Los Alamos
NATIONAL LABORATORY

Development of Cryocooler Systems for NCRF and SRF Cavity and Component Tests at LANL

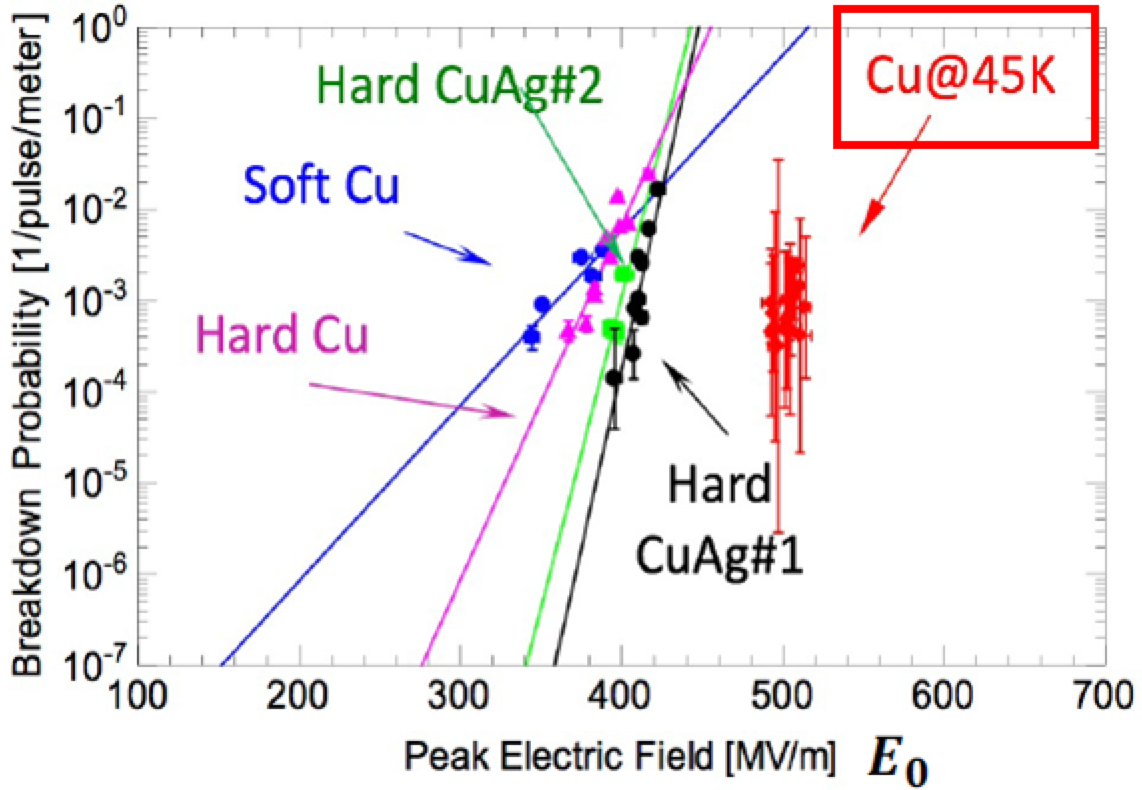
Tsuyoshi Tajima, Paolo Pizzol*, Eric Olivas, Evgenya Simakov, John Lewellen**
(*now at SNS, **now at SLAC)

TTC 2022 Meeting, Aomori, Japan, 11-14 October 2022

LA-UR-22-30566

Background

- We got an internal funding to develop this system in FY2021. It was a 1-year project.
- The main purpose was to develop a capability to cool down NCRF C-Band (5.7 GHz) copper cavities to enhance achievable gradient without using cryogen.
- A secondary purpose was to develop a capability to test SRF cavities without using liquid helium.



A. D. Cahill, et al., *Phys. Rev. Accel. Beams* 21, 102002 (2018)

Background (Cont.)

- We found an existing chamber that can house a cryocooler we purchased, so we did not need to design the outer chamber.
- We designed and built inside parts such as a box with thermal radiation shield.
- We were able to cool down a c-band cavity and a 1.3-GHz single-cell cavity down to <5 K.
- This talk will cover the following
  - Some details of the cooling system with a cryocooler
  - Some cavity RF test results
  - A heating loss test and simulation results using a 1.3-GHz Nb cavity

We have purchased 3 cold heads and 2 compressors so far. They are all Sumitomo. We wanted to buy the ones from CryoMech, but the lead time was too long.

SPECIFICATIONS

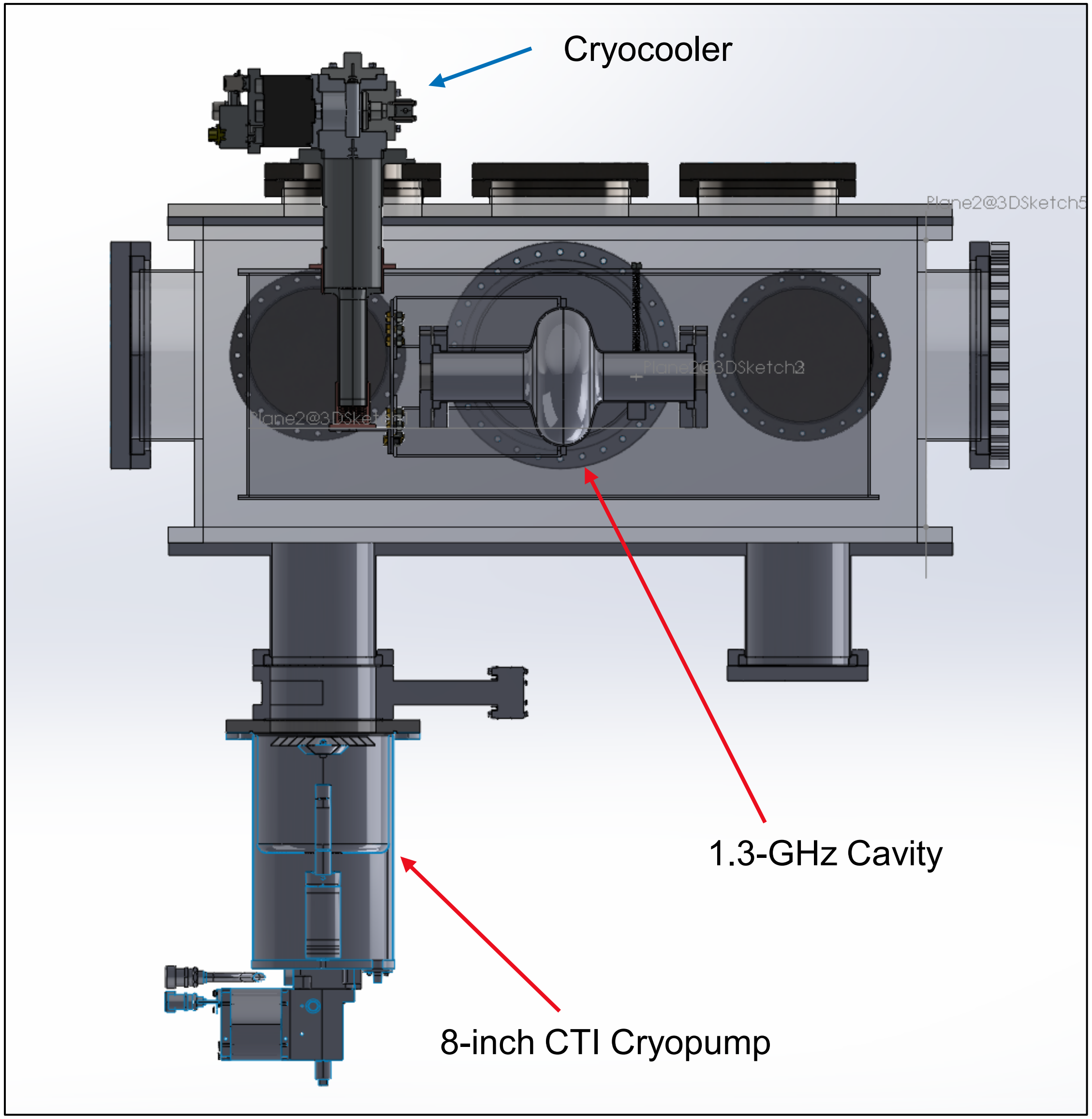
Purchased in SEP2022 (RDK-408D2)

Purchased one in SEP2020 and another one in SEP2022 (RDK-415D)

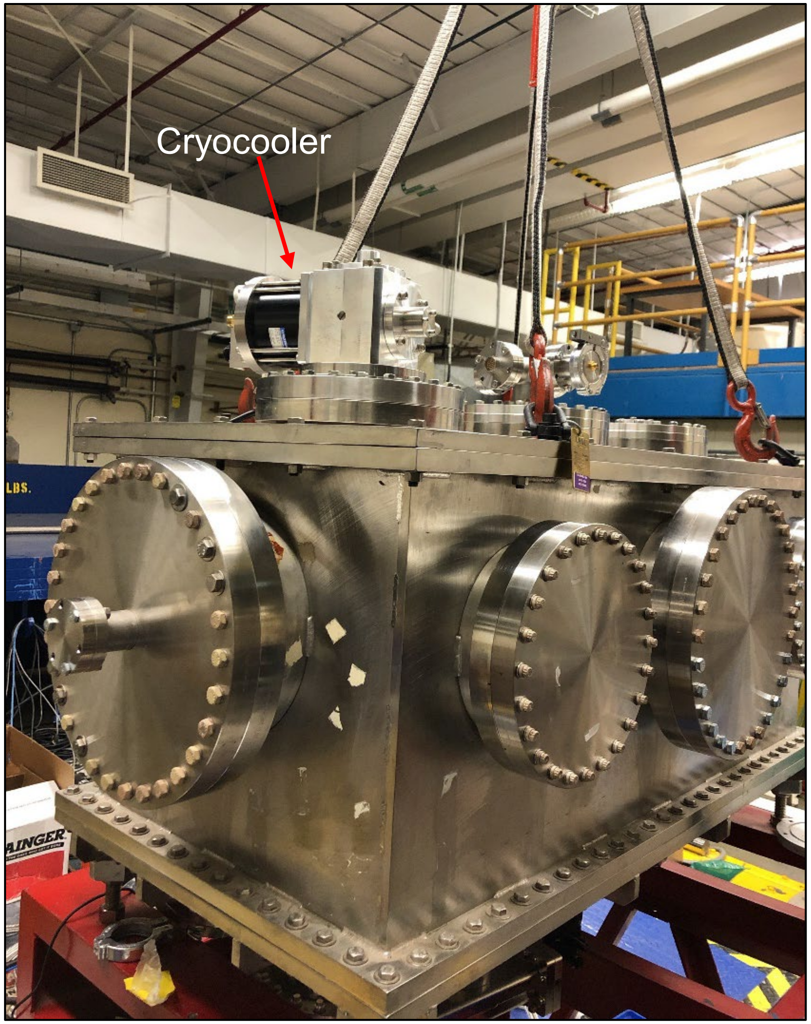
Cold Head Model		RDK-101D	RDK-305D	RDK-205D	RDK-408D2	RDE-412D4	RDK-415D
1st Stage Capacity	50 Hz	3.0 W @ 60 K	15 W @ 40 K	3.0 W @ 50 K	40 W @ 43 K	53 W @ 43 K	35 W @ 50 K
	60 Hz	5.0 W @ 60 K	20 W @ 40 K	4.0 W @ 50 K	50 W @ 43 K	60 W @ 43 K	45 W @ 50 K
2nd Stage Capacity	50 Hz	0.1 W @ 4.2 K[1]	0.4 W @ 4.2 K	0.5 W @ 4.2 K	1.0 W @ 4.2 K	1.25 W @ 4.2 K	1.5 W @ 4.2 K
	60 Hz	0.1 W @ 4.2 K[1]	0.4 W @ 4.2 K	0.5 W @ 4.2 K	1.0 W @ 4.2 K	1.25 W @ 4.2 K	1.5 W @ 4.2 K
Minimum Temperature[2]		<3.0 K	<3.5 K	<3.5 K	<3.5 K	<3.5 K	<3.5 K
Cooldown Time[2]	50 Hz	<150	<120	<90	<60	<60	<60
	60 Hz	<150	<120	<90	<60	<60	<60
Weight		7.2 kg (15.9 lbs.)[3]	16.0 kg (35.3 lbs.)	14.0 kg (30.9 lbs.)	18.0 kg (39.7 lbs.)	20.0 kg (44.1 lbs.)	18.5 kg (40.8 lbs.)

