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Characterization, performance, and future advanced analysis of detectors in the cryogenic dark matter search (CDMS-II)

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Abstract

We present the techniques and results of the calibrations and surface-event rejection cut for the current CDMS-II data set, along with proposals for future analysis of CDMS-II data.

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1. Introduction

CDMS ZIP detectors generate rich information for each event, including ionization and athermal phonon energies, event location, and phonon pulse shape. A limitation of the CDMS detectors' discriminating power is rejecting events near the surface of the detector. The next run, in preparation, has 30 detectors and an expected tenfold increase in exposure over the completed 12-detector run. To remain background-free, the discrimination against near-surface events must be improved.

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2. Calibration and backgrounds

CDMS has taken two data sets at Soudan: one from October 2003–January 2004 [1], with six detectors (4 Ge, 2 Si), and one from March–August 2004 [2], with twelve detectors (6 Ge, 6 Si). Each run included regular in situ calibration with radioactive sources: ^{133}Ba as a source of gammas (electron-recoil events), and ^{252}Cf as a source of neutrons, which scatter from nuclei. The calibration data also characterize the position dependence of the raw ionization and phonon energy estimates. A position-based correction of energy and timing quantities effectively removes this variation. In Ge detectors after correction, the ionization channel has resolution (Gaussian width) better than 10 keV at the 356-keV Ba peak, and as good as 2.5 keV in some detectors; the resolution at 10 keV is approximately 0.3 keV. For the best Ge detectors, the total phonon energy measurement after correction has resolution (Gaussian width) 8 keV at 356 keV, and 0.35 keV at 10 keV.

Electron recoils within the fiducial volume of a detector are effectively (>99.9%) rejected in the WIMP-search analysis by cuts on *yield*, the ratio of ionization to phonon energy. More problematic are beta- and low-energy gamma-emitting contaminants on detector surfaces or nearby objects. These surface electron recoils can have suppressed ionization yield, and occasionally leak into the nuclear recoil signal region. For these events, other discrimination techniques are necessary. Secondary electrons from the ^{133}Ba calibration form a calibration sample of surface events. At the experimental site in the Soudan Underground Laboratory, the rate of neutron backgrounds is negligible at current exposures [2].

3. Surface event discrimination

For events near metallized crystal surfaces, phonons rapidly down-convert in the metal films from quasi-diffusive (higher-energy) to ballistic (lower-energy) phonons, which reach the aluminum collector fins and are absorbed sooner [3]. For this reason, surface events have faster phonon start and rise times than bulk electron recoils, and timing can be used to reject surface events.

Additionally, the smaller ionization of nuclear recoils gives them slower phonon pulses than bulk electron recoils because they have fewer fast Neganov-Trofimov-Luke phonons [4,5] (these phonons created by drifting charges have lower energies than primary phonons and travel ballistically). Typical CDMS timing cuts have a very good efficiency for rejecting surface electron recoils and most bulk electron recoils, and the cuts accept half or more of the nuclear recoils from a neutron calibration.

In each of the first two Soudan runs, the primary blind analysis used phonon rise time and start time to reject surface events. These cuts were defined on a sum of normalized, post-correction start time and rise time, giving slightly better performance than either quantity alone. The primary analysis and its results are discussed in detail in Refs. [6,1,2].

4. Advanced analyses

Ongoing development of CDMS analysis techniques has focused on improving surface-event rejection. New ways of using existing information include a cut set by a neural network; several analyses that compute a chi-squared for each event as compared to a nuclear recoil model and a surface contaminant model (Fig. 1), using all available discriminating parameters; and an analysis that defines distinct cuts near the center of each detector and near the edges, where the phonon signal has different timing properties.

An additional useful quantity is the ratio of phonon energy collected in the most distant quadrant of the detector to that in the quadrant in which the event occurred (Fig. 2). This “phonon fraction” is sensitive to the different proportions of primary and Luke phonons present for different recoil types: Luke phonons are collected more locally, while primary phonons diffuse for a longer time and are more likely to reach the opposite quadrant. It is corrected for energy and position dependence, and used as a discriminator for surface events. The neural network cut and all chi-squared analyses have included the phonon fraction along with rise and start times.

New position estimators have been defined based on a simple model of where and when primary and Neganov-Luke phonons are collected. The model maps 3-D recoil location to observable phonon timing quantities, with adjustable parameters to match the behavior of each detector. Inverting this map, the measured signal of each interaction can be converted into a reconstructed position, which maps more directly onto physical location than

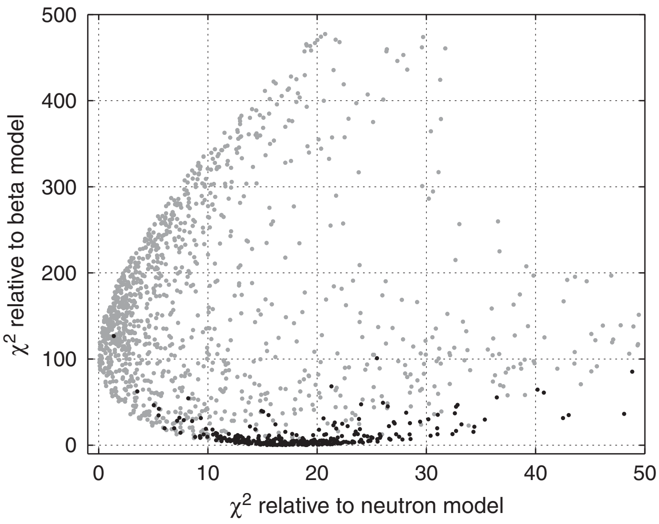

Fig. 1. Chi-squared discrimination. On the *x*-axis is χ^2 relative to the neutron model, and on the *y*-axis is χ^2 relative to the surface contaminant (beta) model for ^{133}Ba surface scatters (dark) and ^{252}Cf neutrons (light).

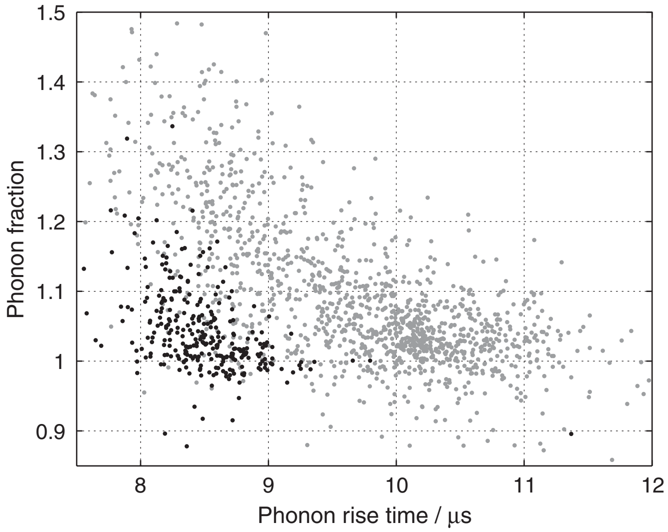

Fig. 2. Phonon fraction, anticorrelated with rise time for neutrons (light), is a useful discriminating parameter against surface scatters (dark).

previously-used estimators do. The estimate of cylindrical radius, r^*, has been used to construct one radius-dependent cut on the existing discriminating parameters. A second radius-dependent analysis is based on the reconstructed depth from the top surface, z^*.

Preliminary results from the advanced analyses agree with the primary analysis of the twelve-detector Soudan run, and achieve improved discriminating power.

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