PAUL SCHERRER INSTITUT

COMSOL CONFERENCE
2016 MUNICH

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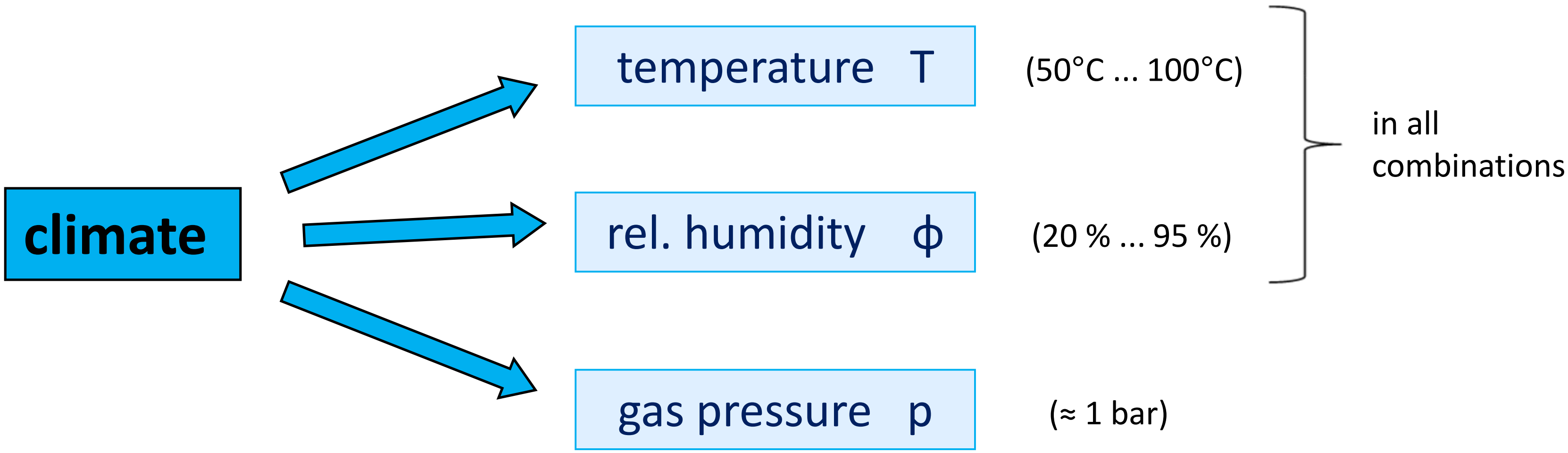
Climate Chamber with Fast Humidity and Temperature Response for Small-angle Neutron Scattering

Technical specification: Climate elements

Climate inside the chamber



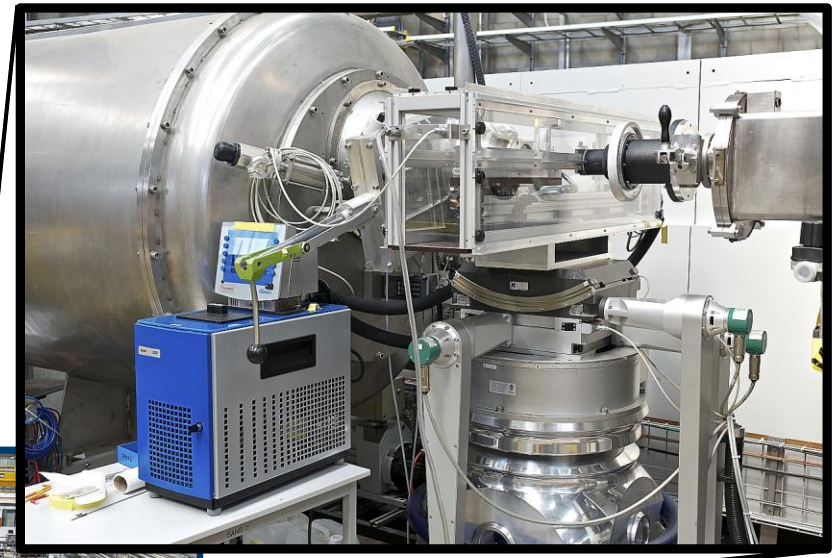
required precision:

ΔT = ± 1°C
Δϕ = ± 2 %

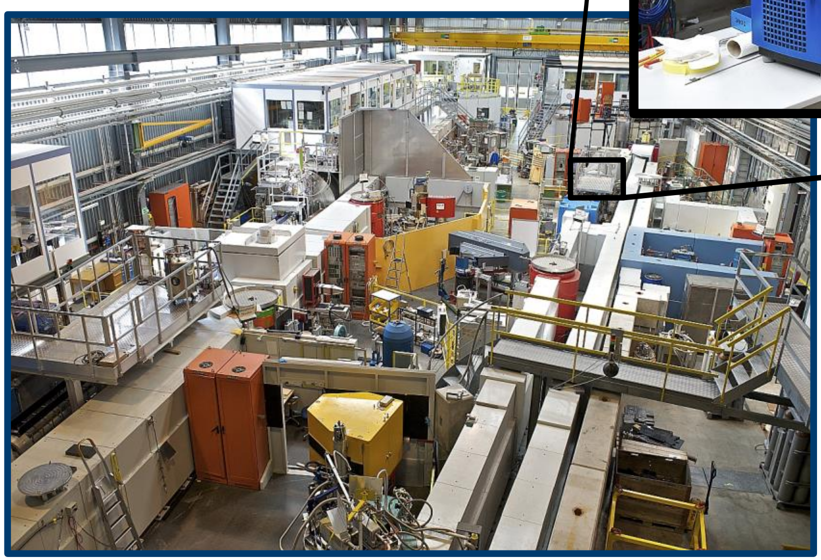
Our Application

Small-angle Neutron Scattering (SANS)

The instrument :

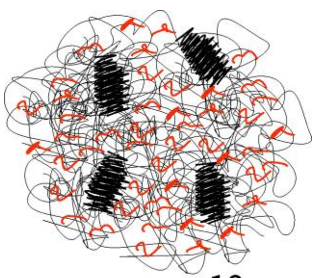


Neutron guide hall



SINQ

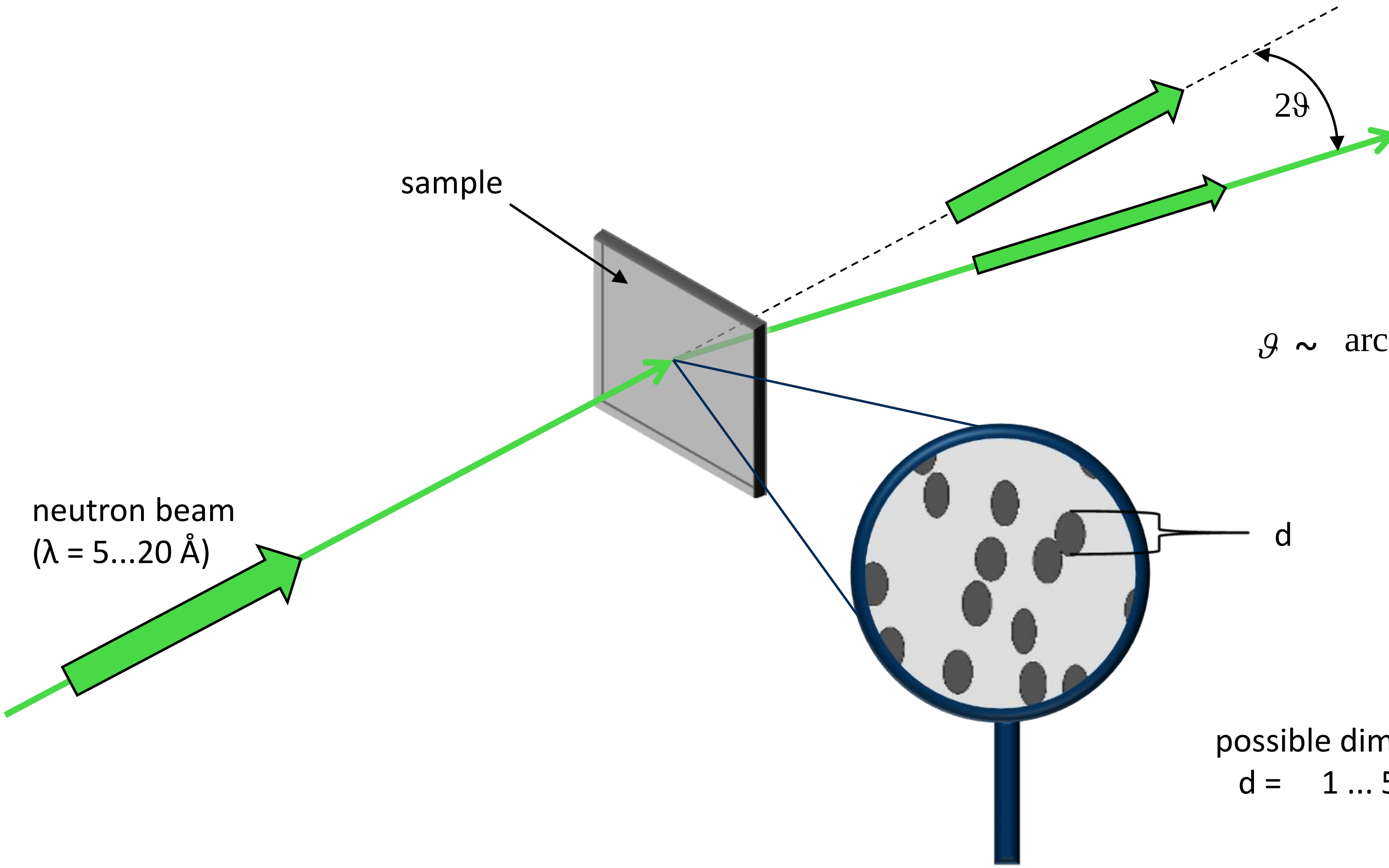
Sample example



Our Application

Small-angle Neutron Scattering (SANS)

The principle :



