CUORE/CUPID : Design and optimization of thermal connectors and switches at cryogenic temperatures

LNGS Hands-on school 2023

Istituto Nazionale di Fisica Nucleare
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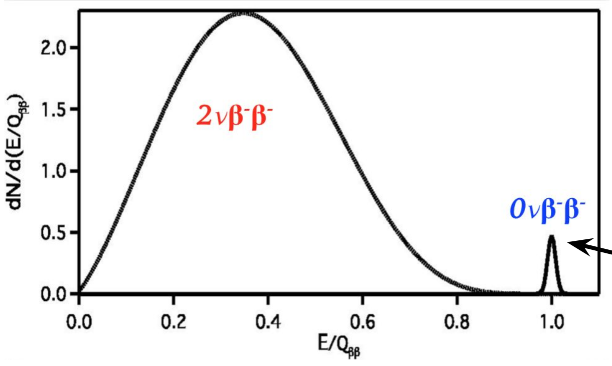
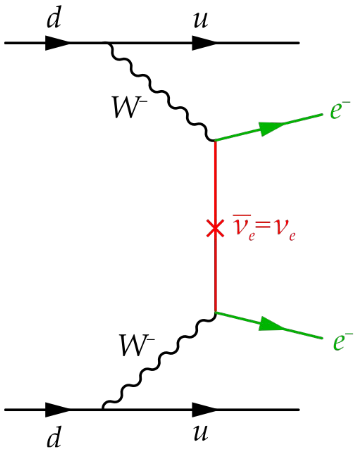
CUORE experiment

- Cryogenic Underground Laboratory for Rare Events ("CUORE")
- Search for neutrinoless double beta decay 0νββ :
  - Violation of lepton number conservation
  - Solution to matter/antimatter asymmetry
  - ν as Majorana particles ?

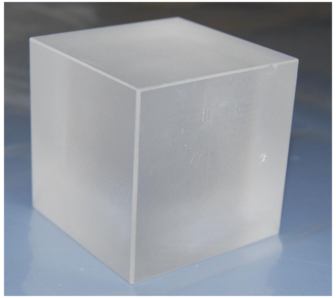


Signature is a peak at the Q value of ββ decay spectrum



A Feynman diagram of neutrinoless double beta decay. Find here.

CUORE experiment

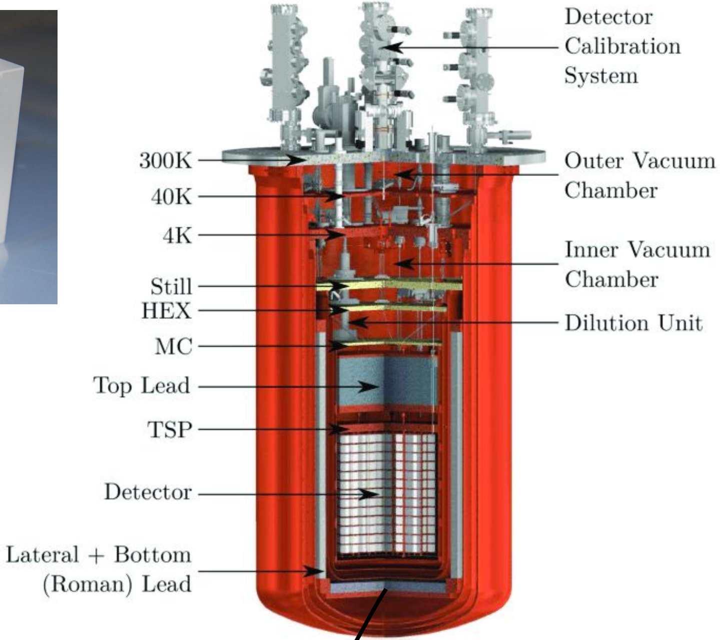


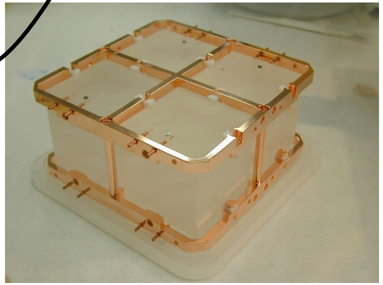
988 detectors of Tellurim oxide TeO_2 ($0\nu\beta\beta$ of ^{130}Te) for an overall **effective mass of 741 kg** !

