Characterizing the NuLat Detector with Coincidence Techniques

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Introduction

The **Neutrino Lattice Experiment (NuLat)** was designed to detect electron antineutrinos via inverse beta decay (IBD). With the use of a scintillating cube lattice that comprises NuLat, signals that appear from the resulting IBD reaction are collected which indicate the presence of the antineutrino. Currently, the NuLat detector requires a calibration before measurements can be taken. The objective of this project was therefore to characterize the response of NuLat to effectively determine a calibration. This was done by employing coincidence techniques that helped overcome some technical challenges. In this case, the gamma spectrum of different radioactive sources was collected with two detectors in coincidence. The signals generated by the radioactive decays were used for coincidence triggering between the detectors. One of the detectors is based on the inorganic scintillator **thallium-doped sodium iodide (NaI(Tl)).** The other is a single plastic scintillating cube from NuLat which initially will be thoroughly characterized, and this information will be extended to the full NuLat detector.

Neutrino Lattice Experiment (NuLat)

- NuLat focuses on the detection of electron antineutrinos that induce Inverse Beta Decay (IBD). The presence of an antineutrino is determined by the detection of the signals from the energy depositions of the IBD products. These signals correspond to electron-positron stopping annihilation and neutron capture.

$$\bar{\nu}_e + p \rightarrow e^+ + n \qquad \text{(inverse beta decay)}$$

- The NuLat detector consists of 125 scintillating plastic cubes based on **polyvinyl toluene (PVT),** each ^{6}Li-doped allowing for neutron capture. The cubes are arranged in a 5×5×5 lattice such that light generated from the energy depositions is directed towards **photomultiplier tubes (PMTs)** through total internal reflection. This arrangement uses the concept of the Raghavan Optical Lattice (ROL), and it is key for the reconstruction of the topology of the events.

- Light signals are collected by 75 PMTs installed on three of the exterior faces of the detector. These enter the PMTs where electrical signals are generated, which then are converted into digital signal using an ADC (analog-to-digital converter) for data analysis.

Coincidence Measurements with Gamma Sources

Before we could collect data with NuLat, we had to characterize the response of the detector to eventually calibrate it. We began with a smaller version of the PVT scintillating cubes used in NuLat and collected different gamma spectra using a NaI(Tl) detector in time coincidence with the single cube. Figure 1 shows the configuration of the experiment. Once the response of the PVT cube is completely determined, we can then extend the information to the full lattice in NuLat.

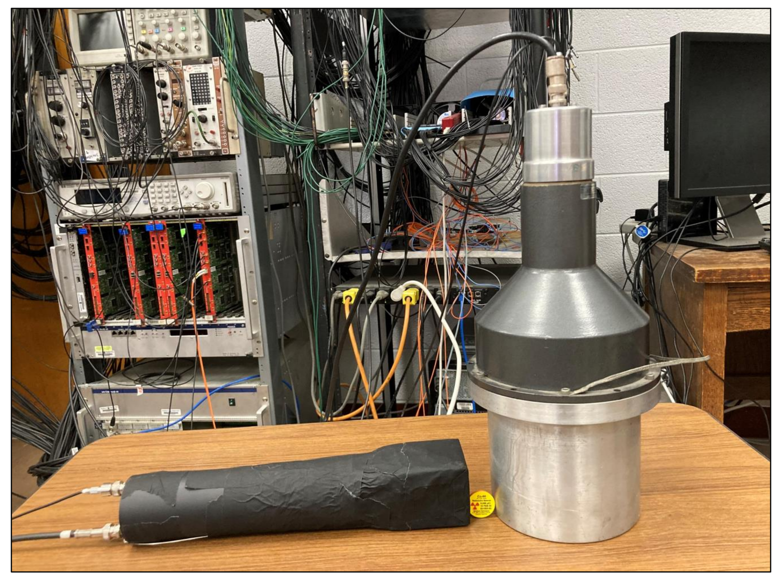

FIG. 1. The PVT detector is shown on the left, covered with paper to avoid external light. A sample of Co60 is between the PVT and the NaI(Tl) detector on the right.

Cobalt-60

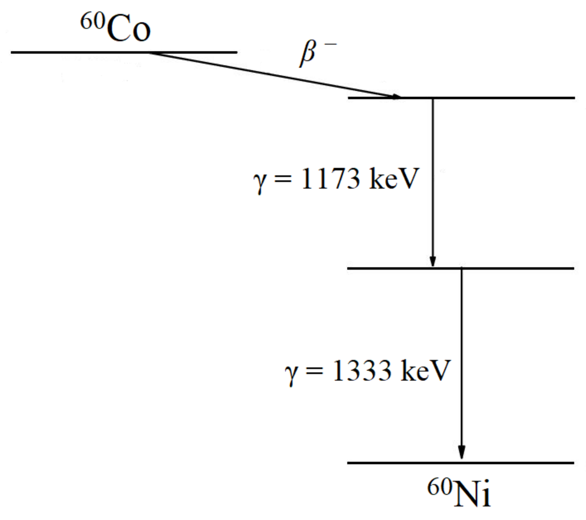

FIG. 2. The energy level diagram of Cobalt-60.

