Northwestern

SUPER CDMS
Cryogenic Dark Matter Search

# An ERDM Search with SuperCDMS HVeV Detectors at SNOLAB

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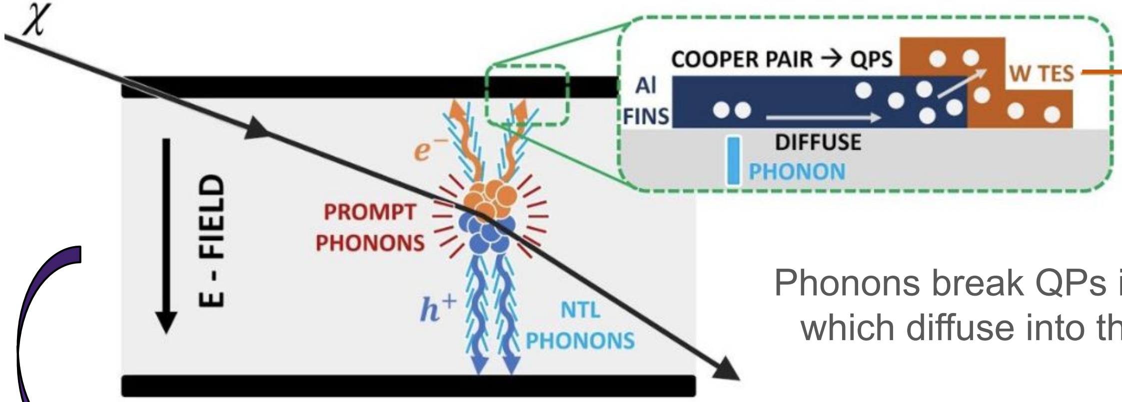
on behalf of the SuperCDMS Collaboration

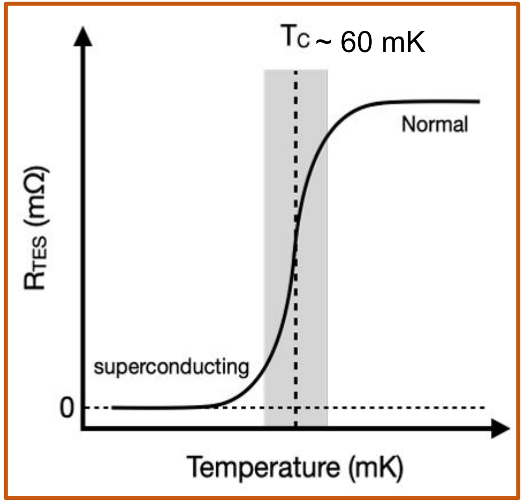
# The SuperCDMS Collaboration

Searching for **sub-GeV dark matter** via direct detection
Need detectors with excellent energy resolution

# Detector Schematic




Phonons break QPs in Al fins which diffuse into the TES




Voltages biases usually O(10-100 V)

**DM interacts with cold crystal**
Generates phonons and charge carriers

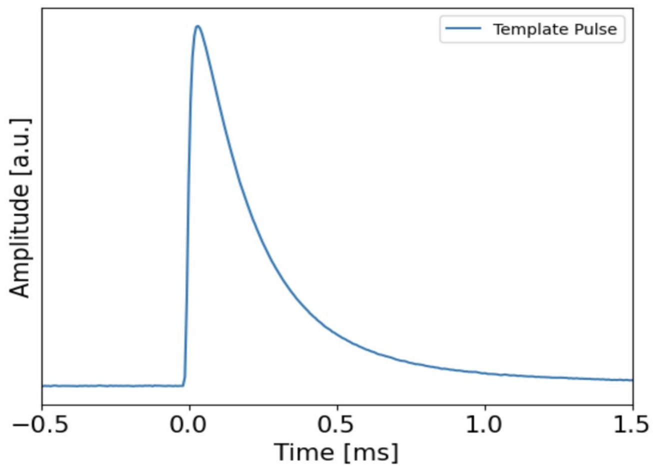
**Freed charges accelerated by E-Field**
Charges emit more phonons

