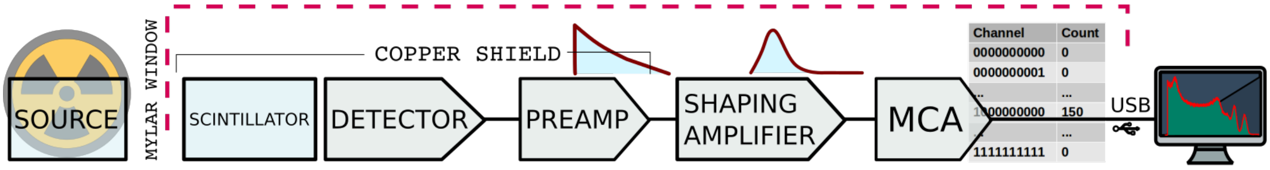
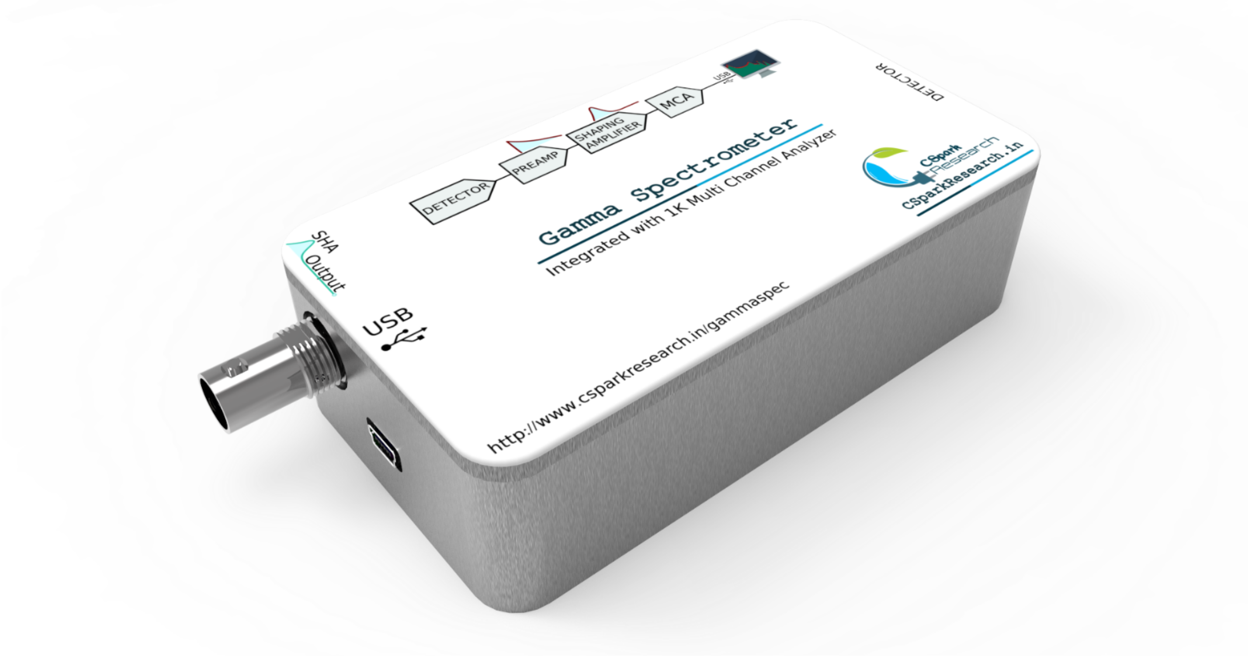
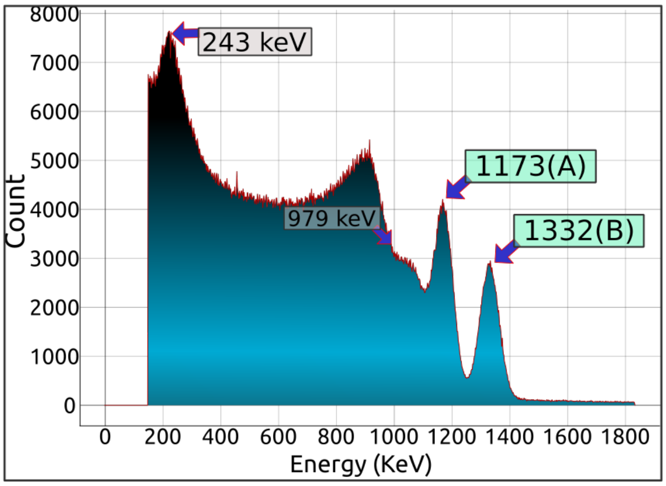


GammaSpec-1K

USB interfaced Gamma Spectrometer with integrated 1K Multi-Channel Analyzer



* *2 MeV Full-Scale Range*
* *1K Multi-Channel Analyzer*
* *16 Million Counts/Channel*
* *Cross-Platform Software*



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Contents

Figure 1: Gamma spectrometer

1 Introduction

Nuclear science has immense importance in fields ranging from medical sciences to power generation, and defence. However, factors such as a lack of indigeneous equipment, high prices, and highly regulated processes for procurement of sources, has resulted in neglect of a more hands-on approach to studying this field. Human resource development is integral to economic and scientific progress in this field, and this requires education at the graduate level and beyond.

Therefore, there is an urgent need to indigenously develop instrumentation for research and teaching in nuclear physics, as well as work out experiments which rely on easily accessible apparatus and raw materials without compromising on pedagogical value.

This document explains a device that can measure the energy of gamma particles and also some of the experiments that can be done using various radioactive sources. It has an ultra compact design that incorporates the detector, all necessary pulse processing tools, and a 1k channel MCA in a aluminium enclosure you can hold in the palm of your hand. An adjustable DAC for theshold setting , and a monitoring output for the shaper signal is included. In addition, only a computer is required.

2 Acknowledgements

We would like to thank Prof.(Dr.) O.S.K.S Sastri from the Central University of Himachal Pradesh and his physics education research group for his valuable inputs which have been essential for developing the instrument from an education perspective for UG and PG laboratories. This instrument has been presented at two international conferences by Jithin BP; SYMPNP- DAE Symposium held at BARC, and RINP2. Whilst the former exhibited its various capabilities, the latter dealt with coincidence experiments carried out with this instrument. Our gratitude towards Prof Devinder Mehta, and Dr. Ashwini Jain from Panjab University cannot be expressed enough. Their active support and feedback were essential in the designing stages.
Special mention must be made for the developers of the Python project, and various analytical and visualization modules such as numpy, scipy, and pyqtgraph, without which software development could not have taken the form it has.

The following are the links to the conference proceedings:

- Jithin B.P. and O.S.K.S Sastri, "Indigenously developed gamma spectrometer," in *Proceedings of the DAE Symp. on Nucl. Phys. 63 (2018) 1072*, 2018, pp. 1072–1073. [Online]. Available: http://sympnp.org/proceedings/63/G19.pdf
- Jithin BP and O.S.K.S Sastri, "International Conference on Recent Issues in Nuclear and Particle Physics (RINP2) Gated MCA technique for demonstration of coincidence phenomena with a set of indigenously developed gamma spectrometers Primary author(s)." [Online]. Available: https://indico.cern.ch/event/763807/contributions/3274494/contribution.pdf

3 Instrument Design

Figure 2: Entire experiment setup of the Gamma Spectrometer '**GammaSpec-1K**'. Also shown is a laptop connected via the USB port with an example spectrum. Signal outputs from the shaping amplifier are connected to a 50MHz oscilloscope where the nature of this signal is shown

A labelled graphic of the equipment is provided in Figure 2. The radioactive source is kept in front of the gamma detector window, and has been removed while taking the photo to show the window. The oscilloscope displays the output of the shaping amplifier, and is optional. It is merely used to show students the shaper signal.

