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Index

Introduction

This Application Note is meant to give an overview of several characterization measurements performed to have a comprehensive overview of the Hexagon performances in different working conditions. This report has been done including several kinds of measurement performed in different moments during a period of several months and it might not reflect the best performance that Hexagon could achieve. Additional improvements in the Hexagon algorithm and configuration has been indeed introduced after these measurement (like the use of the A387 filter as explained later in the text). Nevertheless, this Application Note would still provide a good general overview of the Hexagon capabilities.

The first part of this document describes some preliminary tests to characterize Hexagon before connecting it to the detector:

1. INL and DNL
2. Gain and Offest Drift as a function of the temperature

The second part of this document describes 3 measurement sessions performed with several kind of HPGe and Scintillator detectors and radioactive sources aimed to evaluate the Hexagon performances in terms of energy resolution as a function of shaping time, coarse gain and input rate. The Net/Live ratio when increasing the ICR has also been evaluated.

More details about the Hexagon technical specifications and operations can be found in **[1]**,**[2]** and **[3]**.

Hexagon preliminary characterization measurements

Integral Non-Linearity

The Integral Non Linearity (INL) is measured according to the IAEA Procedure MRNI-514 REV.D0 **[4]** using a pulse generator (namely a CAEN Digital Detector Emulator DT5800 **[5]**). The pulse generator produced 26 peaks in the full range of Hexagon, then an external attenuator compensated for its gain.
The generated pulses have an exponential shape with periodic rate of 1 kHz. The corresponding peaks in the amplitude histogram are fitted with a gaussian curve to obtain the centroids. The latter "Centroid vs DT5800 Amplitude" plot is fitted with a straight line. The same analysis is repeated for all the Hexagon input gain stages.

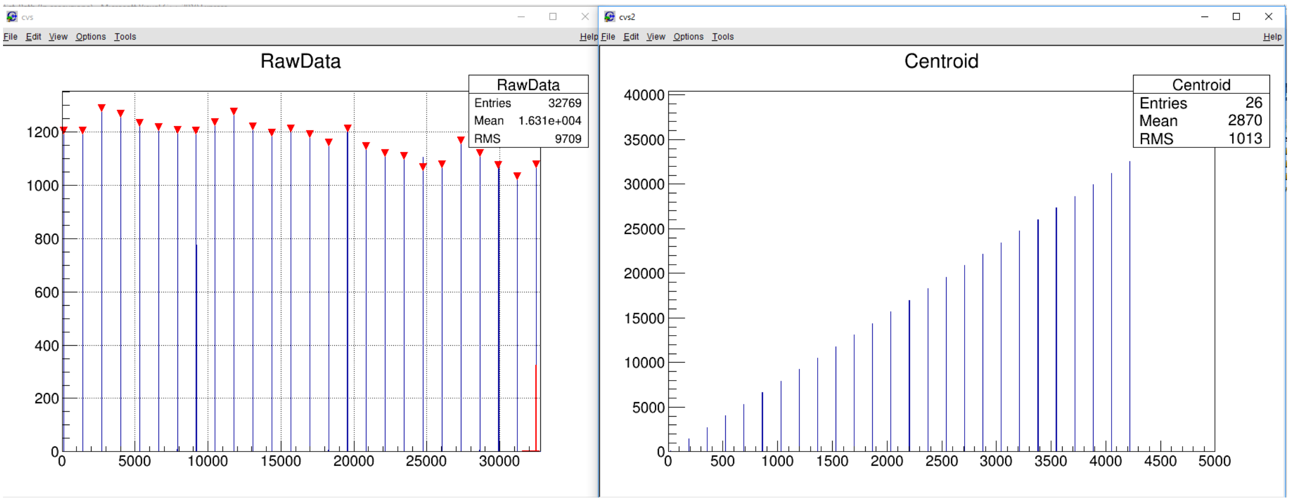


Figure 1: Histogram of the peaks corresponding to the amplitudes emulated by the CAEN DT5800 (left) and Centroid vs DT5800 Amplitude plot (right).

The INL is then defined as follows:

$$INL\ (i)_{(\%)} = \frac{100 * (C_{ideal} - C_{real})}{C_{ideal}}$$

where C_{ideal} is the "ideal" peak centroid position according to the fit result and C_{real} is the "real" peak centroid position according to the histogram fit. The following picture shows the analysis results[1]: the INL, which increases with the gain, results to be less than 0.09%.

[1] The INL at Gain=256 cannot be evaluated on the 99% of the full range due to a noise peak; it has been done on the 90% of the full scale with a result of 0.4‰.

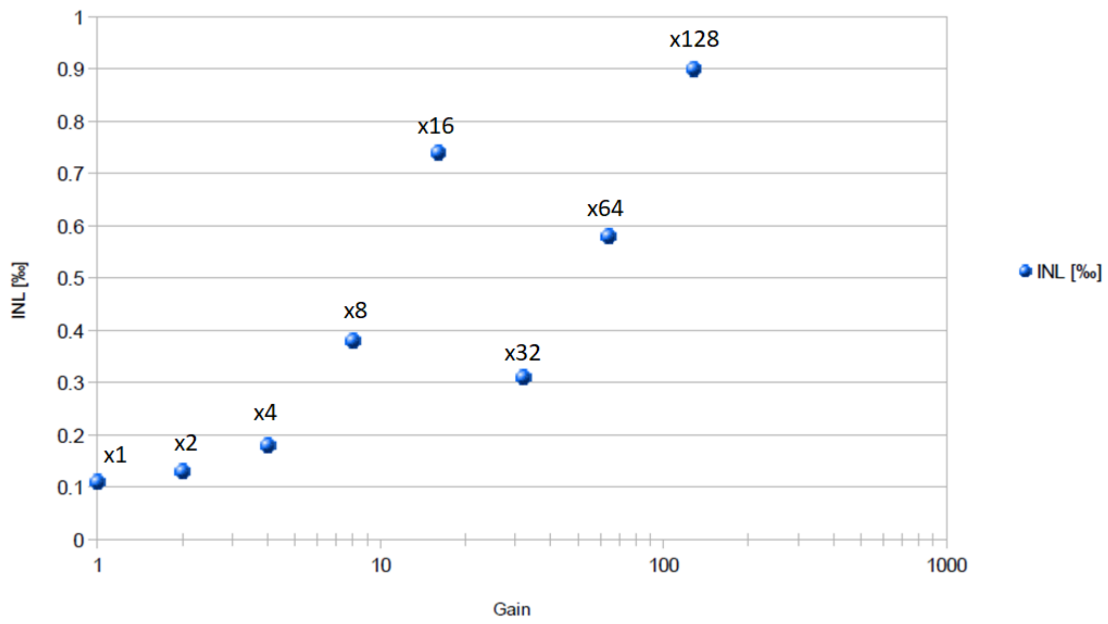


Figure 2: Hexagon Integral Non-Linearity as a function of the Coarse Gain.

Gain and Offset drift as a function of the temperature

These measurements are performed using a pulse generator DT5800 emulating a fixed amplitude pulse for all the Hexagon coarse gain values from x1 to x 256. The variation in the corresponding centroid position is evaluated at the environmental temperature of 0°C and 50°C with respect to the position of the centroid at the reference temperature of 25°C. Possible variation in the environmental humidity are not taken into account.

Material and methods

The used instrumentation is here listed:

- 1 thermal chamber MCT130;
- 1 Hexagon;
- 1 digital thermometer Data Logger RC-5;
- 1 Digital Detector Emulator (DDE) DT5800;
- 2 attenuators: 1dB and 10dB;
- MC^2 Analyzer acquisition software

Hexagon and the digital thermometer (used to have a more precise temperature evaluation) are placed in the thermal chamber while the DT5800 remains outside at the constant temperature of about 25°C. The DT5800 generates fixed amplitude pulses at 2 kcps constant rate. Six different amplitudes are generated in order to cover the full dynamical range. To avoid as much as possible non-linearity effects due to the DT5800, the six amplitudes are kept the same irrespective of the Hexagon coarse gain stages. In case the signal amplitude saturates the input stage, the attenuators are used to reduce the amplitude and cover the input stage itself.

Figure 3 shows the used DT5800 settings.

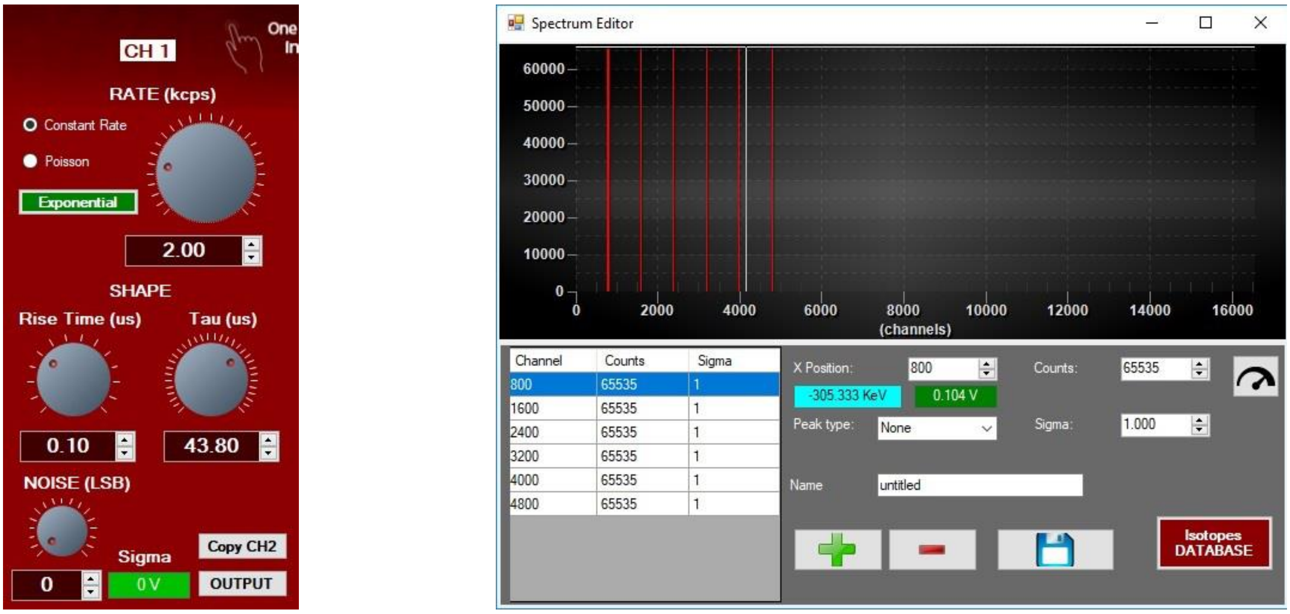


Figure 3: DT5800 settings used during the measurements

In order to reduce the statistical uncertainties, the measurement live time is preset at a value that allowed to have at least 5000 counts under the peaks (at least 10000 counts for the coarse gain values up to x8).