**Total Phonon Energy**

$$E = E_R + n_{eh}eV$$

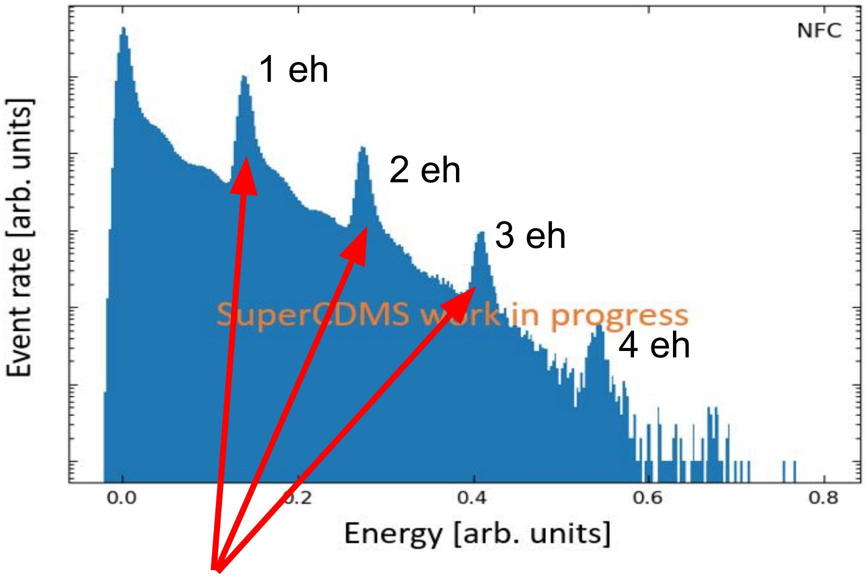
# Expected Response

### Response from Particle Interaction




Height of pulse gives estimate of energy

### Example Energy Spectrum

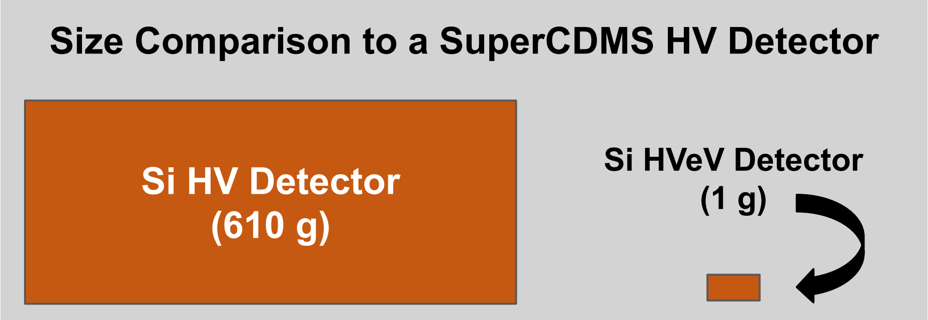


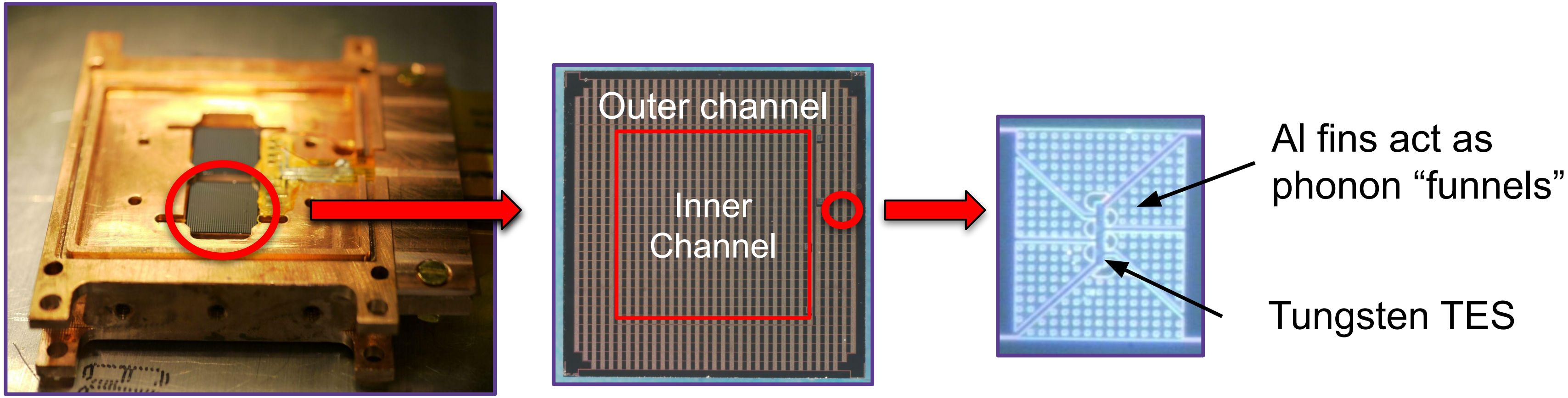

Peaks correspond to number of electron-hole (eh) pairs produced

# The HVeV Program — SuperCDMS R&D

**Uses gram-scale detectors aimed at achieving eV-scale energy resolution for:**

- Background classification
- Charge-transport studies
- **Low-mass DM searches**

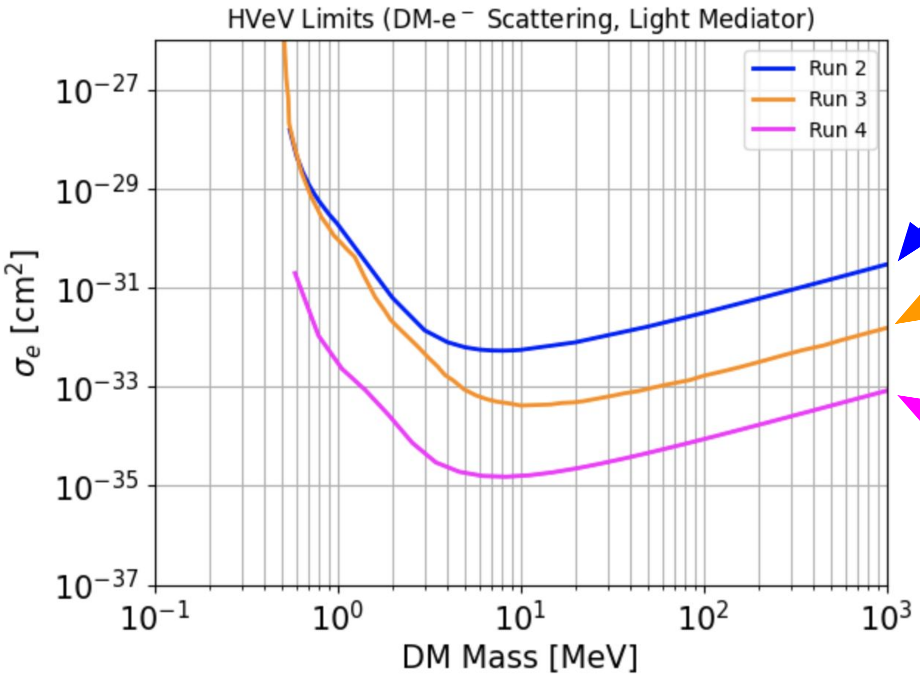


# HVeVs as a Maturing Technology

**HVeVs are a relatively new technology**

~5 years of studying backgrounds and operation techniques have yielded improvement




**2019:** Search at surface facility
**~3.5 eV Resolution**

**2021:** Search at NEXUS
Coincidence rejection
Overburden
**~3 eV Resolution**

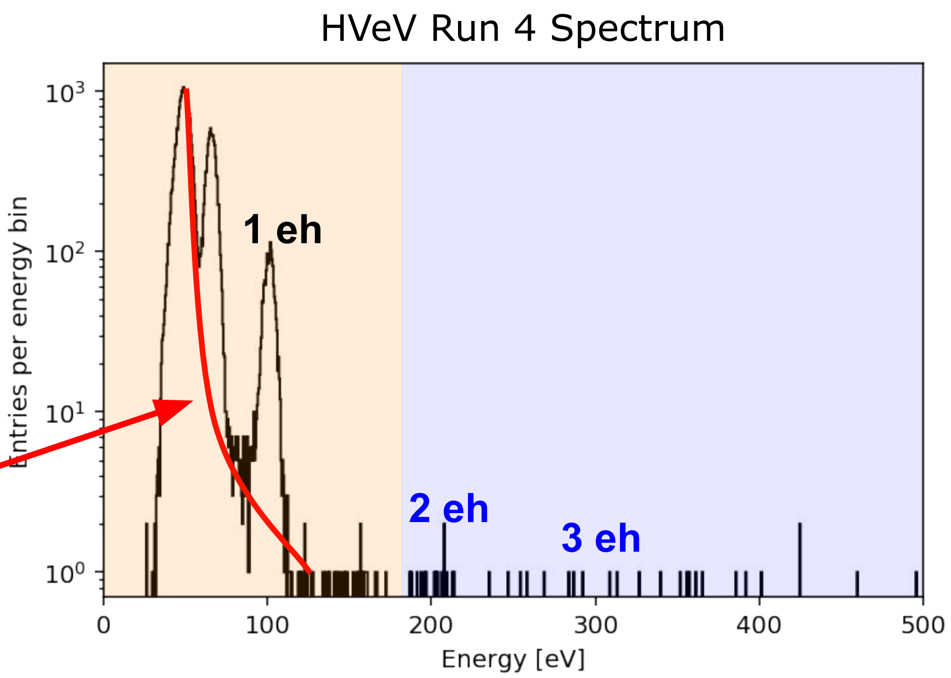
**2022:** Search at NEXUS
Improved housings using low bkg materials
**~2.5 eV Resolution**

# The Next Generation of Improvement

**Want to improve on the latest search— HVeV Run 4:**

- Run 4 improved by mitigating **high energy backgrounds (2+ eh)**
- We are now limited by **low energy backgrounds!**
  - 1 eh Rate
  - Low Energy Excess (LEE)

