Active 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) – an elusive process that has been predicted long time ago but never observed experimentally. This process 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. Elastically scattered neutrons may produce events that have signatures identical to CNS. The MINER experiment uses the TAMU megawatt reactor at the Nuclear Science Center 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.

We have built two types of neutron detectors – ^{6}Li glass scintillator detectors for thermal neutrons and P-terphenyl scintillator detectors for fast neutrons. In the ^{6}Li glass detector thermal neutrons (0.025 eV) are measured through the neutron capture reaction,

$$^{6}\text{Li} + \text{n} \rightarrow {}^{4}\text{He} + {}^{3}\text{H} + 4.78\ \text{MeV}$$

Since every thermal neutron capture releases the same amount of energy, 4.78 MeV, there should be a clear signal for those thermal capture events. The ^{6}Li glass scintillator has a diameter of 43 mm and a

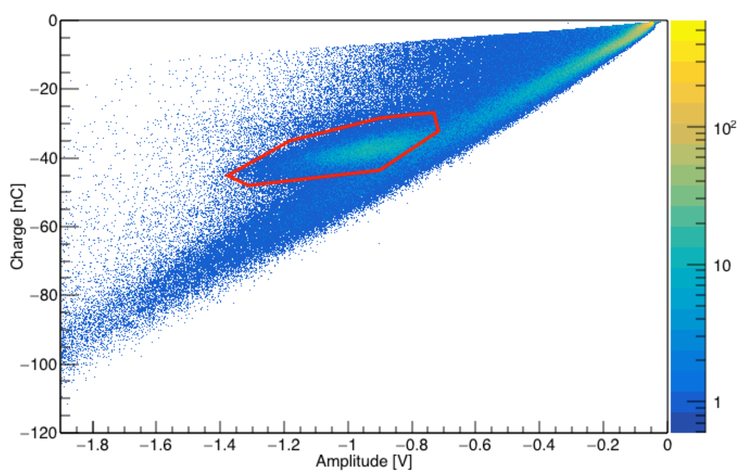

FIG. 1. Plot of the Amplitude vs Total Integrated Charge for the ^{6}Li Glass at 1800V bias. Events in the red outline are the thermal neutron events while those outside are mostly gamma rays.

thickness of 3 mm. It is connected to a Hamamatsu Photonics R7724-100 Photomuplier tube (PMT). Fig. 1 shows the amplitude vs total integrated charge scatter plot that is used to identify thermal neutron peak in the ^{6}Li glass scintillator. The thermal neutron events are circled by the solid red curve.

As we record the waveforms of the signals, we can apply advanced analysis techniques to enhance pulse shape discrimination. Typical neutron and γ-ray waveforms for the P-terphenyl scintillator are shown in Fig. 2. The decay time for the signals associated with neutrons (black) is longer than those

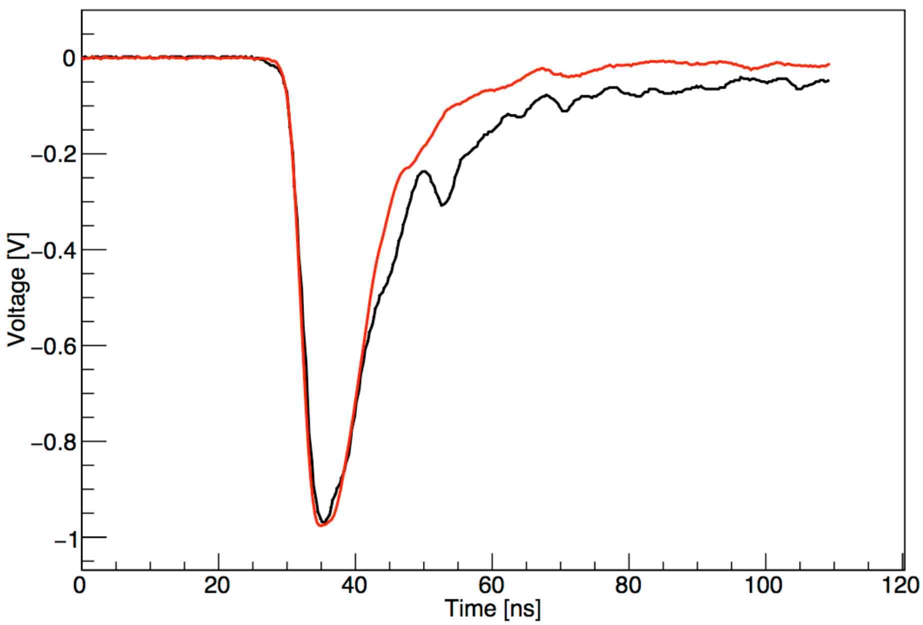

FIG. 2. Example waveforms from the P-terphenyl scintillator. The red signal is from a gamma ray while the black is a neutron signal. The neutron signal has a longer decay time than the gamma ray signal.

