# Multiplexed TES based light detectors using transition edge sensors for CUPID and beyond

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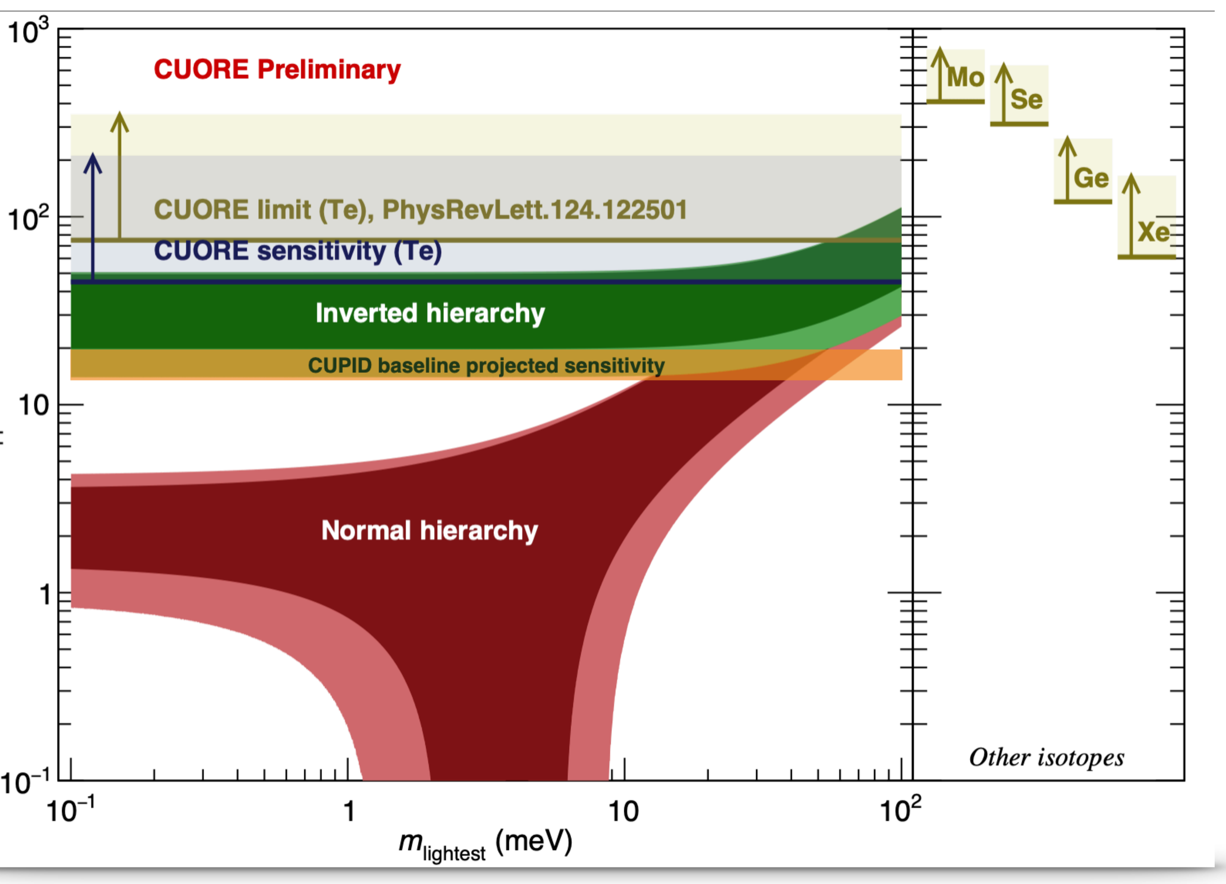
## CUPID: CUORE Upgrade with Particle ID

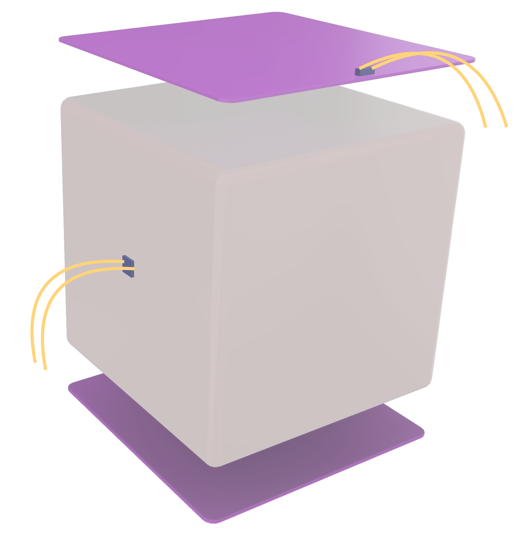
Next generation bolometric search for $0\nu\beta\beta$ experiment.