**Need to understand these new limiting backgrounds**



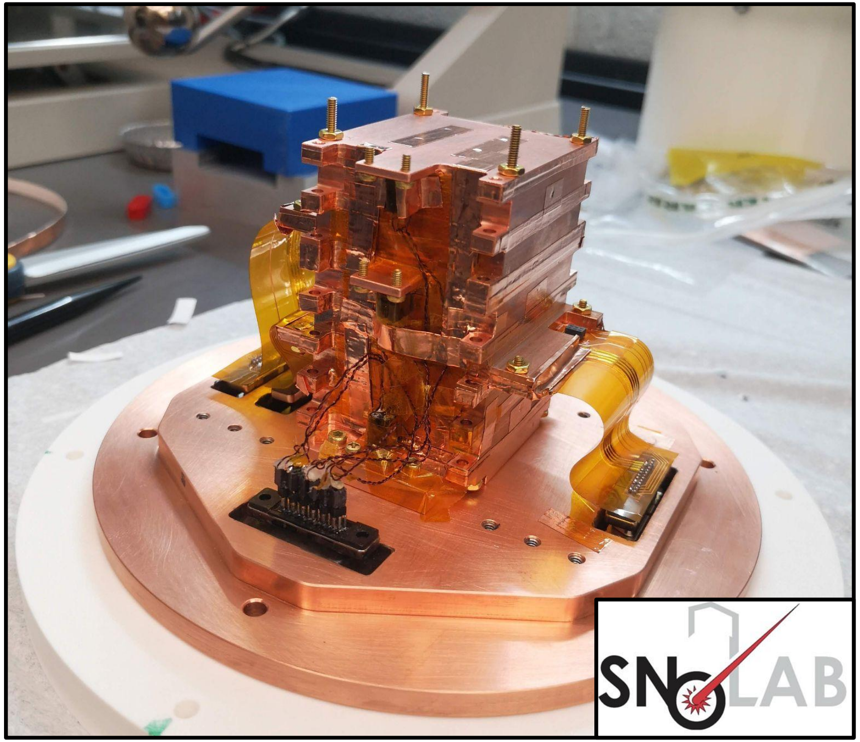
# Detector Payload

**Operated in dilution fridge (~14 mK) at the CUTE facility in SNOLAB**

- ~100,000x lower muon flux than NEXUS!
- Payload of six HVeV detectors
  - R4 detectors
  - Two new detectors
- LEDs for calibration

**Primary Goal:**
Study the Low Energy Excess (LEE)

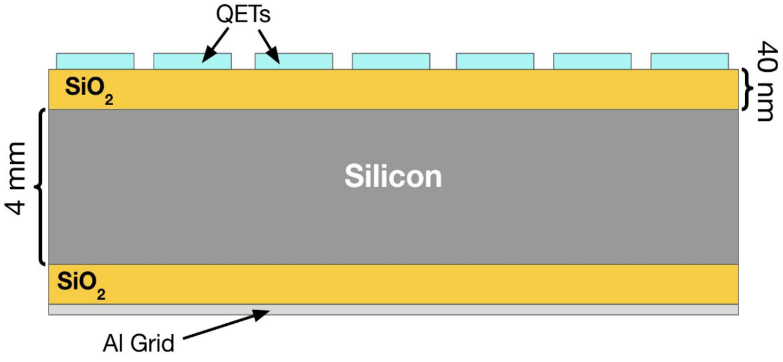
**Performed an ERDM search when we realized we had low backgrounds**

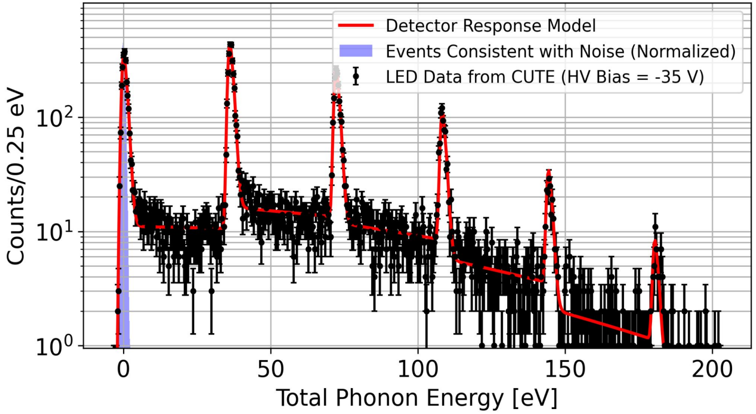


# The Next Generation HVeV

**ERDM search used data from a single, new HVeV detector**

- Has lower $T_C$ TESs for better resolution
- Included an $SiO_2$ layer to prevent leakage from Al films into the substrate



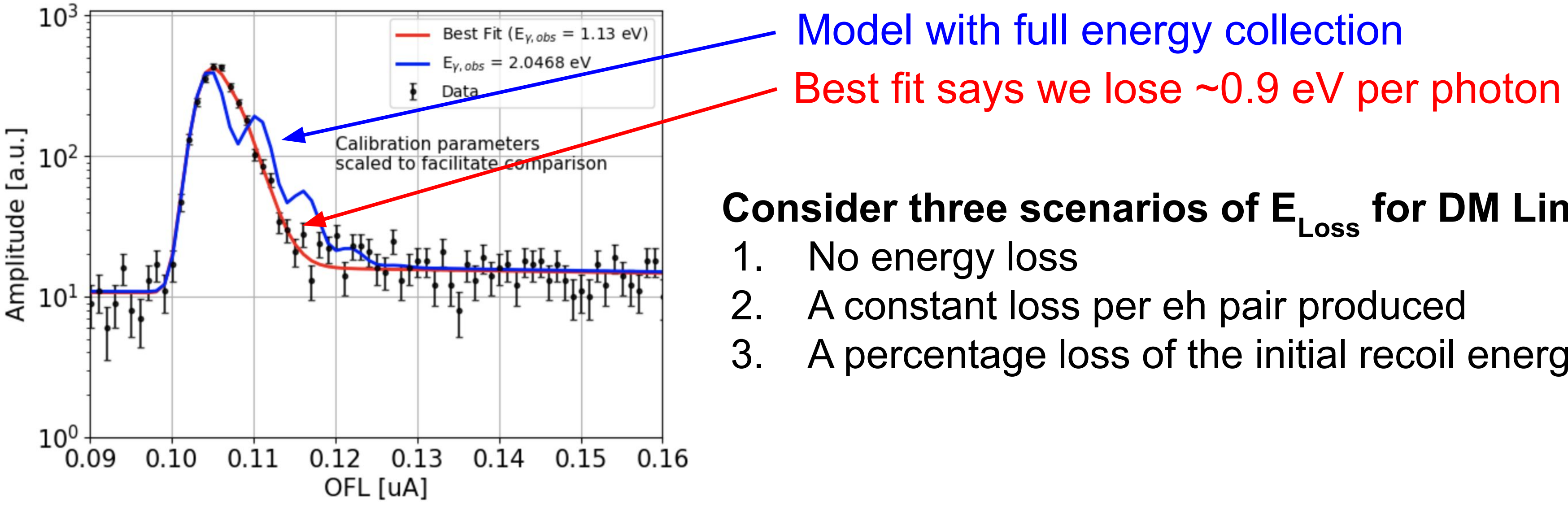




Calibrated with ~2 eV photons → **Achieved a 589 meV resolution**

**New personal best for HVeVs!**

# Energy Loss Mechanism

- Structure in eh peaks is complicated by **surface-trapped events:** In a surface-trapped event, eh pairs recombine near surface and don't yield NTL energy
- Gives peaks an underlying Poisson distribution




