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Ionization collection in regions of distorted electric field in the CDMS ZIP detector

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Abstract

We present the phenomenology of ionization pulses for interactions close to the outer edge of the CDMS ZIP Detector and our current interpretation based on the distortion of the electric field in this region.

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1. Introduction

The Cryogenic Dark Matter Search (CDMS) Z-dependent Ionization and Phonon (ZIP) detector discriminates between those events that occur close to its cylindrical crystal surface and those events that do not by using an outer guard electrode (Q_{outer}) and an inner fiducial electrode (Q_{inner}). The ionization pulses for events occurring in regions of distorted or reduced electric field, such as close to the edge of the detector crystal or below the gap between Q_{inner} and Q_{outer}, exhibit complex phenomenology.

While these events are cut out of our physics analysis, it is important to check that we fully understand their origin. We consider ionization energy (charge) q_i collected on the inner electrode, and q_o, the ionization energy collected on the outer electrode. Plotting these two parameters normalized to the independently measured phonon recoil energy allows us to examine charge collection in an energy-independent way.

"Q_{inner} Events" are events for which q_i is the only non-trivial charge. The complementary "Q_{outer} Events," are excluded from our physics analysis.

For an event of total ionization energy, q_{tot}, it turns out that we find three other interesting features, which we also exclude from our analysis (Fig. 1):

- Ear Events: Events with negative q_i and positive q_o
- Shared Events: Events with positive q_i and positive q_o, such that $q_i + q_o = q_{\text{tot}}$
- Funnel Events: Events with positive q_i and positive q_o such that $q_i + q_o < q_{\text{tot}}$.

2. Study of the Ear events

We can simulate the Ears by considering charges that originate on Q_{outer} and terminate on the detector crystal's outer cylindrical surface. The image charge seen by Q_{inner} due to such a trajectory is negative. Inspired by Broniatowski [1], we use the method of Ramo [2], which is equivalent to Green's Reciprocity Theorem, to calculate the image charge. Following this method, we use two normalized, unit-less "weighting potentials;" one for each of the electrodes—Q_{inner} and Q_{outer}. These "potentials" describe how a moving charge will induce an image charge on the respective sensing electrode.

The image charge induced on a given conductor due to the motion of a charge is proportional to the difference in that conductor's weighting potential evaluated at the initial and final points of the charge's trajectory.

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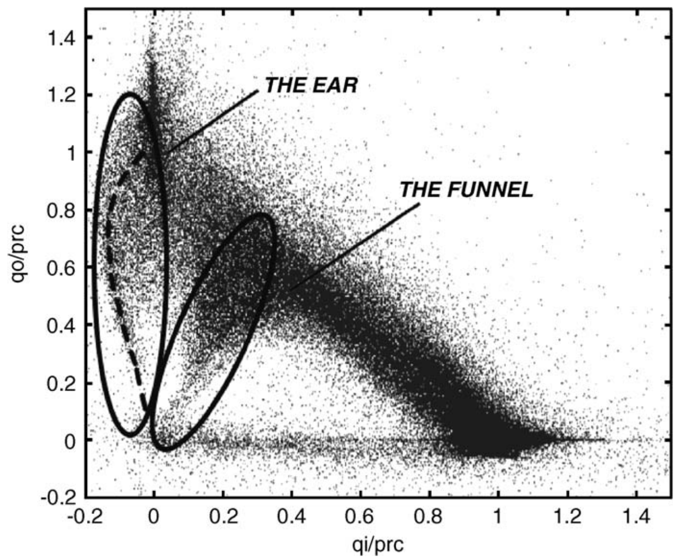

Fig. 1. Ionization pulse heights for Q_{inner} and Q_{outer} normalized by phonon recoil energy. Dashed line shows the result of the simulation described in text.

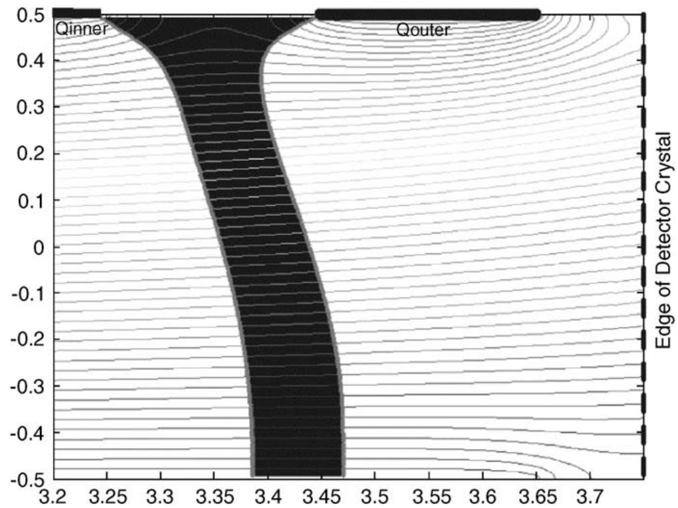

Fig. 2. Electric field lines traced from gap-side edges of Q_{inner} and Q_{outer} define the boundary of the region we believe causes the funnel. Equipotential lines describe the distorted electric field.

