Measurement of heat-flow for the ATLAS Liquid-Argon FCal under HL-LHC conditions

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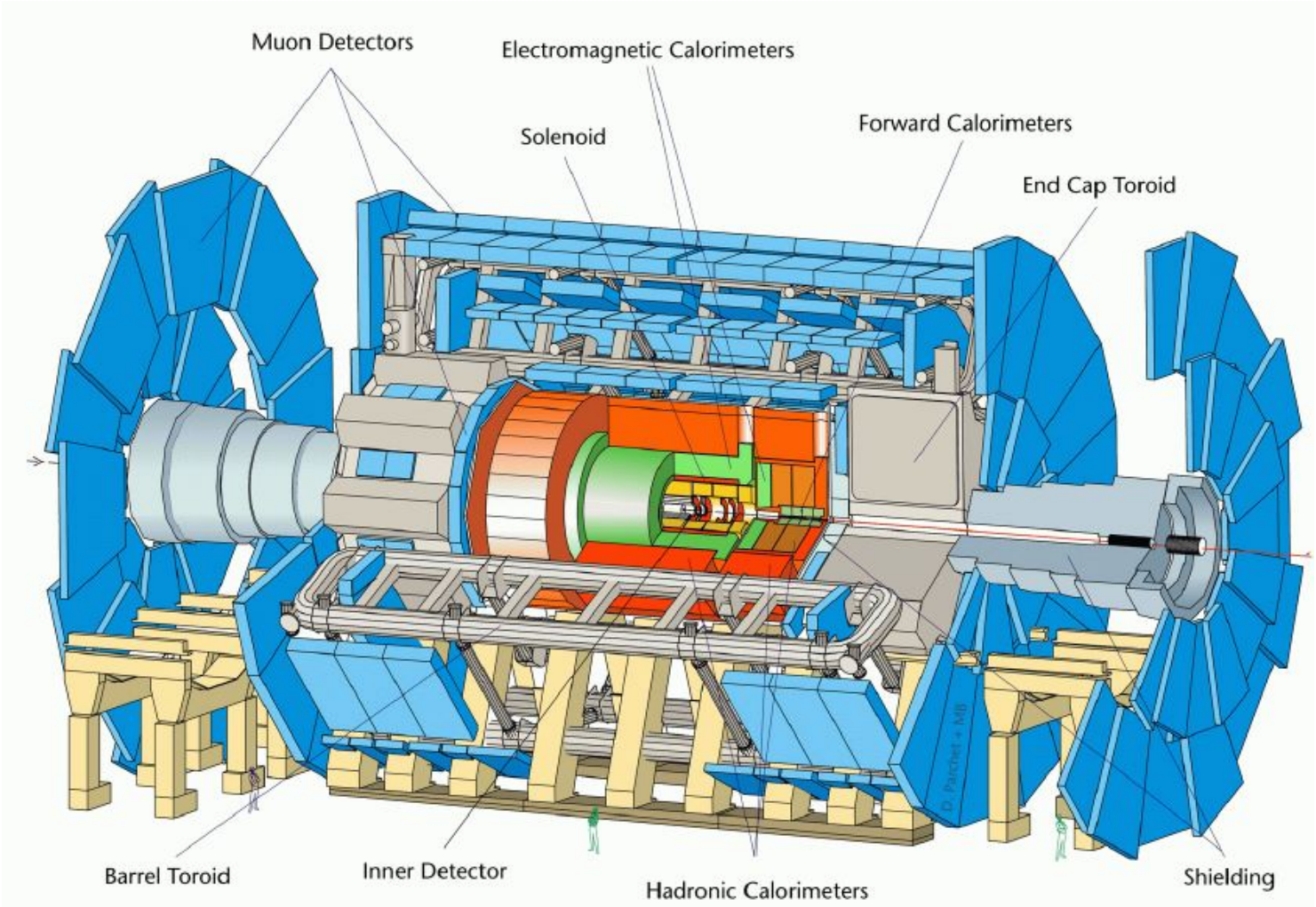