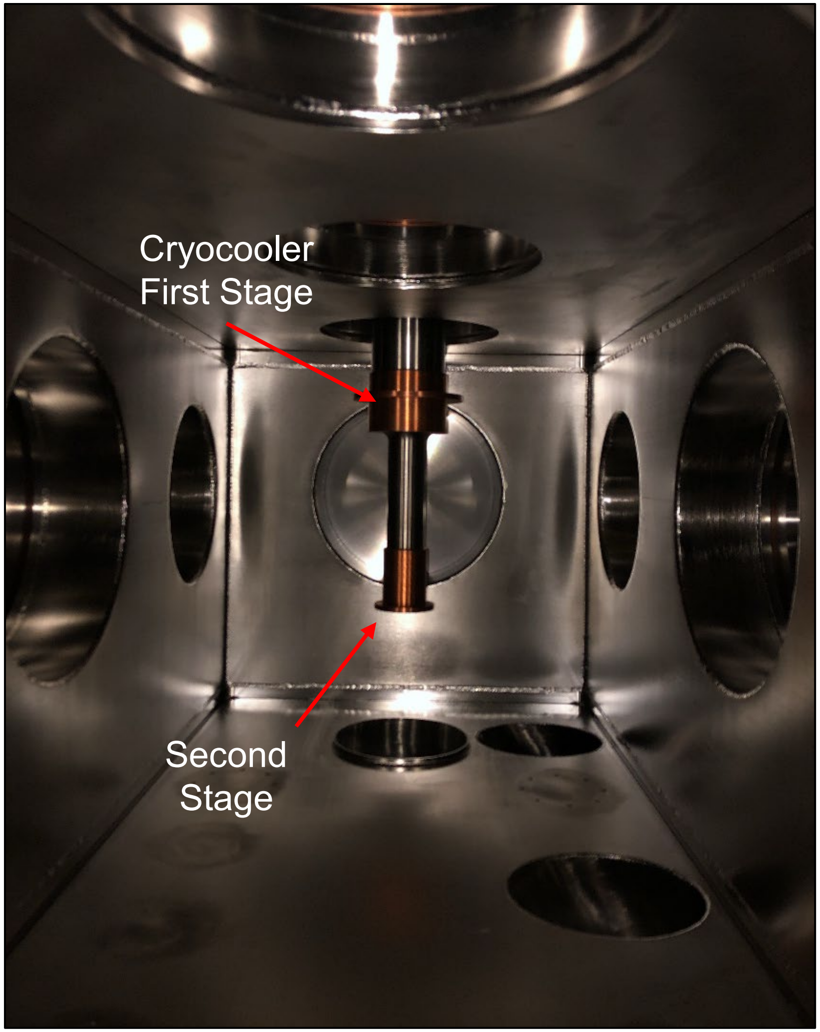
[Sumitomo catalog at http://www.shicryogenics.com/products/4k-cryocoolers/]

Front view (model) of the assembly

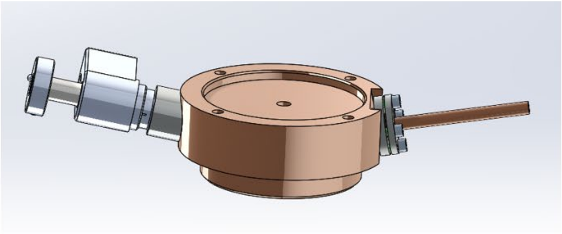


Sumitomo RDK-415D cryocooler





Cavities tested

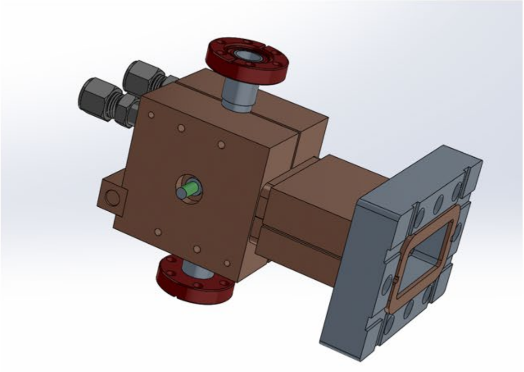


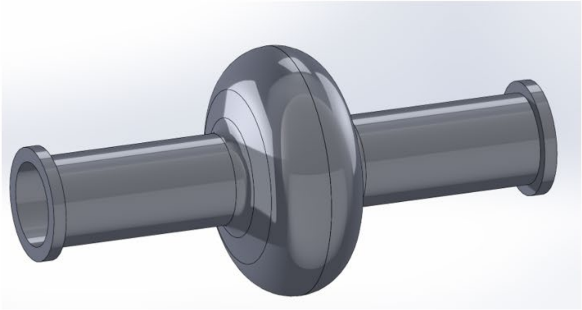
5.1 GHz copper NCRF

cavity provided by LANL.

5.7-GHz C-band copper NCRF

cavity provided by SLAC.



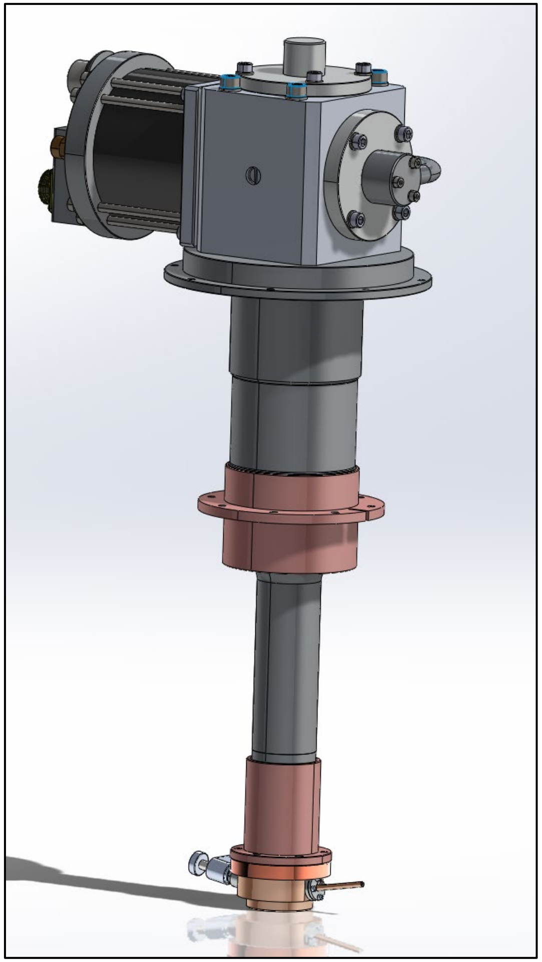


1.3 GHz Nb SRF cavity

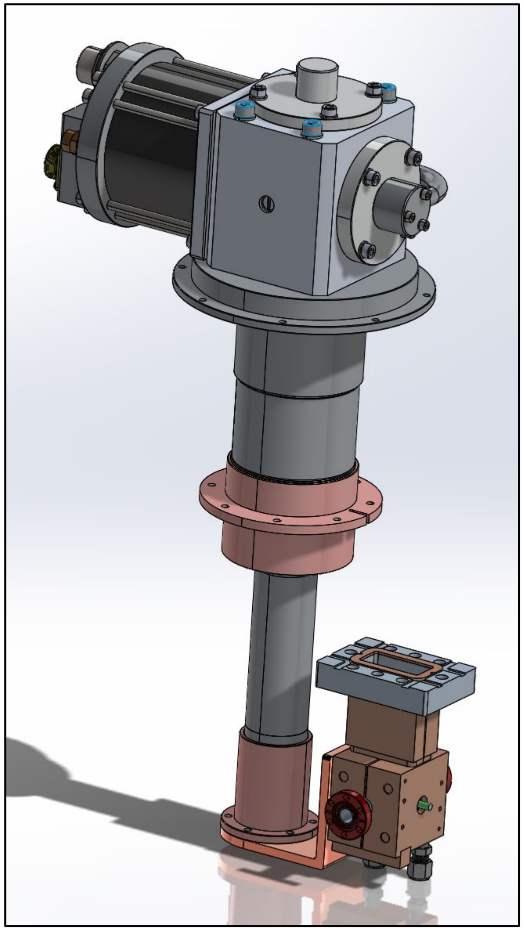
provided by LANL.

