FAKULTA STROJNÍ
ZÁPADOČESKÉ UNIVERZITY
V PLZNI

UNIVERSITY
OF WEST
BOHEMIA

Design of electromagnetic calorimeter top cooling system

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PANDA GSI

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Project overview

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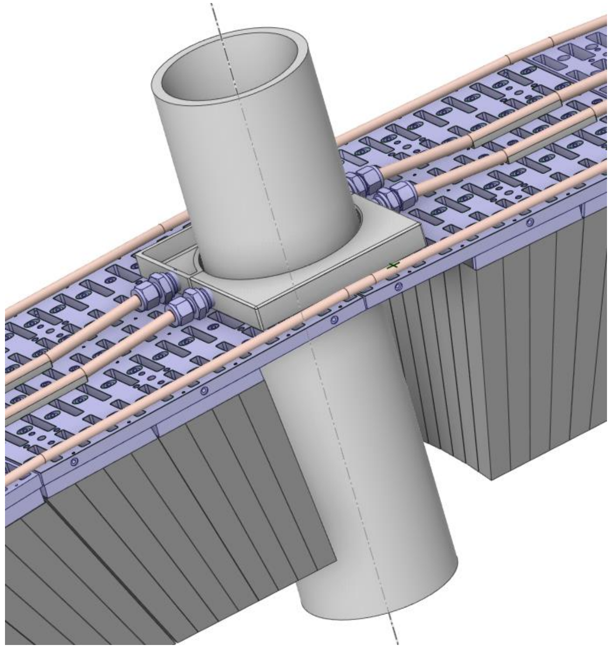
Outcomes of 2021

- CFD simulation of the temperature field for the current cooling circuit design was performed
- The entire cooling system has been designed
- CFD simulation of pressure drop on the designed cooling system was performed
- A 1D calculation tool was created for the design of the cooling system distribution piping

Current year (2022)

- CFD simulation of the pressure drop on the cooling circuit for the target slice was performed
  - For the original design
  - In addition, two other connections around the beam pipe were proposed
  - The original design was found to be satisfactory



- Several proposals have been put forward to achieve leakless cooling system
- A design for a new cooling circuit has been proposed
- CFD simulations of the pressure drop on the newly designed cooling circuit were performed in order to tune/optimize it
- To optimize the cooling circuit, a mass flow reduction option was selected
- To better understand the behaviour of the system under the new conditions, an experiment was set up and CFD simulations were performed

Outcomes of 2021

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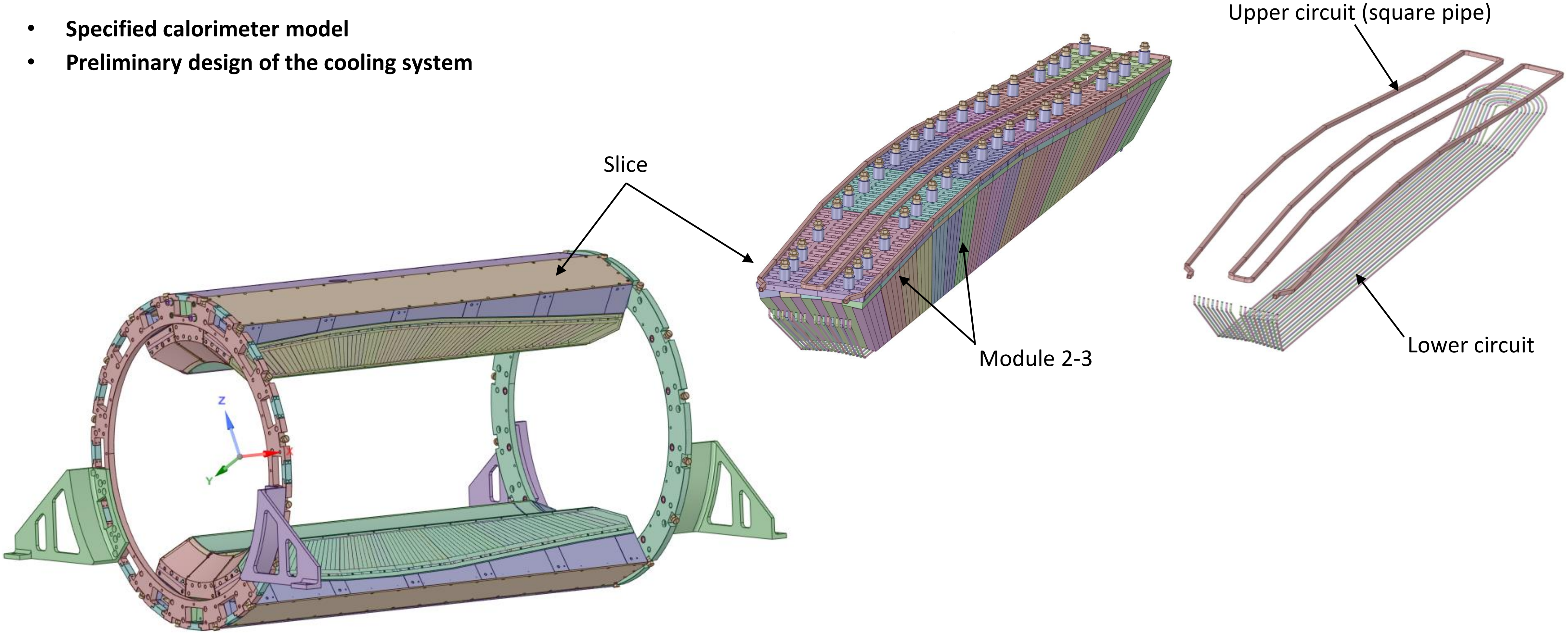
Preliminary design

- **Specified calorimeter model**
- **Preliminary design of the cooling system**



Outcomes of 2021

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System requirements

- Initial requirements for the proposed cooling system
  - Operating temperature range
  - Tepmerature field homogenity
  - Pressure loss
  - Mass flow rate (wrong assumption)

t [°C]	Δt [°C]	Δp [bar]	$\dot{m}$ [kg/s]
-30 to -20	≤ 1	≤ 1	≤ 2,78

Outcomes of 2021

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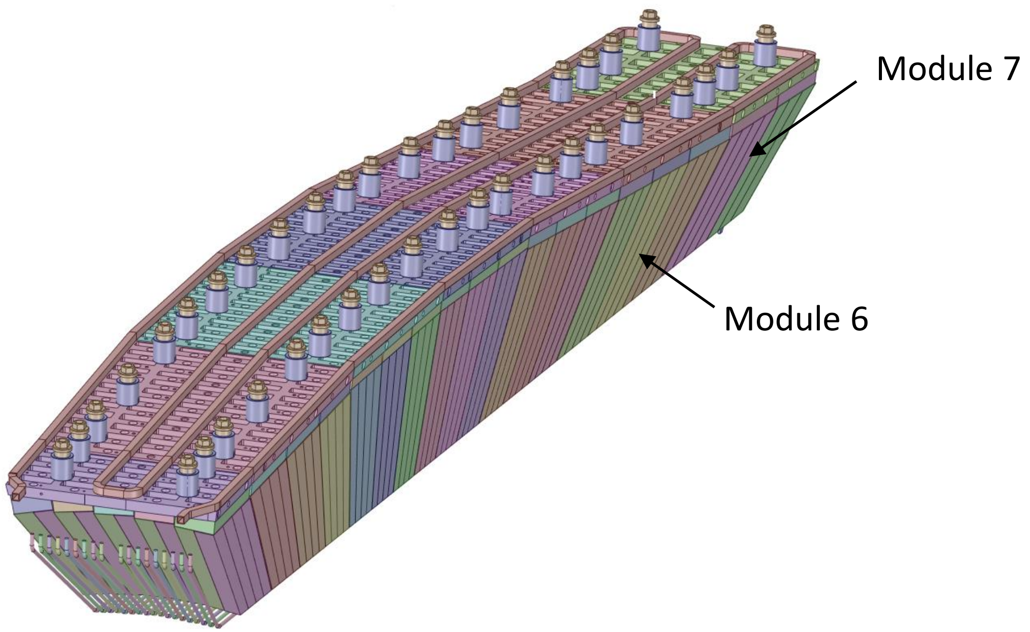
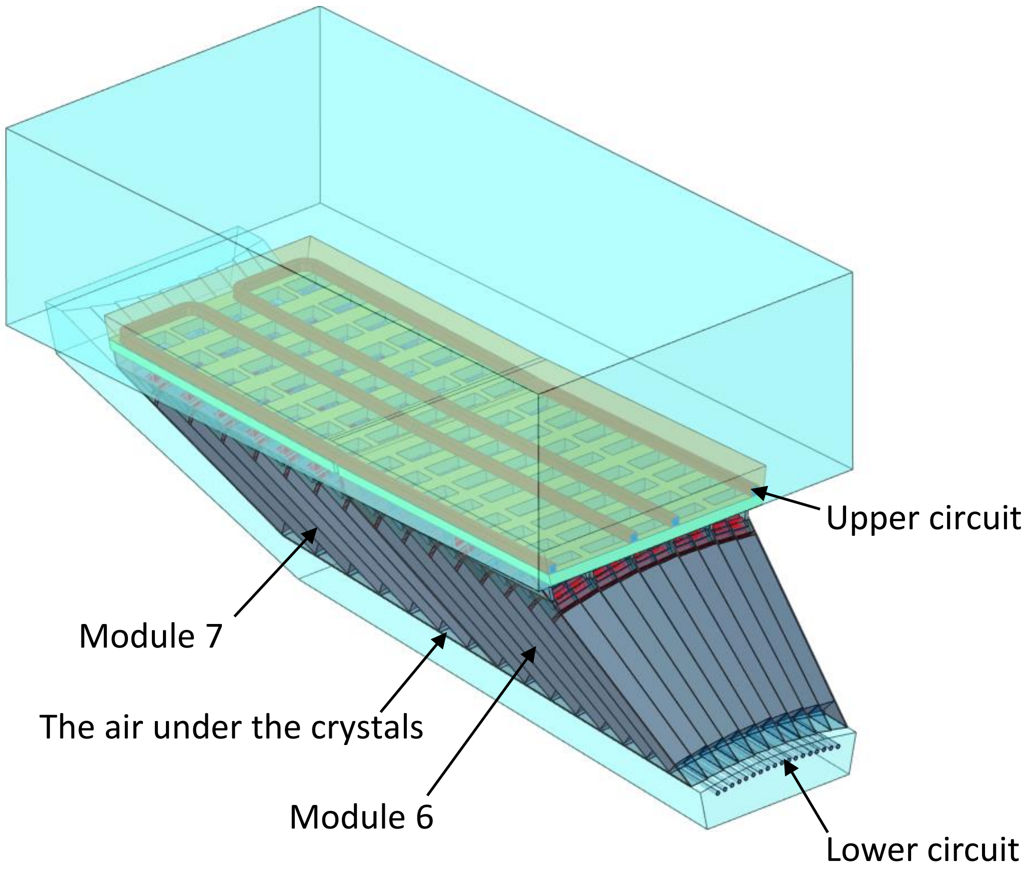
Design in terms of temperature field

- **Simulation of the calorimeter part**
- **Extended computational domain (air)**





