PANDA 17/2 Collaboration Meeting
08.06.2017

BWEC Cooling shell design

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O. Noll, D. Rodríguez Piñeiro, S. Wolf

Contents

Overview

What is our aim?

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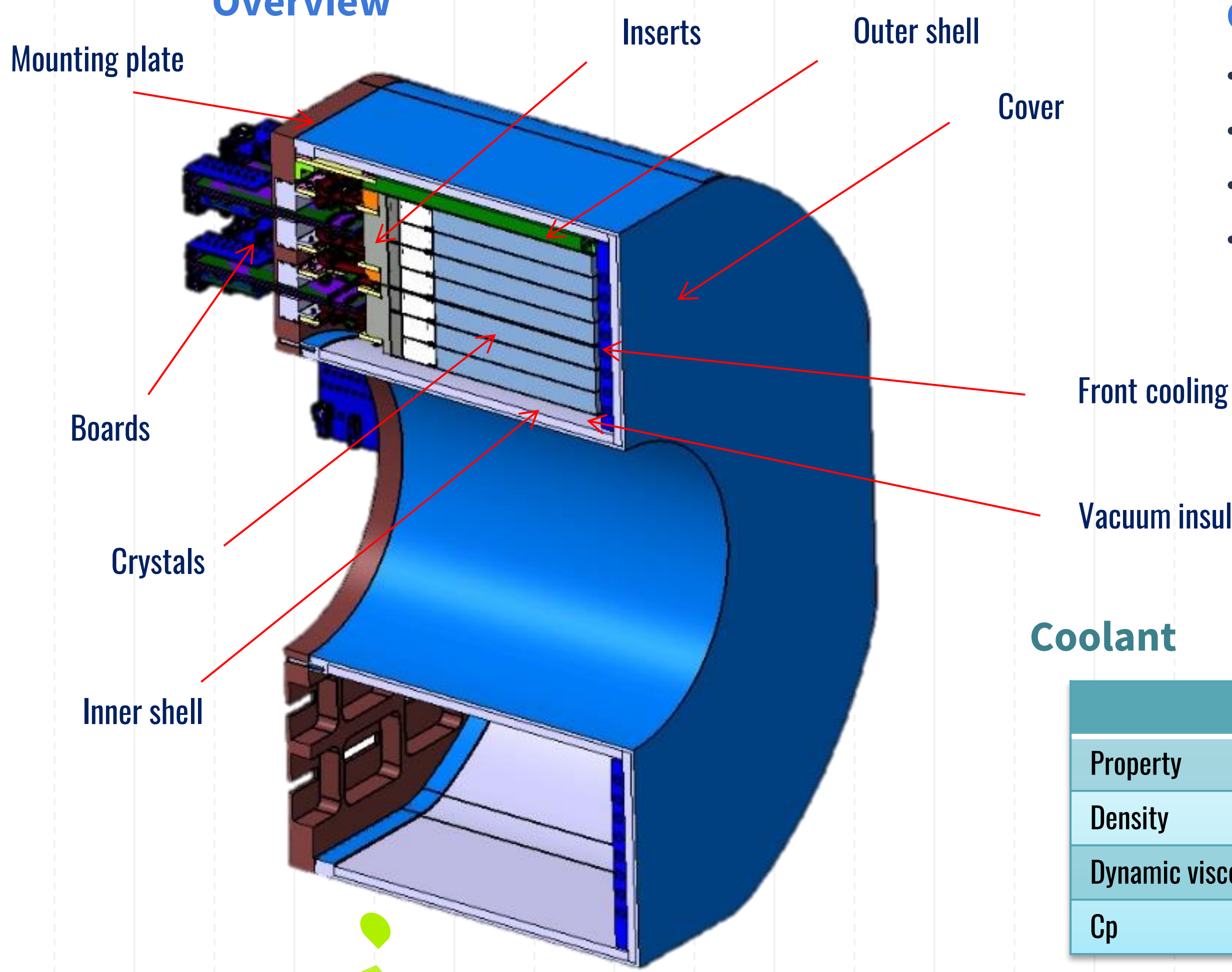
Overview

Overview



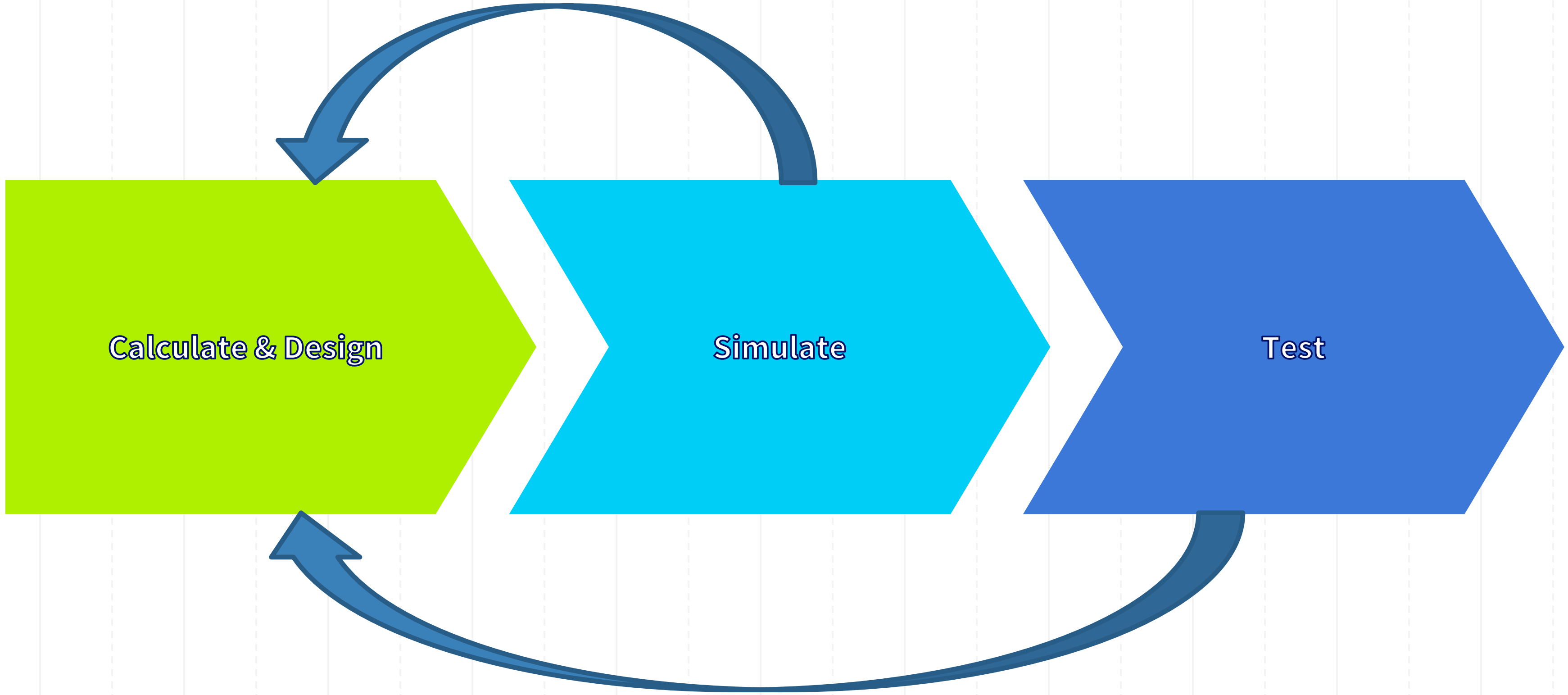
Cooling requirements

- Work at -25°C
- Maximum 500 mbar pressure drop (leakless-mode)
- Limited space
- Low temperature gradient

Coolant

Methanol 60% Water 40%		
Property	Value	Units
Density	930	kg/m3
Dynamic viscosity	0.0077	kg/s/m
Cp	3151	J/kg/K

THE PROCESS IS THIS



Calculations

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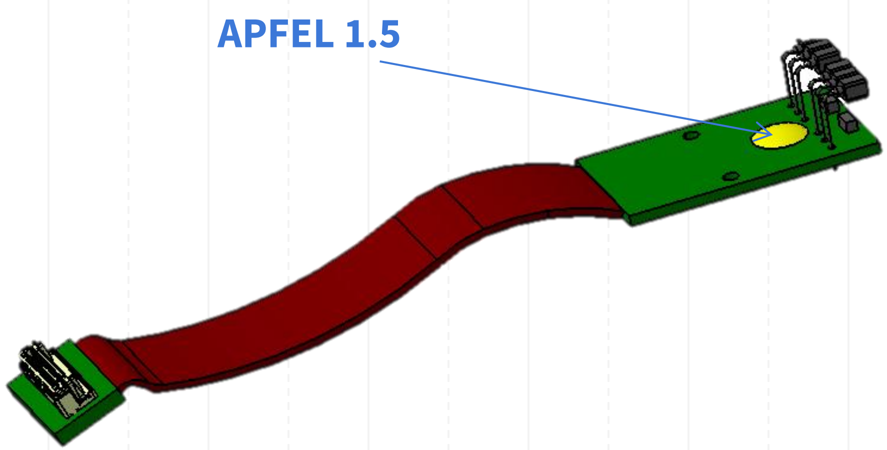
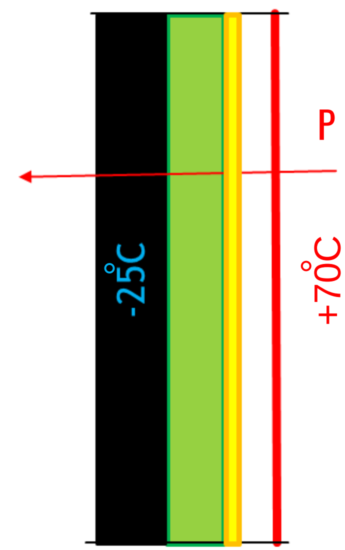
Thermal and fluid mechanics calculations of the cooling shells

Thermal calculations

Heat sources

- Electronics
- Heat flow through the walls
- Power to cool down

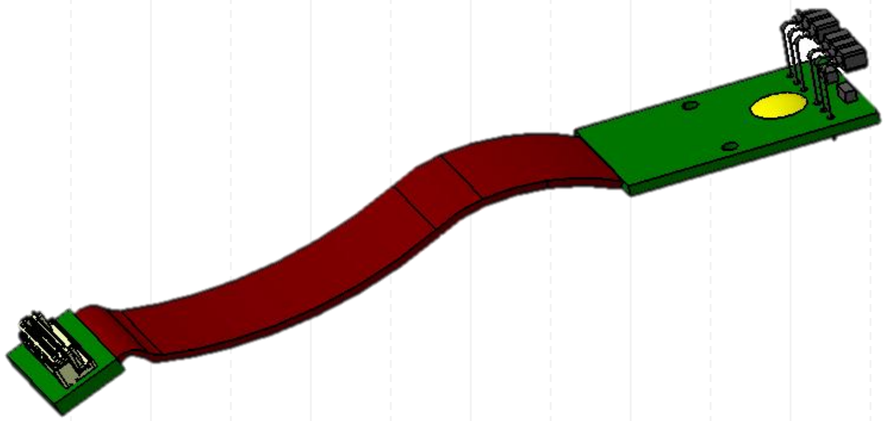




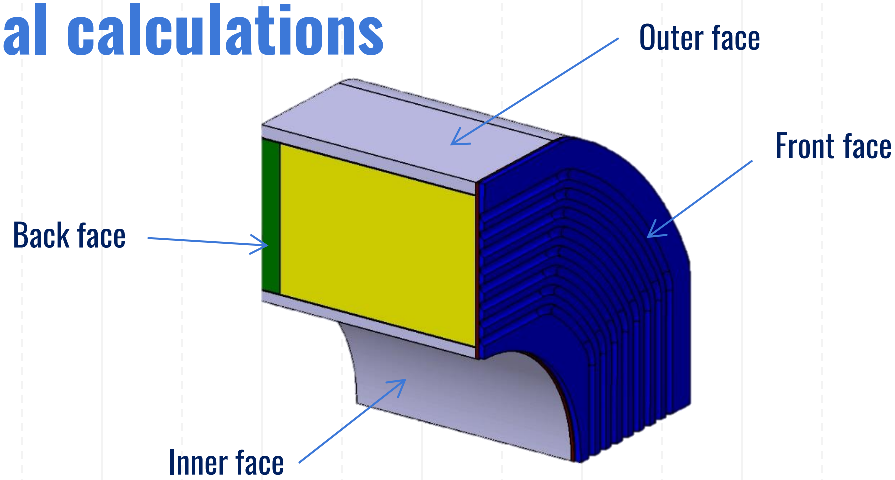
Thermal calculations

Electronics

- 150 mW/crystal * 524 crystals =78.60 W
- Applied in back side of crystals
- Cables out of the detector are not taken into account



Thermal calculations



Heat flow through walls

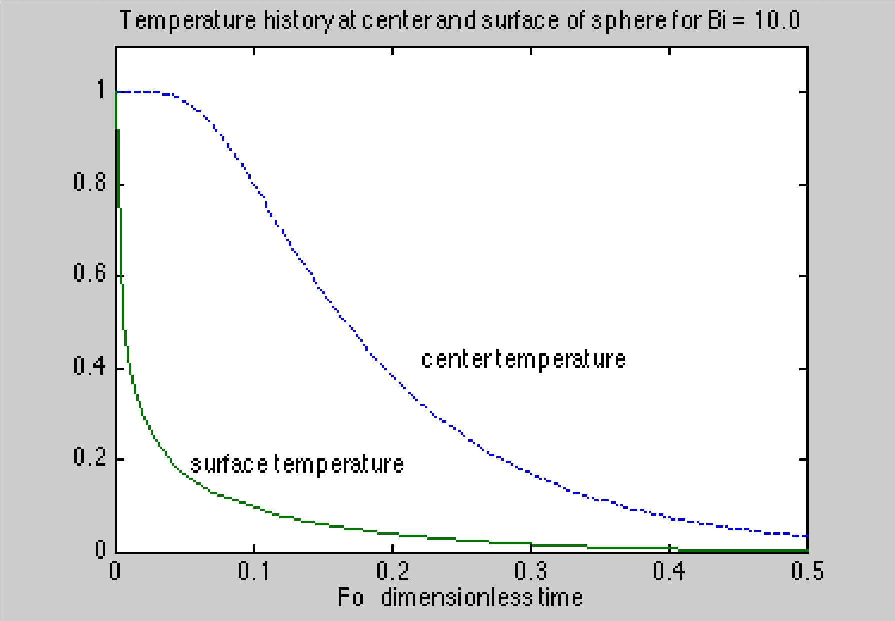
Worst case at 70°C surrounding temperature

Source	Value [W]
Outer face	40.23
Inner face	17.25
Front face	16.63
Back face	18.59
Radiation	27.92

Thermal calculations

Power to cool down

- Constant cooling flow
- Initial temperature 30°C
- Final temperature -25°C
- Time 24 h



$$P = \frac{m \cdot C_p \cdot \Delta T}{t} = \frac{0{,}06\, m^3 \cdot \frac{8280\, kg}{m^3} \cdot \frac{262\, J}{kg} \cdot (55°C)}{24\, h \cdot 3600\, s} = \mathbf{83.00\ W}$$

Summary of heat sources

Stationary		Transient	
Source	Value [W]	Source	Value [W]
Outer face	40.23	Outer face	40.23
Inner face	17.25	Inner face	17.25
Front face	16.63	Front face	16.63
Back face	18.59	Back face	18.59
Radiation	27.92	Radiation	27.92
Electronics	78.60	Cooling down	83.00
Total	**199.30**	**Total**	**203.70**
Total*1.5	**298.95**	**Total*1.5**	**305.98**

Safety factor 1.5

Thermal calculations

Mass flow calculation

- 0.3 °C between inlet and outlet (homogeneity)