Figure 4 shows an example of the spectrum acquired for one of the Hexagon coarse gain values.

Figure **4**

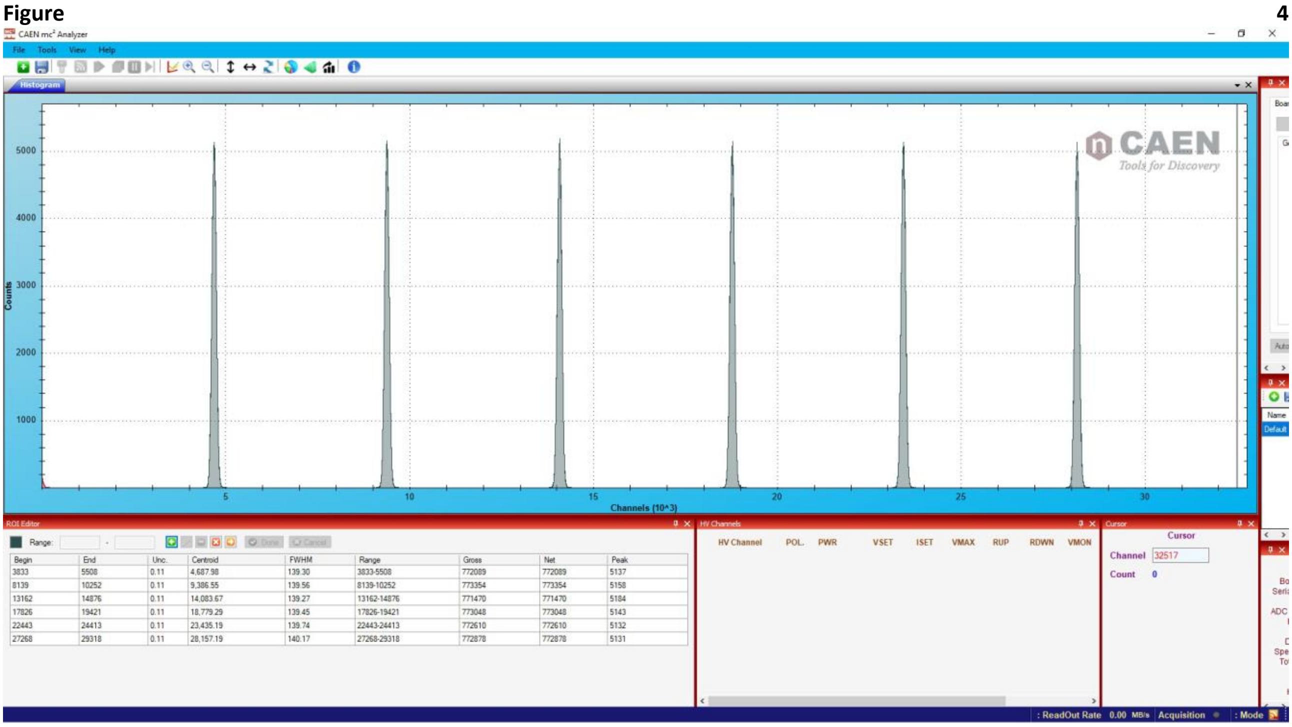


Figure 4: Example of a spectrum acquired with x128 gain @ T = 50°C. The six amplitudes generated by the DT5800 allow to cover almost the full dynamical range. FSR limits have been excluded in order to avoid possible nonlinearity effects.

The following table shows the attenuation values used for the different gain stages combining two variable attenuators (1db and 10db steps respectively).

G	x1	x2	x4	x8	x16	x32	x64	x128	x256
Att.	0dB	6dB	12dB	18dB	24dB	30dB	36dB	42dB	48dB

The measurements are performed at 3 thermal chamber temperature values: 0°C, 25°C and 50°C. For example,

Figure 5 and **Figure 6** show the zoom of the first (the one with lowest amplitude) and the last (the one with highest amplitude) of the six peaks at gain x1 at the three temperatures respectively: on the left the peak at 0°C, on the right the peak at 50°C, at center the peak at 25°C.

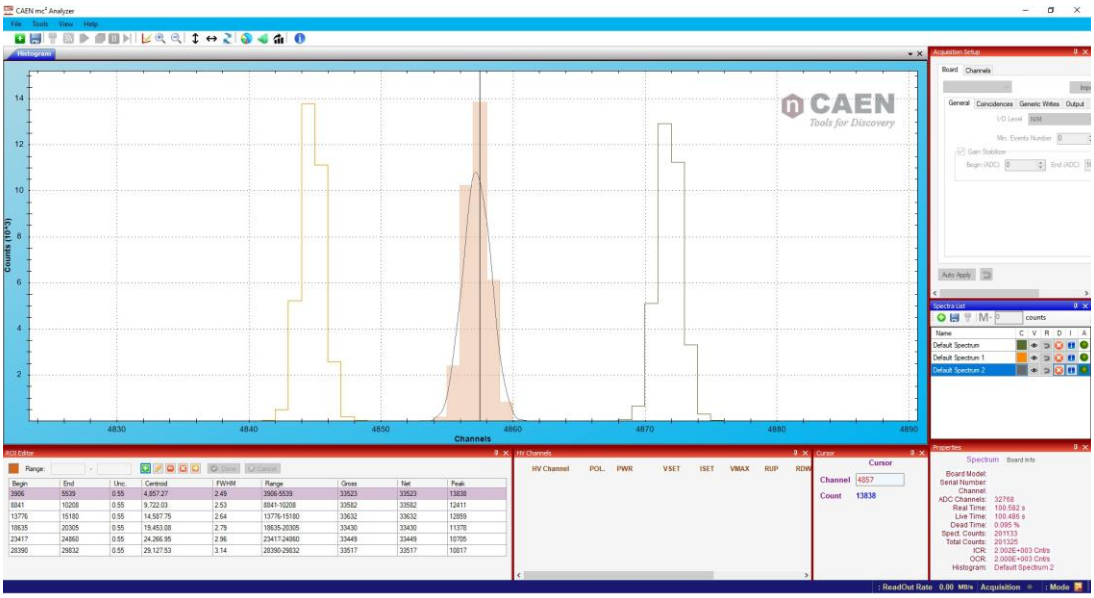


Figure 5: 150mV amplitude peak at gain x1. On the left the peak acquired at 0°C, on the right the peak acquired at 50°C, in the middle the peak acquired at 25°C.

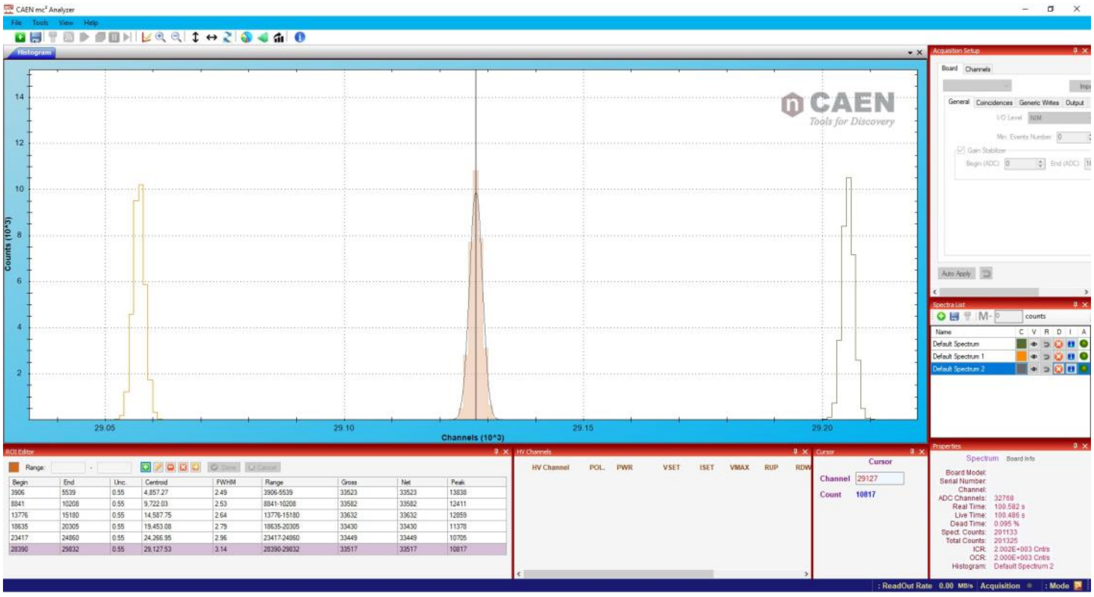


Figure 6: 900 mV amplitude peak at gain x1. On the left the peak acquired at 0°C, on the right the peak acquired at 50°C, in the middle the peak acquired at 25°C.

Results

A linear fit of the centroid position per each gain and temperature is performed as shown for example in **Figure 7** for the gain stage x32.

