



# EXCESS SIGNALS IN LOW- MASS DARK MATTER AND $CE\nu NS$ EXPERIMENTS

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Magnificent  $CE\nu NS$  workshop 2023  
Munich, March 2023



# WHAT IS THE EXCESS INITIATIVE?

**Topic:** excesses (= events above known background level)  
observed in low-mass DM and CE $\nu$ NS experiments

**Format:** series of workshops

Jun. 2021 (online) <https://indico.cern.ch/event/1013203/>

Feb. 2022 (online) <https://indico.scc.kit.edu/event/2575/>

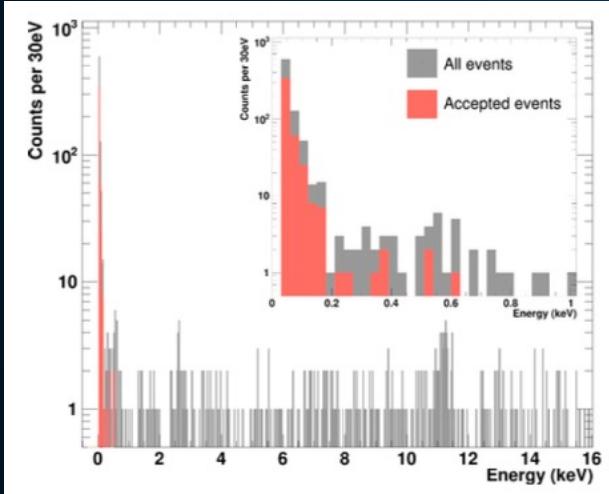
Jul. 2022 (@IDM, Vienna) <https://indico.cern.ch/event/1117540/>

Aug. 2023 (@TAUP, Vienna) <https://indico.cern.ch/event/1213348/>

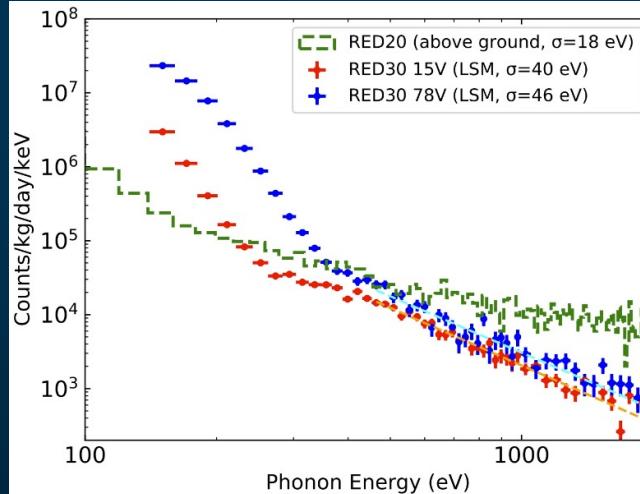
# WHITEPAPER 2021/22 - CRYOGENIC DETECTORS

SciPost Phys. Proc. 9, 001 (2022)

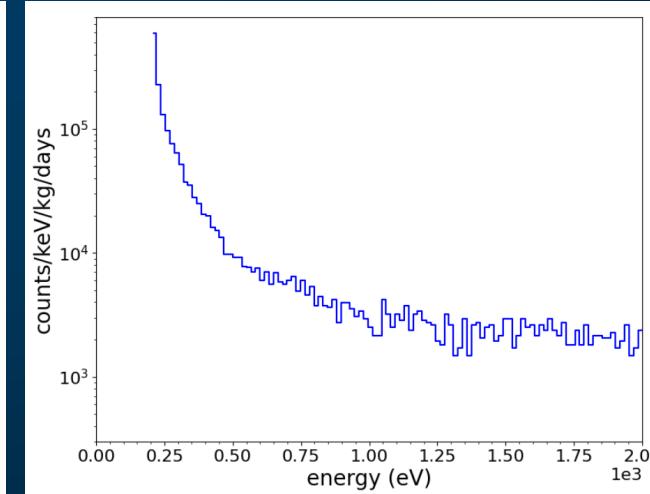
CRESST-III (2019)



EDELWEISS (2019/20)

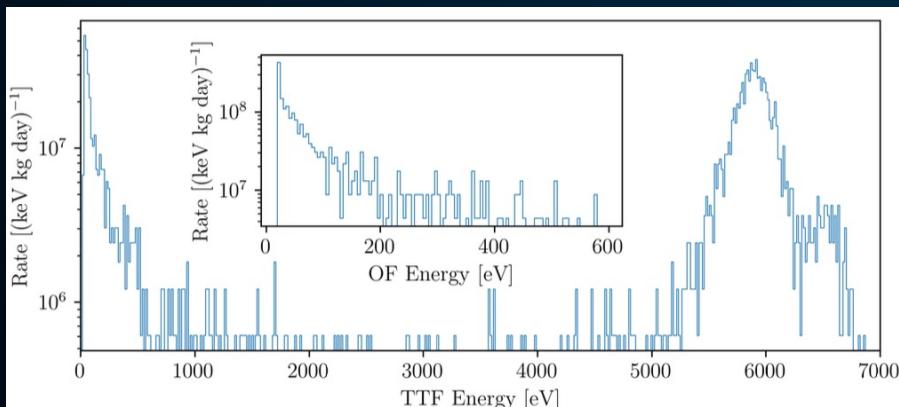


MINER (2021)

