Investigating Compton steps in SuperCDMS Si HVeV detectors

On behalf of the SuperCDMS collaboration

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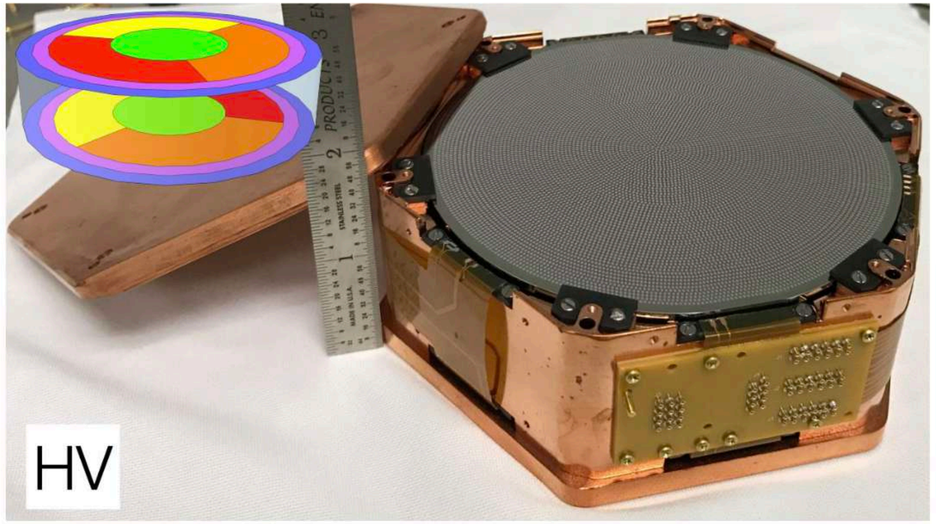
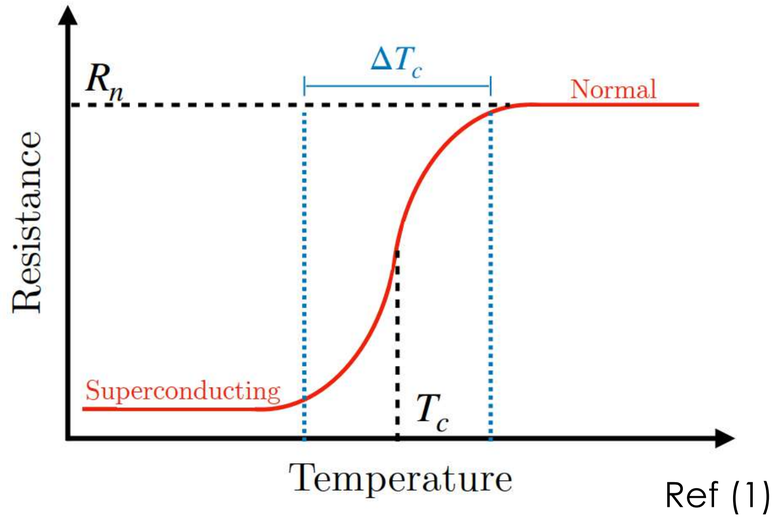
SuperCDMS @ SNOLAB

- **Direct detection Dark Matter (DM) search experiment**
- **Focuses on DM candidates with masses ≤ 10 GeV/c^2**
- **Detectors: Cryogenic Ge (1.4 kg each) and Si (0.6 kg each) calorimetric detectors**
  - HV detector: **Low threshold detector**
  - iZIP detector: **Low background detector**
- **Sensors: Ionisation and phonon sensors**





Ref (1)

Detection mechanism

Energy deposition from particle interaction creates e^-h^+ pairs and primary phonons.

→

Drifting of e^-h^+ pairs in the crystal due to bias voltage creates Luke phonons

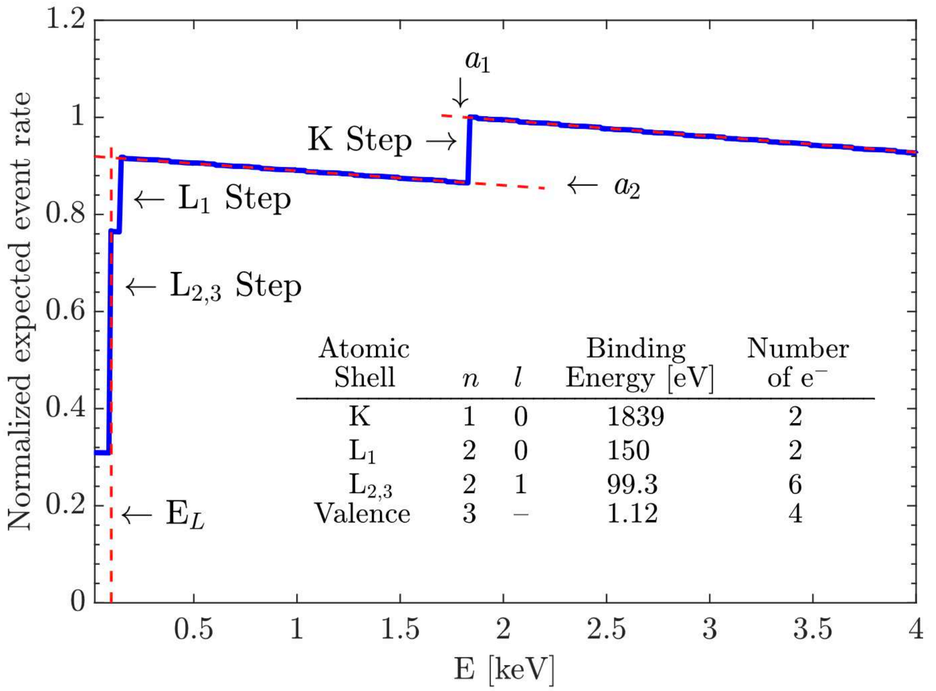
→

Phonons get detected by Transition edge sensor (TES)

