From Analog to Digital DAQ Transition In Physics Application

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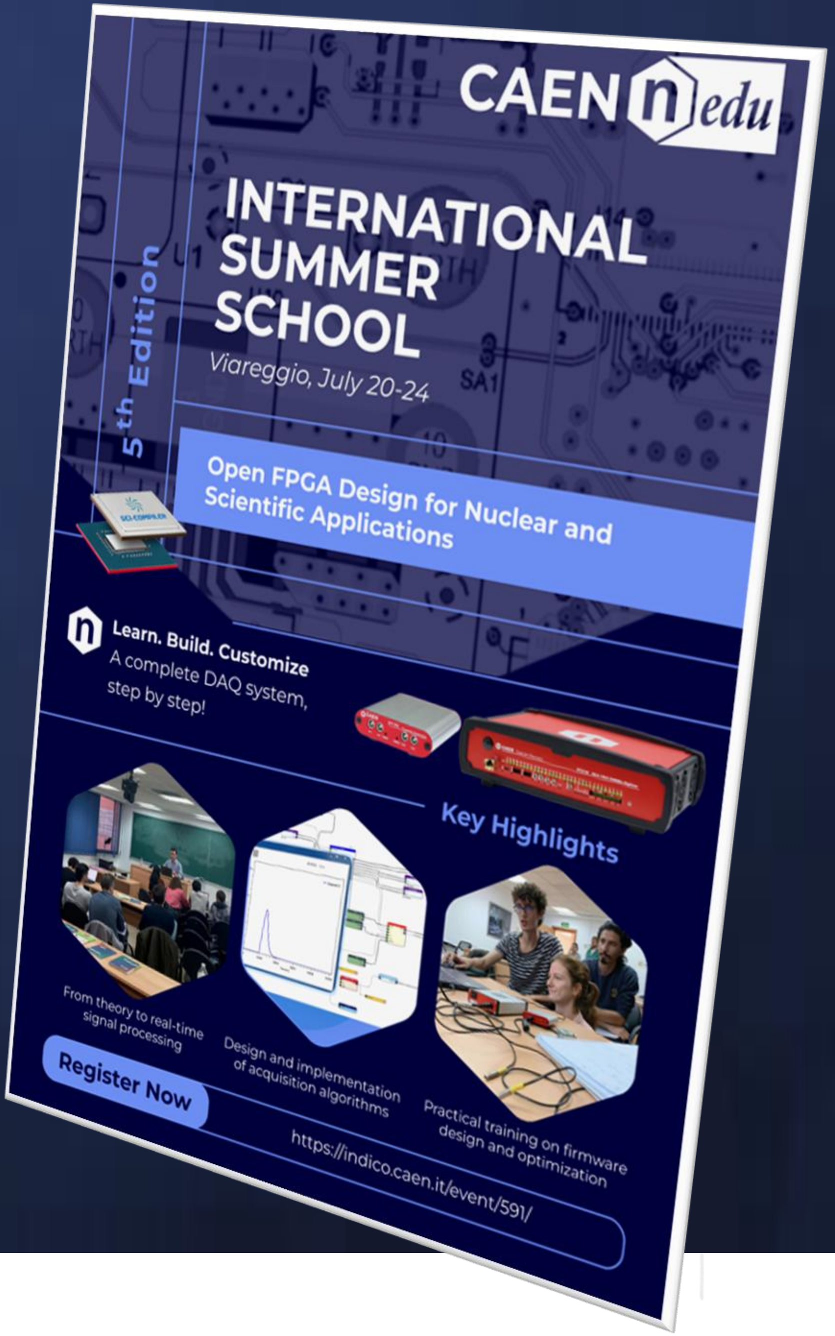

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Summary

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- ›Detectors
- ›Measurements and analysis

02 **Detector Readout Electronics**

- ›Preamplifiers (CSP, Shaping Amplifiers, Wideband)
- ›Analog Electronics (ADC, QDC, CFD, TDC, TAC)
- ›Comparison between analog and digital readout chain
- ›Waveform digitizers
- ›Data streaming and online data processing
- ›Oscilloscope mode and List mode

