EVALUATION OF INNOVATIVE COOLING CONCEPTS WITH HIGH PERFORMANCE CARBON MATERIAL FOR VERTEX DETECTORS OPERATED IN VACUUM

DPG FRÜHJAHRSTAGUNG IN MÜNSTER

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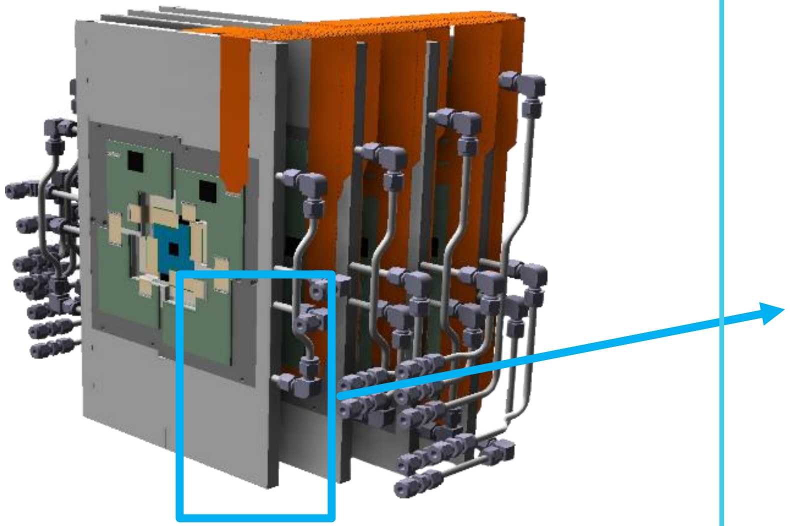
OUTLINE

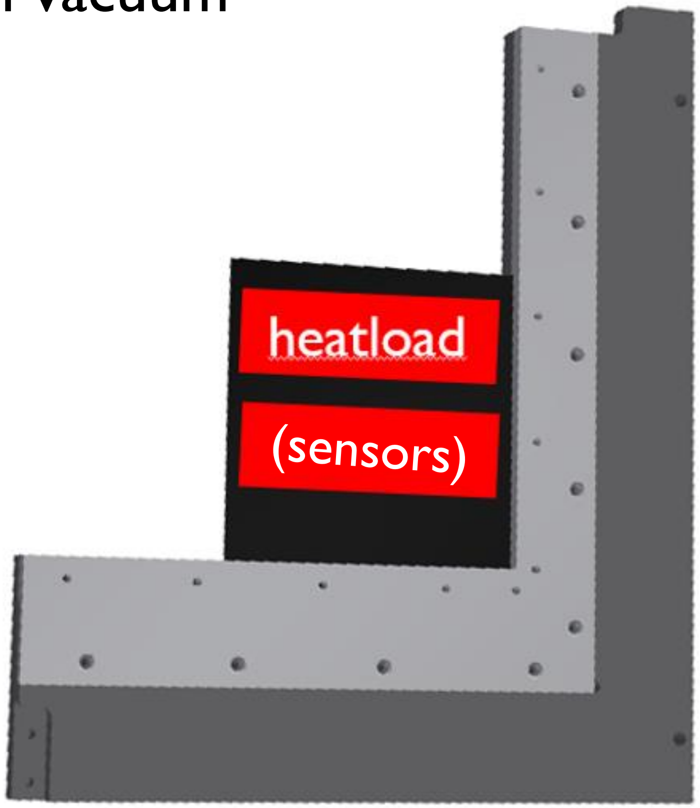
1. Motivation
2. Thermal Pyrolithic Graphite (TPG)
3. Experimental Setup
4. Thermal Performance Measurements
5. Comparison to Simulation
6. Summary

MOTIVATION



Micro-Vertex-Detector (MVD) for CBM

In vacuum



In-situ cooling is necessary because there are no cooling effects by convection.

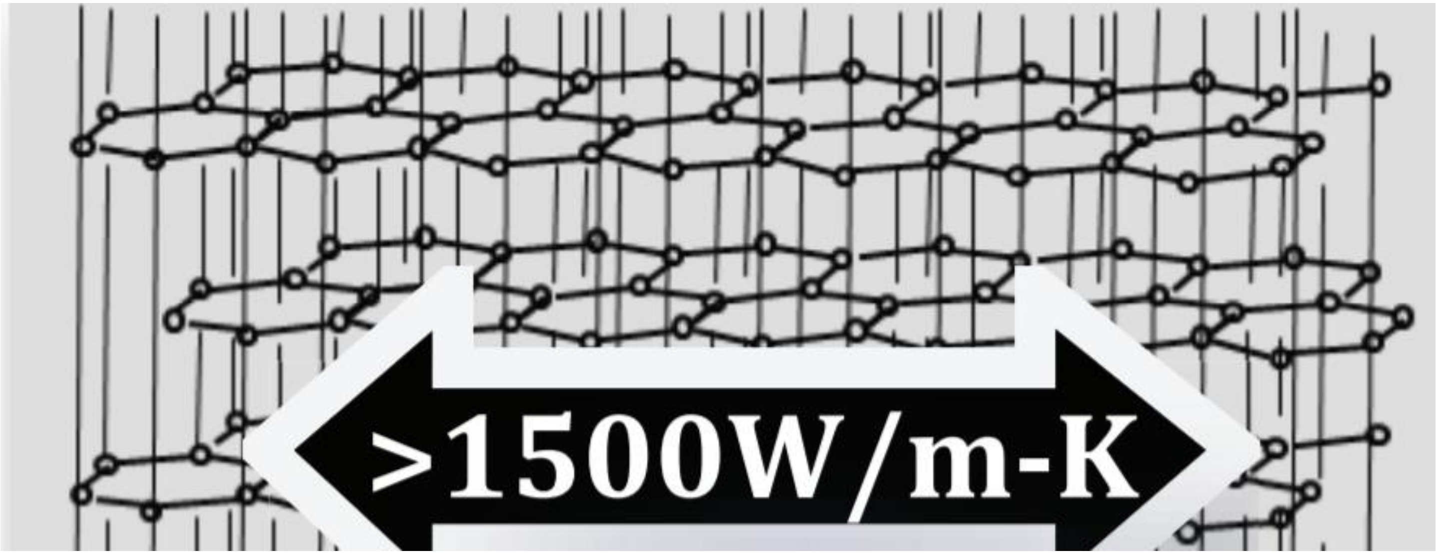
Solution:
Materials with a high heat conductivity are a good option to transport the heat of the sensors to the cooling system.

THERMAL PYROLITHIC GRAPHITE

TPG (Thermal Pyrolithic Graphite)

Requirements to the carrier material	Features of TPG
Excellent heat conductivity (total heat input in a range of 200-500 $\frac{mW}{cm^2}$)	in-plane heat conductivity (1600 W/mK) heat conductivity in z-direction (20 W/mK)
Low material budget to avoid multiple scattering (0.3-0.5% X_0)	Thickness chosen: 500 µm and 254 µm
Stability	Young's Modulus: 1050 Gpa Stiffness due to layered structure