Ref (1) : M. Wilson. 'A new search for low mass dark matter…', https://supercdms.slac.stanford.edu/dissertations

Compton steps for Energy Calibration

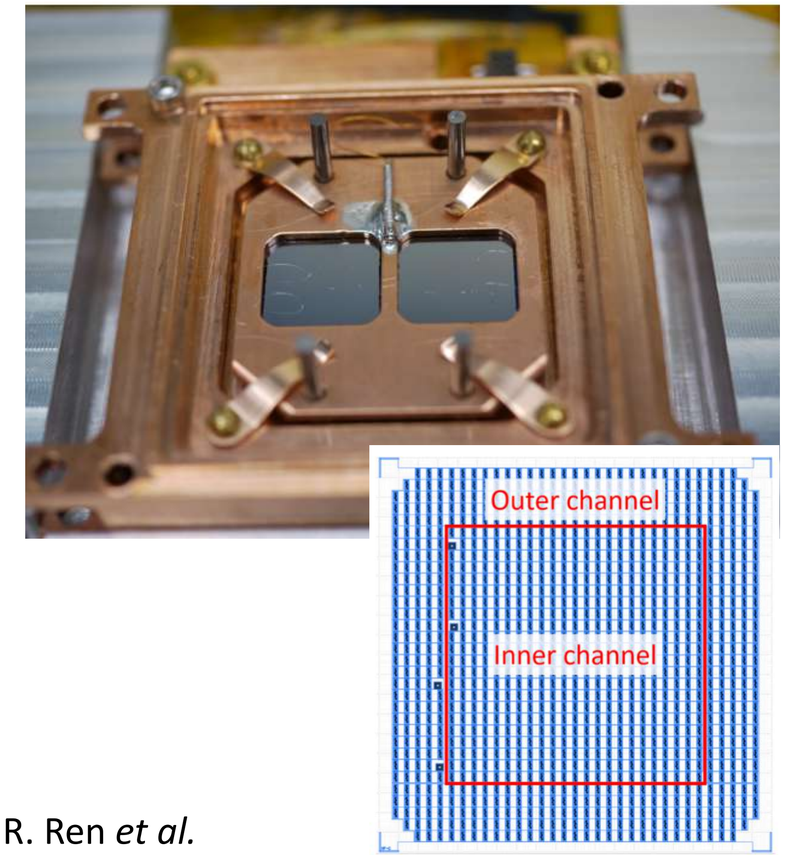
- Low energy calibration ~ O(keV) is important for low mass dark matter search
- Unlike Ge detectors, Si lacks activation lines suitable for low-energy calibration
- Si K shell and L shell Compton steps can be utilized
  - K shell: 1.8 keV
  - L shell: 0.15 and 0.1 keV
- The scattering cross section for the Compton process decreases below the atomic binding energies, and forms Compton steps



Ref: K. Ramanathan et al
Phys. Rev. D 96, 042002 (2017)

HVeV Detectors

- Si HV ⟶ Si HVeV (High Voltage electron-Volt resolution)
- Gram scale detector, excellent energy resolution (O(eV)) , easier to understand
- Sensitive to single charge excitation, O(eV) scale threshold with O(100 keV) scale dynamic range
- Sensitive to sub-GeV dark matter particles



Ref: R. Ren *et al.*
Phys. Rev. D 104, 032010 (2021)

Data sets & analysis flow

~2 eV optical photons

HV LED data

Identify individual eh pair peaks

Perform energy calibration

^{137}Cs data

Identify the photo peak, Compton edge, and **Compton step (K shell, L shell)**

Verify step position using cross calibration obtained from optical photons

~662 keV gamma

Energy estimators

OFL (Optimum Filter Limited)

