Microwave Multiplexers for the Ricochet Experiment

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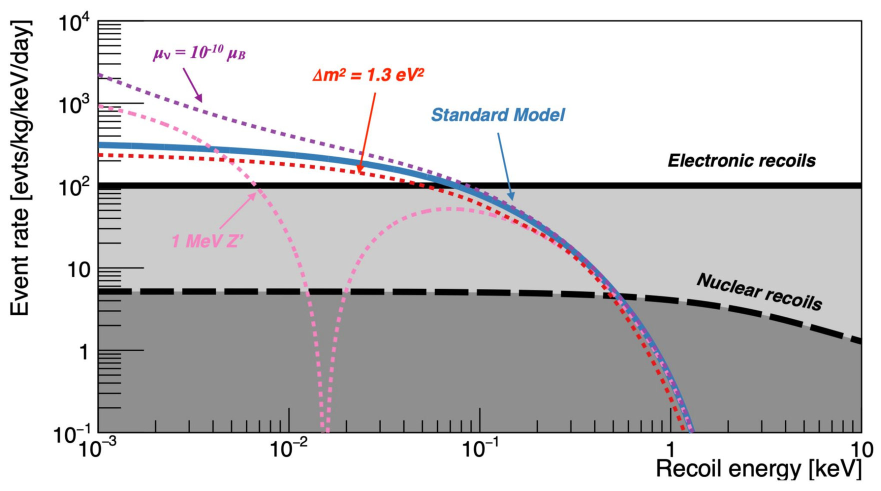
Please check out Valentina Novati's poster (No. 339) for more information about the Ricochet experiment!

Poster ID: 614

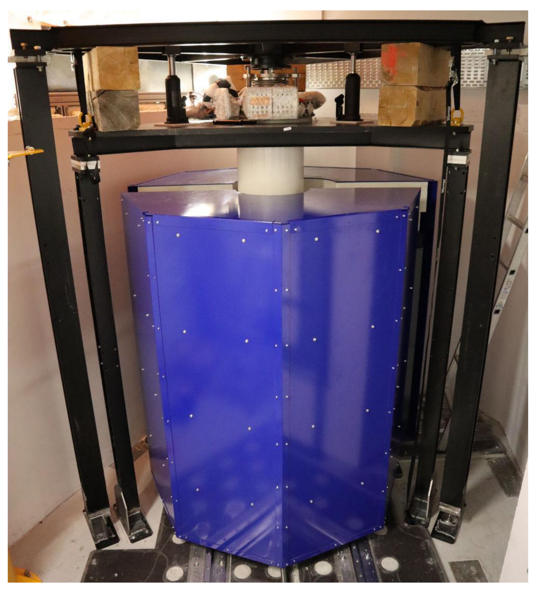
1. Introduction

The Ricochet experiment aims to measure the **Coherent Elastic Neutrino-Nuclear Scattering (CEvNS)** spectrum of reactor neutrinos at low energies to search for physics beyond the Standard Model.



Ricochet detectors

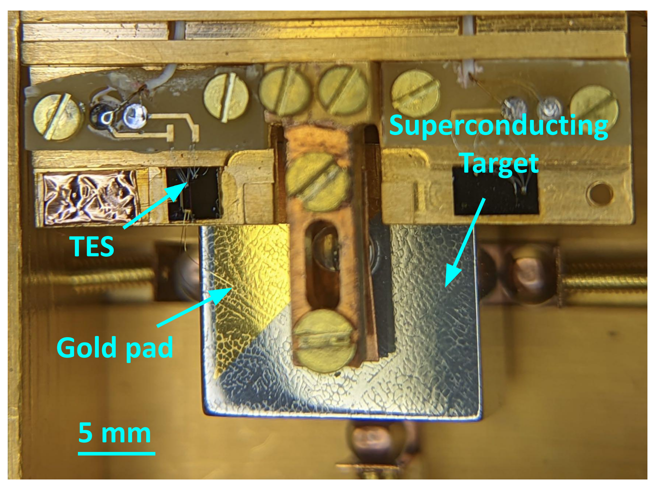
- **The CryoCube:** High purity germanium crystals target with germanium neutron transmutation doped (NTD) sensors for heat readout and aluminum electrodes for ionization readout.
- **Q-Array:** Superconducting crystal targets read out with transition-edge sensors (TESs).



