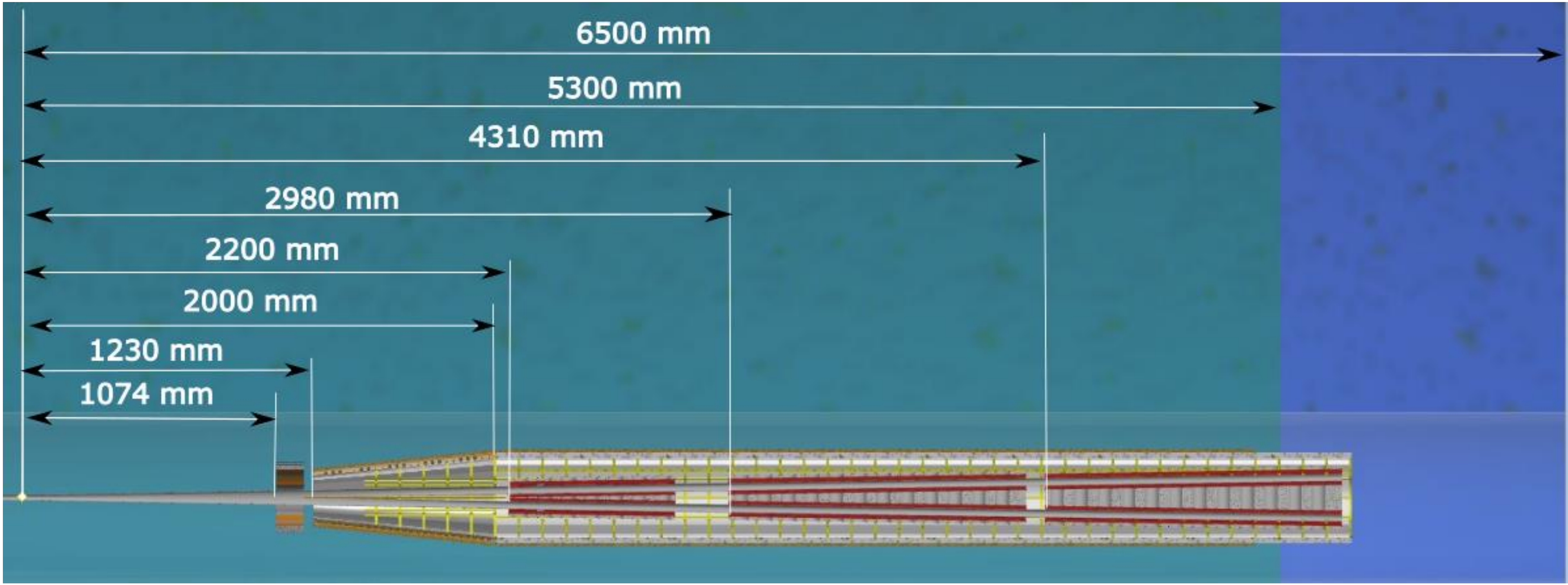


Preliminary assembly of the MDI (table 1)

Coordinates for the assembly elements:

Element	Initial coordinate of the element [mm]	Final coordinate of the element [mm]	Length [mm]	Diameter[mm]
Compensation solenoid	1230	2000	770	D_{int1}=166 D_{ext1}=236 D_{int2}=318 D_{ext2}=390
Compensation solenoid skeleton cryostat	1445	2000	555	D_{int} =120
Screening solenoid	2000	5600	3600	D_{ext}=392
Screening solenoid skeleton cryostat	2000	5600	3600	D_{int}=180
Pipe (ID)	0	90		20
	90	1175		Crotch and transition from 20 to 30 mm
	1175	5560		30
LumiCal	1074	1190	116	D_1=115 D_2=135 D_3=145

Preliminary assembly of the MDI (table 2)

Coordinates for the assembly elements (optics v241):

