INTERN: ISABEL NARANJO DE CANDIDO
SUPERVISOR: CHARLES COOPER

FINAL PRESENTATION

IARC

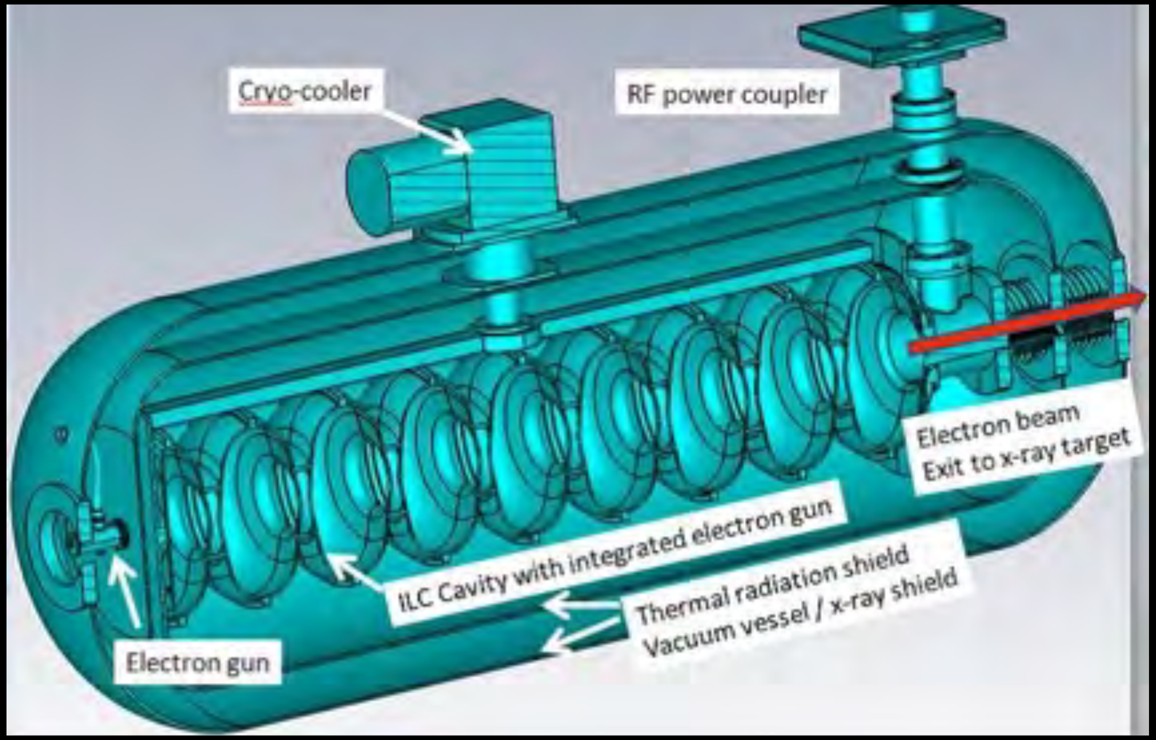
- **Mission**: To partner with industry to exploit technology developed in the pursuit of science to create the next generation of industrial accelerators, products, and new applications
- **Vision**: To be the preeminent technology source for accelerator based products and services, serving as the seed for US industrial growth

SRF COMPACT ACCELERATOR

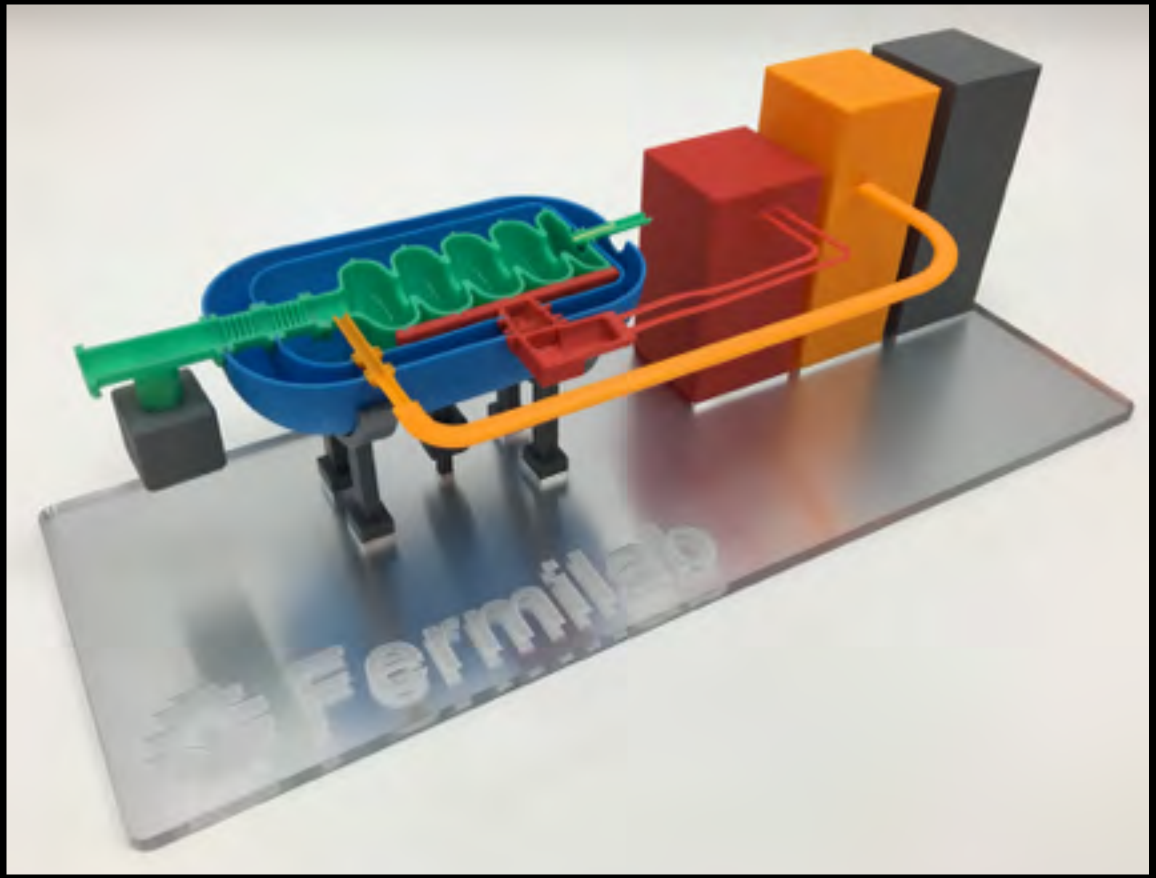
- Industrial accelerators must be cost-effective, simple, versatile, efficient, and robust
- Accelerator technology developed for science can be applied to industrial, medical and security applications
- Recent advances in multiple Superconducting Radio Frequency (SRF) technologies allow for the design of a novel compact, portable, high average power electron linac

SRF COMPACT ACCELERATOR

- 5-50 kW average power and continuous wave operation, electron beam energies up to 10 MeV
- Small and light enough to mount on mobile platforms: new in-situ environmental remediation, in-situ crosslinking of materials, and security applications
- The first of a new class of simple, turn-key SRF accelerators that will find broad application in industry, medicine, security, and science



Compact accelerator showing critical developmental technologies including Cryo-cooling. The 8.5 cell 1.3GHz cavity shown is based off geometry optimized under the ILCP



The 4.5 cell 650 MHz cavity (250kW) shown is based of technologies optimized under the Proton Improvement Plan – II

SRF CAVITIES COOLING

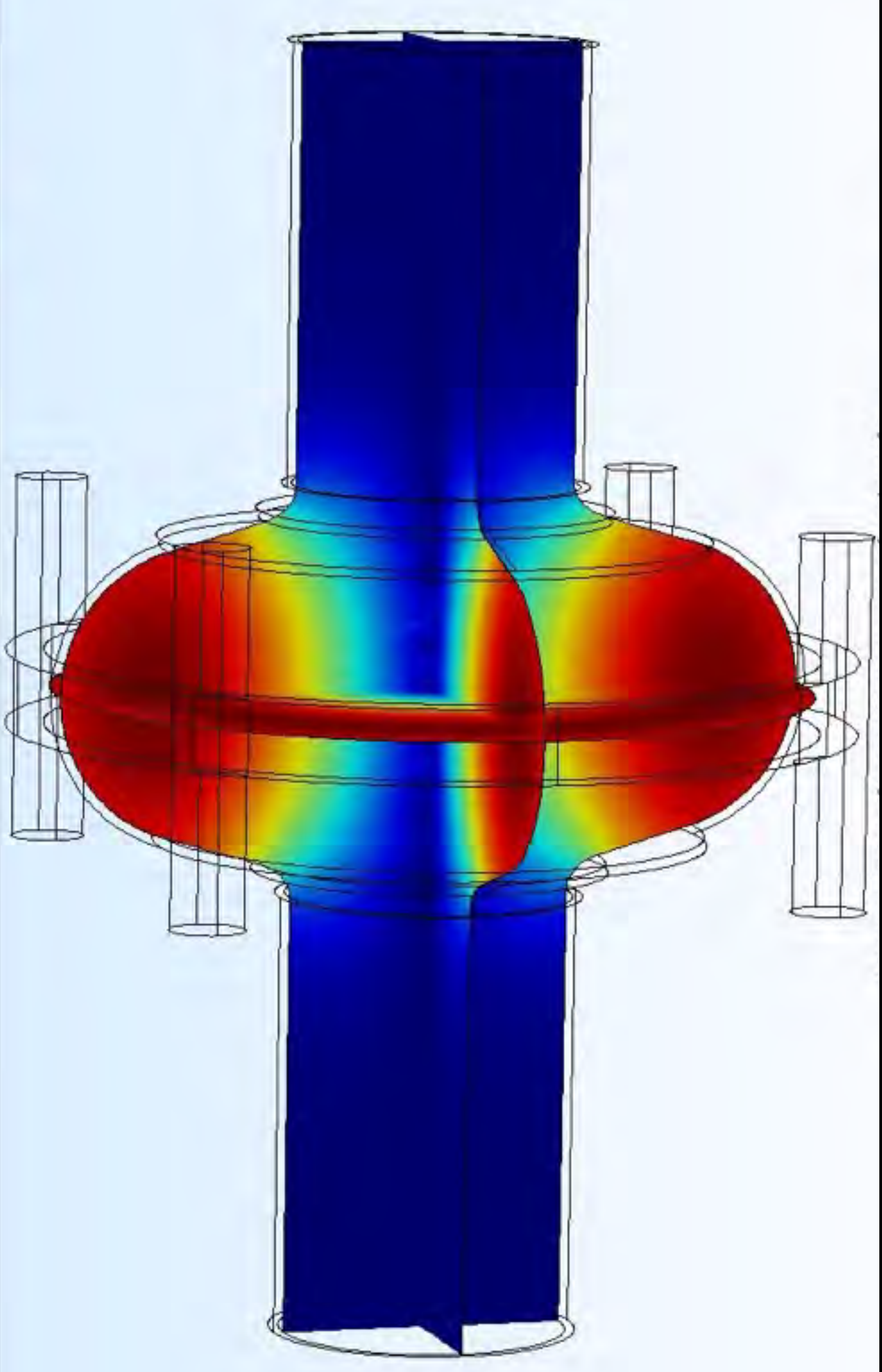
- Avoiding liquid He cooling would be of great importance for portable applications
- New SRF cavities coated with Nb_3Sn are more efficient and should allow the substitution of liquid cooling with thermal conduction cooling through high purity Al connected to a cryocooler

