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Abstract

This application note intends to present some examples of the veto performances of **CAEN dual MCA Hexagon [1]** in reducing the Compton background of ^{60}Co and ^{137}Cs gamma sources spectra.

The three experiment proposed in the application note used a high purity germanium detector (HPGe) and a series of scintillators acting as active and passive anti-Compton shielding. In particular, a BGO detector, a plastic scintillator detector, and a series of five NaI detectors were used in three different configurations.

Energy spectra of ^{60}Co and ^{137}Cs gamma sources have been acquired and the *Peak-to-Compton* and *Peak-to-Total* factors measured. A key point to get satisfying result is the correct configuration of the Hexagon inputs, as it has been highlighted in Sec. **Appendix: Settings Optimization**. The results are in agreement with the expectations, as reported in Sec. **Conclusions**.

Introduction

In ideal conditions, photons always interact with detectors through photoelectric effect, however, a photon might scatter, release only a part of its energy in the detector, and then escape. This phenomenon is a consequence of the Compton effect and its result is to increase the measurement background, which might hide low-intensity peaks from other gamma-ray energies **[2]**.

The Compton suppression technique consists in adding a surrounding detector to the main detector (HPGe in this case), and rejecting the escaping photons, which are identified as coincident events between the two detectors ("anticoincidence" or "veto" mode). This will reject most of the continuum background, without affecting the full-energy peak **[2]**.

The surrounding detector is often chosen among scintillators like NaI(Tl) and BGO. In particular, BGO has the advantage of high atomic number and density, thus allowing more compact configurations. Due to the availability for these measurements of a single BGO detector and of multiple NaI(Tl) detectors, the configurations described in Sec. **Materials and methods** were used.

The "**Peak-to-Compton**" ratio (P/C) is an indication of the performances of the detector and of the anti-compton shielding. It is traditionally calculated for the 1332 keV peak of the ^{60}Co source by dividing the counts of the peak over the mean counts in the region [1040,1096] keV **[3]**. In case of ^{137}Cs, the peak counts must be divided by the mean counts in the region [358,382] keV **[2]**. Though the actual value of P/C of the available HPGe was unknown, acceptable values are in a range of 40:1 – 60:1 for the 1332 keV peak of ^{60}Co **[4]**.

Another figure of merit has been evaluated, the "**Peak-to-Total**" ratio (P/T), which corresponds to the sum of the ^{60}Co peak net areas divided by the total number of counts in the spectrum for energies from 100 to 1350 keV **[5]**. A similar definition was applied for the ^{137}Cs source too, by defining the total region from 50 to 680 keV. Finally, the "**suppression ratio**" defined as [(P/T without veto)/(P/T with veto)] **[6]** was also evaluated. We report hereafter measured P/T values for the ^{60}Co source from a different setup **[7]**, which will be used as reference for the comparison with the setups discussed in this application note. Measured P/T without suppression from a single detector was in the range [0.13,0.14], P/T with suppression for a single detector was in the range [0.21,0.24], the ratio defined as [(P/T without suppression)/(P/T with suppression)] is in the range [0.542,0.666].

Materials and methods

Three different experiments have been designed to test Hexagon performances using ^{137}Cs and ^{60}Co sources. In the first two cases, the emitted photons were aligned to travel through a scintillator before reaching the HPGe, while in the third case the source was placed on top of the HPGe and surrounded by five scintillators. The Hexagon employed was a dual channel model, with one channel connected to the HPGe and the other one to the scintillator(s). In the case where five scintillators were used, the five signals where summed before being sent into the Hexagon channel. Spectra were collected from the HPGe, in all the configurations and for all the sources, in both ”normal” and ”anti-coincidence” acquisition mode.

BGO shielding and collimated beam configuration

In the first setup configuration (Fig. **1**) a single 2-inches BGO detector was put in between the HPGe detector and the source. The source was placed close to the BGO scintillator and 6 cm far from the HPGe. To have a collimated low intensity beam of radiation passing through the detectors and to avoid natural background radiation, the setup was surrounded by blocks of lead. Lead was placed also on top of the setup to reject cosmic radiation.

