TESSERACT R&D

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12/10/2021
2021 Snowmass at LBNL

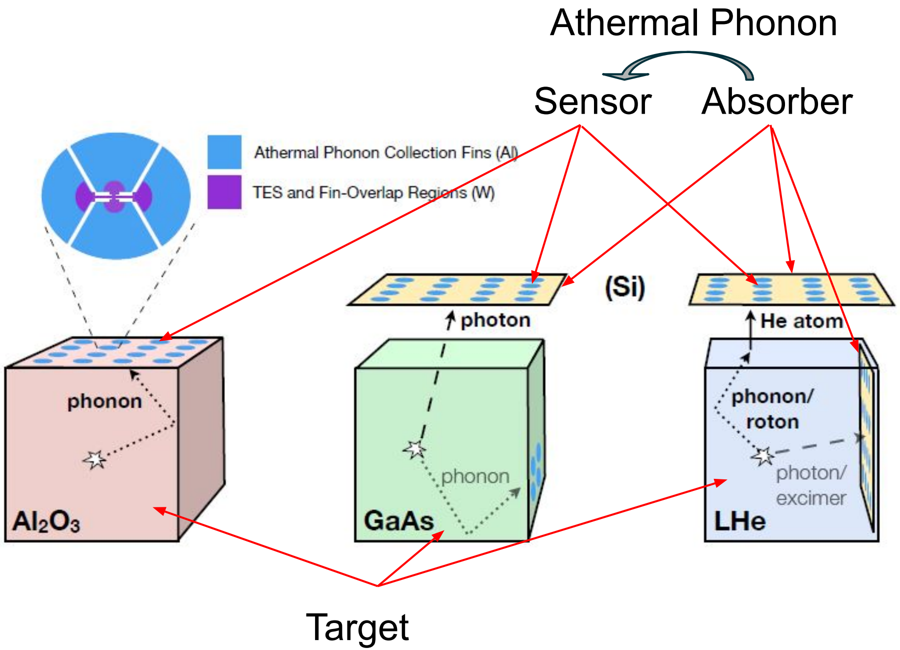
TESSERACT Instrumentation R&D at LBNL

- TES sensors
  - Superconductor R&D
  - TES characterization
  - Fridge background reduction
- RF sensor design and fabrication
  - TES with RF multiplexing, MKIDs.
  - Readout: VNA / SMURF / GroundBIRD
- Low energy calibration
  - 10~100 eV photon source
  - Thomson scattering

Developments performed with
Physics div. Dilution Refrigerator

Reminder of TESSERACT concept

- Multiple DM detection methods: From ~10eV photons to meV phonons and rotons.
- Low temperature sensors to detect athermal phonon.
- Sub-eV detector energy threshold



