Radial Fiducialization In CDMSlite

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Abstract

The Super Cryogenic Dark Matter Search (SuperCDMS) searched for direct evidence of dark matter in the form of Weakly Interacting Massive Particles (WIMPs) by measuring charge and phonon energy in cryogenic Germanium crystals. In the CDMS low ionization threshold experiment (CDMSlite), a large electric potential was applied to one face of the detector to convert charge into additional phonon energy in a process called Luke amplification. Without explicit charge information, accurate event reconstruction through phonon signals is necessary both to reject high-radius surface events (reducing background), and to remove regions of reduced Luke amplification at high radius due to field non-uniformity. The shape of the phonon pulses and the geometry of the sensors allow for an approximate radial reconstruction based on the relative sharpness of the rises of pulses in different sensors. This poster discusses the CDMSlite experiment and how the pulse information is used to extract the information necessary to achieve the most sensitive measurement.

Motivation

- Dark matter may occasionally interact with normal matter, and deposit kinetic energy through a nuclear recoil
- In Ge crystals, nuclear recoils leave energy in the form of heat (phonons), and charges.
- CDMSlite amplifies the phonon signal by drifting charges freed in initial interaction through electric potential (Luke amplification)
- Charges colliding with the crystal deposit their kinetic energy as more phonons
- Non-flat E-field (Figure 1) leads to some charges not experiencing full potential, and receiving less Luke amplification (Figure 2)
- This is a radial dependent effect. High radius events (Figure 3) have energy reconstructed improperly and must be removed.

