Calorimeter R&D WG report

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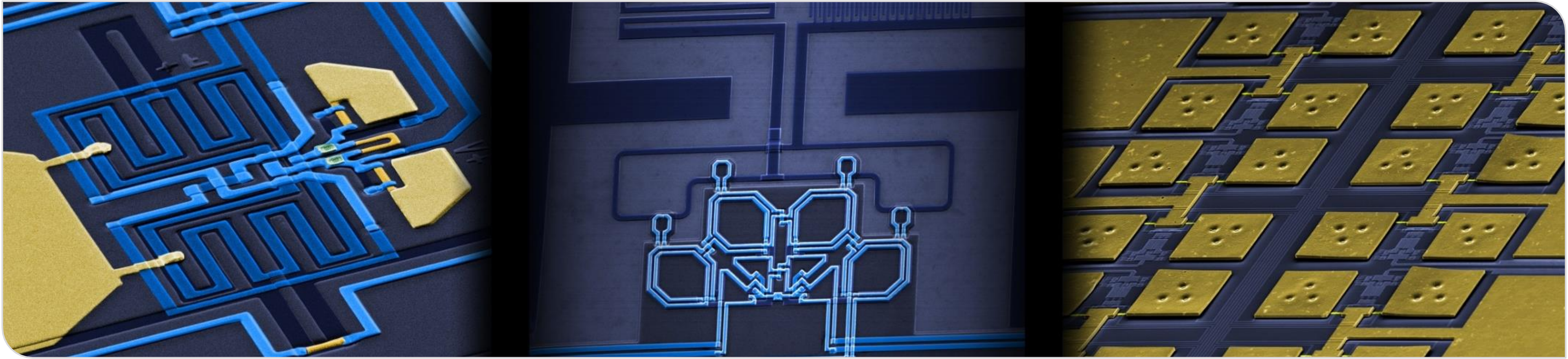
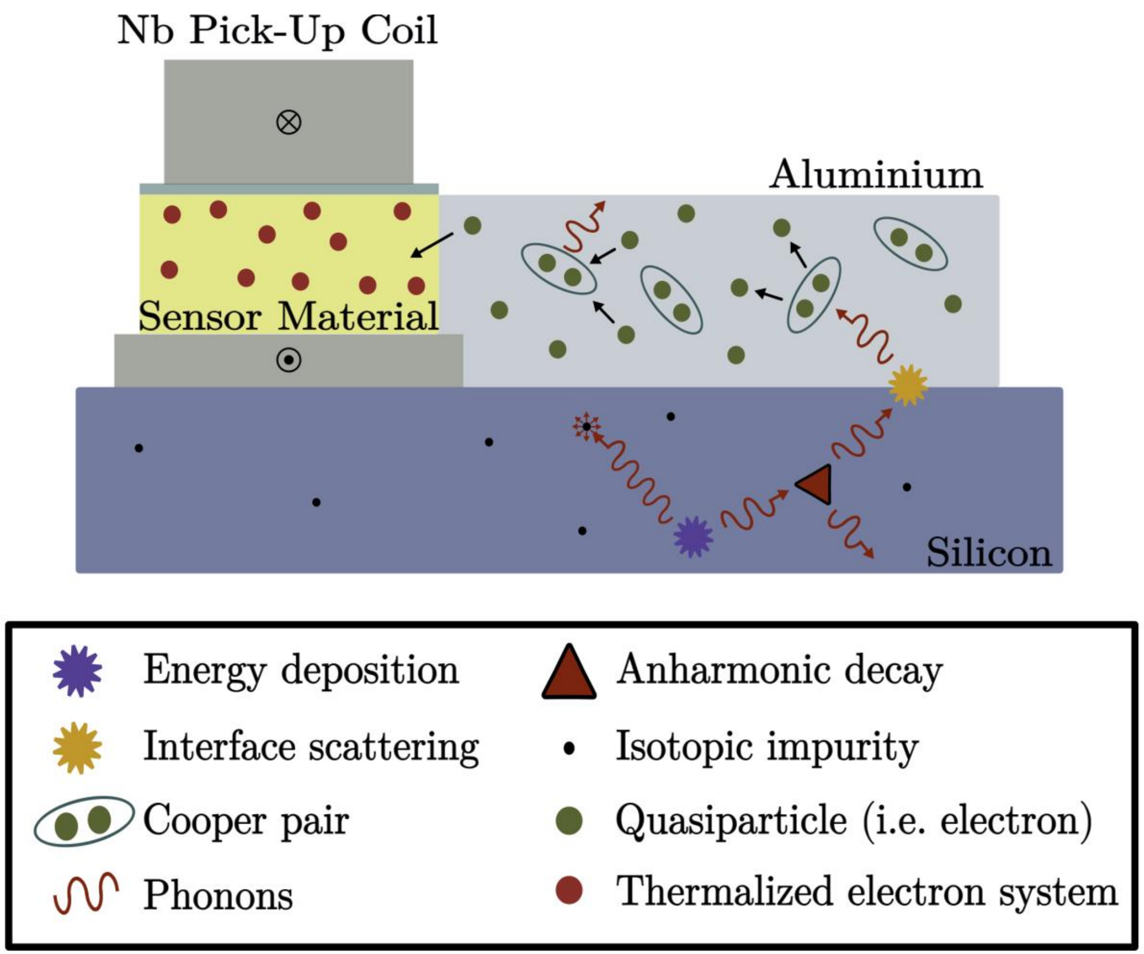
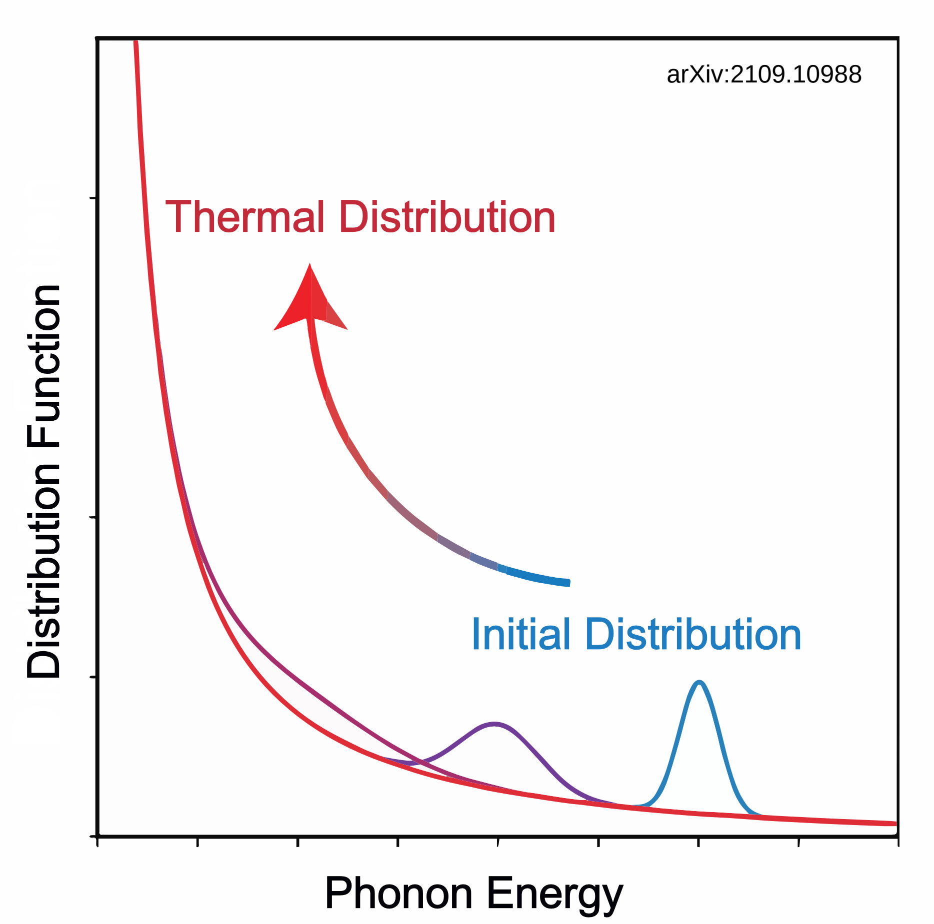
DELight Collaboration Meeting | Heidelberg | September 13, 2024



Athermal Calorimeter



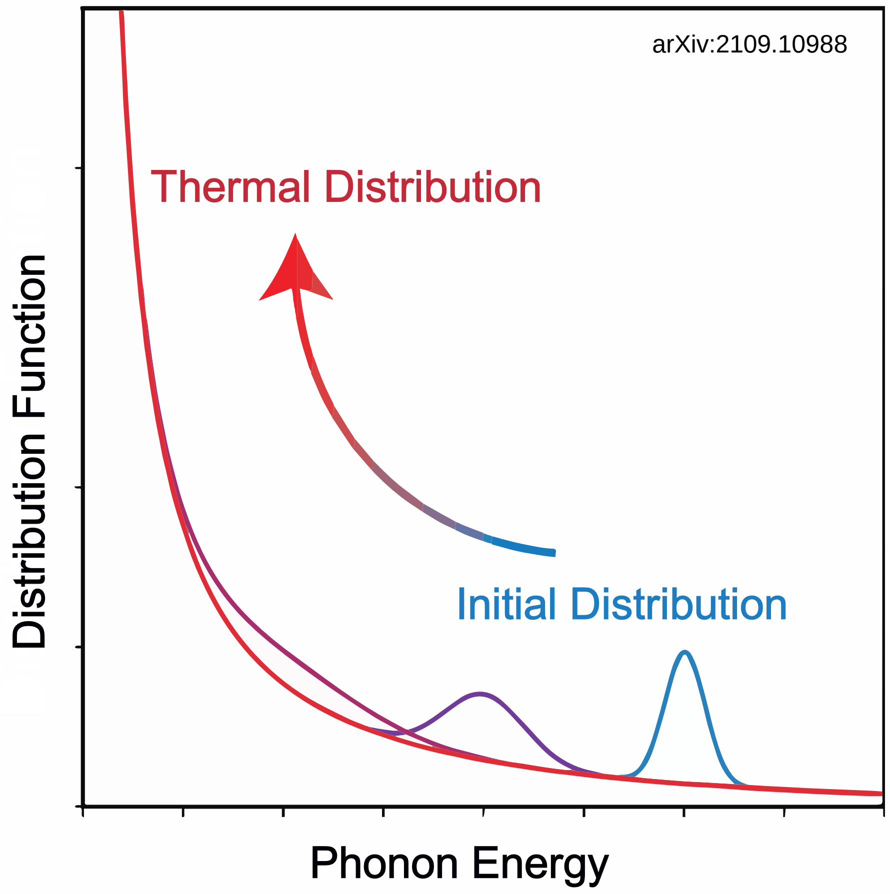


Athermal Calorimeter

- Athermal detection: Capture phonons before thermal distribution is reached

  - ✚ **Potentially much faster rise time**
  - ✚ Reduced influence of absorber heat capacity
  - ▬ **Losses due to phonon down-conversion**
  - ▬ Quasiparticle recombination loss

