Investigation of the low energy excess in SuperCDMS HVeV detectors and its potential subtraction for enhanced dark matter sensitivity

Osmond Wen

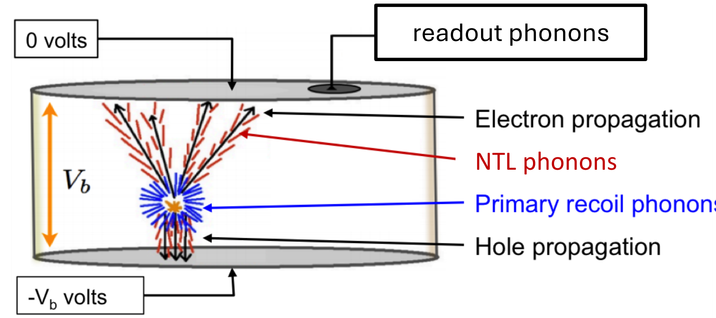
CPAD Workshop 2023

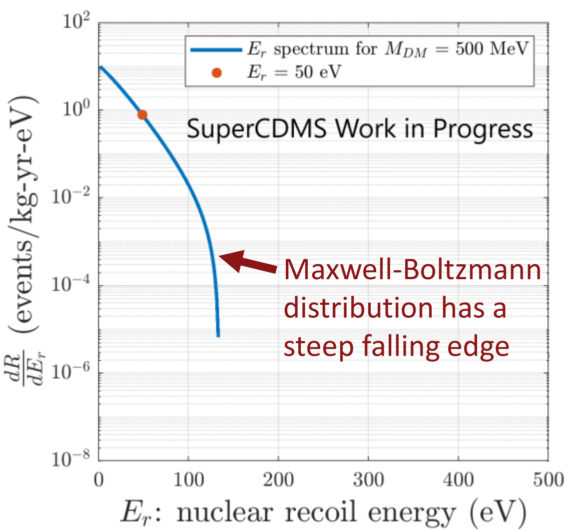
High voltage operation of phonon-mediated detectors

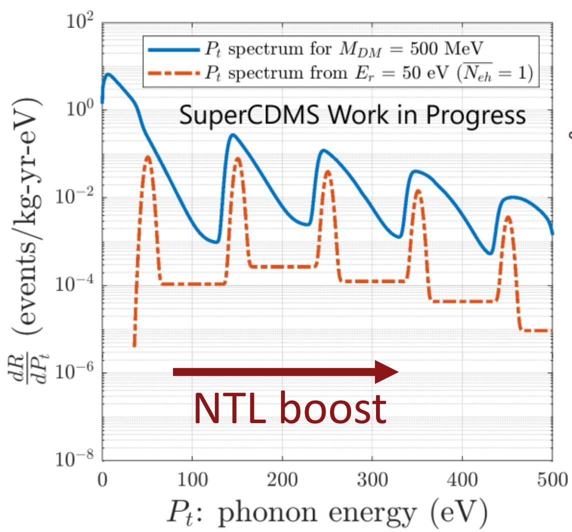
The Neganov Trofimov Luke (NTL) effect

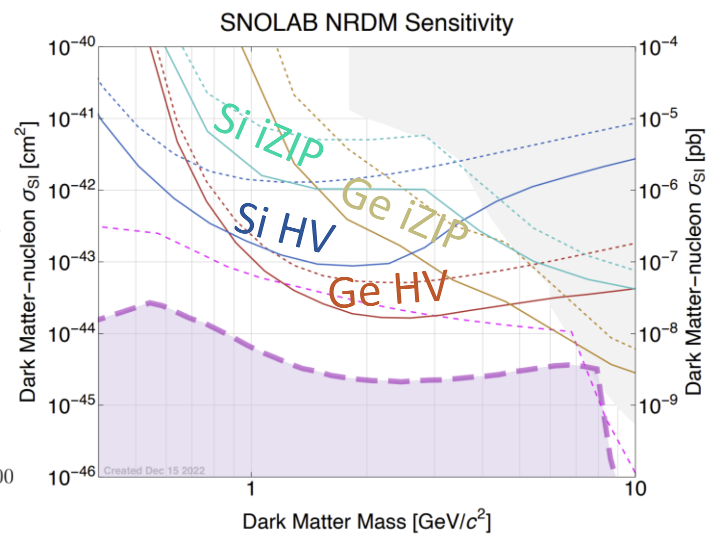
$$P_t = E_r + N_{eh} e V_b$$

Primary recoil phonons (E_r) NTL phonons ($N_{eh} e V_b$)







