Neutron monitors for MINER experiment

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The Mitchell Institute Neutrino Experiment at Reactor (MINER) is an international collaboration across 10 institutions over 4 countries that aims at measuring coherent neutrino-nucleus scattering (CNS) and sterile neutrinos. Measuring CNS is a sensitive probe for physics beyond the Standard Model and has cross section that is two-three orders of magnitude higher than a neutrino-nucleon cross section, making it possible to observe CNS using relatively small quantities of detector material (~10 kg of high purity Germanium or Silicon detectors). The CNS events are identified by the low energy nuclear recoils (Si or Ge) they produce as a result of neutrino elastic scattering. There are many challenges associated with this project. Since energy of the nuclear recoils is in the range from 0 to 2 keV a state-of-the-art detector technology has to be implemented to make these measurements feasible. Another challenge, and the one that we focus on in this report, is accurate characterization and in-situ measurement of neutron background. Neutron scattering may produce events that have signatures identical to CNS. The MINER experiment uses the TAMU megawatt reactor at the Nuclear Science Center (NSC) as the neutrino source, therefore neutron flux is a major issue, even after careful shielding is implemented. Development of neutron detectors for neutron background measurements is the main contribution of the Cyclotron Institute to MINER collaboration. A detailed description of the two neutron detectors, ^{6}Li glass for thermal neutrons and p-terphenyl for fast neutrons, can be found in [1].

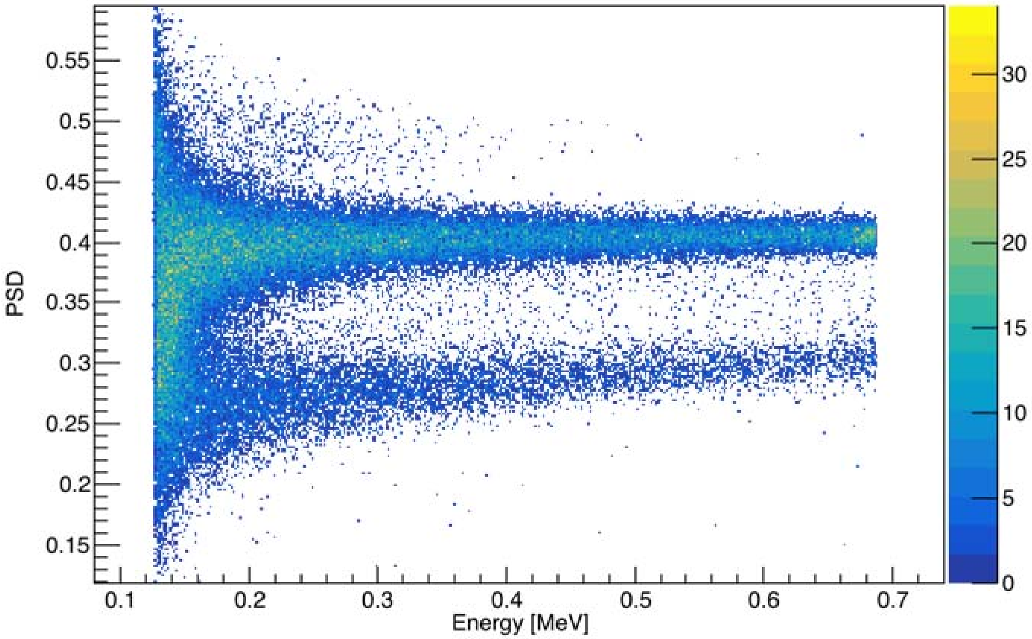

FIG. 1. The PSD vs recoil energies. The top band corresponds to gammas while the bottom band are the neutrons. Pulse shape discrimination is possible down to 160 keV.

An improvement that has been made to the p-terphenyl detector is the addition of a second photomultiplier tube (PMT). This allows for more light collection and subsequently can achieve better pulse shape discrimination (PSD) of fast neutrons and gammas at lower energies. As we record the waveforms of the signals, both PMT signals can be added together and continuous wavelet transforms (CWT) are used for PSD similar to the method used in [2]. The PSD is plotted vs neutron recoil energy in Fig. 1. There is clear separation down to neutron recoil energies of 160 keV.

To measure how well the PSD is between the neutrons and gammas, we can calculate the figure of merit (FOM) at different energies by fitting the neutron and gamma peak with a Gaussian function and calculating

$$FOM = \frac{\mu_n - \mu_\gamma}{2.36(\sigma_n + \sigma_\gamma)}$$

Where μ_n and μ_γ are the means of the peaks for the neutrons and gammas respectively while σ_n and σ_γ are the standard deviations of the peaks. A higher FOM means that the separation and PSD is much better. The FOM vs. energy is shown in Fig. 2. It is clear that the summation of the two PMT signals (purple) provides much better PSD compared to just a single PMT (red and blue). For neutron recoil energies above 500 keV, there is 5σ separation between the neutrons and gammas when summing the two PMTs. 3σ separation is achieved down to 230 keV.

