FASTER Trapezoidal-Spectro MnM USER MANUAL

The FASTER Trapezoidal-Spectro MnM (**M**easurement **n**umerical **M**odule) is the ideal FASTER MnM for the nuclear physics spectroscopy. This MnM can be used with Silicon or HPGe detectors, ionization chambers, proportional counters…

This version of spectroscopy-MnM uses the trapezoidal filter, unlike the CR-RC^4 filter of the earlier version of the FASTER spectroscopy-MnM. It allows to calculate the event time-stamp with an accuracy of 8 ns/2^8 (≈31 ps).

The trapezoidal filter is well suited for detectors that undergo a ballistic deficit. It is more robust in case of high counting rate, because it generates shorter signals.

Cathy Fontbonne

Summary

I Theory of operation

In the Trapezoidal-Spectro MnM, two signals, called "Spectro OUT" and "Fast OUT", are generated in parallel from the signal coming out of a Charge Pre-Amplifier (CPA):

- The Spectro OUT signal: it is a trapezoidal or triangular signal whose characteristics are chosen to maximize the ratio Signal amplitude/Noise: the amplitude measurement of the Spectro OUT signal, thanks to the ADC module (cf. Figure 1), is proportional to the energy deposited per incident particle.
- The Fast OUT signal: it is a trapezoidal or triangular signal, which lasts less than the Spectro OUT signal. It allows an optimal measurement of the particle arrival time. This signal is connected to a constant fraction shaper and trigger. This signal is generally used to trigger the amplitude measurement of the Spectro OUT signal in the ADC module.

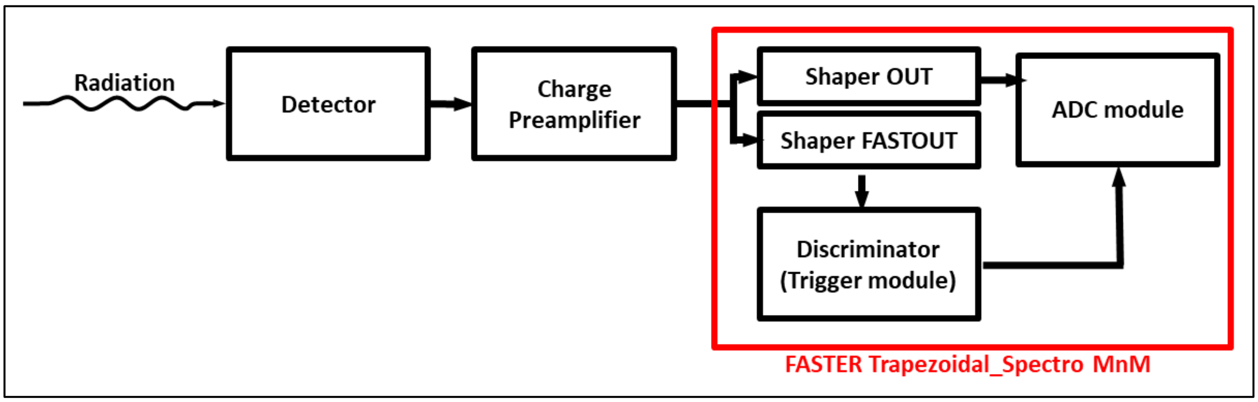


Figure 1: Instrumentation system for spectroscopy.

The ideal signal equation, coming out of a **C**harge **P**re-**A**mplifier (CPA), is:

$$\begin{cases} e(t) = 0 \quad \forall\, t < t_i \\ e(t) = k \cdot E_i \cdot e^{-\frac{t-t_i}{\tau_{\mathrm{CPA}}}} \quad \forall\, t \geq t_i \end{cases} \qquad \textbf{Equation I-1}$$

with τ_{CPA} the CPA time constant, typically ranging from a few 10 µs up to a few 100 µs.

The noise coming from the electronic modules is added to this signal.

Several filters can be applied to maximize the S/N ratio, but the theory is based on a voltage step input signal ($e(t) = k \cdot E_i \; \forall\, t \geq t_i$), and not a decreasing exponential input signal. In the FASTER Trapezoidal-Spectro MnM, the applied filters, which constitute the shaper module, are therefore:

- A module to transform the decreasing exponential input signal into a step input signal (Pole-Zero Compensation= PZC)
- A filter transforming this step signal into a trapezoid/triangle signal (trapezoidal shaper)
- A baseline restorer (BLR).

The first two modules are linear filters, they can be applied in any order. In the Trapezoidal-Spectro MnM, the modules are implemented as follows:

- The filter elaborating the trapezoid/triangle signal(trapezoidal shaper)
- The module correcting the fact that the input signal is not a step (PZC)
- The baseline restorer (BLR).

The Figure 2 shows the signal shapes after every filter module.

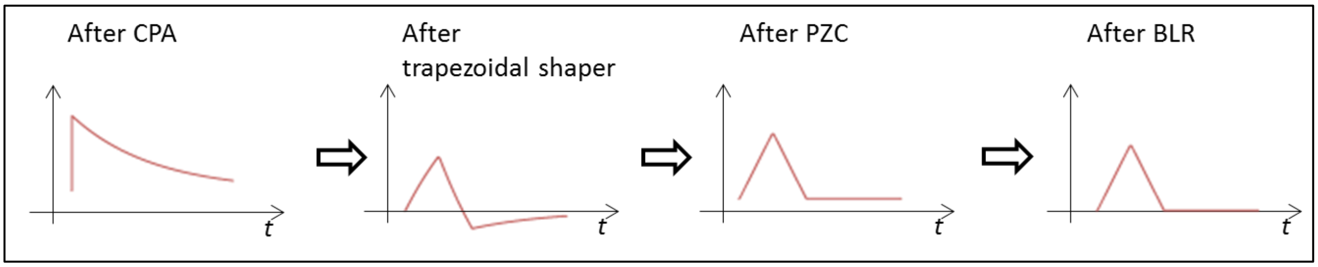


Figure 2: signal shapes after the different filters

It is important to note that the out signal from the trapezoidal shaper is a zero baseline signal, because the trapezoidal shaper is a bandpass filter, as it can be noticed on its Bode diagram on Figure 3.

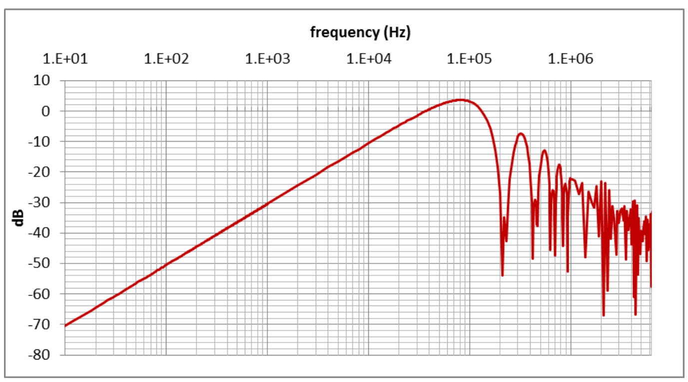


Figure 3: Bode diagram for trapezoidal shaper rising edge=4.3µs, flat top=480ns

It is the pole-zero corrector module that passes the input baseline to the output signal. If the input baseline is BL_i, then the out baseline BL_o, after the pole-zero corrector module, is:

$$BL_o = \frac{rising\_edge\_duration + flat\_top\_duration}{\tau_{CPA}} BL_i$$ **Equation I-2**

rising_edge_duration and *flat_top_duration* are defined in Figure 20, p17.

The Bode diagram of the Figure 3 becomes after pole-zero compensation (CPZ) such as the Figure 4.

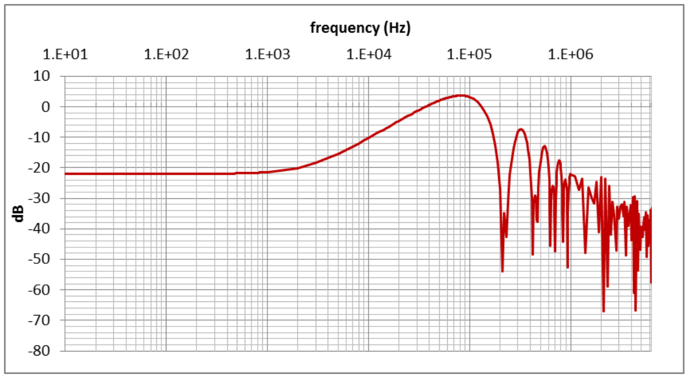


Figure 4: Bode diagram for trapezoidal shaper rising edge=4.3µs, flat top=480ns + PZC (τ_{CPA}=40µs)

In the chapter III of this document, we will describe the various filters or modules implemented in the MnM, namely the trapezoidal shaper, the pole-zero compensation filter, the baseline restorer filter, the discriminator module, the ADC module and the oscilloscope module.

II Preamble

II.A FASTER launching

To take benefit of the "Trapezoidal" spectroscopy of the FASTER acquisition, the experimenter can build his experiment interface with the command `faster_setup_gui`.

The interface, shown on Figure 5, is launched. To use the FASTER Trapezoidal-Spectro MnM, the experimenter must select the "Trapezoidal Spectro" type, by right-clicking on the daughterboard line.

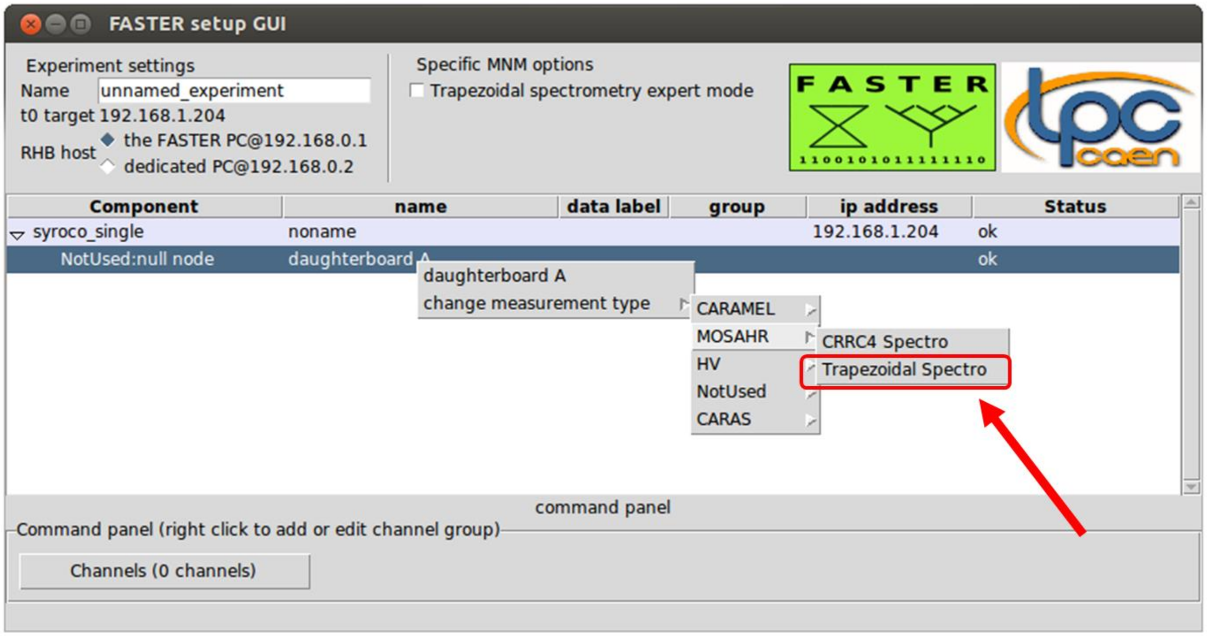


Figure 5: experiment building with "faster_setup_gui".

By checking or unchecking "use expert mode" (cf. Figure 6), the experimenter can choose between two interfaces: an expert or a basic one.

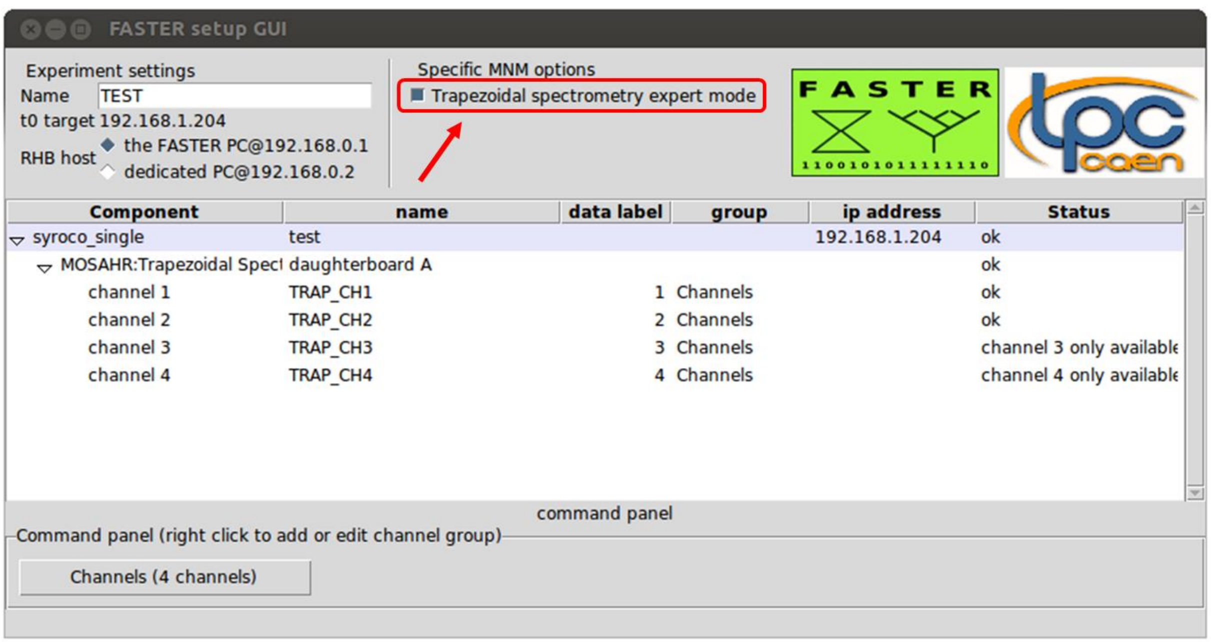


Figure 6: two interfaces (basic or expert) are existing to adjust the parameters of the FASTER Trapezoidal-Spectro MnM.

