



**CAEN**  **Electronic Instrumentation**



**CAEN** MC<sup>2</sup>Analyzer

User Manual UM3182

## MC<sup>2</sup>Analyzer User Manual

Software for digital Multi Channel Analyzer

Rev. 1 - 26 January 2015

## Purpose of this Manual

This User Manual contains the full description of the MC<sup>2</sup>Analyzer software for CAEN 724 digitizer series, 730 digitizer series, DT5780 and DT5781 (N6781) Multi Channel Analyzer. The description is compliant with DPP-PHA firmware release **4.5\_128.30** for 724, DT5780 and DT5781 series, firmware release **4.5\_139.01** for 730 series, and MC<sup>2</sup>Analyzer software release **1.0.3**. For future release compatibility check the firmware and software revision history files.

## Change Document Record

Date	Revision	Changes
14 April 2014	00	Initial release
26 January 2015	01	Added support to 730 and 781 series. Fully revised the Principle of Operation Chapter. Added Quick Start Guide, and Appendices.

## Symbols, abbreviated terms and notation

ADC	Analog to Digital Converter
CSP	Charge Sensitive Preamplifier
DAQ	Data Acquisition
DPHA	Digital Pulse Height Analyser
DPP	Digital Pulse Processing
DPP-CI	DPP for Charge Integration
DPP-PHA	DPP for Pulse Height Analysis
DPP-PSD	DPP for Pulse Shape Discrimination
HPGe	High Purity Germanium
MCA	Multi-Channel Analyser
OS	Operating System
PC	Personal Computer
PHA	Pulse Height Analysis
PMT	Photo Multiplier Tube
TTF	Trigger and Timing Filter
USB	Universal Serial Bus

## Reference Documents

[RD1] Jordanov, V.T. et al., Nuclear Instruments and Methods A **353** (1994) 337-345

[RD2] UM2606 – DT5780 Digital MCA

[RD3] GD2783 – First Installation Guide to Desktop Digitizers & MCA

[RD4] M.Morhac et al.: Identification of peaks in multidimensional coincidence gamma-ray spectra. Nuclear Instruments and Methods in Research Physics A 443(2000), 108-125.

[RD5] GD2827 - How to make coincidences with CAEN digitizers

[RD6] AN2086 - Synchronization of a multi-board acquisition system with CAEN digitizers

[RD7] UM1935 - CAENDigitizer User & Reference Manual

All documents can be downloaded from: <http://www.caen.it/csite/LibrarySearch.jsp>

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# 1 Introduction

Nuclear radiation detectors are able to generate electronic pulses containing information on the nuclear radiation that interacted with them. Depending from the radiation and detector types, the relevant information can be contained in the shape of the pulse (i.e. a Pulse Shape discrimination is possible between neutrons and gammas in a detector sensitive to both radiations, by looking at the shape of the corresponding pulses), in some timing information (i.e. arrival of the pulse compared to a reference starting time " $T_0$ ", as in Time Of Flight detectors measurements or in Position Sensitive Detectors). A major information concerning the radiation energy can be obtained by the measurement of the *pulse height*, for those detectors where the relationship between incident radiation energy and detector output pulse height can be re-conducted to direct proportionality (if needed through a calibration curve). For example, a radio-isotopic source emits gamma radiations of different energies and the corresponding different heights of the pulses at the output of the detector can be histogrammed during the counting time.

The Multi-Channel Analyzer (MC<sup>2</sup>Analyzer) software has been designed as a user friendly interface to manage the acquisition with pulse height algorithms. Indeed MC<sup>2</sup>Analyzer puts the acquisition power of the fast digitizers, such as CAEN DT5780 at the fingertips of users concerned with the acquisition of energy spectra from one up to multiple channels of nuclear radiation detectors systems. The selected format recalls the familiar operation of a conventional analog Nuclear Multi Channel Analyzer, although with some differences which will be described in this manual.

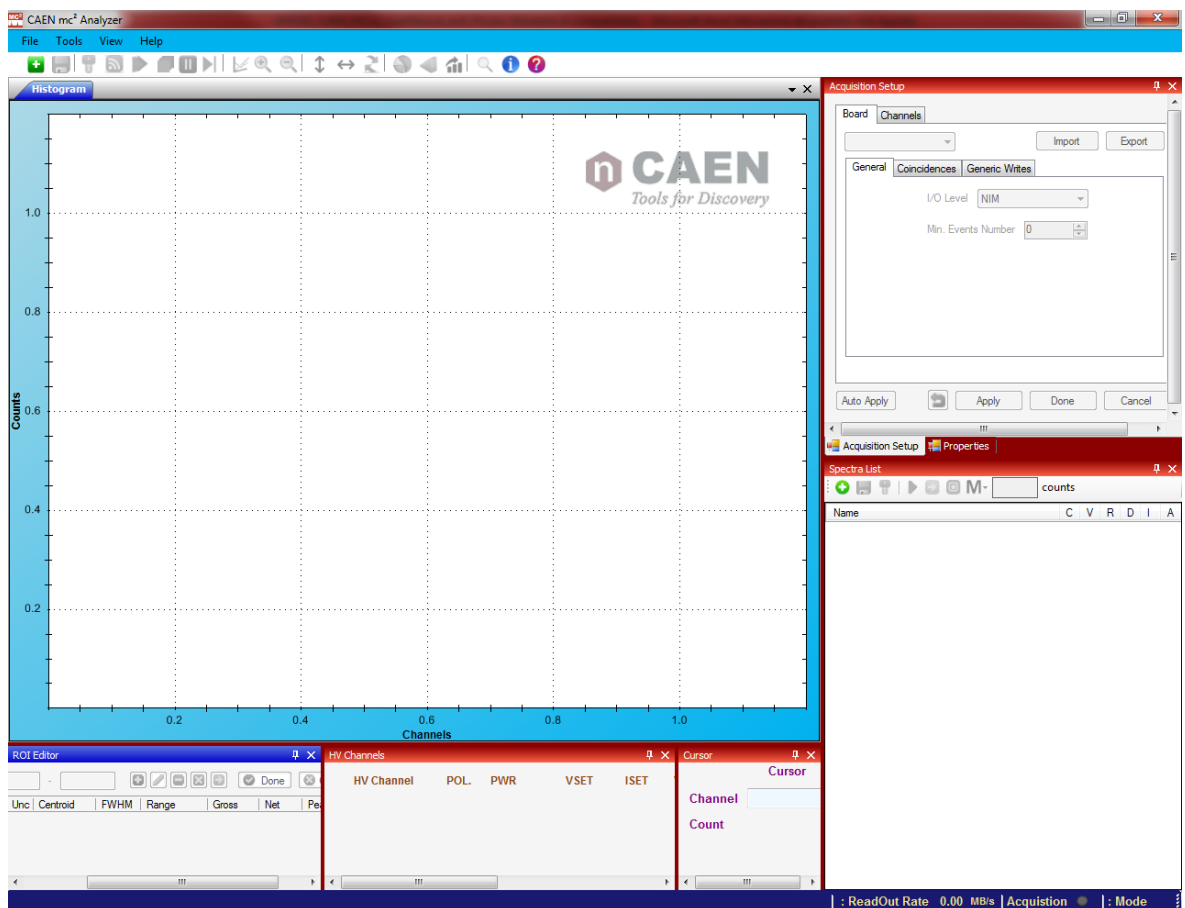


Fig. 1.1: MC<sup>2</sup>Analyzer main screen



The MC<sup>2</sup>Analyzer Software supports the CAEN DT5780 and DT5781 (N6781) MCA Series, as well as the 724 and 730 digitizer families equipped with the DPP-PHA (Digital Pulse Processing for Pulse Height Analysis) firmware. The complete list of supported digitizers is shown in **Tab. 1.1**.

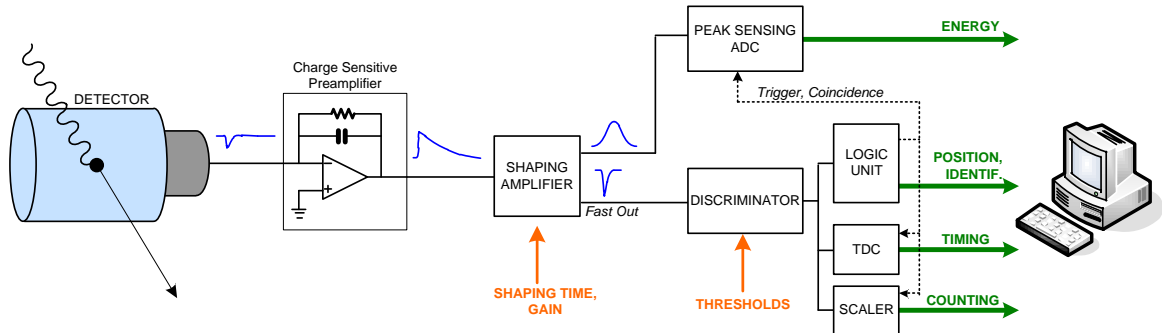
Desktop Digitizers(*)	Description	Product Code
DT5724	4 Ch. 14 bit 100 MS/s Digitizer: 512kS/ch, C4, SE	WDT5724XAAAA
DT5724A	2 Ch. 14 bit 100 MS/s Digitizer: 512kS/ch, C4, SE	WDT5724AXAAA
DT5724D	4 Ch. 14 bit 100 MS/s Digitizer: 4MS/ch, C4, SE	WDT5724DXAAA
DT5724E	2 Ch. 14 bit 100 MS/s Digitizer: 4MS/ch, C4, SE	WDT5724EXAAA
DT5730	8 Ch. 14 bit 500 MS/s Digitizer: 640kS/ch, CE30, SE	WDT5730XAAAA
DT5730B	8 Ch. 14 bit 500 MS/s Digitizer: 5.12MS/ch, CE30, SE	WDT5730BXAAA
DT5780M	2 Channel Digital MCA - Mixed HV (5kV/300uA)	WDT5780XMAAA
DT5780N	2 Channel Digital MCA - Negative HV (5kV/300uA)	WDT5780XNAAA
DT5780P	2 Channel Digital MCA - Positive HV (5kV/300uA)	WDT5780XPAAA
DT5780SDM	2 Channel Digital MCA - Mixed HV (500V/3mA)	WDT5780SDXMA
DT5780SDN	2 Channel Digital MCA - Negative HV (500V/3mA)	WDT5780SDXNA
DT5780SDP	2 Channel Digital MCA - Positive HV (500V/3mA)	WDT5780SDXPA
DT5781	Quad Digital MCA	WDT5781XAAAA
DT5781A	Dual Digital MCA	WDT5781AXAAA
NIM Digitizers(*)	Description	Product Code
N6724	4 Ch. 14 bit 100 MS/s Digitizer: 512kS/ch, C4, SE	WN6724XAAAAA
N6724A	2 Ch. 14 bit 100 MS/s Digitizer: 512kS/ch, C4, SE	WN6724AXAAAA
N6730	8 Ch. 14 bit 500 MS/s Digitizer: 640kS/ch, CE30, SE	WN6730XAAAAA
N6730B	8 Ch. 14 bit 500 MS/s Digitizer: 5.12MS/ch, CE30, SE	WN6730BXAAAA
N6781	Quad Digital MCA	WN6781XAAAAA
N6781A	Dual Digital MCA	WN6781AXAAAA
VME Digitizers(*)	Description	Product Code
V1724	8 Ch. 14 bit 100 MS/s Digitizer: 512kS/ch, C4, SE	WV1724XAAAAA
V1724B	8 Ch. 14 bit 100 MS/s Digitizer: 4MS/ch, C4, SE	WV1724BXAAAA
V1724C	8 Ch. 14 bit 100 MS/s Digitizer: 512kS/ch, C4, DIFF	WV1724CXAAAA
V1724D	8 Ch. 14 bit 100 MS/s Digitizer: 4MS/ch, C4, DIFF	WV1724DXAAAA
V1724E	8 Ch. 14 bit 100 MS/s Digitizer: 4MS/ch, C20, SE	WV1724EXAAAA
V1724F	8 Ch. 14 bit 100 MS/s Digitizer: 4MS/ch, C20, DIFF	WV1724FXAAAA
V1724G	8 Ch. 14 bit 100 MS/s Digitizer: 512kS/ch, C20, SE	WV1724GXAAAA
V1730	16 Ch. 14 bit 500 MS/s Digitizer: 640kS/ch, CE30, SE	WV1730XAAAAA
V1730B	16 Ch. 14 bit 500 MS/s Digitizer: 5.12MS/ch, CE30, SE	WV1730BXAAAA
V1730C	8 Ch. 14 bit 500 MS/s Digitizer: 640kS/ch, CE30, SE	WV1730CXAAAA
V1730D	8 Ch. 14 bit 500 MS/s Digitizer: 5.12MS/ch, CE30, SE	WV1730DXAAAA
VX1724	8 Ch. 14 bit 100 MS/s Digitizer: 512kS/ch, C4, SE	WVX1724XAAAA
VX1724B	8 Ch. 14 bit 100 MS/s Digitizer: 4MS/ch, C4, SE	WVX1724BXAAA
VX1724C	8 Ch. 14 bit 100 MS/s Digitizer: 512kS/ch, C4, DIFF	WVX1724CXAAA
VX1724D	8 Ch. 14 bit 100 MS/s Digitizer: 4MS/ch, C4, DIFF	WVX1724DXAAA
VX1724E	8 Ch. 14 bit 100 MS/s Digitizer: 4MS/ch, C20, SE	WVX1724EXAAA
VX1724F	8 Ch. 14 bit 100 MS/s Digitizer: 4MS/ch, C20, DIFF	WVX1724FXAAA
VX1730	16 Ch. 14 bit 500 MS/s Digitizer: 640kS/ch, CE30, SE	WVX1730XAAAA
VX1730B	16 Ch. 14 bit 500 MS/s Digitizer: 5.12MS/ch, CE30, SE	WVX1730BXAAA
VX1730C	8 Ch. 14 bit 500 MS/s Digitizer: 640kS/ch, CE30, SE	WVX1730CXAAA
VX1730D	8 Ch. 14 bit 500 MS/s Digitizer: 5.12MS/ch, CE30, SE	WVX1730DXAAA
DPP Firmware(*)	Description	Product Code
DPP-PHA (x724,x780,x781)	Digital Pulse Processing for Pulse Height Analysis (x724,x780,x781)	WFWDPPPTFAAAA
DPP-PHA (x730)	Digital Pulse Processing for Pulse Height Analysis (x730)	WFWDPPPTFAA30

**Tab. 1.1:** Supported CAEN digitizers for DPP-PHA firmware

(\*) For accessories and customizations related to digitizers and for multiple DPP-PHA license packs, refer to the board User Manual or have a look at the board page on CAEN web site: [www.caen.it](http://www.caen.it)

## 2 Principle of Operation

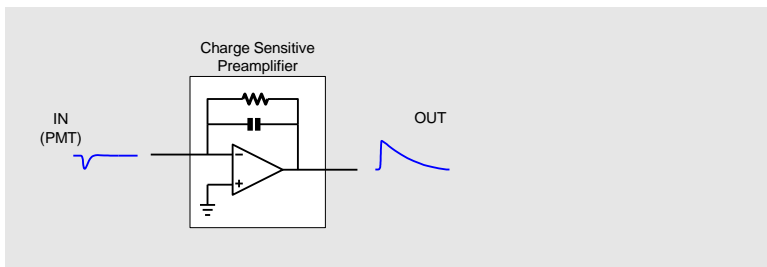
### Traditional Analog Approach



**Fig. 2.1:** Nuclear Radiation Detector (with Charge Sensitive Preamplifier) Analog Chain Block Diagram

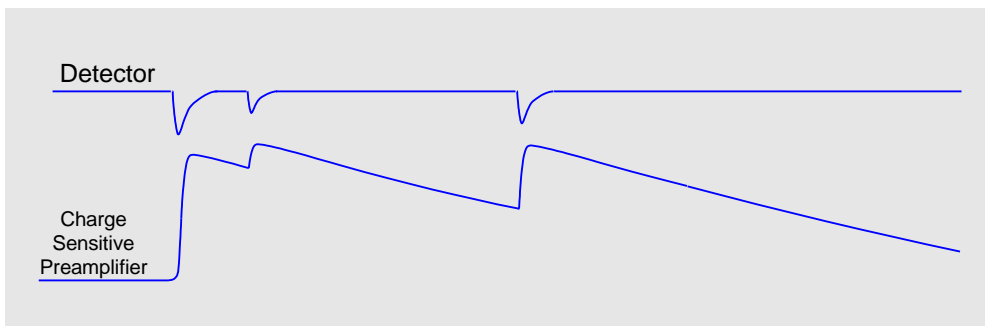
The traditional analog chain for signal readout from nuclear radiation detector usually makes use of almost all-analog chains, where the electronics rely upon three fundamental devices: the Charge Sensitive Preamplifier, the Shaping Amplifier and the Peak Sensing ADC (refer to **Fig. 2.1**).

The Charge Sensitive Preamplifier (**Fig. 2.2**) integrates the signal coming from the detector, as the HPGe, thus converting the collected charge into a voltage step. The integrating capacitor is put in parallel with a discharging resistor, so that the preamplifier output will have pulses with a fast rise time and a long exponential tail with decay time  $\tau$ . The charge information (proportional to the energy released by the particle in the detector) is therefore represented by the pulse height. The charge-amplitude proportionality is set by the capacitor value  $V_{out} = \frac{Q}{C}$  and the decay time of the output signal is  $\tau = RC$ .



**Fig. 2.2:** Simplified schematic of a RC-type Charge Sensitive Preamplifier

In order to have a good charge-amplitude conversion and to minimize the noise, the decay time  $\tau$  is much larger than the width of the detector signal, typically 50-100  $\mu\text{s}$ , and for this reason pile-up of different particle detections can arise (**Fig. 2.3**).



**Fig. 2.3:** Pile-up of detector signals due to the large decay time of the Preamplifier output

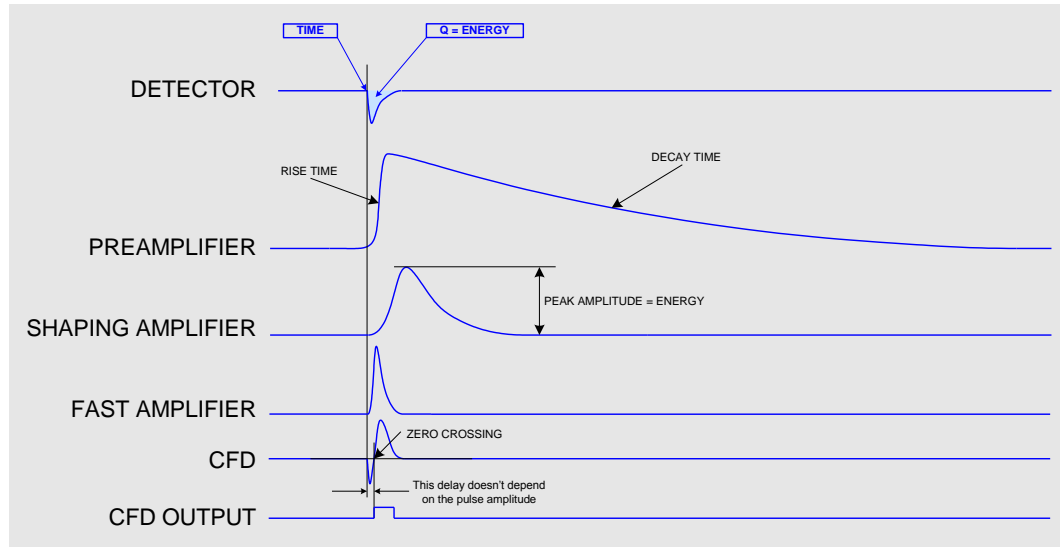
Another drawback when using a Charge Sensitive Preamplifier is when the peak is too sharp for the Peak Sensing ADC to be detected with the required precision.

To avoid these problems the pre-amplified signal is usually feed into a Shaping Amplifier, that provides out a quasi-Gaussian output whose height is still proportional to the energy released by the detected particle.

Finally, the signal from the Shaping Amplifier is fed into a Peak Sensing ADC, which is able to evaluate and digitize the height of the pulses, and filling a histogram with these values, which corresponds to the *energy spectrum*.

In order to preserve the timing information, the fast component of the signal (rising edge) is usually treated by a Fast Amplifier (or Timing Amplifier) that derivates the signal; the output of the fast amplifier usually feeds a chain made out of a Discriminator (CFD), a TDC and/or a Scaler for the timing/counting acquisition. Further modules can be present in order to implement logic units, to make coincidences (giving the position and the trajectory of the particles), to generate triggers or to give information about the pulse shape (time over threshold, zero crossing, etc.) for the particles identification. Usually the Fast Amplifier is included into the Shaping Amplifier module and the relevant signal is provided as a separate fast output (or timing output).

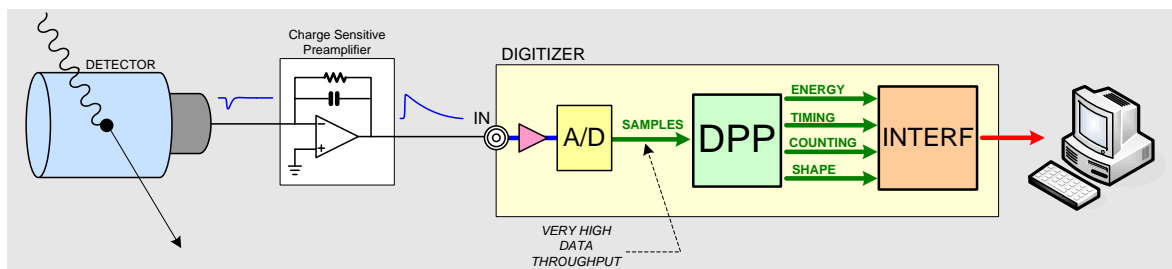
The typical signal shapes from the analog chain is shown in **Fig. 2.4**.



**Fig. 2.4:** Signals in the traditional analog chain

## CAEN Digital Approach

In the CAEN digital approach all blocks from the shaping amplifier to the PC are synthesized into a single device, the digitizer (see Fig. 2.5).

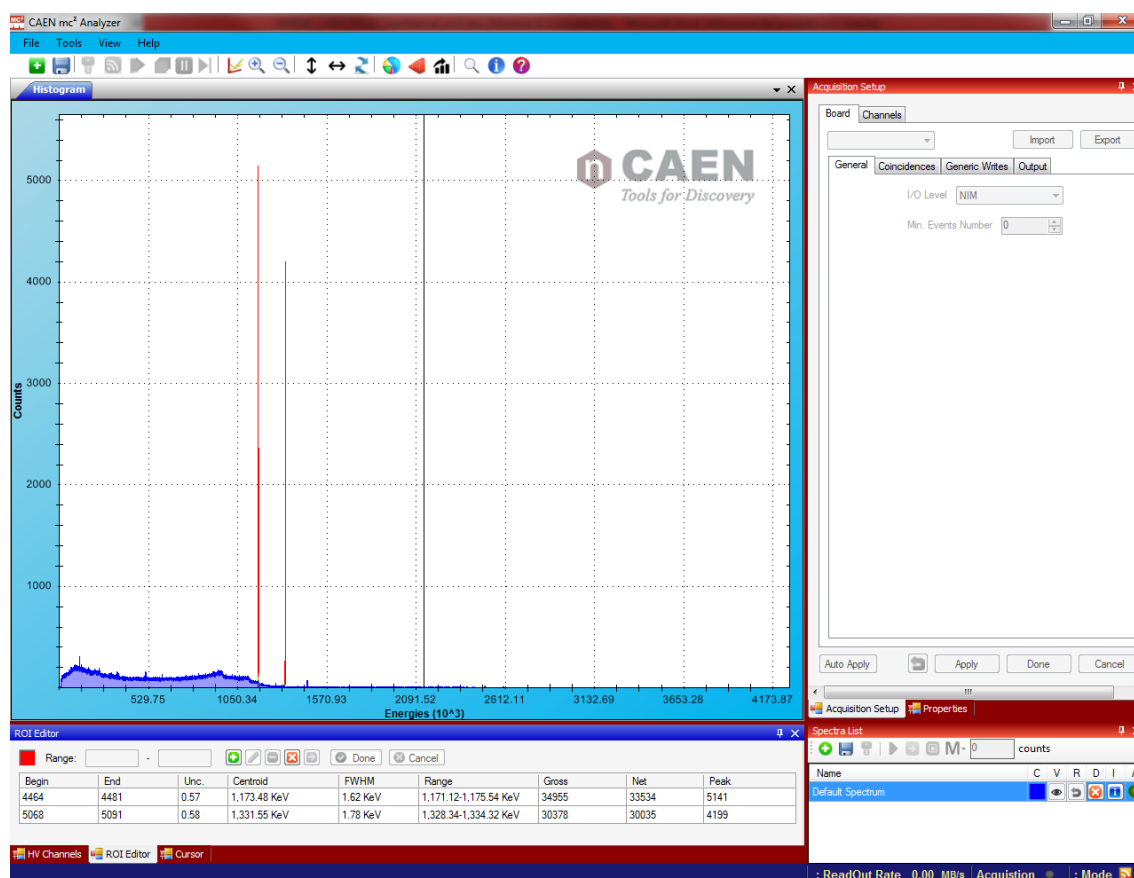


**Fig. 2.5:** Block Diagram of a Digitizer-based Spectroscopy System

Indeed the new FPGA based techniques allow the user to change the readout parameters according to the detector characteristics, thus enabling the measurement of different radiations with different detectors using the same hardware. The digitizer becomes itself a Digital Multi Channel Analyzer (MCA).

In the technique called Multi Channel Analysis the energy spectrum histogram X- axis can be segmented in “bins” or “Channels”, each one representing a pulse height value, in V (or, if calibrated, the corresponding radiation Energy in Kev). The maximum number of available “bins” or “channels” is dictated by the resolution of the ADC. A 14-bit (1:16384) ADC resolution allows a 16 K “Channels” Spectrum to be generated. The spectrum resolution should be matched with the detector Energy resolution for optimal results (i.e. a 1K Channels Spectrum is good enough of basic gamma spectroscopy with NaI detectors while at least an 8K Channels Spectrum is needed to appreciate the intrinsic Energy resolution of HPGe Detectors). The histogram Y-axis values indicate the number of counts accumulated during the measuring time in the corresponding x-axis “bin” or “Channel”.

**Fig. 2.6** shows an example of a typical spectrum of a  $^{60}\text{Co}$  source from HPGe detector, acquired with a DT5780 and the MC<sup>2</sup>Analyzer software.



**Fig. 2.6:**  $^{60}\text{Co}$  energy spectrum from HPGe detector

The algorithm implemented in the digitizer FPGA is based on the Jordanov trapezoidal filter [RD1] and it is called DPP-PHA (Digital Pulse Processing for Pulse Height Analysis). The trapezoidal filter is a filter able to transform the typical exponential decay signal generated by a charge sensitive preamplifier into a trapezoid whose flat top height is proportional to the amplitude of the input pulse (that is to the energy released by the particle in the detector) (see Fig. 2.7). This trapezoid plays almost the same role of the shaping amplifier in a traditional analog acquisition system. There is an analogy between the two systems: both have a “shaping time” constant and must be calibrated for the pole-zero cancellation. For both, a long shaping time gives a better resolution but has higher probability of pile-up. Both are AC coupled with respect to the output of the preamplifier whose baseline is hence removed, but both have their own output DC offset and this constitutes another baseline for the peak detection.

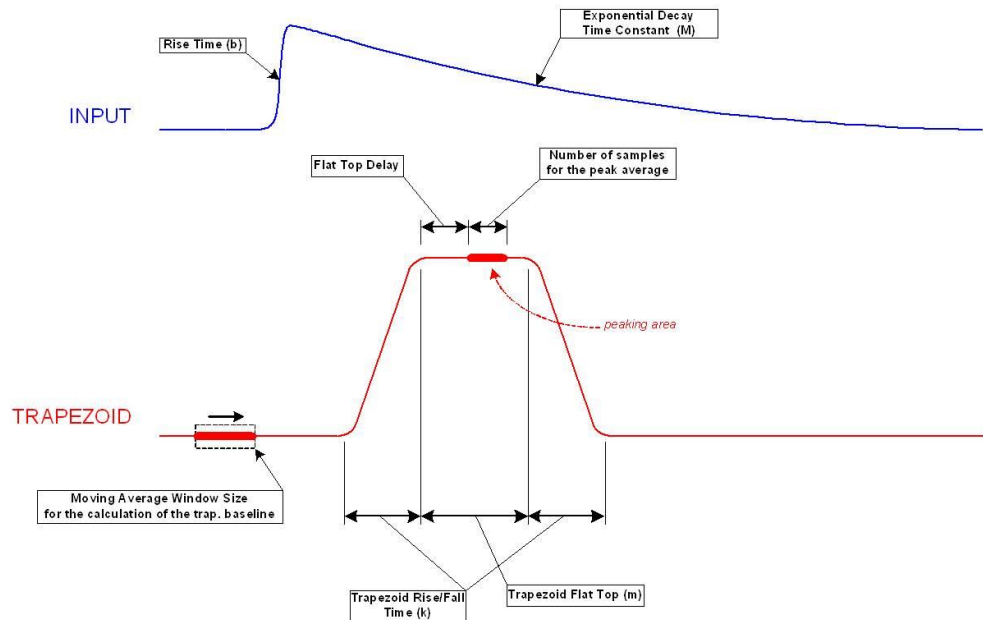


Fig. 2.7: Pulse Height Analysis with Trapezoid Method

The block diagram of the processing chain inside the digitizer FPGA is shown in Fig. 2.8.

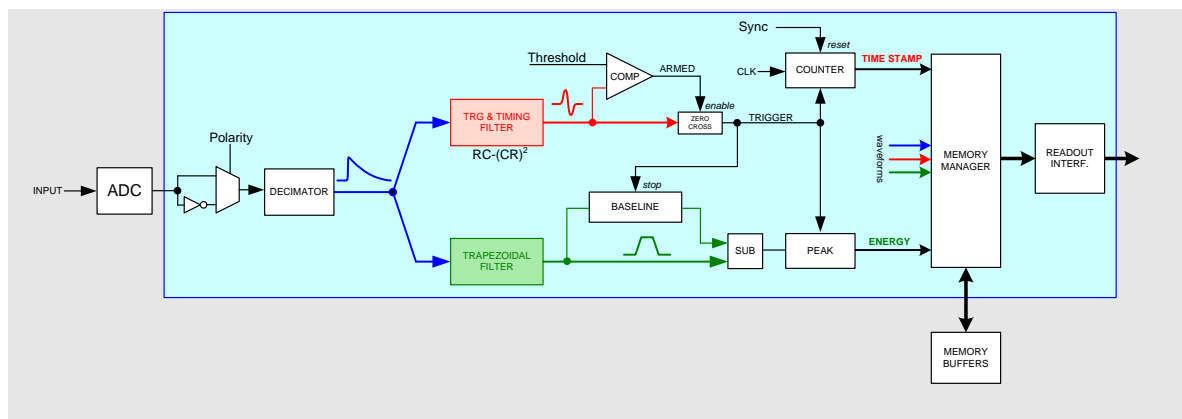


Fig. 2.8: Block Diagram of the processing chain programmed into the Digitizer's FPGA

## Decimator

The first block after the polarity selector is the decimator filter; this can be used in the case the signal is particularly slow, hence it is necessary to set values for the DPP time parameters that are not within the allowed range. The effect of the decimator is to scale down the sampling frequency of a factor 2, 4 or 8; it might have also benefits in terms of noise, since it averages a certain number of samples to make a new sample for the data stream.

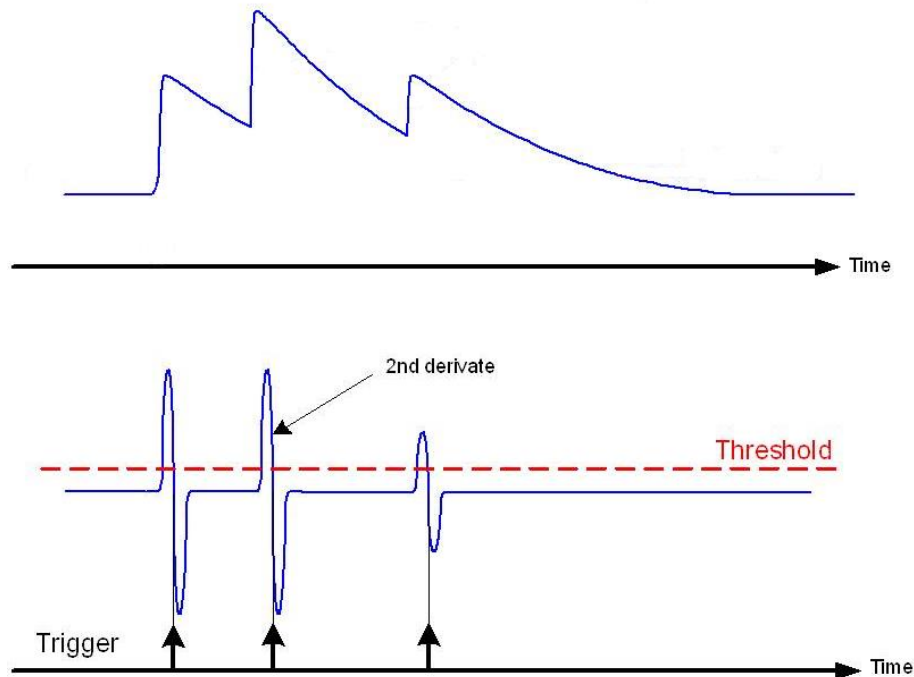


**Note:** The decimation is not yet supported for 730 digitizer series.

### Trigger and Timing Filter

After the decimator, there are two parallel branches: one for timing and triggering, the other one for the energy. The aim of the Trigger and Timing Filter is to identify the input pulses, generate a trigger on them and calculate the time of trigger firing (*trigger time stamp*).

The TTF performs a digital RC-CR<sup>2</sup> filter, whose zero crossing corresponds to the trigger time stamp. In analogy with a CFD – Constant Fraction Discrimination – the RC-CR<sup>2</sup> signal is bipolar and its zero crossing is independent of the pulse amplitude. The integrative component of the RC-CR<sup>2</sup> is a smoothing filter based on a moving average filter that reduces the high frequency noise and prevent the trigger logic to generate false triggers on spikes or fast fluctuation of the signals. The derivative component allows to subtract the baseline, so that the trigger threshold is not affected by the low frequency fluctuation. Moreover the pile up effect is significantly reduced.



**Fig. 2.9:** Triggering on 2<sup>nd</sup> Derivative

The trigger logic gets armed at the **Threshold** crossing, then it generates the trigger signal at the RC-CR<sup>2</sup> zero crossing. Setting the threshold value corresponds to set the LLD (lower level discrimination) of the energy spectrum. The user can check from the histogram which value corresponds to the set threshold level. Refer to Sect. **How to set the Trigger** for further details on how to set the threshold.

Another important parameter for the trigger logic is the **RC-CR<sup>2</sup> smoothing**, corresponding to the number of samples used for the RC-CR<sup>2</sup> signal formation. Increasing this parameter may help in reducing high frequency noise.

Finally the **Input Rise Time** is the time the RC-CR<sup>2</sup> reaches its maximum value. This value should correspond to the input rise time, in such a way the RC-CR<sup>2</sup> peak value corresponds to the height of the input signal. Examples on how to proper set the trigger and timing filter can be found in Sect. **How to set the Trigger**.

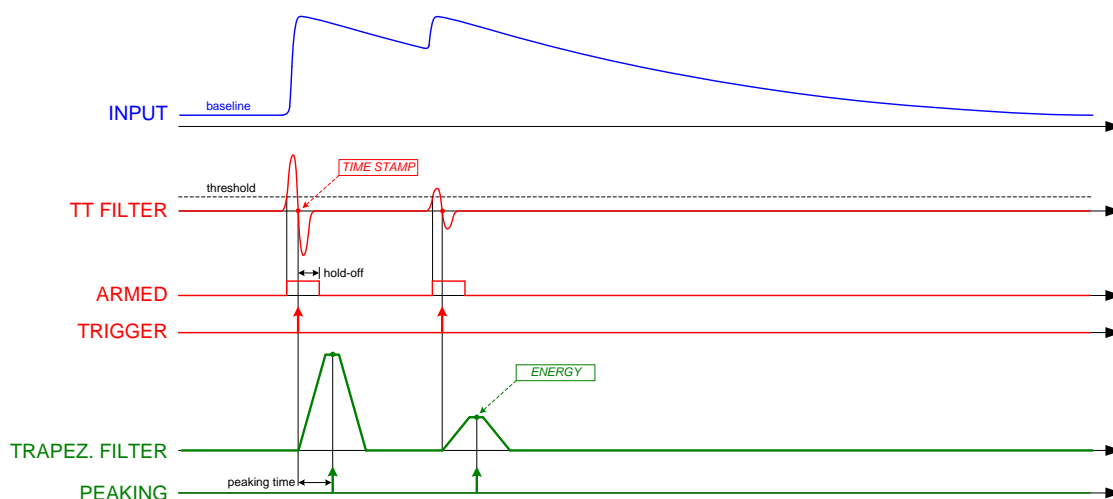
### Trapezoidal Filter (Energy Filter)

As in the traditional analog chain the Shaping Amplifier is able to convert the exponential shape from the Charge Sensitive Preamplifier into a Gaussian shape whose height is proportional to the pulse energy, in the same way the Trapezoidal filter is able to transform it into a trapezoidal signal whose amplitude is proportional to the input pulse height (energy). In this analogy the **Trapezoid Rise Time** corresponds to the Shaping Time times a factor of 2/2.5. Therefore for an analogic shaping of 3us the user can set a trapezoid rise time of 7-8 us (see also Sect. **How to set the Energy Filter and Acquisition Setup**).

In case of high rate signal the trapezoid rise time value should be reduced in order to avoid pile-up effects (see Sect. **Pile-up Rejection**), choosing a compromise between high resolution (high value of trapezoid rise time) and pile-up rejection (and corresponding dead time).

The energy value is evaluated in the **Flat Top** region of the trapezoid. The user must take that the flat top is really flat and that the **Peaking** (i.e. the samples used for the energy calculation) is in the flat region. Moreover the correct setting of flat top and peaking helps in the correct evaluation of the energy especially when large volume detectors are involved and the ballistic deficit may cause a significant error in the energy calculation. In this case it may be convenient to increase the flat top duration and delay the peaking time to wait for the full charge collection.

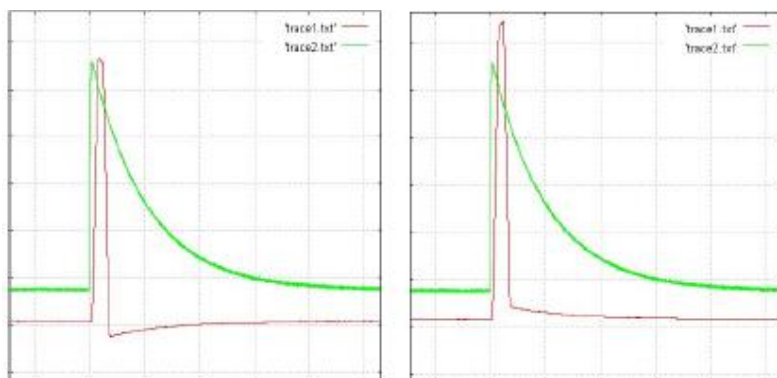
**Fig. 2.10** summarizes the settings for both the Trigger and Timing Filter and for the Trapezoid Filter.



**Fig. 2.10:** Simplified signals scheme of the Trigger and Timing filter (red) and the Trapezoidal Filter (green). In blue the input pulses from Preamplifier

### Pole-Zero Cancellation

Like the Gaussian pulse of the Shaping Amplifier, also the trapezoid requires an accurate pole-zero cancellation in order to guarantee the correct return to the baseline at the end of the falling edge. To correctly set the pole-zero cancellation the user must take care of setting the proper **Trapezoid Decay Time** (which corresponds also to the Input Decay Time value) to avoid either undershoot or overshoot effects (as can be seen in **Fig. 2.11**). Pole Zero Cancellation can reduce the signal artifacts due to pulses pile up occurring when the counting rate is high compared to the pulse decay.