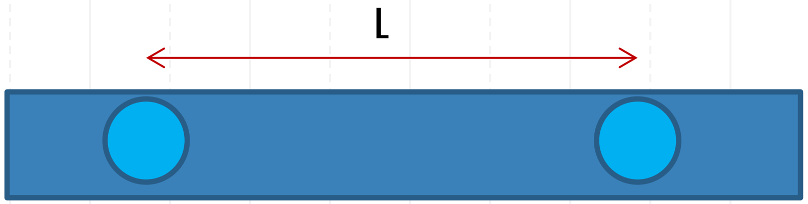
$$\dot{m} = \frac{P}{C_p \cdot \Delta T} = \frac{0.3237kg}{s} \rightarrow \frac{20.88l}{min}$$

- 2 outer shells and 2 inner shells
- **Outer shell 7.34 l/min**
- **Inner shell 3.10 l/min**

Distance between pipes

- 0.25 °C max temperature difference (homogeneity)
- 15 mm thickness

$$\frac{PL^2}{8 \cdot k \cdot t} = \Delta T \rightarrow L = \sqrt{\frac{8\Delta Tkt}{P}}$$

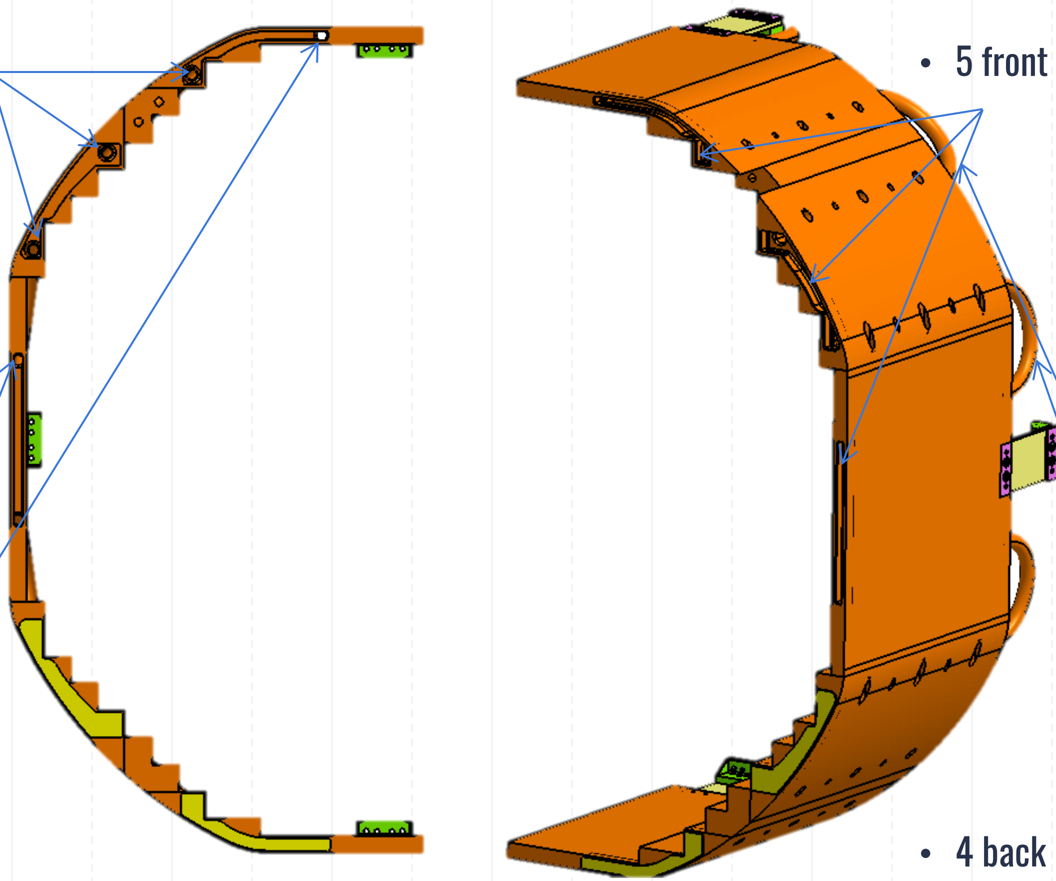


- **L= 150 mm**

Fluid mechanics calculations
(Half outer shell)

Outer shell parts

- 6 pipes → d = 13 mm
- 4 pipes → d = 10 mm



- 5 front square connectors
- 4 back elbow connectors

Fluid mechanics calculations

Pipe with d = 10 mm

$$\Delta p = \frac{8Q^2}{\pi^2}\left(f\frac{L}{D^5}\right)\rho = 11.37mbar$$

Elbow of d = 10 mm

$$\Delta p = \frac{8Q^2}{\pi^2}\left(f\frac{L+L_{eq}}{D^5}\right)\rho = 21.05\, mbar$$

Pipe with d = 13 mm

$$\Delta p = \frac{8Q^2}{\pi^2}\left(f\frac{L}{D^5}\right)\rho = 3.99\, mbar$$

Square connector (estimation)

$$\Delta p = \frac{8Q^2}{\pi^2}\left(f\frac{L+L_{eq}}{D^5}\right)\rho = 27.60\, mbar$$

Fluid mechanics calculations summary

Part	Pressure drop (mbar)	Amount	Total Pd (mbar)
Straight d =13 mm	3.99	6	23.94
Straight d = 10 mm	11.37	4	45.48
Elbow d = 10 mm	21.05	4	84.20
Square connectors	27.60	5	138.00
Total	**291.62 mbar**		

$$291.62mbar < 500mbar$$

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3D design

An overview of the outer shell 3D design

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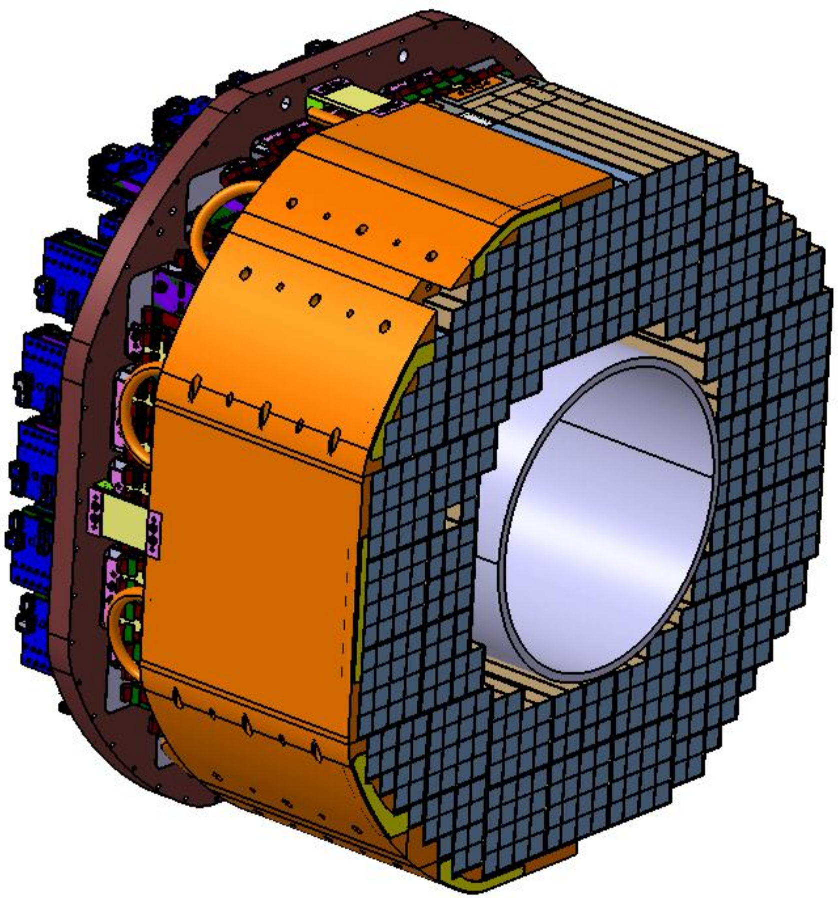
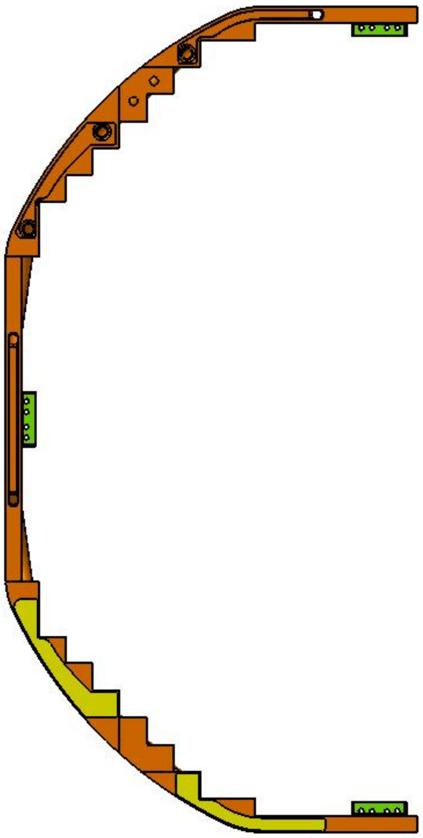
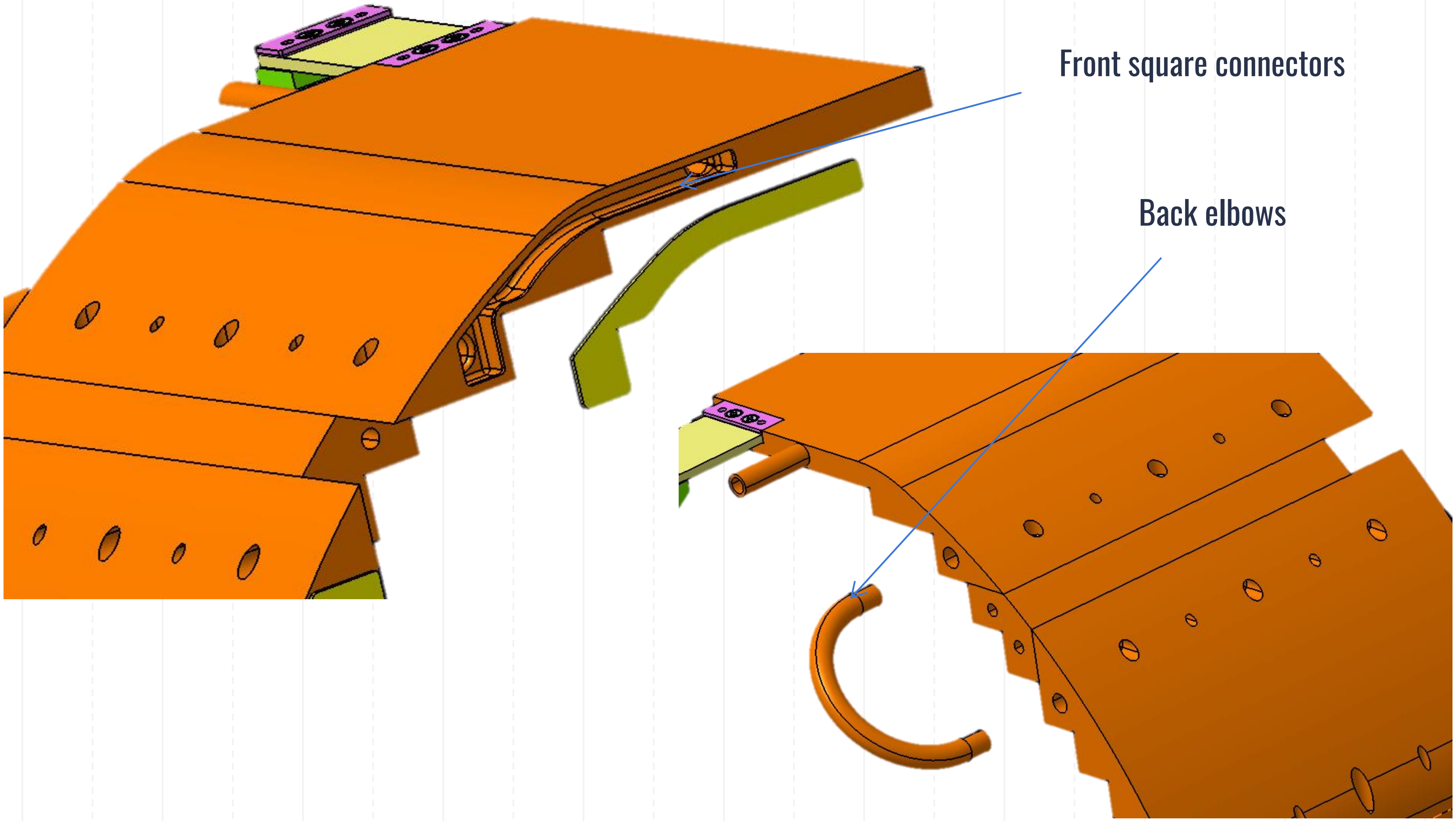
3D design





3D design



Simulations

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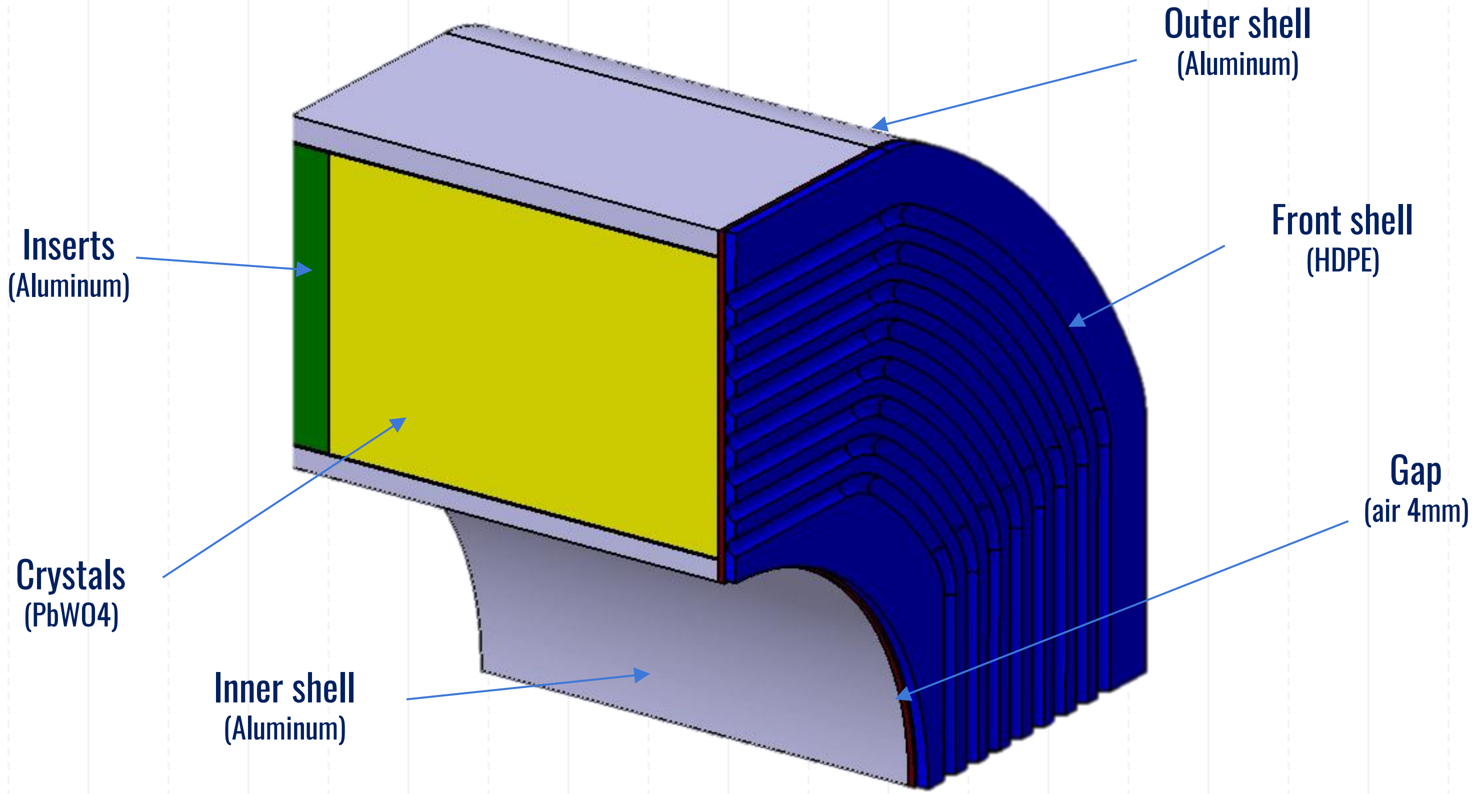
Thermal and fluid mechanics simulations
Autodesk Simulation Mechanical & Autodesk CFD 2016