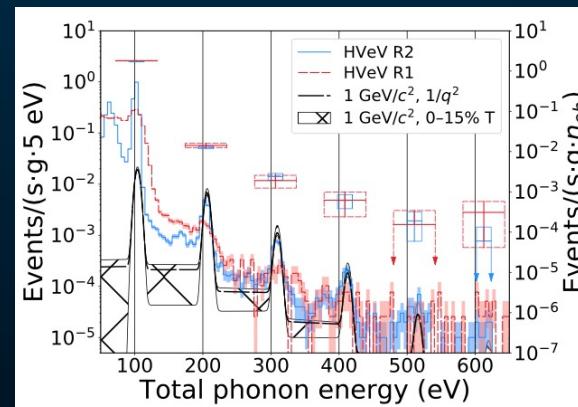


Steeply  
rising  
towards  
low  
energies

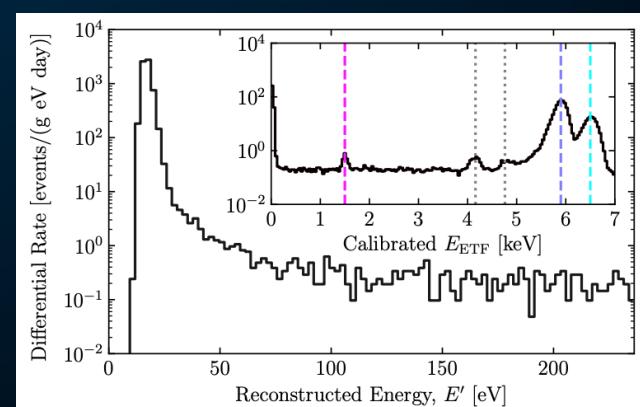
NUCLEUS (2017)



SuperCDMS HVeV (2021)



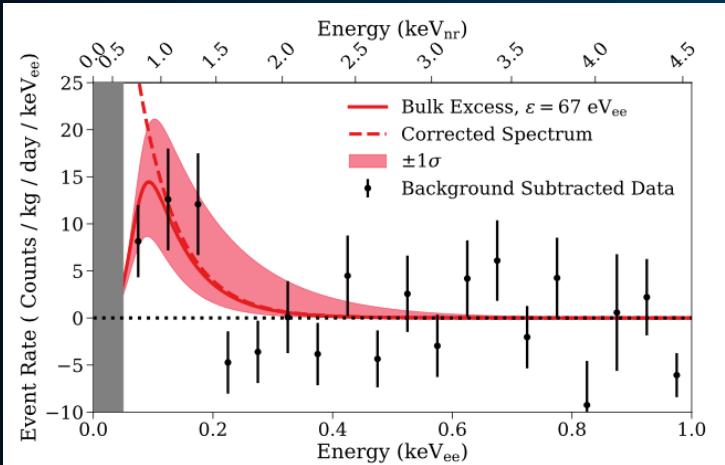
SuperCDMS CPD (2021)



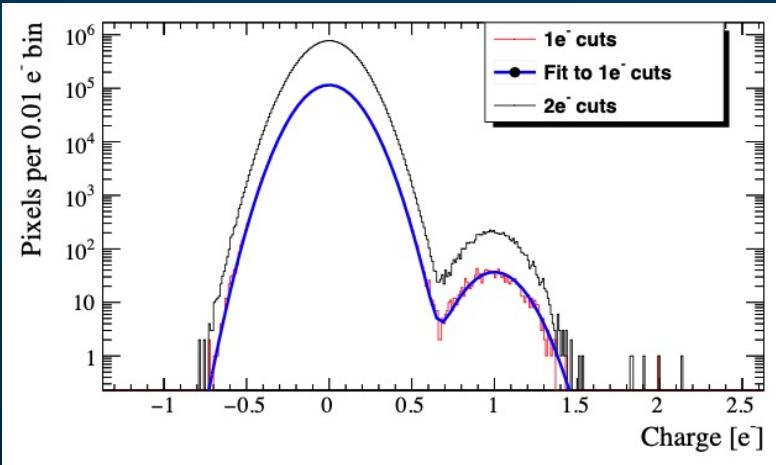
# WHITEPAPER 2021/22 - CCDs

SciPost Phys. Proc. 9, 001 (2022)

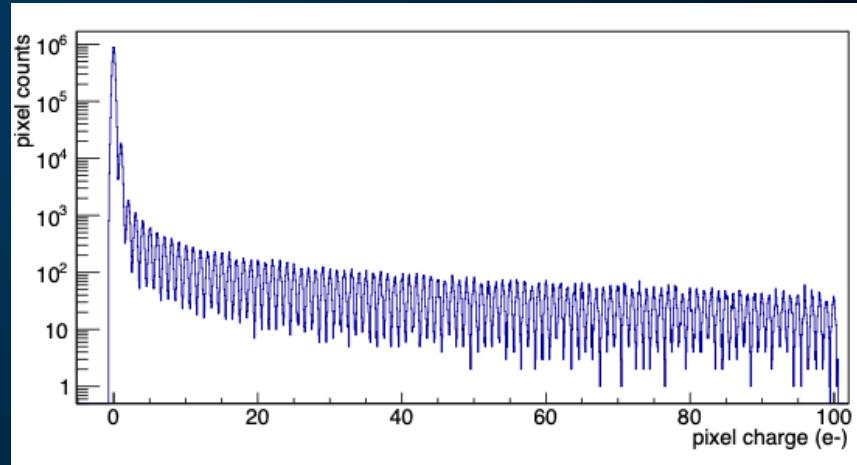
DAMIC (2021)



SENSEI (2020)



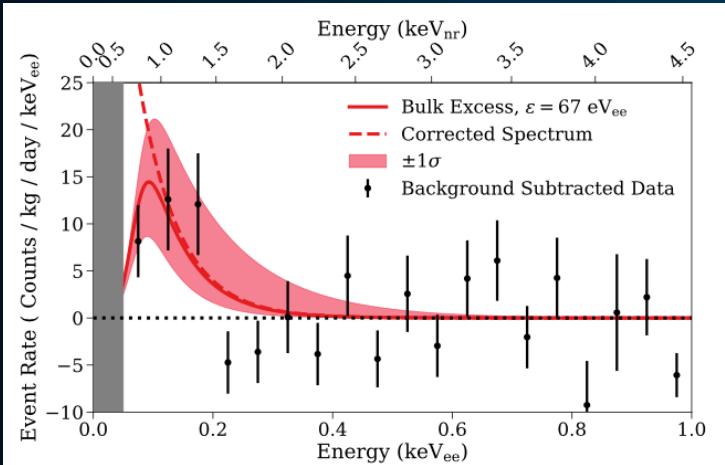
SKIPPER @FNAL (2020)



