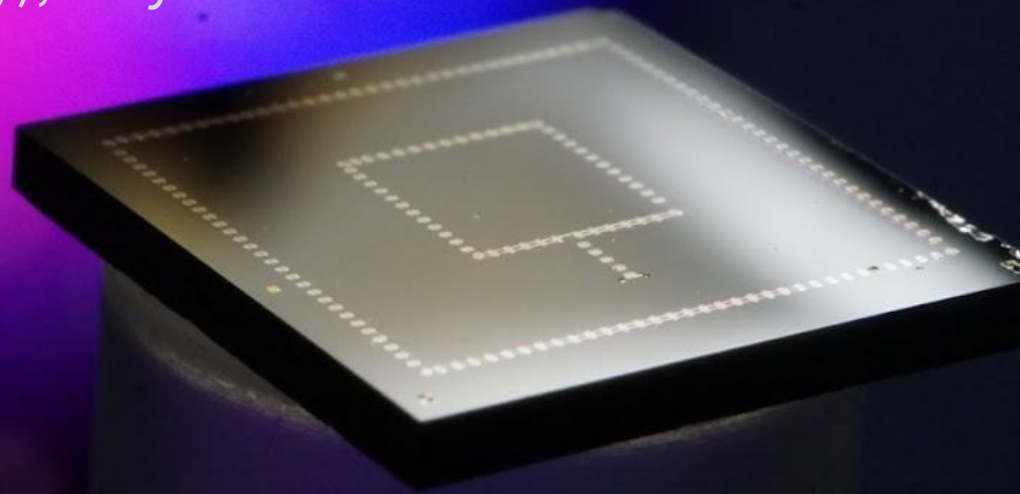
Single and Shared LEE Backgrounds in SPICE Detectors

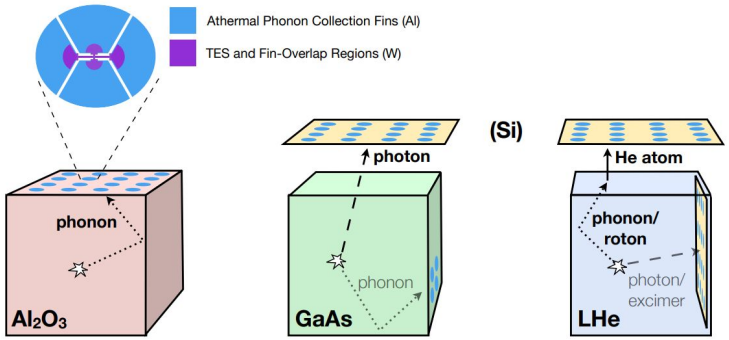
Roger K. Romani (UC Berkeley), July 2024



Who We Are

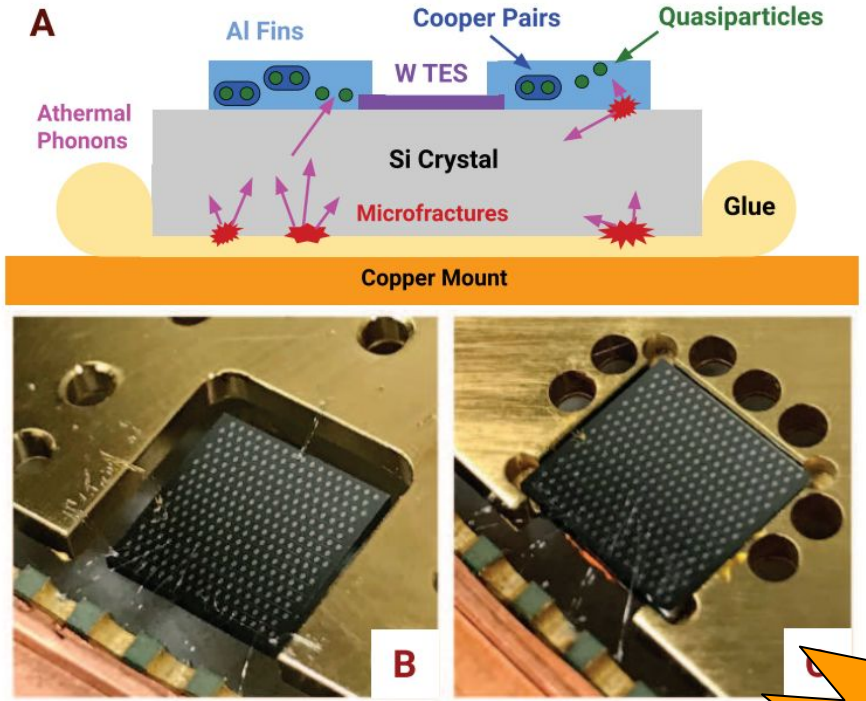
Confused about what our collaboration is called? You're not alone!

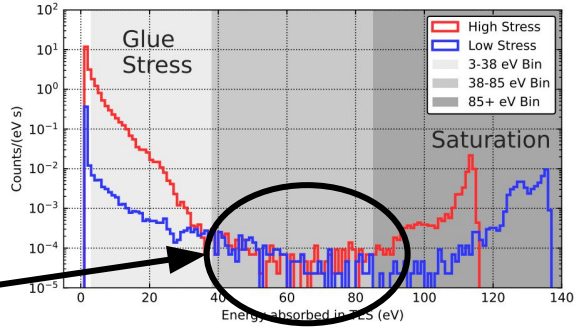
- **TESSERACT:** Entire collaboration
- **HeRALD:** light DM direct detection using superfluid He
- **SPICE:** light DM direct detection using solid state targets (sapphire, silicon…)
- United by a transition edge sensor (TES) based readout
- Mostly US based, collaborators in France



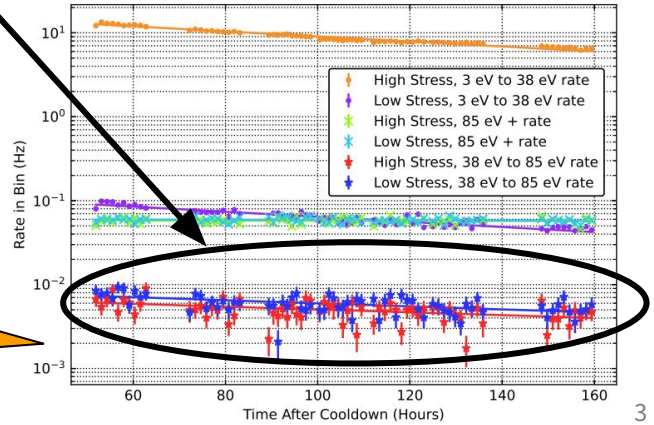
SPICE **HeRALD**

2022: Glue Stress Causes LEE-like Events





Metal relaxation?

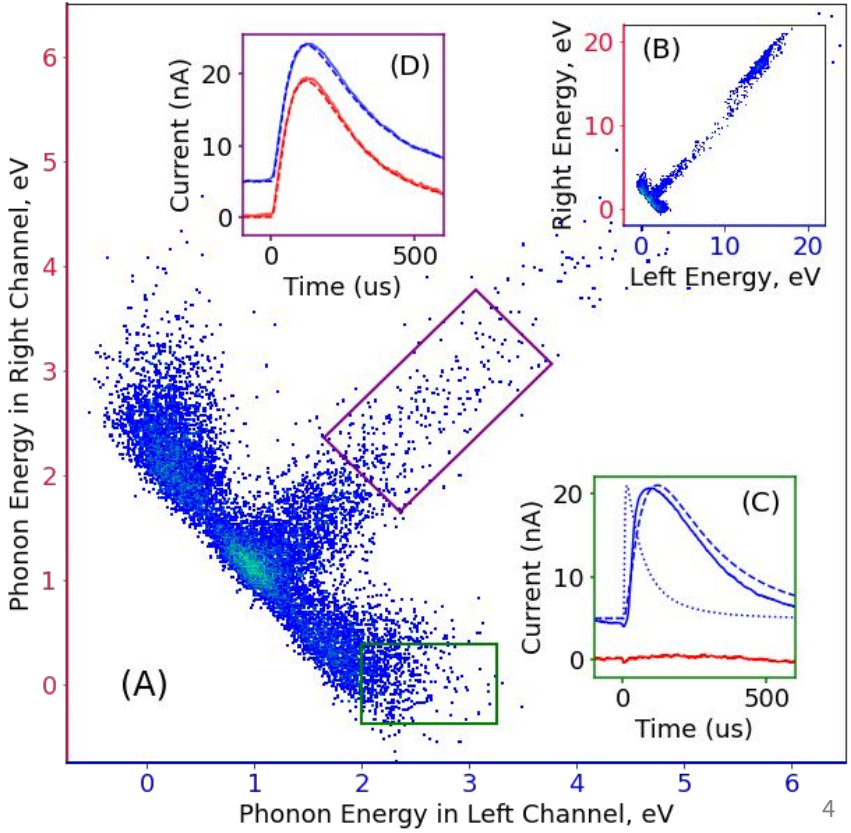


Recently accepted in **nature communications**

2023: Two Channel Detectors

Basic idea: look for local energy deposits in relaxing metal films, shocked to find:

- **Shared** events: phonon mediated
- **Singles**: directly in metal films



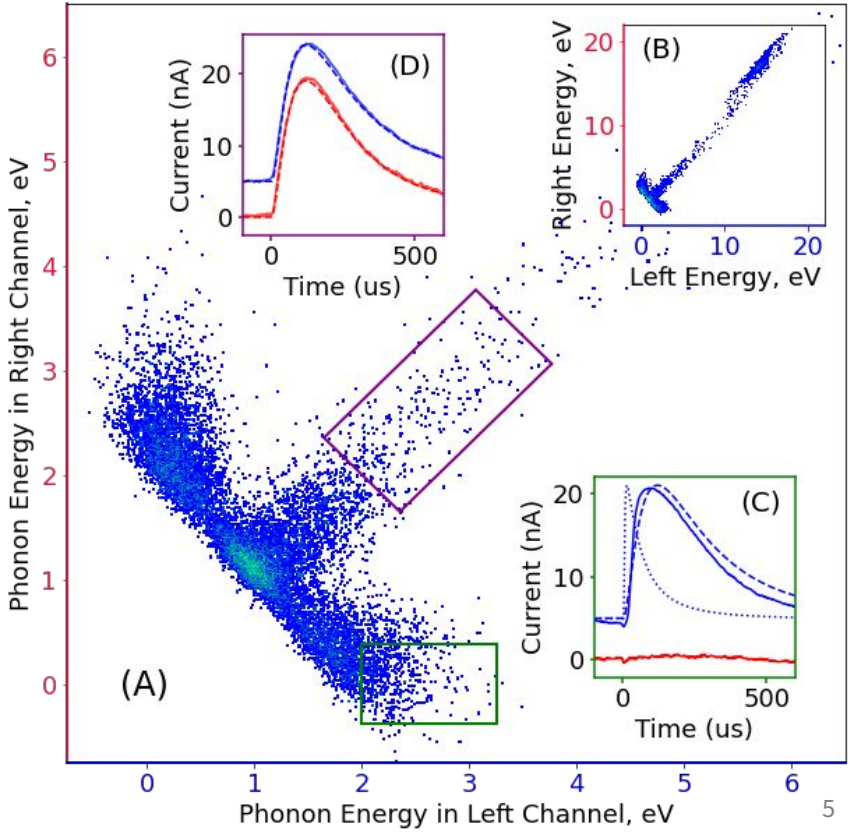
2023: Two Channel Detectors

Basic idea: look for local energy deposits in relaxing metal films, shocked to find:

- **Shared** events: phonon mediated
- **Singles**: directly in metal films

Corrections from last time, after replication with better data quality:

- No singles/shared/noise relaxation
- Better noise decorrelation
- Better single/shared discrimination



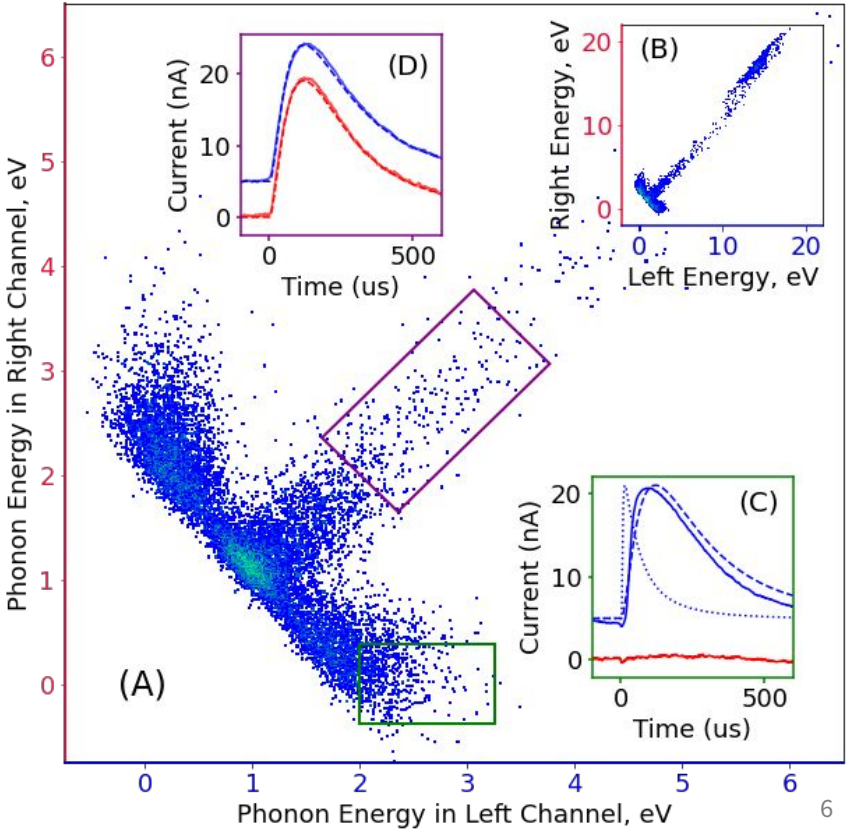
Central Question For 2024

Where do **singles** come from?

- Optical/IR Photons hitting TESs? Film relaxation? Heating from EMI bursts?

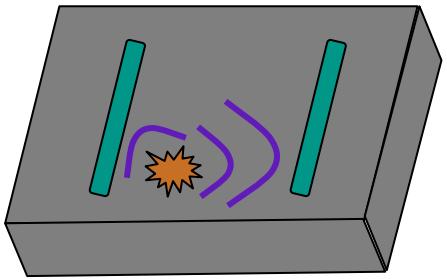
Where do **shared** events come from?

- Film relaxation? Photon bursts? Something else?



Detector Architectures

“Two channel” detector



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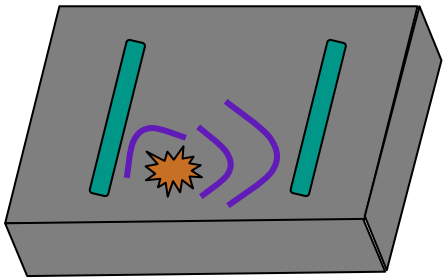
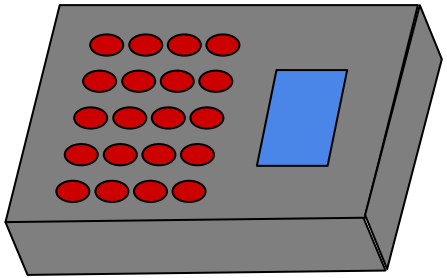


“**TES** + **Veto**” detector



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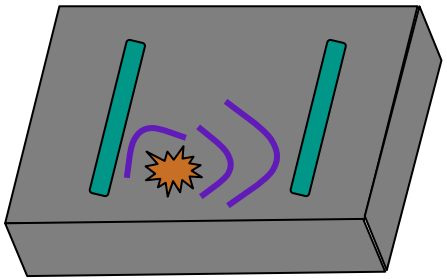

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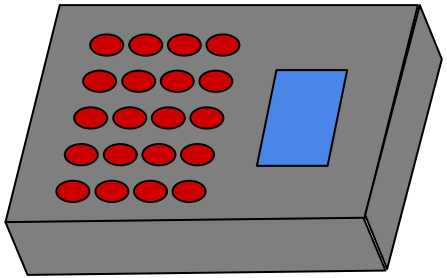

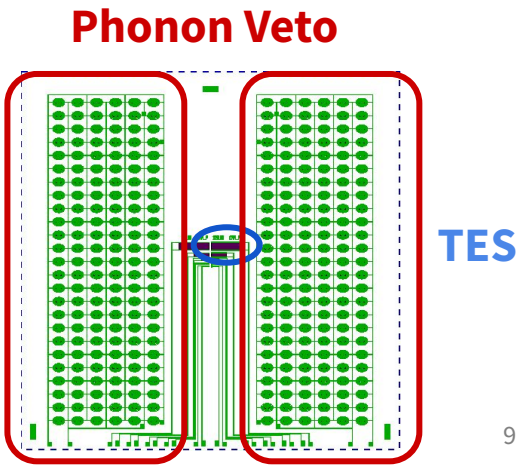

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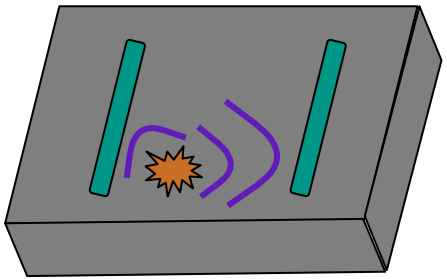

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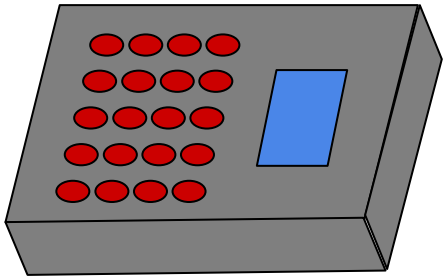
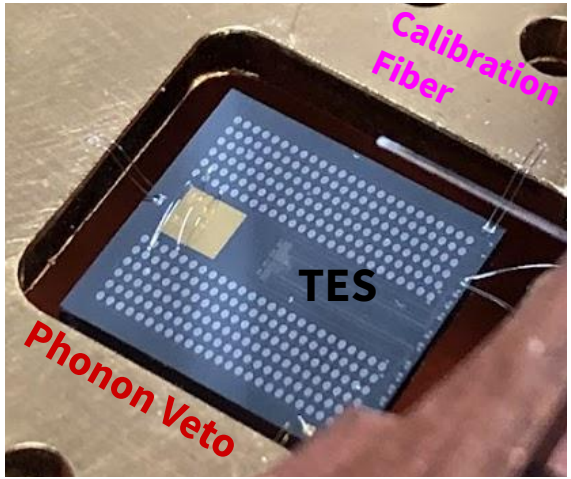
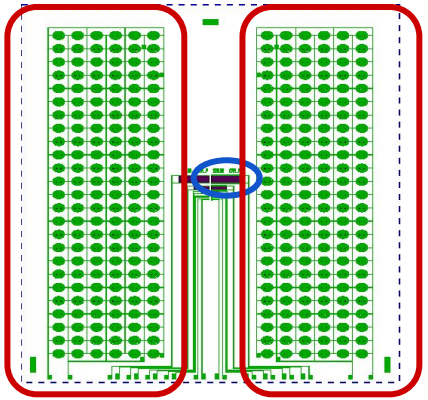




