SIGNALS IN LOW-MASS DARK MATTER AND CEνNS EXPERIMENTS

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TU Wien & HEPHY (ÖAW)

UCLA Dark Matter
Los Angeles, March 2023

WHAT IS THE EXCESS INITIATIVE?

Topic: excesses (= events above known background level)
observed in low-mass DM and CEνNS experiments

Format: series of workshops

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

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

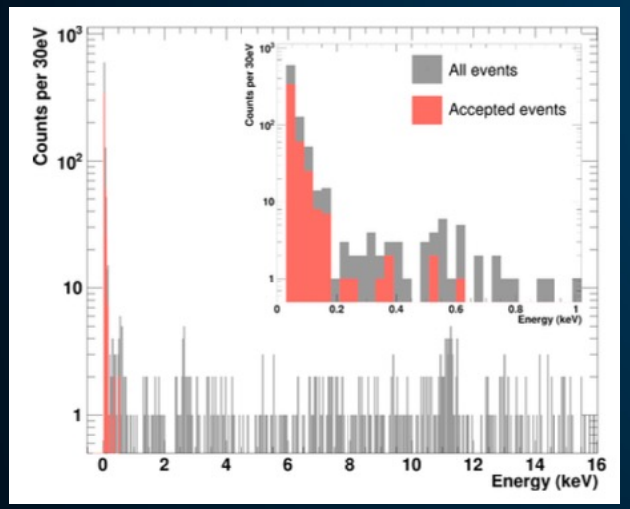
Jul. 2022 (@IDM, Vienna) https://indico.cern.ch/event/1117540/

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

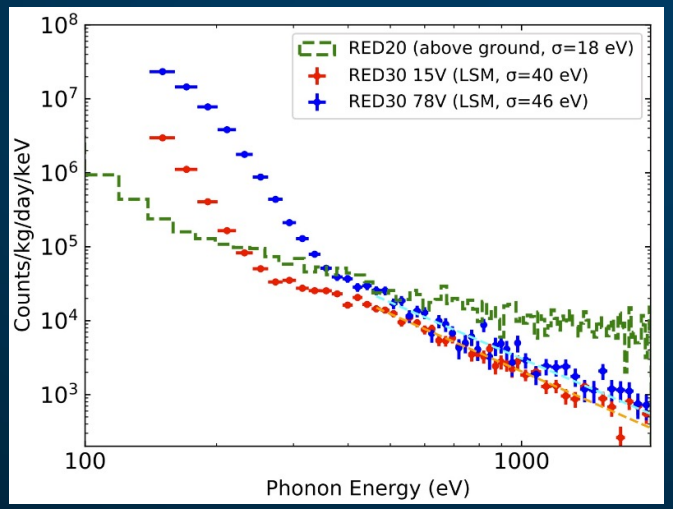
WHITEPAPER 2021/22 - CRYOGENIC DETECTORS

SciPost Phys. Proc. 9, 001 (2022)

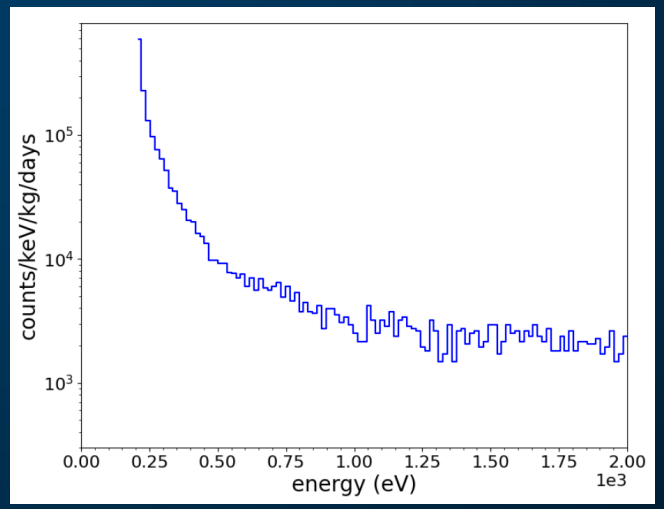
CRESST-III (2019)



EDELWEISS (2019/20)

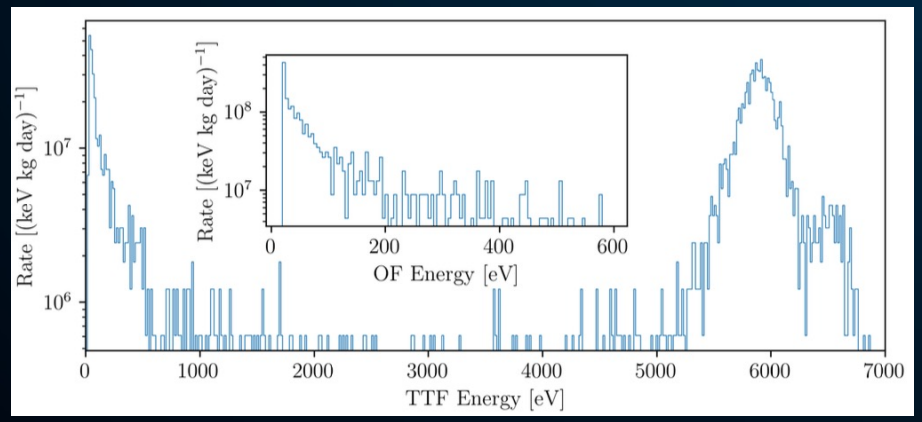


MINER (2021)