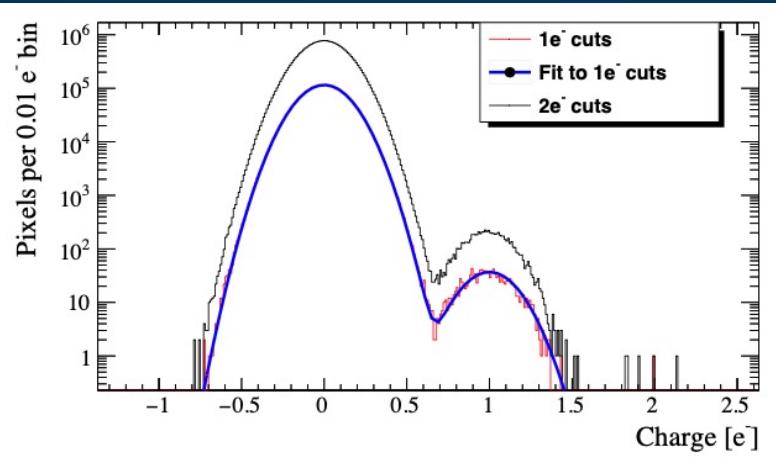
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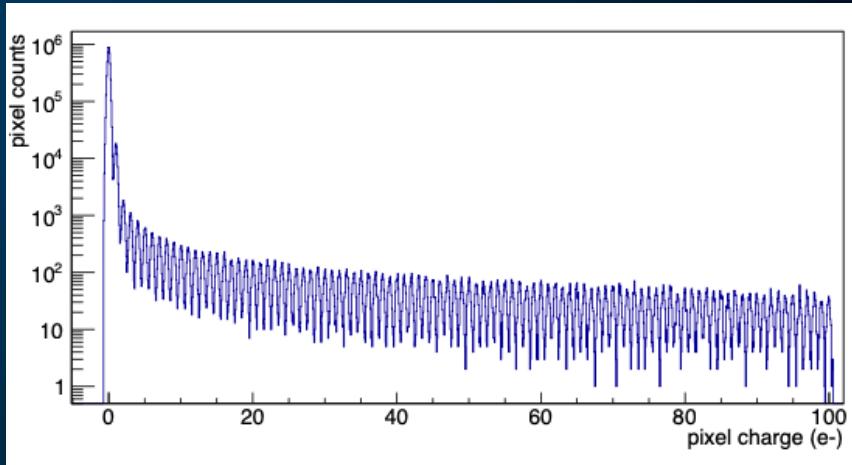
DAMIC (2021)



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SKIPPER @FNAL (2020)

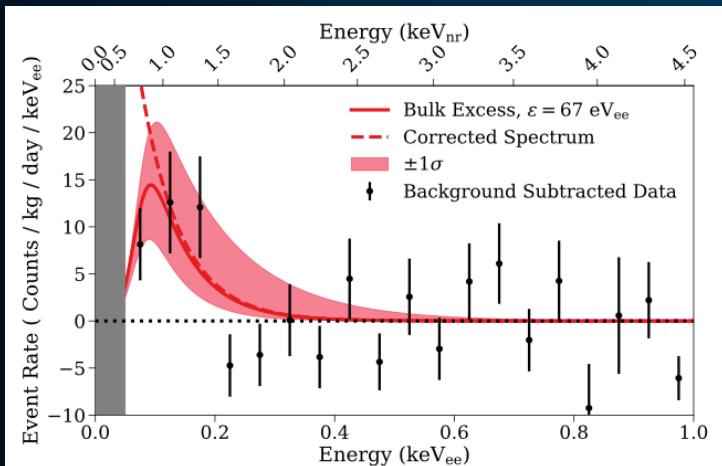


+ Gaseous ionization detectors (NEWS-G)

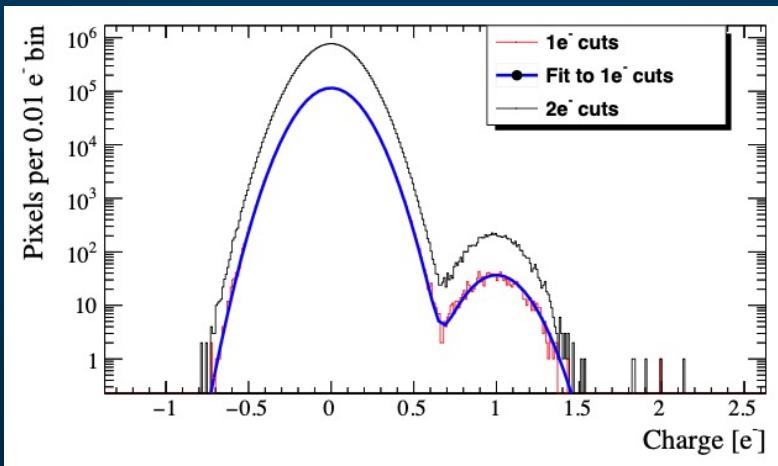
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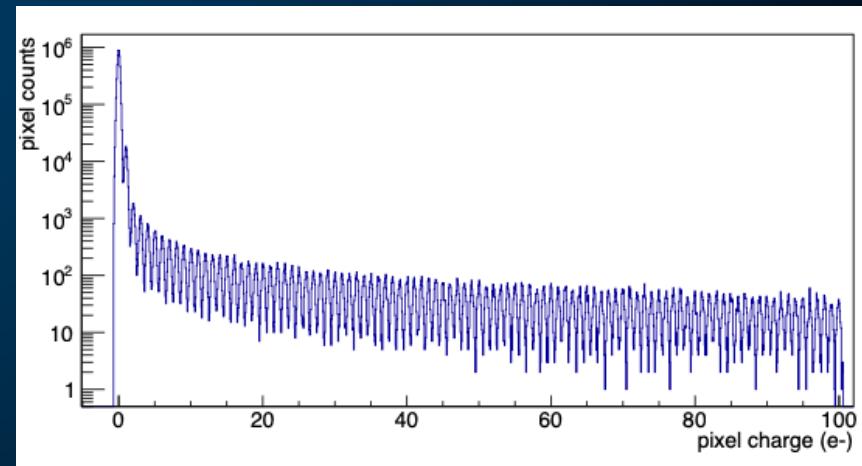
DAMIC (2021)



