Demonstrating Momentum Conservation in Electron-Positron Annihilation in Na-22 using Gamma Ray Coincidence

By: Diya Motagi
Roll No.: 230389

Supervisors: Prof. Aditya H Kelkar, Prof. Zakir Hossain

OBJECTIVE

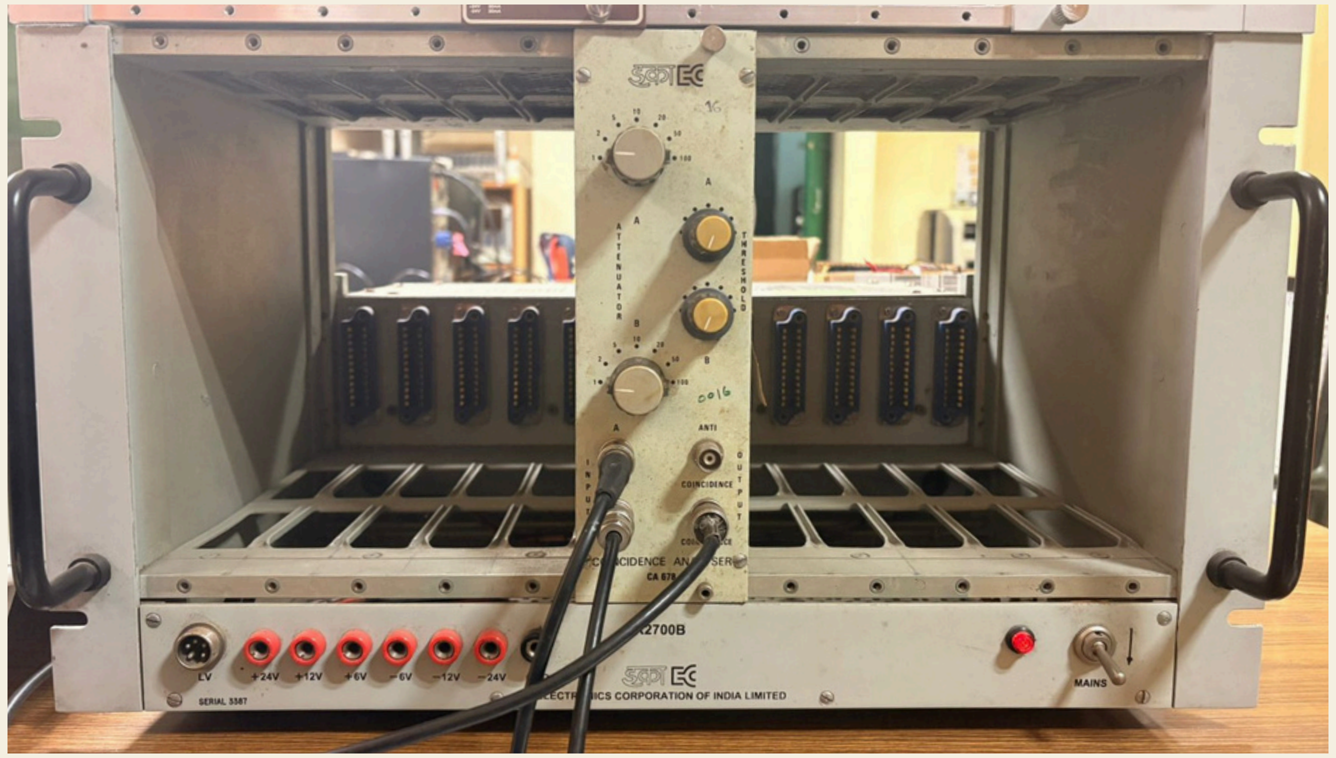
This experiment was conducted to demostrate the momentum conservation in electron-positron annihilation by measuring the simultaneous, antiparallel emission of 511keV gamma-ray photons from a Na-22 source.

APPARATUS USED

The experimental apparatus consisted of:

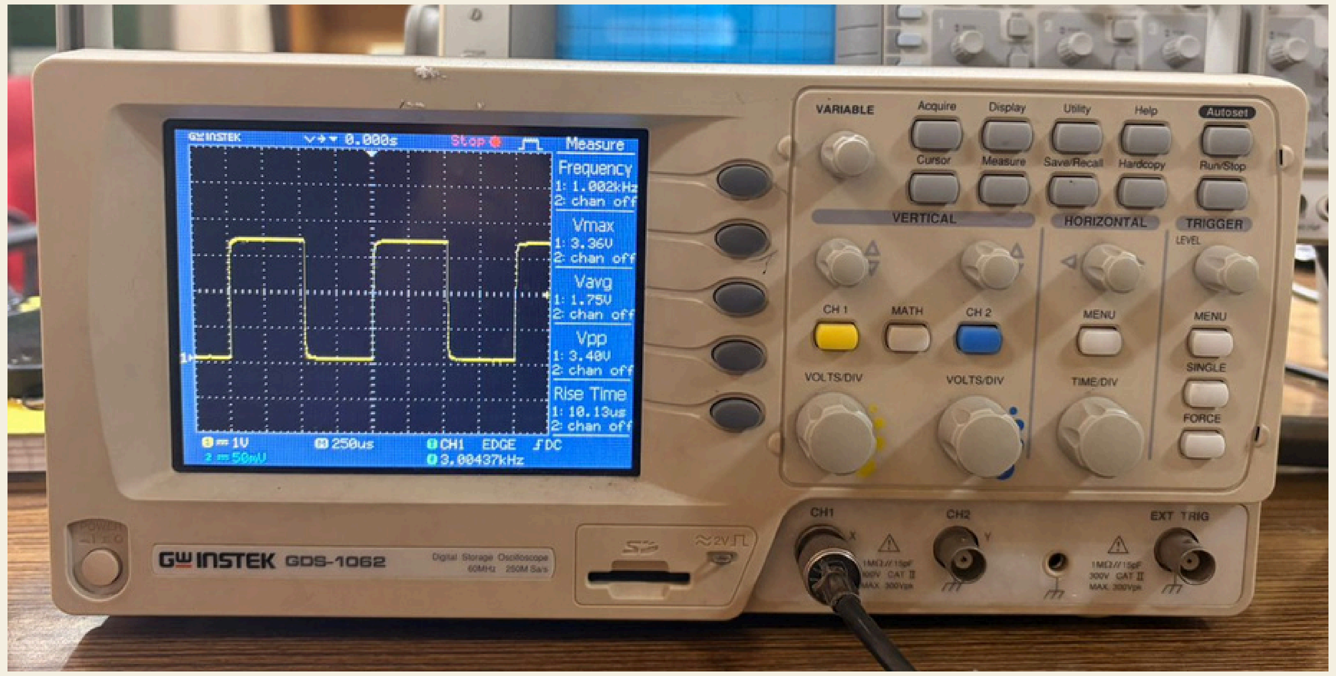
1. Two NaI scintillation detectors
2. Two Single Channel Analysers (SCA)
3. Multi Channel Analyser (MCA)
4. Coincidence Analyser
5. Digital Storage Oscilloscope (DSO)
6. Cs-137, Co-60 and Na-22 sources