TES characterization

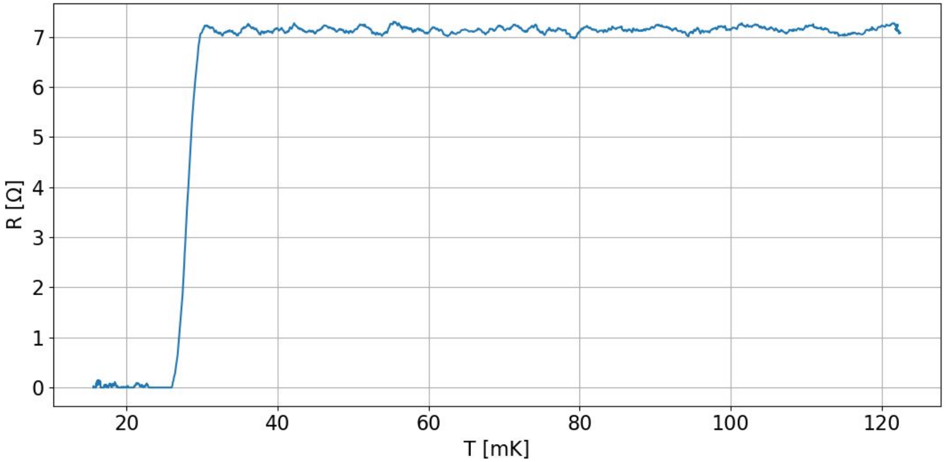
TES Tc measurements

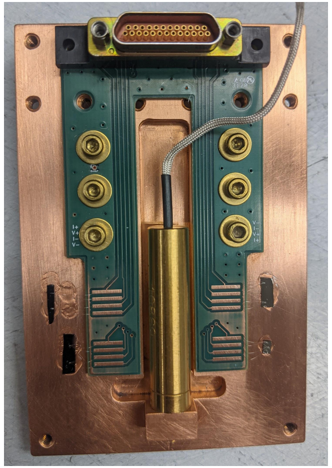
Next generation DM TES sensors require TES with superconducting temperature of **15 mK**

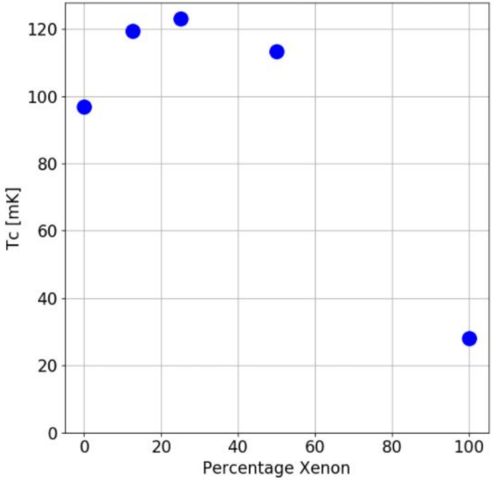
Collaboration developed a fabrication recipe to tune superconducting Tc and transition width.

Characterization of samples were conducted at LBNL

- Transition temperature (Tc)
- TES performance

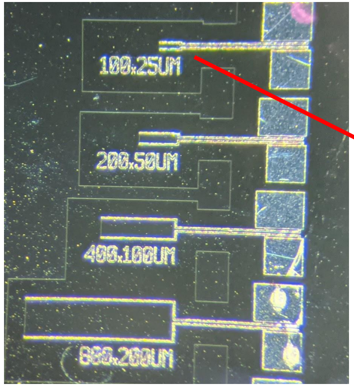




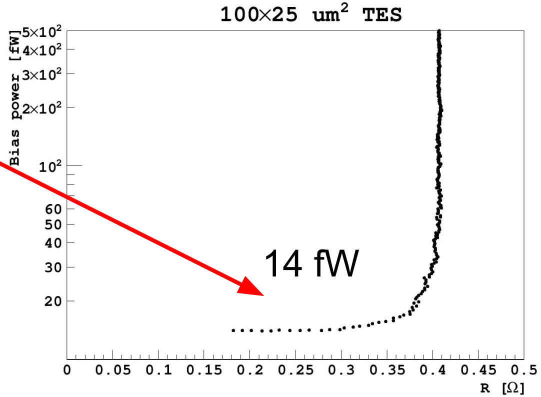


TES characterization

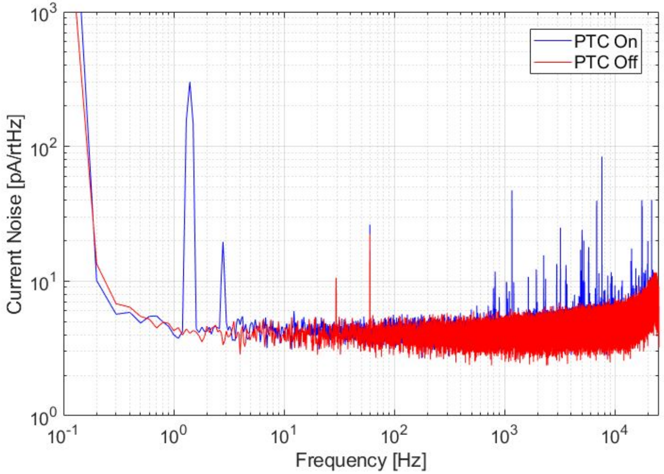
- TES characterization with SQUID readout.
  DC and AC electrical-thermal response.
- Using benchmark chips to understand noise in our fridge (IR, EMI, vibration).
  TESs with 10 fW bias power successfully transitioned.
- Further vibration and electrical noise reduction with liquid helium battery



W benchmark TESs from Matt Pyle's group



Bias power of the 10 fW TES



Very clean baseline with Helium battery

Fridge upgrade for future TES measurements

Future experiment require parasitic power to be less than 100 aW

We are close - actively searching and suppressing parasitic power

In future: Operate large area dark matter detector style devices.

