Sara Gamba, Danaé Valdenaire, Laura Francesca Iacob, Marco Ricci, Daniela Spreng
Supervisor: Andrei Puiu

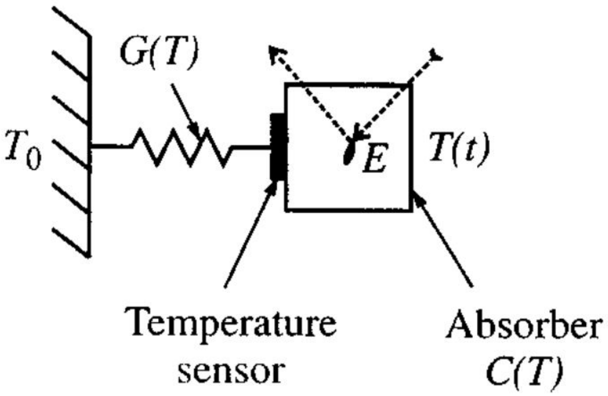
Hands-on cryogenic calorimeters

Mounting of a scintillating calorimeter with double readout
~~and subsequent cooldown to 10 mK~~

Gran Sasso Hands-On 2025

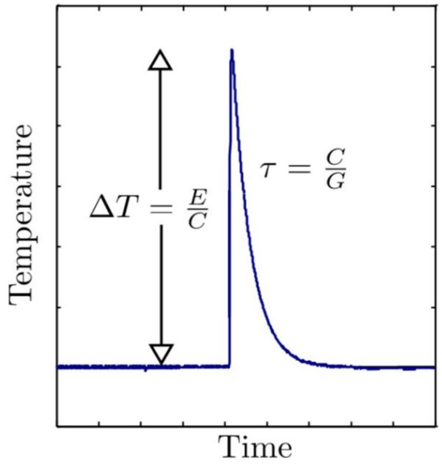
Cryogenic calorimeters

Low temperature detectors (LTD) are detectors that operate at very low temperatures ~10 mK.



When particles interact in the absorber they will deposit an amount of energy E, creating a temperature variation $\Delta T \propto E/C(T)$ in the absorber+thermometer system.

Then the system goes back to equilibrium through the conductance G(T) connected to the thermal bath T_0.



We want to minimize both decay time $\tau \propto C/G$ and the resolution $\sigma^2_E = k_B T^2 C$. This means that we want a high thermal conductance G(T) but a low capacitance C(T).

One of the main advantages of LTDs is their very low thresholds, usually O(1-10) eV.

⚠️ **Smaller** detector → **lower C** → better resolution and speed.

Detectors overview

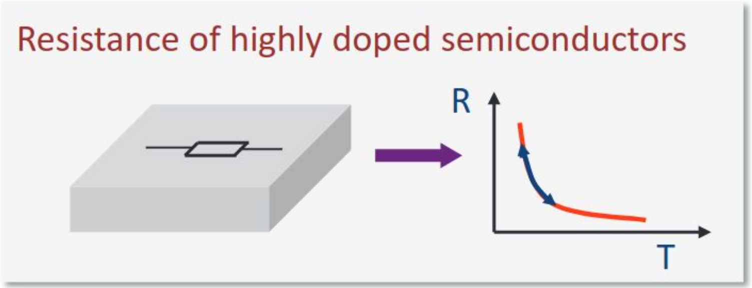
Equilibrium detectors used during the hands-on:

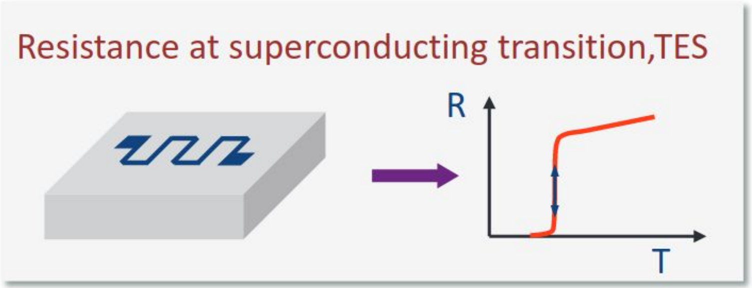
Neutron Transmutation Doped Thermistors (NTD):

- Neutron-doped germanium crystals;
- Semiconductor thermistors with $R(T)=R_0 \exp((T/T_0)^{0.5})$;
- Negative derivative sensor: ΔRΔT<0;
- High impedance;
- Current bias.

