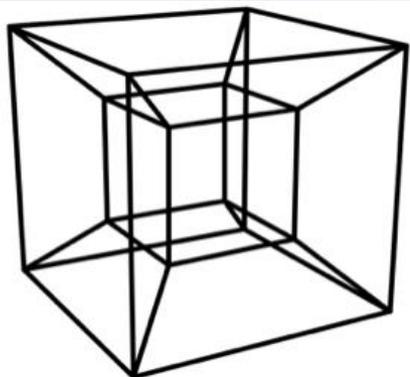
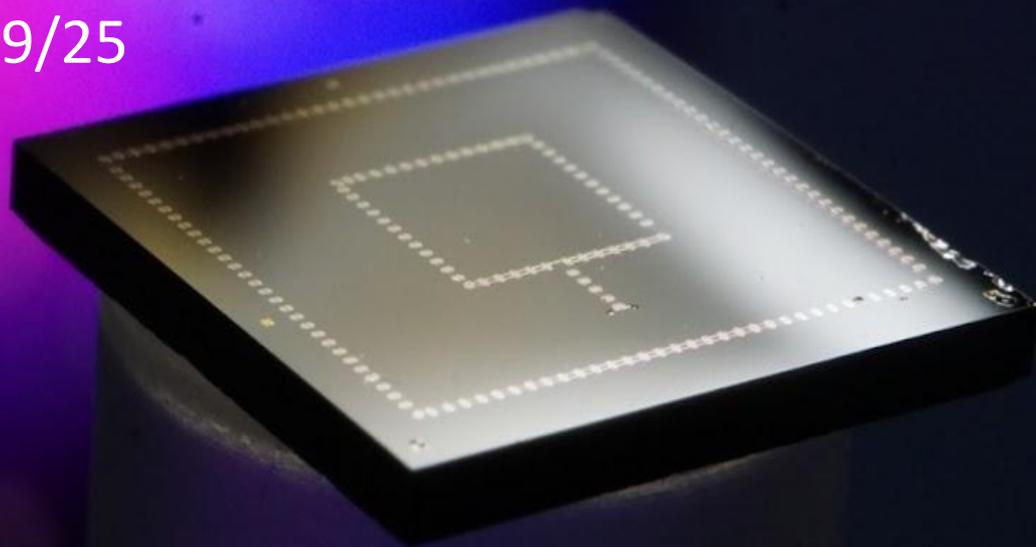


# Understanding the Origin of Non-Ionizing Phonon Bursts seen in Phonon Calorimeters and Superconducting QUBITs

Matt Pyle  
UC Berkeley  
CPAD  
10/09/25



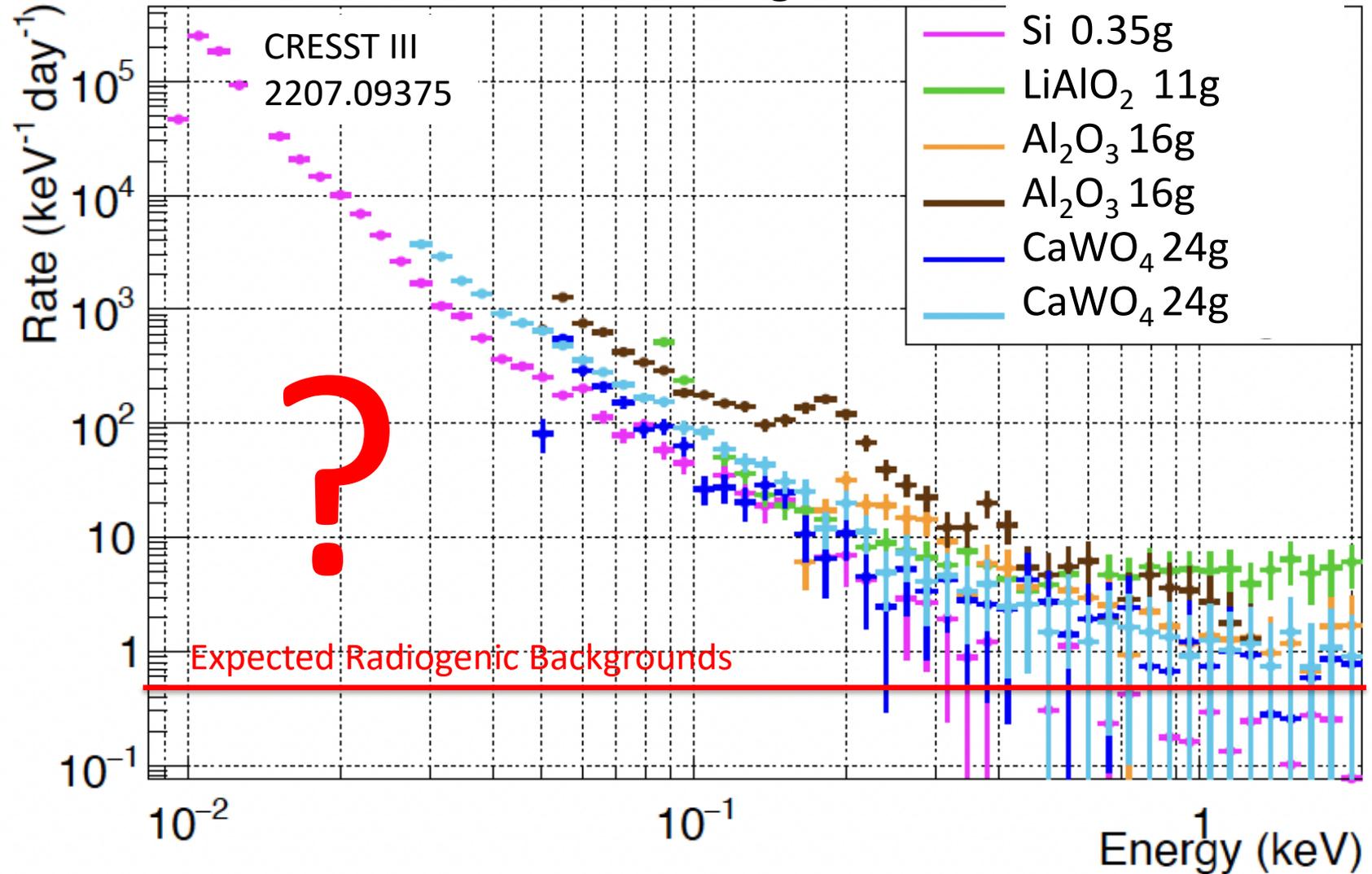
**TESSERACT**



2505.16092v3

# Mysterious Low Energy Excess

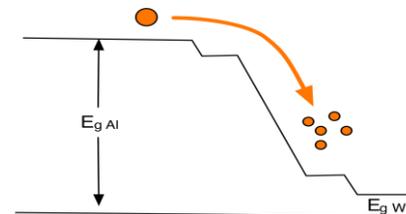
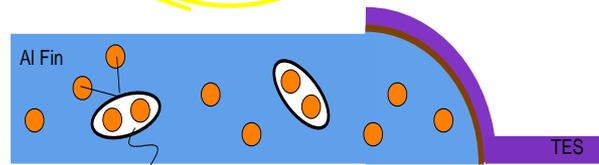
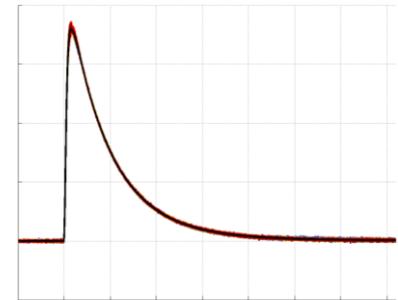
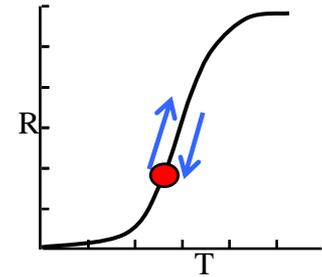
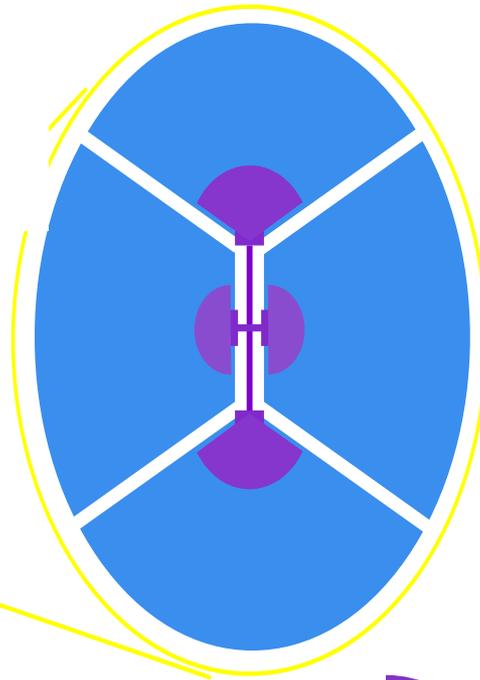
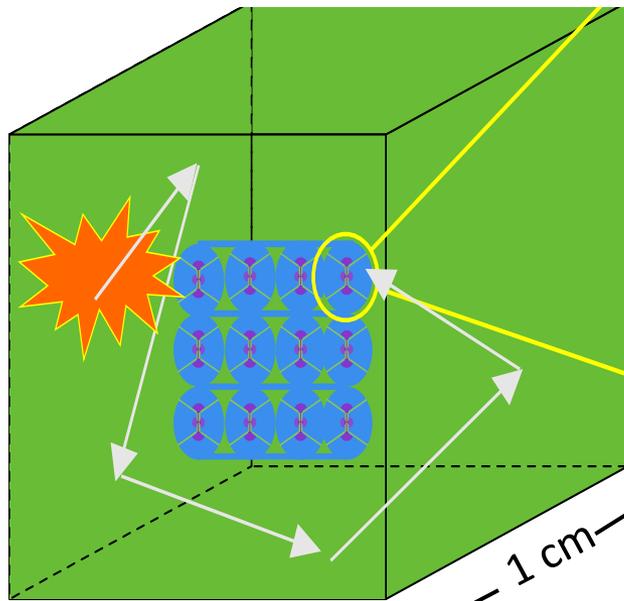
## CRESSTIII Background Studies