Example of a TES on silicon photon detector developed at UCB

TES RF multiplexing and MKID sensor design and fabrication

Where multiplexing would help?

Multiplexing will allow large sensor coverage and small individual pixels.

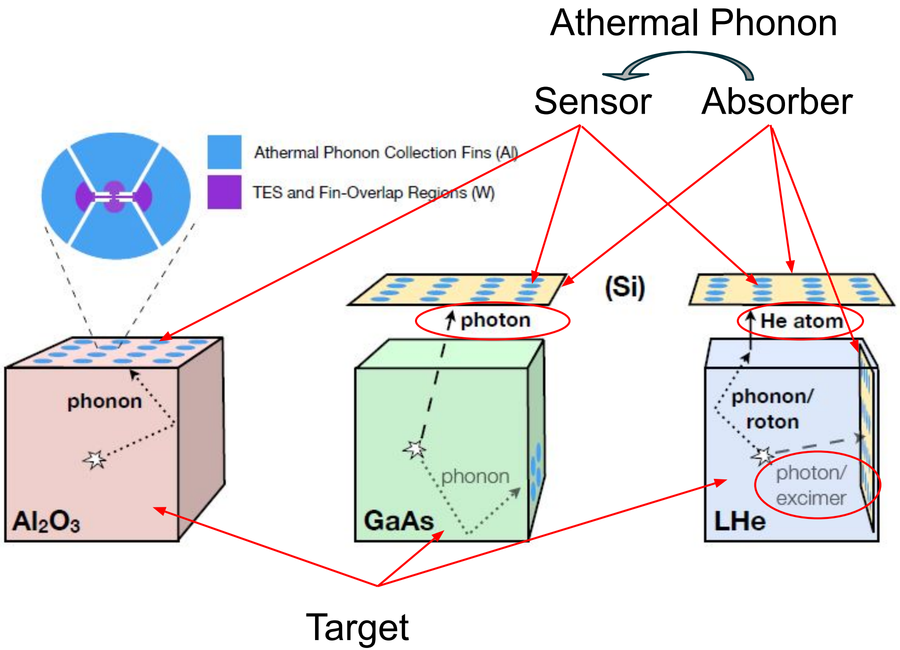
Significantly increase bandwidth and signal to noise ratio.

Useful for high energy (>100 meV) quanta with definitive energy:

Photons (IV, UV) and He_2^* excimer direct absorption in sensors.

Could reach in the future?

^{4}He quantum evaporation?

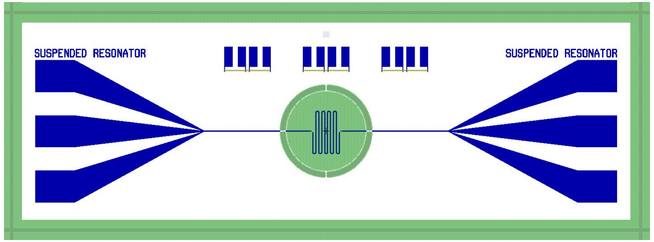


RF sensor R&D

Superconducting resonator design

1. Single high quality resonator.
2. Small scale multiplexing resonator arrays.
3. **Dark matter specific MKID design. Photon detectors.**

Example of a resonator design

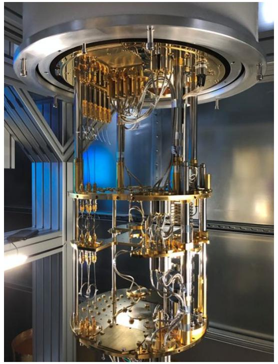


Fabrication

1. Molecular Foundry at LBL
2. Micro Systems Lab at LBL
3. UCB Marvell nanolab
4. Commercial collaborations: SEEQC

Experiment

Fridge, cold electronics, RF readout systems (VNA, SMuRF, GroundBird) will soon be tested!



