Fast Neutron Backgrounds As A Function Of Overburden For Rare-Event Detection

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Introduction

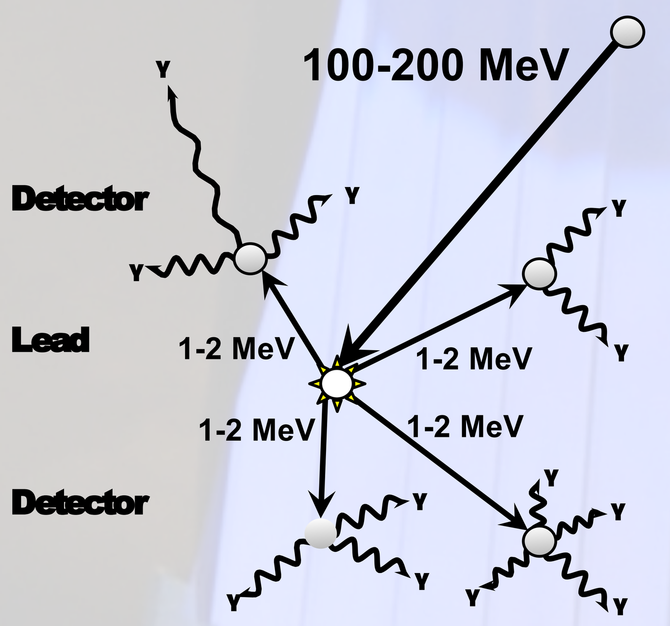
Fast neutrons created from muons produce a depth dependent background for neutral-particle rare-event detectors. Muons that do not pass through but near the active shielding of these detectors are particularly problematic since they may produce high energy neutrons capable of penetrating the shielding. At shallow depths (hundreds of meter water equivalent (m.w.e)) there is disagreement amongst existing measurements/predictions of the fast neutron spectrum and rate [1]. These discrepancies are partially due to the many of the measurements being made by detectors which were not optimized to detect fast neutrons and can result in predictions varying by two orders of magnitude. For detectors at deeper depths the fast neutron rate can be very difficult to measure, therefore the use of theoretical energy dependent predictions from Mei and Hime or Wang et. al based upon the known muon spectrum and Monte Carlo predictions is quite common [2, 3].

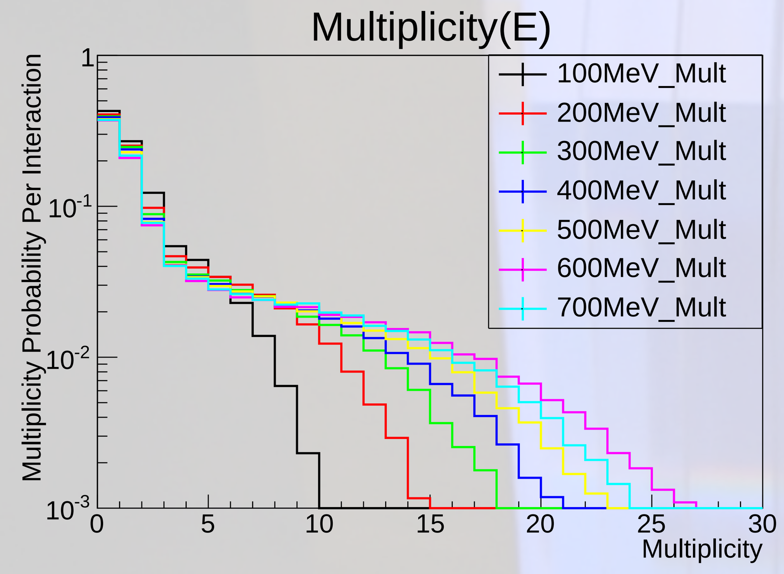
The detector described here has completed measurements at 0, 300, and 600 m.w.e. at the Kimballton Underground Research Facility (KURF). Currently it is making it's last measurement at 1450 m.w.e. This range spans the shallow depths at which there are discrepancies in the literature and provides one deeper measurement for comparison with theoretical predictions. The neutron energy dependent flux will be used as an input into the design of the Water Cherenkov Monitor for Antineutrinos, (WATCHMAN). WATCHMAN is a proposed long-range nuclear reactor monitoring experiment that relies on inverse beta decay interactions of anti-neutrinos with proton targets in a kiloton-scale water detector.