PROJECT WORK PLAN

FIRST TEST OF CONDUCTION COOLED SRF CAVITY

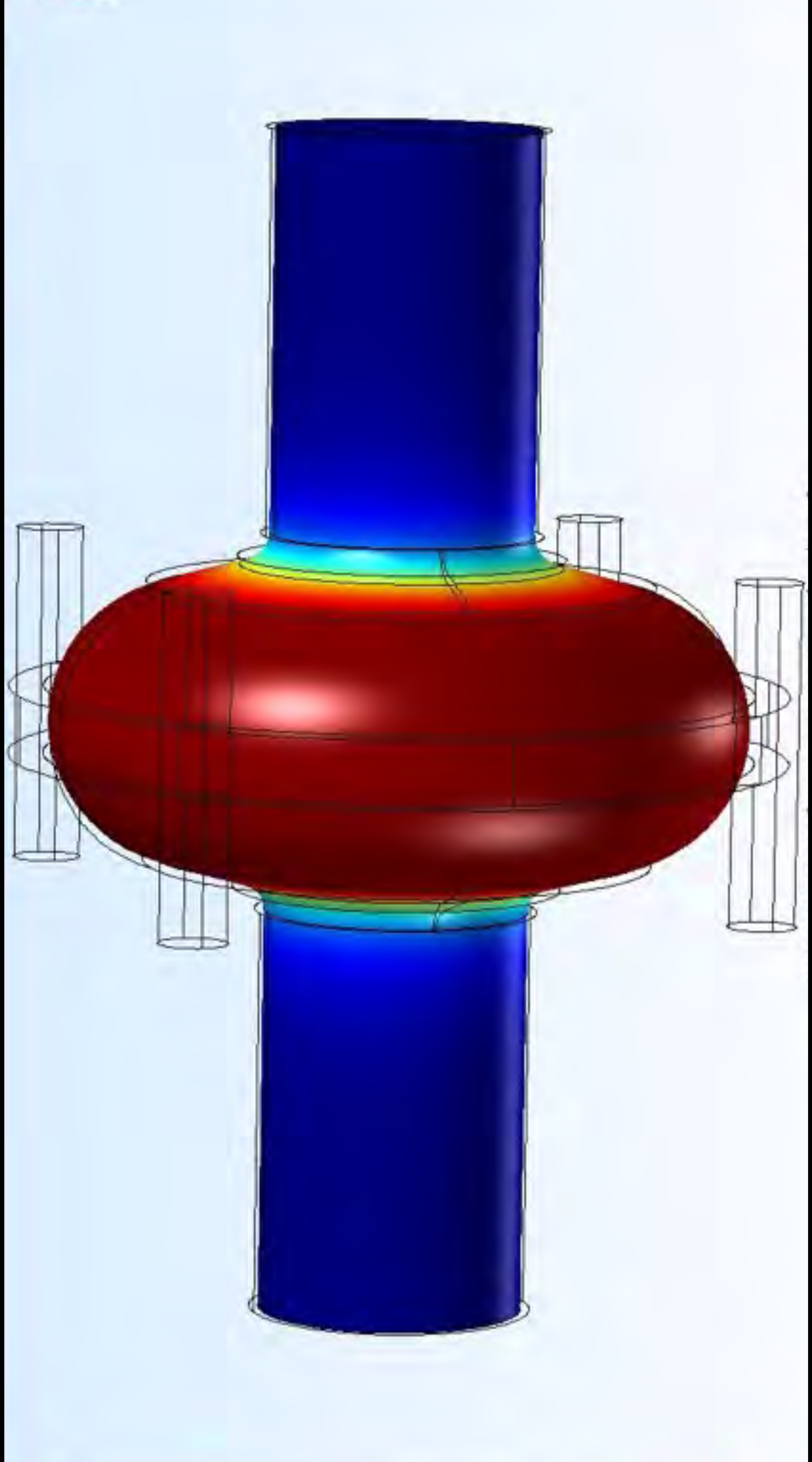
PROJECT WORK PLAN

- Bring an existing 1 Watt cryocooler from IB1 to IARC
- Run the cryocooler with a 1.3 GHz single cell Nb cavity equipped with a resistor to measure the cryocooler capacity at ~4.5 K
- Test a single cell 1.3 GHz pure Nb cavity excited with RF
- When the techniques are optimized, replace the pure Nb cavity with a Nb_3Sn coated cavity



MY TASKS

- Learn how to use COMSOL Multiphysics
- Learn some fundamentals of SFR science and basics of cryocooling
- Perform simulations of the thermal conduction cooling in order to demonstrate the theoretical feasibility of this kind of cooling technique
- Set up the experiment
- Perform the first type of test (1.3 GHz single cell Nb cavity with a resistor)
    - **Perform a thermal conductivity test**

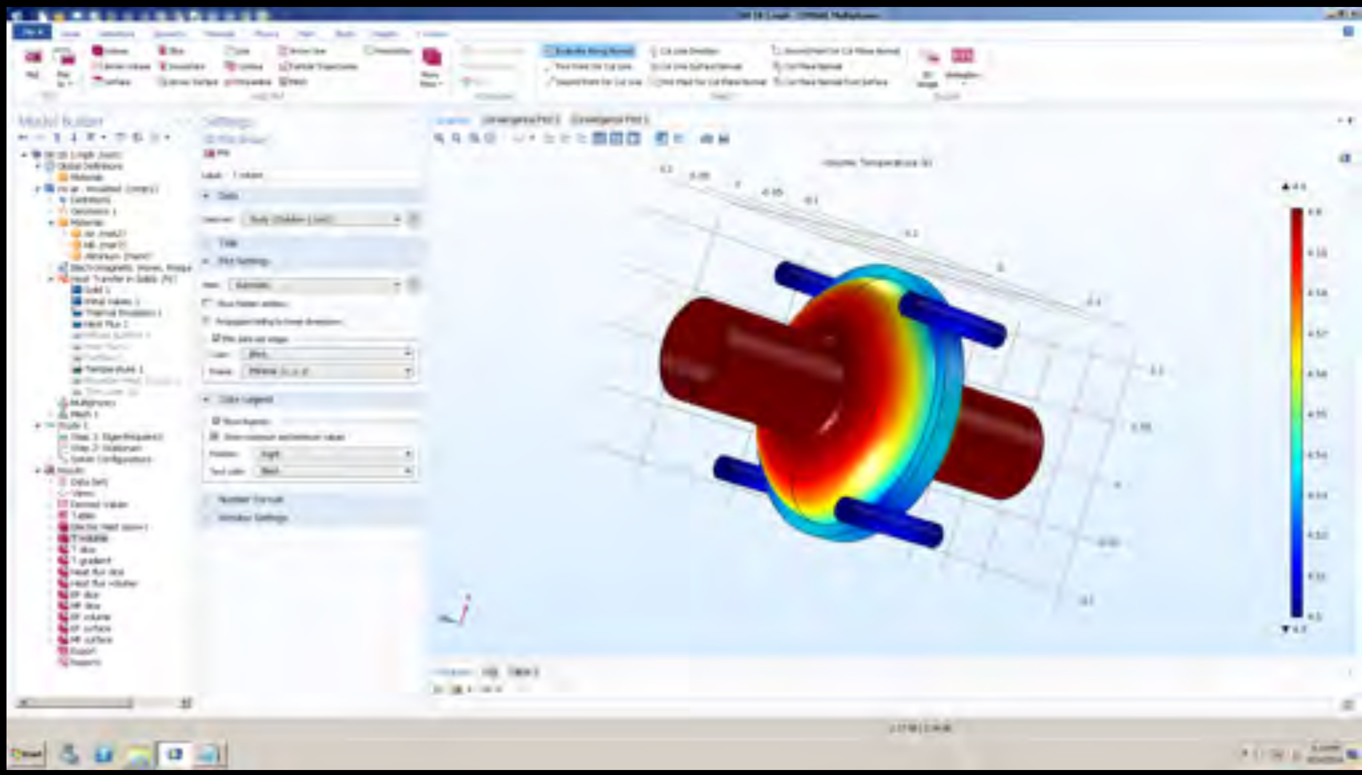


FIRST-TERM WORK: REVIEW

SIMULATIONS

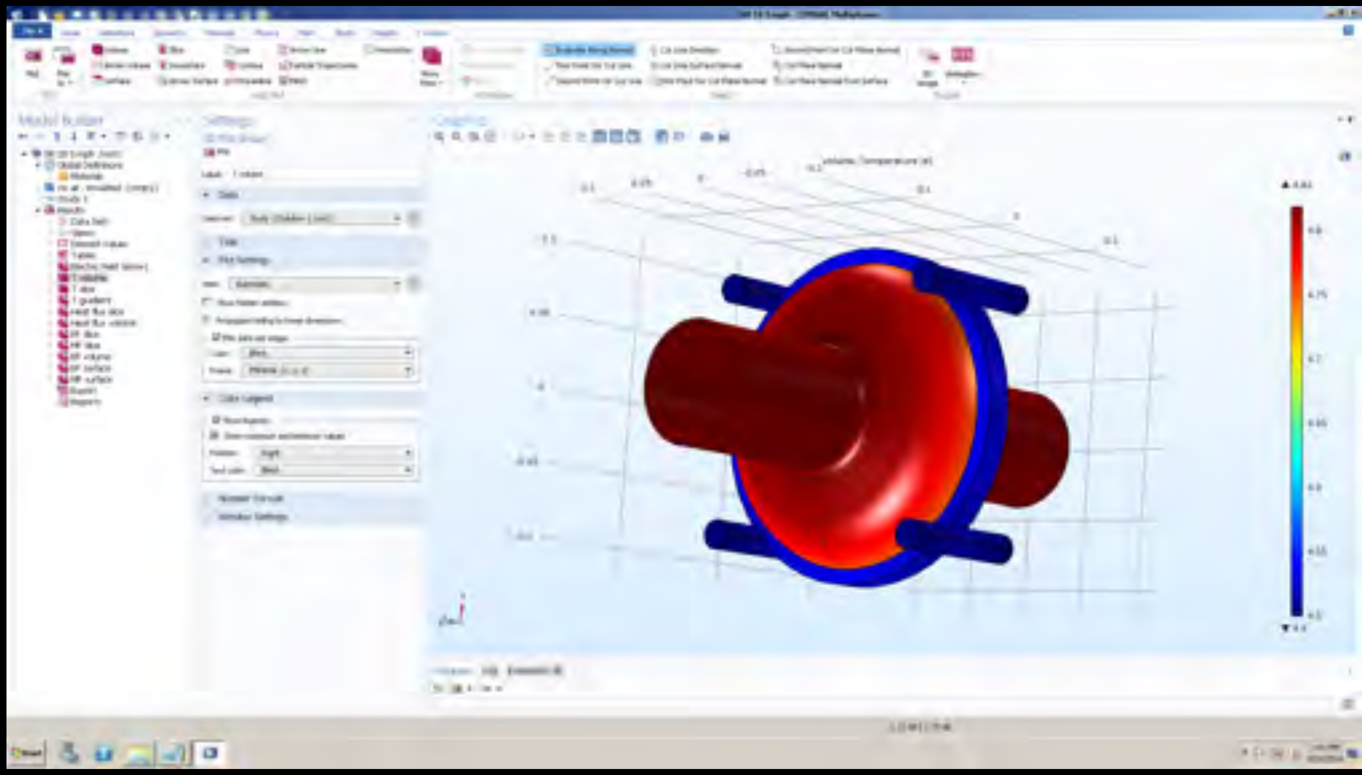
- SW: COMSOL Multiphysics 5.2a
- Simulating RF excitation, RF losses, heat transfer, heat conduction
- Big issue: contact resistance at the interface between Nb and Al
  - **Figure out a good type, shape and dimension of Al-Nb connection**