**Fig. 2.11:** Pole Zero effects of undershoot (left) and overshoot (right) of the trapezoid (red curve)

### Baseline Restoration

The energy filter includes also a baseline restorer; this operates on the trapezoidal filter output and calculates the baseline by averaging a programmable number of points before the start of the trapezoid. The baseline is then frozen during the ramp up and used in the height calculation. Once the trapezoid is returned to the baseline (ramp down), the averaging restarts to run.

The pulse height (i.e. the trapezoid amplitude) is given by the distance between the flat top and the baseline taken in the programmed position; in order to further reduce the fluctuation of this distance due to the noise, it is possible to average a certain number of points in the flat top before subtracting the baseline.

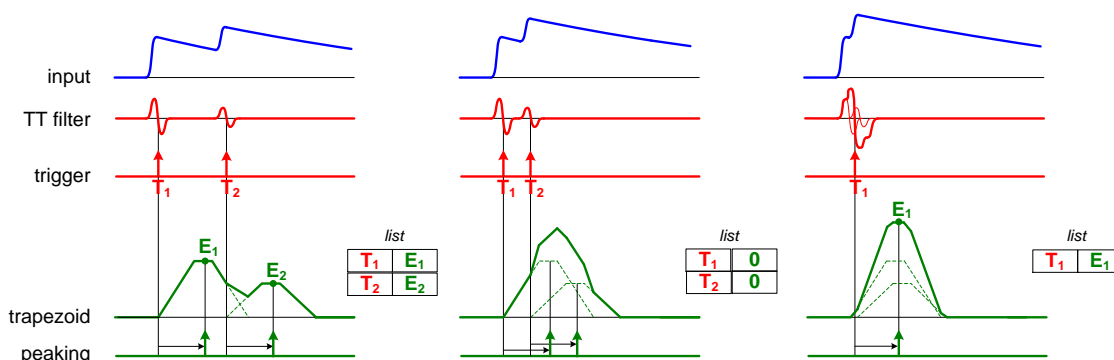
In case of high resolution measurements it is strongly suggested to increase the number of **Baseline Mean** samples at the maximum allowed value. Furthermore the user can also set the **Baseline Hold-Off** value to freeze the baseline calculation beyond the trapezoid end, thus reducing the noise on the baseline calculation. In case of high rate those values have to be reduced in order to avoid pile-up effects.



## Pile-up Rejection

If two pulses are separated by less than the trapezoid duration ( $2 \text{ times the Trapezoid Rise Time (TR) + the Trapezoid Flat Top (T}_F\text{)}$ ), then the relevant trapezoids overlap. There are three different cases (**Fig. 2.12**):

1. the rising edge of the 2<sup>nd</sup> trapezoid overlaps the falling edge of the 1<sup>st</sup> one ( $T_R + T_F < \Delta T < 2T_R + T_F$ ); in this case, the amplitude of both trapezoids is not affected by the pile-up and the energy can be calculated for both them.
2. the 2<sup>nd</sup> trapezoid starts on the rising edge or on the flat top of the 1<sup>st</sup> one ( $\Delta T < T_{PK}$ ); in this case, the amplitude of both the trapezoid is corrupted and the relevant energies cannot be calculated. The firmware saves, in the time stamp and energy “list” of the board RAM, a zero value for the energy. The event can also be tagged as pile-up event (see bit “PU” in Sect. **Channel Aggregate Data Format for 724 series (DT5780 and DT5781)** and Channel Aggregate Data Format for 730 series).
3. The two pulses are too close and the trigger filter is unable to resolve the double pulse condition ( $\Delta T < \text{Input Pulse Rise Time}$ ). In this case, the pile-up cannot be recognized and the two pulses are treated as a single pulse. The algorithm returns only one time stamp and one energy, whose value corresponds to about the sum of the two energies (‘sum peak’ in the spectrum). The use of **Rise Time Discriminator** may increase the probability to detect and reject double pulses.



**Fig. 2.12:** The effect of trapezoids overlapping in three main cases: 1) The second trapezoid starts on the falling edge of the first one (left). 2) The second trapezoid starts on the rising edge ( $\Delta T < T_{PK}$ ) of the first one (center). 3) The second trapezoid starts on the rising edge of the first and  $\Delta T < TR$

Except for the case 3, the DPP-PHA algorithm is able to save into the memory buffer all the incoming events, including the piled-up pulses; for these pulses, only the time stamp is available, while the energy is meaningless. During the readout of the event list, these events won't be accumulated into the histograms (that are calculated in the software), although they participate to the total count, thus giving an accurate estimation of the activity (Input Count Rate). Furthermore, the energy spectrum can be corrected run-time by a statistical redistribution of the missed energies over the spectrum acquired within a specific time slot.

## Dead Time

When a pulse is processed by an analog chain block, the maximum read-out rate is limited by the need to complete the processing of the current pulse before being able to process a successive valid signal. When the processing time of a pulse is larger than the time interval before the arrival of the next pulse, the analog chain is “temporarily blind” and misses one or more successive pulses. Thus the actual live counting time is smaller than the total counting time, and the difference between total time and live counting time is indicated as “Dead time”.

The Digital MCA read out capability is rather independent from the ADC sampling time and processing speed than from the signal width, and in general allows for higher counting rates than the analog chain. The digital MCA dead time is also an information on the relationship between total measurement time and live counting time values.

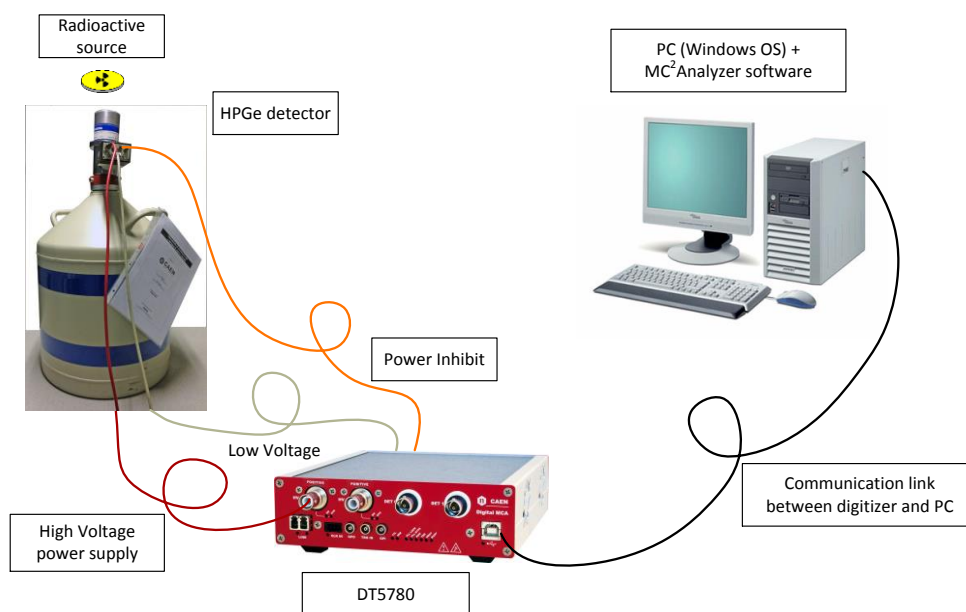
The MC<sup>2</sup>Analyzer software is able to automatically evaluate the dead-time including the contributions of pile-up events, dynamics saturation (see Sect. **Channel Aggregate Data Format for 724 series (DT5780 and DT5781)** and Channel Aggregate Data Format for 730 series), and Trigger Hold-Off. In the latter two cases the software evaluates the corresponding probability (Poisson Distribution) to take into account missing events during the board “blindness”.

## 3 Getting Started

### Hardware setup

We are going to describe a typical application of DPP-PHA algorithm and MC<sup>2</sup>Analyzer software for the characterization of HPGe detectors response in a measurement of resolution of the <sup>60</sup>Co source photo-peaks.

The high and low voltages are provided by the DT5780 which integrates in a single unit both the high voltage power supply, the low voltage, and the readout channels. A scheme of the hardware setup is shown on **Fig. 3.1**.



**Fig. 3.1:** Typical setup for resolution measurements using HPGe detectors and the digital MCA DT5780

Connect the SHV cable for the high voltage power supply to the HV0/HV1 connector of the DT5780. Connect the low voltage and the inhibit (if any) to the back panel connectors of the DT5780. Finally connect the digitizer to the PC with the preferred communication interface between USB and Optical link.

Refer to the DT5780 User Manual for further details about the connector of the digital MCA **[RD2]**.

## Software setup

### Drivers

In order to deal with the hardware, CAEN provides the drivers for all the different types of physical communication interfaces featured by the specific digitizer and compliant with Windows OS:

- **USB 2.0 Drivers for NIM/Desktop** boards are downloadable on CAEN website ([www.caen.it](http://www.caen.it)) in the “Software/Firmware” tab of the digitizer web page (**login required**).



**Note:** Windows OS USB driver installation for Desktop/NIM digitizers is detailed in [RD3].

- **USB 2.0 Drivers for V1718** CAEN Bridge, required for the VME boards interface, is downloadable on CAEN website ([www.caen.it](http://www.caen.it)) in the “Software/Firmware” tab of the V1718 web page (**login required**).



**Note:** For the installation of the V1718 USB driver, refer to the User Manual of the Bridge.

- **Optical Link Drivers** are managed by the A2818 PCI card or the A3818 PCIe card. The driver installation package is available on CAEN website in the “Software/Firmware” area at the A2818 or A3818 page (**login required**)



**Note:** For the installation of the Optical Link driver, refer to the User Manual of the specific Controller.

### Libraries

The MC2Analyzer software relies in the following additional set of C libraries which are embedded into the software **setup**. The user does not need to install them aside, apart in the case he/she wants to write its own readout software:

- **CAENVMElib** is a set of ANSI C functions that allows the user to configure the CAEN Bridges V1718/VX1718 (VME-USB2.0 Bridge), V2718/VX2718 (VME-PCI Optical Link Bridge), and A2818/A3818 (PCI CONET Controller).

The CAENVMElib installation package is available on CAEN website ([www.caen.it](http://www.caen.it)) in the “Download” tab at:

*Home / Products / Firmware/Software / Software Tools / Software Libraries / CAENVMElib Library*

- **CAENComm** library manages the communication at low level (read and write access). The purpose of the CAENComm is to implement a common interface to the higher software layers, masking the details of the physical channel and its protocol, thus making the libraries and applications that rely on the CAENComm independent from the physical layer. Moreover, the CAENComm is based on CAENVMElib and it requires the CAENVMElib library (access to the VME bus) even in the cases where the VME is not used. This is the reason why it is necessary that **the CAENVMElib is already installed on your PC before installing the CAENComm**.

The CAENComm installation package is available on CAEN website ([www.caen.it](http://www.caen.it)) in the “Download” tab at:

*Home / Products / Firmware/Software / Software Tools / Software Libraries / CAENComm Library*

- **CAENDigitizer** is a library of functions designed specifically for the Digitizer family and it supports also the boards running the DPP firmware, as it happens in the DPHA. The CAENDigitizer library is based on the CAENComm which is based on CAENVMElib, as said above. For this reason, **the CAENVMElib and CAENComm libraries must be already installed on the host PC before installing the CAENDigitizer**.

The CAENDigitizer installation package is available on CAEN website ([www.caen.it](http://www.caen.it)) in the “Download” tab at:

*Home / Products / Firmware/Software / Software Tools / Software Libraries / CAENDigitizer Library*

- **CAENDPP** is a high level library of C functions designed to completely control exclusively the digitizers running the DPP-PHA firmware.

The CAENDPP installation package is available on CAEN website ([www.caen.it](http://www.caen.it)) in the “Download” tab at:

*Home / Products / Firmware/Software / Software Tools / Software Libraries / CAENDPP Library*

Currently, the CAENComm (and so the CAENDigitizer) supports the following communication interfaces (see also **Fig. 3.2**):

PC → USB → Digitizer Desktop and NIM form factors

PC → USB → V1718 → VME → Digitizer VME form factor

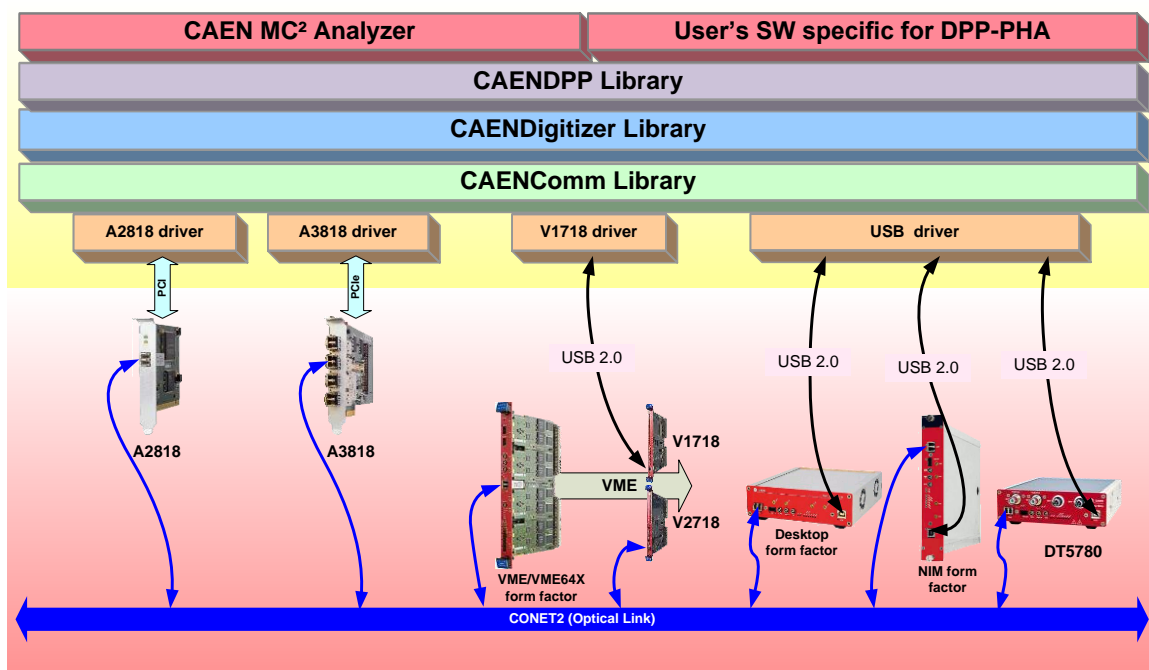
PC → PCI (A2818) → CONET → Digitizer all form factors

PC → PCI (A2818) → CONET → V2718 → VME → Digitizer VME form factor

PC → PCIe (A3818) → CONET → Digitizer all form factors

PC → PCIe (A3818) → CONET → V2718 → VME → Digitizer VME form factor

**CONET** (Chainable Optical NETWORK) indicates the CAEN proprietary protocol for communication interface using Optical Link.



**Fig. 3.2:** Libraries and drivers required for MC²Analyzer

## Software Installation

In order to manage with the MC<sup>2</sup>Analyzer software, the host station needs a Windows OS. The Linux version is not yet supported at the moment. The software requires the third-party software **.NET Framework 4.0 or later**, downloadable from Microsoft® website.

- **Make sure** that your **hardware** (Digitizer and/or Bridge, or Controller) is **properly installed** (refer to the related User Manual for hardware installation instructions).
- **Make sure** you have installed the **driver** for your OS and the physical communication layer to be used. Driver installation packages are downloadable from CAEN website (**login required**) as reported in the section **Drivers** (refer to the related User Manual for driver installation instructions).



**Note:** Hardware and USB drivers installation instructions for desktop digitizers and DT5780 are detailed in [RD3].

CAEN provides the full installation package for the MC<sup>2</sup>Analyzer Software in a **standalone version** for **Windows OS**. This version installs all the binary files and required libraries.

1. Download the MC<sup>2</sup>Analyzer Software from CAEN Website under the path:  
*Home / Products / Firmware/Software / Digitizer Software / Readout Software / MC2 Analyzer*
2. Extract the files and run the executable "**MC2Analyzer\_x.x.x.exe**".
3. The CAEN MC<sup>2</sup>Analyzer **Setup Wizard** will guide you throughout the installation procedure.

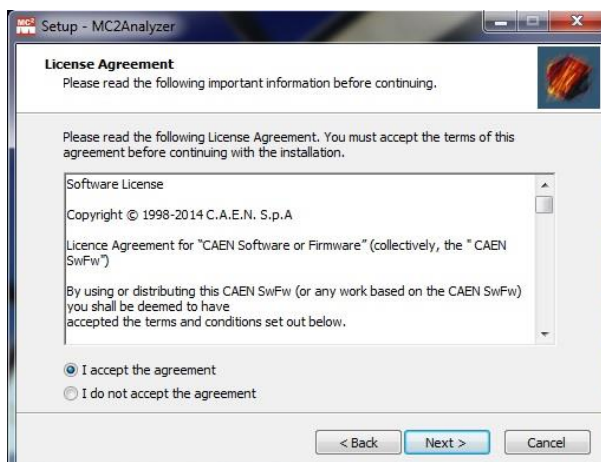


**Note:** the following screenshot are taken with Window 7 OS, and they can be generalized for all Windows OS.



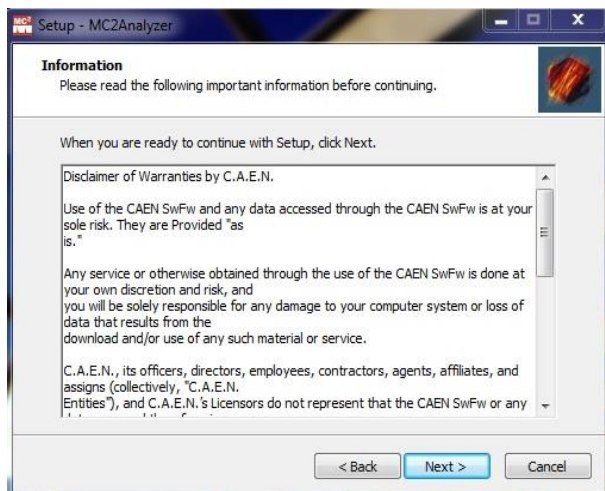
**Fig. 3.3:** MC<sup>2</sup>Analyzer Wizard Dialog Box- Start Installation

Left click on "**Next**" (or left click on "**Cancel**" any time during the installation process to abort the installation).



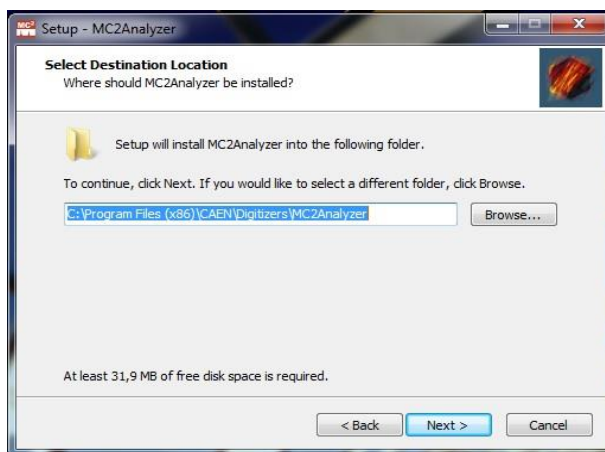
**Fig. 3.4:** MC<sup>2</sup>Analyzer Wizard Dialog Box - License Agreement

Please read the MC<sup>2</sup>Analyzer Software License Agreement and select “**I accept the agreement**” to continue the installation. Left click on “**Next**” (or left click on “**Back**” at any time during the installation process to modify the previous settings).



**Fig. 3.5:** MC<sup>2</sup>Analyzer Wizard Dialog Box - Disclaimer

Please read the CAEN Disclaimer information then left click on “**Next**” to continue.



**Fig. 3.6:** MC<sup>2</sup>Analyzer Wizard Dialog Box – Installation Folder Selection

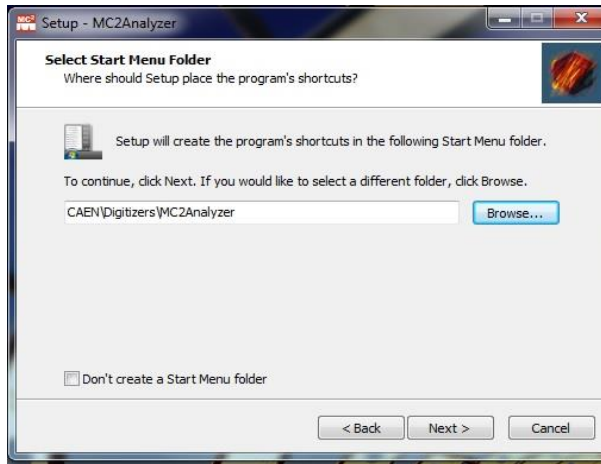
To install the MC<sup>2</sup>Analyzer Software, a minimum free space of about 32 MB of free Hard Disk space is required. Select a folder for the installation of the CAEN MC<sup>2</sup>Analyzer Software by using the “**Browser**” button or by typing the desired path in the white entry box. The default path is :

*C:\Program Files\CAEN\Digitizers\MC2Analyzer (Windows 32 bit)*

or

*C:\Program Files (x86)\CAEN\Digitizers\MC2Analyzer (Windows 64 bit).*

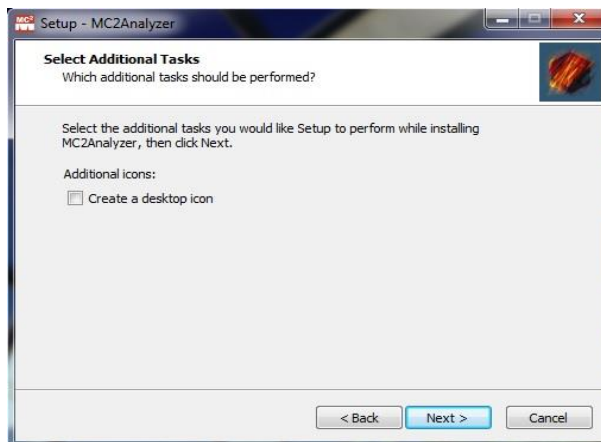
Left click on “**Next**” to continue.



**Fig. 3.7:** MC<sup>2</sup>Analyzer Wizard Dialog Box – Shortcuts

Optionally, select a Start Menu folder for the installation of the CAEN MC<sup>2</sup>Analyzer Software Shortcuts by using the **“Browser”** button or by typing the desired path in the white entry box. The default path is: *C:\Program Files\CAEN\Digitizers\MC2Analyzer* (Windows 32 bit) or *C:\Program Files (x86)\CAEN\Digitizers\MC2Analyzer* (Windows 64 bit). If you do not wish to create a Start Menu folder mark the checkbox labelled **“Don’t create a Start Menu folder”**.

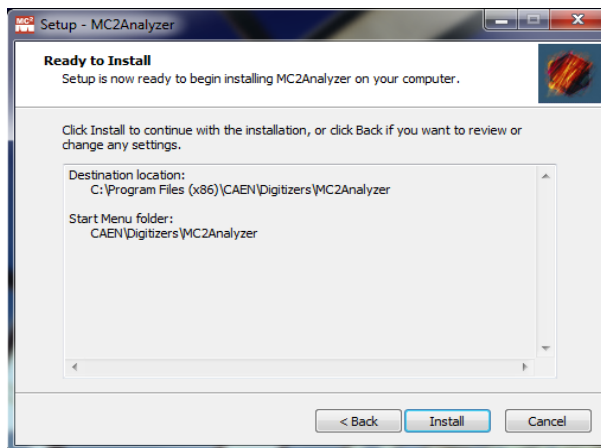
Left click on **“Next”** to continue.



**Fig. 3.8:** MC<sup>2</sup>Analyzer Wizard Dialog Box – Desktop Icon Selection

Optionally, mark the checkbox labelled **“Create a desktop icon”** to create an MC<sup>2</sup>Analyzer icon on your computer Desktop.

Left click on **“Next”** to continue.



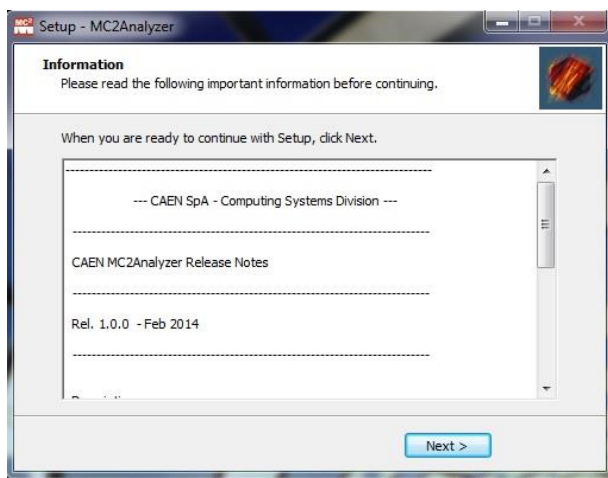
**Fig. 3.9:** MC<sup>2</sup>Analyzer Wizard Dialog Box – Installation



Please revise the MC<sup>2</sup>Analyzer Program Destination path and the Start Menu folder you have selected, if any.

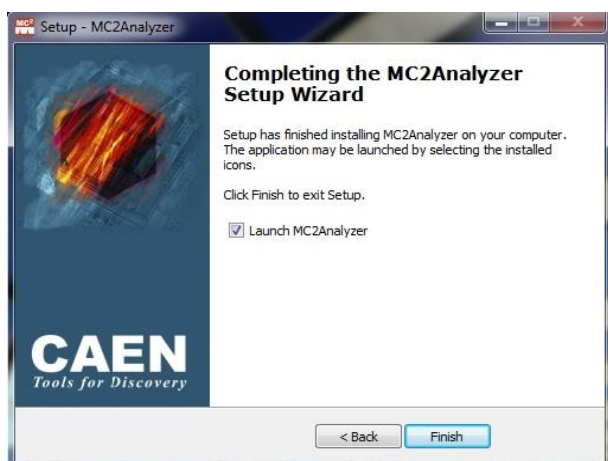
Left click on **“Install”** to install the CAEN MC<sup>2</sup>Analyzer Software.

The CAEN MC<sup>2</sup>Analyzer Setup Wizard will extract and install the relevant files. At the end of the installation, the following Dialog Box will appear:



**Fig. 3.10:** MC<sup>2</sup>Analyzer Wizard Dialog Box – Software Release Version Notes

Please read the Release Notes of the MC<sup>2</sup>Analyzer Software before continuing. This document is updated for every official release of MC<sup>2</sup>Analyzer and it contains various updated information specific to this software which may not be found in the User's Manual, available together with the software or on the CAEN web site: [www.caen.it](http://www.caen.it).



**Fig. 3.11:** MC<sup>2</sup>Analyzer Wizard Dialog Box – Finish Installation

To complete the MC<sup>2</sup>Analyzer Installation left click on **“Finish”**. The MC<sup>2</sup>Analyzer Program can be launched by marking the check box “Launch MC2Analyzer Analyzer” before finishing the installation, or by left clicking on the installed icons in the Start Menu Folder.




## First connection and HV power ON

### Software connection

Once you have installed the required driver for the communication interface and the MC<sup>2</sup>Analyzer software you can launch the MC<sup>2</sup>Analyzer software and connect it to the DT5780.

From the main panel of the MC<sup>2</sup>Analyzer software GUI select

**FILE -> Add Spectrum**, or press the button .

The following window will appear.

Select **“Online Spectrum”** to connect to the digital MCA.

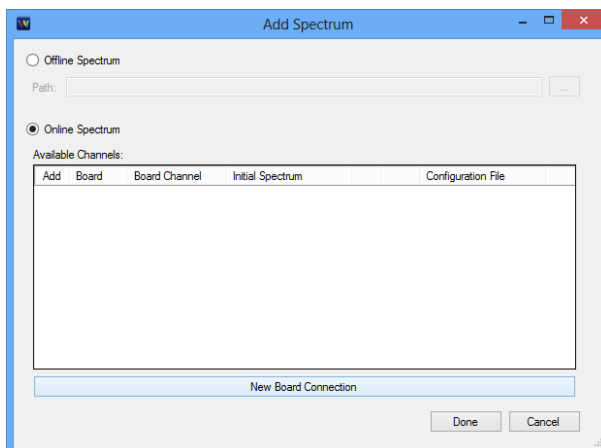


Fig. 3.12: the “Add Spectrum” window to add an offline spectrum from file or an online spectrum from board

Set the device connection parameters. In this example we connect through USB connection interface.

Press **“Connect”** when ready. The device is then recognized by the software and a green line shows that the connection has been successfully established.

Then **“Close”** the **“Device Connection”** window.

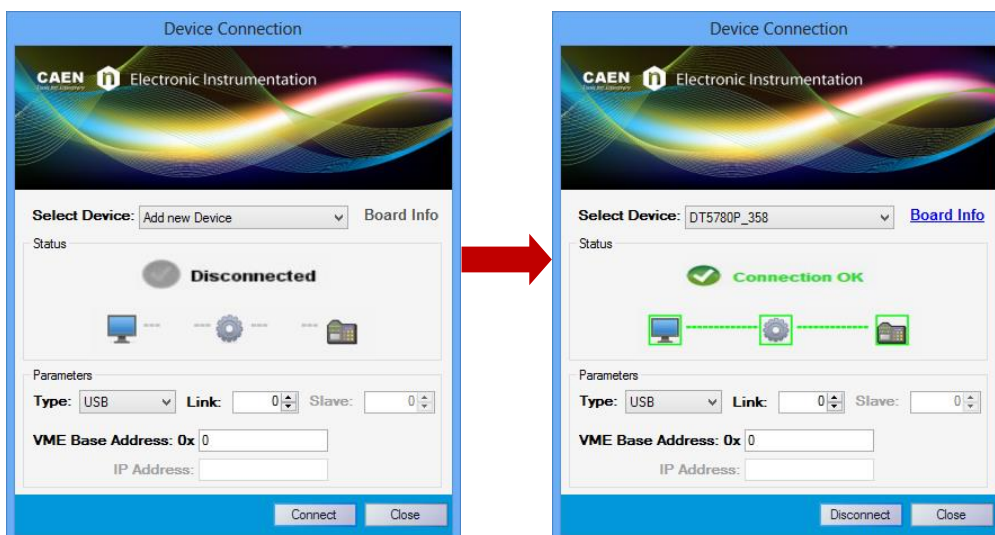
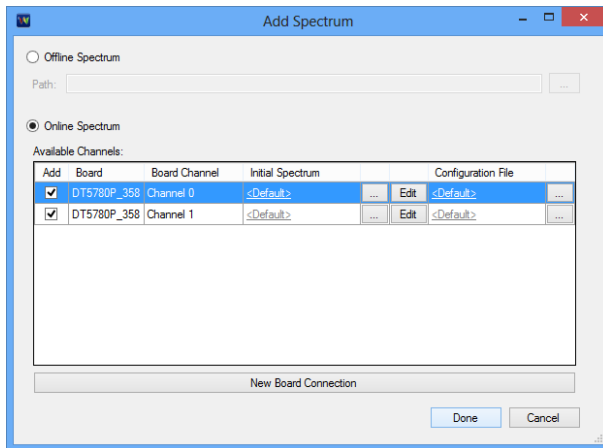


Fig. 3.13: “Device Connection” window. Once connected to the board the link becomes green

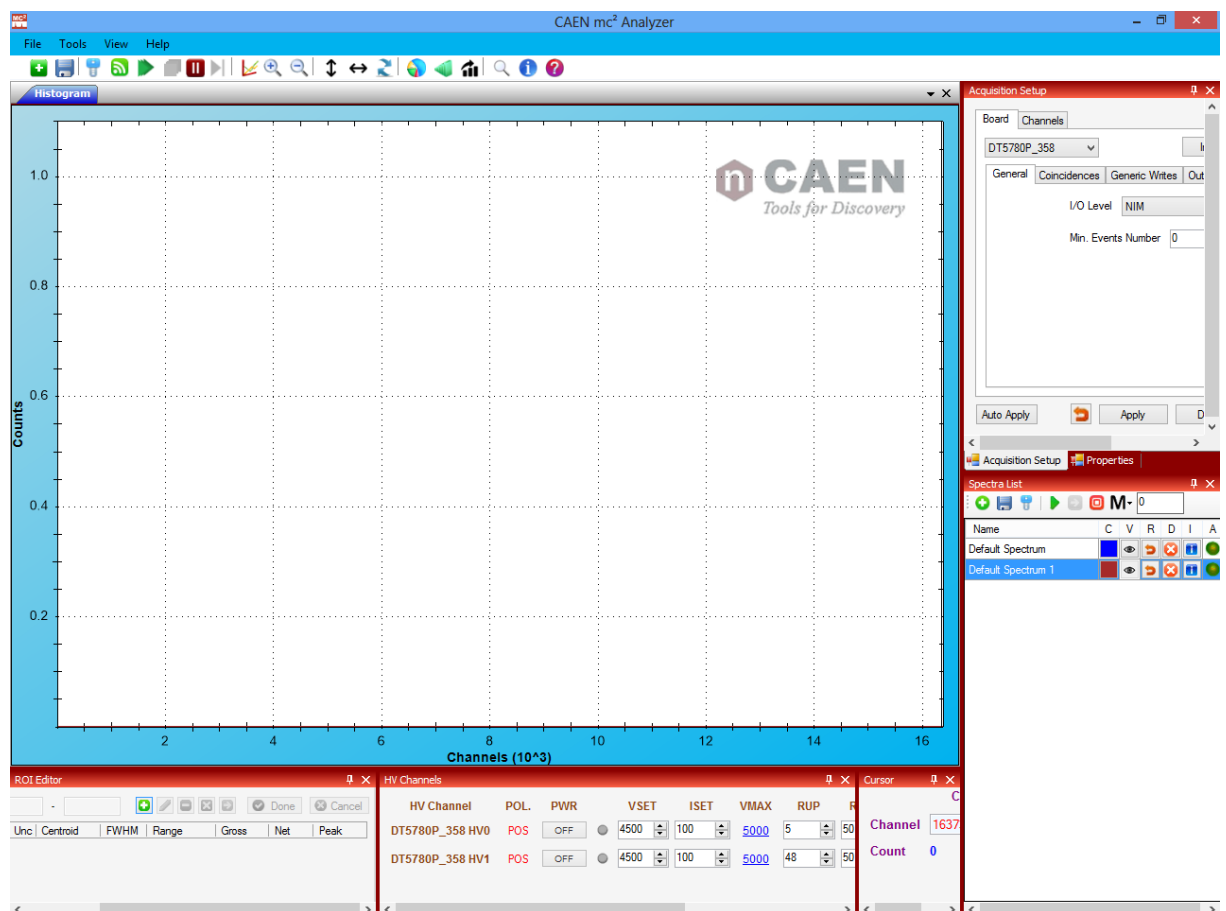
Select the **board channels** you want to enable to acquire the desired spectrum.

Press **“Done”** when ready.



**Fig. 3.14:** this window allows to select the desired board channels for the acquisition

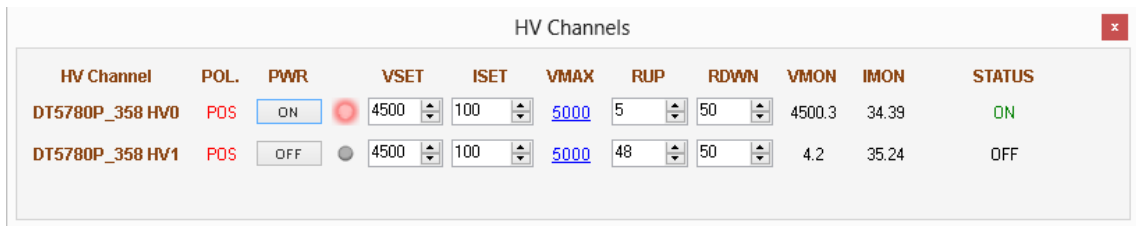
The default GUI interface will be then available.



**Fig. 3.15:** the default GUI at the first connection

### How to power ON the high voltage

Open the “HV Channels” window.



**Fig. 3.16:** “HV Channels” window for the setting and monitoring of the HV channels of the DT5780

Set the desired High Voltage value **VSET**, and the maximum current **ISET** according to your detector specifications.

Set the Maximum allowed Voltage value **VMAX**, beyond which the HV channel goes into protection.

Select the proper values for Ramp UP and Ramp DOWN (**RUP** and **RDWN** respectively), corresponding to the value of V/sec of voltage ramp.

Press **ON** when ready and the check the HV status from the **VMON**, **IMON** and **STATUS** flags.



**Note:** The **HV remains ON** even if the user disconnects the software from the digitizer. When connected again the software automatically reloads the last HV settings.

## Before starting the acquisition

It is **very important** to check the preamplifier output in an **oscilloscope** device before feeding the pre-amplified signal into the digitizer input. The user must check that:


- there are no grounding issues;
- the preamplifier output dynamics is not saturated.

In the unlikely event one of the above conditions is found the user must take care of the proper work around.

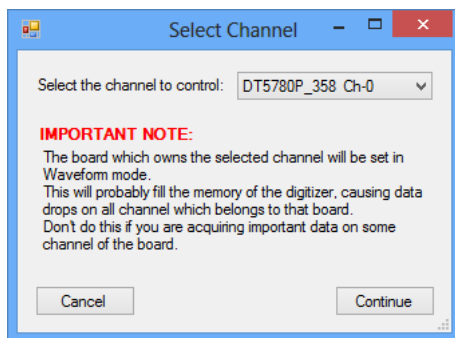
## How to configure the channel settings

The correct configuration of the channel settings allows to reach very precise resolutions in spectroscopy measurement. For this reason it is very important to set them properly. This section will guide the user throughout the settings configuration. The first step is to enable the “Signal Inspector” window to check the effects of the setting modifications on the digital filters.

### Open the Signal Inspector window

To open the “Signal Inspector” window press the button  in the icon bar.

Select the board channel for which you want to check the signal inspector. Then press “Continue”.



**Fig. 3.17:** “Select Channel” window to select the channel for the signal inspector visualization

It is possible to visualize a set of analog and digital traces.

Start with the visualization of:

- “Trapezoid” as “Analog Trace 1”
- “Input” as “Analog Trace 2”
- “Peaking” as “Digital Trace 1”
- “Trigger” as “Digital Trace 2”



**Note:** Any time you change one setting always press “Apply” to apply the setting. Otherwise press “Auto Apply” once for automatically applying the changes.



**Note:** “Gain” and “Offset” of the “Digital Traces” affect only the traces visualization, while have no impact in the internal board filters.



**Note:** move the “Waveform and Pre-Trigger Length” slider to increase or decrease the waveform visualization length.

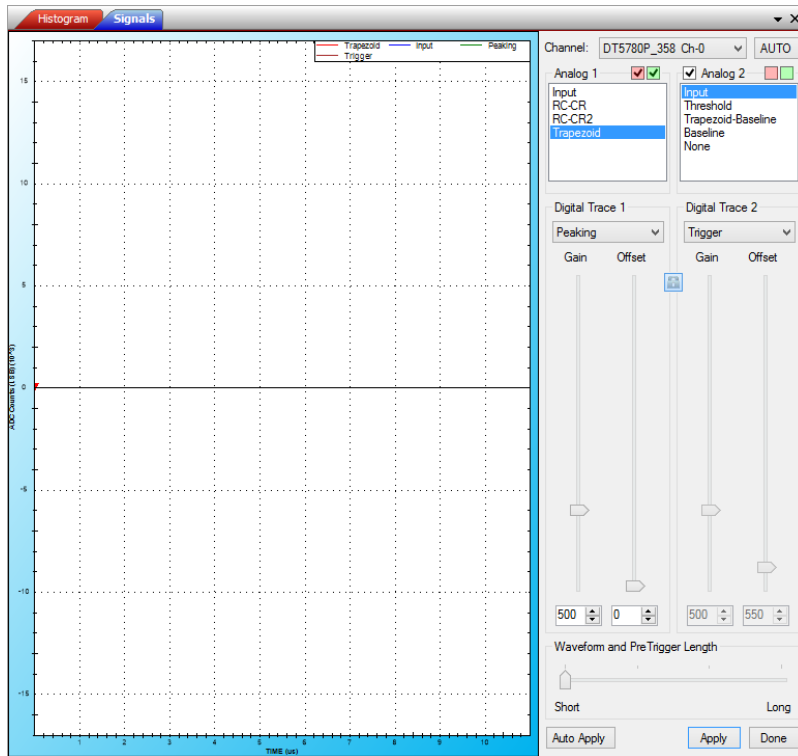



Fig. 3.18: default signal inspector graphical interface

Press PLAY  to start the waveforms visualization.

