FASTER RF MnM USER MANUAL

This document is the user manual of the FASTER-RF MnM (**M**easurement **n**umerical **M**odule). The RF MnM is developed for experiments that need to measure a time of flight, whose reference is the moment of arrival of the particles on the target, synchronized with the cyclic beam phase.

In chapter one, you will find an introduction to the time measurement chain which uses cyclotron time as reference time.

In chapter two, all tuning parameters of the FASTER-RF module are described.

In chapter three, a FASTER-RF module tuning procedure is suggested.

Cathy Fontbonne

Summary

I Theory of operation

I.A Elements of Time Measurement with cyclotron time as reference time.

The TOF measurement is sometimes performed with the arrival of particles on the target as reference time. The arrival of particles on the target is synchronized with the cyclotron phase. Therefore, it is useful to measure this phase with the FASTER time.

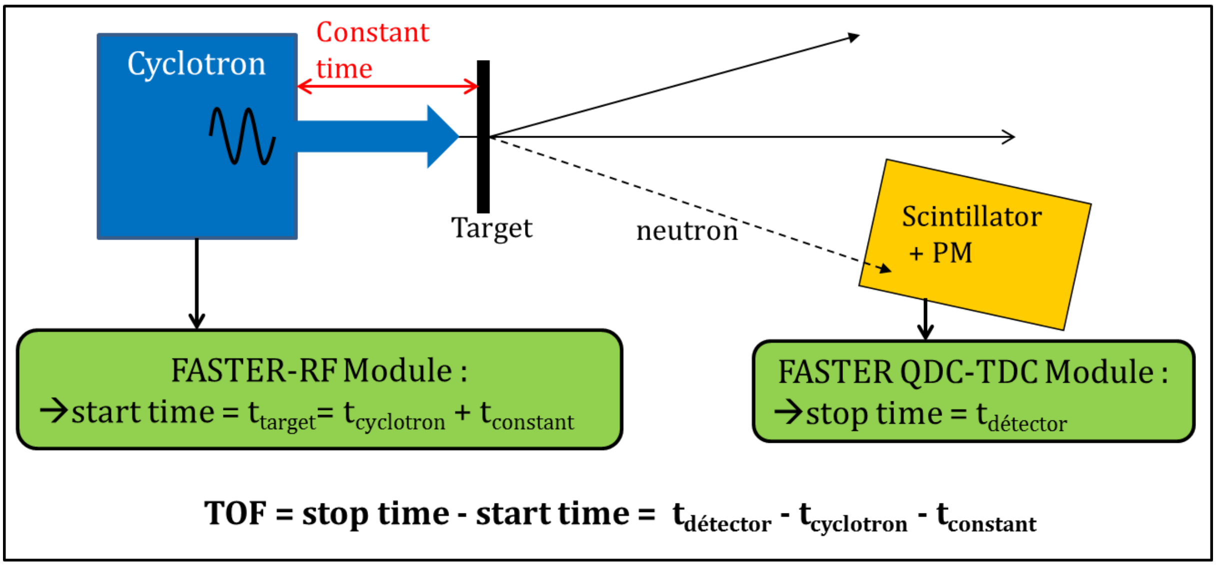

Figure 1: A TOF experiment with the arrival of particles on the target as reference time.

A cyclotron signal is a periodic signal. The time $t_{cyclotron}$ used to calculate the TOF is for example the time when the signal crosses the threshold on the rising edge. It represents the cyclotron phase.

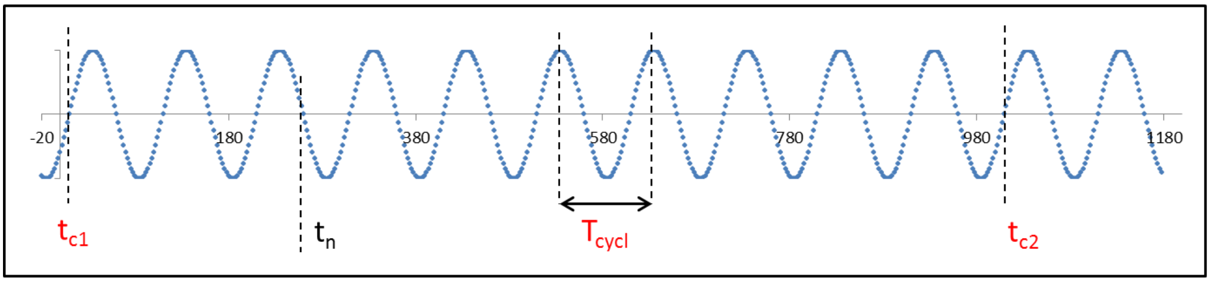

Figure 2: Example of a cyclotron signal.

It is necessary to know every threshold crossing time, in order to calculate every TOF. If all the time of threshold crossing are measured and sent by the FASTER system, the FASTER communication may be saturated by this repetitive data. The solution is to send sometimes the time of the threshold crossing and the exact value of the cyclotron signal. Then, the user can calculate the others times of crossing threshold thanks to the following formula:

$$t_n = t_{c1} + n\, T_{cycl}$$

The More precisely the cyclotron period is measured, the less often the time of threshold crossing is sent.

I.B FASTER-RF Signal Processing

The FASTER-RF module works with the CARAS daughter card. In general, for RF performing, the CARAS daughter card is used in its 50Ω-load configuration.

The FASTER–RF module synchronizes the FASTER system time with the arrival of particles on the target. The FASTER–RF input signal is provided by a cyclotron (for instance). This signal is periodic and possibly noisy. FASTER–RF cleans this signal, by using a band-pass filter, and then calculates the trigger time with an accuracy of 7.8ps, by using a linear interpolation. This trigger time is then going through a Phase-Locked Loop (PLL), in order to build cleaned period, and cleaned trigger time. The FASTER–RF PLL is independent of the input signal frequency. **FASTER-RF is suitable to any cyclotron frequencies ranging from 1 MHz to 100 MHz**. The dynamic range of the FASTER-RF inputs is the dynamic range of the CARAS daughter card, i.e. +/-1.2V. The dynamic range can be shifted by adjusting an offset in FASTER V2 – FASTER GUI software.

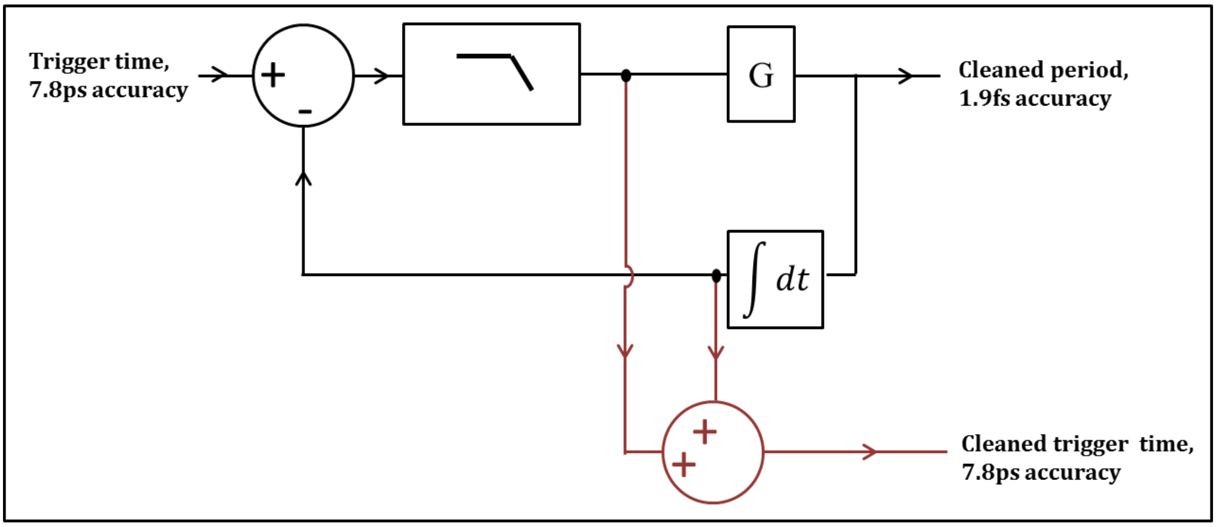

Figure 3: The FASTER-RF module PLL.

