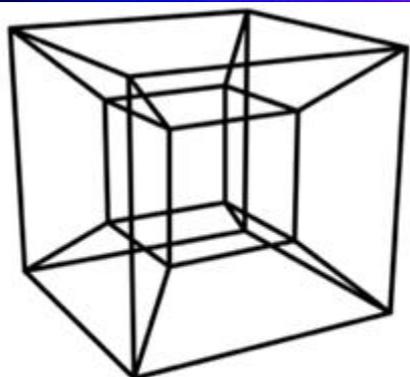
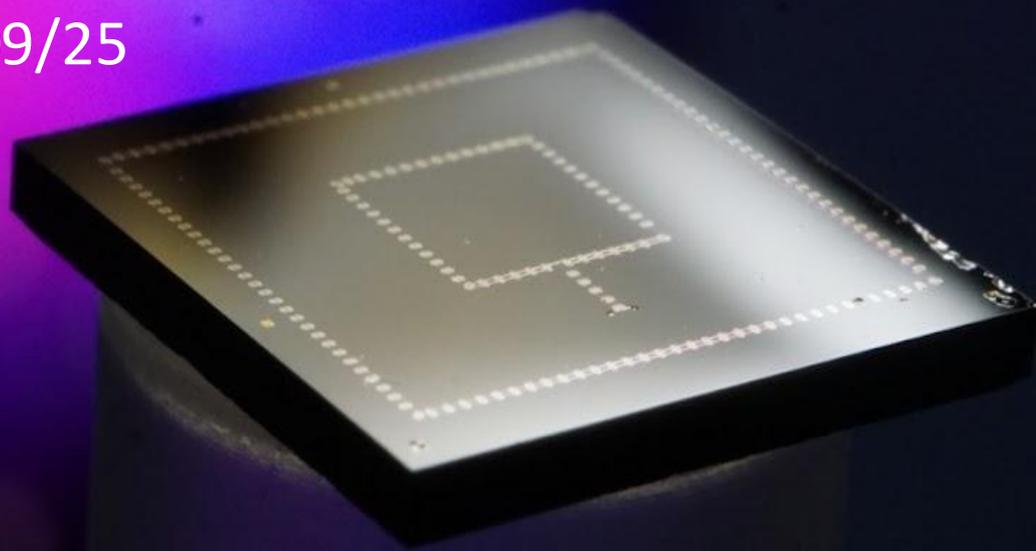


Understanding the Origin of Non-Ionizing Phonon Bursts seen in Phonon Calorimeters and Superconducting QUBITs

Matt Pyle
UC Berkeley
CPAD
10/09/25



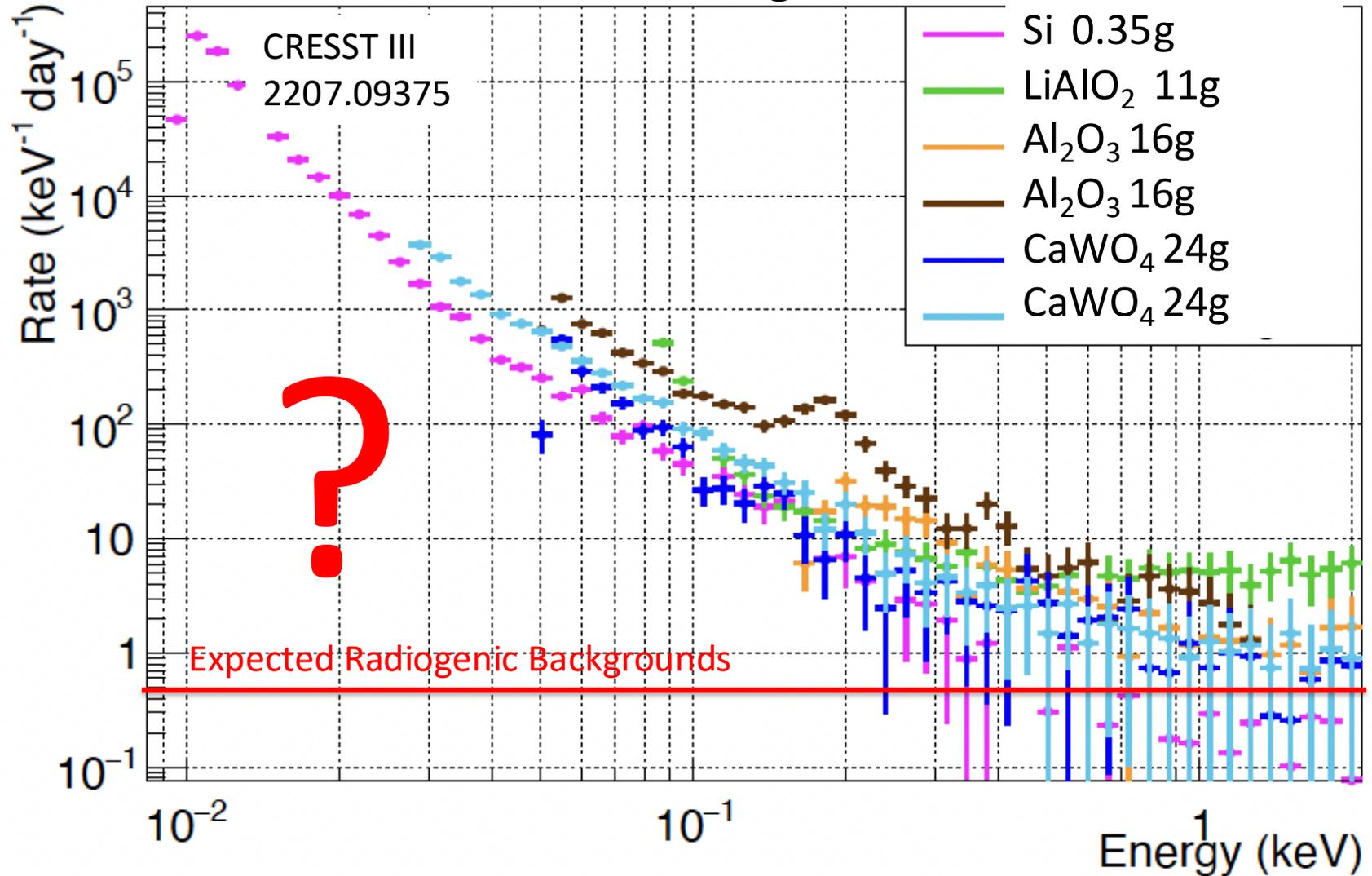
TESSERACT



2505.16092v3

Mysterious Low Energy Excess

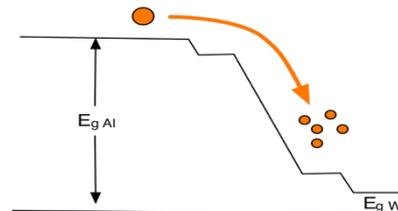
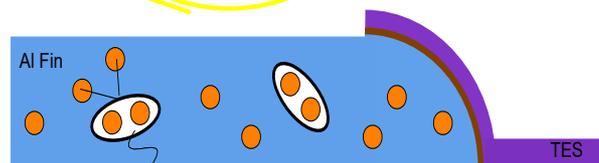
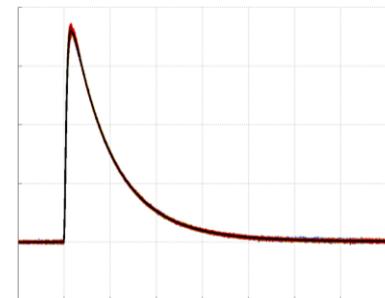
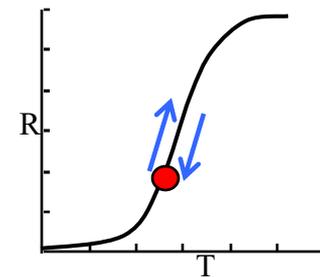
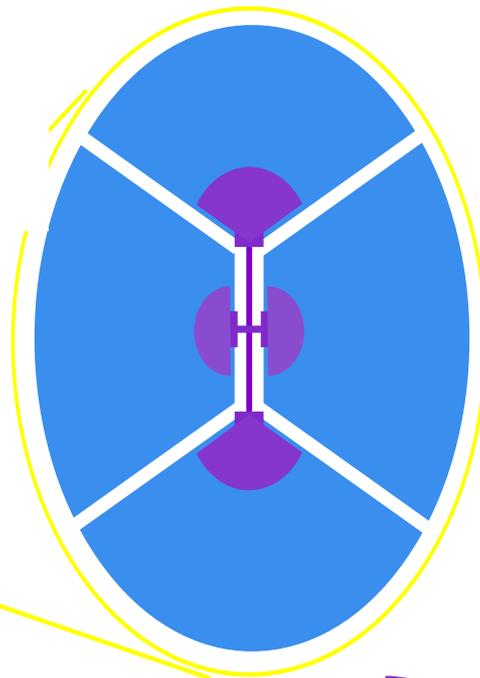
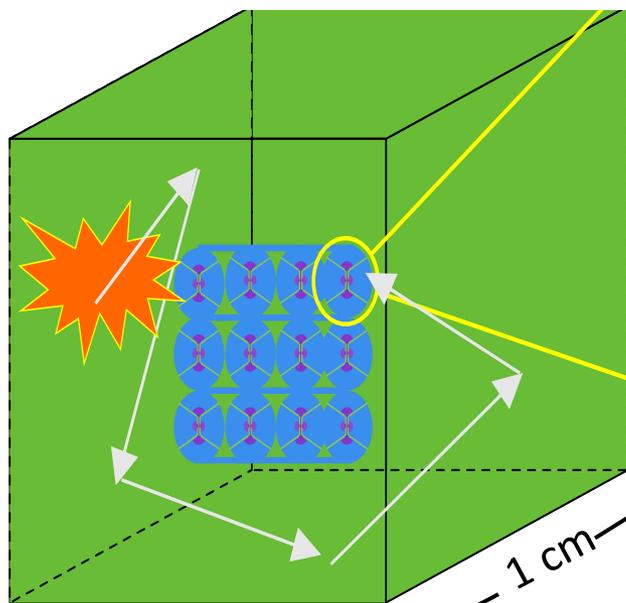
CRESSTIII Background Studies