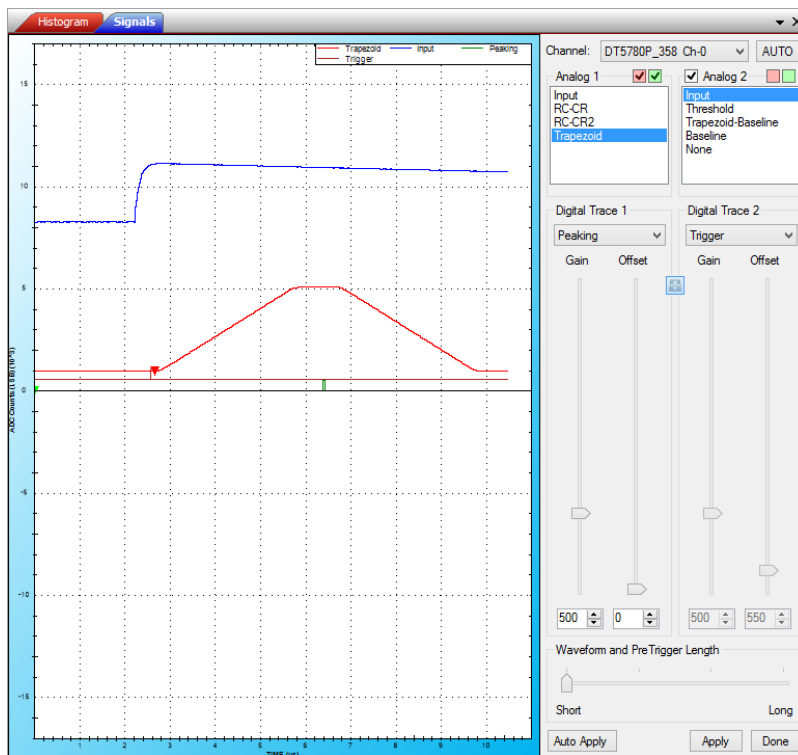
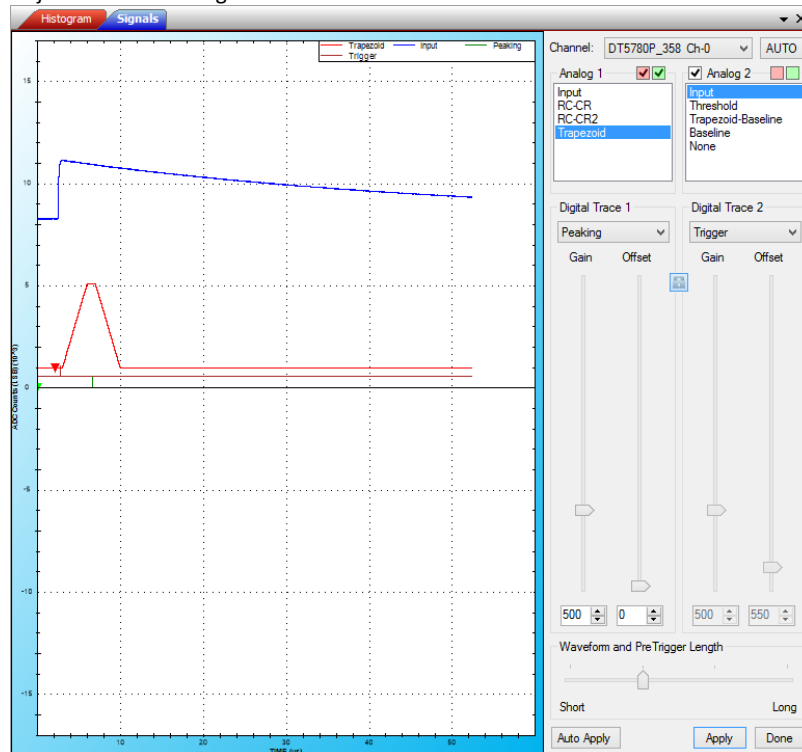


Fig. 3.19: signal inspector visualization of Input, Trapezoid, Peaking and Trigger traces



**Note:** In case you don't see any signal press **"AUTO"** to enable the software-trigger. The software will force the board to trigger the events. Then adjust the channel settings as described in the following sections. Once the parameters are correctly set release the AUTO button to disable the software-trigger.

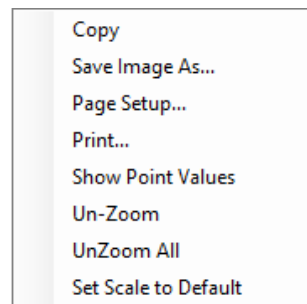
Adjust the record length for a better visualization.



**Fig. 3.20:** modification of the "Waveform and Pre-Trigger Length" slider for a better visualization of the waveforms


Drag and release to **zoom in** a region of the plot.

Right click and select **"Un-zoom"** or **"Un-zoom all"** to zoom out.

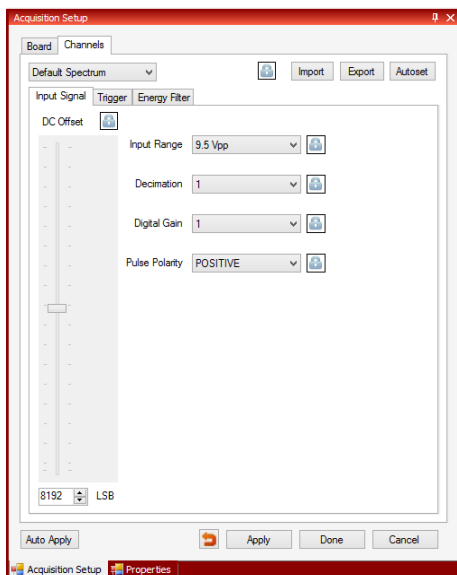


## How to configure the Input Signal settings

The first settings to be configure are those related to the Input Signal.

1. Open the “**Acquisition Setup**” window, either from the button  or from “**Tools -> Acquisition Setup**”.

Select the tab “**Channels**” and select the “**Default Spectrum**”. The input signal settings are in the first tab “**Input Signal**”.



**Fig. 3.21:** The Acquisition Set Up Window – Board Tab - General Tab

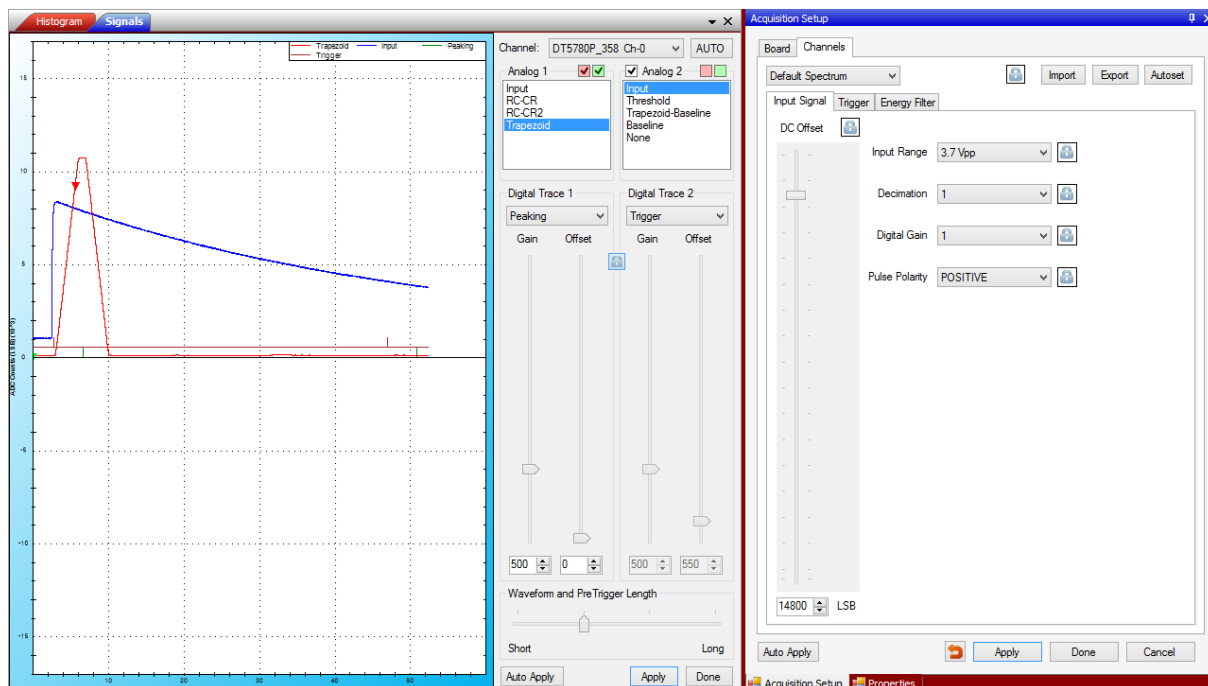
2. Using the measurement of the preamplified pulses from an oscilloscope device (refer to Sect. **Before starting the acquisition**) it is possible to check what is the pulse height range.

It is important to select the proper “**Input Range**”, which corresponds to the input dynamic range of the digitizer in order to get as much as possible all the pulses. Possible choices are 0.6, 1.4, 3.7, 9 Vpp for the DT5780 (0.3, 1, 3, and 10Vpp for the DT5781, and 0.5, 2 Vpp for x730 family, not available for x724 digitizer family). The correct setting of the Input Range is a compromise between the digitizer dynamics saturation and the use of too few channels of the spectrum. The input range corresponds to the *Coarse Gain* of the analog chain.

In our example we choose the 3.7 Vpp.

3. Select the input “**Pulse Polarity**” choosing among “**Positive**” and “**Negative**”. Since the algorithm works with positive pulses only, by setting “**Negative**” the algorithm will invert the digital samples of the input.
4. Adjust the “**DC Offset**” to have the input signal baseline around **1000 LSB** counts. You can safely go below this value, only check that the input does not saturate around 0. In that case the algorithm stops any calculation and increases the dead-time. Also it is important to check that the signal does not saturate in the upper limit of the dynamics (16k LSB). In our example we set DC Offset = 14800.

The result of these settings is shown in the following figure.



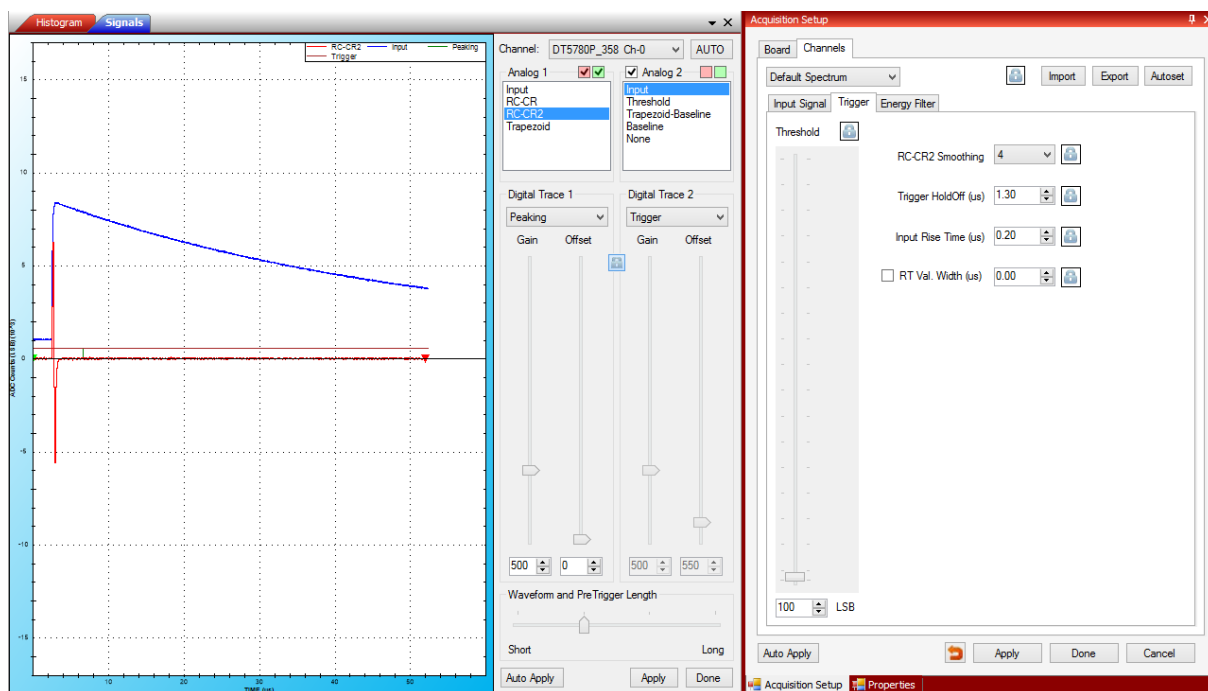
**Fig. 3.22:** “Input Signal” settings and corresponding effect on the signal inspector window

### How to set the Trigger

Since the trigger fires at the zero-crossing of the RC-CR<sup>2</sup> signal (refer to Sect. **Trigger and Timing Filter** for further details) first enable the visualization of the:

- “RC-CR<sup>2</sup>” as “Analog Trace 1”
- “Input” as “Analog Trace 2”

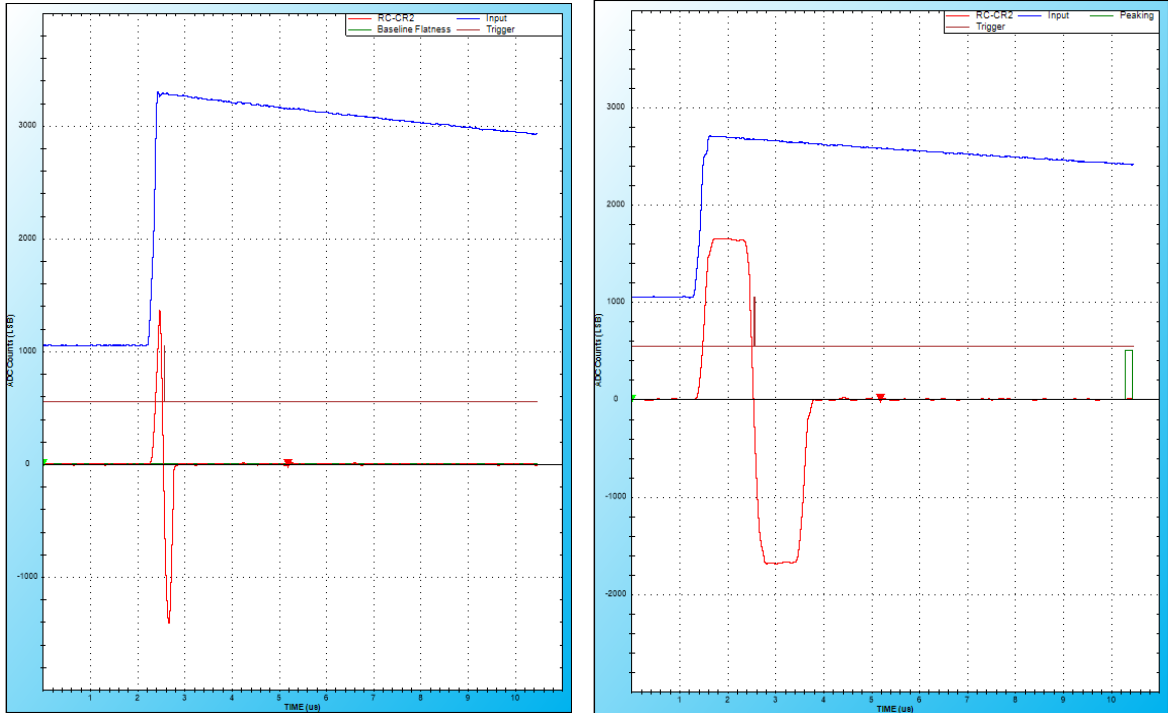
Select the tab “Trigger” from the “Acquisition Setup” window.



**Fig. 3.23:** “Trigger” tab settings and the visualization of the RCCR2 settings and corresponding effect on the signal inspector window

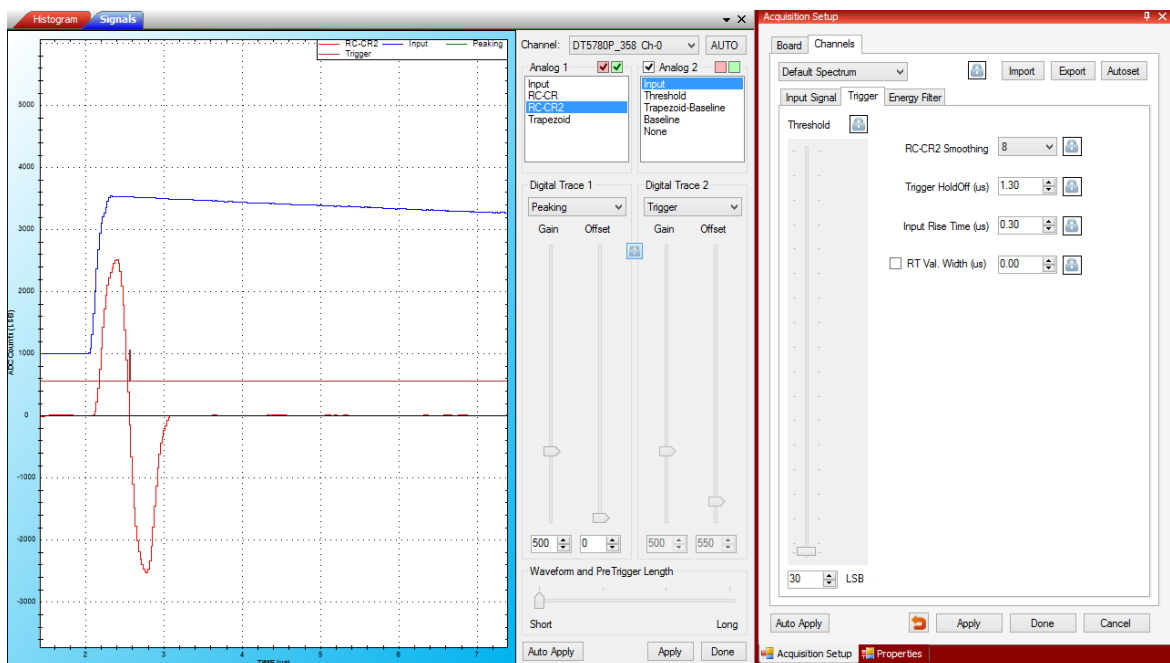


1. Start by setting the “RC-CR<sup>2</sup> Smoothing” factor to **16**. All the other settings has to be tuned according to the smoothing factor (i.e. once you change this value you have to repeat the whole procedure described in this section).
2. Set the “Input Rise Time” value (see Sect. **Trigger and Timing Filter** and **Acquisition Setup** for further details) to have the same height of RC-CR<sup>2</sup> signal and the input pulse. Try to avoid cases where the “Input Rise Time” is too short (the RC-CR<sup>2</sup> height will be less than the input) and where the “Input Rise Time ” is too long, which are represented in the following figure. On the left the value is underestimated, on the right it is overestimated.



**Fig. 3.24:** two examples where the “Input Rise Time” is not correctly set. In the left plot the value is underestimated, on the right it is overestimated

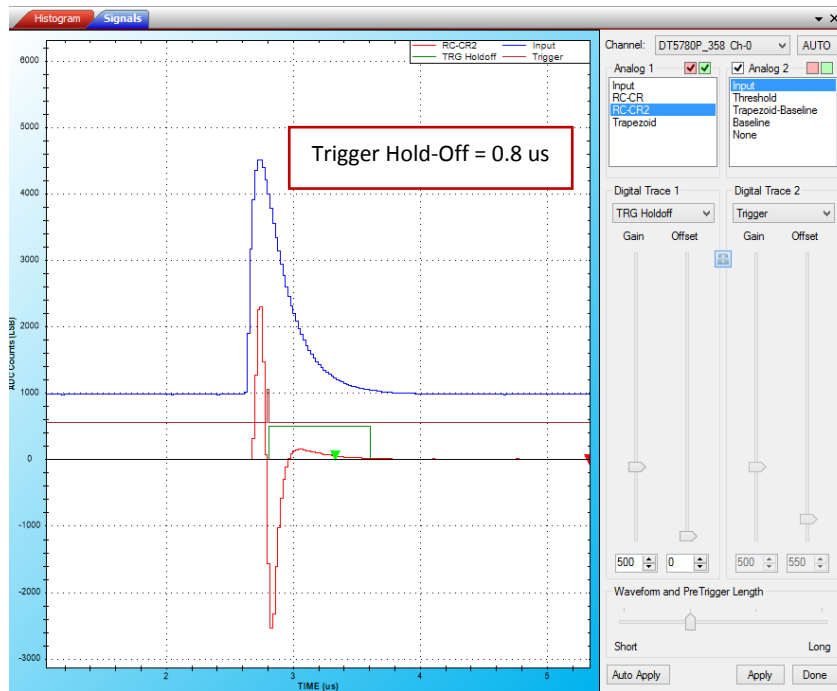
The correct value for our example is **0.3 us**.



**Fig. 3.25:** Set the Input Rise time to have the same pulse height of the input signal and the RC-CR<sup>2</sup> signal

3. In case the RC-CR<sup>2</sup> shows an overshoot (see **Fig. 3.26**), set the **“Trigger Hold-Off”** value as long enough to eventually include the overshoot inside it. The algorithm then inhibits any trigger occurring during the whole **“Trigger Hold-Off”** duration.

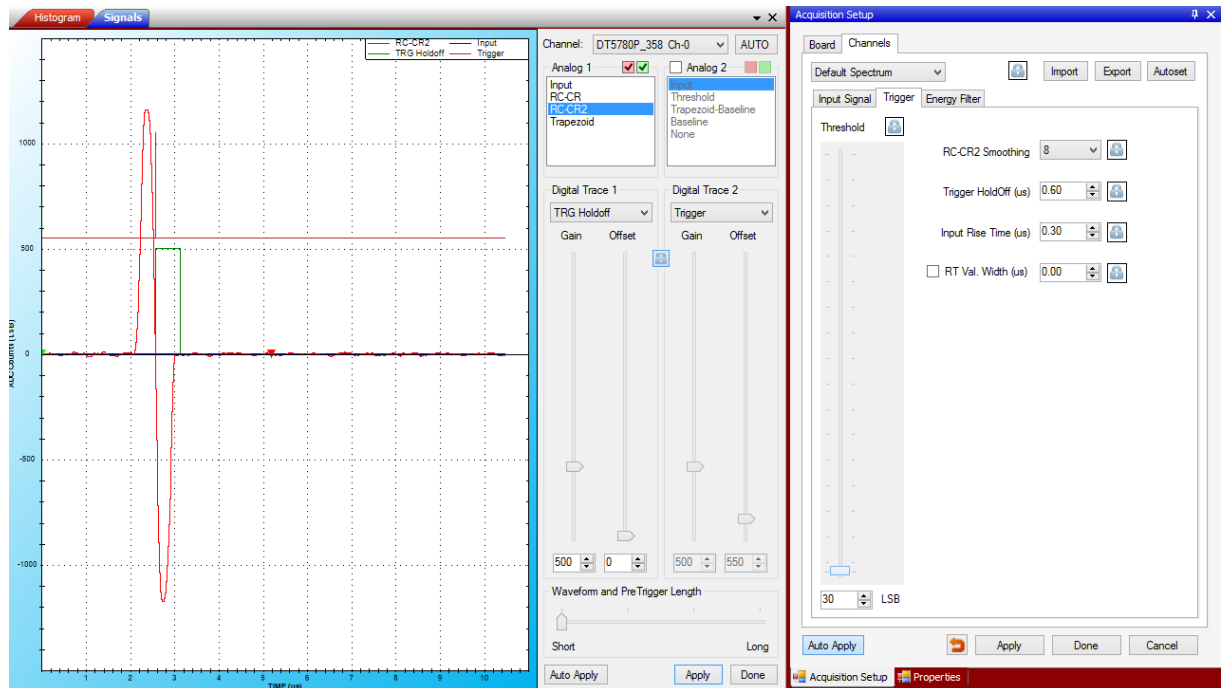
Check the correct value by enabling the visualization of the **“Trigger Hold-Off”** as **“Digital Trace 1”**.



**Fig. 3.26:** RC-CR<sup>2</sup> signal with an overshoot. Set the Trigger Hold-Off to cover the overshoot and avoid re-triggering

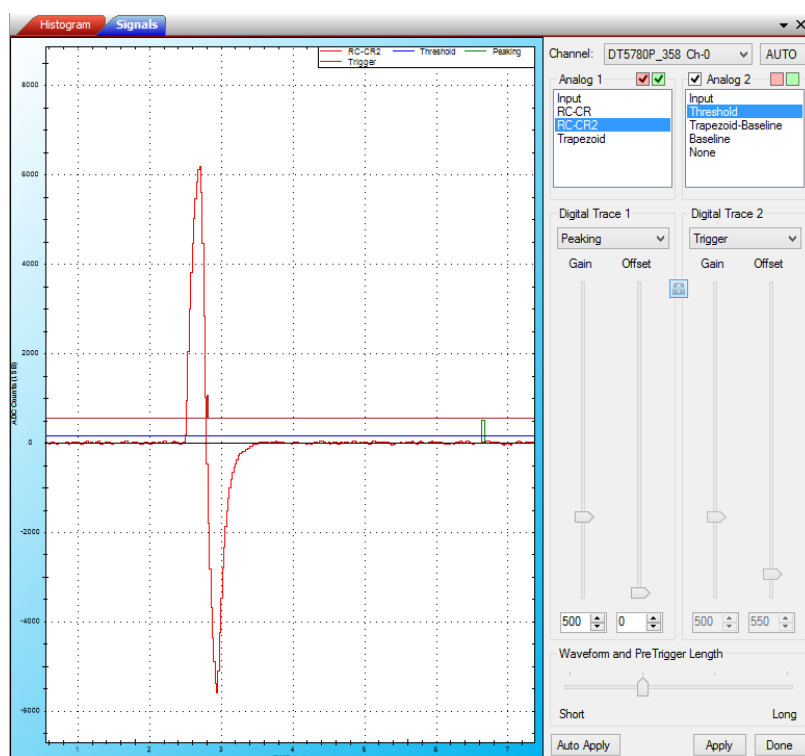
In case there is no overshoot set the minimum value of Trigger Hold-Off in order to cover the RC-CR<sup>2</sup> signal.

In our example, we set **0.6 us**.

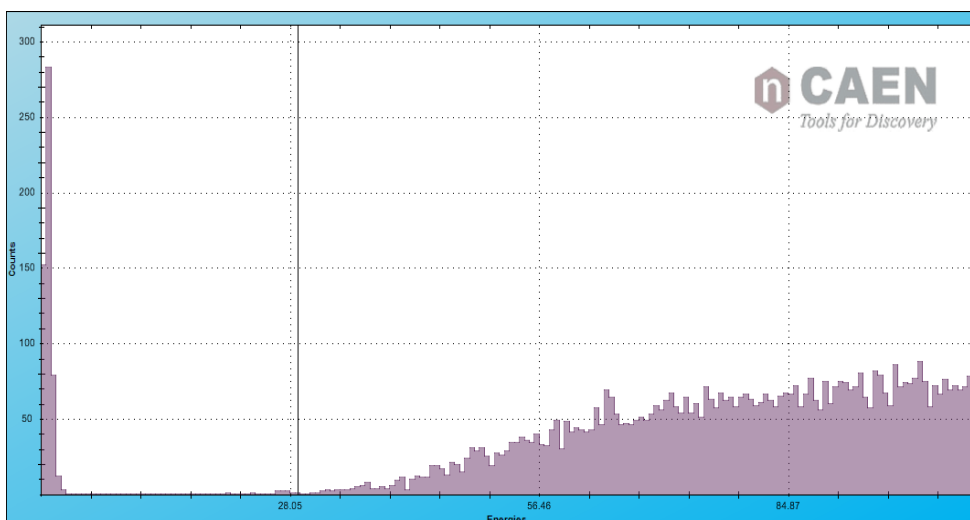


**Fig. 3. 3.27:** RC-CR<sup>2</sup> signal with no overshoot. Set the Trigger Hold-Off to cover the RC-CR<sup>2</sup> signal width

- Set the “**Threshold**” value to avoid the noise level of the RC-CR<sup>2</sup> signal. You can visualize the “Threshold” Analog trace on the Signal Inspector Window.



To correctly set the Threshold value, switch to the “**Histogram**” window. Zoom in in the lowest region of the spectrum and reduce the threshold level until you get a peak close to zero. You are now triggering below the noise level.

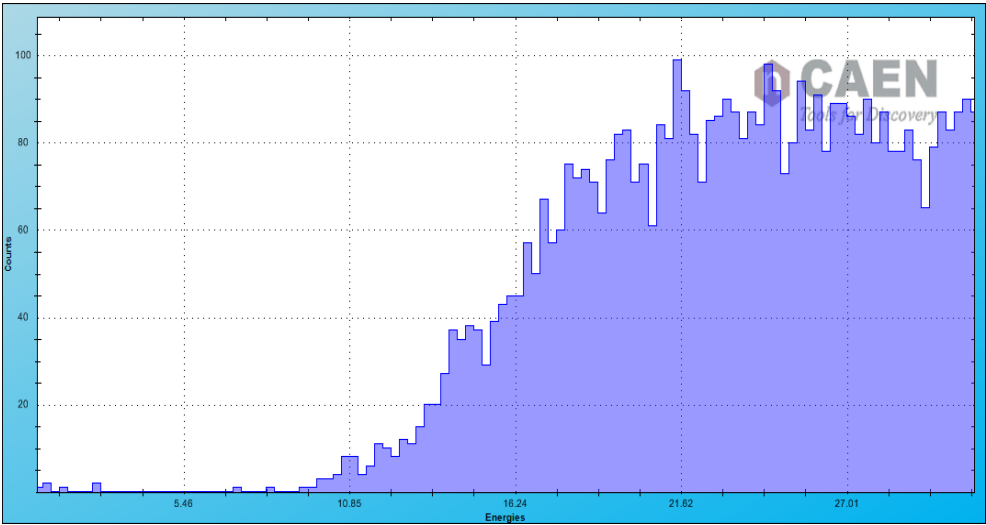


Set a value slightly higher.



**Note:** According to the detector / pre-amplifier conditions it is possible to have particularly noise input signals. In this case the *lower region of the spectrum is cut off*. To overcome this issue set a greater value of RC-CR<sup>2</sup> smoothing to use a greater number of sample for the RC-CR<sup>2</sup> signal. In this way high frequency noise will be significantly reduced. Remember to adjust again the Input Rise Time and Trigger Hold-off in case you change the smoothing factor.

In our example, we can reach up to about 10 keV.



## How to set the Energy Filter

The precise configuration of the Energy Filter strongly affects the final resolution measurement, therefore it is very important to fine tuning the Energy Filter settings. The user must take care of:

- Checking that the trapezoid is correctly shaped;
- Evaluating the energy value (see the Peaking trace) in the flat top region of the trapezoid.

The two typical measurement setups that we are going to discuss are:

1. Low rate (up to few hundreds of Hz) and very high precision measurement;
2. High rate (up to tens of kHz), where the final result is a compromise between high resolution and dead-time.

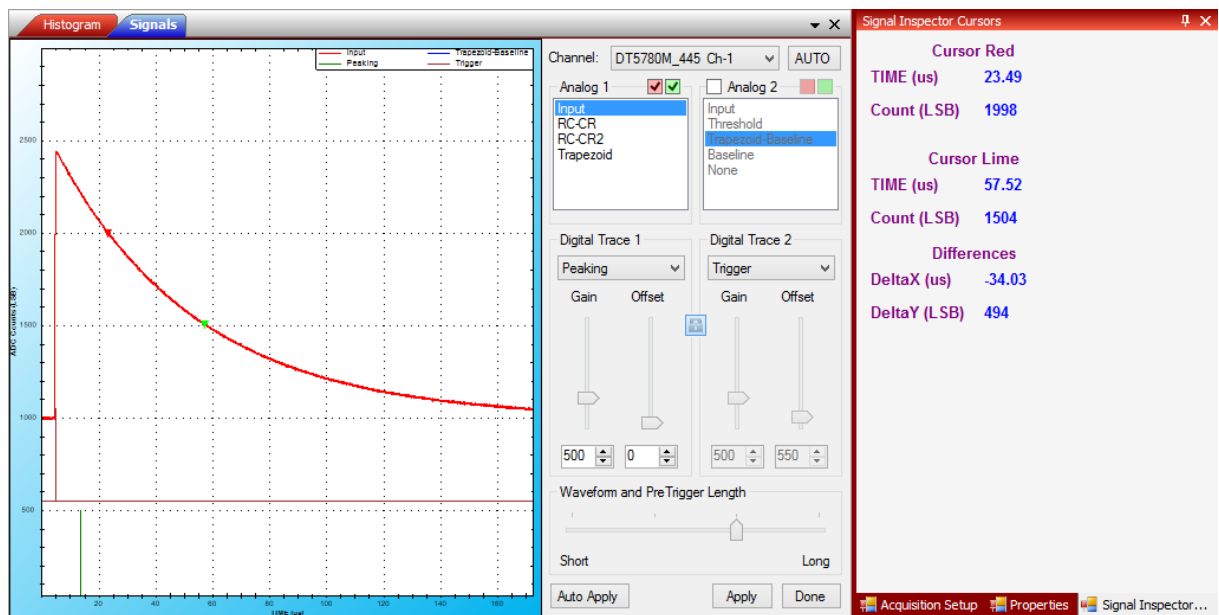
Before starting set an approximate value of “Decay Time”. The fine tuning of this parameter is described in section **Pole-Zero Cancellation**.

To evaluate the decay time value the user can enable the “Input” visualization from “Analog Trace 1”, and measure the input *half-time* using the “Signal Inspector Cursors”. From the half time it is possible to calculate the decay time according to the formula:  $T_{1/2} = \ln(2) \tau$ , where  $T_{1/2}$  is the half time, and  $\tau$  is the decay time.

Left click to point the **red cursor**.

Press the “Shift” key and left click to point the **lime cursor**.

Then open the “**Signal Inspector Cursors**” window to check the corresponding cursor values and their difference. From the “DeltaX” value you can evaluate the Decay Time value . Refer to Sect. **Signal Inspector Cursor window** for further details.



Select now:

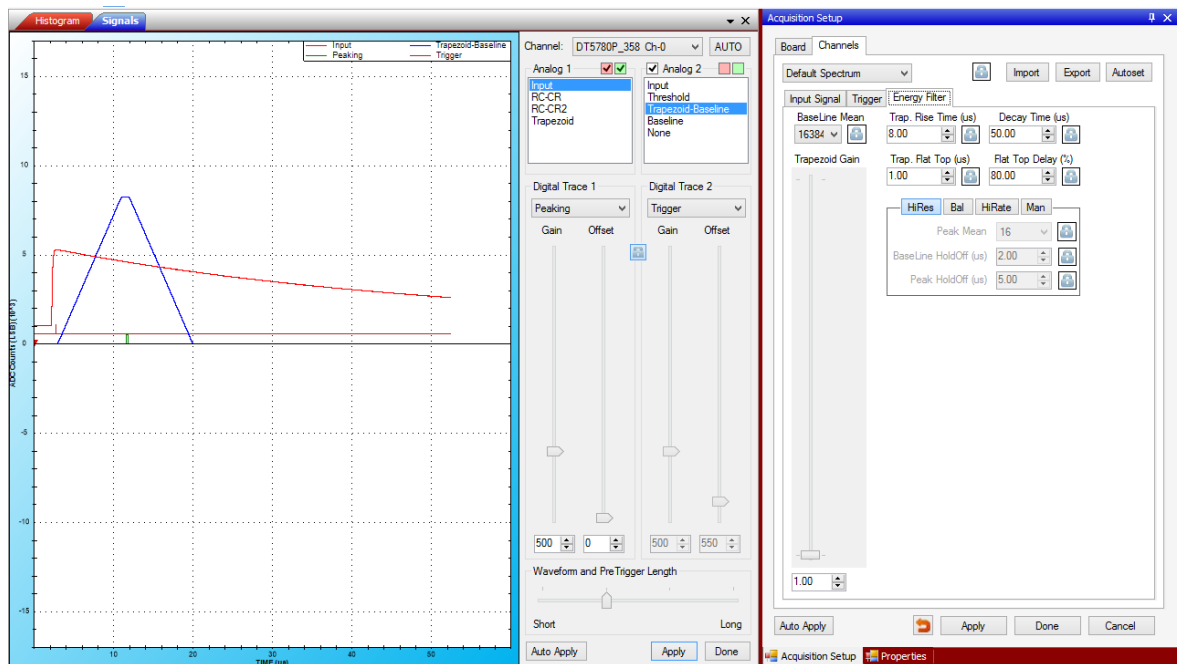
- "Input" as "Analog Trace 1"
- "Trapezoid-Baseline" as "Analog Trace 2"
- "Peaking" as "Digital Trace 1"
- "Trigger" as Digital Trace 2



**Note:** The baseline of "Trapezoid - Baseline" trace should be at 0.

1. In the *low rate case* it is recommended to set a high value of **"Trapezoid Rise Time"**, as for example **8 us**. Considering it in the analogy of the analog chain (refer to Chapter **Principle of Operation** it corresponds to about 3 us of shaping time).  
Then set a value of **"Trapezoid Flat Top"** between **1-2 us**, only check that the flat top region is really flat.  
Adjust – if necessary – the Peaking position (**"Flat Top Delay"**) and the number of samples (**"Peak. Mean"**) for the energy mean calculation.  
Finally for very low rate set the maximum value of **"Baseline Mean"** (i.e. the number of samples for the baseline calculation), i.e. 16K.

You can either choose the preset **"HiRes"** for high resolution settings, or the **"Man"**. For high resolution measurement it is strongly recommended to set the maximum value of **"Baseline Hold-Off"**

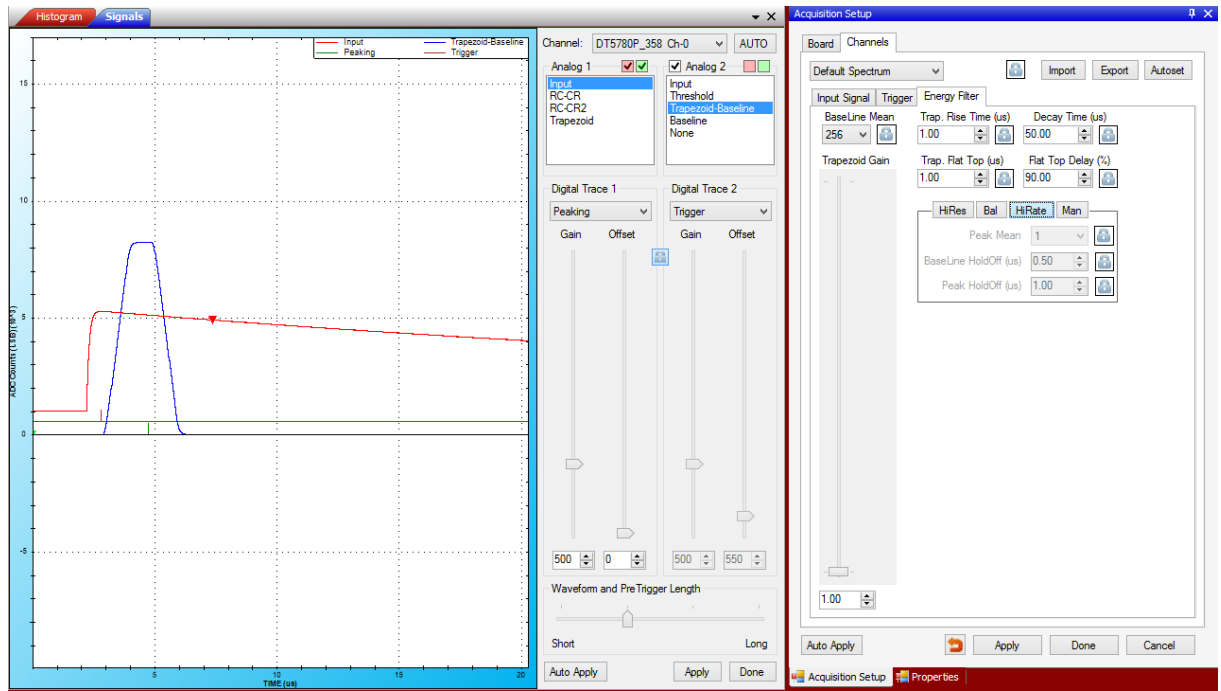


**Note:** the Trapezoid Rise Time and Flat Top Time have a maximum value of about 10 us. In any case their sum should not exceed 15 us for x724, DT5780 and DT5781.

