Beam Induced Quenches in the LHC

Steady State Helium II Heat Transfer and How to Improve the Experimental Design

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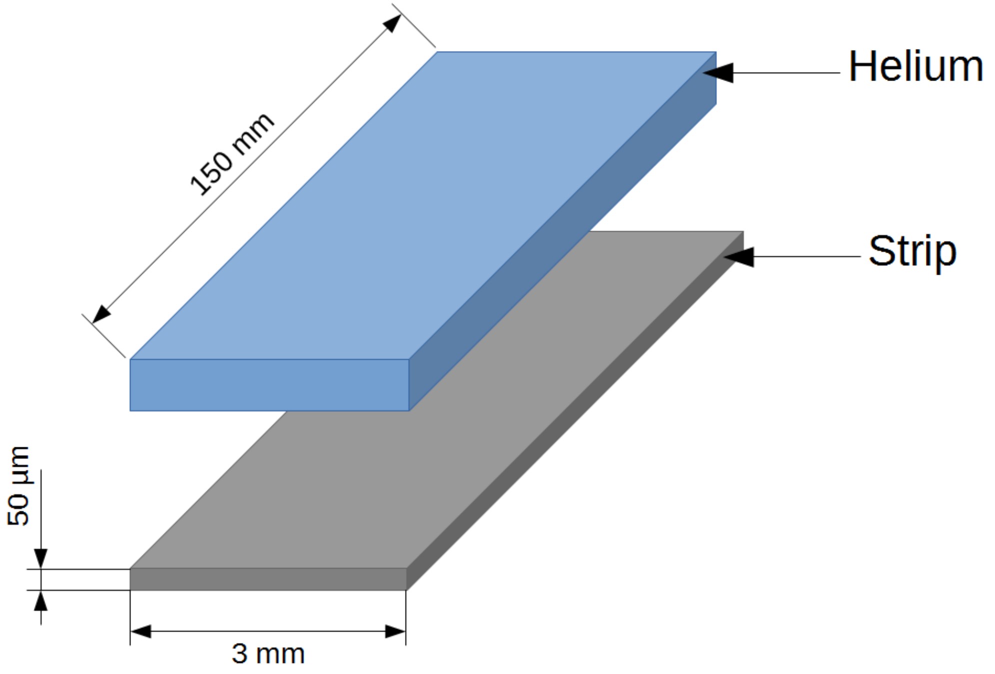
Summary of experimental setup

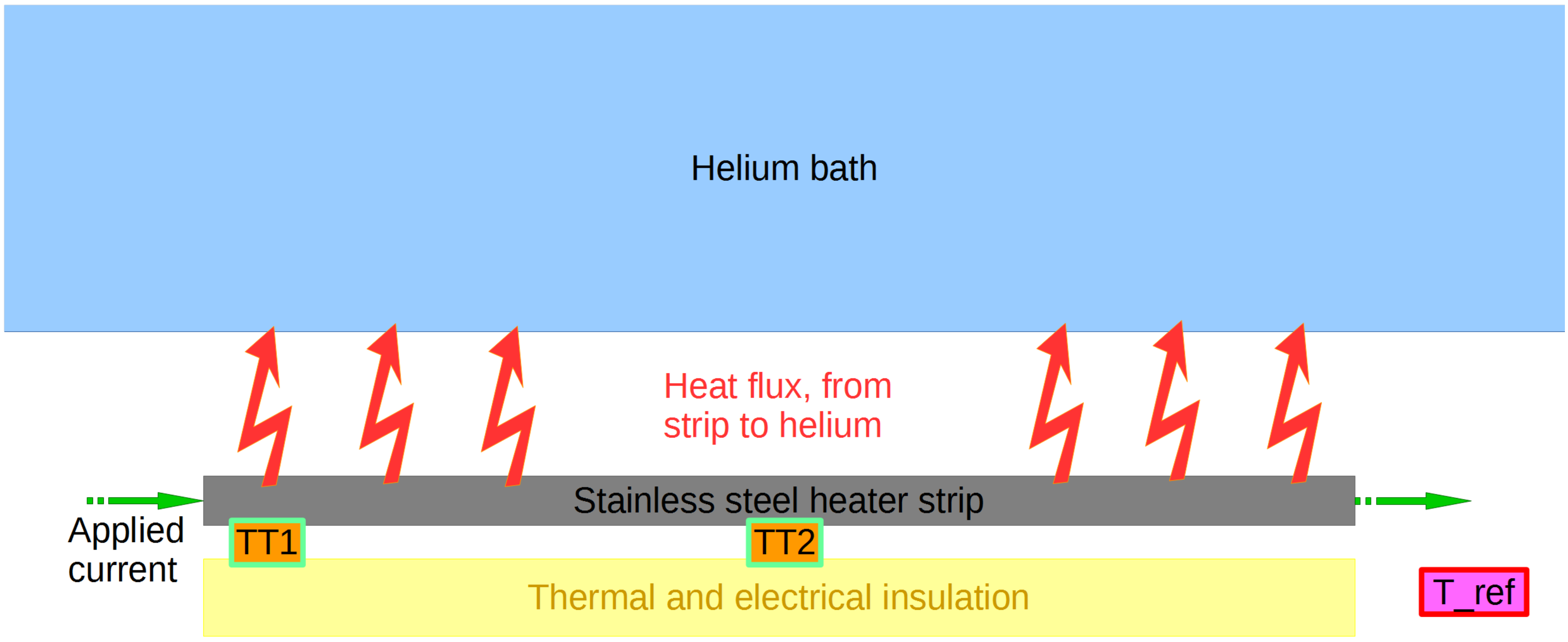
- Current supply feeding a steady power into stainless steel strip
- Dimensions of strip: 3 mm wide, 50 µm thick, 150 mm long
- Energy absorbed by static, open He II bath
- With gravity as reference direction, the helium is on top of the strip, **in direct contact**



What's in the Cryostat (1)

One sensor embedded in glue under the edge of the strip, and one under the middle.

Original design had three sensors under the strip, but one broke after curing of the glue.