3.1 Scintillator based solid state detector

Typically a gamma detector consists of a scintillator mated with a device capable of measuring the quanta of scintillation photons emitted from it as a result of an incident gamma. In this case, a $10mm * 10mm * 8mm$ scintillator is mated to a semiconductor PN junction connected in reverse bias mode. The depletion region thus created acts as an ionisation medium which converts the scintillation photons into a corresponding number of electron-hole pairs. The small amount of charge generated as a result of one gamma ray depositing its entire energy in the scintillator which then gets converted into a charge pulse by the PN junction results in an event in the photopeak region. Other types of interactions such as compton scattering result on different energies being detected. This charge pulse is then fed to the signal processing electronics, followed by the multi-channel analyzer(MCA) which generates a spectrum.

The detector used in this instrument has $10mm \times 10mm$ surface area with an entry window of 8mm diameter. The window is covered with a thin aluminium foil to keep out visible light.

3.2 Signal Processing Electronics

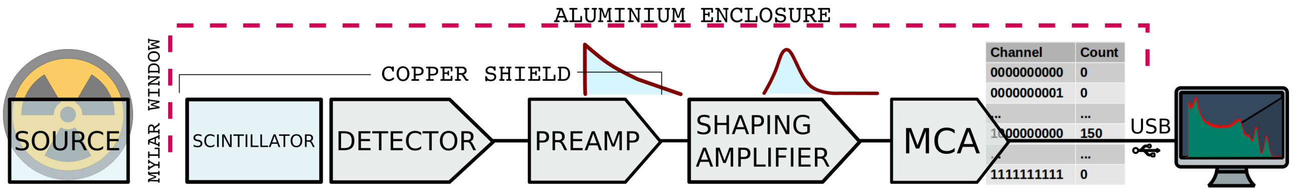


Figure 3: Flow diagram for the entire process

3.2.1 Pre-amplifier

The charge generated by an incident bunch of scintillation photons is converted into a corresponding output voltage by utilising a charge sensitive preamplifier. The main role of the preamp is to ensure impedance matching between high impedance at the detector side (i.e. input), with the low output impedance of the post-processing electronics. This also improves the signal-to-noise ratio (SNR).

3.2.2 Shaping Amplifier

The output of the Shaping amplifier is a Guassian shaped pulse. The amplitude varies from 0 to 3.3 volts, depending on the deposited energy. The shaping amplifier's gaussian pulse output is available on a BNC connector for monitoring purposes (Figure 2). The same buffered signal goes to the input of the built-in Multi Channel Analyzer.

3.3 Multi-Channel Analyzer(MCA):

The hardware performs a variety of tasks ranging from detection of the pulse, post-processing of the signal, and sorting the signals on the basis of their peak height into predefined bins. The MCA does the sorting and histogram generation, and it is designed to have 1024 channel(1K) resolution, with an input voltage range of $0 - 3.3V$. It has a USB interface, and the software works with Linux based systems such as Debian/Ubuntu and Fedora, as well as Windows 7/10.

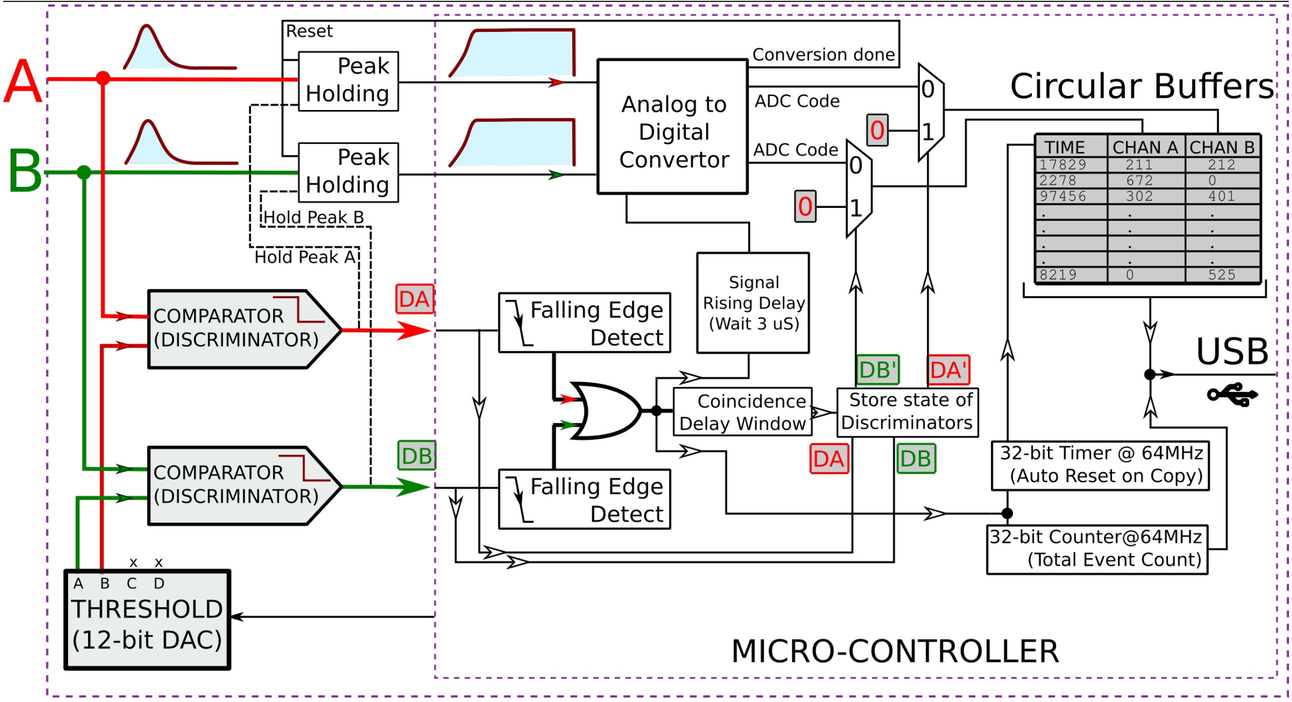
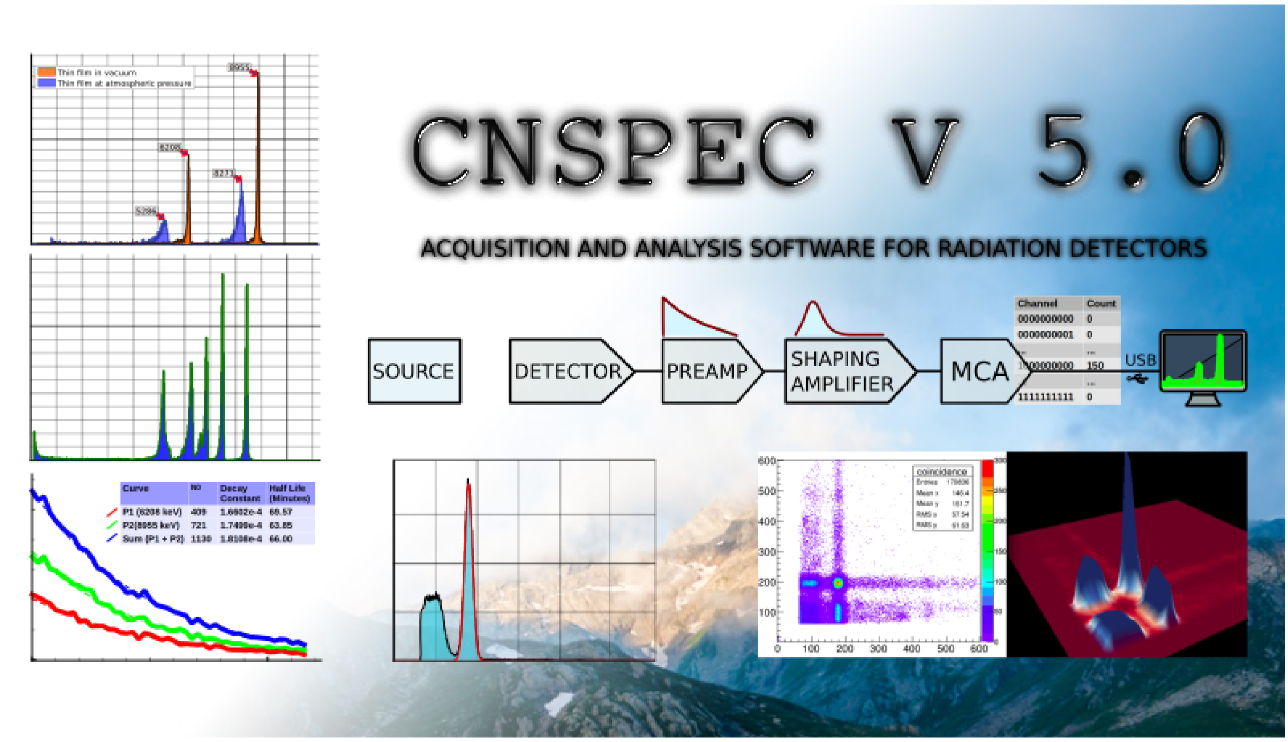