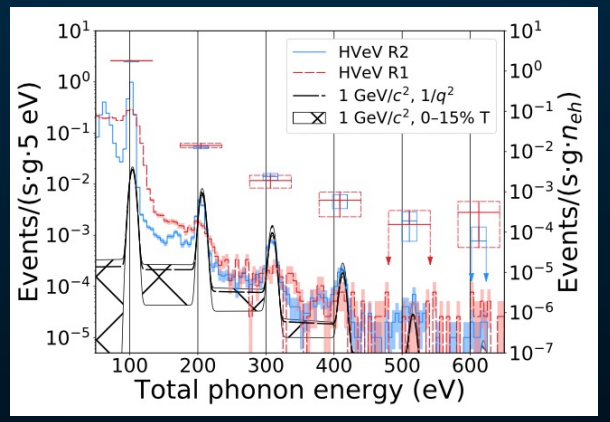


Steeply rising towards low energies

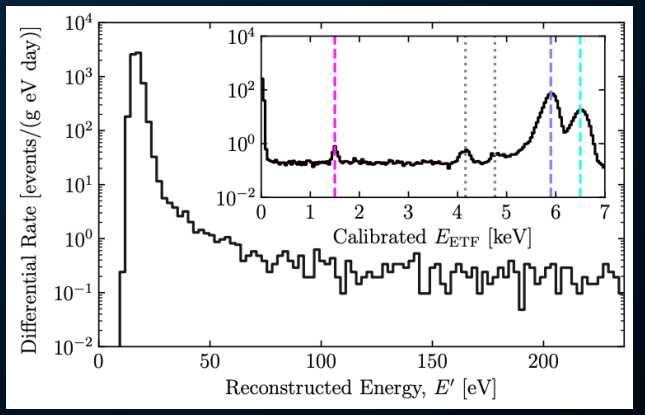
NUCLEUS (2017)



SuperCDMS HVeV (2021)



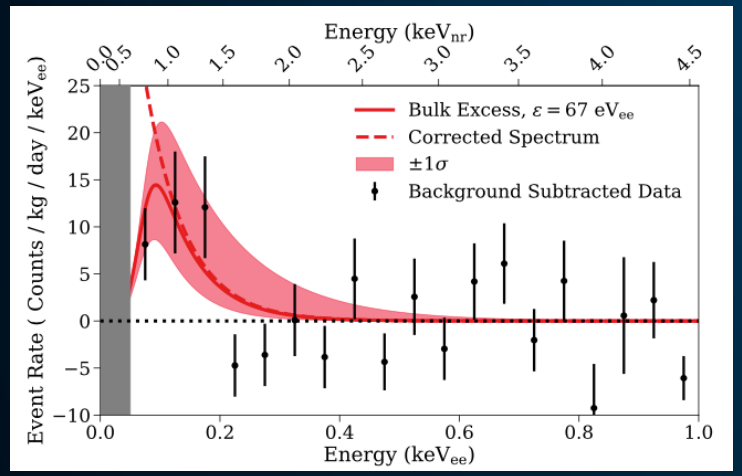
SuperCDMS CPD (2021)



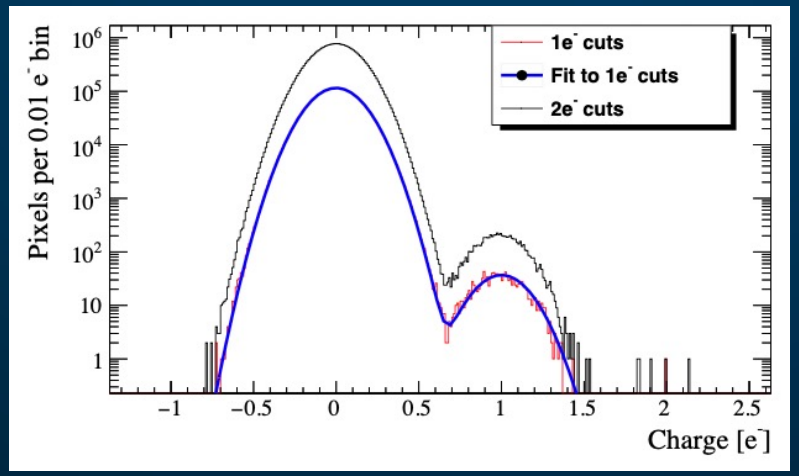
WHITEPAPER 2021/22 - CCDs

SciPost Phys. Proc. 9, 001 (2022)

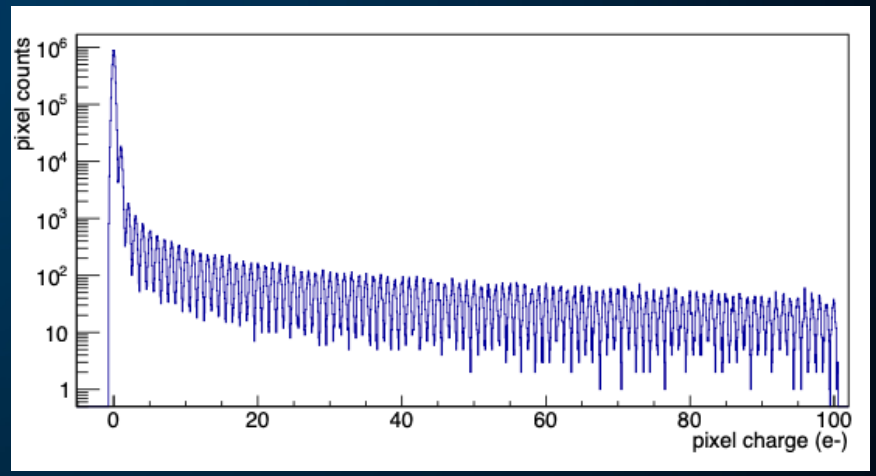
DAMIC (2021)



SENSEI (2020)



SKIPPER @FNAL (2020)



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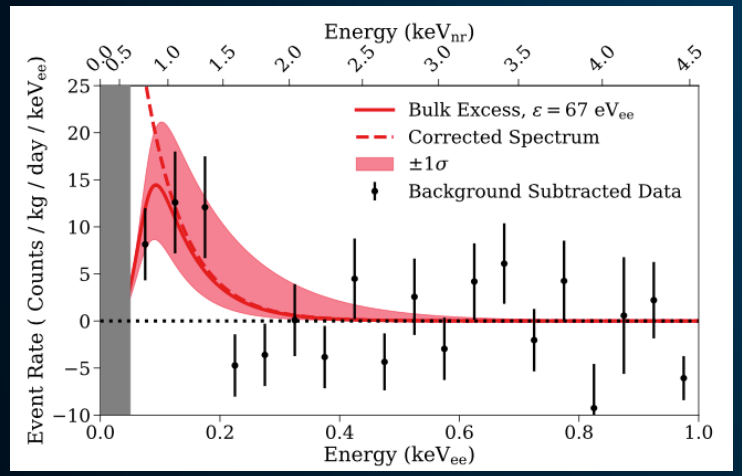

