Performance of a Silicon SuperCDMS HVeV Detector Operated Underground at NEXUS

… and recently in Canada

Ziqing Hong, University of Toronto

On behalf of the SuperCDMS Collaboration

CAP Congress 2023

SUPER CDMS
Cryogenic Dark Matter Search

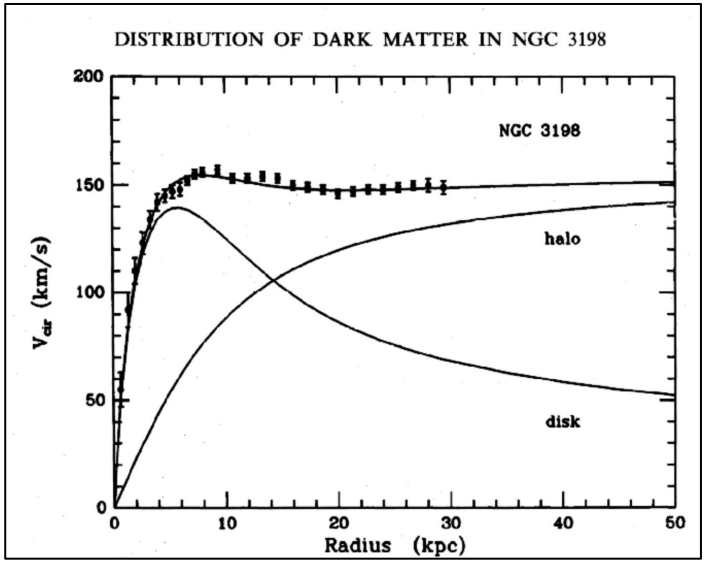
@SuperCDMS

The Evidence for Dark Matter

Gravitational Lensing

smithsonianmag.com

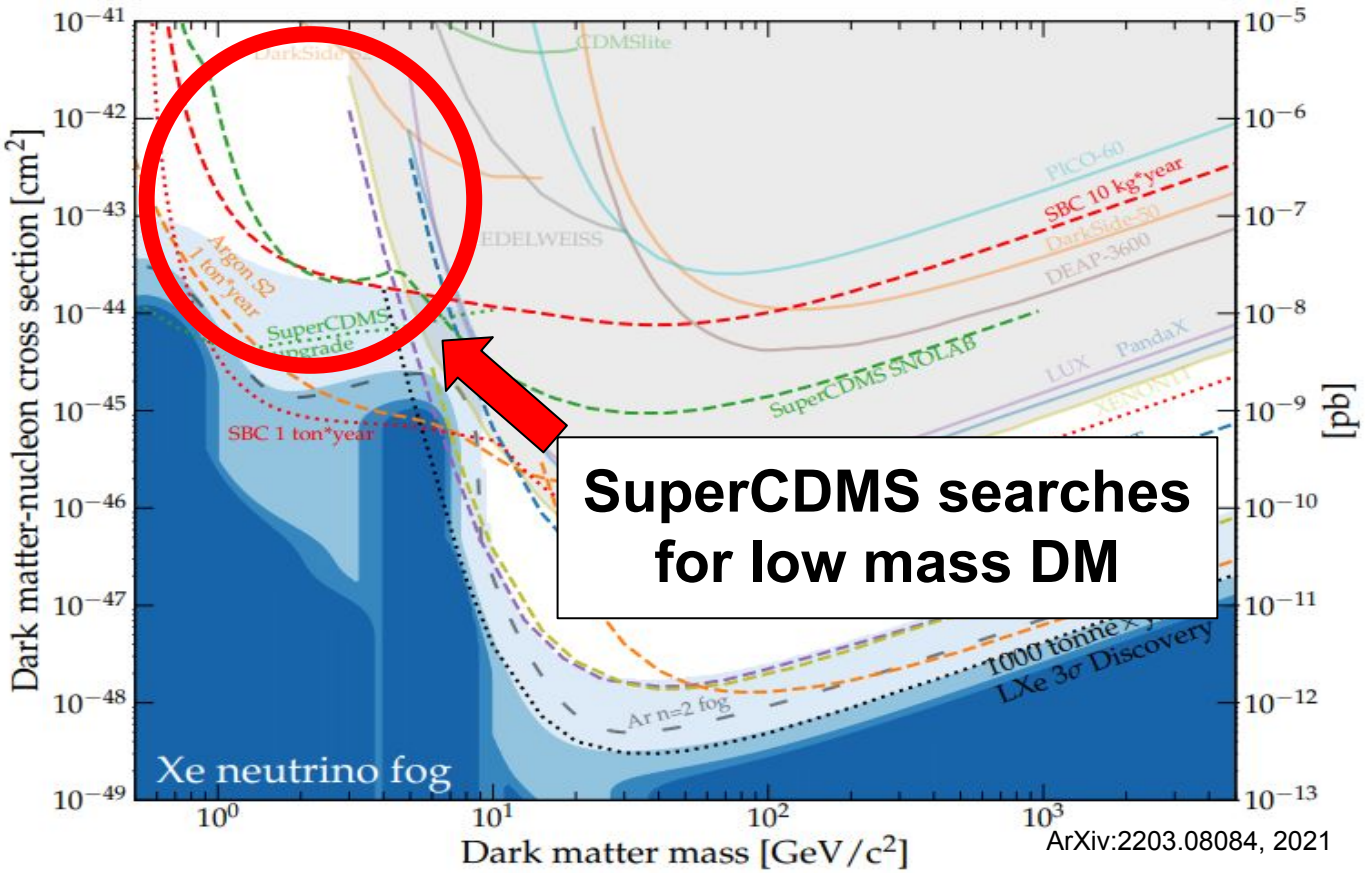
Galactic Rotation Curves



physicsanduniverse.com

