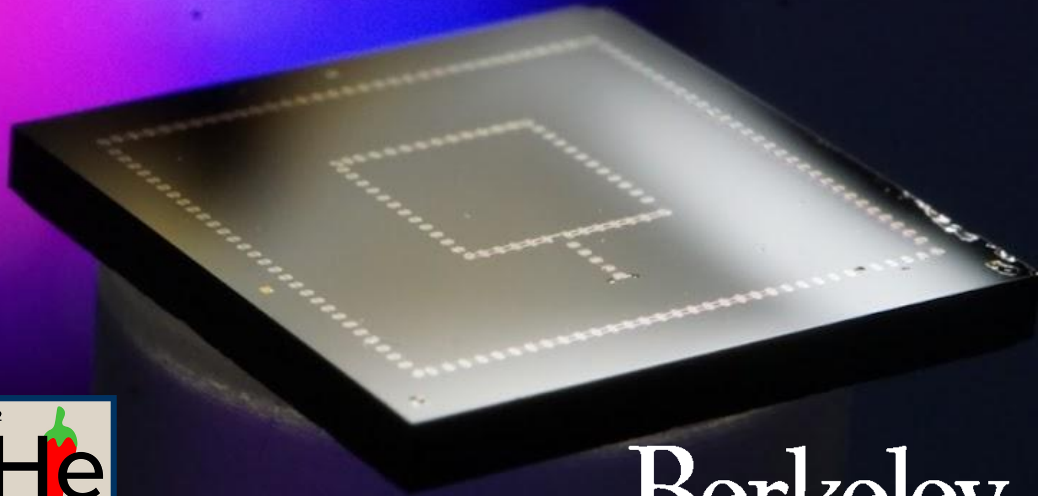
SPICE: a Solid State Dark Matter Direct Detection Experiment from the TESSERACT Collaboration



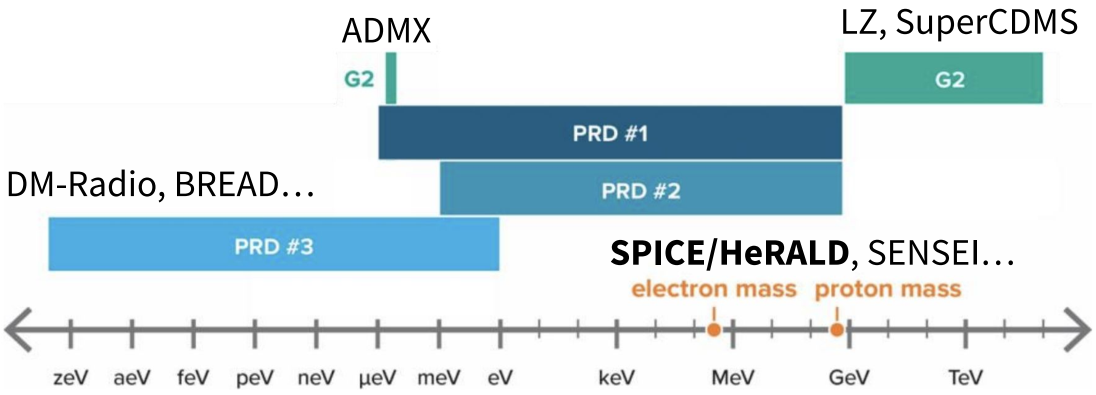
Roger K. Romani for the
TESSERACT Collaboration

Berkeley
UNIVERSITY OF CALIFORNIA

The Search for DM Direct Detection 30 Years On

Still no sign of DM in the laboratory!

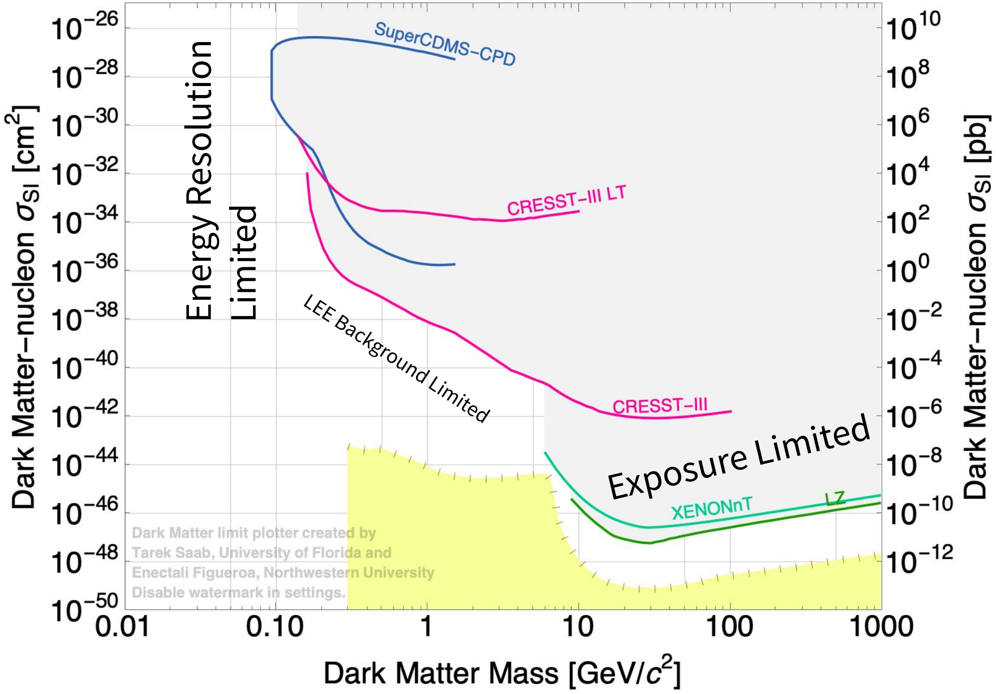
- WIMPs (~10 GeV - ~100 TeV): mature technologies, big collaborations, nearing limits
- Axions/ALPs (less than 1 eV): rapid development of many good ideas
- **“Light DM” (~100 keV- ~1 GeV): exciting new technologies, new motivations**