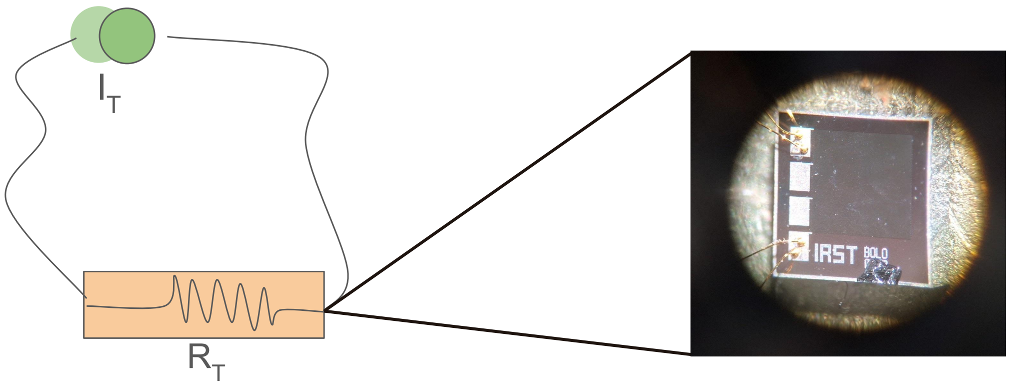
Transition Edge Sensors (TES):

- Working at the transition between normal and superconductivity;
- Positive derivative sensor: ΔRΔT>0;
- Voltage bias.





Heaters to monitor the detector response



A current is sent to the heater

The heater will dissipate a signal in the crystal

The heater signal differs slightly from a particle one to distinguish them

The heater pulses are used to monitor the detector response (energy gain correction) over time

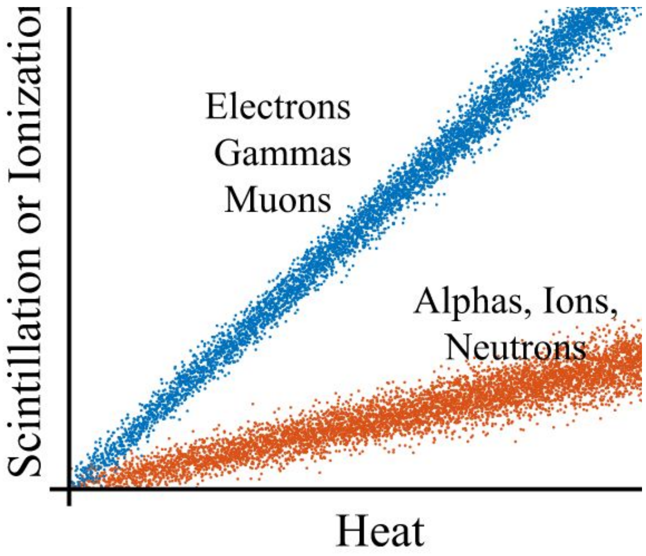
Double readout for particle ID

Double readout:

- Channel 1 (LTD): **phonon detector** (A1);
- Channel 2 **scintillation or ionization light** (A2);

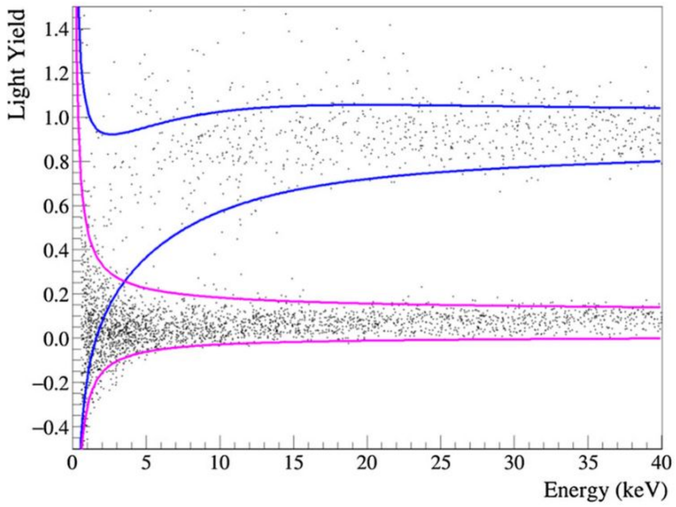
The ratio A1/A2 (light yield) depends on the interacting particle → **Particle identification**