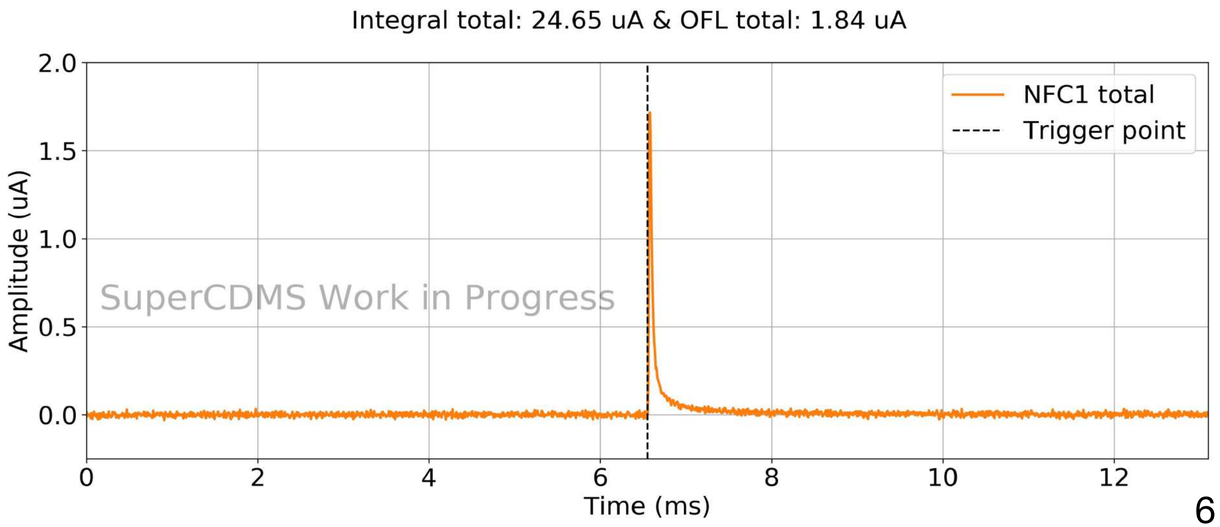
Pulse-amplitude energy estimator

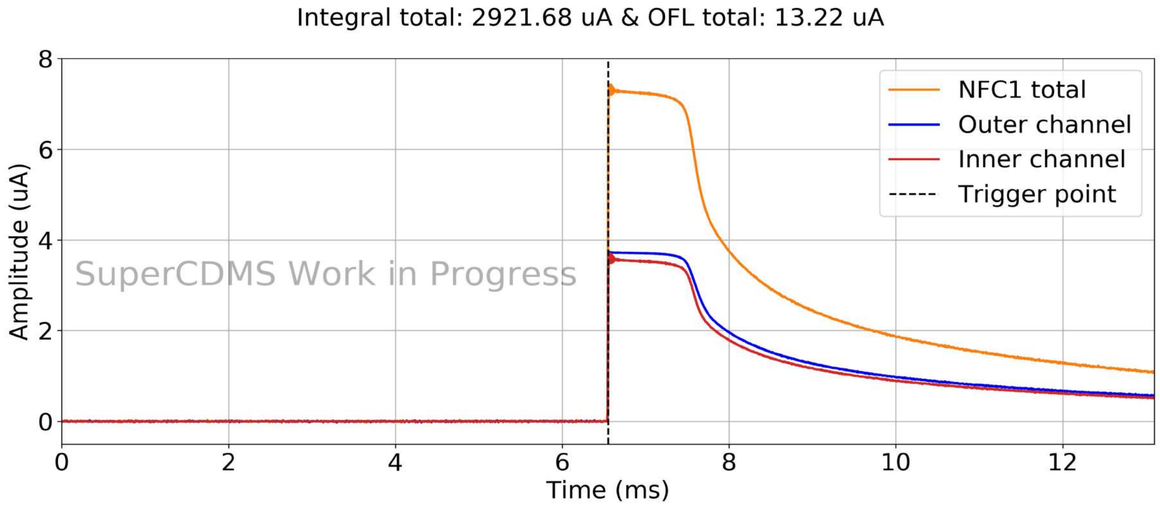
1. Fit triggered signal pulse with a template to determine its amplitude
2. Good energy resolution
3. Fails for saturated pulses

Integral

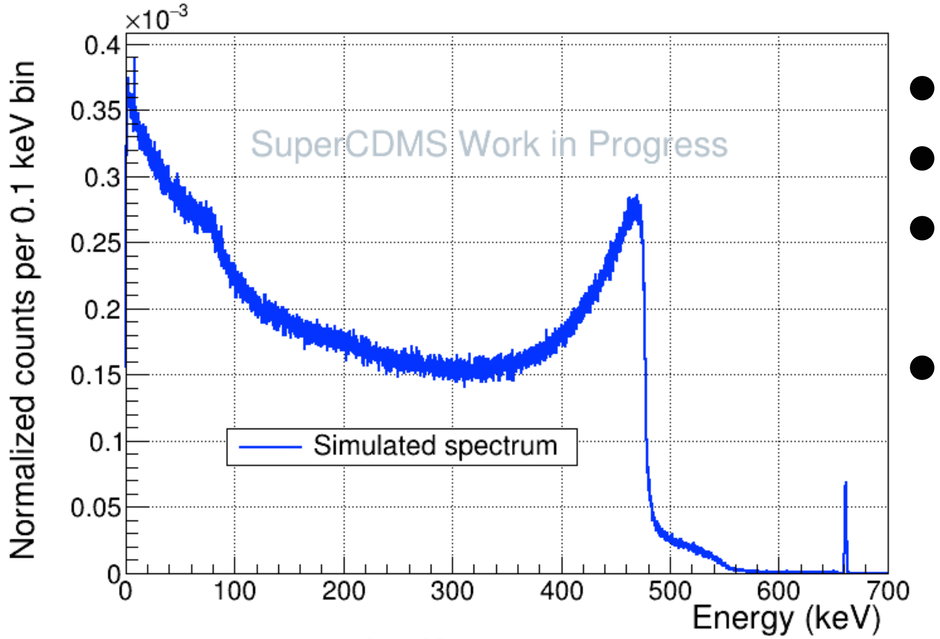
Pulse-integral energy estimator

1. Determine the area of the pulse inside the analysis window (~13.1 ms)
2. Effective for saturated pulses also
3. Less sensitive / poorer resolution in comparison to OFL method



