Commissioning of Data Acquisition System for Gamma Ray Spectroscopy

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Introduction

One of the biggest obstacles present today in rare event experiments studying the properties of neutrinos and dark matter are high energy particles such as gamma rays and muons present in the environment. By screening materials to be used in these experiments, we can identify and locate specific radioactive isotopes in order to prevent contamination in low background experiments. Our group runs multiple High Purity Germanium (HPGe) detectors in coincidence to increase the sensitivity of these screenings by rejecting uncorrelated background events and enabling localization of observed gamma rays to the screened material in question.

Methodology

- Two HPGe detectors run simultaneously while exposed to a radioactive sample
- Each high energy event detected will send an amplified signal to the Data Acquisition unit (DAQ) and is marked with a timestamp and energy level
- We compare the high energy received from the two detectors and look for events where the energy of the event is the same and the time between events is within an accepted threshold
- These events are compared to a background run to determine the contribution due to "accidental coincidences"

HPGe Detectors

This project employs two High Purity Germanium (HPGe) detectors and a CAEN DT5780 Data Acquisition Unit (DAQ). During the detector set-up, we optimized the pulse shaping parameters to result in increased energy resolution and linearity for both detectors.

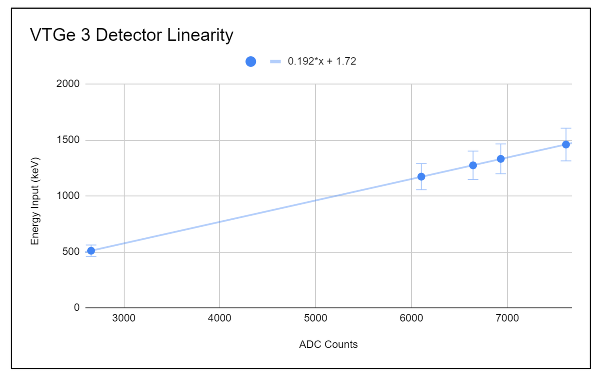


Figure 1: ADC counts vs. Energy to show detector linearity for VTGe3

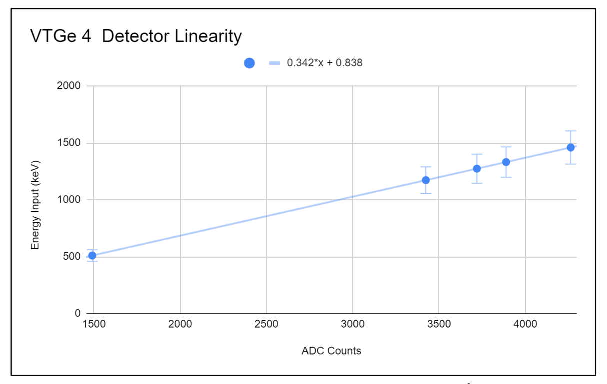


Figure 2: ADC counts vs. Energy to show detector linearity for VTGe4

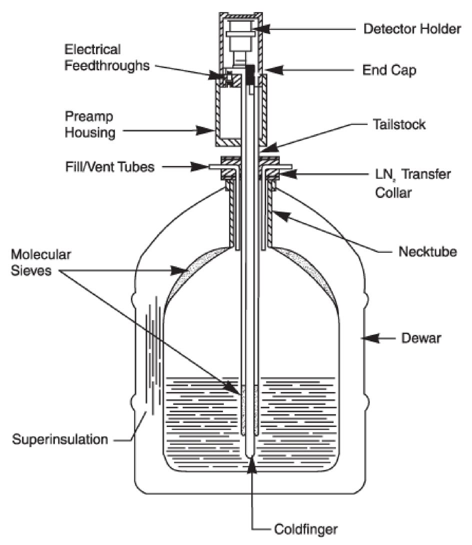


Figure 3: Vertical Dipstick Cryostat for HPGe detector

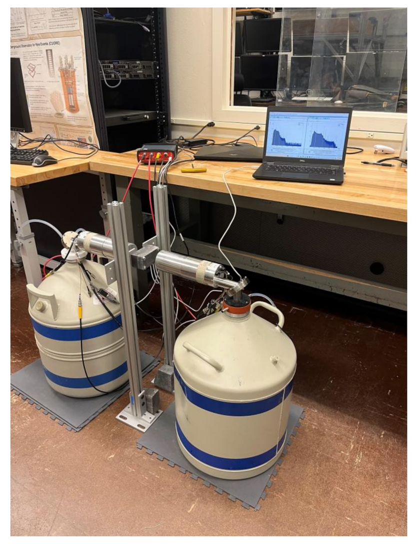


Figure 4: Detector Set-up for Na^{22} Coincidence Test with Lead Collimator

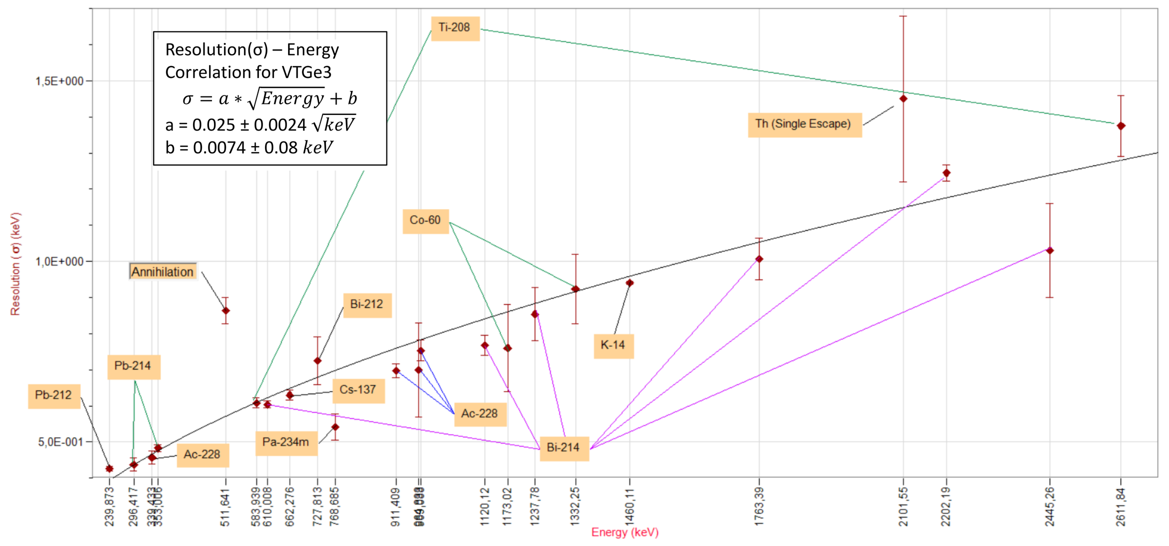


Figure 5: Energy Resolution-Energy distribution for common radioisotopes in the U^{238}, Th^{232}, and K^{40} decay chains commonly found in background measurements. Graph made with LoggerPro Software.

Coincidence Analysis

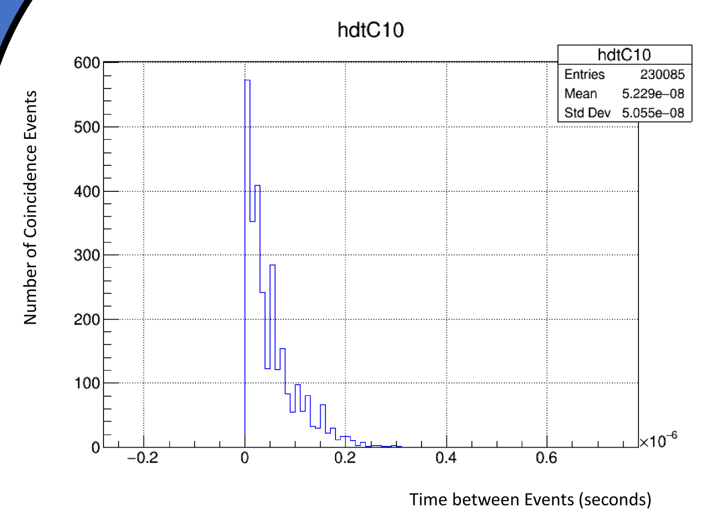


Figure 6: Coincidence Distribution with VTGe3 and VTGe4 for 0.102 µCi of Na^{22}

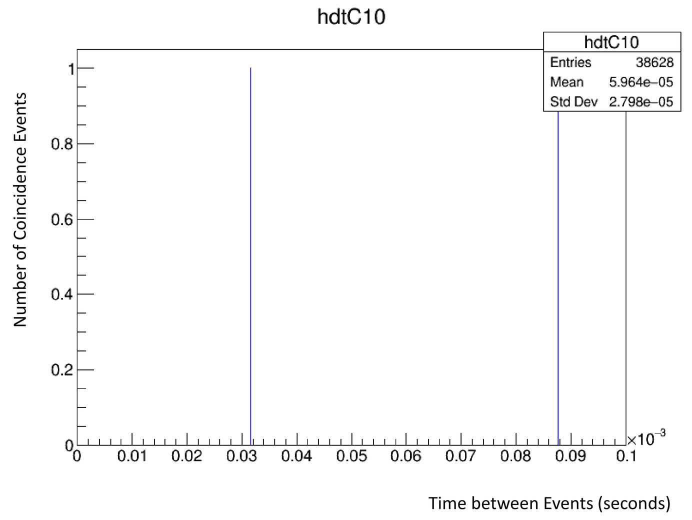


Figure 7: "Accidental" Coincidence Distribution with VTGe3 and VTGe4 for background data

