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Introduction

The aim of this paper is to compare the energy resolution of two gamma ray spectroscopy setups based on two different acquisition chains; the first chain uses an analog V792N QDC, the other one is based on a 12 bit, 250 MS/s V1720 digitizer with a charge integrating Digital Pulse Processing (DPP CI). In order to perform the comparison between the two chains, gamma ray sources were used, ^{137}Cs and ^{60}Co. The spectra of the sources were acquired by the two different chains and compared performing least squares fits on the characteristic emission peaks in order to estimate the energy resolutions.

Traditional analog QDC chain and Digital Pulse Processing [1]

The function of the Front End electronics for nuclear physics applications is to acquire the electrical charge pulses generated by a radiation detector (see Fig. 1), to extract the quantities of interest and to convert them into a digital format that are then acquired, saved and analyzed by a computer. In most applications, the quantities of interest are the particle energy (proportional to the charge released by the particle in the detector) and the time of arrival.

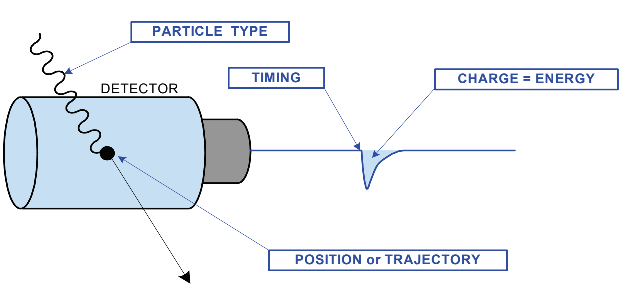

Fig. 1: Electrical charge pulse generated by a detector

The acquisition system is usually completed by digital logic units whose purpose is to make coincidences, generate triggers, vetoes and other signals that take into account the correlation between different channels and may give further information such as the particle position or trajectory.

Traditionally, the electronic readout systems for particle detectors have been made of almost all-analog chains. Each block of the chain has a specific function, so that you need to interconnect several blocks in order to make a system able to extract all the quantities of interest. This approach is rather rigid because you need to change the hardware blocks in case you want to perform another type of acquisition to measure different parameters.

In the case of some detectors, e.g. PMTs, that give a signal sufficiently strong to be fed directly into the readout electronics, the energy information is represented by the area below the pulse and this is normally measured by a Charge ADC (QDC). The QDC (see Fig. 2) is a pure integrator that requires a gate signal to define the integrating window. In some applications (most likely in beam experiments) the gate is provided by the system that knows in advance when the signals have to be integrated. Unfortunately, when this is not the case, it is necessary to generate the gate from the detector signals; to do that, you need to split the signals, send one branch to the discriminators and use a coincidence logic. It is also necessary to add a delay line (typically a long cable) on the signal path to the QDC input in order to match the pulses with the gate (which arrives with some latency respect to the analog pulses that produced it).

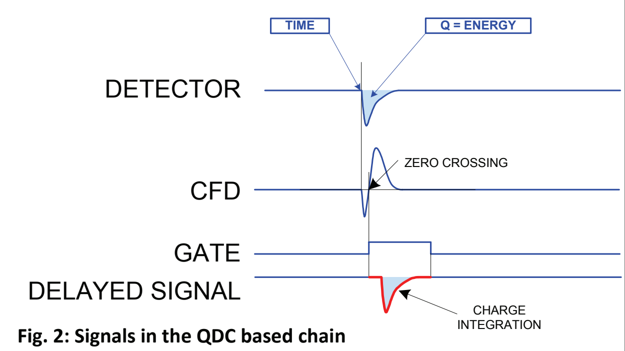

Fig. 2: Signals in the QDC based chain

In an ideal acquisition system, the analog signal is converted into a digital data stream as earliest as possible and then transferred, without any loss of information, to a computer that can make the analysis and measure the quantities of interest off-line. This is the basic principle of operation of a *Waveform Digitizer* (also known as *Transient Recorder or Flash ADC*). However, in the real world, there are some restrictions: the A/D conversion is always affected by an error that depends on the sampling frequency and the number of bit (resolution) of the ADC. Besides the loss of information due to the A/D conversion error, **the major problem of the fully digital approach is the huge amount of data to readout**. It is almost impossible to have a system in which the data throughput rate allows the acquisition (i.e. digitization) to be sustained continuously on all the inputs. Therefore, it is necessary to restrict the acquisition to some selected parts of the signals.

