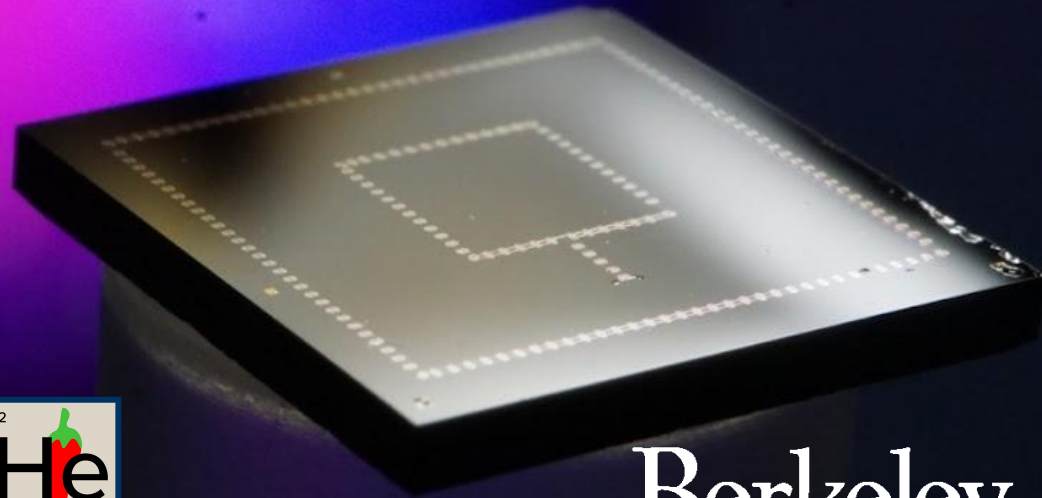


Stress Induced Background in Cryogenic Crystal Calorimeters



Roger K. Romani for the
SPICE/HeRALD Collaboration



Berkeley
UNIVERSITY OF CALIFORNIA

The SPICE/HeRALD Collaboration

(also called TESSERACT)

A new and growing collaboration
searching for low mass Dark Matter!

- 50 + collaborators, 8 institutions
- 3 DM target materials, unified by state of the art TES readout
- Want to learn more about SPICE/HeRALD? Read our Snowmass LOI

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SPICE

HeRALD

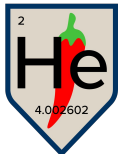
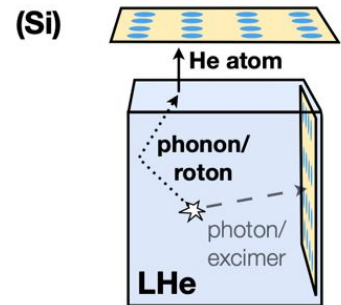
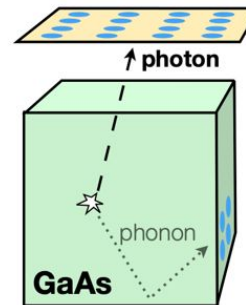
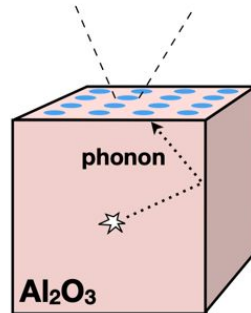
Argonne
NATIONAL LABORATORY



Caltec



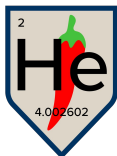
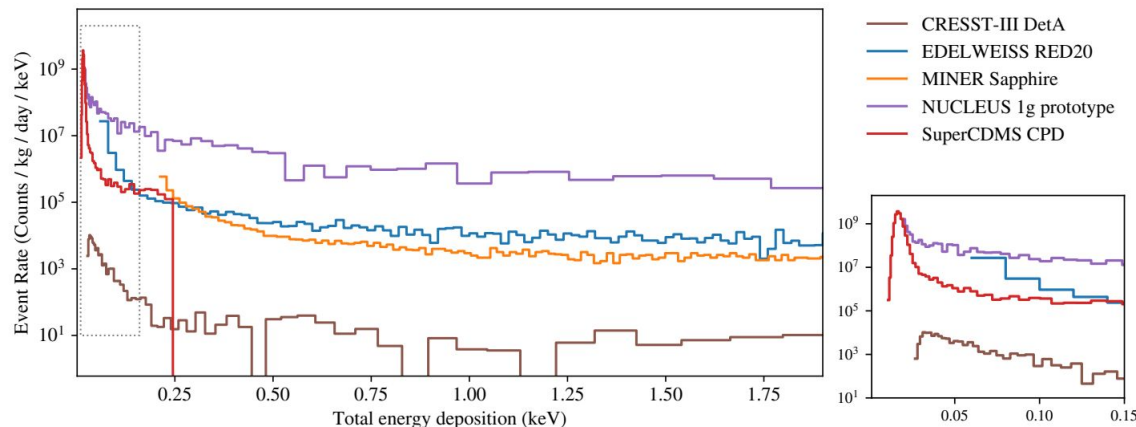
UMassAmherst



Prob 1 – DM Direct Detection: Low Energy Excess

- Unknown source of low energy (below ~ 100 eV) events
 - Seen in many different experiments
 - **Rate varies with time since cooldown** (can't be radiogenic)
 - Non-ionizing for EDELWEISS/RICOCHET
 - Track induced backgrounds (see Daniel Egaña-Ugrinovic's talk!) can account for some, not all
- Reduce the low energy excess and you can look for low mass (MeV - GeV) DM

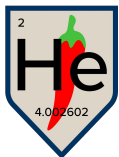
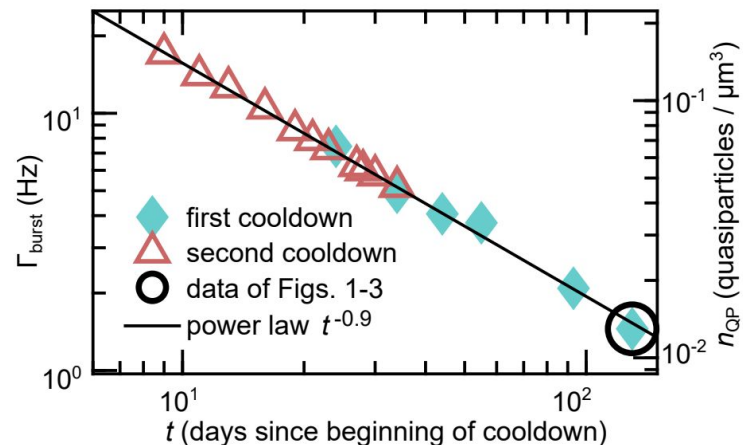
From
arXiv:2202.05097
EXCESS Workshop



