Test et résultats de la carte TEMPORAL

Journées des Métiers de l'Electronique de l'IN2P3 et de l'IRFU
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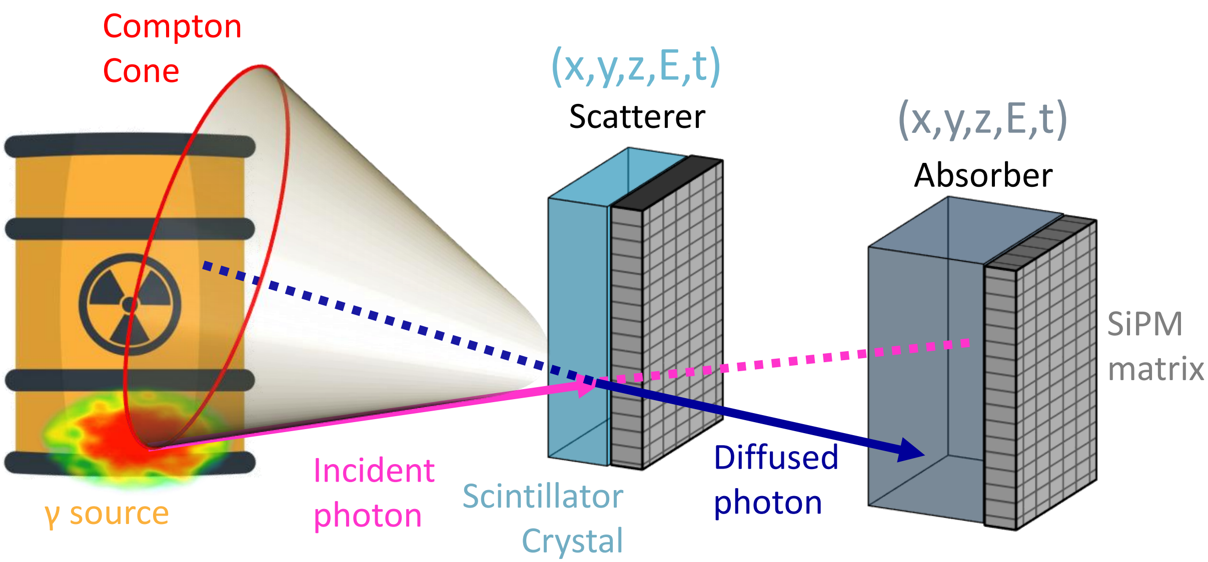
2021 JME contribution:
https://indico.in2p3.fr/event/20437/contributions/99769/

The TEMPORAL project

Industrial research project financed by the ANDRA under the PIA in order to protoype a camera (Compton camera) able to localise, indetify and quantify the ɣ ray radioactive sources during nuclear waste disposal. The desired characteristics are :

- Temporal resolution < 200 ps
- Spatial resolution <2mm on the detector plane and <10mm on the vertical axis
- Energy resolution < 3.5 % FWHM @ 662KeV

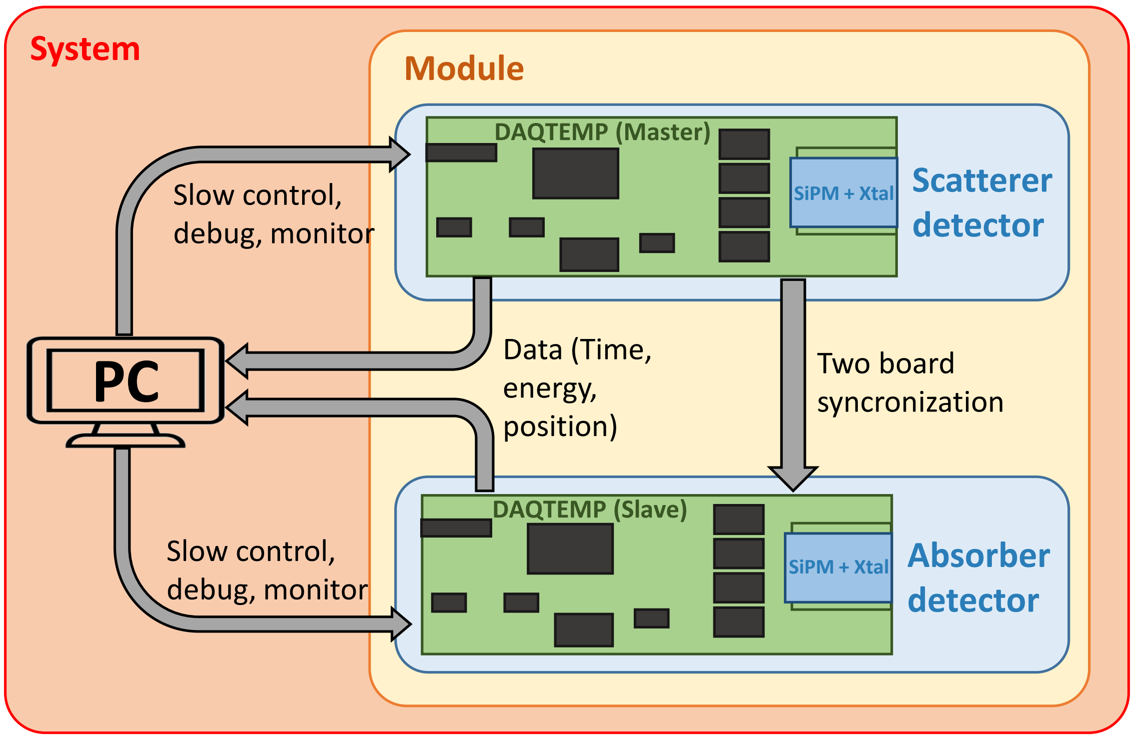


Compton camera principle:
From the position, energy and time information (x,y,z,E,t) of the detected events,we can reconstruct the origin of the gamma source by intersecting the uncentainty cones (Compton cones)

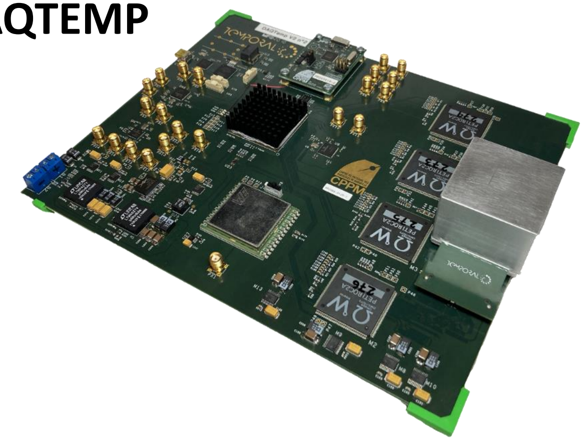
TEMPORAL Compton Camera

The TEMPORAL Compton camera is a measuring instrument with the following 3-level hierarchical architecture :

