Angular Dependence of Compton Scattering Within Plastic Scintillators As a Way to Calibrate a Detector

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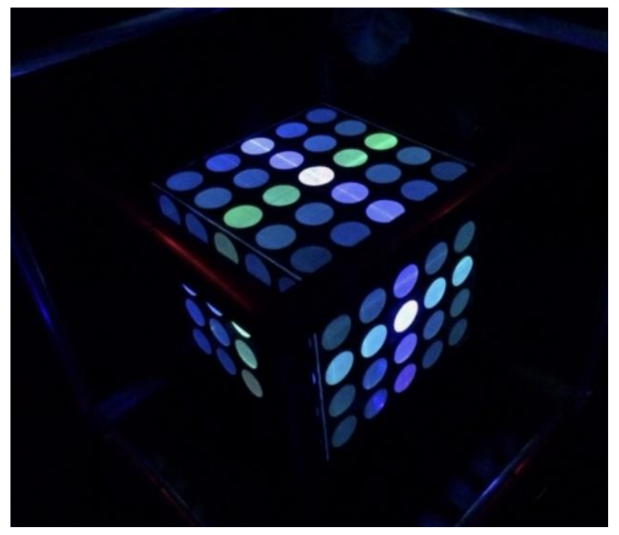
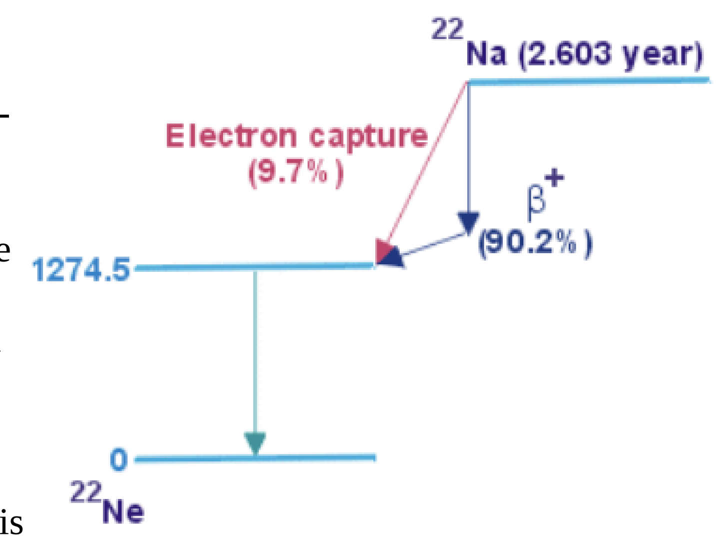
Motivation



The NuLat detector is a 5x5x5 array of plastic scintillator cubes. It is designed to be able to identify neutrino interactions and reject backgrounds even in an unshielded environment, making it useful for sterile neutrino searches and non-proliferation monitoring.

Introduction

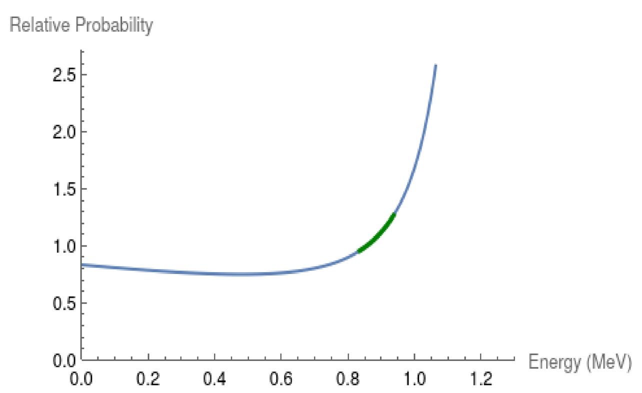


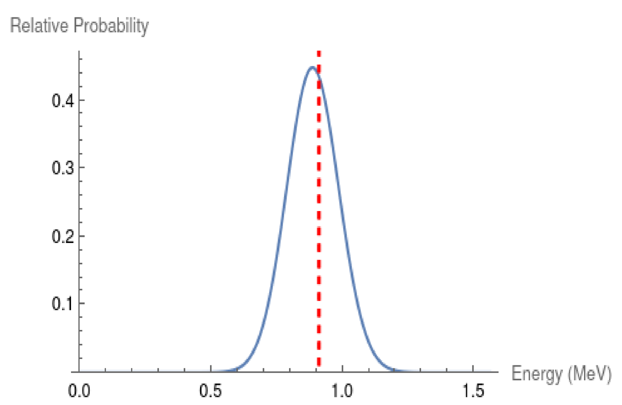
Sodium-22 produces a 1275 keV gamma ray as part of its beta-plus decay. The back-to-back 511 keV rays are spatially correlated; they are helpful for tagging the source decay.