The module provides as output data:

- the cleaned Period,
- the cleaned trigger time and
- the PLL Input trigger time.

Each data is timestamped with a 2ns-accuracy (LSB timestamp value).

The cut-off frequency of the PLL low-pass filter gives the module bandwidth. The user can choose between two bandwidths: 10ppm of input frequency or 150ppm of input frequency. With the 10ppm of input frequency bandwidth, the PLL is slower, and it takes more time to achieve lock. Nevertheless, in this case, the period standard deviation is better, and can reach about 1fs instead of 15fs.

Sometimes, if the input frequency is not steady, the PLL can't lock, or the standard deviation of the period is too high compared to the desired accuracy. In this case, it makes sense to use PLL Input trigger time, because cleaned trigger time has a lag error.

Refer to the CARAS daughter card descriptions for more information.

II Preamble

II.A FASTER launching

To take benefit of the RF MnM of the FASTER acquisition, the experimenter can build his experiment interface with the command `faster_setup_gui`.

The interface, shown on Figure 4, is launched. To use the FASTER RF MnM, the experimenter must select the "RF" type, by right-clicking on the daughterboard line.

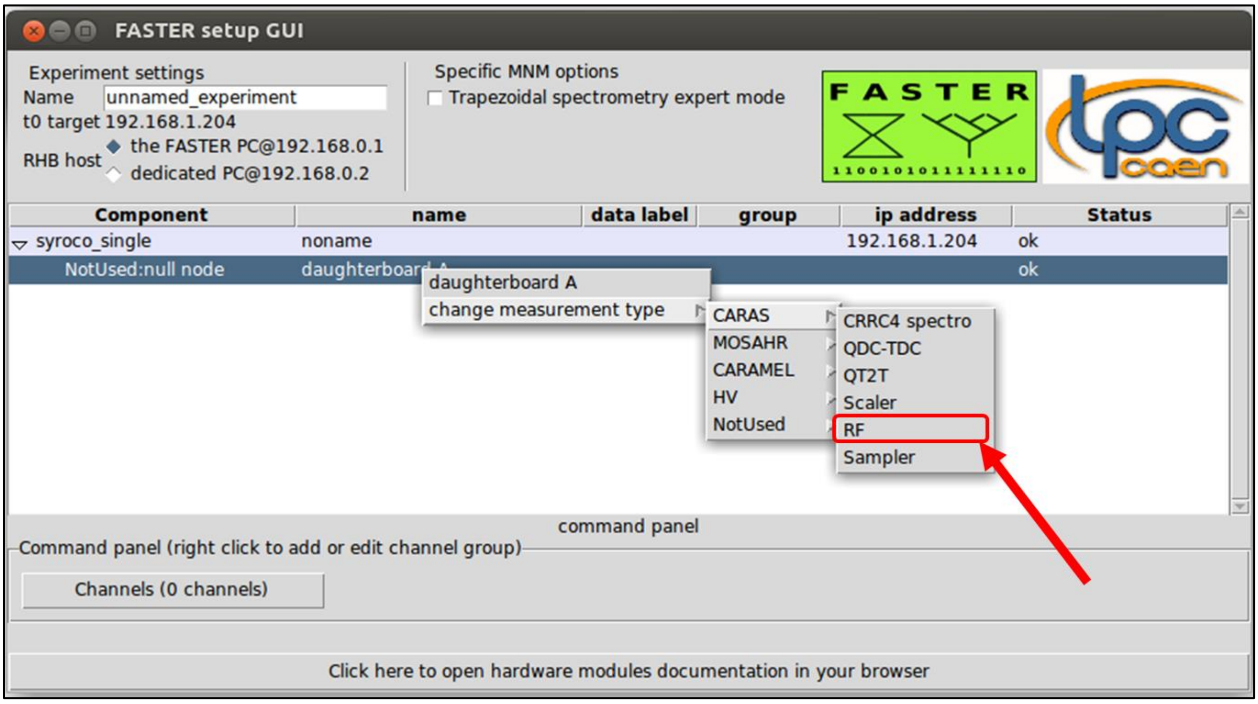

Figure 4: experiment building with "faster_setup_gui".

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 5.

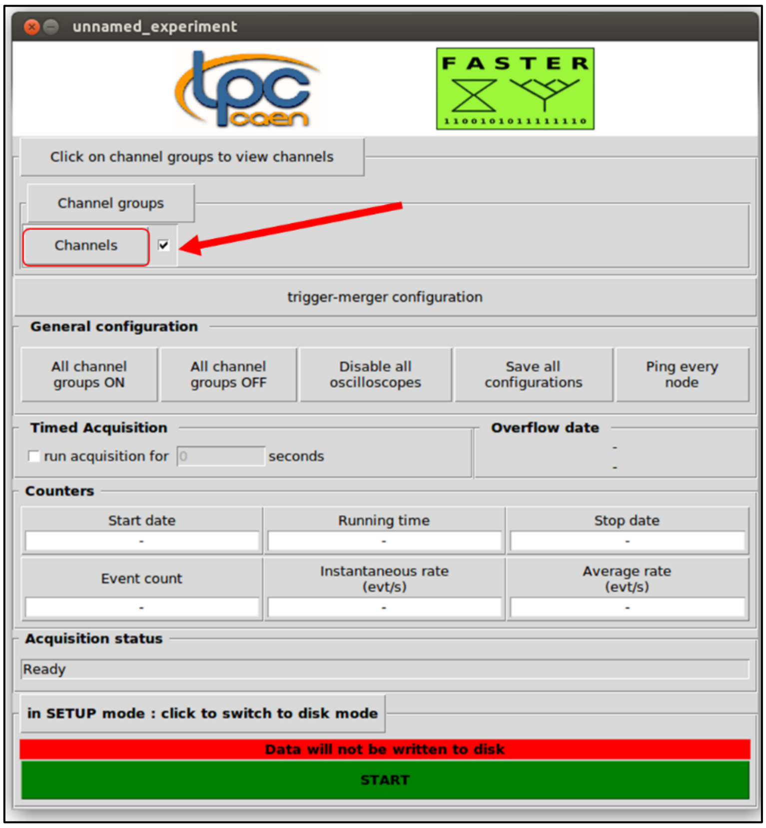

Figure 5: faster_gui interface.

By clicking on "Channels" (cf. Figure 5), the MnM interface is displayed, allowing the user to adjust the different module parameters (Figure 6).