Before exiting the application form, the user can choose the names of the experiment, of the daughterboard and of each channel of the daughterboard.

With the command line `faster_gui`, the experimenter accesses to the FASTER acquisition display, shown on Figure 7.

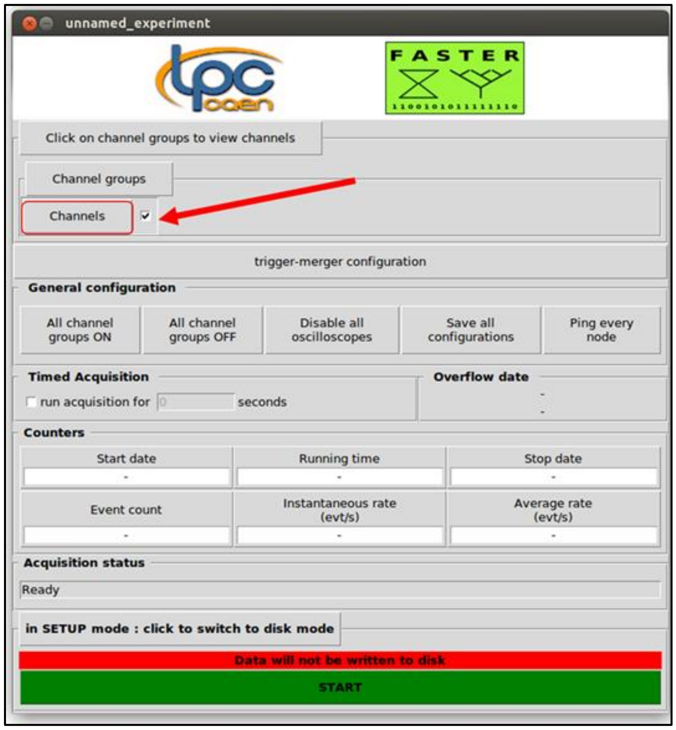


Figure 7: faster_gui interface.

By clicking on "Channels" (cf. Figure 7), the MnM interface is displayed, allowing the user to adjust the different module parameters.

The basic interface (Figure 8) looks like the earlier FASTER CRRC4-Spectro MnM interface:

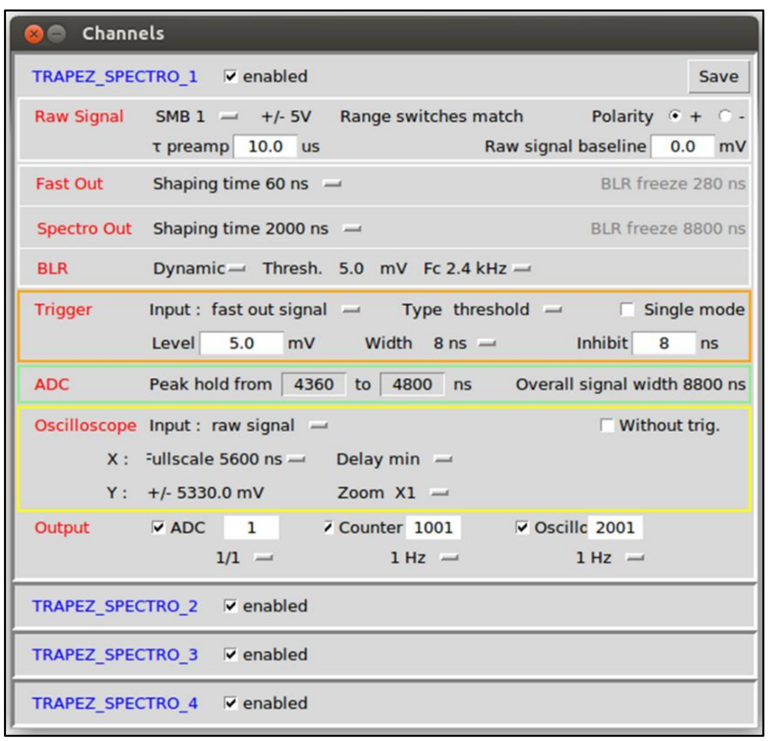


Figure 8: basic interface

The expert interface (Figure 9) allows expert tunings:

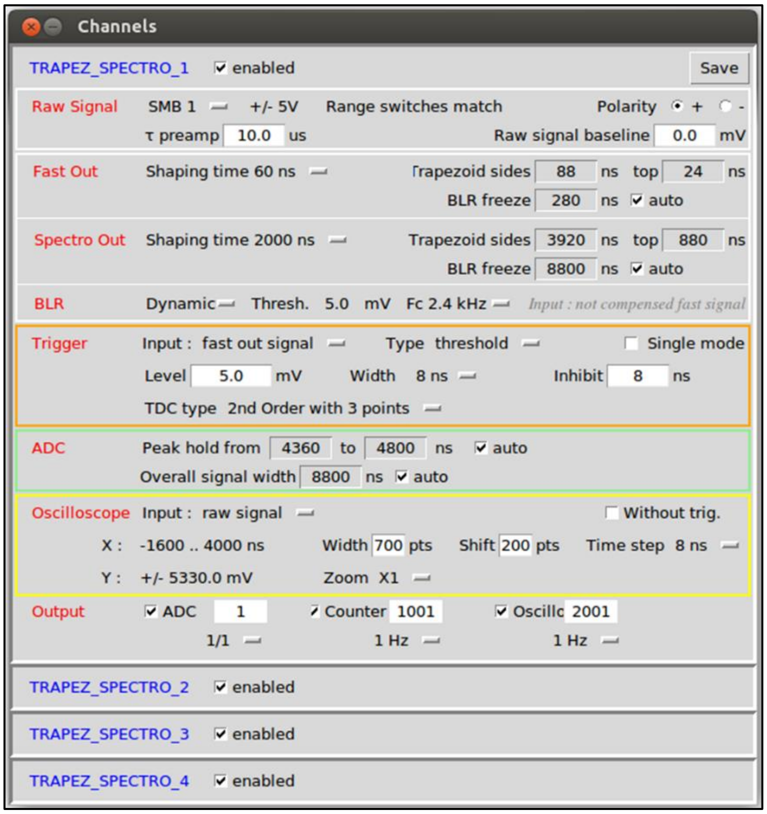


Figure 9: expert interface.

II.B RHB launching

To take benefit of RHB displays, the experimenter shall execute the command `faster_rhb_demo_trap_spectro_copy` in the working directory, in order to have an example of RHB files adapted to the FASTER Trapezoidal-Spectro MnM.

A new repertory `ADC_RHB_Demo` is created. The user shall go in the full_config repertory contained in the repertory `ACD_RHB_Demo`, before launching RHB interface.

```
cd ADC_RHB_Demo
cd full_config
RHB -r
```

III Description of FASTER Trapezoidal-Spectro MnM

Both interfaces include several tuning modules, synthetically described in Table 1 and Figure 10. Each module has some parameters that are adjustable by the user to achieve the best performance.

module	Border color	Purpose
Raw signal module	blue	It describes the raw signal characteristics.
Shaping module (Fast OUT, Spectro OUT, BLR)	white	It makes the both Spectro OUT and Fast OUT trapezoidal signals, with a zero baseline. See Figure 2.
Trigger module	orange	It timestamps the particle arrival time and wakes up the other modules except BLR module.
ADC module	green	It measures the amplitude of the Spectro OUT trapezoidal signal
Oscilloscope module	yellow	It allows the user to visualize several module signals
Data output module	no color	It allows the user to choose output data (label, rate)

Table 1: Description of the Trapezoidal-Spectro MnM

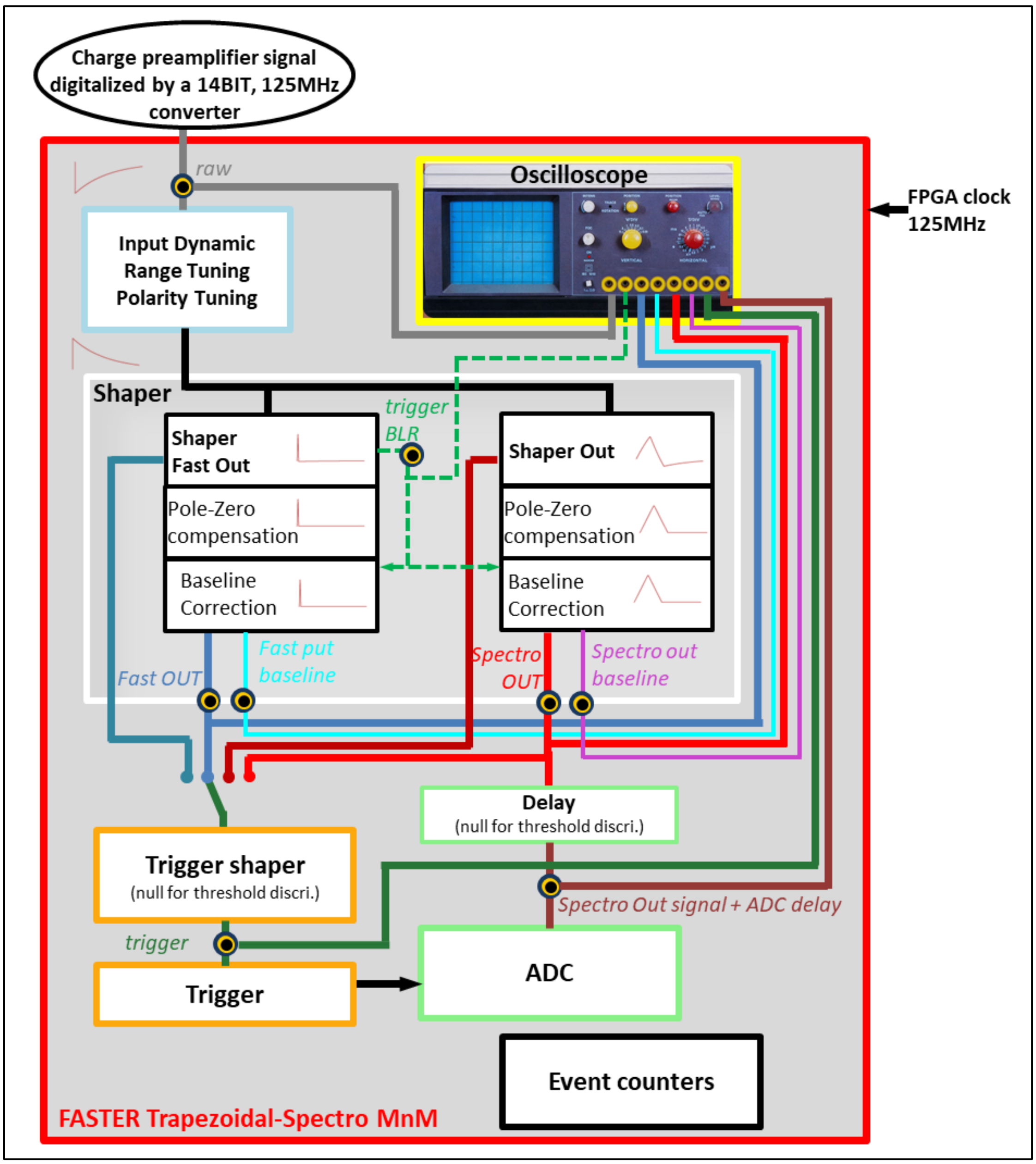


Figure 10: Diagram of FASTER Trapezoidal-Spectro MnM. The border colour of each box is as the one of the MnM interface.

The following chapters describe these different modules and explain how to select all the FASTER Trapezoidal-Spectro MnM parameters to achieve the best signal/noise ratio. We recommend to use RHB facilities to display signal shapes and deposited energy spectra. The signal shapes are observable thanks to the Oscilloscope module. This one is therefore the first to be described.

III.A The Oscilloscope module

Oscilloscope data contains up to 700 points separated by a time step. The time step is a power of 8 ns.

The signal, which is displayed by the oscilloscope module, is defined by the parameter ① (Figure 11 and Figure 13). Each ◉ on Figure 10 indicates the location of an Oscilloscope module input. The use case of this signal is described in Table 2.

