UNIVERSITY OF MICHIGAN

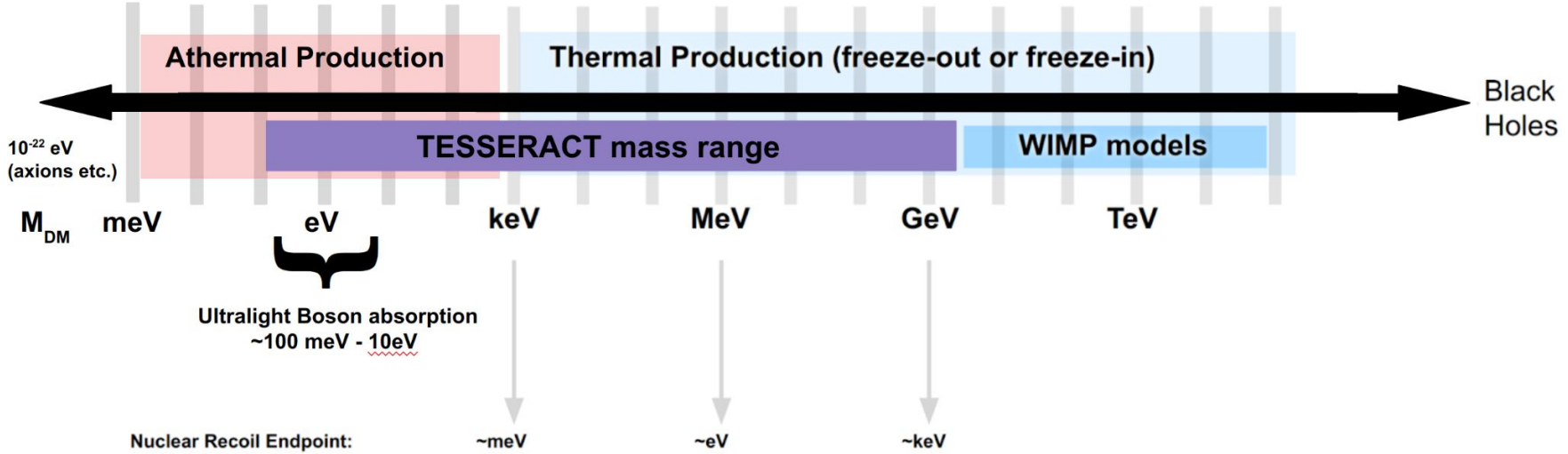
TESSERACT

Research and Development for the TESSERACT Experiment

Michael Williams
On Behalf of the TESSERACT Collaboration

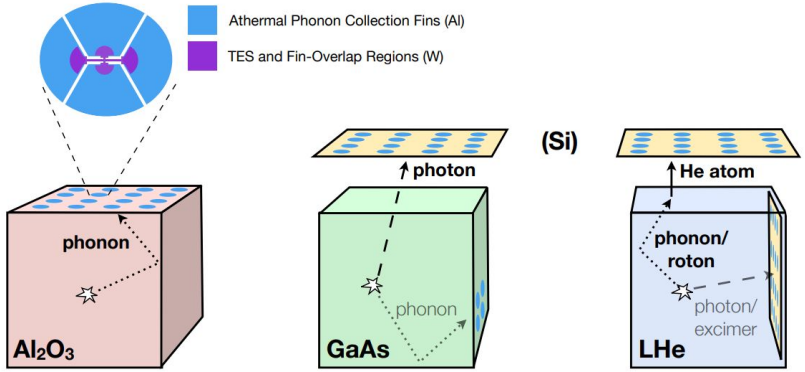
CPAD 2023
7th-10th November, 2023

Low Mass Dark Matter



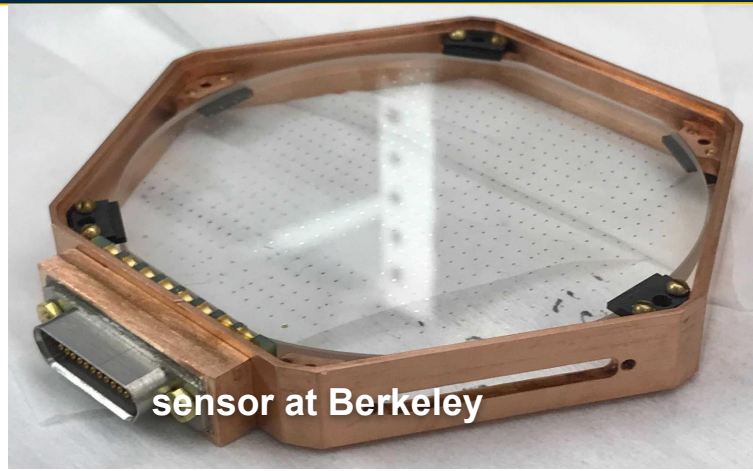
- Sub-GeV dark matter consistent with thermal production and freeze out after inflation (similar to WIMPs)
- Ultralight Bosonic DM is another viable candidate for DM
- Like WIMPs, these particles can recoil off electrons or nucleons or be absorbed and make signals that detectors can measure
- An experiment that has low threshold and multiple targets is ideal - TESSERACT!

