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Towards CUPID-1T: microwave multiplexing for large arrays of macrocalorimeters

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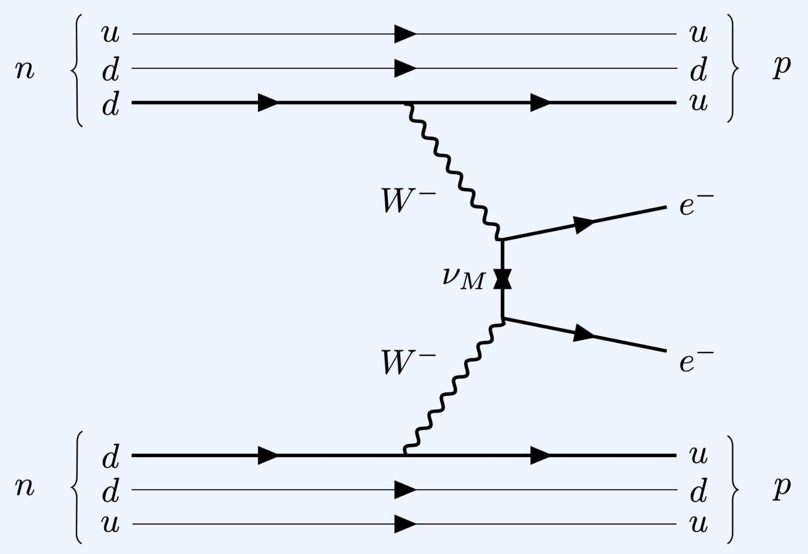
Neutrinoless double beta decay

- **Lepton number violating** nuclear process, Δ(B-L)=2
- Assess **Majorana nature** of neutrinos
- Access to the **absolute neutrino mass** scale
- Leptogenesis (matter creation process)



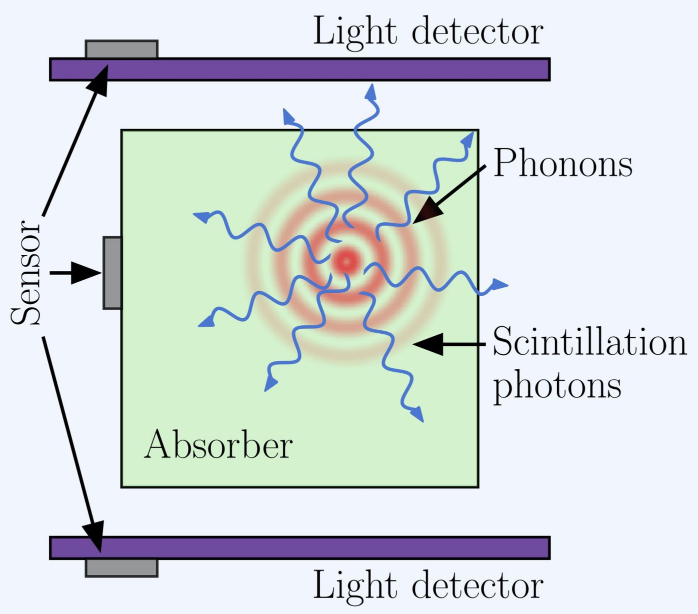
Experimental signature

Two electrons carry all the energy
→ **monoenergetic peak** at $Q_{\beta\beta}$

The cryogenic calorimeters approach

Crystal absorber + temperature sensor operated at ~10 mK

Energy deposit → *Temperature rise* → *Electrical signal*



Key advantages

- **High efficiency** (source = detector)
- **Excellent energy resolution** (~0.3%) at $Q_{\beta\beta}$
- Isotope flexibility (^{130}Te, ^{100}Mo, ^{82}Se, …)
- Heat + light readout → α **background suppression**