CUPID pre-CDR (arXiv:1907.09376)



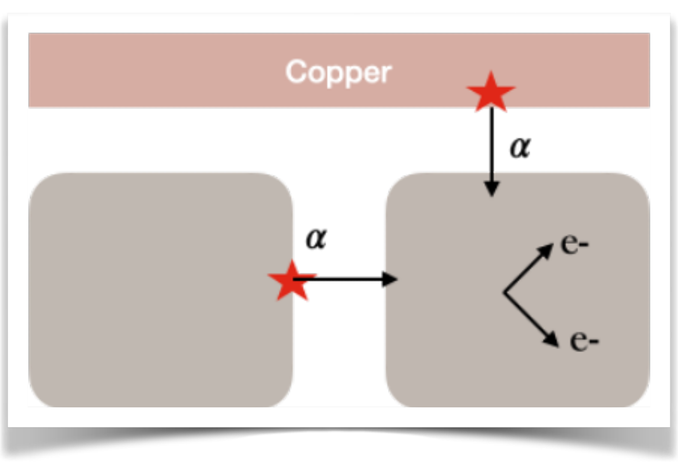

- Increase sensitive mass by enrichment
- Active background rejection through $\alpha$ / ($\beta$-$\gamma$) separation
- Goal:
  - ➡ $\triangle E_{FWHM} \leq 5$ keV @ 2615 keV
  - ➡ B = 0.1 c/ton/y in ROI
  - ➡ $<m_{\beta\beta}>$ ~ 10 meV discovery sensitivity (10 yrs of live time)

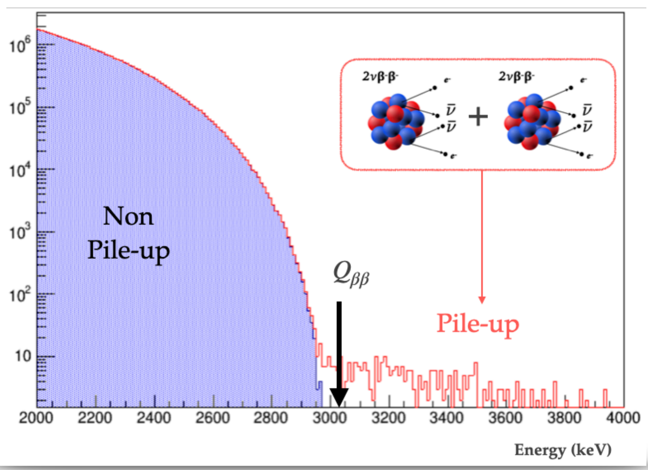
- CUORE has successfully demonstrated that a ton scale bolometric experiment is feasible.
- CUPID will build on the experience of CUORE and use its cryogenic infrastructure.
- 1596 $Li_2MoO_4$ (LMO) detectors + 1710 light detectors
- Demonstrated active background rejection. [see Poster ID 489. on the CUPID-Mo experiment by B Welliver]
- CUPID-1T may host 4x the mass of CUPID using updated technology, including multiplexed readout for >10k channels.



Rendering of crystal flanked by the light detectors.