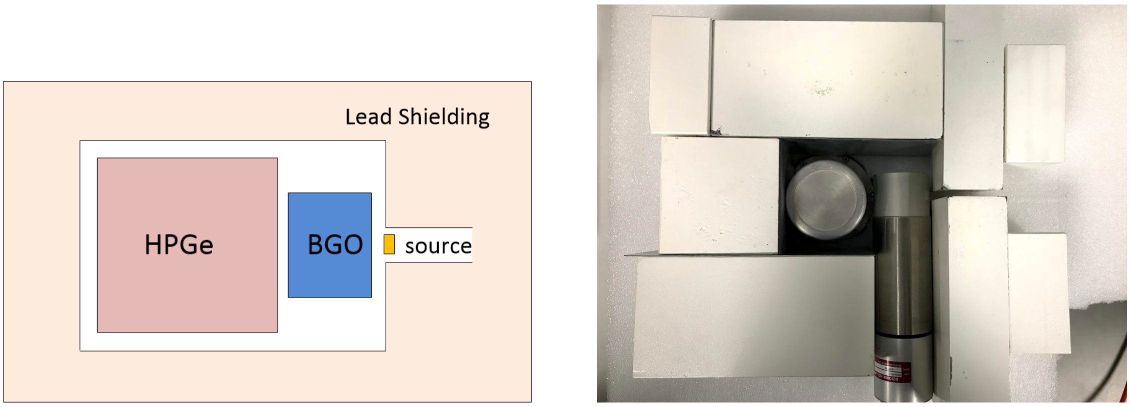

Fig. 1: Top view (diagram on the left and a picture of the setup in the right) of the setup configuration with the HPGe and BGO detectors put inside a lead block shielding. The source was placed on the right of the BGO. Lead blocks were placed also on top of the setup.

The HPGe and BGO were both connected to Hexagon inputs and the parameters used for each channel are listed in Tab. **1**

Section	Name	Value	
		HPGe	**BGO**
Input	Fast discriminator shaping time	0.3 µs	0.1 µs
	DC-Offset	28%	20%
	Threshold	2	2
	Trapezoid tail correction	46 µs	0.40 µs
	Re-trigger Protection time	5µs	5 µs
Energy Filter	Trapezoid Rise time	5 µs	5 µs
	Trapezoid Flat top	1 µs	1 µs
	Peaking Position	50 %	50 %
	PUR Protection Time	6.96 µs	6.96 µs
Concidences	Mode	Anticoincidence	
	Coincidence window	2 µs	
	Start mode	Synchronous	

Tab. 1: HPGe and BGO parameters configuration.

Sec. **Appendix: Settings Optimization** describes how those settings were optimized and chosen.

Plastic scintillator configuration

The setup employed in this case consists of the HPGe encased in a square of lead blocks, covered by an EJ-200 plastic scintillator. The source was placed on top of the plastic, aligned with the HPGe. This kind of experimental setup is qualitatively similar to the one described in the previous section, where photons go through a scintillator before reaching the HPGe. The settings for the plastic and HPGe configuration where the same as used in the previous configuration and they are listed in Tab. **1**.

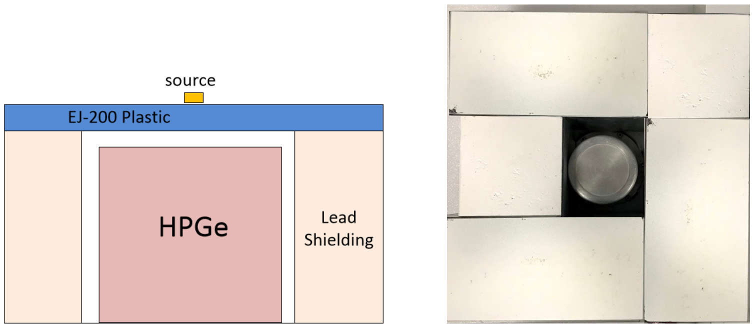

Fig. 2: Front view scheme and top view picture of the setup configuration with the HPGe surrounded by a lead block shielding. An EJ-200 plastic scintillator was put on top of the setup and the source was aligned with the HPGe position.

NaI shielding configuration

The last experiment was done by placing the source on top of the HPGe detector and surrounding it with a series of 5 NaI(Tl) scintillators of 1 liter each, four at the sides and one on top (Fig **3**). The HPGe was connected to one channel of Hexagon input while the signals coming from the scintillators were summed and sent to the other Hexagon channel.