Models for the cavities mounted

5.1 GHz Copper Cavity



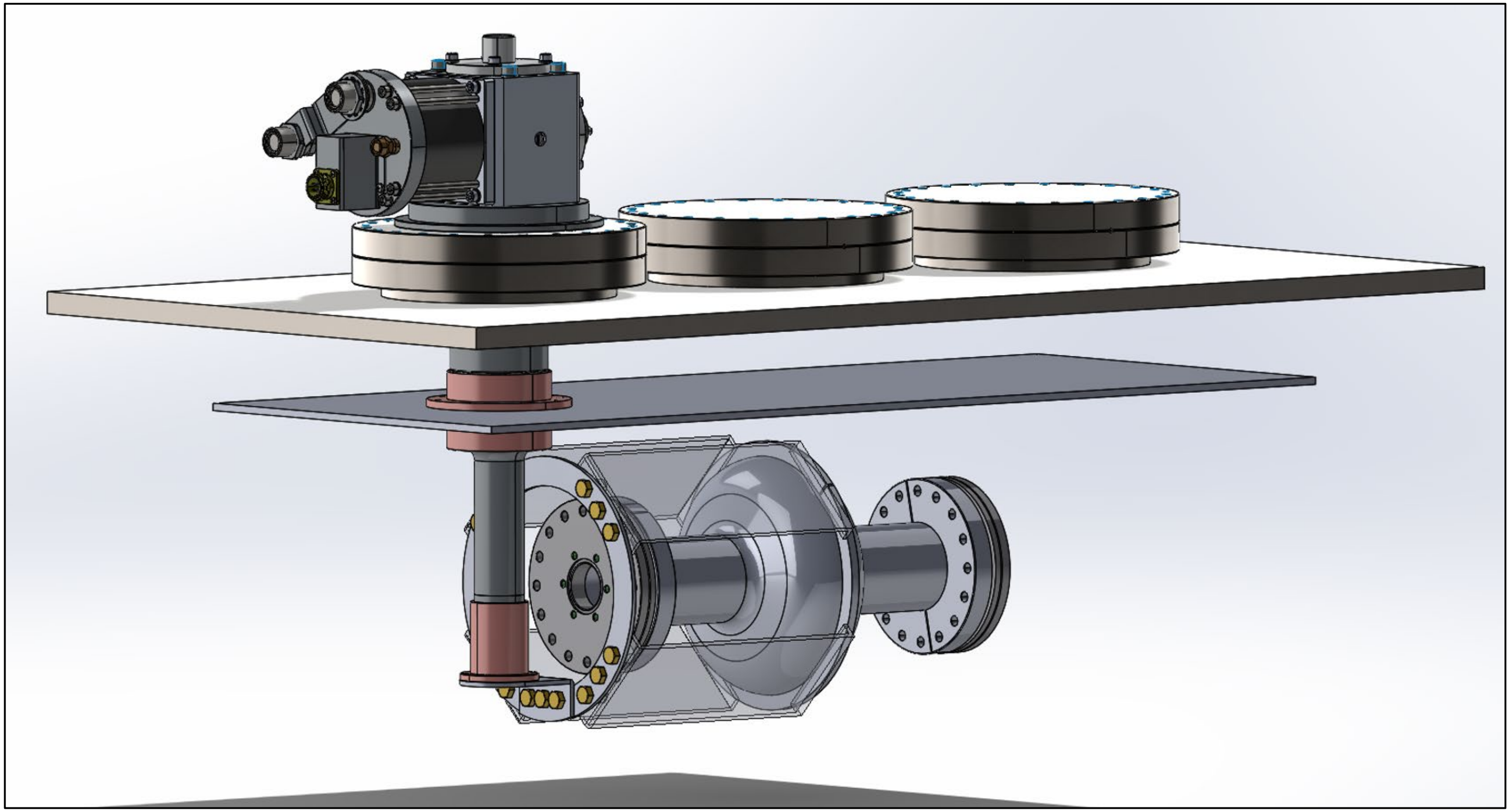
5.7 GHz Copper Cavity



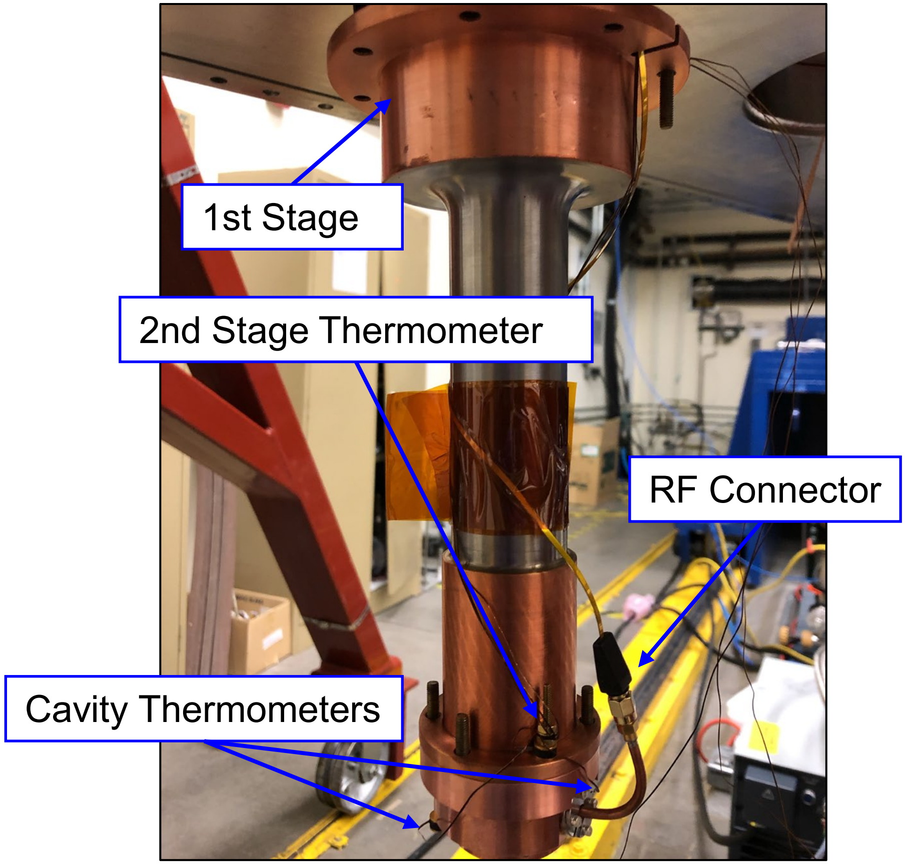
Los Alamos
NATIONAL LABORATORY

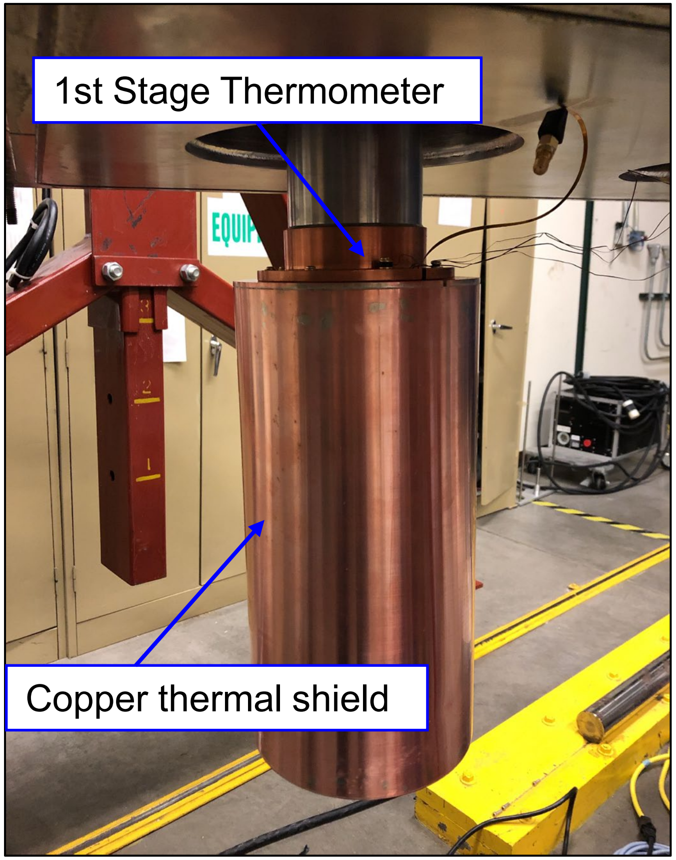
A 3-D model of the 1.3-GHz Nb cavity attached to the cryocooler