Instruments Used



Coincidence Analyser

Single Channel Analyser



Digital Storage Oscilloscope

Scintillation Detector
(NaI Crystal with Photomultipler Tube)

Working of SCA and MCA

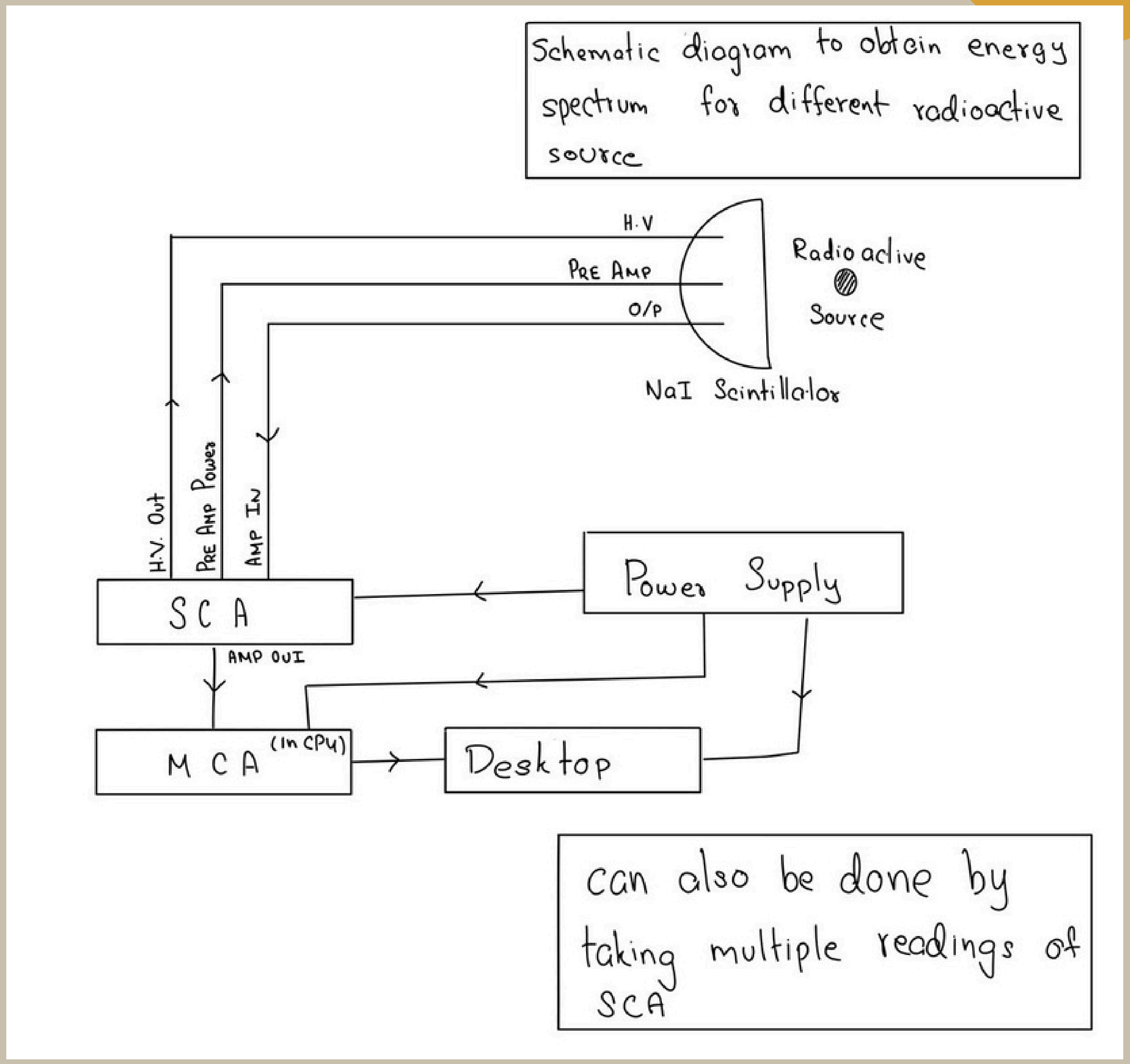
- In NaI(Tl) scintillators, incident radiation excites electrons, which de-excite through thallium "activator" sites to produce flashes of light.

- A sensitive photomultiplier tube (PMT) then detects this weak light and converts it into a corresponding electrical signal.

- The detector pulse from the preamplifier output is first amplified by an amplifier and then processed by the SCA. The SCA basically act as a discriminator which provides a threshold level to the signal amplitude so that the signals above the threshold are only accepted.

- A Single-Channel Analyzer (SCA) can be set in window mode and the window knob is used to change the window (the difference between the upper and lower level thresholds). We use the baseline knob to set the lower level threshold. Thus setting the SCA to count only the pulses that fall within that specific amplitude range.

- A Multichannel Analyzer (MCA), however, performs this function automatically by sorting all incoming pulses into thousands of individual channels simultaneously, building the entire pulse height spectrum at once without manual scanning