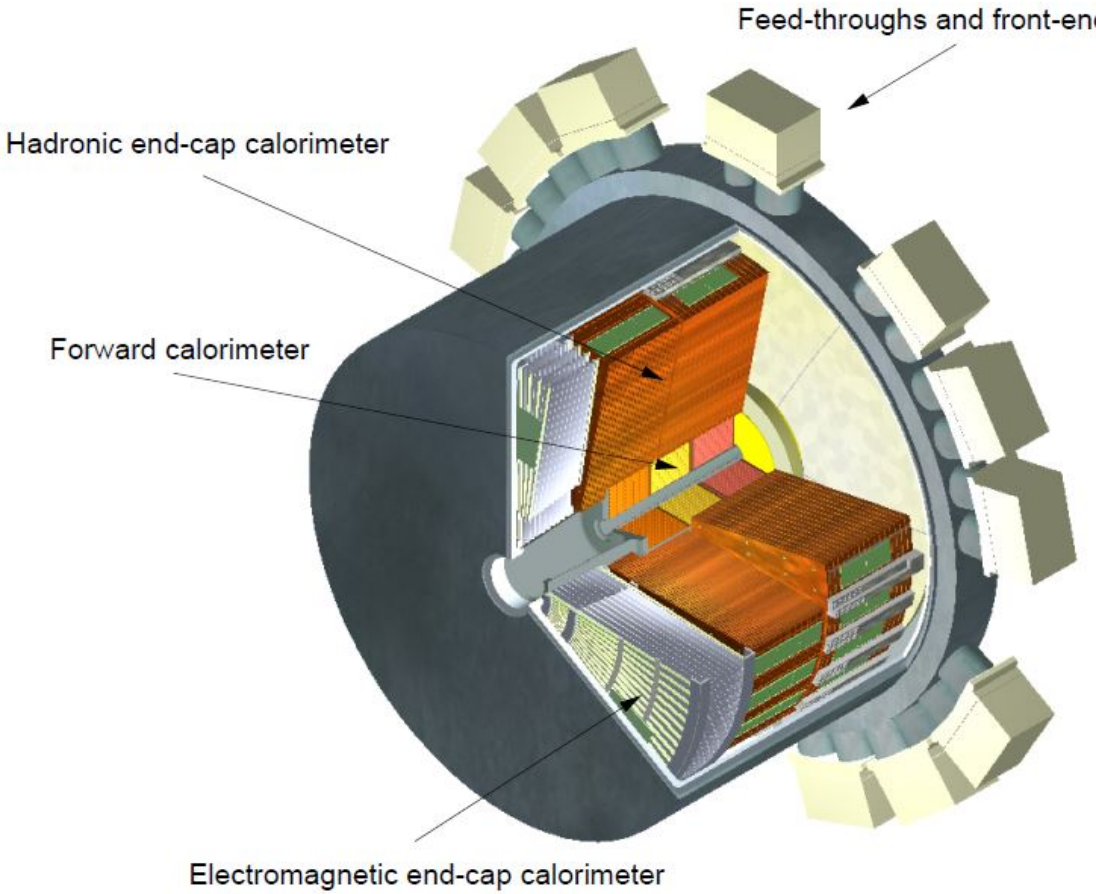
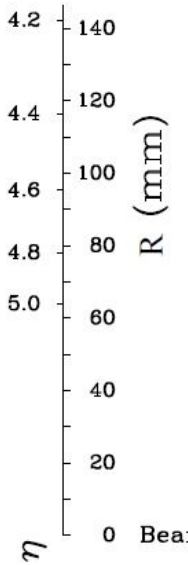
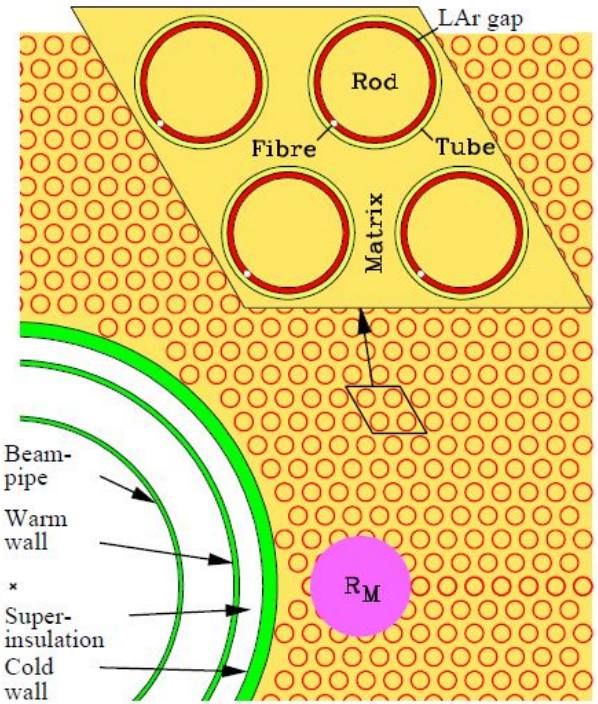
Motivation