First tonne-scale bolometric experiment in the world

Most powerful dilution refrigerator ever built

World leading millikelvin cryostat in size and power





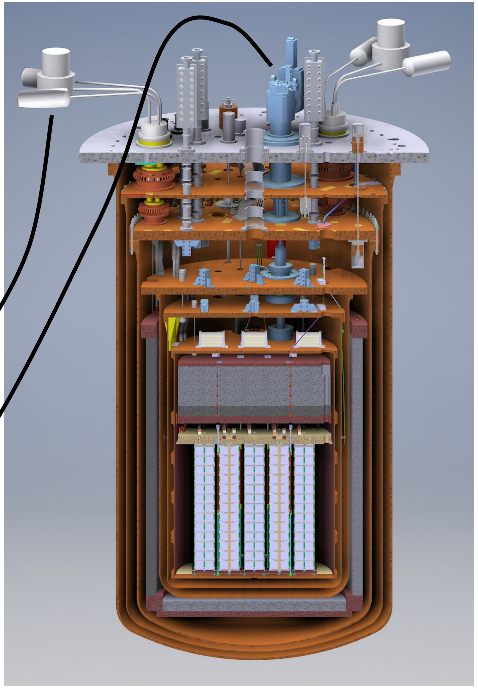
Cryostat

CUORE uses a **dry** cryostat → Pulse Tube (PT) refrigerators (rather than liquid He) to cool metals :

To cool down to ~35K → fast cooling system

To cool down to ~3.5K → 4 pulse tubes (^{4}He gas isoenthalpic expansions)