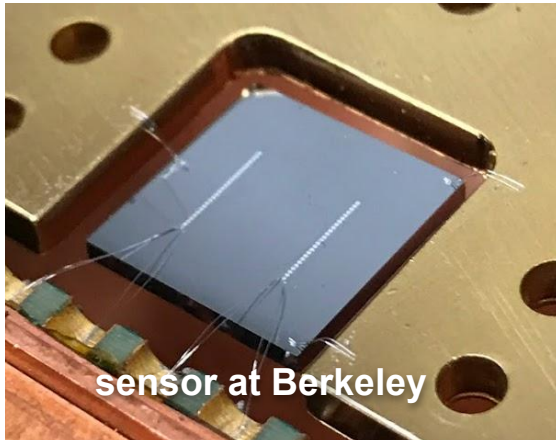
- Collaboration of ~40 people from 9 institutions
- Searching for low mass DM
- Use of three detector targets
- TES readout



SPICE - Polar Crystals

- **Sapphire** (Al_2O_3):
  - **Sapphire** supports optical phonon modes.
  - DM recoiling off the lattice, ‘exciting a **phonon’**
  - Coupling to E&M-like inputs due to electric dipole → **dark photon sensitivity**

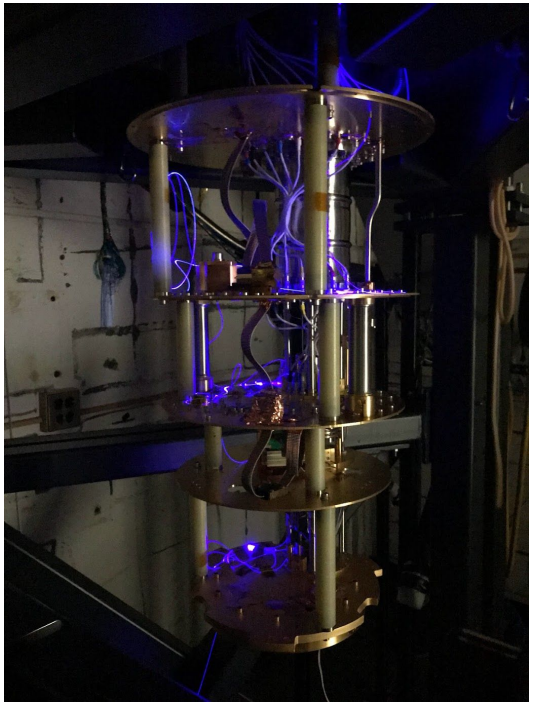


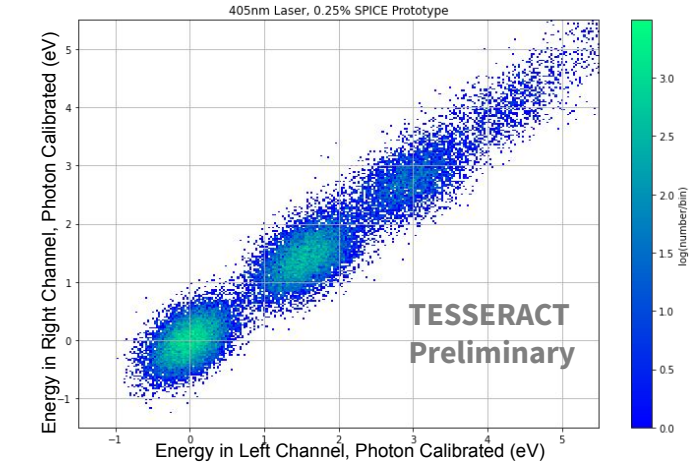


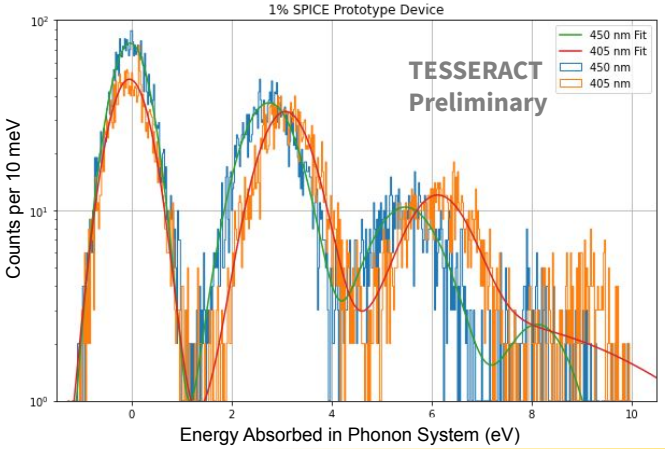
- **GaAs**:
  - **Polar crystal** & **bandgap** well matched to kinematic region of low mass DM
  - **Background discrimination** using phonon/photon ratio
  - Photon-photon and phonon-phonon coincidence can reduce instrumental bkgds
  - High light yield (125 ph/keV, 1904.09362)

Photon Calibration System

- Fiber optic system designed to send in short photon bursts directly onto detector
- ~3eV photons with known trigger - low energy pulse shape measurements!
- We see single photons mediated through phonons!
- Calibrate the energy response to the known photon energy
- First of its kind result!