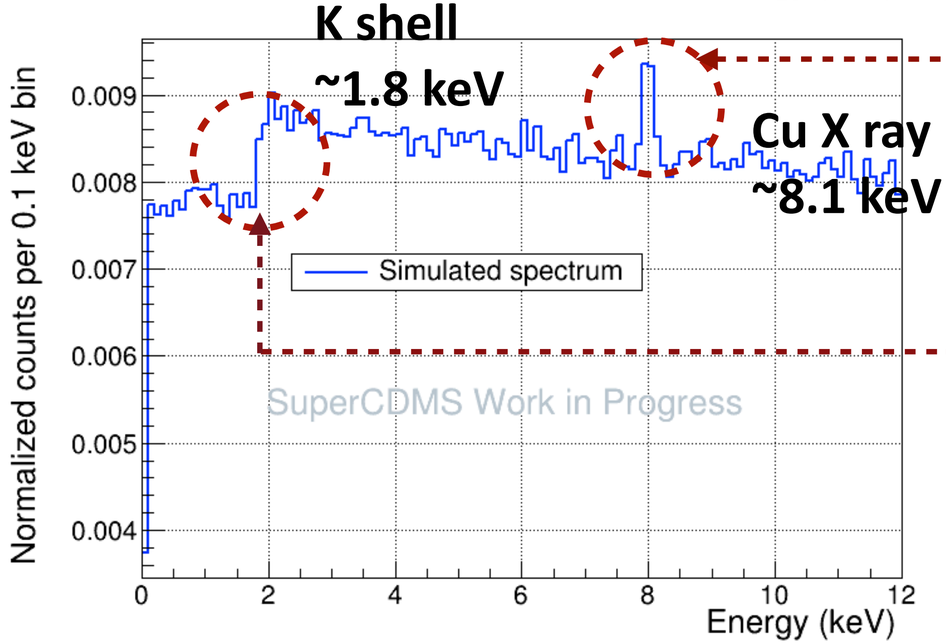


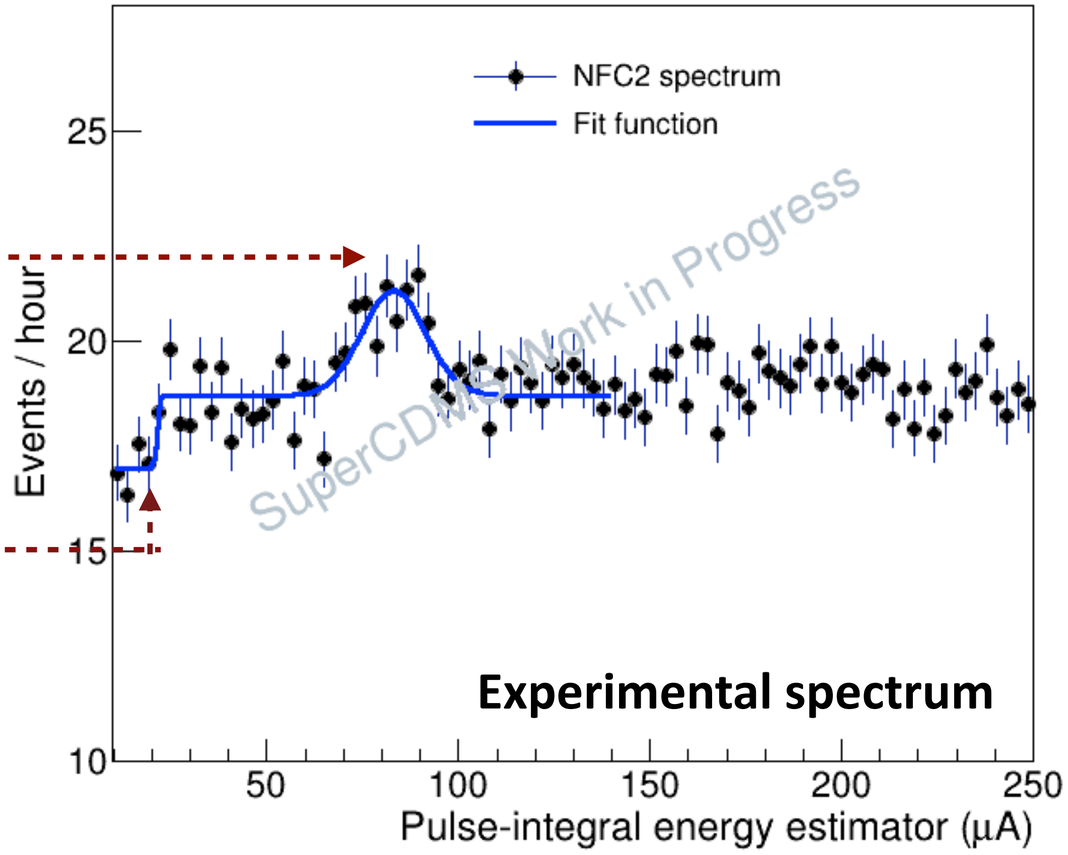
Si K-shell Compton step (^{137}Cs 0V spectrum)



- Cu X-ray peak is visible in ^{137}Cs 0V spectrum
- A step like structure can also be seen
- The step (if assumed to be K step) agrees with Cu X ray peak

