From Analog to Digital DAQ Transition In Physics Application

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Summary

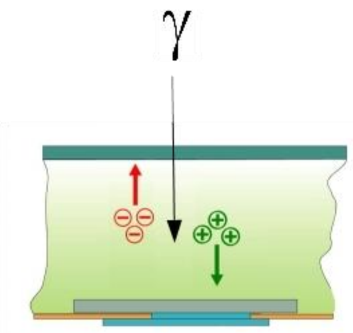
- **Fundamentals**
  - Definitions
  - Detectors
  - Measurements and analysis
- **Detector Readout Electronics**
  - Comparison between analog and digital readout chain
  - Waveform digitizers
  - Data streaming and online data processing
  - Oscilloscope mode and List mode
- **Pulse Processing Algorithms**
  - Digital pulse processing algorithm: DPP-PHA
  - Digital pulse processing algorithm: DPP-QDC and DPP-PSD
  - Advanced zero suppression algorithms: DPP-ZLE & DPP-DAW
- **Digital vs Analog: advantages and drawbacks**
- **CoMPASS**
  - Description
  - Main operation
- **Hands-On Scenarios**

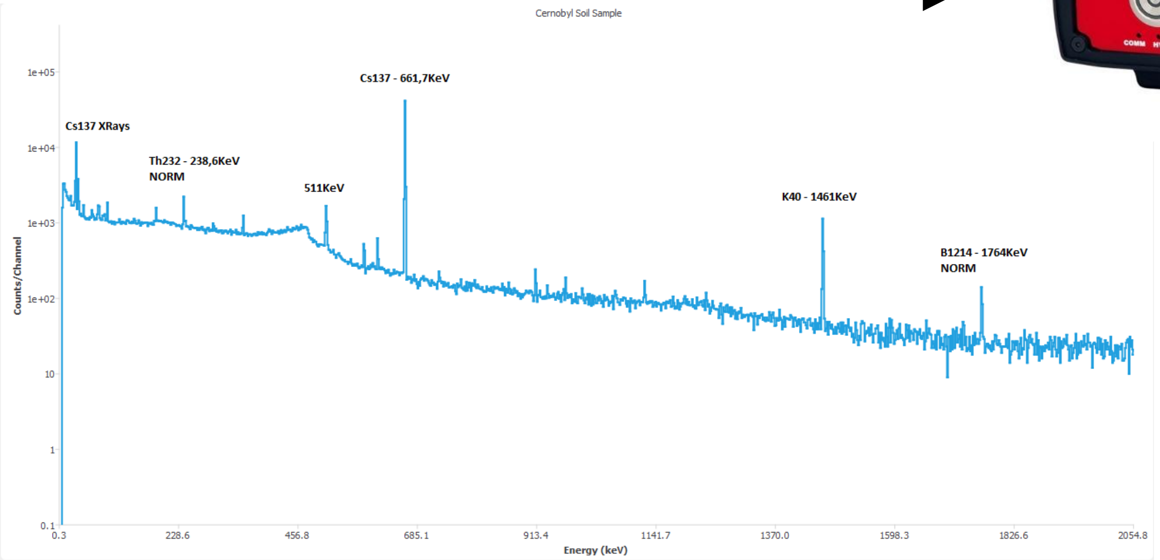
Fundamentals

Definition

Spectroscopy is the study of the interaction between matter and radiation with the aim to get information about the energy distribution of the source

Radiation: charged (α, β, light nuclei) or neutral particles (photons – X and γ in our case – and neutrons)



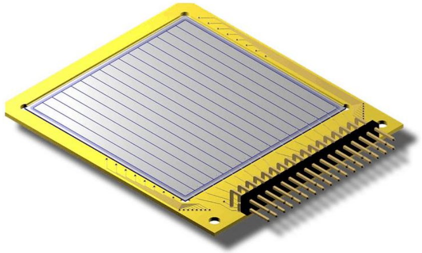


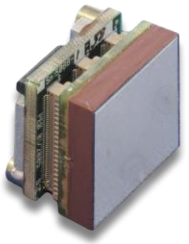
Detectors in a nutshell

High resolution spectroscopy

Semiconductors: **HPGe, Silicon, CZT**

Depending on the detector geometry and thickness, energy range and resolution changes





Mid-resolution spectroscopy

Scintillators: **NaI, CsI, LaBr3, CeBr3, …**

Bigger crystal for higher detection efficiency

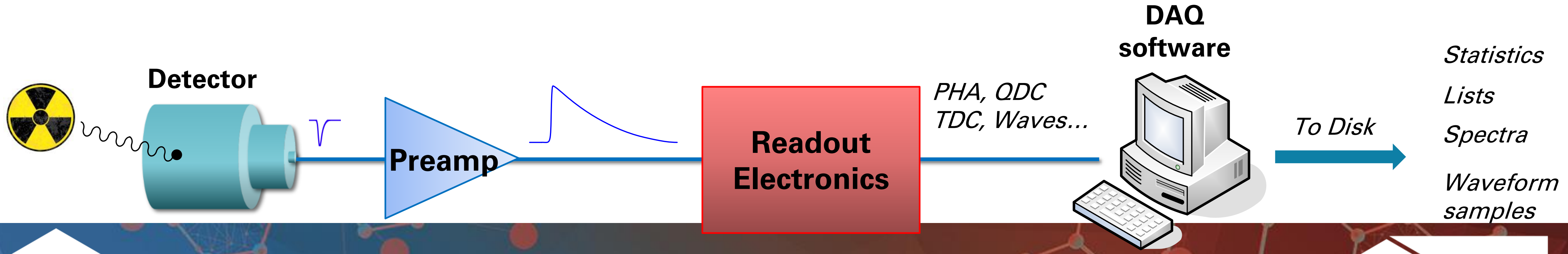
Low-resolution spectroscopy

Scintillators: **BGO, Plastic scintillators, …**

Typically used for active shieldings: AntiCompton or Anticosmic Shield

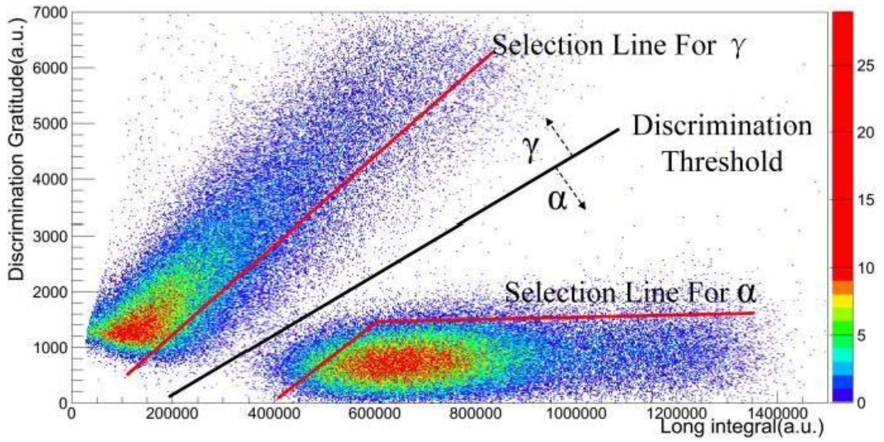
Measurements and analysis - 1

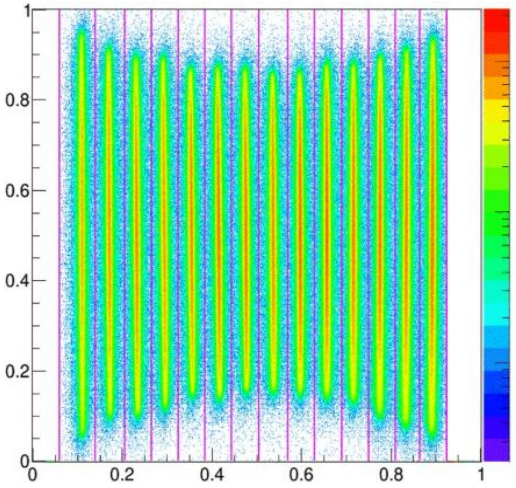
- A **charge pulse** is produced when a particle interacts with the detector. Amplitude and shape of this pulse depends on the detector characteristics as well as the particle type.
- **Preamplifier**: required in most cases to amplify the weak charge pulse generated by the detector. Low noise, high sensitivity, typically installed very close to the detector.
  - **Charge Sensitive Preamps**: optimized for energy resolution, slow output, changes shape
  - **Fast (current) preamplifier**: mostly used for timing applications, fast output
- **Readout electronics**: aims to acquire pulse characteristics such as Pulse Height (PHA), charge (QDC), Timing (TDC), Shape, and, in some cases, full waveforms

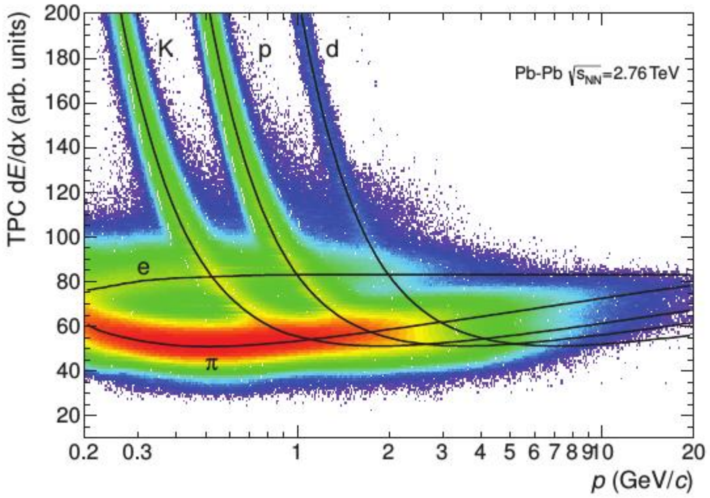


Measurements and analysis - 2

Multiparametric analysis is the study of the interaction between matter and radiation in which different information (energy, time, pulse shape, correlation, position) are used together.







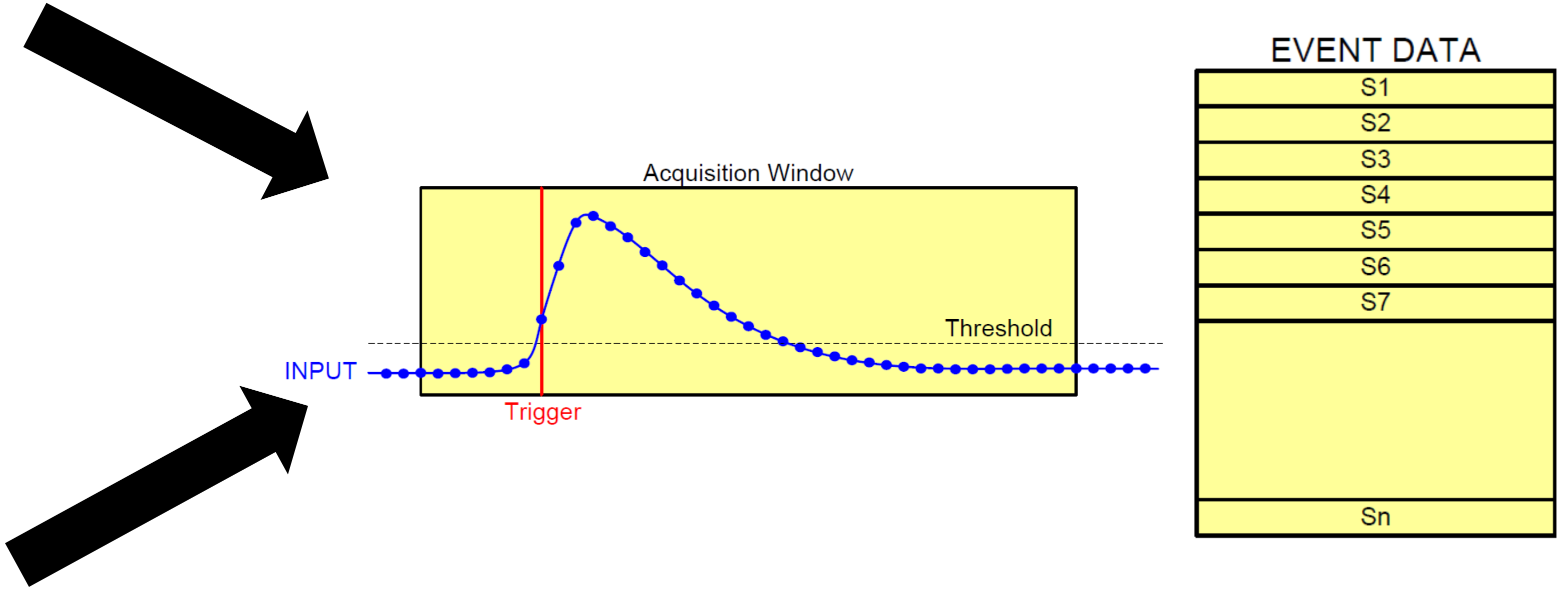
Involved detectors:

- same as traditional spectroscopy
- others (wire chambers, TPCs, GEMs, RPCs,...)

Detector Readout Electronics

Digitizers vs Oscilloscopes

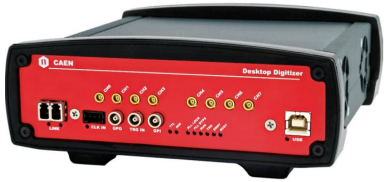
The principle of operation of a waveform digitizer is the same as the digital oscilloscope: when the trigger occurs, a certain number of samples (acquisition window) is saved into one memory buffer

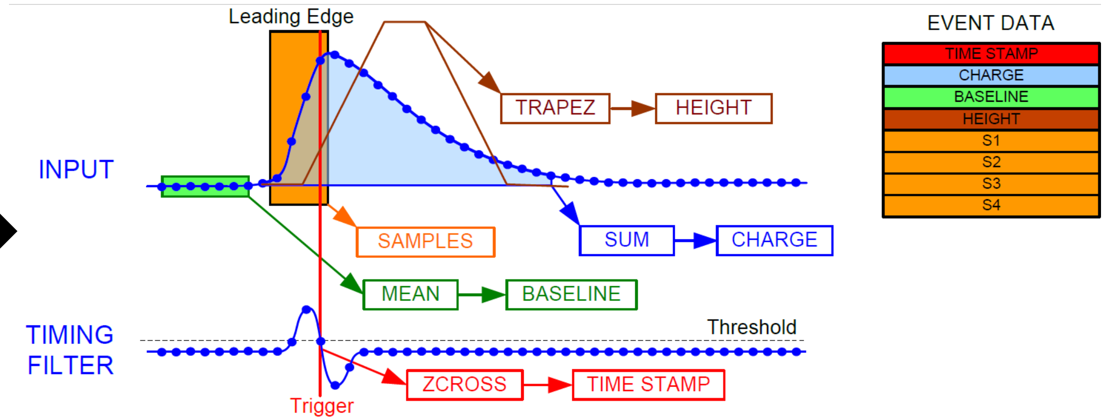


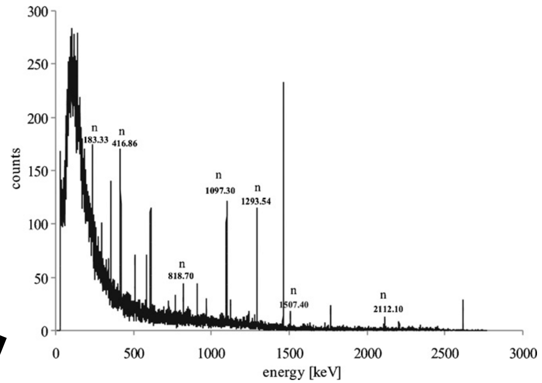
Digitizers vs Oscilloscopes

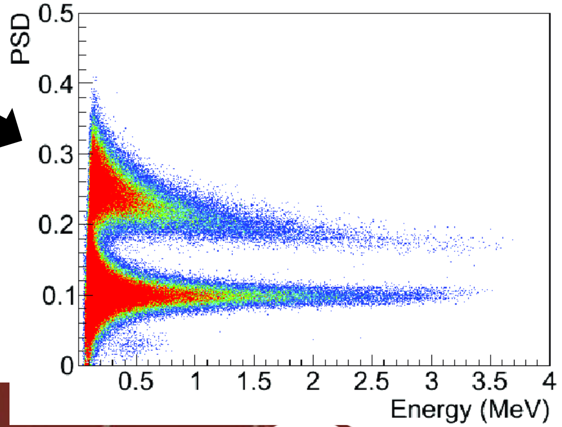
There are important differences:

- no dead-time between triggers (Multi Event Memory)
- multi-board synchronization for system scalability
- high bandwidth data readout links
- on-line data processing (FPGA or DSP)

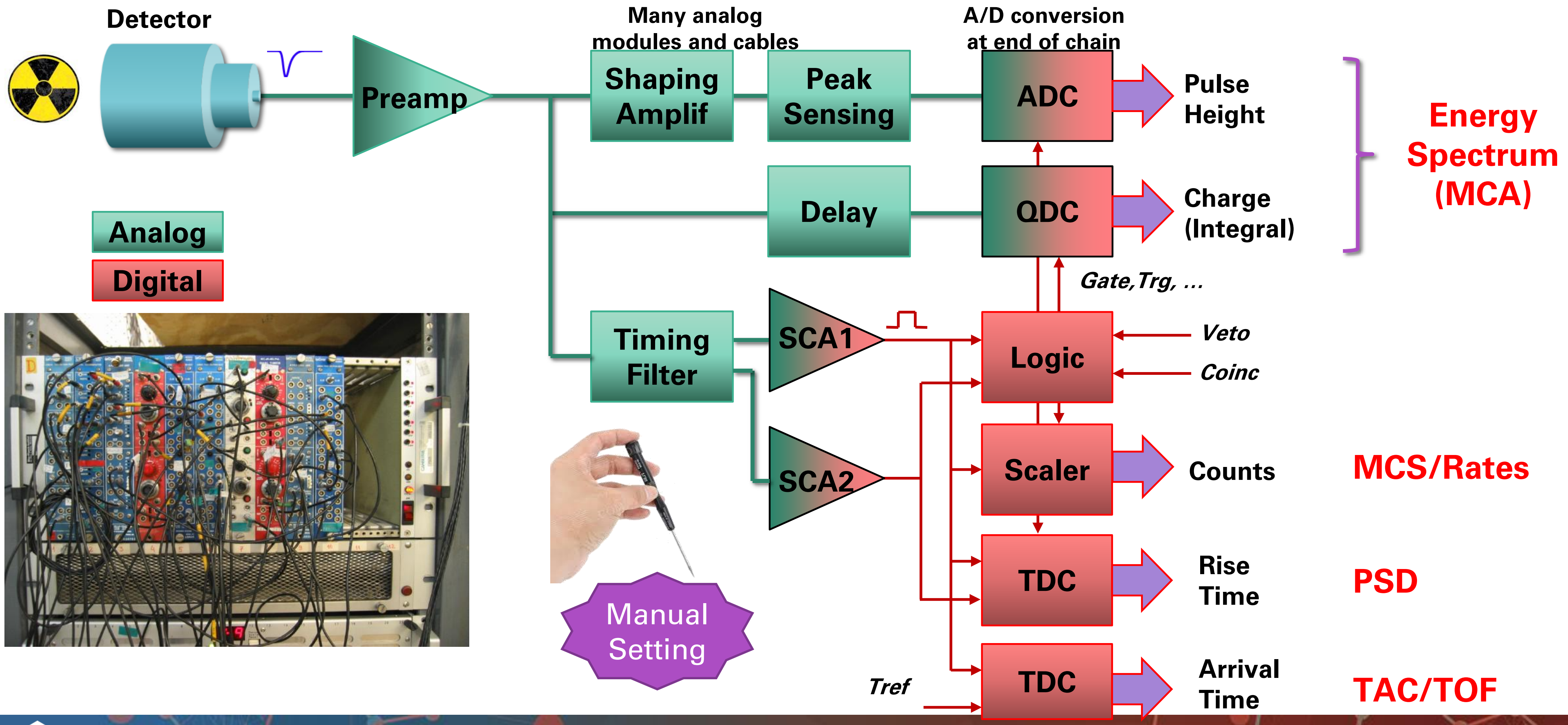




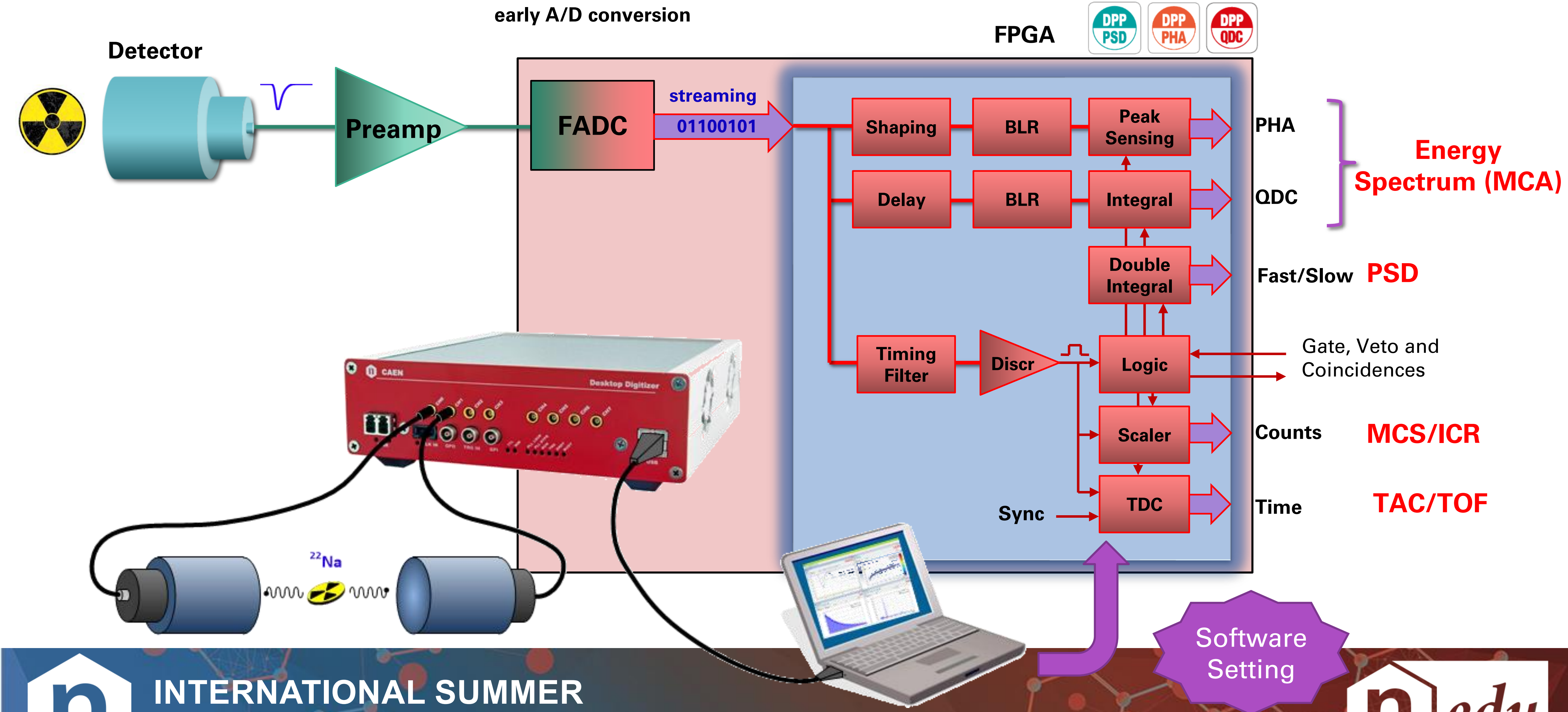




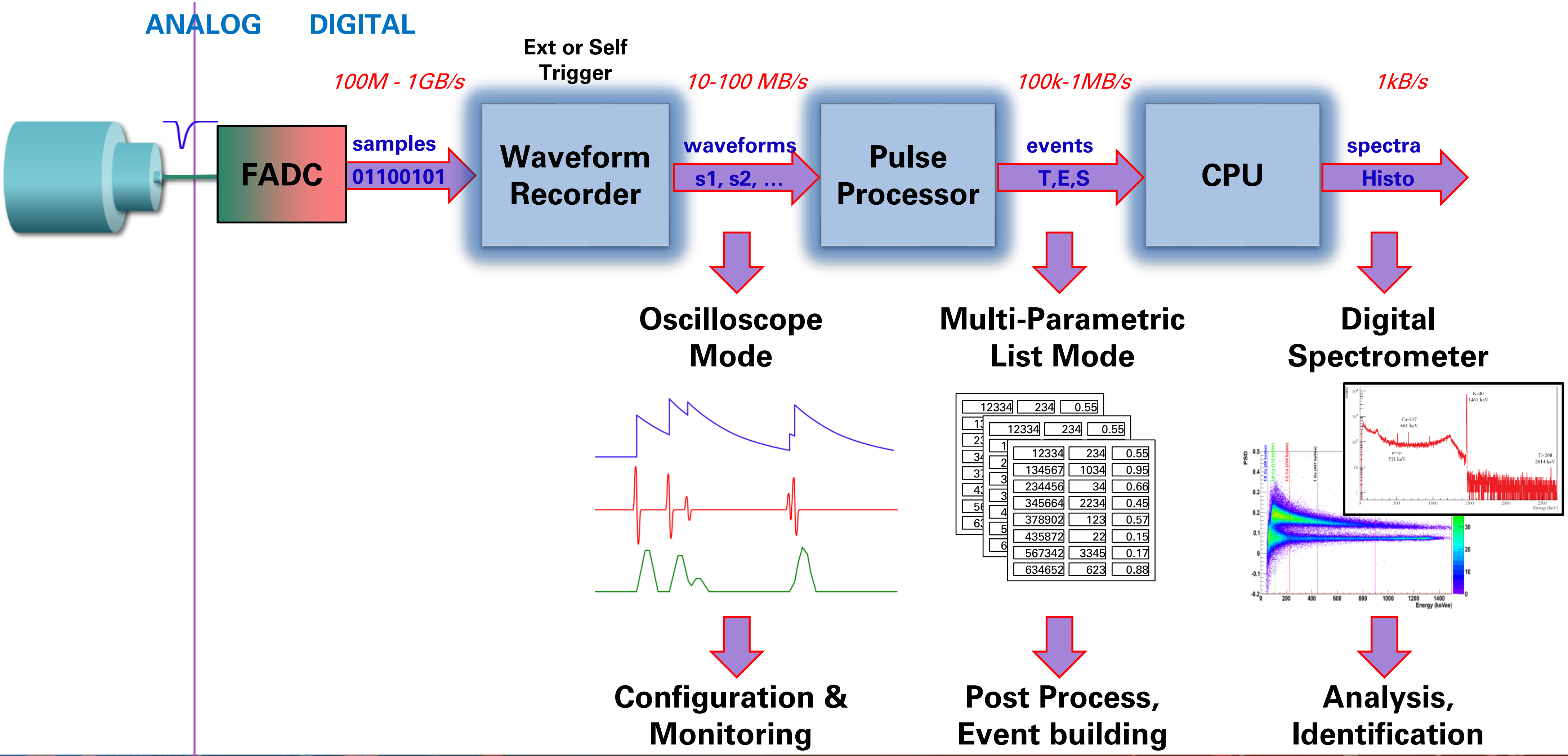
Traditional Spectroscopic/Multiparametric Analog Chain



The Digital Approach: All in one



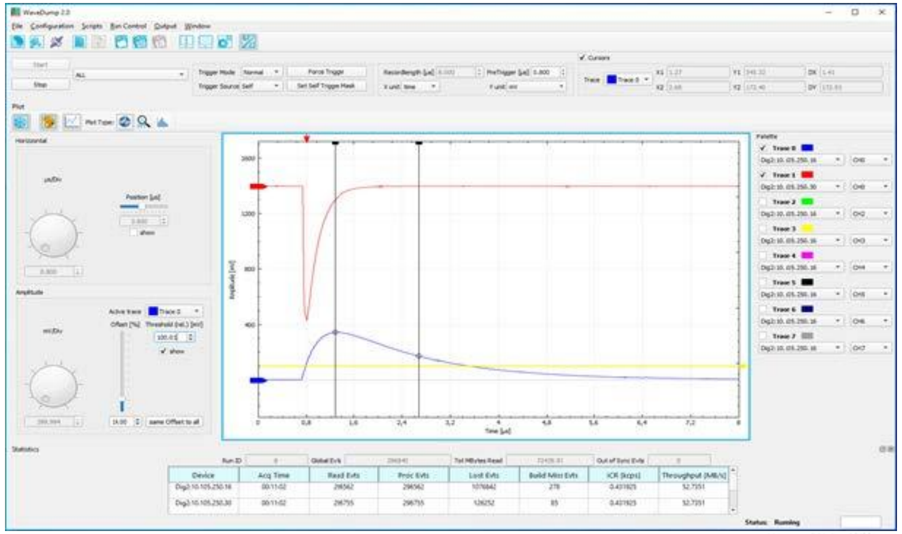
The Digital Approach: Digital Acquisition Chain



Trigger scenarios

1. **Common trigger**: All channels receive the common trigger and save a certain number of samples around this trigger in a local memory buffer.

Oscilloscope Mode: Waveform acquisition

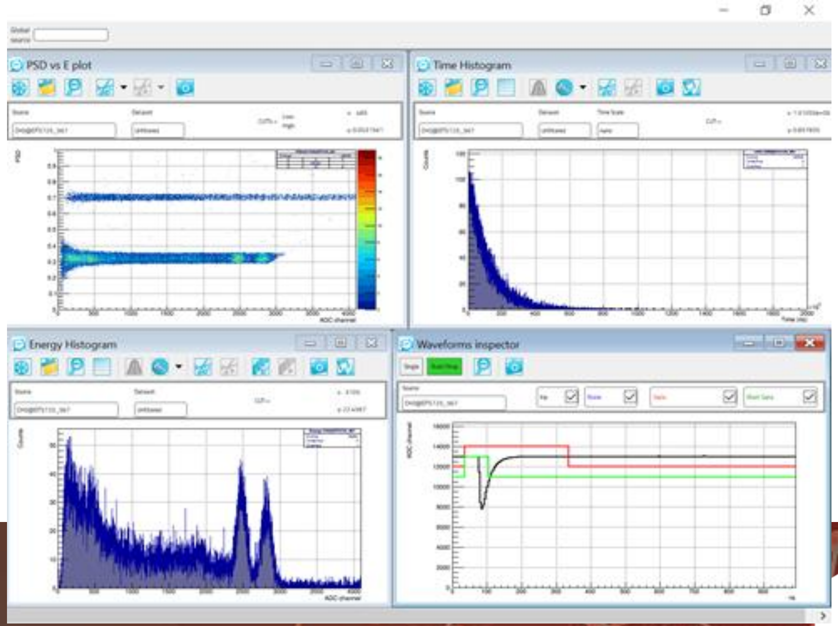


2. **Self trigger/Trigger-less**: Each channel independently acquires data, creating its own self-trigger.

Required information is not the complete waveform but only specific characteristic parameters (pulse height, charge, time stamp..)

Algorithms in the FPGA process the pulse waveform and extract these parameters.

DPP Mode: List acquisition



Trigger scenarios

Intermediate situations between the oscilloscope mode and the DPP mode.