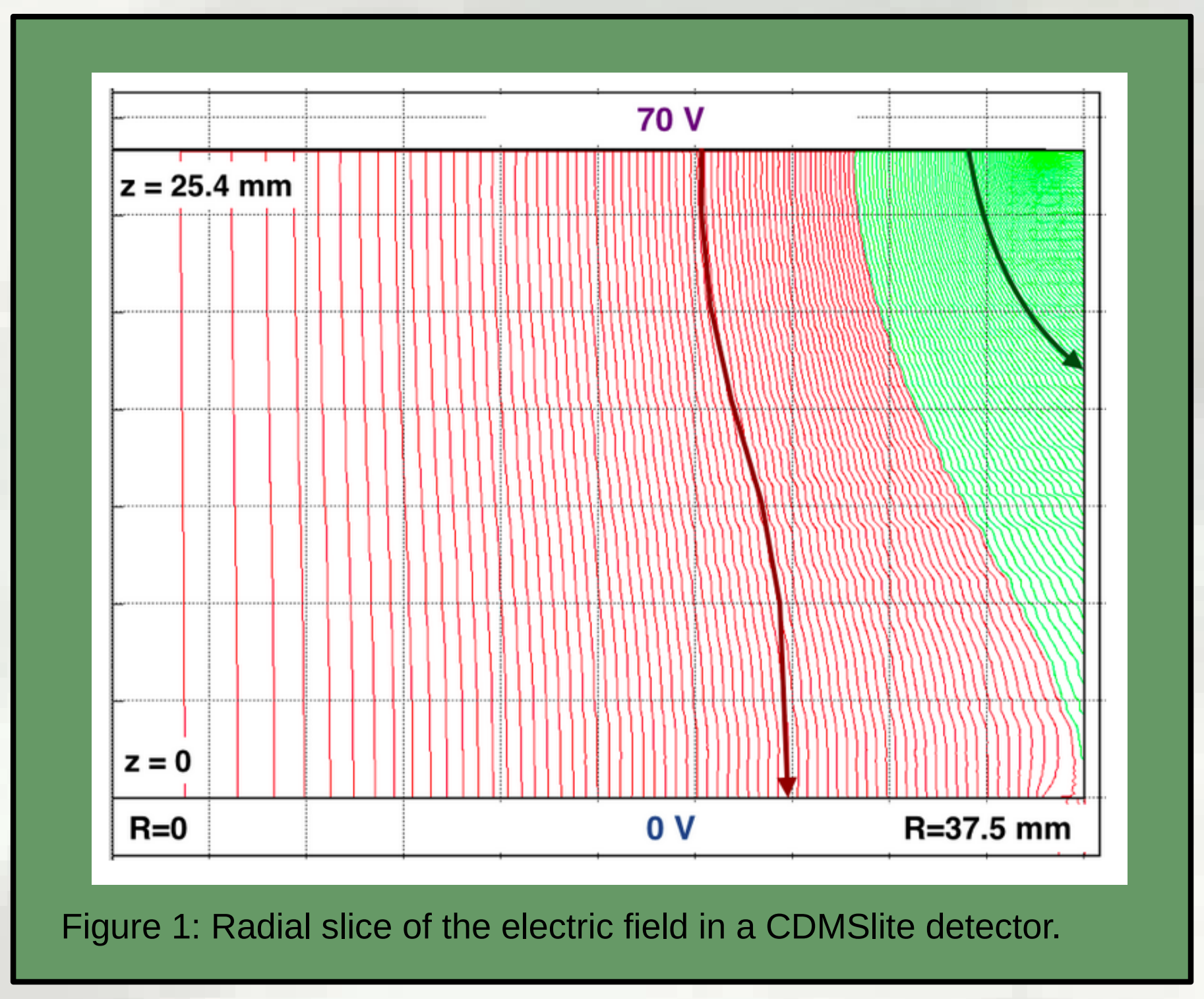

Figure 1: Radial slice of the electric field in a CDMSlite detector.