Putting on the Heat – What to Expect

$$Q_{Kapitza} = a_{Kap}(T_S^{n_{Kap}} - T_{Bath}^{n_{Kap}})$$

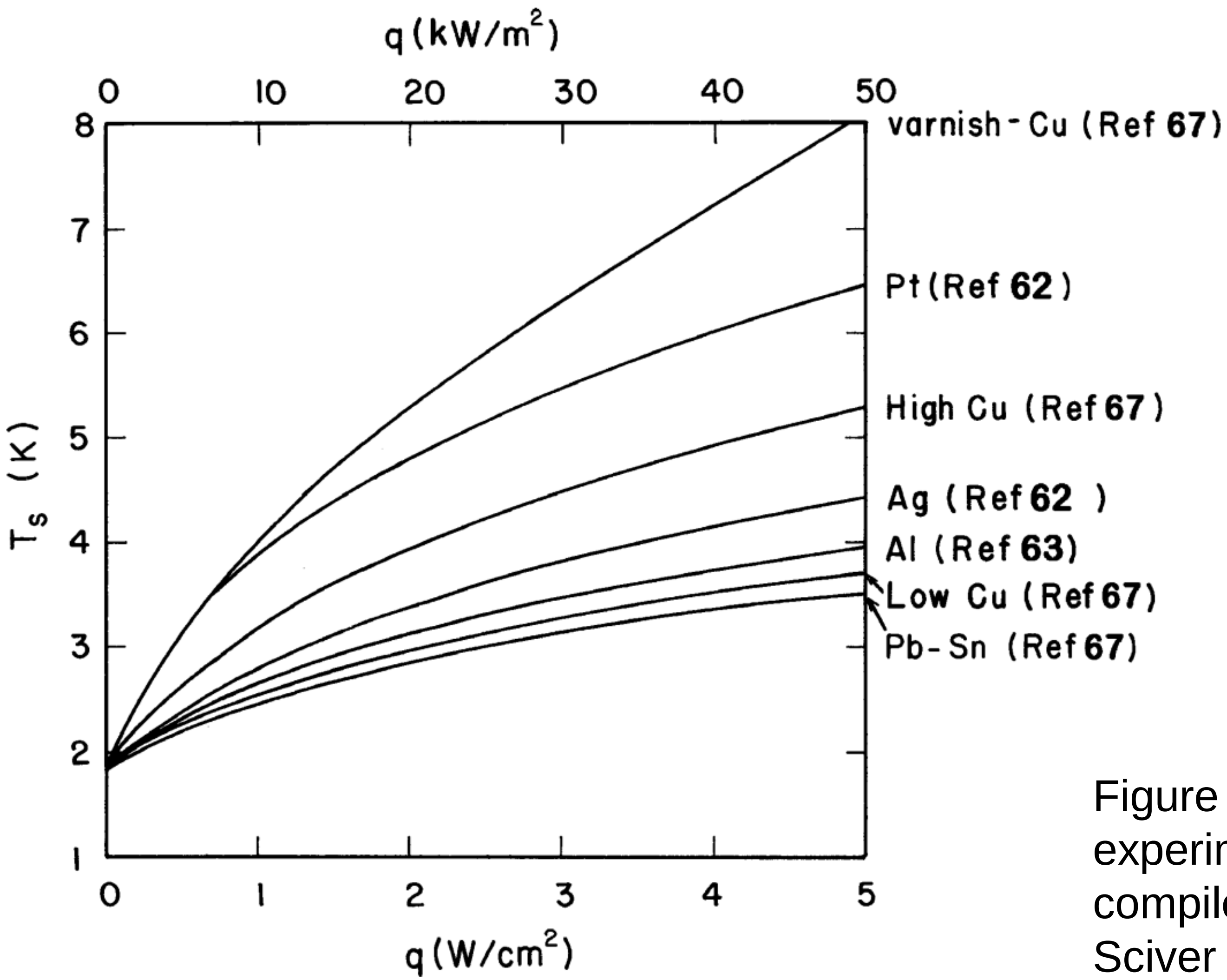
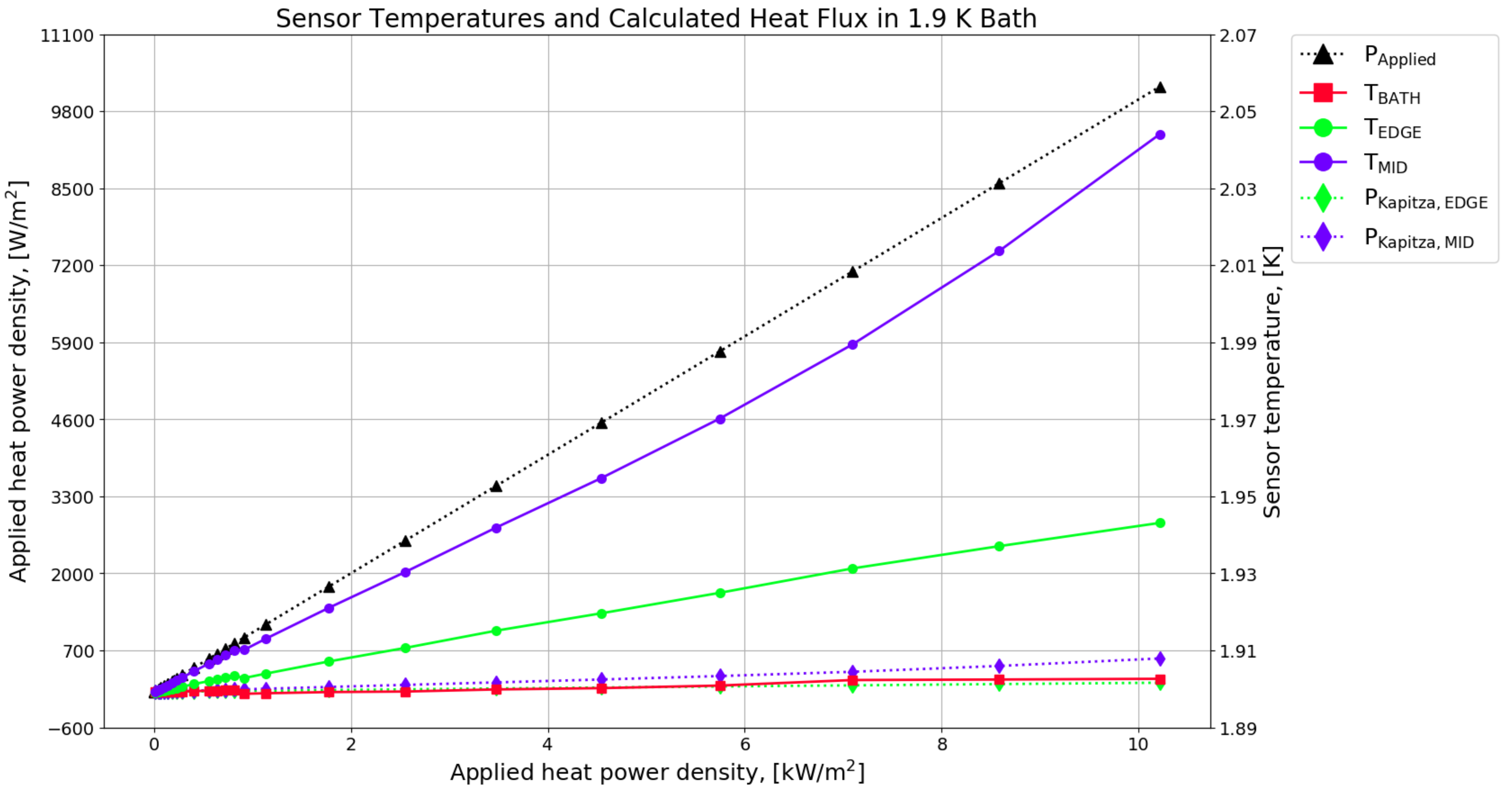


Figure is a summary of experimental results compiled by Van Sciver (Fig. 7.38)

Gist of Run 2 Results

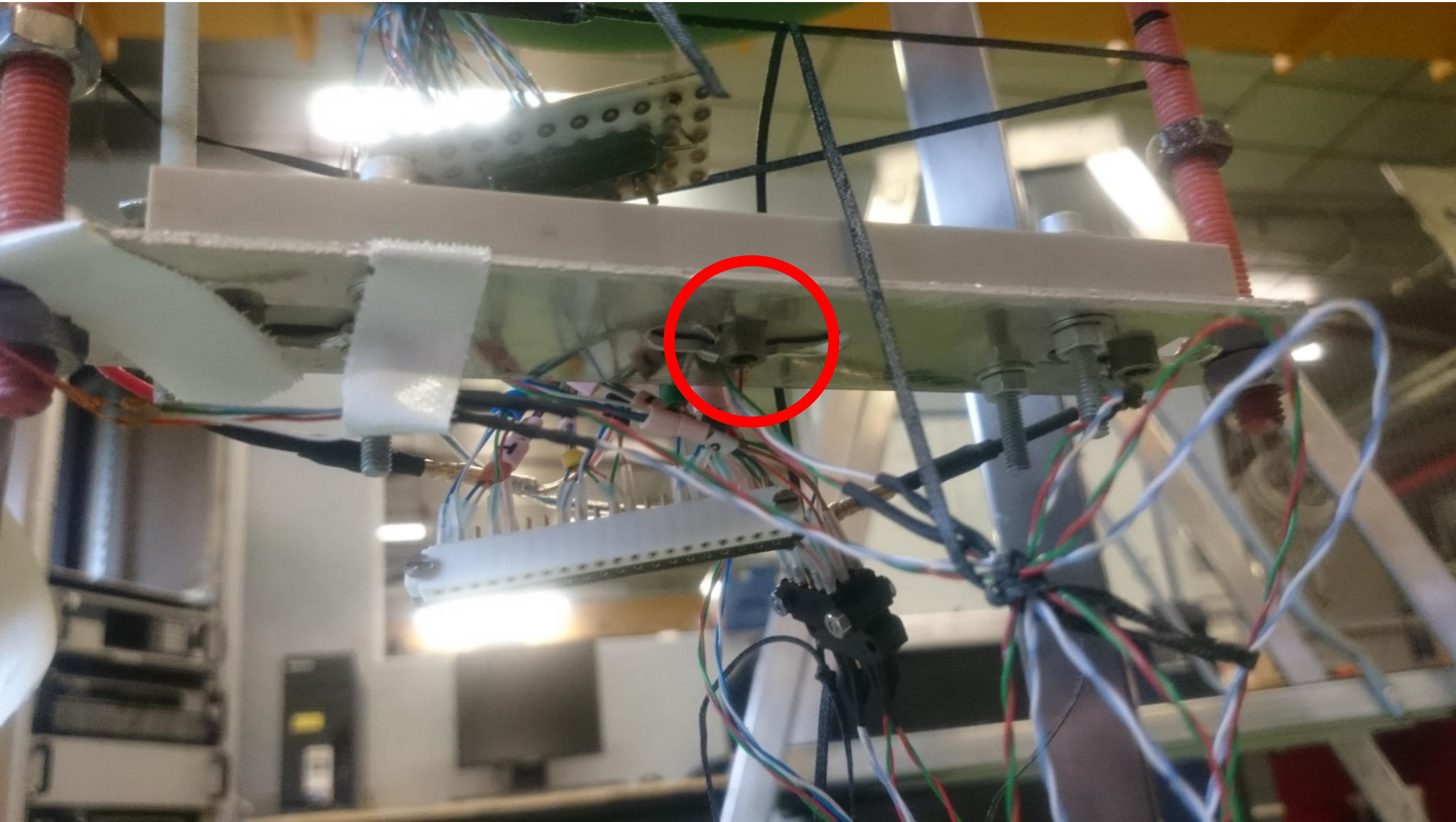
For one, the temperatures reached are nowhere near as large as the ones expected.