- **The detector (Level I)** is composed by a crystal coupled to a SiPM matrix and a first level of data treatment. This detector is hermetically sealed from ambient light.
- **The module (Level II)** is a collection of 2 or more detectors (<16). At this levels, the Compton events with the characteristic vectors (x,y,z,E,t) are identified in real time.
- **The system (Level III)** can include one or more modules that needs to be synchronized. At this level we have the control, the data correction and the image reconstruction



In this project, CPPM is in charge of the development and characterization of the detector front-end board **DAQTEMP**

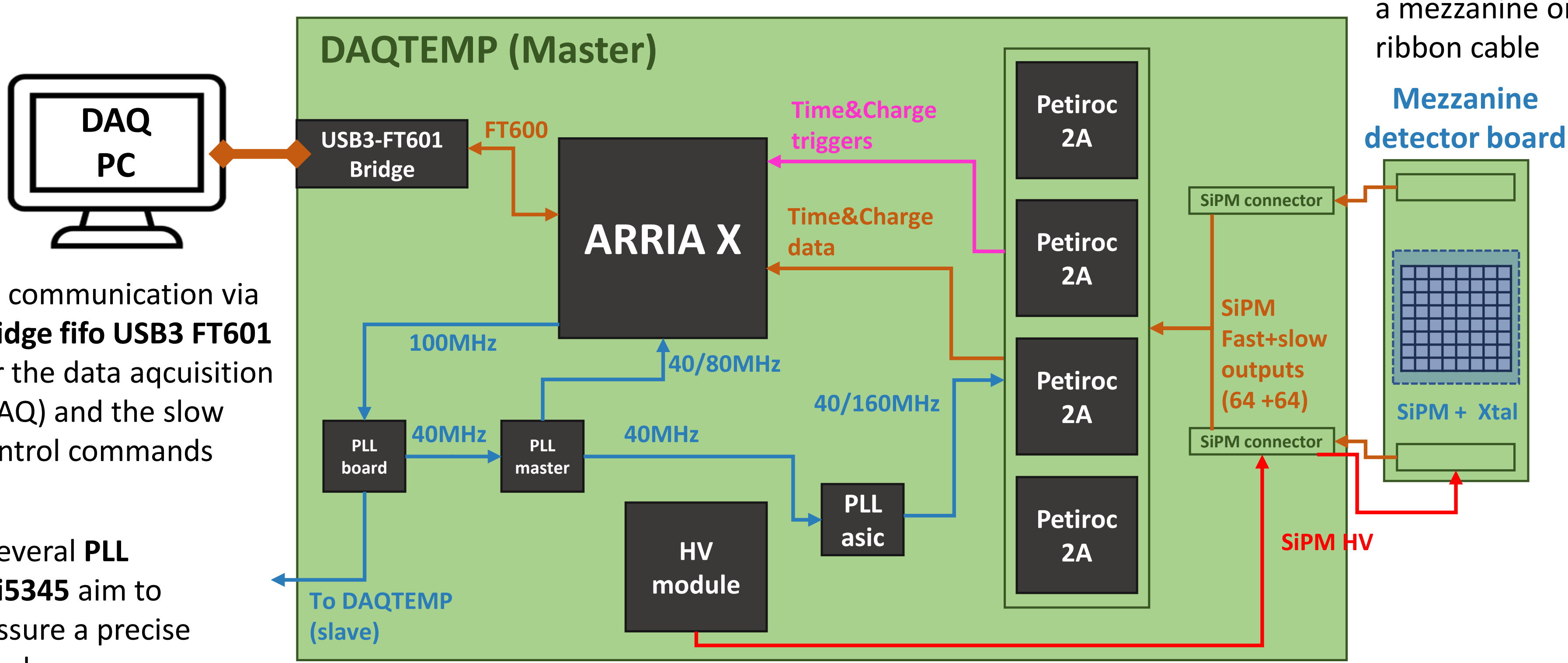


DAQTemp

Front end acquisition board for the digital readout of analog SiPM matrices

An **FPGA ARRIA X** will have the function to centralise all the ASICs data and transmit it to the back end. Also, it will exchange the slow control configuration messages with the back end for the configuration of the various hardware device

The cystal couple to the SiPM can be connected via a mezzanine or a ribbon cable



PC communication via **bridge fifo USB3 FT601** for the data aqcuisition (DAQ) and the slow control commands

Several **PLL Si5345** aim to assure a precise and syncronous clock distribution, especially among the 4 petirocs and between two boards

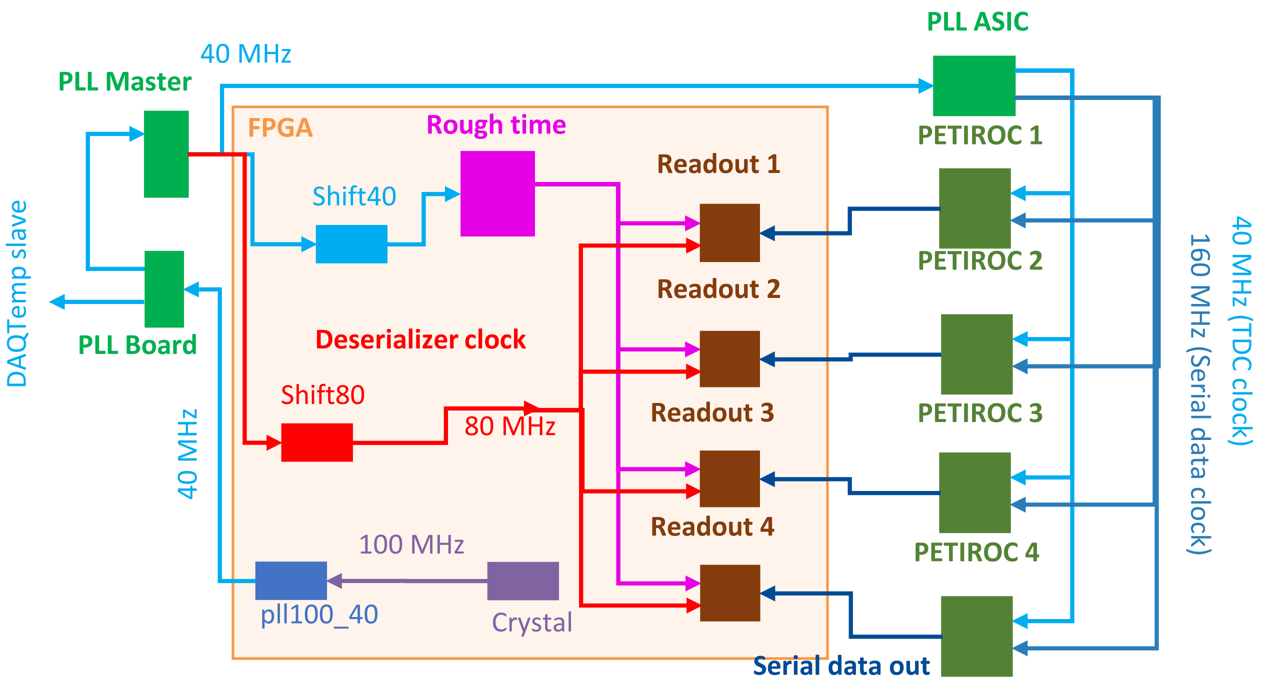
A group of voltage regulators and a High voltage module (**HT Nuclear Instrument**) power the entire board and supply the high voltage necessary for the SiPM. The latter is temperature regulated.