“Basic Research Needs for Dark Matter Small Projects New Initiatives”, 2018

General Light DM Direct Detection Design Drivers

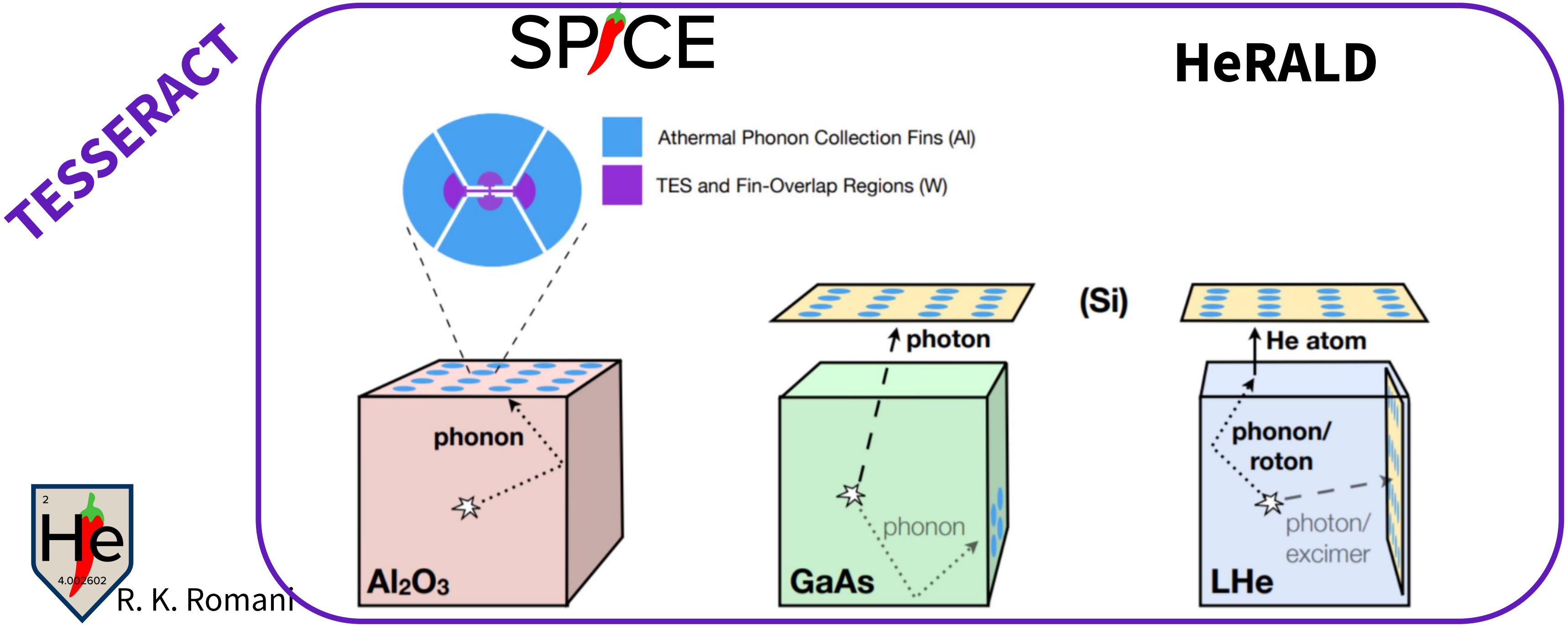
- As M_{DM} goes down, n_{DM} goes up given constant ρ_{DM}
  - **Don't need huge exposure** to get to interesting cross sections
- As M_{DM} goes down, E_{dep} goes down as well
  - Main challenge of light DM direct detection: **detect very small energy depositions**
  - True even for different models, materials



R. K. Romani

SPICE/HeRALD / TESSERACT: A New Light DM Collaboration

Different direct detection mediums unified by a **Transition Edge Sensor** based readout



SPICE/HeRALD / TESSERACT: A New Light DM Collaboration

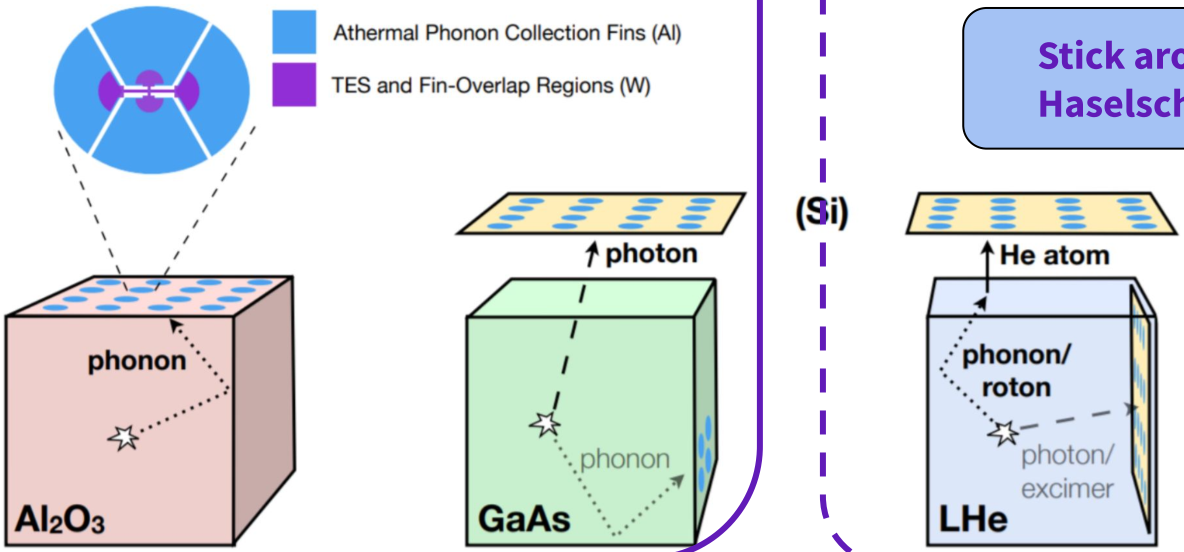
Different direct detection mediums unified by a **Transition Edge Sensor** based readout