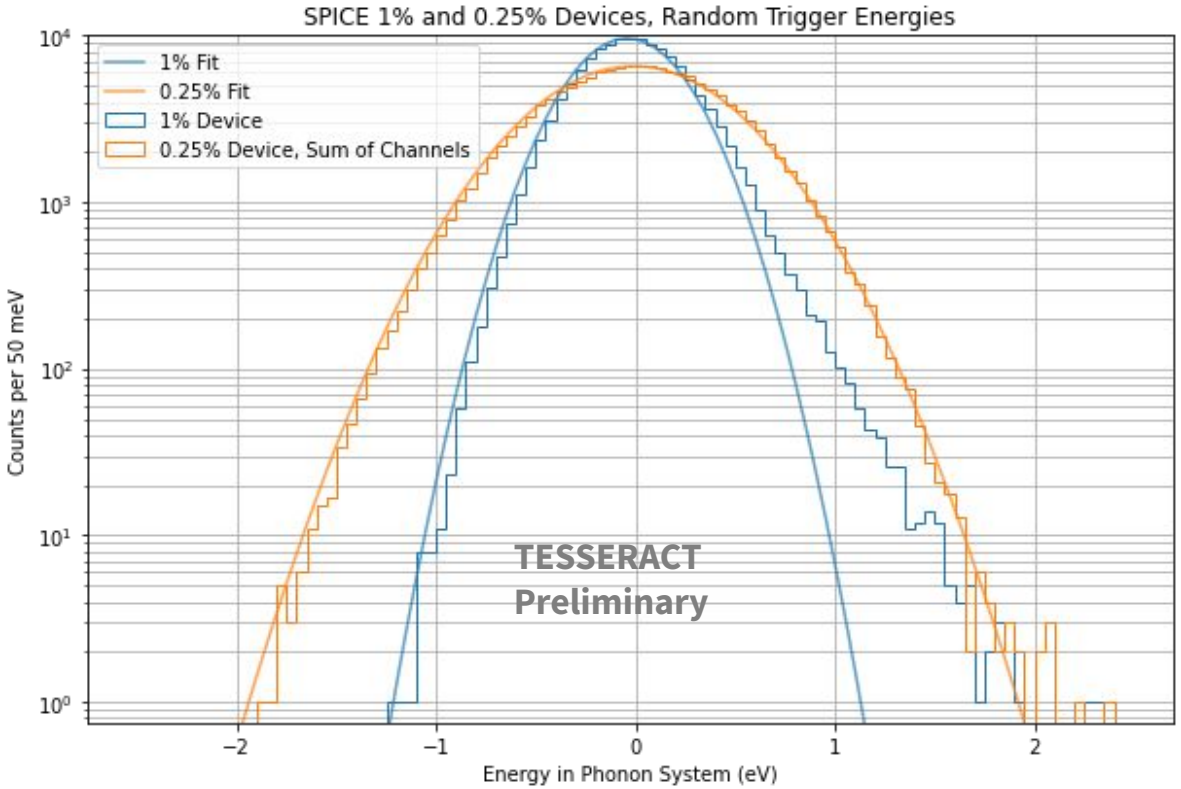




World Leading Energy Resolution

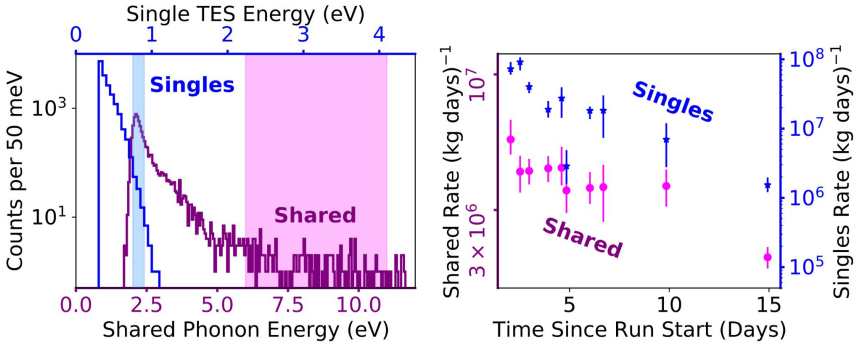
- Two different coverage devices tested
- 1% - 273meV energy resolution in phonon system
- 0.25% - 460meV energy resolution in phonon system
- First of it's kind results and the most sensitive TESs tested to date!
- 5x more sensitive than nearest competitors!

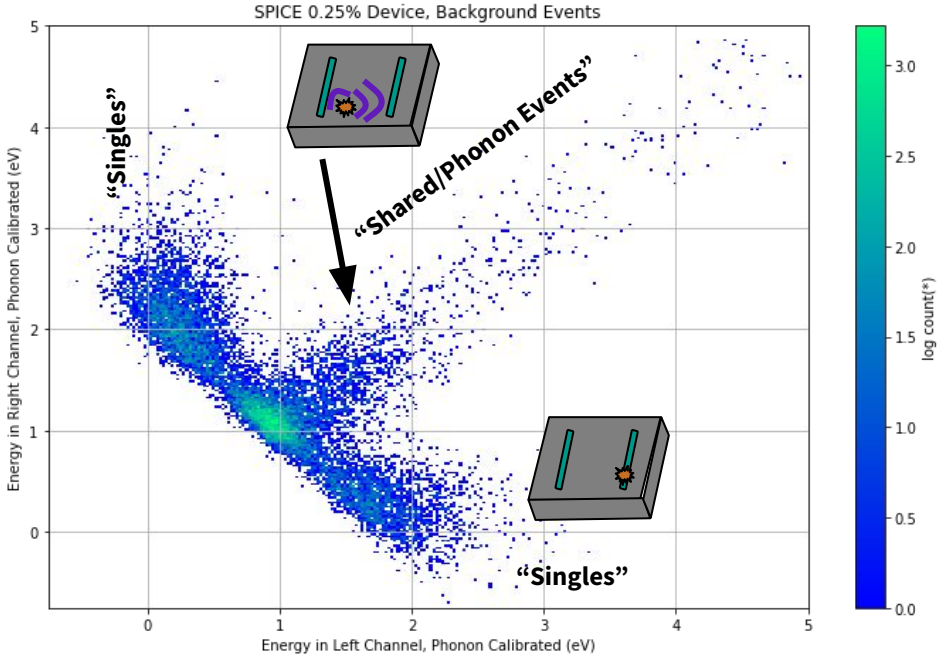
See R. Romani's talk
Session RDC 7+8 11/09 16:00!