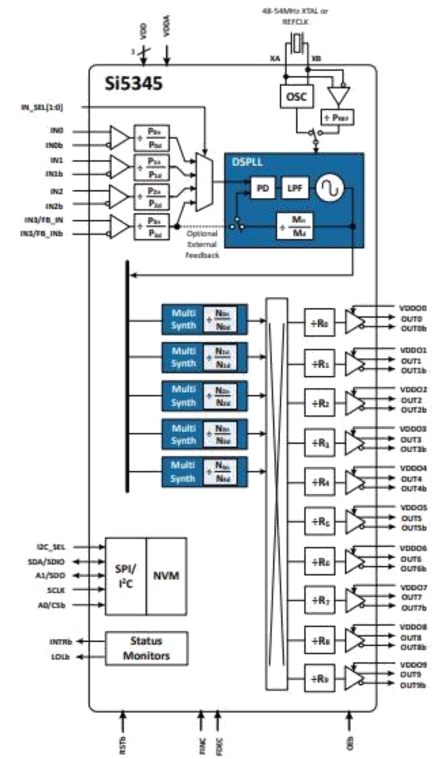
4 **ASICS PETIROC2A** allow to read the 64 slow cannels and the 64 fast channels of the SiPM SensL. The two asics connected to the fast outputs will be used to measure the time and the other two to measure the charge.

Clock Tree

The clock tree has to generate, syncronize and distribute:

- The clock used to regulate the petiroc TDC system and the timestamp used inside the FPGA (40MHz)
- The clock uses to serialize/deserialize the petiroc data output (160MHz/80MHz)





It is important that all Petirocs on the two boards (master & slave) receive a syncronous clock!

The PLL si5345 flexibility allows to compensate the phase shift by dephasing single outputs

Firmware and Software

Firmware functionalities:

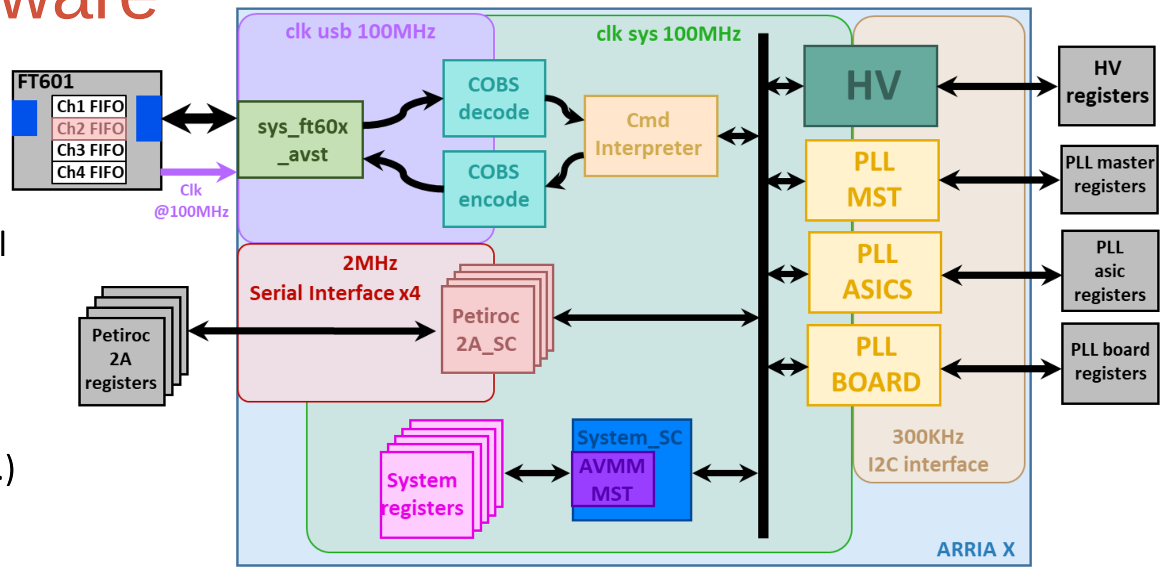
- Handling the configuration of all peripherals (Petirocs, HV Module, PLL, JTAG, FT60 1, etc.)
- Packet data transmission
- Handling the trigger chain and petiroc digital readout protocol

Software functionalities :

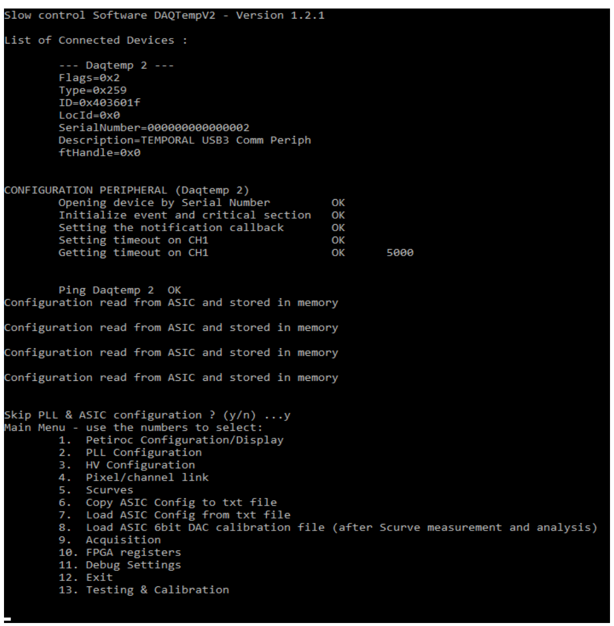
- Pheripherals configuration (Petirocs, FPGA, HV moduel, PLL, JTAG, FT601, etc.)
- Calibration protocols (Scurves, PLL , charge…)
- Handling data acquisition sessions

Data analysis -> Scripts Python

Slow Control



CLI



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Slow control Software DAQTempV2 - Version 1.2.1

List of Connected Devices :

        --- Daqtemp 2 ---
        Flags=0x2
        Type=0x259
        ID=0x403601f
        LocId=0x0
        SerialNumber=000000000000002
        Description=TEMPORAL USB3 Comm Periph
        ftHandle=0x0


CONFIGURATION PERIPHERAL (Daqtemp 2)
        Opening device by Serial Number         OK
        Initialize event and critical section   OK
        Setting the notification callback       OK
        Setting timeout on CH1                  OK
        Getting timeout on CH1                  OK      5000