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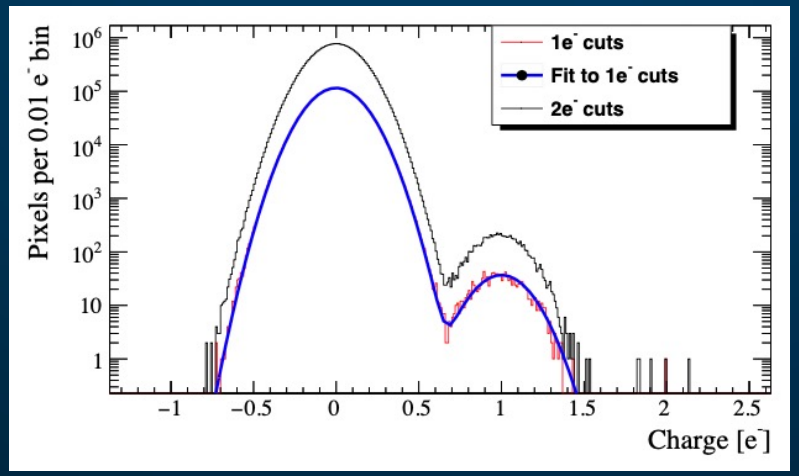

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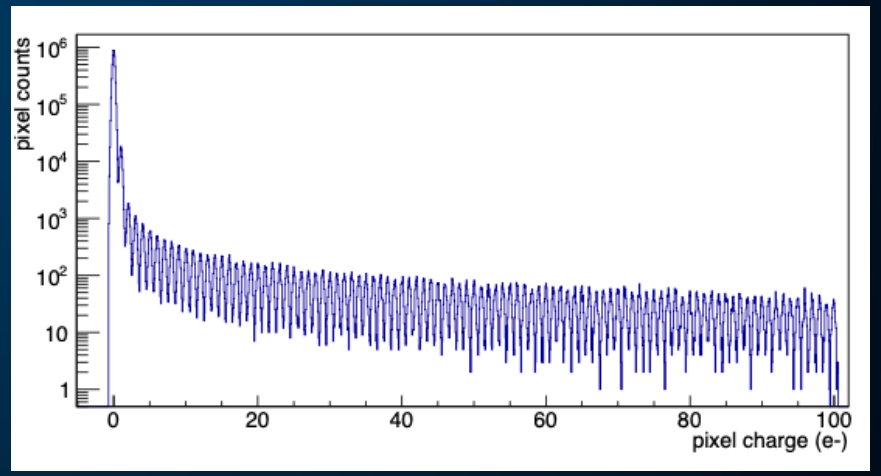

+ Gaseous ionization detectors (NEWS-G)

WHITEPAPER 2021/22 - CCDs

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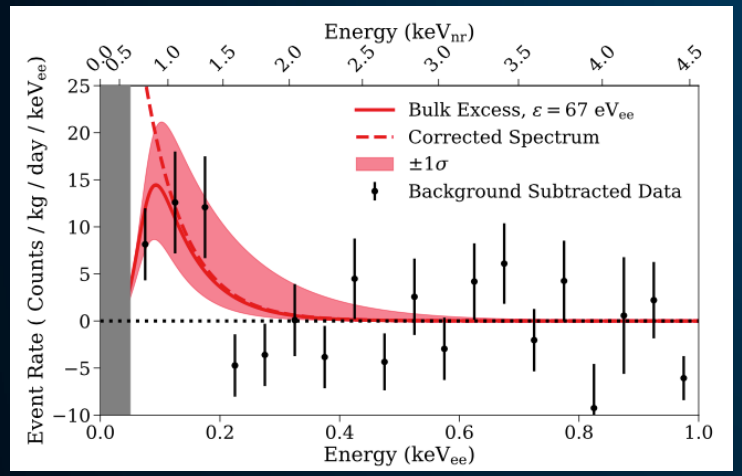

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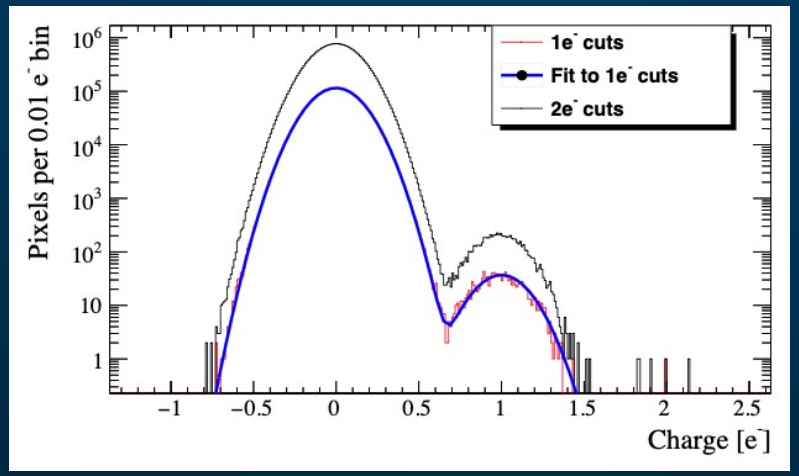

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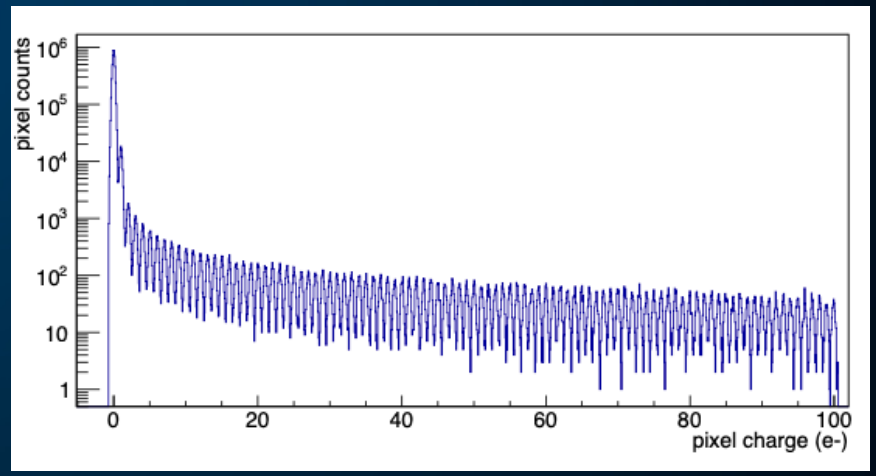


+ Gaseous ionization detectors (NEWS-G)

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 (Si, $CaWO_4$, Ge, Al_2O_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)?