Seen in all calorimeter experiments to varying degree

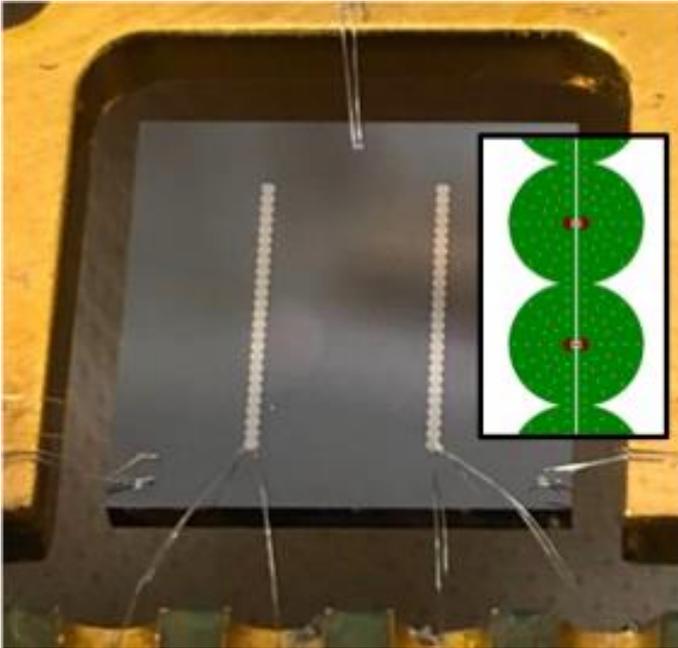
Athermal Phonon Detectors

- TES (W or IrPt)
- Athermal Phonon Collection Fins (Al)
- Substrate (Si, Ge, GaAs, SiO₂, Al₂O₃)



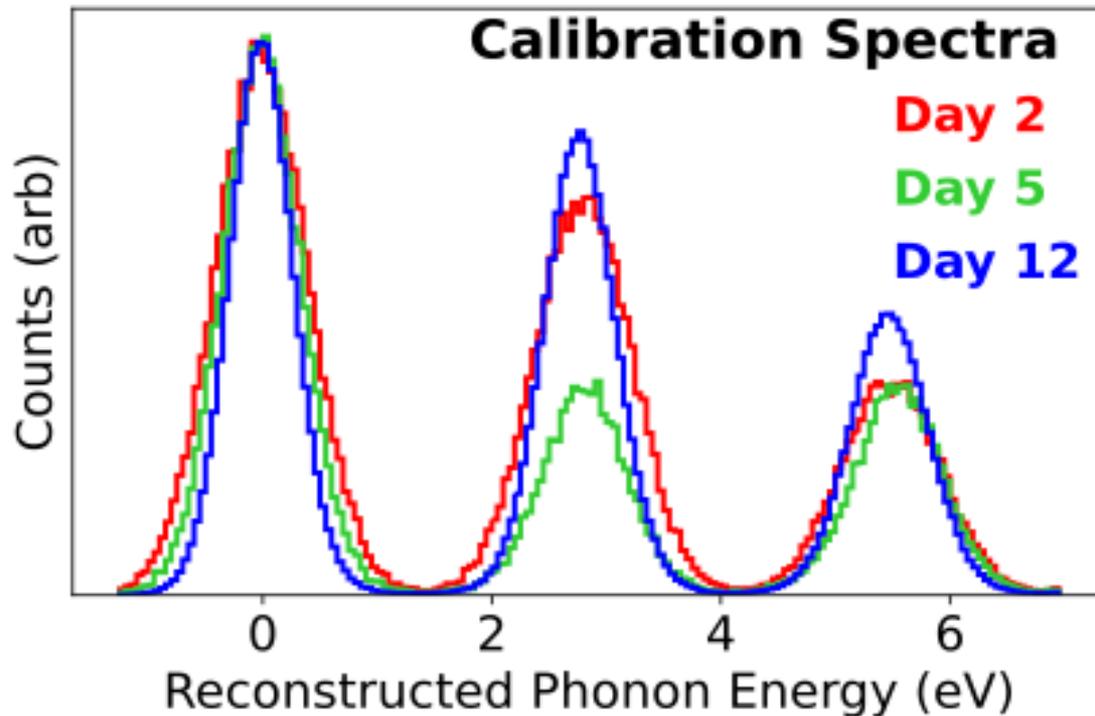
Measured Phonon Collection Efficiency

1cm²x1mm Silicon 1% coverage

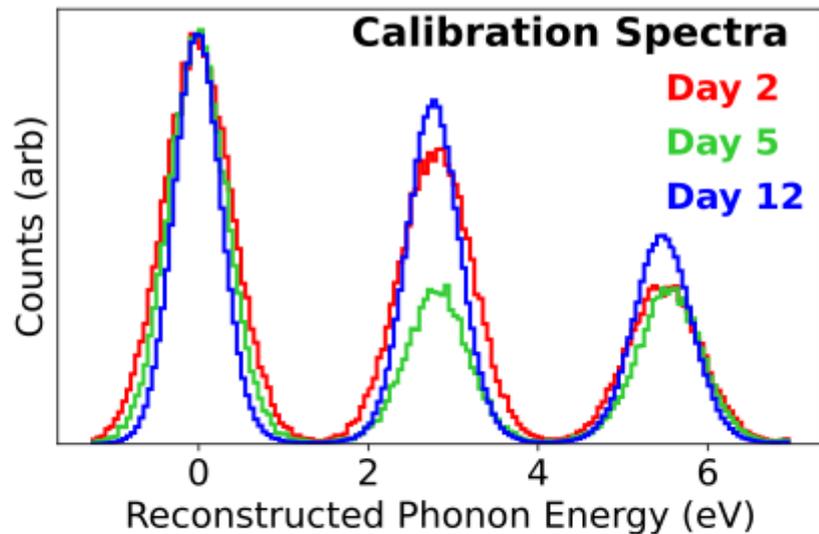
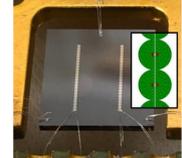


