Thermal design of the He-II suspension tube
Status and outlook

Lennard Busch
Steffen Grohmann

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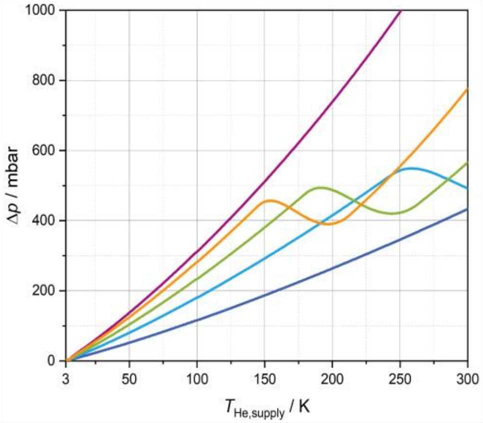
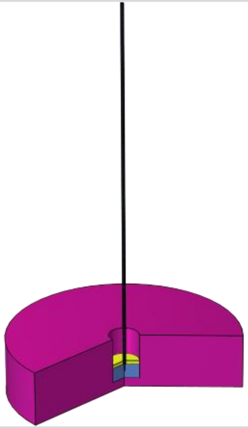
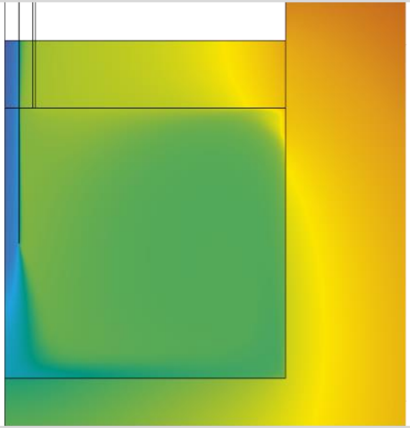






Outline

1. He-II cooling
   - Working principle
   - **Steady-state operation**

2. **Transient thermal simulations of Marionette + test mass**

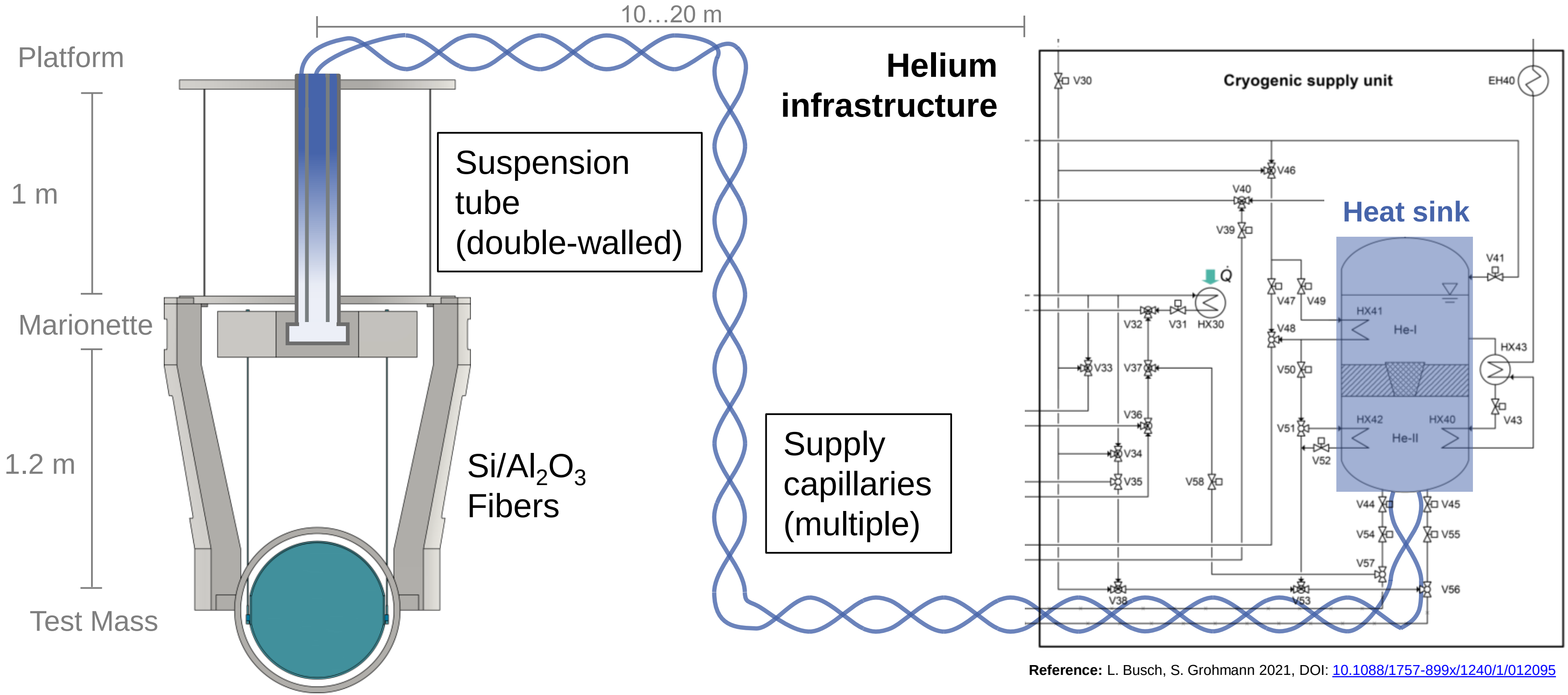
3. **Transient CFD analysis of the Marionette suspension tube**