This Talk

SPICE

HeRALD

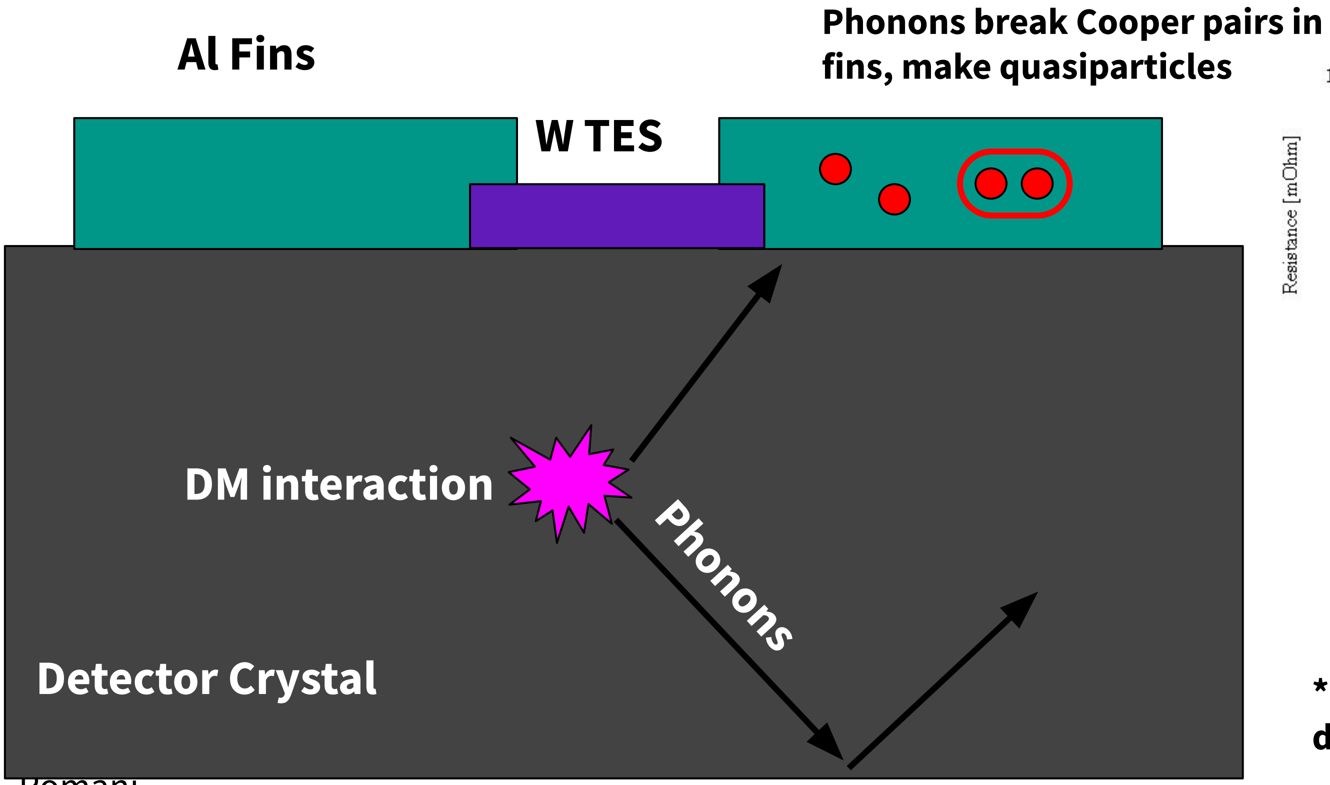
Stick around for Scott Haselschwardt's talk!