- Phonon detectors optimized for maximum phonon collection / energy sensitivity

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

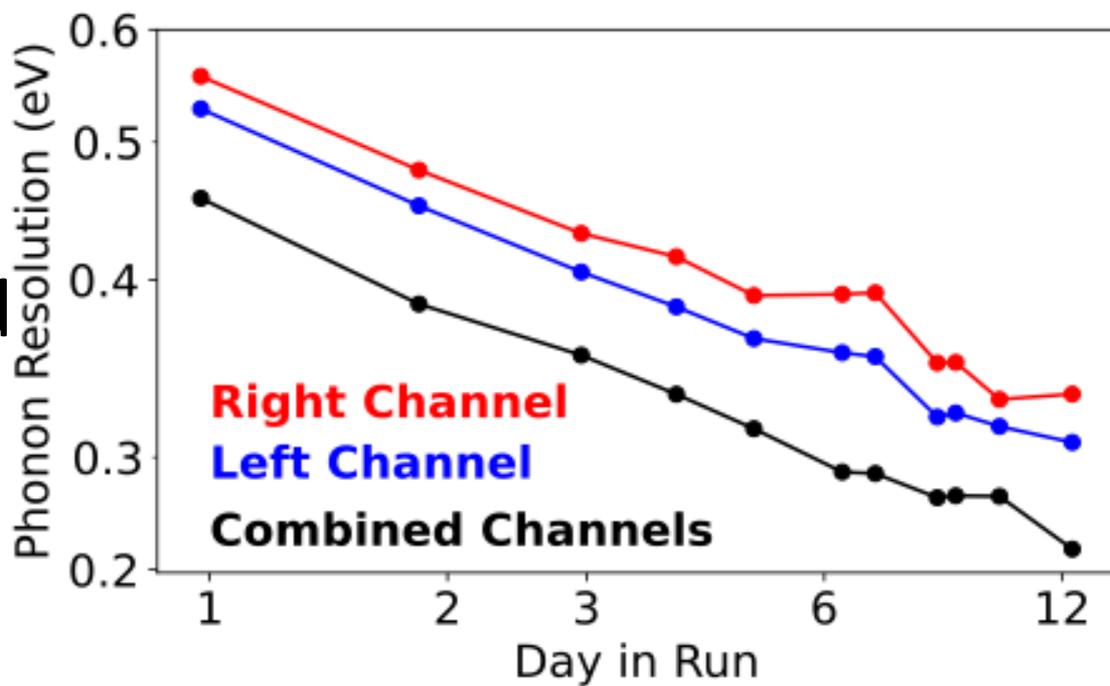


Current Performance: Sensitivity



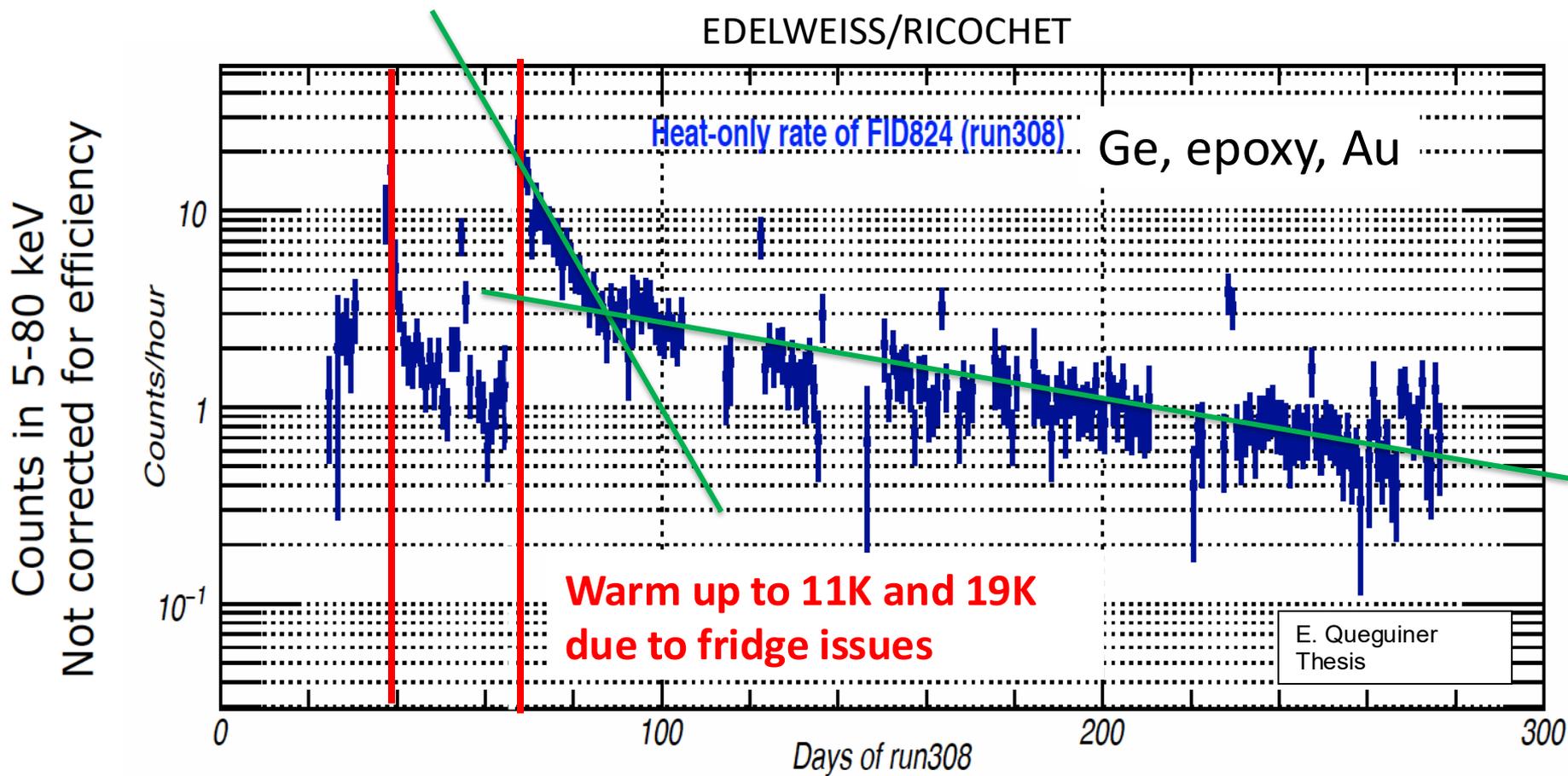
On Day 12, Phonon baseline energy resolution is $259\text{meV}_{\text{rms}}$

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



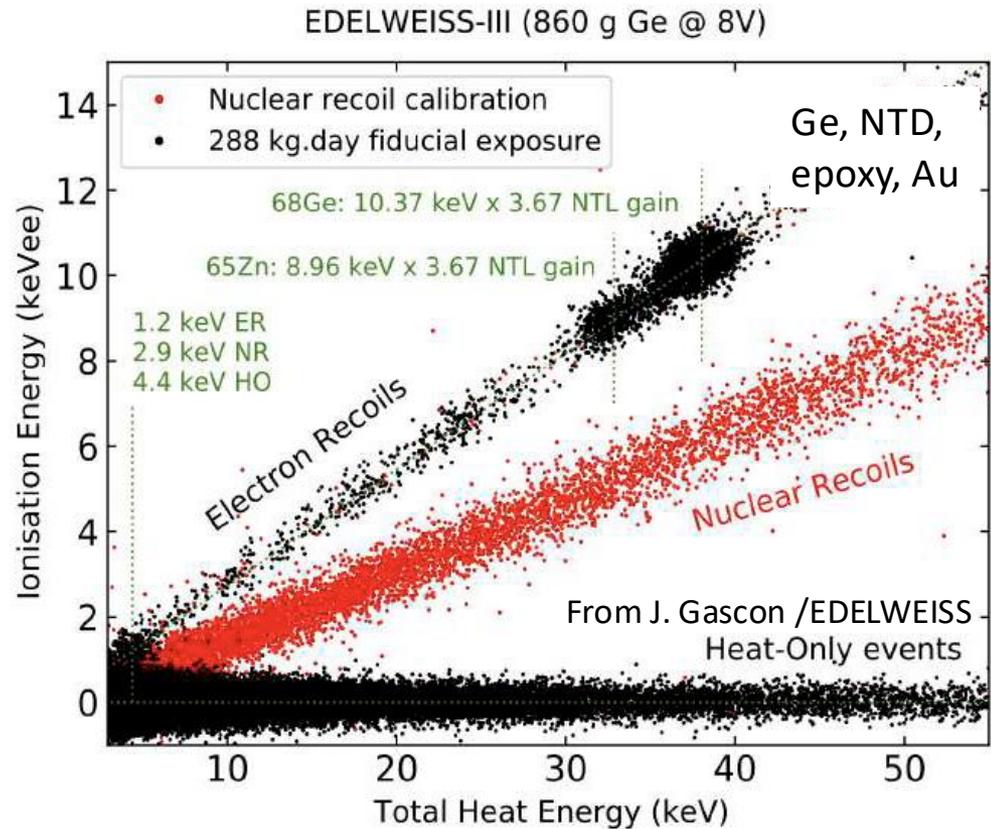
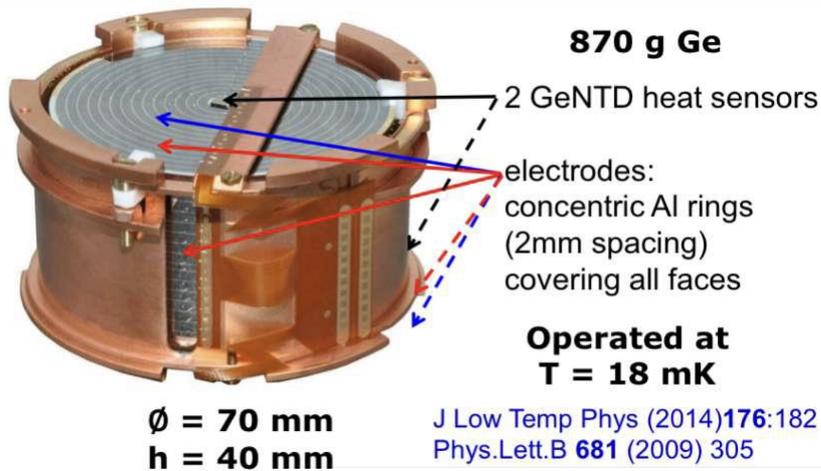
Unexplained Low Energy Excess (LEE) Background(s)

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

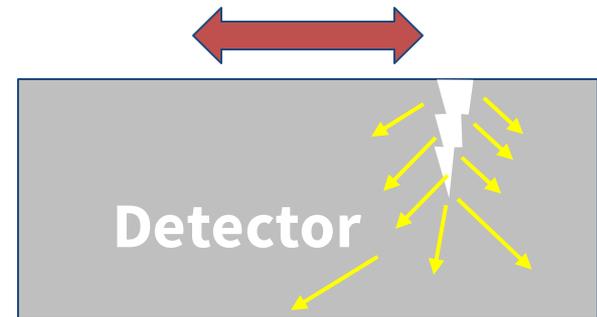
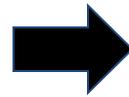
| | SPICE/CDMS | EDELWEISS | CRESST |
|---|------------|-----------|--------|
| 1) Variation with time since cooldown (and/or time since fabrication) | Yes | Yes | Yes |
| 2) Non-Ionizing | Yes | Yes | |

These facts are incredibly restrictive!

Stress Relaxation?