Phonon Veto



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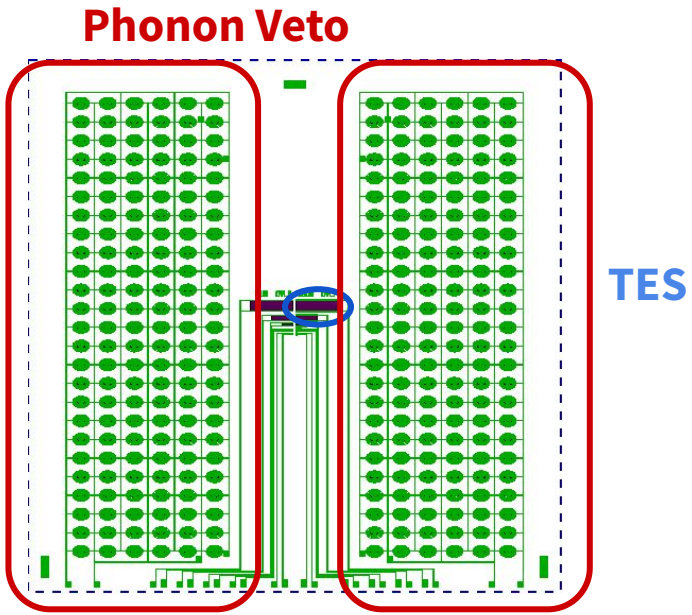
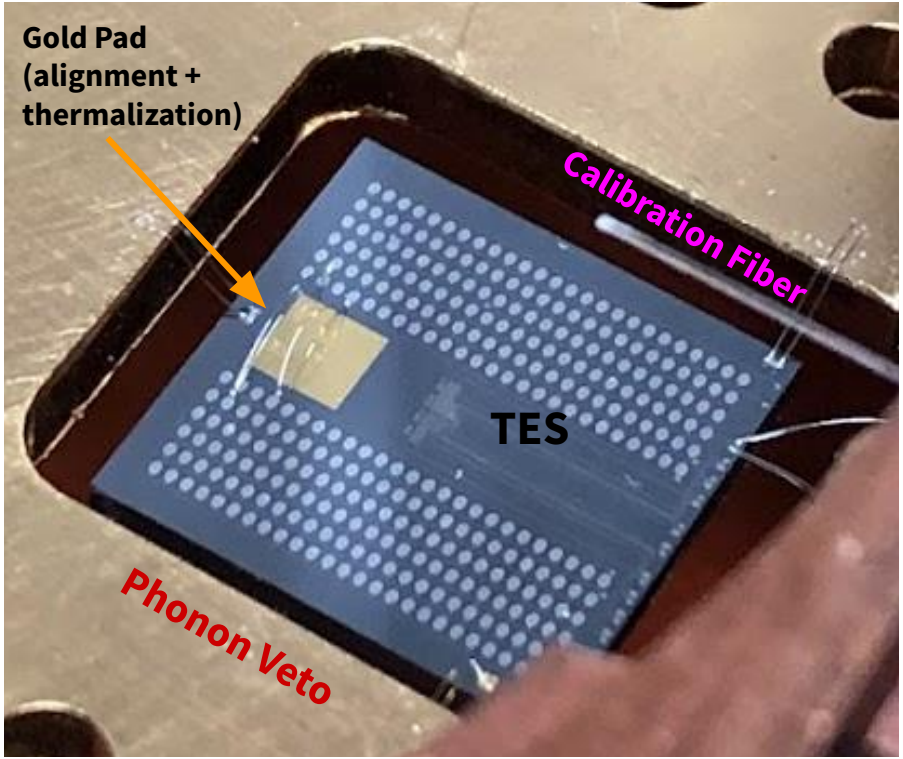
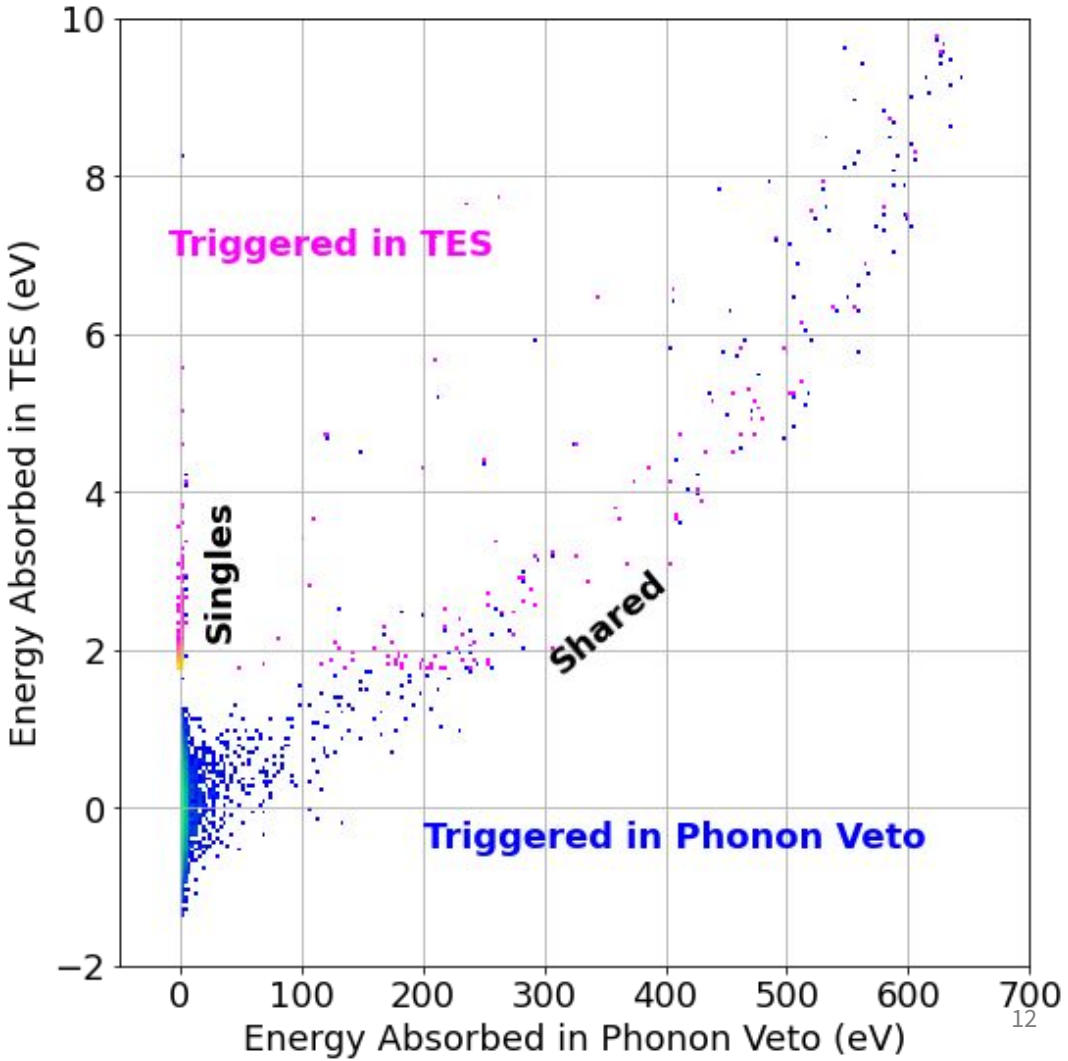




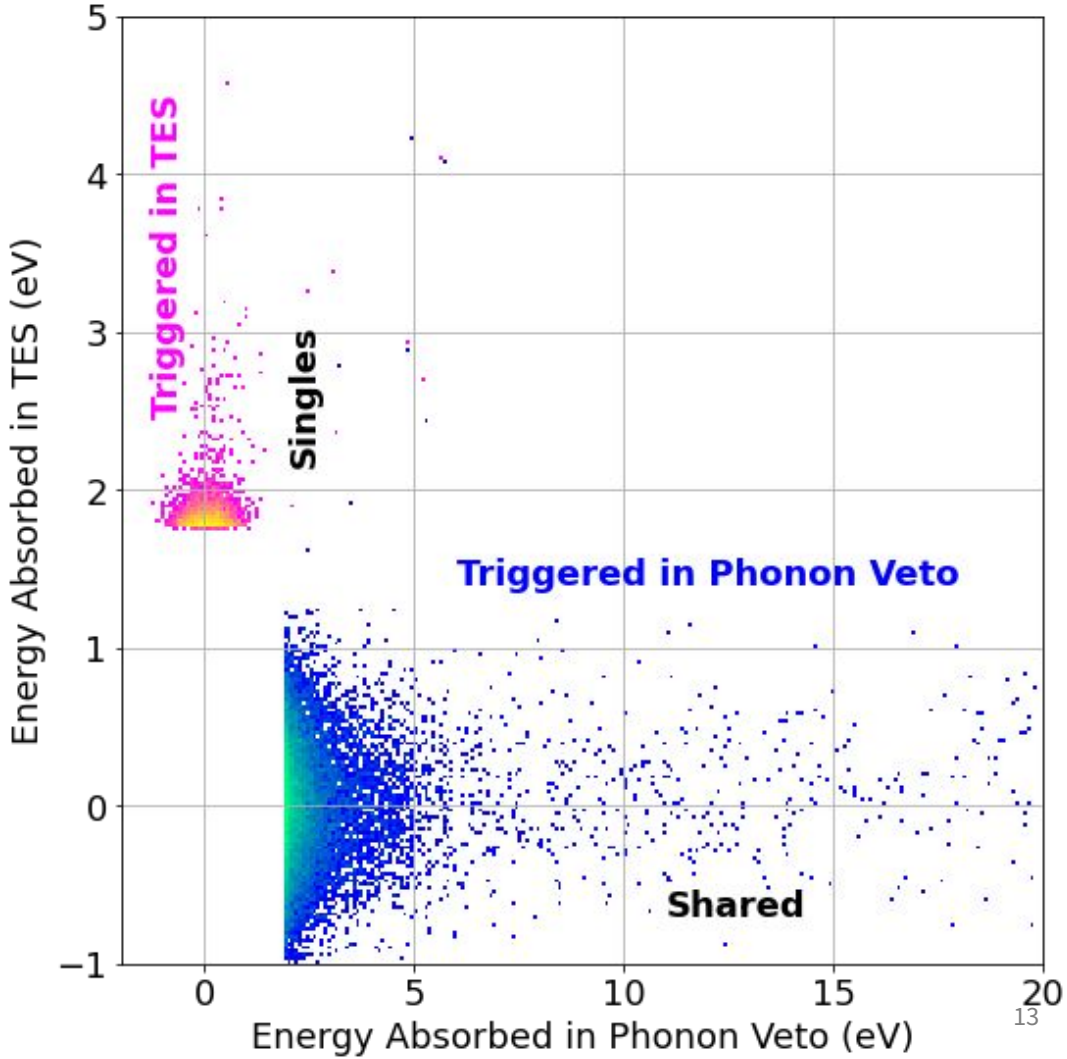
Background Results

For high energy background events roughly 1% of the energy is deposited in the TES that is deposited in the phonon veto