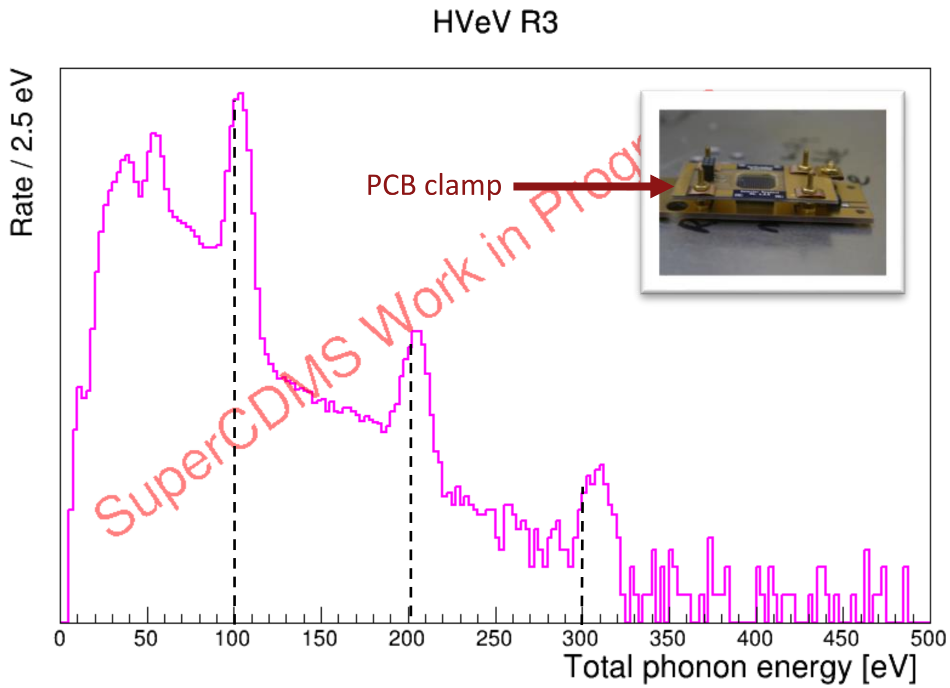


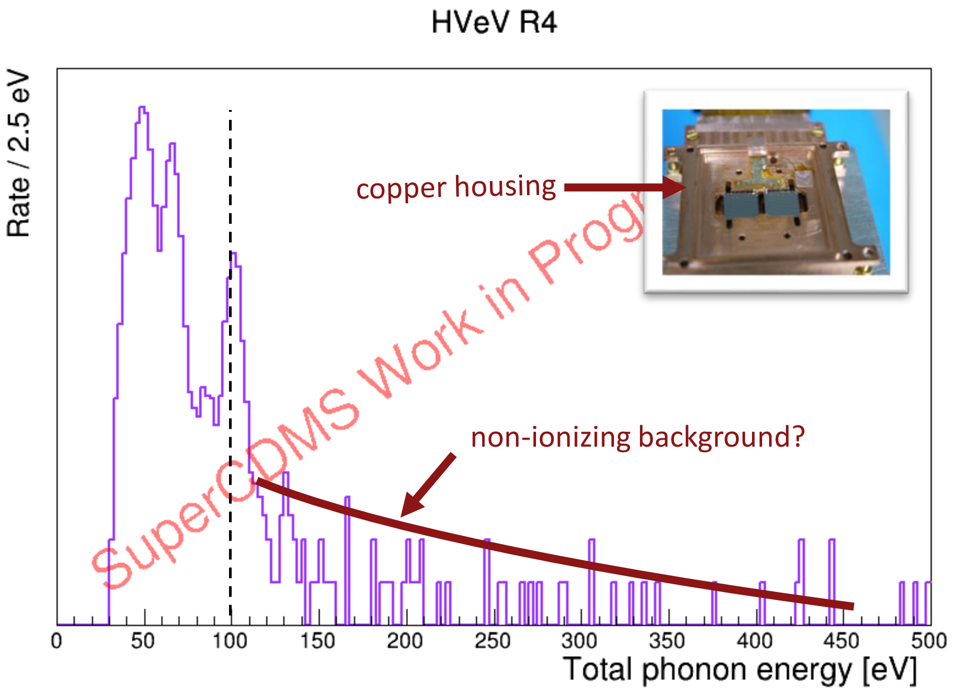
SuperCDMS HV detectors will provide the greatest sensitivity to GeV-scale dark matter at SNOLAB due to NTL amplification

HV detectors in action

$P_t = E_r + N_{eh} e V_b$

- HVeV = prototype of the SuperCDMS SNOLAB HV detector
  - four 1-gram detectors were deployed at the Northwestern Experimental Underground Site (NEXUS)
  - single-charge resolving
  - observed greatly reduced rates of ionizing backgrounds after the removal of an FR4 PCB board
    - we learned that the PCB board was the source of secondary photons
  - non-ionizing backgrounds may dominate the remaining energy spectrum above single charge events: the "low energy excess"

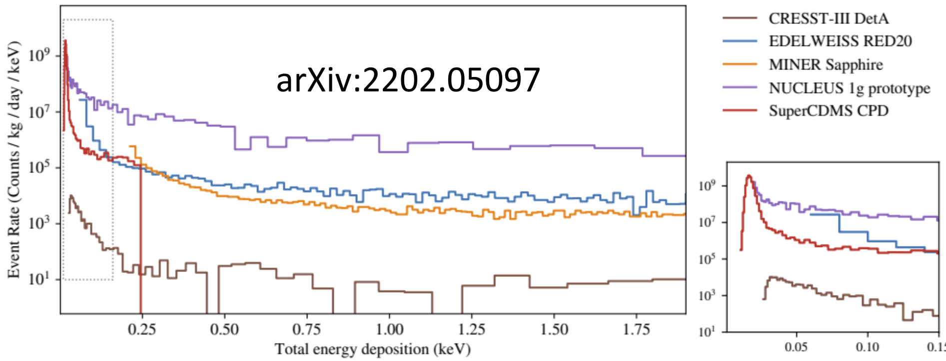




The non-ionizing low energy excess: 0QLEE

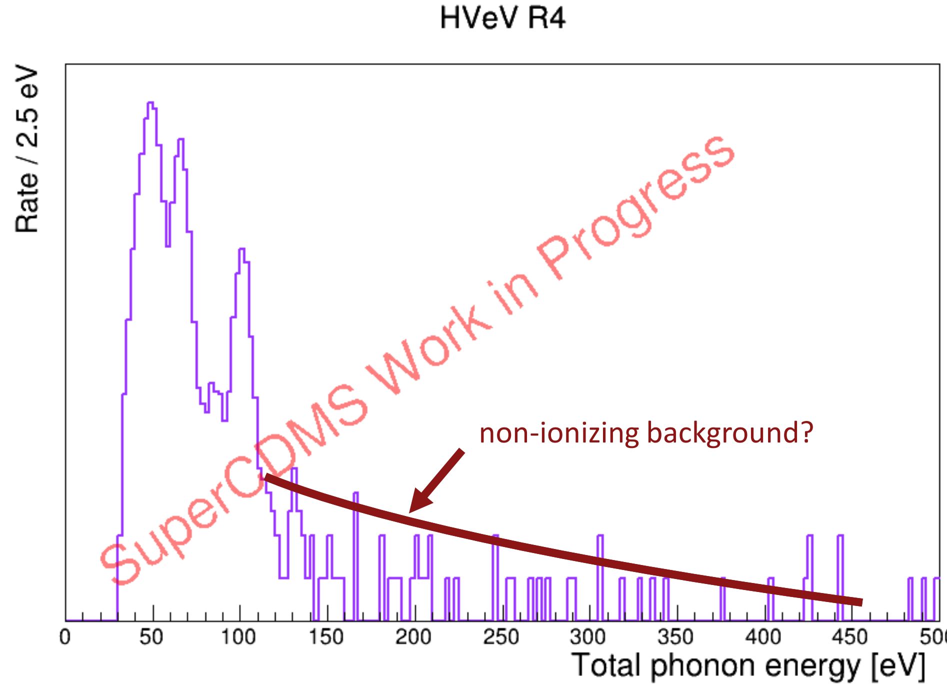
$$P_t = E_r + N_{eh} e V_b$$

- Many low background experiments observed a rising spectrum of unknown source at low energy



Hypothesized to be due to stress events in the substrate and film

SuperCDMS has observed greatly decreased rates of ionizing backgrounds in HVeV detectors and may now be limited by 0QLEE