- Thermal detection: Wait for system to reach equilibrium



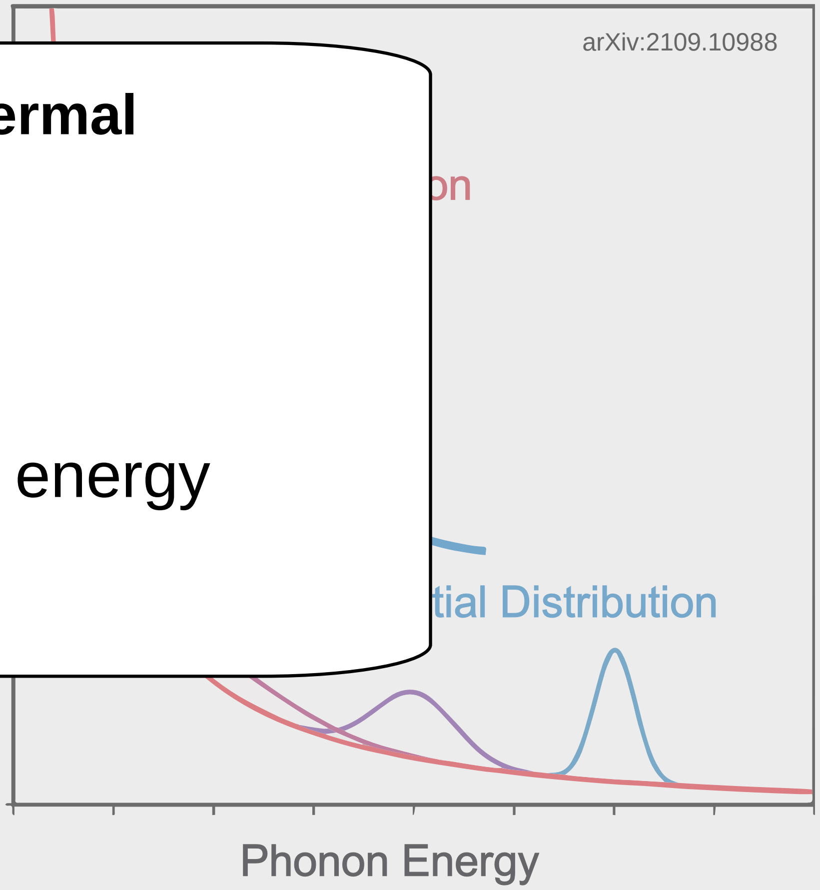
Athermal Calorimeter

- Athermal detection: Capture phonons before thermal
  - ✚ **Potentially mu**
  - ✚ Reduced influe
  - ━ **Losses due to**
  - ━ Quasiparticle re

- Thermal detecti reach equilibriu

Comparison of athermal and thermal detection

- Measurement of rise times
- Investigate the origin of low energy excess



Gradiometric Design

- Two pick-up coils, each equipped with a temperature sensor
- Both coils contribute to the signal with opposite polarity

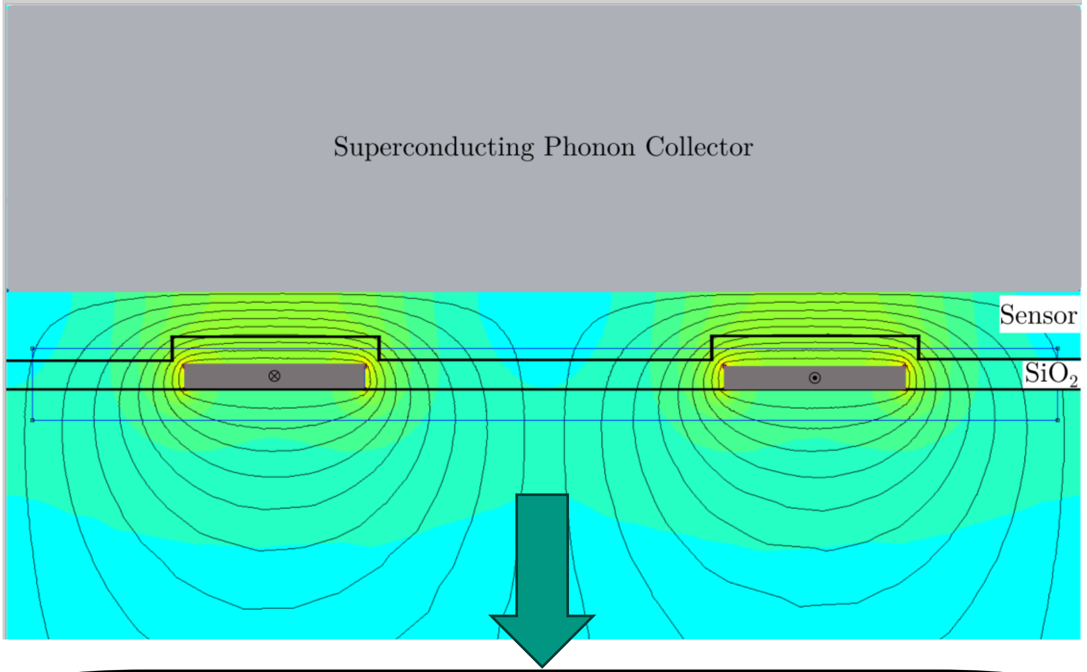
→ Cancellation of thermal contributions

→ Different design modifications allow thermal and athermal comparison

Sensor Geometry Optimization

Karlsruher Institut für Technologie

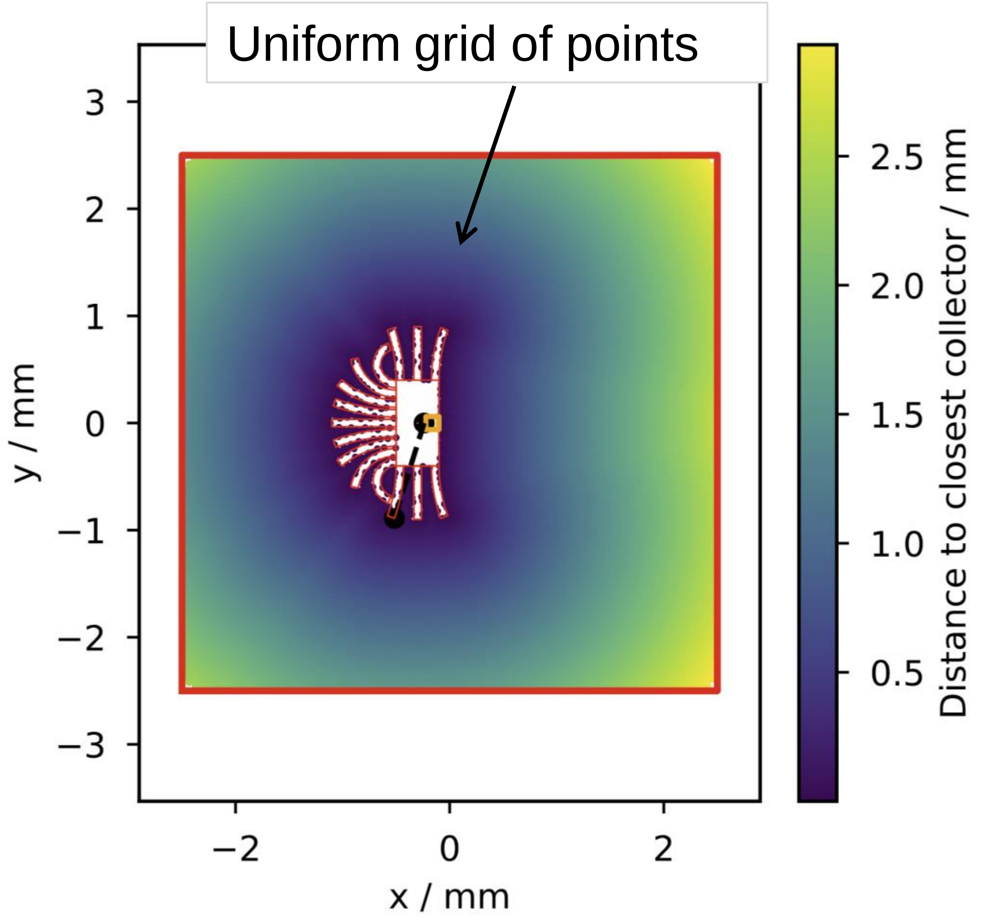
- Starting point: 5x5 mm^2 non-oxidized silicon chip
- Detector simulation to optimize sensor geometry, considering:
  - Heat capacities of detector components (e.g. crystal absorber, insulation layer).
  - *B*-field distribution in sensor layer (simulated in FEMM).



- Found sensor geometry
  - 122 x 122 x 0.54 μm^3
- Meander pick-up coil
  - w = 3 µm, p = 6 µm, d = 250 nm

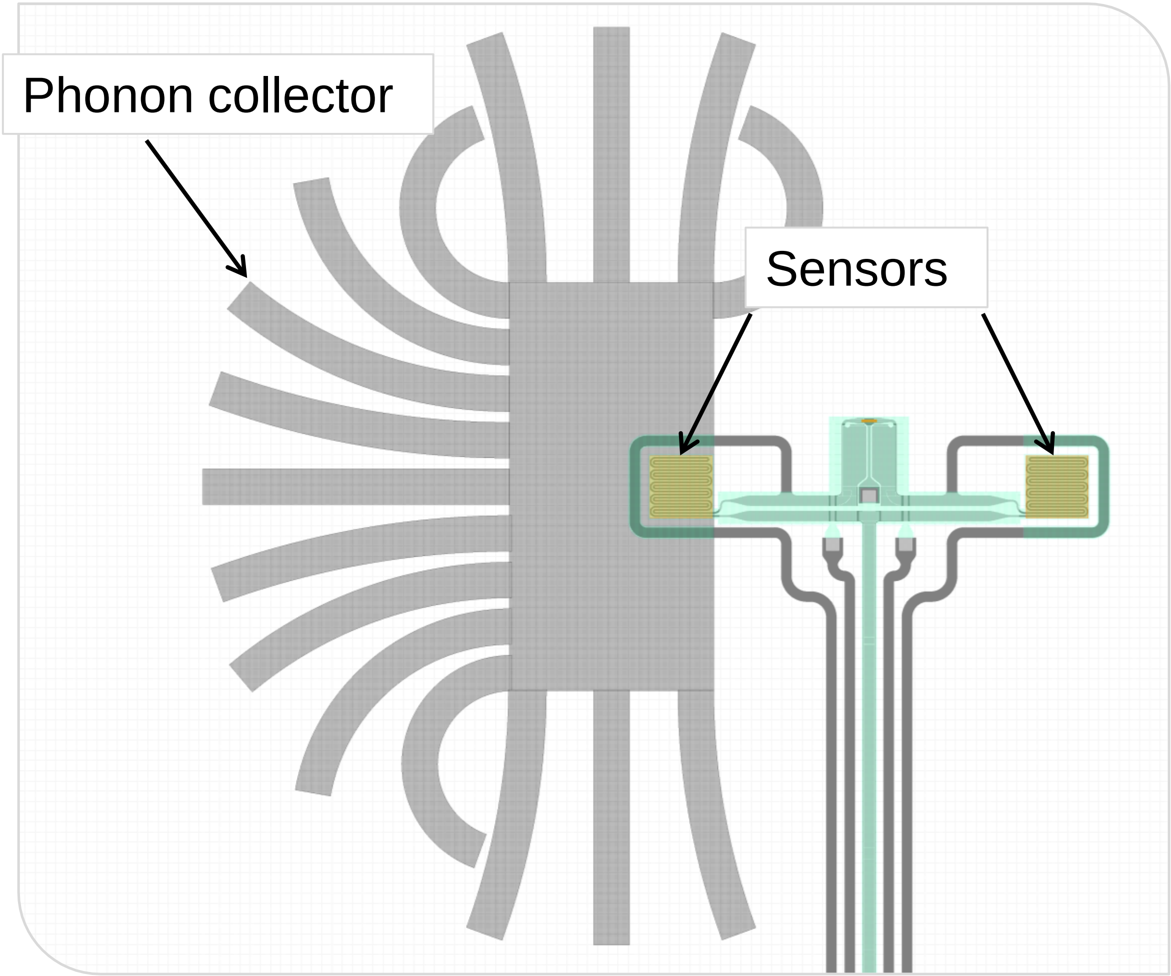
Phonon Collector Geometry Optimization

- Goal: Equal distribution of phonon collectors along the surface while minimizing the maximum distance the quasiparticles have to travel.