        Ping Daqtemp 2  OK
Configuration read from ASIC and stored in memory

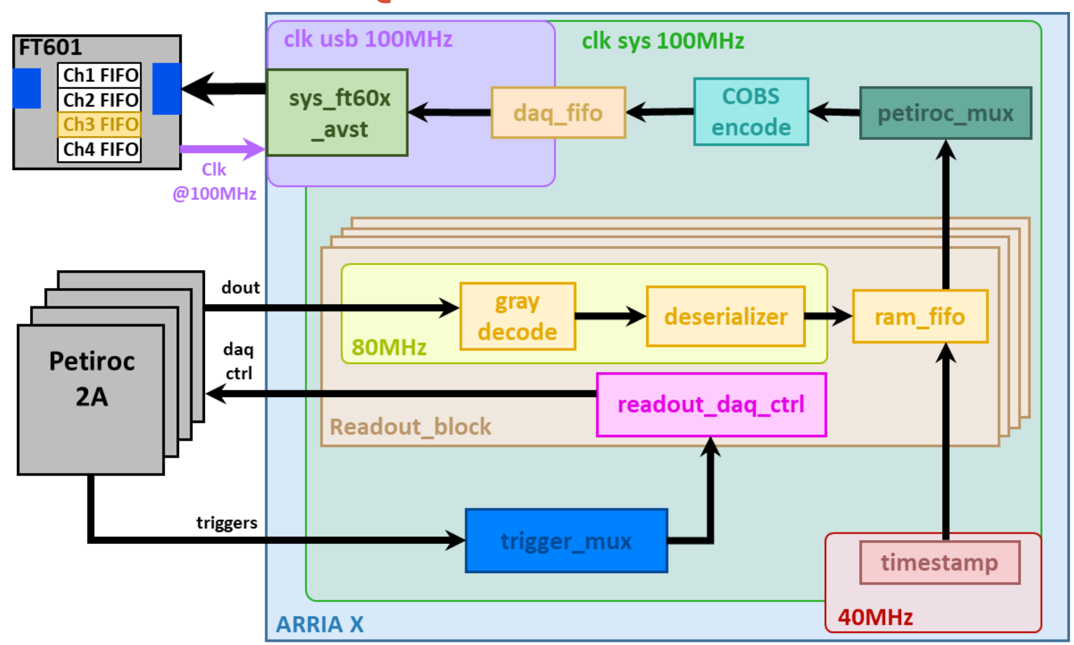
Configuration read from ASIC and stored in memory