Outcomes of 2021

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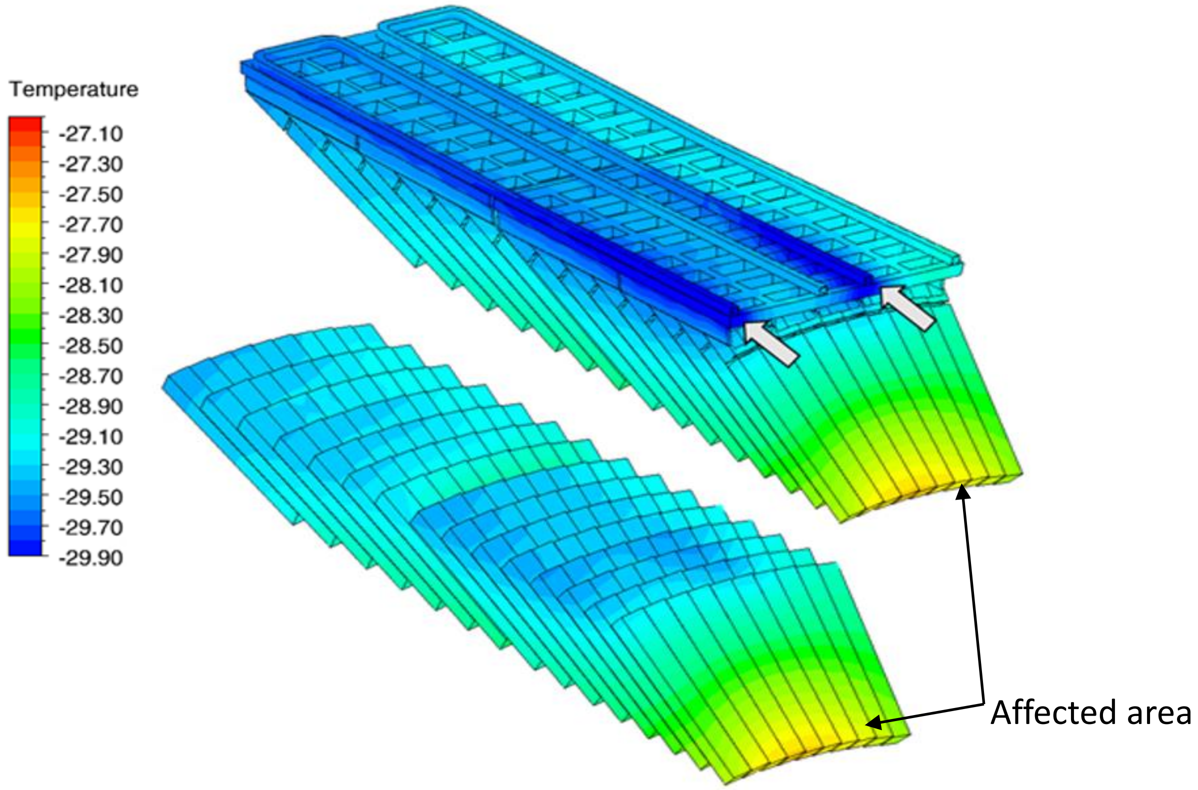
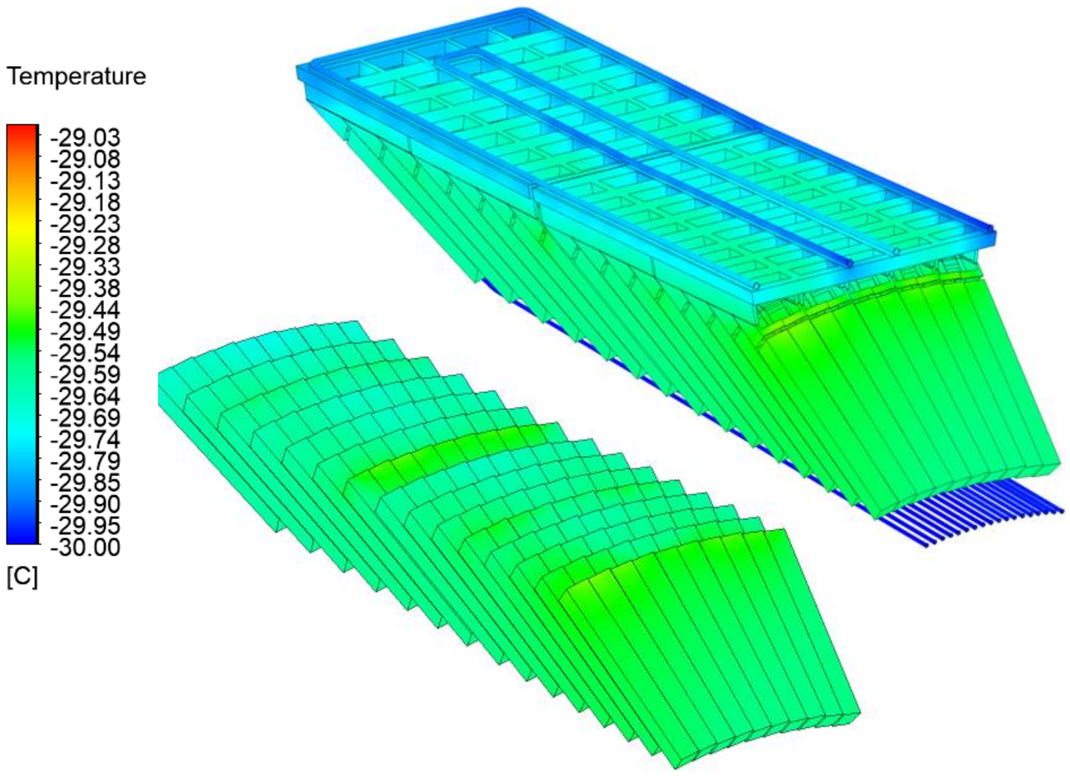
Temperature field analysis

- Constant boundary at the bottom of crystals
- Homogenity



Initial simulation



Extended simulation

Outcomes of 2021

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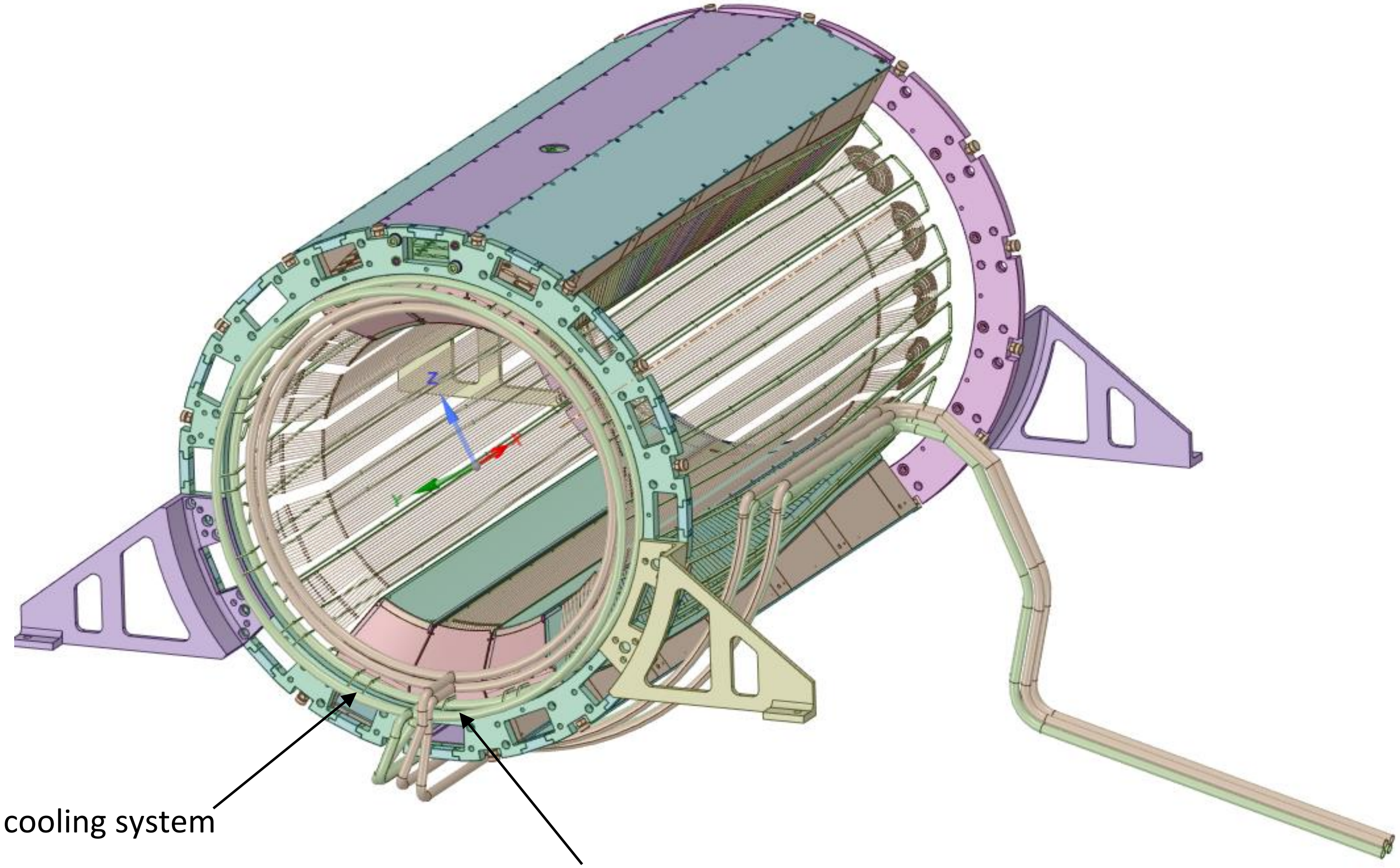
Design in terms of pressure losses

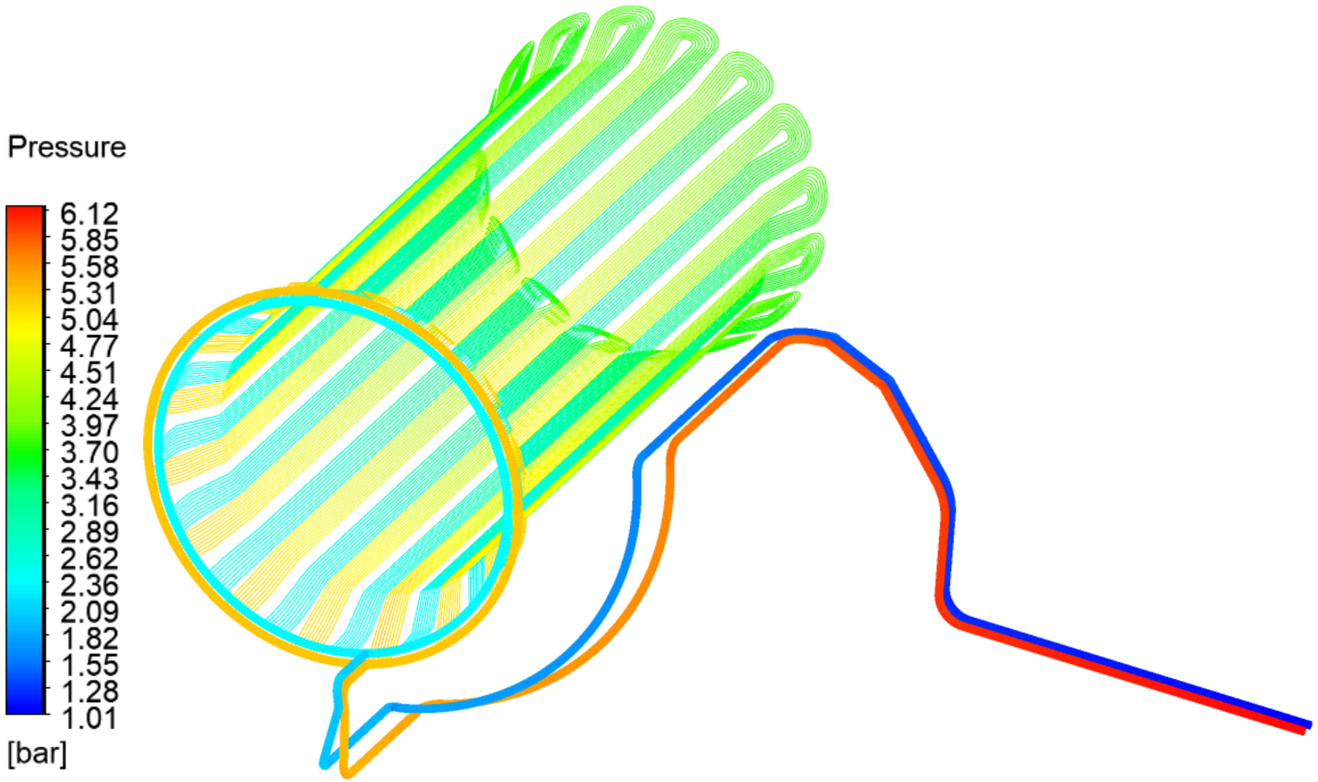
- Distribution piping design
- Simulation of the entire cooling system
- Round pipes
- There are two upper cooling circuits per slice



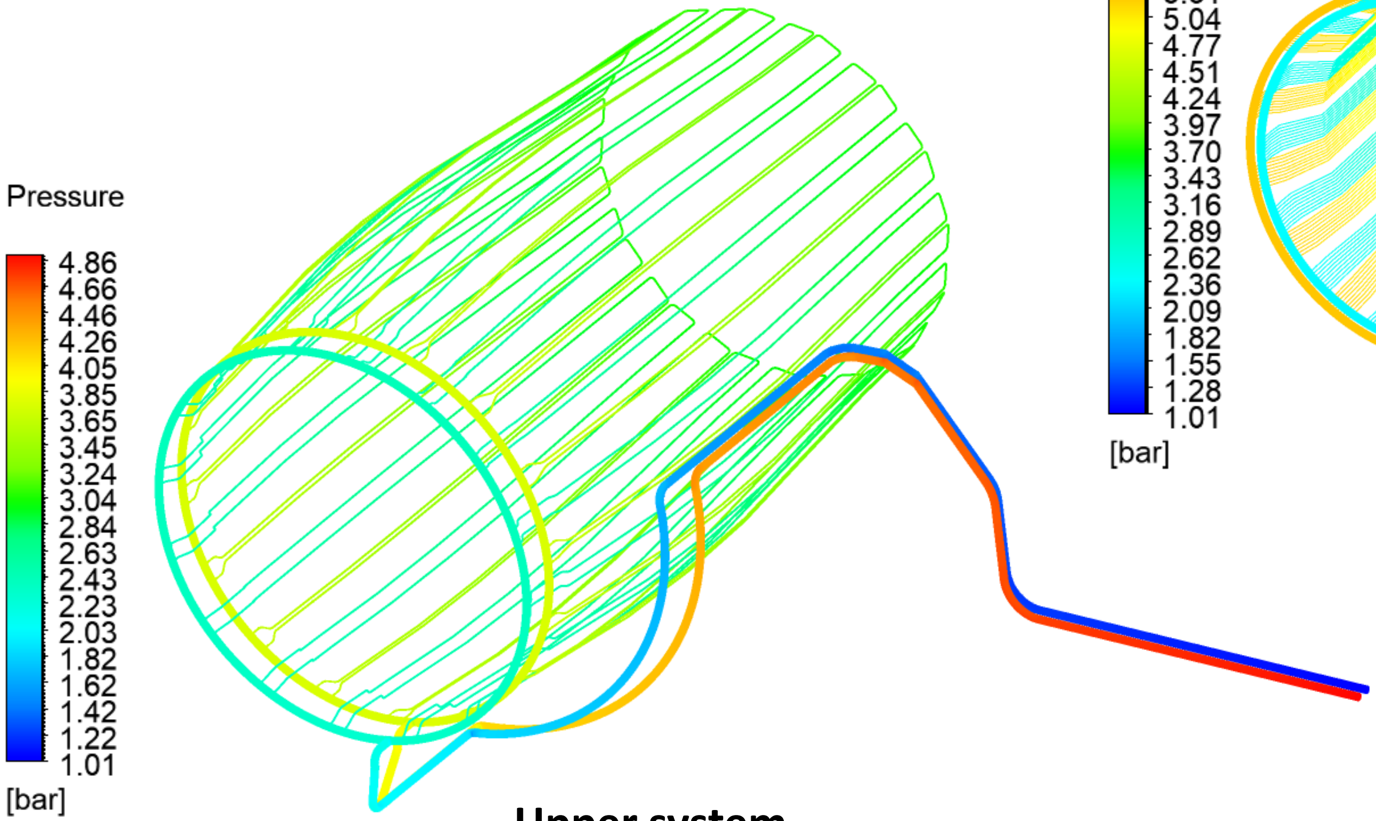
Outcomes of 2021

Pressure loss analysis

- Outlet is at 1 bar
- System is under pressure



Lower system



Upper system

Outcomes of 2021

Analytical calculation

- **Verification of calculation with CFD**
- **The calculation tool is suitable for the design of distribution piping**

