Study of Gamma-Gamma Correlation Spectroscopy

Name: Saumya Prakash Sharma
Roll No: 1911151

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Abstract:

A radiation detection system consisting of scintillation detectors in a gamma-gamma coincidence configuration to study the spectrum of Na-22. Signal to noise ratios of select photopeak pairs for coincident detector configurations in order to quantify the performance of each detector configuration. In this experiment, two 511 keV annihilation gamma rays are radiated from a Na-22 source in coincidence with each other. The purpose of the experiment is to verify that these quanta emanate from the source with an angular separation of 180°. The experiment constitutes an introduction to gamma-gamma angular correlation measurements. Gamma-gamma coincidence successfully reduces the Compton continuum ,revealed coincident gamma energies characteristic of Na-22, and improved the signal-to-noise ratio relative to single detector measurements. Using the CSPARK software we analyse the data and make heat curves, coincidence measurements and applied gates for analysis.

Aim

To study gamma-gamma co relation spectroscopy of Na-22 for different detector angles.

Apparatus Required

- *Gamma Spectrometer(2nos)*
- *Power Supply*
- *Si-diode gamma spectrometers (x2)*
- *Dual Parameter MCA*
- *Picoscope*
- *Radioactive Material (Na-22,Cs-137)*

Theory:

Many nuclear reactions generate two photons at the same time, whereas others generate two or more photons in rapid succession. In such instances, a coincidence detector system can be used to investigate the temporal and angular correlations between the two photons. These emissions can occur at the same time or within a very short time period relative to the detecting system's time resolution. When a nucleus decays by beta emission to a daughter nucleus, which then decays by gamma emission, the beta particle and gamma ray are produced almost simultaneously. Similarly, a single nucleus can produce a cascade of gamma rays that are effectively simultaneous due to the short time between occurrences.

Coincidence systems are employed in nuclear physics applications to detect and identify weak detection signals, as well as to separate a physics signal from background signals, as in Compton suppression or cosmic veto systems. When two accelerated beams meet in high- energy or particle physics, detection systems with thousands of detectors and electronics channels all run in lockstep to look for newly created particles or new decay routes.

The photons that interact in the detector are:

- The source.
- Secondary radiation generated in materials other than the detector
- Background radiation.

The types of interactions in the detector:

- Compton scattering
- Photoelectric effect

– Pair production.

Gamma gamma coincidence is a phenomenon where two gamma rays are simultaneously emitted in a radioactive sample undergoing + decay. It happens when an unstable nucleus decays into an atom of lower atomic charge with an emission of + and a neutrino. The dominating equation is as follows for our given Na-22 sample:

$$_{11}Na^{22} \rightarrow {}_{10}Ne^{22} + e^{+} + \nu$$

^{22}Na radioactively decays to an excited state of ^{22}Ne either by emission of a positron (90% probability) or by electron capture (10% probability). The excited ^{22} Ne nucleus decays with a mean life 3×10^{-12} s to the ground state with the emission of a 1.274MeV gamma.
The positrons are emitted with a range of kinetic energies up to about 0.5MeV. They lose this energy quickly $\left(10^{-9}\ \mathrm{s}\right)$ in the material surrounding the source and, when they reach atomic (eV) energies, capture an electron to form positronium a hydrogen-like "atom." The positronium decays (with a lifetime on the order of 10^{-10} s) by annihilation of the e^{+} and e^{-}into two gammas. By energy conservation, the energy of the gammas must equal the energy (including the rest mass energy) of the positronium and, by momentum conservation, the net momentum of the two gammas must equal the initial momentum of the positronium.

The magnitude of the photon momentum is given by

$$p_{\gamma} = \frac{E_{\gamma}}{c}$$

In the rest frame of the positronium, there is no initial momentum and thus the two annihilation gammas must be of opposite momentum in that frame. Consequently, the two photons must be equal in energy and propagate in opposite directions. Since the initial energy of the positronium (neglecting the binding energy of a few eV) is simply the rest mass energy of an electron and positron (0.511 MeV each), each gamma will have an energy $E_{\gamma} = 0.511$MeV.

In the photoelectric effect, most of the photon's energy is given to the photoelectron. The latter only travels a very short distance (e.g., less than a mm) before it gives up all its energy to the detector. In addition, somewhat less energy is carried off by an x-ray or auger electron. Each photopeak has its own Compton Continuum. The lower the photon energy:

– The closer the Compton edge is to the photopeak

– The smaller the Compton continuum is with respect to the photopeak.

