Dark Matter Search with a low-threshold SuperCDMS HVeV detector

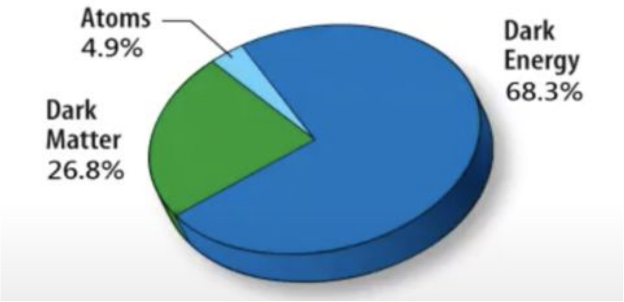
2021/6/7

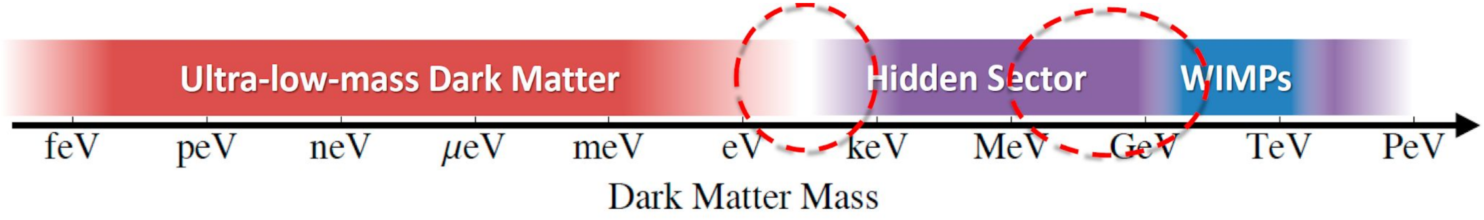
Ziqing Hong, for the SuperCDMS collaboration

Introduction

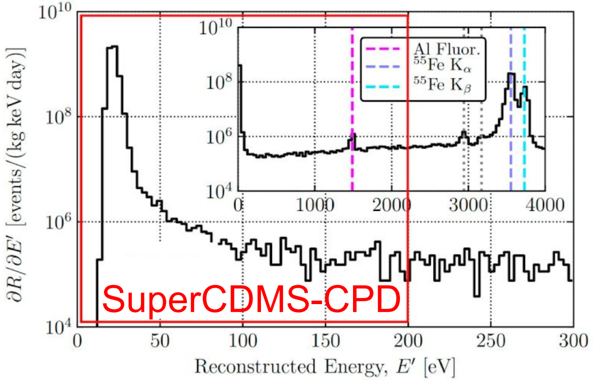
SuperCDMS uses cryogenic phonon-based detectors to look for a wide range of Dark Matter (DM) candidates

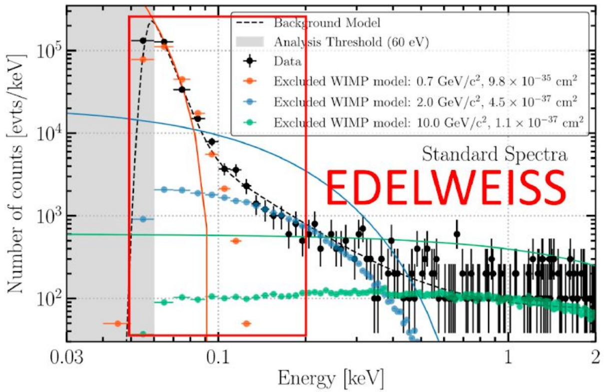
- Direct detection of DM with energy from eV to 10 GeV
- Nuclear-recoil and electron-recoil DM





Low-energy excess in multiple phonon-based DM searches



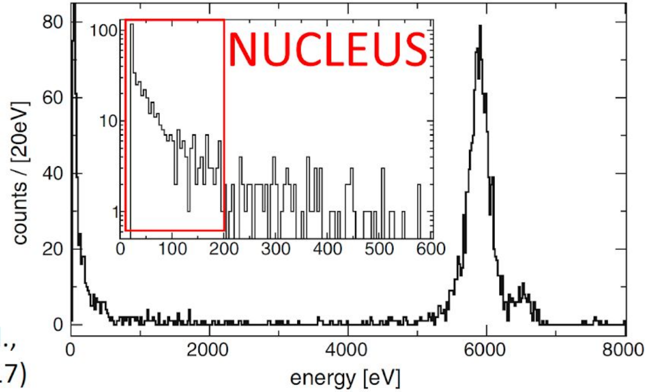


E. Armengaud *et al.*, Phys. Rev. D 99:082003 (2019)

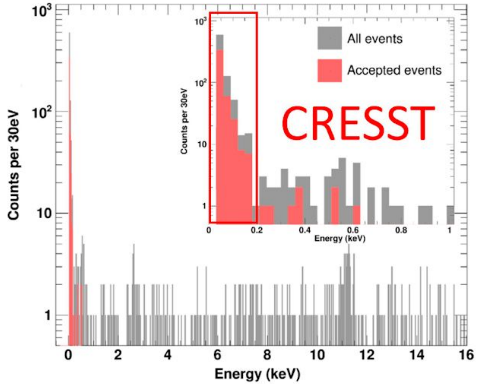
Similar results in an underground search in Phys. Rev. Lett.125.141301(2020)