EXCESS @IDM 2022 (LATEST WORKSHOP)

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

F. Reindl

Dedicated studies on the excesses

Focus on (cryogenic) solid-state detectors

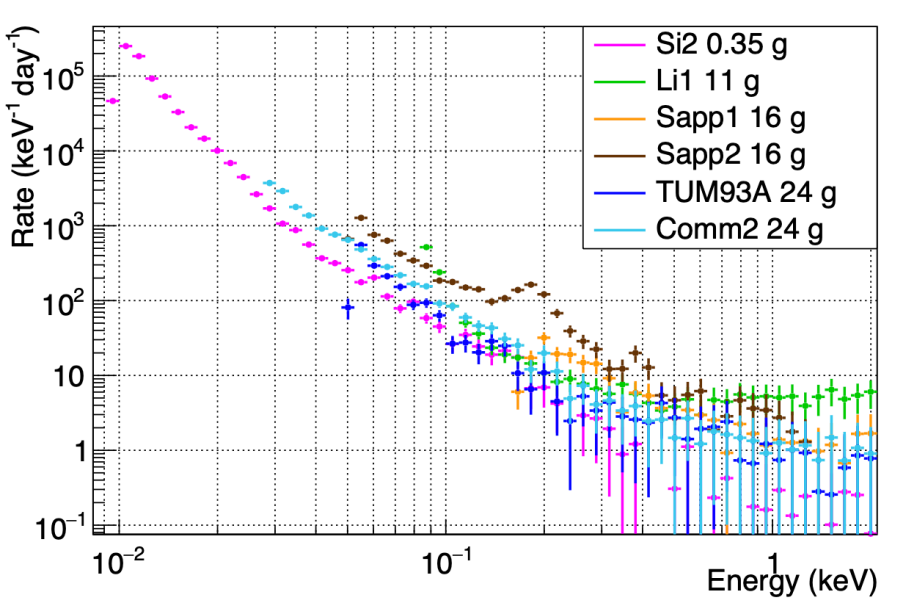
No time to show everything → cherry-picking results.

