EXCESS events in low-threshold particle detectors

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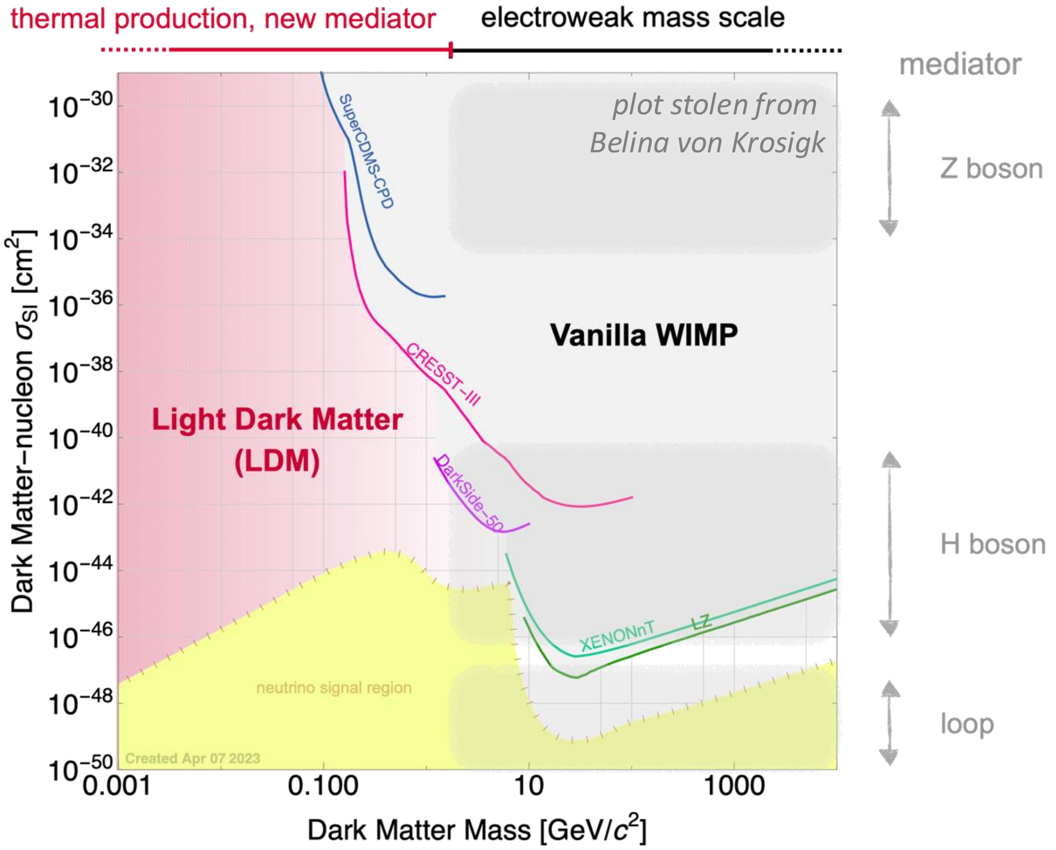
(for the EXCESS Workshop Organizing Committee)