SENSEI (2020)



SKIPPER @FNAL (2020)



+ Gaseous ionization detectors (NEWS-G)

Whitepaper: SciPost Phys. Proc. 9, 001 (2022)

Public data: <https://github.com/fewagner/excess>

Online visualization tool: <https://mybinder.org/v2/gh/fewagner/excess/HEAD>

# EXCESSES ARE OBSERVED

- above ground and in underground laboratories.
- in cryogenic detectors and at room-temperature.
- for TESs, NTDs, QETs, (Skipper) CCDs.
- for different materials ( $\text{Si}$ ,  $\text{CaWO}_4$ ,  $\text{Ge}$ ,  $\text{Al}_2\text{O}_3$  ...).
- with significantly differing rates across detectors and experiments.

and raise questions:

- Single common origin? (spoiler: probably not)
- How well do we understand things at the low-energy frontier:
  - detectors and their calibration?
  - backgrounds (particle and non-particle origin)?

# SITUATION IN 2021

All (solid-state) experiments with a low energy threshold observe excesses significantly affecting their sensitivity, since excesses typically dominate the event rate in the ROI.

What are the origins?

How to mitigate the excesses?

# EXCESS @IDM 2022 (LATEST WORKSHOP)

<https://indico.cern.ch/event/1117540/>



F. Reindl

# DEDICATED STUDIES ON THE EXCESSES



Focus on solid-state  
detectors

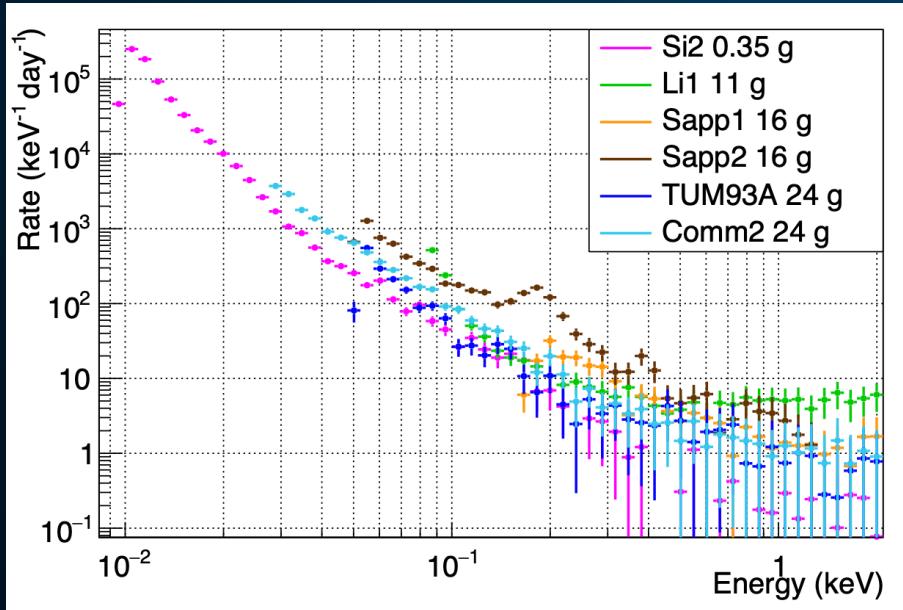
No time to show  
everything →  
cherry-picking  
results.