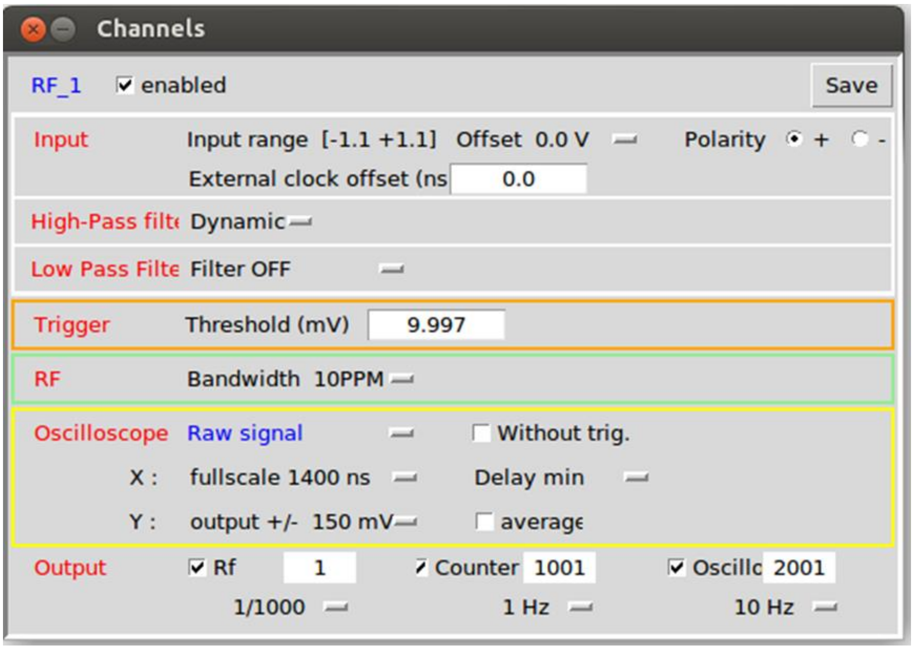

Figure 6: RF **interface**

II.B RHB launching

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

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

```
cd RF_RHB_Demo
cd full_config
RHB -r
```

III Description of FASTER RF MnM

The FASTER-RF module is a signal processing module designed for signals digitalized by a 12-BIT, 500 MHz analogic-to-digital converter. That means that the module receives a 12 BIT-sample every 2 ns, and is able to timestamp its output data with an accuracy of 2ns (every event timestamp value has to be multiplied by 2 ns to have the event date in nanoseconds).

The FASTER-RF module contains the following elements:

- A dynamic range tuning,
- A polarity tuning,
- A baseline restorer,
- A filter if necessary,
- A trigger module including a threshold discriminator,
- A RF module, which precisely defines the cyclic beam period and its phase.
- An oscilloscope,
- An event counter.

It is important to know the role of each element in order to obtain the TOF spectra with the best resolution.

The Faster-RF module provides three kinds of 2ns-accuracy dated data:

- Oscilloscope data
- RF module data, including the precise period, the cleaned phase and the PLL Input trigger phase. These precisions have to be added to the 2ns-accuracy timestamp to obtain the cleaned time, and the PLL input trigger time.
- Event counters data.

This data can be displayed thanks to the Root Histogram Builder provided with FASTER-V2 pack.

The FASTER-RF module structure of processing is shown below.

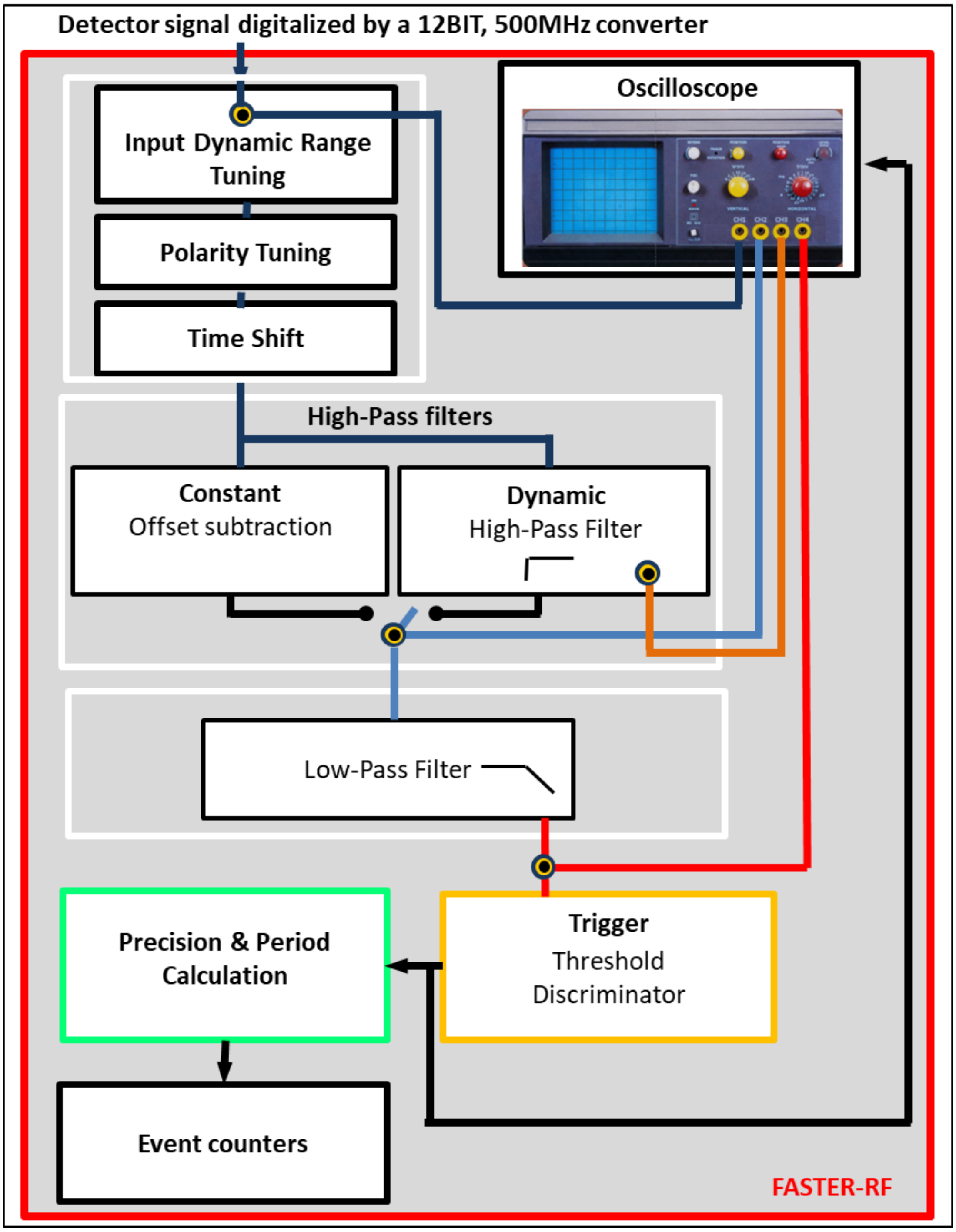

Figure 7: Diagram of the FASTER-RF MnM.

III.A The Oscilloscope module

The oscilloscope displays the signal at the output of the various modules described later.

⚠ It is not calibrated, and the scale in millivolts of the y-axis is only an indication of the voltage.

Nevertheless, the FASTER oscilloscope includes several features found on any ordinary oscilloscope, like trigger choice, channel display choice, horizontal tuning, and vertical tuning. Additionally, the FASTER-RF processing lets you select the acquisition speed.

III.A.1 The oscilloscope trigger choice

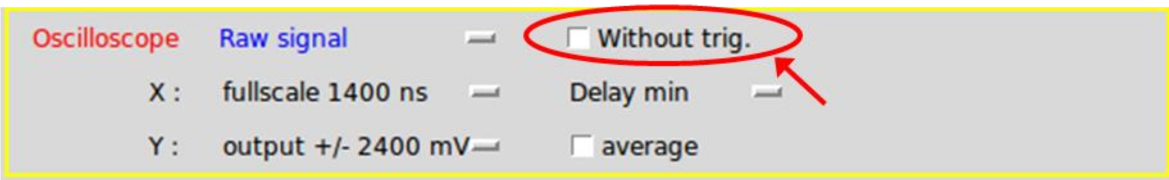

Figure 8: Trigger mode parameter

The oscilloscope display can be triggered by the discriminator module or not. During the initial settings, it's very useful to select "Without trig.". This tuning helps to identify the shape of the signal, its offset and its polarity.