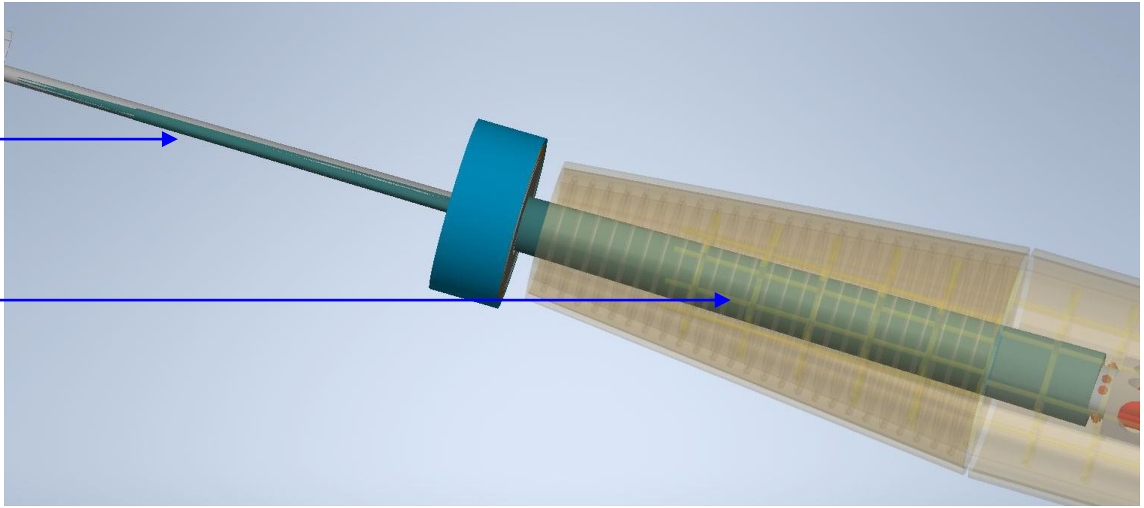
Element	Initial coordinate of the element [mm]	Length [mm]	Internal diameter [mm]
QC2L2	-7190	1250	50
QC2L1	-5860	1.250	50
QC1L3	-4310	1.250	40
QC1L2	-2980	1.250	40
QC1L1.1	-2200	700	40
QC1L1.2	2200	700	40
QC1R2	2980	1250	40
QC1R3	4310	1250	40
QC2R1	5860	1250	50
QC2R2	7190	1250	50
SR mask	-2060	60	
BPM	-2170	30	

Shielding

Tungsten shielding has been considered in the Geant4 model to provide for acceptable background rates in the detector according to the CDR:

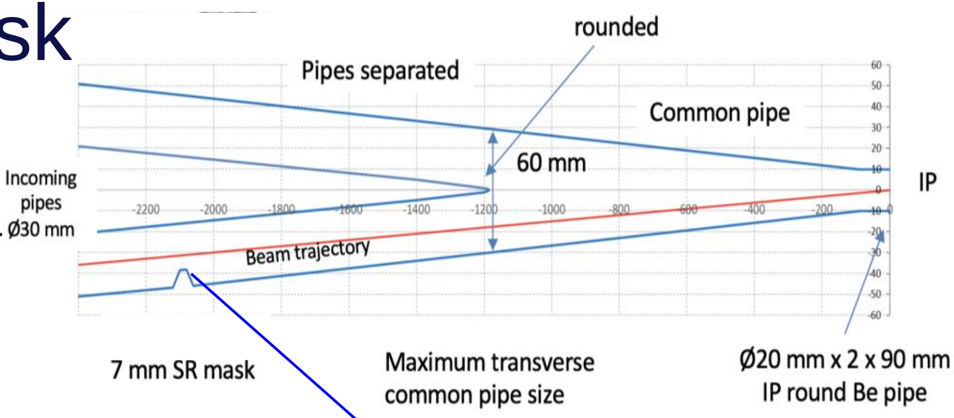
- a truncated cone behind the LumiCal
- a thin layer covering the pipe leaving the LumiCal window open.