Low energy calibration

Low energy calibration

New territory for dark matter search.

Ionization and scintillation → Phonons

Need to understand

1) Material response to low energy interactions: signal creation and propagation.
2) Coupling between sensor and target: collection efficiency.
3) Sensor response.

Energy region of interest: eV to keV

Hard to generate in sub-Kelvin environment

Scintillation photon as calibration source

Using single and multi scintillation photons as O(1) eV scale calibration source.

Scintillators that works at mK:

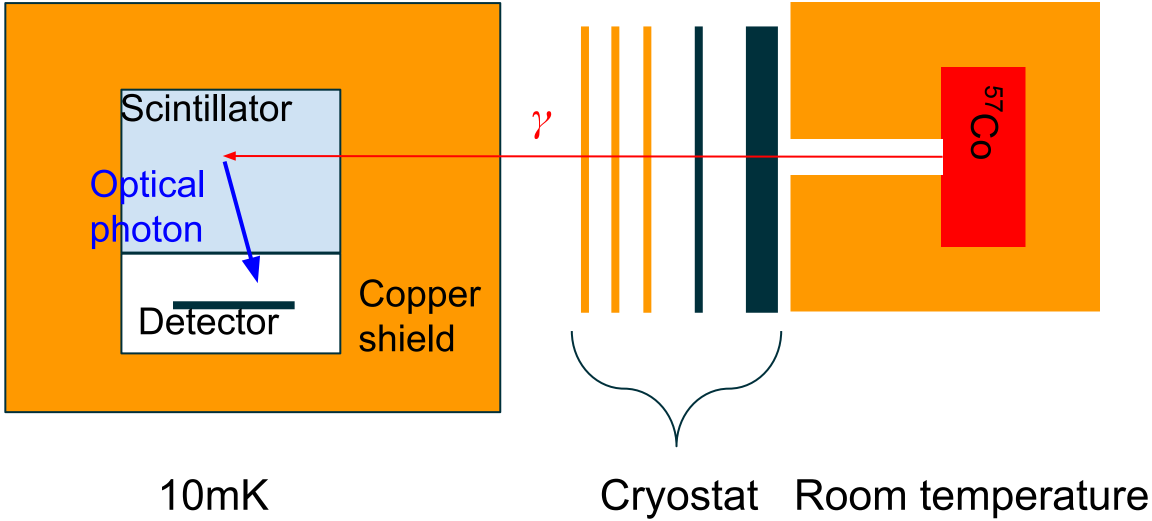
NaI(TI) - 3eV

Easy to deploy, tests coming soon!

Solid Xenon - 7eV

Not possible to deliver through optical fiber. Can be used to calibrate sapphire detector!