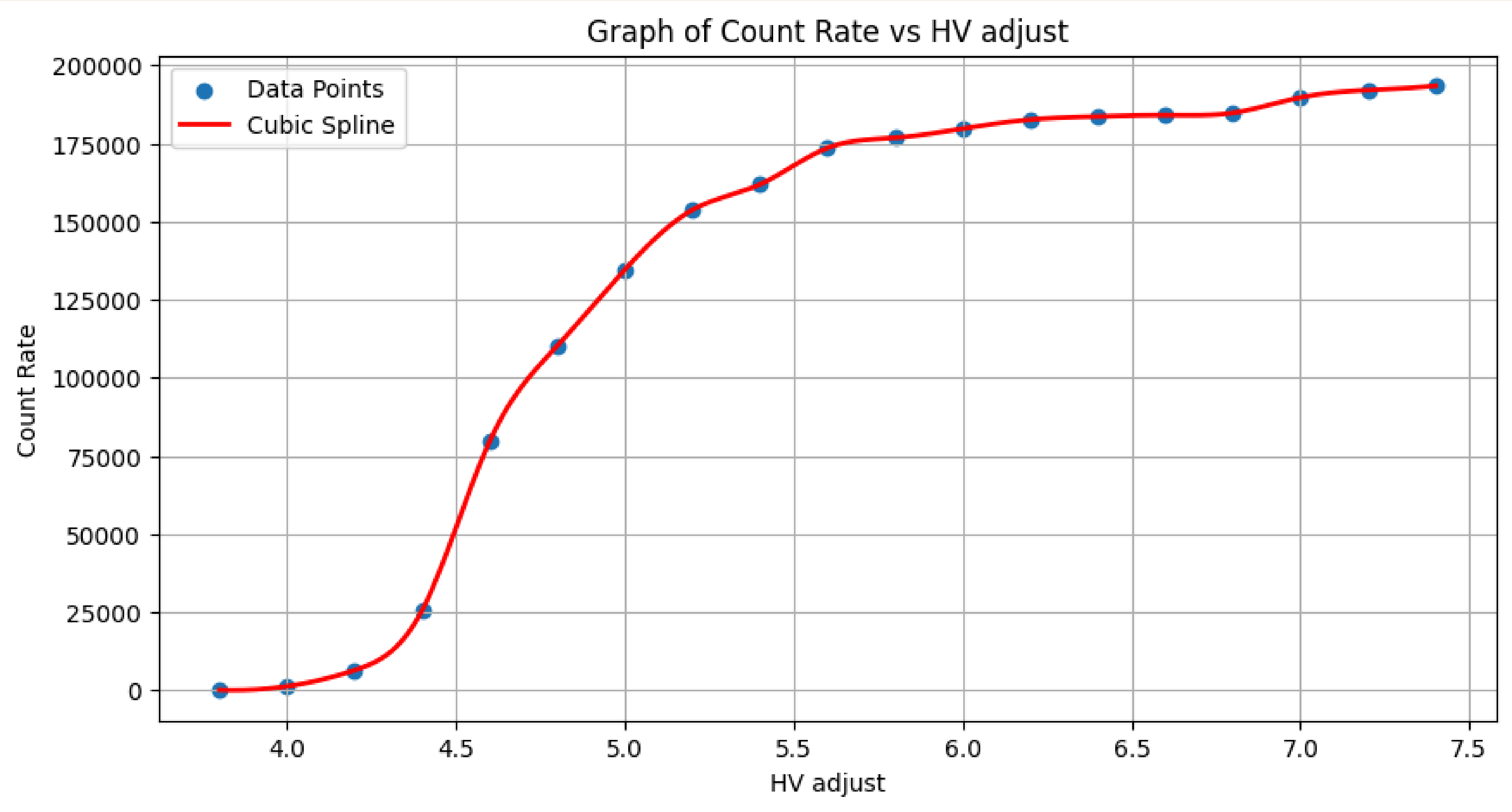


Understanding the Characteristic Curve of the SCA

- This graph shows the characteristic curve of a scintillation detector connect with a photomultiplier tube. It is the most important tool for finding the correct operating voltage.

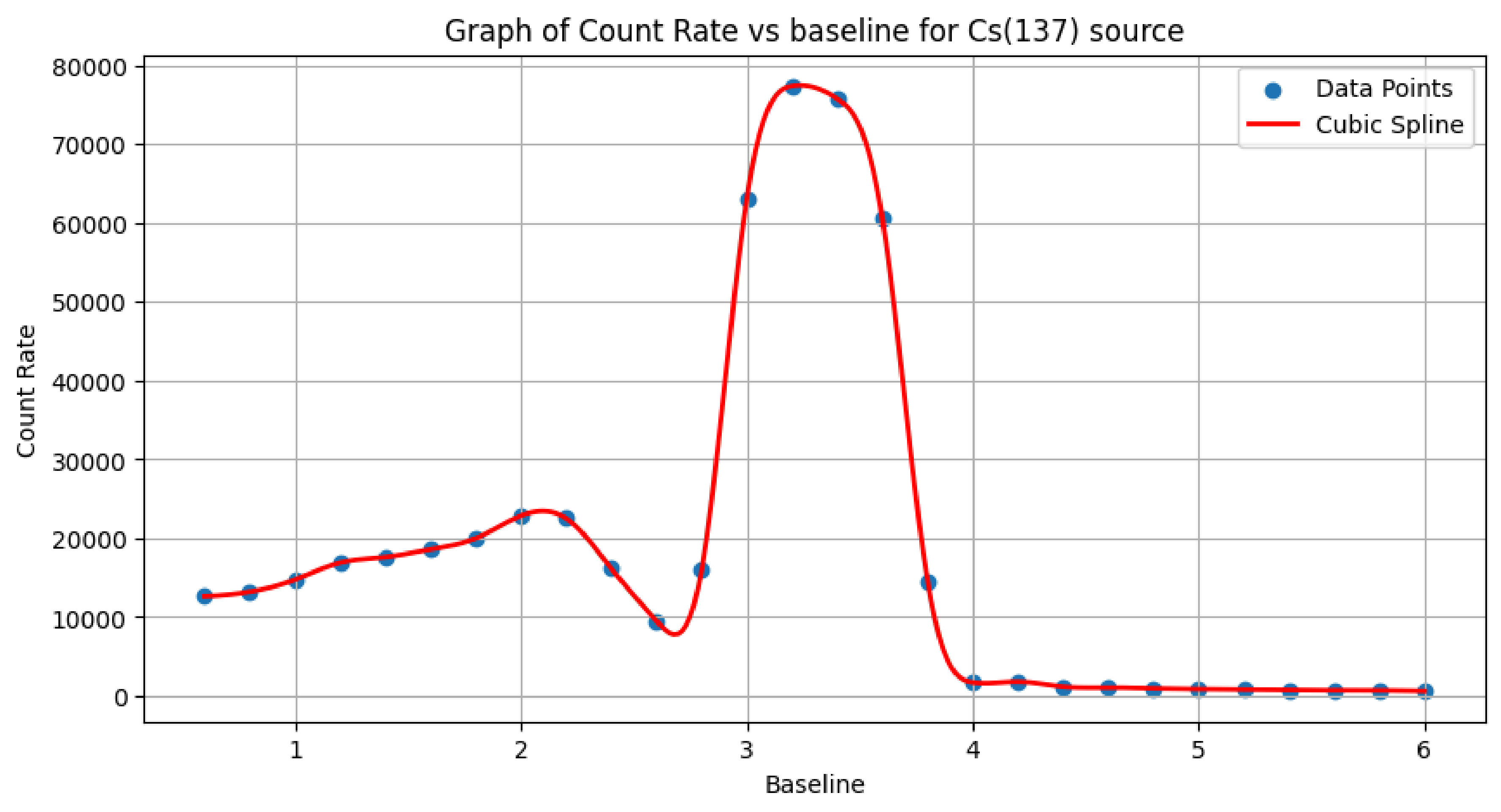
- This graph shows how the number of particles your detector counts changes as you increase the high voltage (HV) supplied to it.