1. DPP algorithms only for pulse identification and trigger generation using appropriate trigger logic (coincidences, multiplicities, etc.) to generate a global trigger that opens the common acquisition window to save waveforms on all channels simultaneously.

2. Acquire in list mode with DPP (independent self-triggers) but with a common validation signal for all channels ---> list data saved only if it belongs to a certain time interval. This approach enables the implementation of coincidence logic, veto logic, etc.

Pulse Processing Algorithms

DPP-PHA

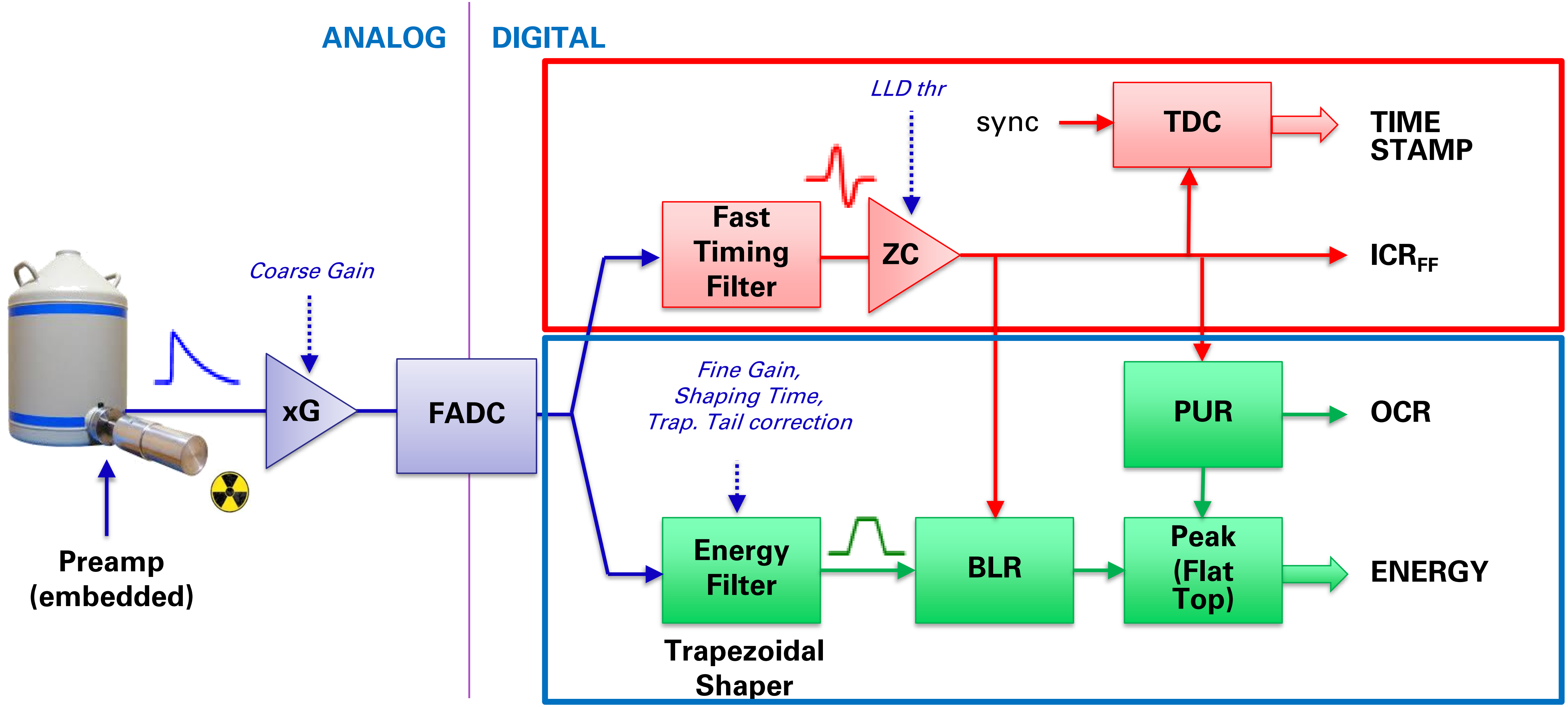
Pulse Height Analysis

The DPP-PHA

Typical signal for DPP-PHA:
Rise Time: ~ 100 ns
Decay Time: ~ us to tens us

x780/x781 - 14 bit 100 MS/s Dual/Quad MCA
V1782- 16 bit 100 MS/s Octal MCA
Hexagon – 16 bit 100 MS/s Single/Dual MCA

The DPP-PHA Algorithms and Block Diagram



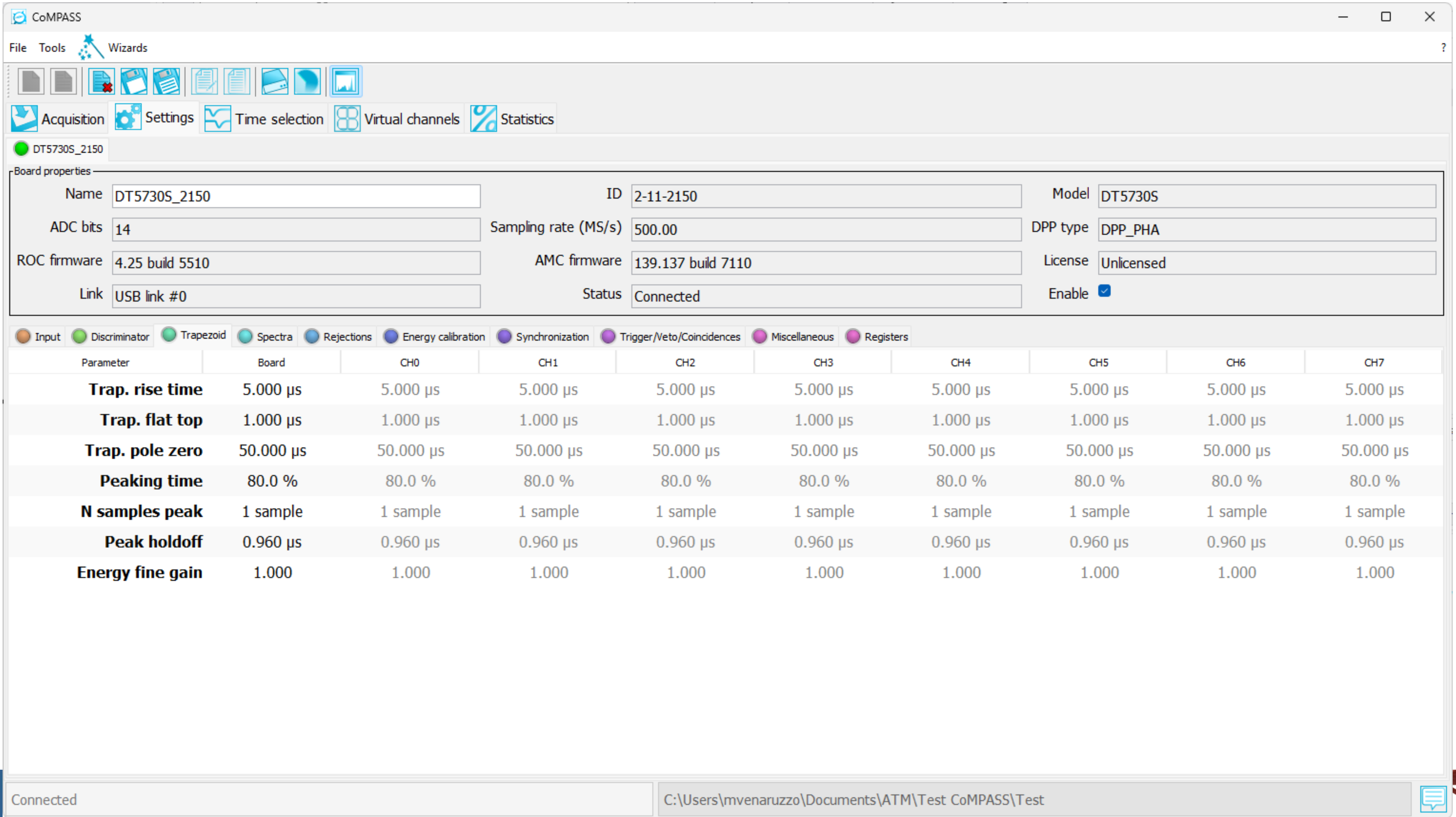
The DPP-PHA Algorithms and Block Diagram

1. Duration of the trapezoid can be programmed:
   - longer duration --> better energy resolution.
   - longer duration --> higher pile-up probability between two trapezoids (more dead time)

2. Dead time not related to the ADC conversion but to the processing algorithm.

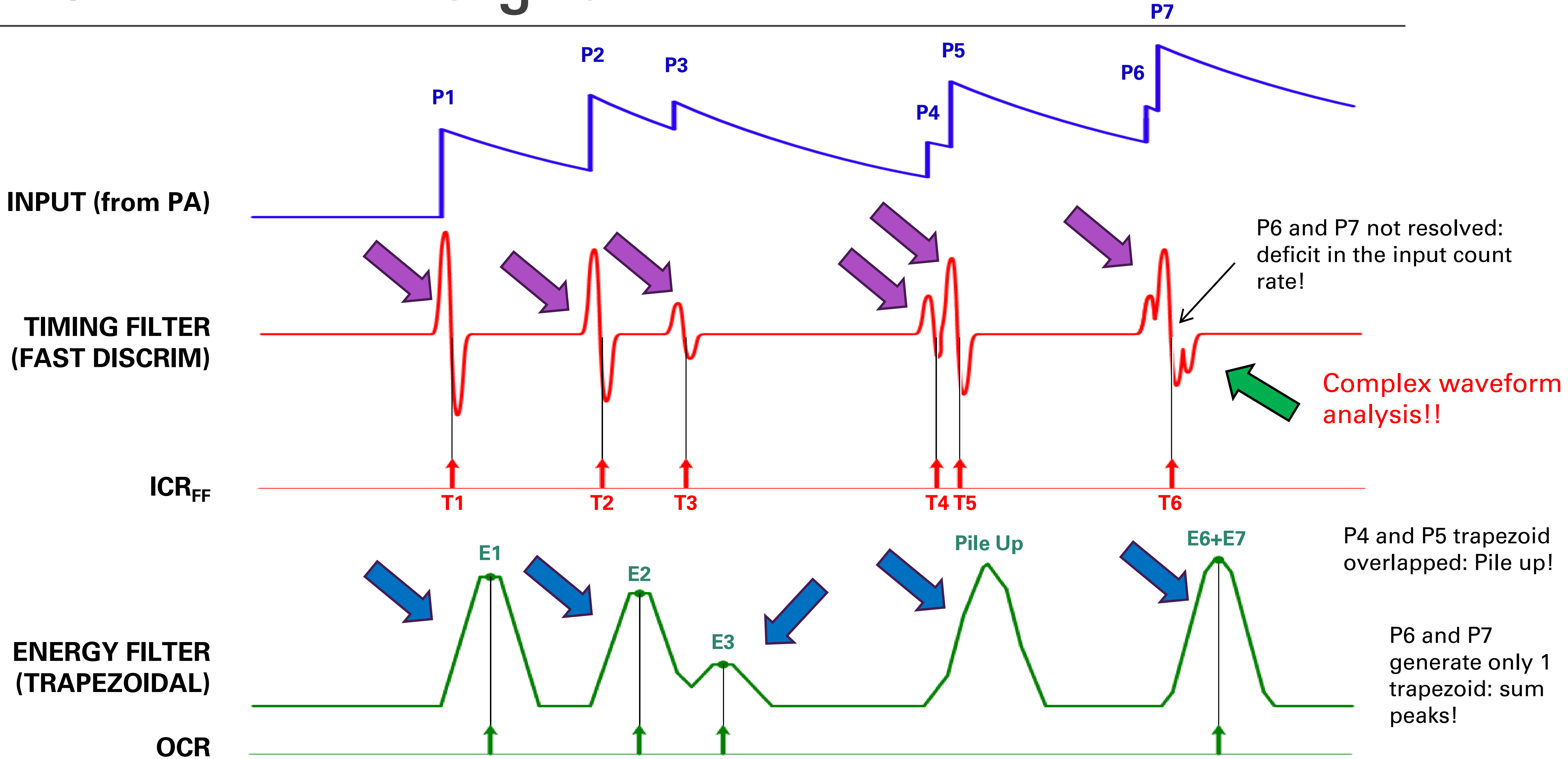
3. Data produced by the DPP-PHA:
   - the time stamp of the pulses
   - amplitude of the pulse,
   - the input and output count rates (ICR and OCR)
   - (if necessary) raw waveforms --> higher data throughput (usually for debug only)

The DPP-PHA Algorithms and Block Diagram



Parameter	Board	CH0	CH1	CH2	CH3	CH4	CH5	CH6	CH7
Trap. rise time	5.000 µs	5.000 µs	5.000 µs	5.000 µs	5.000 µs	5.000 µs	5.000 µs	5.000 µs	5.000 µs
Trap. flat top	1.000 µs	1.000 µs	1.000 µs	1.000 µs	1.000 µs	1.000 µs	1.000 µs	1.000 µs	1.000 µs
Trap. pole zero	50.000 µs	50.000 µs	50.000 µs	50.000 µs	50.000 µs	50.000 µs	50.000 µs	50.000 µs	50.000 µs
Peaking time	80.0 %	80.0 %	80.0 %	80.0 %	80.0 %	80.0 %	80.0 %	80.0 %	80.0 %
N samples peak	1 sample	1 sample	1 sample	1 sample	1 sample	1 sample	1 sample	1 sample	1 sample
Peak holdoff	0.960 µs	0.960 µs	0.960 µs	0.960 µs	0.960 µs	0.960 µs	0.960 µs	0.960 µs	0.960 µs
Energy fine gain	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

The DPP-PHA Signals



DPP-QDC/PSD

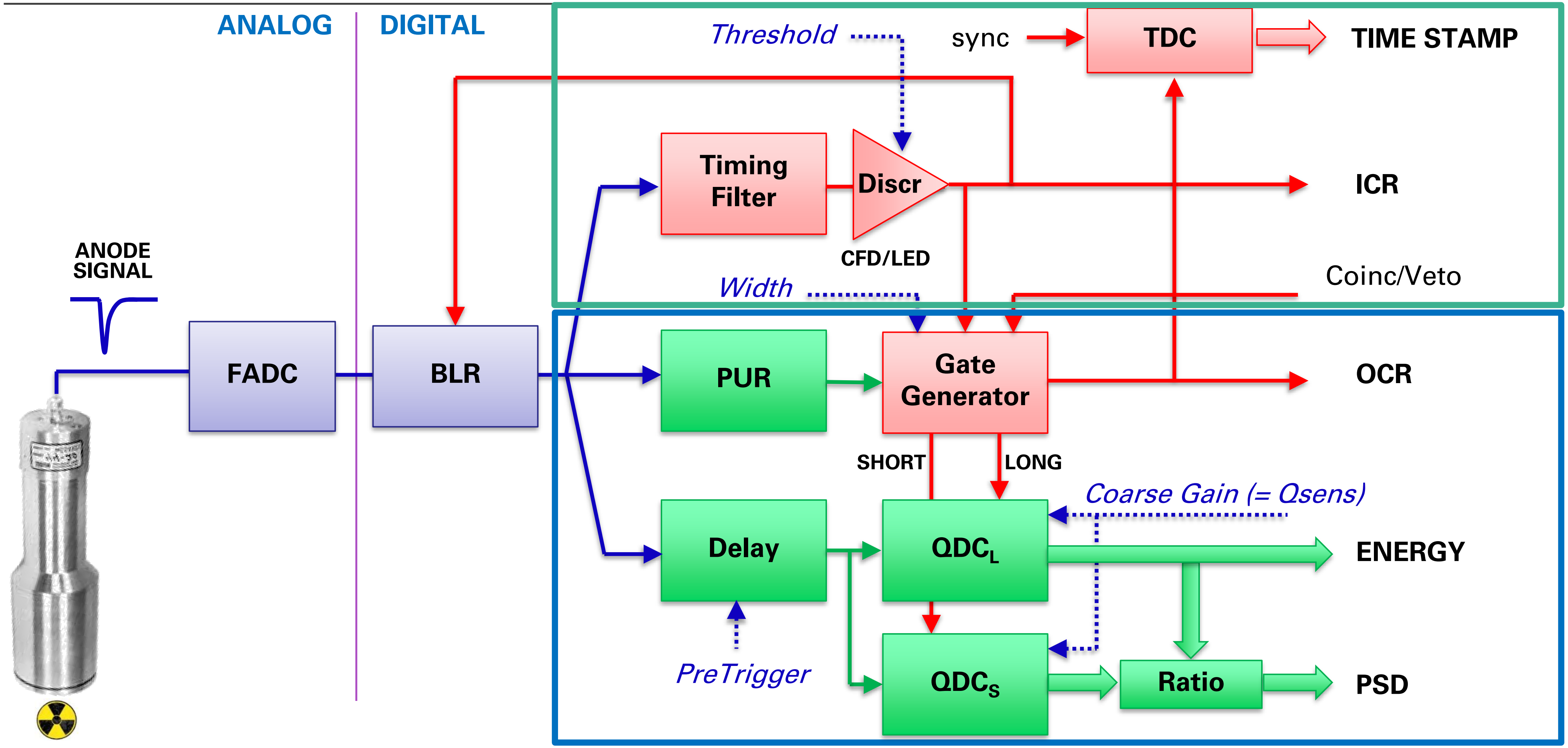
Charge Integration and Pulse Shape Discrimination

The DPP-PSD

Typical signal for DPP-PSD:
Rise Time: ~ few ns
Decay Time: ~ few ns to few us

x725/x730 - 14 bit 250/500 MS/s Digitizer
x751 – 10 bit 1GS/s Digitizer

The DPP-PSD/QDC Algorithm and Block Diagram



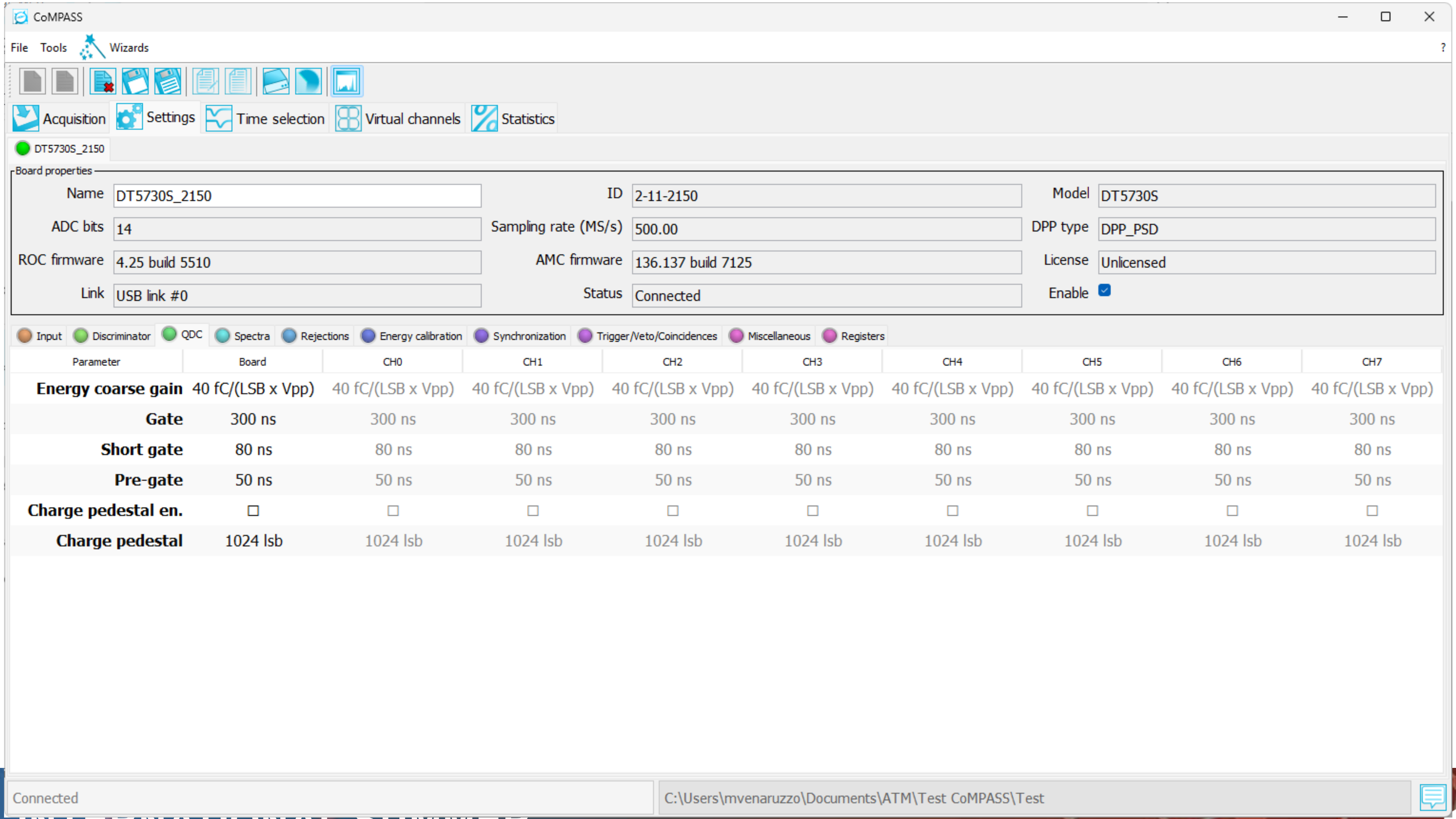
The DPP-PSD/QDC Algorithm and Block Diagram

It is possible to use an external gate, program coincidence or anti-coincidence between external and internal gates.

It is possible to introduce a delay on the signal.

All parameters for integration are programmable!

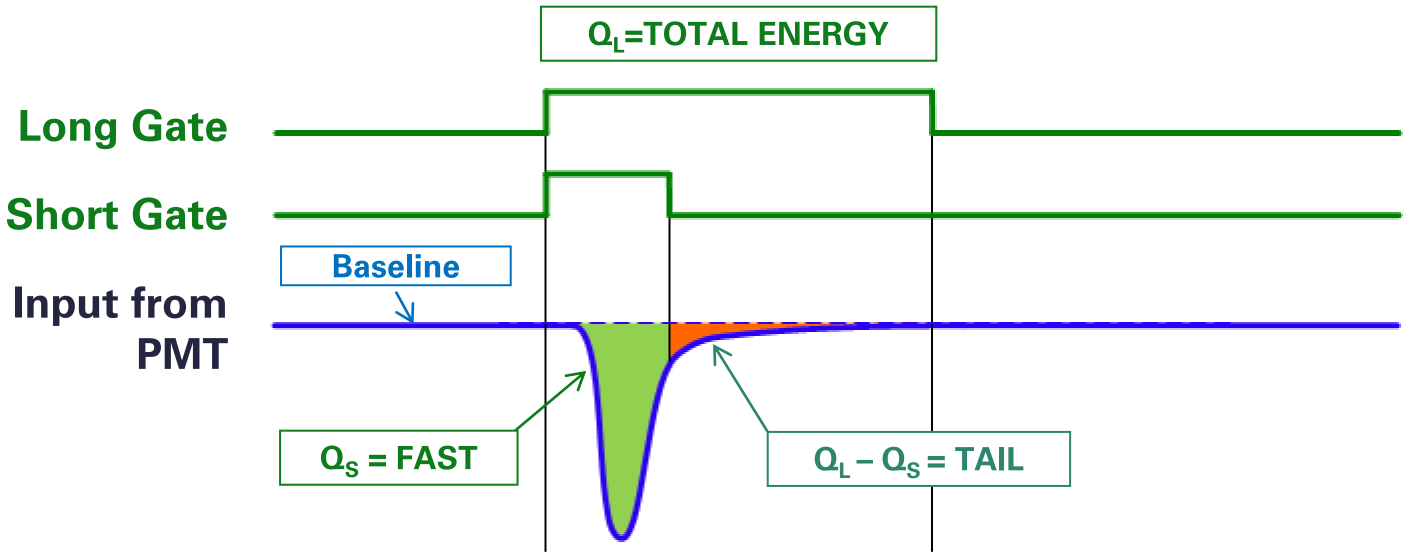
The DPP-PSD/QDC Algorithm and Block Diagram



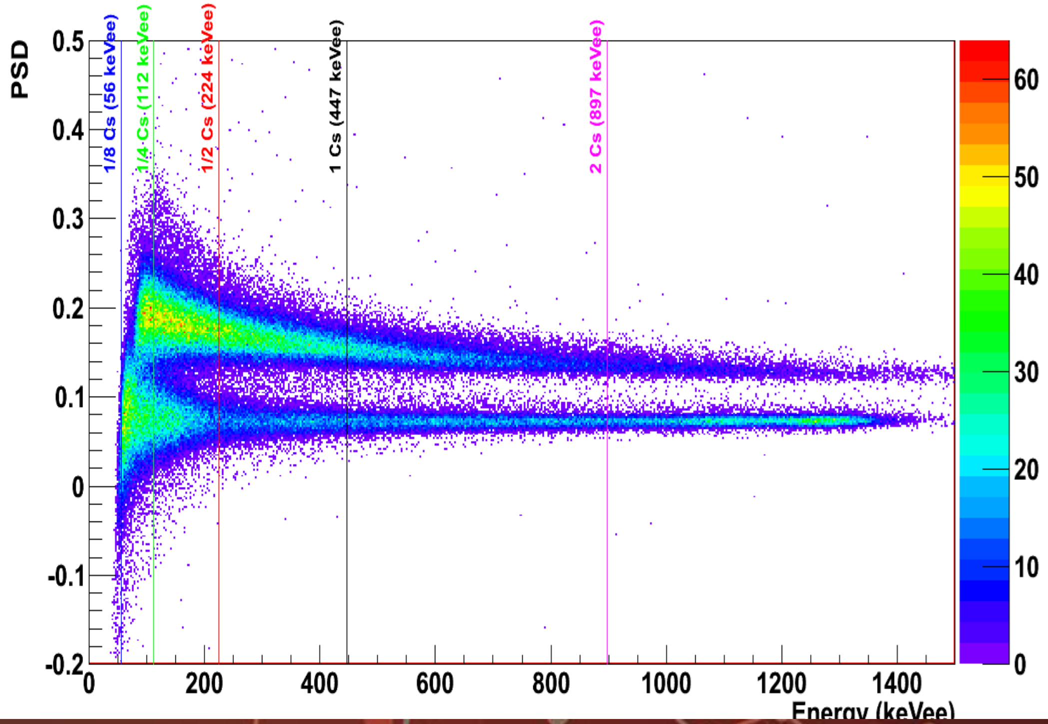
Name	DT5730S_2150	ID	2-11-2150	Model	DT5730S
ADC bits	14	Sampling rate (MS/s)	500.00	DPP type	DPP_PSD
ROC firmware	4.25 build 5510	AMC firmware	136.137 build 7125	License	Unlicensed
Link	USB link #0	Status	Connected	Enable	☑

Parameter	Board	CH0	CH1	CH2	CH3	CH4	CH5	CH6	CH7
Energy coarse gain	40 fC/(LSB x Vpp)	40 fC/(LSB x Vpp)	40 fC/(LSB x Vpp)	40 fC/(LSB x Vpp)	40 fC/(LSB x Vpp)	40 fC/(LSB x Vpp)	40 fC/(LSB x Vpp)	40 fC/(LSB x Vpp)	40 fC/(LSB x Vpp)
Gate	300 ns	300 ns	300 ns	300 ns	300 ns	300 ns	300 ns	300 ns	300 ns
Short gate	80 ns	80 ns	80 ns	80 ns	80 ns	80 ns	80 ns	80 ns	80 ns
Pre-gate	50 ns	50 ns	50 ns	50 ns	50 ns	50 ns	50 ns	50 ns	50 ns
Charge pedestal en.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Charge pedestal	1024 lsb	1024 lsb	1024 lsb	1024 lsb	1024 lsb	1024 lsb	1024 lsb	1024 lsb	1024 lsb