CRYOGENIC: CRESST-III

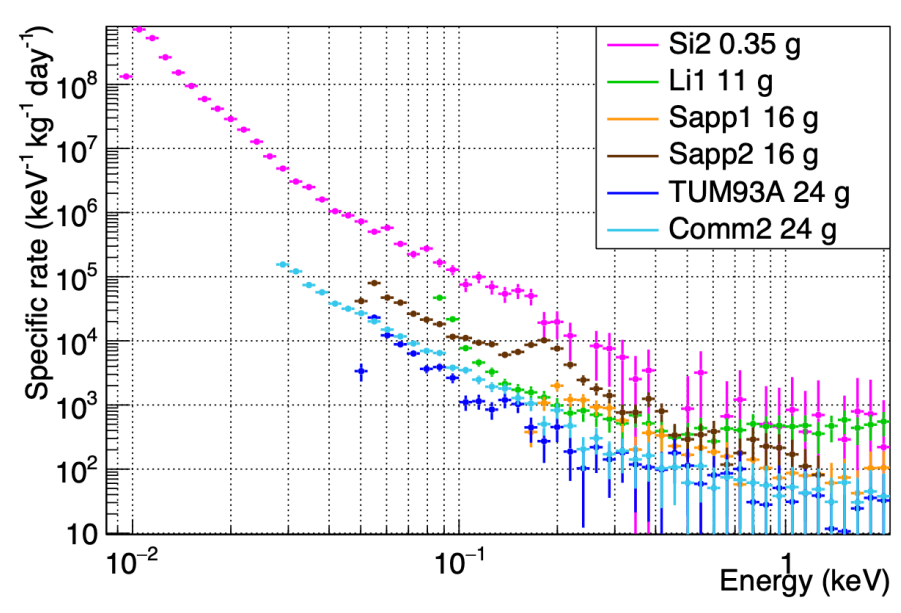
arXiv:2207.09375v2

Rate in different detectors

Scaled by measuring time



Scaled by measuring time and mass

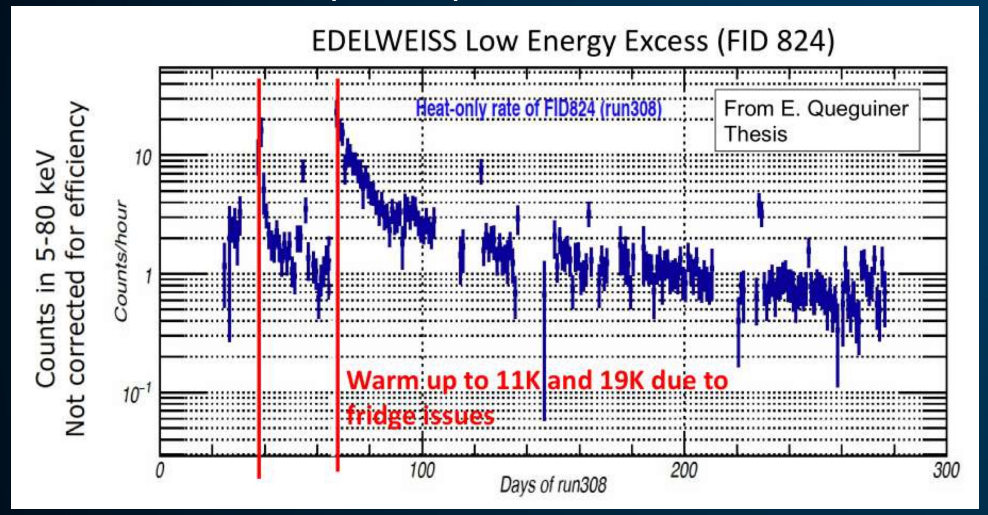


All detectors measure excesses

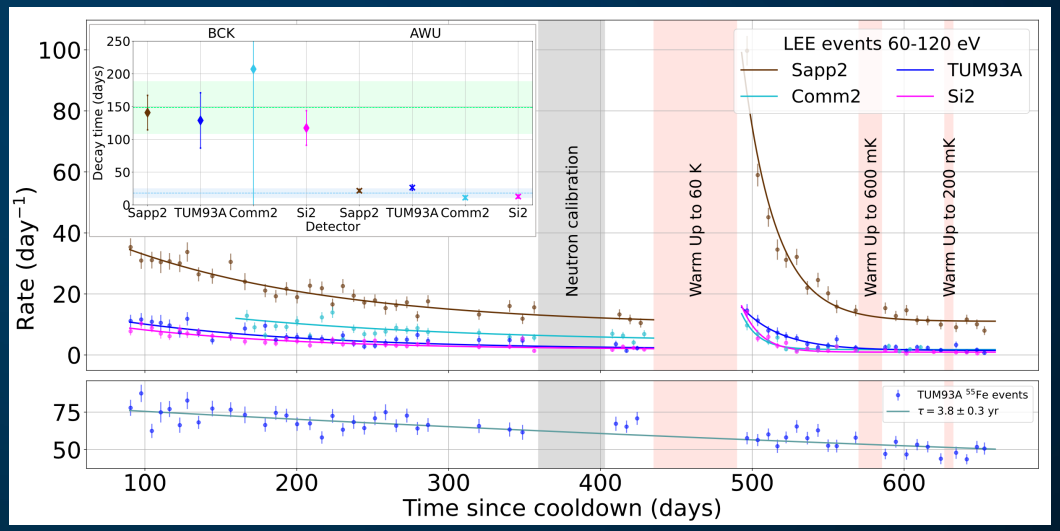
Rates do not scale with mass

CRYOGENIC: TIME EVOLUTION

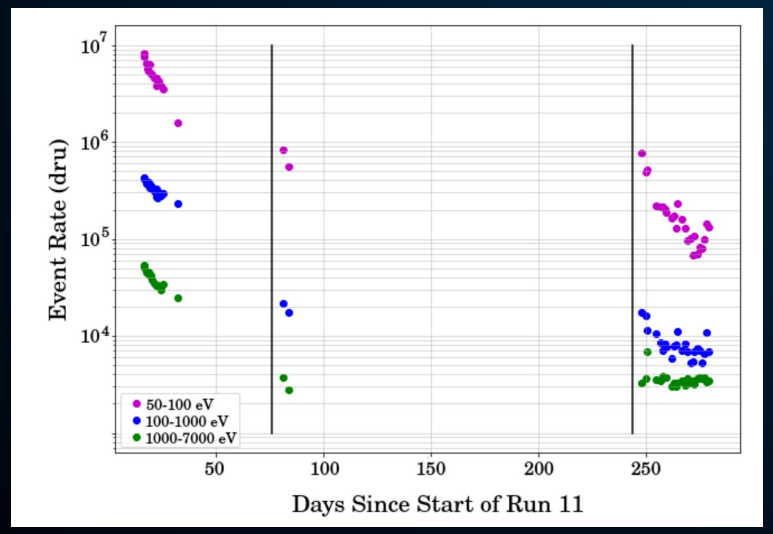
EDELWEISS (2019)



CRESST (2022) arXiv:2207.09375v2



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:

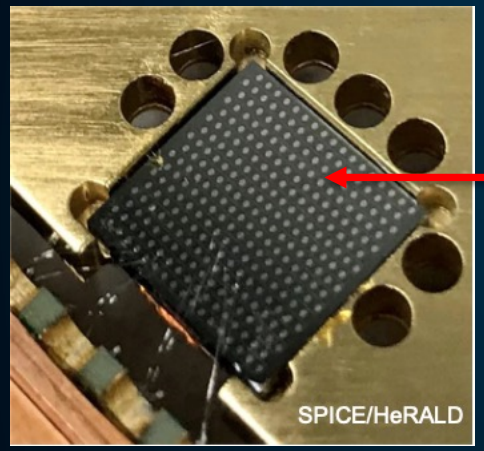
- stress from crystal, sensor or holding.