Figure 4: Flow diagram for the dual parameter MCA used for coincidence measurements.

Threshold Setting: Input pulses are only accepted if the amplitude exceeds a threshold value (to reject low energy peaks which might not be due to gamma rays) which is set to 65 channels. This can be set via a 12-bit, software controlled DAC. If you see a sharp peak to the extreme left of the spectrum, it indicates high electrical noise which needs to be rejected. Open the bottom-right menu, and raise the threshold value to a channel which exceeds the noise peak.

3.4 Power Supply

The spectrometer is USB powered, and does not require any other power supply. All data acquisition controls are via the PC to which the spectrometer is connected. The shaper output is always active, even if the software has not been launched.



4 Software

The software *CNSPEC* is capable of plotting the acquired data in real-time and has a host of utilities for data analysis. The open-source software is written in the Python programming language, and employs a variety of powerful utilities such as Numpy, Scipy, and PyQtGraph for various mathematical and visualization purposes.

It acquires the data from the hardware, and plots it in the form of a histogram showing channel number (corresponding to peak voltage proportional to deposited energy) on x-axis, and the number of events received at each channel on the y-axis, as shown in Figure 5.

Analytical features incorporated as of now in the software are 3-point calibration, fitting with Gaussian plus low-energy tail (Lorentzian part) to obtain peak information, and a summation utility to obtain the total number of counts corresponding to a peak. It also has data-loggers to automatically estimate half lives of peaks based on pre-selected channel regions.

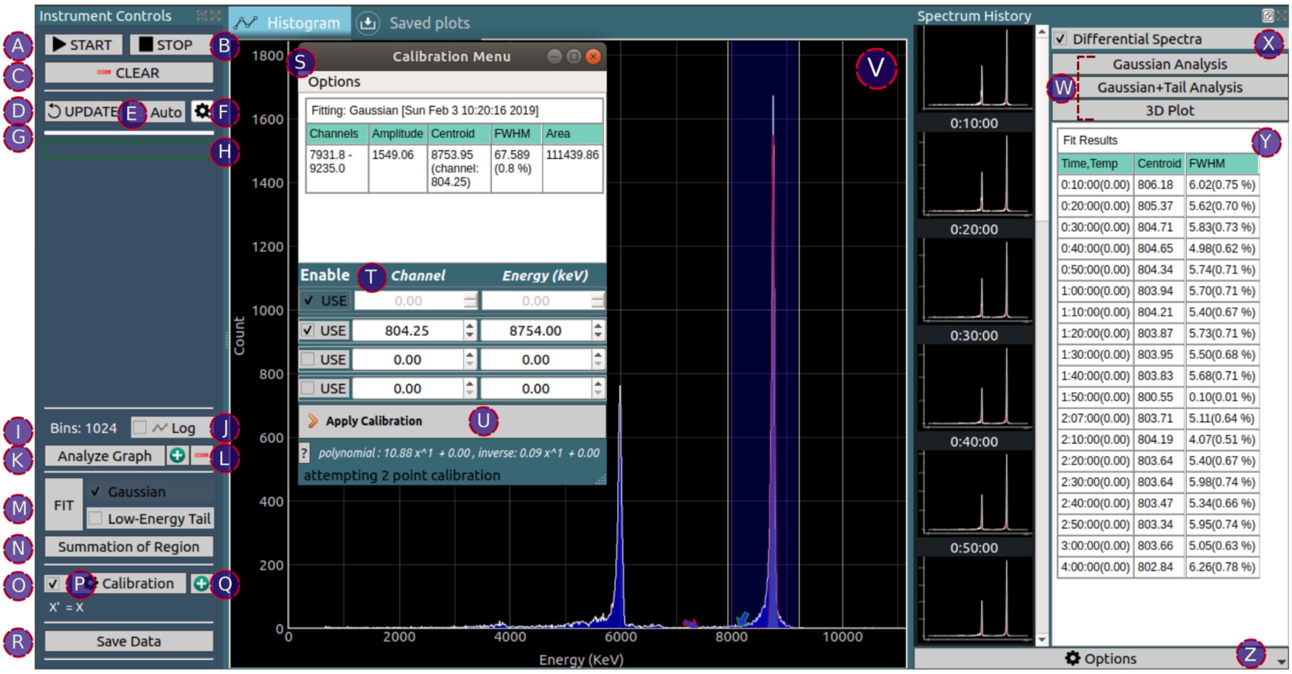


Figure 5: Open-source software provided with the Gamma Spectrometer '**CNSPEC**'. The software is compatible with our range of Alpha Spectrometers, Gamma spectrometers, and multi-channel analyzers. The spectrum shown is from 212-Bismuth, an alpha particle source, and a gamma spectrum screenshot is shown in Figure 6

4.1 Key Elements

The Gamma Spectrometer's companion software features can be broadly classified into the following subheadings

(A) Start Histogram : The hardware will start sorting input pulses into their respective bins

(B) Stop Histogram : The hardware will ignore all pulses until the next start command is issued

(C) Clear Histogram: The energy spectrum stored in the hardware will be cleared , along with the plot.

