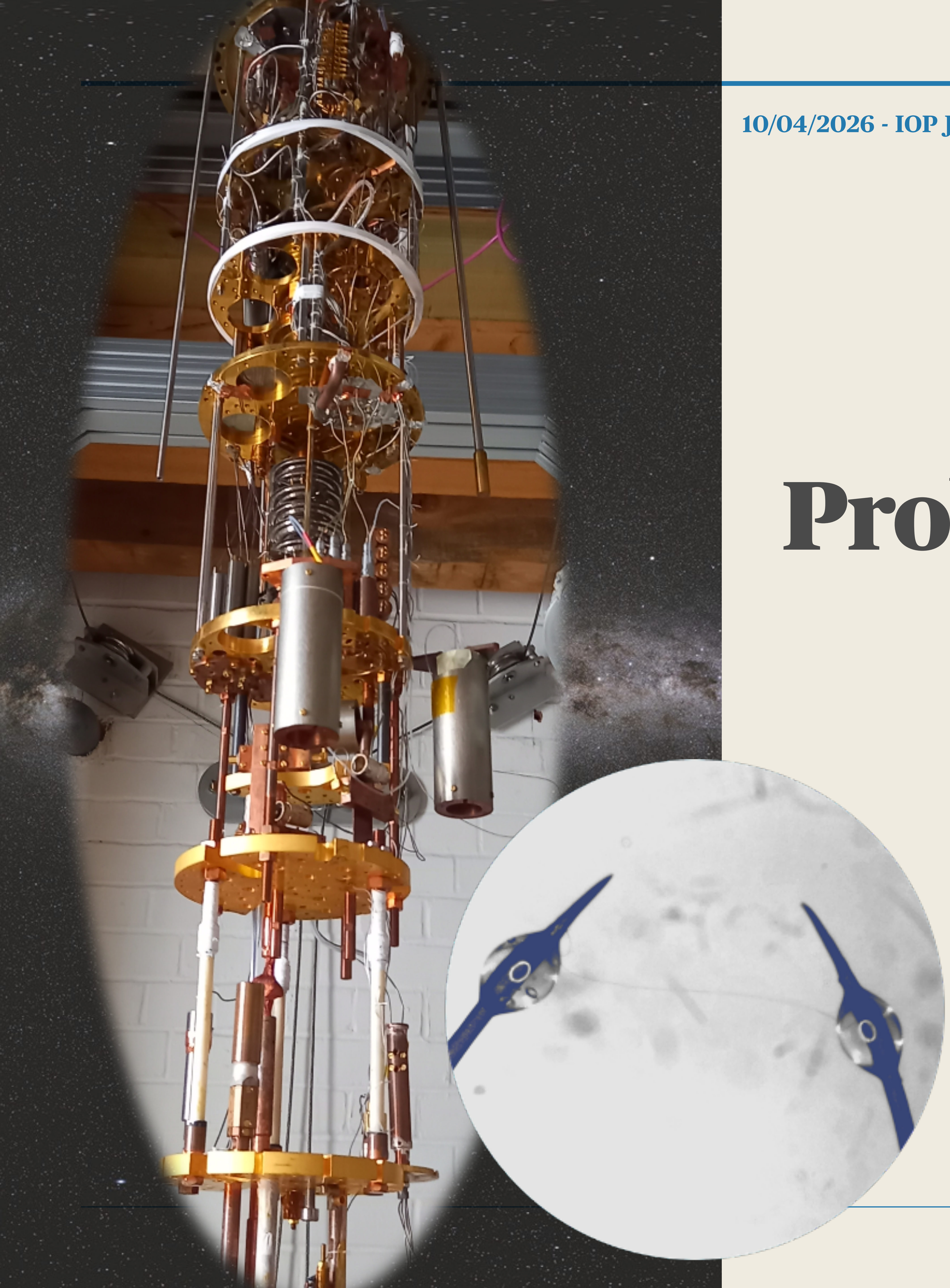


Probing Low Mass Dark Matter with Superfluid Helium-3

Elizabeth Bloomfield
- ON BEHALF OF QUEST-DMC COLLABORATION

UNIVERSITY OF OXFORD

ROYAL HOLLOWAY UNIVERSITY OF LONDON

QUEST DMC

Quantum Enhanced Superfluid Technologies for Dark Matter & Cosmology

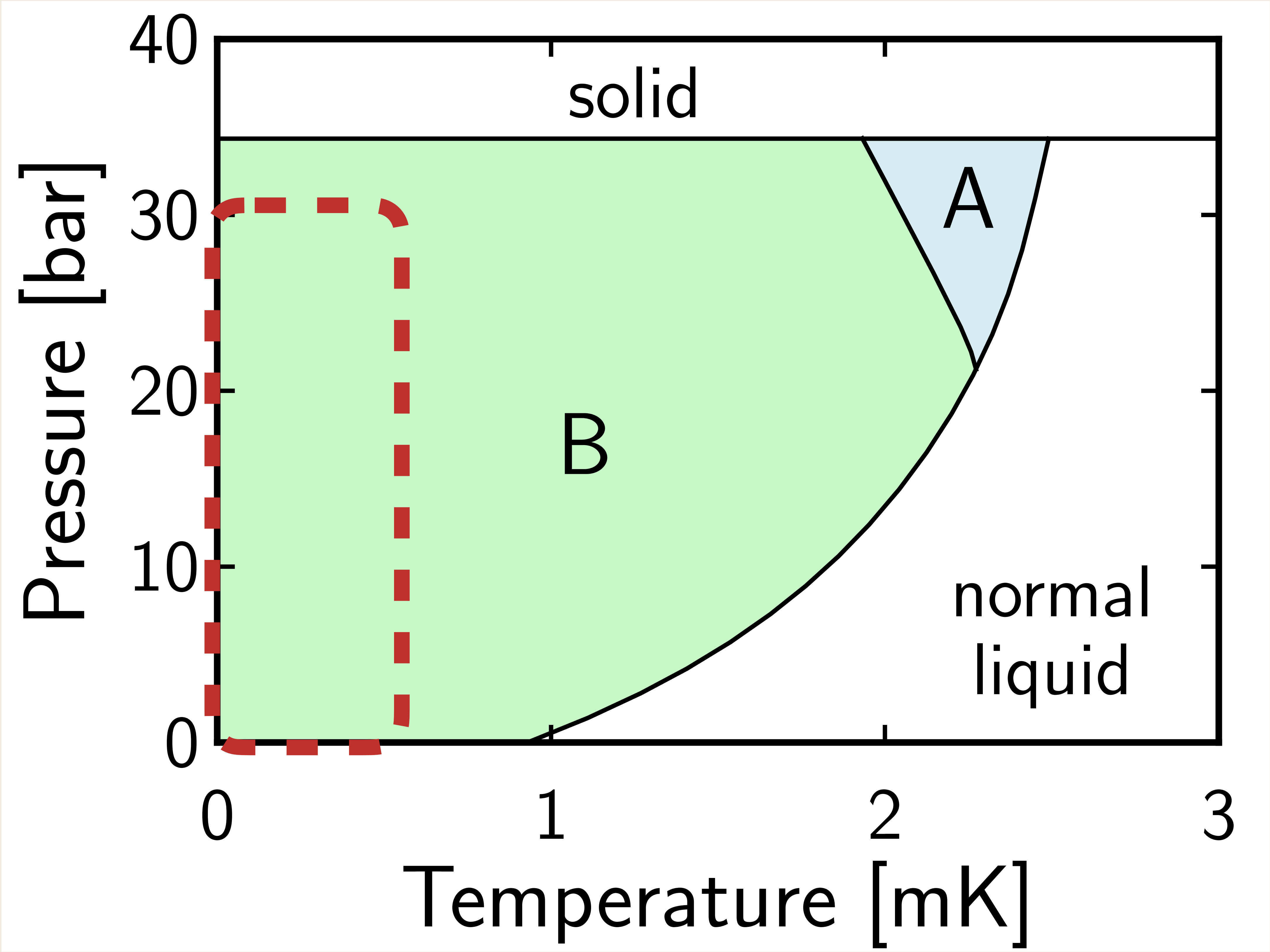
Royal Holloway University of London
Oxford Instruments
SQMS Superconducting Quantum Materials & Systems Center
University of Oxford
University of Sussex
University of Liverpool
Lancaster University
NPL National Physical Laboratory
UKRI Engineering and Physical Sciences Research Council
Science & Technology Facilities Council
UKRI Science and Technology Facilities Council
EMP

QUEST DMC

1. **Detection of sub-GeV dark matter with a quantum-amplified superfluid ^{3}He bolometer.**
2. Phase transitions in extreme matter, relevant to cosmology and gravitational wave production.

Why Superfluid Heluim-3?

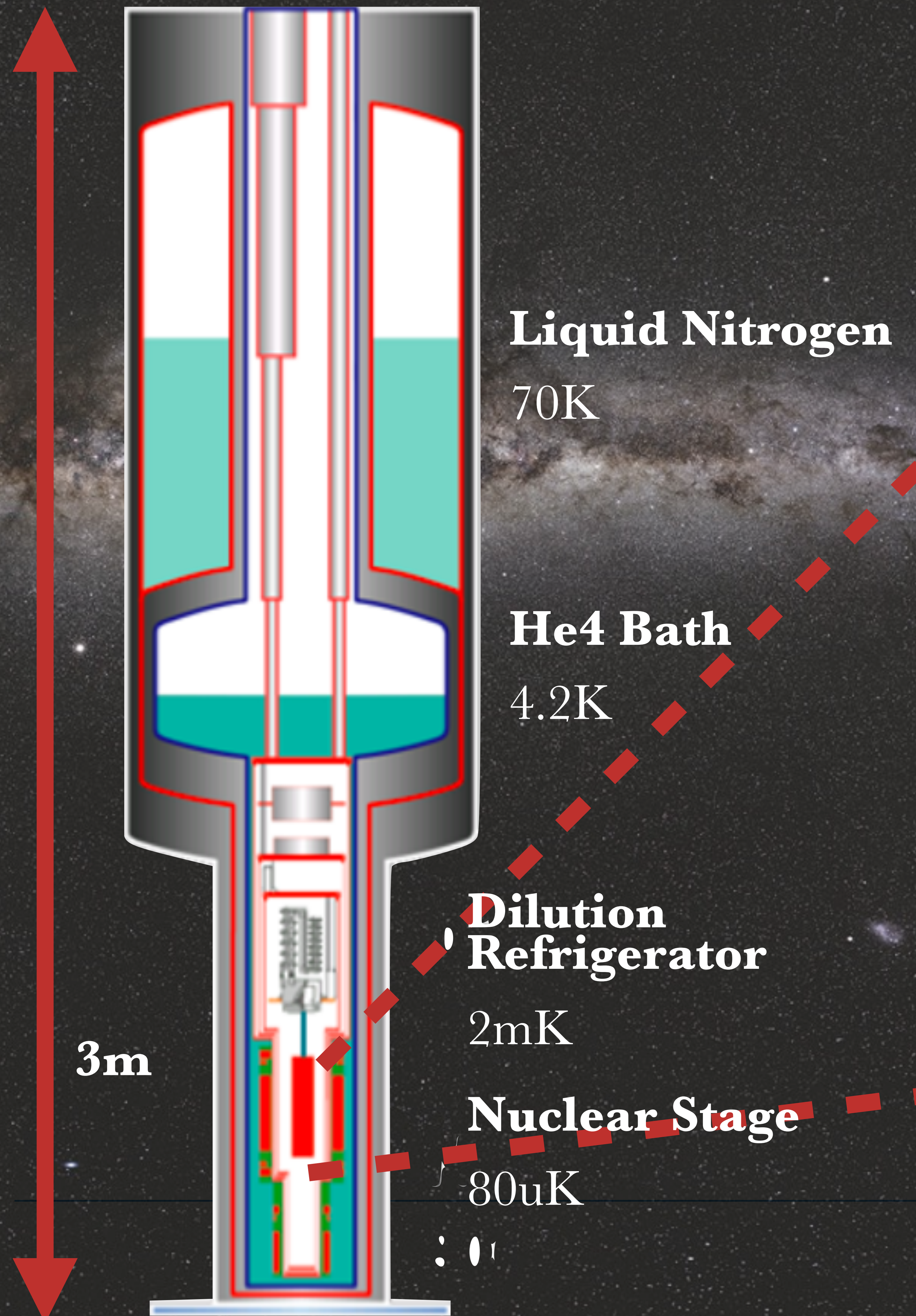
- **Properties**: good kinematics, radiopurity, & light yield
- Helium-3 atoms **follow fermi dirac stastics** — Cooper pairing of He atoms superfluid <2mK
- Energy $\Delta \sim 10^{-7}$eV required to break Cooper pairs and give single quasiparticles (QPs)