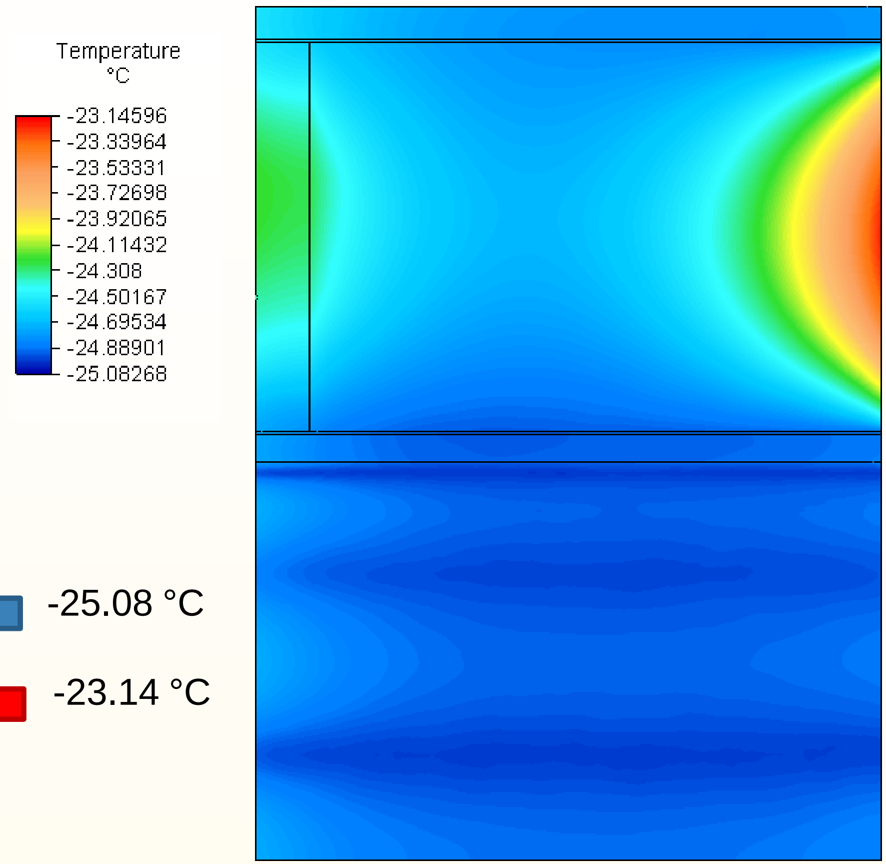
Thermal simulations



1 quarter dummy for simulations

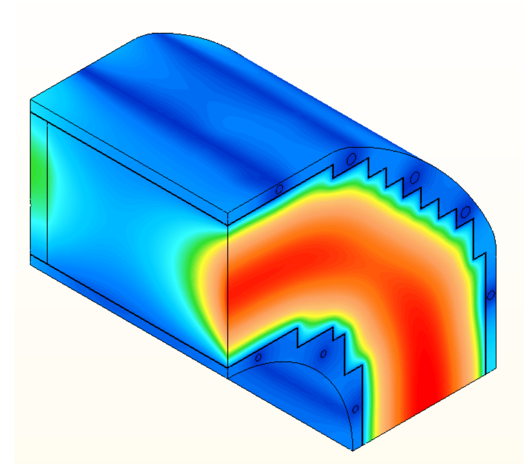
Thermal simulations

Only outer and inner shells



-25.08 °C

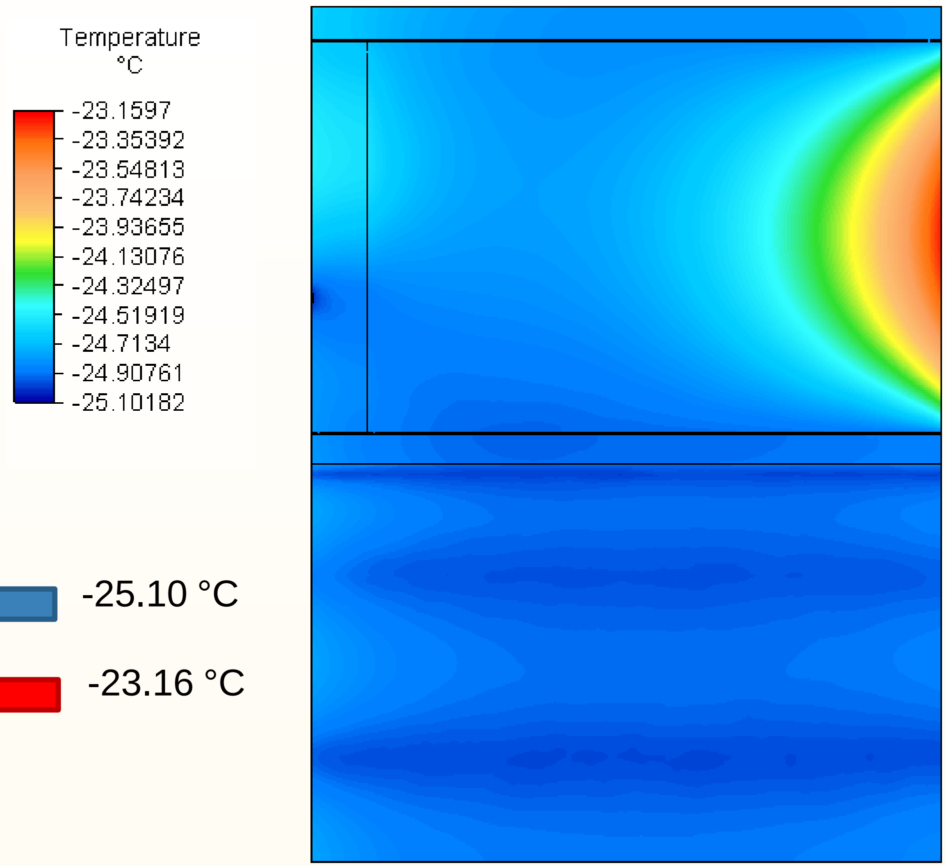
-23.14 °C

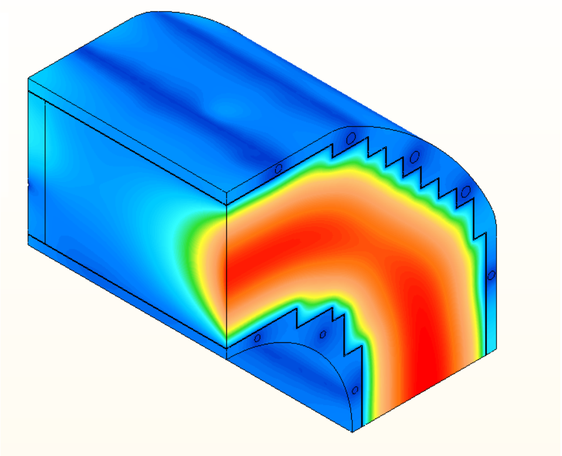


- Not front shielding
- 2°C gradient

Thermal simulations

Back pipe with both inner and outer shells





-25.10 °C

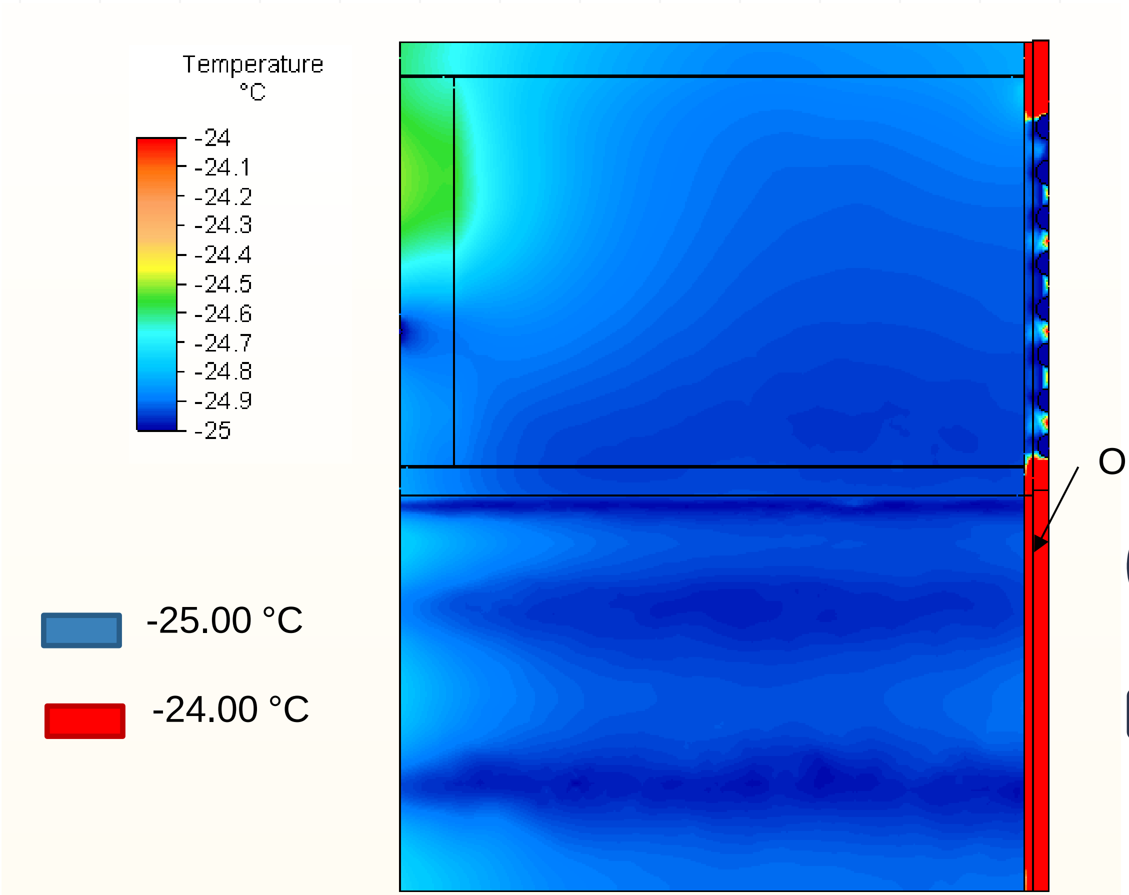
-23.16 °C

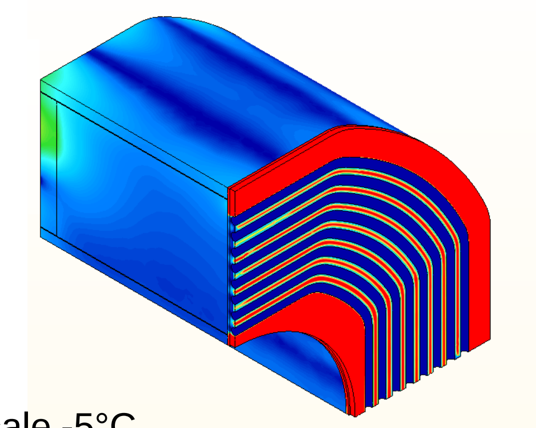
- Back homogeneity

- Not front shielding
- 2°C gradient

Thermal simulations

Front shell, back pipe and both inner and outer shells





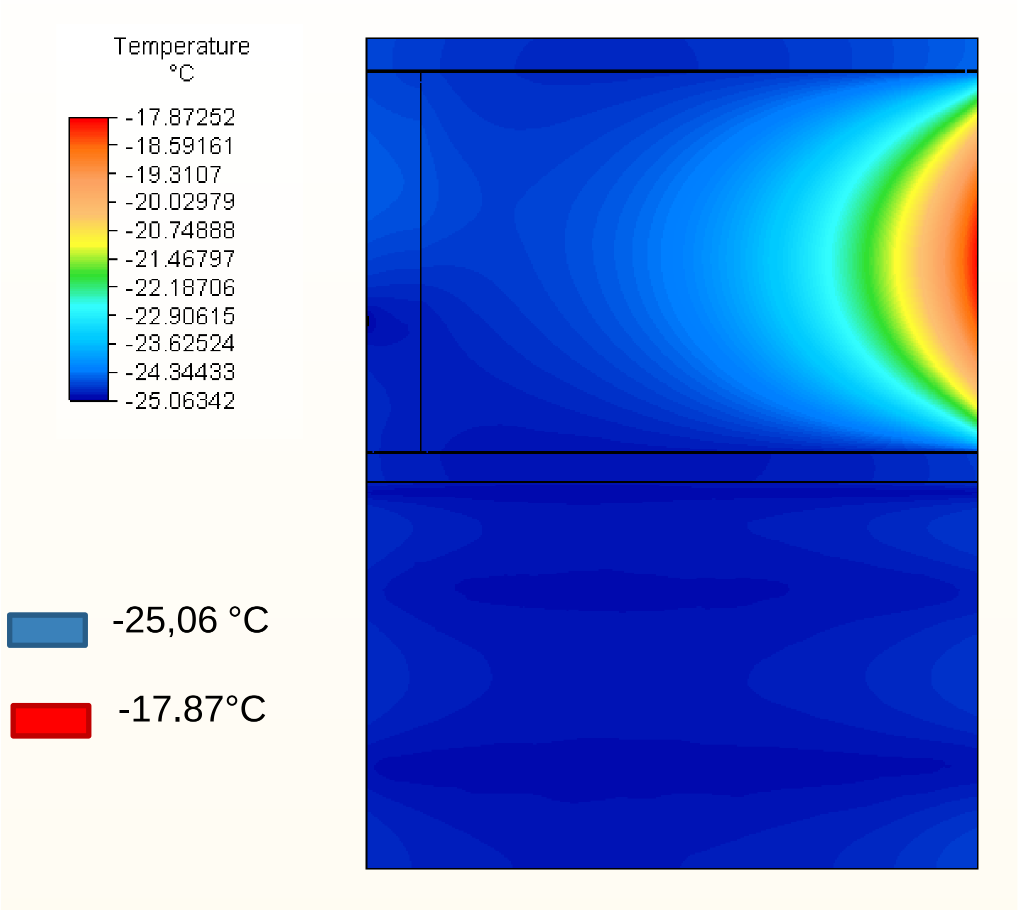
Out of scale -5°C

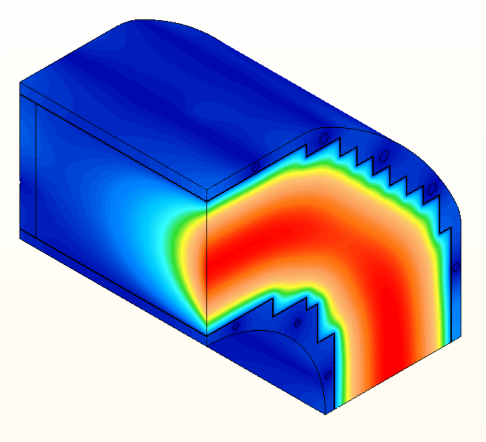
✔
- Front shielding
- Less than 0.5°C gradient

✖
- Solid angle loss (further for the IP)