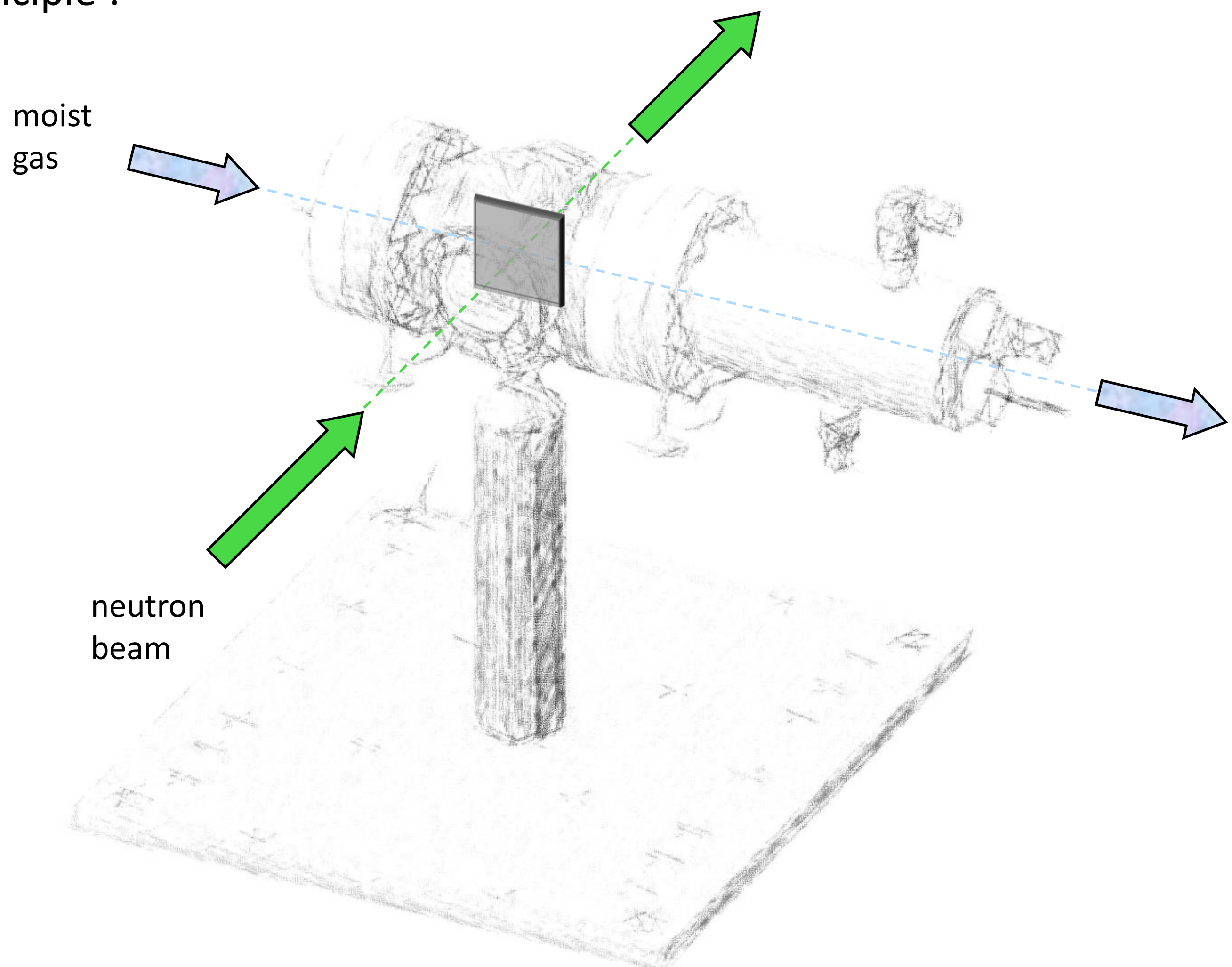
$$\vartheta \sim \arcsin\left(\frac{1}{d}\right)$$

possible dimensions:
d = 1 ... 500 nm

Experimental setup

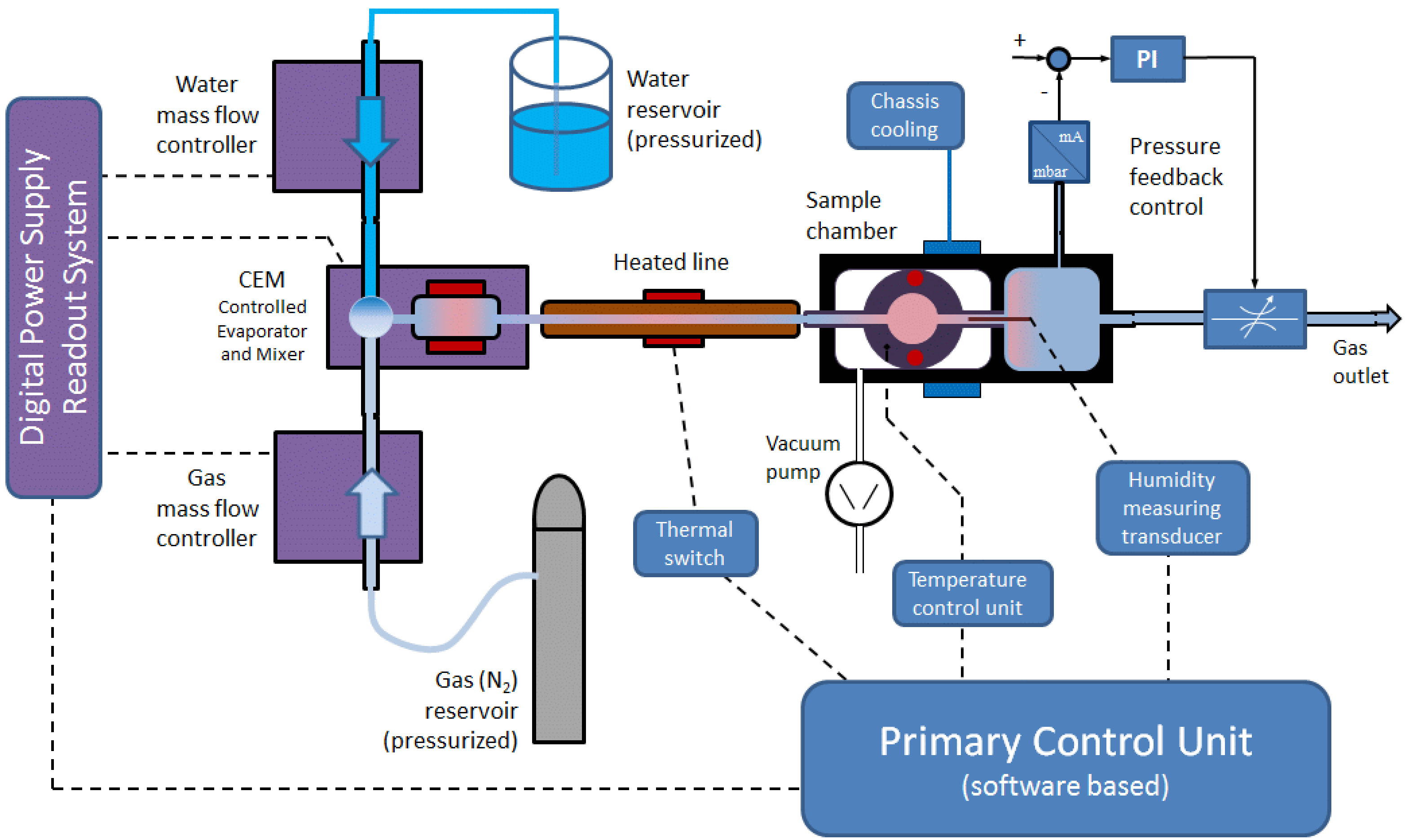
Experimental setup with device sketch

The principle :



System overview

Climate chamber system

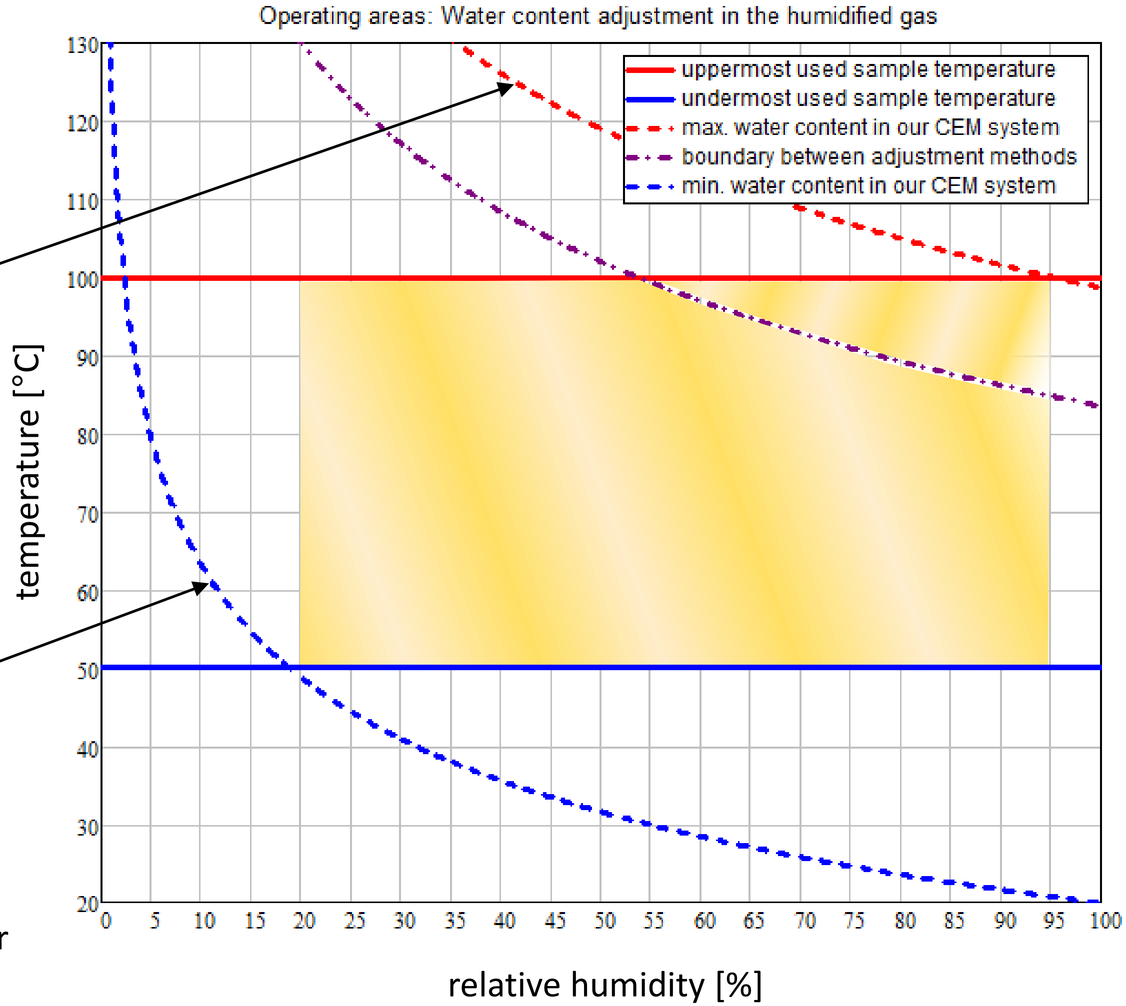


Operation overview

Operating area and limits , Curves with constant water content

max.
water content
$X_{CEM.max}$ = 6.000

min.
water content
$X_{CEM.min}$ = 0.014



$$\frac{X_{CEM.\max}}{X_{CEM.\min}} = 428$$

$p_{process}$ = 1070 mbar

Operation overview

Water content (= moisture content x_{vap})