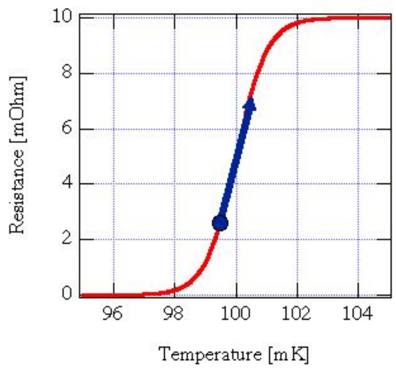


A (Brief) Outline

- TES basics
- Sensor performance
- Backgrounds
- SPICE materials

TES Based Calorimetry Basics

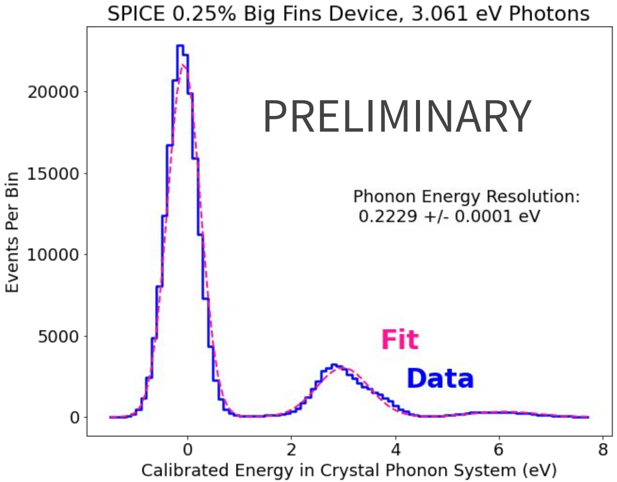


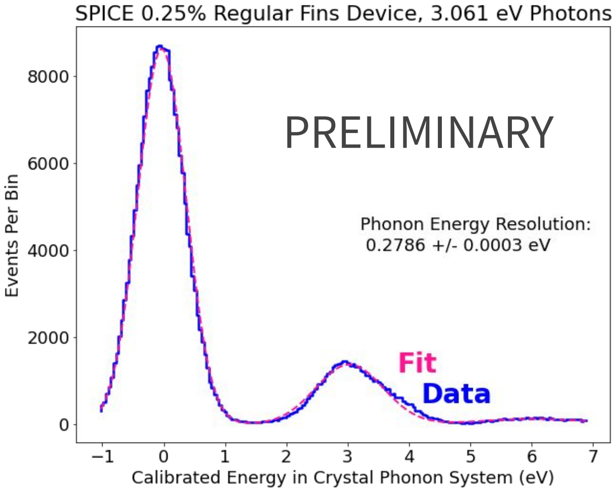


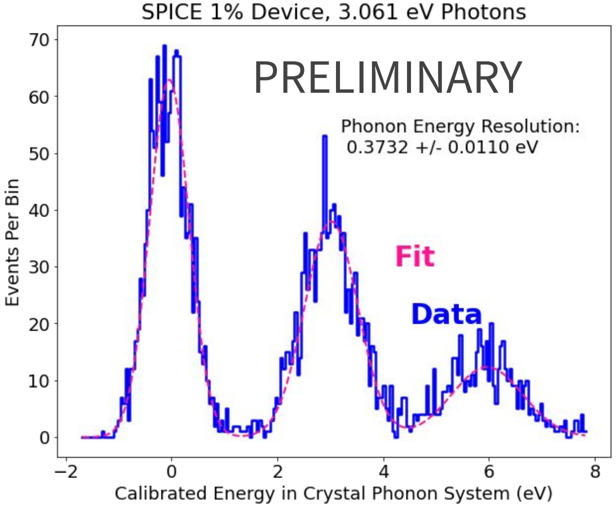
*all at ~10 mK in dilution refrigerator

World Leading Sensors

Baseline (sigma) phonon energy resolutions: 300 meV scale







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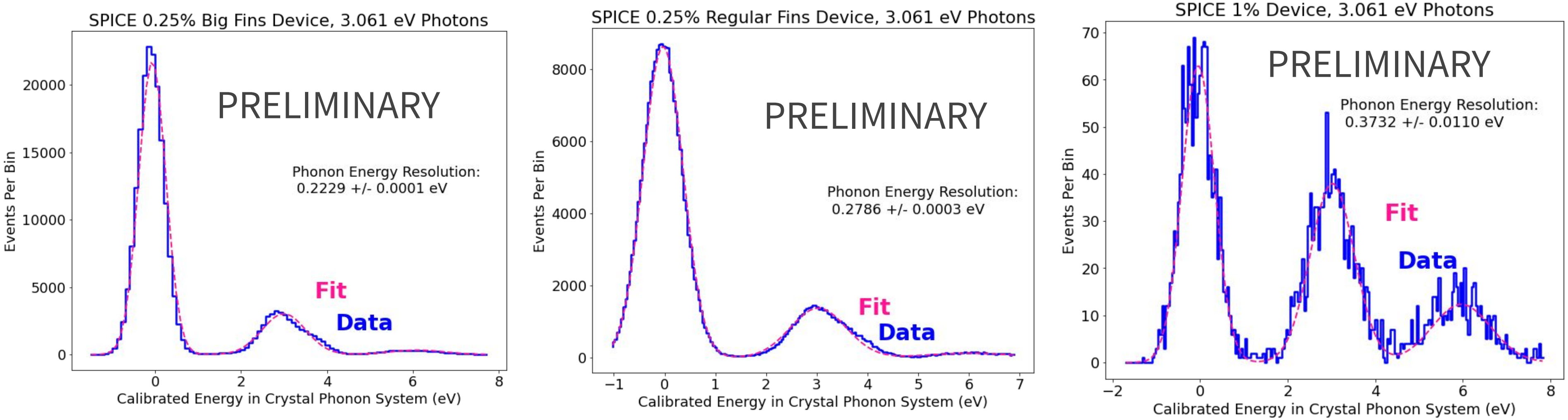
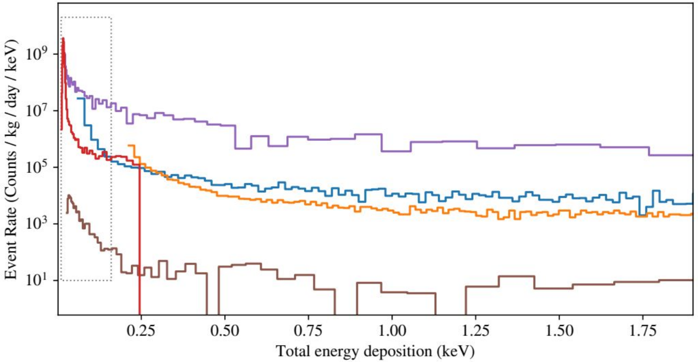


World leading sensors = world leading reach

Background Problem: Low Energy Excess

See D. Baxter, C. Strandhagen talks.



All experiments see unexpected rising background towards low energies

Background Problem: Low Energy Excess

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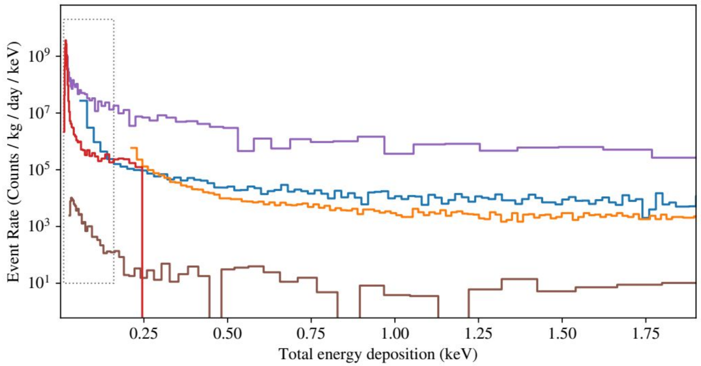
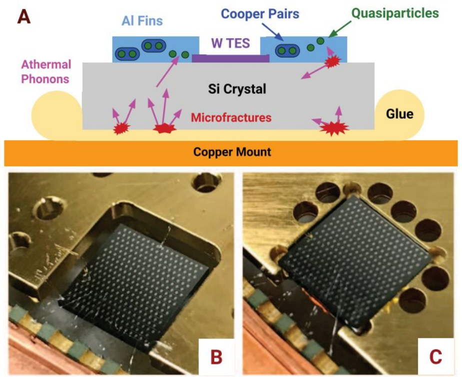
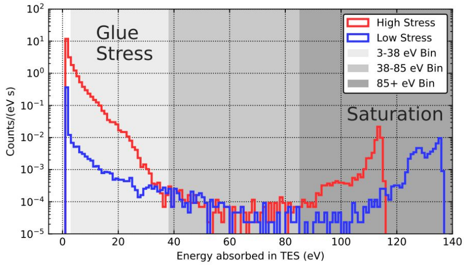
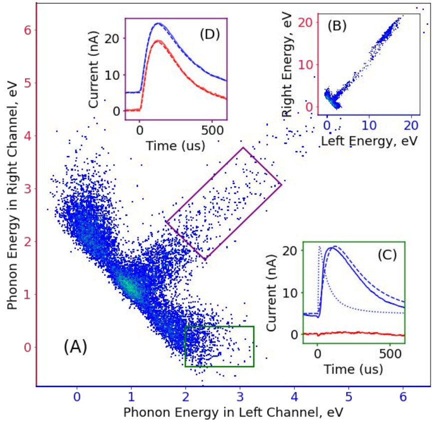


