CAEN
Tools for Discovery

Electronic Instrumentation

Clover Detector Data Acquisition with CAEN V1782 Octal MCA

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Index

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1. Abstract

In recent years a new generation of High-Purity Germanium (HPGe) detectors is having more and more success in low and medium energy nuclear physics applications dedicated to gamma-ray spectroscopy. These detectors, also known as Clover detectors, consist of 4 coaxial N-type high purity germanium crystals, each properly shaped and mounted in a common cryostat to form a structure resembling a four-leaf clover. Typically, these detectors are surrounded by a layer of scintillators like BGO or CsI which act as an Anti-Compton Shield, rejecting those events in which the gamma-ray has undergone a Compton scattering inside the germanium crystals and then escaped from the active volume.

This document described the CAEN digital solution for the clover readout based on the new V1782 Octal and shows the results of a several (not 100% homogenous) measurements performed with clover and segmented HPGe detector at several customer's site. Among them a particular attention is dedicated to the test done at IUAC (Delhi) on the INGA clover detectors array using an ^{152}Eu source.

2. Introduction

In '90s the production of standard n-type large volume Ge crystals reached something of a ceiling as researchers were unable to develop crystals larger than about 300 cm^3 and diameters of about 70 mm. Beyond the latter value, Ge crystal production, ballistic deficit and neutron damage sensitivity problems were encountered. In addition, such large volume detectors placed approximately 90° to the beam direction undergo a large Doppler broadening of the γ-ray lines. The realization of new and more efficient multi-detector arrays was therefore dependent on the production of new types of Ge detectors. A new concept of Ge detector was developed to overcome these difficulties: the composite Ge detector in which several crystals are assembled in a common cryostat leading to active volumes much larger than accessible with monolithic detectors[1].

3. The Clover Detector

The Clover detector consists of four coaxial *n*-type Ge diodes of 50 mm diameter and 70 mm length mounted in a common cryostat. Each crystal is shaped as shown Figure 1.

Figure 1: Left panel: individual Clover crystal. Right panel: close packing of the four shaped Ge crystals of a Clover detector.

The front face has a quasi-squared section, obtained by beveling two adjacent faces with an angle of 7.1° beginning approximately midway of the crystal length and then cutting the two remaining faces parallel to the crystal axis along its whole length. This enables a close packing of the diodes with a Ge-Ge distance of only 0.2 mm. The total active Ge volume is about 470 cm^3, which corresponds to 89% of the original Ge volume. In order to optimize the signal-to-noise ratio of the composite detector the crystals are held on a minimized crystal holder. This reduces the quantity of material surrounding the crystals. The aluminum housing typically used to hold the crystals is replaced by a grip that holds the diodes by their rear side. Additionally, the crystals are packed very closely together to improve the Add-back factor. The four crystals are mounted in a common cryostat with either a tapered or regular square shaped end cap. Distance between end cap and crystals has been reduced to a bare minimum to improve the solid angle and the efficiency of any veto detector arranged around the Clover cap. The distance between the beveled edges of the crystals and the internal surface of the endcap is only 3.5 mm. The thickness of the aluminum endcap is 1.5 mm. A common ground is applied on the outer contacts of the diodes while the high voltage to the inner contacts of the diodes. The energy signal is collected for each crystal from the inner contact via AC-coupling. So called back catcher cryostats are available for given Clover types where a dedicated BGO detector is installed at the rear of the cap. A major advantage of a Clover detector results from of its high absorption efficiency. Results are four times those obtained with a single crystal. Additionally, crystals are mounted without any additional absorbing material, allowing the full energy of a photon Compton scattered and absorbed in a second (or even a third) crystal to be determined. The full energy peak can be obtained by summing (*Add-back*) the energies deposited in the N segments firing. The *Add-back* efficiency is then superior to the sum of the four individual efficiencies[1].

4. The CAEN Octal Digital MCA V1782

The V1782 is an octal 32k MCA in VME 2U wide form factor. The inputs are BNC connectors (1 KOhm input impedeance) with 4 programmable gains (x1, x2, x4, x8, where G=1 corresponds to 1 Vpp dynamic range). An input attenuator (x0.2) is also available by jumper selection; when enabled, the coarse gains are x0.2, x0.4, x0.8, x1.6, where x0.2 corresponds to 5 Vpp dynamic range. AC or DC coupling is also selectable by jumper: DC coupling is used for RC Preamplifiers, AC for Transistor Reset Preamplifiers. The V1782 operates in list mode, providing a sequence of time stamps (10 ns resolution) and energies (pulse height). The software reads the list and builds the energy spectrum (PHA) for each input (individual crystals) as well as for the add-back by looking at time stamps for the coincidences. The software generates output files with spectra, eight individual lists (channel wise) and two merged lists (detector wise, one per 4 channels). Additional detectors, such as LaBr3, NaI, BGO and other scintillators can be read by the V1782, either going through a preamp or directly from the anode signal. Thanks to the capability of the V1782 to implement coincidences and anti-coincidences between channels as well as with the front panels logic I/Os, the V1782 can easily manage Anti Compton Shields, background suppression systems and almost any type of correlation between fast and slow detectors. For the applications where a high resolution timing is required (sub ns), the V1782 can be operated in conjunction with faster digitizers such as the V1730 or V1725 (500 and 250 MS/s respectively); the whole system can run synchronously and guarantee the readout of a wide variety of detectors, providing high resolution energy and timing information, as well as pulse shape discrimination.

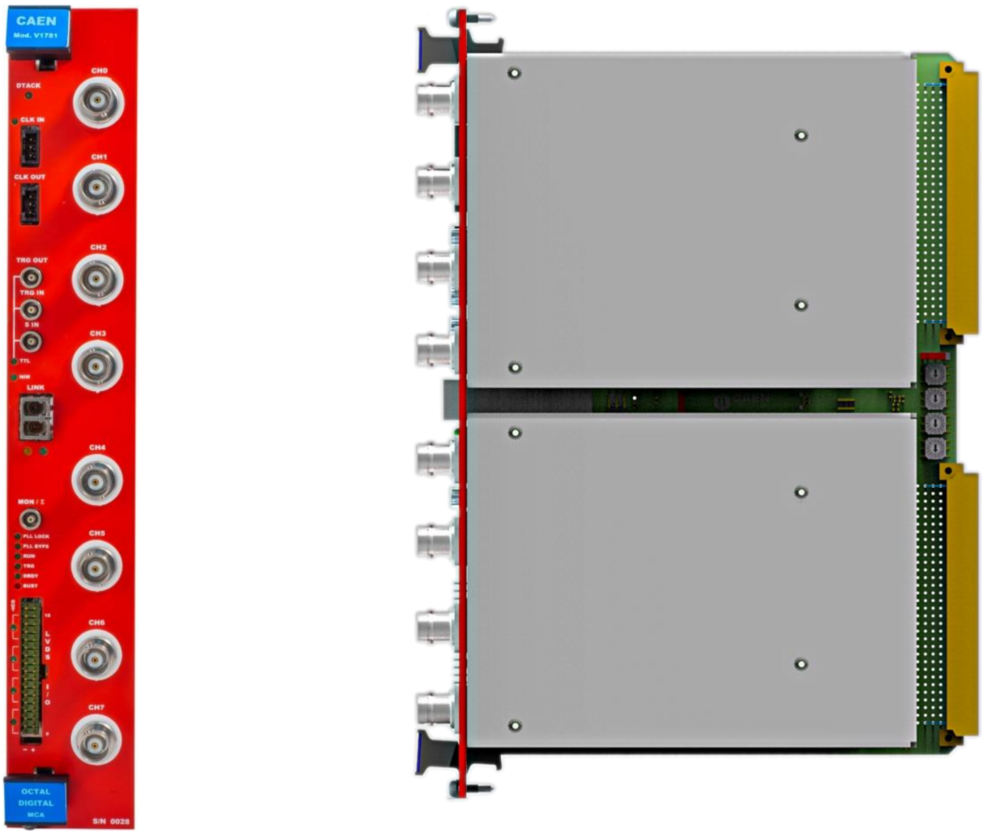


Figure 2: V1782 MCA front panel (left side) and side view (right side).