Seen in all calorimeter experiments to varying degree

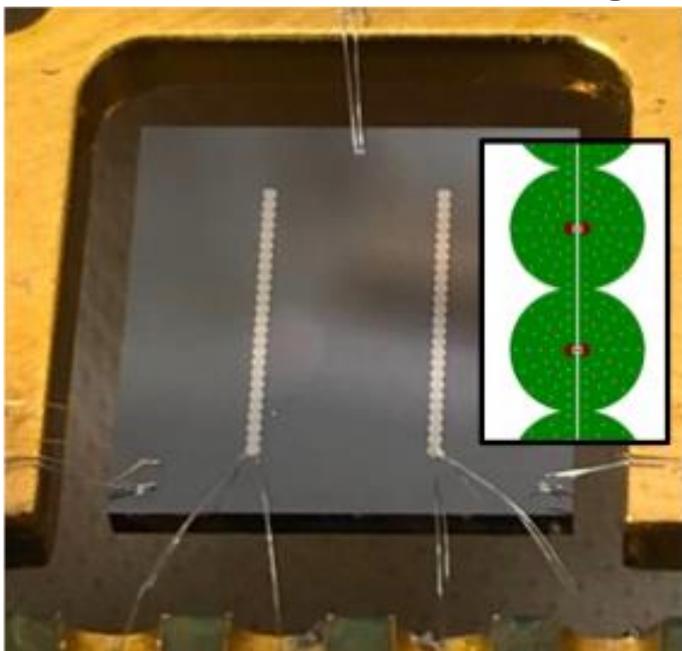
# Athermal Phonon Detectors

- TES (W or IrPt)
- Athermal Phonon Collection Fins (Al)
- Substrate (Si, Ge, GaAs, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>)

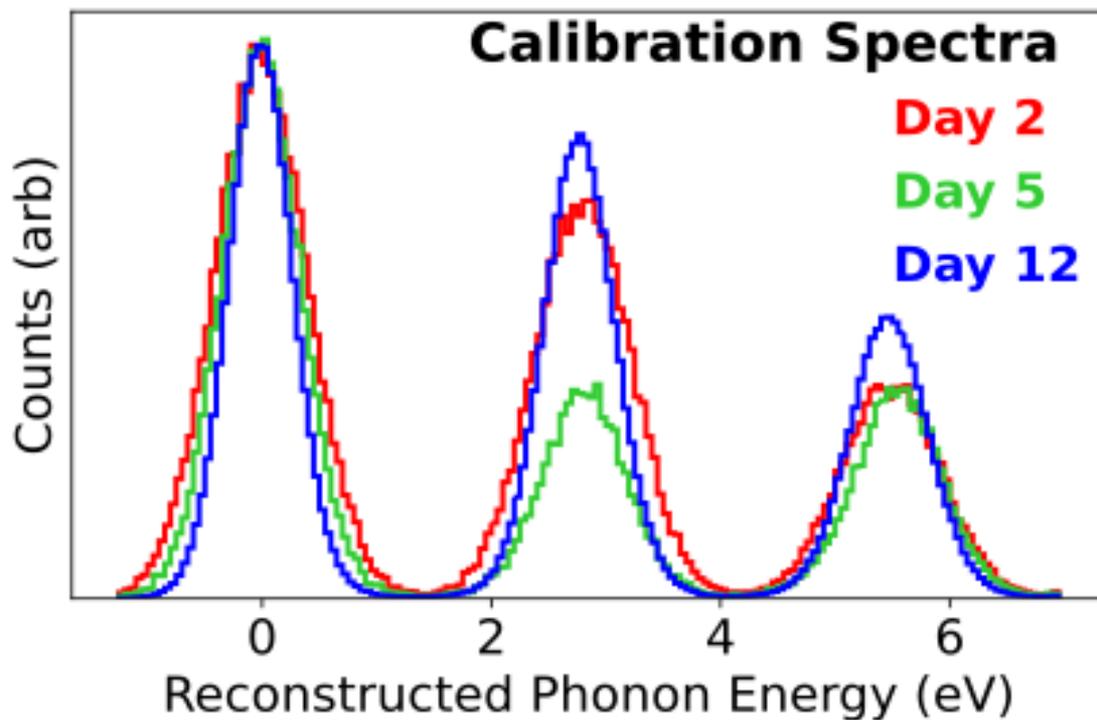


# Measured Phonon Collection Efficiency

1cm<sup>2</sup>x1mm Silicon 1% coverage

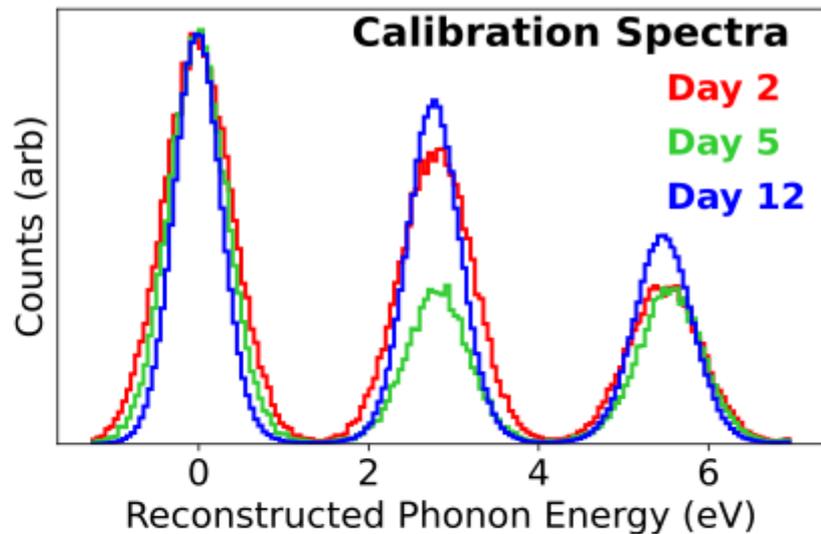
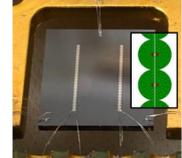


- Phonon detectors optimized for maximum phonon collection / energy sensitivity



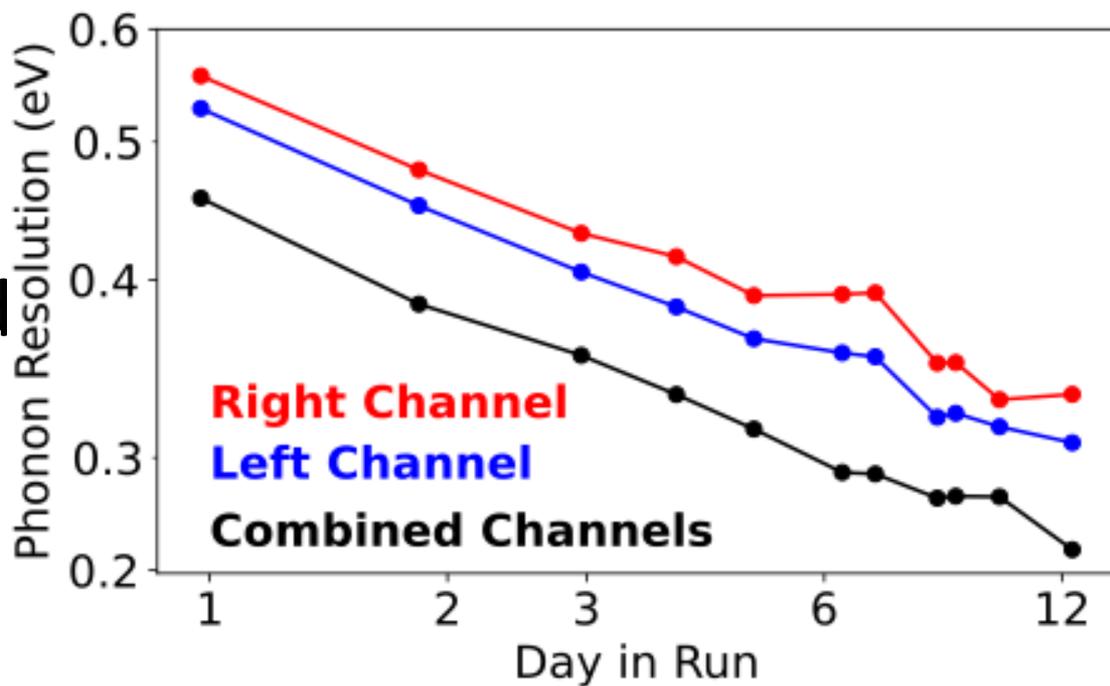
- Single Photon Sensitivity!
- Easy to Calibrate with IR/Optical Photons