1.3 GHz Nb cavity

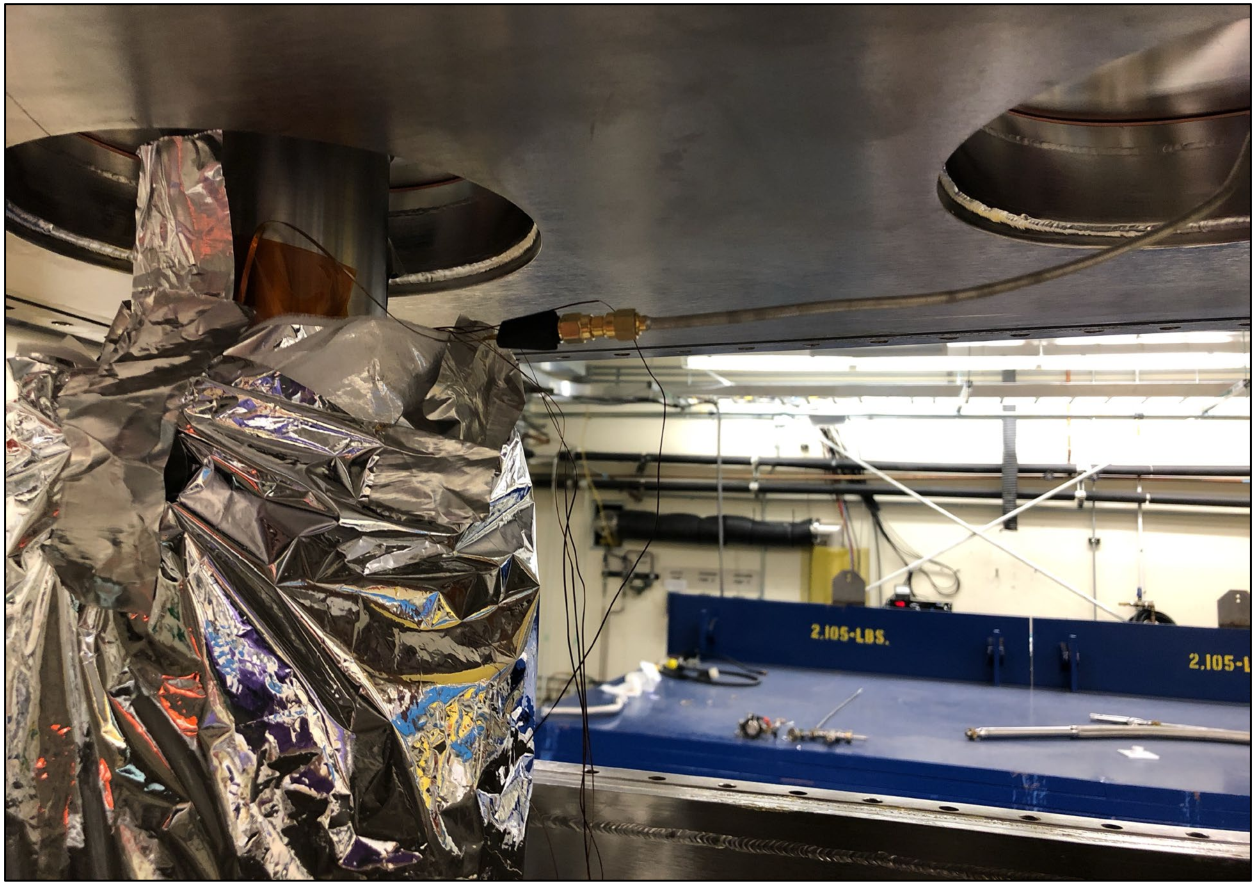


Photos of 5.1-GHz cavity mounted on the cryocooler

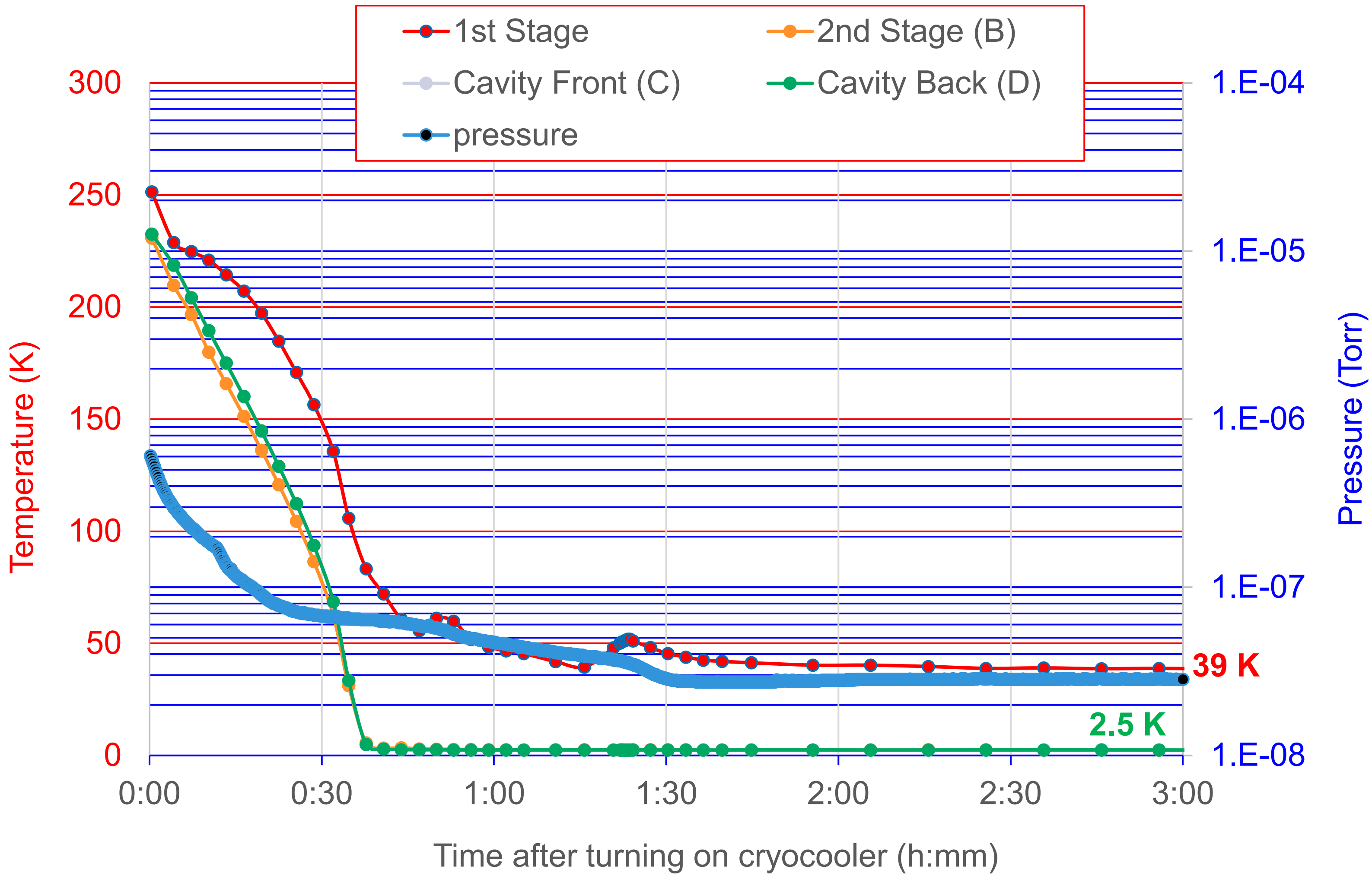




Thermal shield covered with multi-layer-insulation sheets (superinsulation)

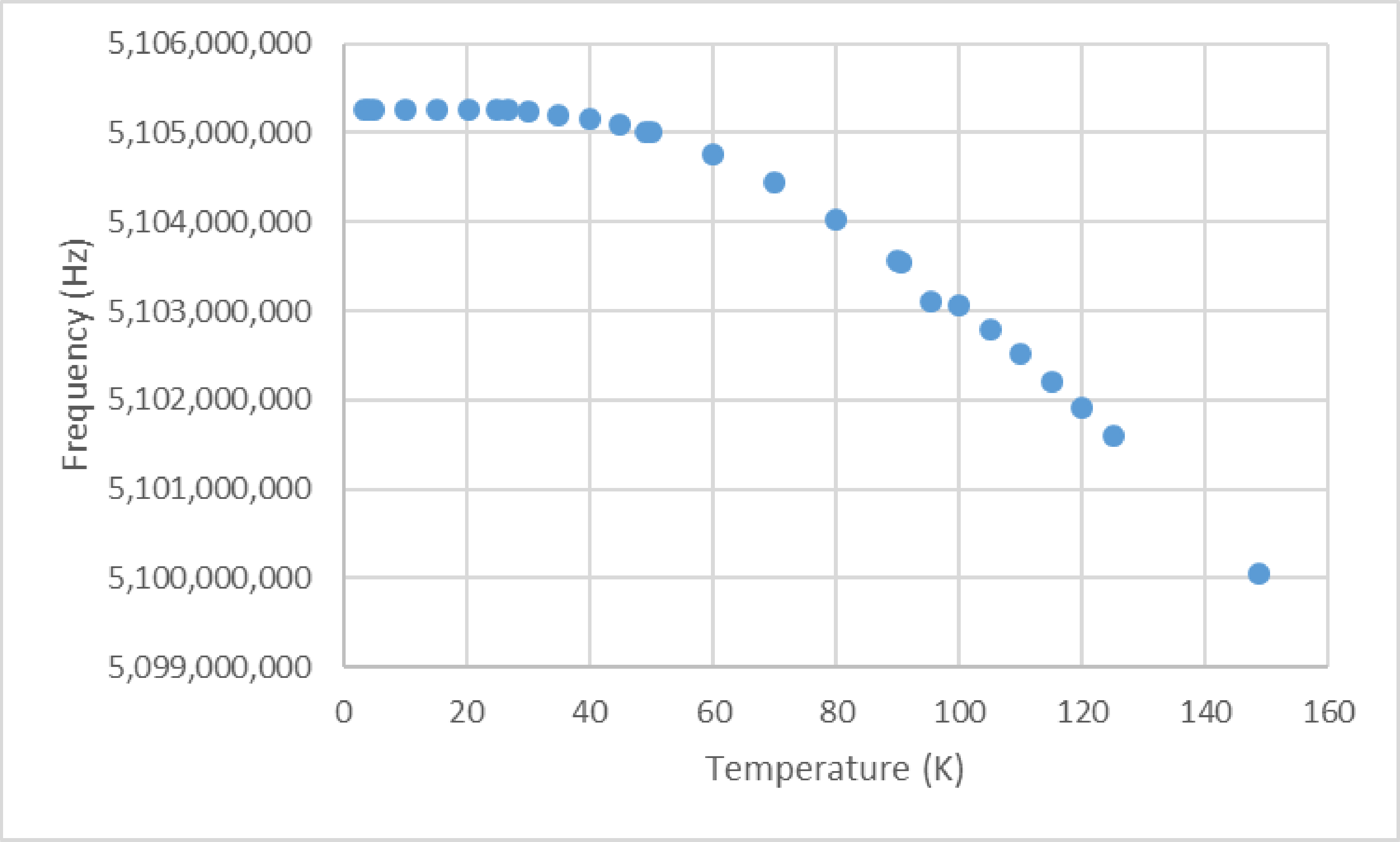


5.1-GHz copper cavity cooldown temperature and pressure evolution

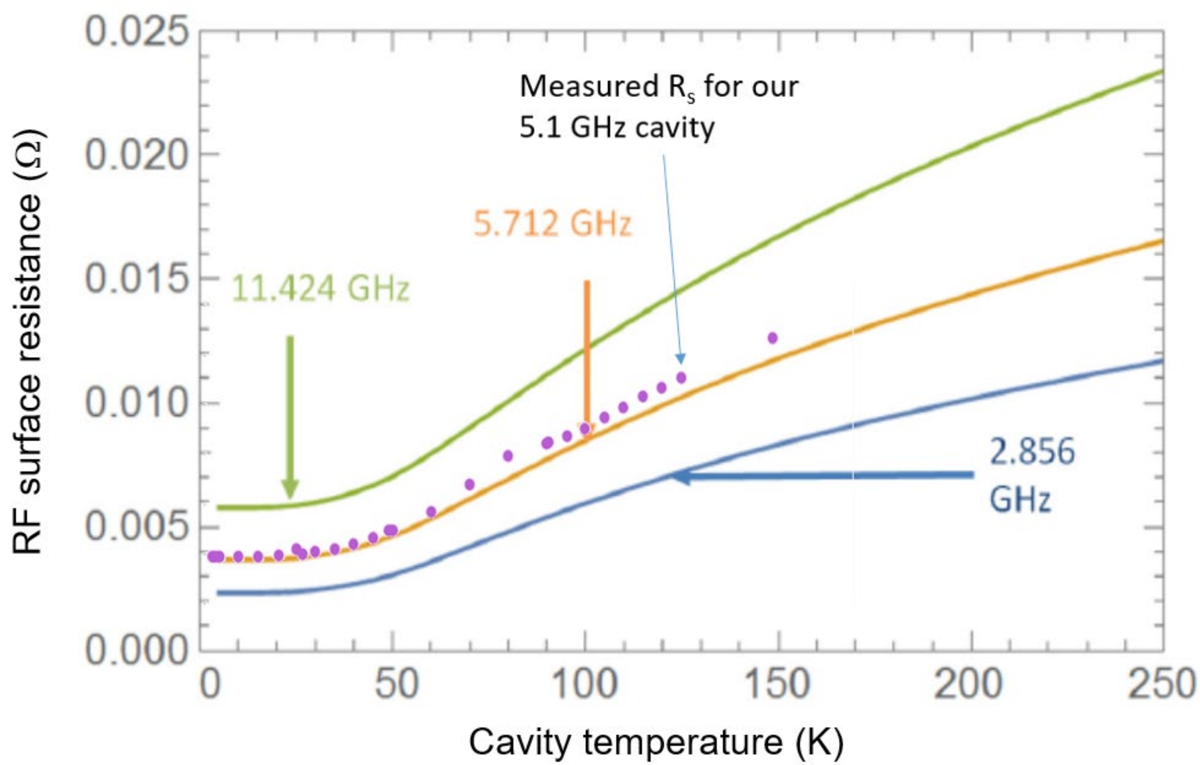


Los Alamos NATIONAL LABORATORY

5.1-GHz copper cavity resonant frequency vs. temperature



Surface resistivity of a 5.1-GHz copper cavity calculated from Q measurements. The result was close to theoretical curve.

