

Scaling the sub-eV frontier

Microwave multiplexing for athermal phonon TESs

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Dan Becker
John Gard

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COORDINATING PANEL ON ADVANCED DETECTORS · APS DPF

CPAD 2026

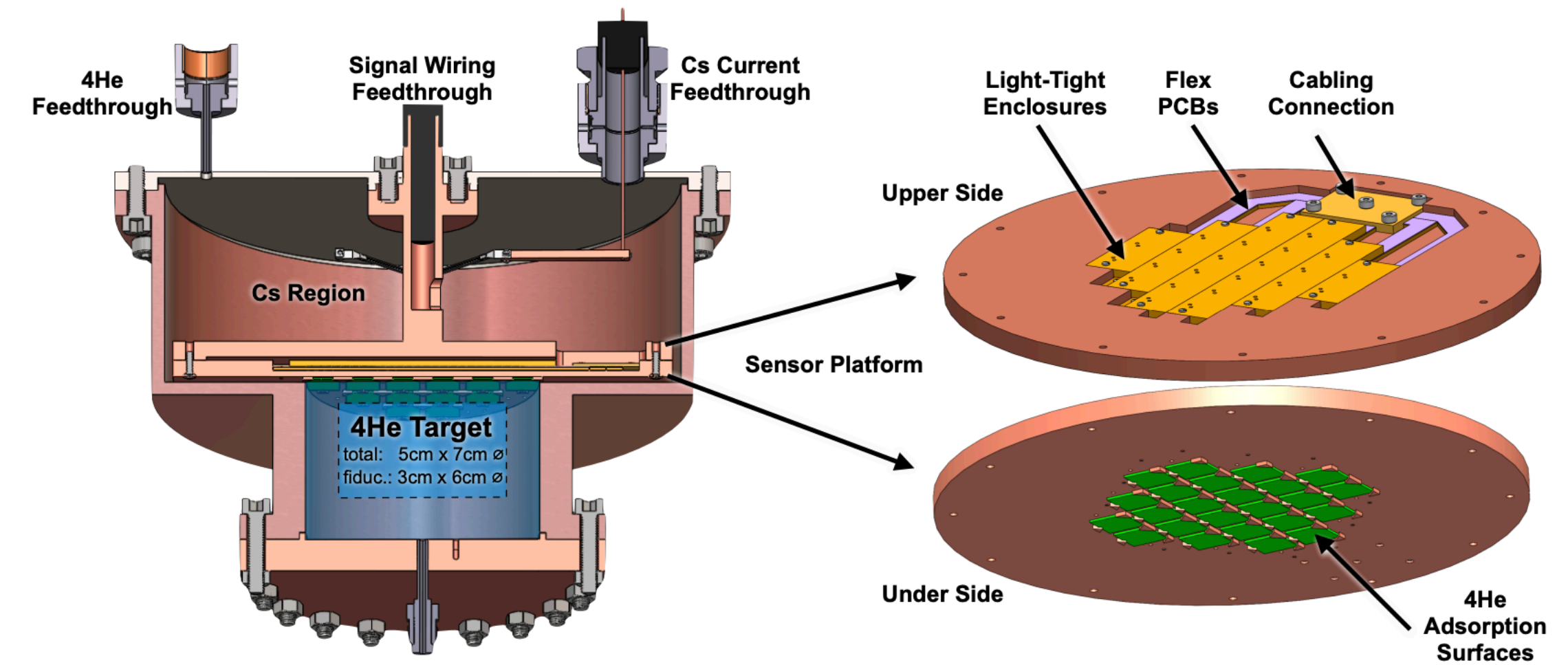
Instrumentation and detector R&D workshop

20–23 October 2026 University of Washington · Seattle, WA

Motivation: scaling up DM searches

sub-GeV projects are starting to cover exciting new ground with a small number of Transition-Edge Sensors

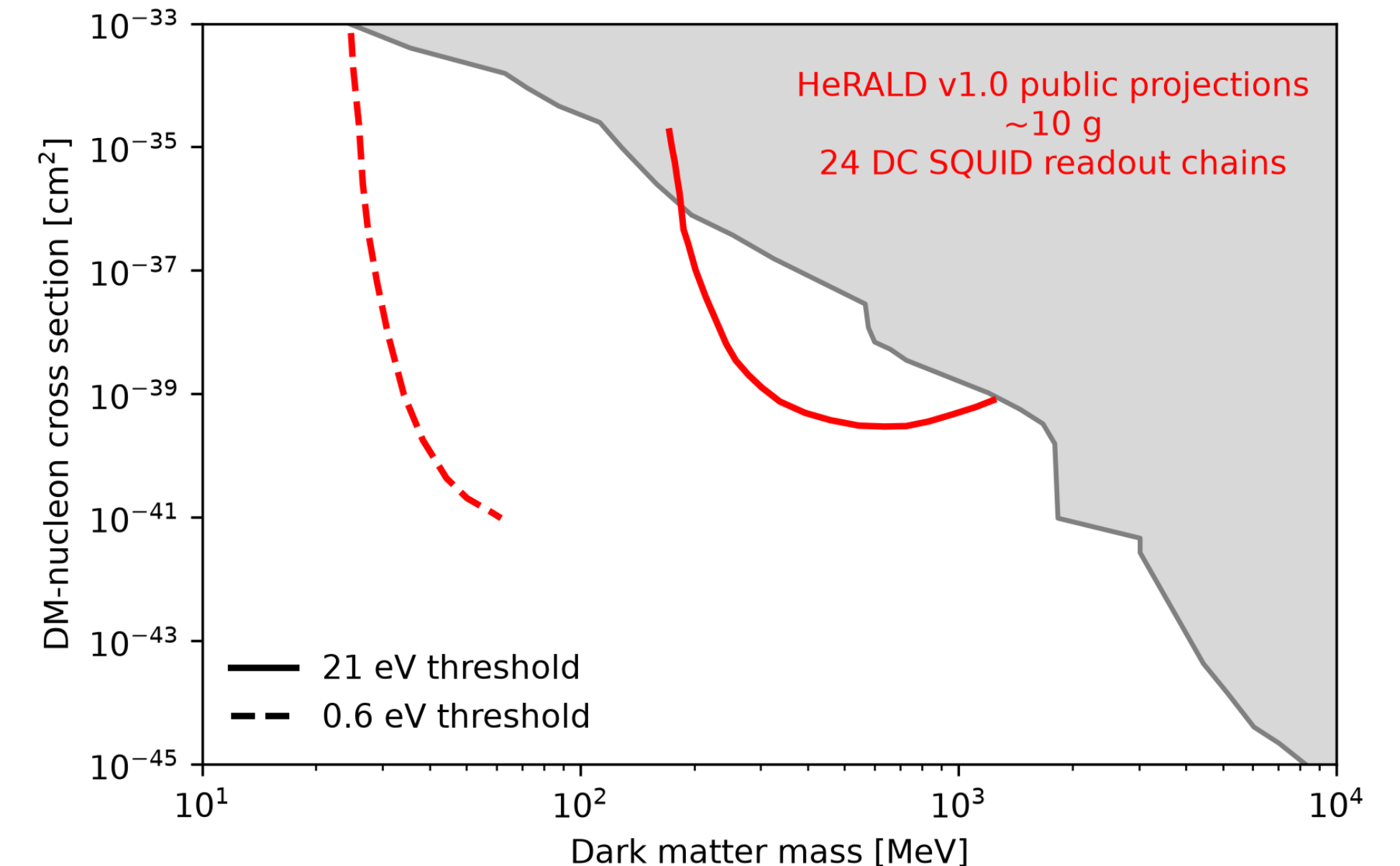
But getting to ~kg targets with current readout techniques is not feasible



Example state of the art detector:

24 channels, ~150 wires

Johanna Wuko, CPAD 2025

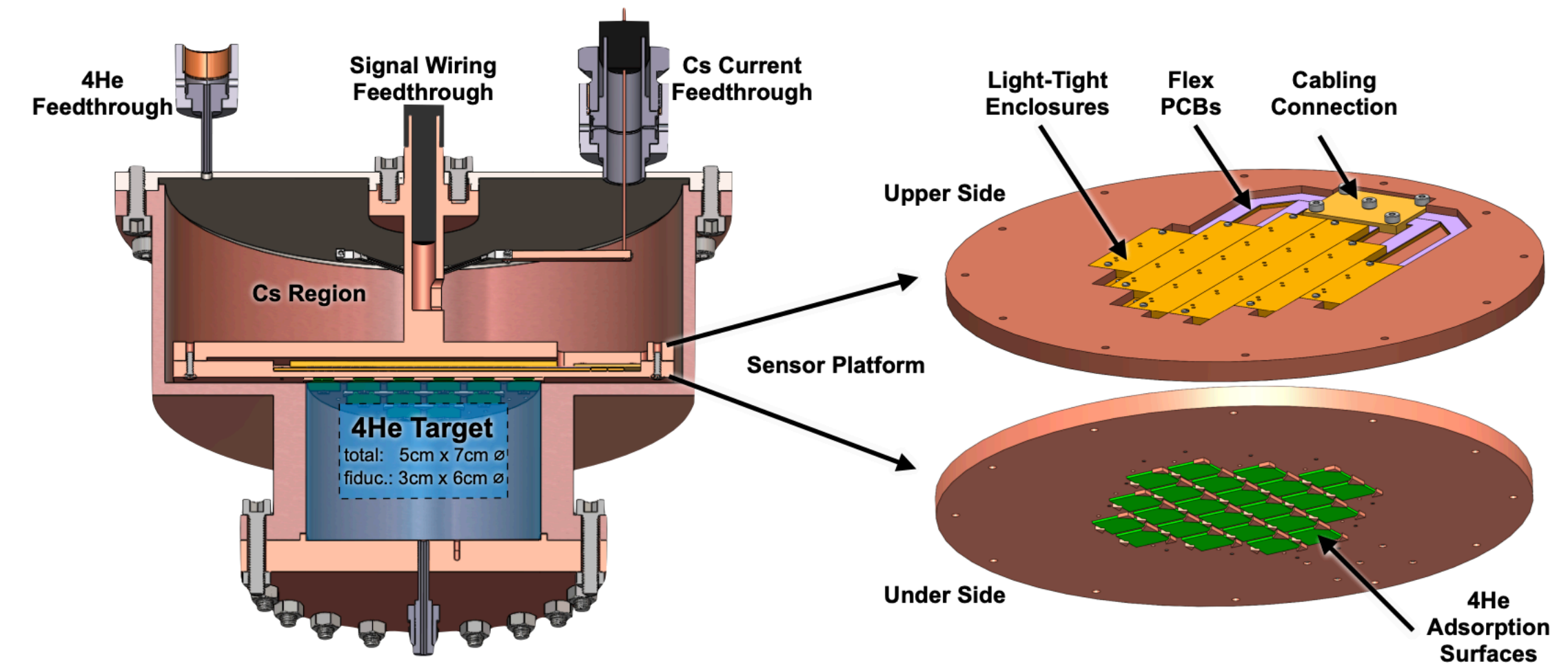


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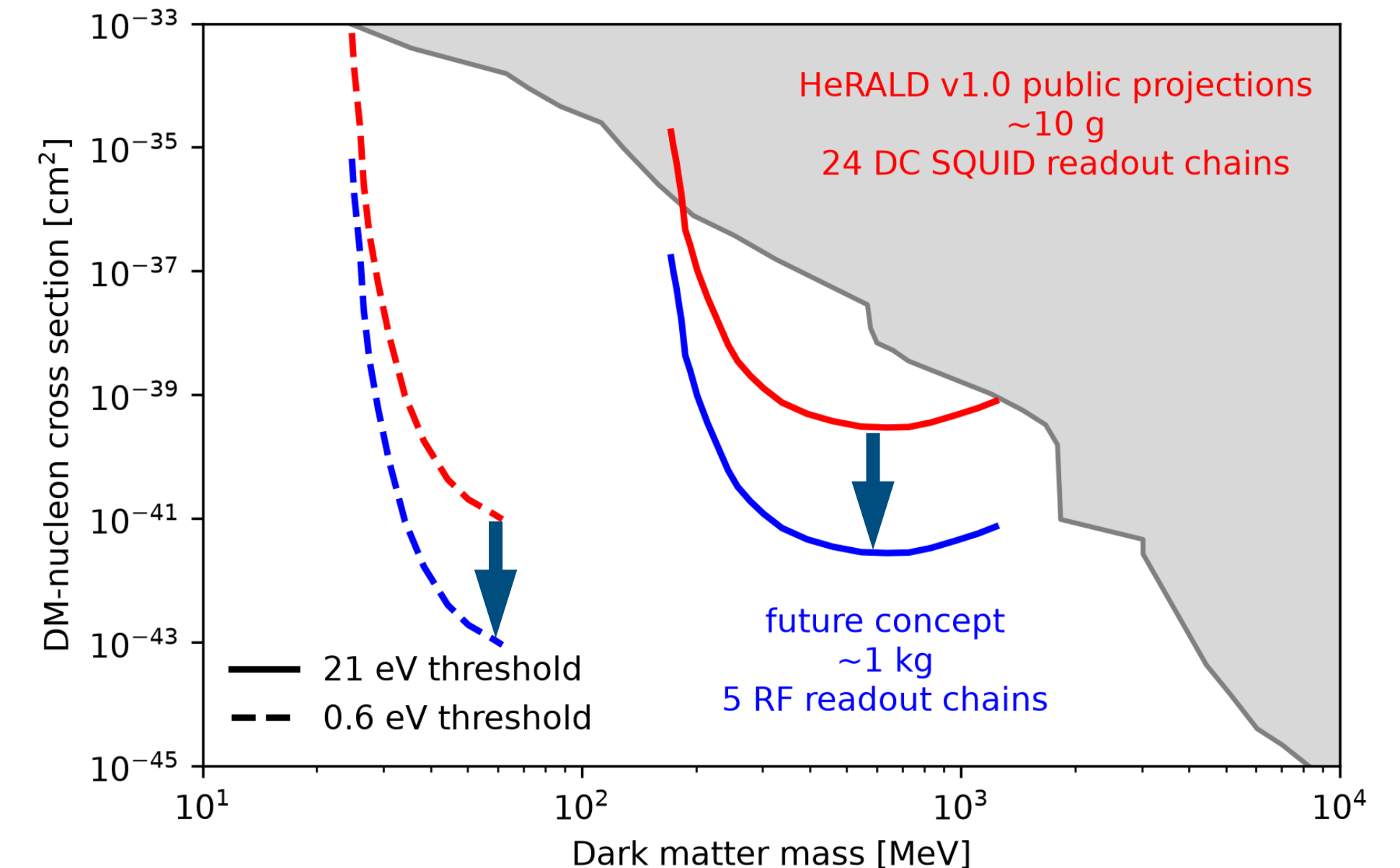
Our focus: enabling the sensor count and wiring needed for future larger detectors