All experiments see unexpected rising background towards low energies

Our contribution: relaxation of mechanical stress in detector materials seems to be likely cause



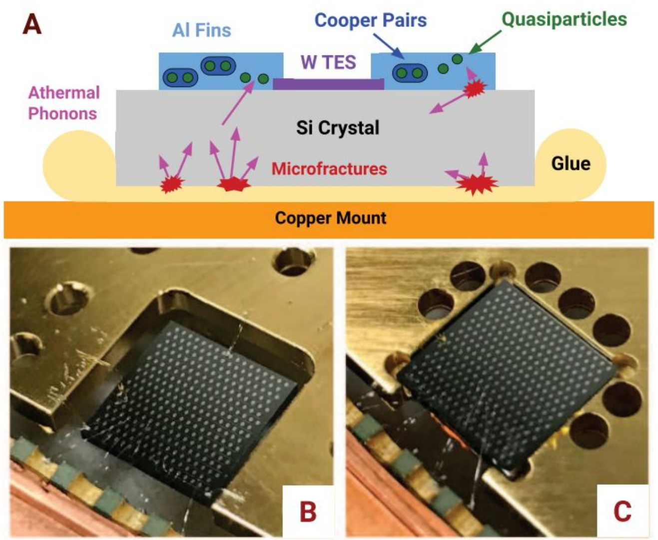


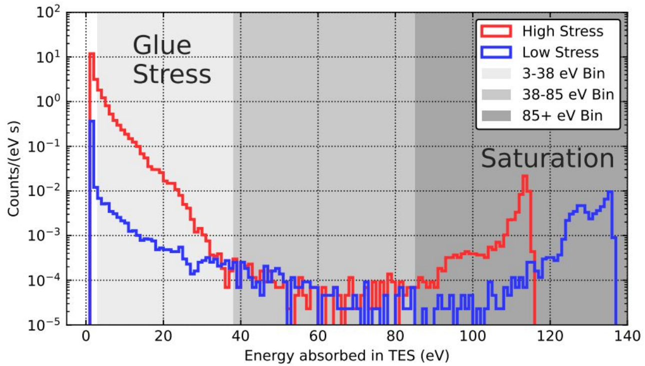


LEE Results: EXCESS 2022

Glue creates one class of LEE!

- Created class of LEE events with similar scale to true excess, relaxation with time
- Compared identical detectors held in different ways
- Remaining LEE population: metal film relaxation?

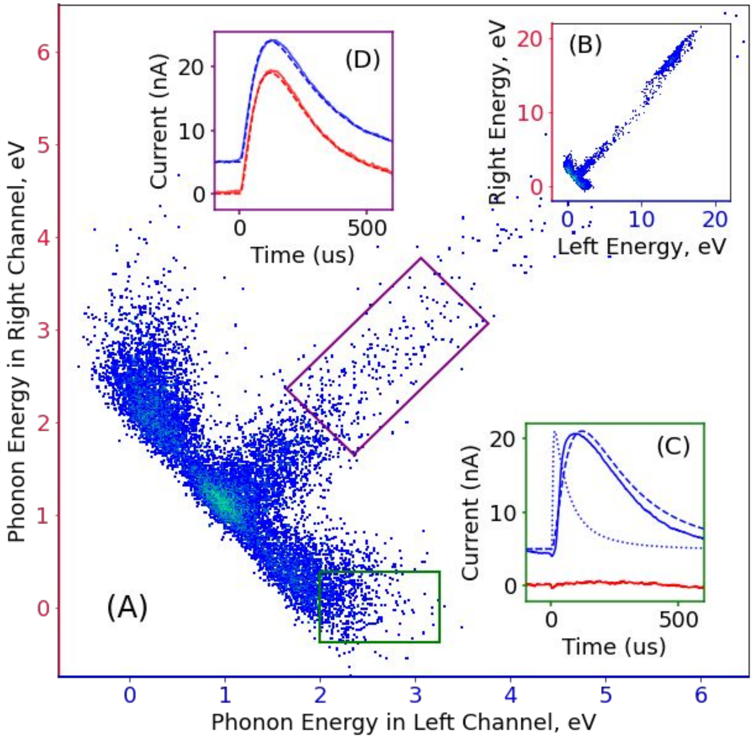




LEE Results: EXCESS 2023

Backgrounds separate into “singles” and “shared” events

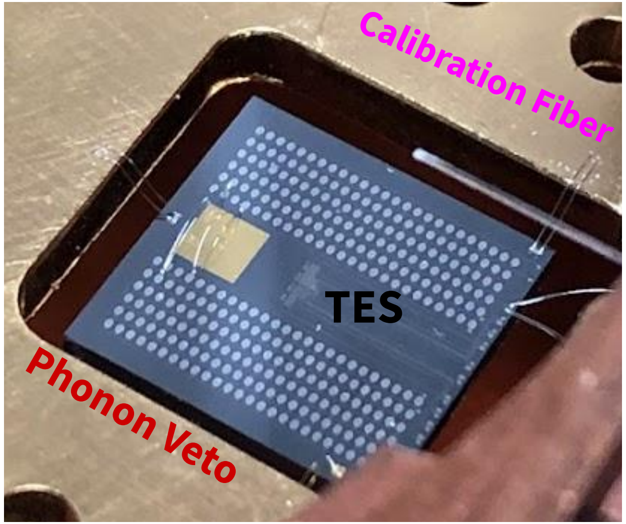
- “Shared” events:
  - Phonon events consistent with DM
  - Most of the LEE problem
- “Singles” events:
  - Energy depositions in sensor films, easy to distinguish from DM
  - Shows events in films are part of the story