   } Test mass cooldown

4. **Summary & outlook**

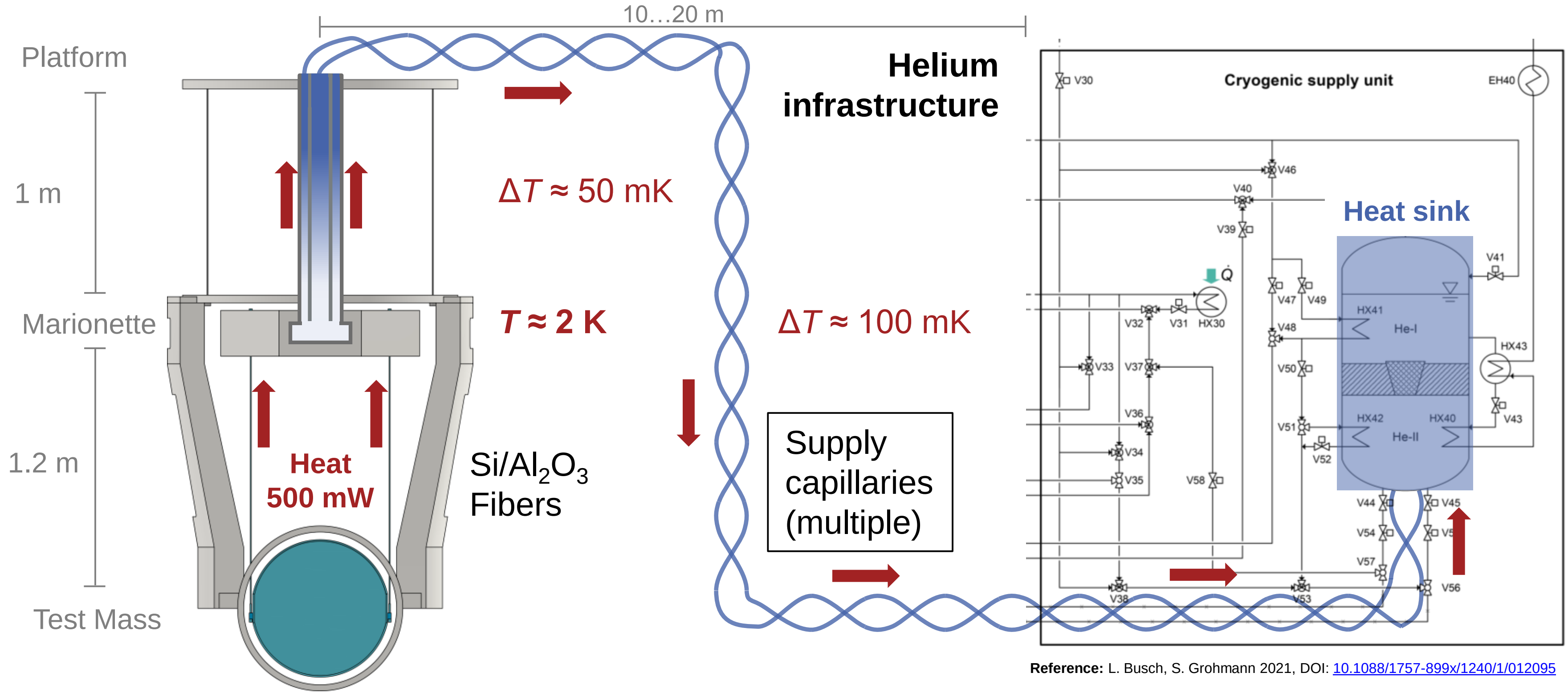
He-II cooling: working principle

He-II cooling: working principle



Reference: L. Busch, S. Grohmann 2021, DOI: 10.1088/1757-899x/1240/1/012095

He-II cooling: working principle



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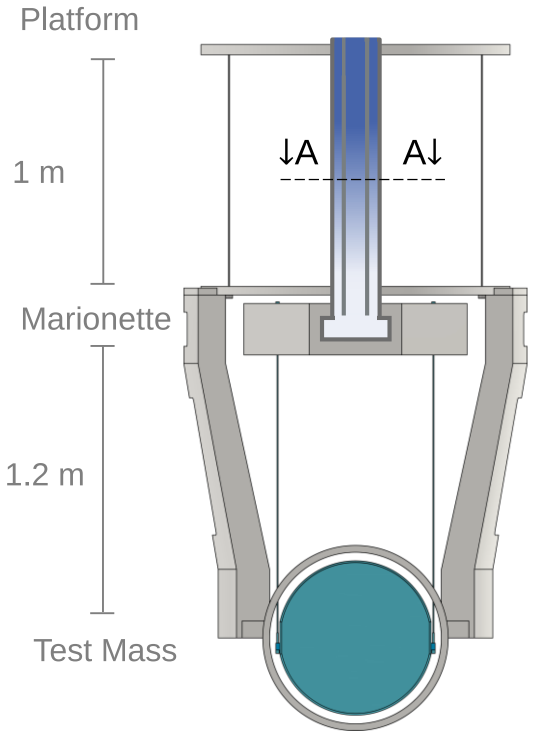
He-II suspension tube design



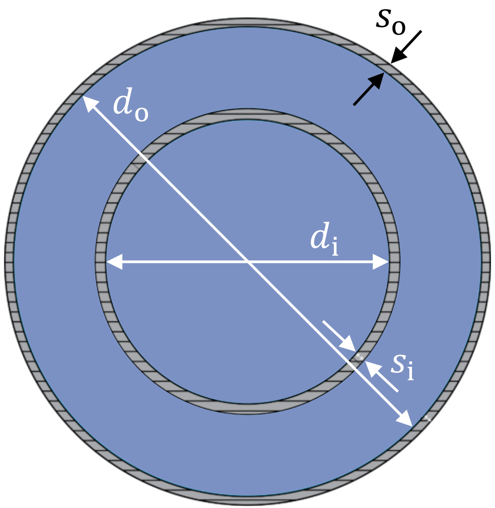
Design parameters:

- $\dot{Q} = \mathbf{500\ mW}$
- $1.85\ \mathrm{K} < T_{\mathrm{He-II}} < 1.9\ \mathrm{K}$

- $L_\mathrm{o} = 1\ \mathrm{m}$
- $d_\mathrm{o} = 8.3\ \mathrm{mm}$
- $s_\mathrm{o} = 0.43\ \mathrm{mm}$

