Searching for Sub-GeV Dark Matter with TESSERACT

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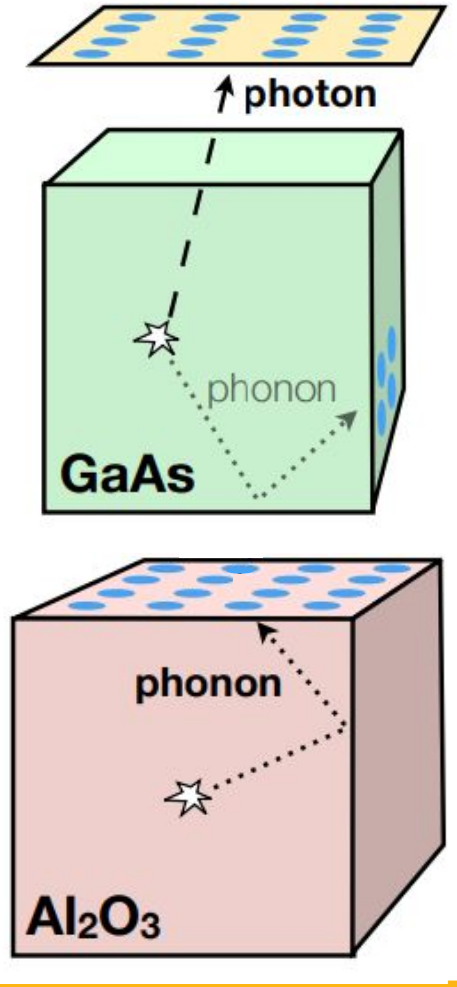
On behalf of the TESSERACT Collaboration

TESSERACT

- **T**ransition-**E**dge **S**ensors with **S**ub-**e**V **R**esolution **a**nd **C**ryogenic **T**argets
  - ~40 collaborators/10 Institutions
  - Direct search for low-mass dark matter
  - Multiple target materials with the same TES readout
    - SPICE: GaAs and sapphire
    - HeRALD: superfluid ^{4}He

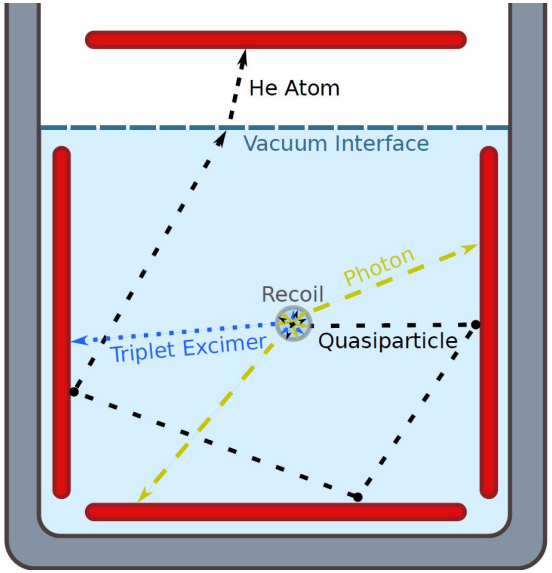
SPICE

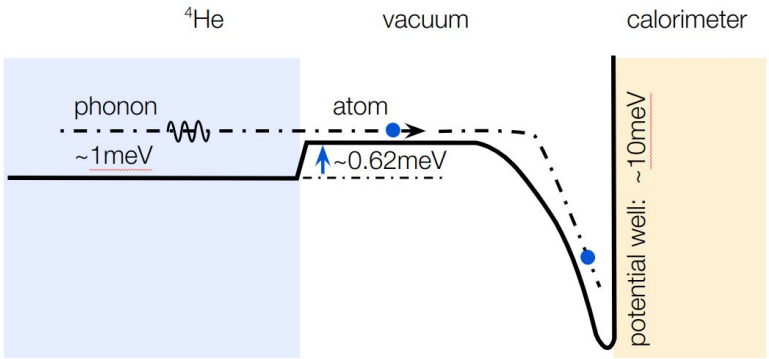
- Low-mass dark matter search using polar crystal targets
  - Gallium Arsenide
    - ~1.5 eV band gap kinematically favorable!
    - Phonon/Scintillation signal
    - High light yield (125 ph/keV!)
  - Sapphire (Al_2O_3)
    - Phonon signal
  - Optical phonon modes: sensitive to dark photons!