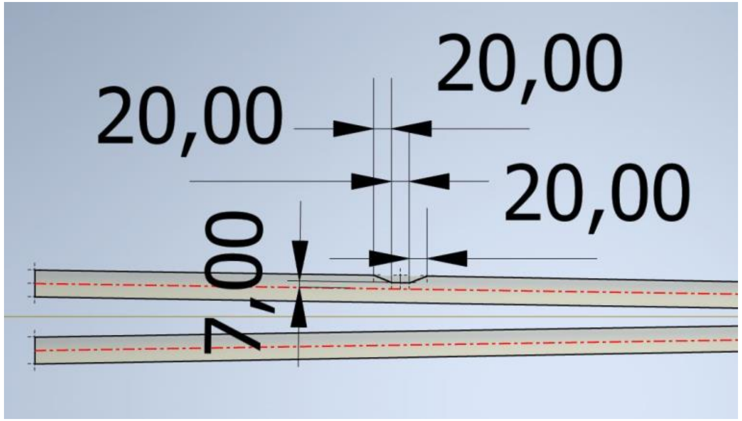
- No study on the weight, support or vibration of this shielding has yet been performed, this is planned as a next step.
- Also, proper shielding around the final focus quadrupoles has not yet been implemented, but it is planned after a dedicated background study and beam losses by the MDI group.

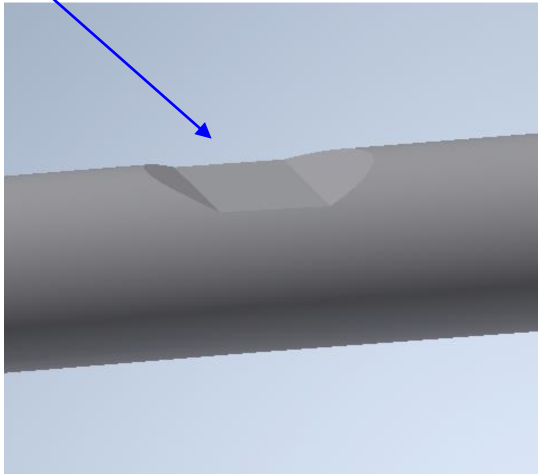


Synchrotron Radiation mask

- Introduced in the CAD using the model made by A. Novokhatski and M. Sullivan
- There are two masks placed at the exit of QC1 (at z = -2060 mm from the IP for the incoming beam)
- The use of tungsten shielding around the mask is projected.
- Synrad+ simulations are also in progress for possible additional or alternative solutions with absorbers