03 **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

04 **Digital vs Analog: advantages and drawbacks**

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Fundamentals

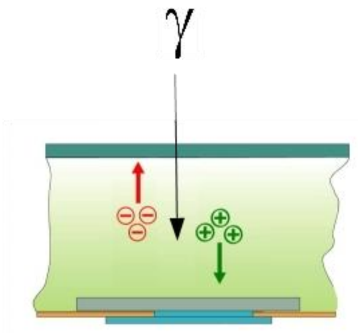
Definition

SPECTROSCOPY

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

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



Detector

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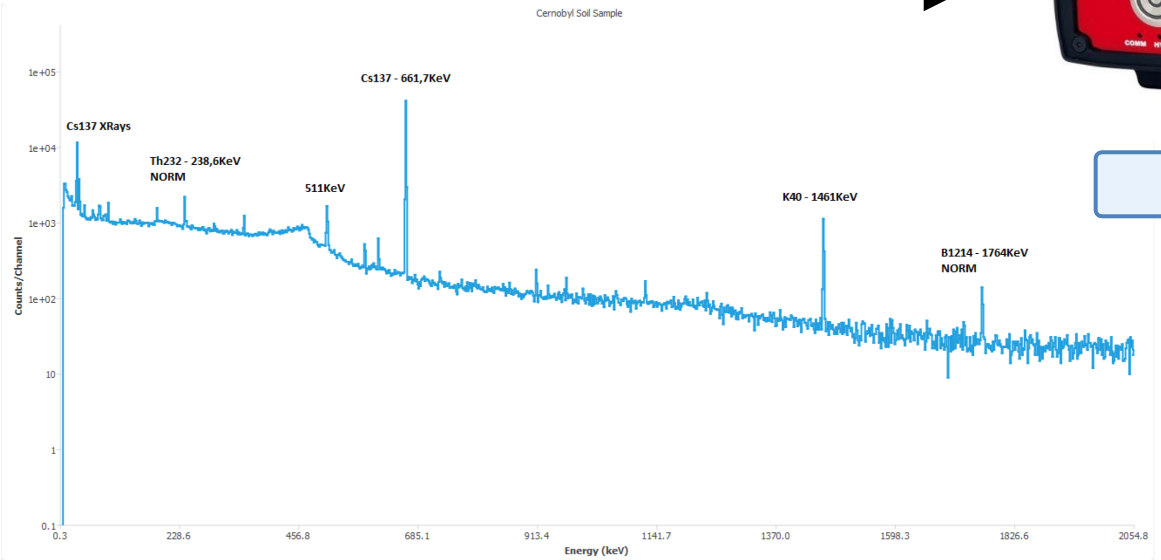


Energy Spectrum

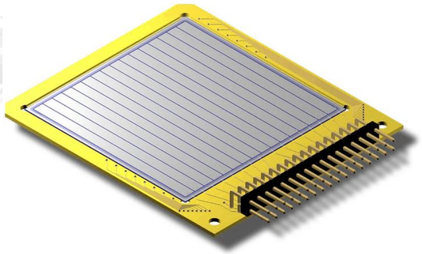
Detectors in a nutshell

High resolution spectroscopy

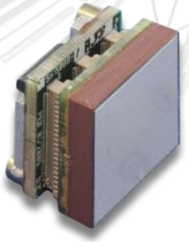
Semiconductors: **HPGe, Silicon, CZT**

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

HPGe



Silicon



CZT

Mid-resolution spectroscopy

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

Bigger crystal for higher detection efficiency

NaI / CsI

LaBr3 / CeBr3

Low-resolution spectroscopy

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

Typically used for counting or active shieldings (AntiCompton or Anticosmic Shield)

BGO / Plastic

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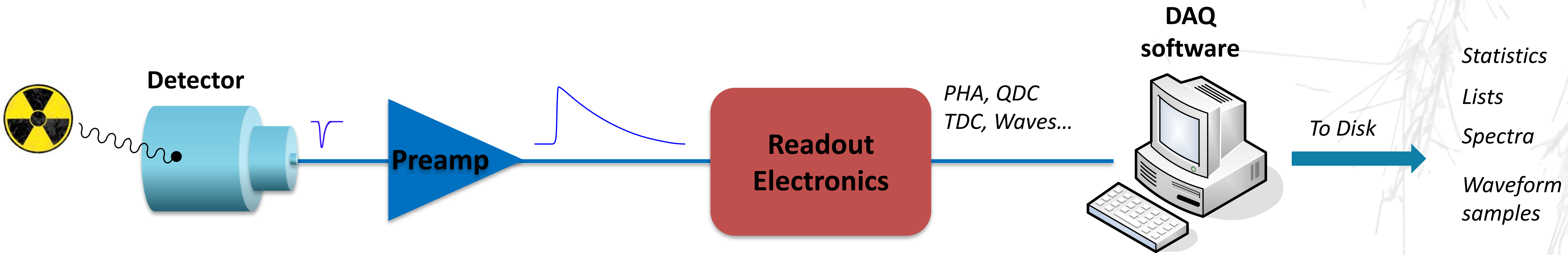
Measurements and analysis - 1

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.

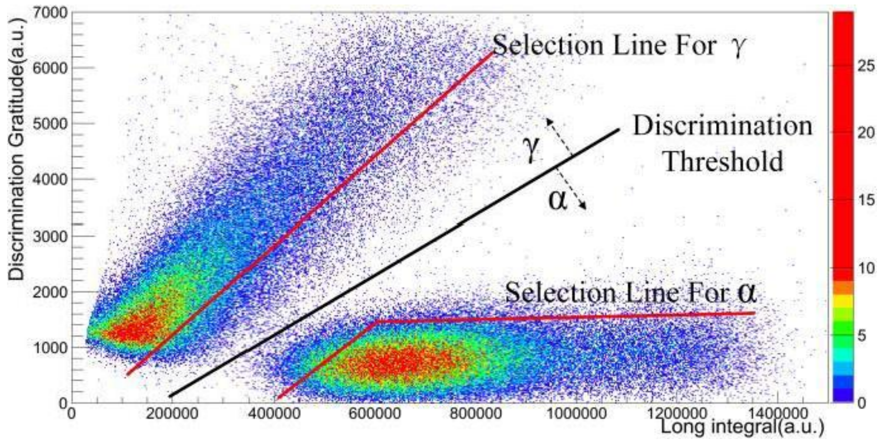
- **Charge Sensitive Preamps**: optimized for energy resolution, slow output, changes shape
- **Fast (current) preamplifier**: mostly used for timing applications, fast output