→ Important to distinguish between nuclear and electronic recoil:



heat-ionization: electrons, photons (higher ionization yield) and α, ions and neutrons;

heat-scintillation: recoil electrons - higher light yield, blue - and nuclear recoil - pink.

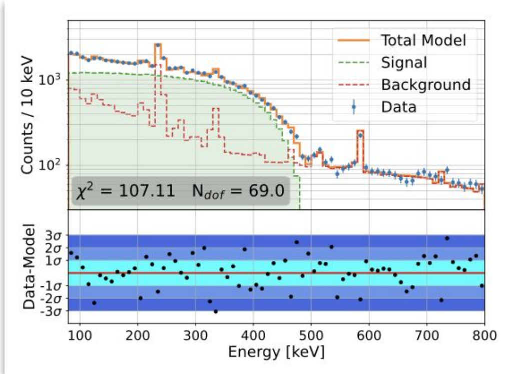


Crystal absorbers

Indium Arsenide (InAs)

Measurement of of forbidden β decays to investigate axial coupling constant g_A

Measurement of the β-decay spectrum of Indium 115
→ Low-energy part is used to study g_A



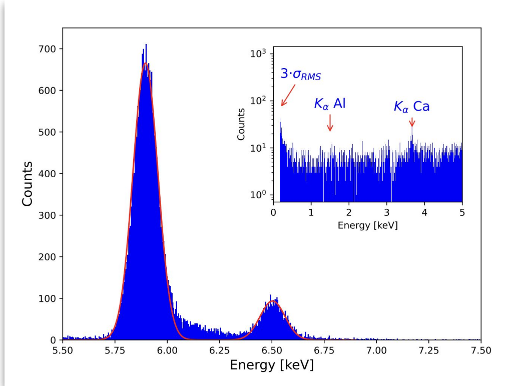
https://arxiv.org/pdf/2507.07119

Beta decay spectrum of In 115

Gallium Arsenide (GaAs)

sub-GeV dark matter search

Threshold as low as possible to increase the sensitivity
→ 2 NTDs improve the signal to noise ratio



https://arxiv.org/pdf/2507.07119

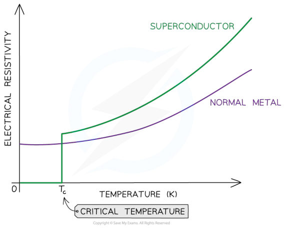
Low energy X-ray spectrum - Mn K_α peak measured with σ = 1 eV

Hands-on overview

Wire bonding

Gluing of detectors and heaters on crystals

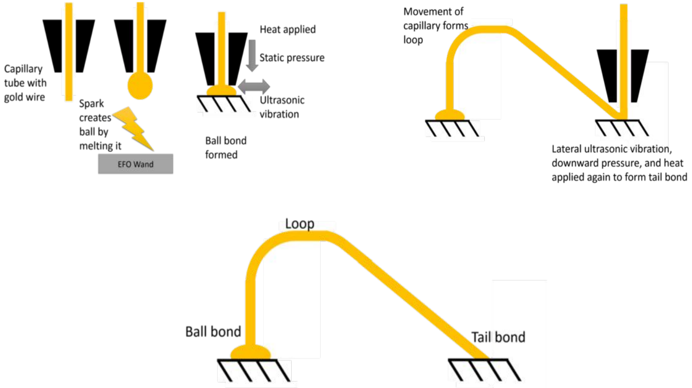
Assembly in the copper frame for future tests at low temperatures