Configuration read from ASIC and stored in memory

Configuration read from ASIC and stored in memory

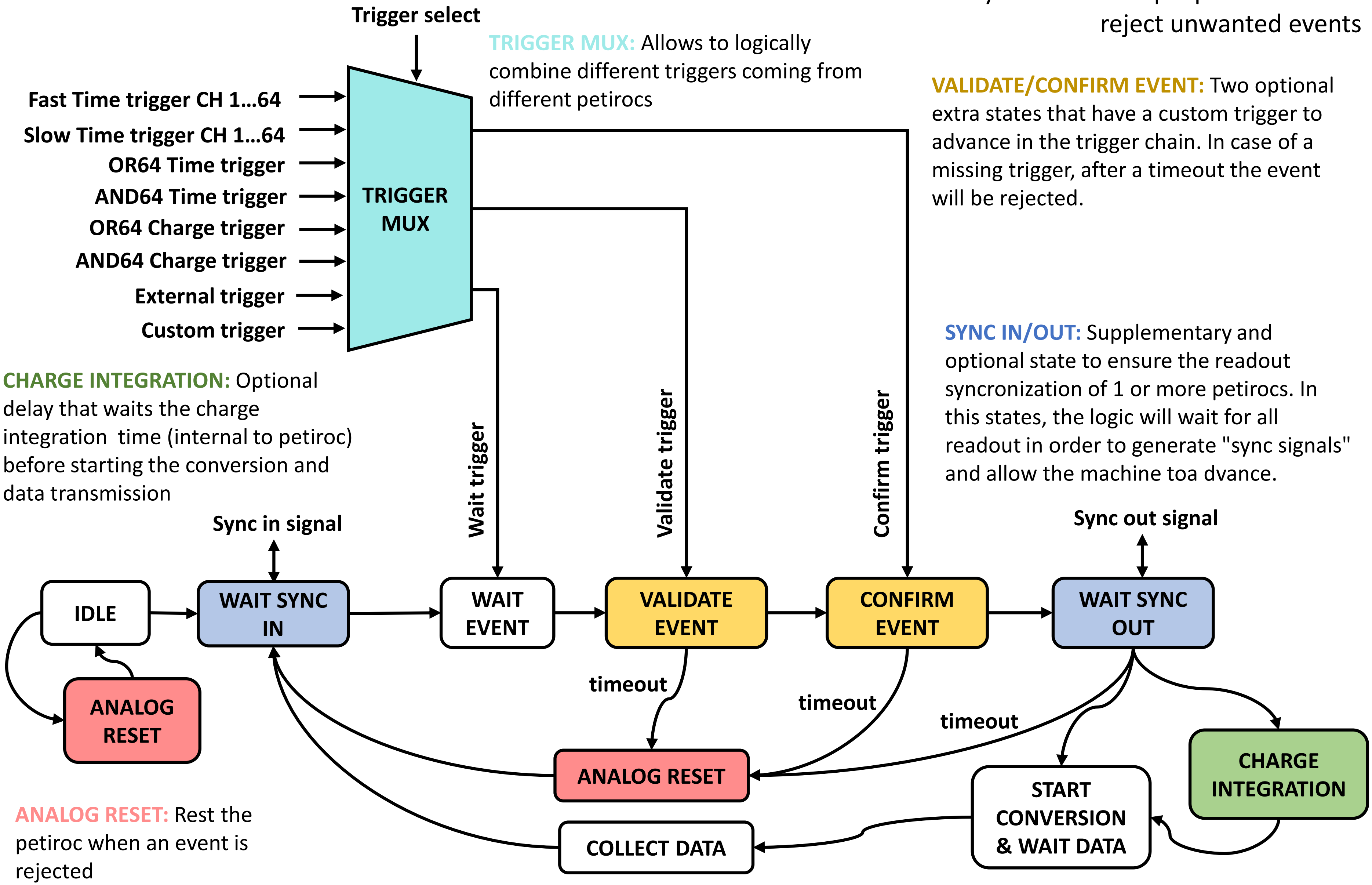

Skip PLL & ASIC configuration ? (y/n) ...y
Main Menu - use the numbers to select:
        1.  Petiroc Configuration/Display
        2.  PLL Configuration
        3.  HV Configuration
        4.  Pixel/channel link
        5.  Scurves
        6.  Copy ASIC Config to txt file
        7.  Load ASIC Config from txt file
        8.  Load ASIC 6bit DAC calibration file (after Scurve measurement and analysis)
        9.  Acquisition
        10. FPGA registers
        11. Debug Settings
        12. Exit
        13. Testing & Calibration
```

DAQ



Readout block state machine

Necessary to handle the digital readout of the petirocs, to syncronize multiple petirocs and to reject unwanted events



TRIGGER MUX: Allows to logically combine different triggers coming from different petirocs

VALIDATE/CONFIRM EVENT: Two optional extra states that have a custom trigger to advance in the trigger chain. In case of a missing trigger, after a timeout the event will be rejected.

SYNC IN/OUT: Supplementary and optional state to ensure the readout syncronization of 1 or more petirocs. In this states, the logic will wait for all readout in order to generate "sync signals" and allow the machine toa dvance.

CHARGE INTEGRATION: Optional delay that waits the charge integration time (internal to petiroc) before starting the conversion and data transmission

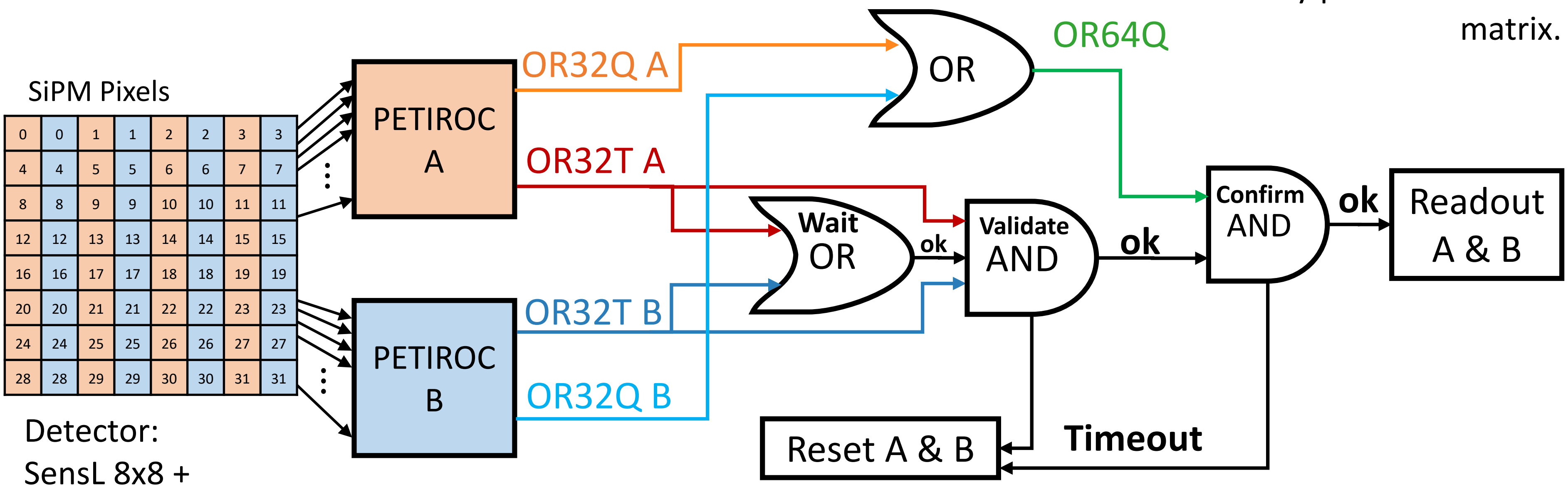
ANALOG RESET: Rest the petiroc when an event is rejected