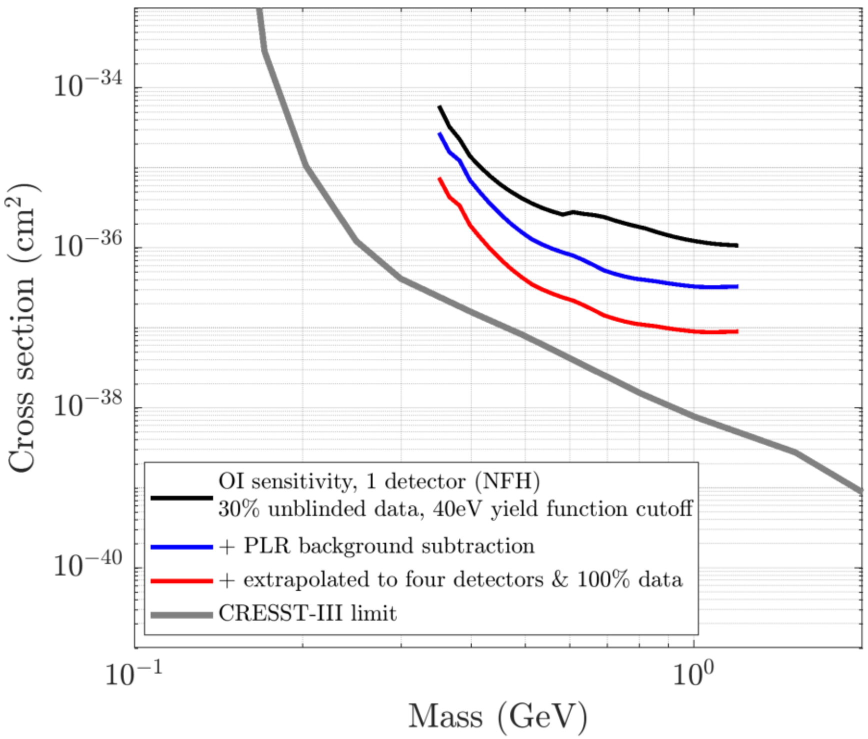


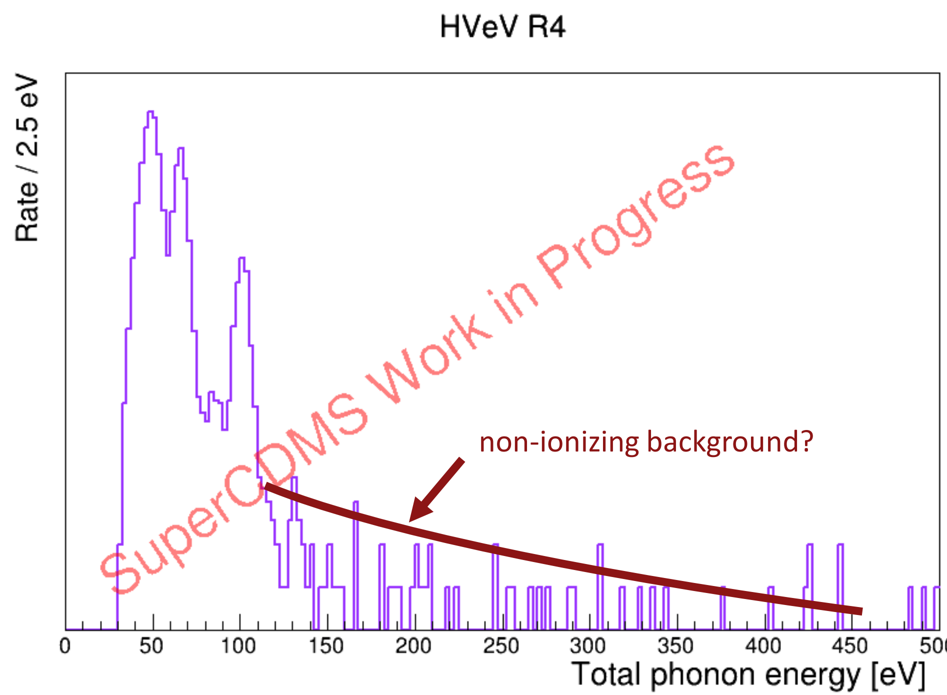
Sensitivity projection with 0QLEE subtraction

$$P_t = E_r + N_{eh} e V_b$$

- As a phonon-mediated detector architecture, HV detectors should also suffer from this low energy excess
- **0V operation may be used to identify the contribution of the low energy excess *in situ* and subtract it for enhanced charge-producing dark matter sensitivity**

blue and red assume 0QLEE can be completely subtracted





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- **0V operation may be used to identify the contribution of the low energy excess *in situ* and subtract it for enhanced charge-producing dark matter sensitivity**
- largest systematic uncertainty on the sensitivity is expected to arise from the yield function, which is extrapolated from the IMPACT yield function

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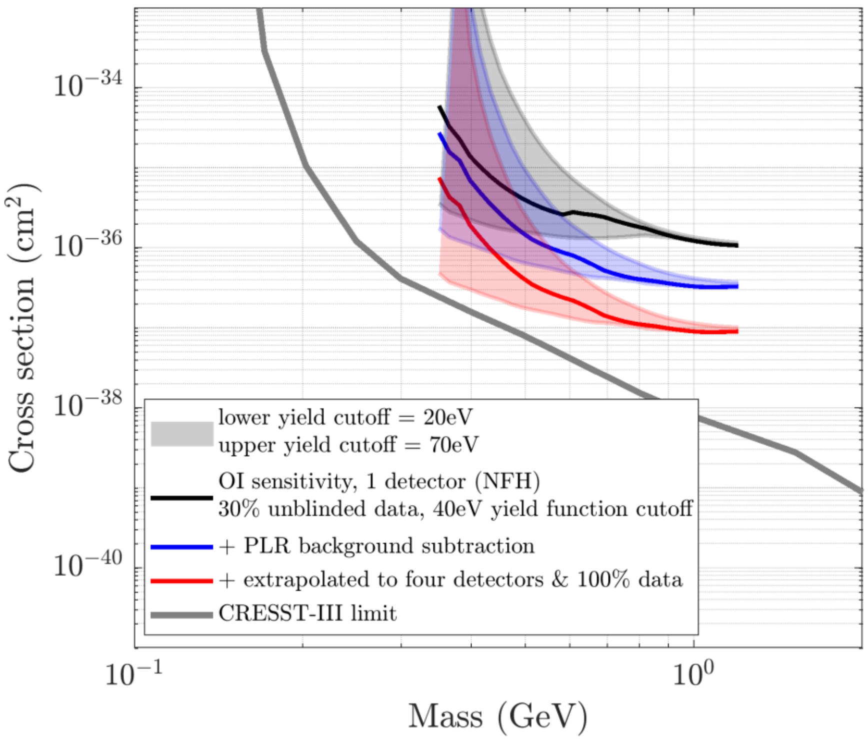
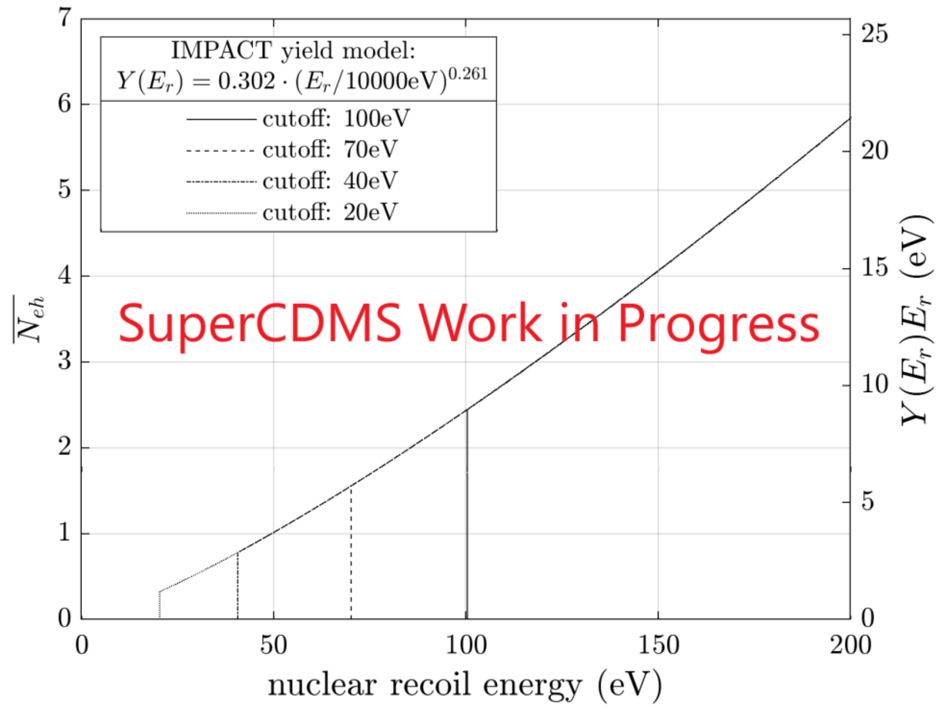
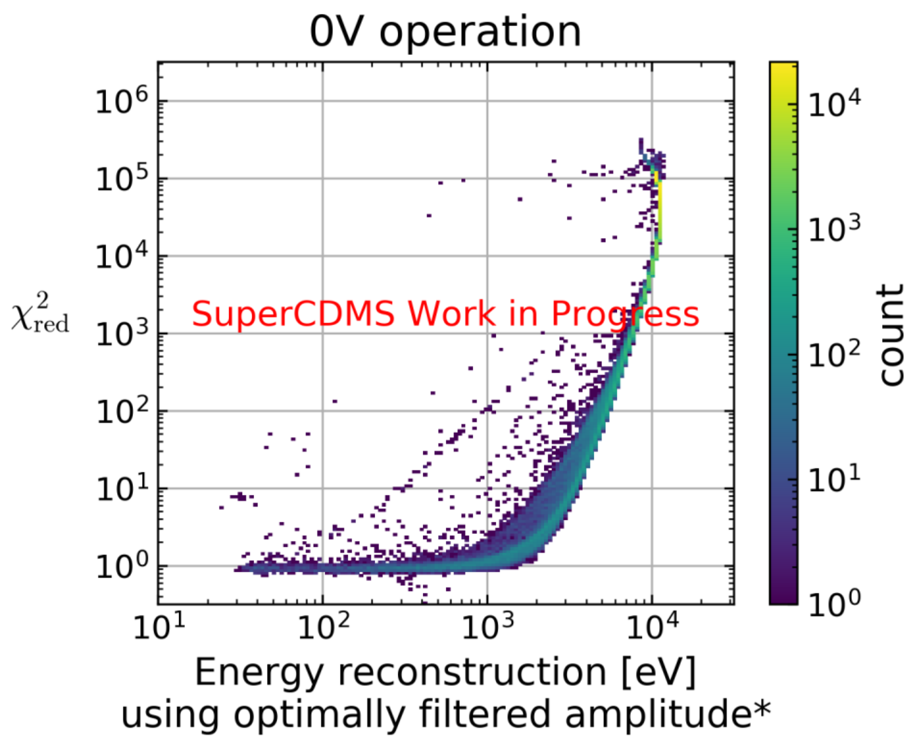