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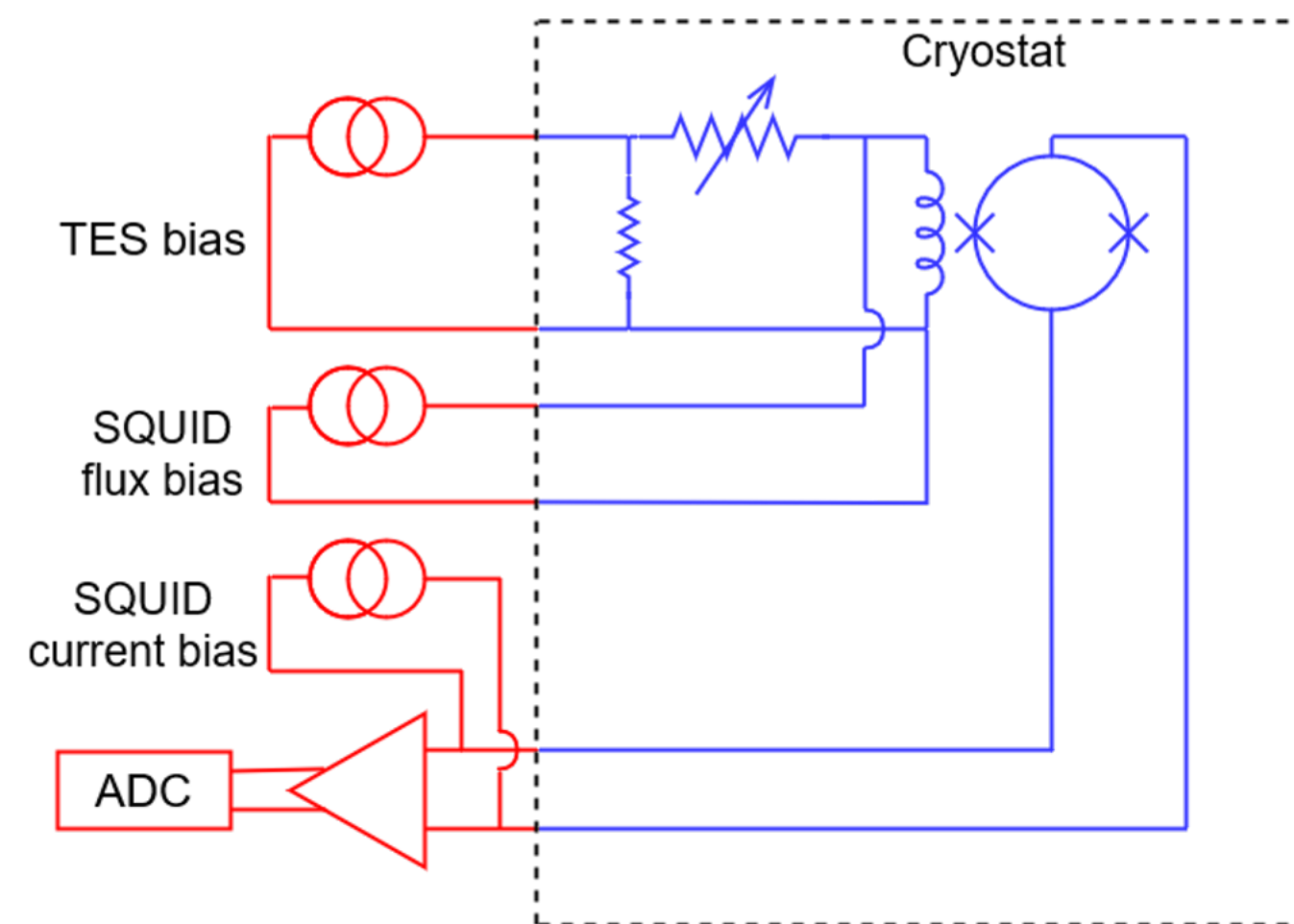
Johanna Wuko, CPAD 2025



The readout problem

Though TESs lead the pack in energy resolution, their readout is not intrinsically scalable

Assuming # of sensors $\sim$ target volume, then a 1 kg target would require $>10,000$ wires running to 10 mK...



Minimum readout circuit for 1 TES w/ direct readout

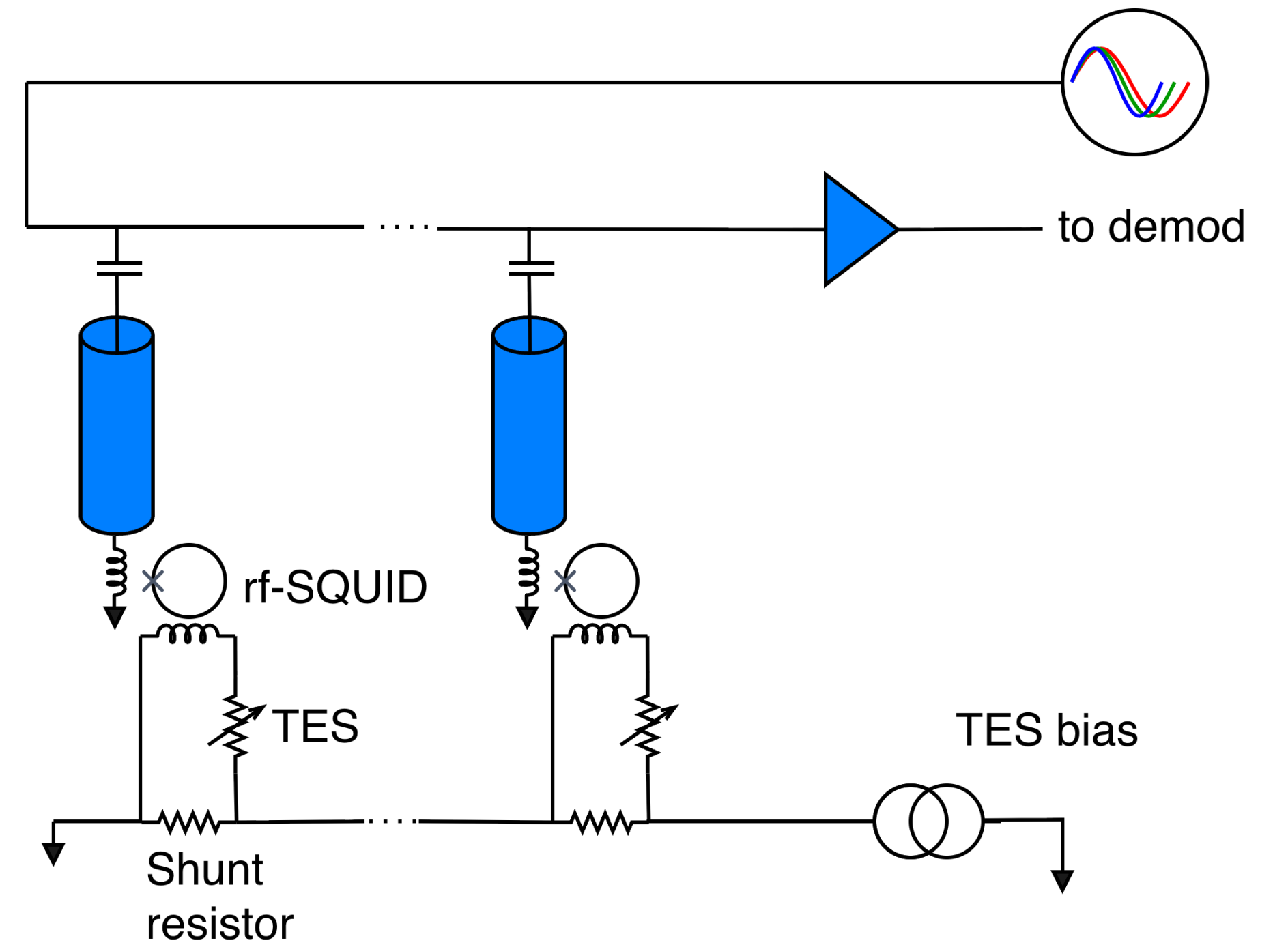


Could read and bias only a few sensors per standard cryogenic ribbon cable



Scalable TES readout via microwave SQUID multiplexing (μ mux)

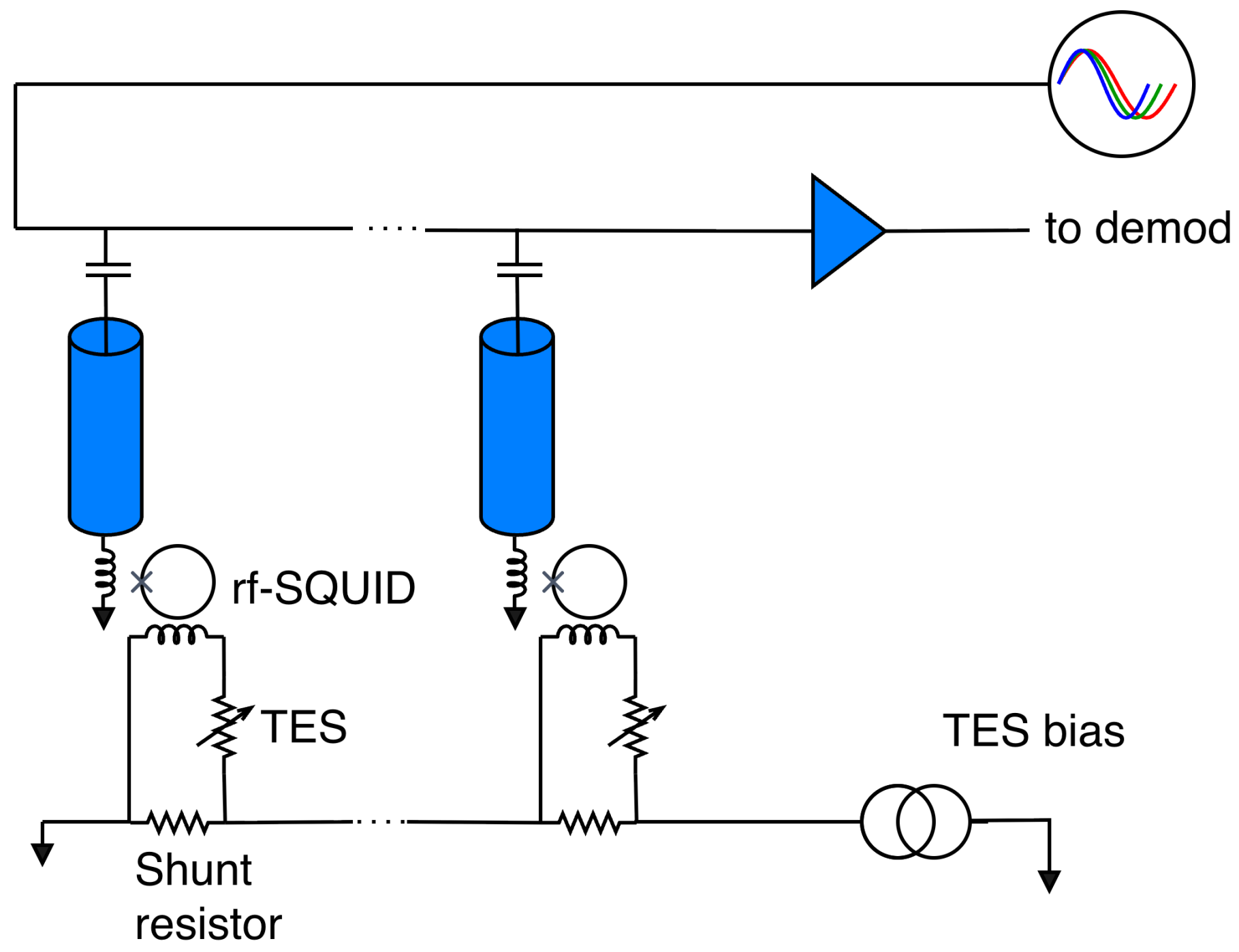
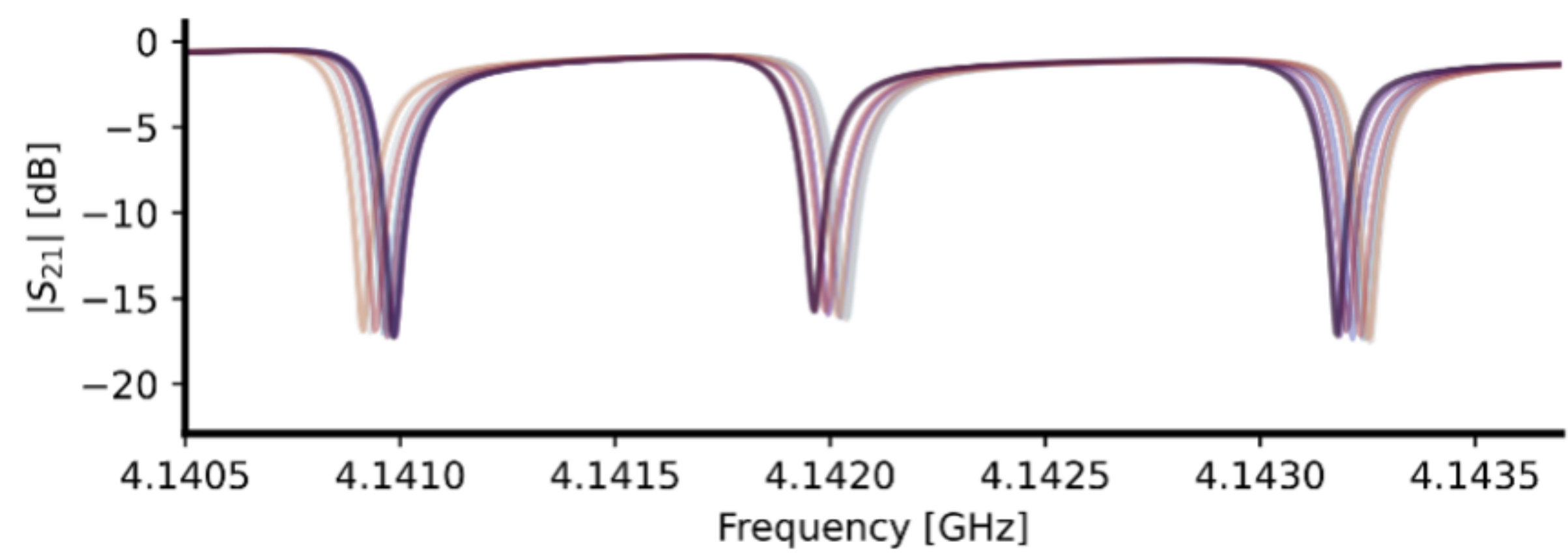
Can achieve very high sensor count with TESs using microwave multiplexing techniques



