Understanding Fast Neutrons Utilizing a Water-Cherenkov Detector and a Gas-filled Detector at the Soudan Underground Laboratory

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Introduction

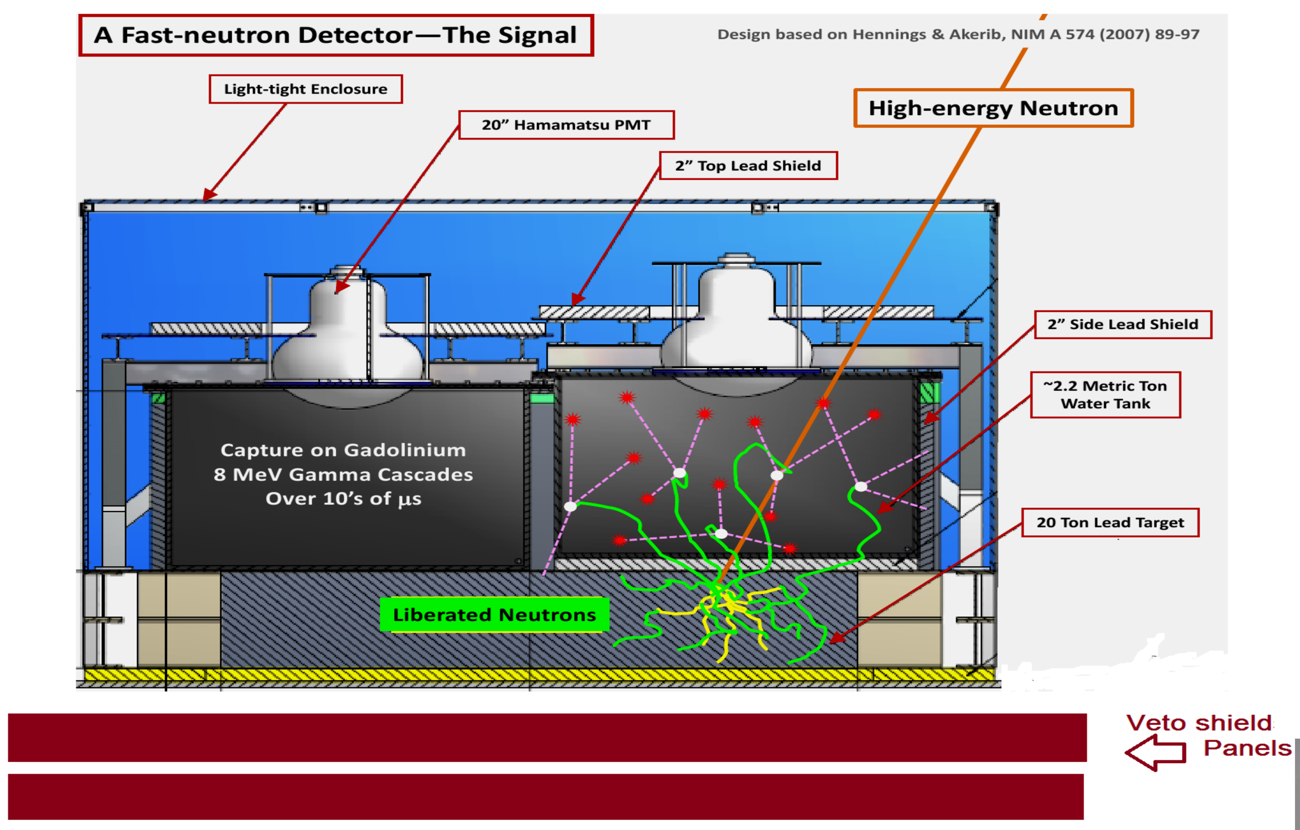
Astrophysical evidence suggests that normal, everyday matter ("baryonic matter") composes only about 18% of the matter in our universe. The remaining "dark" matter – so called because it neither emits nor absorbs light – has only been indirectly observed through its gravitational effects. Many experiments are currently searching for Weakly Interactive Massive Particles (WIMPs), a well-motivated class of hypothetical dark matter candidates. These direct dark matter detection experiments are located in deep underground to shield from cosmic- ray muons and the fast neutrons they produce.

Fast neutrons are particularly dangerous to WIMP detectors because they can penetrate a WIMP-search experiment's neutron shielding. Once inside, these fast neutrons can interact with high-Z material near the WIMP detector, producing slower neutrons capable of mimicking the expected WIMP signal.