## Particle ID

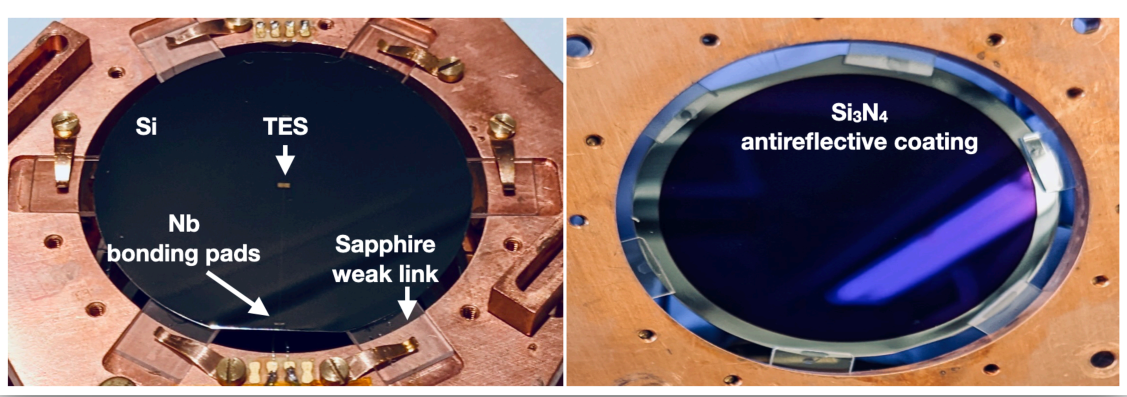


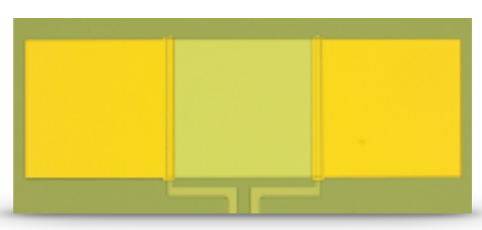




- Dominant background is degraded alphas from surface contamination
- Leverage energy loss mechanism in the crystal to tag particle type
- Use auxiliary low temperature calorimeter to detect light. Should have
  - High radiopurity
  - Low heat capacity
  - High photon collection efficiency
  - Very low threshold (~ 100 eV)
- **Excellent timing resolution to discriminate the $2\nu\beta\beta$ pile up events from $0\nu\beta\beta$ events.**
- **And/or excellent SNR.** [see Poster ID 474. on the NTL detectors by A. Armatol]

## Transition-edge sensor devices

Low impedance devices like TES' are good candidates for multiplexed readout for CUPID-1T — and possibly CUPID if demonstrated in time.



square Ir/Pt bilayer TES in the middle with Au pads on both sides

Specification for tested TES light detectors:

- 2" Silicon wafer as optical photon absorber.
- Ir/Pt (100 nm/60nm) bilayer with Nb traces as electrical leads.
- Sensor dimension 300 $\mu$m x 300 $\mu$m; Transition temperature of ~ 37 mK.
- Typical risetimes ~ 175 µs; Typical decaytimes ~ 800—1000 µs.
- Baseline resolution well below 100 eV
- Satisfies the CUPID requirements for particle discrimination [1].

## TES-Digital Frequency Multiplexing (DfMUX [2]) for CUPID like experiments

- Multiplexing (MUX) has not been demonstrated at 10 mK .
- Radio-purity of the materials used for MUX a concern (cables, resonators, etc). May require additional magnetic/emi shielding.
- Long wires from detector to amplifier — parasitic capacitance and inductance may degrade multiplexing performance.
- SQUIDs amplifier will dissipate power — mount at a higher temperature stage to minimize heat load.