In case of **x730** the sum of Trapezoid Rise Time and Flat Top Time should not exceed 8 us. Suggested settings for x730 are **7 us of Rise Time** and **1 us of Flat Top**.

1. In the *high rate case* (tens of kHz) it is recommended to set a lower value of **"Trapezoid Rise Time"**, as for example **3-4 us**. For rate greater than 20 kHz it might be convenient to set **"Trapezoid Rise Time" = 1 us**.  
Set also **"Trapezoid Flat Top" = 1 us**, only check that the flat top region is really flat.  
Adjust – if necessary – the Peaking position (**"Flat Top Delay"**) and the number of samples (**"Peak. Mean"**) for the energy mean calculation in the flat region.  
Finally decrease the value of **"Baseline Mean"** (i.e. the number of samples for the baseline calculation). A dedicated study of the impact of the Baseline Mean in the final resolution can be made.

You can either choose the preset **"HiRate"** for high rate settings, or the **"Man"** settings for manual adjustments.

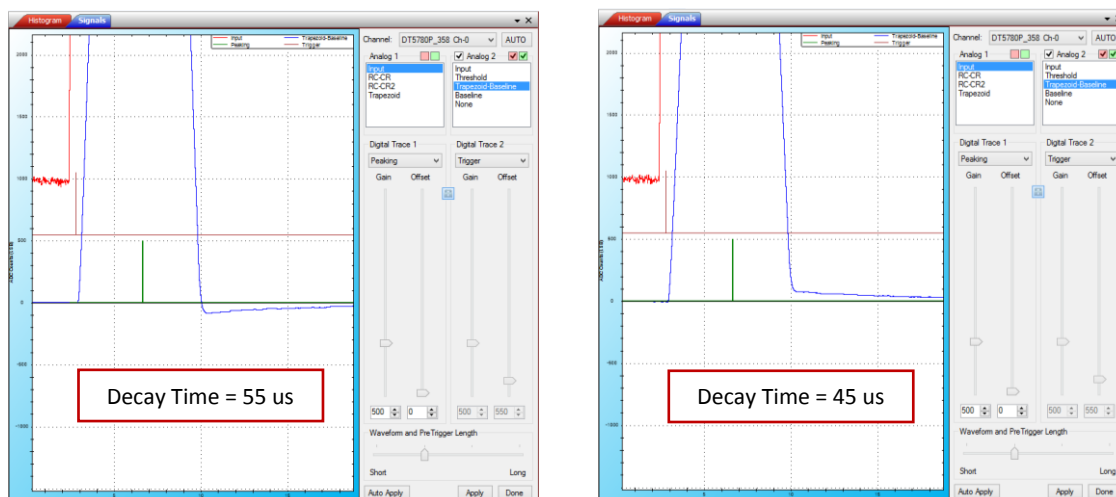


Both in case of low rate and high rate it is very *important* to have a flat “Flat Top” region. The “**Peaking**”, which corresponds to the samples where the pulse energy is evaluated, should be taken in the flat region. Adjust the “**Flat Top Delay**” and the “**Peak Mean**” values accordingly.

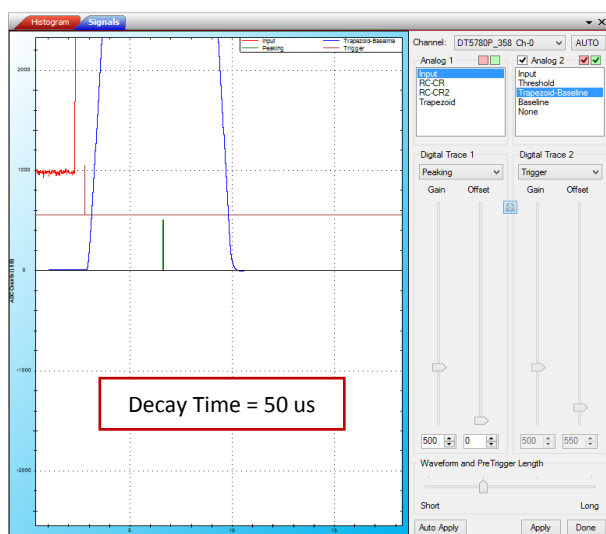
## Pole-Zero cancellation

The pole-zero cancellation is very important for a correct evaluation of the trapezoid baseline and consequently for a correct evaluation of the energy value.

The user must adjust the **"Decay Time"** according to the Pre-Amplifier decay time. Fine adjustments can be done looking at the zoom of the Trapezoid trace (or Trapezoid-Baseline) in order to have no undershoot nor overshoot. The two cases are shown in the following figure, where on the left the Decay Time has been set too high giving an undershoot, and on the right the Decay Time has been set too low thus giving an overshoot.




When the Pole-Zero is correctly compensated the Trapezoid will not make any overshoot not undershoot.





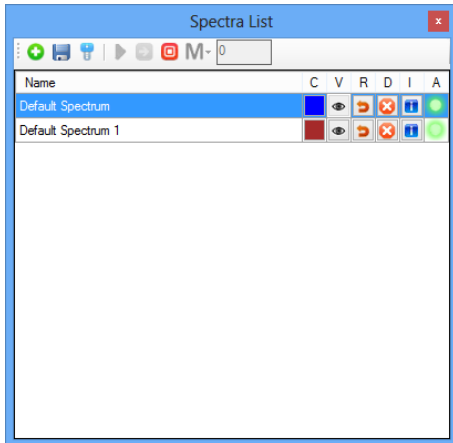


## Start/Stop the acquisition

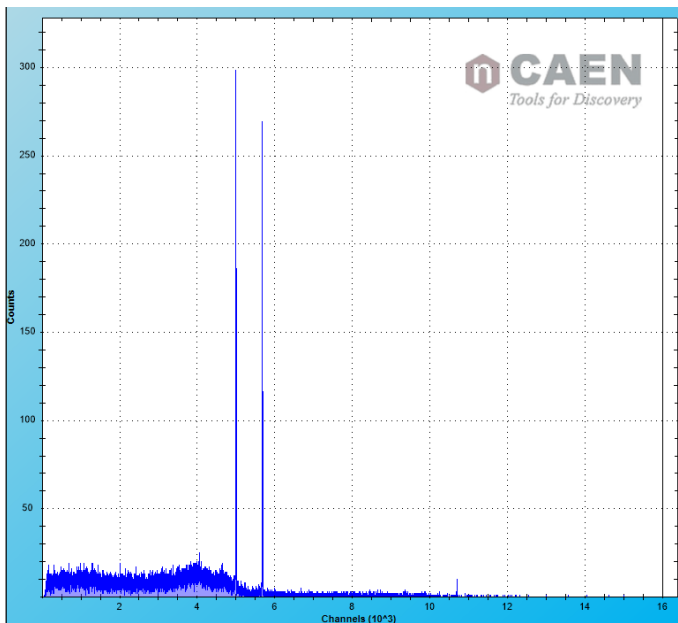
Once you have configured the acquisition close the “Signal Inspector” Window.

Select “Default Spectrum” from the “Spectra list” window. Click “R” to reset all spectra, or  to reset the single spectrum.

Then press PLAY  to start the acquisition, STOP  to stop it. When you select them from the Spectra List window you start/stop only the selected spectrum. If you select them from the main GUI you start/stop all channels.

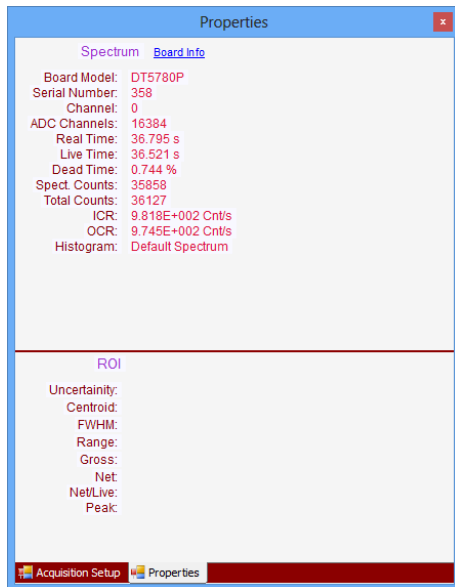


**Note:** The circle under “A” becomes RED in case of dynamics saturation or busy of the data throughput. Refer to Sect. **Troubleshooting** to reduce this effect.



Enable the “log scale” if needed , and the “vertical auto-scale” 

Check the spectrum properties from the “**Properties**” window:




## How to calibrate a spectrum

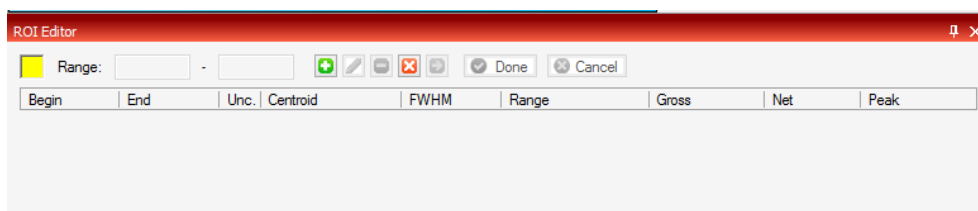
The software allows the user to calibrate a spectrum from counts to keV using two interpolating functions: Linear and Quadratic. For the first function the user must define at least a couple of values, while for the second the user must define at least three values. It is also possible to define more points; the algorithm will then compute the best fit of the defined points. For more details about the energy calibration refer to Sect. **MC2Analyzer Energy Calibration**.

The user can select a Region of Interest (ROI) of the spectrum and take the mean value of the distribution for the energy calibration.

### How to select a ROI

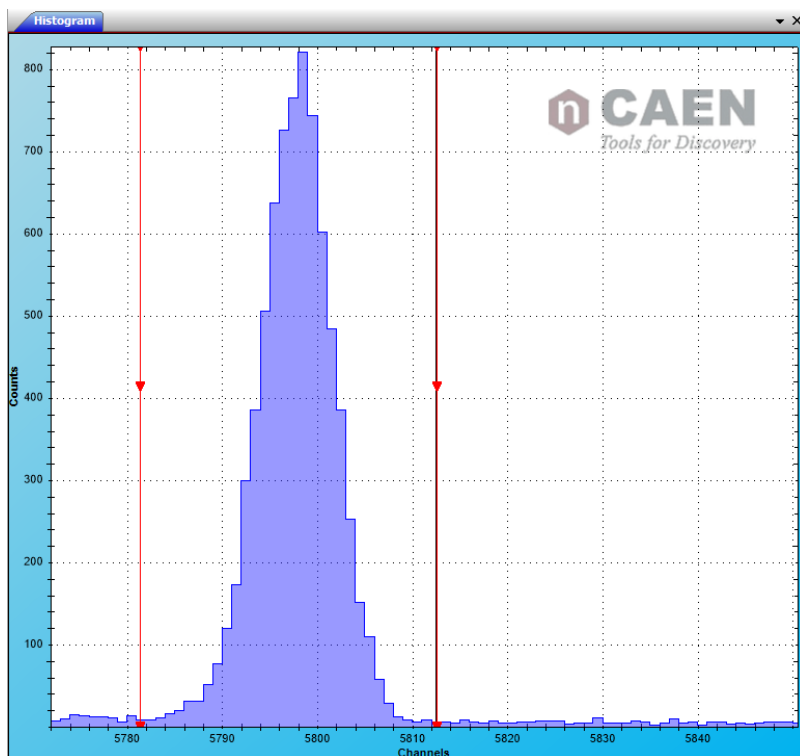
Zoom in (drag and release the mouse to zoom in) in the region of the relevant peaks to select the ROI.

From the “ROI Editor” window select “Add” .

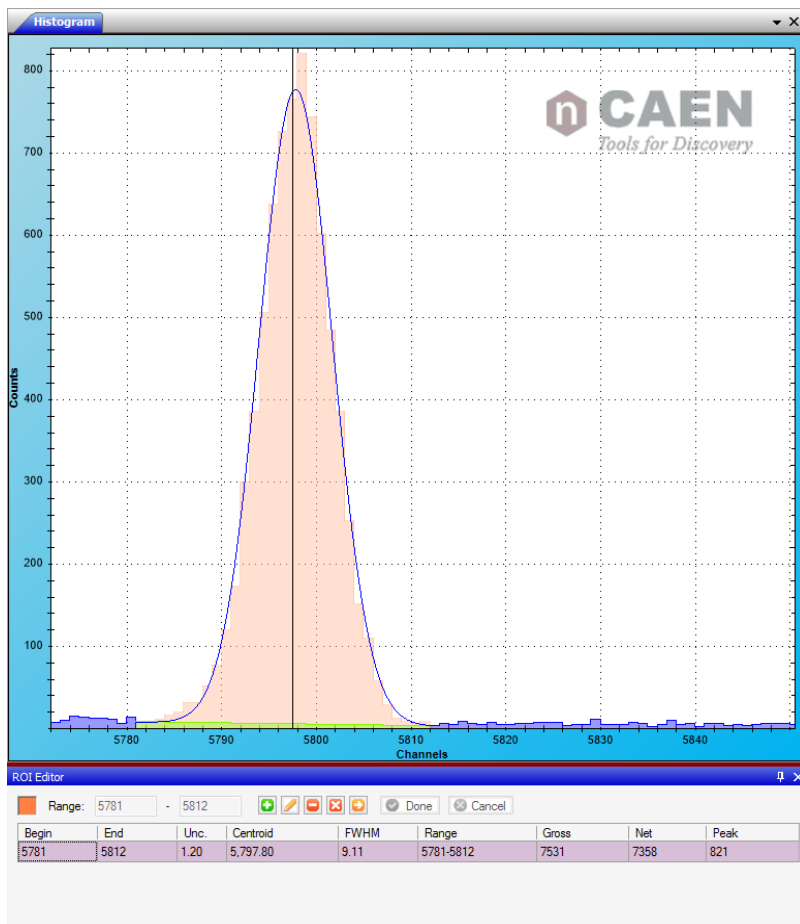


Click on the histogram to select the left and right limits of the ROI.

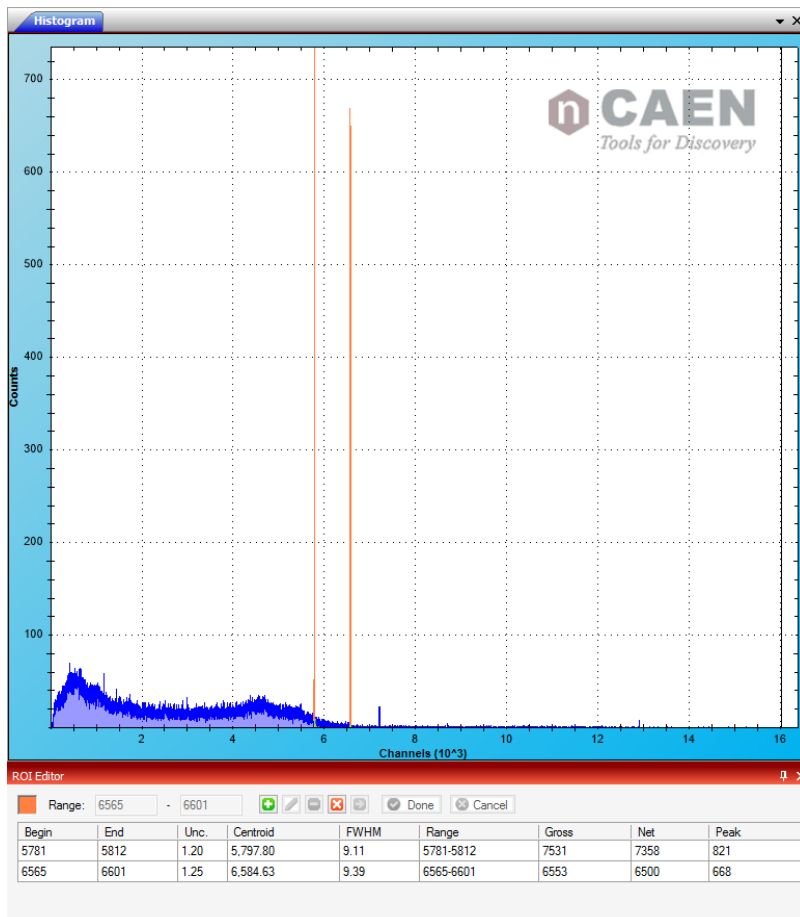
Then press “Done” from the ROI Editor window.



Left click on the ROI to check the fit and to get the parameters. Check Sect. **Menu Bar Items** for more details about the ROI fitting.

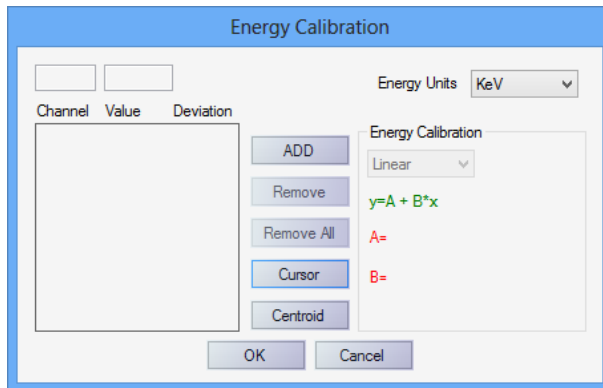


Repeat the same procedure for the second peak:

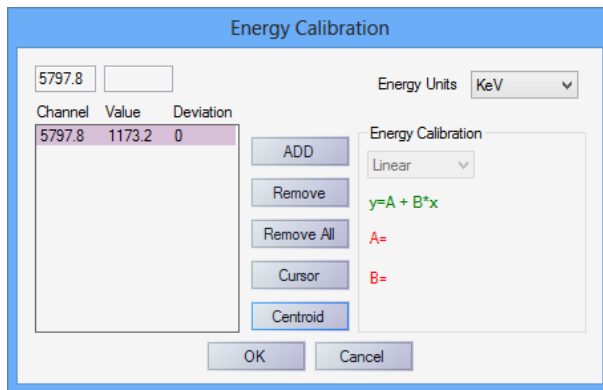


## Energy calibration

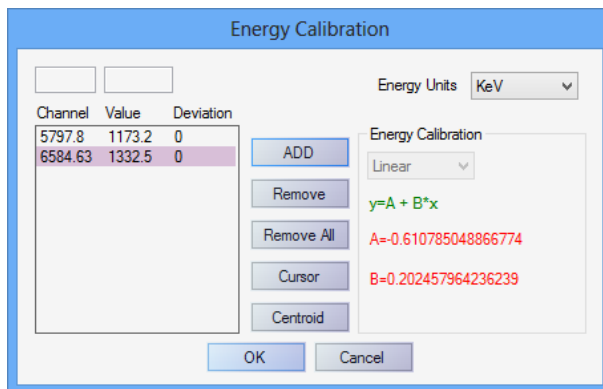
Open the “Energy Calibration” window :




Click on the first ROI and select “Centroid” to use the centroid value of the distribution. Write the desired value of energy, then click **ADD**.



Repeat for the second ROI, then click **OK**



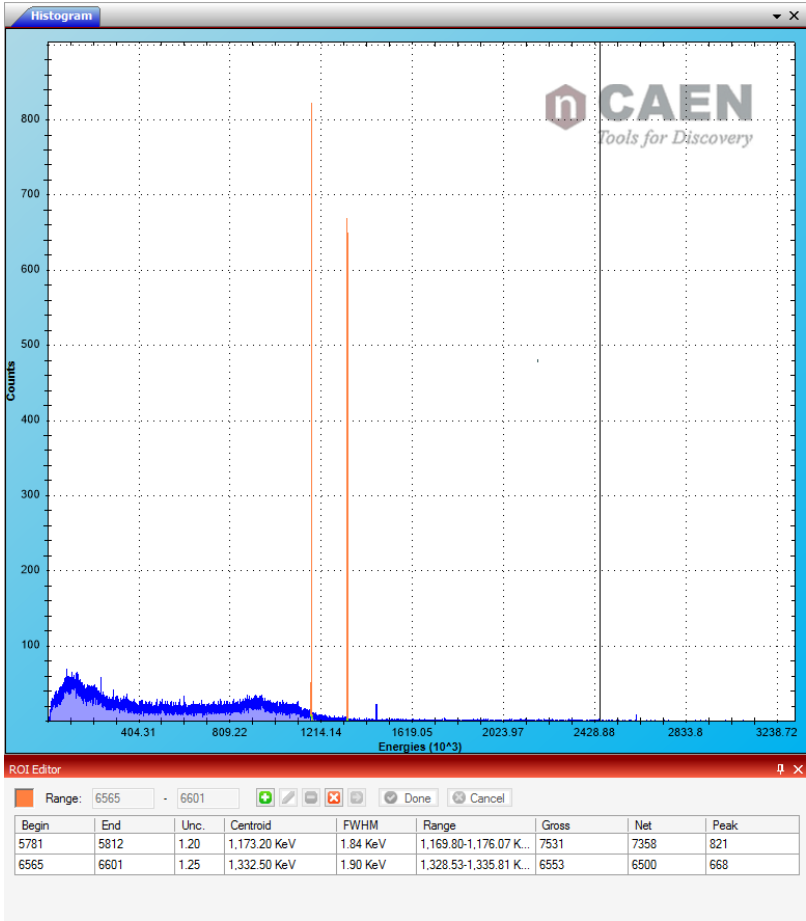
Press “Enable Calibration”  to enable the calibration of the spectrum. All the values on the ROI Editor window are automatically converted.



**Note:** It is usually recommended to choose two points having different energy values. The more the difference is high the more the linear calibration will be accurate.



**Note:** It is also possible to perform a calibration with a single peak, by setting the second point to 0. Set “Channel” = 0 and “Value” = 0.



## How To use Decimation

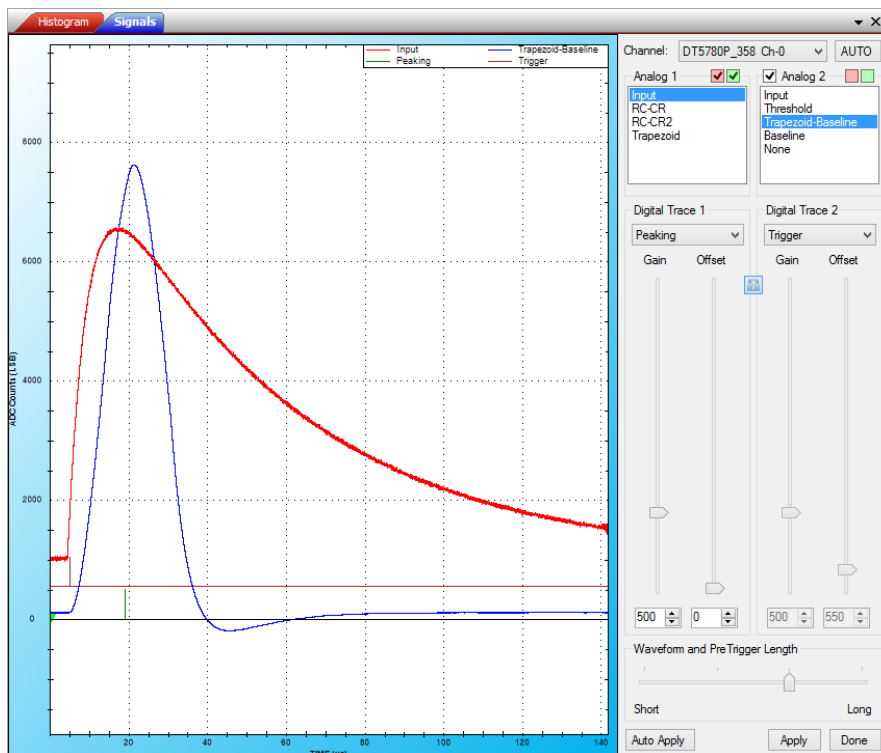
The decimation reduces the sampling rate of the board by means of performing an average value of a programmable number of consecutive samples.



**Note:** The decimation is not available for x730 series.

The decimation is quite convenient when the user wants to measure very long signals, or signals with long rise time. Moreover the decimation allows to increase the range of the trapezoid and timing parameters, as the Trapezoid Rise Time, Input Rise time, Flat Top, etc. by the same factor of the decimation value.

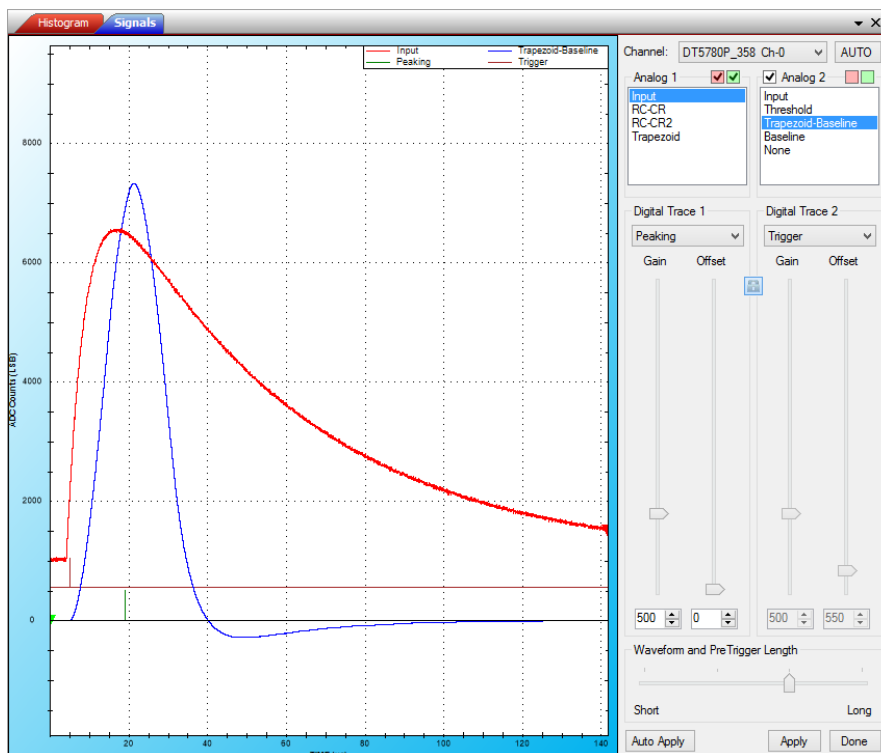
Usually the user can recognize the need of decimation when he/she set the maximum rise time and he/she cannot get a correct trapezoid, as shown in the following picture. In the typical situation the baseline of the “Trapezoid-Baseline” trace is not zero, the trapezoid is in overshoot, and there is no flat region.



Start with “Decimation” = 2.

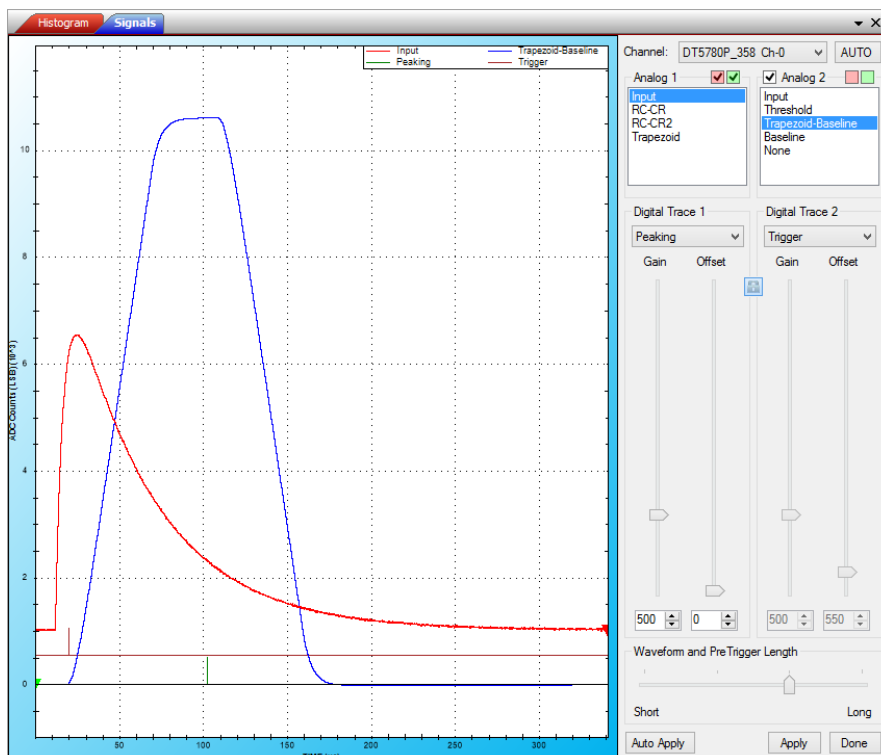


**Note:** When the decimation is enabled (which performs a mean calculation of the digital samples) it might be worth to also set the same value of “Digital Gain”. Anyway carefully check that the digitizer dynamics is not saturated. It is usually recommended to change the “Trapezoid Gain” rather than the “Digital Gain”.



For our example we set the “Input Rise Time” = 5 us (check the overall procedure of **How to set the Trigger**).

Increase the “Trapezoid Rise Time” and “Flat Top” until you reach a correct trapezoid. In this particular case we have to increase the **Decimation** up to 8, and set **Trapezoid Rise Time** = 50 us, and **Decay Time** = 40 us.






## How to save data

It is possible to save data in different ways:

1. Save the energy spectrum;
2. Save the list of Trigger Time Stamp and Energy for each event;
3. Save an image of the energy spectrum.

### Save the energy spectrum

It is possible to save the energy spectrum through the path: **File->Save**, or using the command .

Supported file formats are: .n42, .asc, .txt. For the .txt file there are several options, as shown in the following table.

ANSI N42.42 (*.n42)
ASCII (*.asc)
TXT Single Column (*.txt)
TXT Single Column, First bin Real Time, Second bin Dead Time (*.txt)
TXT Single Column, First bin Real Time, Second bin Live Time (*.txt)
TXT Double Column (ADCCH/Count) (*.txt)
TXT Double Column (ADCCH/Count), First bin Real Time, Second bin Dead Time (*.txt)
TXT Double Column (ADCCH/Count), First bin Real Time, Second bin Live Time (*.txt)
TXT Double Column (Energy/Count) (*.txt)
TXT Double Column (Energy/Count), First bin Real Time, Second bin Dead Time (*.txt)
TXT Double Column (Energy/Count), First bin Real Time, Second bin Live Time (*.txt)

In the .n42 file, the spectrum and the relevant properties are saved.

### Save the list file

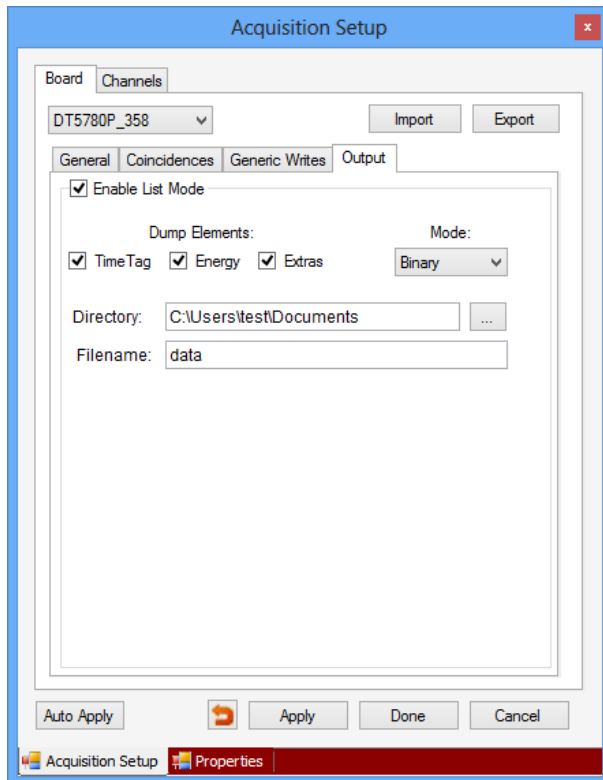
You can save the list file from the “**Acquisition Setup**” window, under the “**Board**” tab, select “**Output**”.

Click on “**Enable List Mode**” to enable the window.

The user can select the information to be saved among: **Time Tag**, **Energy**, and **Extras**.

**Binary** and **ASCII** writing are selectable.

Start the acquisition to start dumping the list file. The dump will stop with the stop acquisition.



To avoid useless file generation, a warning message appears at the bottom of the GUI when the list dumping is enabled.

**WARNING! List Mode Enabled**



**Note:** remember to increment the file name index. In case of a new “start acquisition” the new data events will be added to the previous list file.

### Save the Image

The user can export the spectrum in various image format, as listed in the following table.

Emf Format (*.emf)
PNG Format (*.png)
Gif Format (*.gif)
Jpeg Format (*.jpg)
Tiff Format (*.tif)
Bmp Format (*.bmp)

From “**File**” click on “**Export**”. Otherwise right click on the spectrum and select “**Save Image As**”.

## Troubleshooting

n	Issue	Possible Causes	Fixes
0	It is strongly recommended to first check from an oscilloscope device the signal from the pre-amplifier and check whether there is no grounding issue, and the pre-amplifier dynamics is not saturated. Check also Sect. <b>Before starting the acquisition</b> .		
1	Though I decrease the “Threshold”, I cannot reach lower values in the energy spectrum	The input signal is noisy and the trigger fires on the noise	Try to increase the <b>RC-CR<sup>2</sup> smoothing</b> factor to average the noise samples. Remember to perform all the steps described in Sect. <b>How to set the Trigger</b> when you modify the RC-CR <sup>2</sup> smoothing.
2	Values in the high region of the energy spectrum are cut off before the limit	The input signal is saturating	Check from the “ <b>Signal Inspector</b> ” whether the “ <b>Input</b> ” pulse saturates the dynamics. Try to first adjust the <b>DC Offset</b> . Then you can try to increase the “ <b>Input Range</b> ” (not available for x724 series). Check whether the “ <b>Digital Gain</b> ” is set too high and set it back to 1. It is preferable to modify the “ <b>Trapezoid Gain</b> ” for a fine adjustment of the dynamics.
3	The peaks in the spectrum show an asymmetric left (right) tail	The pole-zero cancellation might be not correct. The baseline restoration can be overestimated/underestimated	Check from the “ <b>Signal Inspector</b> ” whether the “ <b>Trapezoid</b> ” trace correctly returns to zero. Moreover it is suggested to set the maximum value for “ <b>Baseline Hold-Off</b> ”, and the minimum value of “ <b>Trigger Hold-Off</b> ”. This is more evident in case of high rate signal.
4	The resolution is worse than expected	Some settings might be better tuned	In case of low rate it is worth to set high value of “ <b>Trapezoid Rise Time</b> ”, as well high value of “ <b>Baseline Mean</b> ”
5	The BUSY led is ON, i.e. the “A” circle under the Spectra List window is red	There might be a saturation or a memory full	Check point 2. Also check that the <b>Signal Inspector</b> window is closed.

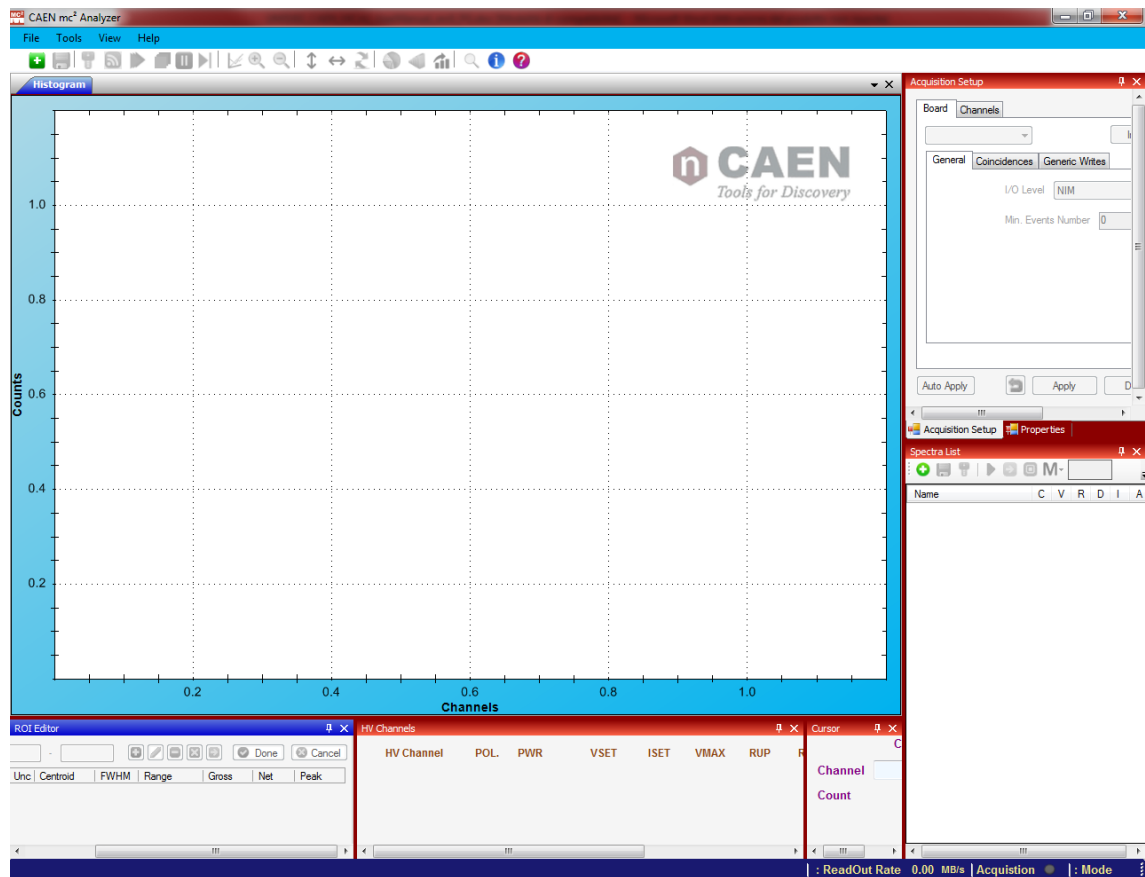
**Tab. 3.1:** Troubleshooting table. For any other specific issue not listed in the table please contact CAEN at the support mailing list (Chapter **Technical support**)

# 4 Software Interface

## GUI Description

### MC<sup>2</sup>Analyzer Initial Main Screen Description

When the MC<sup>2</sup>Analyzer program is launched, the following Initial Main Screen is displayed:



**Fig. 4.1:** MC<sup>2</sup>Analyzer Initial Main Screen

The CAEN MC<sup>2</sup>Analyzer Initial Main Screen is composed of one **Menu Bar**, one **Icon Bar** and 7 adjacent windows with the following functions (by default, clockwise):

- **Histogram Window**
- **Spectra List**
- **Properties Window**
- **Signal Inspector Cursors Window**
- **HV Channels Window**
- **Cursors Window**
- **ROI Editor Window**

Each of the above indicated 7 windows can be left floating, re-positioned and closed independently at the operator convenience. Each window can be recalled to the main screen by using the Menu Bar pull down menu from the items: View/Windows. Mark or unmark the items on the “Windows” pull down menu respectively to show or to hide the corresponding Window on the Main Screen.