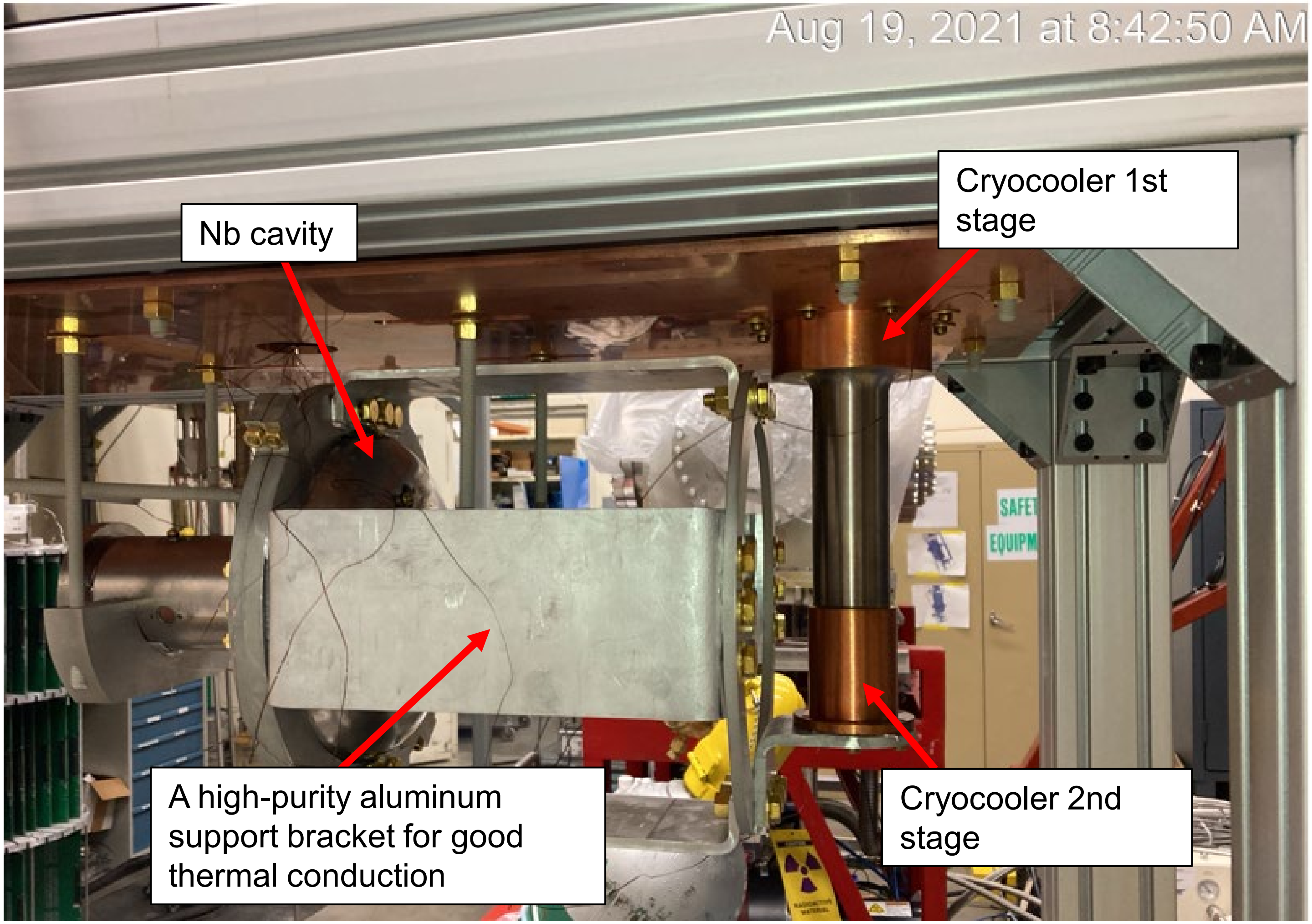


Theoretical curves assume RRR=400 copper (very high conductivity). The 5.1 GHz cavity (made by SLAC) is most likely OFE copper, which typically has RRR = 100-200 (higher resistance than used for the theoretical calculations).

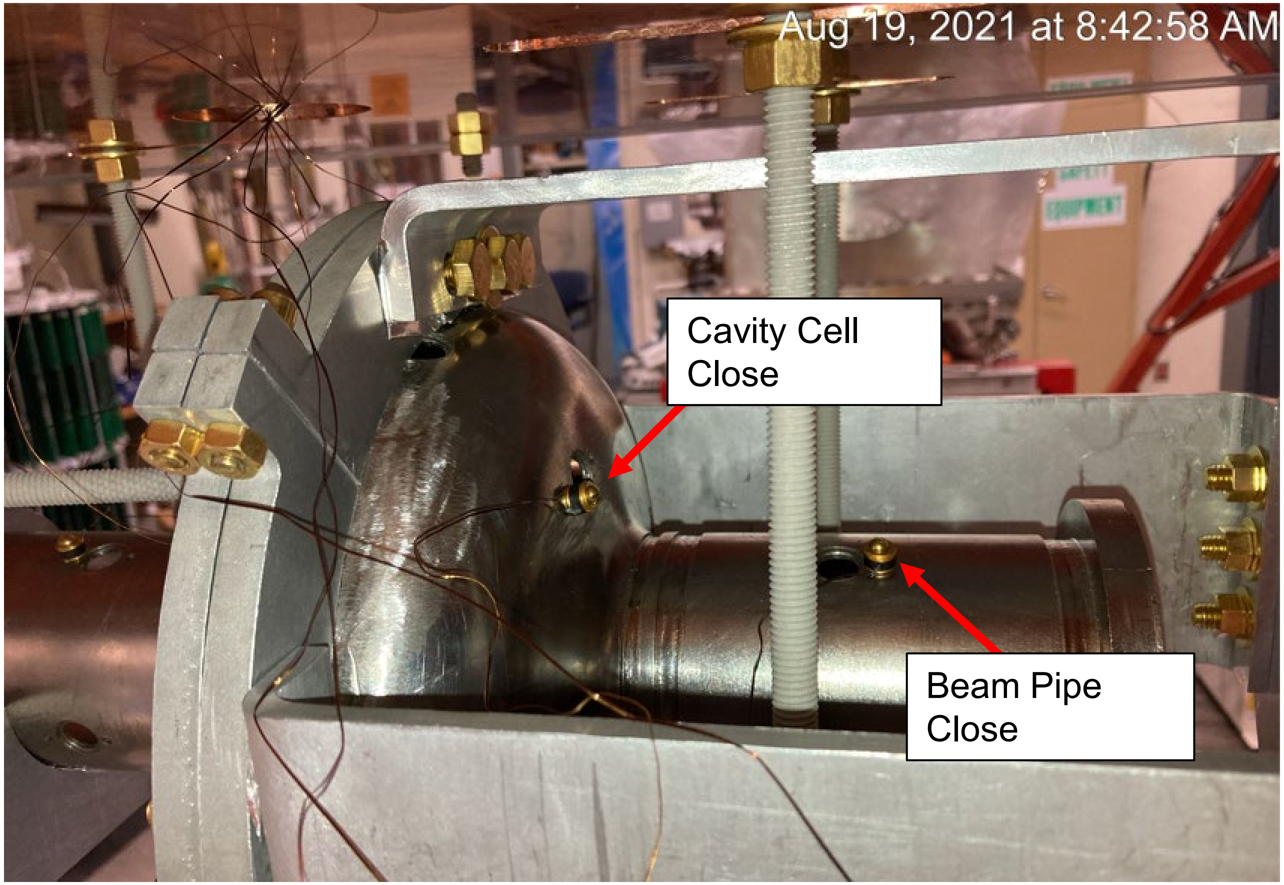
At cryogenic temperature, the R_s scales as $\propto f^{2/3}$, i.e., $(5.105/5.712)^{2/3} = 0.928$. So, the theoretical resistance is about 7 percent lower at 5.1 GHz.

1.3-GHz single-cell Nb cavity cooldown and heating tests

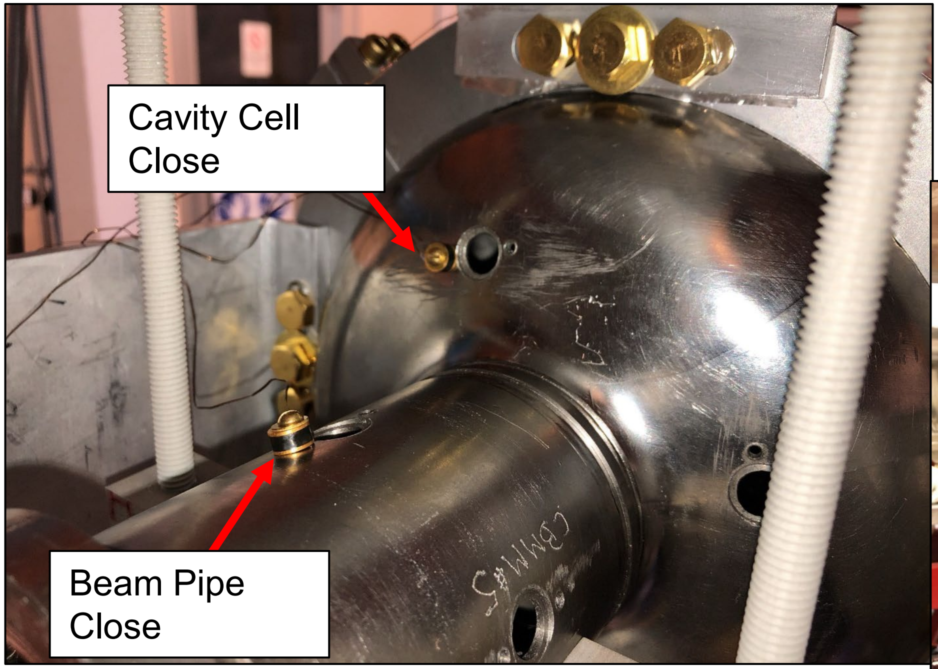
Cernox temperature sensors' locations and designation