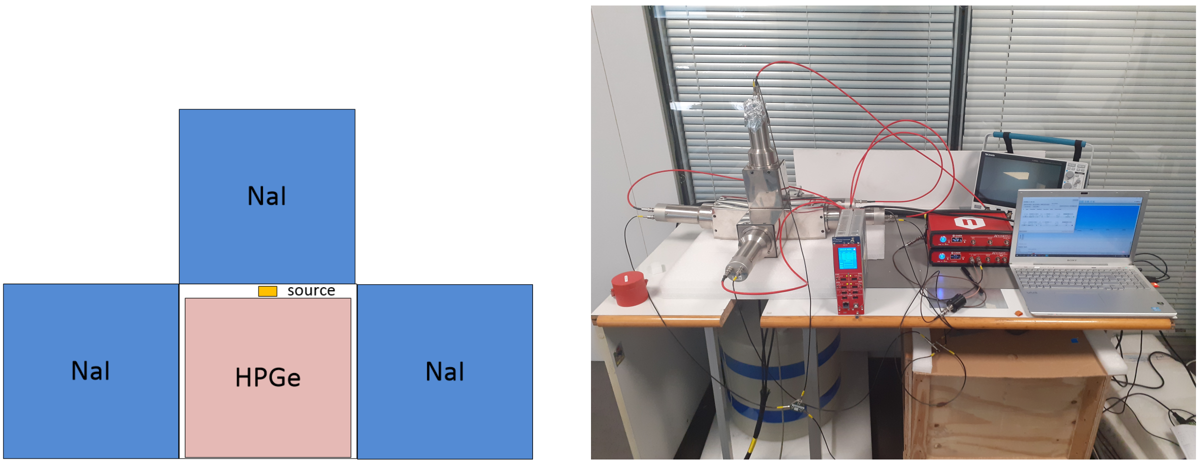

Fig. 3: Front view of the setup with NaI detectors shielding (scheme on the left and picture of the setup on the right).

The parameters for both Hexagon channels are the same as in the previous configurations (Tab. **1**). The voltages of all the scintillators were individually tuned in order to superimpose the spectra coming from each scintillator as much as possible. In this configuration, the majority of photons interacts first with the HPGe and the ones that scatters away after undergoing Compton effect should be captured by the NaI scintillators.

Methods

The Hexagon inputs were configured as reported in Tab. **1**. Measurements were taken for a fixed amount of real time, in particular, 60 minutes for case 1 (BGO shielding and collimated beam configuration), 5 minutes for case 2 (Plastic scintillator configuration), and 30 minutes for case 3 (NaI shielding configuration).

Background spectra were taken in the same configuration without the radioactive source. Background spectra were subtracted channel-by-channel from the spectra with source.

Both spectra taken in "normal" and "anticoincidence" acquisition mode were subtracted and analyzed to retrieve the P/C, P/T, and suppression ratios.

Results

BGO shielding and collimated beam configuration

The spectra, background subtracted, without and with suppression were superimposed (blue and red respectively) to visually check the effects of the anti-Compton reduction. They are shown in Fig. **4** for the ^{137}Cs and ^{60}Co sources (left and right respectively).