Input signal	Basic mode	Expert mode
raw signal	To adjust Raw signal module parameters	To adjust Raw signal module parameters
trigger BLR	To adjust BLR module parameters	To adjust BLR module parameters
fast out signal	To adjust Fast Out module parameters	To adjust Fast Out module parameters (including BLR freeze)
fast out baseline		To check BLR tunings of the Fast Out signal
spectro out signal	To adjust : - Spectro Out module parameters - τ preamp parameter in the Raw signal module for pole-zero compensation	To adjust: - Spectro Out module parameters (including BLR freeze) - τ preamp parameter in the Raw signal module for pole-zero compensation
spectro out baseline		To check BLR tunings of the Spectro Out signal
trigger Threshold	To adjust Trigger module parameters	To adjust Trigger module parameters in case of threshold discriminator
trigger CFD		To adjust Trigger module parameters in case of constant fraction discriminator
spectro out signal + delay		To adjust ADC module parameters

Table 2: Use case of the Input signal of the Oscilloscope module

In **the expert mode** (c.f. Figure 11), it is possible to choose the number of samples of the oscilloscope frame in ⑧. It must be an even number between 2 and 700. The user choose the time step between each point in ⑦. As each particle signal, triggered by the Trigger module or the BLR Trigger, is spotted by the "0 ns" relative time in the oscilloscope frame, the user have to select how many samples he wants before the "0 ns" sample, in the shift parameter ⑥. With an 8 ns time step, the value of the "0 ns" sample is always above the trigger level. In ⑤, the user can visualize the resulting time fullscale range. The Y-fullscale ③ depends on daughter board characteristics (c.f. § III.B). It is always 0 centered, and the experimenter can zoom with the zoom button ④.

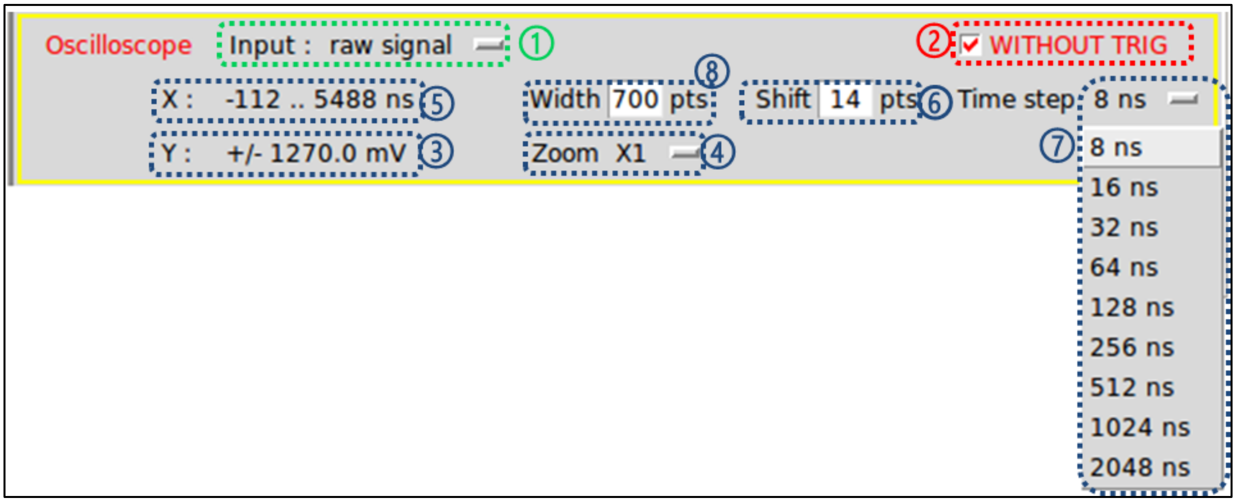


Figure 11: Oscilloscope module / expert mode.

When the time step is greater than 8 ns, an "AVERAGE" button appears (cd. Figure 12). If this button is checked, every sample of the oscilloscope display is the average of many samples (2 for a 16 ns time step, 4 for a 32 ns time step, 8 for a 64 ns time step …). Therefore, oscilloscope display seems to be less noisy than it is in reality. When "AVERAGE" is unchecked, one sample every 2 or 4 or 8 or 16 (etc.), depending on the time step value of 16 ns, 32 ns, 64 ns or 128 ns (etc.) forms the oscilloscope display. The sample, which triggered the Trigger module, is not necessarily apparent.

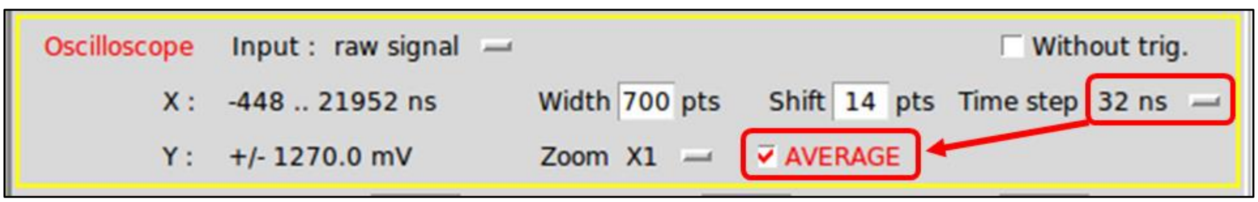


Figure 12: Oscilloscope module. Average button appears for all time step above 8 ns.

In **the basic mode** (c.f. Figure 13), the oscilloscope frame contains 700 samples. Thus, the time fullscale ⑤ is entirely defined by the time step and equal to 700 x *[time step value]*. The time step value can be equal to 8 ns, 16 ns, 32 ns, 64 ns, 128 ns, 256 ns, 1024 ns or 2048 ns, thus, the time fullscale is respectively 5600 ns, 11 µs, 23 µs, 45 µs, 90 µs, 180 µs, 360 µs, 0.7 ms or 1.4 ms. The Delay button ⑥ corresponds to a shift of respectively 14 samples, 176 samples, 350 samples and 490 samples for respectively Delay min, 25%, 50% and 70%. As in expert mode, the Y-fullscale ③ in basic mode depends on the daughter board characteristics (c.f. § III.B) and the experimenter can zoom with the zoom button ④.

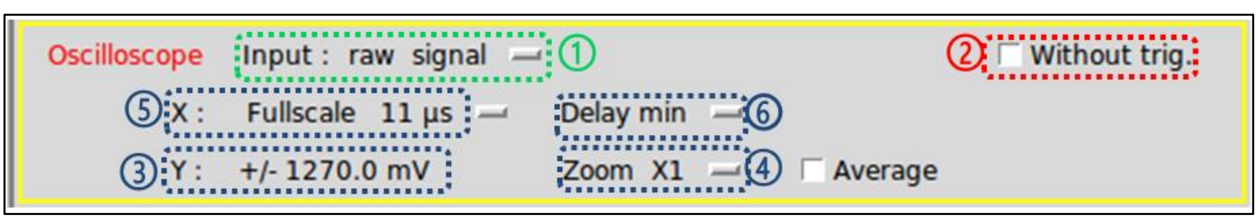


Figure 13: Oscilloscope module / basic mode

If "without trig" is checked in ② (Figure 11 and Figure 13), Oscilloscope module does not use the Trigger module to start storing an oscilloscope frame, but it uses a clock, whose frequency is defined in the "Output" module (cf Figure 14). The user can select either 1 kHz, 100 Hz, 10 Hz as output frequency.

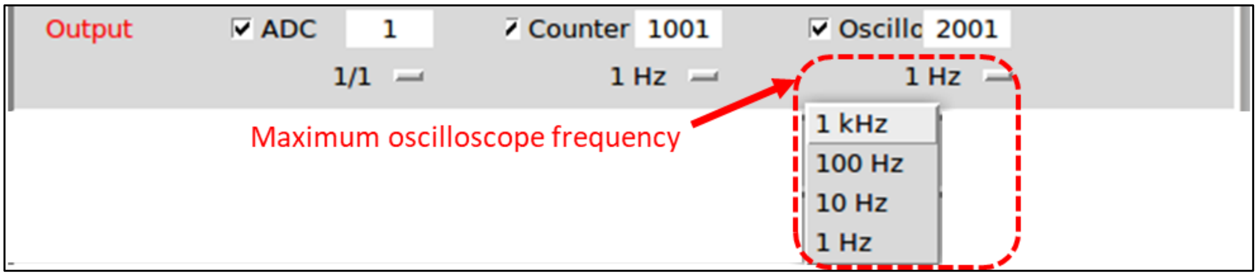


Figure 14: maximum frequency of the oscilloscope frame definition

If "without trig" is unchecked in ② (Figure 11 and Figure 13), the Oscilloscope module is woken either by the BLR trigger if the displayed signal is "trigger BLR", otherwise by the Trigger module. In all case, the maximum oscilloscope frequency is defined by the Output module.

III.B The Raw signal module

In this module, the user has to describe the raw signal (cf. Figure 15). That means its link with one of the four daughter board input channel ①, its polarity ③, its decay time constant ④, its baseline level ⑤.

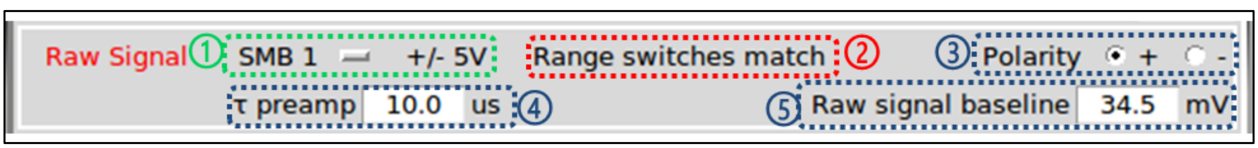


Figure 15: the raw signal parameters.

The MOSAHR daughter board has four input channel called SMB 1 to SMB 4. Each FASTER Trapezoidal-Spectro MnM in the FPGA can be linked with any SMB. Each SMB channel can have a different input fullscale range from ± 1V to ± 10V, set by four mechanical switches on the daughter board. By clicking on "Range switches match" ②, a new interface is launched (cf. Figure 16), the user has to match the fullscale range of the oscilloscope display with the real electronical fullscale range.

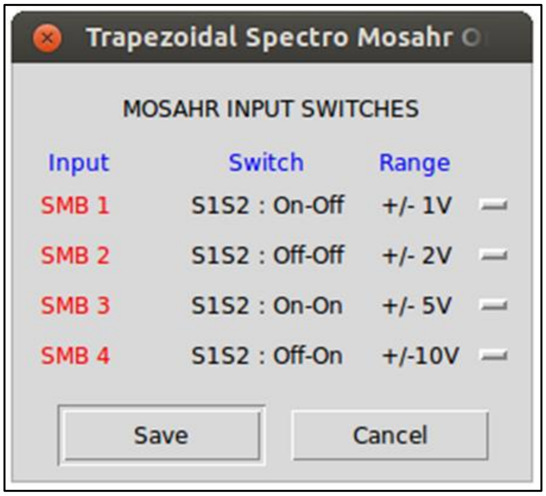


Figure 16: fullscale range interface for MOSAHR daughter board.

The Oscilloscope module allows the user to display the raw signal (Figure 17):

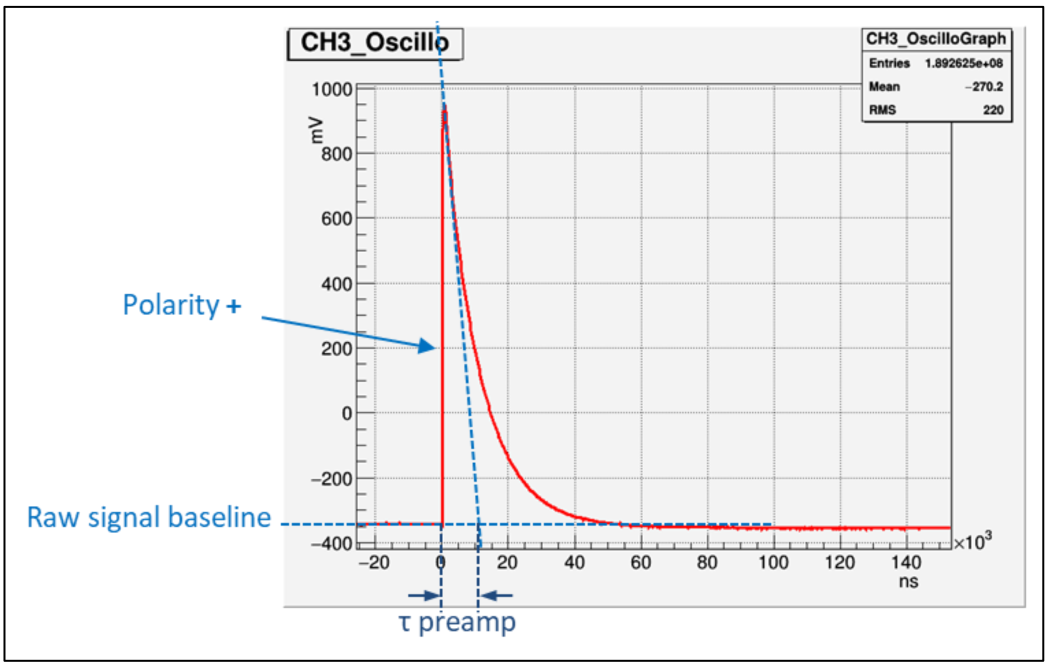


Figure 17: Raw signal example, and parameters definition. To visualize the raw data, it is often necessary to select a wide time fullscale range above 180 µs

The "polarity" (cf. Figure 17) indicates the particle pulse direction (upward: polarity +, downward: polarity -).