Prob 2 – Quantum Computing: Quasiparticle Poisoning

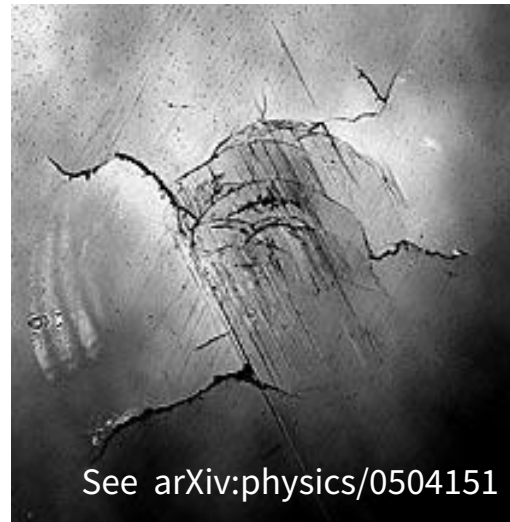
- Superconducting quantum circuits (qubits) see anomalously short decoherence times due to high density of quasiparticles (QP, broken Cooper pairs)
 - Problem has been holding back superconducting qubits for at least a decade
 - With excess quasiparticles, you need to error correct: complexity penalty
 - Lots of sources of excess QPs: radioactivity, muons, IR...
 - See talks by J. Formaggio, J. Hall, N. Kurinsky, X. Li, and G. D'Imperio on Wednesday!
 - **In 2102.00484, excess quasiparticle density decreased as a function of time**
 - Solve excess QP problem, allow quantum computers to make big step forward

arXiv: 2102.00484
Mannila et. al.

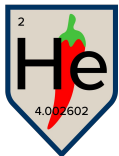


Origin? Stress Induced Backgrounds

- We propose that one effect causes both problems!
- Differential contraction-induced strain
- Strained crystal slowly relaxes over time, releasing energy as athermal phonons
- Where are these stressed sites? Lots of places!
 - Glued down crystals/Neutron-Doped Transistors/samples coupled by vacuum grease (2102.00484)
 - Clamped crystals
 - Metal films on crystal surface
- Not unprecedented, CRESST saw stress-induced microfractures in mid 2000s
 - Clamped sapphire balls cracked crystal substrate
 - Up to 100s of keV/event, ~ 0.1 Hz event rate

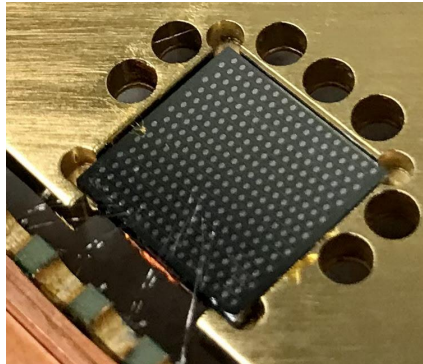


See [arXiv:physics/0504151](https://arxiv.org/abs/physics/0504151)

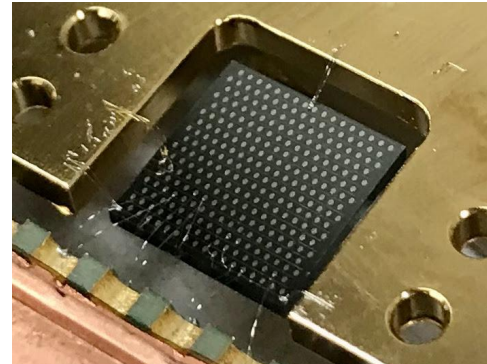


An Apples-to-Apples Demonstration

- Two essentially identical TES/QET based athermal phonon detectors
 - 1 cm² by 1 mm thick silicon absorber
- One glued down to copper substrate (high stress)
- One suspended from wire bonds (low stress)
- No calibrations, but can directly measure energy absorbed in TES

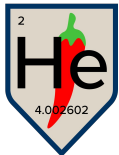
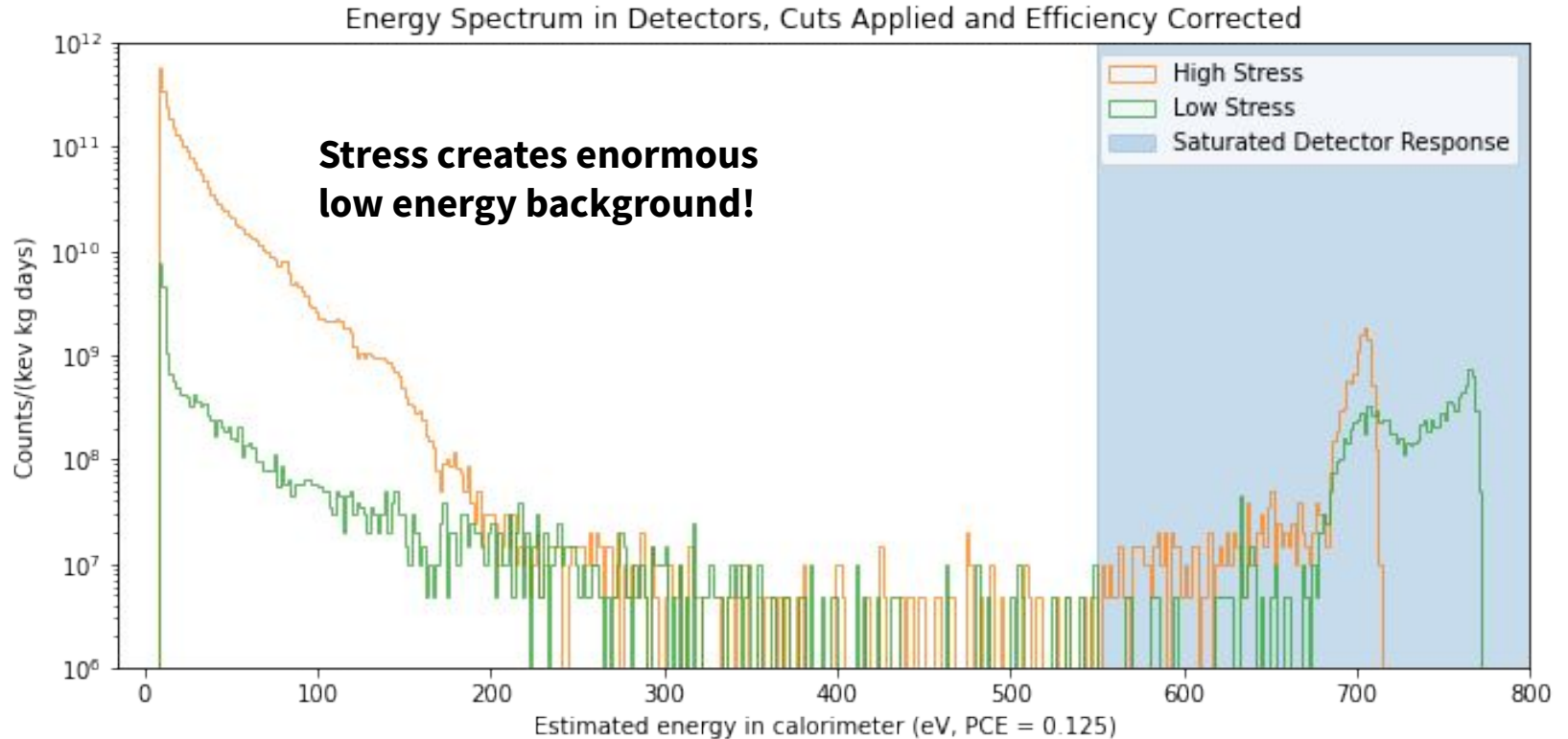