To cool down to ~10mK → ^{3}He/^{4}He dilution fridge

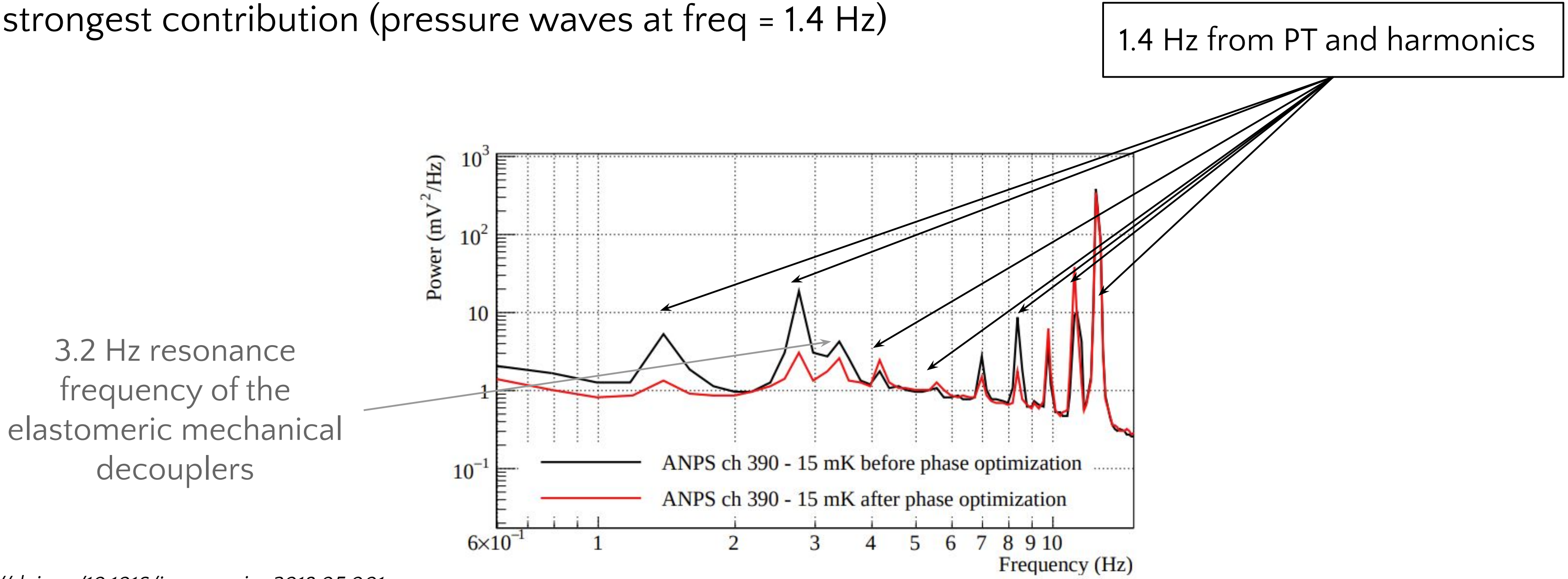


Pulse tubes : cooling effect thanks to periodic pressure variation displacing the working gas in the pulse tube, needs a good thermal coupling with 40K and 4K plates

→ **Problem : induced vibrations**

Problem : thermal coupling of PT

CUORE : strong correlation between the noise of the detectors and the vibration level → PTs give the strongest contribution (pressure waves at freq = 1.4 Hz)



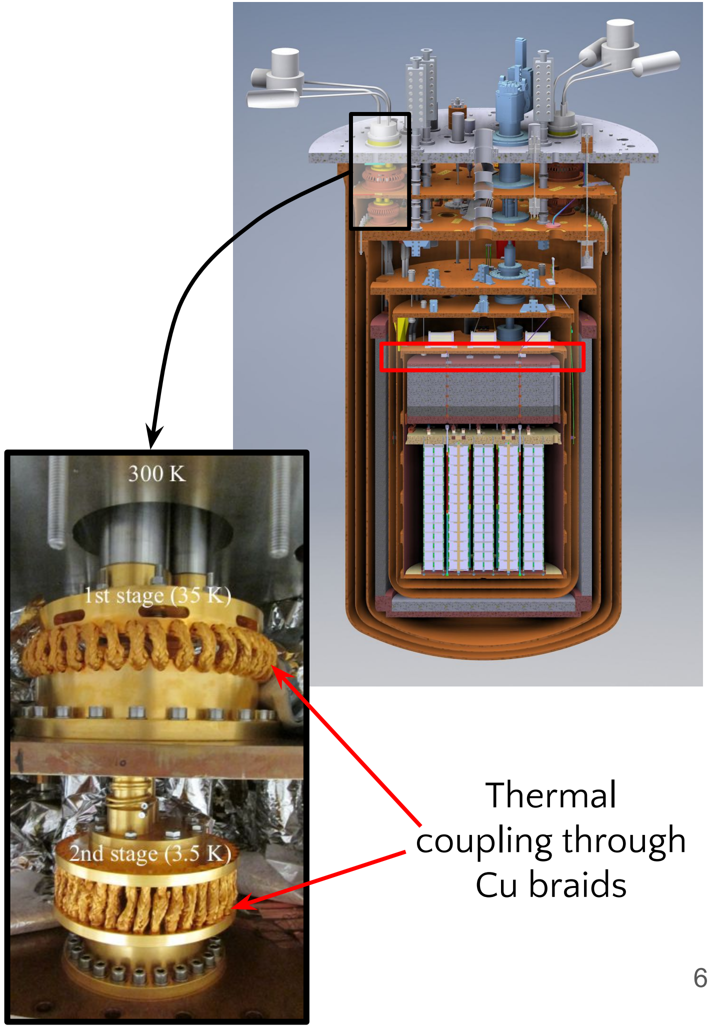
https://doi.org/10.1016/j.cryogenics.2018.05.001

Problem : thermal coupling of PT

CUORE : strong correlation between the noise of the detectors and the vibration level → PTs give the strongest contribution (pressure waves at freq = 1.4 Hz)

PT induced vibrations are observed at two levels :
- temperature of the Mixing Chamber (MC)
- microphonic noise picked up by the read-out wires