A. H. Abdelhameed *et al.*, Phys. Rev. D 100:102002 (2019)

I. Alkhatib et al., ArXiv:2007.14289 (2020)

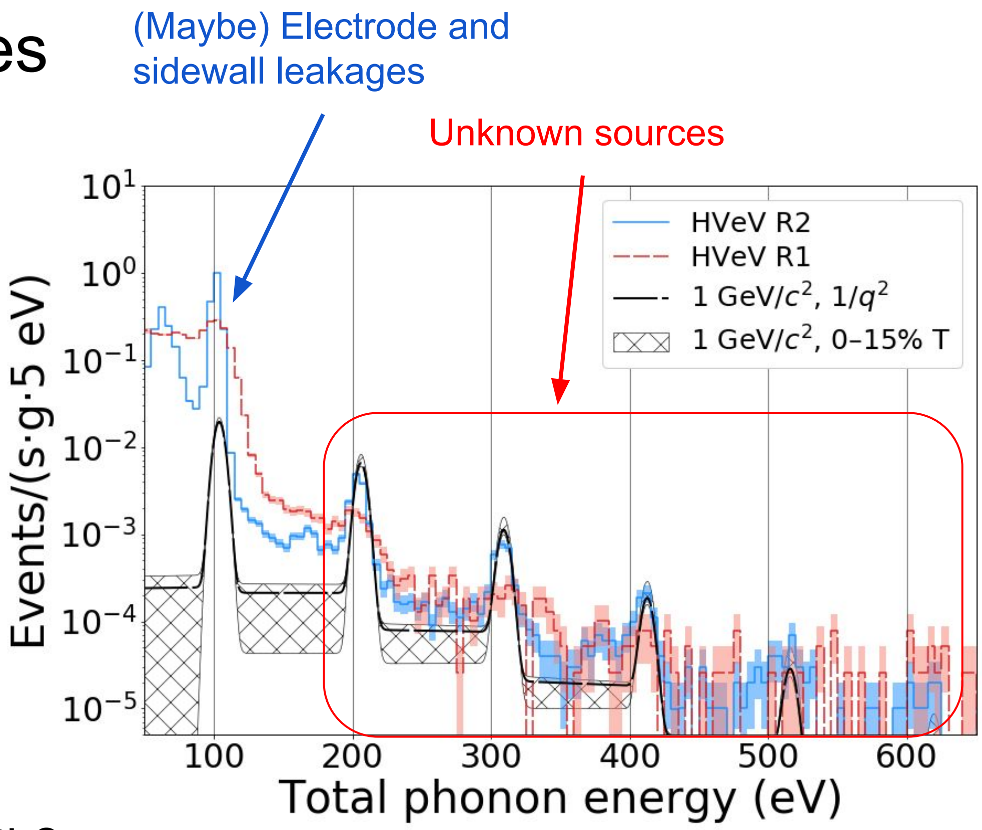


G. Angloher et al., EPJC 77:637 (2017)



Also in HVeV ERDM searches

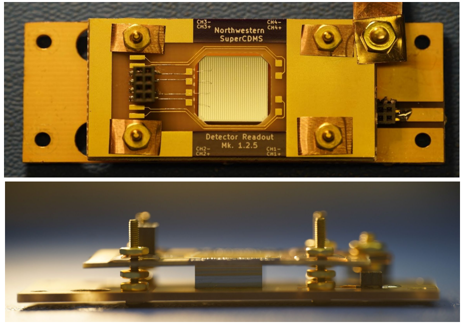
- Unknown sources also observed in multiple **charge based** dark matter searches with SuperCDMS-HVeV detector
- Questions:
- Are these two groups of unknown sources related?
- What information can we extract from these events?
- If they're background, would this lead to ways to eliminate one or both?

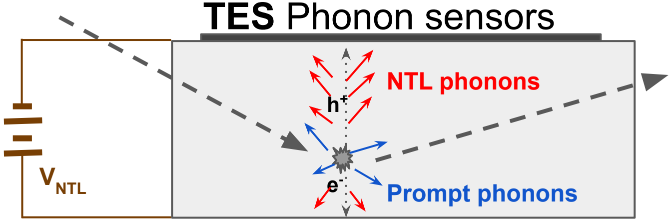


D.W. Amaral et al, Phys. Rev. D 102, 091101 (2020)

SuperCDMS HVeV detector

Measuring energy with phonon sensors on silicon/germanium crystal





- **2.7 eV baseline resolution, 9.2 eV threshold [1]**
  - **Best in class**
- **By measuring the background at different voltages with the same setup, we can better understand the nature of the unexplained excess**
  - **Quantified by ϵ_{eff}, the average energy to create an electron-hole pair**
    - **$n_{eh} = E_{Recoil} / \epsilon_{eff}$**

0V mode (V_{NTL}=0):
Phonon energy = recoil energy

HV mode (V_{NTL}≠0):
Phonon energy = recoil energy + NTL phonon energy

$$\begin{aligned} E_{phonon} &= E_{recoil} + n_{eh} eV_{\mathrm{NTL}} \\ &= E_{recoil} \cdot \boxed{(1 + eV_{\mathrm{NTL}}/\epsilon_{eff})} \end{aligned}$$

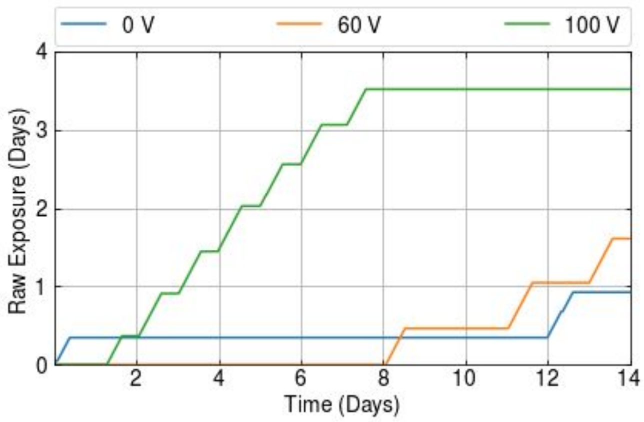
G_{NTL}

The recoil energy is effectively amplified by G_{NTL} via the NTL effect[2].