# Current Performance: Sensitivity



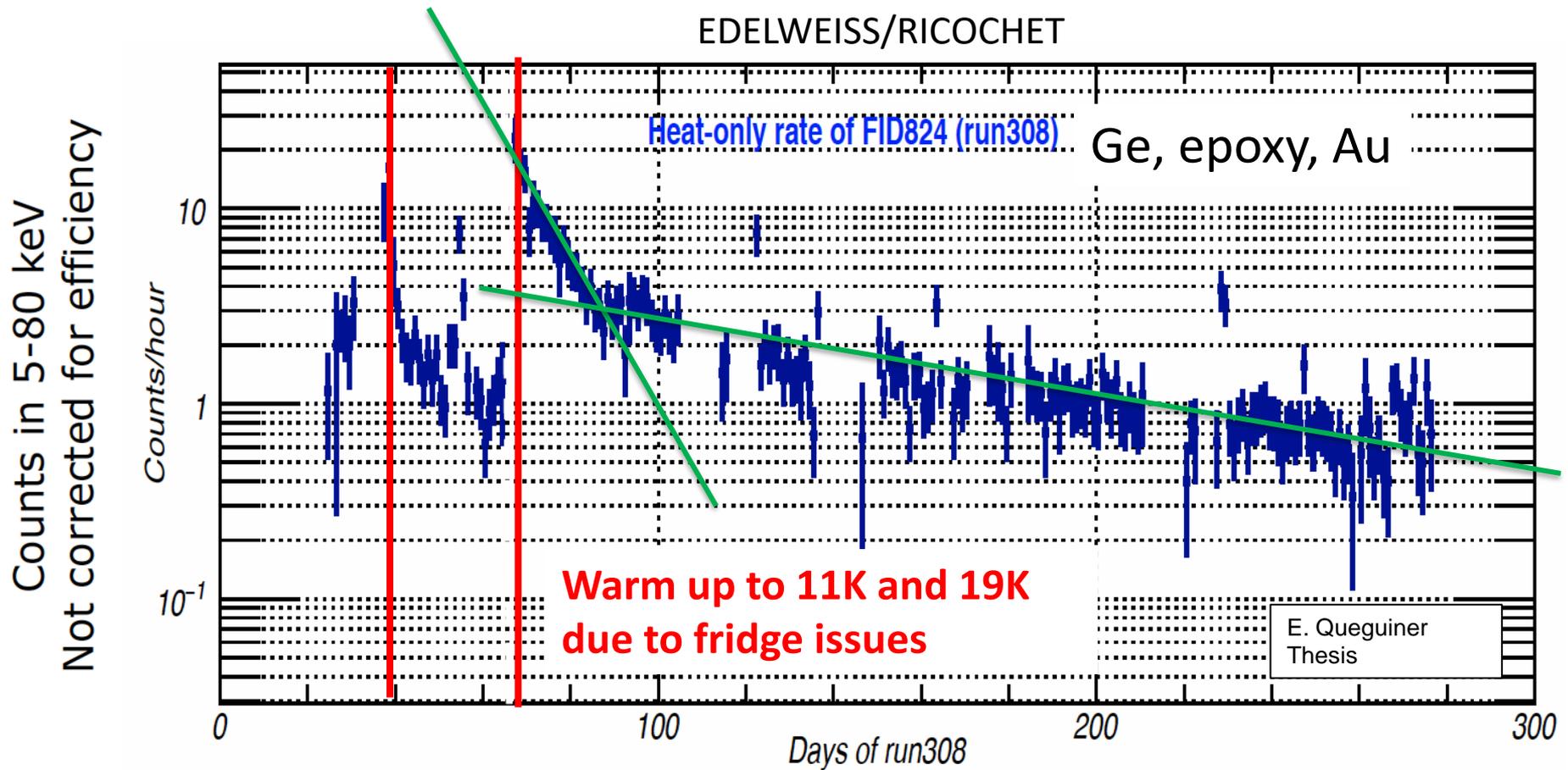
On Day 12, Phonon baseline energy resolution is  $259\text{meV}_{\text{rms}}$

Sensitivity continues to improve pretty rapidly with time cold ...  $231\text{meV}_{\text{rms}}$  at day 10 on a newer device



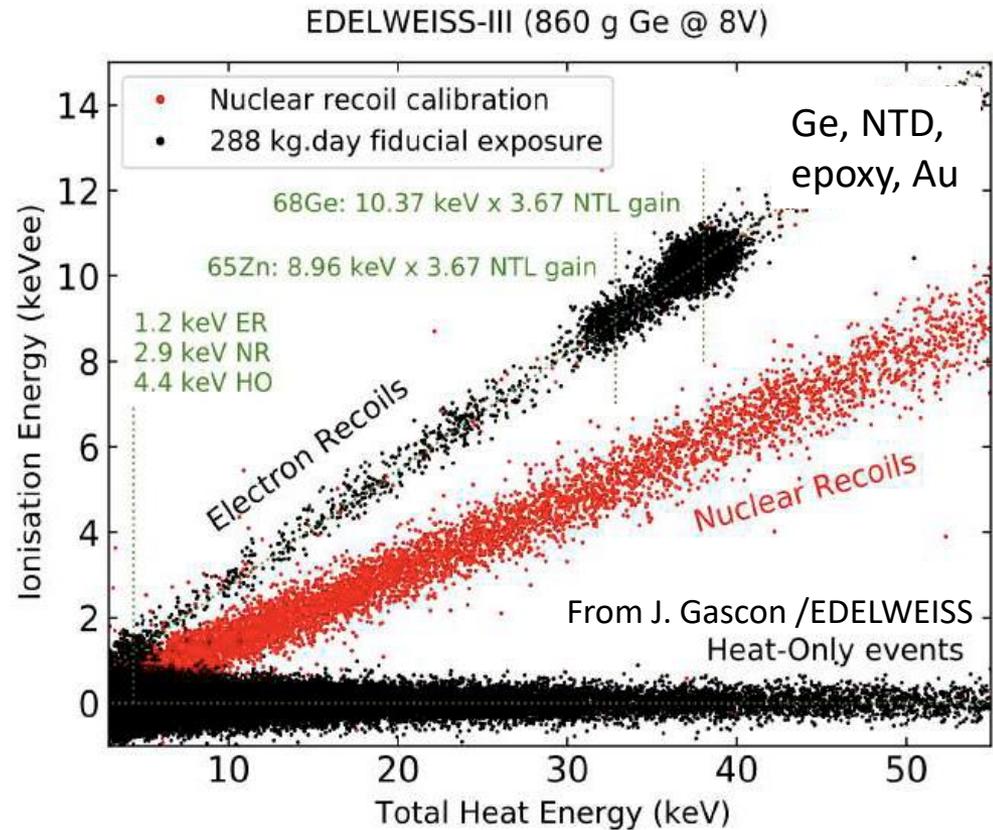
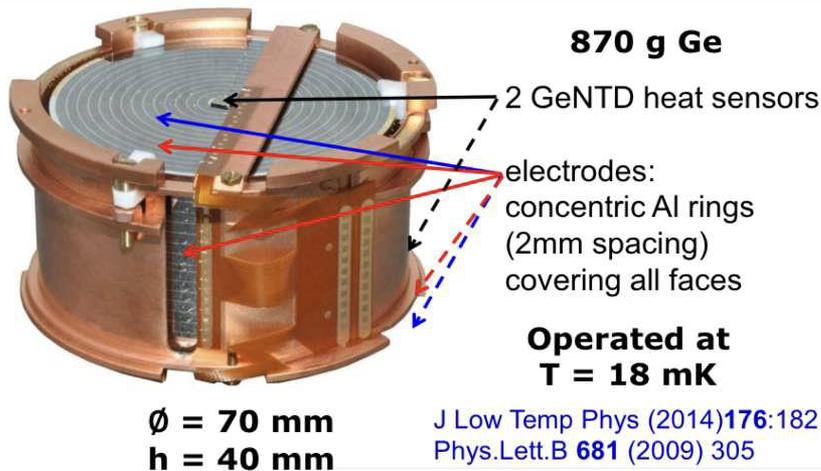
# Unexplained Low Energy Excess (LEE) Background(s)

# 1. Variation with time since cooldown



- Rate partially reset with thermal cycling
- 2 distinctive decay time constants

## 2) Low Energy Excess is Non-Ionizing



- EDELWEISS interleaved detectors measure both phonons (NTD) and ionization production
- Large no ionization background of unknown origin out to pretty high energies

# Low Energy Excess Fact Summary

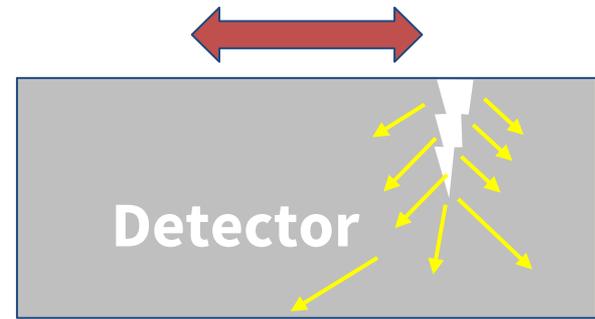
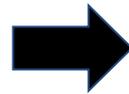
	SPICE/CDMS	EDELWEISS	CRESST
1) Variation with time since cooldown (and/or time since fabrication)	Yes	Yes	Yes
2) Non-Ionizing	Yes	Yes	

These facts are incredibly restrictive!

# Stress Relaxation?



Detector under stress due to thermal contraction, manufacturing, etc.