For another, the heatflux calculated for the measured temperature is near insignificant compared to the applied heat power density.



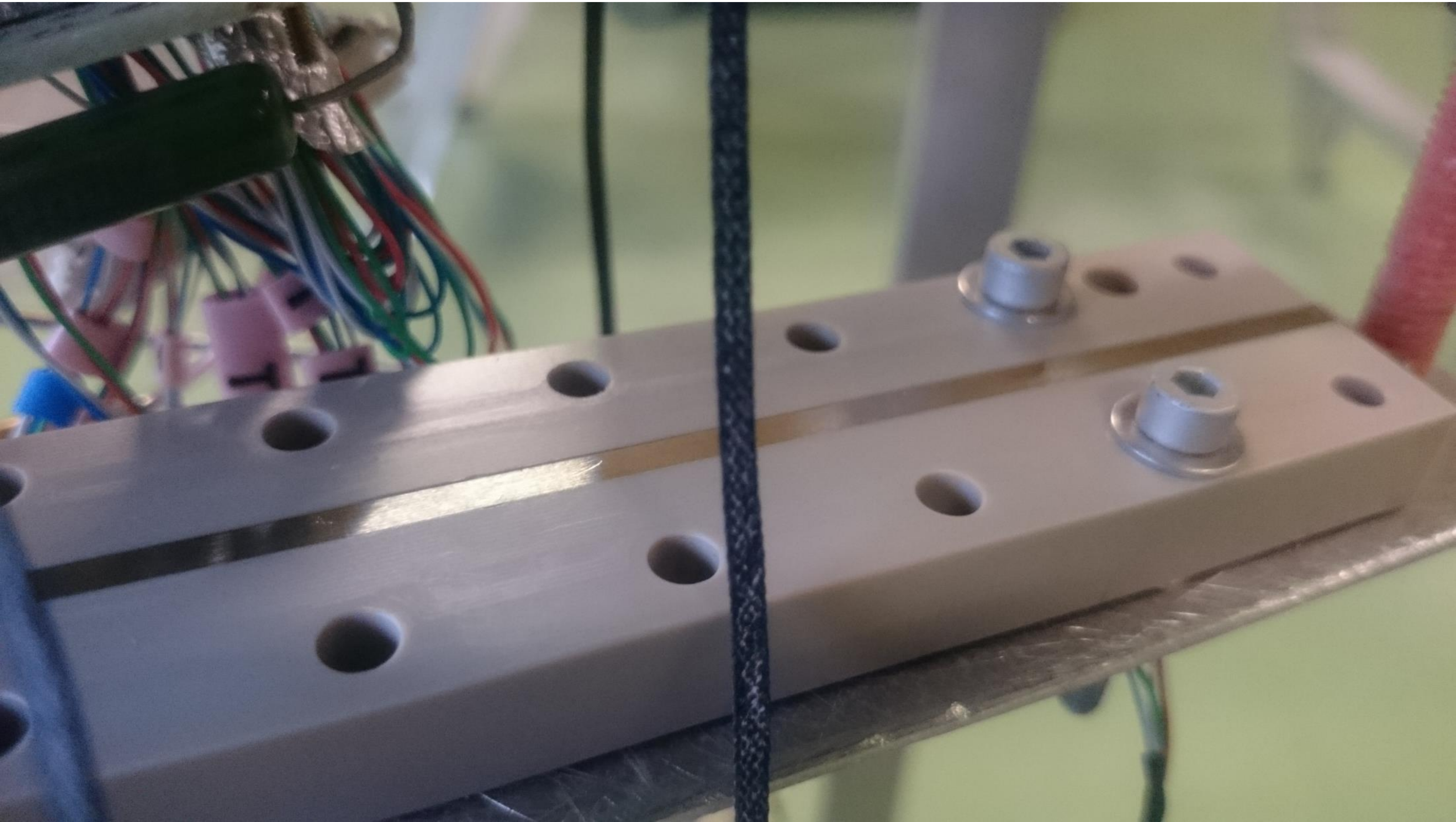
What Might be the Problem (1)

Sensor holders are exposed to the bath from the back



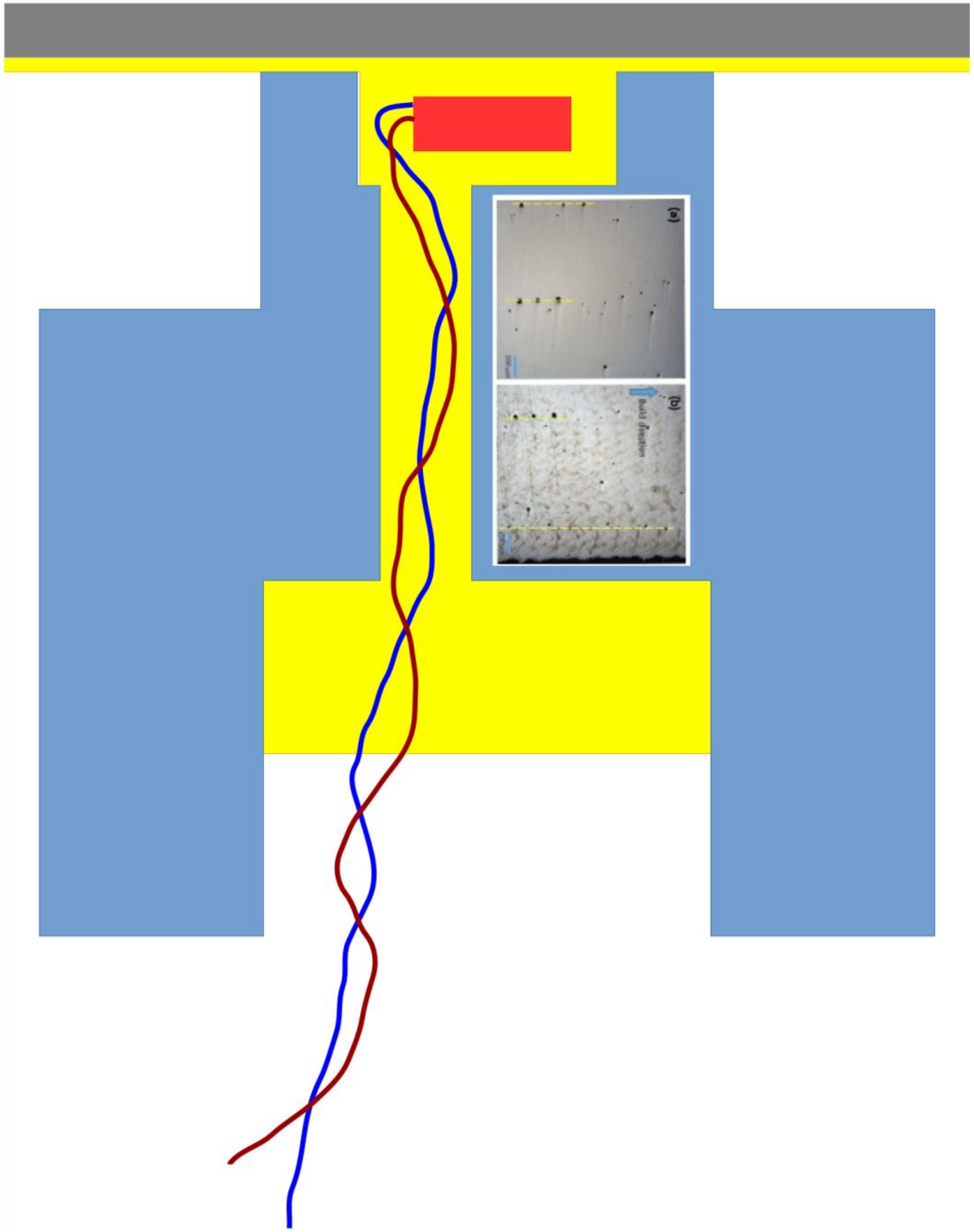
What Might be the Problem (2)