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Each TES coupled to a unique resonator through a variable Josephson inductance

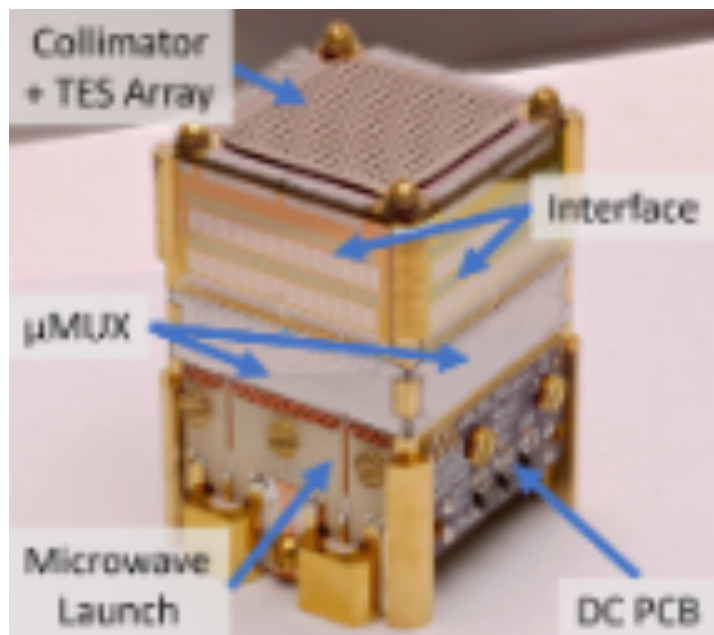
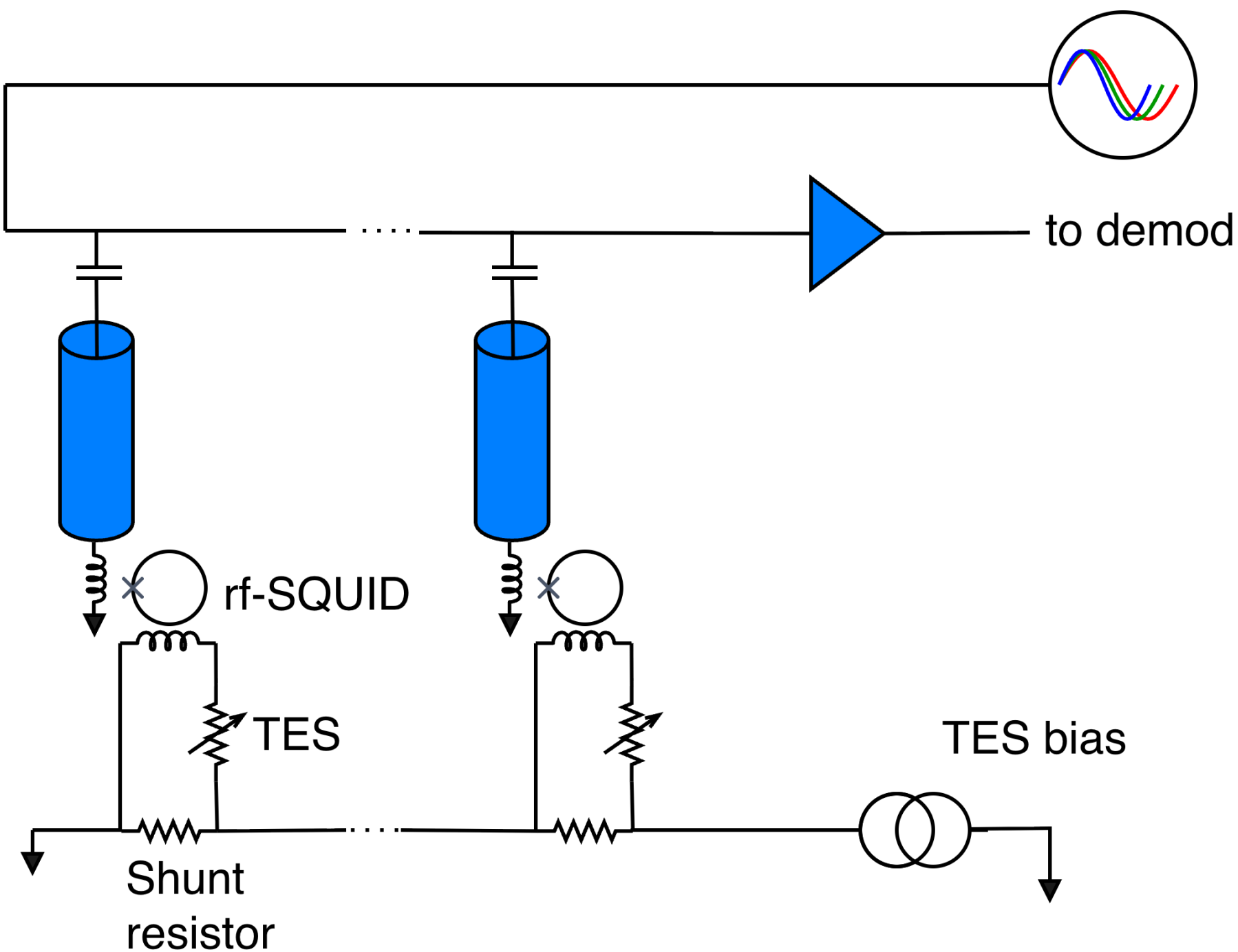
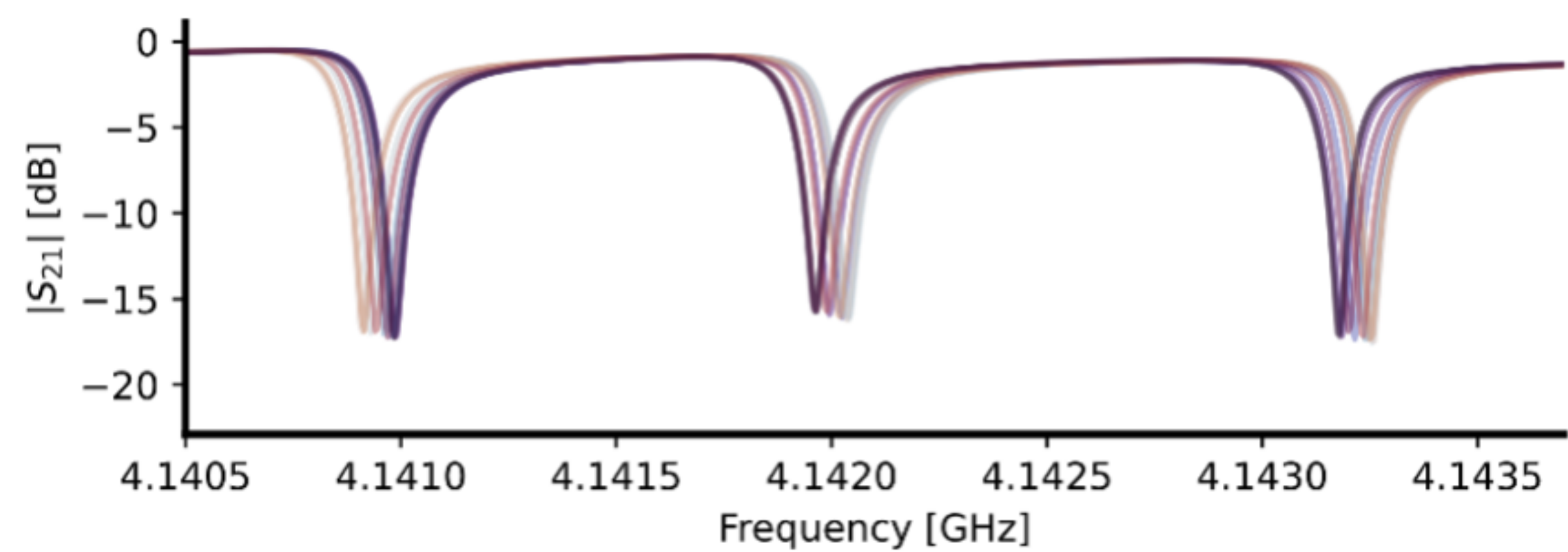


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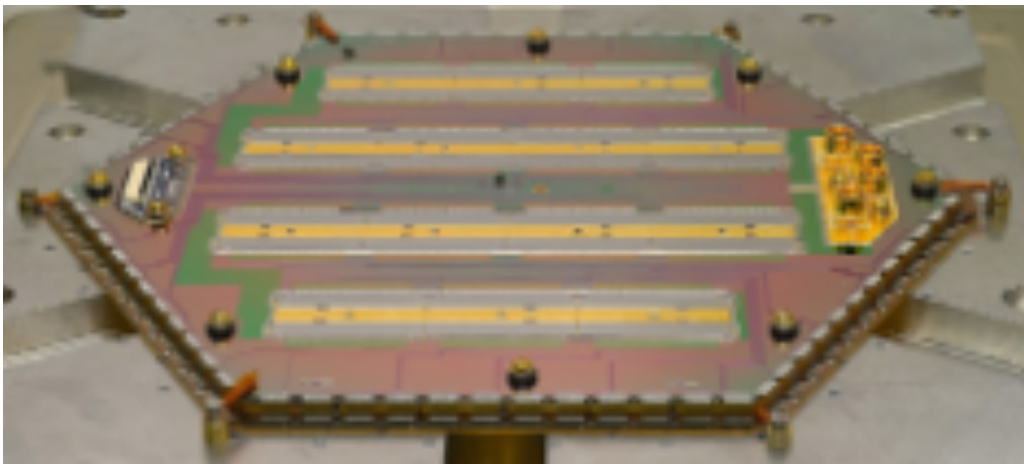
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Many CMB, γ -ray, and x-ray detector systems have been deployed at scale now

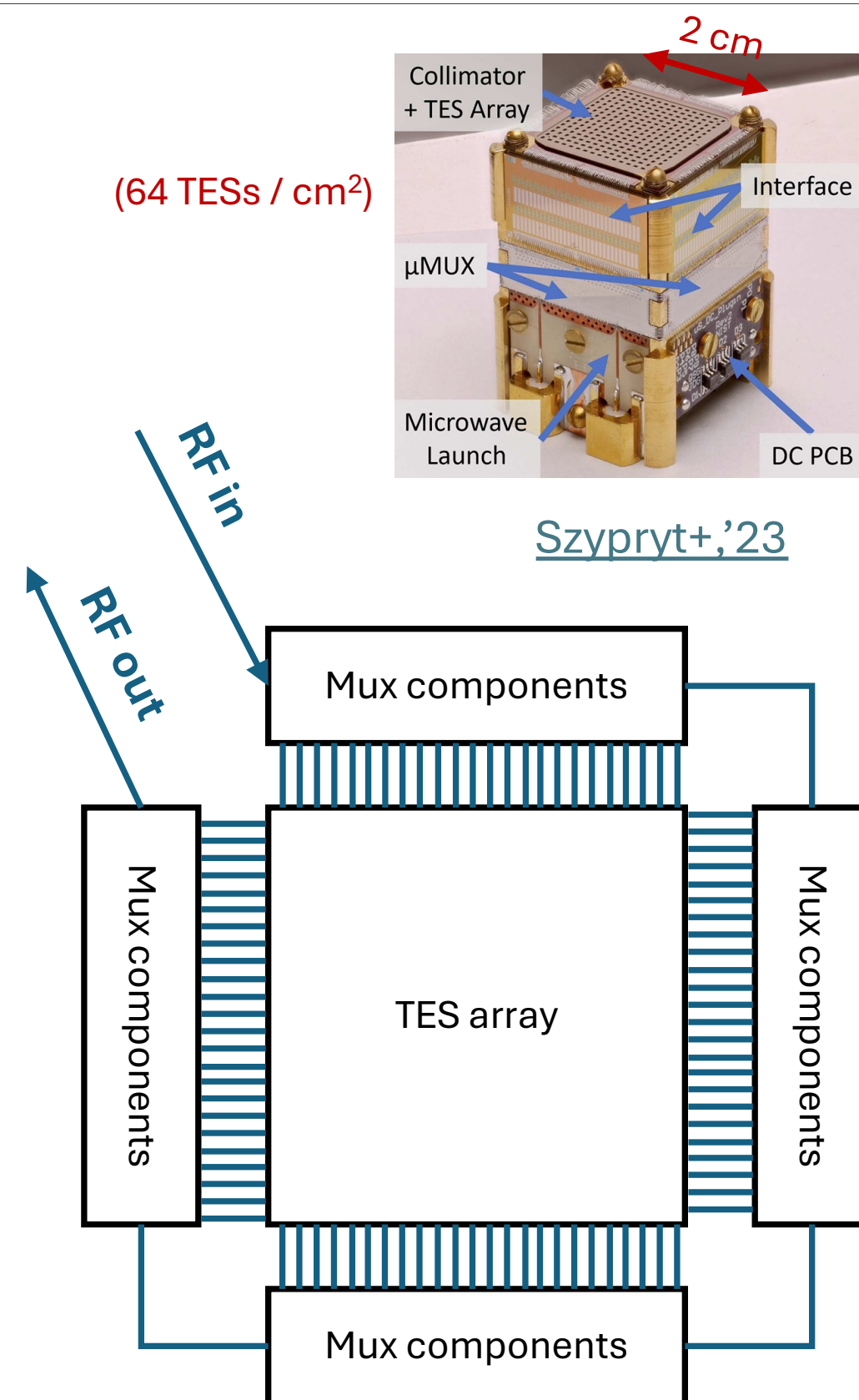


X-ray
256 sensors / line
Szypryt+, [2212.12073](#)



mm-wave
1820 sensors / line
Groh+, [2507.10929](#)

