Unearthing the Secrets of the Universe: Simulating Neutron Calibrations for the MiniCLEAN Dark Matter Detector

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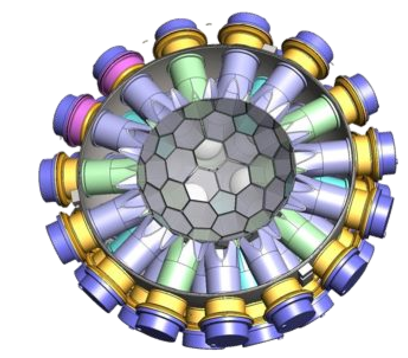
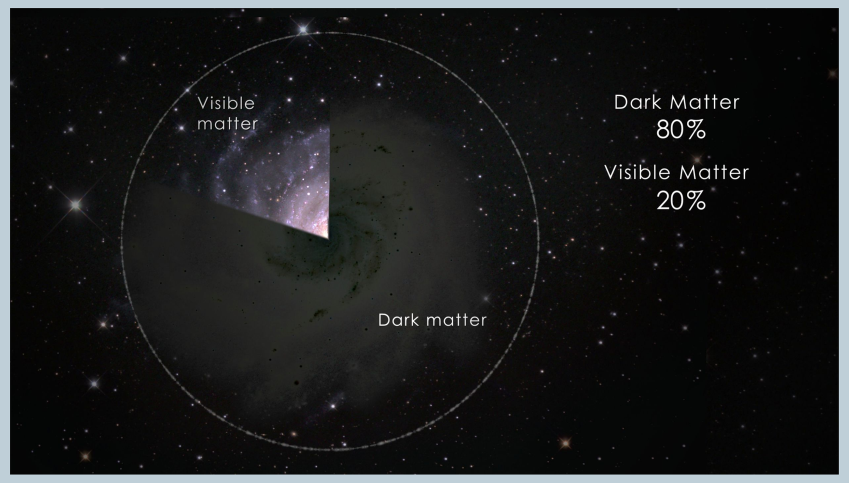
Abstract: Using RAT, a Geant4-based Monte Carlo analysis tool, I have run neutron calibration simulations to estimate the time calibrations will require for the experiment MiniCLEAN. MiniCLEAN is a direct dark matter detection experiment that will begin taking data this spring. It is located 6800 feet underground at SNOLAB in Sudbury, Ontario Canada. The experiment uses liquid argon as its detection medium, searching for Weakly Interacting Dark Matter (WIMPs). The neutron source Americium Beryllium (AmBe) generates neutrons that will scatter off of argon nuclei in the detector to calibrate what a dark matter collision would look like. A framework for data processing, ROOT, was then used to interpret the simulated data set and the source was found to generate 7 to 8 events per minute





What is Dark Matter?

Dark matter is an unidentified form of matter different from normal matter. Like normal matter, it interacts with other matter through gravity, but unlike normal matter it does not interact with light and so we cannot see it directly when observing the universe. One particle candidate is the WIMP which may interact directly with matter with a weak scale force.

Based on its gravitational effects on the matter we can observe it is estimated that about 80% of the matter in the universe is dark matter with the remaining 20% being visible matter.

The MiniCLEAN Detector

MiniCLEAN is a first generation dark matter detector located at SNOLAB, an unique lab located 6800 ft. underground in Sudbury, Ontario Canada. MiniCLEAN utilizes 2000 kg of liquid argon to detect WIMPs. Argon is being used due to its scintillation property and its relatively cheap cost as compared with other alternatives like Xenon. Scintillation is a process where light is emitted by the medium, in this case argon, in response to the interaction of it with a passing particle.

MiniCLEAN is different than other dark matter detectors in that the light detectors (PMTs) which detect this scintillation light are directly in the liquid argon rather than embedded in the walls of the tank that contains the liquid argon.