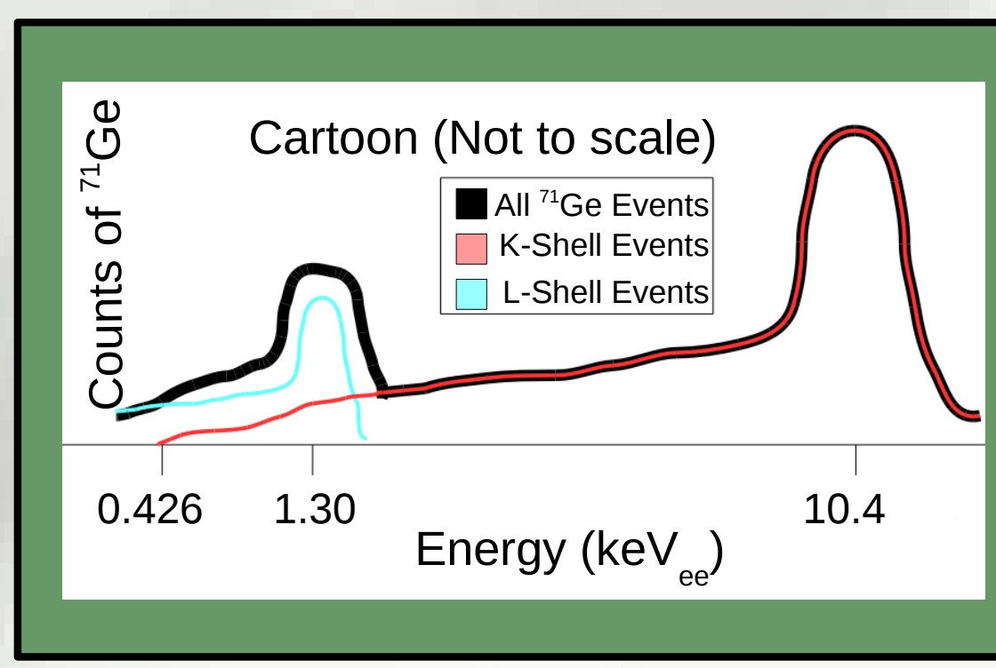

Figure 2: Cartoon of the smearing of calibration peaks due to reduced Luke Gain

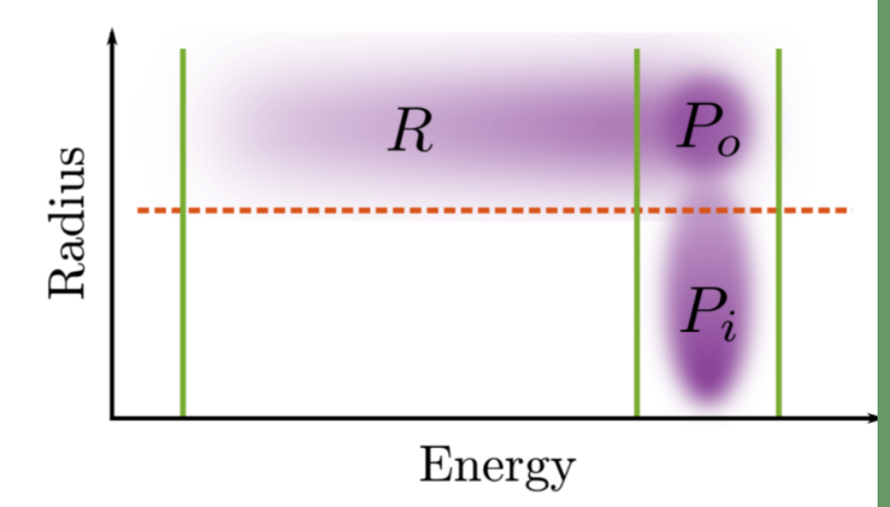

Figure 3: Reconstructed distribution of peak events in radius and energy

Extracting Radius from Pulses

- There are four sensors on the surface of the crystal
- Layout of the sensors allows for position reconstruction (Figure 4)
- Pulse shapes contain information about closeness to a particular sensor (Figure 5)
- Pulses with a sharp rise occur very close to a sensor
- Pulses with a slow rise occur further away.
- Fit with two templates to capture this information
  - First template created by averaging pulses
  - Second template created by averaging residuals after changing the sign of those with negative peaks so that they are positive

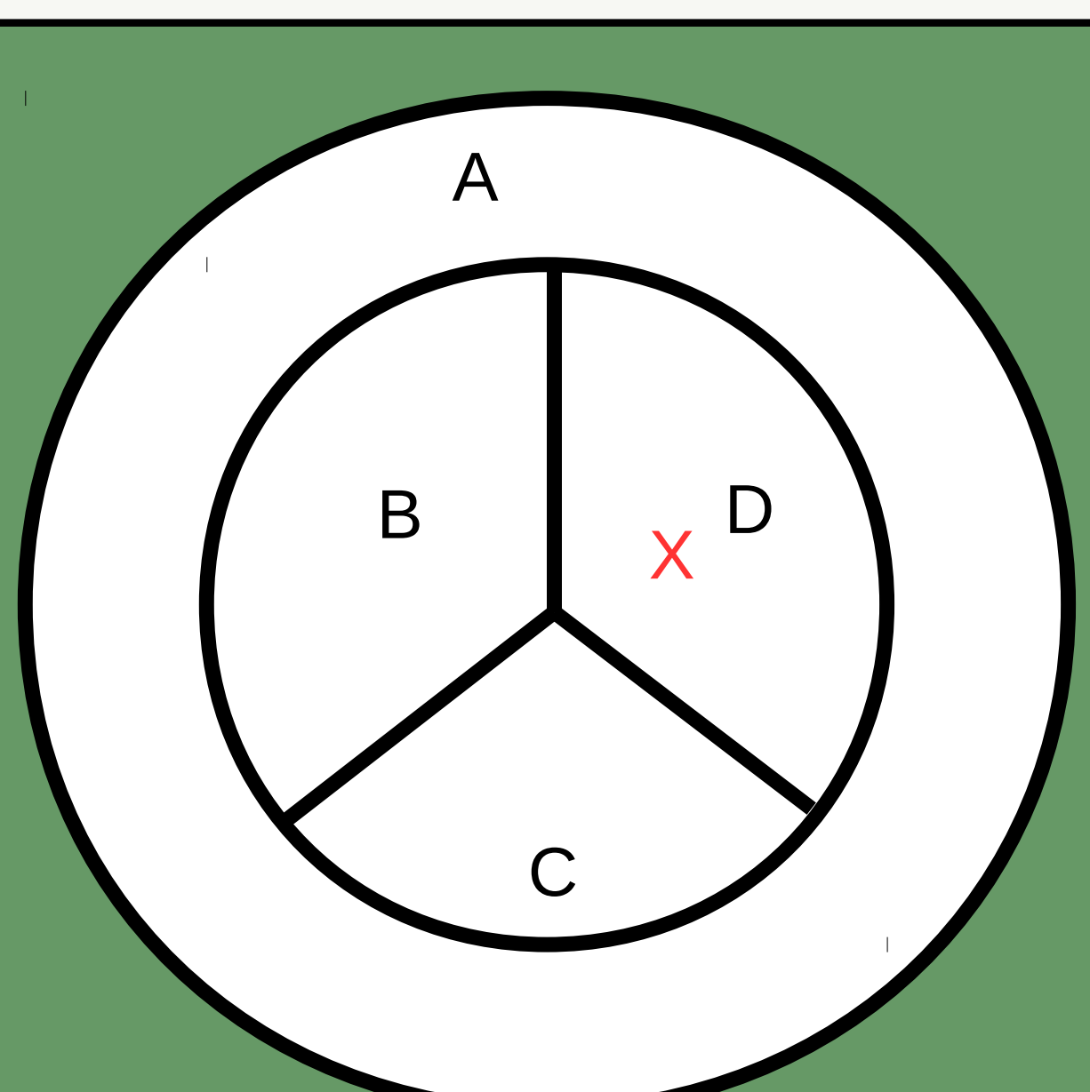

Figure 4: Sensor layout on the surface of a SuperCDMS germanium crystal. Black letters mark the four sensors, the red mark denotes an example event location.