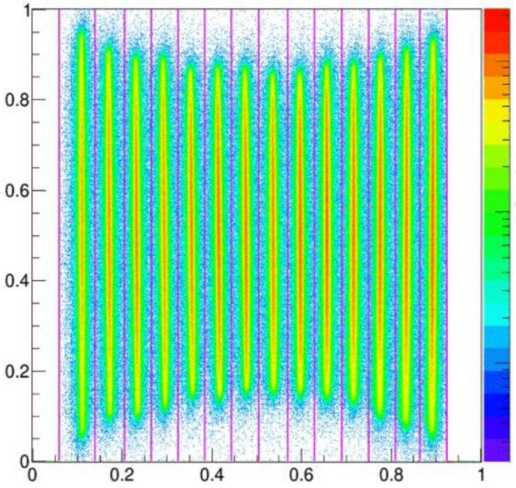
Readout electronics: aims to acquire pulse characteristics such as Pulse Height (PHA), charge (QDC), Timing (TDC), Shape, and, in some cases, full waveforms

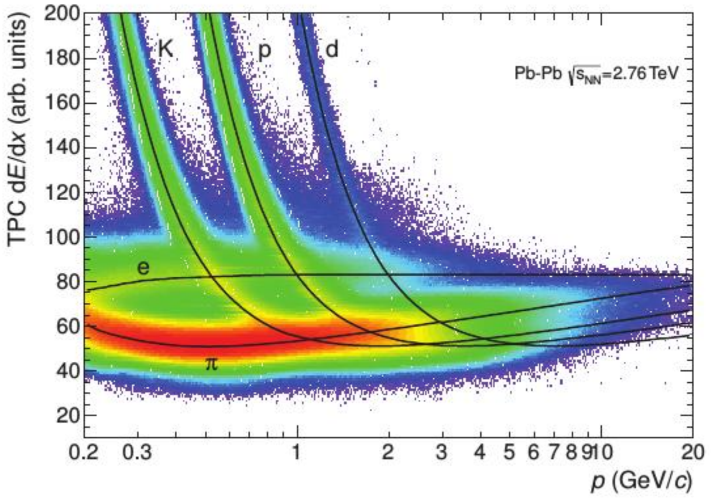


Measurements and analysis - 2

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

Preamplifiers

Preamplifiers: WHY?

- We need to extract the signal from the detector without degrading the signal-to-noise ratio and make it suitable to be handled by other electronics placed, in principle, "far away" to the detector.
- Preamplifiers are the **first stage** of the **Front End** electronics: they have to be placed as close as possible to the detector.
- There are several Preamplifier Types to be chosen according to the **detector features** (gain, timing, dead time, etc.) and to the **information** we want to extract from the signals.
- In most applications, we want to know **Energy** and/or **Time** of the interacting particles:
  - Charge Sensitive Preamplifier
  - Linear Amplifier
  - Transimpedance Amplifier
  - Wideband Amplifier
  - Parasitic-Capacitance Preamplifier

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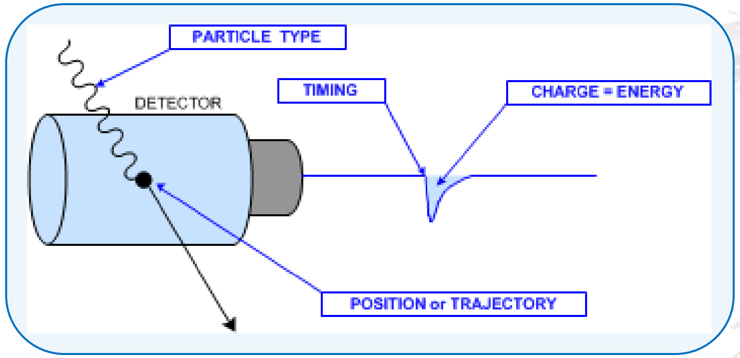
Charge Sensitive Preamplifier

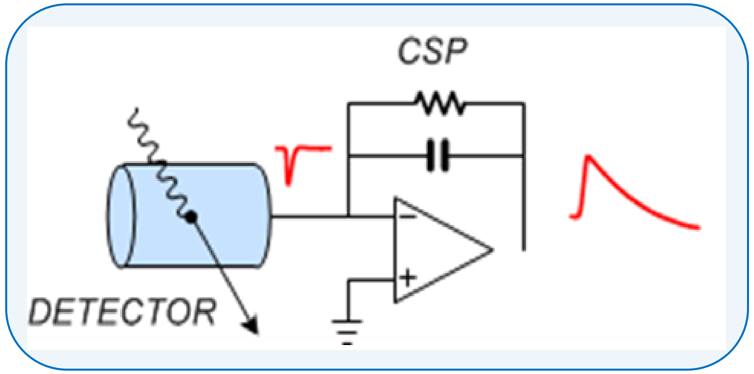
Some detectors (e.g. Scintillator+PMT, Ge, Si, PT,…) give **Energy** as the **Area** of output current pulses = **Charge**



The Charge Sensitive Preamplifier integrates the signal out coming from the detector and **converts** the **charge** into a **voltage amplitude**

Ideally, CSP is just a simple capacitor C, but in order to avoid saturation, C is put in parallel with a discharging resistor R

CSP output pulses have fast rise time (as the detector collection time) and **long exponential tail** with decay time $\tau = RC$



The **sensitivity** (charge-voltage amplitude conversion) is **set by capacitor**: $V_{out} = Q_{in}/C$

Charge Sensitive Preamplifier

CSP is mainly characterized by:

Sensitivity →	Gain
Noise →	Resolution
Rise Time →	Timing
Decay Time →	Maximum Rate (Pile-up)
Input Capacitance →	Detector (+cable) capacitance