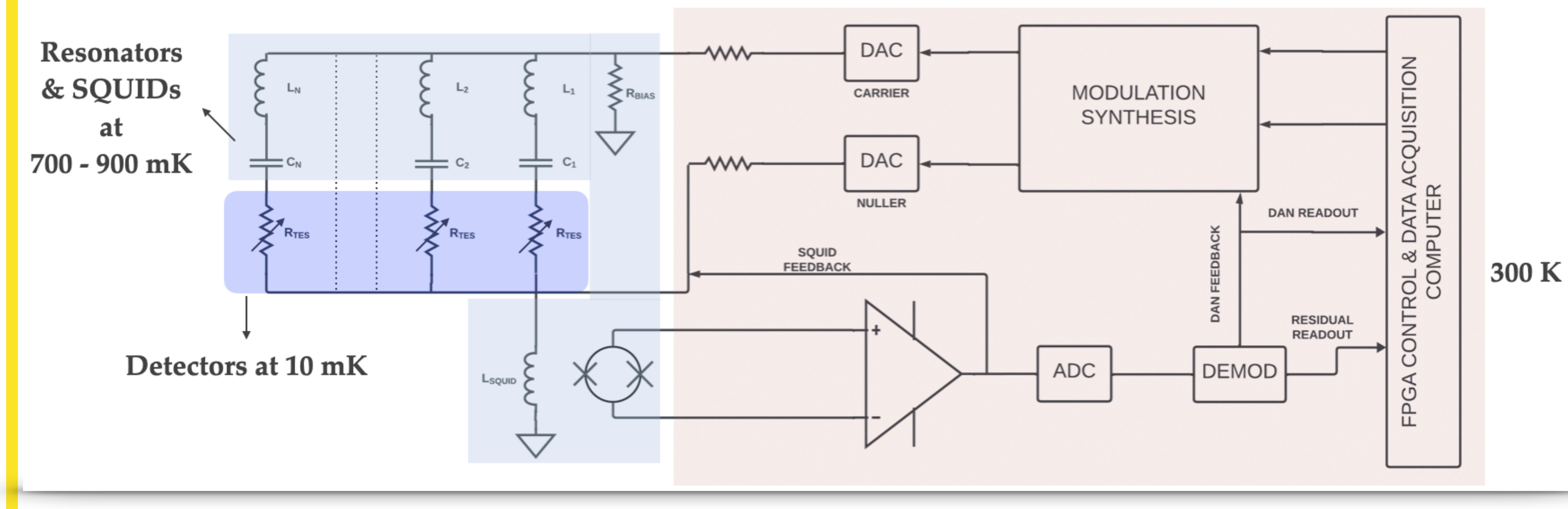
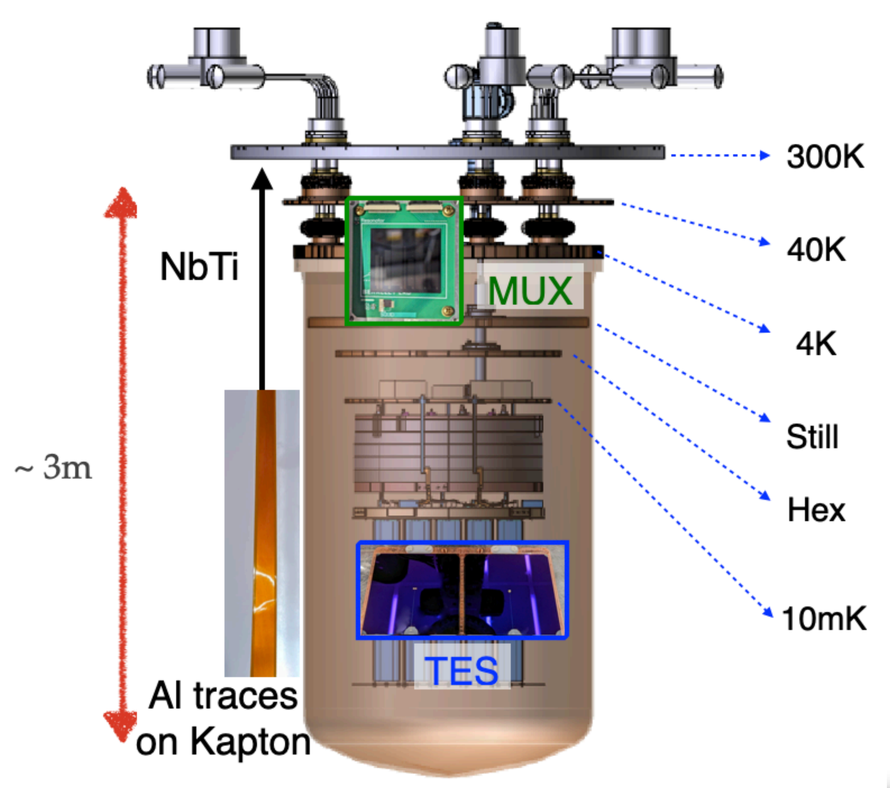


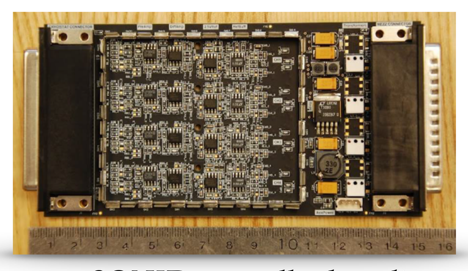

Figure modified from Bender, Amy N., et al. *Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VII*. Vol. 9153. SPIE, 2014.



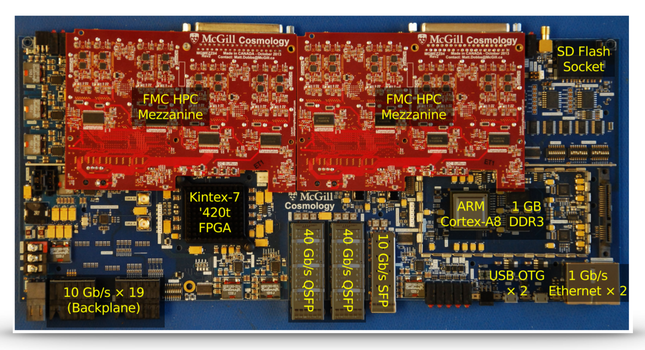

- 10 resonators in series with TESs with L~4 µH and C variable.
- Lithographed, planar spiral inductors combined with interdigitated capacitors on a silicon substrate → UC Berkeley/LBNL
- Modulation frequencies between 1 - 5 MHz.
- Superconducting Al-PCBs made by Omnicircuitboards.com → no resistance on the PCB traces.
- Superconducting flex cable made by qflexinc.com → Aluminum traces on Kapton.