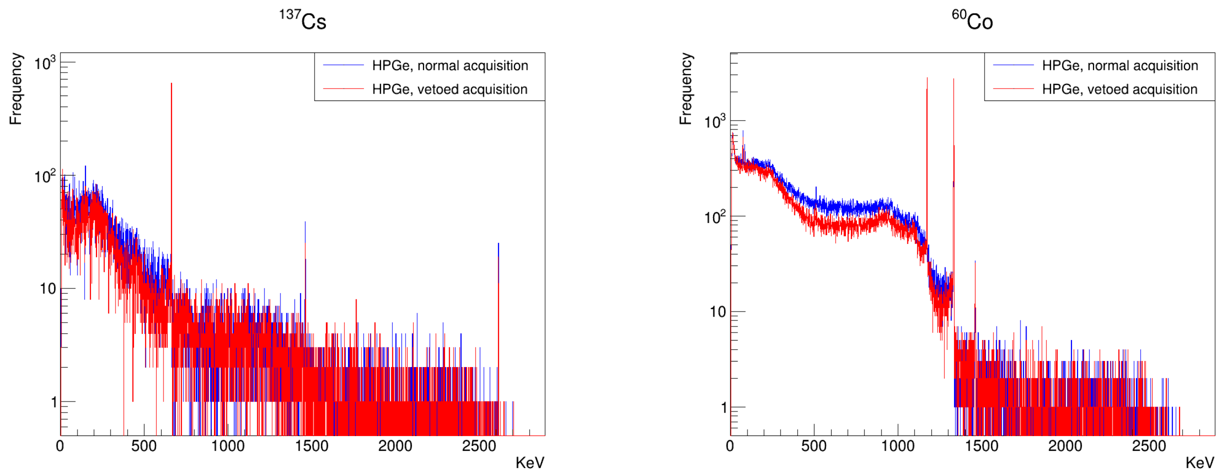

Fig. 4: Superimposition of the ^{137}Cs and ^{60}Co spectra without Compton suppression (blue) and with Compton suppression (red) on left and right panel respectively for the current setup.

Using the definition of Sec. **Introduction**, the P/C, P/T and suppression ratio have been evaluated and reported in Tab. **2**.

Source	Acquisition mode	P/C	P/T	Suppression ratio
^{137}Cs	Normal Anticoincidence	32:1 51:1	0.052 ± 0.001 0.071 ± 0.002	0.73 ± 0.02
^{60}Co	Normal Anticoincidence	32:1 49:1	0.0555 ± 0.0005 0.0741 ± 0.0006	0.75 ± 0.01

Tab. 2: Peak-to-Compton, Peak-to-Total, and suppression ratio values for ^{137}Cs and ^{60}Co in the configuration of BGO shielding.

Though the BGO acts as a passive shielding too also in the normal acquisition mode, there is still a significant improvement in applying the Compton suppression in reducing the background without affecting the peak height.

Plastic scintillator configuration

The same kind of analysis have been performed for the configuration of plastic scintillator shielding; spectra were collected for an acquisition time of five minutes, in normal and anticoincidence acquisition mode and then background subtracted (Fig. **5**).

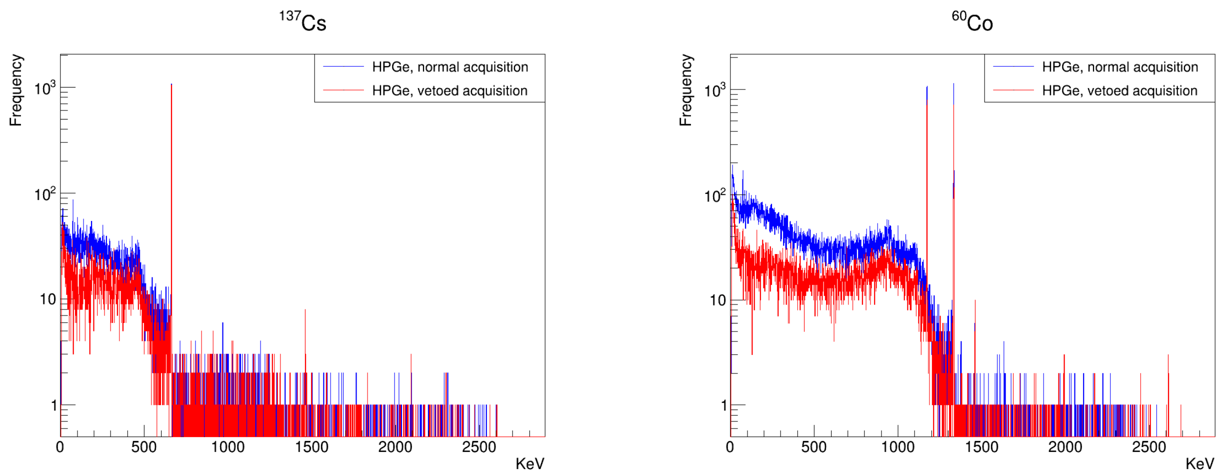

Fig. 5: Superposition of the ^{137}Cs and ^{60}Co spectra without Compton suppression (blue) and with Compton suppression (red) on left and right panel respectively for the current setup.

The Peak-to-Compton, the Peak-to-Total, and the suppression ratio have been calculated, and the resulting values are listed in Tab. **3**.

Source	Acquisition mode	P/C	P/T	Suppression ratio
^{137}Cs	Normal Anticoincidence	56:1 90:1	0.123 ± 0.002 0.207 ± 0.004	0.59 ± 0.01
^{60}Co	Normal Anticoincidence	44:1 50:1	0.097 ± 0.001 0.14 ± 0.002	0.69 ± 0.01

Tab. 3: Peak-to-Compton, Peak-to-Total, and suppression ratio values for ^{137}Cs and ^{60}Co in the configuration of plastic shielding.