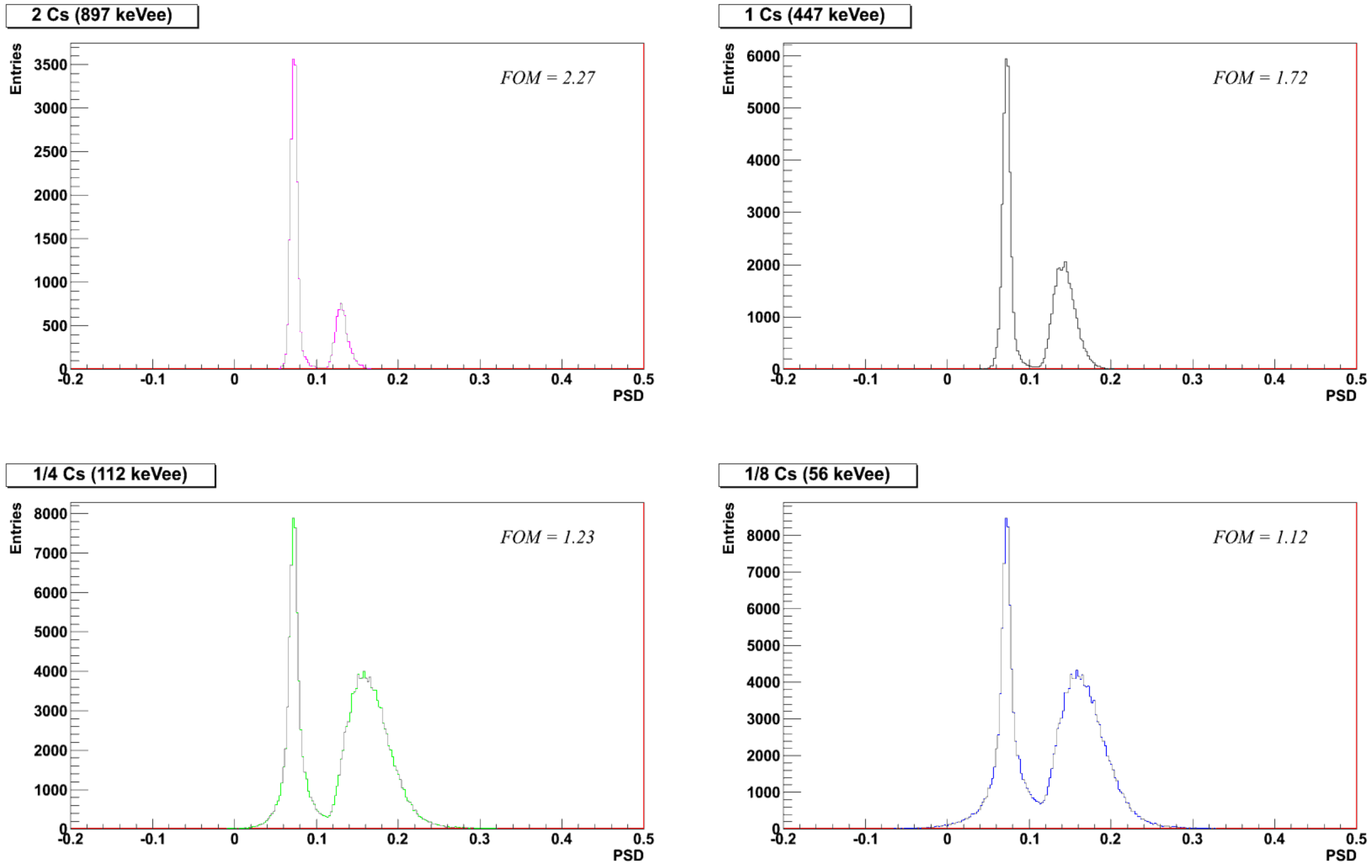
The DPP-PSD/QDC Signals



$$PSD = \frac{TAIL}{TOTAL}$$

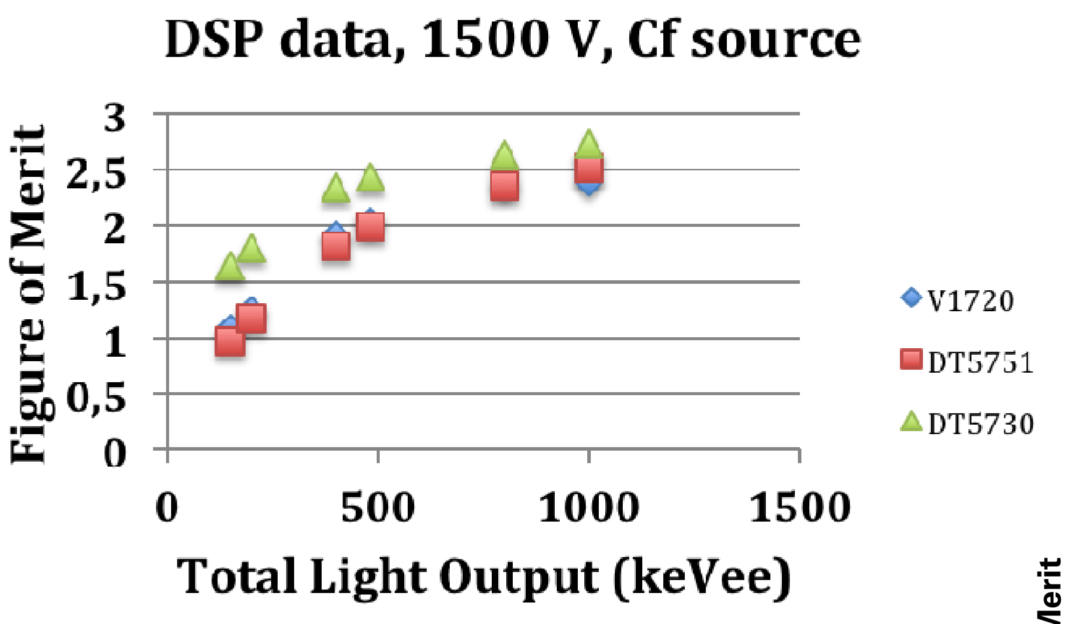


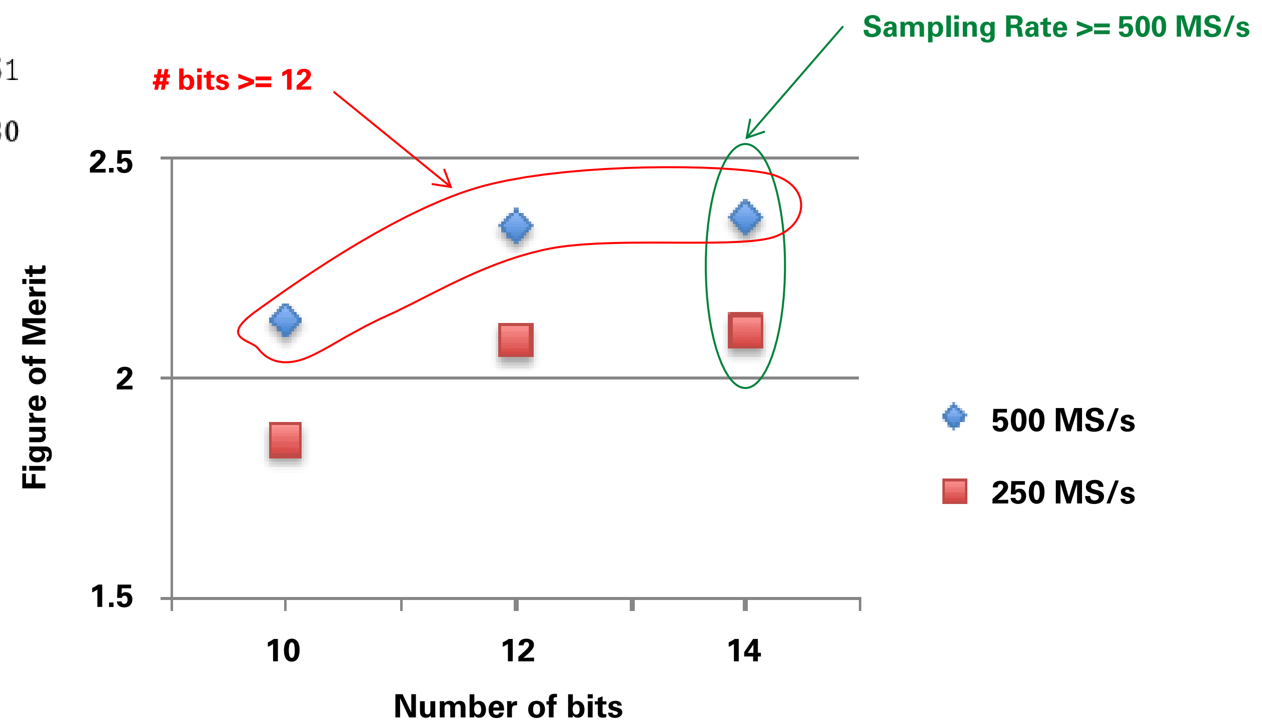
The DPP-PSD/QDC Results



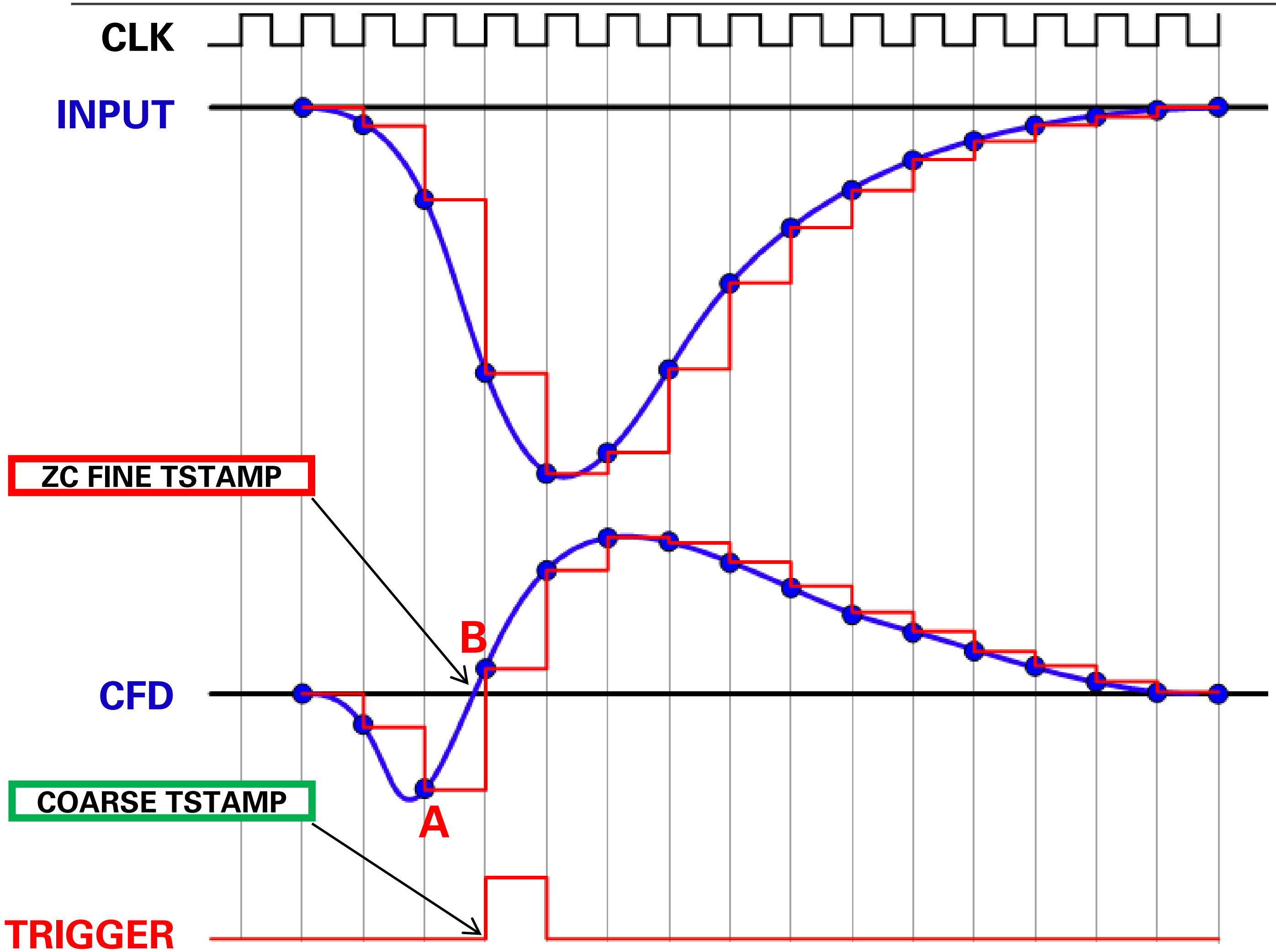
$$FOM = \frac{\Delta PEAK}{FWHM_\gamma + FWHM_n}$$

The DPP-PSD/QDC Results





Digital CFD + TDC



digital CFD: same principle as analog

$CFD_{N+1} = f * S_N - S_{N-D}$ f=Fraction, D=delay

COARSE TSTAMP $= T_{CLK} *$ Clock Counter

FINE TSTAMP $= - T_{CLK} * B/(B-A)$

Digital CFD + TDC

Linear interpolation: good curve fitting if Leading Edge > 3-5 TSAMPLE

Faster signals produce artifacts and bad timing resolution

ZC calibration algorithm corrects interpolation errors for signals as fast as ½ TSAMPLE

x730S - 14bit 500 MS/s digitizer

Resolution: ~100 ps RMS for 2 ns rising edge @ 500 MS/s

Advanced Zero Suppression

DPP-ZLE and DPP-DAW

The Zero Suppression Algorithms

Many applications: necessary to acquire the "raw waveform" of signals from detectors.

Synthetic parameters (height, charge, time stamp) are not sufficient to retrieve the required information.

Advantages:

- Raw waveform preserves the complete signal information
- Possible in offline analysis to extract the desired parameters

Drawback:

- very high volume of data, typically not sustainable ---> dead-time and data loss

Waveform processing algorithms: focused on identifying regions of interest, allowing for the suppression of unnecessary data.

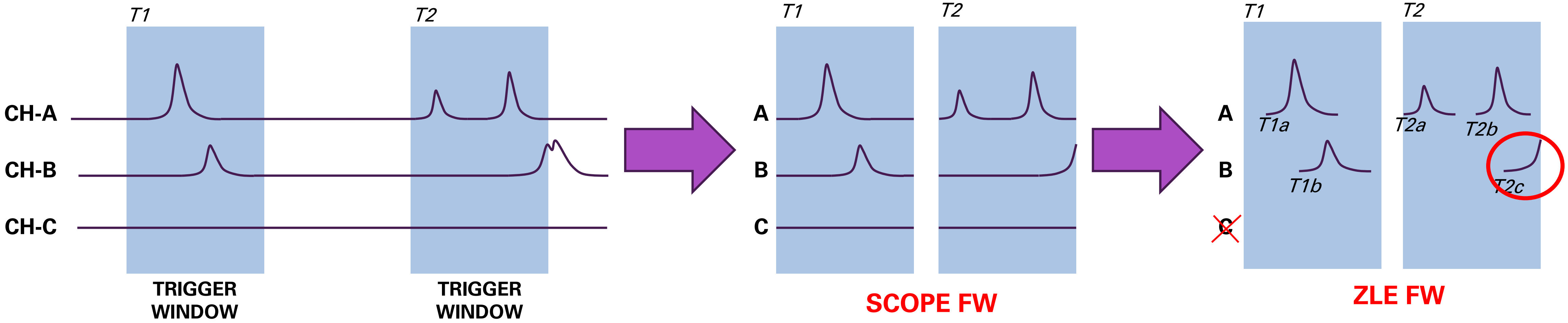
Advanced Zero Suppression - 1: ZLE firmware

Standard scope firmware (raw waveform readout) produces huge amount of data. Data reduction algorithms are often mandatory.

Common triggered acquisition: not all channels are fired and not at the same time => long portions of baseline with no information of interest.

The aim of the ZLE firmware is to **suppress the empty channels** and trim the fired channels to **keep only the significant parts**. Each chunk is time stamped within the window.

Pulses across the trigger window will be cut (loss of regions of interest).



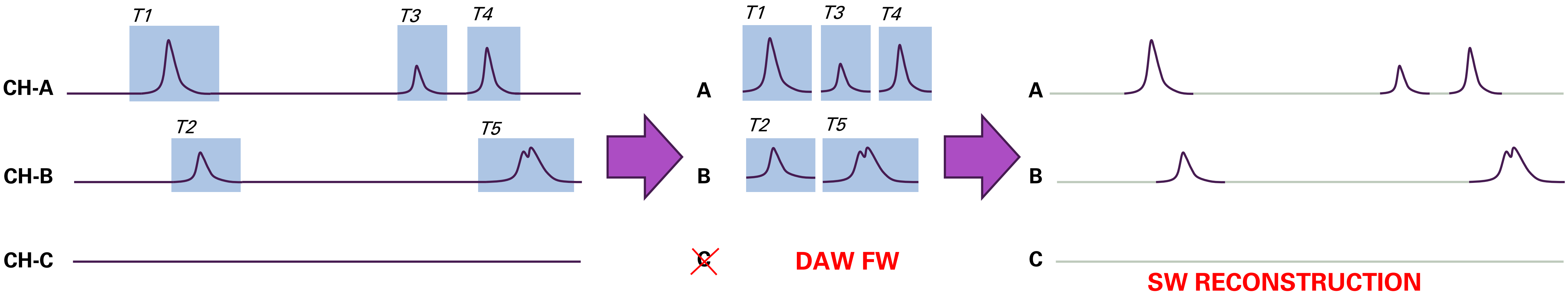
Advanced Zero Suppression - 2: DAW firmware

Triggerless waveform acquisition: no common acquisition window, each channel is self triggered

Input pulses with different width or piling-up => the **acquisition window must be dynamically adapted** to the length of the region of interest

Channels run independently: when fired, a channel saves a waveform of the required size to fit the pulse, together with the relevant time stamp. **No pulse cutting!**

Event building in the software reconstructs the correct position of each chuck by mean of the time stamps



DPP-ZLE and DPP-DAW comparison

DPP-DAW

- unless in case of excessive data throughput, it is dead-time free and no data loss
- less suitable when searching for sparsely correlated events across different channels
- very small pulses that do not exceed the trigger threshold may be lost

DPP-ZLE

- data loss as seen in the case of cut-off events
- thanks to the global trigger, it is possible to set a much lower suppression threshold than the trigger threshold.

Digital vs Analog

PROs and CONs

Digital vs Analog: PROs and CONs

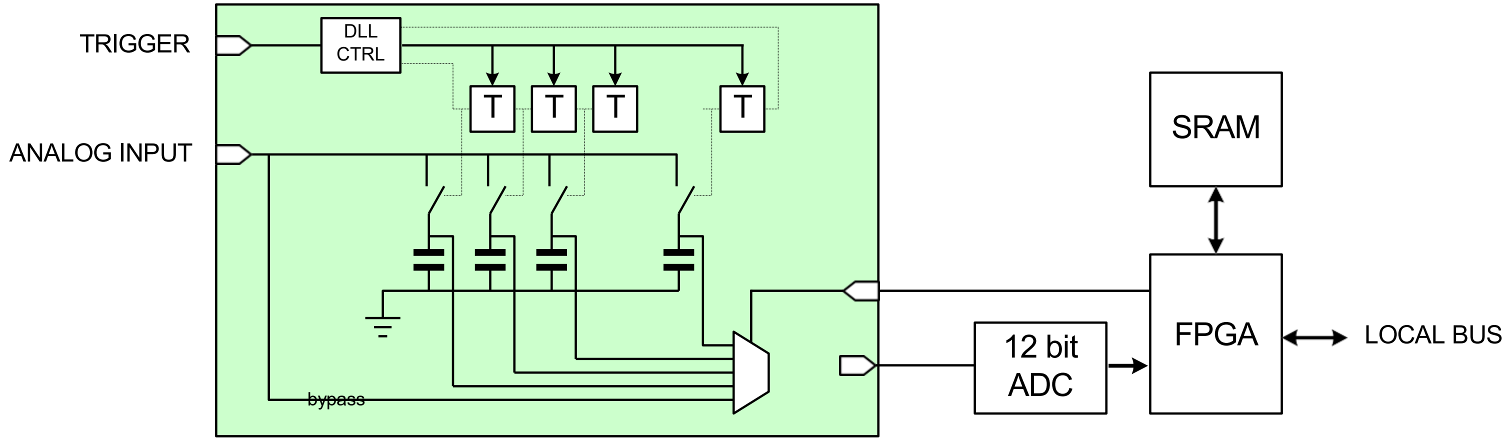
- **Flexibility**: waveform digitizer: a general-purpose readout system that can be tailored to the specific application reprogramming the DPP algorithms. The analog system is "hard-wired".
- **Multi-parametric**: the digital solution provides multiple output parameters (pulse height or charge, arrival time, pulse shape, etc…). More outputs can be provided by reprogramming the algorithms. In the analog chain, more outputs means more boards.
- **Dead-time**: Flash ADC reads the input signal continuously and has no conversion time. Dead time can be in the processing algorithm but is typically lower than analog. Digital allows for higher trigger rate, unless waveform readout is needed; in this case, memory and link occupancy can drastically reduce the rate.
- **Trigger Logic**: Coincidence, Anti-coincidence, Multiplicity… can be embedded in the DPP algorithm. No need of coincidence units and tangled wiring. Time stamped list outputs allow for post-processing event building.
- **Complexity**: digital systems have many parameters to set => complex interface and steep learning curve compared to analog. Embedded oscilloscope helps in debugging and tuning. Once done, digital is easier to replicate and maintain.
- **Cost**: waveform digitizers are cheaper than analog systems for "slow" signals (e.g. charge sensitive preamps). The digitizer becomes expensive for fast signals (need 1 GS/s or more). Switched capacitor arrays can read very fast signals at low cost, but high dead-time and fixed acquisition window must be accepted.

Switched Capacitor Array Digitizers

Switched Capacitor Array Digitizer

Switched capacitor arrays can read very fast signals at low cost

- **x742: 32+2 channels in a VME board, 5 GS/s, 12 bit, 1024 points**
- **x743: 16 channels in a VME board, 3.2 GS/s, 12 bit, 1024 points**



Two drawbacks:

- but high dead-time
- small fixed acquisition window

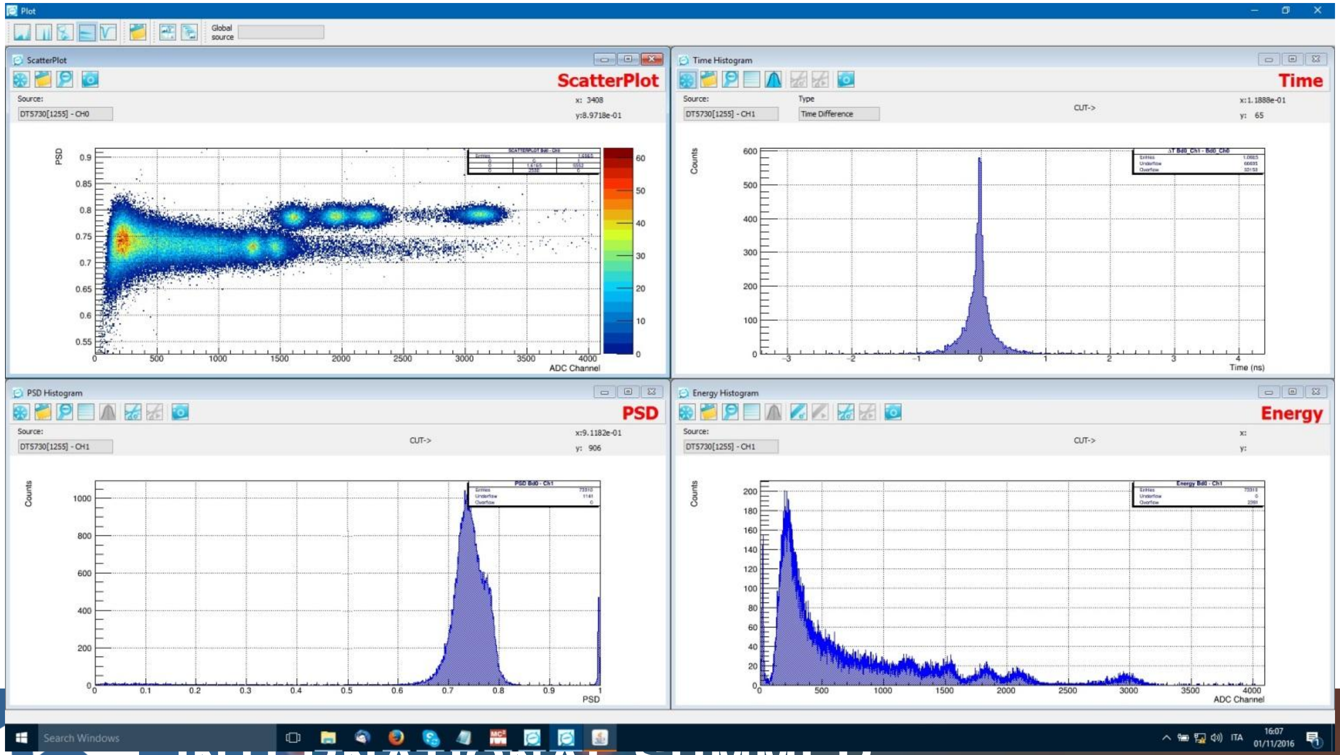
CoMPASS

Outline

- What is CoMPASS
- CoMPASS block diagram
- CoMPASS main operation
- CoMPASS use cases
- What’s next

Compass: root based DAQ

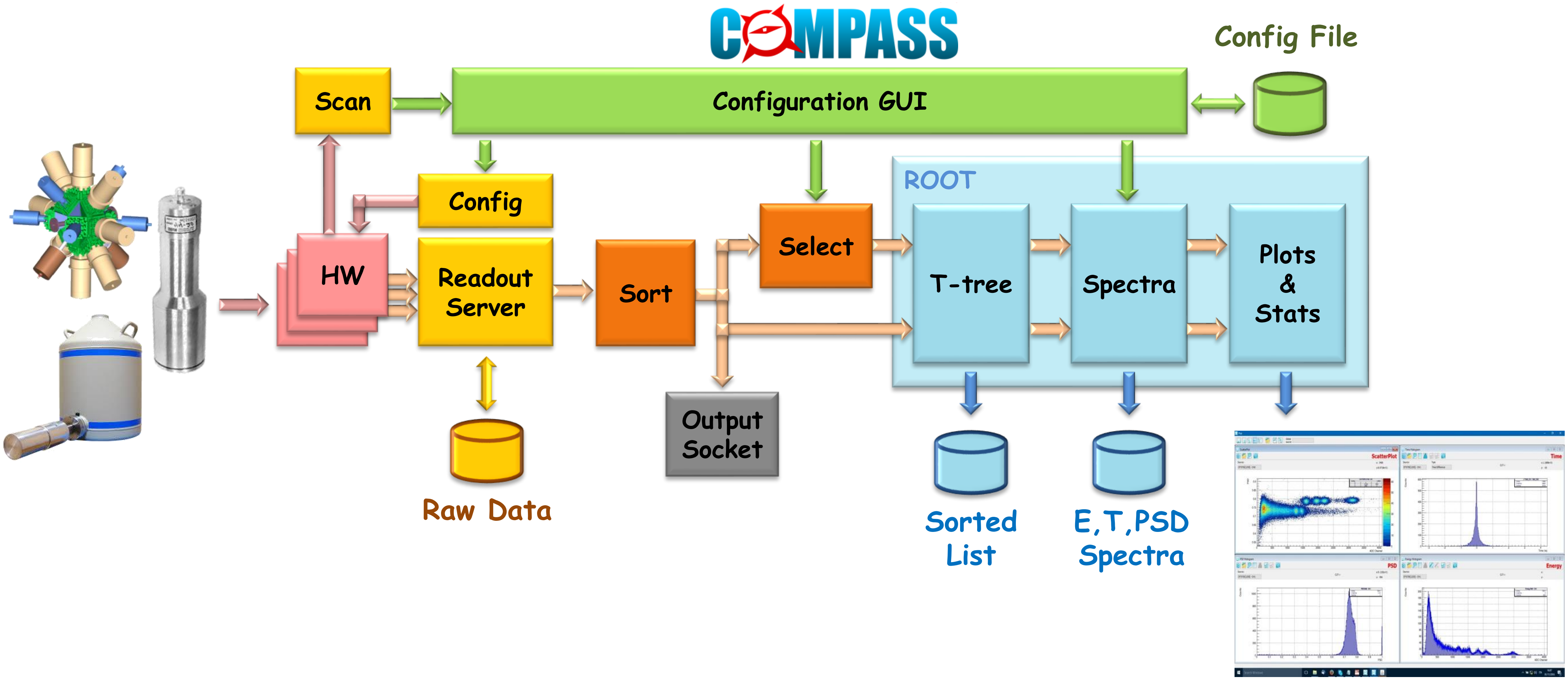
- Multi-board, multi-channel, multi-parametric: **Energy, Time, PSD**
- **Root** data format: T-tree, 1-D and 2-D histograms
- Coincidences (HW or SW), veto/gate, cuts and event selection
- Acquisition mode: live (from boards) or off-line (from data files)



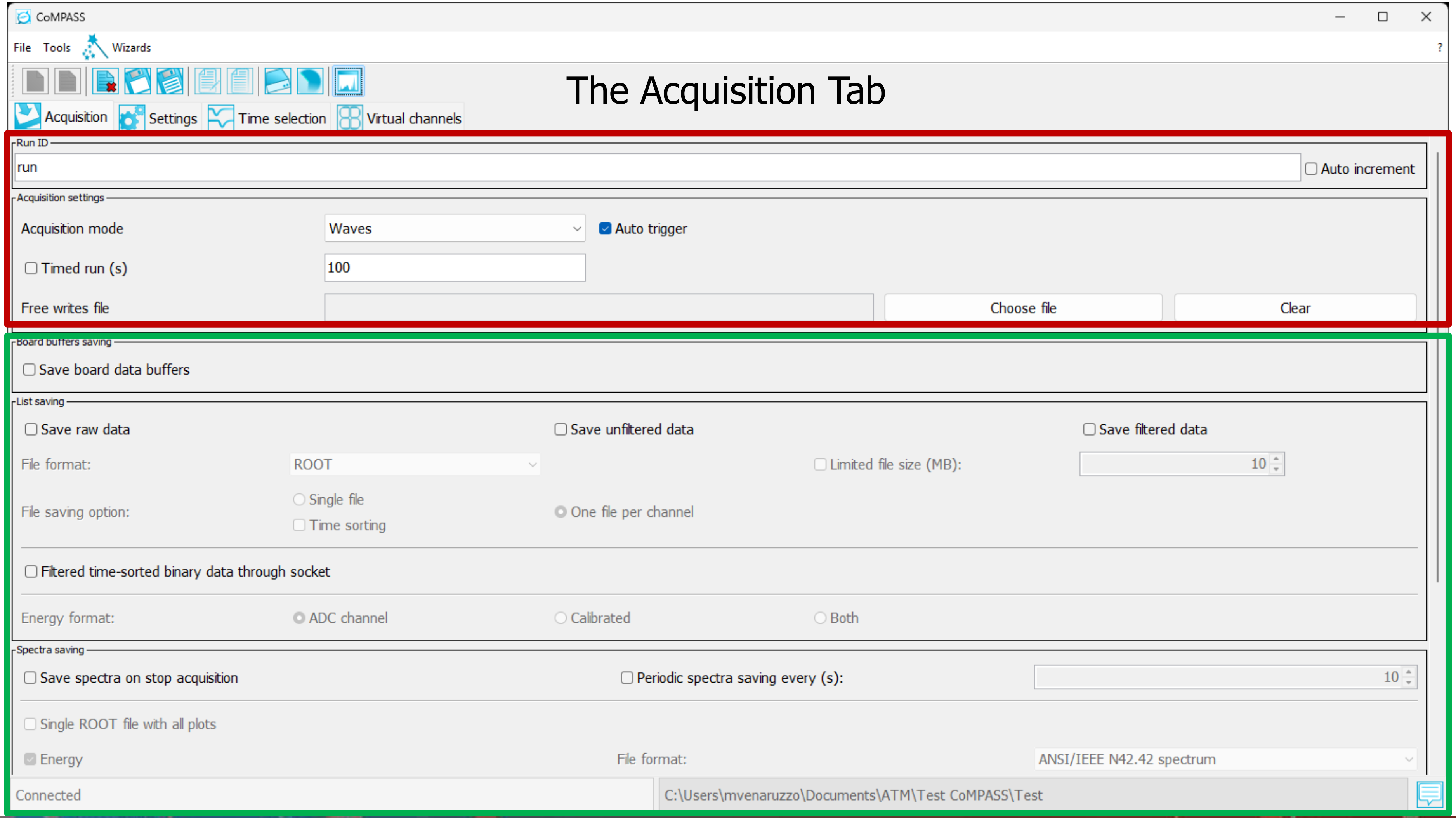
Supported Boards & FW:

- x724/x781 PHA
- x725/x730 PHA & PSD
- x751 PSD
- x720 PSD
- x740 QDC
- x780 MCA
- x790 Pulse Processor
- V1782 MCA
- x2740 PHA & PSD
- x2745 PHA & PSD
- x2730 PSD & PHA
- x2751 PSD