The following table summarize the V1782 technical specification and its compatibility with Clover detectors

ANALOG INPUT	**Input Features** ▪ BNC connector ▪ Single ended, DC and 10 µs AC coupling hardware selectable ▪ Impedance: 1 kΩ ▪ Positive and negative signals accepted ▪ Analog Coarse Gain: x1, x2, x4, x8 software selectable (Gain 1 = 1 V_{pp}); gain attenuation x0.2 by on-board jumper ▪ Programmable DC offset adjustment on each input in the full-scale range	**Number of Inputs** 8
CLOVER DETECTORS	▪ Digital readout (16 bit, 100 MS/s) ▪ No spectroscopy amplifiers required (preamp signals feed the digitizer inputs) ▪ Individual channel self-triggering (fast discriminators) ▪ Digital shaping: trapezoidal filter with programmable rise time and flat top ▪ Pile-up rejection ▪ Acquisition modes: PHA or time stamped list mode ▪ Energy spectrum: singles (channel wise), compton suppressed (channel wise), add-back (detector wise), coincidences (detector wise)	
ANTI-COMPTON SHIELD	▪ PMT Anode signals of the ACS directly read out ▪ Compton suppression in Clovers applied in hardware (before the readout) ▪ Programmable delay and window for the anti-coincidence ▪ Possibility to disable the Compton suppression (Compton events are read with a tag) ▪ ACS signals readout for system health check o Count rate o PHA spectrum	
DIGITAL SIGNAL PROCESSING	▪ Trapezoidal filter for the energy calculation: adjustable rise time 0.02 to 40 µs; flat top 0.02 to 40 µs ▪ Trigger and Timing filter based on integrative-derivative component (30-bit time stamp, 10 ns resolution, 10 s range, 64-bit extension by software, roll-over tracking event) ▪ Trigger threshold adjustment ▪ Digital fine gain: 1 to 2.2 in steps of 0.0001 ▪ Trapezoid tail correction; decay time 0.1 to 650 µs ▪ Trigger time tag discrimination by RC-CR^2 filter; shaping time 0.01 to 2.4 µs ▪ Trigger hold-off (imposed dead-time) to prevent after pulses: 0 to 40 µs ▪ Programmable Pile-up Guard duration: 0 to 80 µs beyond the end of the flat top ▪ Baseline restorer: fast, medium, slow	
OPERATING MODES	▪ Pulse Height Analysis (PHA): 1k-2k-4k-8k-16k-32k pulse height histogram built at software level ▪ List mode: pulse height and time stamp for each event ▪ Oscilloscope mode: signal inspection of input pulses and internal filters outputs	
TRIGGER MODES	▪ Uncorrelated: each channel operates independently (based on channel self-trigger) ▪ Correlated: coincidence/anticoincidence among channels and/or an external trigger (TRG-IN) ▪ External: channels are triggered by external trigger only (TRG-IN)	

COINCIDENCE AND CORRELATIONS	▪ Coincidence between detectors (Clovers and/or Scintillators) can be applied in the hardware (before the readout) or in the software (before writing to disk) without any additional dead time ▪ Programmable coincidence window ▪ Gamma Coincidences o between 2 or more clovers o between clover(s) and scintillator(s) (e.g. NaI, CsI or BGO) o between 2 or more scintillators o custom configurations (t.b.d.)
COMMUNICATION INTERFACE	**Optical Link** ▪ CAEN CONET proprietary protocol ▪ Up to 80 MB/s transfer rate ▪ Daisy chain capability by connecting up to 8 or 32 ADC modules to a single Optical Link Controller (A2818 or A3818 respectively) **VME** ▪ VME 64X compliant interface ▪ Data transfer mode: ▪ BLT32, MBLT64 (70 MB/s using CAEN Bridge) ▪ CBLT32/64, 2eVME, 2eSST (up to 200 MB/s)
SOFTWARE	▪ User friendly GUI ▪ Easy configuration of the acquisition parameters ▪ Clover calibration and add-back ▪ Online spectra plotting: ▪ Energy spectrum of Clovers (single crystals and add-back) ▪ Energy Spectrum of Scintillators and ACS ▪ TAC spectrum for Clovers and Scintillators ▪ Live Statistics report (count rate, live/dead time, etc...) ▪ Signal Inspection (oscilloscope mode) of all detectors
SPECTRUM ANALYSIS	▪ ROIs ▪ Energy calibration ▪ Fit ▪ FWHM ▪ Net/Gross area ▪ Background subtraction
OUTPUT FILES	▪ Binary Raw Data: fast output to disk of whole data readout for off-line analysis ▪ Time sorted list mode (Time stamp + Energy + Flags) o channel wise (e.g. single crystal of a clover) o detector wise (e.g. add-back) o full system (e.g. event building after coincidences) ▪ Energy spectra o channel wise o detector wise ▪ TAC spectra ▪ Configuration

The V1782 implements a digital trapezoidal filter on the input pulse, replacing the traditional analog chain of shaping amplifier and peak sensing ADC. The MCA is directly connected to the charge sensitive preamplifier, with no need of additional devices. The Pulse Height Analysis algorithm can perform online baseline restoration, ballistic effect corrections, and manage the pile-up of live time information. The following picture is a simplified scheme demonstrating how the timing and trapezoidal filter implemented in the DPP-PHA firmware work. More details about the DPP-PHA can be found in [2].

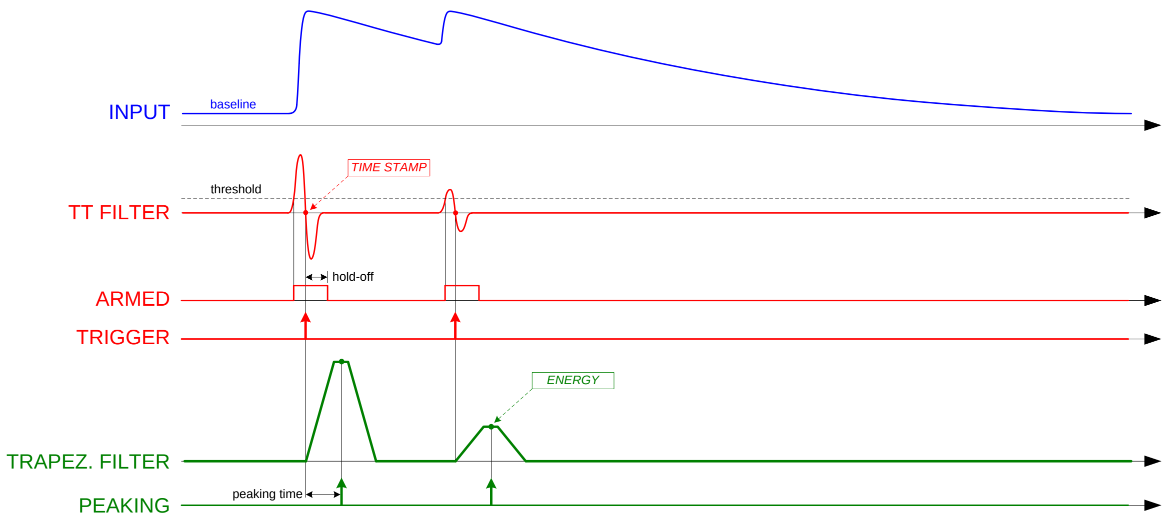


Figure 3: Simplified signals scheme of the Trigger and Timing filter (red) and the Trapezoidal Filter (green). In blue are the input pulses from the preamplifier.