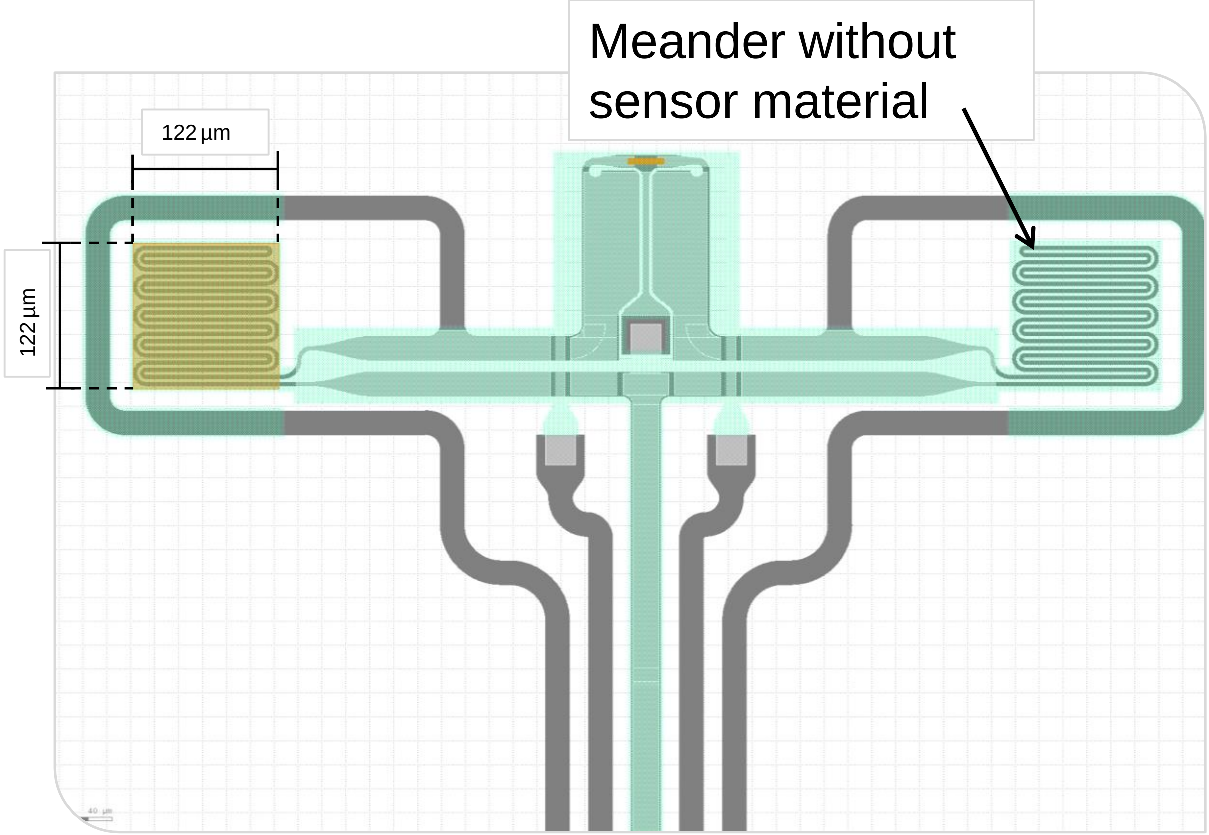
First Layout: Athermal Detector

- Gradiometric design: But one sensor is connected to a phonon collector
  - No thermal contribution
  - Purely athermal signal



First Layout: Thermal Detector

- Non-gradiometric design
  - No athermal contribution
  - Purely thermal signal

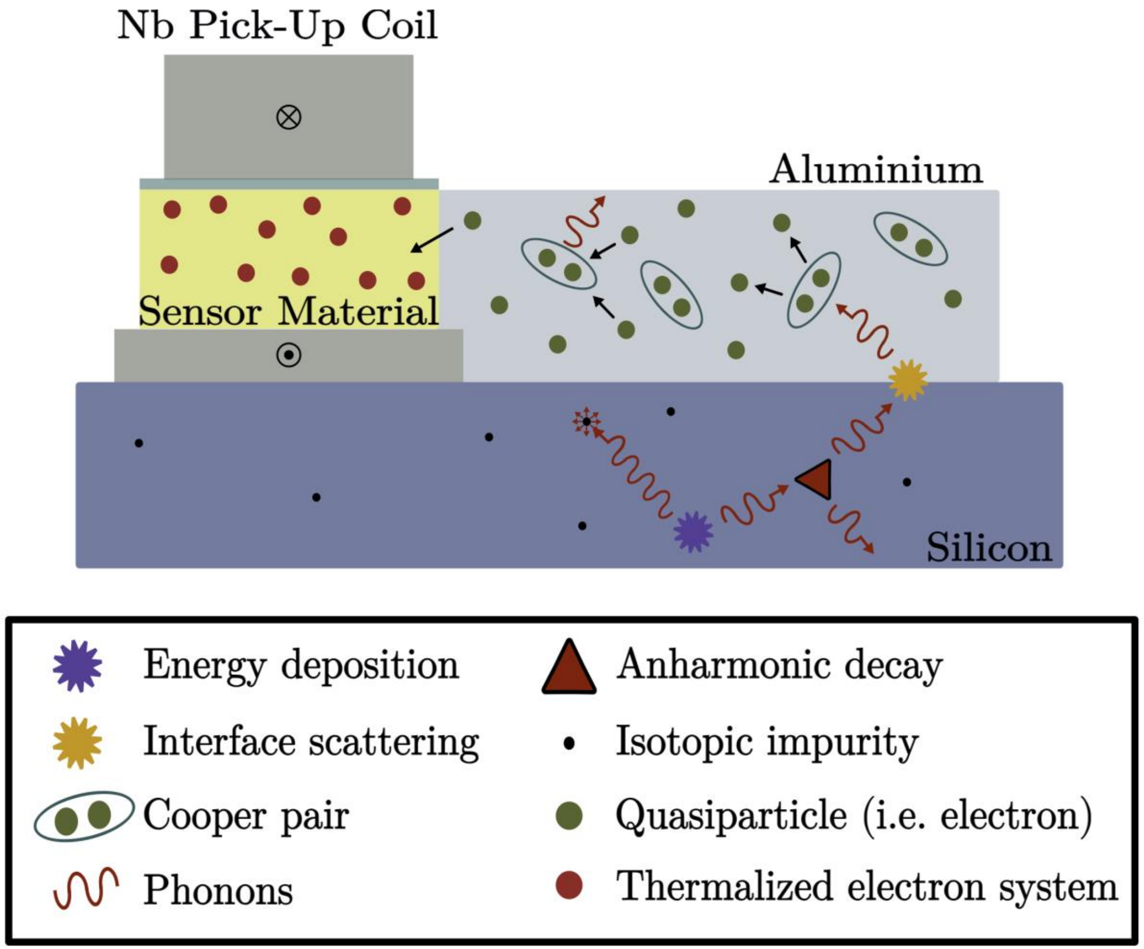


Athermal Calorimeter

- Furthermore: Investigation of quasiparticle losses needed

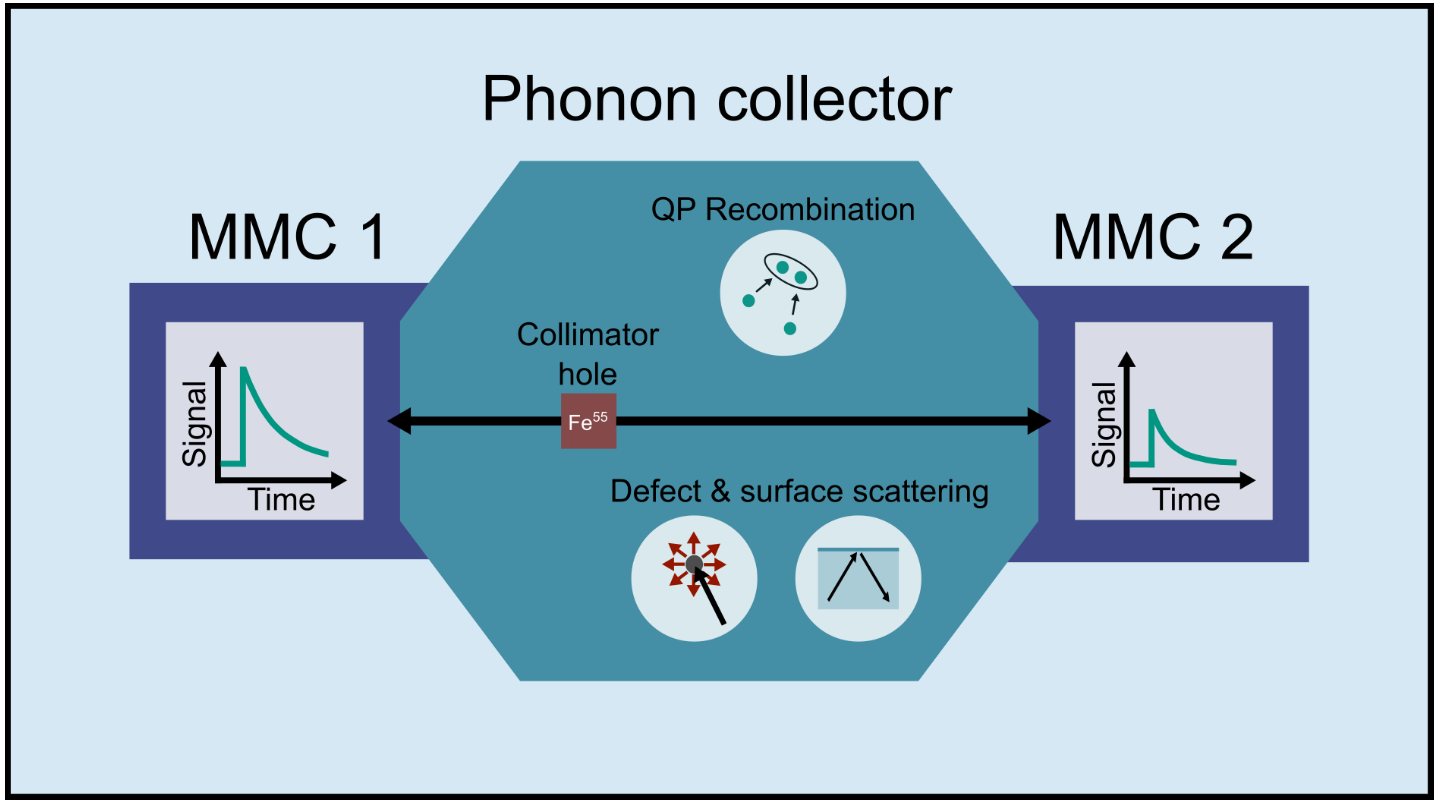
+ Potentially much faster rise time
+ Reduced influence of absorber heat capacity
− Losses due to phonon down-conversion
− **Quasiparticle recombination loss**