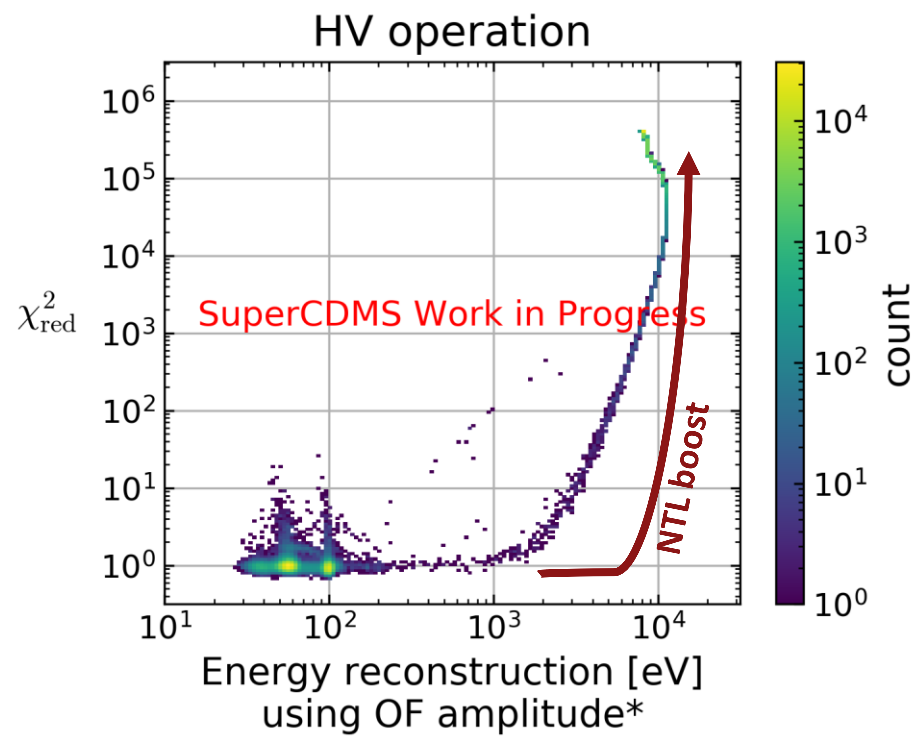
0V and HV operation, Cs-137 source

$$P_t = E_r + N_{eh}eV_b$$

- Recall: HV operation will amplify the phonon response of a particle event via NTL gain



*calibrated with 1eh 100 V data



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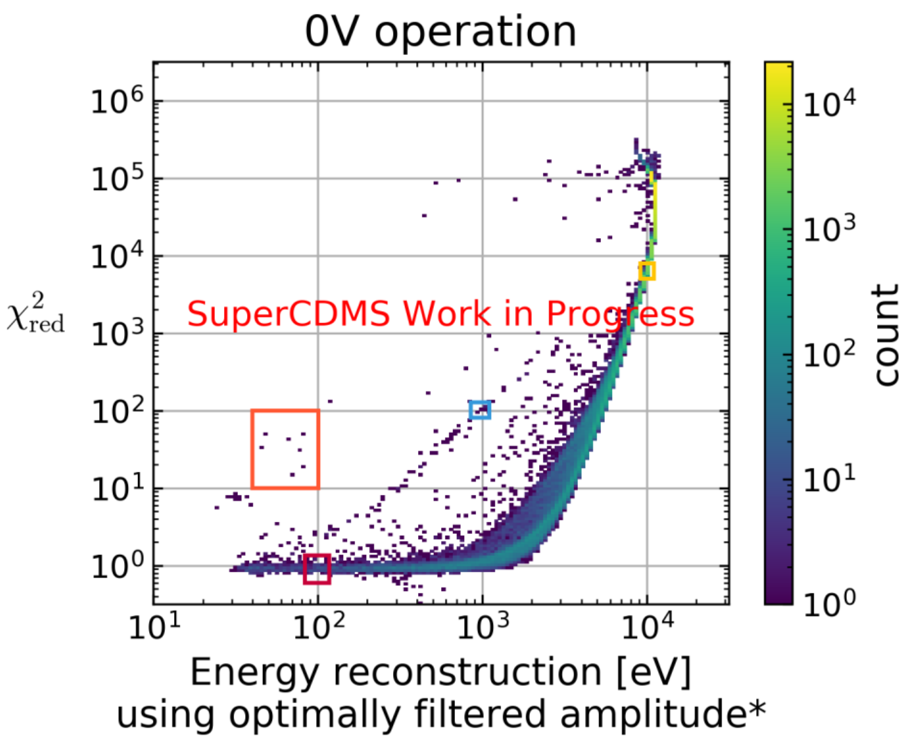
0V operation, Cs-137 source

$$P_t = E_r + N_{eh} e V_b$$

- χ^2-energy plot shows the various kinds of events that are seen in 0V operation



