DPG Frühjahrtagung in Bochum 2018

Evaluation of Innovative Cooling Concepts with High-Performance Carbon Materials for Vertex Detectors operated in Vacuum

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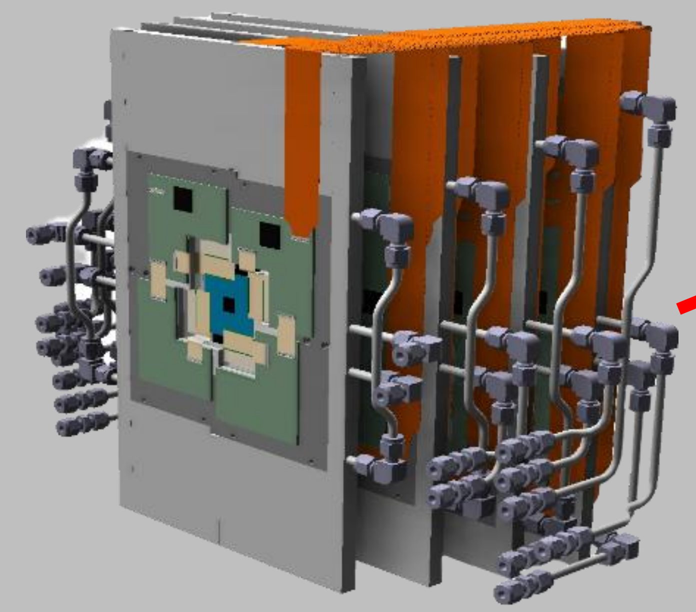
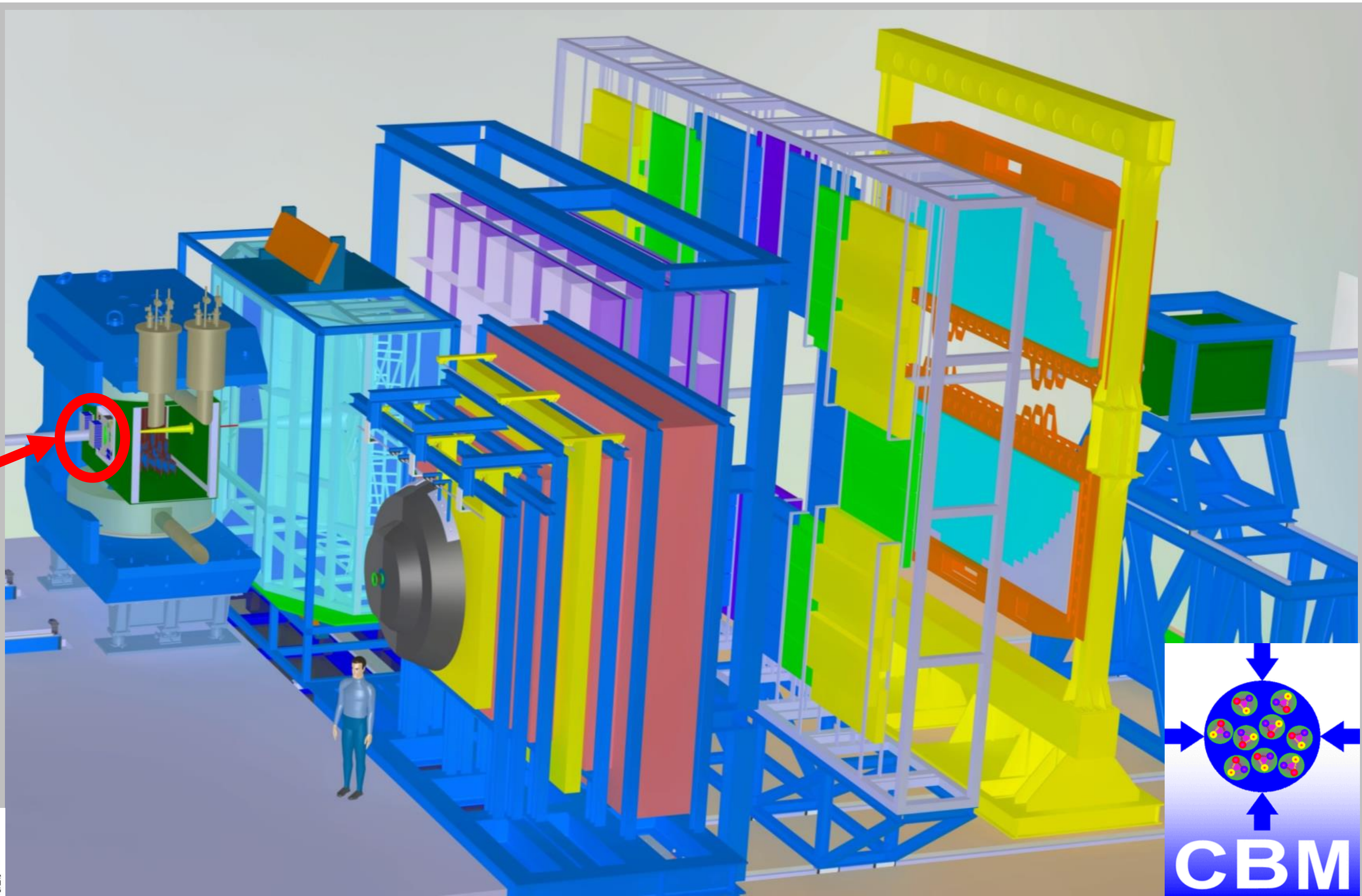
IKF University Frankfurt

This work has been supported by BMBF (05P15RFFC1), GSI and HIC for FAIR.

Motivation
The **M**icro **V**ertex **D**etector **MVD**



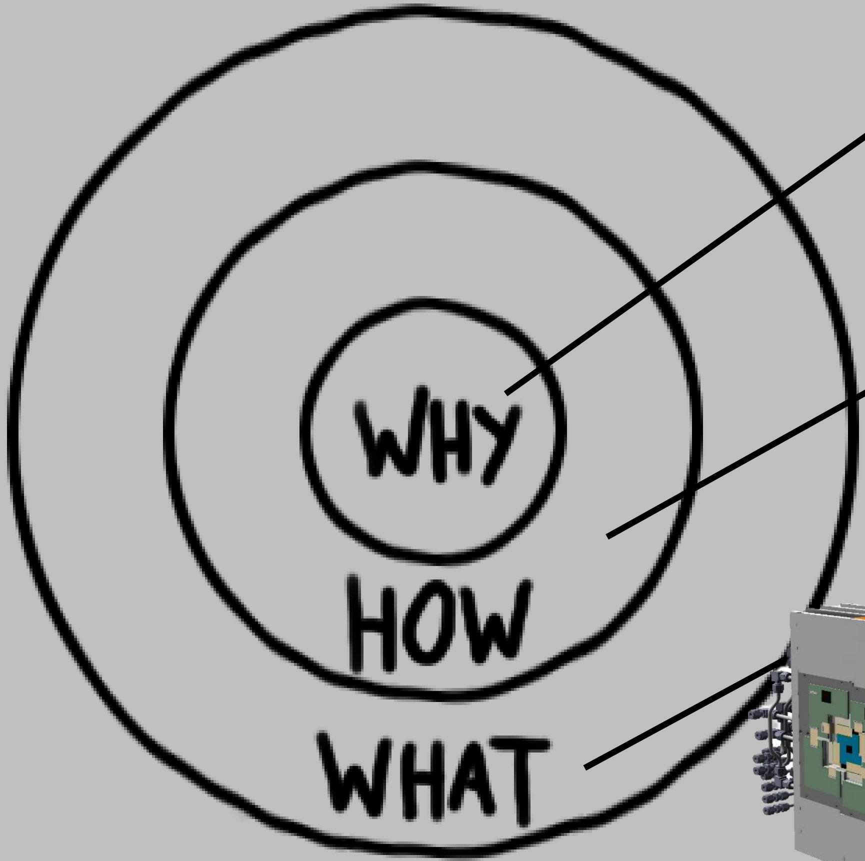


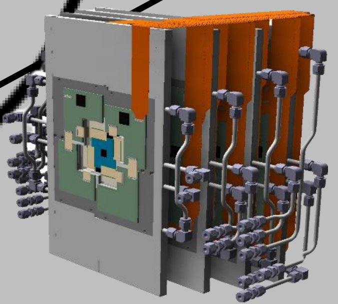
IKF Institut für Kernphysik Frankfurt

IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

CBM

Motivation
The **M**icro **V**ertex **D**etector **MVD**





Task
- **Tracking of charged particles in fixed target set-up**
- **Precise determination of secondary decay vertices of short lived particles**
  (50 - 70 µm along beam axis)

Requirements
- **Close to the target**
- **High radiation hardness**
- **Low material budget and vacuum operation**

⇒ **<u>Actively cooled sensors</u>**

MVD

Inside the acceptance	**Outside the acceptance**
Efficient Cooling ⇔ Low Material Budget → Conductive cooling with high performance sensor carrier	Convective cooling with heat sink

The Sensor Carrier
Thermal **P**yrolithic **G**raphite **TPG**

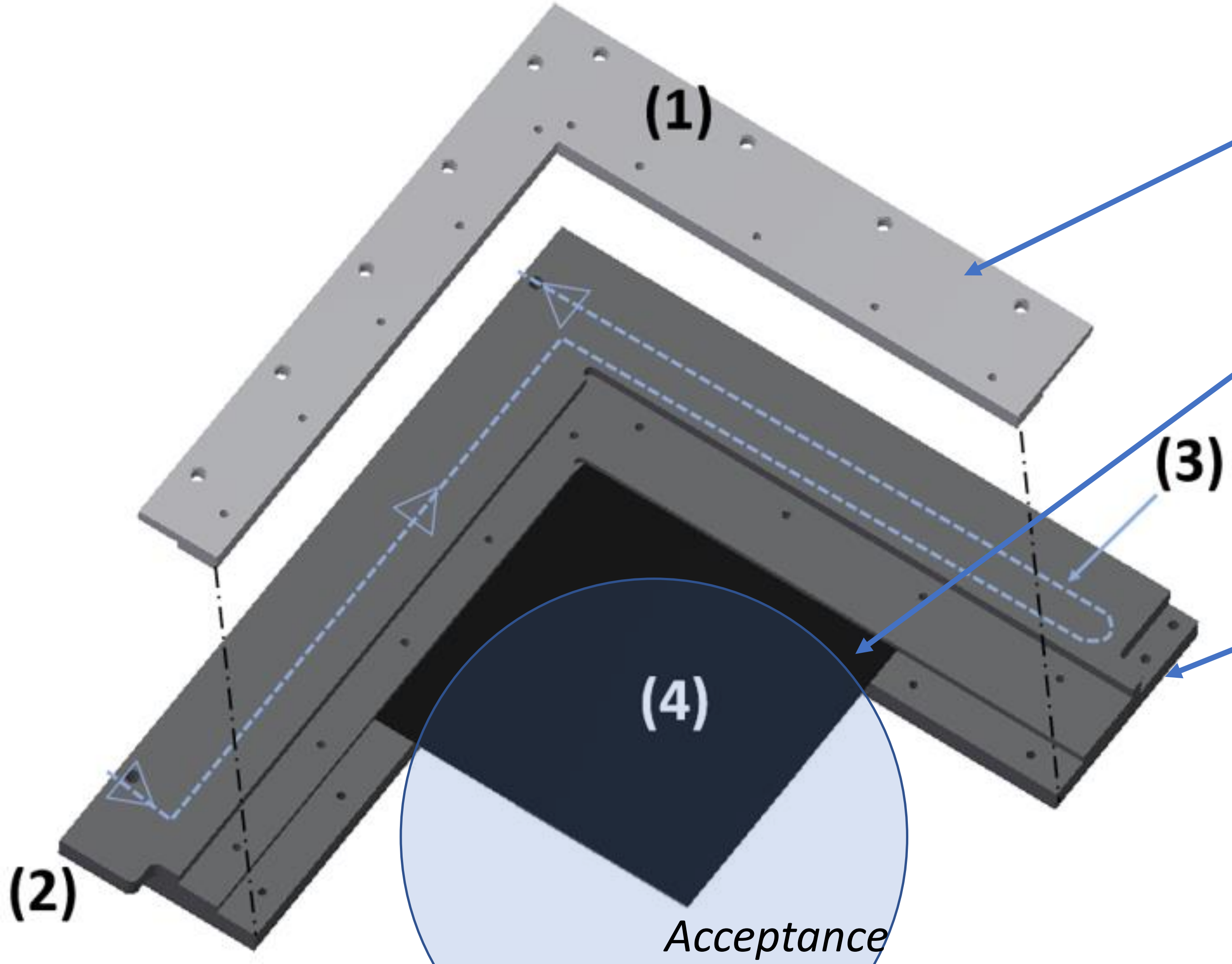
CVD Diamond is used for St. 1 and 2

Thin

Excellent heat conductivity in-plane (1600 W/mK)