Not perfect seal along the edge of the strip



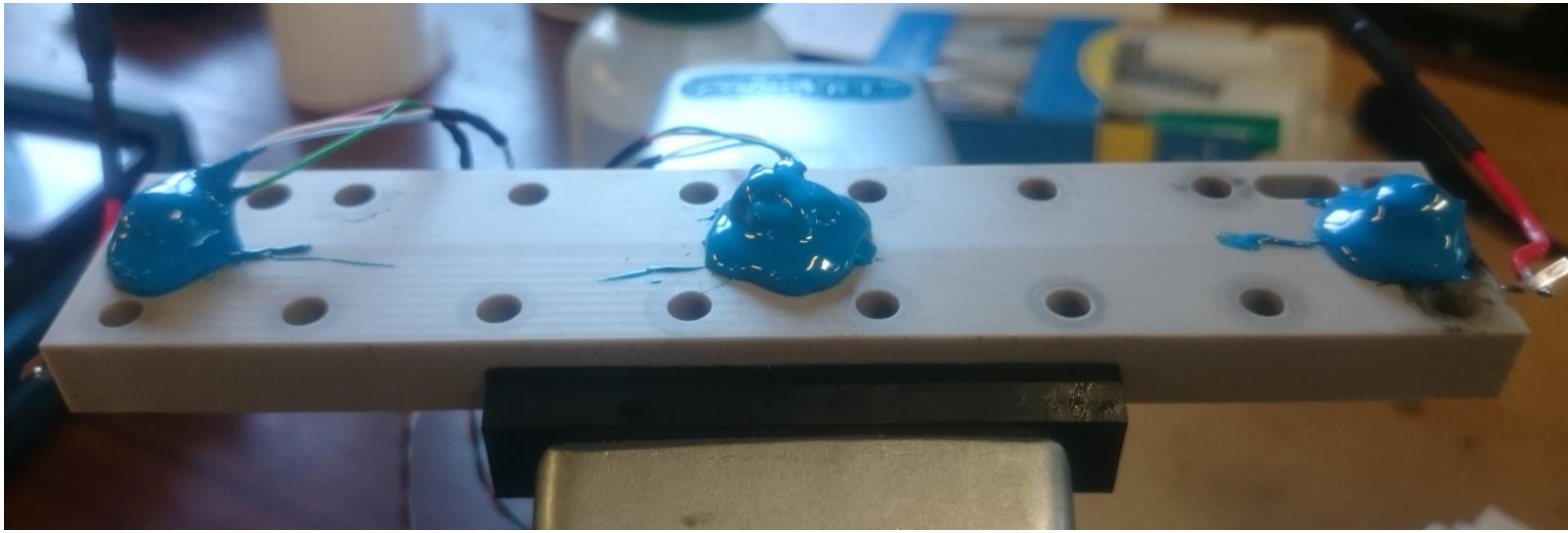
What Might be the Problem (3)

1. Helium can creep in under the strip, effectively increasing the cooled area
2. There can be complete channels though the glue (along leads, or from the top), allowing He II to cool the thermal sensor directly
3. The 3D printed stainless steel holders for the probe is «slightly» porous, which, according to theory, could make it a very good thermal conductor, again cooling the sensor directly

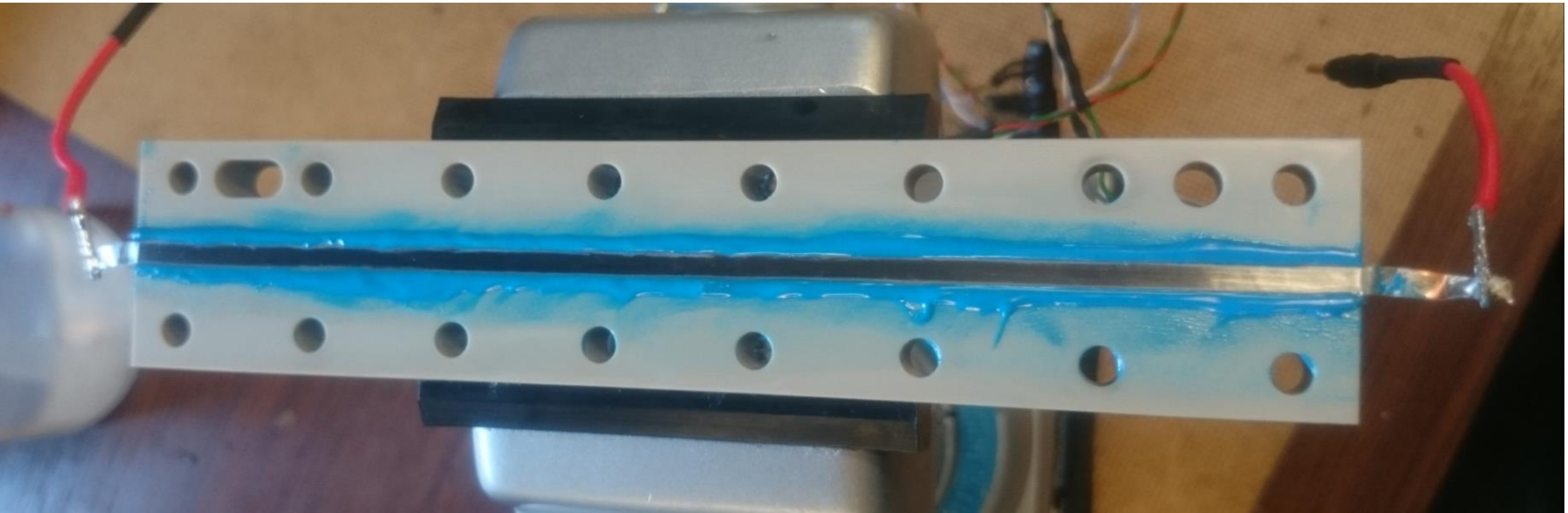


Solution: Use all the Glue

Slather glue on the backside of the sensor holders to plug any back channels and porosity



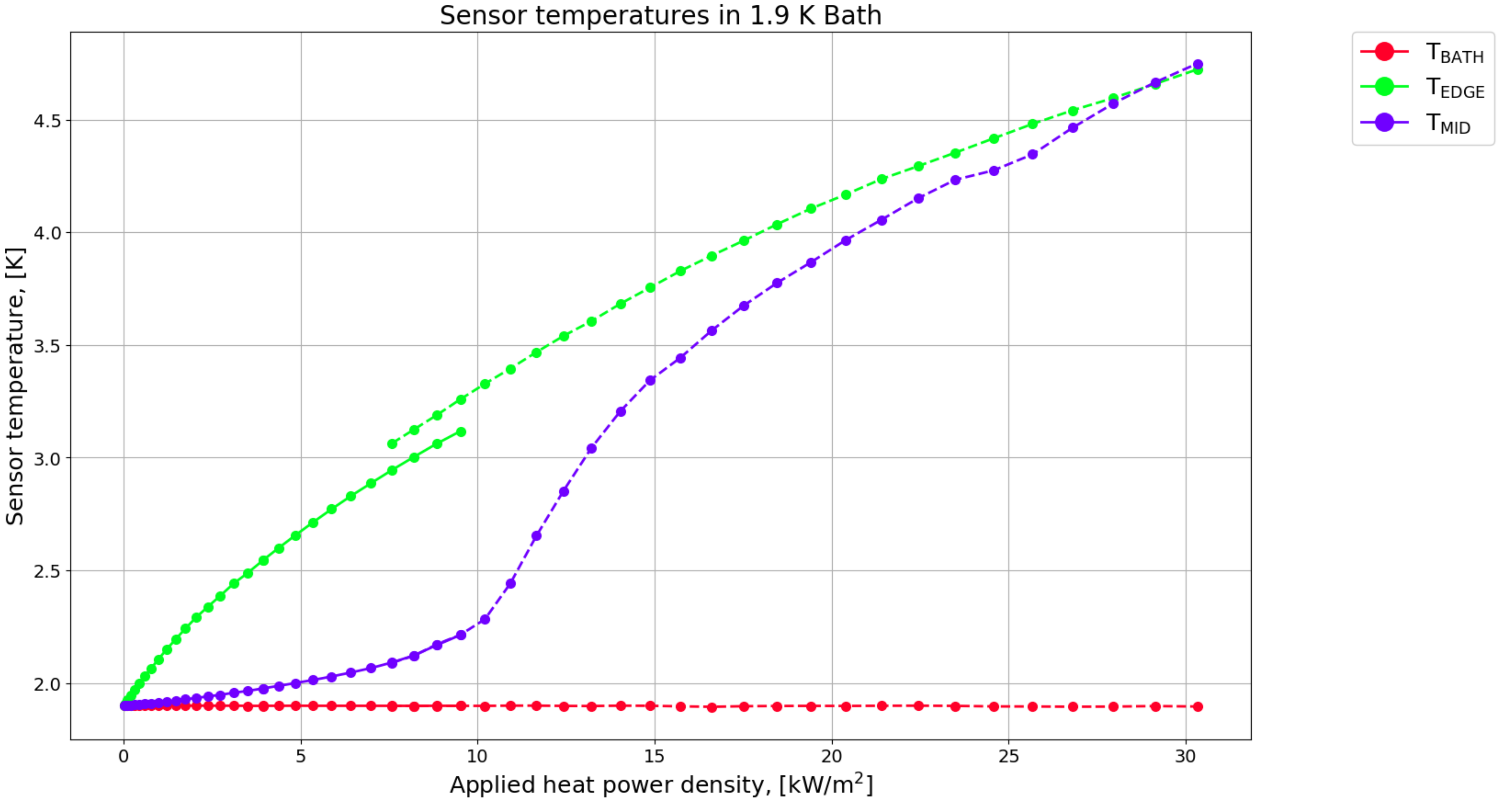
Glue along edge of strip to reduce chance of He II creeping in under the strip



