A custom setup for thermal conductivity measurements.

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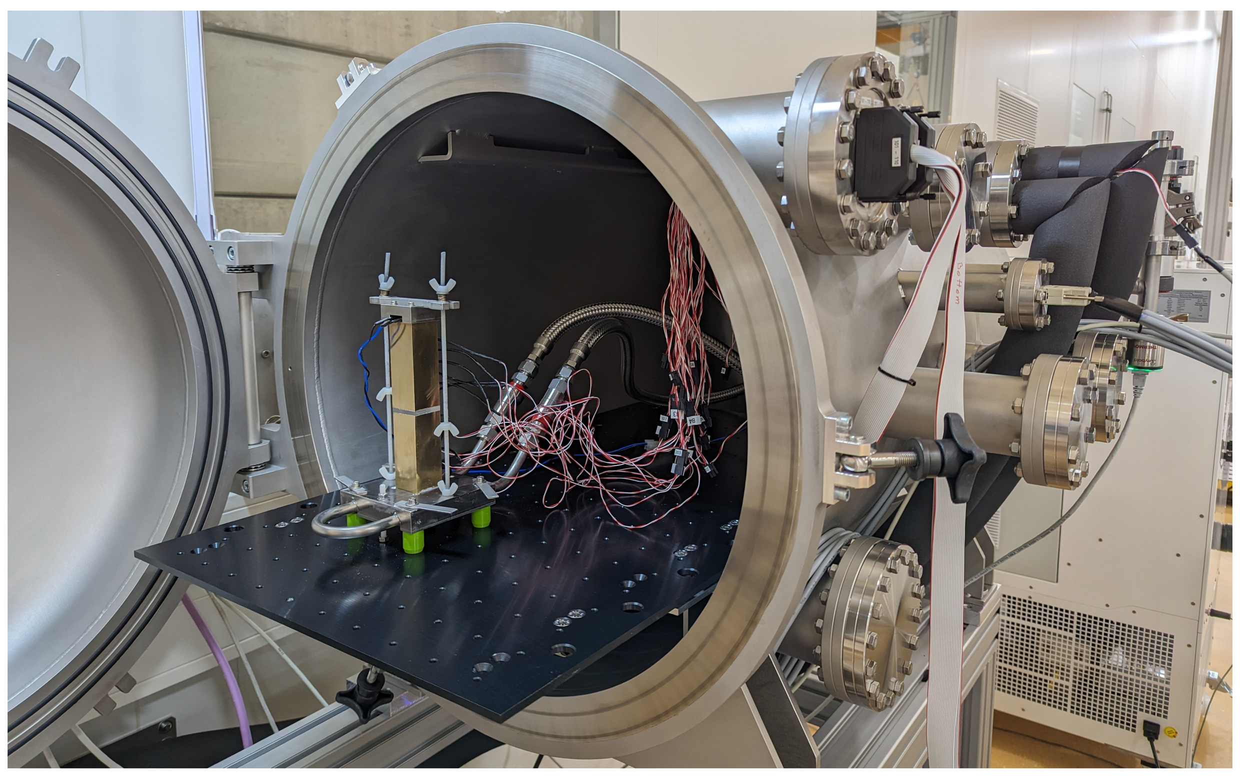
Introduction

Future detector systems have increasing demands on the performance of their mechanical support structures and cooling systems. Novel materials and cooling technics are developed and continuously improved in order to fulfil these requirements. To quantify the thermal performance of these materials, a custom trough-plane thermal conductivity measurement setup was developed.

The setup consists of two heat flux meter brass blocks between which the samples are clamped. A resistive load on top of the upper block acts as a heat source whereas the bottom block is thermally coupled to a cooling plate which acts as the heat sink. Each of the blocks has six temperature sensors embedded at equally spaced positions that allow to measure the heat flux through as well as the temperature gradient across the sample.