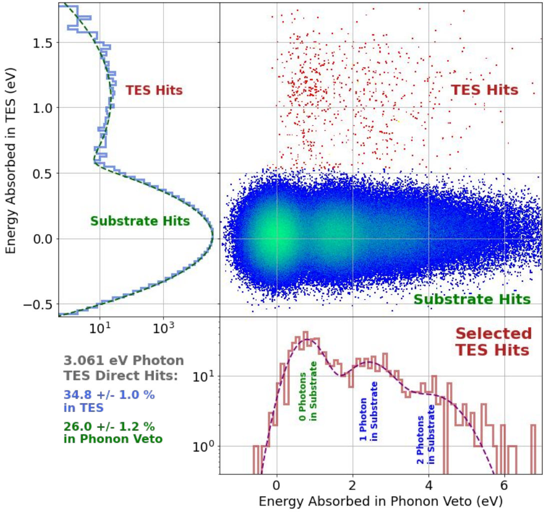


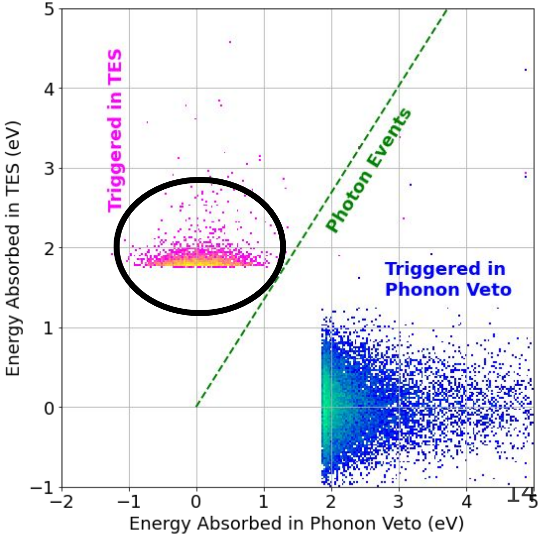
LEE Results: EXCESS 2024

Study of singles results in large TES with direct photon calibration

- Singles: NOT photons absorbed in TES, not high energy phonons (no downconversion)
- Remaining candiates:
  - GHz scale EMI coming down bias lines to TES
  - Film relaxation? Less probable?



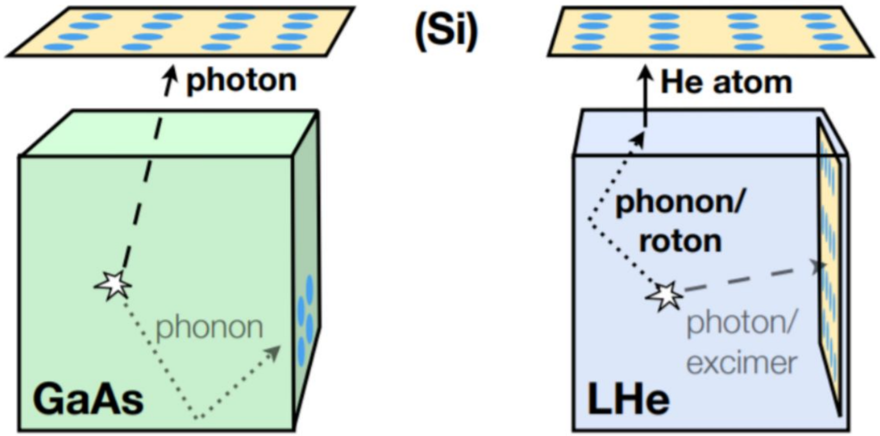




R. K. Romani

Background Solution: Coincidence!

- Separate prototype detectors have significantly reduced correlated backgrounds
  - LEE lives in each individual phonon detector systems
- Use detectors where there are two signals per real DM event
  - GaAs: very low energy scintillator, additional phonon system
  - HeRALD: multi-calorimeter readout possible (see next talk)

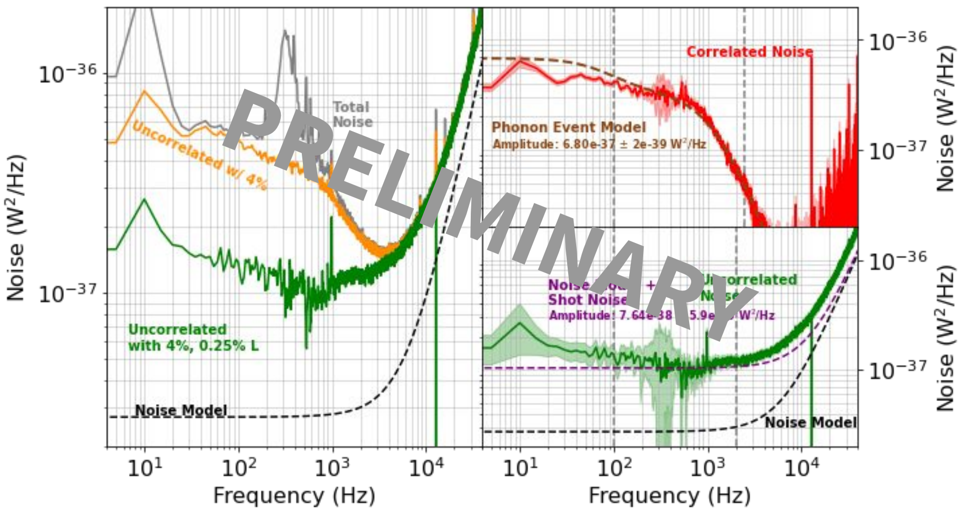


Background Problem: Noise

LEE goes up exponentially towards low energies…

- Really frequent low energy events = shot noise
- Shot noise = higher than expected noise = worse resolutions

