Low energy background: SuperCDMS 0VeV/HVeV

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15 June 2021

Universität Hamburg

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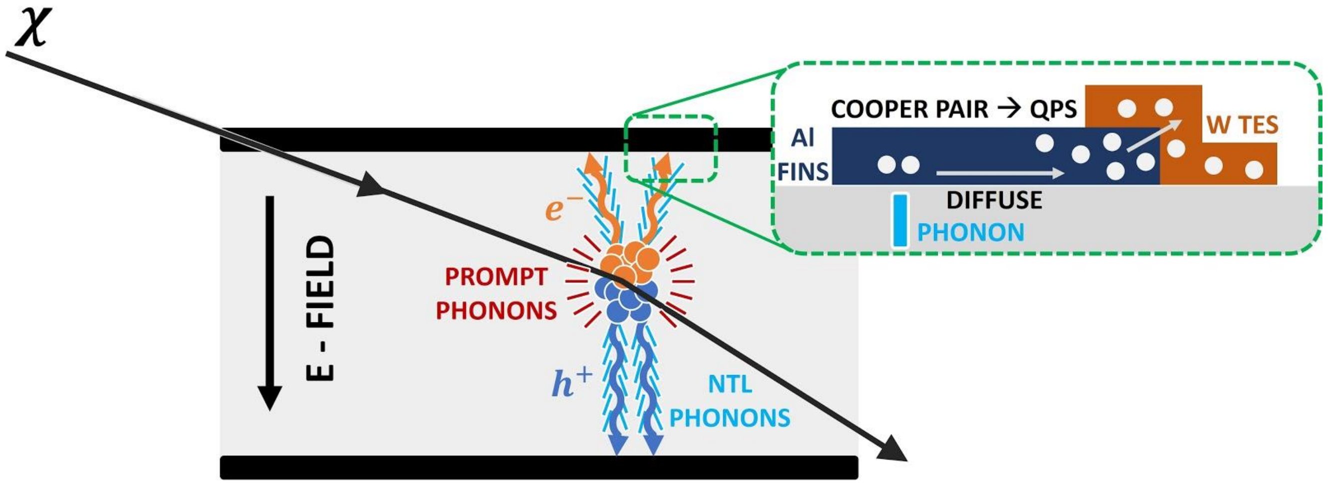
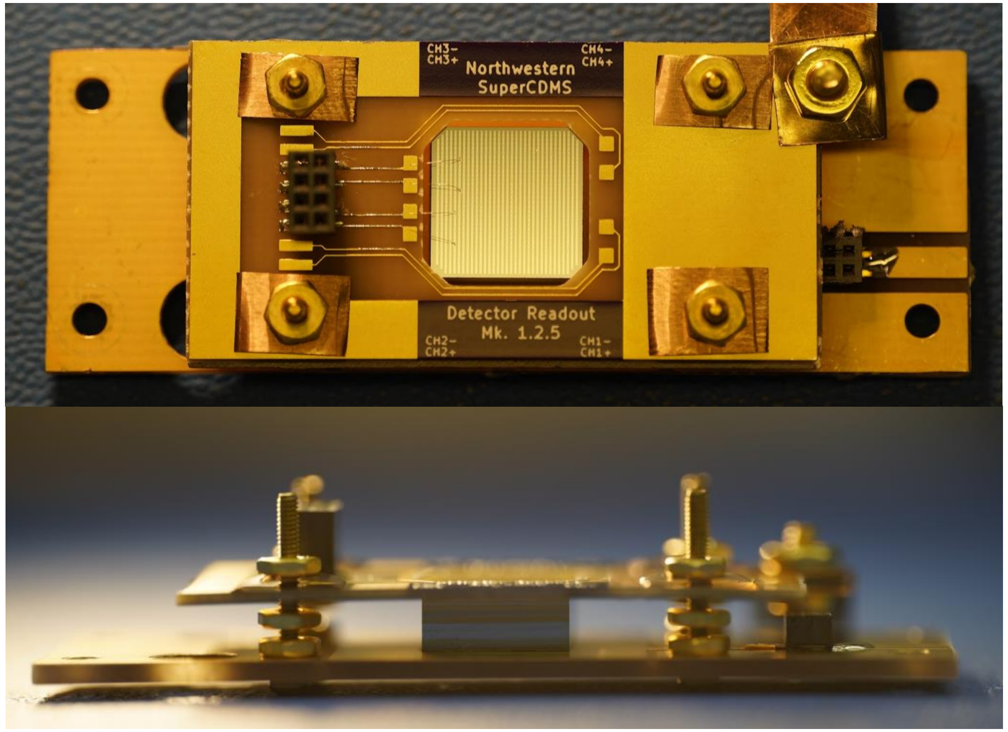
DER FORSCHUNG | DER LEHRE | DER BILDUNG

SUPER CDMS
Cryogenic Dark Matter Search

SuperCDMS HVeV detector





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

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

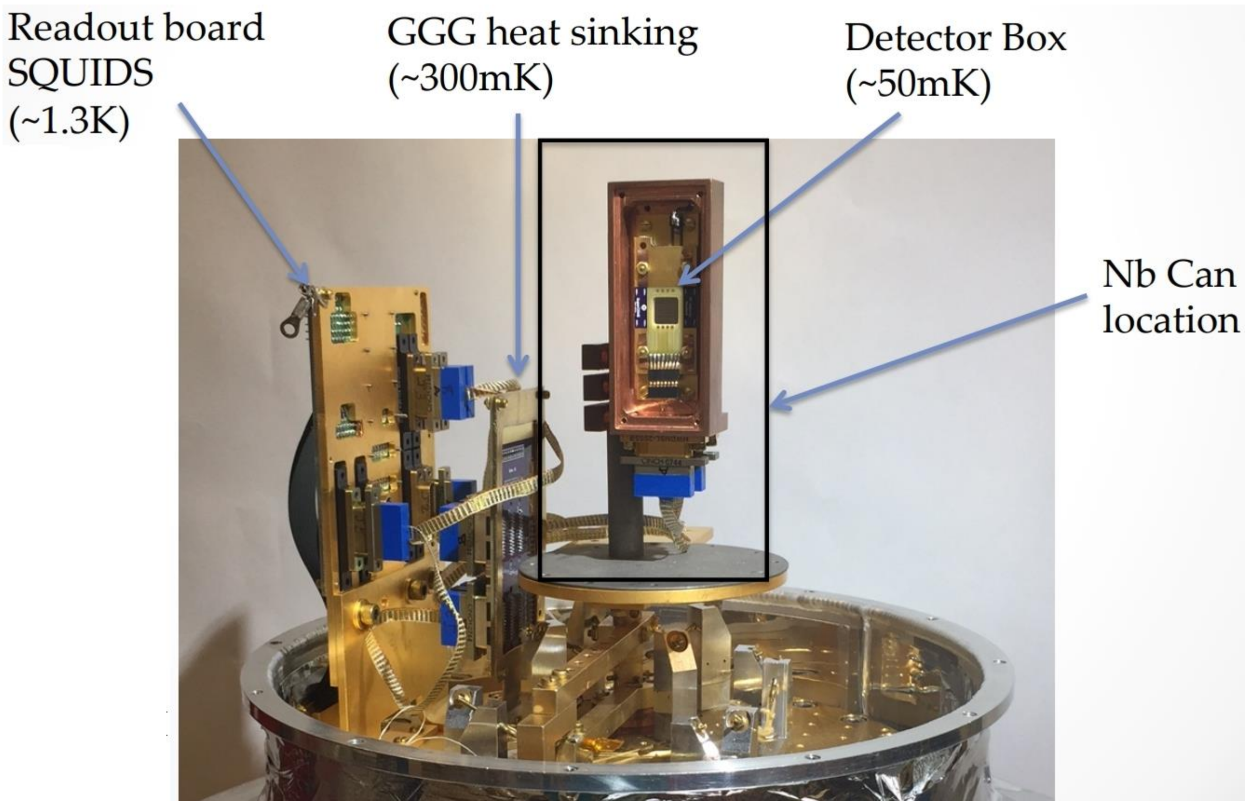
$$E_{\text{phonon}} = E_{\text{recoil}} + n_{\text{eh}} e V_{\text{NTL}} = E_{\text{recoil}} \left(1 + \frac{eV_{\text{NTL}}}{\varepsilon_{\text{eff}}}\right)$$