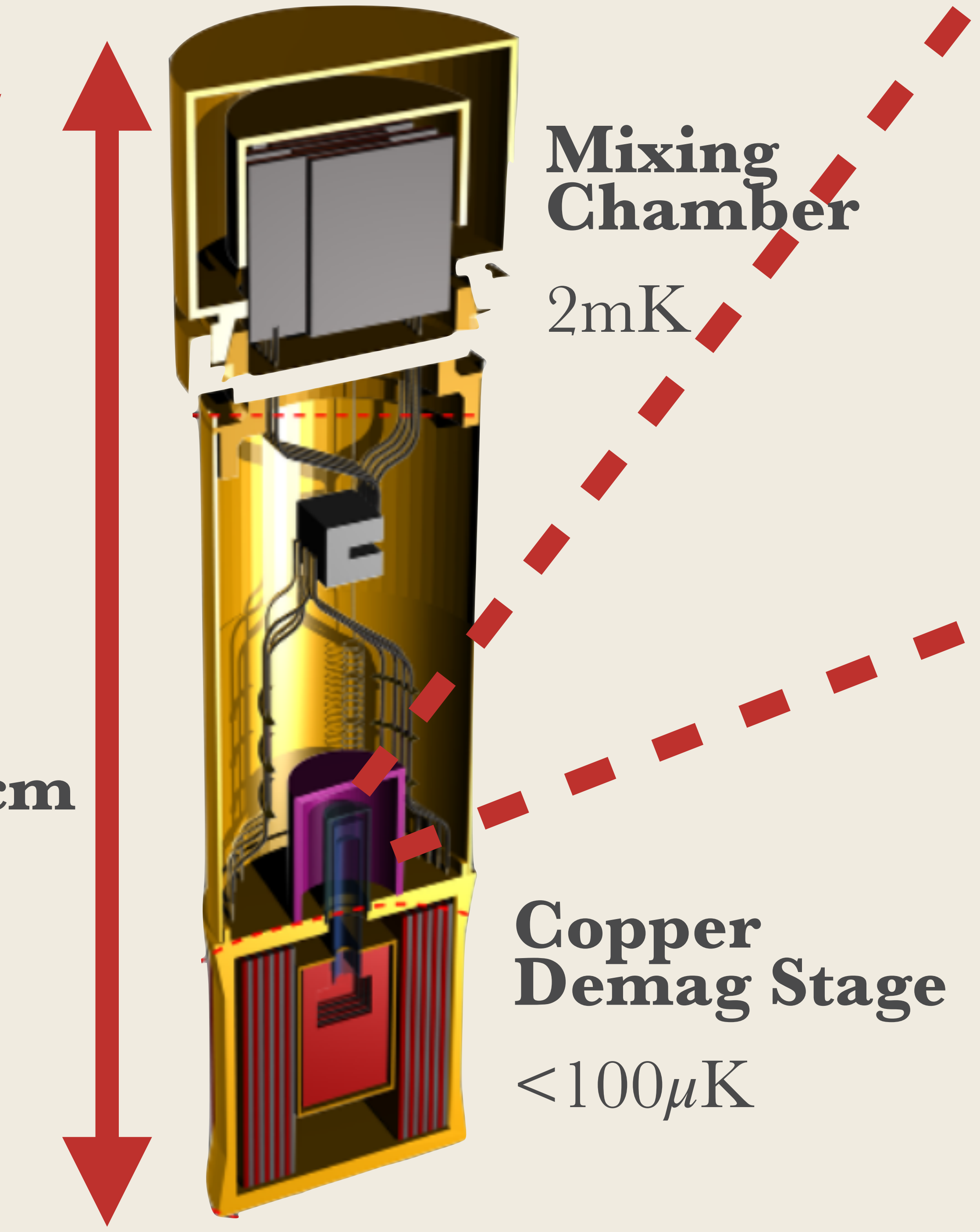


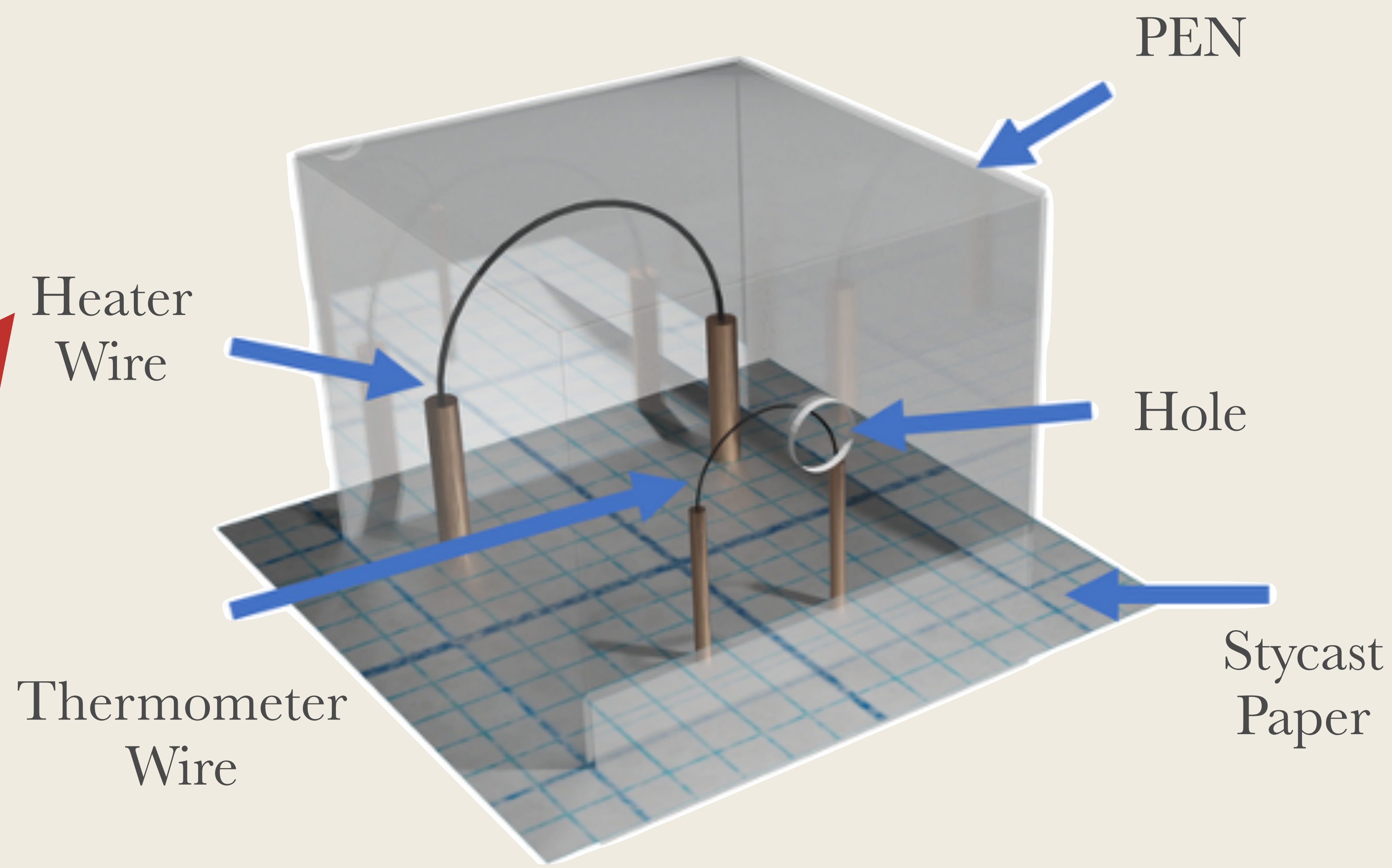
Bonus:

Unpaired nucleon available for Spin Dependent DM-Nucleon Interactions

The Detector





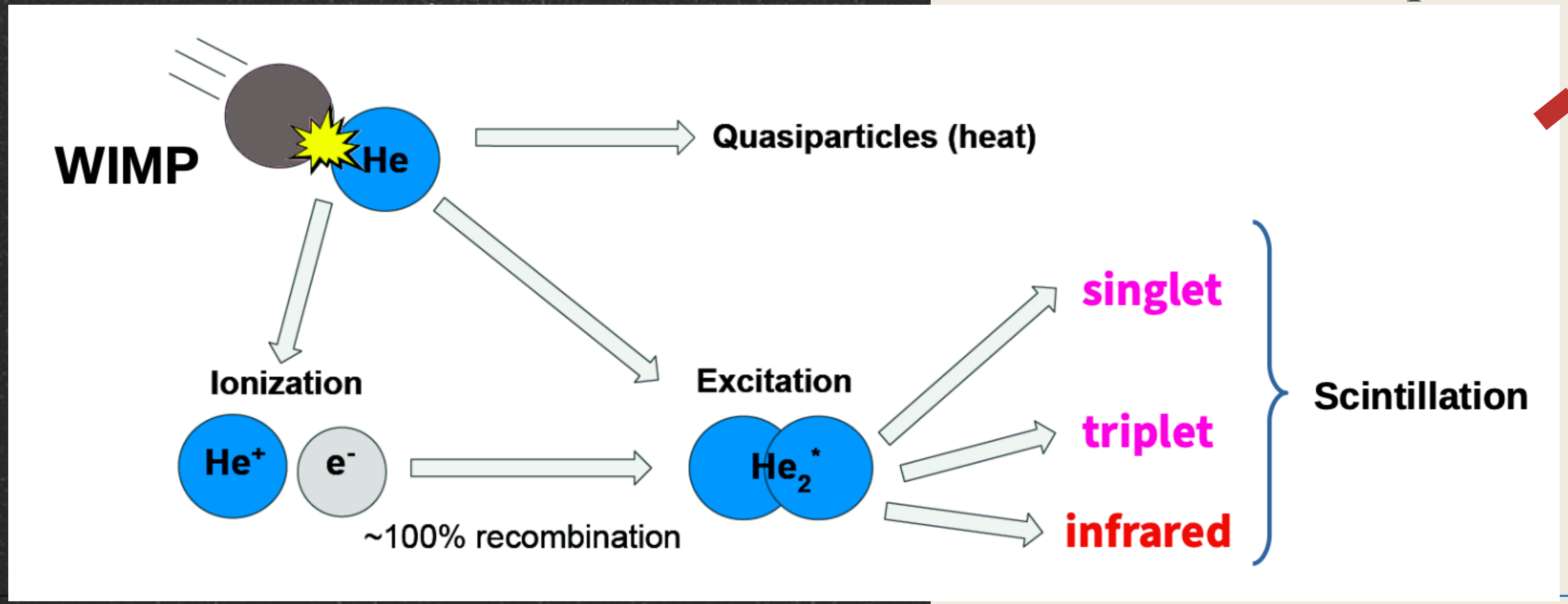


- ULT **requires a nuclear demagnetisation** cryostat
- Superfluid helium inside a bolometer at ~100uK **used to detect a heat signal**
- ~cm3 cubic cell is **instrumented with vibrating nanowire resonators**, which perform the thermometry