Like in a common oscilloscope, this happens firstly by means of the trigger whose purpose is to define a certain time window in which the signal has to be recorded (*acquisition window*). The difference between a common oscilloscope and a digitizer is that the latter has several memory buffers for the triggers and can save subsequent acquisition windows without any dead-time between them. Therefore, the acquisition can take place without the loss of any event, no matter what is the frequency and the distribution of them, at least until the readout rate allows the memory buffer to be read and freed on average faster than they are written, thus avoiding the memory to go full. In a digitizer, there is an FPGA that continuously writes the digital samples coming from the ADC into a circular memory buffer; when it receives the trigger, it keeps saving the post trigger samples, then freezes that buffer (which is made available for the readout) and continues to save the samples into a new buffer. The record length (number of samples in the acquisition window) and the size of the post trigger are both programmable.

In any case, the big advantage of the digitizers respect to the traditional acquisition systems is that the DPP algorithms are implemented in an FPGA and can be reprogrammed at any time. In one single module you have the complete information and the capability to extract all the quantities of interest; just change the algorithm to get another parameter. CAEN is continuously developing new digital algorithms in order to fit as many applications as possible. The user can easily download the firmware he needs into the digitizer and upgrade the functionality of the module.

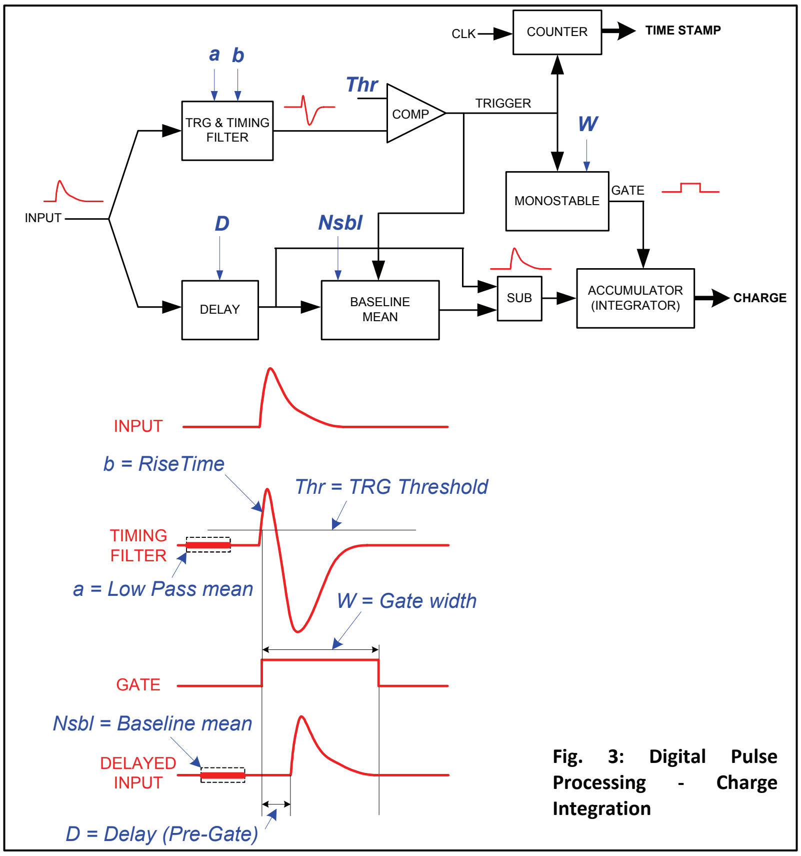

Fig. 3: Digital Pulse Processing - Charge Integration

Digital charge integration (see Fig. 3) is being implemented in the V1720 (8 channel, 12 bit, 250 MS/s digitizer). The main features of the Digital charge integration are as follows:

- Digital implementation of the QDC + discriminator and gate generator
- Implemented in the 12 bit, high speed digitizers Mod. 720
- Self-gating integration; no delay line to fit the pulse within the gate
- Automatic pedestal subtraction
- Extremely high dynamic range
- Dead-timeless acquisition (no conversion time)
- Energy and timing information can be combined
- On-line coincidences between couples of channels
- Input sensitivity: 40 fC per count

Measures: Analog QDC

Equipment used from CAEN

- N1470 4 Channel Programmable HV Power Supply
- N842 8 Channel Constant Fraction Discriminator
- N93B Dual Timer
- N146 Programmable Delay
- N147 Programmable Attenuator
- V792N 16 Channels QDC
- A 315 Splitter

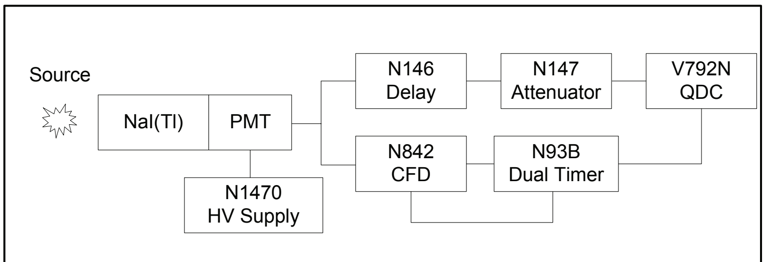

Fig. 4: Analog QDC chain

Other equipment used

- Oscilloscope
- NaI(Tl) Crystal and Photomultiplier Tube Assembly (9265KB)
- Photomultiplier Base (Voltage Divider)
- Spectrum Techniques RSS-5 Sealed Solid Disk Gamma Ray Sources ~1 µC ^{137}Cs, ^{60}Co

Sofware used

- CAEN QTP demo
- ROOT data analysis framework (http://root.cern.ch/drupal/)

Equipment Setup

N1470 HV Power Supply: HV set at about the middle of the acceptable operating range, G ~ 5 10^4 (850 V).