Understanding the Low Energy Excess

- “LEE” is known problem in the field
- By using two channels on same substrate we can find a way to understand the sources
- Singles and shared events both go down over time - singles faster
- Evidence to suggest this excess contributes to excess power noise





See R. Romani’s talk
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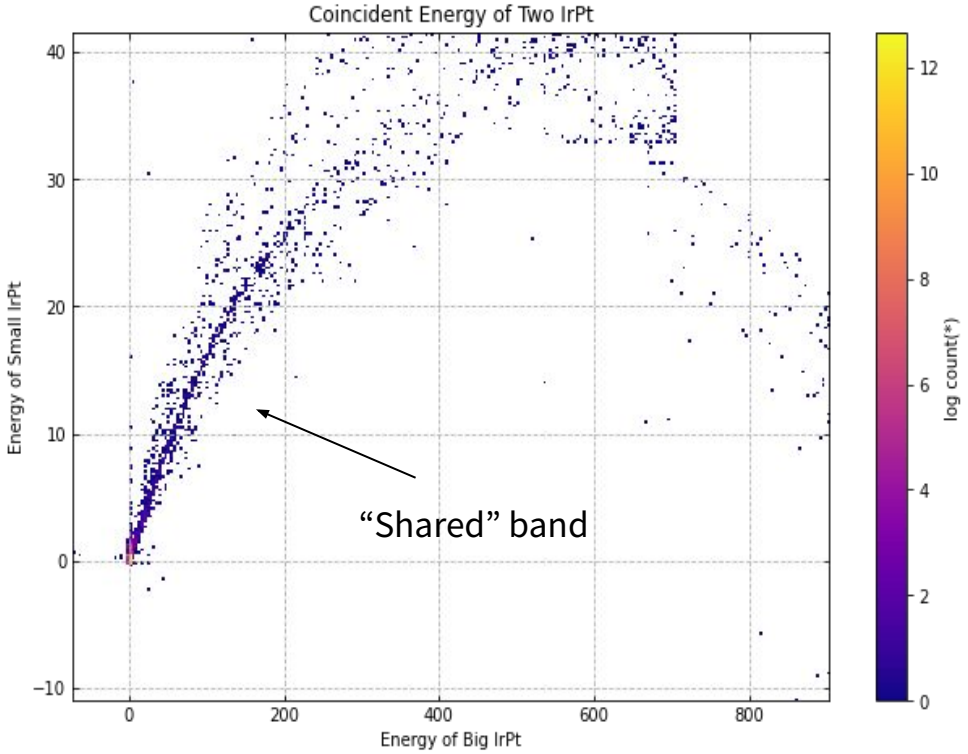
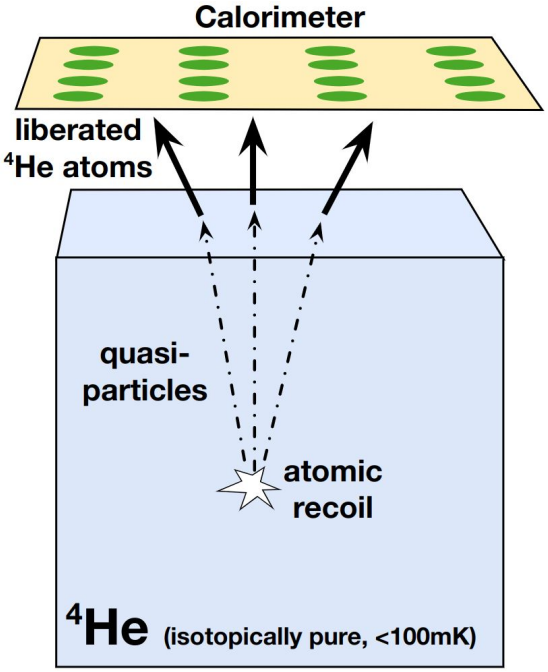
New IrPt TES for Dark Matter

- Spurred by LEE, development of new devices is critical
- IrPt bilayer devices allow tunable Tc -> better resolution
- Measure device characteristics of two different dimension TESs
  - AC/DC responses
- Look for “single” and “shared” events and measure rates
- New ~100meV energy resolution devices!
- Interesting characteristics found in spectrum!

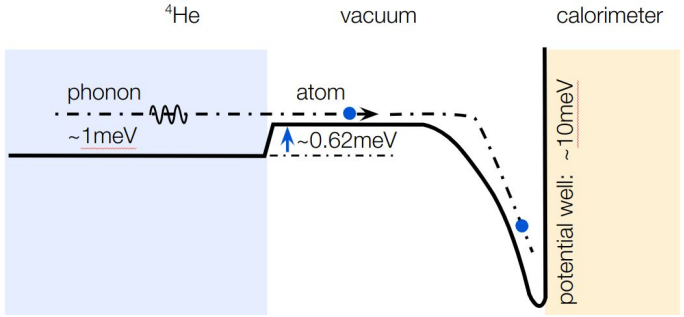


See M. Reed’s talk
Session RDC 7 11/08 16:45!