TeV Particle Astrophysics (TeVPA) 2024
26 August 2024

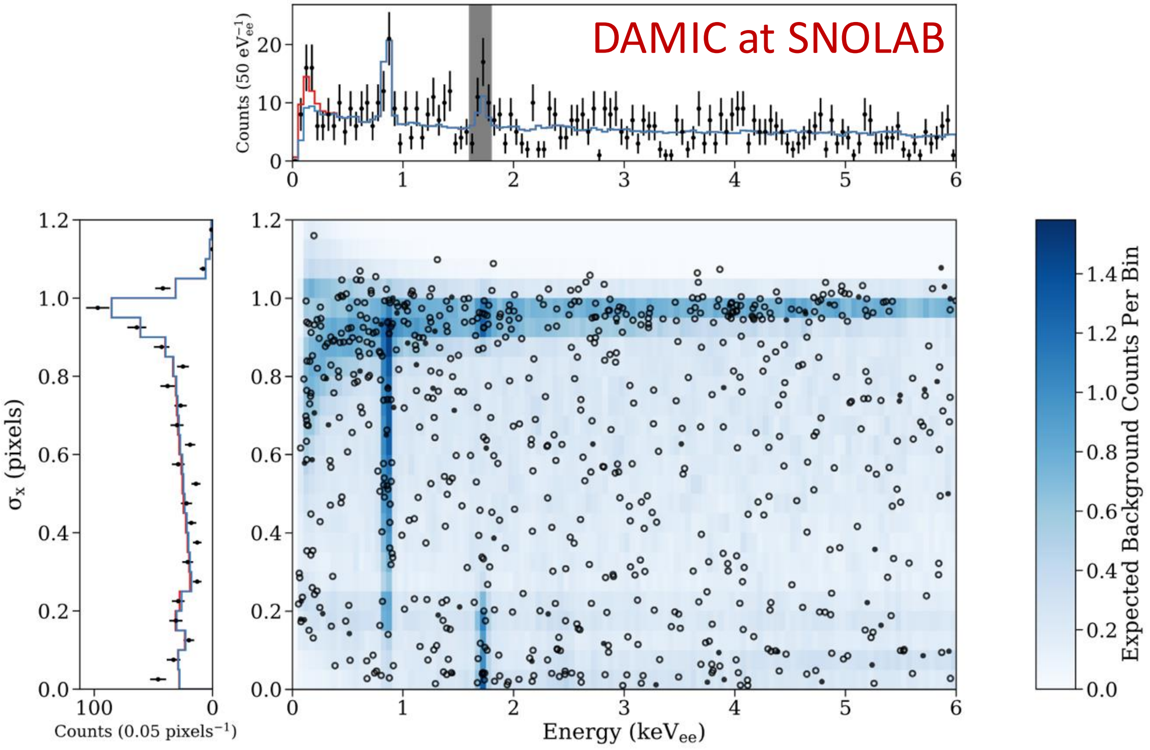
Motivation

- Lots of talks about "traditional" searches at and above GeV mass
- Those searches mostly rely on elastic scattering of DM off of detector nuclei
- Below the proton mass are very well-motivated models of dark matter



Low-Mass Dark Matter Detection

- Energy Threshold
  - At a minimum, need eV-scale thresholds to be competitive
  - R&D is pushing towards meV-scale energy thresholds
- Exposure
  - Not as important as for WIMP searches
  - Current best limits at kg-days
- Backgrounds
  - Complicated, non-radiogenic excess backgrounds plague lower energies



A. Aguilar-Arevalo et al. PRD 105, 062003 (2022) [arXiv:2110.13133]

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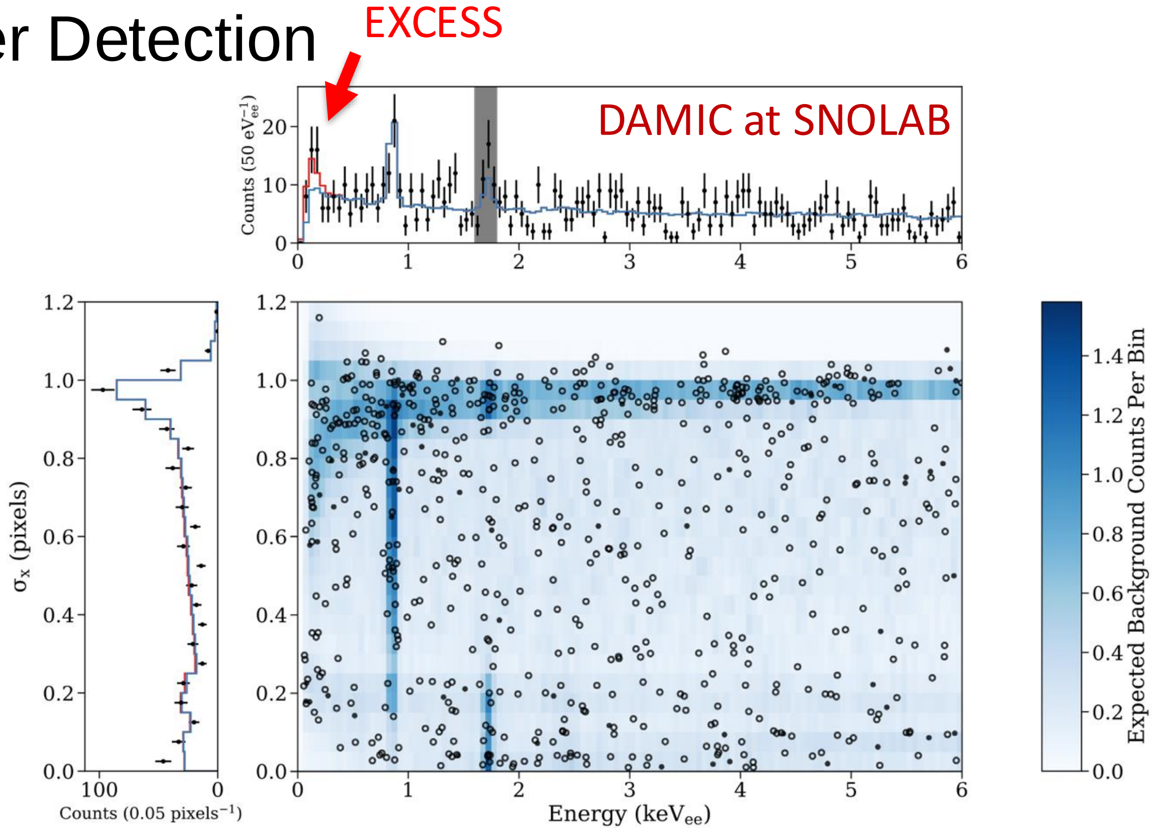