This configuration gave better background reduction for smaller energy values. Indeed, better results are achieved with the ^{137}Cs source, while, when using the ^{60}Co source, also the peaks were slightly affected by the veto. The results showed anyway a good background reduction.

NaI shielding configuration

Fig. **6** shows the ^{137}Cs and ^{60}Co spectra in normal and anticoincidence acquisition mode. The acquisition time for all the measurements was of thirty minutes.

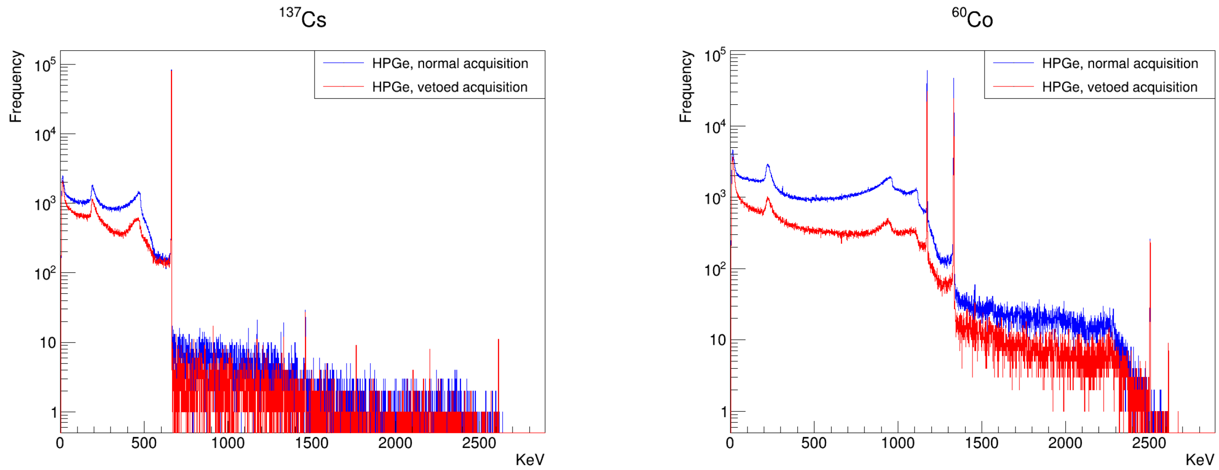

Fig. 6: Superposition of the ^{137}Cs and ^{60}Co spectra without Compton suppression (blue) and with Compton suppression (red) on left and right panel respectively for the current setup.

The results of the Peak-to-Compton, Peak-to-Total, and suppression ratio are listed in Tab. **4**; as expected the results are significantly improved, as a result of the geometry of the setup.

Source	Acquisition mode	P/C	P/T	Suppression ratio
^{137}Cs	Normal Anticoincidence	97:1 271:1	0.211 ± 0.001 0.318 ± 0.001	0.663 ± 0.004
^{60}Co	Normal Anticoincidence	45:1 79:1	0.1392 ± 0.0003 0.2043 ± 0.0005	0.681 ± 0.002

Tab. 4: Peak-to-Compton, Peak-to-Total, and suppression ratio values for ^{137}Cs and ^{60}Co in the configuration of NaI shielding.

Besides the use of NaI(Tl) detectors instead of BGO, this latter configuration is the most similar to the one described in **[7]**, where the HPGe detector is completely covered by BGO detectors. The suppression ratio for ^{60}Co is of the same order of the upper limit 0.666, which makes the results consistent with the expectation. In addition, this configuration showed the best results in terms of Compton suppression, as can be seen in the P/C of both sources.

Conclusions

Hexagon performances have been tested in three different Compton suppression experiments, obtaining consistent results in all the geometries employed with respect to the expectations (refer to Sec. **Introduction**). The anti-coincidence logic and acquisition could be achieved with a single Hexagon MCA, as well as the high voltage and preamplifier power suppy, thus reducing the number of acquisition boards, cables, etc. In addition, in most of the configurations, the peak heights remained almost unchanged when applying the Compton suppression, while the background significantly reduces, as proven by the Peak-to-Total and Peak-to-Compton values which increased when applying the anticoincidence.