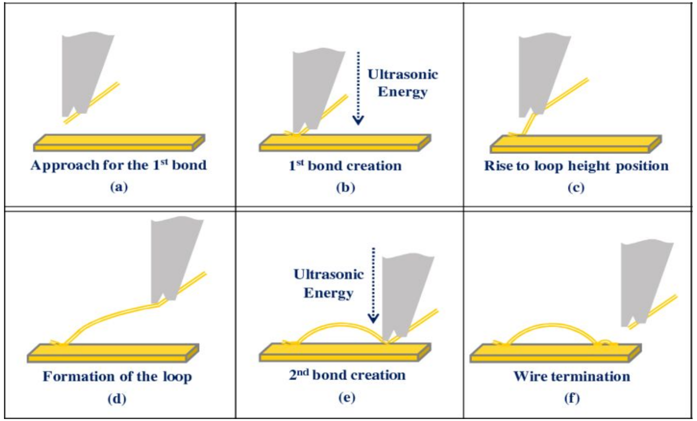
Preparation for measuring the transition temperature of a superconductive film

Wire bonding: micro-welding technique that uses thin metal wires bonded by means of ultrasonic vibration.

Ball Bonding: small ball formed and bonded. No directional constraints.



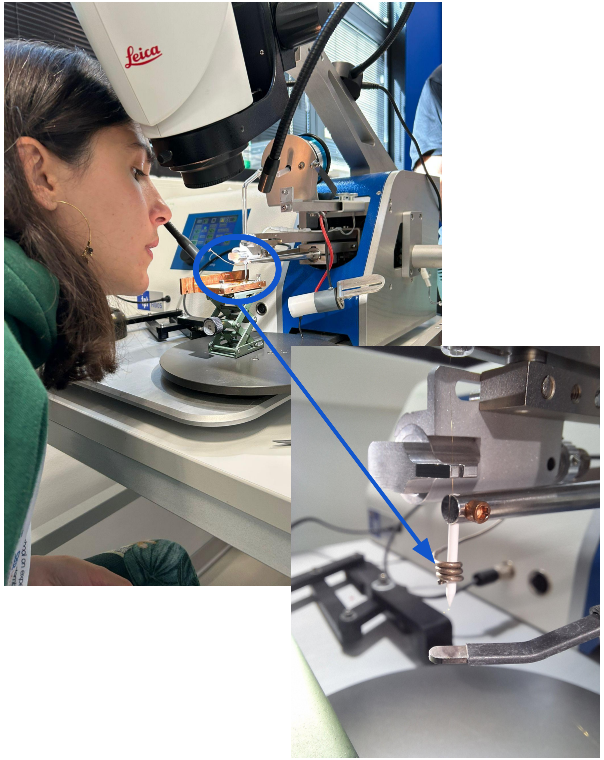
Wedge Bonding – wire pressed and bonded. The wire must follow a straight path from the first bond.



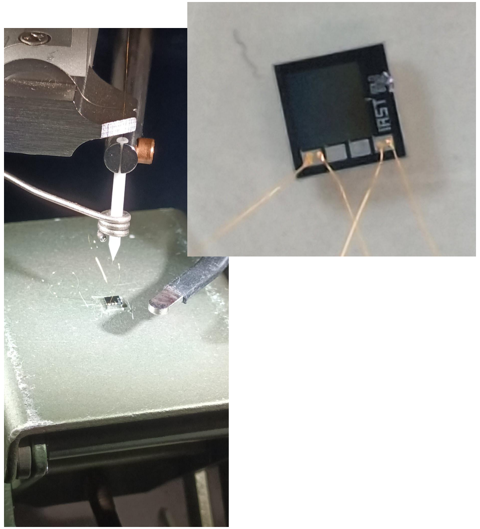
Gold:
- High electrical conductivity;
- ball bonding;
- can be used with heater and NTD elements (high resistance).

Aluminum:
- Forming a ball is difficult because Al does not melt easily due to oxidation.
- Superconducting at low T° → used for TES (small stray resistance in bias circuit).