Reading the charge on a SiPM matrix

Because two petirocs are necessary to read the SiPM matrix, we need:

1. Synchronized readout of both state machines
2. Same triggers to both readout block
3. Charge measured at the same time from both petirocs
4. Reject non-significative events (i.e. noise, low energy)

For every event that passes all the trigger chain, we collect and sum the sampled charge on every pixel of the SiPM matrix.

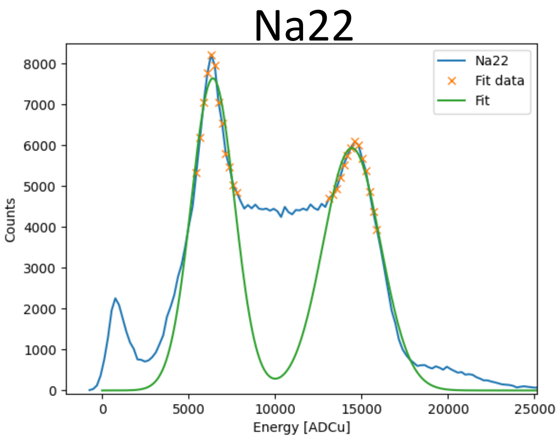


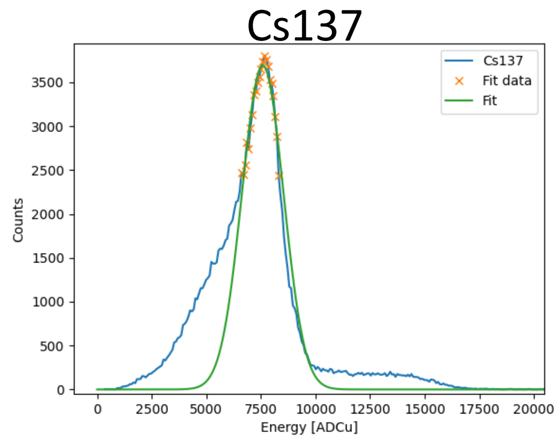
Detector:
SensL 8x8 +
LYSO Crystal

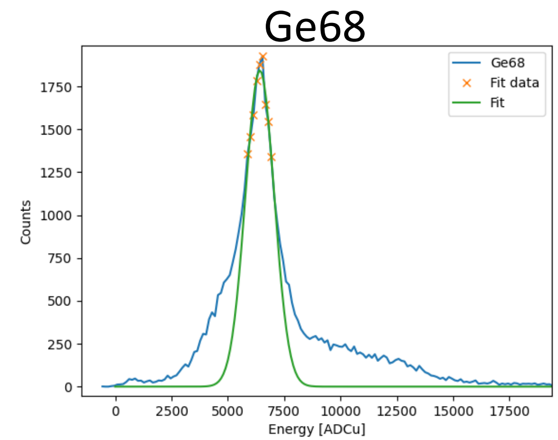
The following trigger signals are used:

Wait phase : Wait for the time trigger from either Petiroc (OR32T)
Validate phase : Check if the time trigger of the other petiroc also activated (Coincidence)
Confirm phase : If the charge trigger (OR64Q) activated, it measn that the charge deposed on the matrix is above a configurable threshold (significative event)

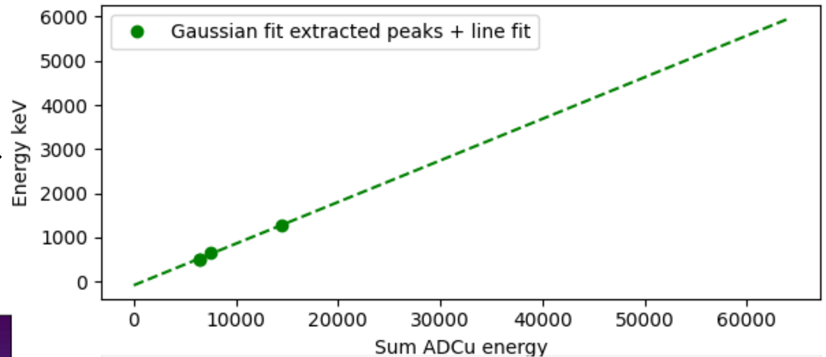
Charge calibration (via software)

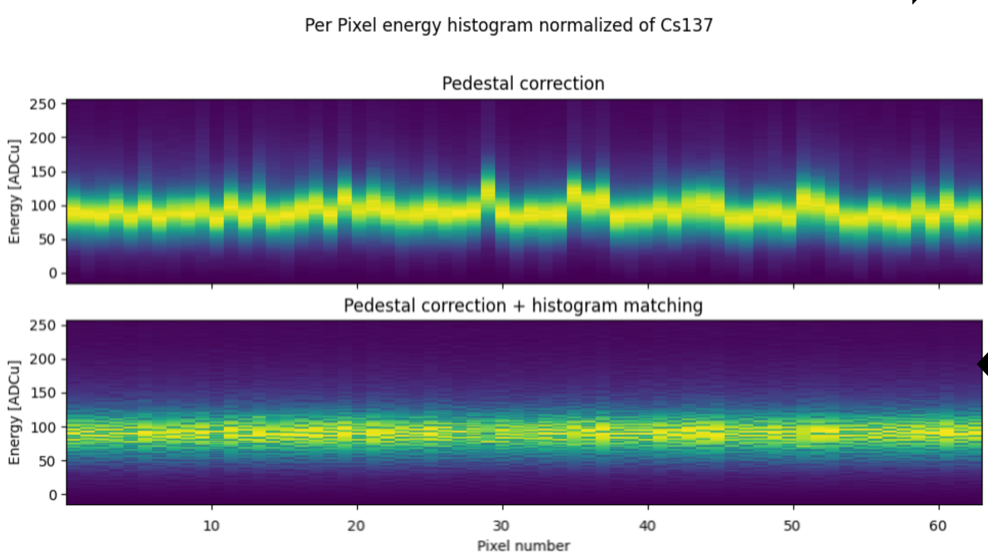


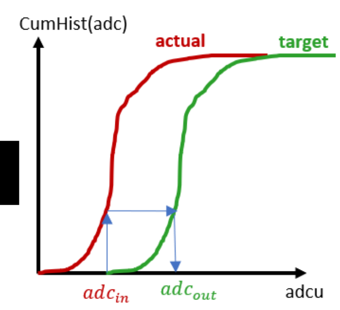




Photopeak fitting: We use radioactive sources with knonw radioactive emission peaks to calculate a calibration curve in order to convert the ADC units into energy (keV).



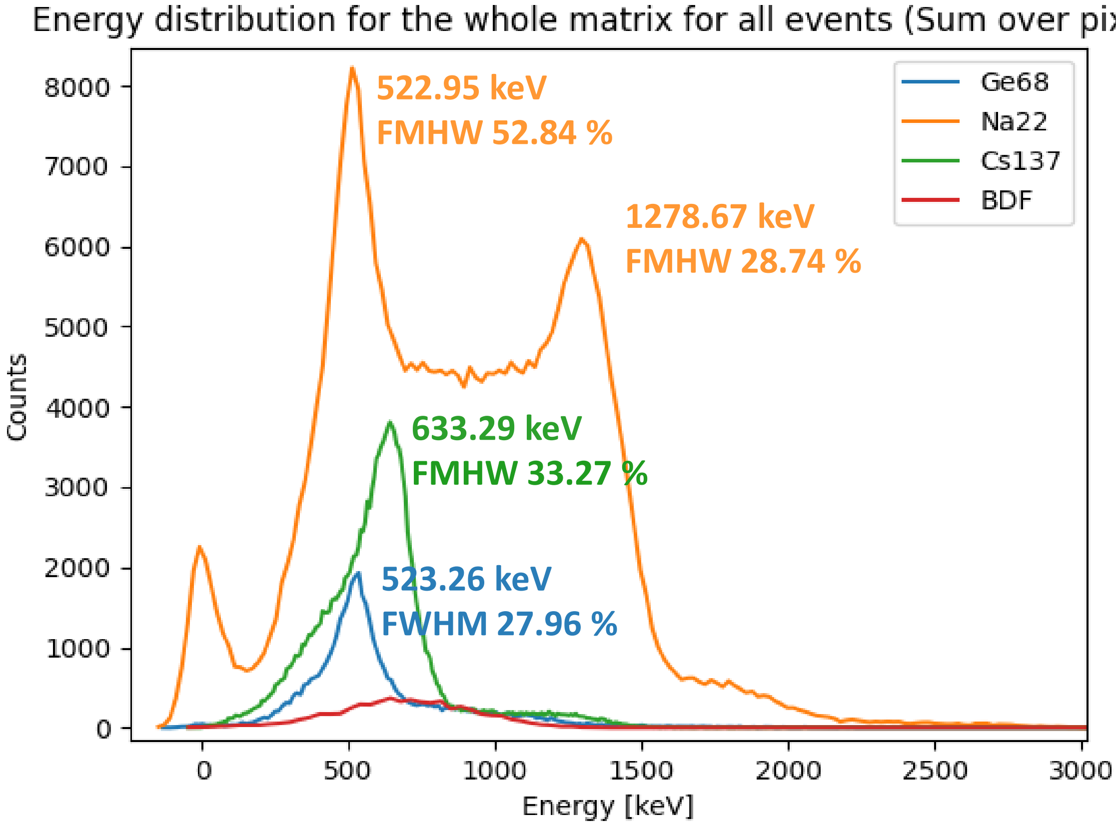




Histogram matching

Equalizing the single SiPM pixel response, in order to increase the resolution when summing the charge on the all matrix.

Spectra after calibration

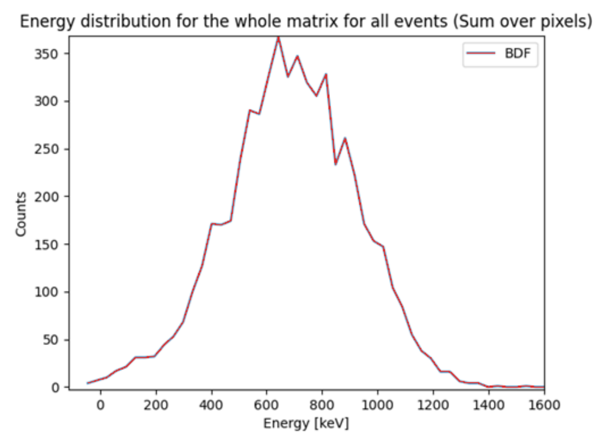