(D) Update : Energy spectrum is fetched from the hardware , and plotted on the screen. An auto-update option is also provided for repeating this at 0.5 Second intervals [Analytical tools are disabled in the auto-update mode].

(E) Auto-Update : Automatically fetch spectrum in fixed intervals. These are also automatically added to the spectrum history section.

(F) Auto-update interval in seconds.

(G) Time left for next automatic spectrum update.

(H) Pulse Counter : Shows total input pulses in real time. It can be used to determine if an update is necessary. Clicking on the counter resets its value to 0.

(I) Total number of bins in the spectrum shown.

(J) Display the Y-axis in log base 10.

Analytical tools

(K) Open the graph selection utilities dock.

(L) Region Selection : Add or remove graph region selectors used for defining regions for fitting, summation etc.

(M) Gaussian Fit : A selection region can be added and relocated to accommodate a peak. The peak can be fitted against a standard gaussian function to extract parameters such as centroid, FWHM, and amplitude. If the theoretical energy value of the peak is already known, the centroid value can also be used to utilize it as a reference point to calibrate the plot.
A low energy tail can also be added to the fitting function to accomodate attenuation by scattering agents.

(N) Obtain total events present inside a selected region. At least one region must be present on the graph in order to use this.

(O) Enable Calibration: Calibration with polynomials up to 3 orders is possible. Calibration points can be added in different ways

(P) Open the calibration window

(Q) Add a manual point for calibration (channel vs energy in keV). You must first click on the relevant peak in the graph (this places a red marker next to the peak) to identify it.

(R) Click on this button to open a spreadsheet with numerical values for the histogram. The spreadsheet will allow saving the data in raw form, or as an image.

(S) **Calibration menu:**

(T) Channel vs energy table. If only a single pair is specified, the origin coordinate is also used to make a 2 point calibration.

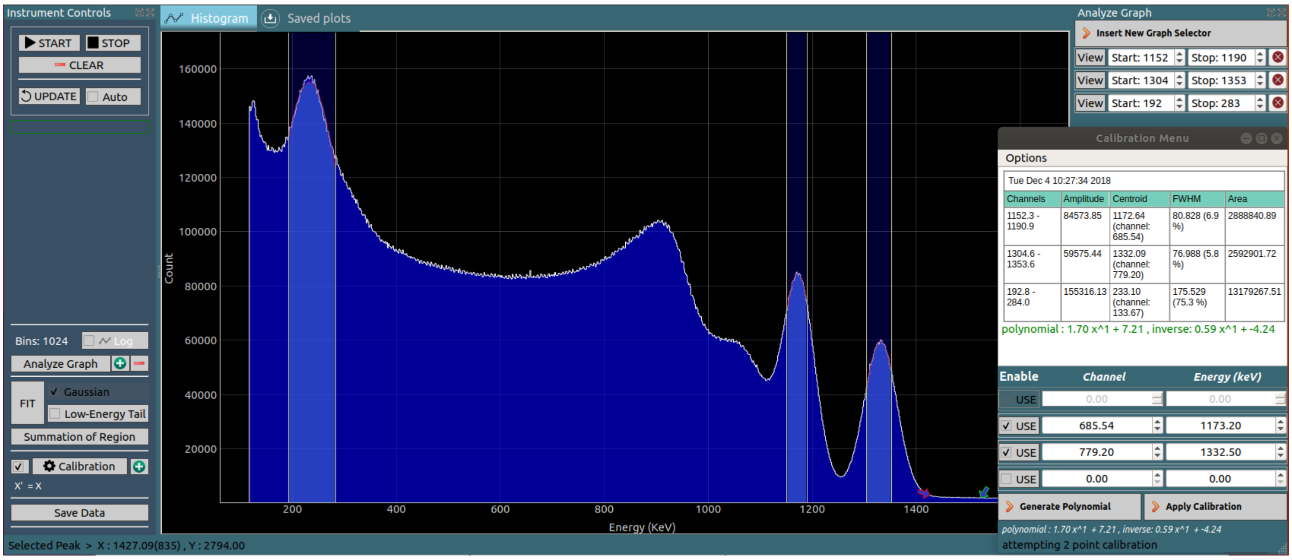


Figure 6: Gamma Spectrum from Cobalt-60

(U) Apply the calibration to the histogram. The polynomial is shown below the button.

(V) The spectrum of channels/energies Vs. counts.

(W) **Spectrum History :** The entire spectrum is saved into an array every time it is fetched from the hardware. In the differential spectra mode, new events recorded in each spectrum is used, and this allows for analysing various parameters such as centroid shifts, and half lives.

(X) Various different analysis options, including a 3D growth profile plot is available.

(Y) The analysis results are displayed in a table, and can also be saved into a collection of files into a directory.

The 'SAVED PLOTS' tab displays thumbnails of saved data. Select the appropriate directory, and click on any plot to load it to the main tab. You can then use the math utilities to further analyze your saved data.

4.2 Additional features

1. **Data Logger :** Data loggers are automatically activated for each selection region. These monitor the total events in the region, and also plot the activity as a function of time. Acquisition interval can be preset, and the loggers automatically calculate decay constants

and half-lives once adequate data is available. *The auto-update button must be selected for the logger to work.*

2. **Threshold setting :** Allows users to ignore low energy channels which under electrically noisy environments can accumulate counts unrelated to gamma rays.

4.3 Installation

The software has been packaged for Windows as well as Ubuntu.

4.3.1 Installation on Windows

Download the setup file from https://csparkresearch.in/gammaspec, and follow the instructions to install it.

4.3.2 Installation on Ubuntu

Download the deb file from https://csparkresearch.in, and install it using a package installer such as Gdebi.

4.4 Installation from source

The source code for the software is Python based, and can be downloaded from github. On Ubuntu :

Install dependencies (Command to be run only once. requires an internet connection)

- sudo apt-get install python3-pyqt5 python3-pyqt5.qtsvg python3-serial python3-pyqtgraph scipy numpy git
- https://github.com/csparkresearch/cnspec
- cd cnspec Run the software:
- python3 MCA.py