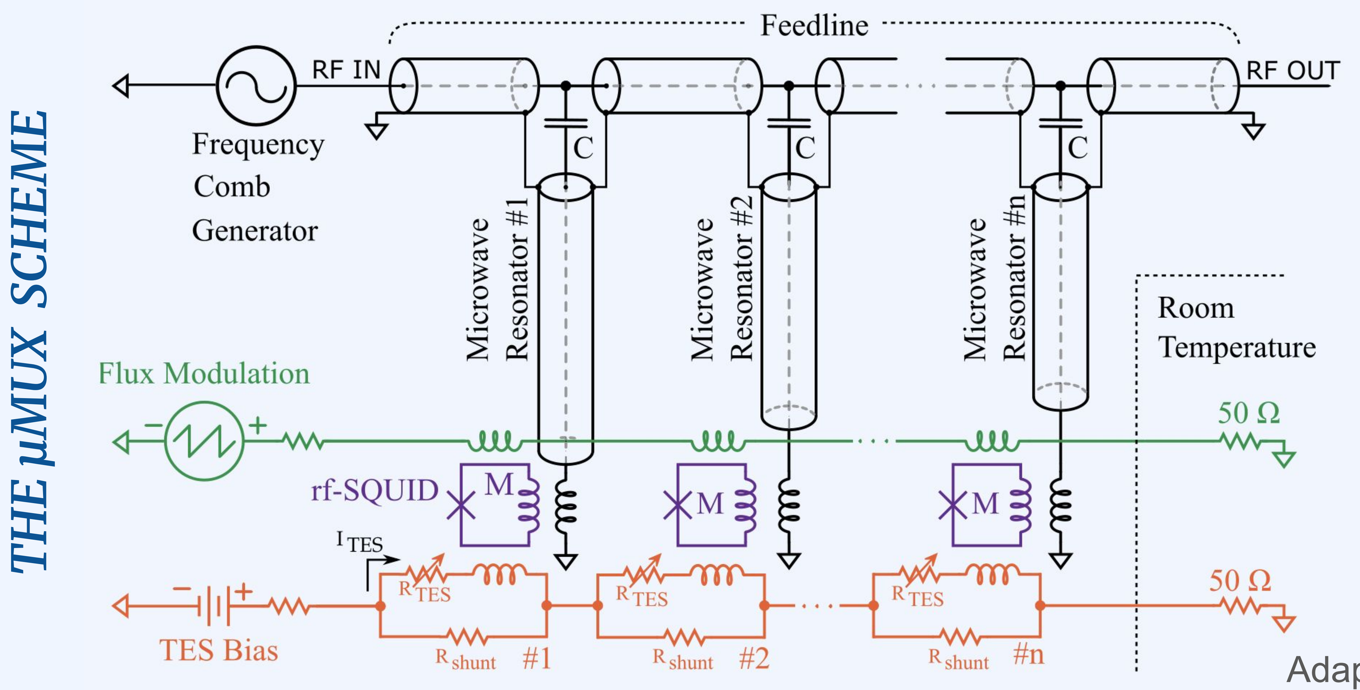
Future limitations and multiplexing techniques

CUPID-1T [1]: scaling cryogenic 0νββ searches to tonne scales
→ requires O(10^3 - 10^4) channels

1 wire-per-channel approach → **unsustainable heat load & complexity**

Multiplexing: read many channels over a single coaxial line

- Reduce wiring, heat load and cost
- Critical technology for next generation bolometric searches
- Different division approaches: time, frequency, code, **microwave**



Adapted from [2]

Current setup @ MIT

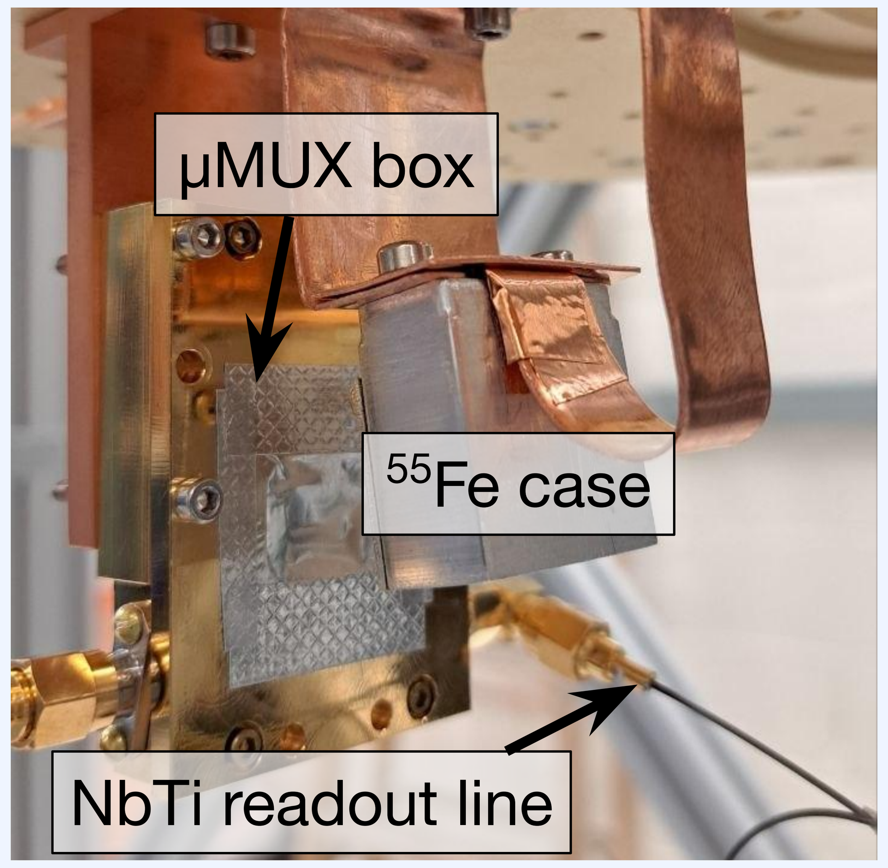
Brand-new dilution cryostat (Oxford Proteox-MX)