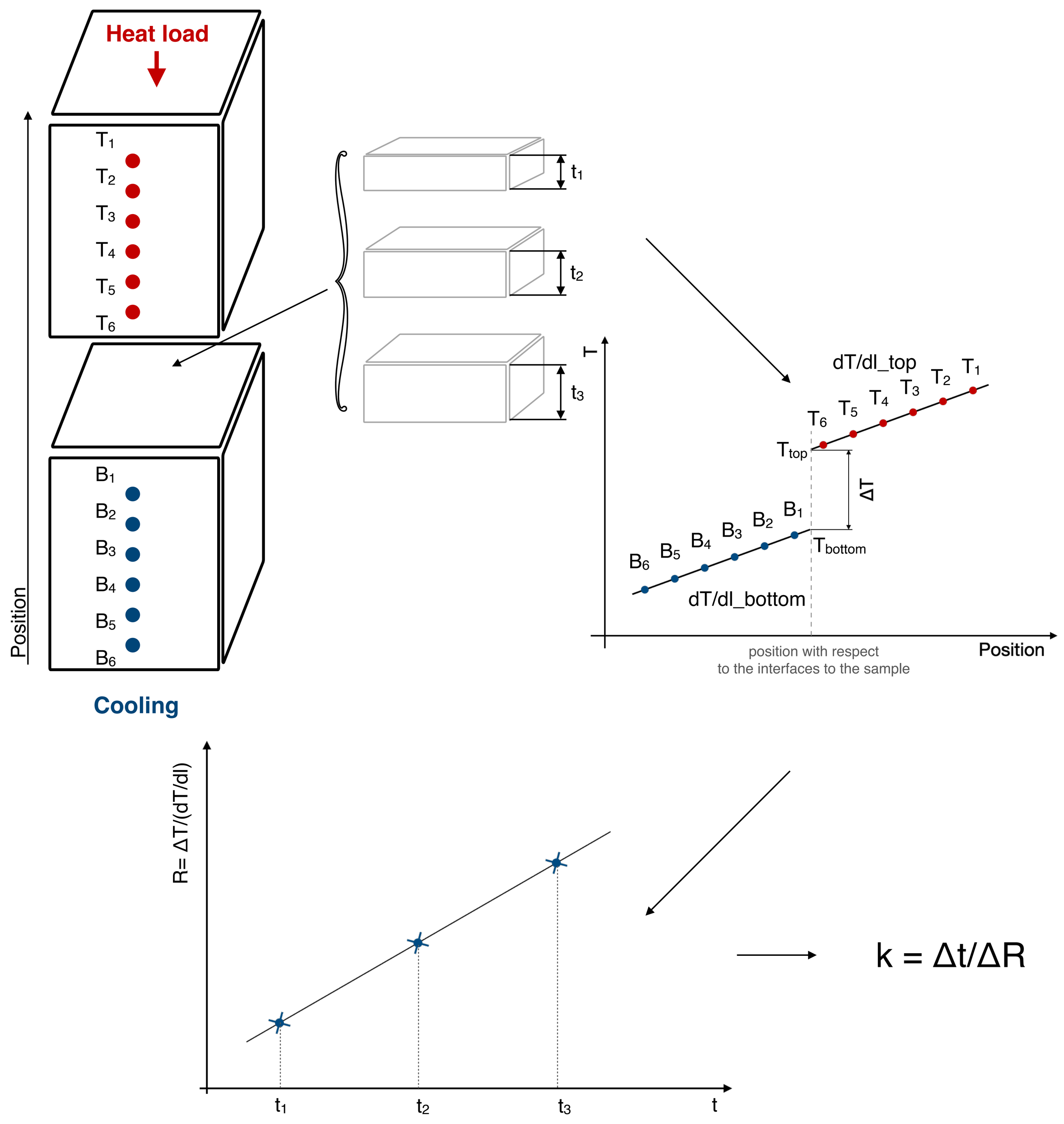
Through-plane thermal test setup



Temperature control system	Huber Unistat 525W
DAQ	Keithley DAQ6510 Data Acquisition. Two Model 7700 Mulitplexer Modules
Power supply	Rohde&Schwarz NGE 103 B
Vacuum pump	Agilent TwisTorr 304 FS AG
Pressure gauge	Leybold THERMOVAC TTR 91 N

