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Proposal for Preliminary Examination

Optimized Dark Matter Search using the SuperCDMS Soudan Data and Monte Carlo Simulations

Abstract. *Previous analyses with the Super Cryogenic Dark Matter Search Experiment (SuperCDMS) have set world leading sensitivity limits to low-mass WIMP interactions, this project will further improve such results. In the low-mass energy range it is hard to discriminate the background from the signal. By using improved, fully validated detector simulations, with Monte Carlo techniques, we will obtain a better background model, optimize the acceptance, and thus obtain the next world leading sensitivity limit for low-mass WIMPs.*

Summary

It is observed that Dark Matter composes 85% of the gravitational mass of the Universe, yet it has never been directly measured. The simplest guess at its particle nature is that it is a Weakly Interacting Massive Particle (WIMP). This analysis is a world leading low-mass WIMP search with the Super Cryogenic Dark Matter Search Experiment (SuperCDMS), improving the previous results by optimizing the background model and rejection.

We will look for a WIMP particle with a mass between 5 and 15 GeV. In this low-mass regime, the bulk of the acceptance is in lower energies where the background discrimination is hard to achieve and to model. This new-generation analysis, is based on improved simulations of the SuperCDMS detectors to enhance the background rejection.

The set of tools and methods for the detector simulation, the Detector Monte Carlo (DMC), is now well set up for producing events in a streamlined process. The DMC will allow us to obtain a better background model and improve our understanding in the detector's measurements. Both of the latter will help us maximize our acceptance and optimize the sensitivity.

Our starting point is the previous analysis background model. We already know we have an improved model because the tools were not accurate, after so many issued we have solved, and it was not carefully validated. Furthermore, the final answer in the previous result was affected by inappropriately accounted *mismeasured events*, which we will add as a background.

The current on-going task is to validate the DMC results against data which we understand (calibration data). Once fully validated we will get a preliminary result and iterate on the dominant issues, until they are no longer relevant to the sensitivity. The tools are still likely to be improved for a few iterations, but the current results are already good enough for a detailed comparison against data.

While we may not discover WIMPs in this data set, we hope to set the world's best limits at low mass. This project will also shape and design the analysis methodology for the upcoming data taking at the next-generation experiment SuperCDMS SNOLAB which will have more and better detectors, and much more data.

Thesis Chapters:

I. Introduction
   A. Overview
   B. Dark Matter Motivation
      1. Cosmology and Dark Matter
      2. WIMPs
   C. Overview of the WIMP Search Analysis
      1. Detection Challenge: WIMP signal v.s. Background
      2. Previous LT WIMP Search Analysis
      3. Current WIMP Cross Section Sensitivity Limits by Others

II. The SuperCDMS Soudan Experiment
   A. Apparatus
   B. iZip Detector Operation *(i.e. how it works)*
   C. Event Discrimination Tools *(i.e. how diff particles leave diff signals)*

III. Signal and Background Model
   A. Signal: Expected WIMP Recoil Energy Spectrum
      1. Spectrum Averaged Efficiency Definition
   B. Sources of Background Events in the Detectors
      1. Cosmogenic Backgrounds
         a) Electron Recoils: Photons and Electrons (also from Multi-scatter Events)

b) Neutron Recoils
c) Muons (Neglected with VETO)
d) Neutrinos and Anything Else (Non-measurable/Neglected)

2. Contaminants in the Detectors
   a) Germanium Activation
   b) Lead Implantation
3. Mismeasured Events
   a) Mixed Events in a Single Trigger (Pileup Events)
   b) Detector or DAQ Malfunction Events (Glitch Events)

C. How the Backgrounds will be Categorized After Preselection for Optimization

IV. Event Reconstruction

A. Summary of Measured and Calculated Variables
B. Event Reconstruction *(i.e. more details about how raw quantities are obtained)*
C. Calculated Variables *(i.e. more details about how calculated quantities are obtained, calibrations discussed here, as they are part of these 'calculations')*
D. List of Preselection and Optimization Variables (*for use later in the event data quality section)*

V. WIMP Search and Calibration Data

1. Source of Electron Recoils: Ba Calibration Data
2. Source of Neutron Recoils: Cf Calibration Data
3. WIMP Search Data
4. Exposure

VI. The SuperCDMS Detector Monte Carlo (DMC)

A. Overview of how the DMC will be used in the Optimization
B. DMC Event Generation Tools
C. Input to the DMC: Geant4/SuperSIM Samples
D. Validation of the DMC: Comparison to Data Calibration Samples
   1. Pulse shape, amplitude and variations
   2. Goodness of fit estimators
   3. Charge energy
   4. Phonon energy
   5. Energy yield

6. Charge channels
7. Phonon channels

VII. Data Quality, Event Selection, and Background Expectations
   A. Determining the Preselection Requirements
      1. Preselection Quality Cuts
      2. Preselection Fiducial Region
   B. Background Expectations
      1. How the Number of Events of Each Source is Obtained and How the Uncertainties are Estimated
         a) Lead Contamination
         b) Germanium Activation
         c) Electron Recoils
         d) Cosmogenic Neutron Recoils
      2. Background Expectation Values and Uncertainties
      3. Comparing the Background Expectations with Data
         a) Phonon Energy
         b) Charge Energy
         c) Energy Yield
         d) Quality Discriminators and Fiducial Quantities

VIII. Efficiency and Exposure
   A. Trigger Efficiency and Uncertainty
   B. Spectrum Averaged Efficiency and Uncertainty
   C. Total Exposure and Uncertainty

IX. Non-Optimized Sensitivity Limit and Systematics
   A. Method for Obtaining the Sensitivity Limit and How the Systematics are Included
   B. Expected Sensitivity Limit
   C. Comments on Dominant Systematics for the Optimization Process

X. Analysis Optimization
   A. Overview of the Optimization Strategy
   B. Optimizing the Event Characterization
      1. Optimized Selection/Characterization Variables

2. Backgrounds as a Function of Optimization Variables
3. Optimizing with a BDT
4. NeuralNet (If applicable, at least worth trying?)

C. Final Cuts, Final Background Expectations and Systematic Uncertainties

D. Expected Sensitivity Limit

XI. Results

A. Opening the Box: Event Descriptions

B. Observed Sensitivity Limit

C. Comparing to Current Results by Others

XII. Conclusions

A. Possible Improvements to a WIMP Search

B. WIMP Searches at SNOLAB