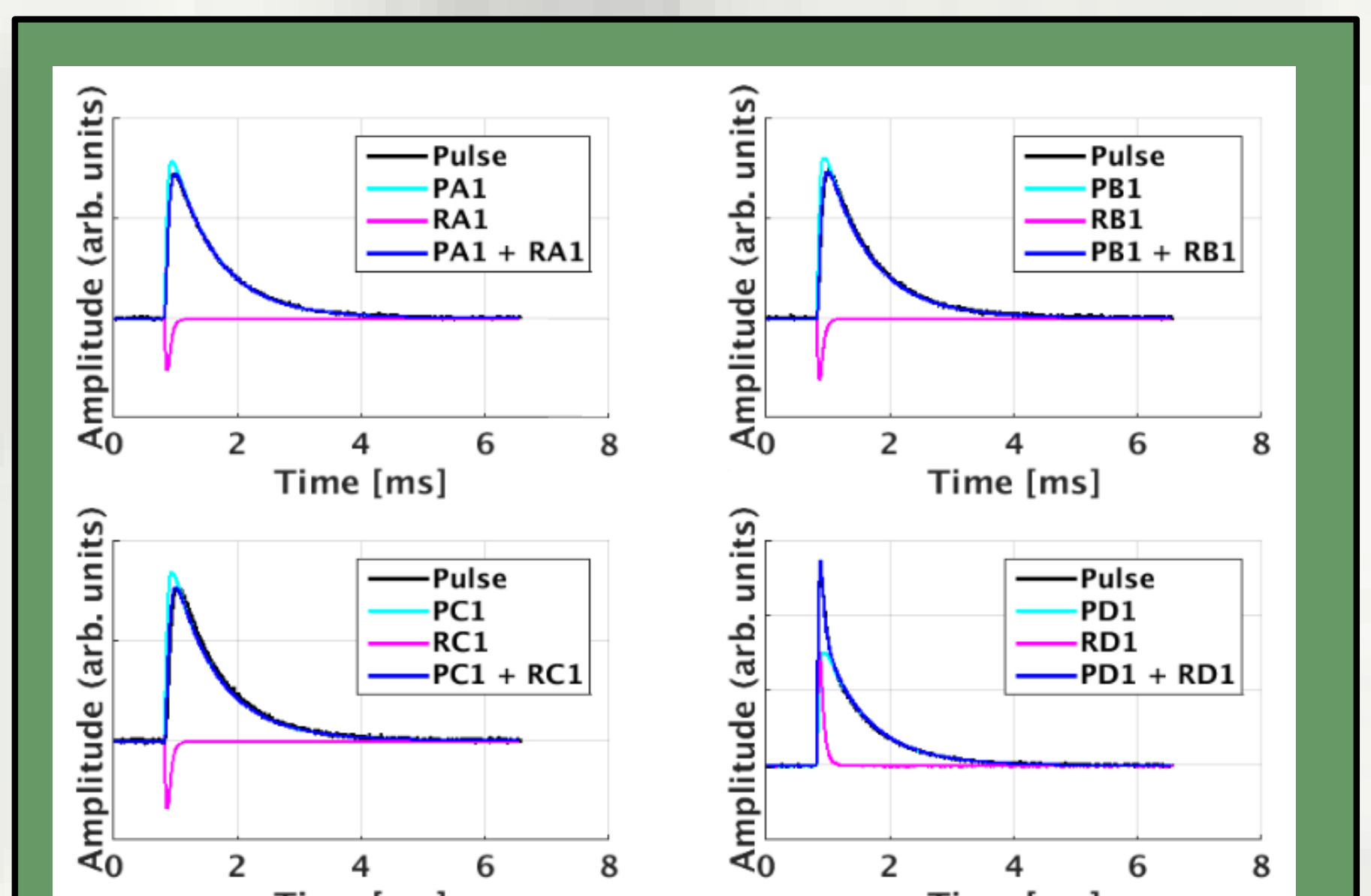

Figure 5: Phonon pulse shapes in the 4 sensors for an event near X. Note the slow rises in channels A, B, C, and quick rise in D.