~5 times as much dark matter in the universe as regular matter

Dark Matter Searches

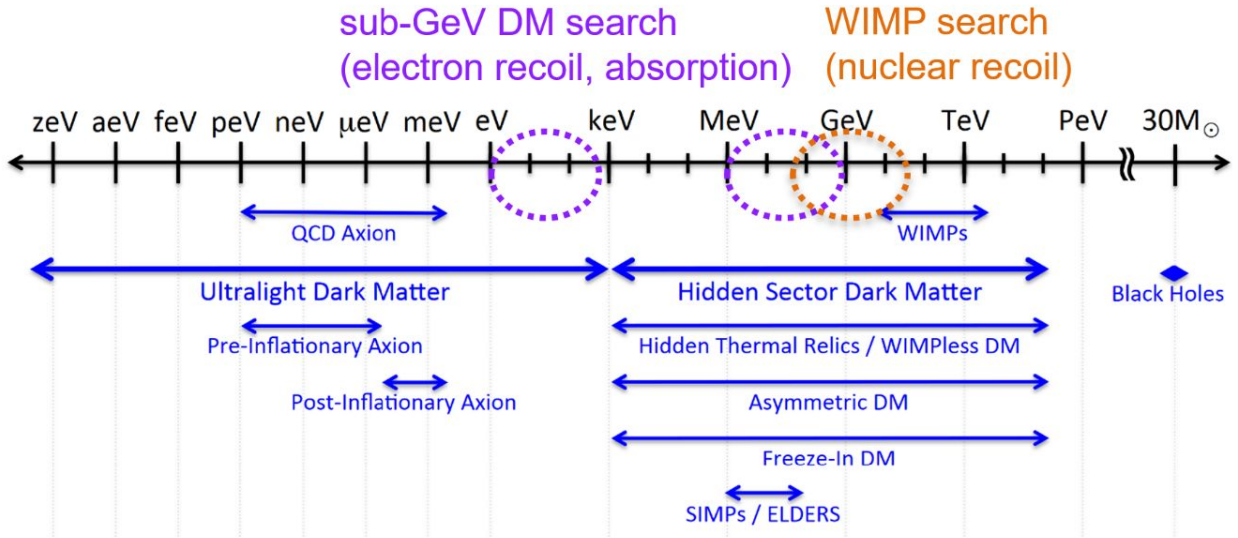


ArXiv:2203.08084, 2021

Dark Matter Candidates

Looking for a wide range of DM candidates

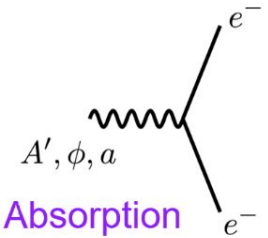
- Dark matter masses from ~5 GeV down to eV



Nuclear interaction processes:

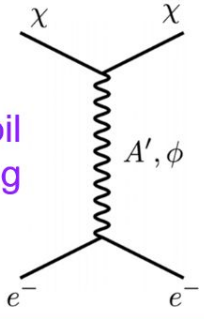
Nucleus-recoil scattering

Electronic interaction processes:



Absorption

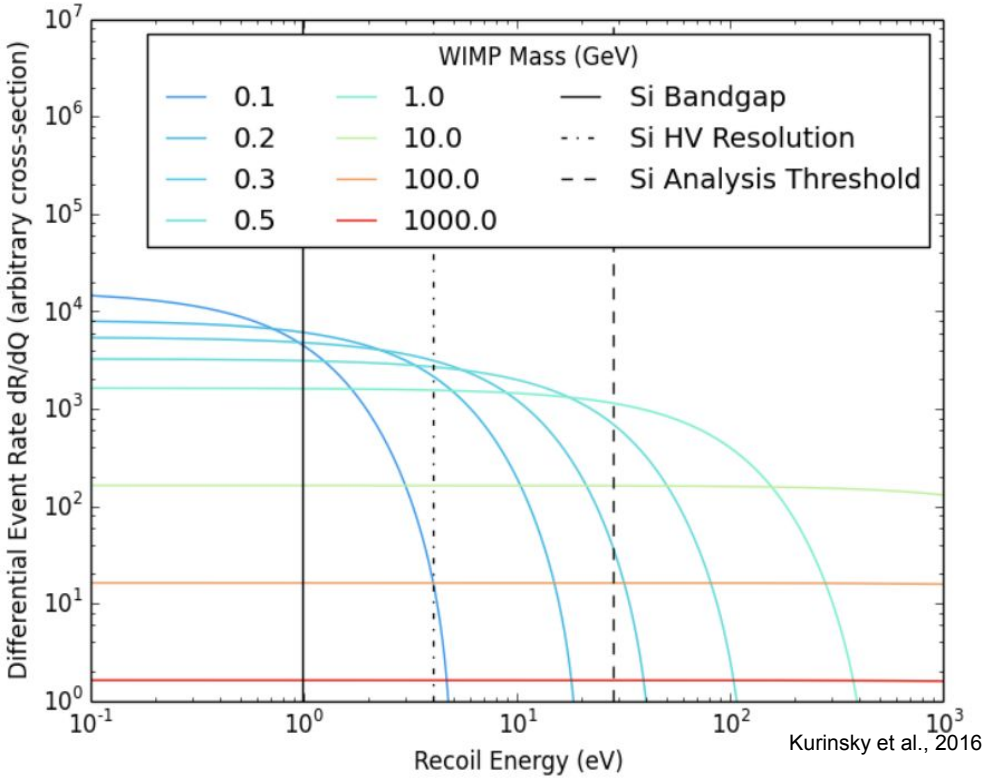
Electron-recoil scattering



US Cosmic vision ArXiv:1707.04591

Detecting Low Mass DM

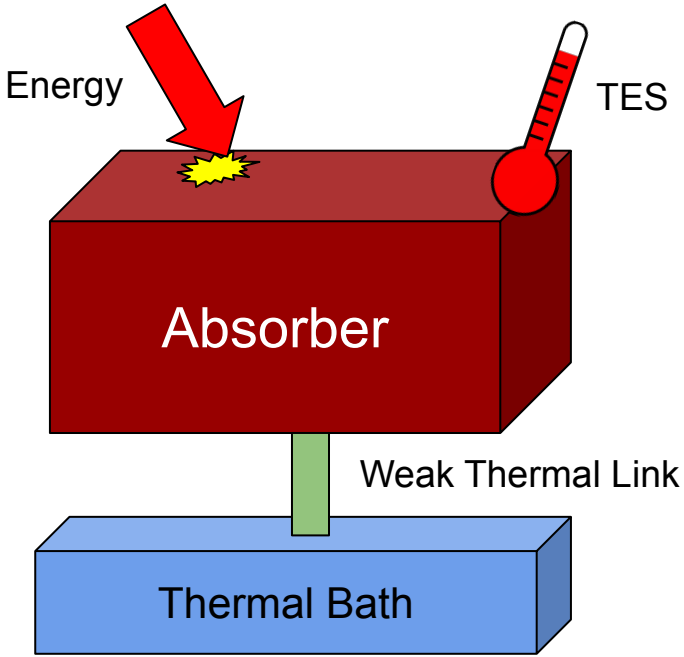
- Low mass DM models predicts low recoil energies
- Direct detection experiments **limited by energy resolution**



Kurinsky et al., 2016

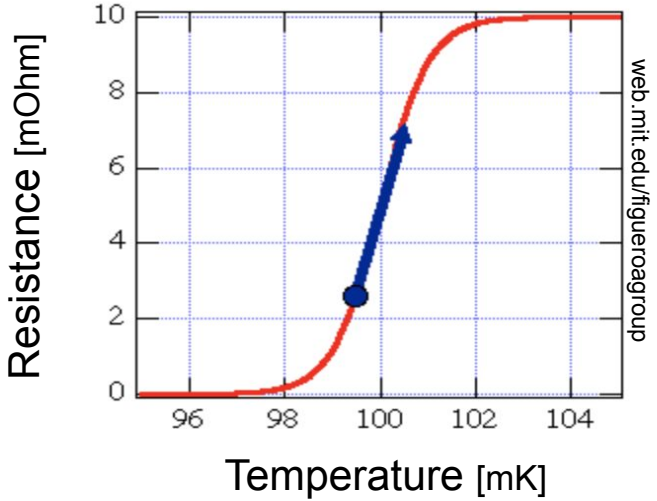
Detector Schematic

Cryogenic Calorimeter

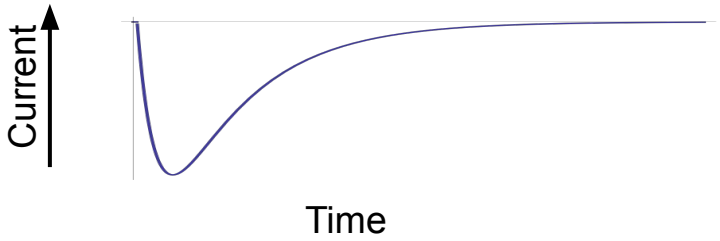


Cryogenically cooled in dilution fridge

Transition-Edge Sensor (TES)