Extensive work to address the issue → upgrade towards **CUPID**



Towards CUPID

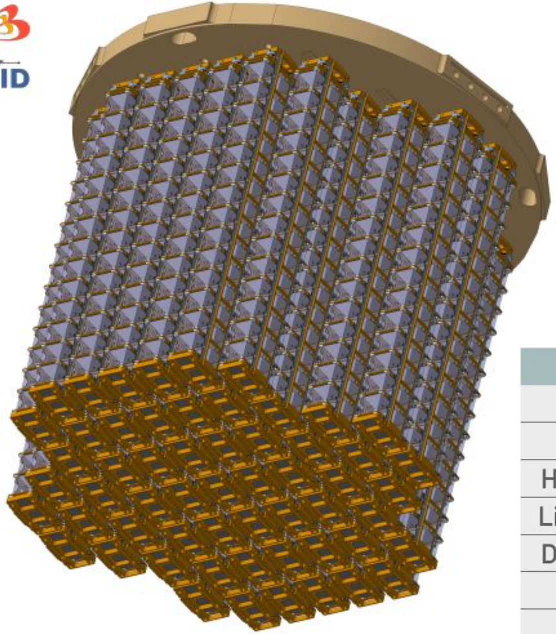
CUORE detector

19 towers, 988 TeO_2 crystals, ~2200 wires

CUPID detector

57 towers, 1596 $Li_2{}^{100}MoO_4$ crystals, 1710 LD, ~7300 wires

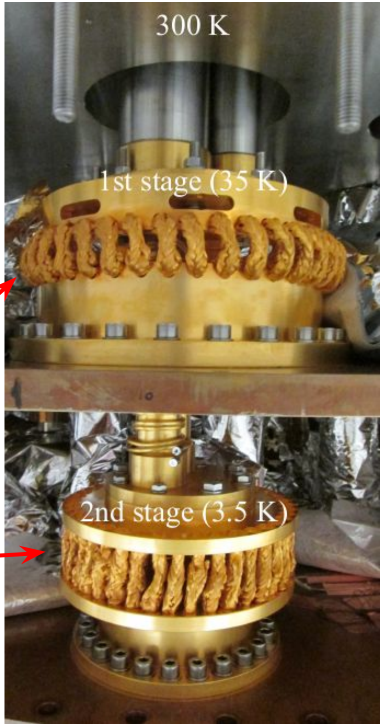
CUPID



Parameter	Value
Crystal	$Li_2{}^{100}MoO_4$
Size	45x45x45 mm^3
Heat Channels	1596
Light Channels	1710
Detector mass	450 kg
Enrichment	95%
^{100}Mo mass	240 kg
E resolution	< 5 keV
Bk index	< e-4 ckky

Addressing the problem

"Easy" solution (i.e. that does not involve major modifications in the cryostat) : change the material of thermal coupling PT-40K, PT-4K.

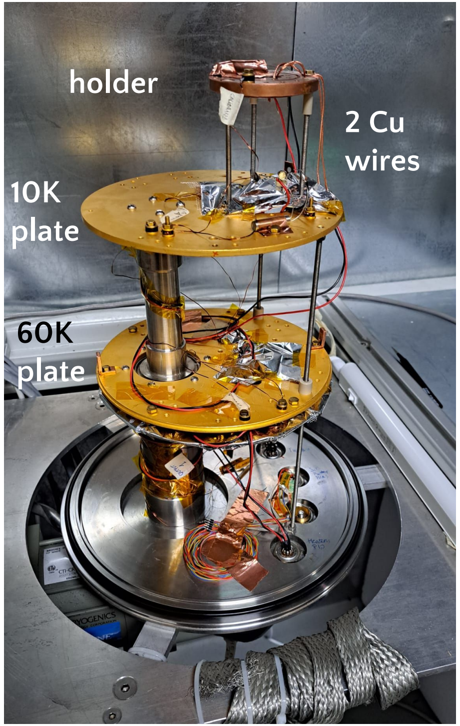


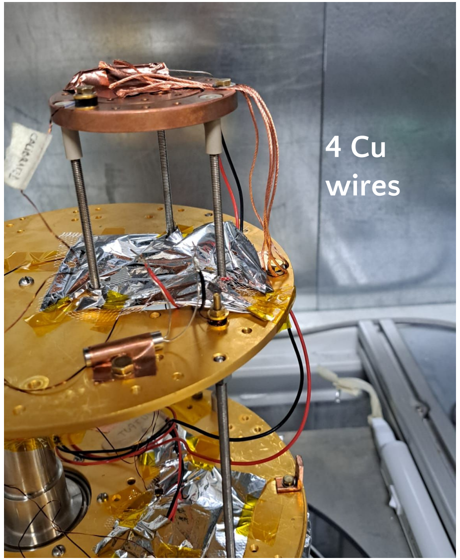
Require a material that :