4.5 Calibration using ^{137}Cs

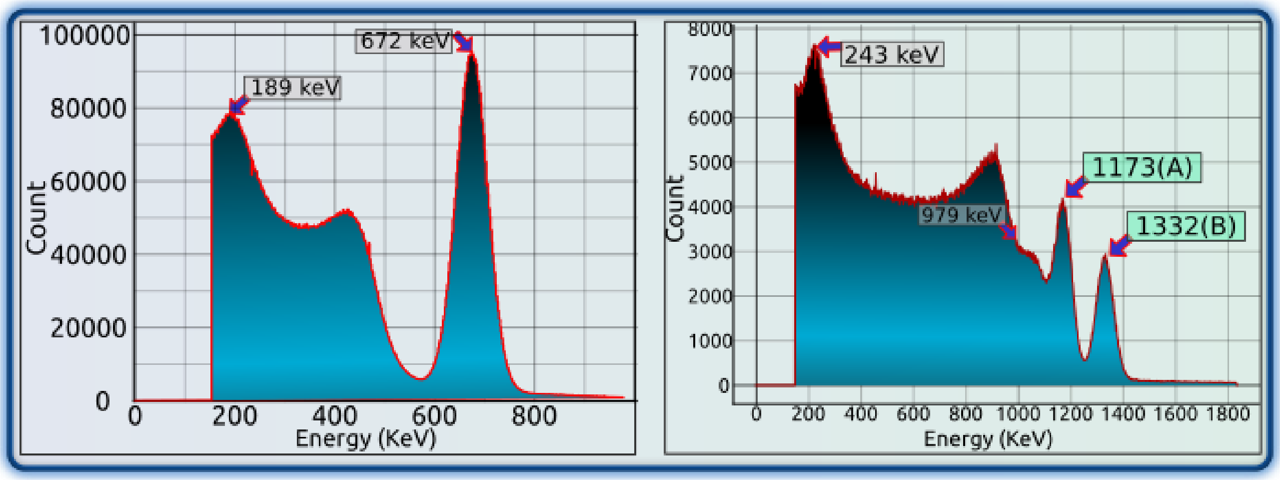


Figure 7: Single point calibration using ^{137}Cs, and linearity check with ^{60}Co

^{137}Cs source has a single photopeak, and can be used to apply a single point calibration which is composed of a scaling factor only. Higher order calibration polynomials can be generated using multi-peak sources such as ^{60}Co.

Steps to calibrate the instrument

- 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.
- Insert a selection region around the photopeak, and ensure that it covers this peak
- Click on the fit button, or press 'f'.
- After a succesful 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. For Cs-137, it is 662 keV.
- Click on 'Apply calibration polynomial' to apply this calibration.
- You will observe that the X-axis now displays energy units rather than channels, and that the photopeak's position is centered around the calibration value you had supplied.

- Finally, you may clear the spectrum, and repeat with an unknown source to determine its energy.

^{137}Cs enriched source is commonly employed for single point calibration purposes since it produces a single photopeak at a known energy. However, since single point calibrations are not equipped to correct offset errors, it is advisable to use a source with at least two gamma emissions at known energies, such as ^{60}Co. We can now cross-check if our calibration remains linear over the entire range of 2 MeV.

5 Gamma Gamma Coincidence

5.1 Coincidence Measurements

Coincidence measurements using multiple spectrometers allows for better identification of events with simultaneous multiple gamma emissions. This requires precise digitization of signals from multiple detectors, and timestamped data.

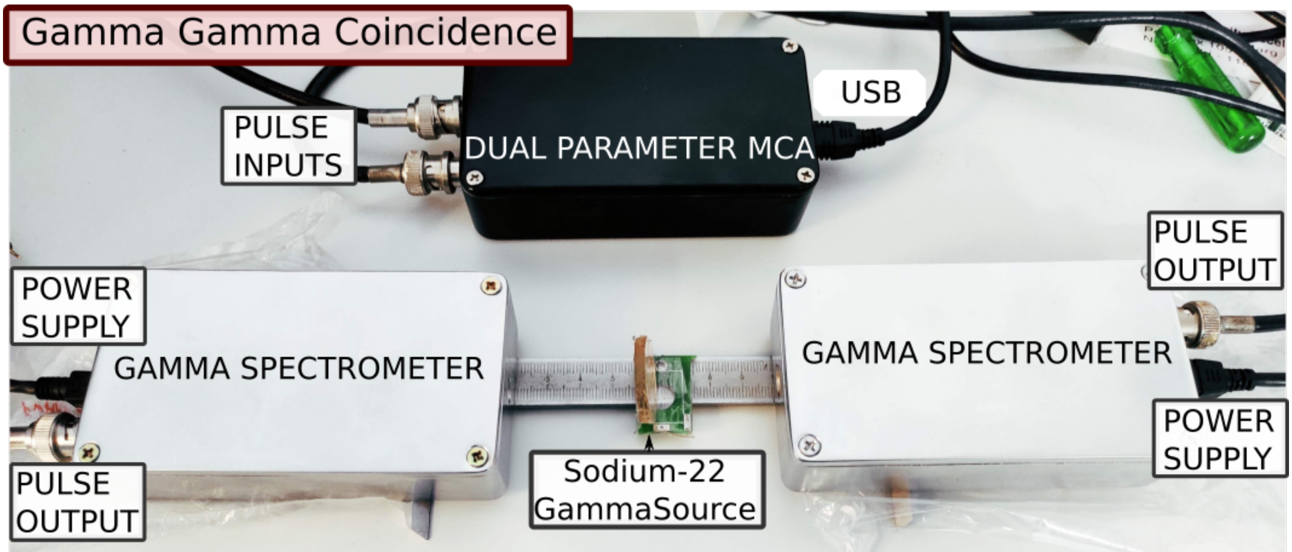


Figure 8: Two gamma spectrometers placed with a Na-22 positron source in the middle. The dual MCA carries out the data acquisition

5.2 Calibration using ^{22}Na

^{22}Na source has a photopeak at 511keV from positron annihilation, and a high energy peak at 1275. We will use the 511keV peak for calibrating the dual MCA. Higher order calibration