Compass: block diagram



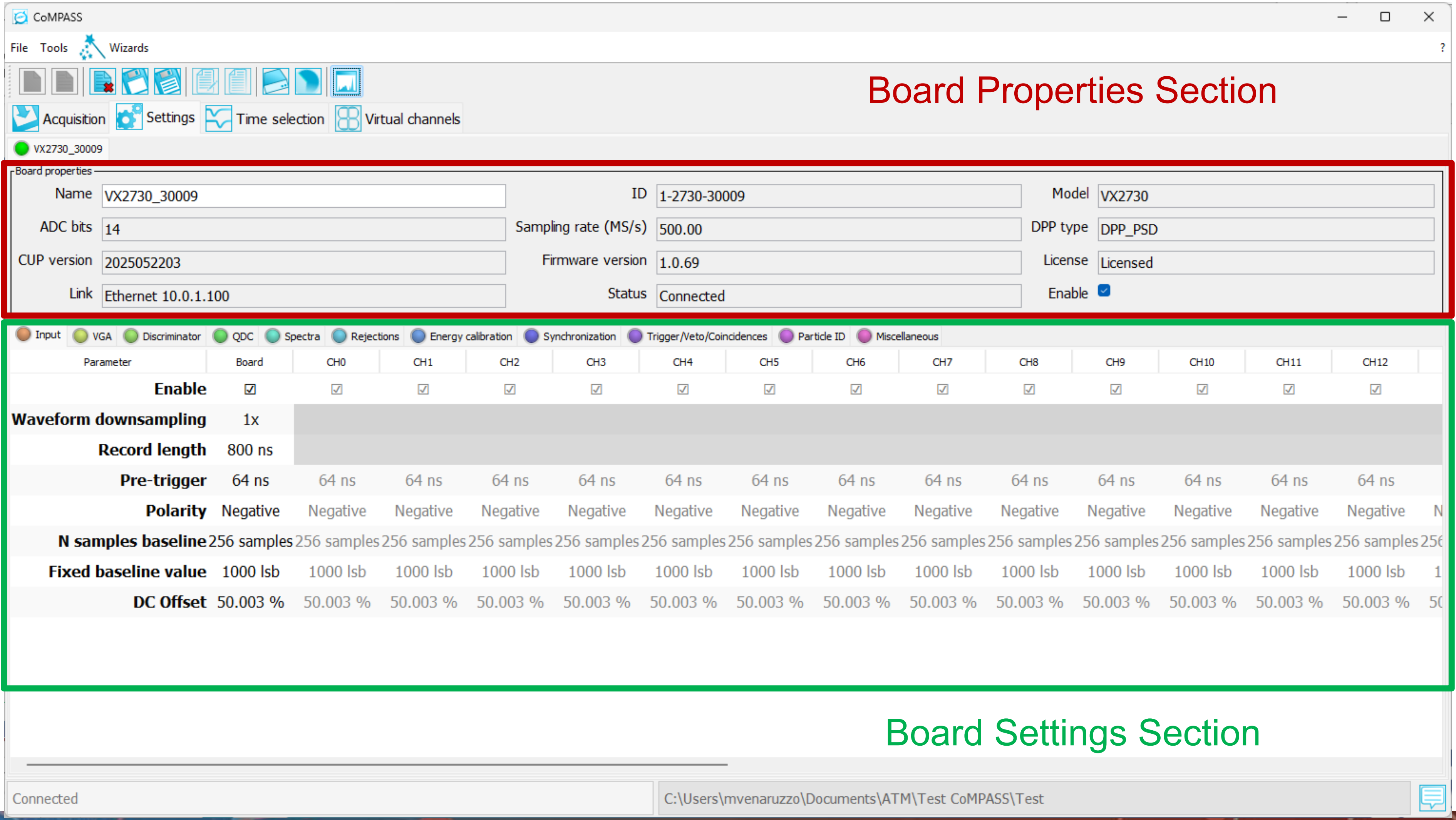
Compass main operation



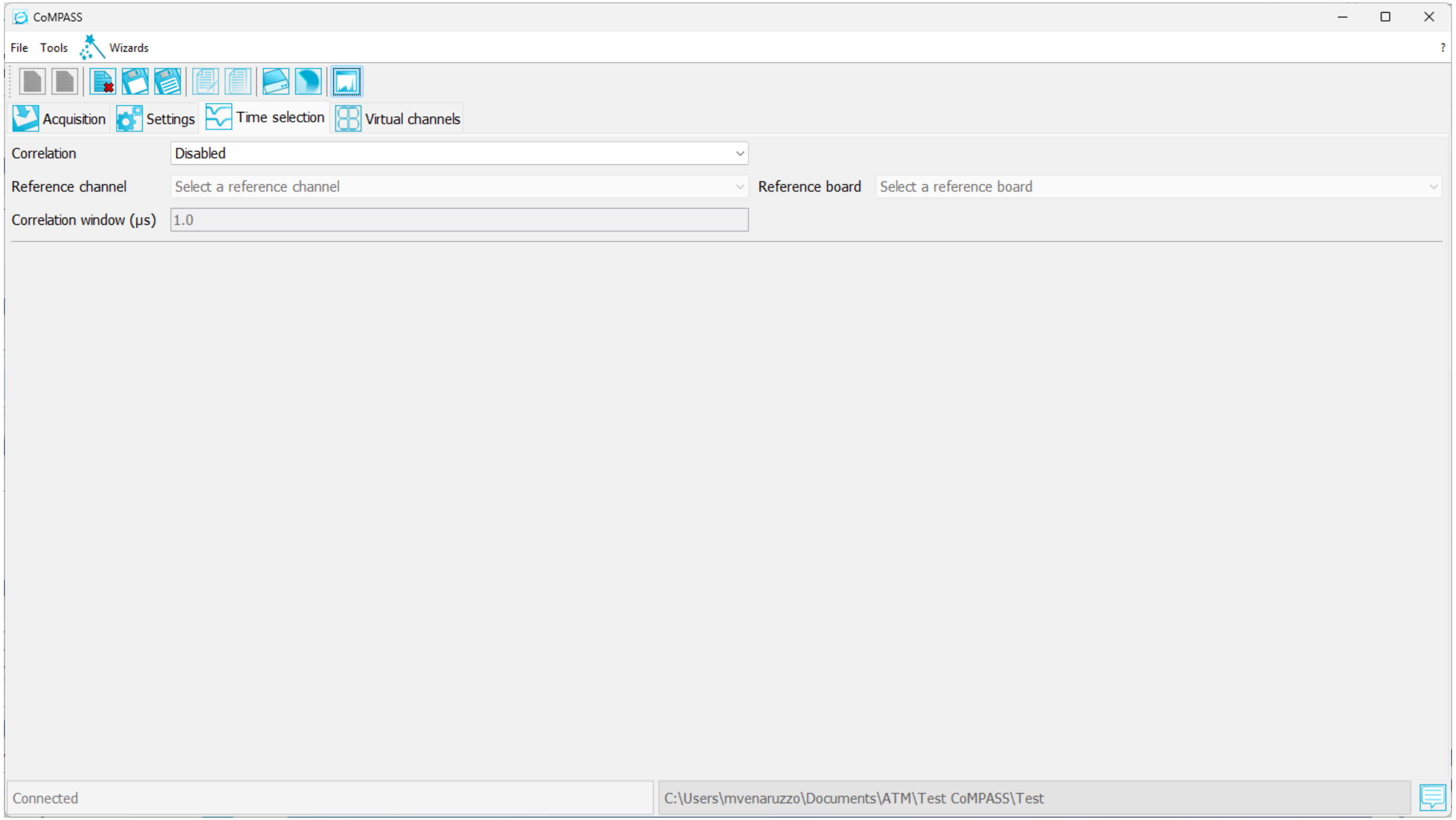
Acquisition Section

Event Saving Section

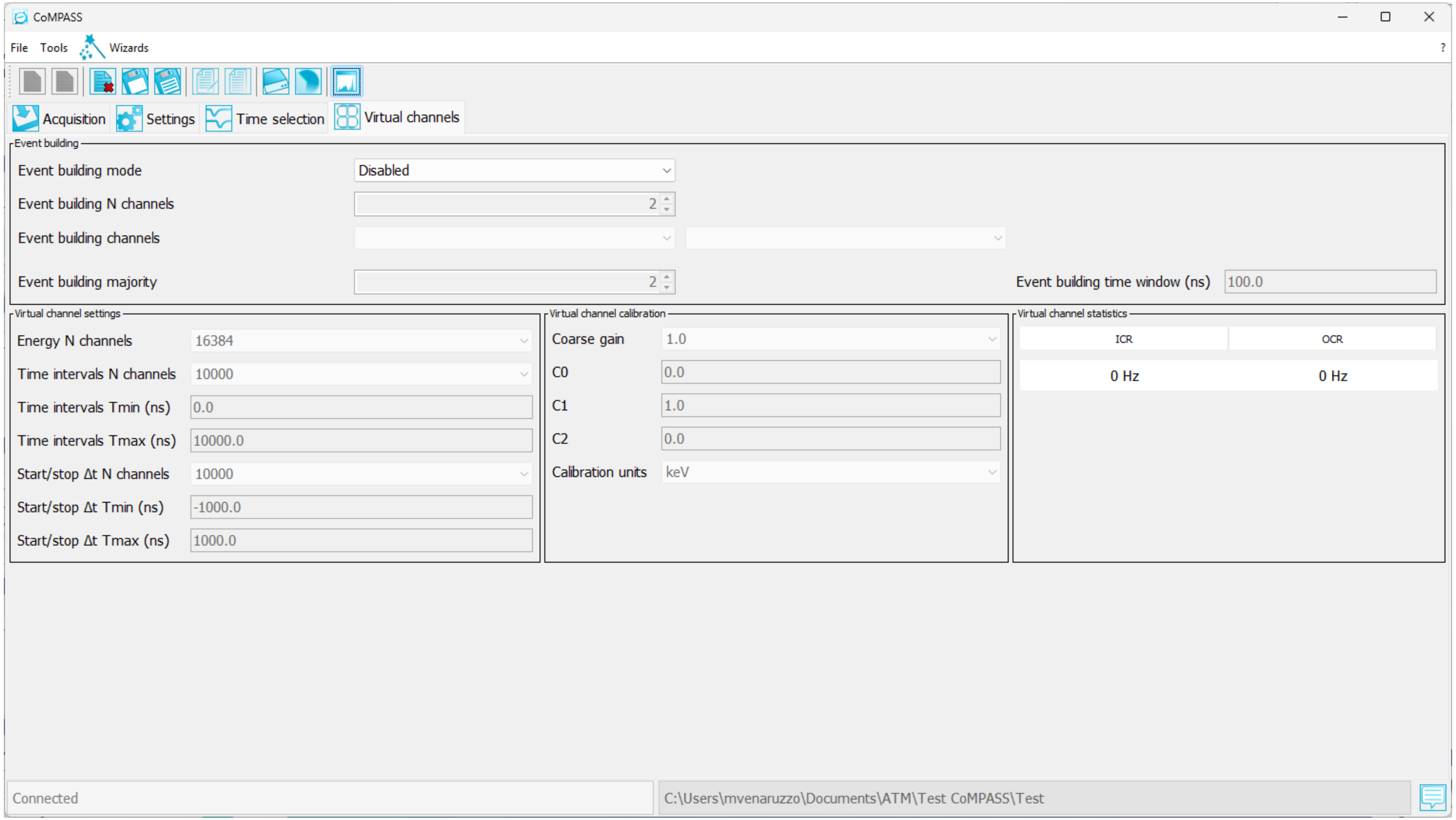
Compass main operation



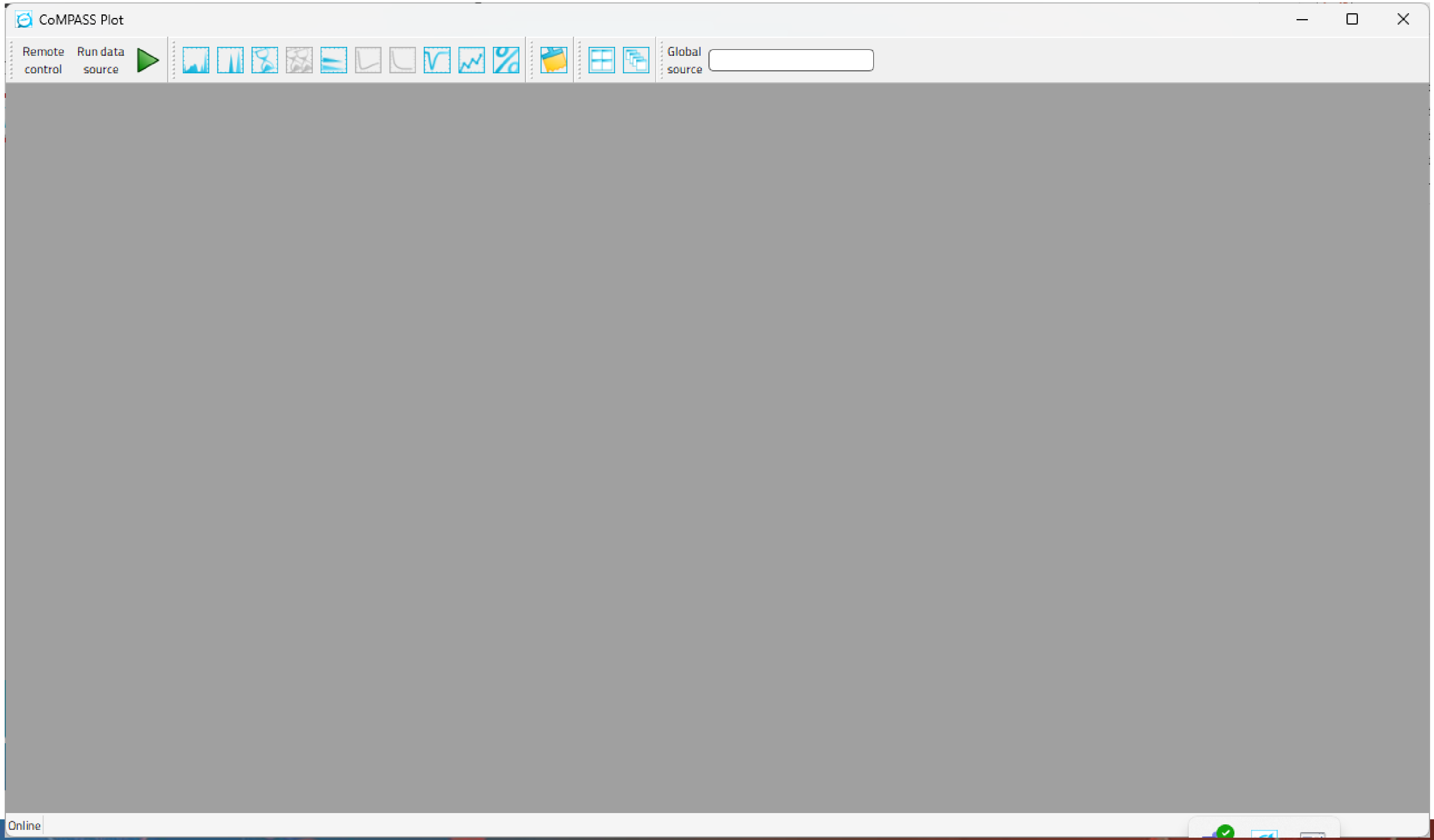
Compass main operation



Compass main operation



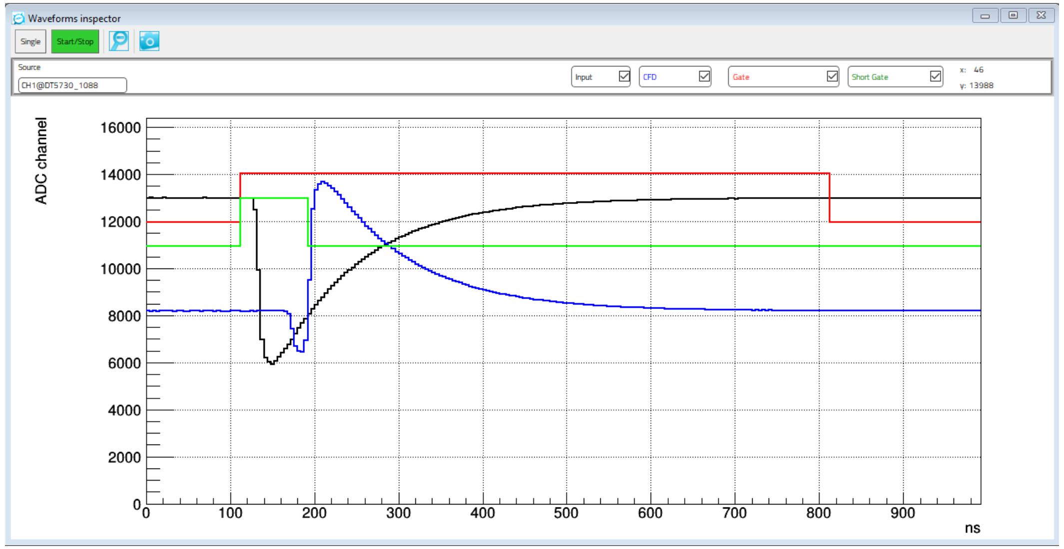
Compass main operation



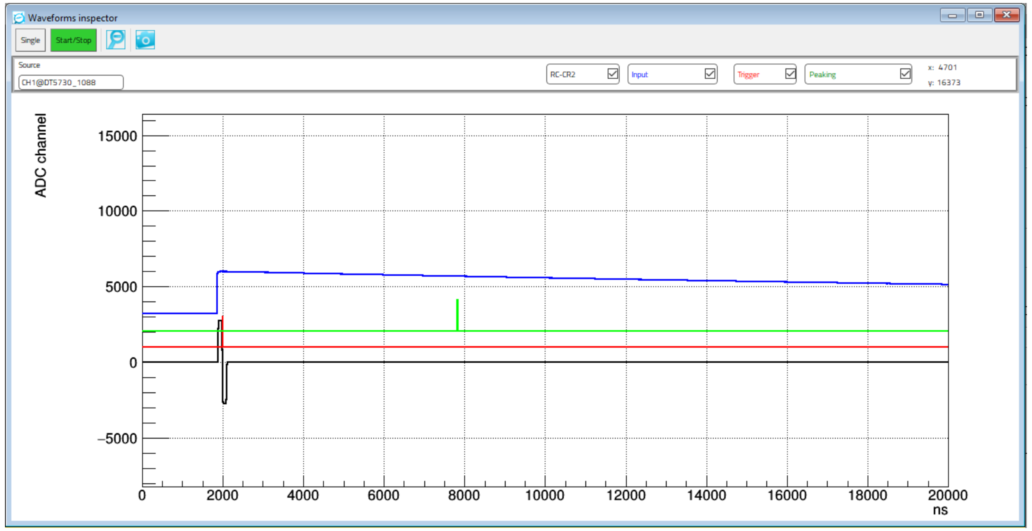
Compass main operation

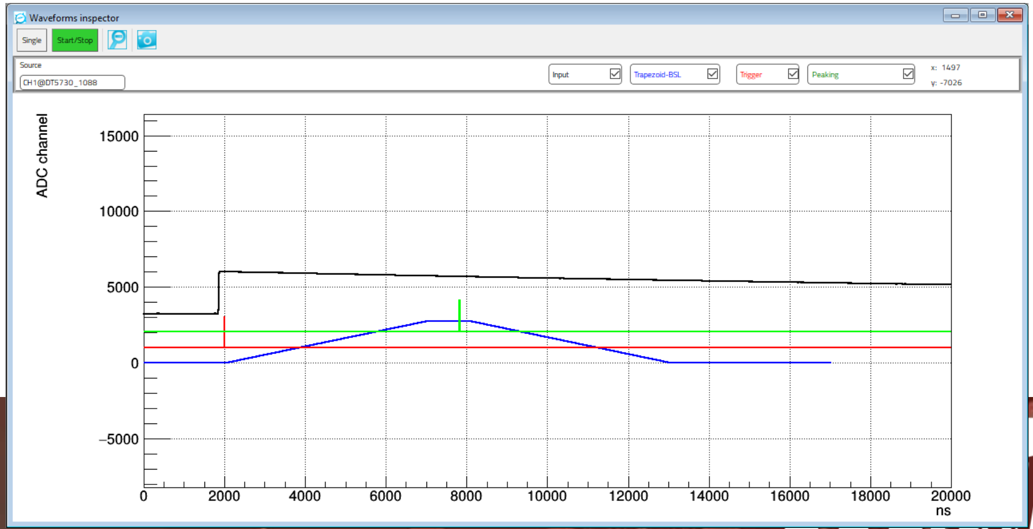
1. Open the Waveform plot, check the waveform and properly set the acquisition parameters

QDC/PSD case



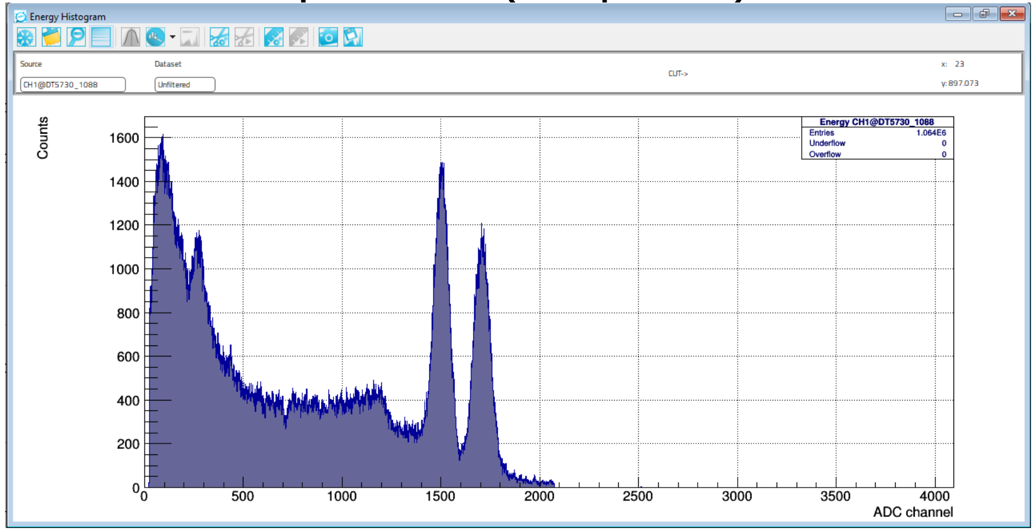
PHA case

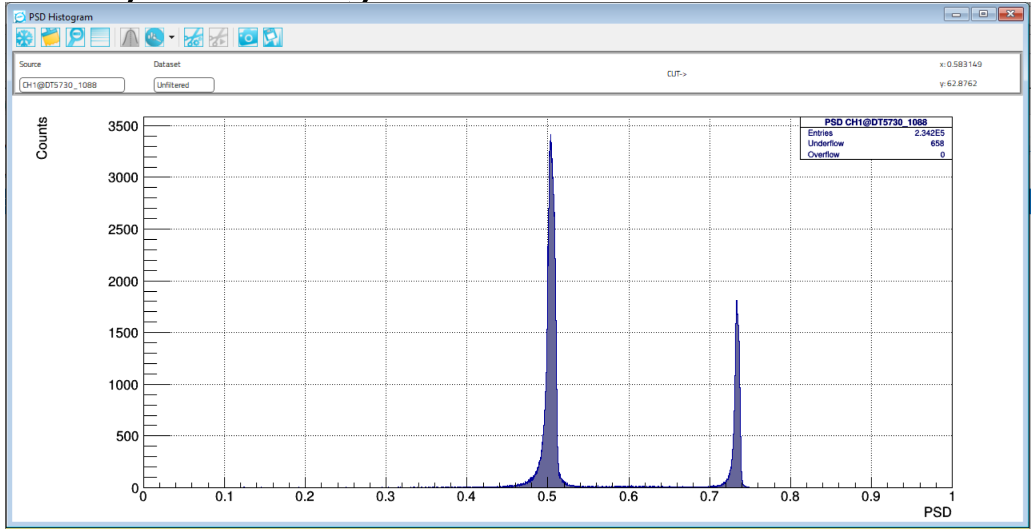


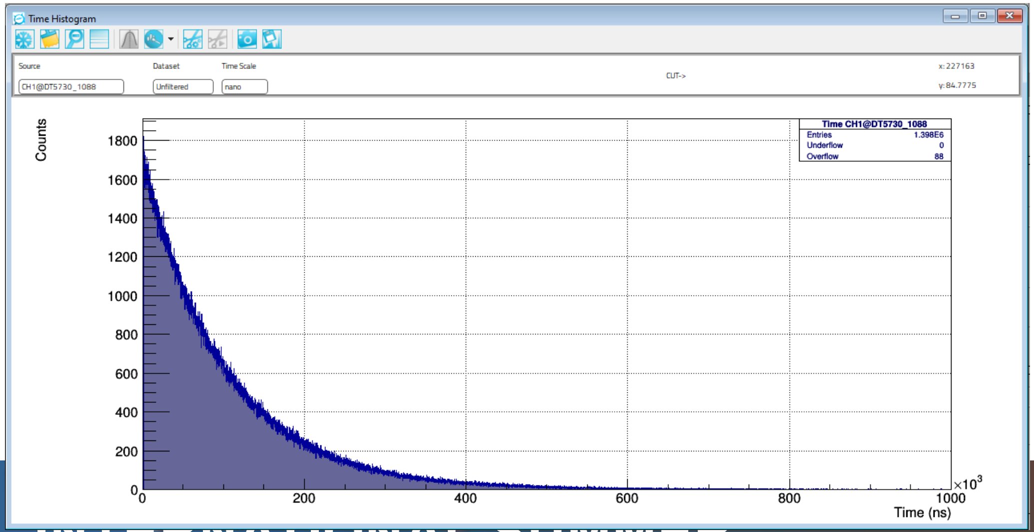


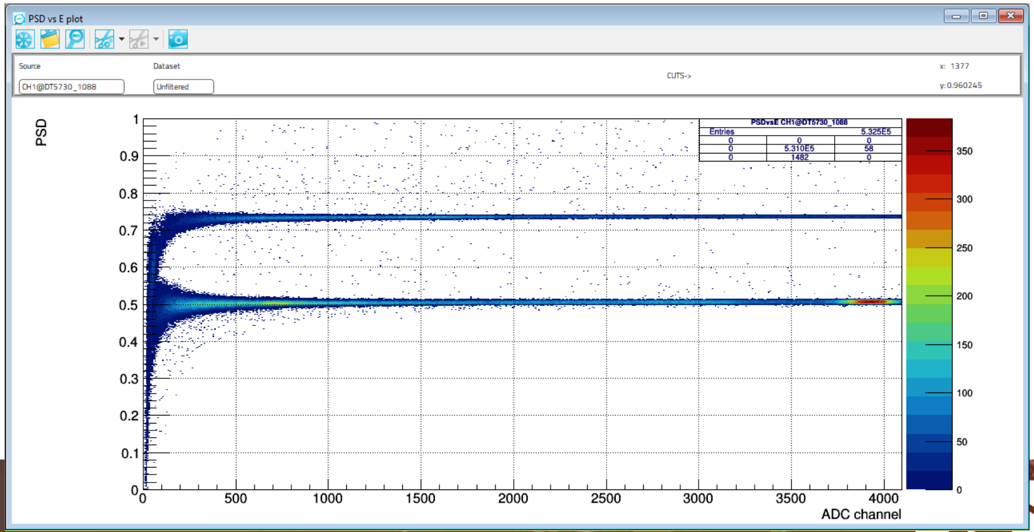
Compass main operation

2. Look at the spectrum (or spectra) and check the how your settings affect them



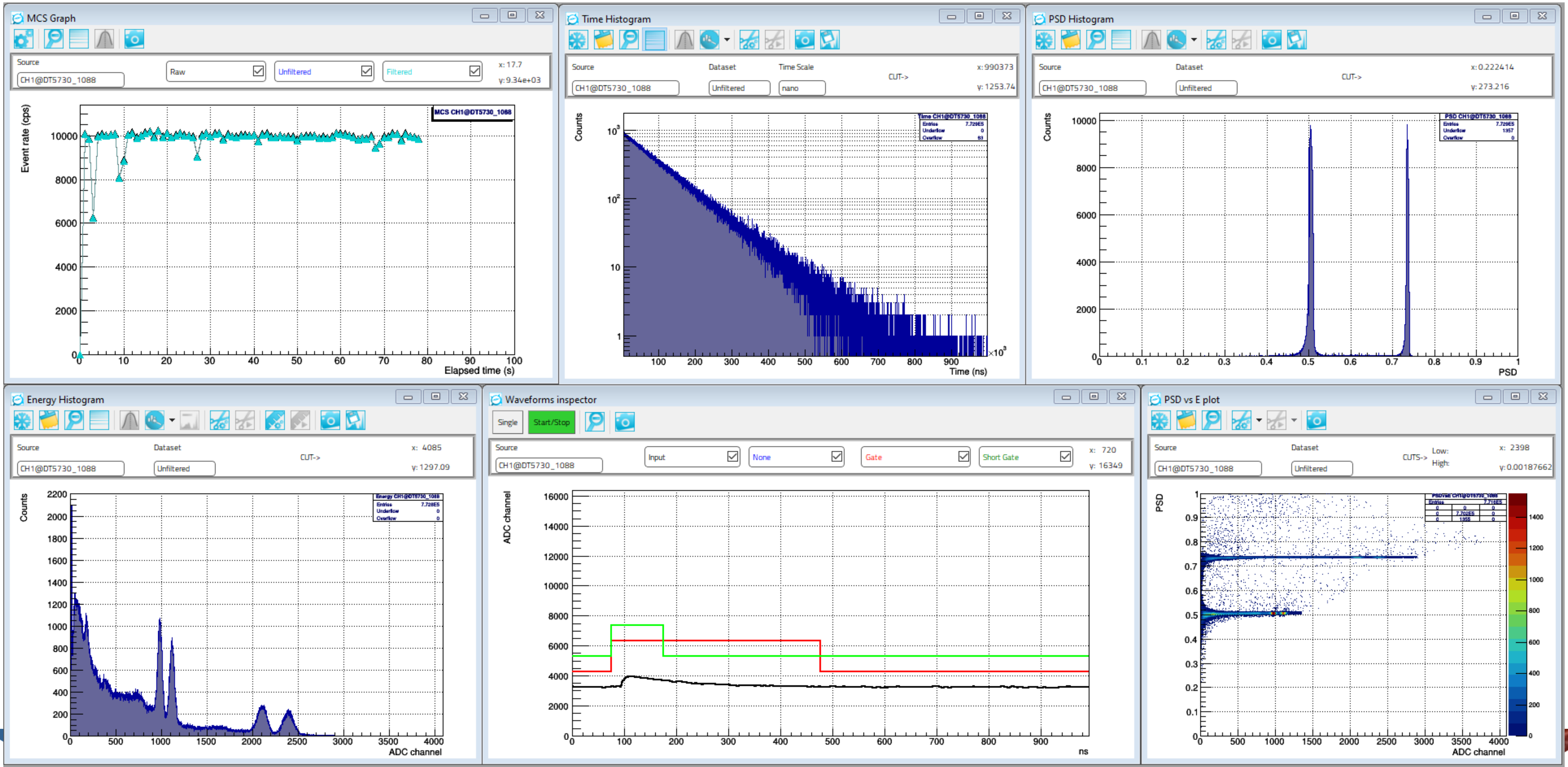






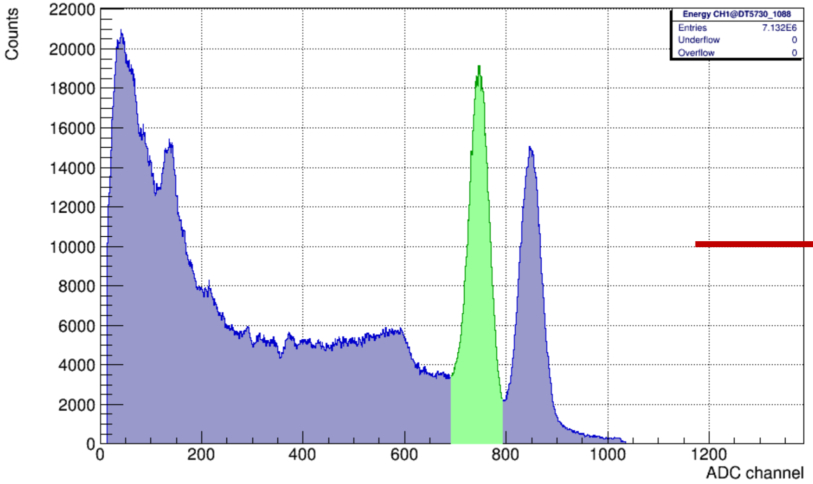
Compass main operation

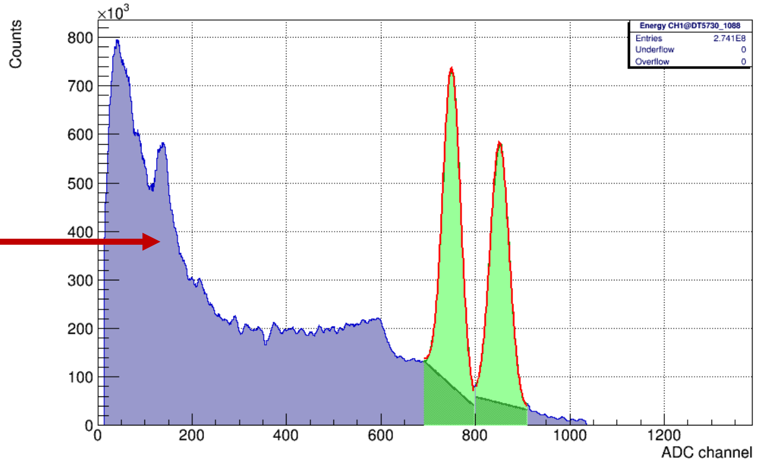
Up to 6 spectra can be plotted at the same time