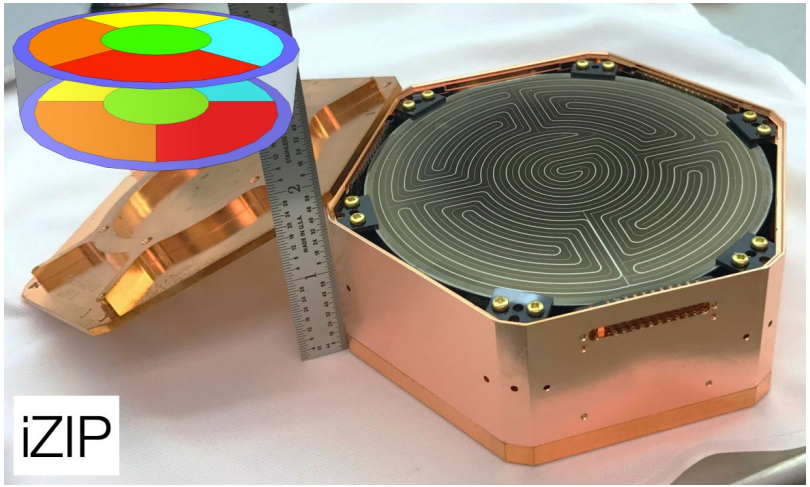


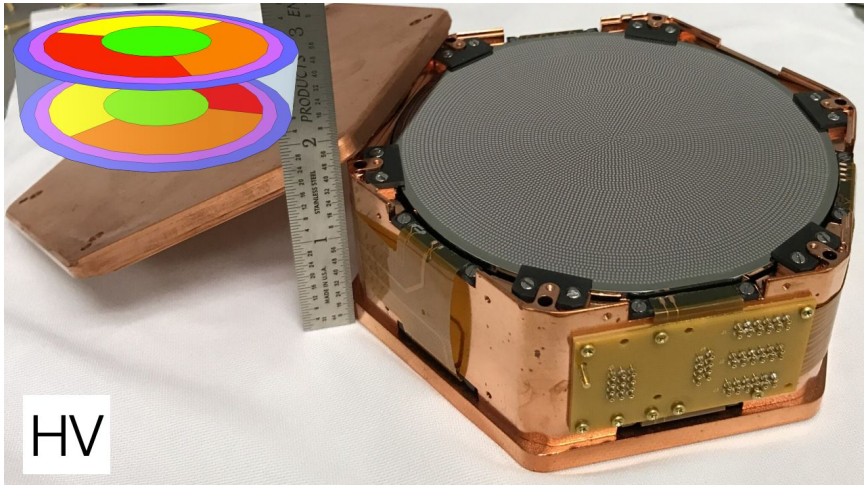
Response of TES



For more details, see the following presentations
- The SuperCDMS SNOLAB Experiment
- Modeling cryogenic Dark Matter detectors for SuperCDMS

SuperCDMS Detectors





Low-background detector:

- Ionization & heat dual readout
  - Allow for discrimination between nuclear recoil (NR) and electron recoil (ER) events

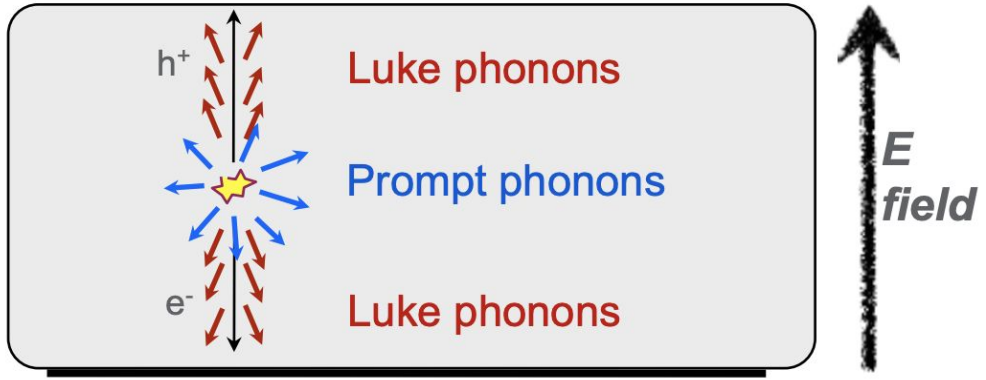
Low-threshold detector:

- Heat readout only
  - No event-by-event NR/ER discrimination
- Drift charge to amplify heat signal, enabling very low thresholds!

Phonon-mediated signal amplification

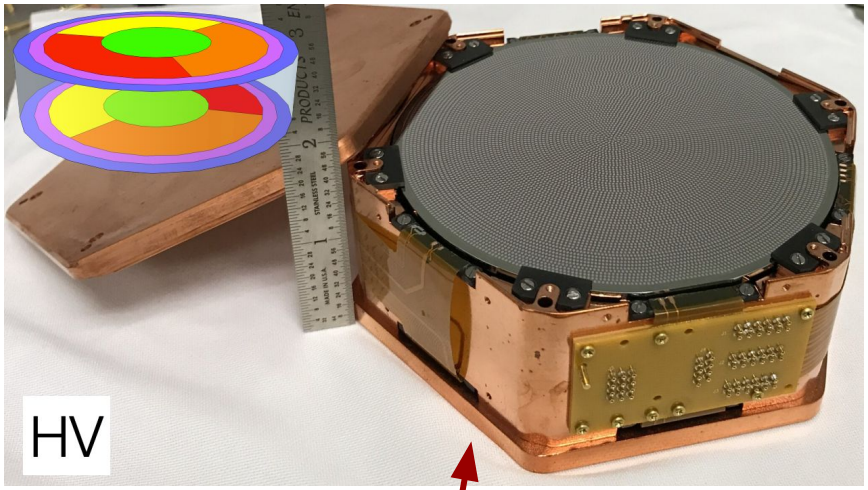
- Energy Deposition can cause ionization in semiconductors
  - A few eV (ϵ_{eff}) per ionization excitation
- Use Neganov-Trofimov-Luke (NTL) effect to amplify ionization signal
- Ionization yield (Y) different between NR and ER interactions
  - Y=1 for ER and Y~0.15 for NR
  - Potential for statistics-based NR/ER discrimination

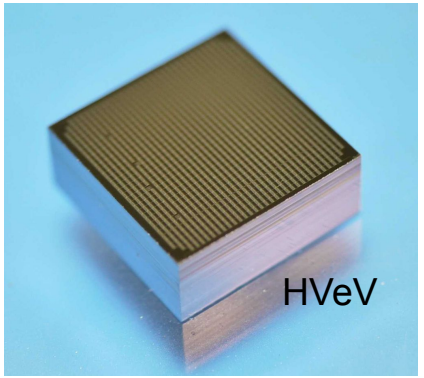
Neganov-Trofimov-Luke Effect



$$E_{total} = E_{recoil} + n_{eh} e V_b = E_{recoil}(1 + eV_b/\epsilon_{eff} \cdot Y)$$