HeRALD - Superfluid He4

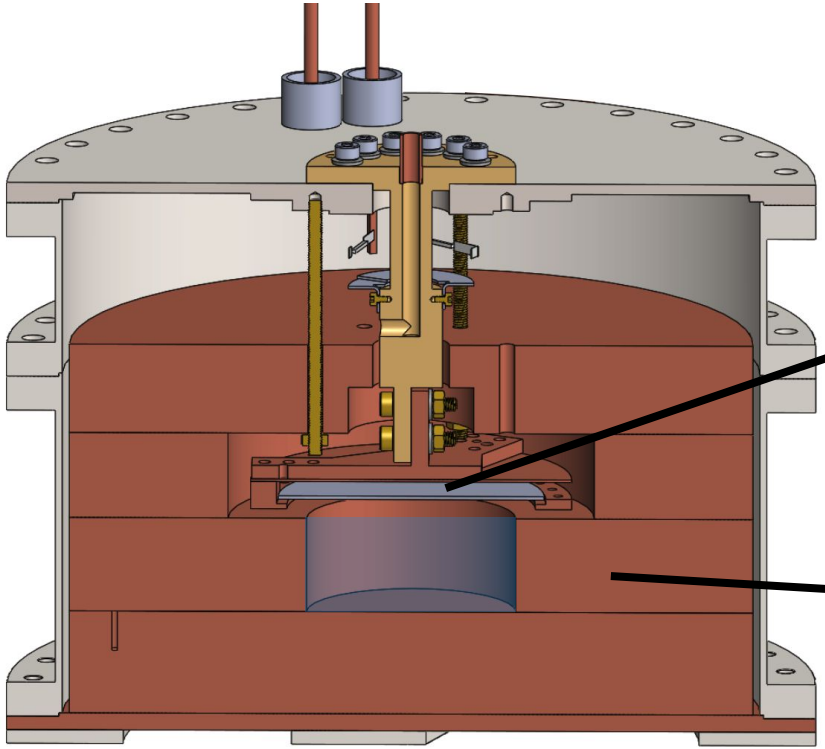


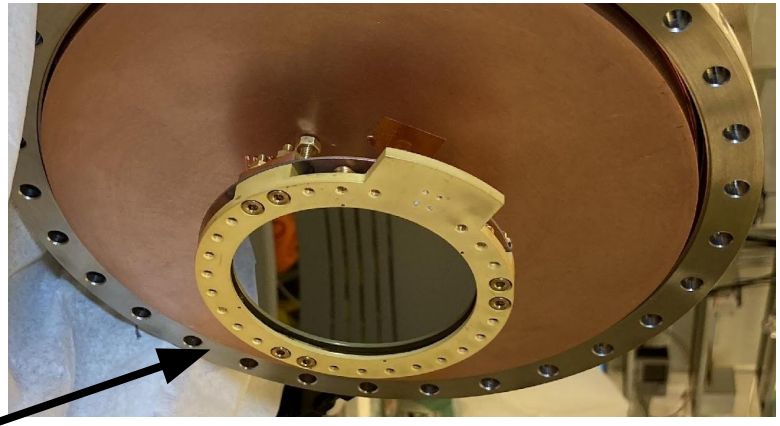
- Primary Signal Channel: Prompt Photon
- Secondary Signal Channel: Quantum Evaporation
  - A single quasiparticle may liberate a single atom from liquid surface
  - Phonon energy in He-4: ~ 1 meV
  - Atomic binding energy: 0.62 meV
- Signal from the binding of He atoms onto the surface of the calorimeter
  - Typical binding energy: 10 meV