- We have set the HV adjust to 4.70, this translates to about 705V (10.0 = 1500V), to provide the optimal gain. Any higher voltage than the 704V would lead to signal clipping.

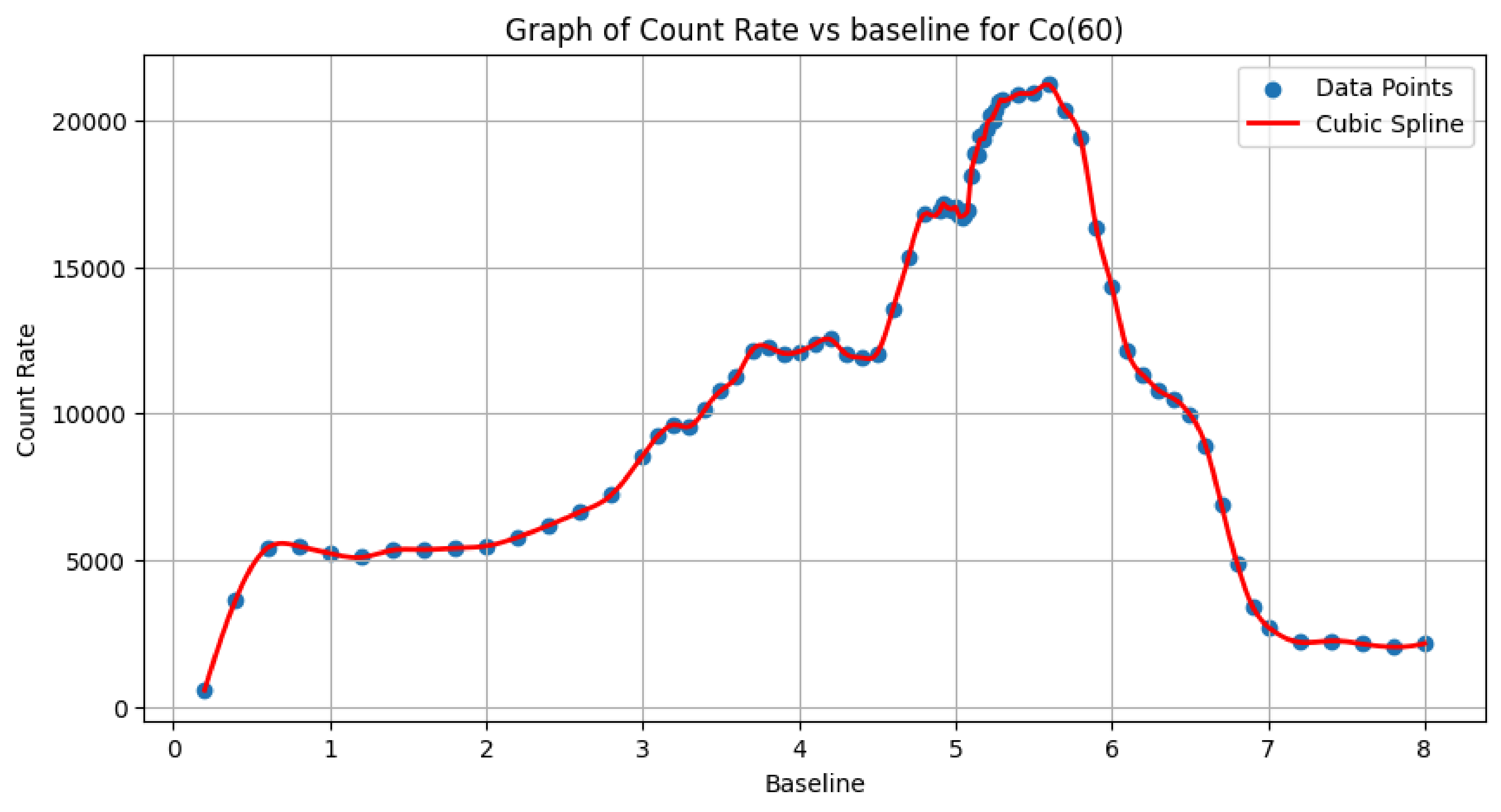


Energy Spectra of Cs-137 and Co-60 obtained using an SCA

- Main Photopeak at Baseline ~3.3 represents the 662 keV energy from the Cs-137 source.
- Compton Edge at Baseline ~2.1
- Compton Continuum at Baseline < 2.1.