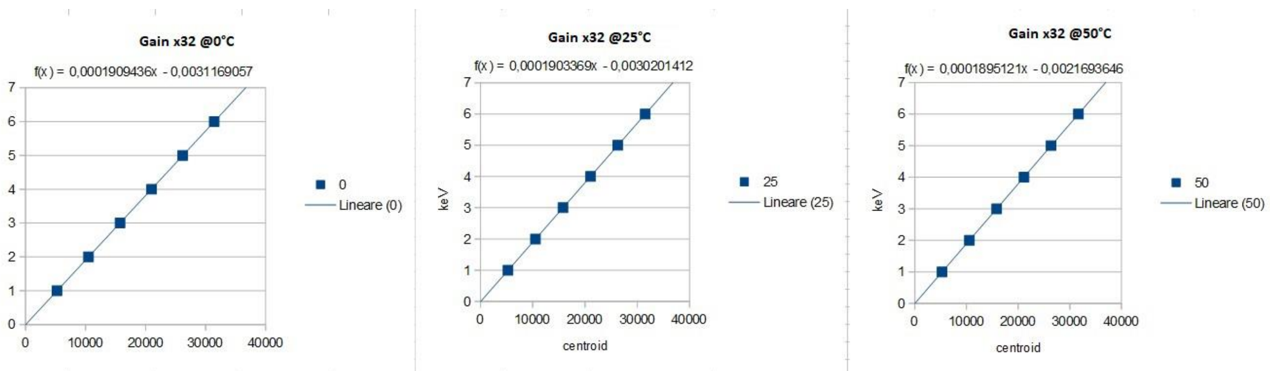


Figure 7: Linear fit of the six centroid positions for the gain stage x32. T = 0°C (left), T = 25°C (middle), and T = 50°C (right).

Per each temperature value and gain stage, the fit *f(x) = mx + q* is evaluated and then we have:

- Gain Drift = $\Delta G / \Delta T * 10^6$ ppm/°C
- Zero Drift = $\Delta q / (m_{25°C} * 2^{15}) * 10^6$ ppm/°C (referred to the full scale range)

where

- $\Delta G = (m_{0°C} - m_{25°C}) / m_{25°C}$ or $\Delta G = (m_{50°C} - m_{25°C}) / m_{25°C}$
- $\Delta T = (T_{0°C} - T_{25°C})$ or $\Delta T = (T_{50°C} - T_{25°C})$

- $\Delta q = (q_{0°C} - q_{25°C})$ or $\Delta q = (q_{50°C} - q_{25°C})$.

Results are:

- **Gain Drift = 132 ppm/°C typical**
- **Zero Drift = 4 ppm/°C typical**

Measurements with detectors: first measurement session.

Material and methods

The measurement setup is composed by:

- n°1 Canberra HPGE p-type (High Resolution), V_{bias} = +3000V
- n°1 Scionix NaI scintillator 76B76/3M, V_{bias} = +600V
- ^{60}Co source (1 µCi)
- ^{57}Co source (5 µCi)
- ^{137}Cs source (0,25 µCi)
- ^{22}Na source (1 µCi)
- CAEN DT5000 - Hexagon

The performed measurements are listed here below:

1. Resolution (FWHM) as a function of the Trapezoid Rise Time with ^{60}Co (1173 and 1332 keV peaks), ^{57}Co (122 keV peak) and ^{137}Cs (663 keV peak)
2. Resolution (FWHM) as a function of the Coarse Gain with ^{57}Co (122 keV peak)
3. Resolution (FWHM) as a function of the use of an external preamplifier (NaI scintillator only)
4. Resolution (FWHM), Centroid position, Net/Live and Dead Time as a function of the ICR using ^{60}Co as reference source and ^{22}Na as disturbing source
5. Resolution (FWHM), Centroid position, Net/Live and Dead Time as a function of the ICR using ^{57}Co as reference source and ^{22}Na as disturbing source

Figure 8 shows the signal waveform acquired by the Canberra HPGe detector with ^{60}Co source and the corresponding trapezoidal filter output, while **Figure 9**, **Figure 10** and **Figure 11** show the ^{60}Co, ^{57}Co e ^{137}Cs spectra acquired by Hexagon respectively.

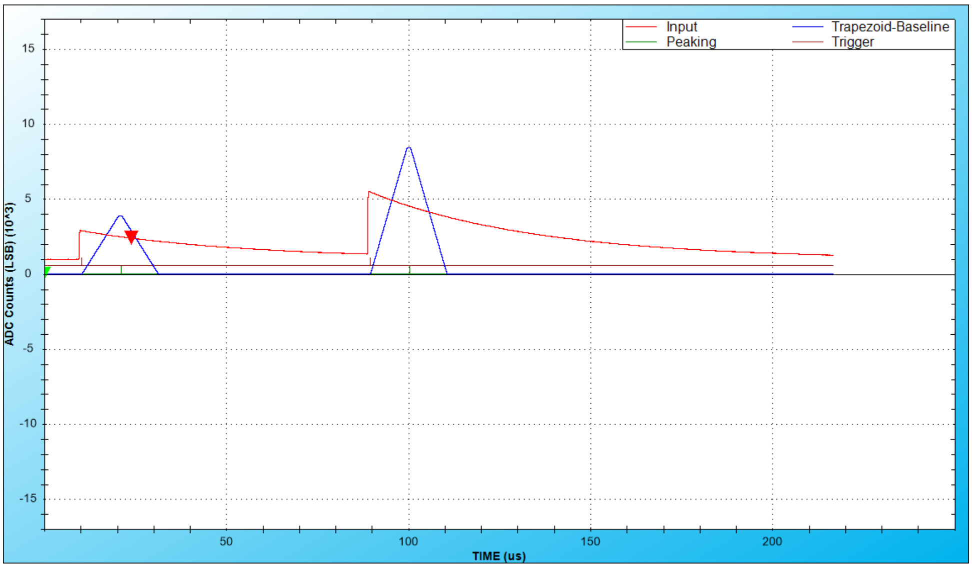


Figure 8: HPGe Canberra signal (red line) and corresponding trapezoidal filter (blue line).

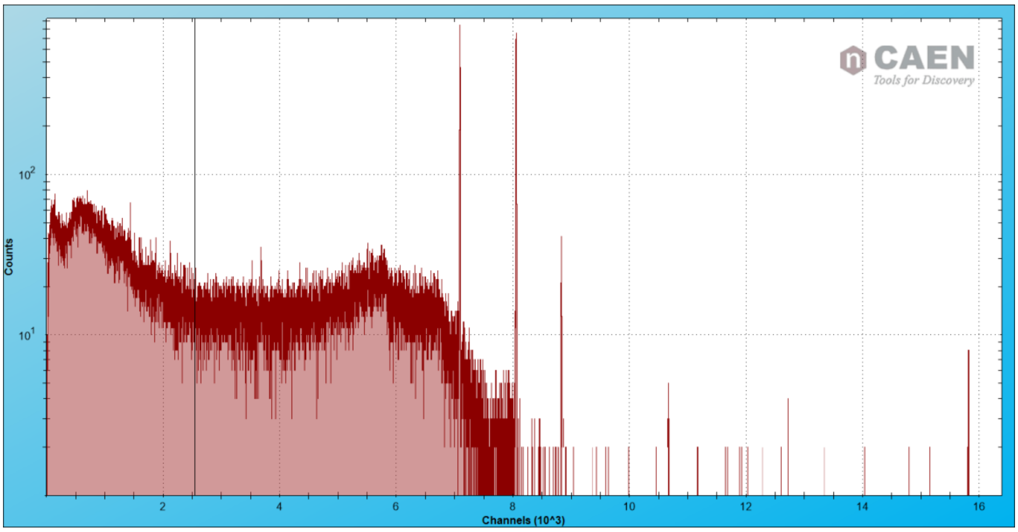


Figure 9: ^{60}Co energy spectrum acquired by the HPGe Canberra detector.

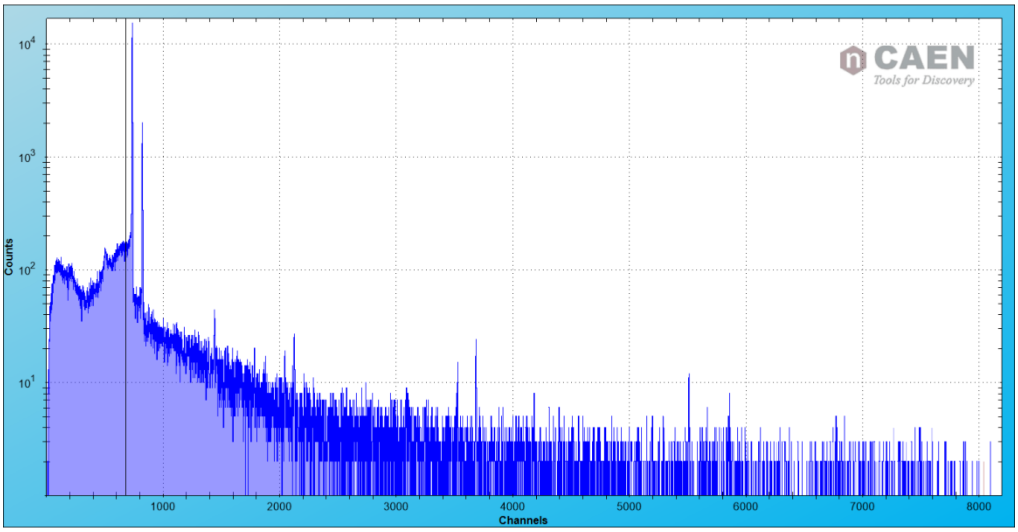


Figure 10: ^{57}Co energy spectrum acquired by the HPGe Canberra detector.