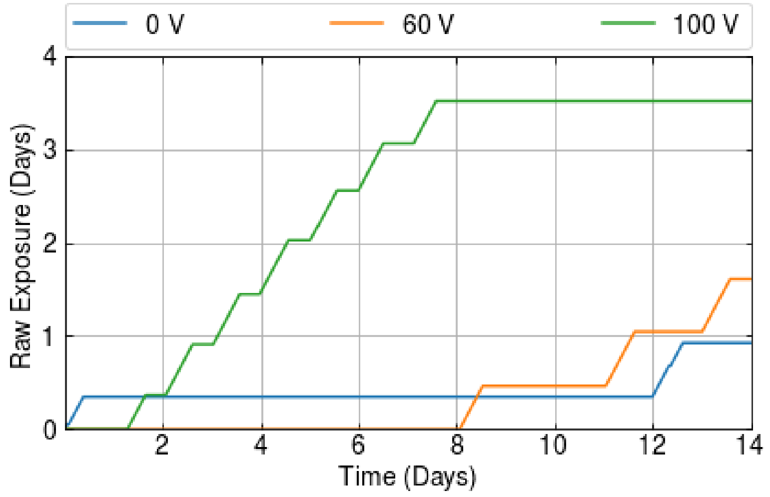
G_{NTL}

By taking data at different voltages we can better understand the background

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 Run 2 setup

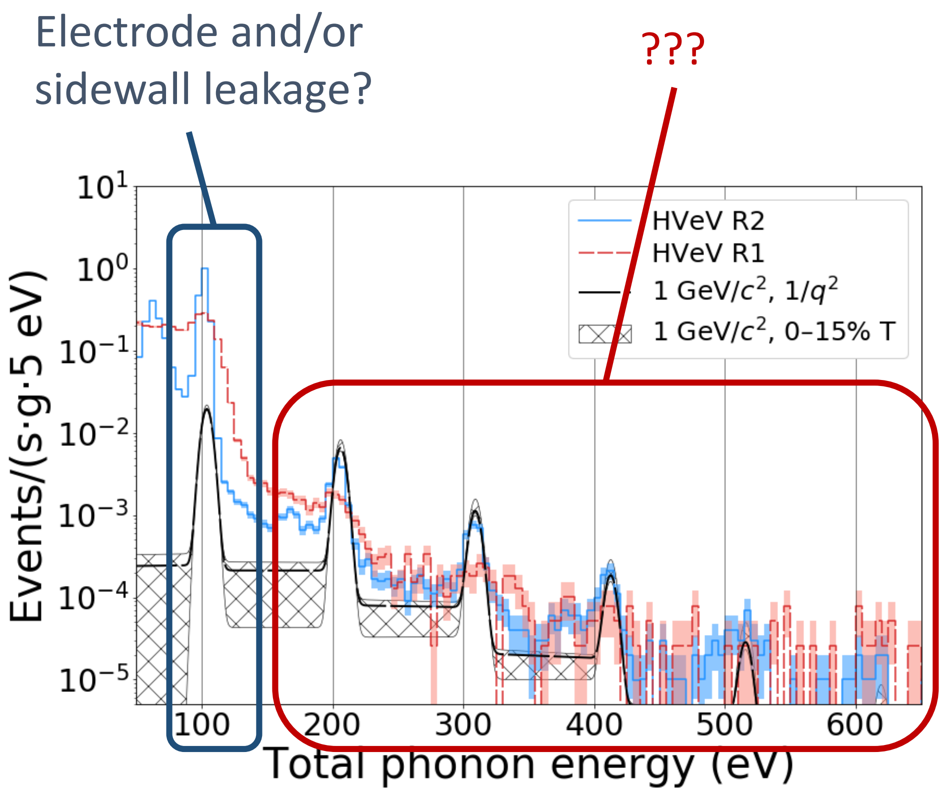




- 0.93 g Si (10x10x4 mm^3)
- **Surface run** (Northwestern University Lab)
- No passive or active shielding
- Surrounding materials: SiO2 (fiberglass PCB), copper, Kapton, tin
- Holdings scheme: mounted between PCBs, ~10-70 gram of force on each corner of the chip
- O(1) days of 0V, 60V and 100V data

HVeV Run 2

HV



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

0V

R. Ren et al. ArXiv:2021.12430 (2020):

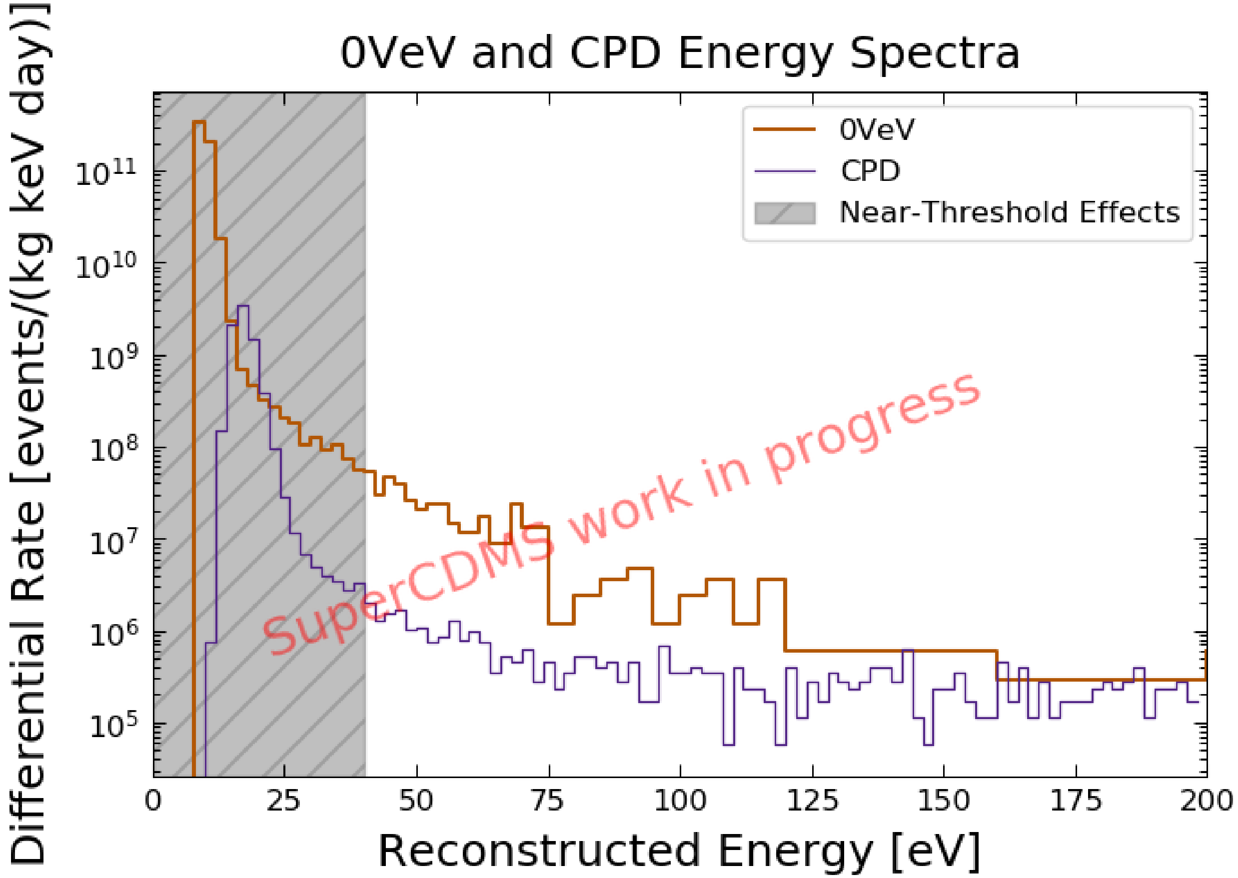
- Optimum Filter triggering
- 2.7 eV baseline resolution
- 9.2 eV threshold

Best in class

Paper in preparation

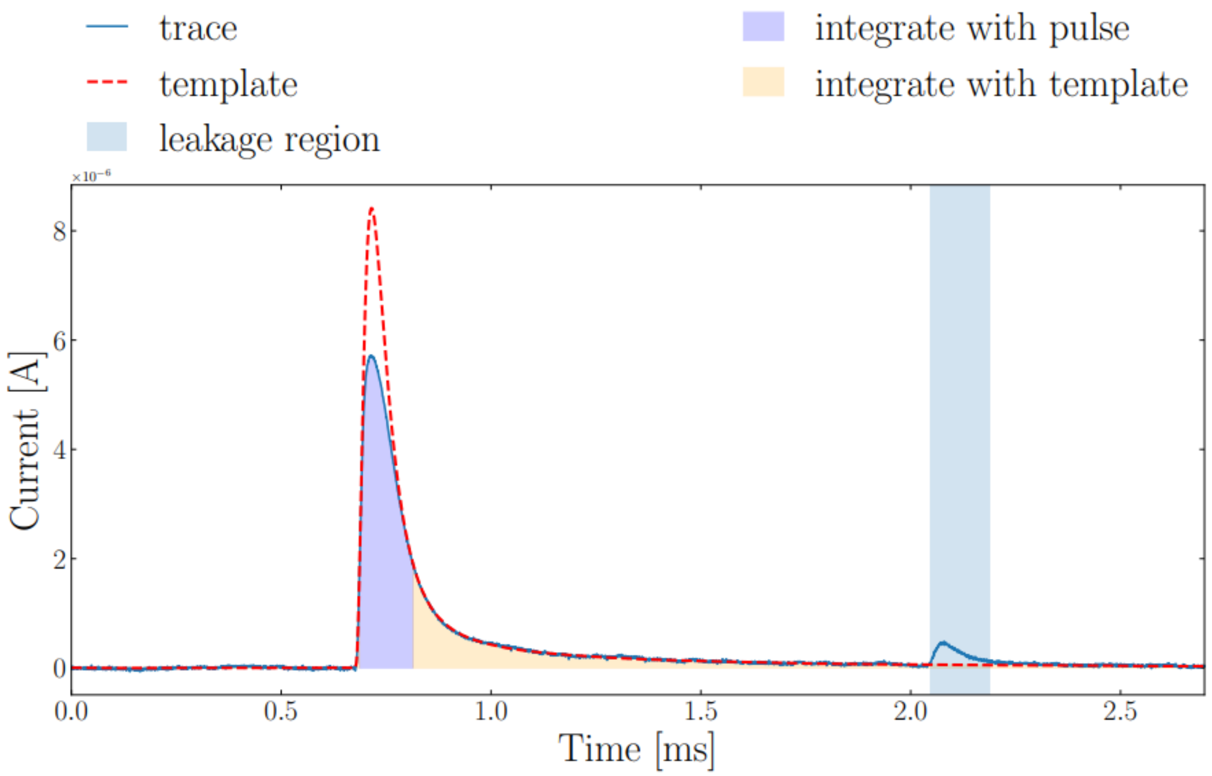
- Dark Matter Nuclear Recoil limit
- 0V-HV comparison to better understand the low energy excess

0VeV energy spectrum

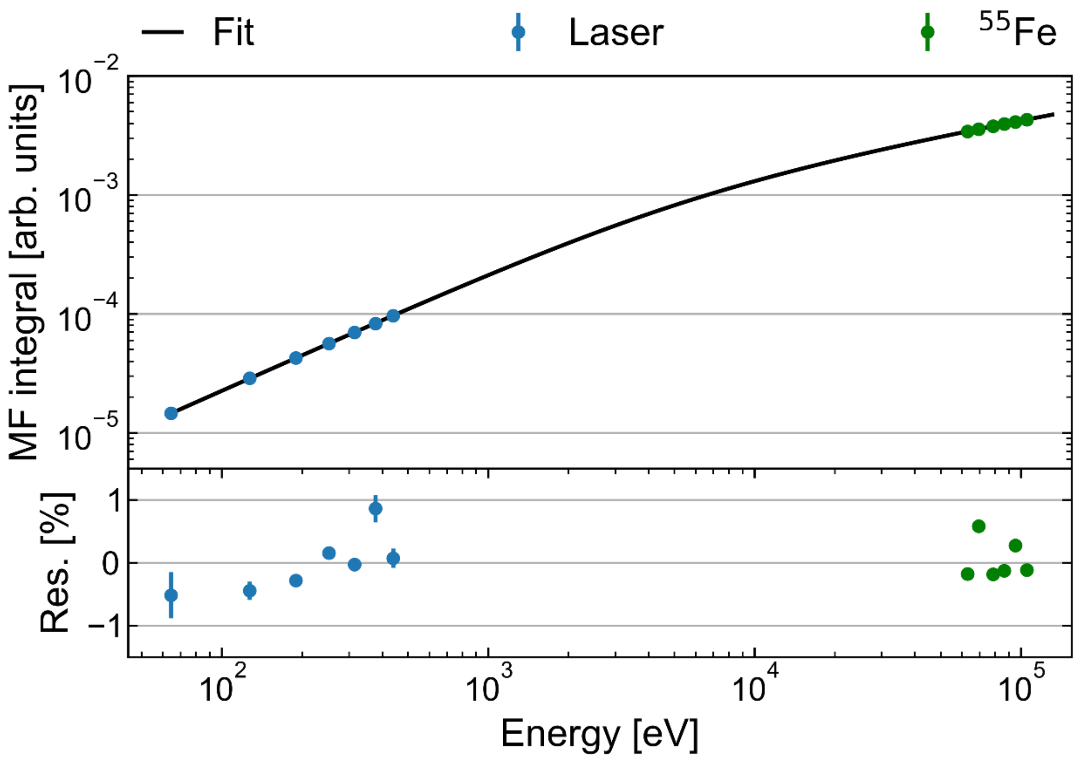


- Live-time cuts:
  - Temperature
  - Mean baseline
  - Periodic noise
- Event-based cuts:
  - template fit chi-square
- Live time: 0.185 g*day
- ~1 order of magnitude higher rate than in SuperCDMS-CPD