Need to understand/reduce impacts of LEE to achieve better resolutions



Materials

Different Models, Different Materials of Choice

Light dark photon mediator (Sec. III, Fig. 1)			
Detection channel	Quantity to maximize to reach ...		Best materials
	... lower m_χ	... lower $\overline{\sigma}_e$	
(Optical) phonons	ω_O^{-1} (Eq. (24))	quality factor Q defined in Eq. (27)	SiO_2, Al_2O_3, $CaWO_4$
Electron transitions	E_g^{-1} (Eq. (28))	depends on details of electron wavefunctions	InSb, Si
Nuclear recoils	$(A\omega_{\rm min})^{-1}$ (Eq. (29))	$(Z/A)^2\,\omega_{\rm min}^{-1}$ (Eq. (31))	diamond, LiF

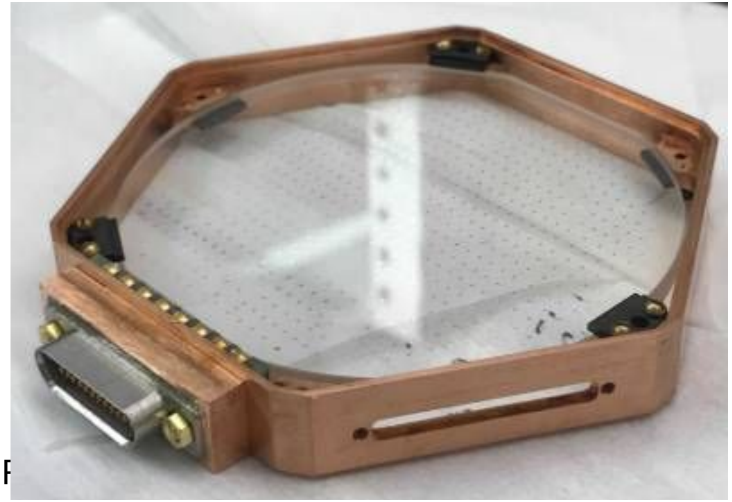
Hadrophilic scalar mediator (Sec. IV, Figs. 2, 3)			
Detection channel	Quantity to maximize to reach ...		Best materials
	... lower m_χ	... lower $\overline{\sigma}_n$	
(Acoustic) phonons	$c_s/\omega_{\rm min}$ (Eq. (36))	Light mediator: $\omega_{\rm min}^{-1}$ (Eq. (35))	diamond, SiO_2
		Heavy mediator: c_s^{-1} or $\omega_{\rm ph}^{-1}$ or $A\omega_{\rm ph}$ depending on m_χ (Eqs. (37), (38), (39))	all complementary
Nuclear recoils	$(A\omega_{\rm min})^{-1}$ (Eq. (29))	Light mediator: $\omega_{\rm min}^{-1}$ (Eq. (40))	diamond, LiF
		Heavy mediator: A (Eq. (43))	CsI, Pb compounds

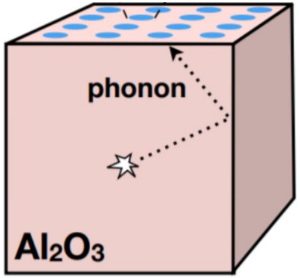
\+ **Superfluid helium!**

arXiv: 1910.10716 Griffin et. al. 2021

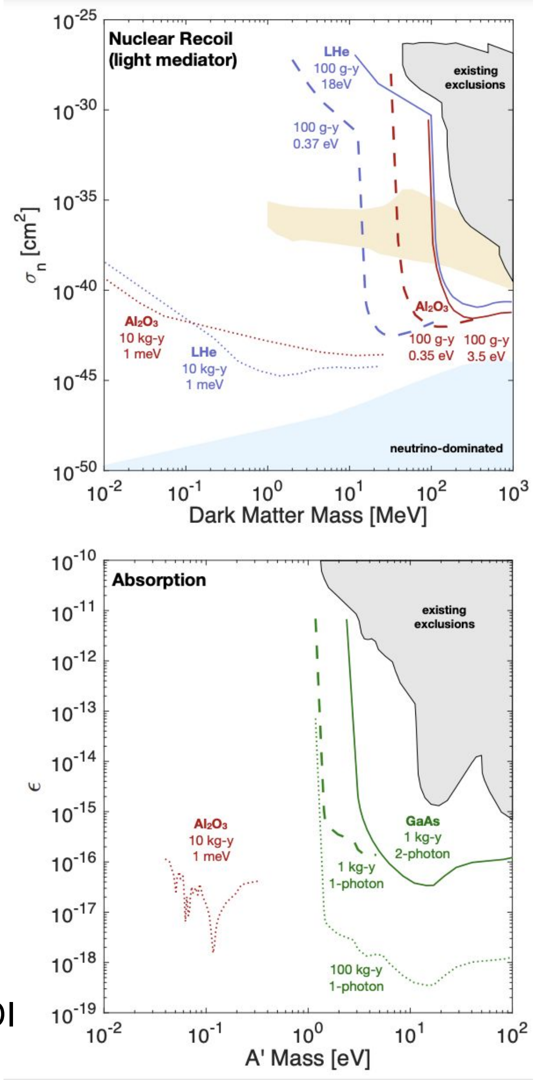
Sapphire as a SPICE Target

- Low mass oxygen nuclei as NRDM scattering target
- Polar unit cell: optical phonons down to 100s of meV
  - Dark photon coupling due to differently charged nuclei
- Prototype detector has been run