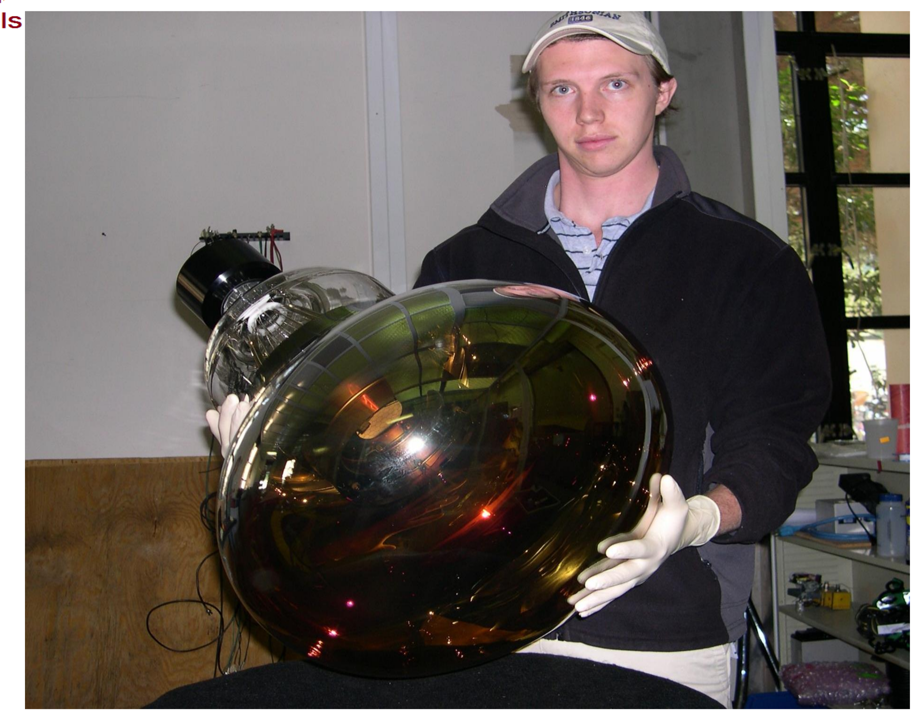
My research uses two detectors located in Soudan Underground Laboratory to understand fast neutron production by muons in an underground environment: a water-Cherenkov detector sensitive to fast neutrons; and a gas-filled detector sensitive to charged particles like muons. This poster describes the fast-neutron detection using data from both detector systems.

Methodology and Apparatus

Neutron Multiplicity Meter (NMM):