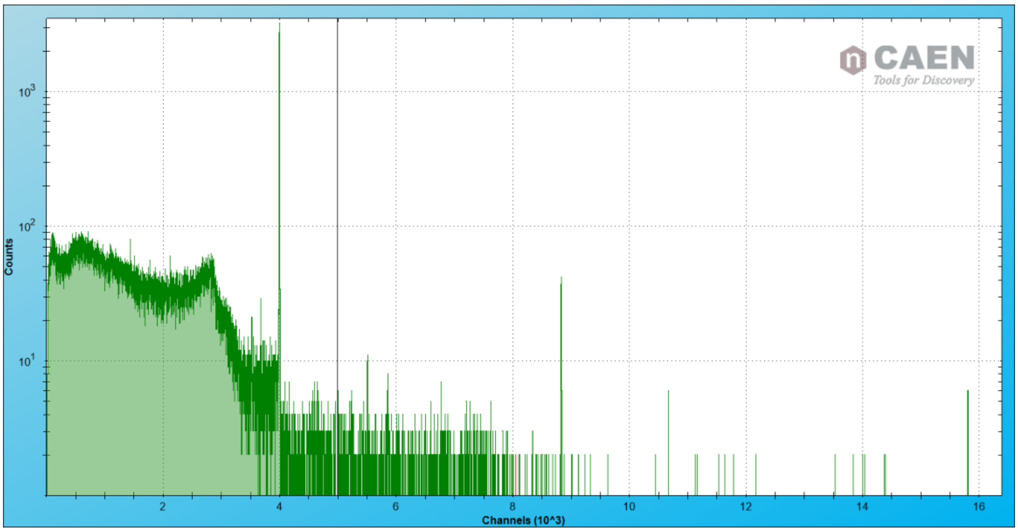
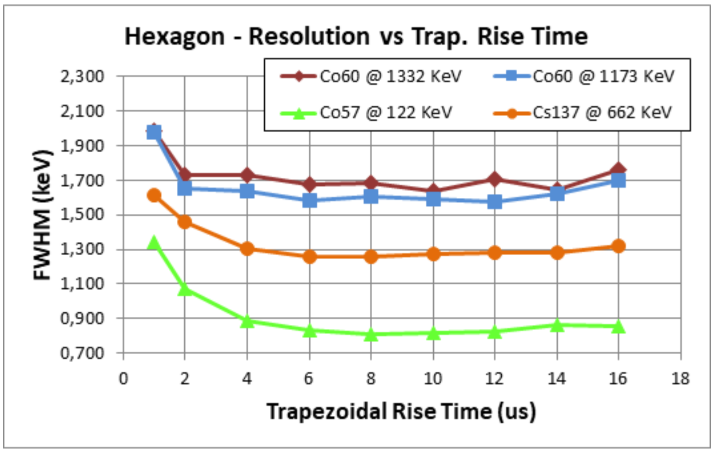


Figure 11: ^{137}Cs energy spectrum acquired by the HPGe Canberra detector.

Resolution vs Trapezoid Rise Time

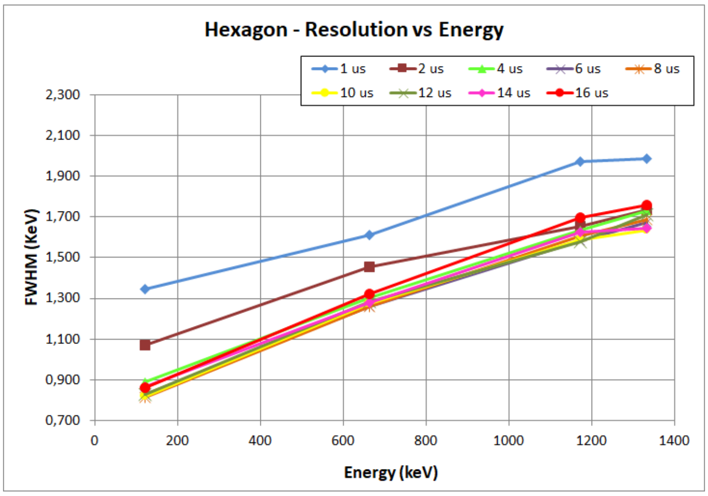
The measurement is performed with the HPGe Canberra detector placing the source at a distance so that the ICR is about 300 cps and setting a preset acquisition Live Time equal to 600 s. All the acquisition parameters except the Trapezoid Rise Time are fixed and they are listed here below:

- Input Rise Time: 0.6 us
- Threshold: 9 LSB
- Trapezoidal Flat Top: 1 us
- Trapezoidal Tail correction: 46 us
- Baseline: 4K



Trise (µs)	Co60 @ 1173 keV	Co60 @ 1332 keV	Co57 @ 122 keV	Cs137 @ 662 keV
1	1,973	1,985	1,346	1,613
2	1,654	1,732	1,069	1,456
4	1,634	1,728	0,891	1,303
6	1,581	1,673	0,830	1,261
8	1,608	1,685	0,812	1,261
10	1,589	1,636	0,817	1,274
12	1,578	1,708	0,827	1,282
14	1,623	1,645	0,865	1,28
16	1,696	1,759	0,860	1,321

Figure 12: ^{57}Co, ^{60}Co and ^{137}Cs peaks Resolution vs Trapezoidal Rise Time.



KeV	1us	2us	4us	6us	8us	10us	12us	14us	16us
122	1,346	1,069	0,891	0,83	0,812	0,817	0,827	0,865	0,86
662	1,613	1,456	1,303	1,261	1,261	1,274	1,282	1,28	1,321
1173	1,973	1,654	1,634	1,581	1,608	1,589	1,578	1,623	1,696
1332	1,985	1,732	1,728	1,673	1,685	1,636	1,708	1,645	1,759

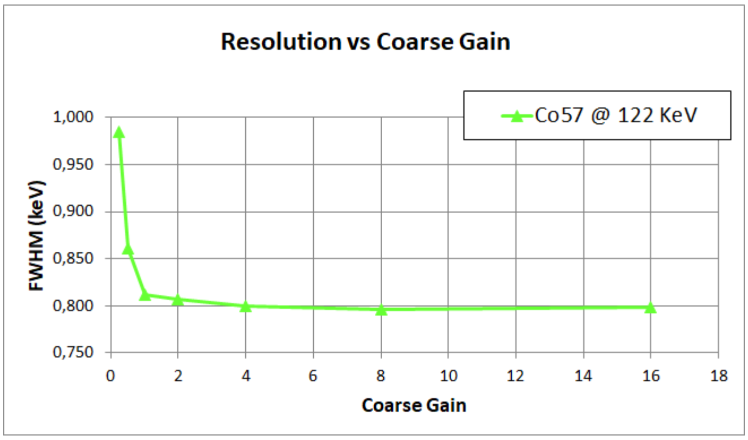
Figure 13: Resolution vs Energy.

The best resolutions are obtained for rise time in the range of 6 to 12 us. Also 2 and 4 us show good results, especially for higher energy values, while 1 us has the worse results for all the energy values. These results are valid for low rate signals.

Resolution vs Coarse Gain

The measurement is performed with the HPGe Canberra detector placing the source at a distance so that the ^{57}Co ICR is about 450 cps and setting a preset acquisition Live Time equal to 600 s. All the acquisition parameters, except the Coarse Gain, are fixed and listed here below:

- Input Rise Time: 0.3 us
- Trapezoidal Rise Time: 10 us
- Trapezoidal Flat Top: 1 us
- Pole Zero: 46 us
- Baseline: 4K



Coarse Gain	Full Scale Equivalent (MeV)	Co57 @ 122 keV (keV)
0,25	12	0,985
0,5	6	0,861
1	3	0,812
2	1,5	0,807
4	0,75	0,800
8	0,375	0,796
16	0,188	0,798

Figure 14: Resolution vs Coarse Gain.

Increasing the Coarse Gain value gives better resolution results until values of x4-x8 after which the resolution remains constant.

Resolution with NaI Scintillator with and without an external preamplifier

This measurement aims to verify the Hexagon energy resolution performance when using a scintillator detector (NaI in our case) at medium-high rate feeding Hexagon directly with the PMT anode signal or using a charge sensitive preamplifier (CAEN A1424 **[6]**) in between. The following pictures show the ^{22}Na and ^{137}Cs spectra respectively.

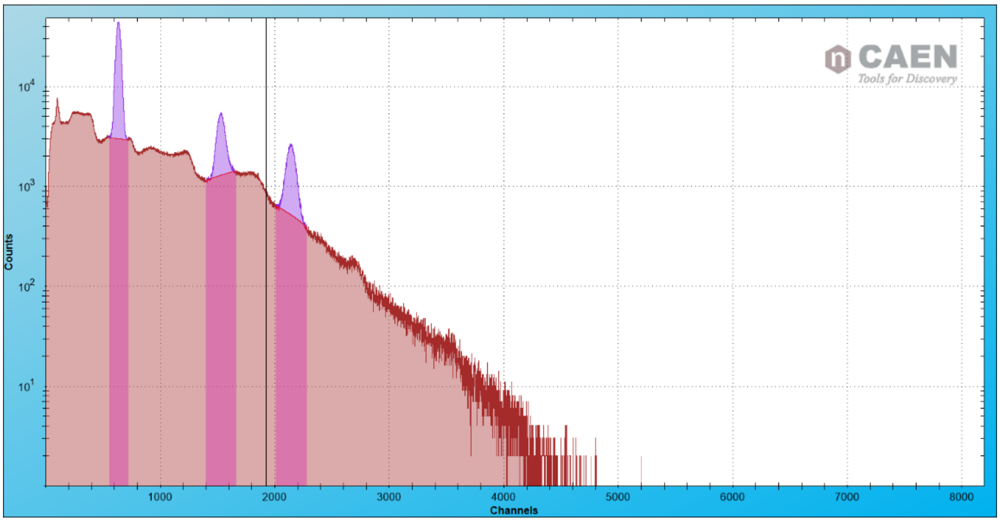


Figure 15: ^{22}Na energy spectrum acquired with the Scionix NaI detector.

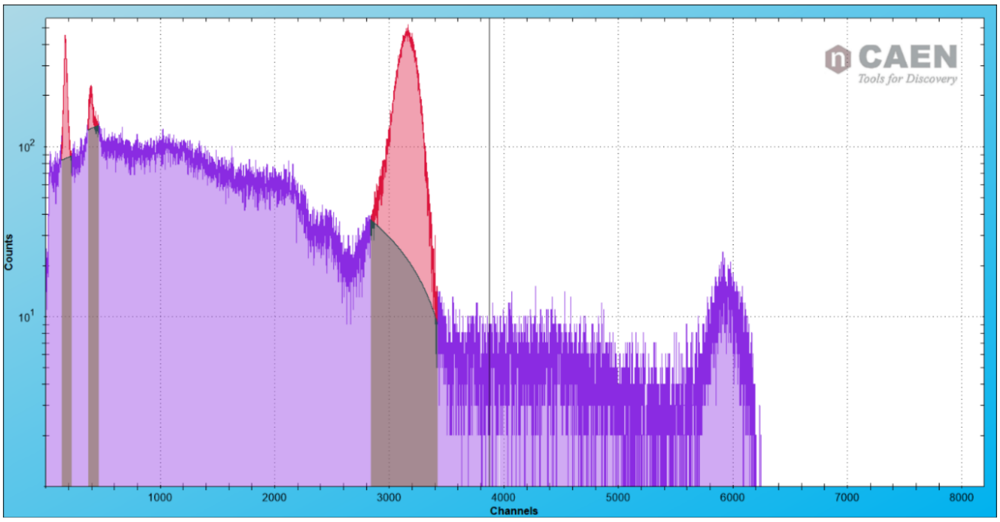


Figure 16: ^{137}Cs energy spectrum acquired with the Scionix NaI detector.