Mechanical Stable

Convective and Conductive Cooling within one Quadrant

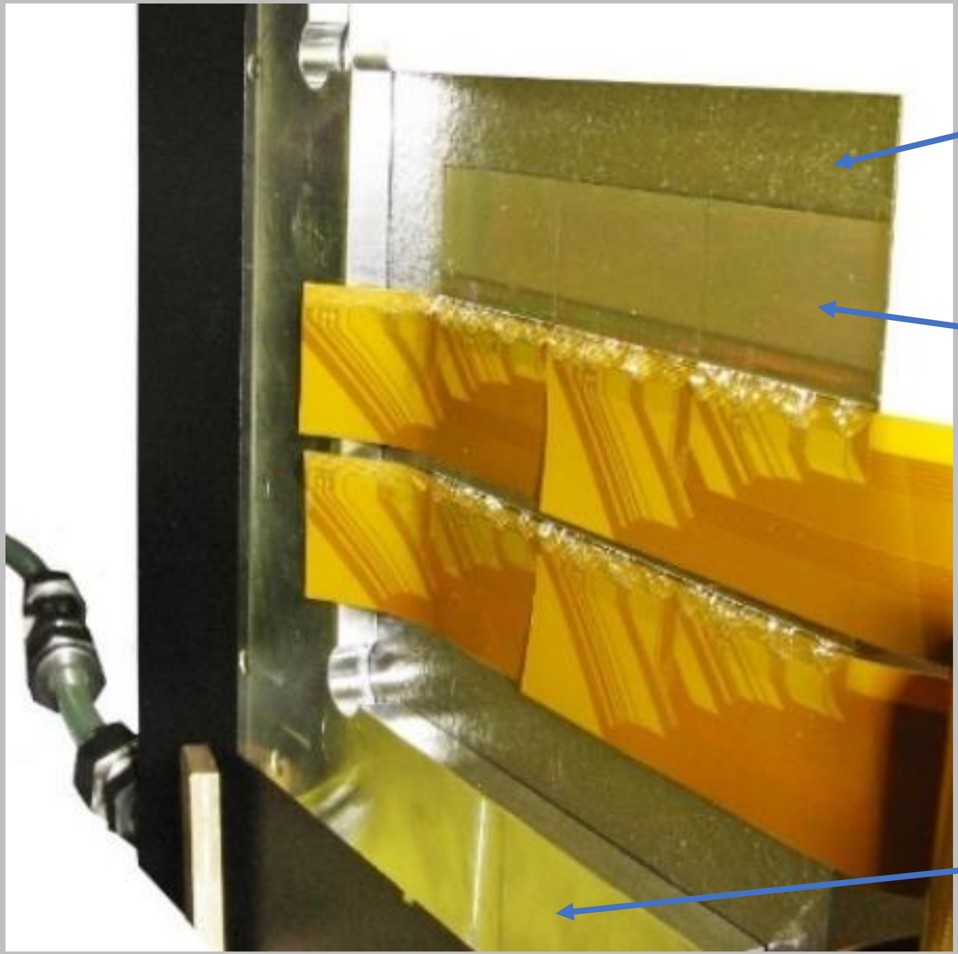


Heat-sink balcony

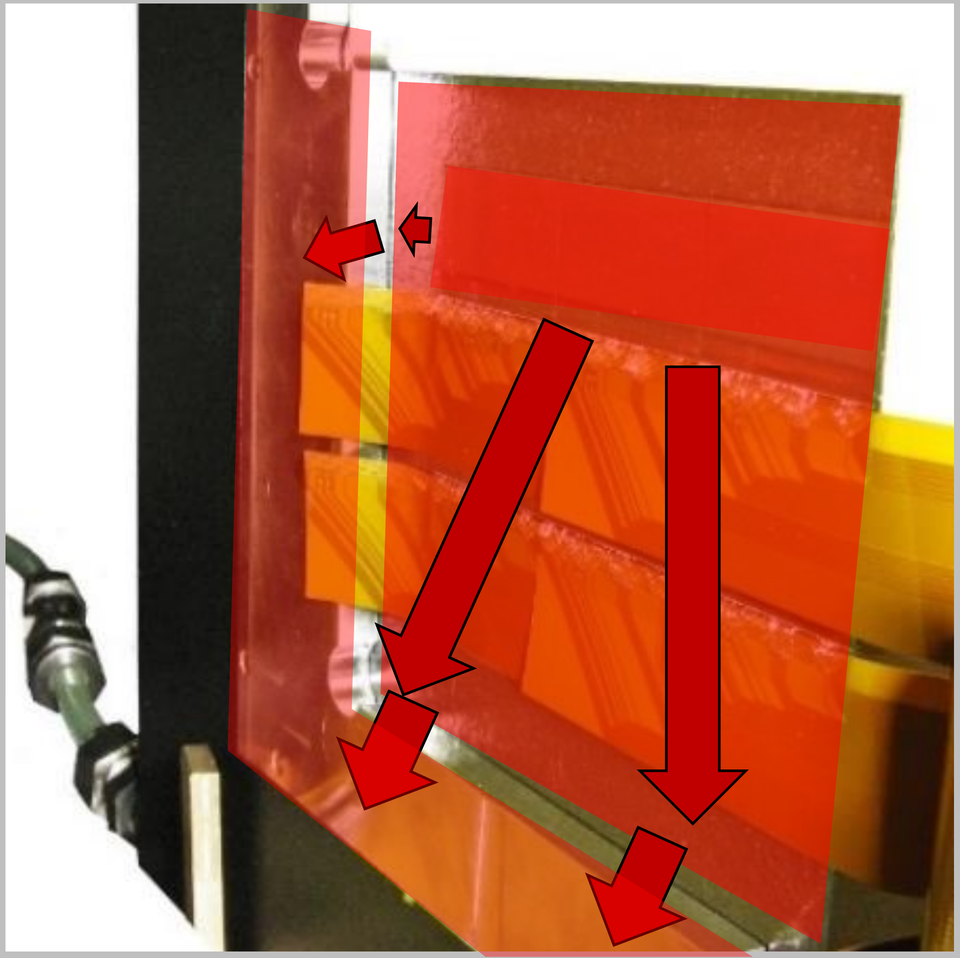
Conductive Cooling:
Sensor carrier clamped to the heat sink (TPG)

Convective Cooling:
Liquid cooled Al-heat sink

Convective and Conductive Cooling
The Quadrant



Convective and Conductive Cooling Heat Flow



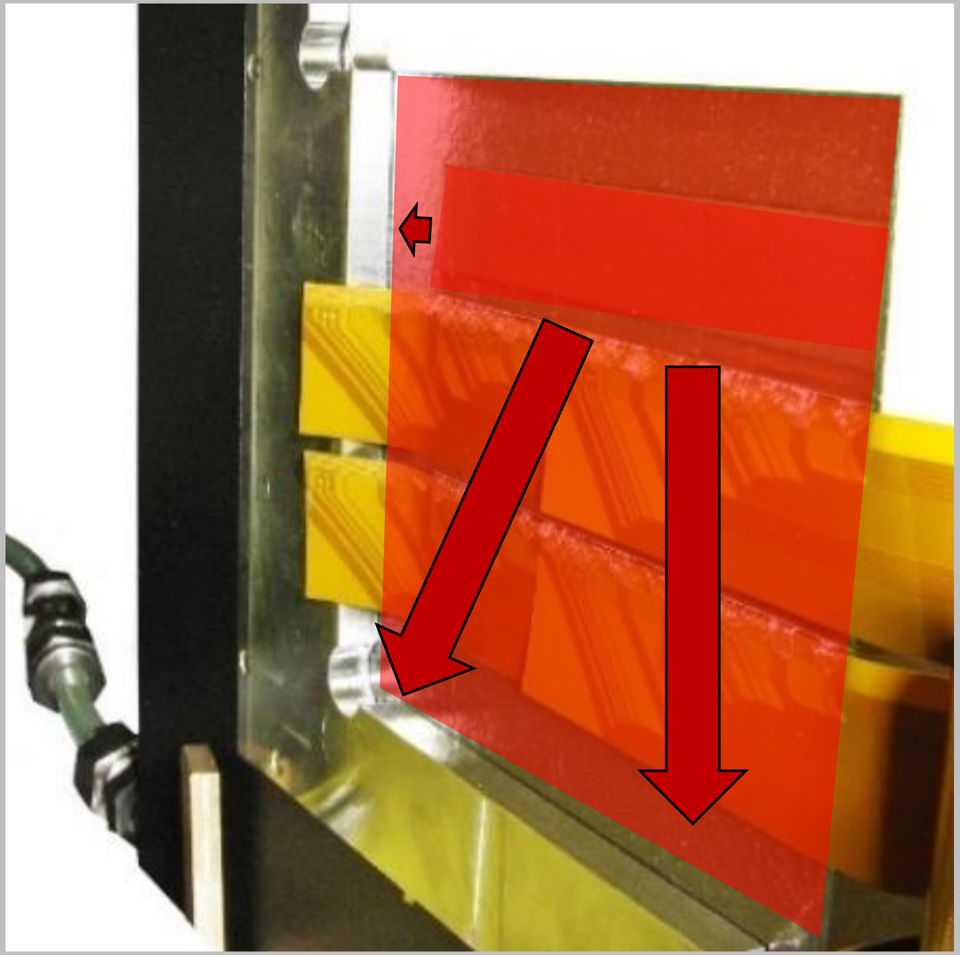
1. Sensors produce heat (200 – 500 mW/cm^2)

2. Heat transferred by conduction over the sensor carrier

3. Sensor carrier is clamped to the Al- heat sink

4. Cooling liquid circulating inside the heat sink transfers the heat by convection

Convective and Conductive Cooling Heat Flow



1. Sensors produce heat

2. Heat transferred by conduction over the sensor carrier

Can be achieved by materials with a very high heat conductivity

3. Sensor carrier is clamped to the Al- heat sink

4. Cooling liquid circulating inside the heat sink transfers the heat by convection

The Experimental Setup

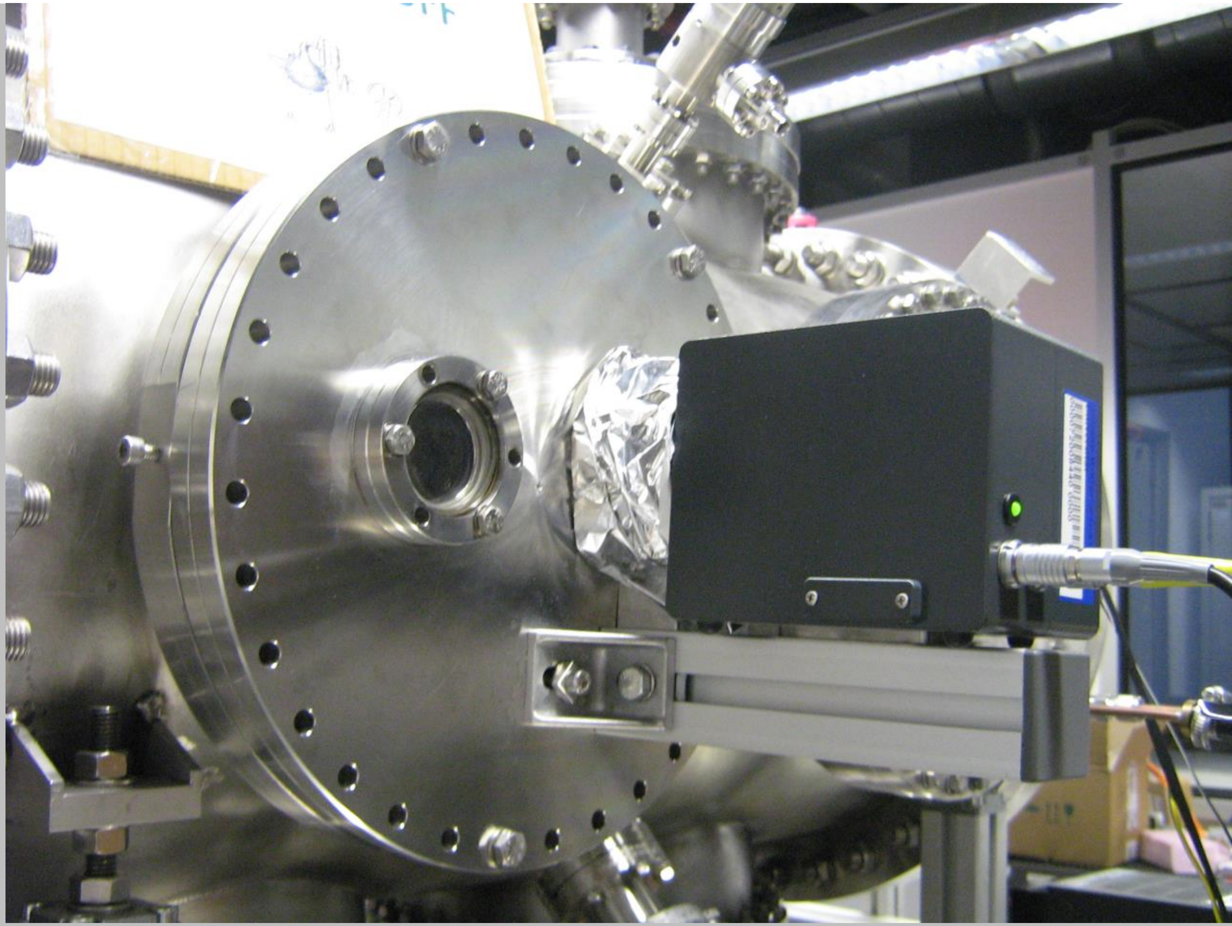
Goal:

Measuring thermal performance with **infrared (IR) thermography** of sensor carriers **in vacuum for quantitative evaluation**

needs → A standardized test setup

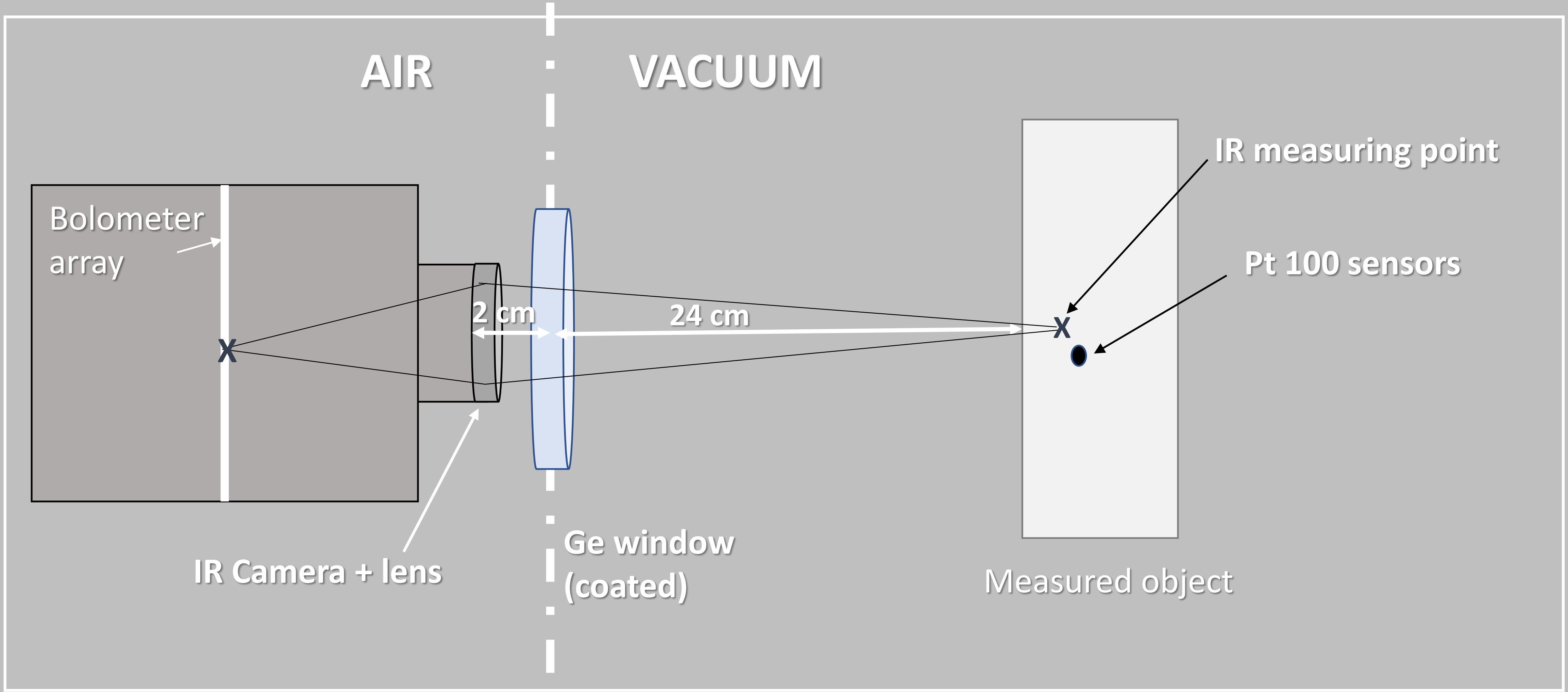
IR advantages:

- Contactless temperature measurement
- High resolution spatial temperature profile

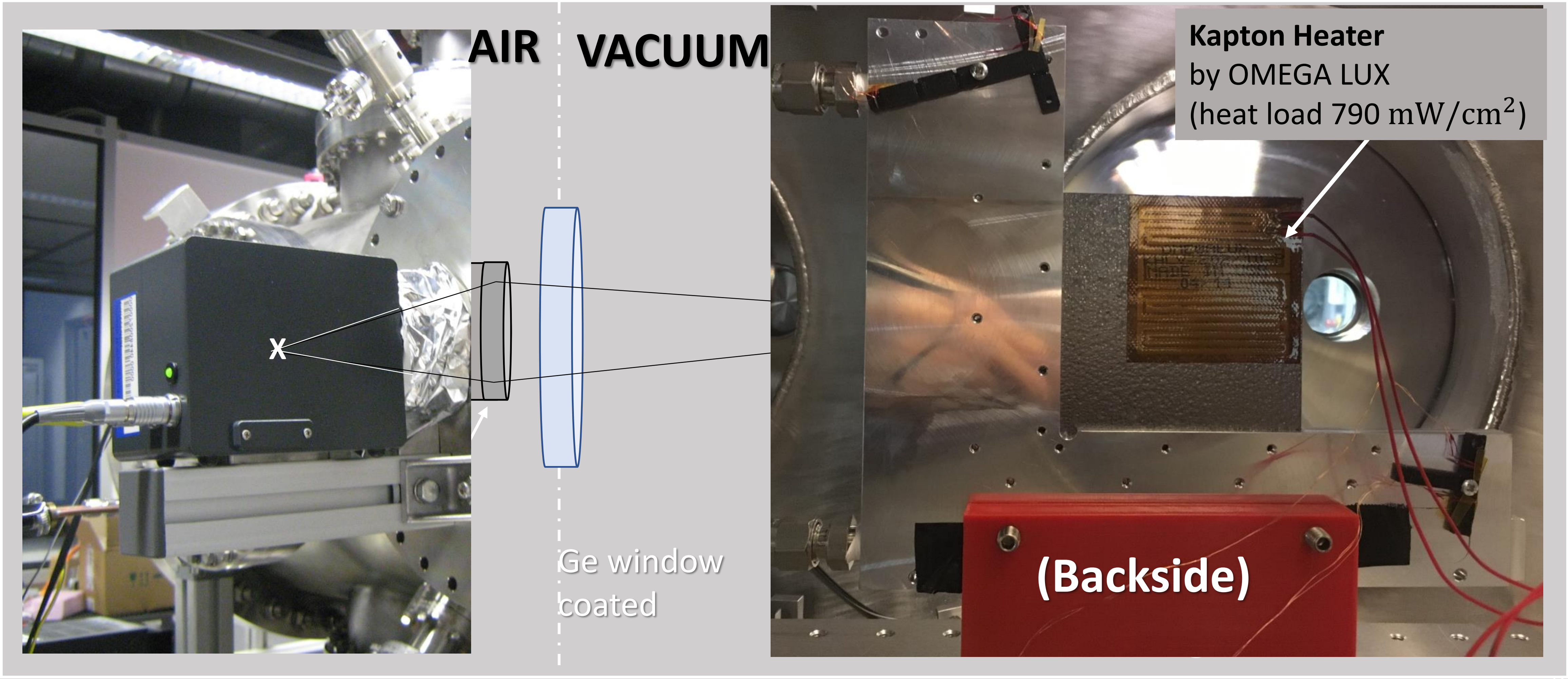


IR Camera:
VarioCAM head HiRes 640

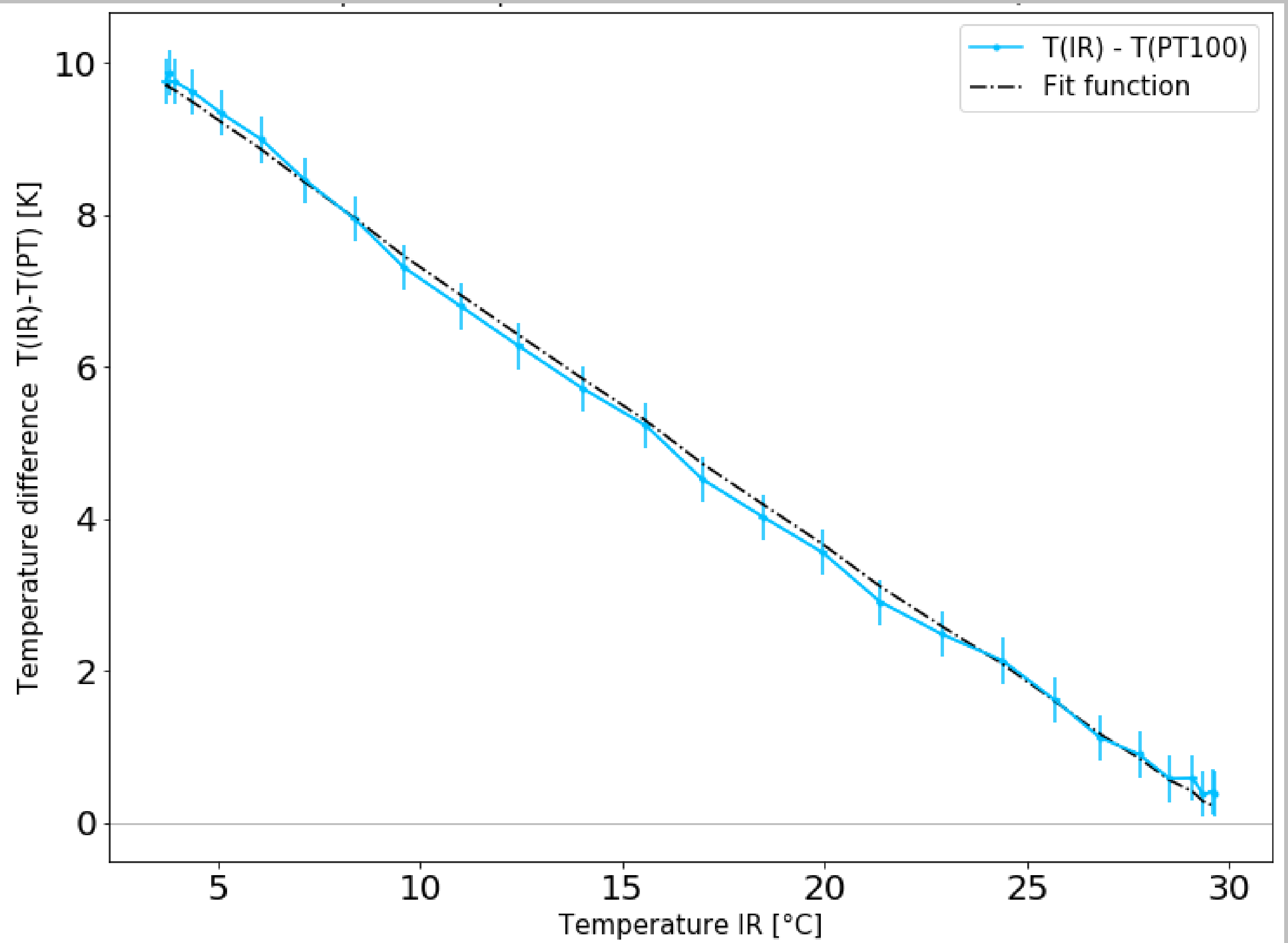
The Experimental Setup



The Experimental Setup



Experimental Setup
Calibration

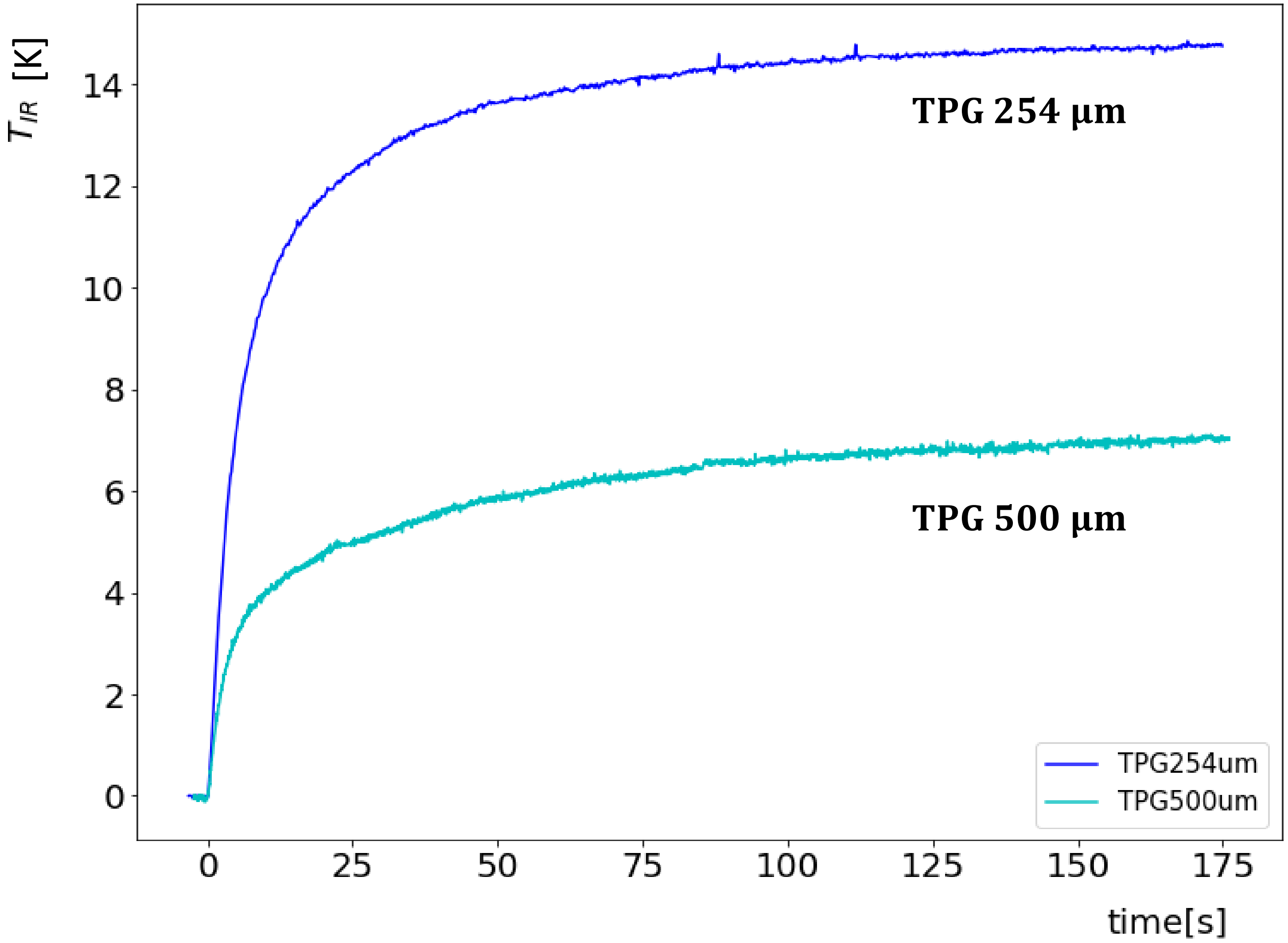


Many parameters influences the measurements. That is why Pt100 sensors were used as reference measurement and calibration

- The calibration is not universal
  ⇨ A continuous re-calibration is necessary

- Absolut temperature is not need to evaluate the thermal performance of a material

