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Fast Neutron Backgrounds for Anti-Neutrino Based Nuclear Reactor Monitoring as a Function of Overburden

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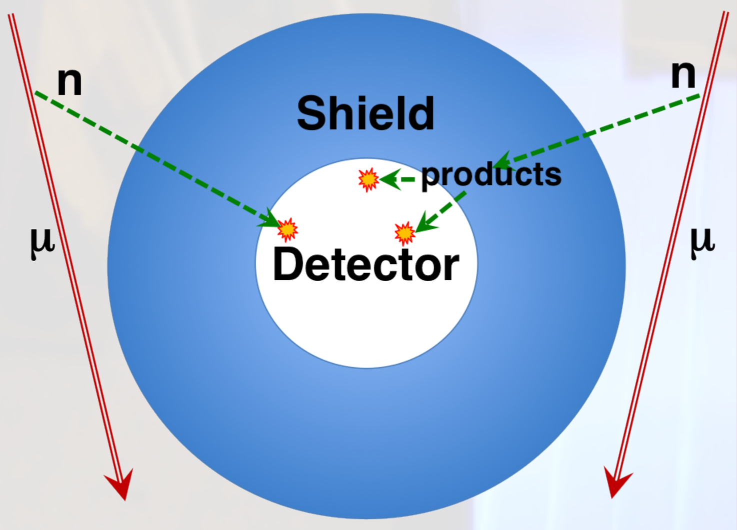
Introduction

Fast neutrons created from muons produce a depth dependent background for neutral-particle rare-event detectors.

- Neutron flux poorly measured at shallow depths and predicted at deep depths
- One energy dependent neutron flux measurements exists at moderate depth [1, 2]
- Must measure the neutron anti-coincident from the muon

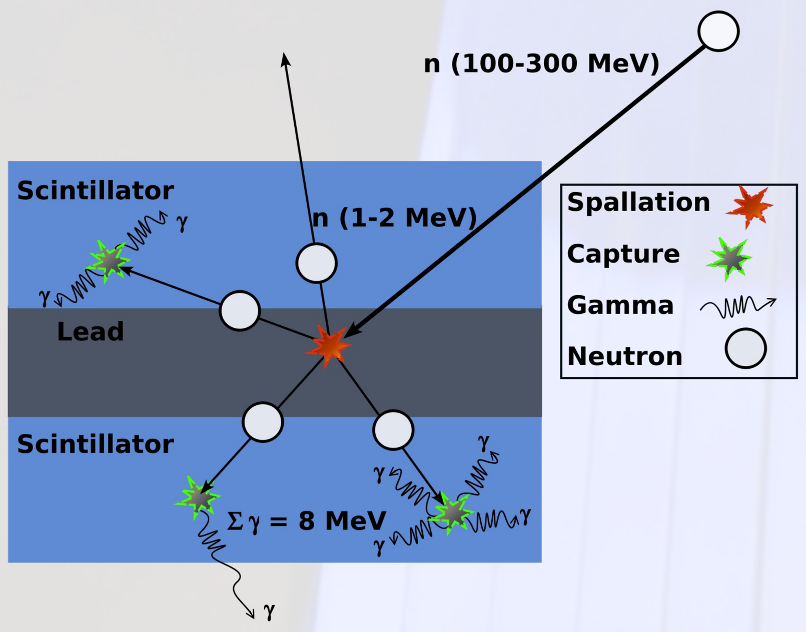


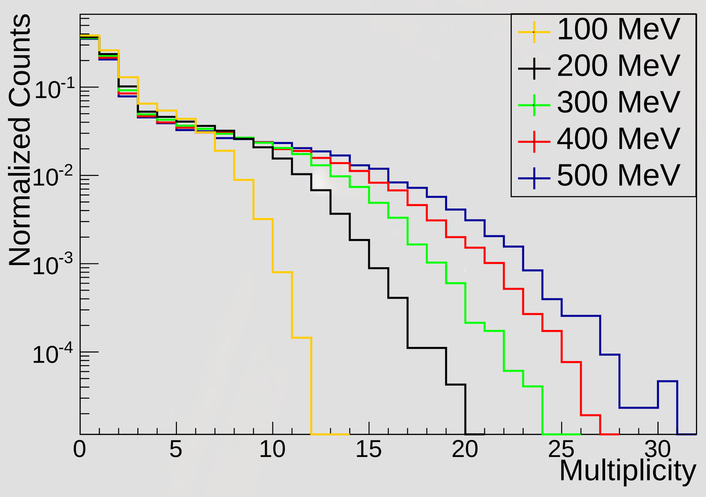
The detector described here has completed measurements at 380 and 600 m.w.e. at the Kimballton Underground Research Facility (KURF). Currently it is making it's last underground measurement at 1450 m.w.e. The neutron energy dependent flux will be used as an input into the design of the WATCHMAN detector, a proposed long-range nuclear reactor monitoring experiment using anti-neutrinos and inverse-beta decay.