5. Characterization of a Clover experimental setup

The characterization of an experimental setup composed of Clover detectors and Anti-Compton shield and the evaluation of its performance is performed by a standard set of experimental measurements aiming to determine well-defined quantities. In particular, the evaluation is performed using a ^{60}Co source placed 25 cm away from the Clover detectors and acquiring spectra in direct and total detection modes, then evaluating the spectra both before and after the application of the Anti-Compton shield:

- the *Add-back* factor: a parameters that allows to evaluate the contribution from scattering between the detectors to the total photopeak efficiency of a Clover detector[3]
- the *Peak to Total* (P/T) Ratio: it corresponds to the sum of the ^{60}Co net peak areas divided by the total number of counts in the spectrum for energies from 100 to 1350 keV[5]
- the energy resolution at 1332 keV ^{60}Co peak

In some cases, since **no Anti-Compton shield** was present, we did not go through all these steps and we performed the first measurement only using a ^{60}Co or a ^{152}Eu source.

6. Laboratory test with Clover detectors

A prototypal eight channel version of the V1782 with a 14-bit ADC has been tested with a 4 crystal Clover detector and a 36 segment HPGe detector. In both cases, only a single High Voltage channel has been used to bias the detector; a 4-way passive splitter has been used for the Clover. A NIM crate has been used to get ±12V for the preamps.

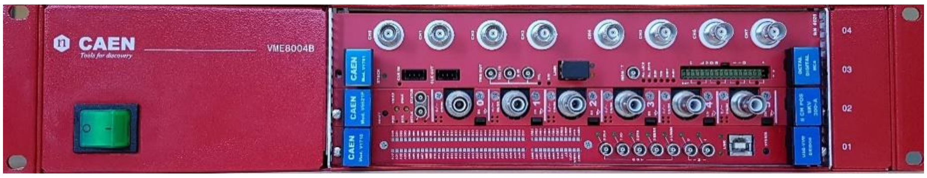
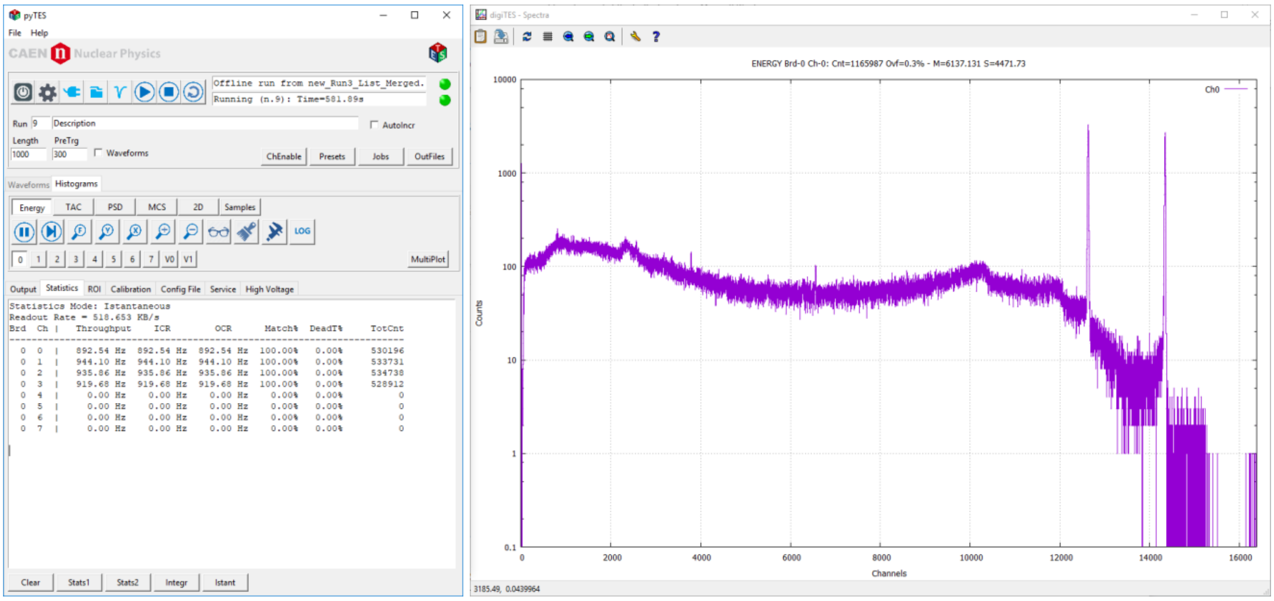


Figure 4: DAQ setup during the measurement with Clovers and Segmented HPGe detectors.

The software used for the acquisition is a very preliminary version of the one supporting the V1782. The picture below shows the GUI (at the time of this test):



6.1 Clover Detector with ^{57}Co source

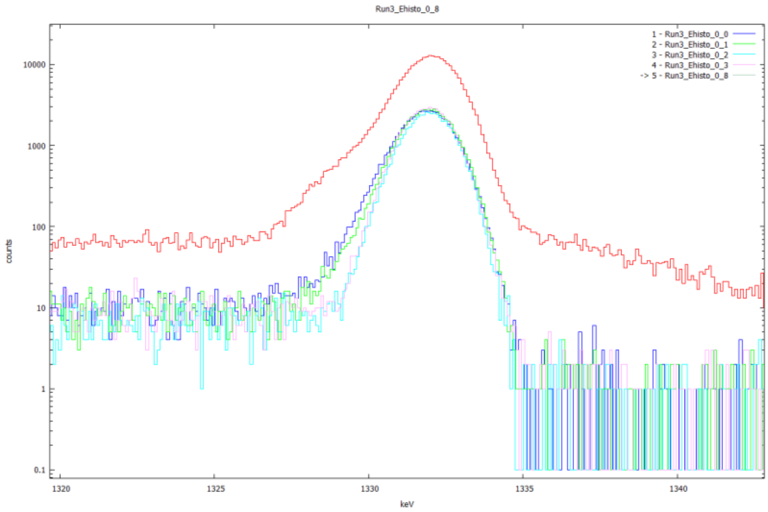
The purpose of this test is to measure the energy resolution of the V7182 at low energy (122 keV). The coarse gain is 8 (0.25 Vpp) and it corresponds to a full scale of 0.4 MeV. The count rate is about 900 cps. The energy resolution of the 4 crystals is the following:

	Crystal 1	Crystal 2	Crystal 3	Crystal 4
FWHM @ 122 keV	0.82 keV	0.81 keV	0.77 keV	0.80 keV

The resolution is equal (or even better) than the characterization of the detector performed with analog acquisition chain.