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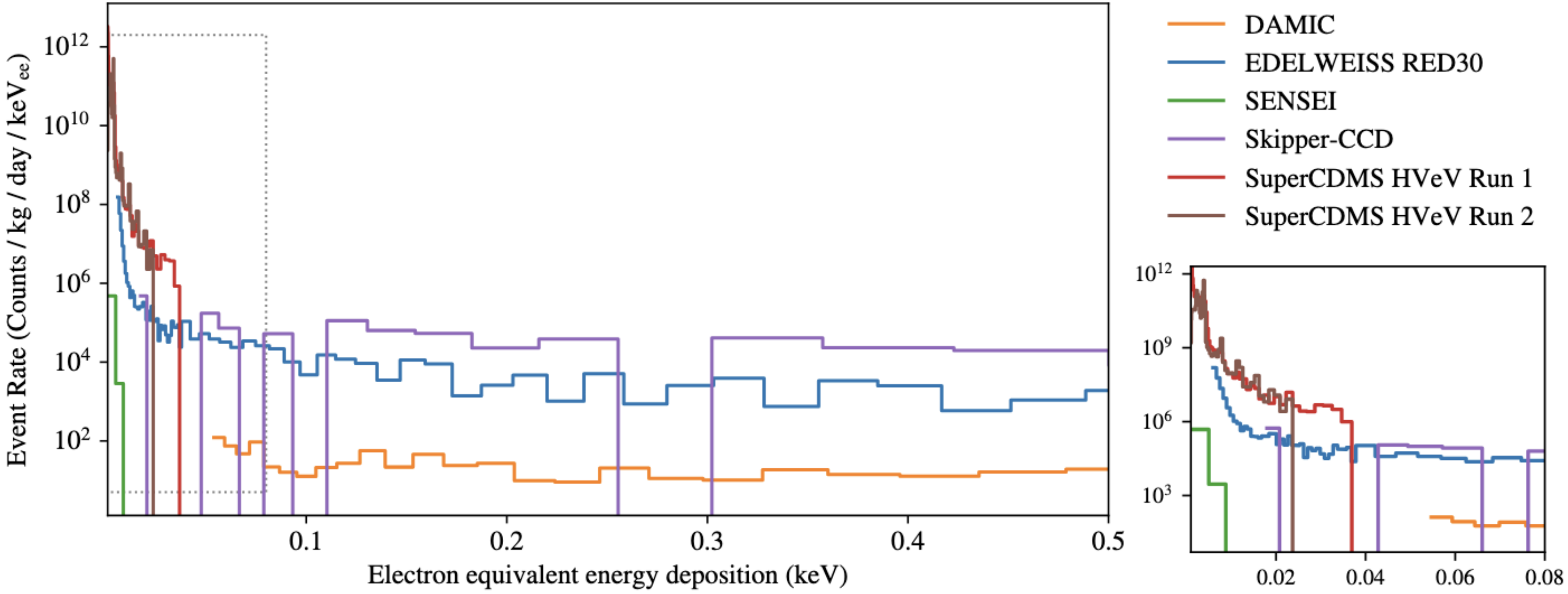
EXCESS