Thermal simulations

Possible 140W (STT worst elect. case) front without front cooling

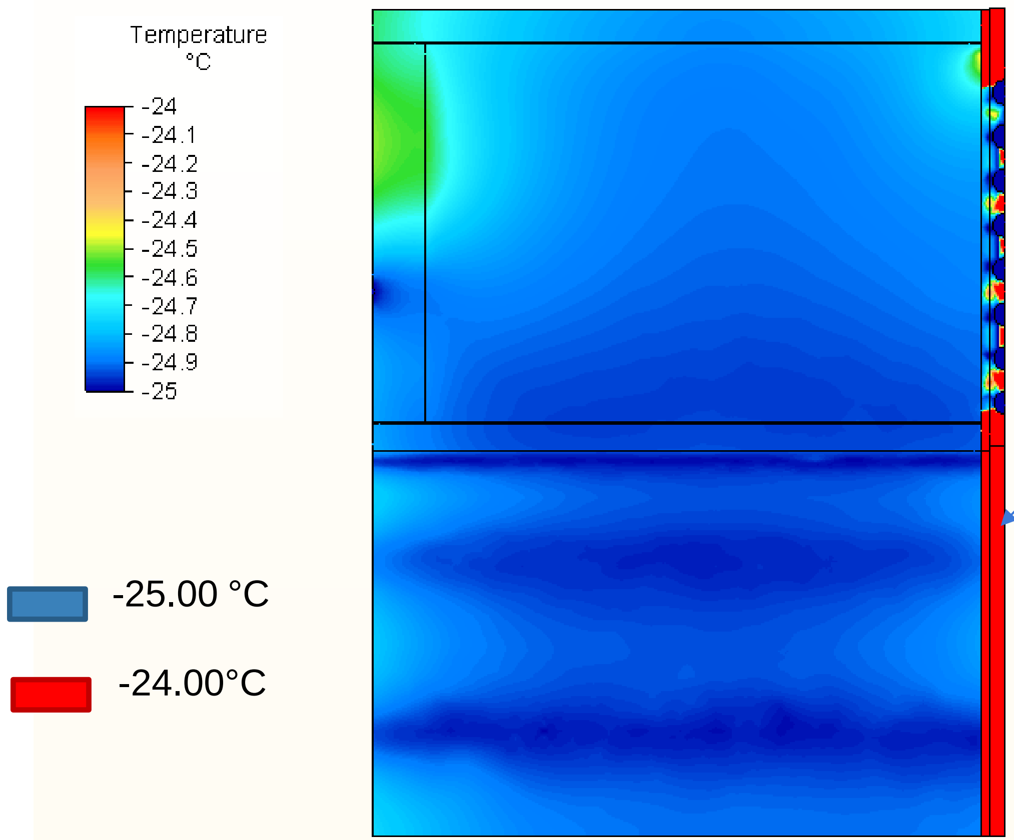


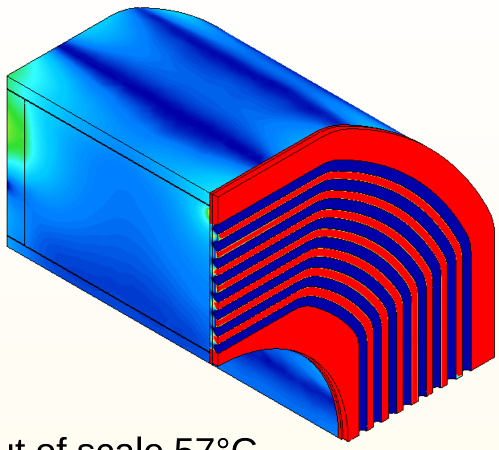


- Huge temperature gradient (7.13°C)

Thermal simulations

Possible 140W (STT worst elect. case) front with front cooling





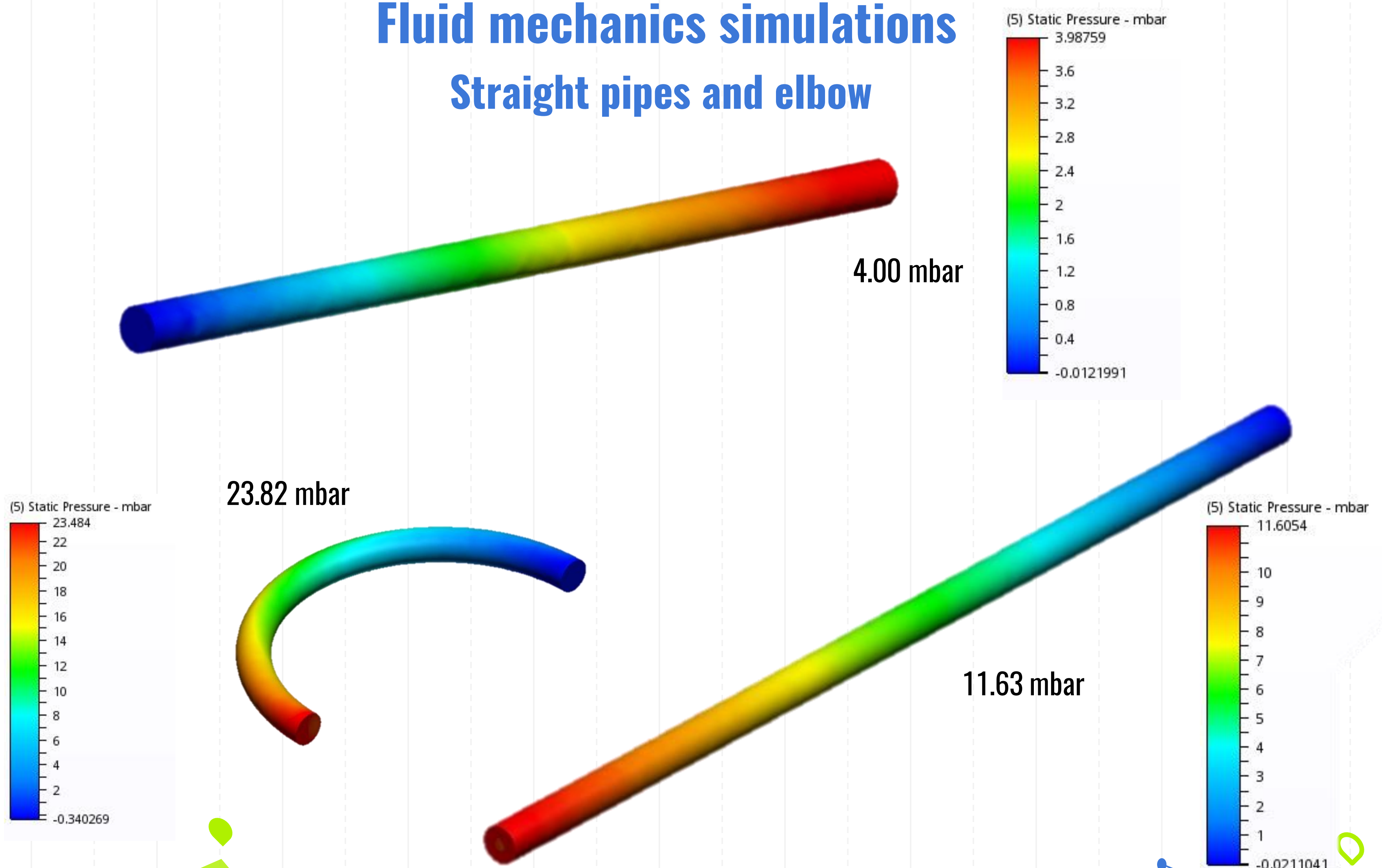
Out of scale 57°C

- Good front protection
- Less than 0.5°C gradient

- Solid angle loss (further from the IP)