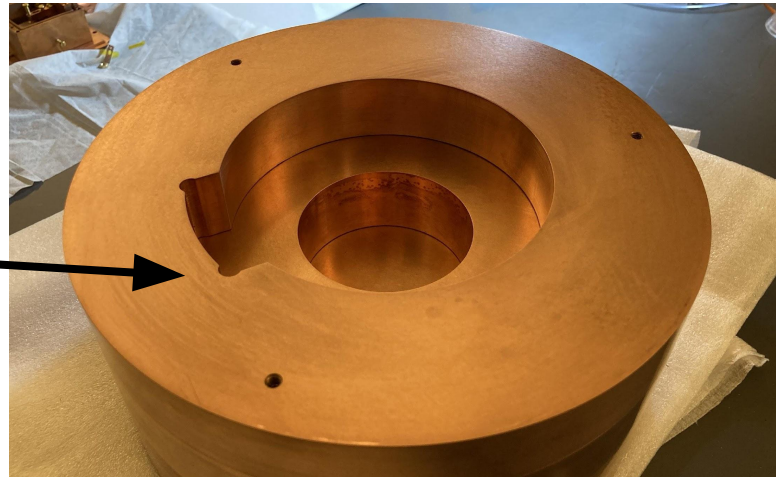


UMass HeRALD v0.1

arXiv:2307.11877

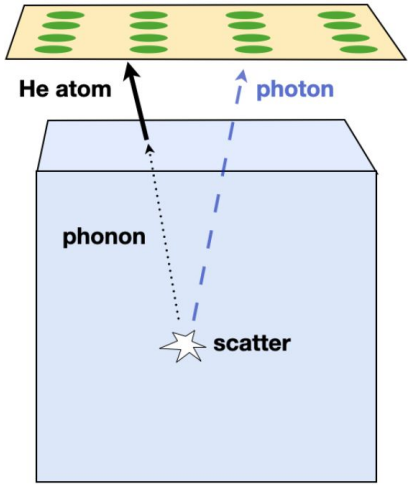


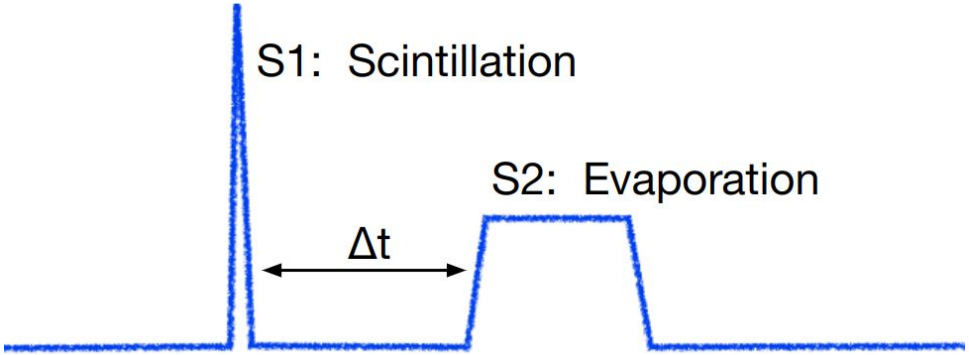




Signals in LHe

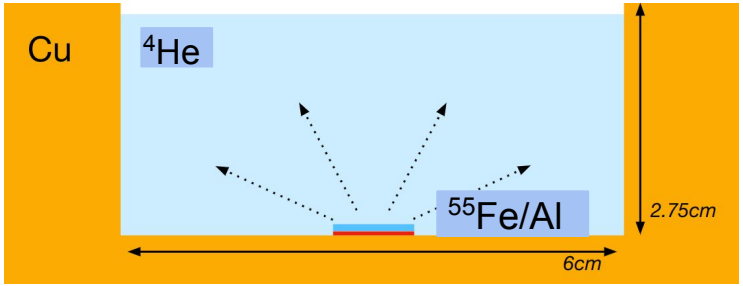
- Signals are analogous to Xe dual phase TPCs
  - S1 - prompt scintillation (singlets)
  - S2 - evaporation