By comparing the amplitude of the 'residual' template *R* between channel *A* and the sharpest rising ('primary', *prim*) inner channel as well as the start time *t* (with some scaling factor *c*) of the two we can extract a radial parameter *r*:

$$r \equiv \left[(R_A + c \cdot t_A) - (R_{prim} - c \cdot t_{prim})\right] \mathrm{correction}(\theta)$$

where refers to the angle of the reconstructed position in the x-y plane.

Setting a Radial Cut

- In CDMSlite Run 2, the radial cut was set by eye to remove the reduced Luke Gain events (Figure 6), and a hardware-related low energy noise blob that was localized to outer radius.
- Efficiency of the radial cut estimated in two steps
  - “Energy Efficiency” (Fraction of events that receive full Luke Gain) (Figure 7)
  - “Peak Efficiency” (Fraction of the events with full Luke Gain that survive radial cut)
- Energy efficiency determination: ^{71}Ge (produced by n-activation with 11.4 day half-life) produces 10.4 keV events. Can determine distrobution of the events with this half life showing up at lower energy.

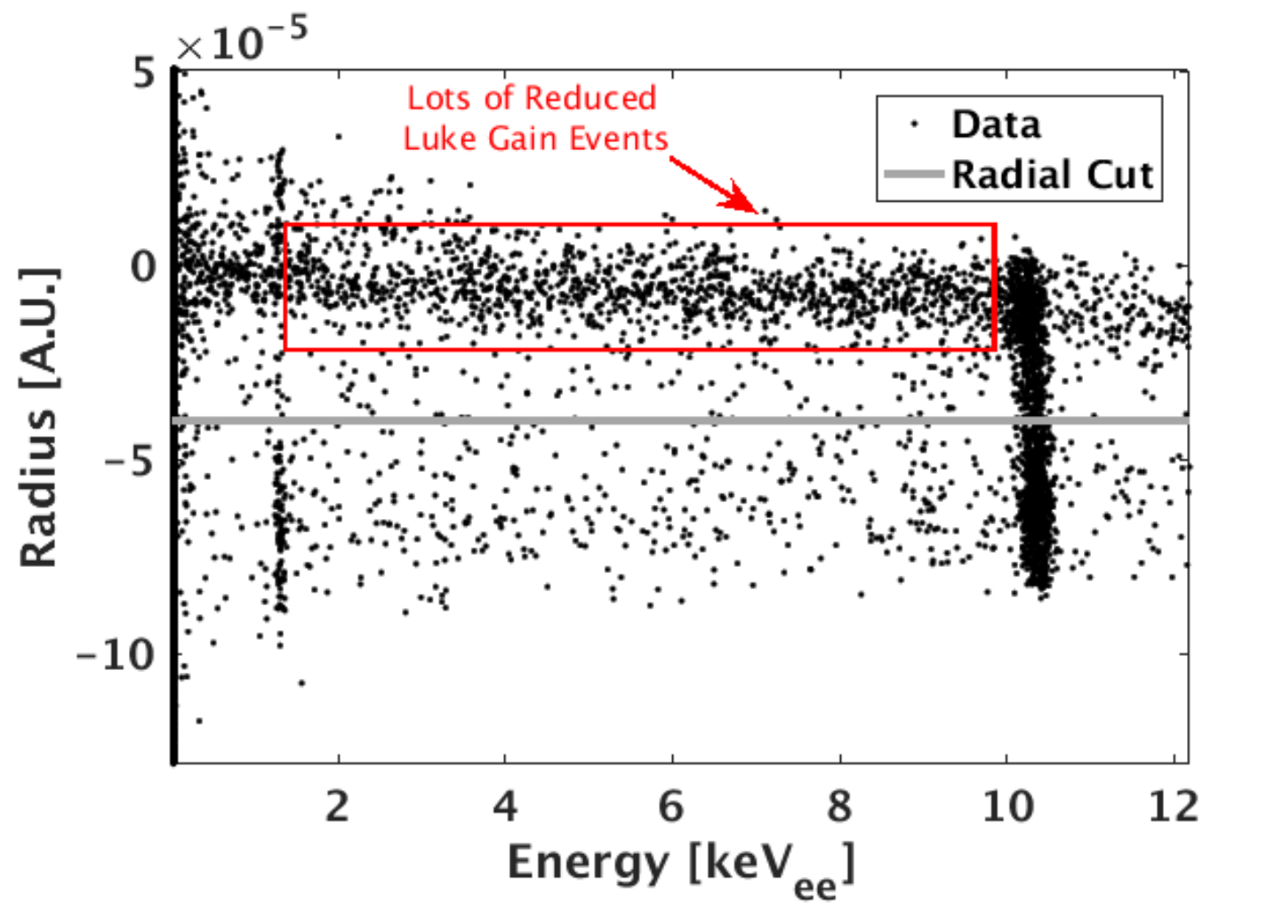

Figure 6: Radial Parameter vs. Energy for CDMSlite. Note the vertical lines at 1.3 and 10.4 keV originate from the decay of ^{71}Ge. The overdensity of points around 0 in the radial parameter are events on the edge of the detector, where events at the bottom of the plot are bulk events.

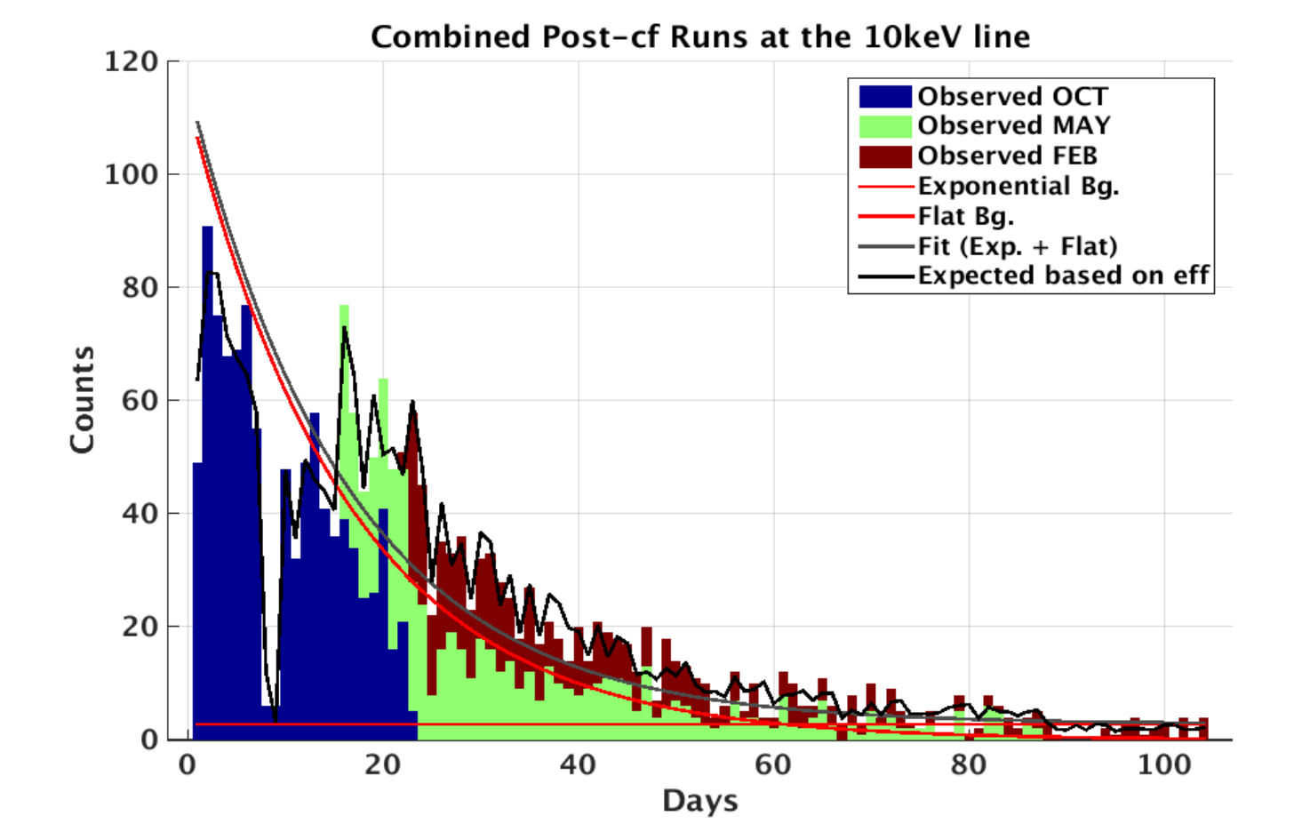

Figure 7: Fitting an exponential to the event count as a function of time reveals the amount of 71Ge in different parts of the parameter space, allowing us to find the Energy Efficiency.