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

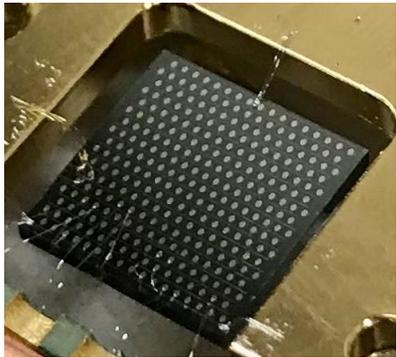


Detector relaxes releasing phonon energy

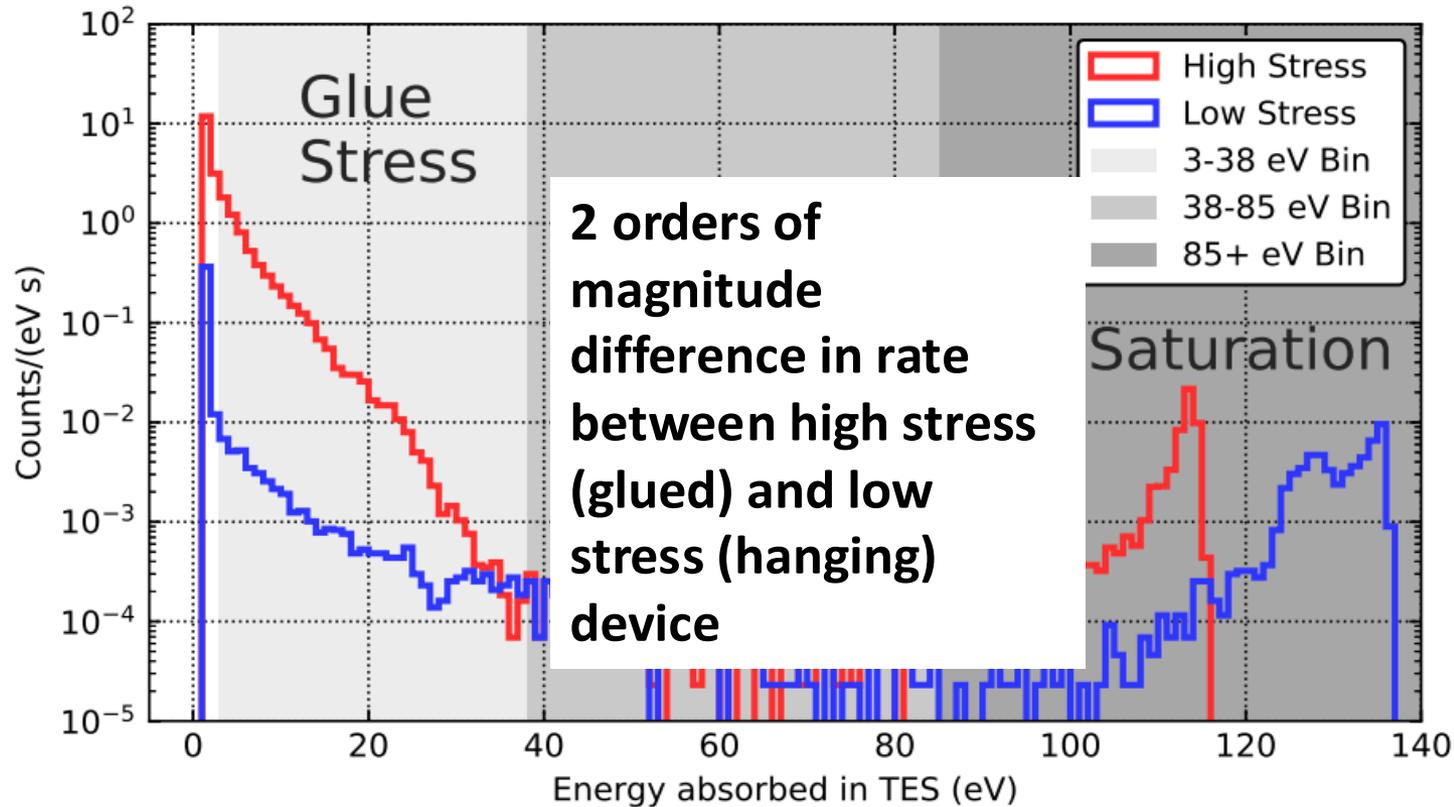
Stress Related Relaxation: 1st Low Energy Evidence

2208.02790

Hanging (low stress)



Glued Down with GE varnish
(High Stress)



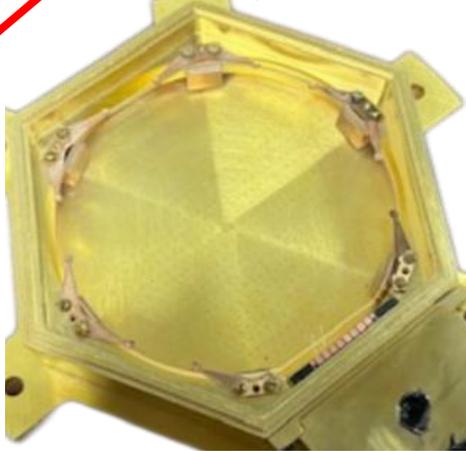
- GE varnish (and rubber cement) significantly increase <38eV backgrounds

Best Structural Support?

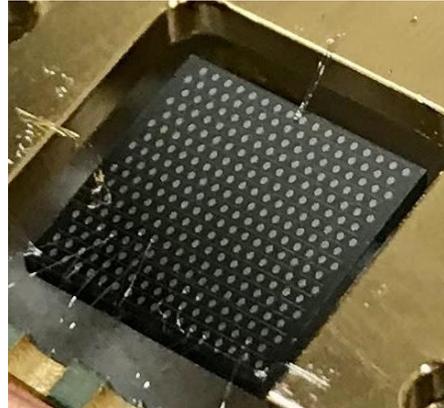
Glue



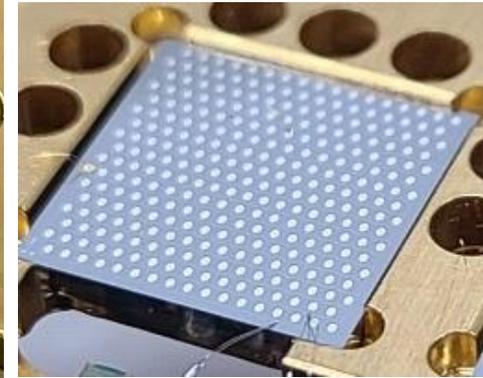
Clamp



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

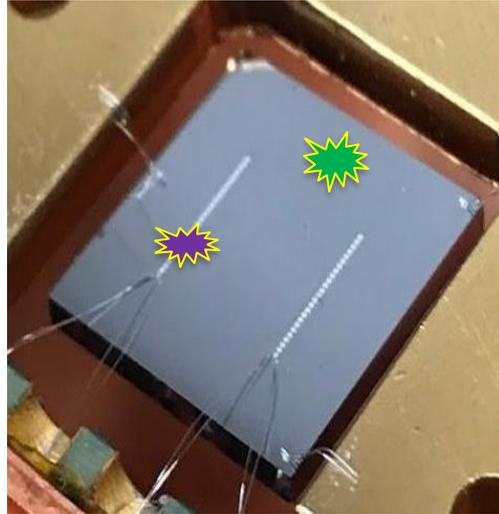
Mitigation for Stress Relaxation Events:

GET RID OF ALL STRESS

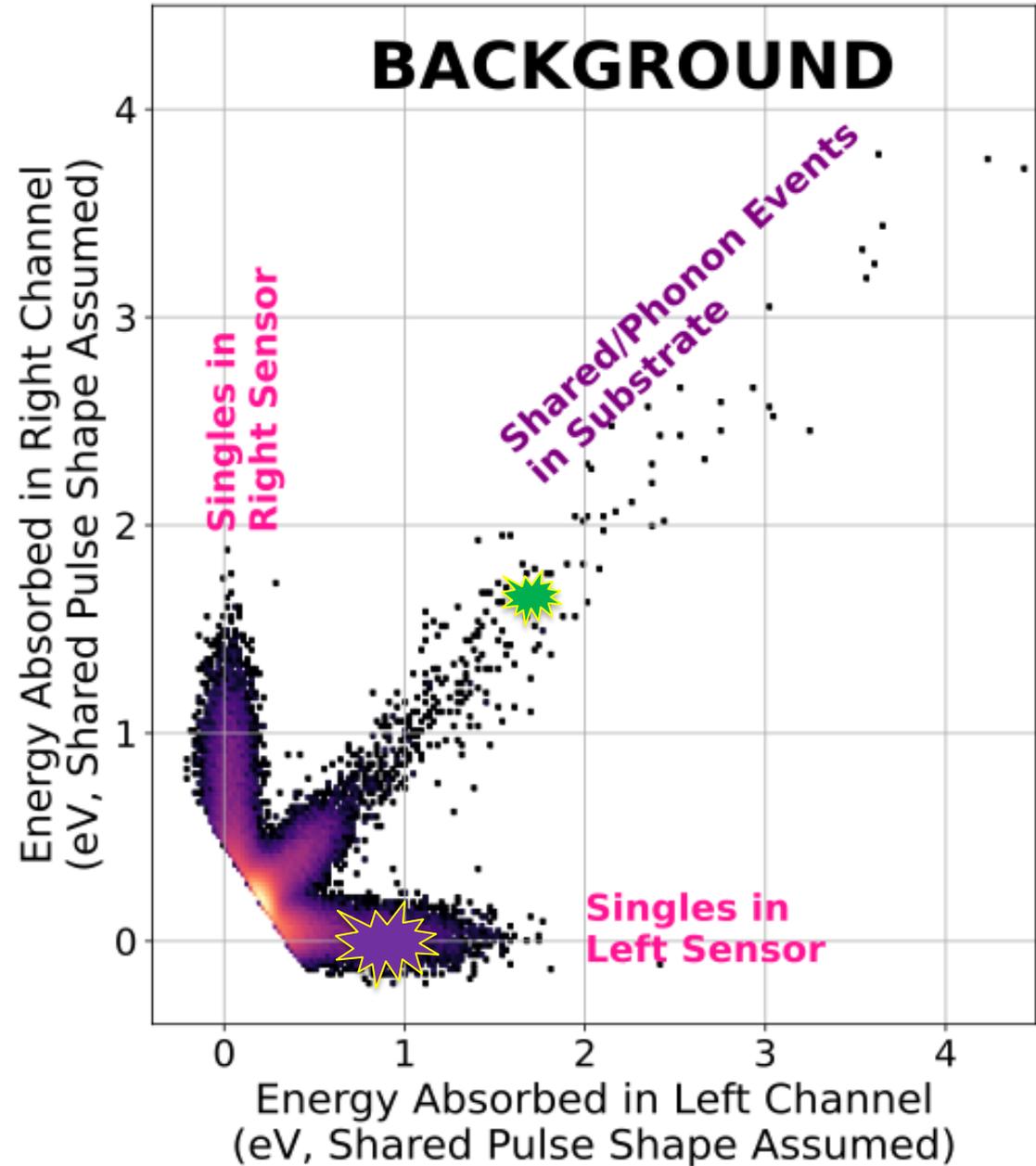
- ~~1. Support Structure~~
2. Sensor Films
3. Crystal Surface Relaxation
4. Bulk dislocation(s) relaxation