The results of the peak resolution (FWHM) are summarized in the following table and are in agreement with those expected for this kind of detector (7% at 511 keV ^{22}Na peak and 6.4% at the 662 keV ^{137}Cs peak) **[7]**.

MCA	Preamp	Na22 @ 511 keV Resolution	Cs137 @ 662 keV Resolution
Hexagon	A1424	7,2 %	6,4 %
Hexagon	-	7,1 %	6,3 %

Table 1: ^{22}Na and ^{137}Cs FWHM with NaI detector with and without the use of a A1424 charge sensitive preamplifer.

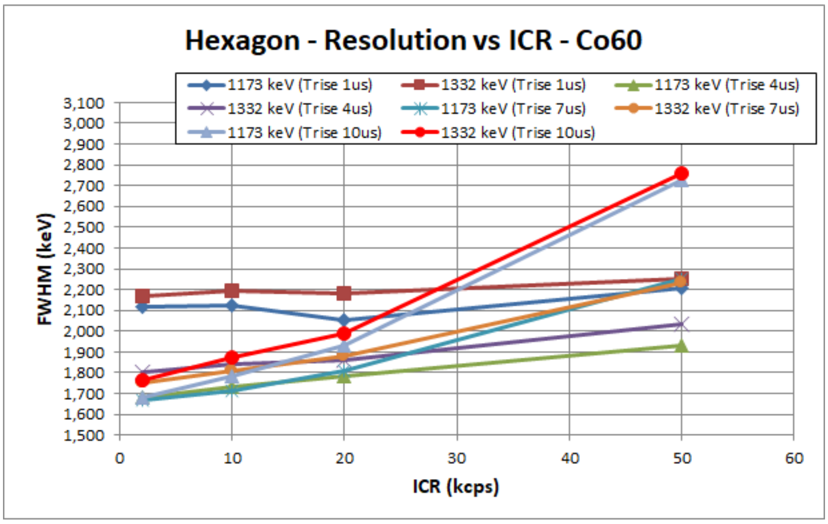
It is worth to notice that the Hexagon performance are pretty good even when the PMT anode signal is directly used without any preamplifier in between.

Resolution, Centroid shift, Net/Live and Dead Time vs ICR (^{60}Co with ^{22}Na disturbing source)

This measurement aims to evaluate the Hexagon performance in terms of resolution (FWHM), peak centroid position stability, Net/Live and Dead Time when increasing the Input Counting Rate (ICR). This is the well-known *"Two sources method"*: a reference source for which the above-mentioned quantities are evaluated and a disturbing one used to increase the input count rate.

The measurement has been performed keeping the ^{60}Co reference source fixed in order to provide a stable ICR of few kcps while the ^{22}Na disturbing source, not present at the beginning, has been gradually moved closer to the detector in order to contribute to the total ICR up to a rate of about 50 kcps.
The use of these two sources aims to verify the Hexagon performance when the disturb on the reference source comes from another one providing peaks at lower energy.

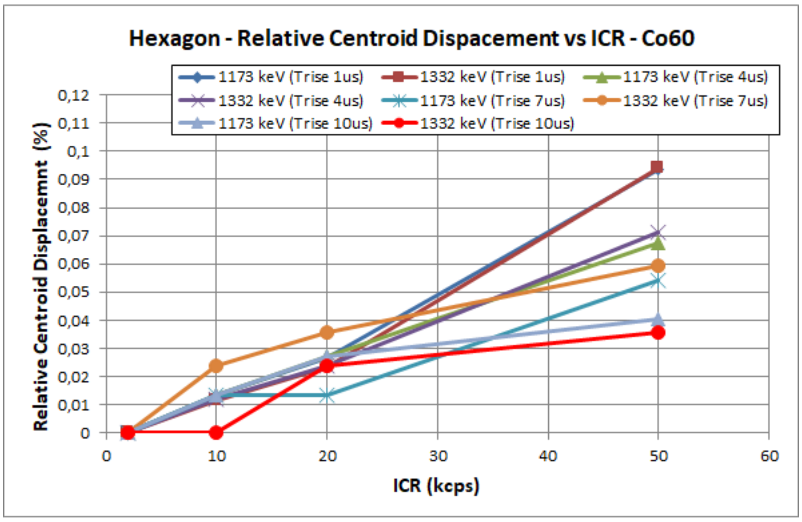
The measurement results are shown in the following pictures.



Trise	1 us		4 us	
ICR (kcps)	FWHM (1173 keV) (keV)	FWHM (1332 keV) (keV)	FWHM (1173 keV) (keV)	FWHM (1332 keV) (keV)
2	2,118	2,170	1,678	1,800
10	2,125	2,197	1,730	1,842
20	2,050	2,182	1,784	1,859
50	2,205	2,249	1,928	2,031
	7 us		10 us	
	FWHM (1173 keV) (keV)	FWHM (1332 keV) (keV)	FWHM (1173 keV) (keV)	FWHM (1332 keV) (keV)
	1,671	1,751	1,683	1,763
	1,714	1,811	1,781	1,875
	1,812	1,878	1,929	1,990
	2,249	2,235	2,724	2,758

Figure 17: FWHM vs ICR for Hexagon.

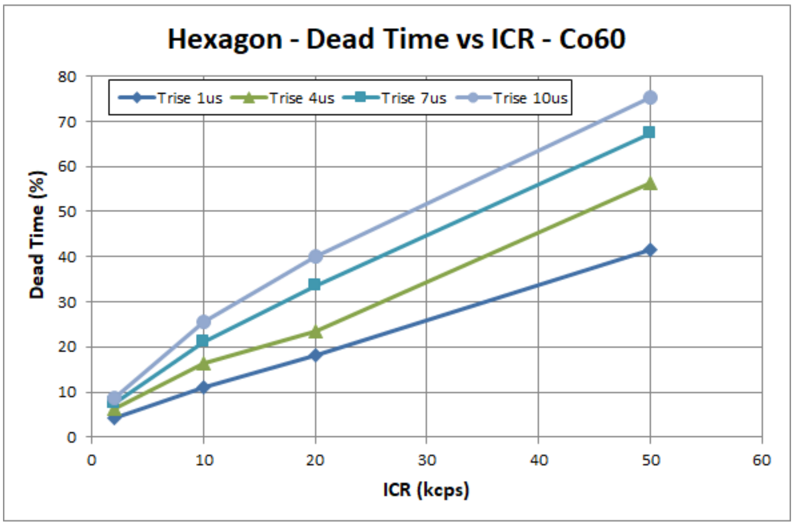
As shown in **Figure 17Figure 17**: FWHM vs ICR for Hexagon., when increasing the ICR, the resolution remains stable with smaller values of rise time. This avoids pile-up effects and resolution decrease possibly due to wrong baseline calculation (the value of the baseline is evaluated at the beginning of the piled-up event).



Trise	1 us		4 us	
ICR (kcps)	Relative Centroid Displacement (1773 keV) (%)	Relative Centroid Displacement (1332 keV) (%)	Relative Centroid Displacement (1773 keV) (%)	Relative Centroid Displacement (1332 keV) (%)
2	0	0	0	0
10	0,0134	0,0118	0,0135	0,0119
20	0,0267	0,0235	0,0269	0,0237
50	0,0935	0,0941	0,0674	0,0712
	7 us		10 us	
	Relative Centroid Displacement (1773 keV) (%)	Relative Centroid Displacement (1332 keV) (%)	Relative Centroid Displacement (1773 keV) (%)	Relative Centroid Displacement (1332 keV) (%)
	0	0	0	0
	0,0135	0,0238	0,0135	0
	0,0135	0,0356	0,0270	0,0238
	0,0540	0,0594	0,0405	0,0357

Figure 18: Relative centroid position displacement vs ICR.

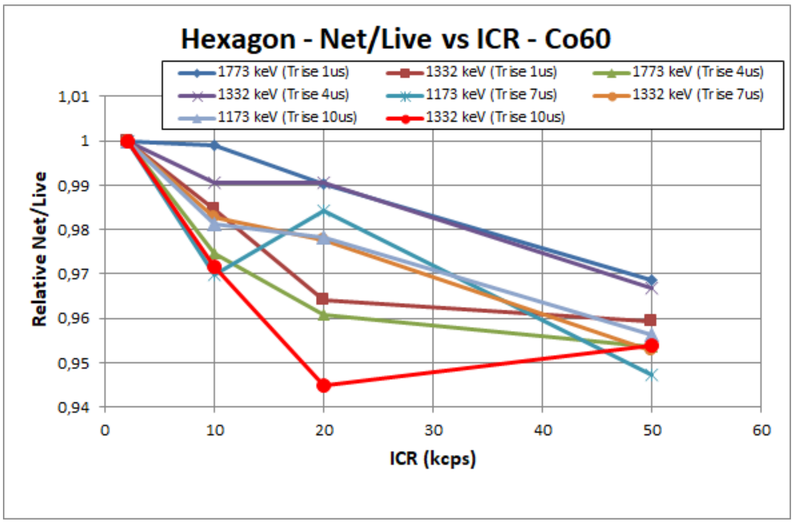
The Relative Centroid Displacement is defined as the centroid position variation with respect to the one at 2 kcps. The displacement is always lower than 0,1% even though a bit worse than the displacement shown by an equivalent competitor MCA that is around 0%.



Trise	1 us	4 us
ICR (kcps)	Dead Time (%)	Dead Time (%)
2	4,26	6,45
10	11,00	16,46
20	18,07	23,43
50	41,44	56,34
	7 us	10 us
	Dead Time (%)	Dead Time (%)
	7,55	8,54
	21,01	25,56
	33,69	40,19
	67,28	75,44

Figure 19: Dead Time vs ICR.

The dead time shows a significant increase when increasing the ICR, which is mostly due to the high pile up occurred at high rate. Indeed, as expected, the higher the set Trapezoid Rise Time, the higher the occurred pile up and so the dead time with comparable results with respect to an equivalent competitor MCA.