Cobalt-60 (^{60}Co) decays via β decay emitting an electron (β^-) and turning into an excited state of Nickel-60. A gamma ray with energy of 1173 keV is emitted by one of the transitions from the higher energy level to lower energy level state, and almost instantly another gamma ray is emitted with energy of 1333 keV as it reaches the ground state. This process is sketched on an energy level diagram shown in figure 2.

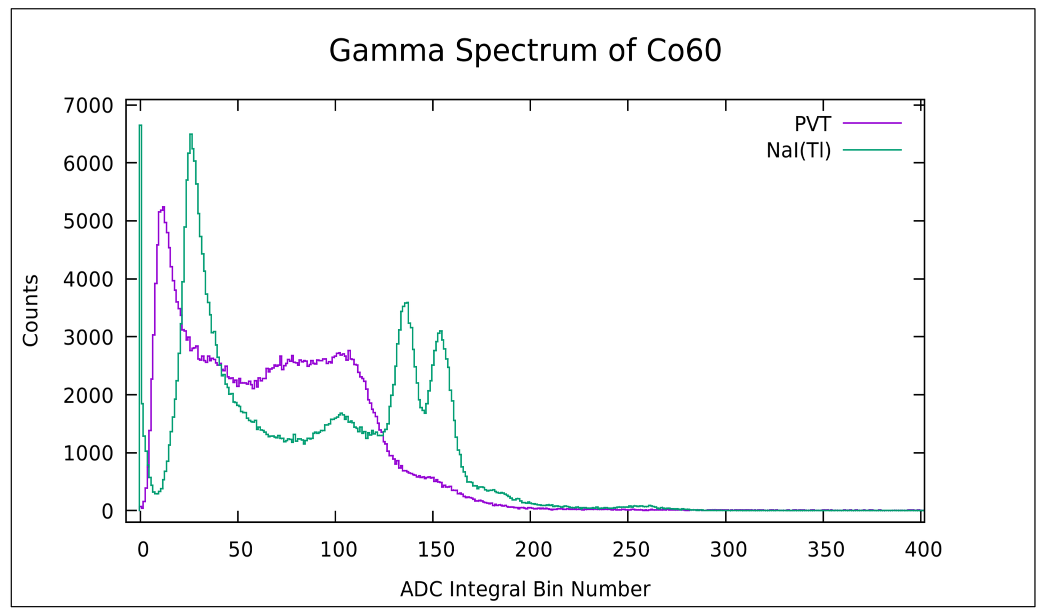

FIG. 3. The gamma spectrum of ^{60}Co triggered in coincidence between the PVT detector and NaI(Tl) detector.

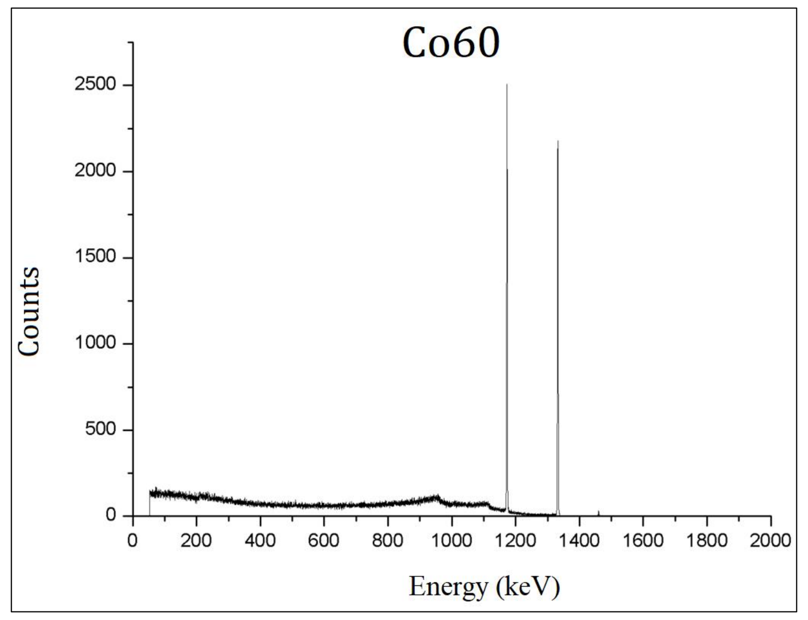

FIG. 4. The gamma spectrum of ^{60}Co taken with a HPGe detector.