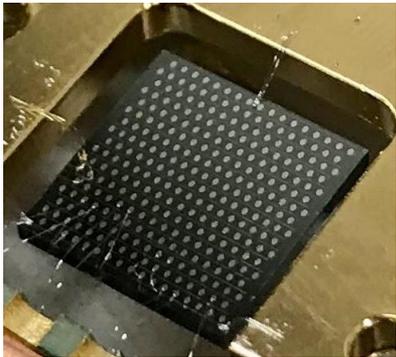


Detector relaxes releasing phonon energy

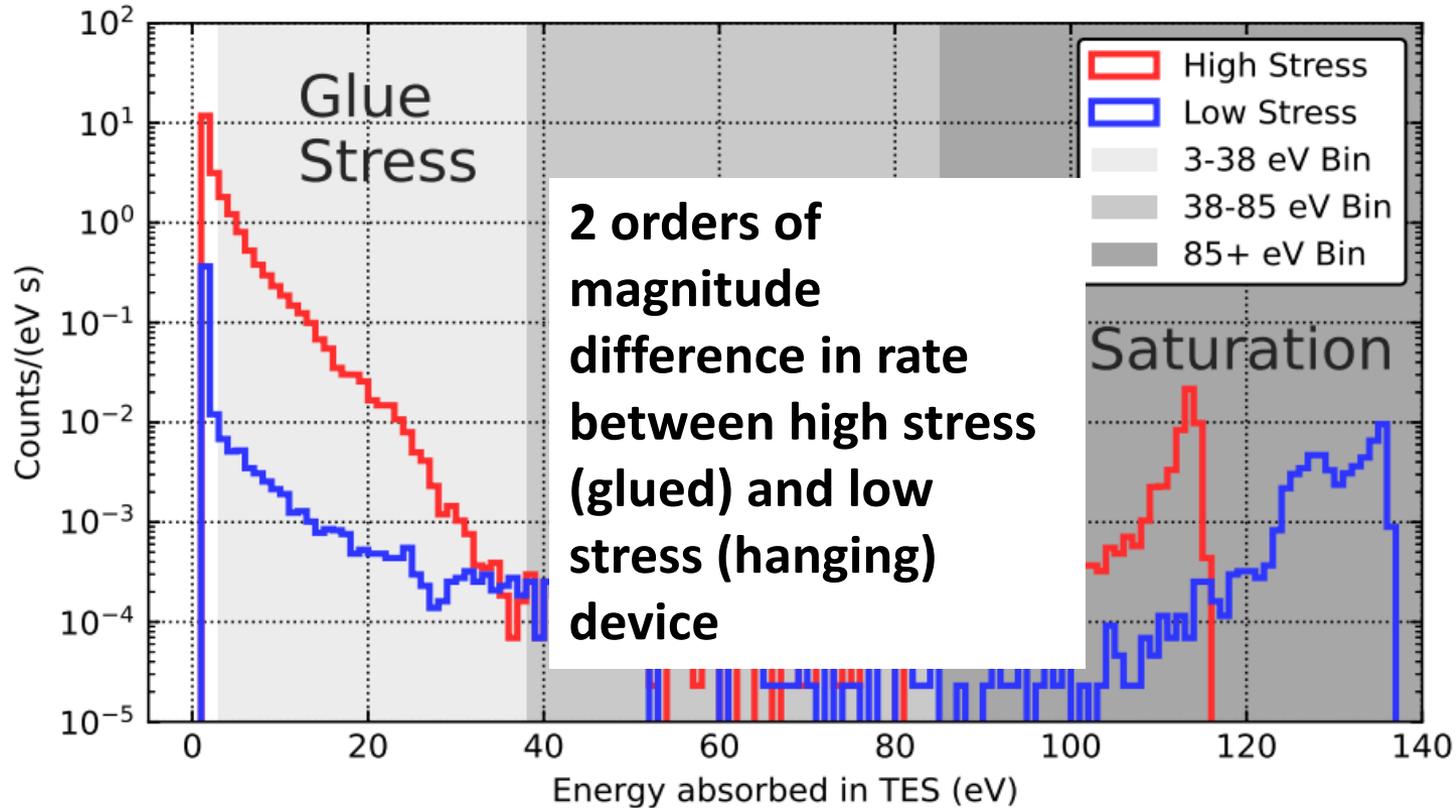
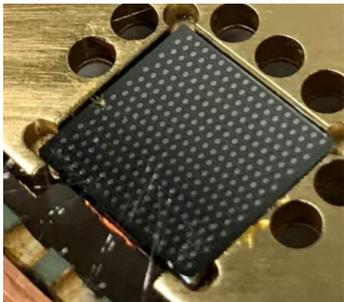
# Stress Related Relaxation: 1st Low Energy Evidence

2208.02790

Hanging (low stress)



Glued Down with GE varnish  
(High Stress)



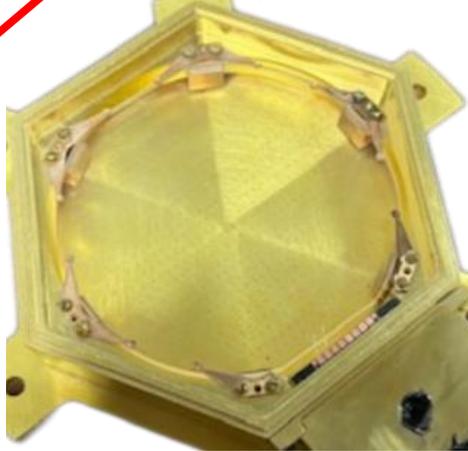
- GE varnish (and rubber cement) significantly increase <38eV backgrounds

# Best Structural Support?

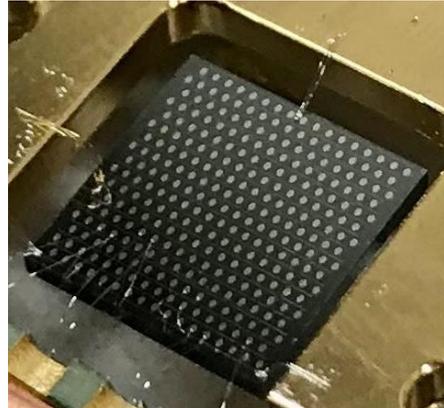
Glue



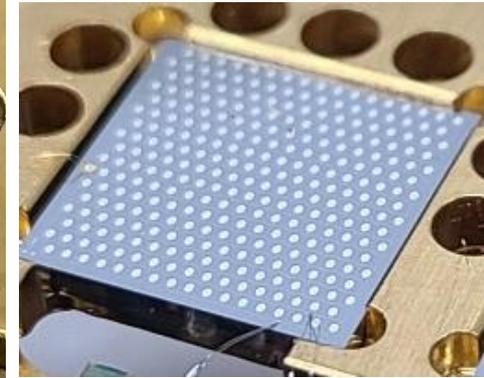
Clamp



Hanging (low stress)



Resting



- Just don't use glue, vacuum grease
- Different clamping schemes have vastly different vibrational requirements:
  - Clamp: frictional rubbing depends upon clamping force
  - Hanging: a natural spring-mass decoupler. Works great except for on-resonance environmental vibrations (paper sometime soon)
  - Resting: huge amounts of frictional rubbing without a vibrational decoupler, but seemingly lowest force
- Primary focus for TESSERACT is clamping/resting

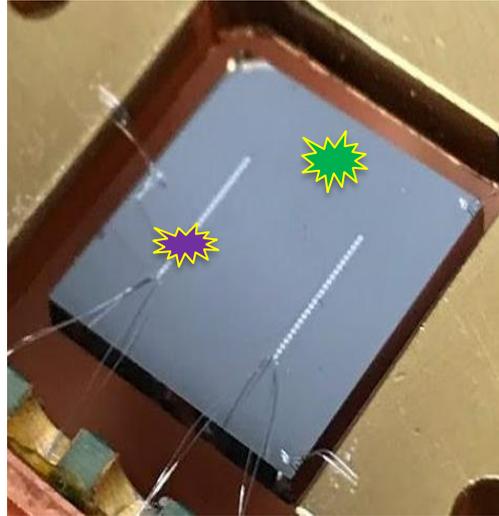
# Mitigation for Stress Relaxation Events:

**GET RID OF ALL STRESS**

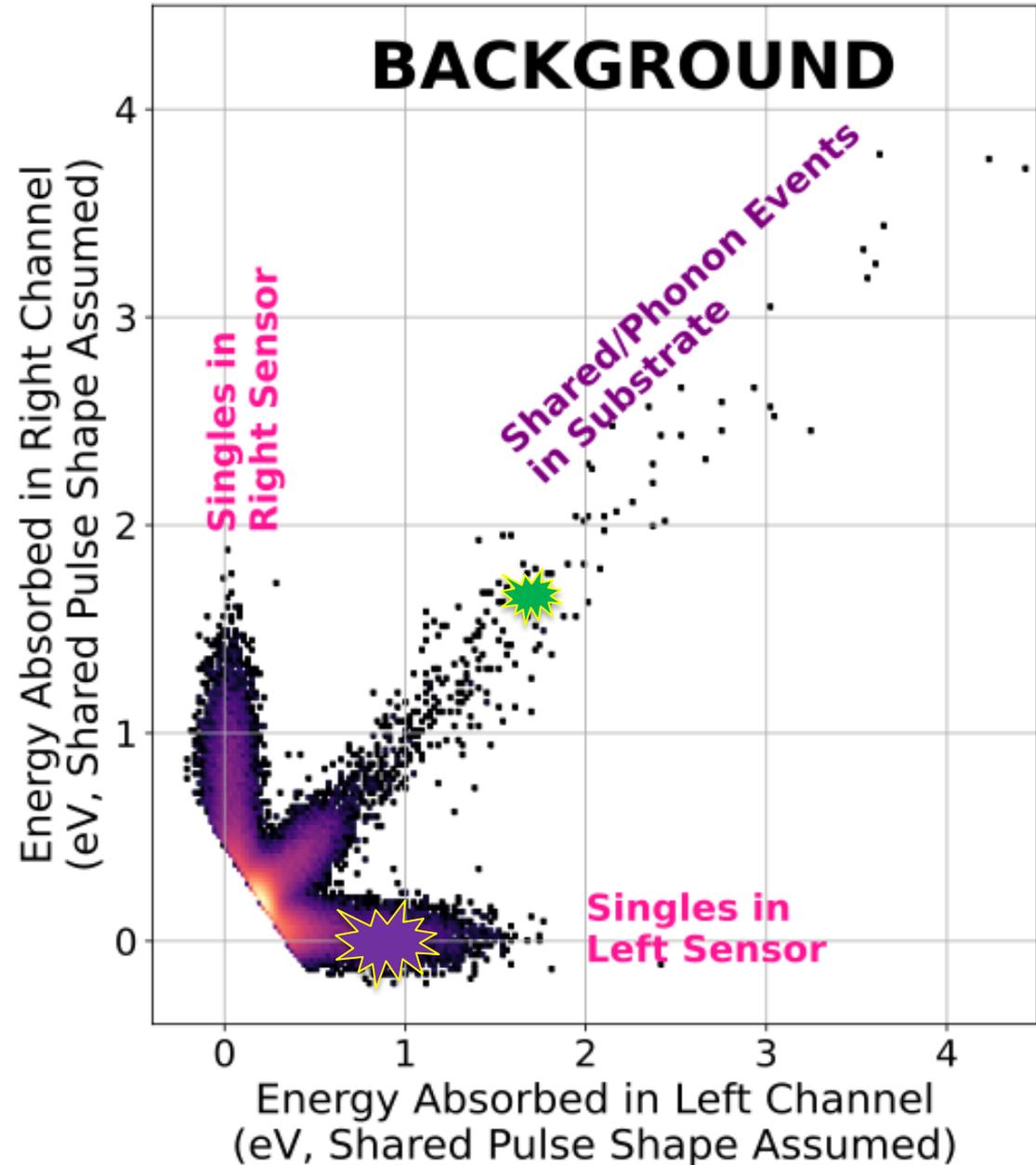
- ~~1. Support Structure~~
2. Sensor Films
3. Crystal Surface Relaxation
4. Bulk dislocation(s) relaxation