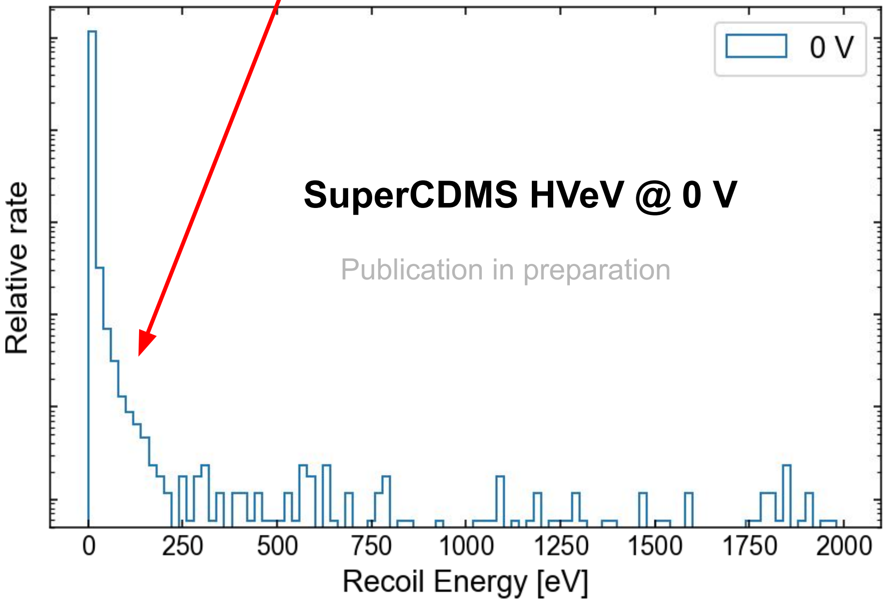
[1] R. Ren et al. ArXiv:2021.12430 (2020)
[2] B.S. Neganov and V.N. Trofimov, Otkrytia i Izobret. 146, 215 (1985), P.N. Luke, et. al, Nucl. Instrum. Meth. Phys. Res. A 289, 406-409 (1990).

HVeV detector with 0V/60V/100V bias

- Detector operated in a surface lab at Northwestern University
- O(1) gram-day exposure at **0 V, 60 V and 100 V [1]**



Similar excess around ~100 eV as on slide 3

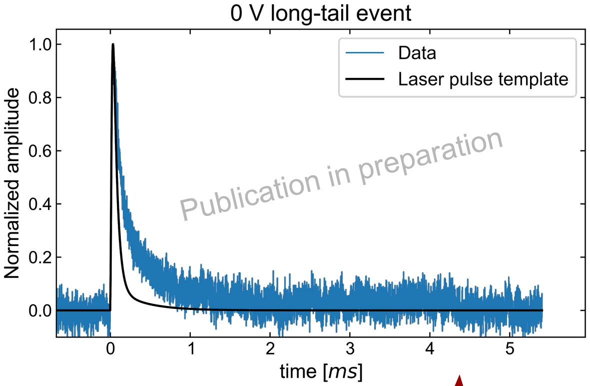


[1] D.W. Amaral et al, Phys. Rev. D 102, 091101 (2020)

"Normal" and "Anomalous" events in 0V and HV data

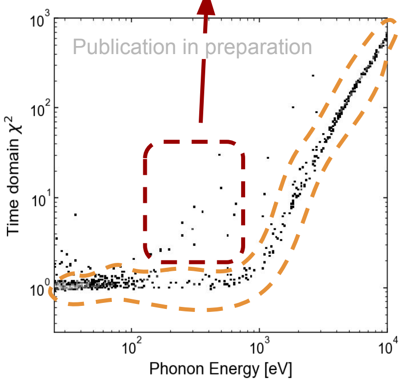
Some events have pulse shape close to the expected shape (from laser calibration).
→ Orange contour in the χ^2 plot.

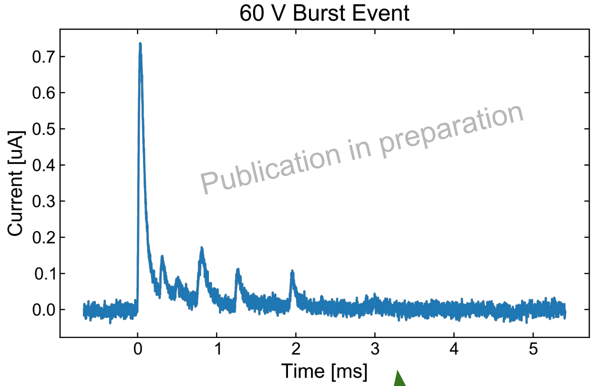
Two anomalies observed:
1. Long-tail pulses@0V
2. Burst events@HV



0V:

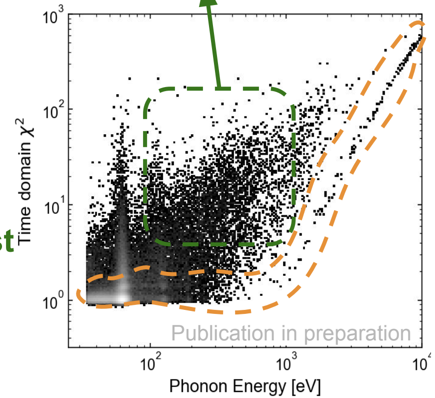
Events have **longer decay time** than laser (photon) events





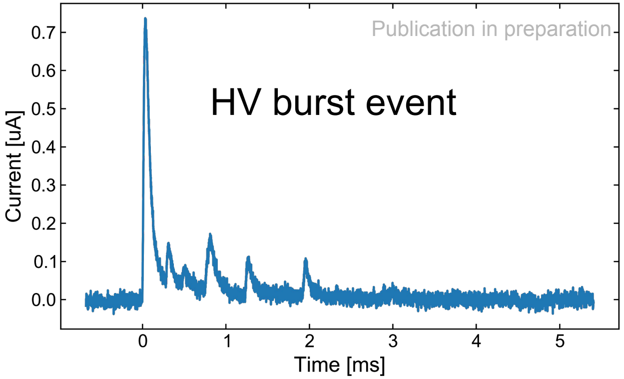
HV:

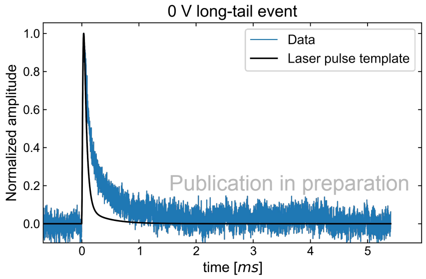
Primary pulse followed by small amplitude pulses. We call these **burst events**

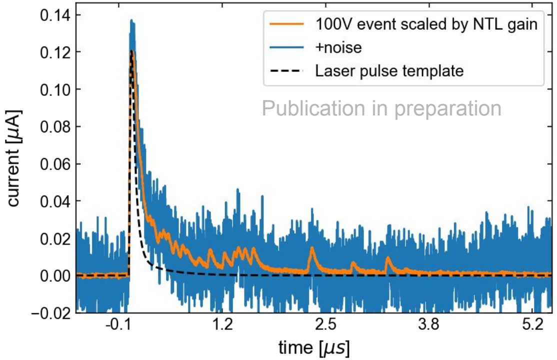


0V-HV comparison: Pulse shape

Burst events can behave like long-tail events if there is no NTL gain.







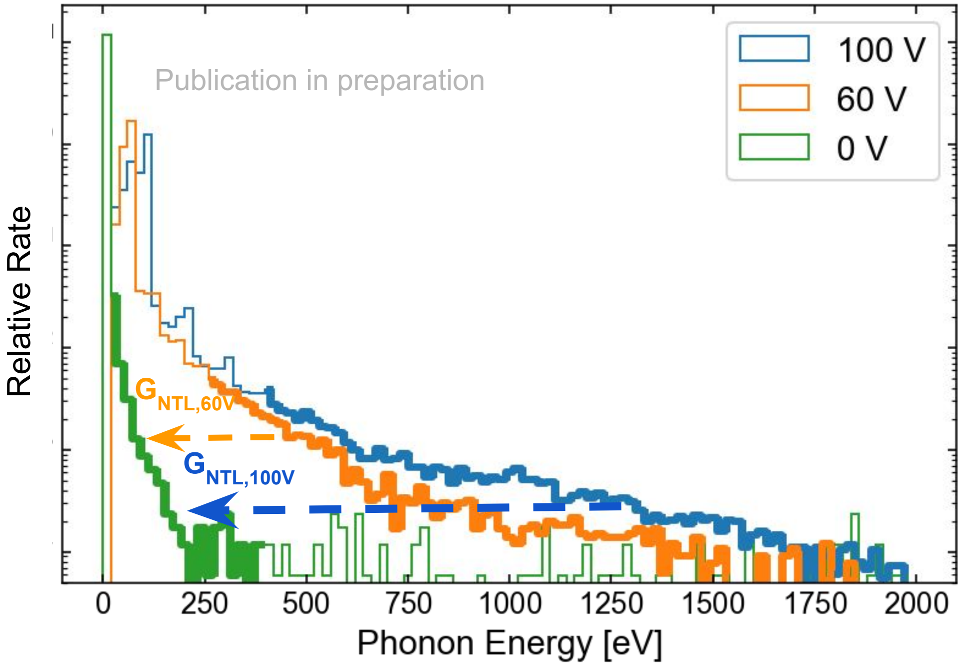
0V-HV comparison: Energy spectra

$$E_{phonon} = E_{recoil} \cdot \boxed{(1 + eV_{\mathrm{NTL}}/\epsilon_{eff})}$$

G_{NTL}

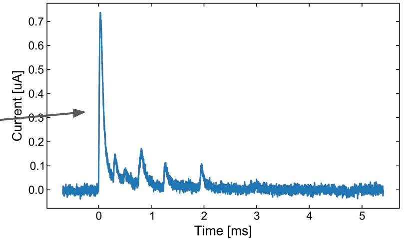
Energy spectrum scales with G_{NTL}.

By looking for the G_{NTL} where the spectra match each other best, we can measure the effective charge pair creation energy $\boldsymbol{\epsilon_{eff}}$ of the background events.