HeRALD

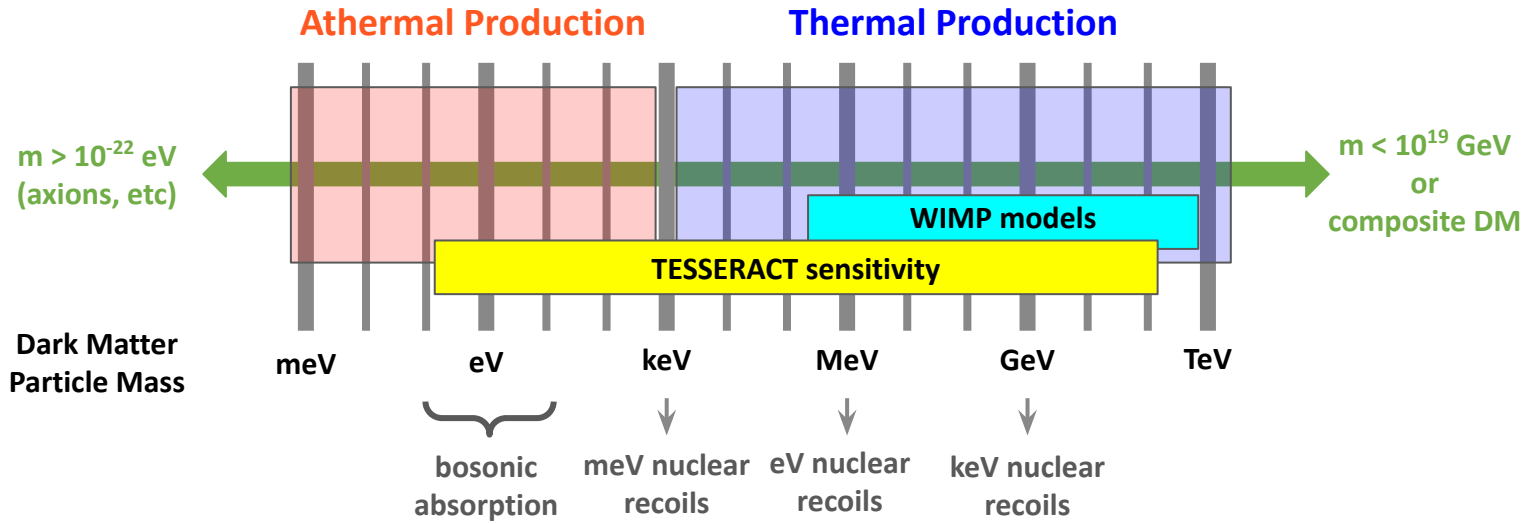
- Low-mass dark matter searches using superfluid He-4 target
  - Nuclear mass kinematically favorable
- 3 Signals (NR/ER discrimination):
  - Quantum Evaporation
    - He-4 atom ejected from surface
    - Van der Waals potential amplifies!
  - Singlet Scint. Photons (τ < 10 ns)
  - Triplet Dimer Deexcitations (τ = 13 s)
    - Only seen in submerged detectors

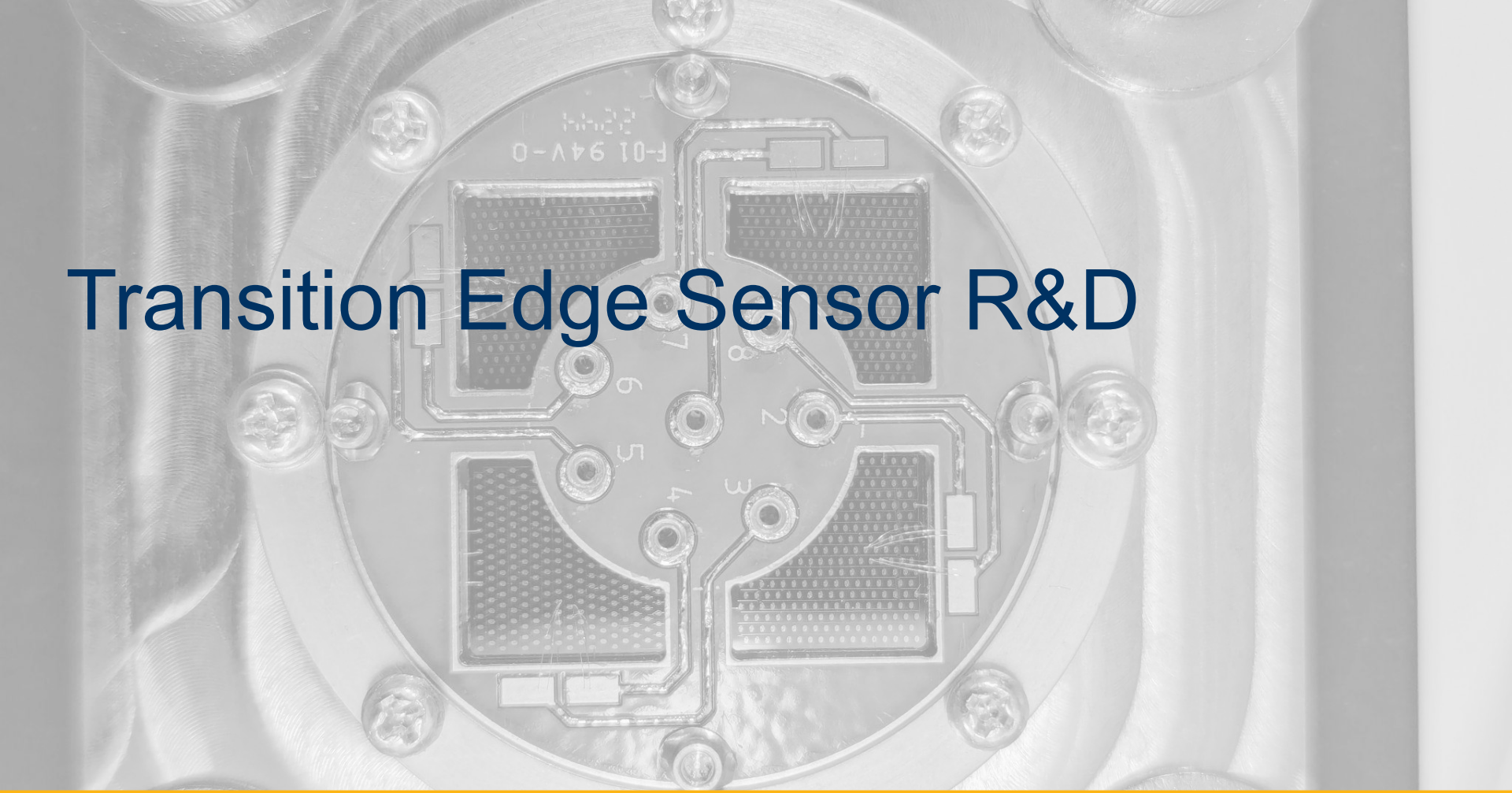




TESSERACT Sensitivity

- Multiple targets => Broad sensitivity to electron and nuclear recoils
  - Also sensitive to eV-scale bosonic absorption!

