Simulating the Cosmic Ray Background for a Liquid Scintillator Neutrino Experiment

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ABSTRACT

Energetic particles produced in cosmic ray showers are a significant source of background noise in many modern liquid scintillator neutrino experiments. Here, we simulate the local cosmic ray background for the upcoming experiment JSNS^2 and study its expected efficiency at eliminating “false positive” cosmic muon, neutron, and gamma ray signals from collected data.

BACKGROUND

Neutrinos are light and abundant particles that oscillate between the three lepton “flavors” (electron, muon, and tau) with certain characteristic frequencies. However, past experiments, including the Liquid Scintillator Neutrino Detector at Los Alamos and MicroBooNE at Fermilab, have recorded imbalances in neutrino flavor that indicate oscillations occurring at frequencies other than those accepted by the Standard Model. The J-PARC Sterile Neutrino Search at J-PARC Spallation Neutron Source (JSNS^2) experiment will search for *sterile neutrinos,* a fourth type that may explain these unexpected observations.

JSNS2 detects neutrinos through inverse beta decay:

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

The positron will interact with a nearby atom and produce a **prompt flash;** the neutron will be captured by a nucleus and produce a **delayed signal** on the order of 30 μs. This double coincidence is useful for determining whether a particular signal is a true or false positive.

SIMULATIONS

The JSNS^2 detector geometry is written using Geant4 and the Reactor Analysis Tool, two C++ toolkits used to model particle interactions in matter. Before simulating any realistic cosmic ray events, two specific parameters were changed in the encoded detector geometry. The first introduced acrylic I-beam support structures to the base of the inner volume as shown in Figure 1.