* For SuperCDMS HvEV, see Phys. Rev. D **105**, 112006 + Novati, EXCESS @IDM2022

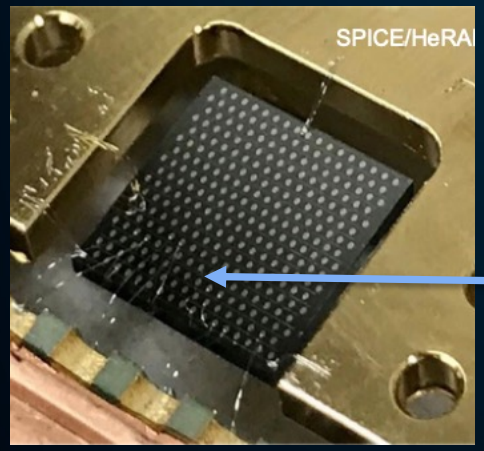
Stress Test

R. Romani, W. A. Page, D. McKinsey

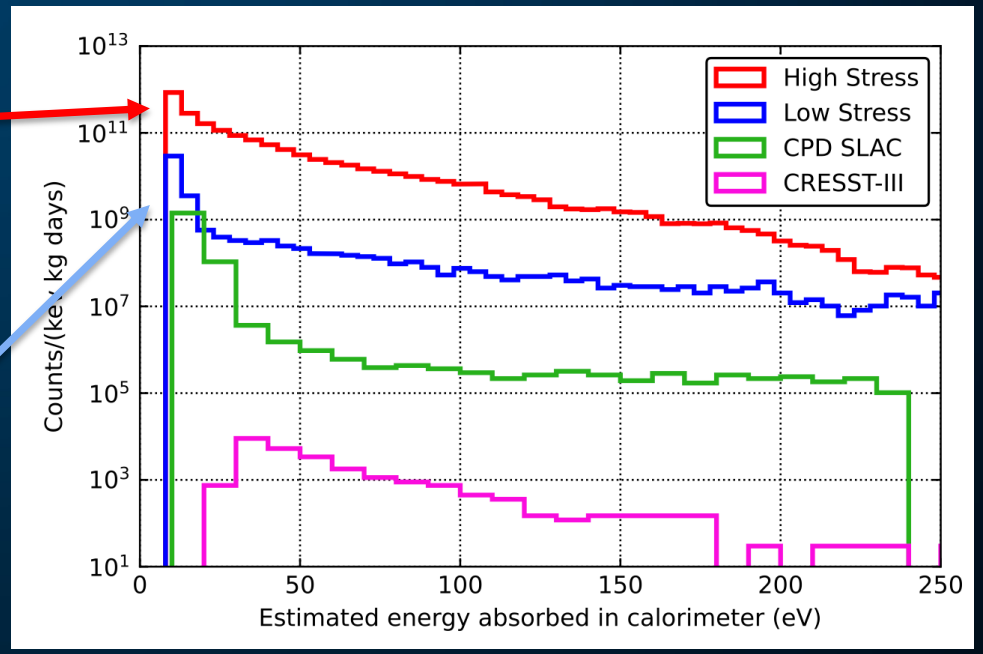
arXiv:2208.02790v1 EXCESS@IDM 2022



glued on copper
= high stress



hanging on
wire bonds
= low stress



"Mitigation Plan: Fanatically minimize stress everywhere in our detectors"

Stress Test

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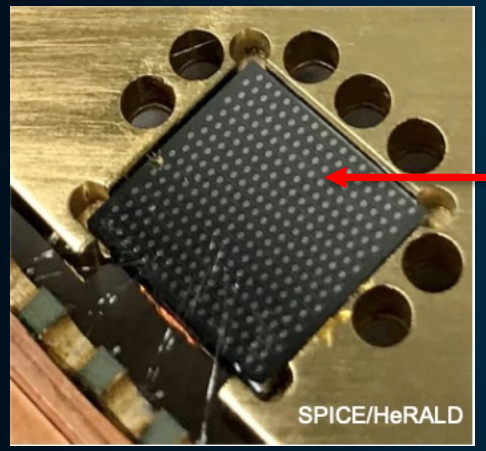

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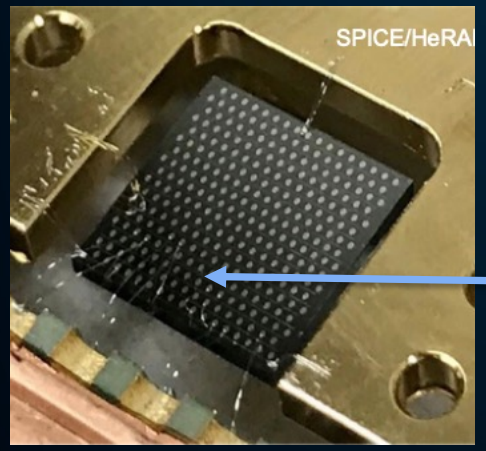

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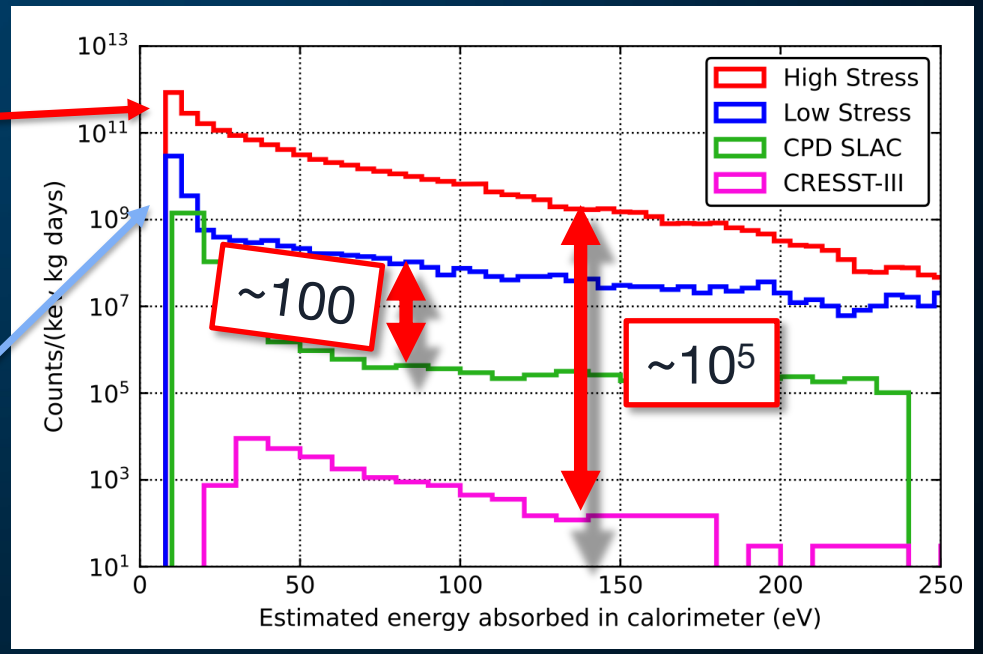
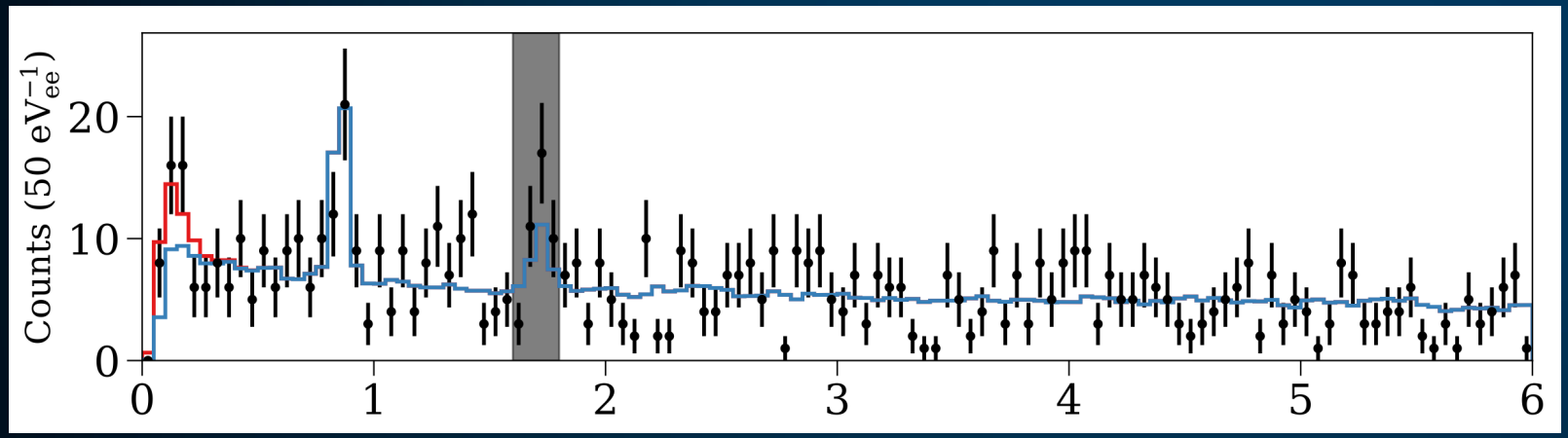