Trise	1 us		4 us	
ICR (kcps)	Relative Net/Live (1173 keV)	Relative Net/Live (1332 keV)	Relative Net/Live (1173 keV)	Relative Net/Live (1332 keV)
2	1	1	1	1
10	0,999	0,985	0,975	0,991
20	0,990	0,964	0,961	0,991
50	0,969	0,959	0,953	0,967
	7 us		10 us	
	Relative Net/Live (1173 keV)	Relative Net/Live (1332 keV)	Relative Net/Live (1173 keV)	Relative Net/Live (1332 keV)
	1	1	1	1
	0,970	0,983	0,981	0,97
	0,984	0,978	0,978	0,94
	0,947	0,953	0,956	0,95

Figure 20: Relative Net/Live vs ICR.

Even though the Net/Live ratio is expected to be constant, a 3 to 5% variation is measured, in particular in case of higher Trapezoid Rise Time values. Indeed, a best practice in case of high ICR is to reduce the Trapezoid Rise Time to avoid a too high dead time and a decrease in the Net/Live ratio. Other equivalent MCAs follow a different approach applying an additional compensation algorithm that on the contrary turns into an overcompensation of the Net/Live ratio of a 2 to 4% factor.

It would be interesting to perform the same measurement using ^{57}Co as reference source so that the disturb comes from another one providing peaks at higher energy. This measurement will be matter of next updates of this Application Note.

Results discussion

The Hexagon resolution results are in agreement with those generally considered as reference values for this kind of HPGe detectors (i.e. about 1.6 keV on the 1332 keV ^{60}Co peak and 0.7 keV on the 1332 keV ^{57}Co peak) and are comparable or even better than equivalent competitor digital MCAs.

Results in agreement with the detector expected resolution values are achieved with NaI detector as well (about 7% on the 511 keV ^{22}Na peak and 6.5% keV on the 662 keV ^{137}Cs peak) showing then a very good Hexagon behavior also when dealing with scintillator fast signals without preamplifier.

For what concern the measurement performed in the so called “Two sources method”, the worsening of the resolution, a small displacement of the peaks centroid position and the dead time increase are expected effects. In this case, Hexagon shows a performance in terms of Resolution and Dead Time comparable with another equivalent competitor digital MCAs, slightly worse but still good results in terms of Centroid displacement and Net/Live estimation. More advanced compensation algorithms would help in improving the Centroid displacement and Net/Live estimation results.

Measurements with detectors: second measurement session

Material and methods

In this second measurement session, two difference HPGe detectors have been used and the results have been compared with those got with another equivalent competitor MCA.

The measurement setup is composed by:

- n°1 Ortec P-Type coaxial HPGE
- n°1 Ortec P-Type planar HPGE for the low energies
- ^{152}Eu source
- ^{226}Ra source
- ^{241}Am source
- ^{55}Fe source
- CAEN DT5000 - Hexagon

The detectors were already powered by an external power supply and it was not possible to change their high voltage source because of their critical stability requirements.

The performed measurements are listed here below:

1. Resolution (FWHM) as a function of the Trapezoid Rise Time with ^{152}Eu (122 keV peak)
2. Resolution (FWHM) as a function of the Coarse Gain with ^{152}Eu (122 keV peak)
3. Resolution (FWHM), Centroid position, Net/Live and Dead Time as a function of the ICR using ^{152}Eu as reference source and ^{226}Ra and ^{241}Am as disturbing source
4. Resolution at low energy with ^{55}Fe (5.9 KeV peak)

The measurement described at point 1 has been done on both the available HPGe detectors while the ones described at points 2, 3 and 4 have been done on the planar HPGe only.

The following pictures shown the ^{152}Eu spectra with the Coaxial and Planar HPGe respectively

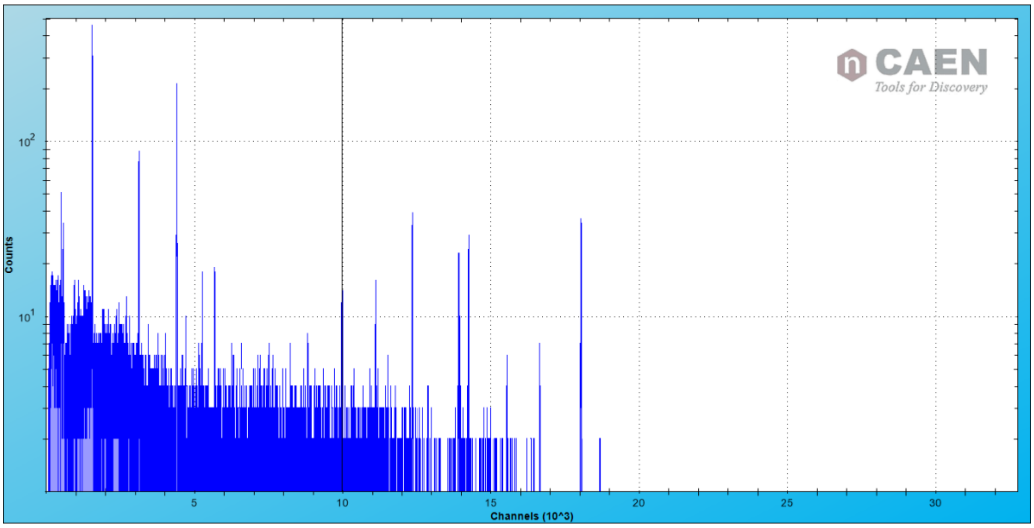


Figure 21: ^{152}Eu energy spectrum acquired by the Ortec coaxial HPGe detector

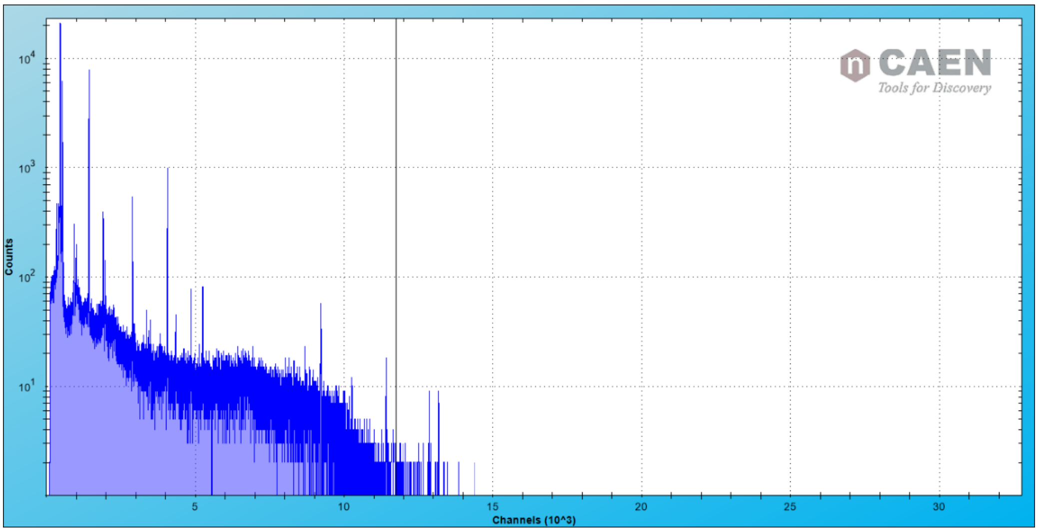
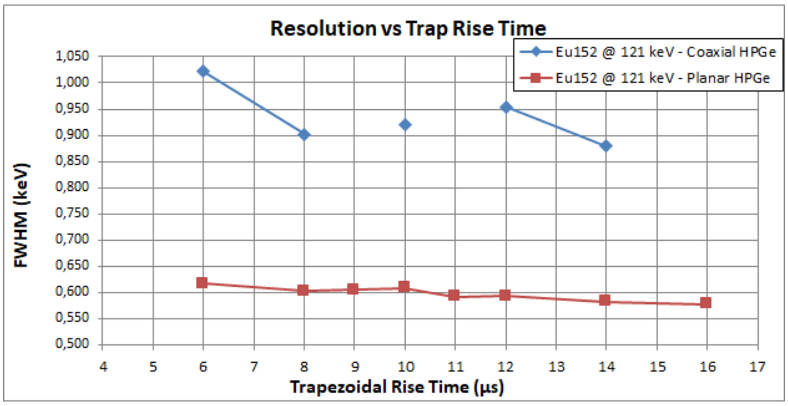


Figure 22: ^{152}Eu energy spectrum acquired by the Ortec planar HPGe detector.

Resolution vs Trapezoidal Rise Time

The measurement has been performed with both the ORTEC HPGe detectors placing the source at a distance so that the ICR was about 200 cps and setting a preset acquisition Live Time equal to 600 s. All the acquisition parameters, except the Trapezoid Rise Time, are fixed and listed here below for the two detectors:

- Input Rise Time: 0.3 us and 0.4 us
- Trapezoidal Flat Top: 1 us both
- Pole Zero: 59 us and 60 us
- Baseline: 4K both
- Peak Hold-off: 7 us both



Trise (µs)	Eu152 @ 121 keV ORTEC Coaxial HPGe	Eu152 @ 121 keV ORTEC Planar HPGe
6	1,022	0,617
8	0,902	0,602
9		0,605
10	0,921	0,608
11		0,592
12	0,954	0,593
14	0,879	0,582
16		0,577

Figure 23: ^{152}Eu 122 KeV peak Resolution vs Trapezoidal Rise Time

The different resolution results between the two detectors are expected. The planar HPGe is indeed optimized for the low energy range while the coaxial one for the medium and high energy range. In both cases the resolution results are in agreement with those expected for this kind of detectors **[8][9]** and are comparable with those achieved with an equivalent competitor digital MCA.