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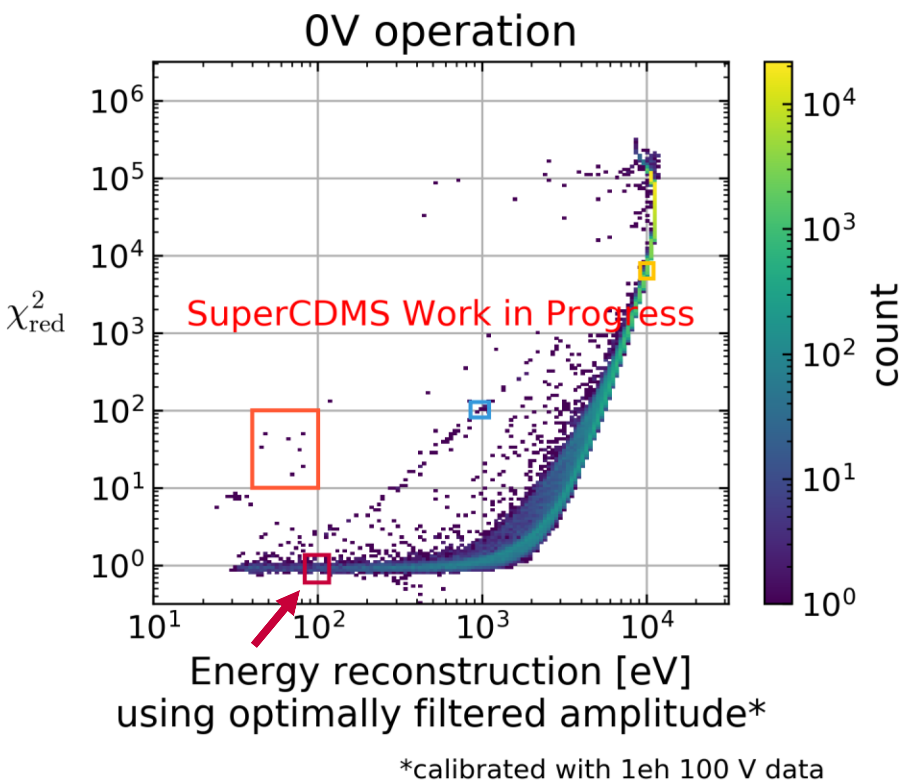

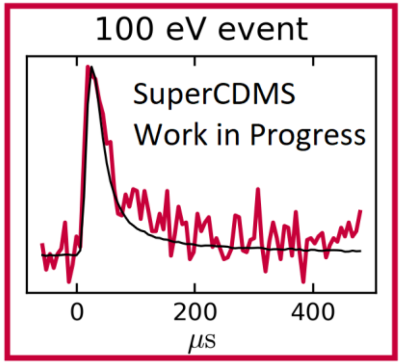

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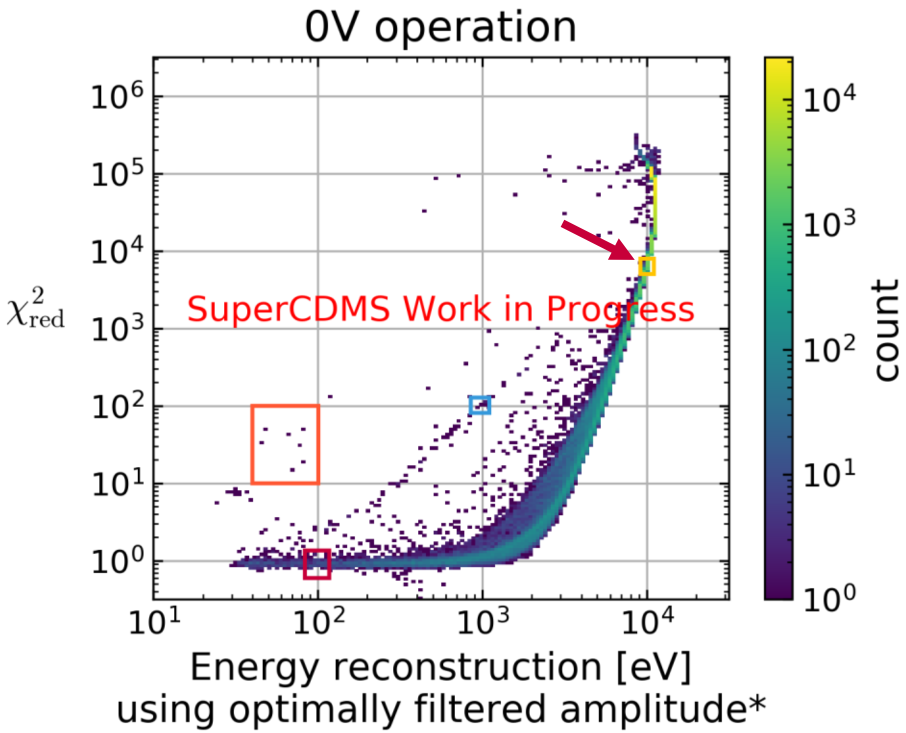