- Important: Quasiparticle recombination time



Quasiparticle lifetime experiment

Goal: Determination of quasiparticle lifetime in aluminum → Phonon collector optimization



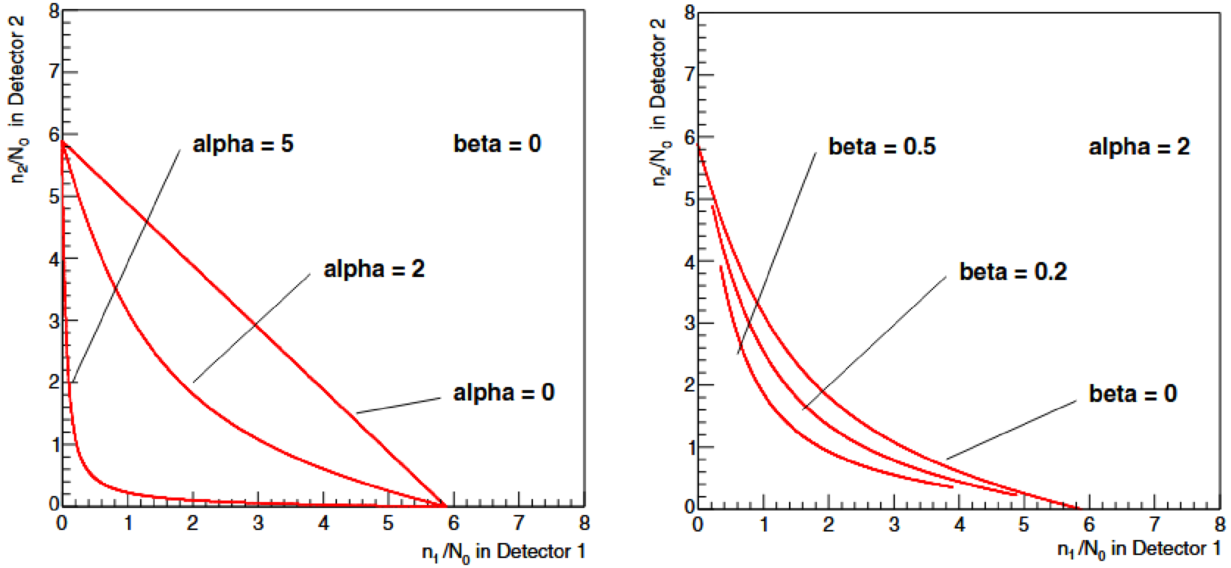
Quasiparticle lifetime experiment

- 1D diffusion equation:

$$\boxed{\frac{\delta n}{\delta t} = D\frac{\delta^2 n}{\delta x^2} - \frac{n}{\tau_{\mathrm{QP}}}}$$

n: Number of QPs
D: Diffusion constant
τ_{QP}: QP lifetime

- Ratio of detected to generated particles:



G. Angloher, …, M. Wüstrich, J Low Temp Phys **184**, 323–329 (2016)

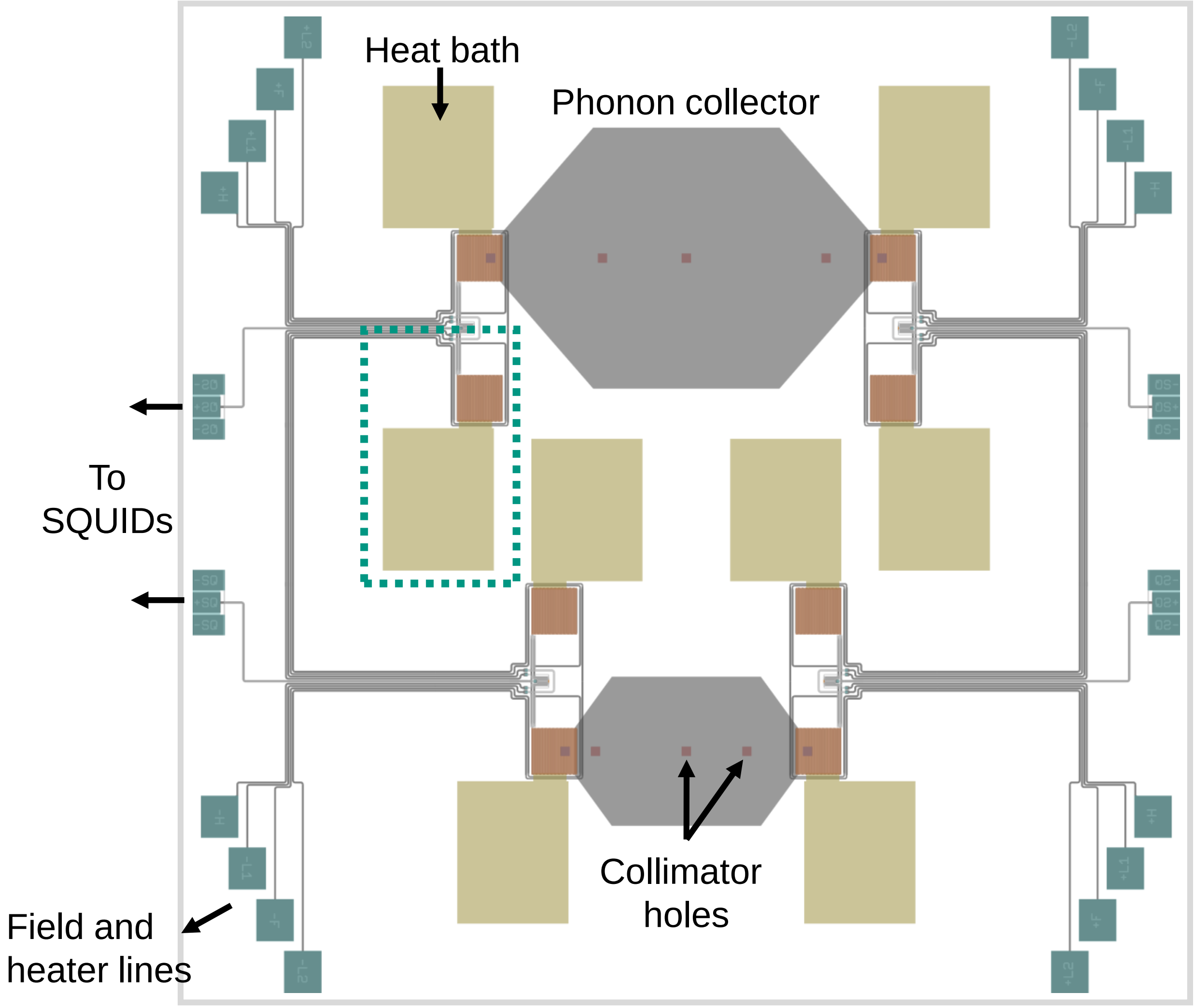
$$\boxed{\alpha = \frac{L}{l_{\mathrm{diff}}} = \frac{L}{\sqrt{D\tau_{QP}}}}$$

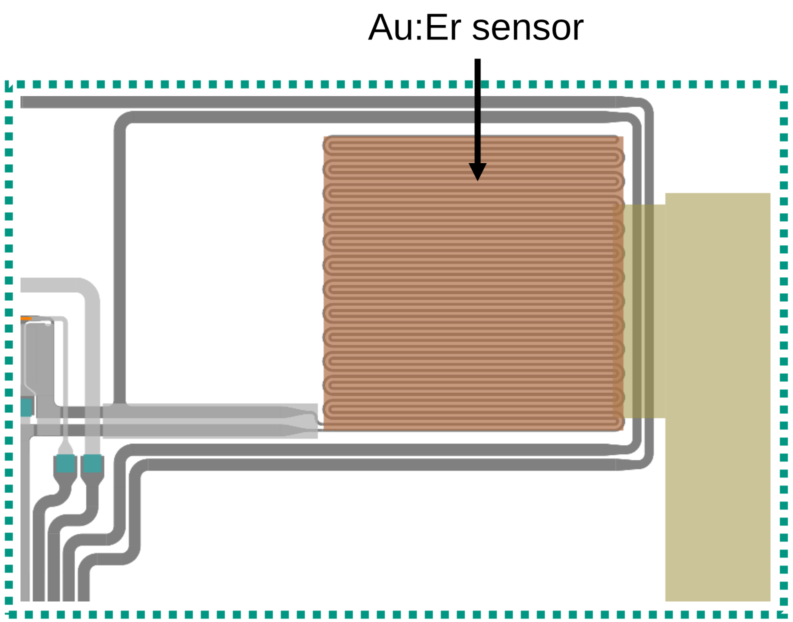
$$\boxed{\beta = \frac{\tau_{\mathrm{Tr}}}{\tau_{\mathrm{QP}}}}$$