High stress



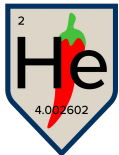
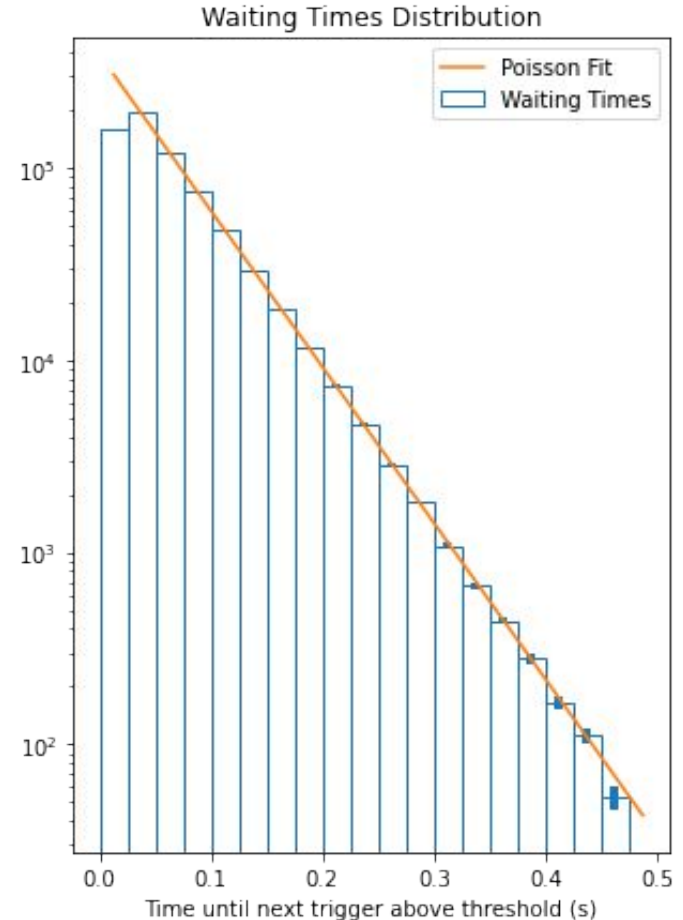
Low stress

Energy Spectra

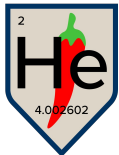
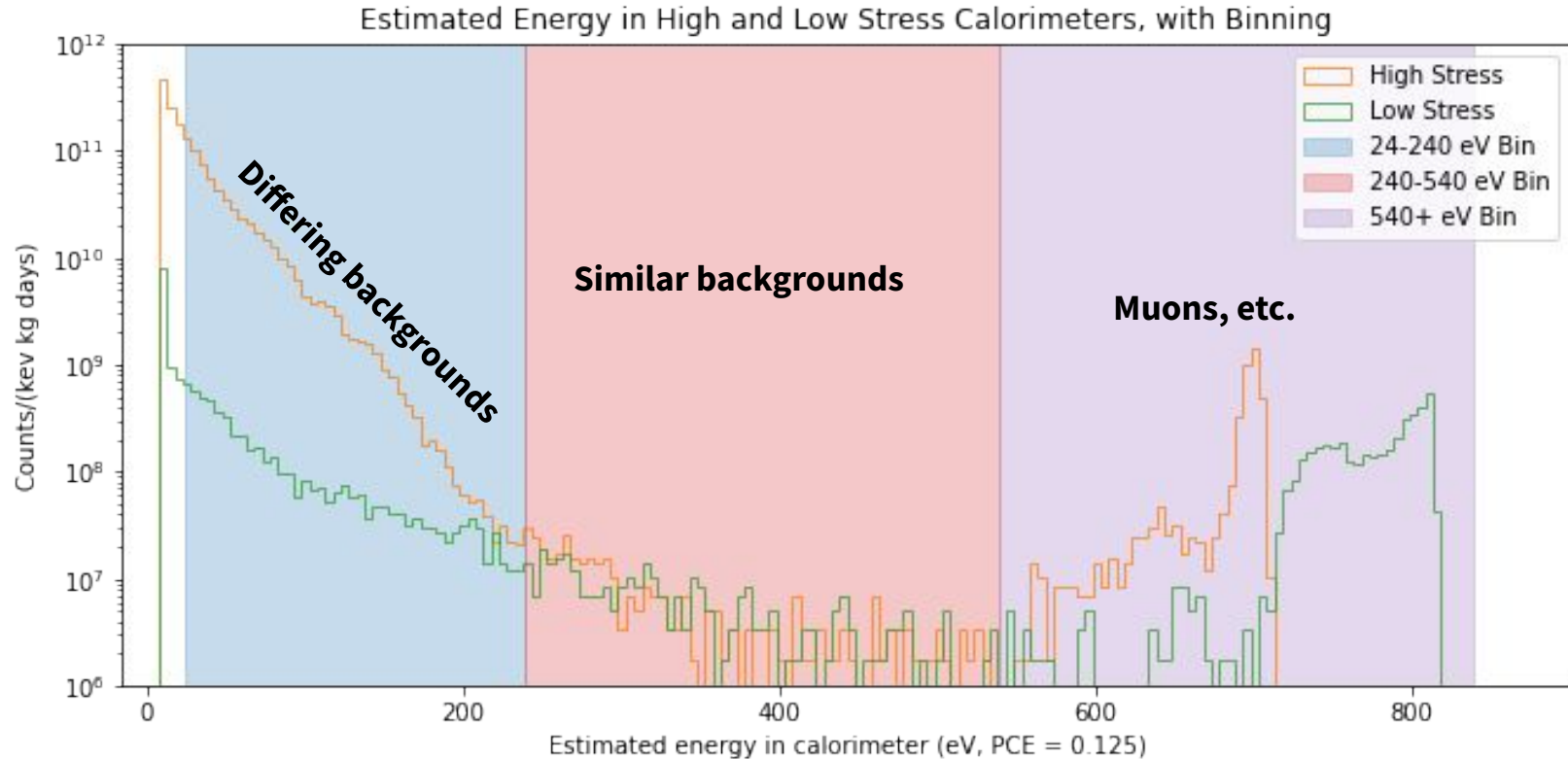


Time Distribution of Events

- Measured “waiting time” between events above a given energy threshold
- Waiting times longer than trace length are Poisson distributed
 - Current software misses some triggers during ~0.02s readout
 - CRESST saw slightly different waiting times distribution... they were 1000 times higher energy