Understanding Relaxation Events: 2 Channel Devices

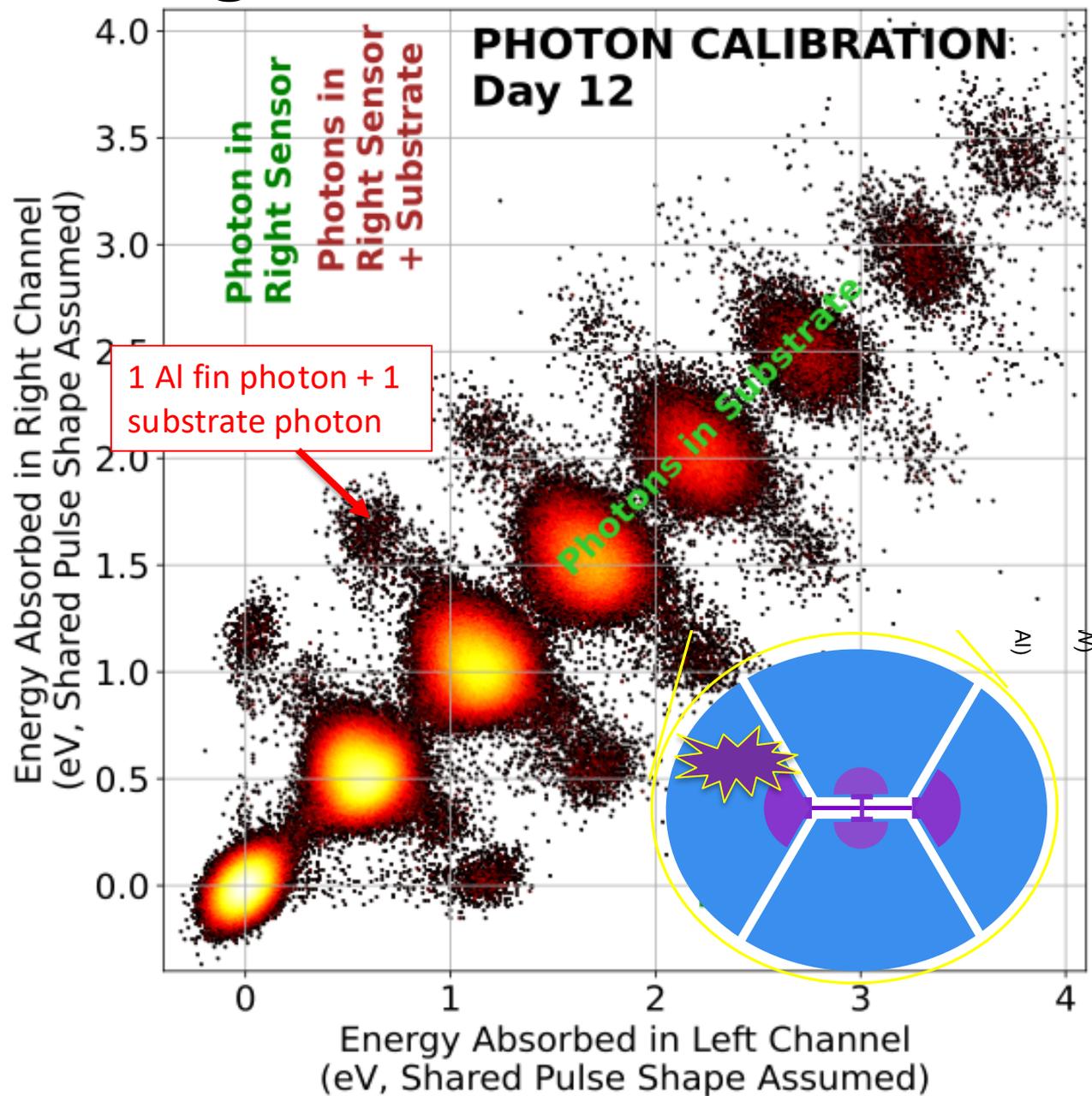
1% 2 Channel Device



We see both shared and single channel relaxation events

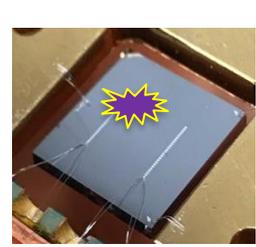


Single Events in Photon Calibration too



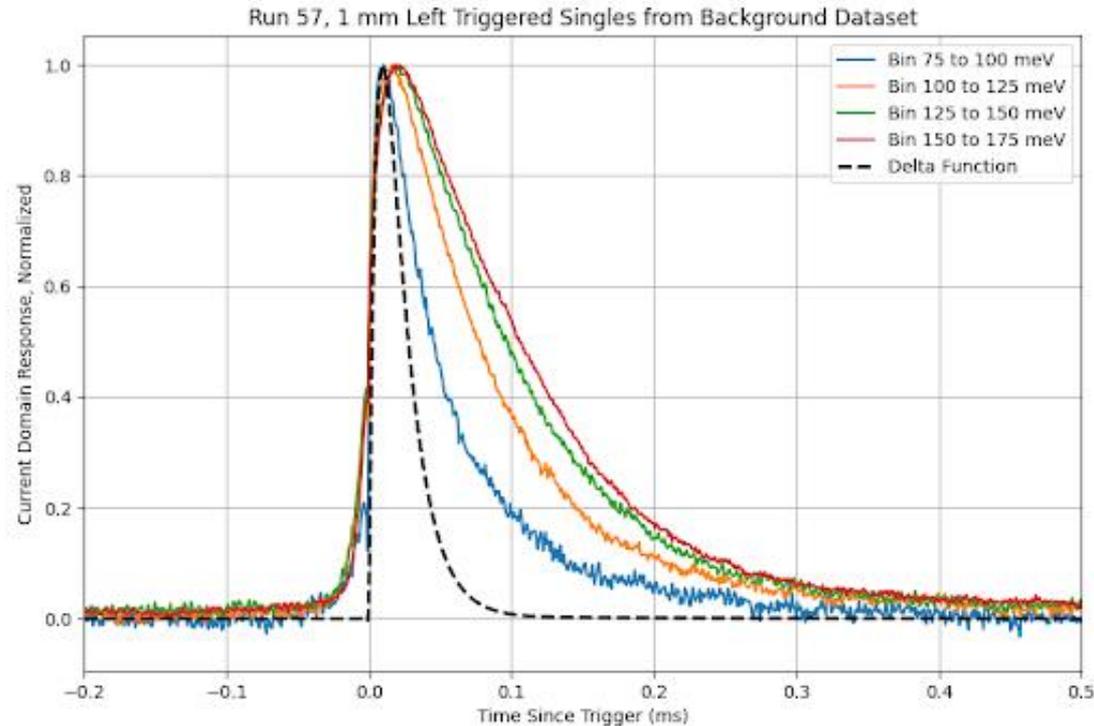
Calibration photons have single and shared events too!
Shared = substrate absorption
Singles = Al fin absorption

Single Relaxation Event Pulse Shape



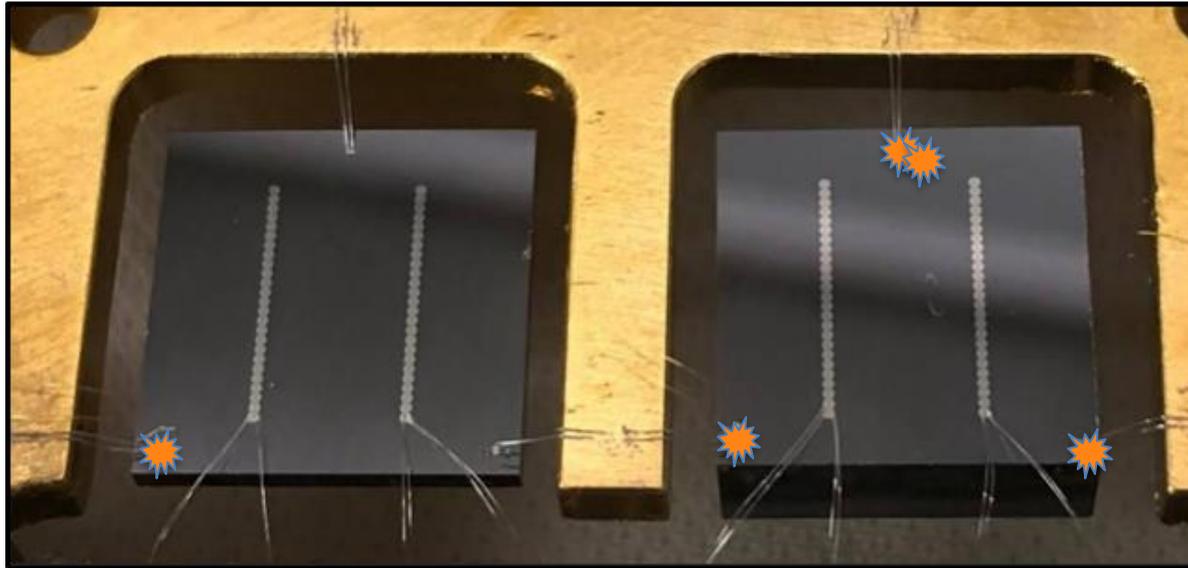
LEE single pulse shapes and Al film calibrations photons have pulse shapes consistent with a dirac delta energy pulse that saturates a single phonon sensor in the channel

- 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!

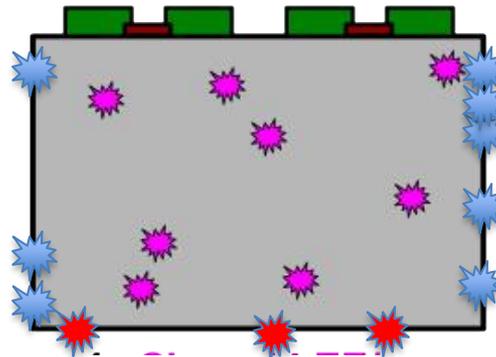
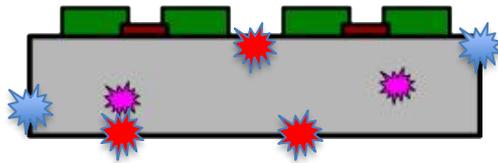
Source Shared LEE Relaxation?