Resolution vs Coarse Gain

The measurement has been performed with the ORTEC planar HPGe detector placing the ^{152}Eu source at a distance so that the ICR was about 200 cps and setting a preset acquisition Live Time equal to 600 s. All the acquisition parameters, except the Coarse Gain, are fixed as reported in the following table and listed here below for the two detectors:

- Input Rise Time: 0.3 us
- Trapezoidal Rise Time: 8 us
- Trapezoidal Flat Top: 1 us
- Pole Zero: 60 us
- Baseline: 4K
- Peak Hold-off: 7 us

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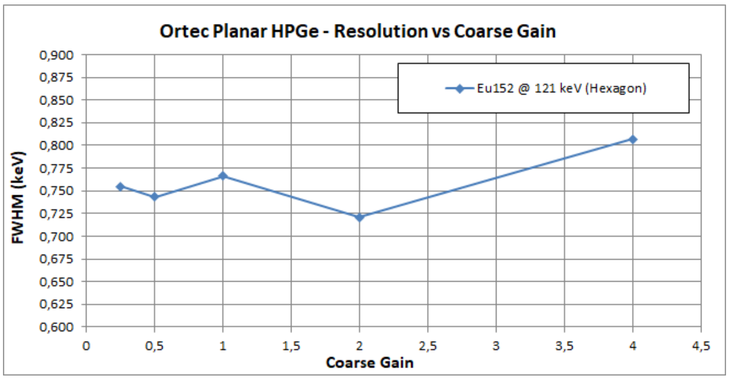


Coarse Gain	Full Scale Equivalent (MeV)	Eu152 @ 121 keV ORTEC Planar HPGe
0,25	3	0,755
0,5	1,5	0,743
1	0,75	0,766
2	0,375	0,721
4	0,188	0,807

Figure 24: Resolution vs Coarse Gain**.**

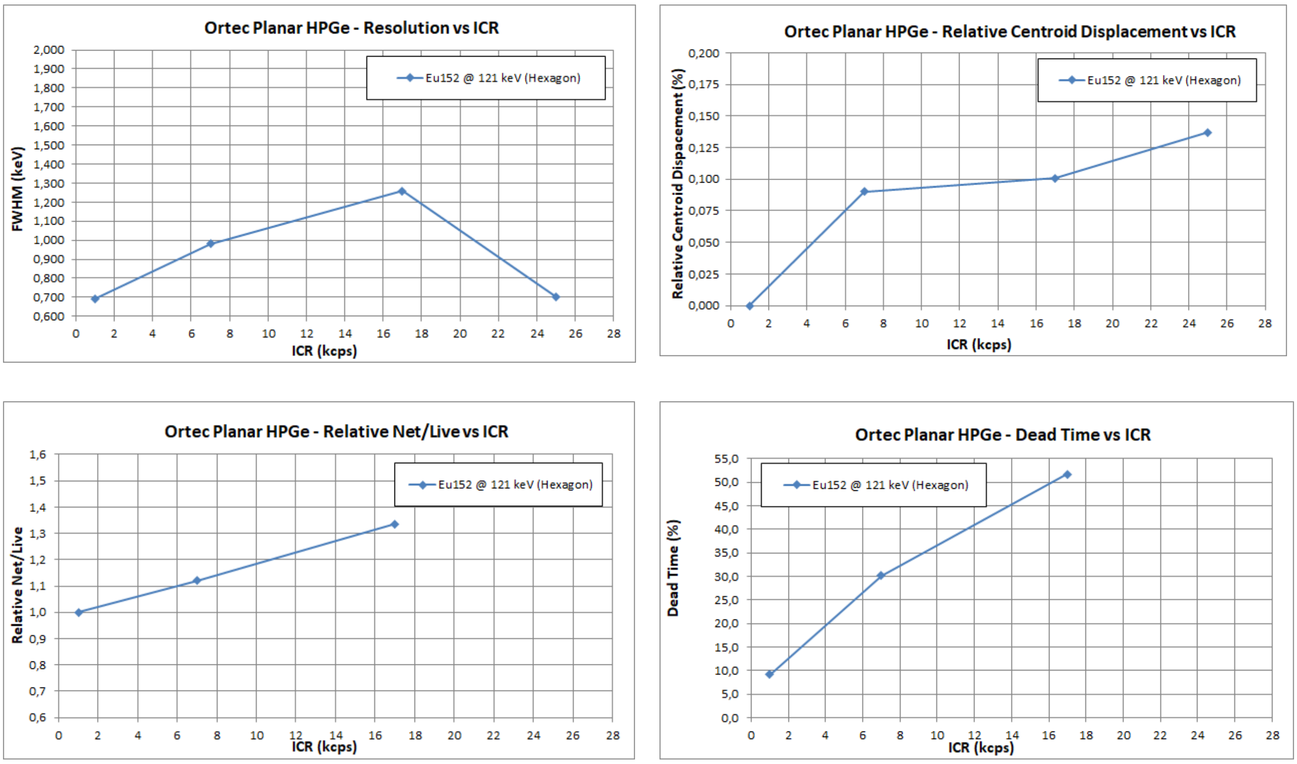
The worse value got at Coarse Gain = 4 is most probably due to the many saturation that occurs in this condition.

Resolution, Centroid shift, Net/Live and Dead Time vs ICR (^{152}Eu with ^{222}Ra and ^{241}Am disturbing sources)

This measurement aims to evaluate the Hexagon performances in terms of resolution (FWHM), peak centroid position stability, Net/Live and Dead Time when increasing the Input Counting Rate (ICR) again using the “Two sources method”.

The measurement has been performed keeping the ^{152}Eu reference source fixed in order to provide a stable ICR of about 1 kcps while the disturbing sources, not present at the beginning, has been gradually moved closer to the detector in order to contribute to the total ICR up to a rate of about 25 kcps.

The use of ^{152}Eu as reference source and ^{226}Ra and ^{241}Am as disturbing sources aims to verify the Hexagon performance when the disturb on the reference source comes from others providing peaks at lower and higher energy at the same time



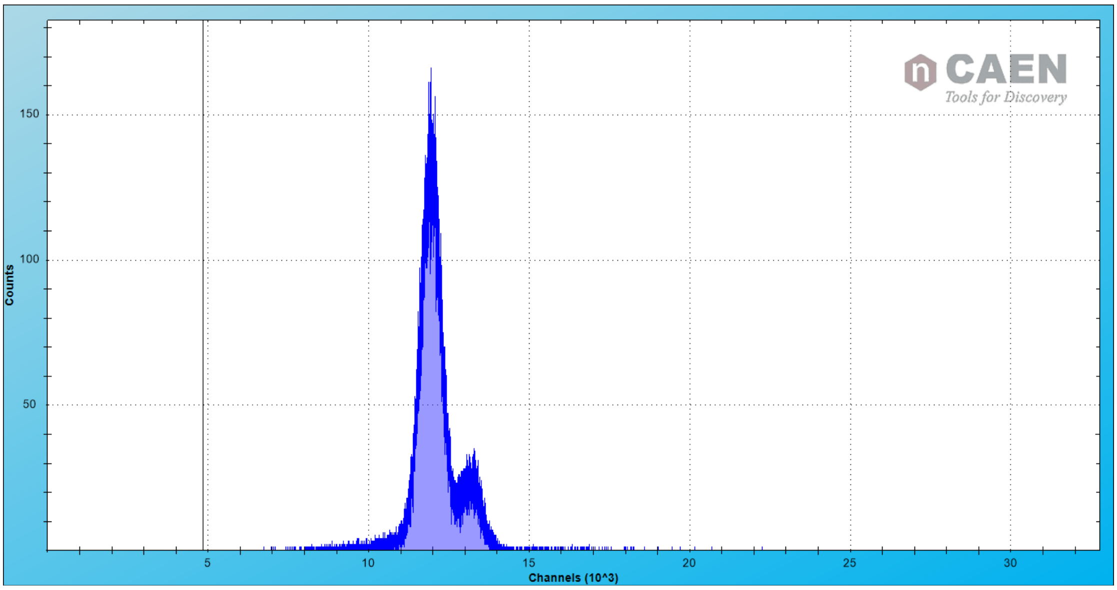
ICR (kHz)	FWHM (KeV)	Relative Centroid Displacement (%)	Relative Net/Live	Dead Time (%)
1	0,694	0	1	9,18
7	0,980	0,0902	1,119	30,20
17	1,258	0,1009	1,335	51,64
25	0,704	0,1370		

Figure 25: Resolution, Relative centroid displacement, Relative Net/Lice, Dead Time vs ICR

The resolution and relative centroid displacement worsening are expected results as well as the deadtime increase and they are similar to those get with an equivalent competitor MCA.
Concerning the Net/Live estimation, the observed behavior is opposite with respect to the one achieved in the first measurement test with Canberra HPGe and ^{60}Co source. This might be due to the fact that while in the 1332 keV ^{60}Co peak case the input rate increase contributes to a pauperization of the events in the peak moving them to lower energy values, in the 121 keV ^{152}Eu peak case the effect is the opposite with events coming from the higher energy regions of the spectrum that contributes to an increase of the events under the peak region.

Low energy test with ^{55}Fe source

The measurement aims to check the Hexagon performance very preliminarily with a low energy source. The used source was ^{55}Fe (5.9 keV peak). In the following the measurement results.



Notes	Fe55 @ 5.9 keV (keV)
Hexagon Baseline Mean - Fast	0,476
Hexagon Baseline Mean - Medium	0,332
Hexagon Baseline Mean - Slow	0,316

Figure 26: Resolution of the 5.9 keV ^{55}Fe peak as a function of the baseline evaluation algorithm.

The results are in agreement with those expected for this kind of detectors **[9]**.

Results discussion

These tests allowed to verify the Hexagon performance with a two kind of ORTEC HPGe detectors. For what concern the resolution, the results are in agreement with the expected values in all the cases.

Even better results could be achieved by using the external filter CAEN A387 which was not present at the time when these measurements were done.

Concerning the peak centroid displacement, the Hexagon results are similar to those achieved in the first measurement session when compared with an equivalent digital MCA while for the Centroid displacement and the Net/Live estimation, it behaves in an opposite way as already explained in the above paragraph. More advanced compensation algorithms would help to improve the Centroid displacement and Net/Live estimation results in this case as well.

Measurements with detectors: third measurement session

Material and methods

A third measurement session has been performed to check the Hexagon performance with electrically cooled HPGe. In this condition, microphonic noise is introduced by the mechanical cooling system and for this reason it is worth to do dedicated tests to check the Hexagon low frequency noise rejector capabilities.