N842 CFD: Used only one channel; other channels disabled. Threshold = -5 mV; Dead Time = 150 ns; Width = 50 ns.

N93B Dual Timer: Section 1: WDT = 800 ns; Section 2 = 1.5 µs.

N146 Delay: 50 ns.

N147 Attenuator: 3.0 dB.

V792N: Sliding Scale enabled; Zero Suppression disabled; Overflow Suppression enabled.

Split the PMT output using the A315, 50 Ohm adapted splitter. One branch, delayed and attenuated using N146 and N147, feeds one of the V792N QDC inputs. The second branch is used as N842 CFD input. The discriminator output is used (see Fig. 5) as Start for the first section of the N93B Dual Timer whose output is the Gate for the V792N and starts the second section of the Dual Timer. The output of this section is used as veto for the CFD in order to prevent the gate to be triggered by the noise of the PMT output and to discard pile-up events and PMT after pulses.

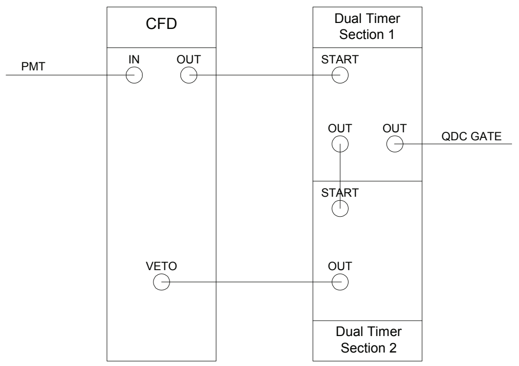

Fig. 5: CDF and Dual Timer setup

Three different spectra were acquired with this setup: ^{137}Cs, ^{60}Co (placing the sources ~2 cm in front of the PMT) and background. Each data taking lasted 15 minutes.

A ROOT script was used for data analysis. This tool reads data files of the spectra, subtracts the background to the ^{137}Cs and ^{60}Co histograms and applies a background removing algorithm which enhances the peaks for a better Gaussian fitting (the algorithm is implemented in the TSpectrum ROOT class).

In Fig. 6, 7, 8 the spectra are shown: raw, with the measured background spectrum subtracted and without the software evaluated background.