+



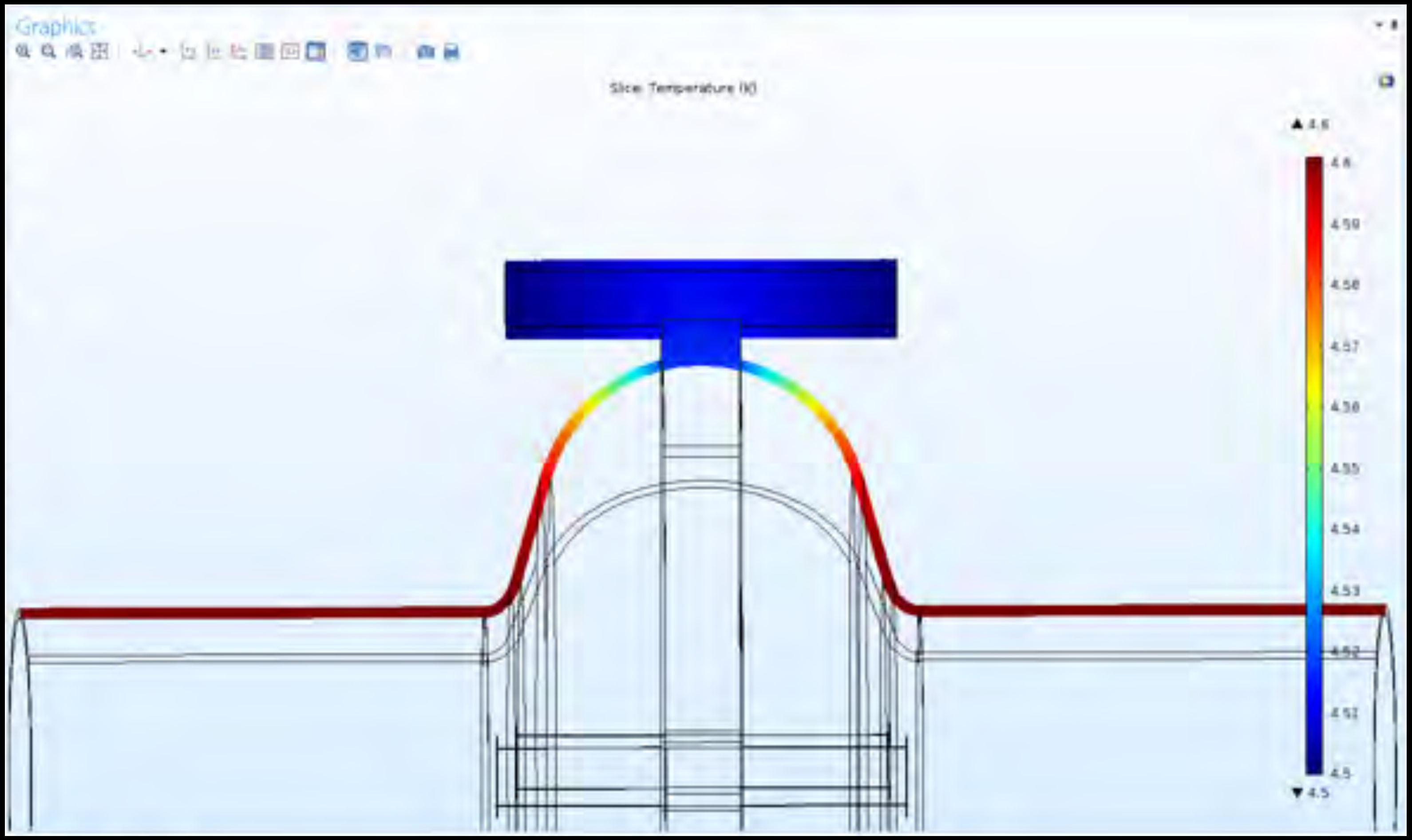
W/O contact resistance

Temperature profile along the cavity



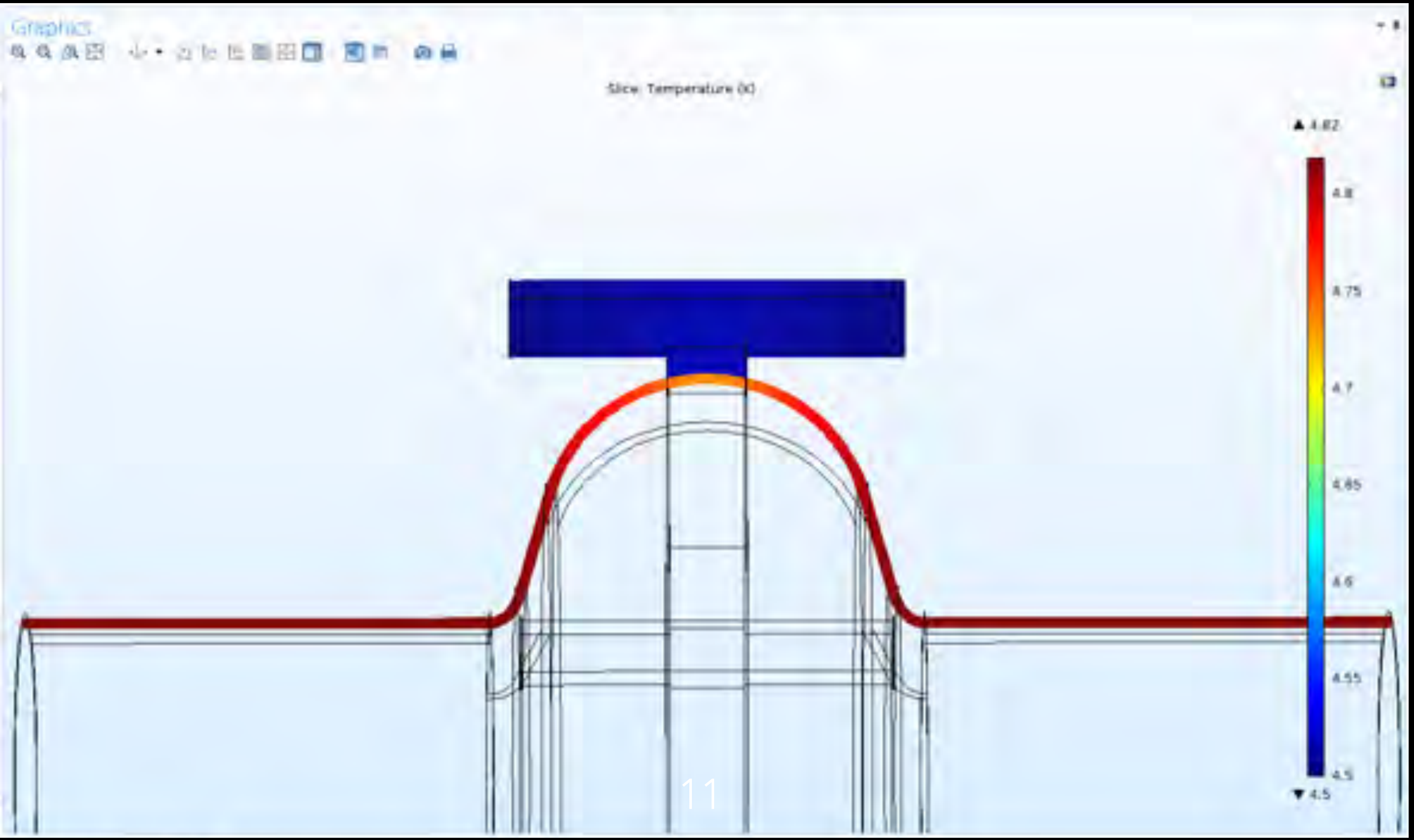
W/ contact resistance

W/O contact resistance



Temperature profile along the cavity

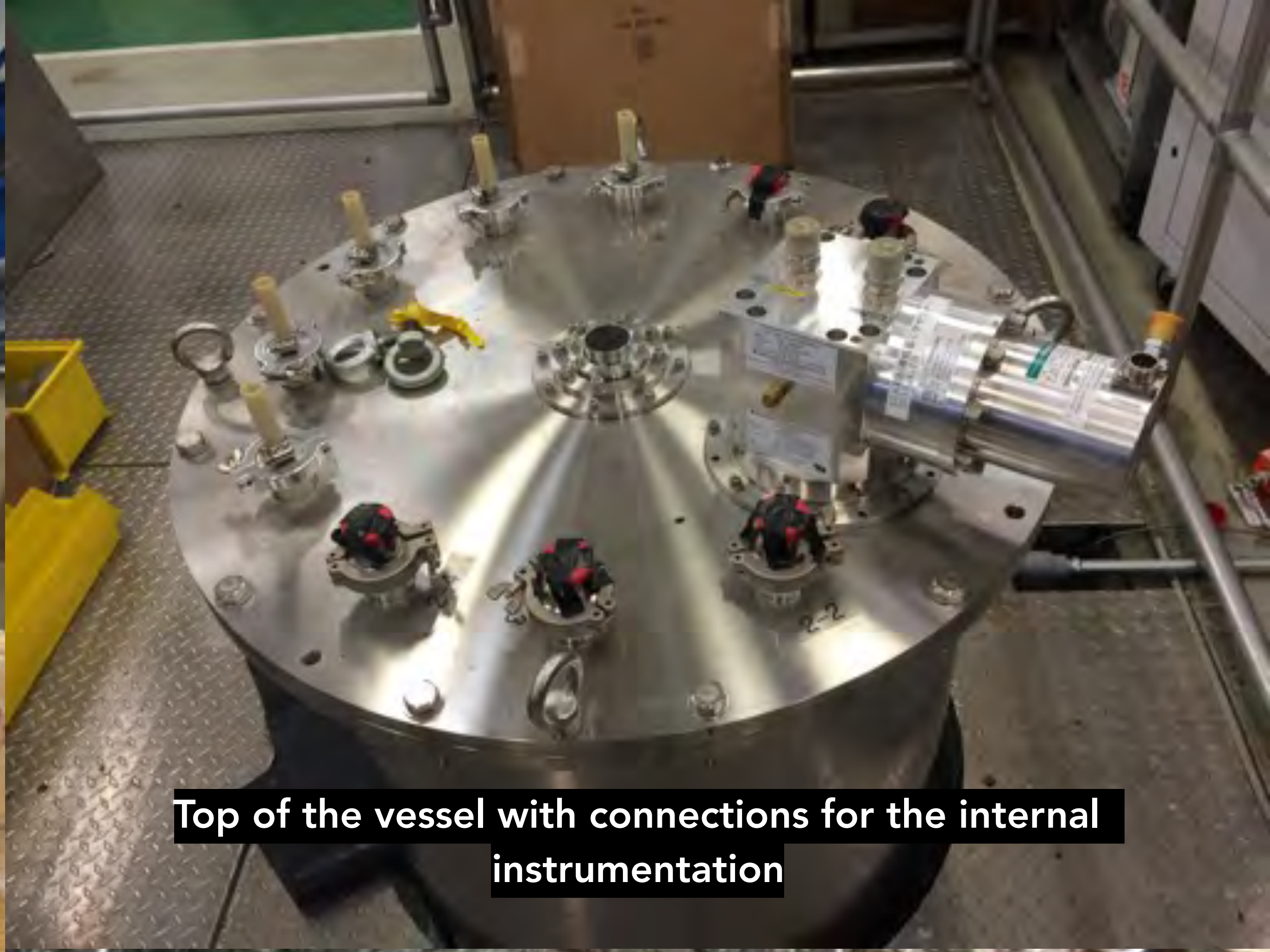
W/ contact resistance



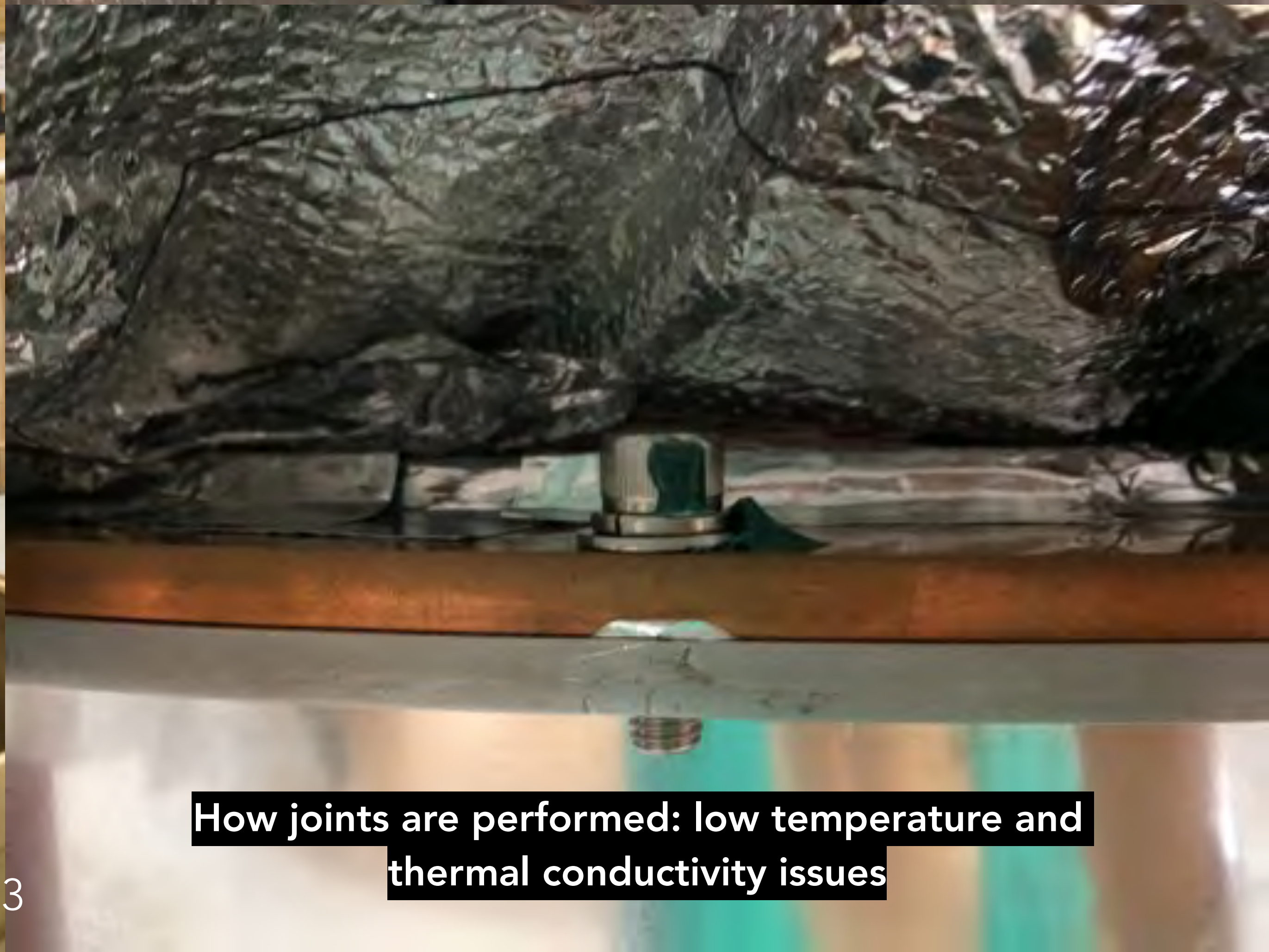
EXPERIMENT SET UP

- Cryocooler transferred from IB1 to IARC
- Some components missing: trying to retrieve them or purchasing them
- Some modifications needed
- Need to figure out how to connect thermally Nb and Al: contact resistance issue