6.2 Clover Detector with ^{60}Co source

The coarse gain has been changed to 2 in order to have a full scale of ~1.6 MeV and include the two peaks of the ^{60}Co. The acquisition software generates online the **add-back** spectrum on a “virtual channel” and it is possible to plot, save and analyze that spectrum while the acquisition is running, as showed in the following picture where the energy spectra of the 4 crystals and the add-back are plotted on a calibrated scale.



The energy resolution of the single crystals and the add-back is the following:

	Crystal 1	Crystal 2	Crystal 3	Crystal 4	Add-back
FWHM @ 1332 keV	1.87 keV	1.81 keV	1.72 keV	1.72 keV	1.91 keV

Furthermore, the software calculates the net areas in the selected ROIs and it is easy to calculate the **add-back factor** (ratio between the net area of the add-back spectrum and the sum of the four net areas of the single crystals for the 1332 KeV peak).

$$Add\ Back\ Ratio\ @1332\ keV = \frac{Net_{AB}}{\sum_{i=1}^{4} Net_i} = 1.3$$

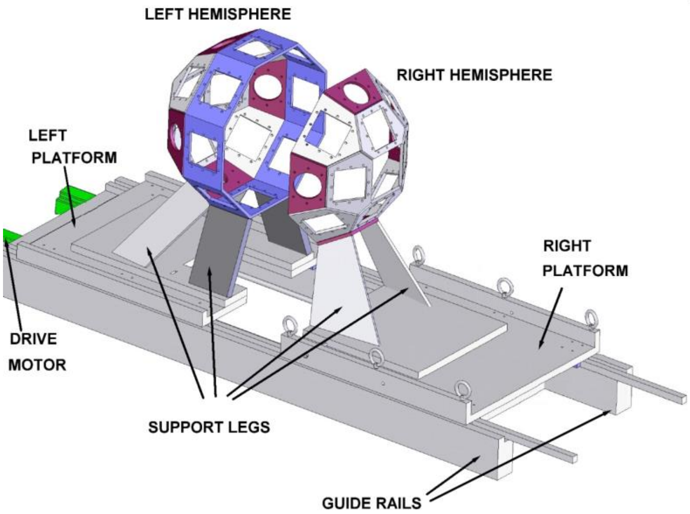
The result is 1.3, which is the expected value for the used clover detector.

7. Test at the INGA Clover detector setup (IUAC, India)

7.1 Experimental Setup

INGA (Indian National Gamma Array) is an array of Compton-suppressed Clover detectors with nearly 4π geometric coverage. Individual shields subtend ~ 30° at the target. A maximum of 24 Clover detectors can be accommodated in the array. The total photopeak efficiency of INGA is ~ 5% and the array is optimized for γ-γ-γ and higher fold data. INGA can be used with auxiliary detectors like CsI-based charge particle detector array[4].

A conceptual scheme of the INGA layout is shown in **Errore. L'origine riferimento non è stata trovata.**.



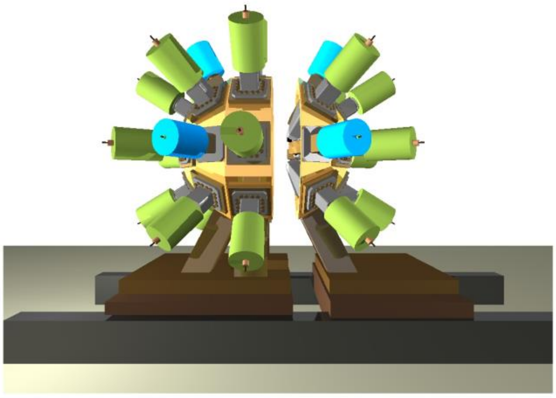


Figure 5: INGA Clover system at the IAUC beamline support structure (left) and final detector geometrical configuration (right).

The CAEN Readout System used during the test was composed by a V1782 readout through the VME bridge V1718.

The connection between the acquisition PC and the V1782 were performed through the CAEN VME USB bridge V1718 (Figure 6).

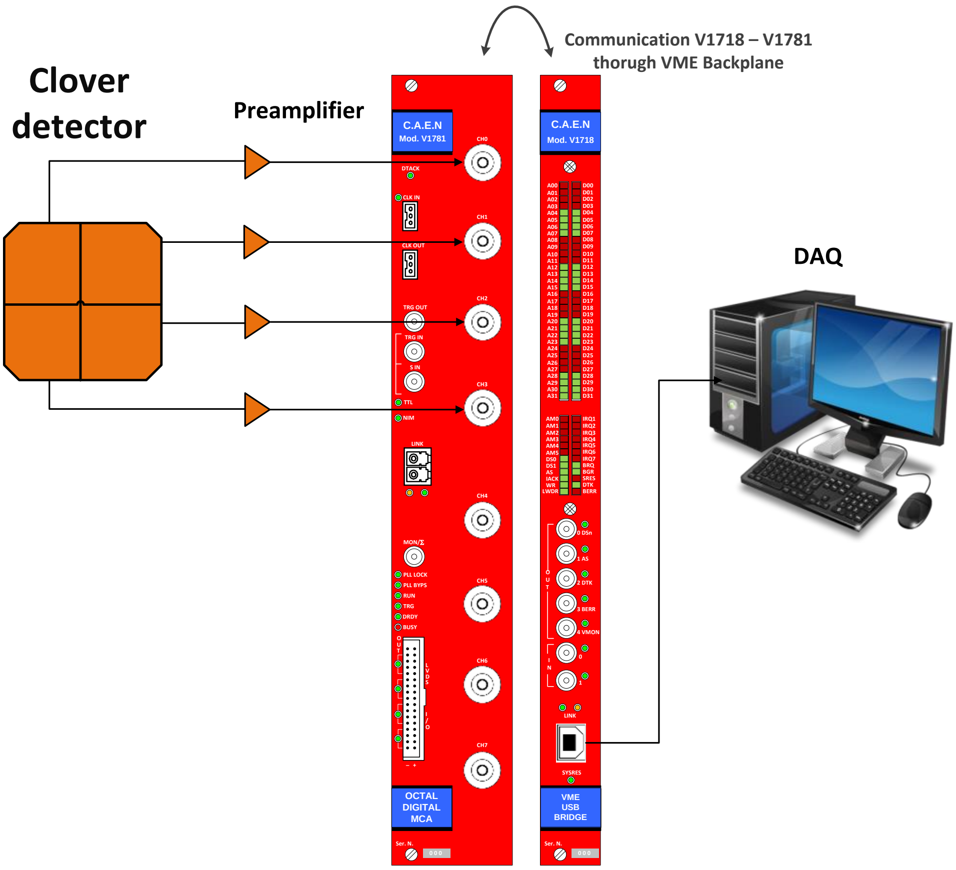


Figure 6: CAEN Readout System for the INGA Clover test setup.

Also in this case, since **no Anti-Compton shield** was present, we evaluated the *Add-Back* factor only

The software reads the list of events from the V1782 (ch 0-3) and makes the *Add-back* in real time in a virtual channel. Since the source is not located at the center of the detector, the ICR in the 4 crystals varies in the range from 500 cps to 1 Kcps; the rate in the *Add-back* spectrum is 2.4 Kcps. The acquisition real time is about 240 s.

Much attention must be payed to the system energy calibration in order to optimize *Add-Back* performance.

The Figure 7 shows the energy spectra of the individual crystals and the *Add-back*; in Figure 8 are the zoomed peaks @ 1408 keV. The table 1 shows the results of three peak fits. The energy resolution of the add-back spectrum is about 2 keV FWHM @ 1408 keV (in line with the expected resolution of the detector) and the add back ratio calculated with the fitted net areas is **1.55**.