Background Results

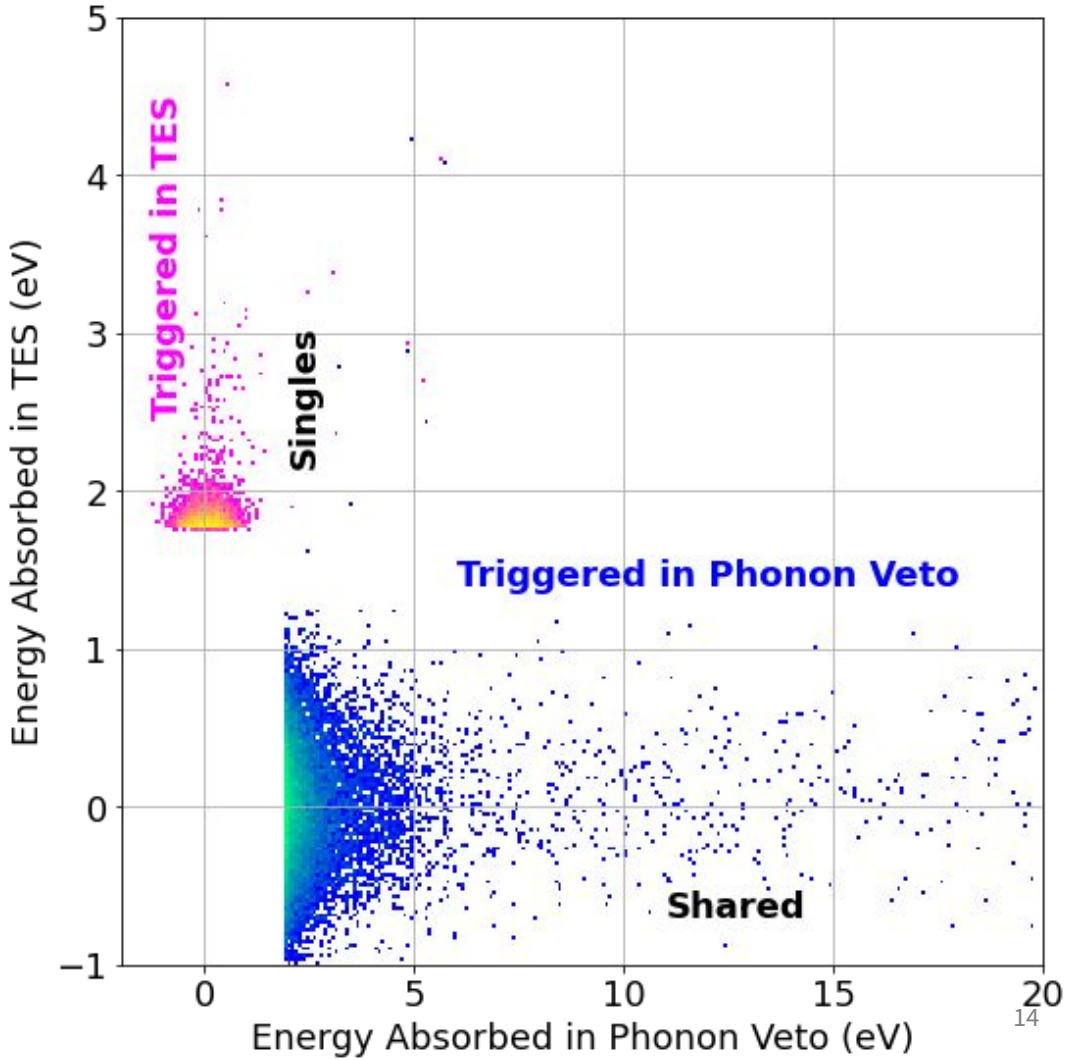
Zooming in…



Background Results

Zooming in…

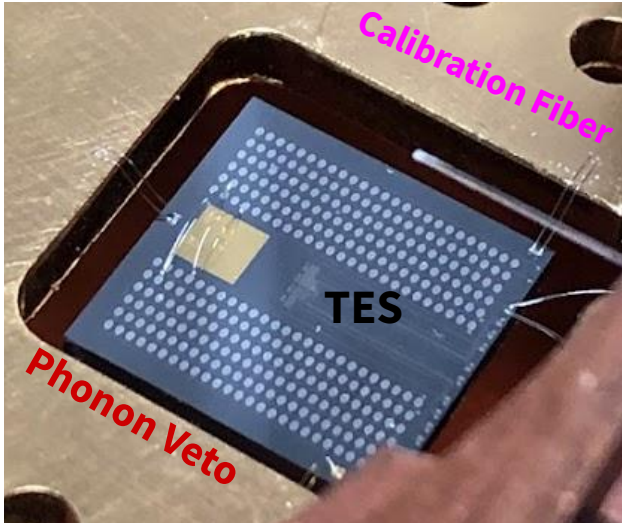
- “Shared” events (very little energy in TES)
  - Consistent with phonon response
- Singles in TES (**no** energy in phonon system)
  - Consistent with instantaneous impulse TES response
- “Loophole free:”* no saturation effects, virtually no phonon collection in TES…



Calibrate with Optical Photon Source

Pulses of 3.061 eV Optical Phonons, evenly diffused across detector. Expect:

- Most events in substrate, partially collect energy
  - Energy lost to subgap phonons, noninstrumented metals
- Small fraction of events: direct hit in TES
  - Energy in both TES and in phonons created during hot electron downconversion
  - Prediction from 2000s optical TES work: ~50/50 division



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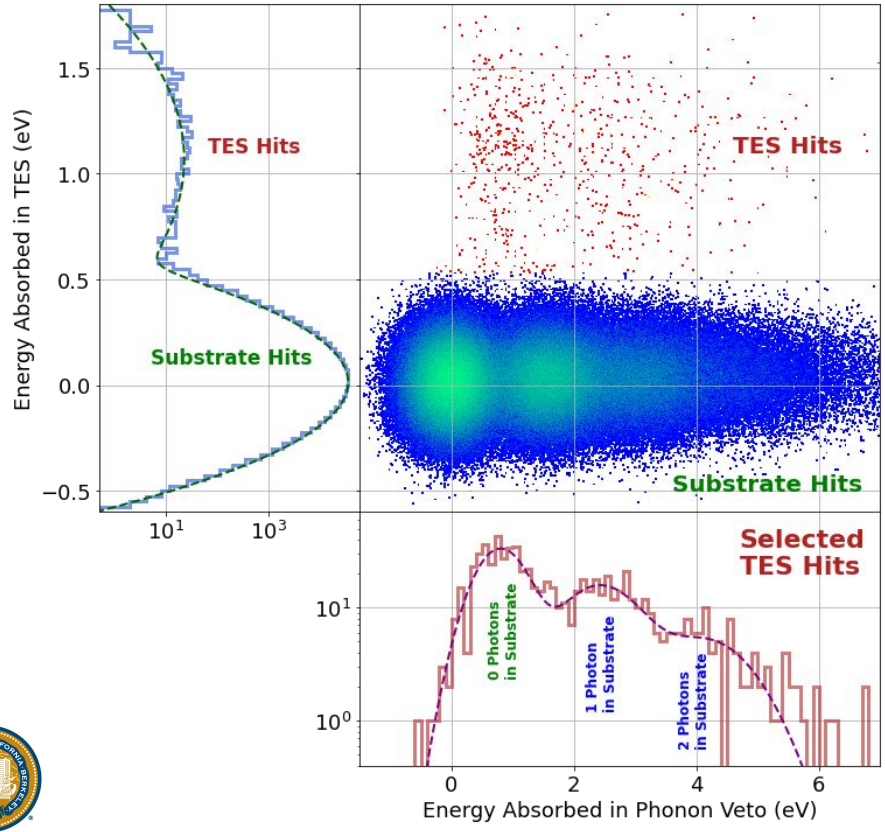

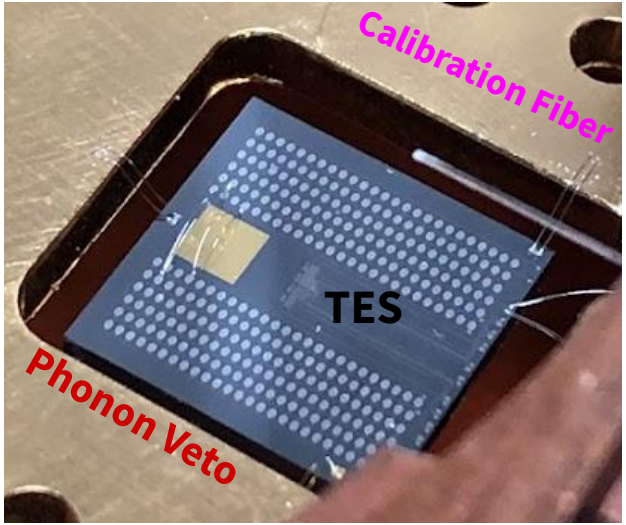

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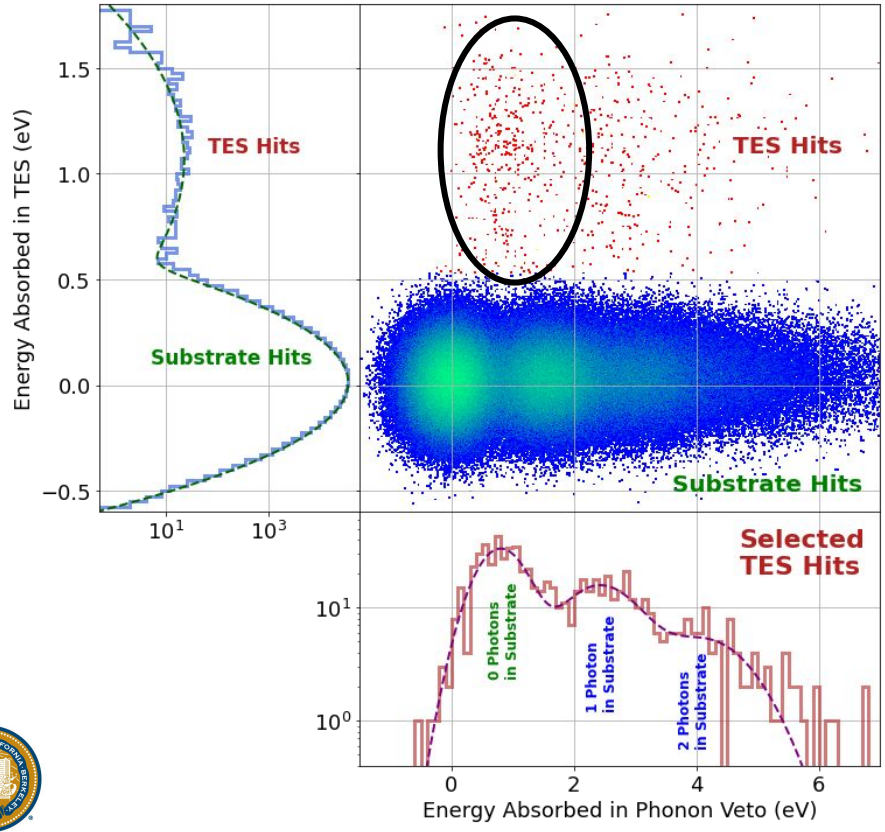

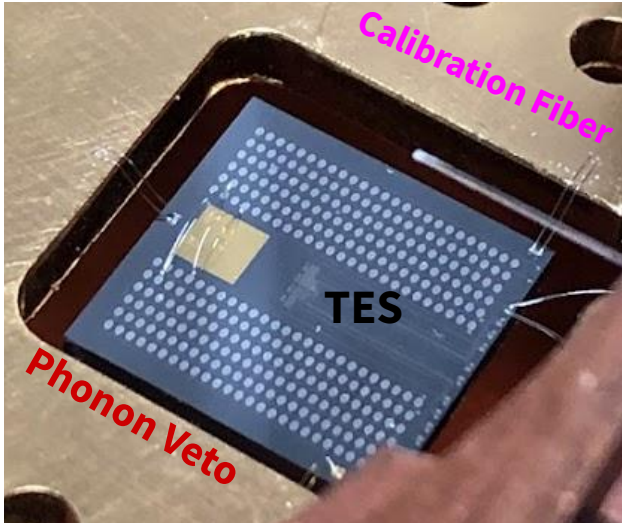

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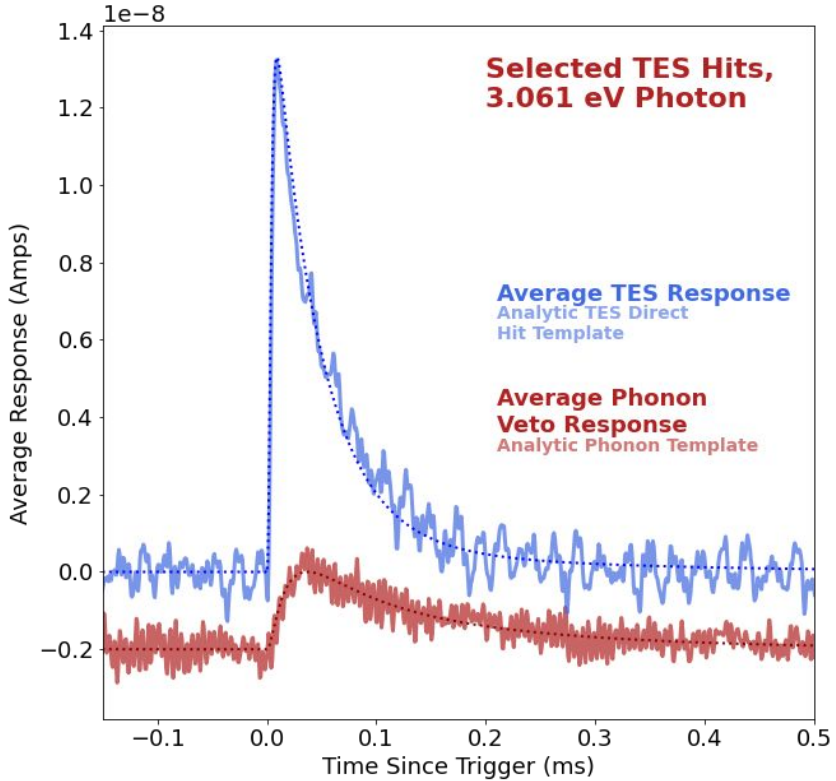