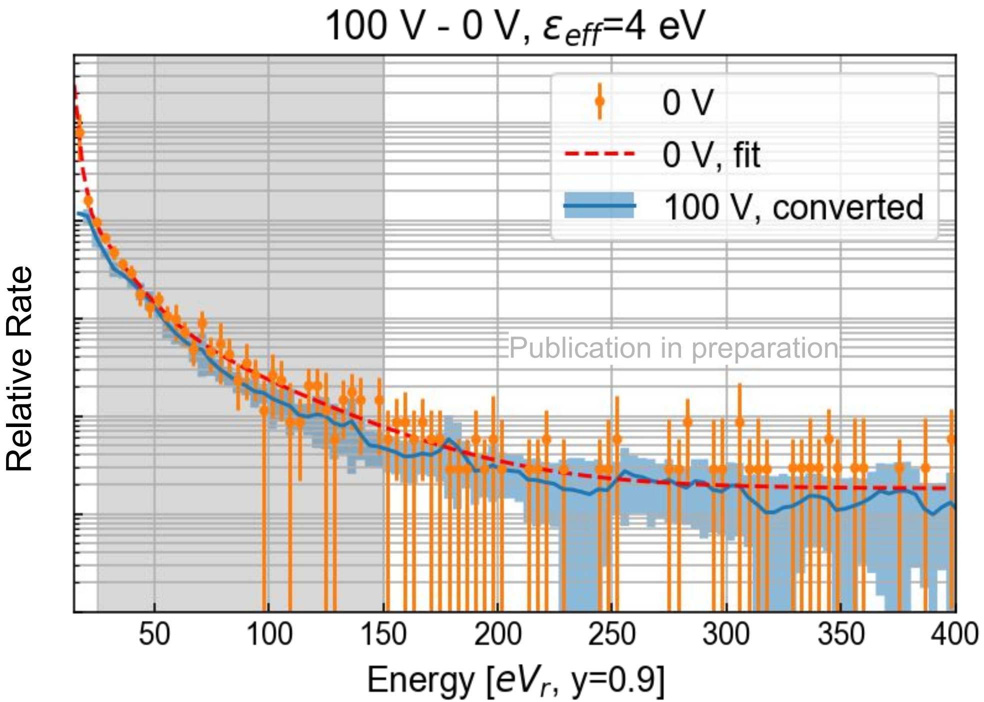


0V-HV comparison: Energy spectra

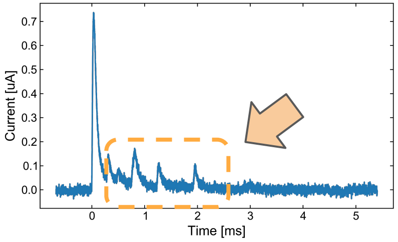
Note: calculated energy of the burst events is close to the energy of the primary pulse



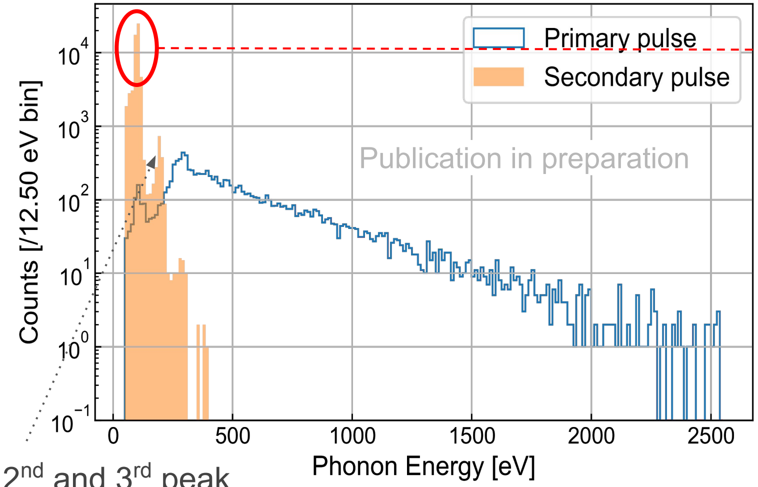
- We scale the HV spectra with different $G_{NTL}(\epsilon_{eff})$
- Minimize the χ^2 between 0V spectrum and the scaled HV spectrum.
- Data favors **ϵ_{eff}~4-5 eV**
  - Just a rough estimate; uncertainty not quantified

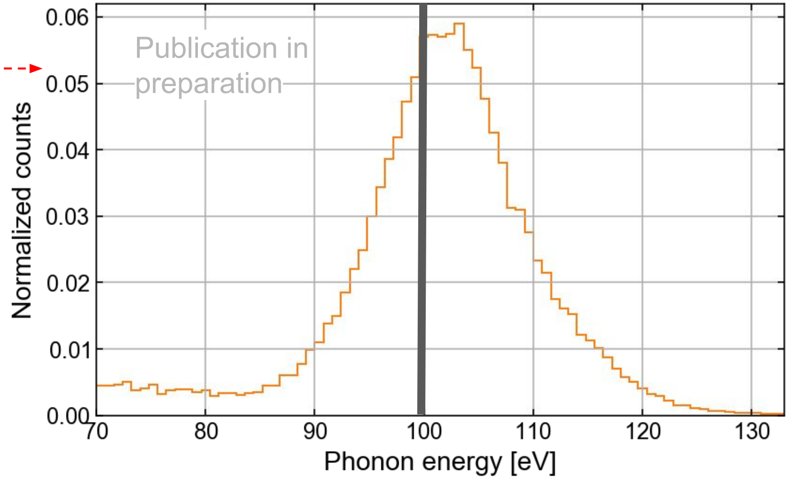


Energy of the secondary pulses in HV burst events



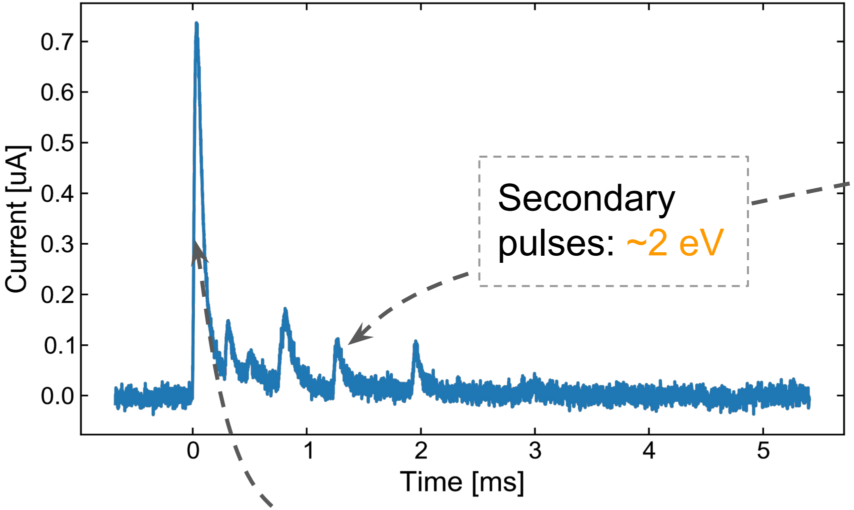
Energy of secondary pulses are compatible with single electron-hole pair events (100 eV) with a recoil energy of ~2 eV





Events in the 2nd and 3rd peak have a rate compatible with pile-up from 1st electron-hole pair events

A model of HV burst events



Secondary pulses: ~2 eV

Primary pulse: ϵ_{eff}~4-5 eV

The HVeV detector holder is made of PCB which contains SiO_2.