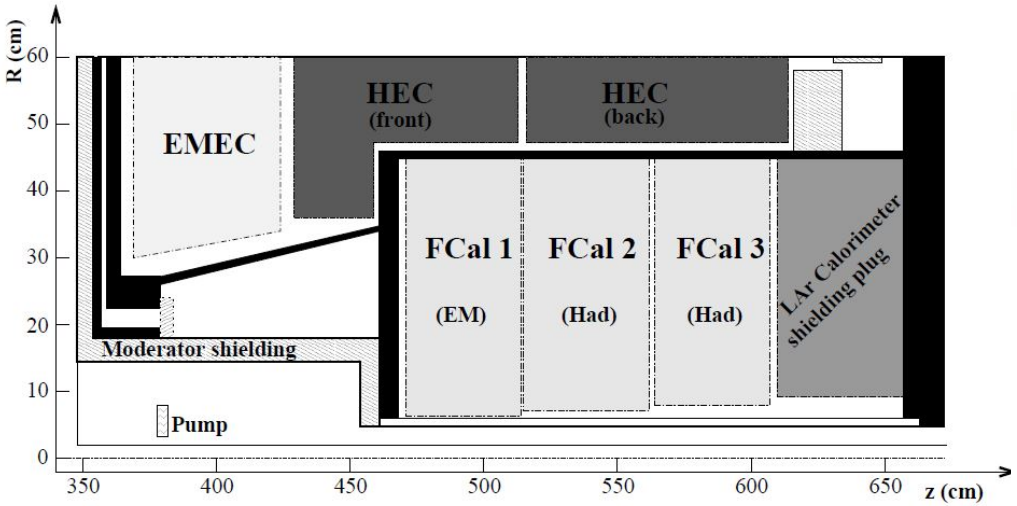

Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

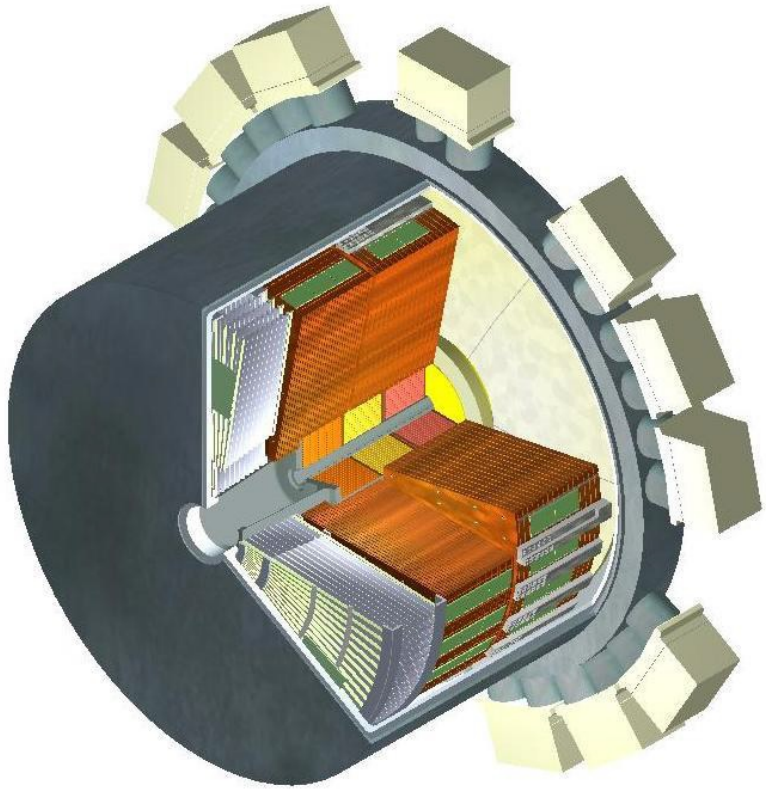

Feed-throughs and front-end crates
Hadronic end-cap calorimeter
Forward calorimeter
Electromagnetic end-cap calorimeter


4.2
4.4
4.6
4.8
5.0
140
120
100
80
60
40
20
0
R (mm)
η
Beams


LAr gap
Rod
Fibre
Tube
Matrix
Beam-pipe
Warm wall
Super-insulation
Cold wall
R_M

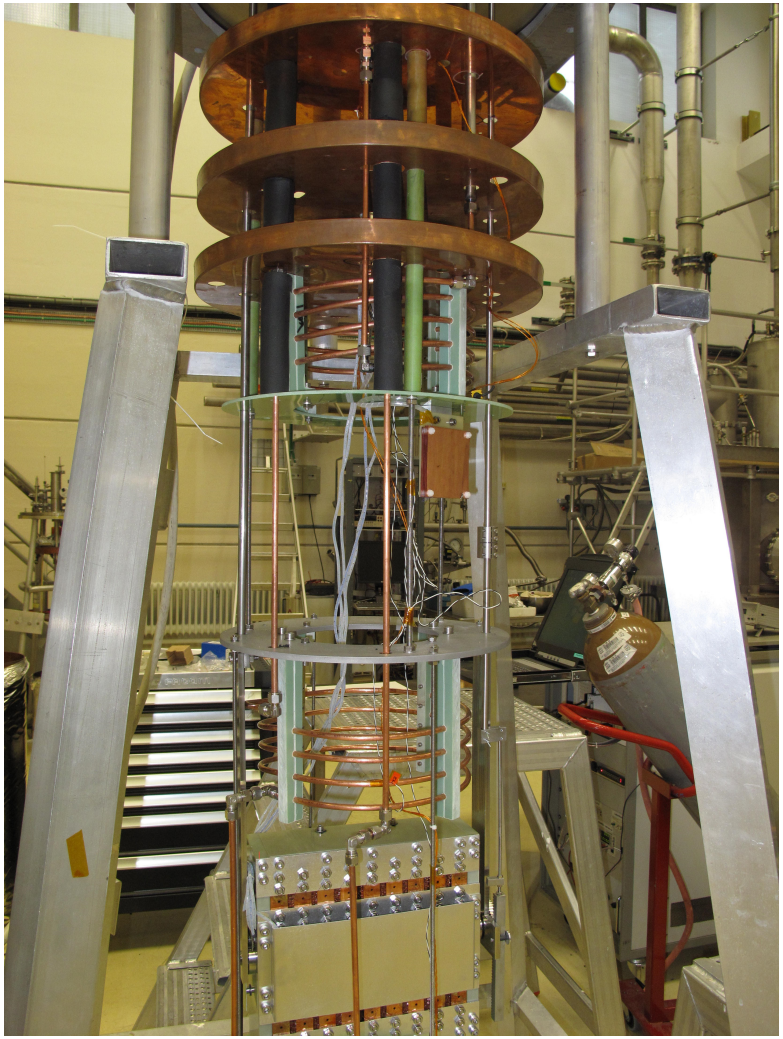
- 5-7x design luminosity
- $\Delta T_{fluid} \approx 4\,K$