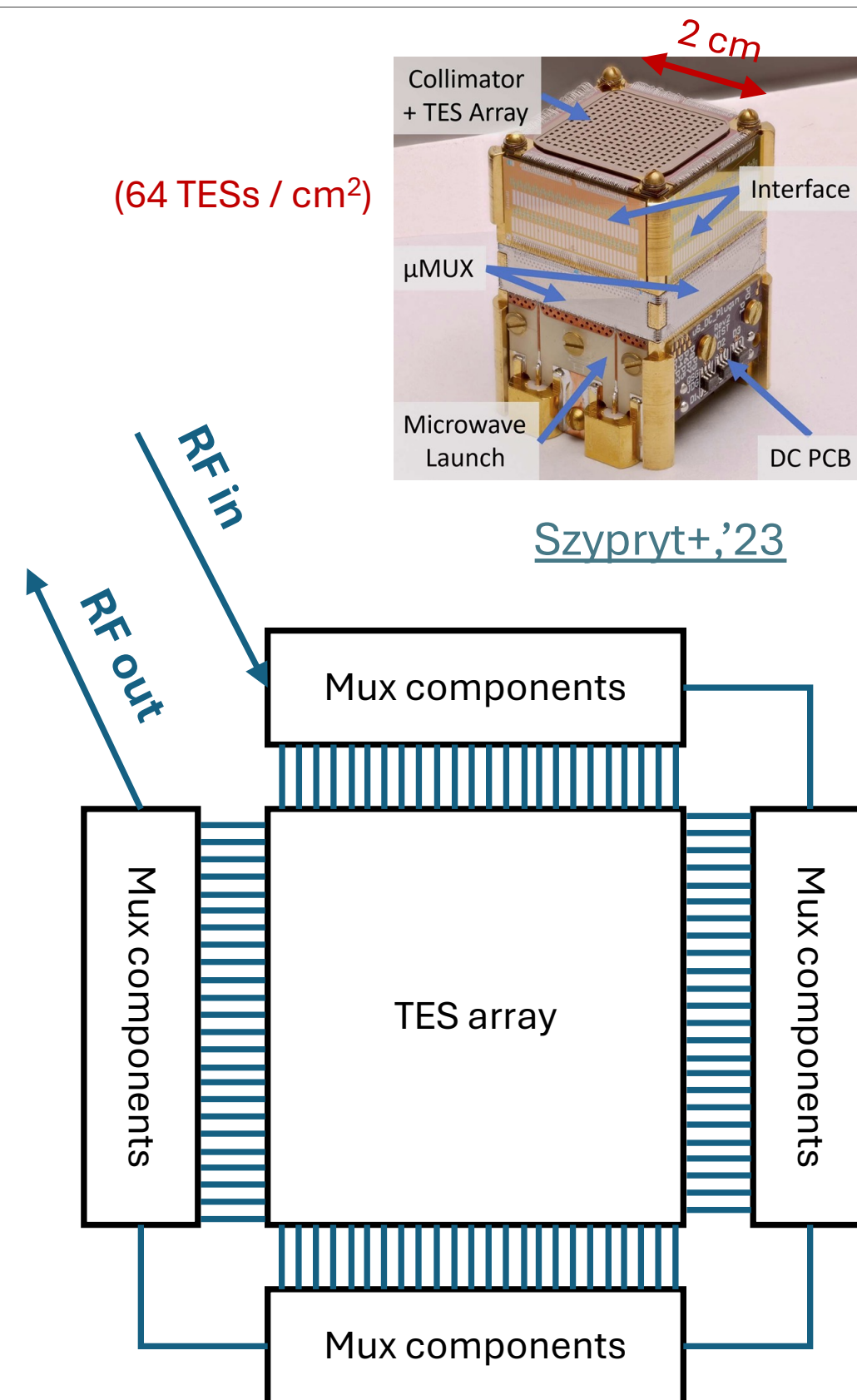
Athermal phonon detector-specific R&D setup



Previous applications:

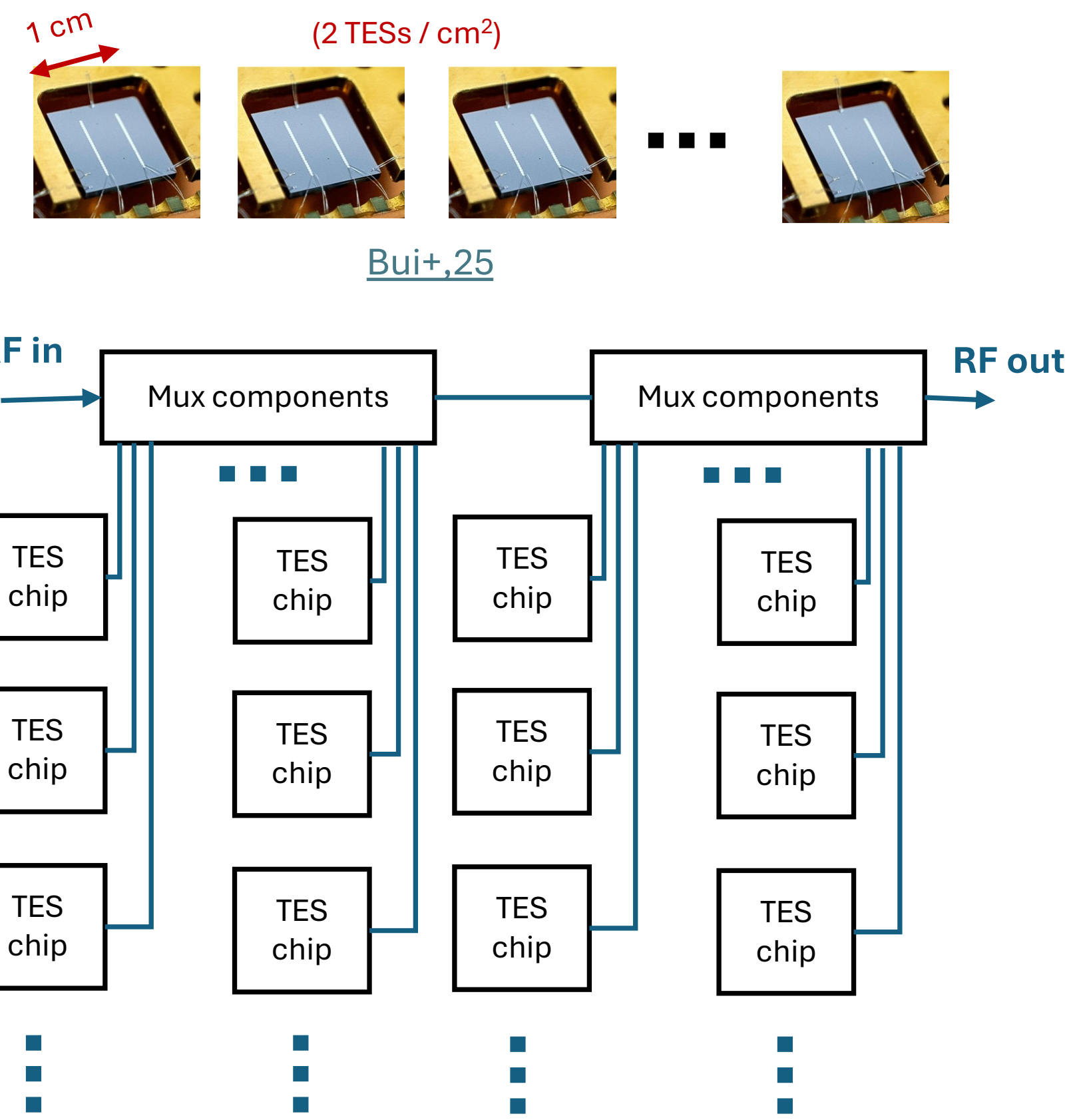
- Dense monolithic TES array
- Interconnects typically wirebonds and/or lithographed traces
- Low TES resistance – cannot tolerate connectors

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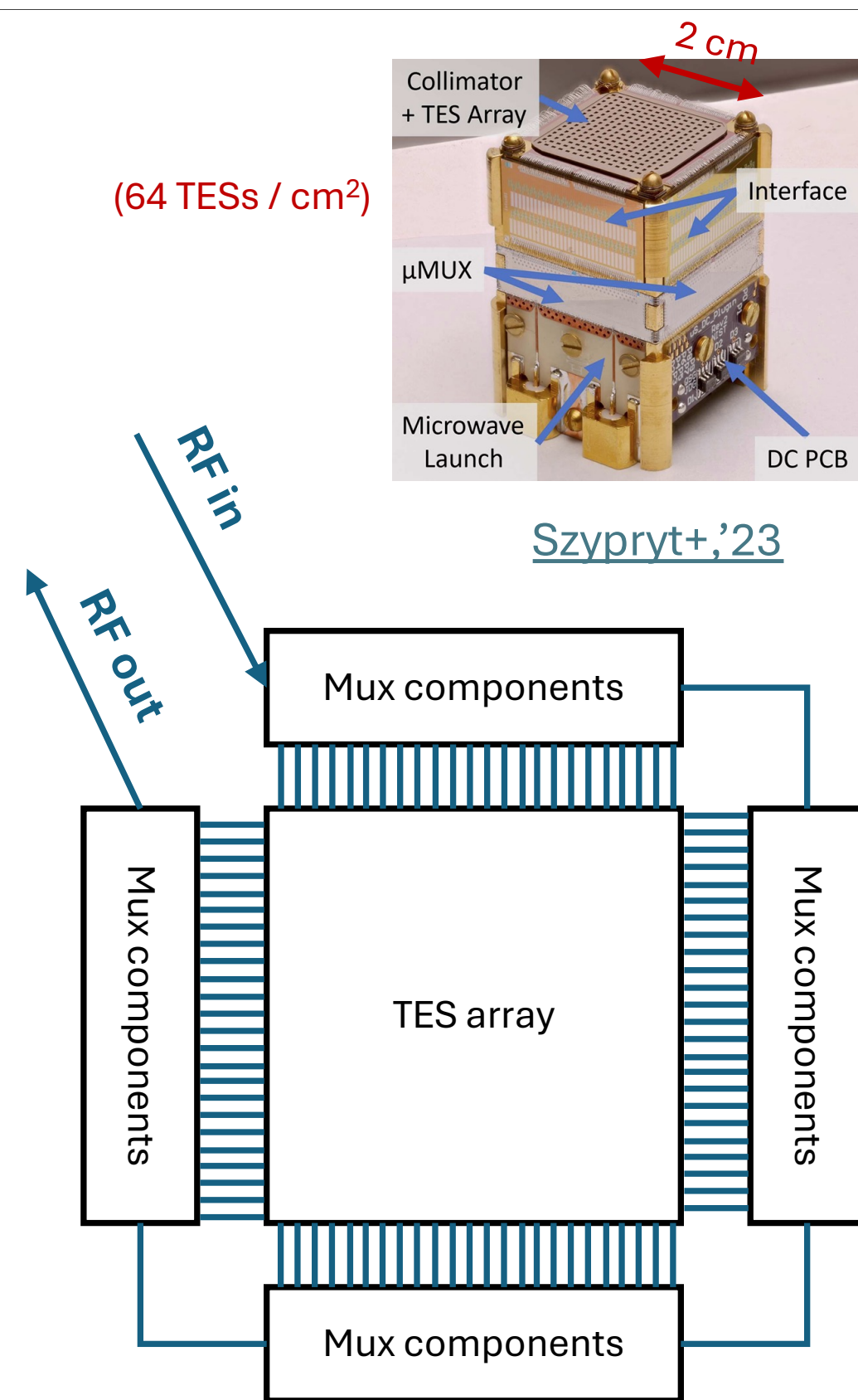
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Dark matter style sensors:

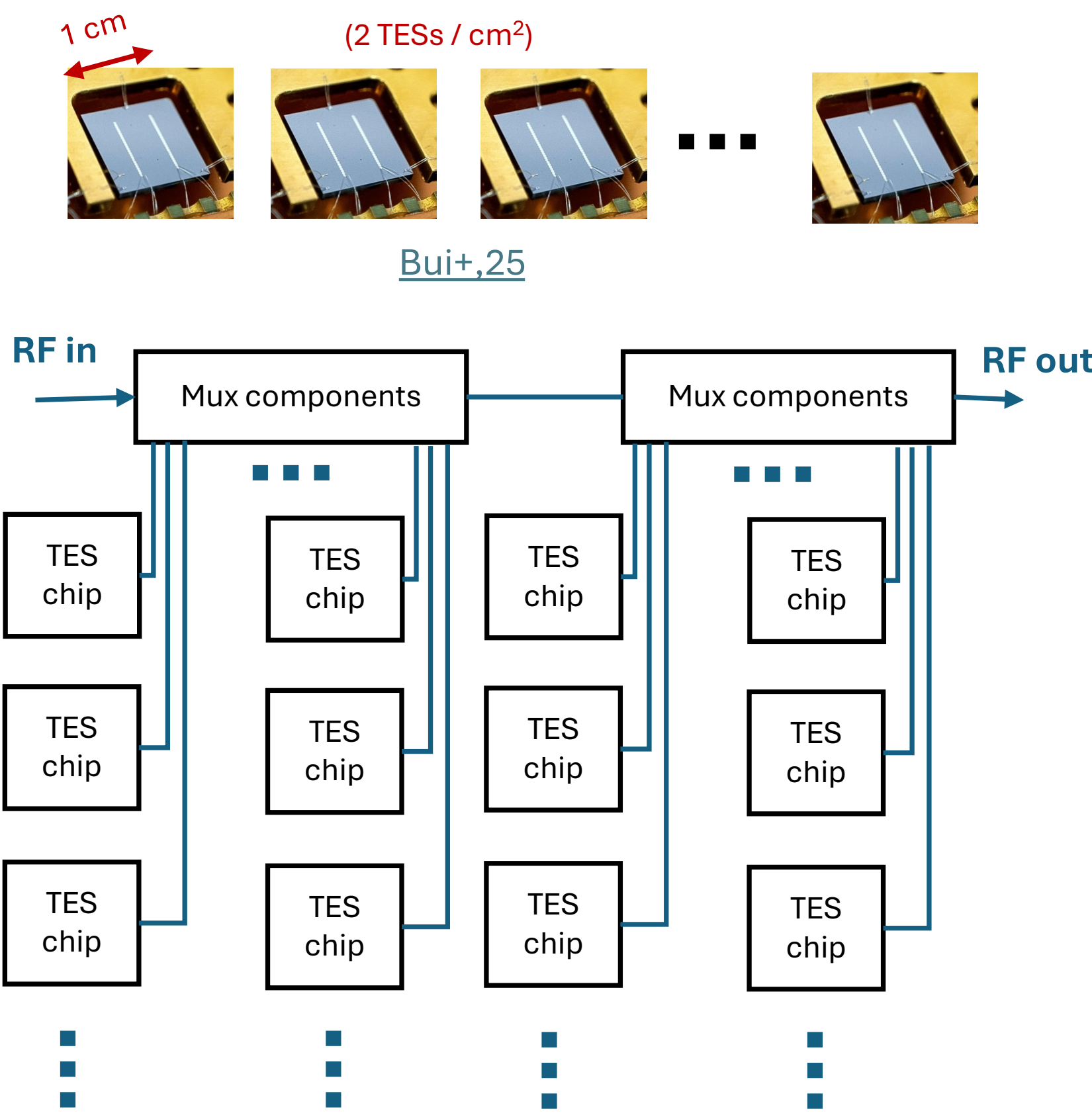
- TES array may not be monolithic
- Interconnects likely to be longer and may need to follow complex 3D path
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Athermal phonon detector-specific R&D setup



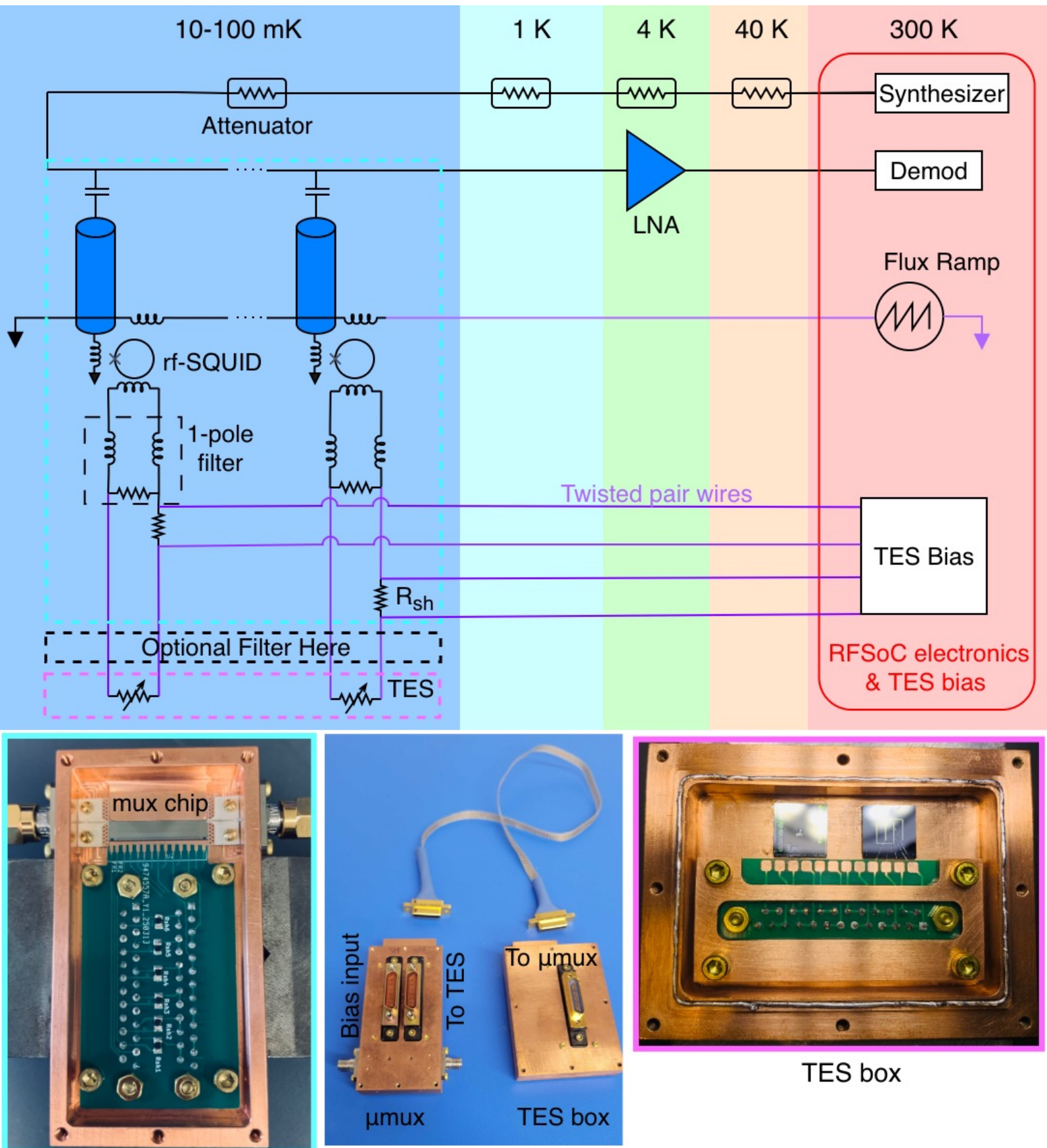
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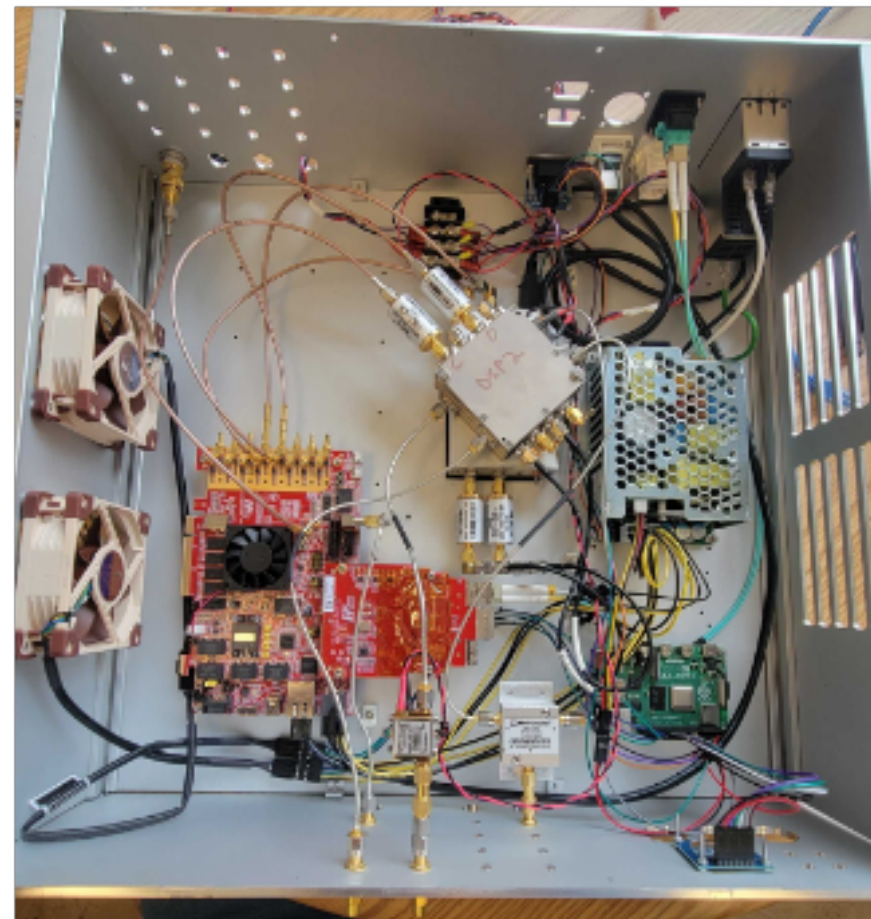
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Our R&D form factor:

- Separate RF/grounding needs for mux chip from IR/vibration needs of TESs via separate packaging
- Twisted pair wiring as proxy for complex wiring

Readout performance in isolation

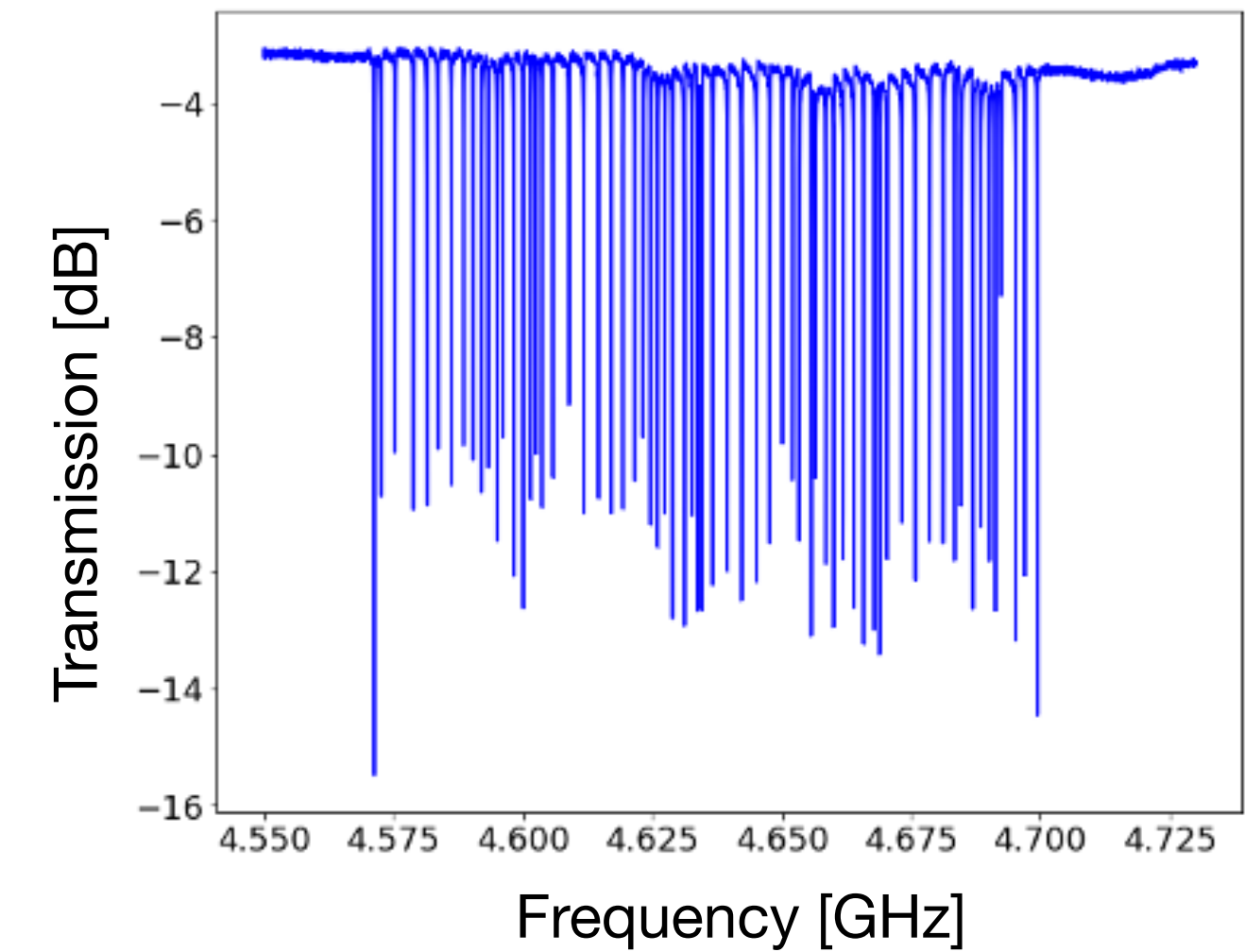


RFSoc-based system from NIST generates 4-8 GHz probe tones and performs demodulation on the fly