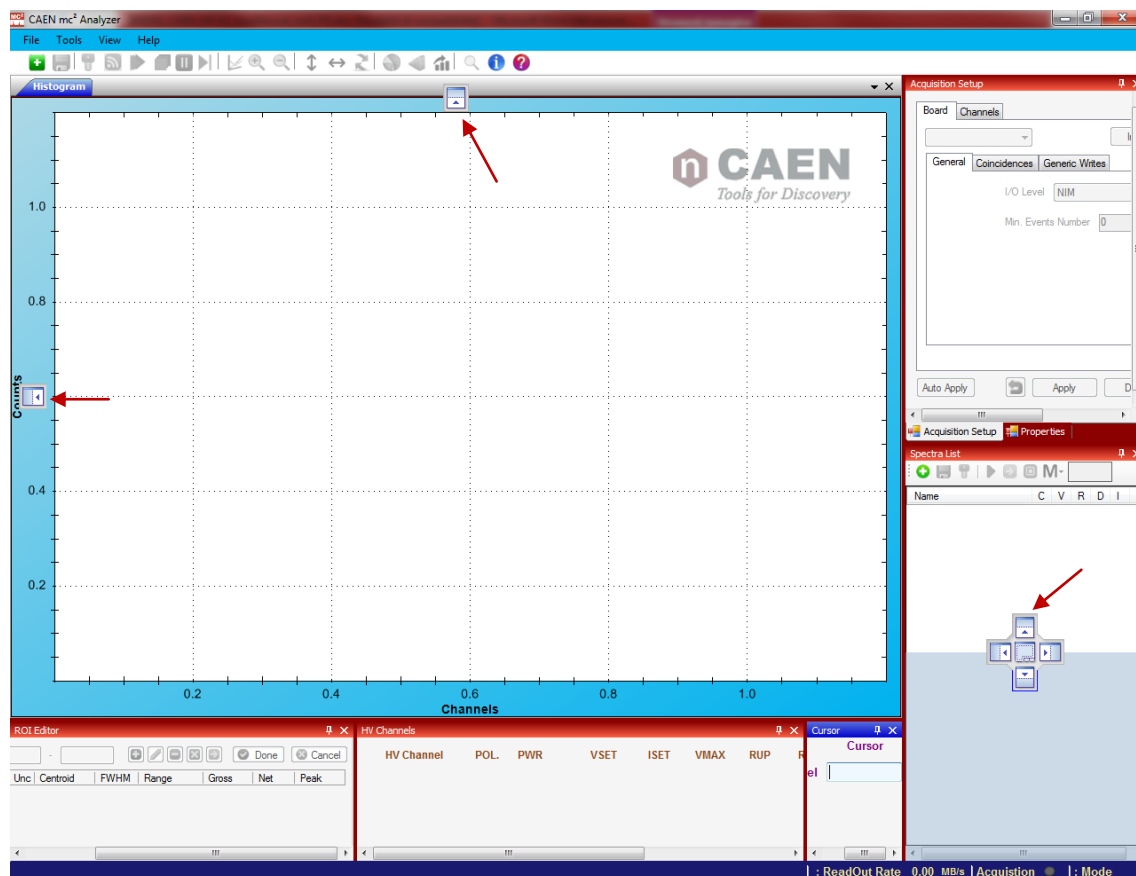


Fig. 4.2: MC<sup>2</sup>Analyzer floating windows

To interact with a window, click on it with the mouse pointer. The upper frame of the active window will turn blue. When another window is activated, the upper frame of the previously selected window turns light brown.



**Note:** The full Initial Main Screen appears when the MC<sup>2</sup>Analyzer program is launched for the first time. Successively, upon launching the MC<sup>2</sup>Analyzer program, the Main Screen will display only the windows that were active upon the previous shutdown of the MC<sup>2</sup>Analyzer program. To return to the full Initial Main Screen display, all windows need to be checked for display from the **View/Windows** pull-down menu (see Sect. **Menu Bar** Items).



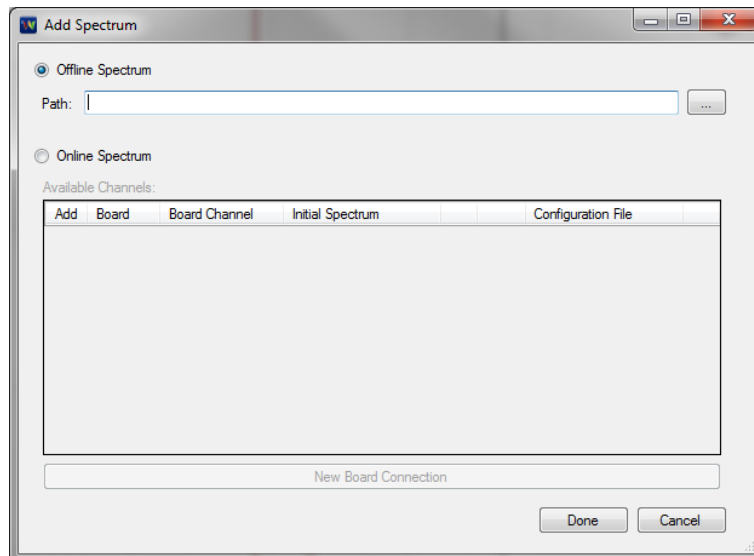
**Note: AutoHide Function.** Each window can be set to AutoHide by clicking on the vertical Tack Pin icon in the upper right frame of the window itself. When enabled, the window will reduce to a Tab along the bottom frame of the Main window. It can be recalled by clicking on that tab, becoming then the active window (frame turns blue). It will AutoHide again when cursor is clicked on another window. When AutoHide is enabled the Tack Pin icon is horizontal. AutoHide is disabled by clicking on the horizontal Tack Pin icon or, automatically, when the window is closed.

At the bottom of the MC<sup>2</sup>Analyzer Main Screen a blue **System Status Bar** displays the following information about the current activity of the System: Rebin Enabled or Disabled./Read-out Rate in MB/sec. /Acquisition Status (LED) /System Mode : Spectrum

### Menu Bar Items

The menu bar is constituted by the following items: **File**, **Tools**, **View**, and **Help**.

- ✓ **FILE**: the pull down Menu shows the following items: **Add Spectrum/Save/Export/Exit**
- **Add Spectrum** : This function allows the user to recall an acquired spectrum or initiate a new spectrum acquisition.



**Fig. 4.3:** MC<sup>2</sup>Analyzer Menu Bar – “File/Add Spectrum” Dialog Box

To recall and display a recorded spectrum, select the **“Offline Spectrum”** button. The recorded spectra files can be recalled either by typing the file path in the **Path** entry box either by left clicking on the **“...”** button on the right of the **Path** entry Box. When clicking on the **“...”** button, a Windows Directory window will open up, allowing the retrieval of a recorded spectrum file from a previously created storage folder.

Accepted file formats are:

- .n42, CAEN Channel Settings;
- .asc, ASCII.

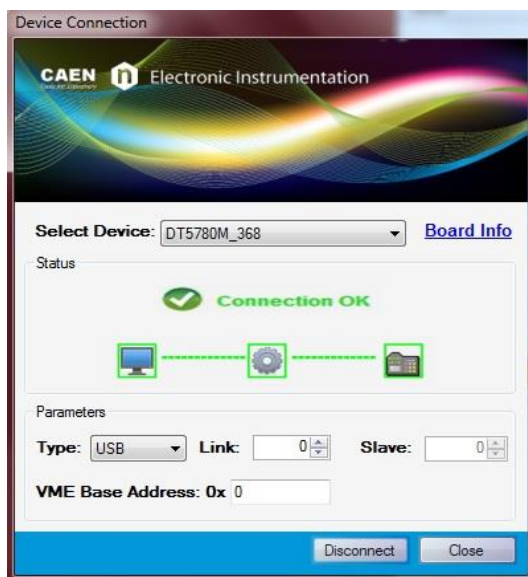
Left click **“Done”** when the file path is entered or the file path is selected, to recall the file data to the display screens. The recalled spectrum will then be displayed in the Histogram window and a line with the corresponding Spectrum filename will be added to the **Spectra List** window.

To set up a new acquisition, select **“Online Spectrum”**. Left click on **“New Board Connection”**. The following dialog box will appear:



**Fig. 4.4:** MC<sup>2</sup>Analyzer Menu Bar - “File/Add Spectrum/New Board Connection” Dialog Box

Select **“Add New Device”** from the **“Select Device”** Pull down menu. Select the proper connection parameters. In the following example we used USB connection to the DT5780, therefore: Type = USB, Link, Slave, VME Base Address = 0. Left click on **“Connect”**.

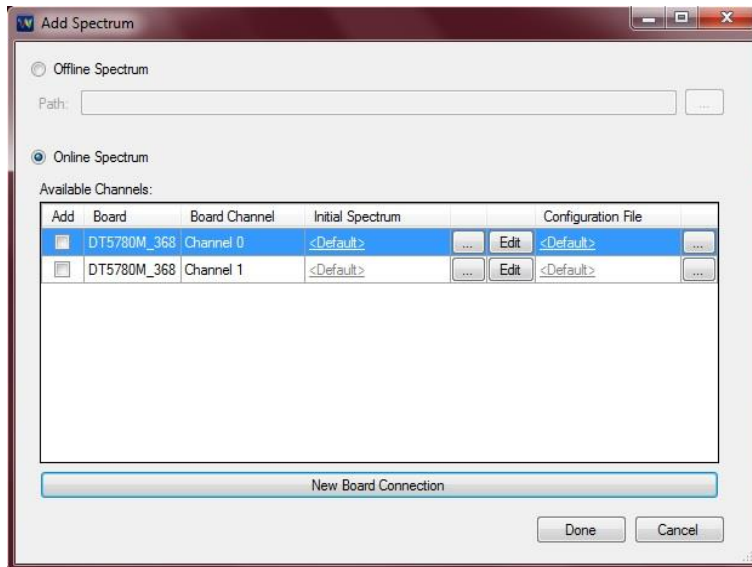


**Fig. 4.5:** MC<sup>2</sup>Analyzer Menu Bar - “File/Add Spectrum/New Board Connection/Connect” Dialog Box

Upon successful connection, a green **“Connection OK”** message will appear. Underneath it, a dotted green link will appear between the Computer Screen Icon, the Settings Icon and the Hardware icon, indicating that the system connections for data acquisition and display have been correctly configured.

Repeat this operation separately for all the hardware devices that have to be connected. Additional devices can be added later at any time by repeating the above procedure after left clicking on the **“New Board Connection”** indicated in **Fig. 4.3**. When done, left click on the **“Close”** button.

The following dialog box will then appear (see **Fig. 4.6**), allowing the user to select and mark the digitizer channels to be enabled for the acquisition and display of new live spectra:



**Fig. 4.6:** MC<sup>2</sup>Analyzer Menu Bar - “File/Add Spectrum/New Board Connection/Connect/Close” Dialog Box

After the connection is made correctly, the Add Spectrum Window will show each acquisition channel recognized by the system. Five columns are available:

- **Add**, that allows to add a specific channel. Click on “**Add**” itself to add all channels;
- **Board**, where the board model and serial number are specified;
- **Board Channel**, where the channel number is specified;
- **Initial Spectrum**, that allows to upload an initial spectrum to be added to the online spectrum. The “...” button allows to browse a spectrum to be loaded. The button “**Edit**” allows to modify the spectrum properties. See **Fig. 4.7** and **Fig. 4.8**;
- **Configuration File**, allows to upload a configuration file.



**Note:** The configuration settings can be modified in the GUI itself.

Recorded Initial Spectrum Files and Configuration Files can be loaded by left clicking on the “...” button to the right of the respective entry boxes, from folders located in the Windows directory. Each channel can then be activated by marking the correspondent check box to the right of the channel line. Only the activated channels can be set and read by the acquisition system. To deactivate a channel, the user can unmark the check box on its line at any time.

Unless a different Spectrum File is loaded, the “defaultSpectrum.n42” file is recalled and the Initial Spectrum Column will show “<Default>” on the Channel lines. This is the File containing the Data and the Settings of the Spectrum from the last acquisition made before the MC<sup>2</sup>Analyzer program was turned off. To upload a different file, right click on the “...” key to the right of the Initial Spectrum column and access the desired “filename.n42” file in the Windows directory that opens up.

Unless a different Configuration File is loaded, the “defaultChannel.ccs” file is recalled and the Configuration File Column will show “<Default>” on the Channel lines. This is the File containing the Data and the Settings of the hardware Channels from the last acquisition made before the MC<sup>2</sup>Analyzer program was turned off. To upload a different file, left click on the “...” key to the right of the Configuration File column and access the desired “filename.ccs” file in the Windows directory that opens up.

The user can tag the spectrum files by left clicking on the “**Edit**” key of the corresponding channel line. The **Add Spectrum Edit Properties** Dialog Box will appear as in **Fig. 4.7**. The five Pull Down menus allow the user to indicate:

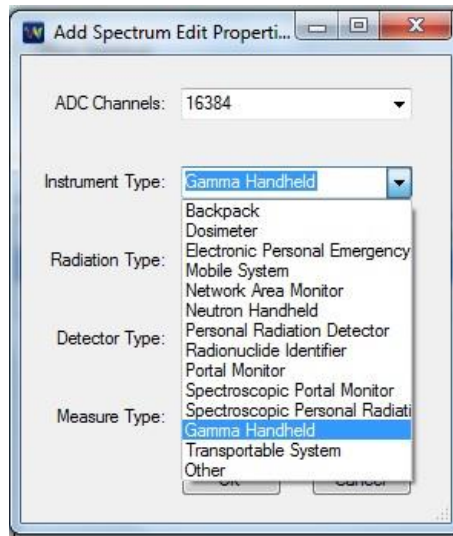
- The Number of Channels in the Spectrum, choosing among: 1024,2048,4096,8192,16384;
- The Type of Instrument used for the data acquisition;
- The Nuclear Radiation detected: Alpha, Beta, Gamma, Neutron, X-Ray;
- The Detector Type;



- The Type of Measurement executed.

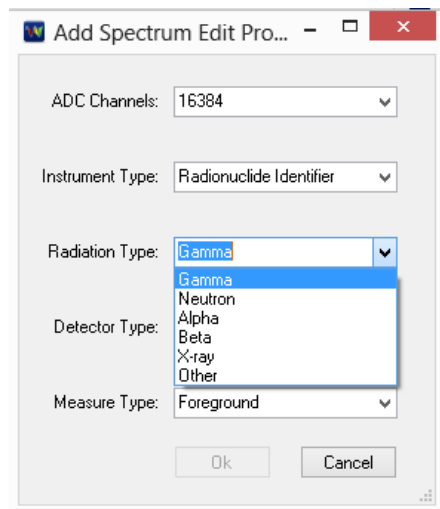
The ADC Channels pull down menu allows the user to select the number of channels of the histogram, i.e. the energy resolution ranging from 1024 channels (10 bits, NaI grade) to 16384 channels (14 bit, HPGe grade).

The Instrument Type pull down menu allows the user to tag the type of equipment being used.



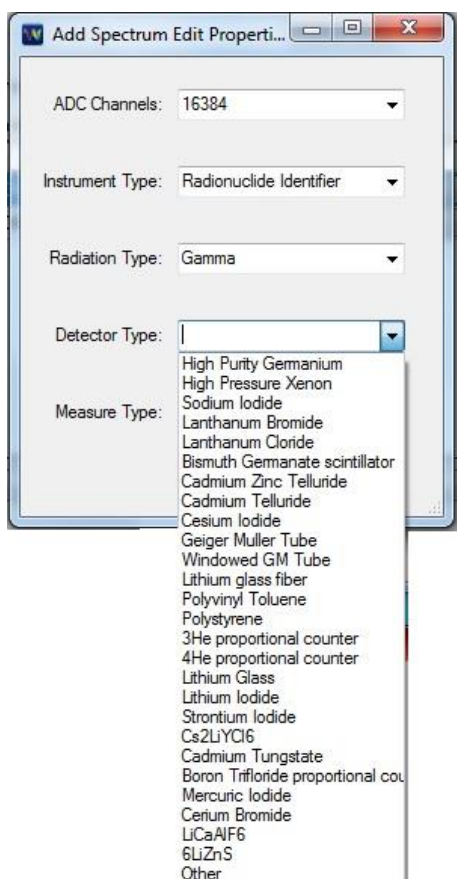
**Fig. 4.7:** MC<sup>2</sup>Analyzer Wizard Dialog Box – “File/Add Spectrum/EditProperties” Dialog Box - Instrument Type Pull Down Menu

The Radiation Type pull down menu allows the user to tag the type of radiation to be measured.



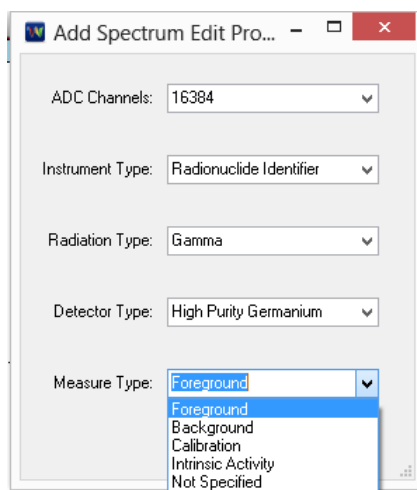
**Fig. 4.8:** MC<sup>2</sup>Analyzer Wizard Dialog Box – “File/Add Spectrum/EditProperties” Dialog Box - Radiation Type Pull Down Menu

From the **Detector Pull Down Menu** (See **Fig. 4.8**) the user can associate to the recorded file the type of Detector that was used to execute the measurement.



**Fig. 4.9:** MC<sup>2</sup>Analyzer Wizard Dialog Box – “File/Add Spectrum/EditProperties” Dialog Box - Detector Type Pull Down Menu

Finally, the Measure Type pull down Menu allows the user to select the type of measurement.



**Fig. 4.10:** MC<sup>2</sup>Analyzer Wizard Dialog Box – “File/Add Spectrum/EditProperties” Dialog Box - Measure Type Pull Down Menu

- **Save:** This Pull Down Menu item allows the user to save an acquired spectrum. To save a new acquisition, left click on **“Save”**. A Windows Directory window will appear, allowing the user to save the acquired file in the desired directory. Accepted file formats are:

- .n42, ANSI N42.42;
- .asc, ASCII;
- .txt, various text file format with single or double column, as shown in the following table.

TXT Single Column (*.txt)
TXT Single Column, First bin Real Time, Second bin Dead Time (*.txt)
TXT Single Column, First bin Real Time, Second bin Live Time (*.txt)
TXT Double Column (ADCCH/Count) (*.txt)
TXT Double Column (ADCCH/Count), First bin Real Time, Second bin Dead Time (*.txt)
TXT Double Column (ADCCH/Count), First bin Real Time, Second bin Live Time (*.txt)
TXT Double Column (Energy/Count) (*.txt)
TXT Double Column (Energy/Count), First bin Real Time, Second bin Dead Time (*.txt)
TXT Double Column (Energy/Count), First bin Real Time, Second bin Live Time (*.txt)

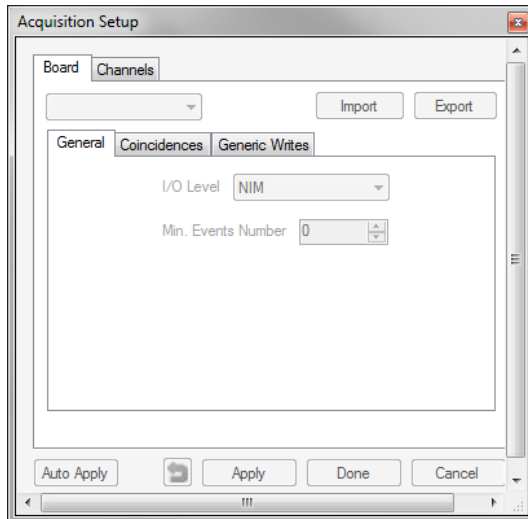
- **Export:** This Pull Down Menu item allows the user to export the acquired spectrum as an image. The same menu is available at the **“Save Image As”** (right click on the spectrum). Accepted file formats are:

- .emf, EMF;
- .png, PNG;
- .gif, GIF;
- .jpg, JPEG;
- .tif, TIFF;
- .bmp, BMP.

- **Exit:** This Pull Down Menu item allows the user to exit the MC<sup>2</sup>Analyzer Program. When it is used, the MC<sup>2</sup>Analyzer program will save automatically the data acquired, the Spectra settings and the channels configuration to the corresponding Default files.

✓ **TOOLS:** the pull down Menu shows the following items: **Create ROI/ Rebin Dialog/ Acquisition Setup/ Start Acquisition/ Stop Acquisition/ Pause Plot Update/ Single Plot Update/ Calibration Setup/ Enable Calibration/ Logarithmic Scale/ Peak Search/ Background/ Peak Fitting**

- **Create ROI:** This function allows the user to define a Region Of Interest (ROI). Left clicking on the Create ROI item opens the ROI Editor window (unless it was already open). Default position is leftmost under the Graph Window. See Section **ROI Editor Window** for ROI creation procedures.
- **Rebin Dialog:** Clicking on the “Rebin Dialog” allows the user to transform a High Resolution Spectrum (i.e. a 16K channels spectrum) into a lower resolution spectrum (i.e. a 2 K channel spectrum) by clustering the values of the counts in the adjacent bins according to the rebin factor (i.e. the counts values of 8 adjacent bins of a 16K spectrum are summed into the corresponding single bin in a 2 K channels spectrum). Accepted vales are: 16K, 8K, 4K, 2K, 1K. The same menu is available from the **“Edit”** function of **Fig. 4.6**, at the pull down menu **“ADC channels”**.
- **Acquisition Setup:** When clicking on the “Acquisition Setup” item, the following window opens up:



**Fig. 4.11:** MC<sup>2</sup>Analyzer Menu Bar/Tools/Acquisition Setup/Board Tab

The **Acquisition Setup** features the **Board** Tab, allowing the user to select the Unit being set from the Pull Down Menu on the upper left corner of the Tab. Current settings values can be imported from the selected hardware unit and values set in MC<sup>2</sup>Analyzer can be exported to the selected hardware unit by using the “Import” and “Export” keys respectively, located in the upper right corner of the Board Tab. See Section **Acquisition Setup** for details about the Acquisition Set Up Dialog Box description.

- **Start Acquisition:** : This function enables the digitizer unit to start the acquisition on all channels. When the unit is ready to acquire data the icon bar the triangle icon is green. Upon clicking on the **Start Acquisition** item, data acquisition begins and on the Icon Bar the Start Acquisition icon turns grey while the Stop Icon turns red.
- **Stop Acquisition:** This function enables the digitizer unit to stop the acquisition on all channels. When the unit is acquiring data the icon bar the square Stop Acquisition icon is red. Upon clicking on the **Stop Acquisition** item, data acquisition stops on all channels and on the Icon Bar the Stop Acquisition icon turns grey while the Start Icon turns green.
- **Pause Plot Update:** This item function freezes the graphic update of the spectra being displayed. The acquisition on the corresponding hardware channels still continues.
- **Single Plot Update:** This item function performs a single update of the spectra being displayed
- **Calibration Setup:** This item function enables the user to enter the relevant energy calibration data. See Section **MC<sup>2</sup>Analyzer Energy Calibration** for a complete description of the procedure and system features.
- **Enable Calibration:** This item function enables the energy calibration. See Section **MC<sup>2</sup>Analyzer Energy Calibration** for a complete description of the procedure and system features.
- **Logarithmic Scale:** This icon function allows the user to toggle between Linear and Logarithmic Scale on the Y-axis.
- **Peak Search:** This item function allows the user to search for peaks. It is only enabled when the **Background “Advanced”** option has been selected and the corresponding data have been entered. Under those conditions by clicking on this item the following dialog box will appear on top of the graph. The user can set the “**Sigma**” and “**Threshold**” values, where “Sigma” is the sigma of the searched peaks, and “Threshold” allows the user to discard events with amplitude less than threshold times the highest peak amplitude. Refer to **[RD4]** for more details.

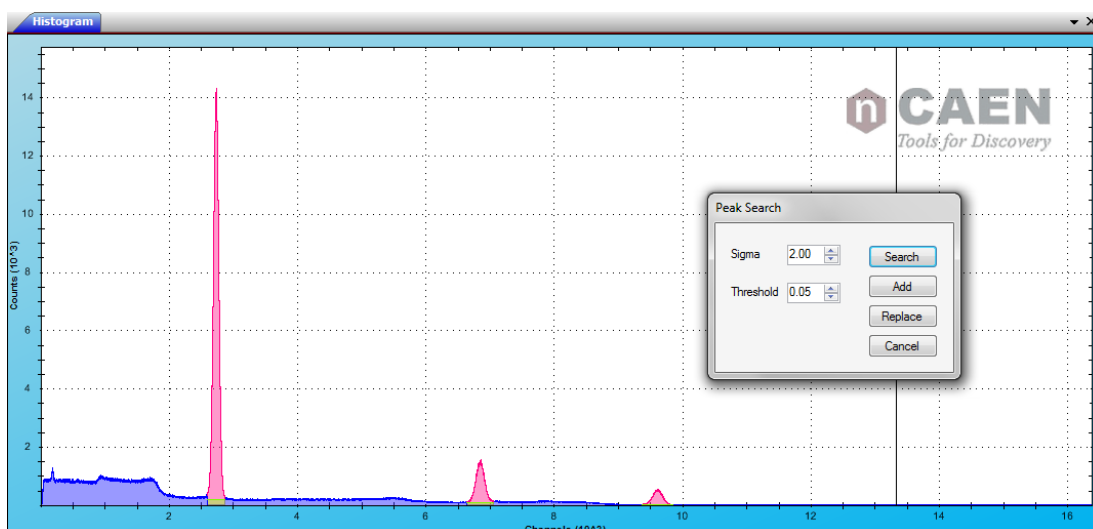


Fig. 4.12: MC<sup>2</sup>Analyzer Menu Bar/Tools/Peak Search Dialog Box

When clicking on the “**Search**” key the relevant peak corresponding to the entered criteria are highlighted, as shown in Fig. 4.12, and the parameter values of each valid Peak are listed as individual lines in the ROI Editor window.

The “**Add**” key allows the user to add to the previous search a new one with different conditions. The “**Replace**” Key allows the user to erase the previous search list and replace it with the new search one.

At any time, the user can cancel the parameters with the “**Cancel**” key. Clicking on the Peak Search Icon or on the Peak Search item in the Tools/Peak Search Pull-Down menu erases the previous search list as well.

- **Background:** This item has a Pull-down Menu with the following items: **Simple/Advanced/ Configure**

The user can toggle between “**Simple**” and “**Advanced**”.

In the Simple option the background is evaluated as a simple line between the ROI edges.

The “**Advanced**” option allows the user to access the “**Configure Background**” item. By clicking on the Configure Background the following Dialog Box appears:



Fig. 4.13: MC<sup>2</sup>Analyzer Menu Bar/Tools/Background/(Advanced)Configure Dialog Box

The user can enter the **LLD** (Lower Level Discriminator) and **ULD** (Upper Level Discriminator) background values in the corresponding entry boxes as well as the desired Number of Iterations **niters** for the Background calculation. While in the Simple option the background is evaluated only in the ROI range, the Advanced option allows the user to include in the background calculation the full spectrum included into the LLD and ULD range. The more the niters value is increased, the more the background shape is smoothed. Decreasing this value will probably discard lower peaks. The user should find the proper compromise.

- **Peak Fitting:** this function determines how the peaks are fitted, choosing between **Simple/Advanced**.

**Simple:** the algorithm makes use of a Gaussian shape, whose centroid is evaluated as the weighted average, and the sigma is evaluated as the distance from the mean value, as the RMS;

**Advanced:** this function enables the Gaussian fit of the ROI using the minimum chi square method.

- ✓ **VIEW:** the pull down Menu shows the following items: **Windows/ Zoom In/ Zoom Out/ Autoscale/ Full X Range/ Restore Scale**
  - **Windows:** Allows the user to select the Windows to be displayed on the MC<sup>2</sup>Analyzer Main Screen from the following Pull Down Menu: Spectrum Properties/ Spectrum List/ Histogram/ HV Channels/ ROI Editor/ Cursor/ Signal Inspector Cursors.
  - **Zoom In:** Allows the user to expand horizontally (and, in proportion, vertically) an area of the Histogram Graph symmetrical with respect to a central vertical marker line which can be set by positioning the crosshair marker in the desired central point and left clicking on it. Upon release the “horizontal expansion center” vertical marker line will remain set until a new position is selected by repeating the above procedure.
  - **Zoom Out:** Allows the user to reduce horizontally (and, proportionally, in vertical) an area of the Histogram Graph symmetrical with respect to the previously set central vertical marker line.
  - **Autoscale:** When enabled, this command will automatically resize the vertical (counts) Y-axis to fit the highest counts peak into the visible Graph area.
  - **Full X Scale:** When selected, this command will restore the graph display to the full X- axis original dimension.
  - **Restore Scale:** When selected, this command will restore the graph display to the full original scale.
- ✓ **HELP:** the pull down Menu shows the following items: **About/ Context Help F1**
  - **About:** This Pull Down Menu item opens a dialog box containing information about the manufacturer and the Version of the MC<sup>2</sup>Analyzer Software.



**Fig. 4.14:** MC<sup>2</sup>Analyzer Menu Bar/Help/About Dialog Box

- **Context Help F1:** (under development)





















## Icon Bar

The following Icon Bar is present under the MenuBar:



Fig. 4.15: MC<sup>2</sup>Analyzer Icon Bar

The above icons correspond to the following functions (from left to right) :

- 1) **Add Spectrum**  : This icon has the same function of the Menu Bar/ File/ Add Spectrum command (see above)
- 2) **Save Spectrum**  : This icon has the same function of the Menu Bar/ File/ Save Spectrum command (see above)
- 3) **Configure Acquisition**  : This icon function allows the user to Configure the Acquisition Parameters of the Board. (See Section **Acquisition Setup**)
- 4) **Signal Inspection**  : This icon function enables the user to visualize on the graphic screen the actual shape of the raw electronic signal(s) coming from the nuclear radiation detector(s)
- 5) **Start Acquisition for All Channels**  : This icon function enables the MCA unit to start the acquisition on all channels. When the unit is ready to acquire data this triangle icon is green. Upon clicking on the icon, data acquisition begins and the icon turns grey while the Stop Icon turns red.
- 6) **Stop Acquisition for All Channels**  : This icon function enables the MCA unit to stop the acquisition on all channels.  
When the unit is acquiring data, this square icon is red. Upon clicking on this icon the acquisition is stopped and the icon turns grey while the Start Icon turns green.
- 7) **Pause Plot Update**  : This icon function freezes the graphic update of the spectra being displayed. The acquisition on the corresponding hardware channels still continues.
- 8) **Single Plot Update**  : This icon function performs a single update of the spectra being displayed.
- 9) **Logarithmic Scale**  : This icon function allows the user to toggle between Linear and Logarithmic Scale on the Y-axis.
- 10) **Zoom In**  : Allows the user to expand a selected area of the graph. The graph is expanded symmetrically with reference to the position of the vertical bar cursor activated by right clicking with the crosshair cursor in the desired position of the graph area. It is also possible to click on the spectrum and press the keyboard command "+".
- 11) **Zoom Out**  : Allows the user to reduce a previously enlarged area of the graph. It is also possible to click on the spectrum and press the keyboard command "-".
- 12) **Enable Vertical Autoscale**  : When enabled, this command will perform an automatic resizing of the Y-axis scale, according to the largest spectrum peak height (highest number of counts in a "bin").
- 13) **Horizontal Autoscale**  : When enabled, this command will perform an automatic resizing of the X-axis scale, according to the number of the highest channel containing significant data.
- 14) **Restore Scale**  : This icon function restores the Graph scale to its originally dimensions, both on the X and the Y axis.
- 15) **ROI Editor**  : This icon function is a shortcut to recall to the MC<sup>2</sup>Analyzer Main Screen the ROI Editor window, in case it had been removed.
- 16) **Enable Calibration**  : This icon function enables the energy calibration. See Section **MC<sup>2</sup>Analyzer Energy Calibration** for a complete description of the procedure and system features.
- 17) **Calibration Setup**  : This icon function enables the user to enter the relevant energy calibration data. See Section **MC<sup>2</sup>Analyzer Energy Calibration** for a complete description of the procedure and system features.
- 18) **Peak Search**  : This icon function allows the user to search the Spectrum for Peaks. It has the same features as the Peak Search item in the Tools/Peak Search Pull Down Menu. Please refer to the Peak Search Item of Section **Menu Bar Items** for the description.
- 19) **About**  : This Icon opens a dialog box containing information about the manufacturer and the Version of the MC<sup>2</sup>Analyzer Software.
- 20) **Context Help**  : (under development)

## Histogram Window

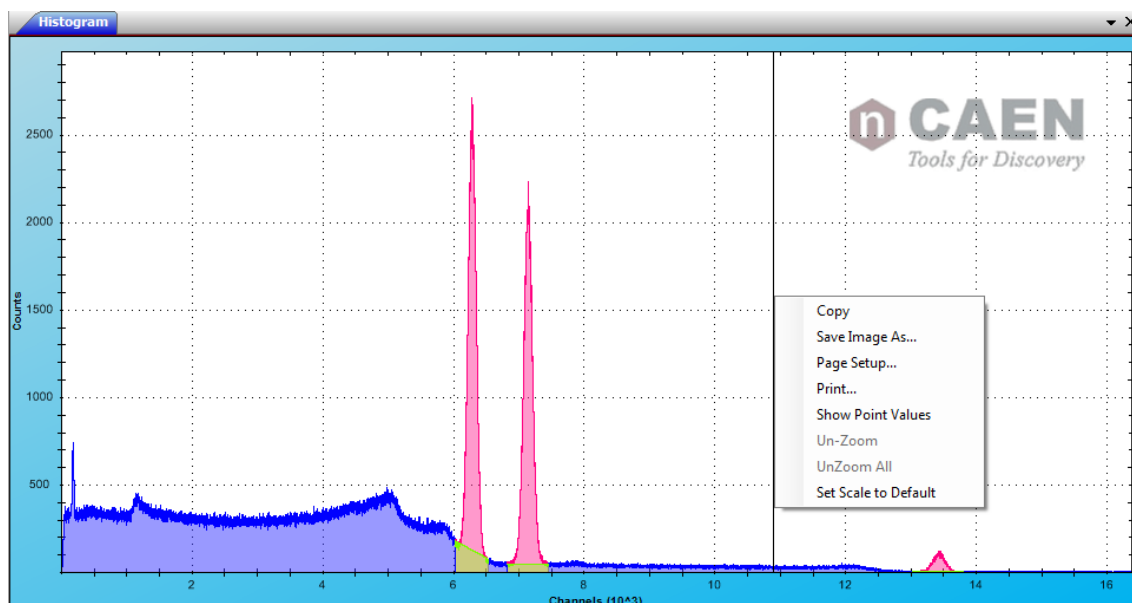


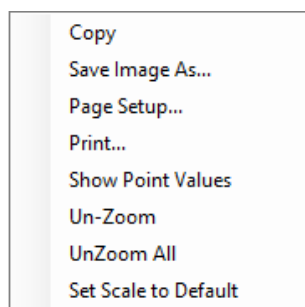
Fig. 4.16: The Histogram Window

The Histogram Window allows the user to display the histogram of the **Counts vs Energy** “bin” or “Channel” when the spectrum is Uncalibrated, and the Counts vs Energy in keV or MeV when the spectrum is calibrated.

**Crosshair cursor:** a crosshair cursor is present on the graph window. By left clicking on it a vertical marker bar is set on the graph. The marker bar can be moved by left clicking in the desired position of the graph, any time.

**Zoom:** any section of the graph can be expanded by positioning the crosshair cursor to the leftmost point of the section of the graph to be expanded, left clicking and holding down while dragging the cursor to the rightmost point of the region of interest. By releasing then the mouse left key the graph section will be expanded.

By positioning the computer pointer on the Graph and right clicking on it, a pull down menu is activated, allowing the user to perform the following functions:



- **Copy:** The Histogram Window image is copied into the clipboard. A Dialog Message will confirm that the image has been copied. Click on “OK” to close the Dialog Message.
- **Save image as...:** This command opens a Windows Directory window allowing the user to store the Graph as a graphic image file in the desired folder. The default format is “filename.emf”. Other available formats are:
  - Emf Format (\*.emf)
  - PNG Format (\*.png)
  - Gif Format (\*.gif)
  - Jpeg Format (\*.jpg)
  - Tiff Format (\*.tif)
  - Bmp Format (\*.bmp)
- **Page setup...:** This command allows the user to set up the page for printing the graph, by selecting the size, margins, page orientation and margins of the print out.
- **Print...:** This command allows the user to print the graph page.
- **Show Point Values:** When enabled, this selection enables the visualization on the graph next to the crosshair cursor of its position (X,Y) values.



- **Un-Zoom:** This command will un-zoom the last previously expanded section of the graph, in successive steps. If this command is in grey shaded color it means there is no current zoom applied to the spectrum.
- **Un-Zoom All:** This command will un-zoom the last previously expanded section of the graph at once to the initial scale.. If this command is in grey shaded color it means there is no current zoom applied to the spectrum.
- **Set Scale to Default:** This command restores the Default Scale on the graph.

## HV Channels Window



**Note:** This window can be used only when the acquisition system includes the CAEN DT5780 MCA units.

Upon starting the MC<sup>2</sup>Analyzer program and when the “HV Channels” window is enabled in the View/Windows Pull-down Menu, the “**HV Channels**” window will list all the HV Channels that are available for set-up.

By positioning the pointer on each of the Header Line items VSET, ISET, VMAX, RUP, RDWN, VMON, and IMON, a label with relevant information concerning the engineering values in which the value is expressed, is displayed (i.e. V, microA, V/sec). Each HV Channel line contains the following information:

- **HV Channel:** The HV Channel is identified by the Hardware Model Number, Serial Number and Channel Number (in the format HVX where X is the Channel Number indicated near the Hardware output of the unit).
- **POL:** Indicates the HV Output Polarity (Positive or Negative).
- **PWR:** Allows the user to turn ON and OFF the High Voltage Output on the unit. The LED light the right of the ON/OFF key of a Positive HV Channel turns red when the HV Output is turned ON. The LED of a Negative HV Channel turns orange. When the HV are switched OFF the LEDs remain lighted and turn grey only when the HV Output ramp down is finished and the HV Output is OFF.
- **VSET:** Allows the user to set the required Voltage in steps of 1 Volt. The value can be either typed into the entry box or increased and decreased by using the up and down arrows. This is the actual value of the Voltage that will be applied to bias the Nuclear Radiation Detector HV input. However, if the value entered is larger than the VMax set value, the VMax value will overrule the VSET request and limit the maximum HV output to the VMax value.
- **ISET:** Allows the user to set the Maximum allowed current in steps of 1 microampere.
- **VMAX:** Displays the Maximum High Voltage allowed on the corresponding channel. When the pointer is on the underlined figure, a small note window will display the value unit (Volts). The Maximum Allowed High Voltage Output can be modified by the user by left clicking on the value number. The Set VMax Dialog Box will appear (see Fig. 4.17):

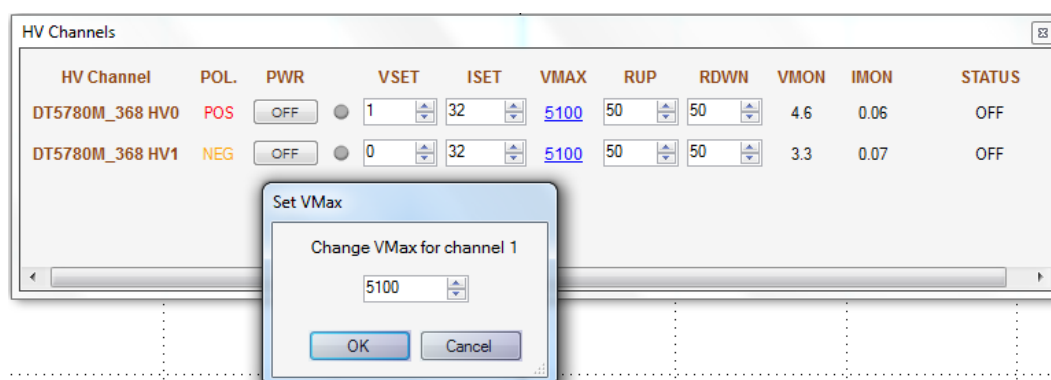


Fig. 4.17: The High Voltage Window with the “Set VMax” Dialog Box overlapping

The Maximum High Voltage value can be set in steps of 1 Volt from 0 up to the maximum output value allowed by the hardware, by typing it into the entry box or by increasing or decreasing it by using the up and down arrow keys. If the VSET value is set to a value larger than VMax, then VMax setting will overrule the VSET request and limit the HV Output to the VMax value. If this happens, the STATUS column will display a red “VMax Protection” warning message.