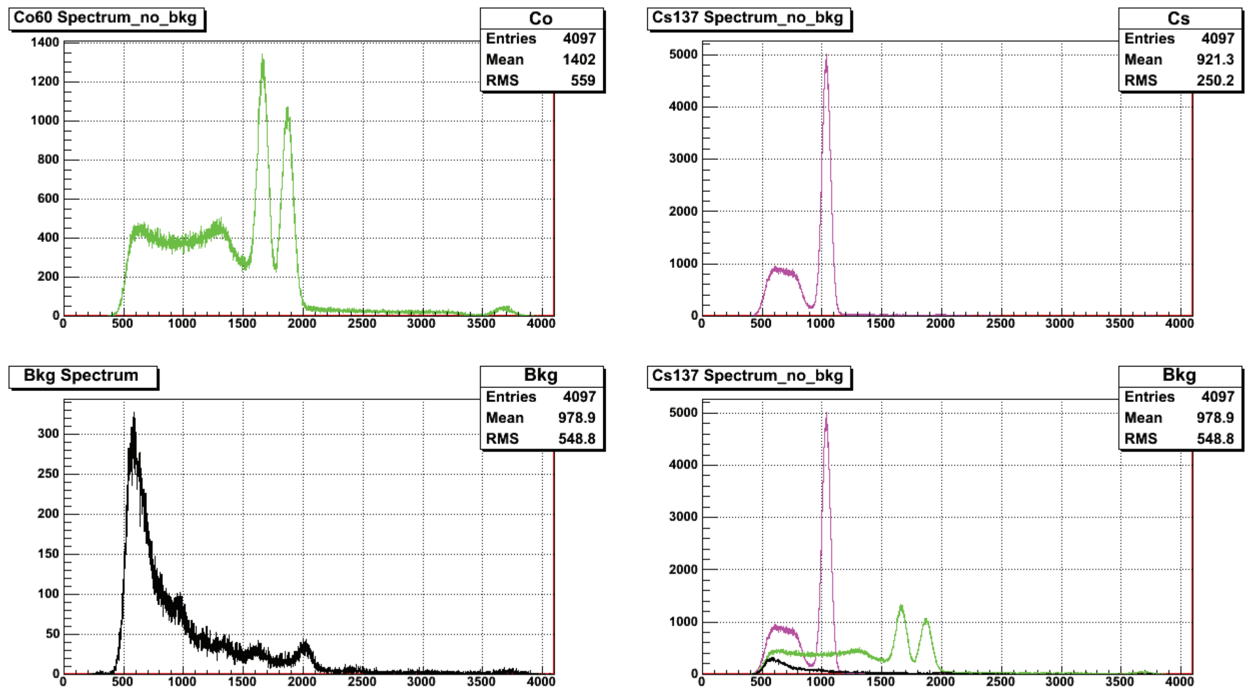

Fig. 6: V792N - Raw spectra

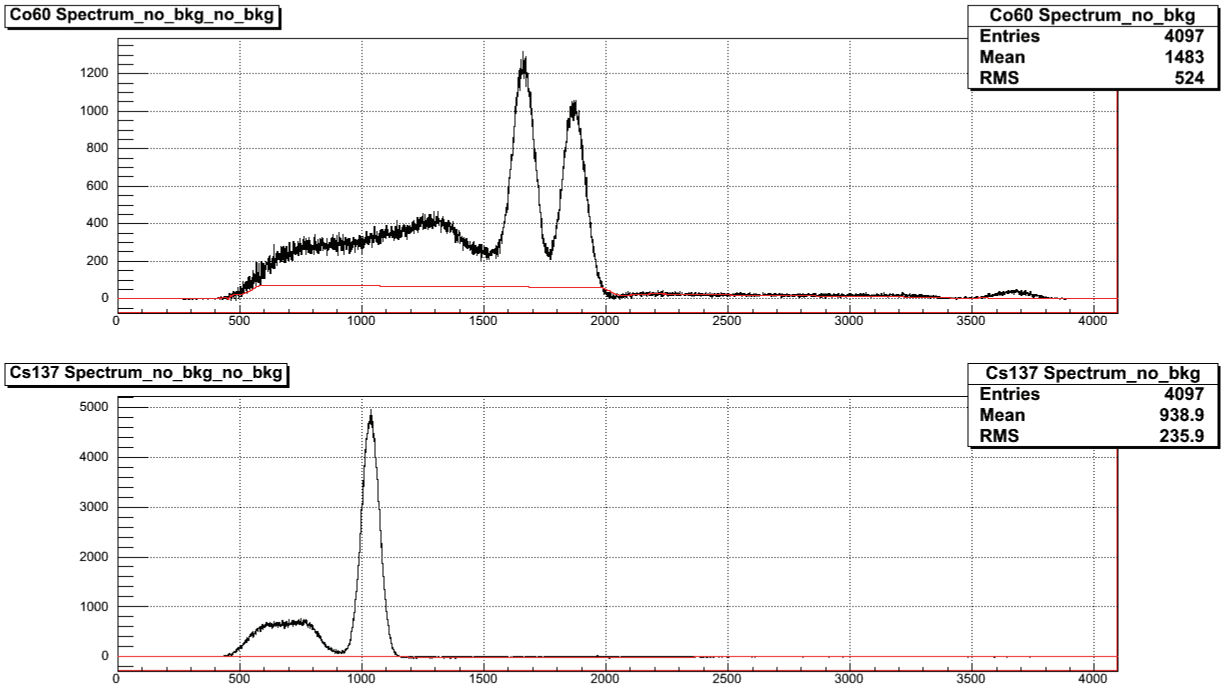

Fig. 7: V792N - ^{60}Co and ^{137}Cs spectra after background subtraction (black) and software evaluated background (red)