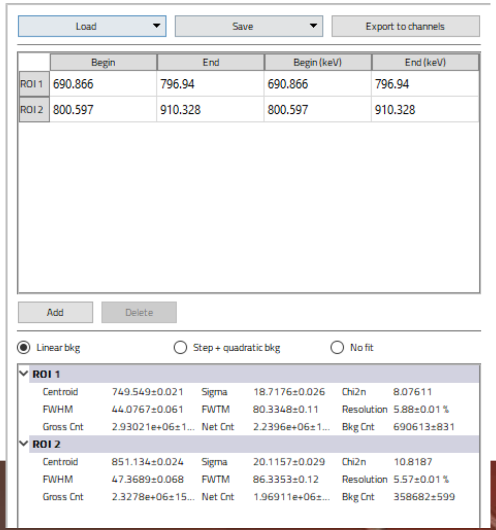


Compass main operation

3. Define ROIs and check the fit results

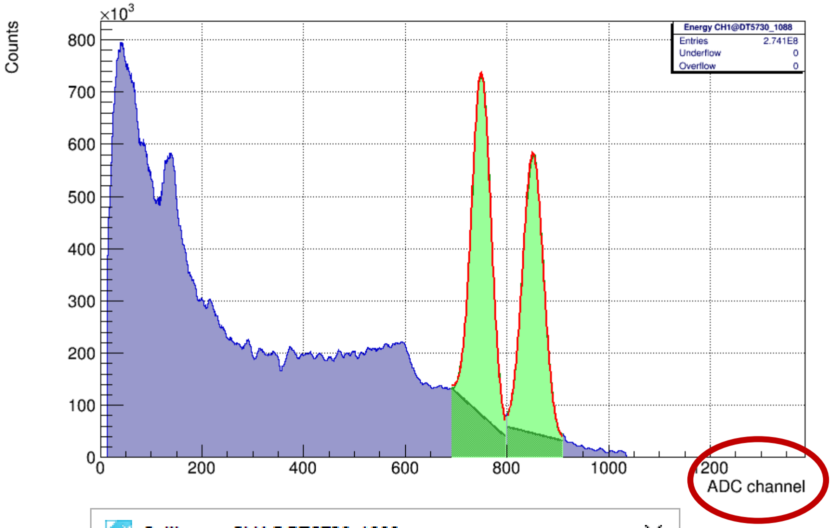


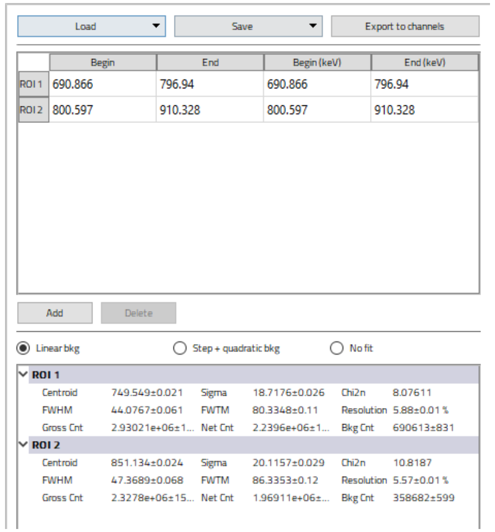


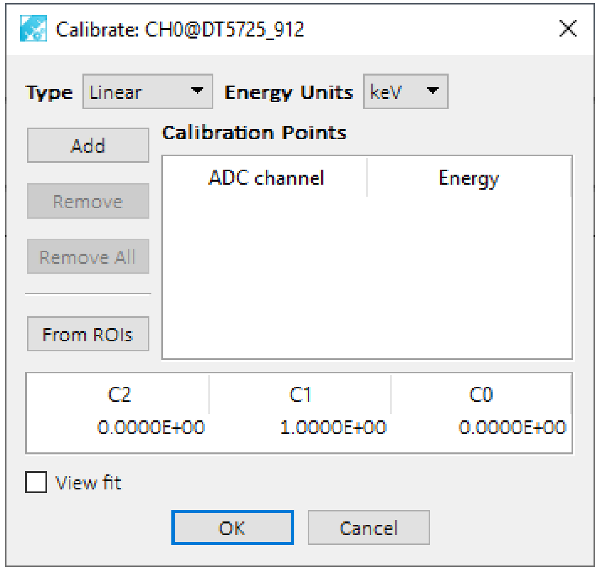


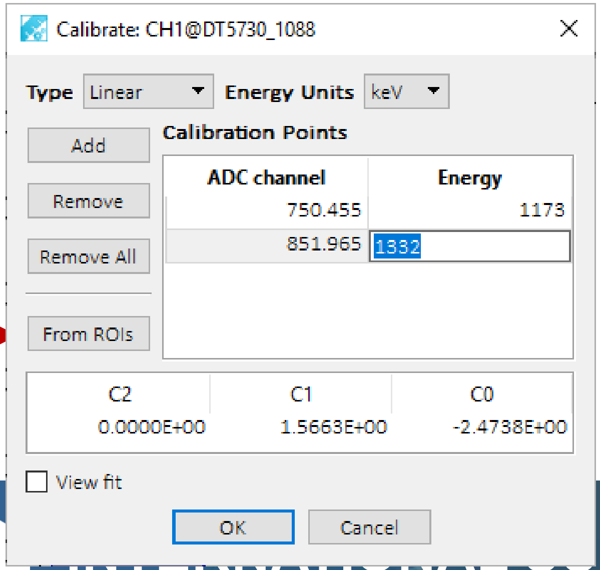
Compass main operation

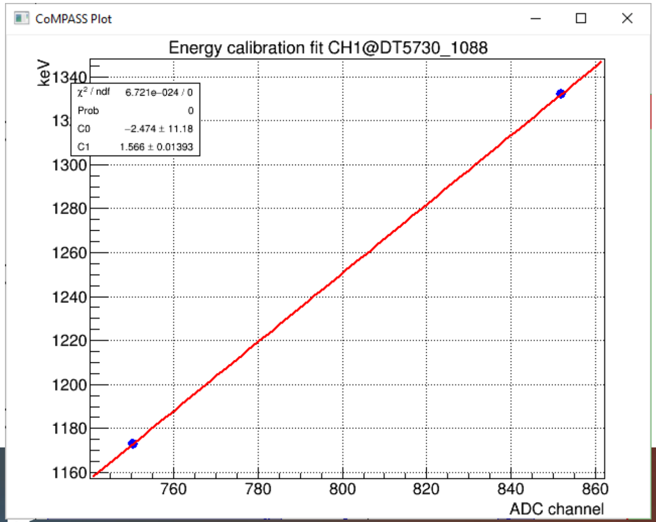
4. Calibrate the spectrum (from ROIs or manually)

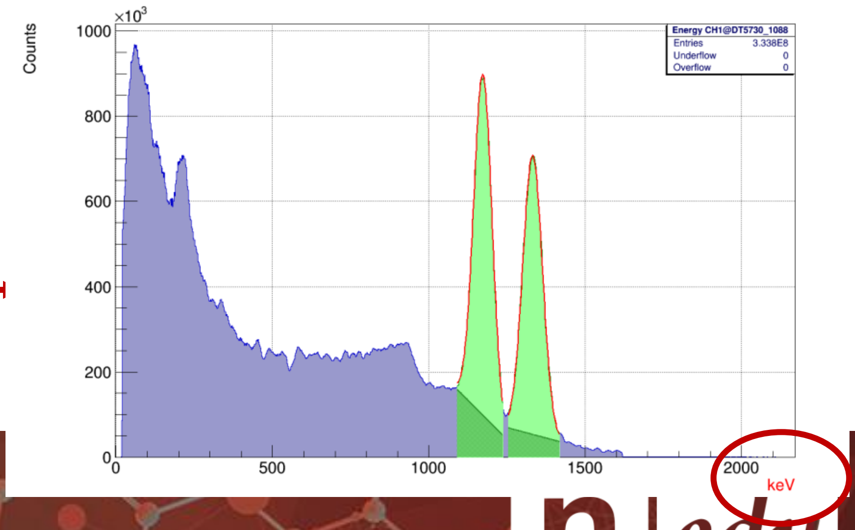






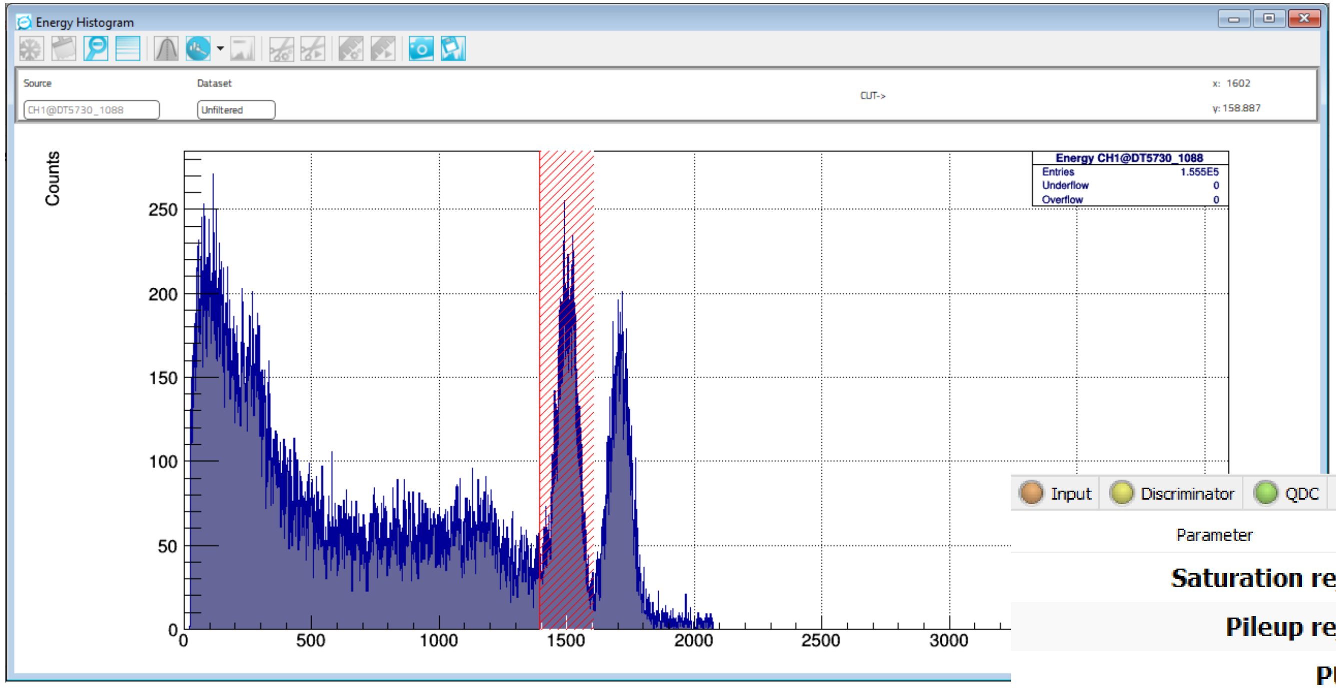






Compass main operation

5. Apply your data selection and check the spectra before and after the selection

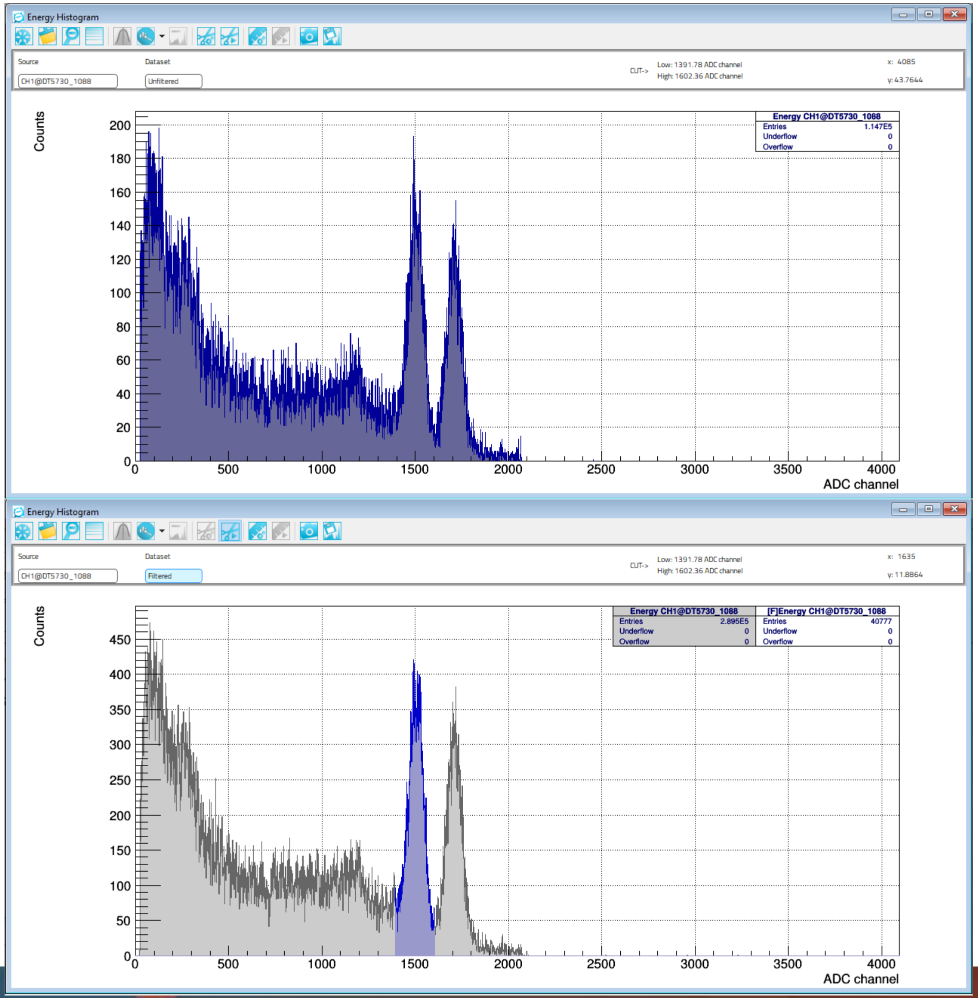


Input | Discriminator | QDC | Spectra | Rejections | Energy calibration | Sync/Trg | Onboard coincidences | Miscell

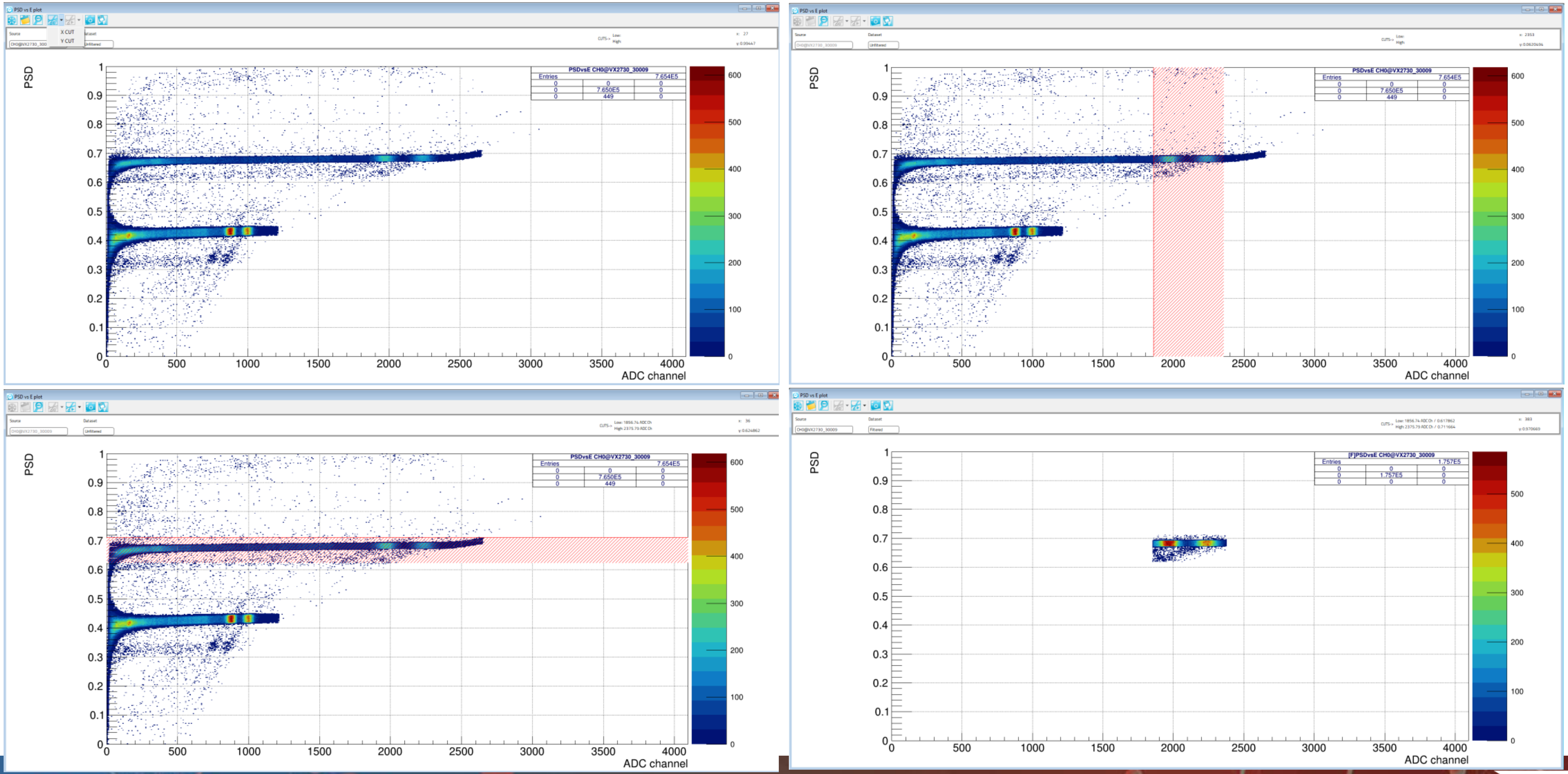
Parameter	Board	CH0	CH1	CH
Saturation rejection	☑	☑	☑	☑
Pileup rejection	☑	☑	☑	☑
PUR gap	1000 lsb	1000 lsb	1000 lsb	1000
E low cut	0.000	0.000	1391.780	0.0
E high cut	0.000	0.000	1602.360	0.0
E cut enable	☐	☐	☐	☐
PSD low cut	0.000	0.000	0.000	0.0
PSD high cut	0.000	0.000	0.000	0.0

Compass main operation

5. Apply your data selection and check the spectra before and after the selection

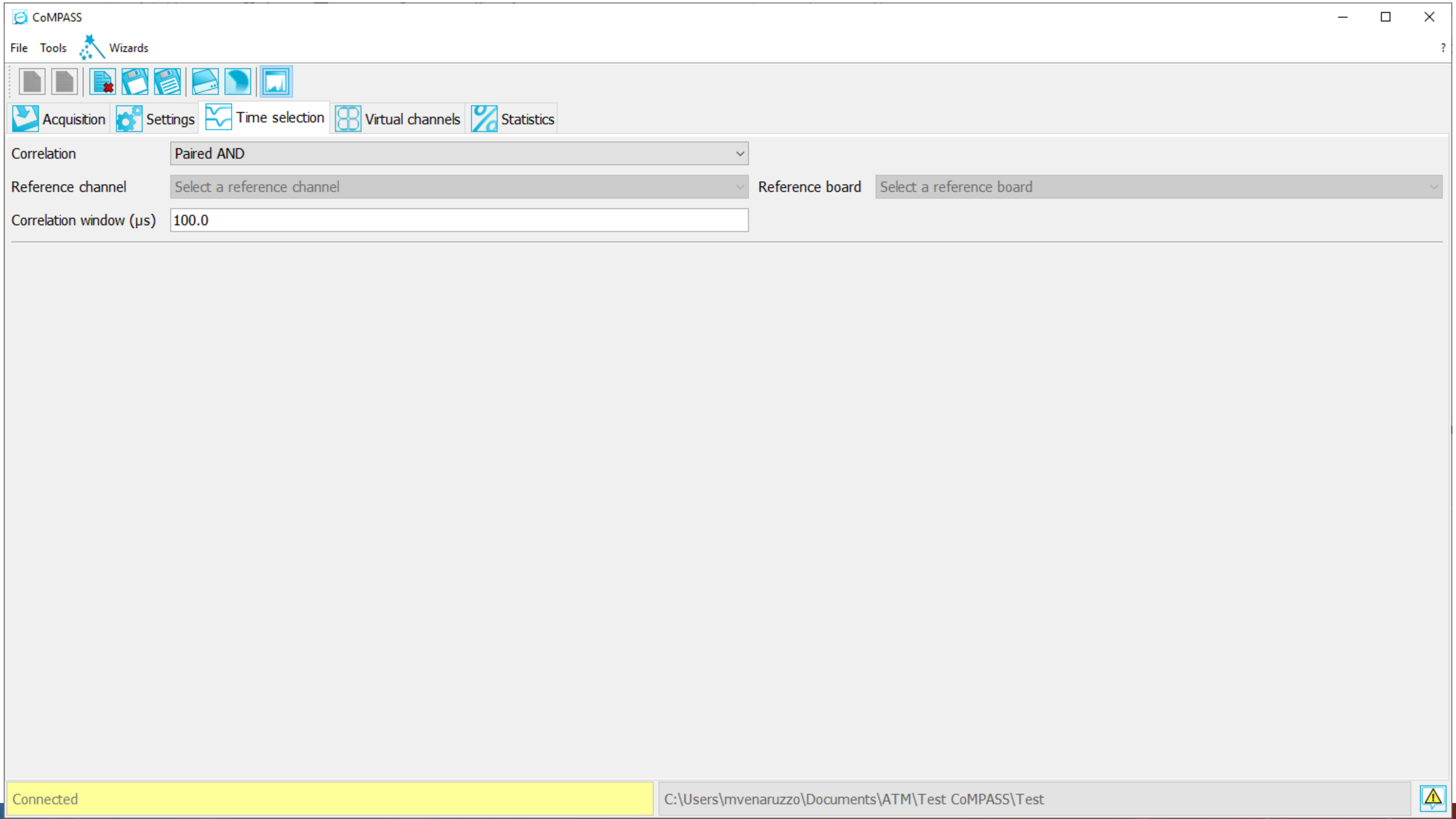


Compass main operation



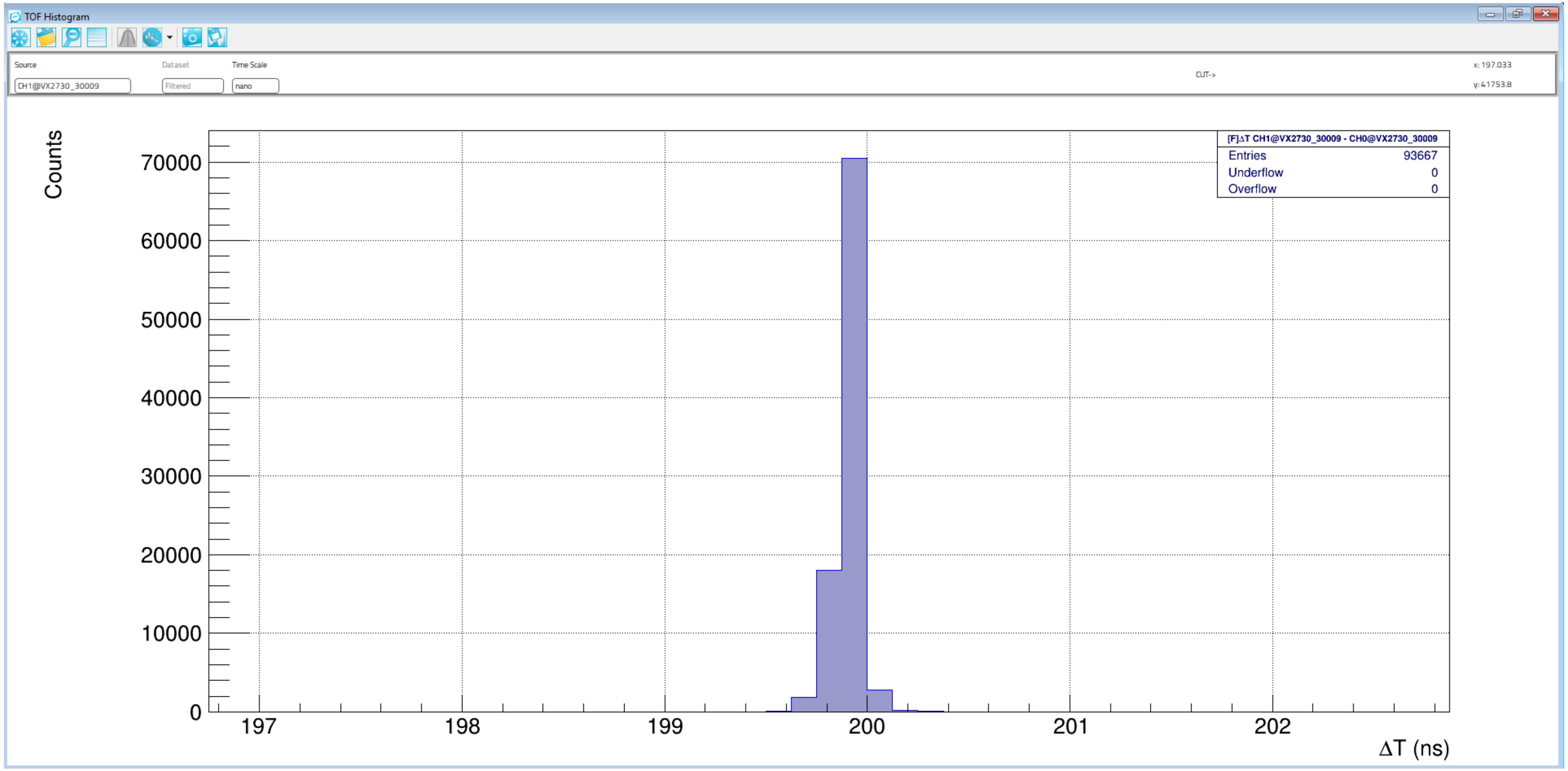
Compass main operation

8. Apply channel correlations



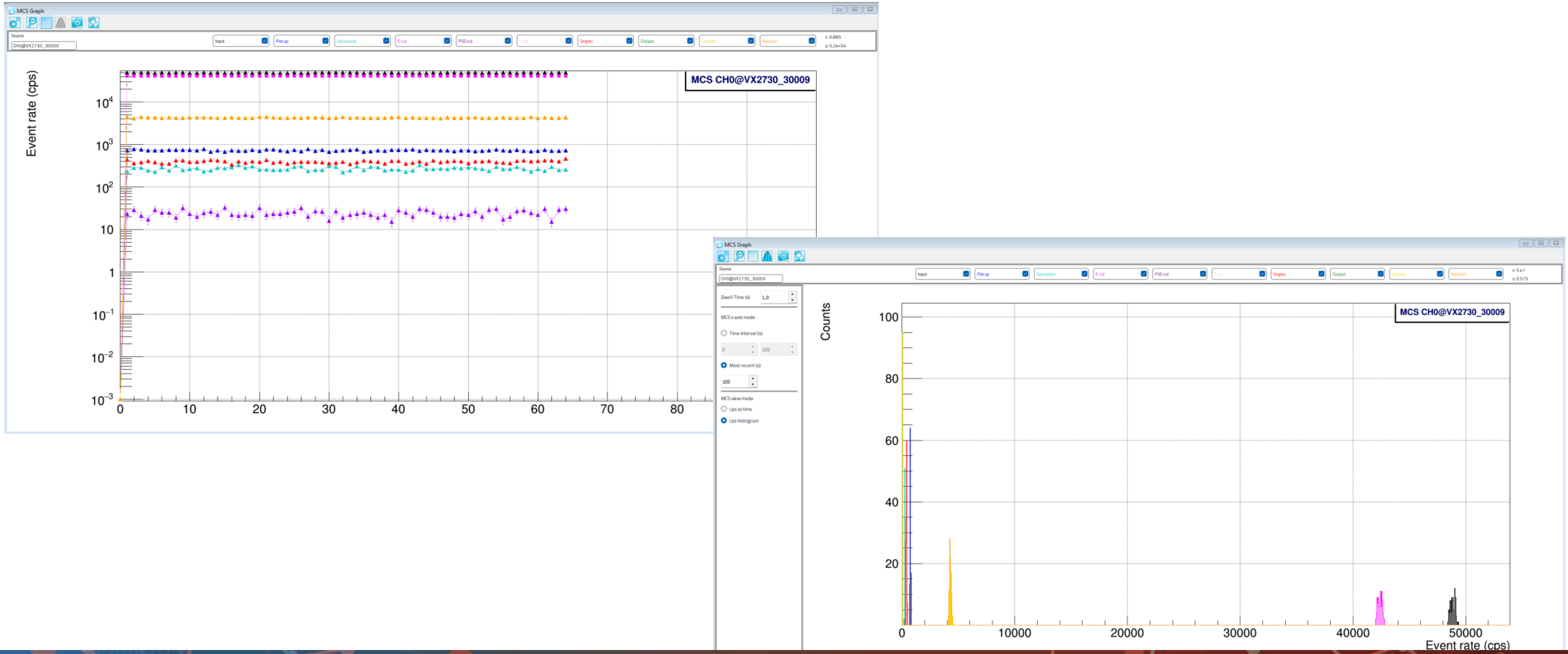
Compass main operation

9. Check the timing resolution looking at the Time-Of-Flight (or deltaT) spectrum



Compass main operation

10. Check the data selection effect on the input rate looking at the MCS plot



Compass main operation

7. Check the statistics to see the effect of the settings and the selection you applied

Statistics

Real Time 0:00:19.381

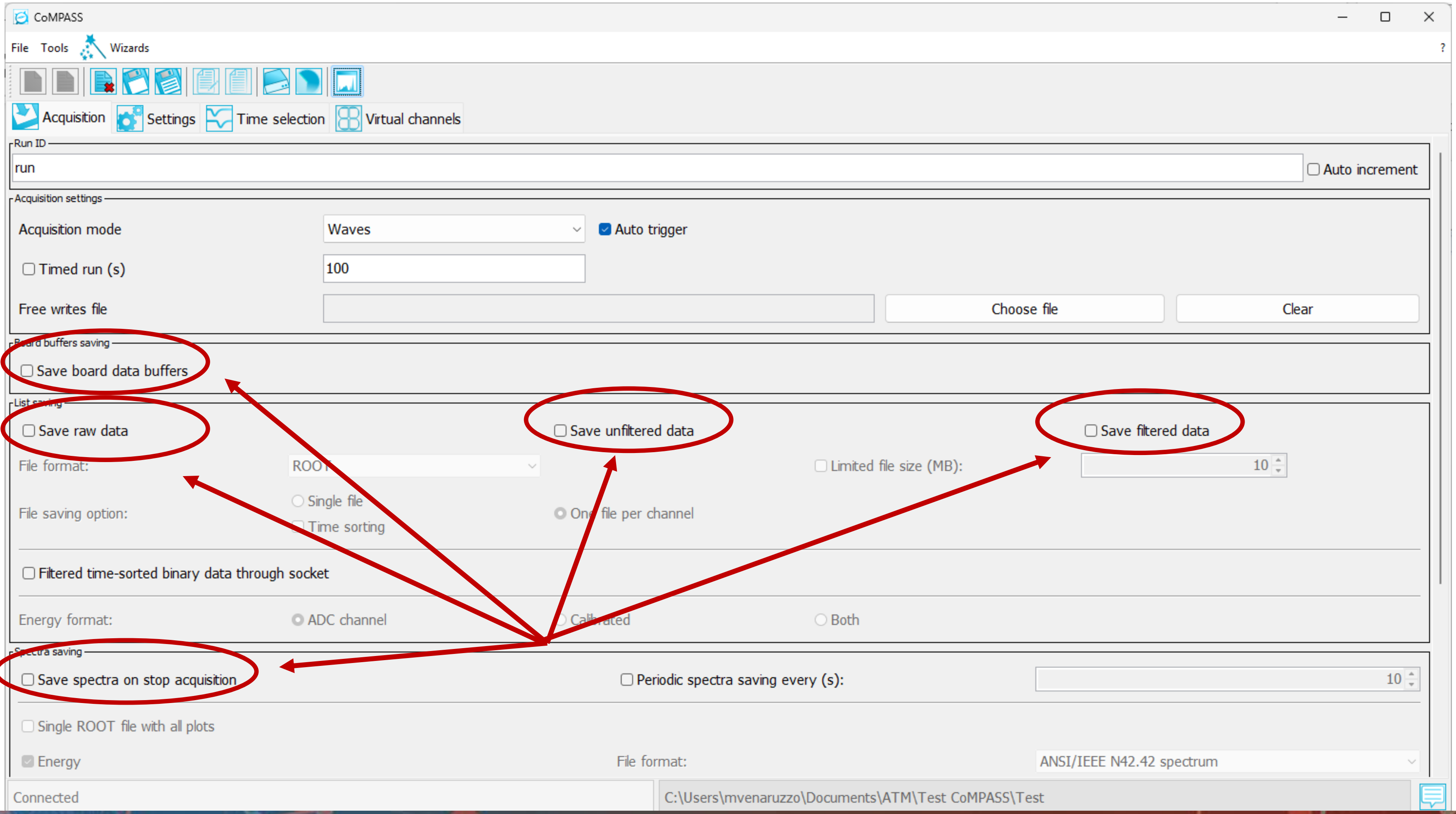
Counters | Instantaneous rates (selected) | Integral rates