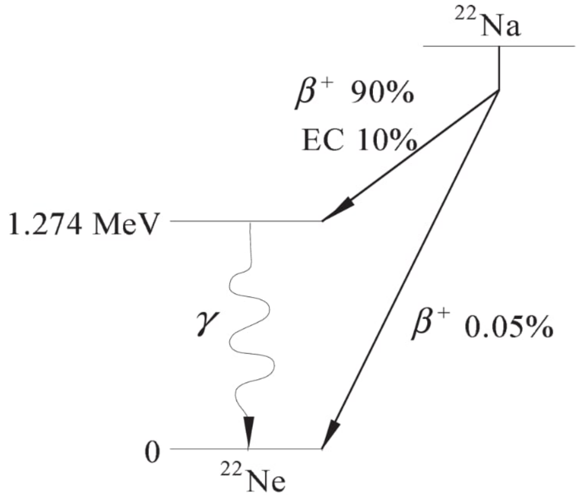

Figure 1: The decay of ^{22}Na proceeds by positron emmision (90%) or electron capture (10%) to produce an excited state of ^{22}Ne which decays by emission of a 1.274 MeV gamma.

Calibration:

- *Place the source in front of the window, and acquire the corresponding spectrum by clicking 'start', and waiting for a sufficient spectrum to build up.*
- *Click on update to fetch the latest spectrum from the hardware, or select the 'auto- update' button.*
- *Select the first input trace, which has a black outline..*
- *Insert a selection region around the 511keV photopeak, and ensure that it covers this peak.*
- *Click on the fit button, or press 'f'*
- *After a successful fit , the software will show the parameters in a dialog box.*
- *In the pop-up window that is now displayed, enter the known energy of the peak against the channel number extracted from the peak.*

- *Click on 'Apply calibration polynomial' to apply this calibration.*
- *Now select the second trace, and move the region to cover the 511keV peak from trace 2 (red colour).*
- *Repeat the calibration process, and click on apply calibration.*

Observations:

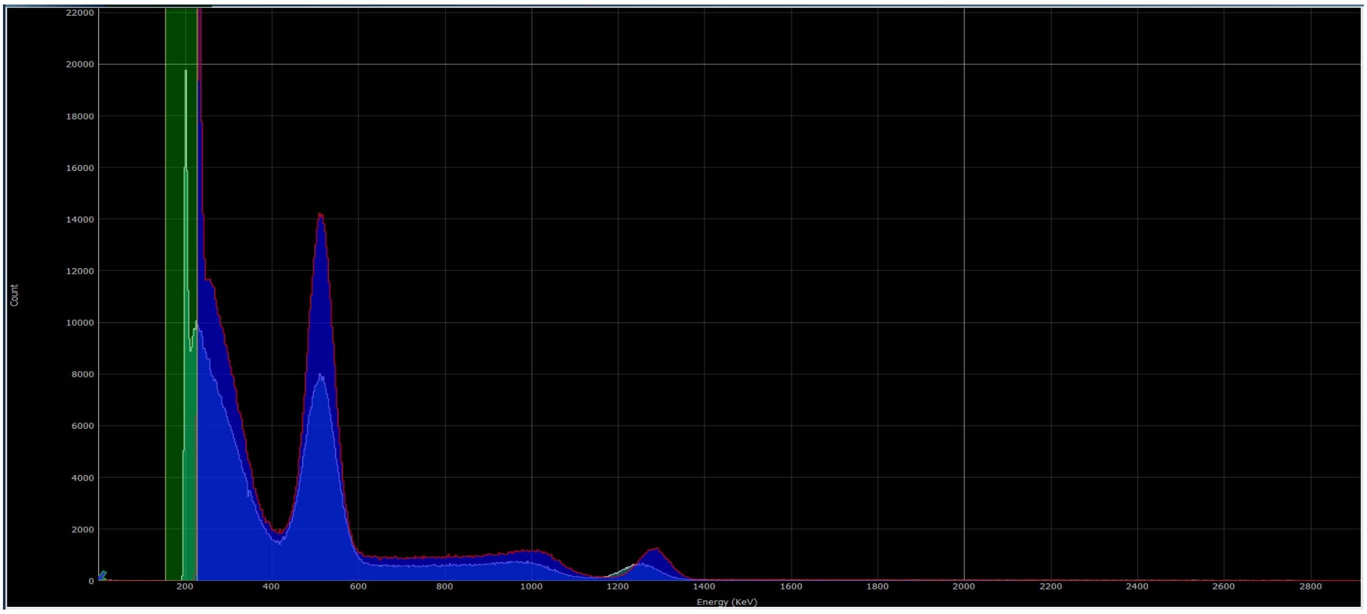

Figure 2: Calibrated Curve for Gamma-Gamma coincidence at 180^0

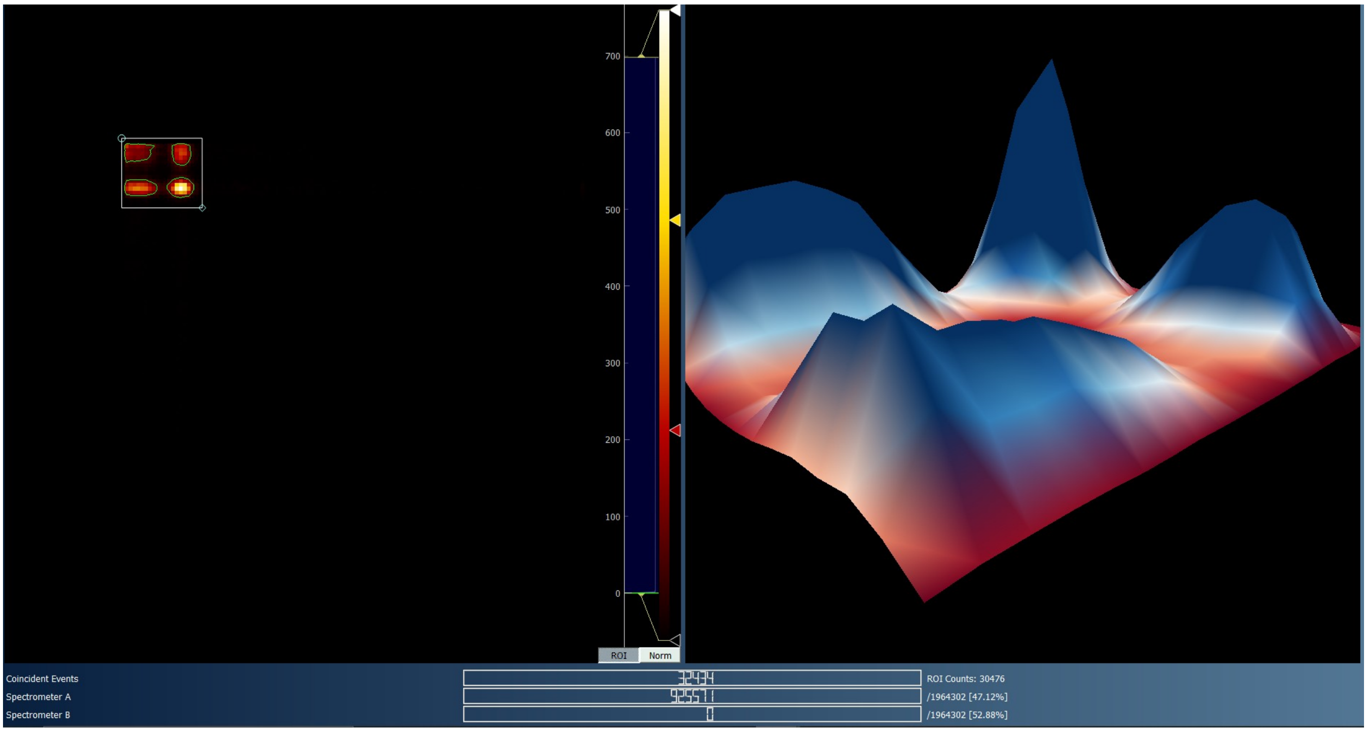

Figure 3: 2D/3D heat curve for Gamma-Gamma coincidence at 180^0

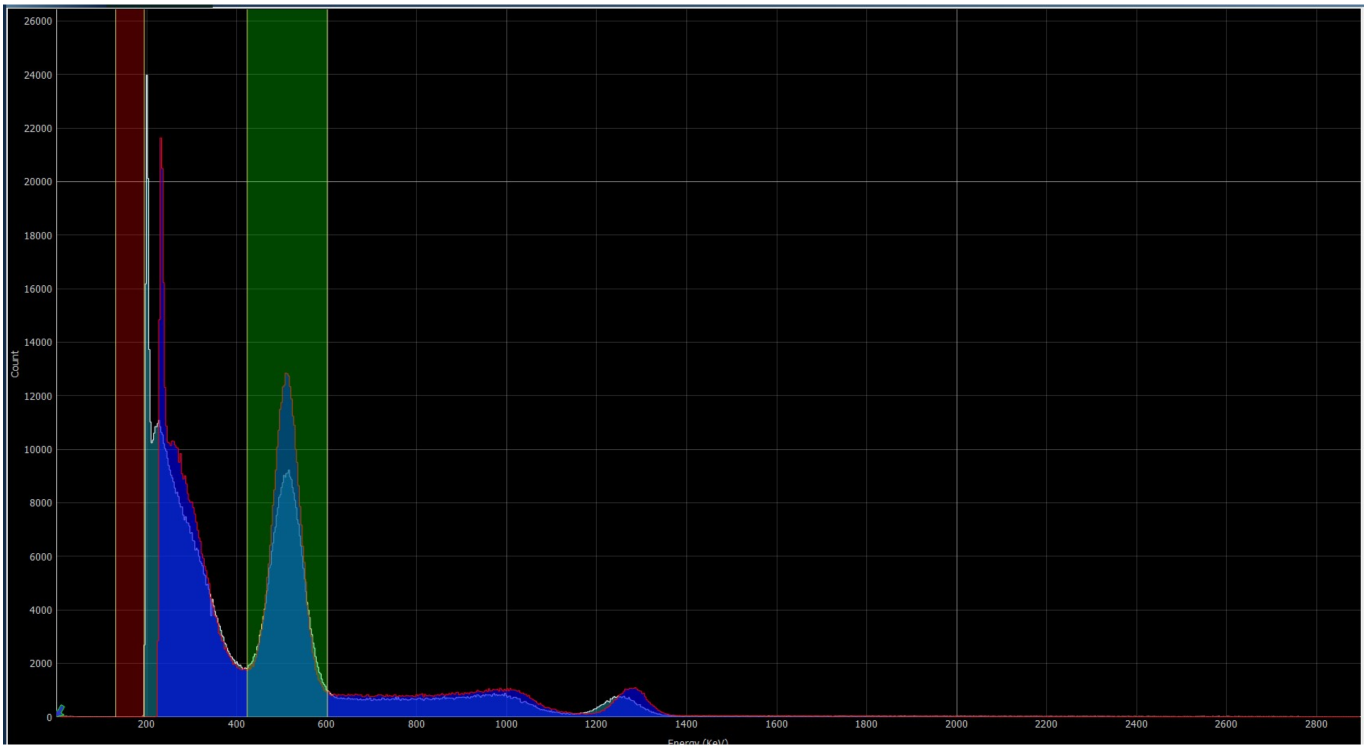

Figure 4: Calibrated Curve for Gamma-Gamma coincidence at 90^0

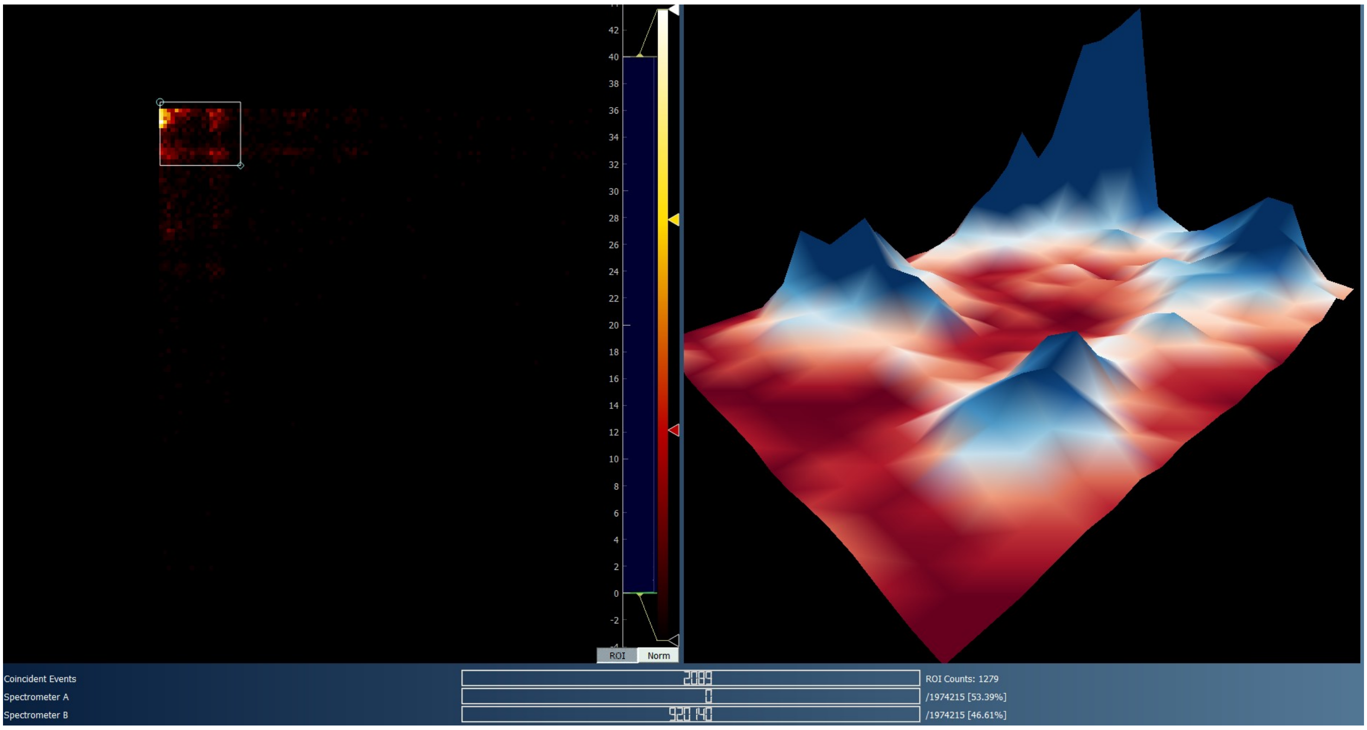

Figure 5: 2D/3D heat curve for Gamma-Gamma coincidence at 90^0