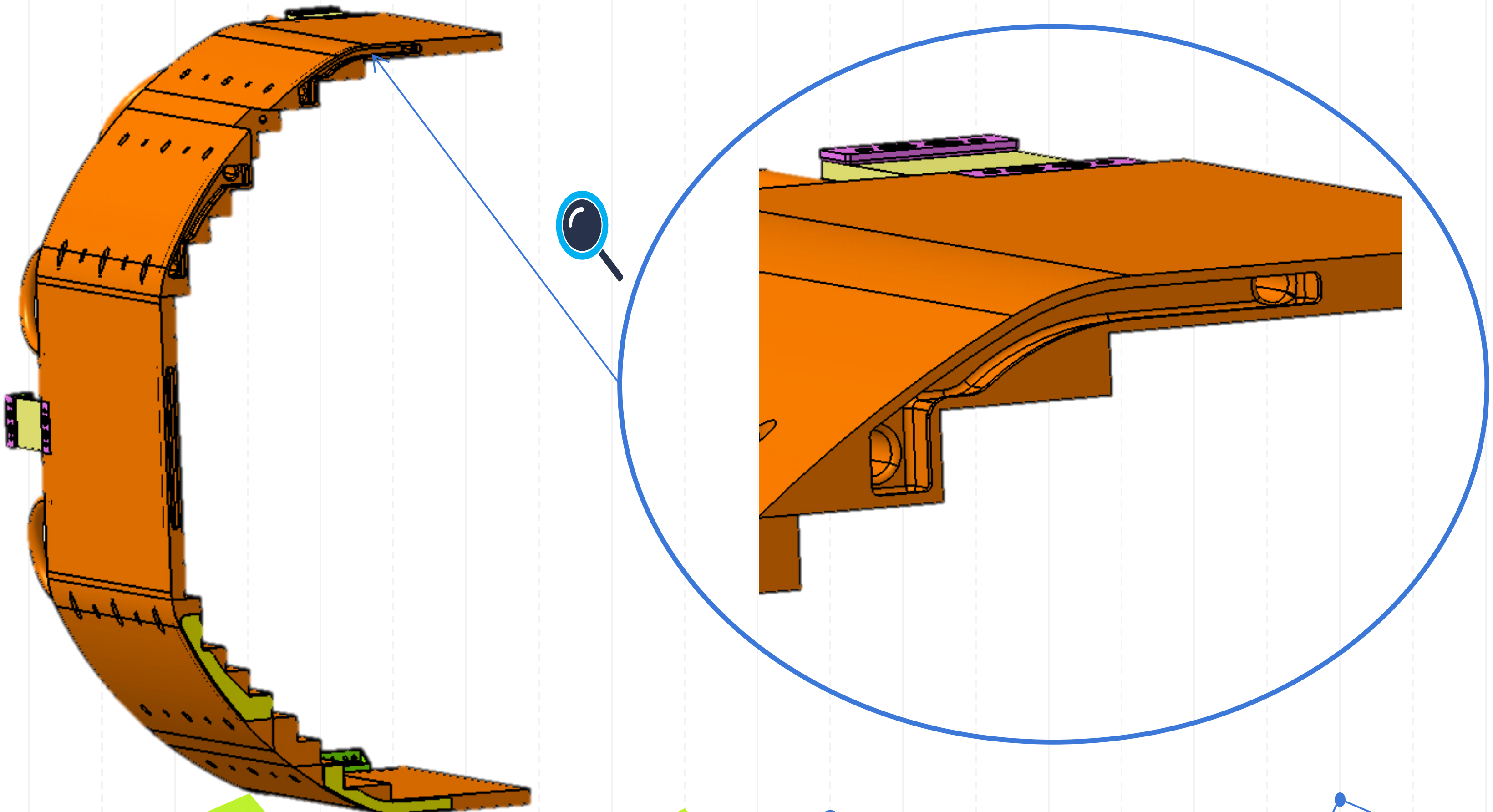
Fluid mechanics simulations

Straight pipes and elbow



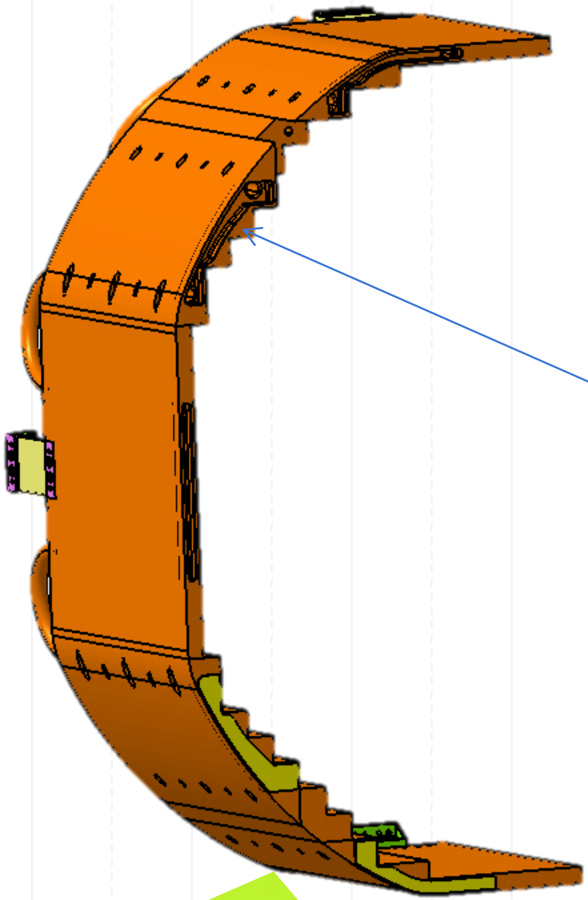
Fluid mechanics simulations

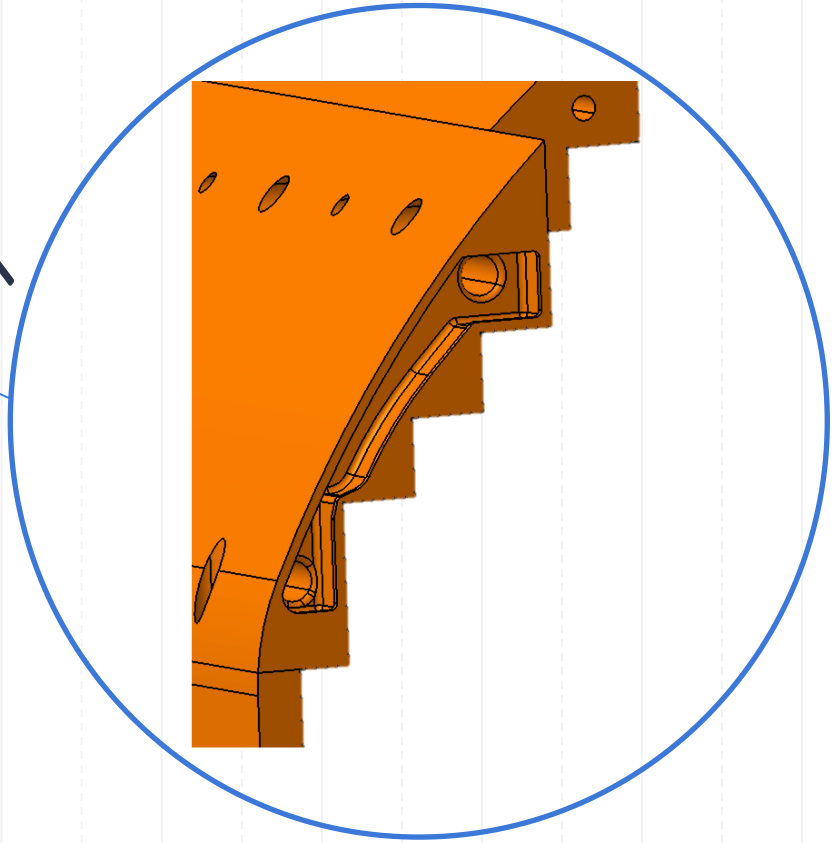
Front square connectors



Fluid mechanics simulations

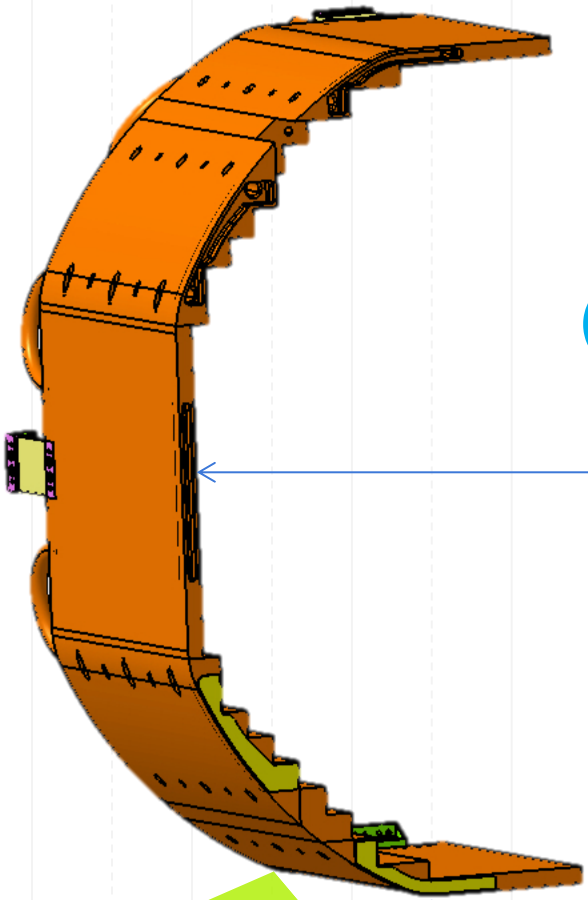
Front square connectors

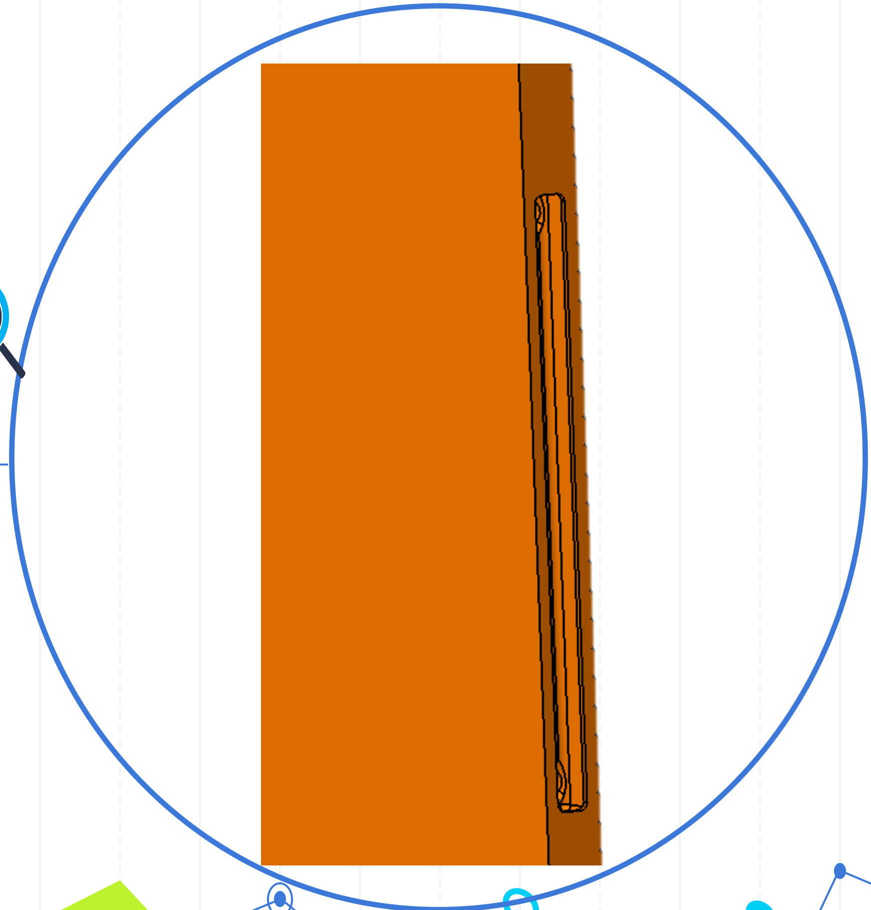




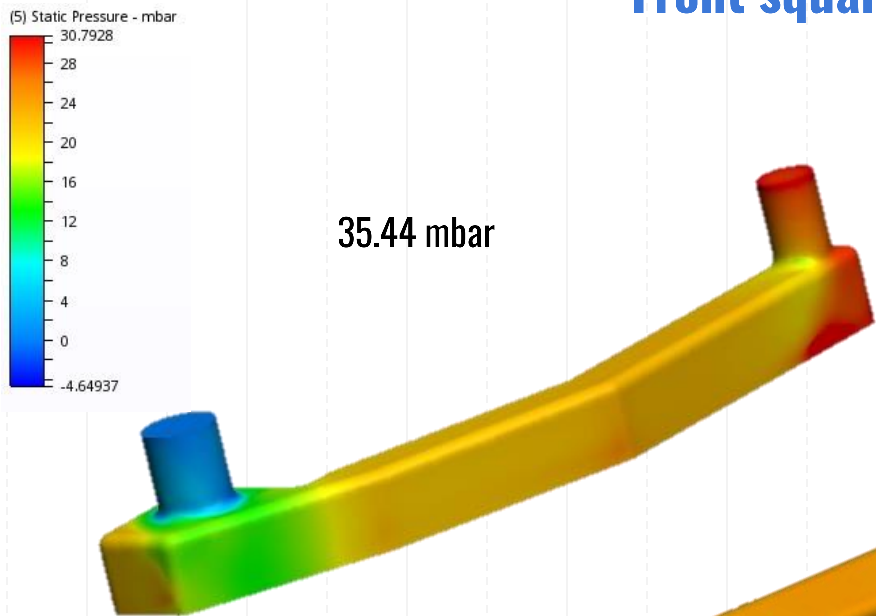
Fluid mechanics simulations

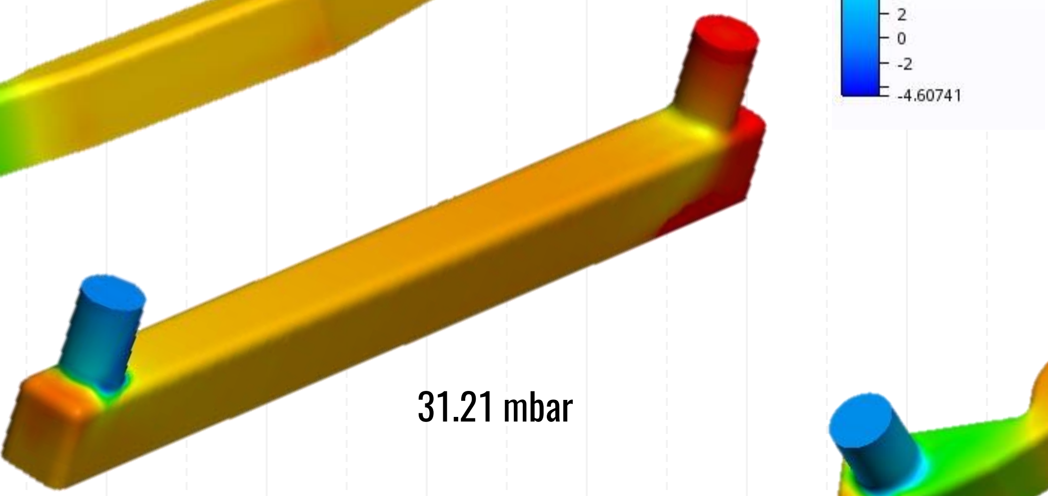
Front square connectors

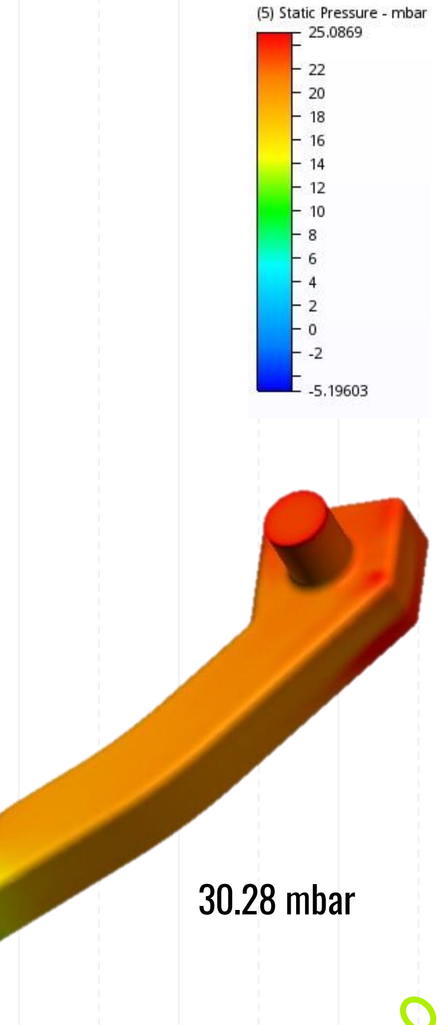




Fluid mechanics simulations
Front square connectors







Fluid mechanics simulations
Summary

Part	Pressure drop/part(mbar)	Amount	Total Pd (mbar)
Straight d = 10 mm	11.63	4	46.52
Straight d = 13 mm	4.00	6	24.00
Elbow d = 10 mm	23.82	4	95.28
Square conn 1	35.44	2	70.88
Square conn 2	31.21	2	62.42
Square conn 3	30.28	1	30.28
Total	**329.38 mbar**		

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PANDA

Fluid mechanics calculations vs. simulations

Part	Pressure drop (mbar)	Amount	Total Pd (mbar)
Straight d =10 mm	11.37	4	45.48
Straight d = 13 mm	3.99	6	23.94
Elbow d = 10 mm	21.05	4	84.20
Square conn 1	27.60	2	55.20
Square conn 2	27.60	2	55.20
Square conn 3	27.60	1	27.60
Total	**291.62 mbar**		

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Elbow d = 10 mm	23.82	4	95.28
Square conn 1	35.44	2	70.88
Square conn 2	31.21	2	62.42
Square conn 3	30.28	1	30.28
Total	**329.38 mbar**		

Summary and future works

What is next?

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Summary

- Less than 0.3ºC of gradient in the coolant temperature
- Good homogeneity with front cooling
- Low pressure drop:

Calculations	Simulation
291.62 mbar	329.38 mbar

- Different pressure drop values because of the square parts (simplifications in calculations for complex geometry)

Future works

- Building an outer shell prototype (on process)
- Make measurements for validating calculations and simulations
- Tests for front cooling with existing prototype (on process)
- Design inner shell with the same procedure

THANKS!

Any questions?

You can write me
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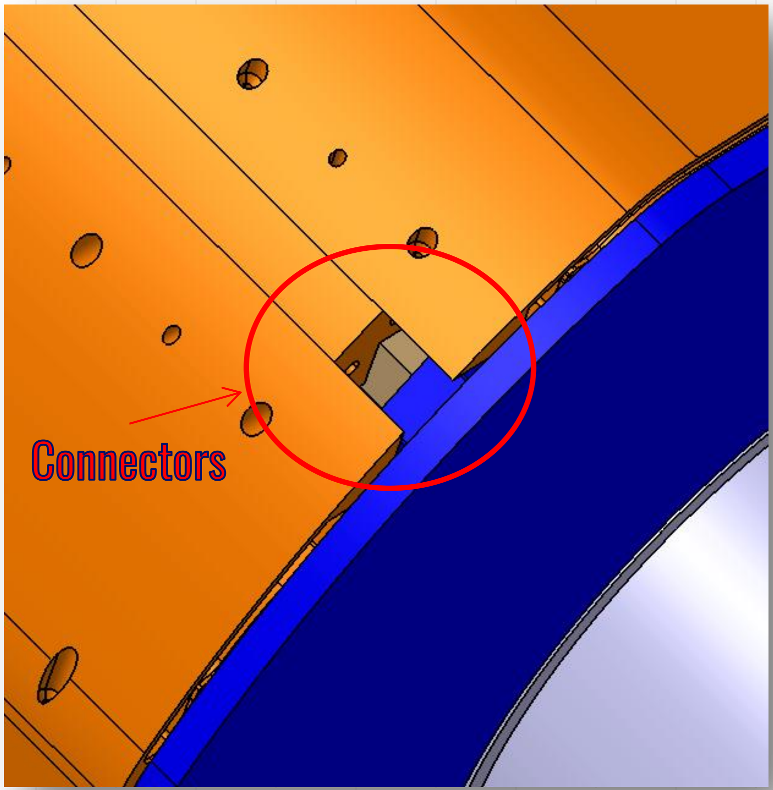
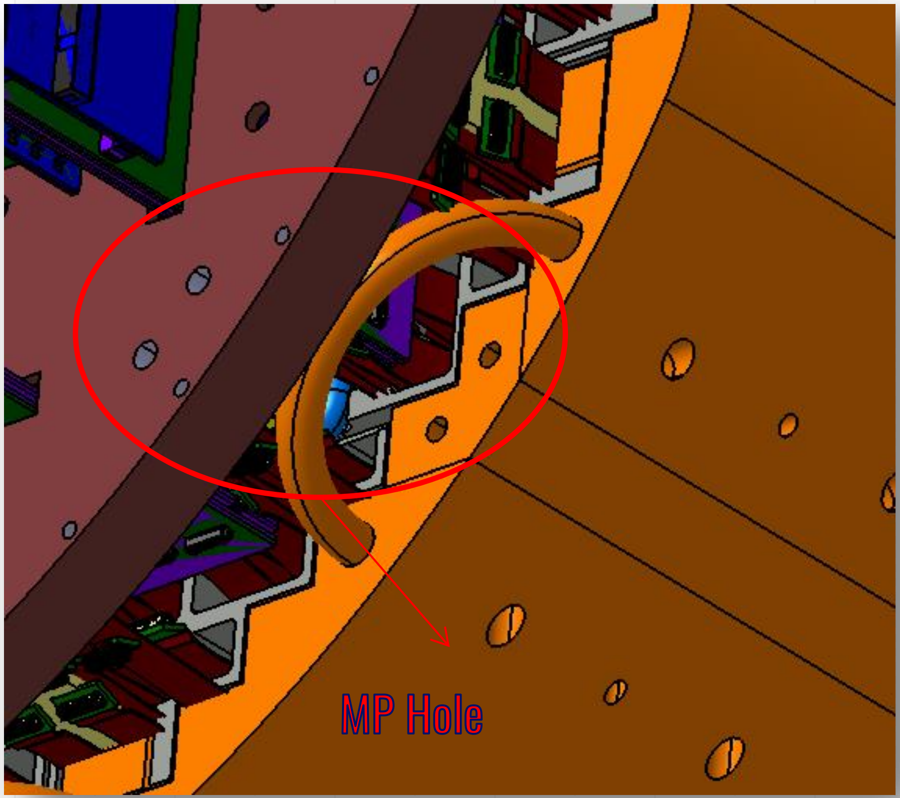
Back Up slides