Ricochet cryostat

Multiplexed readout of Q-Array

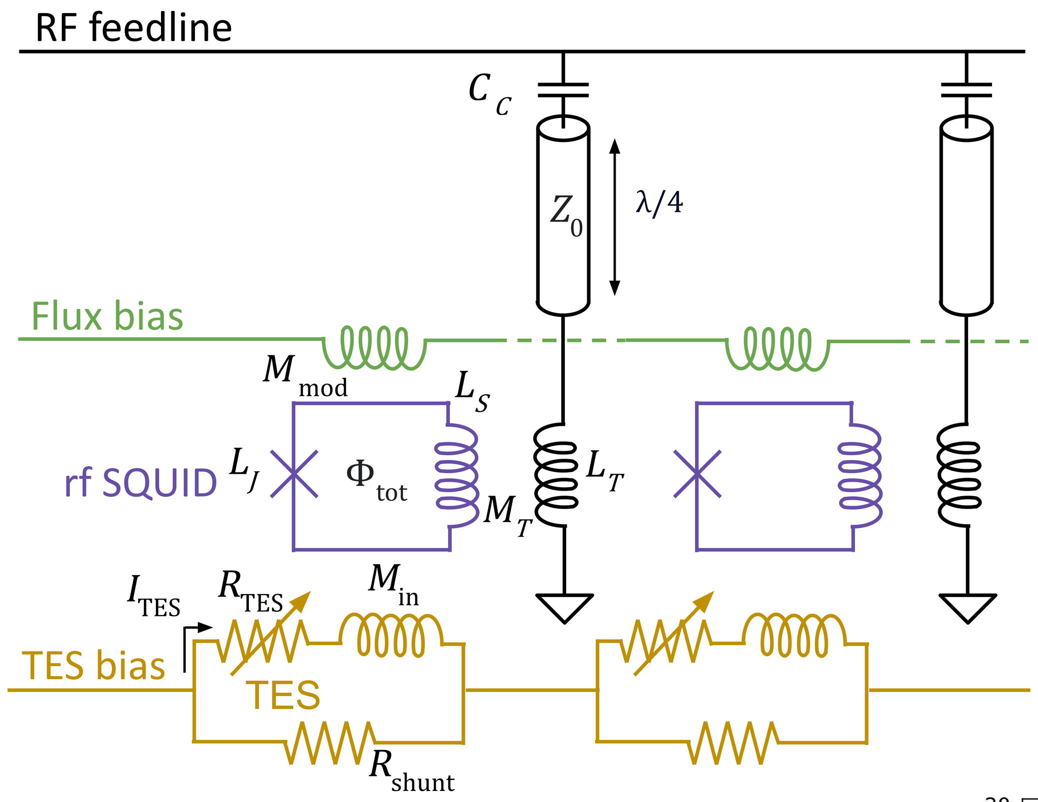
Instead of reading out each of the TESs individually with DC SQUIDs, Q-Array plans to use one **microwave multiplexer** to read out all TESs at the same time. This is especially helpful for scaling up the number of sensors in cryogenic neutrino experiments because it significantly reduces the number of cables and heat load in the cryostat.