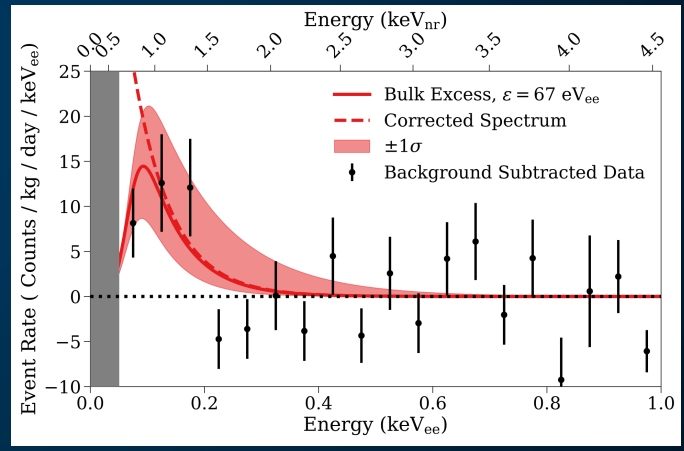
"Mitigation Plan: Fanatically minimize stress everywhere in our detectors"

CCDs

DAMIC @ SNOLAB

Phys. Rev. D 105, 062003 (2022)





3.7σ

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**

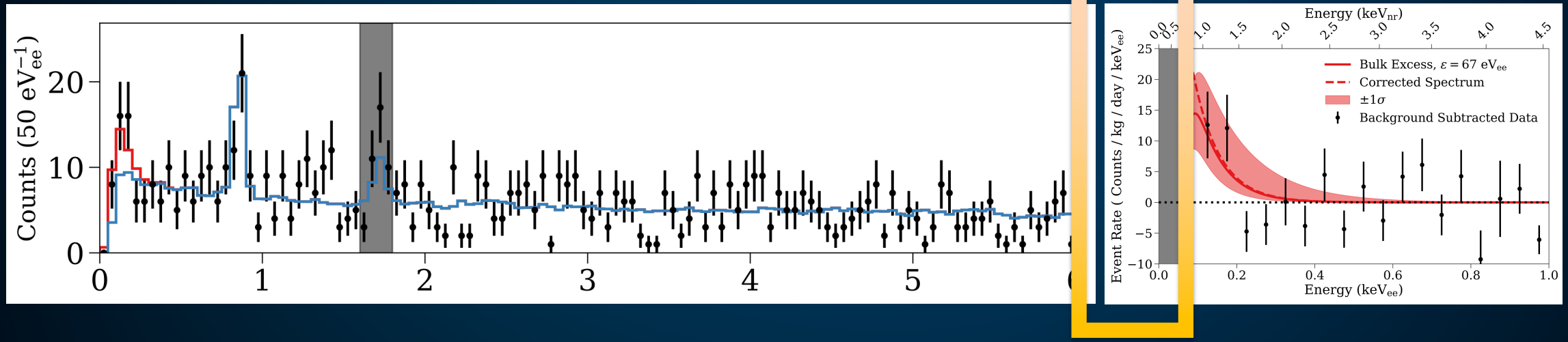
Background Model

New Physics

CCDs

DAMIC @ SNOLAB

Phys. Rev. D 105, 062003 (2022)



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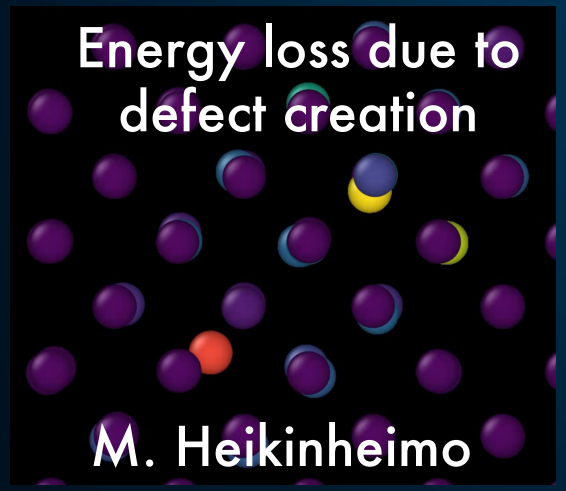
Background Model

New Physics

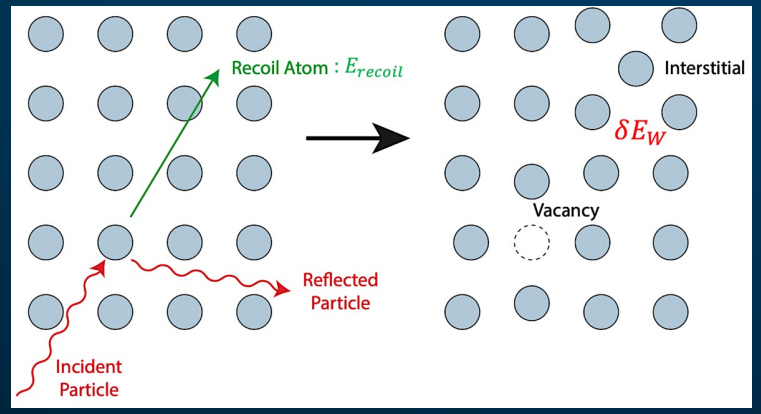
Statistically robust observation of excess despite lowest rates in the field