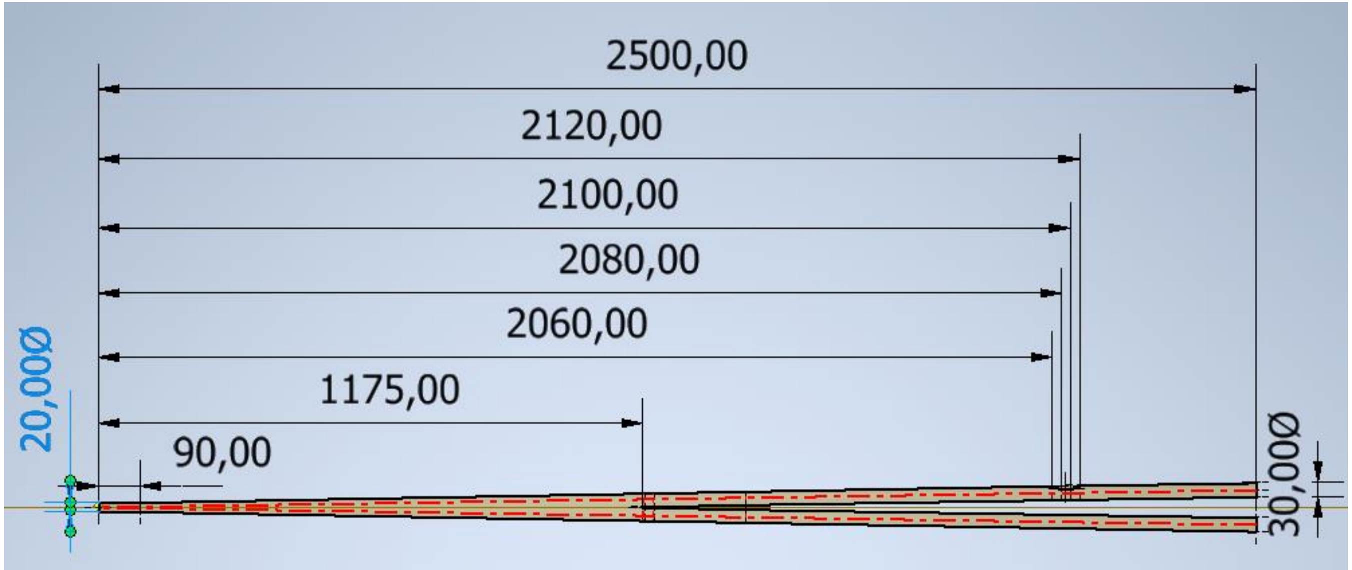






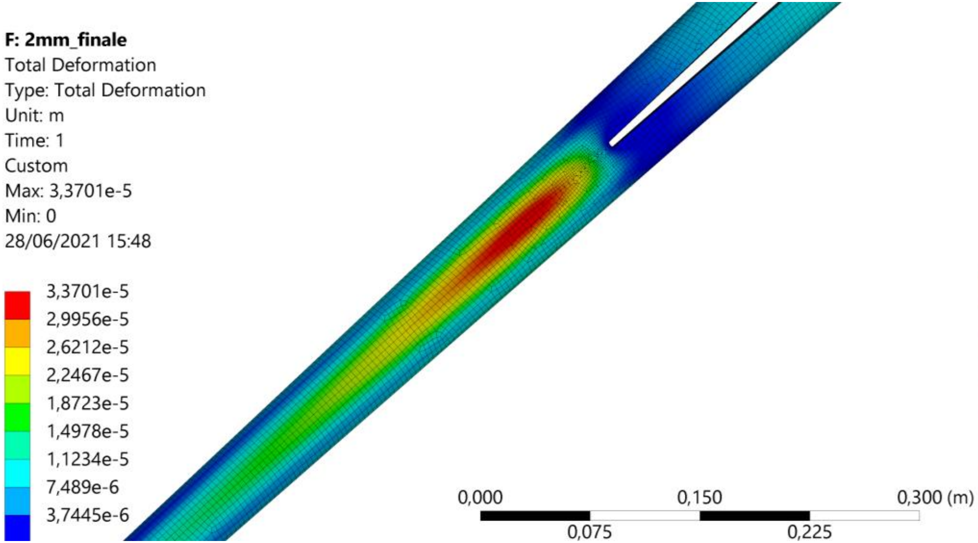
Structural analysis of the vacuum chamber

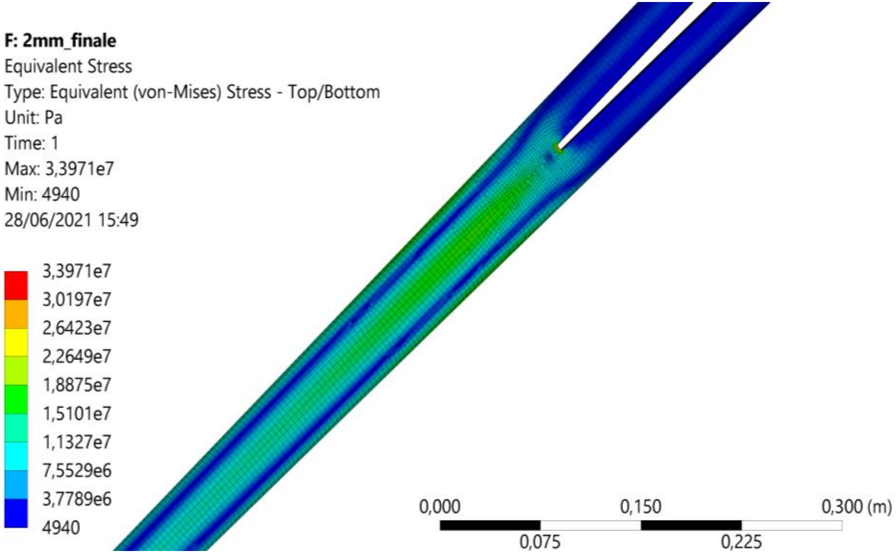
- Thickness of AlBeMet162= 0.35 mm
- Thickness of Copper= parametric design from 1 to 5 mm