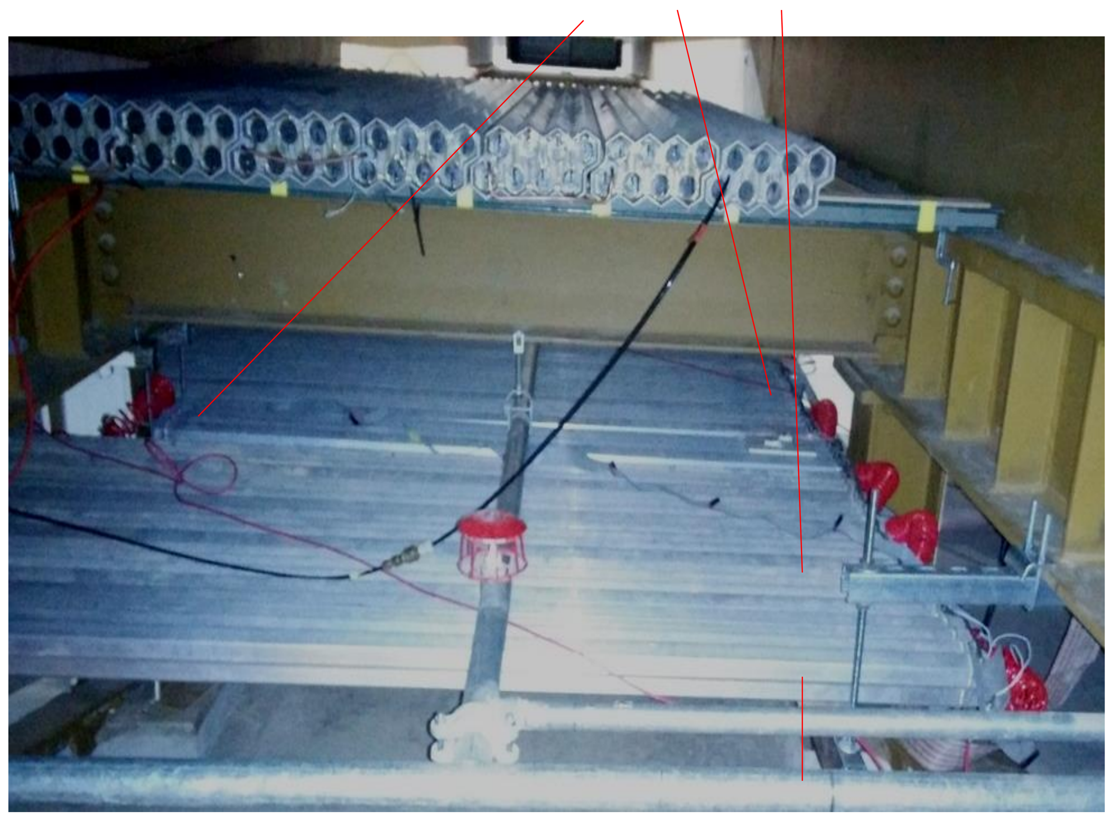


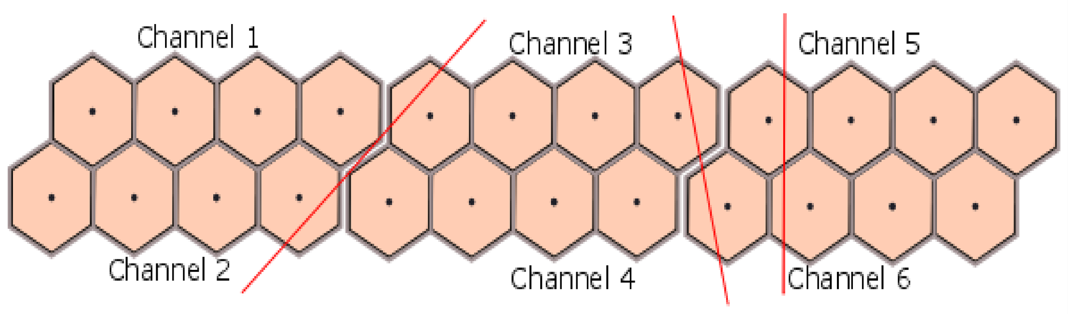
The NMM employs Gadolinium (Gd)-loaded water atop a lead (Pb) target. The high-energy (>60MeV) neutrons create spallation events in the lead, which then produce more neutrons. The neutrons thermalize with a timescale of 30 μs and capture on the Gd which then de-excites by giving off 8MeV in gammas that can interact with electrons and produce Cerenkov light. Photomultiplier tubes detect this light.



This is one of four 20 inch PMT deployed at Soudan. There are two 20 inch PMTs deployed on each of the water tanks. PMTs are used to convert Cherenkov (photon) light signals into electrical pulses.

Veto shield (gas-filled Detector):





This illustrates three possible muon tracks in the same panel. Groups of four hexagonal cells are readout as a single channel and two channels make a tube. The muons may go through the same tube or adjacent tubes as shown in the figure; both cases satisfy the DAQ trigger.

A veto shield is employed under the NMM and is used to tag potentially interesting muon events (because muons penetrate all four layers of the veto shield, they can be distinguished from events due to radioactivity in surrounding materials). Veto-shield muons that pass through the NMM are useful for understanding NMM-veto shield coincident events. Veto-shield muons that miss the NMM but are coincident with a fast neutron in the NMM can provide new information on fast-neutron production. The three possible ways of muons can be seen in red.

Acknowledgement: The veto shield is supported by the NSF through the AARM collaboration. The neutron multiplicity meter was supported by the NSF. I would like to thanks Dr. Sander, my advisor, as well as NMM Veto-Shield working group (including Amy Roberts, Anthony Villano, Matthew Fritts, and Raymond Bunker) for the support and suggestion.

Analysis and plots

The data acquisition system records a microsecond-accurate time for both the veto shield and NMM events. To study the coincidences, I select NMM events which are close-in-time with muon-like veto shield events. I started with 13 days of veto shield and associated NMM data (between Oct. 7, 2013 and Oct. 21, 2013).