The **BDF** (Background noise) originates from the scintillator coupeld to the SiPM matrix. The former is a **LYSO** crystal, which is natually radioactive because of the presence of **Lu176**.

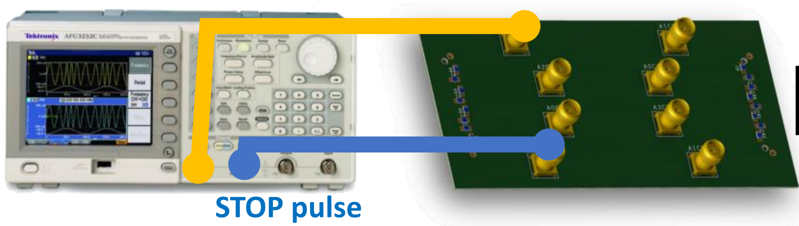
The weak radioactivity of Lu176 is a result of a contribution of gamma rays @ 306.82 keV, 201.83 keV and 88.36 keV. Beacuse of this, the energy resolution of the detector degrades .

Gammas from ^{176}Lu (3.78E10 y 2)

Eg (keV)	Ig (%)	Decay mode
88.34 *3*	13.3 *13*	b⁻
201.83 *3*	86 *5*	b⁻
306.78 *4*	94	b⁻
400.99 *4*	0.329 *19*	b⁻

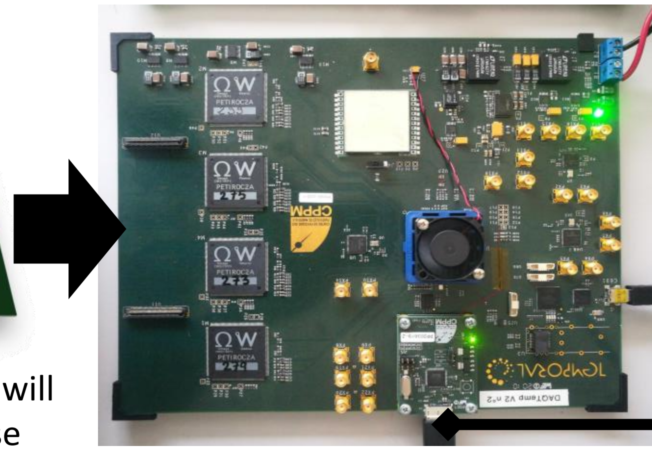


CRT Measures

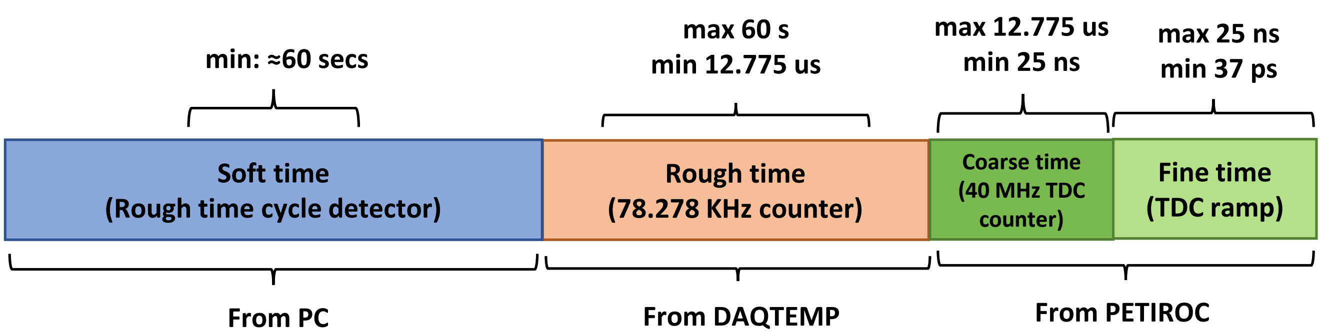


We can use a **function generator** to simulate SiPM pulses, and we can set a delay ΔT between a start and a stop signal.

An injection mezzanine will be used to redirect these signal on the petiroc inputs



$\widehat{\Delta T}$ **Recoverd delay** between start and stop



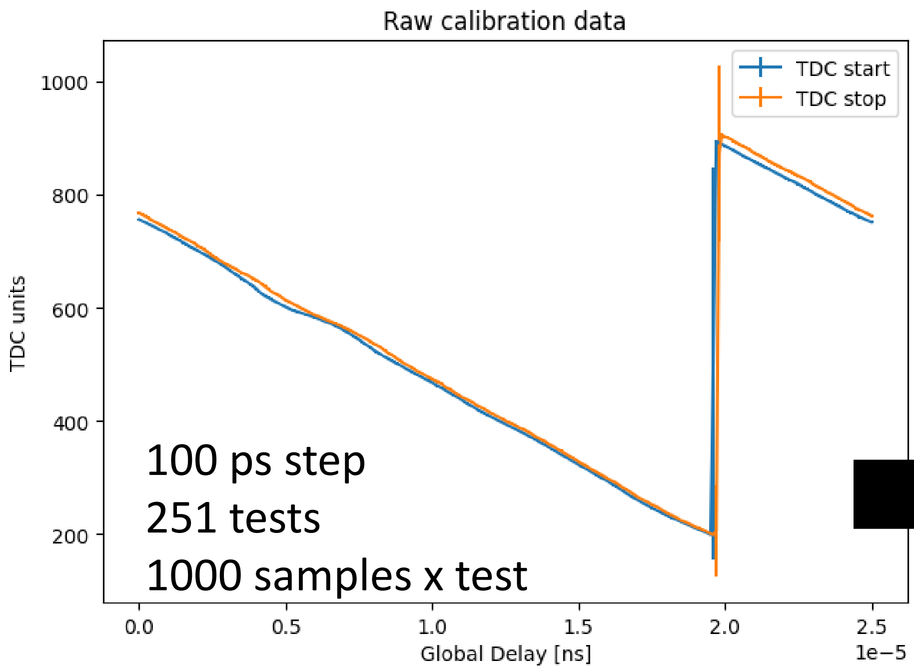
We performed the test using two different petirocs for the start and the stop.

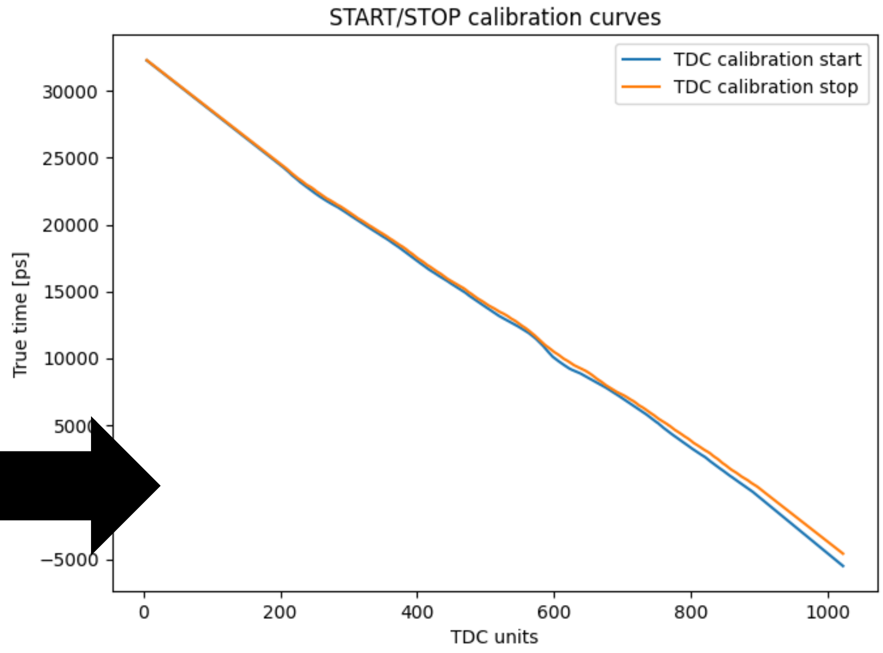
To ensure the precision of the temporal information:

- Both Petirocs needs to have the same TDC clock at their input (Syncronized and with the same frequency, assured by the PLL asic).
- Both Petirocs needs to have the same TDC response (Only possible with a TDC calibration).

TDC calibration (via software)

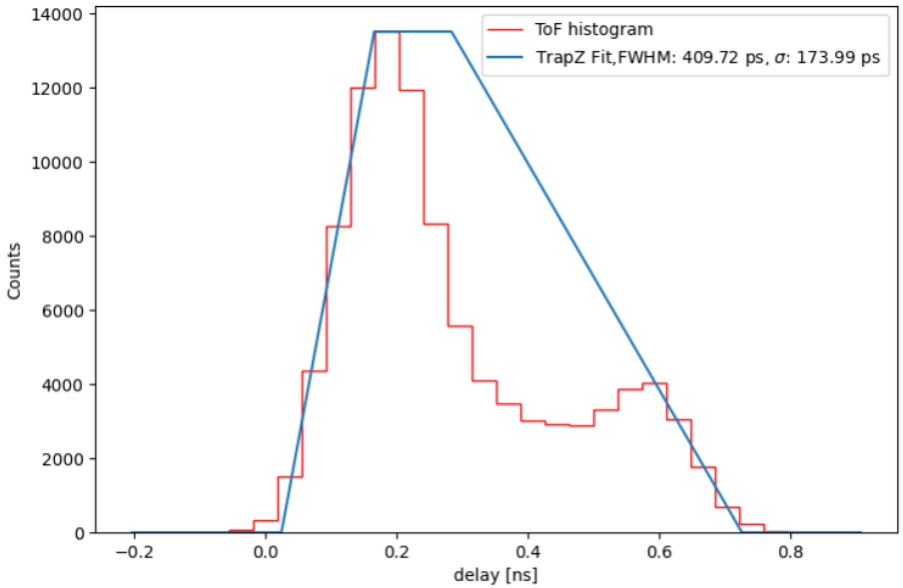
- How to :
  - Align start and stop triggers (Check both petiroc outputs)
  - Syncronize the clock of the function generator with the Petiroc TDC clock