0VeV/HVeV energy reconstruction/calibration



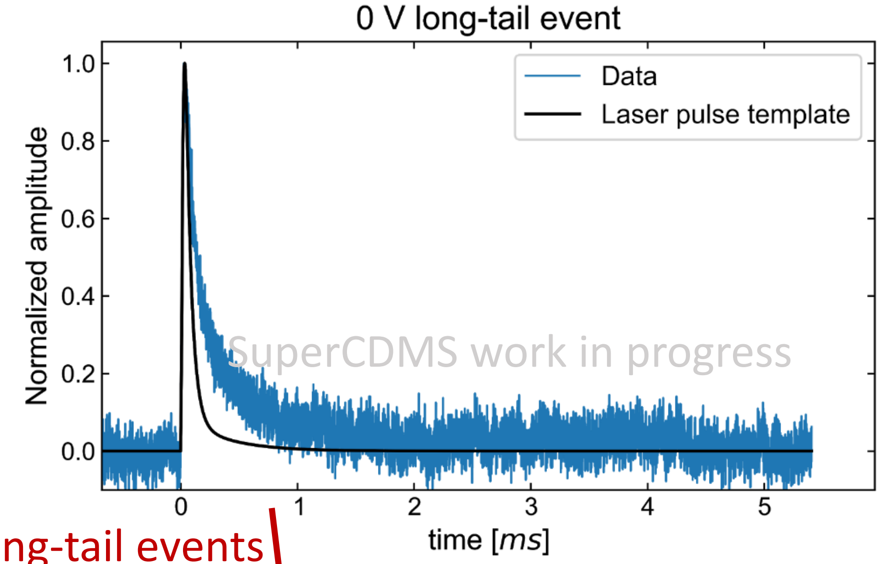
Matching Filter (MF) integral = +



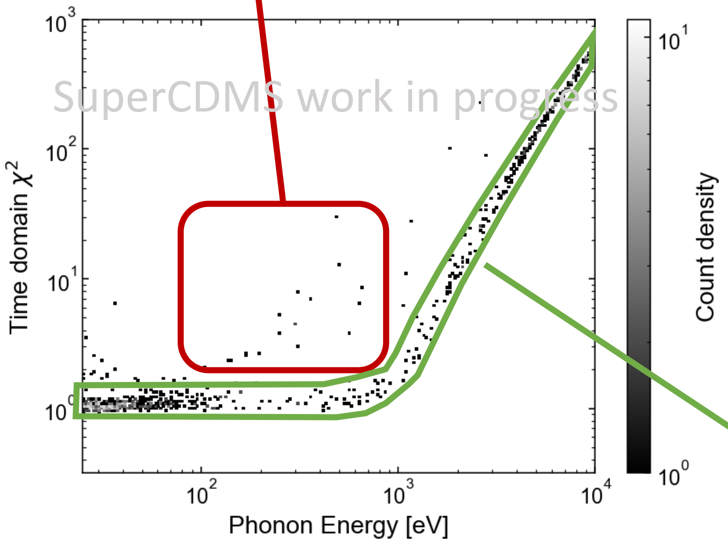
$$E = \begin{cases} E_{OF}, & E_{OF} < 600\ eV \\ (1-k)E_{OF} + kE_{MF}, & 600\ eV \leq E_{OF} \leq 800\ eV \\ & k = \frac{E_{OF}-600}{200} \\ E_{MF}, & 800\ eV < E_{OF}. \end{cases}$$