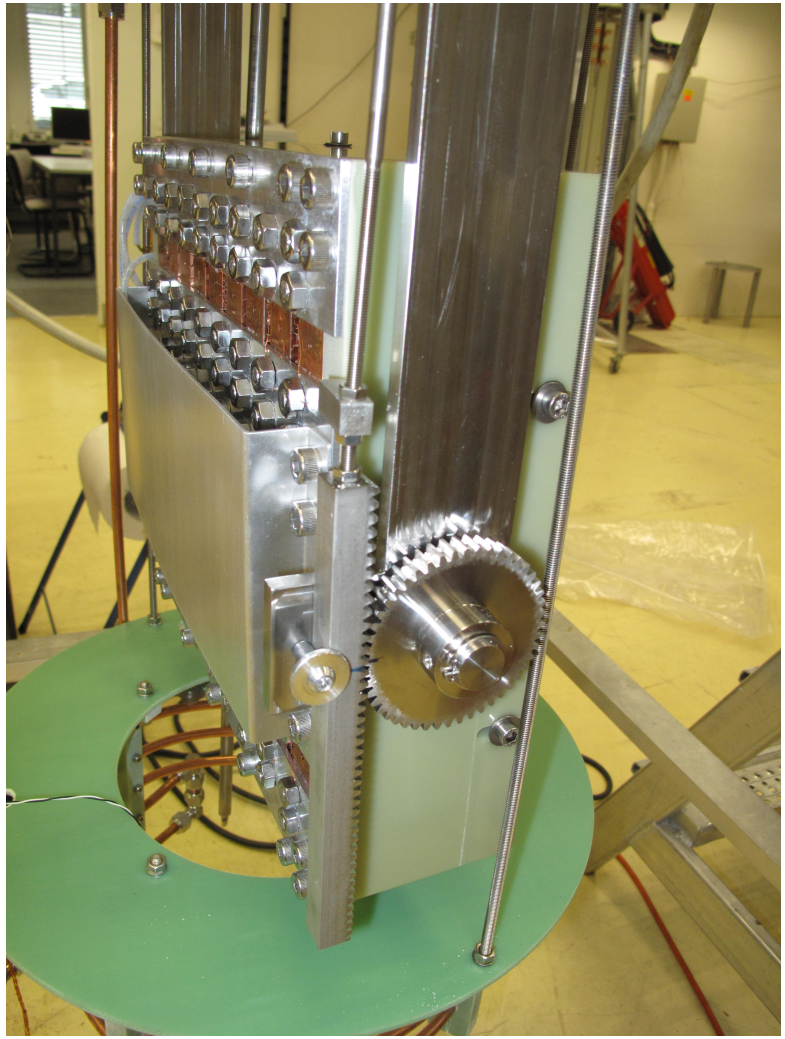


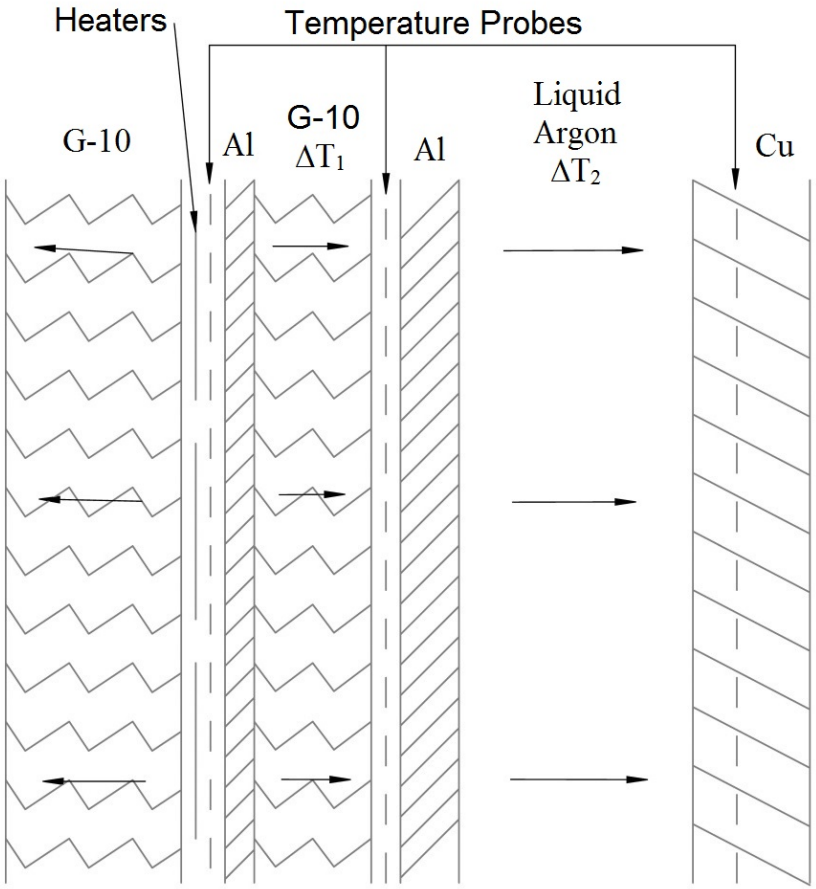


$\Longrightarrow$ Does the argon gap conduct the heat efficient enough to avoid boiling?

Experimental set-up and mode of operation







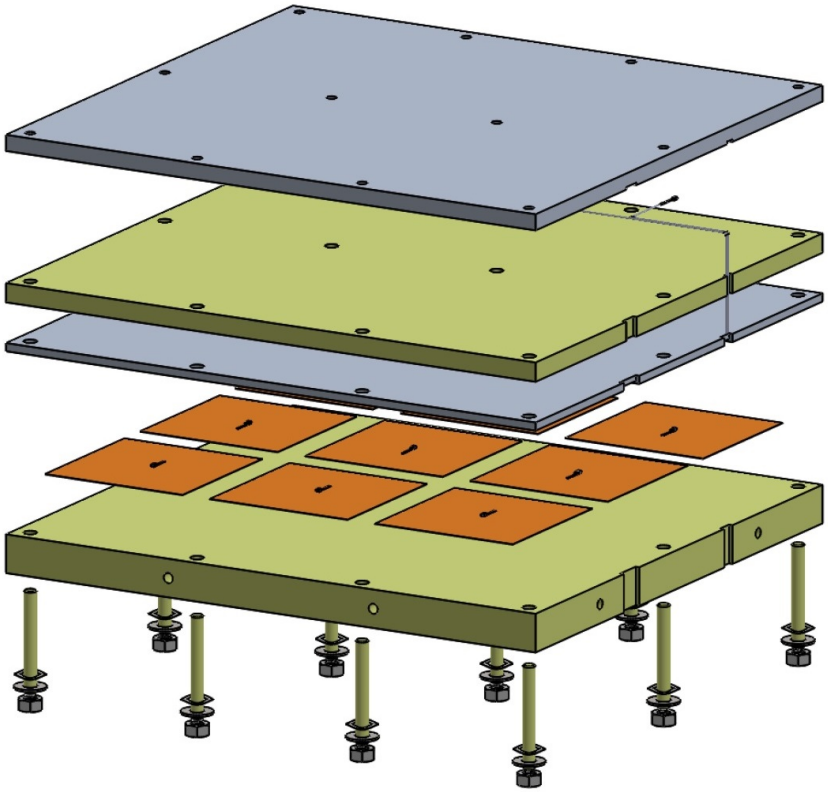
- Simulation: 10 W Heating power
  $\Delta T_1 = 2\,K$
  $\Delta T_2 = 0.8\,K$ with convection
  $\Delta T_2 = 4\,K$ without convection
- exact convection very difficult to model