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

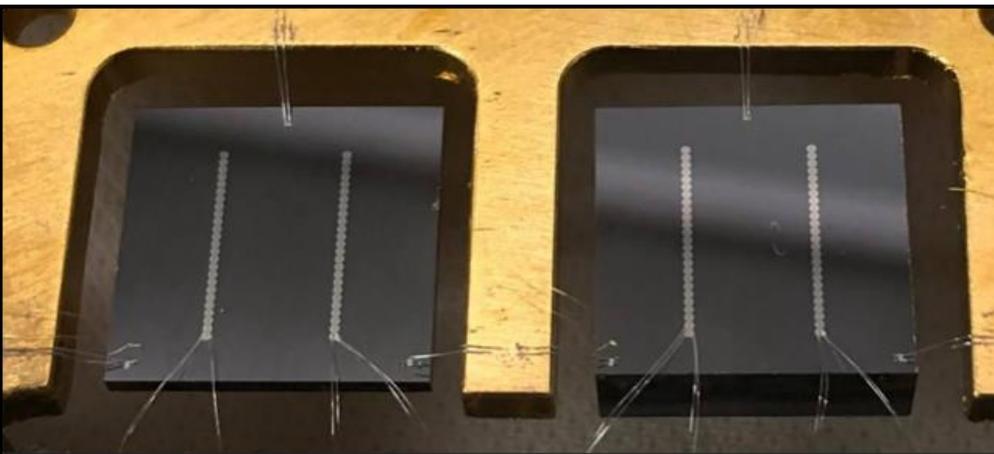
1 mm thick detector

4 mm thick detector



Test hypotheses with different substrate geometries

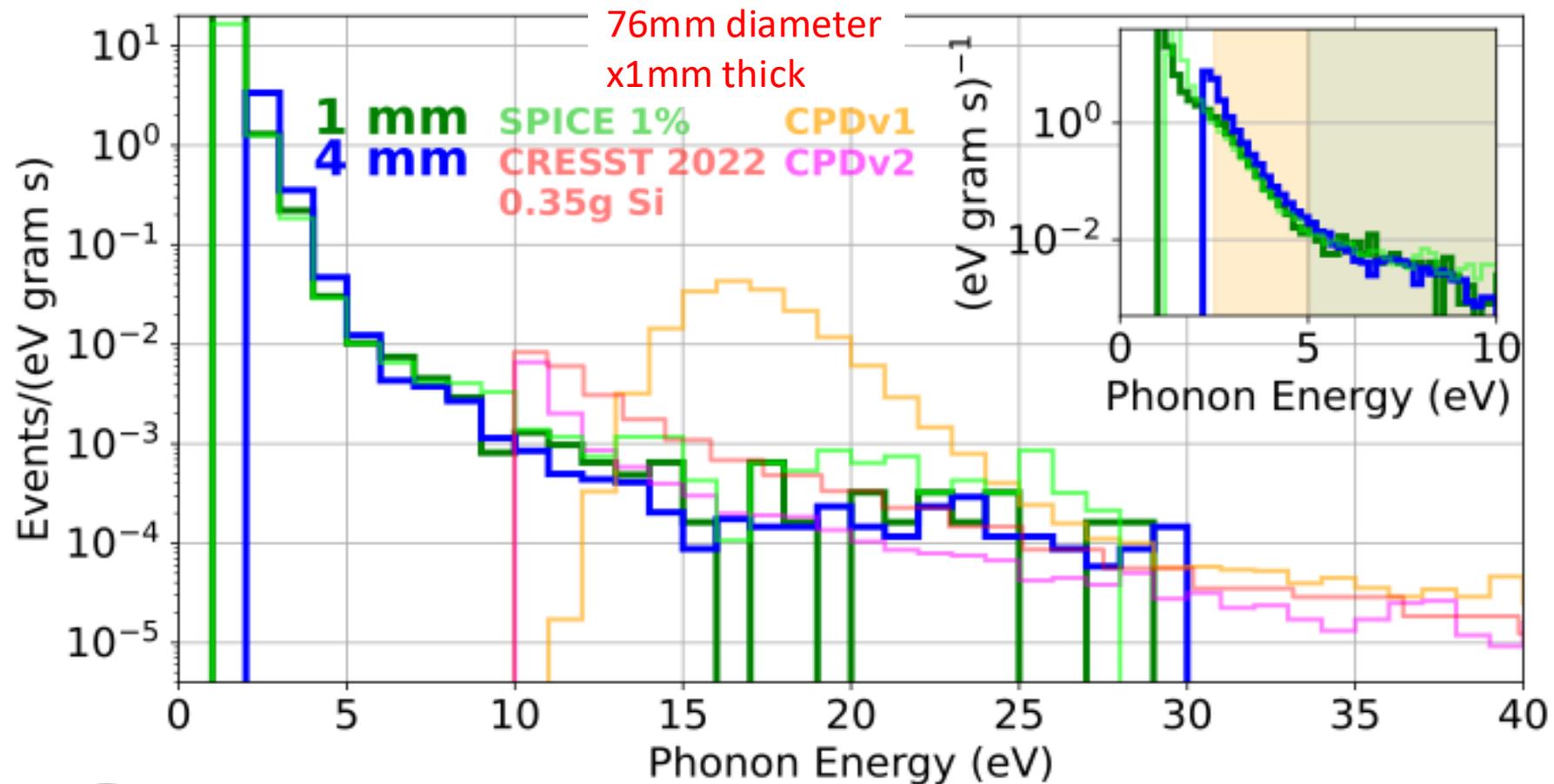
Perfect A/B Test?



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

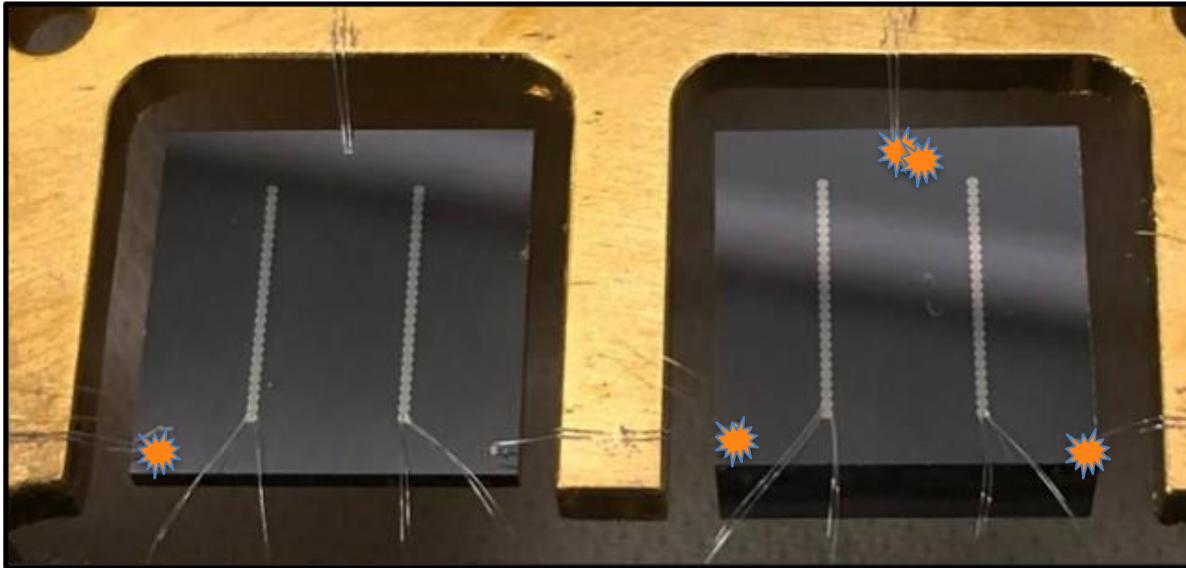
| | Same | Differences |
|-------------------|---|--|
| Design | identical | |
| Substrates | >20kOhm cm Intrinsic Si double side DSP | <ul style="list-style-type: none">• Different Boules• Baking times slightly different |
| Fabrication | Same SOP Texas A&M fabrication facility | Consecutive fabrication 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

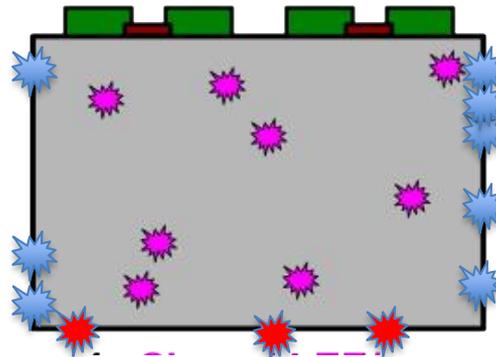
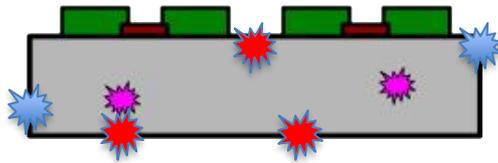
Source Shared LEE Relaxation?