L: Distance MMCs
l_{diff}: Diffusion length

τ_{TR}: Trapping time

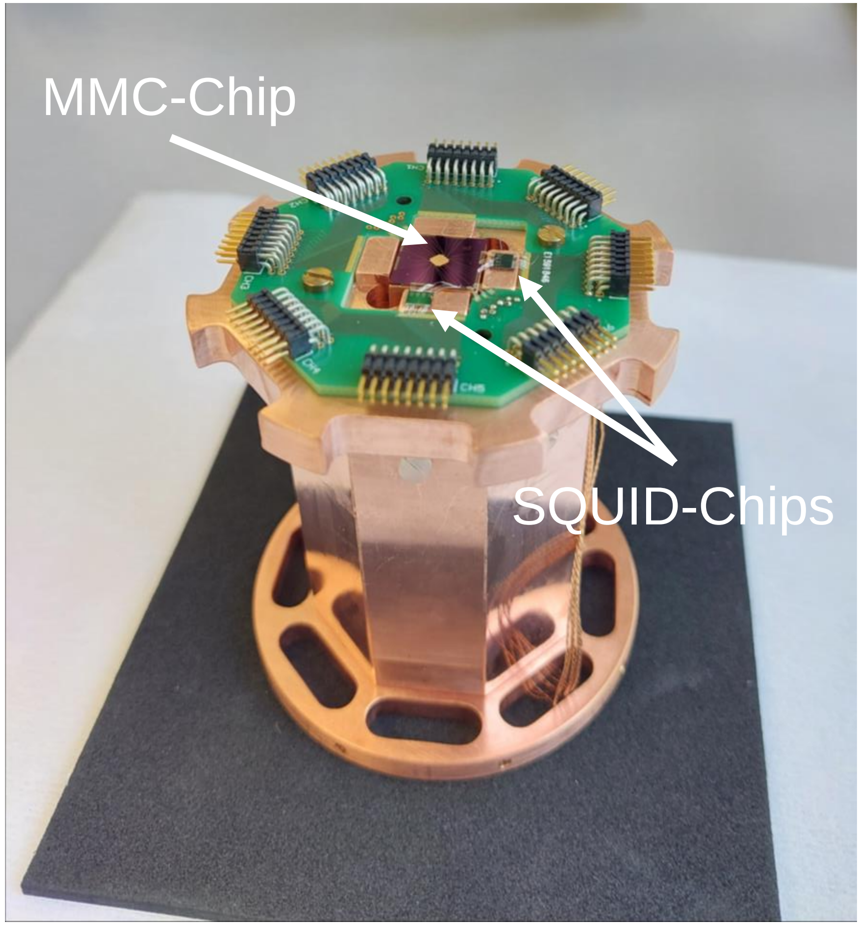
Quasiparticle lifetime experiment





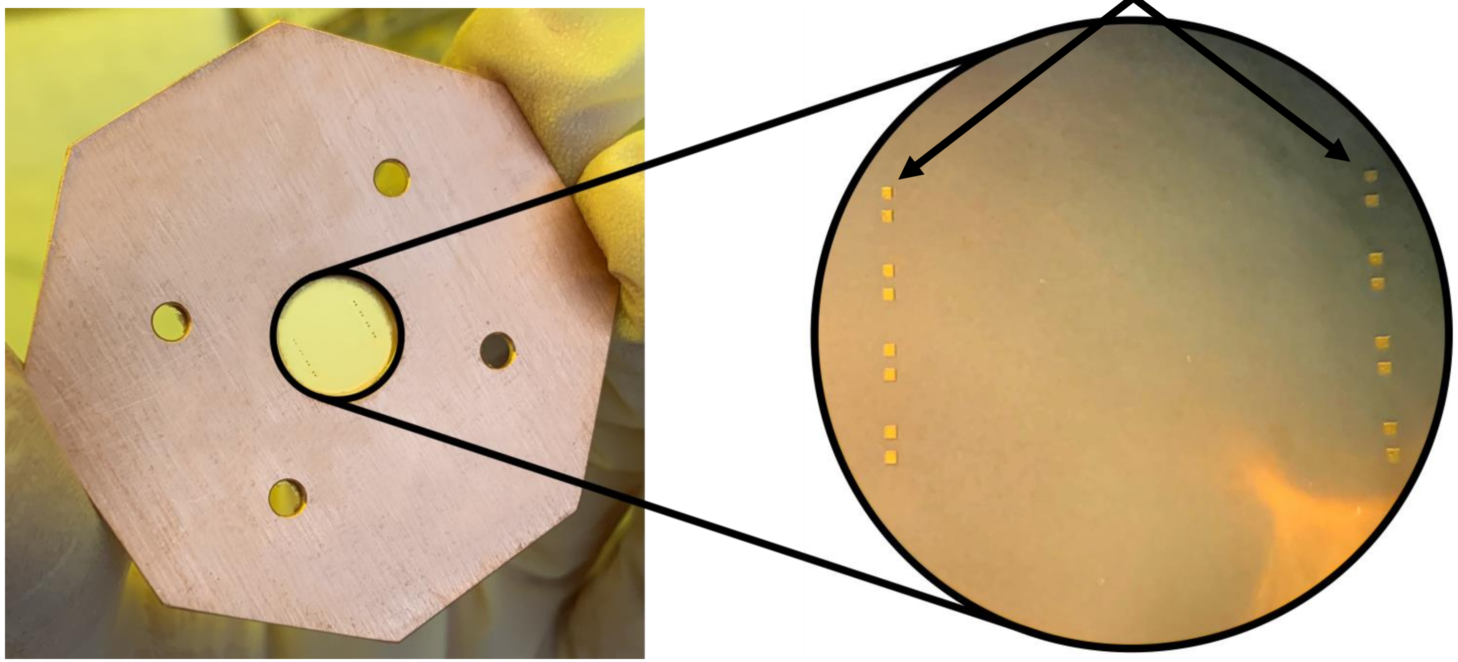
Quasiparticle lifetime experiment

QUASY measurement setup



Collimator with gold foil

Holes in gold foil



New Detector Material

- Detector gain depends on
  - evaporation energy
  - adsorption energy
- Sapphire:
  - Adsorption energy is **factor 2 higher** than on silicon
  - Smaller heat capacity
  - Transparent to IR photons

Recoil Event

↓

Phonon/Roton

↓

He-4 Evaporation

↓

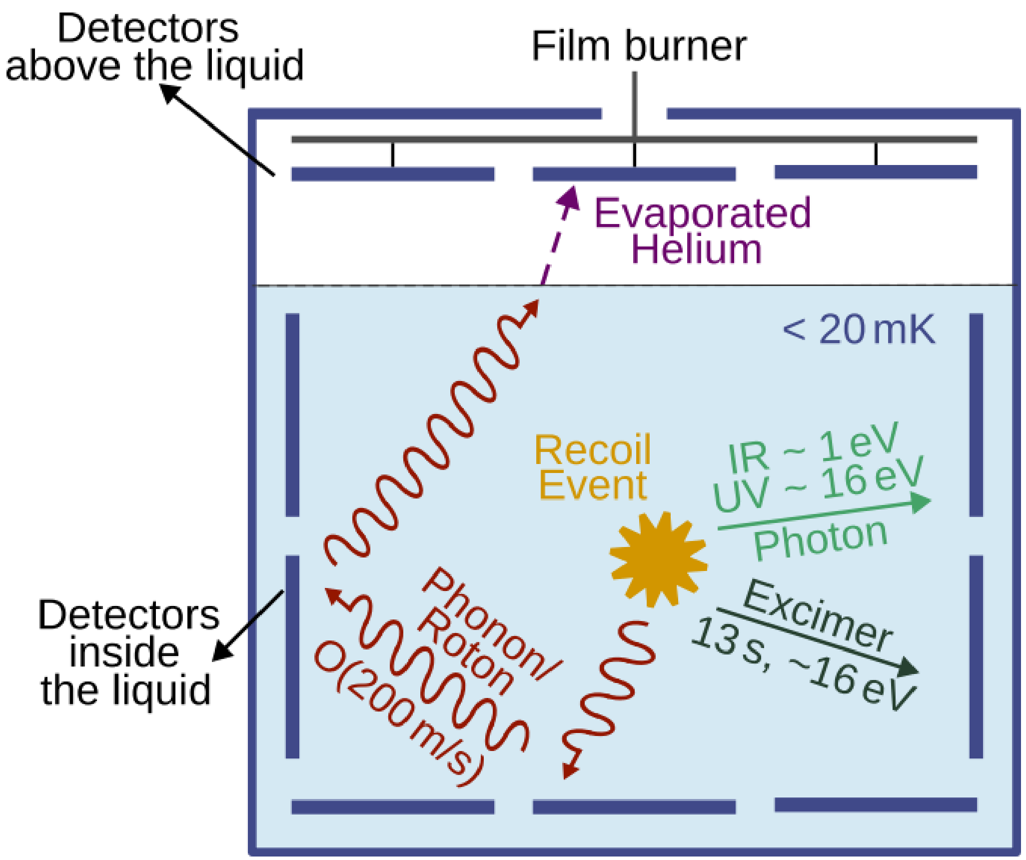
He-4 Adsorption

↓

Absorber heating

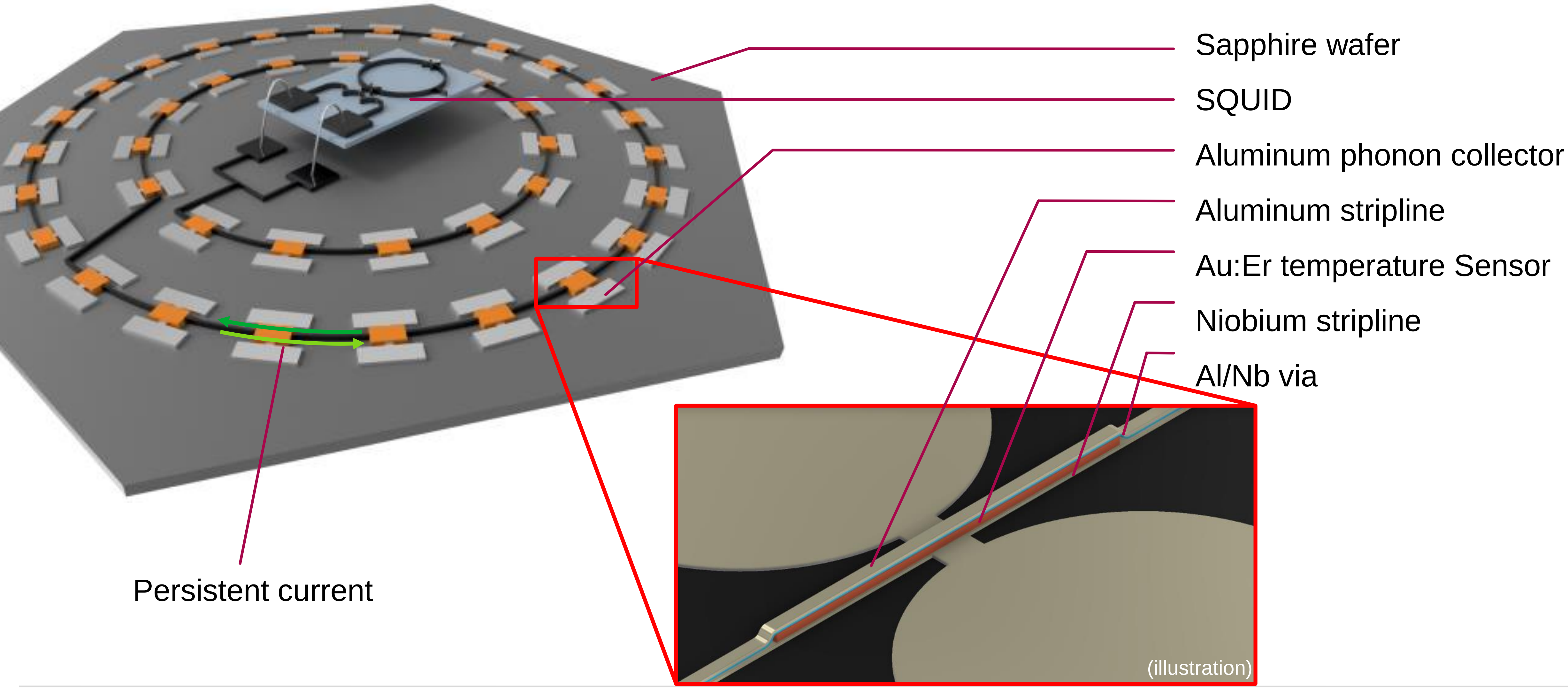
↓

Heat detection



Helium cell with superfluid ^{4}He

Conceptual Detector Structure



New Fabrication Steps

- Niobium on sapphire
- Aluminum on sapphire
- Al/Nb via on sapphire
- Gold on sapphire

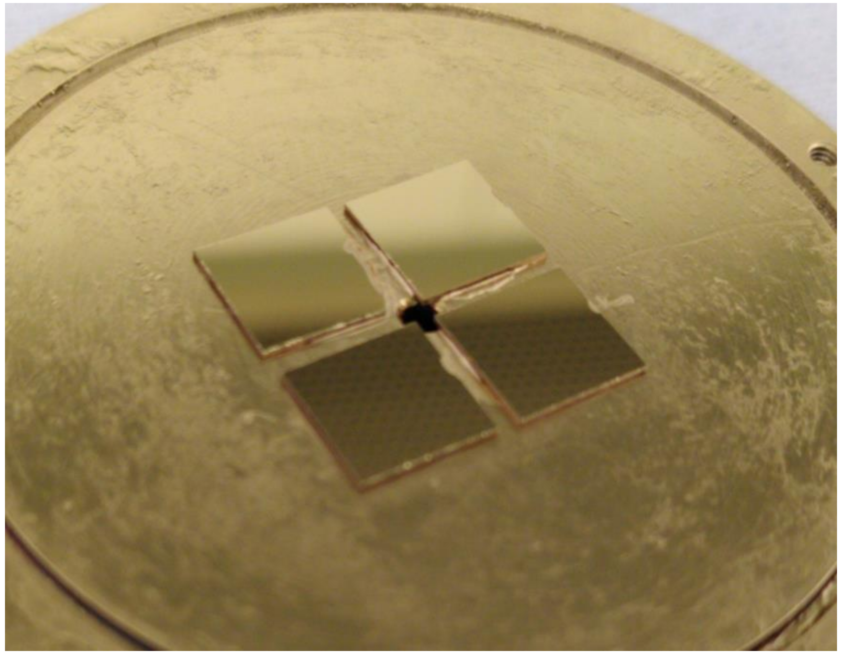
Whats important?