- All experiments with sufficiently low threshold see a steeply rising event rate
- Dark matter direct detection and CEvNS experiments are uniquely affected



P. Adari et al. SciPost Phys. Proc. 9, 001 (2022) [arXiv:2202.05097]

EXCESS Workshop Series

1. June 15-16, 2021: **EXCESS workshop,** community-wide gathering of solid-state experiments to discuss unmodeled low-energy detector rates
2. February 15-17, 2022: **EXCESS 2022**, follow-up workshop focused on phenomenology, calibration, and future detector ideas
3. July 16, 2022: **EXCESS@IDM**, first in-person meeting of the community to discuss this problem
4. August 26, 2023: **EXCESS@TAUP**
5. July 6, 2024: **EXCESS24@IDM**

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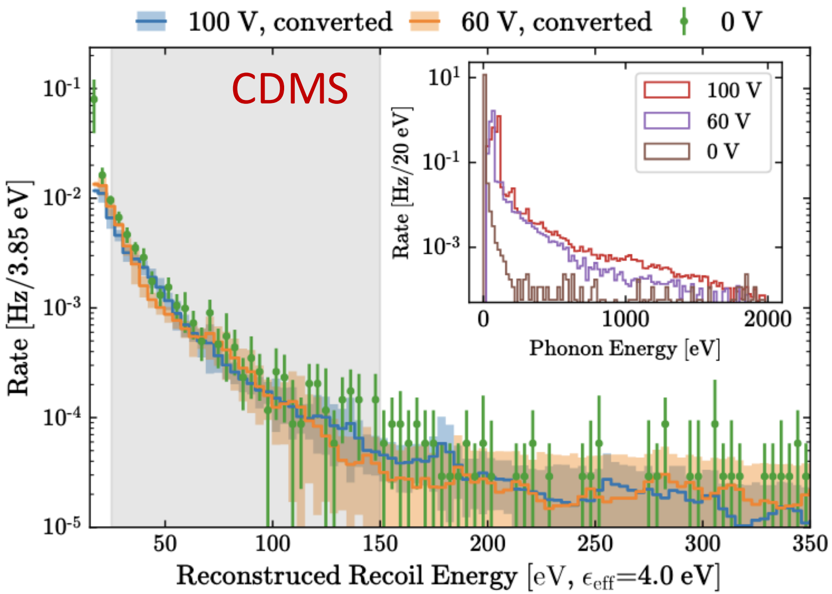
What have we learned so far – phonon detectors

Summary of what we know:

1. **Non-ionizing**: produces a phonon signal, not charge
2. **Power Law**: spectral shape follows a power law out to high energies
3. **Time-since-cooldown**: background seems to decay with a long time constant since reaching mK temperatures
4. **Stress-dependent**: reducing stress from mounting reduces background!



M.F. Albakry et al, PRD 105, 112006 (2022) [arXiv:2204.08038]