"Raw signal baseline" is the voltage level in millivolt, on which the particle pulse is located. As shown on Equation I-2 (p6), a portion of the raw baseline is present after the trapezoidal shaper and PZC module. If the baseline level is well-defined, the baseline restorer by a constant level subtraction will be exact.

At last, "τ preamp" is the CPA time constant τ_{CPA} defined in Equation I-1. It is also the decay slope at time "0 ns" (c.f. Figure 18). This value is used by the Pole-Zero Compensation module (PZC).

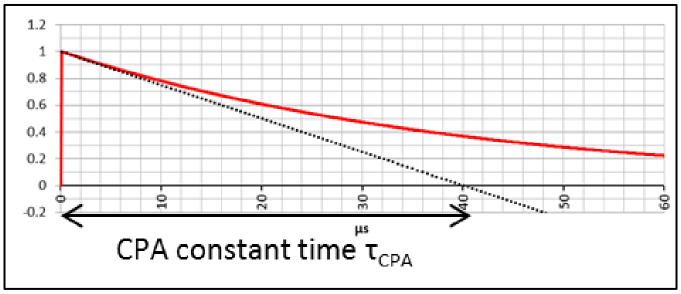


Figure 18: Theoretical signal from CPA. T_{CPA} =40µs

In this MnM, "τ preamp" value has to be selected in the range 8.2 µs to 671 µs.

III.C The Shaping module

The Shaping module role is to make the Spectro OUT and Fast OUT trapezoidal signal, with a zero baseline. As explained in chapter I and Figure 19, it includes a trapezoidal filter, a pole-zero compensation module, and a baseline restorer for each channel Spectro OUT or Fast OUT.

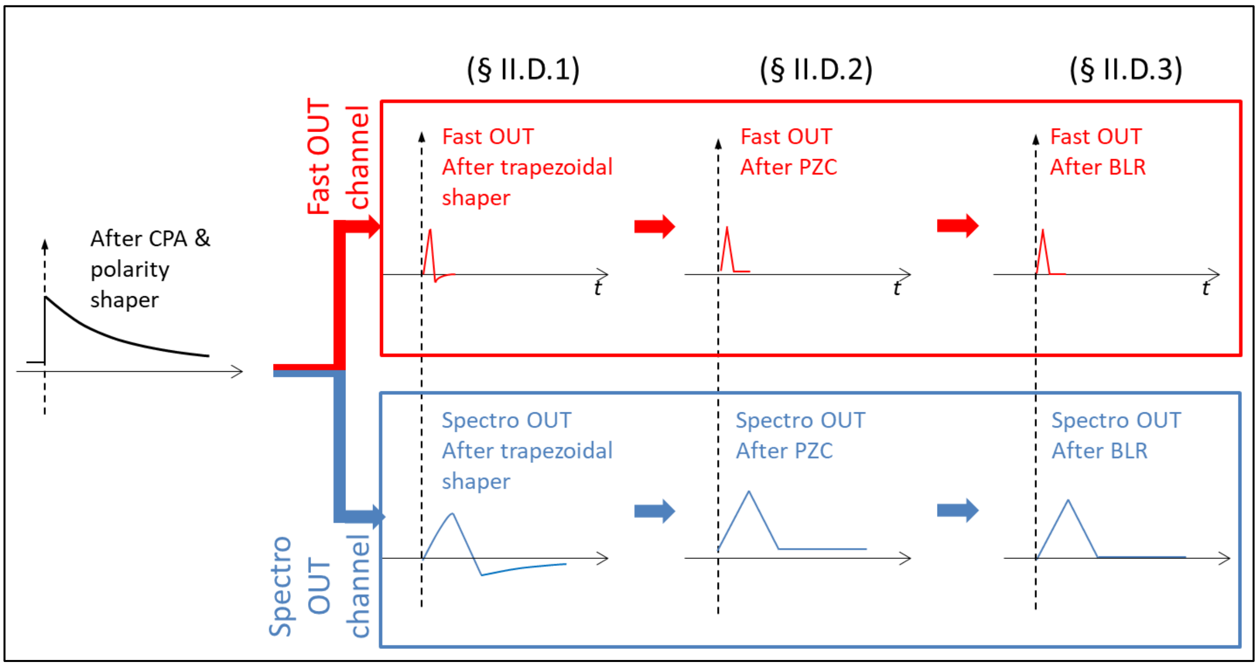


Figure 19: shaping module. It contains a trapezoidal shaper, a PZC module and a BLR module for each channel Spectro OUT or Fast OUT.

III.C.1 The trapezoidal shaper

III.C.1.a Trapezoid description

In the FASTER Trapezoidal-Spectro MnM, the shaper transforms a step signal of amplitude "A" and baseline BL_i, into a trapezoid signal of amplitude "A" located on the baseline BL_o. This is a viewing facility given to the user, because in the FASTER MnM, the amplitude of the trapezoid also depends on the ratio $\frac{rising\_edge\_duration}{T_s}$

where T_s is the sampling period of the digitizer, i.e. 8 ns. It is the reason why the amplitude histogram is also modified, when the rising edge of the trapezoid is changed.

The trapezoid is completely defined by 2 out of 3 of the following durations, multiple of the 8 ns sampling period:

- Rising edge duration
- Flat top duration (or plateau duration)
- Shaping time: although the shaping time is generally defined by the standard deviation of a Gaussian function interpolating the trapezoid, we will use, for convenience, the width at half of maximum of the trapezoid (cf. Figure 20)

$$shaping\ time = \frac{rising\_edge\_duration + flat\_top\_duration}{2}$$

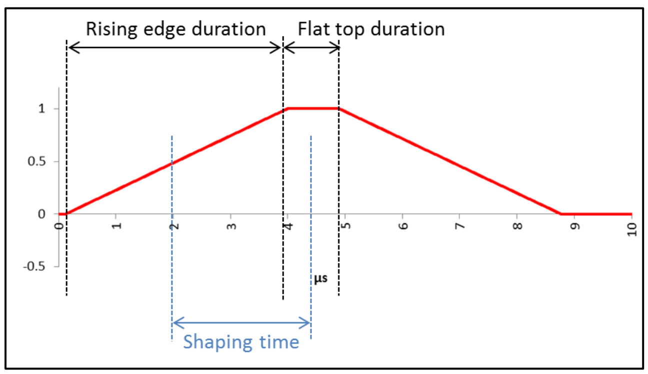


Figure 20: time definition

III.C.1.b Trapezoid parameters tuning of Fast OUT signal

The Fast OUT signal must be a fast signal. It warns of the arrival of an event and timestamps it. Ideally, the Fast OUT trapezoid is however large enough to take into account the rise time of the input signal, in order to locate the low-energy signals as well as possible.

In the basic mode, the experimenter can find the same shaping time choices that he had used with the FASTER CRRC4-Spectro MnM (c.f. Figure 21 ①). That means a 25 ns shaping time and a 60 ns shaping time.

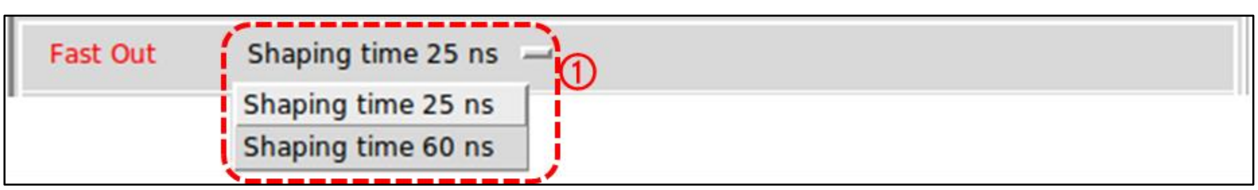


Figure 21: Fast OUT shaper module / basic mode.

The Table 3 gives trapezoid time values of Fast OUT signal, chosen for the user in order to correspond to the Fast OUT shaping time of CRRC4-Spectro MnM.

CR-RC[4] Shaping time	 25ns	 60ns
Trapezoid Rising edge duration (ns) Flat top duration(ns) Shaping time(ns)	 40 16 28	 88 24 56

Table 3: Fast OUT signal correspondence between CRRC4 Spectro MnM parameters and Trapezoid-Spectro MnM parameters.

In the expert mode, the user has a complete freedom in choosing the rising edge duration in ④ (Figure 22), and the flat top duration ③, if he selects "MANUAL shaping" in ①. The associated shaping time is given in ② for information. Nevertheless, the Fast OUT trapezoid durations must check the following inequality:

$$0 < \textit{Rising edge duration} \leq \textit{Rising edge duration} + \textit{Flat top duration} \leq 232 \text{ ns.}$$

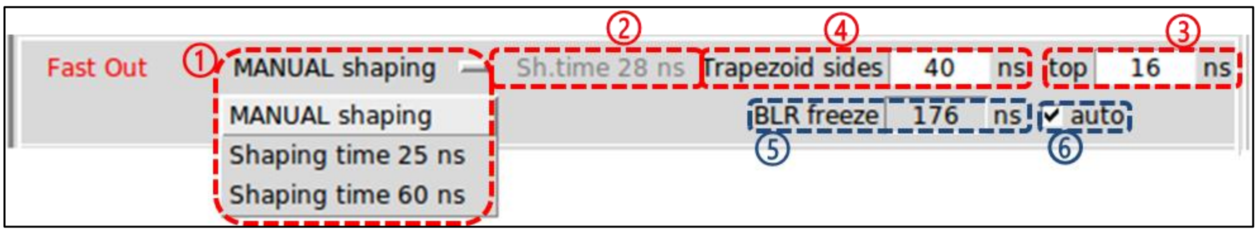


Figure 22: FAST OUT Shaper module / expert mode

To conclude, Fast OUT signal will have two roles:

- It always warns the BLR filter of an event arrival.
- It can be used as the trigger module input signal. This one timestamps the event.

III.C.1.c Trapezoid parameters tuning of OUT signal

In the basic mode, the experimenter can find the same shaping time choices that he had used with the FASTER CRRC4-Spectro MnM (c.f. Figure 23 ①).

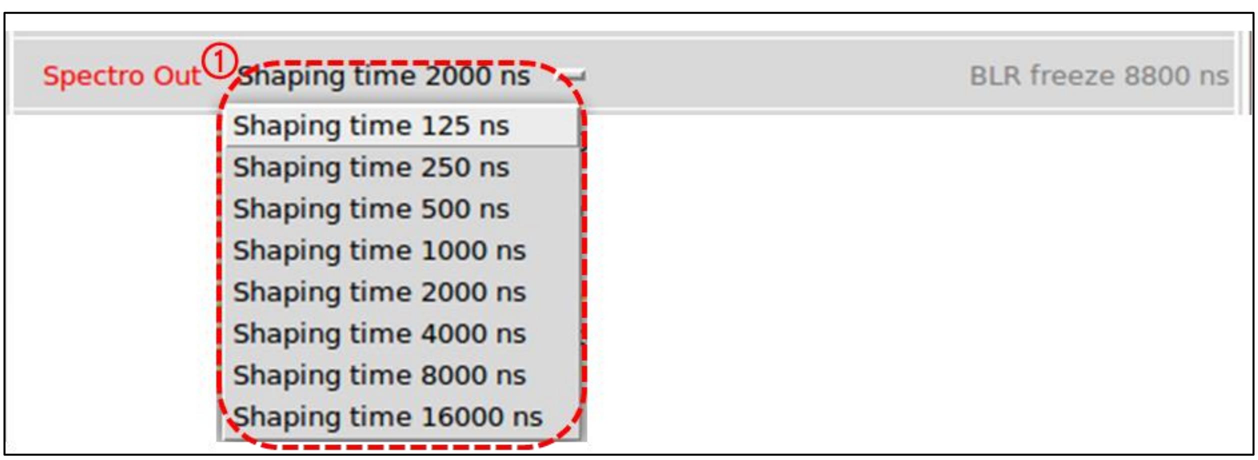


Figure 23: Spectro OUT shaper module / basic mode.

Table 4 gives the duration values of the trapezoid, chosen for the experimenter in order to correspond to the OUT shaping time of FASTER CRRC4-Spectro MnM.

CR-RC⁴ Shaping time	60ns	125ns	250ns	500ns	1µs	2 µs	4µs	8µs	16µs
Trapezoid									
Rising edge duration (ns)	88	216	504	1000	1960	3920	7800	15600	27960
Flat top duration(ns)	24	48	96	200	440	880	1800	3600	4760
Shaping time(ns)	56	132	300	600	1200	2400	4800	9600	16360

Table 4: OUT signal correspondence between CRRC4 Spectro MnM parameters and Trapezoid Spectro MnM parameters.