water content (mixing ratio)

$$X = \frac{m_{water}}{m_{dry.gas}}$$

Relative humidity

$$\phi = \frac{p_{w.vap}}{p_{w.vap.sat}}$$

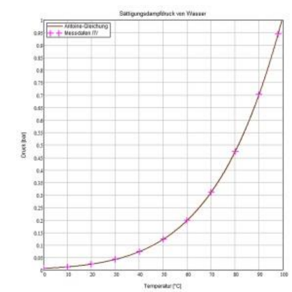
Ideal gas law

$$p_{w.vap} \cdot V = m_{w.vap} \frac{R_{uni}}{M_{water}} \cdot T$$

$$p_{dry.gas} \cdot V = m_{dry.gas} \frac{R_{uni}}{M_{dry.gas}} \cdot T$$

$$X(p,T,\phi) = \frac{M_{water}}{M_{dry.gas}} \cdot \frac{p_{w.vap.sat}(T)}{\frac{p}{\phi} - p_{w.vap.sat}(T)}$$

(main equation)



Partial pressure sum

$$p = \sum p_i = p_{w.vap} + p_{dry.gas}$$

Vapor pressure of water

$$\log\left(\frac{p_{w.vap.sat}}{bar}\right) = 5.19625 - \frac{1730.630}{233.426 + \frac{T}{°C}}$$

(Antoine equation for 1 -100°C)

p – pressure [bar]

T – temperature [°C]

ϕ – rel. humidity (RH)

M – molar mass

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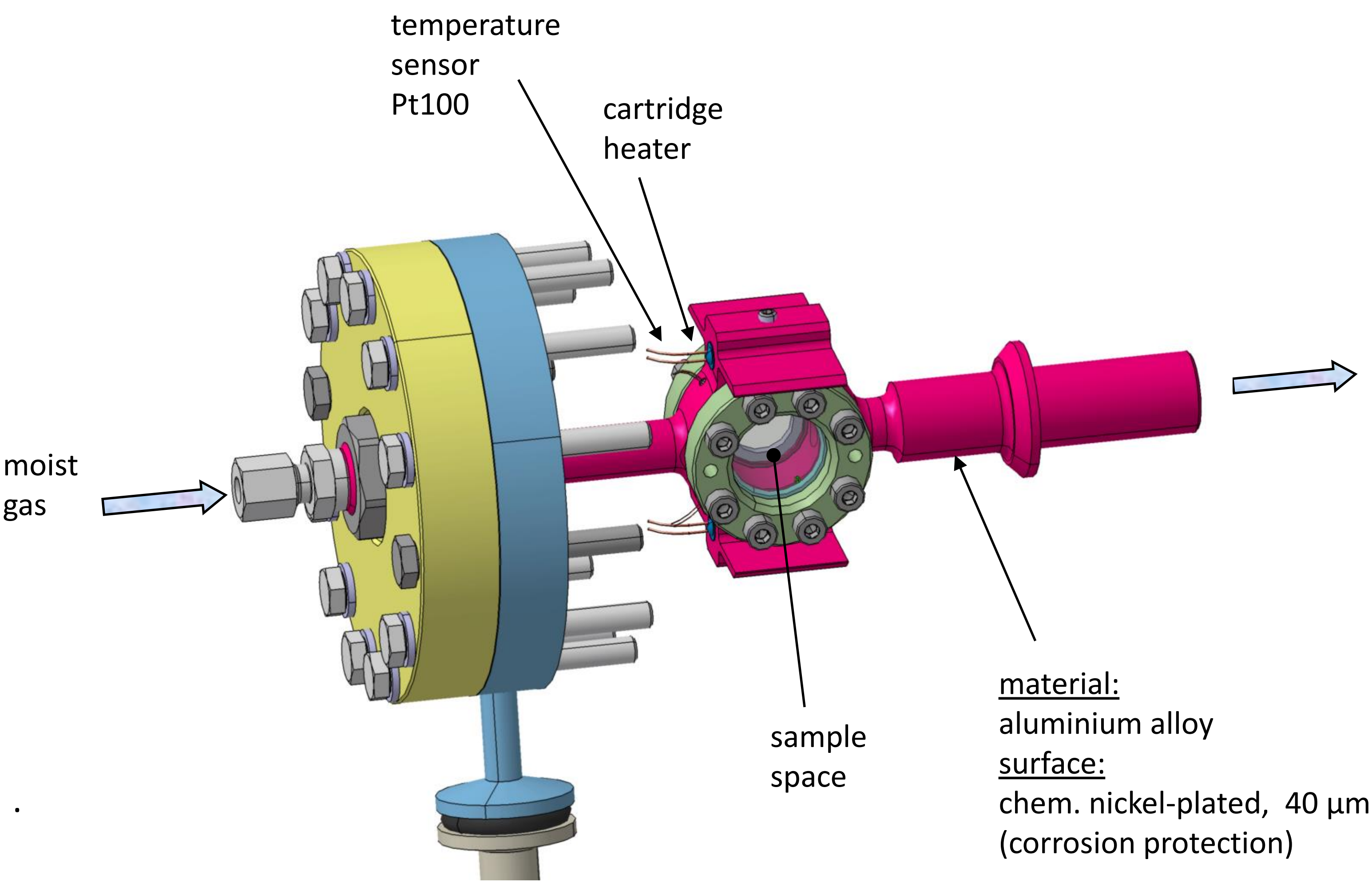
Device details

Internal chamber



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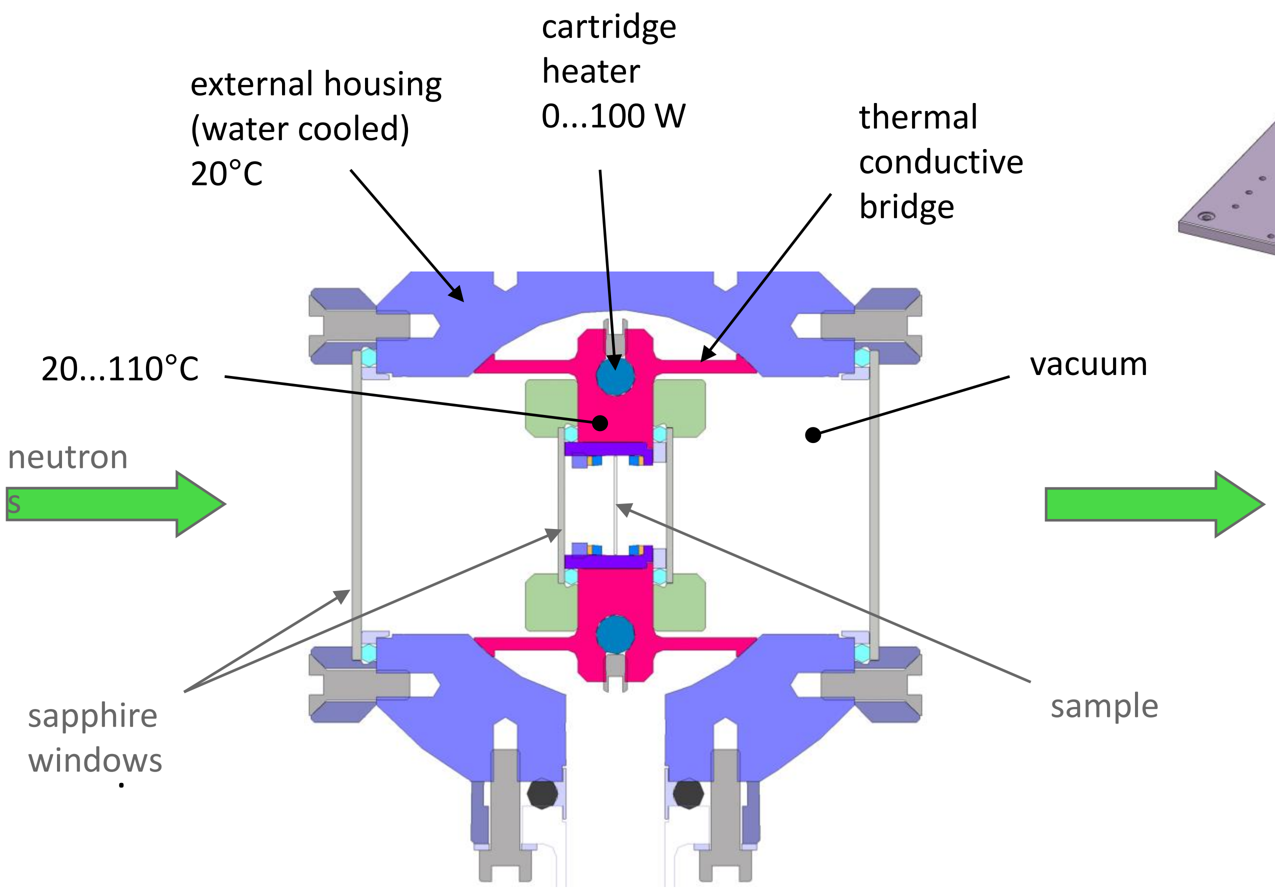
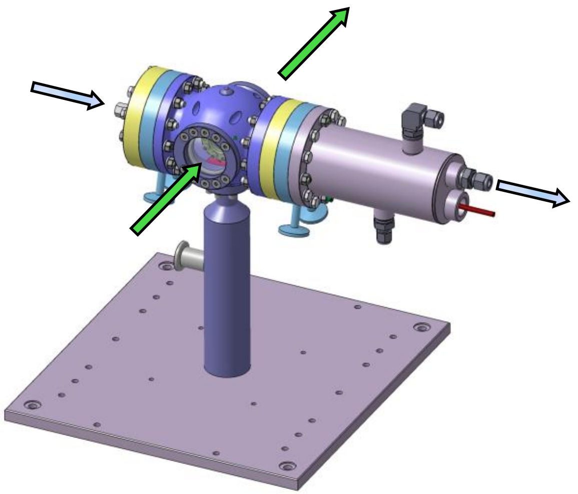
Device details