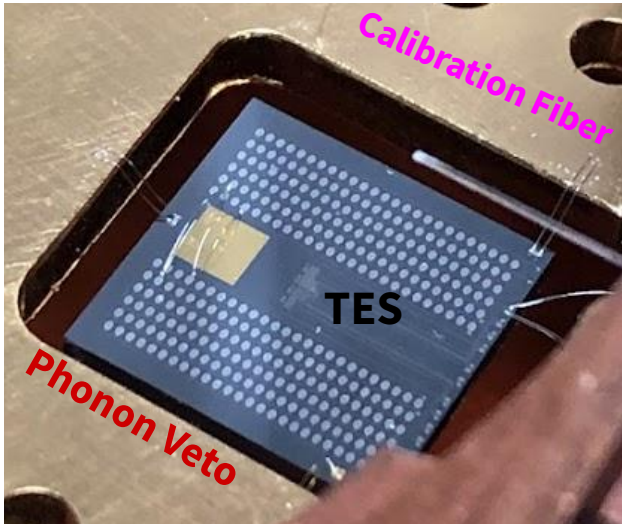

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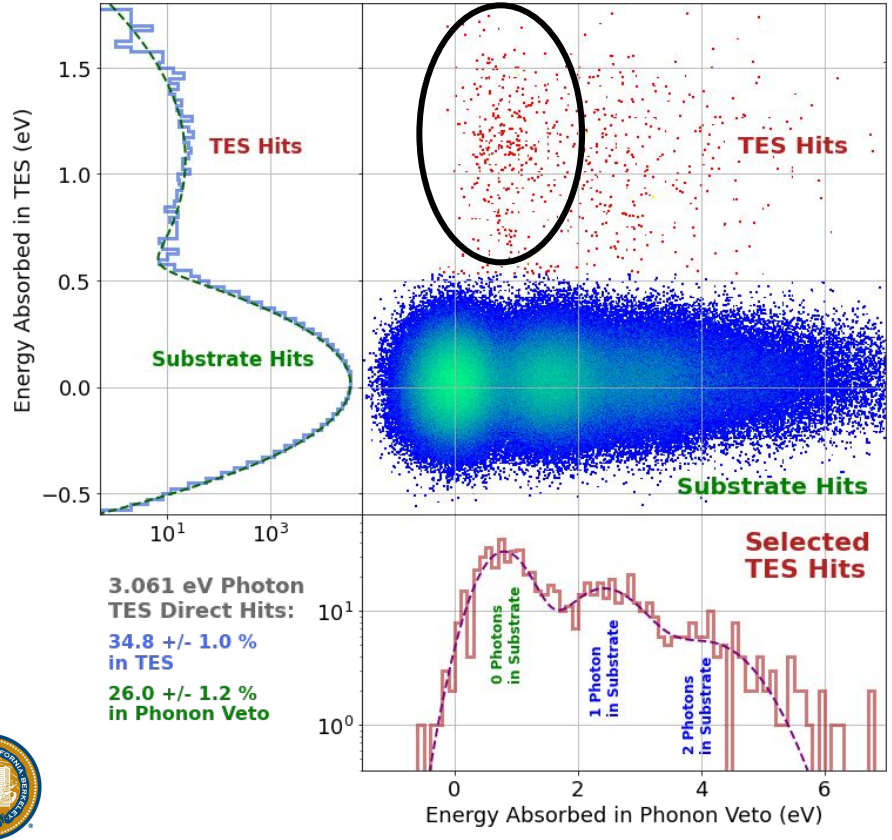
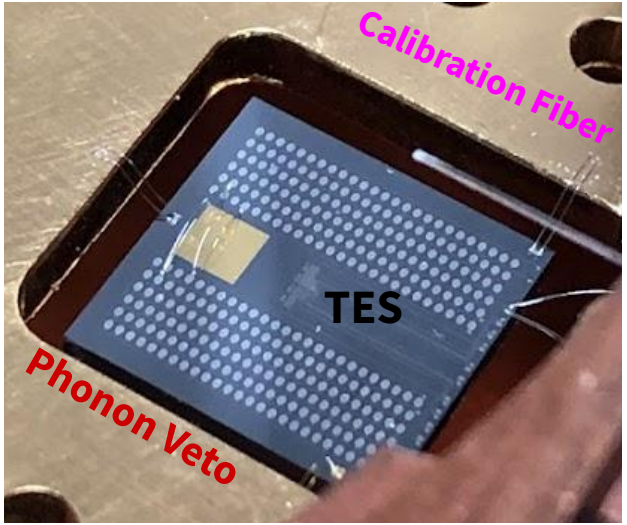
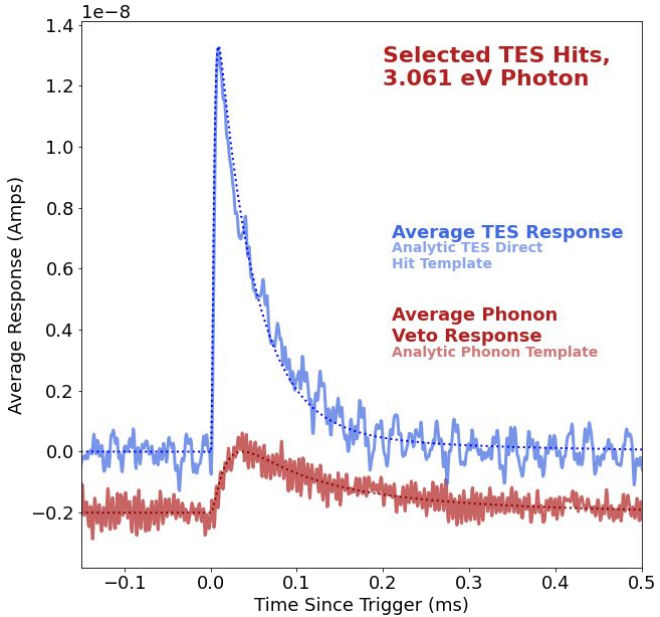




Optical Photon Properties

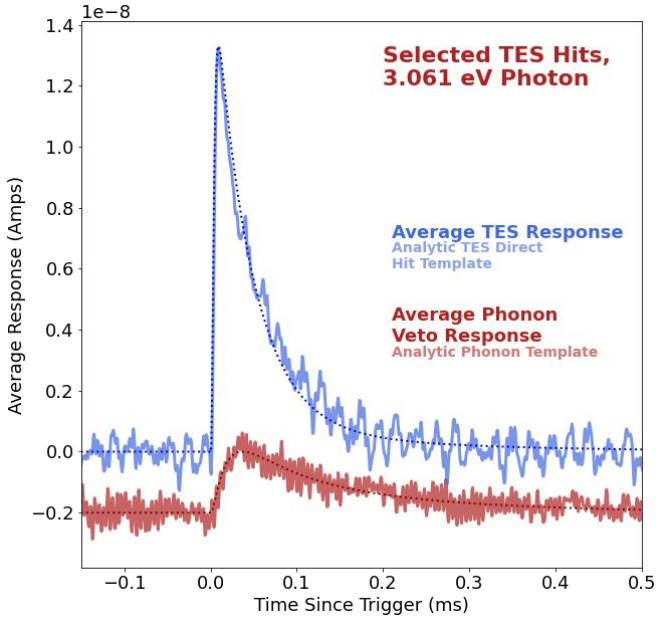


3.061 eV Photon
TES Direct Hits:

34.8 +/- 1.0 %
in TES

26.0 +/- 1.2 %
in Phonon Veto

Optical Photon Properties



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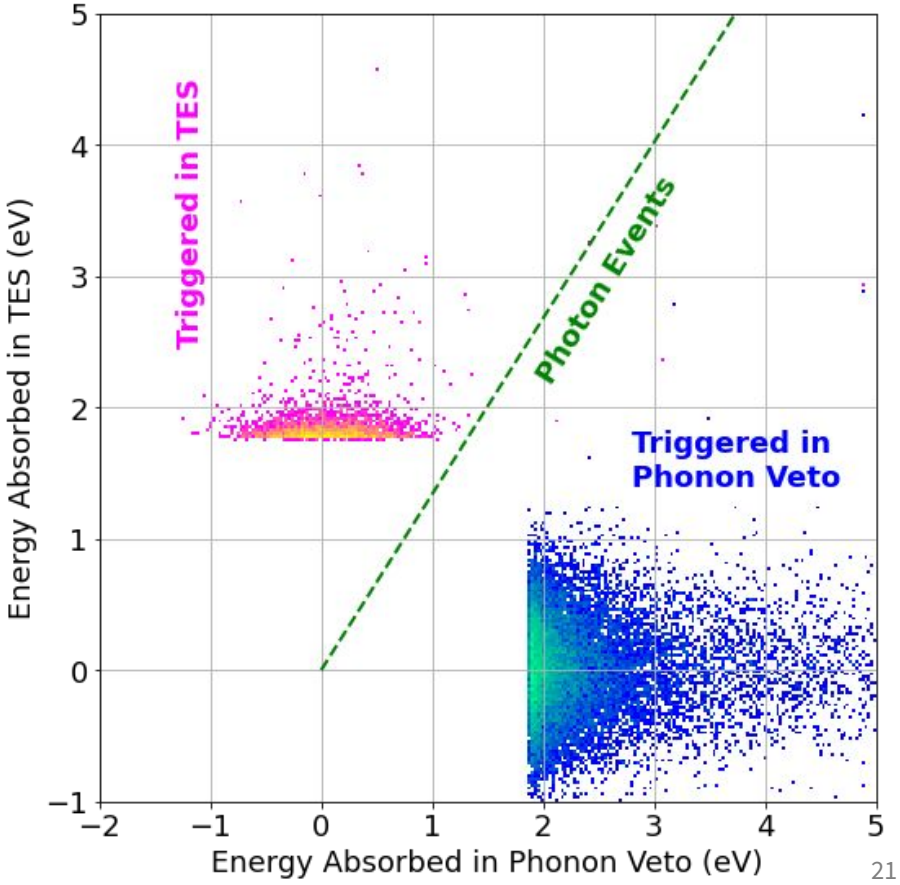
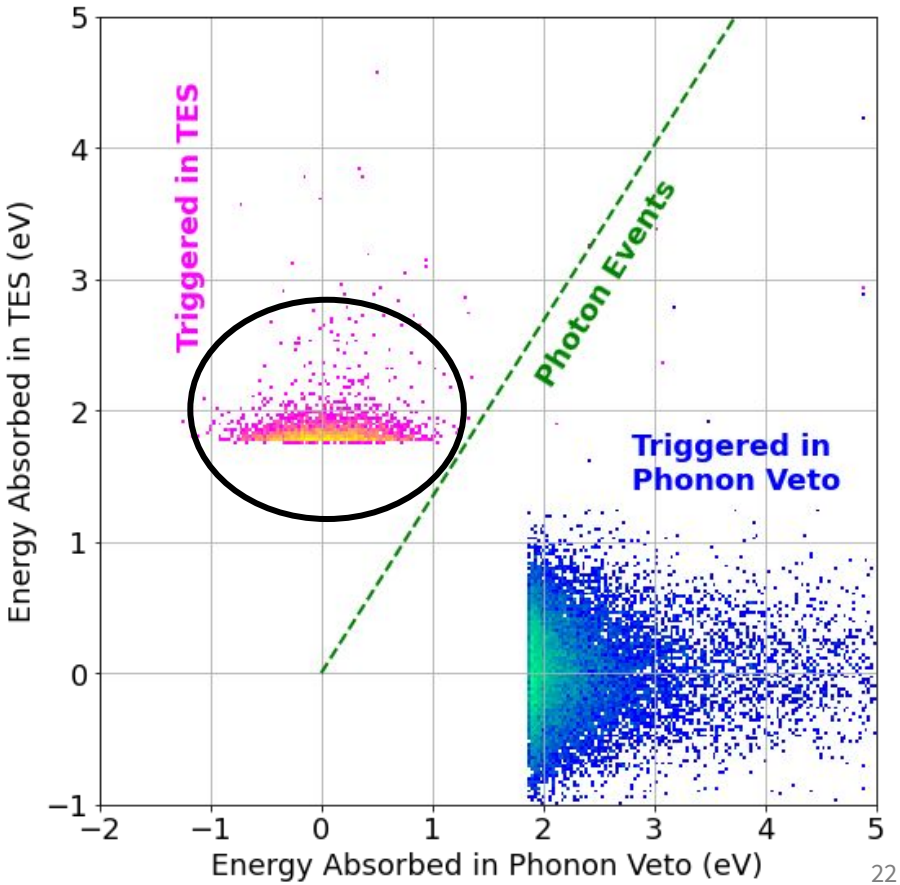