See talks by X. Koroveshi, P. Puppo

- $d_\mathrm{i}, s_\mathrm{i}$: adjustable

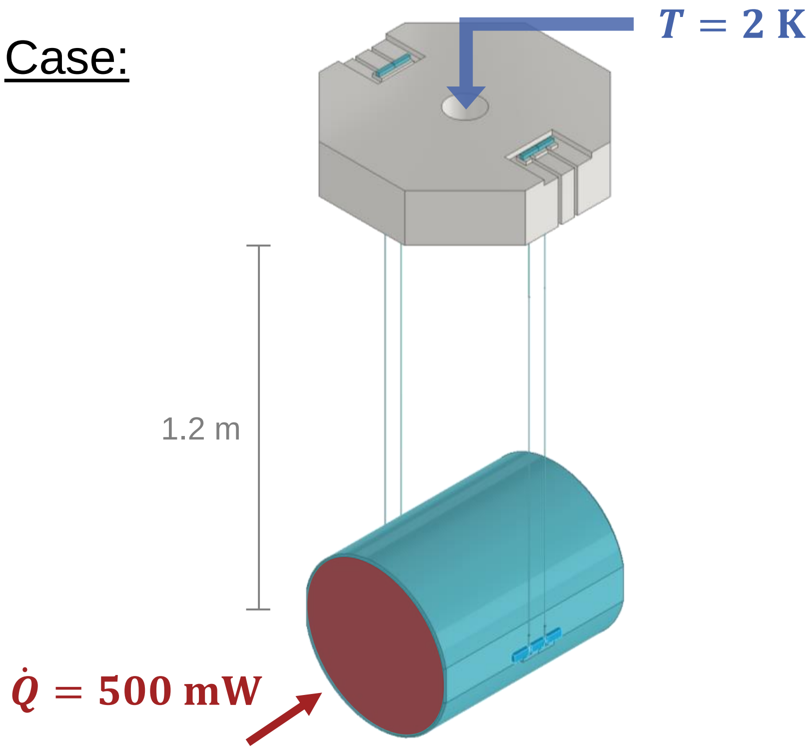


View A - A

He-II cooling: steady-state simulation

Steady-state thermal simulation of MAR + TM

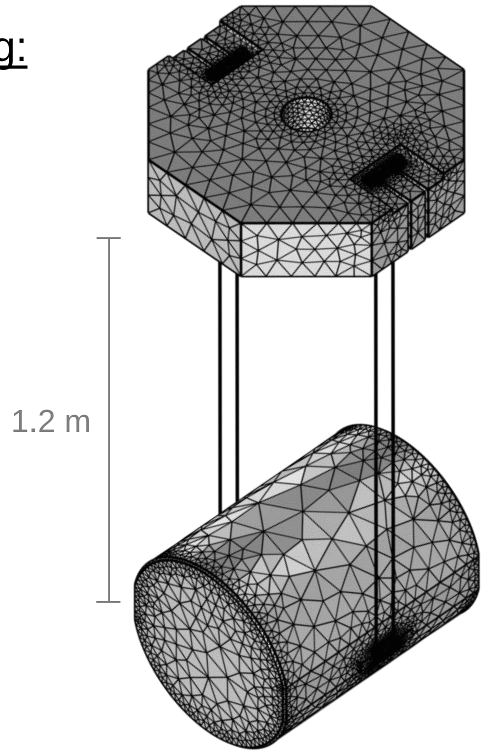
Case:



- Marionette (MAR)
  - $m \approx 400$ kg
  - Stainless steel 316L / Al-alloy
- Suspension fibers
  - $L = 1.2$ m
  - $d = 3$ mm
  - Silicon
- Test mass (TM)
  - $m \approx 200$ kg
  - Silicon

Steady-state thermal simulation of MAR + TM

Meshing:



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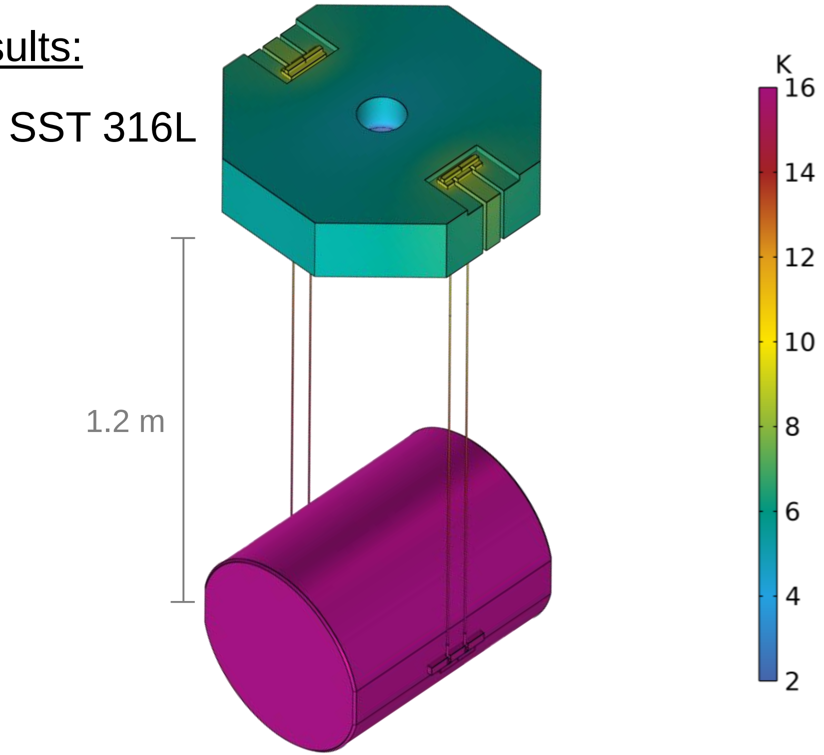
Steady-state thermal simulation of MAR + TM

Results:



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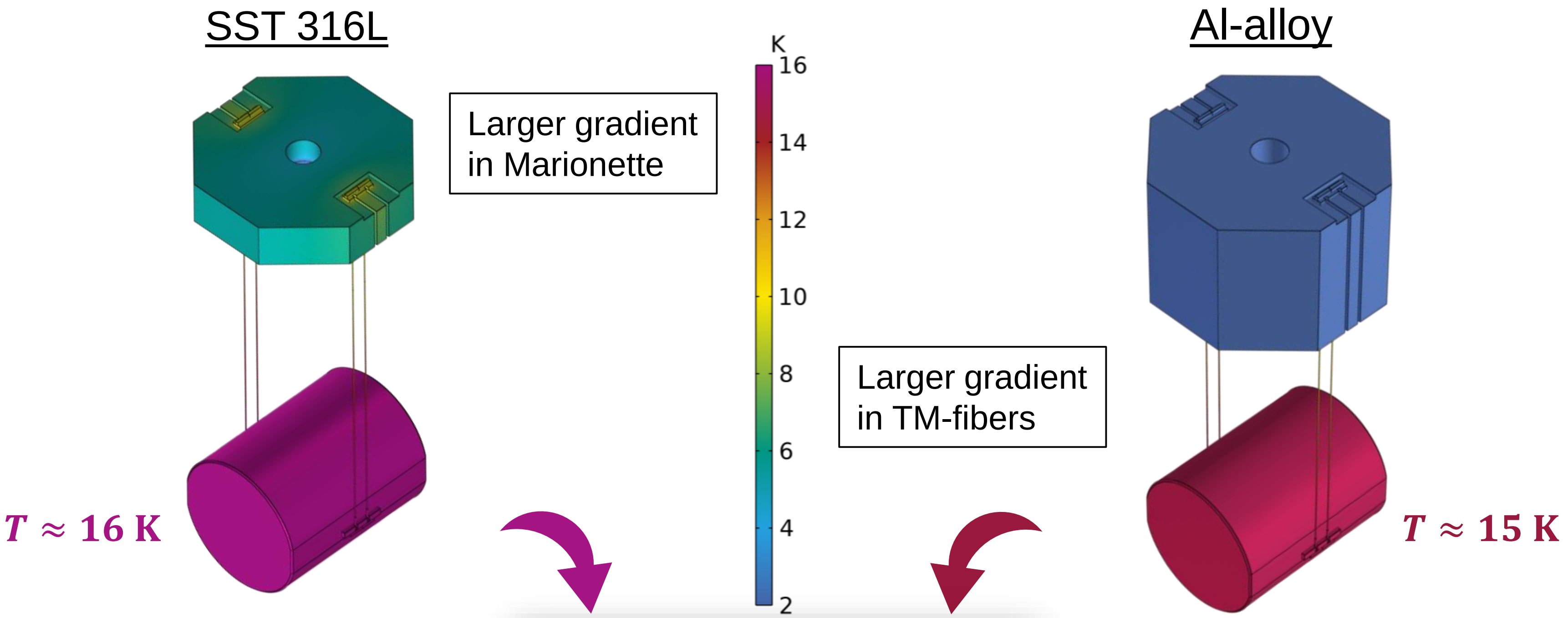


Roughly same TM-temperature

Summary (1/3)

Steady-state operation

- …defines global design parameters
- Stationary fluid (no flow)
- Extremely low temperature gradient to remote heat sink
- Low temperature at Marionette suspension (2 K)

→ $T_{\mathrm{TM}} \approx 16\ \mathrm{K}$ achieveable

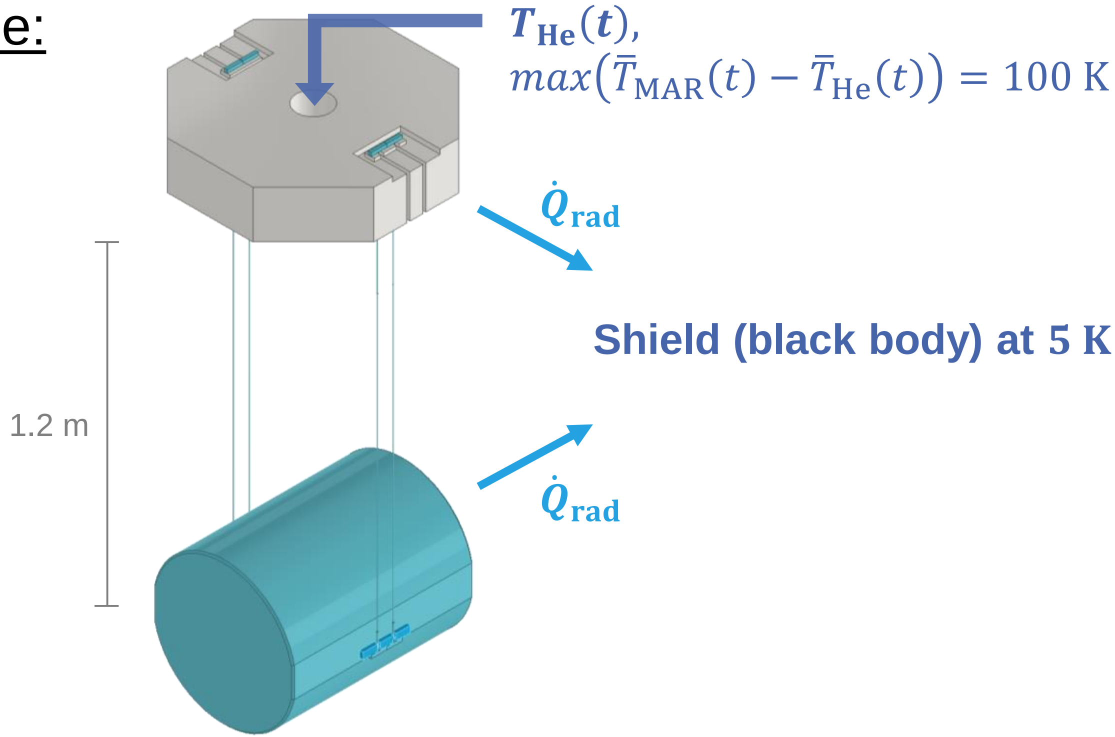
→ High-conductivity Marionette yields little improvement