III.A.2 The oscilloscope input channel

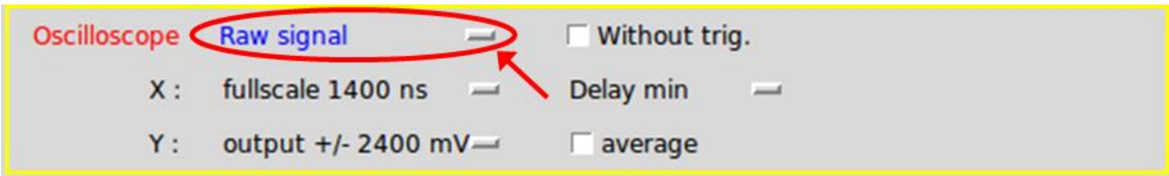

Figure 9: The inspected channels

The oscilloscope displays several signals from different modules:

- "Raw Signal": The FASTER daughter card includes an analogic-to-digital converter. This channel shows data digitalized by this converter.
- "Dyn. HP filter output": This channel shows data after the" high-pass filter" module. Refer to section III.C.2 .
- "Dyn. HP filter baseline": This channel shows the baseline computed by the "the high-pass filter" processing unit. Refer to section III.C.2 .
- "Trigger": This channel shows the signal used by "Trigger" module. Refer to section III.E .

III.A.3 The oscilloscope horizontal tuning

The time base of the signals can be adjusted with 3 parameters: shift, fullscale, subsampling.

III.A.4 The horizontal fullscale

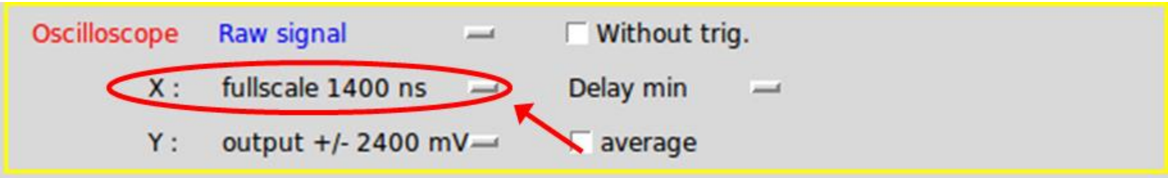

Figure 10: The horizontal fullscale parameter

The user can select between 9 fullscale ranges from 6µs to 1.4ms.

A signal graph contains 704 samples.

The time interval between two samples is: 2 ns for 1400 ns fullscale range; it is the sampling period of the 500MHz analogic-to-digital converter. The time interval is 4 ns for 2800 ns fullscale range, 8 ns for 5600 ns fullscale range, 16 ns for 11 µs fullscale range, 32 ns for 23 µs fullscale range, 64 ns for 45 µs fullscale range, 128 ns for 90 µs fullscale range, 256 ns for 180 µs fullscale range, 512 ns for 360 µs fullscale range, 1024 ns for 0.7 ms fullscale range, 2048 ns for 1.4 ms fullscale range.

III.A.5 The subsampling mode

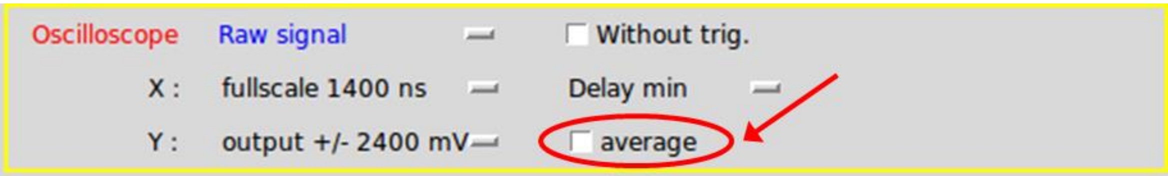

Figure 11: The subsampling mode parameter

As the number of samples is constant, the time interval between two samples is different according to the horizontal fullscale. When this time interval is greater than 2 ns, there are two ways to subsample the signal:

- Either every sample of the oscilloscope display represents the average of several samples. It's the "average" mode.

- Or every sample of the oscilloscope display represents one sample every N samples. It's the "subsampling" mode.

⚠ When a very short signal must be displayed, don't forget to change the horizontal fullscale to 1400ns fullscale. In "average mode", the average of a very short signal within a lot of samples is almost zero. In "subsampling mode", the sample shown is not necessarily the peak sample of the short signal. Therefore, a short signal exits, but it can be not-displayed.

III.A.6 The delay

Figure 12: The delay parameter

This parameter is available only when the oscilloscope display is triggered by the discriminator module.

The sample, that satisfies discriminator module conditions, is set at the very beginning (delay min), 25%, 50% or 75% of the display.

⚠ The sample, which satisfies the discriminator module conditions, is always placed at abscissa “0 ns” in “X fullscale 1400ns, Delay min” configuration. It is not necessarily the beginning of the signal. If “X fullscale” and “Delay” is different from “X fullscale 1400ns, Delay min”, the oscilloscope display may have a time shift.

III.A.7 The oscilloscope vertical tuning

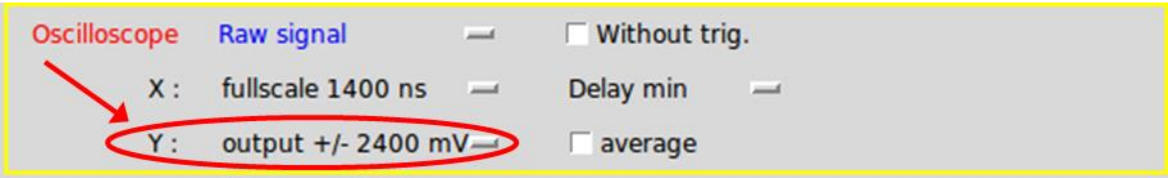

Figure 13The vertical fullscale

The values of the oscilloscope samples are always signed 16 BIT values, centered on 0.

The FASTER-RF module is processing 12 BIT signal samples for a fullscale around 2.4V peak to peak. But, as the signal is not 0-centered, the processing module uses 13 BIT for +/-2.4V fullscale.

In order to perform high-resolution calculations in the processing, 7 BIT are added as accuracy BIT on the signal sample.

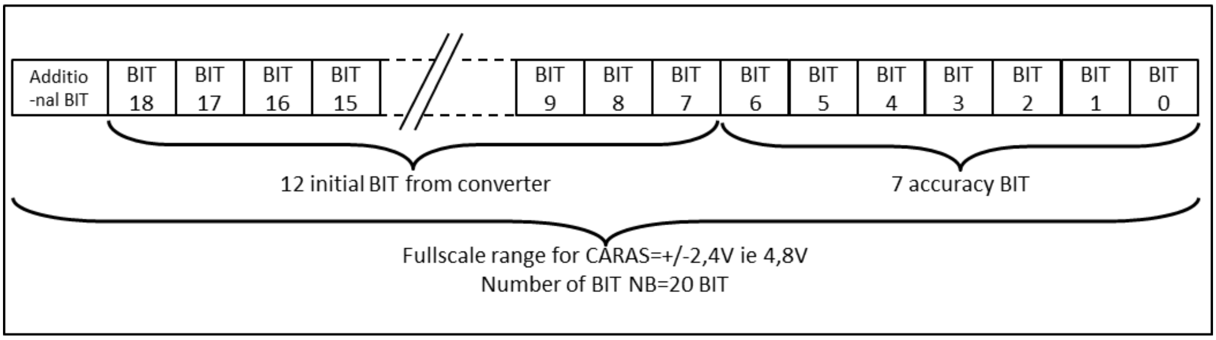

Figure 14: Data representation in the processing module

The values of the oscilloscope module have only 16 BIT. Several oscilloscope fullscale ranges are available to make the most of the maximum accuracy, or of the maximum fullscale of the FASTER-RF module.