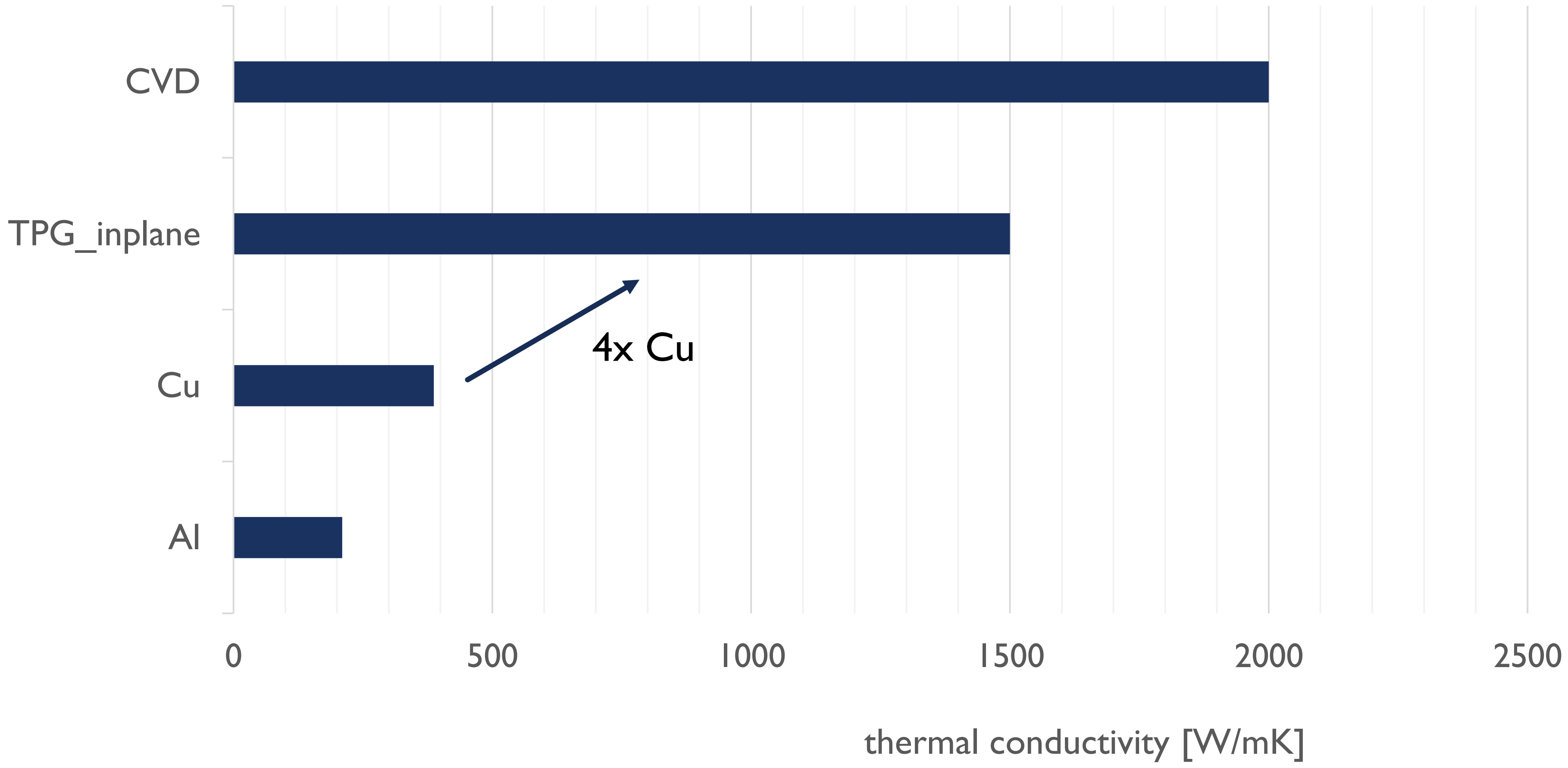
TPG STRUCTURE



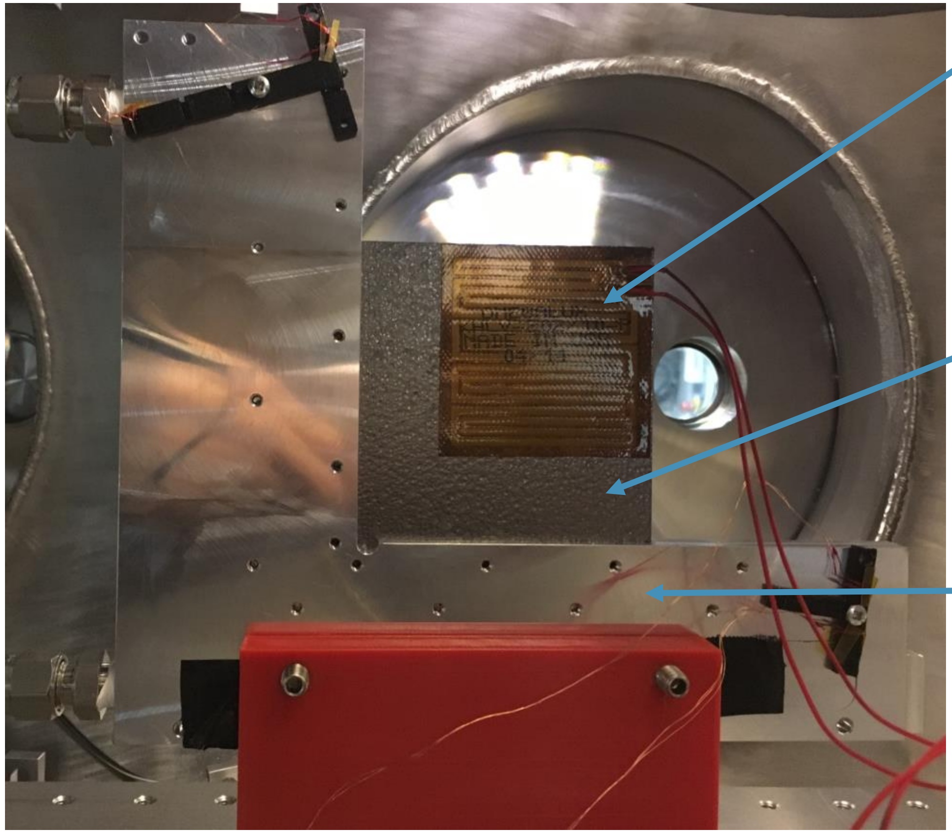
The excellent thermal conductivity comes from a highly oriented crystal structure, which stacks in bulks.

Picture by Momentive

HEAT CONDUCTIVITIES IN COMPARISON



EXPERIMENTAL SETUP



backside

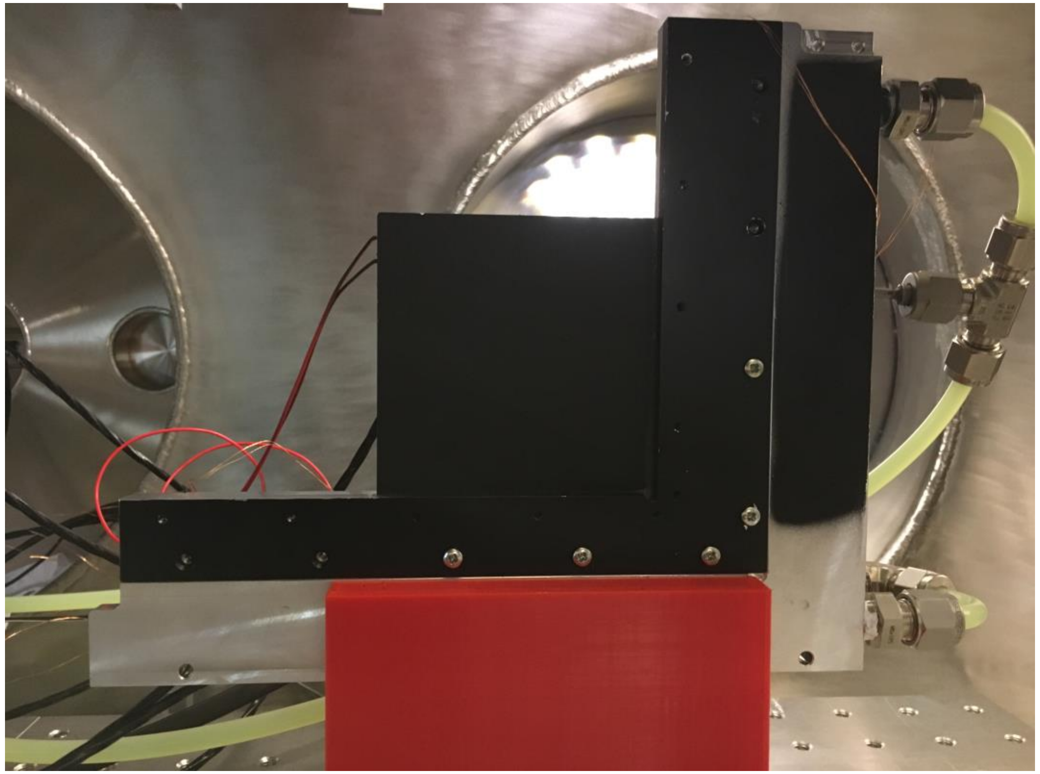
Kapton Heater
by OMEGA LUX
(heat load 790 mW/cm2)

TPG (Thermal Pyrolithic Graphite)
by Momentive
(Thickness: 254 μm and 500 μm)

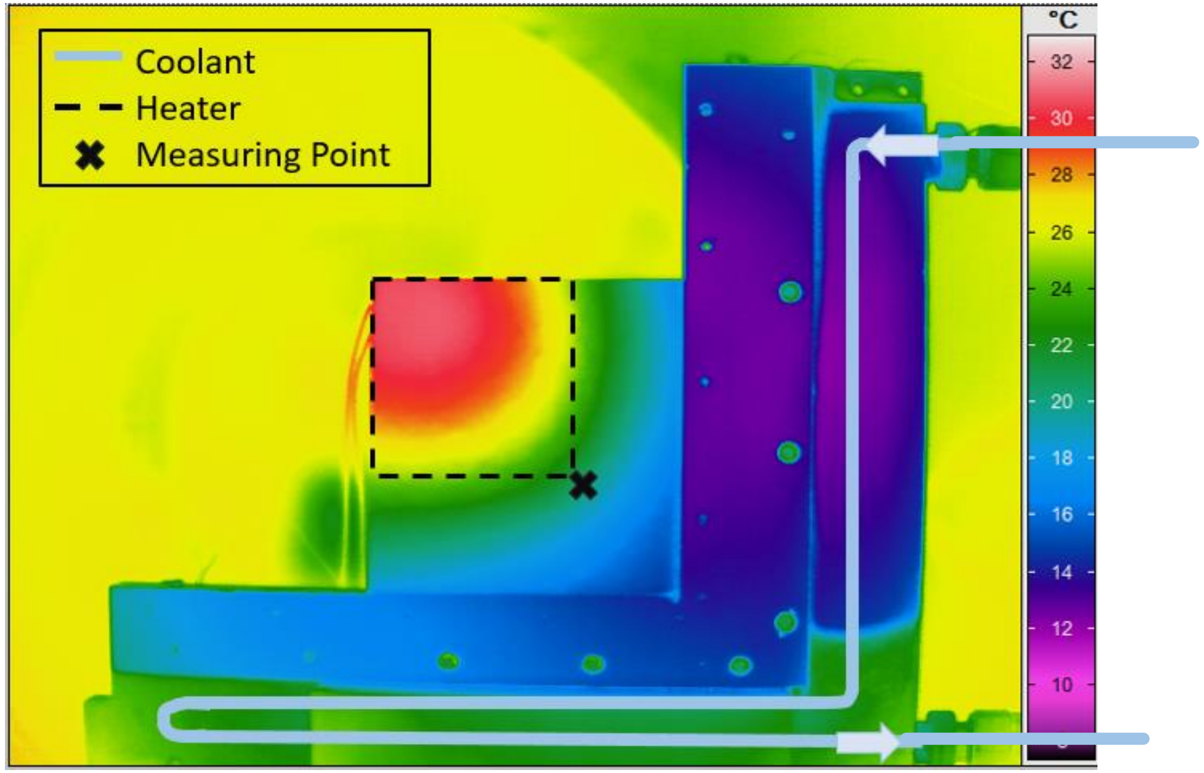
Liquid cooled Al- heat sink
Huber CC-405 (0.7 kW)