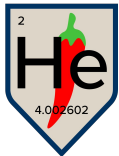


Time Dependence of Excess



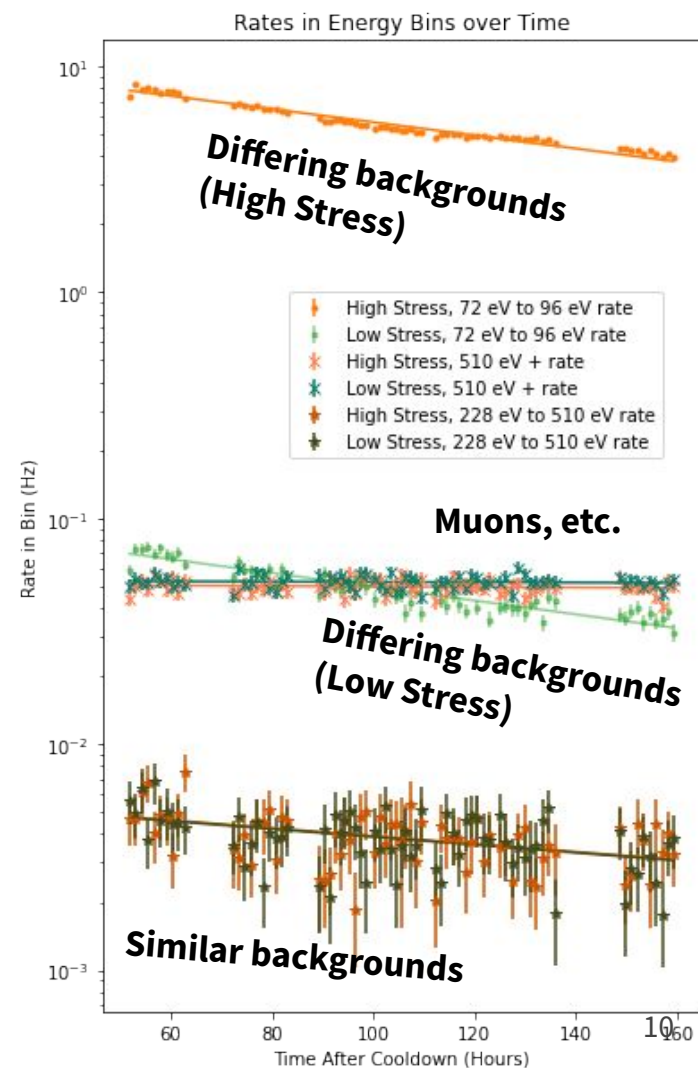
Time Dependence of Excess

- See both lower energy and moderate energy background bins rates decrease over time
 - $\tau \sim 6\text{-}10$ days
 - Both exponential and $1/t$ reasonable fits to data
 - Factor ~ 2 rate decrease during ~ 5 day experiment
- Saturated (high energy) events (muons etc.) don't vary with time (as expected!)
- $<15\%$ of low energy events cut – cuts can't cause 2x rate changes



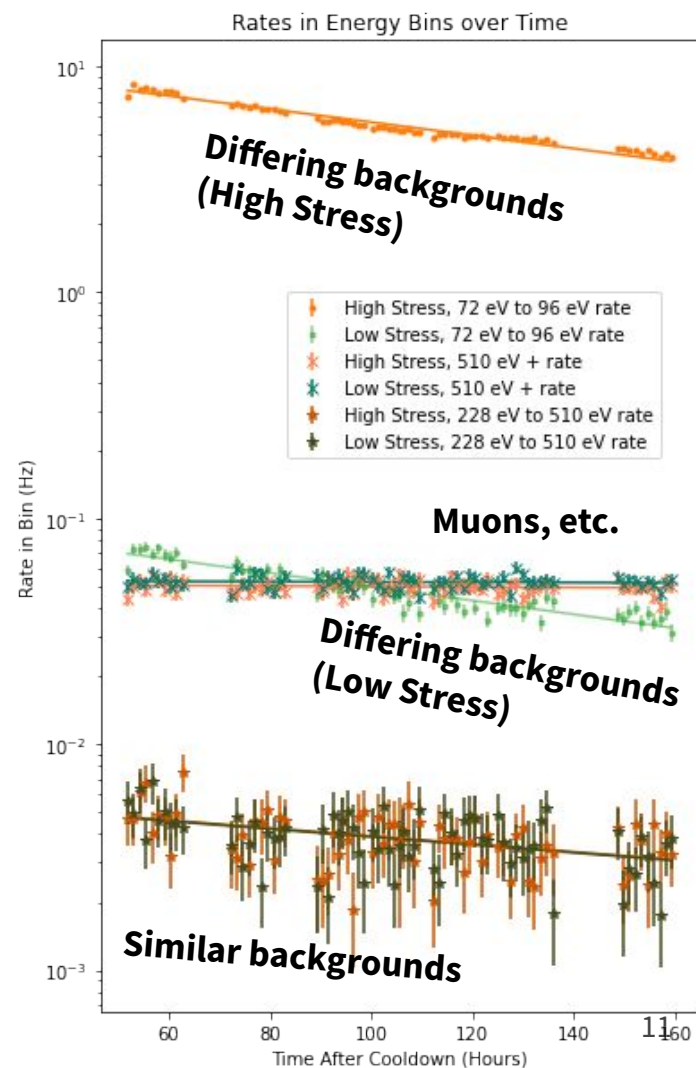
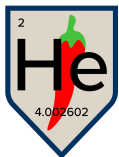
High Stress

Low Stress



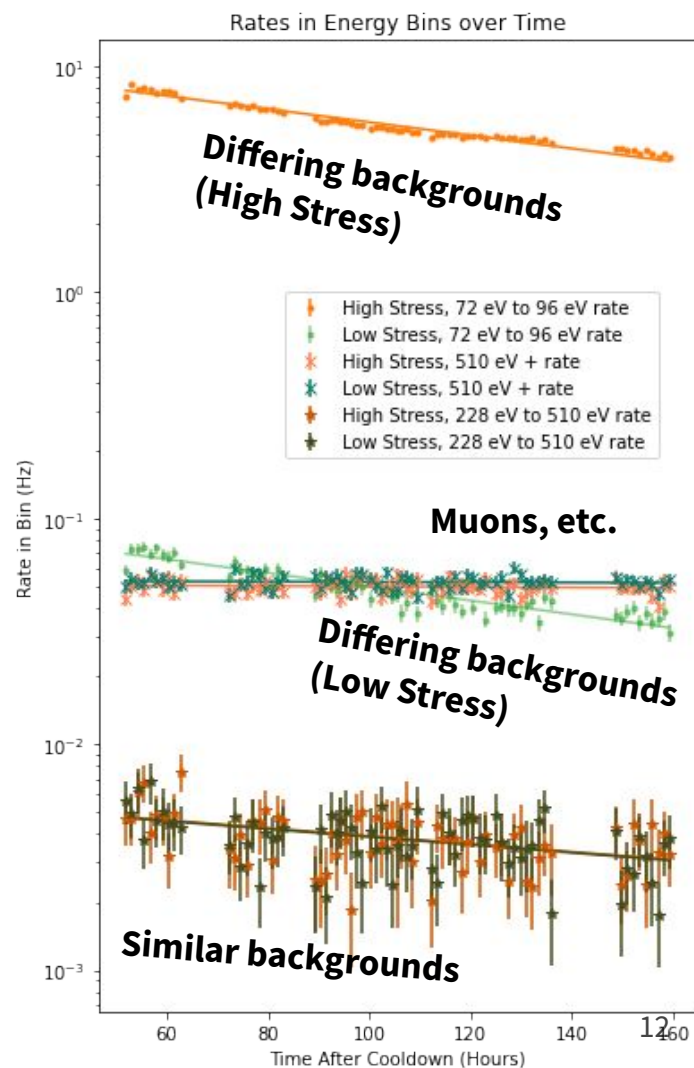
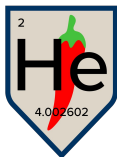
Source of Rates

- Saturated rate makes sense: muons, radioactive backgrounds...
- Differing background region (lower energies):
 - Varies with time: not radioactivity, track backgrounds
 - Glue causes stress, relaxation causes events
 - Much less stress in hanging calorimeter, less stress to relax = fewer events
- Similar background region (higher energies):
 - Still varies with time, similar τ to glued stress events
 - Circumstantial evidence: caused by similar mechanism in both calorimeters
 - Look for source of time varying events present in both calorimeters...