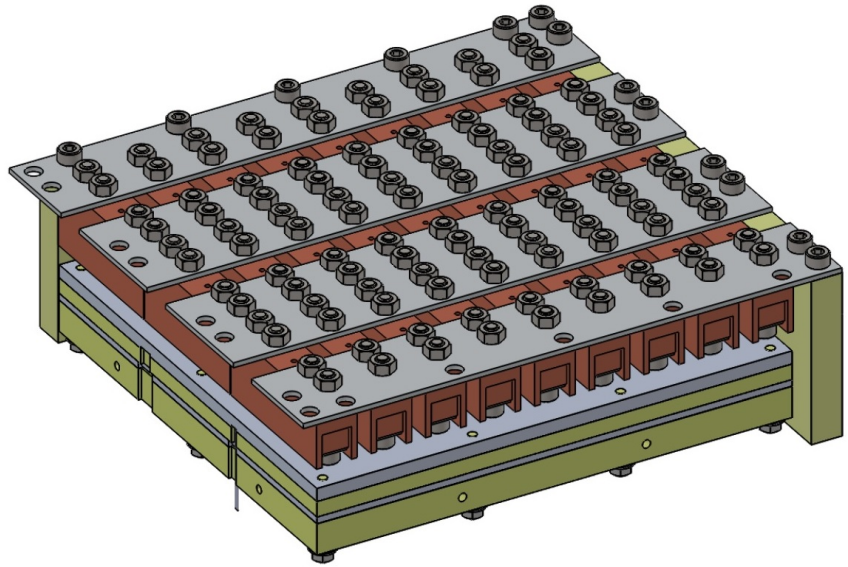
Fourier's law:

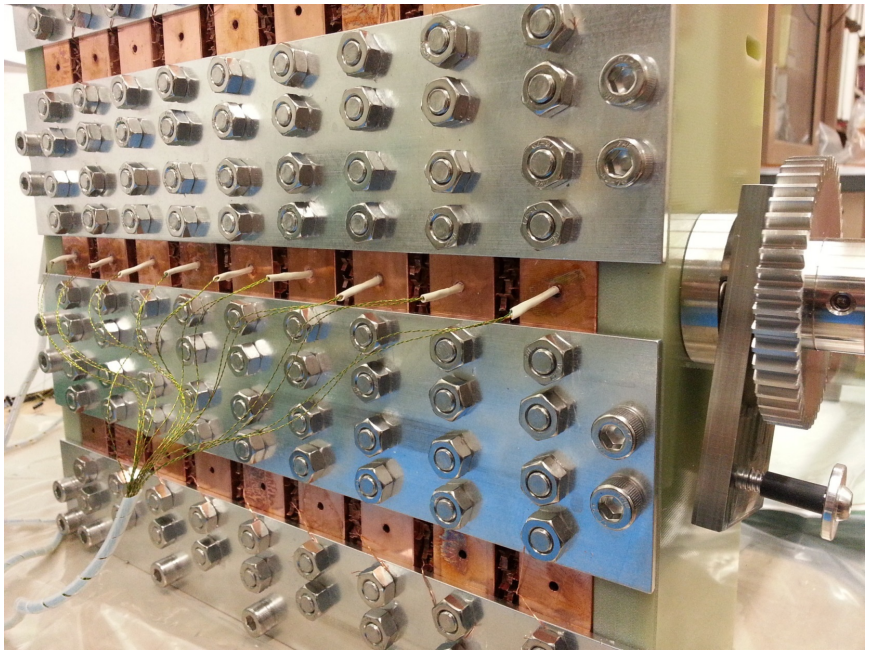
$$\dot{Q}_1 = \frac{\lambda_{G10}}{d_{G10}} A_{G10} \cdot \Delta T_1 \qquad (1)$$

$$\dot{Q}_2 = \frac{\lambda_{LAr}}{d_{LAr}} A_{LAr} \cdot \Delta T_2 \qquad (2)$$

$$\Rightarrow \lambda_{LAr} = \frac{d_{LAr}}{d_{G10}} \cdot \lambda_{G10} \cdot \frac{\Delta T_1}{\Delta T_2} \qquad (3)$$