This approach is very successful in describing the Ear as shown by the dashed line in Fig. 1.

3. Study of the funnel events

In contrast to the Ear, we have not yet developed a solid explanation of the Funnel Events. However, recent investigations of neutralization processes have led us to speculate how Funnel Events may be related to charged impurities. With the naïve and extreme assumption that such impurities are distributed throughout the detector bulk and that they act as carrier trapping centers, we have managed to simulate a Funnel structure using the Ramo Method.

To do this, we trace the electric field lines, which start on the gap-side edges of Q_{outer} and Q_{inner} (Fig. 2). Events occurring in the region between these two field lines create positive image charges on both Q_{inner} and Q_{outer} if their charges are not fully collected on the electrodes. In particular, we can generate a Funnel-like structure by assuming that every point in this region is a start point for a charge, which ultimately terminates its trajectory on the ground electrode. This is equivalent to assuming an even distribution of trapping centers distributed throughout the region.

This simulated Funnel (Fig. 3) does not accurately fit the data. It has the correct qualitative shape, but does not extend as close to the Q_{outer} axis as in the data. This first result is enough to be encouraging, however!

We must also ask ourselves if the scenario implied by the simulated Funnel is consistent with observations from data:

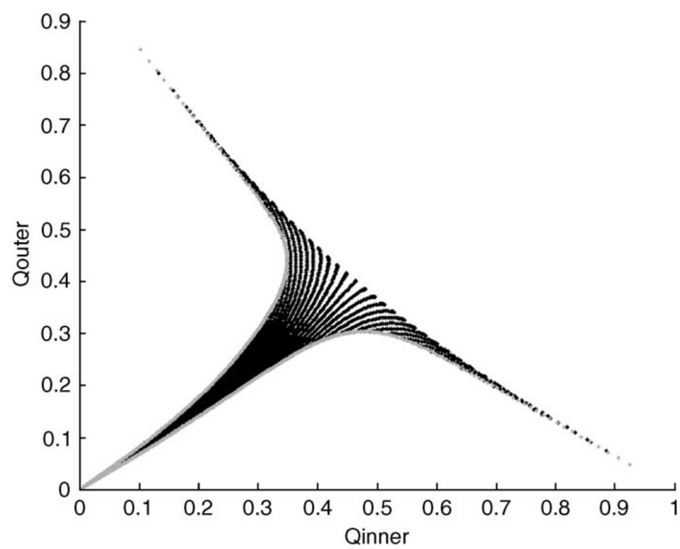

Fig. 3. The Funnel as predicted by our naïve model.

- The phonons from the Funnel Events are localized to large radii in the detector. This is in agreement with the interpretation that the Funnel Events come from the region described above.
- The Funnel is visible only on data sets taken at the Soudan Underground Laboratory and not at the UC Berkeley Test Laboratory. We are investigating the interpretation that the Funnel is seeded by a circumstance of poor neutralization at Soudan, which is not present at Berkeley. In particular, the cosmic ray background at Berkeley maybe enough to maintain neutralization in the low field region between Q_{inner} and Q_{outer}, which may otherwise grow in size in a self-propagating manner.
- The phonon energy spectrum of the Funnel Events is diminished in comparison to Q_{inner} Events. This is what we expect from charges whose full trajectories along

electric field lines to electrodes are cut short due to trapping.

- We observe that when the physical Q_{outer} electrode potential is sufficiently less than the Q_{inner} potential, the Funnel vanishes. This is consistent with an inter-electrode trapping region model: if Q_{outer} is sufficiently less than Q_{inner}, then as the voltage difference between Q_{inner} and Q_{outer} increases, more and more of the electric-field lines which used to start on the gap-side edges of Q_{outer} and Q_{inner} and terminate on the ground electrode now terminate on the crystal's cylindrical surface. Therefore, events no longer have the proper trajectories to account for the Funnel. Would-be Funnel Events now contribute to the Ear.

4. Conclusions

The study of these anomalous pulses provides a powerful probe of the distortion of the fields and the impurity concentration inside our detector.

Acknowledgments

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