GaAs - 0.9eV

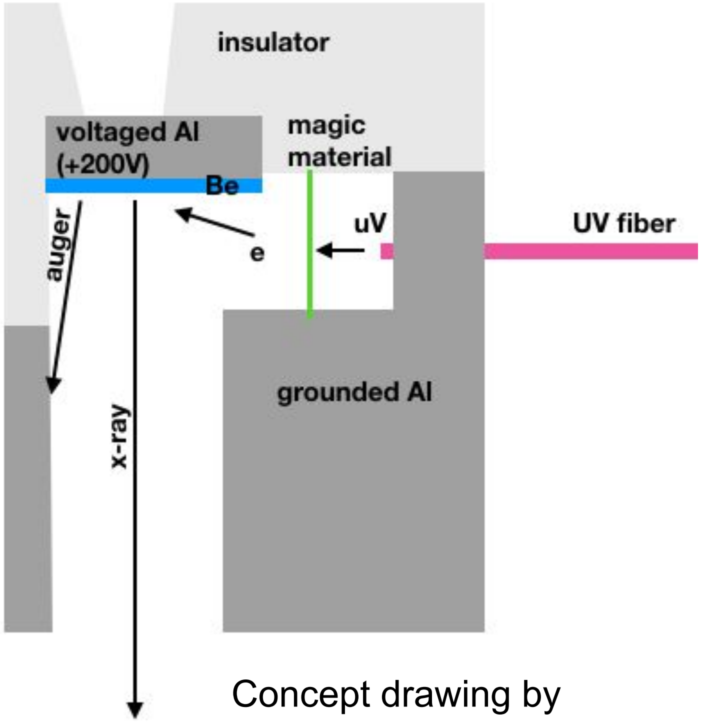


100eV X-ray (EUV) source

- Generate X-ray fluorescence from light elements

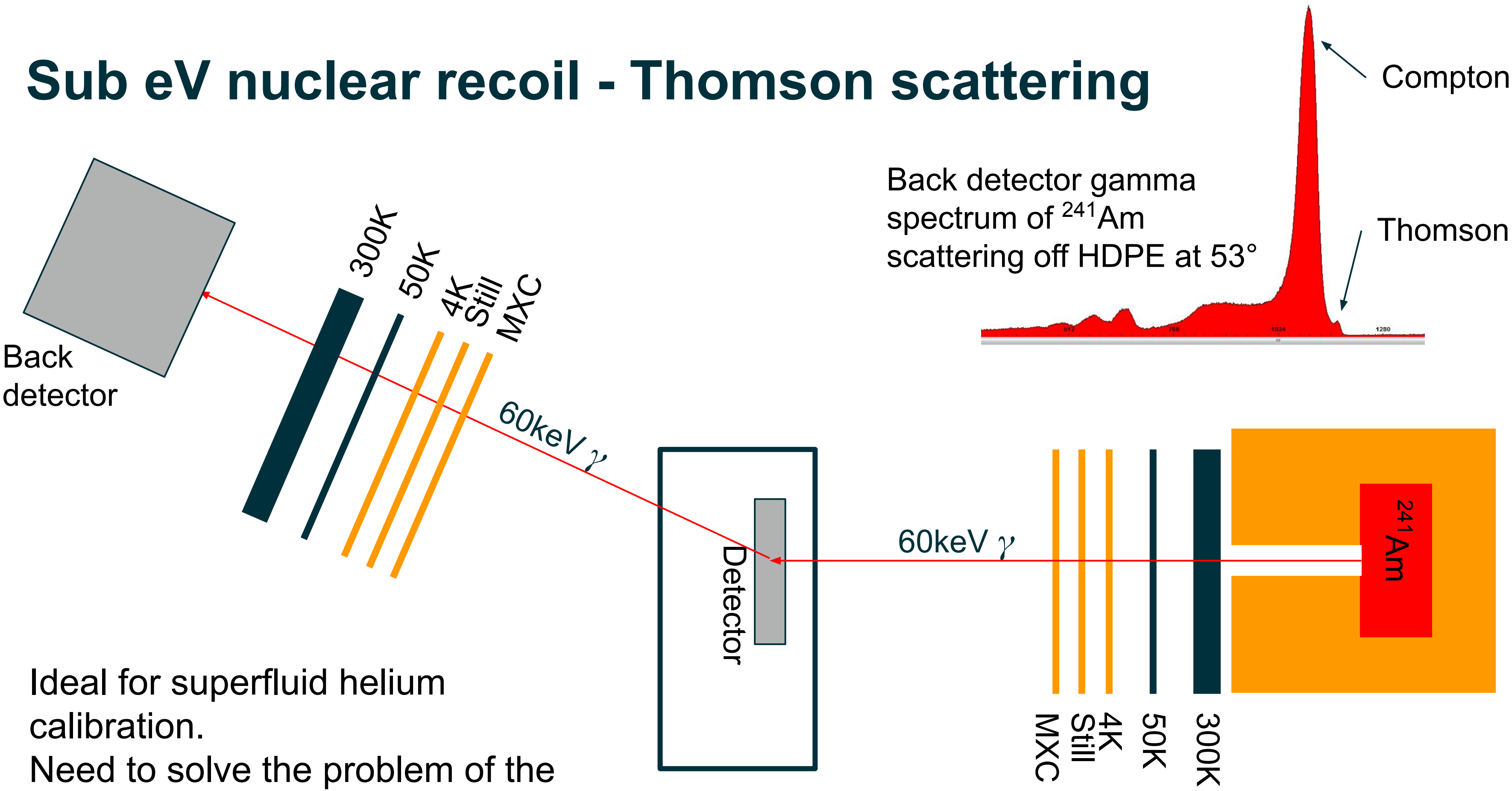
- Excite free electron by UV photons. Delivered through fiber or generated in situ from scintillation.