Vacuum vessel and internal radiation shield



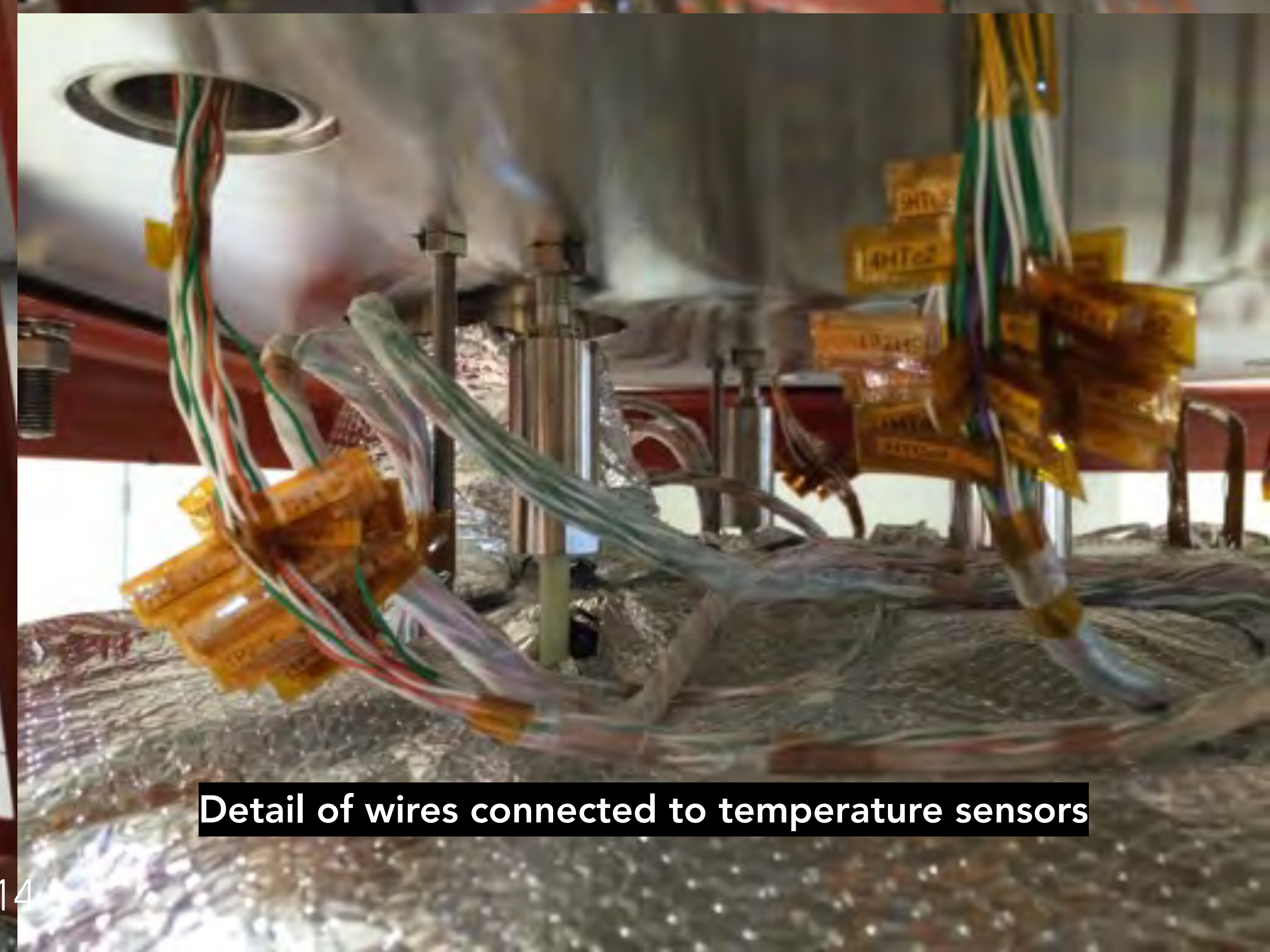
Top of the vessel with connections for the internal instrumentation



How joints are performed: low temperature and thermal conductivity issues


Internal instrumentation needed for the magnet


MLI insulator


Detail of wires connected to temperature sensors

TEST

- Not yet performed
- To be included in final presentation

- **1.3 GHz single cell Nb cavity + resistor**

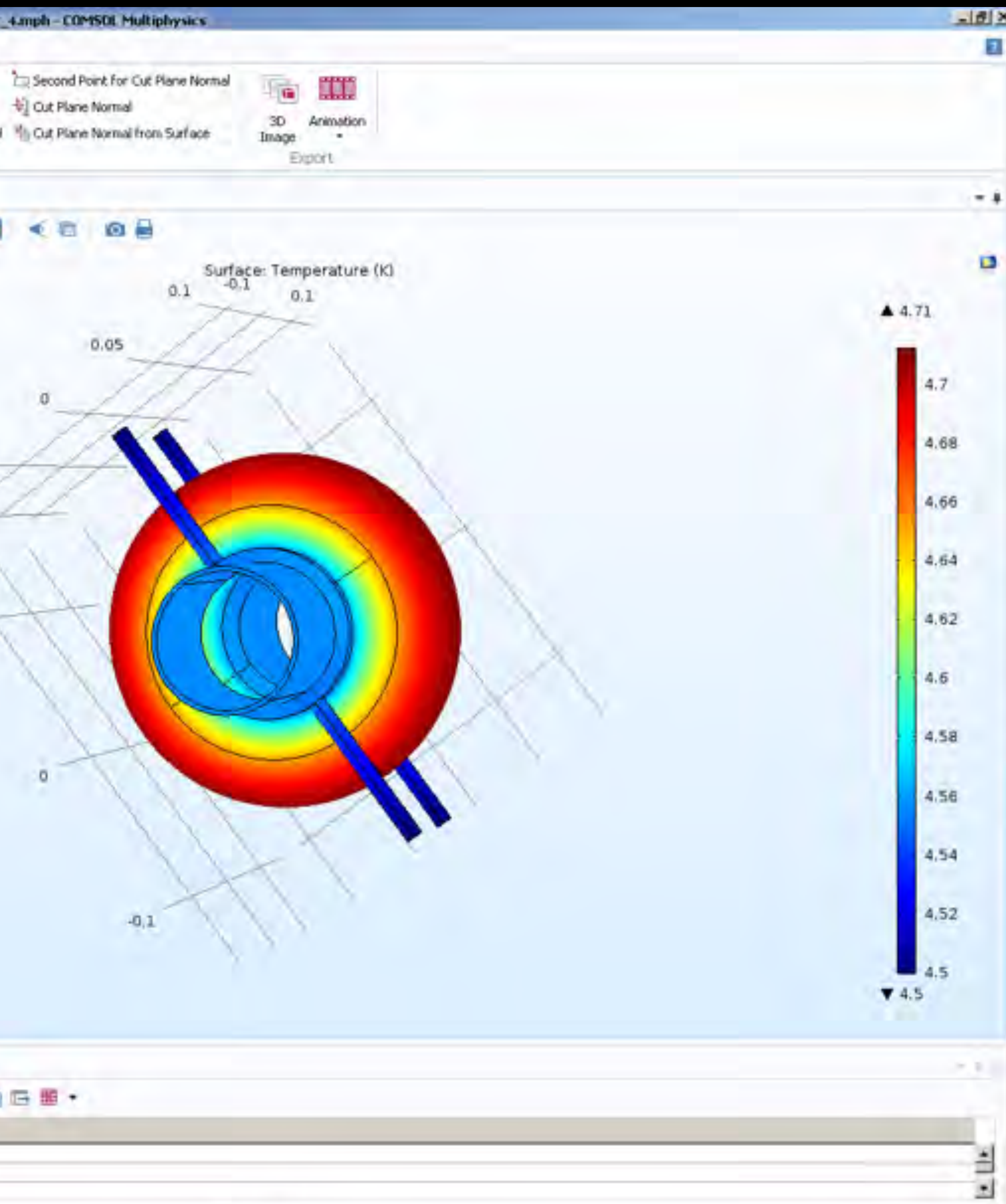
→

- **Nb sheet with a stud and an Al connection + resistor**

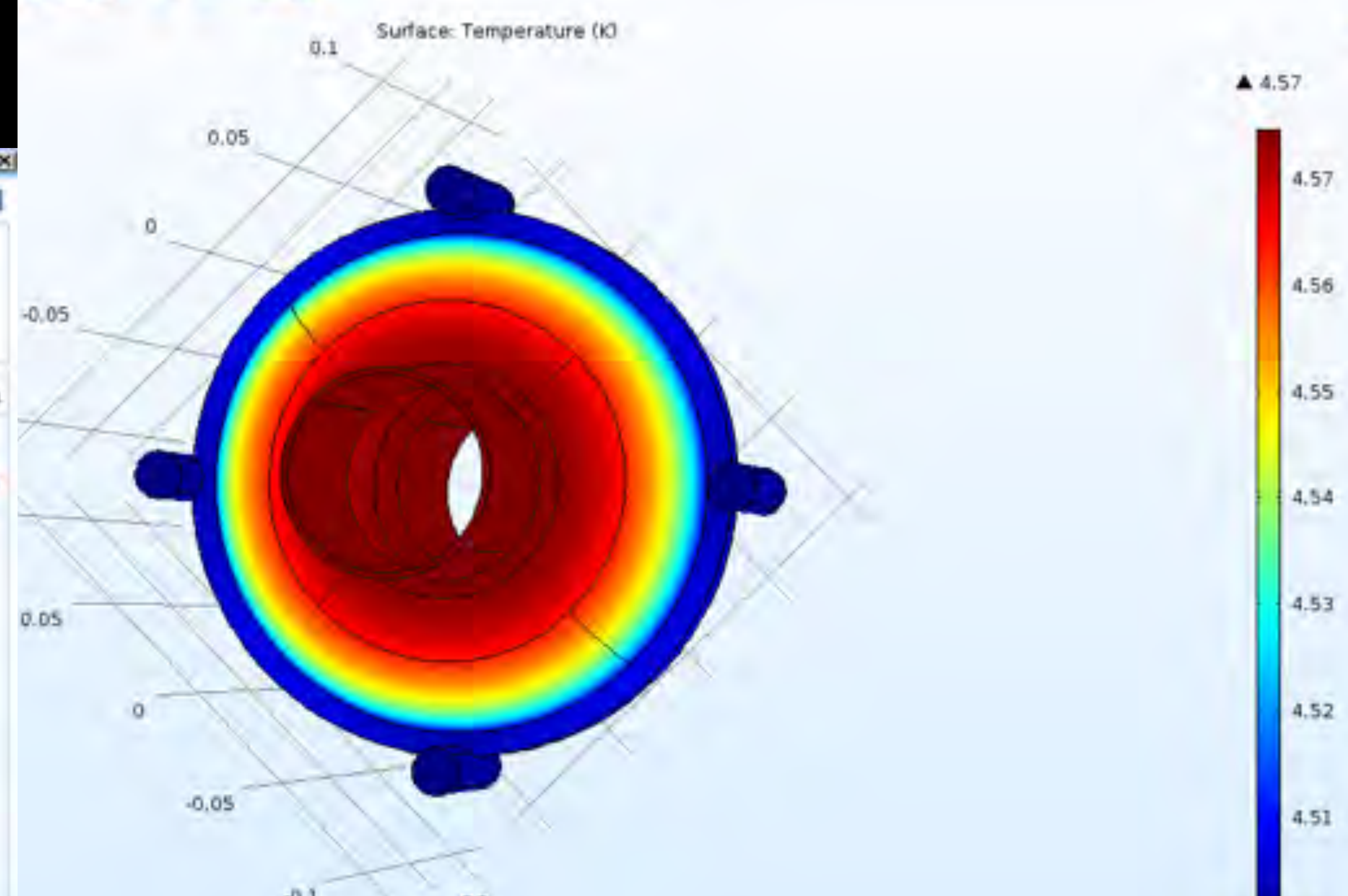
SECOND-TERM WORK

SIMULATIONS

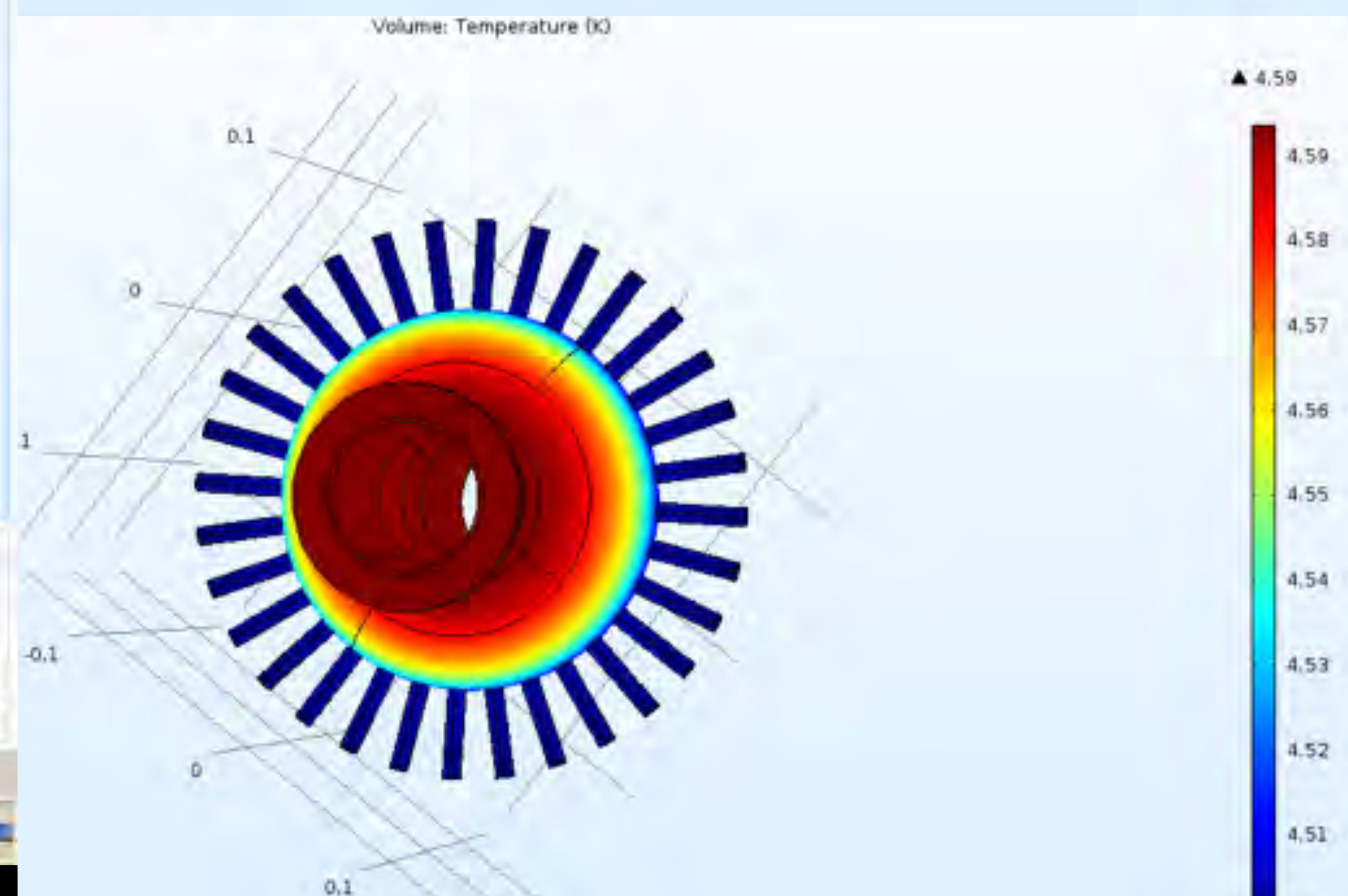
- Goal: figure out a good way to connect thermally Al and Nb.
- Difficulties: material properties, technological issues, feasibility in a large scale, costs
- Many simulations with different geometries



