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Characterizing Photon and Neutron Responses in CDMS Detectors Using Real and Simulated Cf-252 Data

Abstract: *The SuperCDMS collaboration is searching for dark matter via direct detection of WIMPs. We want to better understand how our detectors respond to both WIMP events and other interactions to help us analyze previously-taken data and also prepare for the next experiment. We focus on the Californium-252 calibration source used in the real experiment, as the neutrons it releases will produce signals similar to those caused by WIMPs; by comparing real Cf data and data produced in our simulation framework, we can trace the physical processes that produce the features we see in the output of the detectors. We find that the initial stages of the simulation are consistent with real Cf-252 behavior and have reasonable detector responses. Next steps will be validating that that final output of the entire simulation chain is consistent with data taken in the real experiment.*

Summary

Multiple observations of the universe (fluctuations in the cosmic microwave background, mass distributions of colliding galaxies, velocities of stars around galaxies, etc.) suggest that there is a large amount of invisible, gravitationally-interacting matter--i.e. 'dark matter.' A likely candidate for dark matter is a weakly-interacting massive particle, or 'WIMP'. The Super Cryogenic Dark Matter Search (SCDMS) experiment is searching for these WIMPs--below masses of 10 GeV, specifically-- by direct detection.

The previous CDMS experiment ('Soudan') already has already yielded world-leading limits on low-mass WIMP interactions, and the next experiment ('SNOLAB') will improve on those. In the meantime, we have developed a simulation framework that assists with analysis of Soudan data and helps prepare for Snolab data. In this work, we compare real data and simulation data to better understand the behavior of the CDMS detectors. Specifically, we have modeled the Cf-252 source used for calibration (of nuclear recoils due to neutrons, specifically--i.e. interactions similar to those caused by WIMPs) in the real experiment, running it through a full simulation of the source itself, its interactions in the CDMS detector volumes, the response of those detectors, and reconstruction of the interactions via the official CDMS analysis software used for real data. We want to check that each stage of the simulation produces output consistent both with theory and with data from the real experiment (which we have already seen for the early simulation stages); with that established, we can then trace simulated physical processes in the simulation to better understand the signals we see in the real data.

We start with our 'SourceSim' simulation, where we check that the behavior and results of the simulation of particles between the Cf-252 source and the CDMS detectors agrees with theoretical descriptions. We then apply Lindhard theory to the energy depositions from this stage, to see what sorts of deposition patterns contribute to the charges and phonons collected in the detectors. Next would be 'DetectorSim', which models the CDMS detector readout, and 'Reconstruction' using the same analysis code applied to real data. These last two stages can already be run in our simulations, but full validation and analysis of their output is still ongoing.

Once we've established that our simulations accurately model the Soudan experiment--that we can fully account for Cf-252's data--future students will be well set-up to simulate WIMP-like events in the SNOLAB experiment. With this work done, then, we will be able to get a jump on SNOLAB analysis and be prepared to identify potential WIMP signals in CDMS's most sensitive experiment yet.

Thesis Outline:

- **I. Introduction**
  - A. Overview
    - 1. Dark Matter
    - 2. Searching for Dark Matter
  - B. The CDMS Experiment
  - C. Overview of the Thesis
- **II. CDMS Experiment Description**
  - A. Apparatus
  - B. iZIP detectors
    - 1. Energy deposition in the crystal
      - a) Simple Interactions, Compound Interactions, and Mixed Events
      - b) Lindhard Model
    - 2. Motion of Charges and Phonons in the Crystal
    - 3. FETs and Charge Readout
    - 4. TESs and Phonon Readout

C. Signals and Noise

III. Simulation Infrastructure and Validation

A. SourceSim
  1. Geant4
  2. SuperSim

B. DetectorSim
  1. CrystalSim
  2. FETSim
  3. TESSim
  4. DAQSim

C. Reconstruction
  1. Optimal Filter
     a) Algorithm
     b) Templates
  2. Observables and Measurables

IV. Data Used

A. Samples

B. Cuts

V. Real Cf Behavior and its Simulation

A. Physics of Cf-252
  1. Alpha decay
  2. Spontaneous Fission
  3. Evolution of a Cf-252 source

B. Simulation of Cf-252 Physics
  1. Alpha Decay
  2. Spontaneous Fission
  3. Evolution of the Source and Caveats
     a) Time cut
     b) Missing fission fragments
     c) Evolution of the source
     d) Potential Contaminants

VI. SourceSim Results

A. Energies of the Source Capsule

B. Energies Incident on the iZIP

C. Deposited Energies
  1. Electron Recoils
  2. Nuclear Recoils
  3. Mixed/Pileup Events

VII. DetectorSim Results

- A. SourceSim with Manual Lindhard Calculations
  1. Overall Features
  2. Recoil Type Distributions
     - a) Normal ERs and NRs
     - b) Multi-NRs
     - c) Quasielastics, Neutron Captures, and Inelastics
     - d) Mixed-incident Events
  3. Takeaways
- B. DMC Results

VIII. Reconstruction: Barium Calibration

- A. Charge Measurables
- B. Phonon Measurables

IX. Reconstruction: Comparison to Real Cf-252 Data

- A. Charge Measurables
- B. Phonon Measurables
- C. Yield

X. Evaluation and Next-Steps

- A. Summary
- B. Potential Improvements
- C. Next Steps

XI. Conclusions