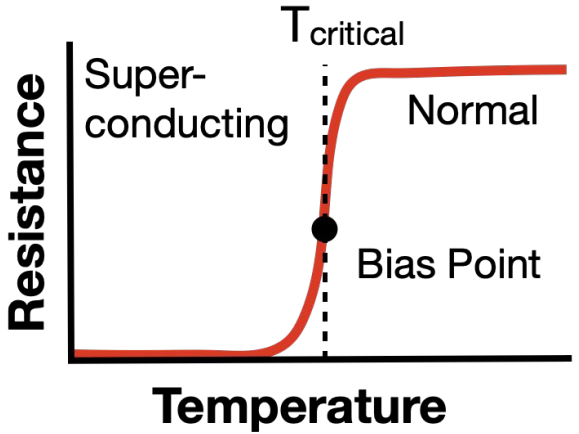


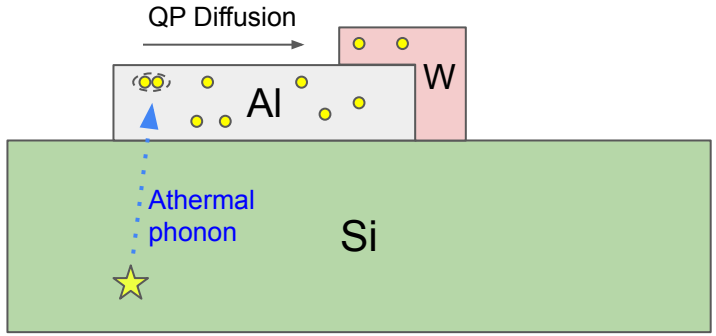


Transition Edge Sensor R&D

Transition Edge Sensors (TES)

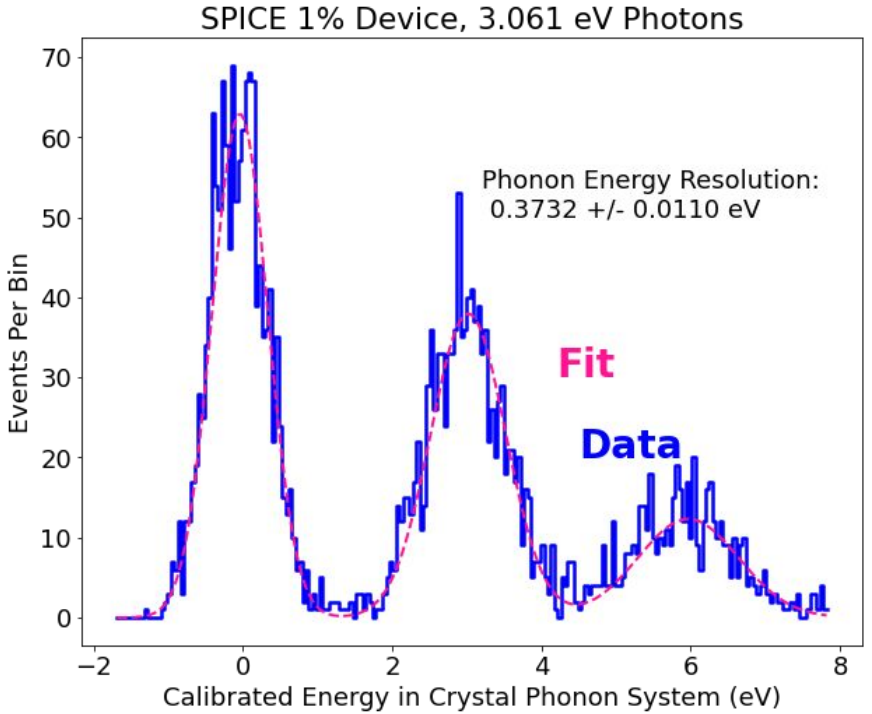
- Steep T vs R of superconductors' transitions
  - Make a great calorimeter!
- Energy resolution scales with $V_W^{1/2}$, making large areas hard to instrument
  - Si calorimeters convert signal to athermal phonons
  - Phonons break cooper pairs in Al, forming QPs
  - QPs diffuse into W, and thermalize, raising T
  - Measured as change in current