- **RUP:** Upon power up the HV Units outputs are always initialized at V=0 Volts. When the HV output is enabled thru the PWR ON/OFF key, the voltage at the channel output will ramp up at the speed set in the RUP by the user, indicated in Volts/second. The RUP value can be set in steps of 1 V/sec by typing it into the entry box or by increasing or decreasing it by using the up and down arrow keys.

- **RDWN:** When the HV output is disabled thru the PWR ON/OFF key, the voltage at the channel output will ramp down at the speed set in the RDWN by the user, indicated in Volts/second, until the 0 Volt value is obtained. The RDWN value can be set in steps of 1 V/sec by typing it into the entry box or by increasing or decreasing it by using the up and down arrow keys.
- **VMON:** Indicates the actual Voltage at the Output of the corresponding channel, in Volts.
- **IMON:** Indicates the actual Current at the Output of the corresponding channel, in microA.
- **STATUS:** When a Channel is turned ON, the STATUS column will display the “Ramp up” message until the VSET value is reached, then the ON Status of the corresponding HV Channel is displayed.

When a Channel is turned OFF, the STATUS column will display the “Ramp down” message until the 0 value is reached, then the OFF Status of the corresponding HV Channel is displayed.

If the system Output tries to exceed the VMax value (for example upon a VSET request for a value larger than VMax) then the “VMax protection” warning message is displayed in red in the STATUS column line of the protected channel.



**WARNING:** When shutting off the HV, it is recommended to wait until the HV ramp down of the HV Outputs is completed before exiting the program.

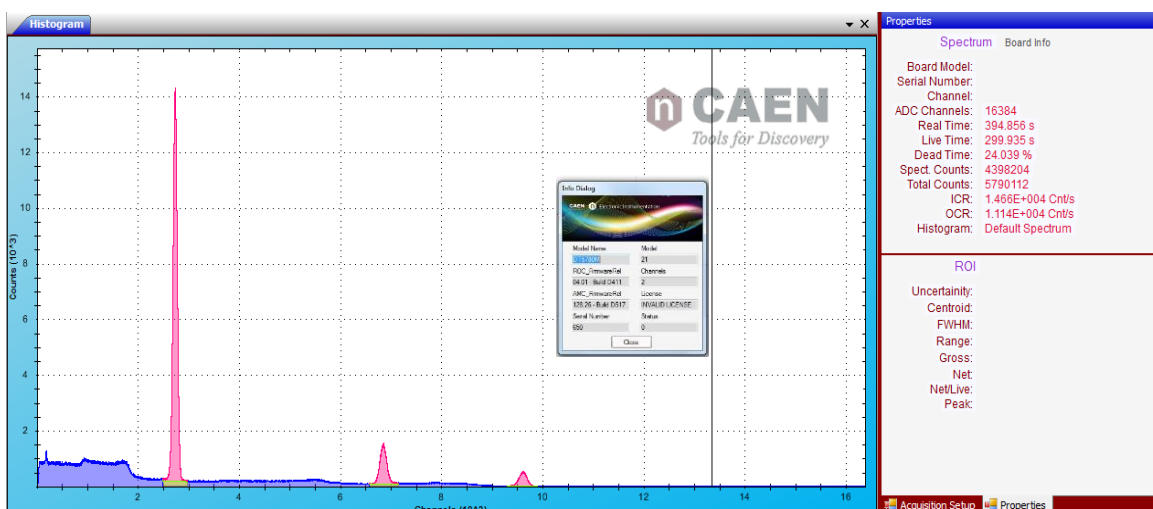
It is mandatory to verify that all the HV Outputs are turned OFF (all LEDs of the HV window must be grey) before connecting or disconnecting the SHV outputs to or from other equipment, to avoid shock hazard.



**Note:** The HV remains ON even in case the user disconnects the software from the digitizer before pressing **OFF**. When connected again the software automatically reloads the last HV settings.

## Properties Window

The Properties window is divided in two sections. The upper one is dedicated to information concerning the Acquisition Set-Up and time measurement values. The lower one provides information about the selected ROI, if applicable.



**Fig. 4.18:** The MC<sup>2</sup>Analyzer Main Screen with the Properties Window on the upper right side and the Board Info Dialog Box overlapping the Histogram Window

In the first section of the Properties window, the following information is displayed:

- **System Mode:** Spectrum. The following information is available:
  - Board Model
  - Serial Number
  - Number of Input Channel being displayed
  - Number of Channels ("bins" on the X-axis) of the ADC
  - Real Time: Full Acquisition Time
  - Live Time: Time Available for Data Taking
  - Dead Time: Time unavailable for Data Taking as % of Full Acquisition Time
  - Spectrum Counts: Number of events converted and histogrammed
  - Total Counts: Total number of events detected during the full Acquisition Time
  - ICR: Input Counting Rate, number of Valid triggers at the input
  - OCR: Output Counting Rate, number of Valid Events read
  - Histogram source: Filename or Default Spectrum
- **Board Info link:** By clicking on it, a Info Dialog Box is displayed with the following Hardware related information:
  - Model Name
  - Model Number
  - ROC Firmware Release Version and Build
  - Number of Board Input Channels
  - AMC Firmware Release Version and Build
  - License Number
  - Board Serial Number
  - Status

If an active ROI is available, the lower section of the Properties window contains information concerning that **ROI**:

- Uncertainty : related to the Centroid Calculation. Smaller contents of the bins yield larger uncertainty on the centroid value calculation.
- Centroid : the value of the peak centroid "bin" is indicated.
- FWHM : the peak Full Width at Half Maximum value is displayed.
- Range : The upper and lower limits of the ROI are displayed.
- Gross : The total number of counts in the ROI is displayed.
- Net: The number of counts in the ROI after the background subtraction is displayed.
- Net/Live: The number of counts in the ROI after the background subtraction and divided by the Live Time is displayed in counts/sec.
- Peak: The Peak Channel Value is displayed in counts.

## Signal Inspector Window

The Signal Inspector tool allows the user to visualize the signal coming from the Nuclear Radiation Detector as well as the trapezoid filter signal applied to it, thus giving the user the capability to optimize if needed the filter parameters to ensure the best measurement conditions and the best read out resolution for any specific detector. Those settings can then be recorded to a “settings” file for successive data taking with that specific detector.

The **Signal Inspector Tool** can be accessed from the Icon Bar by clicking on the 4<sup>th</sup> Icon from the left

**WARNING:** when opening the Signal Inspector tool, a pop up window will inform the user that turning on the Signal Inspector sets the selected channel to Waveform Mode. This means that all raw signal digitized points are sent to the digitizer memory (instead of the reduced processed data that create the energy histogram in MCA Mode). This memory clogging may cause data loss in all the channels data acquisitions. Therefore this procedure must not be carried on any channel of a board currently involved in important data acquisition. If this is the case, click on the “Cancel” key of the pop up window and return to the main program until the important data acquisition is finished.



Fig. 4.19: The Select Channel window of the Signal Inspector

To proceed with the Signal Inspector tool, select the channel to be inspected from the Pull Down Menu on the upper right corner, then click on the “Continue” key. The following Signal Inspector Screen will then appear, overlapping the area of the Histogram Screen.

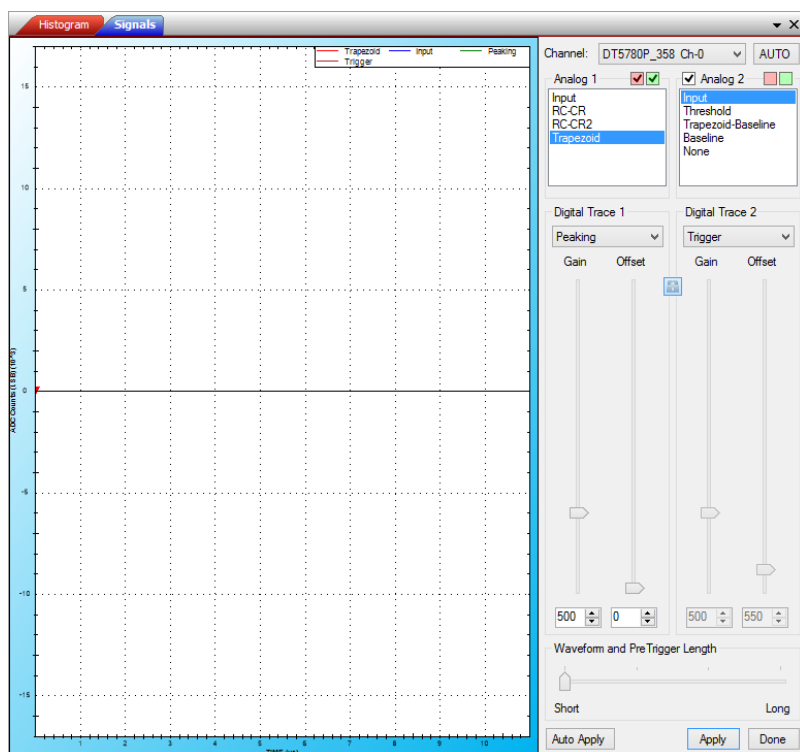


Fig. 4.20: The Signal Inspector Window

In the upper left corner of the window a **“Signals”** Tab is visible together with an **“Histogram”** Tab, allowing the user to toggle between the Signal Inspector and the Histogram screens to verify the results of the acquisition parameters set up on the acquired histogram.

The Signal Inspector Window is divided in two sections. To the left, a graphic display allows the user to visualize the waveforms as in a digital oscilloscope. To the right, a set up panel allows the user to set up the acquisition parameters and adapt them to the specific detector signal characteristics for an optimized result of the measurements. For the meaning of the acquisition parameters and to do this optimization properly refer to Chapter **Getting Started**.




**Note:** **“Gain”** and **“Offset”** of the **“Digital Traces”** affect only the traces visualization, while have no impact in the internal board filters.

### Acquisition Set-up procedure with the Signal Inspector Tool

The user can change at any time the Channel being inspected by selecting it on the Pull Down Menu at the top of the Acquisition Set Up panel.



**Note:** To activate a command from the Acquisition Set up Panel, the **Apply** Key must be clicked after any selection to be implemented. If the user doesn't want to have to confirm each individual selection then the **AutoApply** key should be clicked at the beginning of the selections, then all selections made by the user will be immediately activated.

To operate with the Signal Inspector tool, the user must start the acquisition on the selected channel by clicking on the **Start Acquisition Icon** (  ). A first Analog trace will be visualized on the Histogram Screen.

- **AUTO:** This key enables a software Auto Trigger function, helping the user to find the signal when the trigger conditions are not still set.

The user can select the signal to be visualized on the Analog 1 selection box. Signals that can be chosen are (refer also to **Fig. 4.21**, **Fig. 4.22** and **Fig. 4.23**):

- **Input :** Displays the actual Input signal of the inspected board channel.
- **RC-CR:** Displays the First Derivative of the Input Signal.
- **RC-CR2:** Displays the Second Derivative of the Input Signal.
- **Trapezoid:** Displays the Trapezoid Filter Signal.  
A second Analog trace can be activated by ticking the Analog 2 Check box. The Analog 2 Trace signals that can be selected are:
  - **Input:** Displays the actual Input signal of the inspected board channel.
  - **Threshold:** Displays the Trigger Threshold Level.
  - **Trapezoid:** Displays the Trapezoid Filter Signal.
  - **Trapezoid-Baseline:** Displays the Trapezoid Filter Signal at the Baseline Level.

Two additional Traces can be activated allowing the user to visualize the Digital Outputs available from the Board. The Digital signals will have an High or Low Status respectively when the corresponding function is enabled or disabled.

The Digital Trace 1 selections are (refer also to **Fig. 4.21**, **Fig. 4.22** and **Fig. 4.23**):

- **Zero Cross Window**, corresponds to the RT Val. Wind. (refer to Section **Channels Tab**)
- **Armed**, digital input showing where the RC-CR2 crosses the Threshold;
- **Peak Run**, starts with the trigger and last for the whole event;
- **Pile Up Flag**, shows when a pile-up event occurred;
- **Peaking**, shows where the energy is calculated;
- **Trigger Validation Window**, shows the trigger validation acceptance window (refer to **[RD5]**);
- **Baseline Hold Off**, shows the baseline hold-off parameter;
- **Trigger Hold Off**, shows the trigger hold-off parameter;
- **Trigger Validation**, shows the trigger validation signal TRG\_VAL (refer to **[RD5]**);
- **Saturation Veto**, shows when a saturation occurred that vetoed the acquisition;
- **Baseline Flatness**, monitor the oscillation of the baseline;
- **External Trigger**, shows the external trigger signal, if any.

The Digital Trace 2 allows to visualize only the **Trigger** output signal.

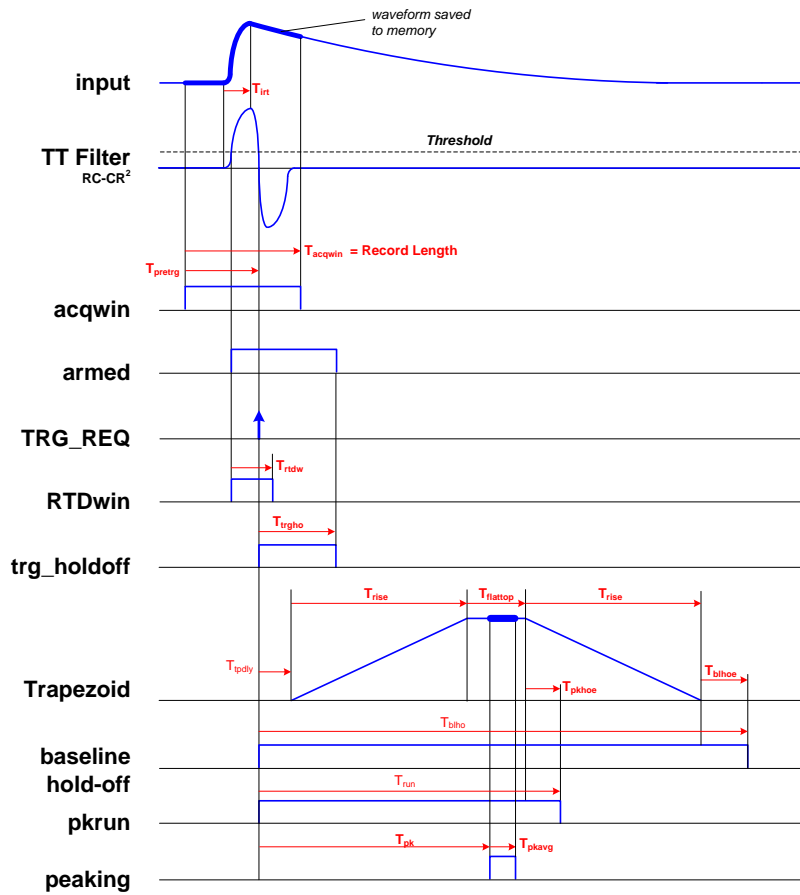


Fig. 4.21: DPP-PHA significant parameters

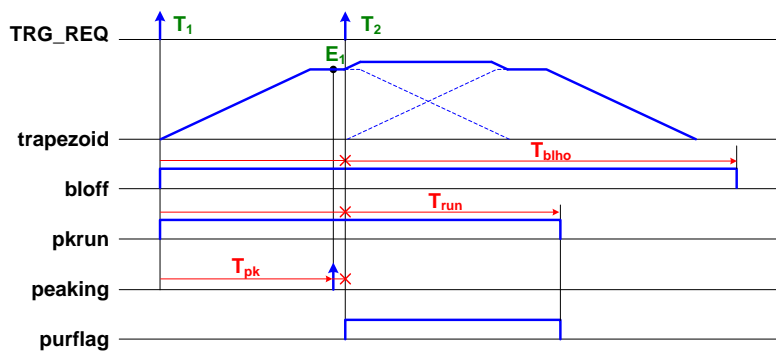


Fig. 4.22: DPP-PHA significant parameters for pile-up

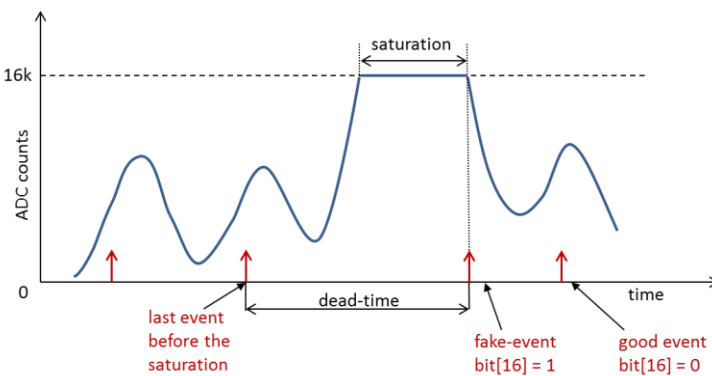
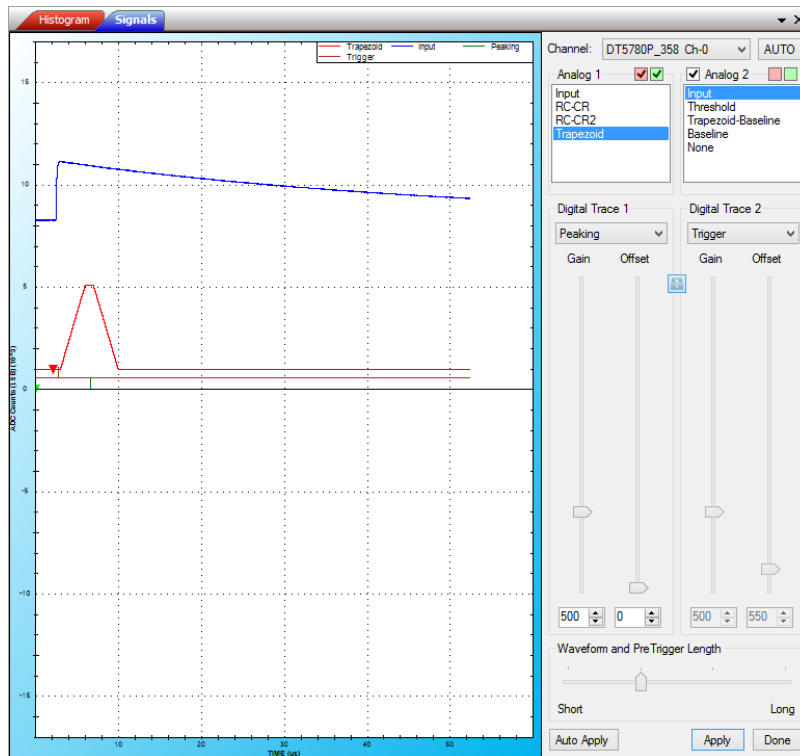


Fig. 4.23: Dead-time in case of signal saturation

The user can change the **Gain** and the **Offset** of the Traces being visualized by entering the desired values in the corresponding entry boxes “Gain” and “Offset”, for each trace independently. The changes can be operated as well with the up and down cursors on the side of the entry boxes, and does not affect the final acquisition.

The user can change the waveform record length and the pre-trigger length by operating on the sliding rule “Waveform and Pre-Trigger Length”



**Fig. 4.24:** Example of Signal Inspector acquisition



### Signal Inspector Cursor window

The User can place two cursors on the trace of the signals being displayed in the Signal Inspector window. The red arrow cursor can be placed on the trace with a left click of the mouse. The Lime Green cursor can be placed on the trace by pressing and holding down the Shift key of the computer keyboard and then with the left click of the mouse.

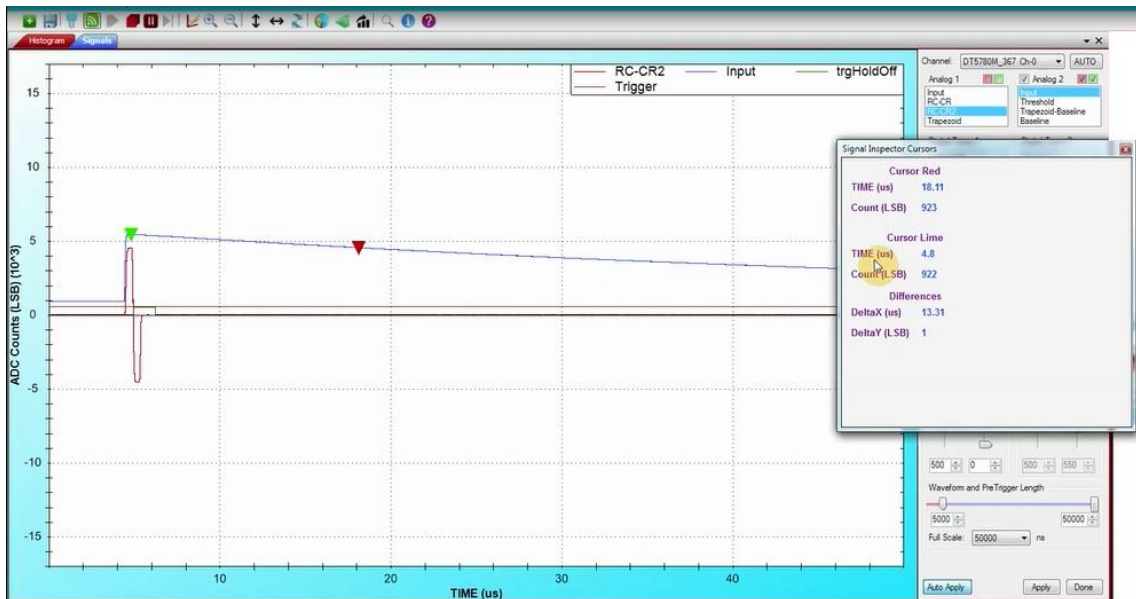


Fig. 4.25: The Signal Inspector Cursors

The cursor values for the X and the Y axis can be read in the Inspector Cursors window, which can be recalled at any time from the Menu Bar/View/Windows Pull Down Menu.

In the Inspector Cursors Window both the Cursor Red Section and the Cursor Lime sections contain the respective values of the time of sampling from the trigger time (in microseconds) and of the signal amplitude (in LSB) at that corresponding time.

The bottom section allows the user to read directly the difference in time (in microseconds) and in amplitude (in LSB) between the two cursors.

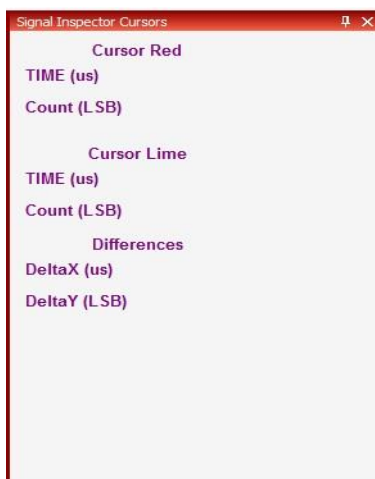


Fig. 4.26: MC<sup>2</sup>Analyzer Signal Inspector Cursor window

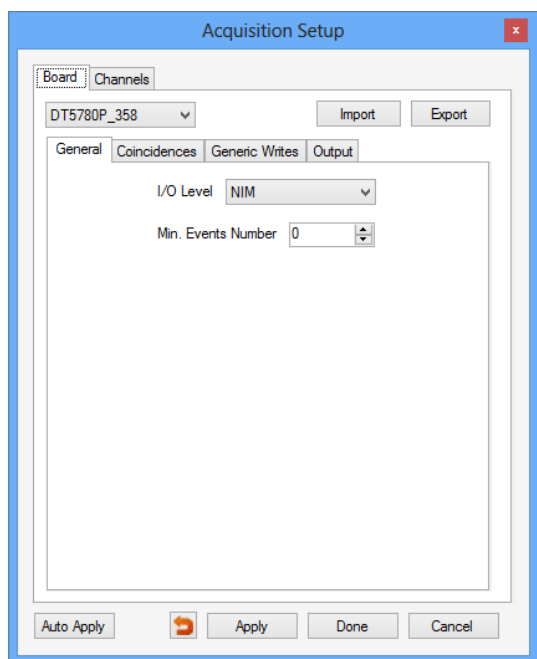
## Acquisition Setup

The Acquisition Set Up Window can be accessed from the Acquisition Set Up Icon in the Icon Bar (3<sup>rd</sup> icon from the left) or from the Spectra List window Icon Bar.

To actually apply to the Hardware the selected parameters the user must Click on the **Apply** key after every selection. To avoid this step by step procedure the **Auto Apply** key can be clicked at the beginning of the selections, for all windows. Clicking on the **Done** key closes the Acquisition Set Up window and the hardware is set to the parameters that were entered until then.

At any time the user can cancel the last Entries Selection from the last set confirmed by the **“Apply”** key with the **“Cancel”** key. All other parameter settings entered until the last **“Apply”** confirmation will anyhow remain as set. At any time the user can restore the system parameters to the Default ones by using the **Brown Return Arrow Key**.

Upon clicking on the Acquisition Set Up icon, the Acquisition Set Up Window will appear as in **Fig. 4.27**:



**Fig. 4.27:** The Acquisition Set Up Window – Board Tab - General Tab

The Acquisition Set Up window features a **Board** Tab and a **Channels** Tab

## Board Tab

This tab allows the user to select the Board being set up, from the Pull Down Menu.

The current settings can be Exported to a File in the desired Windows Directory by using the Export key. A set of parameters can be imported to the hardware from a previous Set Up File by using the Import key.

The **Board Tab** features the Tabs : **General**, **Coincidences**, **Generic Writes**, **Output**.

## General Tab

The **I/O Logic Level** of the Board Digital Inputs/Outputs can be selected between NIM and TTL.

The “**Min. Events Number**” corresponds to the number of events per aggregate (refer to **Appendix A**) and corresponds to the minimum number of events to be acquired in the memory buffer before performing the read-out from the board. A larger value setting optimizes the data transmission system bandwidth while a smaller value improves the display rate. In case of very low rate input signals (few Hz) it is recommended to set a small value, like 1 or 2.

The **0** value indicates the automatic set up of the system.

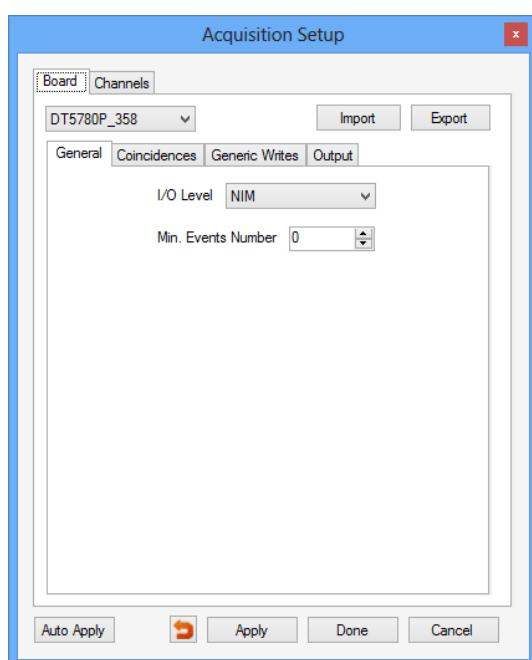


Fig. 4.28: The Acquisition Set Up Window – Board Tab - General Tab

The “**Apply**” button should be enabled to apply the settings. Press “**Auto Apply**” for the auto apply feature.

Settings can be saved through the “**Export**” command, and loaded through the “**Import**” button.

## Coincidences Tab

Coincidence management among channels is described in **[RD5]**. Each individual channel is able to trigger with its individual self-trigger. When the coincidence mode is enabled, each channel continues to self-trigger, and the event is saved only when a validation signal occurs. The validation is made at the mother board level through by configuring the desired operation among channels (choosing among OR/AND/MAJORITY) and the operation of COINCIDENCE/ANTICOINCIDENCE.

In the coincidence tab of the MC<sup>2</sup>Analyzer software, the user can set the validation signal through a matrix (**C**), where for each row it is possible to write the corresponding validation mask. If an external trigger is available, it can be selected through the **E** box. **INV** allows to set the “anti-coincidence” acquisition mode, while the following pull down menu allows to select the operation (AND/OR/MAJ)

**Coinc. Win.** sets the “shaped trigger” width in us (**[RD5]**), corresponding to the coincidence window.

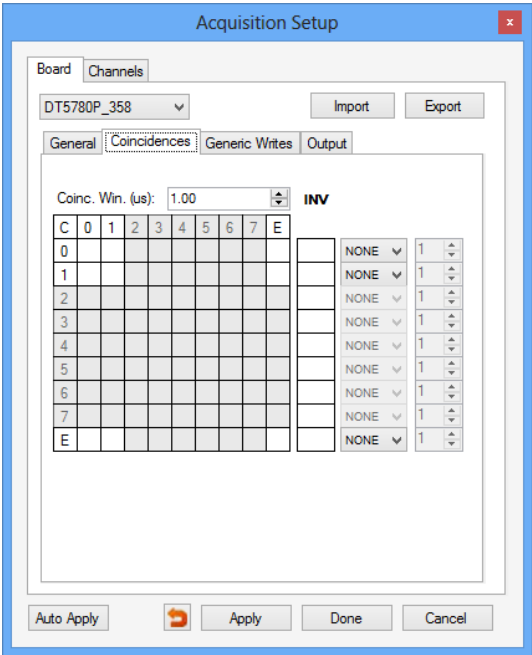


Fig. 4.29: The Acquisition Set Up Window – Board Section - Coincidences Tab

For example, to enable the coincidence among channel 0 and channel 1, the tab coincidence should appear as from Fig. 4.30

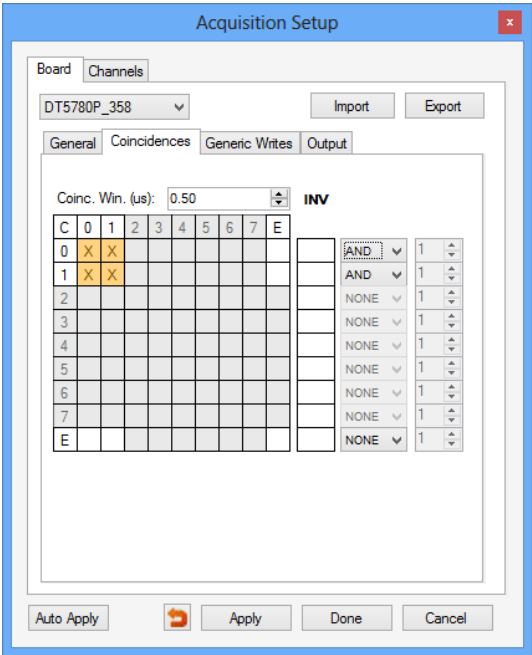
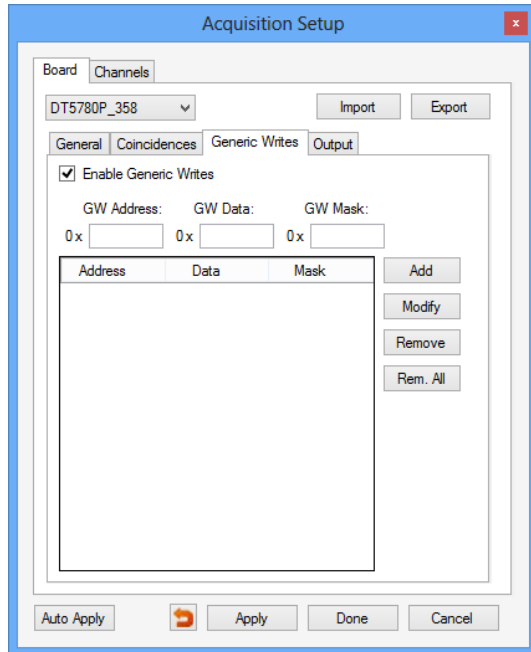


Fig. 4.30: The Acquisition Set Up Window – Board Section - Coincidences Tab. Coincidence on channel 0 and channel 1 enabled

### Generic Writes Tab

The “Generic Writes” tab allows the user to direct access to board registers.

Click on “**Enable Generic Writes**” to enable this function.



**Fig. 4.31:** The Acquisition Set Up Window – Board Section - Generic Writes Tab

Write on “**GW Address**” box the specific register address, on “**GW Data**” the value you want to write in the register, and in “**GW Mask**” the bit mask to be written.

Here some examples:

1. Set only bit [12] of register 1080 to 1, leaving the other bits to their previous value:  
GW Address = 0x1080, GW Data = 1000, GW Mask = 1000
2. Set bit [12] = 1 and bit [13] = 0 of register 1080, leaving the other bits to their previous value:  
GW Address = 0x1080, GW Data = 1000, GW Mask = 3000
3. Set register 1080 to the value of 0x45:  
GW Address = 0x1080, GW Data = 45, GW Mask = FFFFFFFF

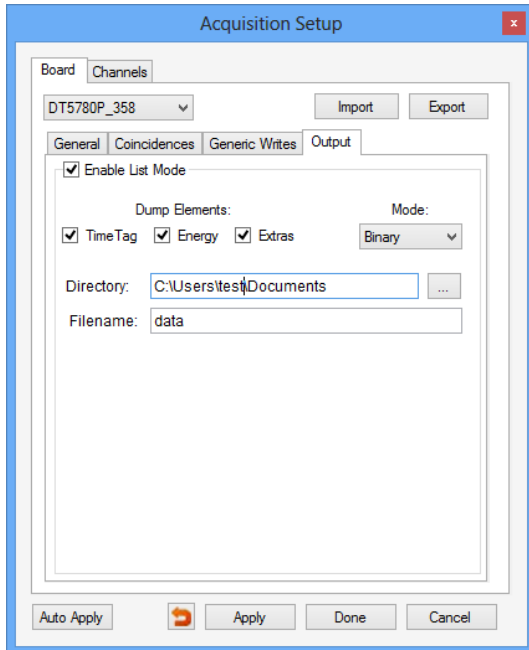
By clicking on the “**Add**” key the GW set line is entered in the GW table. The user can change at any time a GW set by clicking on the correspondent line and then using the “**Modify**” key.

The user can also erase any single line by clicking on it and then using the “**Remove**” key. All GW sets can be removed at once by using the “**Remove All**” key.

## Output Tab

The Output tab allows the user to save the output file in List mode option (see **Fig. 4.32**). Each triggered event is then saved with the information of Time Stamp, Energy, and Extras.

Click on the “**Enable List Mode**” to enable the tab options.



**Fig. 4.32:** The Acquisition Set Up Window – Board Section - Output Tab

Click on the check-box to select which information is saved into the final output file, choosing among:

- **Time Tag:** this is the trigger time stamp, i.e. the time of arrival of the pulse. It is expressed in sampling clock unit, therefore the user has to multiply for the corresponding sampling clock to get the value in ns. Sampling clock values are: 10 ns for x724, DT5780, DT5781, and 2 ns for x730.
- **Energy:** this is the energy value, expressed in 15 bits. Refer to the following subsection **Histogram and list energy format** for more details.
- **Extras:** this is the value of the word EXTRAS, as read from the event structure. Refer to Sect. Channel Aggregate Data Format for 724 series (DT5780 and DT5781) and Channel Aggregate Data Format for 730 series for more details.

It is possible to choose among “**Binary**” and “**ASCII**” under the “**Mode**” menu to select the output file format.

Finally the user can select the **Directory** for the data save and the **Filename**.

The list file dump starts as soon the user starts the acquisition, and stops with the stop acquisition.

A warning message will appear at the bottom of the GUI when the list dumping is enabled.

**WARNING! List Mode Enabled**



**Note:** remember to increment the file name index. A new start acquisition will increment the previous file data.

## Header file format

In case of binary dumping the file header has the following structure:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	BIT						
																NWORDS HEADER											PROTOCOL VERSION											HEADER 0
TYPE FORMAT																											DATA TYPE											HEADER 1
TYPE FORMAT																											DATA TYPE											HEADER 2
...																											...											...
TYPE FORMAT																											DATA TYPE											HEADER n

**Fig. 4.33:** Header file structure

The first word of the header describes the header itself, where:

- Bits[7:0] describes the protocol version number;
- Bits[15:8]: corresponds to the number of words of the header itself, including the first word;
- Bits[31:16]: reserved.



**Note:** the number of bits will be unchanged also for future protocol versions.

From “Header 1” to “Header n” the corresponding word identifies the type of data to be read in the list:

- Bits[7:0]: describes the **“Data Type”** of the event that has been saved into the list. Each header corresponds to a different type, i.e. to a different information saved for each event. The complete list is described below:
  - 0 = Trigger Time Tag type
  - 1 = Energy type
  - 2 = Extras type
  - 3 = Short Energy type (for DPP-PSD only)
  - 4 = DPP Code
  - 255 = Fake (in case of error)
- Bits[31:8]: corresponds to the **“Type Format”** of the corresponding type of the word. Possible choices are:
  - 0 = INT8;
  - 1 = UINT8;
  - 2 = INT16;
  - 3 = UINT16
  - 4 = INT32;
  - 5 = UINT32;
  - 6 = INT64;
  - 7 = UINT64;
  - 8 = STRING;
  - 9 = LONG;
  - 10 = DOUBLE;
  - 11 = CHAR;
  - 255 = none.

For any DPP firmware the protocol version 1 is organized as follows, where words from “Header 1” to “Header 4” are optional, according to the selected type of information for the list dump:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	BIT
																NWORDS HEADER						PROTOCOL VERSION						HEADER 0				
Trigger Time Tag Format																						Trigger Time Tag						HEADER 1				
Energy Format																						Energy						HEADER 2				
Extras Format																						Extras						HEADER 3				
Short Energy Format																						Short Energy						HEADER 4				
DPP Code Format																						DPP Code						HEADER 5				

**Fig. 4.34:** Header file structure for DPP firmware

The order of Header words define the order to read the data list.

For example, in case the header has the following structure:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	BIT
																0x5						0x1						HEADER 0				
0x7																						0x0						HEADER 1				
0x2																						0x1						HEADER 2				
0x5																						0x2						HEADER 3				
0x80																						0x4						HEADER 4				

the user must read 5 words of header, and the data format has to be read as:

- Trigger Time Tag (uint64);
- Energy (int16);
- Extras (uint32)

i.e. 8 Bytes of Time Tag, 2 Bytes of Energy, and 4 Bytes of Extras.

The DPP code 0x80 corresponds to the DPP-PHA for x724 (DT5780, DT5781).



**Note:** In the ASCII format file the header words has to be read as in the binary format. For each event in the list there is a corresponding column with the event type as described in the header.

### Histogram and list energy format

The input waveform is sampled by a 14 bit ADC, then the firmware implements the digital trapezoid filter as described on Sect. **CAEN Digital Approach** to evaluate its energy. Depending to the programmed parameters, the evaluated energy inside the FPGA can be expressed as a number of maximum 48 bits.

The energy information in the list file is expressed as a 15 bit value, which is a simple a truncation of the original 48 bit value, taking the most significant bits. The position of most significant bit depends on the trapezoid rise time (k) and on the input signal decay time (M). The 15 bits value is the most accurate value we can get from the DPP-PHA algorithm. Anyway some numerical value are not decoded, therefore the energy values do not range from 0 to  $2^{15}$ , but from 0 to a value between  $2^{14}$  and  $2^{15}$ , again depending on k and M.