0VeV/HVeV anomalous events

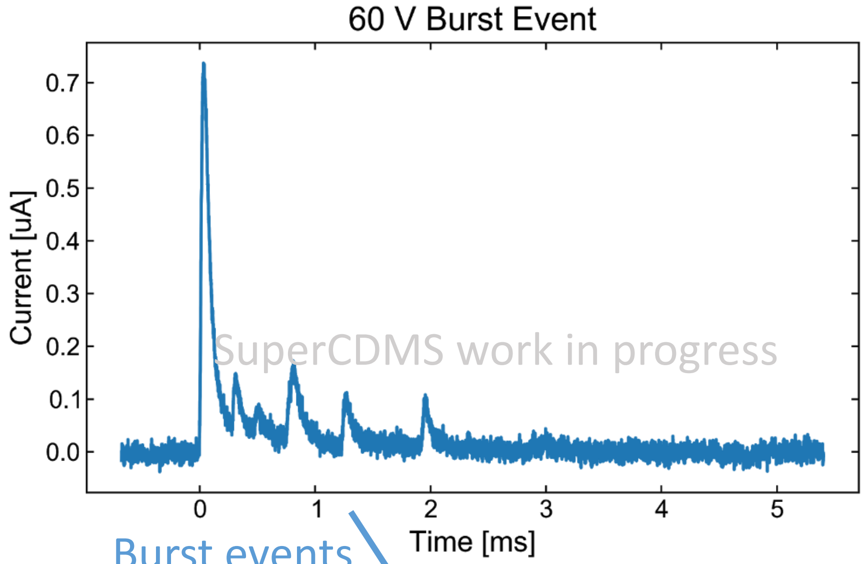
0V



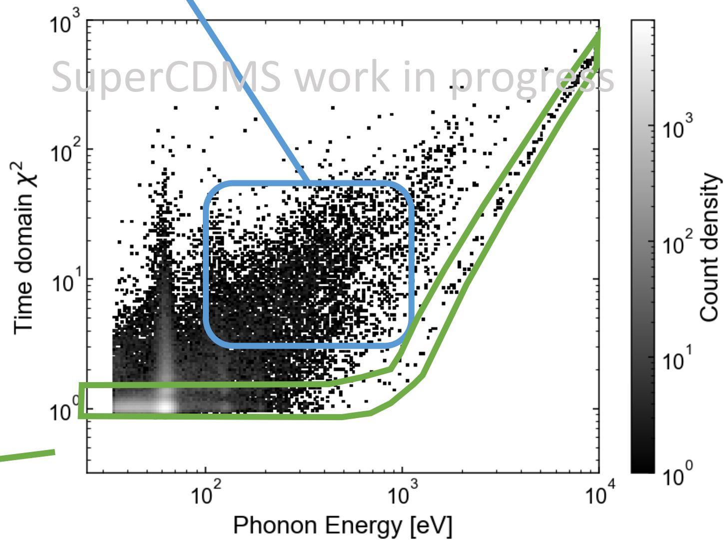
Long-tail events



HV

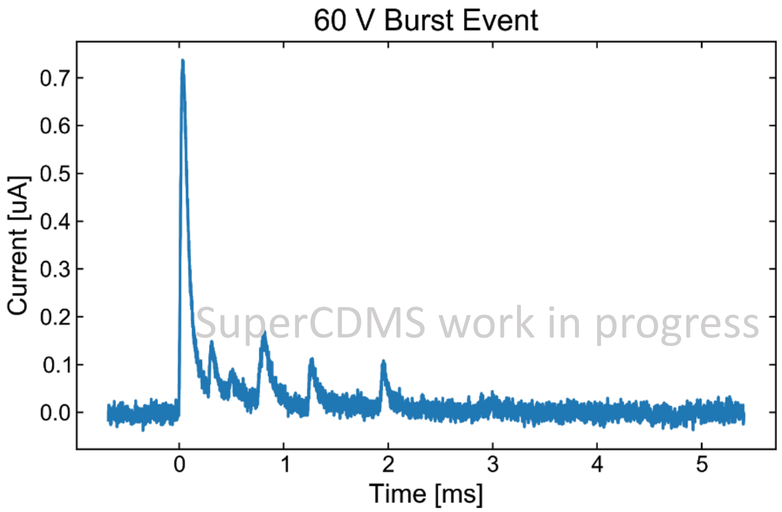


Burst events

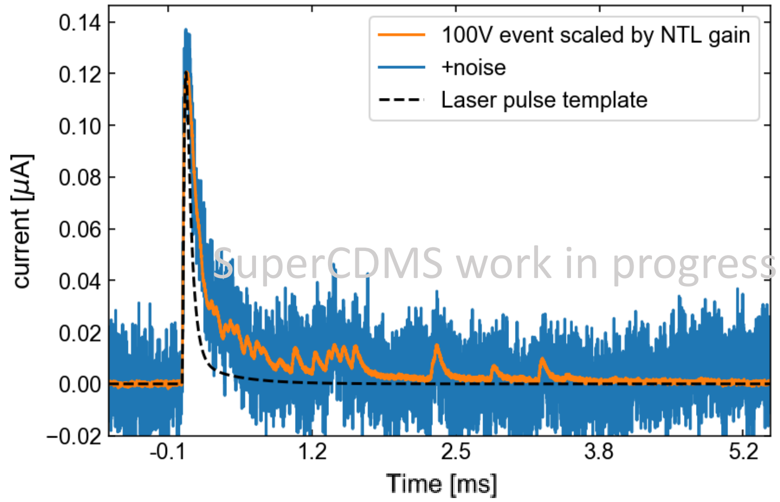


"Normal" events: same pulse shape as in the laser calibration data

0VeV/HVeV anomalous events



÷ G_{NTL} + 0V noise =



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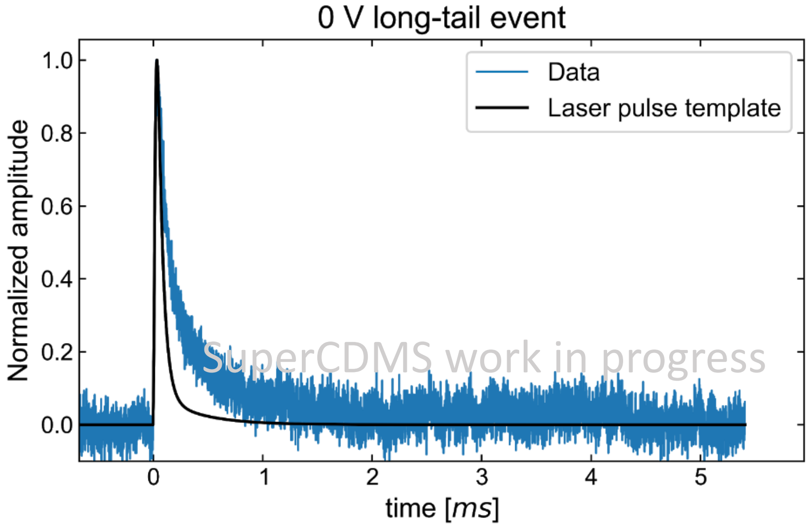
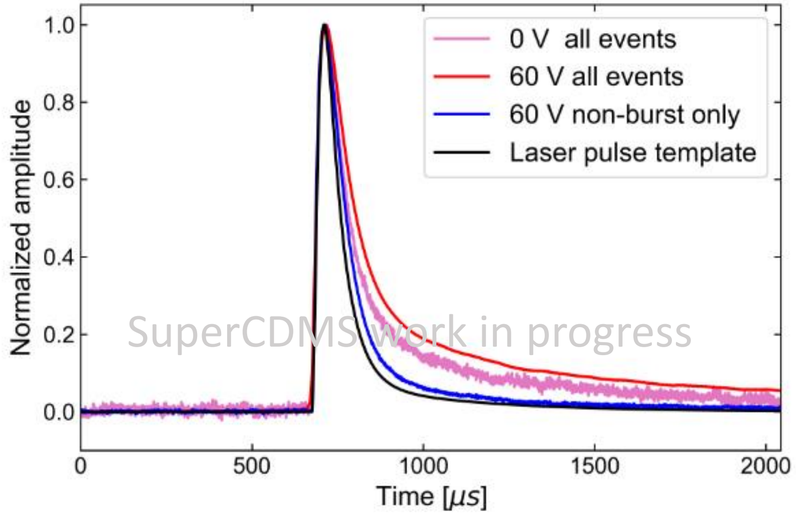
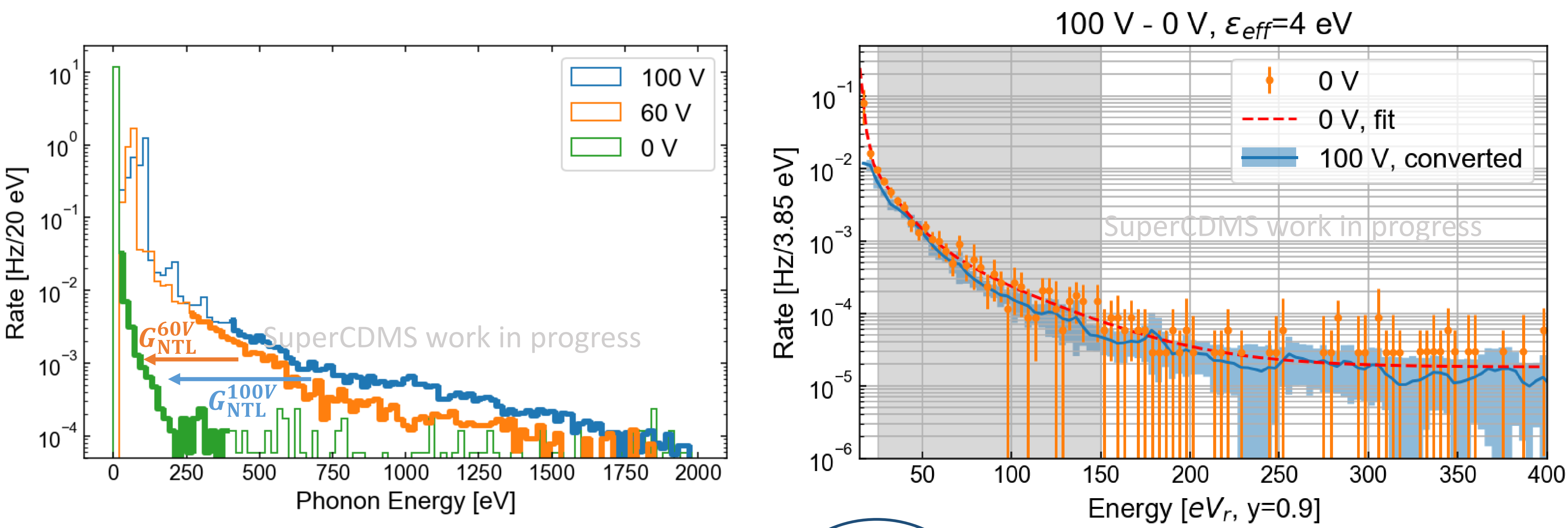




Average of many pulses

0VeV/HVeV spectra comparison

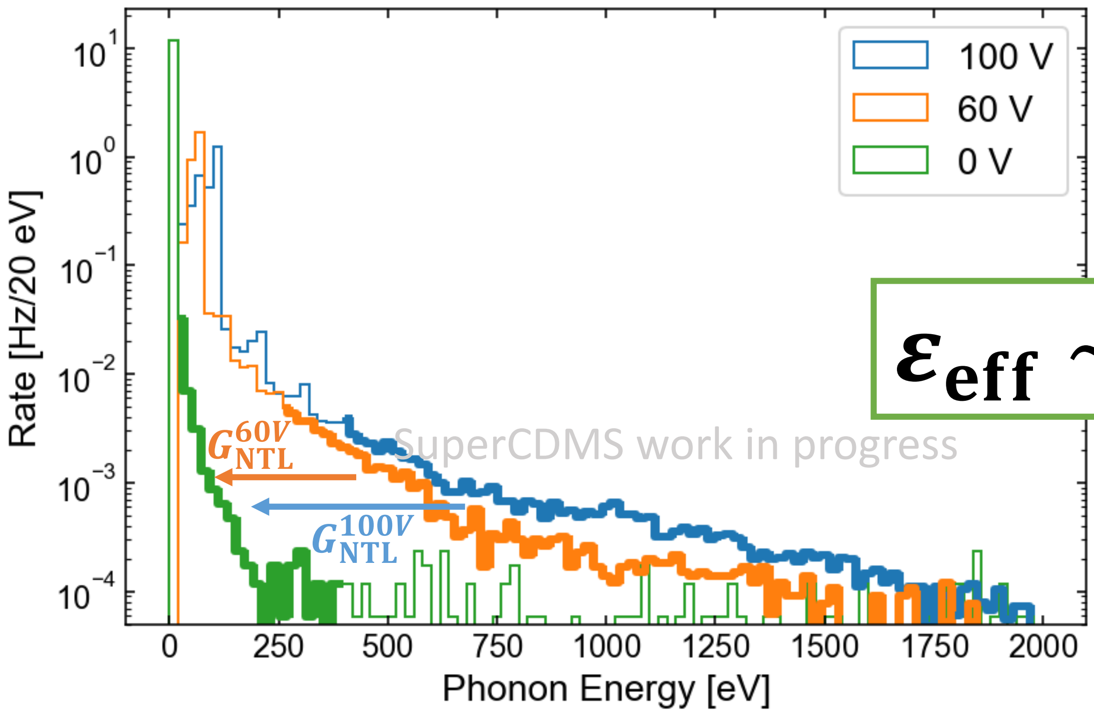


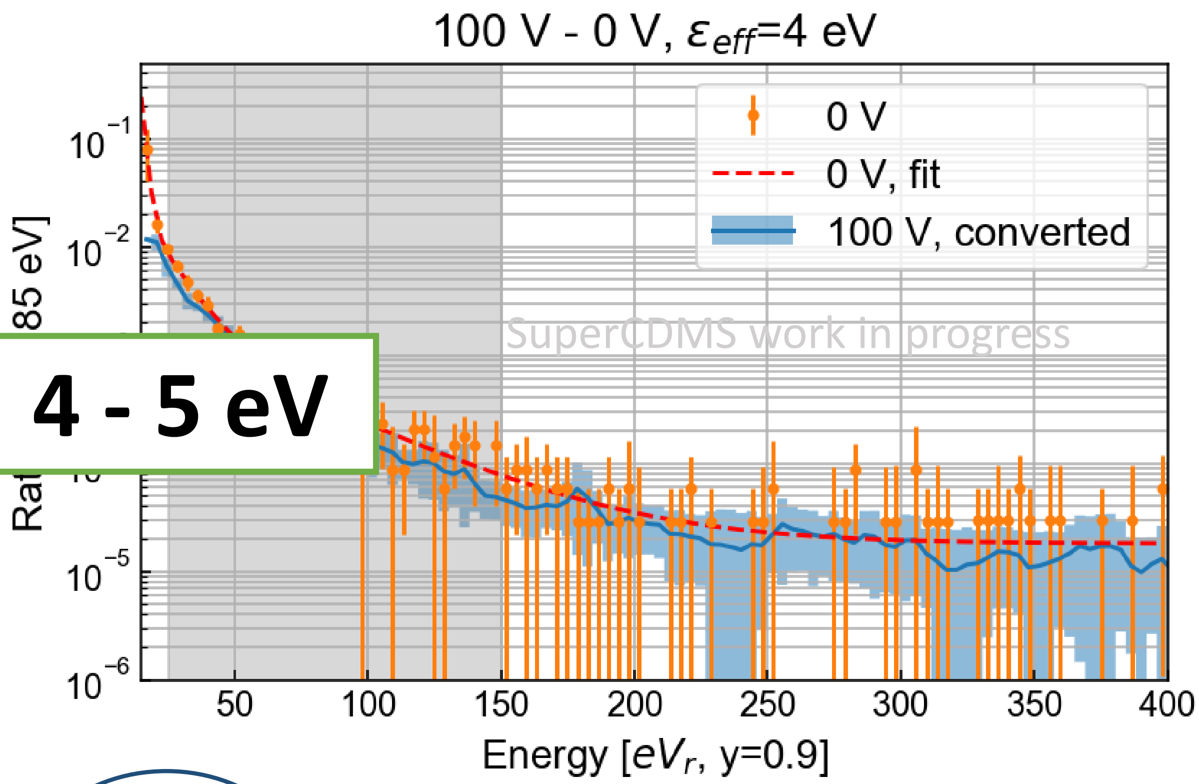
$$E_{\text{phonon}} = E_{\text{recoil}} + n_{\text{eh}} e V_{\text{NTL}} = E_{\text{recoil}} \left(1 + \frac{e V_{\text{NTL}}}{\varepsilon_{\text{eff}}} \right)$$