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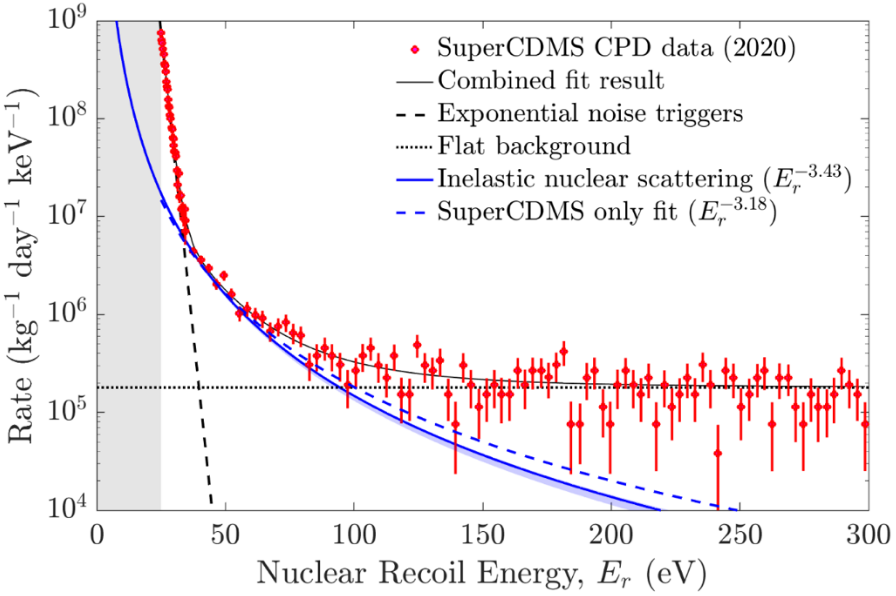

P. Abbamonte et al, PRD 105, 123002 (2022) [arXiv:2202.03436]

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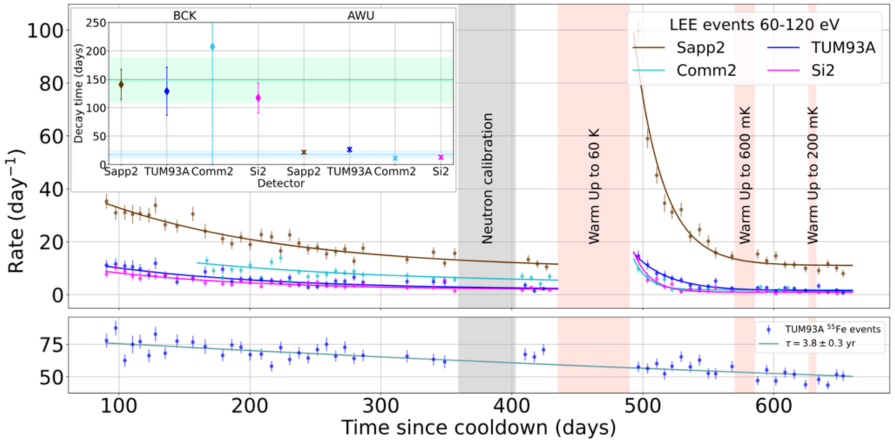

G. Angloher et al, SciPost Phys. Proc. 12, 013 (2023) [arXiv:2207.09375]

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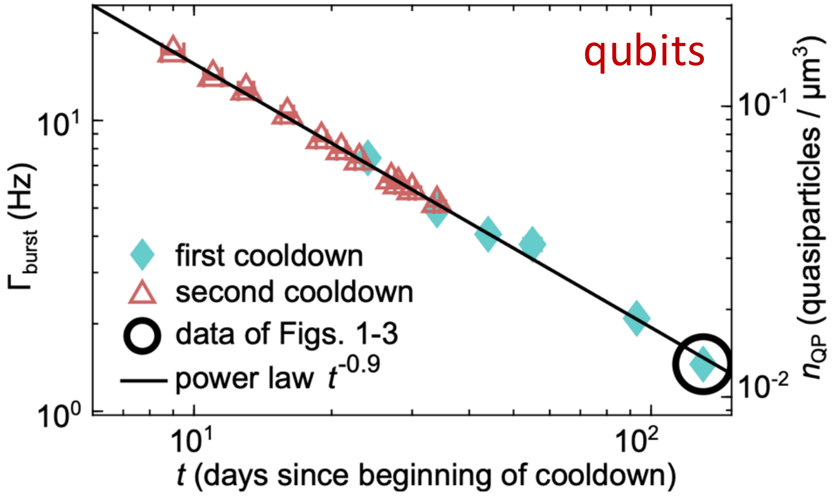

E.T. Mannila et al, Nature Physics 18, 145 (2022) [arXiv:2102.00484]