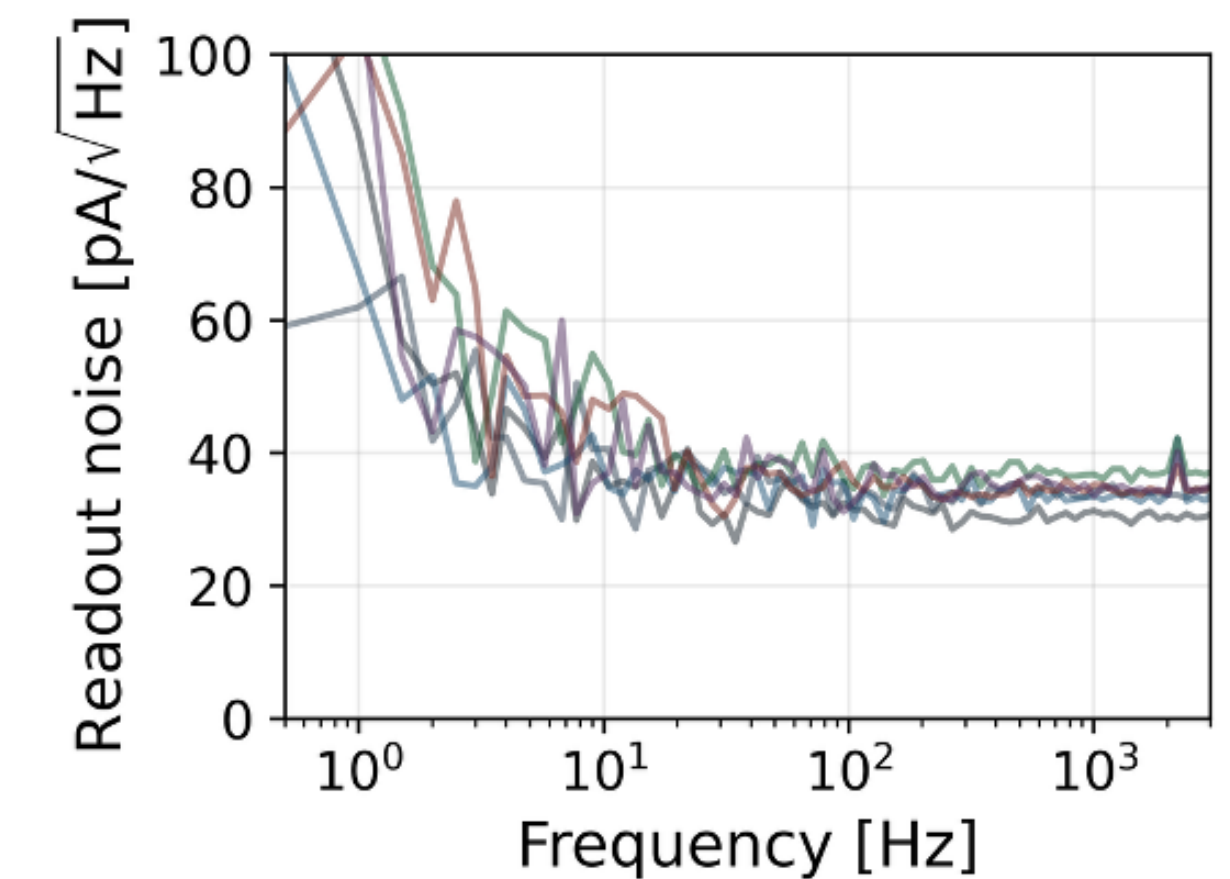
No surprises with the off-the-shelf components we put together

End-to-end test setup works with noise as low as previously deployed at-scale μmux

First tests done w/ spare mm-wave optimized chip. Not optimal for dark matter, but easily swappable



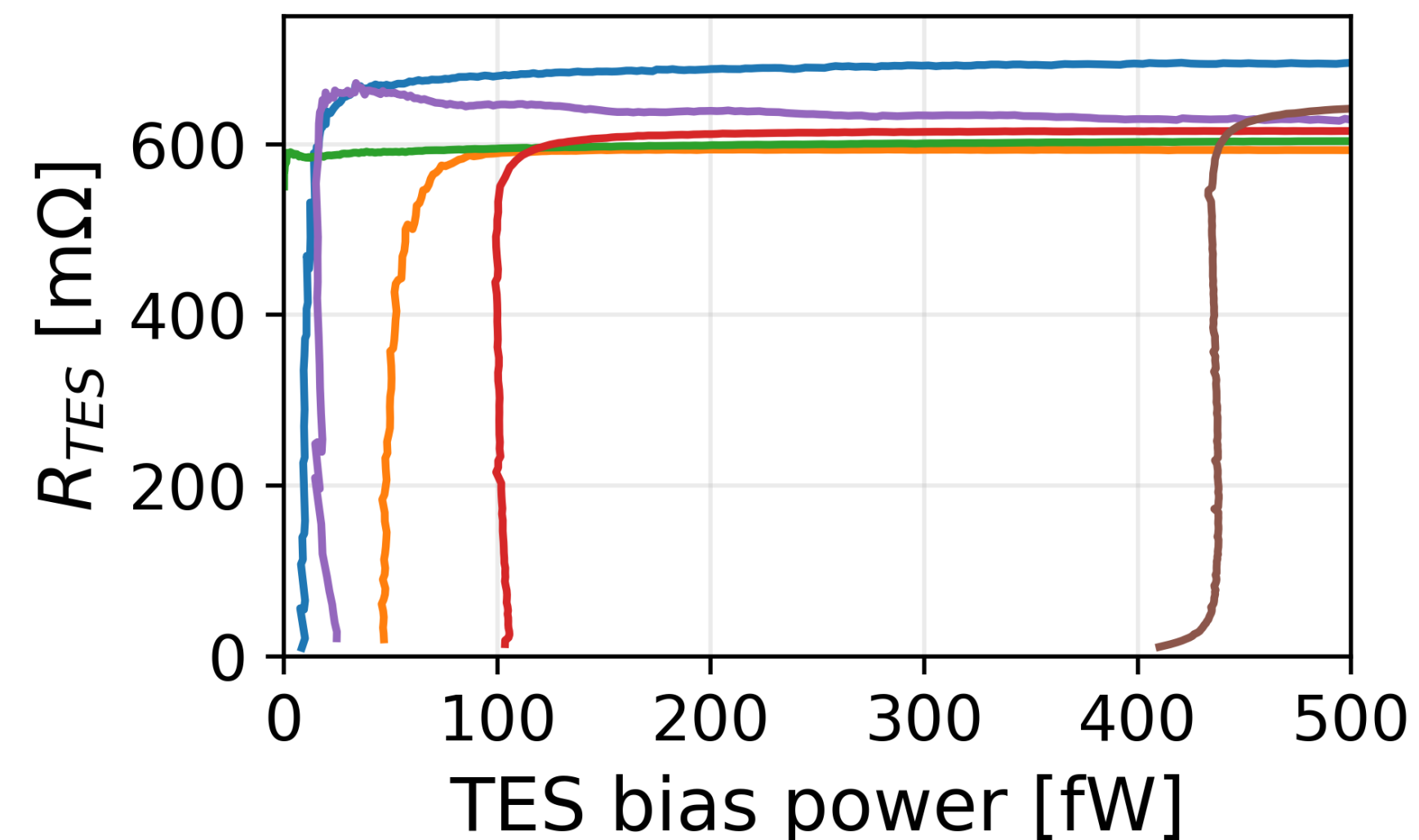
Typical resonances from one chip



$35 \text{ pA}/\sqrt{\text{Hz}}$ readout noise comparable to previous μmux for x-ray & mm-wave TESs

R&D progress: multiplexed TES operation

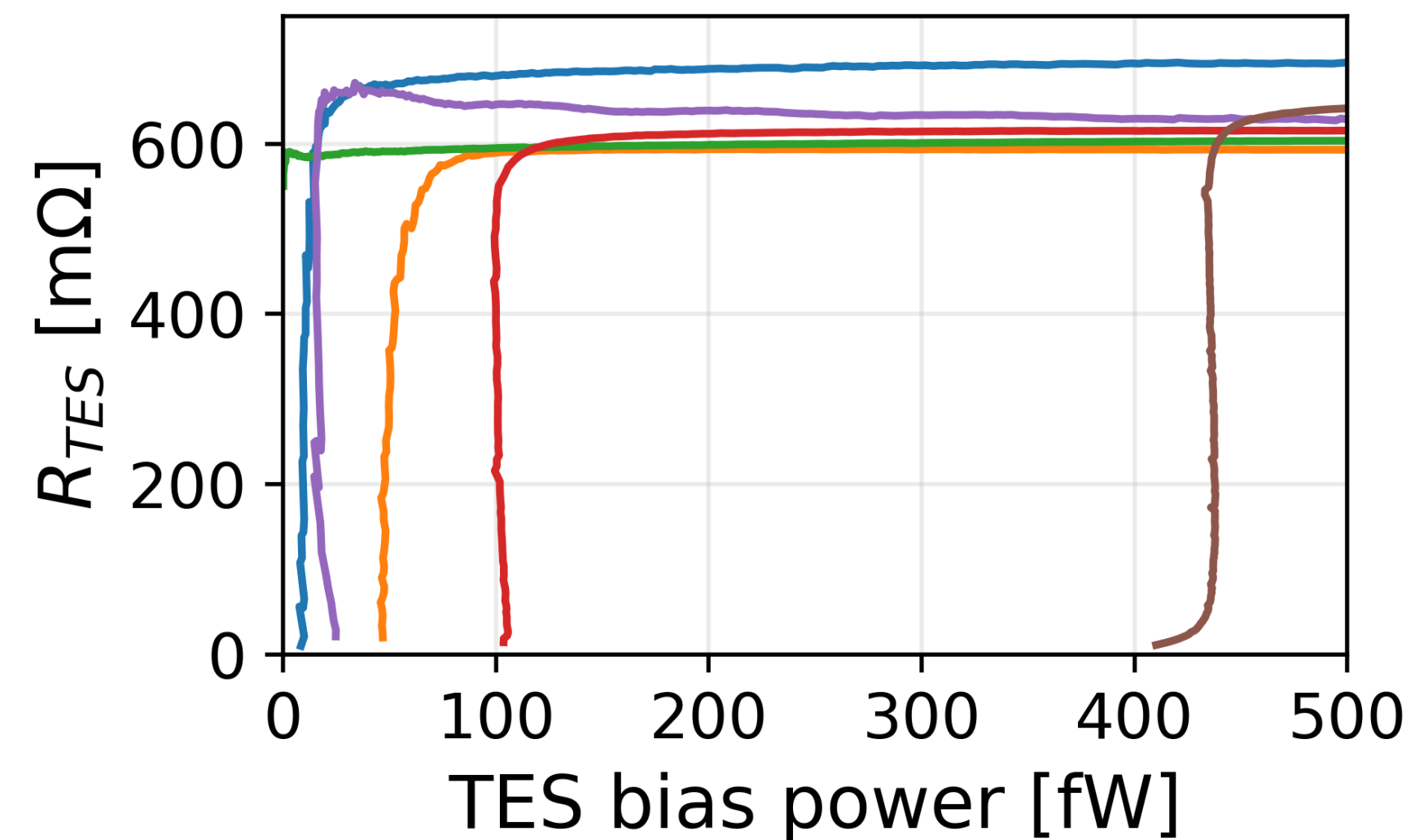
Connected “chocolate box” of TESs with a wide range of saturation powers to measure our background loading. Able to bias all but one during initial testing



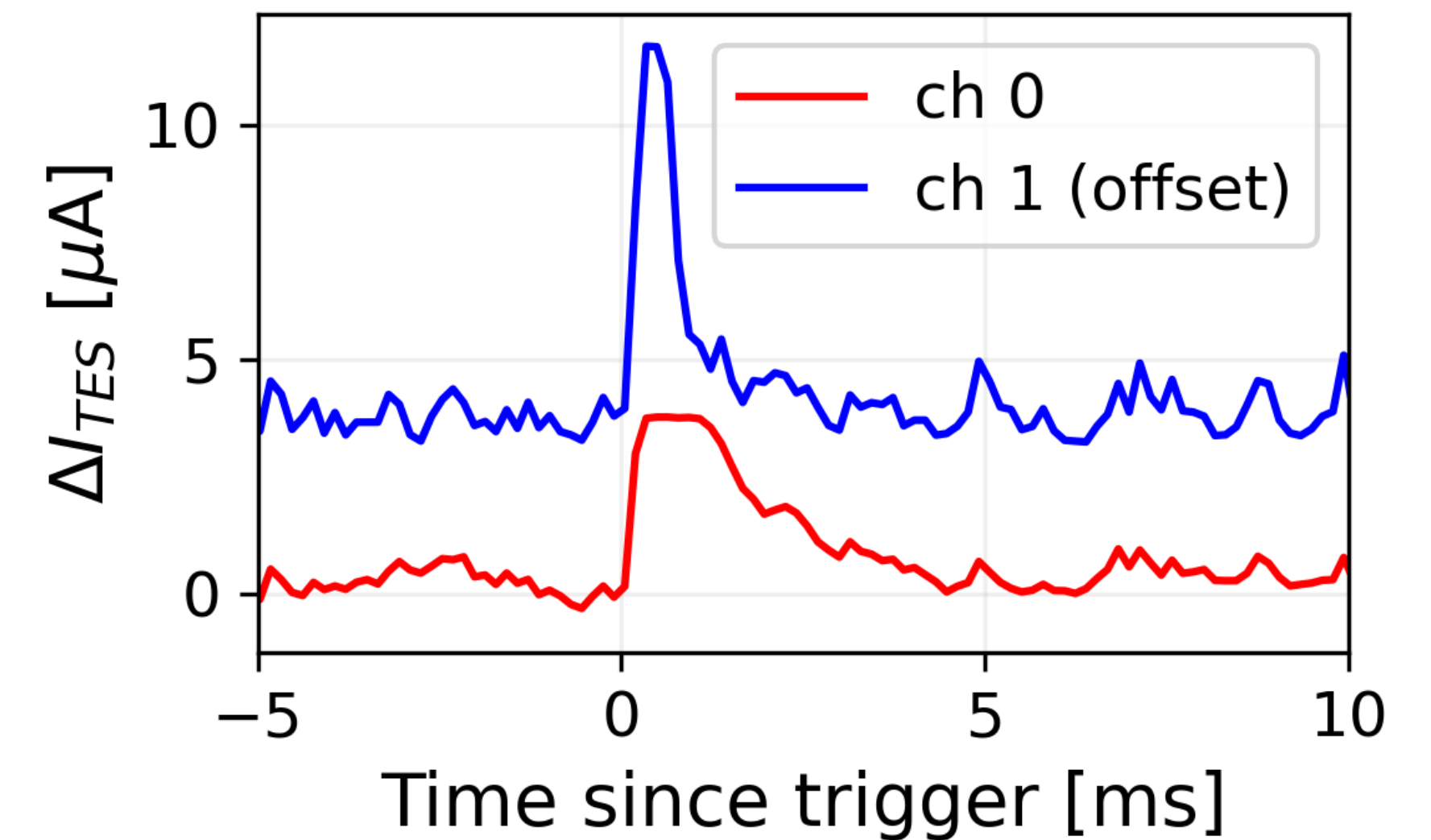
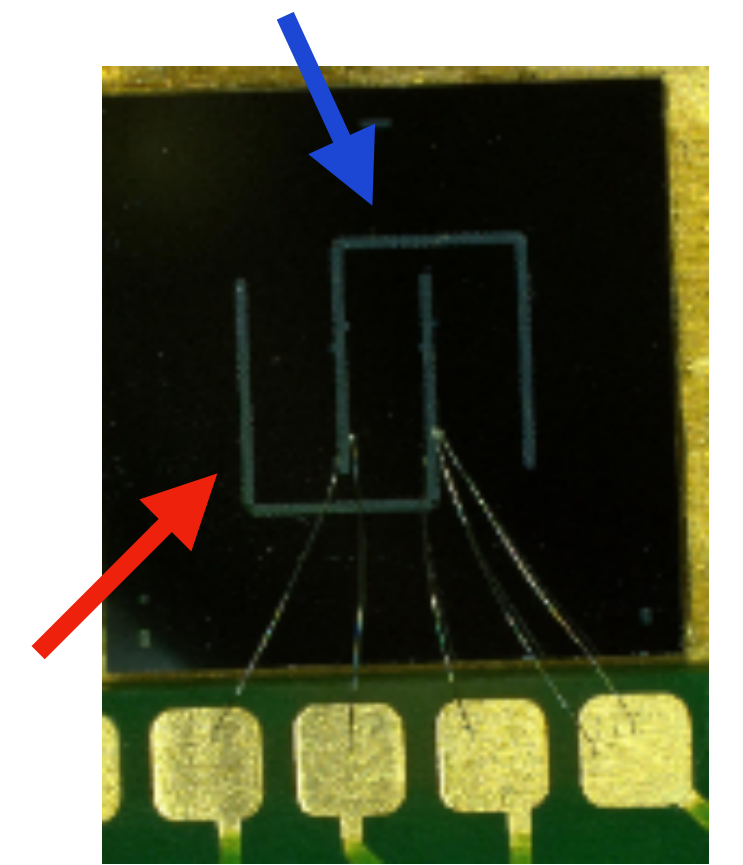
The sample rate, background loading, and chip mounting (which introduces lots of LEE events) are known to be non-optimal. These are next steps for us