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

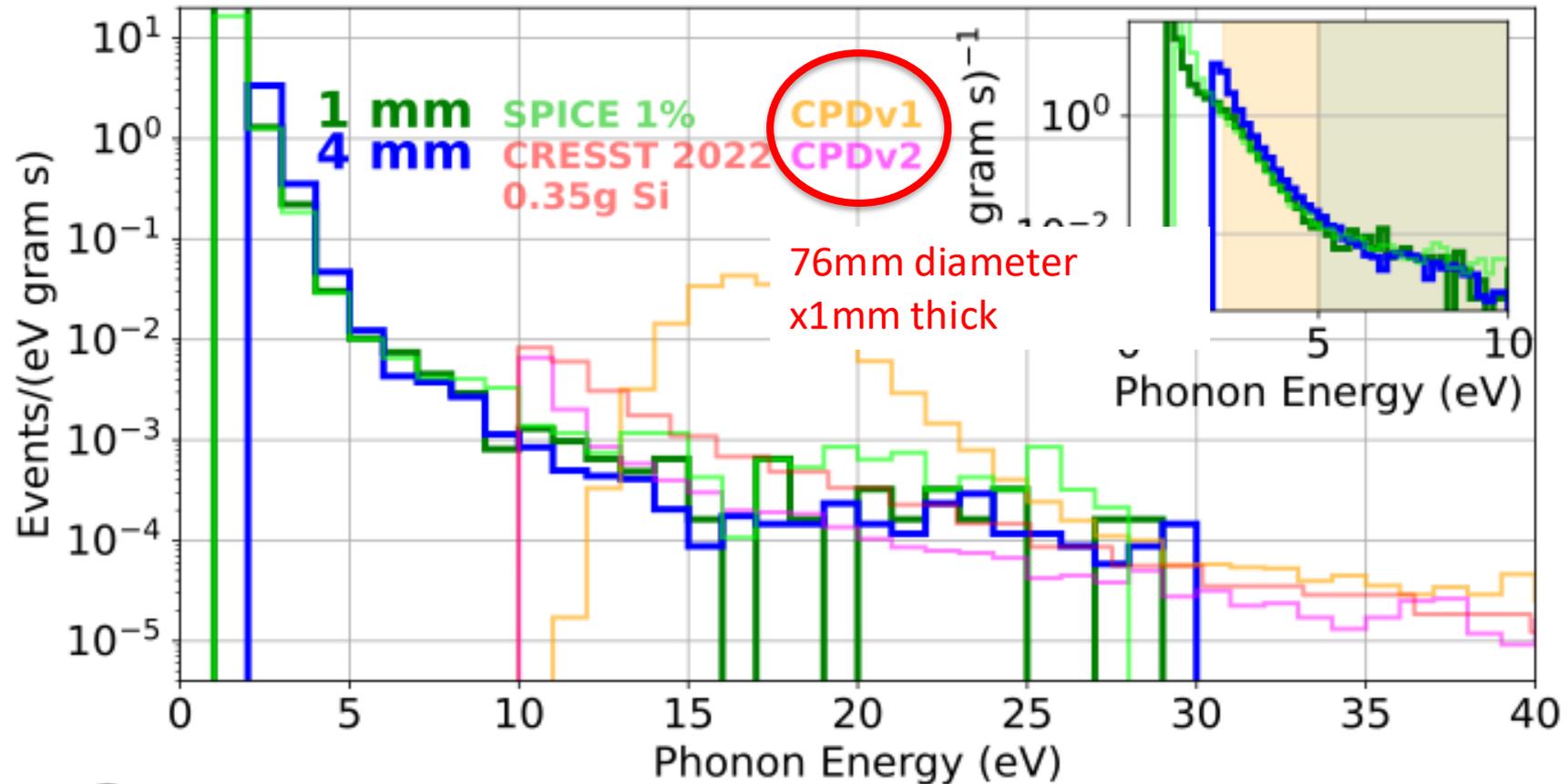
1 mm thick detector

4 mm thick detector



Shared LEE doesn't originate on the polished bare face

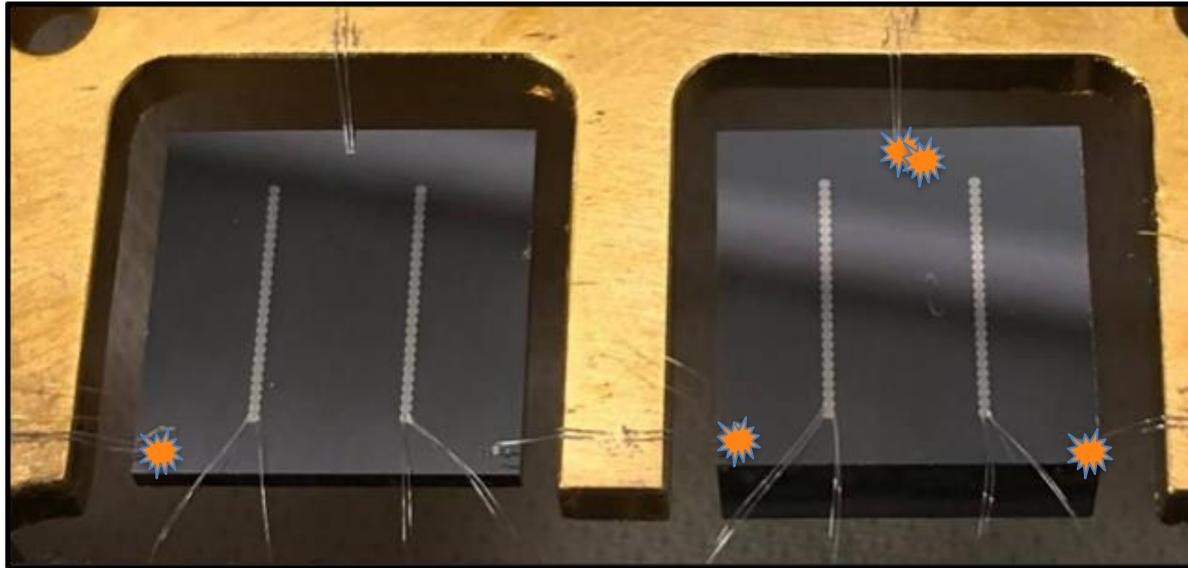
Comparing to LEE of CPDs



CPDs have similar LEE when normalized by mass:

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

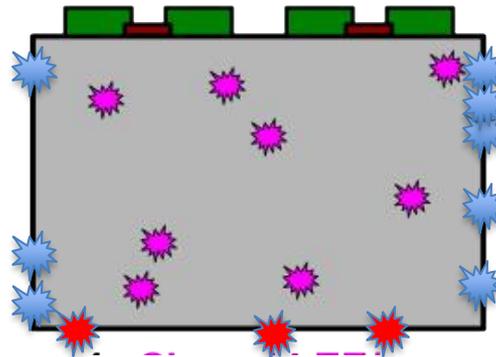
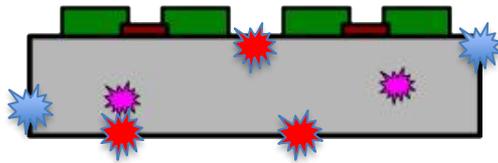
Source Shared LEE Relaxation?