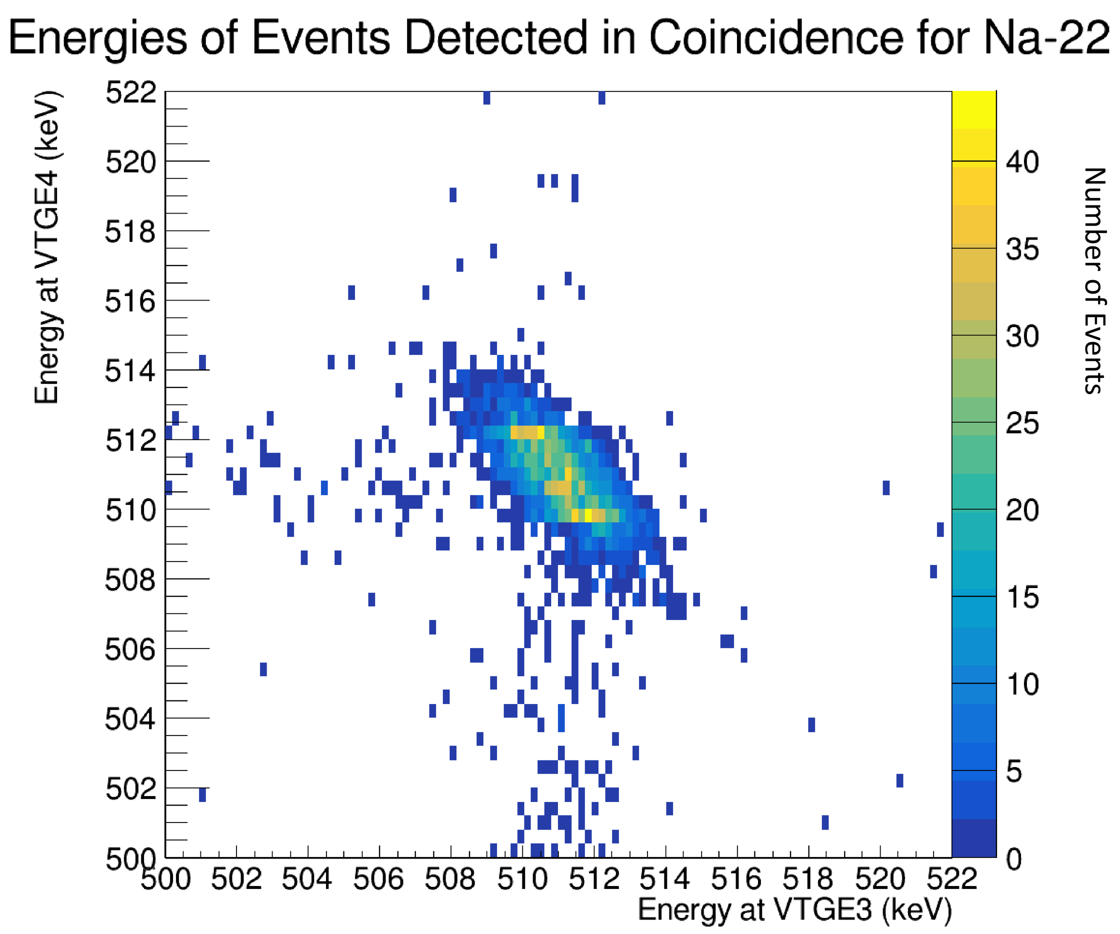


Figure 8: Coincidence event distribution, showing the intensity of coincidence at 511 keV for both detectors as a result of electron positron annihilation from the decay of Na^{22}

Our team compared the 511 keV coincidence events of a 24-hour run with 0.102 µCi Na^{22} source positioned in a lead collimator and a 24-hour background run with no source to determine how many of our detected coincidence events were emitted from the source. We compared the rate of emission for certain gamma rays from a 0.104 µCi Na^{22} source and a 0.05 µCi Co^{60} source to determine the efficiencies of the detectors and estimate the expected number of coincidence events. We also took measurements at varying distances to determine the relationship of the rate of detection and distance.