Simulation Using Pulse Templates

- The Peak efficiency may depend on the energy, but there are not enough low energy events to estimate this efficiency
- Solution: Generate artificial pulses by assuming the underlying pulse shape distribution is energy independent (Pulse Simulation)
  - Convert all events in 1.3 keV calibration line to quasi noise-free pulses using two template fit
  - Scale these pulses to the desired energy
  - Add real noise traces, then extract energy/radial parameter as from real data
- This pulse simulation allows us to determine radial resolution and cut efficiency as a function of energy (Figure 8)
- Future Plan: Use pulse simulation to define an energy dependent radial cut based on expected background leakage from high radius into the inner part of the detector (Figure 9)

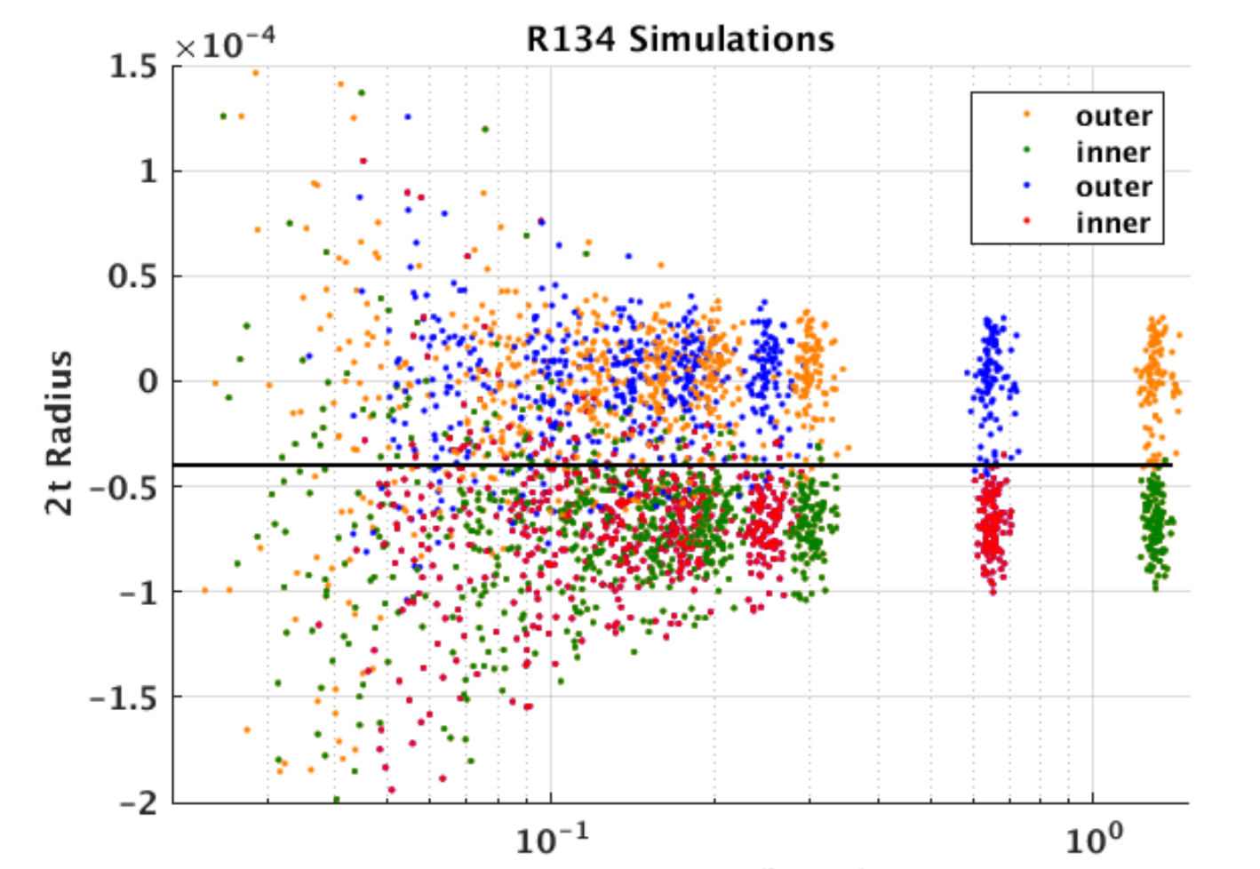

Figure 8: Results of simulations allow us to determine the efficiency of a radial cut as a function of energy.