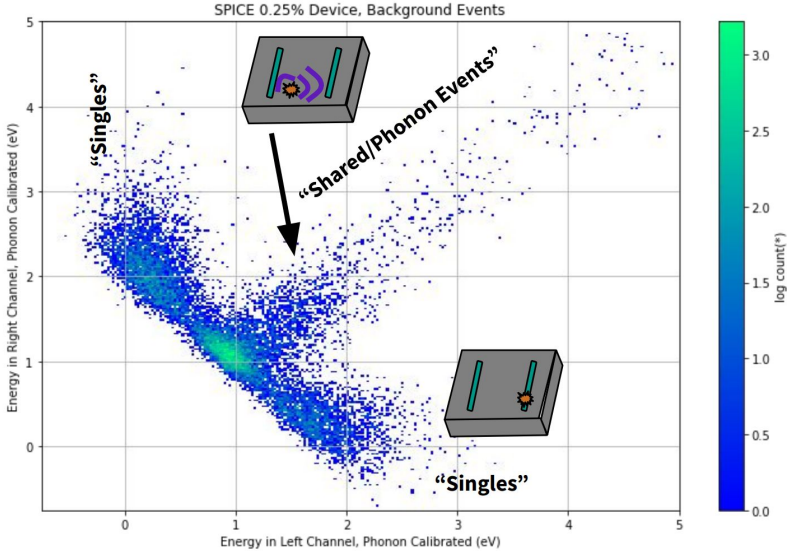
W TES Energy Resolution

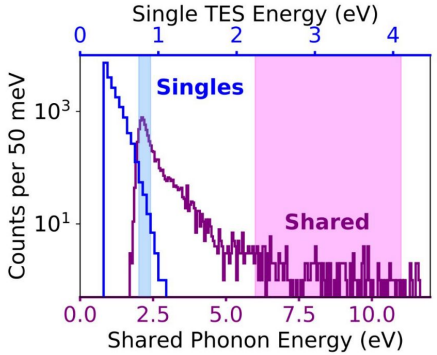
- W(50 mK; 1% coverage) w/ Al Fins
  - Mounted on Si calorimeter
- Photons injected into fridge through optical fiber
  - 373 meV phonon resolution!
  - Clear discrimination between 1/2 photons!
- Most sensitive phonon detection to date!

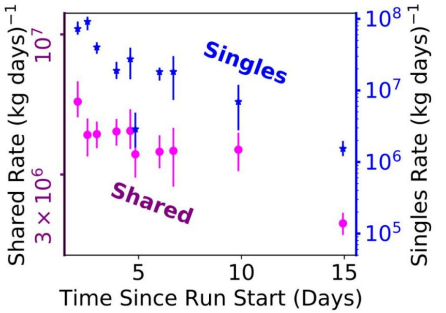


Low-Energy Excess (LEE)

- Surplus of low-energy events seen in all detectors…
- 2 independent TES on 1 calorimeter:
  - No source
  - ‘Shared’ and ‘single’ event bands
    - w/ different energy scales?
  - Event rate decays in time?

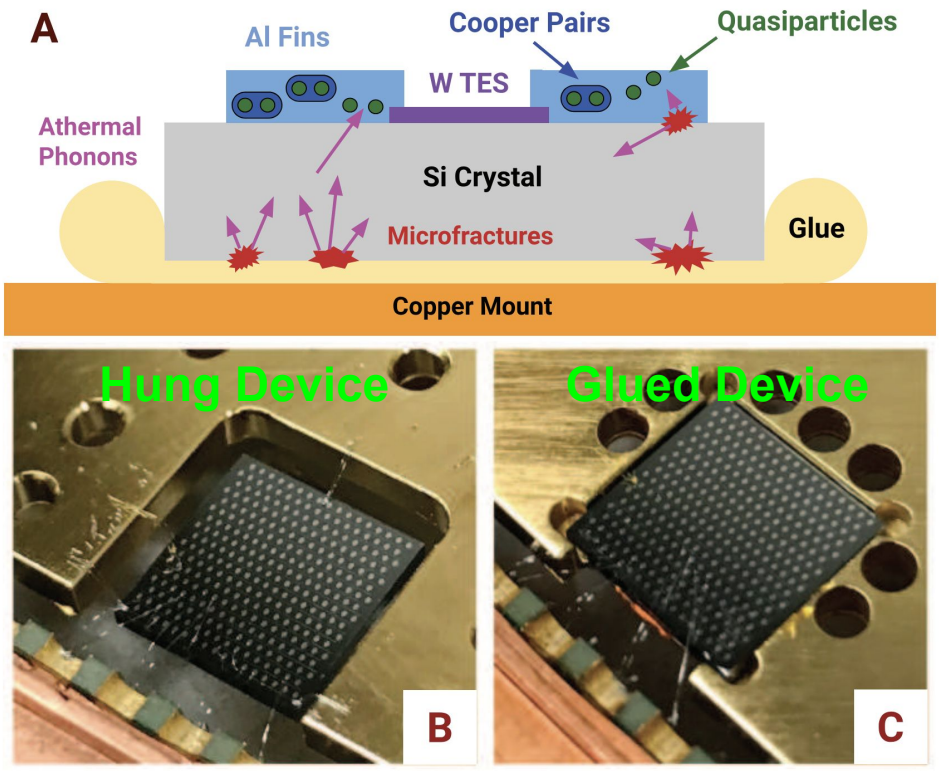






Low-Energy Excess

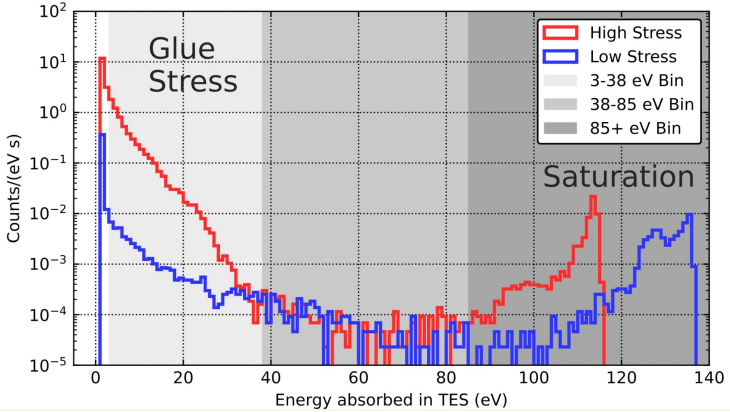
- Solution #1: Understand and prevent LEE
- Hypothesis: LEE due to microscopic stress relaxations?
- Test: Compare 2 similar devices
  - Calorimeter glued to Cu
  - Calorimeter hung from wire bonds

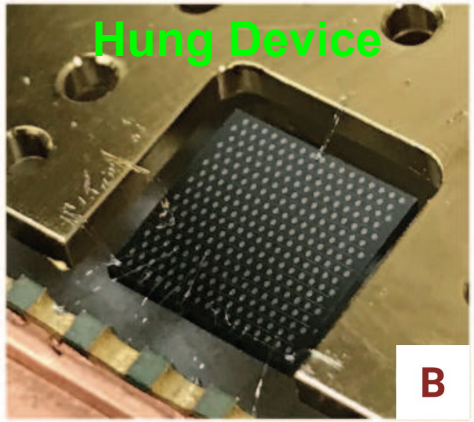


See arXiv:2208.02790

Low-Energy Excess

- Solution #1: Understand and prevent LEE
- Hypothesis: LEE due to microscopic stress relaxations?
- Test: Compare 2 similar devices
  - Calorimeter glued to Cu
  - Calorimeter hung from wire bonds
- Strong reduction in LEE-like event rate in hung devices!