**Consider three scenarios of $E_{Loss}$ for DM Limits:**

1. No energy loss
2. A constant loss per eh pair produced
3. A percentage loss of the initial recoil energy

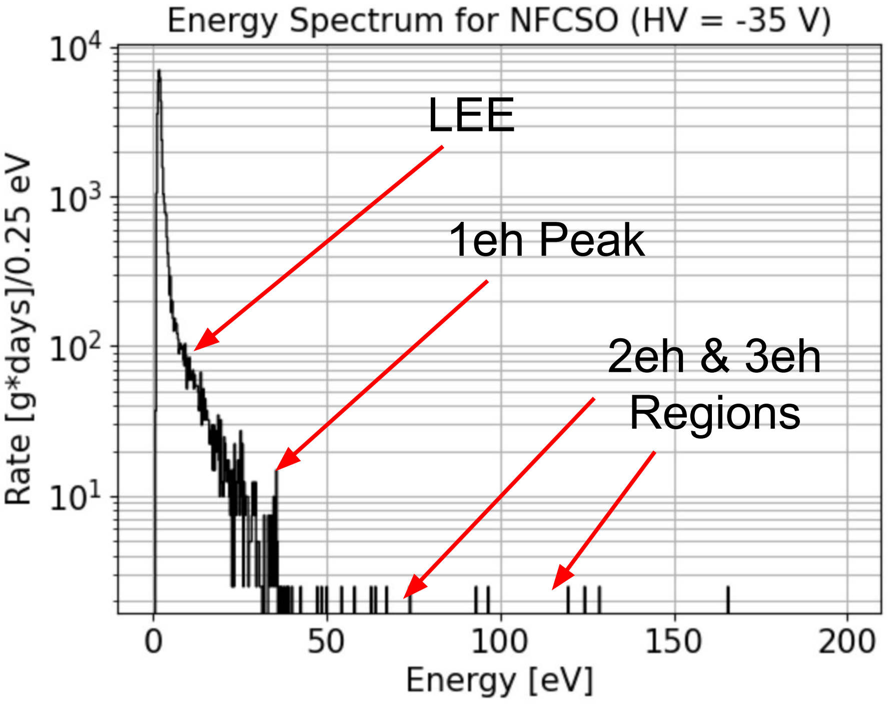
# Electron-Recoil DM Search

- Taking DM search data at -35 V bias
  - ~13 days of exposure
  - 90% of data is blinded

**Reduced 1eh rate compared to previous measurements**

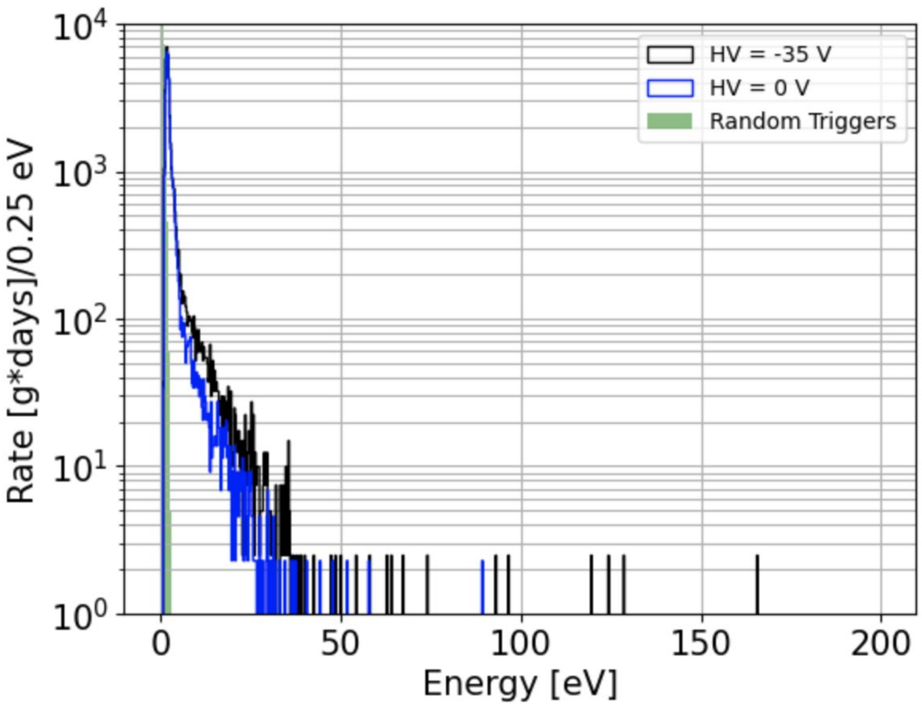
- 1eh Peak has a rate similar to the surrounding LEE
- Other experiments have found that the LEE is primarily non-ionizing…

**~10 Hours of Live Time**



# Non-ionizing Background

- … We can see that by comparing to data taken with 0 V bias



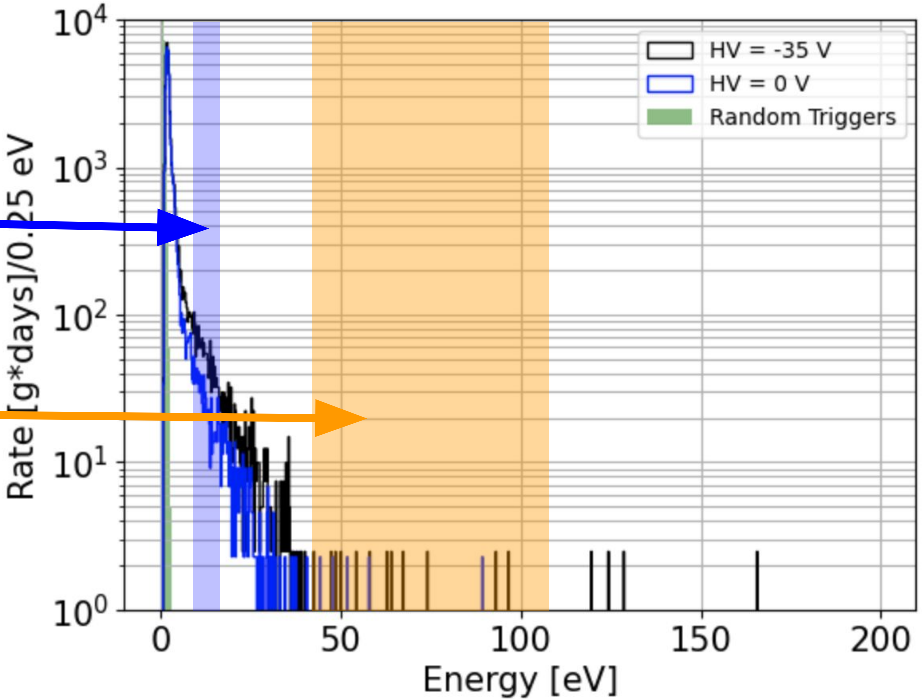
# Non-ionizing Background

If the 0V background were ionizing, then **0V events from here**…

- ~900 events/g*day in 0V

…Would appear **somewhere here with HV on**.

- ~30 events/g*day in HV

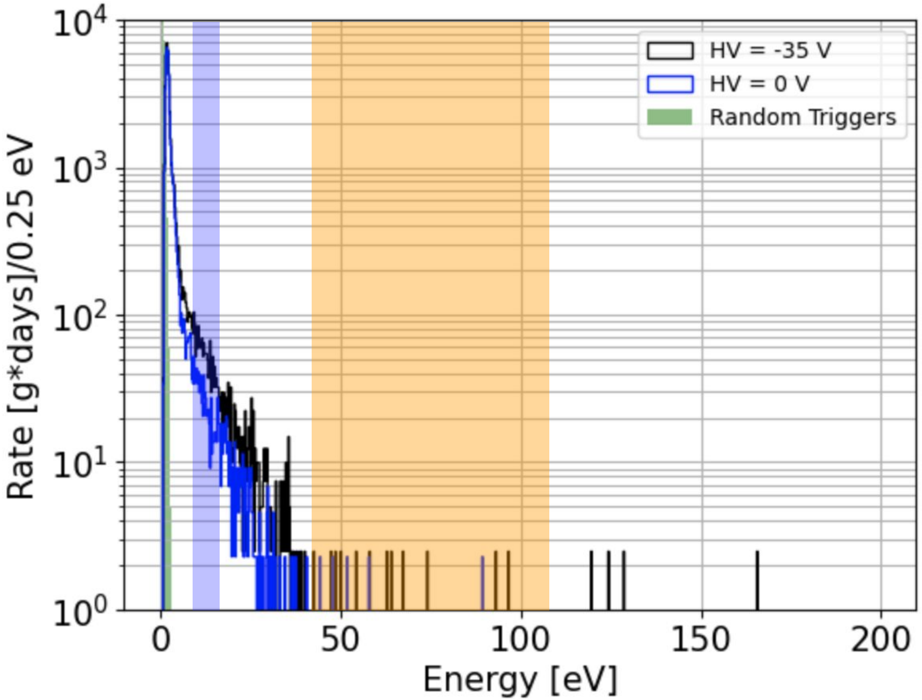


# Non-ionizing Background

But, in HV data, we only see a small number of events in the **orange region**.