Thermal Performance Measurement

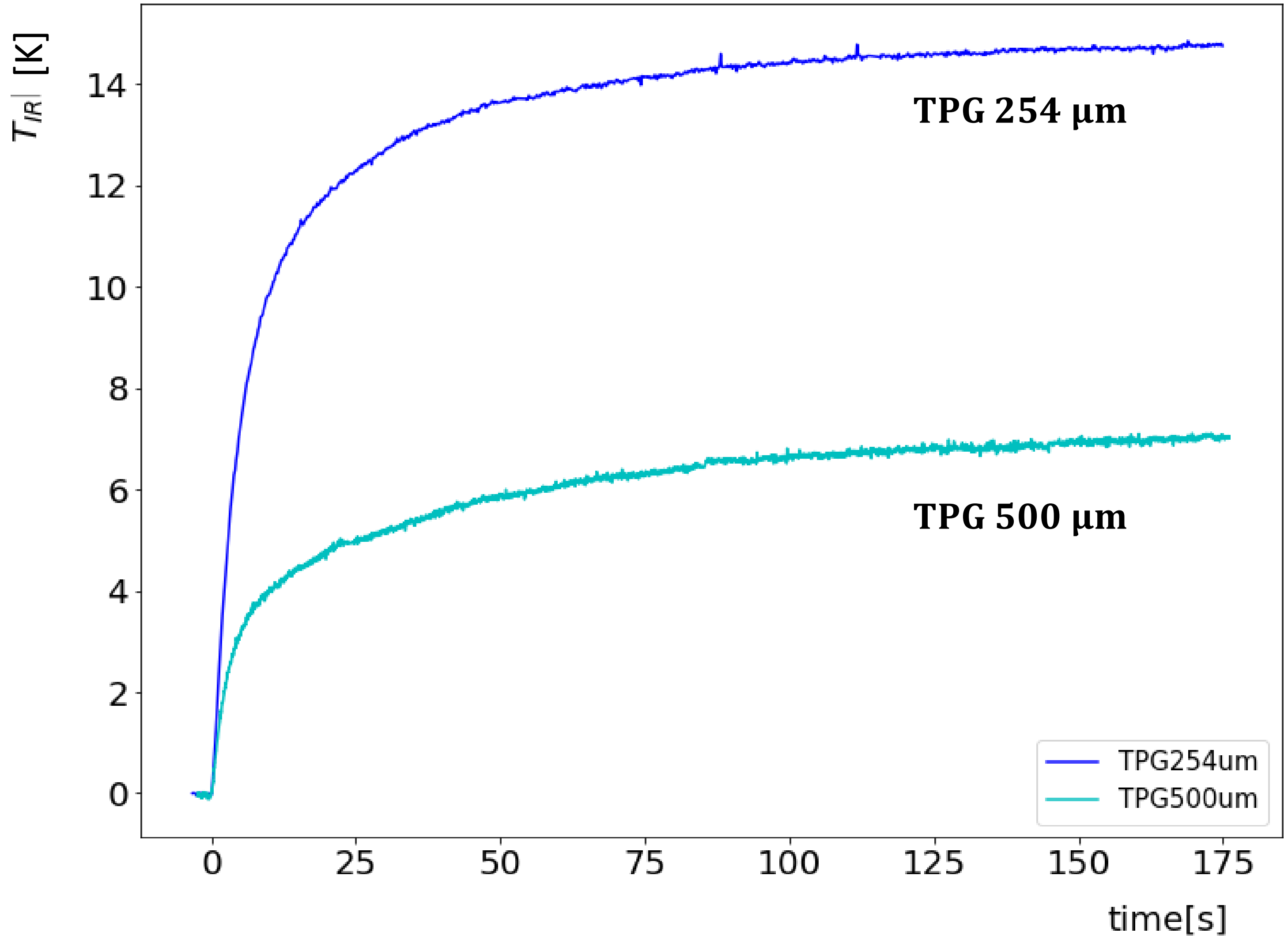


The thermal performance was characterized by analyzing heat-up curves of TPG with different thicknesses (254 µm and 500 µm)

1st Notice:
Thickness of the material effects strongly the end temperature and heat distribution

2nd Notice:
Curves can be described with an exponential function

Thermal Performance Measurement



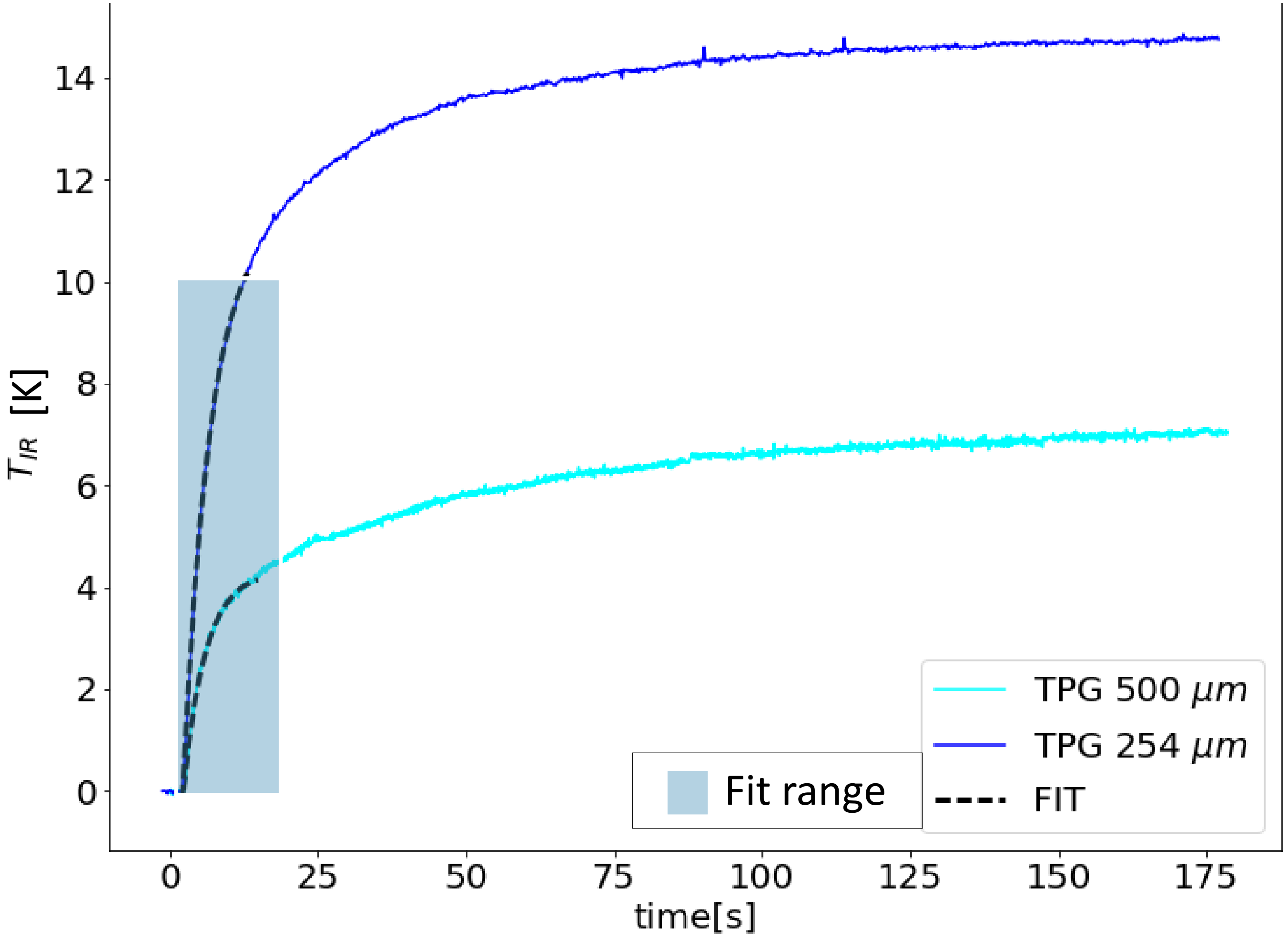
The thermal performance was characterized by analyzing heat-up curves of TPG with different thicknesses (254 µm and 500 µm)

2nd Notice:
Curves can be described with an exponential function

Heat equation:

$$\frac{dT}{dt} = \frac{\lambda}{\rho c_p} * A * (T_{hot} - T_{cold})$$

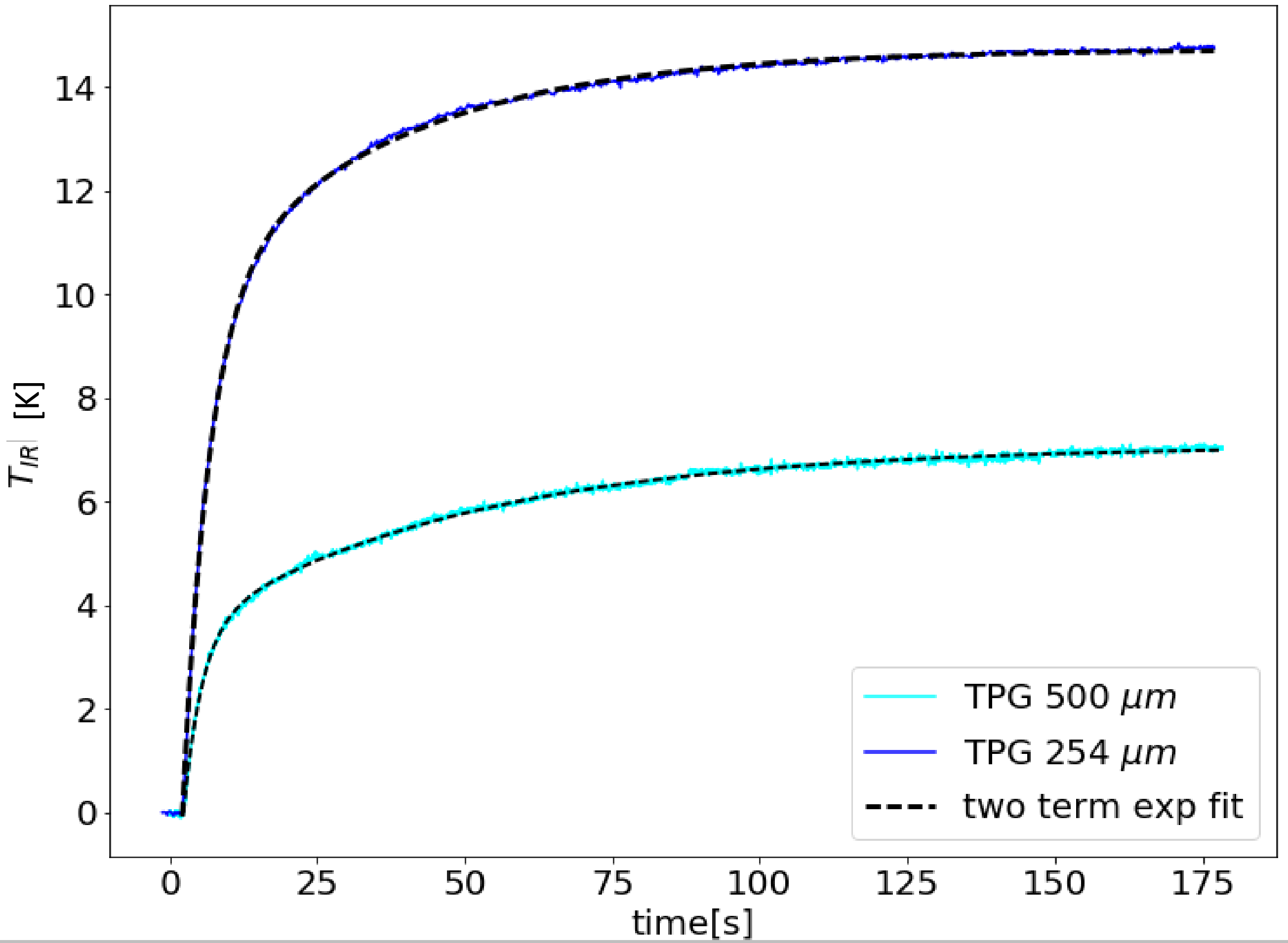
Thermal Performance Measurement
Single exp. Fit



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

$$T(t) = T_{End} - T_{carrier} * \exp\left(-\frac{time}{\tau_{carrier}}\right)$$

Thermal Performance Measurement Two-Term exponential Curve Fit



Fitting the complete heat up curve with a two-term exponential curve fit:

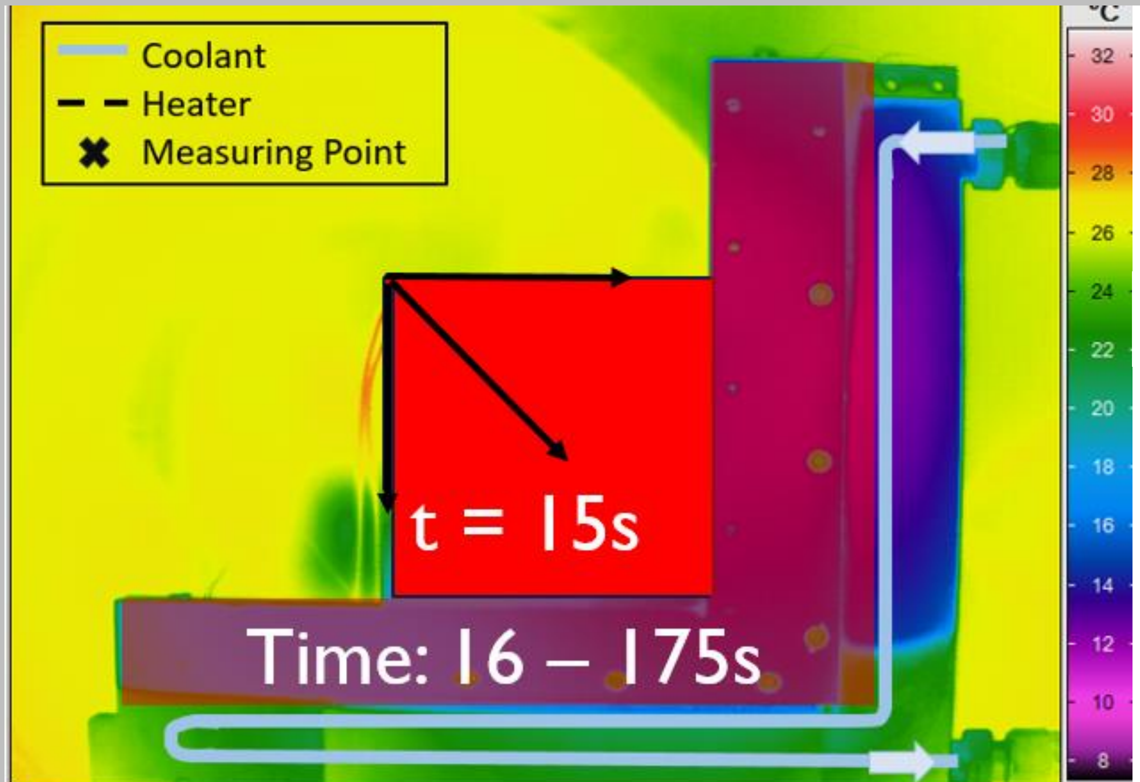
$$T(t) = T_{End} - T_{carrier} * \exp\left(-\frac{time}{\tau_{carrier}}\right)$$

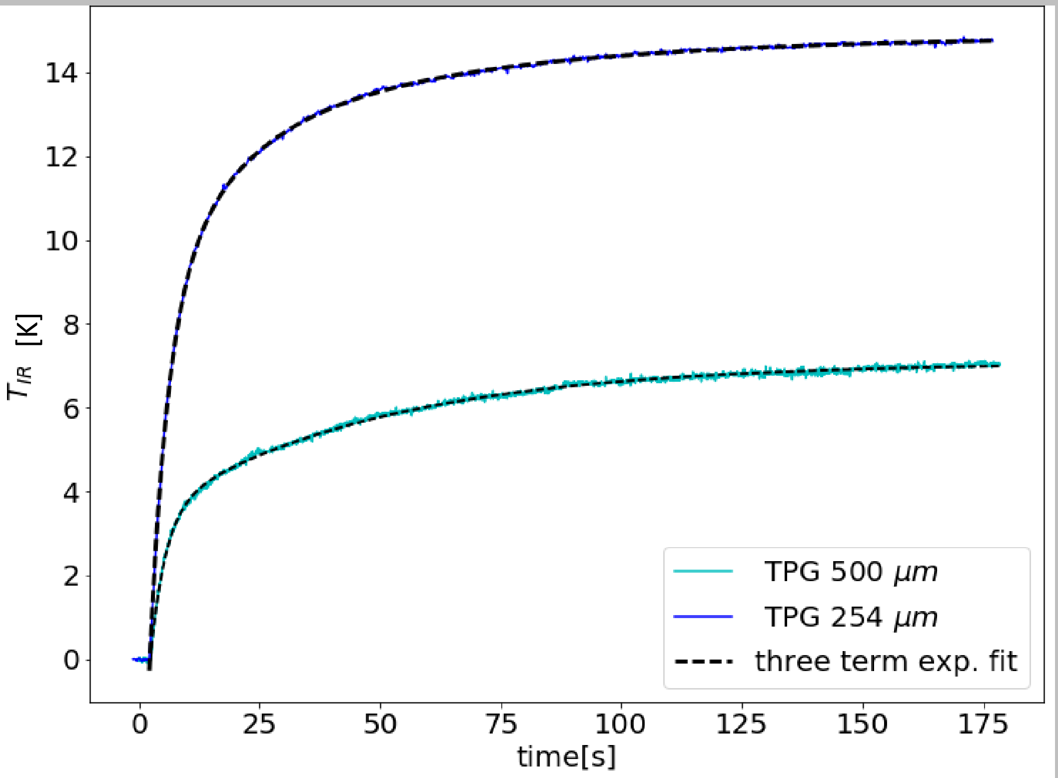
$$- \; T_{HS} * \exp\left(-\frac{time}{\tau_{HS}}\right)$$

Thermal Performance Measurement
Three-Term exponential Curve Fit

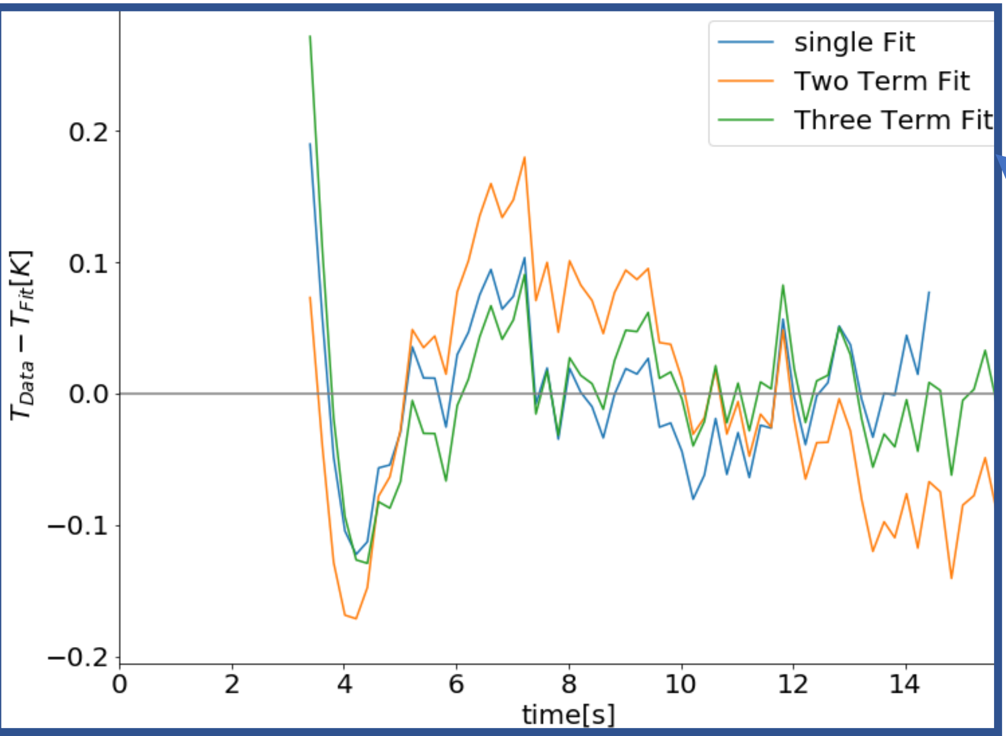
Fitting the complete heat up curve with a three-term exponential curve fit:

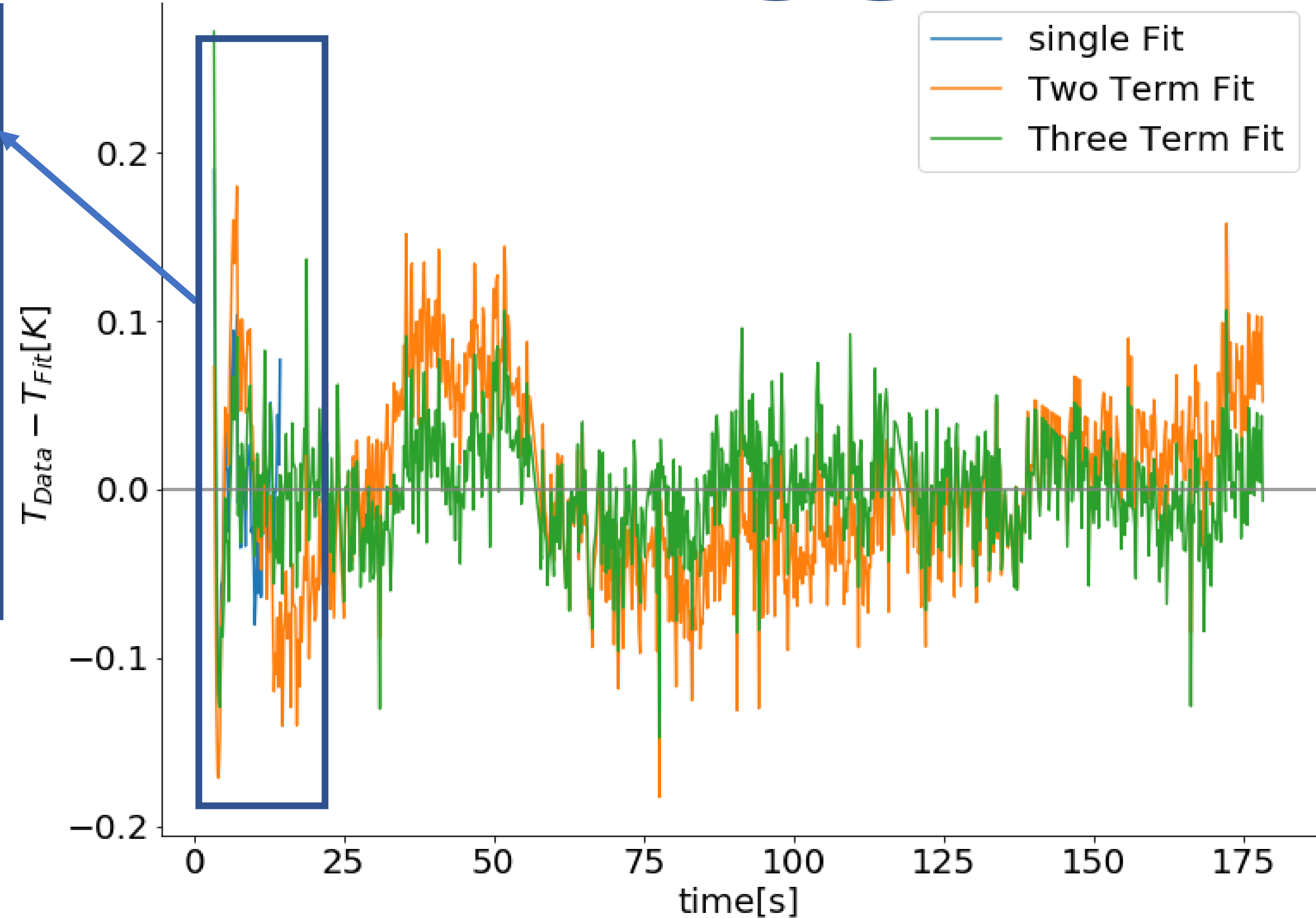
$$T(t) = T_{End} - T_{carrier} * \exp\left(-\frac{\text{time}}{\tau_{carrier}}\right) - T_{contact} * \exp\left(-\frac{\text{time}}{\tau_{contact}}\right) - T_{HS} * \exp\left(-\frac{\text{time}}{\tau_{slow}}\right)$$