Parameter	Cooling system	1D calculation	CFD	Difference [%]
Δp [bar]	Upper	3,8	3,88	**2**
	Lower	4,95	5,14	**4**

Outcomes of 2021

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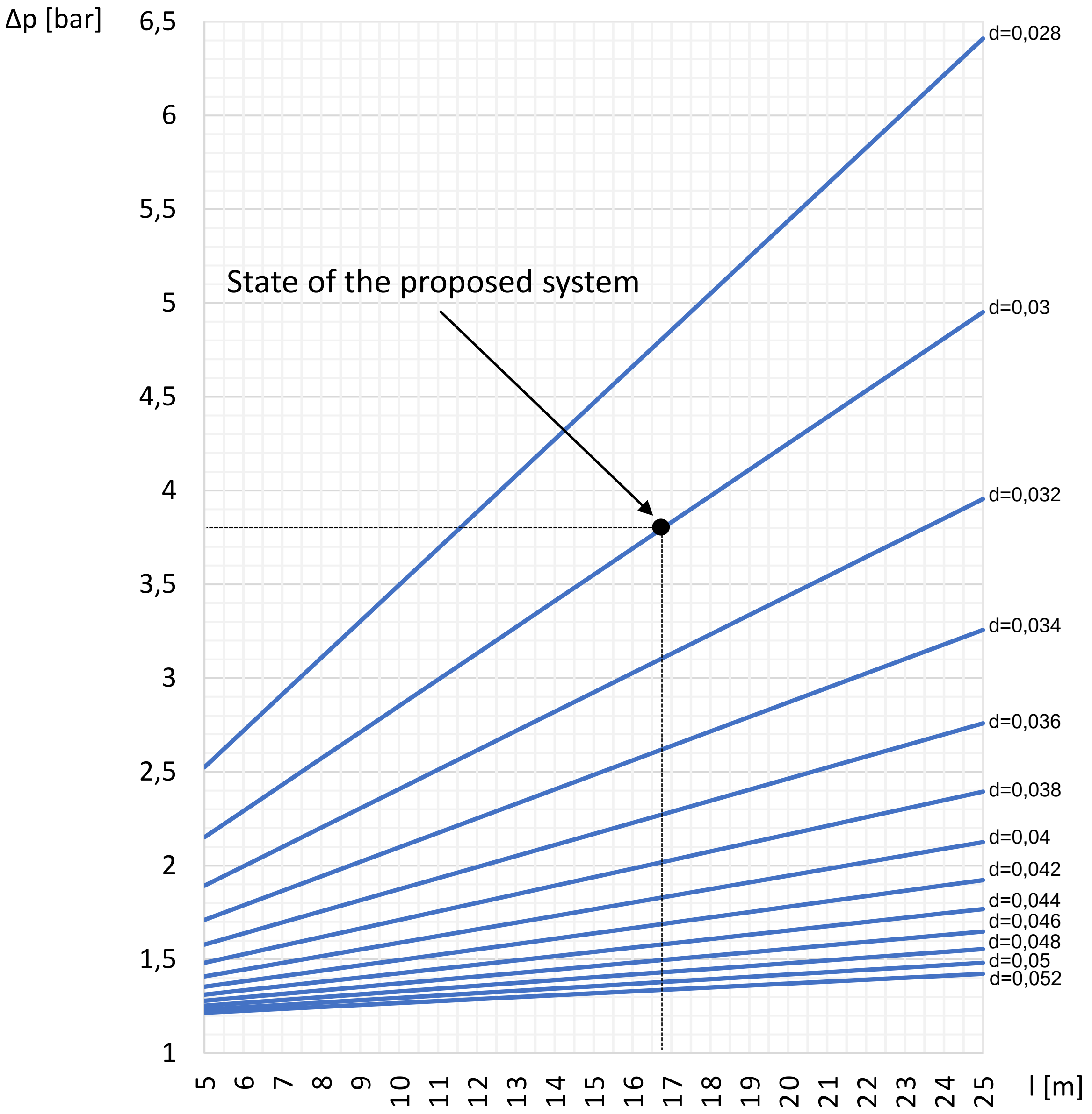
Cooling system variation analysis

- **Reducing the pressure drop value**
- **Nomogram creation**



Current status

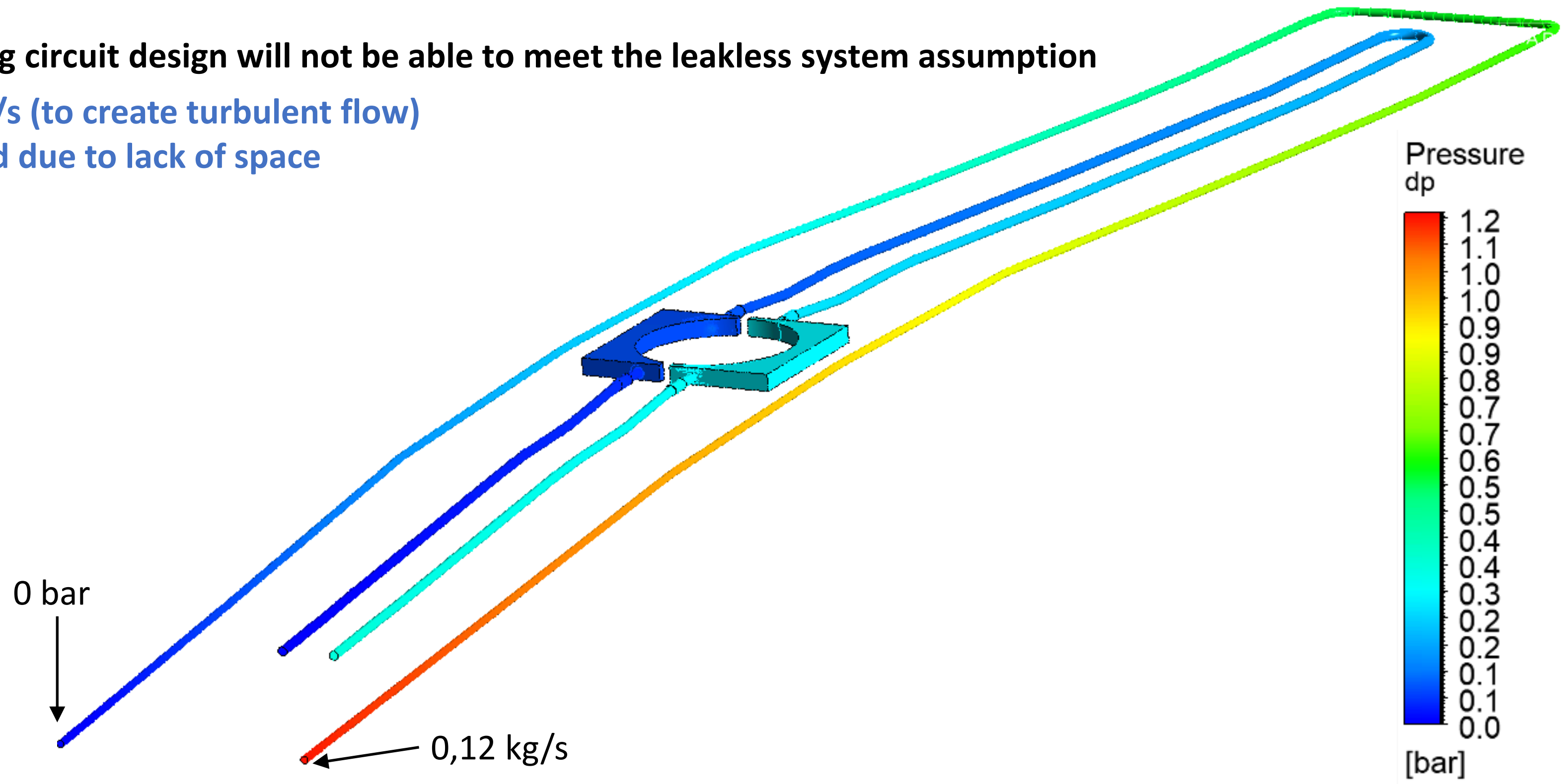
Updated requirements for the cooling system

- **It was found that the mass flow is not limited by the value of 2,78 kg/s**
- **The system was found to be leakless**
- **It was found that the outlet pressure of the cooling system is assumed to be 0 bar**

Current cooling circuit

- **It has been found that the current cooling circuit design will not be able to meet the leakless system assumption**
  - **Mass flow rate have to be 0,12 kg/s (to create turbulent flow)**
  - **Pipe diameter cannot be increased due to lack of space**

- **Present value of pressure drop**
  - **Outer circuit = 1,16 bar**
  - **Inner circuit = 0,37 bar**