Front cooling

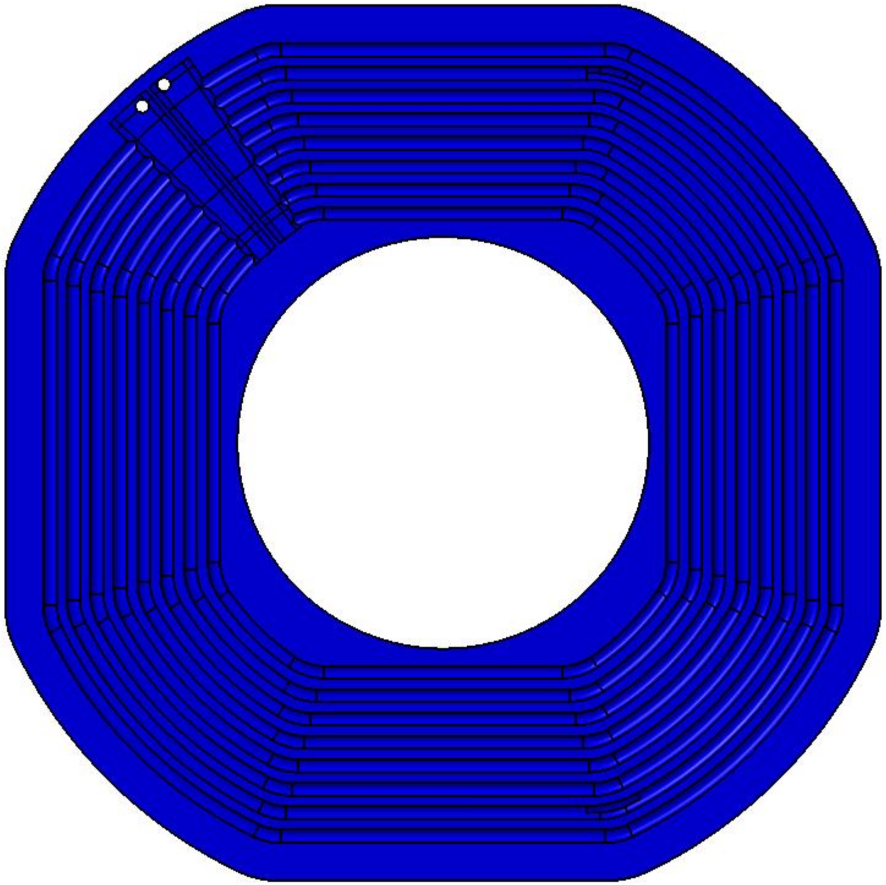
Preparation in Outer shell and MP





Front cooling

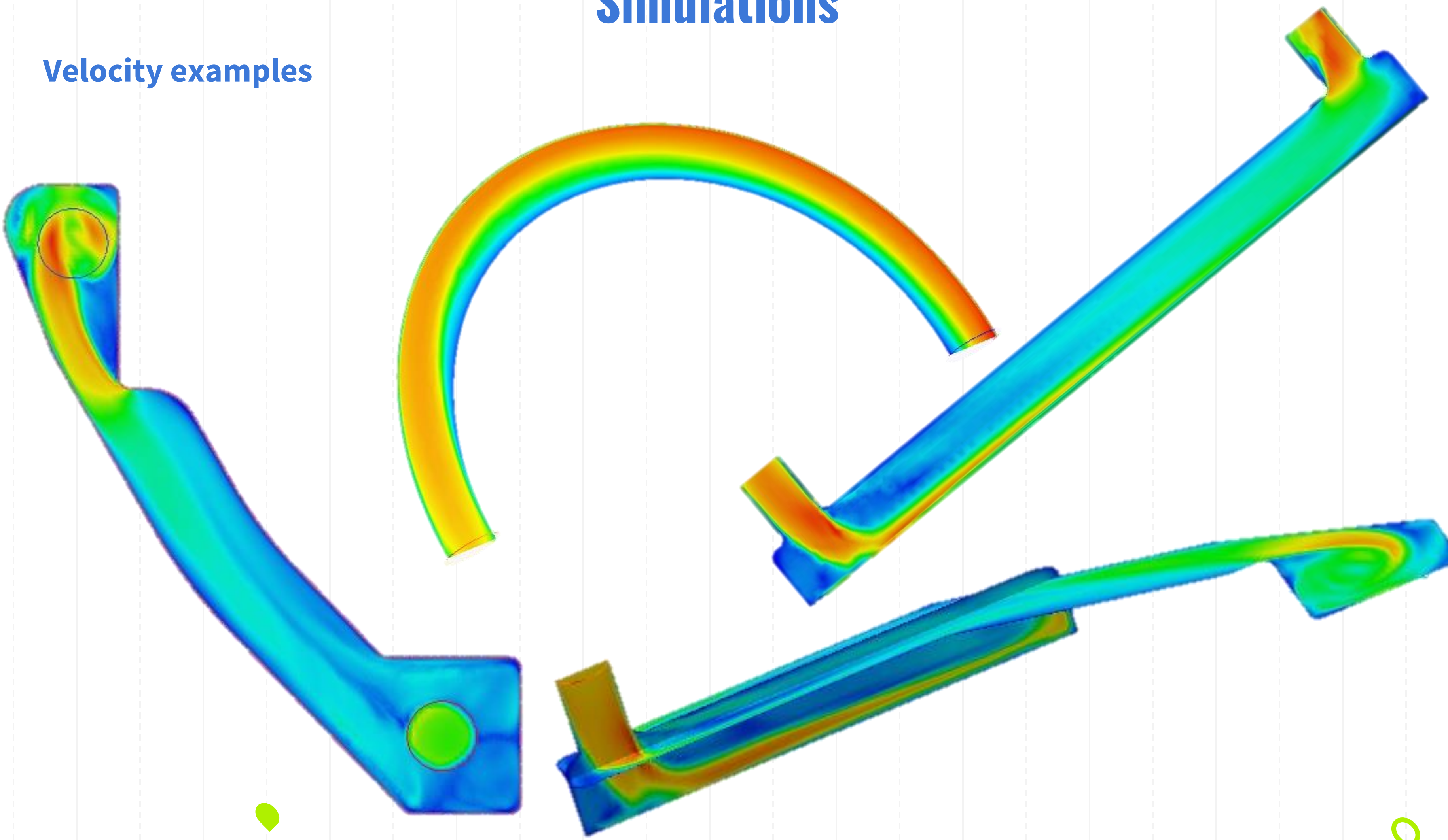
Preliminary design



- Parallel circuits (low pressure drop)
- Different diameter each branch (homogeneity)
- 3D printed (HDPE)

Simulations

Velocity examples



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Thermal calculations

General inputs

Parameter	Value	Units
Round Exterior convection film coefficient (h1)	2,17	W/m2K
Round Exterior convection film coefficient (h2)	2,28	W/m2K
Front Face convection film coefficient (h3)	1,55	W/m2K
Conductivity VIP	0,005	W/m°C
Counductivity aluminum	154	W/m°C
Total BWEC Lenght (depth, z)	0,356	m
Conductivity Glass fiber	0,288	W/m°C
Conductivity MP Isolation	0,063	W/m°C
Conductivy plastic electronic cards	0,228	W/m°C
Aluminum emissivity	0,09	
Stainless Stell emissivity	0,85	
Outer temperature	70	°C
Crystal temperature	-25	°C

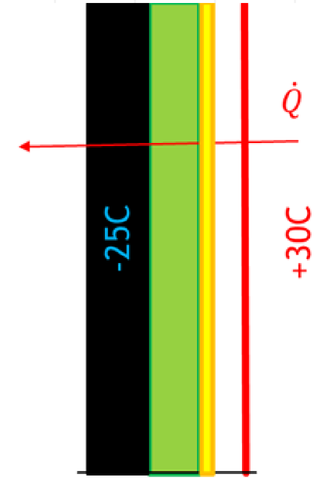
Thermal calculations

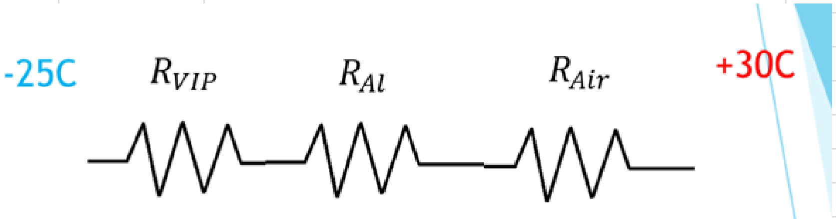
Example

Parameter	Value	Units
Hot temperature	70	°C
Cold temperature	-25	°C
Wall surface	0,463	m^2
VIP thickness	10	mm
Aluminum shell thickness	4	mm
Air gap	5	mm

Spalte1	Spalte2	Spalte3
VIP Resistance	4,319654428	°C/W
Aluminum resistance	5,60994E-05	°C/W
Air convection resistance	1,393436912	°C/W
Total resistance	5,713147439	°C/W
Heat flow	16,62831233	W

Temperature Aluminum sheet end	46,82949581	°C





Thermal calculations

Output summary

Parameter	Value	Units
Total power	305,97	W
Distance between pipes	157,85	mm
Temp in coolant outer shell	-31,16	°C
Tempin coolant inner shell	-30,43	°C
Lower temperature out aluminum	46,83	°C
Lower Temperature in part without shell	59,00	°C
Coolant flow total	20,88	l/min
Coolant flow per outer shell	7,34	l/min
Coolant flow per inner shell	3,10	l/min

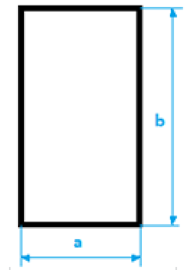
Fluid mechanic calculations

Serial Pressure drop calculator

- Inputs:
  - Coolant
  - Section´s geometry
  - Length
  - Local elements
  - Flow
  - Valve
  - Height

Magnitud	Value	Units
Section shape	Circular	
Flow	7,5	l/min
Pipe hidraulic diameter	13	mm
Total lengh	0,13	m
Pipe rougness	0,01	mm

	0	
	0	



Spalte1	Quantity
NORMAL ELBOWS	
Normal elbow 90°	0
Normal elbow 60°	
Normal elbow 45°	
SHARPED ELBOWS	
Sharped elbow 90°C	2
Sharped elbow 60°C	
Sharped elbow 45°C	
SMOOTH ELBOWS	
Smooth elbow 90°C	
Smooth elbow 60°C	
Smooth elbow 45°C	
LOCAL PRESSURE DROPS	
T´s	
Y´s	
Entries	1
Outlets	1
Valve Kvs	0

Fluid mechanic calculations

Serial Pressure drop calculator

◉ Outputs:
- Reynolds
- Laminar/ Turbulent
- Friction factor
- Pressure drop
- Pressure difference

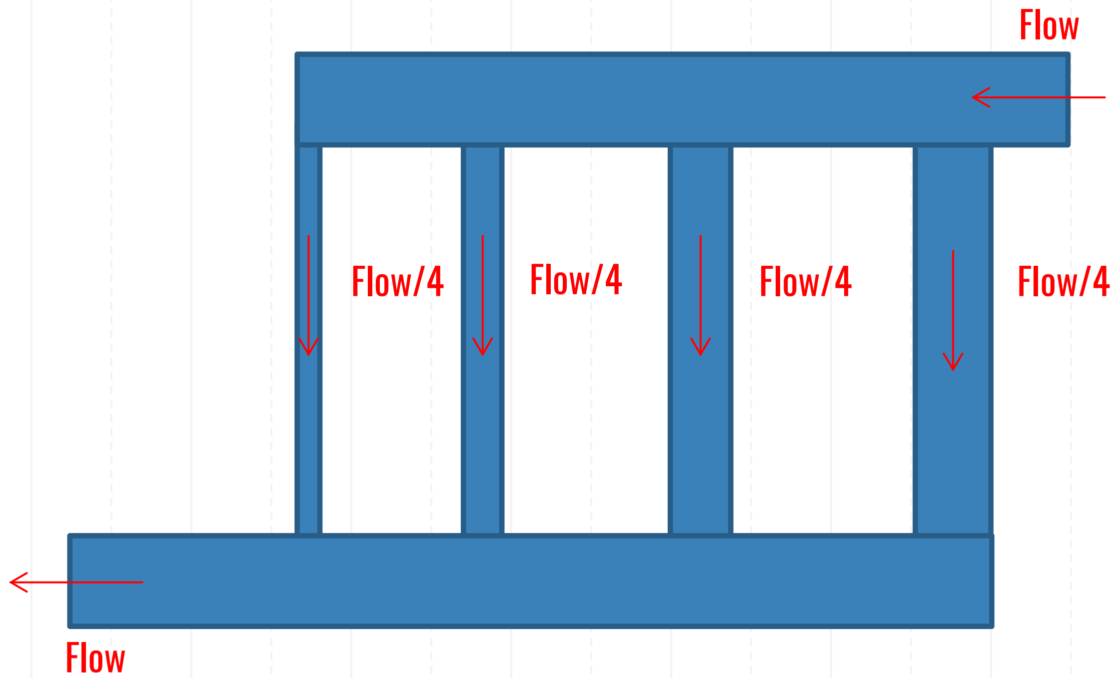
Results	Value	Units
Flow	0,000125	m3/s
Pipe hidraulic diameter	0,013	m
Pipe rougness	0,00001	m
Section area	0,00013273	m2
Velocity	0,94174523	m/s
Reynolds Number	**1478,66231**	
Regimen	**Laminar**	
Friction factor	**0,04328236**	
Pressure drop	**2760,56493**	**Pa**
Pressure difference	**2760,56493**	**Pa**
Pressure drop	**27,6056493**	**mbar**
Presure difference	**27,6056493**	**mbar**

Fluid mechanic calculations

Parallel calculator

◉ Aim:

- Constant flow through all branches.



◉ Procedure:

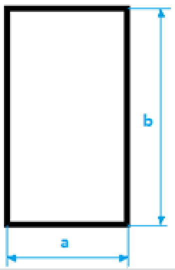
- Change diameter of branches.

Fluid mechanic calculations

Parallel calculator

- Inputs:
  - Coolant
  - Different geometry for sections
  - Lengths
  - Local elements
  - Number of branches
  - Height

Input	Value	Units
Section shape D1	Circular	
Section shape d2	Circular	
Flow in each d2 circuit	3,13E-05	m3/s
Total flow D1	1,25E-04	m3/s
Number of pipeways	4	
Length s	0,15	m
Lenght l	0,29	m
Length L	0,4	m
Main hydraulic diameter D1	0,008	m
Secondary hydraulic diameter d2	0,008	m
D1 pipe roughness	1,00E-05	m
d2 pipe roughness	1,00E-05	m
T'S		
Main number of T D1	1	
Main number of T d2	0	
NORMAL ELBOWS		
Main number of 90 elbow D1	8	
Main number of 60 elbow D1	0	
Main number of 45 elbow D1	0	
Main number of 90 elbow d2	1	
Main number of 60 elbow d2	0	
Main number of 45 elbow d2	0	



Fluid mechanic calculations

Parallel calculator

- Outputs:
  - Total pressure drop
  - Pressure drop in manifold
  - Different diameters

FINAL RESULT OF PRESSURE DROP		
Result	Value	Units
Total pressure drop in common pipe	5,496660775	mbar
Total pressure drop	1035,314272	Pa
Independetn term due to high	0	Pa
Total pressure drop	10,35314272	mbar

Result	n1	n2	n3	n4
Hydraulic diameter(mm)	10,00	10,86	11,62	11,67
Valve value KVs (m3/h;bar)	0,00	0,00	0,00	0,00
Pressure remaining (mbar)	4,71	3,50	2,75	2,70
Pressure remainig after valve (mbar)	4,71	3,50	2,75	2,70

HIM Helmholtz-Institut Mainz

panda

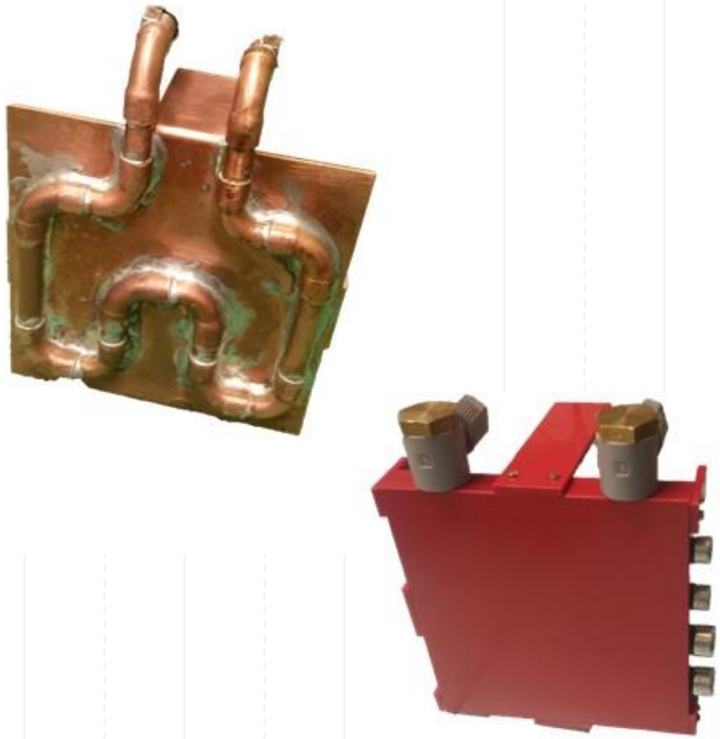
Front cooling test

Different materials

◉ Aim:

- See the effect of different materials in the front cooling

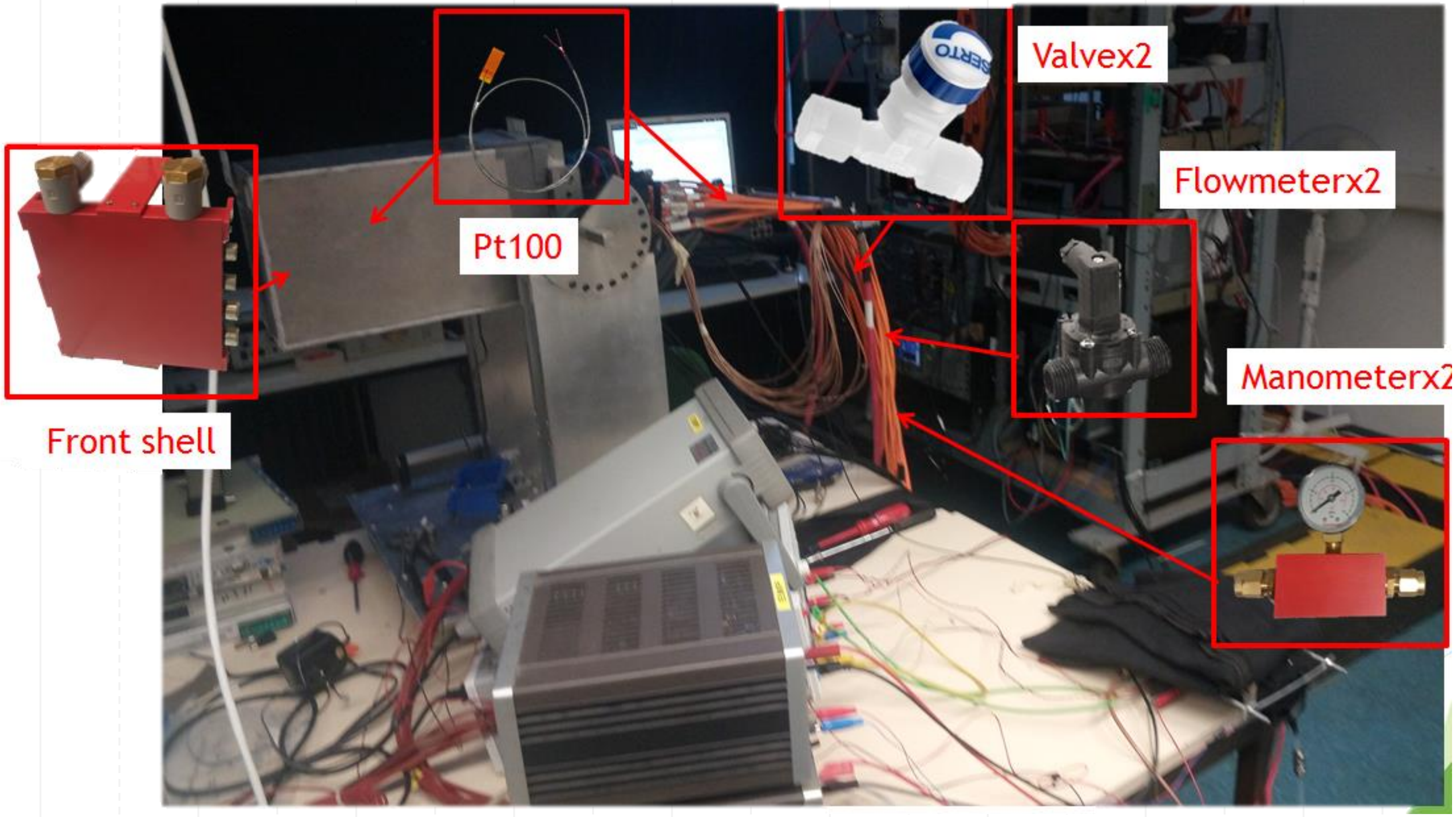
- Effect of different VIP´s configuration
  20mm
  2x10mm
- Validate thermal and fluid mechanic calculation system.



Front cooling test

Different materials

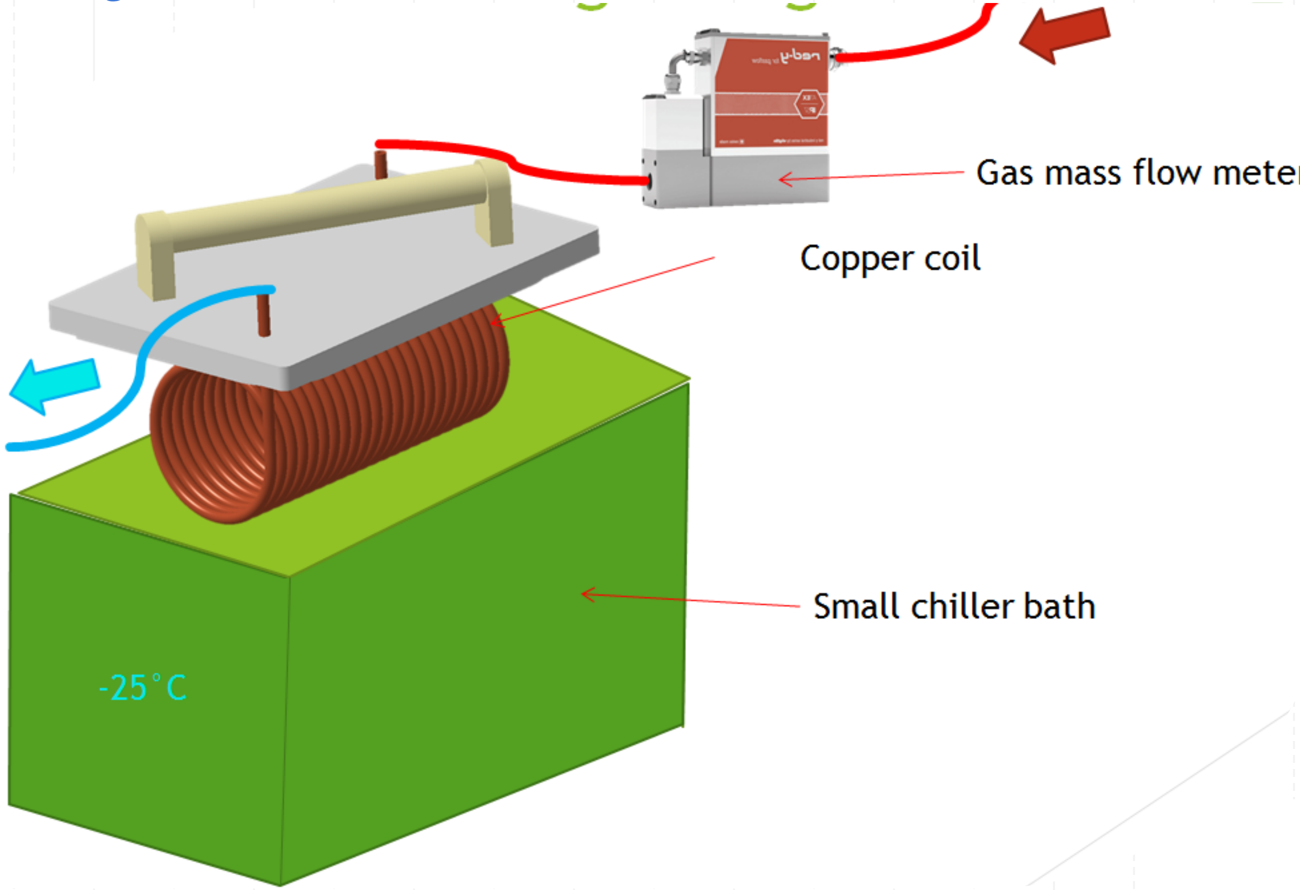
- Layout



Cold nitrogen test

Cool down the nitrogen

- Layout



Dew point at 20°C

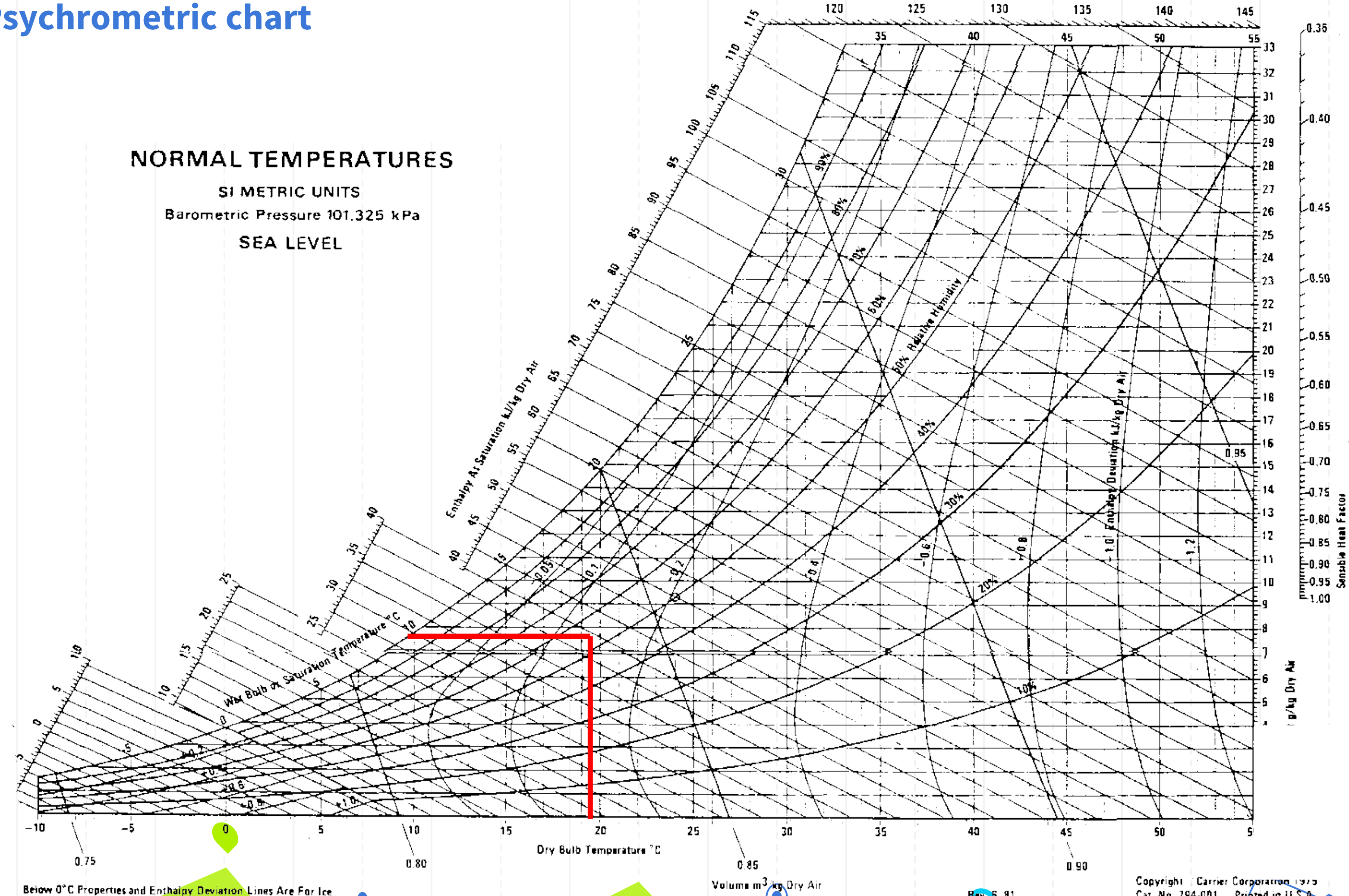
Calculations

Parameter	Value	Units
Round Exterior convection film coefficient (h1)	2,17	W/m2K
Round Exterior convection film coefficient (h2)	2,28	W/m2K
Front Face convection film coefficient (h3)	1,55	W/m2K
Conductivity VIP	0,005	W/m°C
Counductivity aluminum	154	W/m°C
Total BWEC Lenght (depth, z)	0,356	m
Conductivity Glass fiber	0,288	W/m°C
Conductivity MP Isolation	0,063	W/m°C
Conductivy plastic electronic cards	0,228	W/m°C
Aluminum emissivity	0,09	
Stainless Stell emissivity	0,85	
Outer temperature	20	°C
Crystal temperature	-25	°C

Parameter	Value	Units
Total power	214,04	W
Distance between pipes	188,90	mm
Temp in coolant outer shell	-29,42	°C
Tempin coolant inner shell	-28,93	°C
Lower temperature out aluminum	9,02	°C
Lower Temperature in part without shell	18,24	°C
Coolant flow total	14,61	l/min
Coolant flow per outer shell	5,13	l/min
Coolant flow per inner shell	2,18	l/min

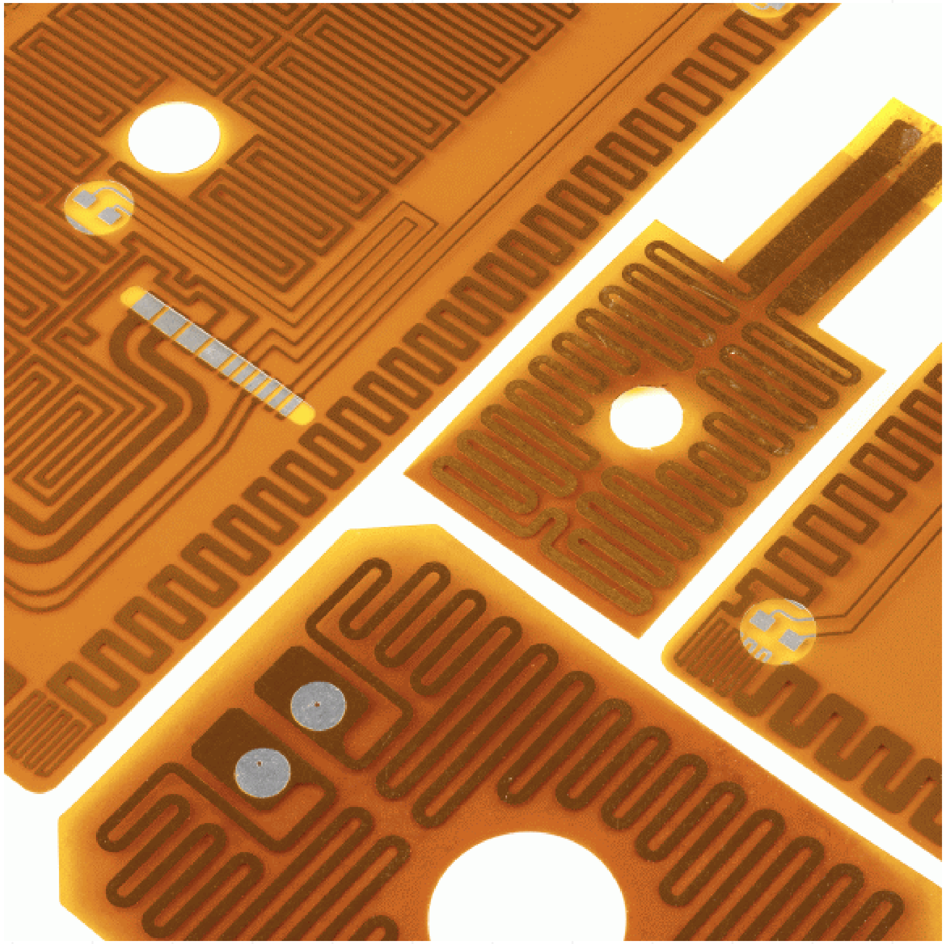
Dew point at 20°C

Psychrometric chart



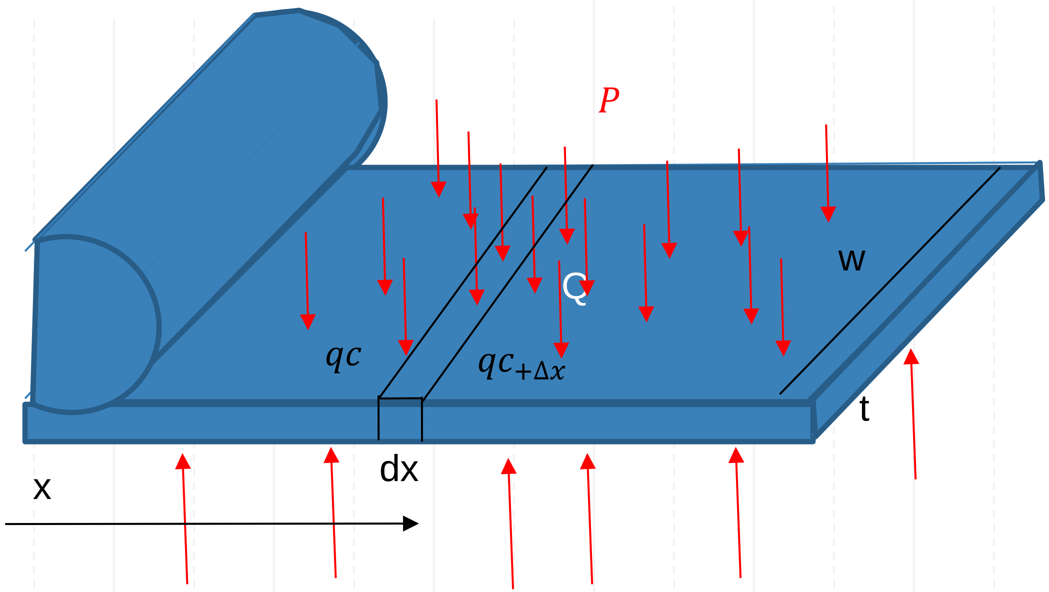
Dew point at 20°C

Kapton heating



Distance between pipes

- All the heat received for the plate is transported by conduction



$$qc_{+\Delta x} = qc + \left(\frac{\partial q}{\partial x}\right) dx + \cdots$$

$$qc_{+\Delta x} - qc = \left(\frac{\partial q}{\partial x}\right) dx + \cdots$$

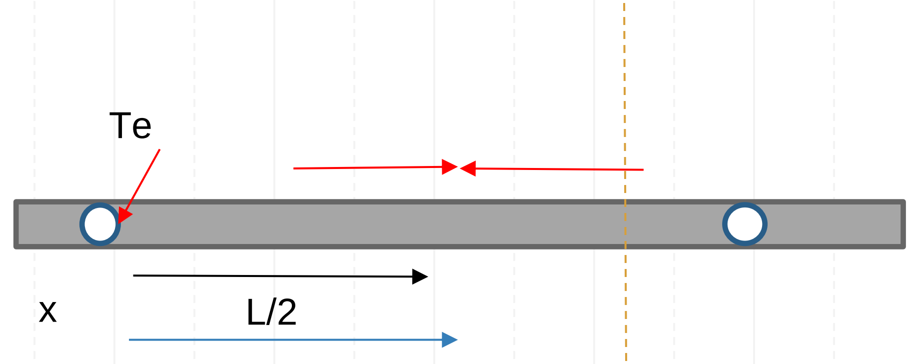
$$qc_{+\Delta x} - qc = \left(\frac{\partial}{\partial x} - k\frac{\partial T}{\partial x}\right) dx + \cdots$$