Measurement Concept

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

- Fast neutrons spallate on lead amplifier
- Multiple lower energy neutrons are produced
- Secondary neutrons are thermalized quickly in the capture detector

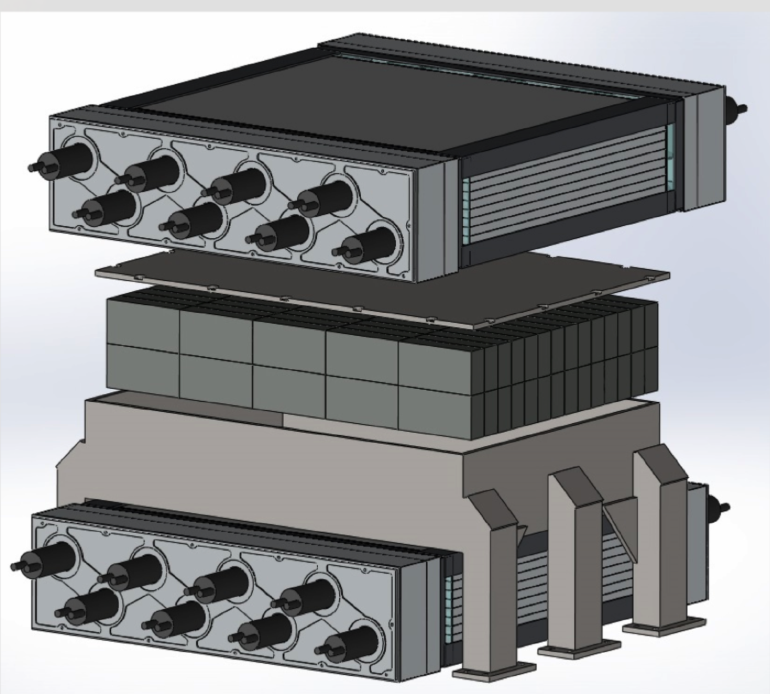




- Thermal neutrons capture on Gadolinium nucleus creating prominent multiplicity signal
- Multiplicity is proportional to the incident neutron energy

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

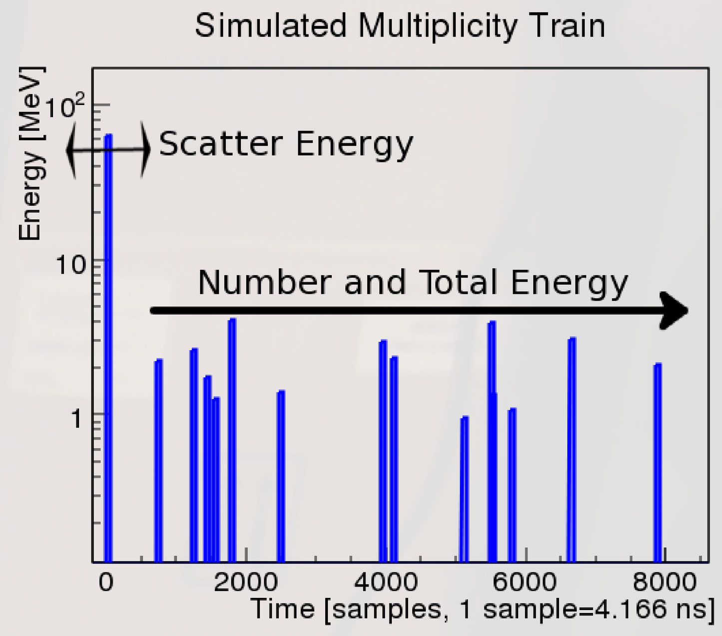


- Twelve 1.0x0.75x0.02m^3 plastic scintillator sheets per active section
- Each sheet's interior is coated in a white reflective paint doped with Gd
- Sixteen 5" PMTs per active section

Expected Detector Response

The energy and multiplicity threshold are currently not optimized. We require 500 keV per interaction and 5 interactions per event to record the following signals:

- Neutron Scatter Energy during thermalization
- Number of neutron captures (multiplicity)
- Total energy of neutron captures