The histogram shown in the MC<sup>2</sup>Analyzer software is made with a conversion of the (hypothetical) 15 bit histogram provided by the digitizer into a 14 bit histogram. The final bin content is obtained "splitting" the content of the starting bins.

The conversion factor (F) can be get as follows. Knowing the signal decay time (M), the trapezoid rise time (k) -- both expressed in ADC clock unit (10 ns), and the trapezoid gain (g), it is possible to evaluate a factor  $G=M*k*g$ . This number has to be divided by a power of 2 (being the only operation that the FPGA can make), where the exponent is unknown. To get the exponent the condition that this final number is between 1 and 2. Once you get the exponent, the conversion factor is  $F = G/(2^n)$ , that is a floating number.

The spectrum linearity is conserved on both spectra.



## Channels Tab

The **Channels Tab** allows the user to set the acquisition parameters for the active channels in the system.

The Live Channels being set are associated with the correspondent Default Spectra which appear in the Pull Down menu in the upper left corner of the Channels Tab.

- **Autoset:** When this key is used, the system analyses the current detector signals and an evaluation algorithm is run to establish the best fit parameters. This may take some time, usually less than 1 minute for each channel. There is a timeout of 5 minutes per channel. If the system is unable to find an optimized set of parameters within the timeout, a pop up window will indicate the system inability to autoset.  
To avoid a specific parameter entry to be modified by the Autoset automatic procedure, the user can click on the Lock icon to the right of that specific entry description before applying the Autoset command. A yellow background in the Lock Icon will indicate the nearby entry is locked against changes when the Autoset function is used.
- **Import:** This key allows the user to import to the hardware a set of parameters from a saved file.
- **Export:** This key allows the user to save the current set of acquisition parameters to a file.

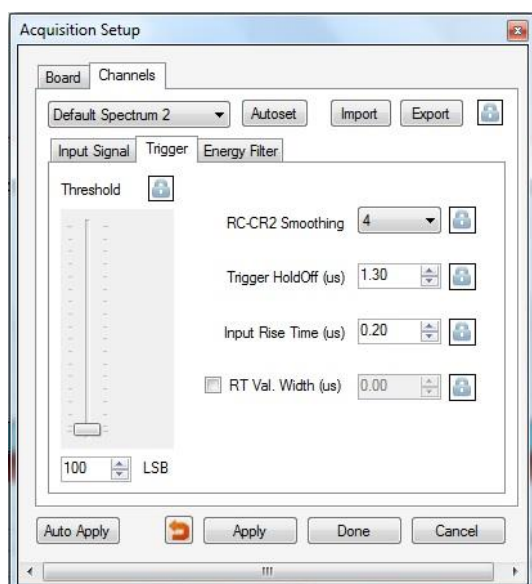
The **Channels Tab** features the following Tabs: **Input Signal**, **Trigger** and **Energy Filter**



Fig. 4.35: The Acquisition Set Up window – Channels Tab - Input Signal Tab

The **Input Signal Tab** allows the user to operate on the following hardware commands:

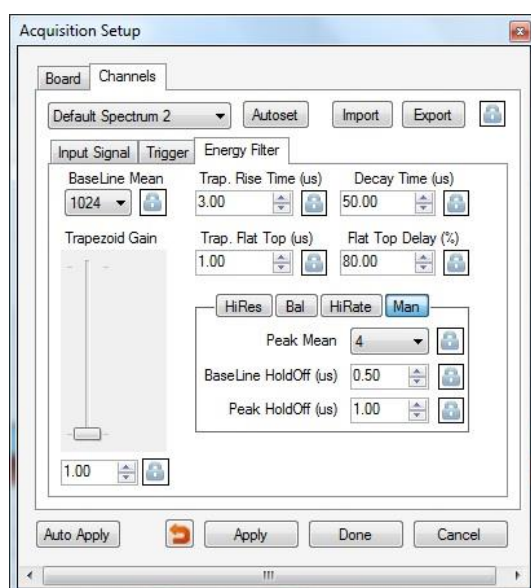
- **DC Offset:** The DC offset value can be set using the vertical slider or entering the value in LSB in the entry box below it.
- **Input Range:** The user can select the following Input Full Scale Values: 0.6, 1.4, 3.7, 9 Vpp for the DT5780; 0.3, 1, 3, 10Vpp for the DT5781; 0.5, 2 Vpp for x730 family; not available for x724 digitizer family.
- **Decimation:** The user can select the following Input Decimation Values: :1 - :2 - :4 - :8. The decimation is not available for x730 family.
- **Digital gain:** The user can select the following Input Digital Gain Values: x1 - x2 - x4 - x 8
- **Pulse Polarity:** The user can select the following Polarity Values : POSITIVE or NEGATIVE



**Fig. 4.36:** The Acquisition Set Up Window – Channels Section - Trigger Tab

The **Trigger Tab** allows the user to operate on the following hardware trigger commands:

- **Threshold** : The threshold value can be set from 0 to the Max Number of Channels (Bins) in LSB.
- **RC-CR2 Smoothing**: The RC-CR<sup>2</sup> input signal second derivative smoothing value can be selected between 4 -8 – 16 and 32.
- **Trigger Hold Off**: The Trigger Hold Off Time, during which trigger signals will not be accepted by the digitizer can be set in microseconds.
- **Input Rise Time**: This is a value set to optimize the shape the RC-CR<sup>2</sup> signal used to trigger the board channels. Maximum allowed value is 2.55 us.
- **RT Val. Width**: A Rise Time Validation Window width can be pre-set in microseconds. This entry cares of the eventuality of pile-up events arriving during the rise time of a pulse being acquired. In such a case the RC-CR2 zero crossing results delayed with respect to a normal event. By setting the appropriate Rise Time Validation Window width, the system will recognize and flag an event as a pile-up if the zero crossing time happens outside the RT Validation Window time boundaries.



**Fig. 4.37:** The Acquisition Set Up Window – Channels Section - Energy Filter Tab

The **Energy Filter** Tab allows the user to set the following Spectrum Data processing values (see **Fig. 2.7**):

- **Baseline Mean:** The baseline mean can be calculated on the following range of Spectrum Channels : 0-16-64-256-1024-4096-16484.
- **Trapezoid Rise Time:** The user can set the Trapezoid Rise time from 0 to 10,20 microseconds in 0.01 microseconds steps.
- **Decay Time:** The user can set the Trapezoid Decay time from 0 up to 655.35 microseconds, in 0.01 microseconds steps
- **Trapezoid Gain:** The user can set the Trapezoid Gain from x1 to x10 by using the vertical slider or by entering the value in the entry box or incrementing and decrementing it with the Up and Down Arrows.
- **Trapezoid Flat Top:** The user can set the Trapezoid Flat Top width Value from 0 to 10,20 microseconds in 0.1 microseconds steps
- **Trapezoid Delay:** The user can set the Trapezoid Flat Top Delay Value from 0% to 95 % in 0.1% steps.



**Note:** the sum of the Trapezoid Rise Time and Flat Top should not exceed 15 us.



**Note:** the maximum values can be increased by using the Decimation. See Sect. **How To use Decimation** for a specific example.

**HiRes:** This key enables a Set of Hold Off Parameters optimized for the best spectrum resolution.

**HiRate :** This key enables a Set of Hold Off Parameters optimized to minimize the dead-time.

**Bal(anced):** This key enables a Set of intermediate Hold Off Parameters balanced for best compromise between High Resolution and High Rate acquisition.

**Manual:** This key enables the manual setting of the Hold Off Parameters.

## Spectra List Window

The Spectra List Windows can be accessed from the *Tools/View/Windows Pull Down Menu*.







Upon clicking on the item the following window appears:



Fig. 4.38: The Spectra List Window

The Spectra List allows the user to Acquire, Save, Resume Acquisition, Recall from a Directory **the selected spectrum**. The Spectra List Window features an Icon Bar and a Spectra List Table.

### Spectra List Icon Bar:

- **Add Spectrum**  : Same function as the “Add Spectrum” Icon on the Main Screen Icon Bar
- **Save Spectrum**  : Opens a Windows Directory and allows the user to save the Spectra file into the desired folder.
- **Configure Acquisition**  : Allows the user to configure the acquisition system (see Section **Acquisition Setup** for setting procedures).
- **Start Acquisition**  : Acquisition will start upon clicking on the “Start Acquisition” icon.
- **Arm Acquisition**  : Acquisition will start upon reception of valid data (valid trigger).
- **Stop Acquisition**  : Acquisition will stop upon clicking on the “Stop Acquisition” icon for the specific highlighted channel.
- **Stop Acquisition Criteria:** Acquisition will stop upon reaching a criteria among:



<b>M</b>	Manual	To manually stop the acquisition
<b>L</b>	Live Time	To stop on a specified Live Time;
<b>R</b>	Real Time	To stop on a specified Real Time;
<b>C</b>	Counts	To stop on a specified total counts number;







**Note:** all the spectra list commands act on a single channel. To work with all the channels simultaneously use the main GUI commands.

Under the Spectra List Icon Bar there is the Spectra List Table. Every line corresponds either to an activated live acquisition channel spectrum either to a recalled file spectrum. All Spectra Files listed in the Spectra Table are tagged by their Filename followed by 5 interactive icons and the Acquisition Status LED referred to that file.

### Spectra List Table Header :

- **Name:** This is the name either of a recalled spectrum file or of the file where an active live channel acquisition is being written to. This can be determined at a glance by looking at the Acquisition Status LED color ( See the Item A in the list below)
- **C: Color** . Allows the user to select a color for the corresponding Spectrum graphic representation
- **V: Toggle Visible/Invisible** . When two or more spectra are being acquired or recalled to the screen, this icon allows the user to toggle the correspondent spectrum away from the screen and back on it.

- **R: Reset to Default Configuration** . This icon allows the user to reset the configuration to the default settings.
- **D: Delete File** . This icon allows the user to delete the selected (highlighted) spectrum file.
- **I: Information** : This icon recalls the Board Information Dialog Box (see Fig. 4.18).
- **A: Acquisition Status LED** . This LED indicates whether the Spectrum is being acquired in real time (light green/red) or recalled from file (dark green). When it turns red the board is busy due to a dynamics saturation or to memory busy.

## Cursor Window

The Spectra Cursor window allows the user to read the histogram Y-axis value in correspondence with the X-axis Channel indicated by the Crosshair Cursor. The X- axis value can be also entered into the Channel entry box. Upon confirmation with the Enter key of the keyboard, the correspondent Y-axis value is displayed.

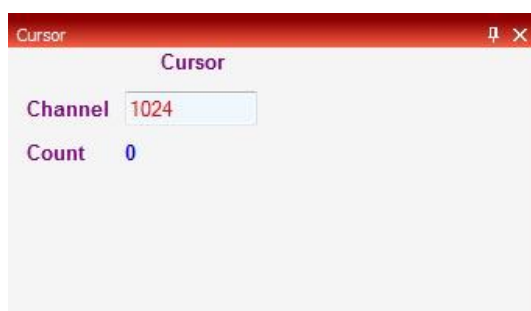


Fig. 4.39: The Cursor Window

## ROI Editor Window

In the ROI Editor window the user can define one or more Regions Of Interest. Left clicking on the Create ROI item opens the ROI Editor window (unless it was already open). Default position is leftmost under the Graph Window.

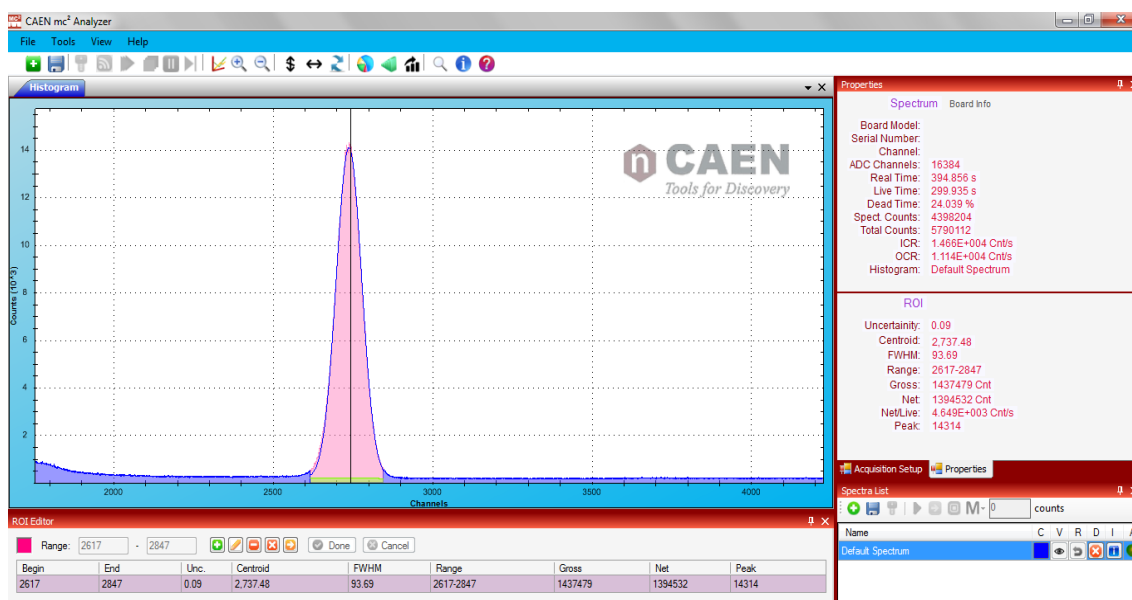


Fig. 4.40: MC<sup>2</sup>Analyzer Main Screen Graph with ROI Editor window

In the ROI Editor Window, a new ROI can be set by the user by left clicking on the green “+” key to the right of the Range Entry boxes and then by:

- typing the values corresponding to the leftmost channel of the ROI in the first “Range” entry box and the value corresponding to the rightmost channel of the ROI in the second “Range” entry box.
- either, placing the crosshair cursor of the graph on the leftmost point of the ROI to be defined and left clicking on it. A vertical marker line with a red arrow will indicate the left border of the ROI. Then by placing the crosshair marker on the rightmost point of the ROI being defined and left clicking on it, a second vertical line

marker with a red arrow will mark the rightmost border of the new ROI. At the same time the new ROI line will be added to the table of ROIs in the ROI Editor Window, and a best fit curve of the ROI will be drawn on the graph.

The user can select a **color** to characterize the ROI regions of the graph by clicking on the square to the left of the "Range" entry boxes.

**Additional ROIs** can be created by repeating the above procedure, starting by clicking on the green "+" key. The selected color will apply to all the ROIs in the graph.

The user can **modify a ROI** by clicking on the second key over the ROI Table then redefining the ROI either with the crosshair marker graphic procedure or by entering the new numeric Begin and End border values in the corresponding entry boxes.

The user can **delete a single ROI** by clicking on the "-" red key over the ROI Table then left clicking on the correspondent line in the ROI Table and confirming the ROI cancellation in the dialog box that opens up.

The user can **delete all ROIs** by clicking on the "X" red key over the ROI Table then confirming the ROIs cancellation in the dialog box that opens up.

Once the ROI is selected, the following data will be automatically displayed in the ROI Editor window last line:

- **"Begin"**: number of the first ROI channel.
- **"End"**: number of the last ROI channel.
- **"Unc."**: Uncertainty, referred to the Centroid position.
- **"Centroid"**: Number of the channel corresponding to the Centroid of the Peak, calculated with the above Uncertainty.
- **"FWHM"**: This is the value of the Full Width at Half Maximum of the peak, expressed in channels.
- **"Range"**: Indicates the ROI Range (from initial channel to final channel)
- **"Gross"**: indicates the Gross count value, as counted in the whole ROI.
- **"Net"**: indicates the net value of the counts in the whole ROI, corresponding to the Gross counts less the Background value within the ROI.
- **"Peak"**: indicates the number of counts in the channel corresponding to the highest peak of the ROI.

## MC2Analyzer Energy Calibration

The Energy Calibration of a Spectrum is performed by measuring the spectra of known radio isotopic sources and by assigning Energy values (In keV or in MeV) to the number of the spectrum “bins” or “channels” where the peaks of corresponding known peak energies of the radiation emitted by the source have been located. By calibrating a spectrum with at least two peaks values it is possible to interpolate the value of all other channels. For example, a classic calibration for gamma spectra includes the two photopeaks of the  $^{60}\text{Co}$  respectively at 1,17 MeV and at 1,33 MeV, and the photopeak of the  $^{137}\text{Cs}$  at 662 keV.

To perform the calibration on the MC<sup>2</sup>Analyzer Spectra, a calibration spectrum should be uploaded, either from file or from a channel in live acquisition from a known calibration source. The user can then left click on the **Enable Calibration Set up Icon** in the Icon Bar (see Fig. 4.41).

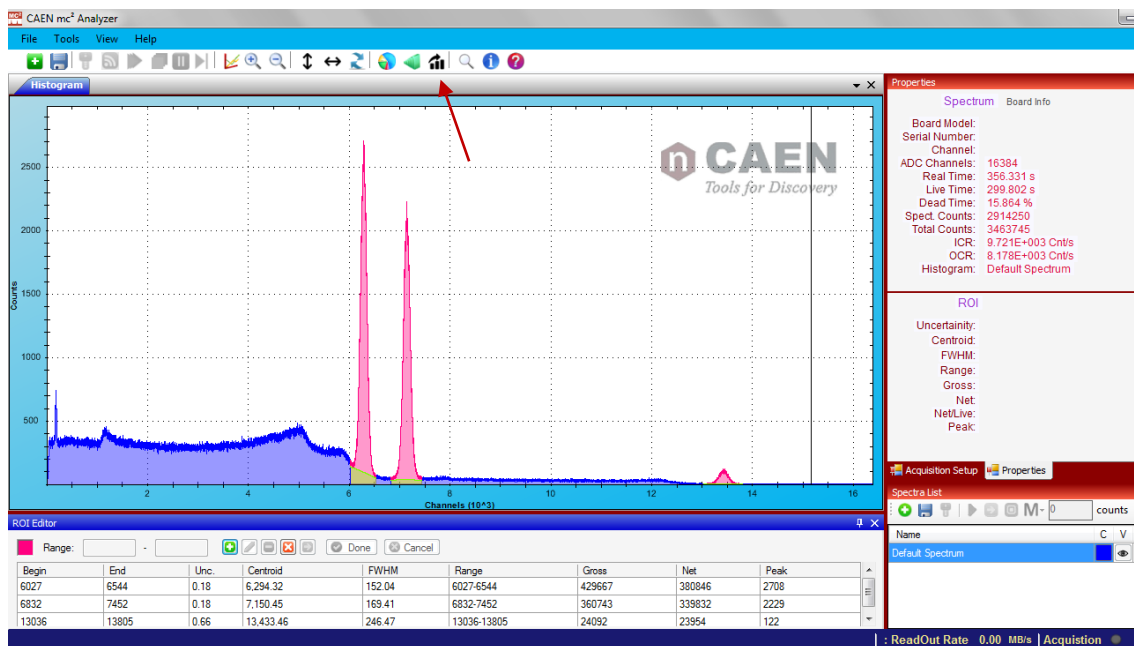


Fig. 4.41: MC<sup>2</sup>Analyzer Enable Calibration Set up Icon

This icon function enables the user to enter the relevant energy calibration data. Upon clicking on the icon, if no calibration values were previously entered in the program, the following dialog box appears:

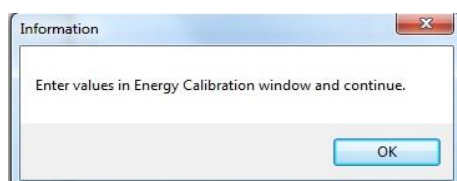
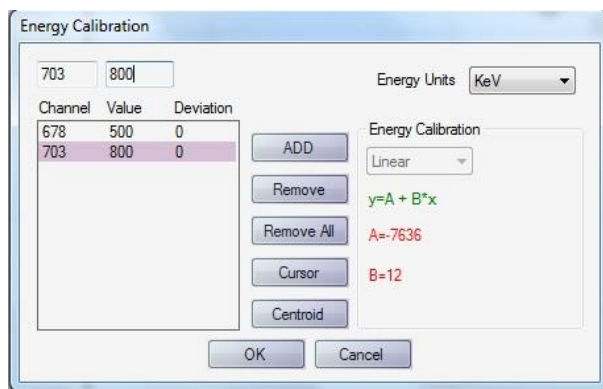


Fig. 4.42: MC<sup>2</sup>Analyzer Energy Calibration Pop Up Confirmation window

Upon clicking on “OK”, or if previous values have been entered in the MC<sup>2</sup>Analyzer program, the following Energy Calibration Window appears:



**Fig. 4.43:** MC<sup>2</sup>Analyzer Energy Linear Calibration Dialog window

The user can then select the desired Energy units, KeV or MeV, from the pull down menu to the upper right corner of the window.

Then the user can locate the desired peaks of known energy on the calibration spectrum (either recalled from records either acquired live from a calibration source). By clicking on a peak the correspondent channel number will appear in the “**Channel**” value entry box. The user can then enter in the “**Value**” value entry box the Energy corresponding to that peak and associate this calibrated value by clicking on the “**ADD**” key. The corresponding values will appear on the calibration values list below the value entry boxes. This operation can be repeated to add other calibration peaks values. Any calibration line can be removed by clicking on it (this will highlight the line) and by clicking on the “**Remove**” key. The “**Remove All**” key clears all entered values at once.

If the user defines a ROI around a reference energy peak, then with the “**Centroid**” key the Peak Centroid Channel is automatically located and its value written in the channel entry box. The user can then enter the corresponding reference peak energy in the “Energy value” entry box and include this peak in the calibration by using the “**ADD**” key. This operation can be repeated for all available reference energies. If no ROI has been defined an error message pop up window is issued when the “Centroid” function is invoked.

#### Energy Calibration Interpolation Type

##### - **Linear** Interpolation

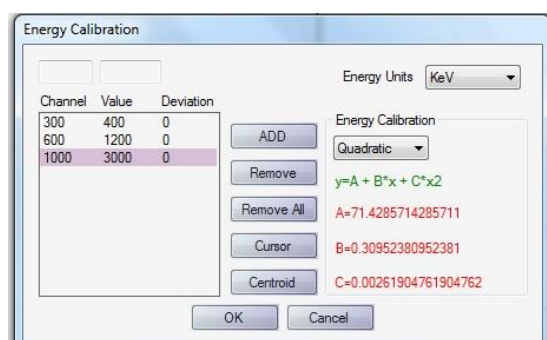
If at least 2 channel values are entered, then in the Energy Calibration Pull Down Menu the **Linear** Calibration Function appears. The Energy Calibration is performed with a simple linear interpolation where the Y (Energy value) is calculated as a function of the X ( energy “bin” or “channel” number) multiplied by a factor B, added to a constant A. Both the A and B values calculated from the linear interpolation best fit to the entered reference energy values are shown in the calibration window.

##### - **Quadratic** Interpolation

If at least 3 channel values have been entered then the **Quadratic** Interpolation function is also made available. The Energy Calibration is performed with a quadratic interpolation where the Y (Energy value) is calculated as a quadratic function of the X ( energy “bin” or “channel” number) with the formula :

$$Y = A + B \cdot X + C \cdot X^2$$

The A ,B and C values calculated from the quadratic interpolation best fit to the entered reference energy values are shown in the calibration window (see **Fig. 4.44**).



**Fig. 4.44:** MC<sup>2</sup>Analyzer Energy Quadratic Calibration Dialog window



### Software Exit

How to exit the program

- **Stop the Acquisition.**
- **Turn off the HV** on all channels from the HV Window.
- **Exit the MC<sup>2</sup>Analyzer** program by clicking on the standard Windows red “X” key in the upper rightmost corner of the window, either use the “Exit” item in the Menu Bar “File” Pull Down Menu.



**Note:** The Acquired spectrum will be saved automatically together with the settings and reloaded as acquisition default file when the user restarts the MC<sup>2</sup>Analyzer program.

## 5 Technical support

CAEN makes available the technical support of its specialists at the e-mail addresses below:

[support.nuclear@caen.it](mailto:support.nuclear@caen.it)  
(for questions about the hardware)

[support.computing@caen.it](mailto:support.computing@caen.it)  
(for questions about software and libraries)

# Appendix A

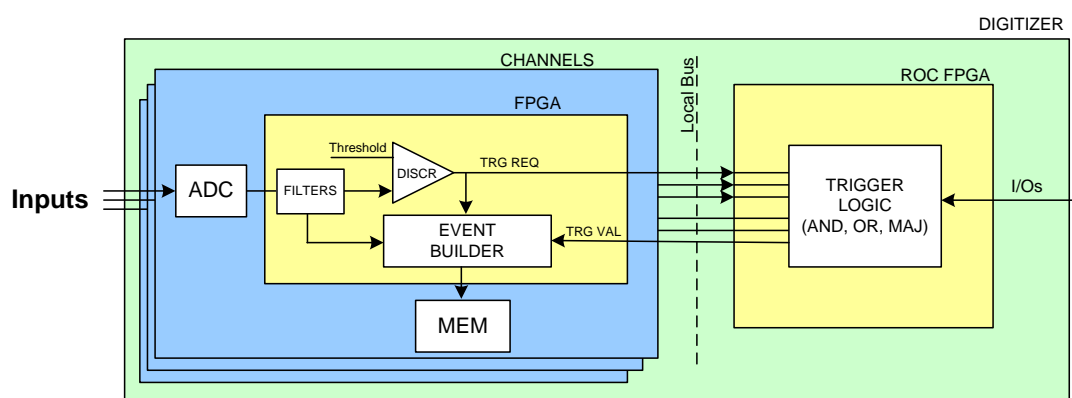
## Acquisition Modes

The DPP-PHA firmware allows for three main acquisition modes: Oscilloscope, List and Mixed.

1. **Oscilloscope Mode:** this acquisition mode is mainly intended to debug and to set the DPP parameters. For each trigger (internal or external), the digitizer saves a portion of the waveform (i.e. a sequence of samples within the acquisition window) into a local memory buffer. Running in Oscilloscope Mode, the user can view the input signal, the baseline, and other control signals (such as the trigger, the gate, the trigger hold-off, etc...) in the same plot. This makes easier to adjust the parameters for the acquisition. Running in oscilloscope mode implies a very high data throughput, due to the huge amount of samples saved into the board memory and then read out by the DAQ software.
2. **List Mode:** this is the mode where the DPP algorithm is applied runtime by the FPGA on the input signals. Once the parameters are properly set in the Oscilloscope Mode, the acquisition can be switched to the List Mode (histogram mode in the DPP Control Software). The waveform recording is disabled, while time stamp and integrated charge are calculated and saved into the local memory buffer for each triggered pulse. As soon as the list reaches a certain size, it is made available for readout and the acquisition continues in another buffer. This feature assures an acquisition with *no dead time*. Being the size of the event very small (typically few bytes), the throughput is extremely reduced.
3. **Mixed Mode:** in some applications, the simple charge/time stamp information is not enough and it is necessary to save also few samples (as raw waveforms) belonging to a specific region of interest. This is useful in sophisticated pulse shape analyses, as pulse fitting, that cannot be implemented on-line by the FPGA. Another example is when, to increase the timing resolution (10 ns for the x724 module) it is required to interpolate the samples around the threshold and evaluate the crossing timing. In all these cases, it is possible to read the charge, the baseline and the time stamp information together with a portion of the waveform, so that the user can retrieve further information and use it off-line, still keeping a reasonable level of throughput bandwidth.

### Trigger Modes

The general operating principle of a digitizer running with DPP-PHA firmware is summarized in **Fig. A.1**. Each channel of the board can trigger on the input pulse independently from the other channels. When the input is over-threshold the channel FPGA sends a "Trigger Request" (TRG\_REQ) signal, that enables the event building.



**Fig. A.1:** Schematic chain of the trigger architecture of a DPP system

There are three possible ways to acquire the events and save the information on the board memory (**Fig. A.1**). In the simplest case each channel acquires through its individual TRG\_REQ independently from the other channels. This is the "Normal (Individual) trigger mode".

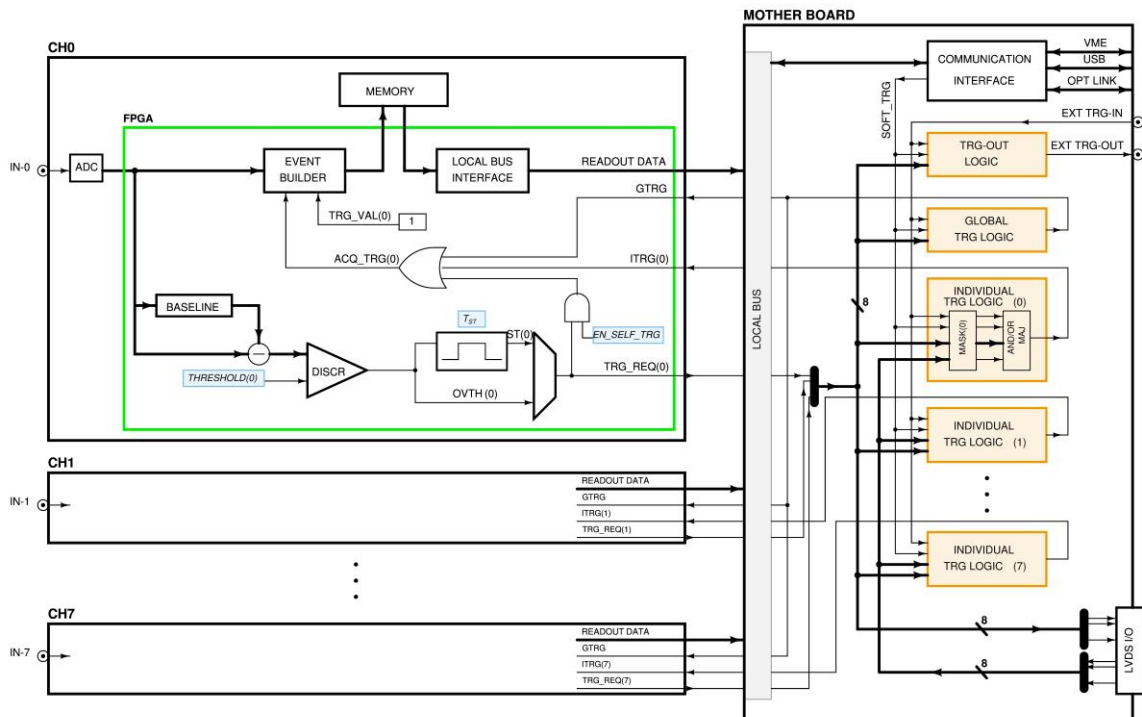
Otherwise, in the "Coincidence/Anticoincidence Trigger Mode" all the trigger requests can be sent to the common "ROC FPGA" for the coincidence evaluation. The ROC can be programmed to look for triggers within a programmable window, through the Individual Trigger Logic (ITL) that can perform the logic operation of AND, OR, or Majority. When the coincidence condition is met, the ROC sends back a "trigger validation" signal, one per channel. The coincidence logic is individual, so that it is possible to program different coincident conditions for each channel. The trigger validation enables the data saving into the memory buffer. In this way the channel uses its local trigger for the event building (time stamp, gate, etc...) but only those events having the validation are saved into the memory.

The last way is called “*Neighbour Trigger Mode*”. In this case the event building can be enabled with a TRG\_VAL signal only, even if no TRG\_REQ has been occurred for that channel. This may happen when a “neighbour” channel is over-threshold and generates a TRG\_REQ. Then its previous and consecutive channels receive a TRG\_VAL signal too, and they can start the event building with the TRG\_VAL signal as reference. This is particularly useful in case of strip detector where you want to read data not only from the channel that triggered, but also from its “neighbours”.

### Normal (Individual) Trigger Mode

In the normal (individual) trigger mode each channel can trigger on the input pulse independently from the other channels.

Referring to **Fig. A.2** the input signal is discriminated if over-threshold (OVTH). After the discrimination, through a multiplexer, it is possible to select the output itself, or a logic pulse of adjustable time width  $T_{ST}$ . This is the *shaped trigger* that enables the “trigger request” (TRG\_REQ) for data acquisition. Unlike the Coincidence or Neighbour acquisition modes, the TRG\_VAL signal is always set to 1, so the event builder is activated when either a TRG\_REQ, or an Individual Trigger (ITRG), or a Global Trigger (GTRG) signal arrive.



**Fig. A.2:** Block diagram of the Trigger Architecture in a DPHA board

In the DPHA the input pulse is fed into a Trigger and Timing Filter for the proper trapezoid calculation. When its output exceeds the programmed threshold, the trigger logic gets armed (the signal “armed” goes high), then it waits until the zero crossing to fire the Trigger Request TRG\_REQ (**Fig. A.3**). It is also possible to enable the Rise Time Discriminator whose purpose is to detect double pulses the pile-up on the rising edge; in fact, in this case, the rise time of the input signal gets longer. The user can define an acceptance window RTDwin timed by the armed signal; if no TRG\_REQ (zero crossing) occurs within that window, then the trigger logic assumes that two or more pulses are piling up and two triggers are issued. The RTD is disabled when Trtdw = 0.

After the TRG\_REQ, it is possible to program a trigger hold-off time window to prevent a new trigger to be generated on the tail of the RC-CR2 signal. This might happens especially when the input pulses have an over-shoot that causes a small end pulse at the output of the timing filter. Another reason for using the trigger hold-off is to create a known dead-time in the acquisition.

When TRG\_REQ is generated, the energy filter goes into the run state (pkrun = 1) and the calculation of the trapezoid baseline is frozen (baseline\_off = 1). Note that there is a small delay (16 clock cycles) between the TRG\_REQ and the start of the trapezoid; this prevents the baseline to be frozen when the trapezoid already started.

The peaking time Tpk defines the position on the flat top where the energy is calculated; in this trigger mode, Tpk starts with the TRG\_REQ. Starting from the peaking time Tpk, it is possible to average a certain number of points on the flat top (Tpkavg).

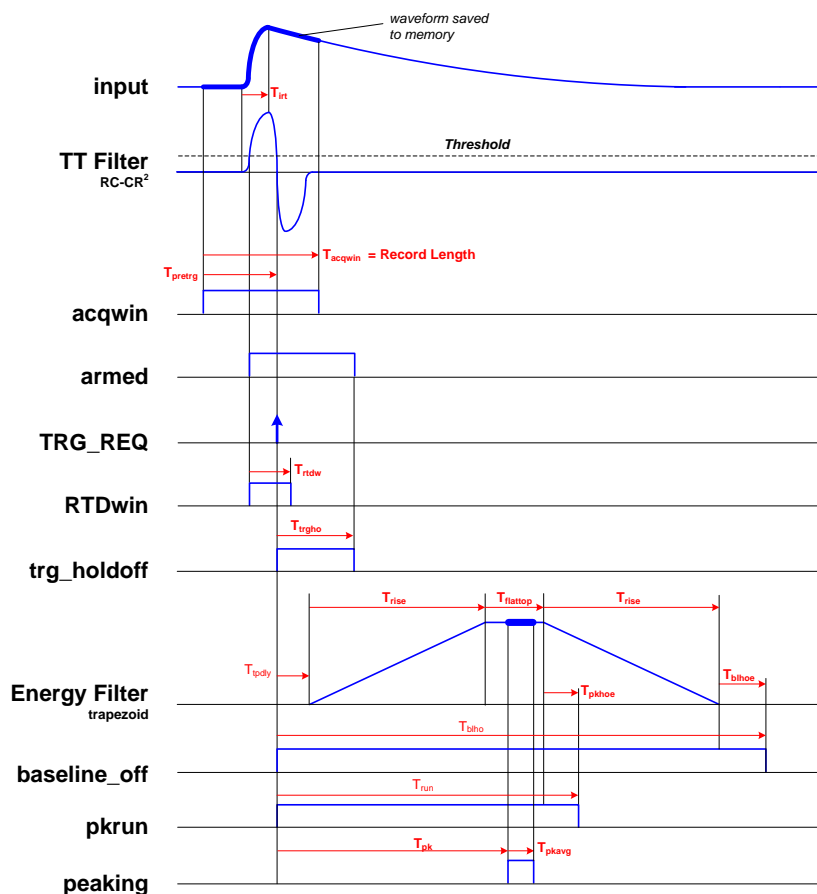


Fig. A.3: Timing diagram (Normal Trigger Mode)

According to the theory of the trapezoid filter, it is possible to accept a new trigger as soon as the flat top of the previous one is finished. However, it is always better to keep some safety margin ( $T_{pkhoe}$ ); the effect of this parameter is to increase the width of the  $pkrun$  window. If a new  $TRG\_REQ$  arrives within that window, then this event is identified as pile-up. There are three different cases, as shown in the following pictures:

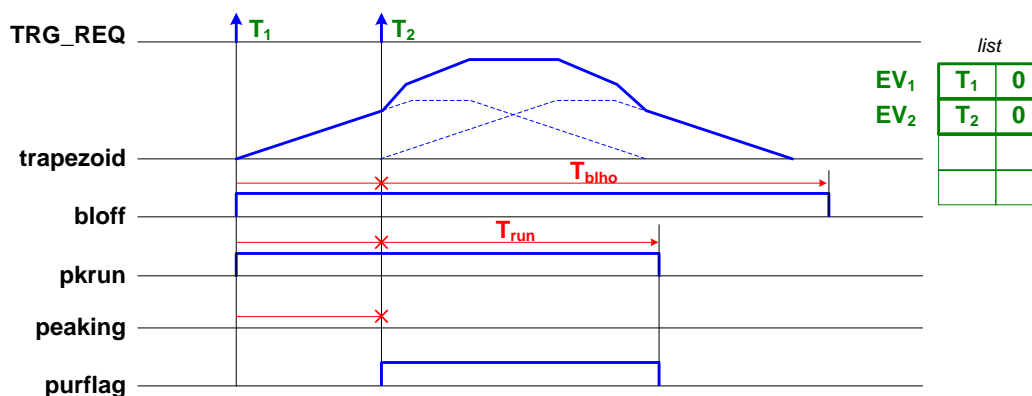


Fig. A.4: Pile-up occurred before the peaking time

When the second  $TRG\_REQ$  occurs before the peaking time (Fig. A.4), then the energy filter output becomes meaningless and the pile-up inspector rejects both TRs. In this case, the event builder saves two time stamps and zero for the relevant energies (see the memory content represented in green). Notice that the second  $TRG\_REQ$  restarts the timer for  $T_{run}$  and  $T_{blho}$  while  $T_{pk}$  is aborted (red crosses).

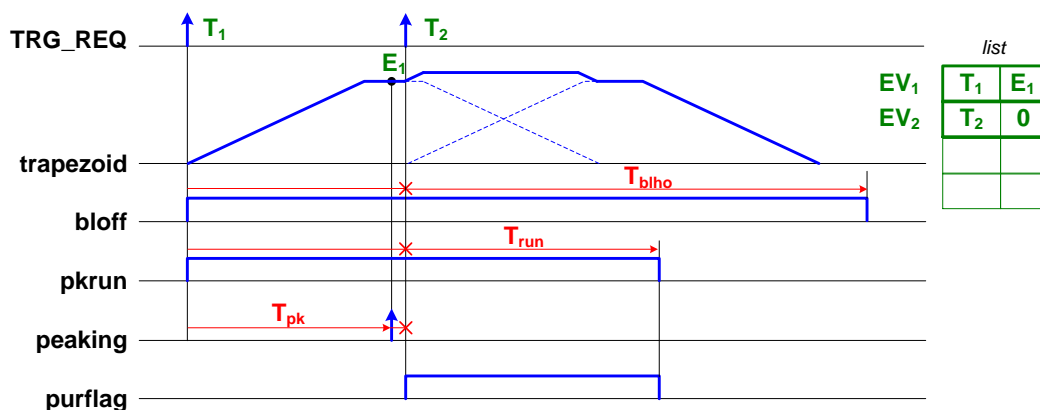


Fig. A.5: Pile-up occurred after the peaking time

If the second TRG\_REQ occurs after the energy of the previous has been saved (but still before the end of pkrun), then only the second TRG\_REQ will be rejected (see Fig. A.5).