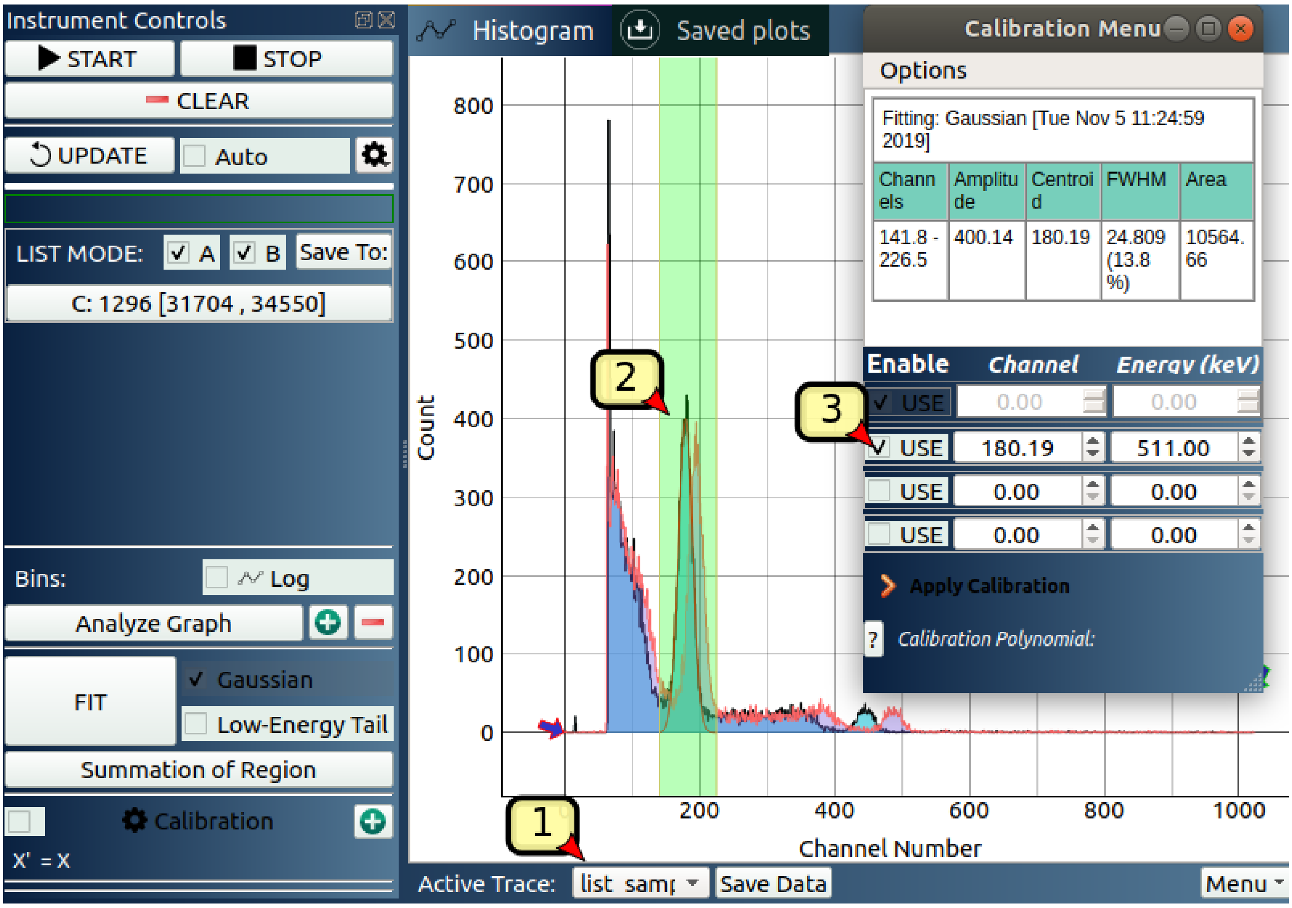


Figure 9: Single point calibration using 511 keV peak from ^{22}Na

polynomials can be generated using high energy peak as well.

Steps to calibrate the instrument

- 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 (Labelled **1**), which has a black outline.
- Insert a selection region around the 511keV photopeak(labelled **2**), and ensure that it covers this peak
- Click on the fit button, or press 'f'.

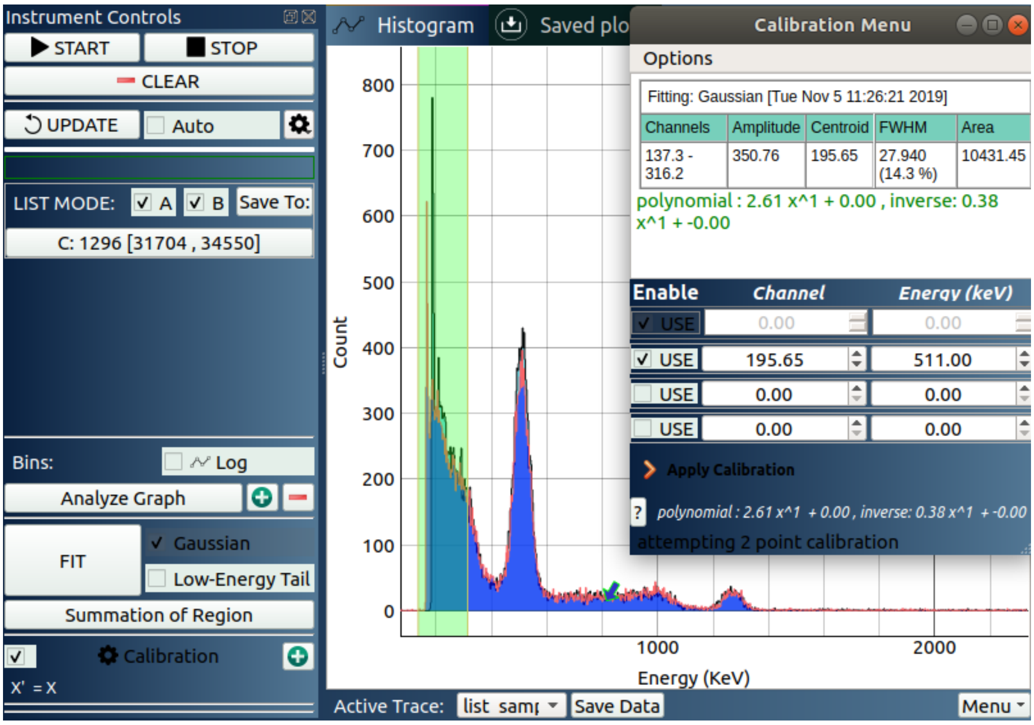


Figure 10: Spectrum after single point calibration using 511 keV peak from ^{22}Na

- After a succesful 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(from the menu **labelled 1**), and move the region to cover the 511keV peak from trace 2 (red colour)
- repeat the calibration process, and click on apply calibration.

5.3 3D data and heat maps

The coincidence data is also represented in the form of a surface plot and a heat map as shown in figure 11 . in order to calculate total coincident counts in a region, click on the ROI(Region of Interest) button, and drag the rectangular box to cover it. The total counts are shown in the bottom of the window, and the 3D surface plot automatically updates and rescales to show the selected area.

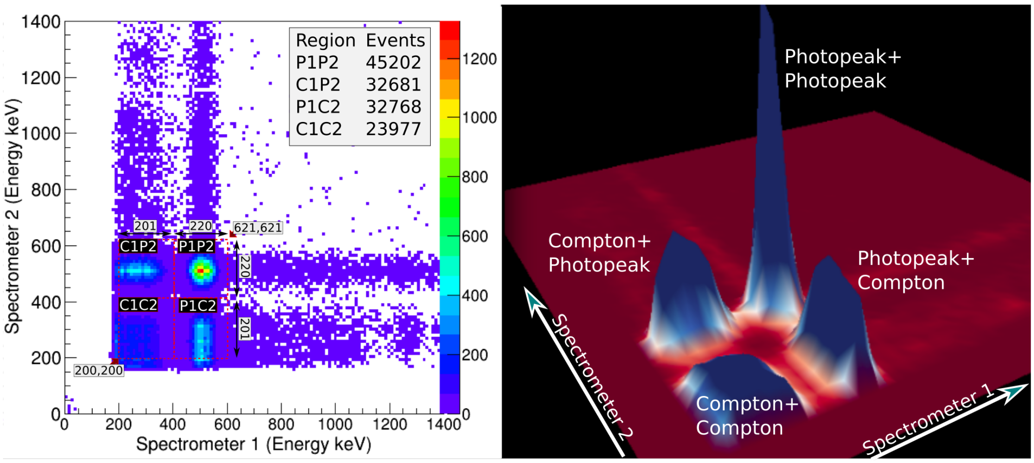


Figure 11: Coincidence spectrum from ^{22}Na shown as a heat map and a surface plot