# CRYOGENIC: CRESST-III

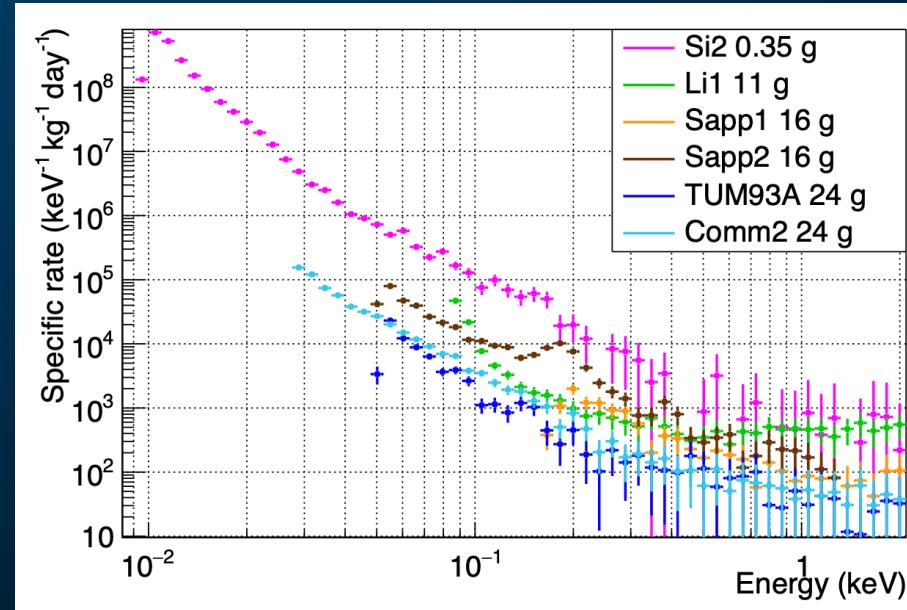
arXiv:2207.09375v2

## Rate in different detectors

Scaled by measuring time



Scaled by measuring time and mass

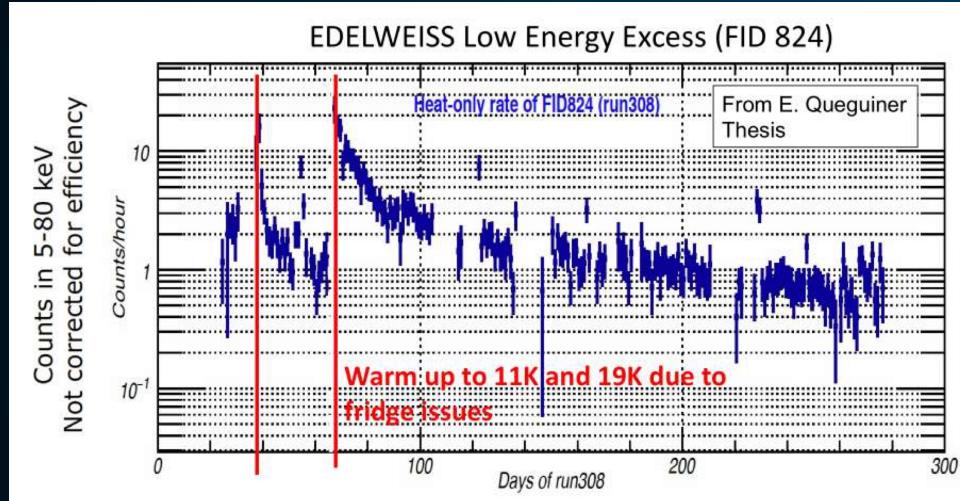


All detectors measure excesses

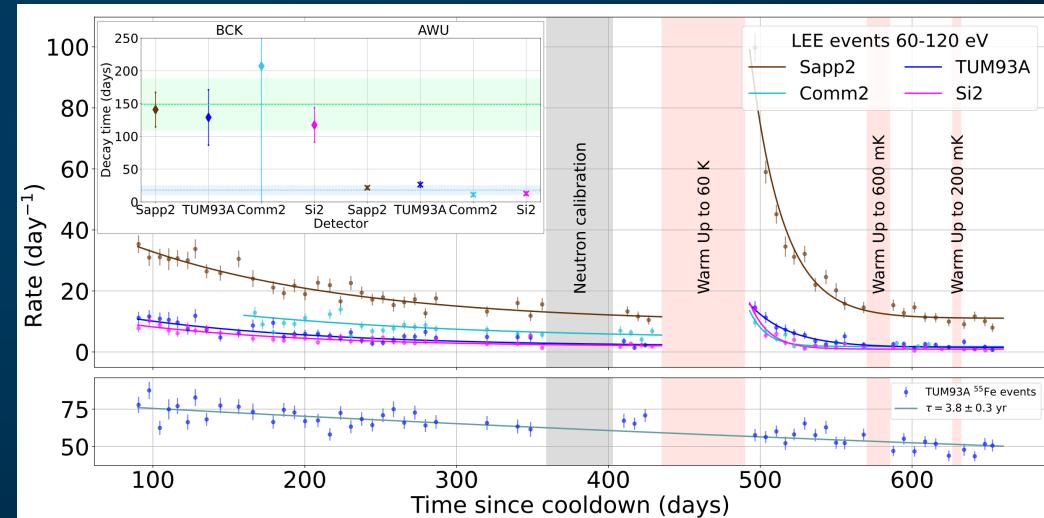
Rates do not scale with mass

# CRYOGENIC: TIME EVOLUTION

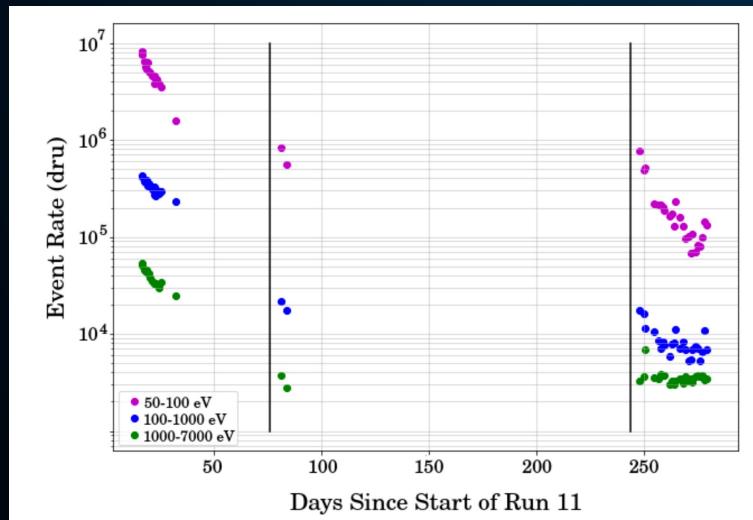
EDELWEISS (2019)



CRESST (2022)



CPD @ CUTE (2022) [R.E. Underwood](#)



## Excesses decay with time since cool-down

More dedicated studies ongoing  
(time-consuming business)

# CRYOGENIC: TRY OF AN INTERPRETATION

Observations and dedicated tests show that excesses are not dominated by:

- dark matter.
- radioactivity (neither external nor internal).
- scintillation light\*.
- noise triggers or artifacts from electronics.
- ionizing events.

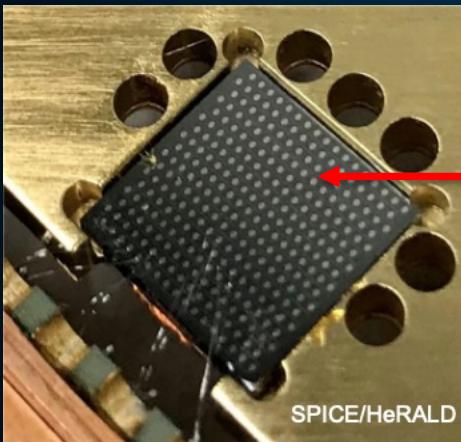
“Most favored” hypothesis:

- stress from crystal, sensor or holding.