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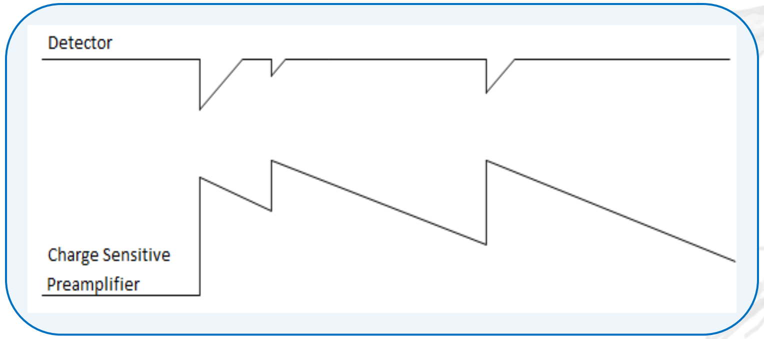
Shaping Amplifier

CSP decay time τ ≫ detector signal width: **pile-up** of successive events can arise

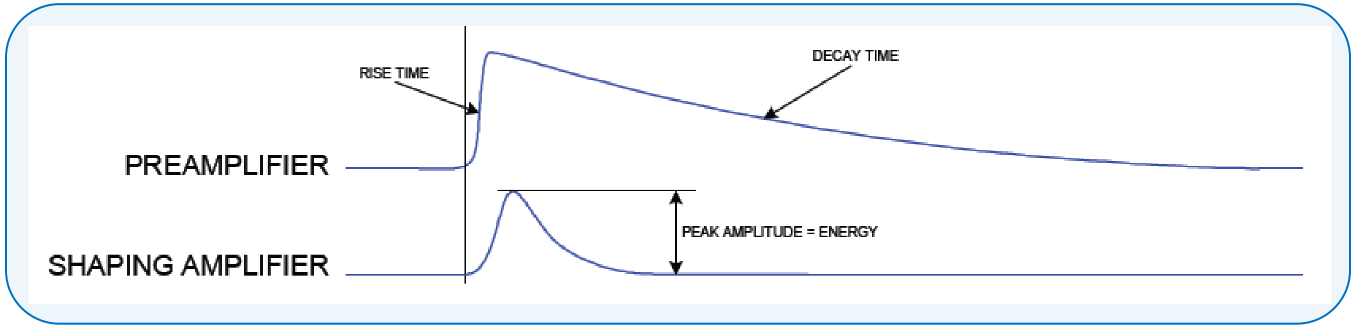


Sharp CSP output peak: a peak-sensing ADC can introduce a **conversion error**

A **Shaping Amplifier** solves both issues:

Reshapes the CSP signal into a **quasi-Gaussian** pulse; width set by the **shaping time** (affects energy resolution)

Pulse **height** remains proportional to the energy deposited by the particle



Multichannel Analyzer

- A **Multichannel Analyzer** (MCA) is used in order to perform the digitization of the peak value of the Shaping Amplifier output signal
- Based on a **peak sensing circuit:** it recognizes the maximum amplitude of the input signal within a gate and holds this value
- The MCA can internally generate the gate, using a Low Threshold Discriminator (external gate can be provided)
- An ADC performs the **digitization** of the peak value of the input signal. It needs a conversion time to complete the operation.
- For each pulse, the MCA adds a count to one of the bins of an **histogram** according with the pulse height. The histogram is then transferred to the user PC for the data analysis.
- In order to precisely know the **dead time** of the system (i.e. the time when the acquisition was “blind”) a live time clock is also provided

Wideband Amplifier

Whenever a **fast detector** is used (e.g. diamonds, fast PMTs, SiPMs…), if you do not want to loose timing capabilities, a **fast amplifier** must be used.

In this case, **a CSP is not the right choice!**

An amplifier that does not modify the signals shape is requested:

$$Bandwidth \approx \frac{0.35}{Rise\ Time}$$

- Fast Linear Amplifier
- Wideband Amplifier

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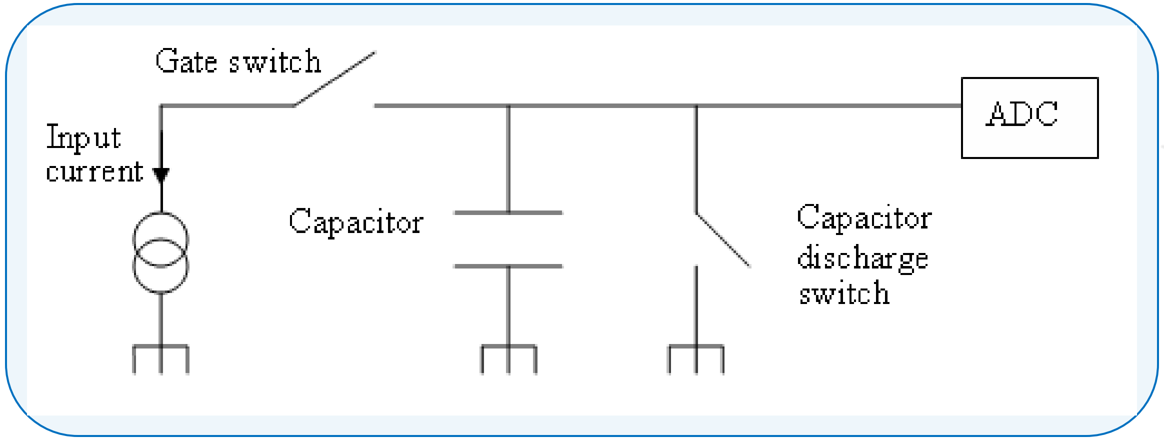
Charge to Digital Converter – QDC

In this case, it is possible to **digitize** directly **the area** of the pulses with no charge-to-amplitude conversion.