Measurement method

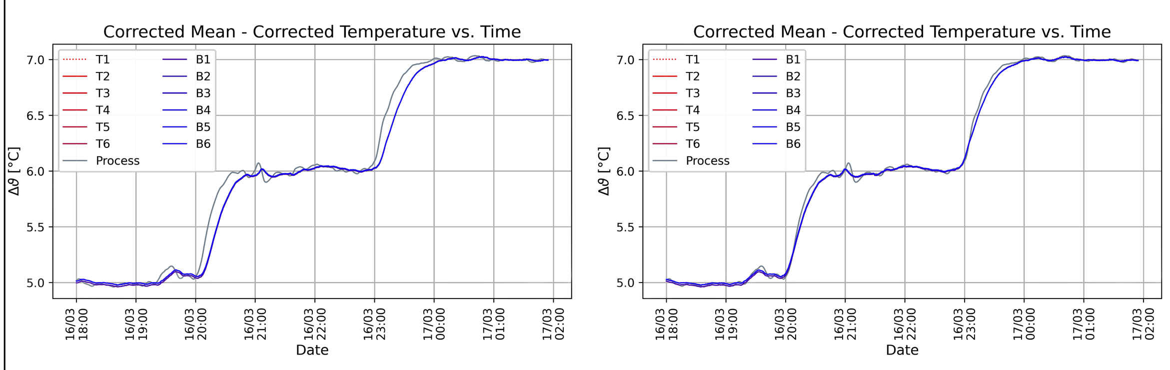
- The thermal conductivity is given by k = q · t/ A · ΔT, where q is heat flux through the sample, t - thickness of the sample, A - area of the sample and ΔT - temperature gradient.
- Measurement starts with placing a sample between two brass blocks.
- Between sample and the blocks thermal grease is applied.
- To insure the same conditions of the measurement, samples are compressed with compression spring. Resulting clamping force is ~70 N.
- To minimise the radiation heat exchange, the setup is covered with a radiation shield.
- The heater on top and cooling on bottom create the heat flow through the sample.
- The heater and chiller should be tuned to set the temperature of the sample to the ambient temperature.
- Temperatures are measured as a function of the position in the blocks.
- The temperature gradient dT/dl is obtained for both blocks.
- Heat flux through the sample q is obtained from the temperature gradient:
  $q = dT/dl \cdot k_{block} \cdot A_{block}$
- Temperature at the interfaces to the sample are obtained from a fit of the temperature measurements by extrapolation. $\Delta T = T_{top} - T_{bottom}$ is measured.
- Thermal resistance is calculated:
  $R = \Delta T/q$



- Thermal resistance includes the bulk thermal resistance and contact resistance between the sample and the blocks.
- The contact resistance should be subtracted from the thermal resistance measurements. Hence, the thermal resistance is measured on samples with different thicknesses and the thermal conductivity is extracted from a linear plot R vs t.
- The difference of the thermal resistance and the change in thickness are used to calculate conductivity k = Δt/ΔR.