Measurement Concept

Fast-to-Slow spallation lead amplifier with a neutron capture detector

- Fast neutron (hundreds of MeV) enters the detector and spalls on the lead
- Multiple low energy (∼1-2MeV) neutrons are produced
- Low energy neutrons are thermalized quickly in the capture detector
- Thermal neutrons capture on gadolinium nucleus creating prominent multiplicity signal
- Spallation neutron multiplicity is proportional to the incident neutron energy

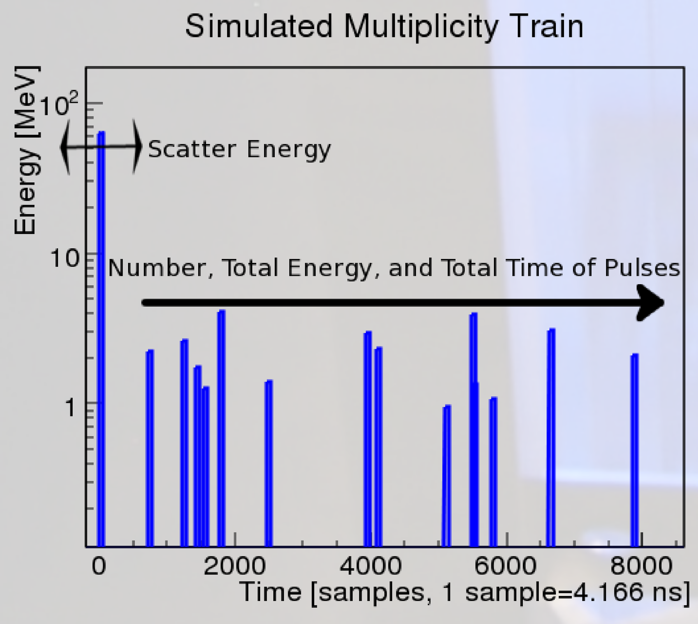




Expected Detector Response

We record the following signals to unfold the neutron energy:

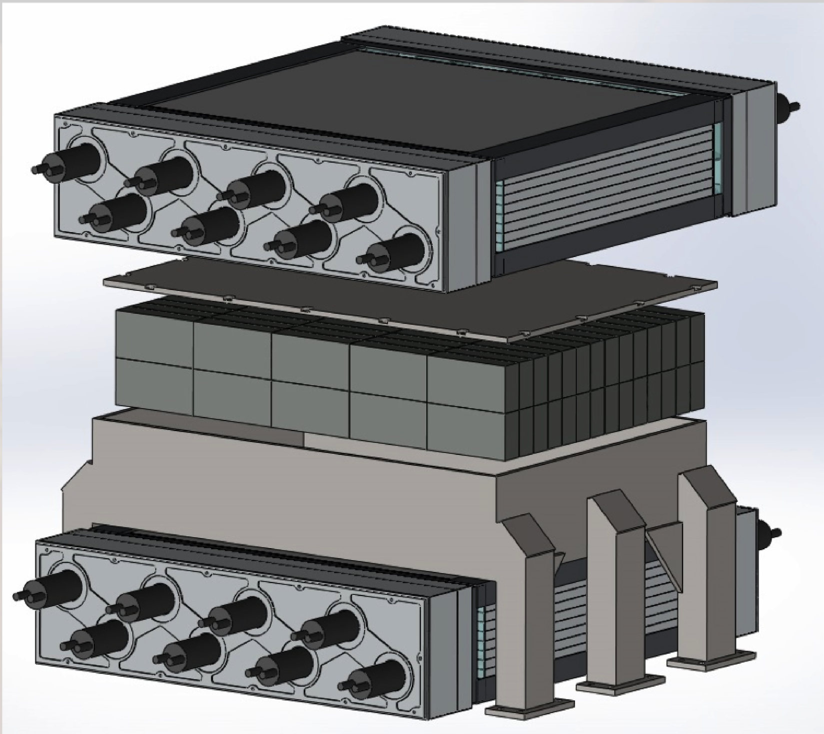
- Neutron Scatter Energy during thermalization
- Number of neutron captures
- Energy in neutron captures
- Time between first and last neutron capture



Experimental Setup

To measure the multiplicity signal we have constructed a detector composed of two active sections which surround a steel table holding 1.5 metric tons of lead bricks.