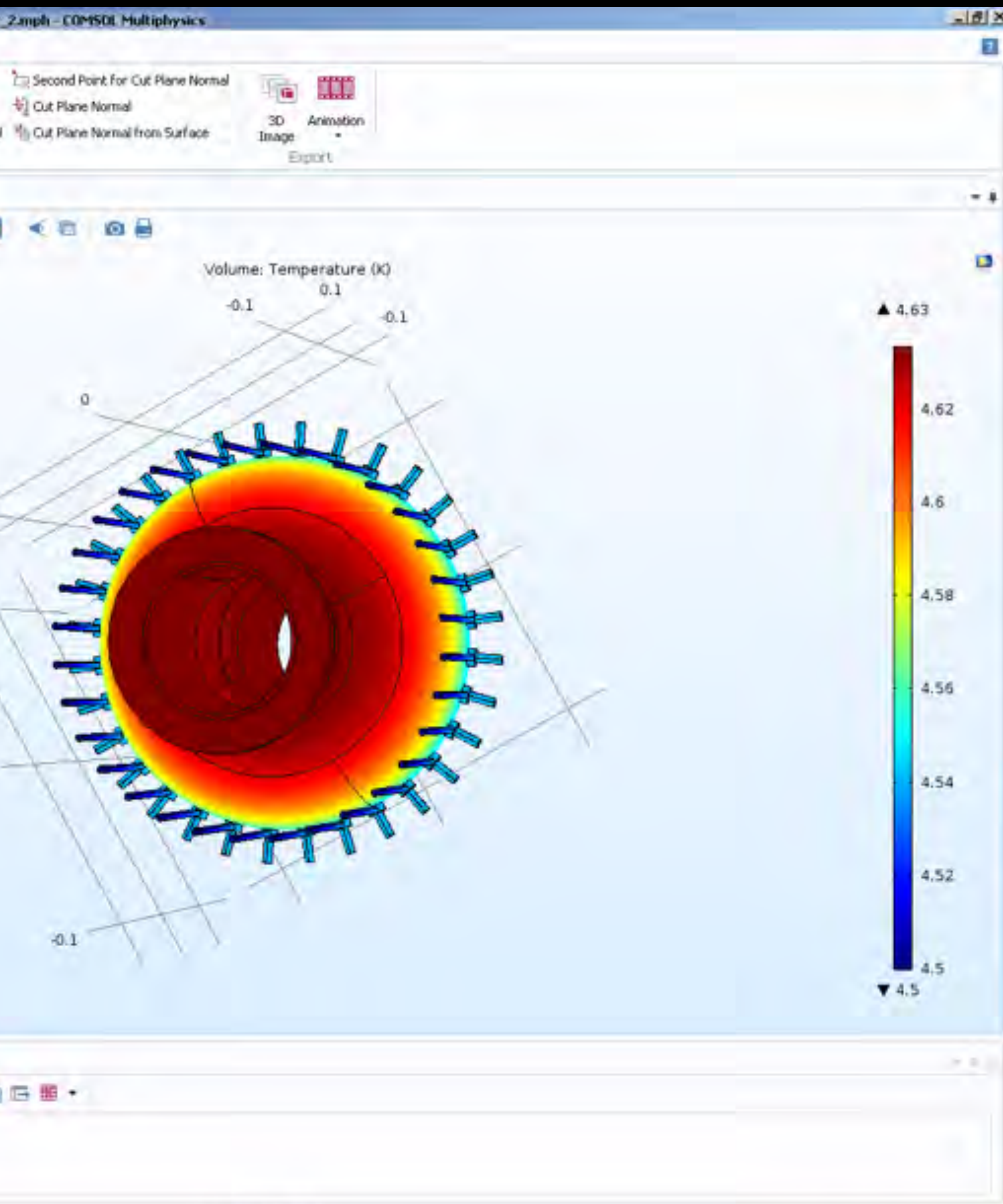
Ring around the connection between the cells



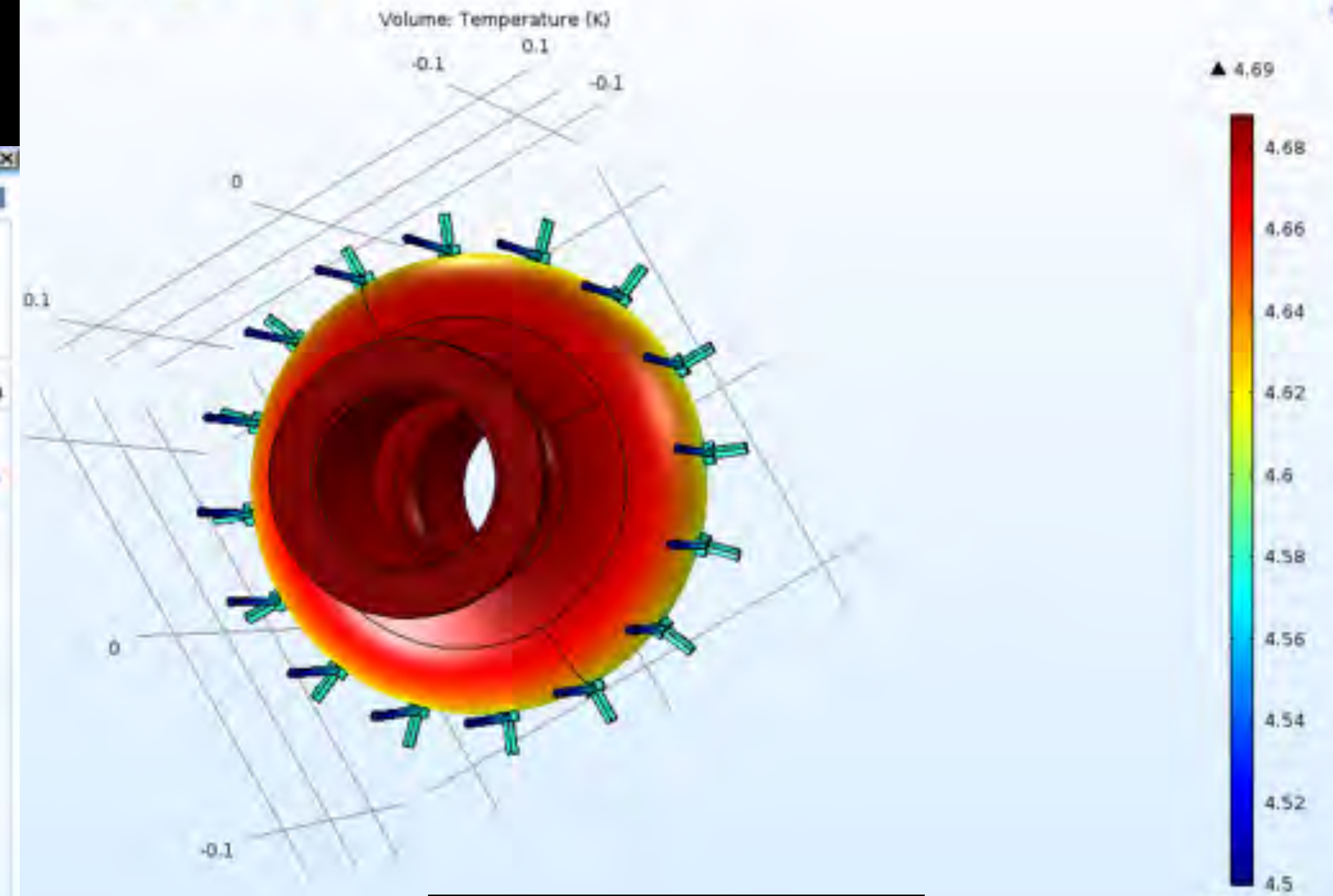
Ring around the equator of the cells



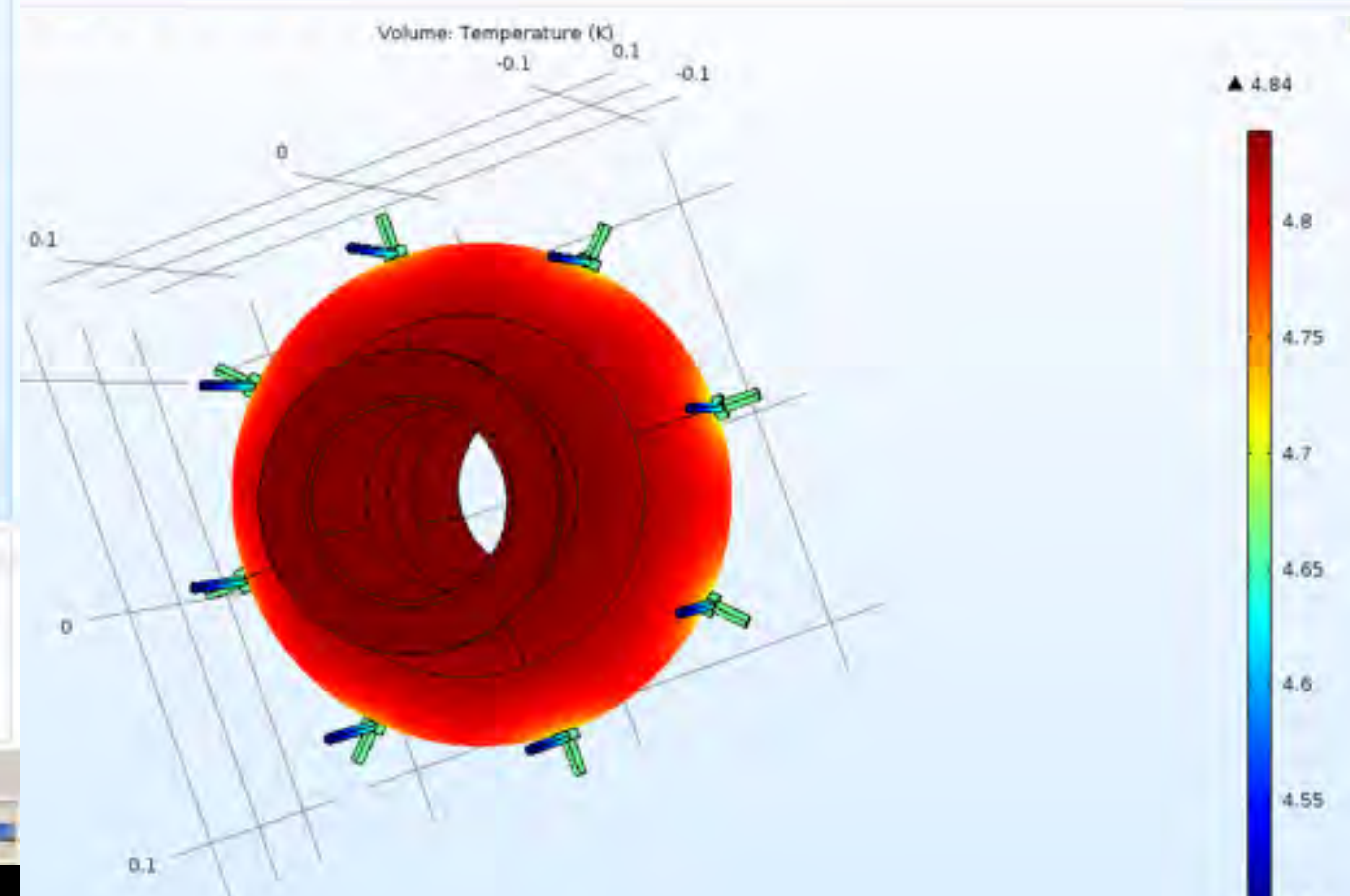
Stud-welding + radial rods



Stud-welding + strips (32)



Stud-welding + strips (16)



Stud-welding + strips (8)