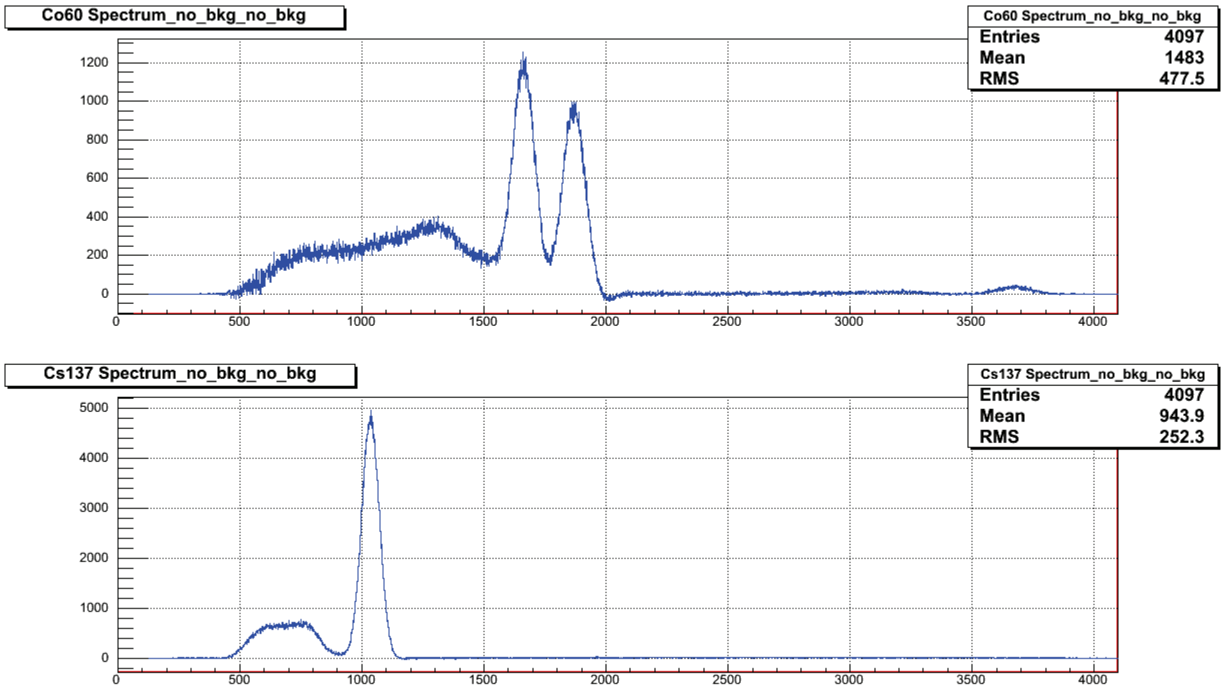

Fig. 8: V792N - ^{60}Co and ^{137}Cs spectra after the software evaluated background subtraction

Measures: Digital Pulse Processing – Charge Integration

Equipment used from CAEN

- N1470 4 Channel Programmable HV Power Supply
- V1720 8 Channel 12bit 250 MS/s Digitizer with DPP CI

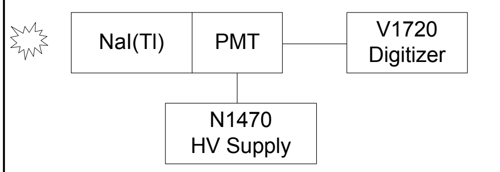

Fig. 9: Digital QDC Chain

Other equipment used

- Oscilloscope
- NaI(Tl) Crystal and Photomultiplier Tube Assembly (9265KB)
- Photomultiplier Base (Voltage Divider)
- Spectrum Techniques RSS-5 Sealed Solid Disk Gamma Ray Sources ~1 μC ^{137}Cs, ^{60}Co

Sofware used

- CAEN DPP_CI_Runner
- ROOT data analysis framework (http://root.cern.ch/drupal/)

Equipment Setup

N1470 HV Supply: HV set at about the middle of the acceptable operating range, G ~ 5 10^4 (850 V)

V1720 – DPP CI: Trigger: Threshold = 27 LSB; Mean (a) = 256 ns; Rise Time (b) = 56 ns
Gate (Fixed): Gate width = 800 ns; Gate PreTrigger width = 80 ns; Holdoff width = 1.5 μs
Baseline: BSL Inhibit Threshold = 5 LSB; BSL Inhibit Width = 2.6 μs; BSL Mean = 2 μs

V1720 channel 0 was fed directly by the PMT output. CAEN DPP_CI_Runner was used to control the digitizer, i.e. to set parameters for data taking and DPP CI and to monitor the signals using the digitizer as oscilloscope. Once the parameters were set properly, the oscilloscope mode was disabled asking the DPP CI to store in memory only the energy, i.e. charge, values calculated in order to reach higher rates avoiding the memory to go full. Fig. 10 shows the waveforms used and calculated by DPP.