ε_{eff} – effective e-h-pair creation energy

G_{NTL} – Neganov-Trofimov-Luke gain

0VeV/HVeV spectra comparison





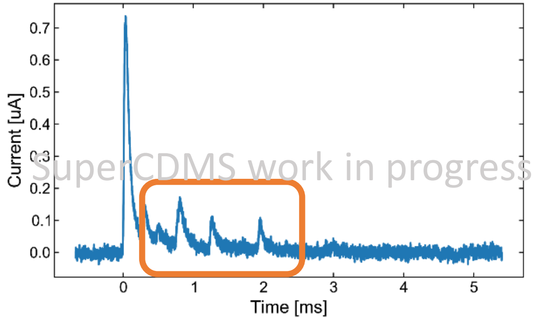
$\varepsilon_{\mathrm{eff}} \sim$ 4 - 5 eV

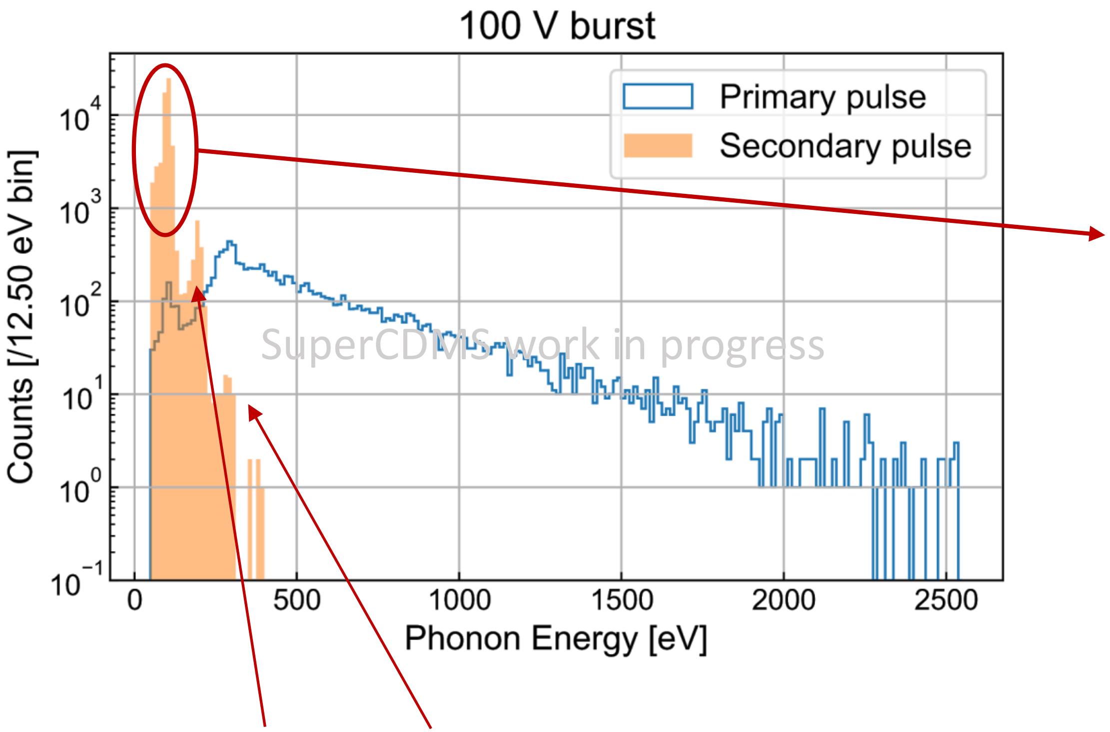
$$E_{\mathrm{phonon}} = E_{\mathrm{recoil}} + n_{\mathrm{eh}} eV_{\mathrm{NTL}} = E_{\mathrm{recoil}} \left(1 + \frac{eV_{\mathrm{NTL}}}{\varepsilon_{\mathrm{eff}}}\right)$$

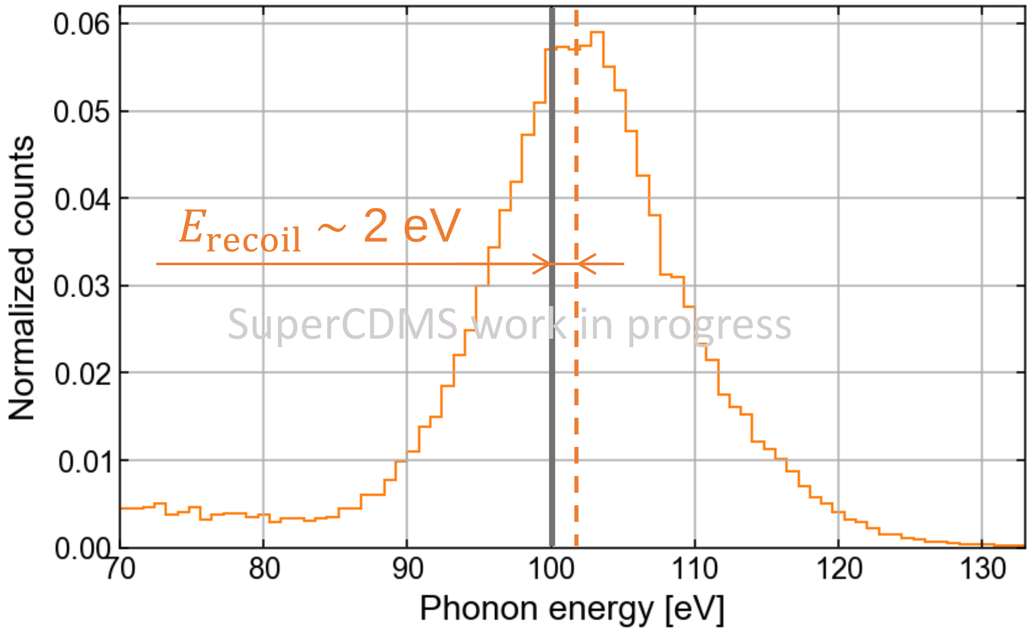
effective e-h-pair creation energy

G_{NTL} – Neganov-Trofimov-Luke gain

Energy of the burst secondary pulses



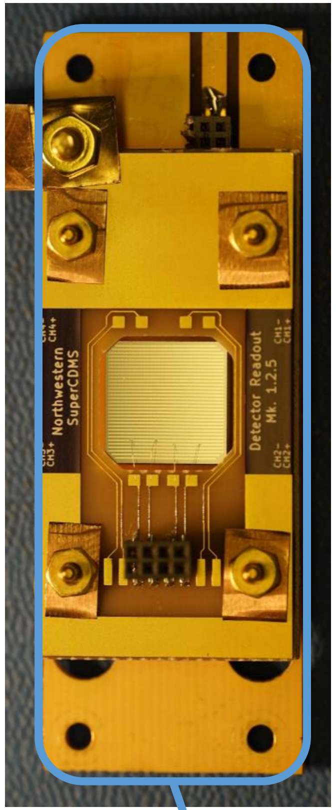




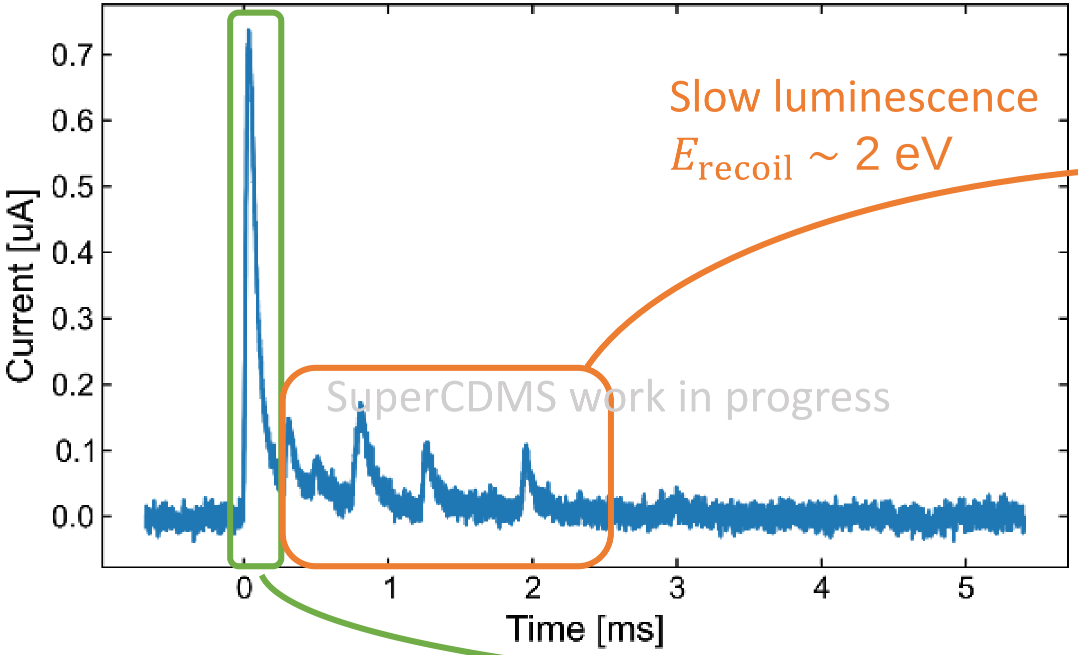
Events in the 2nd and 3rd peak have a rate compatible with pile-up from 1st electron-hole pair events

$$E_{\mathrm{phonon}} = E_{\mathrm{recoil}} + n_{\mathrm{eh}} e V_{\mathrm{NTL}}$$