What are TES Singles?

These are not single photon absorption events!

Needs to be:

- Direct hit-like response in TES
- Consistent with no phonon response

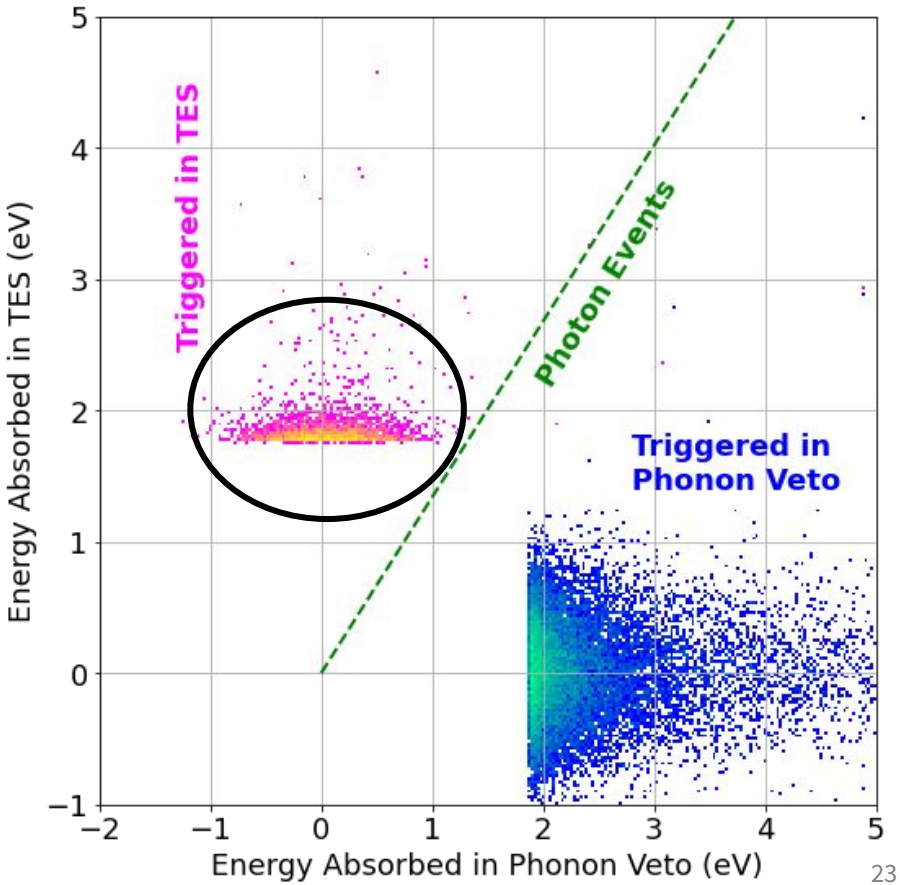


What are TES Singles?

These are not single photon absorption events!

Could be:

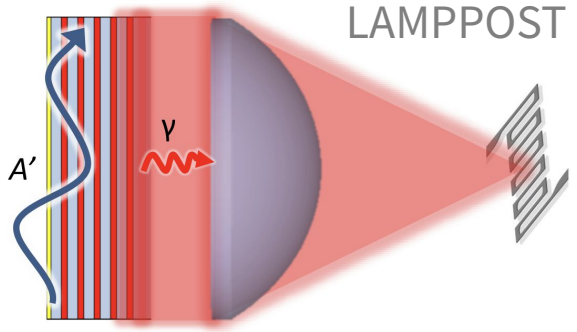
- GHz EMI bursts absorbed in TES coming down bias lines
  - Naively expect “direct hit” pulse shape, don’t see in 2 channel devices, why?
- Film relaxation?
  - No phonon component, why?
  - No decrease in rate w/ time (?)



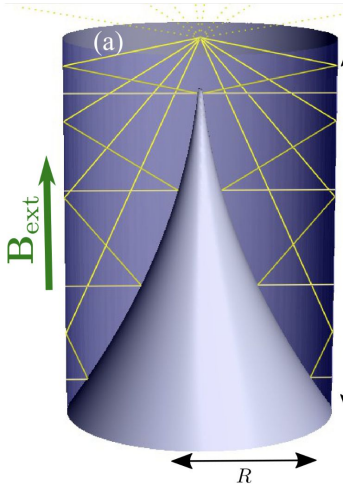
Important for Axion Searches

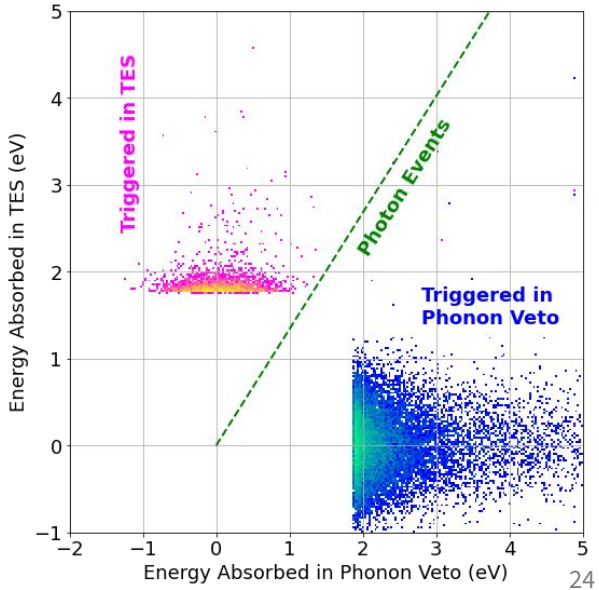
Axion (+ other rare event) searches: look for axion converting to photon, count photons

- TESs in some ways ideal photon counter, but suffer from dark counts (singles)
- We can now cut the vast majority of dark counts by requiring coincidence with a photon veto pulse!
- Can extend below threshold by looking at noise correlations



BREAD





Where Do Shared Events Come From?

Aluminium Relaxation as the Source of Excess Low Energy Events in Low Threshold Calorimeters

Roger K. Romani

A previously unexplained background called the Low Energy Excess (LEE) has negatively impacted the reach of a variety of low threshold calorimeters including light dark matter direct detection and coherent elastic neutrino-nucleus scattering experiments. The relaxation of stressed aluminium films as mediated by the motion of dislocations may account for these observations.

Comments: 11 pages, 6 figures
Subjects: **Instrumentation and Detectors (physics.ins-det)**; Materials Science (cond-mat.mtrl-sci)
Cite as: arXiv:2406.15425 **[physics.ins-det]**
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https://doi.org/10.48550/arXiv.2406.15425

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Warning:

- My views, not those of TESSERACT collaboration
- Internal data: this isn't the full story
- But, maybe this is **your** LEE, or matters in future

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- I am not a dislocations expert
- Ideal: a true expert says “no no no, *this* is what’s actually going on”

arXiv:2406.15425

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Need to Explain

- Where these events come from
- Why they seem like 100% phonon events
- Why (and how) they go down with time
- Their overall rate
- Their energy scale