EXPERIMENT SET UP

- Missing components retrieved and/or loaned
- Test of all the equipment performed
- Ready for the experiment

Vacuum vessel, temperature and heat instrumentation

Compressor and chiller

Vacuum station

Radiation shield closing

New MLI around the radiation shield

MLI and Indium washer

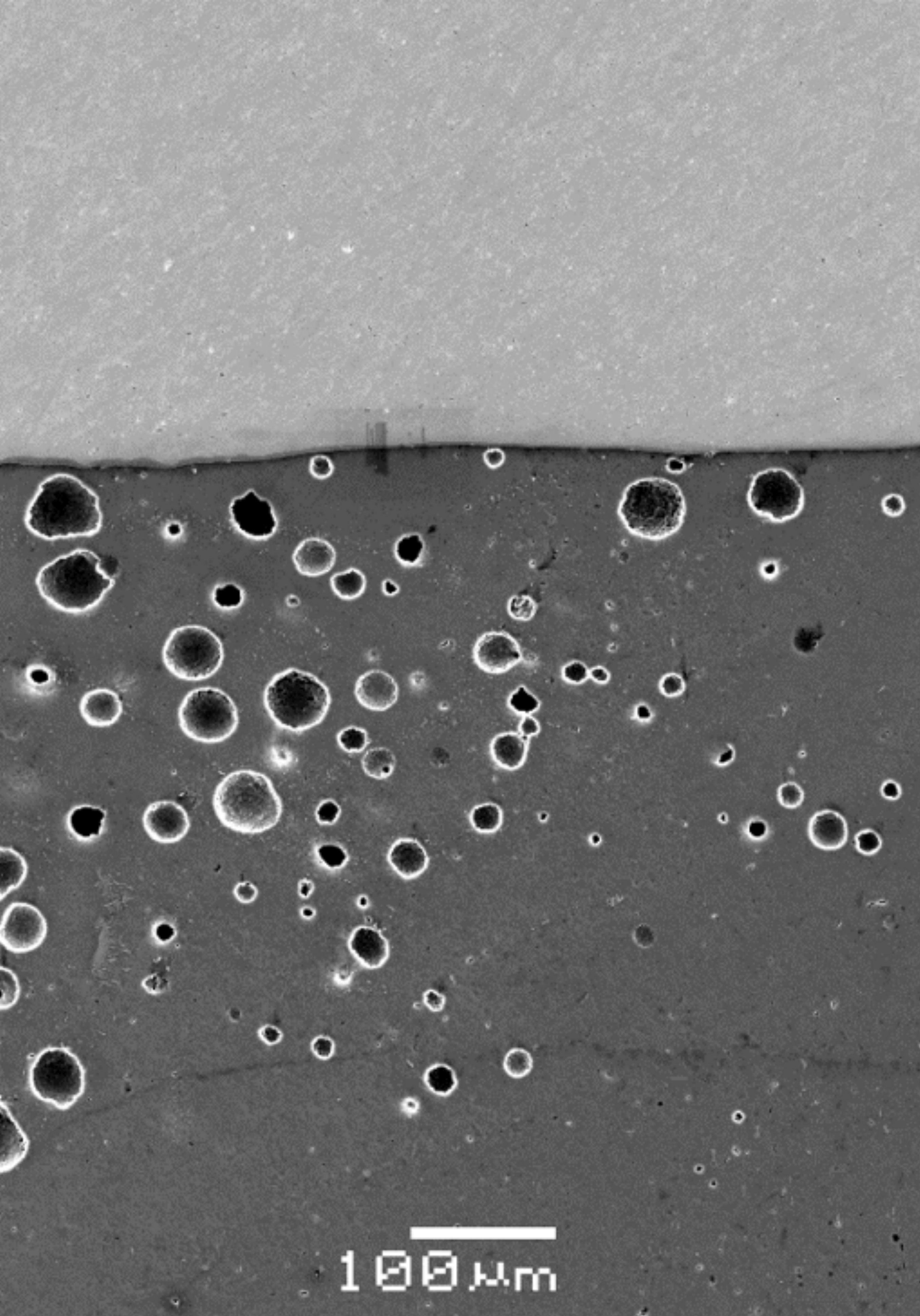
TEST

- Unfortunately, too few time in order to be able to perform the test on the cavity
- More knowledge about the Al-Nb connection needed
- One possibility: studs on the equator of the cavity
- Thermal conductivity test: information about thermal contact resistance and thermal conductivity