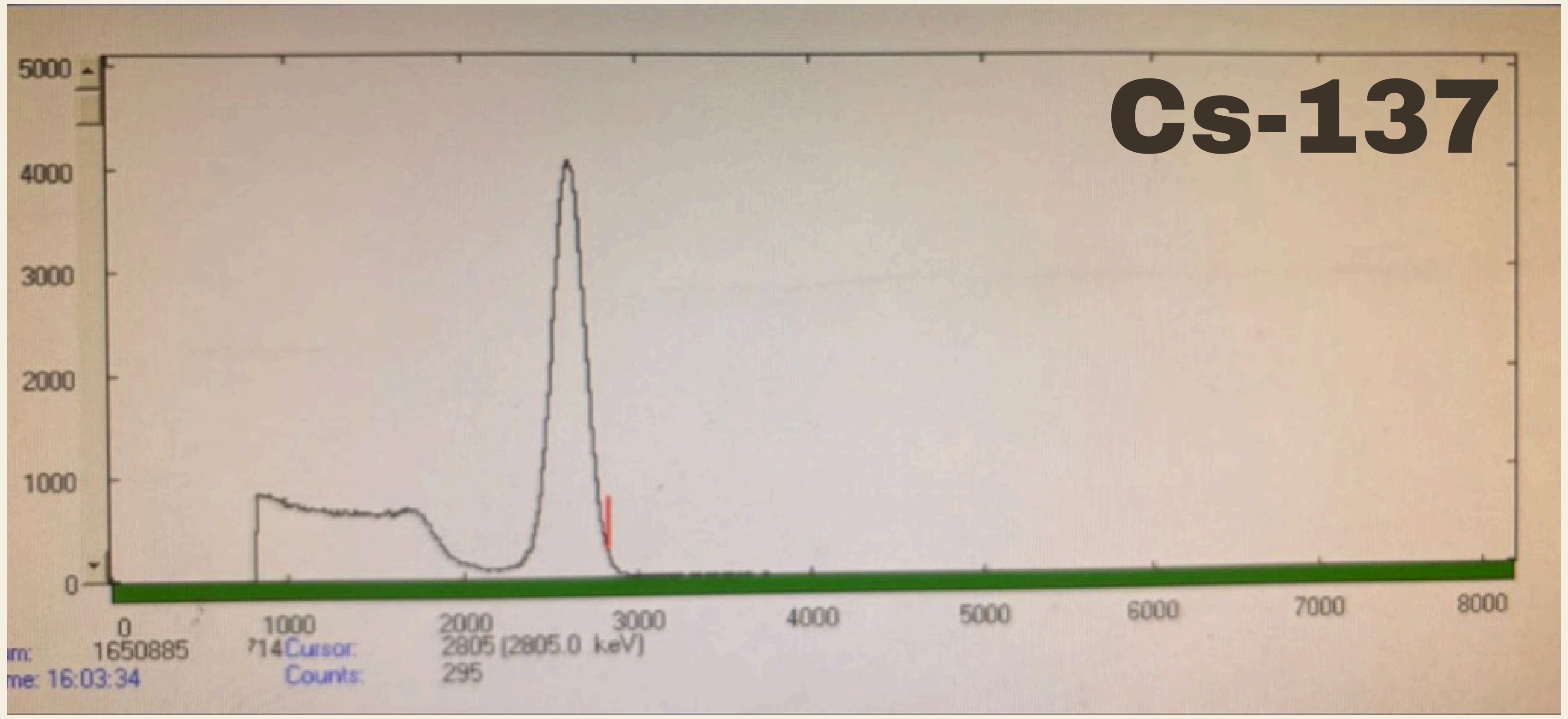


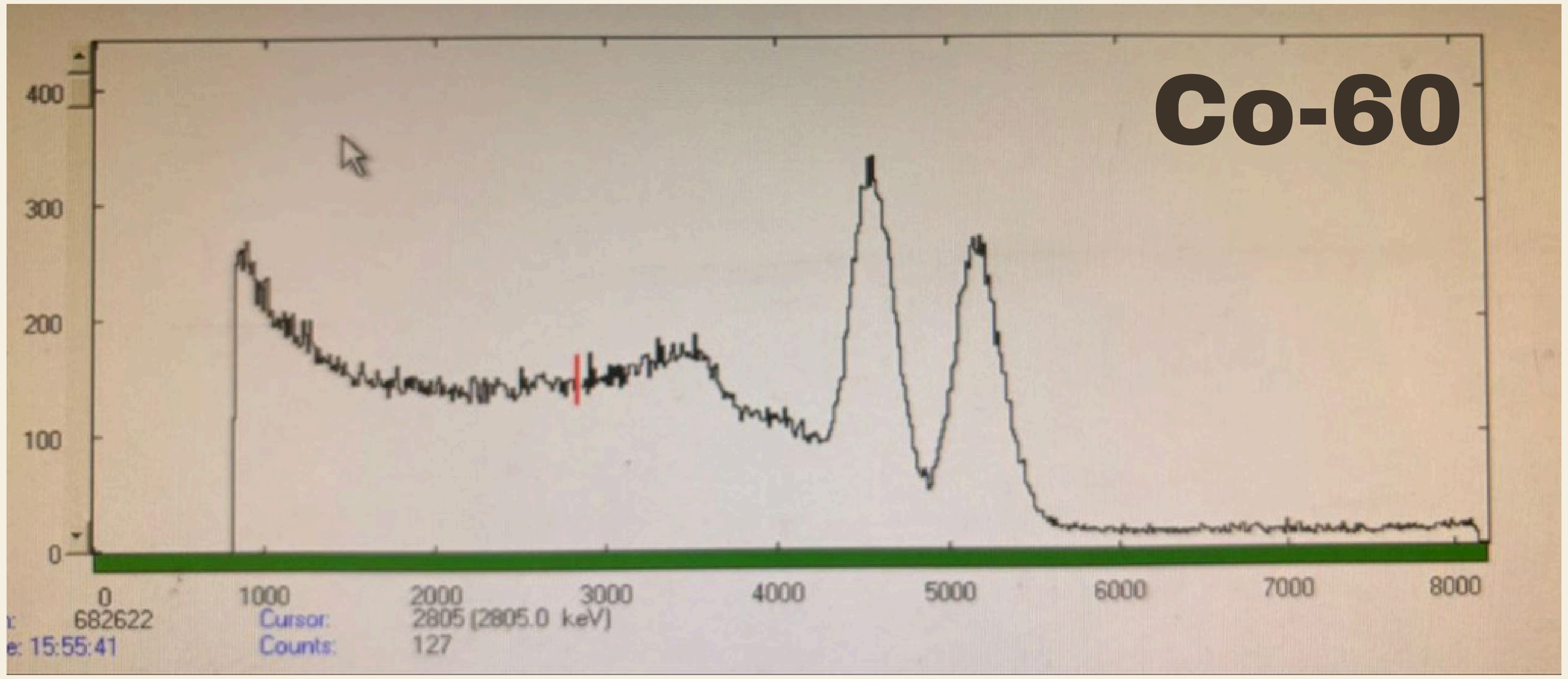
- Two main Photopeaks at Baseline ~5.0 and ~5.5 represent the 1173 keV and 1332 keV energy from the Co-60 source (the two peaks are not very distinctly separated because of poor detector resolution)
- Compton Edge at Baseline ~4.0 to 4.2
- Compton Continuum at Baseline < 4.0.