Multiplexing and readout systems developed and provided by NIST

- *Input line*: RF attenuators at each thermal stage
- *Chip*: Copper box with Al window
  - Multiplexer with 33 resonators at ~5 GHz coupled to rf-SQUIDs
  - 24 MoAu TES array with T_c within [40,80] mK
  - Sub-mm absorbers coupled to TESs
- *Output*: RF circulator to adjust impedance mismatch and avoid reflections
  Three-stage amplification: 4K HEMT, 40K, and 300K
- *DAQ*: Xilinx RFSoC FPGA with RF tone synthesis and digitization at GHz frequencies

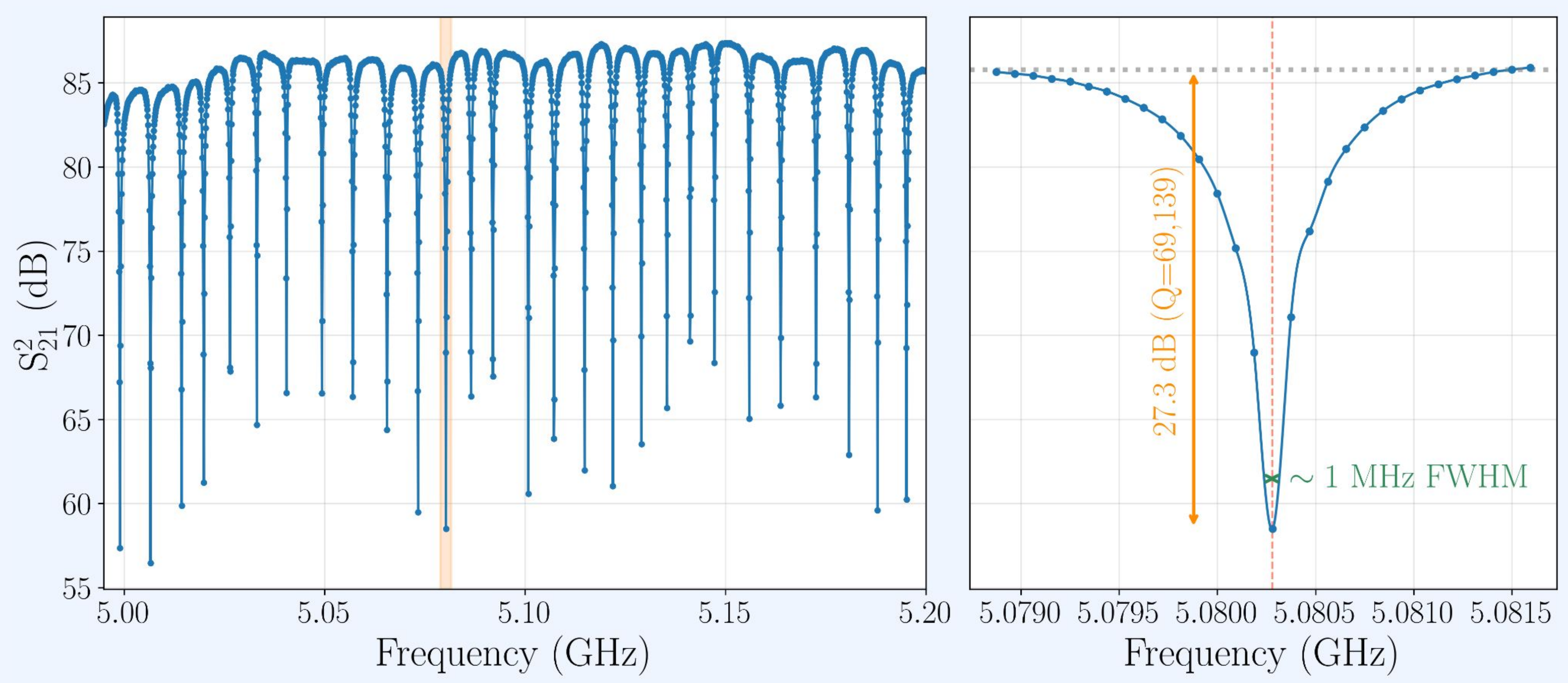
First characterization steps

1. Commissioning of the cryostat
2. *Run 1*: characterization of multiplexer and resonators
3. *Run 2*: TES noise characterization in the following parameter space:
   - tone power
   - temperature
   - DC bias
4. *Run 3*: ^{55}Fe X-ray source included to characterize the energy response of the TESs
5. Next run: test with 2-layer Cryoperm magnetic shield



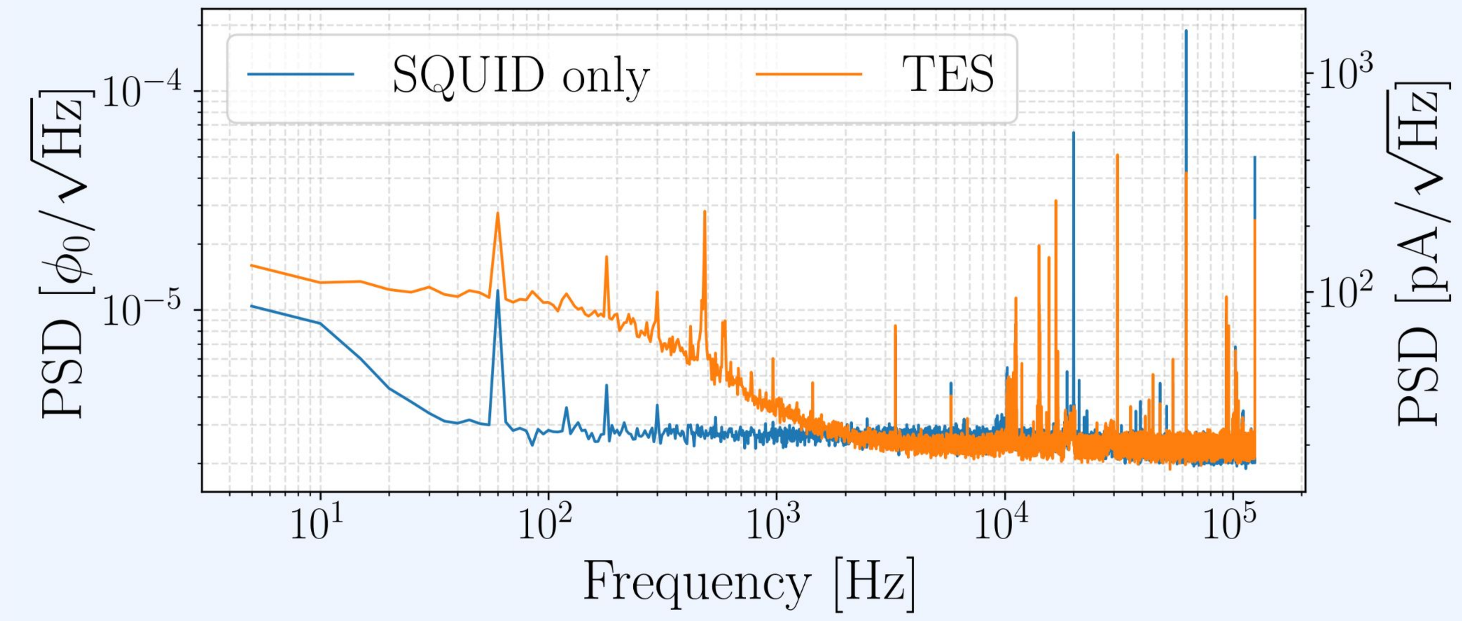
Multiplexer chip

The **µMUX chip has satisfying performance** and very nice resonances!

