Detector Simulations in the Search for Dark Matter

Nick Decheine, Hans Zhang, Kimberly Palladino

Abstract:
MiniCLEAN is a direct dark matter detection experiment located in SNOLAB, 2km underground near Sudbury Ontario Canada. It is a technology demonstrator for the detection of nuclear recoils from Weakly Interacting Massive Particles (WIMPS), a likely candidate particle for dark matter. For this experiment, Reactor Analysis Tool (RAT), a Monte Carlo simulation tool for liquid scintillator detectors that relies on particle interactions in Geant4 software, is used to simulate the detector environment. We primarily study signal recoil calibrations and background events. I studied the effect of upgrading Geant4 from version 9 to 10 to help decide whether the MiniCLEAN version of RAT should upgrade. In key physical simulations, the outputs of the two versions are consistent and the newer Geant4 version shows better performance.

Simulation Comparison of different Geant4 versions

What is Geant

- Geant stands for GEometry ANd Tracking. It is a software toolkit for simulating particles passing through matter that is widely used in physics research.

What is RAT

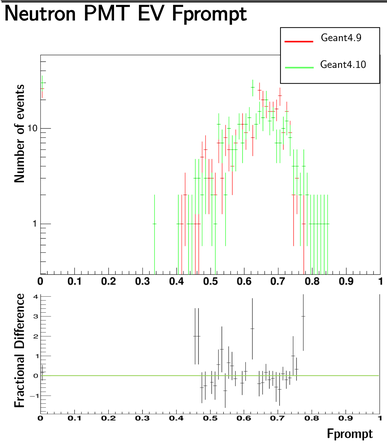
- RAT is short for Reactor Analysis Tool, a Monte Carlo analysis tool for liquid scintillator detectors using Geant4 to simulate particle interactions in the detectors.
- It's also the tool that allow handling specific details of MiniCLEAN.

Why study the difference

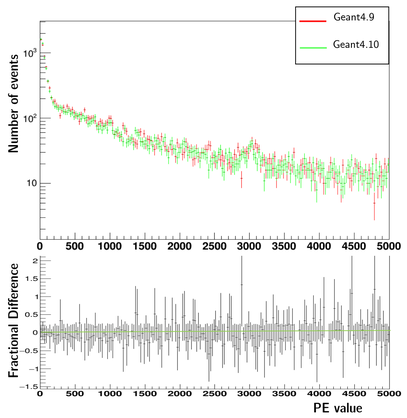
- The way particles are simulated and interact might have changed between the two versions of Geant (geant4.9 and geant4.10).
- We want to verify that simulations made with the newer version have results consistent with previous simulations.

Neutron PMT Simulations

Neutron PMT EV Fprompt



Neutron EV PE



Fprompt:

- ratio of prompt light (<100ns) to late light (<15us)
- WIMP events are expected to cause nuclear recoils which have high Fprompt values
- Events such as beta and gamma events have low Fprompt values – these events are cut

PE: Photo-Electron counts

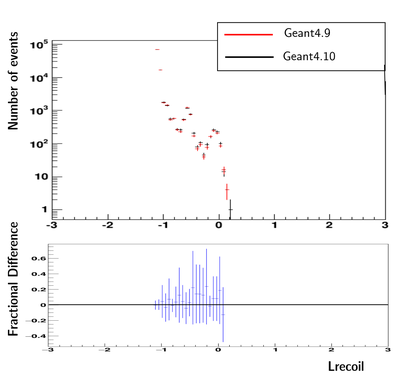
- Proportional to energy
- Plots shown has no cuts

Lrecoil:

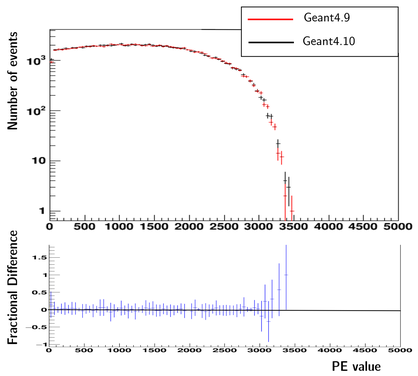
- Nuclear recoil energy value
- Tells similar information as Fprompt

Argon39 Simulations (main background)

Ar39 Lrecoil



Ar39 PE



We can see here data points of the two versions are generally close to each other (well aligned and have fractional differences near 0). We conclude that the simulation results of the 2 versions agree with each other for both neutron and electron background.

Comparison Conclusions

- RAT with these 2 versions of Geant4 seem to conform well
- RAT with Geant 4.10 is faster and produces slightly smaller output files
- There are occasional spikes in the difference of the results
- Geant 4.10 version generally has smaller output files

What is Dark Matter?

Dark Matter

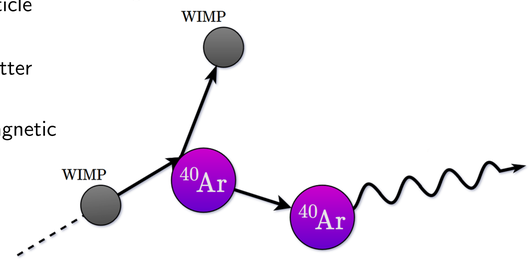
Dark matter is a theorized form of matter that accounts for many unexplained gravitational effects in astrophysics and cosmology.