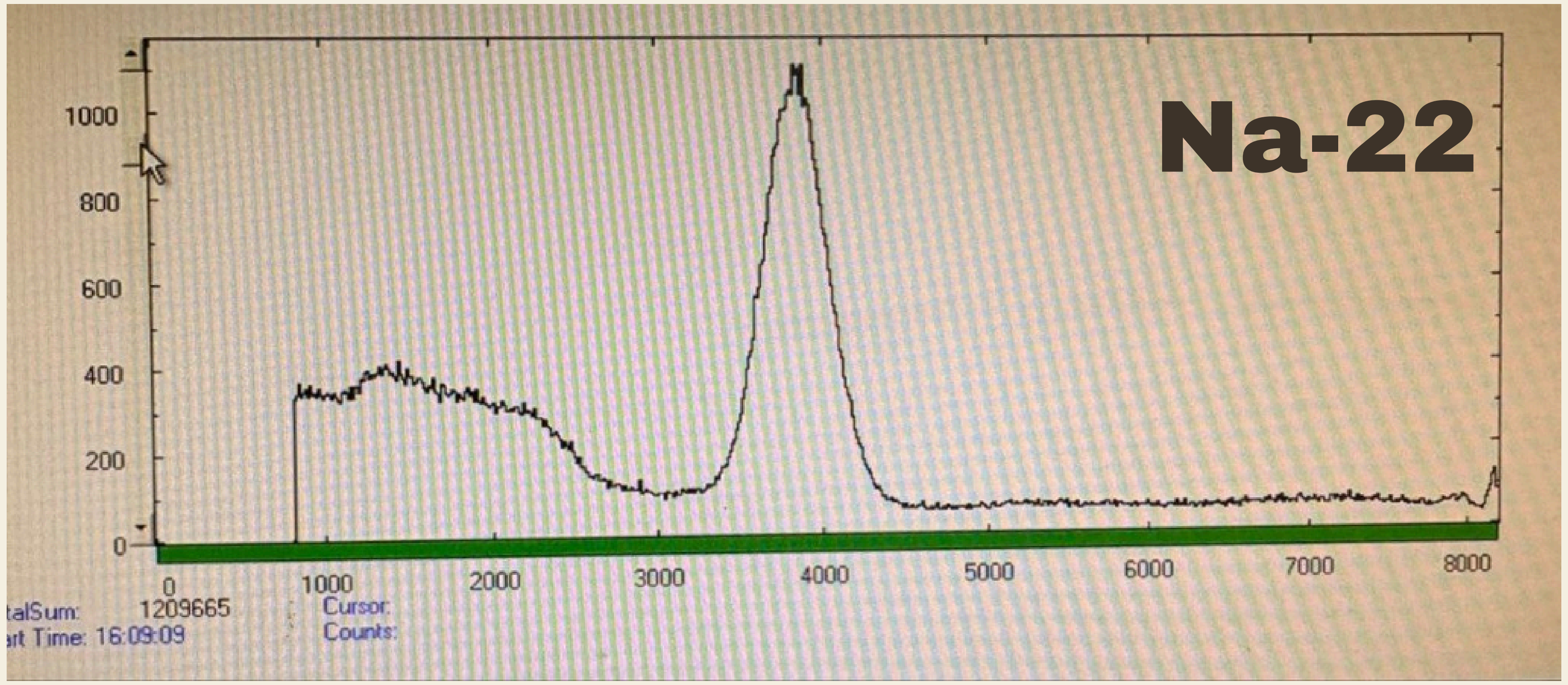


- Photopeak: A peak representing the complete absorption of a gamma ray's full energy.
- Compton Edge: The maximum energy deposited by a single Compton scattering event.
- Compton Continuum: The full range of partial energies deposited by Compton scattering events.