Neutron Calibrations

Scientific Motivation: When a WIMP scatters off of argon nuclei, it imparts some of its energy and excites the argon which then emits scintillation light. Natural radioactivity will create background events that are primarily interactions with electrons, and not the nuclei. In a single phase detector like miniCLEAN it is crucial to be able to differentiate between these electronic recoils and neutron recoils and the typical way to do this is to look at the fraction of light that gets detected in the first 90 nanoseconds which we denote "fprompt". In order to calibrate what these nuclear recoils look like we utilize neutrons, whose interaction with the argon look very similar to a WIMPs interaction. However because of the sensitive experiments going on in SNOLAB, we must understand how long the neutron source will be needed.

The AmBe Source: The neutron source miniCLEAN will be using for its calibrations is the Americium Beryllium (AmBe) source. The source emits about 5000 neutrons per second.

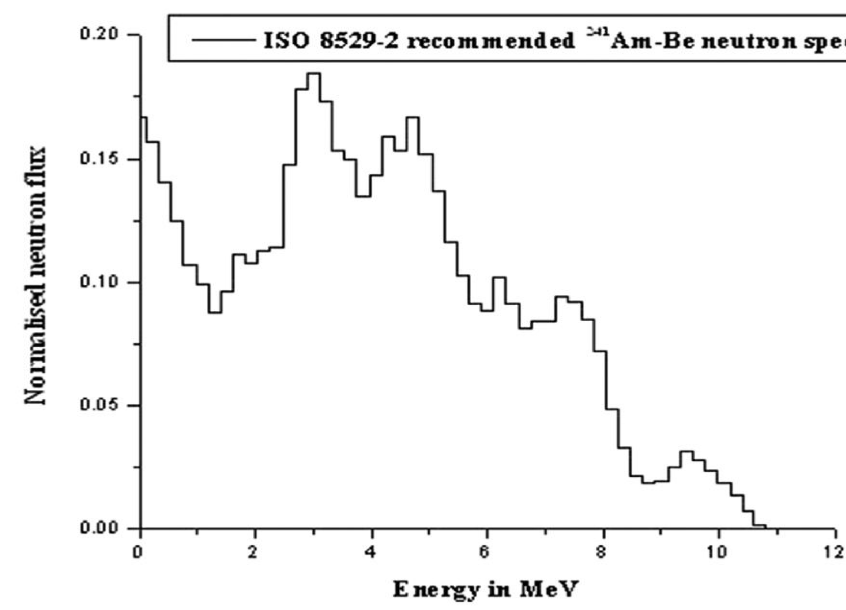


Figure 1. The AmBe neutron source emission spectrum.