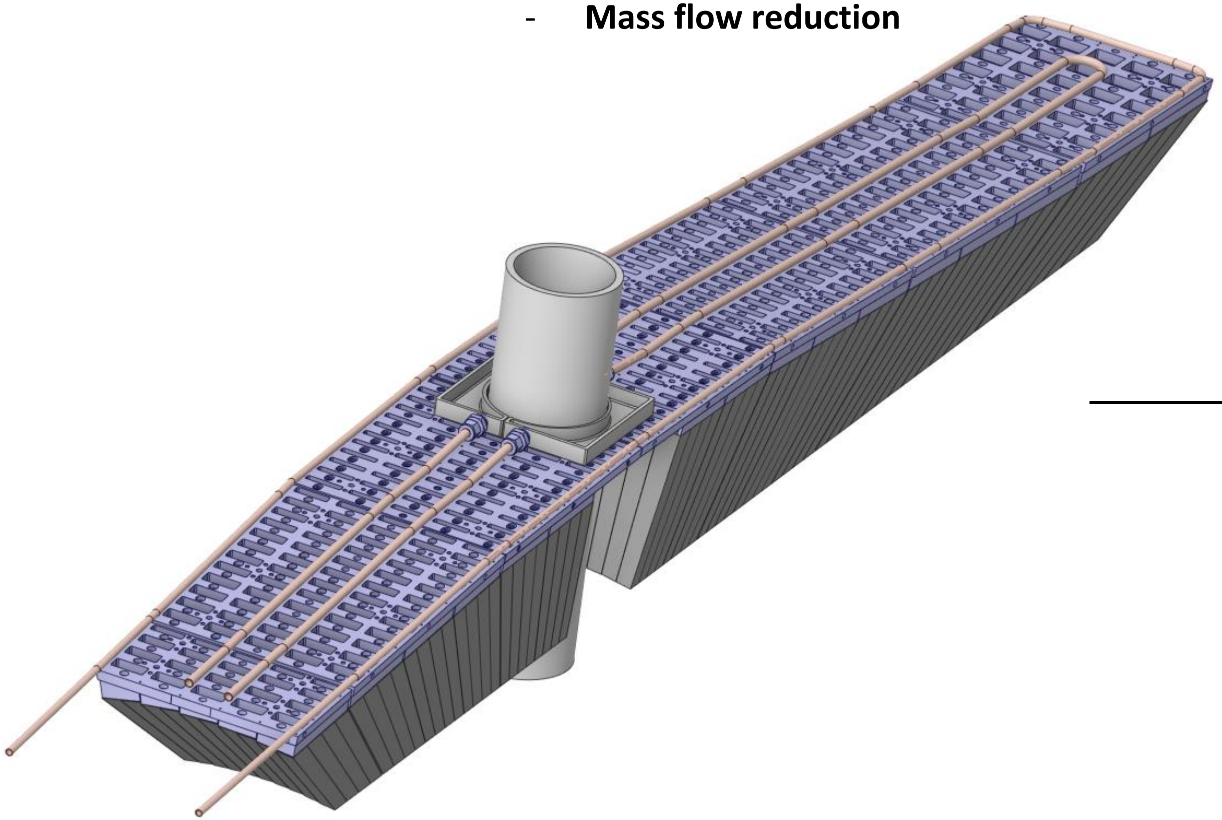


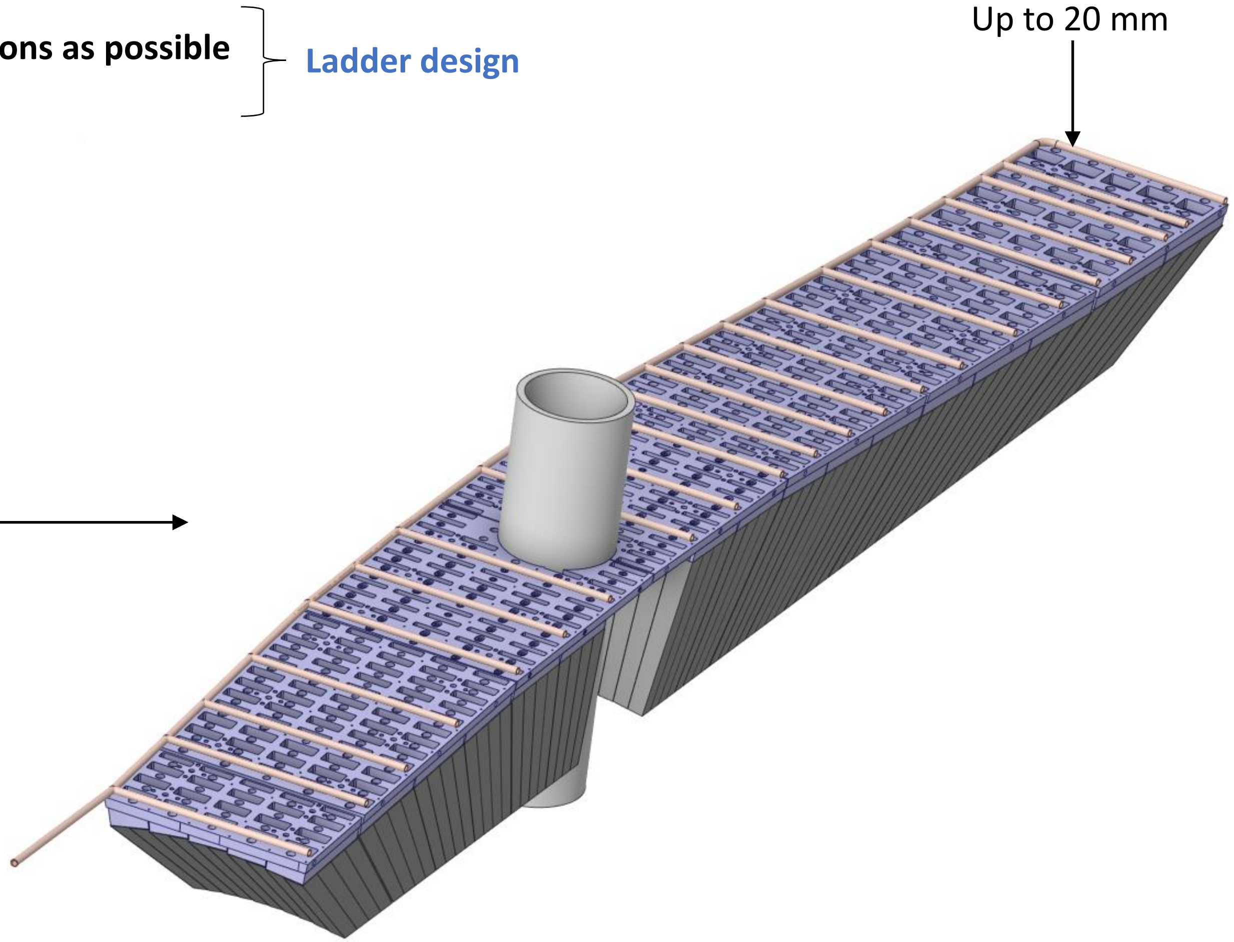
Troubleshooting

Cooling circuit optimalization

- The design should provide a leakless system
- Possible solutions
  - Ensure a larger pipe diameter
  - Trying to create as many parallel connections as possible
  - Different topology
  - Mass flow reduction

(Ladder design)





Troubleshooting

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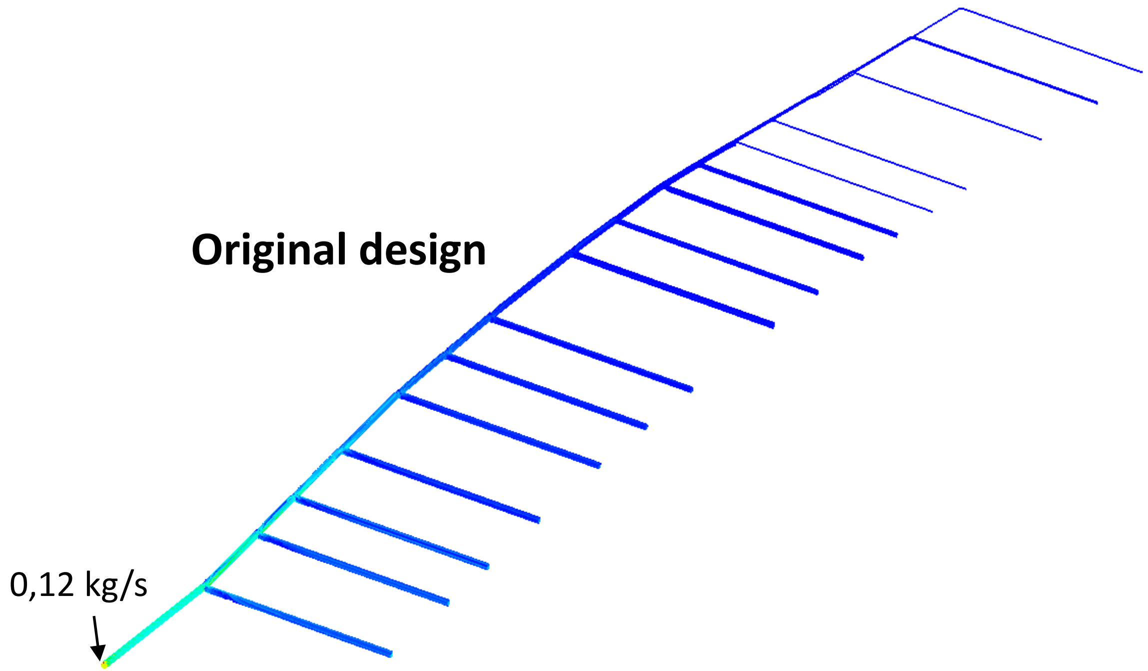
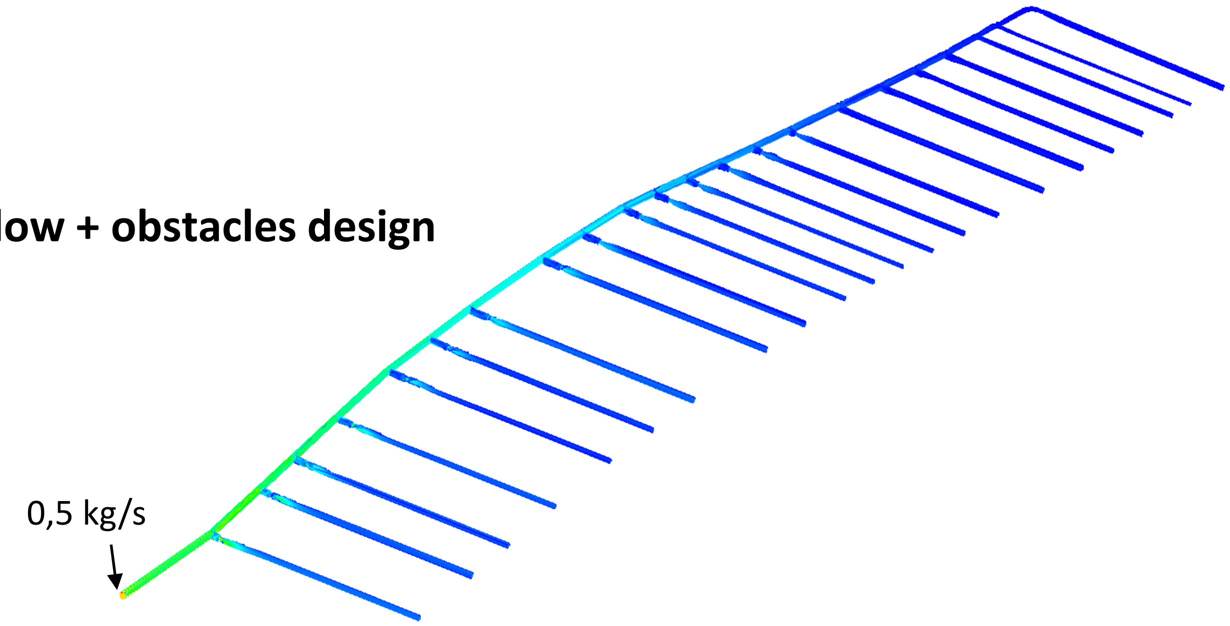
Encountered problem

- The flow does not continue until the end
- Possible solutions
  - Create obstacles for the flow
  - Change pipe diameter (probably not due to homogenity)
  - Higher mass flow rate (pressure drop increasses dramatically)

Original design

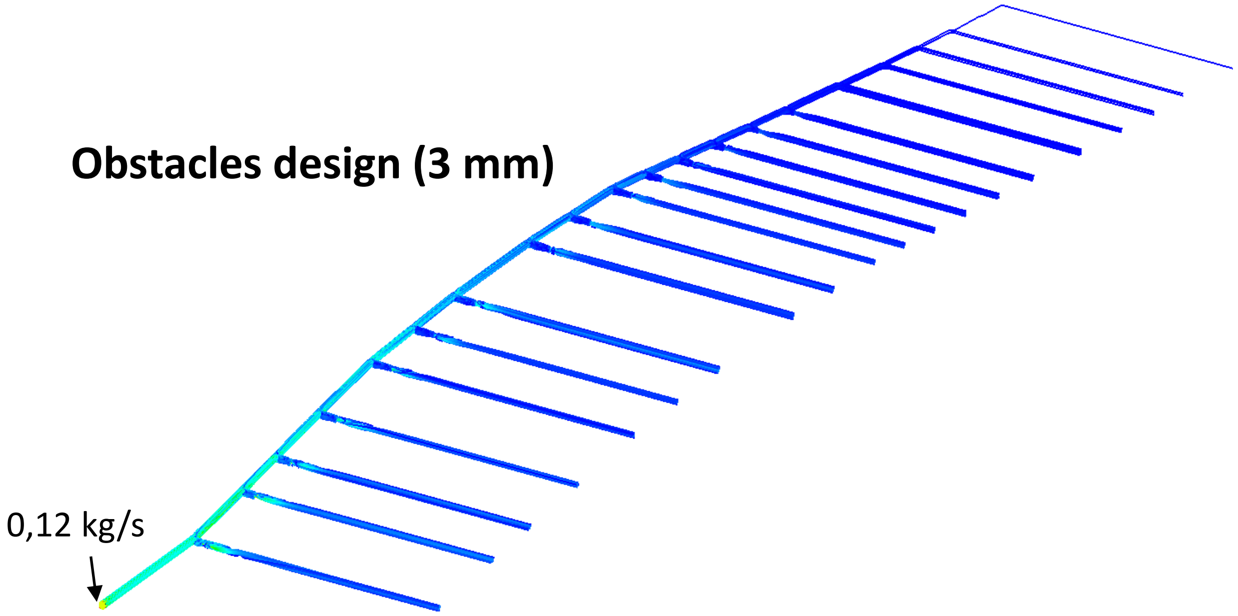


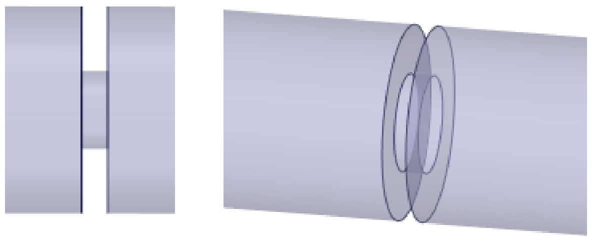
Flow + obstacles design

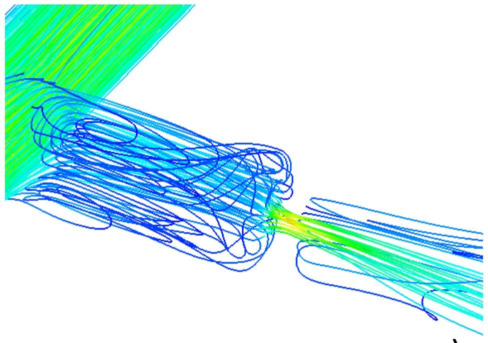


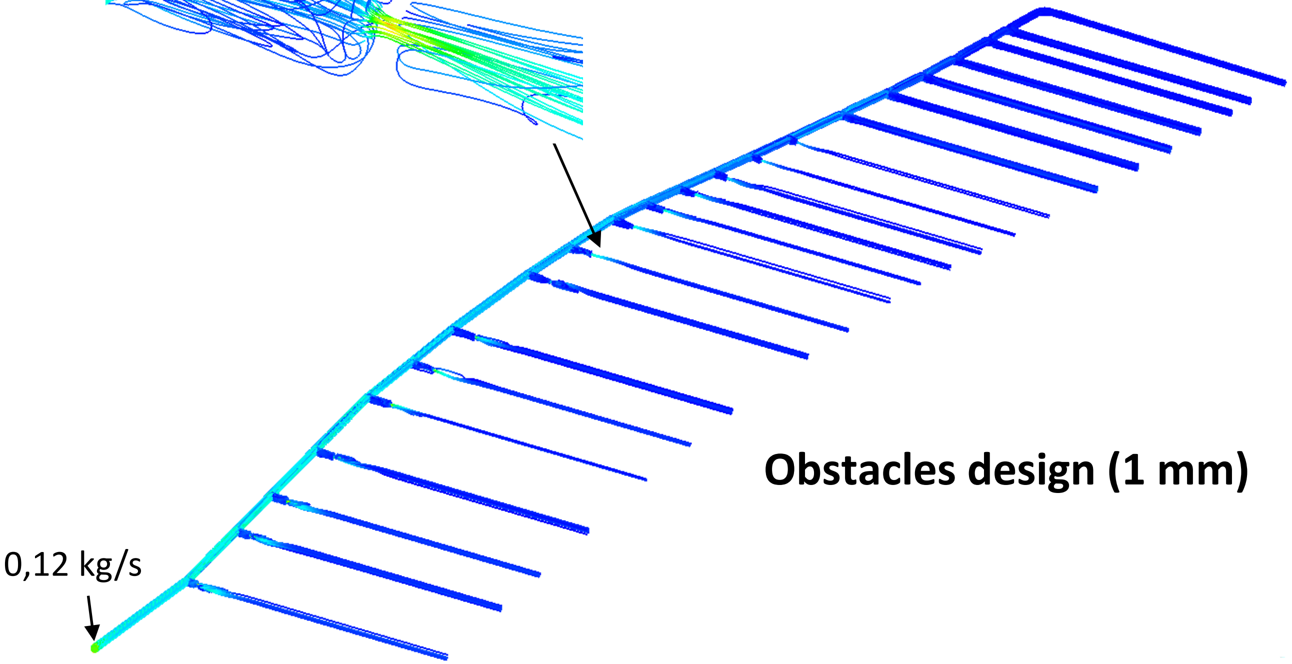
Troubleshooting

Obstacles design (3 mm)