Energy Spectra of Cs-137, Co-60 and Na-22 obtained using an MCA

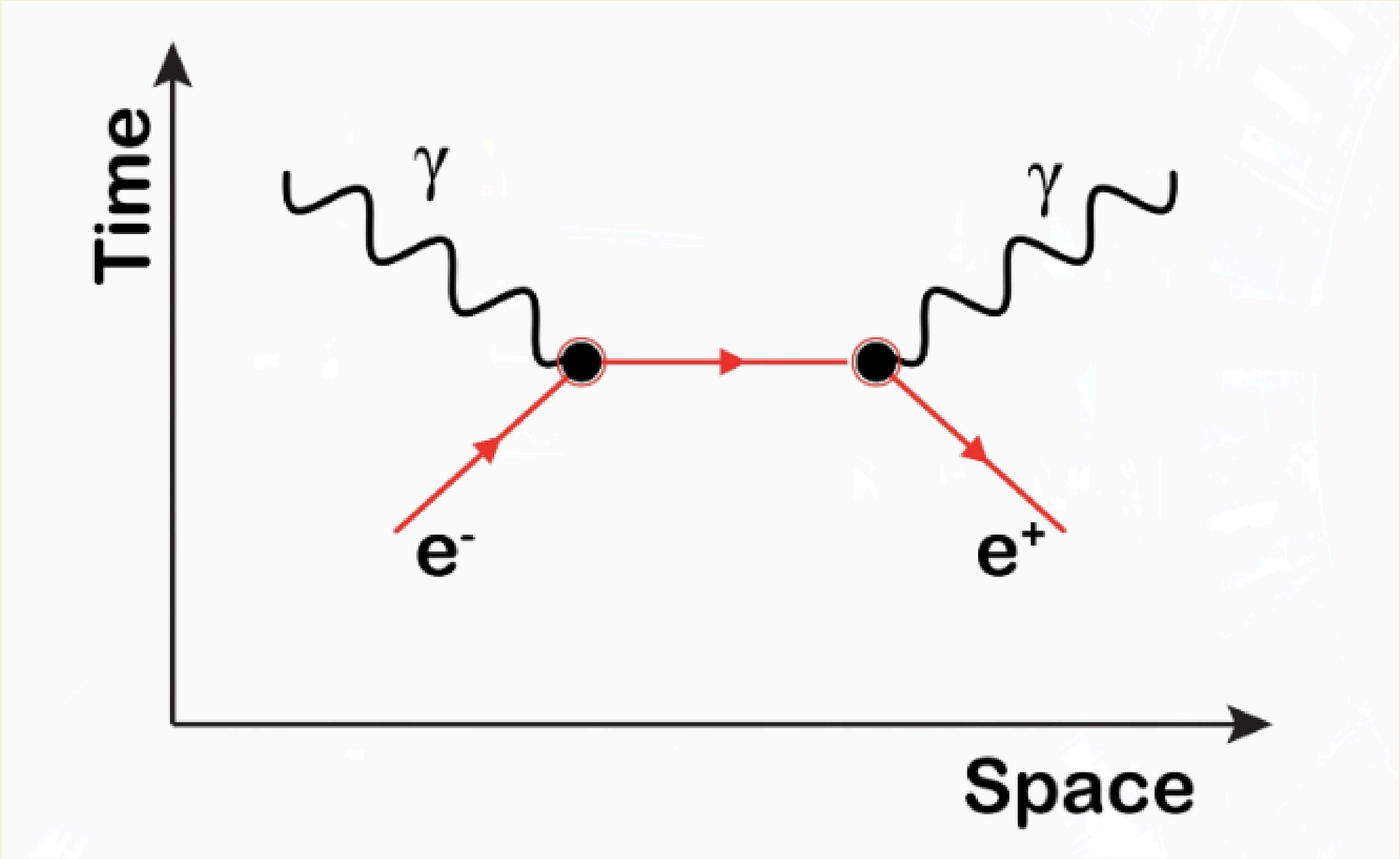


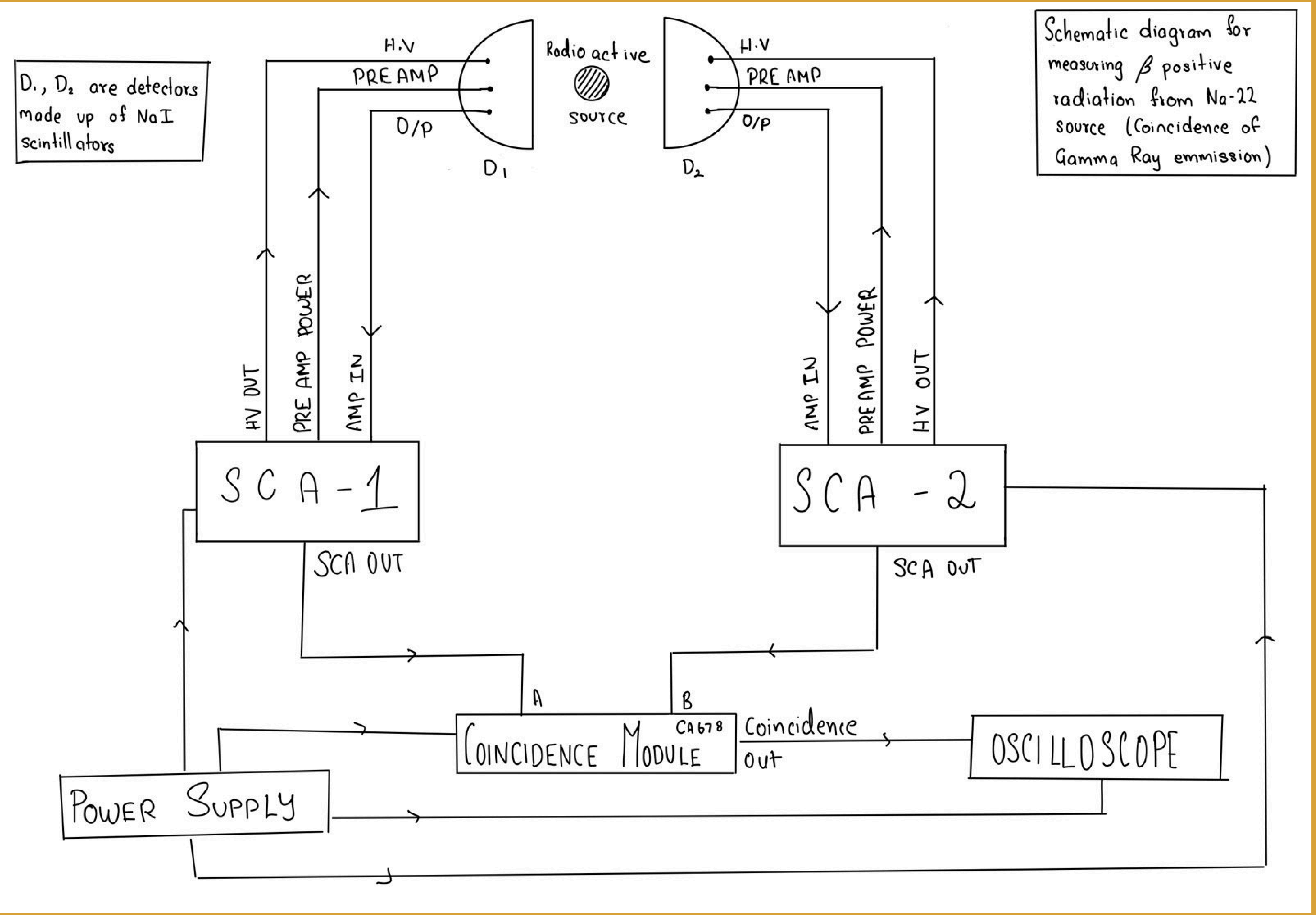




Electron-Positron Annihilation in Na-22

- The Sodium-22 nucleus emits a positron when it decays. This positron travels a tiny distance into the surrounding material and finds an electron.
- Just before they meet, both the positron and the electron are essentially at rest. This means their total momentum, as a system, is zero.
- The positron and electron annihilate each other, converting their entire mass into pure energy, as per E=mc^2. This energy is released as two gamma-ray photons.
- From the conservation of momentum, we know that because the total momentum before annihilation was zero, the total momentum after must also be zero.
- The only way for two photons (which are now carrying all the momentum) to have a combined momentum of zero is if they fly off in exactly opposite directions.