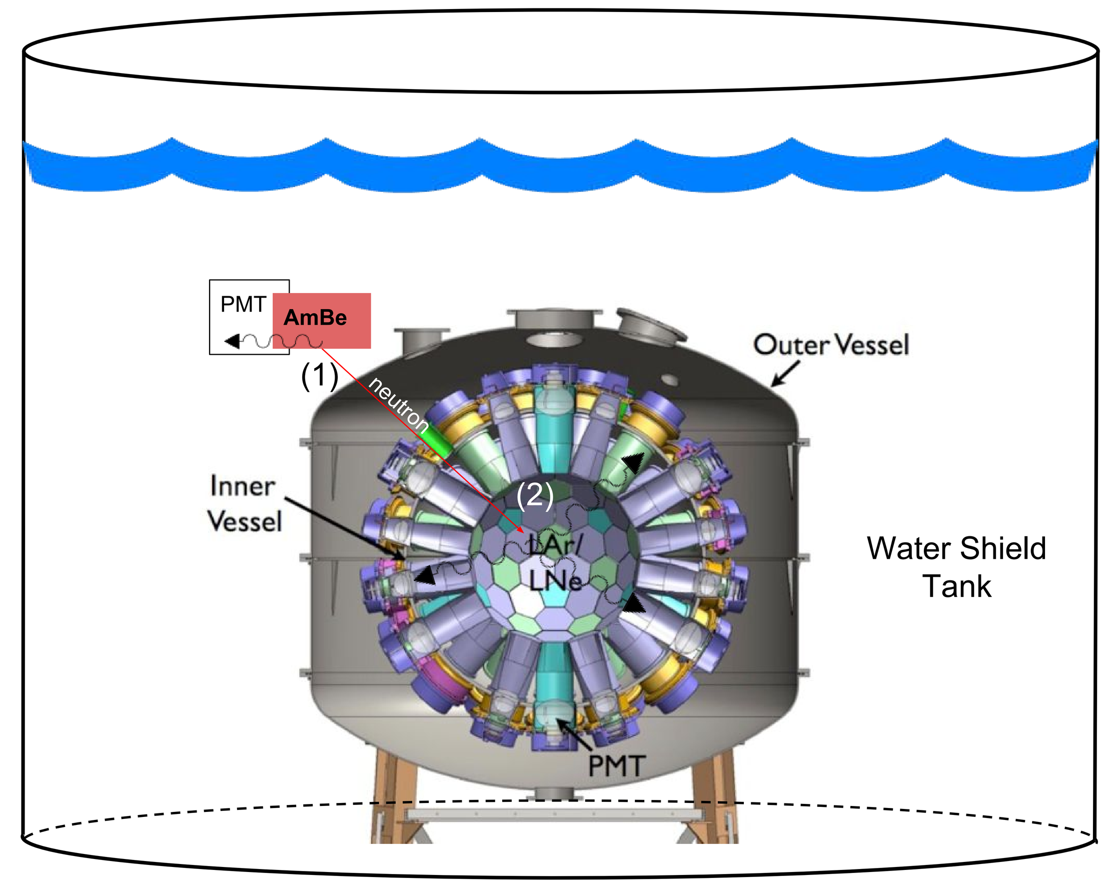


Figure 2. An americium atom decays into neptunium and an alpha particle which then collides with beryllium to make a carbon atom and a neutron (1). The carbon is in an excited state which decays and emits a photon that is detected by a pmt with the source (1). This allows the ability to "tag" a released neutron. The neutron then travels into the argon where it scatters off an argon nucleus, which takes some of the neutrons energy. This excited argon then emits this energy in the form of UV scintillation light which is absorbed by tetraphenyl butadiene (TPB) on the acrylic and re-emitted as blue light that can be detected by the pmts in the IV (2).