Bolometer Principles

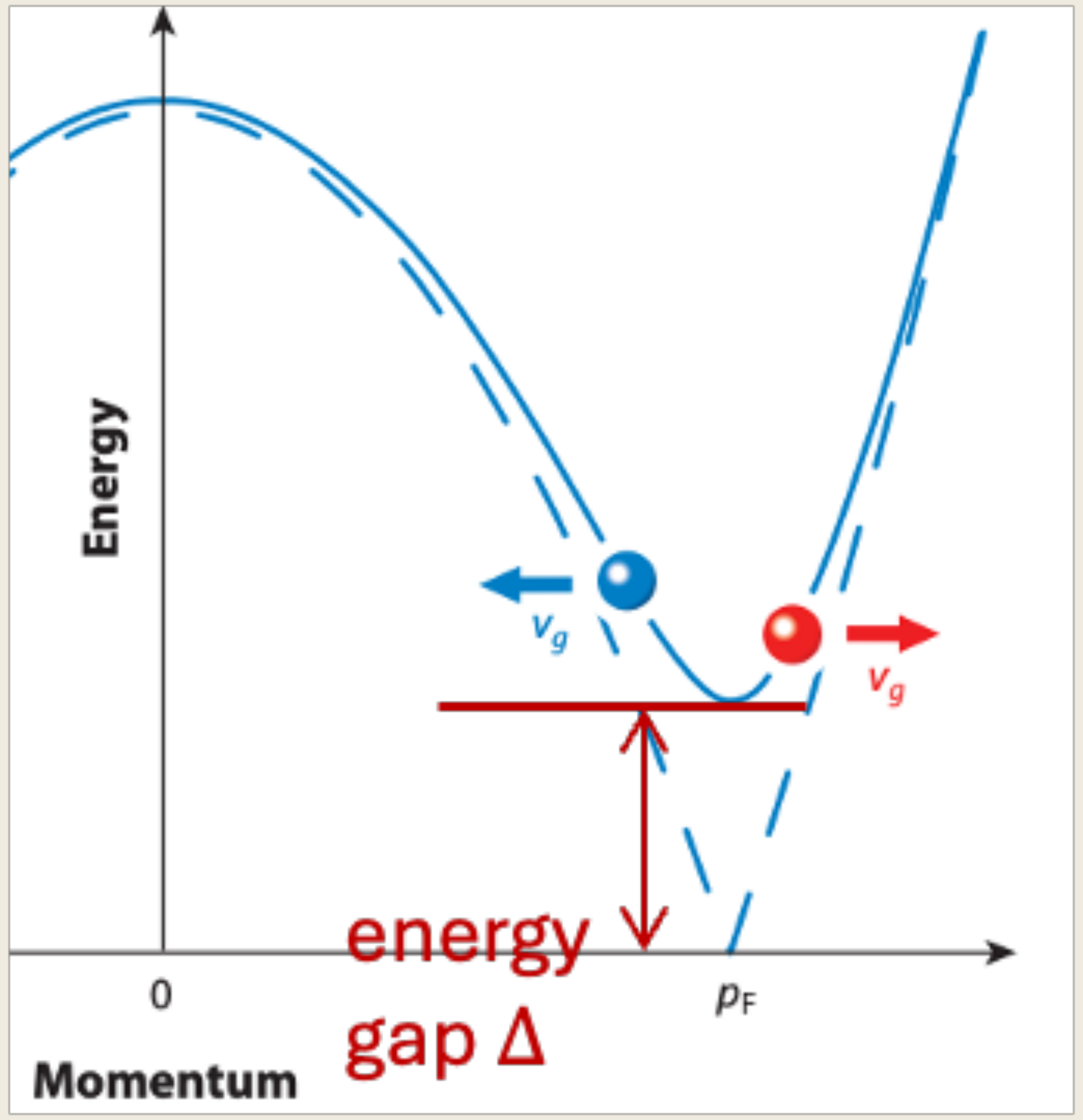
1. WIMP Interaction & Energy Deposit

DM – helium scattering produces quasiparticles (QPs) 1eV → 10^7 quanta



2. Ballistic Propagation

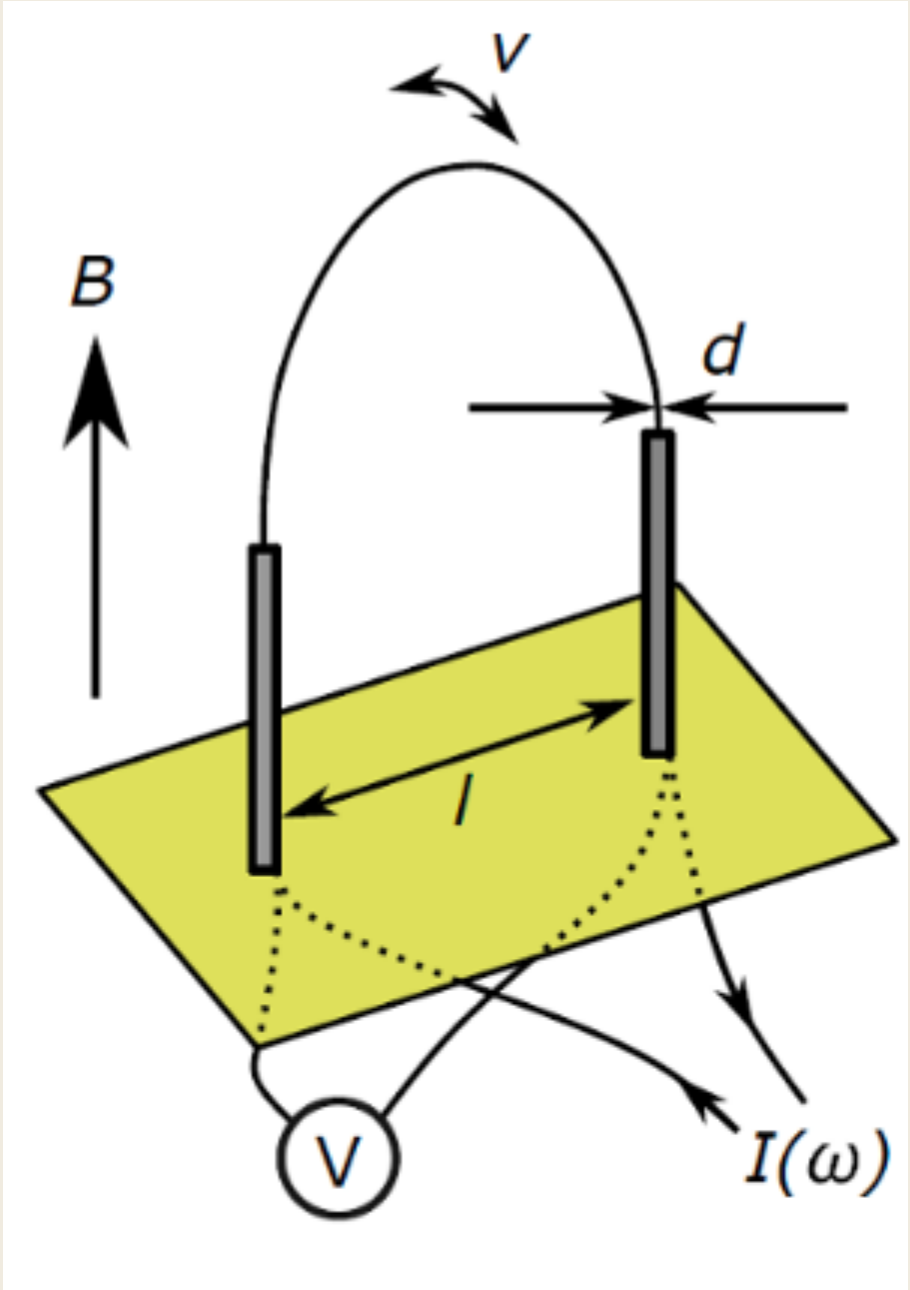
QP collisions with nanowire exert damping force



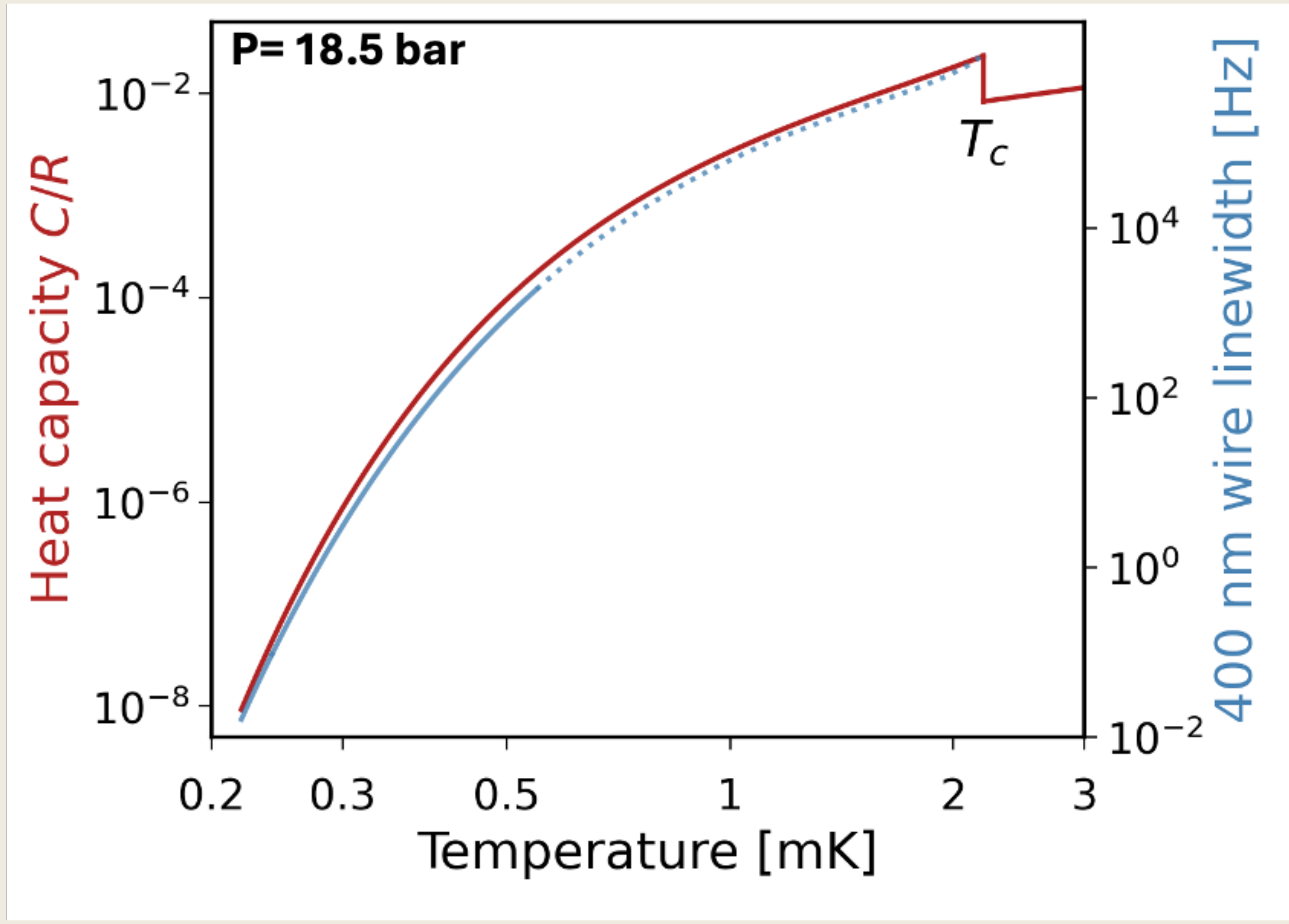
3. Bolometer Readout

Nanowire driven by AC current in vertical B field.