Board: VX2730_30009 | Readout: 767.57±0.83 kB/s

Channel	ICR	Throughput	Pileup	Saturation	ECUT REJ	PSDCUT REJ	TCUT REJ	Time selection	OCR	Particle (below thr.)	Particle (above thr.)
CH0@VX2730_30009	19.79±0.14 kcps	19.66±0.13 kcps	95.3±9.6 cps	18.3±4.2 cps	17.62±0.13 kcps	4.8±2.2 cps	0 cps	225±15 cps	1.726±0.041 kcps	0 cps	1.726±0.041 kcps
CH1@VX2730_30009	19.79±0.14 kcps	19.66±0.13 kcps	98.2±9.7 cps	18.3±4.2 cps	17.66±0.13 kcps	2.9±1.7 cps	0 cps	186±13 cps	1.726±0.041 kcps	0 cps	1.726±0.041 kcps
CH2@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH3@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH4@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH5@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH6@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH7@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH8@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH9@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH10@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH11@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH12@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH13@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH14@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH15@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH16@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH17@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH18@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH19@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH20@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH21@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH22@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH23@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH24@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH25@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH26@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH27@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH28@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH29@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH30@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps
CH31@VX2730_30009	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps	0 cps

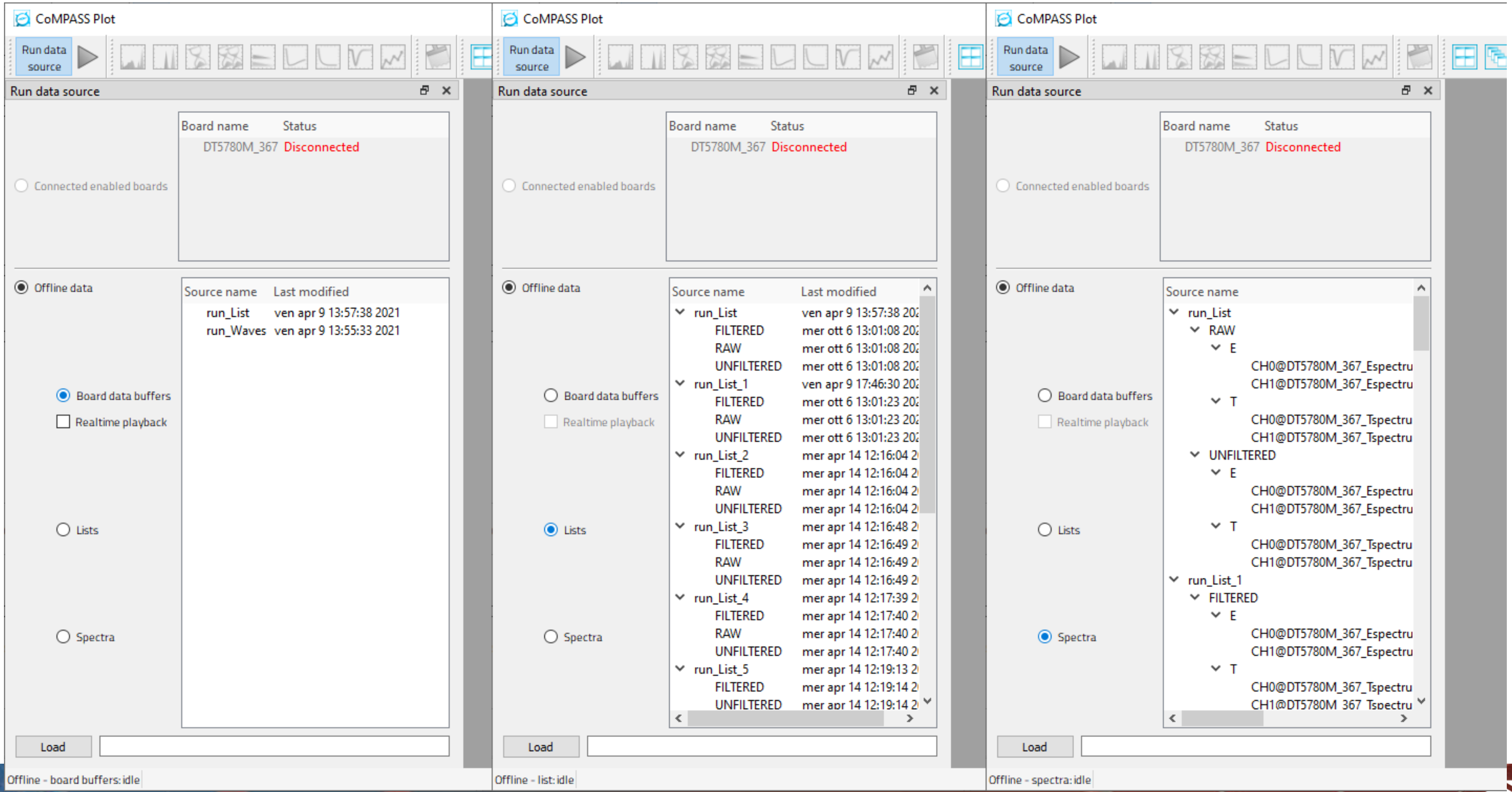
Compass main operation

8. Remember to save the data for your own following analysis



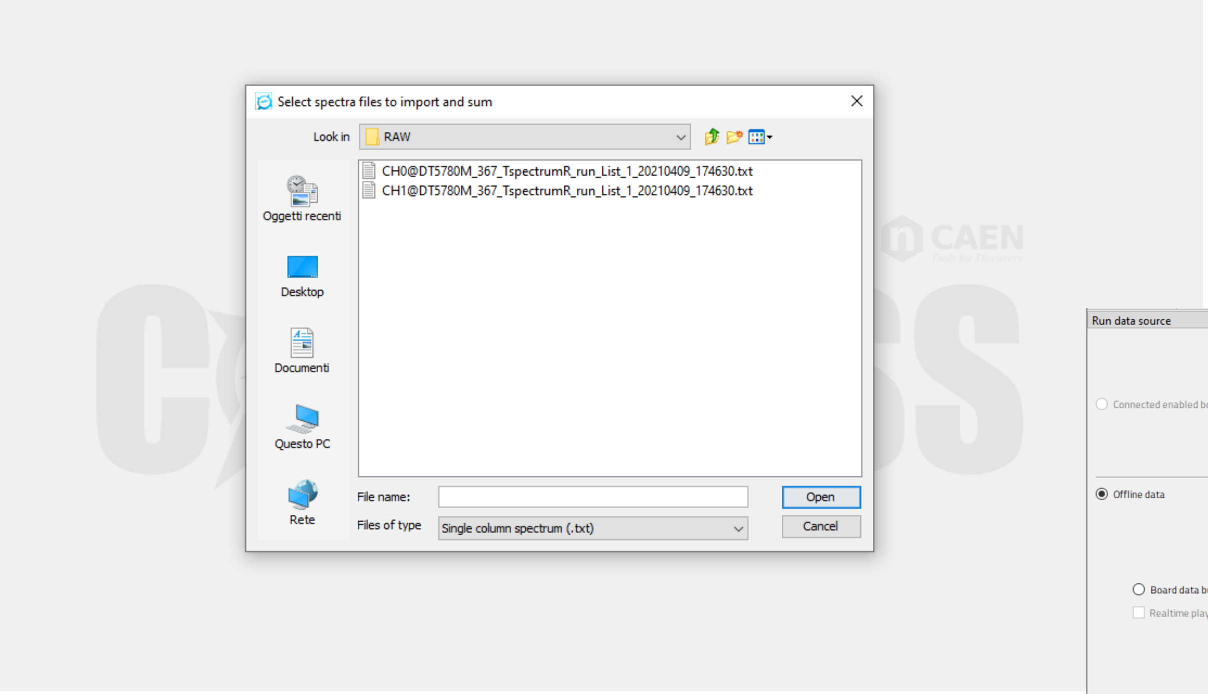
Compass main operation

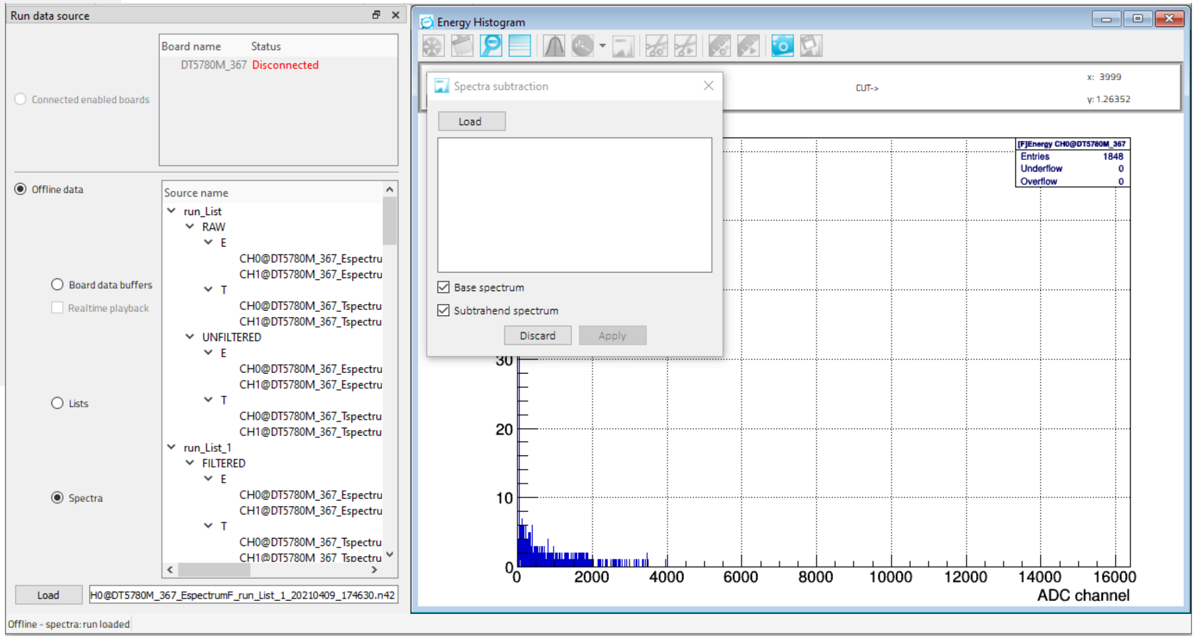
9. Offline reprocess of your data (board data buffers, time ordered list files, spectra)



Compass main operation

10. Sum and subtract spectra





Compass main operation

11. Remote control and batch acquisition

For those users who have the requirement to (remotely) control CoMPASS from an external script or software, CoMPASS now allows such possibility (HTTP based communication protocol)

Control trough external script then allow also programmable batch acquisitions

C:\Users\mvenaruzzo\source\repos\x64\Debug\remoteControl.exe

```
Connection to CoMPASS is working
Parameter 'loadConfigFile' set to value 'freeRun.xml'
Parameter 'runId' set to value 'freeRun'; Parameter 'timedRunEnabled' set to value 'FALSE'; Parameter 'autoIncrementRunId' set to value 'TRUE'
Started acquisition
Stopped acquisition
Started acquisition
Stopped acquisition
Started acquisition
Stopped acquisition
Started acquisition
Stopped acquisition
Started acquisition
Stopped acquisition
Parameter 'loadConfigFile' set to value 'timedRun.xml'
Parameter 'runId' set to value 'timedRun'; Parameter 'timedRunEnabled' set to value 'TRUE'; Parameter 'autoIncrementRunId' set to value 'TRUE'
Parameter 'timedRunDuration' set to value '10'(s)
Started acquisition
```

Compass use cases

Application:

1. α, β, γ (high resolution) spectroscopy (depending on the used detector)
2. Pulse shape discrimination, eg γ-n discrimination
3. High resolution timing measurements (eg positronium lifetime)
4. Cosmic rays studies
5. Correlation studies
6. …

Hands On 1 – Gamma Spectroscopy

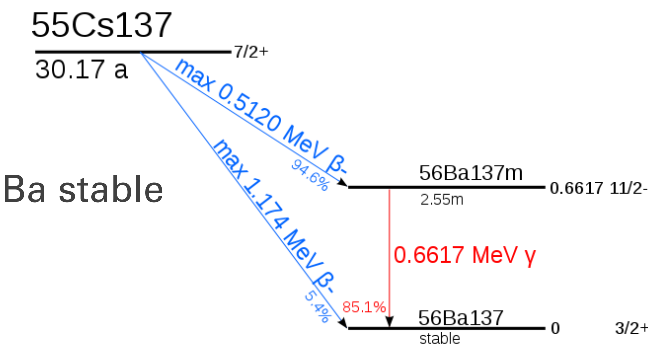
Hands-on 1 overview – Goal and Physics

Goal: study the energy resolution of the ^{22}Na, ^{137}Cs, ^{57}Co and ^{60}Co γ peaks

Physics: ^{137}Cs decay

Two decay modes:

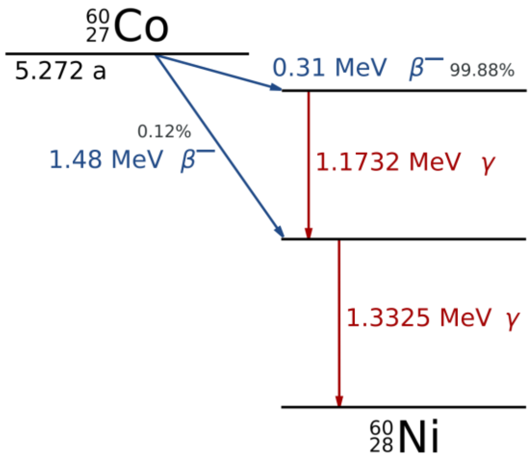
- 94.6 % → β- decay (Max energy 0.5120 MeV) into excited ^{137}Ba metastable → γ decay into ^{137}Ba stable
- 5.4 % → β- decay (Max energy 1.174 MeV) into excited ^{137}Ba stable



Physics: ^{60}Co decay

Two decay modes:

- 99.88 % → β- decay (Max energy 0.31 MeV) into excited ^{60}Ni → double γ decay into ^{60}Ni stable
- 0.12 % → β- decay (Max energy 1.48 MeV) into excited ^{60}Ni → single γ decay into ^{60}Ni stable

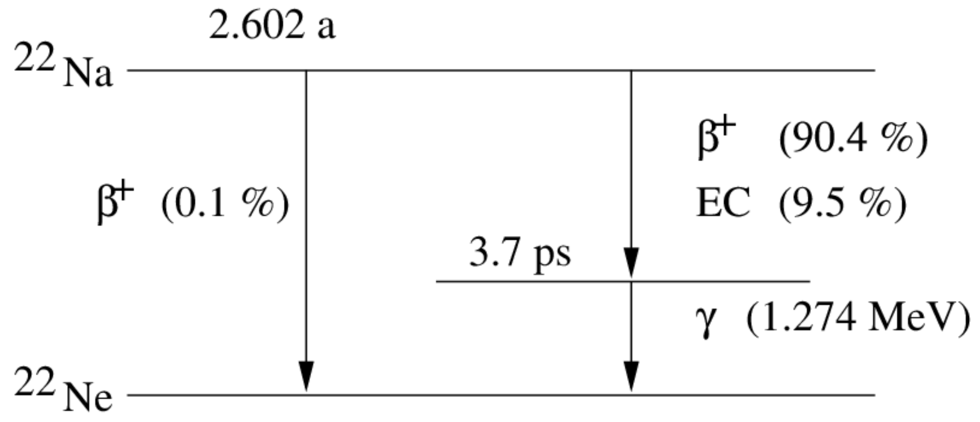


Hands-on 1 overview – Goal and Physics

Physics: ^{22}Na decay

Three decay modes:

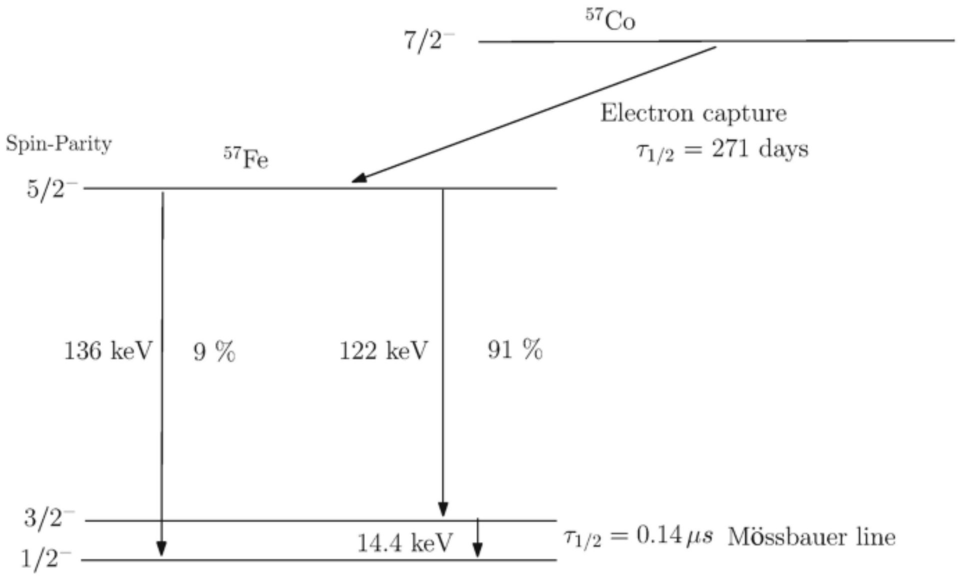
- 90.4 % → β+ decay into excited ^{22}Ne → single γ decay into ^{22}Ne stable + annihilation γ
- 9.5% → EC decay into excited ^{22}Ne → single γ decay into ^{22}Ne stable
- 0.1 % → β+ decay into stable ^{22}Ni → only annihilation γ



Physics: ^{57}Co decay

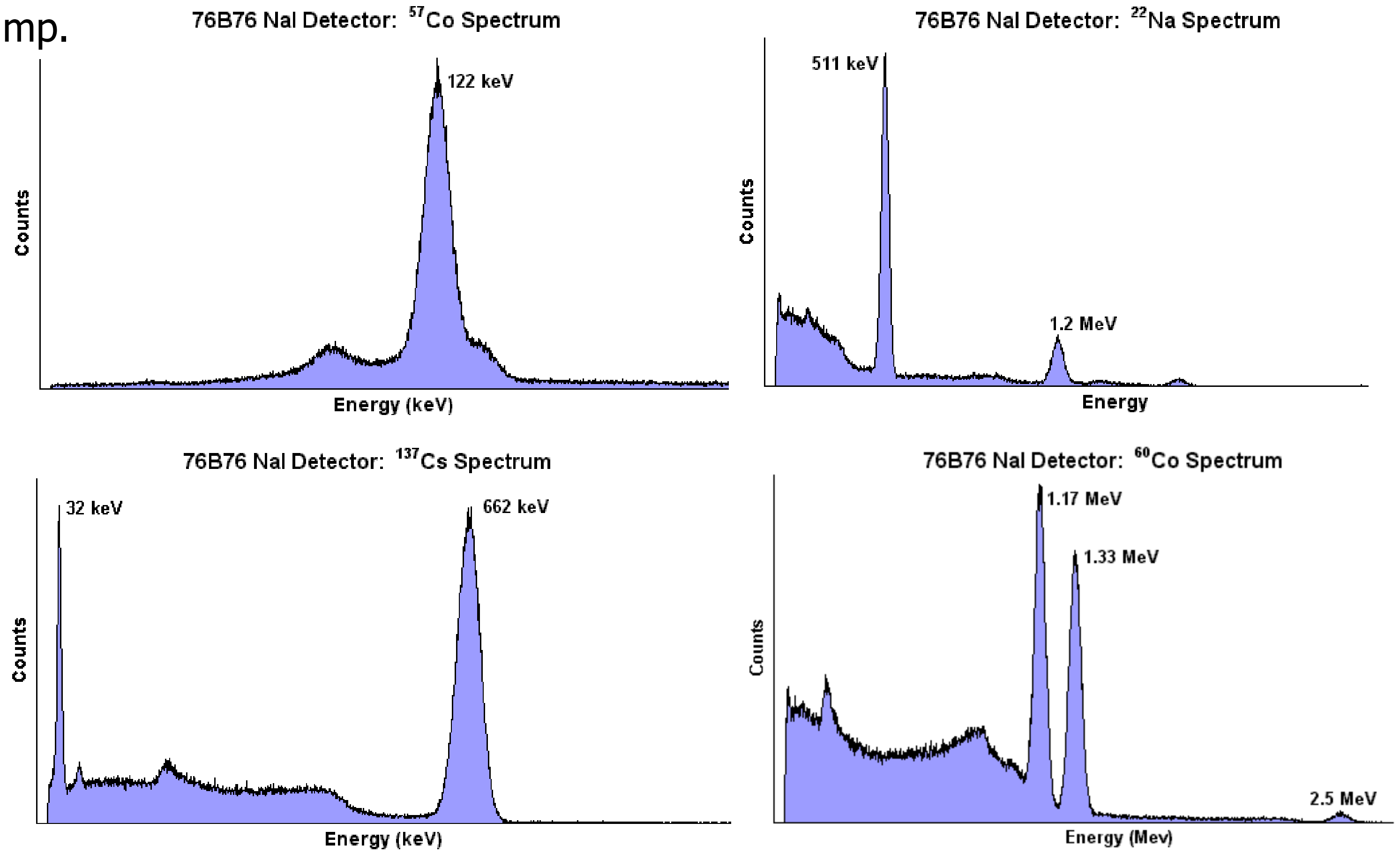
One decay mode:

- 100 % → EC decay into exited ^{57}Fe
  - → 91% double γ decay into ^{57}Fe stable
  - → 9% single γ decay into ^{57}Fe stable



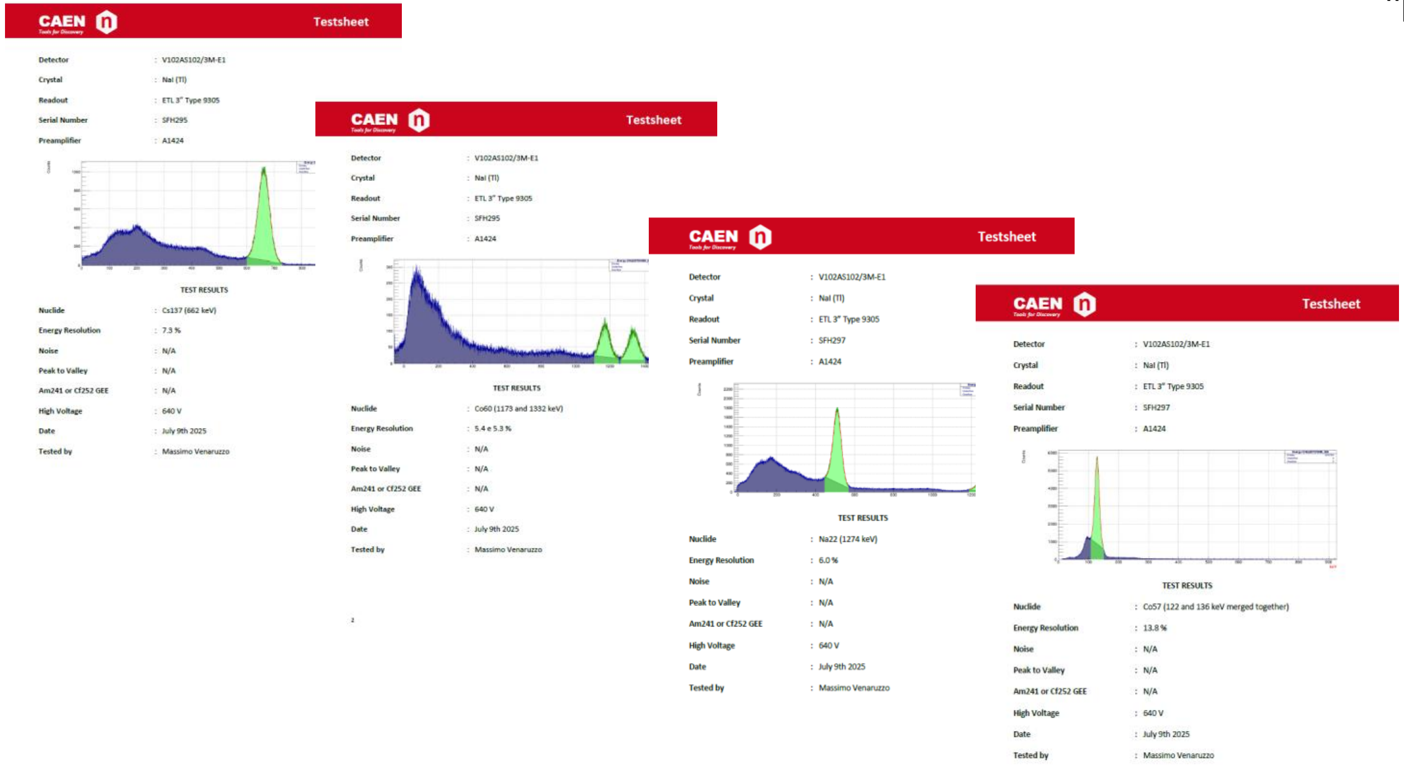
Hands-on scenario for all the groups

- Detector: NaI
- HV: DT5780
- Premaplifier: A1424 charge sensitive preamp.
- DAQ: DT5780 (DPP-PHA embedded)
- Software: CoMPASS
- Sources: ^{22}Na, ^{137}Cs, ^{57}Co and ^{60}Co
- Goals:
  - Raw signal check
  - Parameter setting and optimization
  - Energy Spectrum display
  - ROI definition
  - Energy resolution calculation
  - Report compilation



Hands-on material

- NaI detector testsheet to check the resolution



CAEN Tools for Discovery — Testsheet

Detector	: V102AS102/3M-E1
Crystal	: NaI (Tl)
Readout	: ETL 3" Type 9305
Serial Number	: SFH295
Preamplifier	: A1424

TEST RESULTS

Nuclide	: Cs137 (662 keV)
Energy Resolution	: 7.3 %
Noise	: N/A
Peak to Valley	: N/A
Am241 or Cf252 GEE	: N/A
High Voltage	: 640 V
Date	: July 9th 2025
Tested by	: Massimo Venaruzzo

CAEN Tools for Discovery — Testsheet

Detector	: V102AS102/3M-E1
Crystal	: NaI (Tl)
Readout	: ETL 3" Type 9305
Serial Number	: SFH295
Preamplifier	: A1424

TEST RESULTS

Nuclide	: Co60 (1173 and 1332 keV)
Energy Resolution	: 5.4 e 5.3 %
Noise	: N/A
Peak to Valley	: N/A
Am241 or Cf252 GEE	: N/A
High Voltage	: 640 V
Date	: July 9th 2025
Tested by	: Massimo Venaruzzo

CAEN Tools for Discovery — Testsheet

Detector	: V102AS102/3M-E1
Crystal	: NaI (Tl)
Readout	: ETL 3" Type 9305
Serial Number	: SFH297
Preamplifier	: A1424

TEST RESULTS

Nuclide	: Na22 (1274 keV)
Energy Resolution	: 6.0 %
Noise	: N/A
Peak to Valley	: N/A
Am241 or Cf252 GEE	: N/A
High Voltage	: 640 V
Date	: July 9th 2025
Tested by	: Massimo Venaruzzo