- K shell step?? Use cross-calibration with optical photons

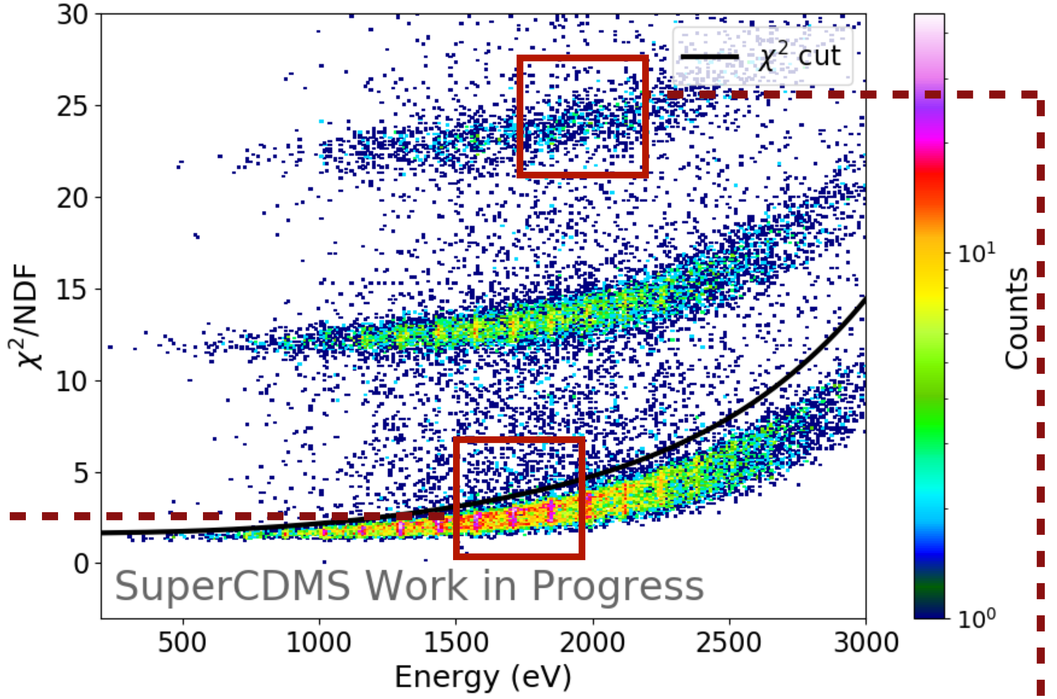


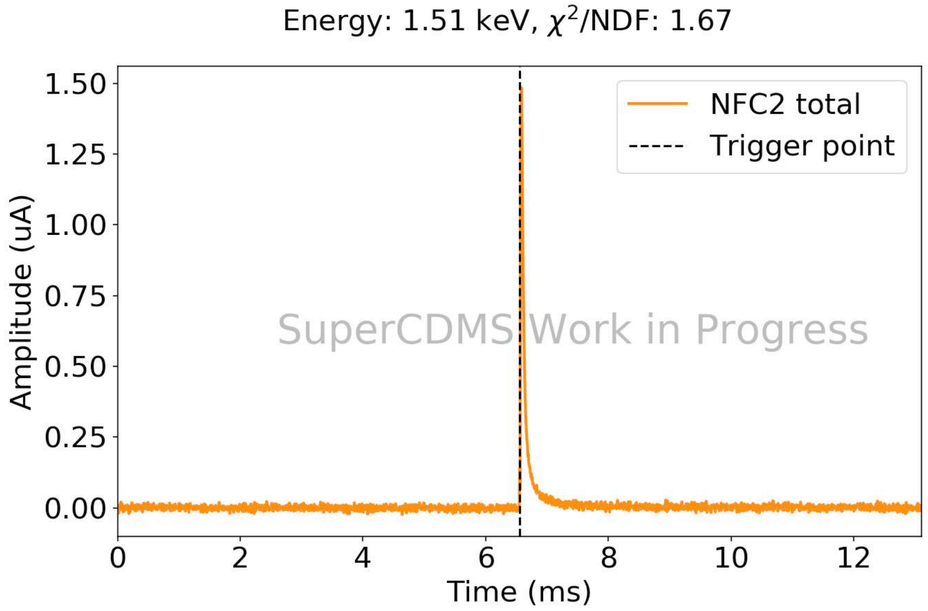


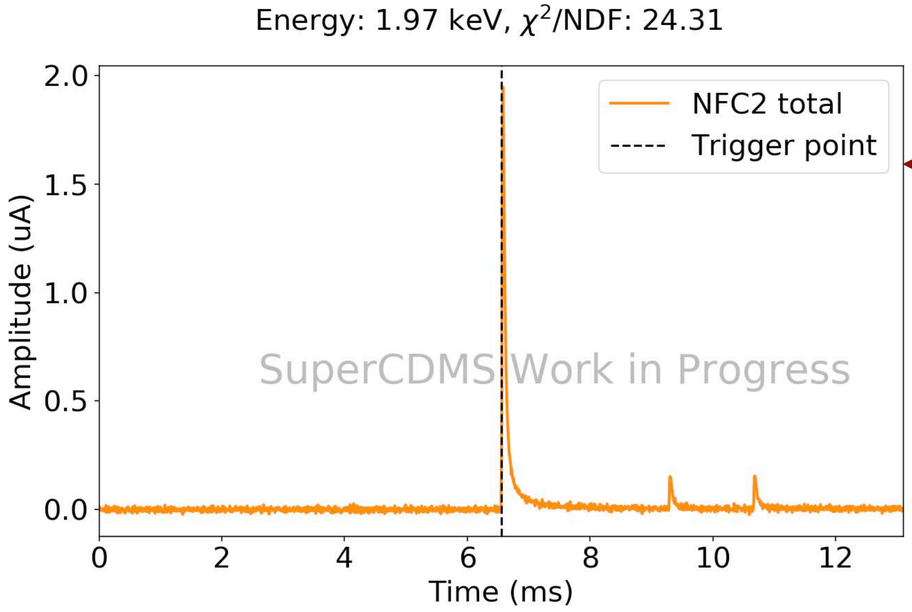
LED 150V spectrum

Data filtering

- An energy dependent OFL Chi2 cut is used to remove pulses that are not consistent with single phonon pulses
- Events with bad pulses are mostly pile-up events