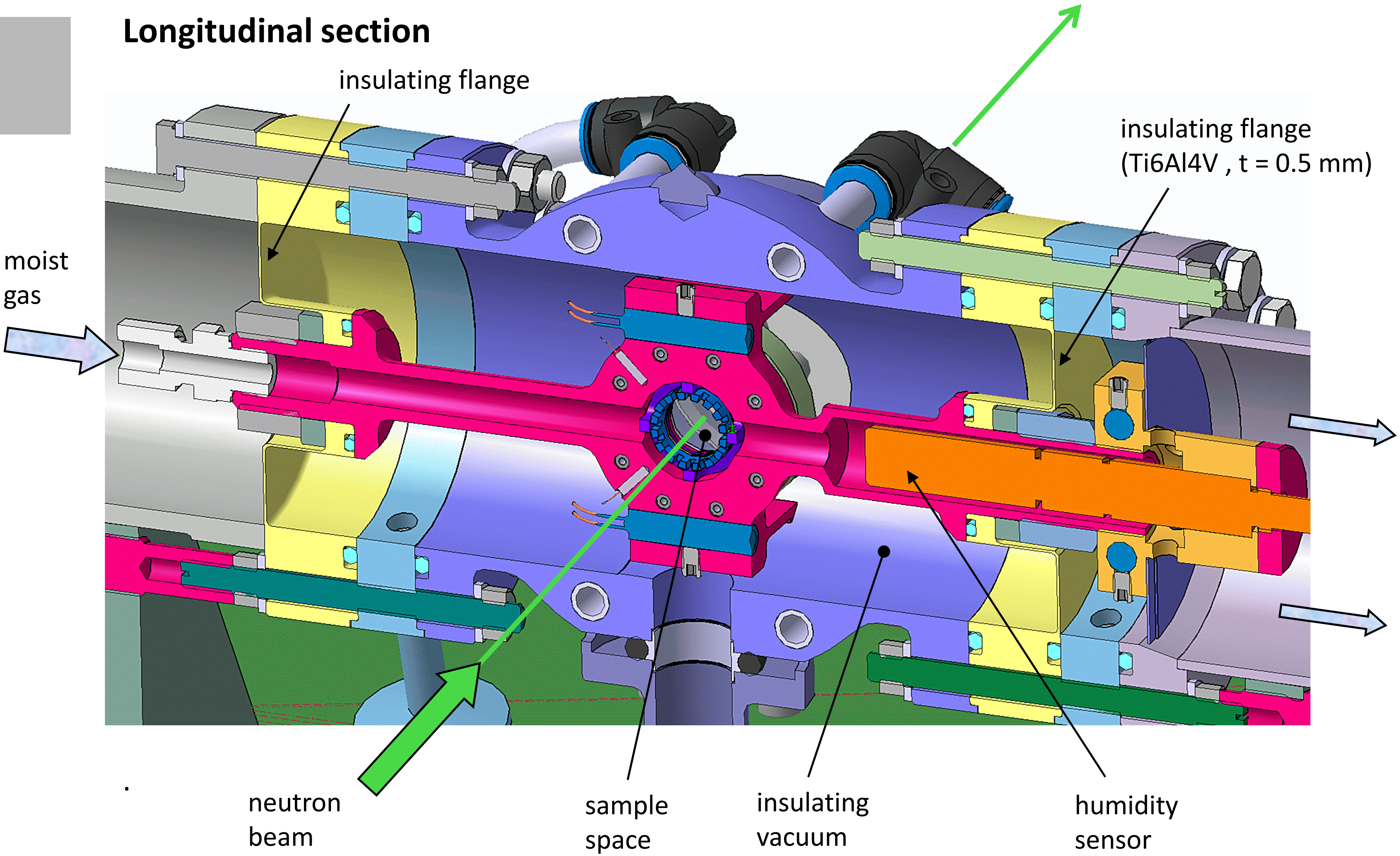
Fast heating & cooling the internal chamber





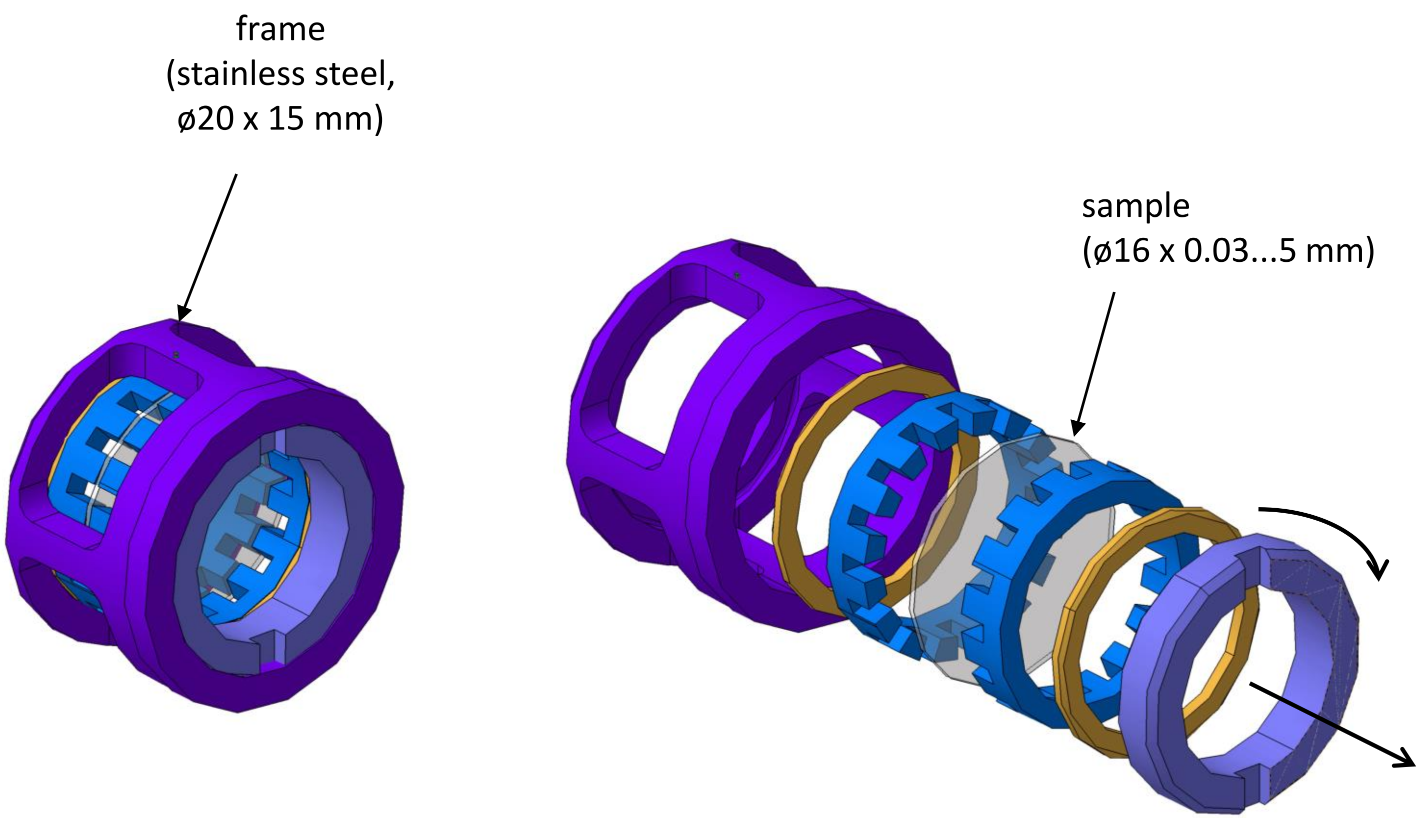
Device details

Longitudinal section



Device details

Sample holder



Design criteria

Our goals:

① Gas flow distribution
near the sample surface: as uniform as possible

② Climate precision: temperature $\Delta T =$ ± 1°C
rel. humidity $\Delta\phi =$ ± 2 %