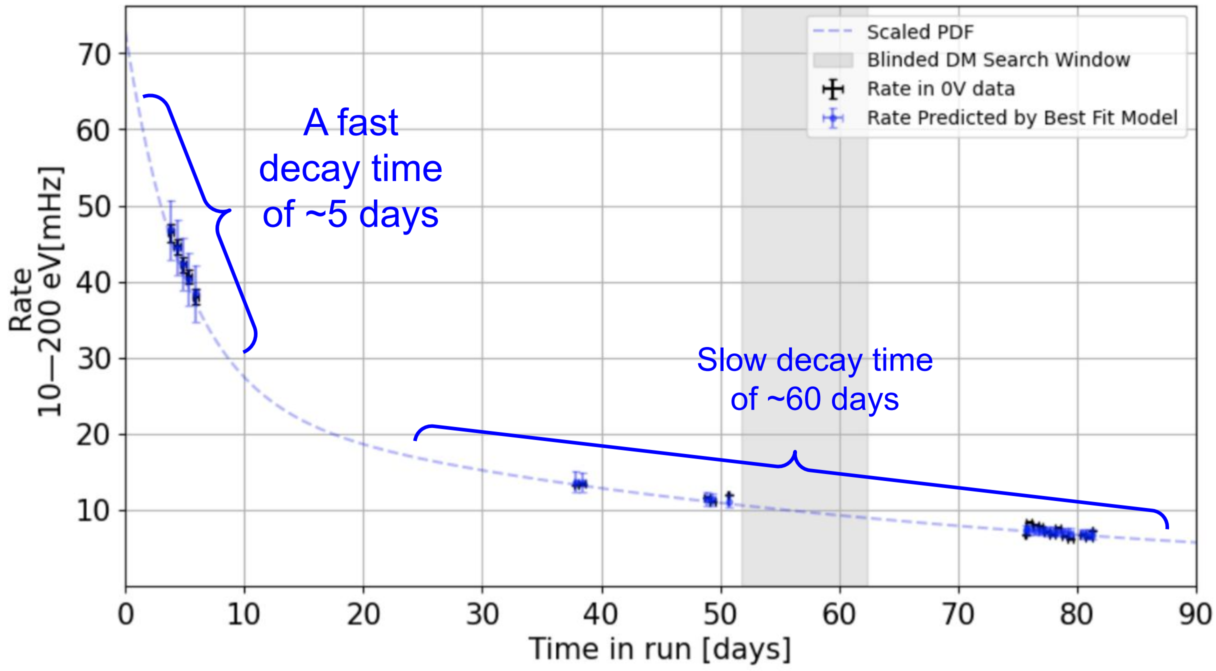
→ **0V is mostly non-ionizing**

**Want to account for non-ionizing background in DM Search!**



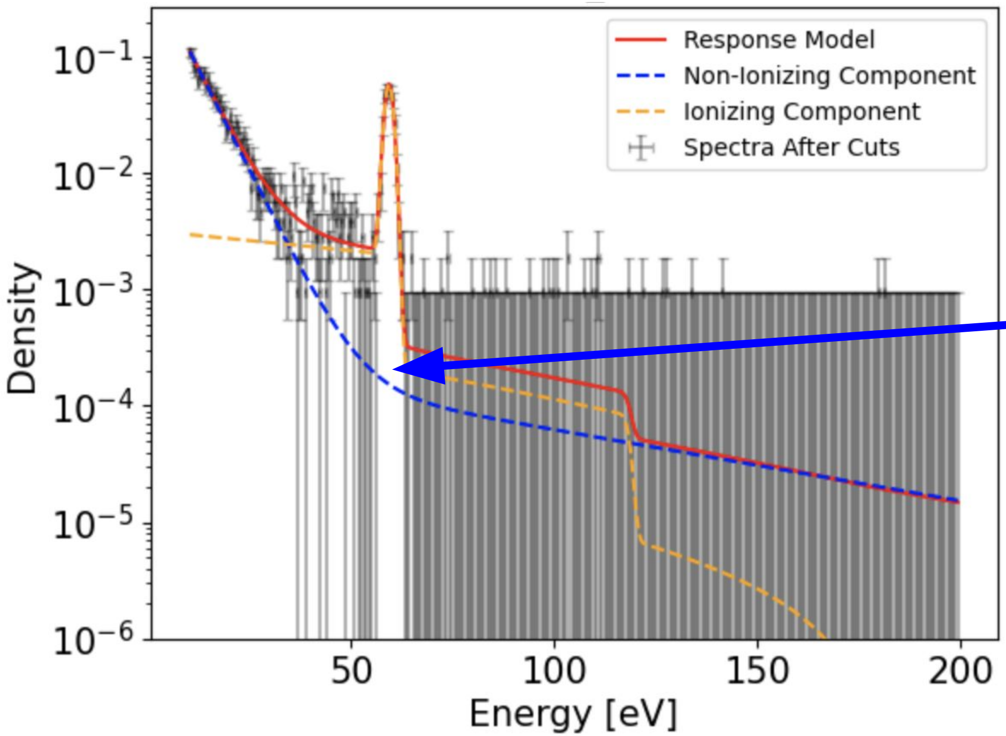
# Non-ionizing Background

- Shape of 0V spectrum remains constant with time
- **Rate of 0V background changes with time**