Figure 24 shows an example of an adjustment correspondence between the CR-RC4 filter of CRRC4-spectro FASTER MnM, and the trapezoidal filter for a shaping time of 2 µs.

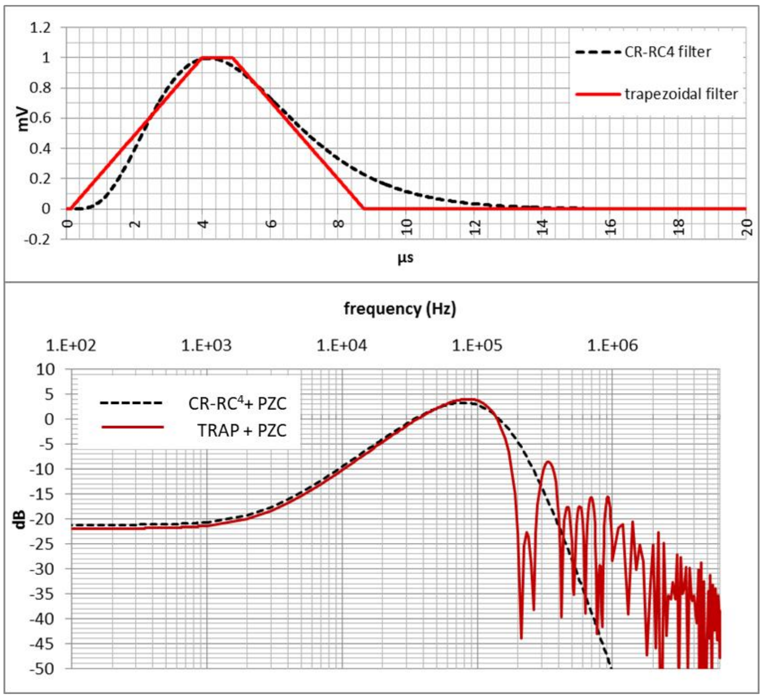


Figure 24: trapezoidal and CR-RC^4 filters, shaping time=2µs. Theoretical signal and Bode Diagram

In the expert mode, the user has a complete freedom in choosing the rising edge duration in ④ (Figure 25), and the flat top duration ③, if he selects "MANUAL shaping" in ①. The associated shaping time is given in ② for information. Nevertheless, the OUT trapezoid durations must check the following inequality:

$$0 < \textit{Rising edge duration} \leq \textit{Rising edge duration} + \textit{Flat top duration} \leq 32744 \text{ ns.}$$

$$\text{and } [\textit{Rising edge duration}]_{FASTOUT} < [\textit{Rising edge duration}]_{OUT}$$

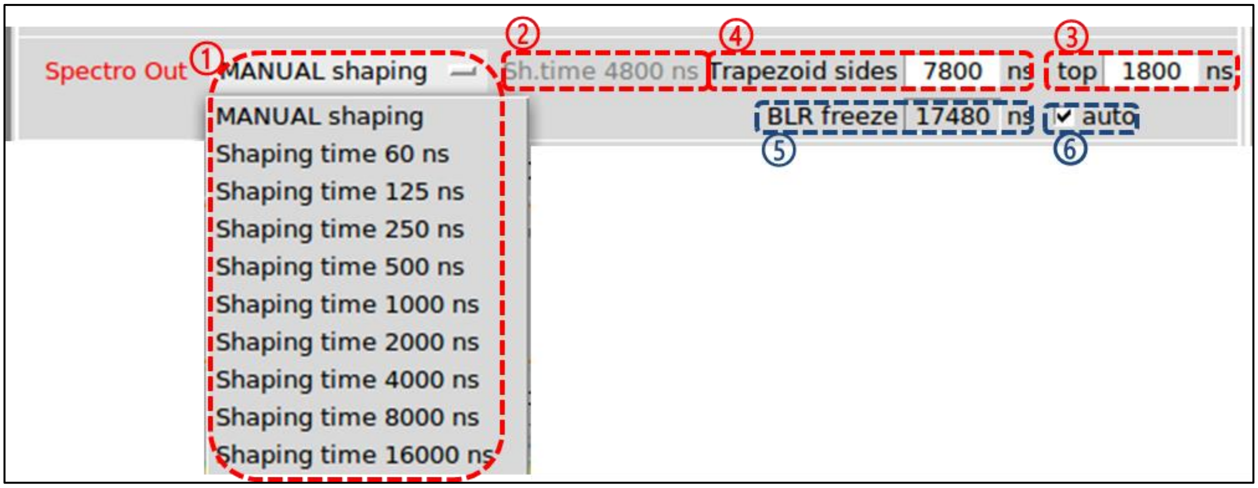


Figure 25: Spectro OUT Shaper module / expert mode

Adjusting the trapezoid parameters is a fastidious operation, but several tips can guide the choices:

- When there is no ballistic deficit, it is preferable to move towards a triangular filter, closer to the optimal filter. $flat\ top\ duration \approx 0$
- When there is some ballistic deficit, the duration of the flat top is at least equal to the variation of the rise time of the event.
- In order to maximize the S/N ratio, the shaping time must be around the same as the optimal filter, depending on the detectors and the CPA.
- The amplitude peak-hold window must include the second half of the flat top.

The Figure 26 shows the Bode diagram difference, depending on triangular filter (flat top=0ns) or trapezoid filter (flat top 880ns). The shaping time is the same. We can notice that the Bode diagram is shifted left for a triangular filter.

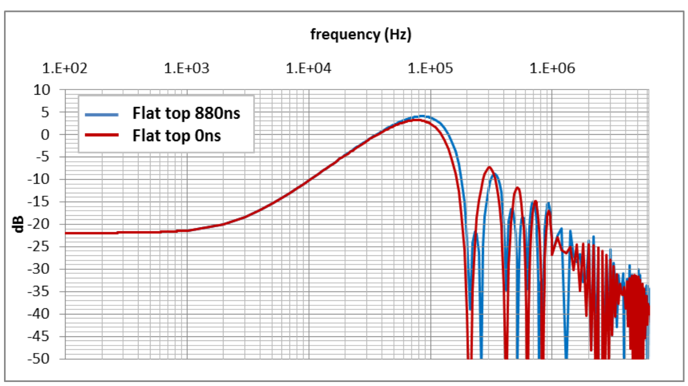


Figure 26 : flat top duration effect on theoretical Bode diagram. Shaping time = 2.4 µs.

III.C.2 Pole-Zero Compensation Filter (PZC module)

This filter converts an "exponential decay" input signal into a step signal. In the global transfer function, it is indeed necessary to compensate for the pole, induced by CPA time constant τ_{CPA}, by adding a zero τ_{PZ}. The user has therefore to choose the constant τ_{PZ} to make it equal to τ_{CPA}.

$$\tau_{PZ} = \tau_{CPA}$$

“τ preamp” in Input module (c.f. III.B p14) represents τ_{PZ} rather than τ_{CPA}. “τ preamp”= τ_{PZ}

By selecting “Input: out signal” in the Oscilloscope module, the user is able to check if he correctly evaluated “τ preamp”. This displayed signal is in fact the resulting signal after the BLR module, and not after the PZC module. That is why, it is very important to select a constant BLR in the BLR shaper (c.f. Figure 27), so as not to impact the decay of the signal.

Figure 27: necessary adjustment of BLR module to check “τ preamp” value

If “τ preamp” is greater than CPA time constant τ_{CPA}, then OUT signal is under-compensated as it is shown Figure 28.

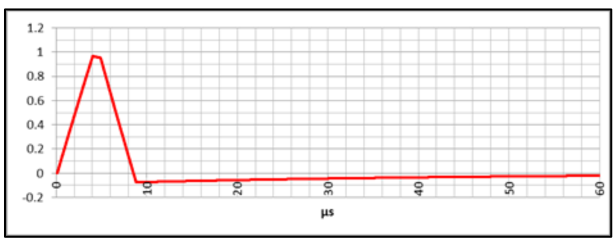


Figure 28: theoretical Spectro OUT signal. “τ preamp”=134µs and τ_{CPA}=40µs

If “τ preamp” is smaller than CPA time constant τ_{CPA}, then OUT signal is over-compensated as it is shown Figure 29.

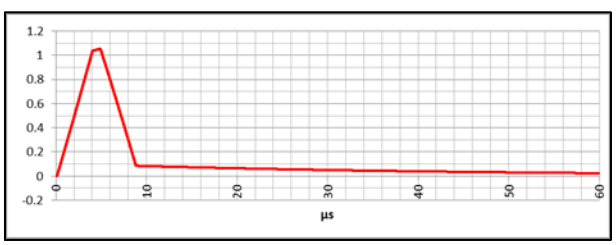


Figure 29: theoretical Spectro OUT signal. “τ preamp”=24µs and τ_{CPA}=40µs

Figure 30 yields an example of Spectro OUT signal produced from a real CPA signal. We recommend to zoom the Y-scale to check “τ preamp”, and to select an X-fullscale range to be able to analyze baselines before and after the trapezoid.

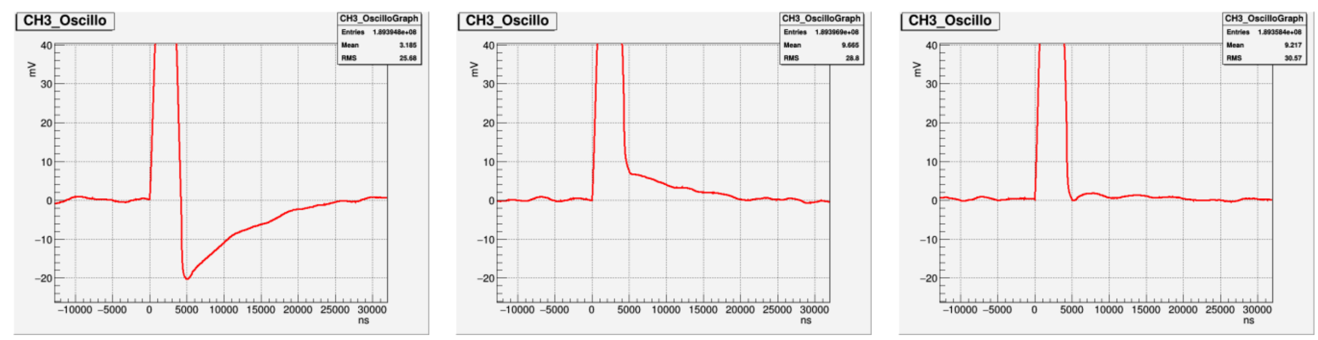


Figure 30: (a) "τ preamp"=8.2 µs Spectro OUT signal is under-compensated, (b) "τ preamp"=50 µs Spectro OUT signal is over-compensated, (c) "τ preamp"=10.5 µs Spectro OUT signal is well-compensated,

In this module, "τ preamp" value has to range within 8.2 µs and 671 µs.

Note that this "τ preamp" adjustment can be performed using the Fast OUT signal, but this is less convenient, because the Fast OUT signal is less impacted.

III.D Baseline Restorer Filter module

The role of the BLR module is to put the baseline at 0 mV. There are two BLR modules. The first one operates on Spectro OUT signal after PZC module, and the second one on Fast OUT signal after PZC module, as shown on Figure 19. The user can choose between two kinds of baseline restorer: a constant one and a dynamic one.

III.D.1 Constant BLR

The constant BLR (c.f. Figure 27) simply subtracts a constant level from PZC module output signals. As this level is directly deductible from Equation I-2 p6, the only level to be adjusted is the Input baseline level (§III.B p14). The "Constant level" of Spectro OUT signal after PZC module, and the one of Fast OUT signal after PZC module is calculated for the user. We recommend that the user check the adjustment by displaying "input: out signal" with the Oscilloscope module. Improper tuning has indeed more impact on Spectro OUT signal than Fast OUT signal.

III.D.2 Dynamic BLR

Figure 31 explains the dynamic BLR concept. The dynamic BLR filter follows the slow variations of the baseline as long as it does not detect an event. If it detects one, it maintains the last constant level during all the event duration. The resulting signal is therefore the baseline, which is then subtracted from the input signal.