A **Charge to Digital Converter** (QDC) is a device often used for this purpose: it operates the current pulse integration through a capacitor and the potential difference due to the stored charge is converted to a digital number by an ADC.

The QDC needs a logic signal, a Gate, that enables the charge integration: while the Gate is active, the QDC integrates the input pulse. The Gate falling edge stops the charge integration and freezes the charge value.

After the digital conversion, the QDC needs to discharge the capacitor: **a dead time** is needed to complete the discharge and make the QDC ready for a new conversion.

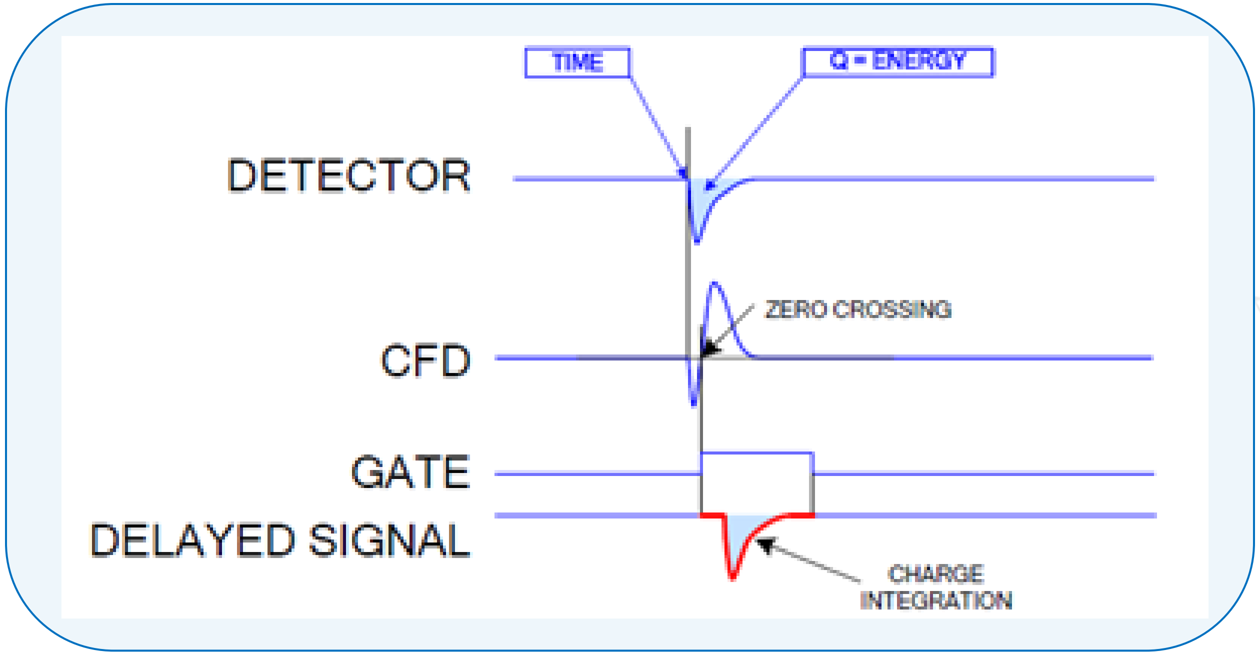


Charge to Digital Converter – QDC

In some applications (most likely in beam experiments) the Gate is provided by the system that knows in advance when the signals have to be integrated.

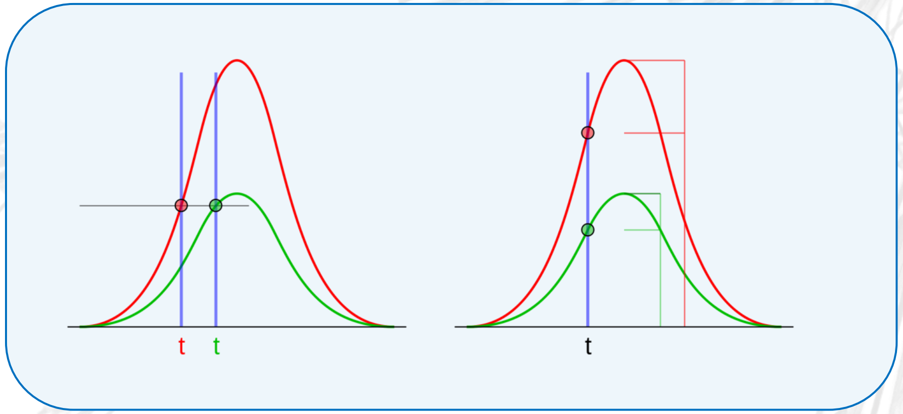
When this is not the case, **Gate generation** from the detector signals is needed: the input is split in two branches, one sent to a **discriminator** to produce the logic gate.

A **delay line** (typically a long cable) on the other branch ensures the analog pulse arrives within the active Gate window.