Transient thermal simulations of Marionette (MAR) + test mass (TM)

<u>Transient</u> thermal simulation of MAR + TM

Karlsruhe Institute of Technology

<u>Case:</u>



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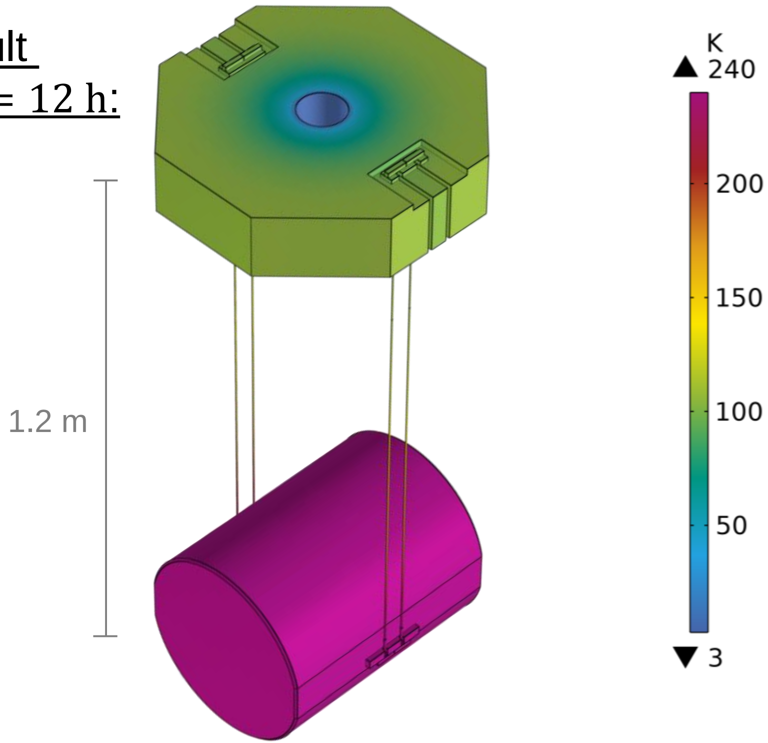
Transient thermal simulation of MAR + TM

Result
at $t = 12\ \mathrm{h}$:



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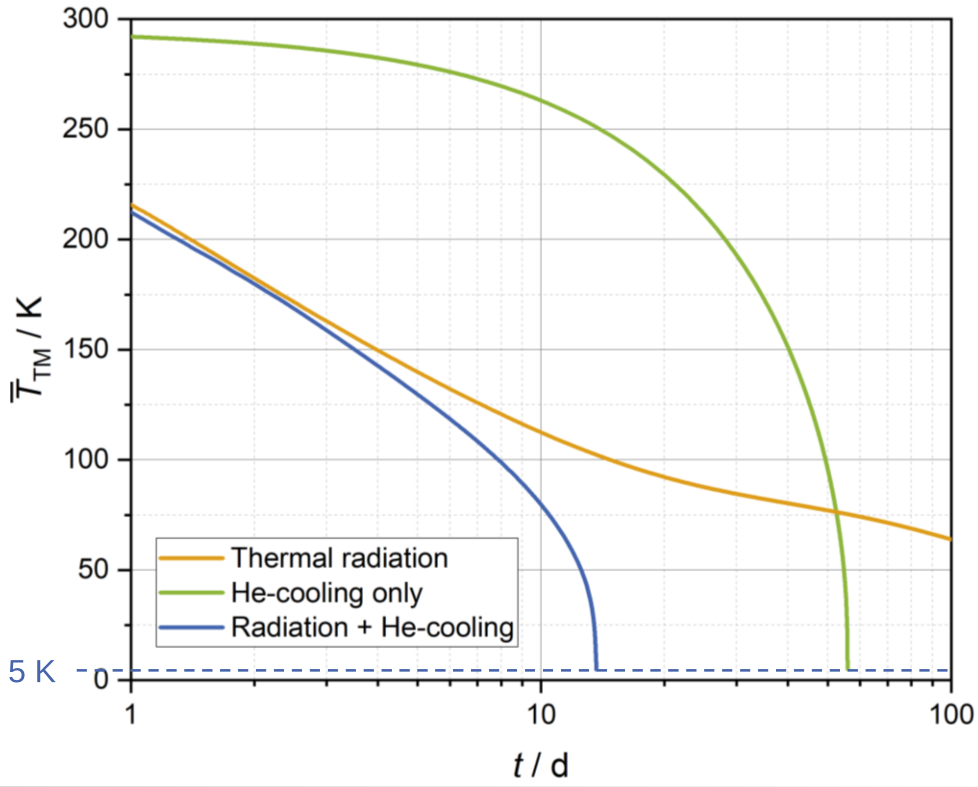
<u>Transient</u> thermal simulation of MAR + TM



- Cool-down rate with radiation insufficient ($t_{end} \gg 100$ d)
- He-cooling only also insufficient ($t_{end} > 50$ d)

Combination of He-cooling and radiation sufficient

Summary (2/3)

Steady-state operation	Transient thermal simulations of MAR + TM
...defines global design parameters	Heat extraction bottleneck TM-suspensions

Steady-state operation

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- Stationary fluid (no flow)
- Extremely low temperature gradient to remote heat sink
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  $\rightarrow T_{\mathrm{TM}} \approx 16\ \mathrm{K}$ achieveable