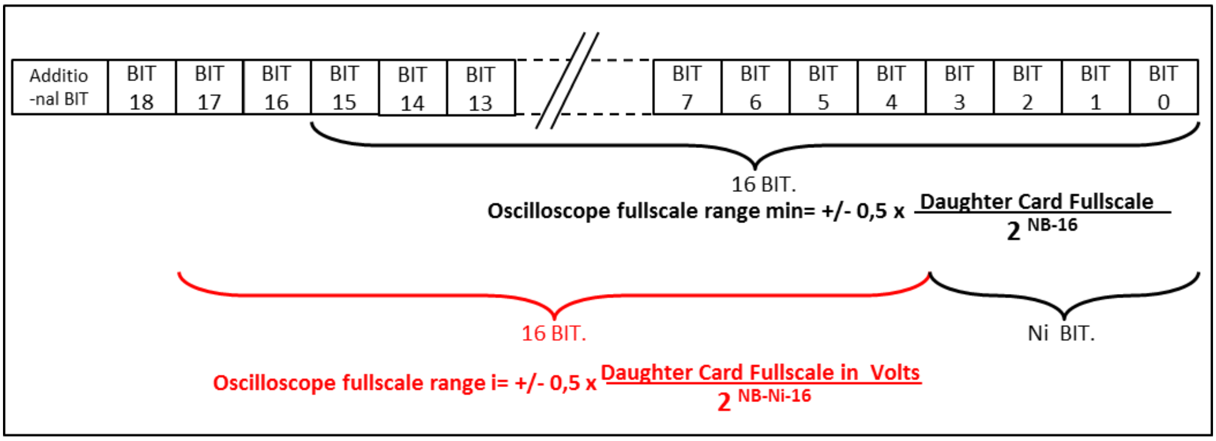

Figure 15: The oscilloscope fullscale ranges

For example:

$$\text{Oscilloscope fullscale range min} = \pm\frac{2.4\text{V}}{2^4} = \pm 150\text{mV}.$$

The oscilloscope fullscale range does not affect the internal representation of the signal used by the module.

III.A.8 The oscilloscope acquisition speed

Figure 16: The acquisition speed parameter

There are 4 choices of acquisition speed:

- One acquisition every millisecond: 1 kHz,
- One acquisition every 10milliseconds: 100Hz,
- One acquisition every 100 milliseconds: 10Hz,
- One acquisition every second: 1Hz.

III.A.9 The “output enable” parameter

Figure 17: The oscilloscope‘s “enable” parameter

The oscilloscope data is only sent to the acquisition chain if the “enable” parameter is checked.

III.B The Input module

III.B.1 "Input Dynamic Range Tuning" module

Figure 18: Input range adjustment for CARAS daughter card

The first parameter to adjust is the dynamic range. The input ranges from -1.195V to 1.195V, if you don't change anything.

By electrically changing the offset level, you can take advantage of the full scale range of about 2.4V. You can increase or decrease the input signal baseline level from -1.1V to 1.1V.

The raw data (that means the data digitized by the converter) is viewable with the "Oscilloscope" module. It is always between -1.1V and 1.1V.

III.B.2 The "Polarity Tuning" module

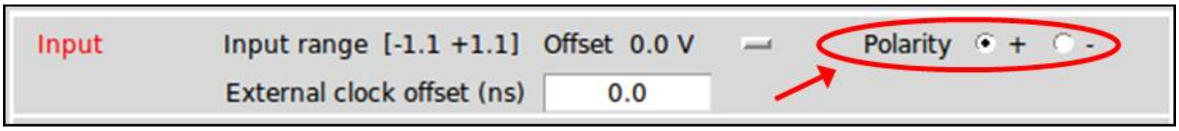

Figure 19: The polarity parameter

The FASTER-RF process detects the threshold crossing on rising edge. For a good time determination of the threshold crossing, it is better that the rise time is the fastest. Thanks to this parameter, you can work with the best edge of the cyclic beam signal.

III.B.3 The "Time shift" module

Figure 20: The time shift parameter.

This parameter is used to compensate the delay between the different channels on your experience. The shift is positive or negative, and has an 8ns-step.

III.C The "High-Pass filters" module

In order to obtain TOF spectra with the best resolution, it is necessary to zero the acquired signal baseline. The "Baseline Restorer" module provides two ways to zero the baseline:

-Either by subtracting a constant level: that is the constant BLR

-Or by subtracting a signal which follows the low input signal variations: that is the dynamic BLR.

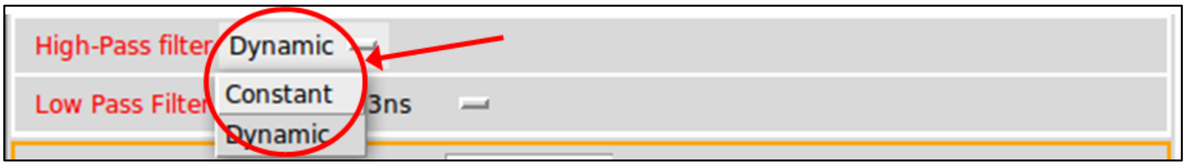

Figure 21: the BLR choice parameter.

III.C.1 The "Offset subtraction" module

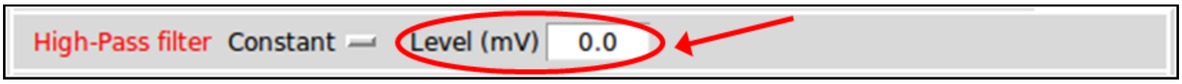

Figure 22: The "Level" parameter of the "Constant High-Pass Filter" module.

This module simply subtracts a constant level. You can adjust it if you want to center the signal.

III.C.2 The "High-Pass Filter" module

This module is used to remove the low-frequency noise. A third order high-pass filter is implemented. Its cutoff frequency is 157 kHz.

Figure 23: The "High-Pass Filter" module.

III.D The "Low-Pass Filter" module

You can use a low-pass filter or not. If you don't want to use a low-pass filter, select "Filter OFF", otherwise you can choose the filter rise time: either 13 ns, 27 ns or 57 ns.

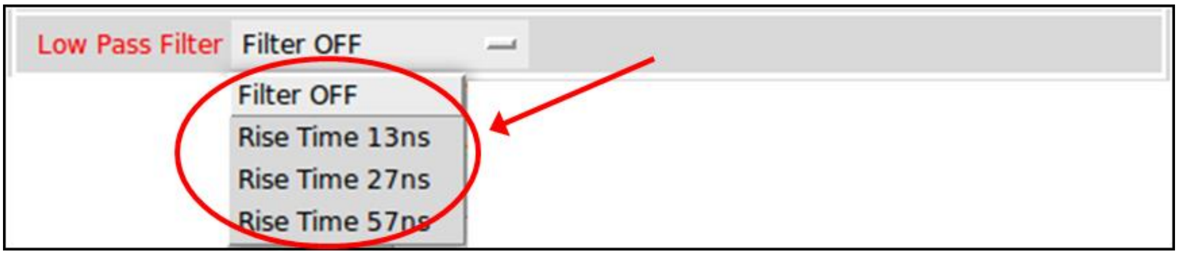

Figure 24: Low-pass filter parameter.

💡 It is often necessary to use a low-pass filter when the cyclic beam frequency is under 10MHz.

III.E The "Trigger" module

The "Trigger module" includes a threshold discriminator. The only parameter to select is the threshold value.

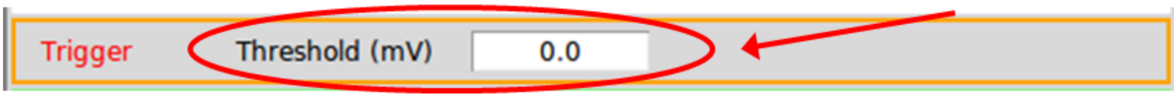

Figure 25: The Threshold parameter.

When an event is detected by the trigger module, this event is timestamped with a 2ns accuracy clock. A 7.8ps precision is calculated thanks to a linear interpolation.