Luminescence in SiO_2:

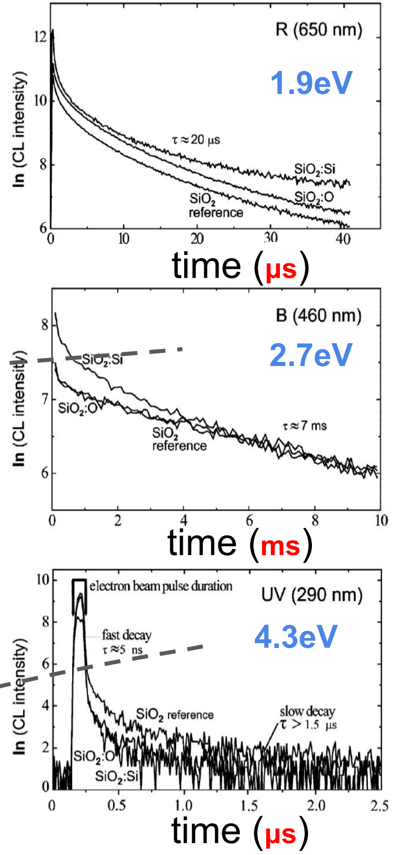


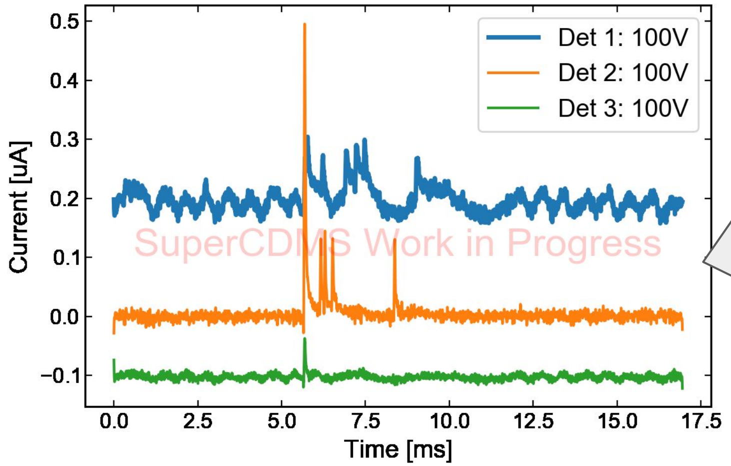
Fig. 3. Decay kinetics of the red R, blue B and UV luminescence in thin SiO_2 films partially doped with Si^+ and O^+ ions and excited by a pulsed electron beam at liquid nitrogen temperature (LNT).

Trukhin, A. N., Jansons, J., Fitting, H. J., Barfels, T., & Schmidt, B. (2003). Cathodoluminescence decay kinetics in Ge+, Si+, O+ implanted SiO2 layers. *Journal of non-crystalline solids*, *331*(1-3), 91-99.

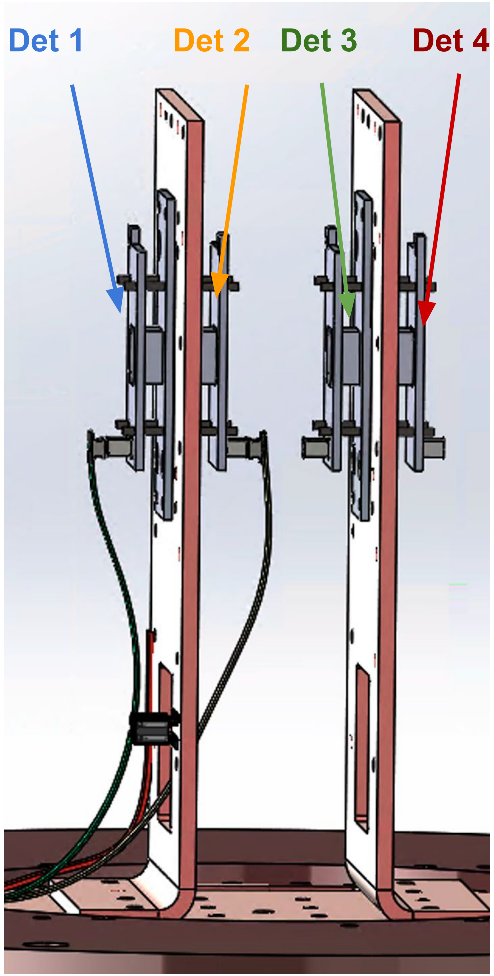
Coincidence of burst

In a new setup, we have four detectors in the same cavity:

We see coincidence of burst events in multiple detectors.



Burst events are likely to have external origin, since they are usually seen in more than one detectors.



Comprehensive data analysis ongoing. Stay tuned!