The gamma rays can interact with nearby electrons and scatter, resulting in a less energetic gamma ray and a higher energetic electron. This is known as Compton Scattering.

Modeling

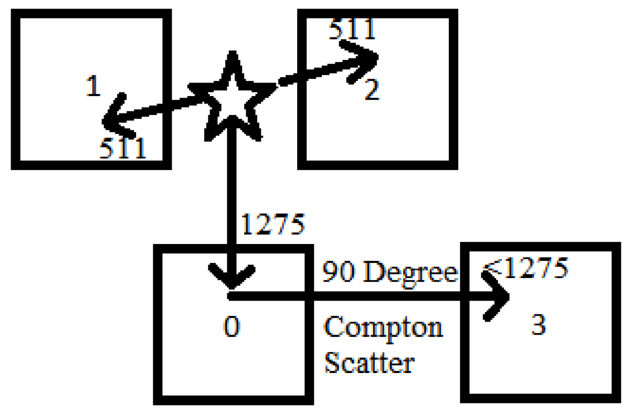
We can tag each instance the scattering event occurs at specific energy by constricting the angle.



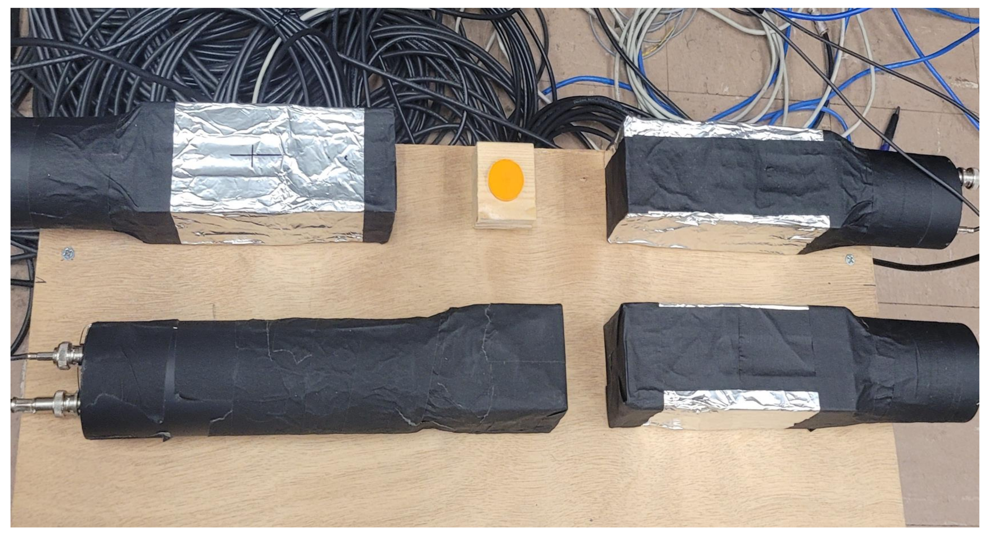


Here we focus on a model of what one photomultiplier tube (PMT) would detect if we observe 90° scatters. The graph on the left highlights in green the ideal curve we would observe for 90° plus or minus 6° uniformly. The graph to the right is that curve convolved with a Gaussian. This is meant to model the detection resolution. We observe some slight asymmetry; however, it is possible that uneven light collection may skew it more, as we see in our results. It also doesn't have a tail to the left which we predict may arise from the 1275 scattering in different materials or going to cube three first, resulting in a much less energetic ray in cube zero (refer to the diagram in the center). It is during this process that we can explain how something that would ideally be a peak shows up looking like a Klein-Nishina curve and why we measure its energy at the peak rather than the half height.