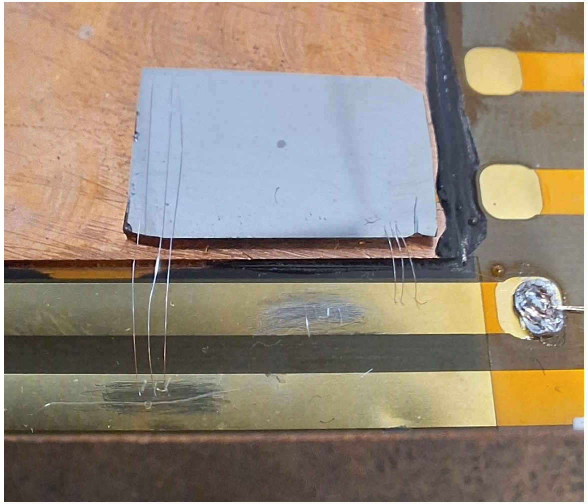
Wire bonding



Gold bonding

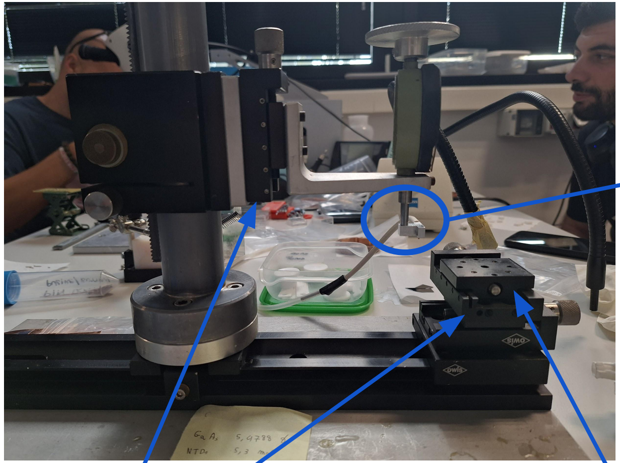


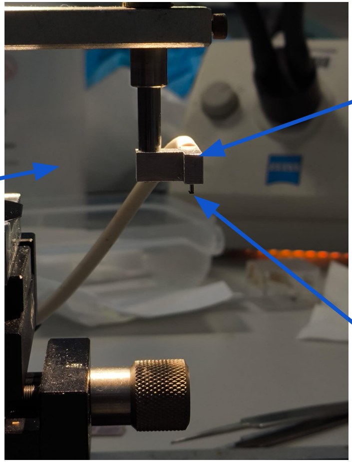
Aluminum bonding

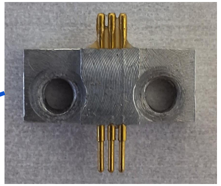


More wires ⟶ better connection to thermal bath

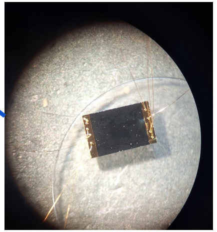
Gluing setup





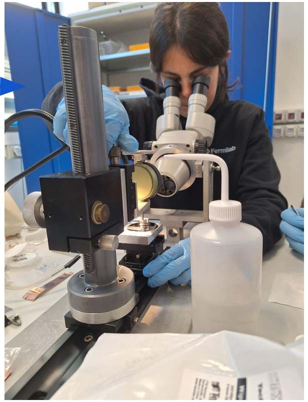


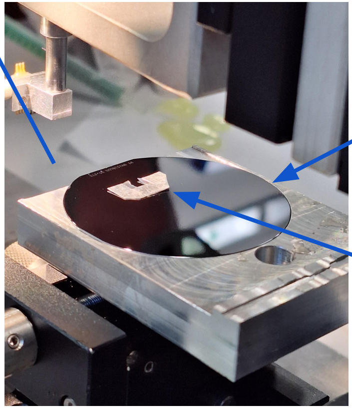
1. Pins to apply the glue; dot shaped → compromise between phonon collection and thermal mismatch