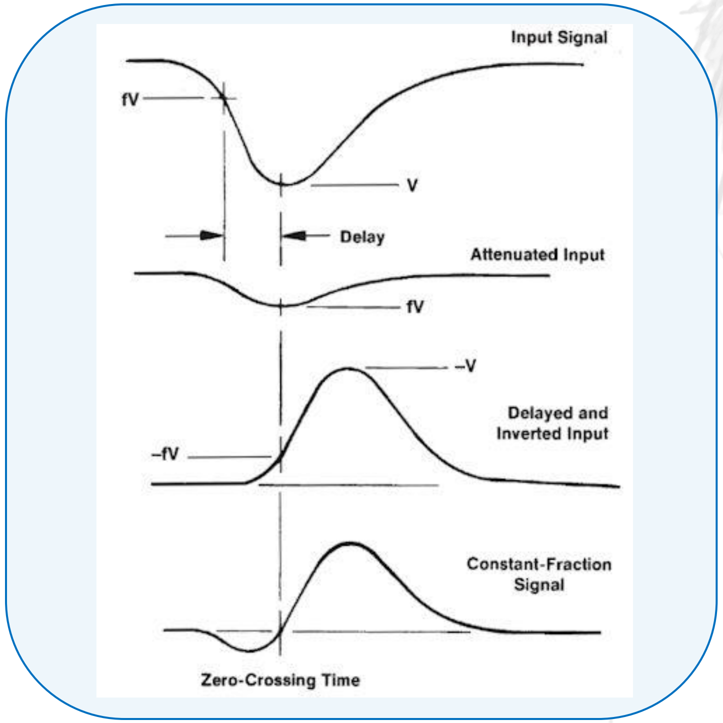
Charge to Digital Converter – QDC

A **Constant Fraction Discriminator** (CFD) eliminates the **time walking effect**: unlike a fixed threshold, it triggers when the signal reaches a fixed **fraction** of its peak, making timing independent of amplitude.



The CFD splits the input: one branch is **attenuated**, the other **delayed** and **inverted**. Their sum has a zero crossing **independent of pulse height**, triggering the discriminator output.

If the discriminator output is too narrow for the QDC Gate, a **Gate Generator** (monostable) produces a fixed-width output pulse to provide a proper Gate signal.



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Time Measurements

Another important information in physics measurements is **Time:** crucial to study the **time behavior** of the phenomena under investigation

It is also necessary to establish **event correlations** especially whenever a multi-detector system is used, necessary to associate the time information to the energy data

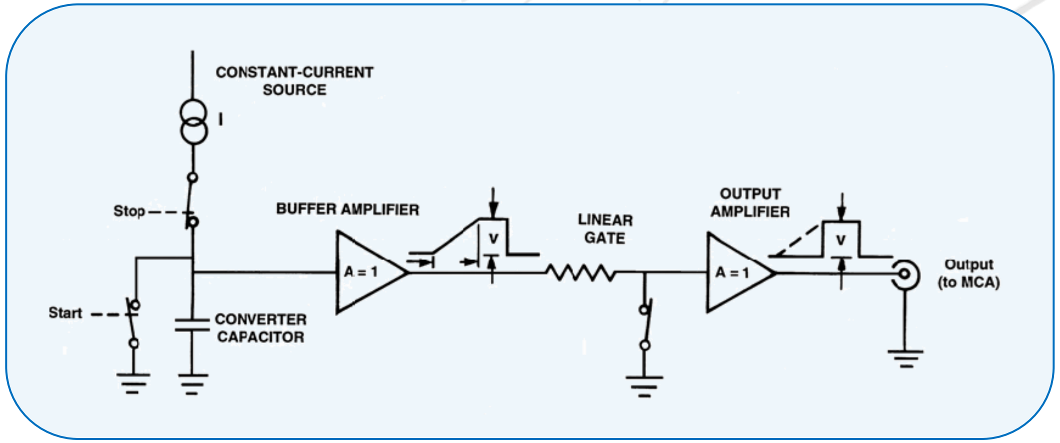
The timing resolution required in physics experiments can be as low as a **few ps**

Achieving ps-level timing resolution is extremely demanding:
at 1 ps, even 0.3 mm of extra cable length introduces a measurable delay — mechanical precision matters as much as electronics.

Time to Amplitude Converter – TAC and Time to Digital Converter – TDC

The **Time to Amplitude Converter** is a device able to measure the time interval between two consecutive pulses usually provided by CFD (because of the improved timing resolution of these devices): **Start and Stop**

It provides an analog output whose amplitude is proportional to the time interval



The output is then sent to a MCA to digitize the amplitude value

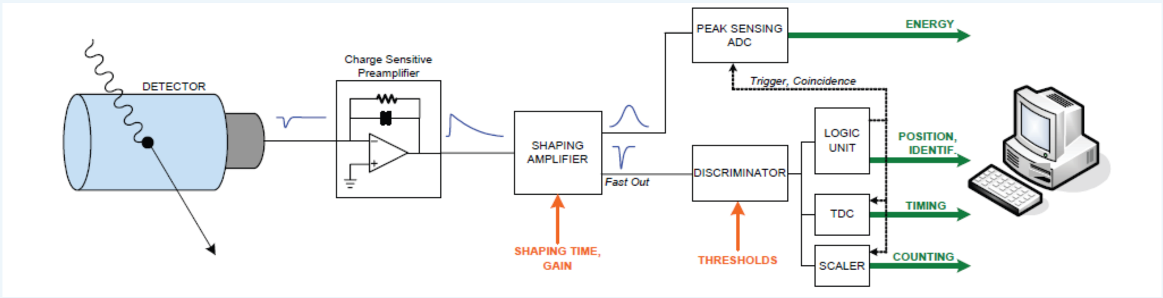
The **Time to Digital Converters** can provide a digital representation of time intervals between pulses with digital counters