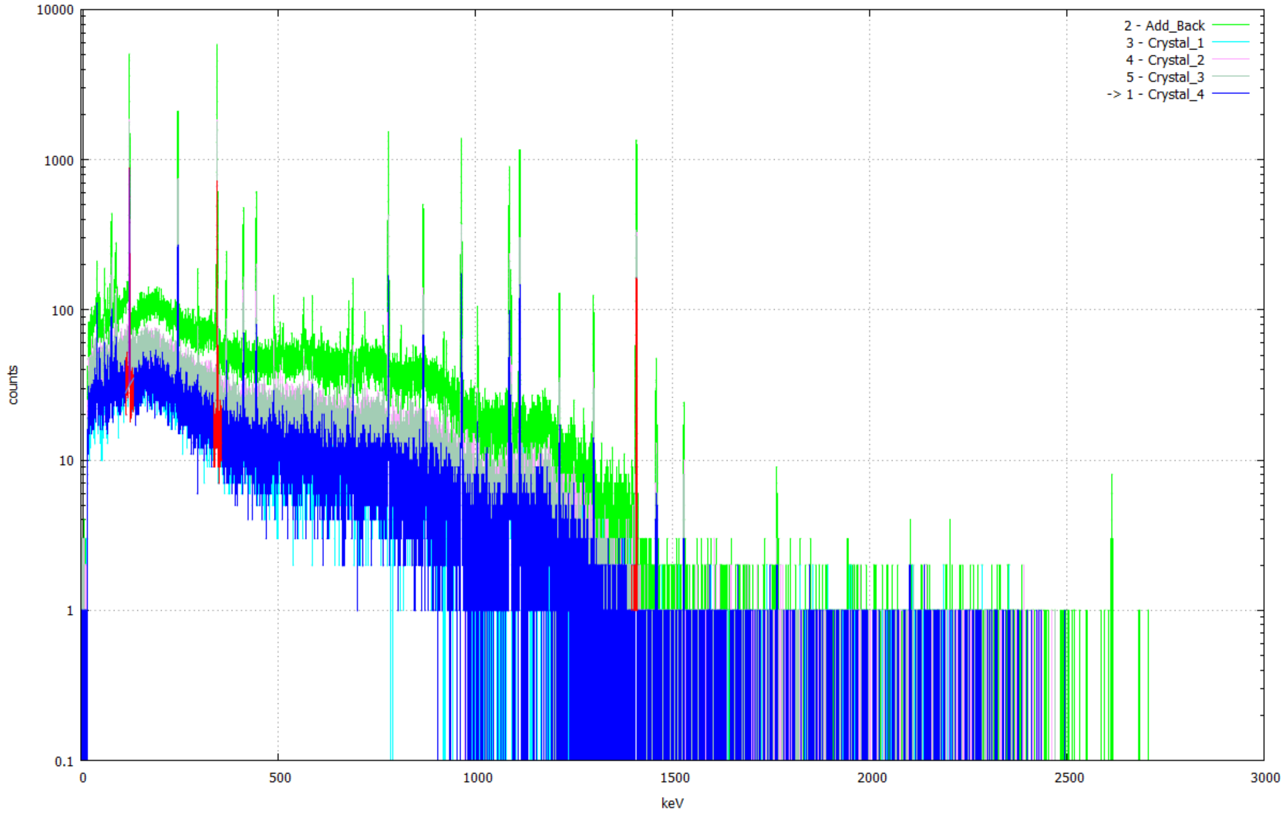


Figure 7: Individual crystals and add-back ^{152}Eu energy spectra

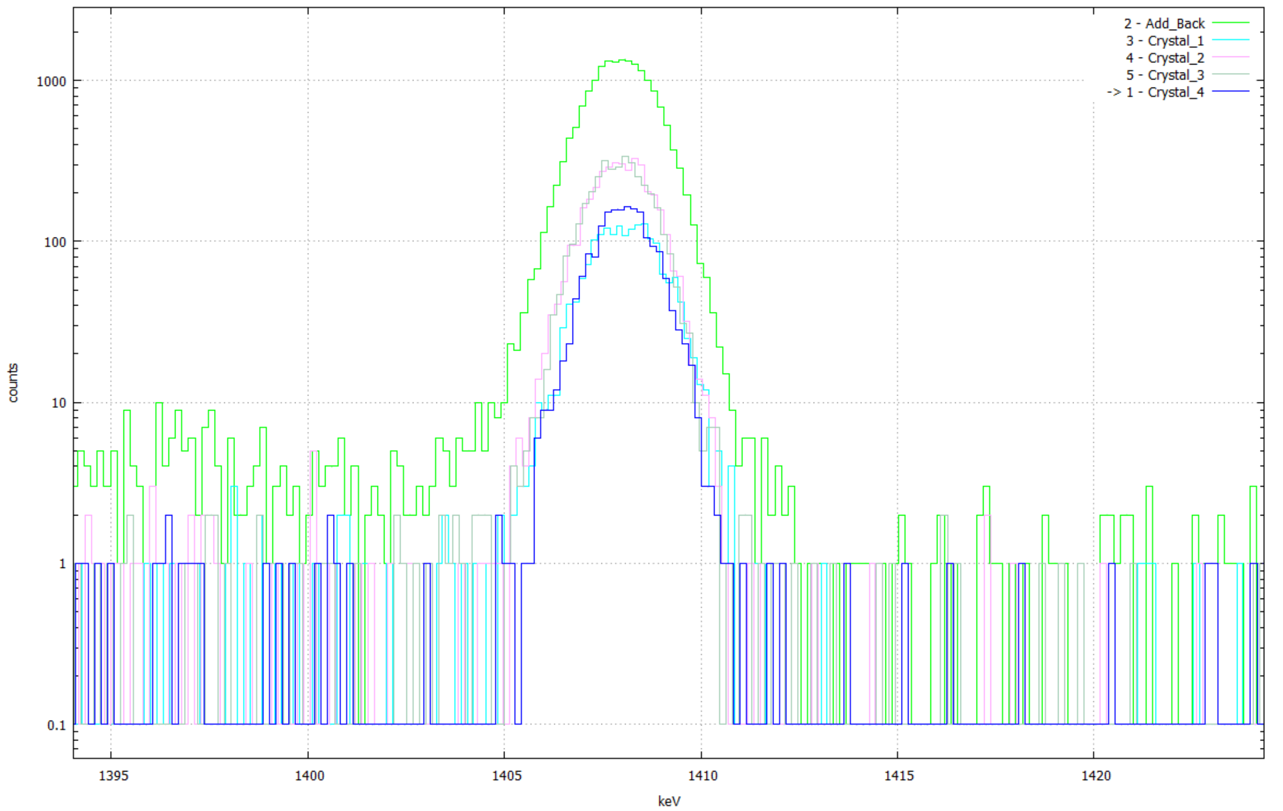


Figure 8: ^{152}Eu energy spectra. Zoom on the peak @ 1408 keV.