SiO_2 Luminescence as a possible source of bursts



Printed Circuit Board (PCB): SiO_2



Slow luminescence

$E_{\mathrm{recoil}} \sim 2$ eV

Pile-up of fast luminescence

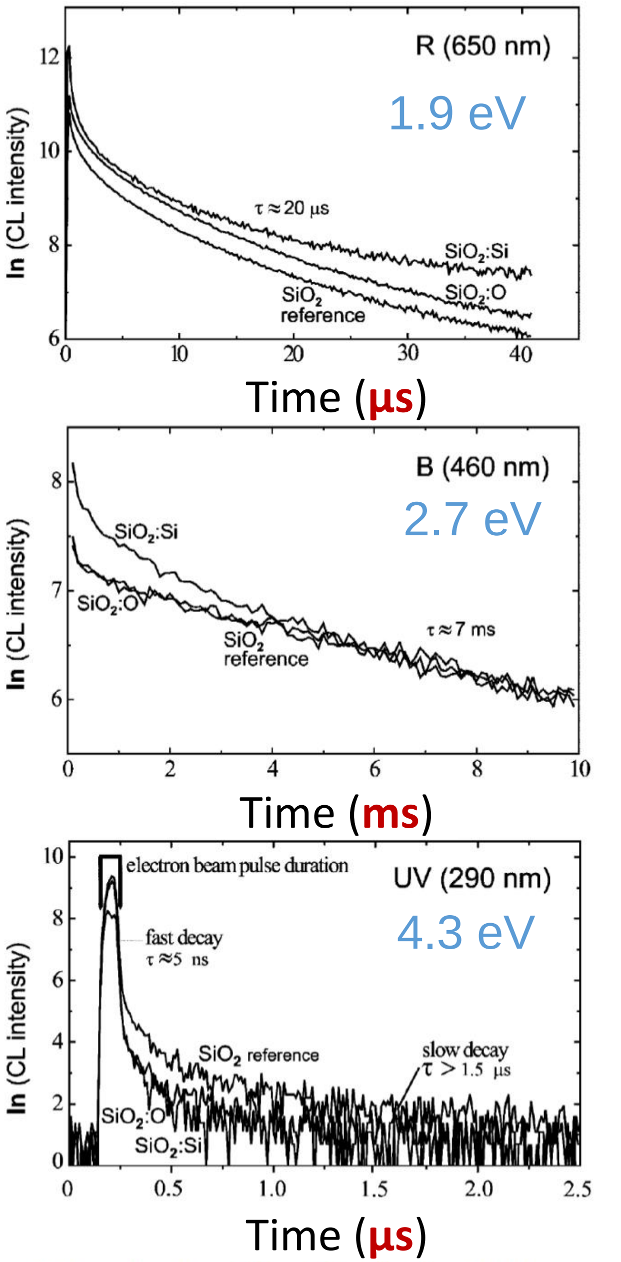
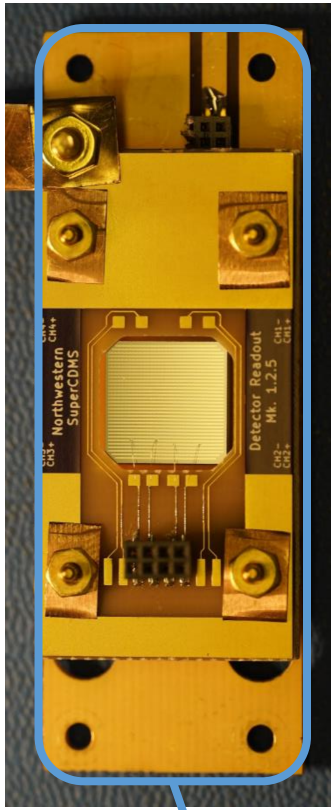


Fig. 3. Decay kinetics of the red R, blue B and UV luminescence in thin SiO_2 films partially doped with Si^+ and O^+ ions and excited by a pulsed electron beam at liquid nitrogen temperature (LNT).

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.

SiO_2 Luminescence as a possible source of bursts



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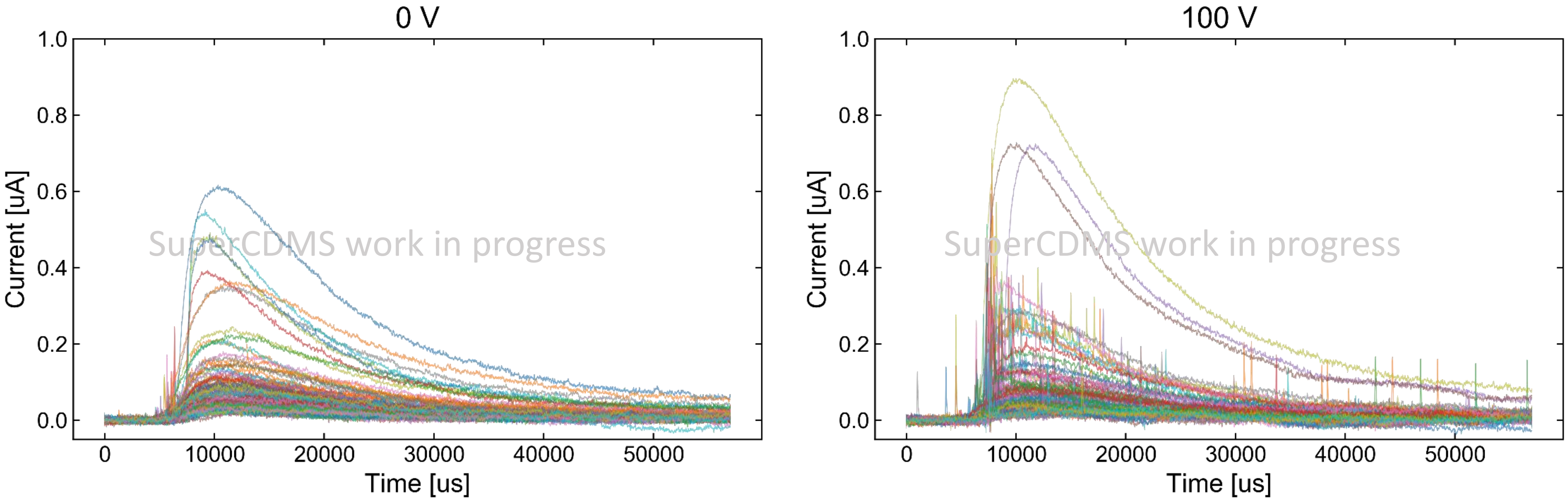


- Seeing very slow pulses in both 0V and HV data.
  - O(10) events/hour
  - τ ~ O(10) ms
  - High-energy particles heating up the PCB?
- Many slow pulses are coincident with burst events in the HV data

HVeV Run 3

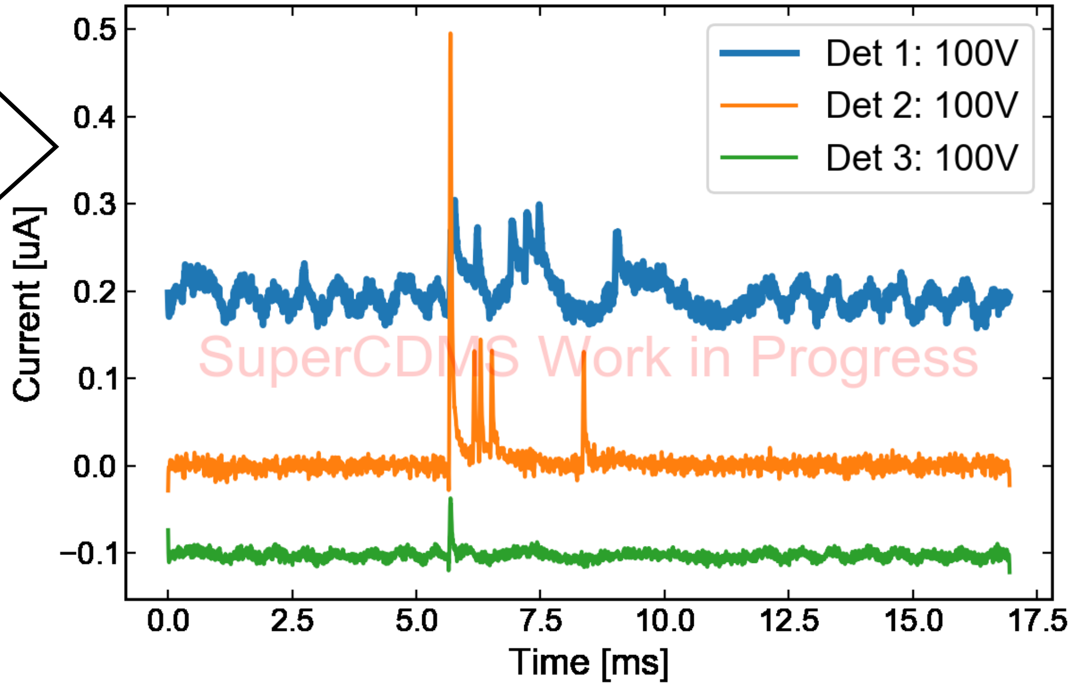
- 100m underground (NEXUS@FNAL)

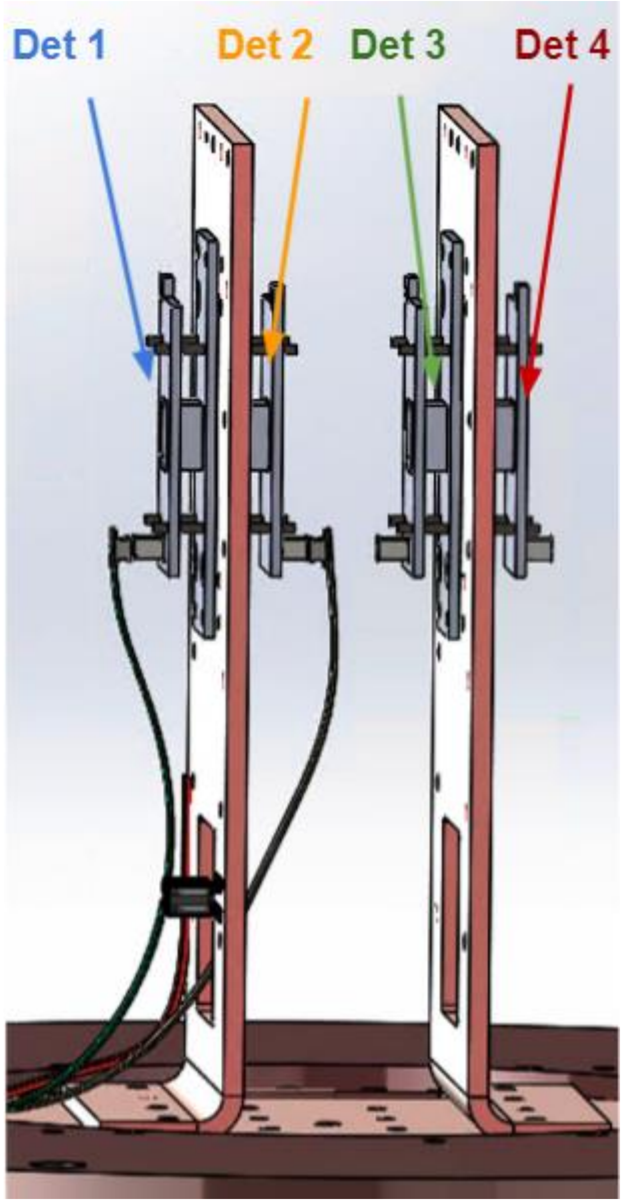
HVeV Run 2 (on surface) vs Run 3 (underground) comparison will show how the overburden affects the burst events

HVeV Run 3

- 100m underground (NEXUS@FNAL)
- 3 working HVeV detectors

Burst events are likely to have external origin, since they are seen in multiple detectors simultaneously