Obstacles design (1 mm)

Troubleshooting

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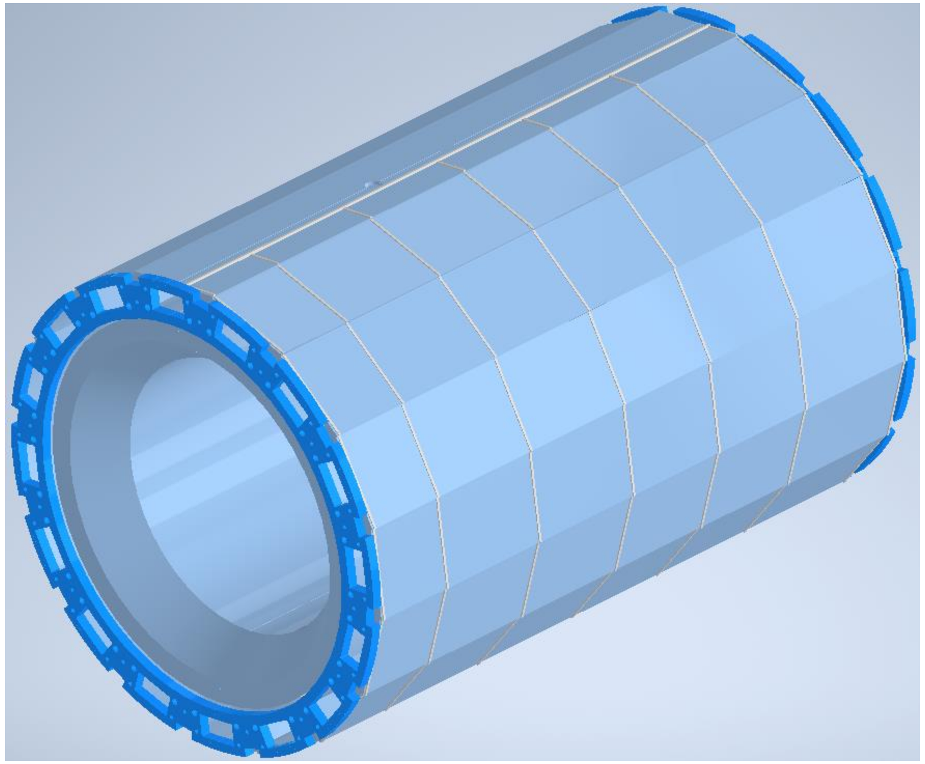
Ladder design summary

- Ladder design is not suitable for use inside the slice
- **However, it could be used around the barrel to help cool the electronics and stabilize temperature of the support beam**



Type	$\dot{m}$ [kg/s]	Δp [bar]	Flow path
Original	0,12	0,06	X
Flow + Obs. 5 mm	0,5	1,17	OK
Obs. 3 mm	0,12	0,1	X
Obs. 1mm	0,12	0,18	OK

Troubleshooting

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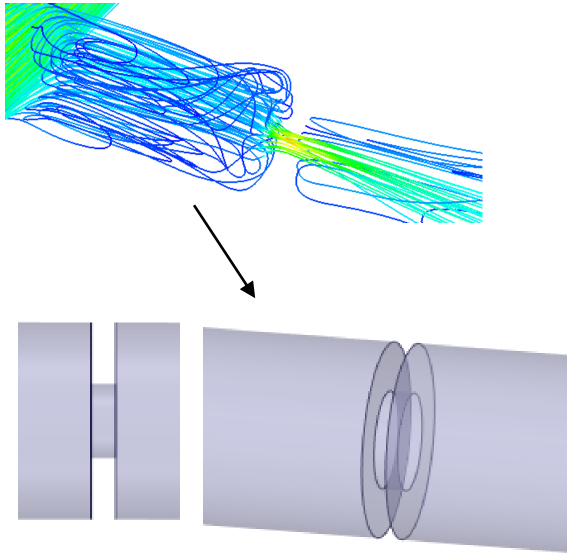
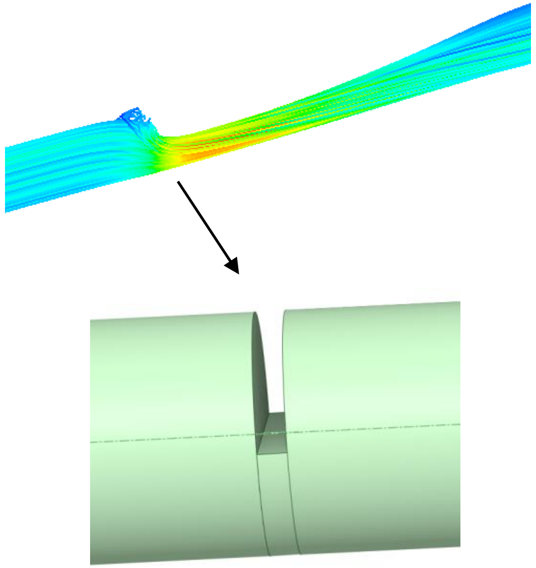
Mass flow rate reduction

- Causes laminar flow (problem with heat transfer)
- Obstacles
  - Rings, half rings
  - Sieves
  - Turbulizers





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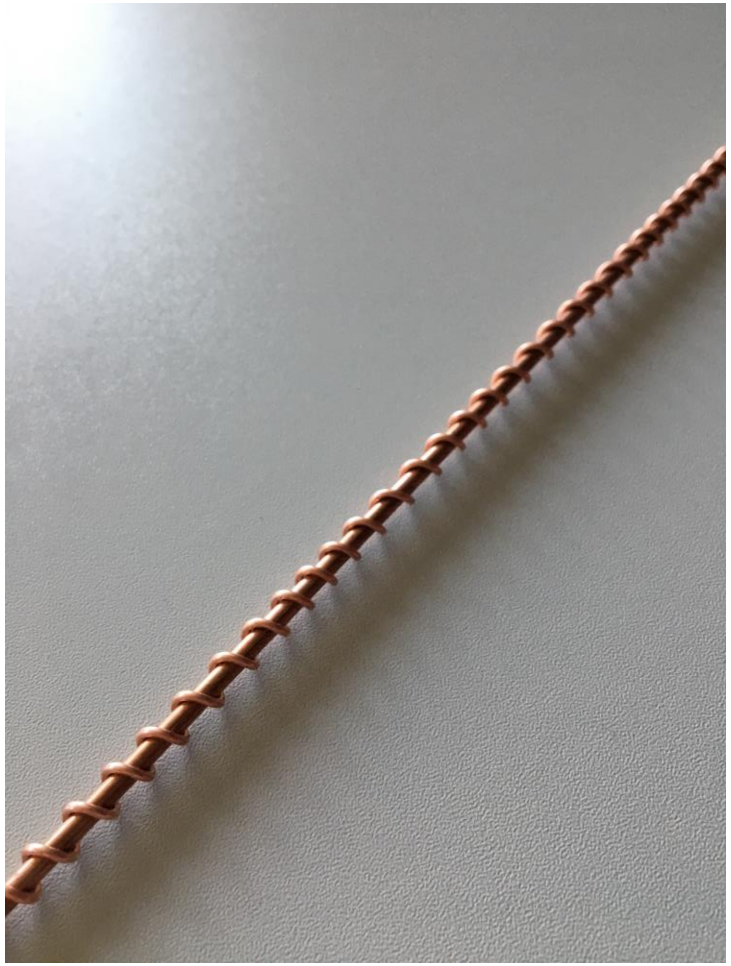
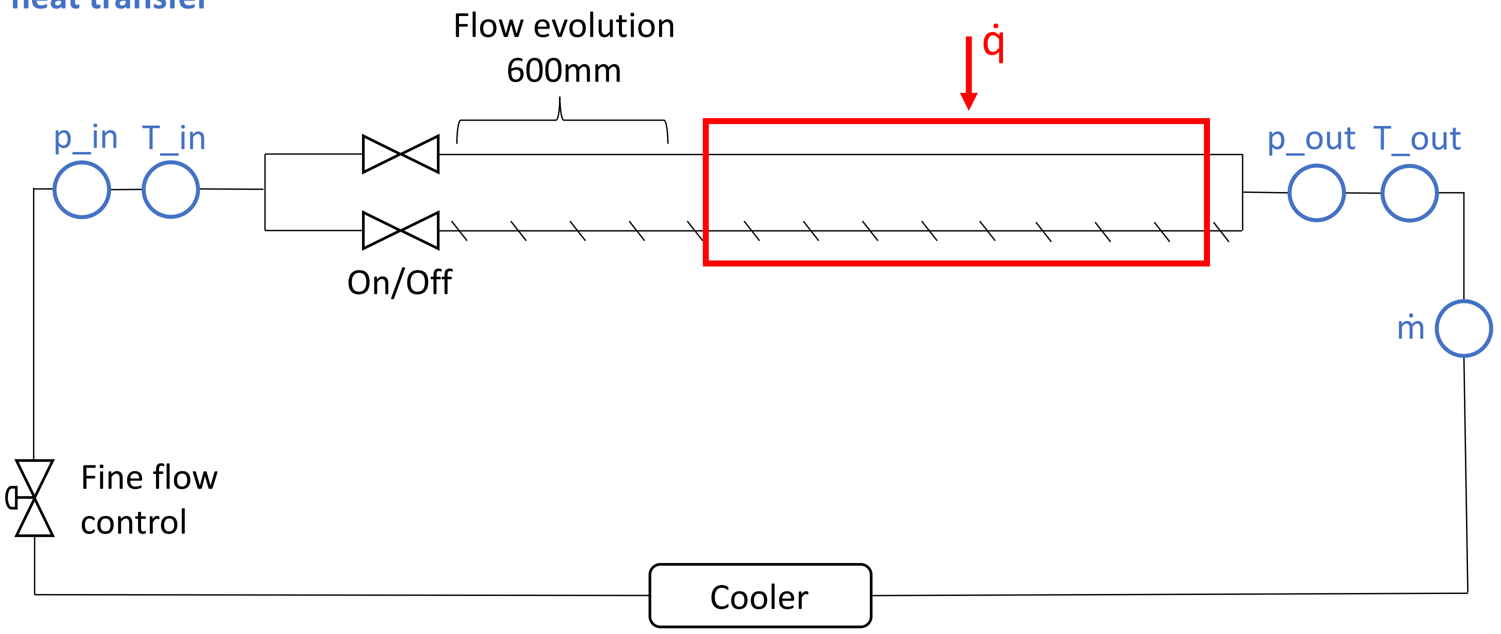
Turbulizer



Experiment

Meassurement

- Pressure is measured by pressure gauges at the inlet and outlet of the pipe
- For now, we expect to measure the temperature with a thermal camera around the pressure sensor
- We are also considering the possibility of measuring the temperature in the flow using thermocouples. However, these are less suitable in terms of flow distortion.
- We will use an electric heater as a heat source (not yet installed)
- The volumetric flow rate will be measured with a flow meter
- The aim of the measurement is to determine whether, for a defined mass flow rate, an improvement in heat transfer can be observed for the turbulizer pipe
- It is then possible to determine the efficiency of the turbulizer as it can be assumed that this will vary for different flow rates and pipe diameters. We can then define the point at which the smallest possible pressure drop can be achieved at a given mass flow rate, with the greatest possible heat transfer