Measure increase in resonance width from damping.

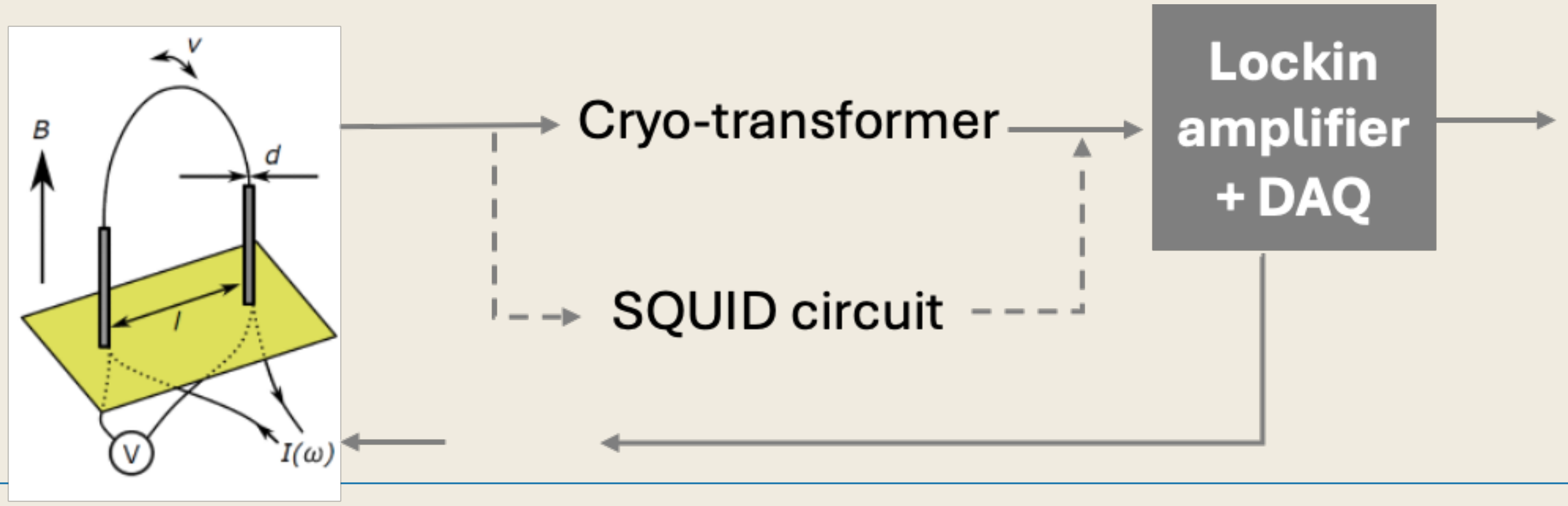


Achieving Low Threshold



Ultra-low temperature operation:

- Small energy → small width change
- Linewidth follows heat capacity



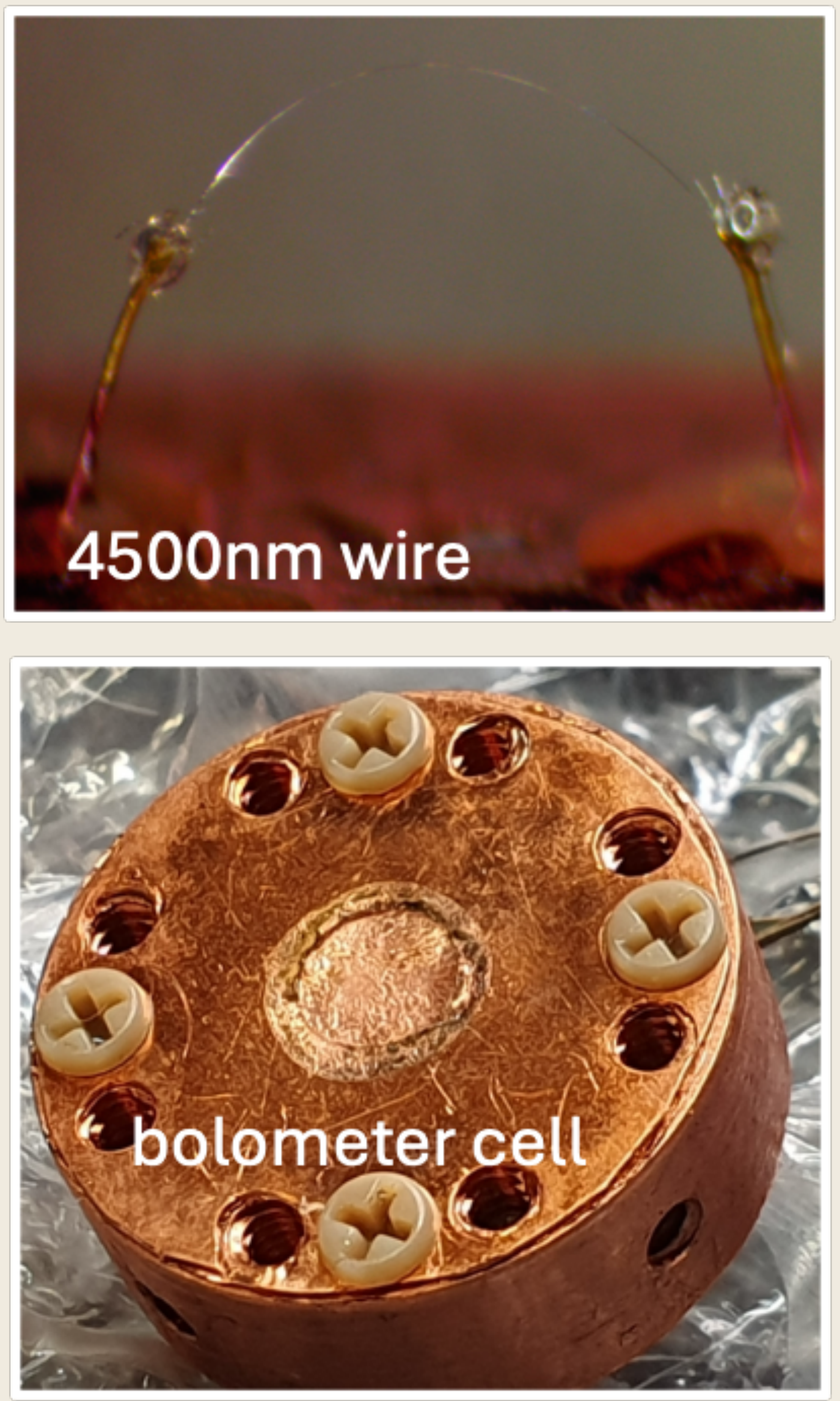
Low noise readout:

- Conventional readout: passive cryo-transformer.
- SQUID preamplifier, higher gain and lower noise.
- Simulated energy thresholds: 39 eV with conventional readout, 0.71 eV with SQUID readout, QUEST-DMC:*Eur. Phys. J. C* **84**, 248 (2024)

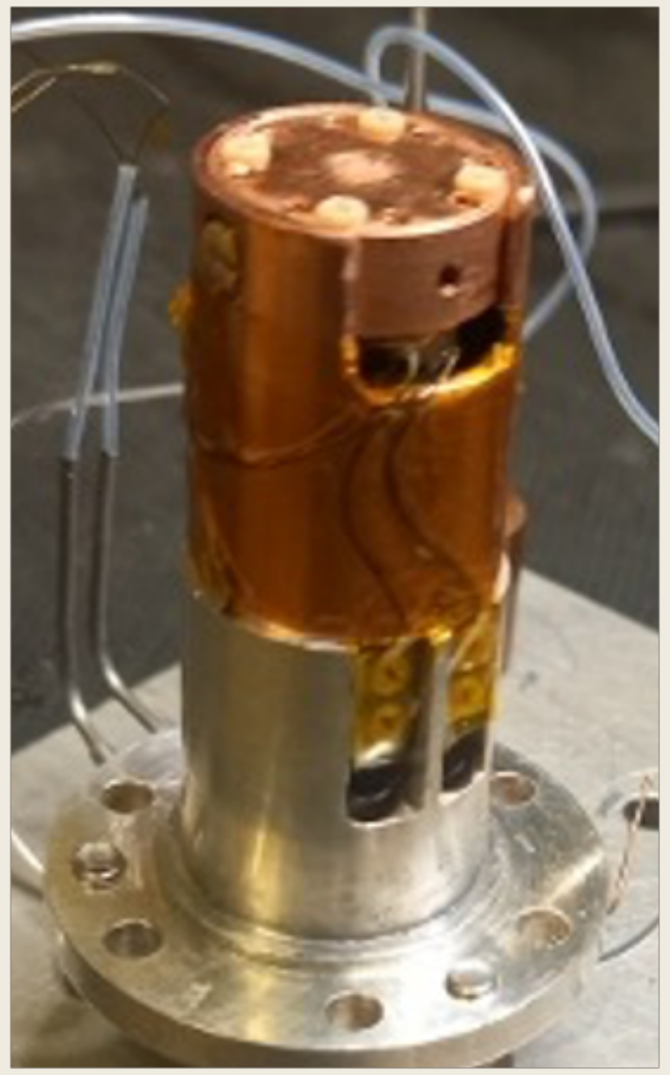
SQUID Readout Tests

400nm nanowire: NbTi vibrating wire resonators made in Lancaster

NEW paper: [QUEST-DMC, J Low Temp Phys 222, 39 (2026).]