IR THERMOGRAPHY

Setup
(view of the camera into the vessel)

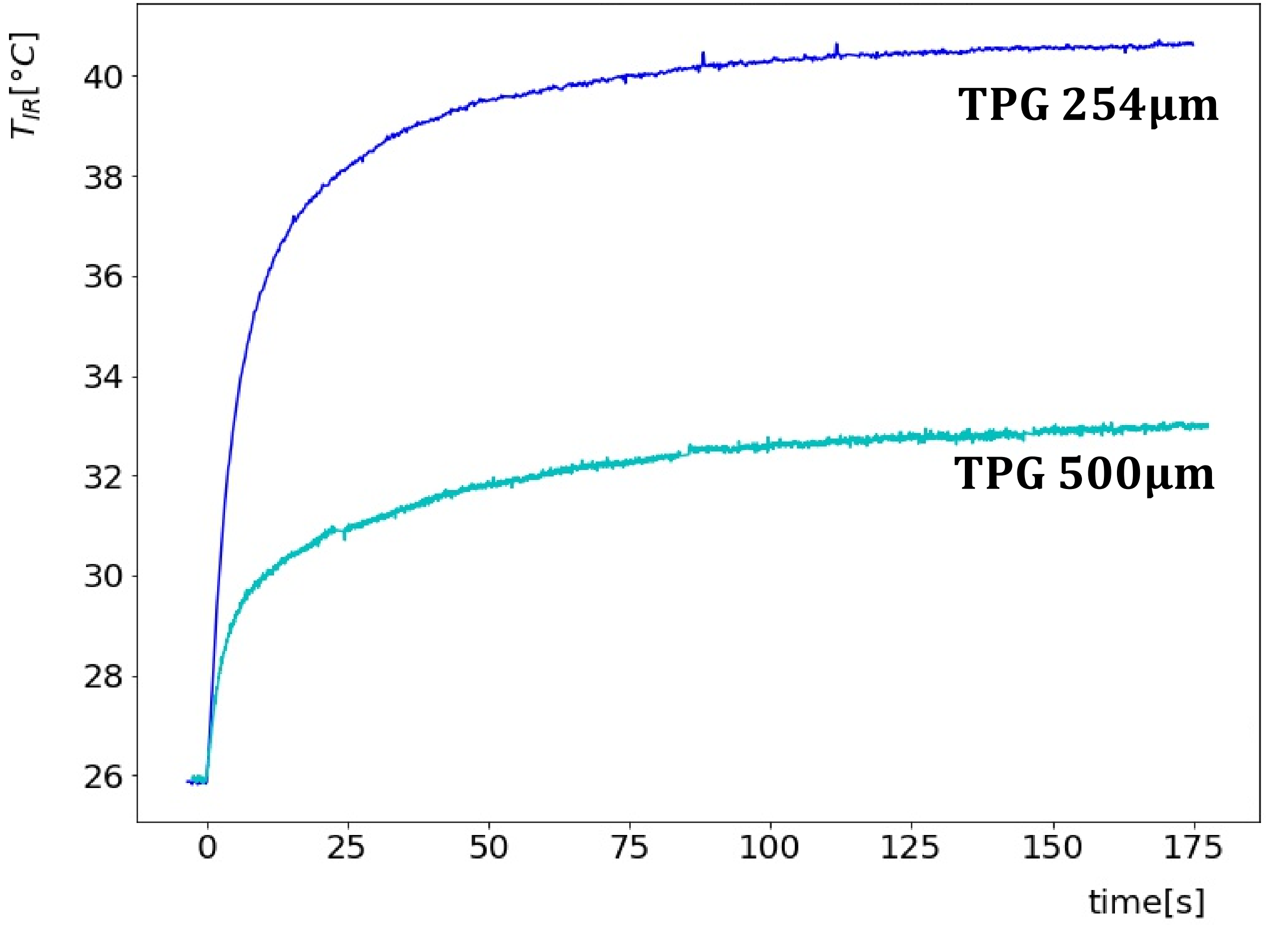


IR Image
(vacuum test stand)



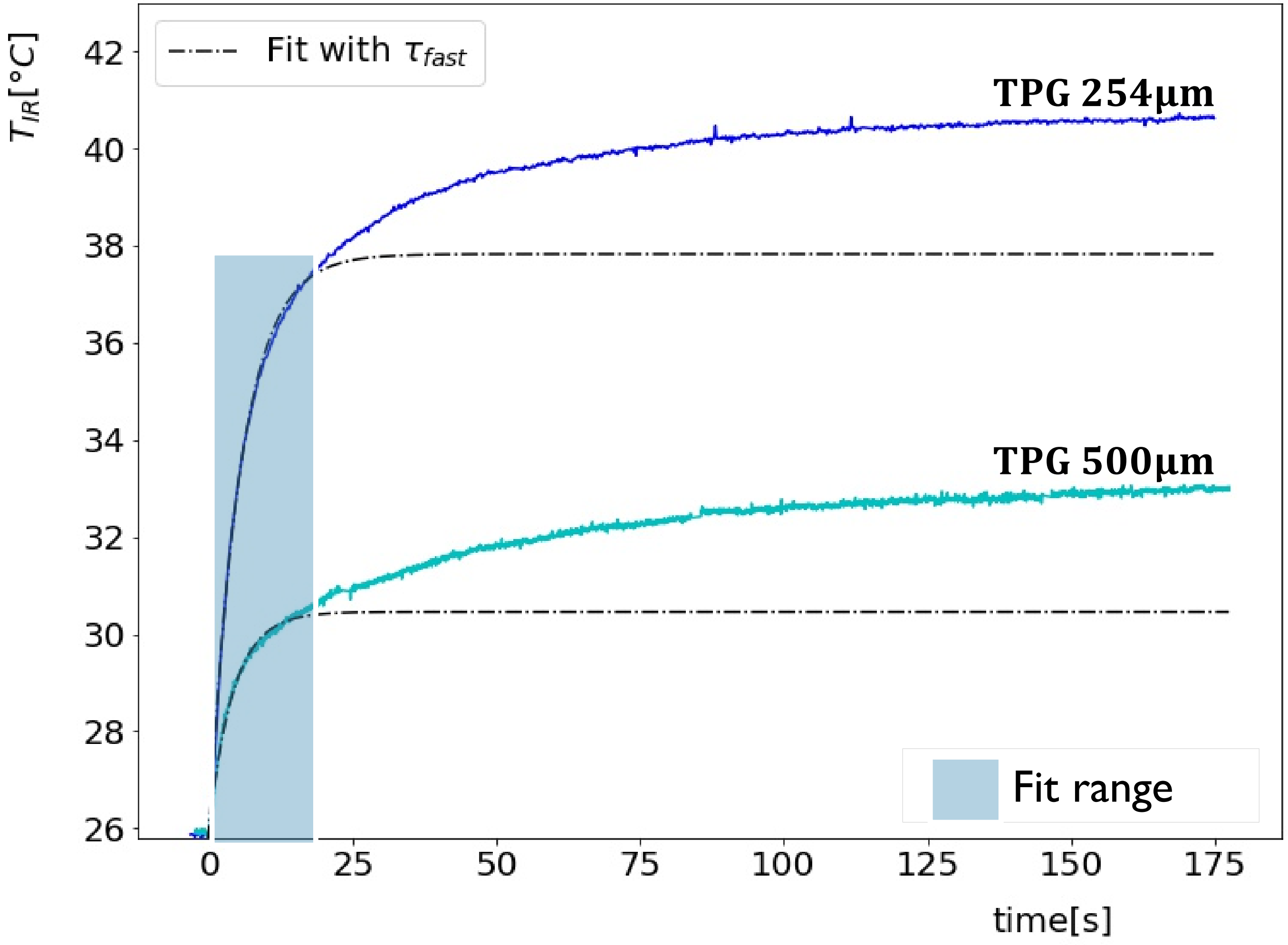
VARIOCAM hr head by InfraTec

THERMAL PERFORMANCE MEASUREMENTS



The thermal performance was characterized by analyzing heat-up curves of TPG with different thicknesses (254μm and 500μm)