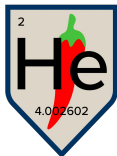
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 - **Stress between TES films and crystal?**



Looking for TES stress events

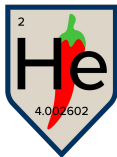
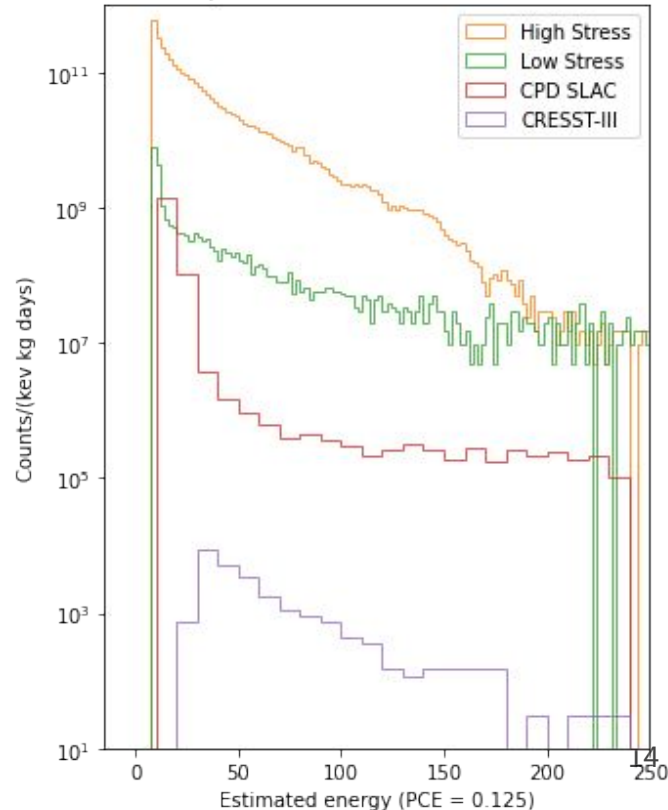
- Look in multiple channels
 - Presumably a stress event only happens in one TES channel at a time, more energy will end up there
 - Veto TES events, hopefully get more background free region
- Look at pulse shape
 - If TES fall times are much shorter than phonon collection times (not true for these calorimeters), energy that goes directly into TES should have different pulse shape vs. collected phonons
- Tag as a TES stress event/substrate event, see what the remaining excess is made of in low stress calorimeters



Comparison to Other Low Mass DM Experiments

- Note: our low stress detector rate is still $\sim 200\times$ CPD, $\sim 10^5\times$ CRESST
- Why are we so much worse?
 - Not fridge or shielding specific, ran CPD in this fridge, saw background that agreed with published measurement within factor of ~ 2

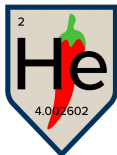
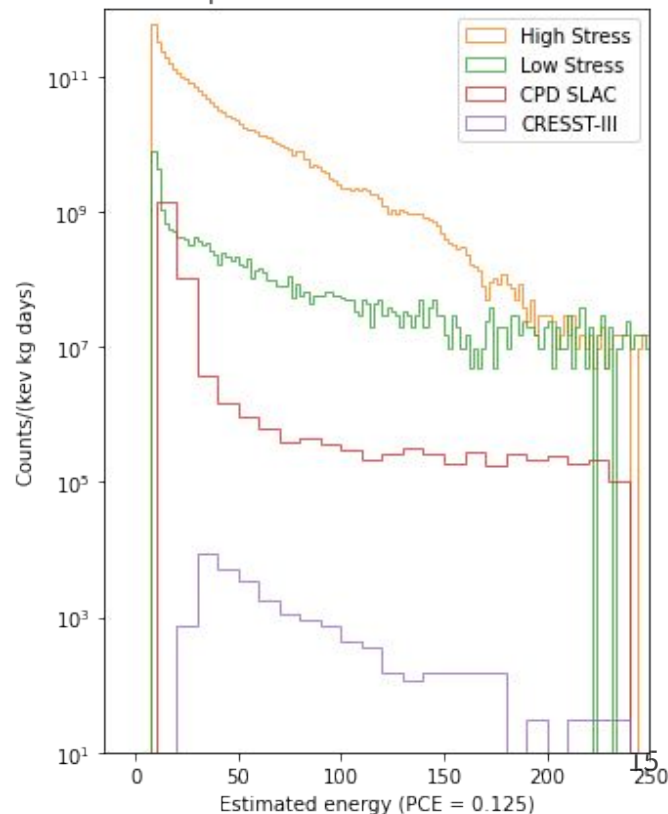
Energy Spectrum in High and Low Stress Detectors, Compared to CPD-SLAC and CRESST-III



Comparison to Other Low Mass DM Experiments

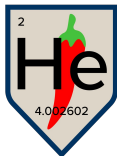
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- Why are we so much worse?
 - Not fridge or shielding specific, ran CPD in this fridge, saw background that agreed with published measurement within factor of ~ 2
- Hypothesis: fabrication-induced strain at TES interface varies greatly between detectors
- Stress events rate decreases while cold, may anneal out while warm too
- **Mitigation Plan: Fanatically minimize stress everywhere in our detectors**

Energy Spectrum in High and Low Stress Detectors, Compared to CPD-SLAC and CRESST-III



Implications for Low Mass DM Direct Detection

- Mount-associated stress release is a new background we have to worry about
 - Pretty much unimportant for high threshold detectors
 - Extremely important for low threshold (low mass) direct detection
- Don't use glue on your detectors!
- More generically, look for stress everywhere, try to eliminate it
 - Clamping schemes
 - Films on crystals
- Time variation is a powerful tool for understanding these backgrounds