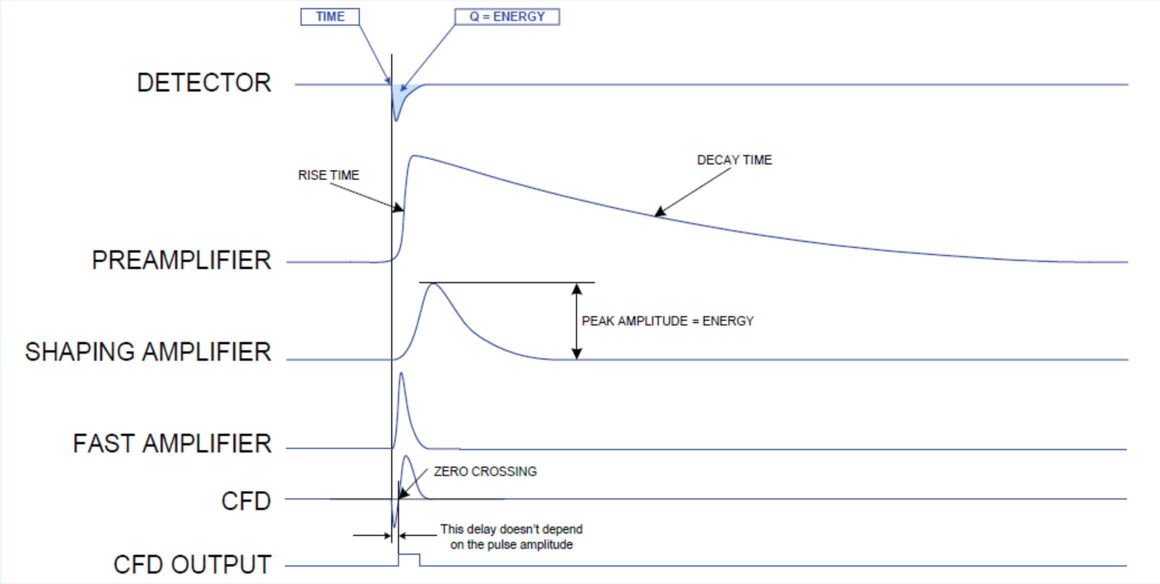
Two main families of TDC are commonly used, according to the needs:

- **Start – Stop**: it measures the time interval between two consecutive pulses
- **Multi-hit**: the time of arrival of different pulses within a gate is measured latching a clock counter every time a hit is observed (**time stamping**)

- **CSP** integrates the detector signals → it converts the charge into voltage amplitude. The charge information (energy) is here represented by the **Pulse Height**.
- A **Spectroscopy Amplifier** follows the CSP. Its role is to further amplify the signal, reduce the width of the CSP signals and make it suitable for a **Multichannel Analyzer (MCA)**.
- The MCA detects the peaks of the input pulses, digitizes these values and builds a histogram (Energy Spectrum) of the heights: **Pulse Height Analysis**.

- To preserve the timing information, the rising edge can be treated by a **fast (or timing) amplifier** that usually feeds a chain made out of a discriminator, a TDC and/or a scaler for the timing/counting acquisition.
- Further modules can make coincidences, generate triggers or give information about the pulse shape for particle identification.





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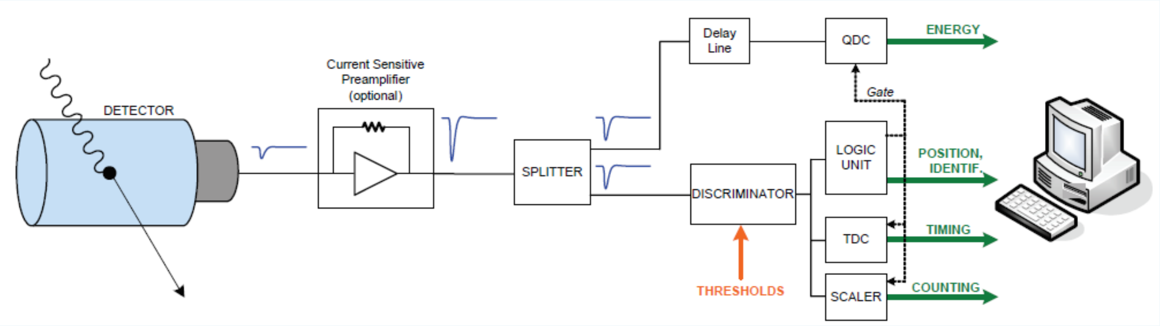
The QDC Chain