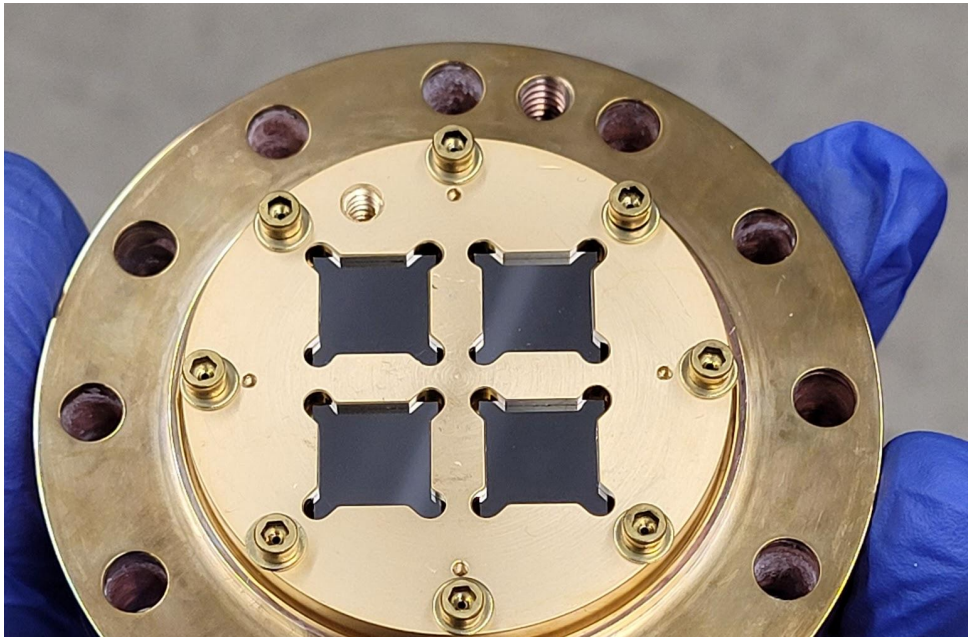




See arXiv:2208.02790

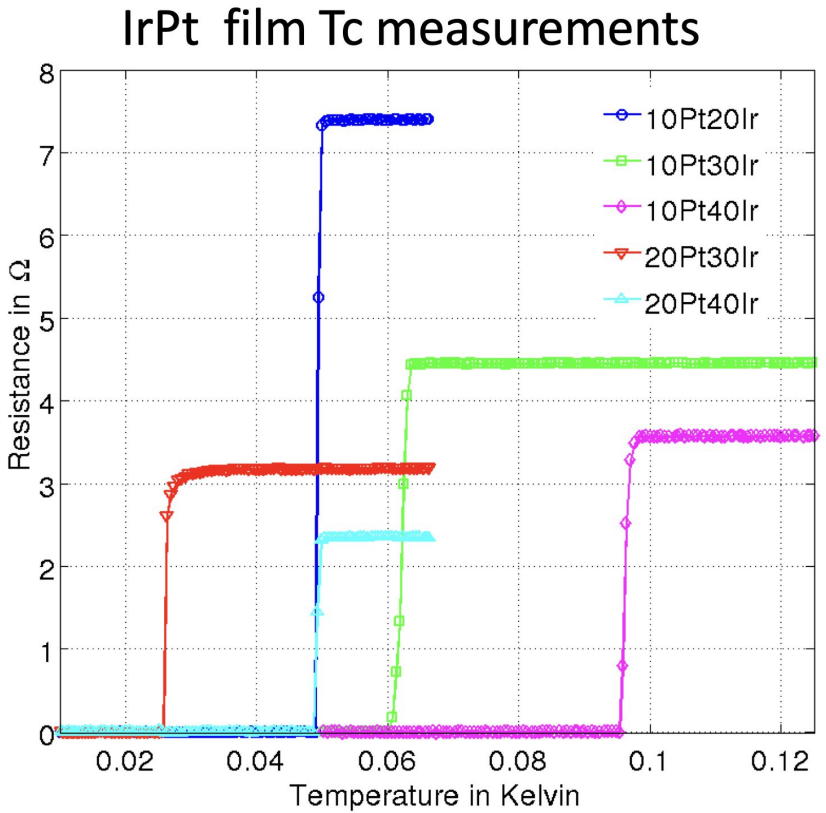
Low-Energy Excess

- Solution #2: Coincidence and discrimination
  - LEE occurs entirely within a calorimeter
  - Have multiple detectors per target; require coincidence