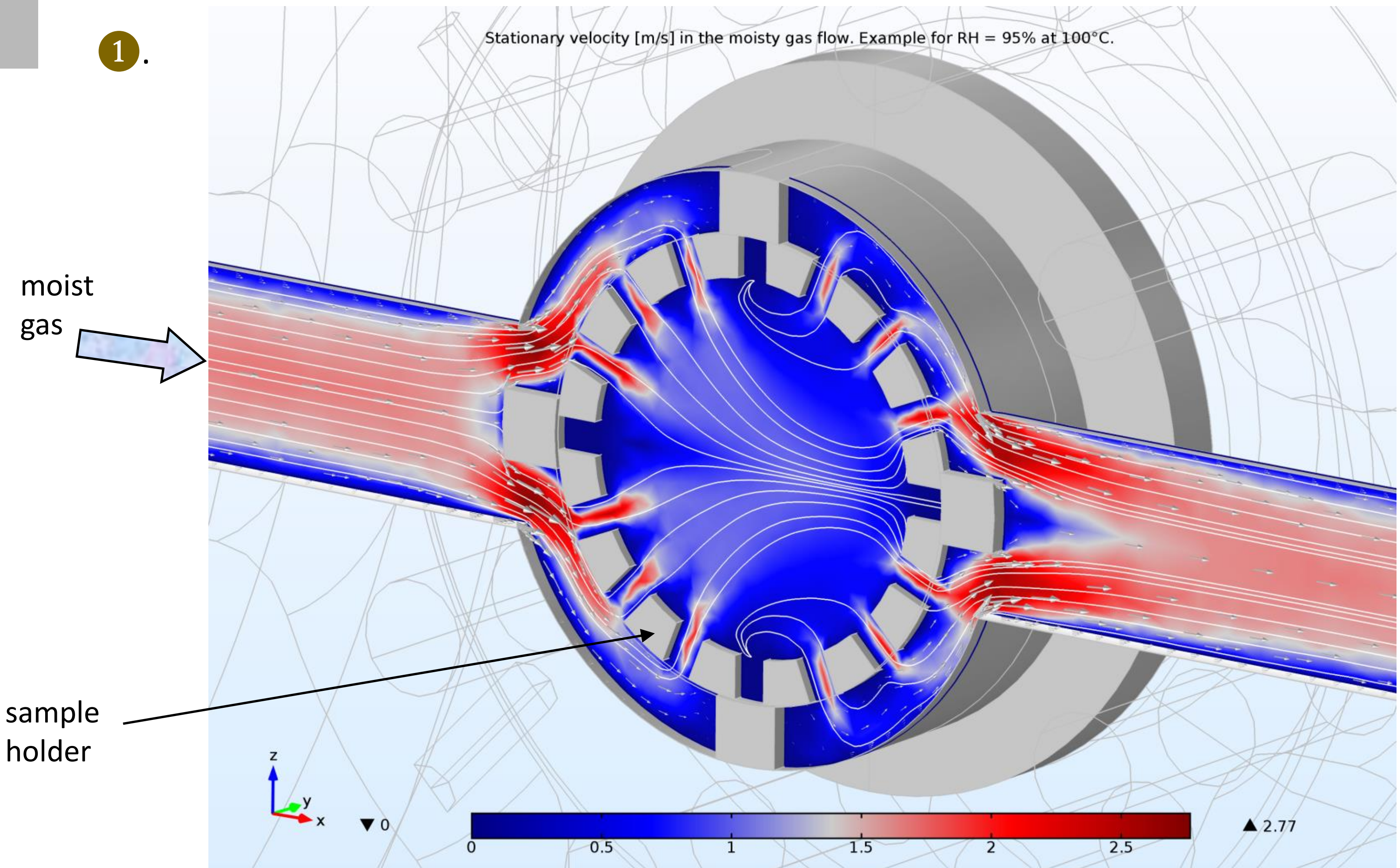
③ Change of temperature: time constants $T_{heating} \approx T_{cooling}$
→ improved temperature controllability

④ Change of climate: as fast as possible

Stationary velocity distribution

Example with moisty gas flow for ϕ = 95% at 100°C

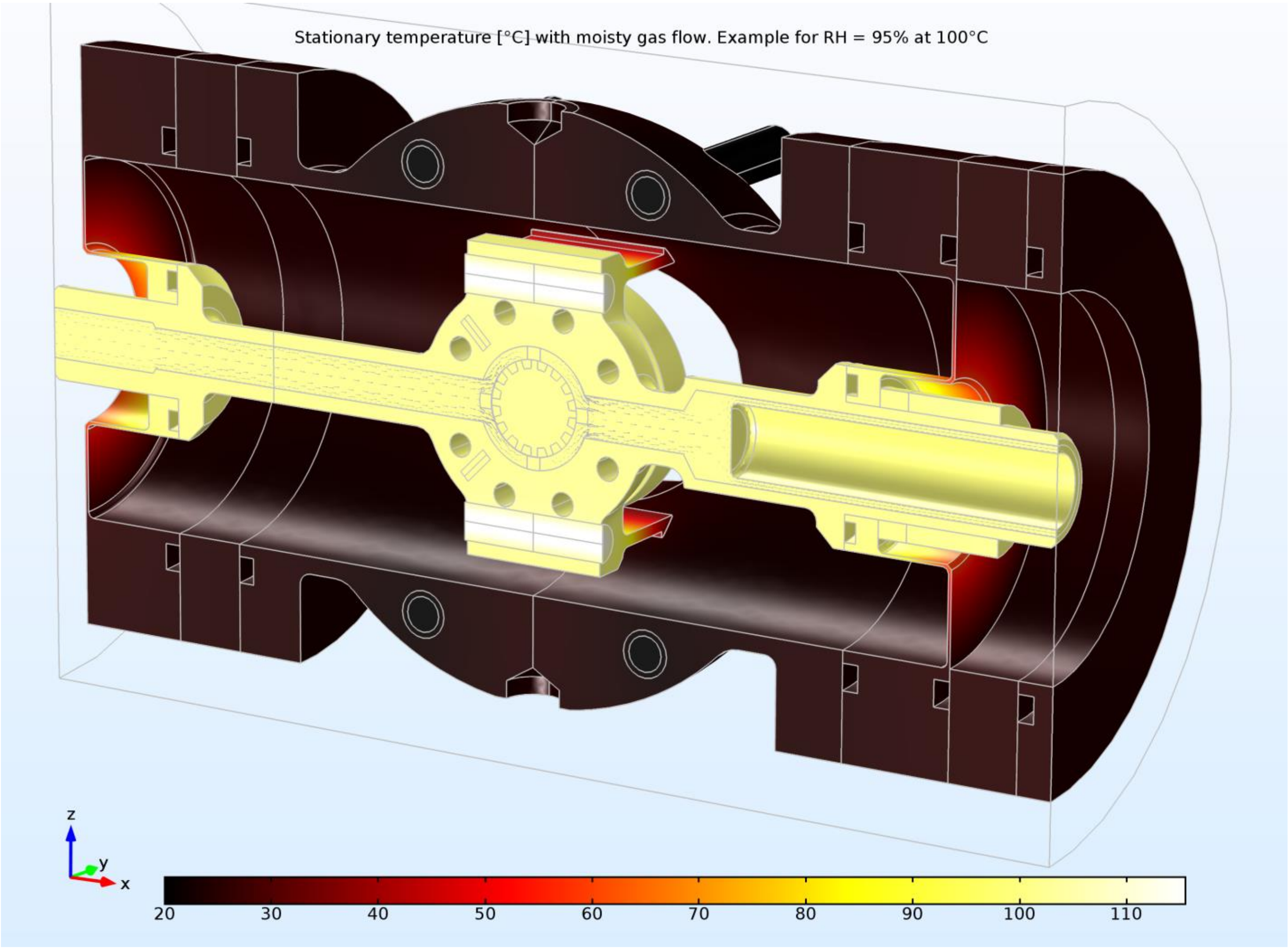
1.



Stationary temperature distribution

Example with moisty gas flow for ϕ = 95% at 100°C

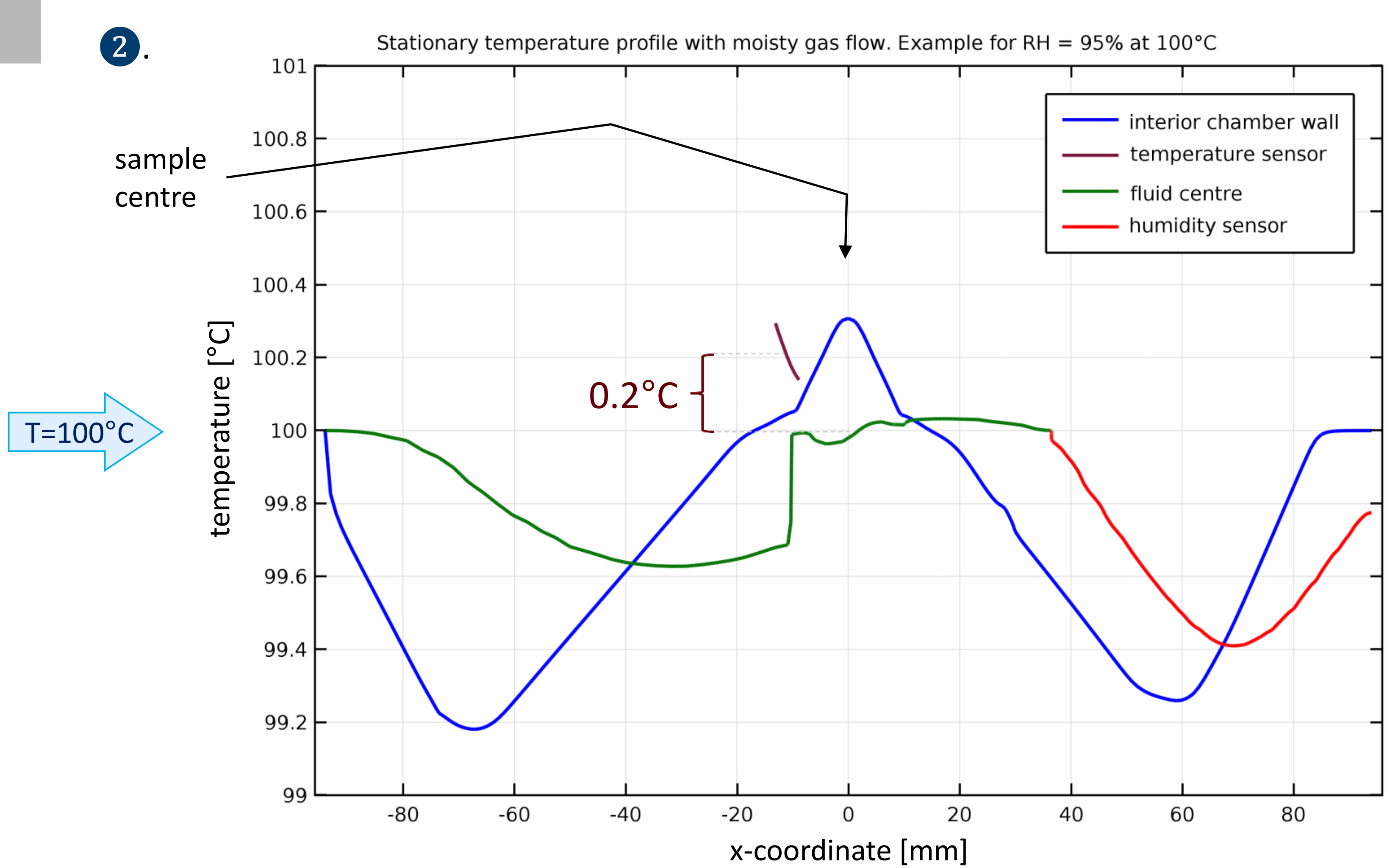
❷.