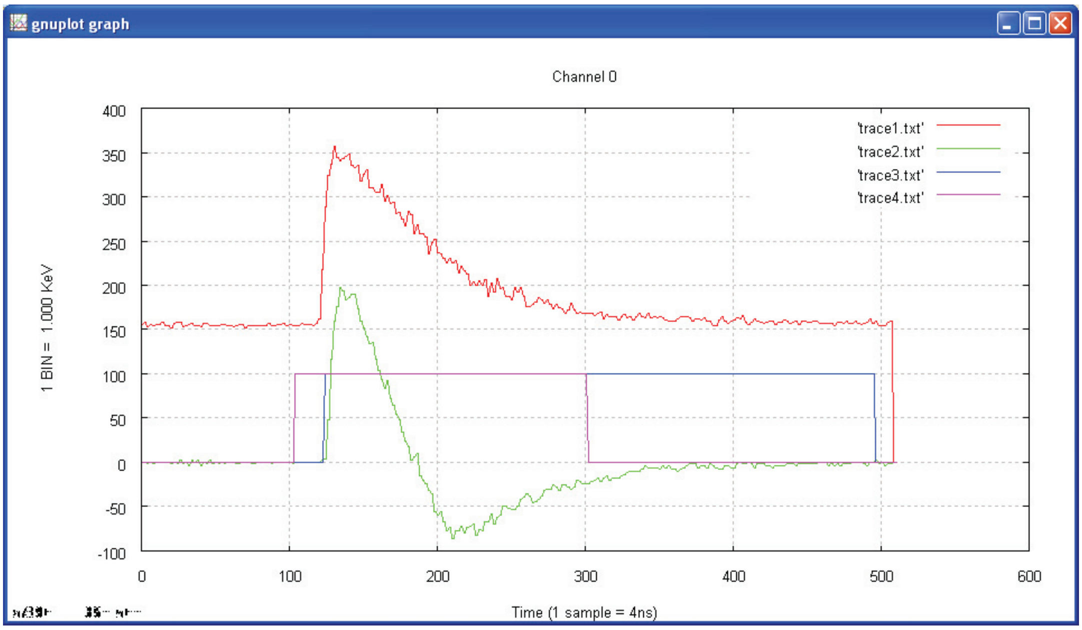

Fig. 10: V1720 – Red: inverted input; Green: delta signal (used in Trigger generation); Blue: Holdoff (Gate generation inhibit); Purple: Gate

Three spectra (^{137}Cs, ^{60}Co and background) were acquired as previously described for 15 minutes. The same ROOT script was used for data analysis.

In Fig. 11, 12, 13 the spectra are shown: raw, with the measured background spectrum subtracted and without the software evaluated background.