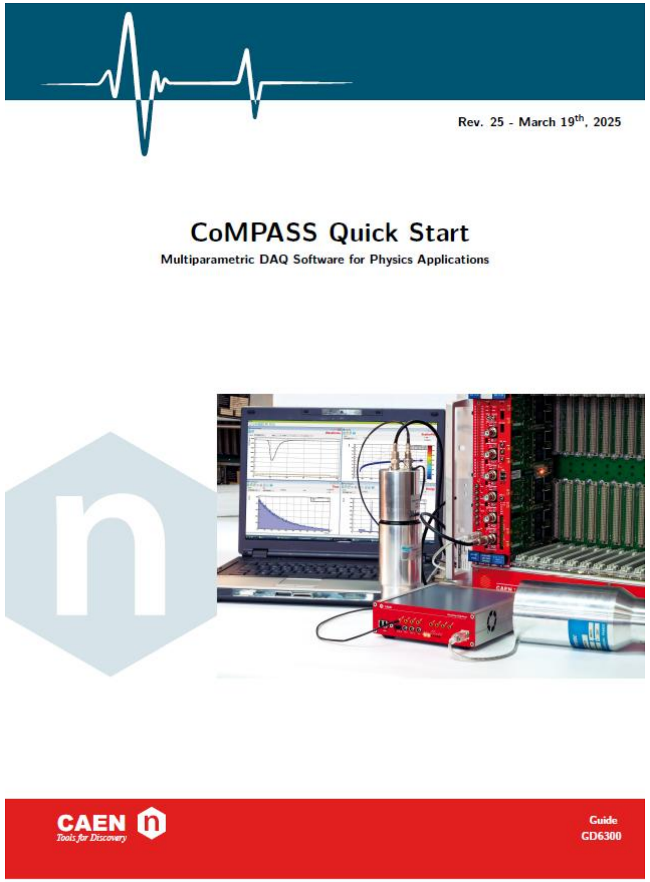
CAEN Tools for Discovery — Testsheet

Detector	: V102AS102/3M-E1
Crystal	: NaI (Tl)
Readout	: ETL 3" Type 9305
Serial Number	: SFH297
Preamplifier	: A1424

TEST RESULTS

Nuclide	: Co57 (122 and 136 keV merged together)
Energy Resolution	: 13.8 %
Noise	: N/A
Peak to Valley	: N/A
Am241 or Cf252 GEE	: N/A
High Voltage	: 640 V
Date	: July 9th 2025
Tested by	: Massimo Venaruzzo

- CoMPASS Quick Start Guide for the operation "how to…"



Hands On 2 – Pulse Shape Discrimination

Hands-on overview – Goal and Physics

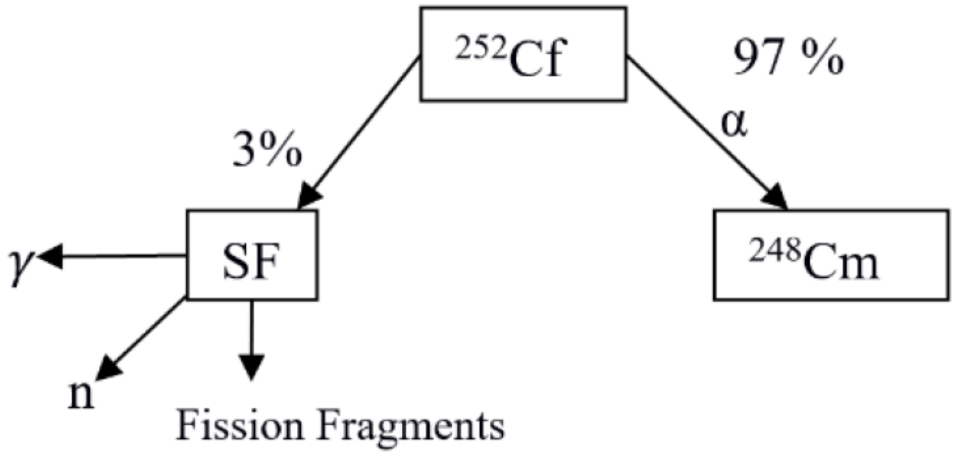
Goal: study the pulse shape discrimination algorithm and performance on a ^{252}Cf source whose gamma and neutron are detected by Liquid and Plastic Scintillators

Physics: ^{252}Cf decay

Two decay modes:

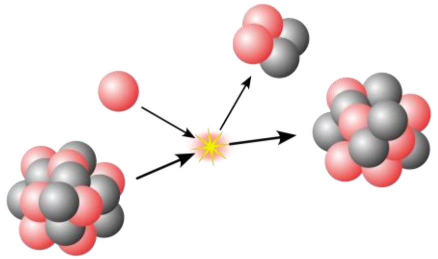
•96.9 % → α decay

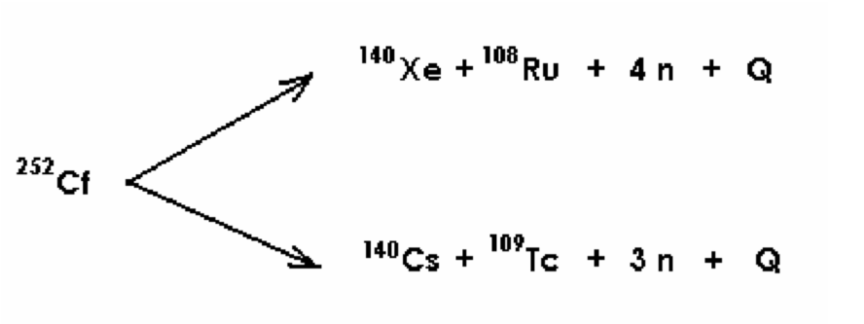
•3.1 % → Spontanous fission decay



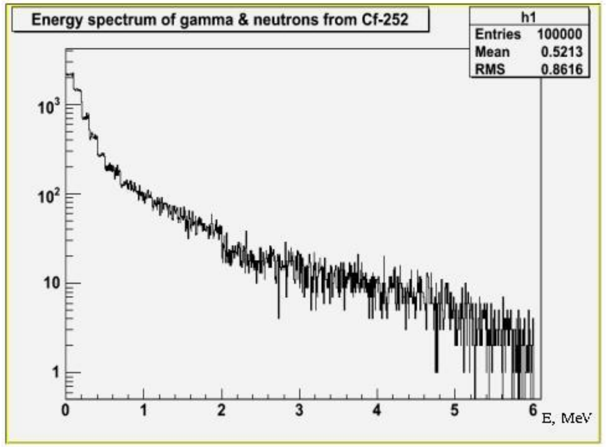
Hands-on overview – Goal and Physics

Example of two decay branches for the ^{252}Cf fission fragment decay

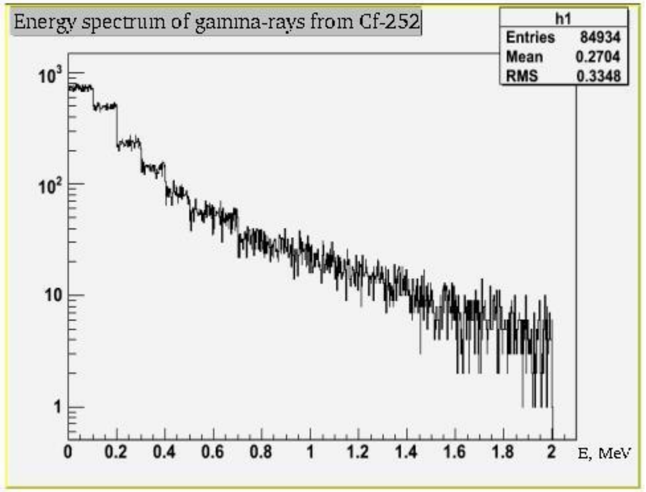




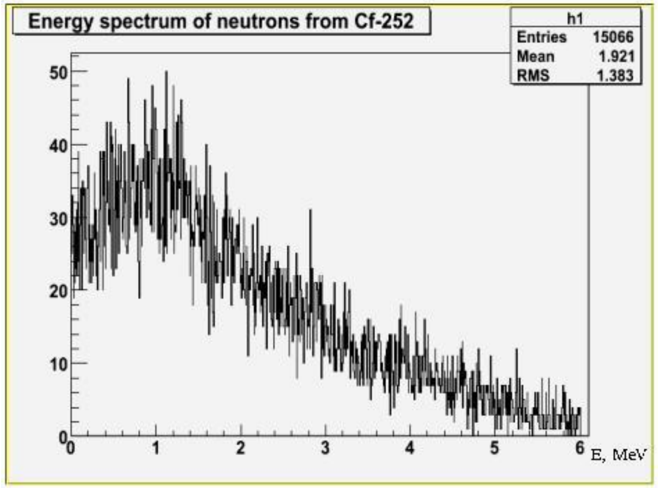
Multi-body decay → γ energy distribution has no peaks



Energy spectrum combined from energy spectrum of gamma-rays and neutrons emitted by Cf-252 source.

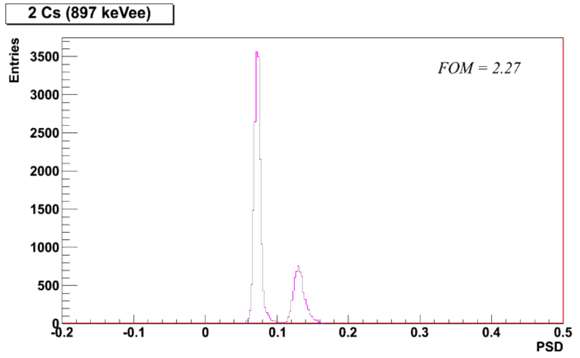


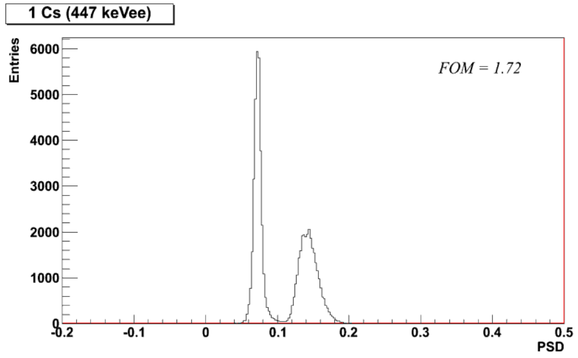
Energy spectrum of gamma rays from Cf-252 source.

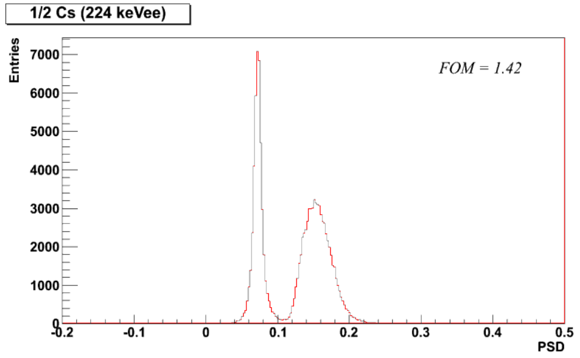


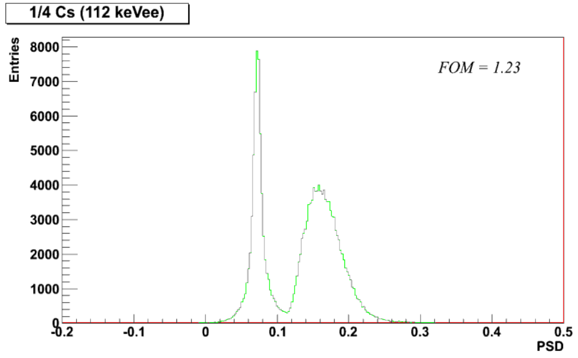
Energy spectrum of neutrons from Cf-252 source.

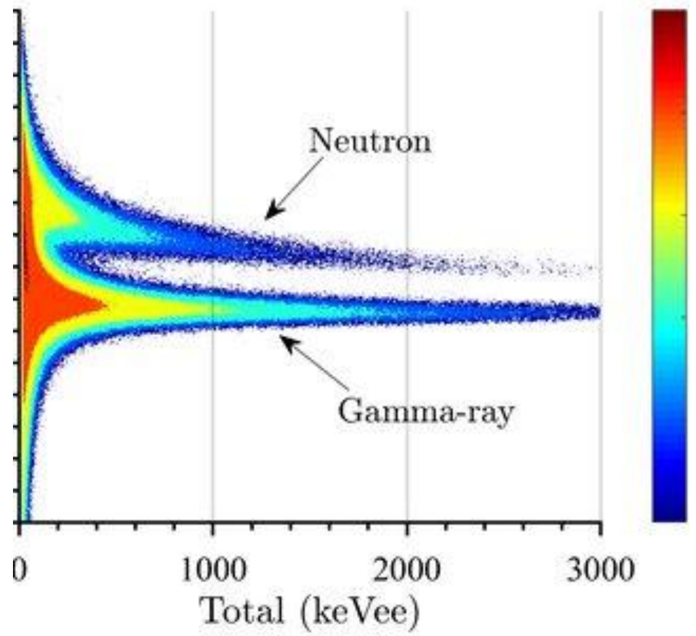
Hands-on overview – Goal and Physics











$$FOM = \frac{\Delta PEAK}{FWHM_{\gamma} + FWHM_{n}}$$

Hands-on scenarios

Group 1

- Detector: EJ-200
- HV: DT5790
- DAQ: DT5790 and DT5730 + DPP-PSD
- Software: CoMPASS
- Sources: ^{252}Cf
- Goals:
  - Raw signal check
  - Parameter setting
  - Energy and PSD Spectrum display
  - Energy selection set
  - PSD Spectrum ROI definition
  - FoM calculation and optimization
  - Check both DT5790 and DT5730 for performance comparison
  - Report compilation

Group 2

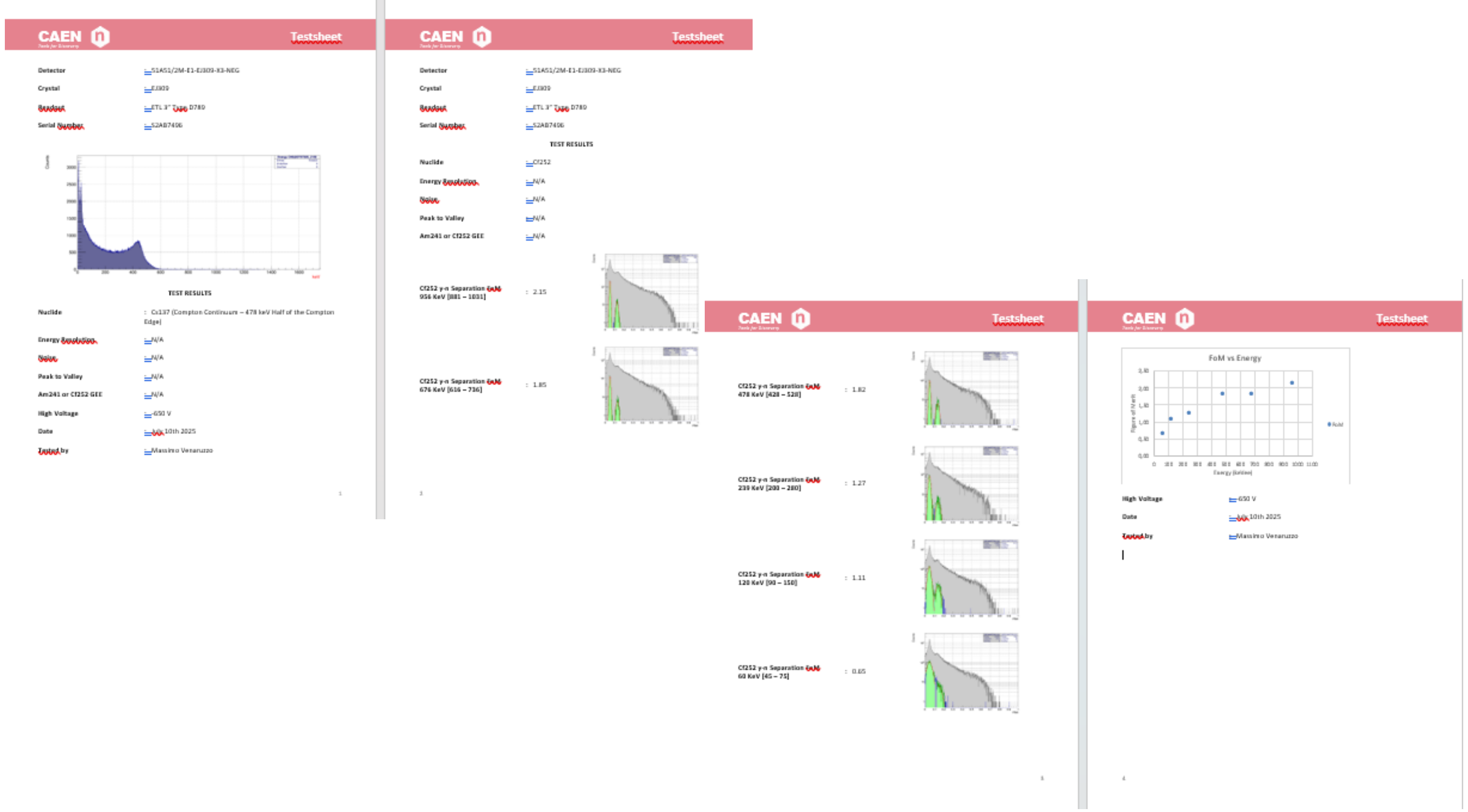
- Detector: BC599
- HV: DT5790
- DAQ: DT5790 and DT5730S + DPP-PSD
- Software: CoMPASS
- Sources: ^{252}Cf
- Goals:
  - Raw signal check
  - Parameter setting
  - Energy and PSD Spectrum display
  - Energy selection set
  - PSD Spectrum ROI definition
  - FoM calculation and optimization
  - Check both DT5790 and DT5730S for performance comparison
  - Report compilation

Group 3

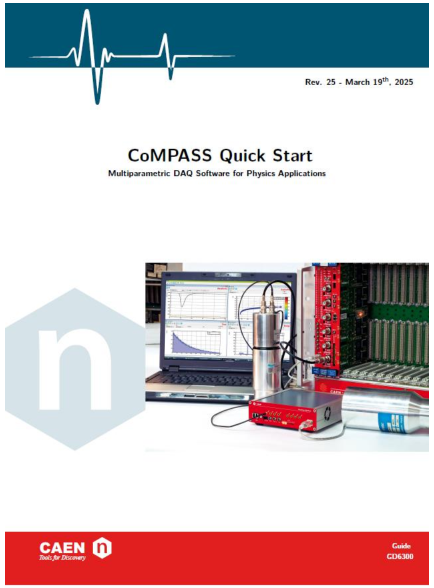
- Detector: Organic Glass Scintillator (OGS)
- HV: DT5790
- DAQ: DT5790 and DT5725S + DPP-PSD
- Software: CoMPASS
- Sources: ^{252}Cf
- Goals:
  - Raw signal check
  - Parameter setting
  - Energy and PSD Spectrum display
  - Energy selection set
  - PSD Spectrum ROI definition
  - FoM calculation and optimization
  - Check both DT5790 and DT5725S for performance comparison
  - Report compilation

Hands-on material

- CAEN Detector datasheet to check the ^{137}Cs Compton continuum and FoM Reference Test Report



- CoMPASS Quick Start Guide for the operation "how to…"



THANK YOU!

INTERNATIONAL SUMMER SCHOOL 2025

BACKUP SLIDES

Multiparametric Acquisition

Application Examples

Multiparametric DAQ Applications

(Some) **Experiments**:

- Gamma-ray spectroscopy of fission fragment nuclei with Clover detectors
- Dark Matter
- Neutrino experiment
- Photonuclear reactions
- Neutron capture

Medicine and radiopharmacy production

- Gamma Camera and nuclear medicine imaging
- Very Low Background Whole Body Counting System
- TDCR

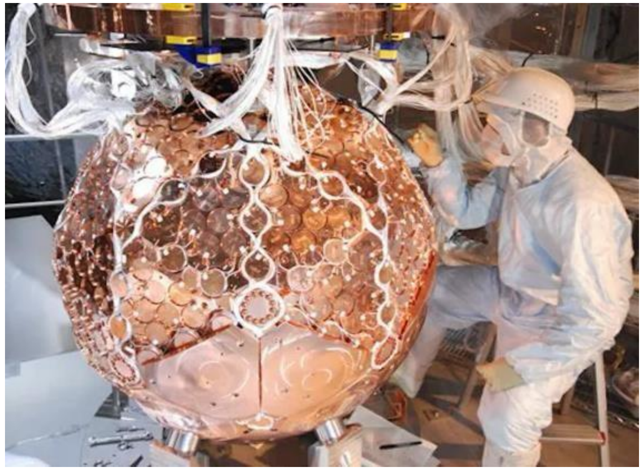
Safeguards

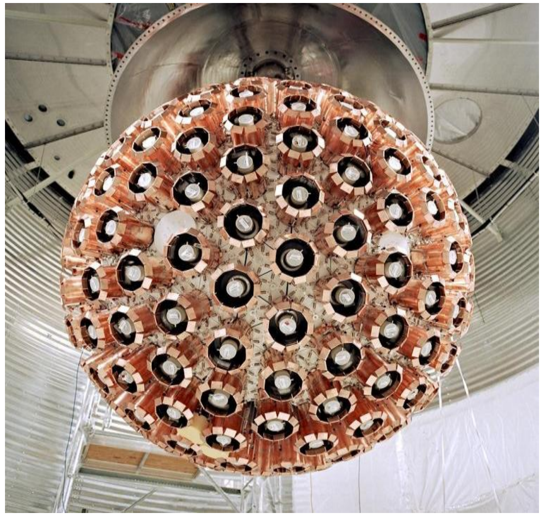
- Nuclear Fuel Verification (Fast Neutron Coincidence Collar System);
- Combined Gamma and Neutron measurements for SNM detection;
- Tagged neutron inspection systems
- Tap water monitoring system

Waste Assay Measurements

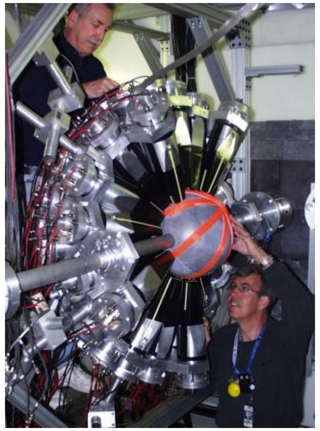
Multiparametric DAQ Applications: Experiments

- **Xmass** @ Kamioka (Japan): Dark Matter → **672** channels = 84 V1751s (1 GS/s, 10 bit) with custom FW (**ZLE**)





- **DEAP-3600** @ Snolab (Canada): Dark Matter. **255** PMTs = 32 V1720s (250 MS/s, 12 bit) + 5 V1740 (62.5 MS/s, 12 bit). Tot: **576** readout channels

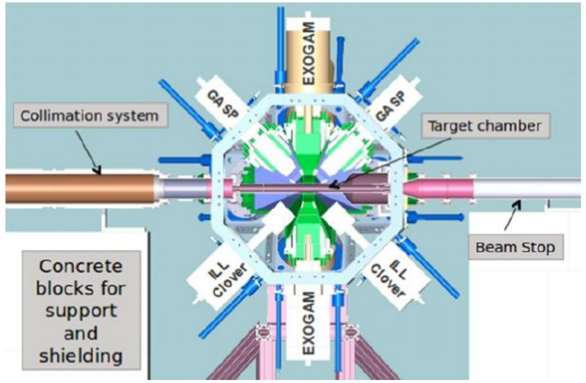


- **Dance** @ Los Alamos (USA): neutron capture. **162** segments (BaF_2 crystals): 12 V1730s (500 MS/s, 14 bit) with **DPP-PSD**

Multiparametric DAQ Applications: Experiments

- **Dhruva** @ BARC (India): gamma-ray spectroscopy of fission fragment nuclei → **Multi-detector** readout: 8 **Clover** detectors with **ACS** + 16 **$LaBr_3$** => 4 V1724s (100 MS/s, 14 bit, **PHA**) + 1 V1720 (250 MS/s, 12 bit) + 1 V1730 (500 MS/s, 14 bit, **QDC-PSD**)

- **Prospect** @ Yale/ORNL (USA): oscillation signature of sterile neutrinos. **360** PMTs = 22 x V1725s (250 MS/s, 14 bit) with **ZLE**

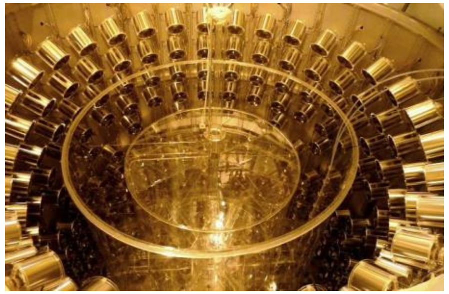


- **Exill** @ ILL (France): lifetimes of low-lying excited states. HPGe => 10 V1724s (100 MS/s, 14 bit + PHA) + $LaBr_3$ => V1751s (1 GS/s, 10 bit)

Multiparametric DAQ Applications: Experiments

- **XENON1T** @ LNGS (Italy): Dark Matter→ **248** PMTs = 32 V1724s (100 MS/s, 14 bit). **Trigger-less** DAQ with custom FW (**DAW**)

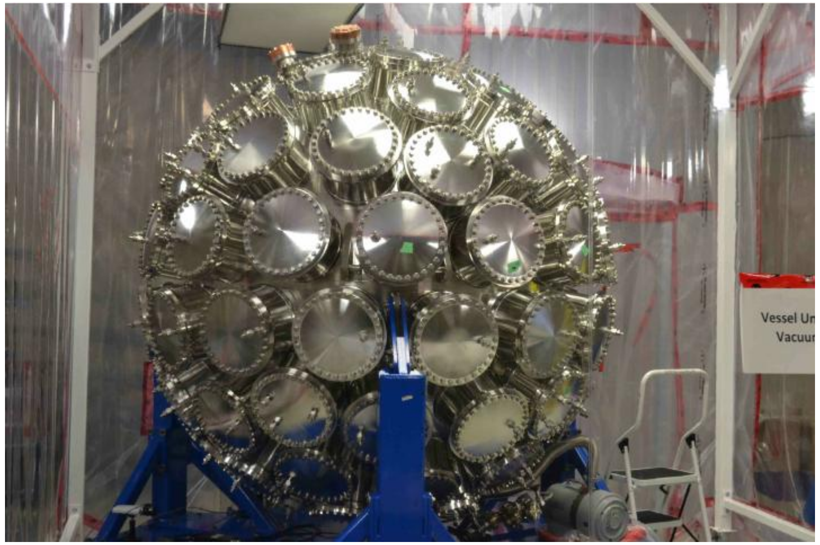
- **Eliade** @ ELI-NP (Romania): photonuclear reactions at Extreme Light Infrastructure → **Clover** detectors: 36 V1725 (250 MS/s, 14 bit + PHA) + **$LaBr_3$**: 2 V1730 (500 MS/s, 14 bit + QDC-PSD)

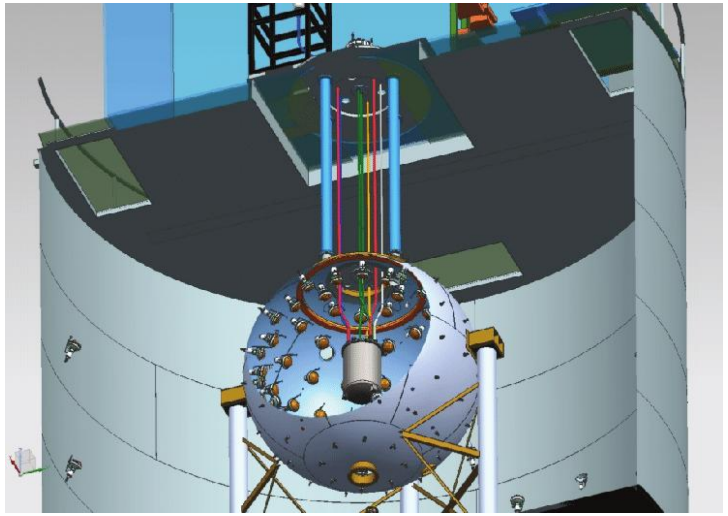


- **Double-Chooz** @ Chooze Power Plant (Ardenne, France): neutrino oscillation → **368** PMTs = 46 V1721s (500 MS/s, 8 bit)

Multiparametric DAQ Applications: Experiments

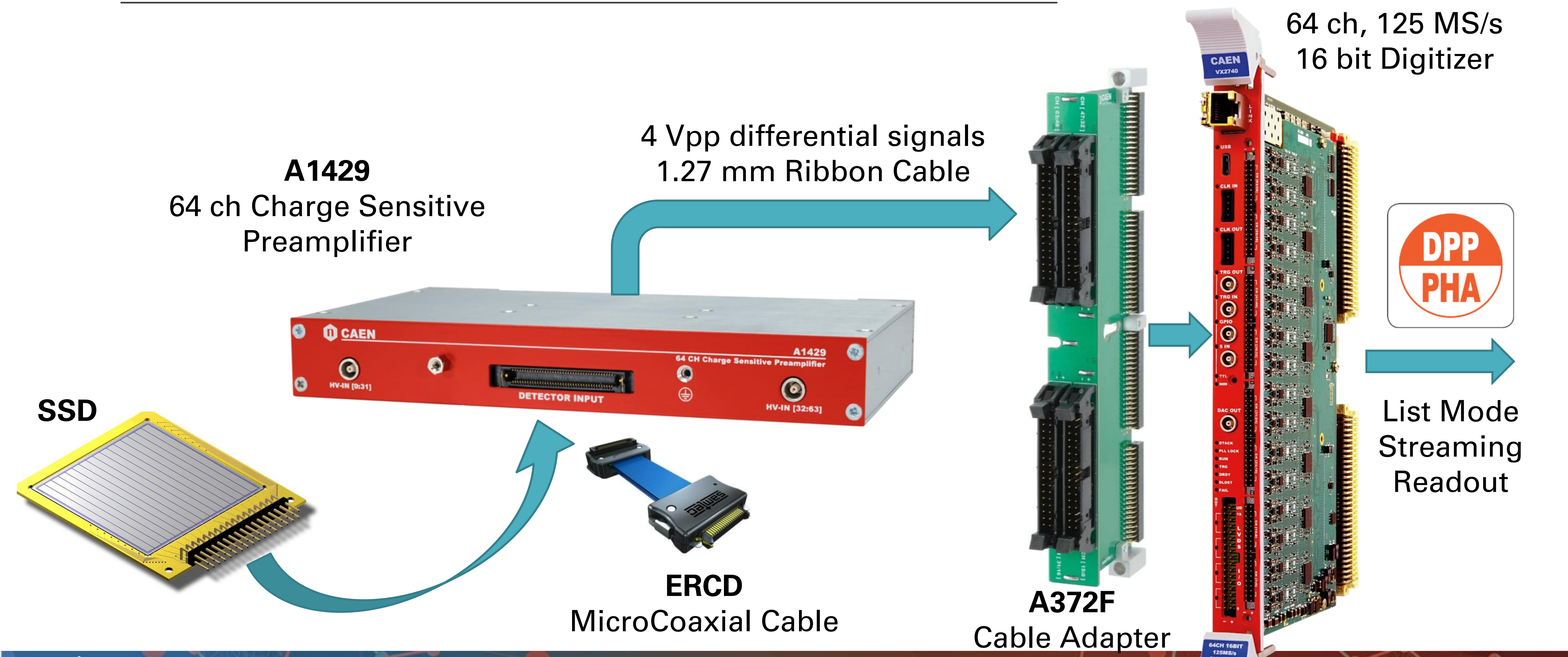
- **Mini Clean** @ Snolab (Canad): Dark Matter. 150 kg fiducial volume of liquid argon or 85 kg fiducial volume of liquid neon. with 92 sensitive photodetectors == > 8 V1720 (12bit, 250 MS/s) with Waveform Recoding firmware