HV → HVeV Detectors





HVeV: Prototype HV detector

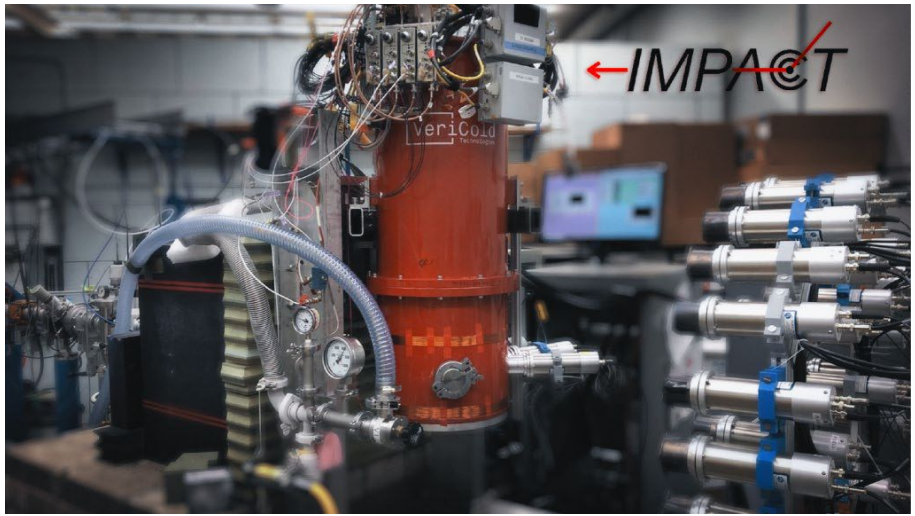
- Gram scale
- eV level resolution

Keep exploring the sensor limit!

Tune into presentation "The SuperCDMS SNOLAB Experiment" to learn about these!

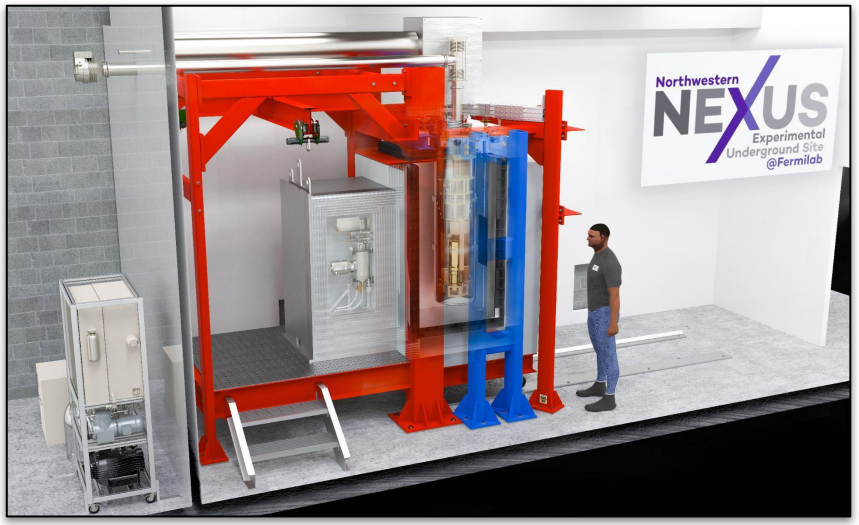
Facilities

Two facilities for HVeV R&D and operations



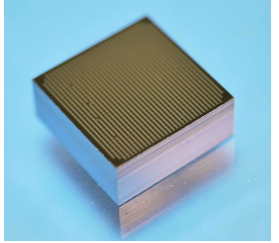
Mobile refrigerator, can be deployed in calibration facilities

Currently residing at U of Toronto!