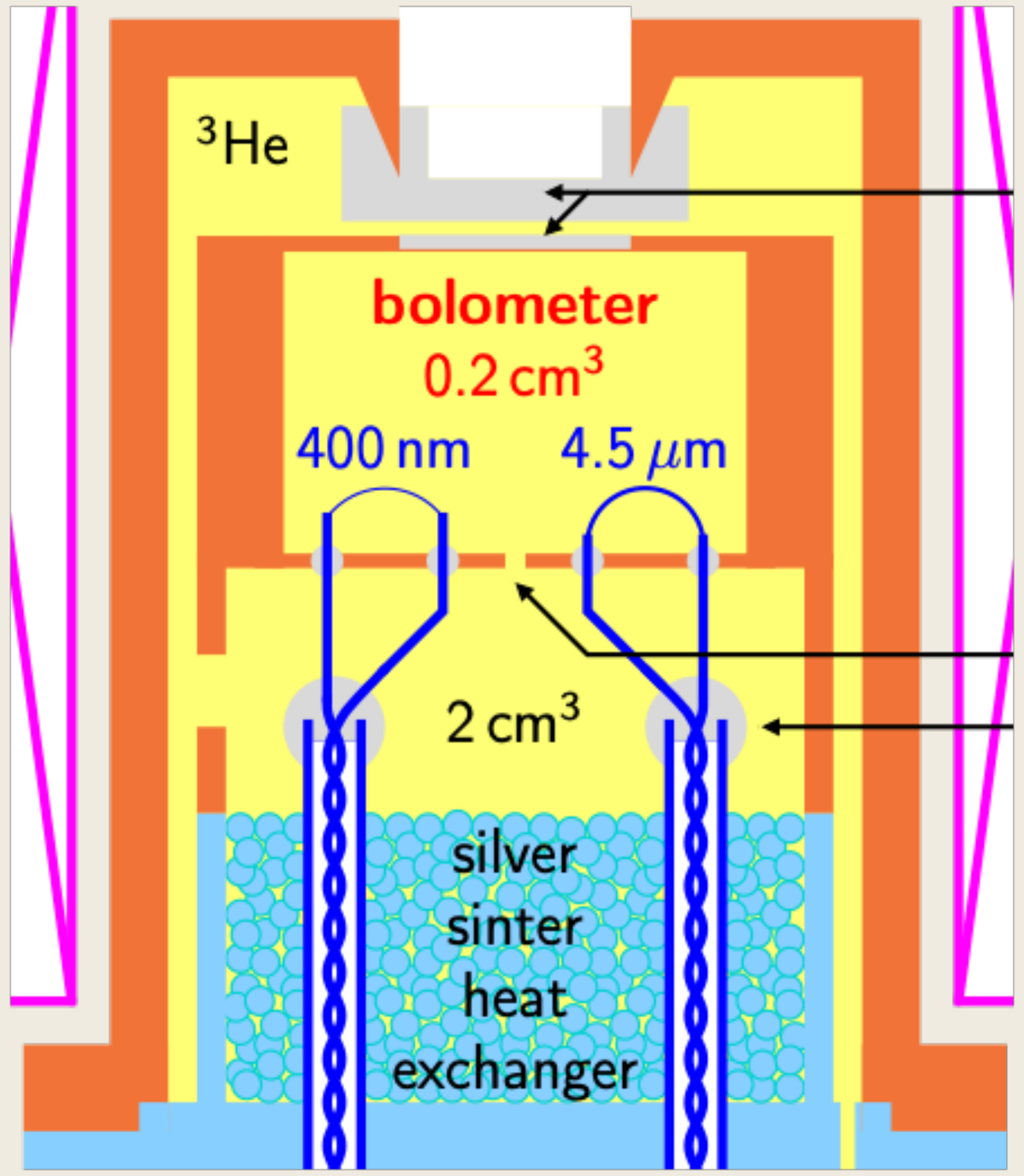


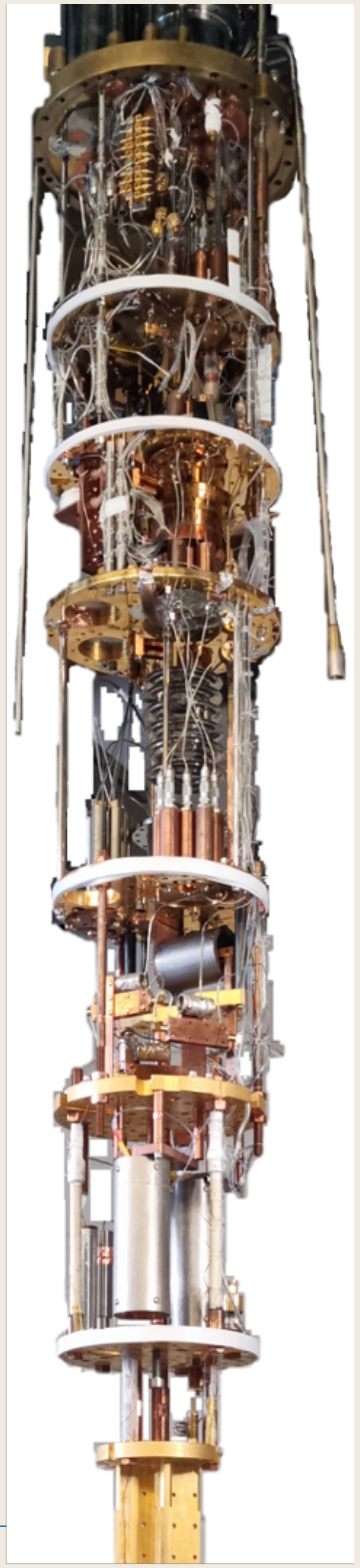
cell holder & heat exchanger



wet dilution fridge with copper nuclear demag. stage

cuboid copper bolometer inside 3He cell



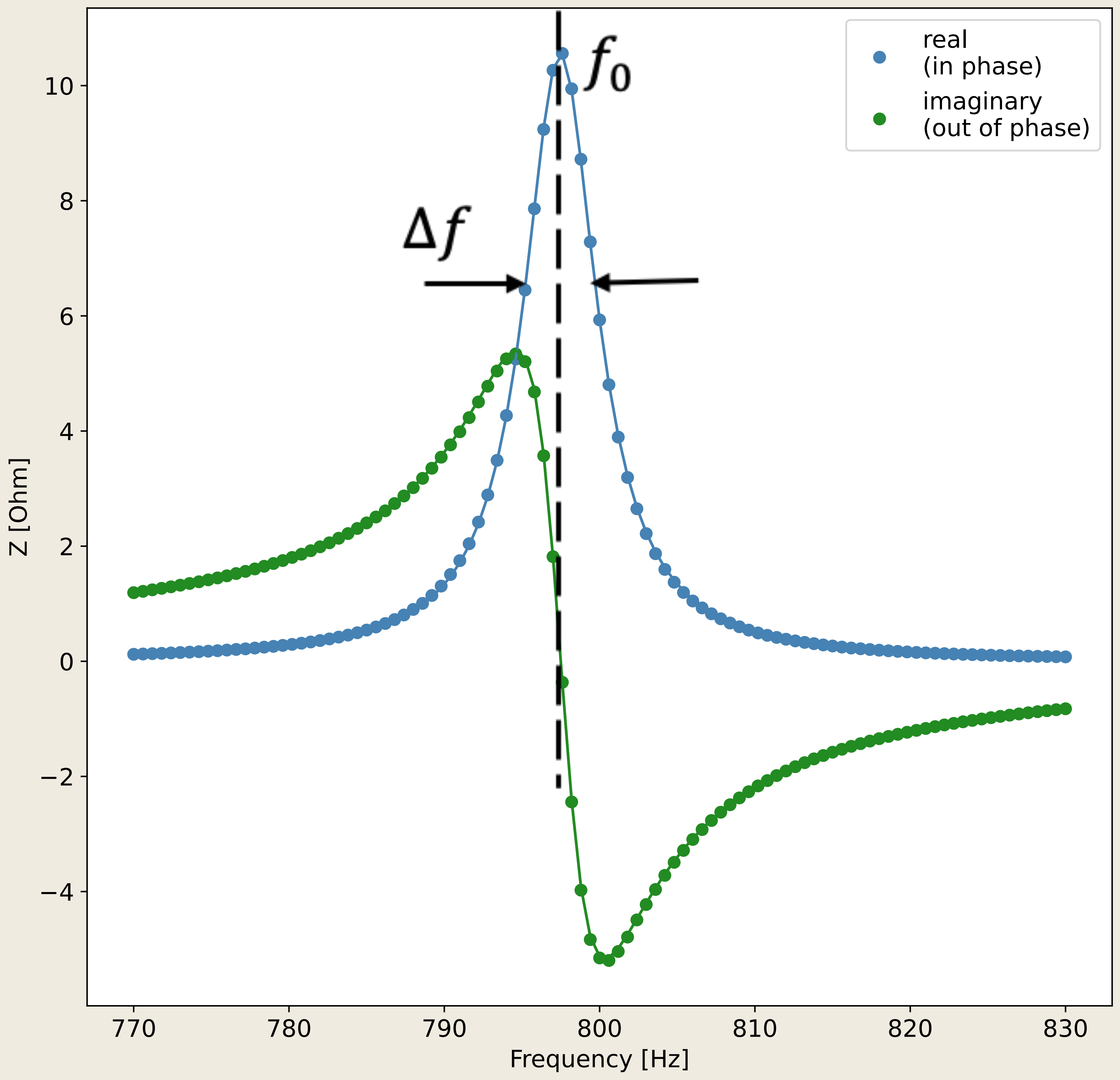


Bolometer Measurements

→

Frequency sweep – find resonant frequency, base width and amplitude from Lorentzian fit