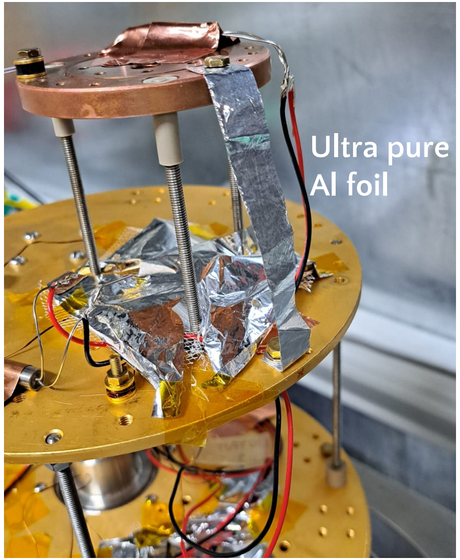
- Has good thermal conductivity
- Reduces mechanical coupling

High purity Al is a good candidate.

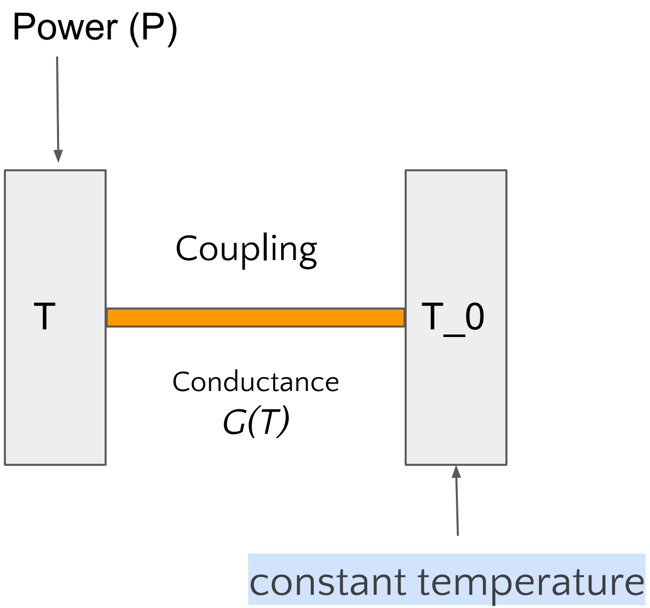
Experimental setup







Thermal conductance



- The change of temperature satisfies the following equation

$$C(T)\cdot\frac{dT}{dt} = P - \int_{T_0}^{T} G(T)dT$$

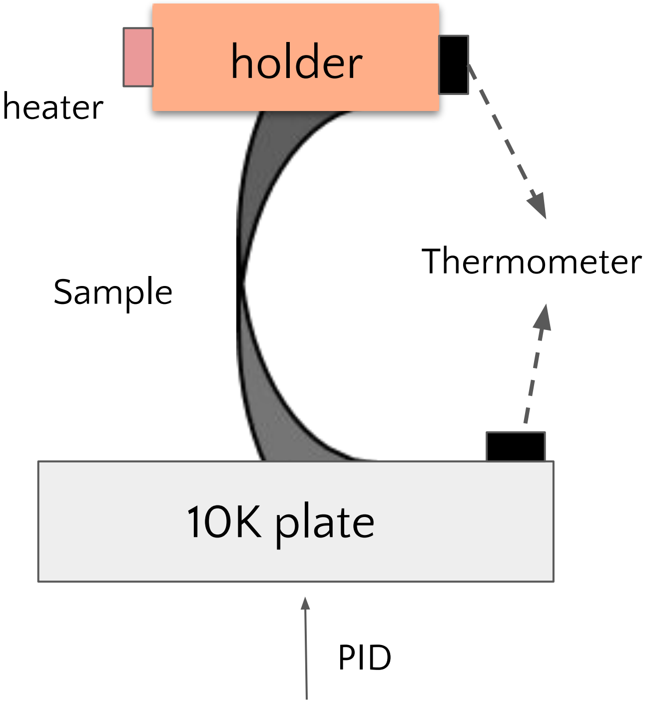
- If the temperature does not change much:

$$\frac{dT}{dt} = \frac{P}{C} - \frac{G}{C}\cdot(T - T_0)$$

- So the decay time $\tau = C/G$
- If the temperature is stable:

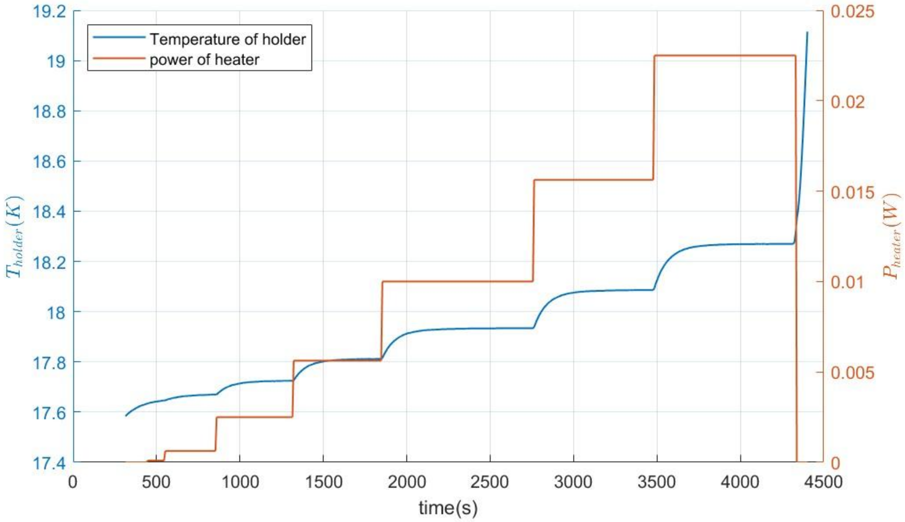
$$P = G\cdot\Delta T$$

Measurement method



- Stabilize the temperature of 10K plate using PID
- Usual stable temperature of 10K plate @14 K

- Increase the power of heater step by step
- Wait for temperature stabilize then increase the power

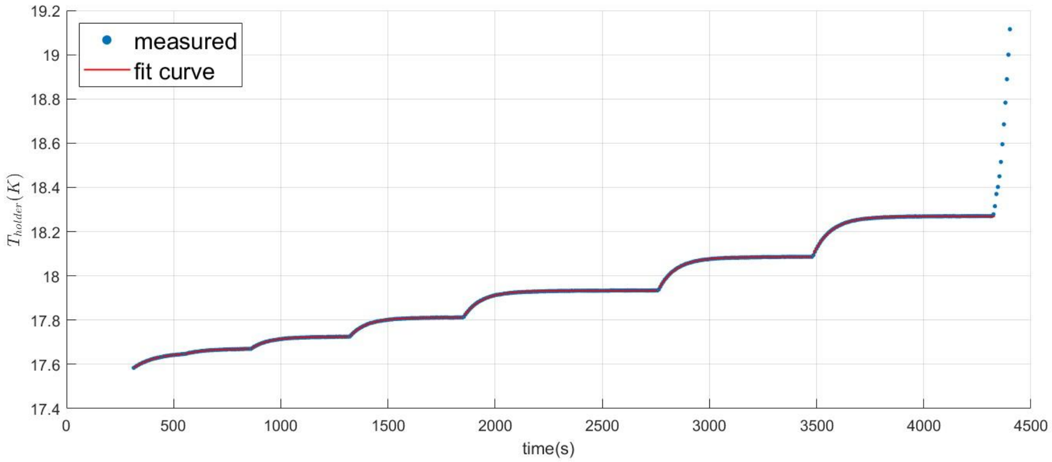


Data analysis – get ΔT

- The heating curve is exponential.
- Fit the curve using following formula to get the stable temperature of holder