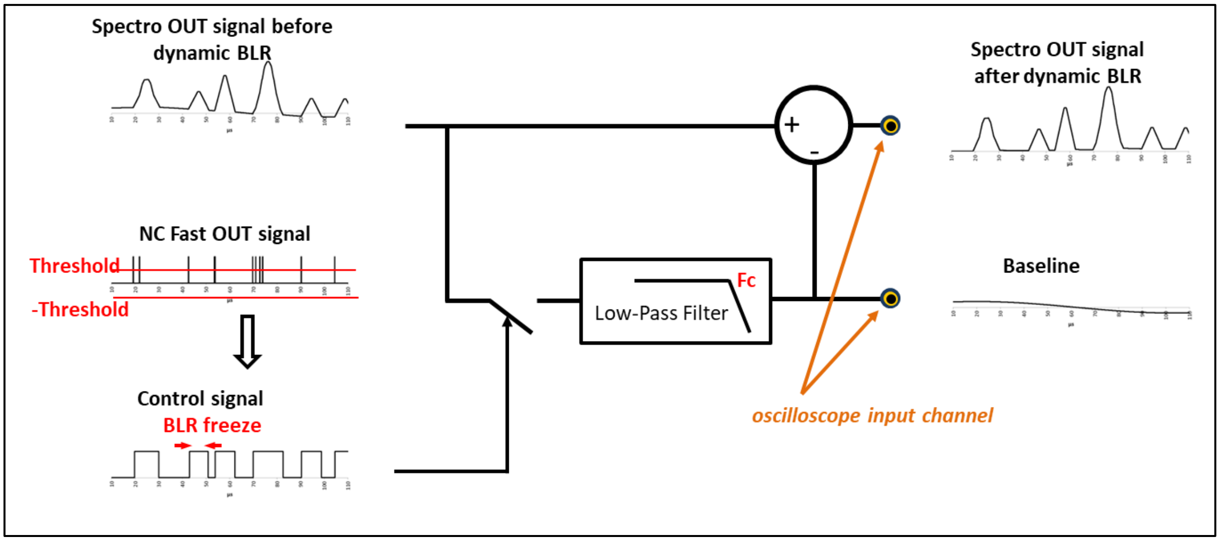


Figure 31: BLR concept

The BLR module has its own trigger, which must be properly adjusted. It uses the Fast OUT signal not compensated by the PZC module (that means "Fast OUT After trapezoidal shaper" on Figure 19) to detect the arrival of a physical event, whose amplitude is not included in the interval [-Threshold; + Threshold]. The tracking is then inhibited, i.e. the last baseline level is "frozen" during the "BLR freeze" duration (see Figure 31). Therefore "BLR freeze" duration depends on the signal on which the BLR module operate (Fast OUT or Spectro OUT) "BLR freeze" duration is at least equal to the base duration of the Spectro OUT or Fast OUT trapezoid. **In basic mode and expert mode**, the both durations are calculated for the experimenter, and equal to the trapezoid duration plus 80 ns. But **in the expert mode,** the user can modify "BLR freeze" values duration (Figure 22 ⑤ and Figure 25 ⑤), by unchecking "auto" button (Figure 22 ⑥ and Figure 25 ⑥).

The tracking of the signal will be carried out by means of a low-pass filter. The user can choose its cut-off frequency Fc = 2.4 kHz or Fc = 78 kHz, as shown on Figure 32.

Figure 32: 2 of the 3 parameters of the dynamic BLR shaper: BLR threshold and cut-off frequency.

To adjust BLR threshold, the experimenter must display "Input: trigger BLR" with the Oscilloscope module. This signal is the Fast OUT signal "After trapezoidal shaper". It is very important that the BLR adjustment is minutely performed by observing this oscilloscope display:

- The BLR threshold should be as small as possible, and selected just above the electronic noise. If this threshold level is too low, the BLR will never have the opportunity to follow the baseline. If it is too high, it will take physical events as baseline disturbances.
- "BLR freeze" values duration, where tracking is disabled, must be large enough to encompass the entire input signal Spectro OUT or Fast OUT of the BLR.

- The low-pass filter frequency Fc is preferentially chosen at 2.4 kHz, in order to improve the signal-to-noise ratio. The frequency 78 kHz is chosen in case of large and fast disturbances on input channel.

III.E The Trigger module

The trigger module triggers the energy measurement and timestamps the event. Two triggers are available to the user:

- a threshold discriminator
- a Constant Fraction Discriminator (CFD)

III.E.1 The threshold discriminator

All input pulses (Figure 33 ①) of the Trigger module, whose signal has crossed the threshold "Level" (Figure 33 ②) on rising edge and remains above this level during at least the duration "Width" (Figure 33 ③), are detected.

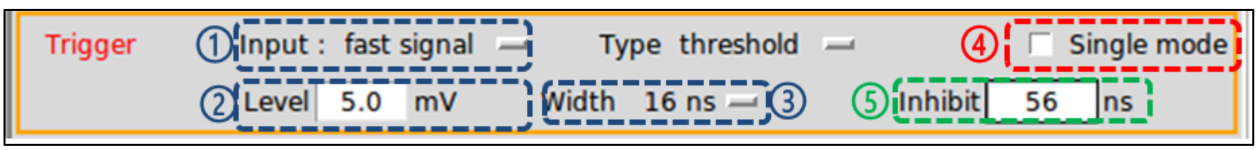


Figure 33: parameters of the threshold discriminator.

On Figure 34, we can see that a judicious value of "width" parameter can discriminate physical event from noise. "width" parameter is a multiple of 8 ns, between 8 ns and 120 ns. The event time-stamp is the FASTER interpolated date of the threshold crossing, with an accuracy of 8 ns/2^8. The chapter III.E.2 p28 explained how this interpolation is performed. In the basic mode, the interpolation is made with a 2nd order polynomial. In the expert mode, the user can also choose 2 other different linear interpolations.

In **the basic** or **expert mode**, the user must just select "Input: trigger threshold" in the Oscilloscope module, to display the input signal of the Trigger module

When displaying the Input Trigger signal with an 8 ns step, the sample at time "0 ns" is the first sample above the threshold level.

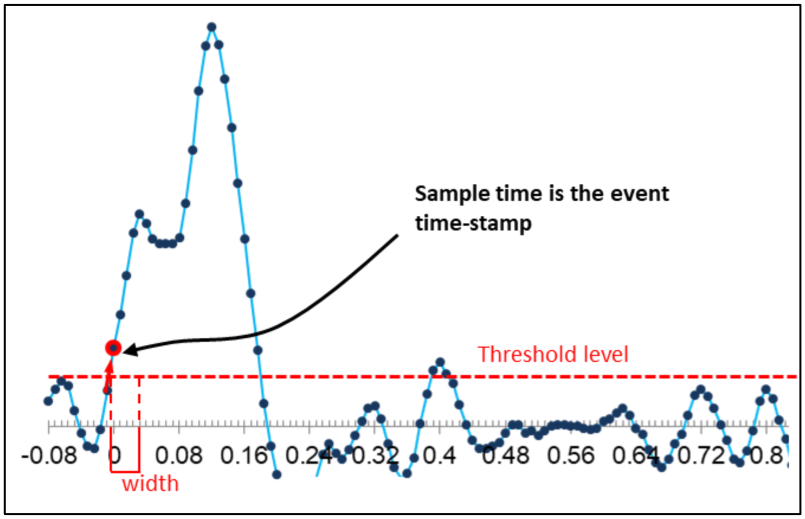


Figure 34: the first pulse, which has crossed the threshold level is detected. The second is not, thanks to a judicious value of the "width" parameter.

In **the basic mode**, the Input signal of the Trigger module, which are available, are:

- "fast out signal": it is the Fast OUT signal after CPZ and BLR. This choice is best when the measurement of the pulse time-stamp is important, and when the event rate is high.
- "spectro out signal": it is the Spectro OUT signal after CPZ and BLR. This choice is best when the low energy pulse detection is more important than pulse time-stamp.

In **the expert mode**, two selections of Input signal are added. There are

- "fast out signal"
- "out signal"
- "not compensed fast out signal": This one is the Fast OUT signal "After trapezoidal shaper", that means the BLR trigger. It has always a null baseline. It can be useful when BLR adjustment is fastidious.
- "not compensed spectro out signal" : This one is the Spectro OUT signal "After trapezoidal shaper" . It has always a null baseline.

By checking "Single mode" (Figure 33 ④), the "Single Arm" button appears (Figure 35). A cursor click on this button will trigger a single pulse detection.

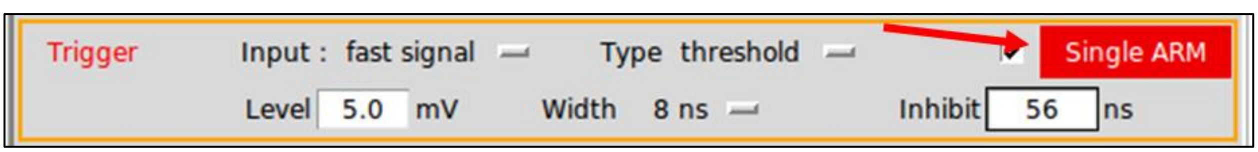


Figure 35: "Single Arm" button

Finally, the experimenter can adjust the minimum duration between two detections with the "Inhibit" parameter (Figure 33 ⑤), in order to ensure dead time duration (cf. § III.H). This duration must be wider than the pulse width, otherwise it has no impact. It is a multiple of 8 ns between 8 ns and 1 048 568 ns.

III.E.2 Expert mode: the Constant Fraction Discriminator (CFD)

When CFD is used, the input signal of the Trigger module (Figure 36 ①) is first shaped by a CFD shaper module, which performs the following operation:

$$signal_{CFD}(t) = signal(t - \theta) - f.signal(t)$$

with θ : the delay (Figure 36 ②) multiple of 8ns from 8 ns to 120ns,
and f: the fraction 1/2, 1/4 or 1/8 (Figure 36 ③) .

This signal can be displayed by selecting "Input: trigger CFD" in the oscilloscope module.

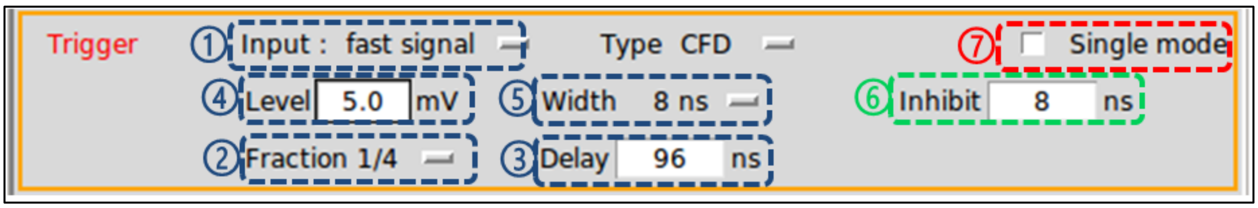


Figure 36: parameters of the CFD discriminator.

The CFD module detects first 0 crossing, and discriminate the pulse if it also crosses the threshold "Level" (Figure 36 ④) on rising edge and remains above 0 mV this level during at least the duration "Width" (Figure 36 ⑤). The FASTER time-stamp of the event is nevertheless the 0 crossing date.

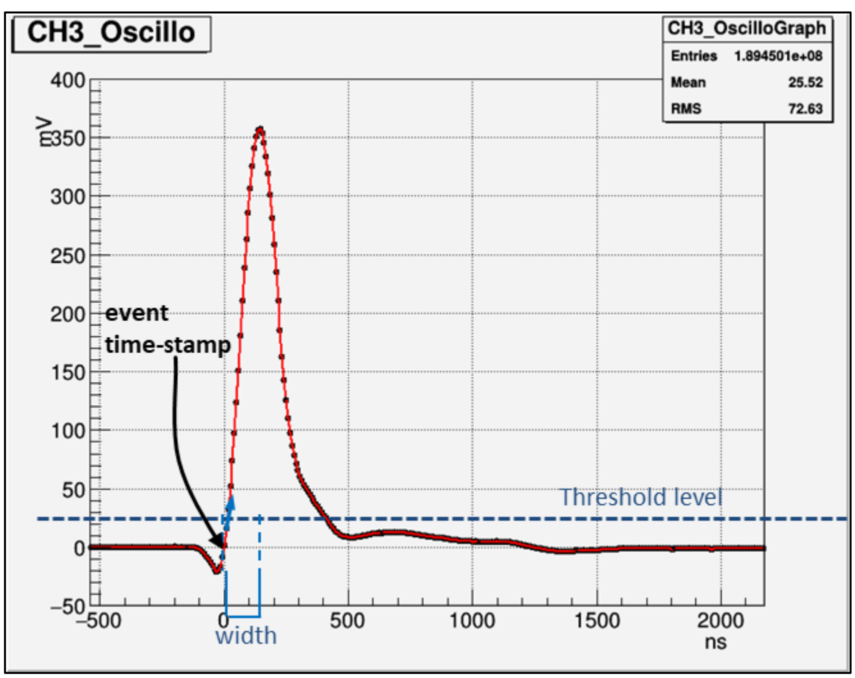


Figure 37: the CFD trigger signal, displayed by the Oscilloscope Module. This signal is shaped by the operation

$$\boldsymbol{signal_{CFD}(t) = signal(t - \theta) - f.signal(t)}$$

The event time-stamp is calculated with an accuracy of 8 ns/2^8. There are 3 implemented method to interpolate the 0 crossing:

- A second order interpolation using one sample before 0 –crossing, and 2 samples after 0-crossing.

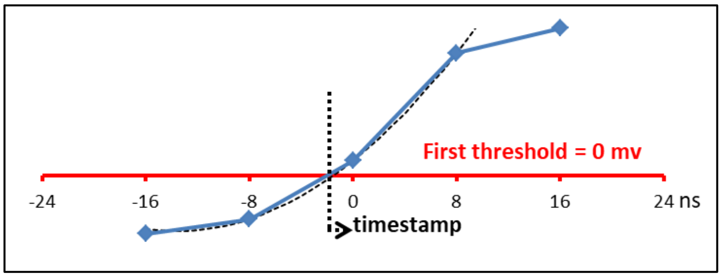


Figure 38: 2nd order interpolation

This interpolation is use by default **in the basic mode**. The user can choose this interpolation **in the expert mode**, by selecting "TDC type 2^{nd} order with 3 points".