  - Shift both pulses in time and collect TDC data. Repeat until all the TDC ramp values are covered
  - Rebuild and realign the ramps and finally invert the ramps to find the inverse map betwee the TDC value and the absolute time.



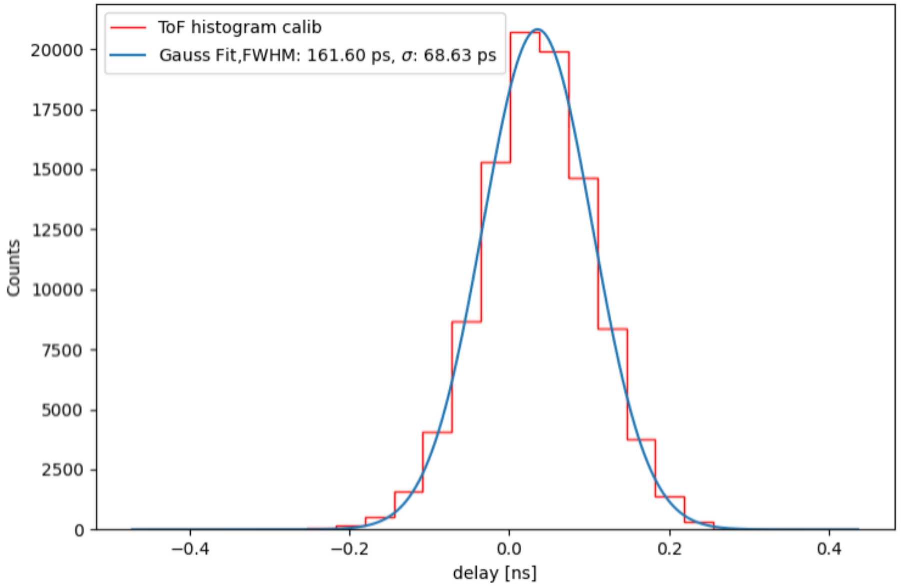


CRT Before/after calibration

CRT (2 petirocs digital mode) pre-etallonage



CRT (2 petirocs digital mode) post-etallonage



CRT Measures (digital mode, Petiroc internal TDC)	σ (ps)	FWHM (ps)
Weeroc* (Single petiroc, Pre tdc calibration)	83.64	219.99
Weeroc* (Single Petiroc, Post tdc calibration)	53.93	127.27
CPPM (Two Petirocs on DAQTemp, Pre tdc calibration)	**173.99**	**409.72**
CPPM (Two petirocs on DAQTemp, Post tdc calibration)	**68.63**	**161.60**

The presence of non-linearities on the TDC curves increase the variance of the CRT distribution. By applying the calibration correction, we can significatively reduce this problem.

* S. Ahmad , J. Fleury, J. B. Cizel, C. de la Taille, N. Seguin-Moreau, S. Gundacker, E. Auffray Hillemanns (2018), Petiroc2A: Charaterization and Experimental results, *2018 IEEE Nuclear Science Symposium and Medical Imaging Conference*

Conclusions

- Preliminary results on the time and energy resolution
- Future works:
  - Automatic and complete board calibration (via software) for time and charge
  - Two board syncronization
- After calibration, more tests planned
  - Using a different cystal (CrBe3) with the SiPM matrix to improve the energy resolution
  - Using a finer TDC calibration to improve the CRT resolution

Thanks for your attention!