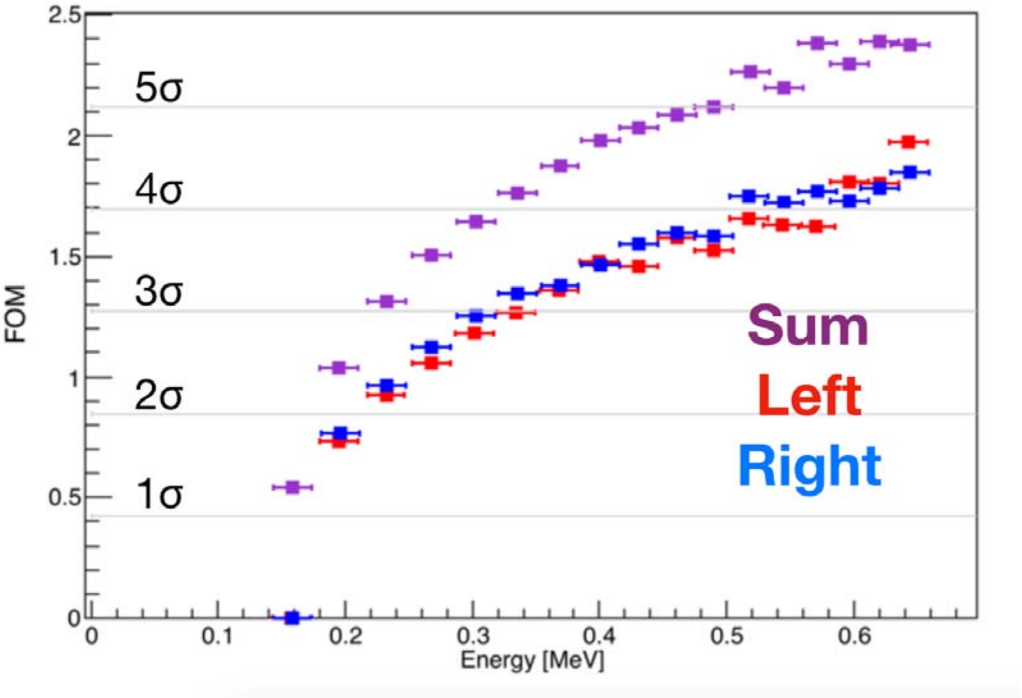

FIG. 2. The Figure-Of-Merit calculated for different neutron recoil energies. The red and blue points correspond to the individual PMT signals, the purple are the combined sum of both PMTs.

With the addition of the second PMT and the improved PSD we now achieve, we can provide even better neutron background measurements for the MINER collaboration. By measuring the flux of neutrons in both detectors, we can then test configurations of materials that reduce neutron background. A measurement of the integrated flux of fast neutrons inside the thermal column at the NSC was performed between 11/13/2017 and 11/17/2017 and is shown in Fig. 3. The neutron flux increases only by about a factor of two relative to the background when the reactor is "on" indicating that the shielding is working very well. The ^{6}Li glass scintillator measuring the thermal neutrons produced similar results when compared to the reactor "off" background. Another measurement was done between 04/20/2018 – 04/25/2018 outside the thermal column where the first MINER measurements are expected to take place. We saw no increase in the flux when the core was on.

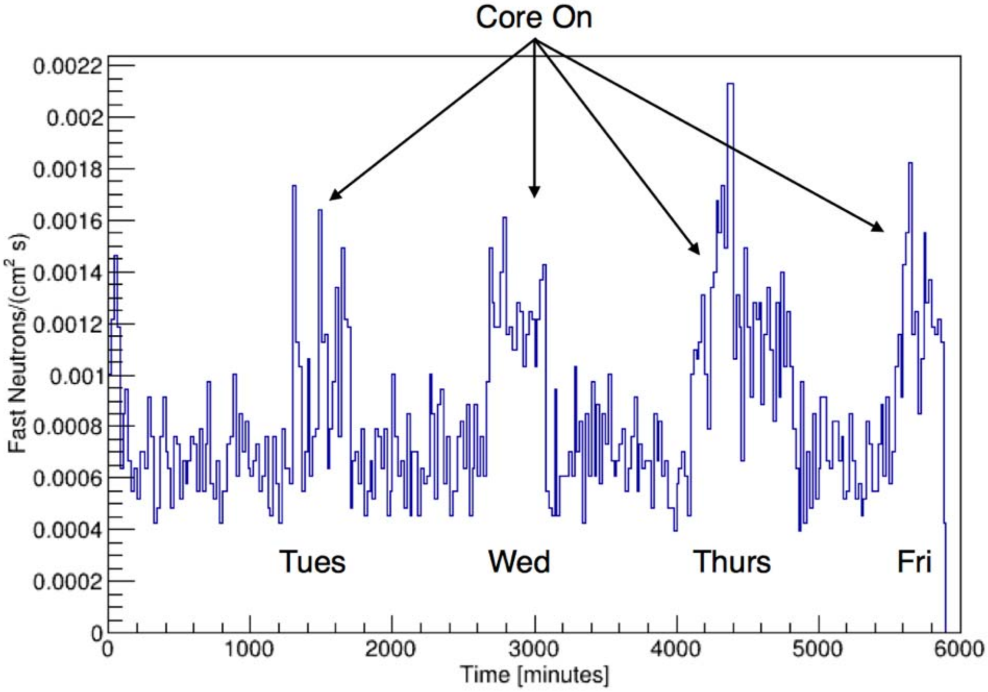

FIG. 3. The integrated fast neutron rate from measured in the p-terphenyl at the NSC.

Advanced computational techniques such as machine learning are currently being investigated to provide further improved discrimination of neutrons and gammas in both the p-terphenyl and ^{6}Li glass detectors.

[1] J. Hooker, G.V. Rogachev *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2016-2017) p. IV–53.

[2] S. Yousefi, L. Lucchese, and M.D. Aspinall, Nucl. Instrum. Methods Phys. Res. **A558**, 551 (2009).