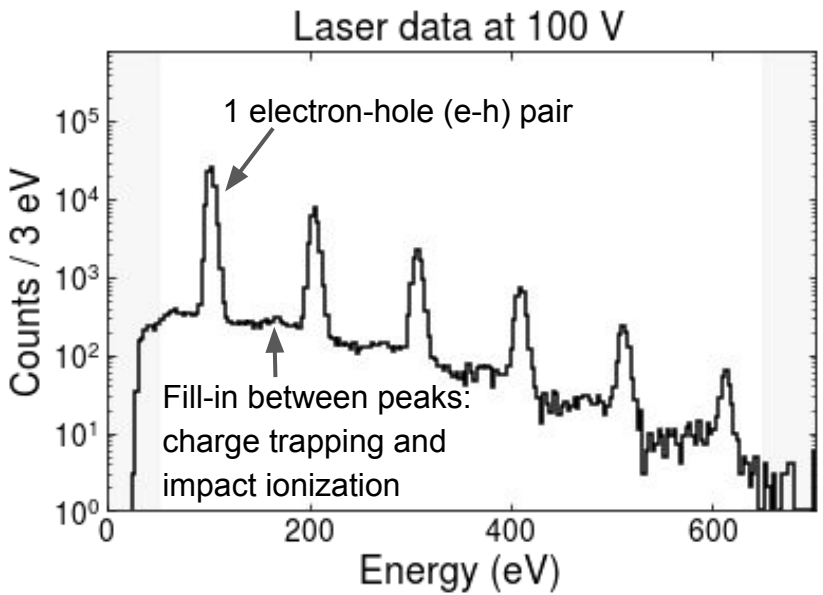


Cleanroom located ~100 m underground at Fermilab

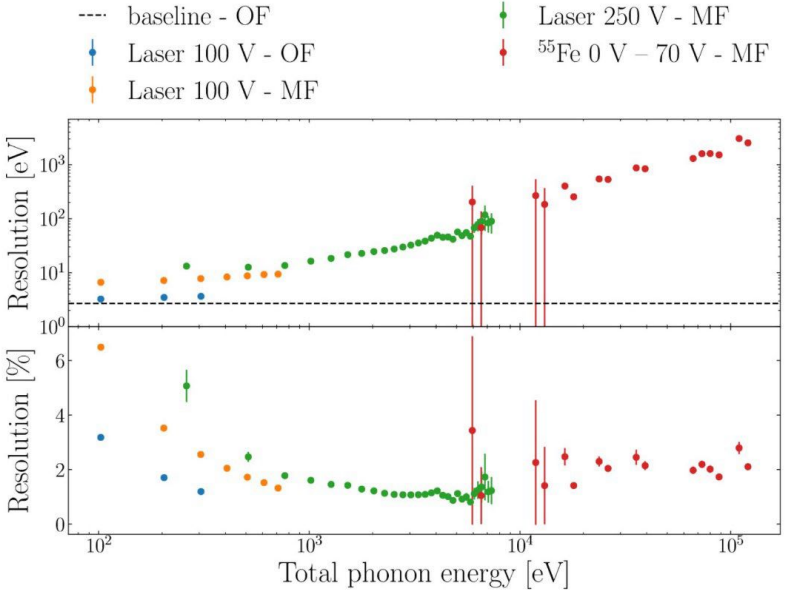
Single electron-hole pair sensitivity



- "Version 2" of HVeV detectors
- ~3 eV resolution

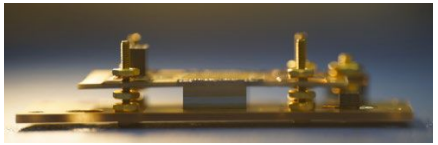


- Calibrated to hundreds of keV
- Energy resolution < 5% over the full range

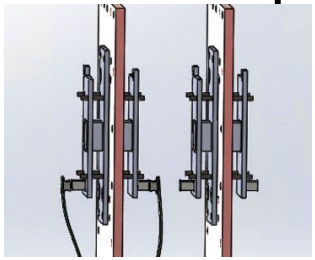


D. W. Amaral *et al.*, Phys. Rev. D 102, 091101(R), 2020
F. Ponce, et al., Phys. Rev. D 101, 031101(R), 2020
R. Ren et al., Phys. Rev. D 104, 032010, 2021

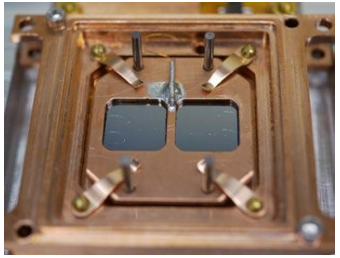
Iterations of HVeV dark matter experiments



- Burst events detection and study
- Hypothesis: originated by SiO_2 in the detector holder (PCB)

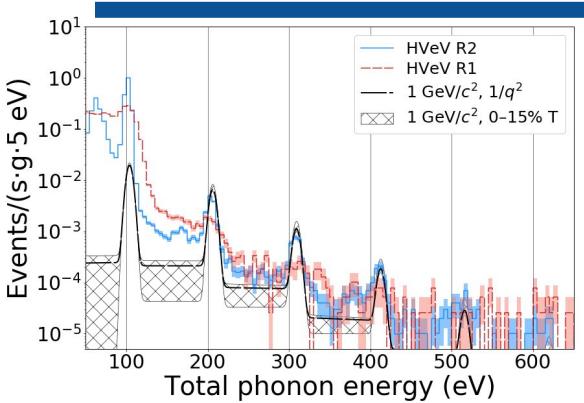


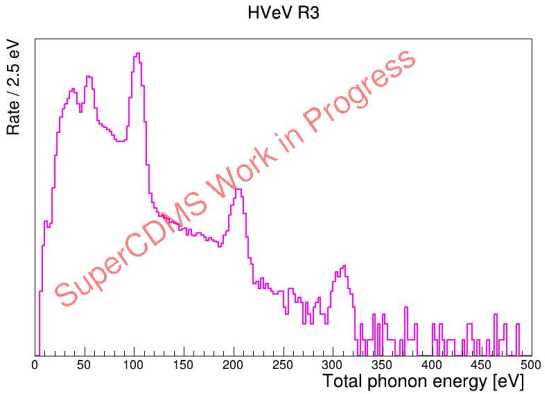
- Coincidence measurement
- Confirmed external origin of this background and its reduction with coincidence detections

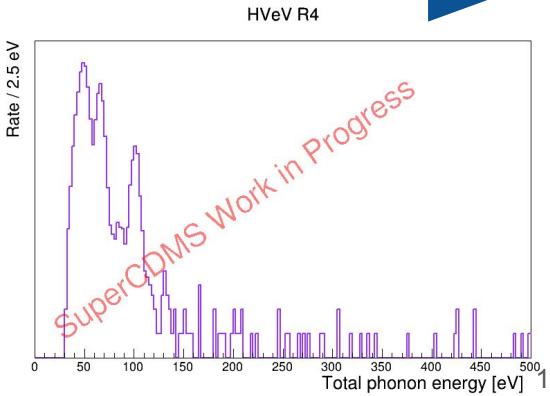


- Removed PCB from detector holder
- Elimination of quantized background above 1eh peak