2. NTD held by vacuum pump

5. xyz-stage to align first the pins and later the NTD with the mask



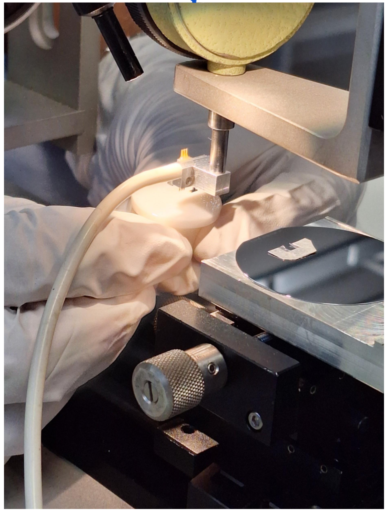


3. Crystal (InAs or GaAs)

4. Mask for alignment + fix glue to defined thickness of 25μm

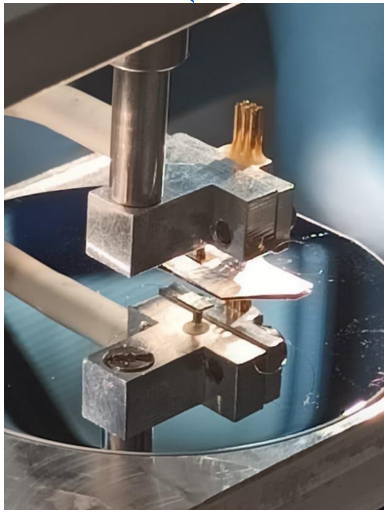
Gluing procedure

1. Prepare the epoxy glue



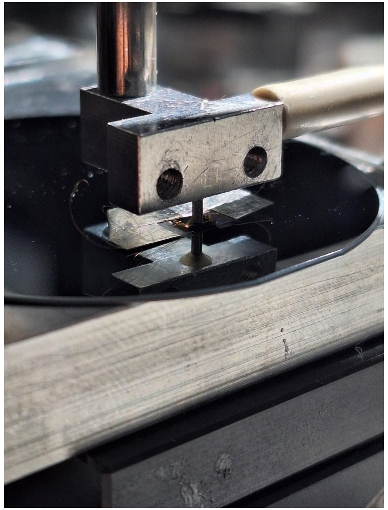
2. Apply some glue on the pins

3. Align the pins with the mask



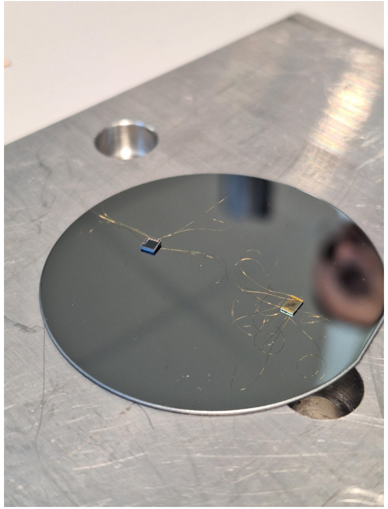
4. Apply the glue pattern on the wafer lowering the pins (springs prevent damage)

5. Unscrew the pins without touching the NTD



6. Align the NTD with the mask and press down

7. Wait for the glue to dry (~2h)



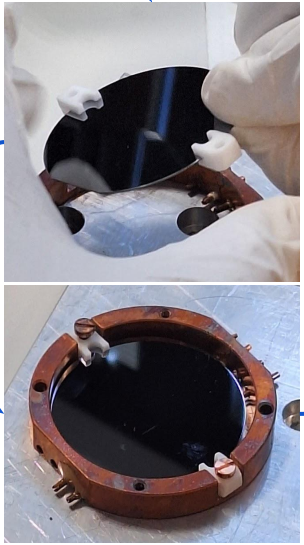
8. Remove the mask

Final assembly

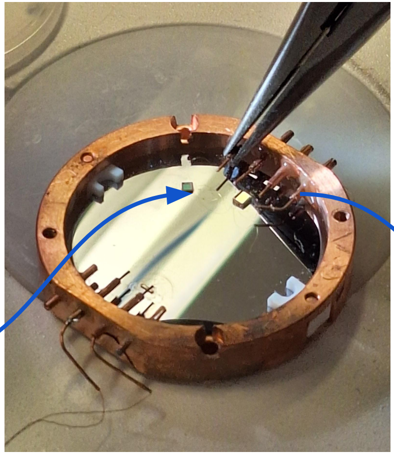
1. Clean copper frame with citric acid + deionized water to better couple to the bath (cryostat).