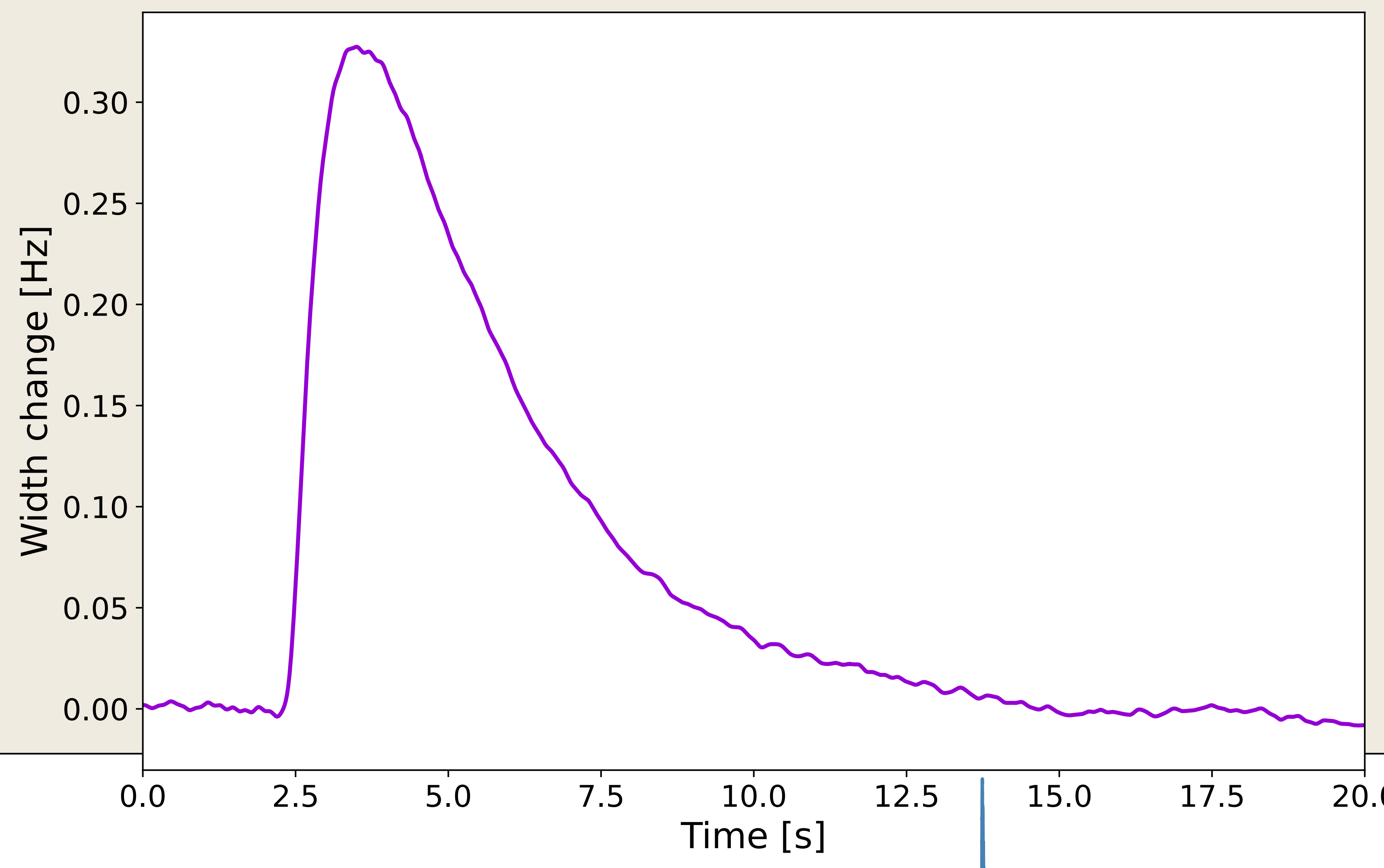
→

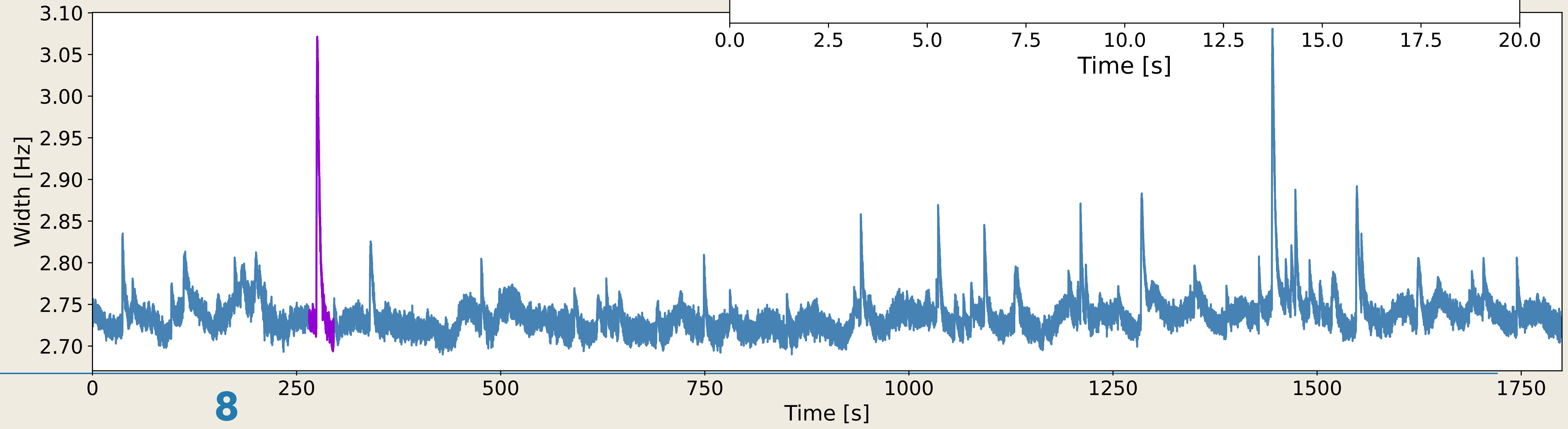


Response tracking – drive on resonance

- Measure induced voltage across wire
- Convert to resonance width change
- Apply pulse finding and fitting

↓ ↓



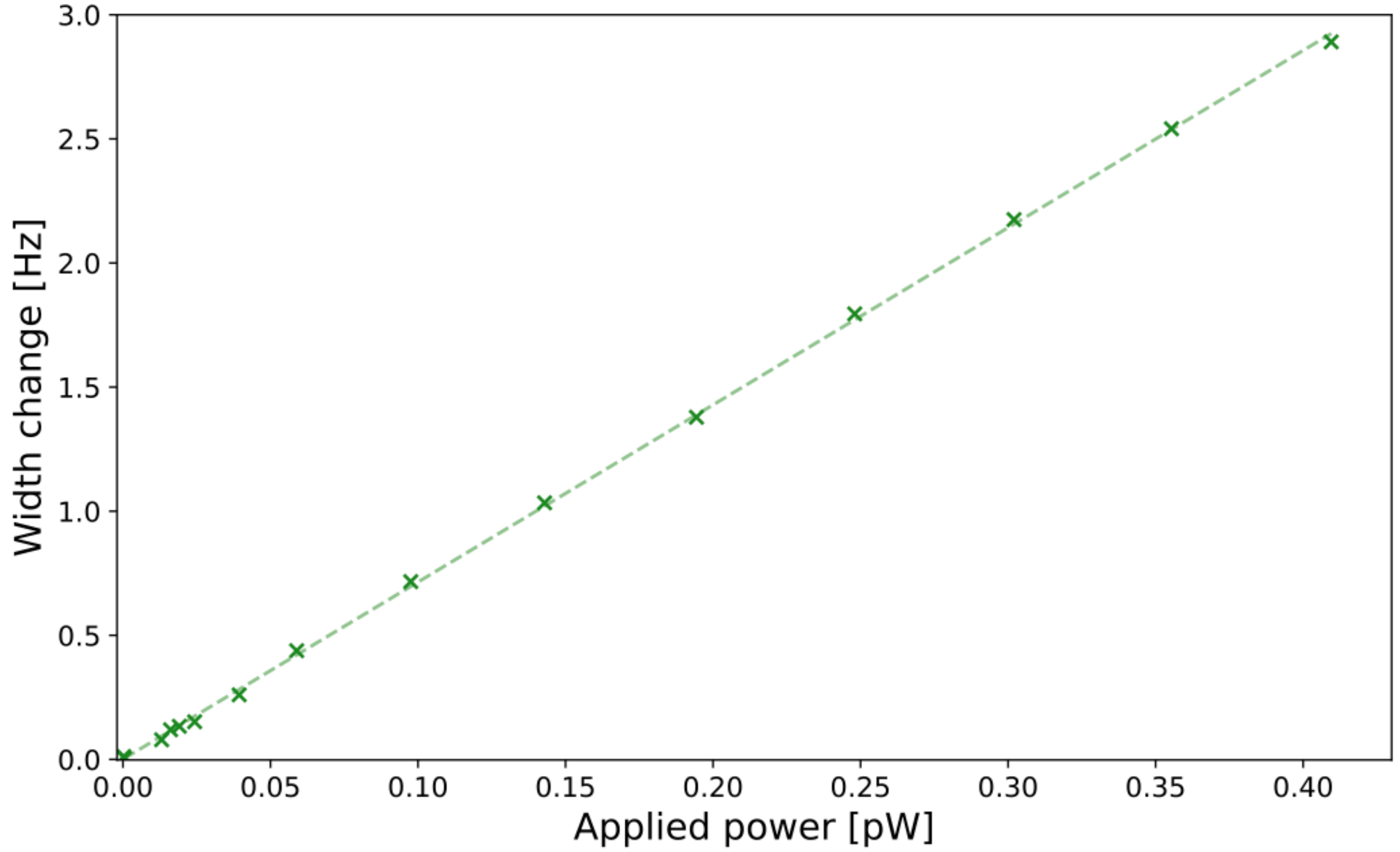


Heater Wire Calibration

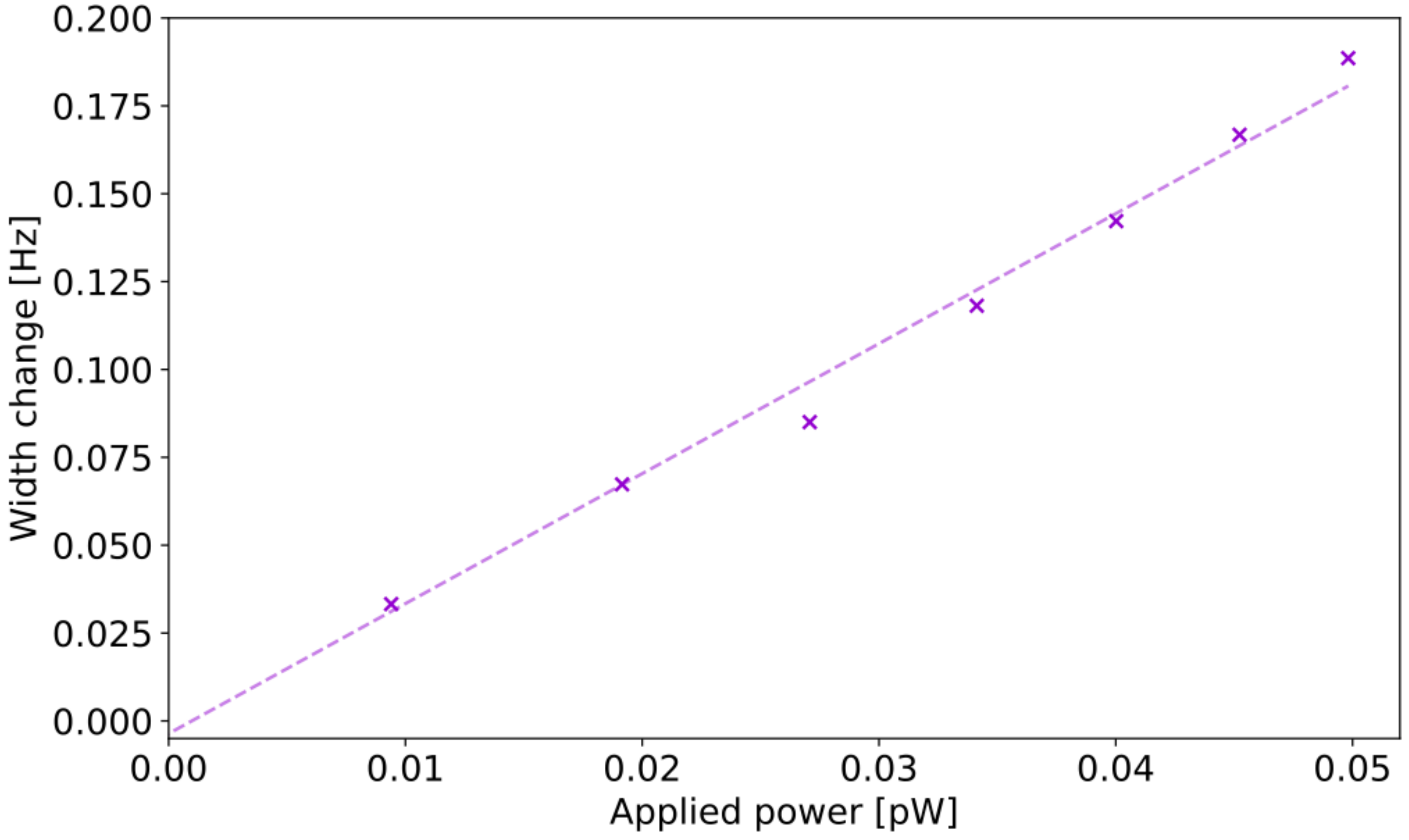
Direct injection of QPs into superfluid by driving wire above critical velocity, observe proportional response on other wire.