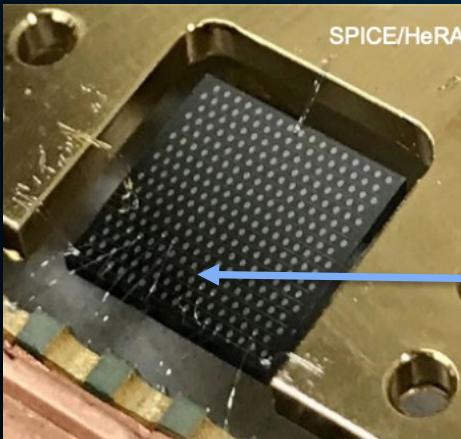
\* For SuperCDMS HvEV, see [Phys. Rev. D 105, 112006](#)  
+ [Novati, EXCESS @IDM2022](#)

# STRESS TEST

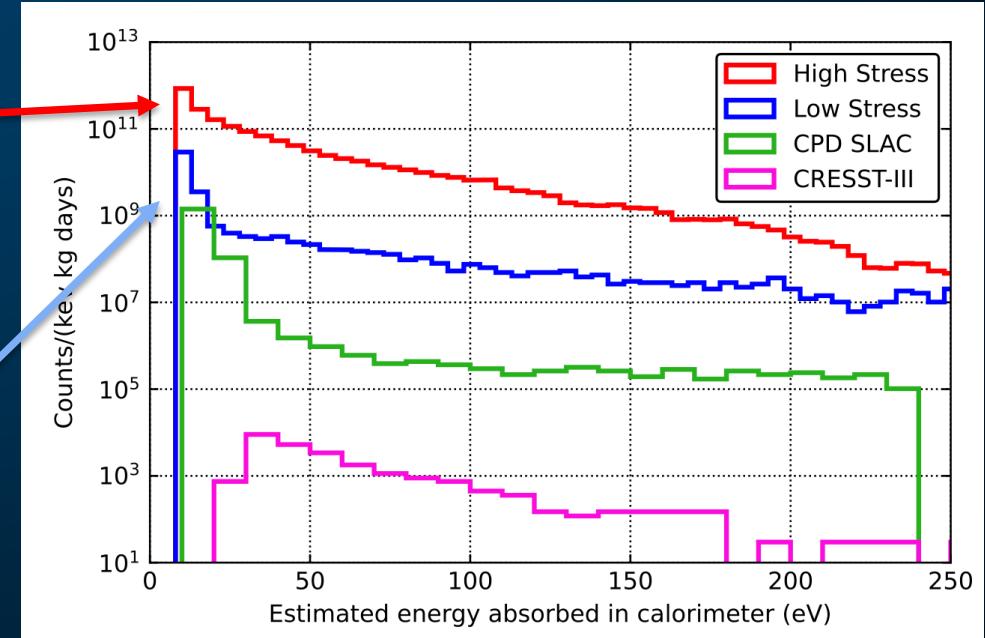
R. Romani, W. A. Page, D. McKinsey  
arXiv:2208.02790v1 [EXCESS@IDM 2022](#)



glued on copper  
= high stress



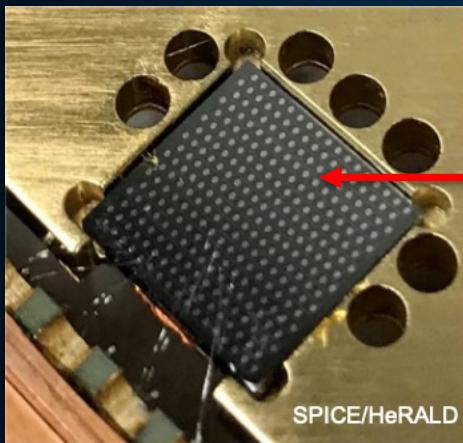
hanging on  
wire bonds  
= low stress



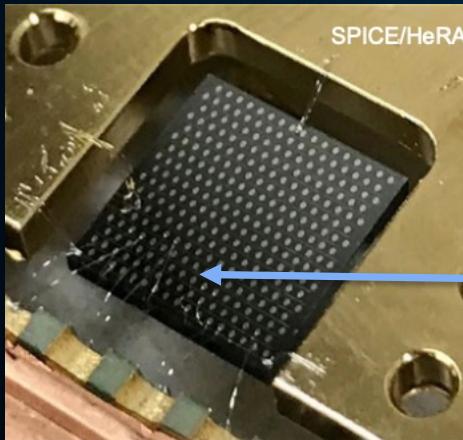
“Mitigation Plan: Fanatically minimize stress everywhere in our detectors”