- Likely candidate is a WIMP particle
- Makes up ~26% of the universe
- Barely interacts with normal matter
  - Interacts via gravity
- Does not interact via electro-magnetic force (no light)

WIMP

Weakly Interacting Massive Particle

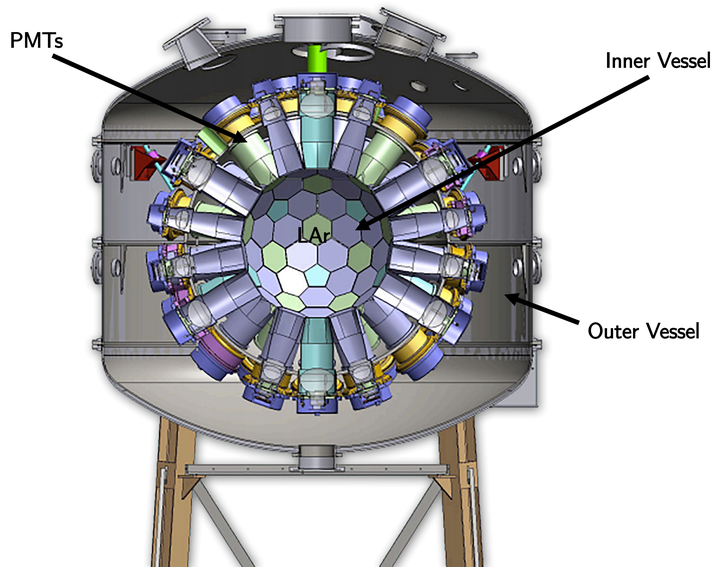
- A new hypothetical particle (as of now)
- Interacts via gravity and other weak forces
- Large mass compared to standard matter



MiniCLEAN Direct Dark Matter Detector

- MiniCLEAN detects light emitted by the argon target in response to incident particles, which might include a dark matter WIMP. The detector is designed to be filled with two tonnes of liquid argon. Data has been taken from the detector when filled with gas and we are using it as preliminary calibration data while the detector is filling.
- In order to calibrate the detector, SNOLAB will collect data for a neutron source AmBe.
- Our simulations must therefore use this same source to predict what the real detector must calibrate with.

MiniCLEAN Detector

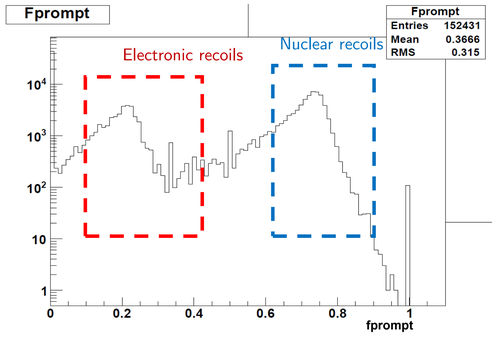


Neutron Calibration Simulations

Using RAT and Geant4, we have simulated events from neutrons created by an AmBe neutron source to model what the true calibrations of the detector will look like.

fprompt: a measure of how quickly light is released after the scattering, allows us to separate signal nuclear recoils from background electronic recoils.

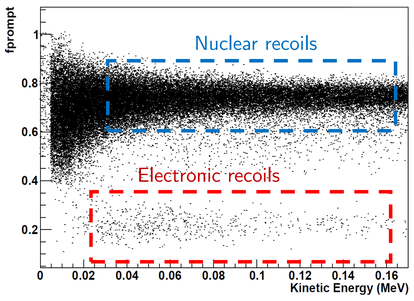
Nuclear recoils have higher fprompt



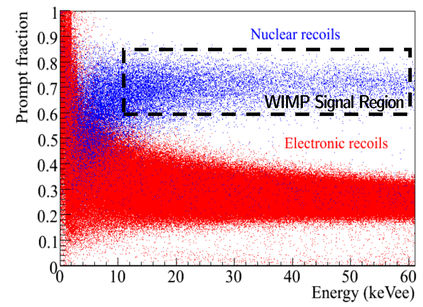
Detecting WIMPs (Dark Matter)

- WIMP scatters off argon nuclei, exciting argon dimers and giving off light.
- Ar39 is radioactive and trace amounts are present with Ar40
  - Ar39 causes argon to recoil *electronically* but not with the nucleus.
- We distinguish these recoils by looking at the fraction of early light that is emitted, or **fprompt**. – we are looking for late light.
- We simulate neutrons to show what nuclear recoils would look like – very similar to a WIMP interaction.
- However, neutrons can have an inelastic collision with the argon and cause a gamma ray, which then causes electronic recoils.
  - This side effect is mitigated by the use of **lrecoil** to differentiate the nuclear recoils and electronic recoils from these gamma rays.

My Simulations



Data from arXiv:0801.1531[1]



- The dark top band depicts a stark correlary to the published data for liquid simulations, showing a promising distribution of nuclear recoil events from simulated neutrons in gas.

Because we can produce a similar distribution to simulated WIMP events in liquid from a simulated neturon source in gas, this is valuable for future calibration of the detector even while it fills.

Future Plans

- Support filling and data taking operations
- Simulate more AmBe neutron calibration events in gas
- Simulate AmBe neutron calibration events in liquid argon.
- Support calibration and discrimination analysis

after filling completely with liquid argon.

[1]Scintillation time dependence and pulse shape discrimination in liquid argon - Lippincott, W.H. *et al.* Phys.Rev. C78 (2008) 035801, Erratum: Phys.Rev. C81 (2010) 039901 arXiv:0801.1531 [nucl-ex]