Run 3 – 1.9 K Bath (1)

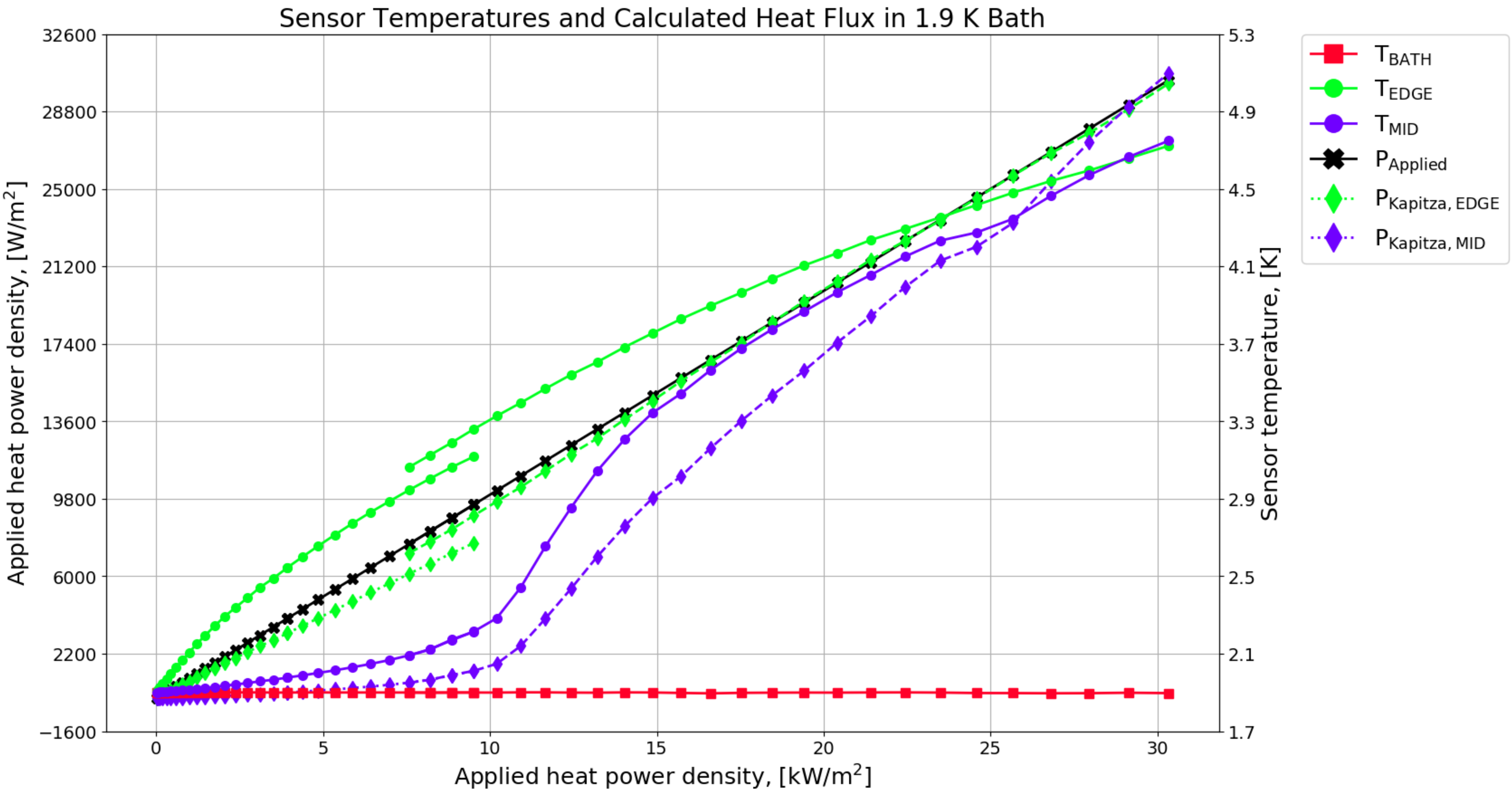
Jump is caused by odd calibration issue

Main conclusions at this point: general shape is much closer to the expected result for the edge sensor, and the mid sensor, although not as well isolated from the bath, behaves more like the edge sensor for high heatfluxes



Run 3 – 1.9 K Bath (2)

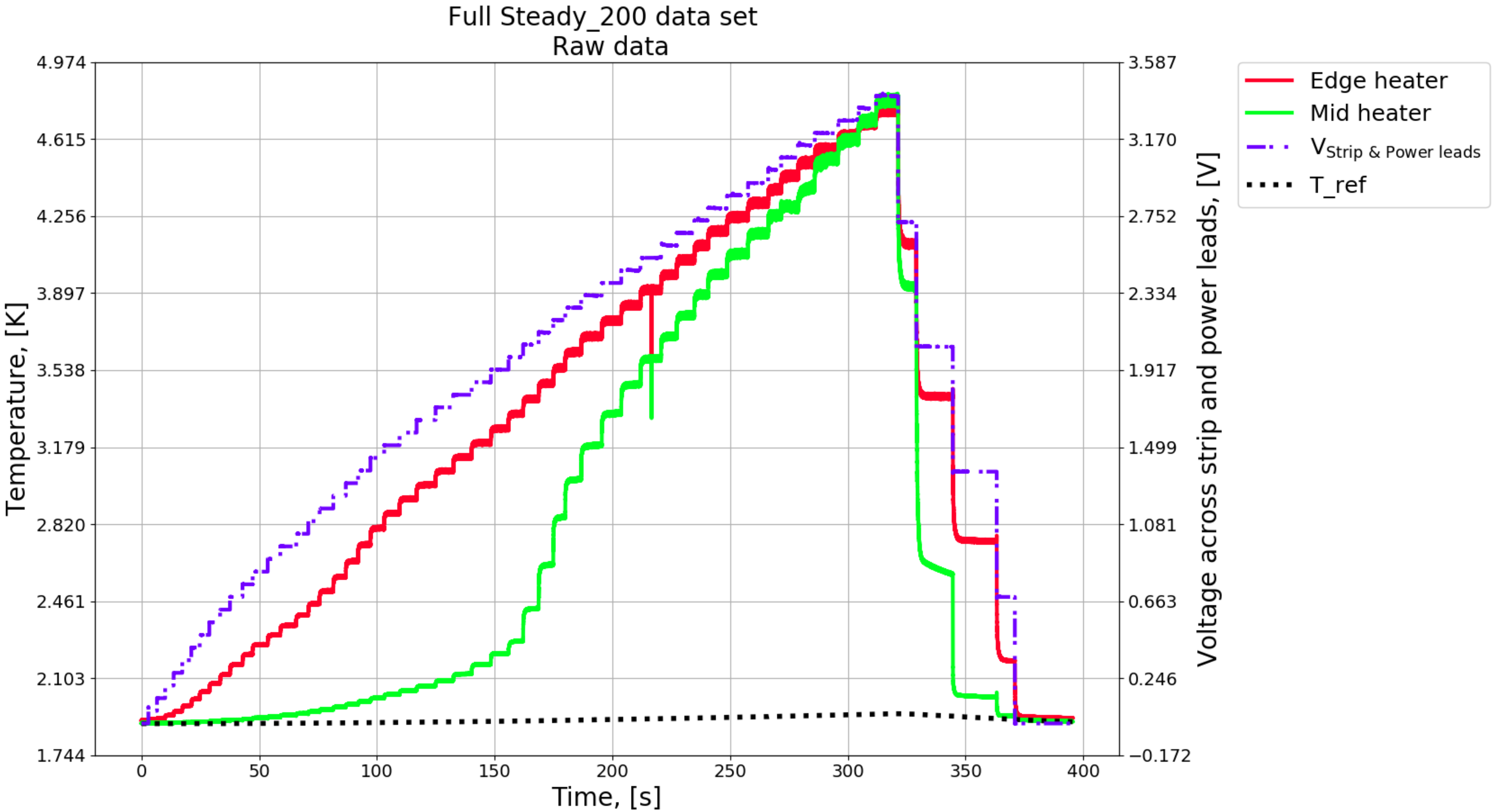
Clearly, the usual Kapitza expression does a much better job at approximating the heat load for the edge sensor (this is for a_{Kap}= 410 W/m^2, n_{Kap}= 2.82)



Run 3 – 1.9 K Bath – Up and Down (1)

