A Study of Background Particles for the Implementation of a Neutron Veto into SuperCDMS

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Abstract

Astronomical observations have revealed that most of the matter in the universe is non-luminous, non-baryonic dark matter. The Cryogenic Dark Matter Search (CDMS) was designed to look for Weakly Interacting Massive Particles (WIMPs), a strong candidate for dark matter. The CDMS experiment used Ge and Si crystal detectors to search for WIMPs by using ionization yields; the ratio of ionization and the recoil energy. To extend upon this research, the Super Cryogenic Dark Matter Search is proposed to include more sensitive Ge crystal detectors with greater target mass of 100 kg and a reduction in the number of background events. To greatly decrease the background counts, the implementation of a neutron veto has been introduced. Neutrons and WIMPs produce similar interaction signatures within the Ge crystal detectors to the point where neutrons can cause a "false positive" reading. These neutrons come from the cosmogenic sources and radioactive decay in materials surrounding the detector. In this research, an increased understanding of shielding from the intrinsic environmental background is achieved. To do this, Geant4 is used to simulate particle interactions with the shielding material of the neutron veto. By studying various geometrical configurations, the reduction in background can be optimized for a liquid scintillator veto.

Introduction

Many astronomical observations have indicated that there is a large amount of non-luminous and non-baryonic dark matter within our universe. One candidate for this type of matter is the Weakly Interacting Massive Particle (WIMP). The search for dark matter in the form of a WIMP has been conducted through the Cryogenic Dark Matter Search (CDMS) which was located at the Soudan Underground Laboratory. The CDMS used Si and Ge crystals to detect and measure phonons and ionization from every particle that entered the detector in which the ionization yield can determine the particle. Most particles produce electron recoils while neutrons and WIMPs would produce nuclear recoils.

While the physical depth of the CDMS and Super CDMS experiments can block out a great deal of cosmic particles, background events are still very prevalent. Background particles can be eliminated for the most part from shielding, ionization yields, and by events with multiple scattering events (usually caused by a neutron). The problem lies within the similarities between a neutron and what we believe of a WIMP. Both neutrons and WIMPs are electrically neutral and very weakly interacting. Both also will scatter off of a Ge nucleus causing a phonon signal. Neutrons come from three main sources; internal radiogenic neutrons, cosmologically produced neutrons, and from radiogenic rock.

Gamma "particle" simulations were studied to determine the best shielding configuration for the gamma background. Initial studies were performed to validate Geant4 based simulations for neutron veto studies as well help improved tuition for shielding methods. Simulation methodology was based on simple shielding configurations with modified geometry in which the data was analyzed in ROOT.

γ-"Particle" Simulations

Study 1: ~1D Simulation: Effective Attenuation Length of Materials

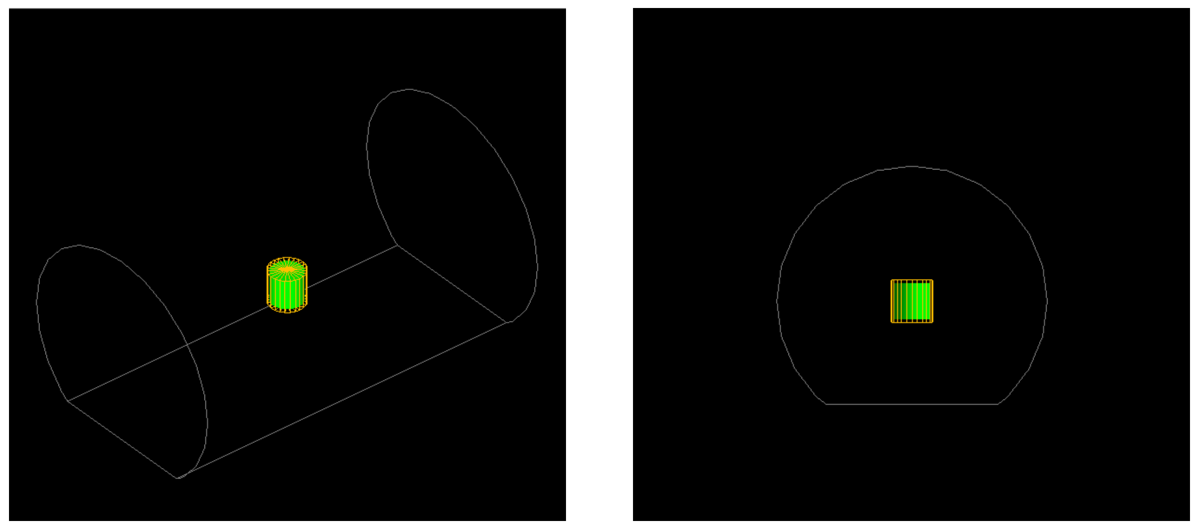


Figure 1: This initial study deals primarily with 1 MeV gammas, which are found within the range of gammas found in ^{238}U + ^{232}Th decay chains. To simulate the SuperCDMS, a particle detector was placed within the simulated cavern which would determine the number of particles of any energy that entered.