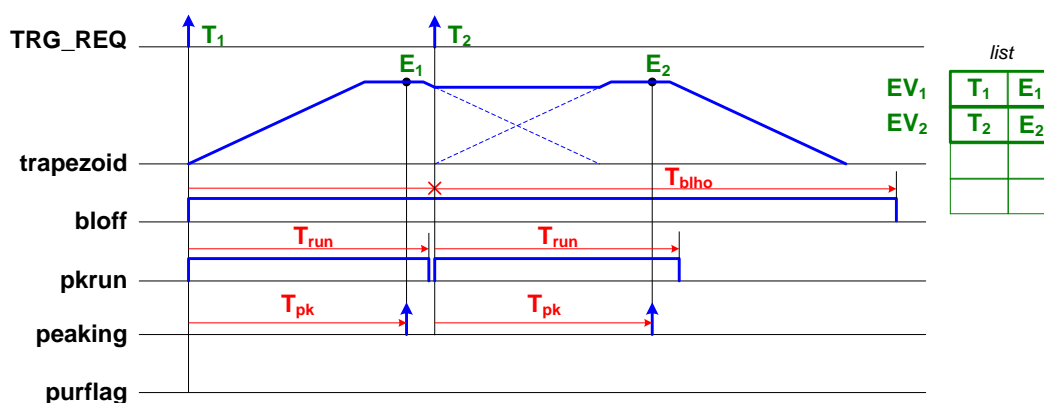


Fig. A.6: Overlapped trapezoids that don't cause pile-up rejection

If instead the second TRG\_REQ occurs outside the pkrun window, although the two trapezoids are piled-up, both energies can be calculated and there is no pile-up rejection. However, in this case, the baseline of the second trapezoid cannot be recalculated, thus the same baseline calculated for the first trapezoid will be used for the second one too (see Fig. A.6).

When the counting rate is high, it might happen that the baseline is kept off for many subsequent pulses and this can significantly worsen the energy resolution. In this case, it is possible to increase Tpkhoe and make pkrun longer than the full trapezoid width or even more. Doing that, the pile-up inspector will reject all the pulses but those that are well separated, thus allowing the baseline to be properly calculated for every pulse. By default, the baseline calculation starts again at the end of the trapezoid but it is possible to delay it by the Tblhoe value.

## Coincidence Trigger Mode

Acquiring coincident events is a common task in physics, and the DPP-PHA firmware allows you to make online coincidences among channels. As already introduced, the TRG\_REQ signal can be sent to the ROC FPGA (mother board) that makes a programmable Individual Trigger Logic (ITL) calculation among the logic AND, OR, or Majority<sup>1</sup> (see Fig. A.7). The ITL has the same multiplicity of the number of channel, and each ITL can be programmed with a different logic function. Moreover the ITL can receive as input not only the TRG\_REQ from all channels, but also the signal from the front panel output GPIO (line 0 to 7 of the LVDS I/O connector – VME only), the software trigger (SOFT\_TRG), and the external trigger (EXT TRG-IN).

The user has the possibility to rather program a Global Trigger Logic (GTL) or a “TRG\_OUT logic”. The GTL and the TRG\_OUT logic can receive as inputs the TRG\_REQ from all channels, the EXT TRG-IN and the SOFT TRG. They cannot receive the inputs from the LVDS I/O. At the moment these logic units can perform only the OR operation. There is one GTL for all channels, since its output triggers all channels simultaneously, while the TRG\_OUT logic allows to send the trigger request outside the board.

Either the ITRG and the GTRG can generate the TRG\_VAL signal. To save the event into the memory the TRG\_VAL signal has to arrive within a programmable time window TVAW (Trigger Validation Acceptance Window). If the TRG\_VAL signal is outside the TVAW than the event is rejected.

In this trigger mode, all timings are referred to TRG\_REQ, and the TRG\_VAL never causes pile-up.

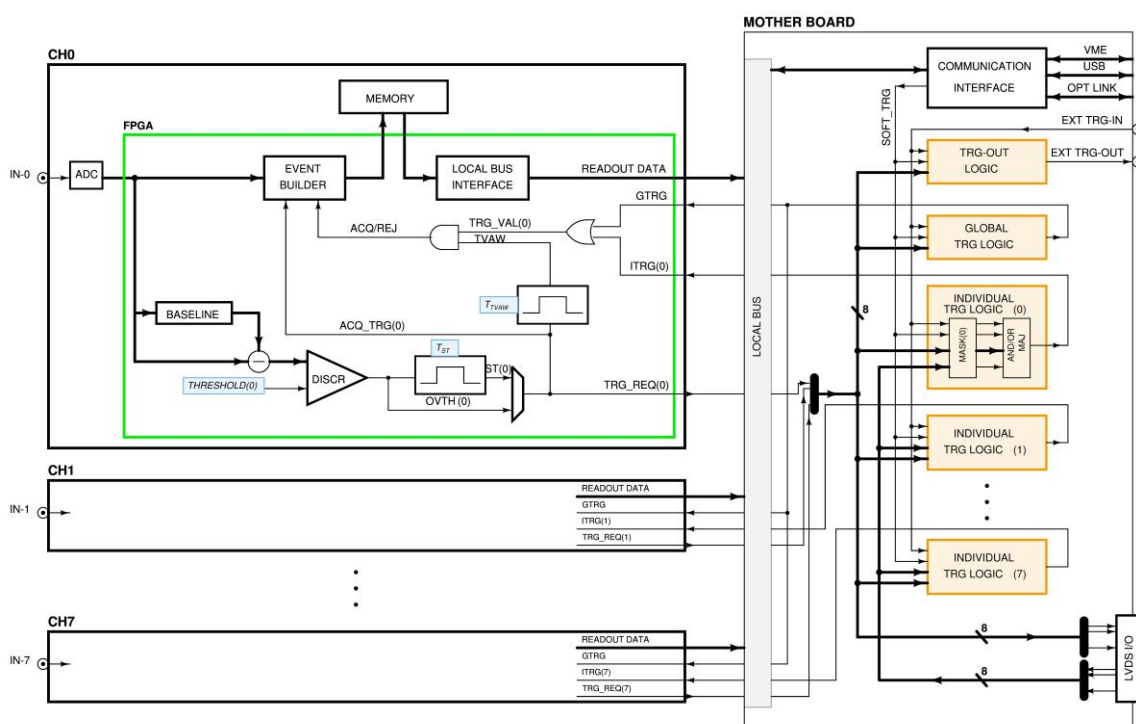


Fig. A.7: Block diagram of the Trigger Architecture in a board with DPP-PHA firmware

More information and detailed instructions on how to make coincidences among channels of the same board can be found in [RD5].

## Anti-coincidence Trigger Mode

The structure of the anti-coincidence trigger mode is exactly the same of the coincidence one, the only difference being the logic operation performed between the TRG\_VAL signal and the TVAW. Indeed the event is saved into memory when no TRG\_VAL signal arrives within the TVAW window.

Refer to [RD5] for more information and detailed instructions on how to make anti-coincidences among channels of the same board.

<sup>1</sup> The Majority is true when at least a programmable “majority level” number of enabled inputs are in coincidence.

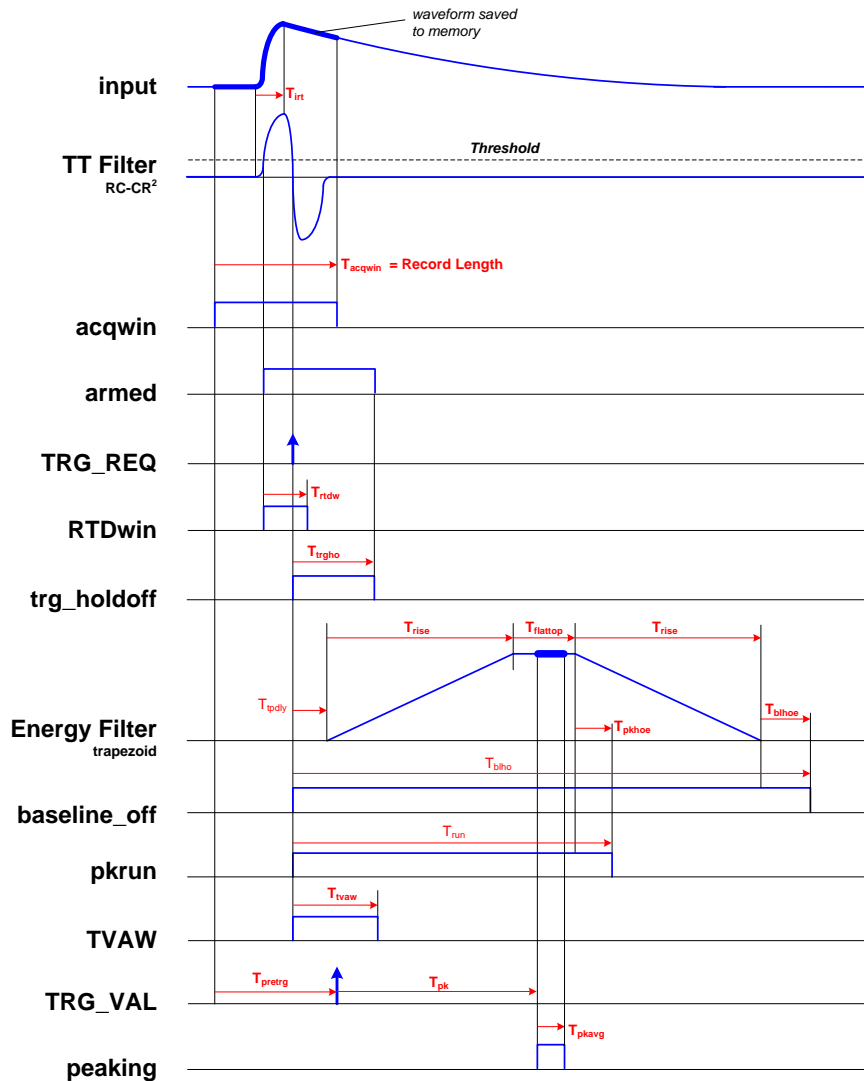
### Neighbour Trigger Mode

In the neighbour trigger mode, each channel still self-trigger on the input pulse. Moreover its TRG\_REQ generates a TRG\_VAL signal that enables the data writing of the channel itself and of the “neighbour” channels, i.e. the previous and the consecutive.



**Note:** The neighbor trigger mode is particularly useful with strip detectors.

In order to have the same peaking times and the same waveform acquisition window in both cases (channel triggered by TRG\_REQ or by TRG\_VAL), Tpk and Tpretrg are referred to TRG\_VAL instead of TRG\_REQ. For this reason, the trigger logic that generates TRG\_VAL must keep the jitter between TRG\_REQ and TRG\_VAL as low as possible. Also the time stamp saved in the event data is that one of TRG\_VAL.



**Fig. A.8:** Timing diagram (Neighbour Trigger Mode)

If TRG\_VAL signal arrives outside the TVAW window (see **Fig. A.9**), then the event will have the pile-up flag. Indeed TRG\_VAL is not related to the event that caused the TRG\_REQ in that channel and the calculated energy value is not properly evaluated.



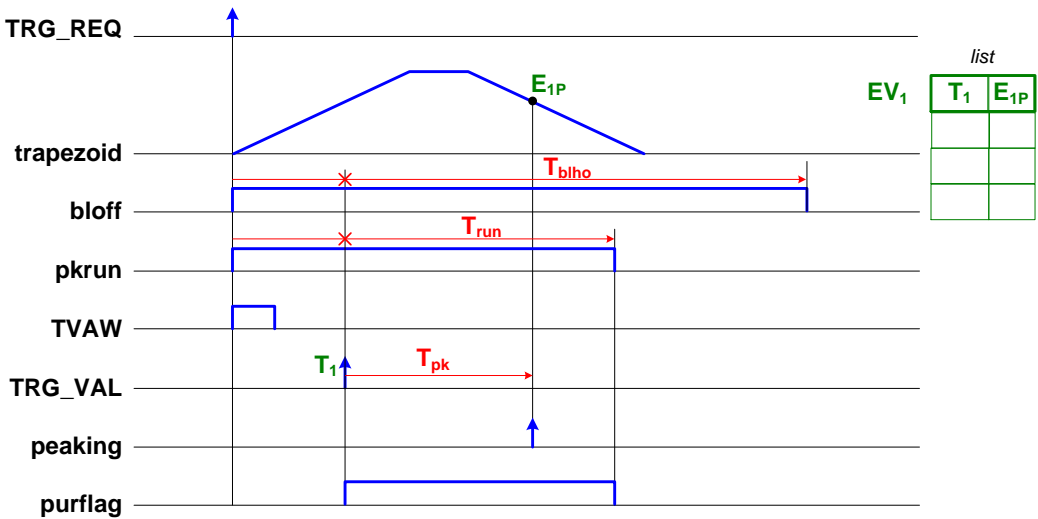


Fig. A.9: TRG\_VAL outside the acceptance window

If a “neighbour” channel triggers and gets a valid TRG\_VAL signal, then also the neighbour channels, even if they do not have enough charge to enable their own TRG\_REQ, they receive the same TRG\_VAL signal (see Fig. A.10). Please note that, unlike in the Normal Trigger Mode, the energy value latched at Tpk is saved into the memory with bit[15] = 1 (see **Channel Aggregate Data Format for 724 series**) indicating the pile-up condition. When the neighbour channel receives the TRG\_VAL signal it starts its Tpk and Trun counters even though the value measured will be probably close 0.

Refer to [RD5] for detailed instructions on how to enable this trigger mode with DPHA.

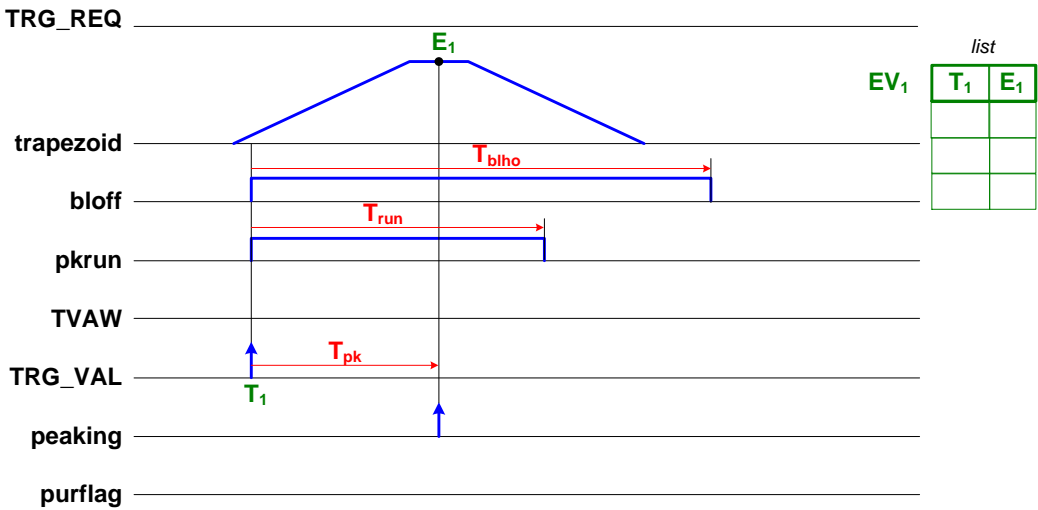


Fig. A.10: TRG\_VAL without TRG\_REQ

The TRG\_REQ pile-up condition for the Neighbour Trigger Mode is similar to Normal Trigger Mode (see the following figures).

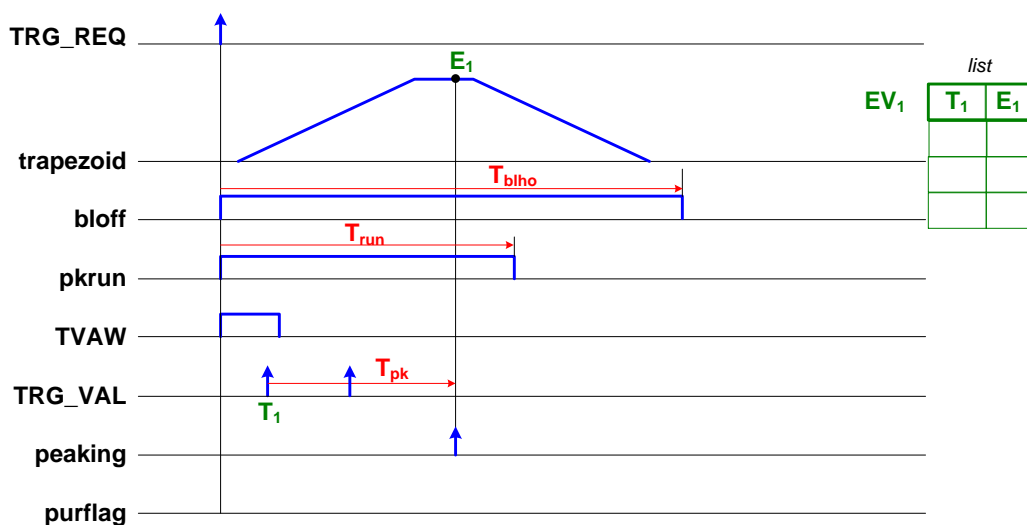


Fig. A.11: Second TRG\_VAL occurring within pkrun

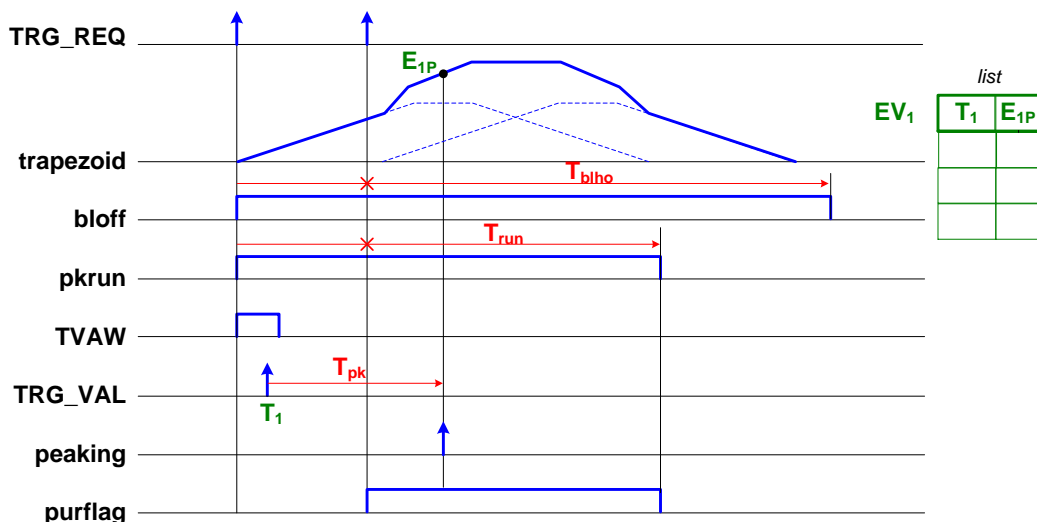


Fig. A.12: Pile-up occurred before the peaking time (Neighbour Trigger Mode)

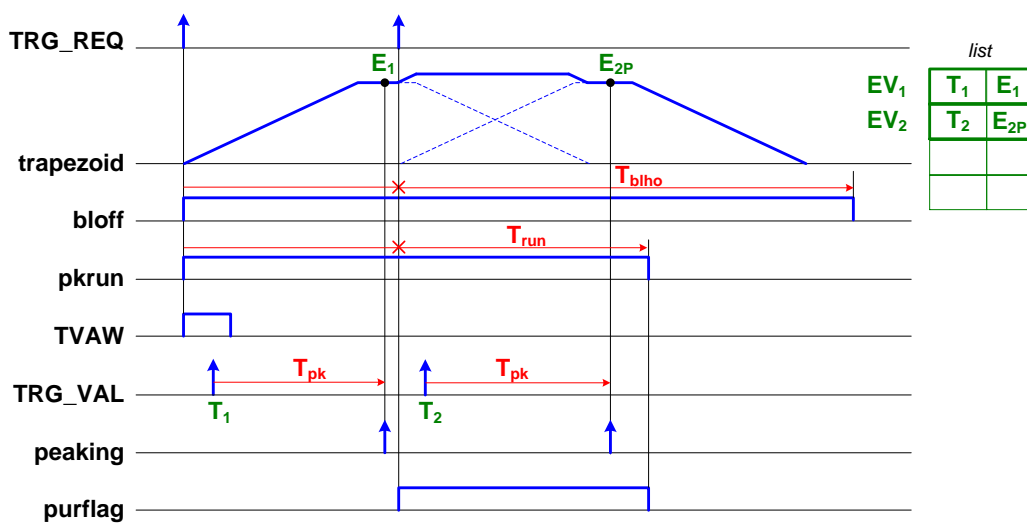


Fig. A.13: Pile-up occurred after the peaking time (Neighbour Trigger Mode)



**Fig. A.14:** Overlapped trapezoids that do not cause pile-up rejection (Neighbour Trigger Mode)

## Synchronization among different boards

In cases when multi-board systems are involved in the experiment, it is necessary to synchronize different boards. In this way the user can acquire from N boards with Y channel each, like if they were just one board with  $(N \times Y)$  channels.

The main issue in the synchronization of a multi-board system is to propagate the sampling clock among the boards. This is made through input/output daisy chain connections among the digitizers. One board has to be chosen to be the “master” board that propagates its own clock to the others. A programmable phase shift can adjust possible delays in the clock propagation. This allows to have both the same ADC sampling clock, and the same time reference for all boards. Having the same time reference means that the acquisition starts/stops at the same time, and that the time stamps of different boards is aligned to the same absolute time.

There are several ways to implement the trigger logic. The synchronization tool allows to propagate the trigger to all boards and acquire the events accordingly. Moreover in case of busy state of one or more boards, the acquisition is inhibited for all boards.

Refer to **[RD6]** for more details on how to synchronize CAEN digitizers.

## Memory Organization

This chapter is intended to provide the encoding of how the software reads the board memory to get the proper information. Those who need to write their own acquisition software must take care of the following sections.

## Event Data Format

The Channel Aggregate is composed by the set of  $N_e$  events, where  $N_e$  is the programmable number of events contained in one aggregate. The structure of the Channel Aggregate of two events (EVENT 0 and EVENT 1) is shown in **Fig. B.1**, where:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	BIT		
FI																	AGGREGATE SIZE															SIZE		
DT	ES	EE	ET					AP1	AP2		DP			NUM SAMPLES/2															FORMAT					
TT		TRIGGER TIME TAG																														EVENT 0		
T <sub>1</sub>	D <sub>1</sub>	S <sub>1</sub>															T <sub>0</sub>	D <sub>0</sub>	S <sub>0</sub>															
T <sub>3</sub>	D <sub>3</sub>	S <sub>3</sub>															T <sub>2</sub>	D <sub>2</sub>	S <sub>2</sub>															
T <sub>n-1</sub>	D <sub>n-1</sub>	S <sub>n-1</sub>															T <sub>n-2</sub>	D <sub>n-2</sub>	S <sub>n-2</sub>															
										EXTRAS					PU	PEAK (ENERGY)																	EVENT 1	
TT		TRIGGER TIME TAG																																
T <sub>1</sub>	D <sub>1</sub>	S <sub>1</sub>															T <sub>0</sub>	D <sub>0</sub>	S <sub>0</sub>															
T <sub>3</sub>	D <sub>3</sub>	S <sub>3</sub>															T <sub>2</sub>	D <sub>2</sub>	S <sub>2</sub>															
T <sub>n-1</sub>	D <sub>n-1</sub>	S <sub>n-1</sub>															T <sub>n-2</sub>	D <sub>n-2</sub>	S <sub>n-2</sub>															
										EXTRAS					PU	PEAK (ENERGY)																		

FI: when 1, the second word is the Format Info  
DT: Dual trace enabled flag (0 = disabled, 1 = enabled)  
ES: Waveform (samples) enabled flag  
EE: Energy enabled flag  
ET: Time Tag enabled flag

AP1: Analog Probe 1 Selection. AP1 can be selected among:

- 00 = "Input": the input signal from pre-amplified detectors
- 01 = "RC-CR": first step of the trigger and timing filter
- 10 = "RC-CR2": second step of the trigger and timing filter
- 11 = "Trapezoid": trapezoid resulting from the energy filter

AP2: Analog Probe 2 Selection. AP2 can be selected among:

- 00 = "Input": the input signal from pre-amplified detectors
- 01 = "Threshold": the RC-CR2 threshold value
- 10 = "Trapezoid-BL": the trapezoid shape minus the baseline
- 11 = "Baseline": displays the input baseline

DP: Digital Virtual Probe Selection. DP can be selected among:

- 0000 = "TRG Window": shows the RT Discrimination Width
- 0001 = "Armed": digital input showing where the RC-CR<sup>2</sup> crosses the Threshold
- 0010 = "Peak Run": starts with the trigger and last for the whole event (see **Fig. A.3**)
- 0011 = "Peak Abort": shows when there is a pile-up event and corresponds to the time interval when the energy calculation is disabled due to the pile-up event
- 0100 = "Peaking": shows where the energy is calculated
- 0101 = "Trg Validation Win": digital input showing the trigger validation acceptance window TVAW (refer to **Acquisition Modes** chapter and **[RD5]**)
- 0110 = "BSL Holdoff": shows the baseline hold-off parameter
- 0111 = "TRG Holdoff": shows the trigger hold-off parameter
- 1000 = "Trg Validation": shows the trigger validation signal TRG\_VAL (refer to **Acquisition Modes** chapter and **[RD5]**)
- 1001 = "Acq Veto": this is 1 when either the input signal is saturated or the memory board is full

TT: Trigger Type (0=self trigger, 1=external trigger)

$S_m$  ( $m = 0, 2, 4... n-2$ ): Even Samples of AP1 at time  $t = m$

$S_{m'}$  ( $m' = 1, 3, 4... n-1$ ): if DT=0, then  $S_{m'}$  correspond to the odd Samples of AP1 at time  $t = m'$ . Otherwise, if DT=1, they correspond to even Samples of AP2 at time  $t = m' - 1$

$T_n$ : bit identifying in which sample the Trigger occurred

$D_n$ : Digital Virtual Probe for each sample. The Probe type can be read from the "DP" field in the header

PU: Pile Up. This bit is usually set to zero. The user can recognize a pile up event when also the Energy value is zero. The user can also choose to have this bit equal to 1 in case of pile-up event, by enabling bit[27] of the DPP\_CTRL register (0x1n80 register address). In that case the energy value is what read from the algorithm

EXTRAS: bit[16] = DEAD\_TIME. This is set to 1 when a dead time occurred before this event. The dead time can be due to either a signal saturation or a full memory status. Check **Fig. B.2** and **Fig. B.3** for more details

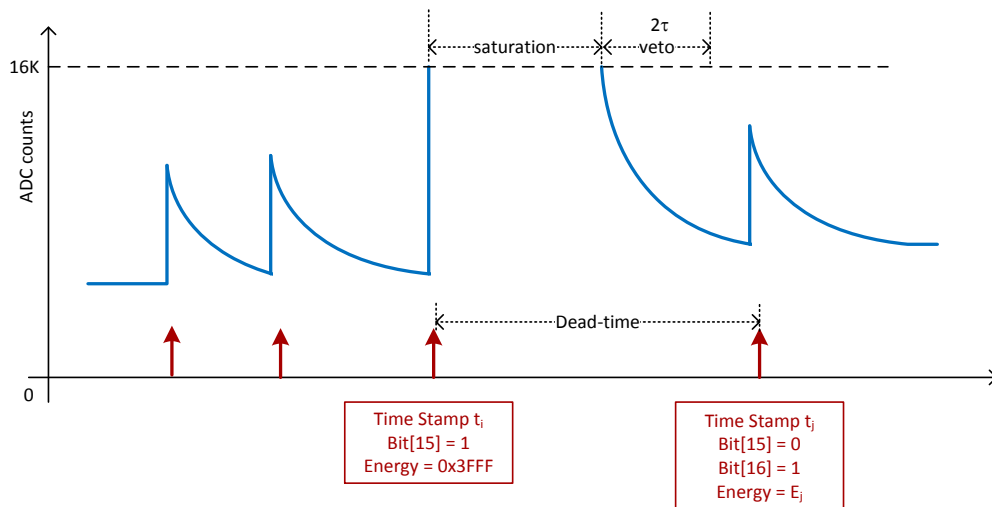
bit[17] = ROLL\_OVER. Identify a trigger time stamp roll-over that occurred before this event

bit[18] = TT\_RESET. Identify a trigger time stamp reset forced from external signals in S-IN (GPI for Desktop)

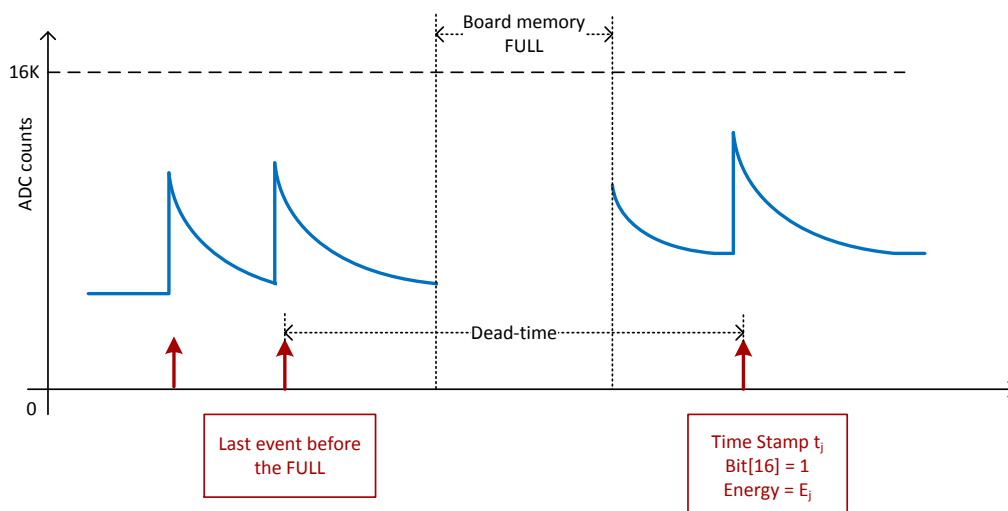
bit[19] = FAKE\_EVENT. This is a fake event (which does not correspond to any physical event) that identifies a time stamp roll-over. The roll-over can be due to an external or internal reset. The user can set to 1 bit[25] of the DPP\_CTRL register (0x1n80 register address) to enable the fake-event saving in case of reset from S-IN, and bit[26] of the DPP\_CTRL register (0x1n80 register address) to enable the fake-event saving in case of internal roll-over. In the first case the event will have both bit[19] and bit[18] set to 1, while in the second case the event will have both bit[19] and bit[17] set to 1.

**Notes:**

- 1) DEAD\_TIME in case of signal saturation (see **Fig. B.2**). If the input signal is over-range (exceeds the input dynamic range of 16k ADC channels) then the acquisition is inhibited. As soon as the input signal is in saturation an event is saved with the corresponding time tag, and bit[15] set to 1. The energy value is set to the maximum. This event has to be discarded for the energy spectrum, anyway this can be considered for the dead-time calculation. Once the signal is out of saturation a new trigger is inhibited for a time window of  $2 \times \text{Decay Time}$ . The first event after the saturation is tagged with bit[16] = 1.
- 2) DEAD\_TIME in case of FULL board memory (see **Fig. B.3**). When the memory of the board is full, the board is not able any more to transfer the event data. When the board is ready again, the first event after the FULL will have the bit[16] set to 1, and the energy value as read from the algorithm. The dead-time is equal to the time difference between the last trigger occurred and the trigger after the FULL status.



**Fig. B.2:** Dead-time in case of signal saturation



**Fig. B.3:** Dead-time in case of FULL memory status

### Channel Aggregate Data Format for 730 series

The Channel Aggregate is composed by the set of  $N_e$  events, where  $N_e$  is the programmable number of events contained in one aggregate (see the previous section). The structure of the Channel Aggregate of two events (EVENT 0 and EVENT 1) for 730 series is shown in **Fig. B.4**, where:

#### “CHANNEL AGGREGATE” DATA FORMAT

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	BIT		
FI																CHANNEL AGGREGATE SIZE (in lwords)																SIZE		
DT	EE	ET	E2	ES	EX		AP1		AP2		DP							NUM SAMPLES/8												FORMAT				
CH		TRIGGER TIME TAG																														EVENT 0		
T <sub>1</sub>	DP1 <sub>1</sub>	S <sub>1</sub>														T <sub>0</sub>	DP1 <sub>0</sub>	S <sub>0</sub>																
T <sub>3</sub>	DP1 <sub>3</sub>	S <sub>3</sub>														T <sub>2</sub>	DP1 <sub>2</sub>	S <sub>2</sub>																
...																																		
T <sub>n-1</sub>	DP1 <sub>n-1</sub>	S <sub>n-1</sub>														T <sub>n-2</sub>	DP1 <sub>n-2</sub>	S <sub>n-2</sub>																
EXTRAS 2																																		
										EXTRAS				PUR	ENERGY																			
CH		TRIGGER TIME TAG																															EVENT 1	
T <sub>1</sub>	DP1 <sub>1</sub>	S <sub>1</sub>														T <sub>0</sub>	DP1 <sub>0</sub>	S <sub>0</sub>																
T <sub>3</sub>	DP1 <sub>3</sub>	S <sub>3</sub>														T <sub>2</sub>	DP1 <sub>2</sub>	S <sub>2</sub>																
...																																		
T <sub>n-1</sub>	DP1 <sub>n-1</sub>	S <sub>n-1</sub>														T <sub>n-2</sub>	DP1 <sub>n-2</sub>	S <sub>n-2</sub>																
EXTRAS 2																																		
										EXTRAS				PUR	ENERGY																			

**Fig. B.4:** Channel Aggregate Data Format scheme for 730 series

FI: if 1, the second word is the Format Info

DT: Dual trace enabled flag (1 = enabled, 0 = disabled)

EE: Energy enabled flag

ET: Time Tag enabled flag

E2: Extras 2 enabled flag

ES: Waveform (samples) enabled flag

EX: Extras option enabled flag:

000 = the word “EXTRAS 2” will be read as:

[31:16] = extended time stamp: those 16 bits can be added (left) to the Time Stamp representation, which becomes a 31+16=47 bit number;

[15:0] = the trapezoid baseline value.



**Note:** to enable the “EXTRAS 2” word set bit[17] of register 0x8000.

AP1: Analog Probe 1 Selection. AP1 can be selected among:

00 = “Input”: the input signal from pre-amplified detectors

01 = “RC-CR”: first step of the trigger and timing filter

10 = “RC-CR2”: second step of the trigger and timing filter

11 = “Trapezoid”: trapezoid resulting from the energy filter

AP2: Analog Probe 2 Selection. AP2 can be selected among:

- 00 = "Input": the input signal from pre-amplified detectors
- 01 = "Threshold": the RC-CR2 threshold value
- 10 = "Trapezoid-BL": the trapezoid shape minus the baseline
- 11 = "Baseline": displays the input baseline

DP: Digital Virtual Probe Selection. DP can be selected among:

- 0000 = "TRG Window": shows the RT Discrimination Width
- 0001 = "Armed": digital input showing where the RC-CR<sup>2</sup> crosses the Threshold
- 0010 = "Peak Run": starts with the trigger and last for the whole event (see **Fig. A.3**)
- 0011 = "Peak Abort": shows when there is a pile-up event and corresponds to the time interval when the energy calculation is disabled due to the pile-up event
- 0100 = "Peaking": shows where the energy is calculated
- 0101 = "Trg Validation Win": digital input showing the trigger validation acceptance window TVAW (refer to **Acquisition Modes** chapter and **[RD5]**)
- 0110 = "BSL Holdoff": shows the baseline hold-off parameter
- 0111 = "TRG Holdoff": shows the trigger hold-off parameter
- 1000 = "Trg Validation": ": shows the trigger validation signal TRG\_VAL (refer to **Acquisition Modes** chapter and **[RD5]**)
- 1001 = "Acq Veto": this is 1 when either the input signal is saturated or the memory board is full

CH: since two consecutive channels share the same buffer, the CH flag identifies whether the even channel or the odd channel participated to the event (0 for even, 1 for odd).

$S_m$  ( $m = 0, 2, 4... n-2$ ): Even Samples of AP1 at time  $t = m$

$S_{m'}$  ( $m' = 1, 3, 4... n-1$ ): if DT=0, then  $S_{m'}$  correspond to the odd Samples of AP1 at time  $t = m'$ . Otherwise, if DT=1, they correspond to even Samples of AP2 at time  $t = m' - 1$

$T_n$ : bit identifying in which sample the Trigger occurred

$D_n$ : Digital Virtual Probe for each sample. The Probe type can be read from the "DP" field in the header

PU: Pile Up. More generally this bit is used to flag events whose energy value is meaningless.

EXTRAS: bit[16] = DEAD\_TIME. This is set to 1 when a dead time occurred due to memory board FULL. Check **Fig. B.3** for more details;

Bits[19:17] = RESERVED.



**Notes:** regardless the x724 family (DT5780 and DT5781) when a trigger time stamp roll-over occurs the board x730 saves an event with Time Stamp = 0, bit[15] = 1, and Energy = 0.



## Board Aggregate Data Format

For each readout request (occurring when at least one channel has available data to be read) the “interface FPGA (ROC)” reads one aggregate from each enabled channel memory. No more than one aggregate per channel is read each time. The set of Channel Aggregates is the Board Aggregate. If one channel has no data, that channel does not come into the Board Aggregate.

The data format when all 8 channels of a VME have available data is as shown in **Fig. B.5**, where:

### “BOARD AGGREGATE” DATA FORMAT

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	BIT	
1	0	1	0	BOARD AGGREGATE SIZE (in lwords)																								HEADER					
				BOARD ID		BF		PATTERN												CHANNEL MASK													
								BOARD AGGREGATE COUNTER																									
				BOARD AGGREGATE TIME TAG																													
																												CHANNEL AGGREGATE CH0	CH 0				
																												CHANNEL AGGREGATE CH1		CH 1			
																												...	...				
																												CHANNEL AGGREGATE CH7	CH 7				

**Fig. B.5:** Board Aggregate Data Format scheme

BOARD AGGREGATE SIZE: total size of the aggregate

BF: Board Fail flag. This bit is set to “1” after a hardware problem, as for example the PLL unlocking, or over-temperature condition. The user can investigate the problem checking the error monitor register 0x8178, or contacting CAEN support (refer to Chapter **Technical support**).



**Notes:** BF bit is meaningful only for ROC FPGA firmware revision greater than 4.5. It is *reserved* for previous releases.

PATTERN: is the value read from the LVDS I/O (VME only);

CHANNEL MASK: corresponds to those channels participating to the Board Aggregate;

BOARD AGGREGATE COUNTER: counts the board aggregate. It increase with the increase of board aggregates;

BOARD AGGREGATE TIME TAG: is the time of creation of the aggregate (this not corresponds to any physical quantity);

### Data Block

The readout of the digitizer is done using the Block Transfer (BLT, refer to **[RD7]**); for each transfer, the board gives a certain number of Board Aggregates, consisting in the Data Block. The maximum number of aggregates that can be transferred in a BLT is defined by the READOUT\_BTL\_AGGREGATE\_NUMBER. In the final readout each Board Aggregate comes successively. In case of  $n$  Board Aggregates, the Data Block is as in **Fig. B.6**.

### **DATA BLOCK**

BOARD AGGREGATE 0
BOARD AGGREGATE 1
...
BOARD AGGREGATE $n-1$

**Fig. B.6:** Data Block scheme



CAEN SpA is acknowledged as the only company in the world providing a complete range of High/Low Voltage Power Supply systems and Front-End/Data Acquisition modules which meet IEEE Standards for Nuclear and Particle Physics. Extensive Research and Development capabilities have allowed CAEN SpA to play an important, long term role in this field. Our activities have always been at the forefront of technology, thanks to years of intensive collaborations with the most important Research Centres of the world. Our products appeal to a wide range of customers including engineers, scientists and technical professionals who all trust them to help achieve their goals faster and more effectively.

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