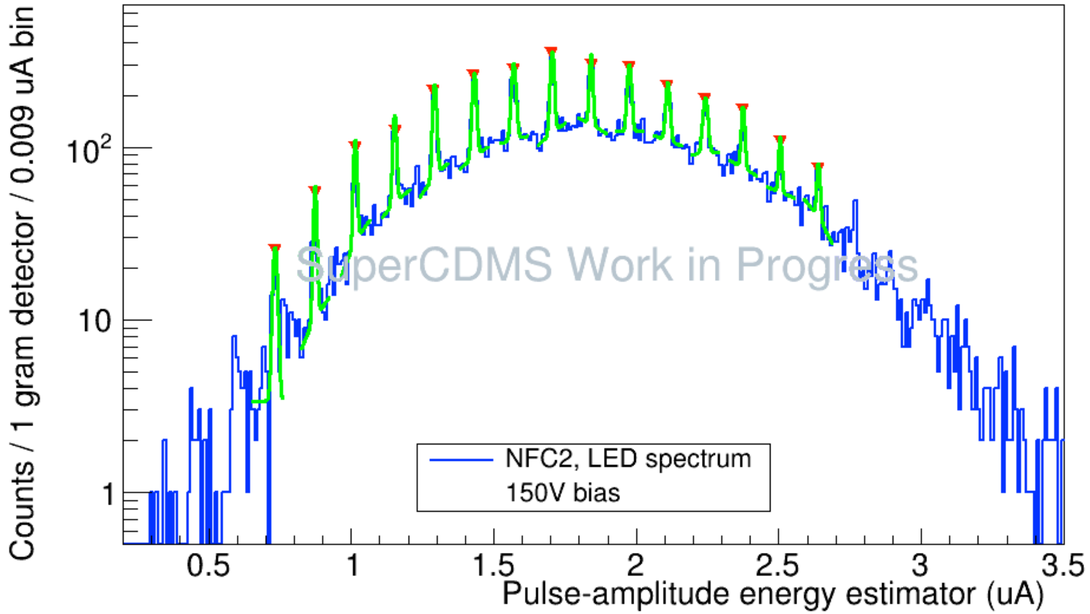


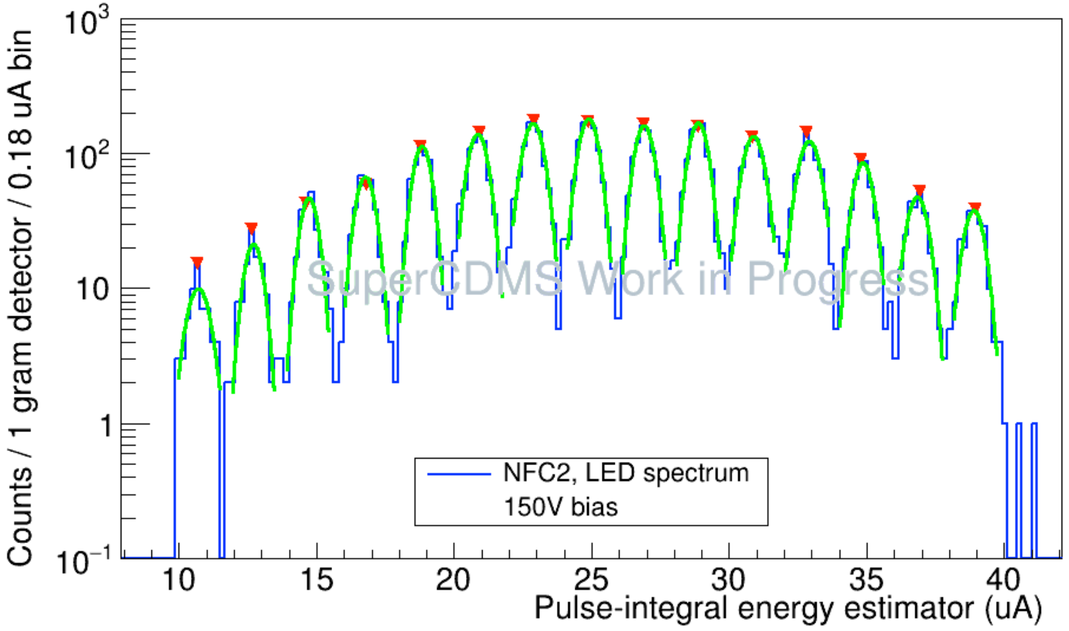


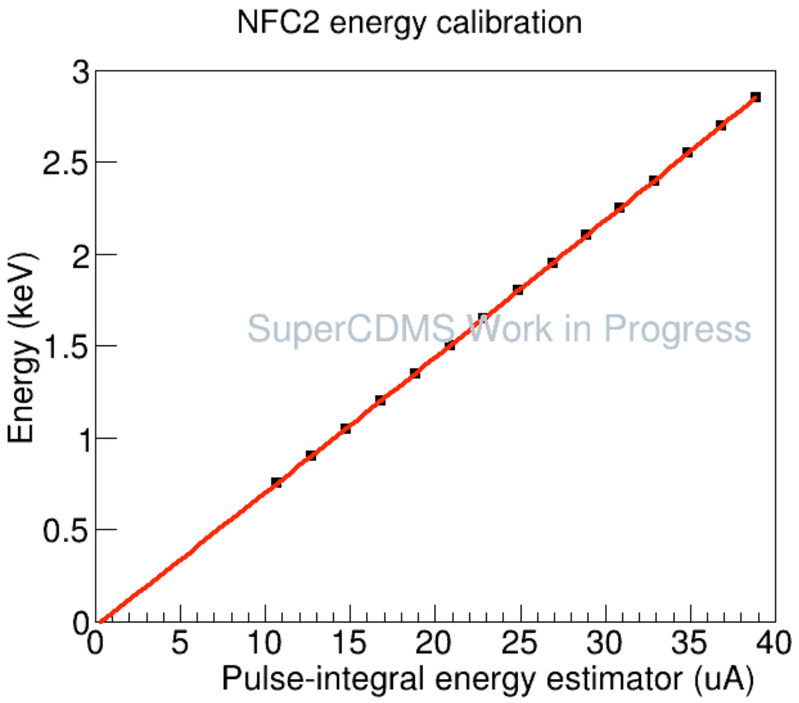


Energy calibration

- Prominent eh peaks in OFL spectrum
- Select events in OFL spectrum within +/- 3 sigma around the eh peaks
- Look at the Integral distribution of selected events
- Use eh peaks in Integral spectrum for energy calibration