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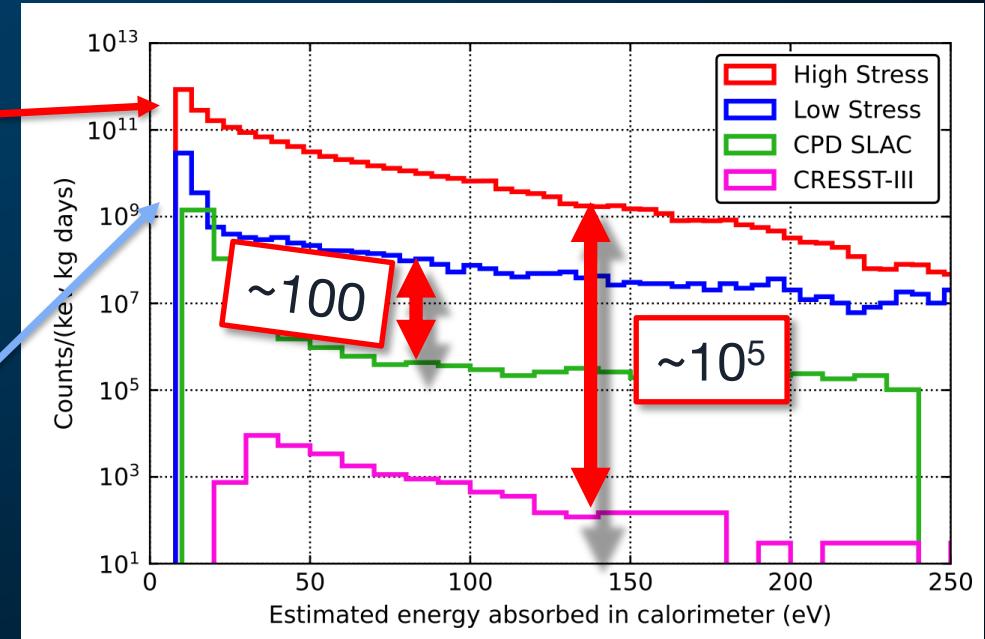
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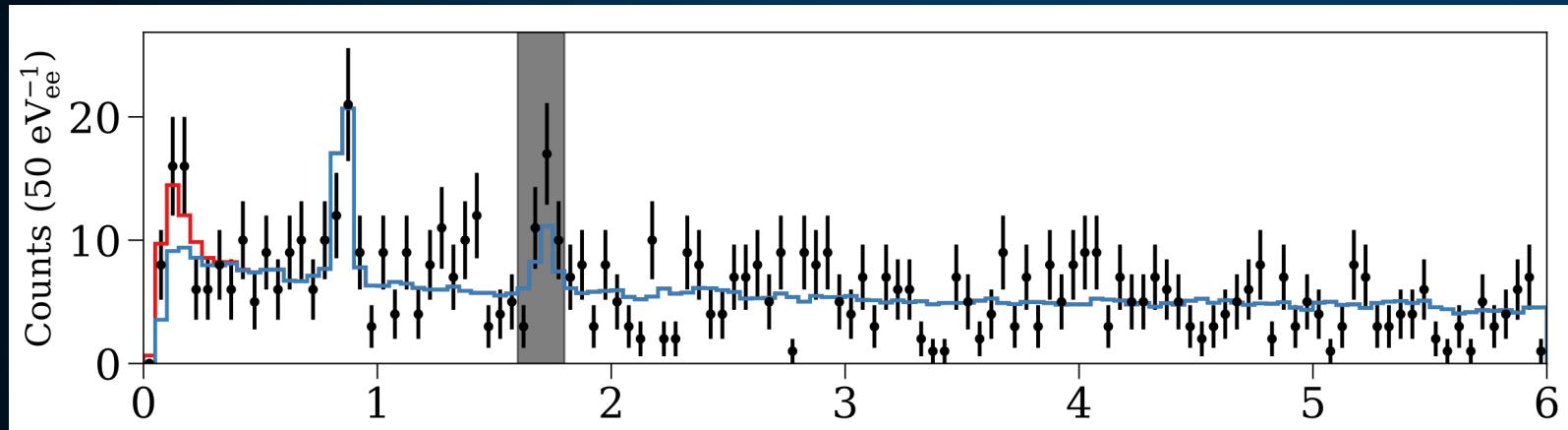
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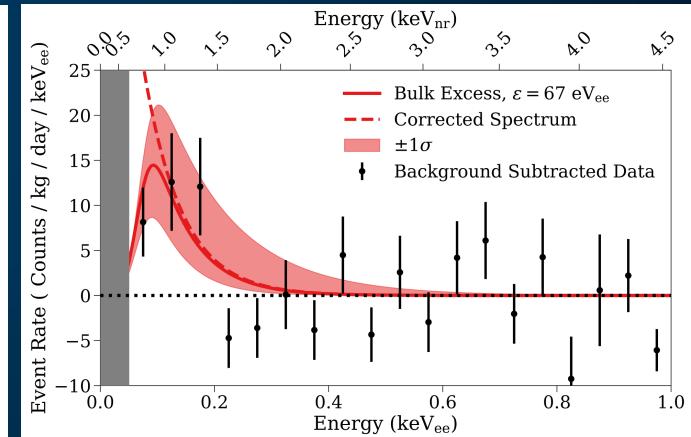
“Mitigation Plan: Fanatically minimize stress everywhere in our detectors”

# CCDs

DAMIC @ SNOLAB



[Phys. Rev. D 105, 062003 \(2022\)](#)



$3.7\sigma$

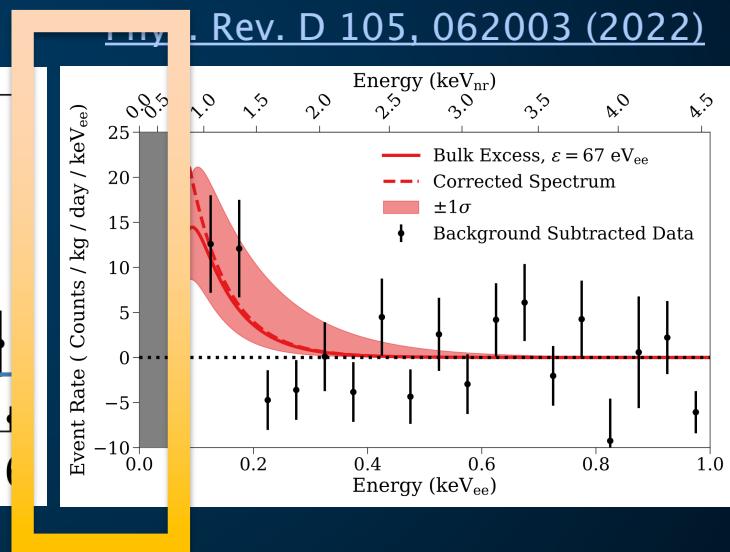
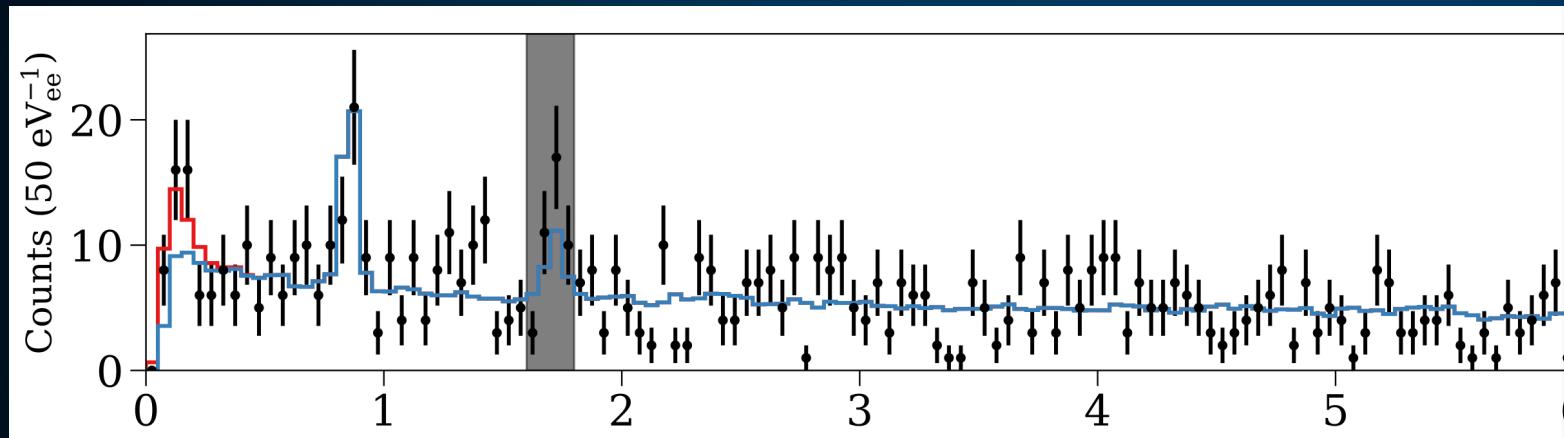
D. Baxter, EXCESS @IDM2022