HVeV Run 2 → **HVeV Run 3** → **HVeV Run 4**

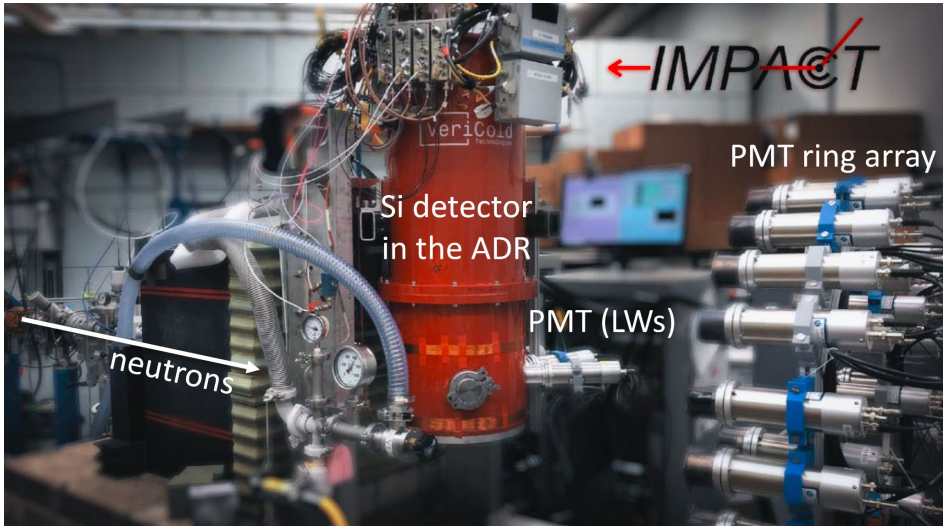




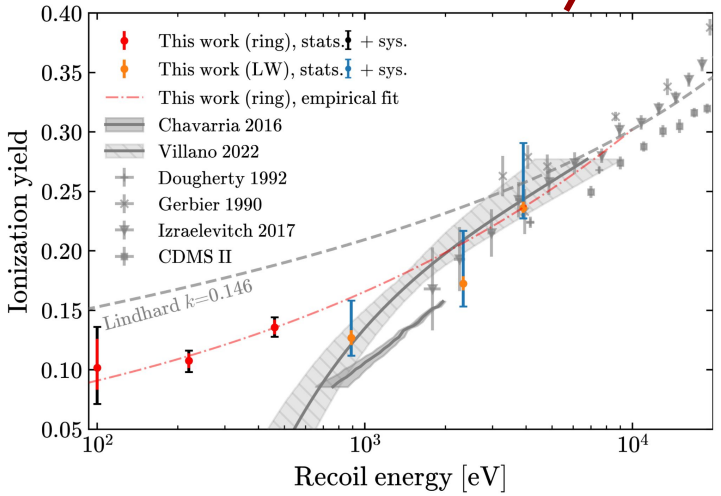


D. W. Amaral *et al.* Phys. Rev. D **102**, 091101(R)

Nuclear recoil calibration



$$E_{total} = E_{recoil} + n_{eh} e V_b$$
$$= E_{recoil}(1 + eV_b/\epsilon_{eff} \cdot Y)$$



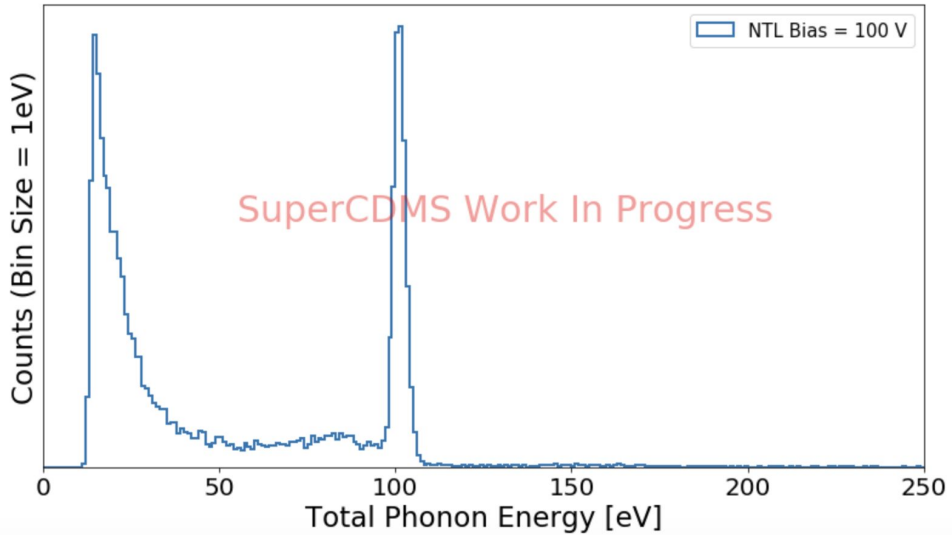
M.F. Albakry et. al, arXiv: 2303.02196

Latest Detector Performance

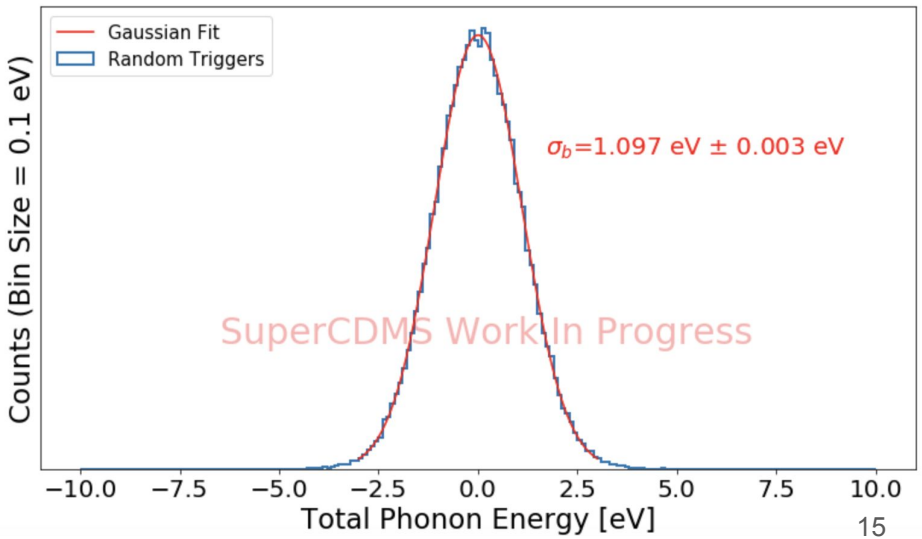
- "Version 3" of HVeV detectors
- Lower transition temperature
- Operated at NEXUS