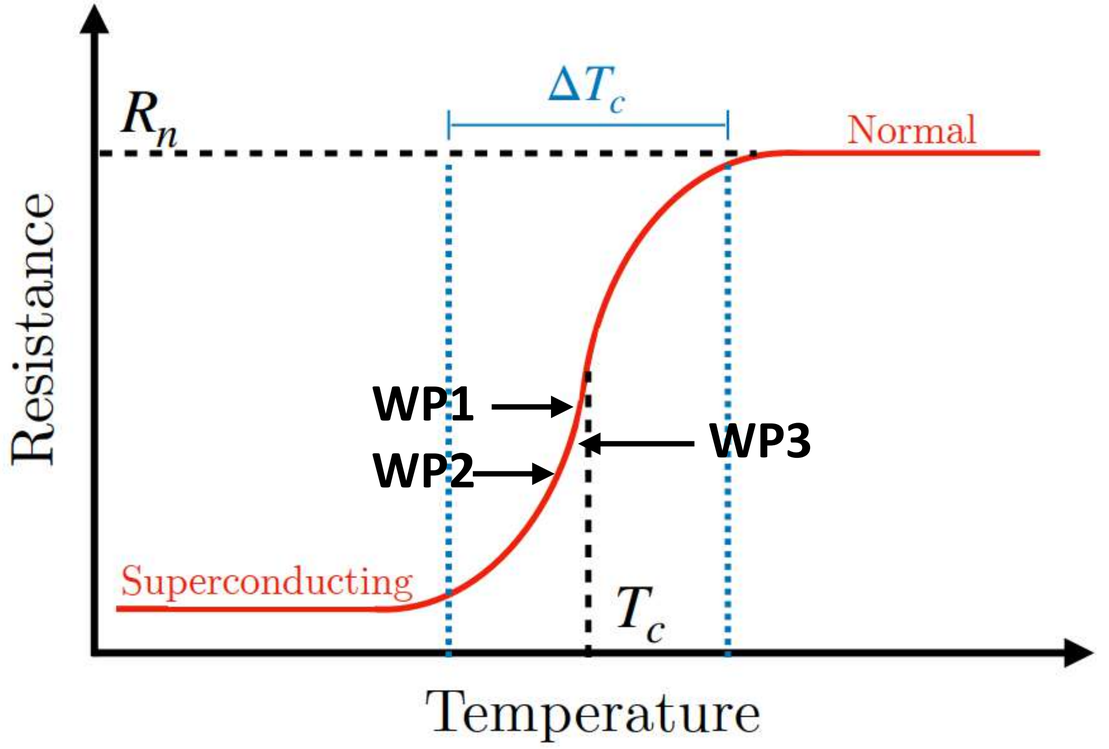




Working Point (WP) and Current scale

- **Final goal is to apply LED calibration to Cs spectrum to verify step positions**
- **Current scale changed between Cs and LED spectrum!! (addition of LED box)**

- Change in WPs changes the current scale
- **A scan on the WP is done to get the closest current scale between Cs and LED spectrum**
- In addition to that a **linear WP correction** is applied to match the current scale



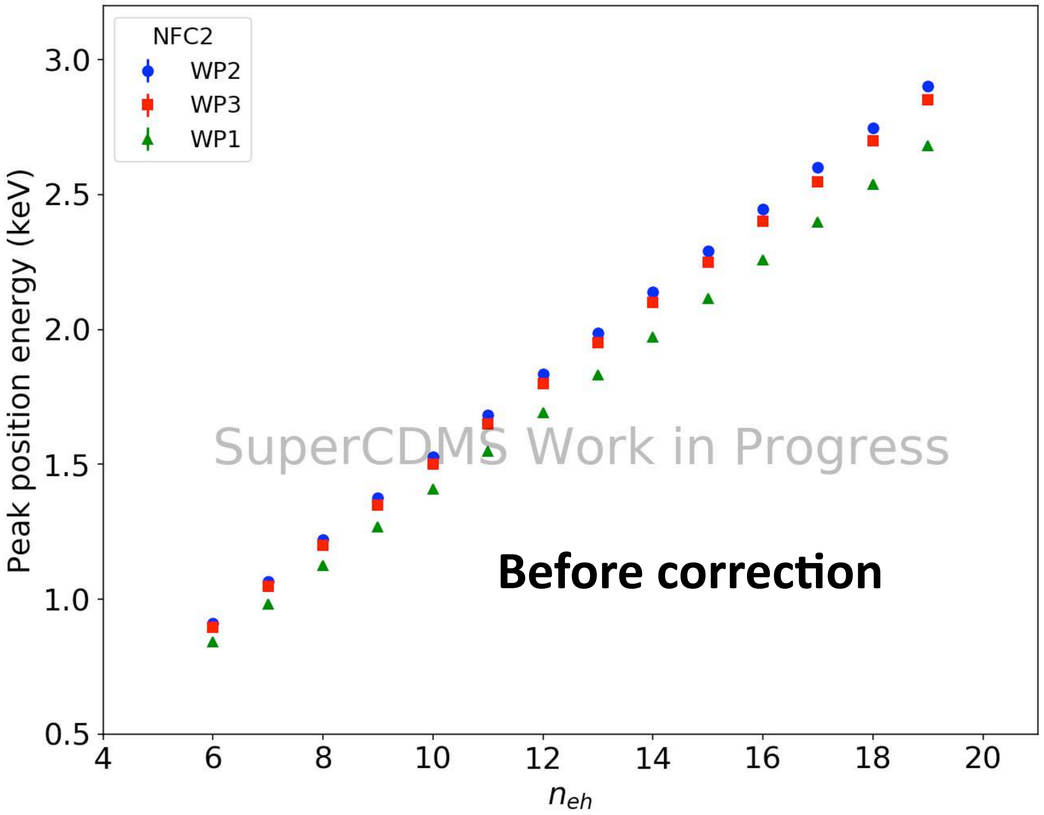
Ref (1)