# Understanding Relaxation Events: 2 Channel Devices

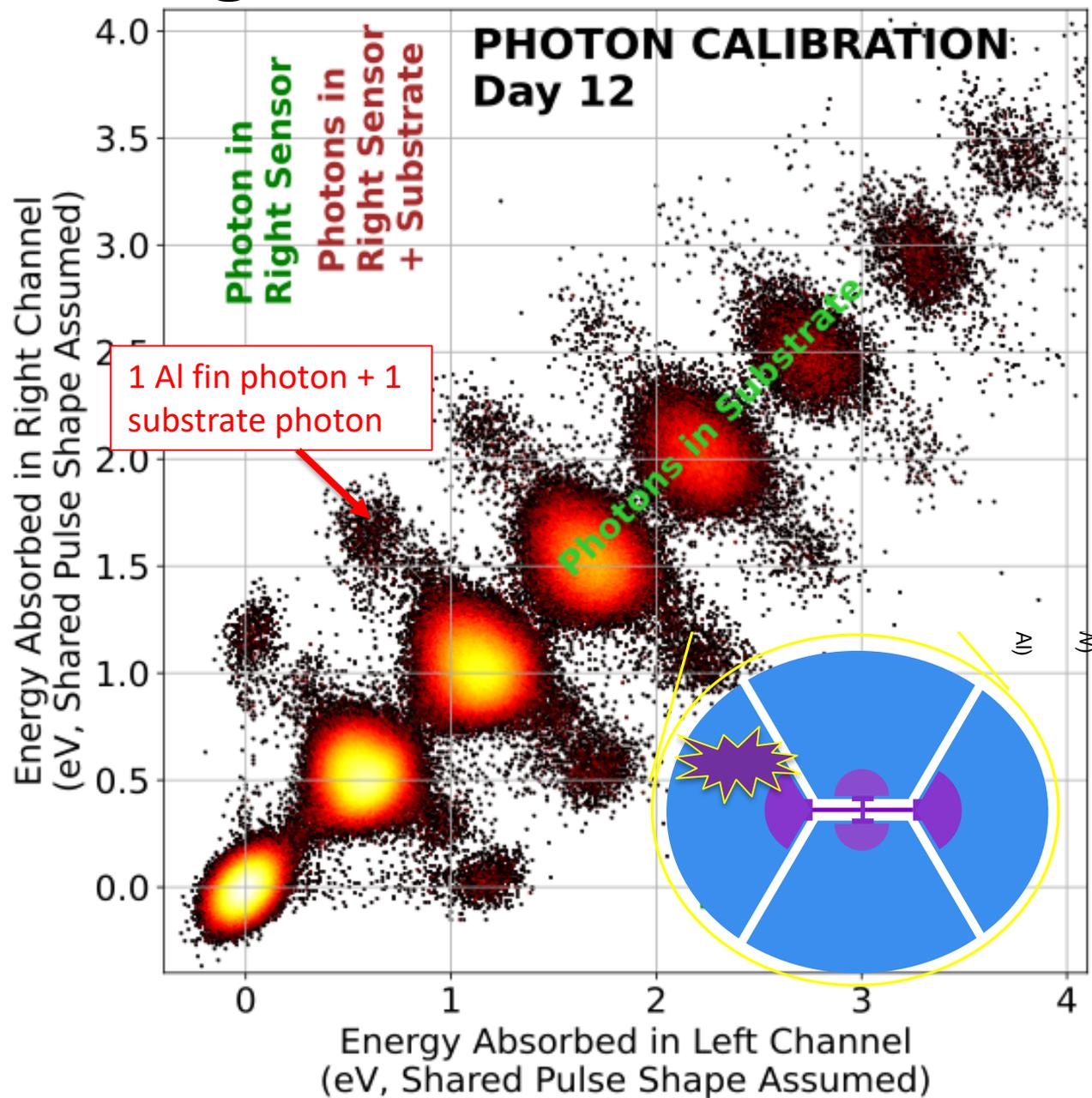
1% 2 Channel Device



We see both shared and single channel relaxation events

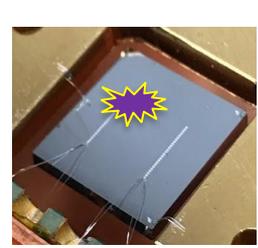


# Single Events in Photon Calibration too



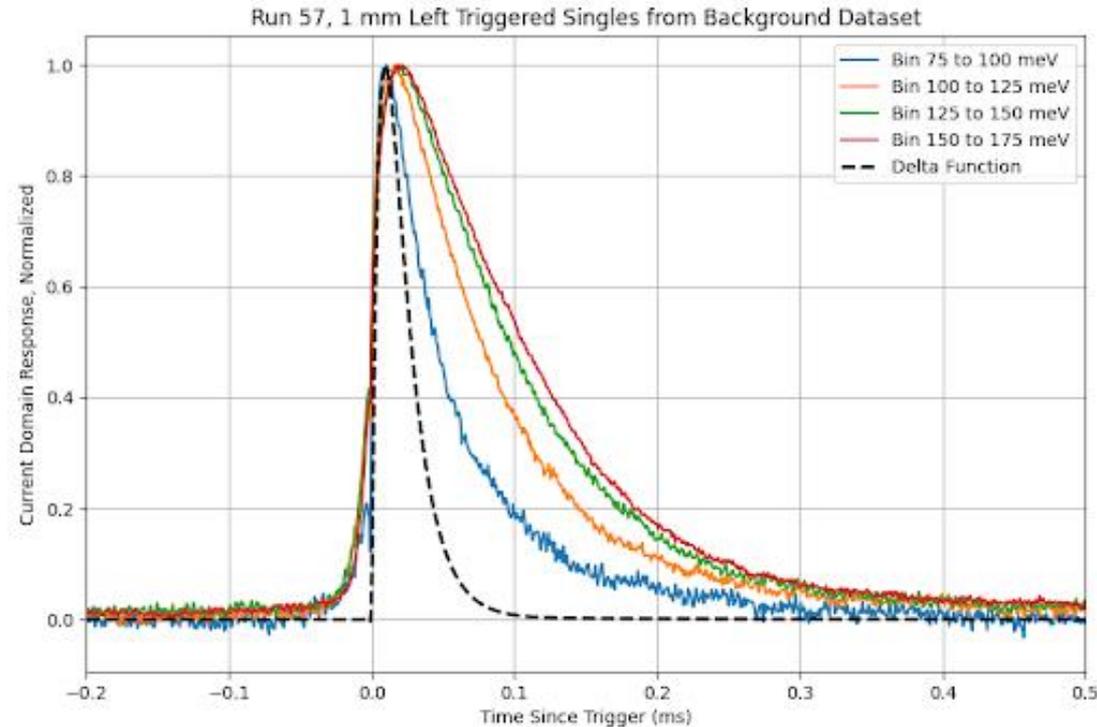
Calibration photons have single and shared events too!  
Shared = substrate absorption  
Singles = Al fin absorption

# Single Relaxation Event Pulse Shape



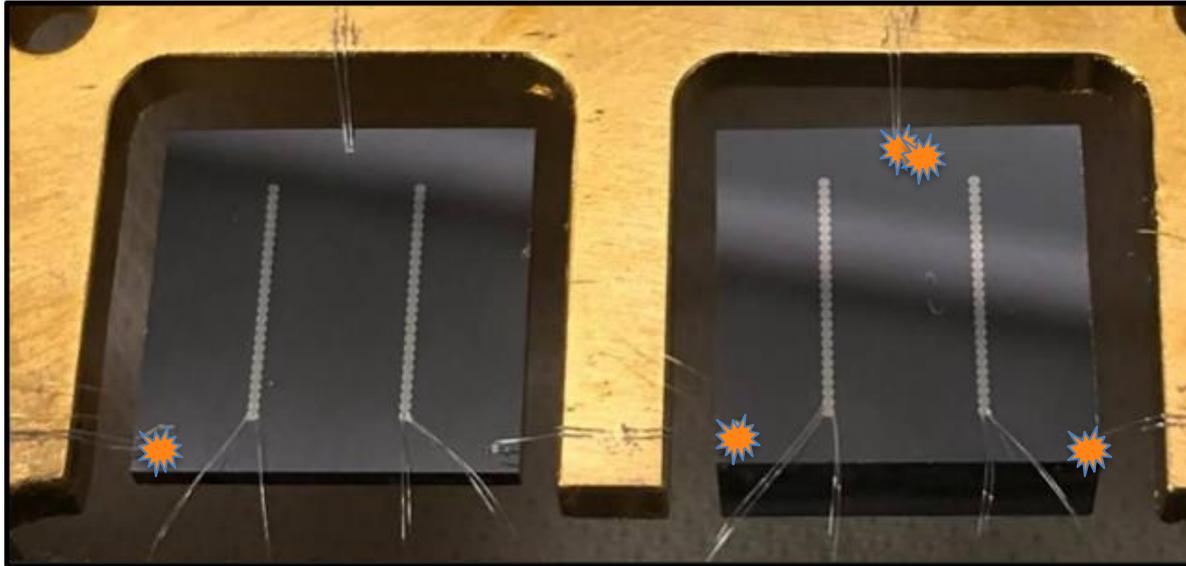
LEE single pulse shapes and Al fin calibrations photons have pulse shapes consistent with a dirac delta energy pulse that saturates a single phonon sensor in the channel

- As LEE energy drops, pulse shape looks more like a dirac-delta energy deposition (known from dIdV)



Single LEE background source is Al film relaxation!