THERMAL PERFORMANCE MEASUREMENTS: FAST RISE FIT



Fitting the heat- up curves during the first 15 seconds with

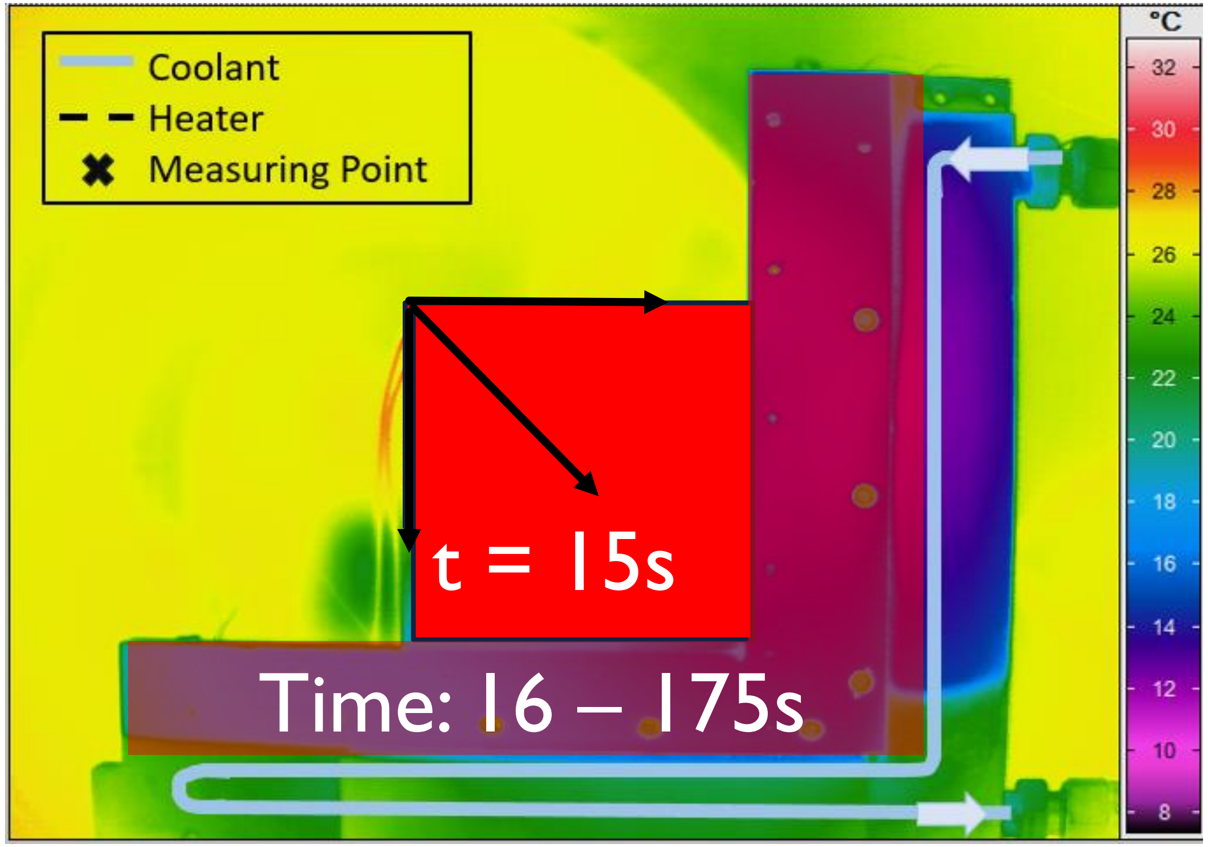
$$1 - \exp\left(-\frac{time}{\tau}\right)$$

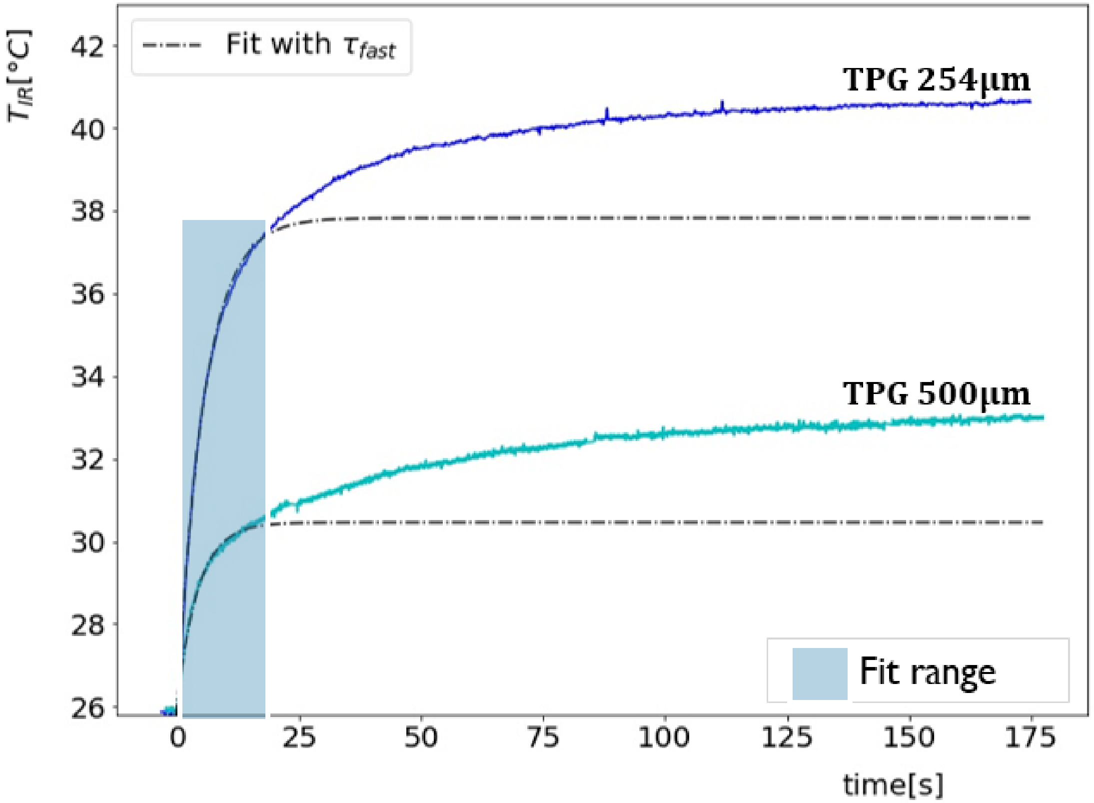
$$\tau_{fast,TPG\ 254um} = 4.7s$$
$$\tau_{fast,TPG\ 500um} = 3.8s$$

$$\tau = \frac{l^2 \rho c}{\lambda}$$

The short relaxation times describe the excellent thermal performance of TPG (heat conductivity λ =1600 W/mK)