$$\frac{d}{dx} Q_C = P \cdot w \cdot dx \longrightarrow (qc_{+\Delta x} - qc) \cdot t \cdot w = P \cdot w \cdot dx$$

$$-k \cdot t \cdot w \cdot \left(\frac{d^2 T}{dx^2}\right) dx = P \cdot w \cdot dx \longrightarrow \boxed{\left(\frac{d^2 T}{dx^2}\right) = -\frac{P}{k \cdot t}}$$

Distance between pipes

$$\boxed{\left(\frac{d^2T}{dx^2}\right) = -\frac{P}{k \cdot t}}$$



- Boundary conditions
- Symmetry: Q(L/2)=0
- T(0)=Te

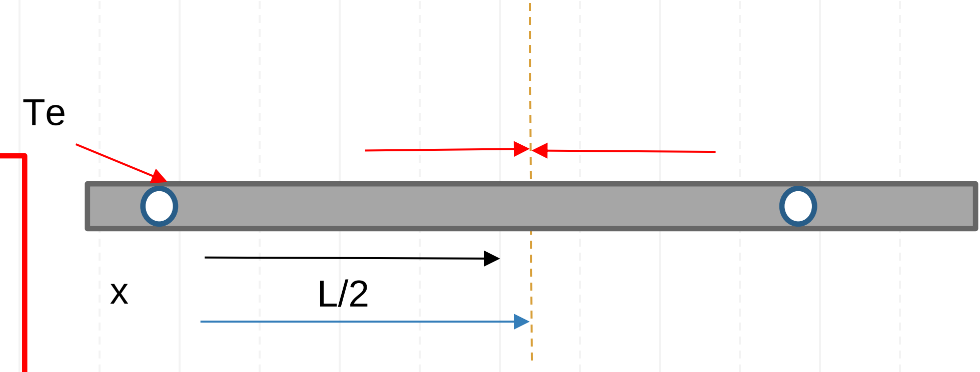
$$T(x) = -\frac{P}{2 \cdot k \cdot t} \cdot x^2 + A \cdot x + B$$

$$T(0) = -\frac{P}{2 \cdot k \cdot t} \cdot 0^2 + A \cdot 0 + B \rightarrow B = Te$$

$$\frac{\partial T}{\partial x}(L/2) = -\frac{2P}{2 \cdot k \cdot t} \cdot \left(\frac{L}{2}\right) + A = 0 \rightarrow A = \frac{PL}{2kt}$$

Distance between pipes

$$\boxed{T(x) = -\frac{P}{2 \cdot k \cdot t} \cdot x^2 + \frac{PL}{2 \cdot k \cdot t} \cdot x + Te}$$



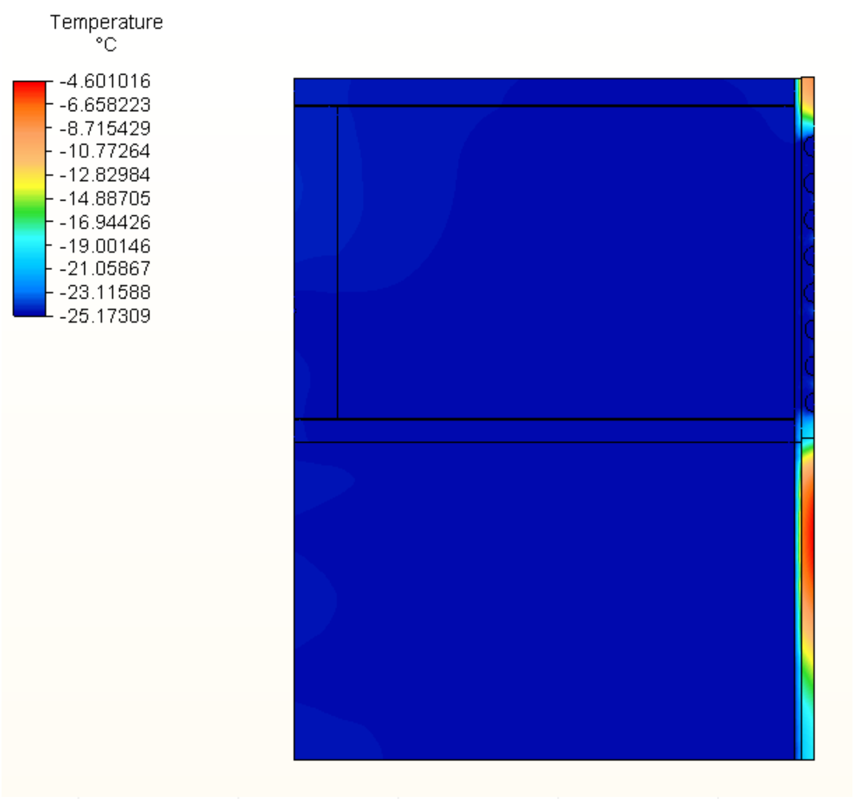
We want $T(L/2) \leq Te + 0{,}5$

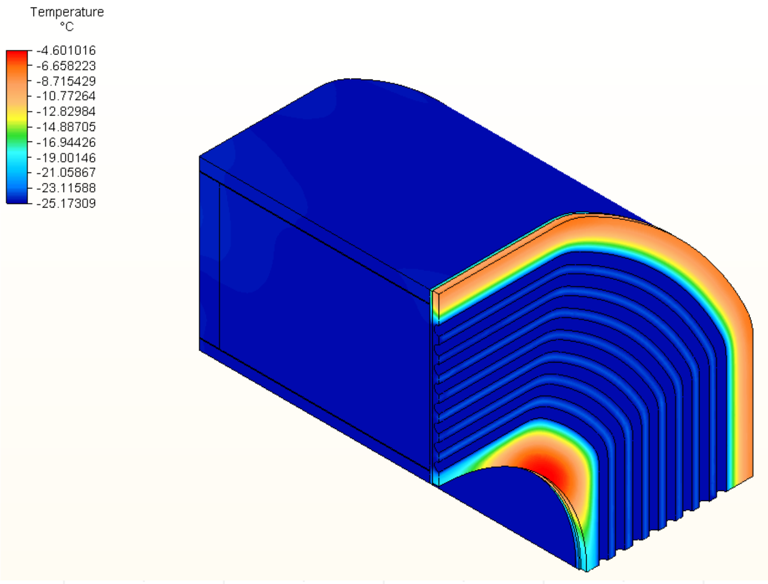
$$T(L/2) = -\frac{PL^2}{8 \cdot k \cdot t} + \frac{PL^2}{4 \cdot k \cdot t} + Te = Te + 0{,}5$$

$$\frac{PL^2}{8 \cdot k \cdot t} + Te = Te + 0{,}5$$

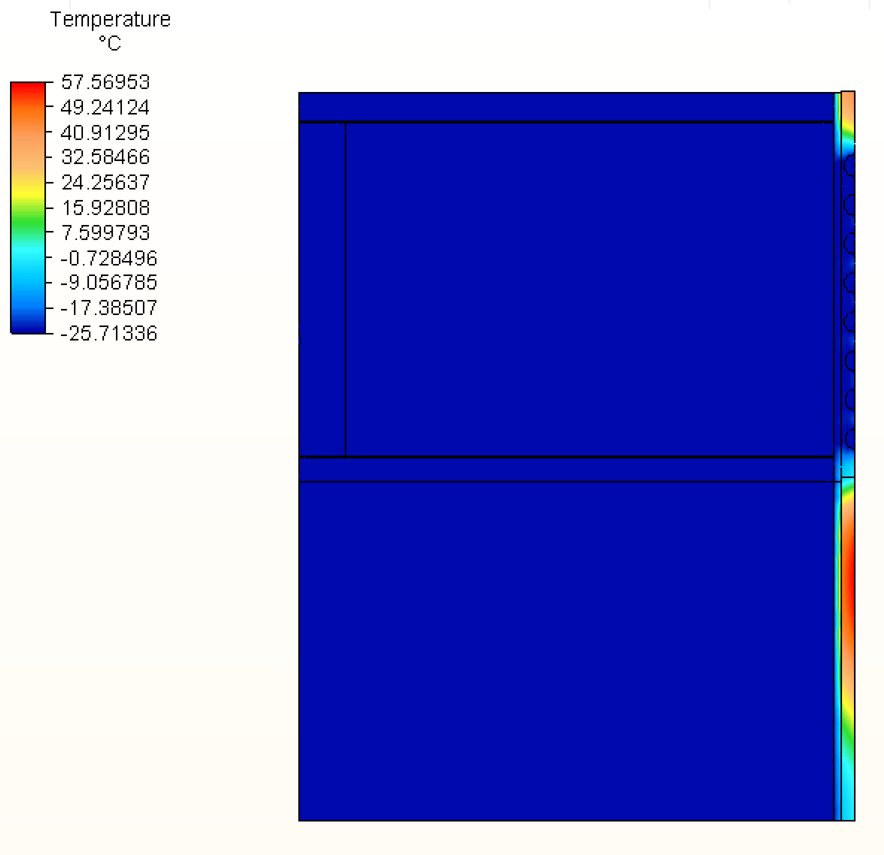
$$\boxed{\frac{PL^2}{8 \cdot k \cdot t} = \Delta T \rightarrow L = \sqrt{\frac{8kt\Delta T}{P}}}$$

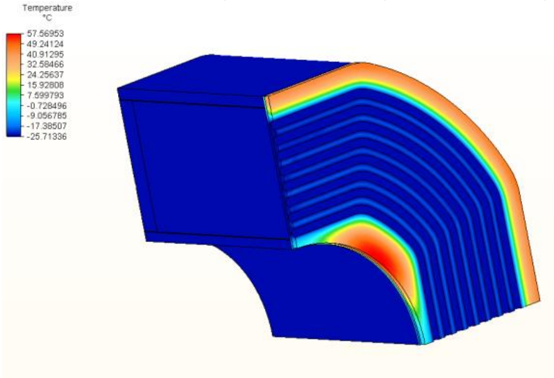
Thermal simulations Out of scale





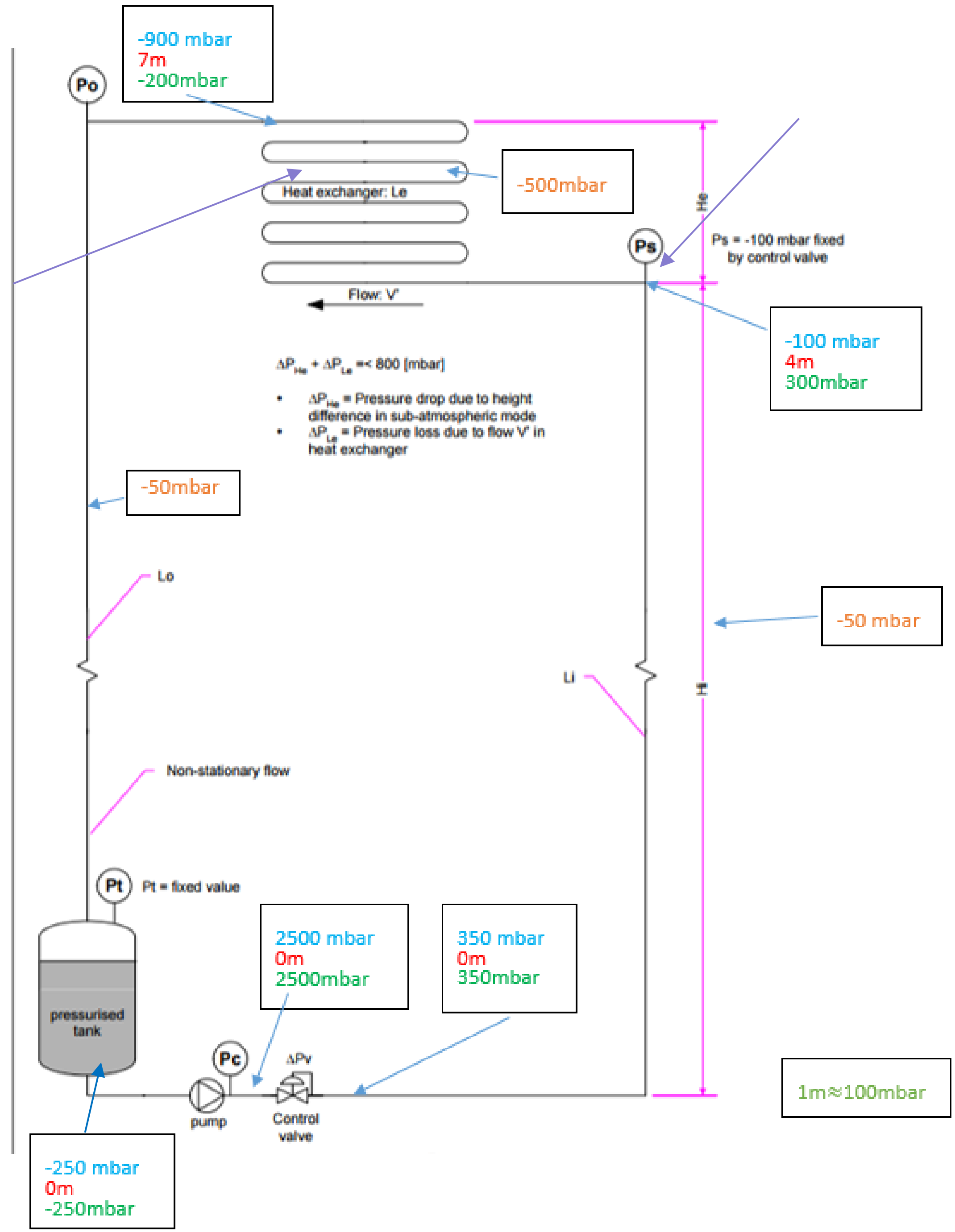
Thermal simulations Out of scale





Leakless mode

Calorimeter



Pressure

Height

Total static energy

Losses