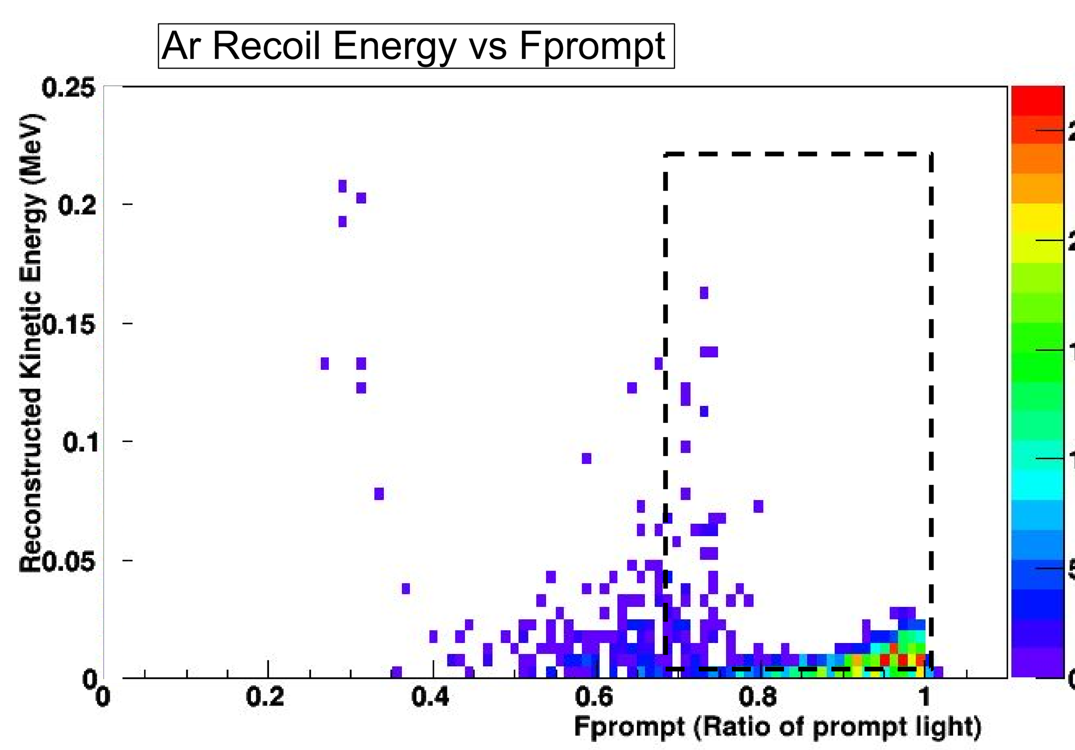


Figure 3. 2D Histogram looking at the neutrons that triggered a response in the PMTs. The dashed box encloses the collisions that are nuclear recoils and therefore are of use for calibrations.

Results

Out of 200000 simulated events, only 28 passed all the cuts and are therefore "clean" nuclear recoils. By generating 5000 neutrons per second, this corresponds to getting 7 to 8 good recoils per minute.

Number of Simulated Events	200000
Number of Triggered Events	3186
Pass energy Cuts	838
Pass Position Cuts	1756
Pass Fprompt Cuts	772
Pass All Cuts	28

This is an upper bound on the rate as the AmBe source is isotropic whereas in the simulations the neutron source only emitted neutrons toward the center of the IV

The future of MiniCLEAN

- Finish filling and then calibrate the detector.
- Take data looking for dark matter, however it isn't expected to be found (see figure 6).
- Dope the detector with extra argon-39, a beta-decaying isotope found in argon taken from the atmosphere, to increase the background electronic recoils and determine if a larger liquid argon detector is a viable option in the search for dark matter.

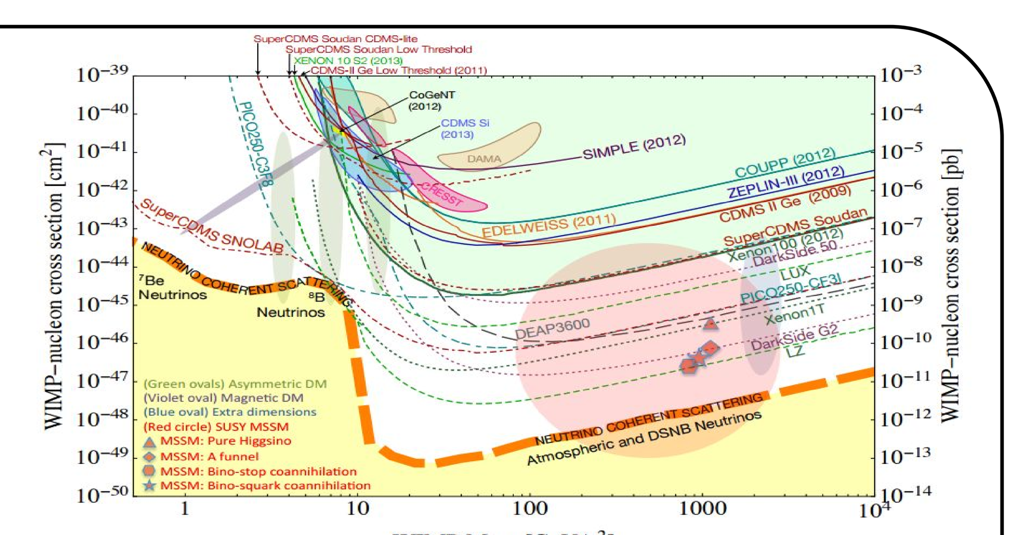


Figure 6. The detection limits of direct dark matter experiments. MiniCLEAN has a projected limit equal to Xenon100 (2012) while the current limit is the LUX curve (arXiv::1310.8327).