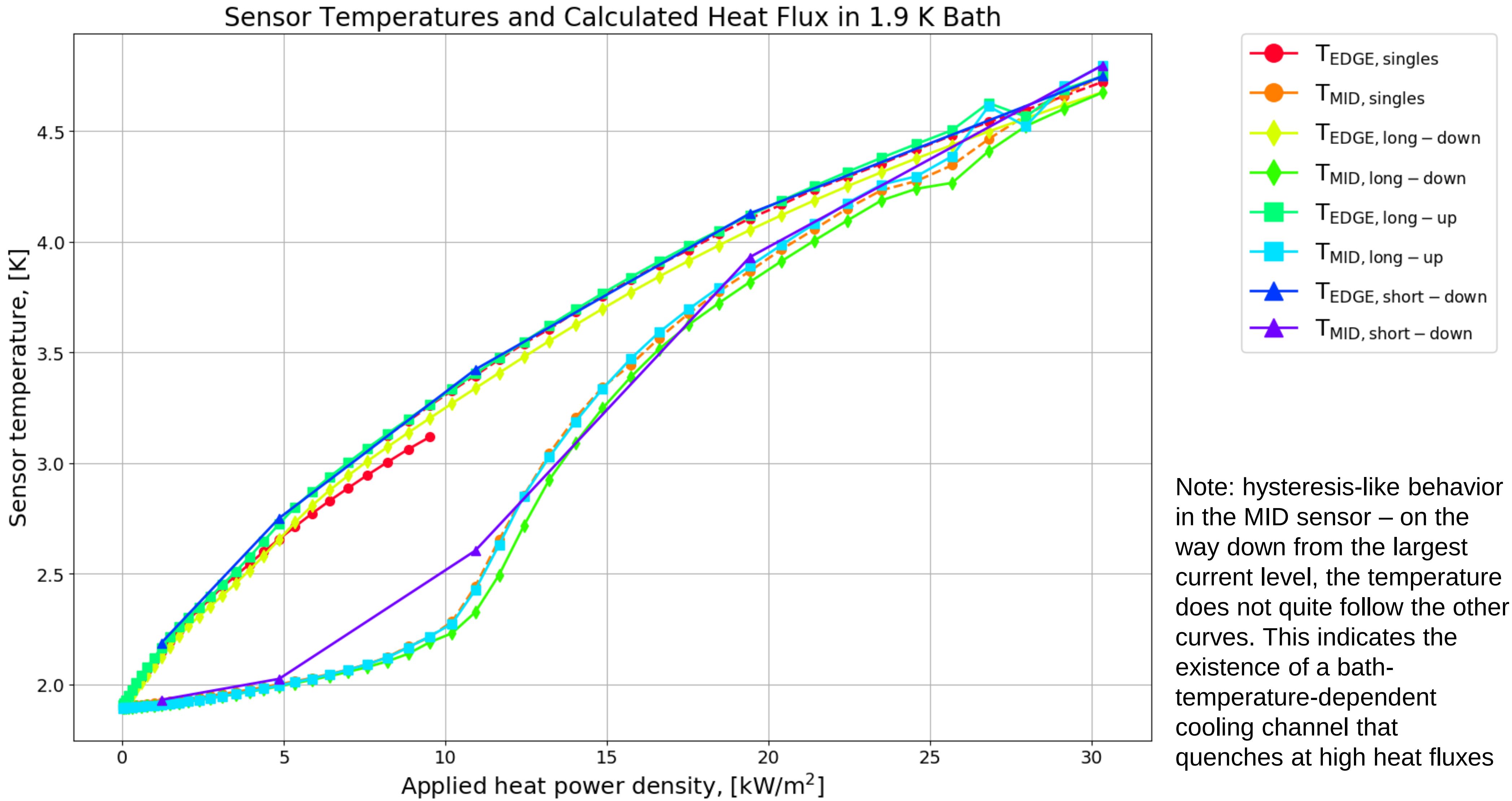
Stepping up current from source without turning off the power

Have similar for a downwards stepping



Run 3 – 1.9 K Bath – Up and Down (2)

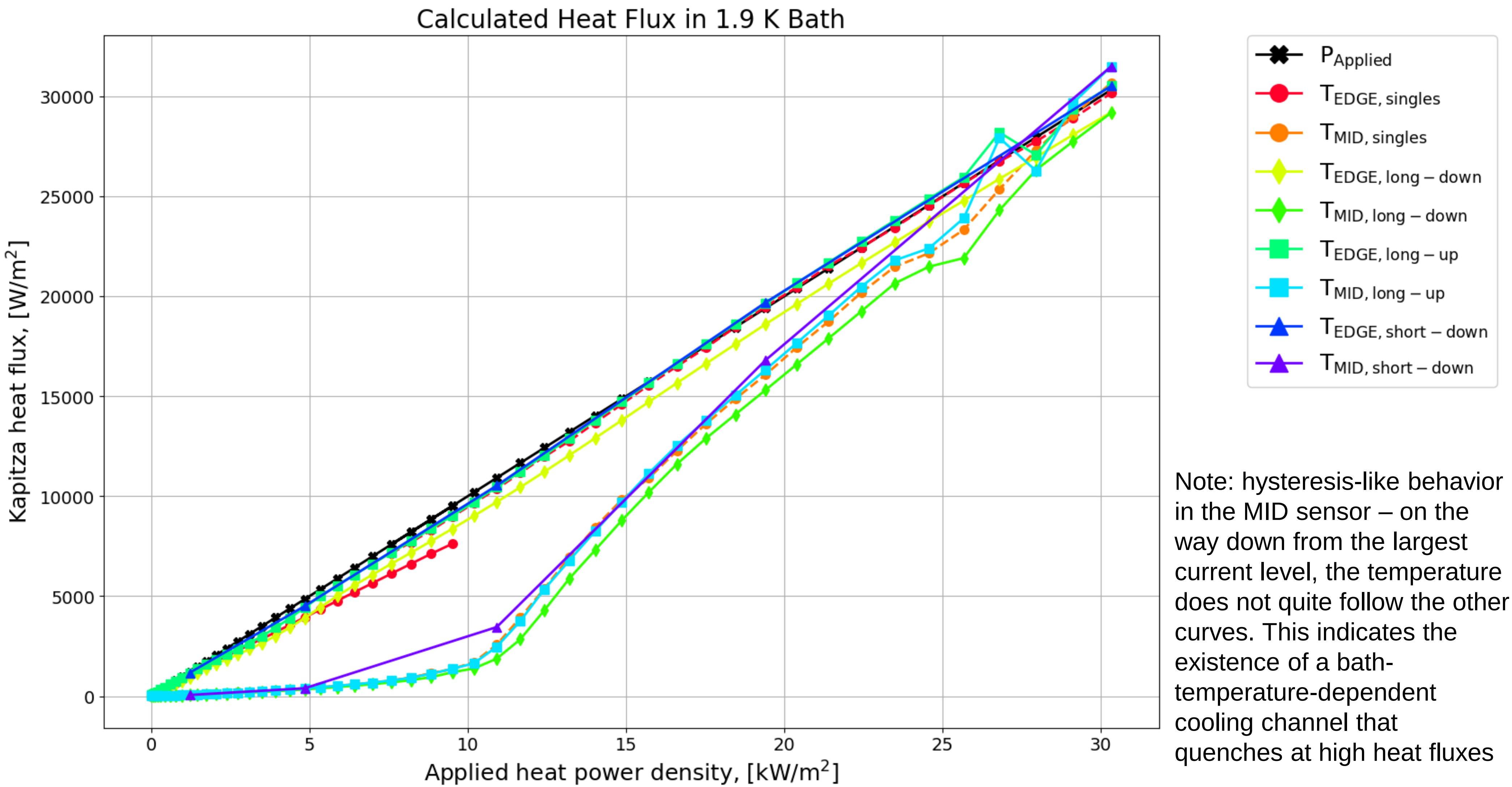
While certainly a bit spread out, the two sensors register the same data for the same situation



Note: hysteresis-like behavior in the MID sensor – on the way down from the largest current level, the temperature does not quite follow the other curves. This indicates the existence of a bath-temperature-dependent cooling channel that quenches at high heat fluxes

Run 3 – 1.9 K Bath – Up and Down (3)