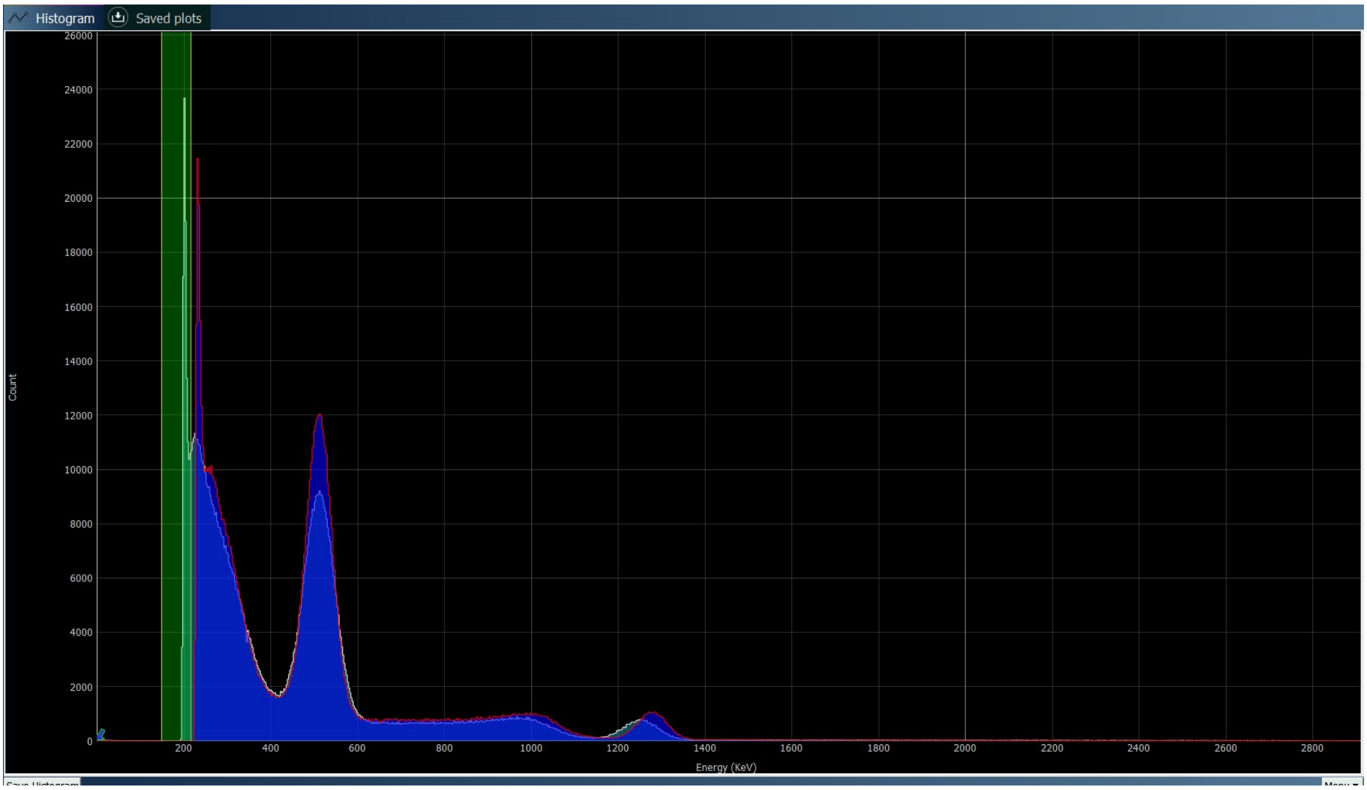

Figure 6: Calibrated Curve for Gamma-Gamma coincidence at 175^0

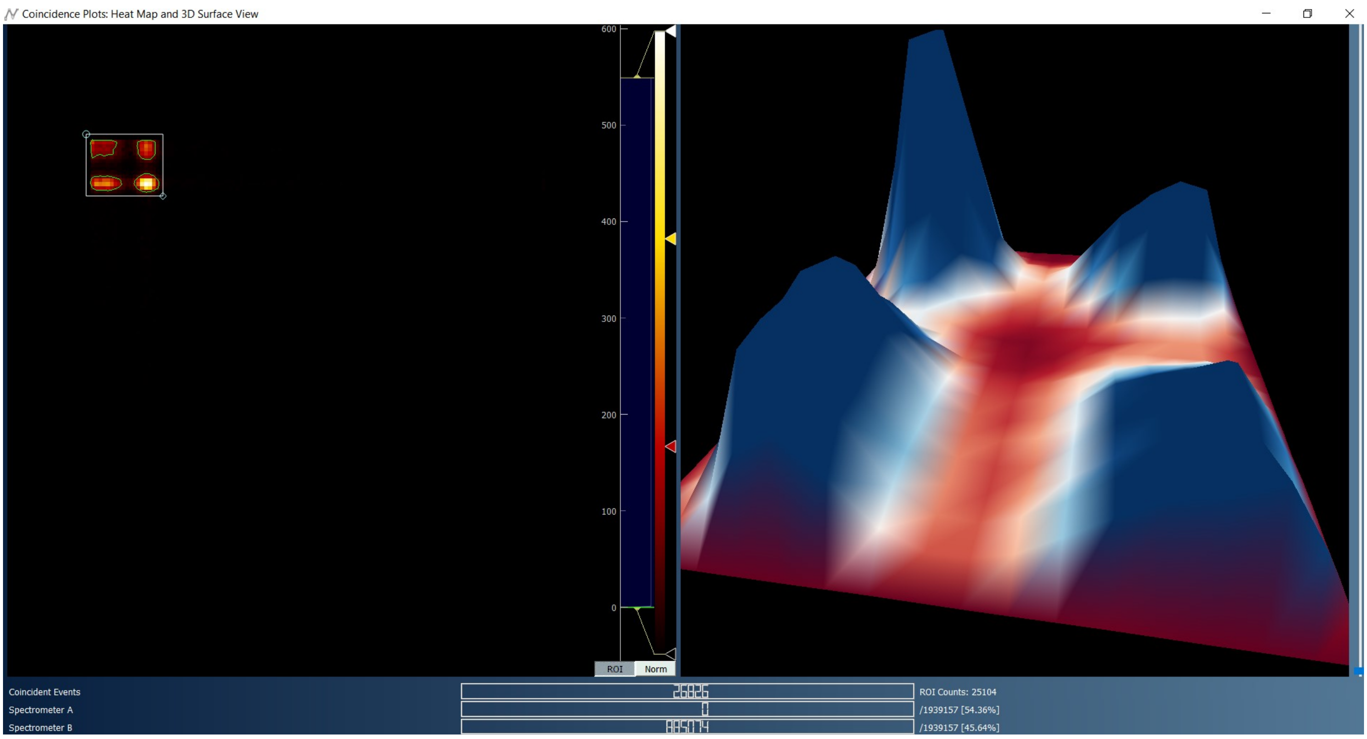

Figure 7: 2D/3D heat curve for Gamma-Gamma coincidence at 175^0

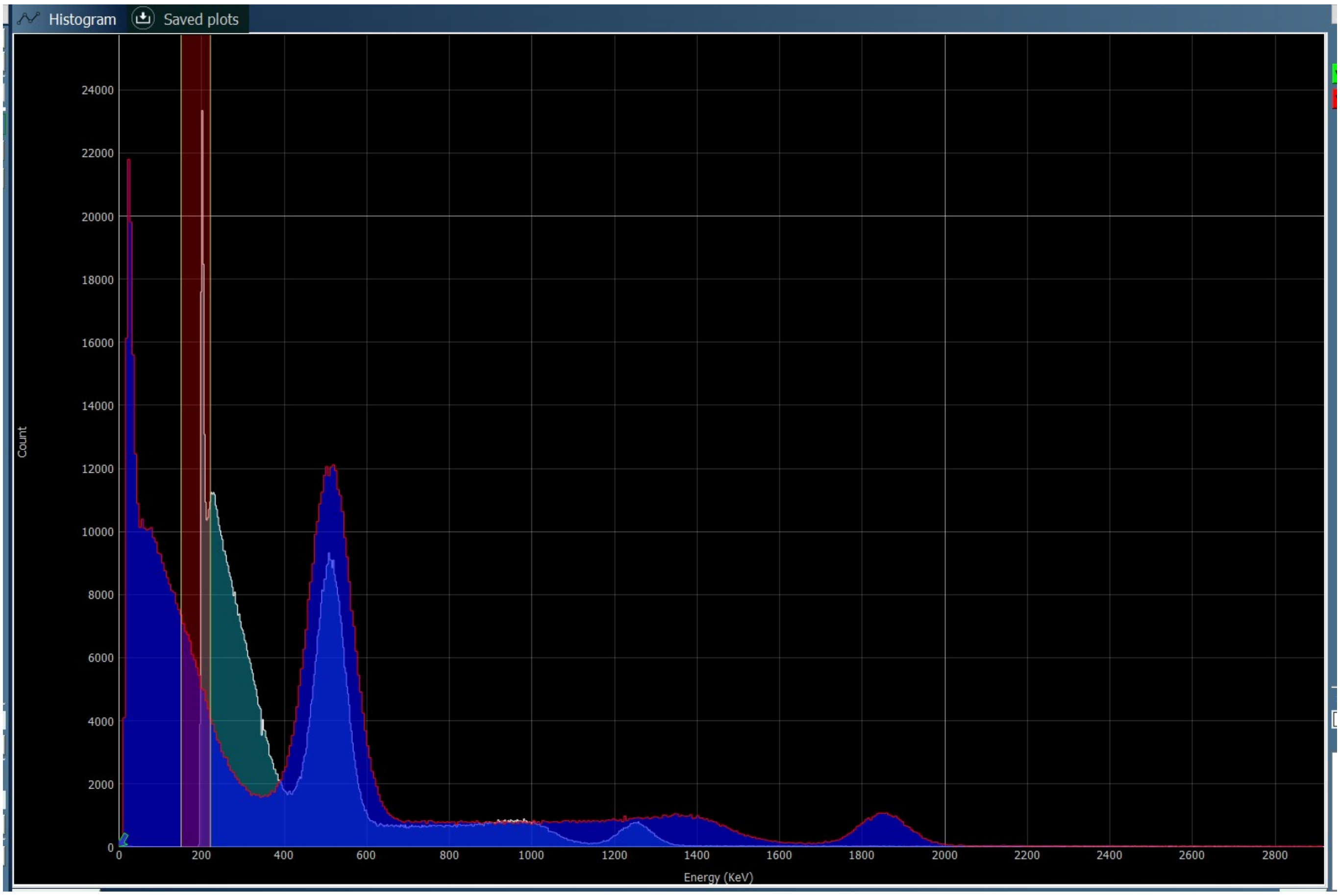

Figure 8: Calibrated Curve for Gamma-Gamma coincidence at 185^0

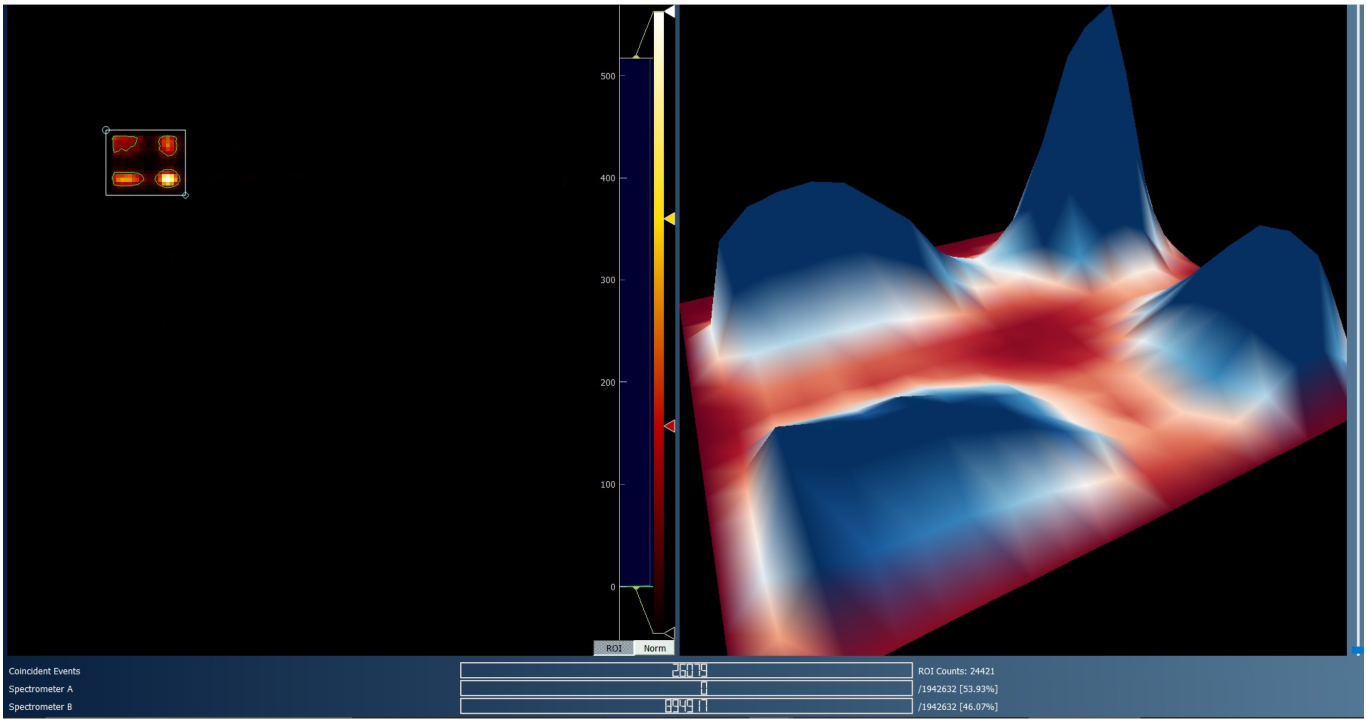

Figure 9: 2D/3D heat curve for Gamma-Gamma coincidence at 185^0