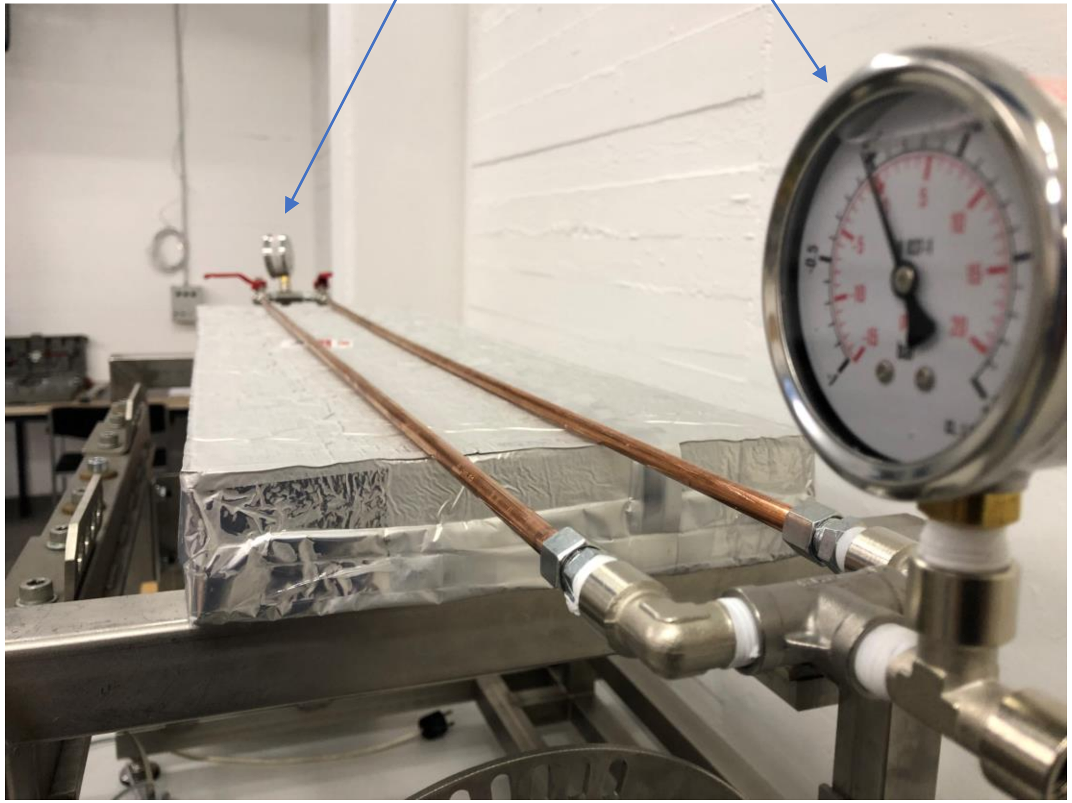


Experiment

Assemmbly

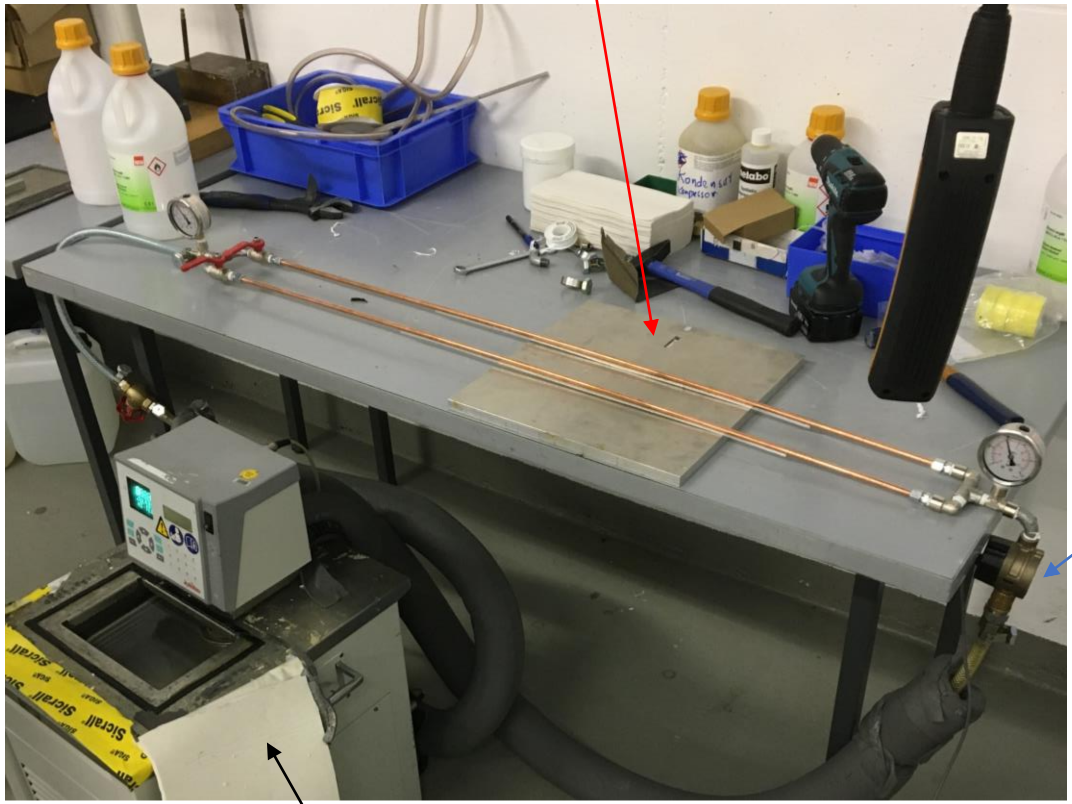
p_in

p_out



$\dot{q}$

$\dot{m}$

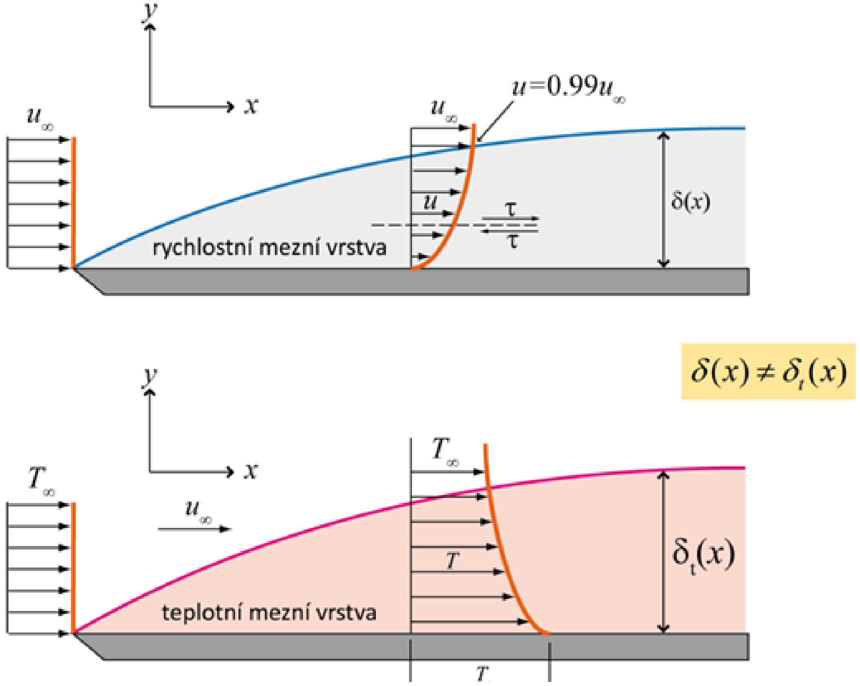


Cooler

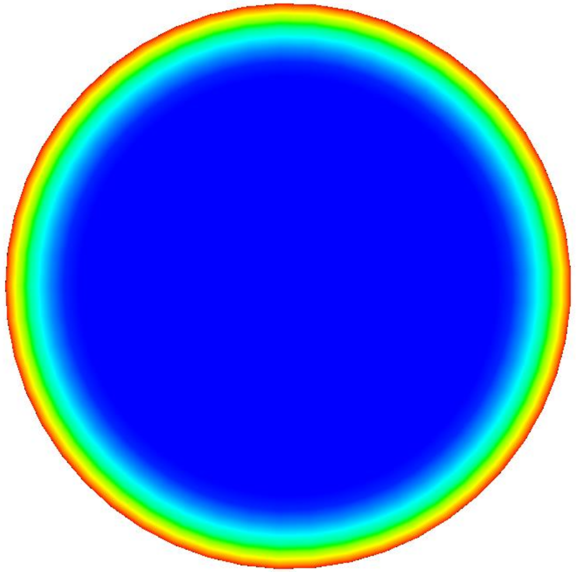
Experiment analysis

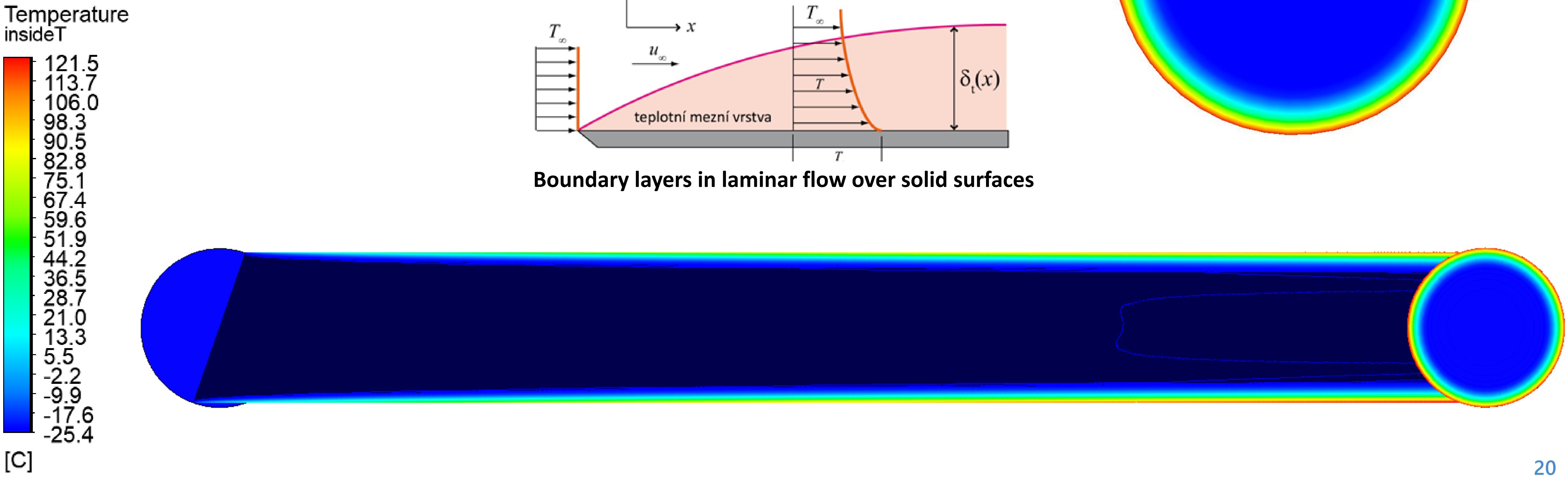
Temperature field

- **Pipe specification** - **L = 0,5 m**
  - **d = 0,008 m**
- **Heat flux = 91 735 W/m2**
- **Temperature difference = -23 °C**



Boundary layers in laminar flow over solid surfaces





Experiment analysis

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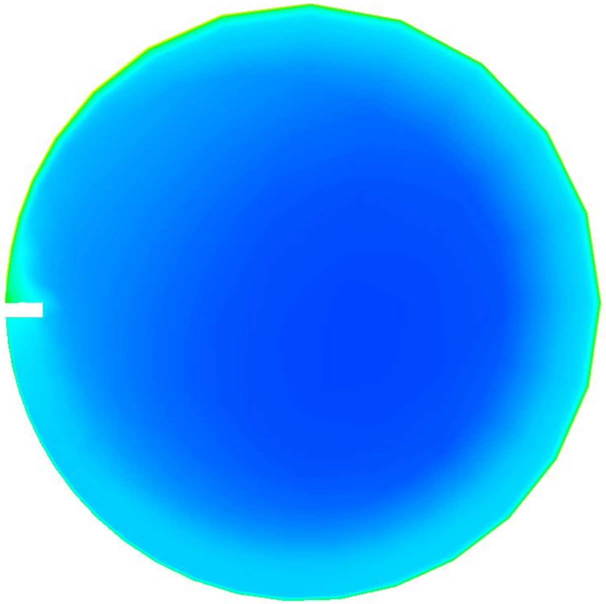
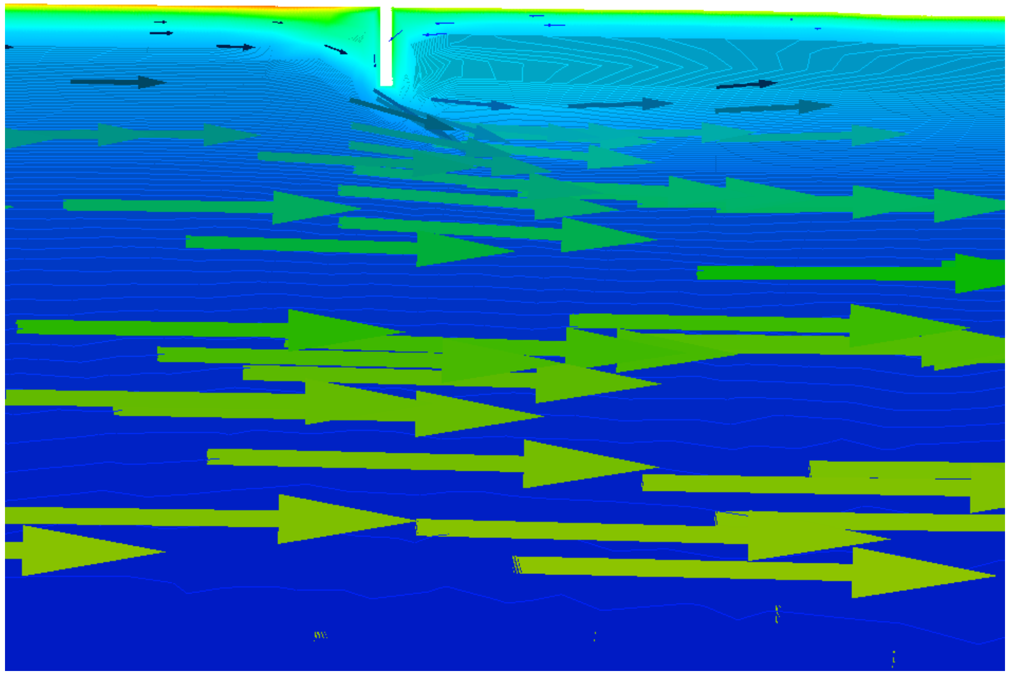
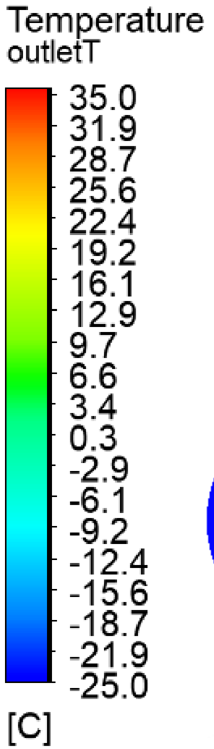
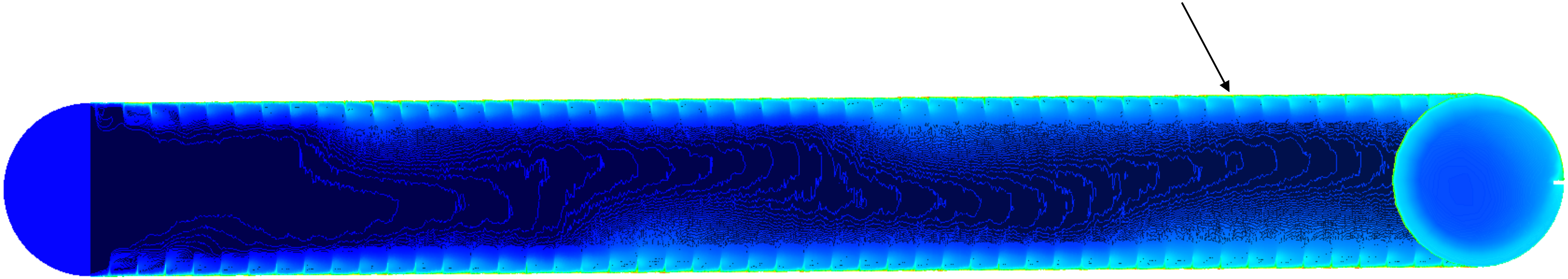
Temperature field