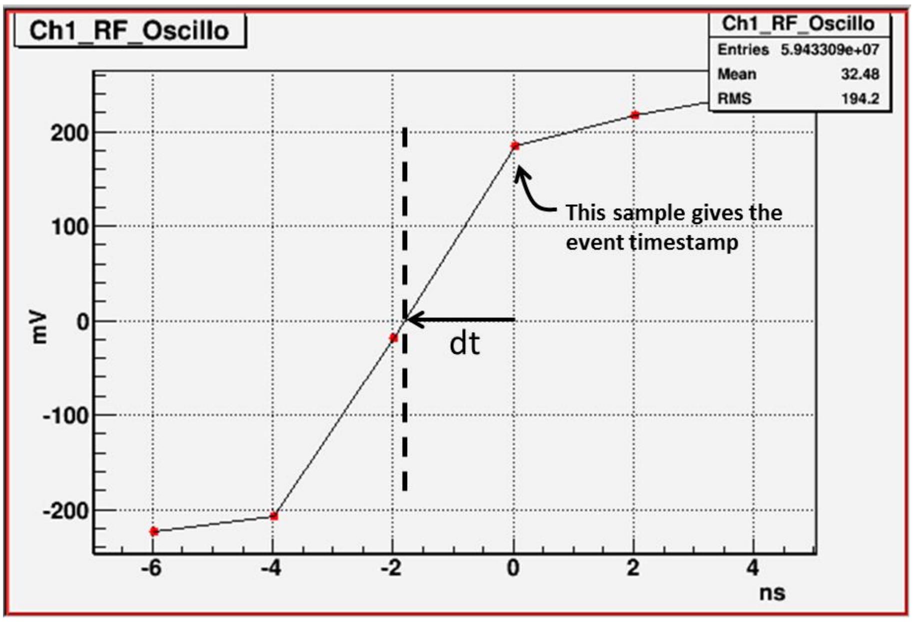

Figure 26: The "dt" data.

III.F The RF module

The role of the RF module is to calculate the beam period and phase.

Figure 27: The PLL bandwidth parameter.

This module contains a PLL (refer to Figure 3). As explained in chapter I.B , the role of the PLL is to accurately calculate the cyclic beam period and a more precise value of the phase. The low-pass filter of the PLL defines its bandwidth. The user can choose between two bandwidths (cf. Figure 27)

- 10 ppm of F_{beam},
- 150 ppm of F_{beam}.

⚠ When F_{beam} has a too high jitter, the PLL couldn't lock if you select the bandwidth of 10 ppm F_{beam}. Therefore, you must select 150 ppm F_{beam}, because the bandwidth is wide enough to follow the variation of F_{beam}.

III.G Data output module

The Data output module (Figure 28) defines the output data sent to the computer by checking buttons ①. These data are:

- the data processed by the RF module ③,
- the counting data ④,
- the data from the Oscilloscope module ⑤.

To distinguish these data in the stored file, they have different labels ②. The user can moreover control the rate of output data (⑥⑦⑧).

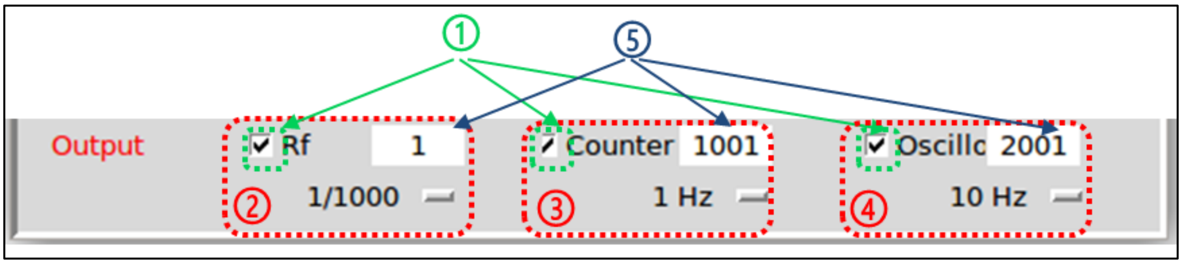

Figure 28: Parameters of the data output module

When the data comes out the FASTER-RF 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 RF MnM are called RF 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:RF: 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 "RF" data

It is convenient to reduce the data flow to prevent from the saturation of the communication. The user can select to send:

- All the data that the FASTER acquisition is able to transfer: 1/1.
- One out of 10 data: 1/10.
- One out of 100 data: 1/100.
- One out of 1000 data: 1/1000.
- One out of 10000 data: 1/10000.
- One out of 100000 data: 1/100000.

⚠ *Ideally, you have to choose the decimation according to the resolution of the TOF. You must have decimation x standard_deviation(Beam_Period) < wanted standard_deviation(TOF)*

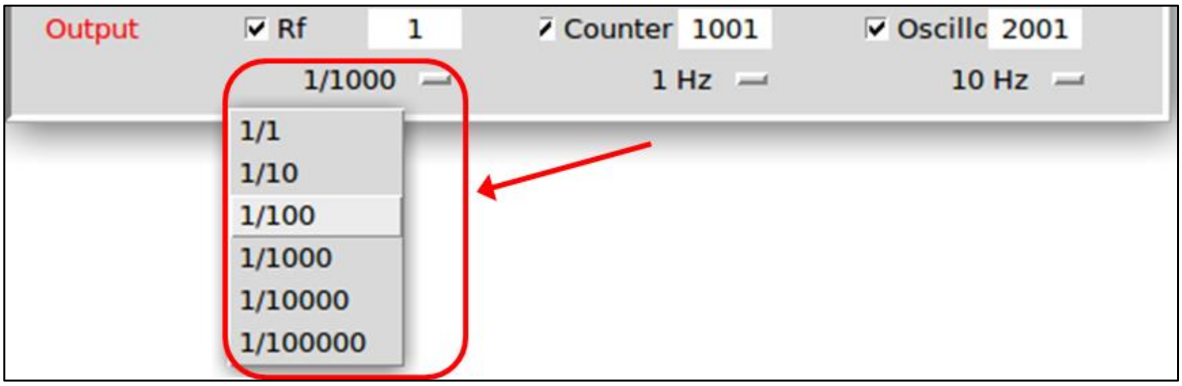

Figure 29: RF data decimation parameter.

The experimenter has, as output data (cf. Figure 30):

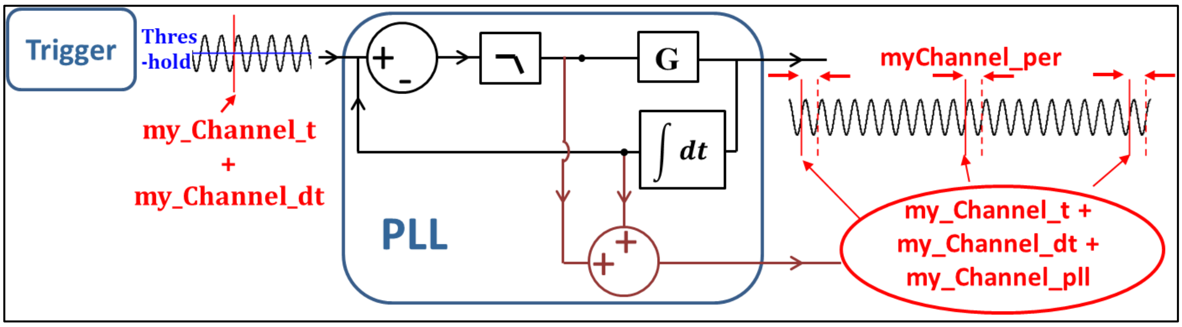

Figure 30: RF data for decimation 1/10. myChannel_saturated is not displayed.

- **myChannel_per**: the period value. It is a 31-BIT unsigned integer that has been divided by 2^{19} to have this value in nanosecond, with an accuracy of 1.9 fs
- **myChannel _saturated**: the saturation flag. The value 1 informs that the raw signal is outside the input range of the daughter card.
- **myChannel_t**: the time-stamp in nanosecond of the phase, with an 2 ns accuracy.
- **myChannel_dt**: an additional accuracy (in nanosecond) of the time-stamp, to achieve an accuracy of 7.8 ps (=2 ns/2^8). This time is processed by the Trigger module
  Time phase before PLL (ns) = my_Channel_t + my_Channel_dt

- **myChannel_pll**: an additional accuracy (in nanosecond) of the time-stamp, to achieve an accuracy of 7.8 ps (=2 ns/2^8). This time is processed by the RF module
  Time phase after PLL (ns) = my_Channel_t + my_Channel_dt + my_Channel_pll

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.