- 100eV is very interesting for the near-future dark matter search.



Concept drawing by Scott Hertel

Sub eV nuclear recoil - Thomson scattering



Back detector gamma spectrum of ^{241}Am scattering off HDPE at 53°

Ideal for superfluid helium calibration.
Need to solve the problem of the relatively low cross section.

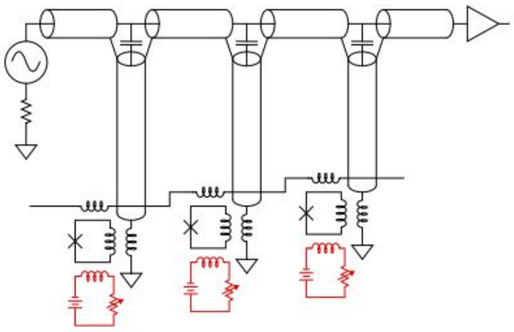
Conclusion

- TES measurement
    - We achieved a very clean system for the TES sample characterization.
    - Tc measurement and TES characterization on going.
    - We are further improving the dilution fridge for TES detectors with lower Tc and higher energy resolution.
- TES RF multiplexing and MKID sensor design and fabrication
    - Readout systems for RF sensors will be ready soon.
    - Actively investigating the possible applications of TES RF multiplexing and MKIDs in the TESSERACT detectors.
    - Sensor R&D will soon start.
- Low energy calibration
    - Scintillation photon, 100eV X-ray, and Thomson scattering.

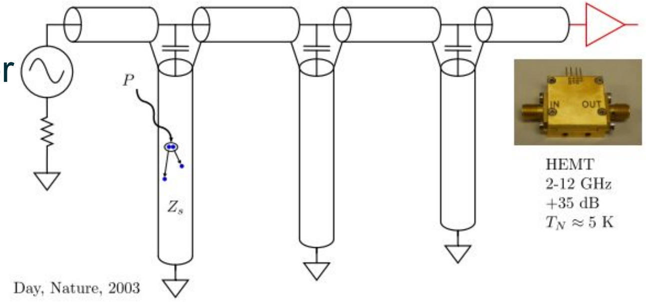
Back up

TES with RF multiplexing, MKIDs

TES array with resonator coupling for RF multiplexing



Microwave kinetic inductance detector (MKIDs)

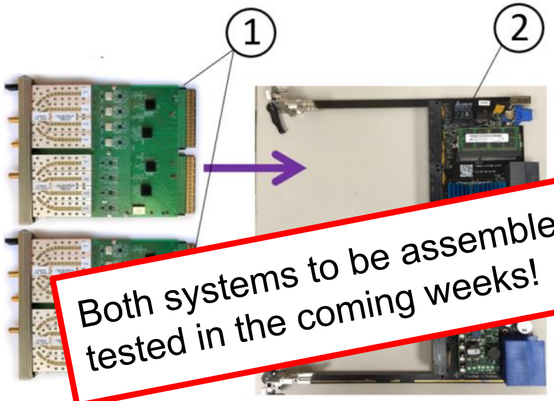


Day, Nature, 2003

The Microwave SQUID Multiplexer, thesis by J. Mates

SMuRF (SLAC Microresonator Radio Frequency), provided by SLAC.