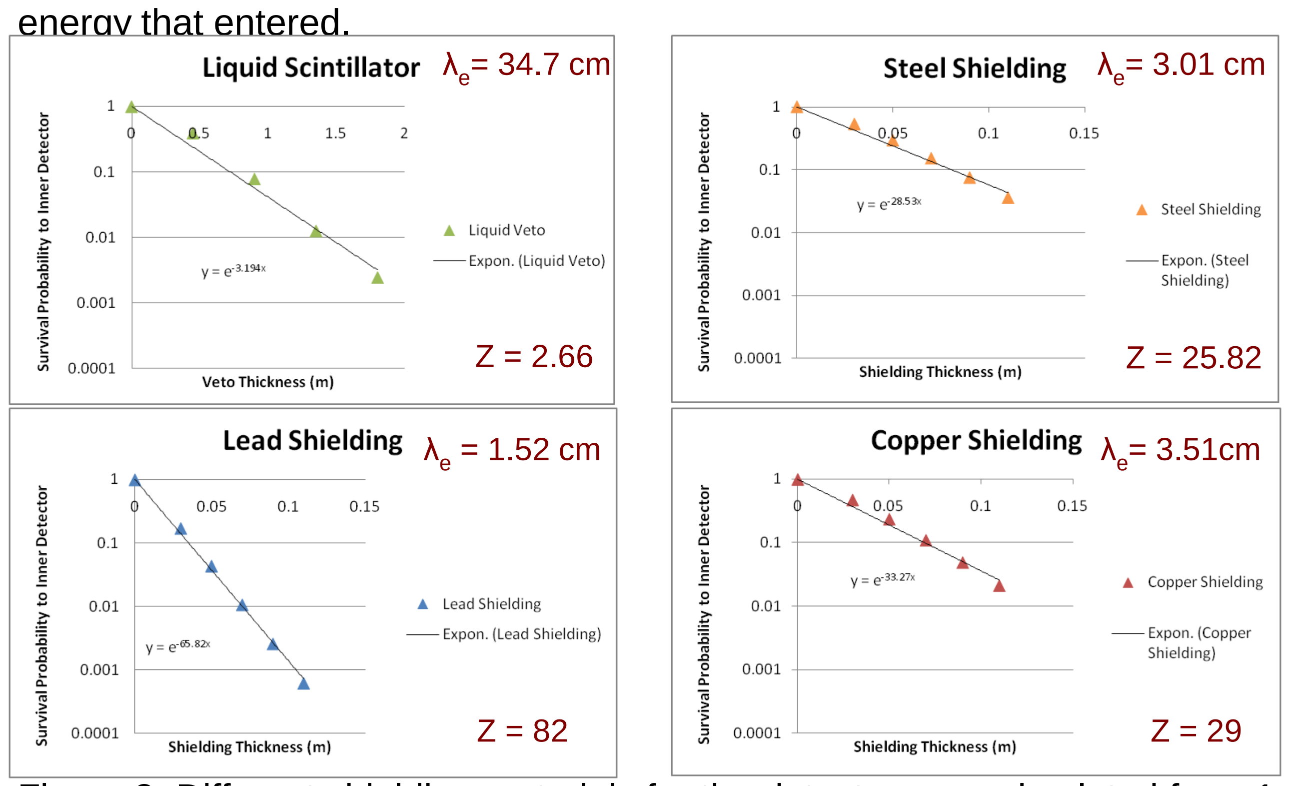


Figure 2: Different shielding materials for the detector were simulated for a 1 MeV gamma to understand their respective effective attenuation lengths.