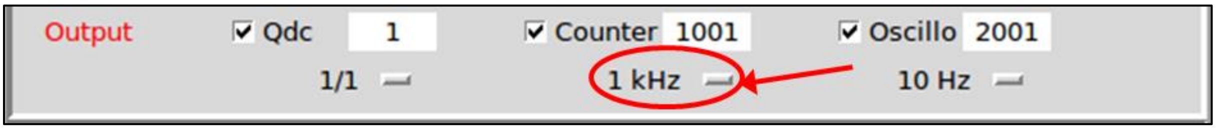

Figure 31: The counters acquisition speed parameter

Each “Counters” data has:

- **myChannel_COUNT_t:** the time-stamp of the “Counters” data
- **myChannel_TRIG**: the number of events triggered by the MnM.
- **myChannel_SENT**: the number of data from RF module, temporally stored in the FPGA buffers, and waiting for being sent to the computer.

The following inequality is always verified: myChannel_SENT≤ myChannel_TRIG.

These 2 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.

IV First experience with The Faster-RF module

Or "how to adjust the Faster-RF instrumentation module"

This chapter describes step by step, how to adjust the FASTER V2 – FASTER GUI (RF) Config parameters, The input signal is a periodic signal with a 90ns period from TGA12102 waveform generator.

IV.A Preliminary Step

You have previously run on your terminals:

```
~/ your_work_directory/faster_gui
~/ your_work_directory/RF_RHB_Demo/full_config/RHB -r
```

You may use an "Oscilloscope" display and a "RF Period Histogram" display of the channel you want to adjust.

Click on the "Start" button on the FASTER GUI application. Start displaying on RHB –r.

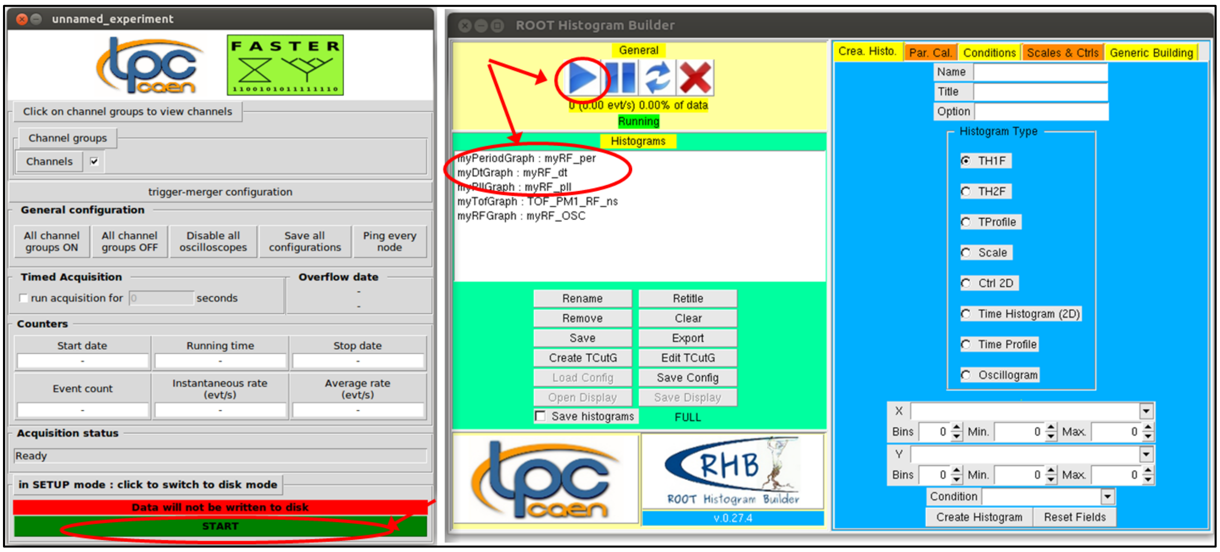

Figure 32: Start the acquisition, start displaying.

IV.B Input parameter selection

It is important to inspect the input signal of the FASTER-RF module to adjust the input dynamic range and to verify that the signal from the analogic-to-digital converter is not saturated. To do that, you must inspect the raw signal with the Oscilloscope module.

Adjust the oscilloscope parameters

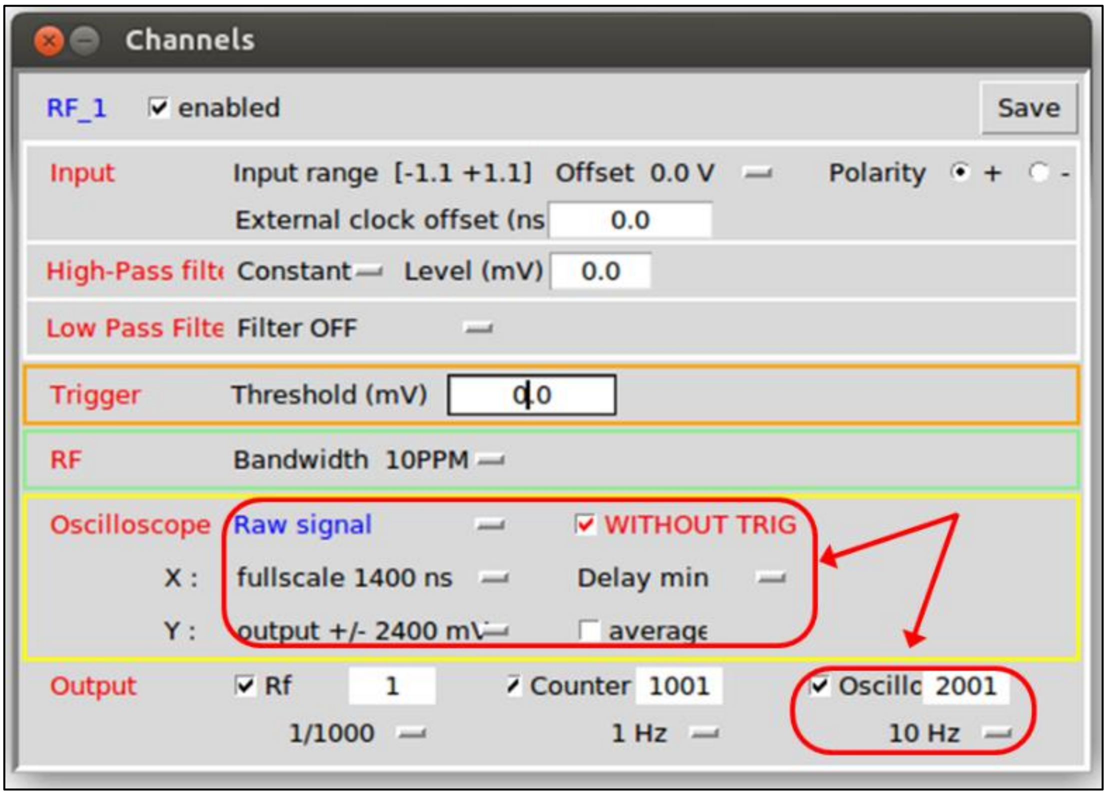

Figure 33: Oscilloscope tunings to inspect raw signal

You may tune the oscilloscope parameters as shown on Figure 33, i.e.:

- Oscilloscope input: “Raw signal”;
- Time fullscale 1400ns;
- Y-fullscale: the greatest proposed fullscale. That means +/-2400mV;
- “Without Trig” mode checked, in order to display the signal, even if the trigger module has not been adjusted;
- “Output Oscillo“ enabled with a 10Hz frequency.

Inspect the input raw waveform

For example, here is the obtained graph.