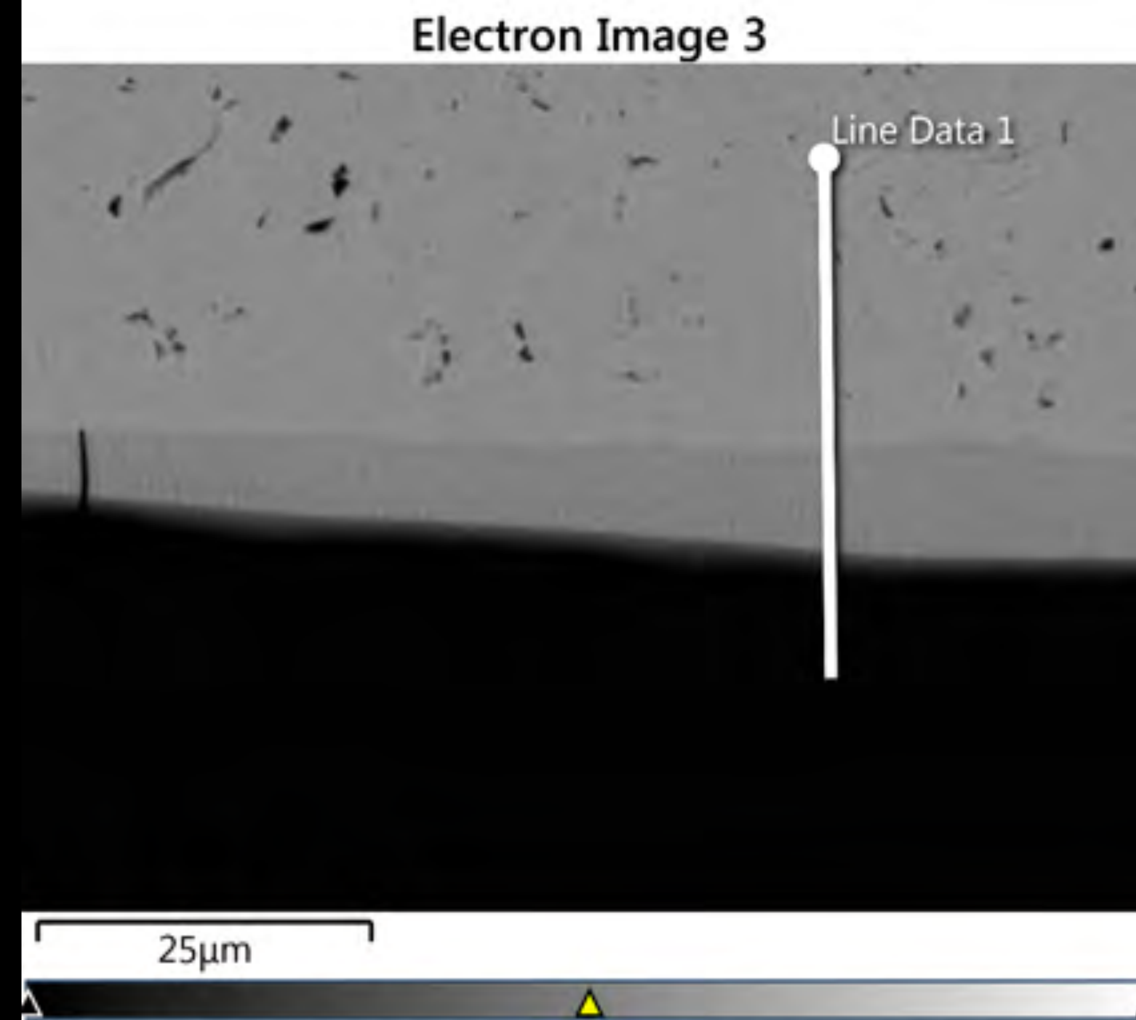
Internal setup

Niobium plate after stud-welding

Stud-welding



Voids in the Al

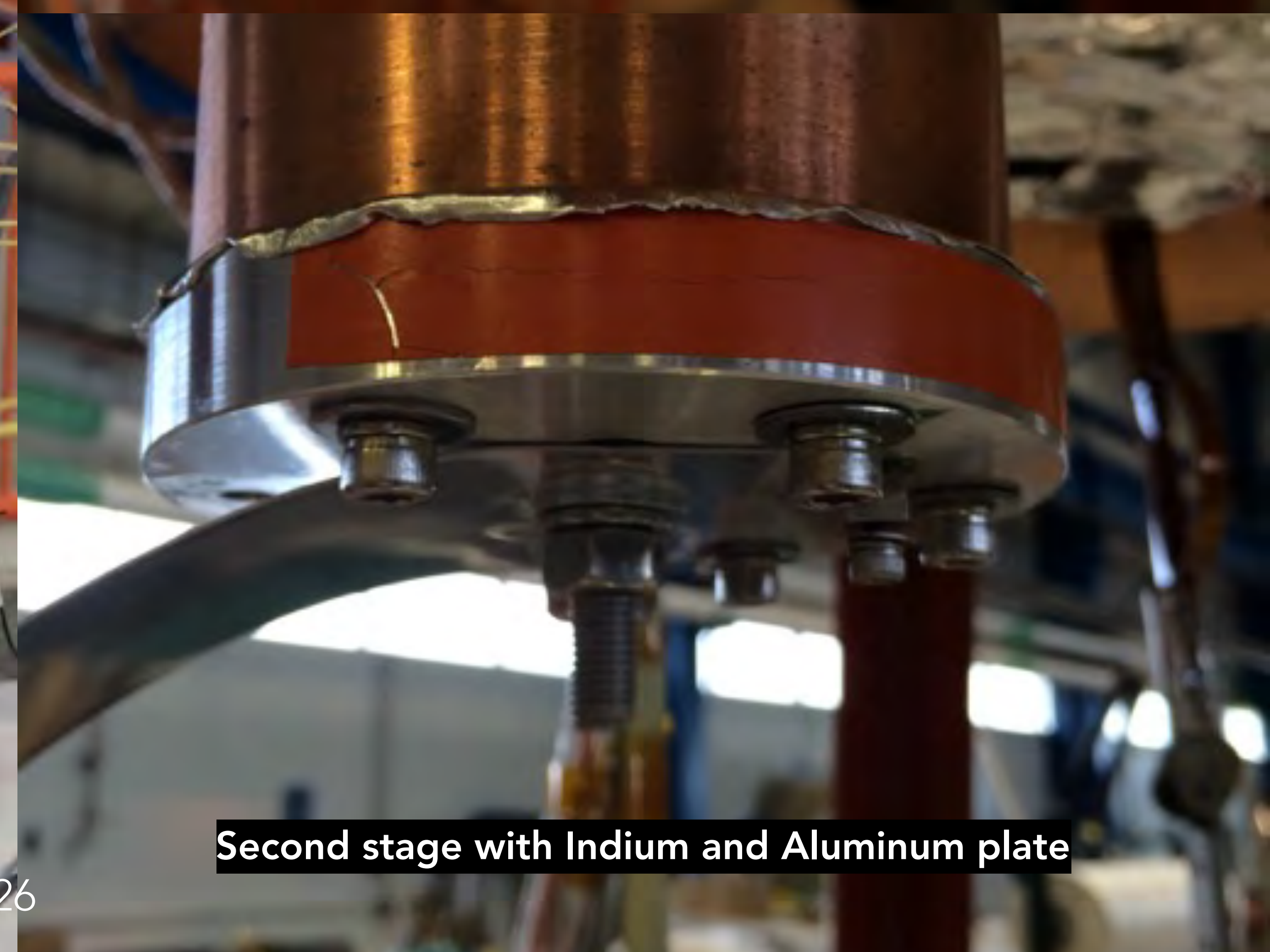


Nb-Al interface

% of Nb and Al along the line

Temperature sensors posing

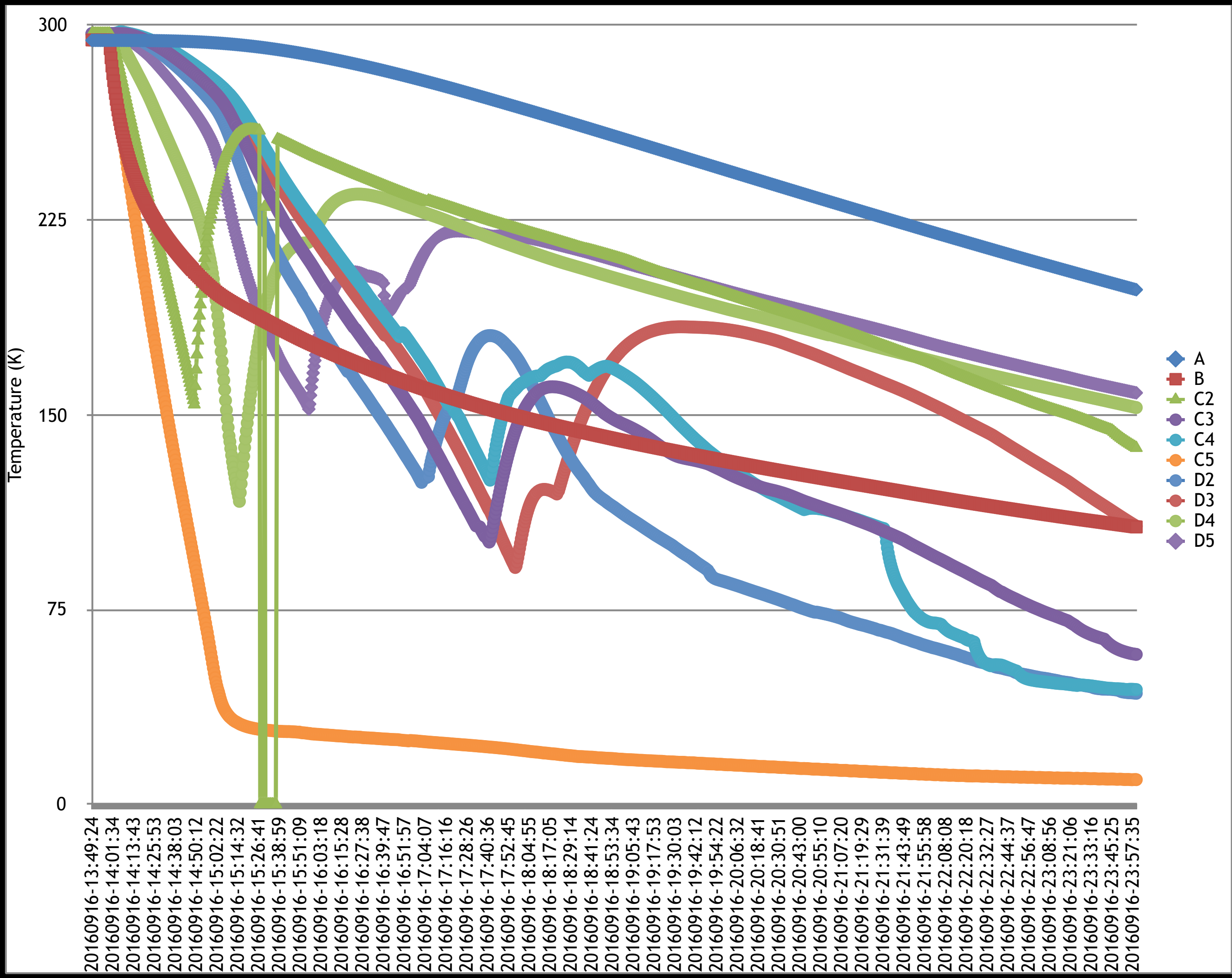
Niobium-Aluminum junction

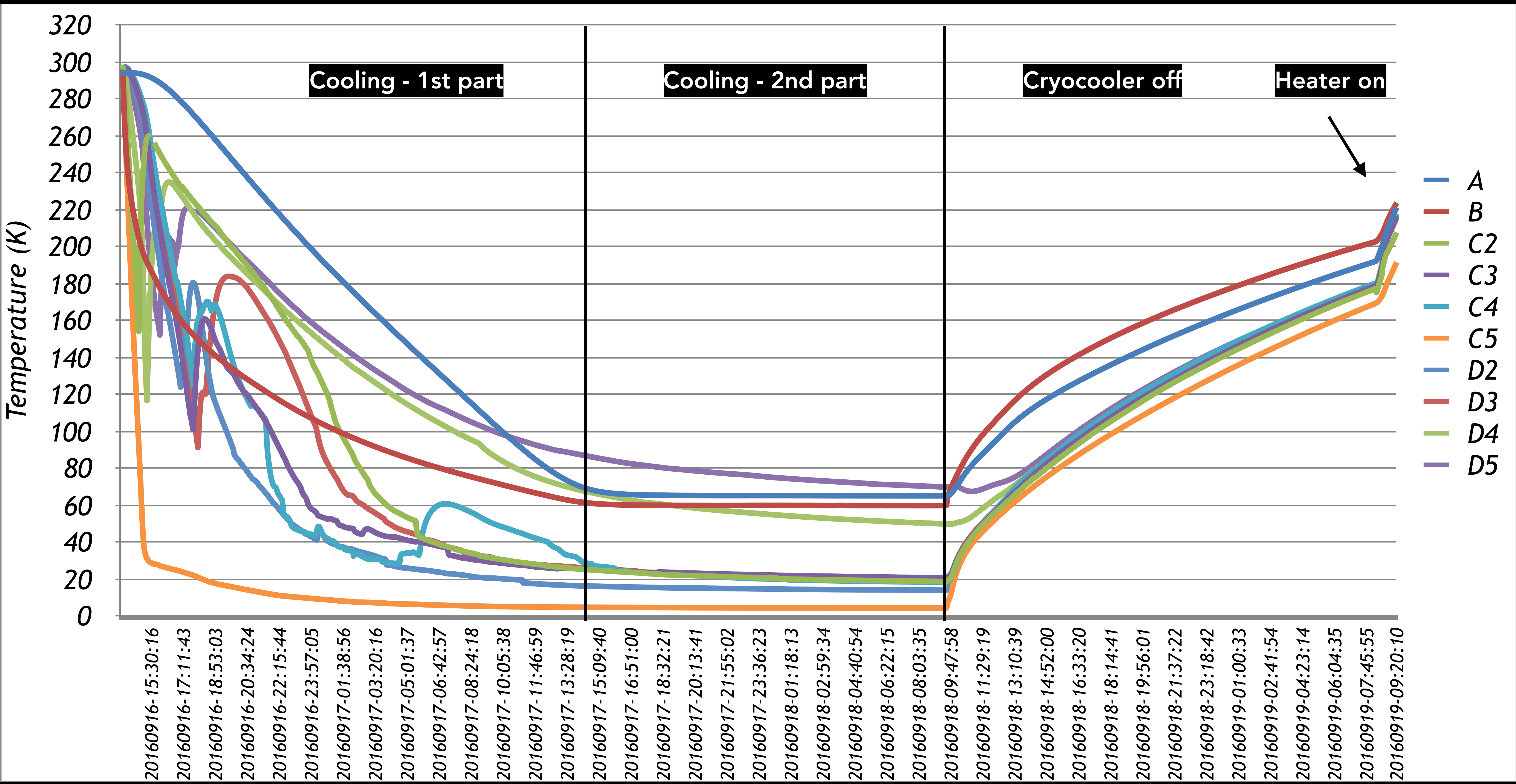


Second stage with Indium and Aluminum plate

1ST TEST

- 7/10 temperature sensors failed
- All the ones that failed shared the connection method
- The cause of the failure was identified as the detachment of the sensors from the surface of the material





Temperature vs time - 1st test

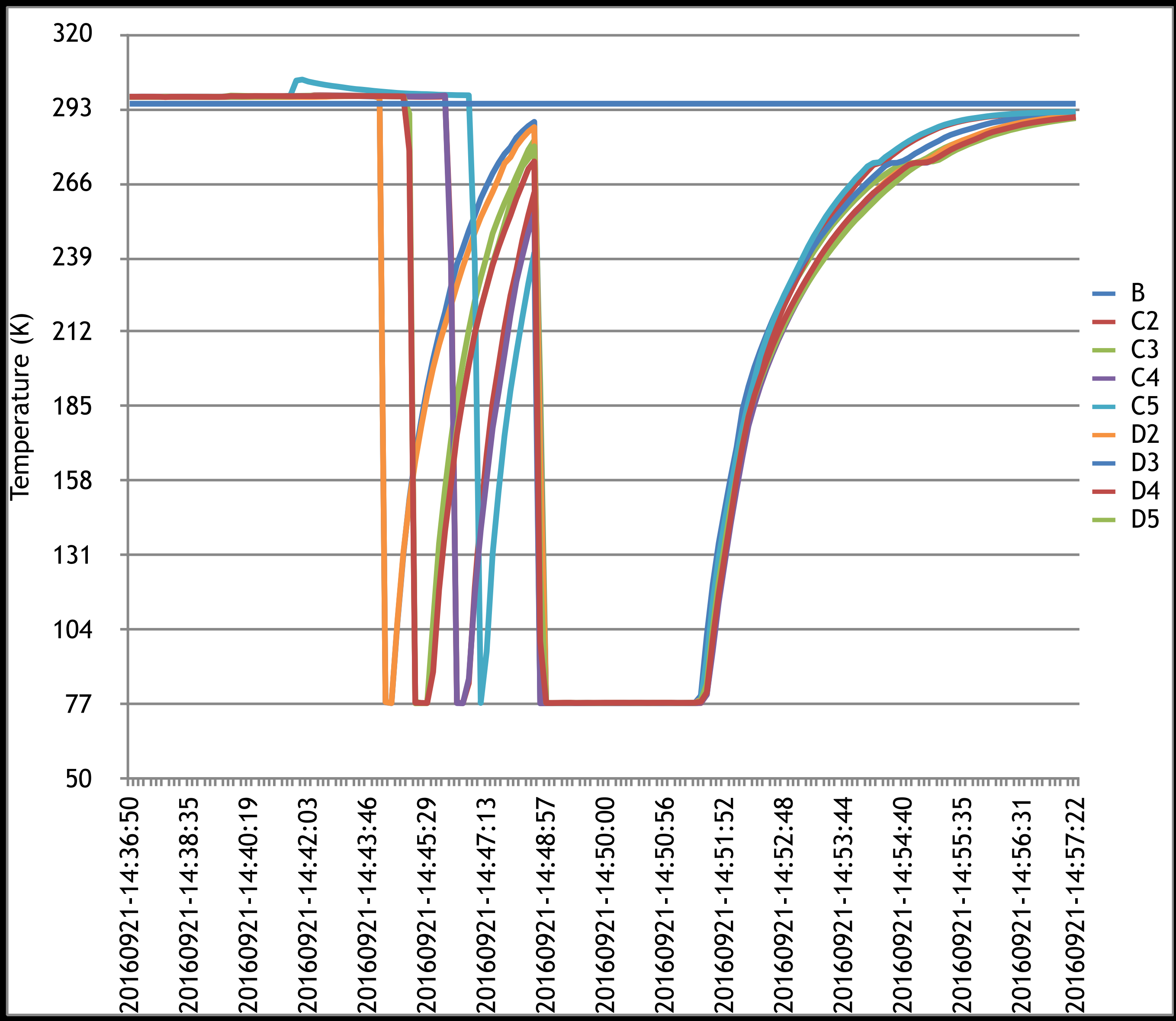
Before the cooling


After the cooling

Sensor visibly detached from the Niobium

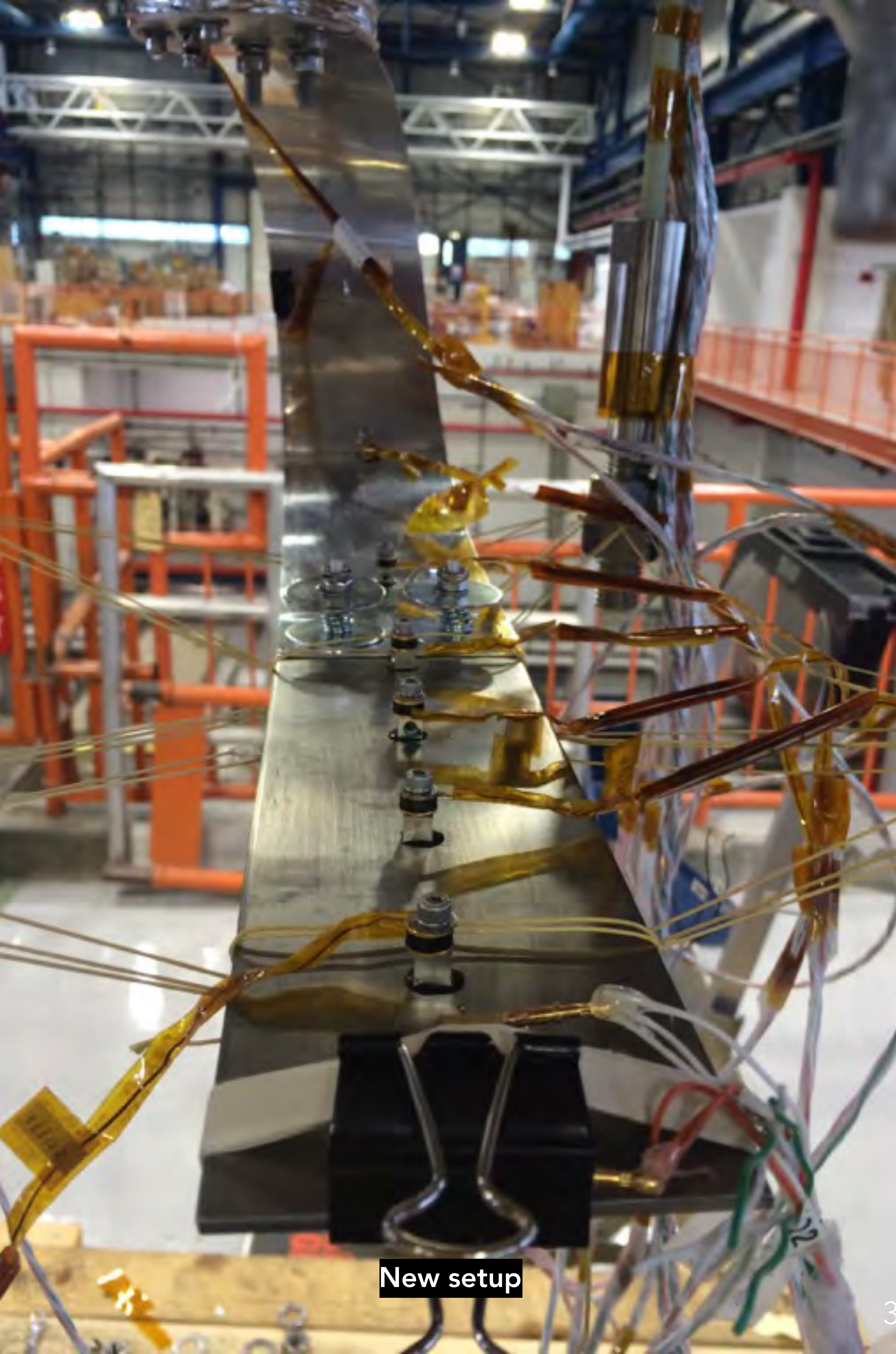
NITROGEN TEST

- The sensors were dipped inside liquid Nitrogen
- The curve looked smooth and all the sensors read 77K
- Discarded both a malfunctioning of the sensors, both a calibration issue