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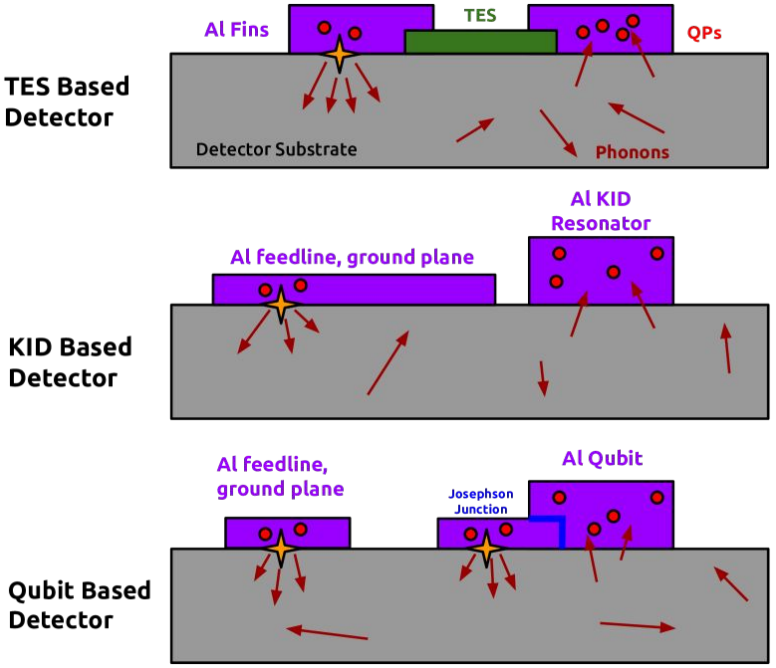
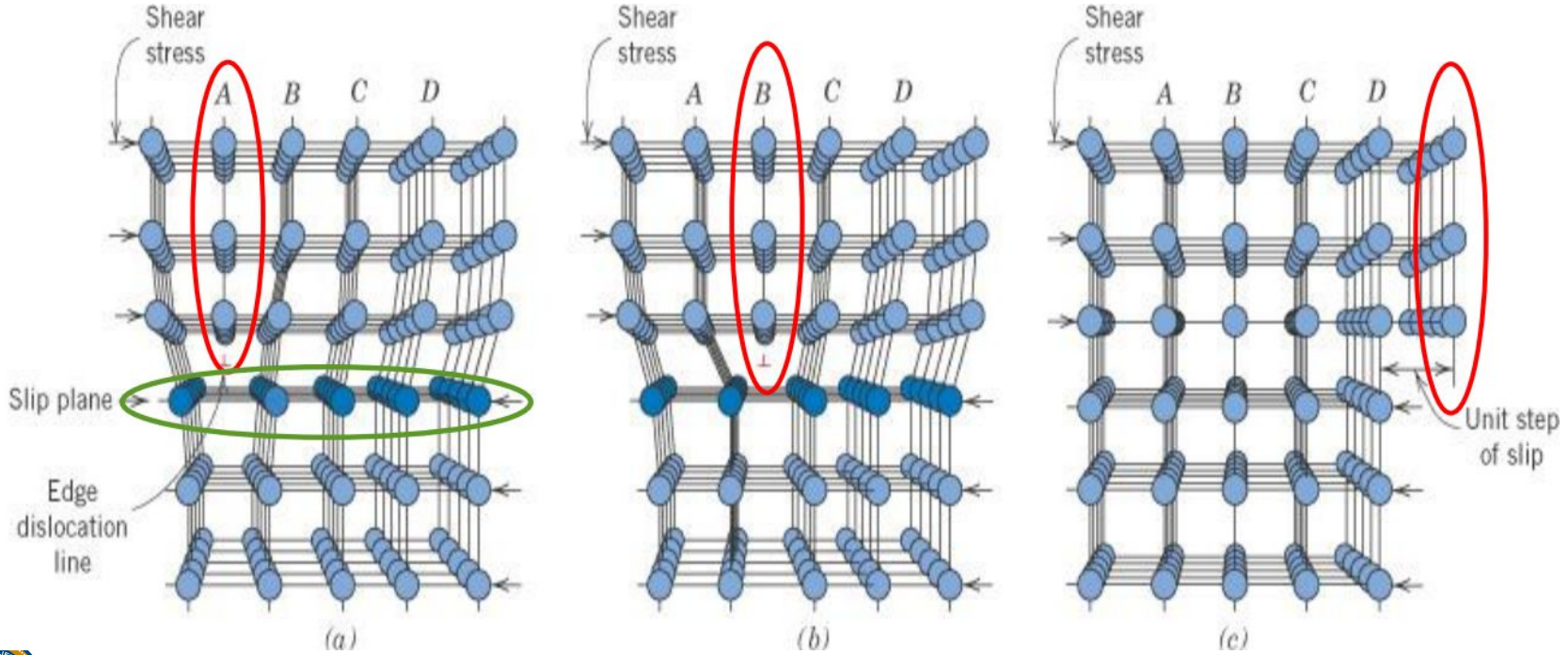
- Why they seem like 100% phonon events
- Why (and how) they go down with time
- Their overall rate
- Their energy scale

My answer: **aluminum relaxation** through the motion of dislocations

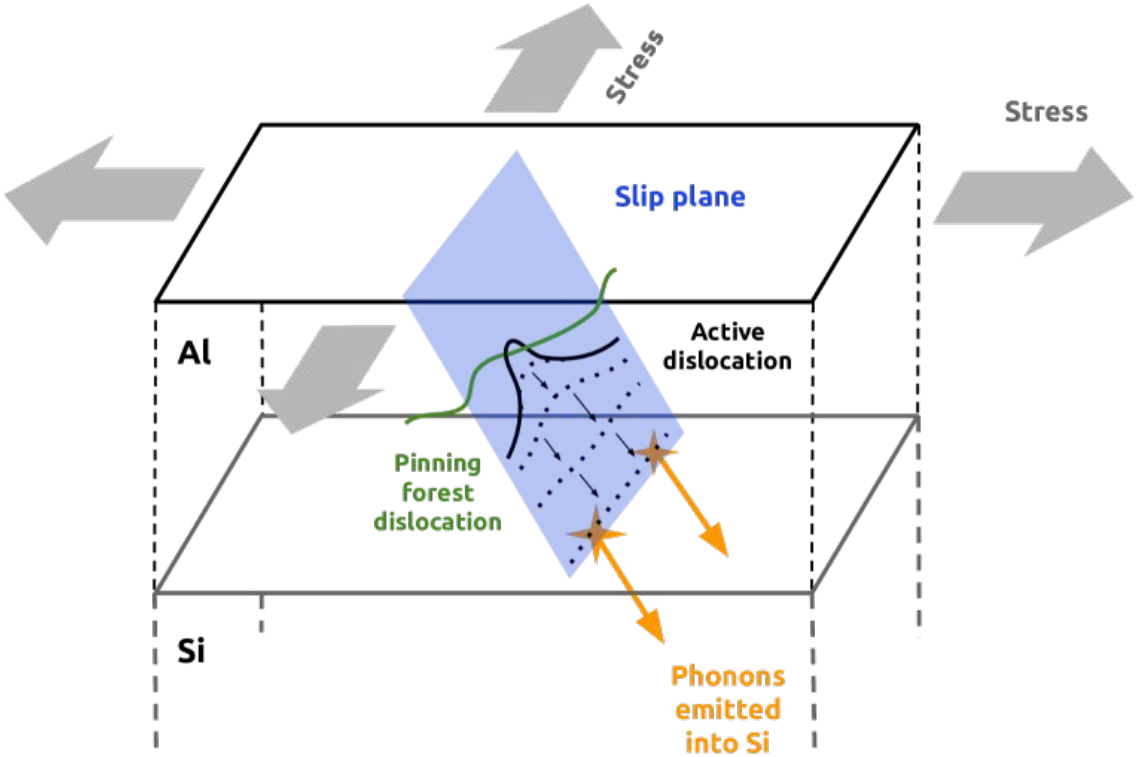


What's a Dislocation?



How Does This Work?

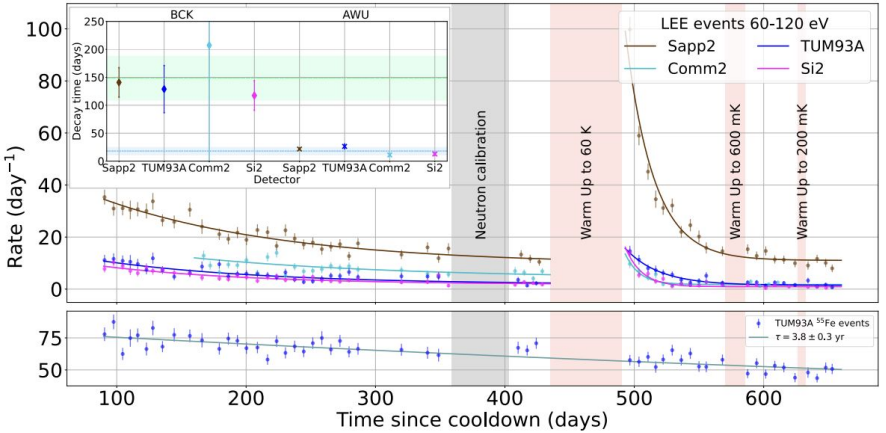
1. During cooldown, dislocations get stuck
2. Over time, they tunnel free
3. They get released and slam into film-crystal interface
4. When they stop suddenly, they create a burst of phonons (analogous to bremsstrahlung)

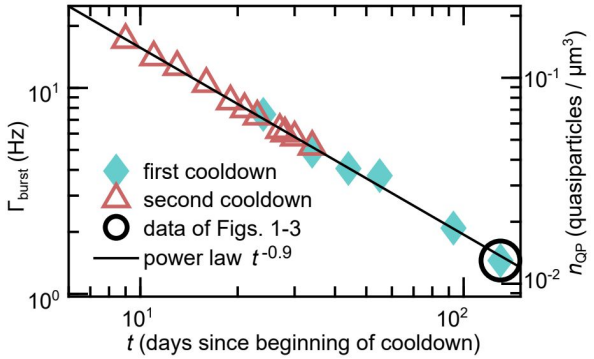


Rate Over Time Dependence

My model predicts 1/t rate dependence from tunneling

- Weakly bound states fail first, strongly bound states fail later
- Seemingly compatible with experimental observations
- We should compare our data to 1/t models

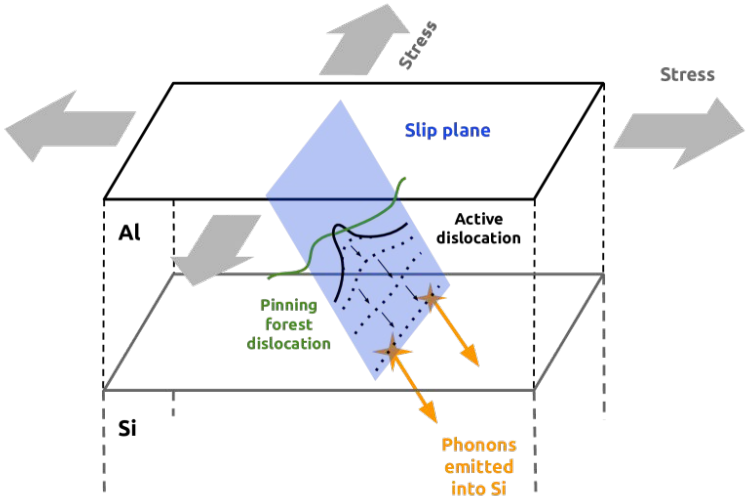




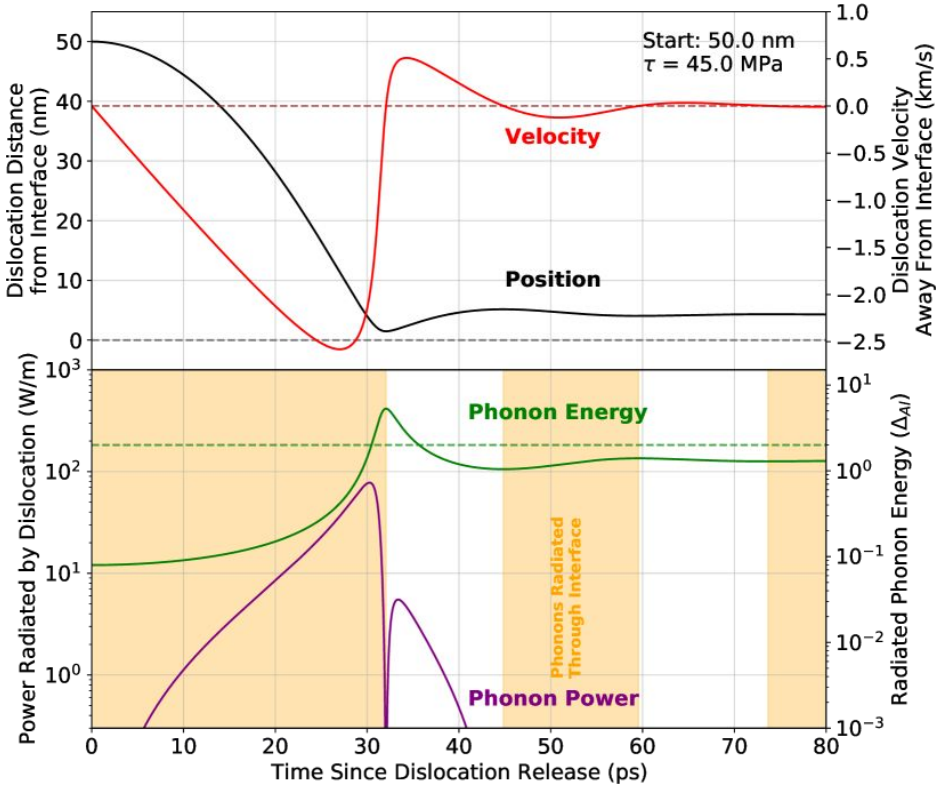
CRESST Collaboration, 2022, "Latest observations on the low energy excess in CRESST-III"

arXiv: 2102.00484
Mannila et. al.