Physical Properties	AlBeMet162(central part)	Copper (lateral part)	Unit of measurement
Density	2.10	8.942	g/cm^3
Modulus	193	126	GPa
Poisson's Ratio	0.17	0.345	
Yield Strength	276	250	MPa
Ultimate Strength	386	343	MPa

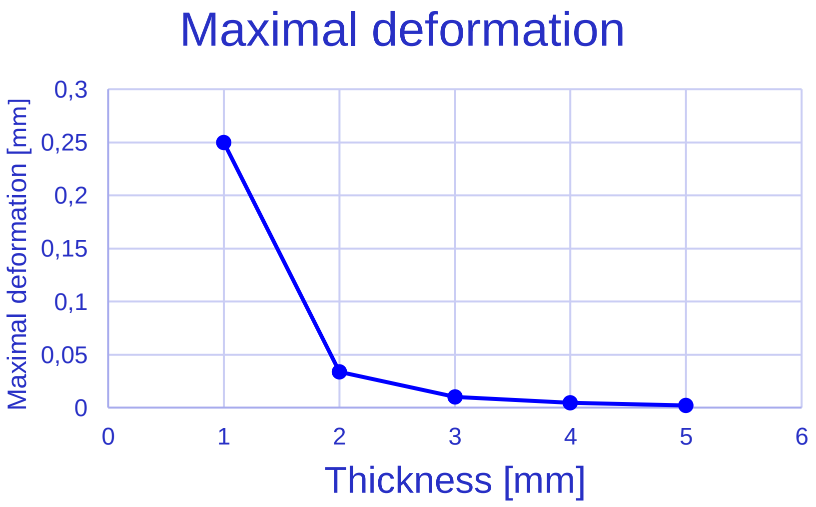
- **LOAD:** atmospheric pressure over the vacuum chamber.
- **CONSTRAINT:** fixed by supports attached to the four extremities.
- **RESULTS:** the stress and strain according to Von Mises theory

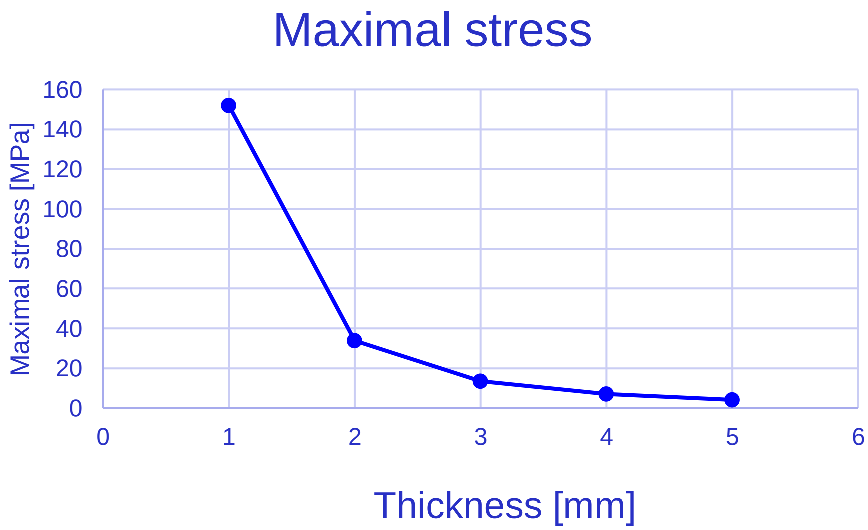




Results:

Thickness of copper [mm]	Max Deformation [mm]	Max Stress [MPa]
1	0.25	152
2	0.0337	33.9
3	0.0103	13.5
4	0.00451	6.97
5	0.00243	4.18





Study of heat removal

System characteristics:

- Paraffin as coolant liquid.
- 1mm gap between the beam pipe and the covering.
- Velocity less than 1 m/s (for laminar flow).
- Heat load of 100 W/m.
- Initial coolant temperature of 20°C

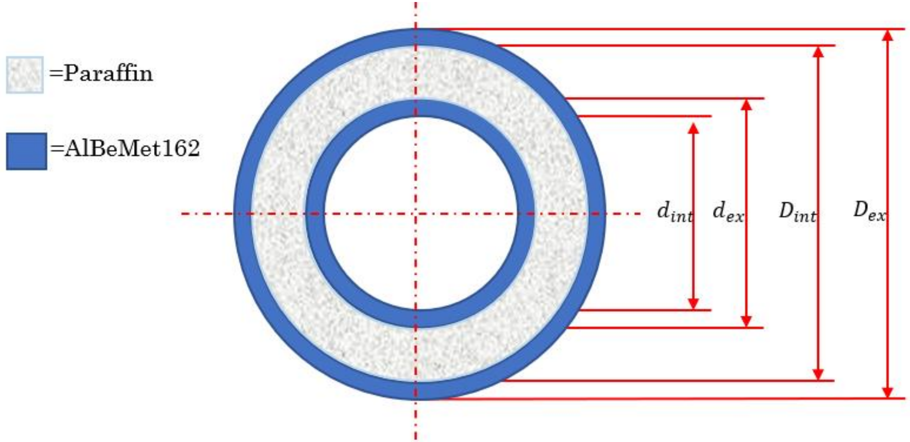
Objectives:

- Temperatures.
- Pressure drop needed for the flow.

Coolant requirements:

- Low viscosity.
- High thermal capacity.
- Coolant must not corrode AlBeMet162

Symbol	Value [mm]	Description
$t_{paraffin}$	1	Thickness of paraffin flow gap
$t_{AlBeMet162}$	0.35	Thickness of the AlBeMet162 wall
D_{ex}	22.4	External diameter of the covering
D_{int}	21.7	Internal diameter of the covering
d_{ex}	20.7	External diameter of the beam pipe
d_{int}	20	Internal diameter of the beam pipe
L	180	Length of the exchanger



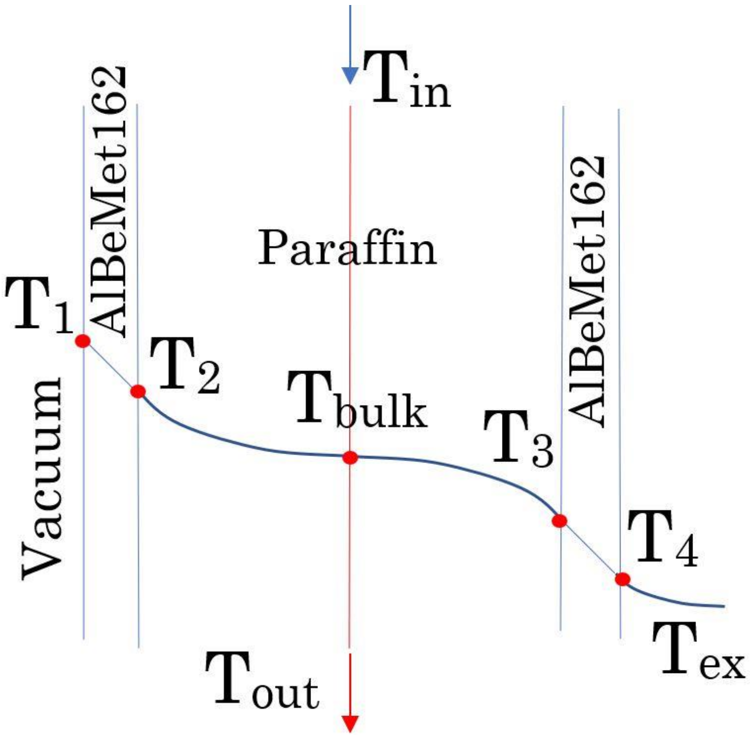
Used fluid: Paraffin ($C_{10}H_{22}$)