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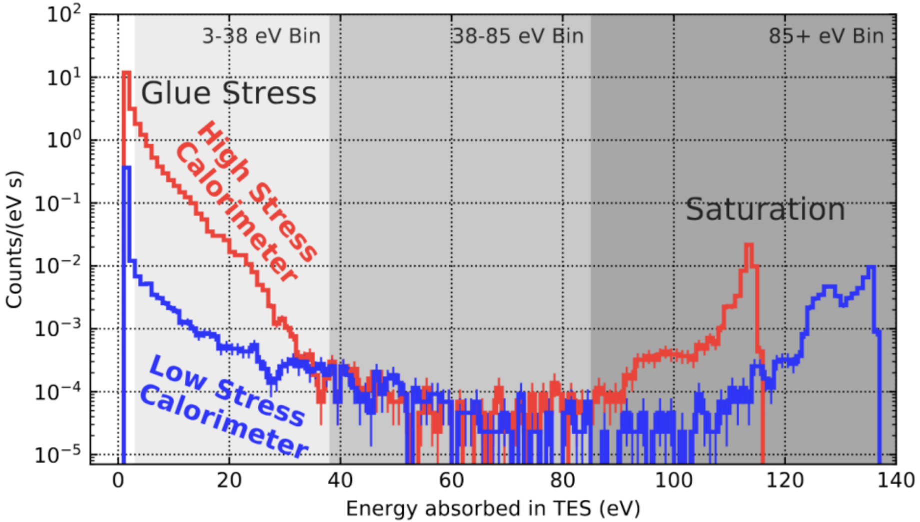
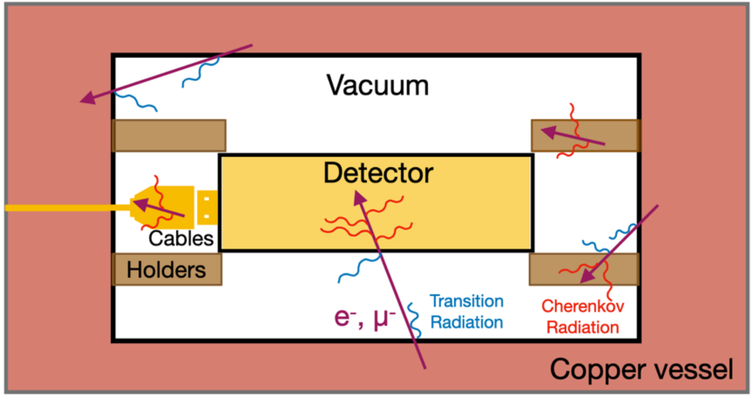


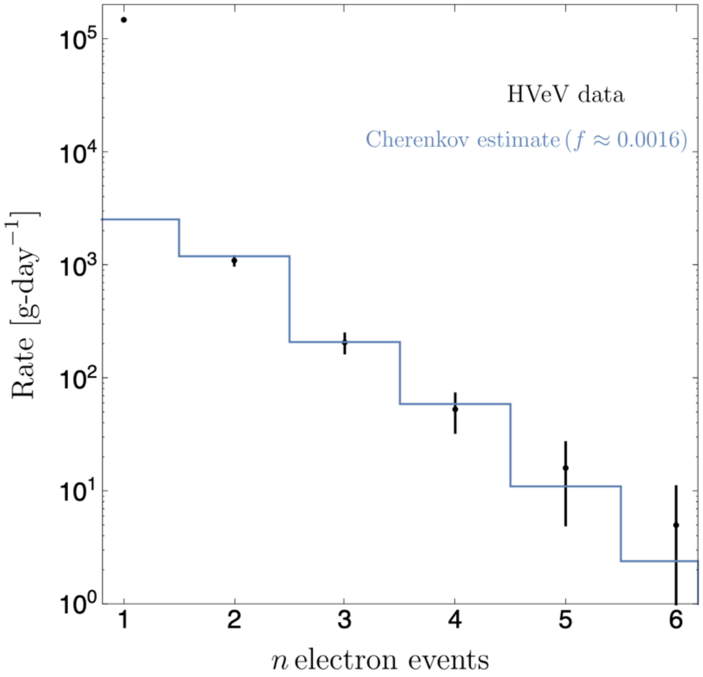
R. Anthony-Petersen et al, Nat. Comm. 15, 6444 (2024) [arXiv:2208.02790]

What have we learned so far – charge detectors

Dark rate contributions:

1. **Cherenkov and transition radiation**: produces a photon signal that yields individual e-h pairs





P. Du et al, PRX 12, 011009 (2022) [arXiv:2011.13939]

What have we learned so far – charge detectors

Dark rate contributions:

1. **<u>Cherenkov and transition radiation</u>**: produces a photon signal that yields individual e-h pairs
2. **<u>IR radiation</u>**: light leaks are a ***major*** contributor to existing dark rates

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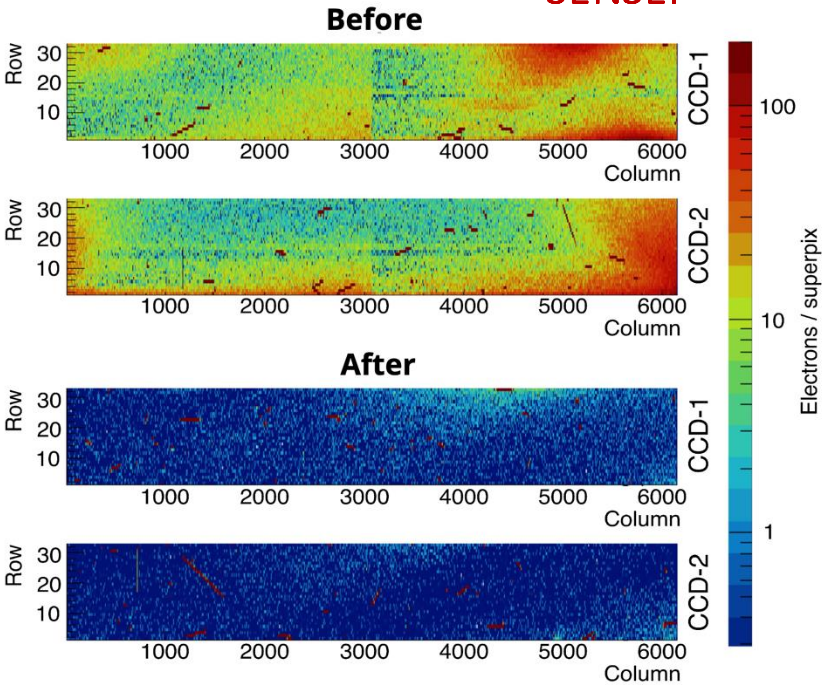

A.M. Botti, EXCESS24 at IDM Workshop (2024)

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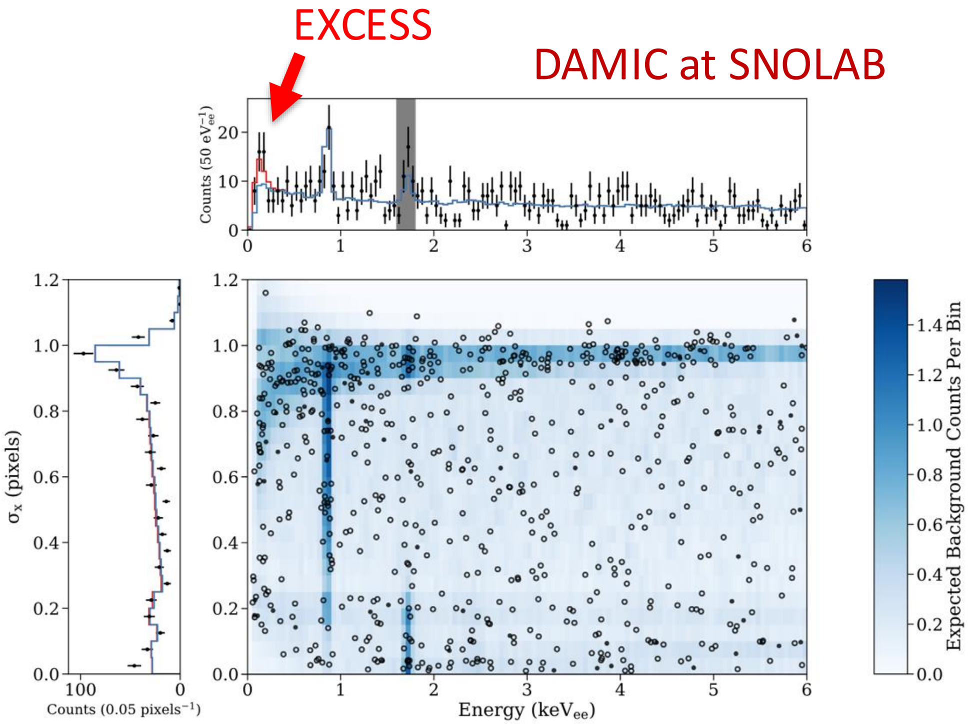