~10keV heat injection

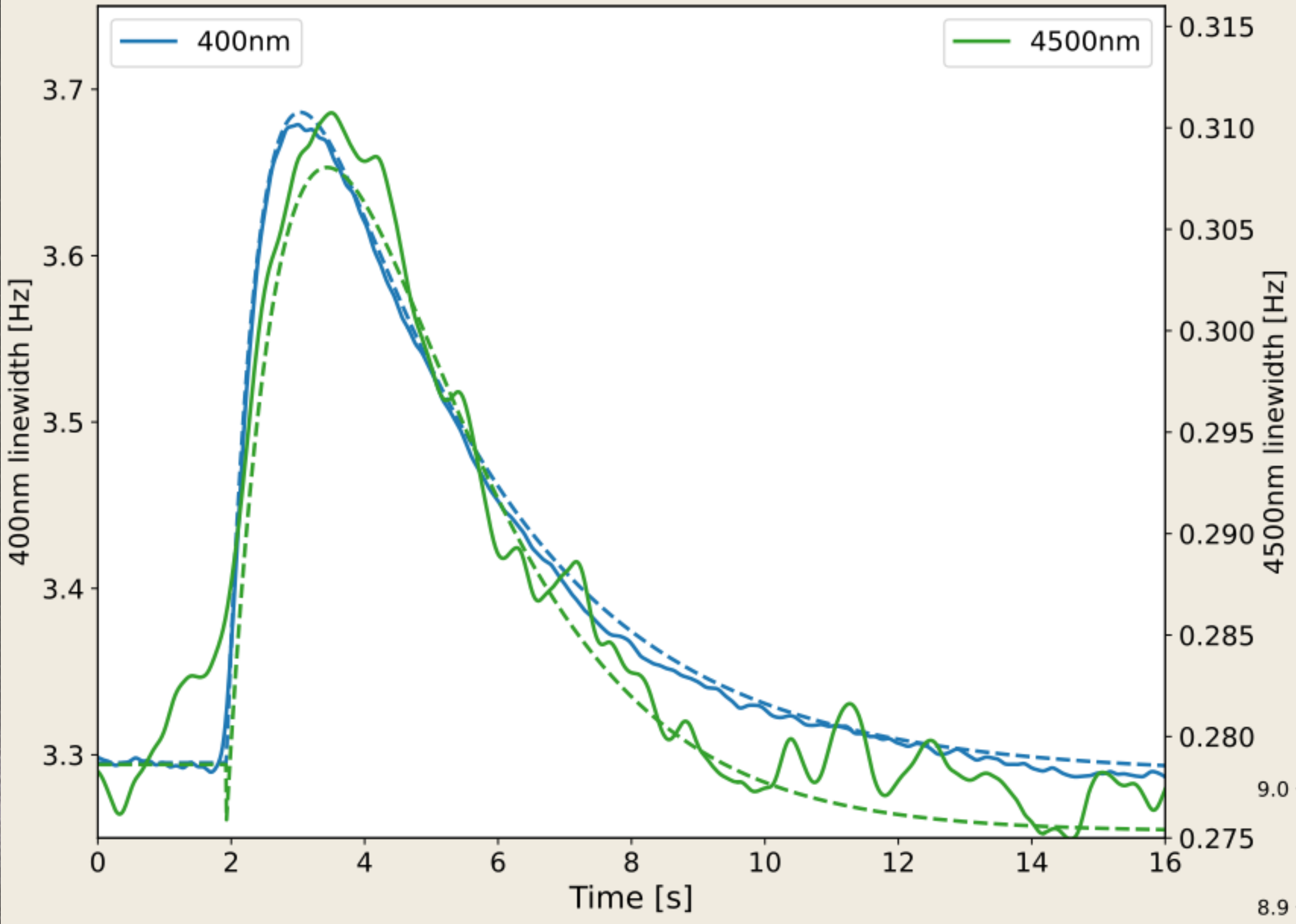
A) 400nm detector (4500nm heater)



B) 4500nm detector (400nm heater)

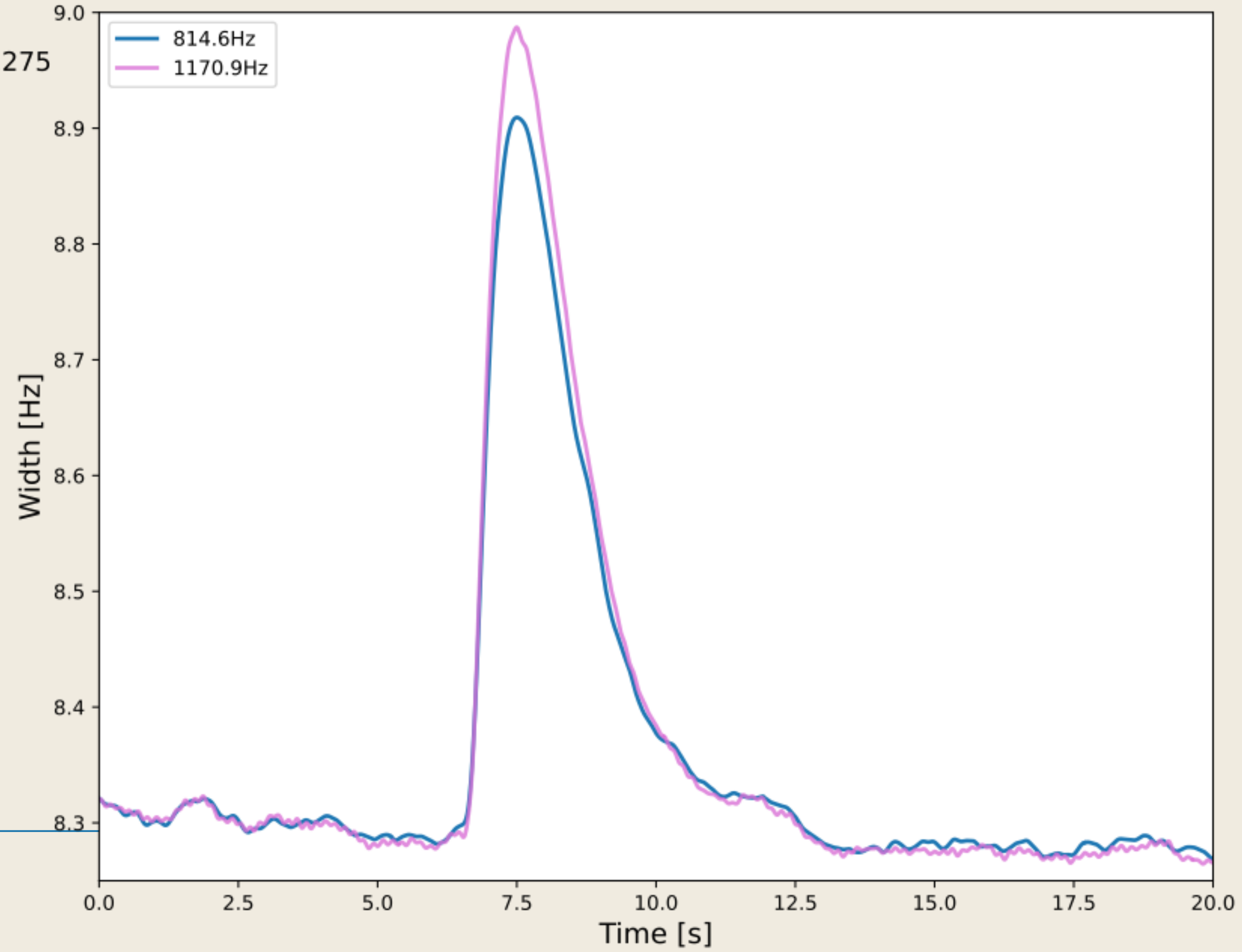


Additional Analysis

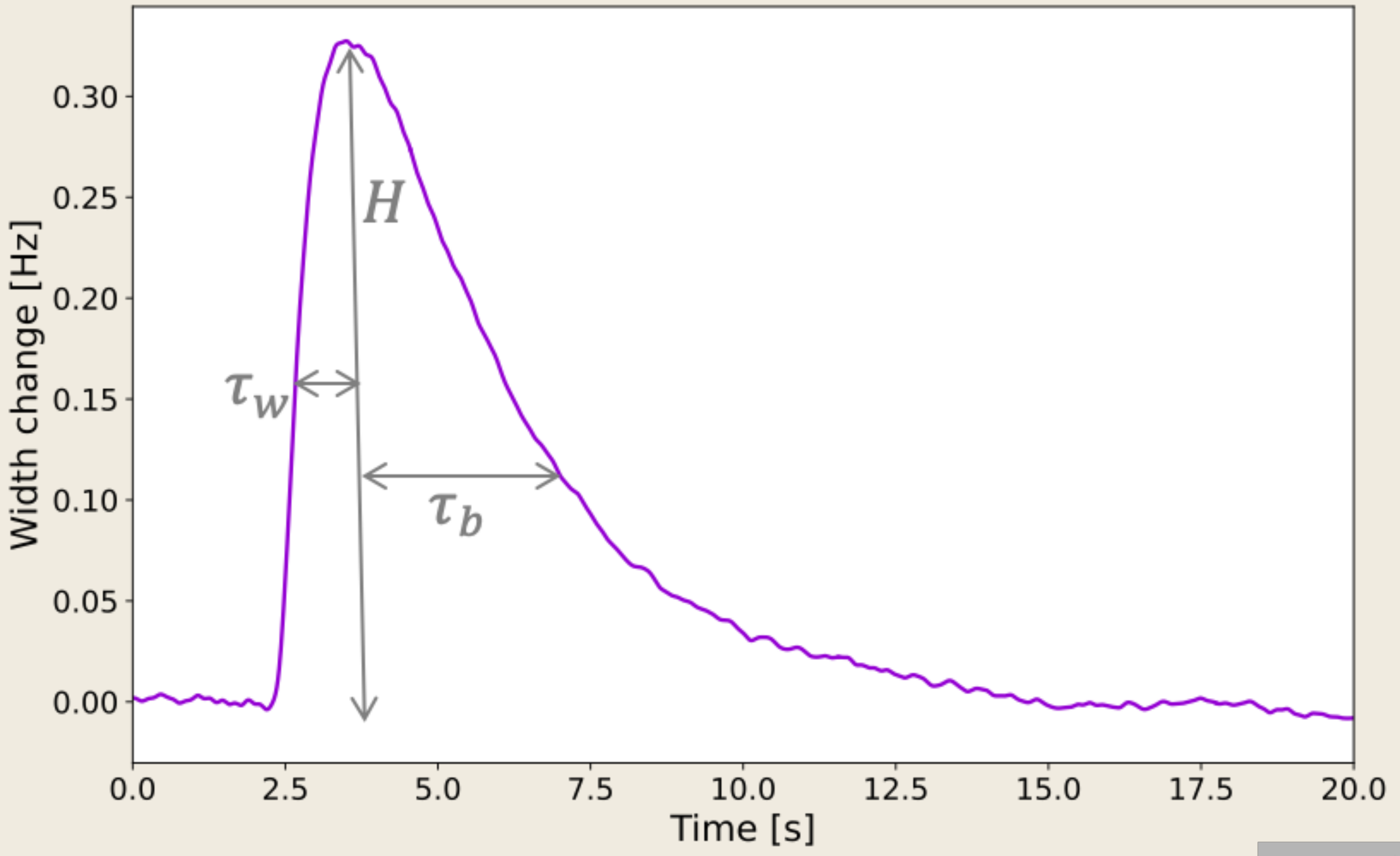


Simultaneous tracking: on both wires, observe coincident bolometer pulses.