- **Pipe specification**
  - **L = 0,5 m**
  - **d = 0,008 m**
- **Heat flux = 91 735 W/m2**
- **Temperature difference = -7 °C**









Experiment analysis

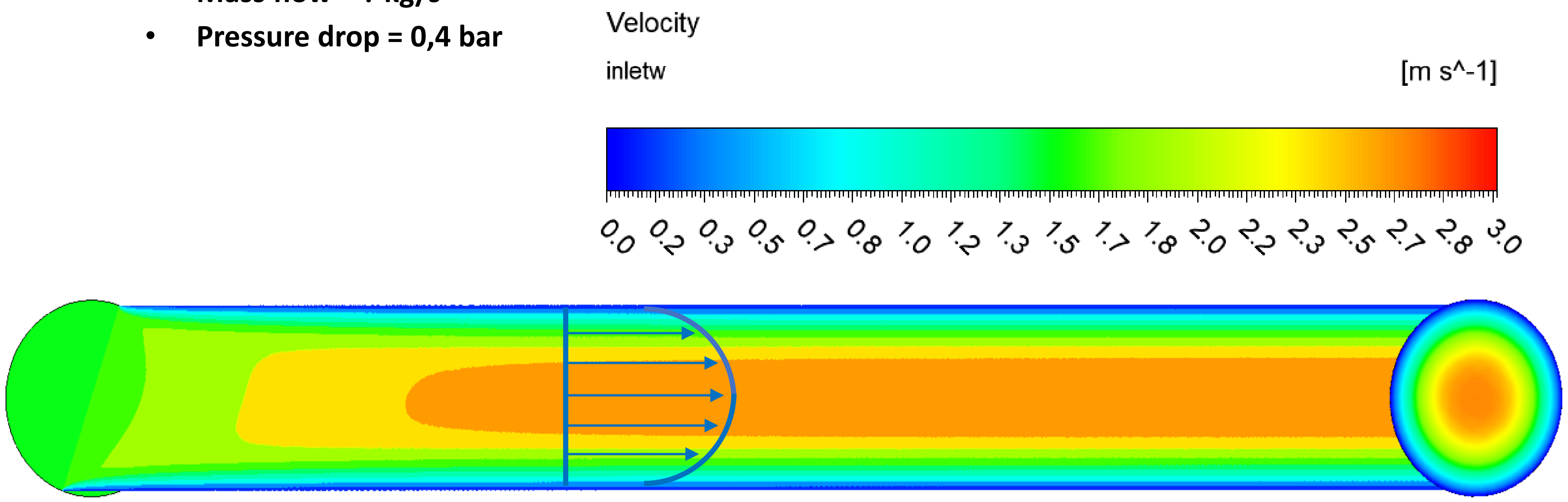
Velocity field

CFD

- **Mass flow = 0,07 kg/s**
- **Pressure drop = 0,042 bar**

Experiment

- **Mass flow = ? kg/s**
- **Pressure drop = 0,4 bar**



Experiment analysis

Velocity field

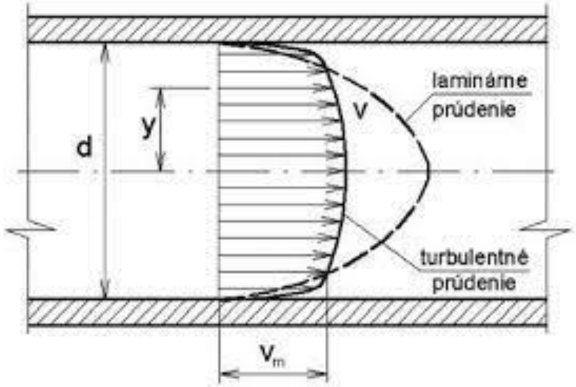
CFD

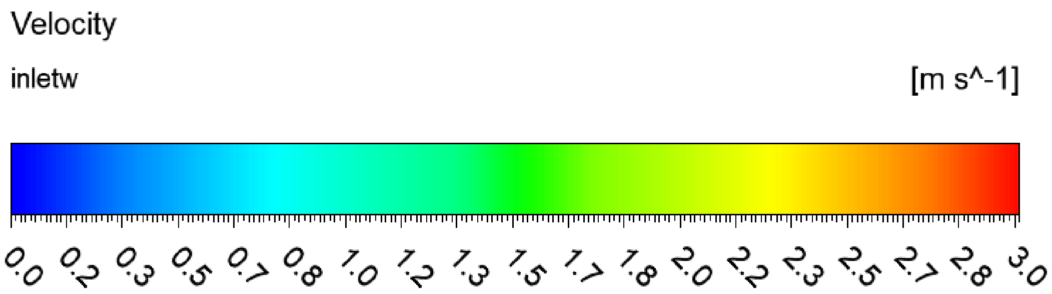
- **Mass flow = 0,07 kg/s**
- **Pressure drop = 0,082 bar**

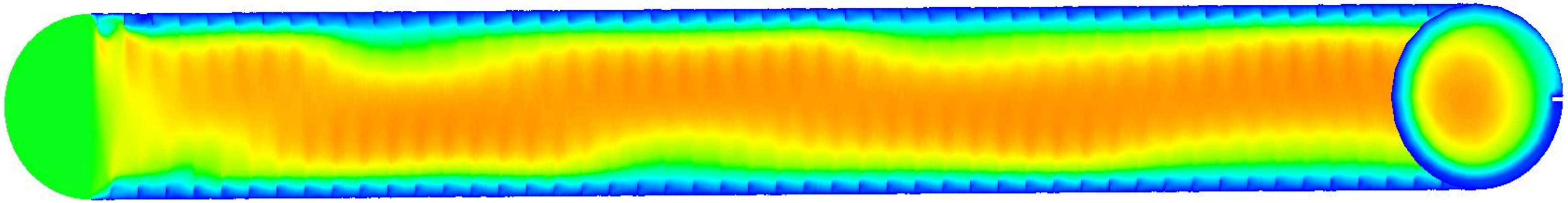
Experiment

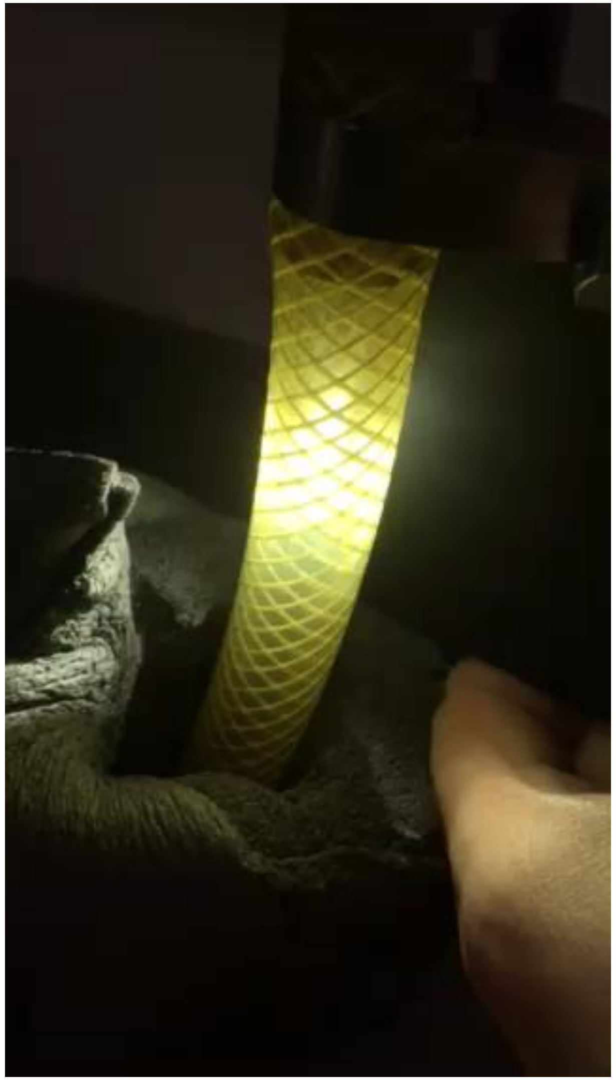
- **Mass flow = ? kg/s**
- **Pressure drop = 0,7 bar**
- Add velocity sensor
- Check for leakage