# Non-ionizing Background

HV data taken at 60 V

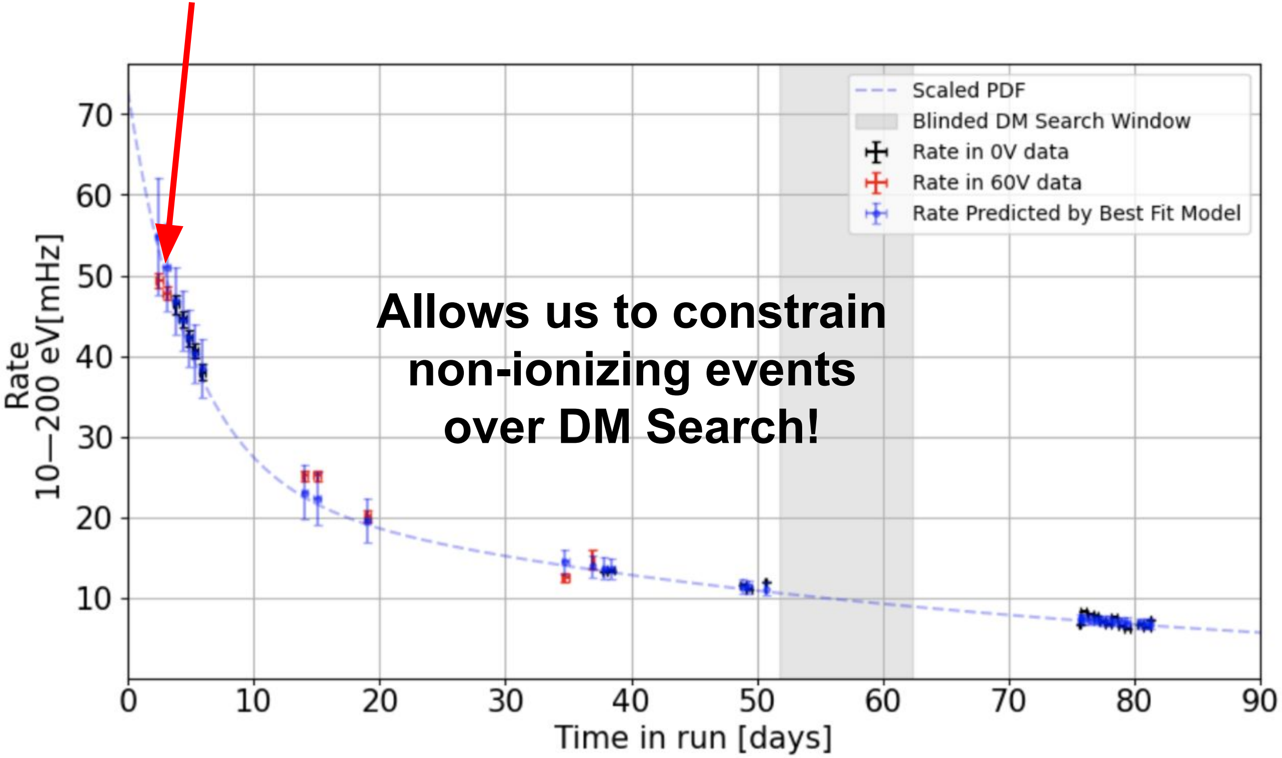



Model HV spectra with a **non-ionizing component**

Extract rate of the non-ionizing component in HV data

# Non-ionizing Background

- **Non-ionizing rate from fits to HV data** matches rate measured from 0V!



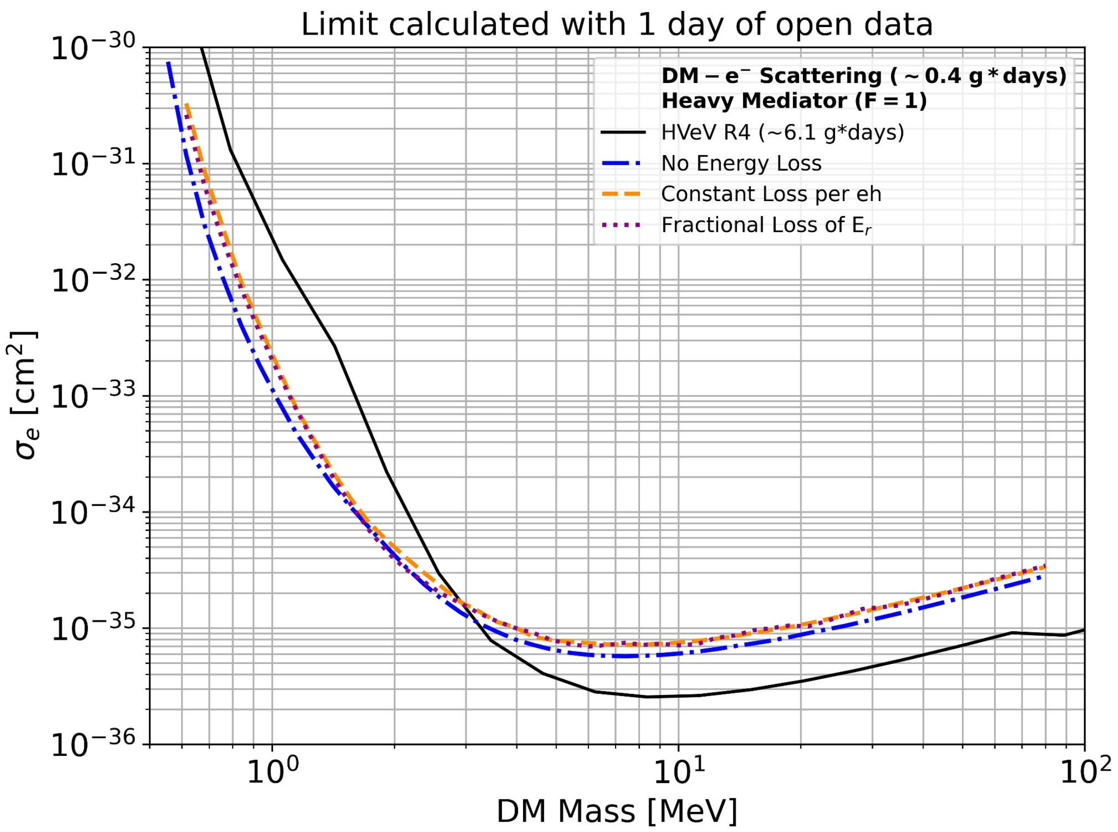
# Preliminary Limits

Full unblinded limits currently in progress
Currently showing 1 day of data

**Calc limit under three scenarios:**

1. No energy loss
2. Constant loss per eh
3. Percent loss of recoil E

Poised for another factor of ~10 improvement over Run 4!



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Full unblinded limits currently in progress!
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**Calc limit under three scenarios:**

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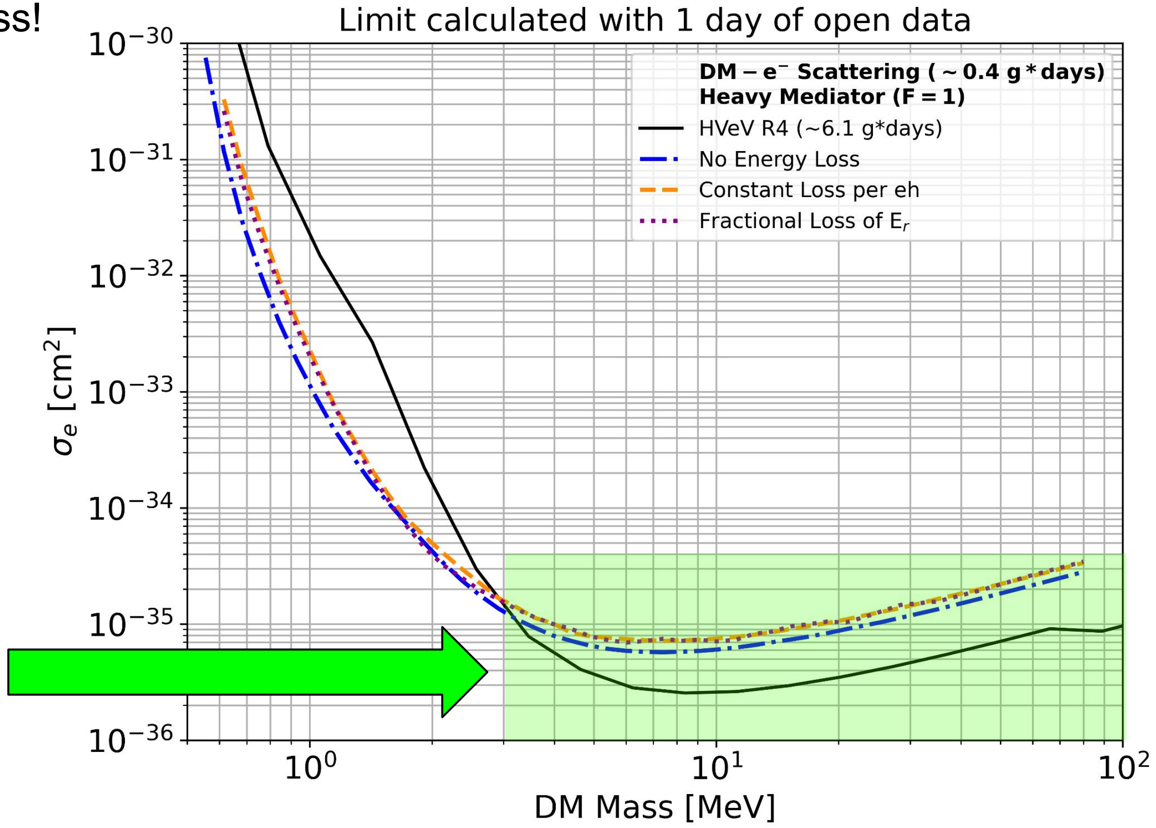
Poised for another factor of ~10 improvement over Run 4!