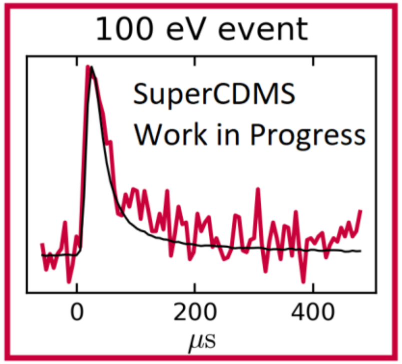

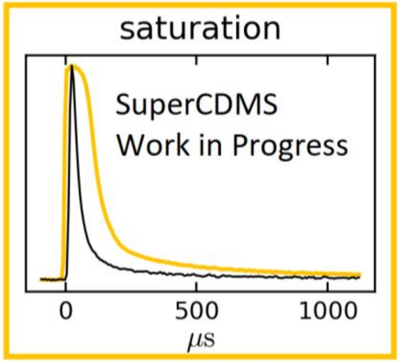

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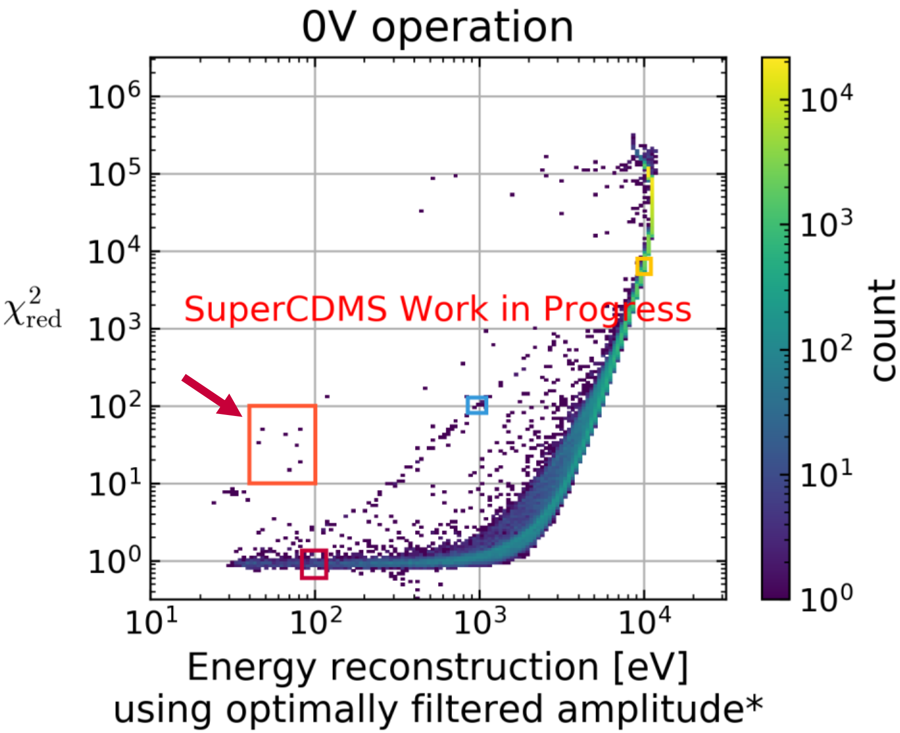

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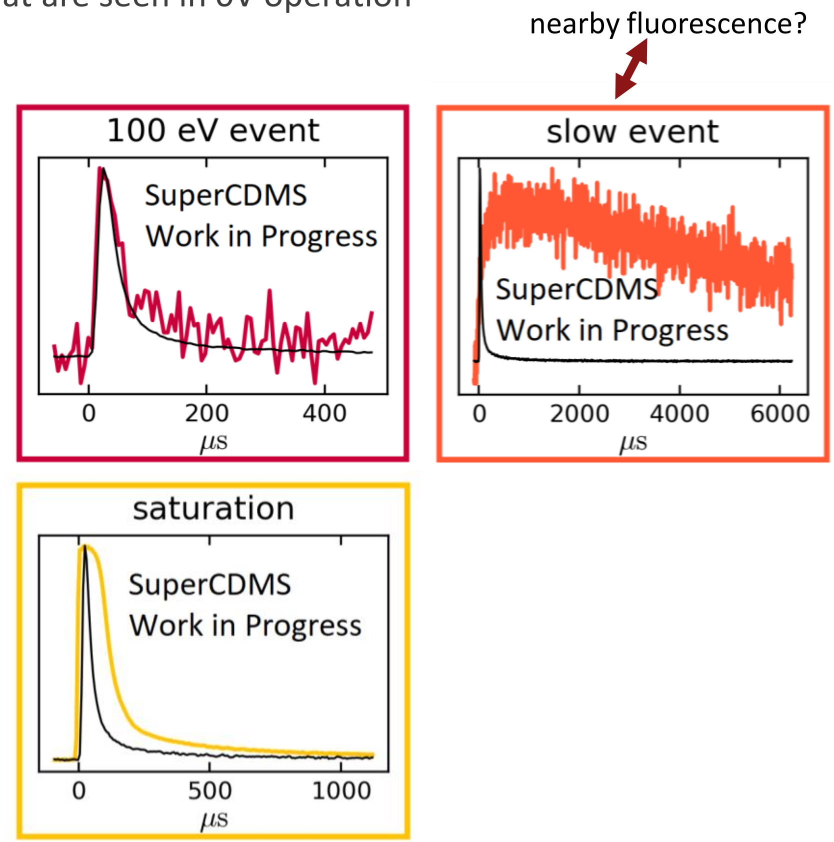

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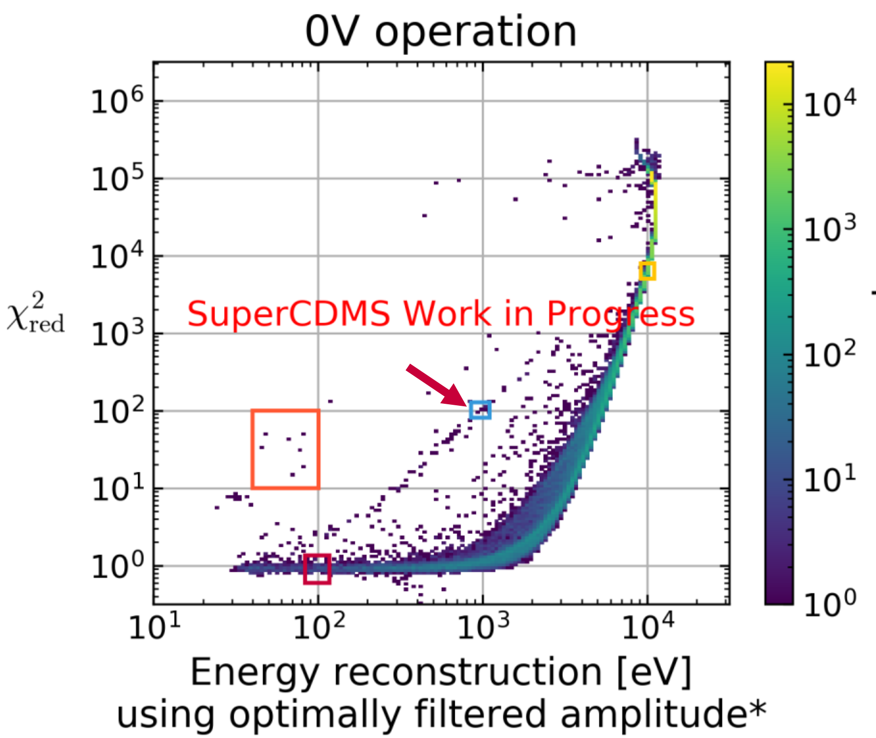