Ir/Pt TES Development

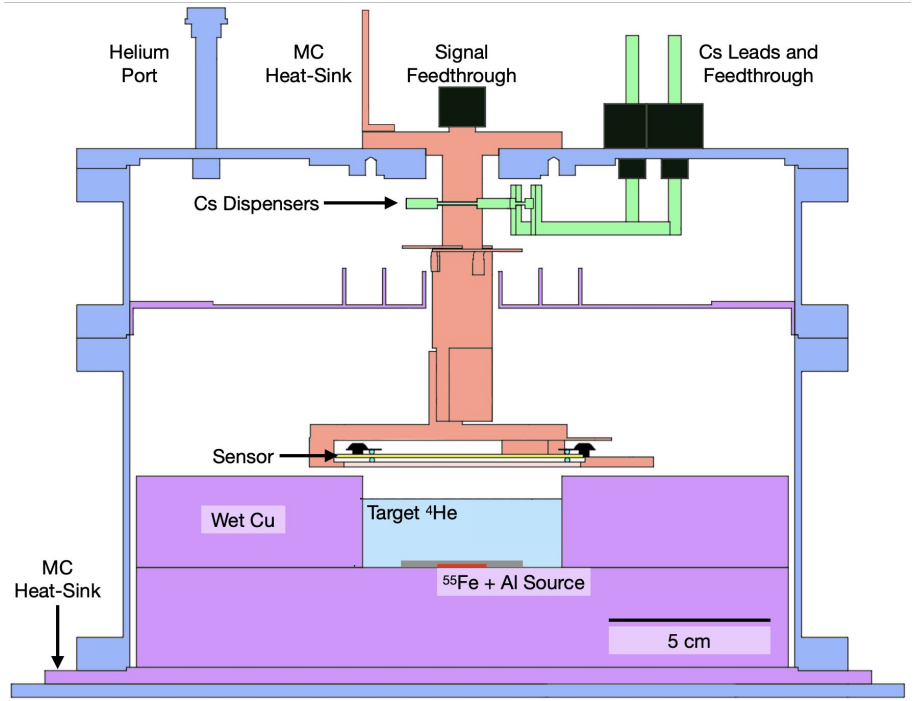
- Solution #3: look for new detectors less subject to LEE?
- Alternative to W film: Ir/Pt bilayer
  - Changing relative thicknesses allow tuning of T_C
- LEE Results forthcoming!



Dark Matter Search R&D

HeRALD @ UMass Amherst

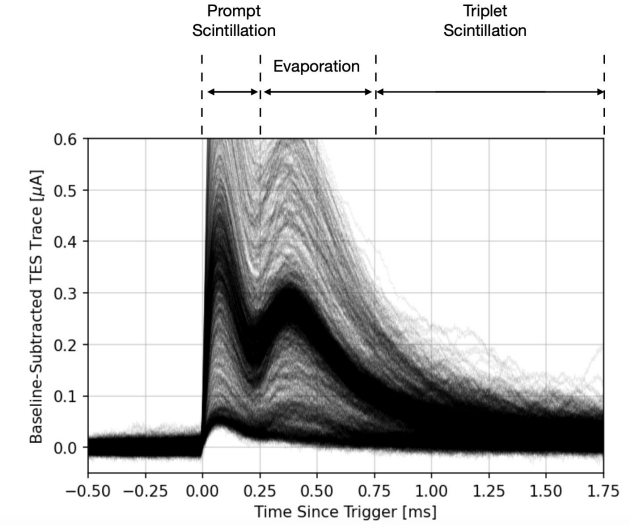
- ~10 g of ^{4}He
  - Single detector above He Surface
- Superfluid ^{4}He forms Rollin films, creeping up most surfaces
  - ^{4}He won't wet Cs
  - Use Cs dispenser to prevent ^{4}He from coating the detector

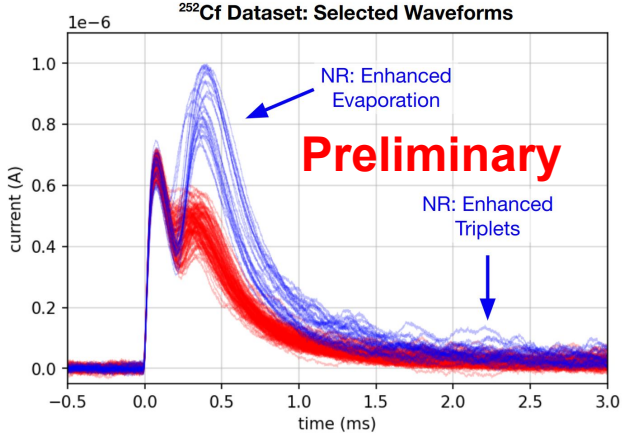


See arXiv:2307.11877

HeRALD @ UMass Amherst

- Internal ^{55}Fe source (5.9 keV) w/ layer of Al foil (1.5 keV x-ray)
  - Singlet/Evaporation signals are distinguishable
  - Clear separation between the two x-rays
- ^{252}Cf source (~MeV neutrons; gammas)
  - Nuclear recoils exhibit more evaporation; triplet scintillation
  - Great for ER/NR discrimination!