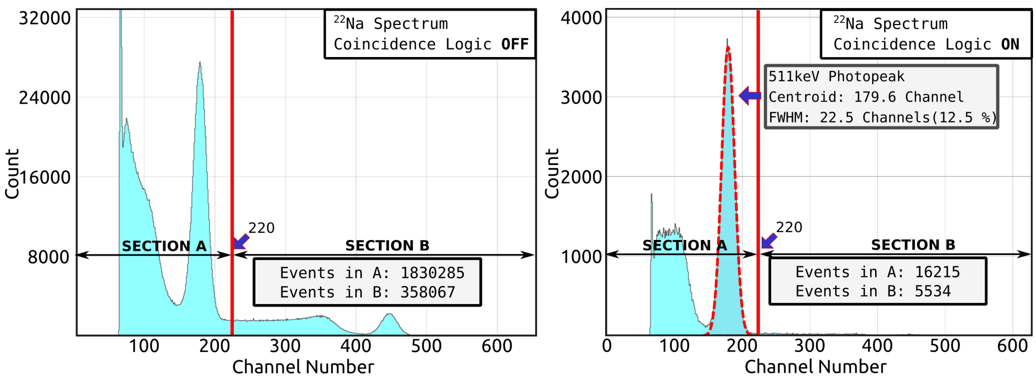


Figure 12: Coincidence gate applied for 511keV events from B shows the high energy 1275 keV events getting rejected

5.4 Applying energy gates

The ideal way for enhanced analysis currently is to use the saved csv file with a tool such as CERN-Root. However, some energy gating features have been implemented.

In this, one can isolate the counts obtained through input 1 where the corresponding Input 2 signal is between channels A and B. In order to configure a gate on B, press the c key on the keyboard, and input the starting channel, and ending channel. You will observe that spectrum 1(black trace) is automatically updated to represent the events that satisfy the criteria.

6 Experiments

Using this equipment, one can study the decay patterns of various radioactive elements. It is also possible to study the energy loss of gamma rays in materials, by using attenuators. One can also carry out dosimetry applications, or $\frac{1}{r^2}$ dependence of counts. In this section we explain several experiments that can be done with this equipment.

6.1 Energy spectrum of ^{137}Cs

Cesium 137 is a radioactive isotope that emits gamma rays at 662 keV. Its monoenergetic nature makes it ideal for single point calibration. The results of this experiment have been shown in Figure 9 in the previous section.

6.2 To study the effect of distance on total counts

The ^{137}Cs source was placed at different distances from the window of the gamma spectrometer, and total counts are recorded for a fixed interval of time. Total counts are shown below the update button in the software. The dependence of counts per unit time as a function of distance follows a $\frac{1}{r^2}$ dependence similar to what can be estimated using a Geiger counter.

6.3 Study of naturally radioactive sources

The sandy beaches in southern India are rich in Thorium-232, as well as natural uranium. The activity is low, and of the order for a few ten counts per second for a gram of monazite sand, so spectrum must be acquired for a few hours to get good data. Energies such as 2.6MeV from 208 Thallium can be clearly identified. The double escape peak from the same source can also be spotted around 1.6MeV.[3]

References

[1] Jithin B.P. and O.S.K.S Sastri, "Indigenously developed gamma spectrometer," in *Proceedings of the DAE Symp. on Nucl. Phys. 63 (2018) 1072*, 2018, pp. 1072–1073. [Online]. Available: http://sympnp.org/proceedings/63/G19.pdf.

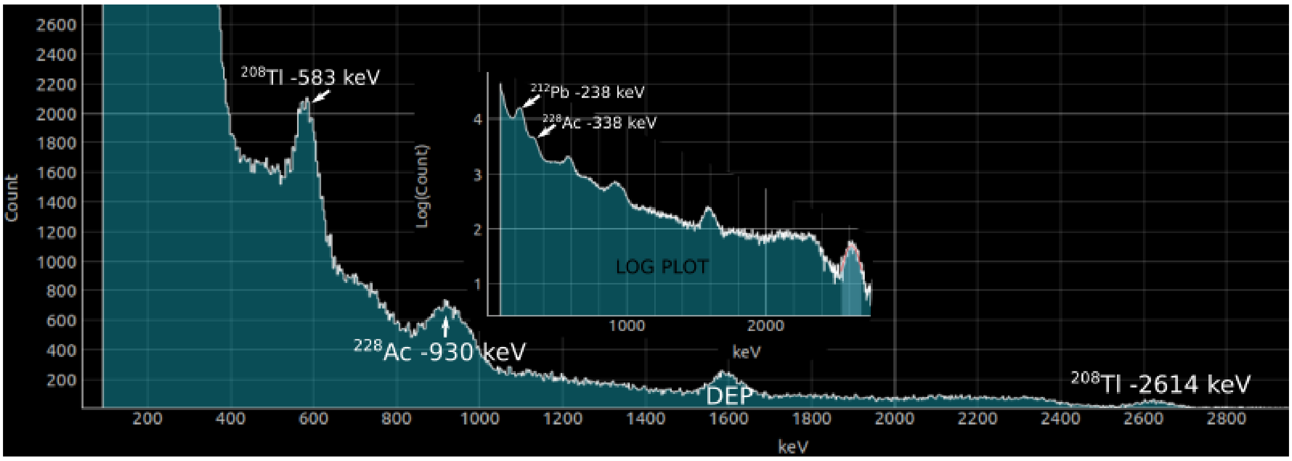


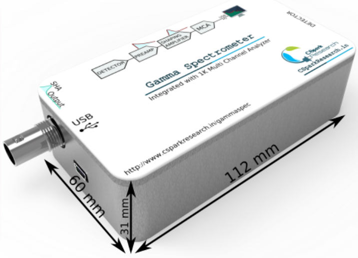
Figure 13: Spectrum acquired from 1gm of monazite sand over a period of 14 Hours. The source was separately analyzed, and contained 330becq of thorium 232, and 30becq of natural uranium

[2] Jithin BP and O.S.K.S Sastri, "International Conference on Recent Issues in Nuclear and Particle Physics (RINP2) Gated MCA technique for demonstration of coincidence phenomena with a set of indigenously developed gamma spectrometers Primary author(s)." [Online]. Available: https://indico.cern.ch/event/763807/contributions/3274494/contribution.pdf.

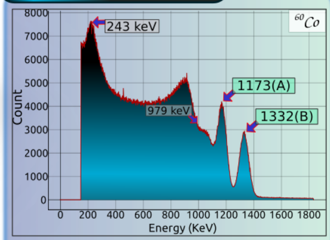
[3] J. Bhagavathi, S. Gora, V. Satyanarayana, O. Sastri, and B. Ajith, "Gamma Spectra of Non-Enriched Thorium Sources using PIN Photodiode and PMT based Detectors," *Physics Education*, vol. Manuscript, 2020.

Key Points

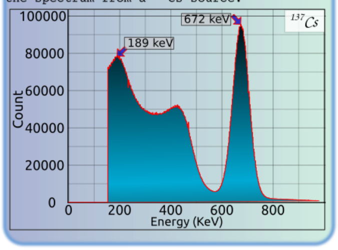
* **2 MeV** Full Scale Range.
* **< 80keV** FWHM for 1.33MeV peak from ^{60}Co
* Entirely **USB Powered.** All necessary voltages are generated internally using charge pumps.
* **1K MCA** designed using 64MHz PIC24E processor and a 12-bit ADC.
* Shaper output provided for monitoring and pedagogical value.
* **Open-Source,** Python based **Software** developed with all necessary analytical capabilities.
* Linearity verified to better than 1% .