Expect limits to improve for higher masses after unblinding

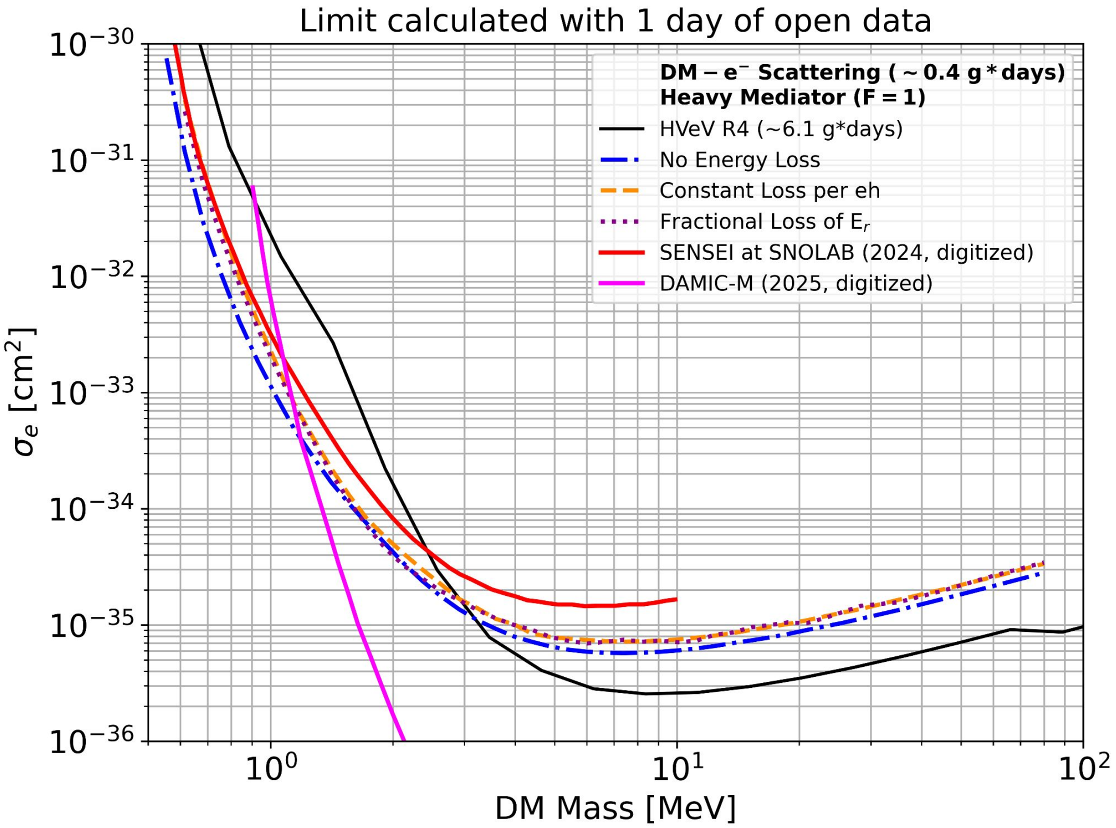


# Preliminary Limits

In the most conservative case:

- **World leading below ~1.2 MeV**
- Competing with dark matter dedicated experiments, SENSEI & DAMIC-M

**This is with only 1 day of data**



# Conclusion

- SuperCDMS has been improving HVeVs steadily over the past ~5 years

- HVeVs are now competing with the most sensitive DM-dedicated experiments in the field!

  **World leading below ~1.2 MeV!**

- Unblinding currently in progress

  **Stay tuned for final results**

- More HVeV developments on the way
  - Position reconstruction
  - Studies of the LEE
  - And more!

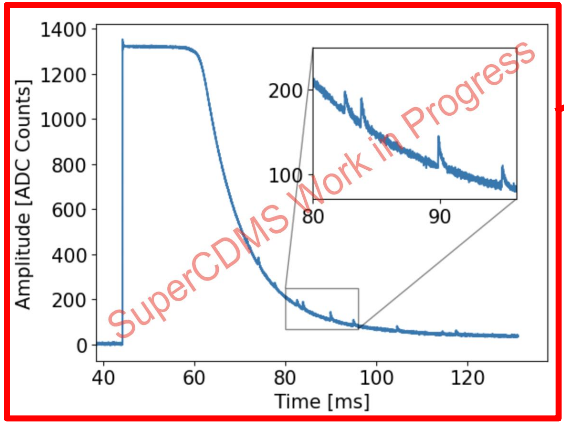
# Bonus Slides

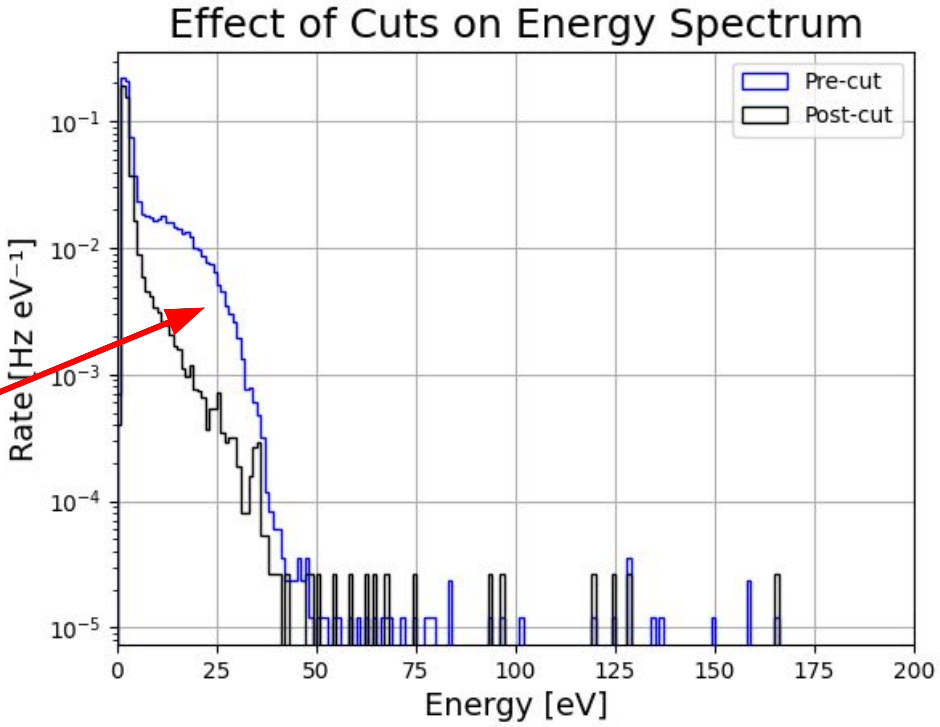
# Pesky Background: "Burst Events"

We see "bursts" of low energy events occurring after some high energy events

Trigger Rate can jump by a factor up to ~100 during a burst!