THERMAL PERFORMANCE MEASUREMENTS: FAST RISE FIT





$\tau_{fast,TPG\ 254um} = 4.7s$

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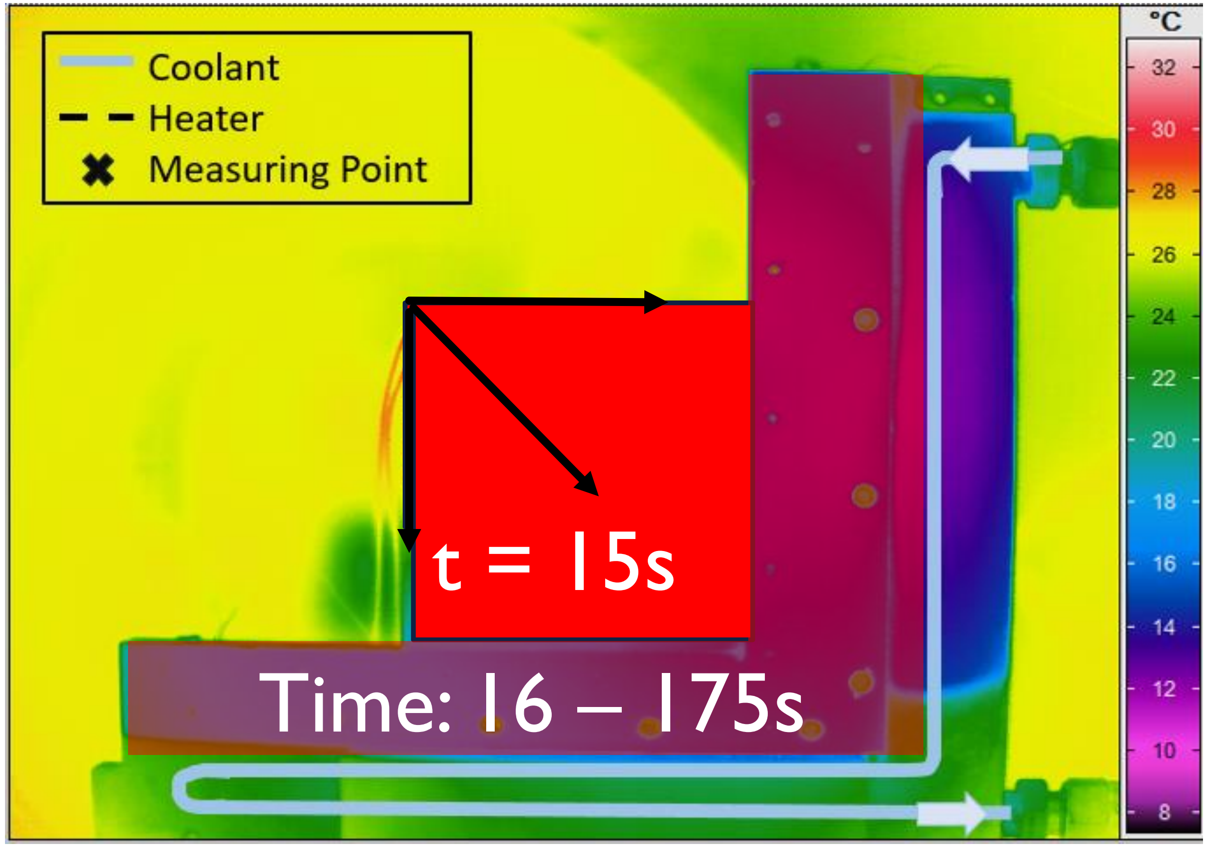
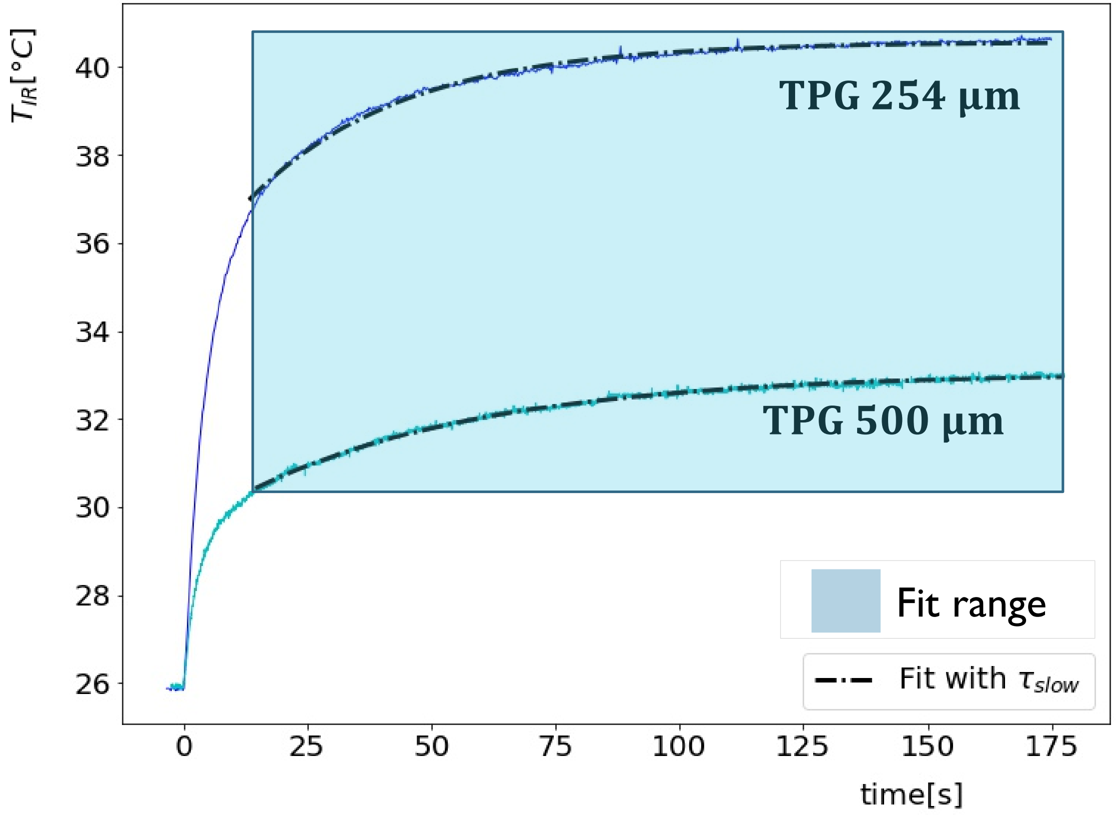
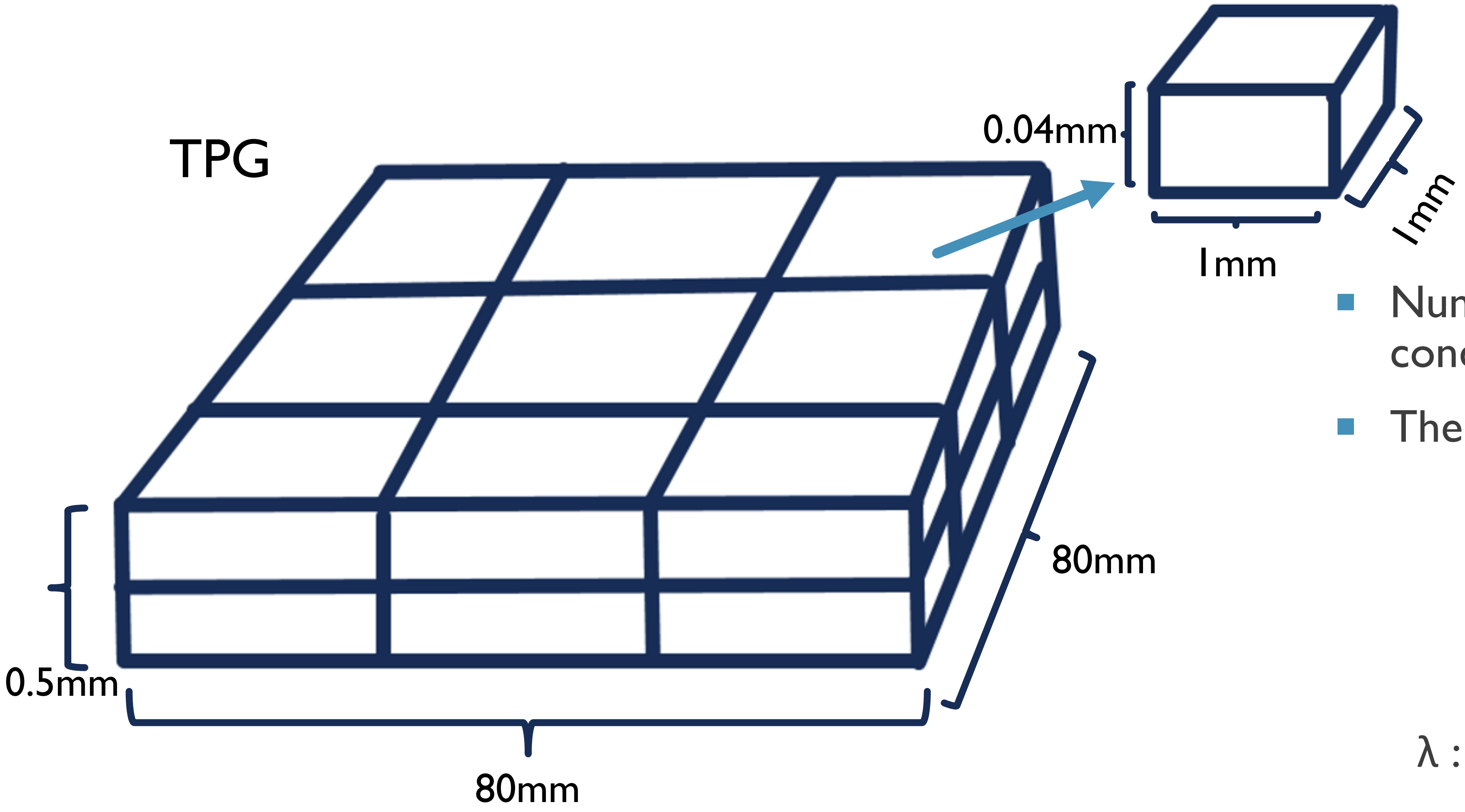
THERMAL PERFORMANCE MEASUREMENTS: FAST RISE FIT





$$\tau_{slow,TPG\ 254um} = 31s$$
$$\tau_{slow,TPG500um} = 48s$$

MODELLING OF SIMULATION

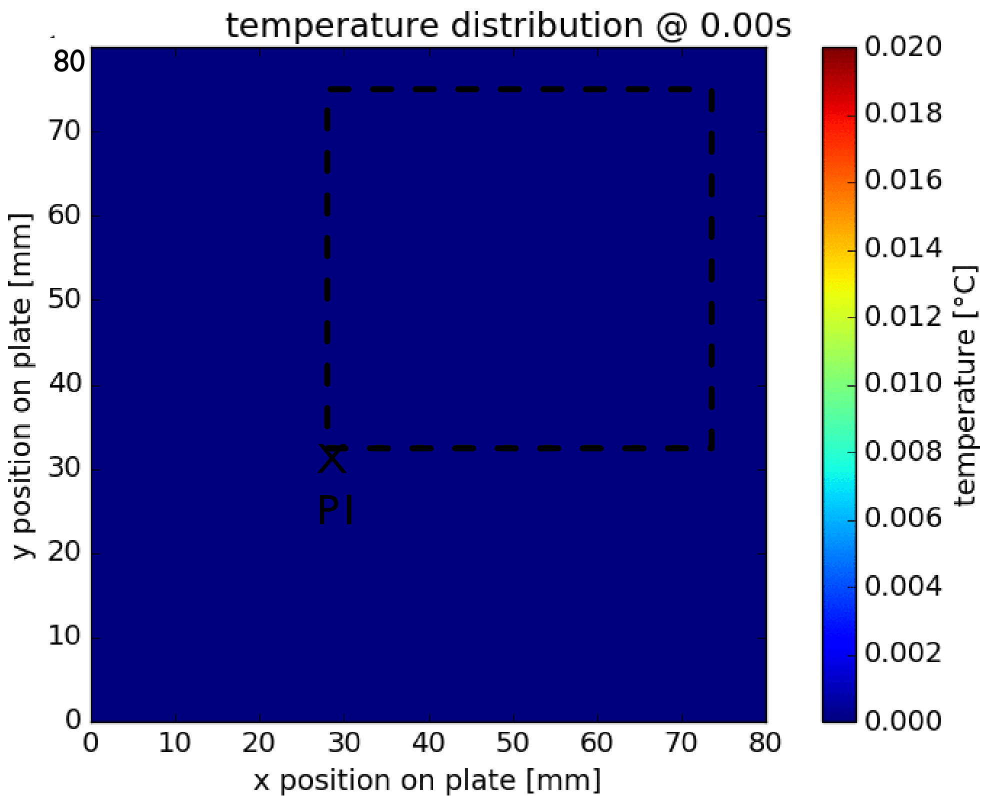


- Numerical solution of transient heat conduction
- Thermal conduction equation :

$$\dot{\mathrm{T}} = \frac{1}{\rho c} div\,(\lambda\, grad\, T)$$

λ : heat conductivity [W/mK]