Conclusion

- We see low energy excess in SuperCDMS HVeV detector
- 0V-HV comparison:
  - The excess at 0V **in HVeV detector** can be partly explained by burst events seen at HV
- Burst events are likely to have an external origin:
  - Most burst events have coincidence events in other detectors
  - Luminescence of SiO_2 in PCB may be one of the origins
  - This accounts for a good fraction of the unknown events in the HVeV ERDM search

Next steps:

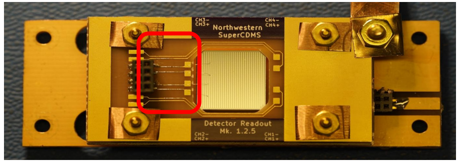
Designing a new detector payload scheme with

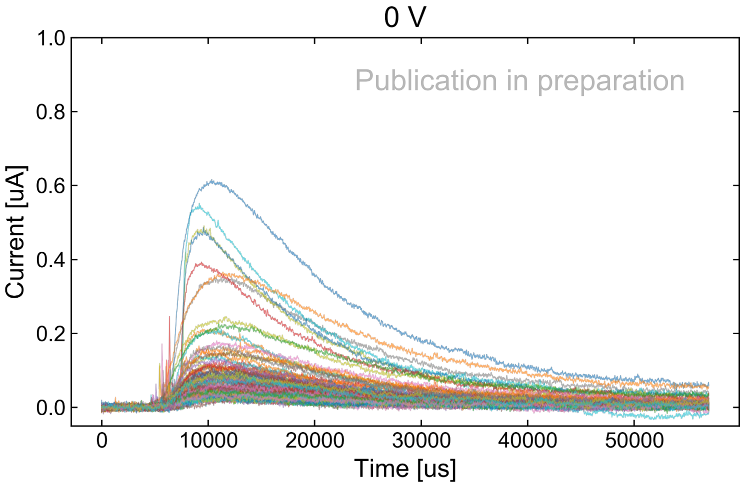
- Minimal use of PCB/insulator
- Maximal detector coincidence tagging capability

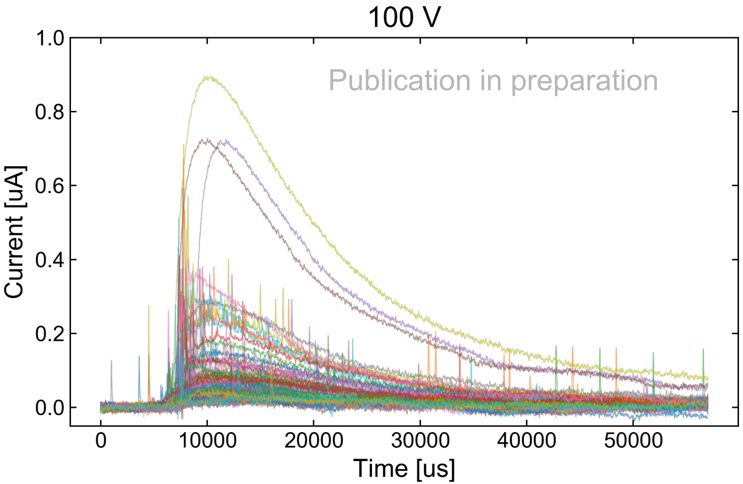
Backup slides

Events that are compatible with PCB hypothesis

We see a group of ultra-slow (~10 ms) pulses in 0V and HV data.
1. They have ~100 times longer decay time than the events happen in detector crystal
2. A series of single electron-hole events can happen along the slow pulse in HV data







A paper on source of low-energy background

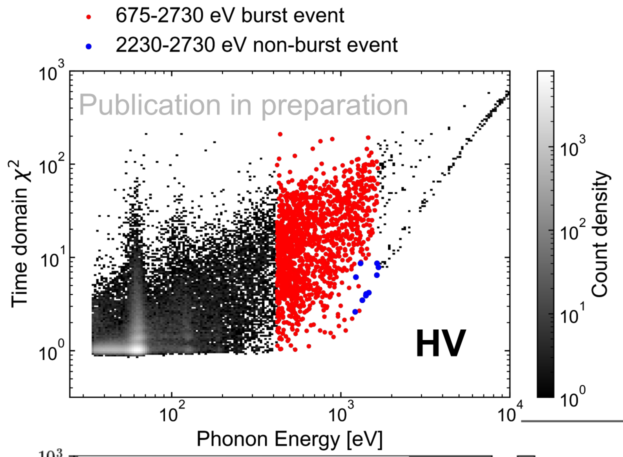
Du, P., Egana-Ugrinovic, D., Essig, R., & Sholapurkar, M. (2020).
Sources of low-energy events in low-threshold dark matter detectors. *arXiv preprint arXiv:2011.13939*.

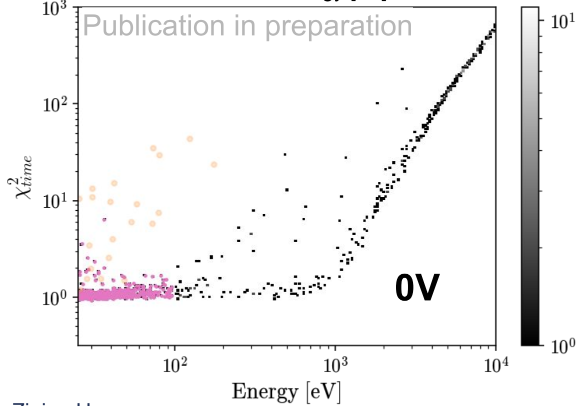
Three sources of low-energy background arising from interaction of high-energy particles:

- Cherenkov radiation
- Transition radiation
- Luminescence

Different experiments may have different dominating background origins.