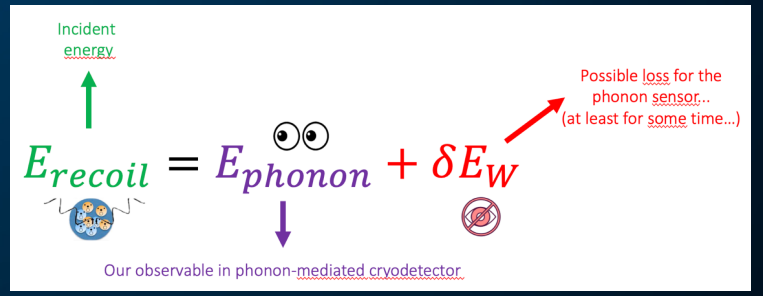
ENERGY DEPOSITION AT LOW ENERGIES + CALIBRATION
EXCESS@IDM2022



Impact of Crystal Lattice Defect Quenching on CEνNS at reactors

Thierry Lasserre





We try to establish connections to solid-state physics, but developing a common language is more challenging than naively thought.

Relations

Energy scale at low energies / calibration

Particle backgrounds? Monte Carlos at low energies

Condensed matter community

Connection to quantum sensing

EXCESS@TAUP2023

August 26 in Vienna

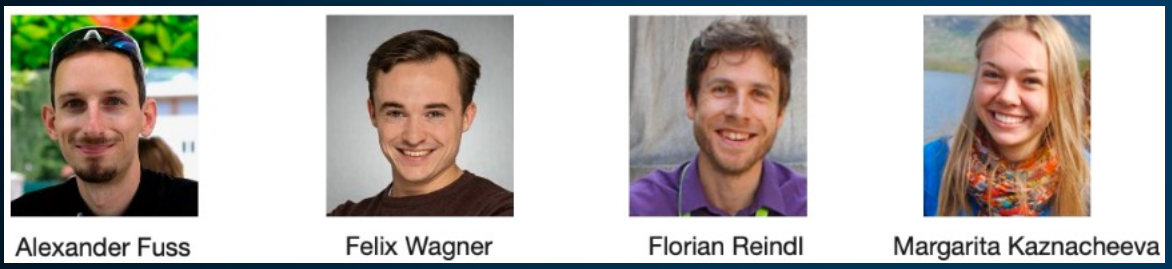
B. von Krosigk, D. Baxter, F. Wagner, F. Reindl, M. Kaznacheeva, M.C. Piro, R. Essig, V. Novati, V. Wagner, Y. Hochberg

https://indico.cern.ch/event/1213348/
https://taup2023.hephy.at

Registration is already open!

EXCESS IS A COMMUNITY EFFORT

Chairs of 1st edition



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

Summary

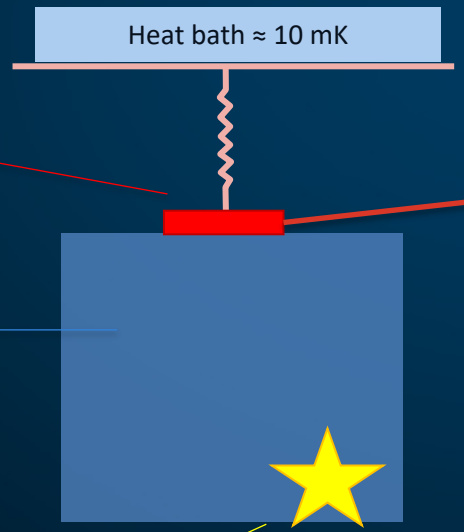
- Rare event searches keep pushing the thresholds
- Excesses observed “everywhere”, in particular in cryogenic experiments
- One single common origin unlikely

→ Shared problem requires common effort: the EXCESS initiative

BACKUP

WHITEPAPER 2021/22 - CRYOGENIC DETECTORS

SciPost Phys. Proc. 9, 001 (2022)

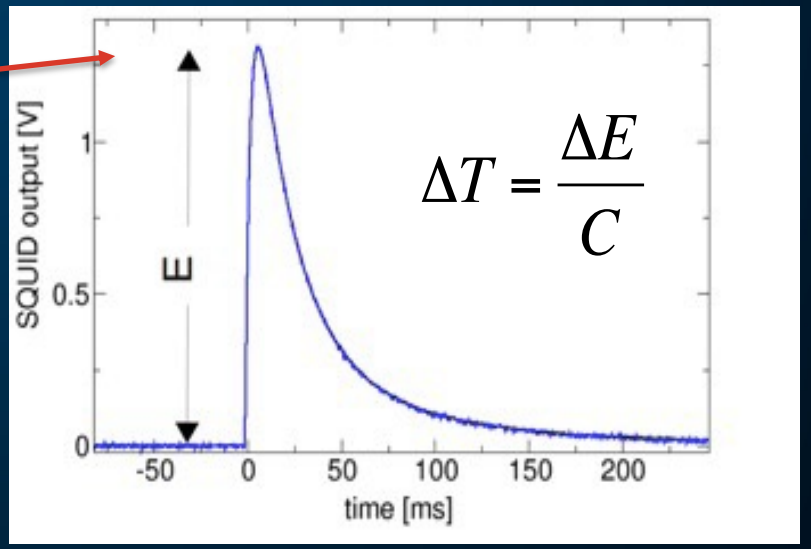


Thermometer

Target crystal

Particle interaction

Temperature pulse



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
  - *"First measurement of the nuclear-recoil ionization yield in silicon at 100 eV"*, SuperCDMS, arXiv:2303.02196
  - *"A portable and high intensity 24 keV neutron source based on ^{124}Sb-^{9}Be photoneutrons and an iron filter"*, SPICE/HeRALD, arXiv:2302.03869
  - And many more (sorry for being incomplete here)