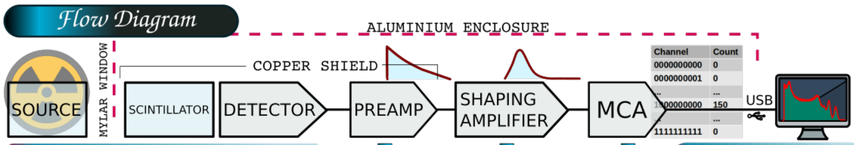
Calibration



- A 2-point calibration was applied using the known peaks from a ^{60}Co spectrum.
- This was used to measure the backscatter and compton edges, as well as characterise the spectrum from a ^{137}Cs source.



Flow Diagram



The scintillator is coupled with a 10*10mm PIPS detector which generates a charge pulse proportional to the deposited energy.

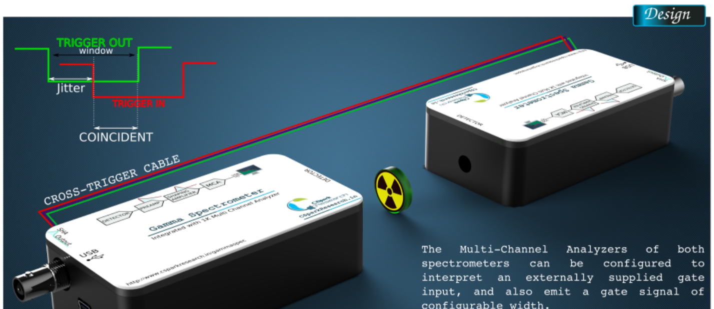
- The **PREAMPLIFICATION** stage converts the charge pulses into a corresponding voltage spike. Due to the extremely sensitive nature of the signals, it must be electrically shielded.
- The output of the preamp is directly fed to the **SHAPING AMPLIFIER** which is also fabricated on the same PCB, but with ground plane segregation. A series of op-amps in the shaper generate a corresponding output pulse with a pseudo-gaussian appearance.
- This signal is then sent to the peak sensing circuitry of the 1K-MCA, as well as its ADC.
- The same signal is also buffered and sent to a BNC connector for external monitoring

We developed Python based software compatible with Linux/Windows/Mac. It Includes all essential utilities for curve fitting, summation, and half-life estimation purposes. Mobile app development is also possible, and is included in future goals.

- The MCA uses a 12-bit ADC to digitize the input pulses within 0 - 3.3V range. 2-bits are discarded, and the resultant value is sorted on-the-fly into a histogram which can be accessed via the USB interface.
- A 12-bit DAC is used to set the threshold value for rejecting the noise floor, and typically 70 channels are discarded. The MCA takes 7 uS to digitize and sort the value, and including the shaper's rise time, total time per event is 10 uS.

Summarized poster from DAE symposium, SYMPNP, 2018

Design



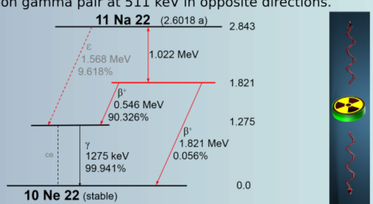
* Discriminator pulse is generated from the shaper input .
* 500nS window to account for pulse jitter.
* Coincidence logic interpretation is handled by the 64Mhz processor of the MCA

The Multi-Channel Analyzers of both spectrometers can be configured to interpret an externally supplied gate input, and also emit a gate signal of configurable width.

This enables coincident detection but **without energy discrimination** since energy information is not available at the time of decision making.

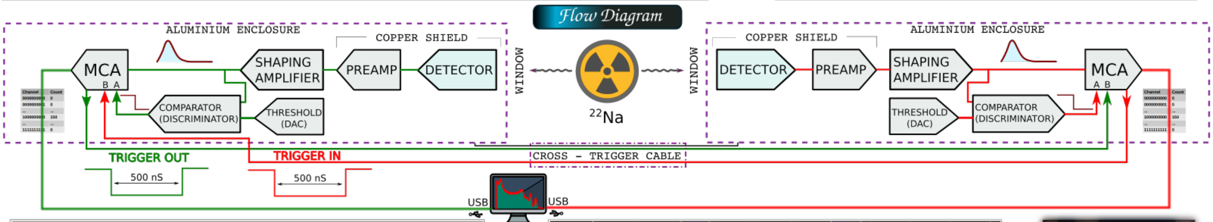
Measurements with ^{22}Na

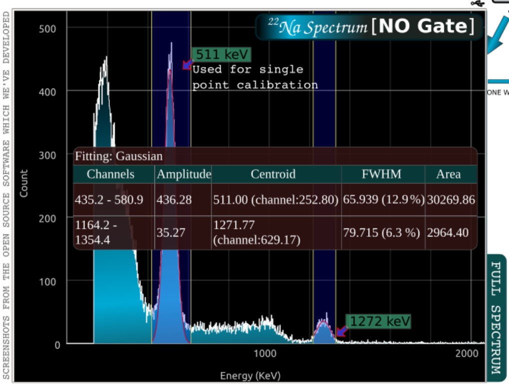
* ^{22}Na undergoes decay into an excited state of Neon via positron(β+) emission with 90% probability.
* The emitted positrons lead to a characteristic annihilation radiation gamma pair at 511 keV in opposite directions.



* The 511keV gamma rays are always accompanied by a counterpart emitted in the opposite direction.
* Coincidence measurements with spectrometers aligned linearly with the source can detect these, but the 1275 keV high energy peak from the de-excitation of Neon will be ignored due to lack of angular correlation

Flow Diagram

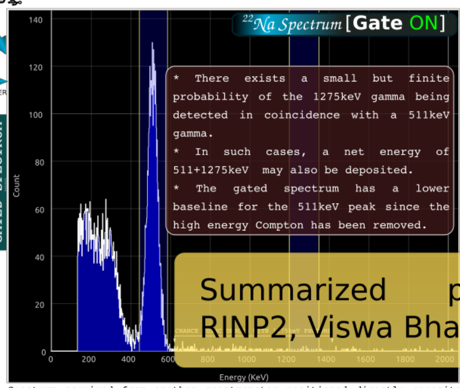




Fitting: Gaussian

Channels	Amplitude	Centroid	FWHM	Area
435.2 - 580.9	436.28	511.00 (channel:252.80)	65.939 (12.9%)	30269.86
1164.2 - 1354.4	35.27	1271.77 (channel:629.17)	79.715 (6.3 %)	2964.40

Complete energy spectrum of 22Na showing the high energy peak at 1275keV, the 511keV annihilation peak, and associated compton regions.



* There exists a small but finite probability of the 1275keV gamma being detected in coincidence with a 511keV gamma.
* In such cases, a net energy of 511+1275keV may also be deposited.
* The gated spectrum has a lower baseline for the 511keV peak since the high energy Compton has been removed.

Summarized poster from RINP2, Viswa Bharati, 2019.

Spectrum acquired from another spectrometer positioned directly opposite the one on the left, and configured to use its trigger signal to ensure coincidence. The 1275keV photopeak and its compton region is missing!

Photograph of the setup: ^{22}Na point source is kept center aligned