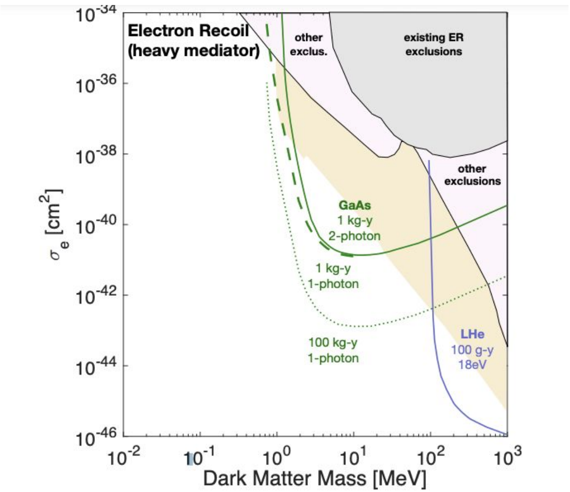


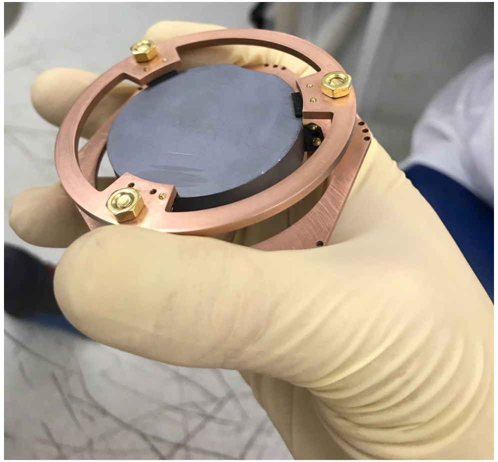
TESSERACT
SNOWMASS LOI

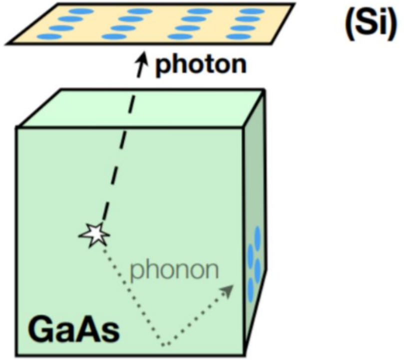


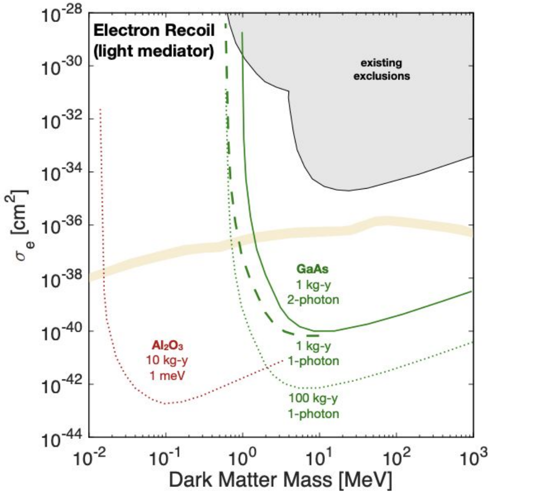
GaAs as a SPICE Target

- Polar crystal: coupling to dark photons
- Scintillation + phonon signal allows for NR/ER discrimination down to eV scale signals
- GaAs scintillation yield being measured





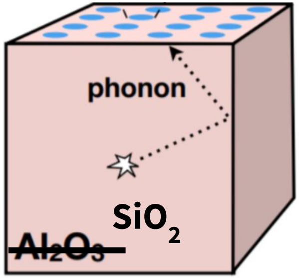


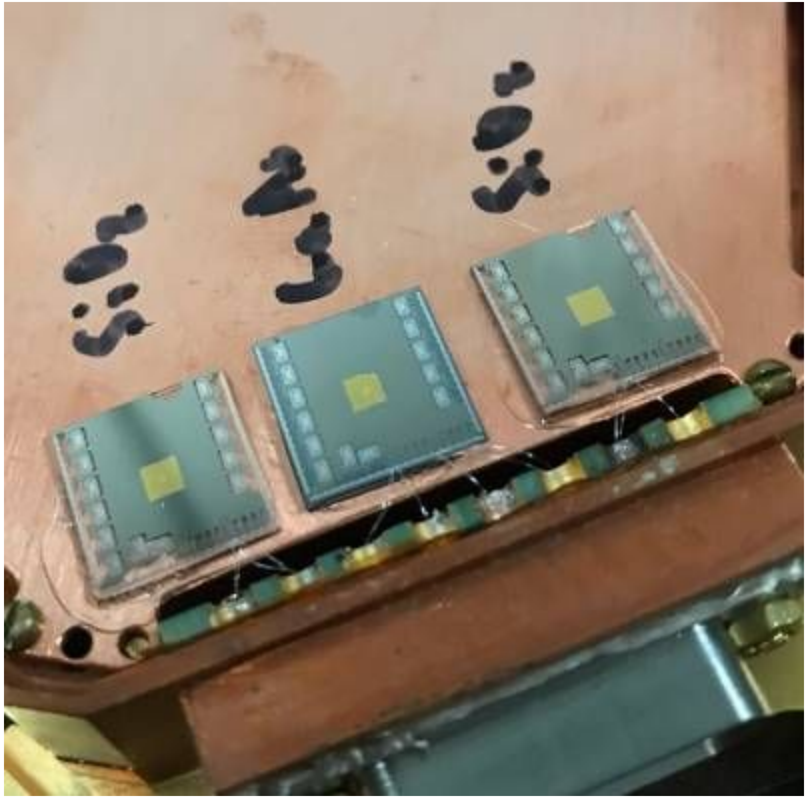


TESSERACT
SNOWMASS LOI

SiO2 as a SPICE Target

- Excellent coupling to dark photons, high “quality factor”
  - See arXiv: 1910.10716
- TESs on SiO2 substrate tested





SPICE: An Exciting Light DM Program

- A suite of materials, with advantages for different model and readouts
- Cutting edge calorimeter R&D, making strong progress towards solving LEE
- An exciting near-term program of DM science expected