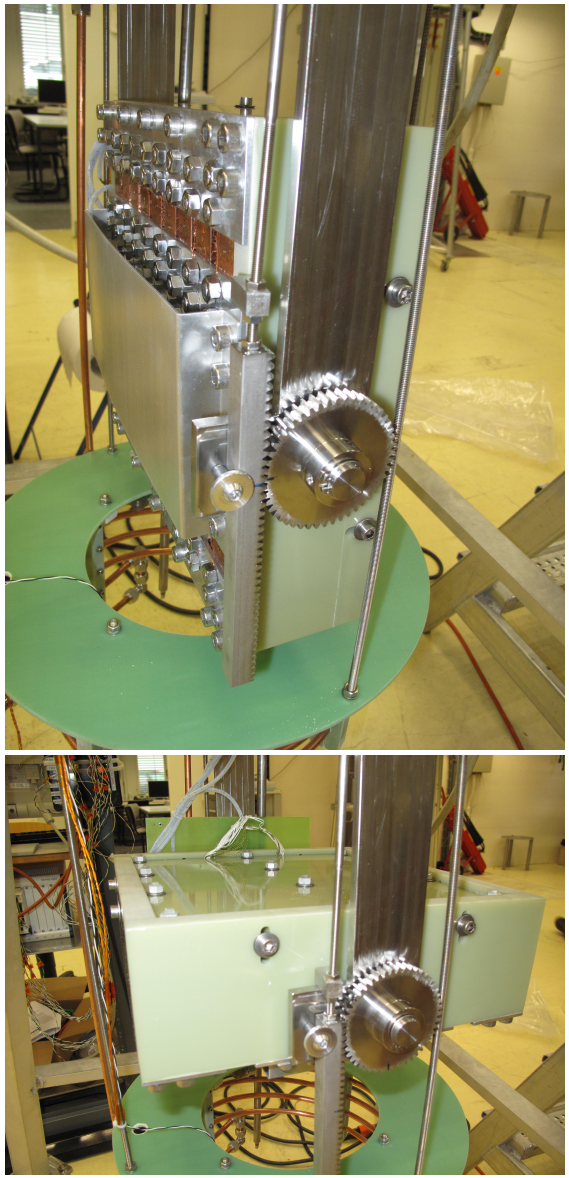


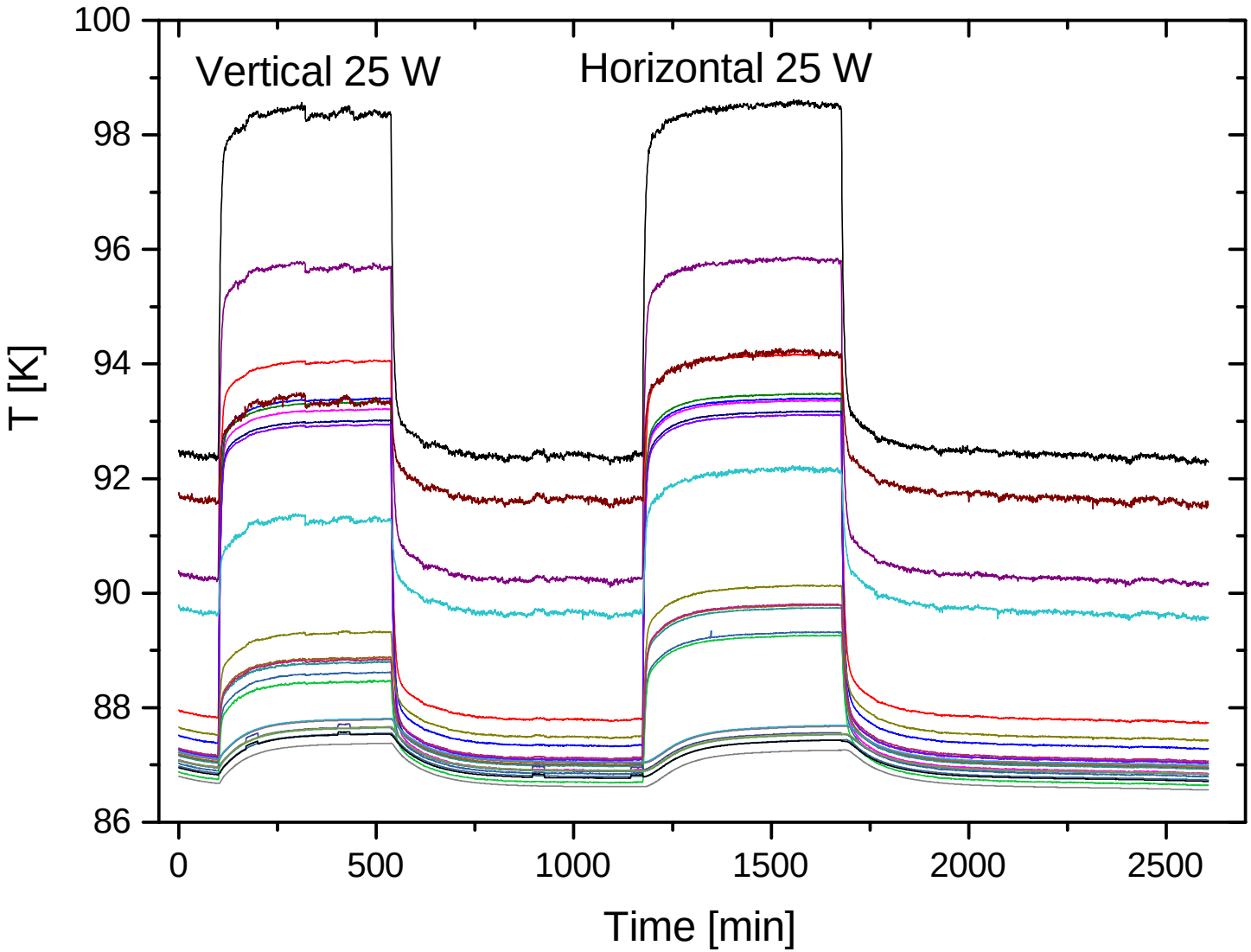


Measurements

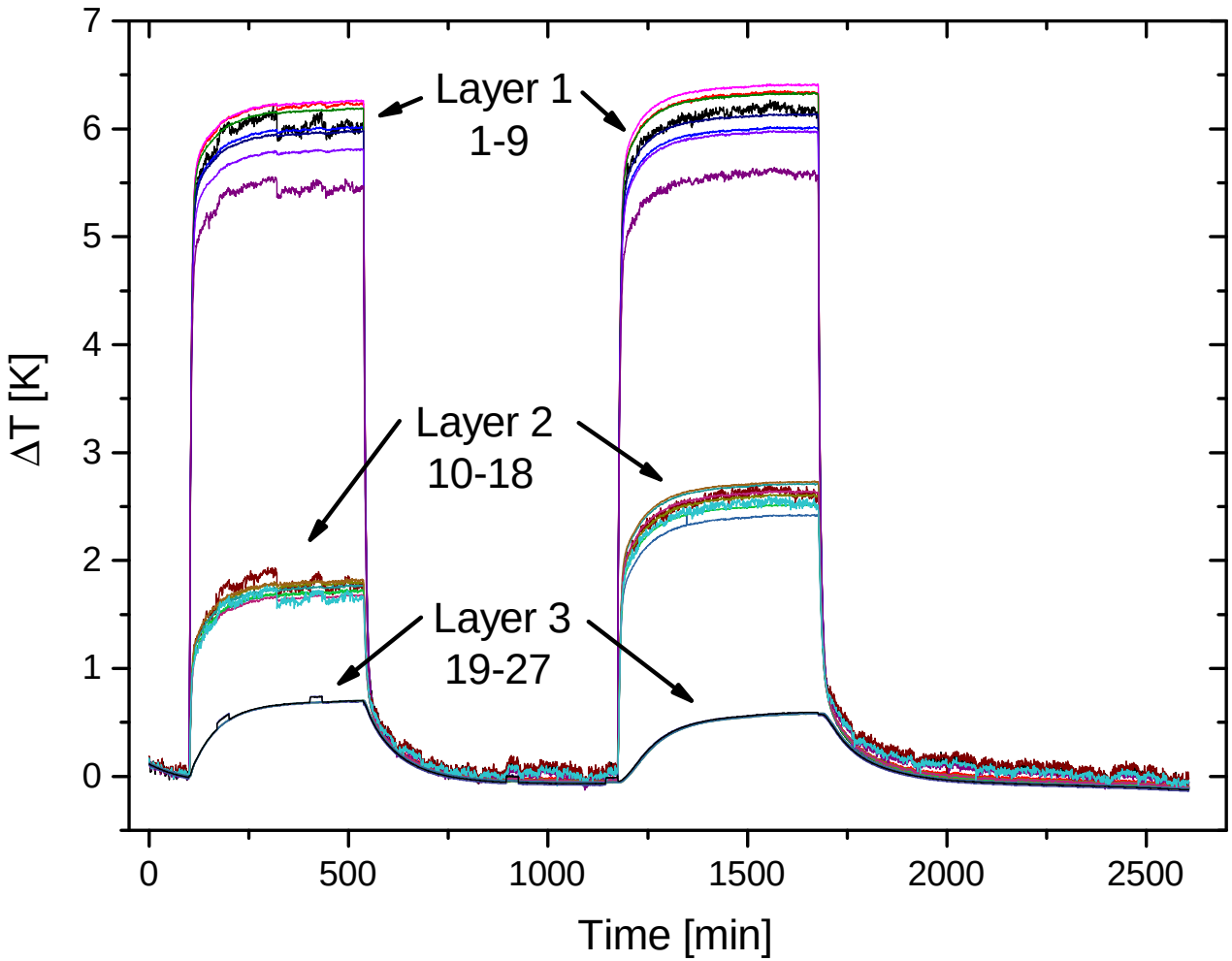
Variation of:

- Heating power (up to $\approx 29\,\mathrm{W}$)
- Angle (vertical and horizontal position)
  $\rightarrow$ simulation of cylinder form
- Gap size (6 mm and 12 mm)




Vertical 25 W
Horizontal 25 W
T [K]
Time [min]
100
98
96
94
92
90
88
86
0
500
1000
1500
2000
2500