Detector	511 keV	1173 keV	1332 keV
VTGe3	0.05% ±5.9E-8%	0.03% ±6.724E-8%	0.02% ±5.448E-8%
VTGe4	0.03% ±4.515E-8%	0.02% ±5.652E-8%	0.01% ±4.326E-8%

Figure 9: Efficiency of the detectors for different gamma rays when the Co^{60} and Na^{22} sources are 30 cm from each detector

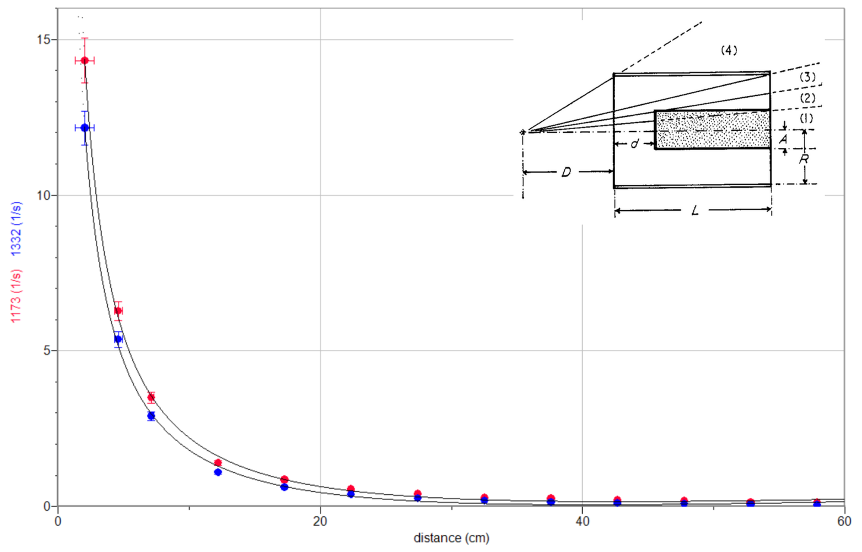


Figure 10: Distance from VTGe3 - Count Rate distribution for 1332 keV events (red) and 1173 keV events (blue). The image in the top right is an illustration of the Ge crystal geometry. The difference in crystal thickness may explain why we did not get the predicted inverse square relation.

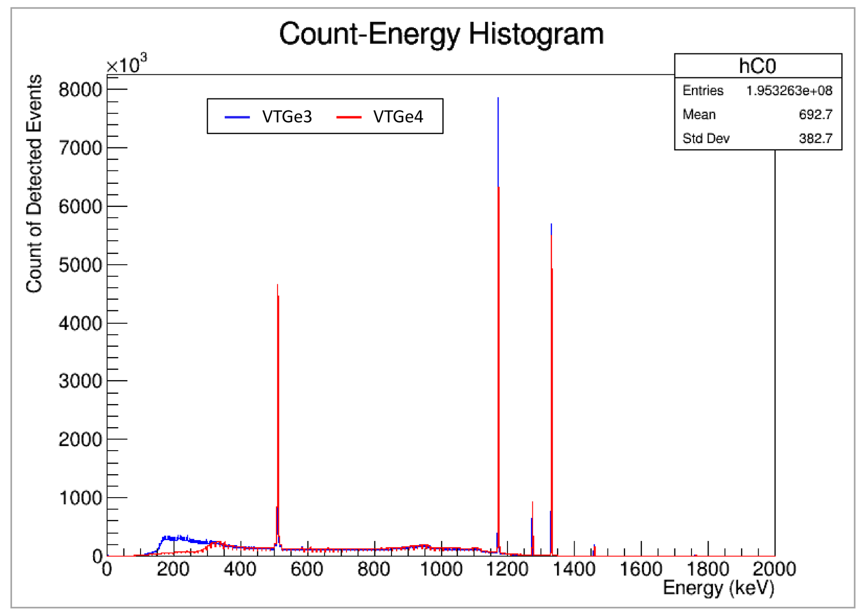


Figure 11: Energy-Count Histogram in root of VTGe3 and VTGe4 events illustrating relative detector efficiencies