While the configuration of the BGO and the plastic shielding were qualitatively similar, the results are quite different due to the high atomic number of the BGO, which acts as a passive shielding too even in the normal acquisition mode. In addition, the source was collimated and shielded by the lead blocks, which reduced the flux with respect to the other configurations.

In the latest setup, the HPGe was completely surrounded by active NaI(Tl) shielding, which gave a better detection of the Compton photons, and therefore better results than in the two previous configurations.

Appendix: Settings Optimization

To perform a correct measurement of the anticoincidence mode, both the Hexagon inputs must be correctly configured. In particular, while the settings for HPGe with charge-sensitive preamplifier (CSP) are almost straightforward, settings for the scintillator detector might require an additional care. The great advantage of using Hexagon is that two different signals like the CSP output and the PMT output - without preamplifier - can be fed into the Hexagon inputs.

The following screenshots are taken with the *Quantus* spectroscopy software **[8]**, which can control the Hexagon settings as well perform an advanced γ spectroscopy analysis.

The ”Settings” window has many tabs to control and correctly shape the input into a trapezoid. We will start from the ”**Input**” tab, where the input type can be specified by selecting the corresponding item in the drop down menu **Input Type**. For example, in the case of a signal from PMT select **PMT anode**, in the case of HPGe with CSP choose **Resistive feedback preamplifier**.

The effect of the settings **must** be checked by looking at the **Signal Inspector** window in *Quantus*. Fig. **7** shows how the signal from PMT (in blue) appears in the Signal Inspector window and what can be adjusted.

- The **Signal Inspector** window shows the relevant traces. By looking at it, we have some hints about the settings to be adjusted. In particular:

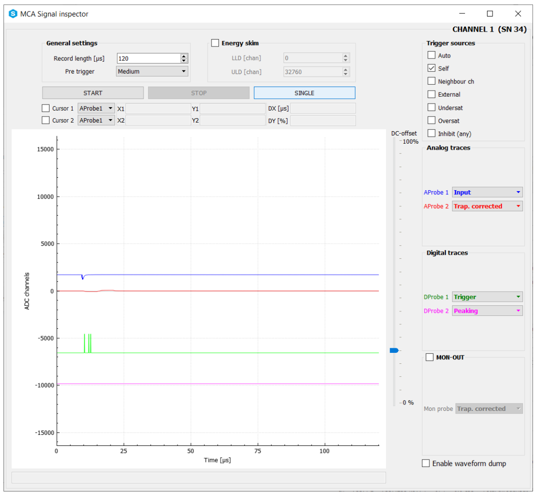

Fig. 7: Not correctly shaped signal, where the indicated polarity is wrongly set.

- **Input Polarity**: besides the real input polarity, the algorithm always shows *positive signals*. In case of negative input, the user must set ”*Input polarity = Negative*” to have the correct polarity.

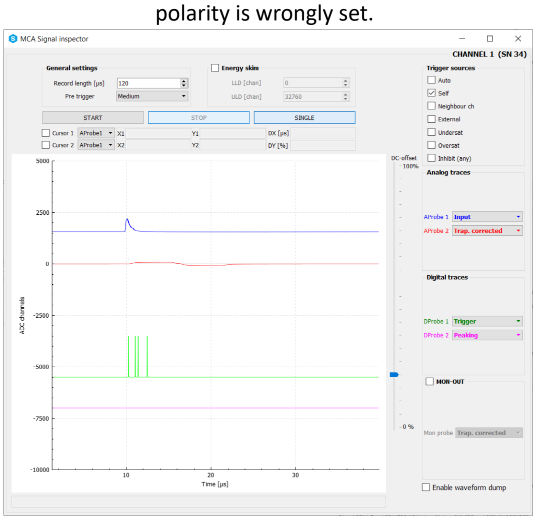

Fig. 8: Input polarity correctly set, but a wrongly shaped trapezoid.

- **Trap. Tail Correction**: From the "Input" tab, modify the Trap. Tail correction setting, which corresponds to the decay time (tau) of the input pulse.
  NOTE: minimum value is 0.4 µs.
  Trap. Rise Time and *Trap. Flat Top* were set to 5 µs and 1 µs respectively (from the "Energy filter" tab).