Experimental Methods



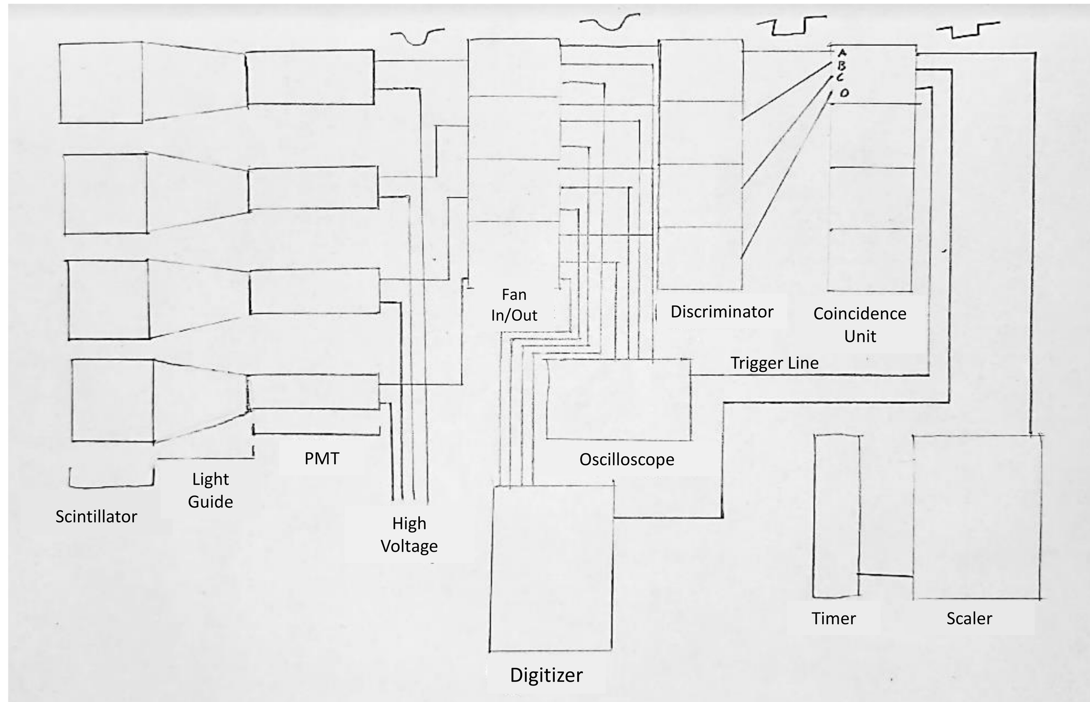
Our arrangement of scintillators. 1 and 2 tag the 511s because they're back-to-back, allowing us to be sure we see the 1275 keV gamma ray in cube 0 (see top right cell). We will observe the 1275 keV ray scattering from 0 to 3. The angle between them varies the energy deposited.



A quadruple coincidence setup for ninety degrees.

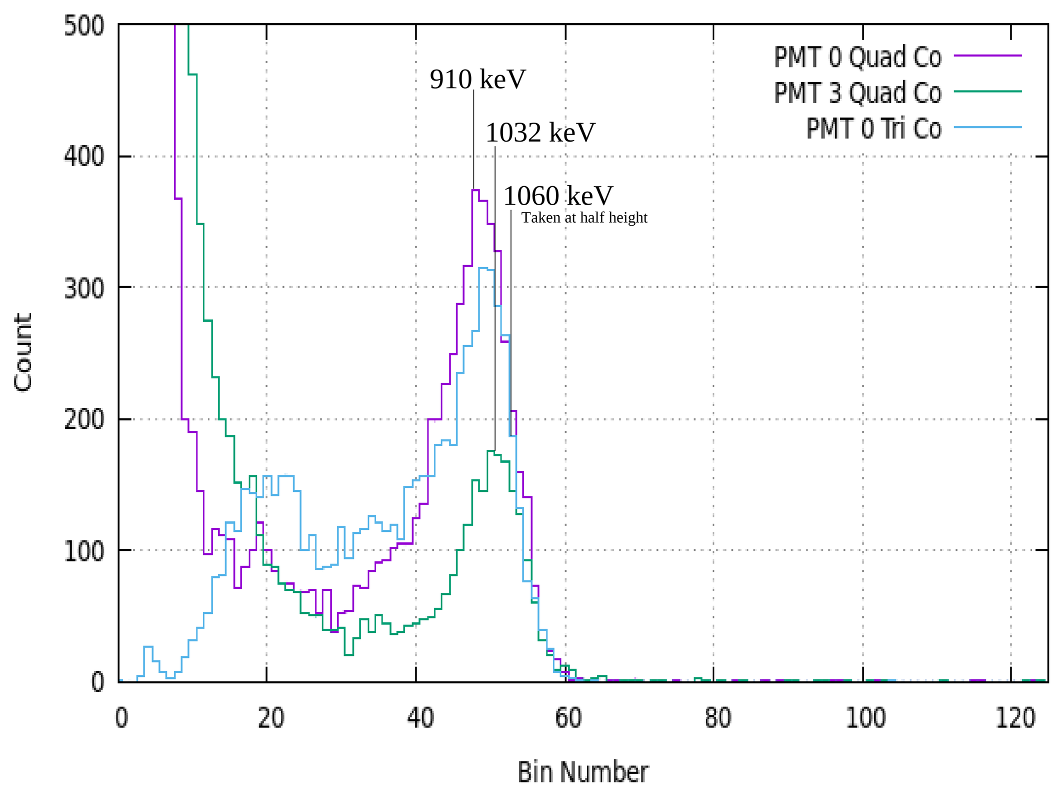
Because of the size and poor resolution of the detectors, we must be careful of how we interpret the data (see lower left). We had to balance improving the rate whilst keeping the graphs interpretable. There are a few ways we arranged the detectors to reduce the opening angle as well as 511 contamination:

- Moving 1 & 2 further from the source
- Moving 0 & 3 further from the source
- Lead shields (prevent scattering from 1 & 2 to cube 0)
- Vary energy thresholds

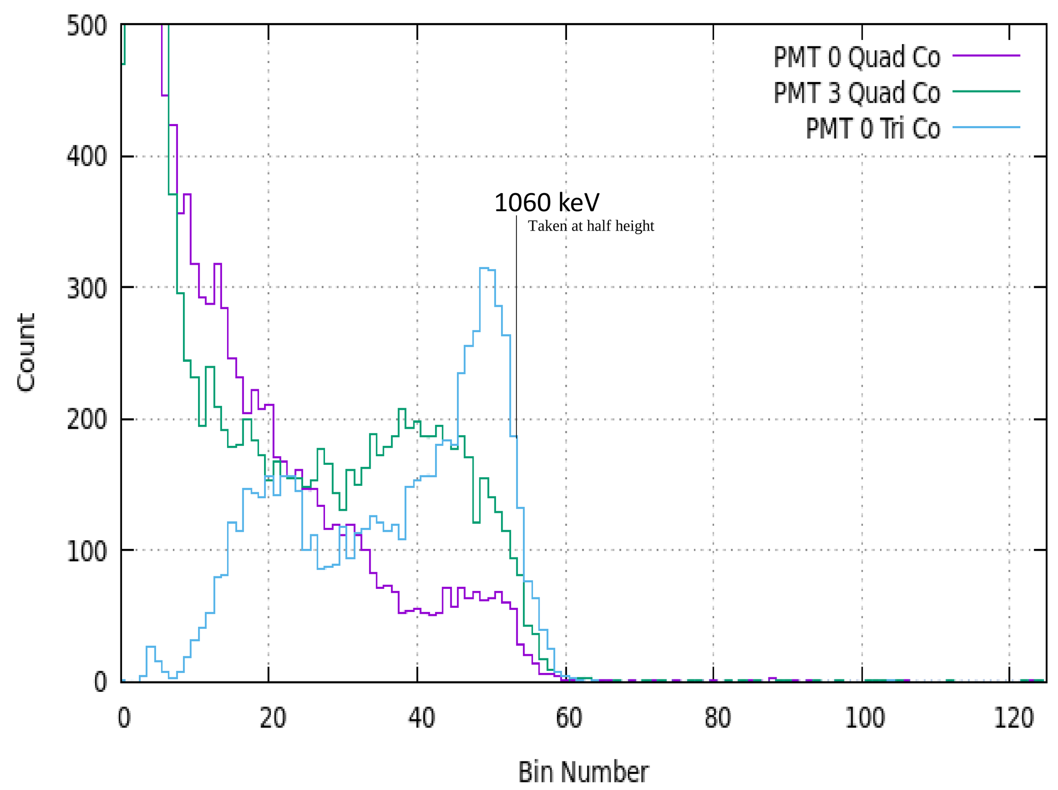


Signal logic to allow single and up to four-fold coincidence detection

Results and Limitations

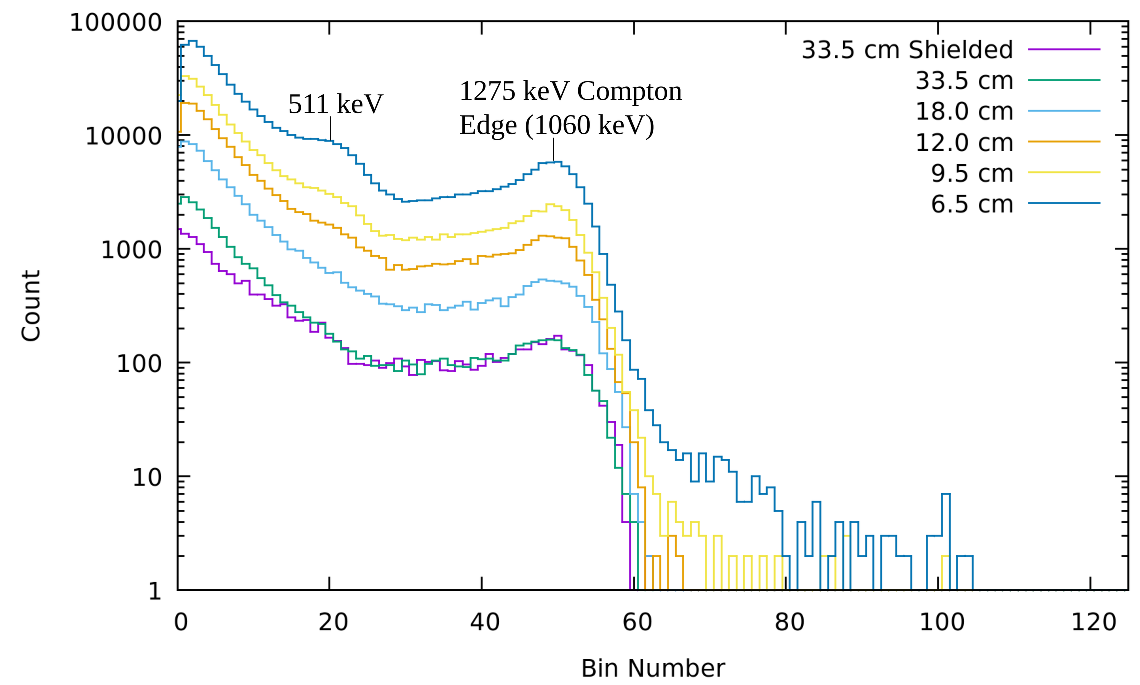


Spectra for 90 degrees. Labels refer to quadruple and triple coincidence data. The relative energies are measured in different places because some are actual peaks while others have a Klein-Nishina shape (we look at the half-height). More on this in the bottom left cell. Bin number is linearly proportional to energy, but the energies we know aren't quite spaced properly; a zero offset is likely what causes this.



This graph shows the spectra for 0°, where PMT 3 is "below" PMT 0. Ideally, a zero-degree Compton scatter would deposit no energy; however, the size of the cubes creates a range of angles, so we actually see what is shown above. It is likely that the 1275 backscatters from cube 3 into cube 0.

Results and Limitations



One way in which we decreased 511 contamination was by moving PMT 0 further from the source. We observe fewer low-energy events when we prevent scattering from cubes 1 and 2 down to cube 0 by placing lead shielding between them.

Some limitations we have observed throughout this project are as follows:

- Size of the individual scintillators
  - Restricting the angles between them
  - Types of interactions with gamma rays
- Scattering in materials other than the scintillators
- Scale of bin number to keV
- Size of the NuLat detector
- Strength of the source

Conclusion and Ambitions

The tabletop setup behaved as expected. In most cases, we were able to plot roughly what we predicted. It is promising that we can use this sodium source to calibrate the NuLat detector in the future. The source will be placed on top of the array, and if we can identify the angle between the first and second Compton scattering, we will know what energy to expect in a given cell. Placing the source above a certain column and looking at a single horizontal plane is one way we can do this. If the only light is in that plane, then it is likely that the first Compton scatter is directly under the source, and that the angle at which it scattered was 90°. If the detector reads a different energy, we can calibrate accordingly. Figuring out a gamma ray's energy from the energy it leaves behind is oftentimes challenging, but it is certainly possible.

Acknowledgments

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1. *Research on Neutrinos and NuLat*, (available at https://www.phys.hawaii.edu/~nulat/pages/research.html).
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