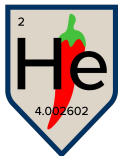


Implications for Quantum Computing

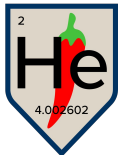
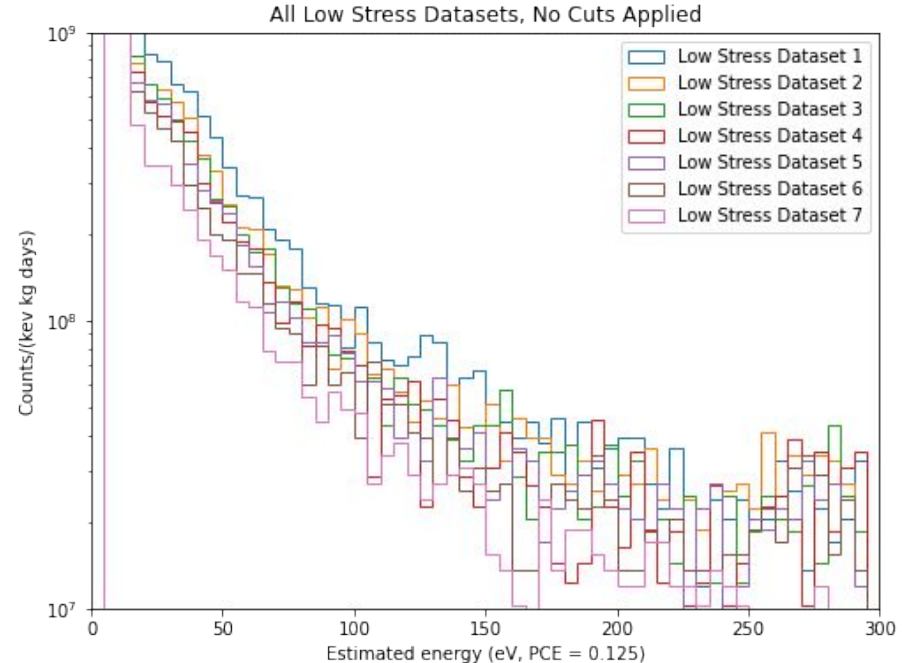
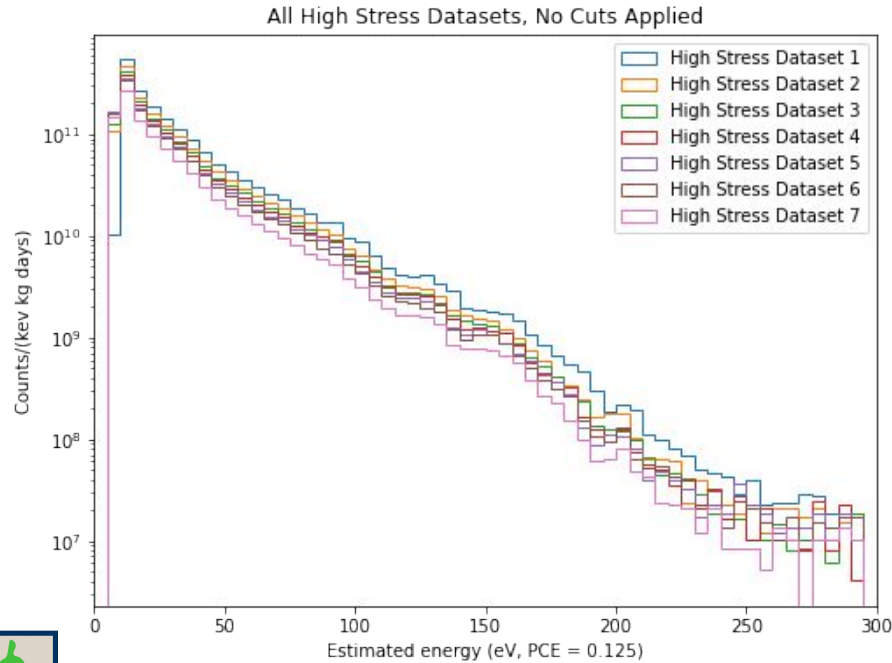
Our model for quasiparticle poisoning:

- Stress-release radiates athermal phonons in quantum computer Si substrates, these phonons when absorbed in quantum circuits create quasiparticles
 - Higher rate than muons + other high energy backgrounds (for setups that have high stress)
- We may have identified a source of quasiparticle poisoning
 - This has plagued superconducting quantum computers for more than a decade
 - Long coherence times are of course important
 - Even more critical: stress-release “burst events” could decohere all qubits on a chip at once, make error correction difficult/impossible

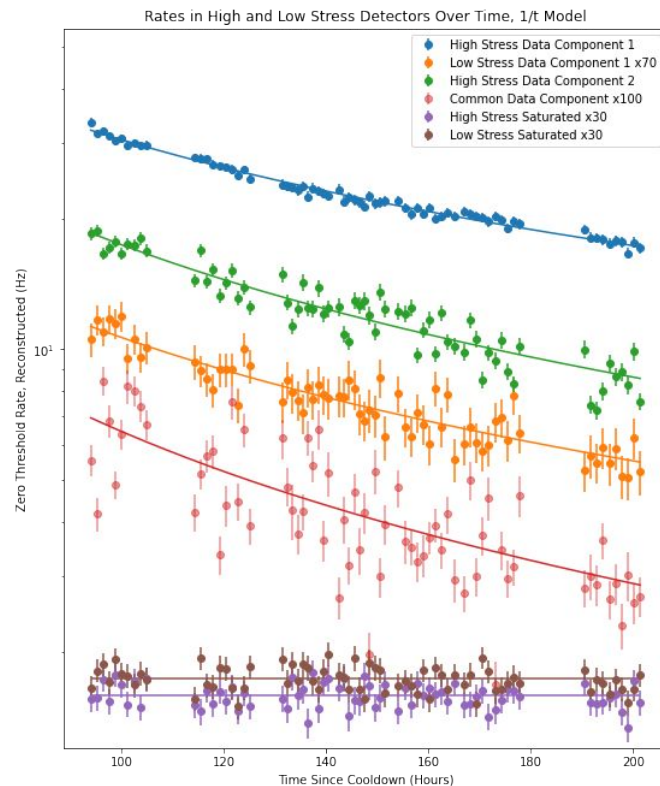
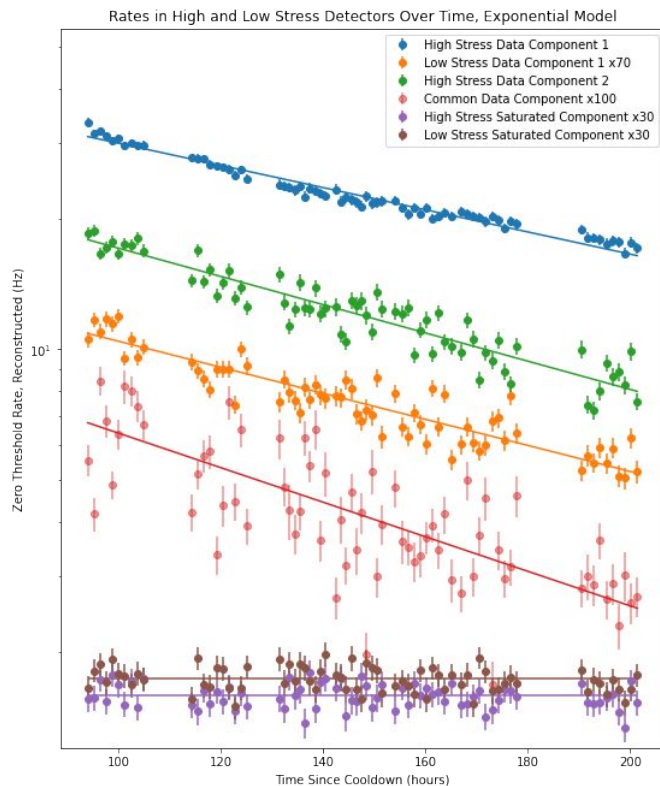
Many talks: low background techniques can be a huge boon to quantum computing groups (and visa versa!)