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

1 mm thick detector

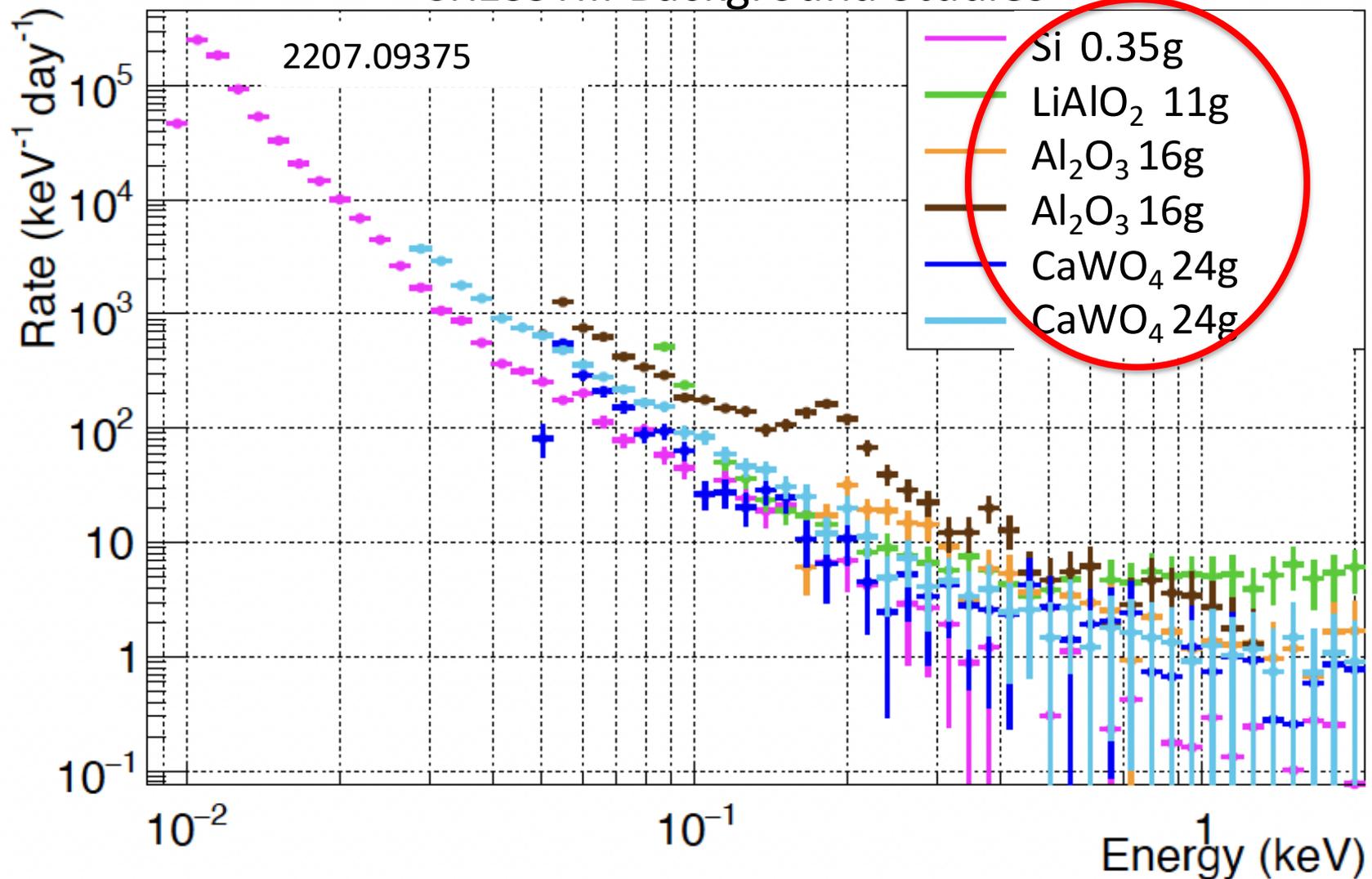
4 mm thick detector



CPD vs 1cm^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

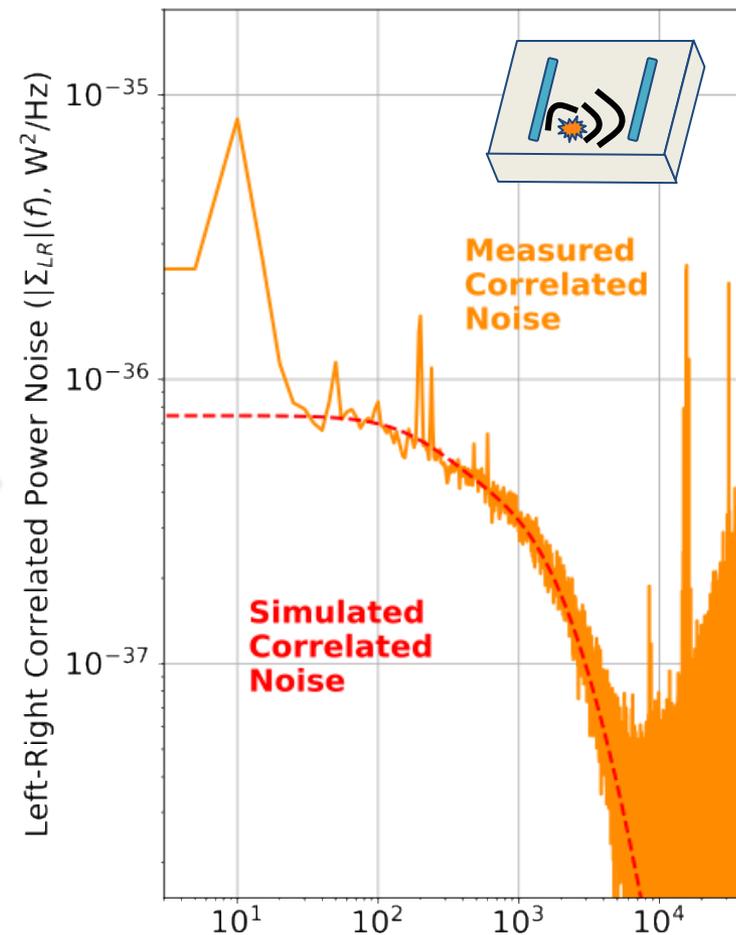
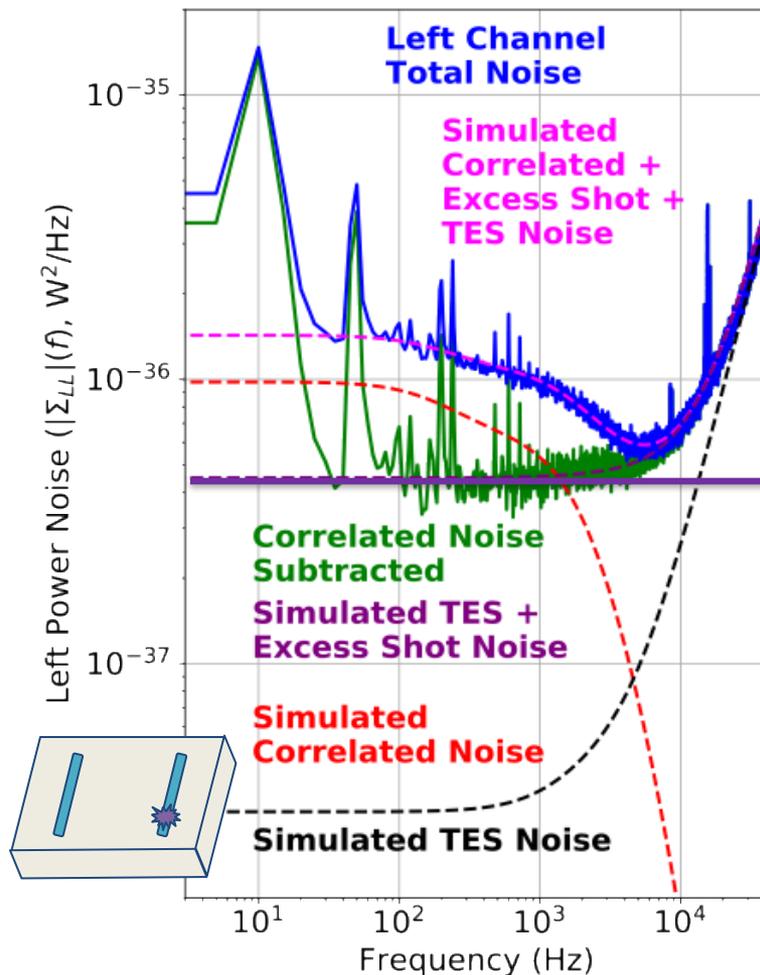


Noise

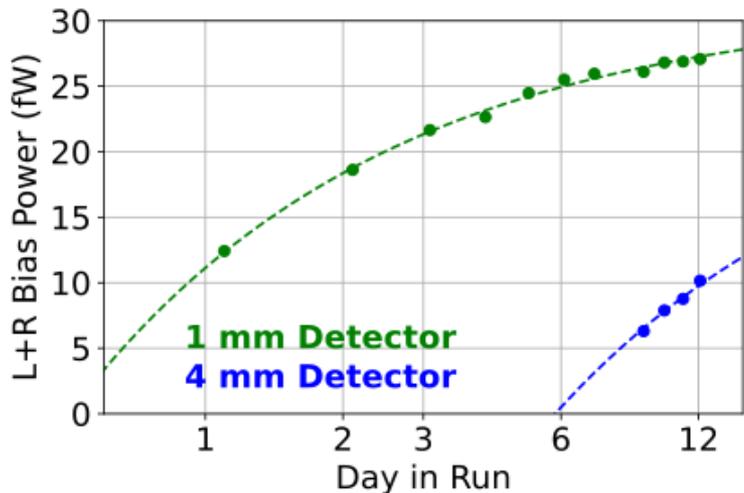
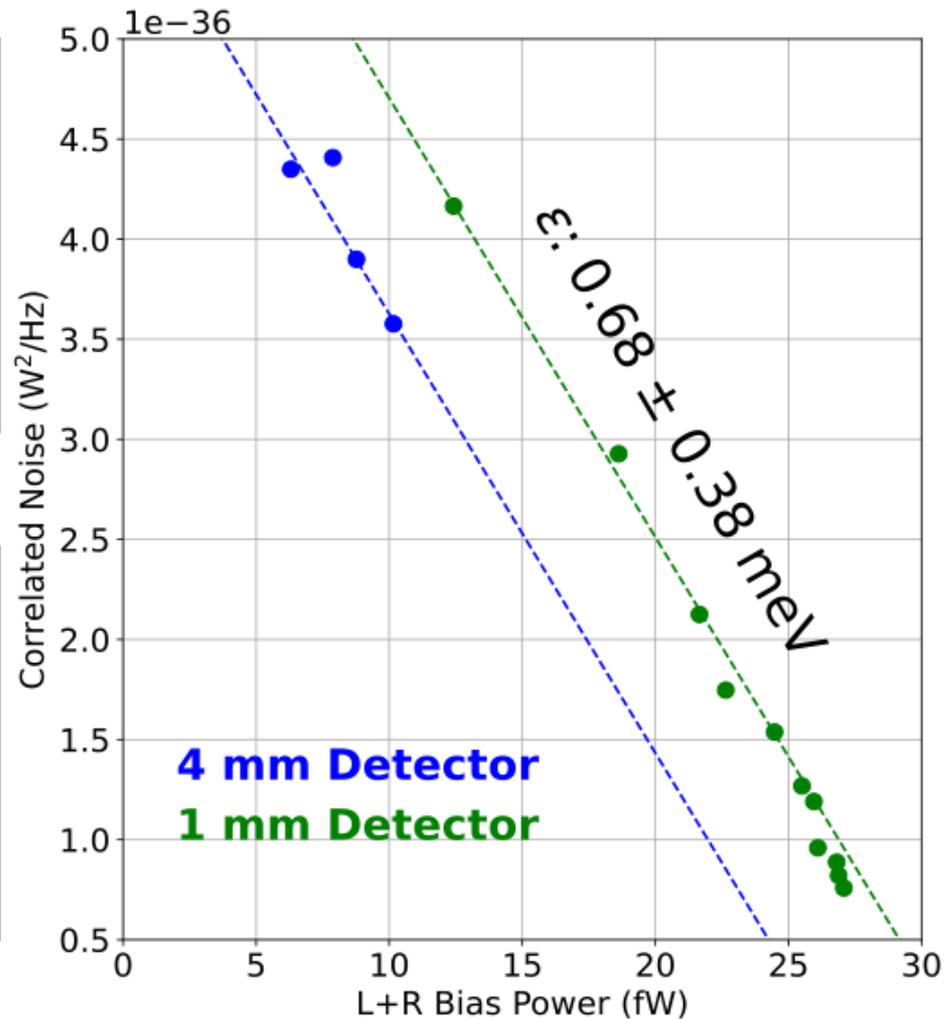
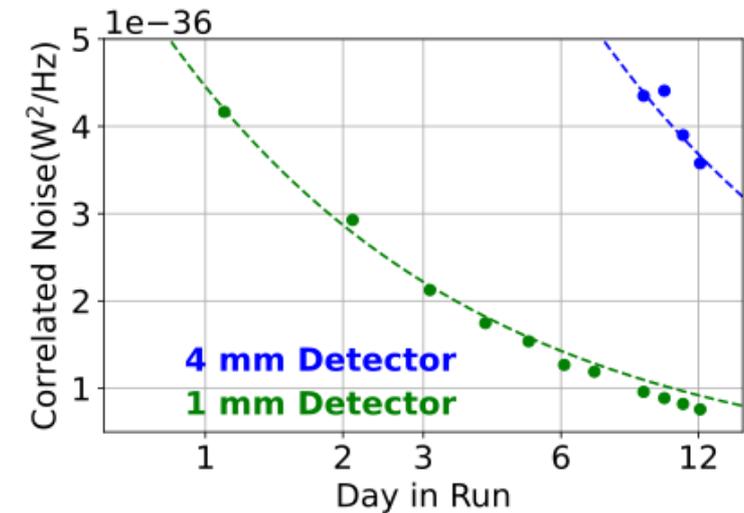
Measured Noise

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