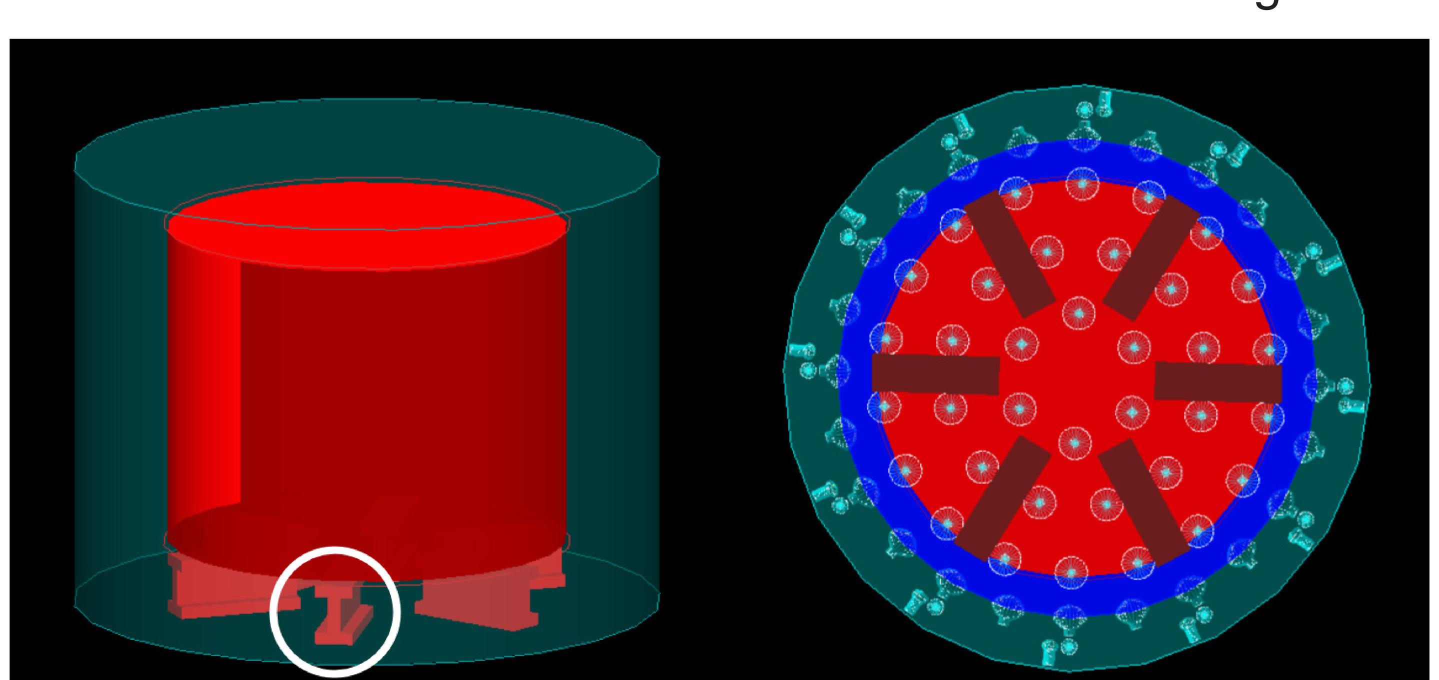

Figure 1. The layers of the detector geometry are clearly distinguishable, with the acrylic supports highlighted at the base of the inner volume. Both the six-fold symmetry of the supports and the twelve-fold photomultiplier tube (PMT) symmetry are visible.

The second consisted of the investigation of an unphysical light leak between volumes. This occurred due to encoded PMT volumes overlapping with and therefore overwriting the optical separator layer. This left a ring at the edge of each PMT through which photons could pass without contacting the optical separator or the PMT photodiode.

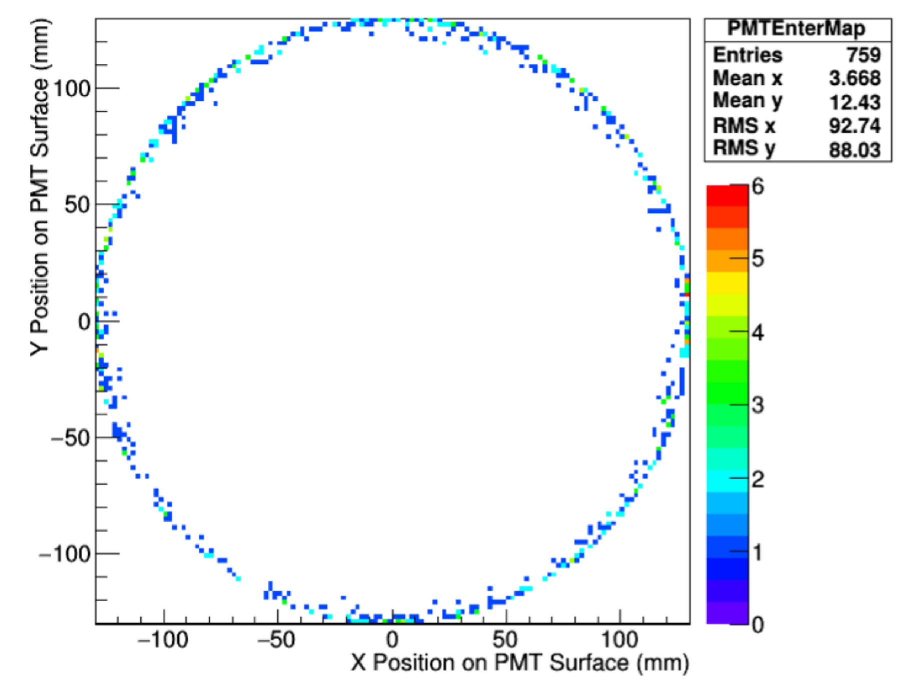

Figure 2. A map of the locations where leaking photons entered each PMT. This suggested that the optical separator was not functioning properly inside the PMT volume.

To combat this, the PMT structure was divided into multiple volumes, none of which overlapped with the optical separator. The light leak was extinguished after this change was implemented.

Certain results from Ajimura et al. (2017) were reproduced in order to verify that the new detector geometry was operating as expected. Background cosmic ray showers were then simulated using the Cosmic-Ray Shower Library (CRY), specifically focusing on cosmic muons, neutrons, and gamma rays.

RESULTS

A clear indicator of a particle’s characteristic interaction with the detector is its *energy deposition spectrum,* shown below in Figure 3 for muons, neutrons, and gamma rays.