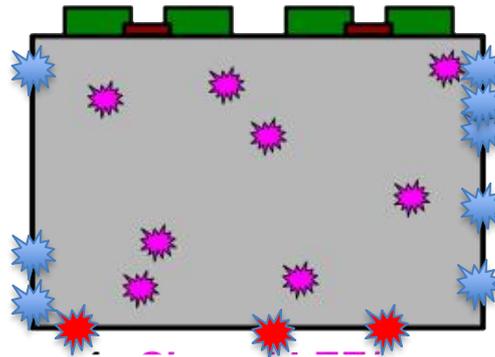
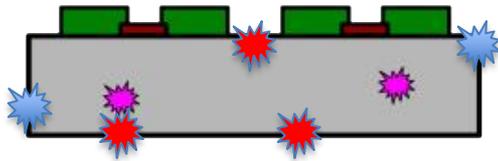
# Source Shared LEE Relaxation?



- Substrate Volume?
- Dicing Saw Sidewall Surface?
- Polished z face?
- Wirebond support interface?

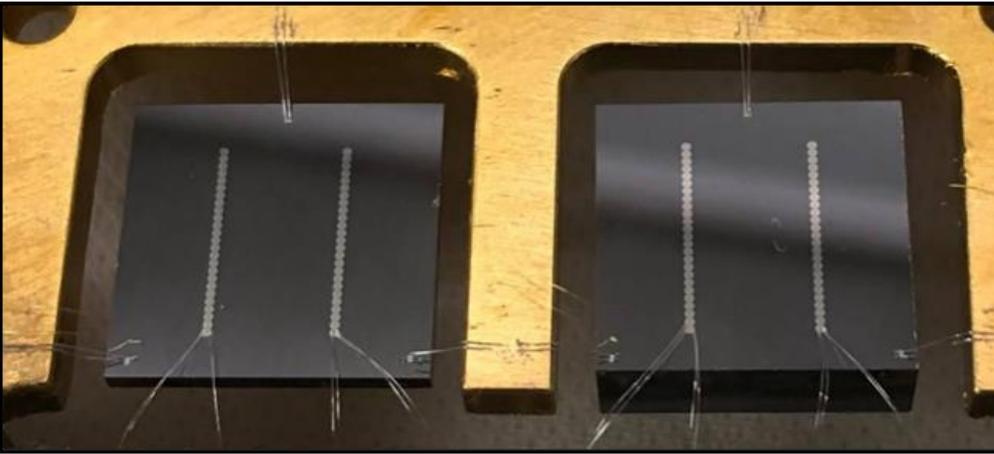
1 mm thick detector

4 mm thick detector



Test hypotheses with different substrate geometries

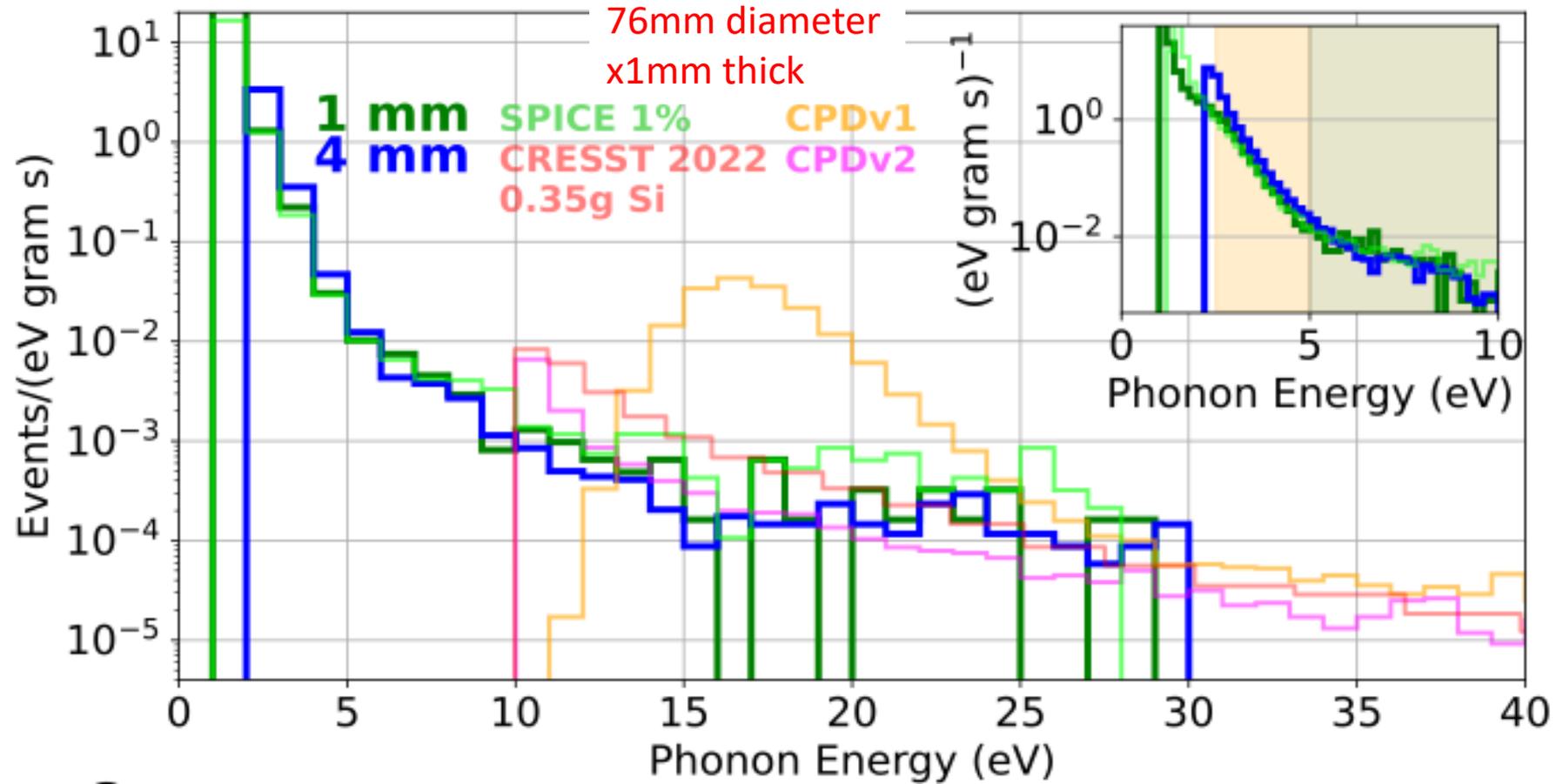
# Perfect A/B Test?



For a systematically clean measurement of LEE dependence on thickness, we must keep all other variables identical

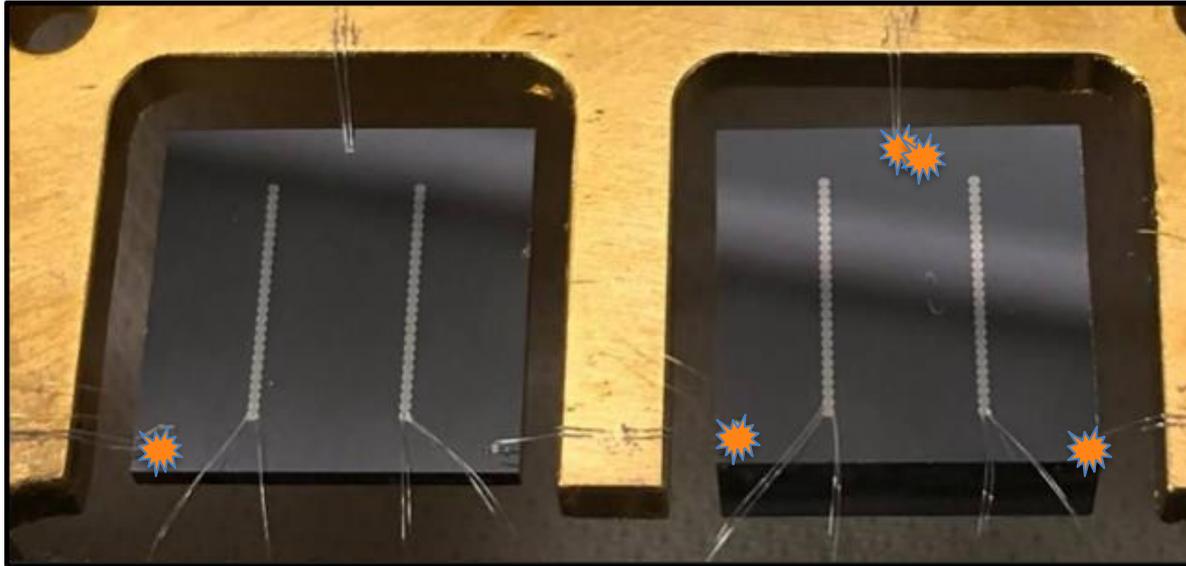
	Same	Differences
Design	identical	
Substrates	>20kOhm cm Intrinsic Si double side DSP	<ul style="list-style-type: none"><li>• Different Boules</li><li>• Baking times slightly different</li></ul>
Fabrication	Same SOP Texas A&M fabrication facility	Consecutive fabrication runs separated by 1 week
Dicing	Same vendor	Different blade thickness
Storage, Shipping	Identical	
Measurement	Same run/cooldown, nominally same electronics chain	Different vibration susceptibility

# Shared LEE Rate



Shared LEE scales with thickness

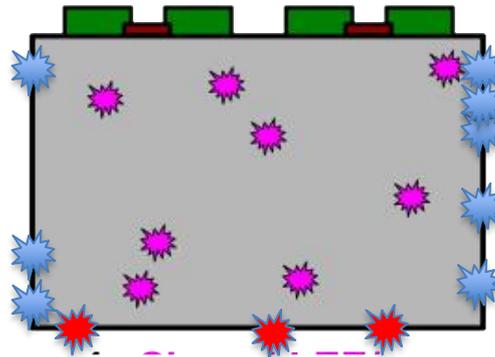
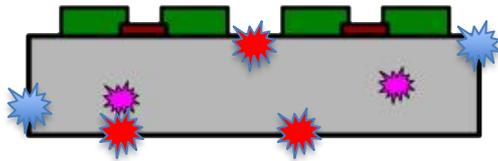
# Source Shared LEE Relaxation?



- Substrate Volume?
- Dicing Saw Sidewall Surface?
- ~~Polished z face?~~
- Wirebond support interface?