MiniCLEAN Filling

To help speed up the cooling process of the Argon, I was fortunate enough to be able to travel to Sudbury and set up a condenser (as seen in figure 4), which was designed to cool the argon and condense it before flowing into the detector. I formed and cleaned the piping that connected the purification system to the condenser and then the condenser to the detector.

Figure 4. The condenser while in operation, which utilizes liquid nitrogen, at 77 K, to cool down the argon to its liquid form below 87 K.

The condenser went into operation in late august last year and Figure 5 shows the effect it had on the cooling of the Inner Vessel.

Since returning to Madison, I have continued to work with the experiment by monitoring remotely while the IV cooled. Recently the IV has finished cooling and filling with liquid argon has begun.

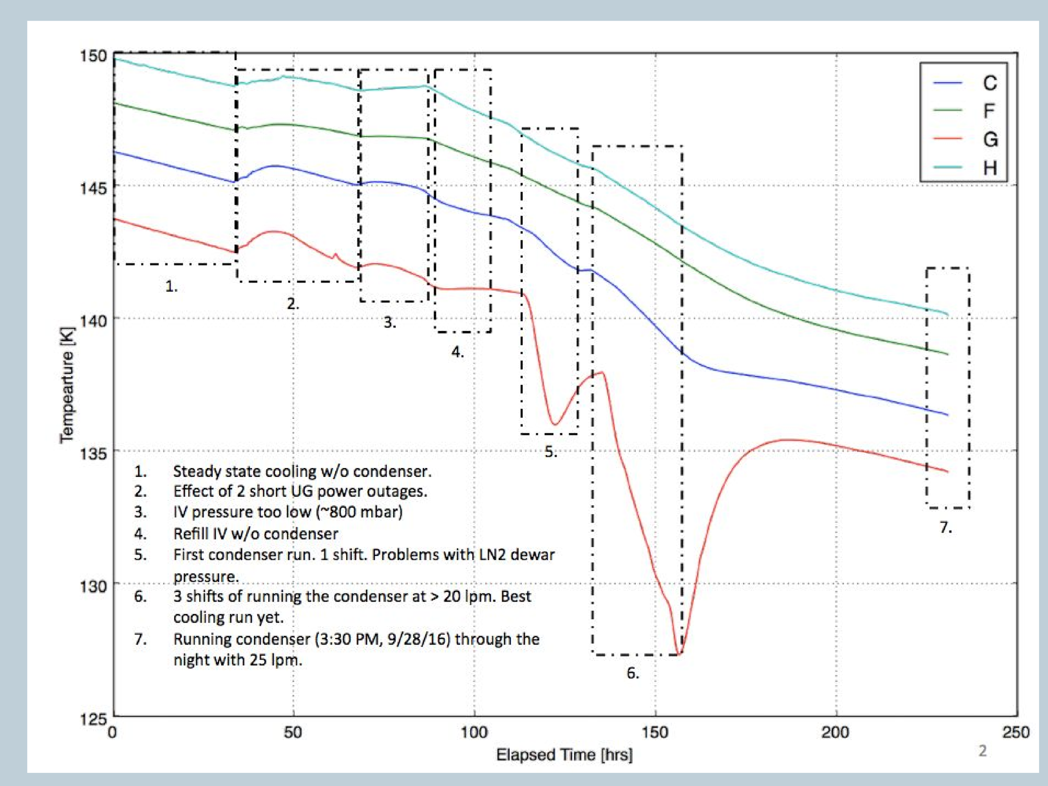


Figure 5. Cooling curve during one of the condenser runs made late last year (2016).