Difference between turbulent and laminar velocity profiles





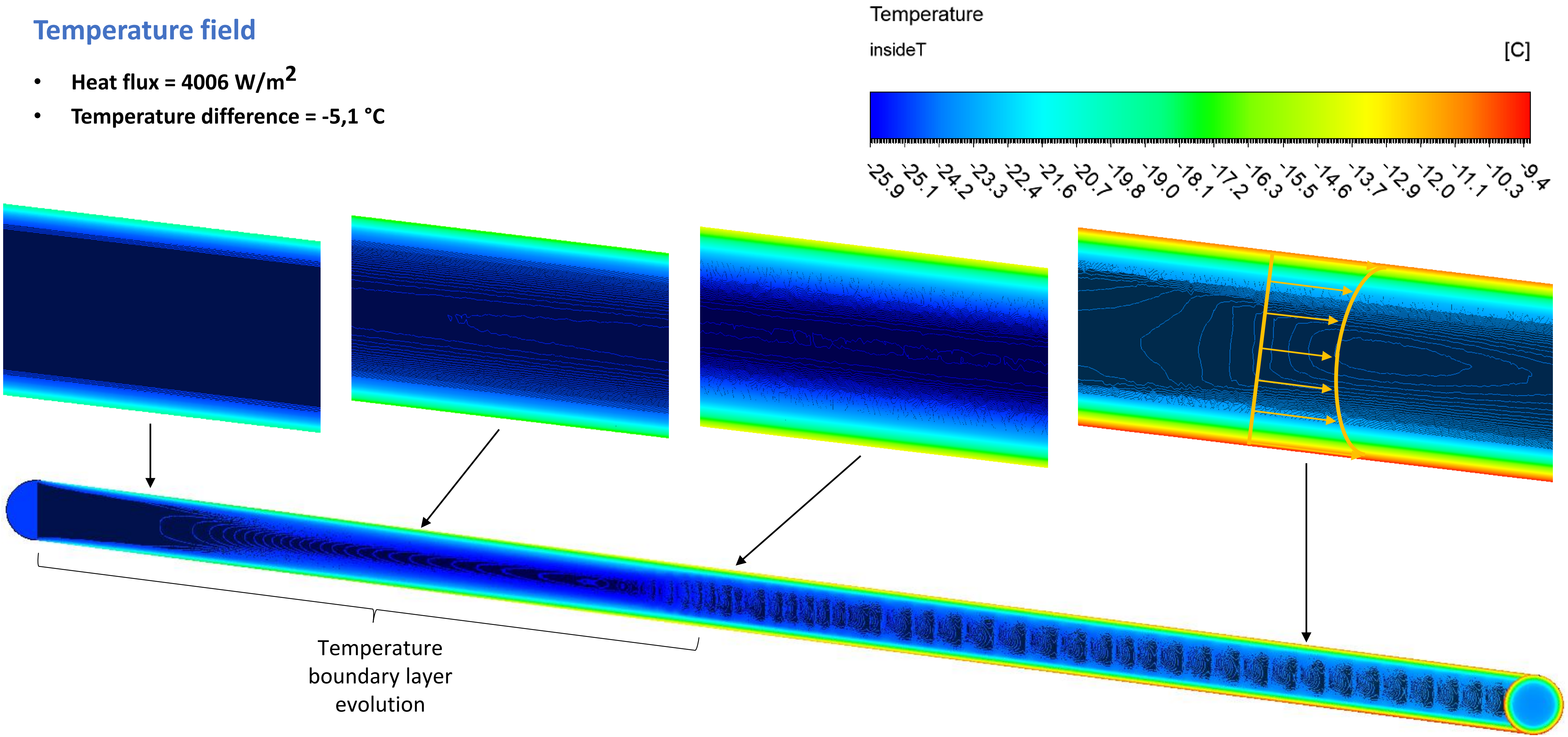




Experiment analysis

Temperature field

- **Heat flux = 4006 W/m^2**
- **Temperature difference = -5,1 °C**



Experiment analysis

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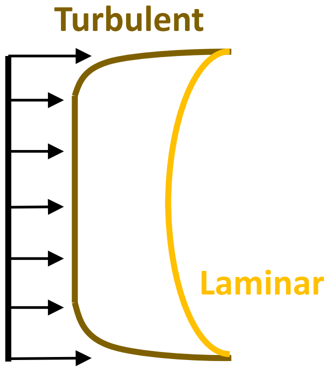
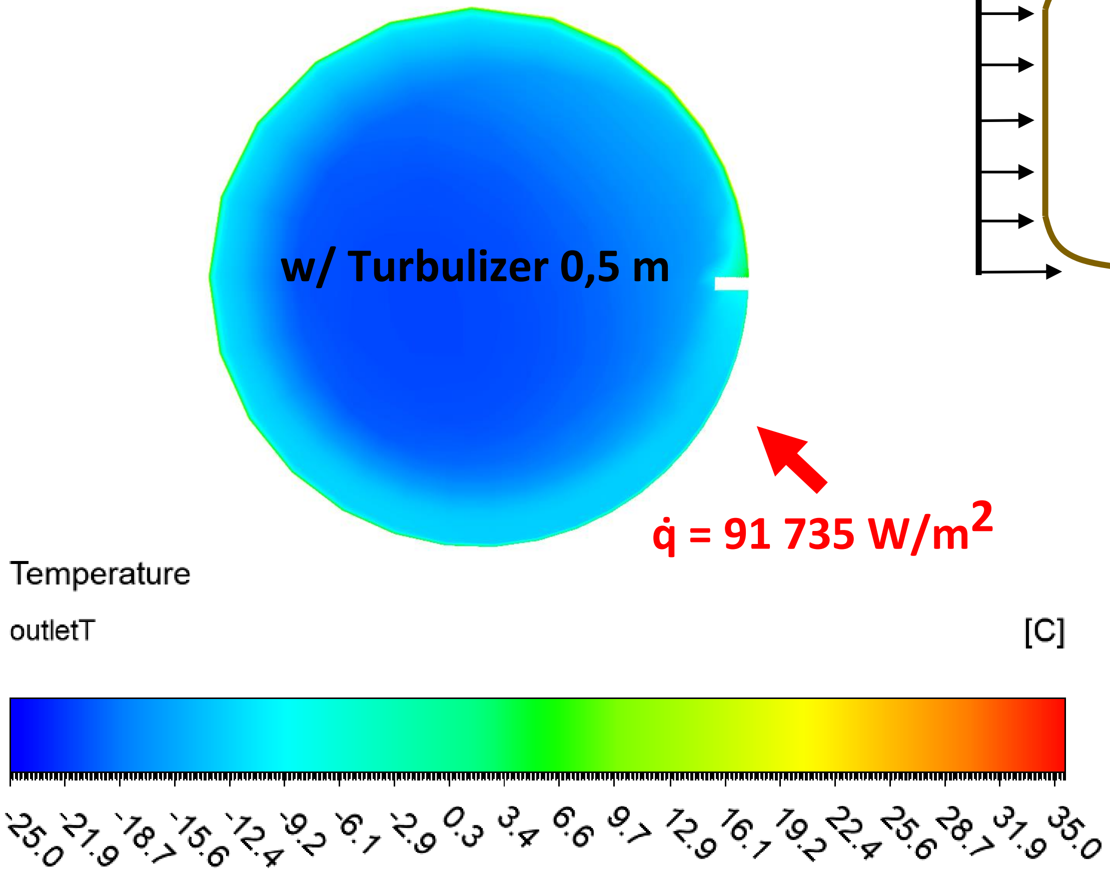
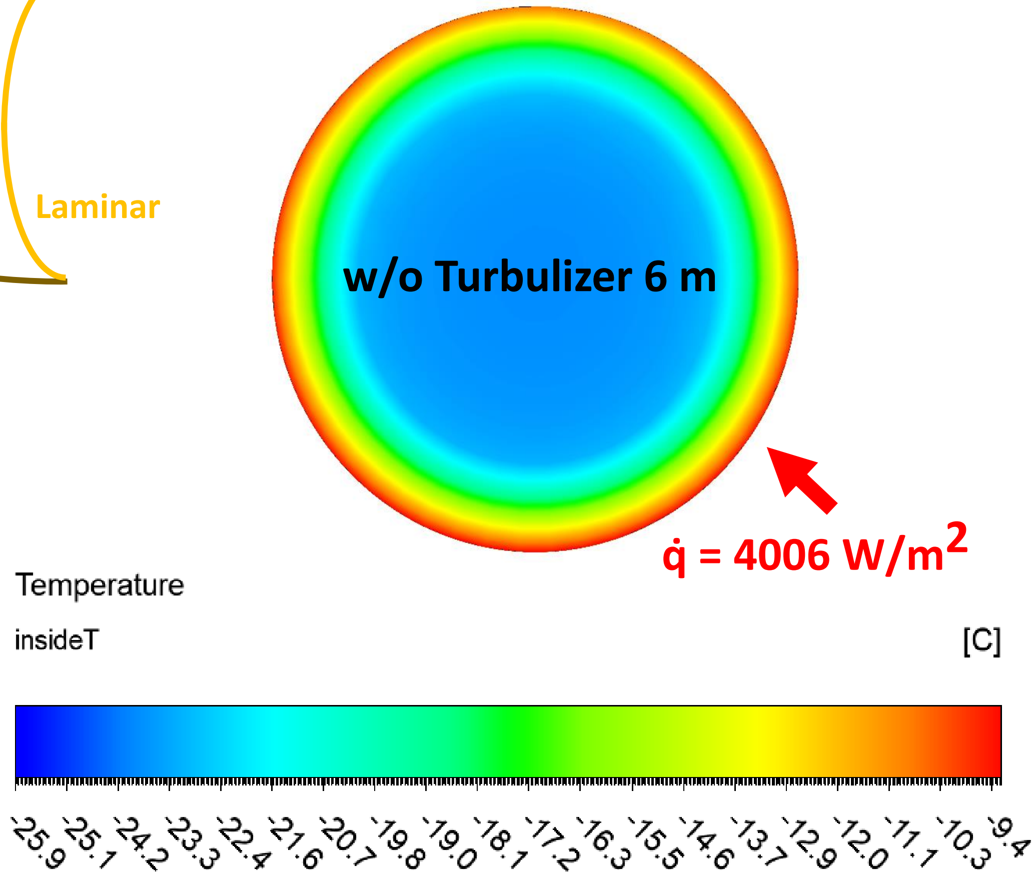
Temperature field

- **Slice heat source = 1162 W**
- **Set the same heat flux**

Difference between turbulent and laminar temperature profiles



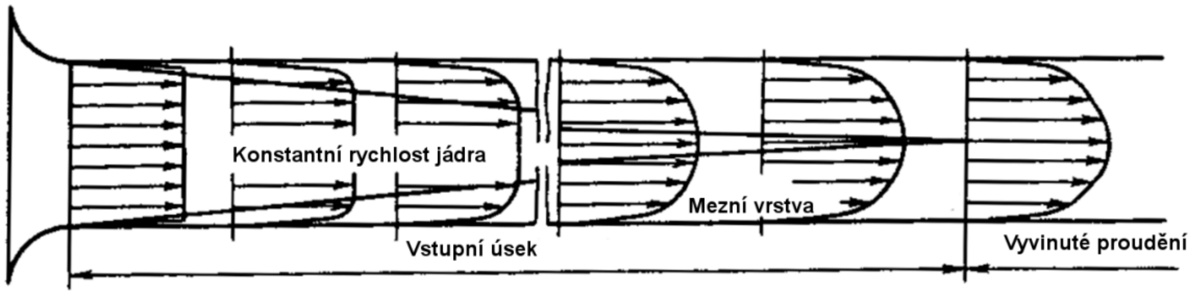


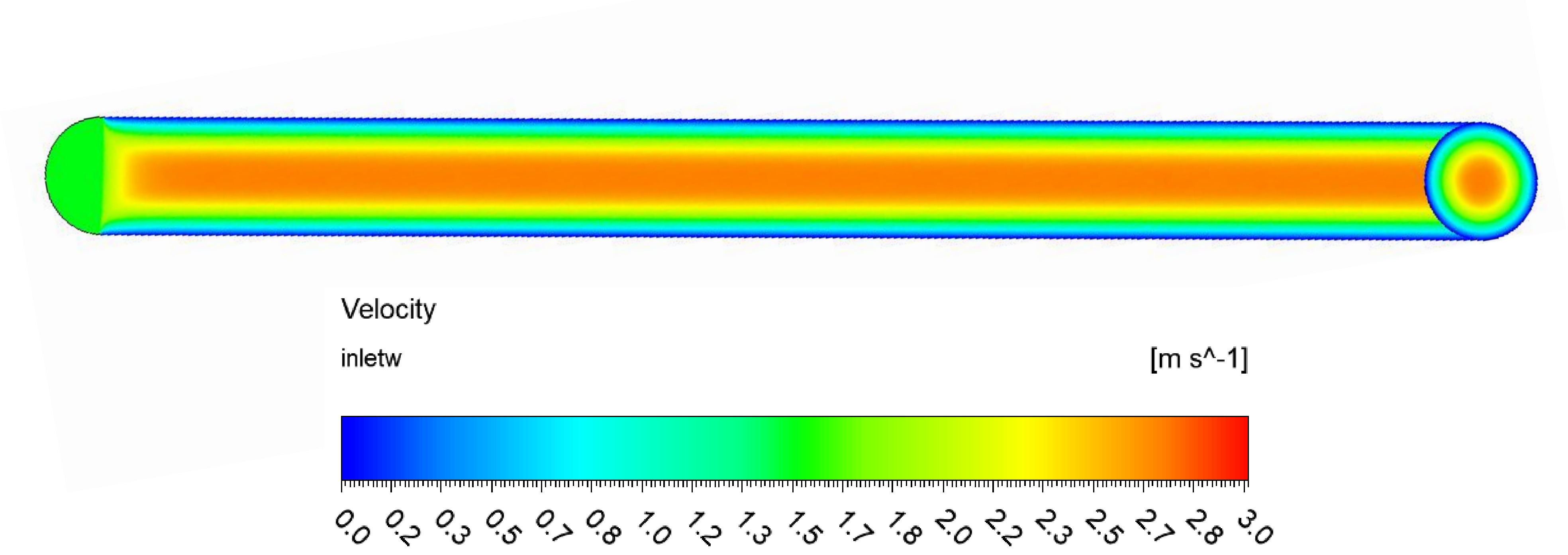


Velocity field

CFD

- **Mass flow = 0,07 kg/s**
- **Pressure drop = 0,374 bar**





Experiment analysis

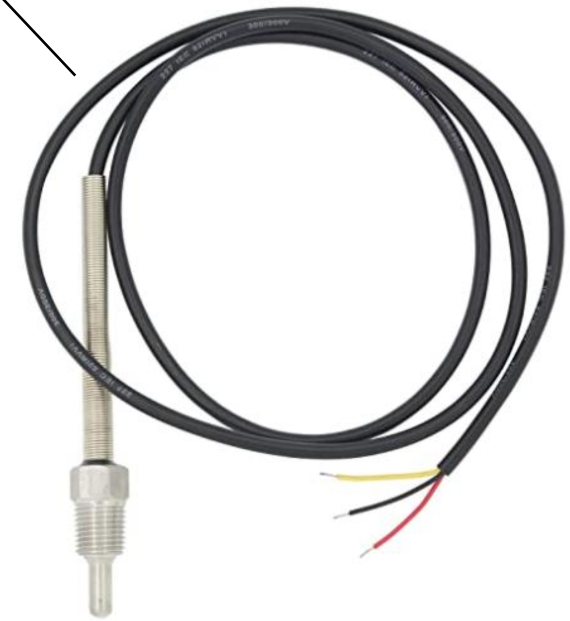
Turbulizer design summary

CFD

- Simulation of a 6 m long pipe with a turbulizer and the same heat flux
- Simulation of whole cycle

Experiment

- We can use temperature sensors next to the flow, but this will affect the flow, needing pipes of greater length. We probably need to make the pipes longer
- The turbuliser appears to turbulate only the temperature boundary layer
- It is possible to run a water/methanol coolant.
- We can add sight glass



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Thank you for your attention

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