Thermal Performance Measurement Fits in Comparison for TPG 254 µm



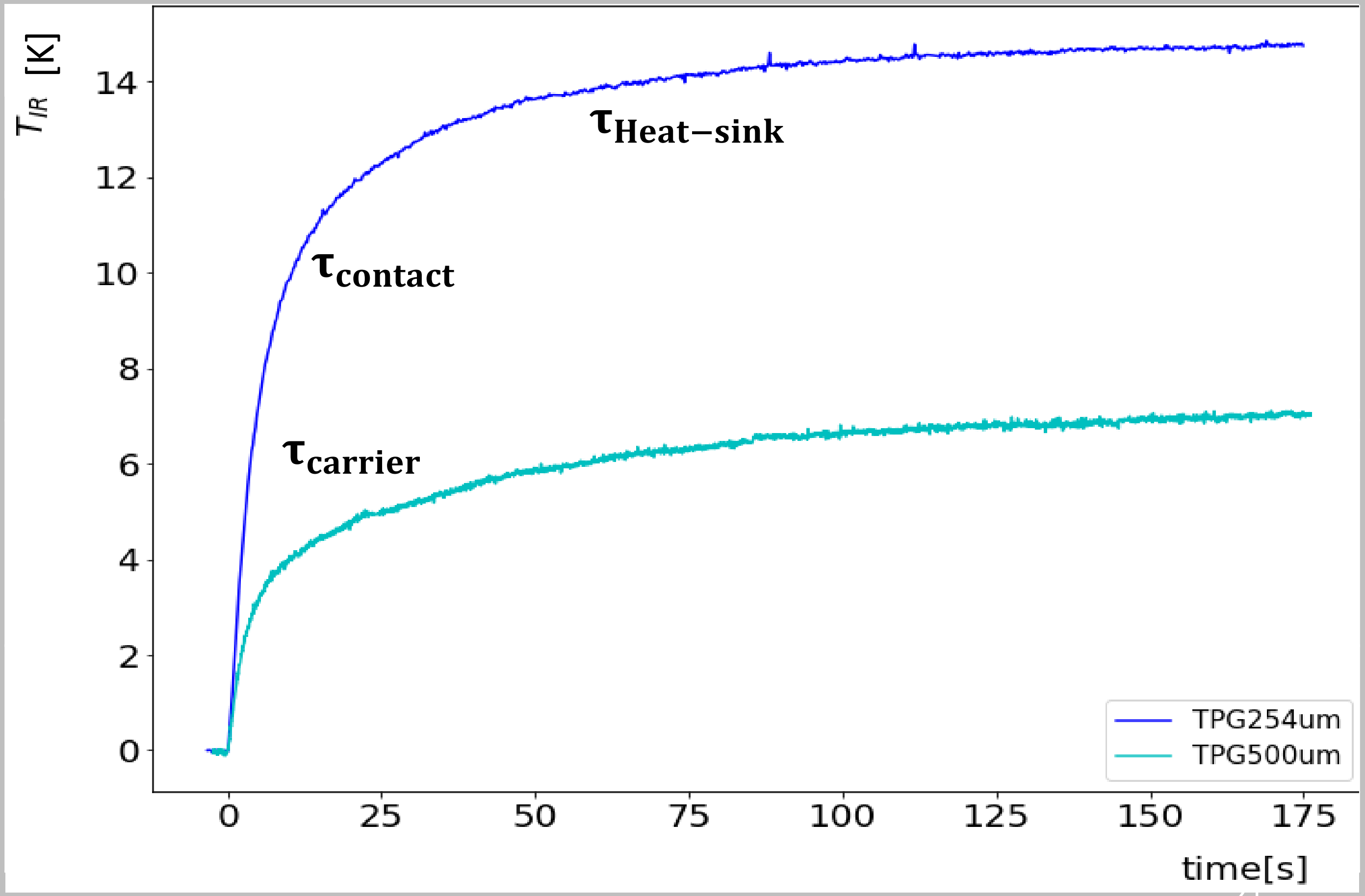


Thermal Performance Measurement Fits in Comparison

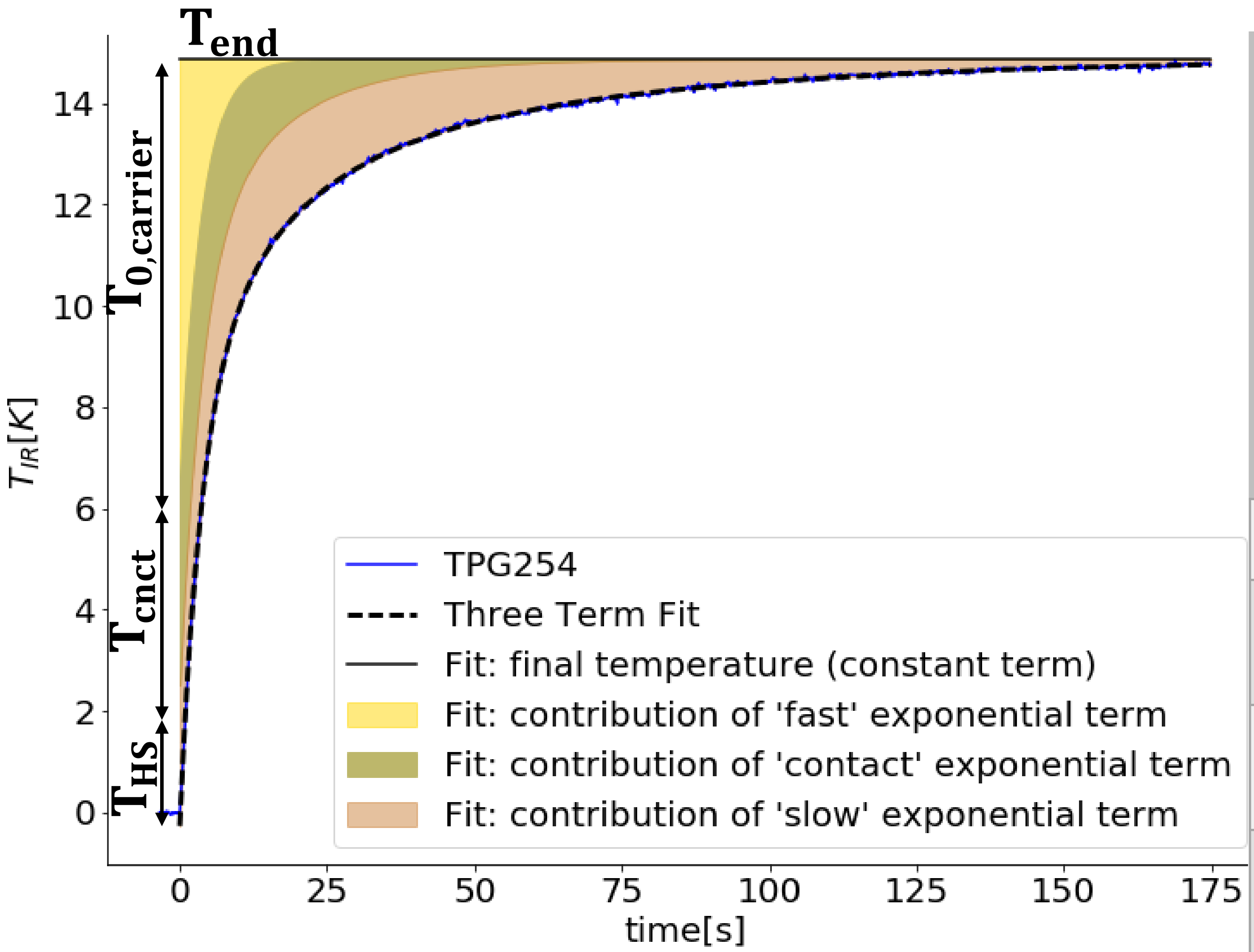
$$\tau = \frac{l^2 \rho c}{\lambda}$$

The relaxation time τ is connected to the heat conductivity.
A short relaxation time is an indicator for a high heat conductivity.

- $\tau_{carrier}$ describes relaxation time of the sensor carrier (TPG)
- $\tau_{contact}$ gives information about the contact between carrier and heat sink
- τ_{HS} gives information about thermal performance of the heat sink



Thermal Performance Measurement Fits in Comparison for TPG 254 µm



$$T(t) = T_{End} - T_{carrier} * \exp\left(-\frac{time}{\tau_{carrier}}\right) - T_{contact} * \exp\left(-\frac{time}{\tau_{contact}}\right) - T_{HS} * \exp\left(-\frac{time}{\tau_{slow}}\right)$$

T_{end}	**14.87 ± 0.01**
$T_{0,carrier}$	8.23 ± 0.11
T_{cnct}	4.14 ± 0.08
T_{HS}	2.78 ± 0.14

Summary

Established Experimental Setup with IR Thermography:

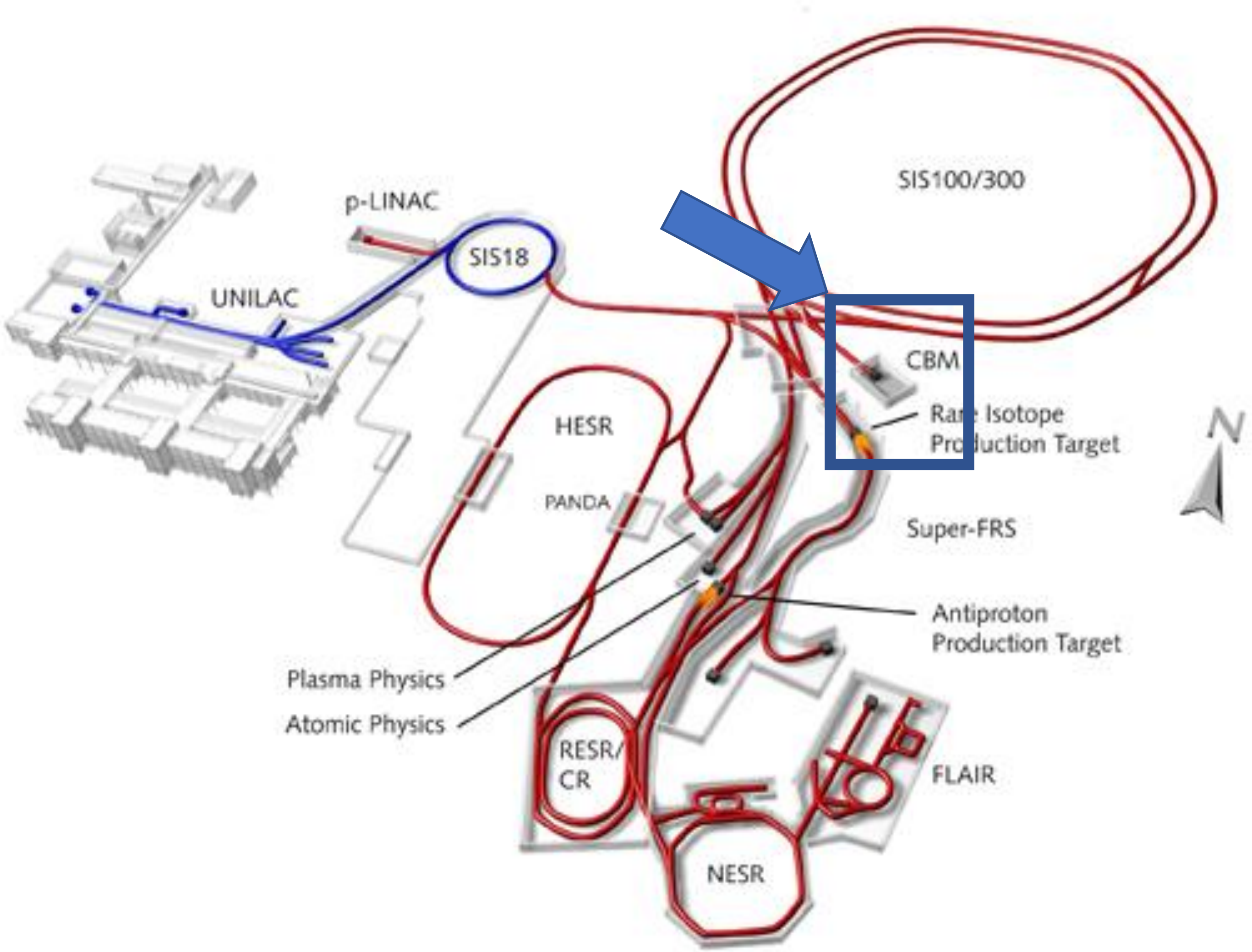
- Setup too complex to achieve reliable absolute values **without calibration**.
- Empiric calibration with a reference measurement (Pt100) is not universal.
- Reliable results achievable with continuous recalibration.

Measurement of Thermal Performance with IR Thermography:

- Thermal performance of TPG was evaluated.
- An analytic function was used to fit our measurements.
    - Single exponential Fit fits the best to the data but to understand the whole system a two / three term fit is necessary

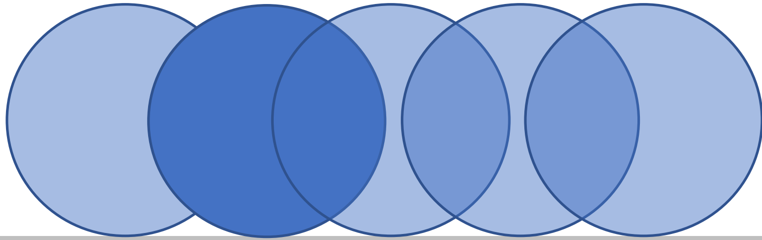
Backup

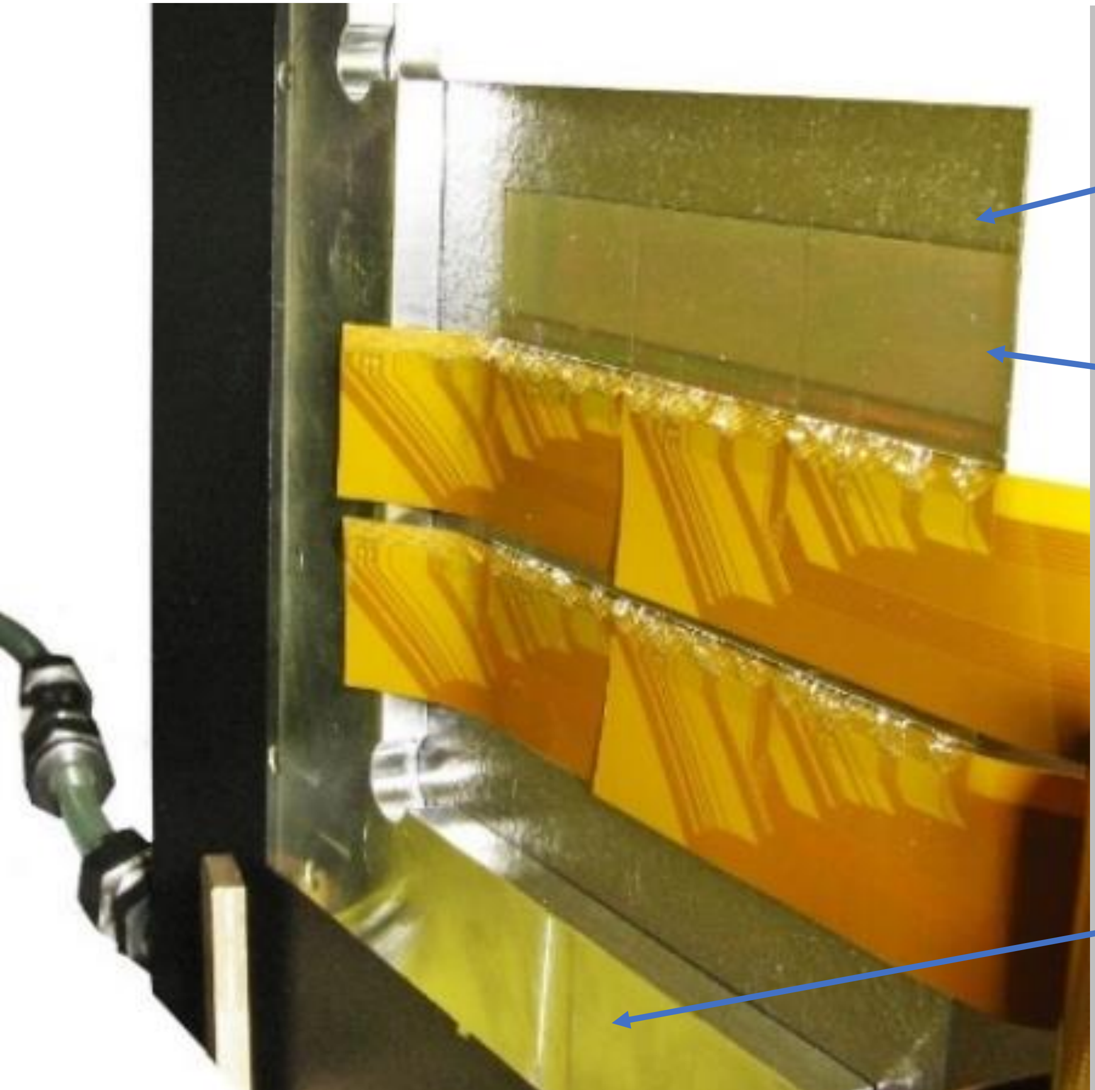
The Compressed Baryonic Matter **CBM** Experiment