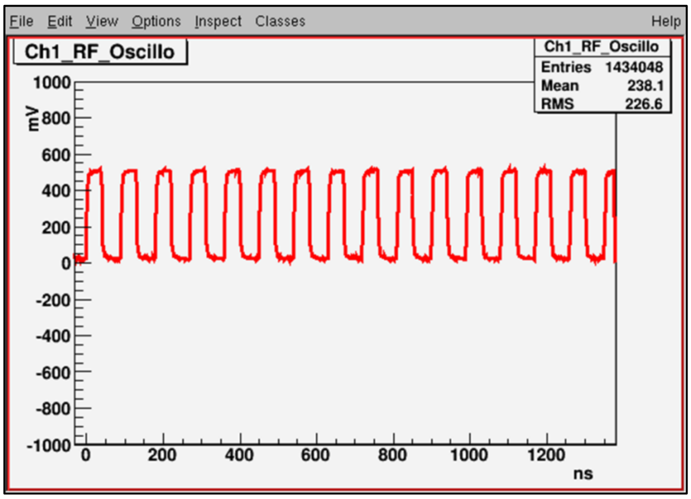

Figure 34: Example of an input raw signal graph

We can notice that:

- all the signal is within the dynamic range of CARAS: "Input range offset" remains on 0 mV.
- the rising edge and the falling edge are equivalent : no need to change the polarity.

IV.C The Filter & Trigger parameter selection

Adjust the filters and trigger parameters.

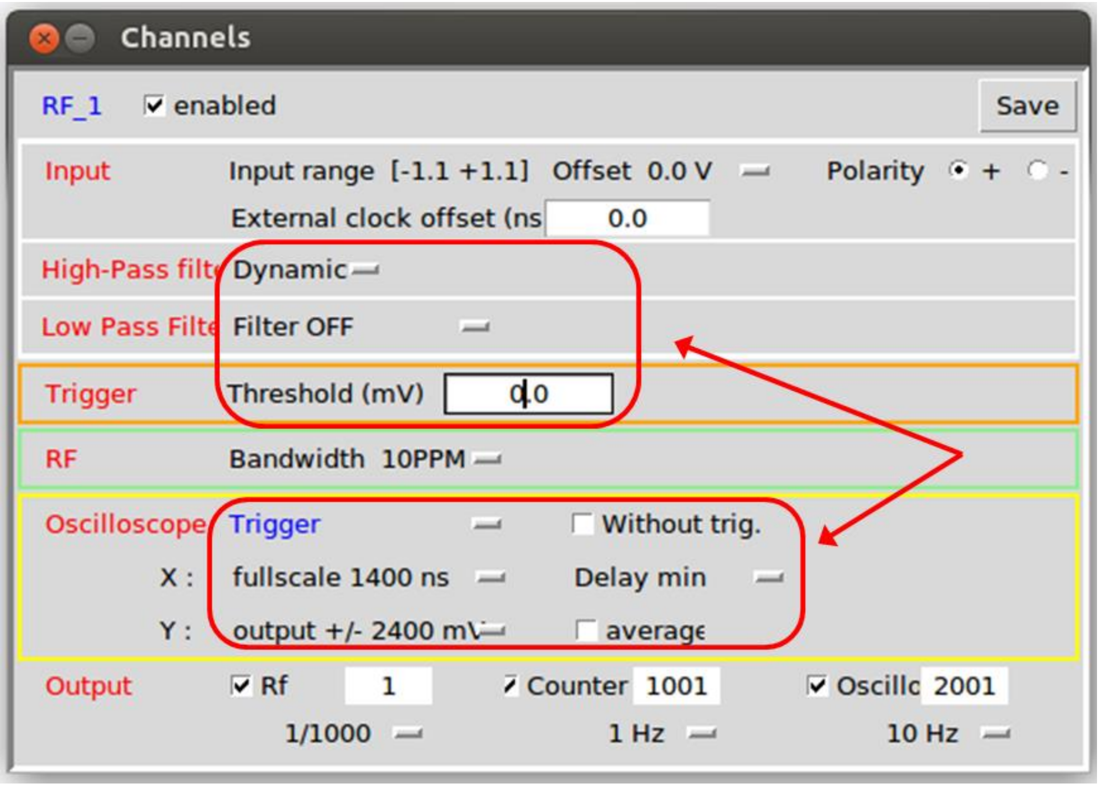

Figure 35: Oscilloscope tunings to inspect the signal at the input of the "Trigger" module

You may tune the parameters as shown on Figure 35, i.e.:

- High-pass Filter : Dynamic
- Low-pass Filter : OFF
- Trigger: Threshold = 0 mV
- Oscilloscope input: "Trigger"
- Time fullscale 1400 ns;
- Y-fullscale: +/- 2400 mV;
- Average parameter: any settings are equivalent.
- "Without Trig" mode unchecked.

Inspect the "Trigger" waveform.

The high-pass filter removes the DC component of the signal. You can verify that the 0mV trigger threshold is on the middle of the rising edge.

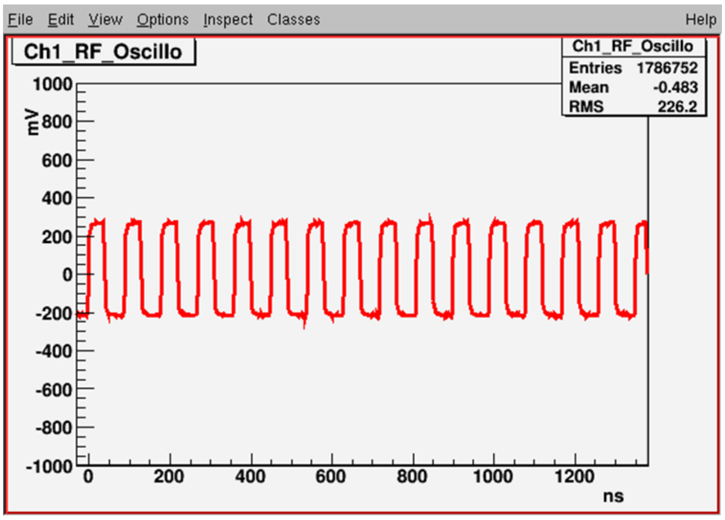

Figure 36: Input signal of the trigger module.

IV.D The RF module parameter definition

Display the RF period histogram with RHB

⚠ You should display with an adequate histogram resolution. If not, change the spectrum display parameters in RHB-v. Refer to the RHB user manual.

Here is your desired histogram:

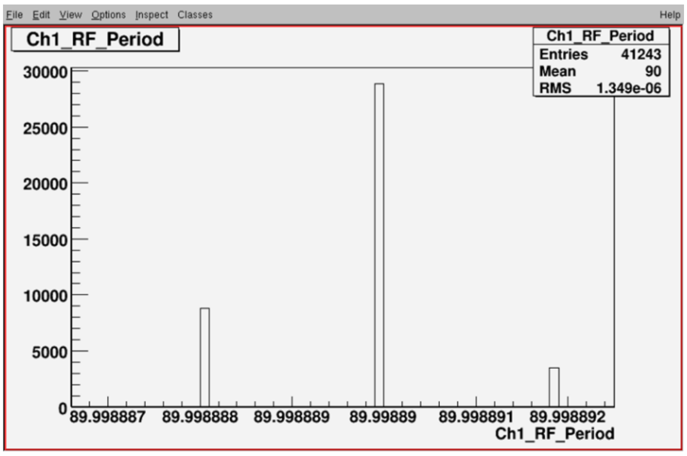

Figure 37: The period histogram.

Adjust the RF module bandwidth:

If the period standard deviation is better, you can change the RF bandwidth.

Figure 38: the RF bandwidth.

Select an adequate decimation to avoid the saturation of the communication. As shown on Figure 37, the standard deviation is about 1.4fs. For example, with a decimation of 1/10000, the contribution of the calculation of the TOF start time is about 1.4fs x 10000 = 14ps.

Click on the “Save” button to prevent from loss of your settings.