Dislocation Dynamics

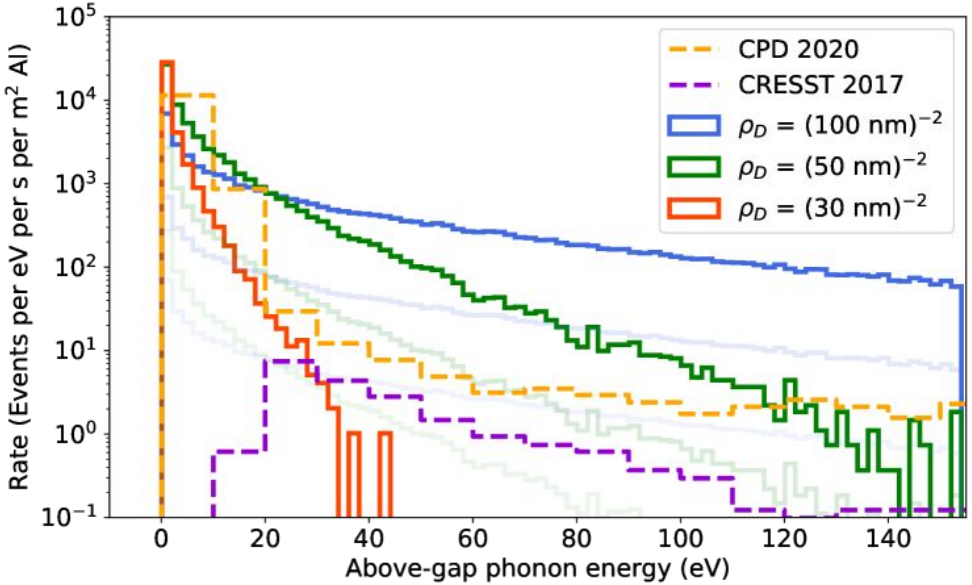


Dislocation decelerates at interface: almost all energy emitted into crystal



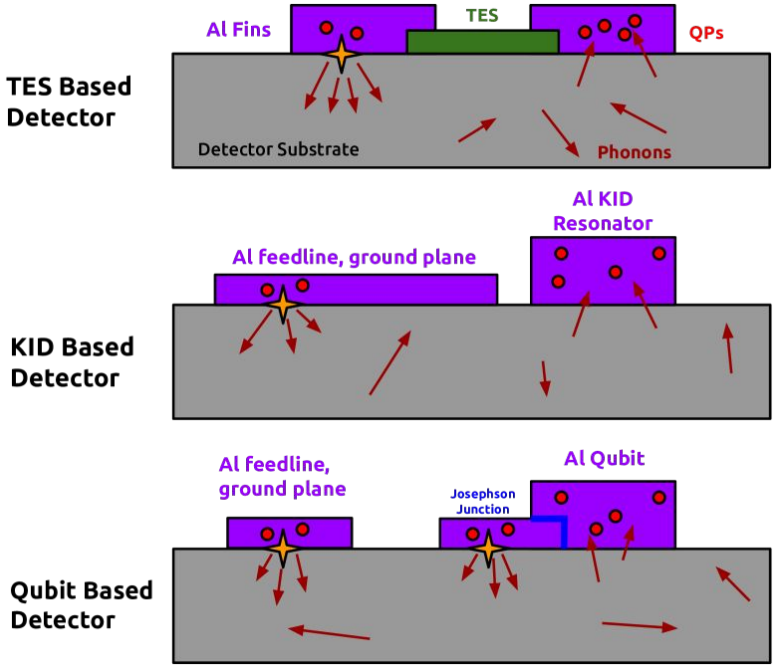
Predicted Spectra

- Put in reasonable dislocation density, no grain structure, turn crank on Monte Carlo…
- Seemingly, much higher than predicted rates
- But, you can easily imagine the true rates being lower
  - Add grain structure



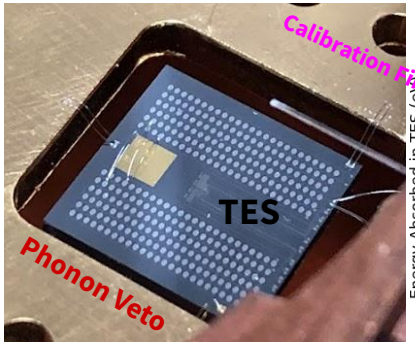
Takeaways

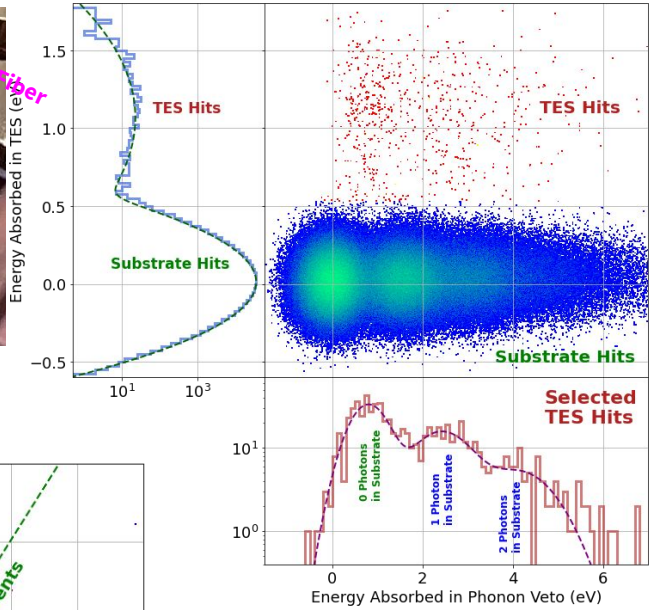
- Look for and fit 1/t rate vs. time relationships
- Think carefully about aluminum in our experiments
  - Almost everyone uses aluminum: JJs, phonon collectors, resonators, wiring…
- Try to understand/control film properties: dislocation density, grain size at interface…
- More broadly: think about how other films relax
  - W for instance would relax in very different ways

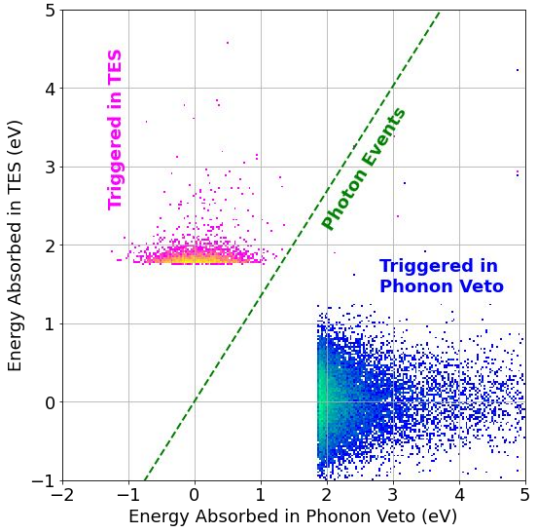


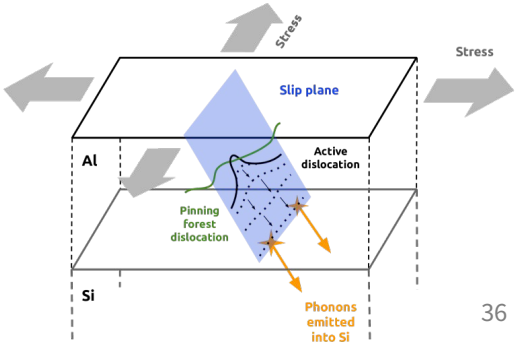
Conclusions

- Loophole free* test: **no phonon component of singles, no local component of shareds**
- **Singles not from optical/IR photons**
- Two remaining possibilities: **EMI bursts, relaxation**
- **Aluminum**: one source of shared LEE?





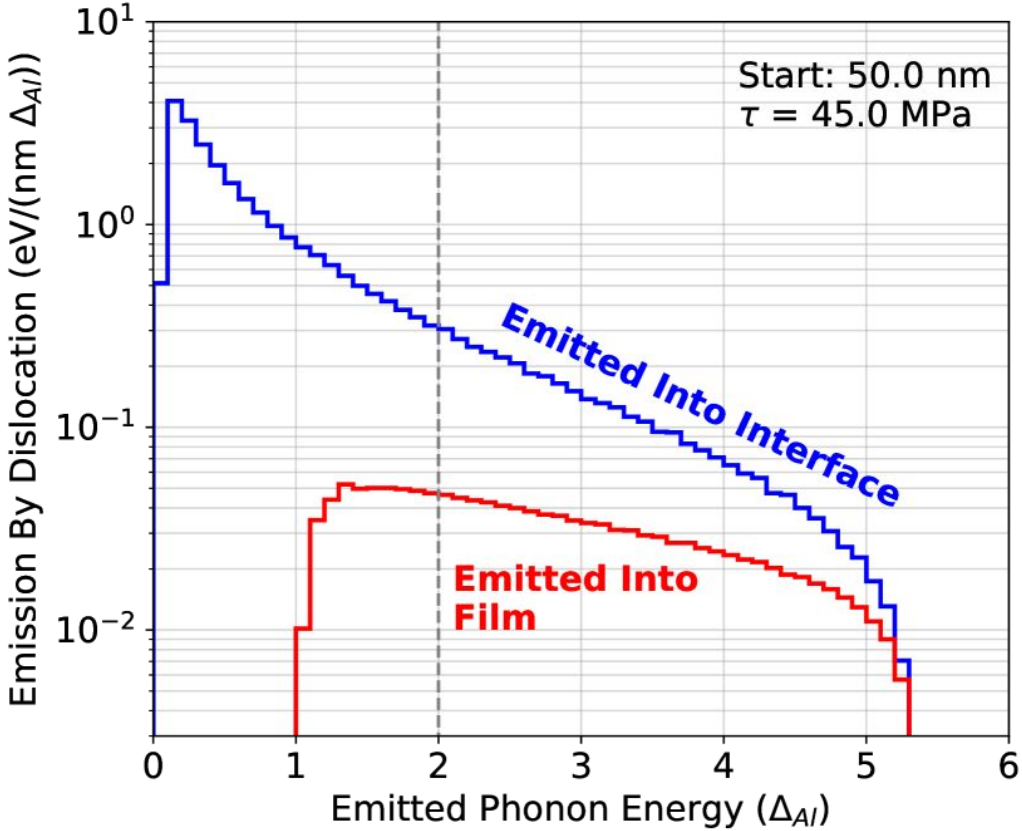




Backup: Phonon Emission

Almost all phonon energy emitted into crystal!

Consistent with shared phonon events



Backup: Energy and Fraction In Film