Property	Value	Unit of measurement
Density @ 25ºC	0.734	g/cm^3
Specific Heat @ 20˚C	2.21	J/gK
Thermal conductivity	0.34	W/m°C
Kinematic viscosity @ 30˚C	1.1	mm^2/s
Dynamic viscosity @ 20˚C	0,92	mPa·s
Melting point	-27.9	˚C
Boiling point	174.1	˚C
Autoignition temperature	210	°C
Flash point	51	˚C

Thermal calculation

It is possible to create a thermal diagram for the system.
The following schema is a longitudinal section along the pipe's axis, showing the temperature's trend.

- Due to AlBeMet162's thinness and its high rate of conduction, it is possible to set T_1=T_2 and T_3=T_4
- The preliminary study assumes that:
  $T_{bulk} = \frac{T_{in}+T_{out}}{2}$
- If the heat transfer with the external environment is ignored, it is possible to analyse only half of the temperature diagram



This study uses two fluid velocity values; to reduce the pressure drop the two velocity values are taken to remain in the laminar regime:

$$D_{eq} = 4\frac{A_{flow}}{p_{wet}} \Rightarrow Re = \frac{vD_{eq}}{\nu}$$

$$\dot{m} = \rho v S$$

Velocity [m/s]	Re	Flow rate [kg/s]	Flow rate [l/min]
0.2	363.6	0.005	0.41
0.5	909.1	0.012	0.980

Now it is possible to express the heat transfer from the paraffin side, in terms of convection and temperature trend. The heat that the paraffin receives from the convection causes the temperature increase from the paraffin's entry to its exit.

From diagram

1 $\dot{q}_{experiment} = \dot{m}c_p(T_{out} - T_{in})$ $\quad h = \frac{Nu * k}{D_{eq}} = 903.9\ \frac{W}{m^2K}$

2 $\dot{q}_{experiment} = hA(T_2 - T_{bulk})$

- D_{eq} : equivalent diameter
- ν: kinematic viscosity
- h: convective heat transfer coefficient
- $A = 2\pi r_{ex}\ L$: convective area

The following formula is used for the pressure drop calculation:

From diagram

3 $\Delta p = f\frac{L}{D_{eq}}\frac{v^2}{2}\rho$

1+2+3 ⇒

Temperature	V=0.2 m/s	V=0.5 m/s
T_{out}°]C]	21.63	20.679
T_{bulk}°]C]	20.81	20.34
T_2°]C]	22.5	22.04
Δp	$31.71\ kPa$	$192\ kPa$

Conclusion for the heat removal:

- With a **flow rate** of **0.41 l/m**, **initial paraffin temperature** of **20°C** and a pressure drop of $\mathbf{31.71\ kPa}$ it is possible to maintain the chamber wall temperature at **22.5 °C**
- With a **flow rate** of **0.98 l/m**, **initial paraffin temperature** of **20°C** and a **pressure drop** of $\mathbf{192\ kPa}$ it is possible to maintain the chamber wall temperature at **22.04 °C**

These results are consistent with those of SuperKEKB (*thanks to K. Kanazawa*)

Future steps

- **Progress with the mechanical assembly:** adding the main components as they are provided by the different systems experts
- Input the components' weight to design the **supports** and start the structural studies.
- Study the **transition** from AlBeMet162 to the copper
- Introduce the **bellows** to design a functional chamber
- Space for the alignment system to fulfill the stringent requirement
- Define the **integration** strategy

THANK YOU FOR YOUR ATTENTION.

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