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Multiplexing demonstration: simultaneous readout of coincident phonon pulses from 2 TESs coupled to the same absorber

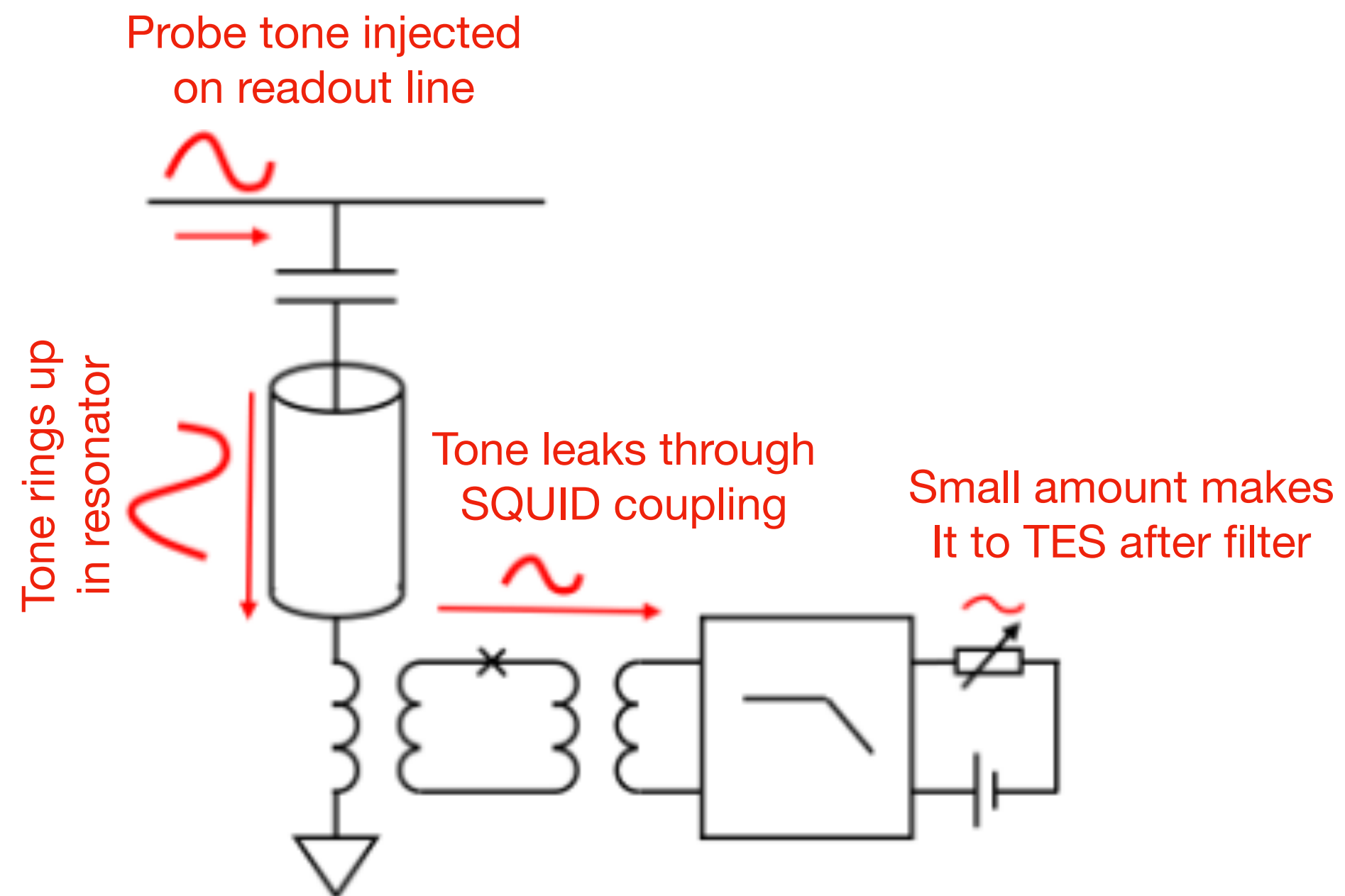


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R&D progress: TES parasitics

Readout itself should contribute parasitic power loading on the TES from the microwave tones.

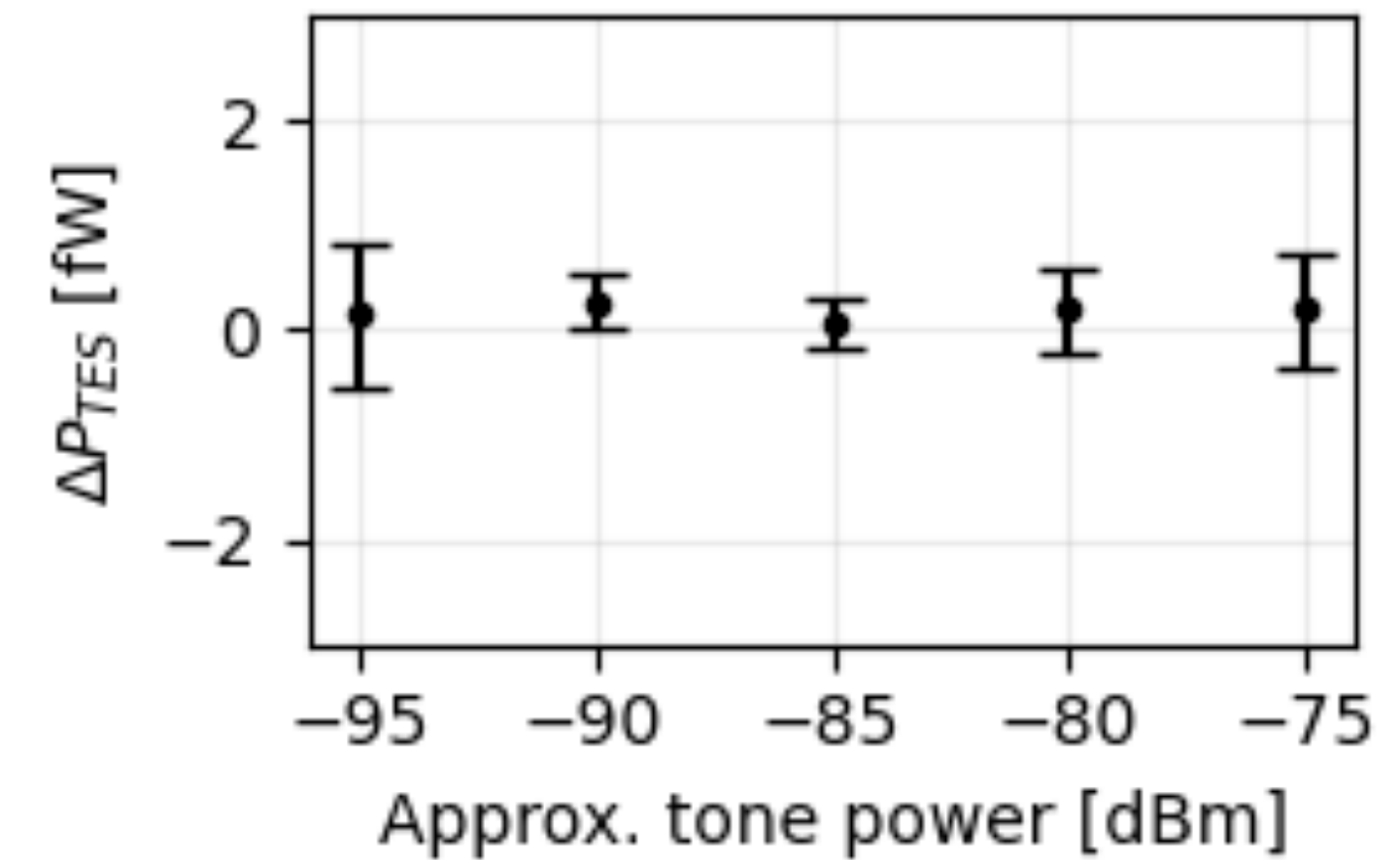
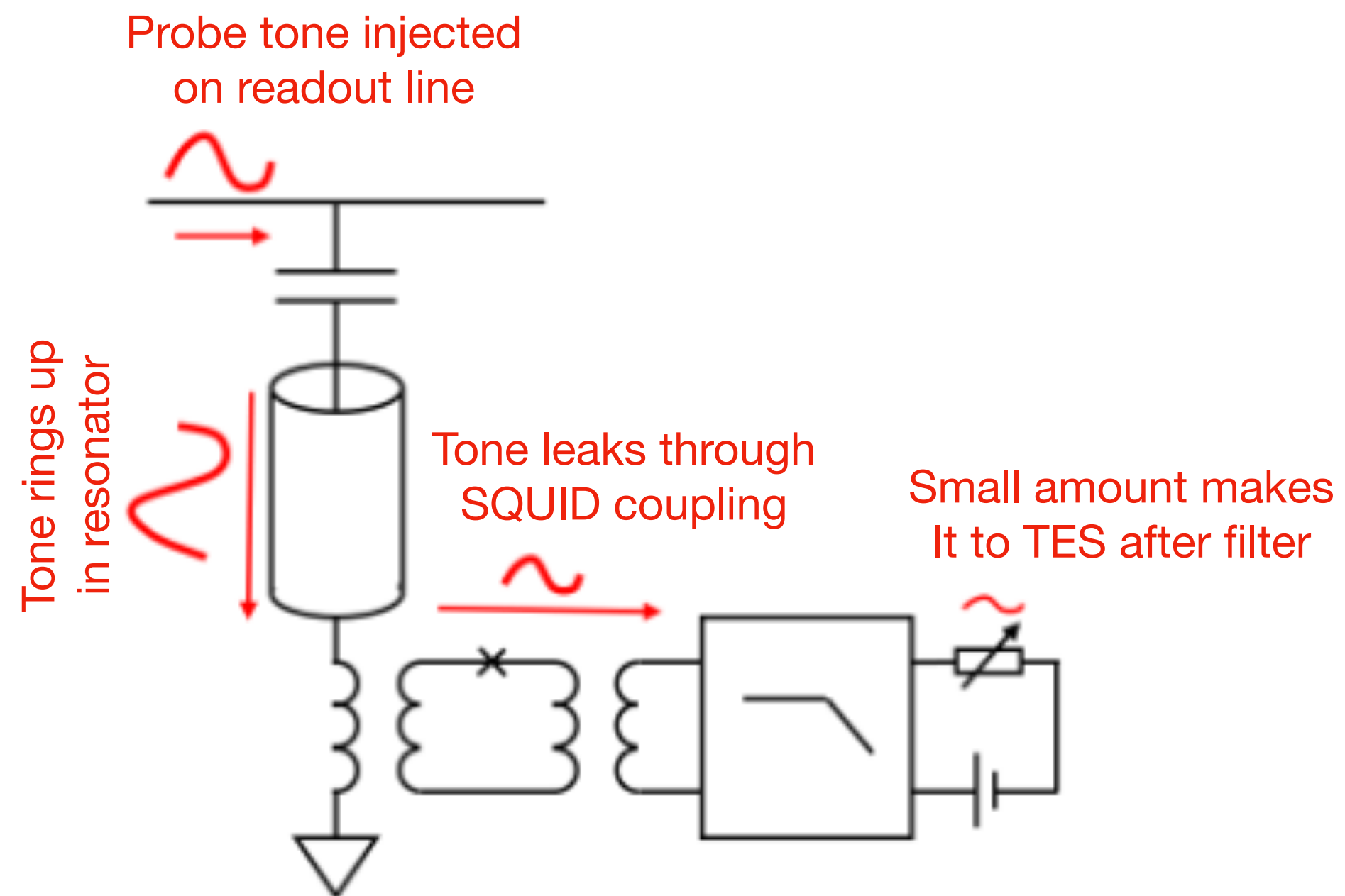
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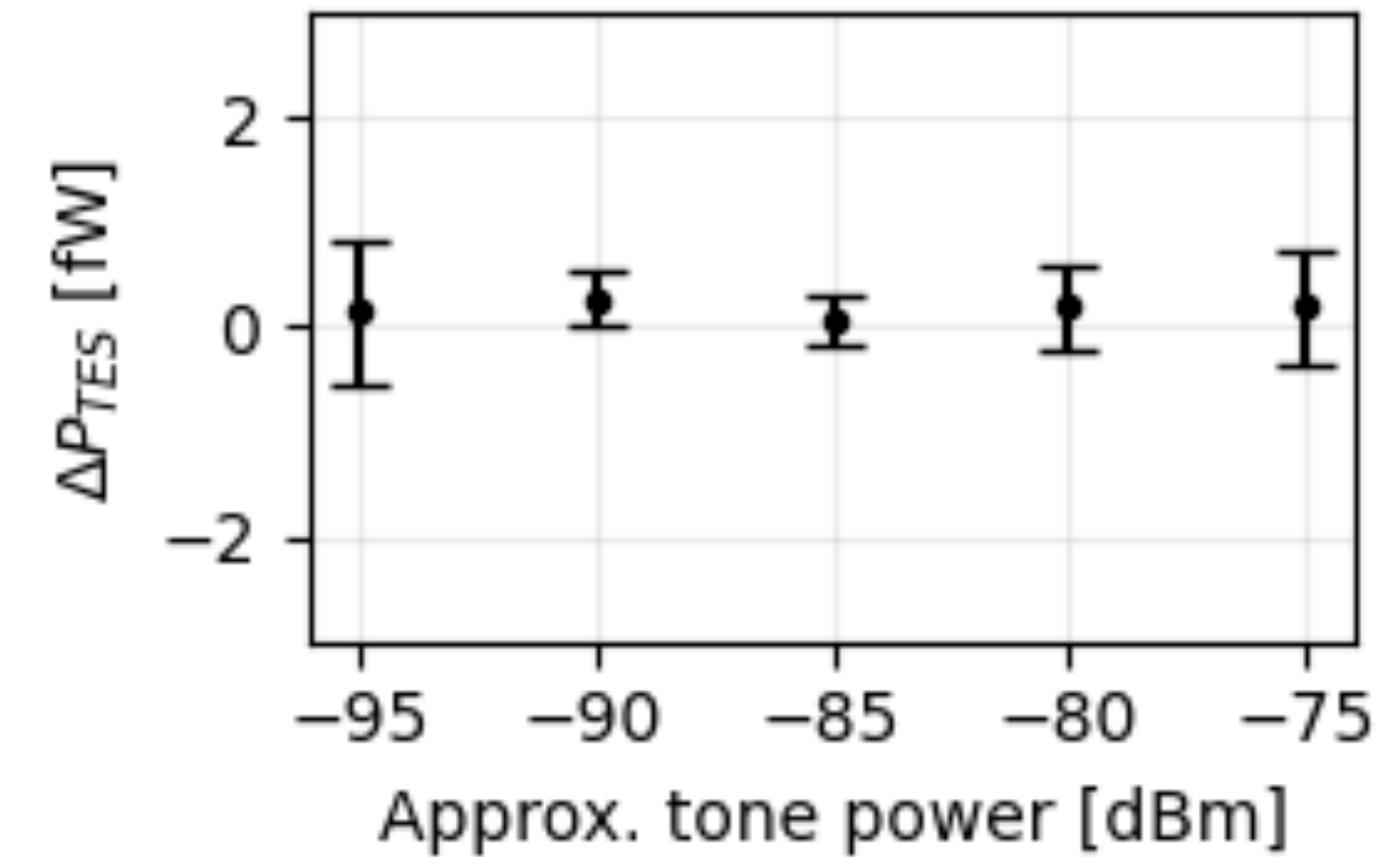
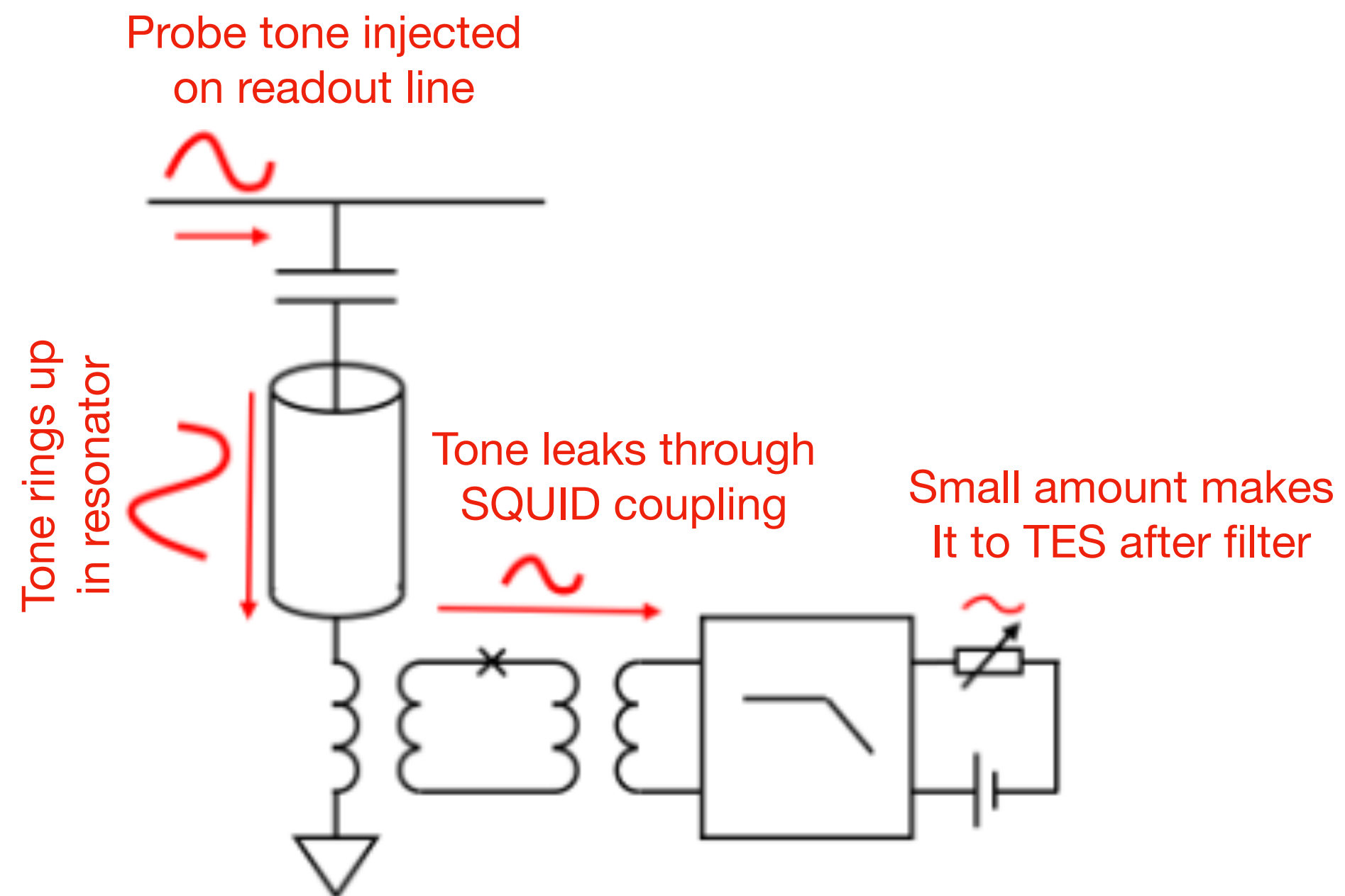