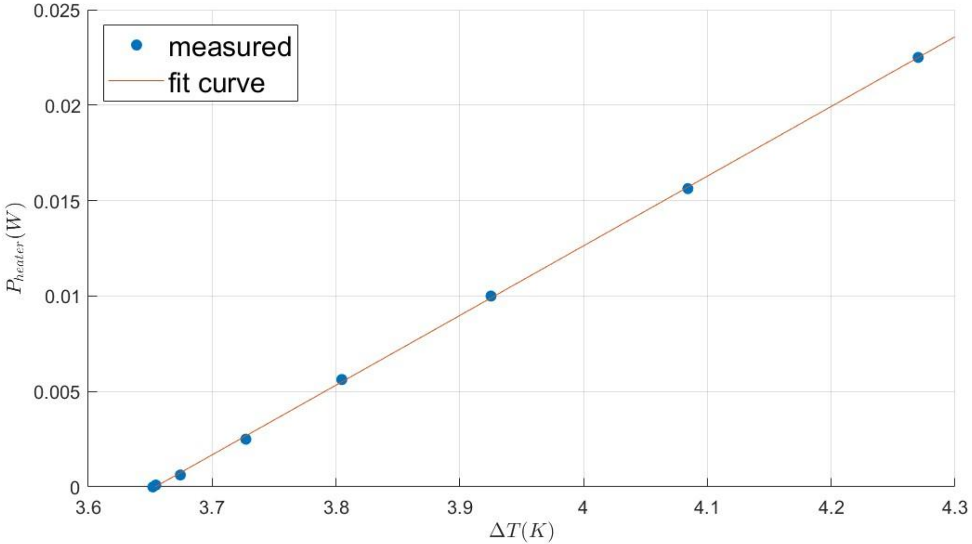
$$T_{holder}(t) = T_{stable} - A \cdot \exp\left(-\frac{t}{\tau}\right)$$

