Introduction to Dark Matter and the CDMS Experiment

For years the standard model of Physics has accurately accounted for all observed particles and their interactions. Current cosmological research has yielded observations which are unexplainable in this model, and has led to the development of several extensions in an attempt to explain these phenomena. The modern cosmological model is built upon several fundamental parameters of the Standard model, such as the Hubble parameter, which relates the geometry of the Universe with its matter and energy content. Observations of the rotational curvatures of distant galaxies suggest that there must be large amounts of unseen mass-energy to account for their flat appearance and relatively constant mass-density profile. In the standard model these values should decline, \( \propto \frac{1}{r^2} \) as the distance from the center of the galaxy is increased. These observations are also supported by additional observations of gravitational lensing, which is the distortion of light, around distant galaxies. This extra mass does not emit or scatter electromagnetic radiation, leading to its naming; dark matter. Despite the mounting evidence, dark matter has yet to be observed by direct experimental observation or created in particle colliders. One of the many experiments attempting to make these observations is the Super Cryogenic Dark Matter Search (CDMS).

In the supersymmetric extension of the Standard Model the most likely dark matter candidate is the neutralino, which should have a mass in the range of 10-1000 GeV, making it the lightest particle in this extension. This particle should show a small, but still measurable, reaction through weak forces when it collides with normal matter. This fact combined with relatively large mass has led to the particle being labeled a Weakly Interacting Massive Particle (WIMP). CDMS utilizes super cooled high purity Germanium (HPGe) crystal detectors known as 2-axis sensitive ionization and Phonon detectors (ZPs) to observe the nuclear recoils of these WIMPs. The extremely low cross-sections of WIMPs lead to an expected rate of events of less than 0.1 event Kg \(^{-1}\) Day \(^{-1}\). For this reason the detector must be well-shielded from outside particle contamination. This contamination creates a background spectrum which can obscure the presence of the particle. Steps to eliminate this background include locating the experiment deep underground to block cosmic rays and constructing the detector from components with low as possible levels of radioactive isotope contamination. Neutrons from the radioactive decay chains would be observed as the same nuclear interaction as a WIMP and would therefore distort results.

Research Goals

The detectors for the CDMS experiment are currently located deep underground at the Soudan mine in northern Minnesota and has a detector mass of roughly 10 kilogram. Currently the experiment is beginning to shift from the Soudan mine, to the SNOLAB facility in Sudbury Canada. The SNOLAB facility is significantly deeper underground and provides even better shielding from cosmic rays, which are a primary source of background for the WIMP. It will also increase the detector mass of the experiment by a factor of 20 and greatly increase the likelihood of direct interaction observation.

With the move to SNOLAB a new shield will need to be constructed. In order to obtain the most pure materials possible for the new shield the components are screened in Gopher, the University of Minnesota's high purity Germanium detector. This detector is used to analyze the radioactive contamination of the components that would emit gamma rays, and contaminate experimental results.

Components are analyzed in the detector for up to four weeks, and the resulting gamma spectra are mapped. The components of the detector themselves also contain some level of radioactive contamination that contributes to the resulting spectra. For this reason a background for the detector is mapped and subtracted from any sample results. One interesting result has been observed in which the background spectra for samples have a lower “peak” at certain energy levels than the background of the empty detector. This leads to the belief that the geometry of the sample and its orientation within Gopher are actually blocking some of the background gamma ray contamination. For this reason it is important to know exactly where the contamination of the shield causing this background is coming from within Gopher. Knowing this would allow for more accurate analysis of screened samples.

Procedure

To achieve this modelling, gamma ray Monte Carlo simulations within Gopher, a software toolkit developed for simulating the passage of particles through matter, were utilized. Within this simulation world there was constructed a virtual detector which models the physical properties of Gophers different elemental components. The detector consists of an inner chamber with 10 inch walls of Oxygen Free High Thermal Conductivity (OFHC) Copper. This is surrounded by 10 inches of Ultra Low Activity (ULA) lead, also called ancient lead, which was mined long ago and has much lower levels of radioactive isotope contamination. All of this is then enclosed by 10 inches of Aluminum to provide the outer shield. This can slightly offset from the center of the chamber.

All of these elements and their geometries have been modeled with great care within the G4 environment. Now the objective is to model the exact source of gamma contamination to create the most accurate simulations and calibration of Gopher. In previous simulations the observed background of Gopher was simply simulated as a whole. In this research the individual background components of each element are analyzed independently to determine their unique contributions. This includes gamma events from the bulk of the materials as well as from the exposed inner Cu surface and additional modeling of the Aluminum detector can itself.

Once these elements were accurately modeled in the G4 environment simulations were run with 1 million gammas per isotope emitted randomly from within each shield component. These events are then peak fitted and a histogram is utilized for appropriate energy binning. These are then plotted to produce the background spectra of each individual component.

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Next Steps

Now that these elements and their unique contamination contributions have been accurately modeled within the G4 environment the next step is to fit these models to the observed background of Gopher. This fitting will be done by minimizing the \( \chi^2 \) value between the data and a weighted sum of Monte Carlo sources. These best fit values for the Monte Carlo weights will correspond to the location and relative strength of the radioactive contamination in the shield. These contamination values are the final goal of this project. Once these are known they can be used to more accurately screen materials to ensure the best possible shielding for the SNOLAB CDMS experiment.

References:
[1] Indirect Dark Matter Searches and Models
[2] Particle Dark Matter: Evidence, Constraints, and Constraints,
[3] Exclusion Limits on the WIMP-Nucleon Cross-Section from the First Run of Cryogenic Dark Matter Search in the Soudan Underground Lab
[5] Indirect Dark Matter Searches and Models

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Figure 1: Left: Rotation curve for the Milky Way galaxy. Predicted line is red and observed line is blue.

Figure 2: (Above) Photos of Gopher. Rear cylinder is Aluminum detector can. Front circular detector of HPGe Purified Germanium. The white block is a poly block used to hold samples.

Figure 3: (Above) Vertical view flux as a function of depth, normalized to meter water equivalent. The red curve is for the SNOLAB environment, with current (circles) and past (triangles) underground facilities.

Figure 4: (Above) Monte Carlo simulation of gamma events with a sample surface (dark). Green lines indicate gamma ray paths.

Figure 5: (Above) Monte Carlo simulation of gamma events with a sample surface (dark). Green lines indicate gamma ray paths. Figure 6: Aluminum detector can. Rear cylinder is Aluminum detector can. Figure 7: Aluminum detector can. (Above, clockwise from top left) Background Gamma Spectrum.

Figure 6: Background Gamma Spectrum.