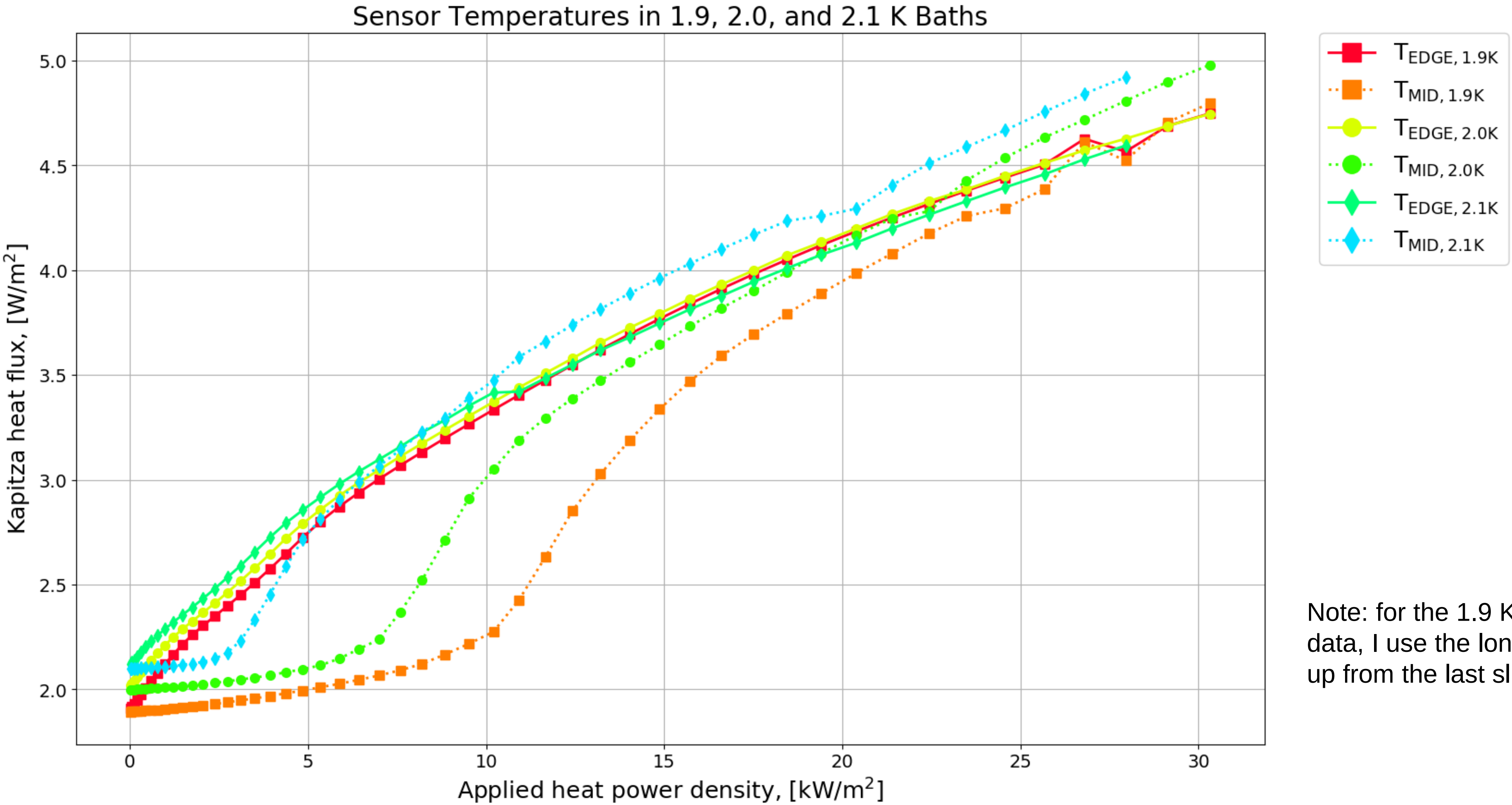
For the same model parameters, the data gives actual heat fluxes very similar to the applied one. Note that for the EDGE sensor for long-down stepping, the fit is somewhat poor.



Note: hysteresis-like behavior in the MID sensor – on the way down from the largest current level, the temperature does not quite follow the other curves. This indicates the existence of a bath-temperature-dependent cooling channel that quenches at high heat fluxes

Run 3 – Several Bath Temperatures (1)

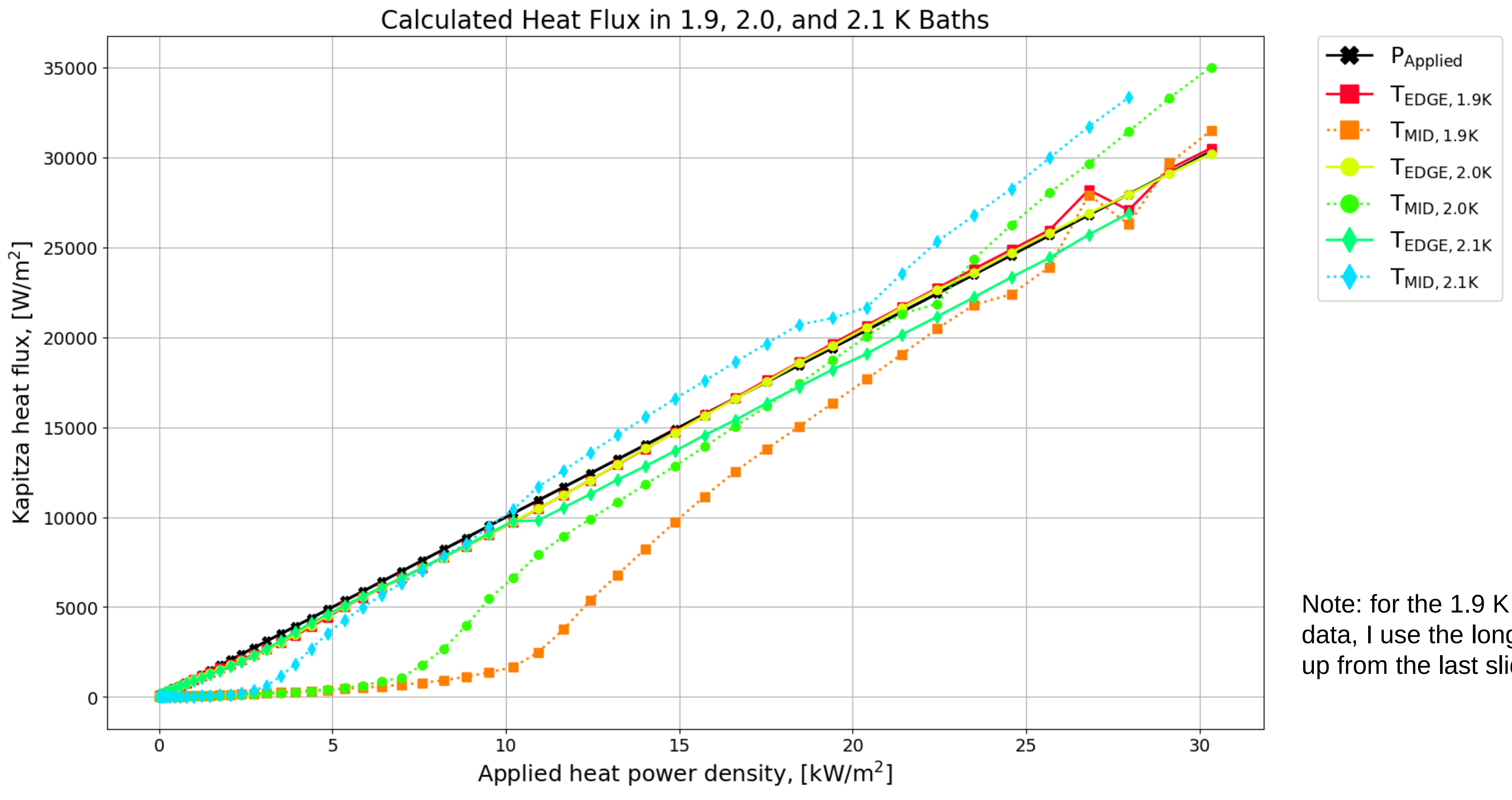
- It is odd that the 2.1 K data jumps right around 10 kW/m2
- It is odd that the MID sensor goes higher than the EDGE for high heat fluxes
- It might be coincidental, but the inflection point for the MID sensor to start approaching the EDGE is right around the Lambda temperature



Note: for the 1.9 K data, I use the long-up from the last slide

Run 3 – Several Bath Temperatures (2)