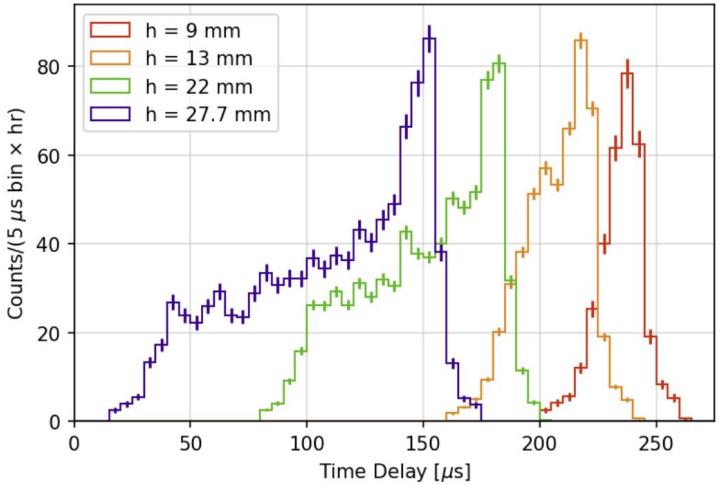




See arXiv:2307.11877

HeRALD @ UMass Amherst

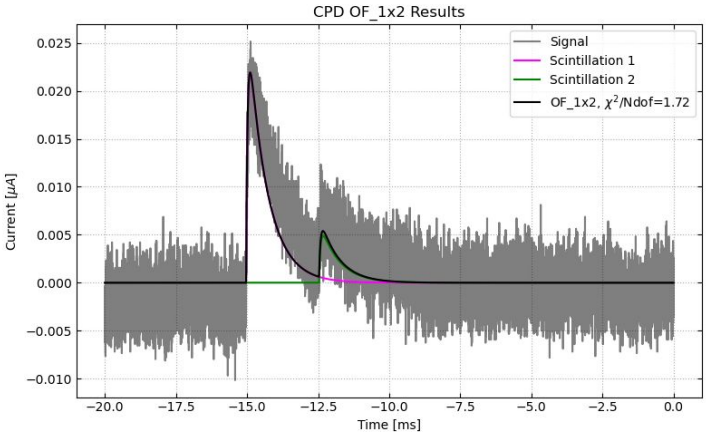
- ^{55}Fe data taken with multiple ^{4}He heights
  - Delay between prompt scintillation and delayed evaporation gives speeds:
    - Ejected ^{4}He atoms: ~200 m/s
    - Quasiparticles in He: ~100 m/s
  - Knowledge of microphysics allows us to develop/tune simulations:
    - QP speeds
    - Reflection probabilities
    - Evaporation Parameters

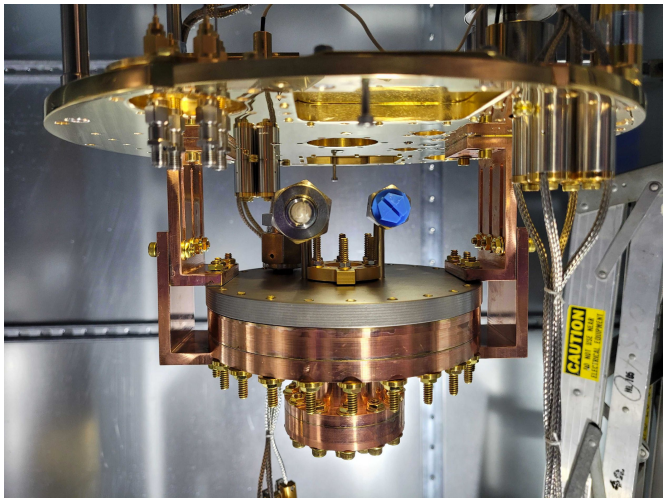


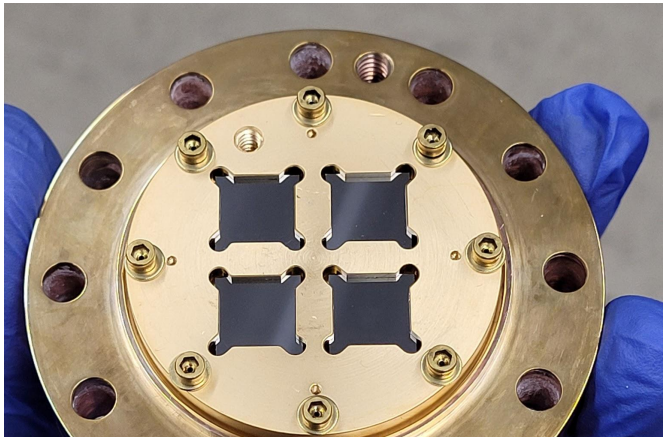
See arXiv:2307.11877

HeRALD @ LBNL

- ~10 g of ^{4}He
  - 4 detectors above the He surface
  - 4 detectors submerged (triplet signals)
- Currently calibrating TES w/ CaF_2 crystal
  - Next steps: fill with ^{4}He and calibrate!