## Possibilities:

1. We are missing a bulk component in our background model
  2. We are missing a front component in our background model
  3. We are incorrectly modeling detector threshold effects
  4. We are missing a front detector effect
  5. **We are observing interesting new silicon physics**
  6. **We are observing some type of dark matter interaction**
- Background Model  
New Physics

# CCDs

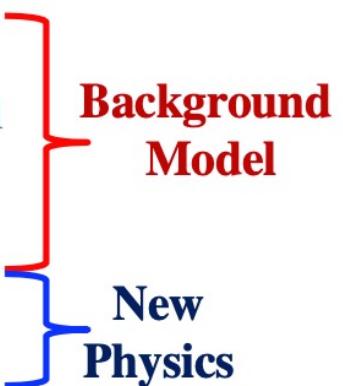
DAMIC @ SNOLAB



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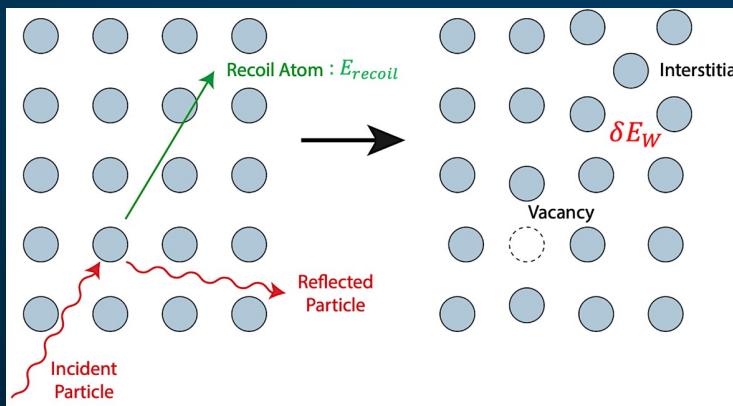
**Statistically robust  
observation of excess  
despite lowest rates  
in the field**

# ENERGY DEPOSITION AT LOW ENERGIES + CALIBRATION

## EXCESS@IDM2022



### Impact of Crystal Lattice Defect Quenching on CE $\nu$ NS at reactors



Thierry Lasserre

An equation for energy deposition in a phonon-mediated cryodetector. It shows the total recoil energy  $E_{recoil}$  as the sum of phonon energy  $E_{phonon}$  and energy loss  $\delta E_W$ . The equation is  $E_{recoil} = E_{phonon} + \delta E_W$ . A green arrow labeled "Incident energy" points upwards. A red arrow labeled "Possible loss for the phonon sensor... (at least for some time...)" points downwards. A blue circle with a wavy arrow is labeled "Our observable in phonon-mediated cryodetector".

We need a connection to solid-state physics, but developing a common language is more challenging than naively thought.

# CALIBRATION OF (NR) ENERGY SCALE



- Two full sessions at EXCESS2022 (Xu, Rode, Privitera, Collar, Saab, Hertel, Stifter, ...)
- A heavily incomplete list of recent works:
  - “*Observation of a nuclear recoil peak at the 100 eV scale induced by neutron capture*”, CRAB NUCLEUS, [arXiv:2211.03631v1](https://arxiv.org/abs/2211.03631v1)
  - “*First measurement of the nuclear-recoil ionization yield in silicon at 100 eV*”, SuperCDMS, [arXiv:2303.02196](https://arxiv.org/abs/2303.02196)
  - “*A portable and high intensity 24 keV neutron source based on  $^{124}\text{Sb}$ - $^9\text{Be}$  photoneutrons and an iron filter*”, SPICE/HeRALD, [arXiv:2302.03869](https://arxiv.org/abs/2302.03869)
  - And many more (sorry for being incomplete here)

# RELATIONS

Energy scale at  
low energies /  
calibration

Particle  
backgrounds?  
Monte Carlos at  
low energies

Condensed  
matter  
community

Connection to  
quantum  
sensing



# SUMMARY

- Rare event searches keep pushing the thresholds
  - Excesses observed “everywhere”
  - One single common origin unlikely
- Shared problem requires common effort: the EXCESS initiative

# XVIII International Conference on Topics in Astroparticle and Underground Physics 2023

28.08. – 01.09.2023

University of Vienna

SCROLL

EXCESS@TAUP2023

August 26 in Vienna

B. von Krosigk, D. Baxter, F. Wagner, F. Reindl, M. Kaznacheeva, M.C. Piro, R. Essig, V. Novati, V. Wagner, Y. Hochberg

<https://indico.cern.ch/event/1213348/>

<https://taup2023.hephy.at>

Registration is already open!

# EXCESS IS A COMMUNITY EFFORT

## Chairs of 1<sup>st</sup> edition



Alexander Fuss



Felix Wagner



Florian Reindl



Margarita Kaznacheeva

[excessworkshop@gmail.com](mailto:excessworkshop@gmail.com)

We provide the canvas, you may fill it!

- Further initiatives and ideas are highly welcome

To stay in touch, subscribe to our mailing list at:  
<https://lists.lrz.de/mailman/listinfo/excess>





# Ludwig II.

Born 1845 at castle Nymphenburg

„Ein ewiges Rätsel  
will ich bleiben mir  
und anderen...“  
(1876)