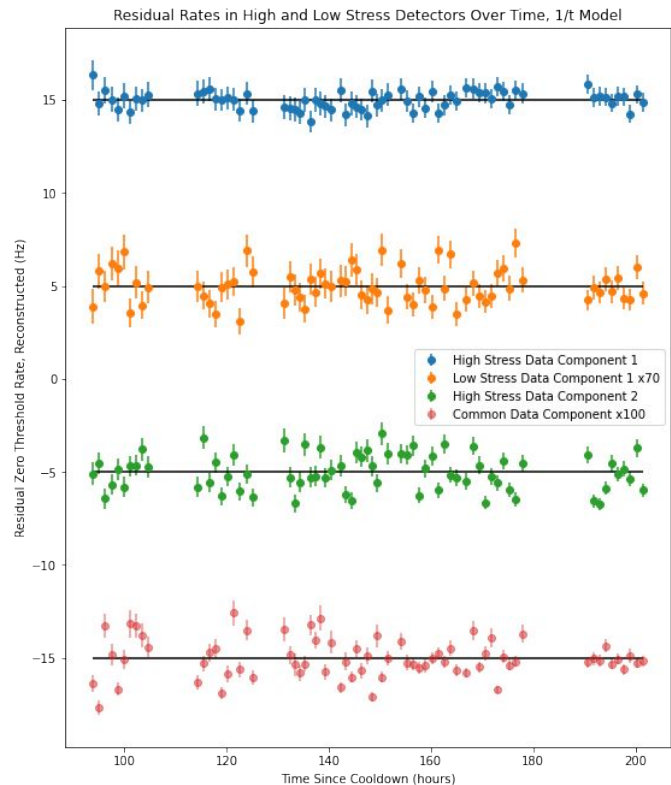
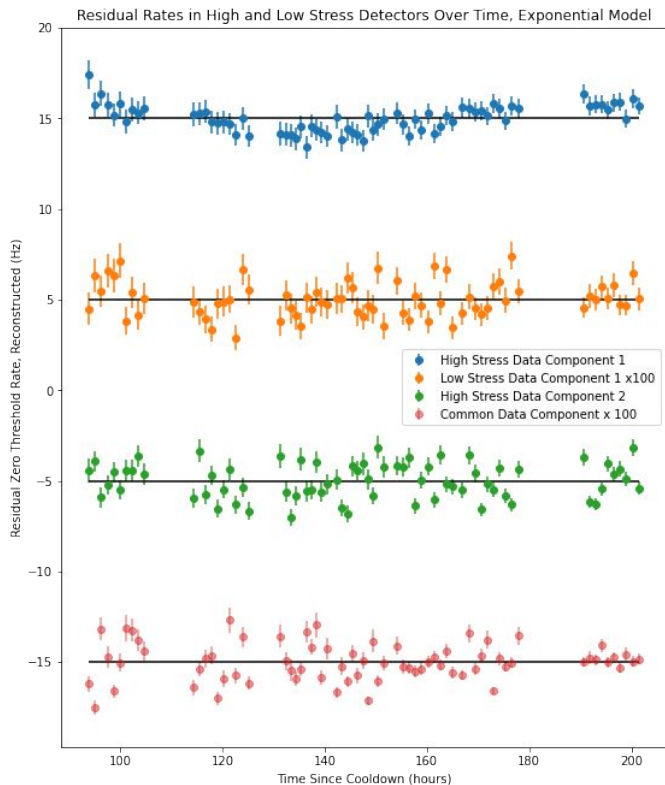
Backup: Spectra Over Time Without Cuts



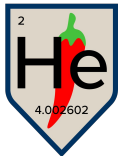
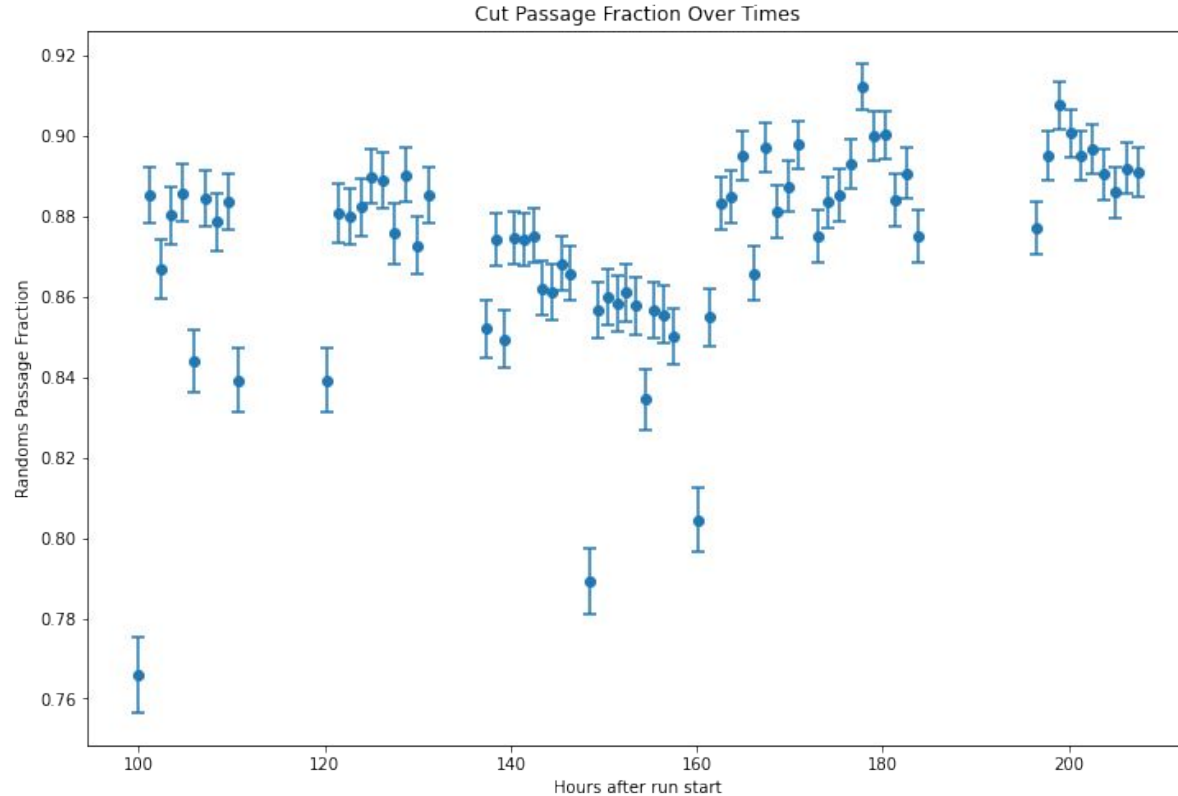
Backup: $1/t$ vs. Exponential Fits to Rates