	Peak	Peak Area		Centroid		FHWM	
		Gross (cnts)	Net (cnts)	channels	keV	channels	keV
Crystal 1 ICR = 516 cps	@ 121.78	*9536*	*6242*	*770.43*	*121.78*	*8.68*	*1.37*
	@ 344.28	*8248*	*5713*	*2180.02*	*344.27*	*9.42*	*1.49*
	@ 1408.0	*1872*	*1872*	*8920.03*	*1408.09*	*13.59*	*2.14*
Crystal 2 ICR = 950 cps	@ 121.78	*18174*	*12147*	*744.14*	*121.80*	*5.93*	*0.97*
	@ 344.28	*17078*	*13819*	*2105.30*	*344.26*	*7.01*	*1.15*
	@ 1408.0	*3925*	*3925*	*8613.95*	*1407.98*	*11.47*	*1.87*
Crystal 3 ICR = 930 cps	@ 121.78	*17334*	*10647*	*734.22*	*121.79*	*6.18*	*1.02*
	@ 344.28	*18833*	*13497*	*2077.06*	*344.24*	*7.10*	*1.18*
	@ 1408.0	*3828*	*3828*	*8498.21*	*1407.94*	*11.12*	*1.84*
Crystal 4 ICR = 508 cps	@ 121.78	*9384*	*5434*	*740.68*	*121.80*	*5.90*	*0.97*
	@ 344.28	*7240*	*4842*	*2095.55*	*344.29*	*6.89*	*1.13*
	@ 1408.0	*1911*	*1911*	*8573.52*	*1408.06*	*10.69*	*1.76*
Add Back ICR = 2.39 kcps	@ 121.78	*50046*	*36366*	*734.75*	*121.77*	*6.41*	*1.06*
	@ 344.28	*56862*	*46450*	*2077.70*	*344.24*	*7.64*	*1.27*
	@ 1408.0	*18124*	*17869*	*8498.85*	*1407.96*	*12.12*	*2.01*

Table 1: Fit results of three ^{152}Eu peaks at 121.78, 344.28 and 1408.0 keV.

$$Add\ Back\ Ratio\ @1408\ keV = \frac{Net_{AB}}{\sum_{i=1}^{4} Net_i} = \frac{17869}{1872 + 3925 + 3828 + 1911} = 1.55$$

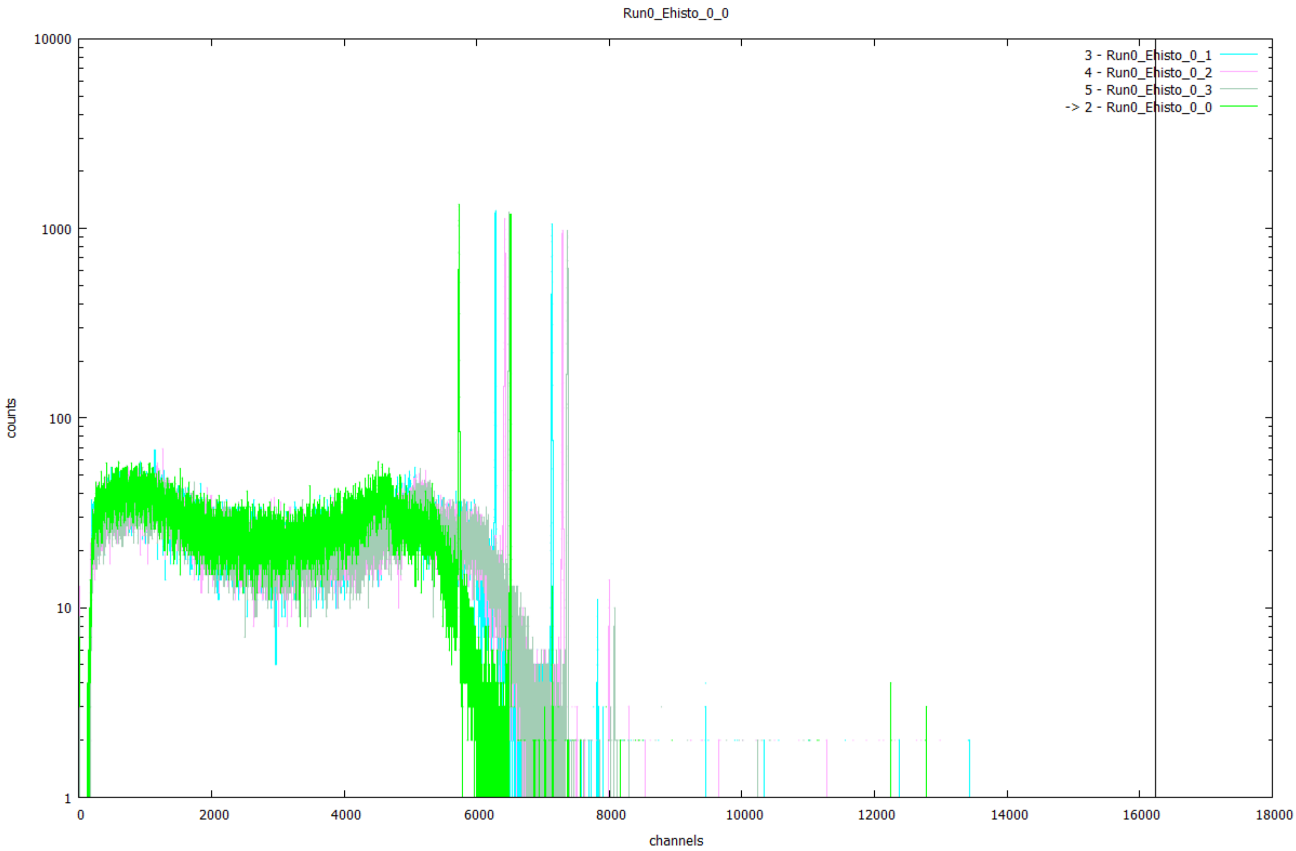
8. Test with ORTEC Clover detectors and CAEN MCA DT5781 with ^{60}Co source

Additional comparison tests have been performed with ORTEC clover detectors and other CAEN Quad MCA DT5781. The electronics embedded in these modules is similar to the V1782 one even if a bit less performing from the energy resolution point of view.

The detector used in this test is an ORTEC Clover one with Liquid Nitrogen cooling. The bias voltage and the low voltage are provided from Ortec NIM module while the used MCA was the DT5781 (4 channel, 14 bit, 100 MS/s Desktop digitizer with PHA algorithms).

The energy resolution of the single crystals and the add-back is the following:

	Crystal 1	Crystal 2	Crystal 3	Crystal 4	Add-back
FWHM @ 1332 keV	2.10 keV	2.13 keV	2.10 keV	2.11 keV	2.38 keV