  $\rightarrow$ High-conductivity Marionette yields little improvement

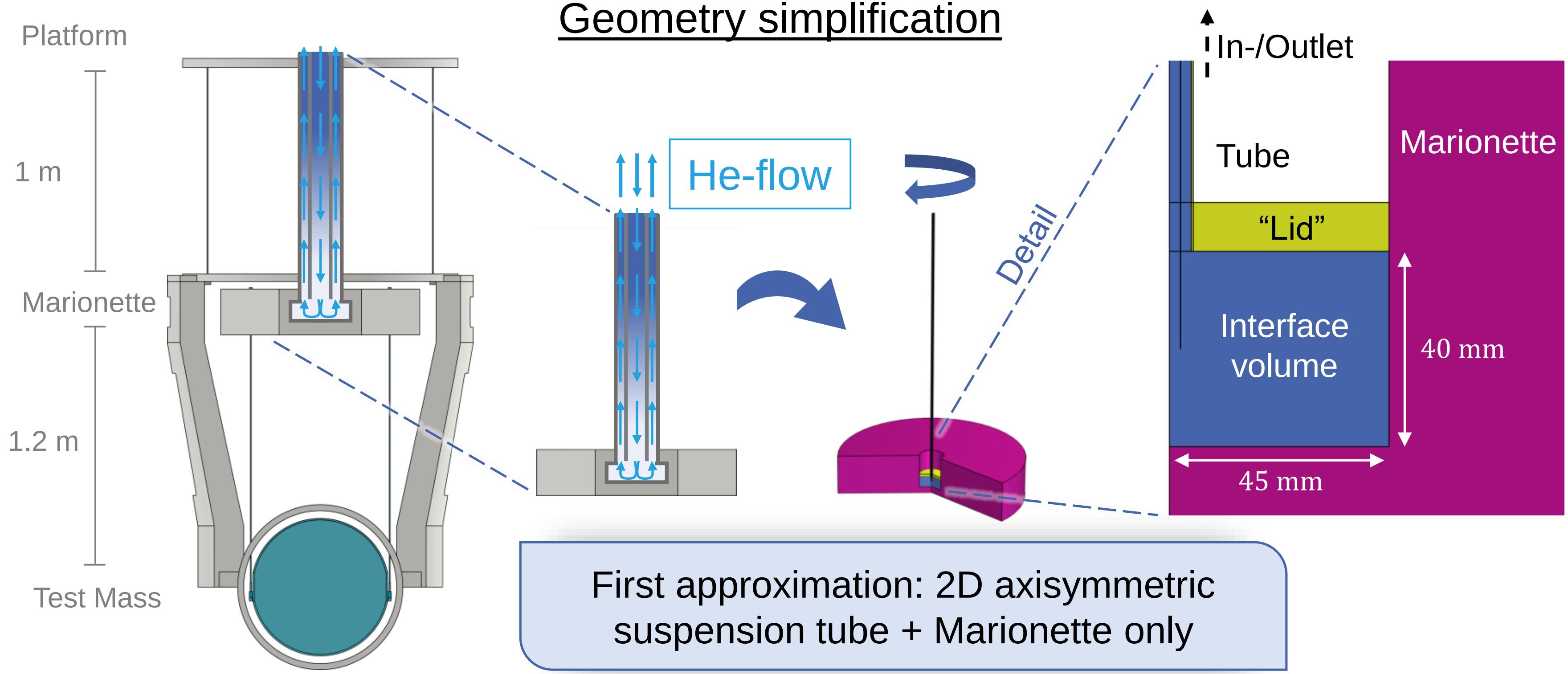
Transient thermal simulations of MAR + TM

- Heat extraction bottleneck TM-suspensions
- Marionette:
  SST possible, high-conductivity material not necessary
- Cool-down:
  Radiation to 5 K-shield + solid conduction to suspension tube interface enable TM-cooldown in ca. two weeks