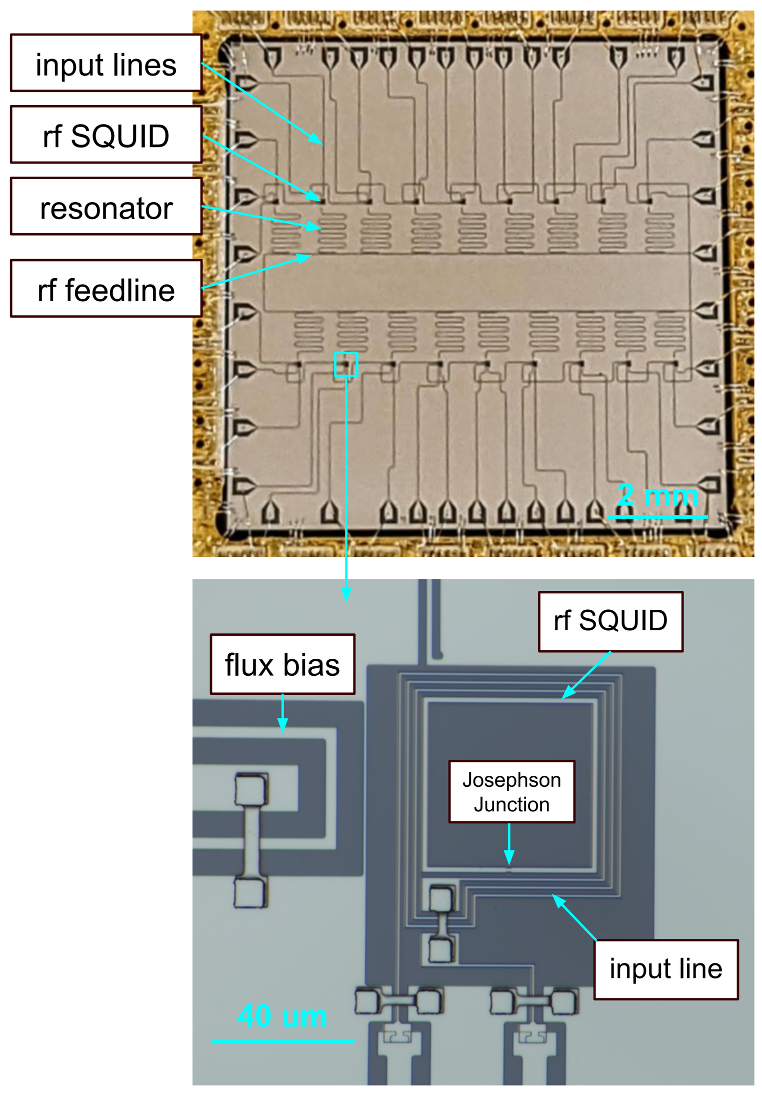


Q-Array detector box

2. Device design

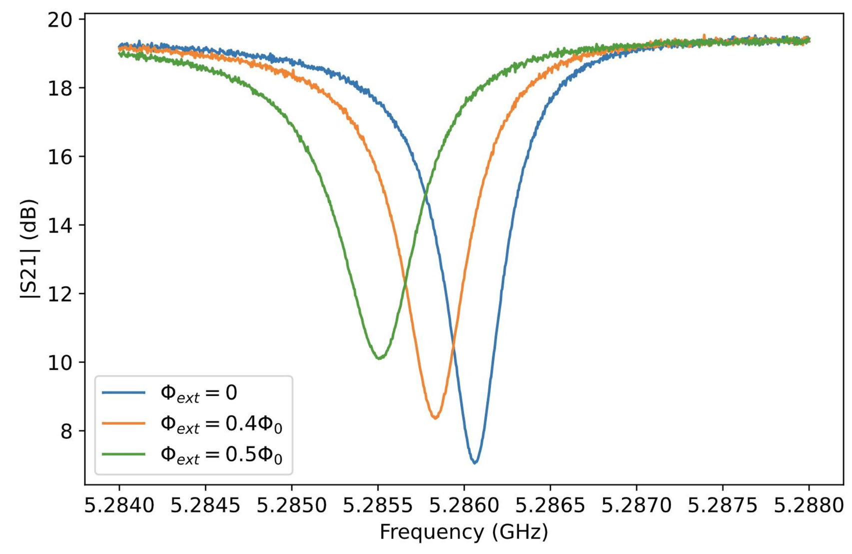
Each channel of the multiplexer consists of an RF SQUID inductively coupled to a λ/4 resonator.