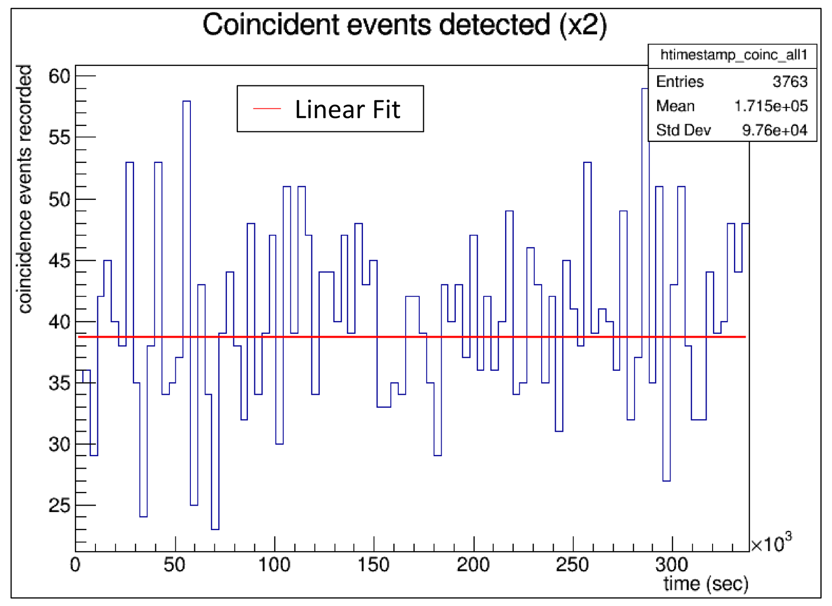


Figure 12: Number of 1173 keV 1332 keV coincidence events detected over time in hour-long intervals. This informs us of the long-term stability of the coincidence set-up over time. Data was collected with 1 µCi of Co^{60} 10 cm from each detector.

Results and Applications

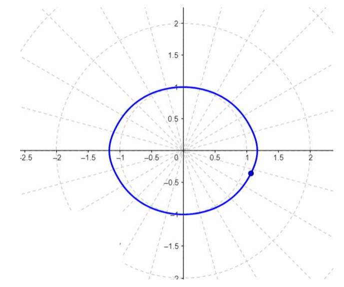
After finding successful coincidence events with low contamination with accidental background, our group tested several of the applications of the multiple detector set-up. Potential applications include:

- Measuring the angular correlation of emitted gamma rays
- Testing Compton scattering from one detector to another
- Precise localization of emitted gamma rays
- Screening of materials for present radioisotopes

Our group measured the angular correlation of the detector set-up with a sample of Co^{60} by measuring the 1173 keV and 1332 keV γ-ray emissions. The angular distribution of a γ-ray depends on the spin axis of the nucleus from which they are emitted.

By detecting the first γ-ray at angle θ=0 we gain information in probability form about the spin of the nucleus. The second γ-ray that is emitted also has an angular distribution with respect to the spin axis of the nucleus.

Figure 13: γ-γ angular distribution for Co^{60}



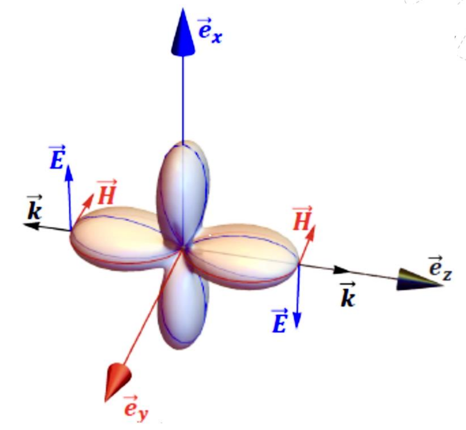


Figure 14: Spherical Harmonic of quadrupole radiation emitted by Co^{60} decay

The probability of the second γ-ray to be emitted at an angle θ is called angular correlation factor $W_{(\theta)} = 1 + \frac{1}{8}\cos^2(\theta) + \frac{1}{24}\cos^4(\theta)$

Measurements were taken over a 9-day period and each detector change was recorded with a timestamp. As we analyzed the data, we began to see no coincidence events later into the angular correlation run. This called into question the stability of the set-up for long periods of time.

Conclusion

Our group was successfully able to detect and identify coincidence events for specific gamma rays and localize them to the tested radioactive source. We were able to double the resolution of the detectors by modifying the energy thresholds to 300 lsb for VTGe3, 70 lsb for VTGe4, and doubling the coarse gain of VTGe4. Near the end of our project, we discovered a potential issue with the stability of the detector over long run times Our next step is to take data for a weeklong run and analyze how the number of coincidence events changes over time under non changing conditions to test for corruption in the timestamp over time.

Acknowledgements & References

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