Transient CFD analysis
of the Marionette suspension tube

Transient CFD simulation of MAR suspension tube

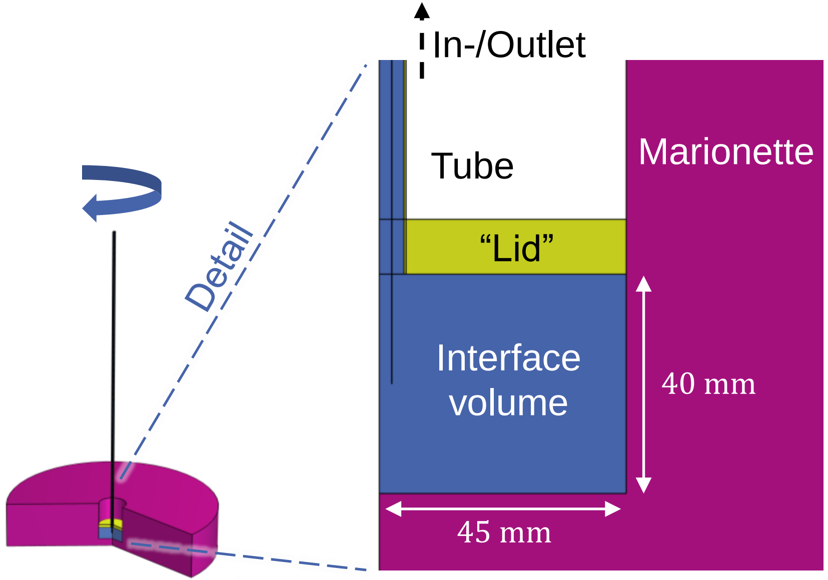
Geometry simplification

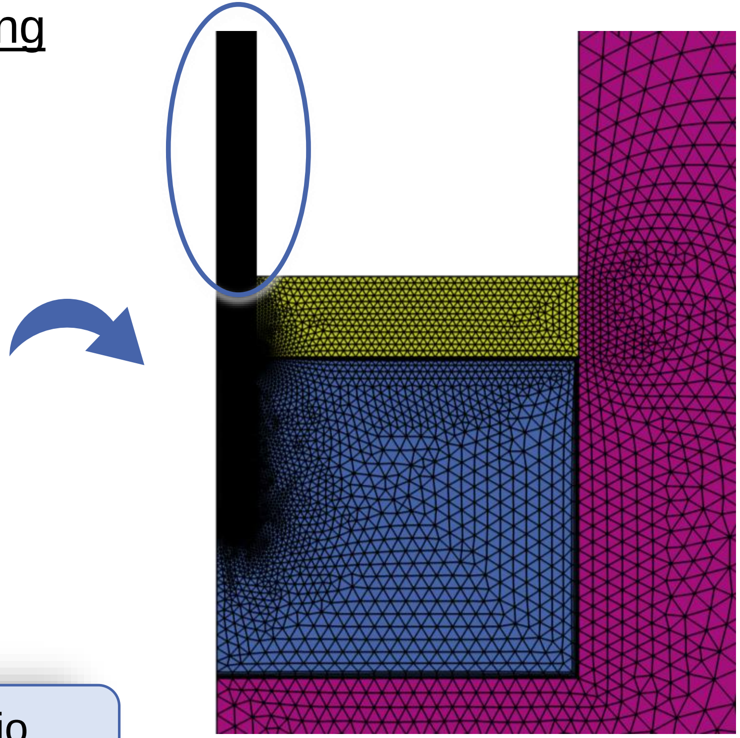


First approximation: 2D axisymmetric suspension tube + Marionette only

Transient CFD simulation of MAR suspension tube

Meshing





Large mesh due to high L/d ratio

Key system parameters and boundary conditions

Parameter	Description	Expression / value
$\dot{m}_{\mathrm{He}}$	Helium mass flow	$\text{up to} > 1000\ ^{\mathrm{mg}}/_{\mathrm{s}}$
$T_{\mathrm{He,in}}(t)$	Helium supply temperature	$\max(\bar{T}_{\mathrm{MAR}}(t) - \Delta T)$
ΔT	Initial temperature difference	50…150 K
$\boldsymbol{p}_{\mathbf{He,out}}$	**Absolute pressure at helium outlet**	**3.0…4.0 bar(a)**

Helium domain modelling:

- Compressible flow
- Algebraic y^+ turbulence model
- EOS: Peng-Robinson-Twu

$\mathbf{5\ bar(a)} - \boldsymbol{\Delta p}$

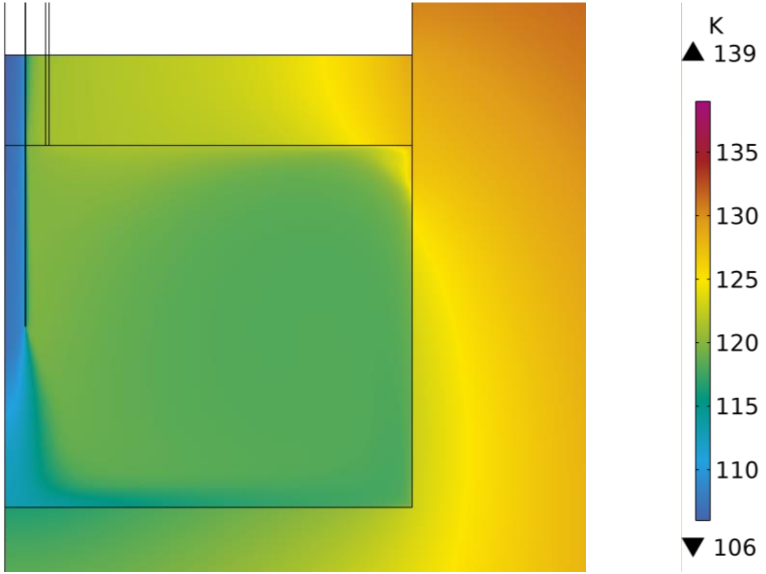
He-infrastructure outlet — Supply capillaries

CFD simulation results

$t \approx 5$ days

- $\dot{m}_{\mathrm{He}} = 1.0\ ^{\mathrm{g}}/_{\mathrm{s}}$
- $p_{\mathrm{He,out}} = 4.0$ bar(a)
- $\Delta T = 100$ K
- SST 316L
- 400 kg

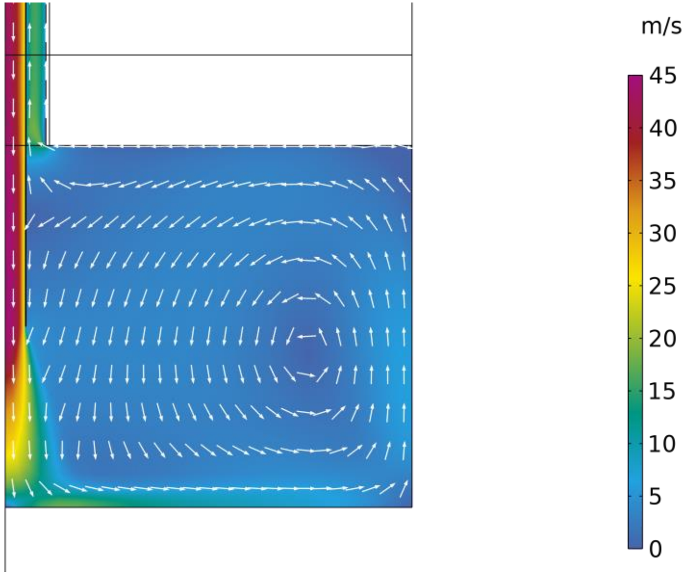
Temperature profile



CFD simulation results

$$t \approx 5 \text{ days}$$

Velocity field



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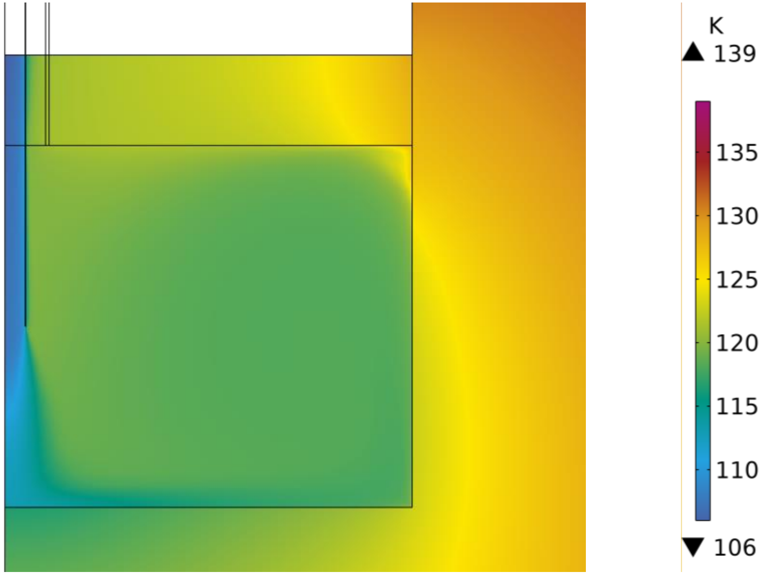