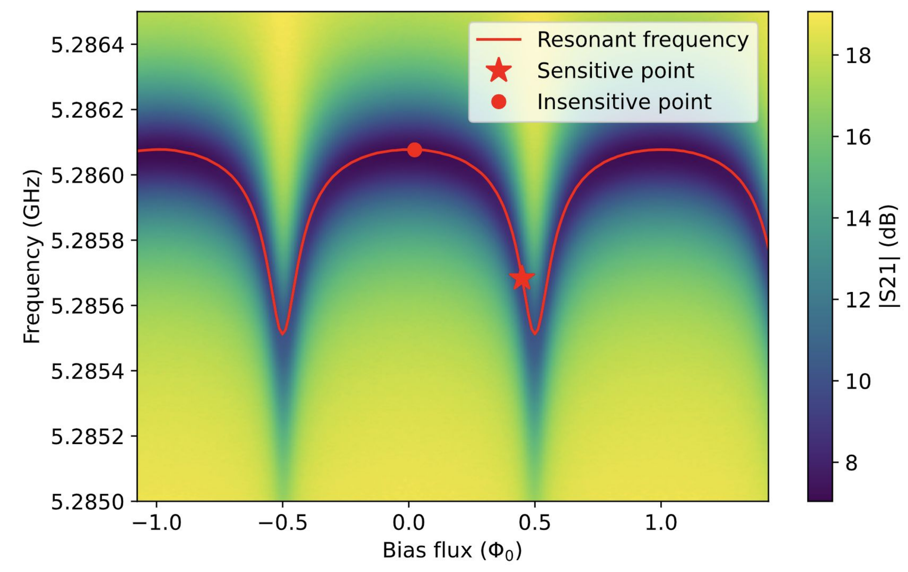




Working principle

Particle interactions in the superconducting target
↓
Energy transfer from target to TES
↓
Change in TES resistance and TES current
↓
Change in magnetic flux through the rf SQUID
↓
Change in the effective inductance of the SQUID and resonator termination
↓
Shift in resonant frequency of the resonator
↓
Change in the rf signal amplitude and phase





Fabrication

These devices were based on the design proposed by J.A.B. Mates in [1] and fabricated at Lincoln Laboratory with high quality factor MBE Al base metal and Dolan-style Josephson junctions.

Design objectives

- **Response time:** Crystal pulse rise time around 100 us. $\tau_{res} = Q_l/(\pi f_{res}) \approx 1$ us.
- **Input coupling:** Designed to reach the TES sensitivity of 10 pA/√Hz
- **Number of channels:** 9 crystals * 2 = 18 channels

Flux ramping

Since it is hard to bias all resonators at a fixed bias point with one flux bias line, we bias the resonators with a **sawtooth flux signal** instead. The slow flux signal thus shows up as a **phase modulation** of the free oscillation signal induced by sawtooth flux bias.

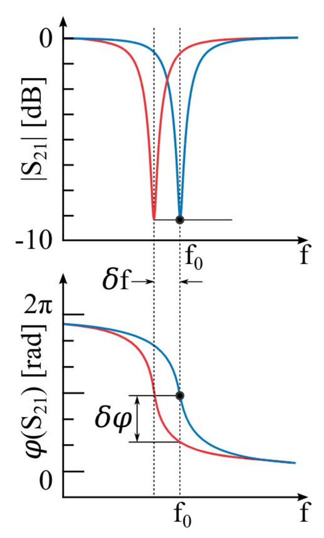
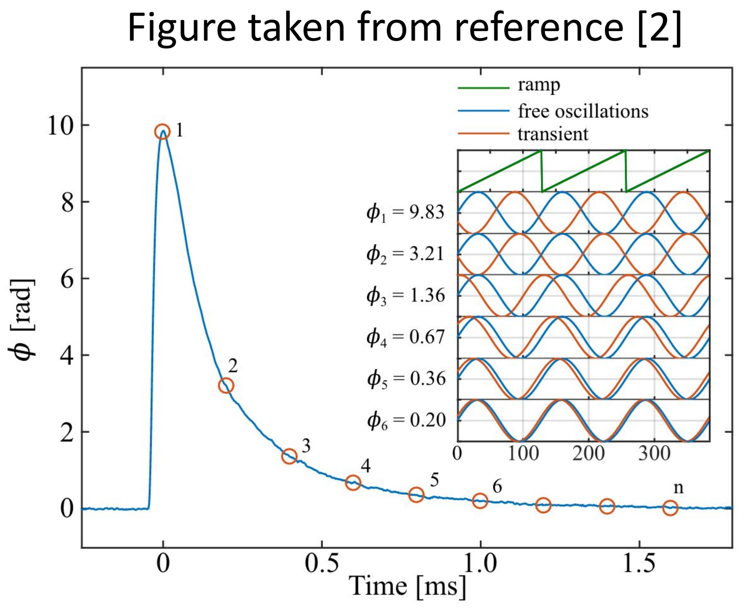