Stationary temperature distribution

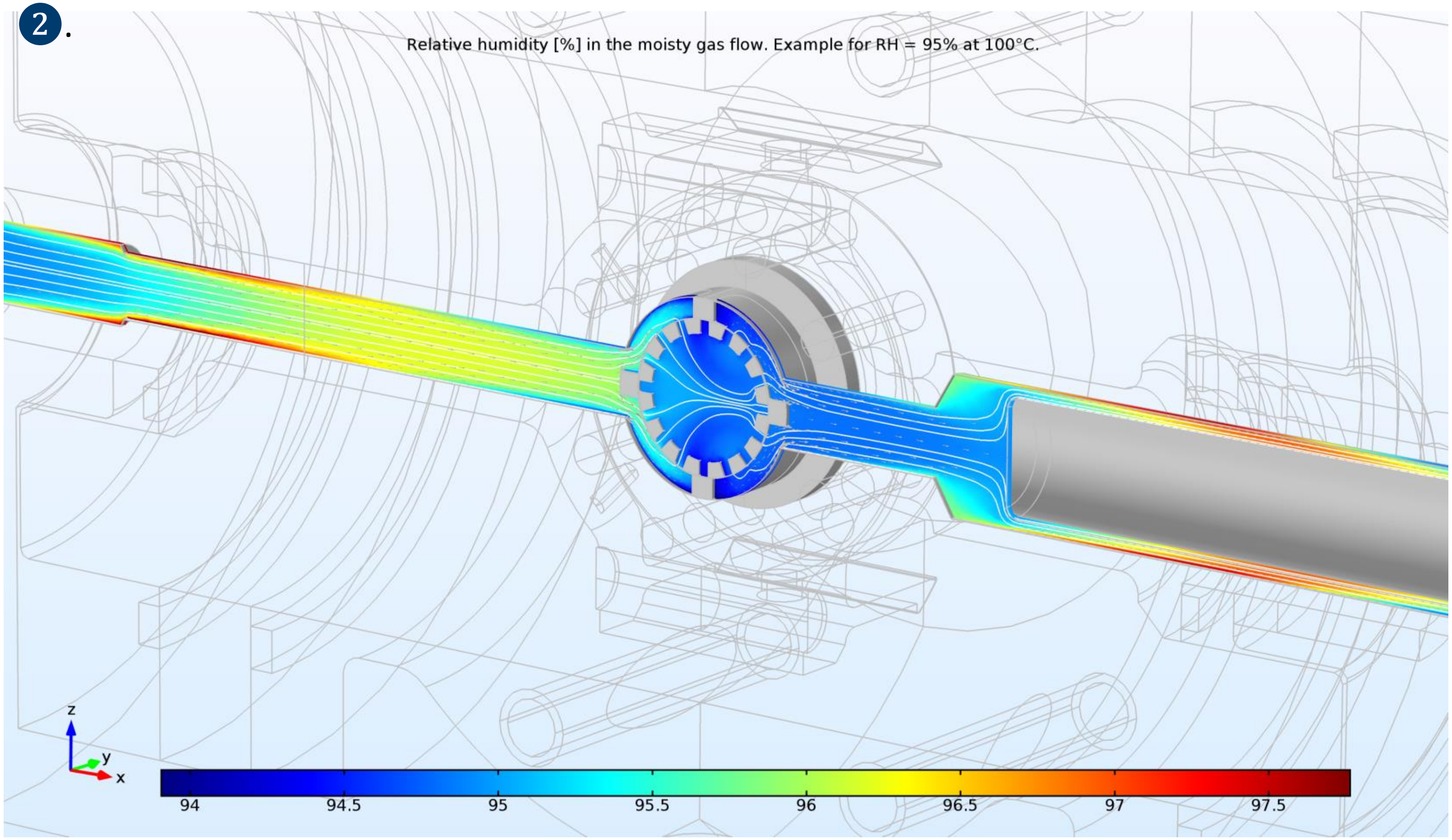
Temperature scan in gas flow direction (x-axis) , climate: ϕ = 95% at 100°C

2.



Humidity distribution

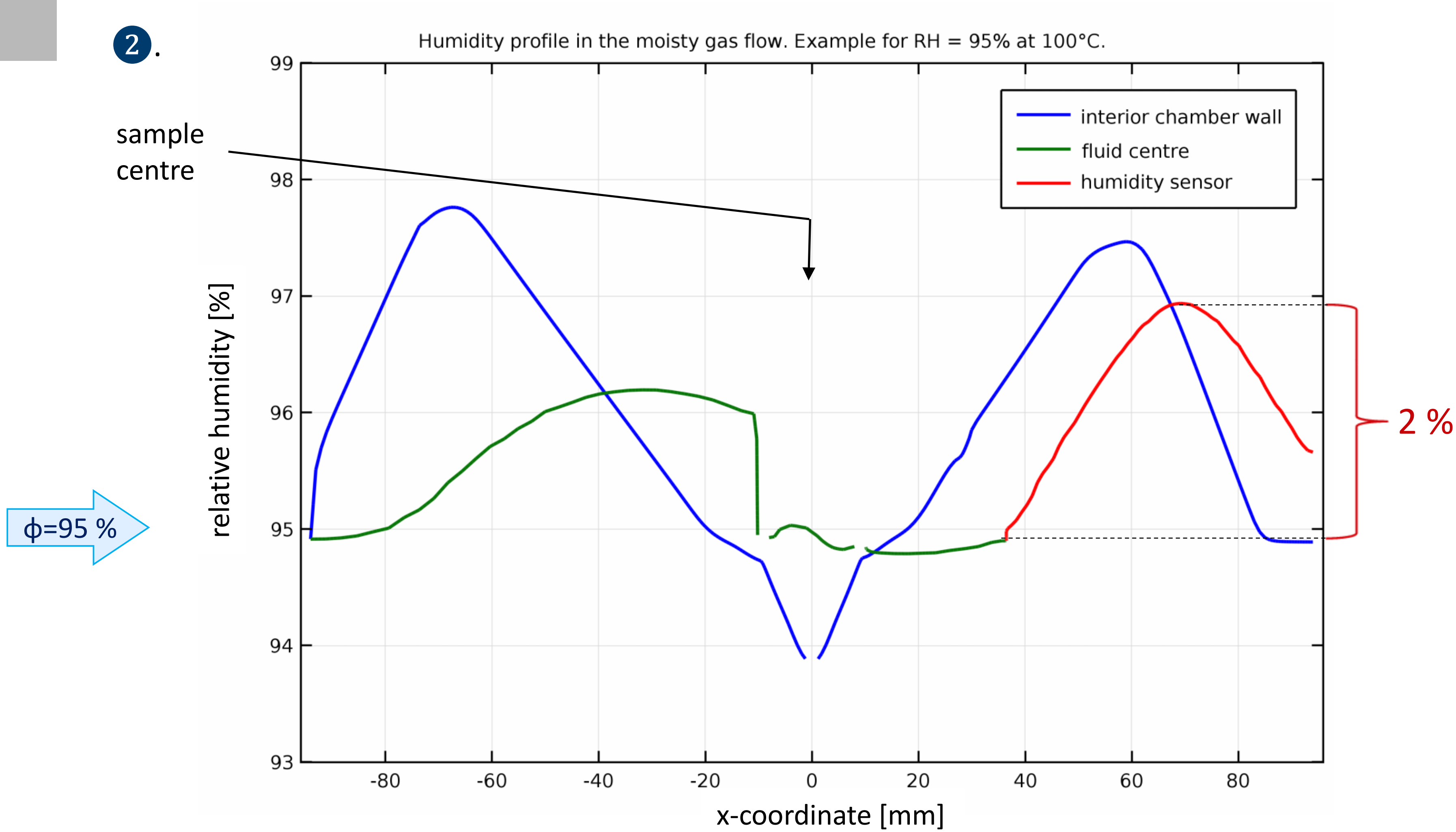
Example with moist gas flow for ϕ = 95% at 100°C



Humidity distribution

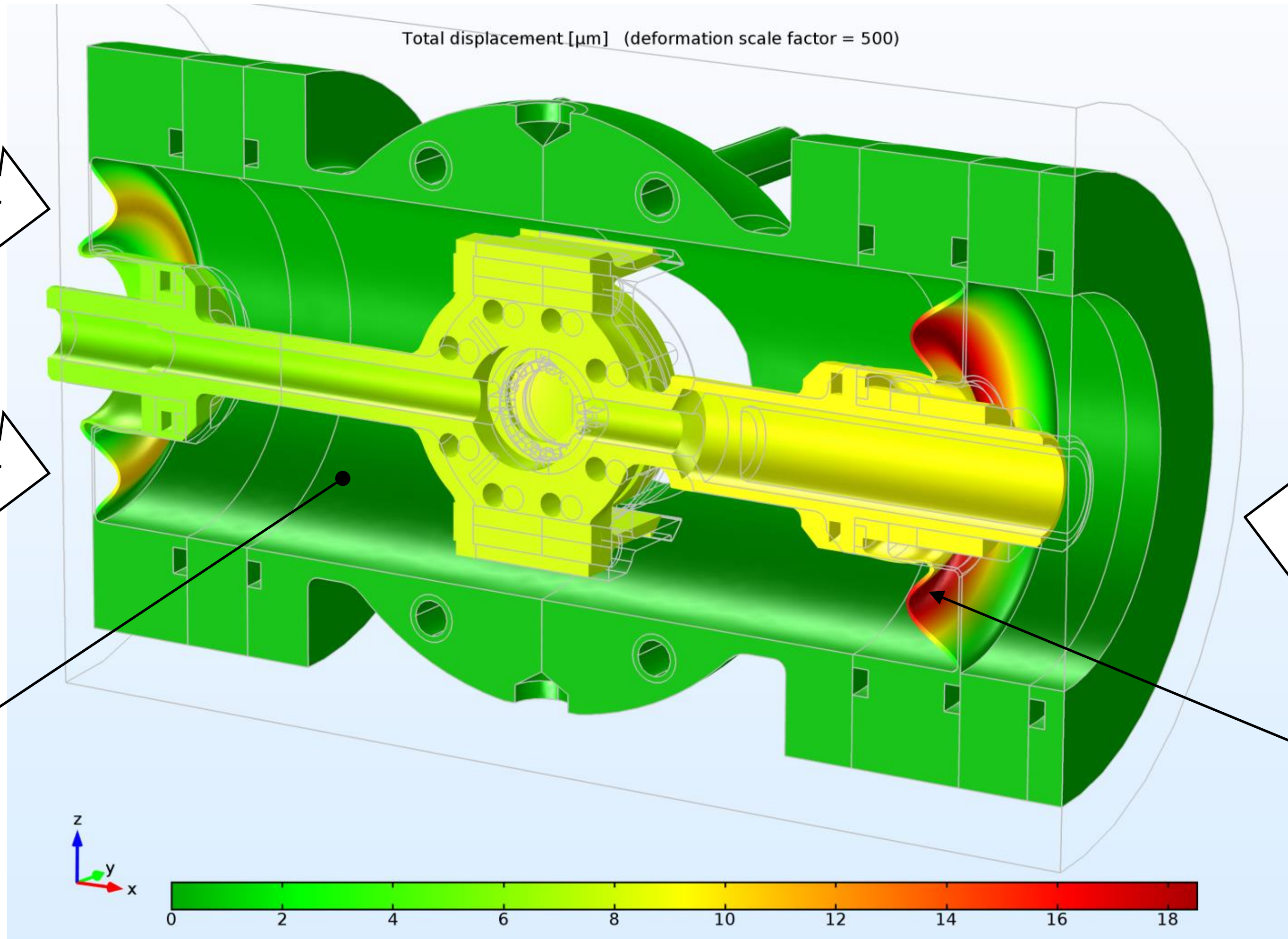
Humidity scan in gas flow direction (x-axis) , climate: ϕ = 95% at 100°C