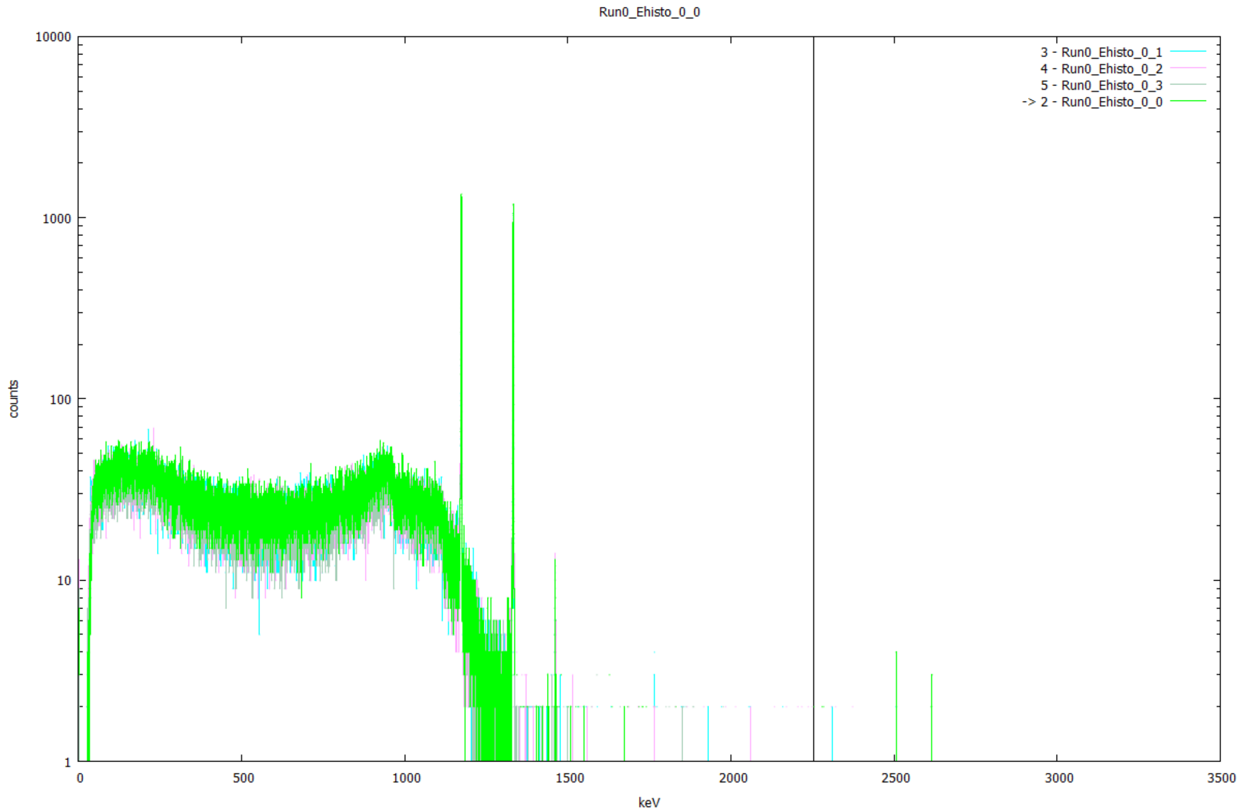


Figure 9: ^{60}Co Energy spectra of the four Clover crystals before (top) and after (bottom) calibration.

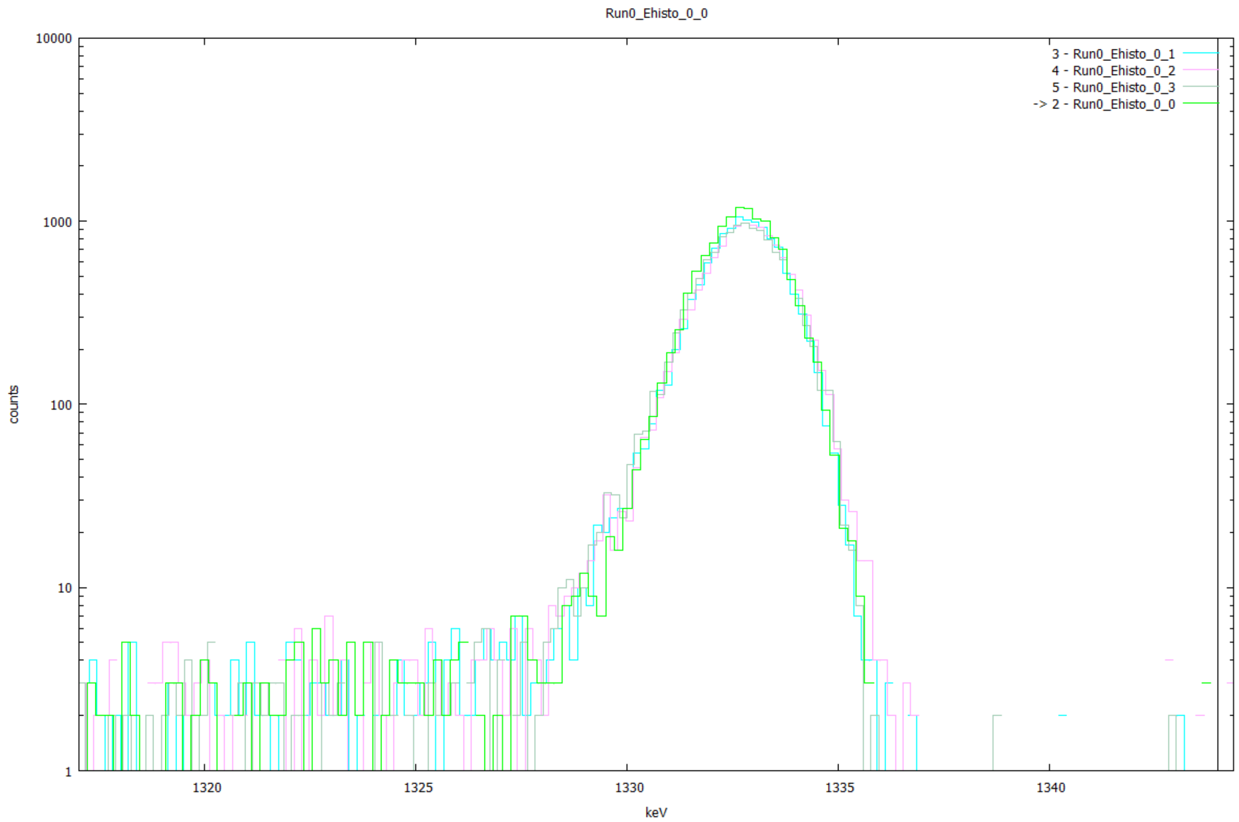
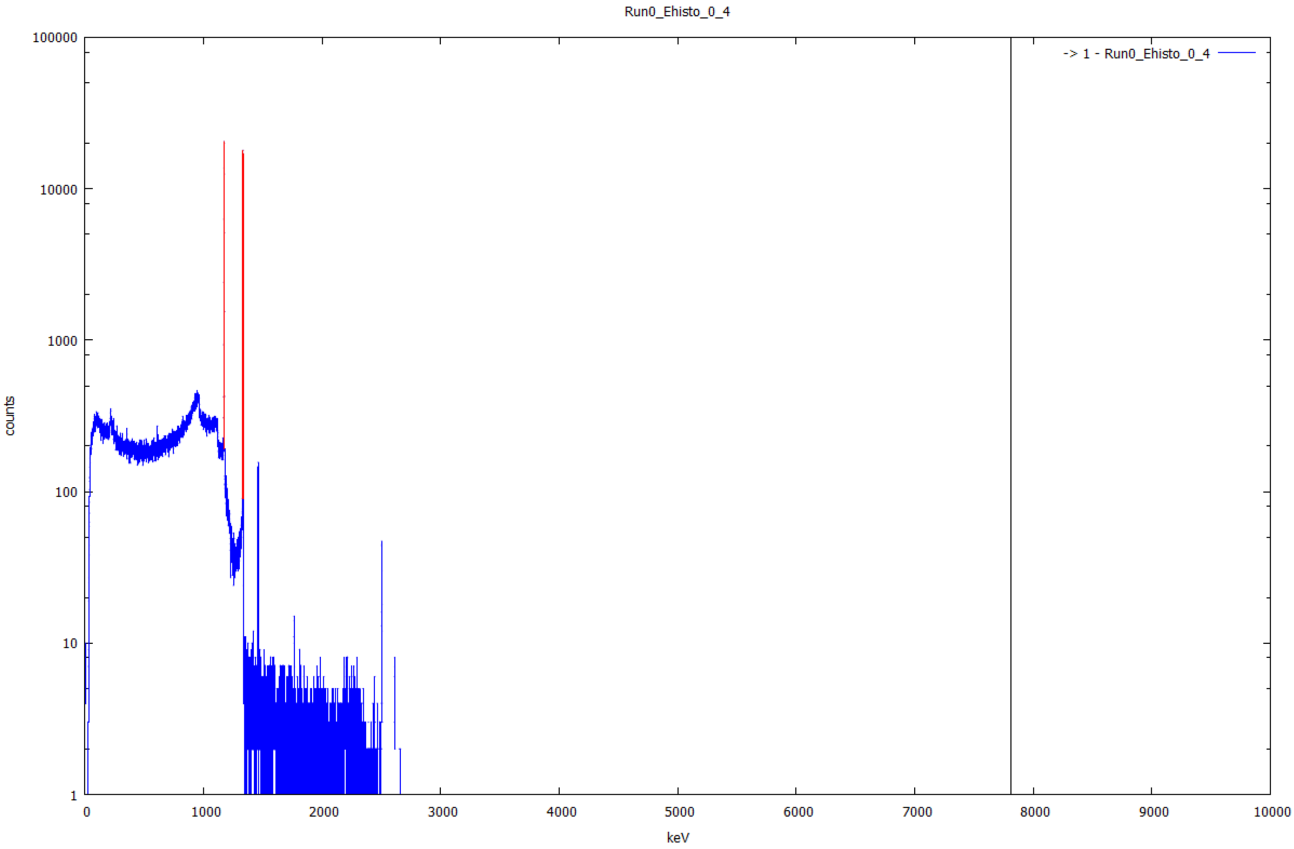