Figure taken from reference [2]



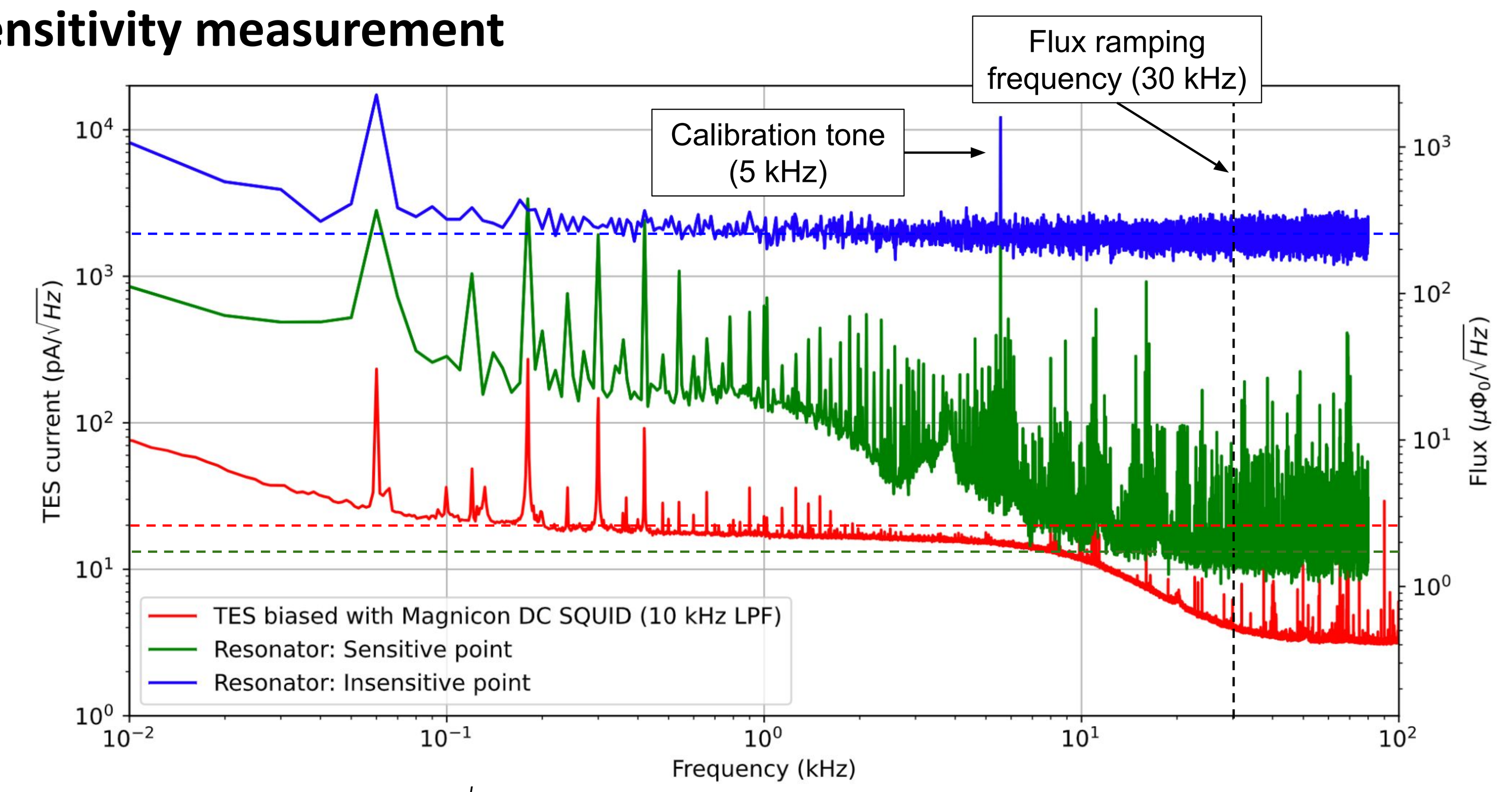
3. Characterization results

Circuit parameters

We extract the circuit parameters of the multiplexer by fitting the resonant frequency vs bias flux data measured at low rf powers to existing analytic models detailed in [1] and [3].