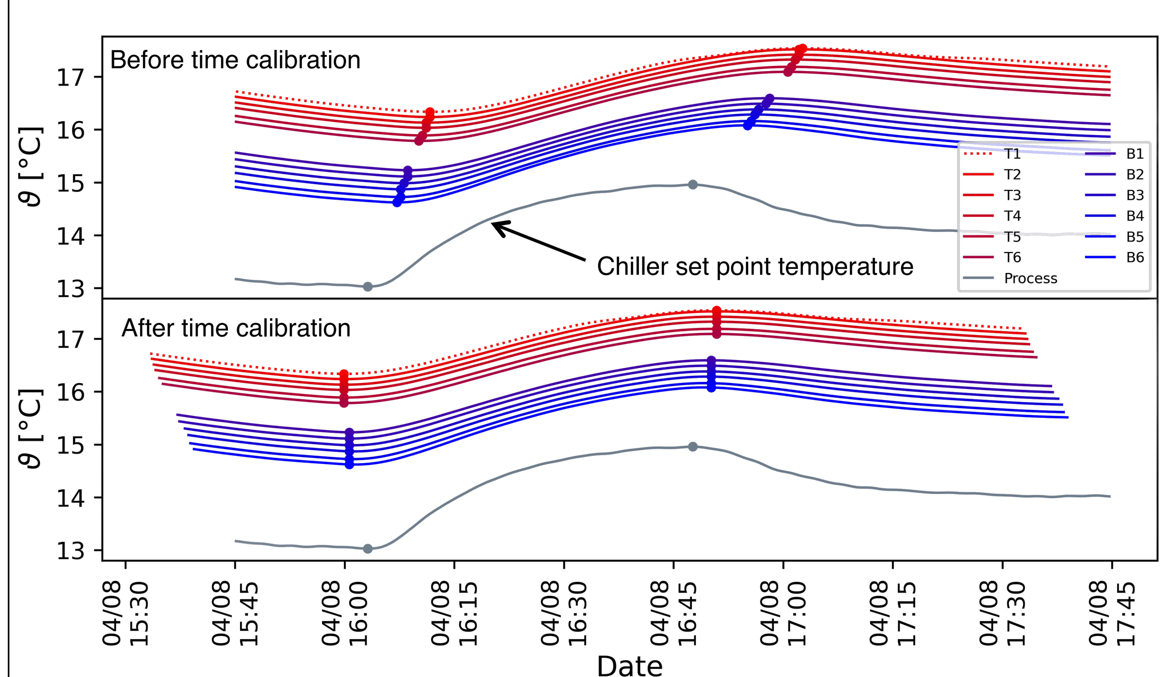
Time alignment

- Thermal mass of the samples introduces a slight time shift of the thermistors readings along the blocks.
- To correct the temperature readings, the thermistor data is shifted in order to align it to the chiller data



Without time calibration   With time calibration

- In the beginning of each measurement the data from the thermistors is taken at several additional chiller set point temperatures to create corresponding timestamps.



Offset correction

- Temperature offsets are calculated as the difference of a temperature reading for all 12 thermistors to the process temperature. The offset correction performed at several chiller set points in the range from +5°C to +35°C.
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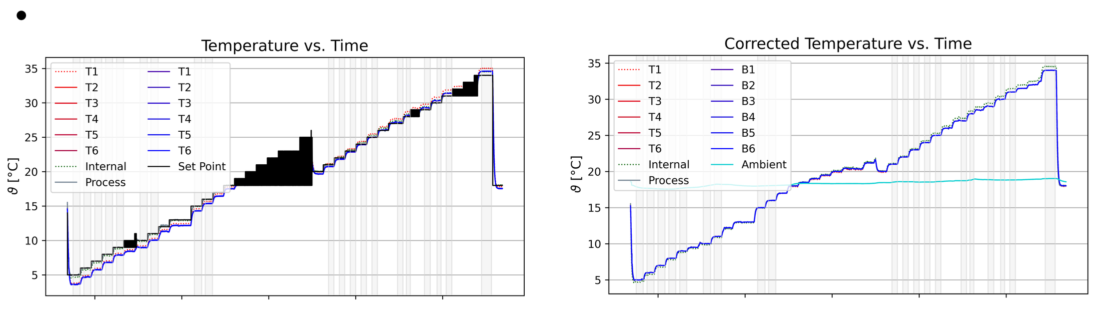
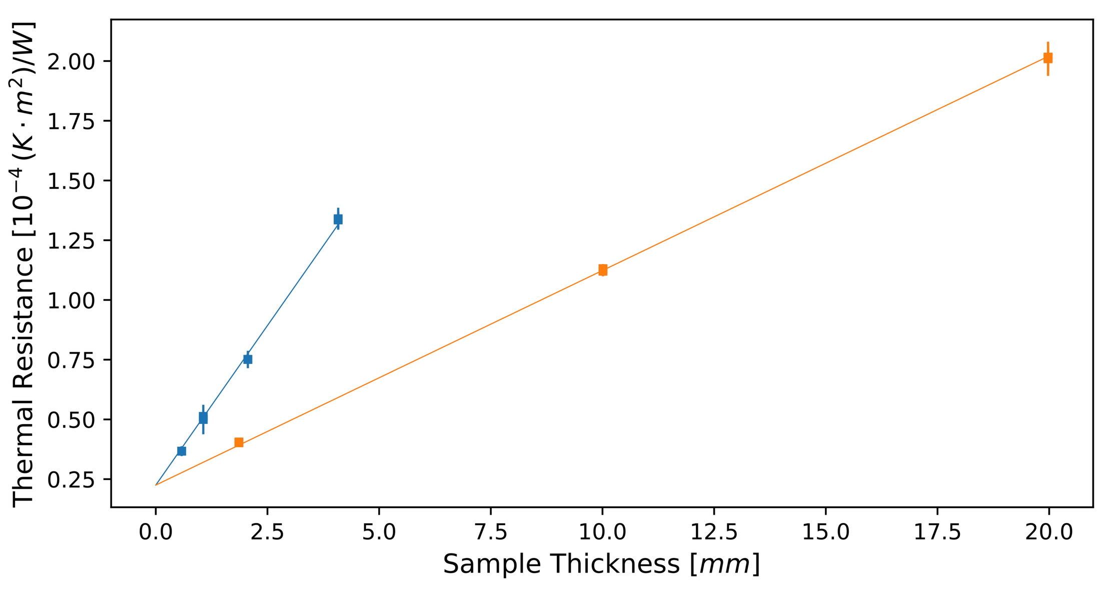


Calibration

- The calibration of the setup was performed using sapphire glass and brass samples.
- The calibration is performed on two materials with different thermal conductivities to calibrate the setup in a broad range of values.