Figure 10: ^{60}Co Energy spectra of the four Clover crystals. Zoom on the 1332 keV peak (after calibration).



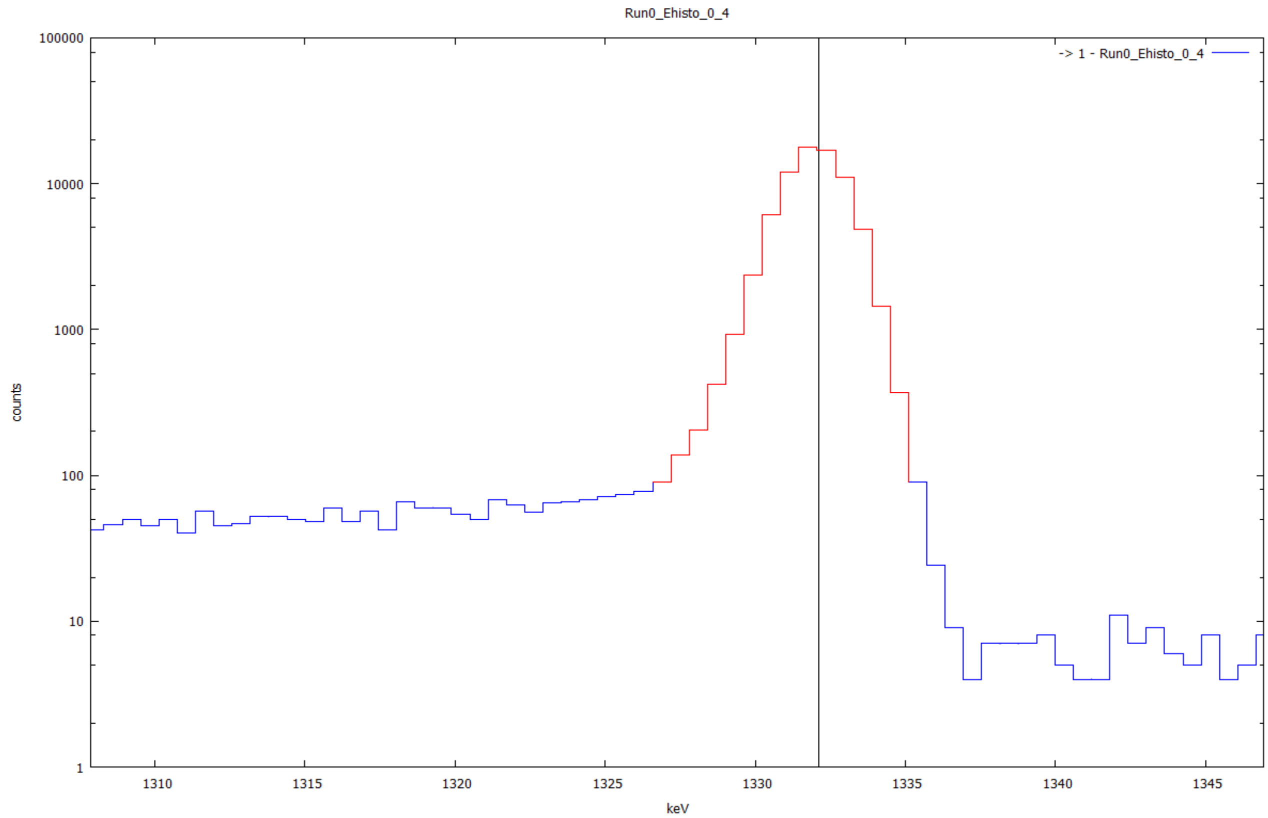


Figure 11: ^{60}Co Energy spectra energy spectra after the add back. Zoom on the 1332 KeV peak (Bottom plot).

NOTE: The add-back spectrum has a different binning and full-scale range. In fact, the channels are summed in energy and the back-conversion from energy to channels is done by the software with an arbitrary gain.

9. Conclusions

The Clover detector is a composite detector consisting of four ~21% efficiency crystals mounted in a compact geometry. Typically, it is surrounded by an array of BGO and/or CsI crystal acting as an Anti-Compton Shield. The CAEN acquisition system for such an experimental setup is based on new generation front-end electronics boards (Digitizers), which are based on flash-ADC and FPGA running dedicated digital pulse processing firmware which will perform, in a single board, all operations traditionally performed by a full analogue chain.
CAEN realized the V1782, a new digital Octal MCA tailored for segmented detector like Clovers, tested it in several laboratory detector setup and get very good results in terms of resolution (0.77÷0.82 KeV at the 122KeV ^{57}Co peak, 1.72÷1.87 KeV at the 1332 KeV ^{60}Co peak, 1.76÷2.14 KeV at the 1408 KeV ^{152}Eu peak) and *Add-Back* factor (**1.3** at the 1332 KeV ^{60}Co peak and **1.55** at the 1408 ^{152}Eu KeV peak)
The latter results in terms of resolution and Add-Back factor have been achieved at the the INGA Clover Setup at IUAC (India).
Comparison test with other CAEN module has also been done showing the increased performance of the new V1782 with respect to the other modules when used with this kind of detector.

10. References

[1] G. Duchêne et al., "The Clover: a new generation of composite Ge detectors", Nuclear Instruments and Methods in Physics Research A 432 (1999) 90-110
[2] CAEN S.p.A., "UM3182 - DPP-PHA and MC2Analyzer User Manual"
[3] D. N. Poenaru and Waltre Greiner, "Experimental Techniques in Nuclear Physics", de Gruyter, Berlin-New York, 1997
[4] http://www.iuac.res.in/research/np/inga/inga_main.html
[5] Yuri Kopach and Hans-Jürgen Wollersheim, "Testing of the GSI Clover Detector under Experimental Conditions", Gesellschaft für Schwerionenforschung, Darmstadt, March 2000

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