## DfMUX readout — McGill ICE system

- Derived from SPT-3G firmware, adapted for CUPID
- Lower fMUX ratio, much higher output bandwidth
- **10x DfMUX (will go to 15x) —** Going down from 128x DfMUX of SPT-3G
- 20 MHz sampling rate
- **156.25 kSPS output data rate —** Going up from 153 SPS output data rate of SPT-3G
- Very fast Digital Active Nulling (DAN) feedback [3]
- Scaling up: 8 modules = 120 TES channels / board
- **15 ICE boards for 1800 TESs**

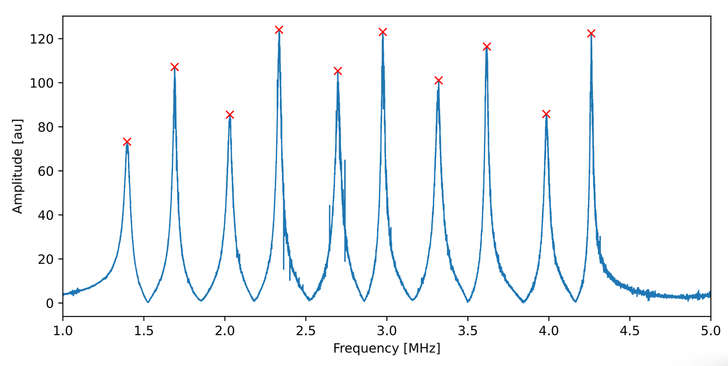


*SQUID controller board[1]*

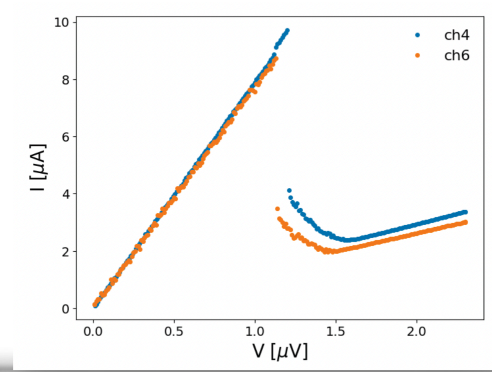


*Kintex-7 FPGA based ICE motherboard (blue) with ADC/DAC mezzanine cards (red)[1]*

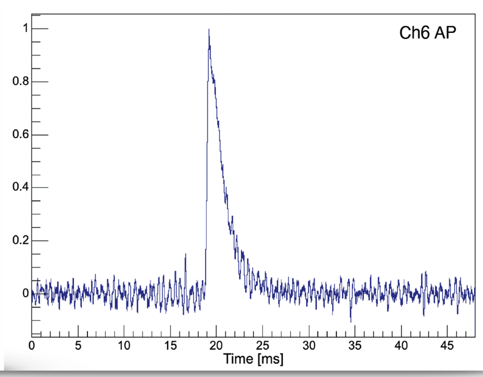
## Premiliminary Results




*Resonances across a fixed 100 mOhm resistor for frequency calibration.*




*IV curves after demodulation for a couple of multiplexed detectors.*




*Sample pulse after demodulation with a risetime of ~294 µs for a voltage biased TES .*

- Validated that the ICE system works.
- Enough bandwidth for meeting the CUPID criteria on rise-time.
- Frequencies within ~5% of the design will cross-talk less than 0.5%.
- Good yield on the resonator board ~ 97%.
- Parasitic impedance is still a concern → affecting detector stability and energy resolution; reducing parastics in connector and cable a work in progress.

### References

[1] Singh, V., et al. "Large-area photon calorimeter with Ir-Pt bilayer transition-edge sensor for the CUPID experiment." *Physical Review Applied* 20.6 (2023): 064017.
[2] Bender, Amy N., et al. "Digital frequency domain multiplexing readout electronics for the next generation of millimeter telescopes." *Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VII*. Vol. 9153. SPIE, 2014.
[3] de Haan, Tijmen, Graeme Smecher, and Matt Dobbs. "Improved performance of TES bolometers using digital feedback." *Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VI*. Vol. 8452. SPIE, 2012.