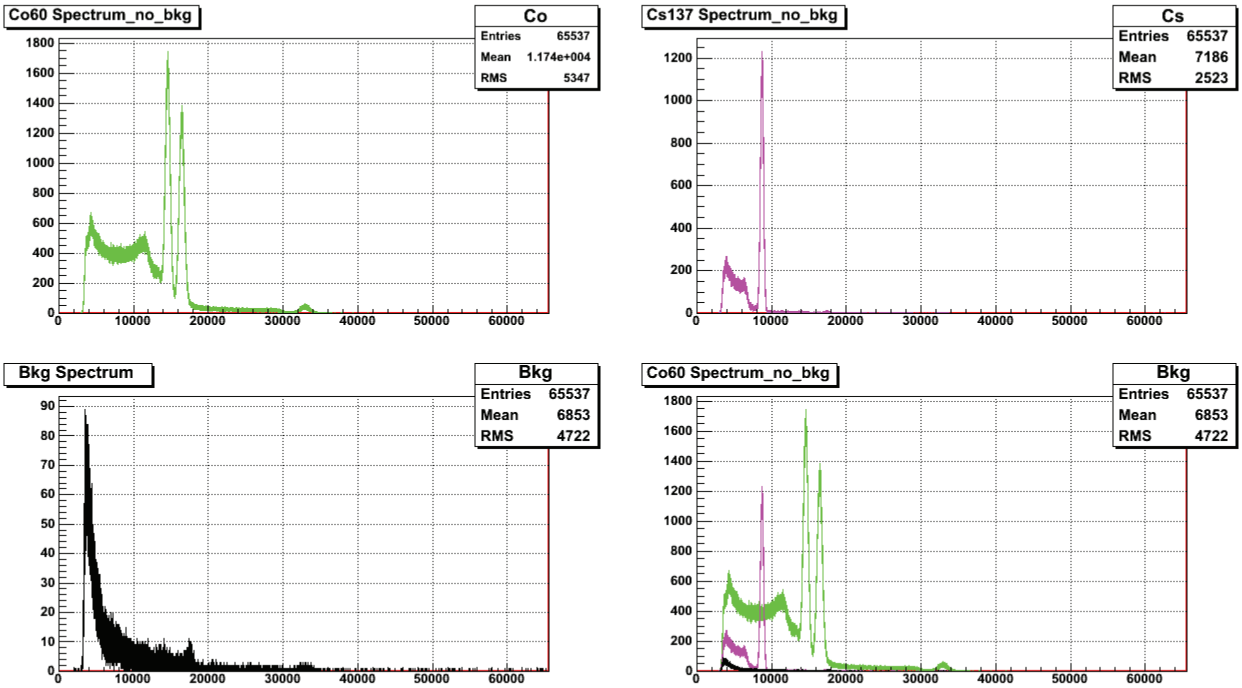

Fig. 11: V1720- Raw spectra

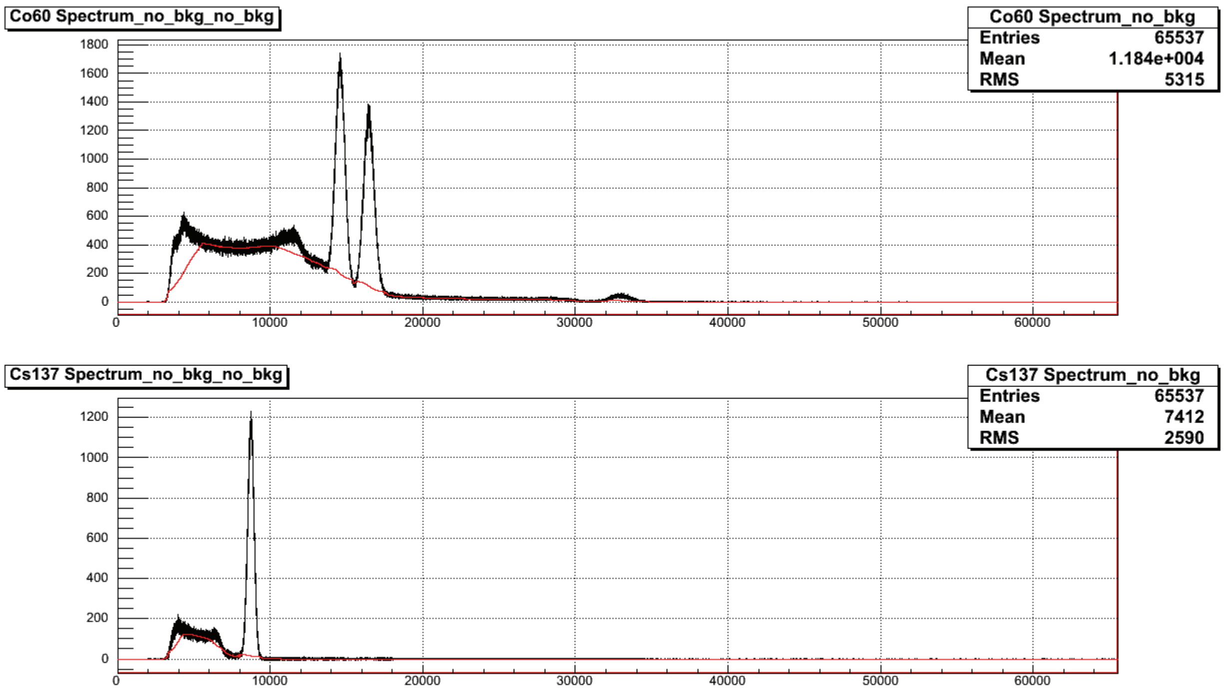

Fig. 12: V1720 - ^{60}Co and ^{137}Cs spectra after background subtraction (black) and software evaluated background (red)

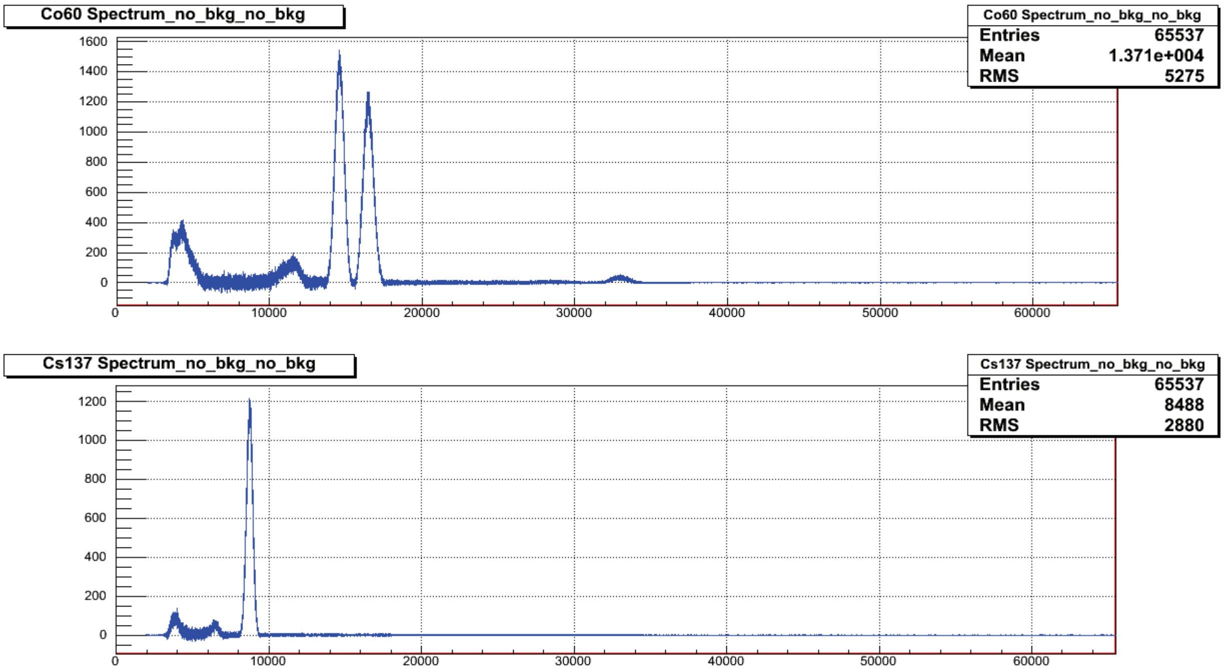

Fig. 13: V1720 - ^{60}Co and ^{137}Cs spectra after the software evaluated background subtraction