- Process parameters
- Adhesion
- Critical current

Achievements So Far

Adhesion testing

- Sapphire R-Plane:
  - No adhesion for niobium → no further tests ✗
- Sapphire A-Plane:
  - Niobium sticks ✓
  - Aluminum sticks ✓
  - No adhesion for gold ✗
  - Gold sticks with 2 nm Nb adhesion layer ✓

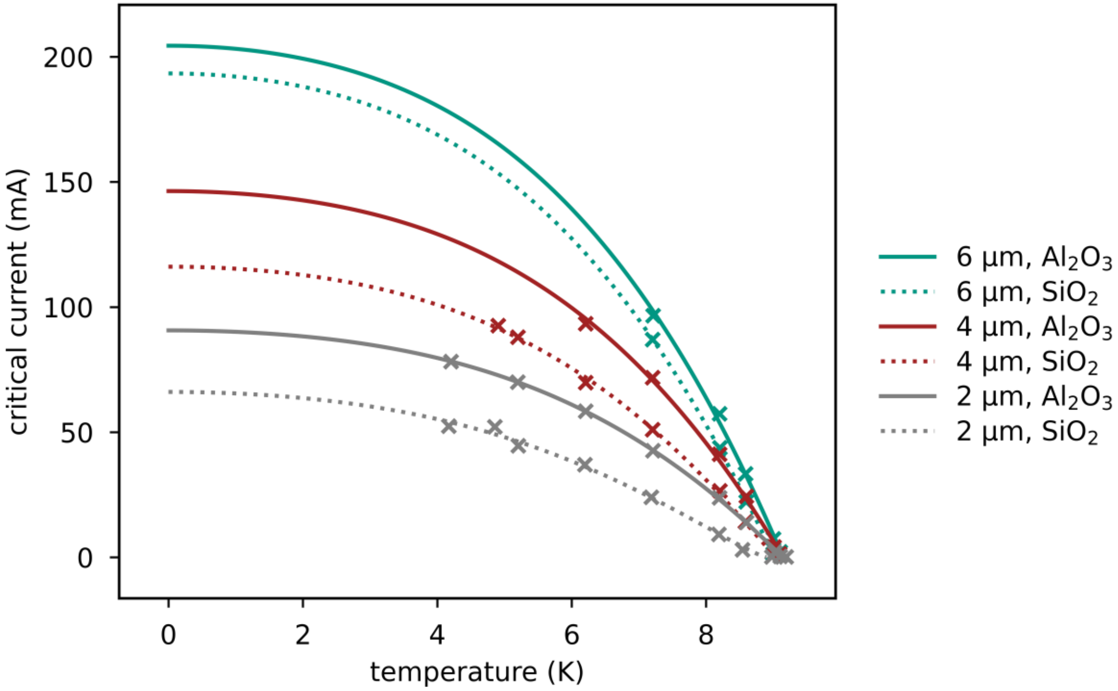


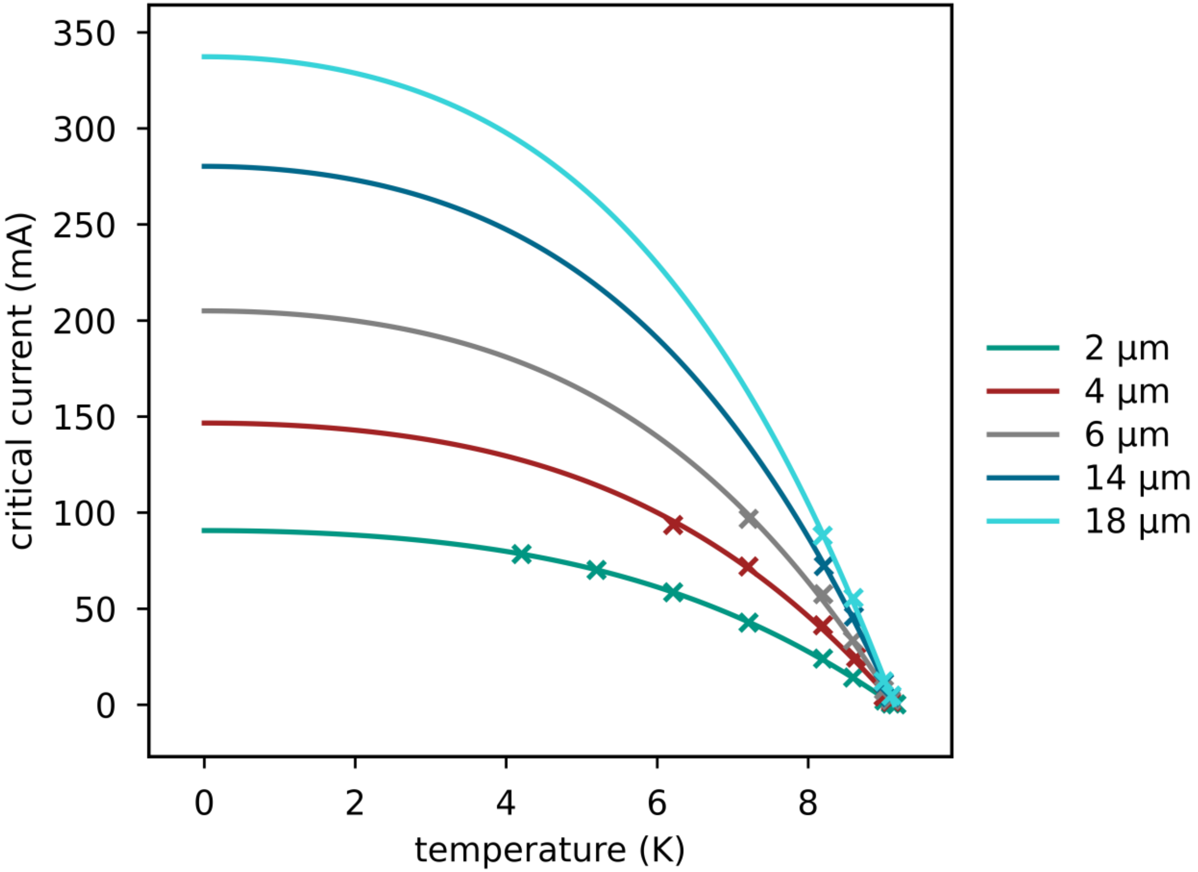
gold on sapphire

Achievements So Far

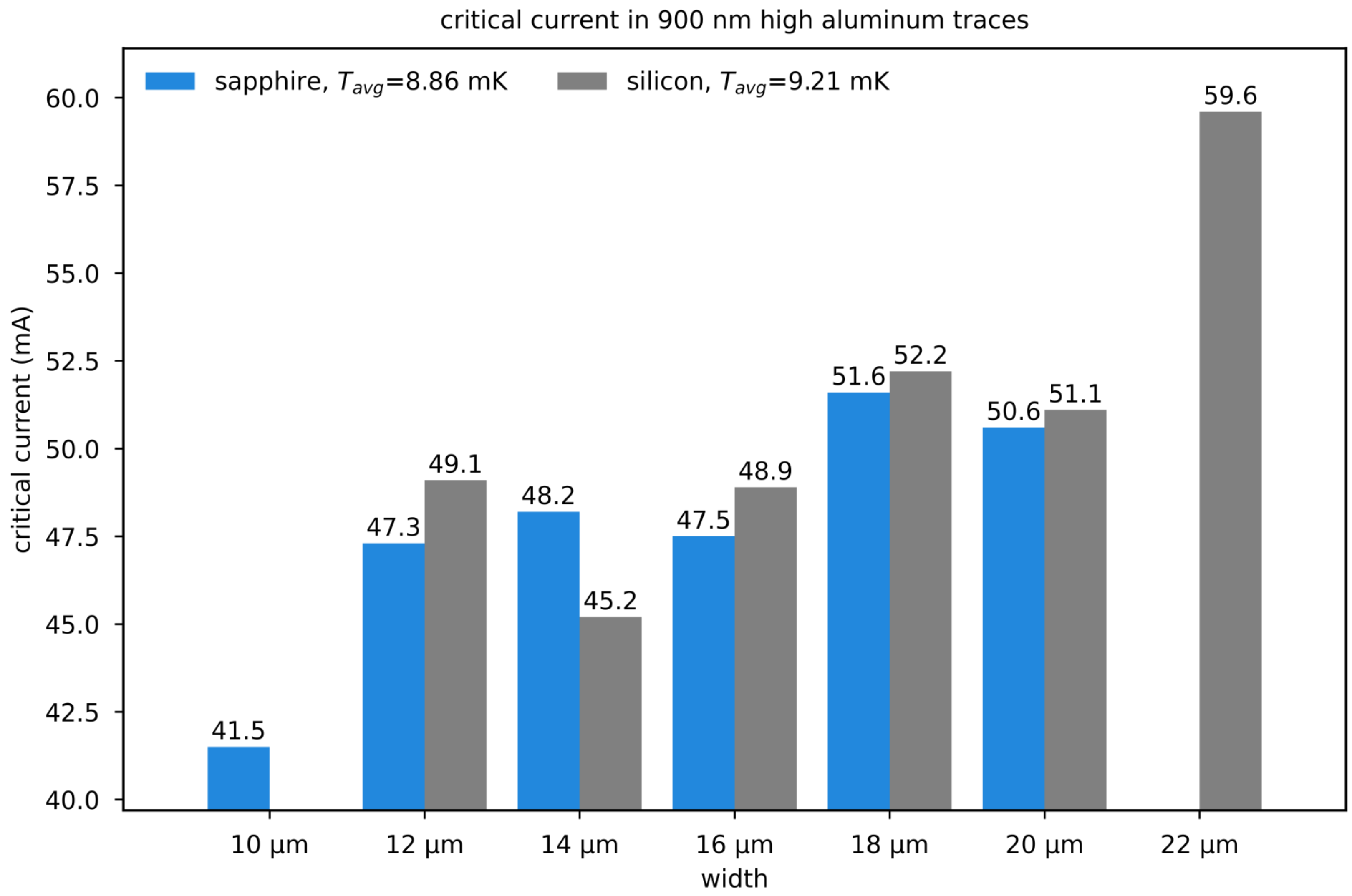
- Critical current in 200 nm high Niobium traces

$$I_c(T) = I_c(0) \cdot \left(1 - \left(\frac{T}{T_c}\right)^2\right)^{\alpha} \cdot \left(1 + \left(\frac{T}{T_c}\right)^2\right)^{\frac{1}{2}}$$