Results

- Average Coincidence at 180^0 =33644
- Average Coincidence at 90^0 = 158
- Average Coincidence at 175^0 =7667
- Average Coincidence at 185^0 = 6754
- Count Rate at 180^0 $=\frac{33644}{5400}$=6.2303704
- Count Rate at 90^0 $=\frac{158}{5400}$=0.0029259
- Count Rate at 175^0 $=\frac{7667}{5400}$=1.41981
- Count Rate at 185^0 $=\frac{6754}{5400}$=1.25074

Conclusion:

- The system was successfully calibrated using Na-22 source and the corresponding peak was set to 511KeV.
- The energy spectrum of Na-22 source at 90○, 180○, 175○ and 185○ shows a similar nature with a peak at about 511 KeV
- We get the maximum count for scattering angle of 180^o and least for 90^o, which is expected behaviour.
- We got nearly similar coincidence for 175^o and 185^o and is less relative to scattering angle of 180^o which is expected behaviour.

Source of Error:

- Due to its alternate Si-diode-based design with small photo-detectors, the detector was exceedingly inefficient in capturing the source's energy spectrum. This can be avoided by allowing the spectrum to be built over a long period of time (like letting it run overnight).
- Compton scattering causes a lot of noise to be picked up by the detectors. This could be caused by Compton scattering in the detector (again affected by the build of the detectors).
- Using an oscilloscope, check that the signal input to the MCA is appropriately shaped until it reaches the desired amplitude. (This is why an oscilloscope is included in the apparatus list.)
- By ensuring that the detectors are equidistant from our source, we can ensure that our spectrum is symmetric for both detectors.