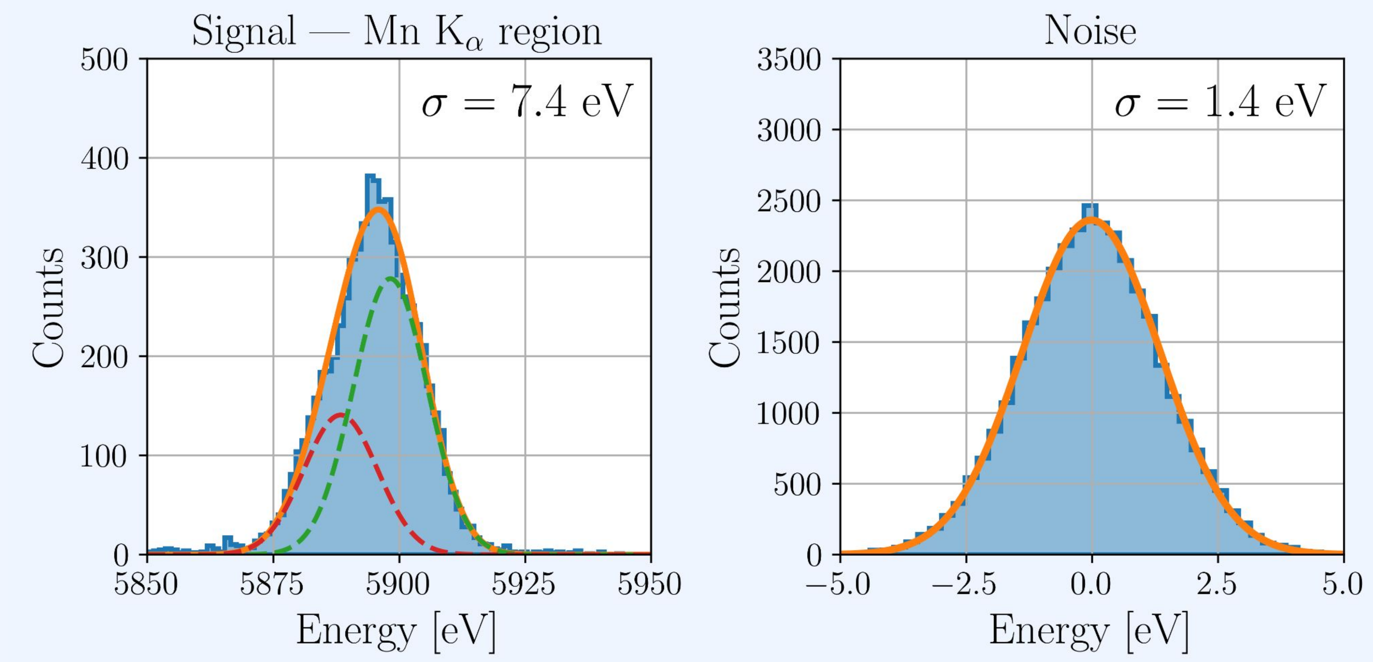


Preliminary results

- **Excellent SQUID noise** (2-3 µϕ_0/sqrtHz floor) and TES noise with no bias (10 µϕ_0/sqrtHz at low frequency)



- Satisfying noise energy resolution: 1.4 eV σ
- Excess noise when TES is biased → under investigation
- Future improvements:
  - Improving DC bias isolation
  - Adding magnetic shielding (ready to be tested)
  - Developing additional analysis tools for better thermal gain correction



Towards macrocalorimeters: future steps

Current characterization will serve as reference baseline. The following upgrades will be tested toward macrocalorimeter integration:

- **Larger absorbers** → O(1cm^3) TeO_2 crystals
- **Larger input coils** → adapt to the bigger thermal capacity of the crystals
- **Lower T_c TES** → get the maximum sensitivity (dV/dE)
- **Flexible superconductive connections** → distribute the uMUX over a larger volume
- **Novel holder** → mechanically decoupled from the main detector volume to suppress spurious modes and reduce noise

First paper in preparation, stay tuned!

References

[1] 10.48550/arXiv.2203.08386 [2] D.T. Becker et al 2019 JINST 14 P10035

Acknowledgments

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