With 13 days of livetime, the NMM records 28,472 total events. Only 3,037 of these NMM events are close in time with veto shield muon-like events. 'Close in time' events are within five seconds of each other (though most are within 7 musec). Looking at the distribution of time differences between veto shield and NMM events (see Fig. 1 below), it is clear that the overwhelming majority of coincidences are from prompt muons.

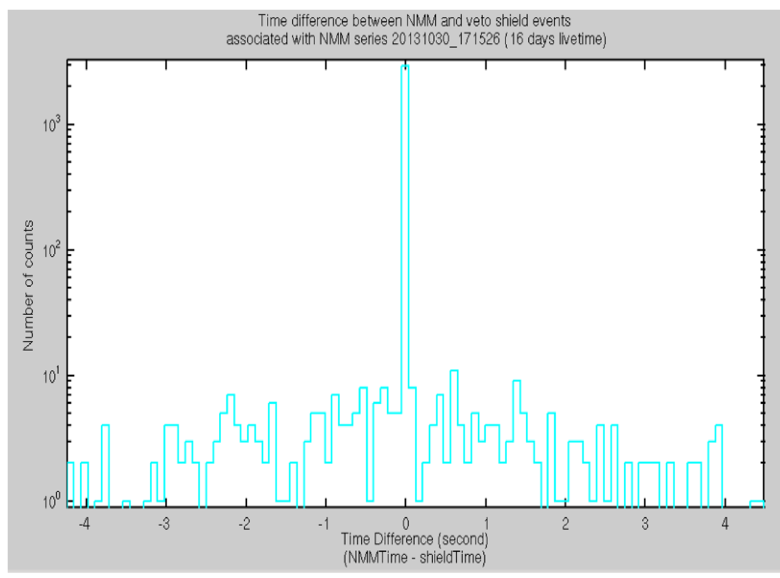


Fig. 1: **This is a histogram of time differences between veto shield and NMM events. The peak (coincident peak) at zero indicates muons that went through both the NMM and veto shield. The events on the left side of coincidence peak are non physical for neutrons.**

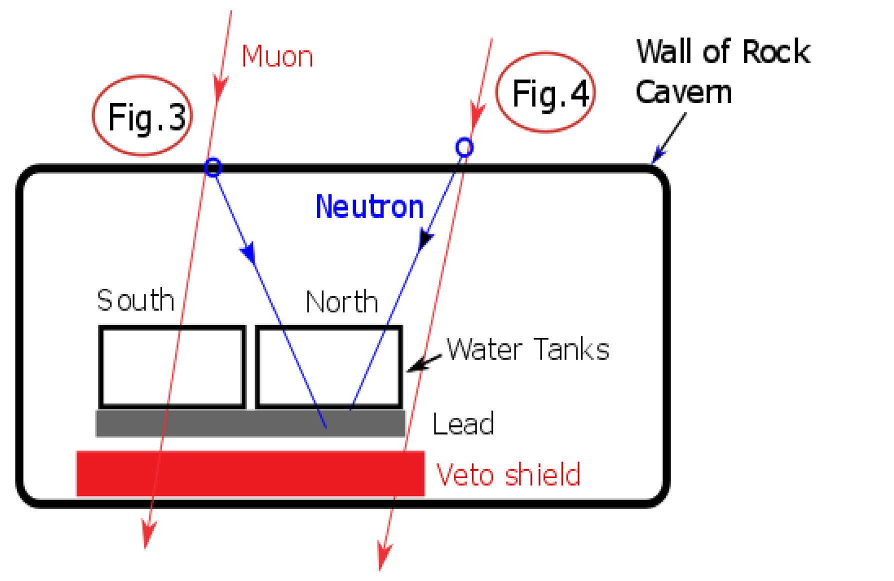


Fig. 2: **A diagram of two possible scenarios. In one scenario, the muon path is restricted to the south tank. This allows the north tank to observe slow neutrons produced by a muon-induced high-energy neutron interacting with lead. In the other scenario, only the veto shield observes a muon. This leaves both NMM tanks sensitive to neutrons.**