Results

The two gamma emissions of ^{60}Co were convenient for coincidence triggering and studying the coincident spectra taken by the detectors. Our trigger was set so that signals were collected only if they were received in the two detectors, which enabled us to associate the signals of the PVT by performing cuts on the response function of NaI(Tl). In figure 5, the cut on the 1333 keV gamma gives rise to the Compton shoulder of the 1173 keV and vice versa. This is because we can infer that if one of the energies was deposited in one of the detectors, the other must have been deposited in the other detector.

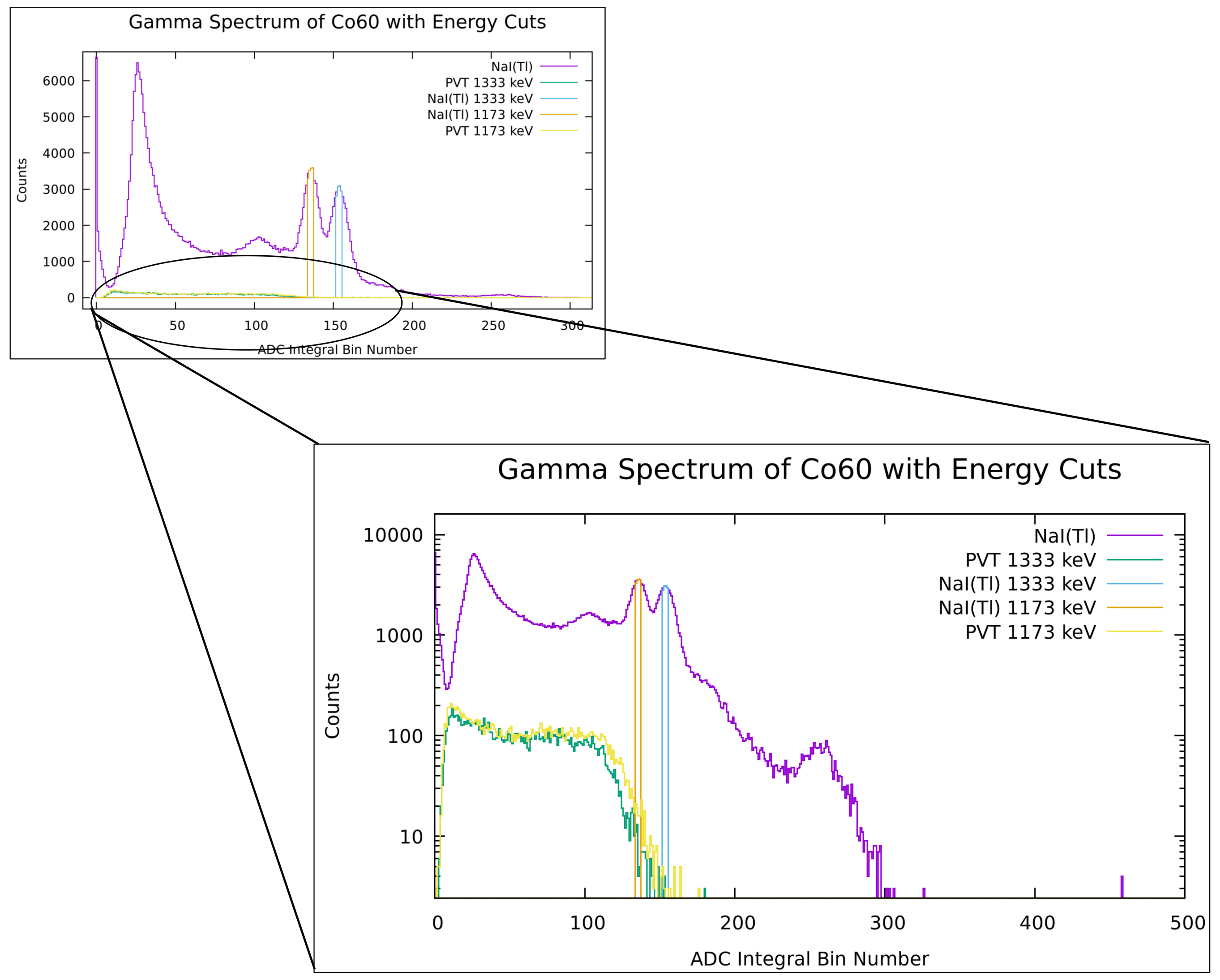

FIG. 5. The coincidence gamma spectra of Co60 with energy cuts shown in linear scale (back) and log scale (front). The Compton shoulders of the full energy peaks are visible in the log scale.

Acknowledgments

We acknowledge the outstanding support from the National Science Foundation, the Virginia Tech Physics department, and the Virginia Tech Center for Neutrino Physics. This work was made possible by the National Science Foundation, the immense collaboration of Tristan Wright and Brian Crow, and the wise mentorship of Dr. Bruce Vogelaar.

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