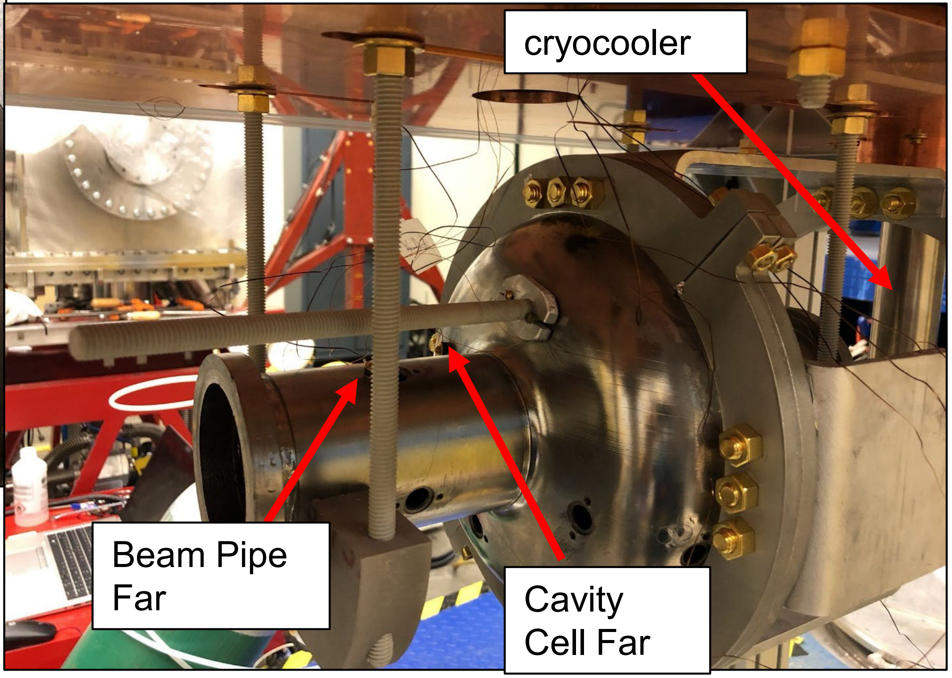


Cernox sensors' locations: "Close" and "Far" are relative to the cryocooler location



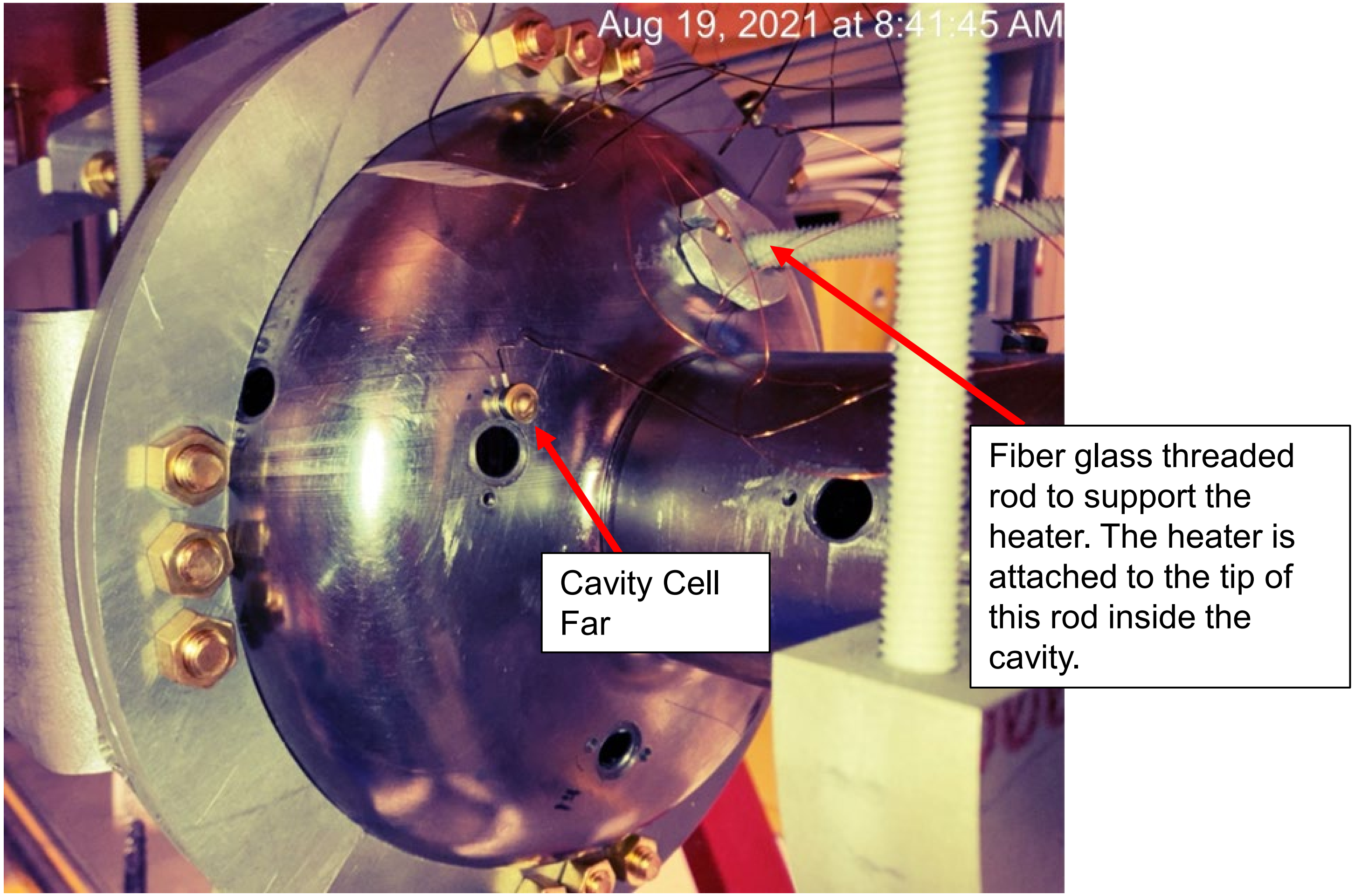
Cernox sensors' locations: "Close" and "Far" are relative to the cryocooler location