SIMULATION



Goal

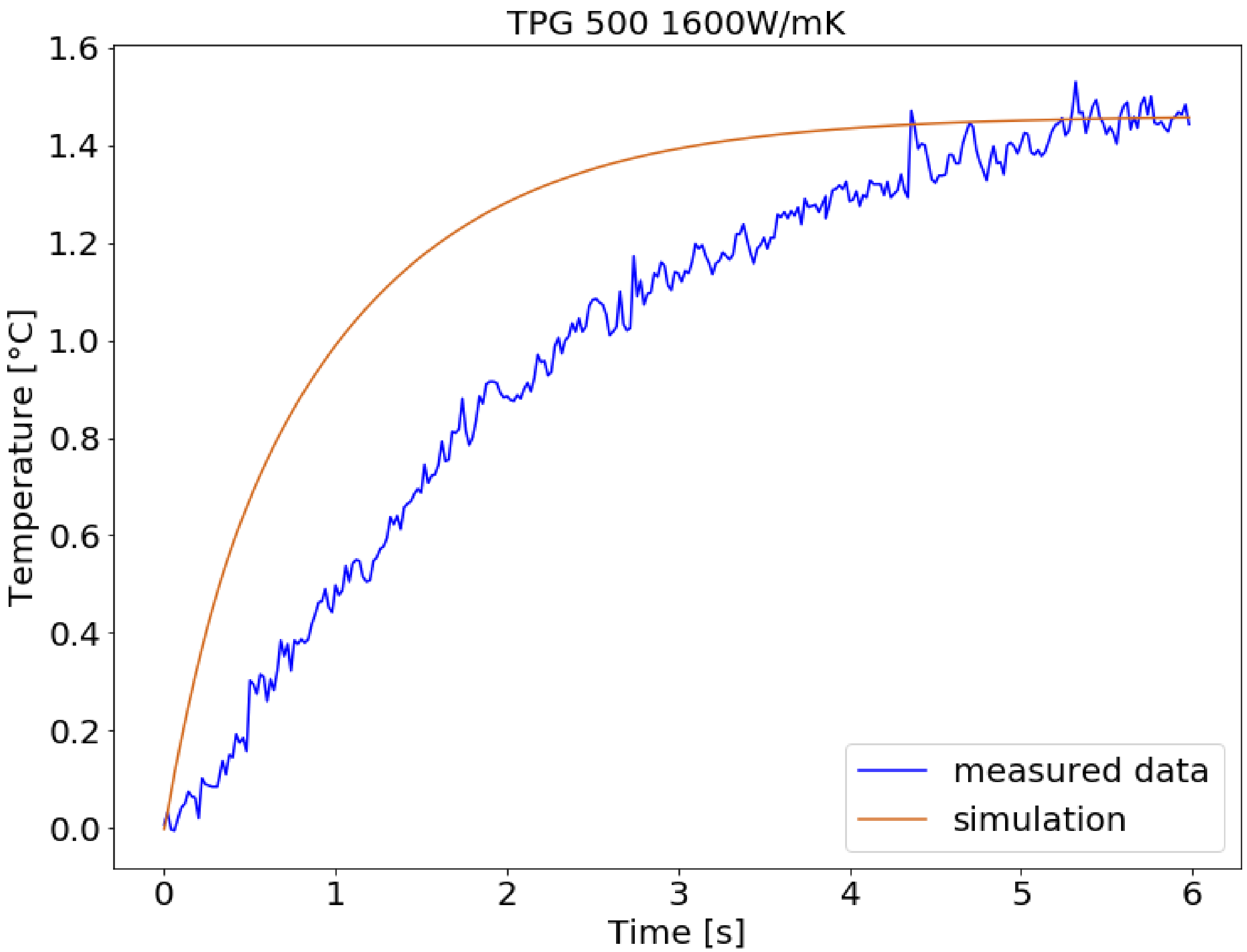
Finding a function which fits perfectly to our measurements

Boundary condition

- Fixed temperatures at two edges (0°C)
- Heater (4.5 x 4.5 mm^2) in right corner
- Simulated time steps of 10 μs (total time 6s)

Thanks to P. Klaus

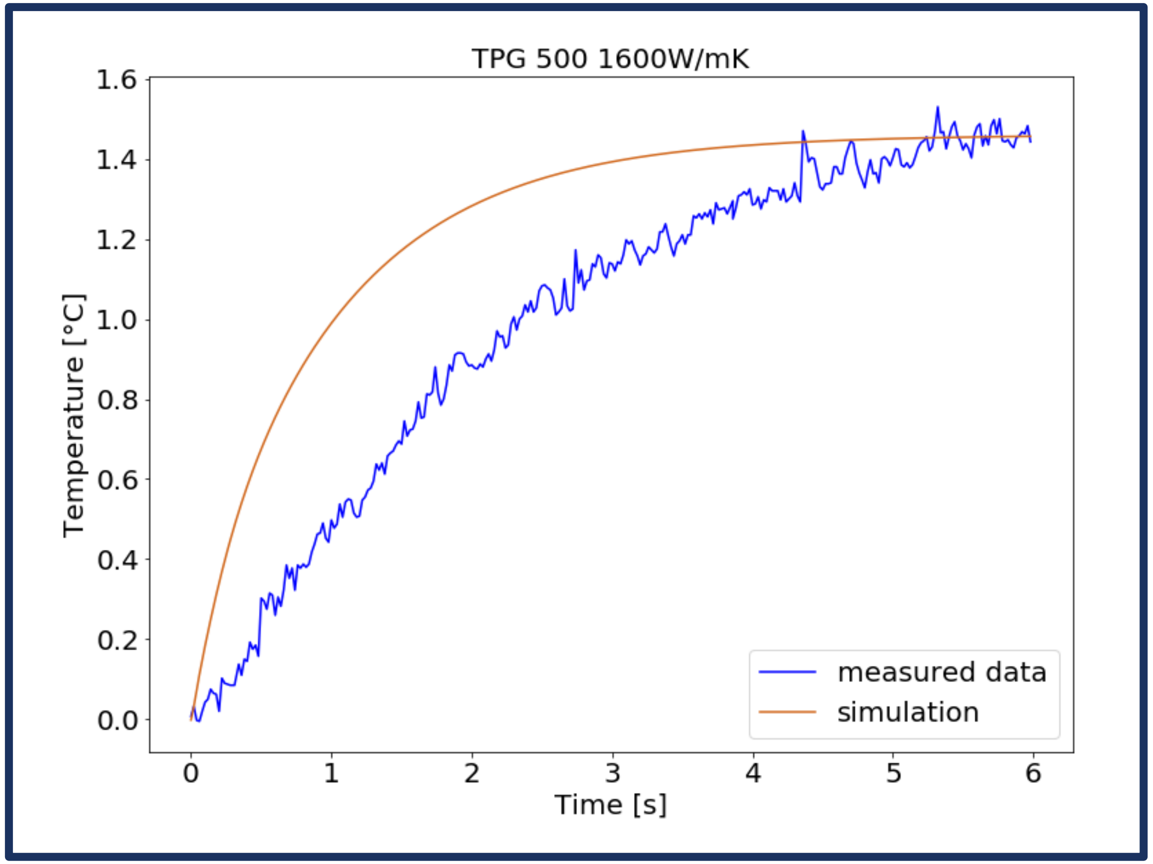
COMPARISON TO SIMULATION



Possible explanation for small mismatch:

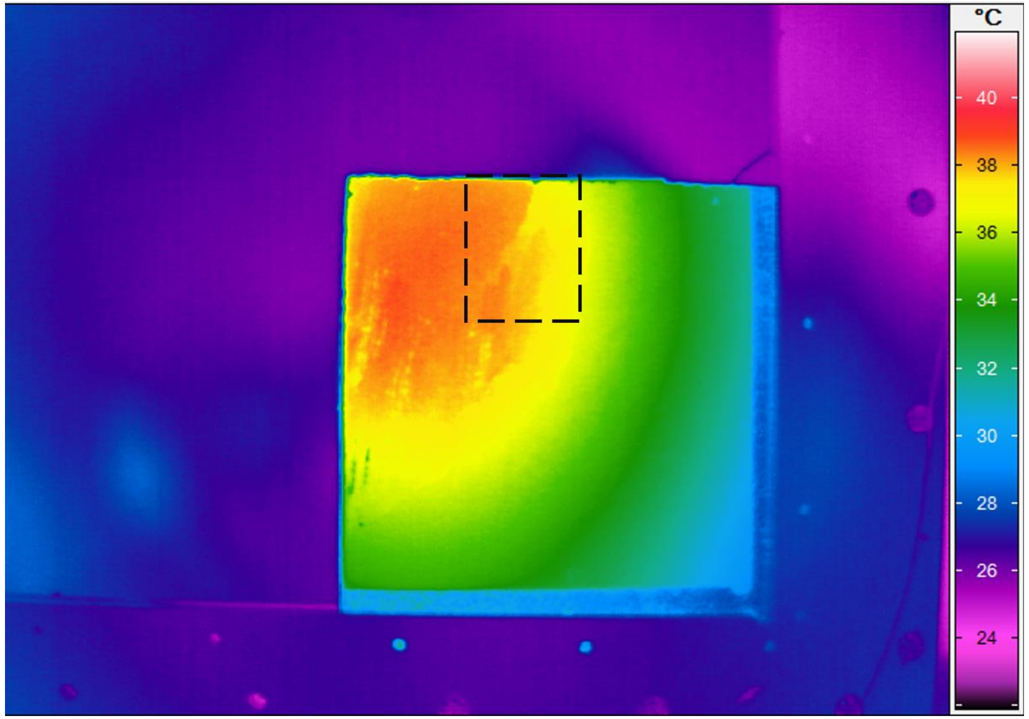
- Worse heat conductivity
- Heat capacity is higher than assumed
- Mismatch between reference points in measurement and experiment