New upper bound: <1 fW

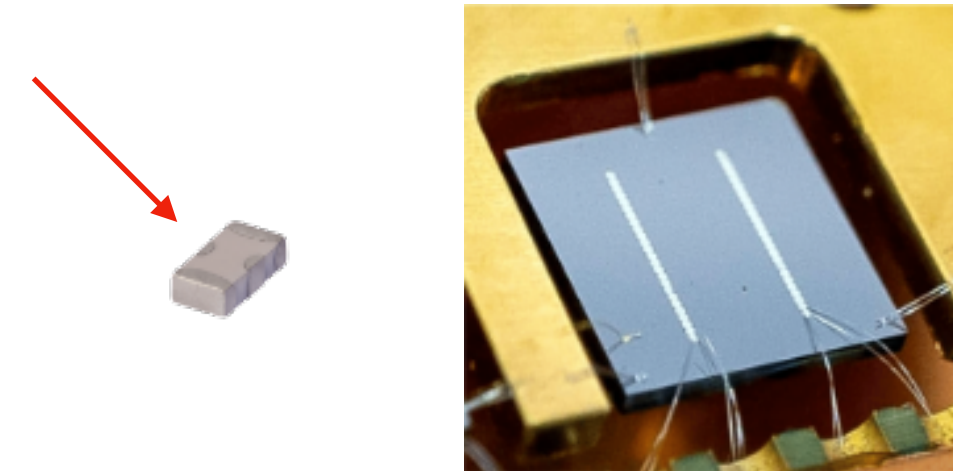
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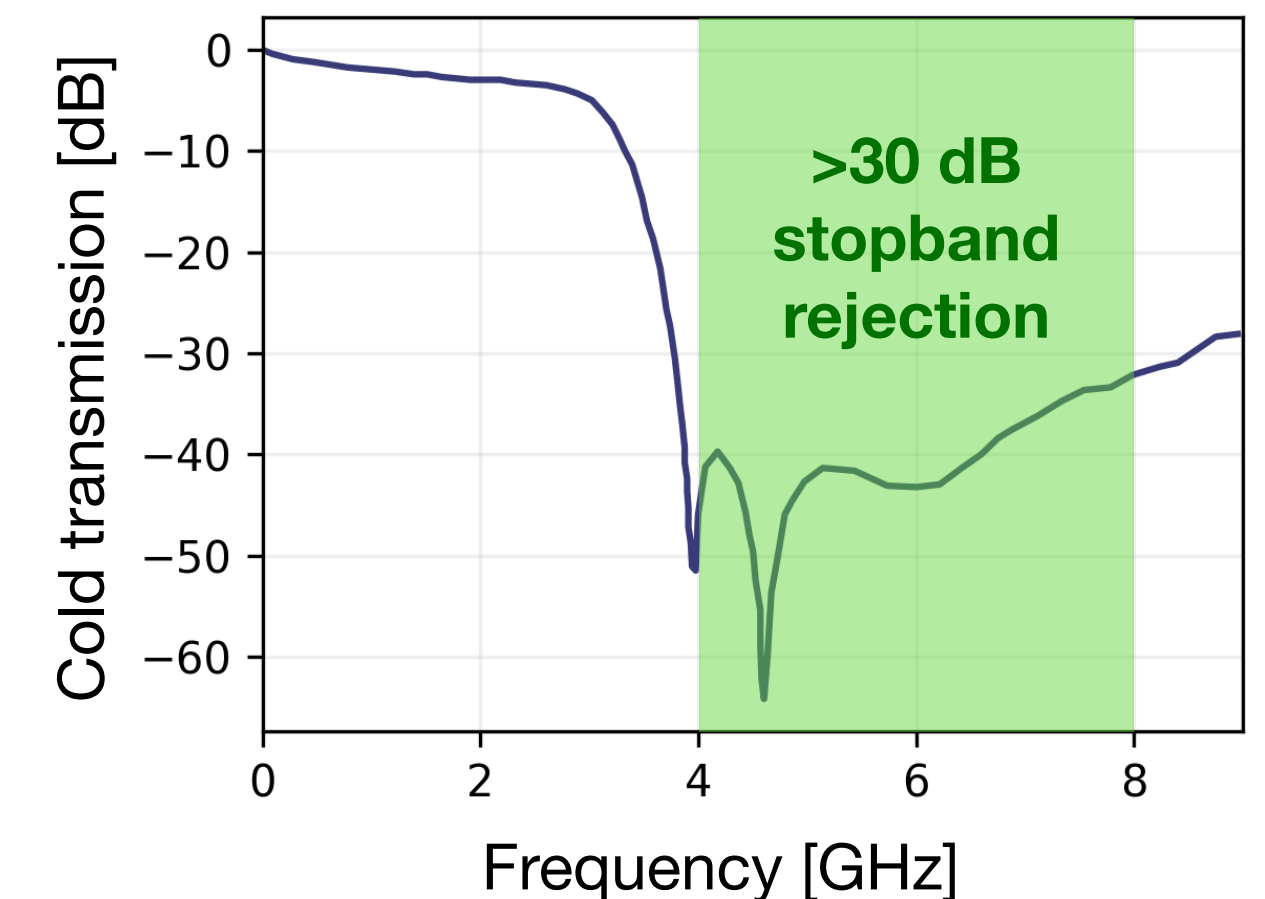
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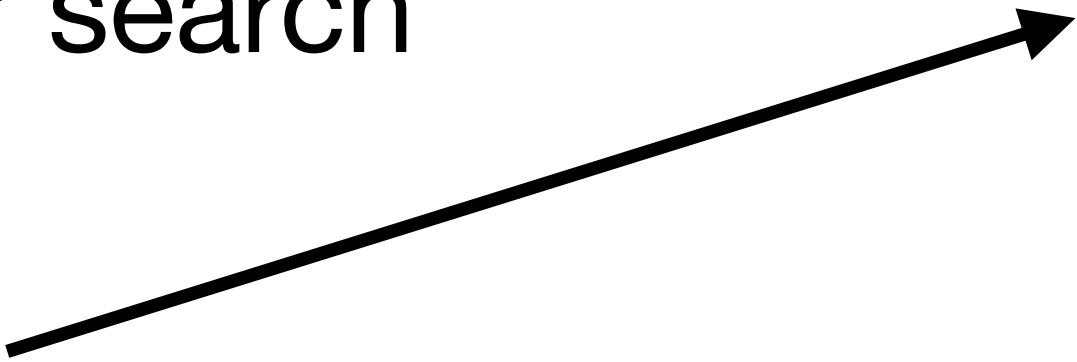
SMD component next to 1 cm² TES chip for scale



In parallel, we have identified a cryo-compatible inline filter that could be used if needed

Summary

- TESs suitable for dark matter searches will need multiplexing to scale
- We've demonstrated basic compatibility of microwave SQUID readout w/ thermal phonon TES detectors
- Future work will focus on demonstrating sufficient sensitivity for a competitive dark matter search
- For further reading, see Tsan+, [arXiv:2610.24300](https://arxiv.org/abs/2610.24300)



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