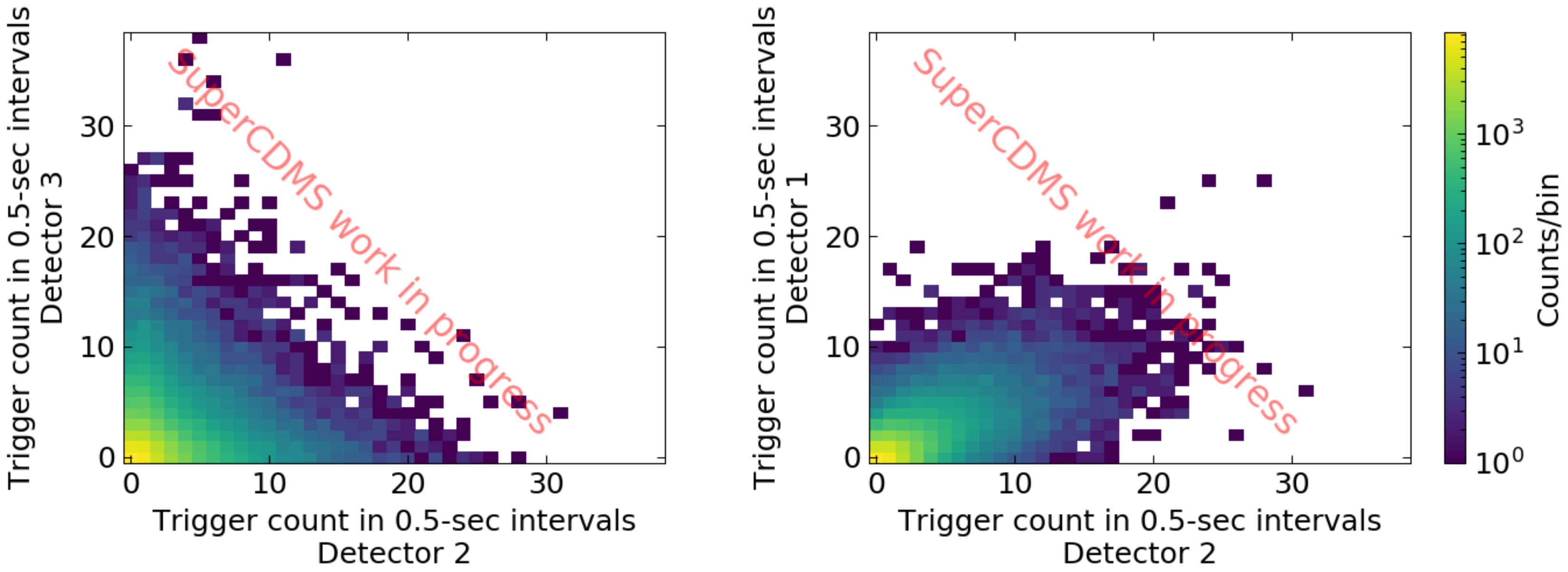


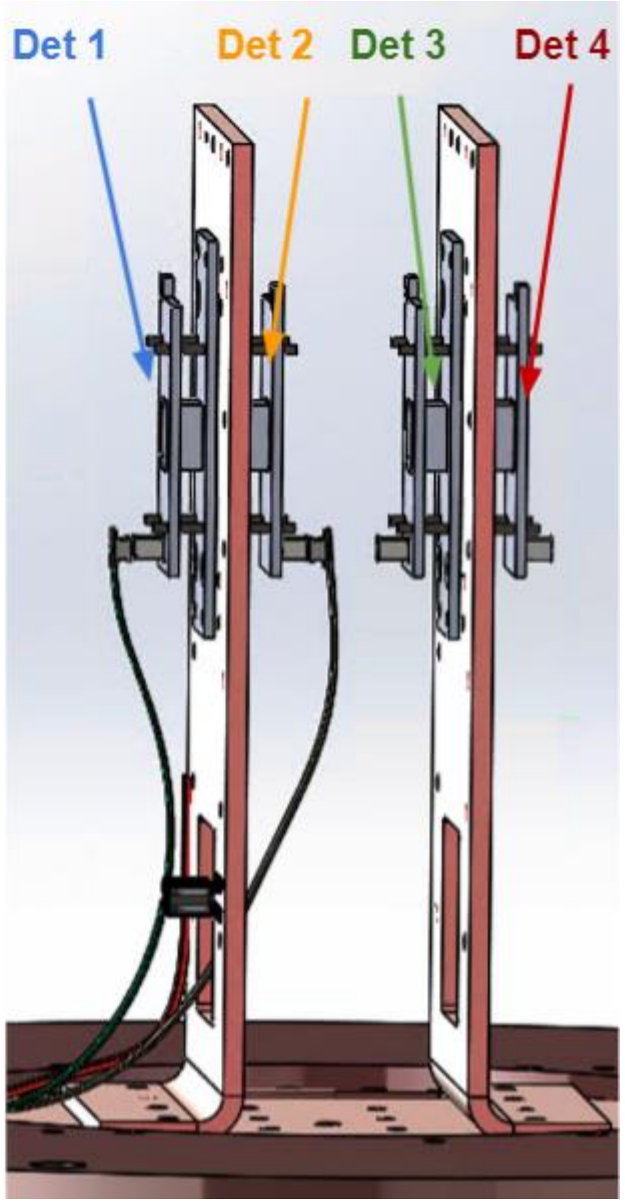


HVeV Run 3

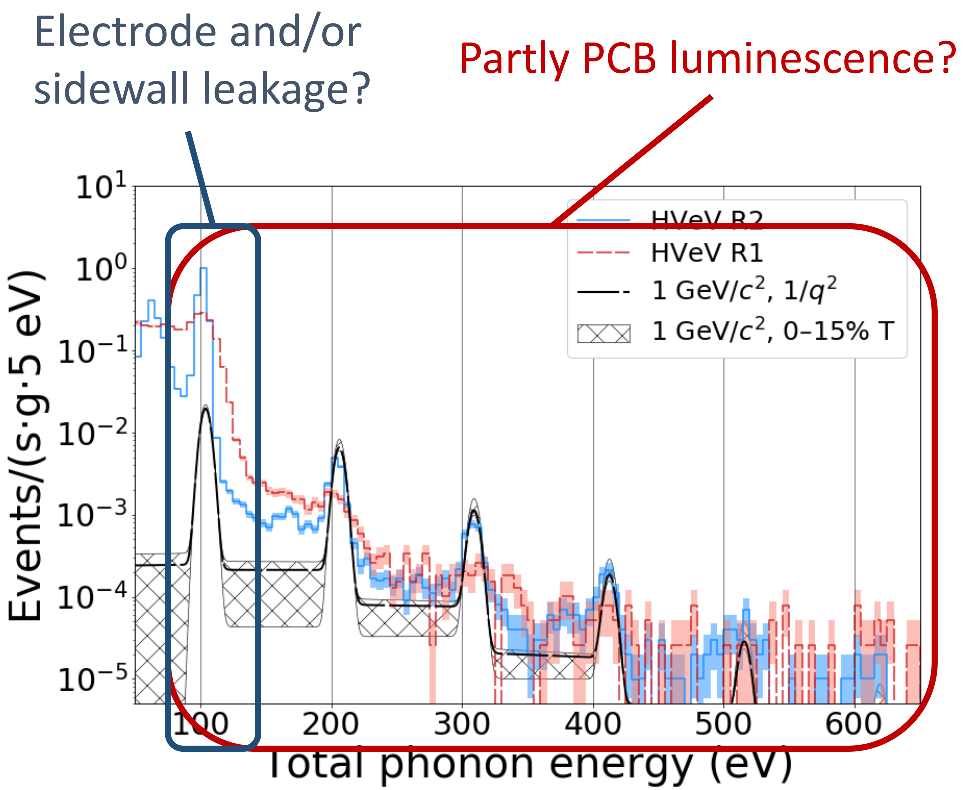
- 100m underground (NEXUS@FNAL)
- 3 working HVeV detectors

Comprehensive data analysis ongoing. Stay tuned!





Conclusion



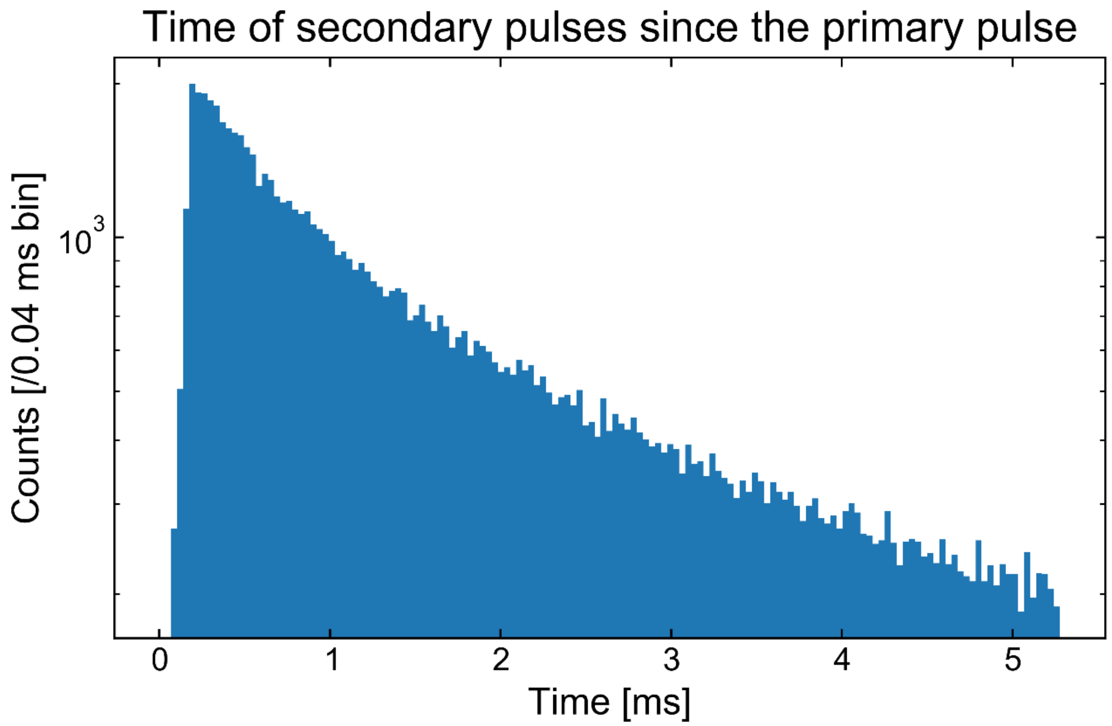
- We see a low energy excess in SuperCDMS HVeV detectors in both 0V and HV modes
- Burst events account for a large fraction of the background in the HV mode
  - Need to understand how efficient the existing cuts at removing the burst events are
- A part of the 0V background seems to have the same origin
- The data favors an external origin
- PCB luminescence could be the culprit
- Next steps:
  - Designing a new detector payload scheme with minimal use of PCB/insulator
  - Maximal detector coincidence tagging capability