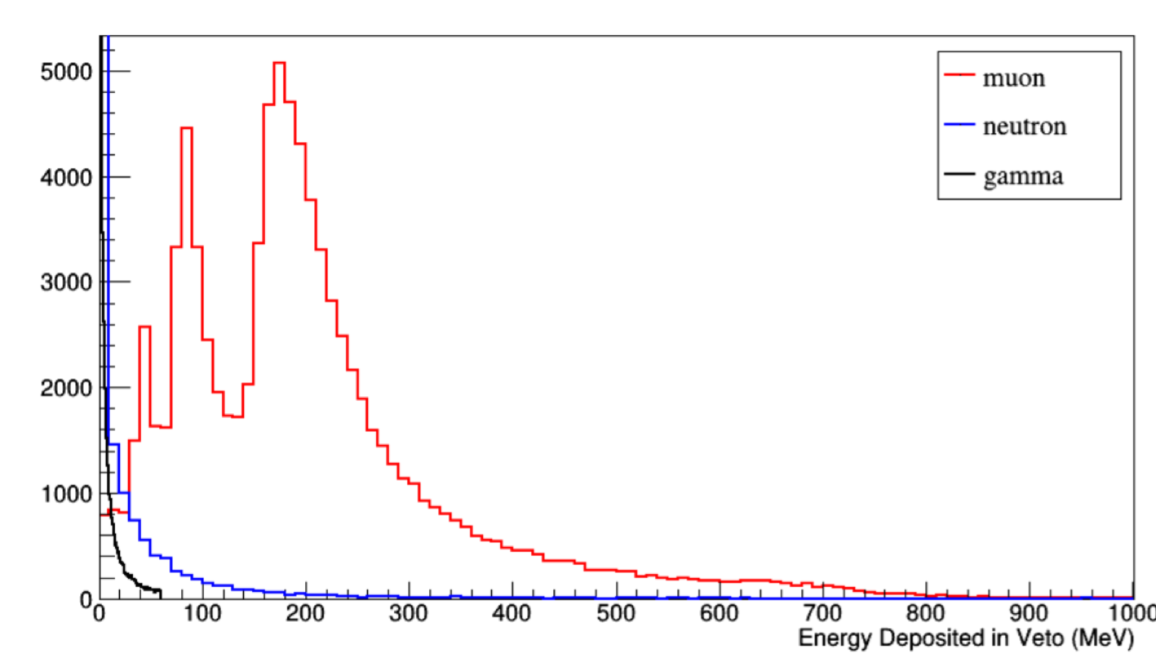

Figure 3. Energy deposition spectra for muons, neutrons, and gamma rays. From this plot it is clear that neutrons and gamma rays interact only minimally due to their electrically neutral states, whereas charged particles leave much stronger signatures.

However, although useful in simulations, the energy deposition spectra are not observable by an experiment such as JSNS^2. Therefore some observable quantity must be determined in order to synthesize these spectra.

One such observable is the *number of photoelectrons* (PEs) detected by PMTs in the outer layer of the detector. A histogram of this quantity is shown in Figure 4.