Los Alamos NATIONAL LABORATORY

Heating test with a resistor

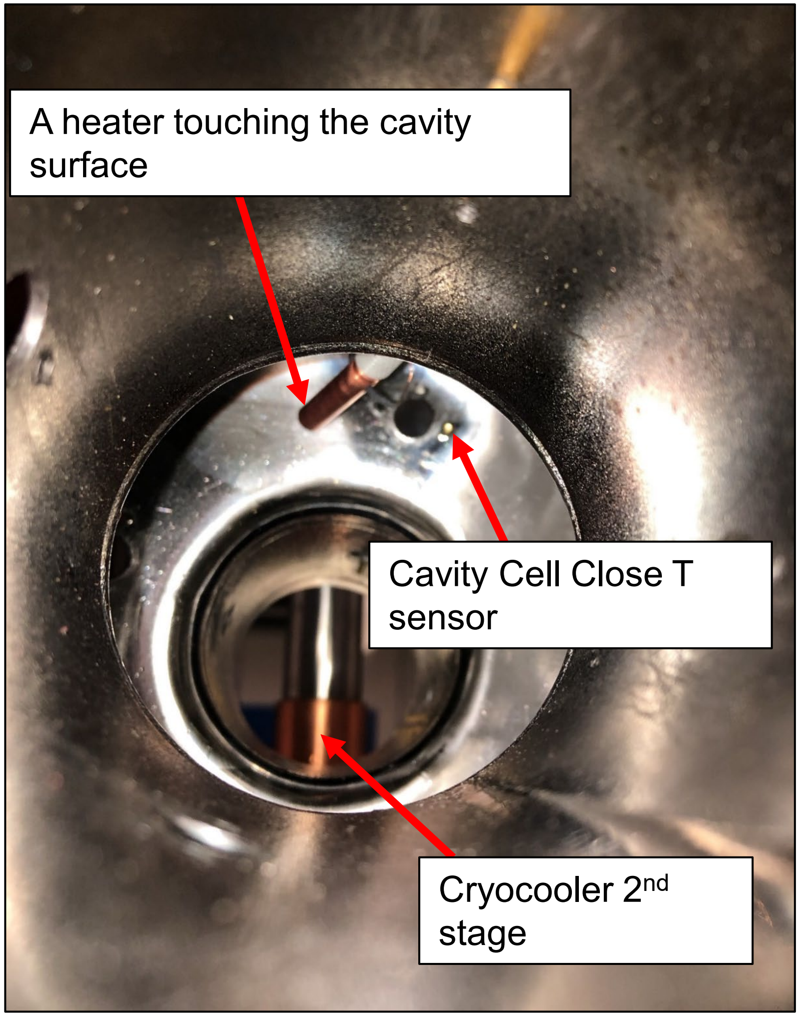


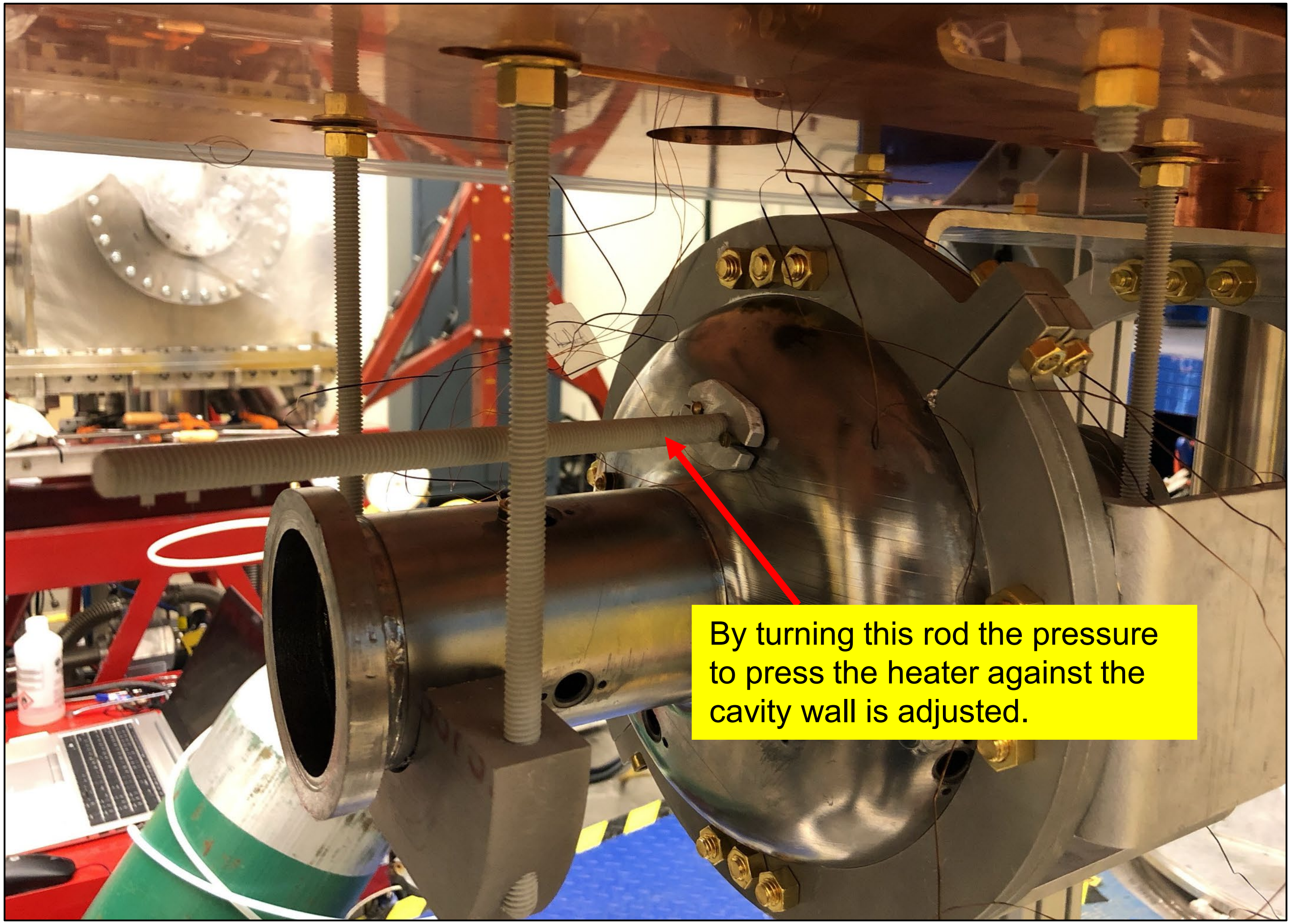
Heating test with a resistor

Heater installation

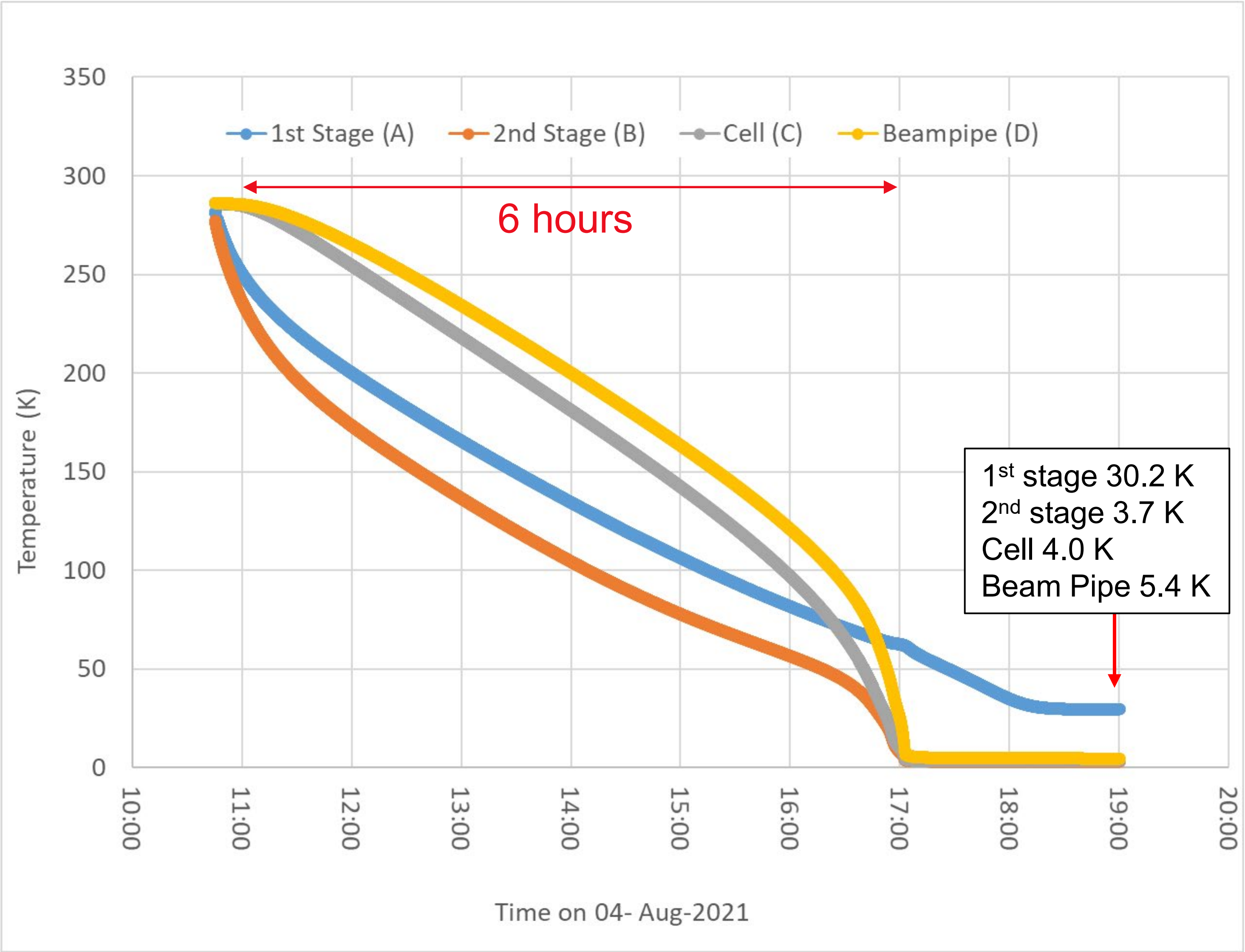
The heater is made of the following components:

- A 50 Ω resistor (48 Ω measured)
- A copper capsule to hold the resistor, minimize the point of contact on the surface of the cavity, provide a support
- A fiberglass threaded rod to hold the capsule in position and pressed against the cavity inner surface



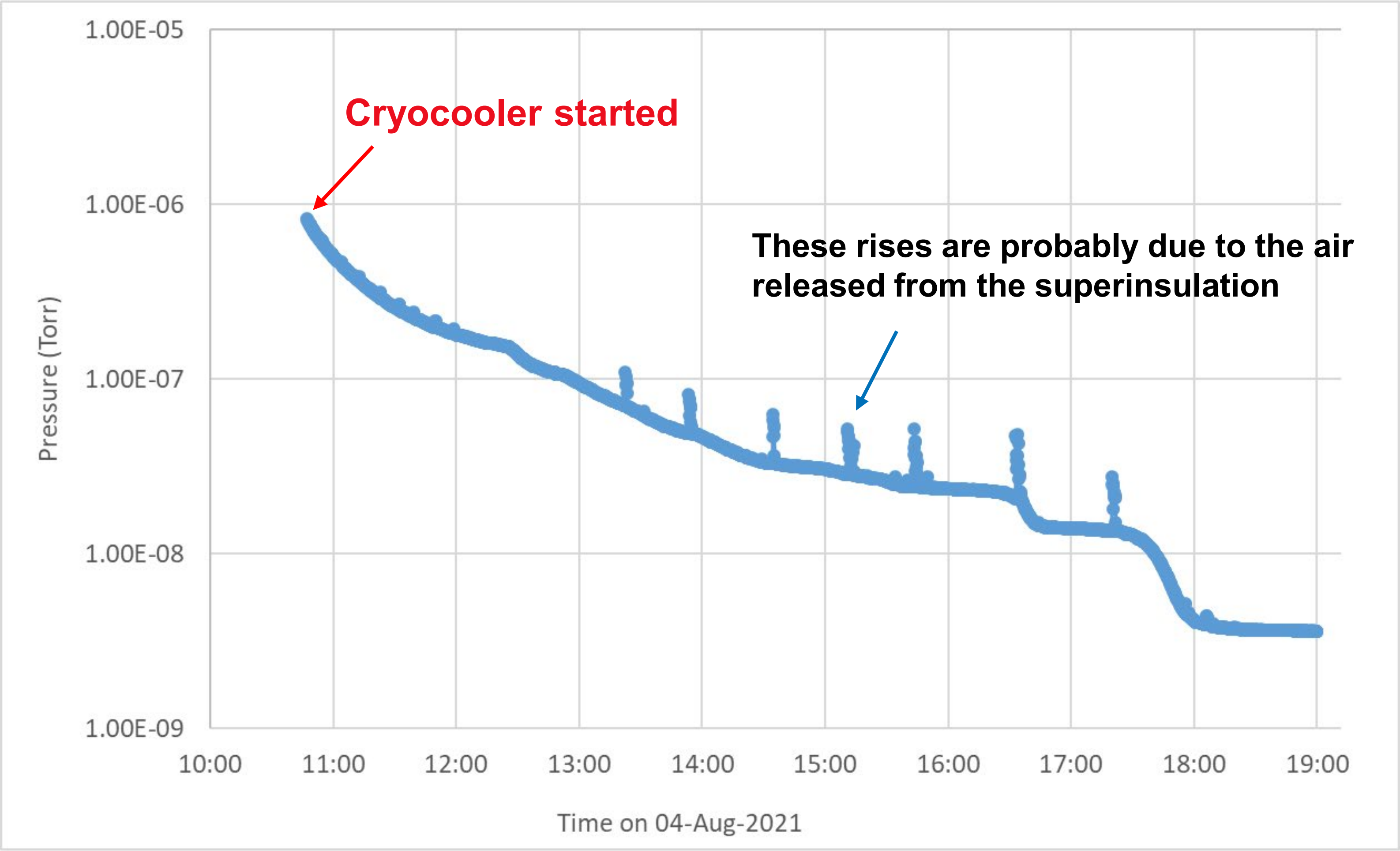

By turning this rod the pressure to press the heater against the cavity wall is adjusted.

Cooldown of the Nb cavity. It took a little over 6 hours to reach the ~lowest temperature.