Backup: Residuals for Rate Fits

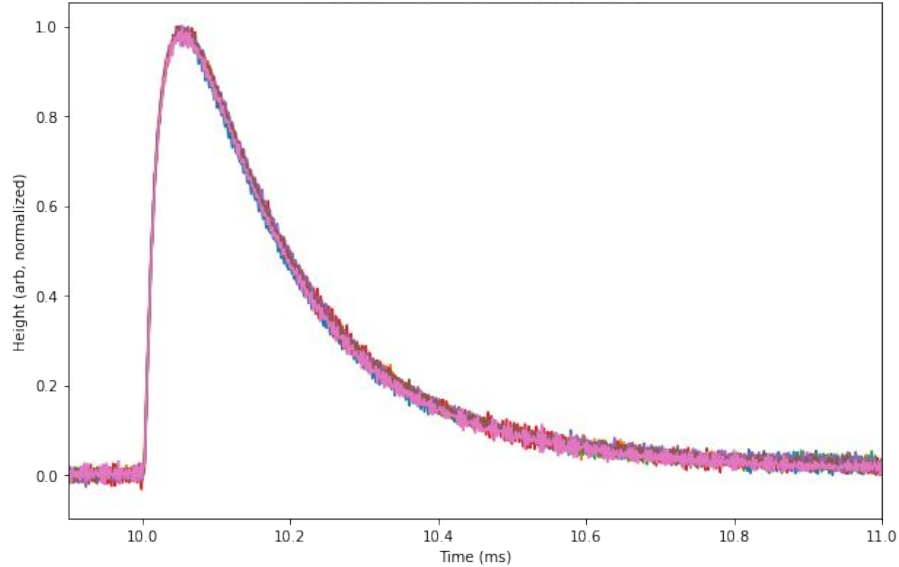


Backup: Cut Passage Fraction over Time

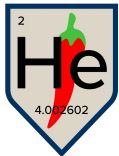
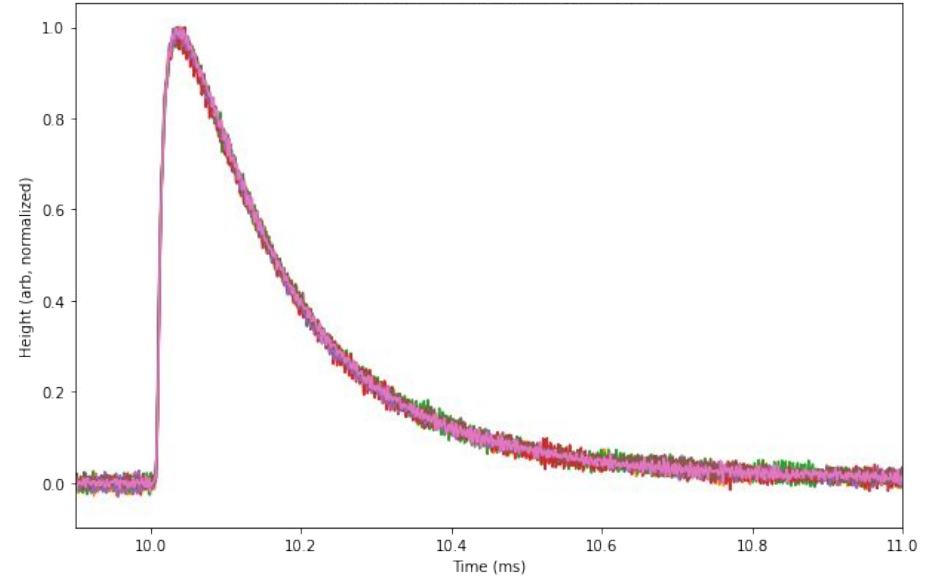


Backup: Pulse Shape Over Time

Low Stress Templates, All 7 Datasets

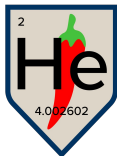


High Stress Templates, All 7 Datasets



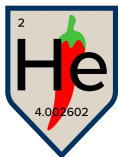
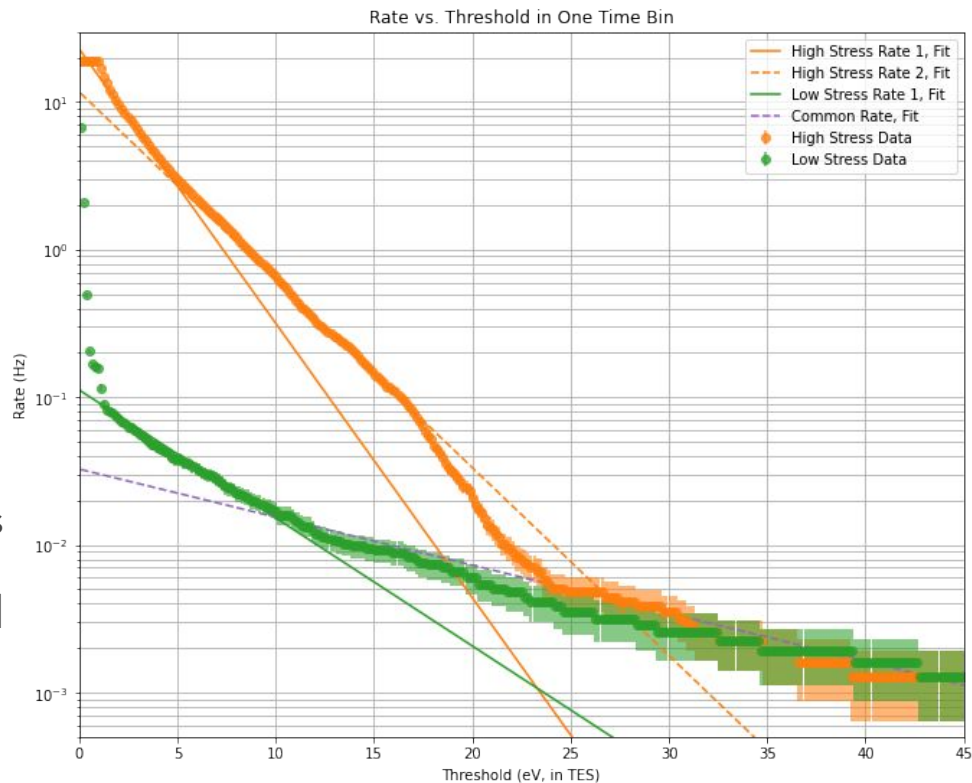
Backup: Observed Rates Time Constants

- Differing backgrounds region (low energy):
 - High stress: 6.2 ± 0.15 days
 - Low stress: 5.9 ± 0.30 days
- Similar backgrounds region (higher energies):
 - High stress: 10.3 ± 2.5 days
 - Low stress: 10.3 ± 2.4 days
- Saturated region:
 - High and low stress statistically consistent with constant w.r.t. time model



Threshold Rate Dependence

- Very large background seen in high stress detector, not seen in low stress detector
 - This is our key finding
 - As detectors are otherwise identical, we attribute this to stress events caused by glue joint
- High threshold background present in both detectors
 - 10+ eV in low stress, 25+ eV in high stress
 - But events not coincident!
- Can fit rate vs. threshold data to find extrapolated rate at zero threshold



Time Dependence in Rate

- See both common (high threshold) and unique (lower threshold) background rates decrease over time with $\tau \sim 6$ days
 - Both exponential and $1/t$ reasonable fits to data
 - Factor ~ 2 rate decrease during experiment
- Saturated (high energy) events (muons etc.) don't vary with time (as expected!)
- $<15\%$ of low energy events cut – cuts can't cause 2x rate changes