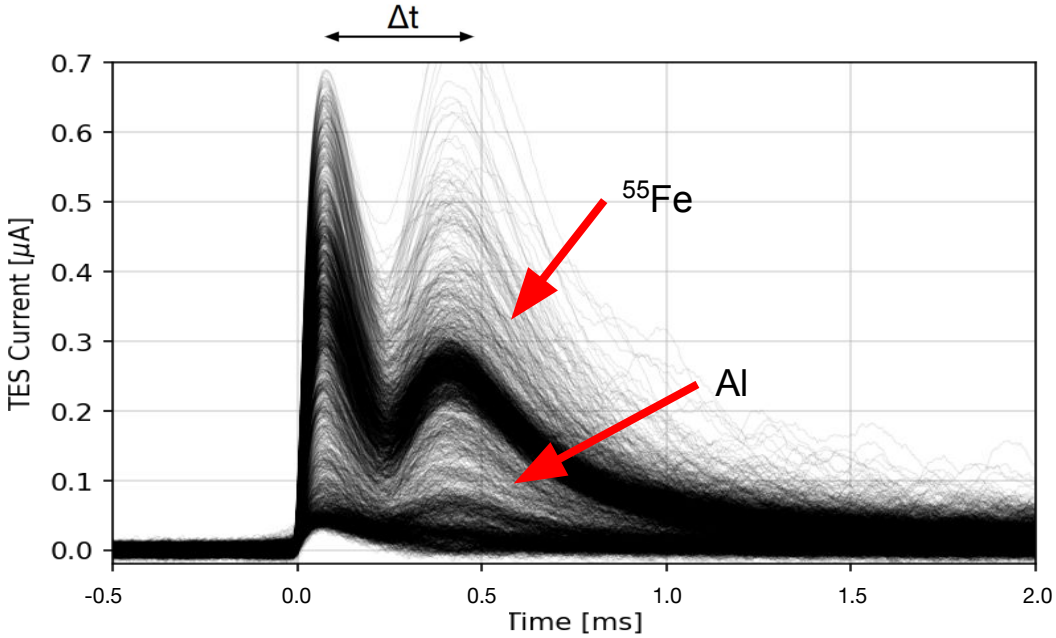




Measured Signals

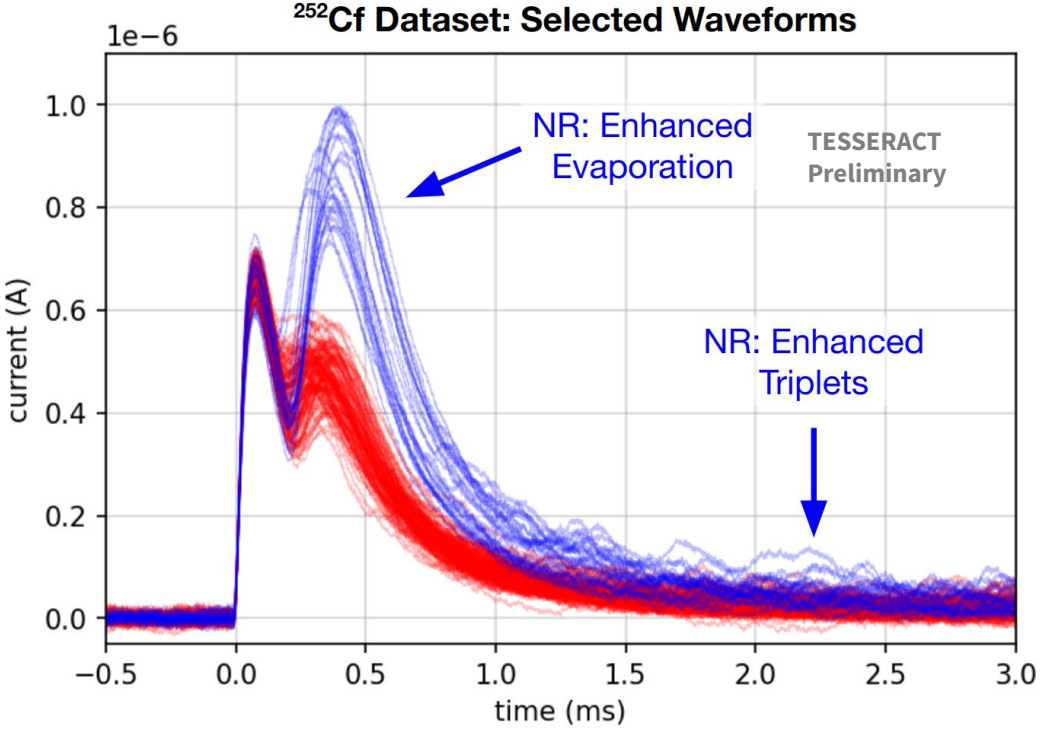
- Wanted two pulses - got two pulses!
- Pulses from a low energy x-ray source
  - ^{55}Fe 5.9 keV
  - Al 1.5 keV





Comparing ER/NR Response

- Use Cf-252 for n and γ
- Larger evaporation to scintillation ratio for neutrons
- Larger triplet fraction
  - Above ~10 keV