- Achieve σ_b = 1.097 eV ± 0.003 eV

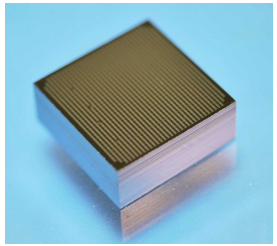
Detector Spectrum



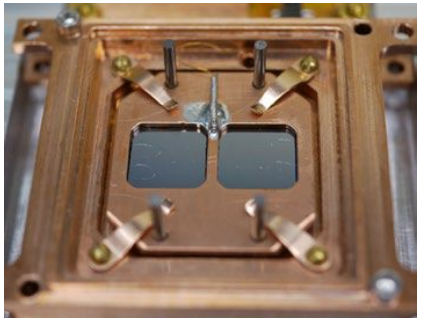
Energy of Random Triggers

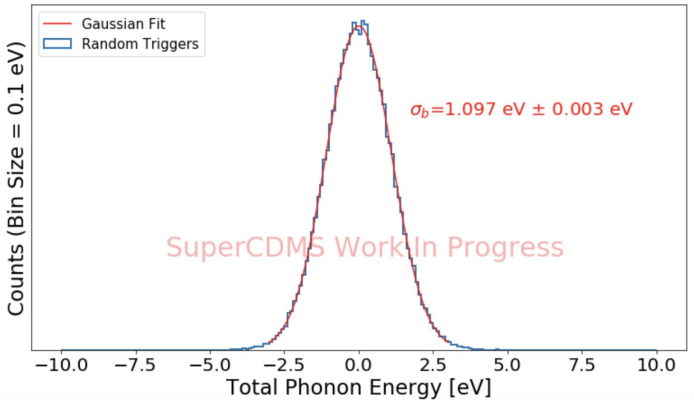


Conclusions



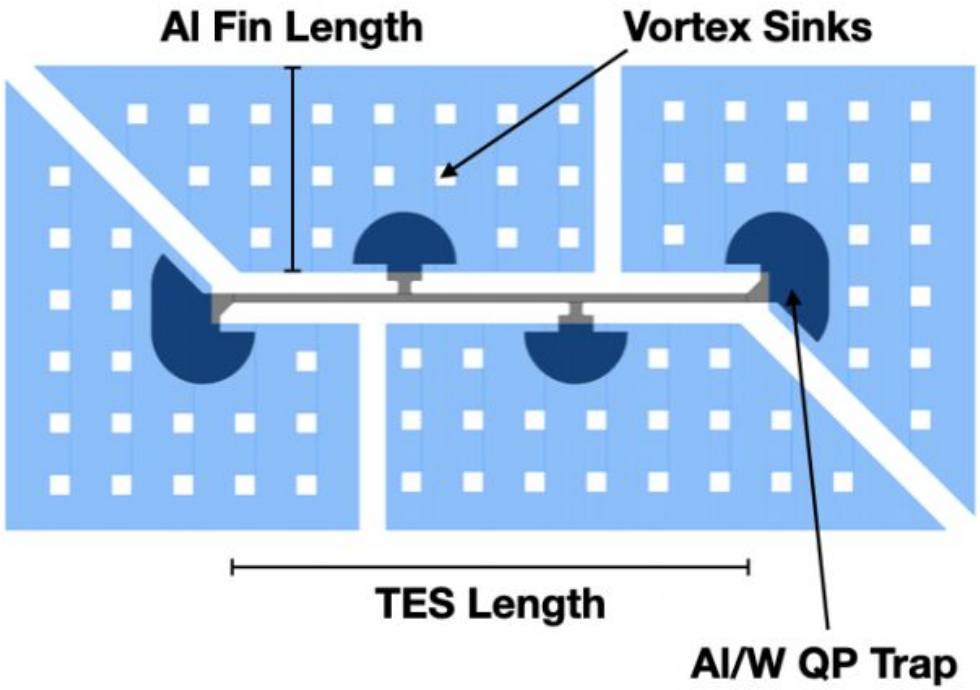
- Well-motivated DM candidates below ~5 GeV
- HVeV detectors can obtain exceptional resolutions and high signal to background ratio
- “Version 2” of HVeV detectors achieved ~3 eV resolution and single electron-hole sensitivity
- “Version 3” achieved **~1eV baseline resolution**
- More science results anticipated
- **Stay tuned!**

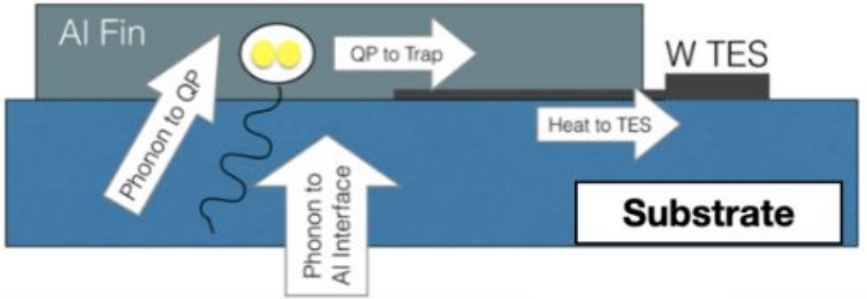




Bonus Slides

QET Design and Transport





Low threshold detectors also needed in CEvNS studies

- Coherent Elastic neutrino-Nucleus Scattering (CEvNS) cross section as a function of recoil energy for typical neutrino energies at
  - Spallation Neutron Source (30 MeV)
  - a reactor (3 MeV)
  - with an electron capture source (1 MeV).
- Low threshold detectors are also critical for neutrino experiments