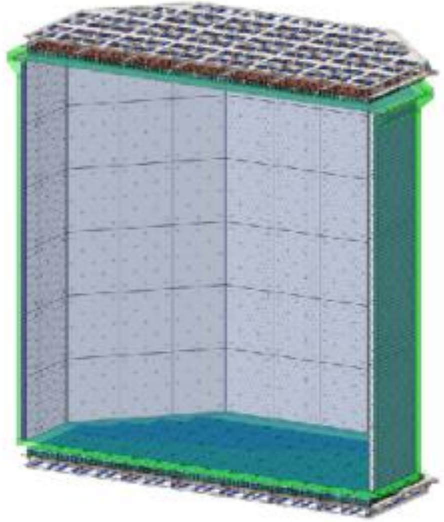
- **Dark Side** @ LNGS (Italy): Dark matter. Currently using V1720s **=> VX2745** (64 ch, 125 MS/s, 14 bit)

Use Case: SSD readout @ Numen (LNS)

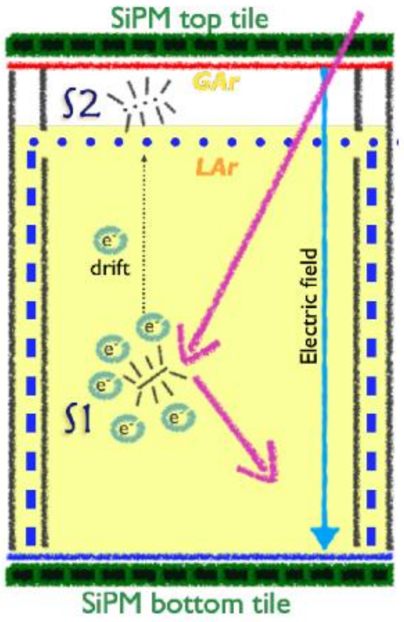


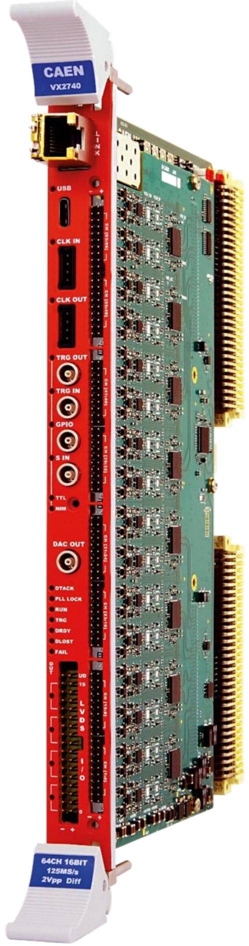
Use Case: Dual Phase TPC @Dark Side (INFN – LNGS)

Dual phase Time Projection Chamber (TPC) instrumented with large area SiPMs arrays, called Photo Detection Units (PDUs)



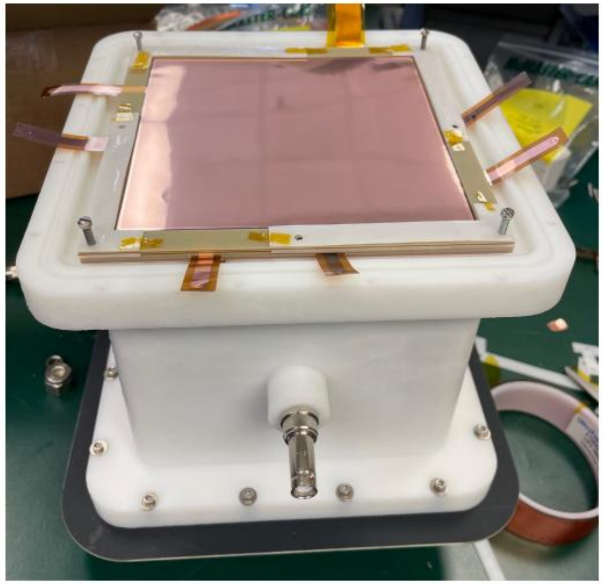
Dual Phase TPC (SiPM based)



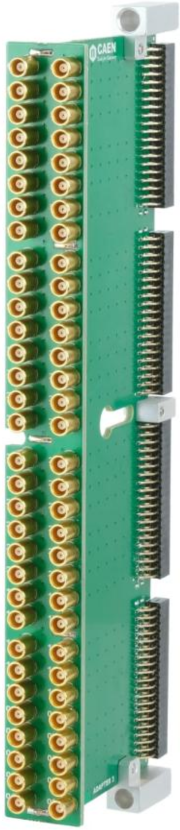


WAVEFORM RECORDING

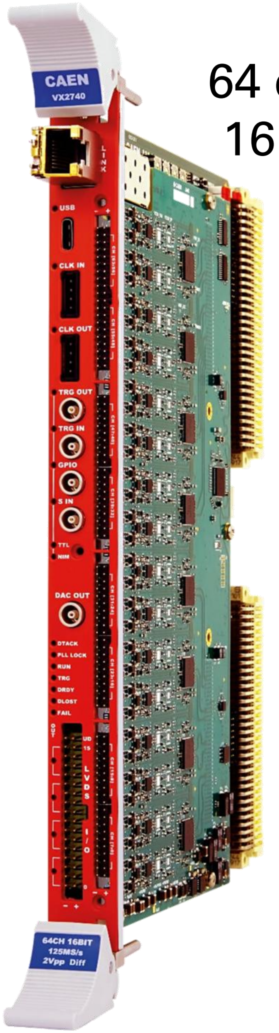
Use Case: SREFT (Spatially Resolved Fission Tracker) @ Los Alamos National Lab (USA)



GEM based TPC



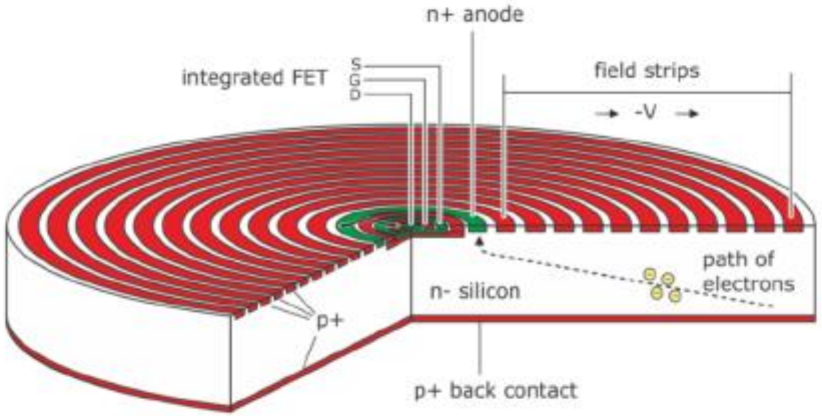
A372M
Cable Adapter



VX2745
64 ch, 125 MS/s
16 bit Digitizer

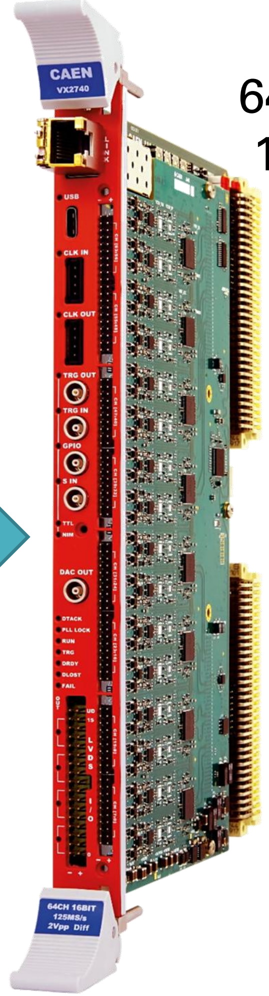
DPP PHA

Use Case: SDD detector @ Tristan (Katrin - KIT)



SDD Detector

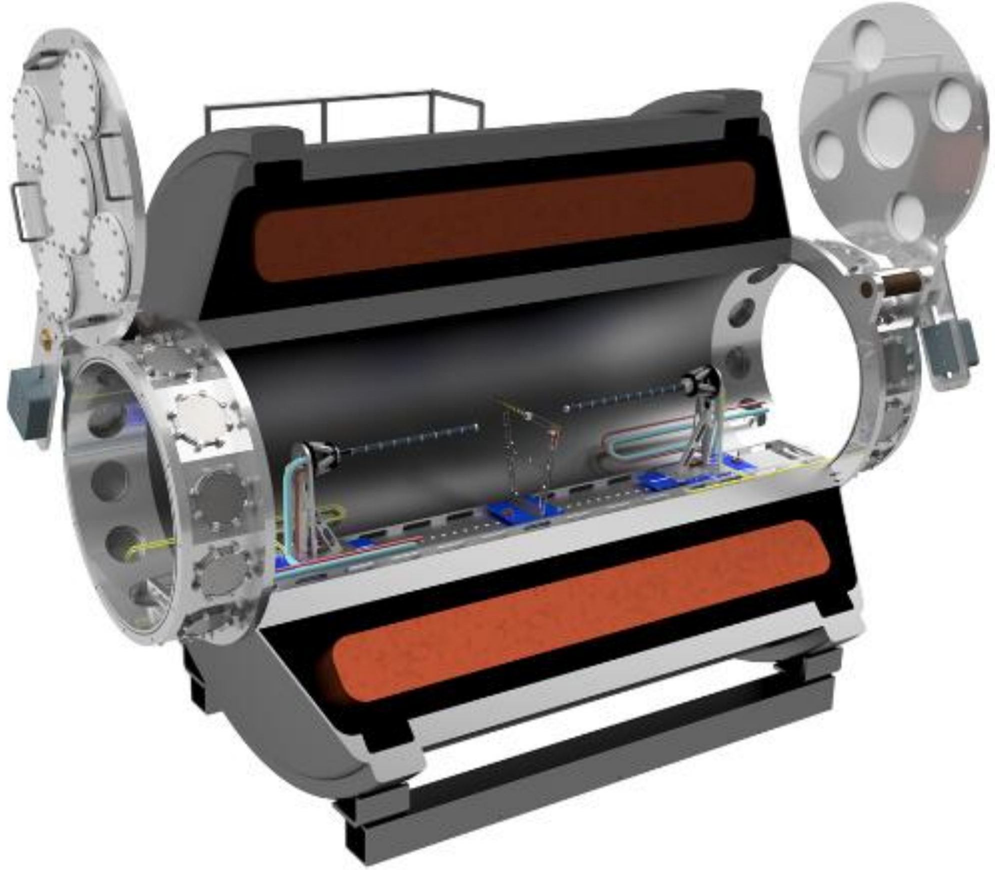
A372F
Cable Adapter

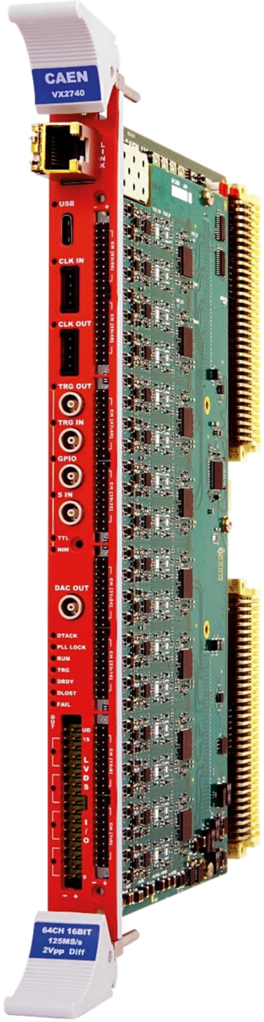


VX2745
64 ch, 125 MS/s
16 bit Digitizer

DPP PHA

Use Case: Solaris spectrometer @ FRIB (Michigan State Univ. – USA)



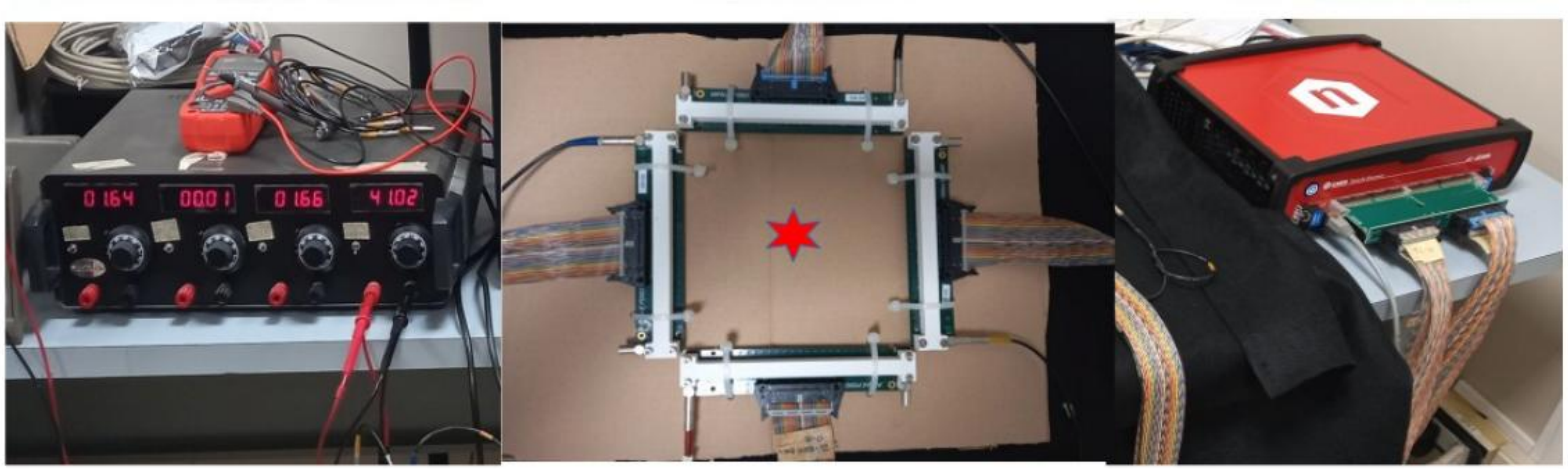


VX2745
64 ch, 125 MS/s
16 bit Digitizer

DPP PHA

Use Case: PI3SO project @ by INFN-Energy project

- PI3SO project: Proximity Imaging System for Sort and Segregate Operations):
- Low and intermediate level radioactive waste classification, conditioning and characterization
- Scanning system based on a set of **128 gamma-ray detectors based on CsI(Tl) crystal** scintillators readout by a silicon photomultiplier



DT2745
64 ch, 125 MS/s
16 bit Digitizer

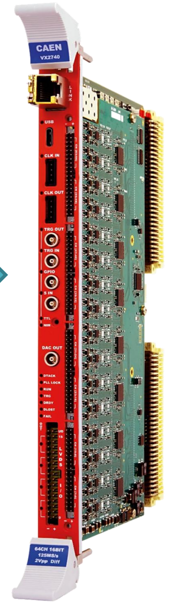
DPP PSD

A372F
Cable Adapter

Use Case: VENUS experiment @ VECC (India)

- 12 Clovers (total 48 channels)
- 12 BGO for each Clover (total 12 channels)
- 4 LEPS (segmented into 4) (total 16 channels)
- 2 segmented Clover (total 8 central contacts and 32 segments)
- 2 BGO corresponding to segmented Clovers (total 2 channels)
- 16 Fast scintillators (total 16 channels)

A372M
Cable Adapter



VX2745
64 ch, 125 MS/s
16 bit Digitizer

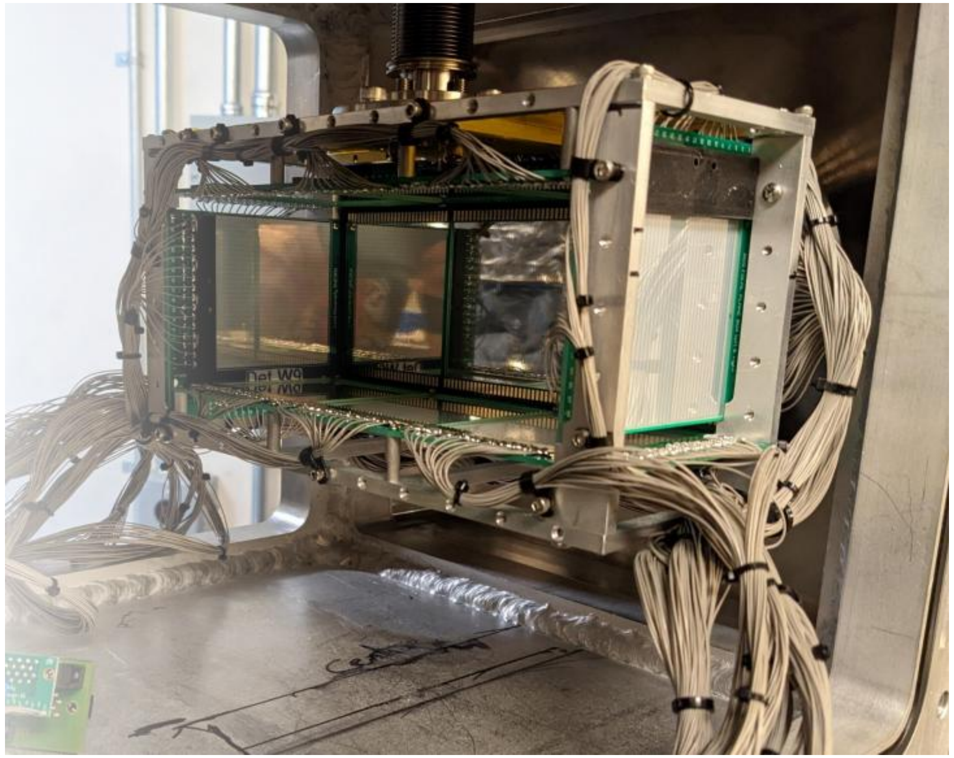
DPP PHA

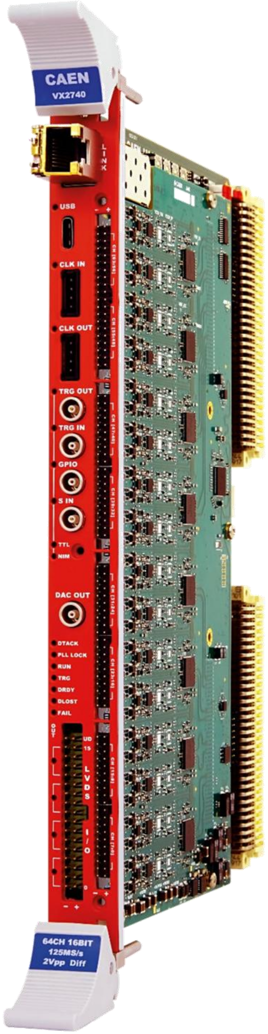
VX2730
32 ch, 500 MS/s
14 bit Digitizer

DPP PSD

Use Case: Livermorium (Z=116) Production @ LBNL

SuperHeavy RECoil (SHREC) detector: three side-by-side double-sided silicon-strip detectors (DSSDs) by Lund University





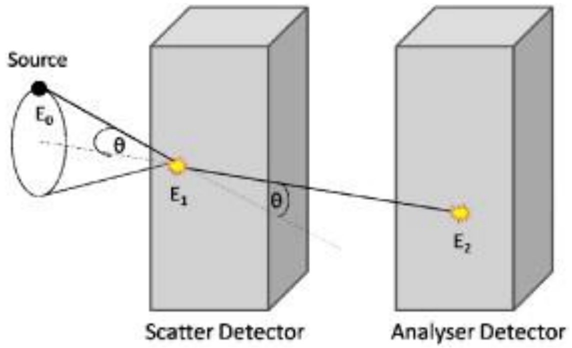
VX2740
64 ch, 125 MS/s
16 bit Digitizer

DPP PHA

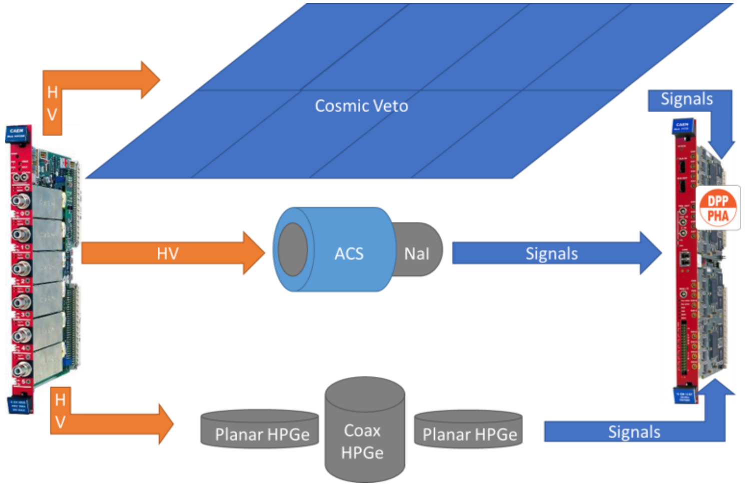
CoMPASS
CAEN

Multiparametric DAQ Applications: Medicine and radiopharmacy production

- **SPECT**: Single Photon Emission Computed Tomography @ Liverpool University (UK). Localization of a gamma-ray source through the reconstruction of interaction sequences in position and energy sensitive strip detectors: 4 V1724s + PHA



- **WBC**: Whole Body Counter system @ JRC (Italy): measurement in very low background. Gamma Spectroscopy with multi-input 16 k MCA and Anticoincidence with plastic cosmic veto: 2 V1725s + PHA and PSD

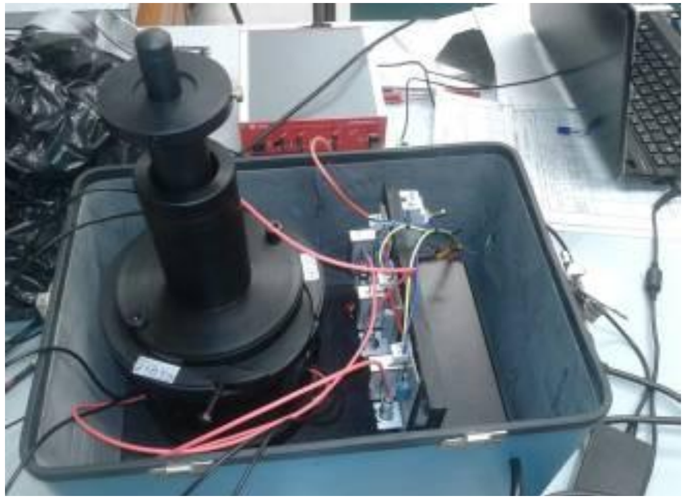


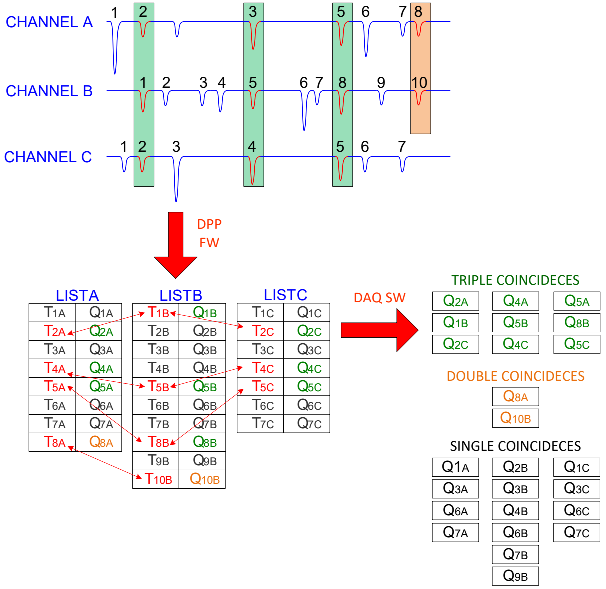
Multiparametric DAQ Applications: Medicine and radiopharmacy production

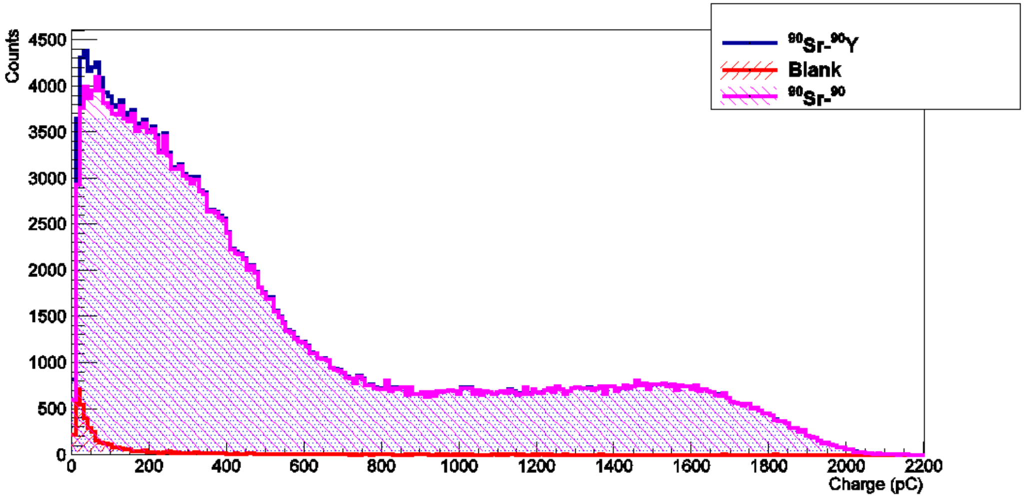
- **TDCR** @ ENEA (Italy): evaluation of a radiosource activity by means of the Triple to Double Coincidence Ratio.

Replacement of the traditional analog chain (based on the MAC3 analog module) to readout and process the signal from 3 scintilattors

==> DT5720/DT5725/DT5730/DT5751 + DPP-PSD firmware and dedicated software running the TDCR analysis on the acquired data

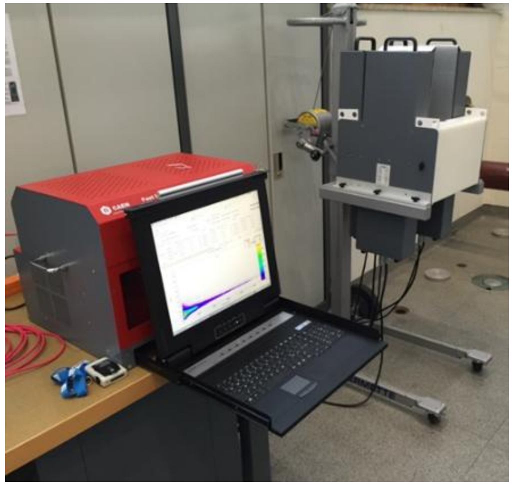




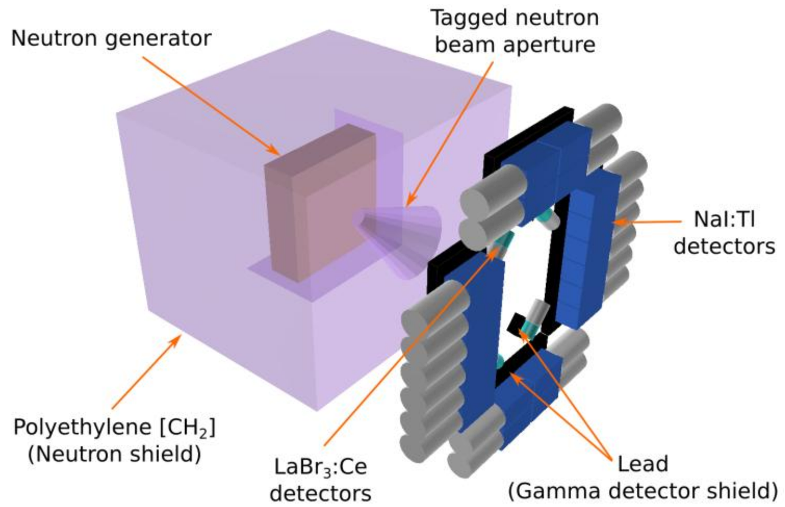


Multiparametric DAQ Applications: Safeguards

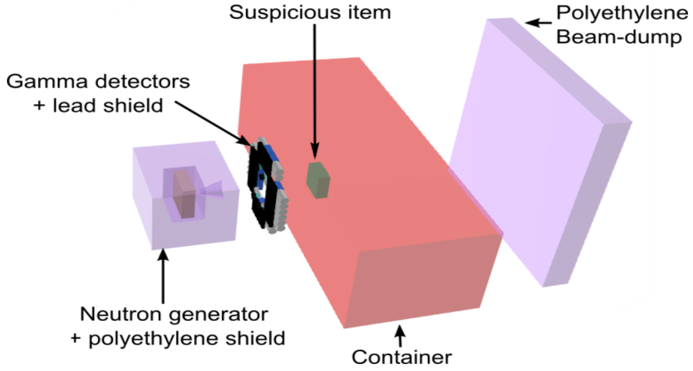
- **Fast Neutron Collar** @ IAEA (Austria): non destructive assay of NPP's Fresh Fuel Rods . 4 V1730s (500 MS/s, 14 bit) **with fast waveform readout (300 MB/s) and PSD**



Statistical uncertainty in the measurement of the ^{235}U enrichment < than 1% with 15 minutes acquisition time. System immune to Gd mass variation

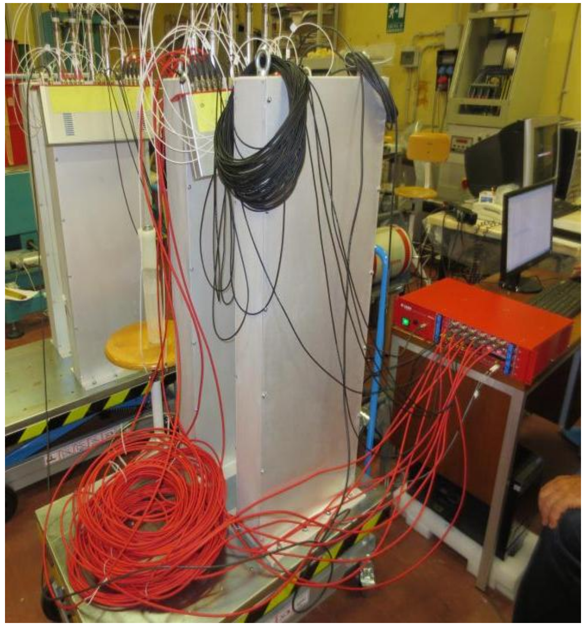


- **Relocatable Tagged Neutron Inspection System (C-BORD)** @ Rotterdam port (The Netherlands): movable system for detection of illicit material via TOF (alpha-gamma) and Energy correlation.



Multiparametric DAQ Applications: Safeguards

- **EDEN** @ ENEA (Italy): uncover radioactive and nuclear threats including those in the form of Improvised Explosive Devices (IEDs), the so-called “dirty bombs” via the Neutron Active Interrogation (NAI) technique and Differential Die-Away Time Analysis method ==> He3 tubes + **V1495 and custom coincidence and counting FW**



- **Tap Water Monitoring (Water-NET)** @ North Waterworks Plant, Warsaw (Poland). Mitigate radiological threats like:
    - Emergency at nuclear facilities
    - Transportation accident involving the shipment of radioactive material
    - emergency involving the loss, theft, or discovery of radioactive material (as the so-called orphan sources);
    - a terrorist attack utilizing radioactive materials, such as a "dirty bomb”...