- A linear interpolation using the sample before the 0 crossing and the sample after the 0-crossing. The user can choose this interpolation **in the expert mode**, by selecting "TDC type linear between 2 points".

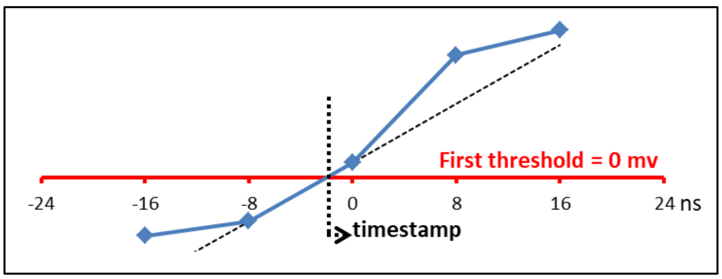


Figure 39: linear interpolation "linear between 2 points"

- A linear interpolation using the sample using the 2 samples following the 0-crossing. The user can choose this interpolation **in the expert mode**, by selecting "TDC type linear before 2 points".

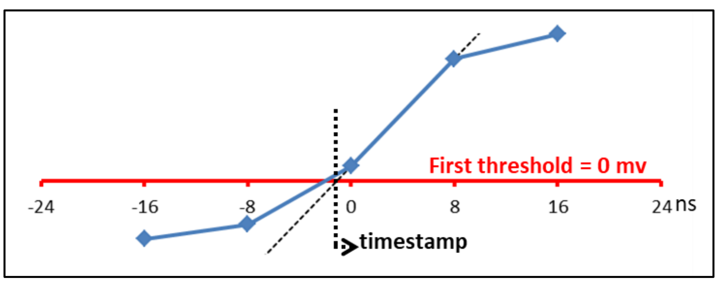


Figure 40: linear interpolation

Selecting a linear interpolation is sometimes preferable, when the rising edge cannot be interpolated by a 2^{nd} order polynomial.

It can be noticed than, owing to the CFD shaping, the FASTER time-stamp of the event has always a constant delay with respect to the start of its Spectro OUT signal. The consequences will be seen in chapter III.F.1 p28.

Such as when using the threshold discriminator, there are the "Inhibit" parameter (Figure 36 ⑥) and the "Single mode button" (Figure 36 ⑦).

III.E.3 The external discriminator

The experimenter has the opportunity to use the discriminator from another linked channel of the FASTER daughter card. When using the MOSAHR daughter card, the channels 1 and 2 are linked, as well as the channels 3 and 4.

Figure 41: external discriminator of channel 1 setup

III.F ADC module and piled-up rejection

III.F.1 ADC parameters

As soon as a pulse is detected by the discriminator, the ADC module finds the maximum of the amplitude of the Spectro OUT signal in a time window chosen by the user.

In order to adjust ADC parameter, the experimenter must display Spectro OUT signal. But the trapezoidal signal is shifted when using CFD, because the Trigger module use the CFD shaped signal. That is why in CFD mode, the ADC module input signal is displayed by the Oscilloscope module by using "spectro out signal + ADC delay" input signal (cf. Figure 42).

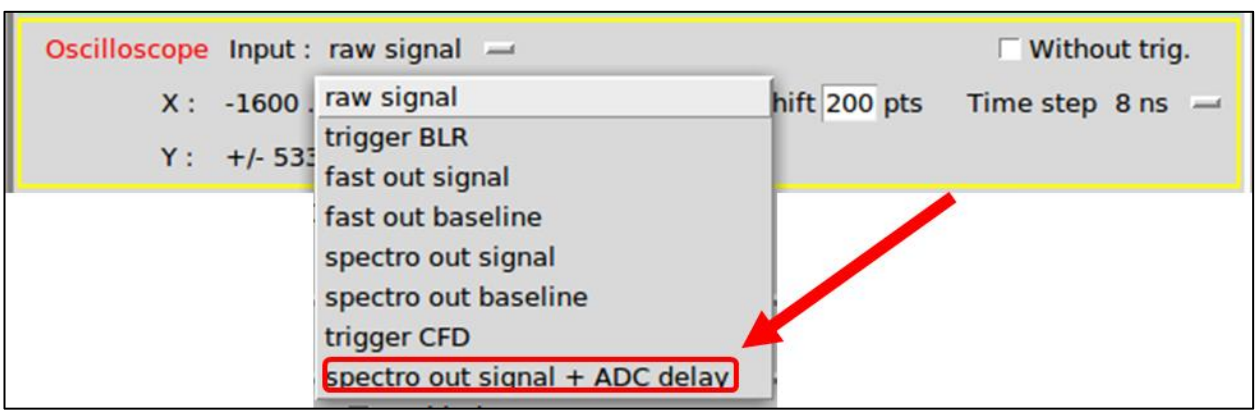


Figure 42: when using CFD, select "out signal + ADC delay" to display the signal on which the amplitude is measured. When using the threshold discriminator, just select "out signal".

Therefore, in CFD mode, you must ensure that "spectro out signal + ADC delay" signal begins at time "0 ns" by adjusting "ADC delay" parameter in the ADC module (cf. Figure 43 and Figure 44). "ADC delay" must be under 296 ns.

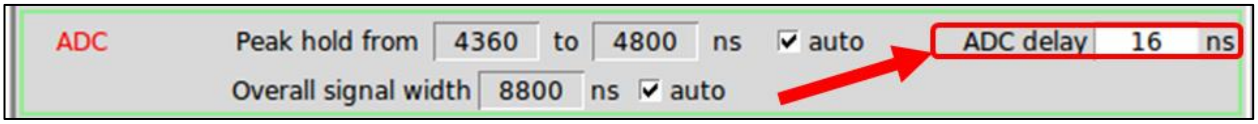


Figure 43: ADC delay parameter in CFD mode.

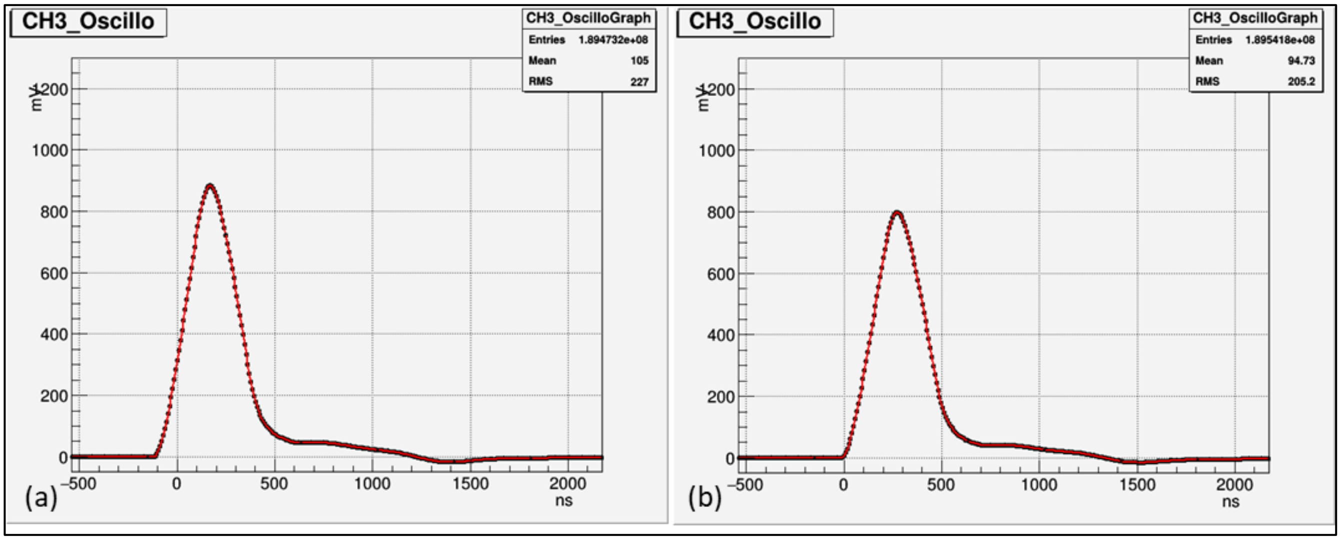


Figure 44: "out signal + ADC delay" signal. (a) ADC delay = 0 ns. (b) ADC = delay = 100 ns.

As soon as the ADC module input signal begins at "0 ns", the user has to adjust two parameters in expert mode (Figure 45):

- "Peak hold" gate (**expert/basic mode for information only**)
- "Overall signal width" (**expert mode**)

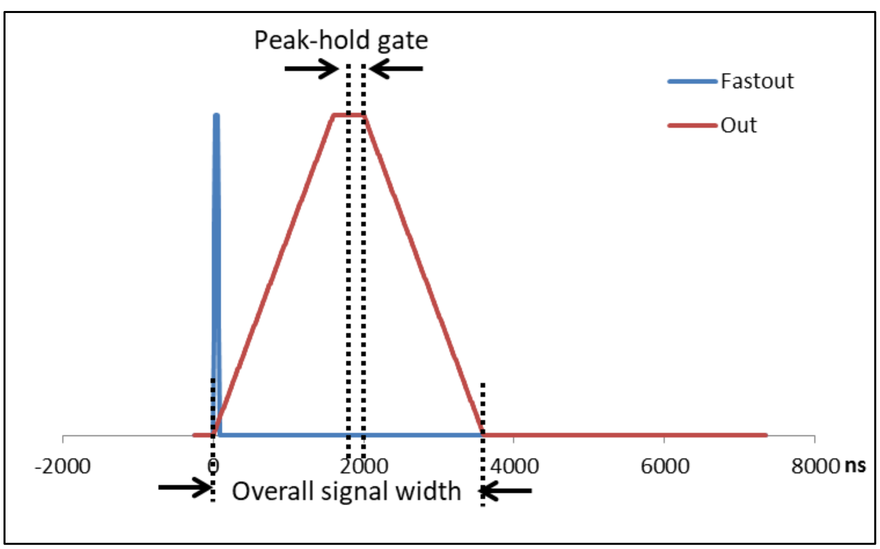


Figure 45: ADC parameters "Peak hold" gate and "Overall signal width".

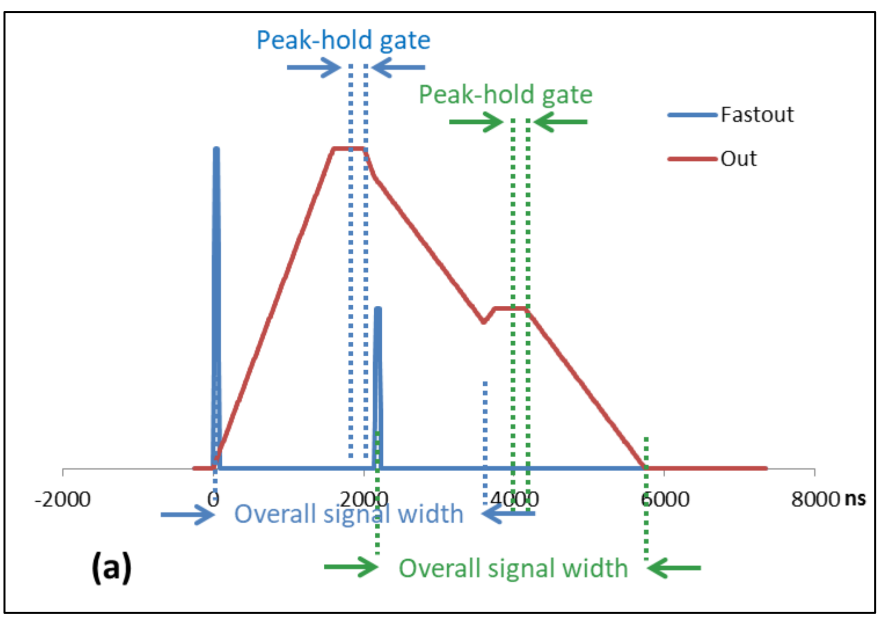
It is recommended to choose the "Peak hold" gate as small as possible - including the second half part of the top - because the ADC module is not reset until this gate is completed. Closer is the "Peak hold" gate, less likely it is to count piled-up data. The “Peak hold” parameter is set by default in **the basic mode**, as in “auto” mode in **the expert mode**, depending on the shaping time of the Spectro OUT signal. When “auto” (expert mode) is unchecked, the user can choose to begin this zone between 0 and 32720 ns. And the duration of this gate cannot be greater than 32720 ns.

The “Overall signal width” parameter corresponds to the temporal spreading of the Spectro OUT signal. In **the basic mode**, as in “auto” mode in **the expert mode**, it is equal by default to the width of the trapezoidal basis, plus 80 ns. With some detectors, the Spectro OUT signal may have a tail, too short to be properly corrected by the BLR module. The “Overall signal width” has to encompass this tail to ensure the best measurement of the deposited energy, because this width has an important role in the determination of the piled-up events. This parameter cannot be selected above 262080 ns.

III.F.2 Piled-up rejection

If the Trigger module input signal (generally Fast OUT signal) is able to discriminate two consecutive events, it is possible to establish whether the amplitude measurement is piled or not. All the events, that have a "peak-hold" window affected by the preceding or following events, are flagged as “piled-up”. In order that the piled-up rejector operates properly, the Trigger module input signal must have the shortest duration possible, while being able to detect low-energy events.