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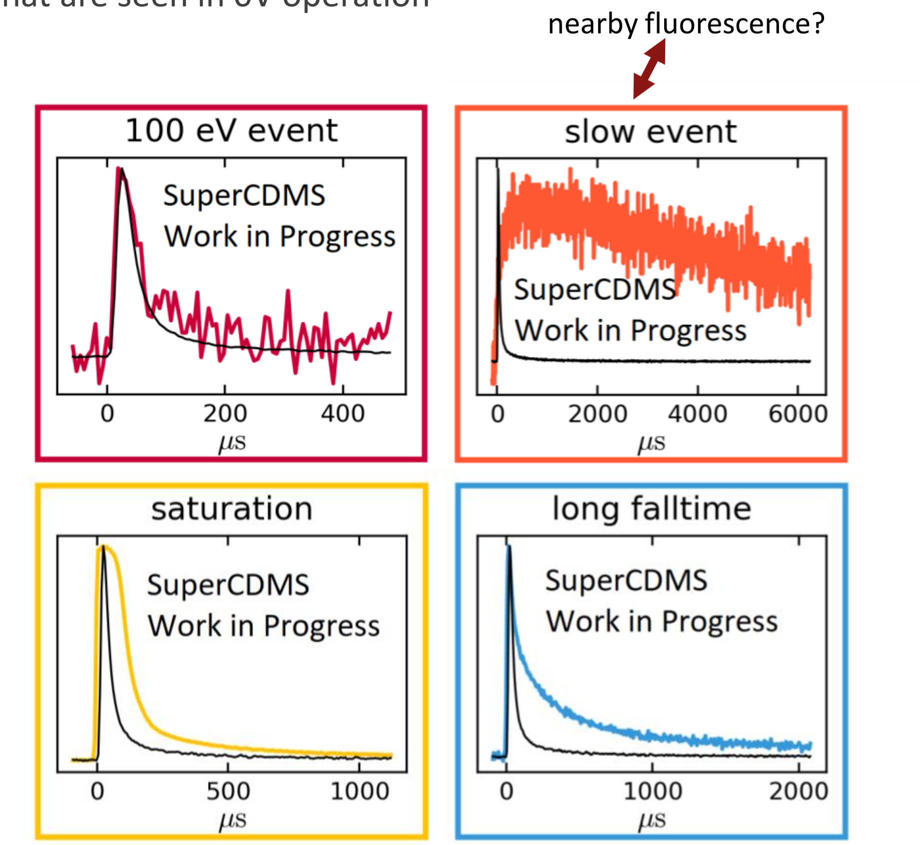
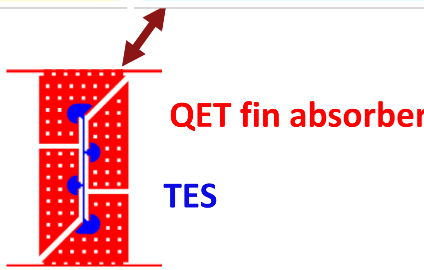
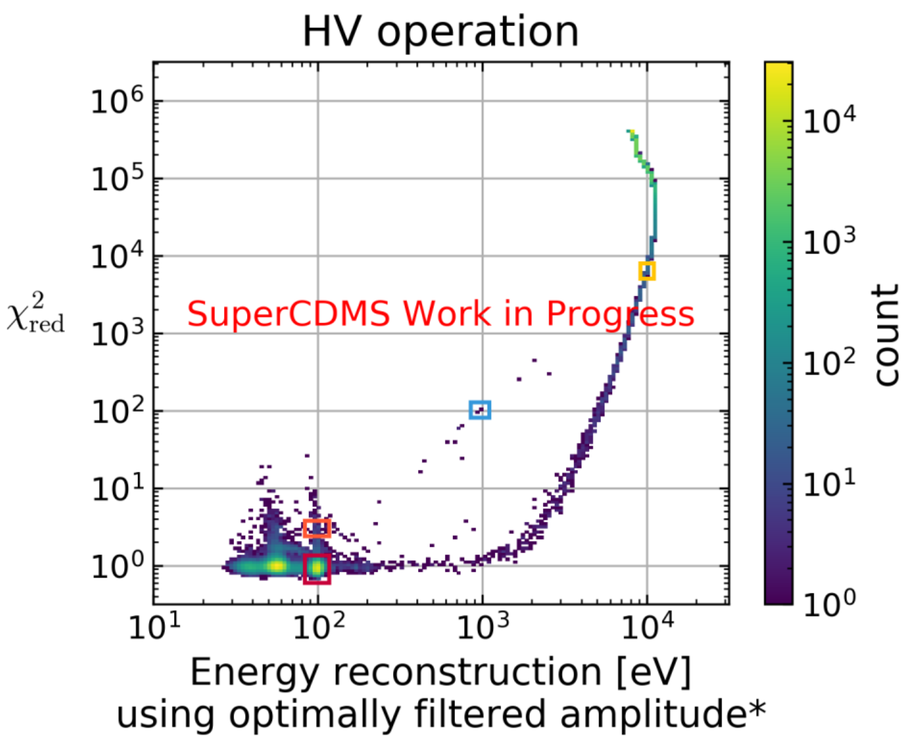




HV operation, Cs-137 source

$$P_t = E_r + N_{eh} e V_b$$

- χ^2-energy plot shows the various kinds of events that are seen in HV operation