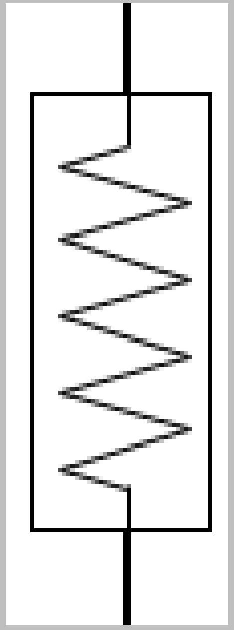


- **Fixed-target experiment**
- **High energy: 11AGeV**
- **Nucleus-Nucleus & Proton-Nucleus collision: very high interaction rate: 100kHz / 1MHz**
- **Research goals:**
  - **Open Charm**
  - **Di-Leptons**
  - **Multi-strange-particles**

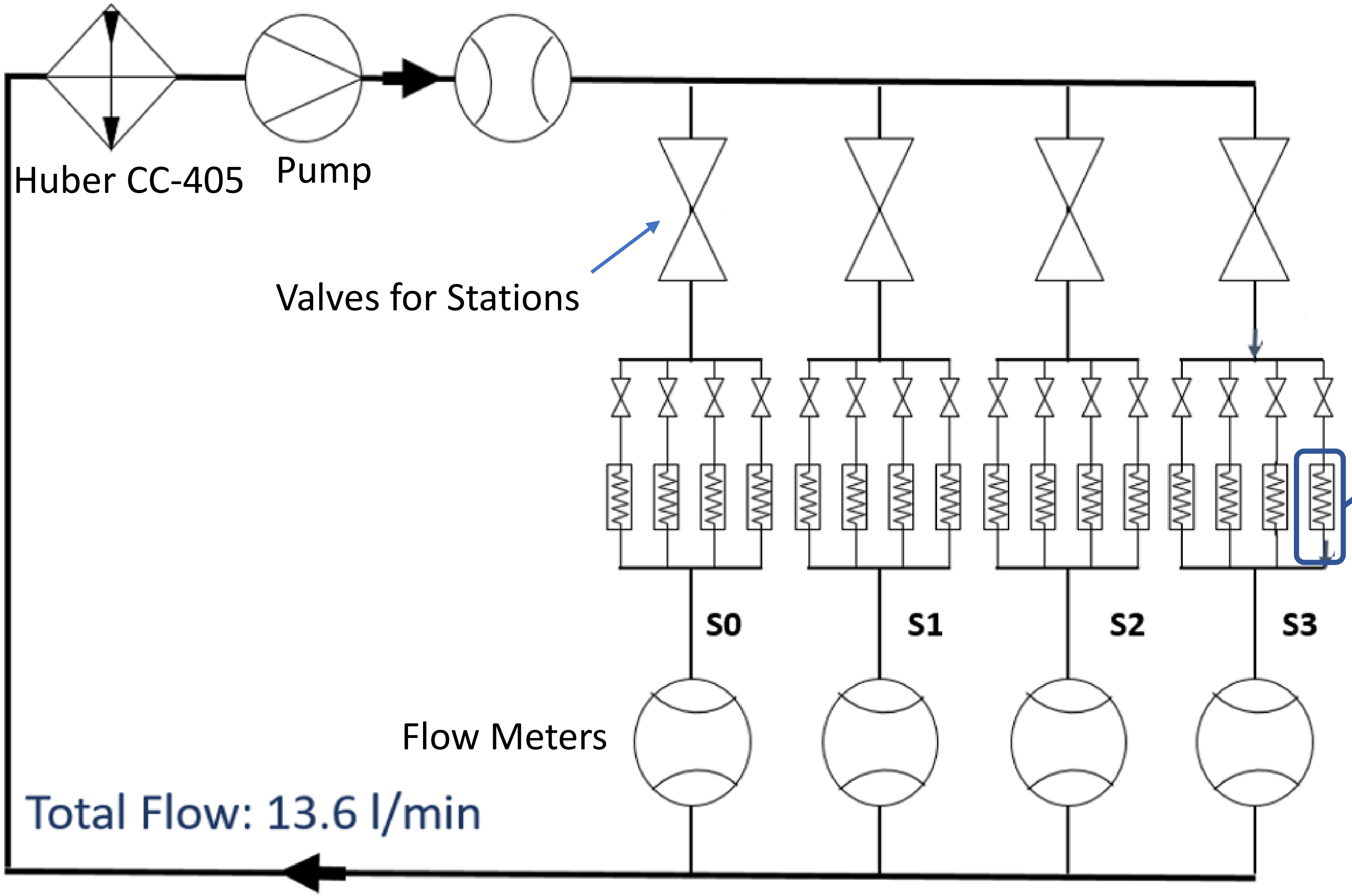
The Cooling Concept
The Quadrant

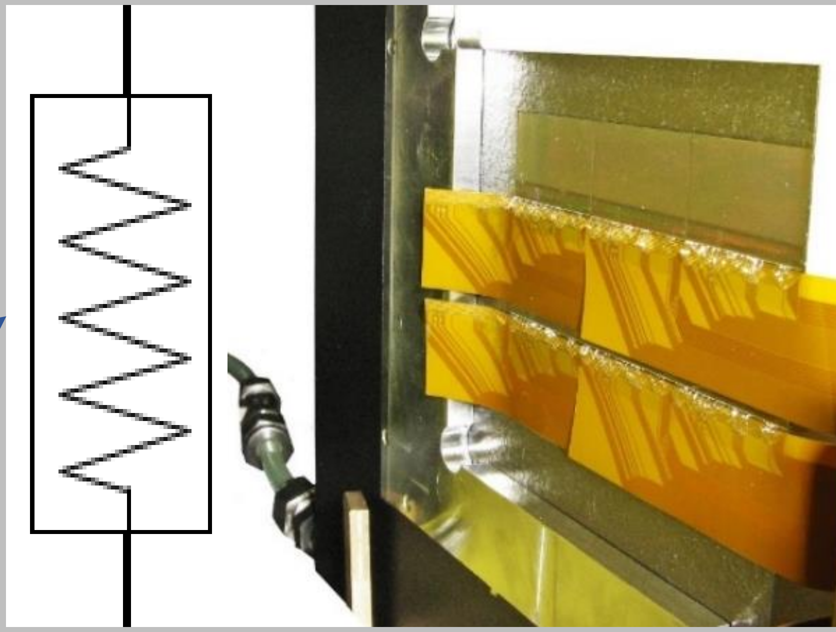






The Cooling Concept





One Quadrant

The Sensor Carrier
Thermal **P**yrolithic **G**raphite **TPG**

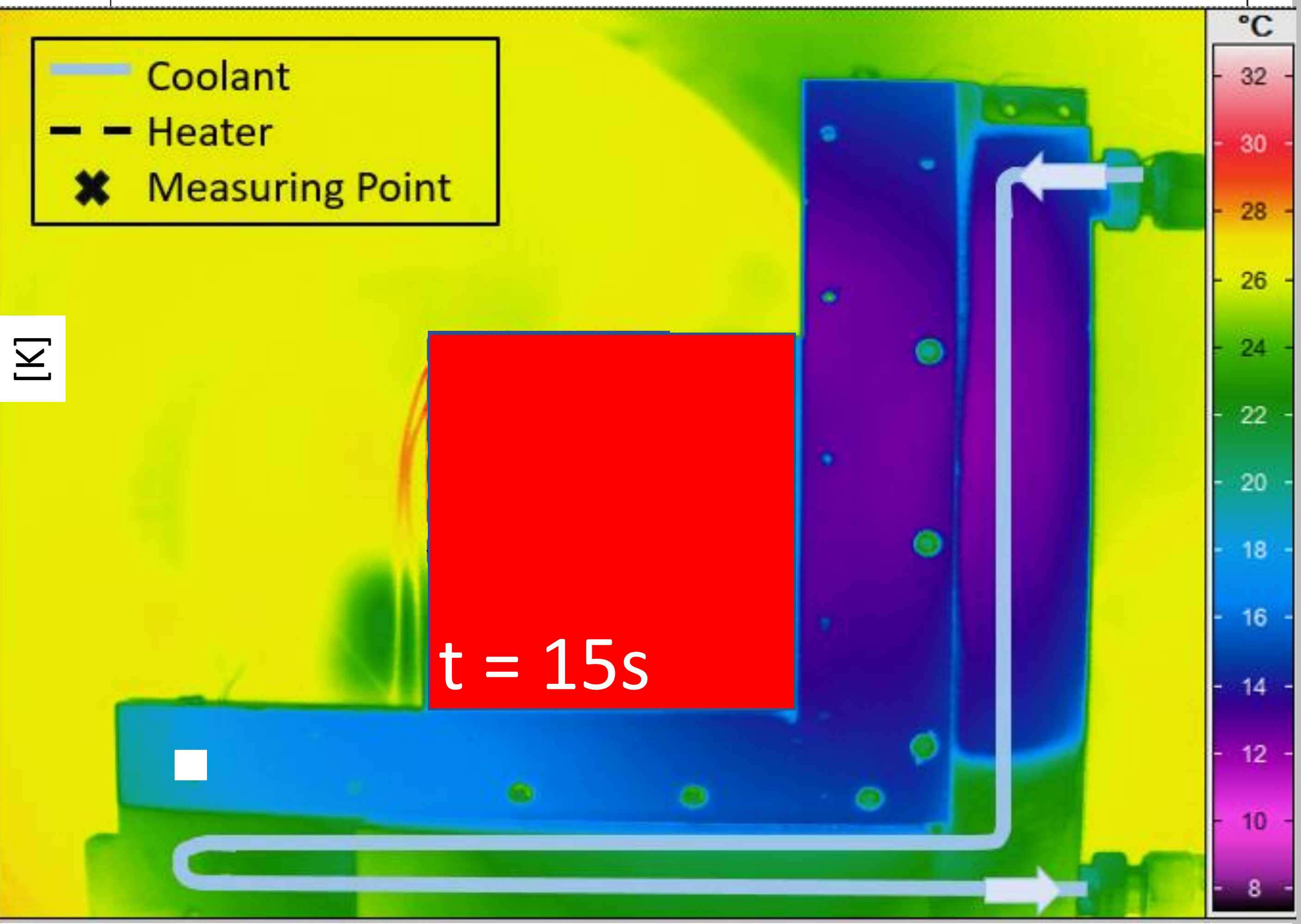
Requirements to the carrier material	Features of TPG
Excellent heat conductivity (total heat input in a range of 200-500 $\frac{mW}{cm^2}$)	in-plane heat conductivity (1600 W/mK) heat conductivity in z-direction (20 W/mK)
Low material budget to avoid multiple scattering (0.3-0.5% X_0)	Thickness chosen: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

Calibration

Aspects that could influence the measurement:

- Window between vacuum chamber and camera
- Temperature of the window
- Ambient Light
- Shiny Surfaces (reflections) with low emissivity
- Software settings
  Emissivity
- Reflection of the chamber

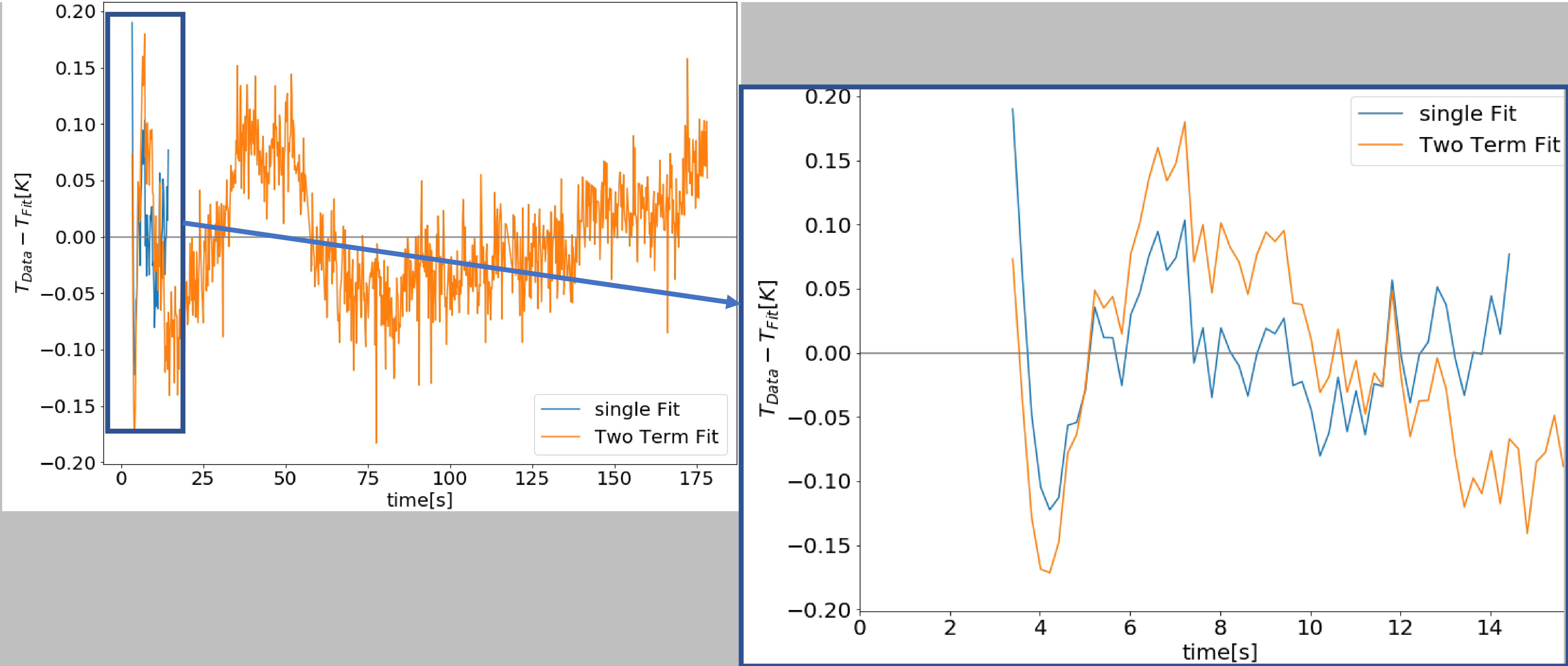
Thermal Performance Measurement
Single exp. Fit