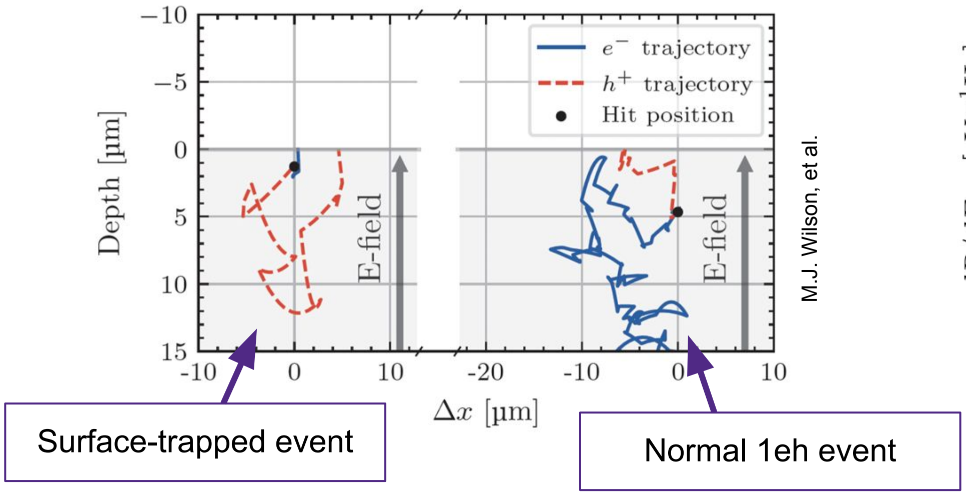
**We believe these explain the difference between 0V and HV events data!**



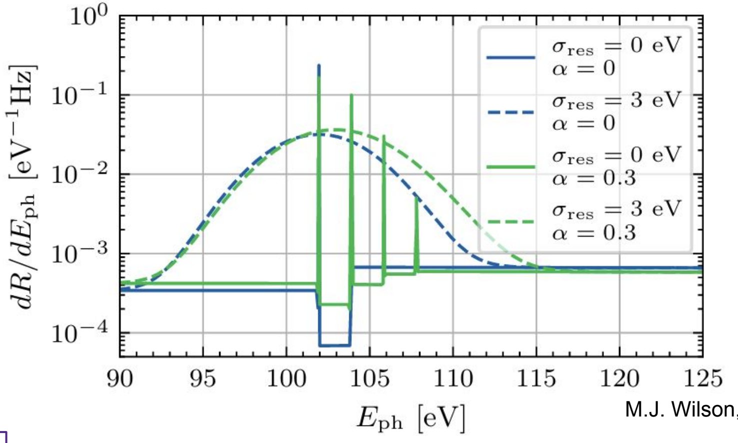



# Surface-Trapping: Structure in eh Peaks

PhysRevD.109.112018




M.J. Wilson, et al.




M.J. Wilson, et al.

- Simulations show a possible surface-trapping (ST) effect
- ST events don’t yield any NTL energy but only give the photon energy
  - Underlying Poisson structure in eh peaks!
- In R4, $\sigma_{res} \sim E_\gamma$ so ST manifests as broadening and shifting of eh peaks

# Charge-Trapping & Impact Ionization

Events that can happen on a charge's journey through the crystal…

## Charge-Trapping

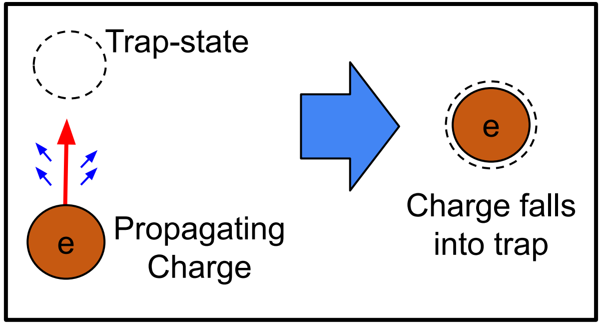
- Propagating charge falls into a trap state
- Gain back a portion of recombination energy
- Lose NTL energy

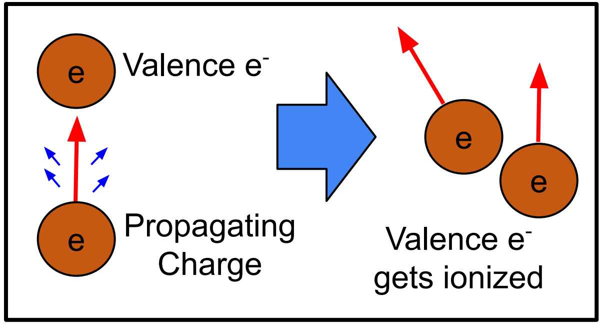
## Impact-Ionization

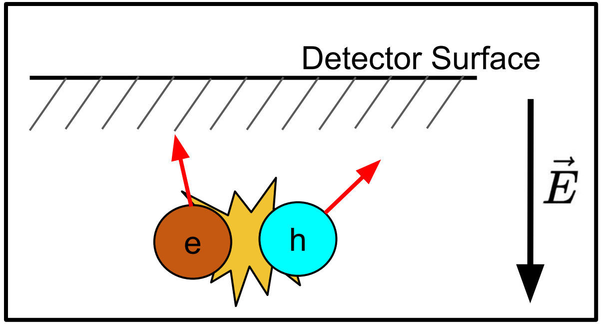
- Propagating charge scatters off electron and ionizes it
- Gain NTL energy

## Surface Trapping

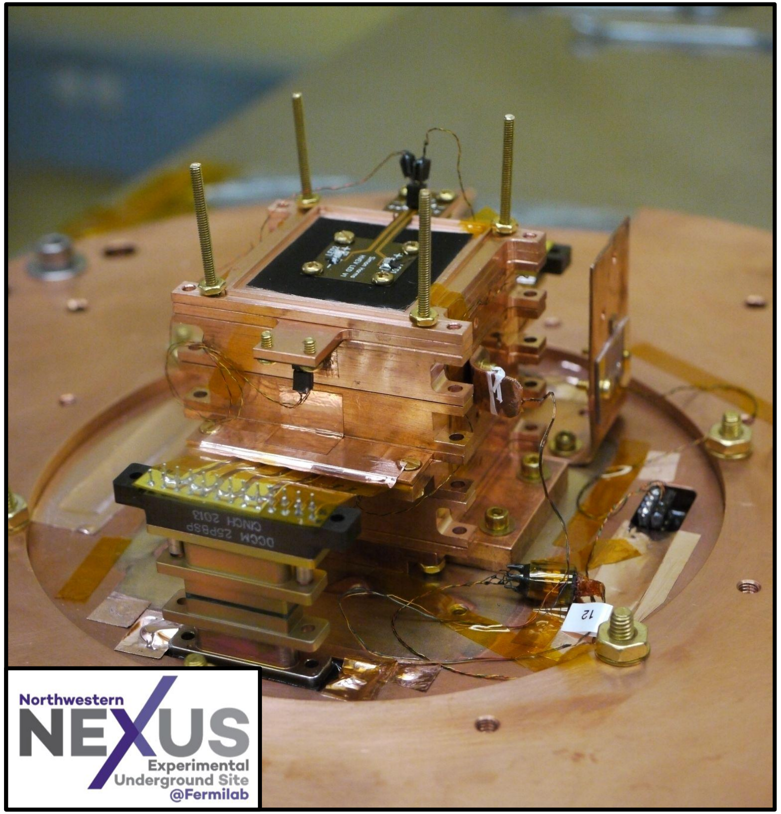
- Charges recombine on surface instead of propagating through E-Field
- Lose ~100% of NTL energy



# Reducing Backgrounds — HVeV Run 4




Dark Matter Search at the **N**orthwestern **Ex**perimental **U**nderground **S**ite (225 m.w.e)

Boxes with LEDs (used for calibration)

New light-tight copper housings!

- Attempt to reduce IR backgrounds
- Avoids scintillating materials