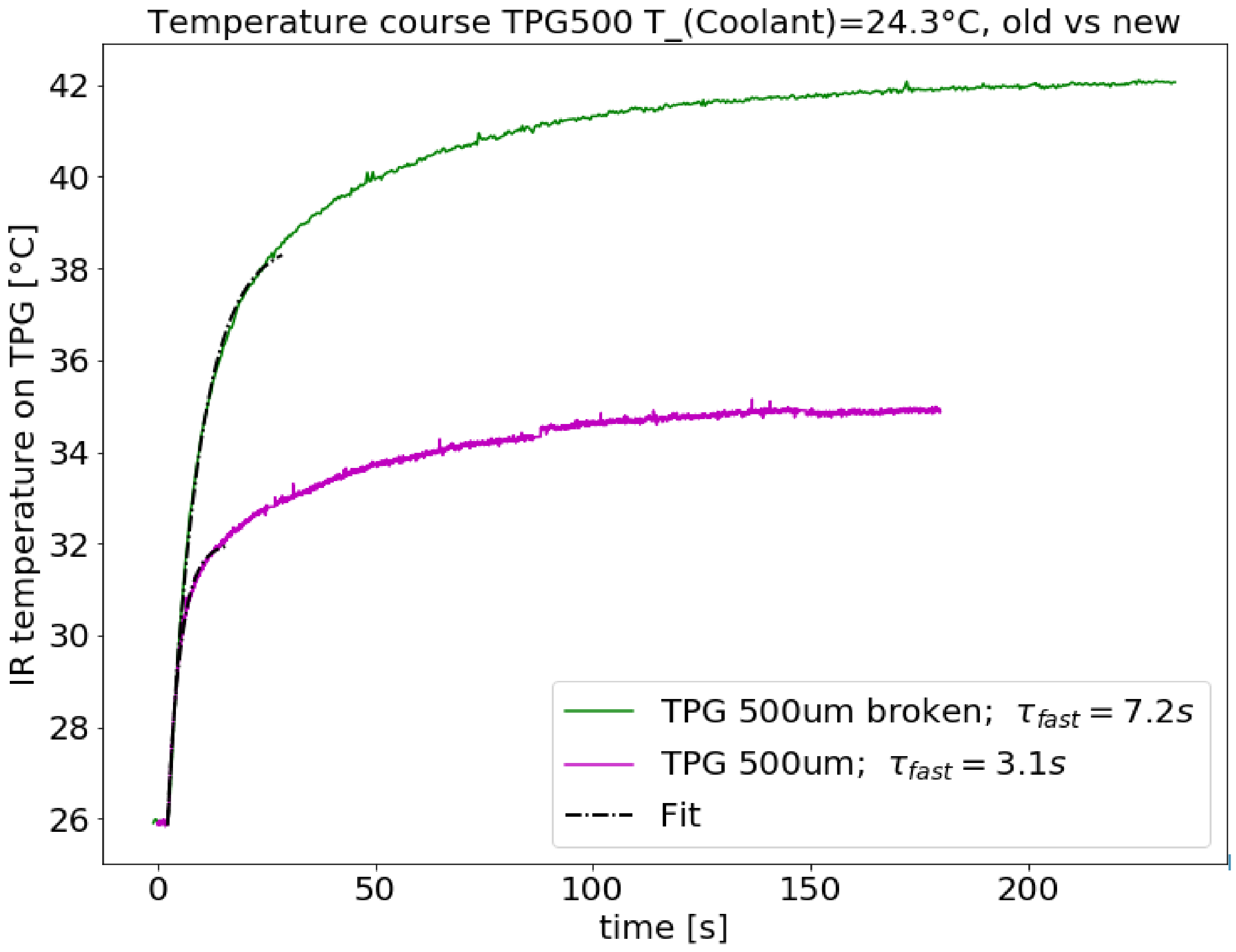
SUMMARY



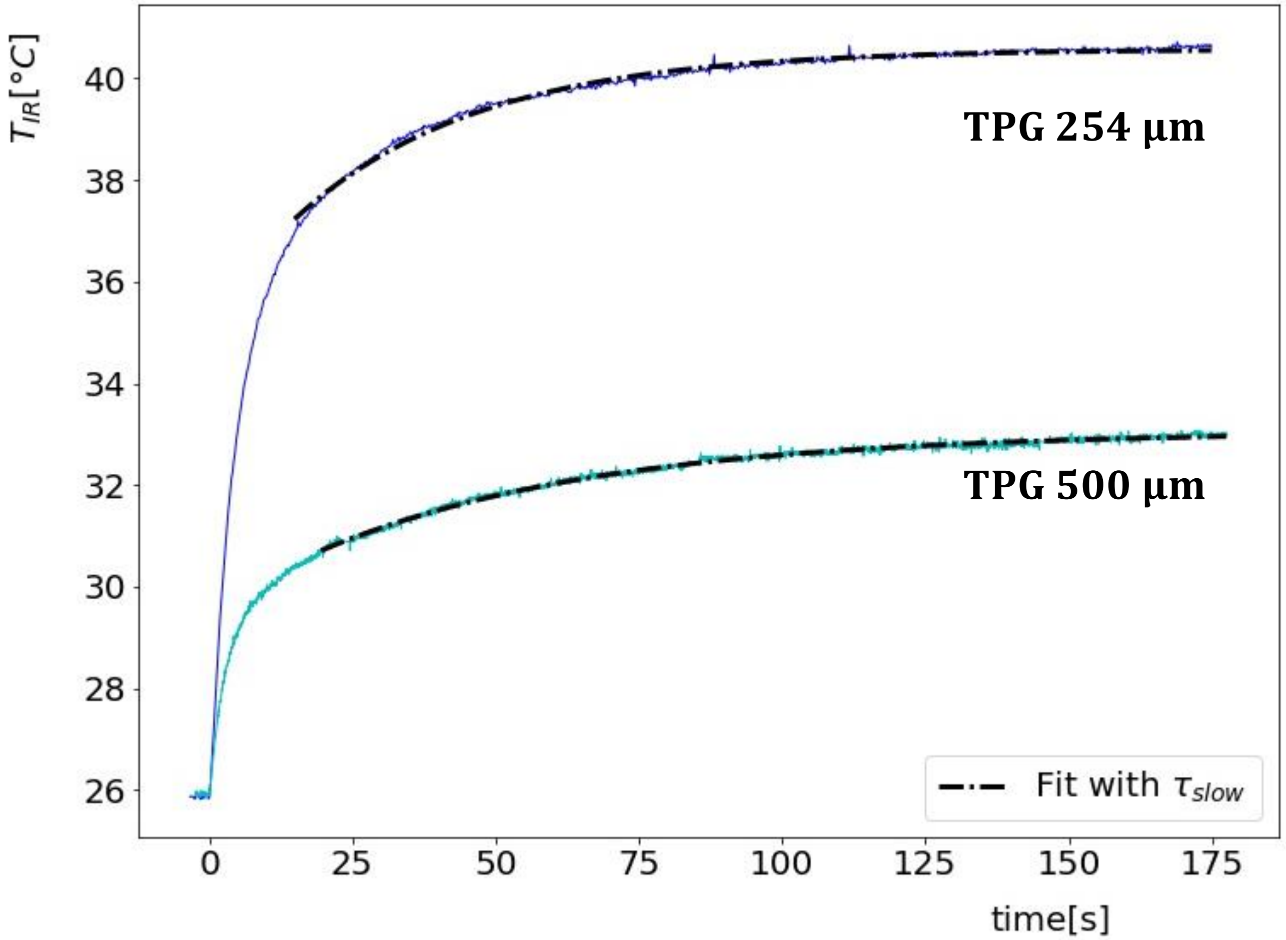
- An experimental set up was constructed up to measure the thermal features of TPG in vacuum.
- An analytic function was used to fit our measurements.
- Numerical simulation was used to model our geometry realistically and to understand the material properties by changing them.

BROKEN TPG


°C
40
38
36
34
32
30
28
26
24


Temperature course TPG500 T_(Coolant)=24.3°C, old vs new
IR temperature on TPG [°C]
42
40
38
36
34
32
30
28
26
0
50
100
150
200
time [s]
TPG 500um broken; $\tau_{fast} = 7.2s$
TPG 500um; $\tau_{fast} = 3.1s$
Fit