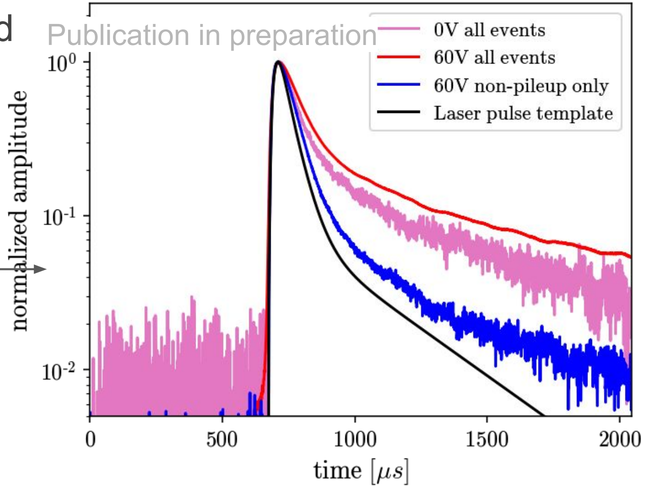
0V-HV comparison: Pulse shape



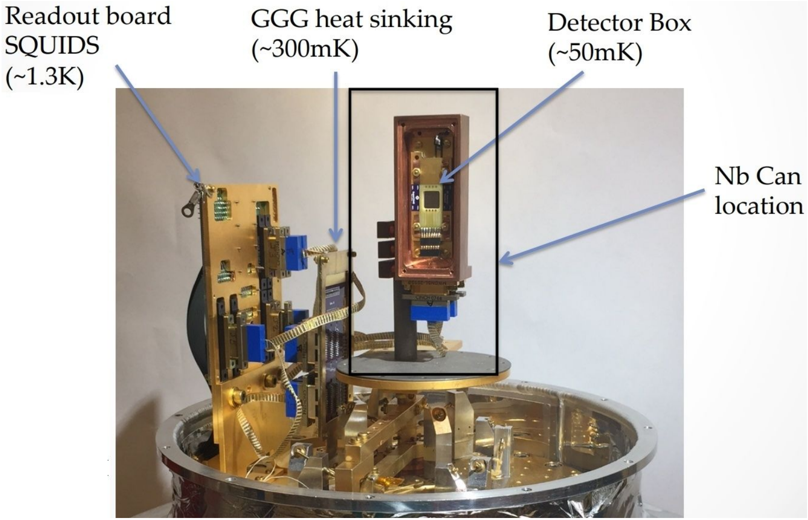


The averaged 60 V pulse shape shows a prolonged decay time like the averaged 0 V events.

The long decay time cannot be explained by saturation (blue line)

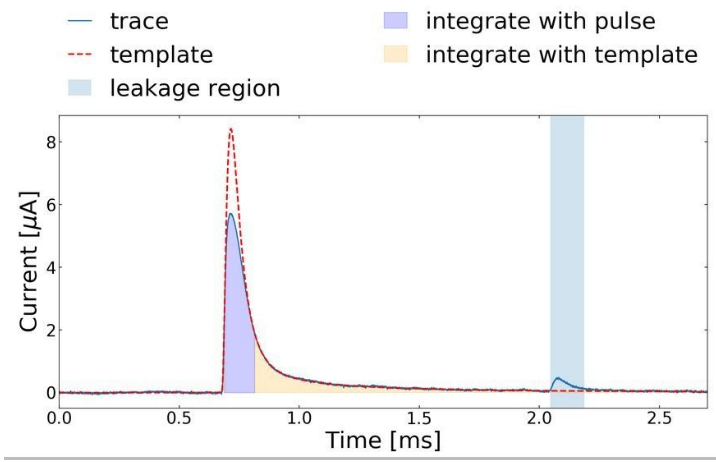


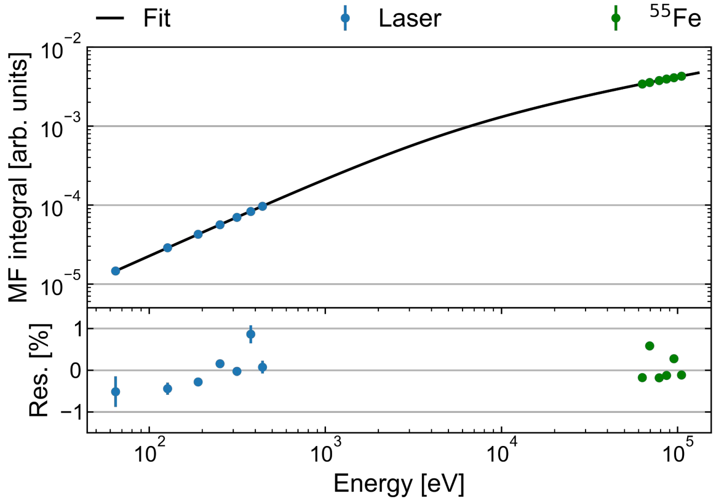
Experimental setup



Energy estimator

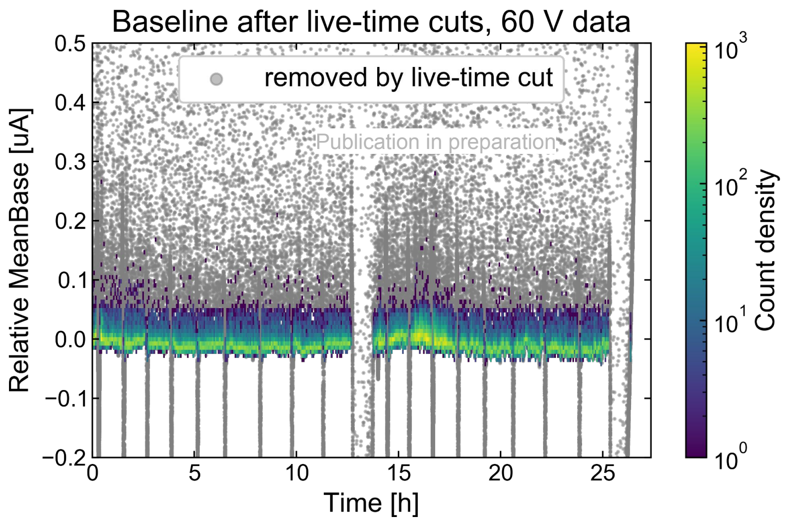
MF = area of purple+yellow region





Cuts

Livetime cut



Pulse width cut