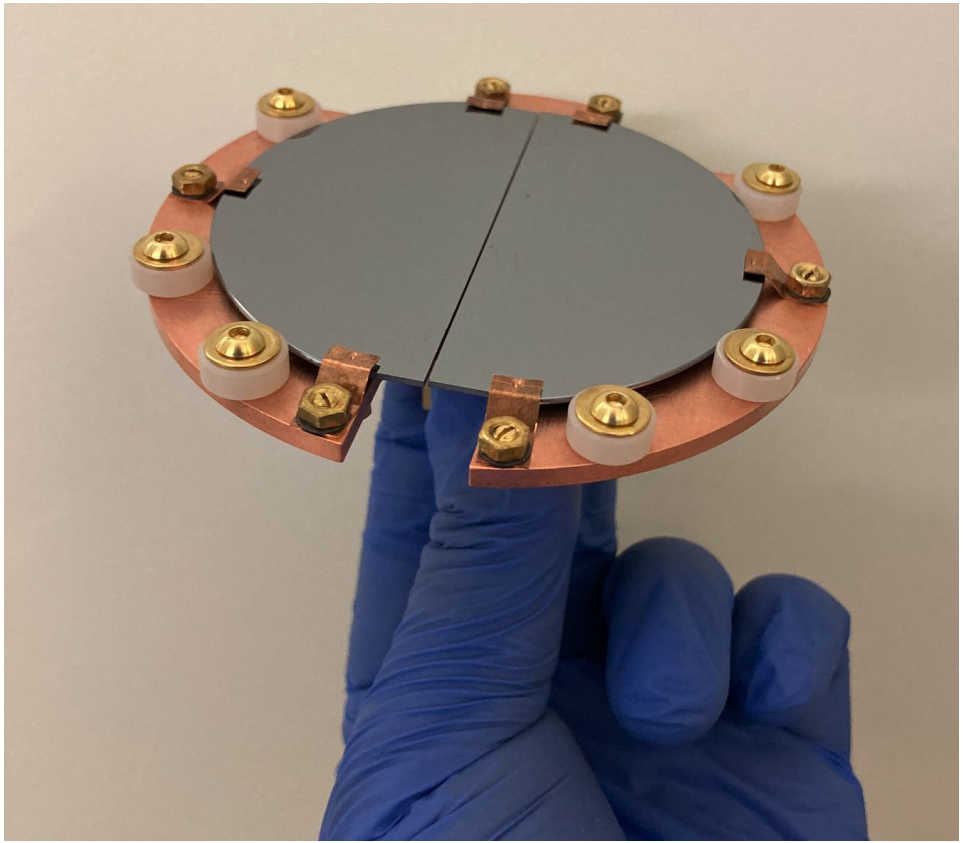


Red - ER

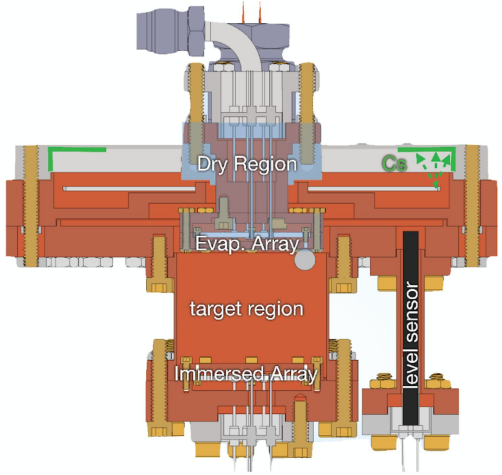
Blue - NR

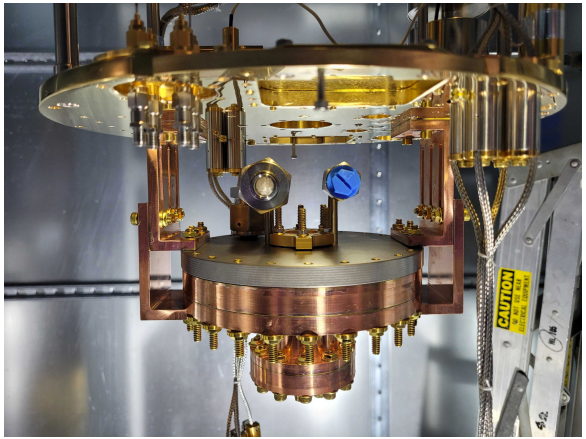
Coming HeRALD Tests at UMass

- New split CPD being used now!
- Hope to lower threshold with LEE rejection!



HeRALD v0.2



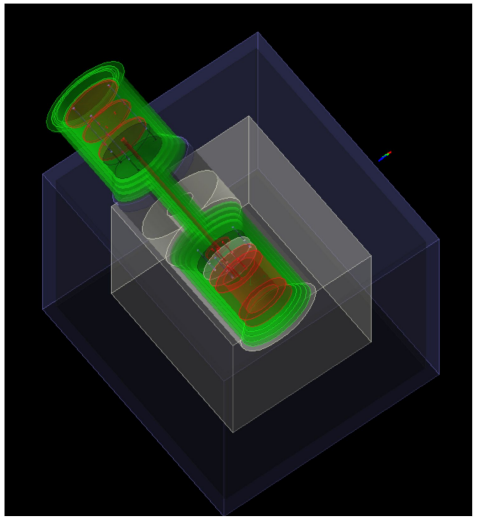


- New DR installed at LBNL will serve as testbed for helium detectors
- 4 immersed and 4 suspended calorimeters
  - Important to reject LEE events!
- Calibrations with immersed x-ray source and compton scatters

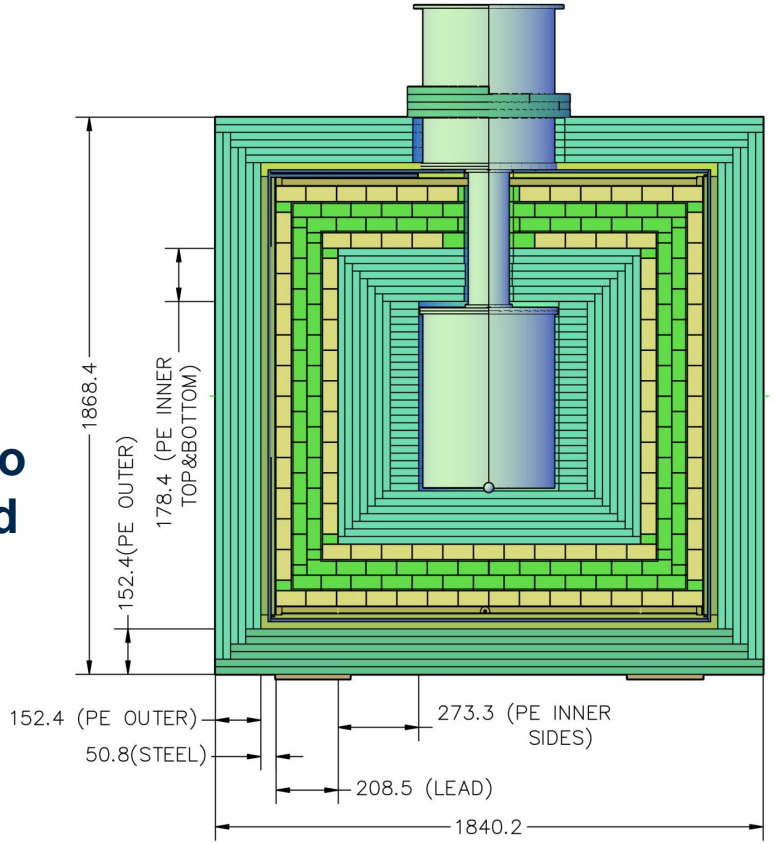
See V. Velan's talk
Early Career session 11/09
9:30!

Bringing It Together Underground

- Novel shielding concept: **TESSERACT Design**
  - Simulated in various underground labs
  - **1.2 DRU** at 1 keV
  - About **0.75 DRU** with **ancient lead**
- **Advanced design** considering fabrication, installation, operations, budgeting & underground constraints



We plan to go underground soon!



Summary

- TESSERACT brings together multiple novel detectors to search for low mass dark matter
- SPICE uses polar crystals for and TESs for exceptional ER DM reach
- New optical calibration mechanism for TESs shows single photon detection and new low energy resolution
- Dual channel devices can help us understand, and potentially mitigate, LEE
  - These events may be contributing to excess power noise seen before
- HeRALD uses superfluid helium and TESs
  - HeRALD is seemingly unplagued by LEE thanks to quantum evaporation
- First proof of principle shows detection mechanism works as planned!
- Coming HeRALD runs aim to calibrate down to 1keV and below!
- TESSERACT has developed underground shielding designs for the underground detector
- Underground in the coming years! More world leading physics to follow!

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Thank you!