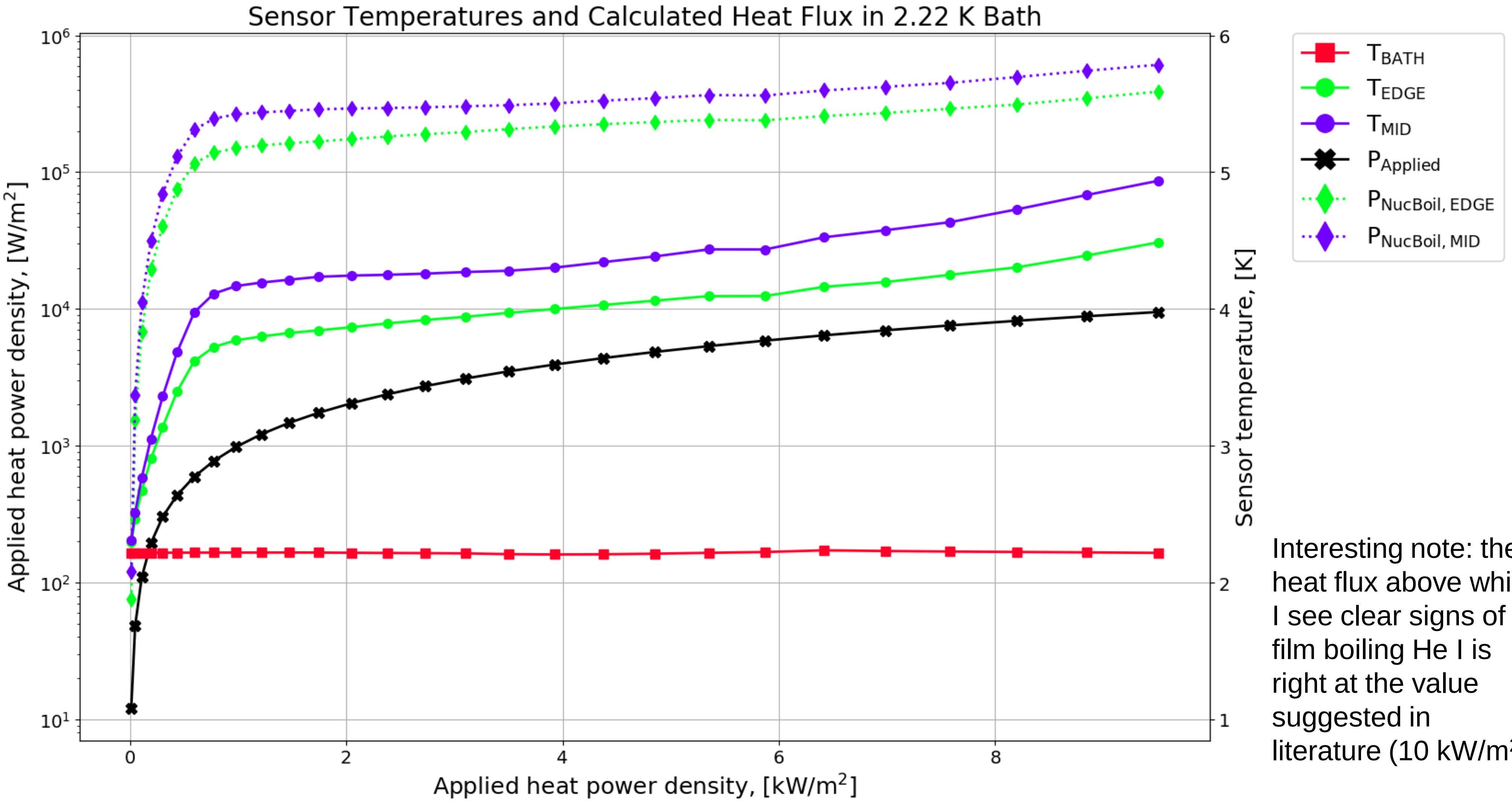
All calculations of Kapitza heat flux use the same material parameters as before; the fit is quite good across the three bath temperatures.



Note: for the 1.9 K data, I use the long-up from the last slide

Run 3 – In He I

He I is supposed to be well understood, but these results are not in agreement with theory. Note that maintaining a steady bath temperature in the cryostat I used is very hard, so these measurements are not without fault

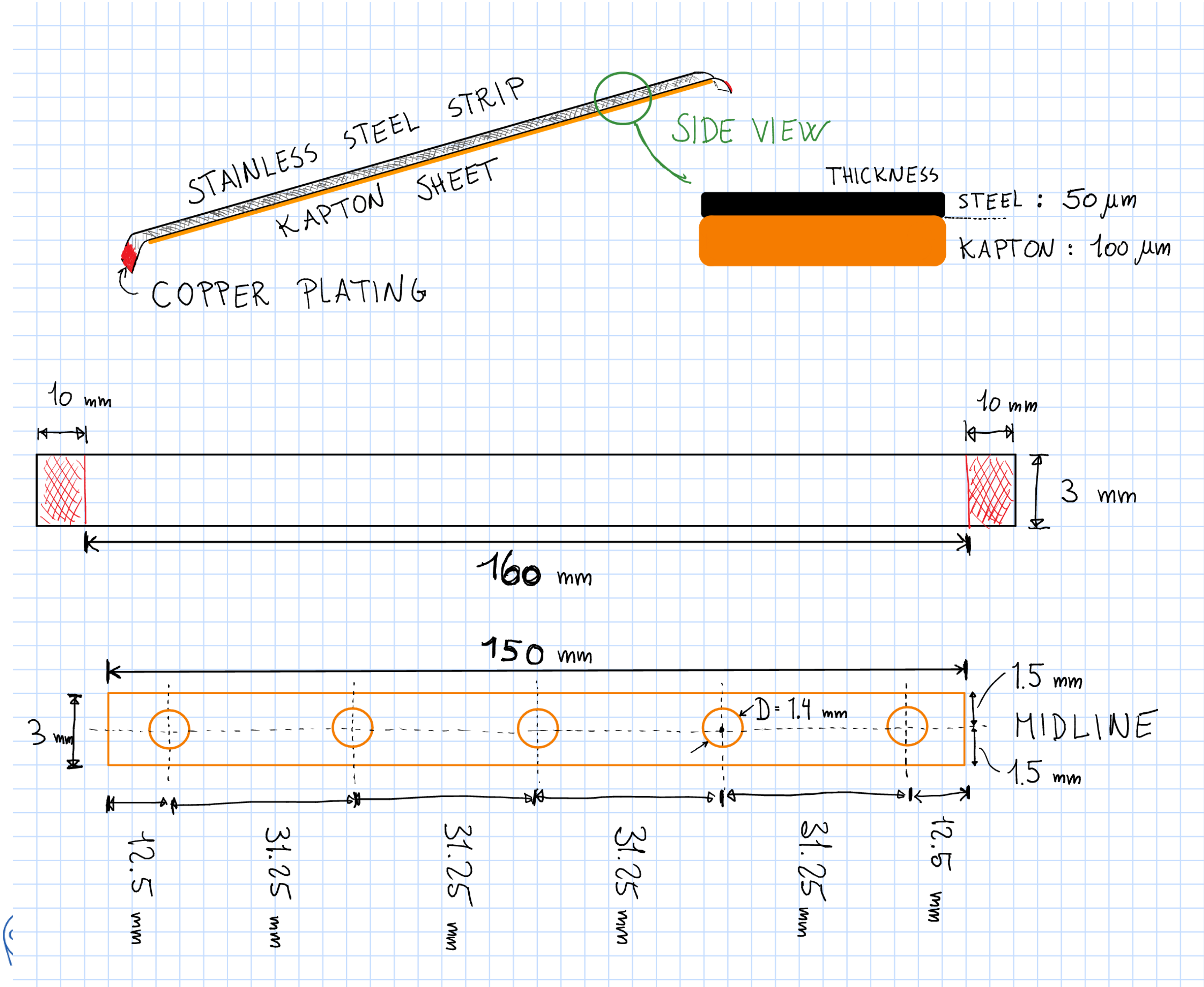


Interesting note: the heat flux above which I see clear signs of film boiling He I is right at the value suggested in literature (10 kW/m^2)

Next Iteration

- I believe the approach of enclosing the backside with glue is good. The reason for the MID and EDGE sensors to disagree at lower applied heat fluxes is probably because I applied the glue too late for the MID sensor (the glue had passed its working time, and the higher viscosity made application imperfect)
- Sensors should be mounted upside down, directly onto the heater strip with high thermal conductivity glue; this will solve two problems at once. It will put the sensor in better thermal contact than now, and it will allow us to completely skip the porosity problem
- Ultimately, we want to do transient measurements in confined space, meaning we need to close off a small volume of helium. This means some sort of top plate with its own sensors in it. To avoid the porosity issue here as well, we need to mount the sensors directly to the top plate material, with the sensing part down into the helium
- A perpetual problem with the sensors is their fragile wiring. LakeShore (supplier) can deliver sensors with thicker leads that should be more robust, and, importantly, insulated from the factory

New Heater Strip



Approach for Top and Bottom Plates

- A challenge has been sharp edges and bends of the sensor leads, so in the new iteration, I intend to have the sensor mounting holes tilted by 45 degrees, and slide the wires out sideways. This will minimize the bending required right at the sensor-to-lead soldering point

Some Conclusions

- This latest iteration of the experiment, where the main point was to completely encapsulate the sensors and strip in glue looks to have been sufficiently successful that the gluing approach can be used also for the next iteration
- Care must be taken to not exceed the working time of the glue during application
- Ideas regarding improved calibration are needed. It is difficult to control the temperature above 2.17 K, and almost impossible above 4.2 K, so this is an important drawback to the cryostat we are using (it works by moving along the saturation line of helium. At 5 K, the vapor pressure is already 200 kPa; the cryostat is not built for overpressure. Furthermore, above 5 K, we pass the critical point of helium anyway)