- Then we can get $\Delta T = T_{holder}^{(stable)} - T_{10K\,plate}$

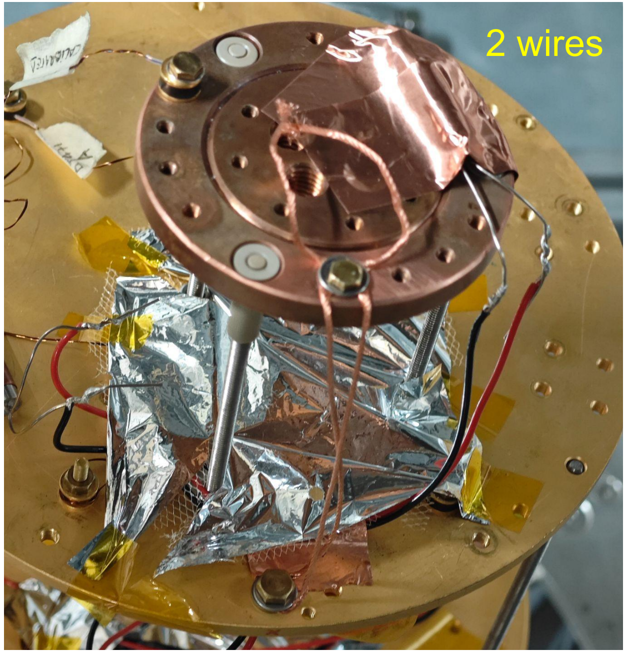


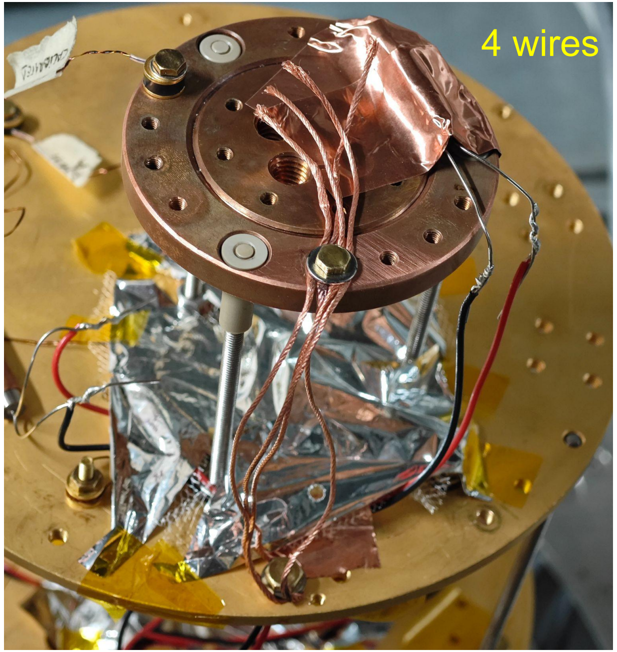
Data analysis — get *G*

- $P_{total} = P_{heater} + P_0 = G \cdot \Delta T$
- So apply a linear fit to $P_{heater} - \Delta T$ relationship
- The slope is *G* (conductance), the intercept is – P_0 (residual power)



Result – copper





Same length and only different number of wires

Result — copper

2 copper wires:

$$G_2 = 0.0365\,W/K$$

$$A_2 = 2 \times 0.1963\,mm^2$$

$$l = 90\,mm$$

$$g_2 = G_2 \frac{l}{A_2} = 8.367\,W/(K \cdot mm)$$

$$P_{0,2} = 0.1334\,W$$

4 copper wires:

$$G_4 = 0.0611\,W/K$$

$$A_4 = 4 \times 0.1963\,mm^2$$

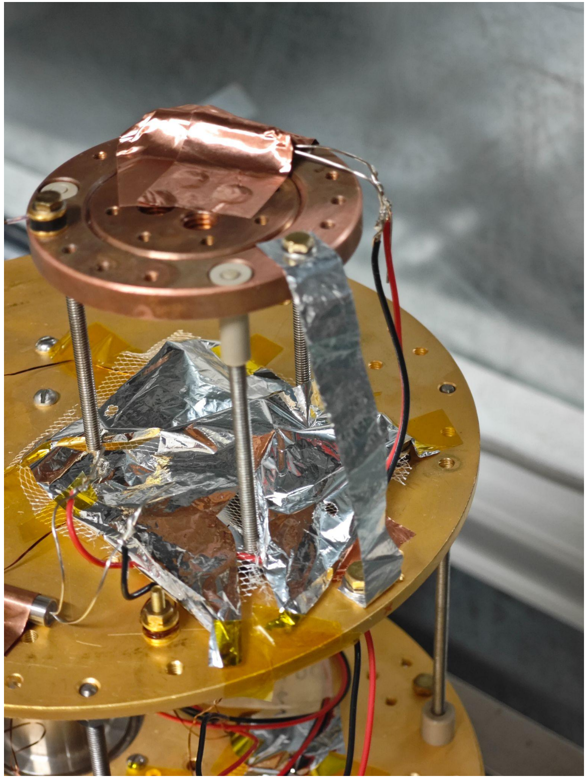
$$l = 90\,mm$$

$$g_4 = G_4 \frac{l}{A_4} = 7.003\,W/(K \cdot mm)$$

$$P_{0,4} = 0.1221 W$$

- The conductivity of 4 wires is almost twice that of 2 wires
- P_0 in two cases are similar to each other

Result – aluminium



$$G_{Al} = 0.0426\, W/K$$

$$A_{Al} = 0.5926\, mm^2$$

$$l_{Al} = 90\, mm$$

$$g_{Al} = G_{Al}\frac{l_{Al}}{A_{Al}} = 6.469\, W/(K \cdot mm)$$

$$P_{0,Al} = 0.1002\, W$$

- There was a leak during this running
- the aluminum oxide affects the conductivity

Summary

- We measured the conductivity of copper and aluminum

- From the result of copper, we prove that this measurement method is reliable

- Al results seem inconsistent → might be due to cryogenic problems

- To do :
  - Test different purity Al samples
  - Compute uncertainties (lack of time)
  - Try different configurations of wires (+/- thick, ...)


LAKE TAHOE
UNKNOWN PLEASURES


Thanks

Backups

- ? $G_{other} = 2G_2 - G_4$
- If we can measure more number of copper wires, and we can get the conductance of other coupling structure (support, electric wire)
- We can get the decay time (C/G) which is helpful to calculate the capacity