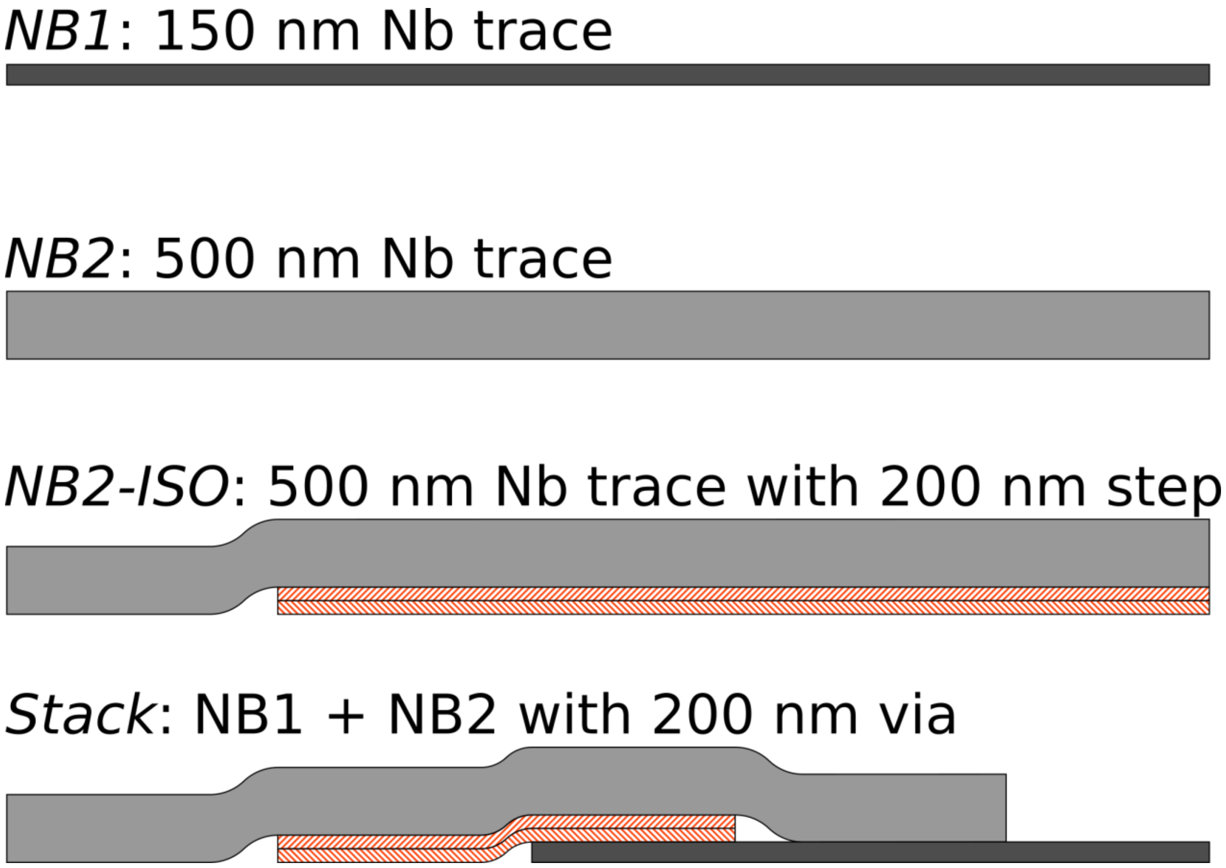


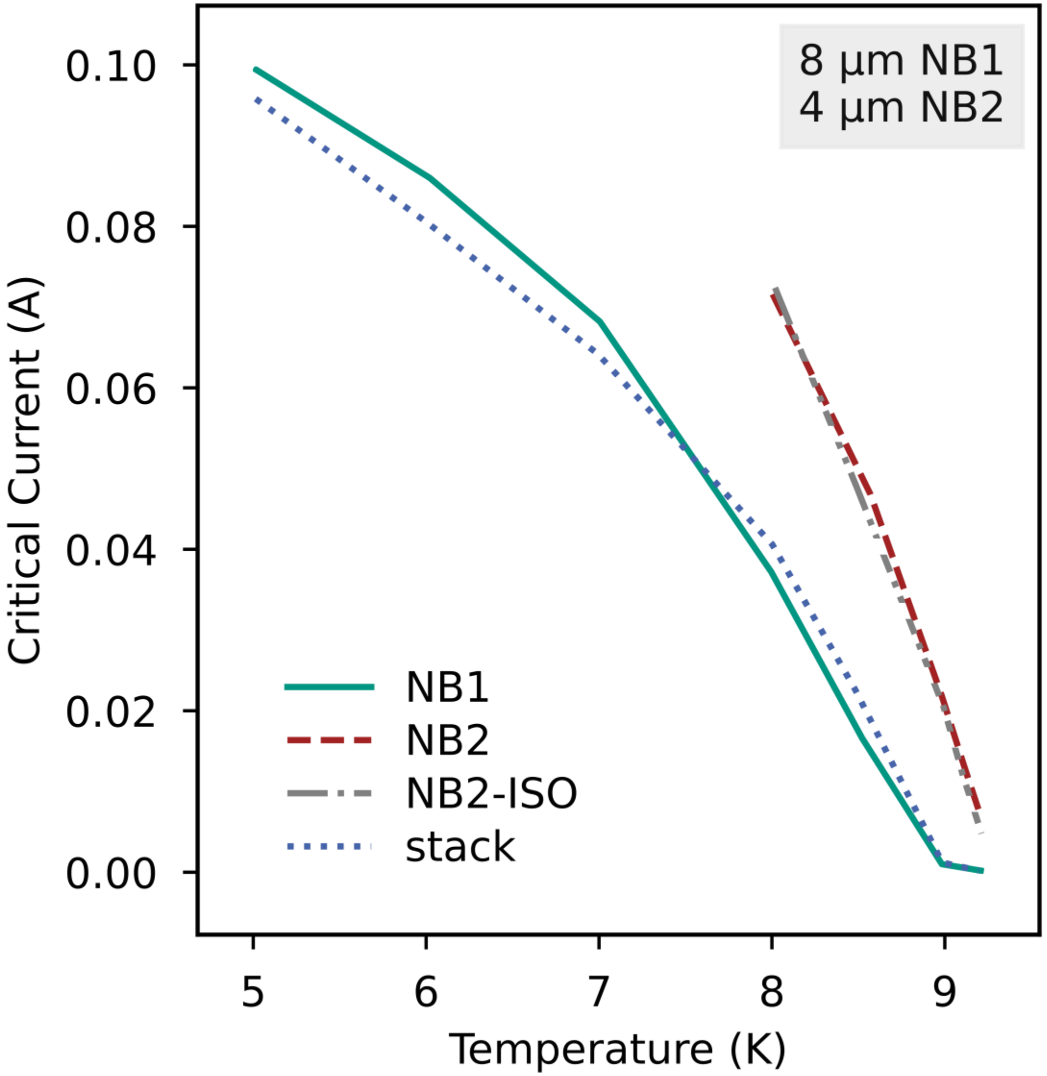


Achievements So Far

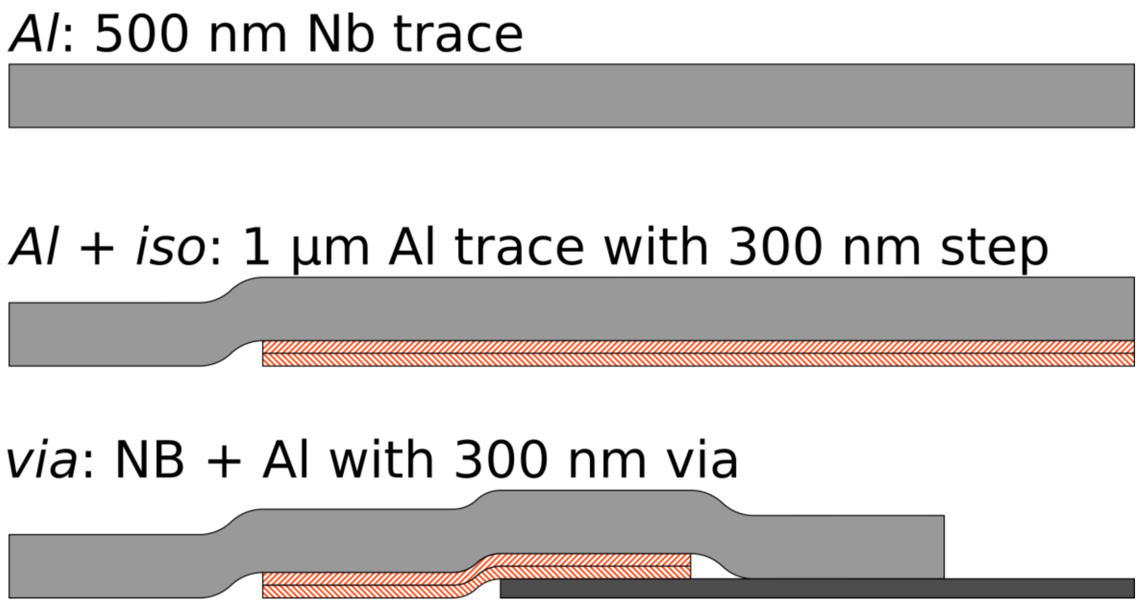


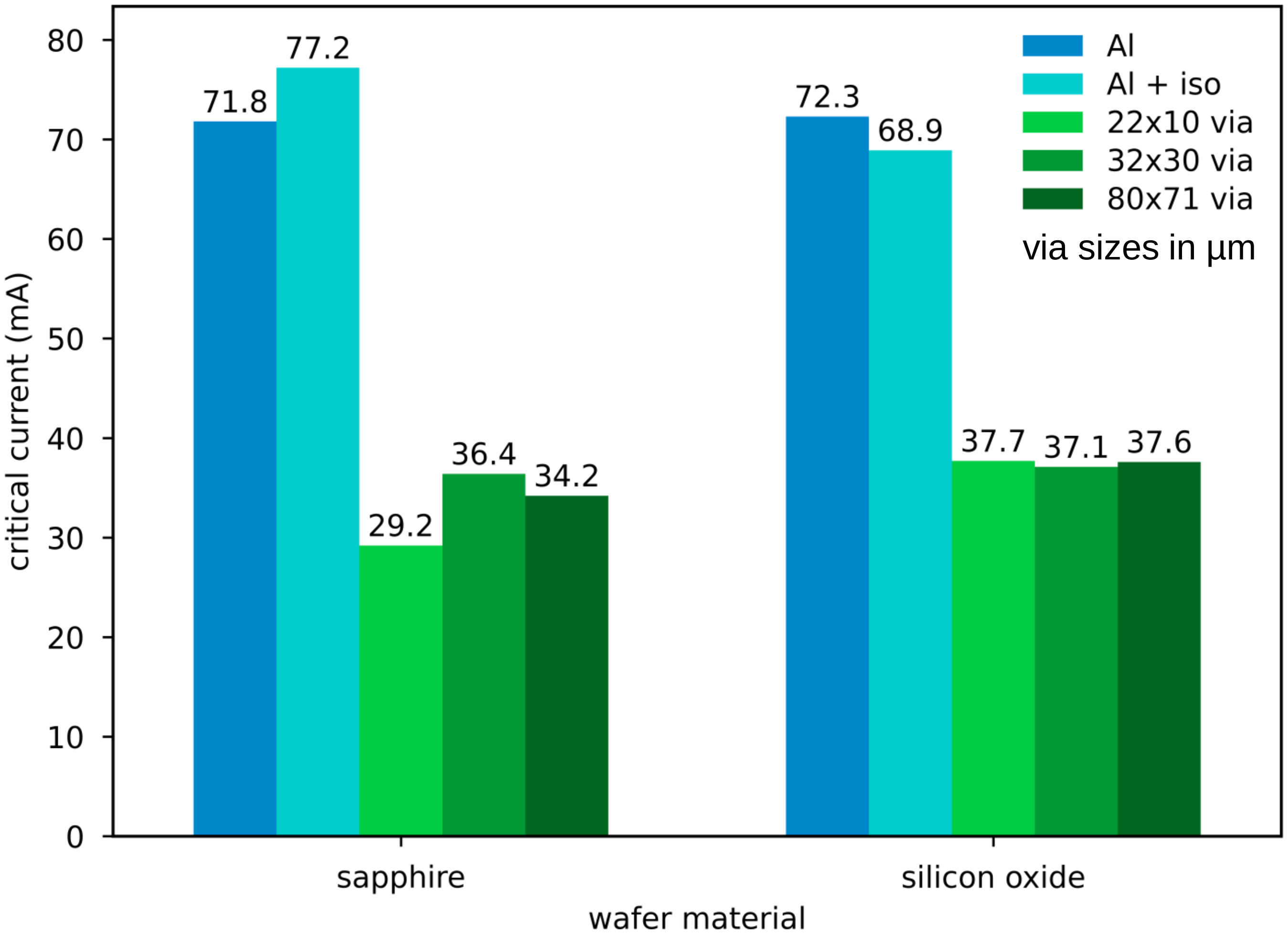
Niobium-Niobium via





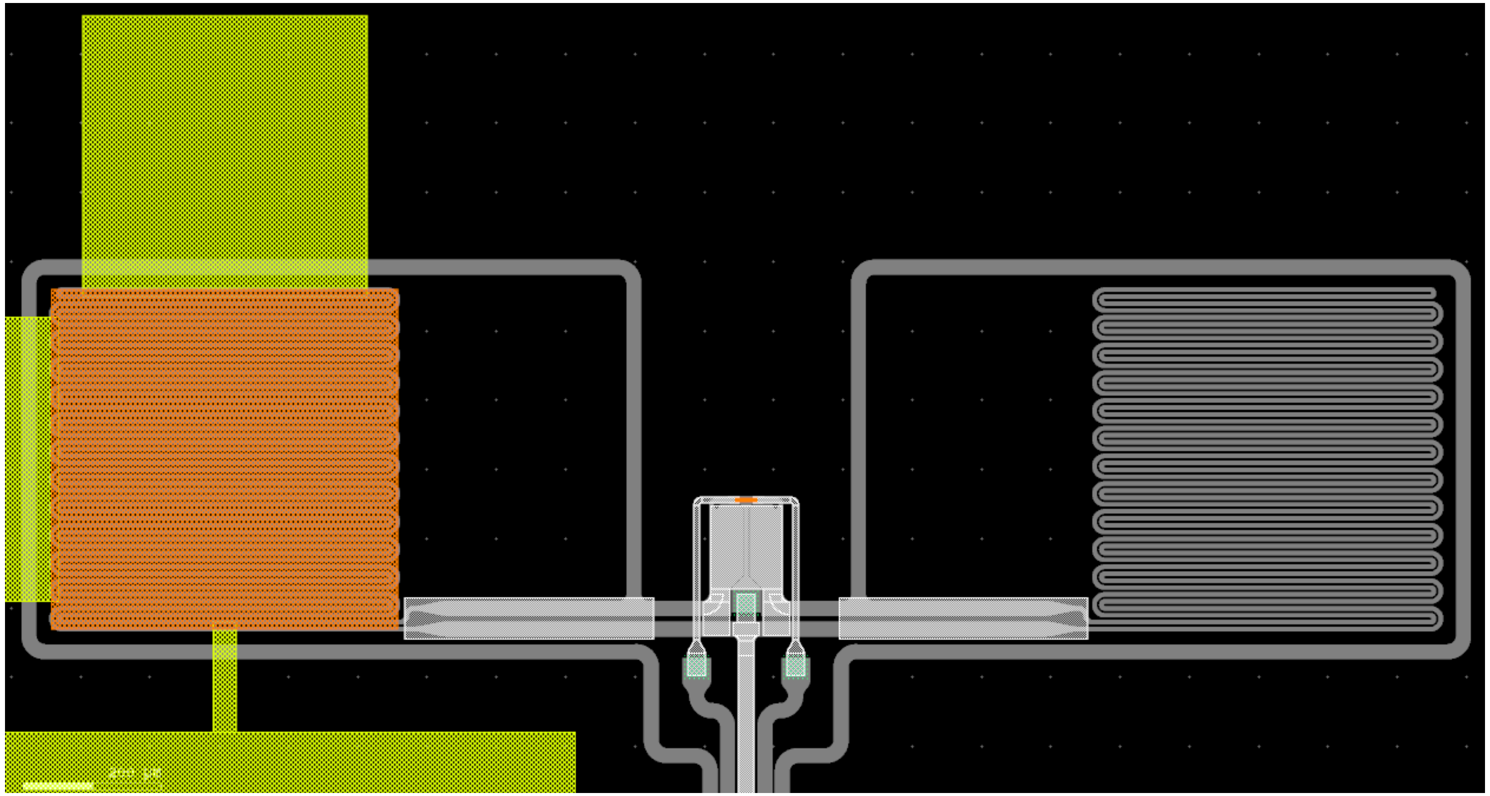
Niobium-Aluminum via





Further Goals

- Introducing persistent superconducting current
- Full MMC on sapphire



Preliminary design for magnetization measurement

New measurement setup

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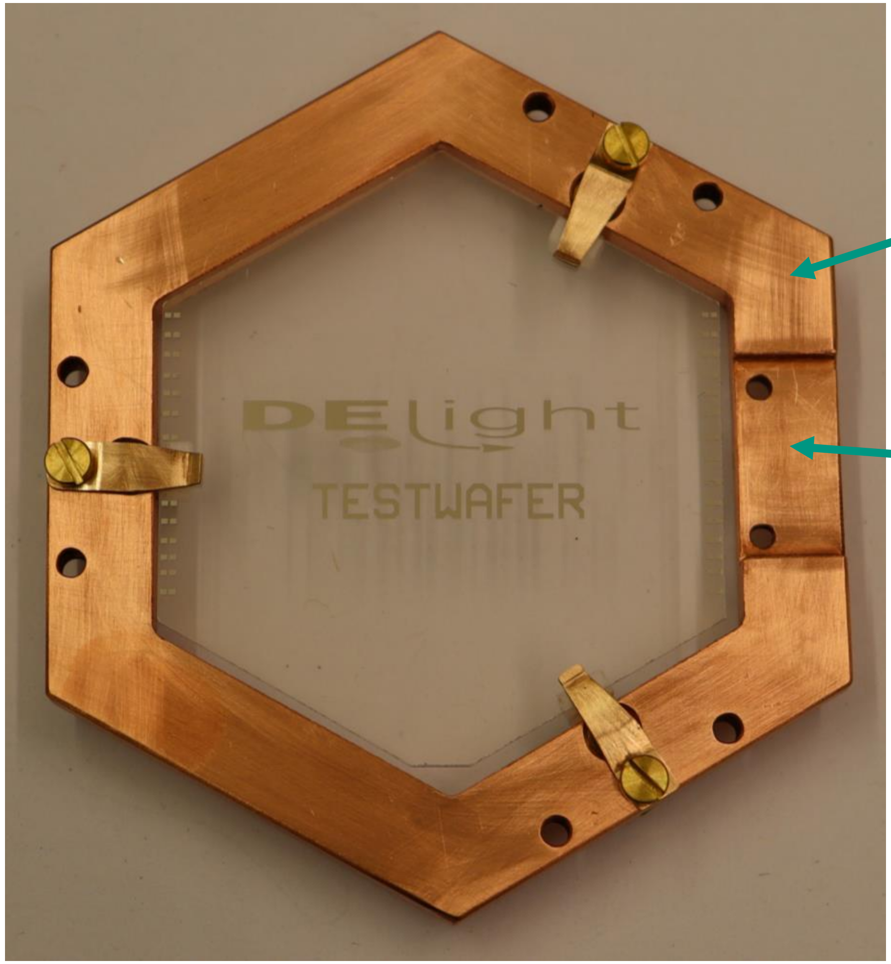
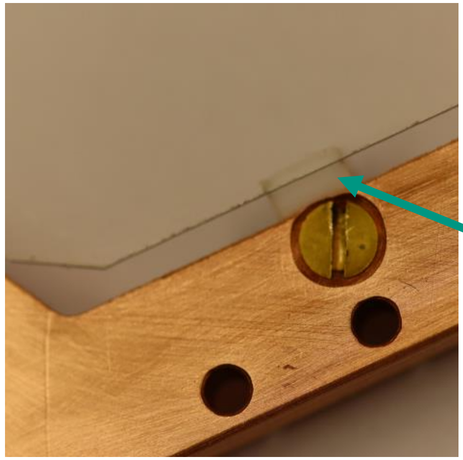