Frequency multiplexed readout: with single SQUID, coincident events seen on both modes Could consider separate wires in future (scale up experiment)



Pulse Analysis & GEANT4 Comparison



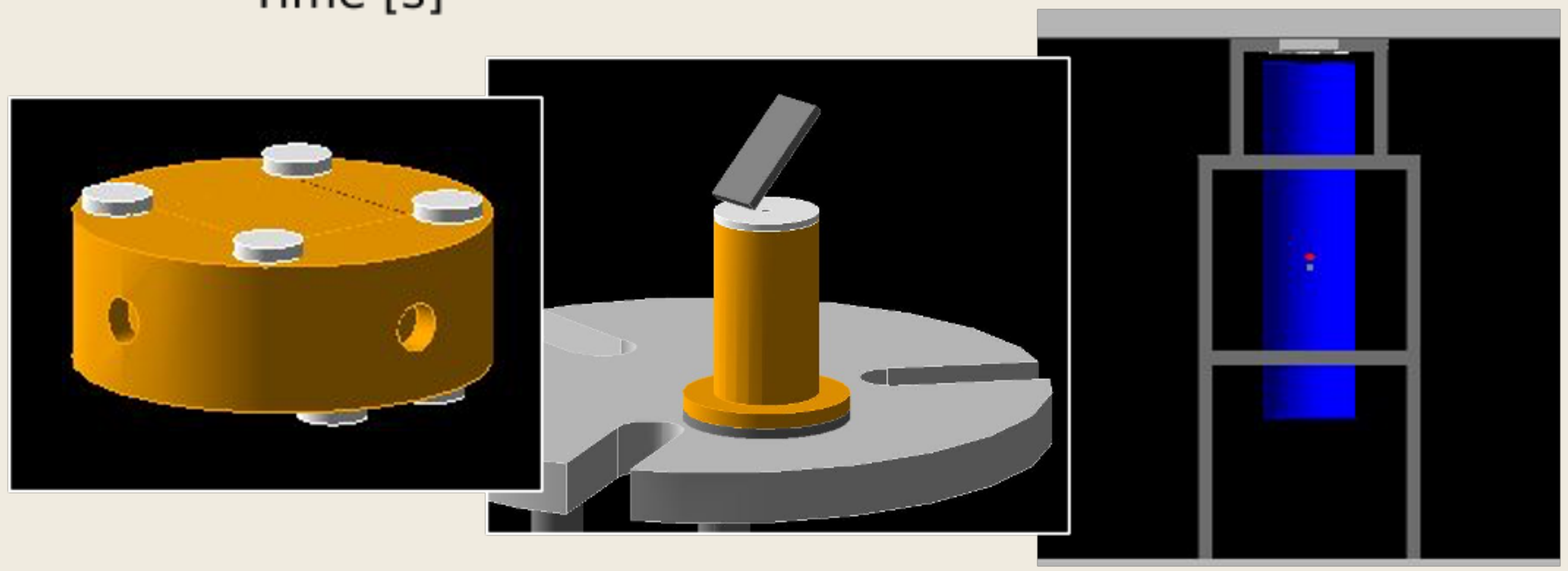
Characteristic heat pulse shape, three parameters:

- Rise Time, τ_w - nanowire
- Decay Time, τ_b - bolometer
- Height, H - heating event (energy)

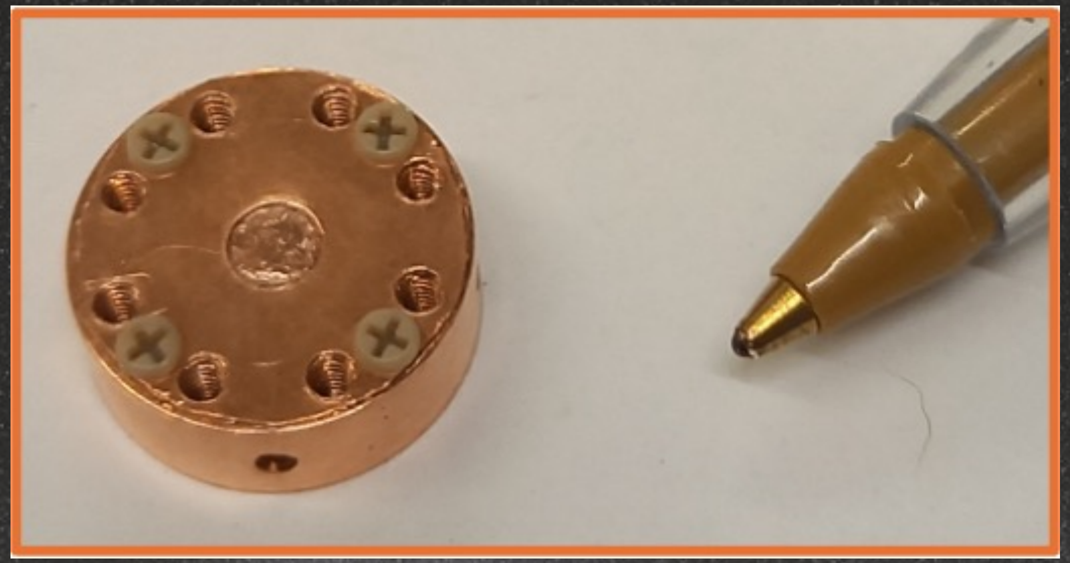
[C.Winkelmann, NIMA(2007)]

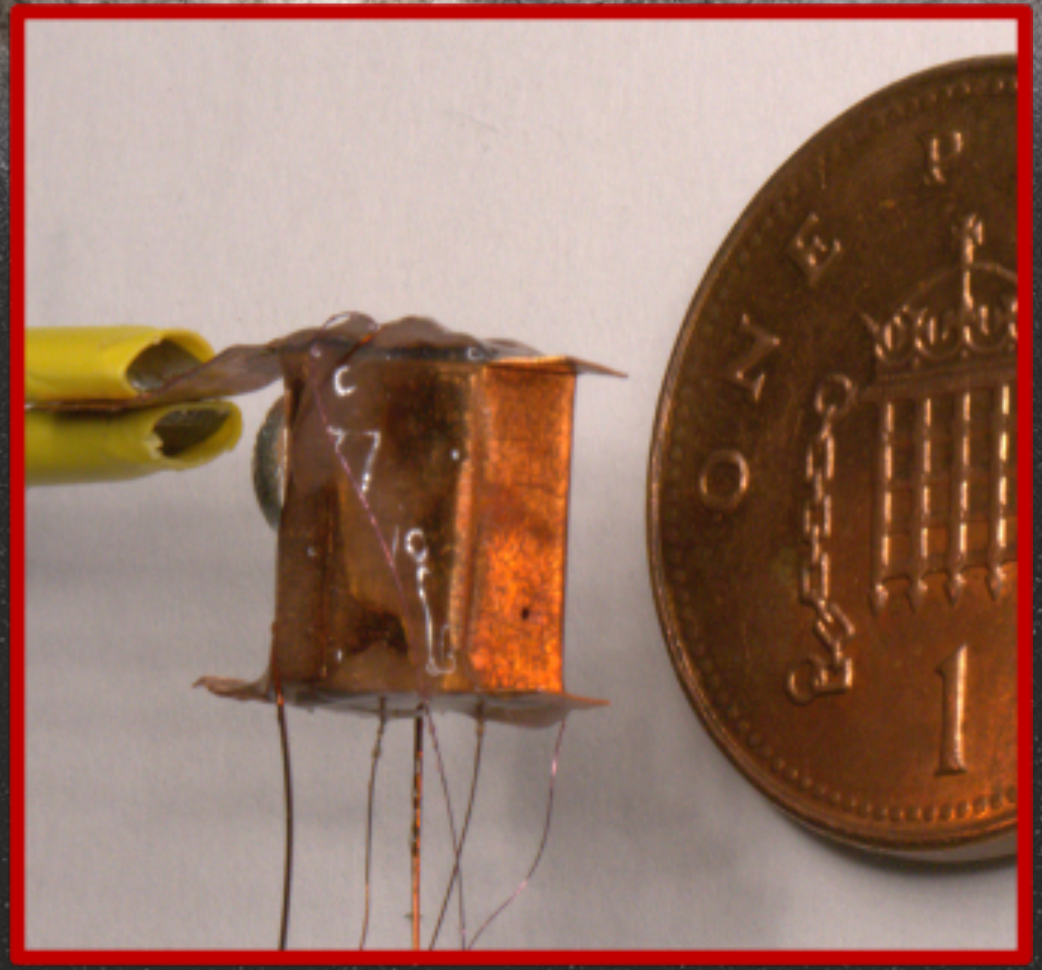
Background model (cosmic ray, gamma, detector radiogenics):

- Full Geant 4 model
- Boulby material screening JLTP(QFS2023)



Summary

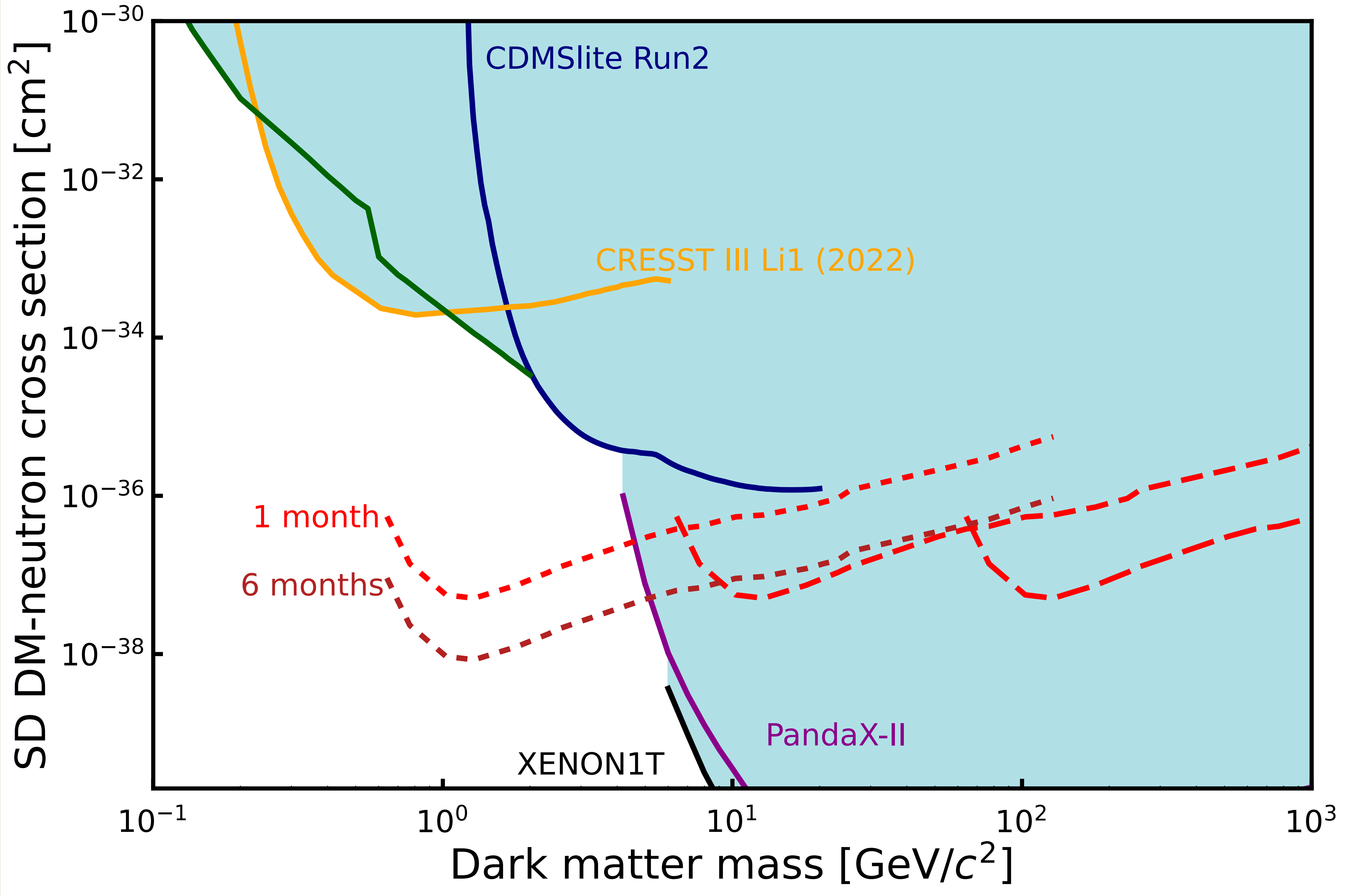




Demonstrated superfluid helium-3 bolometer with SQUID readout of nanomechanical resonators [QUEST-DMC, J.Low Temp.Phys. 222 (2026)]:

✓heat injection calibration
✓simultaneous tracking
✓frequency multiplexing

Upcoming Goal for QUEST-DMC: <100 eV energy threshold for < GeV/c^2 dark matter



Additional QUEST-DMC Papers:

- *Earth shadowing effects* *JCAP04(2025)017*
- *Non-relativistic EFT operators* *JCAP10(2025)044*