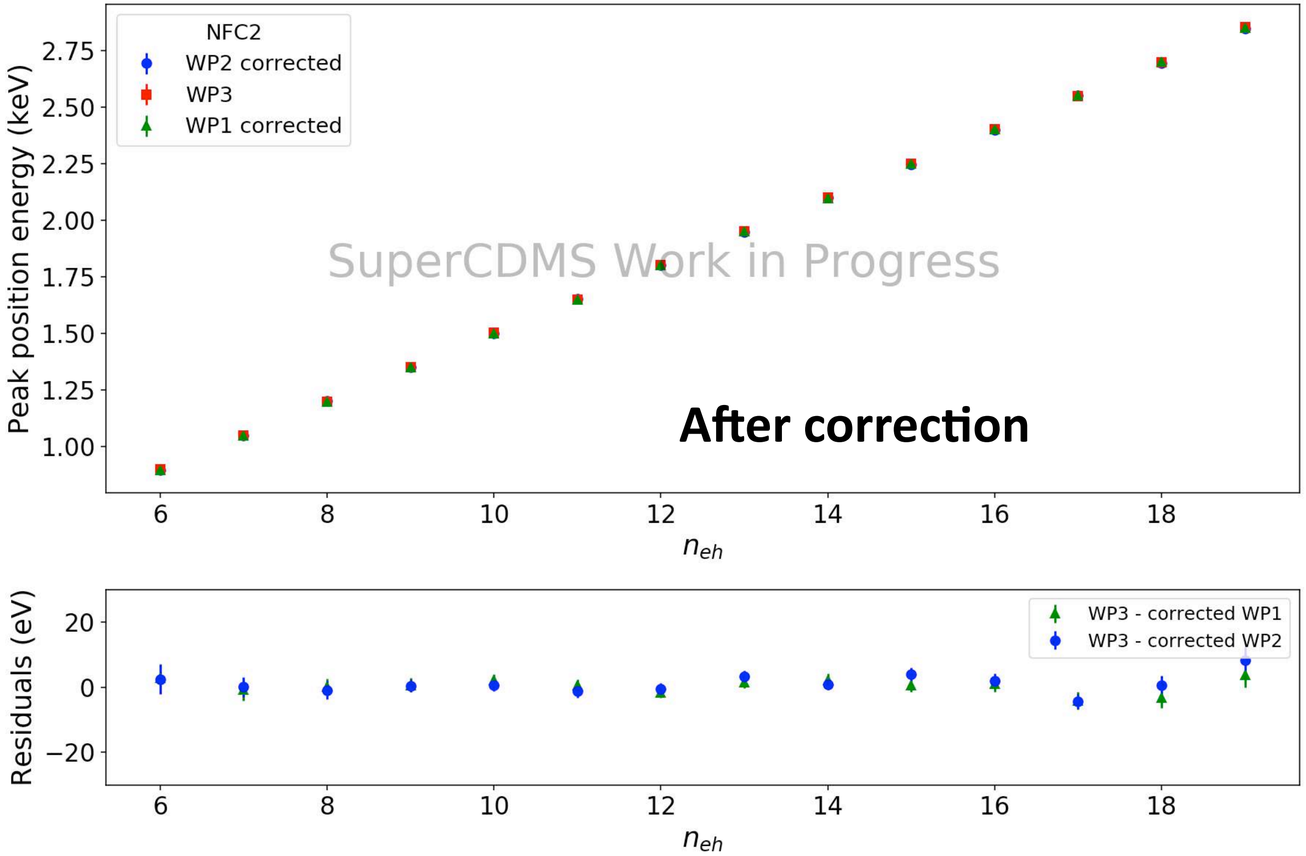
Is linear correction sufficient?

Ref (1) : M. Wilson. 'A new search for low mass dark matter…', https://supercdms.slac.stanford.edu/dissertations

Linear WP correction

- The differences in energy values for each eh peak among different WPs estimate the differences in the current scales
- The linear WP correction works fine with deviations well below 1%



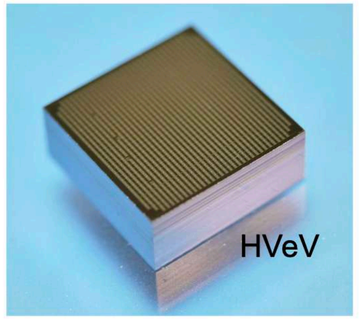


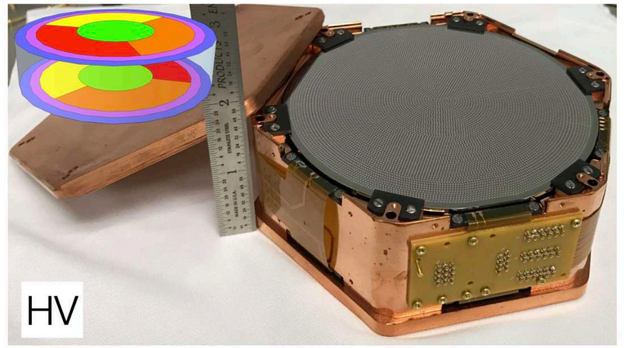
Summary

- A step feature and Cu X ray peak in ^{137}Cs 0V spectrum can be seen in Si HVeV detector
- An energy calibration with LED photons is performed up to the keV scale
- A linear WP correction works well to match the current scale between Cs and LED spectrum

Outlook

- Immediate goal is to apply linear WP correction to LED calibration and verify the K shell step (1.8 keV) in Cs 0V spectrum
- Analysis of L shell Compton step is ongoing
- Ultimate goal is to use Compton steps for low energy calibration in big Si HV detectors at SuperCDMS SNOLAB





Thank you

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