❷.



Total displacement

Chamber with insulating vacuum, under process pressure, at 100°C



$p_{ambient}$
1013 mbar

$p_{ambient}$
1013 mbar

$p_{process}$
1070 mbar

insulating vacuum

max. 18 µm

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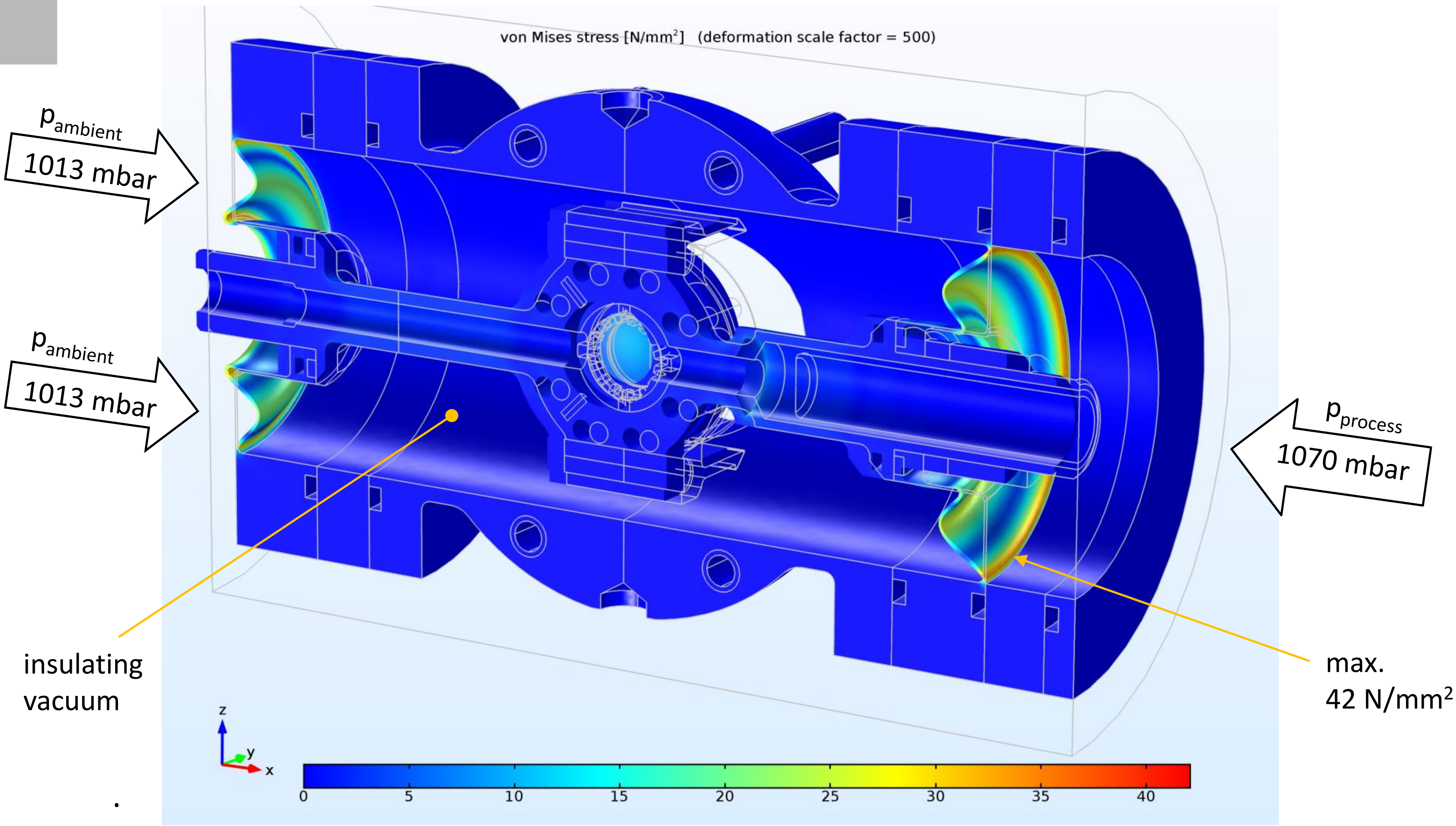
Mechanical stress

Chamber with insulating vacuum, under process pressure, at 100°C



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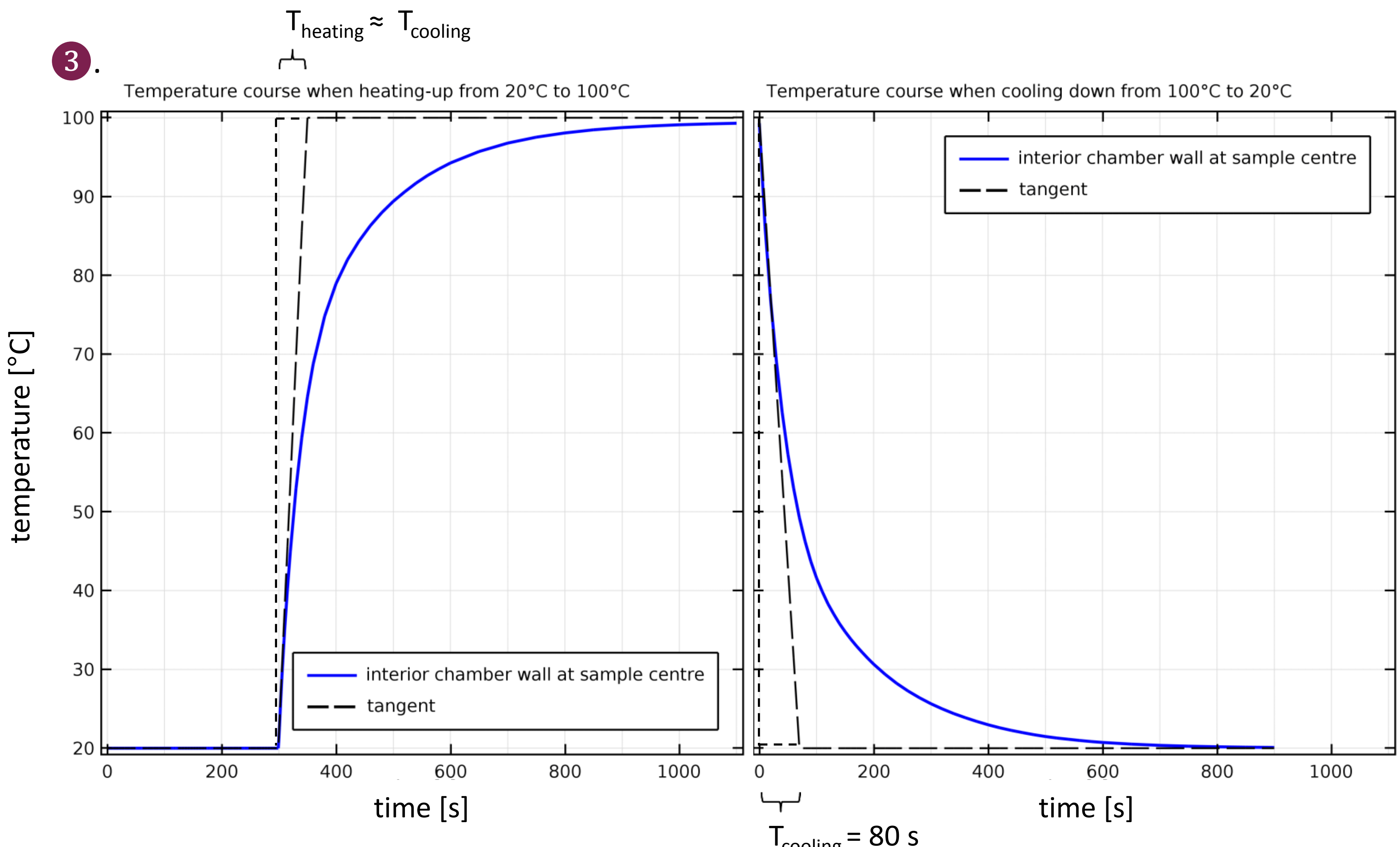
Temperature change