for γ rays (red) and that makes the basis for PSD. As shown in [1], continuous wavelet transforms can be applied to vastly improve PSD. By calculating the wavelet coefficients, we can sum the square of these coefficients, or the power spectrum, which can yield different properties for the type of signal that is being transformed. This transformation can be done over different scales to probe different frequencies. Continuous wavelet transform appears to be a very valuable tool as shown in Fig. 3 where the PSD is the ratio of the power spectrum for two different scales vs the amplitude of the signal. Huge PSD improvement was achieved by using continuous wavelet transform analysis as compared to just using the integrated charges as we are able to clearly separate neutron and γ events down to much smaller energies. An initial energy calibration was done using a ^{22}Na and ^{133}Ba sources. By finding the Compton Edge with the P-terphenyl scintillator, we can calibrate the electron equivalent energy. Currently, the lowest separation for the P-terphenyl scintillator is 20 keVee which is also shown in Fig. 3.

The next step for this project is to characterize the efficiency of the neutron detectors as a function of neutron energy with the P-terphenyl scintillator. This is done by measuring the time of flight between the neutron/gamma signal in the P-terphenyl vs the ^{252}Cf fission product measured in another scintillator close to the source.

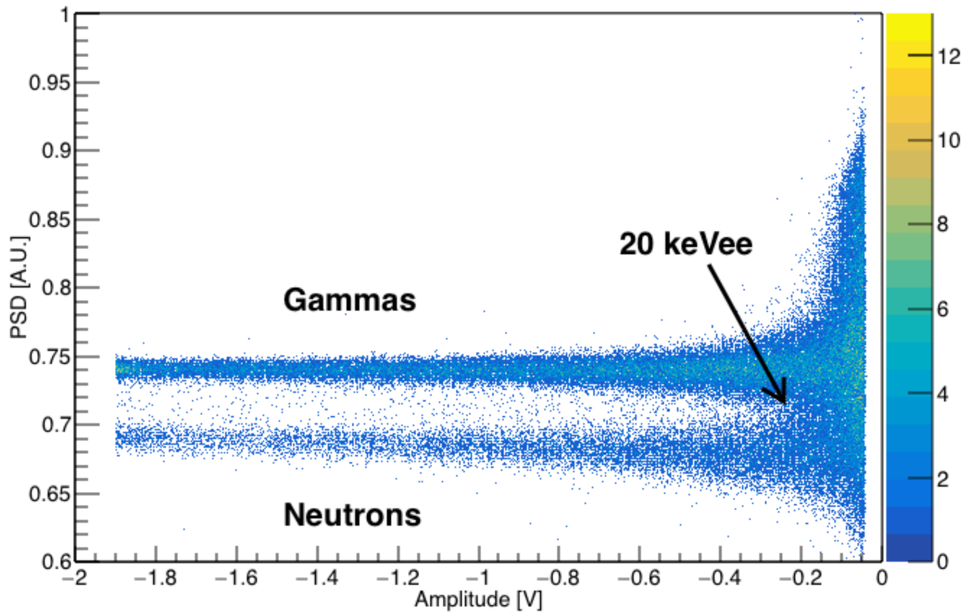

FIG. 3. Plot of the Amplitude vs PSD (using Wavelet Transforms) for the P-terphenyl scintillator at 1800V bias. As shown, there is a clear separation between neutrons and gammas down to 20 keVee.

In summary, two neutron detectors have been developed to characterize neutron background for reactor coherent neutrino scattering experiment (MINER). The ^{6}Li glass scintillator is used for thermal neutron measurements and the P-terphenyl scintillator for the fast neutrons. We now have a complete set of tools that will allow us to characterize neutron background for MINER experiment at all energies except for a small low energy region from about 1 eV to 50 keV, which can be extrapolated from the Monte Carlo simulation coupled to actual measurements at all other energies.

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