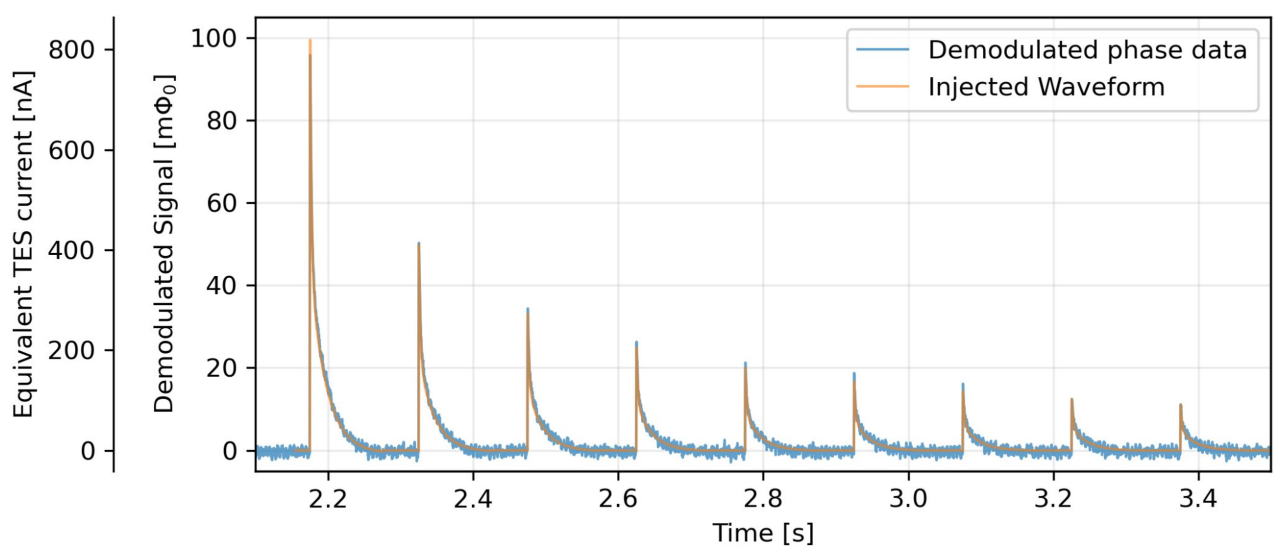
Channel #	Resonant frequency [GHz]	Q_c	Q_i	L_S [pH]	β_L	M_T [pH]	Sensitivity [$\mu\Phi_0/\sqrt{Hz}$]
Target	**/**	**20k**	**/**	**200**	**0.51**	**10**	**/**
1	4.03	17k	>100k	209	0.51	12.1	1.3
3	4.86	17k	>100k	192	0.47	10.1	1.6
4	5.43	17k	18k	187	0.46	7.2	2.3

Sensitivity measurement



- **TES noise level:** 20 pA/√Hz.
- **Multiplexer noise level:** ≈10 pA/√Hz at sensitive point.
- **Flux ramping:** Cycles through sensitive and insensitive points, thus degrading the sensitivity by a factor of at least √2 compared to sensitive point.
- **Conclusion:** Current multiplexer sensitivity is not yet below TES noise, but they are on the same order of magnitude.

Flux ramping and signal demodulation - in progress



We use SMuRF, the readout electronics designed by SLAC to perform flux ramping and signal demodulation. We injected pulse templates through the flux bias line and successfully demodulated them as a proof of concept.

4. Next steps

- **Noise hunting:** Get rid of excess noise peaks in the spectrum.
- **Input lines:** Calibrate the input line with current sources. Connect TES to the multiplexer.
- **Measurements with quantum amplifiers:** Using TWPA (Travelling Wave Parametric Amplifier) for multiplexer readout could potentially lower the white noise floor.
- **SMuRF readout:** Explore capabilities of SMuRF readout. Measure flux ramping sensitivity.
- **Design new devices:** Further optimize circuit parameters for better sensitivity.

Acknowledgments

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References

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