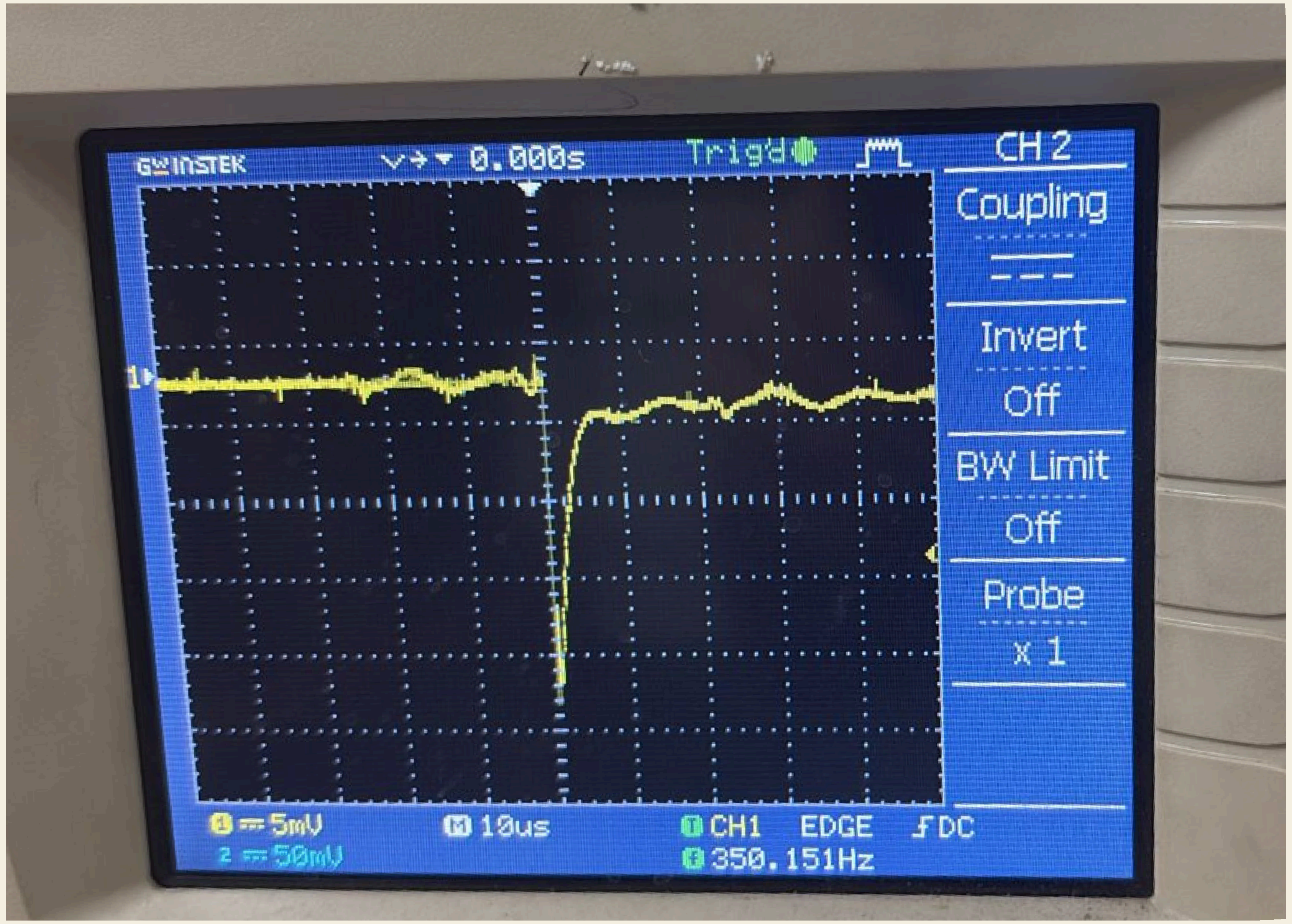


Schematic for Coincidence Measurement for Na-22 Source

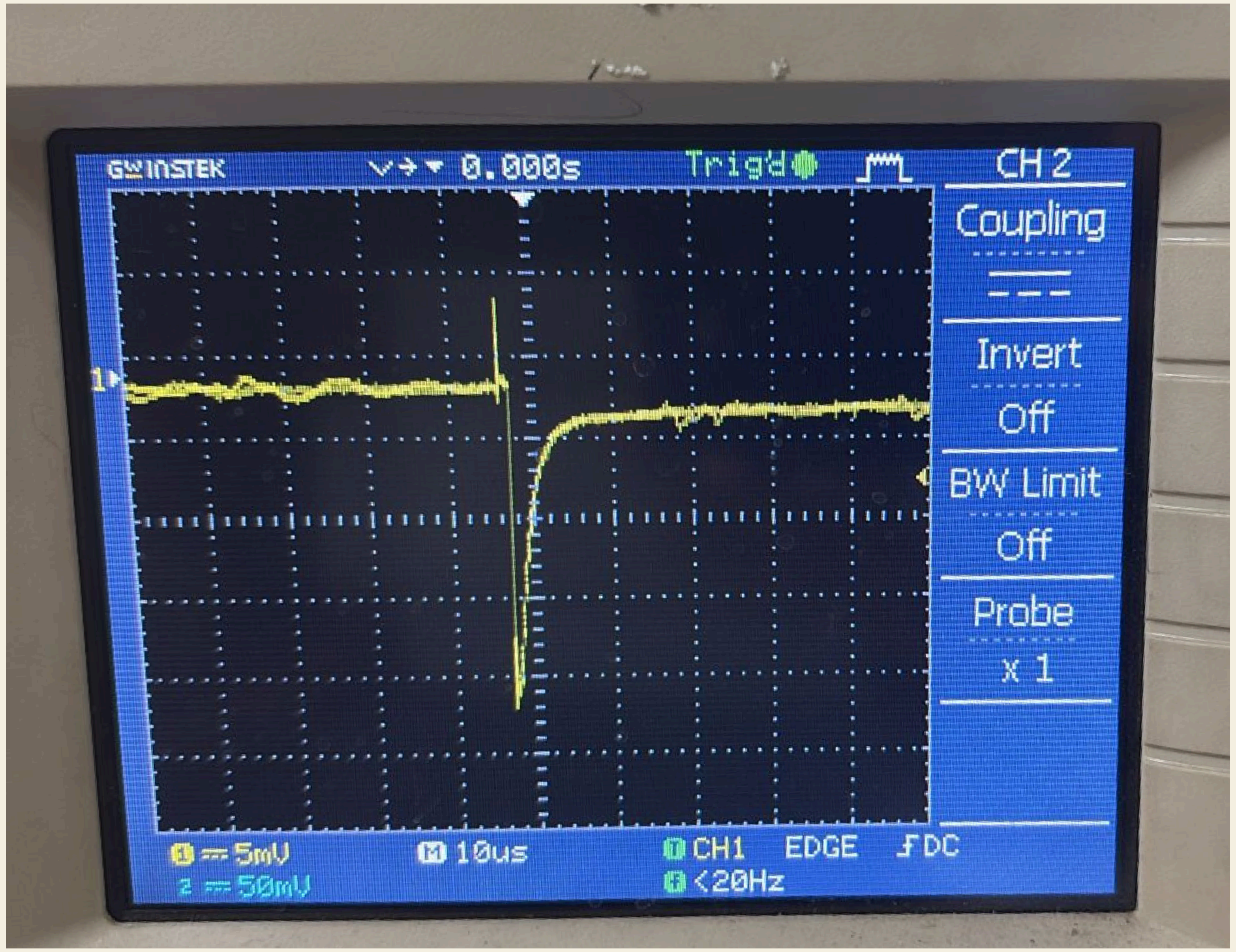
Coincidence Measurement for Na-22 Source

- We first checked the working of the coincidence analyser by using a pulse waveform of 1000Hz and 5.0V amplitude, that matches the signal we get from SCA output, using a function generator.
- After setting up the instruments according to the schematic, we observed the coincidence signals directly from the SCA amp-out (before connecting in the coincidence analyser), on the oscilloscope (in Normal mode and in XY mode), for both Na-22 and Cs-137 sources and compared them.
- We noticed that the signals for Na-22 were coinciding a lot more frequently than for Cs-137, though the ideal case would be to not see any coincidence for Caesium at all, we deduced that this could be be because of the background cosmic radiations.
- Next we connected the SCA outputs to the coincidence analyser and the output of the coincidence analyser to the DSO. We observed that the frequency of the coincidence signals from Na-22 was significantly higher (~ 350 to 400 Hz) than that from Cs-137 (~ 20 to 60 Hz). Thus proving that there were two antiparallel gamma rays emitted in the case of Na-22.
- Upon changing the angle between the two scintillation detectors, it was observed that the frequency of the coincidence signals decreased as the angle tended to 90 degrees. Thus verifying the conservation of momentum.

Coincidence Measurement for Na-22 Source



Frequency: ~ 350 to 400 Hz for Na-22



Frequency: ~ 20 to 60 Hz for Cs-137

Thank you!

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