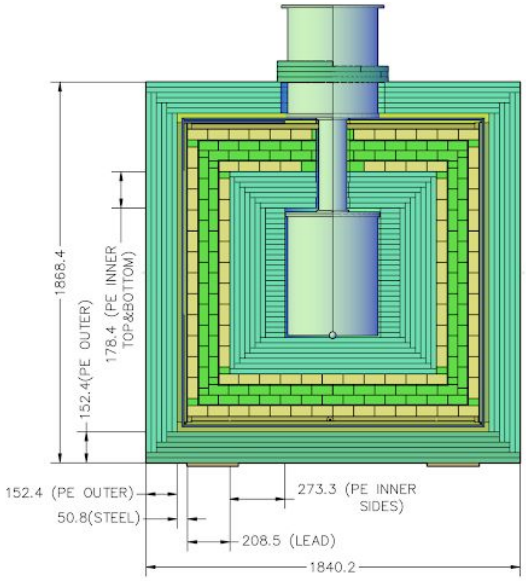


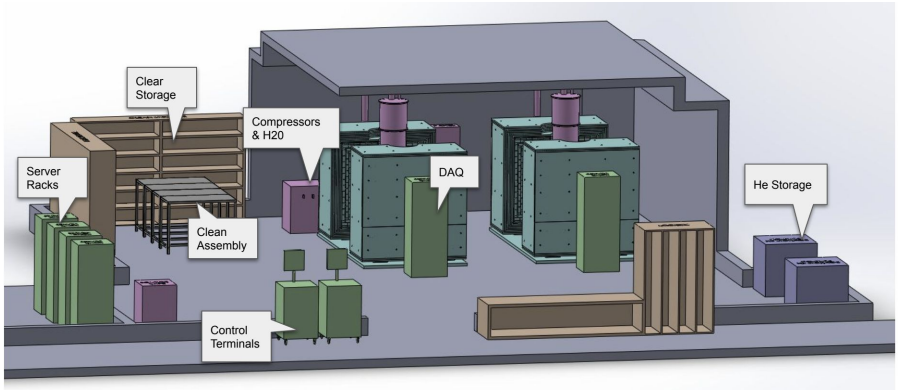




Moving Underground

- End goal: Long-term dark matter search underground
  - 100-1000 g target masses
- Multiple targets = Multiple underground labs?
  - Site #1: Modane in France (w/ DOE funding)
- Multilayer passive shielding
  - Borated polyethylene: neutrons
  - Lead: gamma rays
- Target: 1 DRU Backgrounds





Summary

- Search for low-mass dark matter
  - SPICE: GaAs/Sapphire targets
  - HeRALD: Superfluid ^{4}He target
- TES-based readout
  - Attacking LEE on multiple fronts
- HeRALD demonstrated in 1 setup (2 soon!)
- Eager to move underground **soon** for extended, low-background searches!

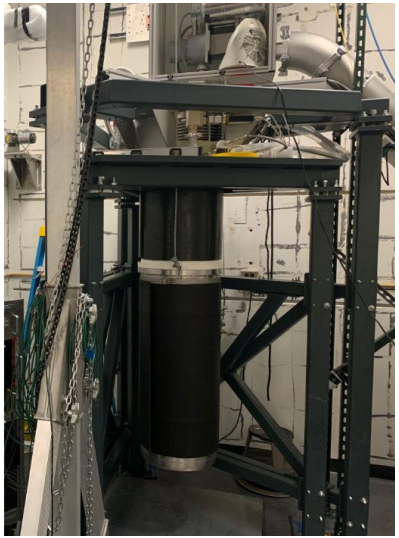
Extra Slides

R&D Testbeds

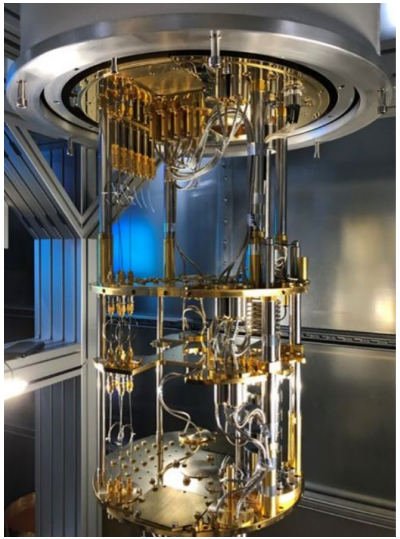
- 5 dilution fridges for TESSERACT R&D
  - One more being commissioned @ KEK!

Leiden MNK126-500
@ UCB

Cryomech UQTB-200
@ UCB

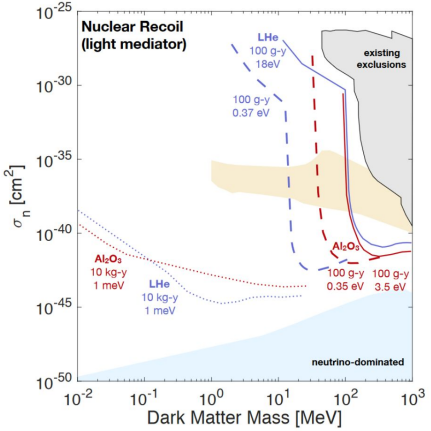


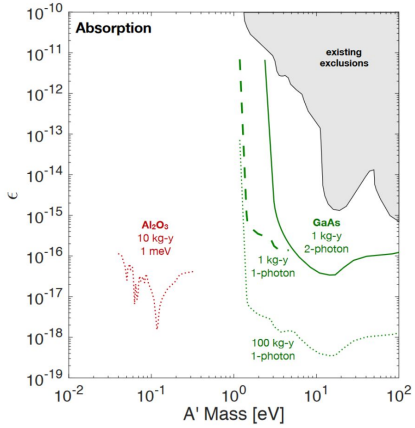
Bluefors LD400
@ LBL (x2)

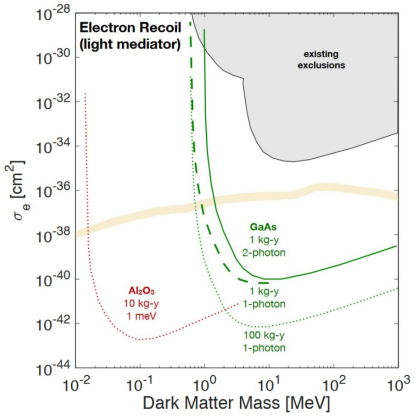


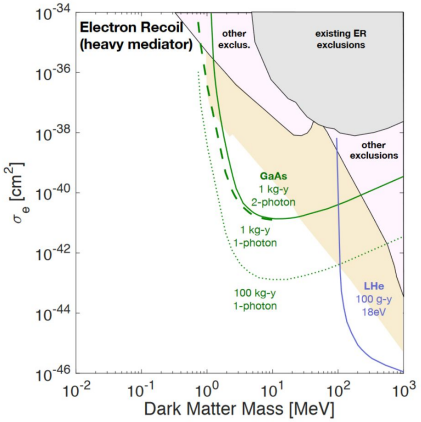
Cryomech UQTB-400
@ UMass Amherst

Projections









2-channel, .25% Device

- 3 eV photons injected via optical fiber