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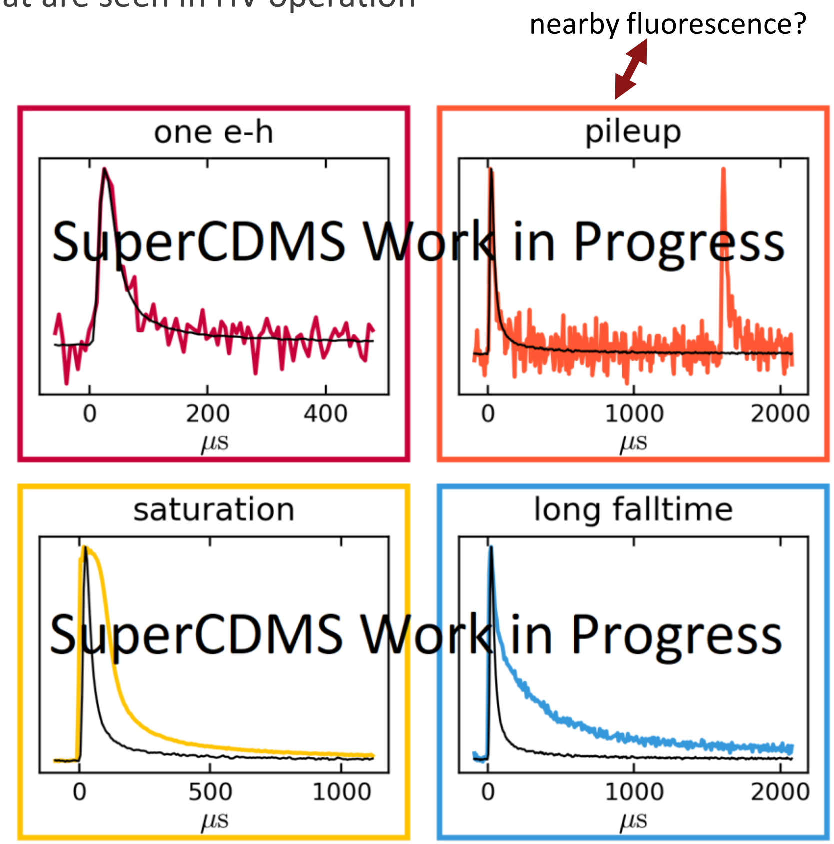
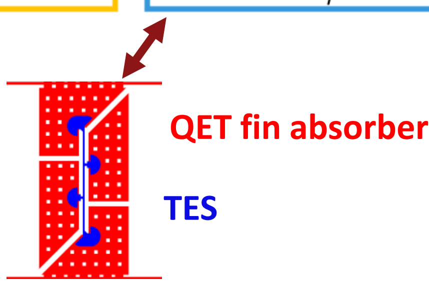
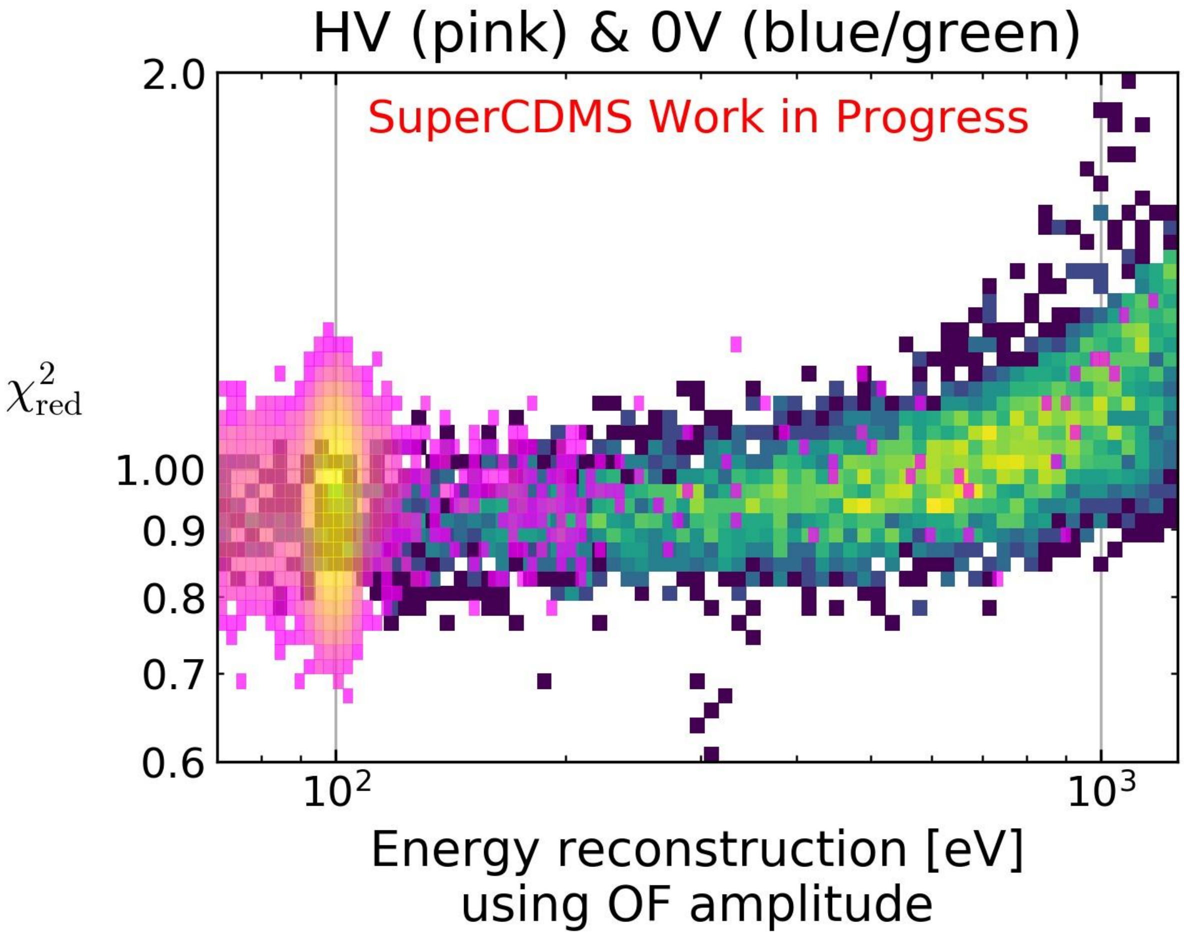




0V vs HV comparison, Cs-137 source

$P_t = E_r + N_{eh} e V_b$

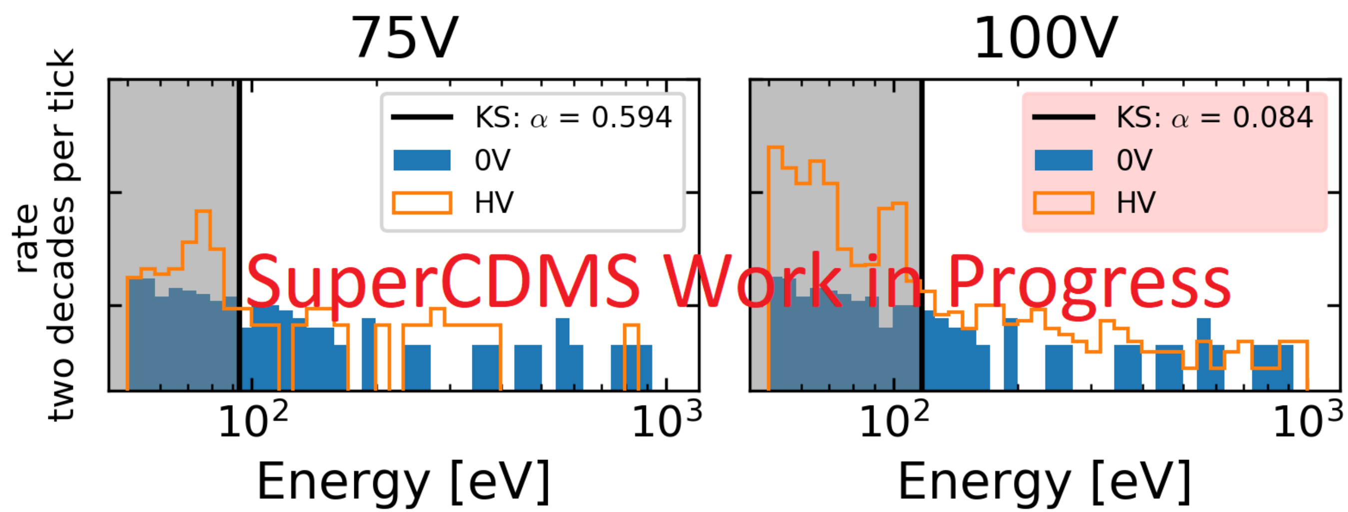
- χ^2-energy plot after all data quality cuts shows rough consistency between the 0V and HV χ^2-distributions versus energy



0V vs HV comparison, background data

$$P_t = E_r + N_{eh} e V_b$$

- 0V vs HV background data for one HVeV detector after all data and pulse quality cuts
- Kolmogorov-Smirnov test is applied 5σ above the first eh peak
  - 100V fails the KS test – is the spectra perhaps composed of other ionizing events?



- Ideas:
  - Could use more statistics; this is 30% of data
  - What component of the HV data are well-collected charge producing events?
    - Partition cut may help for identifying bulk events
    - Studying the relative rate of saturated events in 0V vs HV may help to understand the effect of the NTL boost
  - Could still consider subtraction of 0QLEE, but would then be background limited by the remaining spectrum

Summary & outlook

- HV detectors are sensitive to both ionizing and non-ionizing backgrounds
- With greatly decreased rates of ionizing backgrounds, SuperCDMS HVeV backgrounds may be dominated by the 0QLEE
- Subtracting the 0QLEE can lead to enhanced sensitivity
- May yet be other backgrounds in the HV data in excess of the 0V spectrum → requires further study