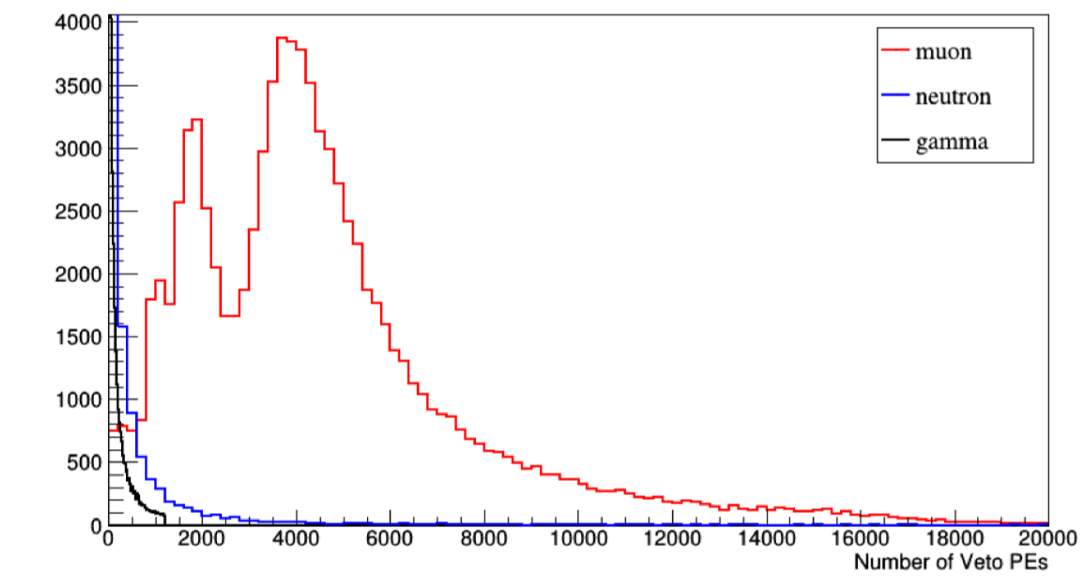

Figure 4. PEs detected in the veto layer, again for muons, neutrons, and gamma rays. The spectrum for each particle type has a shape similar to that of the energy deposition spectrum.

Figure 5 below shows the *efficiency* of the outer layer of the detector. This provides an estimate of the number of veto PEs detected at which any candidate signal can be attributed to the cosmic ray background.

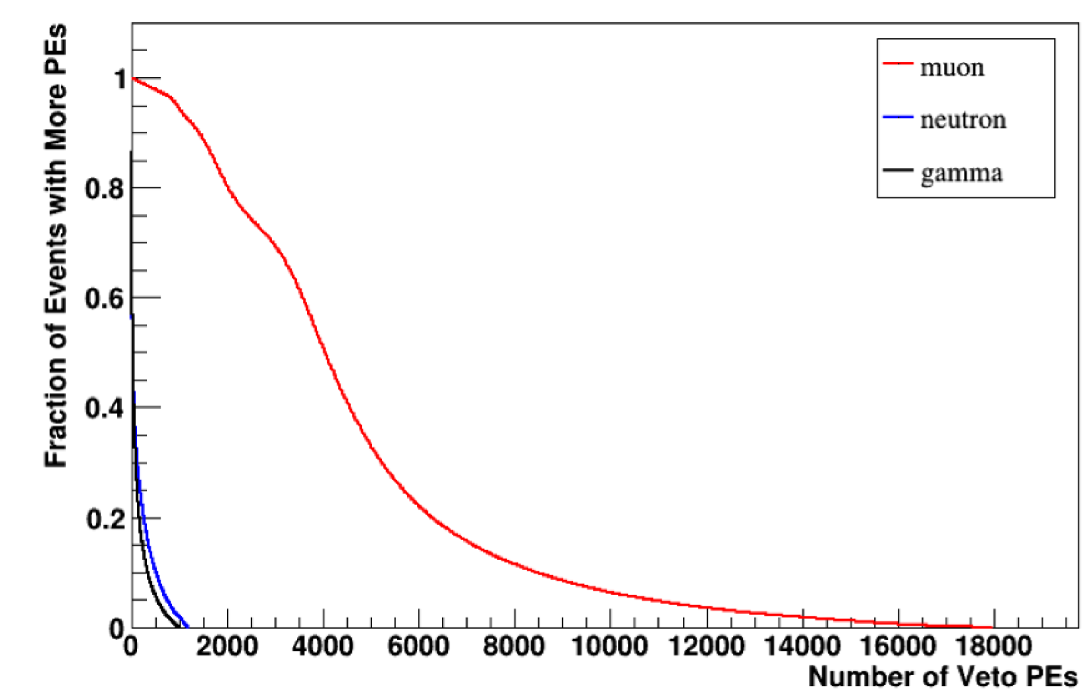

Figure 5. Efficiency of the external (veto) layer by number of veto PEs detected.

For example, establishing a “trigger” of 2000 PEs will completely eliminate signals from neutrons and gamma rays, as well as approximately 80% of muon detections.

SUMMARY

- Several changes to the encoded detector geometry were implemented in order to improve simulation quality.
- Tests of veto efficiency are now underway, starting with simulations of cosmic ray showers in CRY.
- JSNS^2 is currently under construction and will begin taking data in the first half of 2019.

ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under Grant No. 1559988. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the work of the National Science Foundation.

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