- Twelve 1.0x0.75x0.02m^3 plastic scintillator sheets per active section
- Each sheet's interior is coated in a white reflective paint doped with Gd
- Sixteen 5" PMTs per active section



Preliminary Unfolding Results

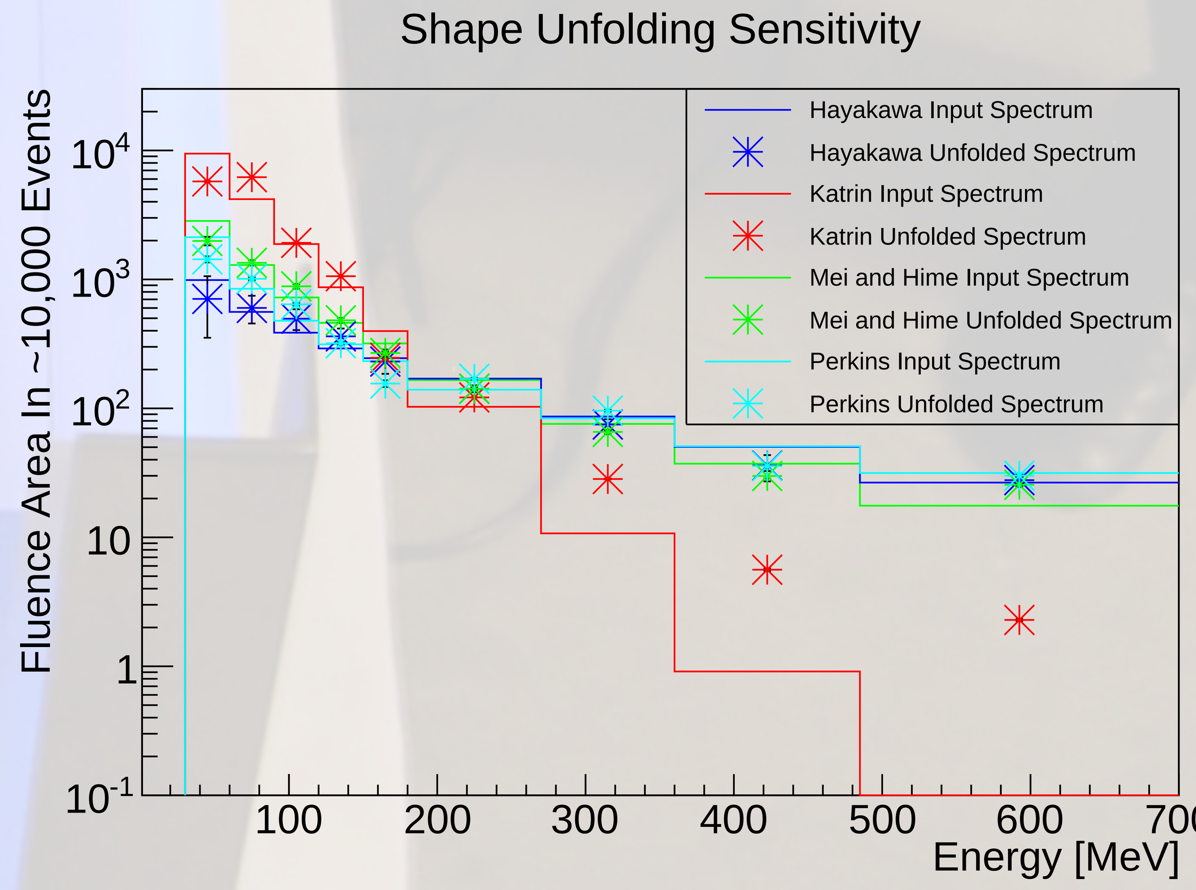
To unfold the energy spectrum we use a Maximum-Likelihood Expectation-Maximization (MLEM) algorithm. We attempt to solve the matrix equation

$$\vec{g} = \mathbf{A}\vec{f} + \vec{b}, \tag{1}$$

where g is the 4 vector recorded space, A is the kernel matrix created from a Geant4.9.6.p02 [4, 5] model using modified neutron carbon physics from MENATE_R [6, 7], f is the energy dependent neutron flux, and b is the background. To solve Eq. 1 we use the algorithm developed by Shepp and Vardi [8]

$$f^{k+1} = \frac{f^k}{\sum_{i=1}^{n} \mathbf{A_{ij}}} \sum_{i=1}^{n} \mathbf{A_{ij}} \frac{g_{meas,i}}{g^k_{pred,i}}, \tag{2}$$

where k is the iteration, g_{meas} is from Eq. 1, and $g^k_{pred}=\mathbf{A}\vec{f}^k$. The figure below indicates our MLEM's ability to unfold four candidate spectra shapes with roughly the same statistics as the already performed measurements.



Conclusions

Fast neutrons are an important background for rare-event neutral-particle detectors. The energy dependent neutron flux has been poorly measured at shallow overburden and predicted at deep depths from the muon flux. We have constructed and deployed a detector capable of measuring the energy dependent neutron flux using a fast-to-slow neutron amplifier. Several shallow depth measurements have been performed and one deep depth measurement is being performed. Monte Carlo data predicts an ability to reconstruct the energy dependent flux using a MLEM algorithm.

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