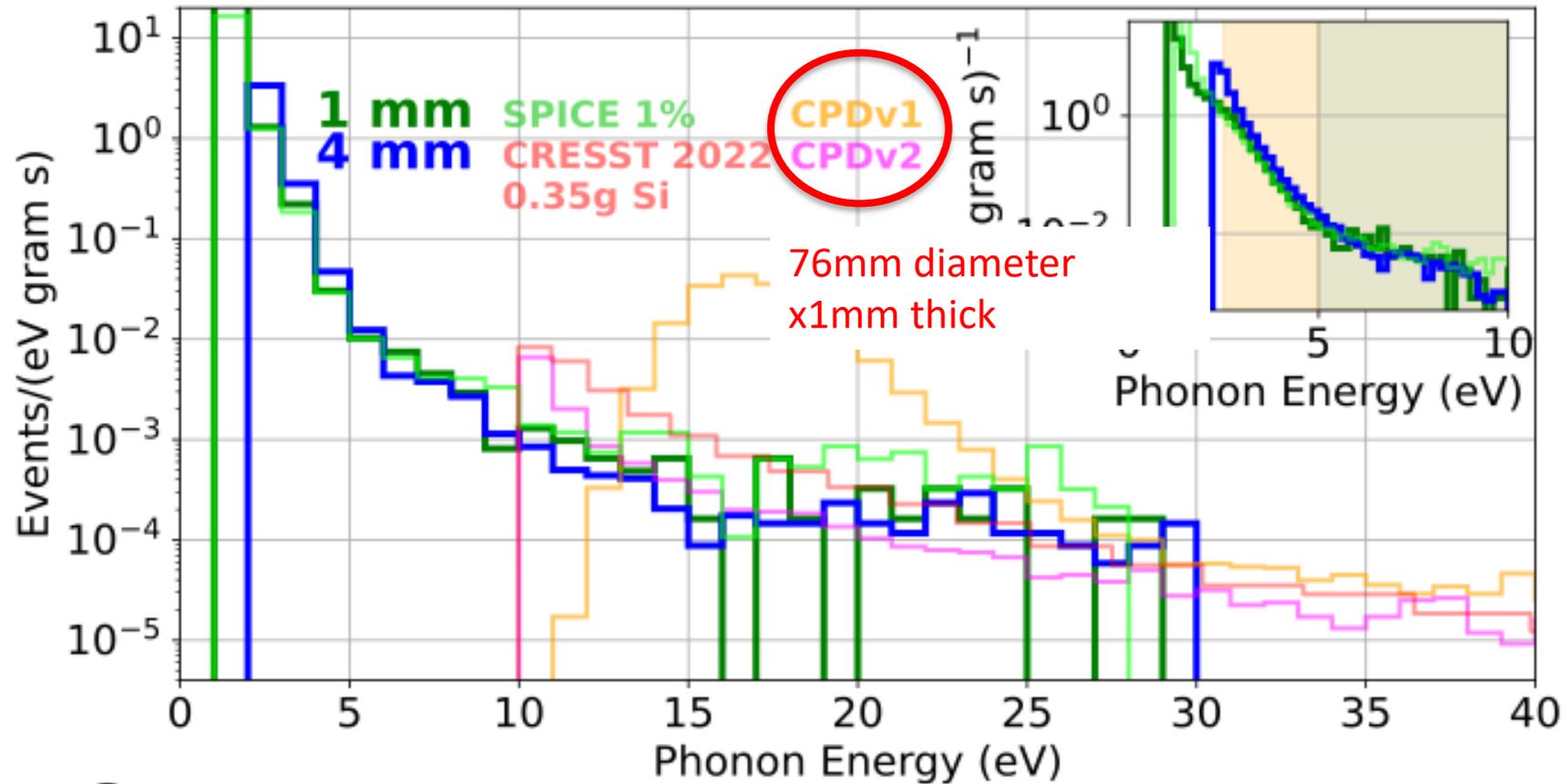
1 mm thick detector

4 mm thick detector



Shared LEE doesn't originate on the polished bare face

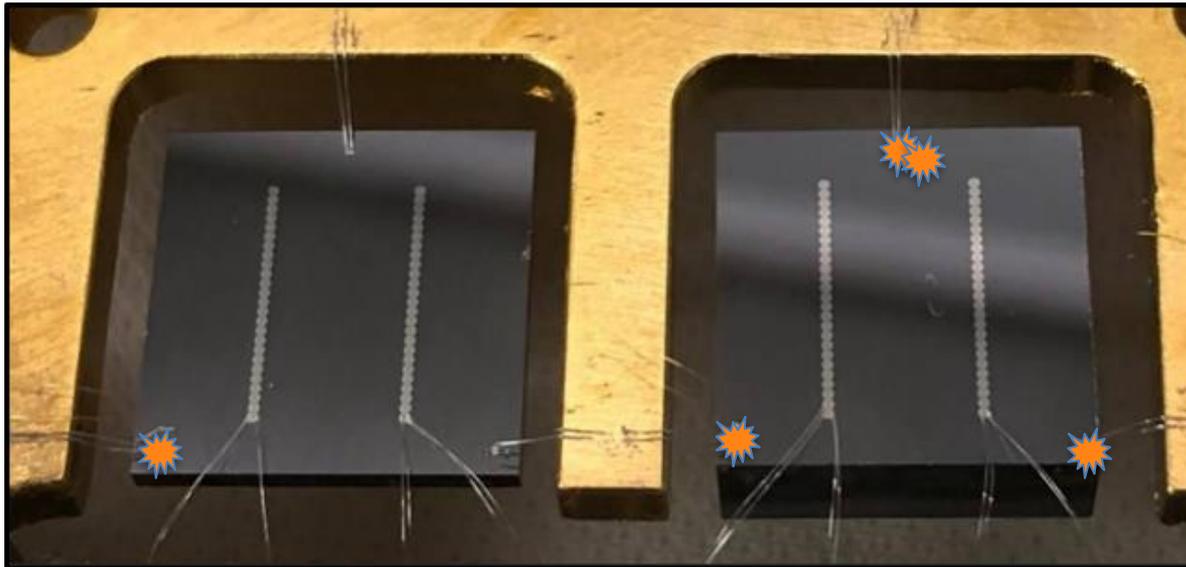
# Comparing to LEE of CPDs



CPDs have similar LEE when normalized by mass:

- x8 smaller sidewall/volume ratio
- clamped, not hung

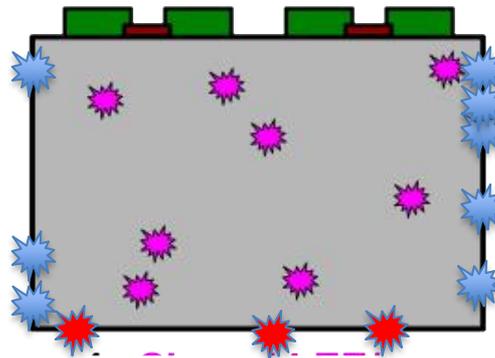
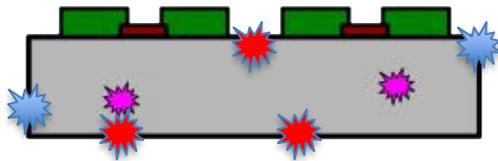
# Source Shared LEE Relaxation?



- Substrate Volume?
- ~~Dicing Saw Sidewall Surface?~~
- ~~Polished z face?~~
- ~~Wirebond support interface?~~

1 mm thick detector

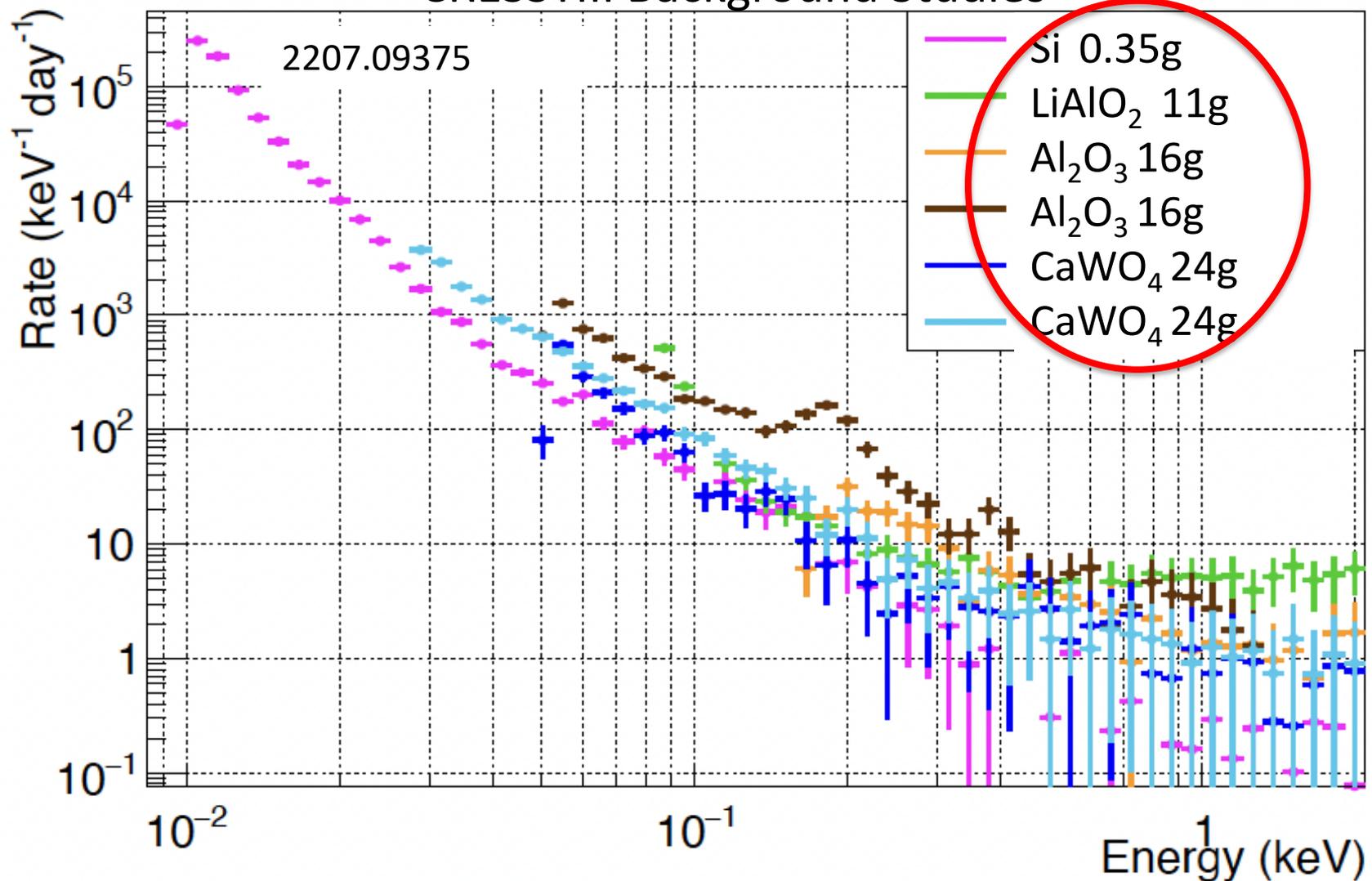
4 mm thick detector



CPD vs  $1\text{cm}^2$  comparison suggests that LEE is in the substrate volume ...  
but definitely not an ideal A/B test