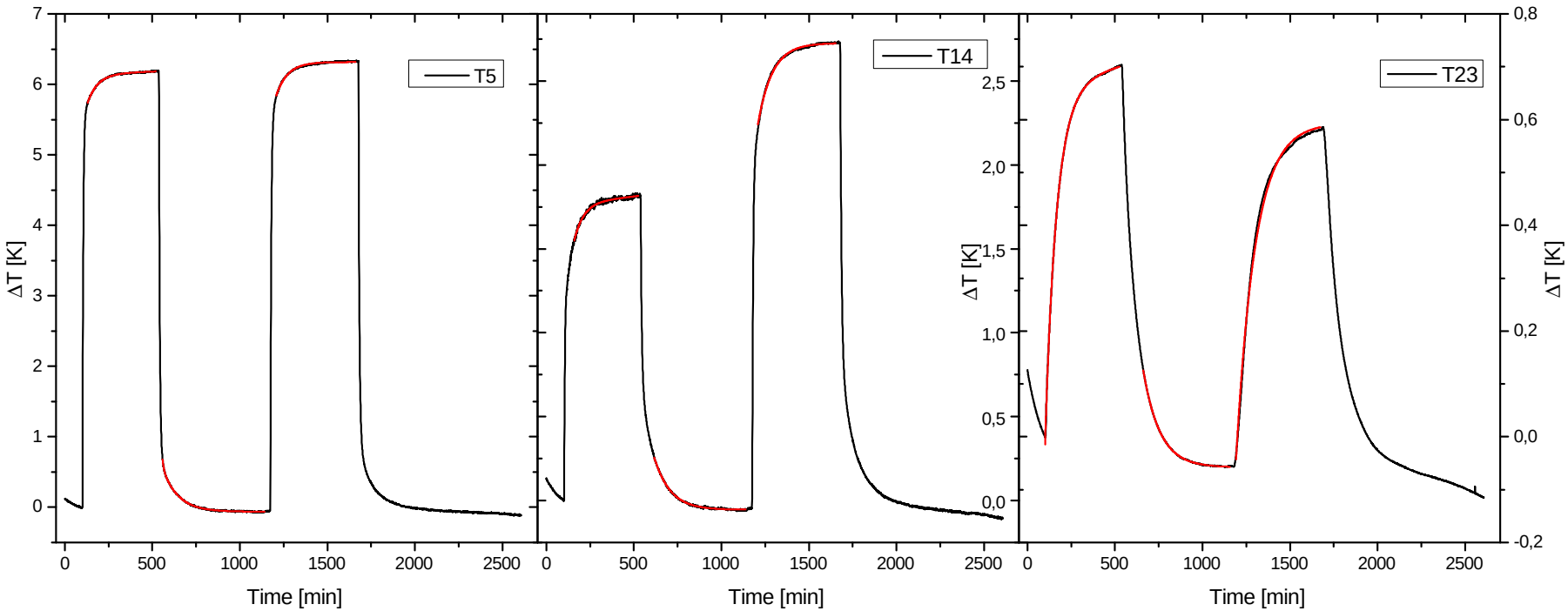
Analysis

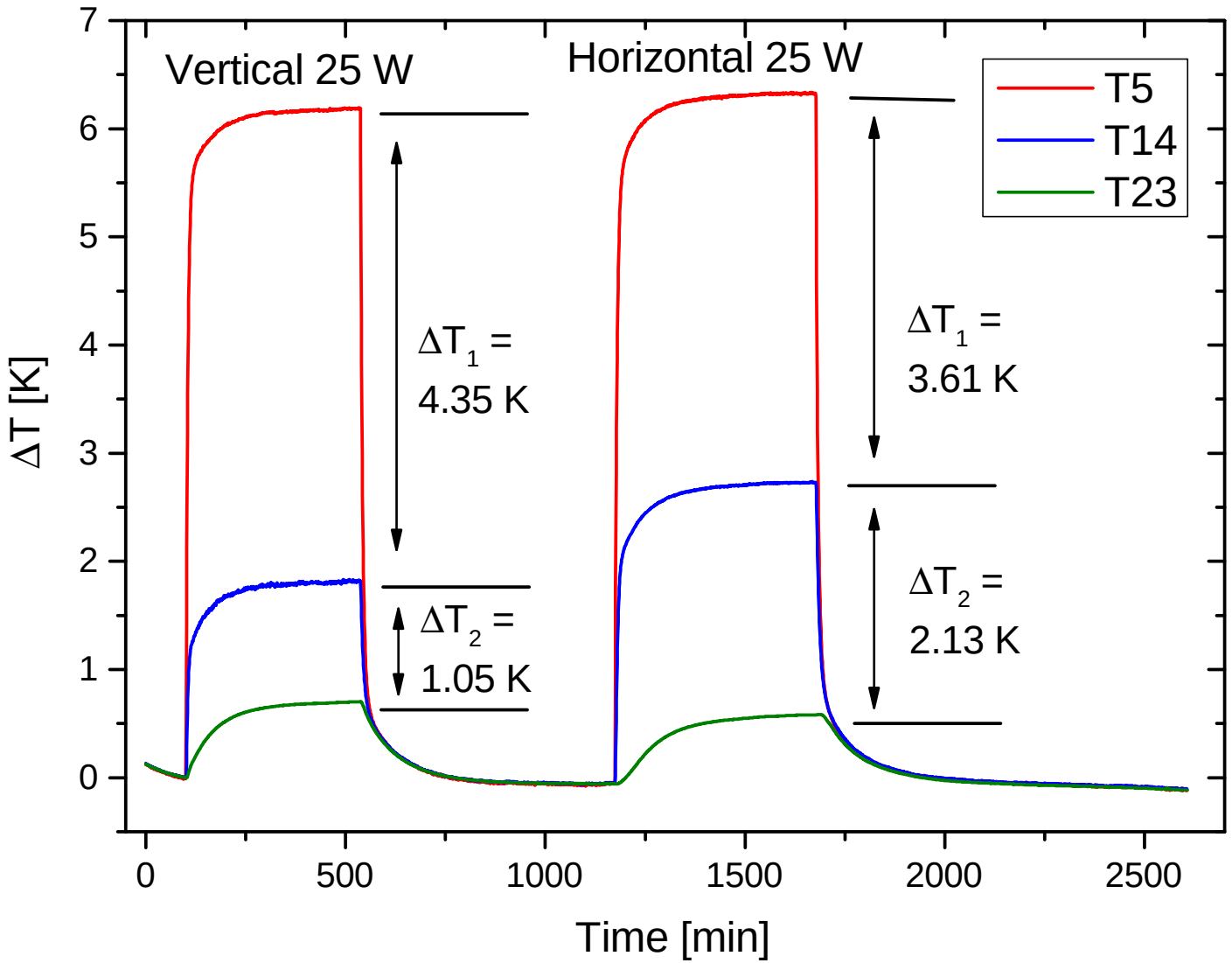

Layer 1
1-9
Layer 2
10-18
Layer 3
19-27
ΔT [K]
Time [min]
0
1
2
3
4
5
6
7
0
500
1000
1500
2000
2500

$$T_{heating}(t) = T_0 + A_1 \cdot \left(1 - e^{-\frac{t}{\tau_1}}\right) + A_2 \cdot \left(1 - e^{-\frac{t}{\tau_2}}\right) \quad (4)$$

$$T_{cooling}(t) = T_0 + A_1 \cdot e^{-\frac{t}{\tau_1}} + A_2 \cdot e^{-\frac{t}{\tau_2}} \quad (5)$$

Temperature probes 5, 14 and 23: Heat flow in the center of the mock-up




Vertical 25 W
Horizontal 25 W
T5
T14
T23
ΔT1 = 4.35 K
ΔT2 = 1.05 K
ΔT1 = 3.61 K
ΔT2 = 2.13 K
ΔT [K]
Time [min]
0
1
2
3
4
5
6
7
0
500
1000
1500
2000
2500

Results

for 25 W heating power
Vertical position:

$$\lambda_{LAr} = (1.54 \pm 0.10)\,\frac{W}{m \cdot K} \tag{6}$$

Horizontal position:

$$\lambda_{LAr} = (0.63 \pm 0.03)\,\frac{W}{m \cdot K} \tag{7}$$

- Thermal conductivity higher for vertical position due to convection
- modelling the convection for the ATLAS FCal simulation
- High enough to avoid boiling?
- in case of boiling: another detector in front or replacing the FCal