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… except for DAMIC at SNOLAB

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- Spatially uniform
- Reproducible after switching out CCDs

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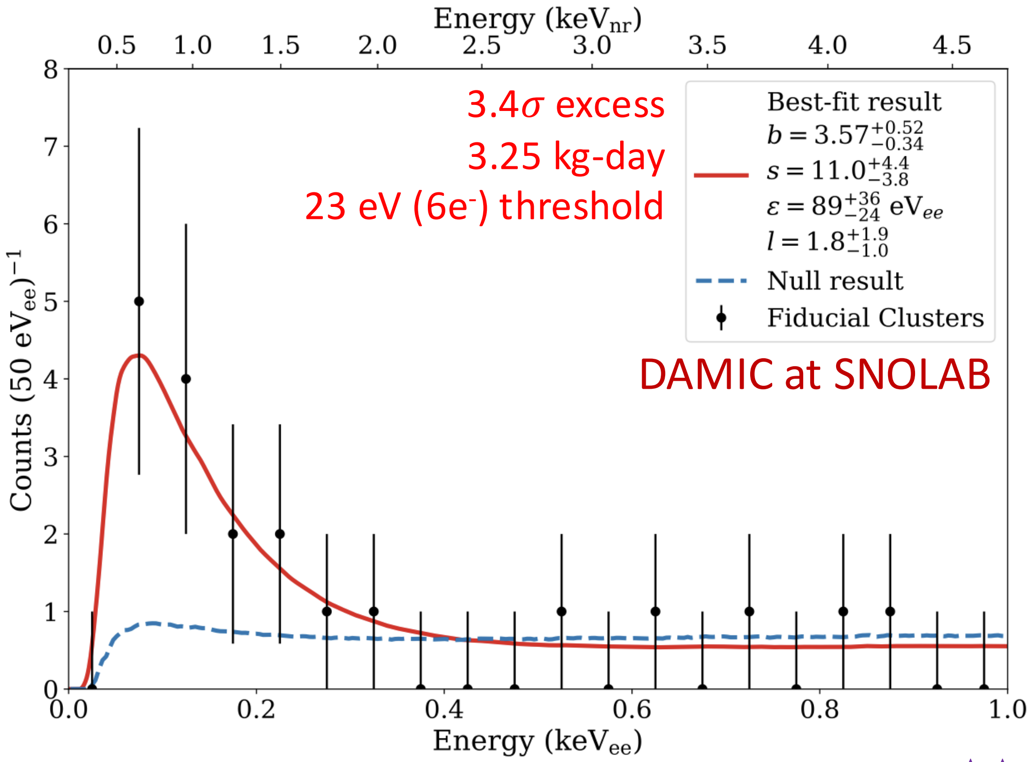

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A. Aguilar-Arevalo et al. PRD 109, 062007 (2024) [arXiv:2306.01717]

Summary

Immense progress has been made in understanding the origins of the low-energy EXCESS (LEE) in the past five years, in large part through the EXCESS Workshop series and related communications

- Cryogenic phonon detectors appear to be seeing a signal that is some combination of non-ionizing, spectrally a power law, decaying in time since cooldown, and dependent on mounting stress
  - Excess rates slightly differ across detectors for still unknown reason
  - Stress mitigation methods are being actively pursued with the goal of isolating, reducing, or eliminating such backgrounds moving forward
- Charge-sensitive detectors are far more sensitive to IR radiation and other single-photon backgrounds than previously assumed, which can dramatically increase detector dark rates
- **The DAMIC at SNOLAB excess rate remains unexplained with a statistical significance of 3.4σ**

EXCESS 2025 needs a host

Reach out to
excessworkshop@gmail.com