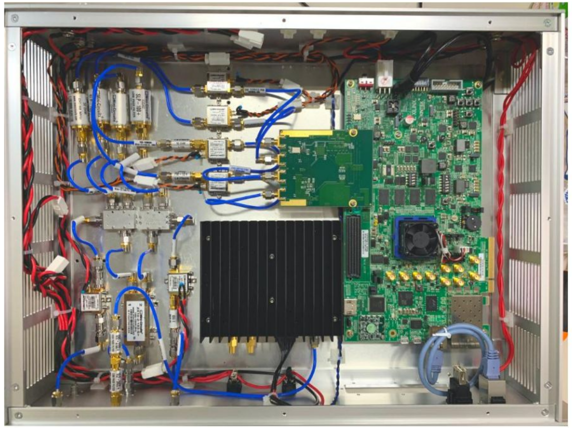
4000 channels between 4 to 8 GHz.



Both systems to be assembled and tested in the coming weeks!

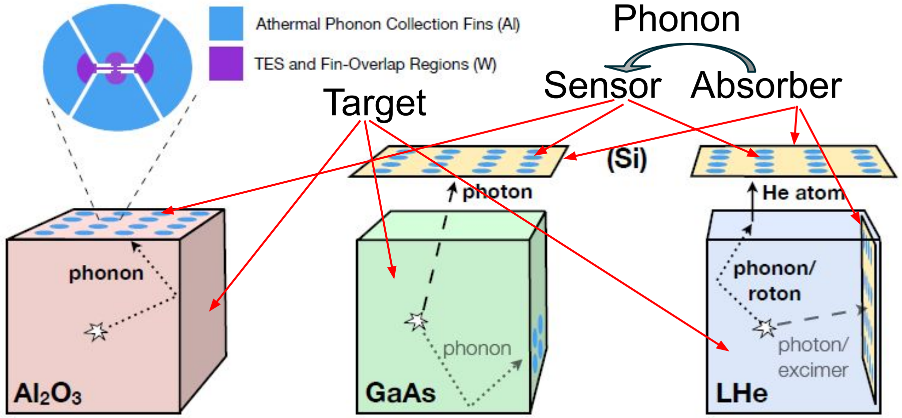
GroundBird readout system
An CMB experiment with MKIDs

annels
n 4 to 8 GHz.



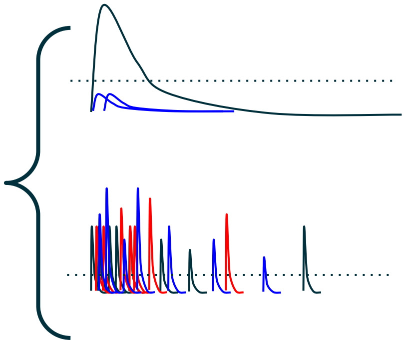
Signal channels and detector concept of TESSERACT

Busy slide, so write out a simple take away message



Signal type	Energy	Propagation time scale	Collection efficiency
Crystal athermal phonon	O(10) meV	O(10) ~ O(100) us Prop to (sensor coverage)$^{-1}$	Sensor efficiency (QET), Surface down-conversion (Defects/dead area)
Crystal (GaAs) IR photon	900 meV	O(10) us (or instant)	Absorber (or sensor) coverage
He phonon / roton (Quantum evaporation)	~ 1 meV (O(10) meV)	~ 1 ms	Surface down-conversion, QE efficiency, Surface absorption gain...
He IR photon	~ 1 eV	O(10) us (or instant)	Absorber (or sensor) coverage
He UV photon	16eV	O(10) us (or instant)	Absorber (or sensor) coverage
Triplate state He^*_2	16eV	O(10) ms, v = 2 m/s	Absorber (or sensor) coverage

Single channel sensor energy threshold: O(10) meV



Integration mode: Individual energy quanta non resolvable. Optimal signal bandwidth should match with signal propagation time.

Counting mode: Individual energy quanta resolvable. **Localized signal.** Signal bandwidth defined by sensor bandwidth. Multi-channel & multiplexing will **improve SNR**.

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