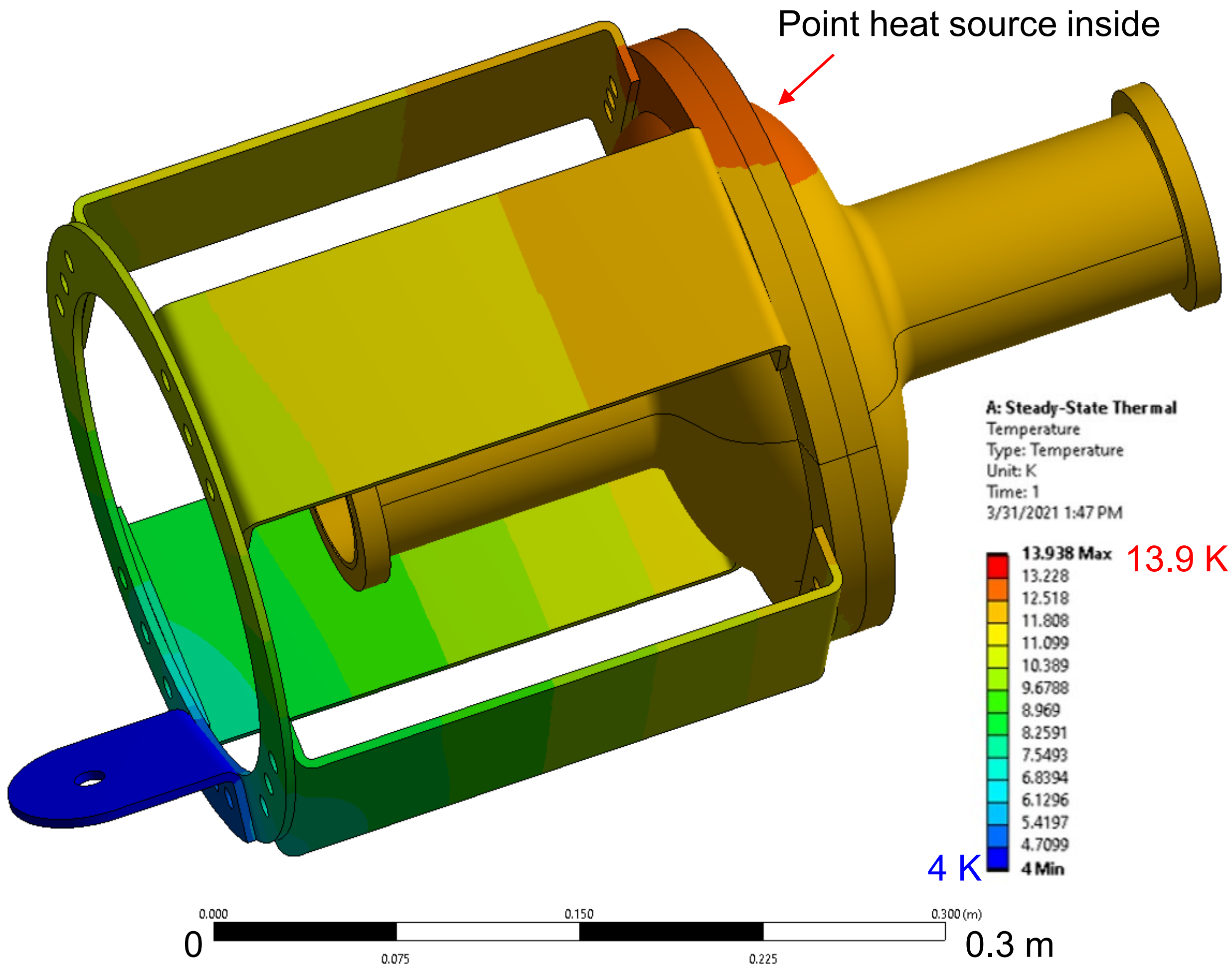
Los Alamos NATIONAL LABORATORY

Pressure evolution during the cooling of the Nb cavity



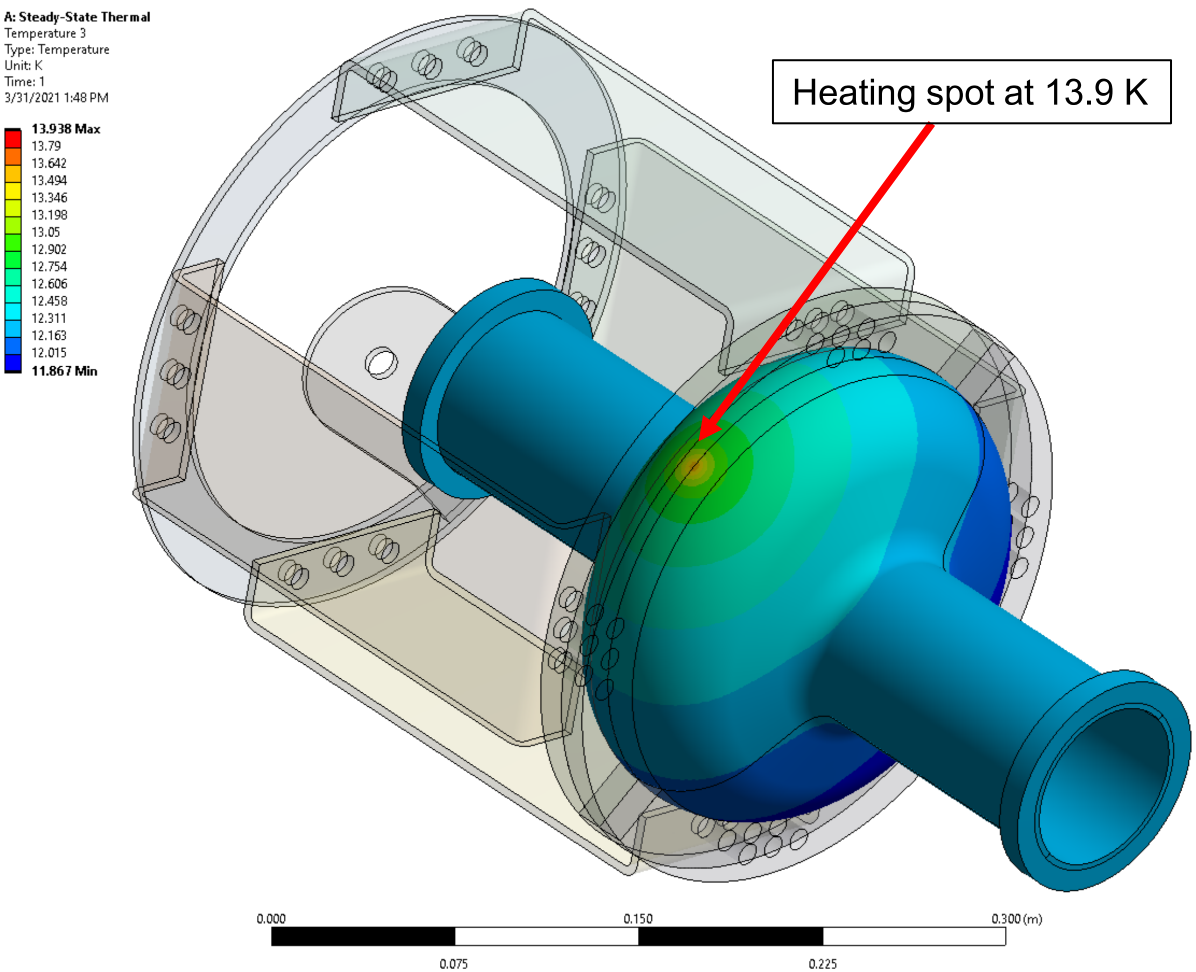
An ANSYS simulation result of the temperature profile with a 2 W heating spot on the 1.3-GHz Nb cavity inner surface with the cryocooler 2nd stage kept at 4 K.

2 W

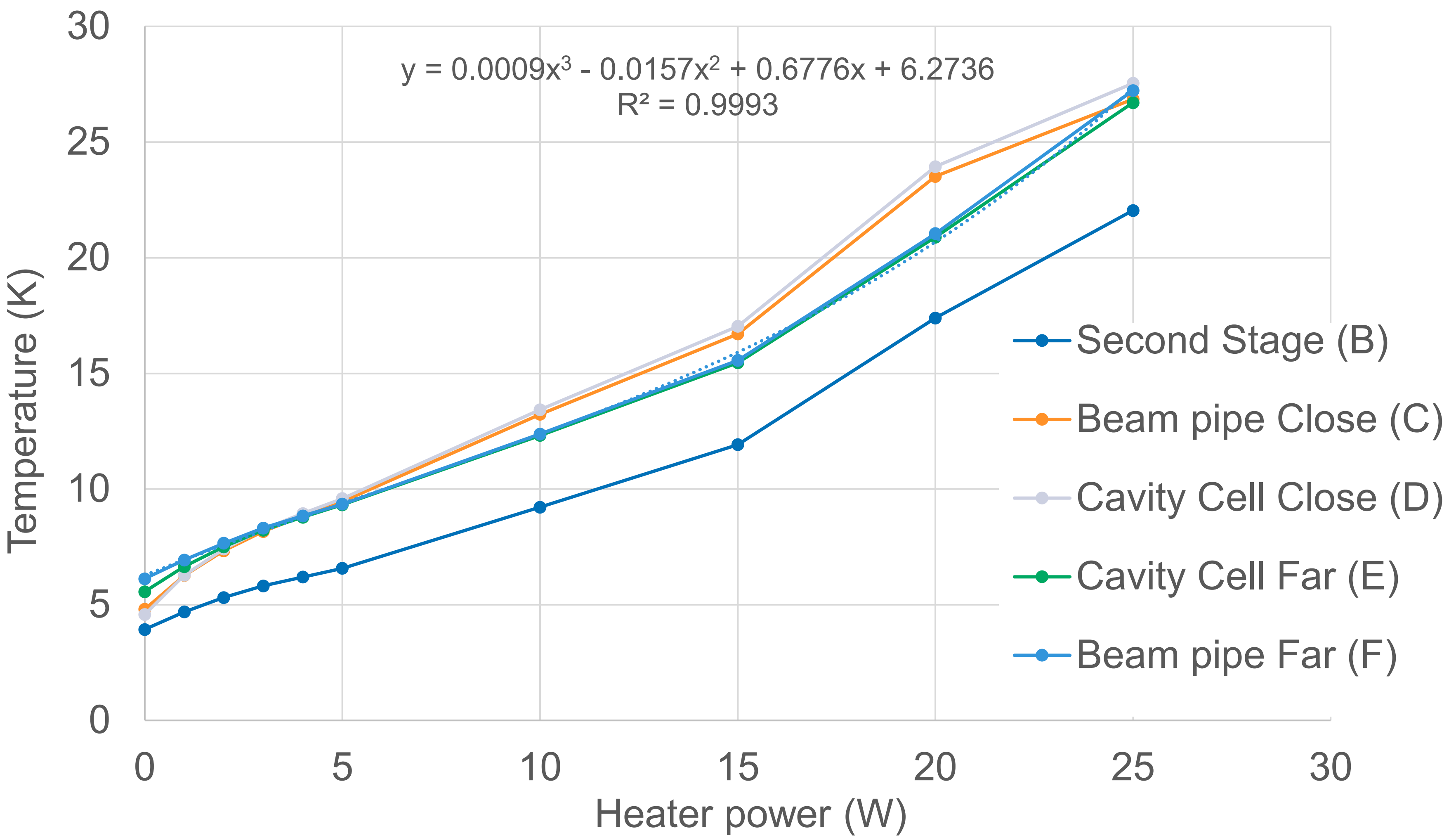


The temperature profile on the cavity with a 2 W heating spot on the cavity inner surface

2 W



Experiment: Temperatures at the sensors vs. heater power. No detailed comparison with simulation was done.



Summary and future plans

- We acquired some experience in developing a system to cool down cavities with a cryocooler and successfully cooled down NCRF and SRF cavities to the temperatures low enough to be useful for future tests.
- We plan to develop cryocooler-based cooling systems for
  - C-band (5.7-GHz) NC RF cavities for low-power and high-power tests.
  - Low-power tests for MgB_2 coated 1.3-GHz single-cell cavities. High-power tests will be performed at KEK through a US-Japan cooperation project.