The measurement setup is composed by:

- electrically cooled Canberra BEGe with CP5plus
- electrically cooled BSI MONOLITH Gamma & X-ray HPGe Spectrometer
- ^{57}Co source
- ^{60}Co source
- ^{137}Cs source
- ^{109}Cd source
- CAEN DT5000 - Hexagon

The performed measurements verified the resolution (FWHM) results got by Hexagon as a function of the Trapezoid Rise Time with ^{57}Co, ^{60}Co, ^{109}Cd, ^{137}Cs sources.

The tests have been done using the Canberra and BSI HPGe. The following pictures show some examples of the acquired spectra.

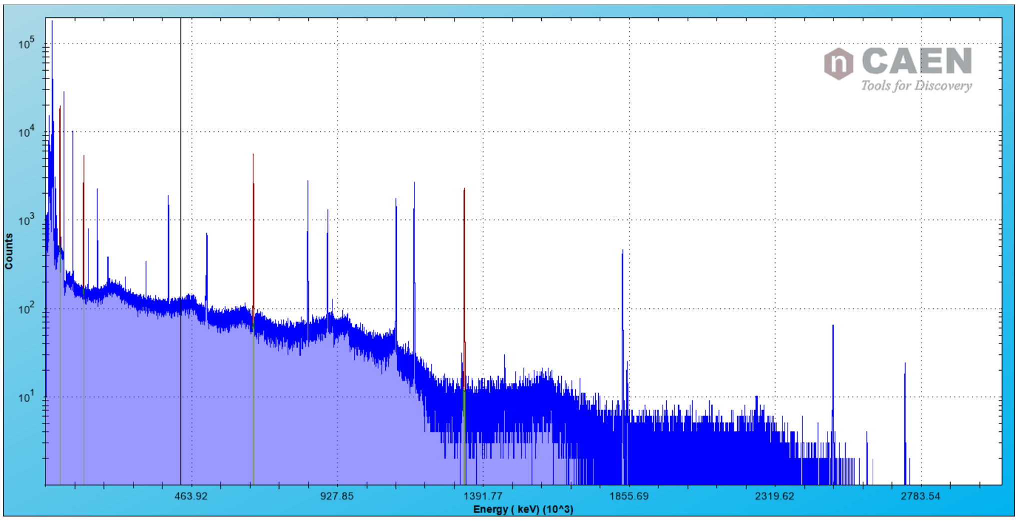


Figure 27: mixed source energy spectrum acquired by the Canberra HPGe detector

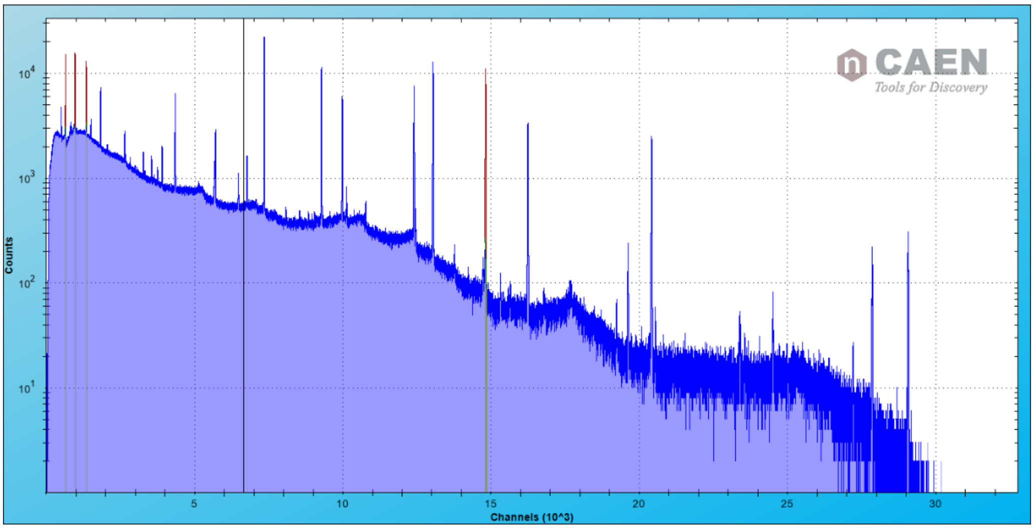
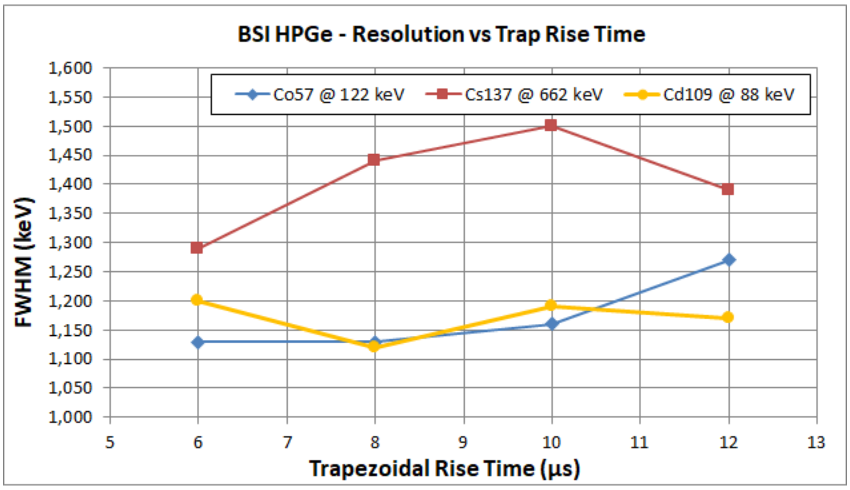


Figure 28: mixed source energy spectrum acquired by the BSI HPGe detector.

Resolution vs Trapezoidal Rise Time

The measurement has been performed with the Canberra and BSI HPGe detectors placing the source at a distance so that the ICR was about 1 kcps and setting a preset acquisition Live Time equal to 120 s. All the acquisition parameters, except the Trapezoid Rise Time, are fixed and listed here below for the two detectors:

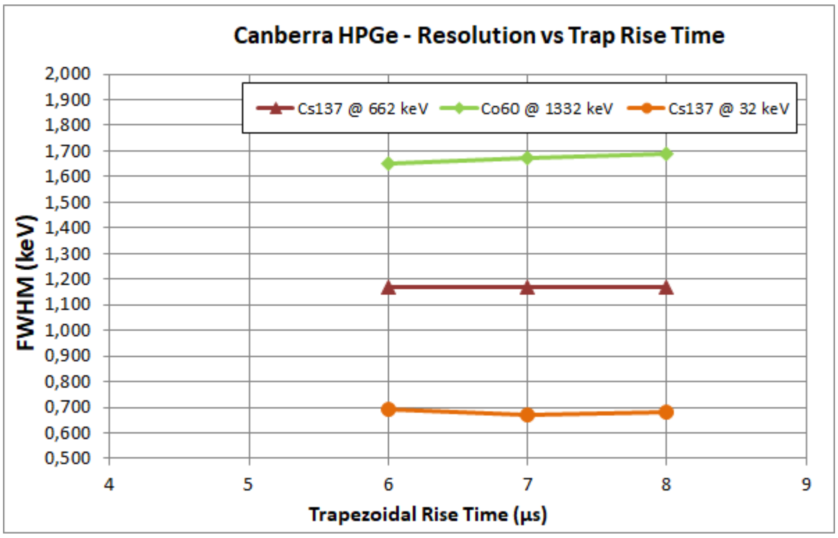
- Input Rise Time: 0.3 us for both
- Trapezoidal Flat Top: 2 us for both
- Pole Zero: 92 us and 50 us
- Baseline: 4K for both
- Peak Hold-off: 5 us for both



Trise (µs)	Co57 @ 122 keV (keV)	Cd109 @ 88 keV (keV)	Cs137 @ 662 keV (keV)
6	1,130	1,200	1,290
8	1,130	1,120	1,440
10	1,160	1,190	1,500
12	1,270	1,170	1,390

Figure 29: ^{57}Co, ^{109}Cd, ^{137}Cs peaks Resolution vs Trapezoidal Rise Time (BSI Detector).

The resolution results at the 1332 keV ^{60}Co peak are better if compared with those expected for this kind of detectors **[10]**.



Trise (µs)	Cs137 @ 32 keV (keV)	Cs137 @ 662 keV (keV)	Co60 @ 1332 keV (keV)
6	0,690	1,170	1,650
7	0,670	1,170	1,670
8	0,680	1,170	1,690

Figure 30: ^{137}Cs and ^{60}Co peaks Resolution vs Trapezoidal Rise Time (Canberra Detector).

The resolution results at the 122 keV ^{57}Co peak are better if compared with those expected for this kind of detectors **[11]**.

Results discussion

These tests allowed us to verify the Hexagon performances with two kinds of electric cooled HPGe detectors. In both cases, the resolution results are better than those expected for these kinds of detectors.

Conclusions

A wide set of characterization and performance tests have conducted in order to test the Hexagon performances in different working condition and with different detectors, HPGe and scintillators. Detectors from all the main providers (Canberra, ORTEC and BSI) have been tested even though not a full test campaign has been performed with all of them.

Hexagon showed a general good behavior in all the tested conditions.

The resolution values achieved are in agreement with expected values for the tested detectors and comparable or even better than those achieved with an equivalent competitor digital MCA. It is worth to mention that after the described test sessions further improvements could be obtained by adding an additional filter on the Hexagon input stage, like CAEN A387. Other digital MCAs embeds such filter. Future Hexagon revision will be designed so that the filter will be embedded within the MCA.

In order to evaluate the Hexagon performances when increasing the input rate, the so called “Two source method” has been applied. This is a common procedure used in such a test.

The worsening of the resolution, a small displacement of the peaks centroid position and the dead time increase are expected effects in these tests. In this case, Hexagon shows a performance in terms of Resolution and Dead Time comparable with another equivalent competitor digital MCA, slightly worse but still good results in terms of Centroid displacement and Net/Live estimation.

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[3] CAEN SpA, “UM6907 – Quantus User Manual”
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[7] Scionix, “76B76/3M NaI Detector Datasheet”
[8] ORTEC, “GEM Series Coaxial HPGe Detector Product Configuration Guide”
[9] ORTEC, “GLP Series Planar HPGe Low-Energy Detector Product Configuration Guide”
[10] Mirion Technologies, “BEGe™ - Broad Energy Germanium Detectors Datasheet”
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