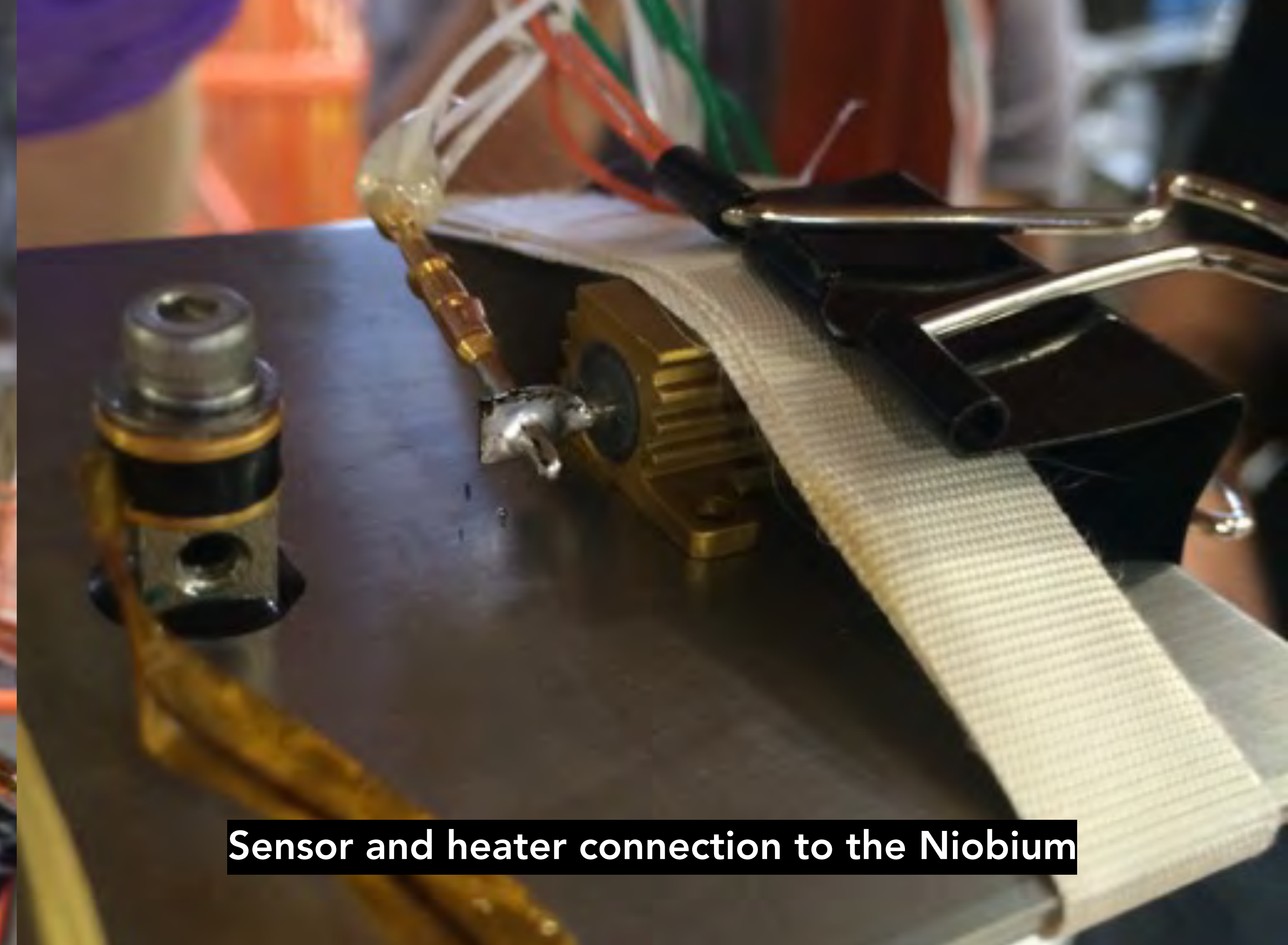


NEW TEST SETUP

- The only one Cernox RTD that did not fail was the one screwed
- All the sensors in the new configuration were attached like this one
- Hopefully, this will solve the problem



New setup

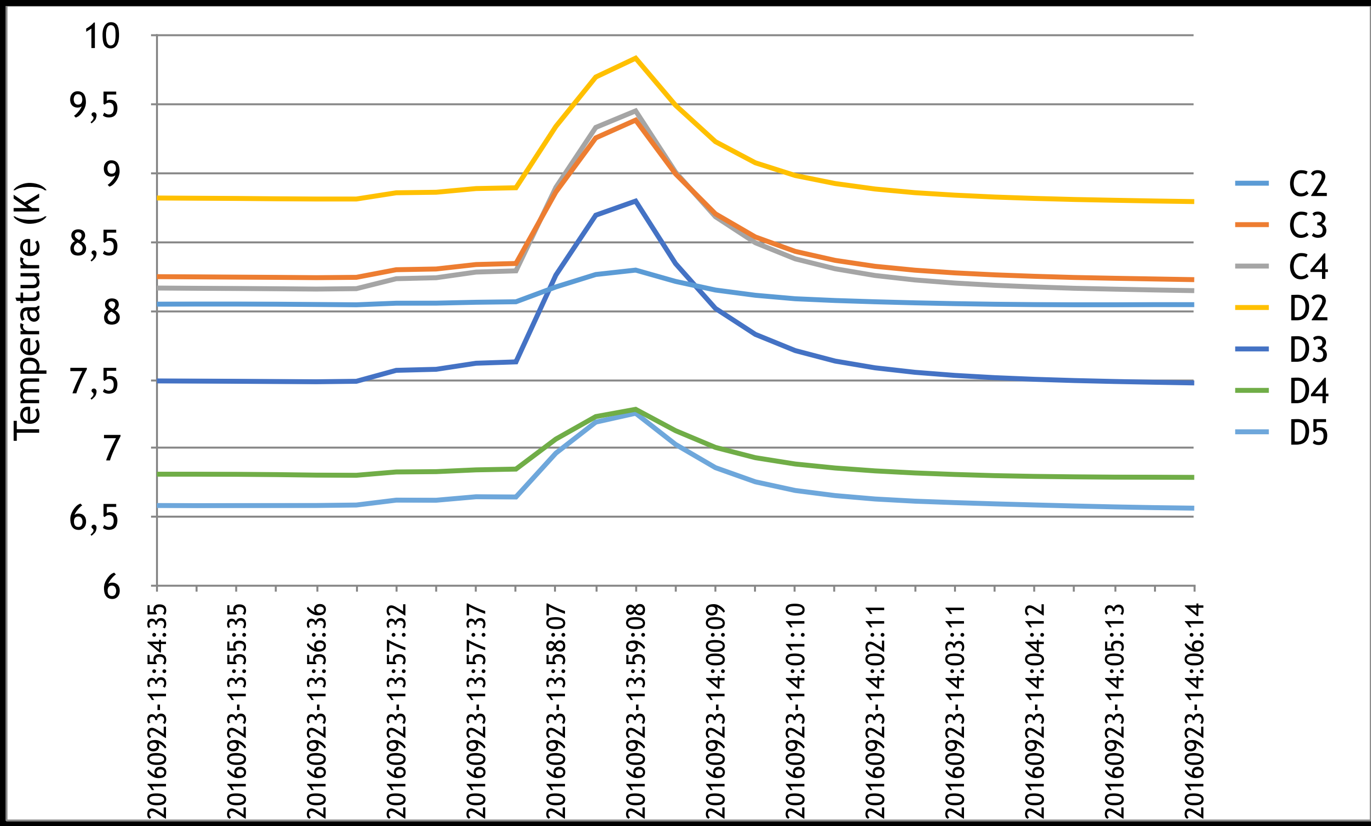


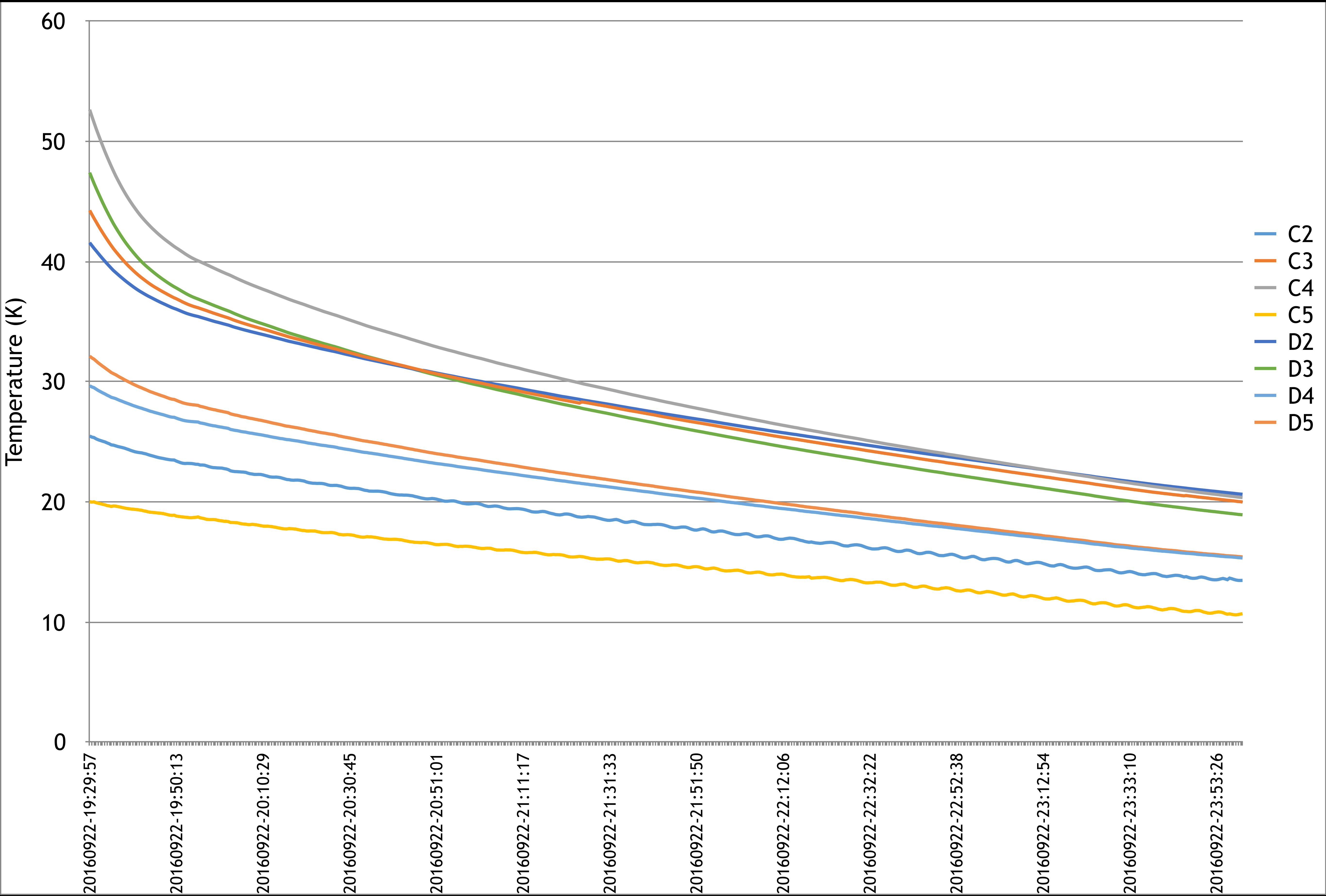
Sensor and heater connection to the Niobium

1st sensor on Aluminum clipped

2ND TEST

- The temperature goes down smoothly
- It seems that the sensors are not displaying the correct temperature
- The ones that should be hotter are cooler, but not in a meaningful order
- Heater pulse 0.3 W for 33″ = 10 J
- When heated, they respond with reasonable slopes and peak heights





Temperature vs time - 2nd test

WHAT I LEARNED

KNOWLEDGE ACQUIRED

- COMSOL
- Superconductivity
- SRF cavities
- Material science and technology
- Cryogenics
- Vacuum
- Sensors technology
- Hands-on work
- Safety
- Timing

THANK YOU FOR THE ATTENTION!