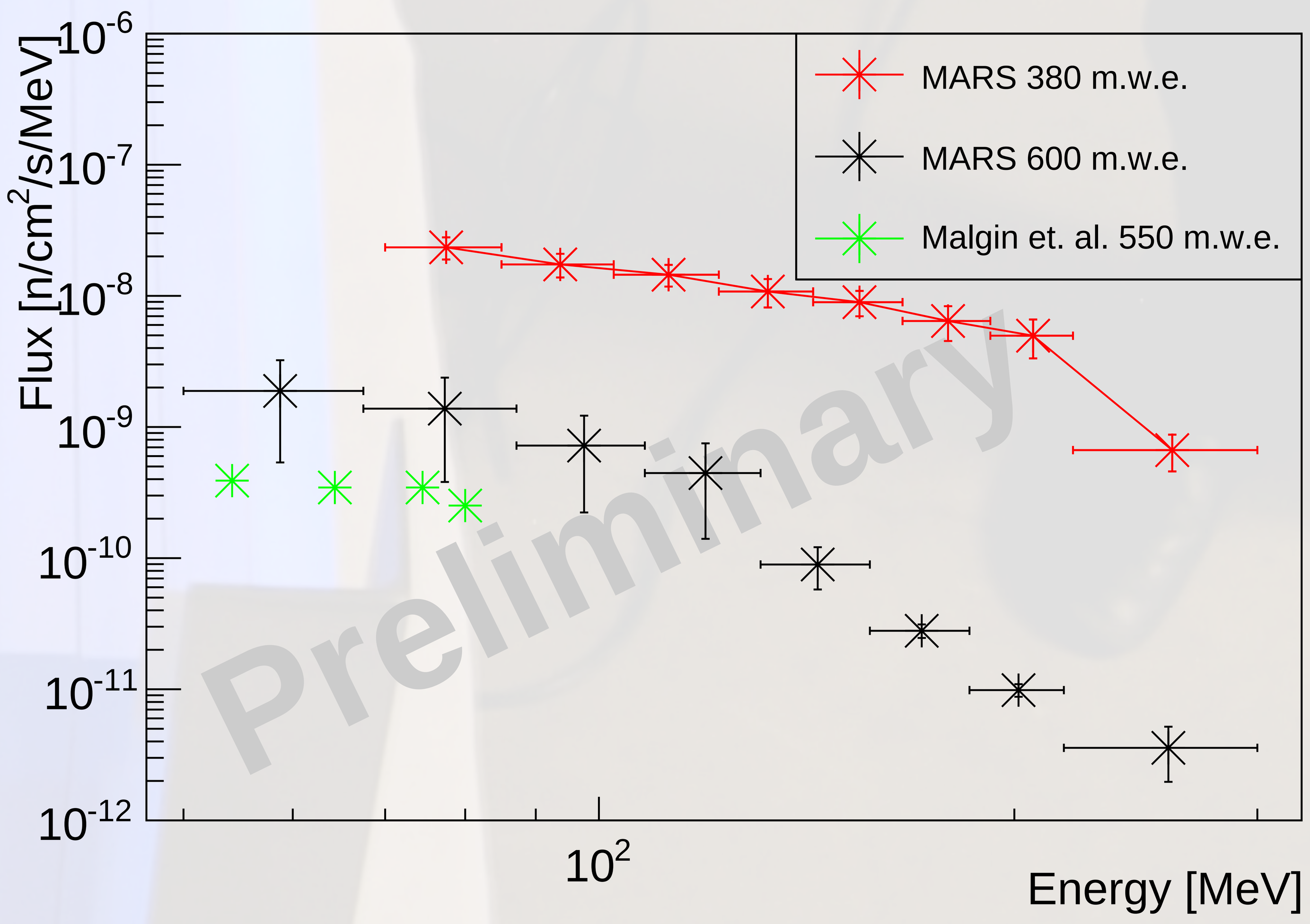


Preliminary Results

To unfold the energy spectrum we use a Maximum-Likelihood Expectation-Maximization (MLEM) algorithm [3] with regularization [4]. We solve the matrix equation

$$\vec{g} = \mathbf{A}\vec{f} + \vec{b}, \quad (1)$$

where g is the 3 vector recorded space, A is the kernel matrix created from a Geant4.9.6.p02 [5, 6] model using modified neutron carbon physics from MENATE_R [7, 8], f is the energy dependent neutron flux, and b is the background. The figure below represents preliminary results at 380 and 600 m.w.e.; systematic error bars are generated by using the MLEM algorithm with different multiplicity requirements.



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. Two shallow to moderate depth measurements have been performed and one deep depth measurement is being performed. A MLEM algorithm has been used to produce preliminary results at 380 and 600 m.w.e.

References

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