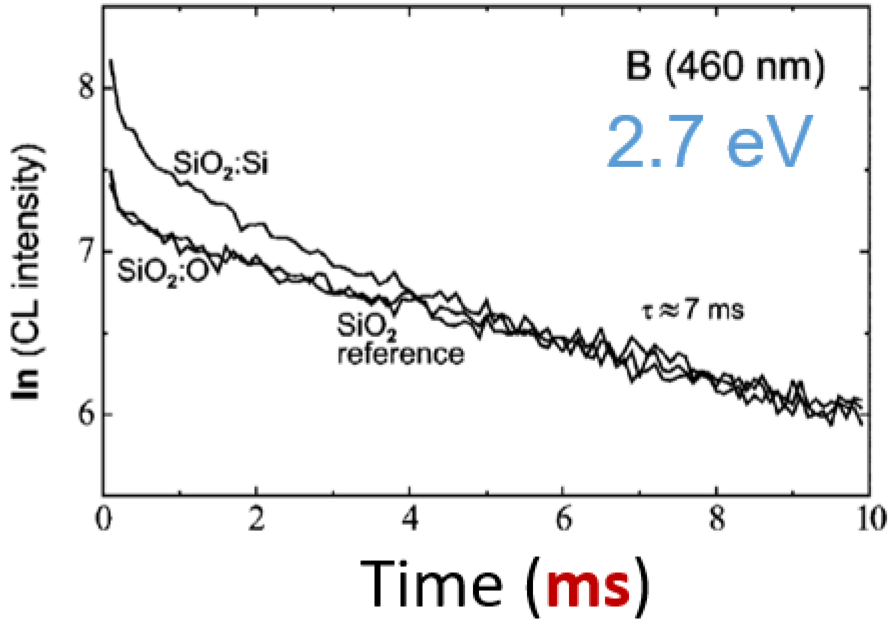
Backup slides

Questions to address during the talk

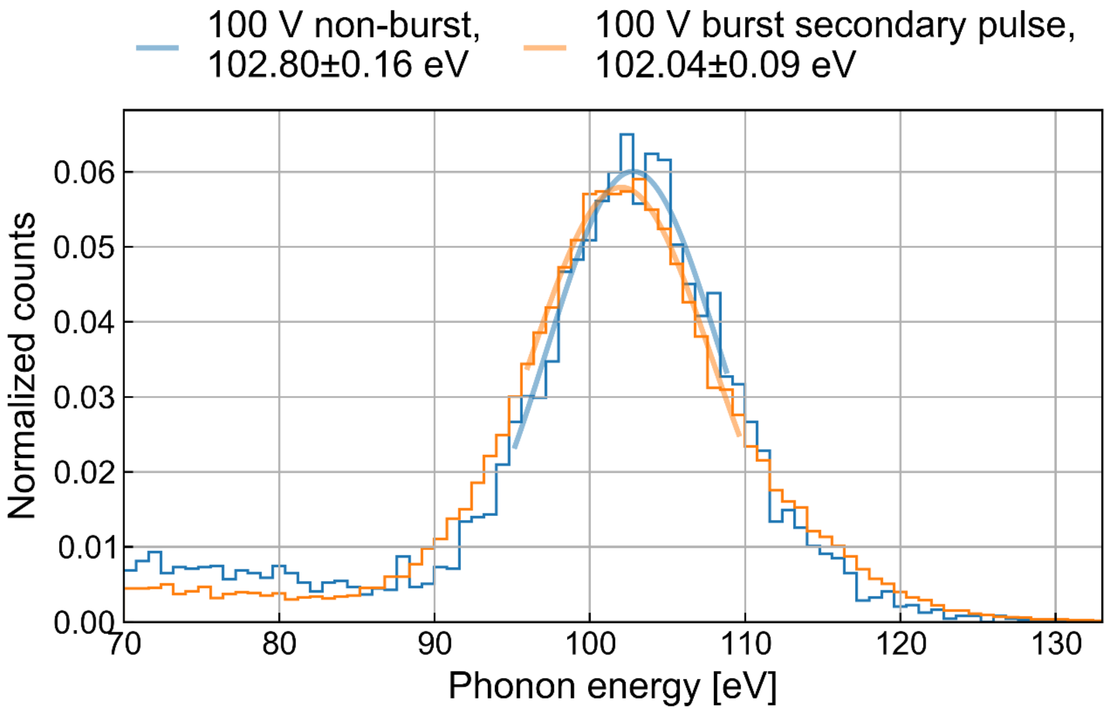
- Detector concept: slide 3
- Observed energy spectrum: slide 4
- Time dependency and known correlations of the excess: some events come in bursts
- Are there approaches to explain the excess: PCB luminescence?
- What are other known backgrounds: charge leakage?
- Are there uncertainty estimates for the energy scale: ~11% uncertainty in the MF calibration

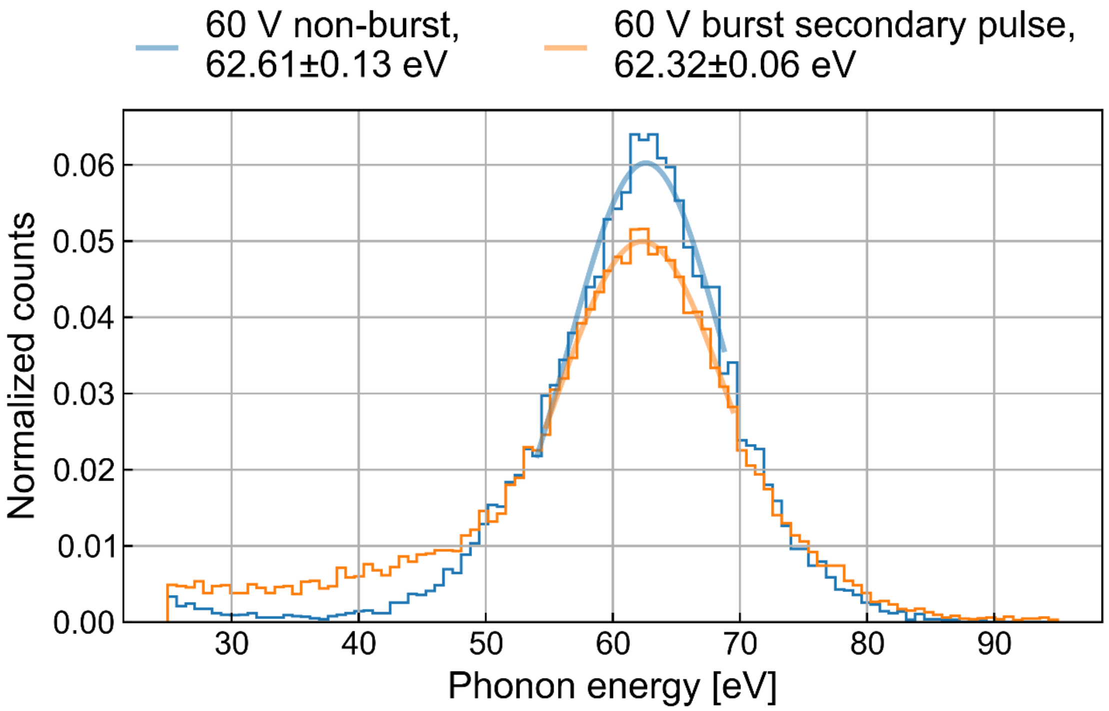
Time distribution of the secondary pulses



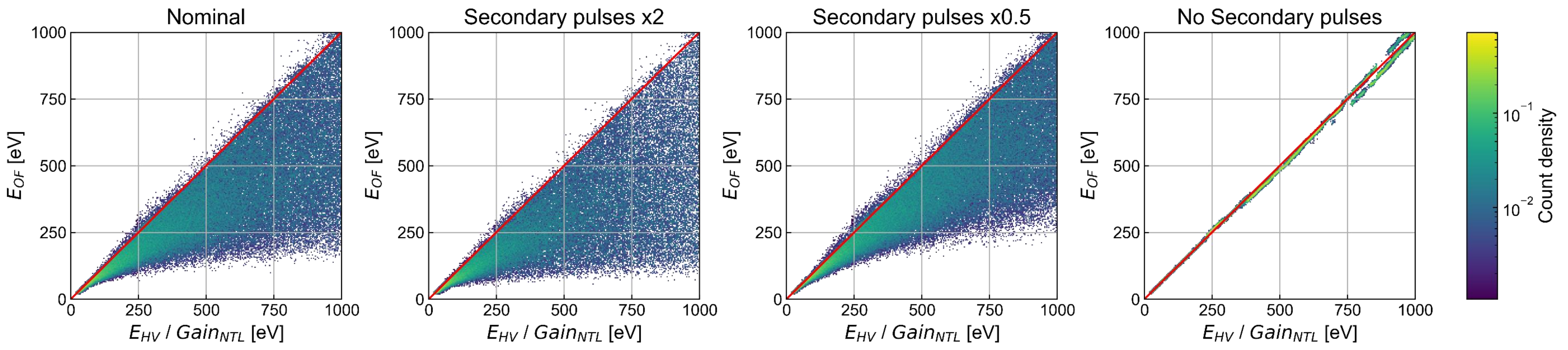


Burst secondaries vs non-burst events





OF-MF response matrices



- The response matrices convert the energy estimator used in the HV data (MF integral) to the one used in the 0V data (OF).
- The matrices are built using the simulations assuming 4 cases:
  1. nominal number of secondary pulses
  2. double of secondary pulses
  3. half of the secondary pulse
  4. no secondary pulses.

HVeV R1 – HVeV R2 rates

	HVeV-R2		HVeV-R1
Voltage [V]	100	60	-140
σ_E $[e^-h^+]$	0.03	0.05	0.1
	Events/(gram-day)		
1 e^-h^+	$(149 \pm 1)\,10^3$	$(165 \pm 2)\,10^3$	$(157 \pm 2)\,10^3$
2 e^-h^+	$(1.1 \pm 0.1)\,10^3$	$(1.2 \pm 0.2)\,10^3$	$(1.3 \pm 0.2)\,10^3$
3 e^-h^+	207 ± 40	245 ± 86	171 ± 59
4 e^-h^+	53 ± 20	77 ± 48	58 ± 34
5 e^-h^+	16 ± 11	20 ± 25	16 ± 18
6 e^-h^+	5 ± 6	10 ± 17	24 ± 22

HVeV-R1: R. Agnese et al, Phys. Rev. Lett. 121, 051301 (2018)
HVeV-R2: D.W. Amaral et al, Phys. Rev. D 102, 091101 (2020)