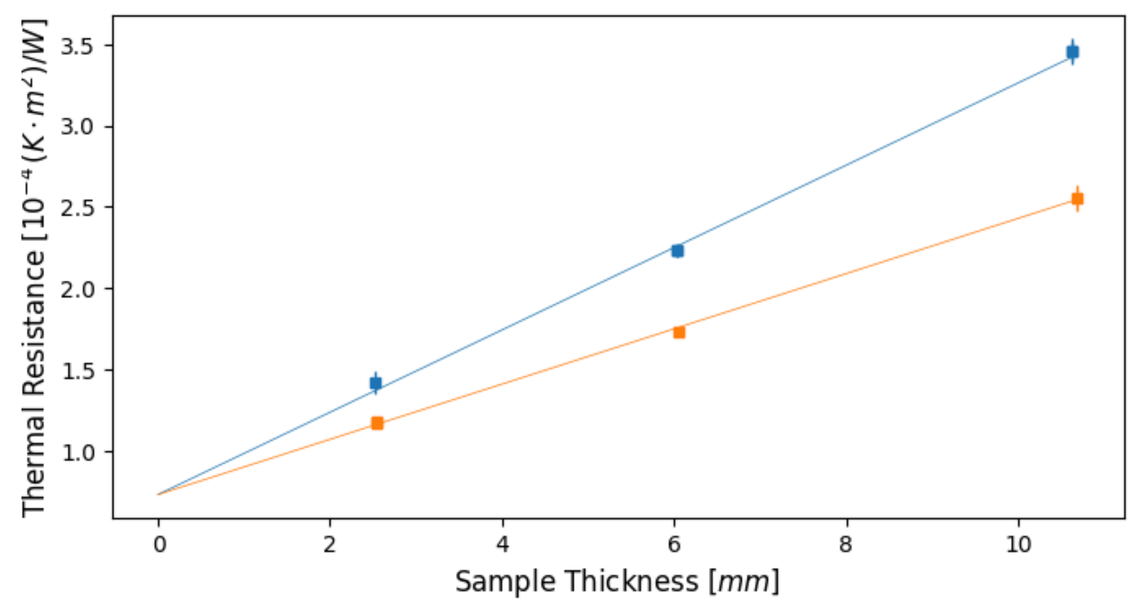


Material	nominal thermal conductivity W/(m·K)	measured thermal conductivity W/(m·K)	nominal / measured thermal conductivity
Sapphire Glass	37.67	37.44	1.0062
Brass (CW614N)	113.00	111.34	1.0149

Example measurement

10.5 mm thick K9 carbon foam sample

- Lockheed Martin Corporation K9 carbon foam is one of the candidate to be used as a part of the PS-modules cooling system for the CMS Phase 2 Outer Tracker upgrade.
- Specification stands that K9 carbon foam has thermal conductivity not lower than 20 W/(m·K).
- The thermal conductivity measurements were performed on the samples from different locations on the block to define the thermal performance of the K9 foam from the produced blocks.
- Samples of three different thicknesses (2.5 mm, 6 mm, 10.5 mm) were used for the thermal conductivity measurement
- An even layer of Keratherm KP12 thermal grease is used between the blocks and carbon foam sample.
- In both locations thermal conductivity of the K9 carbon foam is not less than a specified value.



Material	nominal thermal conductivity W/(m·K)	measured thermal conductivity W/(m·K)	measured thermal conductivity ≥20 W/(m·K)
K9 Location 1	≥20	58.09 ± 0.9	✓
K9 Location 2	≥20	39.5 ± 0.4	✓

Summary

- The offset correction is performed for the thermistors readings.
- The thermal mass of the samples of various thickness is taken into account. The time alignment is introduced.
- The setup was successfully calibrated using brass and sapphire glass samples.

Outlook

- To estimate the systematic uncertainty, additional studies are ongoing, including studies at various chiller set points, heat loads and vacuum pressures.