# Tension with CRESST Measurements?

## CRESSTIII Background Studies

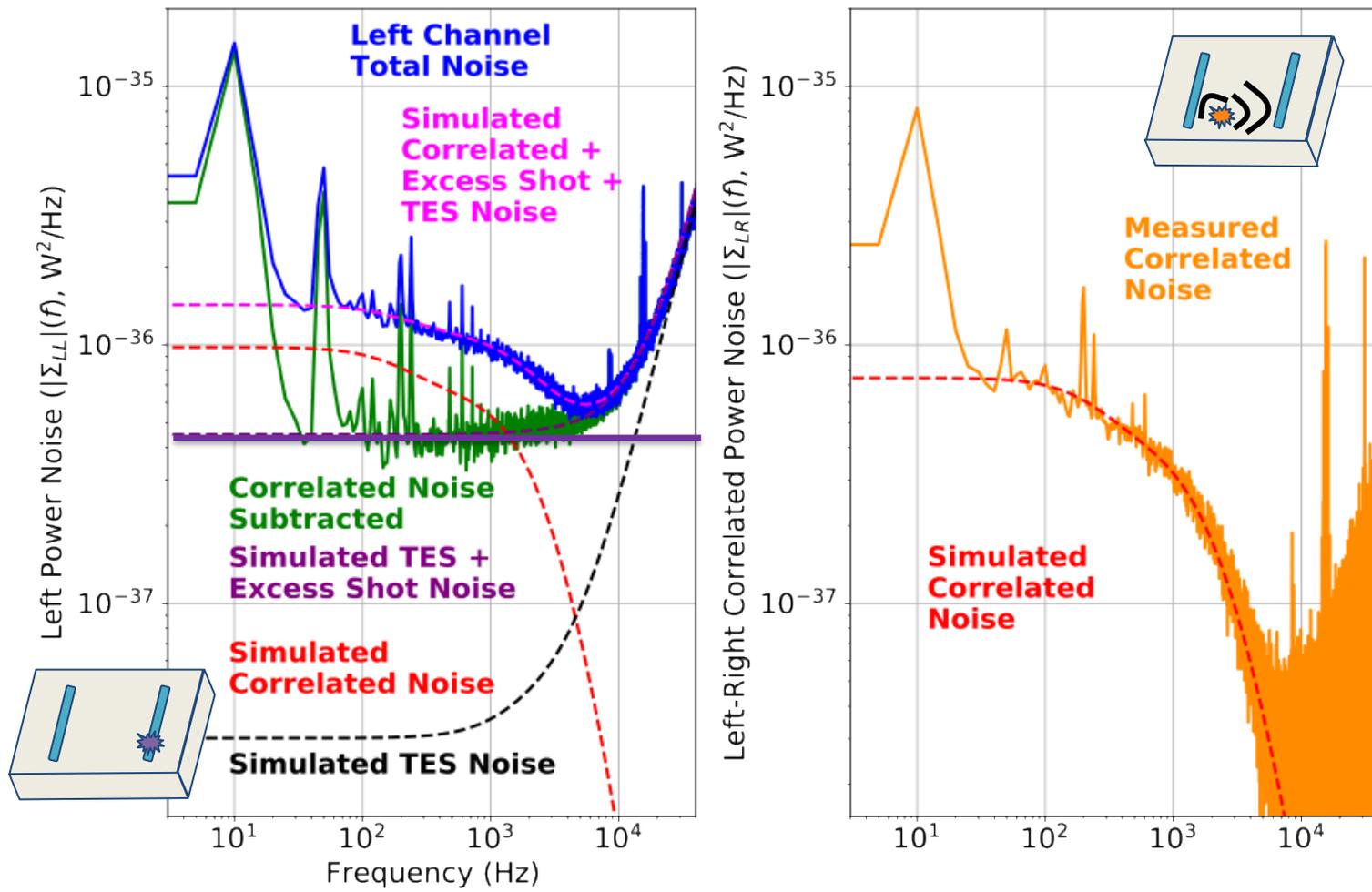


Noise

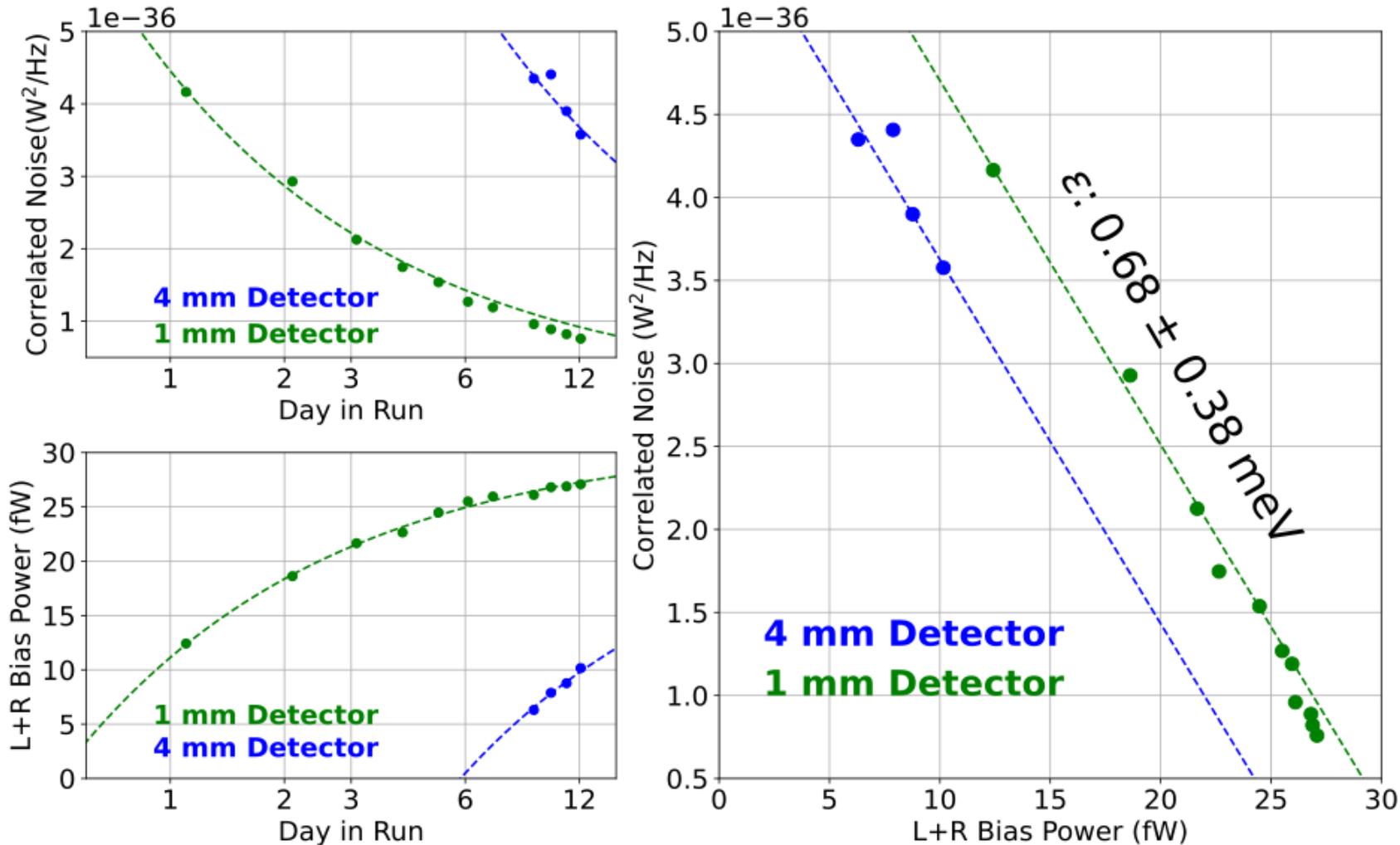
# Measured Noise

Excess nominated splits into 2 pieces:

- **Correlated noise whose pulse shape -> shot noise from substrate phonon events**
- **Uncorrelated white power noise -> shot noise from localized sensor events**



# Correlated Shot Noise vs Time



- Correlated shot noise scales with thickness
- Correlated Shot Noise and DC bias power have same time dependence ... same source?
- Correlated shot noise has different time dependence than above threshold shared LEE

# Summary

- LEE is **the** problem of light mass dark matter calorimeters
- Evidence that there is at least 3 sources of LEE
  - Al film relaxation (singles)
  - Above threshold shared LEE scales with substrate thickness. Comparison with CPDs suggests substrate volume origin
  - Below threshold shared LEE (different time dependence)
- Future:
  - new paper on LEE soon
  - Mostly concentrating on vibration mitigation and EMI mitigation for next 6 months