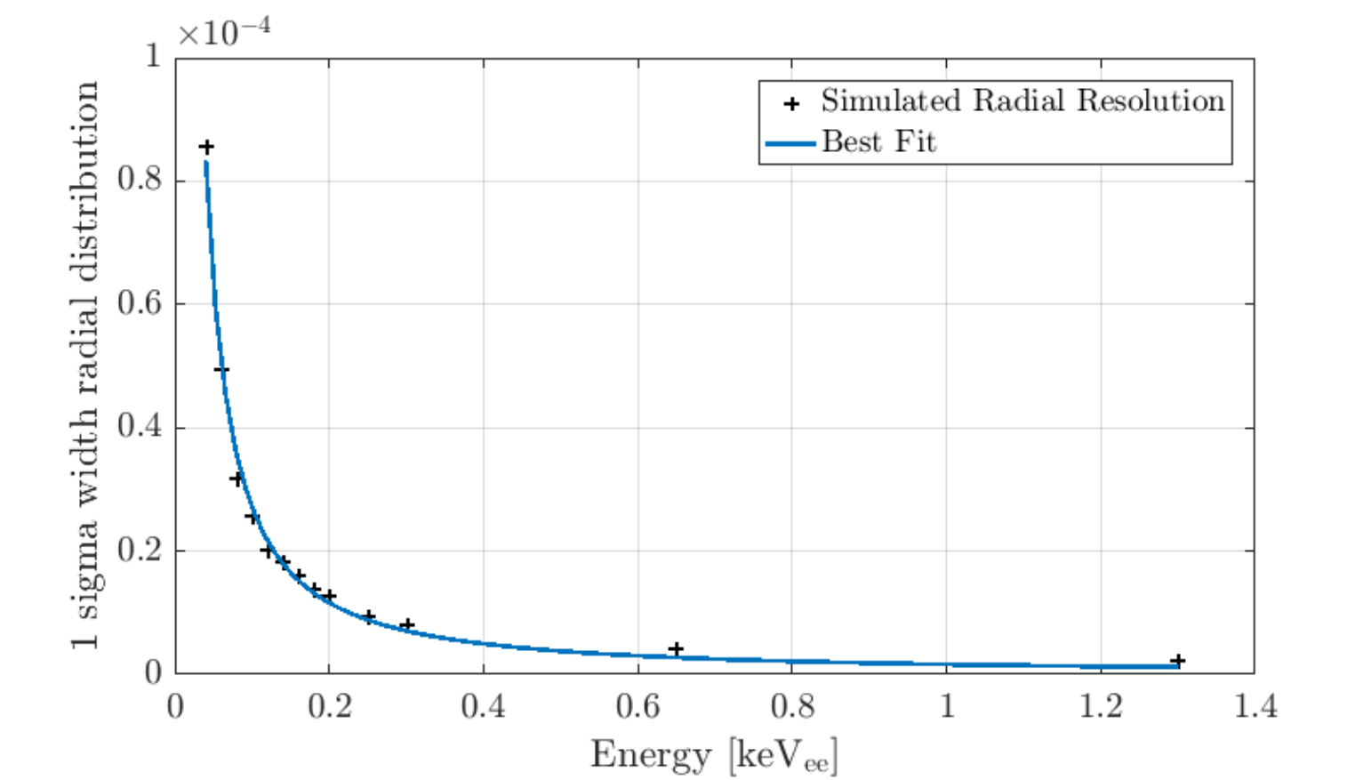

Figure 9: Radial resolution as a function of energy follows a negative power law, and can be used to set a leakage passage fraction

Conclusions

- High radius events in the detector present a background because the energy is improperly reconstructed
- Radial information extracted from a fit involving two templates enables the exclusion of these events
- Simulated events constructed from the templates can present a realistic radial distribution at any energy, and allow us to estimate the energy dependent efficiency
- This technique was used in the CDMSlite Run 2 analysis [1] and due to the cut reducing the background by a factor of ~ 5 new spin-independent WIMP-nucleon cross sections were excluded for WIMPs below ~6 GeV.
- The simulation techniques will be used again with the 3rd CDMSlite data set. The simulations can also be used to set an energy dependent radial cut based on leakage

Reference

1. SuperCDMS Collaboration. New Results from the Search for Low-Mass Weakly Interacting Massive Particles with the CDMS Low Ionization Threshold Experiment. Physical Review Letters, 116(7):071301, February 2016. doi:10.1103/ PhysRevLett.116.071301.