CFD simulation results

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Marionette temperature and pressure drop vs. cool-down time

- $\dot{m}_{He} = 1.0\ {}^{g}/_{s}$
- $p_{He,out} = 3.0$ bar(a)
- $\Delta T = 100$ K
- SST 316L
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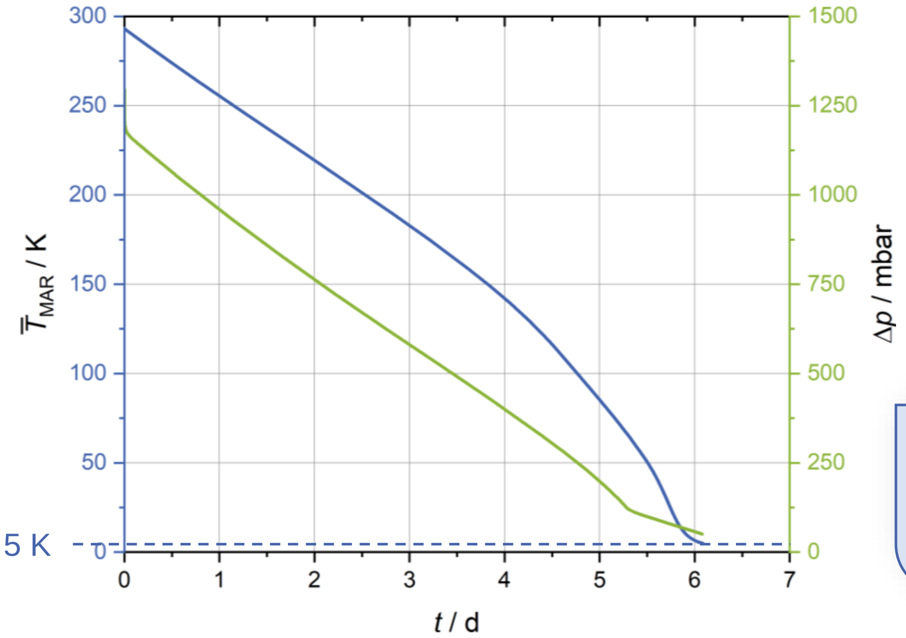

Forced convection allows Marionette cool-down times of < 1 week

Summary (3/3)

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  → $T_{\mathrm{TM}} \approx 16\ \mathrm{K}$ achieveable

  → High-conductivity Marionette yields little improvement

Transient thermal simulations of MAR + TM

- Only heat extraction bottleneck: TM-suspensions
- Marionette:
  low-conductivity materials possible
- Cool-down:
  Radiation to 5 K-shield + solid conduction to suspension tube interface yield sufficiently low time constants

MAR suspension tube fluid-dynamical analyses

- Consideration of supply capillaries’ pressure loss:

  → Suspension tube pressures up to ca. 4.5 bar(a)
- Numerical verification of MAR-cooldown

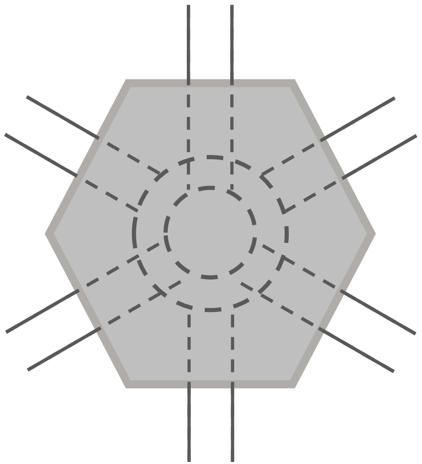
  → Pressure drops in order of $x \cdot 100\ \mathrm{mbar}$ (compatible with He-infrastructure)

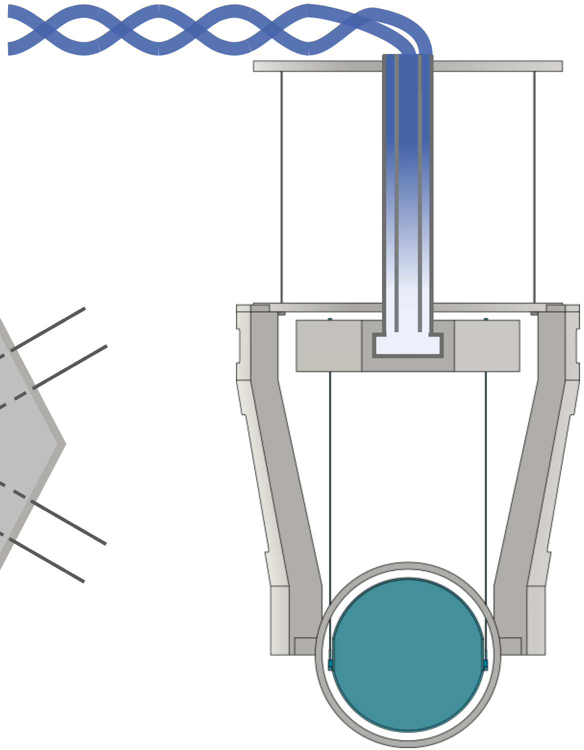
  → Complete payload cooldown in ca. two weeks confirmed

Outlook

Karlsruhe Institute of Technology

- Conceptualize interface between supply capillaries and suspension tube
- Determine optimal supply capillary configuration (amount + diameter)





Thank you for your attention!

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