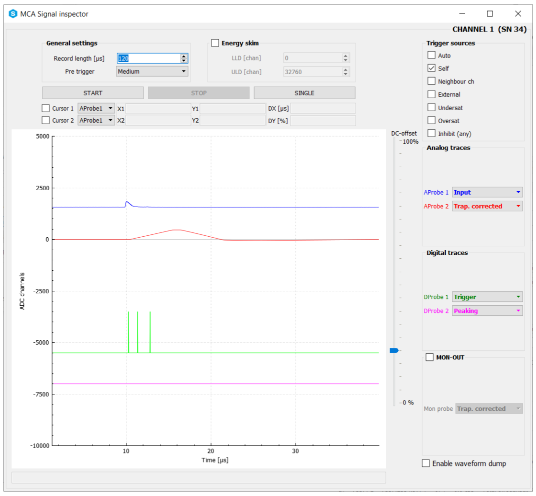

Fig. 9: Trapezoid properly shaped, but too short hold off time, which result in multiple triggers.

- **Re-trigger protection time**: Due to multiple triggers, the event is considered as piled-up and the trapezoid height is not calculated. This problem can be solved by tweaking the *Re-trigger protection time* (in the **input section**) and increase it until only one trigger is present. The Re-trigger protection time, expressed in µs, is the time in which are not accepted any other events, starting from the current one.

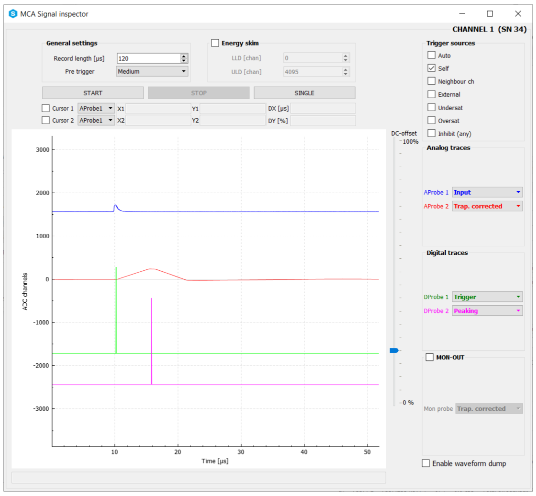

Fig. 10: Properly shaped signal.

- **Fast discriminator, shaping time and threshold**: the shaping time must be set according to the slope of the input rise time. For example, for HPGe you can set 0.3 µs, for PMT set 0.1 µs. The threshold must be set as low as possible to get as much events as possible (events from PMT are those vetoing the Compton!). Decrease its value, until the peak at zero appears in the spectrum, which corresponds to noise. Then slightly increase the threshold to reject it. This is the minimum value for threshold.

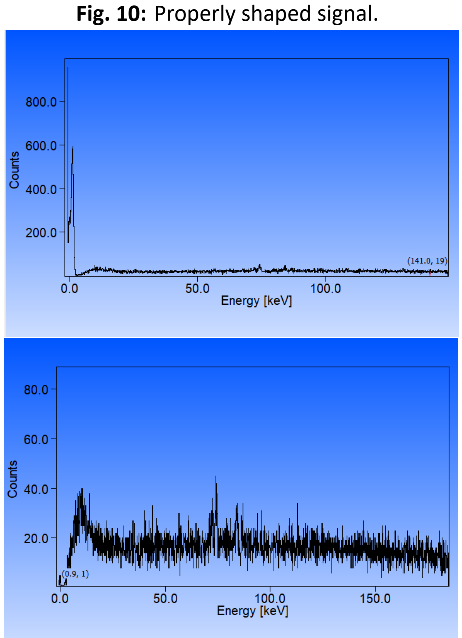

Fig. 11: Energy spectrum. On top, the threshold is too low and the peak at zero appears, on the bottom, the threshold is set just slightly above the noise.

Concerning the signal from HPGe, the most important setting to be tuned is the **Trap. Tail Correction**. Zoom in the trapezoid baseline trace to check that it returns to zero. See for example Fig. **12**, where on the left the value of decay time is over-estimated, while on the right it is set correctly. Fig. **13** finally shows a signal correctly shaped from HPGe.