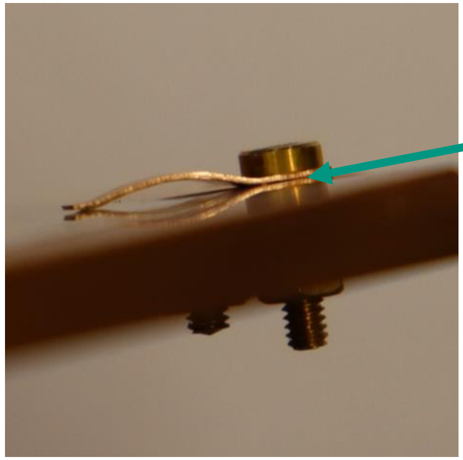


Oxygen-free copper

Circuit-board & SQUID space



Teflon piece



Copper clip

Summary, conclusion and outlook

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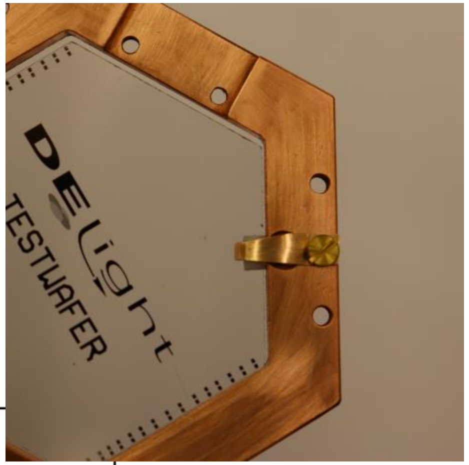
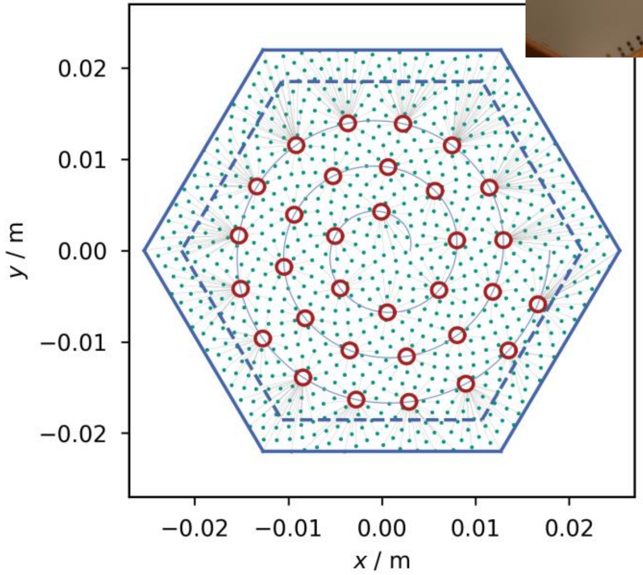
Summary:

- Comparison of thermal and athermal signal
- QP lifetime determination
- Fabrication on sapphire
- New measurement setup

Outlook:

- Detector optimization (Phonon collector size, …)
- First hexagonal wafer calorimeter prototype on sapphire





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