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

$$T(t) = T_{End} - T_{carrier} * \exp\left(-\frac{time}{\tau_{carrier}}\right)$$

Thermal Performance Measurement Single and Two-Term in Comparison

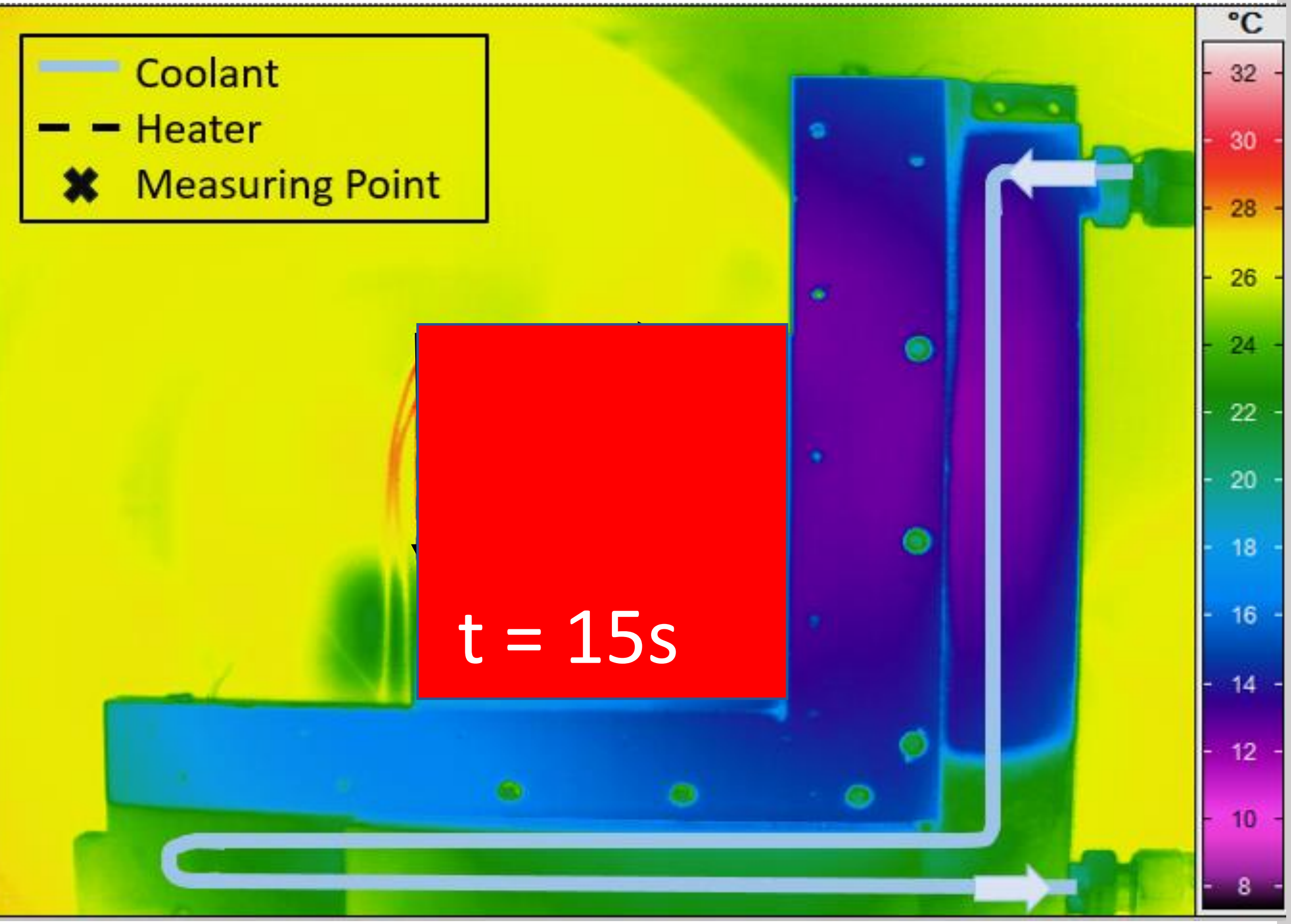


Thermal Performance Measurement Fits in Comparison

Fits	Time range [s]	$\tau_{carrier}$ [s]	τ_{HS} [s]	$\tau_{contact}$ [s]	T_{End}	$T_{carrier}$	T_{HS}	$T_{contact}$
Single Fit	13.2	4.69 $\pm$ 0.04	XX	XX	11.25 $\pm$ 0.04	11.87 $\pm$ 0.02	XX	XX
Two Term Fit	175	4.48 $\pm$ 0.03	34.17 $\pm$ 0.23	XX	14.73 $\pm$ 0.04	9.85 $\pm$ 0.03	4.96 $\pm$ 0.03	XX
Three Term Fit	175	3.65 $\pm$ 0.04	54.59 $\pm$ 2.23	14.92 $\pm$ 0.67	14.87 $\pm$ 0.01	8.23 $\pm$ 0.11	2.78 $\pm$ 0.14	4.14 $\pm$ 0.08

- $\tau_{carrier}$ describes relaxation time of the sensor carrier (TPG)
- $\tau_{contact}$ gives information about the contact between carrier and heat sink
- τ_{HS} gives information about thermal performance of the heat sink

Thermal Performance Measurement
Single exponential Fit



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

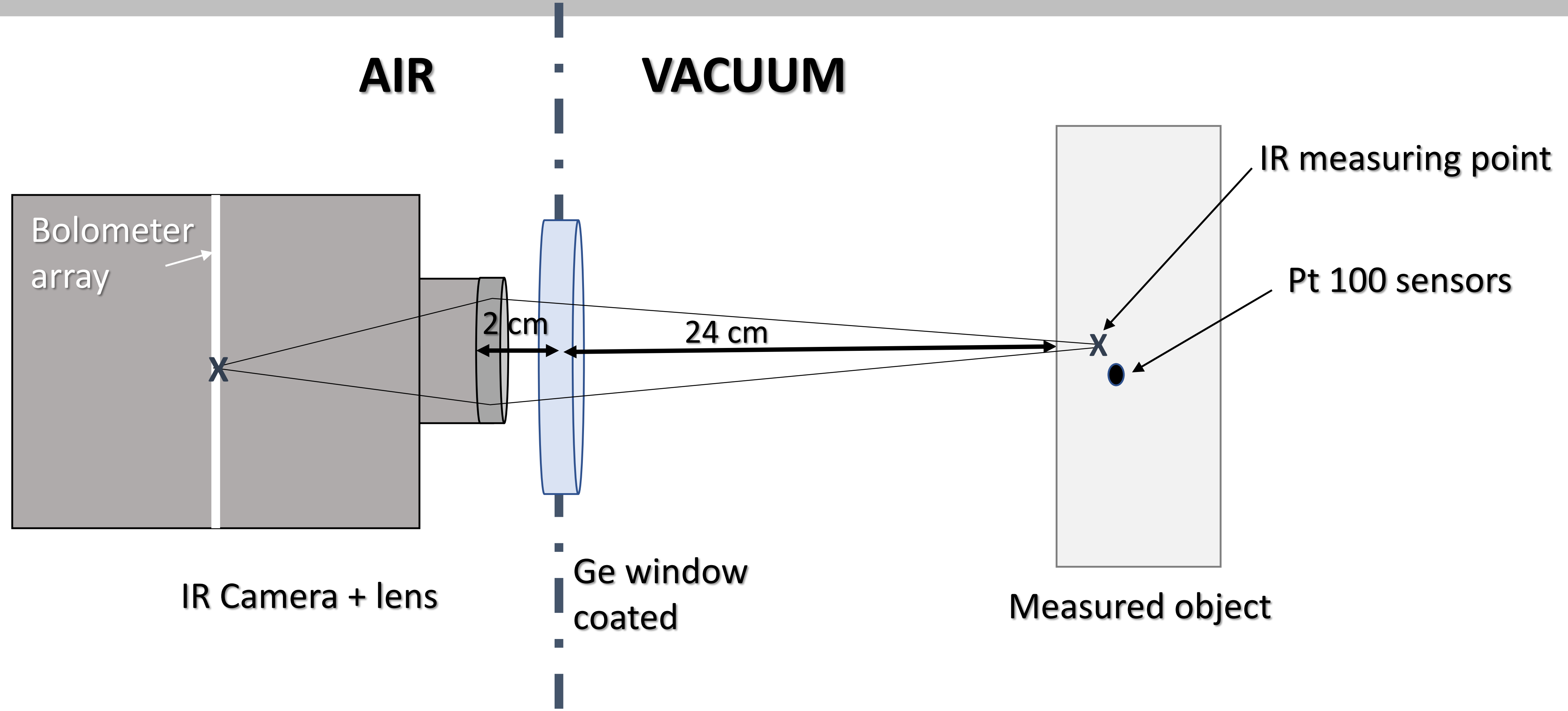
$$t_0 - (\, p_{fast} * \ \exp\left(-\frac{time}{\tau}\right)\,)$$

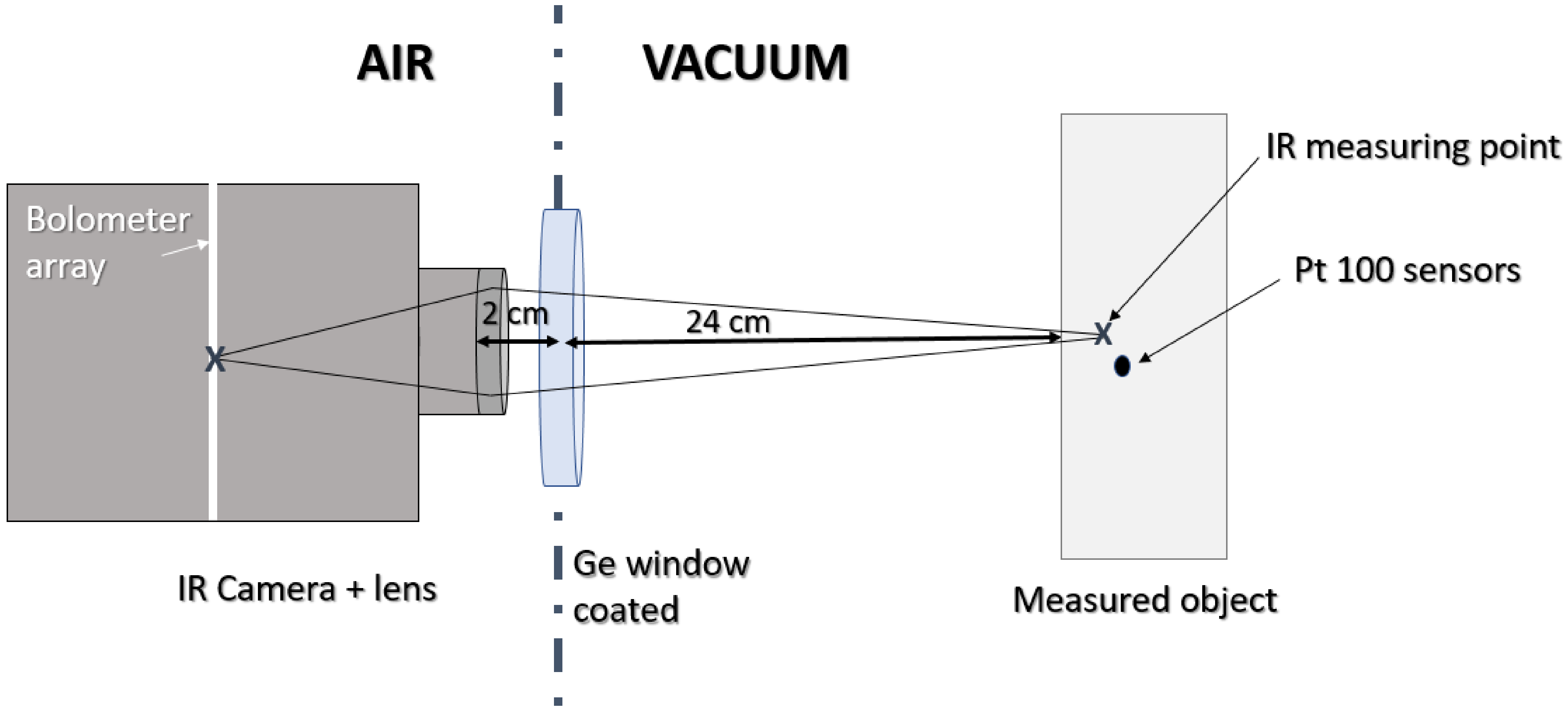
	Time [s]	τ_{fast}	Covarianz	Chi-Square
TPG 254 um	13.2	4.6968	0.0416	0.0059
TPG 500 um	15.0	3.7837	0.0074	0.0861

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

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

The Experimental Setup




AIR
VACUUM
Bolometer
array
2 cm
24 cm
IR measuring point
Pt 100 sensors
IR Camera + lens
Ge window
coated
Measured object