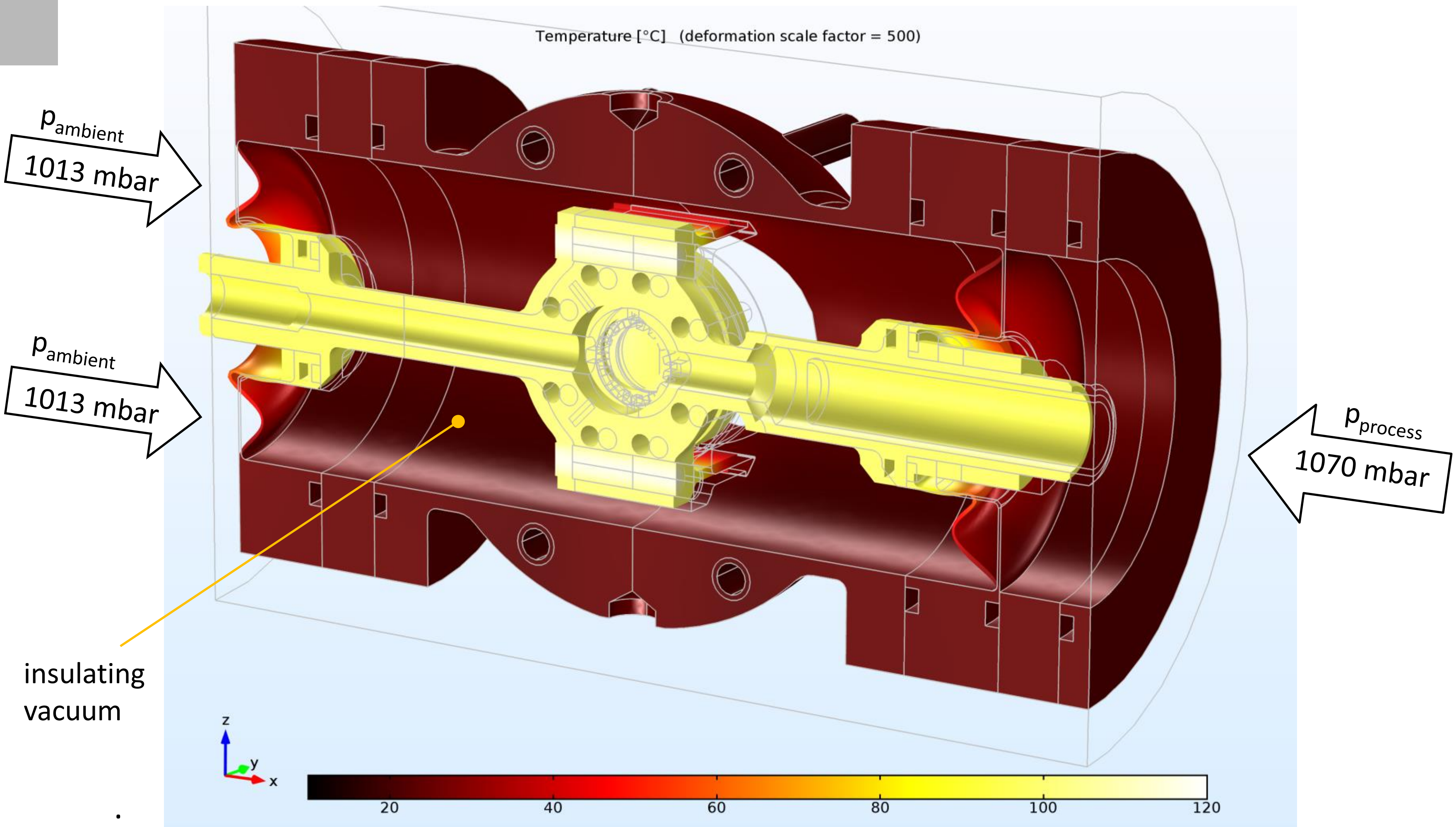
Step function response when heating-up or cooling-down

3.



Temperature distribution and displacement

Chamber with insulating vacuum, under process pressure, at 100°C



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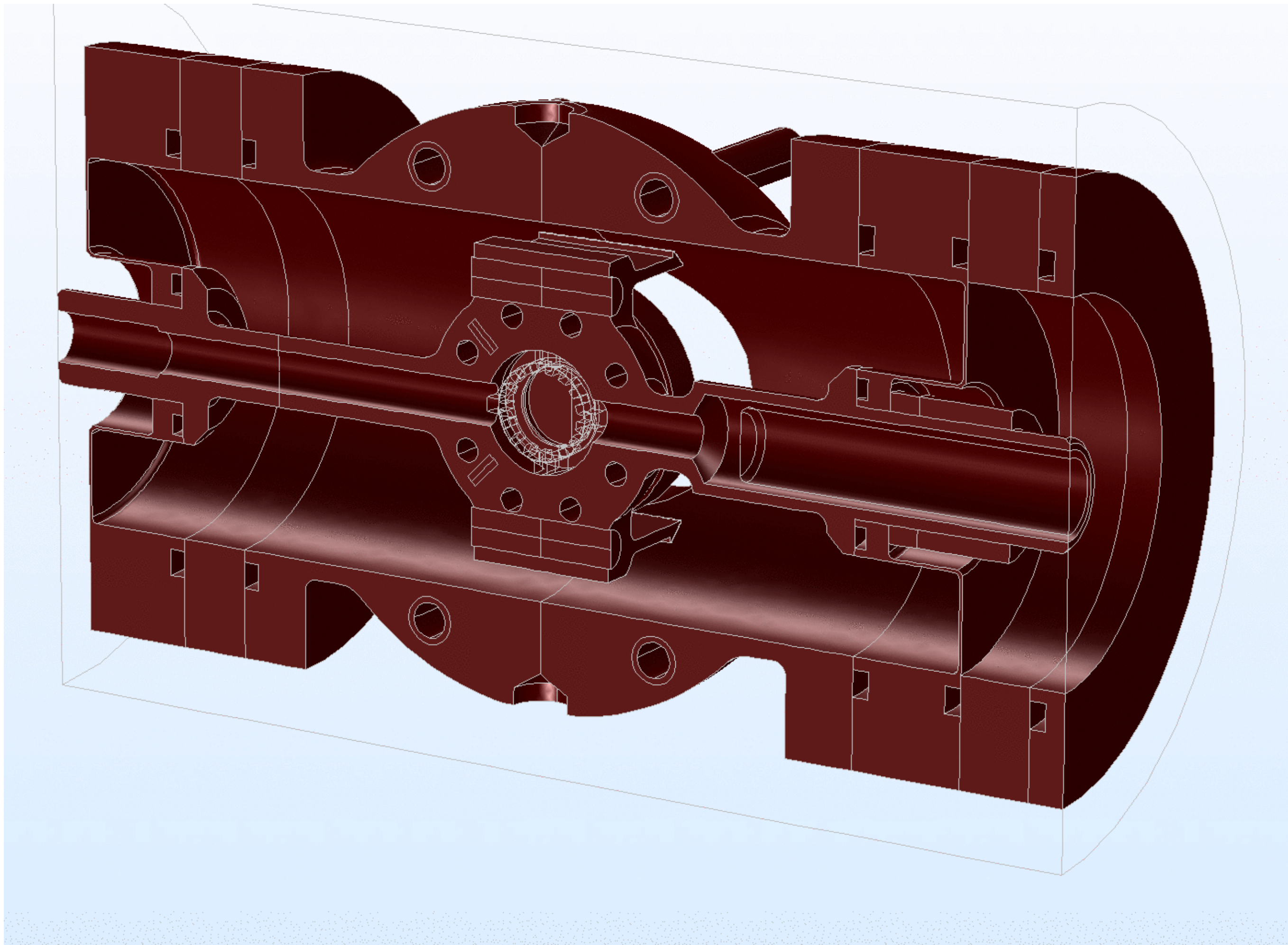
Animation

Starting sequence (insulating vacuum → process pressure → temperature change)



1. switch on vacuum pump

2. apply process pressure

3. set sample temperature

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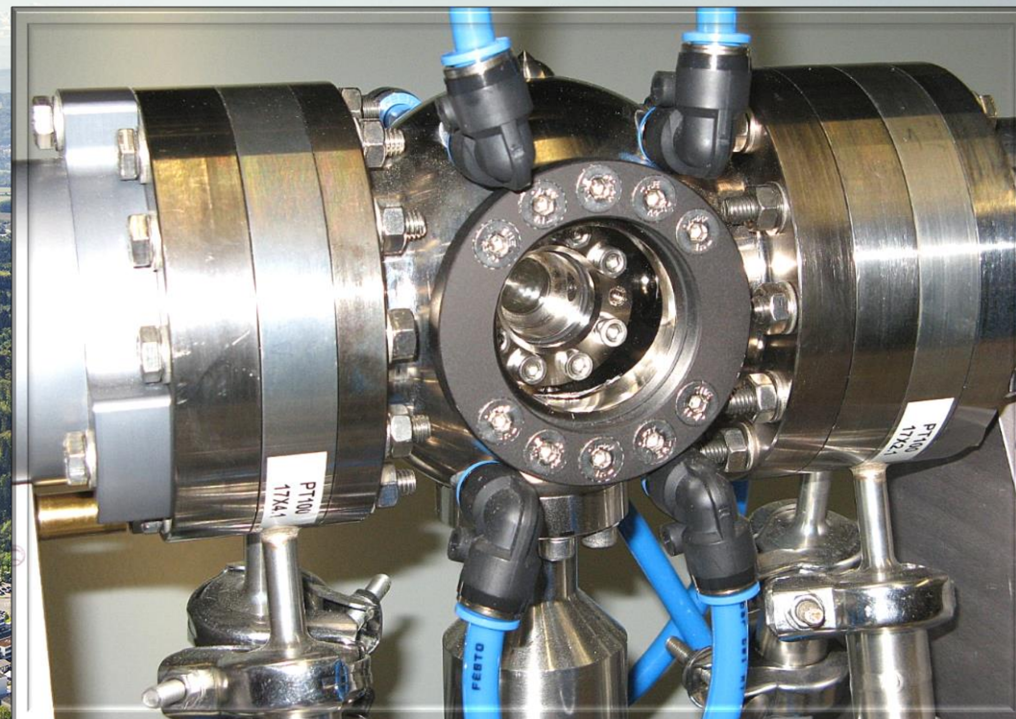
At PSI we used COMSOL Multiphysics to design a climate chamber as research environment. Design goals were, to understand und optimise

… temperature effects.
… humidity distribution.
… fluid flow.
… structural mechanics effects.



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- Juerg Thut [1)]
- Manuel Lehmann [3)]
- Philipp Looser [3)]

[1)] Electrochemistry Lab. (LEC)

[2)] Neutron Scattering Lab. (LNS)

[3)] Scientific Develop. Lab. (LDM)

[4)] PSI Mech. Prod. (AMI)