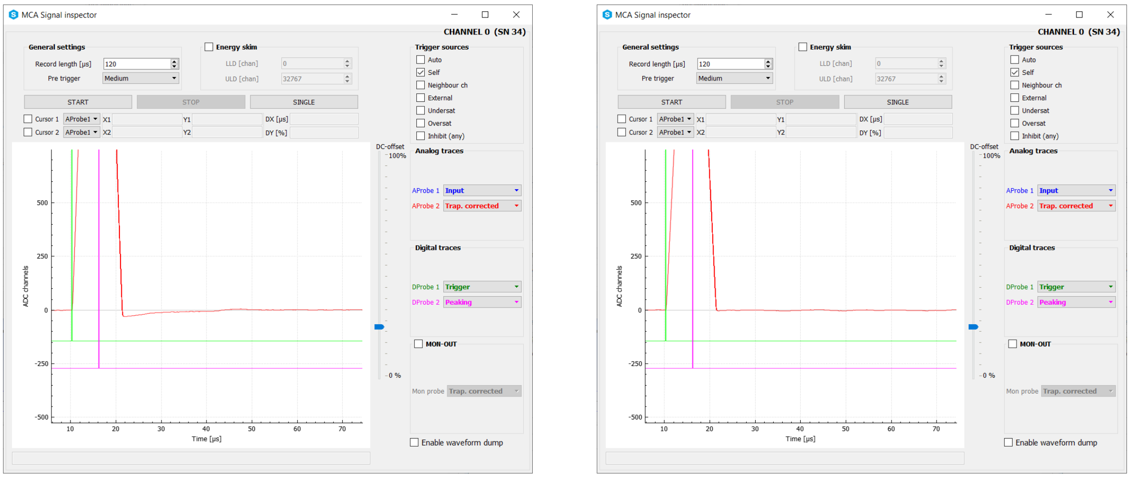

Fig. 12: Left panel shows the trapezoid tail for an incorrect value of trapezoid tail correction, while the right one shows the correct case.

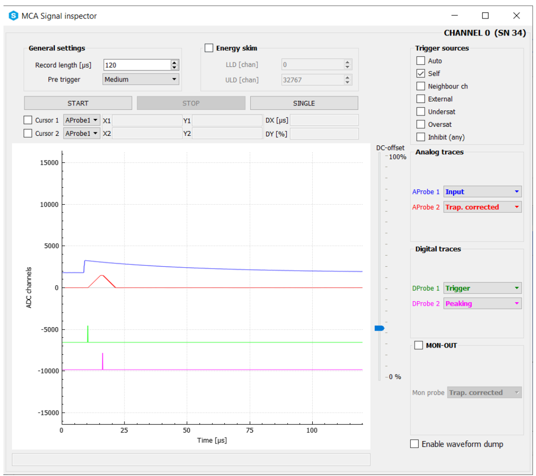

Fig. 13: Signal from HPGe and charge sensitive preamplifier correctly shaped.

Last, but not least, the anti coincidence measurement requires to set a coincidence window, where simultaneous events from the two detectors are discarded. Quantus allows the user to verify, in the ”ΔT” plot of the ”Coincidence” window, how many events fall in the coincidence window and to fine tune its width. In our case we selected 2 µs width.

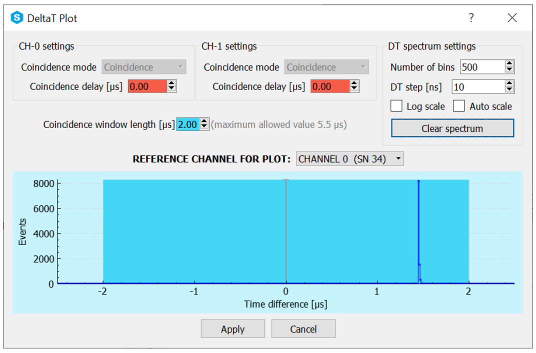

Fig. 14: Δt plot of Quantus, where the coincident events are shown. Coincidence window has been set to 2 µs.

References

[1] DS6511 – Hexagon Digital Multi-Channel Analyzer with Quantus Spectroscopy Software.

[2] G. F. Knoll. *Radiation detection and measurement*. Ed. by J. Wiley and sons. IV ed.

[3] ANSI/IEEE Standard 325-1986. *Test Procedures for Germanium Gamma Ray Detectors*. 1986.

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[5] G. Duchêne et al. “The Clover: a new generation of composite Ge detectors”. In: *NIM A* 432.1 (1999), pp. 90–110.

[6] Mirion (Canberra) AN-D-8901 – Compton Suppression... made easy.

[7] CAEN AN5157 – A Readout System with CAEN Digitizer for Clover Detectors with Anti-Compton Shield.

[8] CAEN UM6907 – Quantus User Manual.

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