Results

Least squares fits were performed on the spectra with the software evaluated background subtracted using Gaussian functions. The fitted peaks were:

^{137}Cs

- 481 keV Compton edge
- 662 keV gamma ray emission peak

^{60}Co

- 1,17 MeV gamma ray emission peak
- 1,33 MeV gamma ray emission peak
- 2,51 MeV sum peak

The results are shown in Tab. 1, 2; Fig. 14 summarizes the results.

Energy (MeV)	Mean (channel)	σ (channel)	Resolution (FWHM*100/Mean)
0.481	763.2 ± 1.3	41.6 ± 0.7	12.8 ± 0.7
0.662	1036.0 ± 0.1	35.92 ± 0.06	8.17 ± 0.04
1.17	1661.4 ± 0.4	47.0 ± 0.4	6.66 ± 0.18
1.33	1868.0 ± 0.4	46.7 ± 0.3	5.89 ± 0.13
2.51	3671.9 ± 1.1	63.9 ± 1.3	4.1 ± 0.24

Tab. 1: V792N - Fit results

Energy (MeV)	Mean (channel)	σ (channel)	Resolution (FWHM*100/Mean)
0.481	4503±5	180±8	9.41±1.18
0.662	6737.1±0.4	200.4±0.4	7.01±0.04
1.17	12588.7±0.5	303.0±0.6	5.67±0.03
1.33	14471.7±0.5	340.8±0.5	5.546±0.024
2.51	30937±4	502±5	3.82±0.11

Tab. 2: V1720 - Fit results

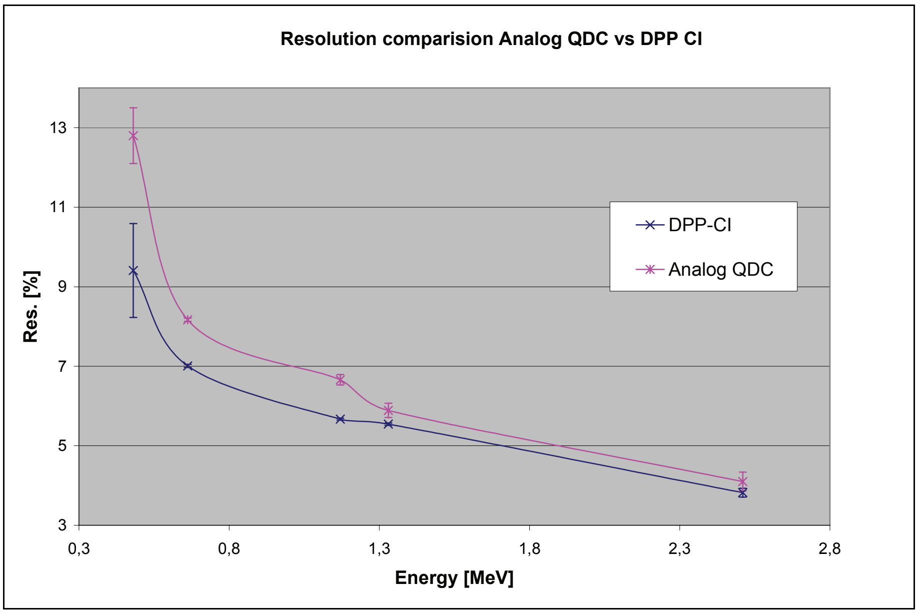

Fig. 14: Resolutions of the V792 and V1720 based QDC chains

Conclusion

Two different acquisition chains for gamma ray spectroscopy were tested, one based on an analog V792N QDC and the other based on a V1720 digitizer with a charge integrating DPP. Two different gamma ray sources were used in order to compare the energy resolutions of the two setups, ^{137}Cs and ^{60}Co.

The preliminary results seems to highlight the better energy resolution of V1720 with DPP CI than the V792N one, especially considering the three gamma ray emission peaks (^{137}Cs – 0.662 MeV, ^{60}Co – 1,17 1,33 MeV) whose shape and high statistics minimize fit uncertainties.

References

[1] C. Tintori, WP2081 Digital Pulse Processing in Nuclear Physics CAEN White Paper.

CAEN
Tools for Discovery

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