The management of parameters “peak-hold” gate and “Overall signal width” make it possible to optimize piled-up rejection: if a “overall signal width” of a preceding or following event encroaches on the “peak-hold” gate of the studied event, this event is flagged as “piled-up”, as shown in the three example of Figure 46.



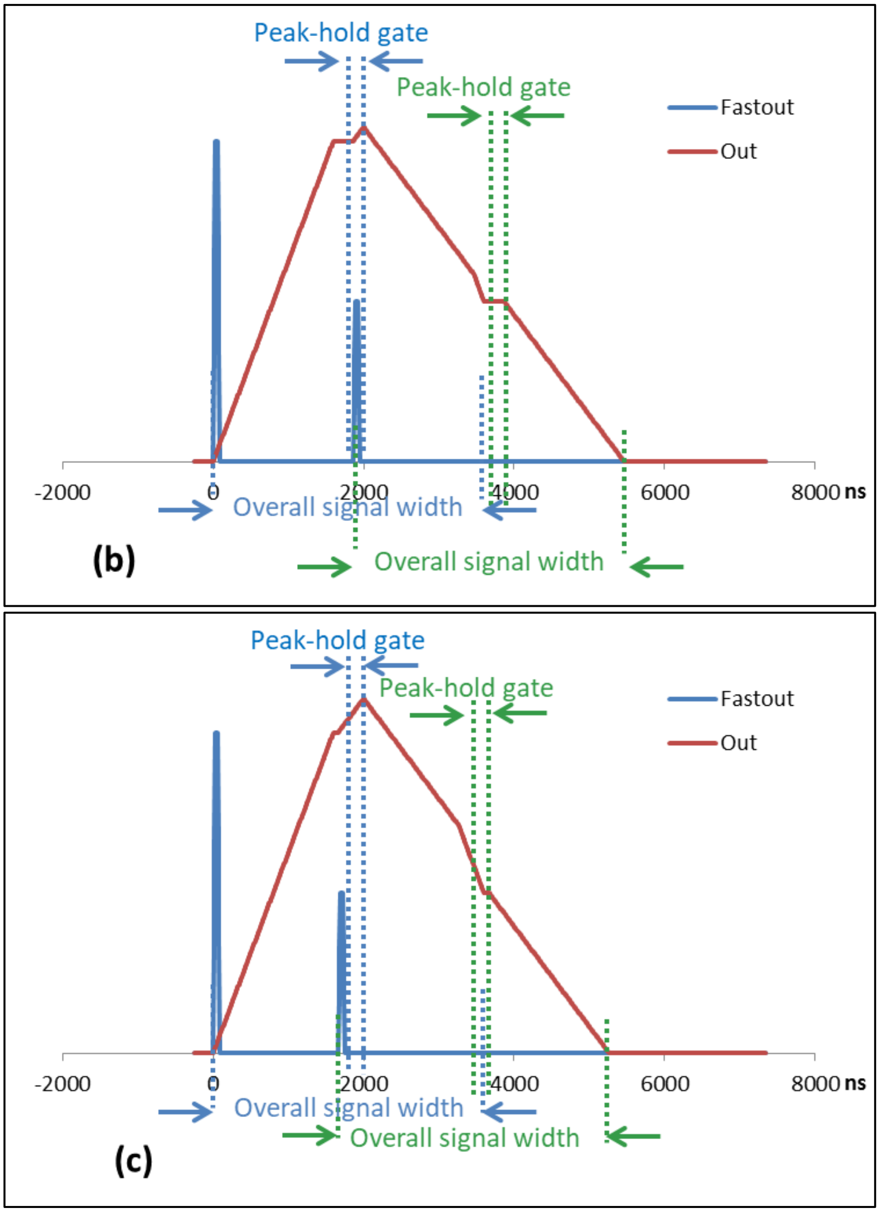


Figure 46: example of piled or not-piled events
(a) Both events are not piled-up
(b) The first event is piled-up, the second not
(c) Both events are piled-up

III.G Output module

The Output module (Figure 47) defines the output data sent to the computer by checking buttons ①. These data are:

- the data processed by the ADC module ②,
- the counting data ③,
- the data from the Oscilloscope module ④.

To distinguish these data in the stored file, they have different labels ⑤. The user can moreover control the rate of output data.

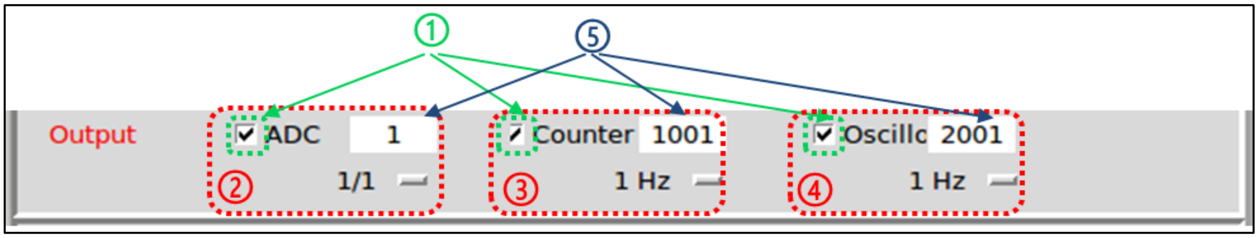


Figure 47: parameters of the Data output module

When the data comes out the FASTER Trapezoidal-Spectro MnM, they are temporally stored in some buffers of the FPGA, waiting for being sent to the computer by the Gigabit Ethernet communication.

Here are described the content of each data. If the experimenter uses RHB facilities, data from FASTER Trapezoidal-Spectro MnM are called TRAPEZ_SPECTRO in the RHB file "*.pid". In this file, the prefix label of each channel of the FASTER acquisition is defined. For example, if there is

1:TRAPEZ_SPECTRO: myChannel

that means that all data from the first channel of FASTER acquisition must have the prefix "**myChannel_**" in the configuration file of RHB (i.e. "*.facqConf" file). The "RHB –r" command, made in the directory including these files, starts RHB interface.

III.G.1 "ADC" data

The experimenter can store or display all "ADC" data processed by the ADC module by selecting 1/1 (cf.Figure 48). But, when the event rate is too high and saturates the FASTER acquisition, the user can choose to store a percentage of this rate: one event data every 100 event data is sent, or every 10^4 event data, or one event data every 10^5 event data. With this decimation, the acquisition efficiency can be controlled.

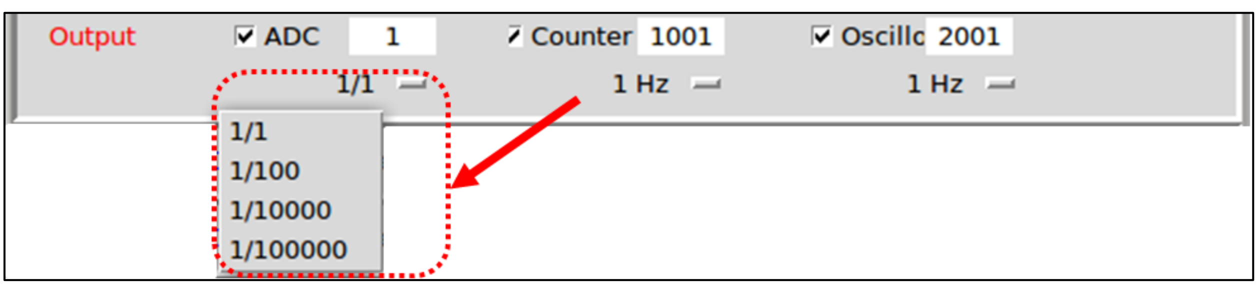


Figure 48: decimation of "ADC" data

In "ADC" data, the user has, for each event:

- **myChannel_ADC**: the amplitude of the Spectro OUT signal. myChannel_ADC is a 23-bit signed integer.
- **myChannel_pileup**: the piled-up event flag. The value 1 indicates that the event is piled-up.

- **myChannel_saturated**: the saturation flag. The value 1 informs that the raw signal, that has generated the Spectro OUT signal, is outside the input range of the daughter card.
- **myChannel_t**: the time-stamp (in nanosecond) of the event, with an 8 ns accuracy.
- **myChannel_dt**: an additional accuracy (in nanosecond) of the time-stamp, to achieve an accuracy of 8 ns/2^8.

III.G.2 "Counters" data

The experimenter can store and display the counting data, called "Counters" with a selected frequency of 1 Hz, 10 Hz 100 Hz and 1 kHz.

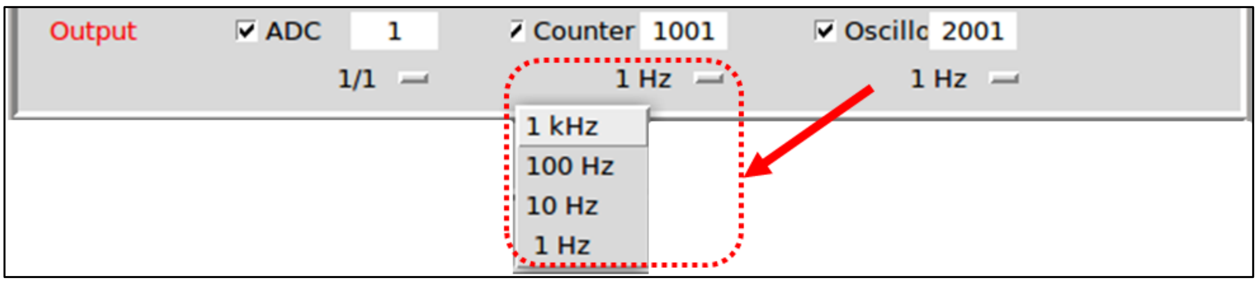


Figure 49: out frequency of the "Counters" data

Each "Counters" data has:

- **myChannel_COUNT_t:** the time-stamp of the "Counters" data
- **myChannel_TRIG**: the number of events discriminated by the Trigger module of the MnM.
- **myChannel_CALC**: the number of events N_{ADC} that the ADC module has processed. At high event rate, if the "peak-hold" gate is wider than the input signal spreading of the Trigger module, this number may be less than myChannel_TRIG. This number is then multiplied by the decimation rate (cf. Figure 48):

$$\text{myChannel\_CALC} = \text{decimation} \cdot N_{ADC}$$

- **myChannel_SENT**: the number of data from ADC module, temporally stored in the FPGA buffers, and waiting for being sent to the computer.

The following inequality is always verified: myChannel_SENT≤ myChannel_CALC ≤ myChannel_TRIG.

These 3 numbers are reset each time any module parameters is changing.

III.G.3 "Oscillo" data

The "Oscillo" data, already explained in chapter III.A , are defined in RHB by the variables:

- **myChannel_OSC_t**: the time stamp of the "0 ns" sample of the oscilloscope frame.
- **myChannel_OSC**: the Oscilloscope frame.

III.H Dead time

Depending on the considered data, the dead time is not the same.

III.H.1 Dead time of the counting data

III.H.1.a myChannel_TRIG

The dead time of the event discriminated by the Trigger module depends on the spreading of the input signal of the Trigger module and on the "inhibit" duration parameter:

$$DT_{trig} = \max(\ duration\ of\ the\ trigger\ module\ signal + 8\ ns, inhibit\ duration) \qquad \textbf{Equation III-1}$$

This dead time DT_{trig} is either expandable if the duration of the Trigger module is predominant, either non-expandable if the inhibit duration is greater than the signal duration of the Trigger module.

III.H.1.b myChannel_CALC

The dead time of the event processed by the ADC module depends on DT_{trig} and the duration of the "peak-hold" gate:

$$DT_{calc} = \max(\ DT_{trig}, Peak\text{-}hold\ gate\ duration) \qquad \textbf{Equation III-2}$$

If the duration of the "peak-hold" gate is predominant, DT_{calc} is non-expandable. It is as DT_{trig} otherwise.

III.H.1.c myChannel_SENT

The dead time of data sent to computer depends of the data rate and the depth of FPGA buffers.

If the data rate is too high for FASTER acquisition, typically above 500 000 events per second, the dead time is not constant. It is equal to DT_{calc} at the beginning, (typically the first 10 s if the rate is under 3.10^6 events per second). As soon as the FIFO are full, all the data of all the channel belonging to the same µTCA carrier are sent with the rate of the Gigabit Ethernet communication. The FIFO are emptied in turn and a constant dead time is not guaranteed. The experimenter can increase the "ADC" data decimation in order to reduce the rate of the sent events. He must likewise disable the sending of the oscilloscope data, or reduce the number of samples of the oscilloscope data frames.

III.H.2 Dead time of the "ADC" data

The dead time of the "ADC" data is equal to $\mathrm{DT_{calc}}$ if the data rate is under 500 000 events per second. Some data can be lost otherwise

The user must take care to buffer depth of the computer. He can then check the match between the stored data number with myChannel_CALC and myChannel_SENT.

III.H.3 Dead time of the "Oscillo" data

The dead time of an oscilloscope frame is

$$DT = oscilloscope\ frame\ duration + 88\ \mathrm{ns}$$ **Equation III-3**

In the basic mode, the oscilloscope duration is equal to 700 x time step. In the expert mode, the oscilloscope duration is equal to the number of samples x time step.