THERMAL PERFORMANCE: SLOW RISE FIT

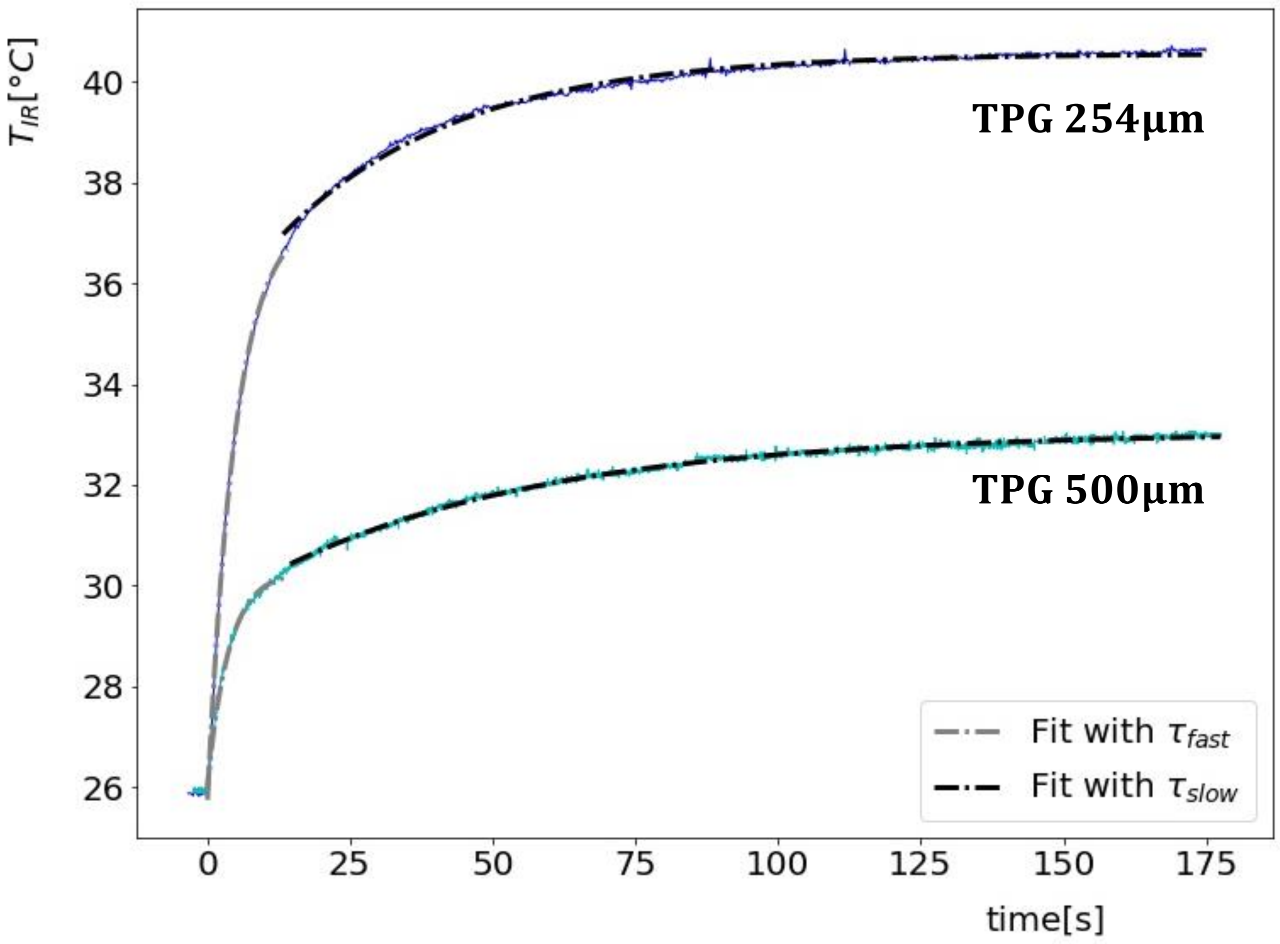


The second fit, within the time of t = 16 -175s, characterize the saturations phase.

$$\tau_{slow,TPG\ 254um} = 31s$$
$$\tau_{slow,TPG500um} = 48s$$

The long relaxation times describe the heat capacity and the power of the cool sink to evacuate the heat on the carrier

THERMAL PERFORMANCE: ROUNDUP



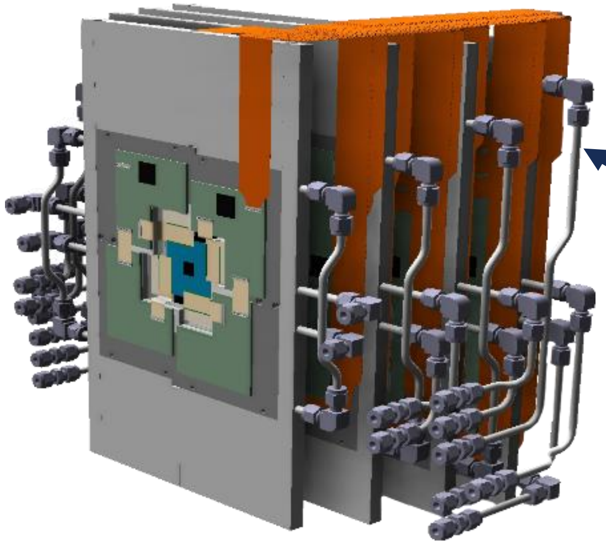
- Thickness of the material effects the heat distribution

- The plots show us:
  - → the material properties of the TPG (τ_{fast})
  - → power to evacuate the heat from the carrier (τ_{slow})

- τ_{fast} substantiate the excellent thermal performance of the TPG

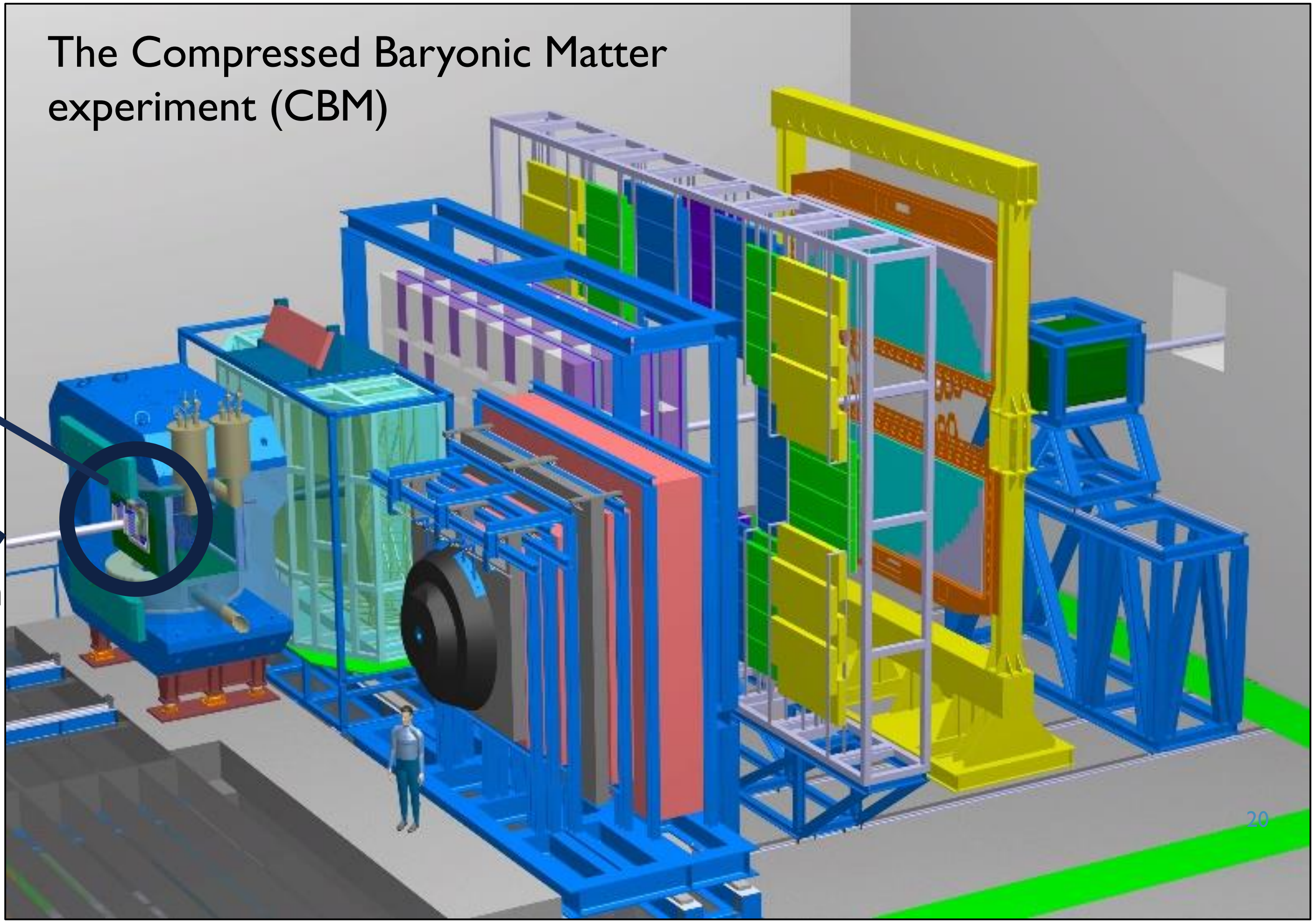
- τ_{slow} will help us to improve the heat evacuation and cool sink

OVERVIEW: MVD

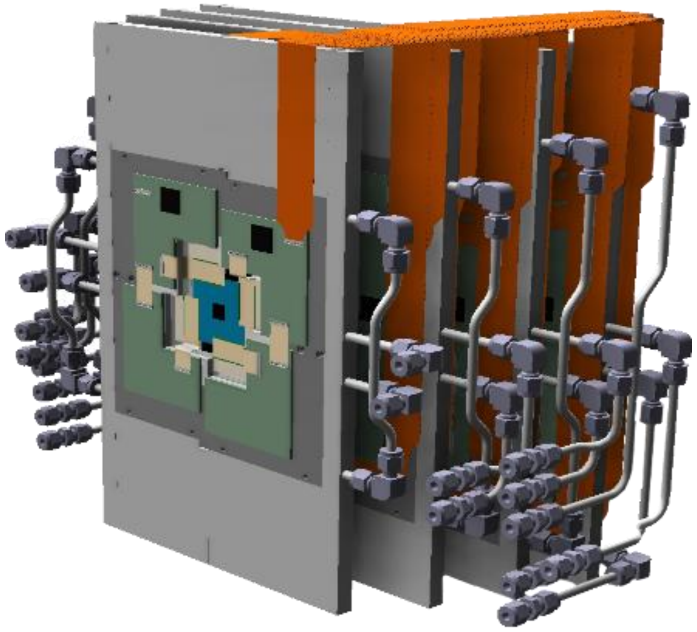


Micro Vertex Detector (MVD)

beam



OVERVIEW: MVD



Micro Vertex Detector (MVD)

- 1st subdetector of CBM
  - → vertexing
  - → micro-tracking
- 4 planar station, divided in quadrants
- Equipped with CMOS Sensors, which have to be cooled to ensure their efficiency
- Operates in vacuum

HEAT CONDUCTIVITIES IN COMPARISON