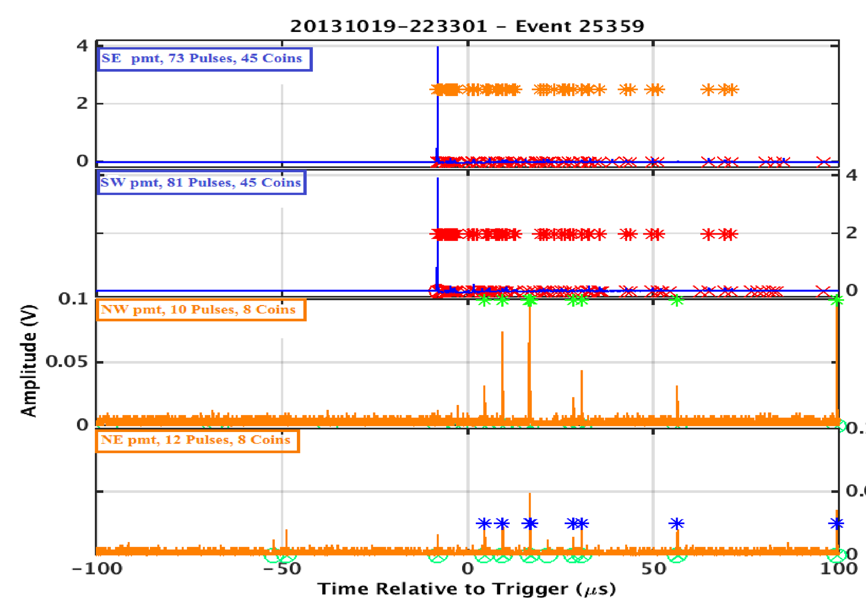


Fig. 3: **This plot shows muon event on south tank while the north tank observed neutron event. In upper half plot (blue), the muon (with high pulse ~4 V) is observed by both PMTs of south tank at the same time (the stars indicate the number of coincidences). In lower half, both PMTs observe multiple low-energy neutrons produced by muon-induced high-energy neutron.**

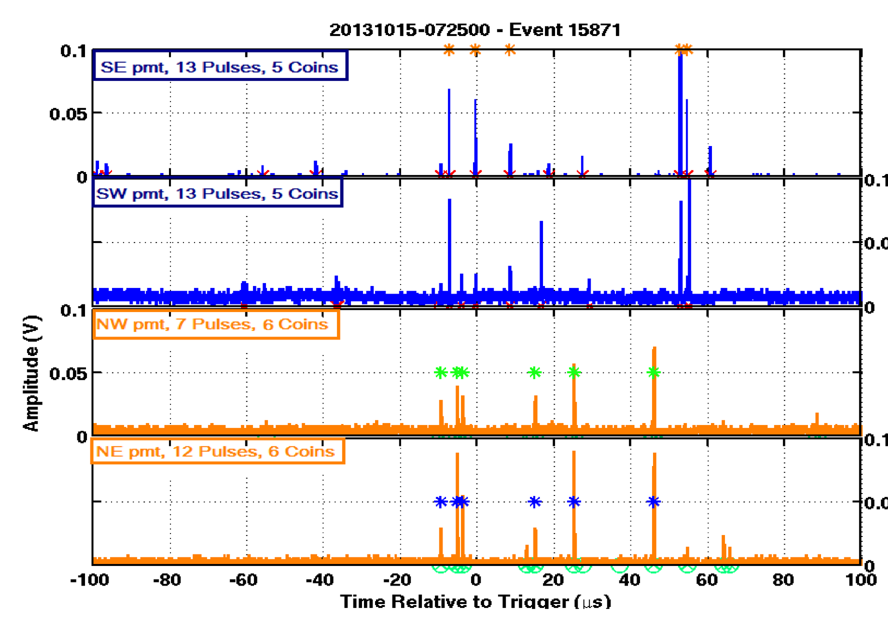


Fig. 4: **This plot shows neutrons observed by PMTs of both (south and north) tanks. We distinguish neutrons from gammas by the high multiplicity and pulse height (summed pulse height near 0.1 V). The pulse height distribution for neutrons and gammas was constructed by Ray Bunker, Yu Chen, and Richard Schnee.**

Conclusion and Future Work

The muon-induced high-energy neutron is a potentially dangerous background for WIMP detector. I am identifying and measuring the rate of the background events. I found ~9 neutron-like events on both tanks (events like Fig. 4) from 13 days of data set. This data is preliminary. In the future, I will look at more data for additional interesting events.

The veto shield has interesting data available for analyzing to anyone interested. Additionally, there is also space in the veto shield to add new experiments.