Study 2: 3D Simulation: Liquid Scintillator

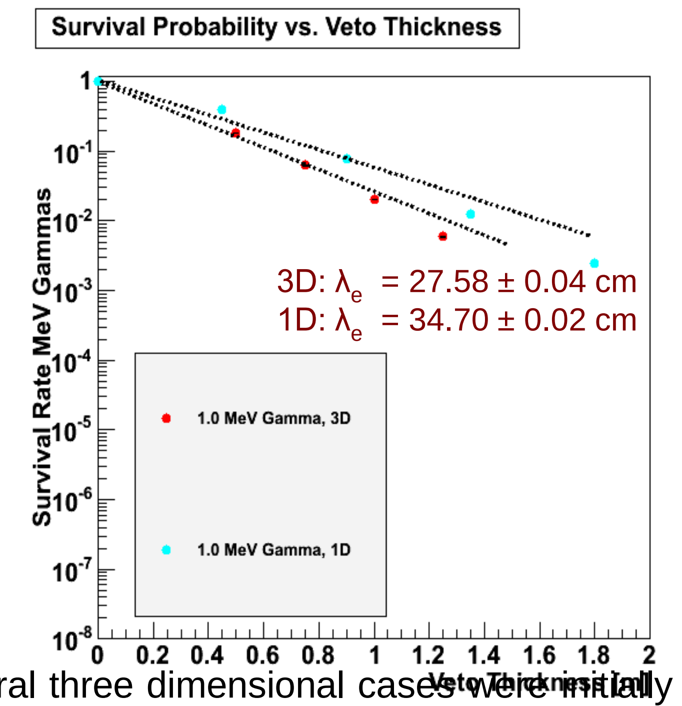
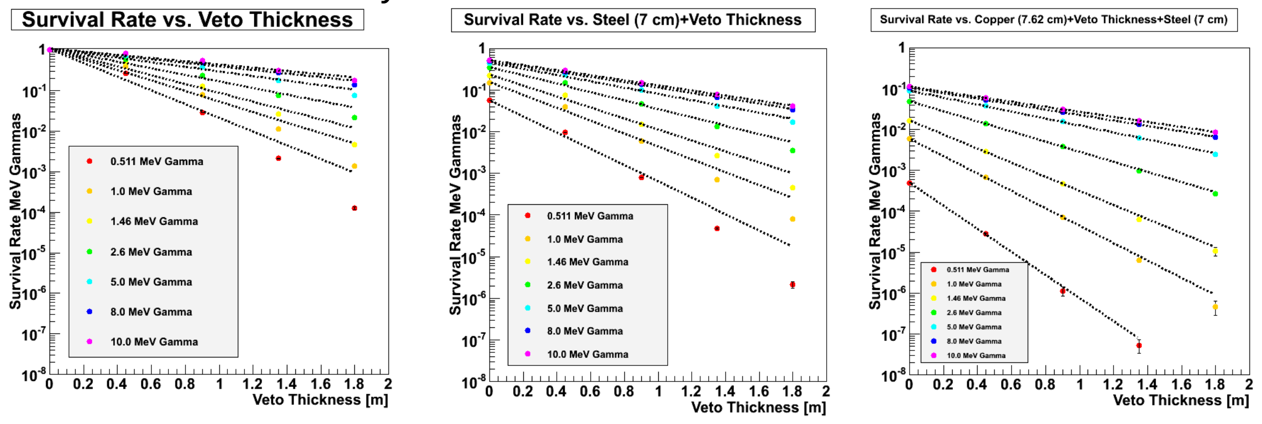


Figure 3: Several three dimensional cases were initially completed in which liquid scintillator was simulated using various thicknesses to a isotropic barrage of 1.5 million 1 MeV gamma particles. A one dimensional case for the liquid scintillator was compared to the three dimensional case.

Study 3: 1D Simulation: Stacked Materials



In this simulation, a at 25 m diameter disk of detector and material(s) was hit by a beam of gamma particles of individually simulated varying energies. Further studies of the one dimensional type were done with the liquid scintillator, lead, copper, and steel using 0.511 1, 1.46, 2.6, 5, 8, and 10 MeV gamma particles as well as combinations of the materials, where effective attenuation lengths were determined.

Conclusions and Future Work

As mentioned previously, background events are problematic for the SuperCDMS experiment. It was found that Geant4 is a valid for Monte Carlo simulations of background particles in which the results matched the theory of attenuation length.

Based on the results, gamma "particles" are attenuated by higher Z materials. With a greater energy gamma, comes the need for more material to attenuated it. This can give way to how much shielding material is needed. Effective attenuation lengths were determined by an exponential relation based on the Beer-Lambert law.

Further research needs to be done on these particles in determining effective attenuation lengths of combinations of materials as well as with the inclusion of studies with neutron particles and the inclusion of the full energy spectrum of both gamma and neutron particles. From these studies, estimates on effective attenuation lengths can be determined to then be used towards the
final version of the SuperCDMS's shielding con
figuration which will not only be useful in severely reducing the amount of intrinsic environmental background, but also be useful in cost effectiveness of materials.

References

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