2. Glue pins in frame with same glue as for NTDs; wrapped with tape for electrical insulation.

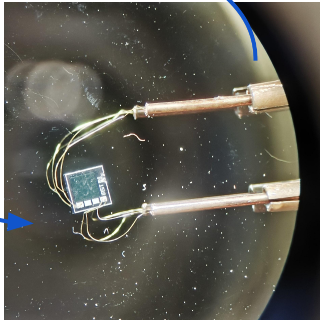
3. Tack crystal between PTFE stripes.



4. Mount crystal on copper frame.



5. Insert small copper pins and squeeze it tight.

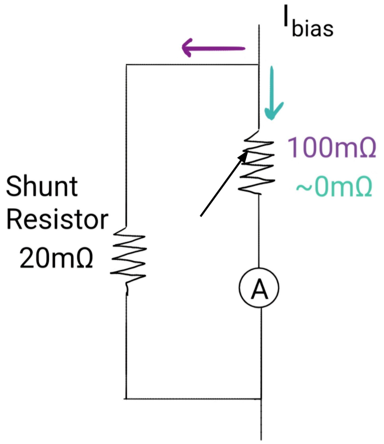


6. Insert the gold wires into the small pins and crimp them.

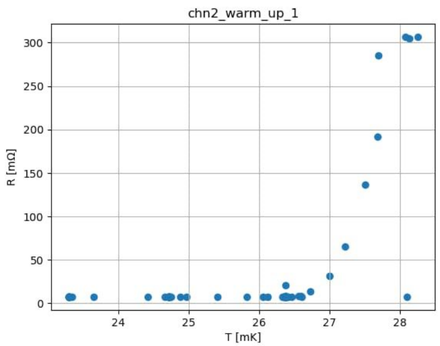
7. Check resistance of the devices and insulation against the frame.

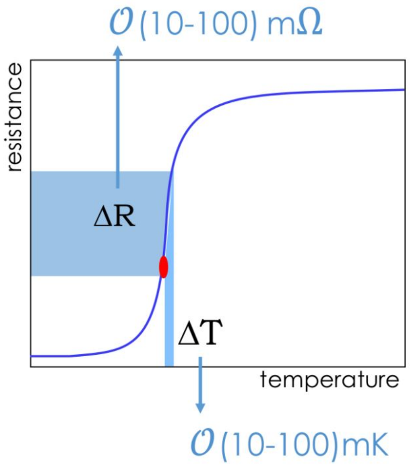
Now it can be mounted in the cryostat.

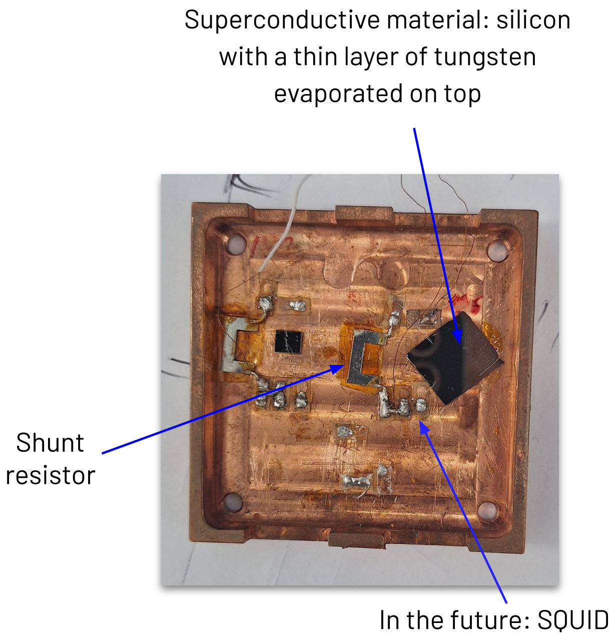
Setup to measure the transition temperature T_c



The bias current flows through the shunt resistor and switch to the superconductive material when the superconductive state is reached.







Tungsten is used because it can tuned Tc, meaning that the transition can be adjusted according to the need of the detector operation.

Thank you very much!