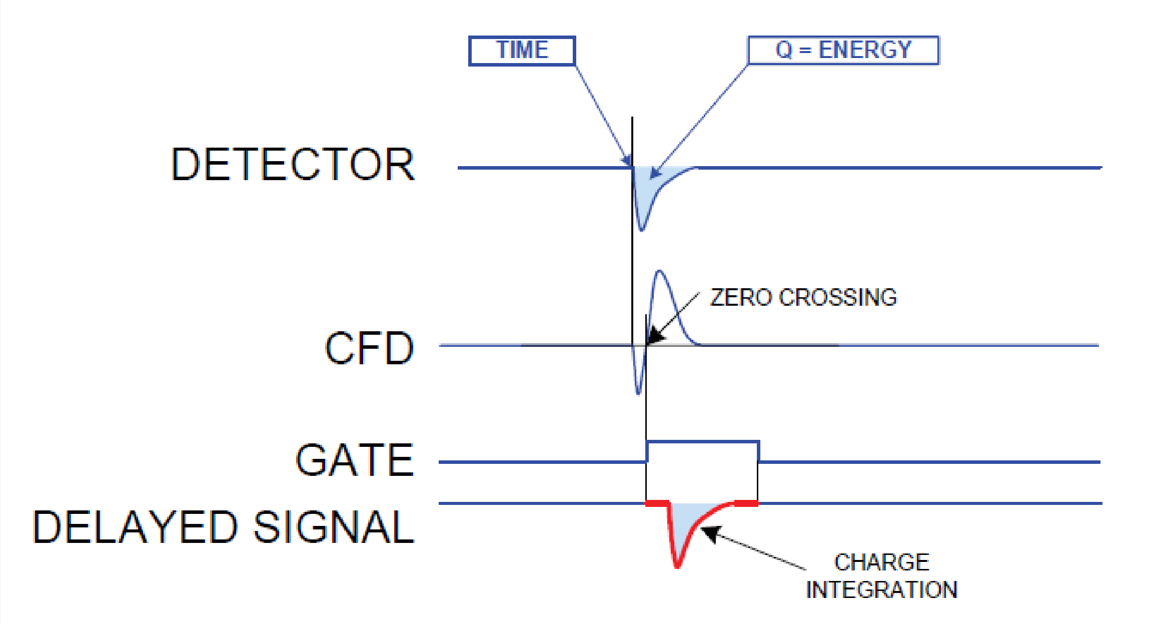
- Unlike the CSP, the **Current Sensitive Preamplifier** is a linear fast amplifier that **doesn't change the shape** of the signal. Its output is normally a very short pulse (some tens of ns or even less)

- Sometimes the preamplifier is not even necessary, like in the case of some PMT-based detectors.

- The **QDC** is a **pure charge integrator**. It requires a gate signal that defines an integrating window.
  In some applications (e.g. beam experiments) the gate is provided by the system

- In other cases, it is necessary to generate the gate from the detector signals; to do that, you need to split the signals, send one branch to the discriminators and use a coincidence logic. It is also necessary to add a delay line (typically a long cable) on the signal path to the QDC input in order to match the pulses with the gate (which arrives with some latency respect to the analog pulses that produced it).





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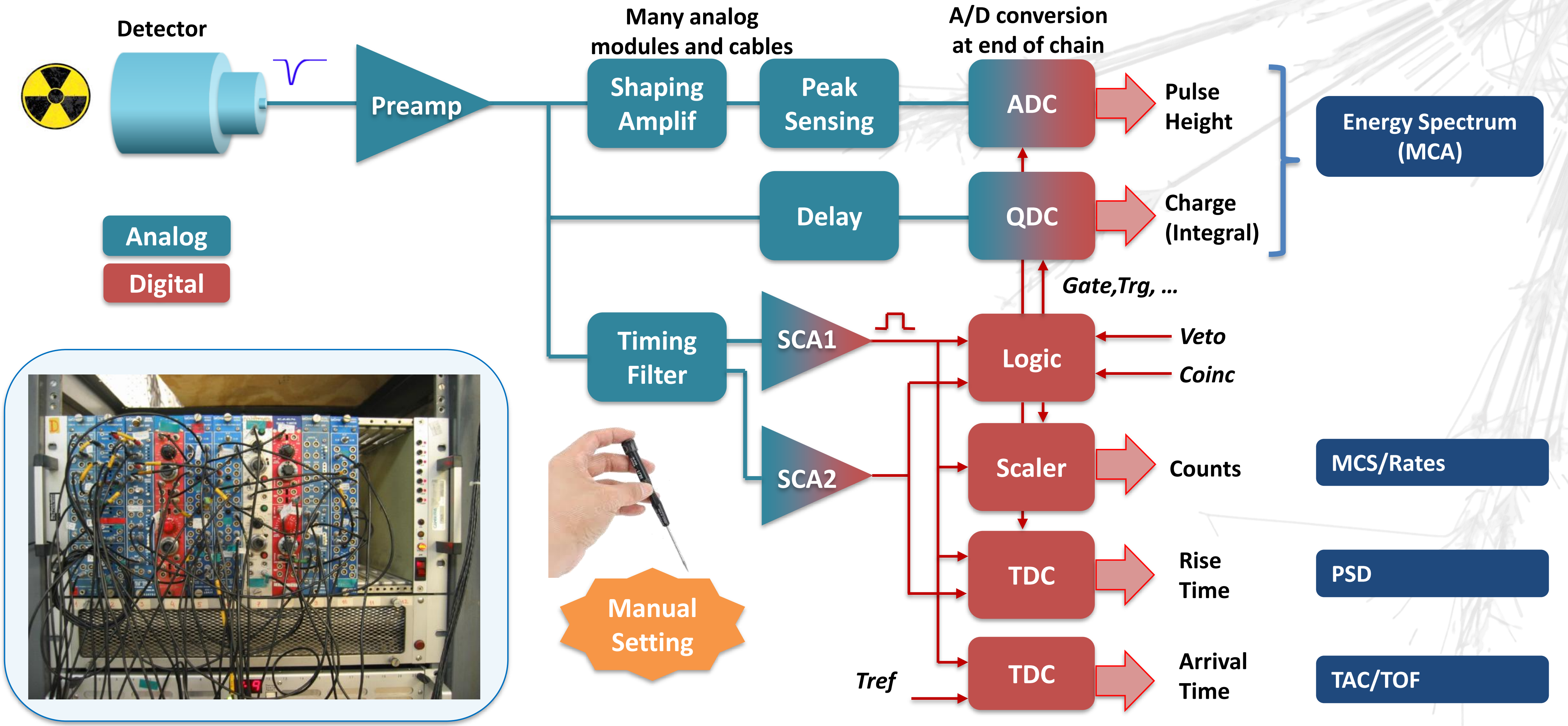
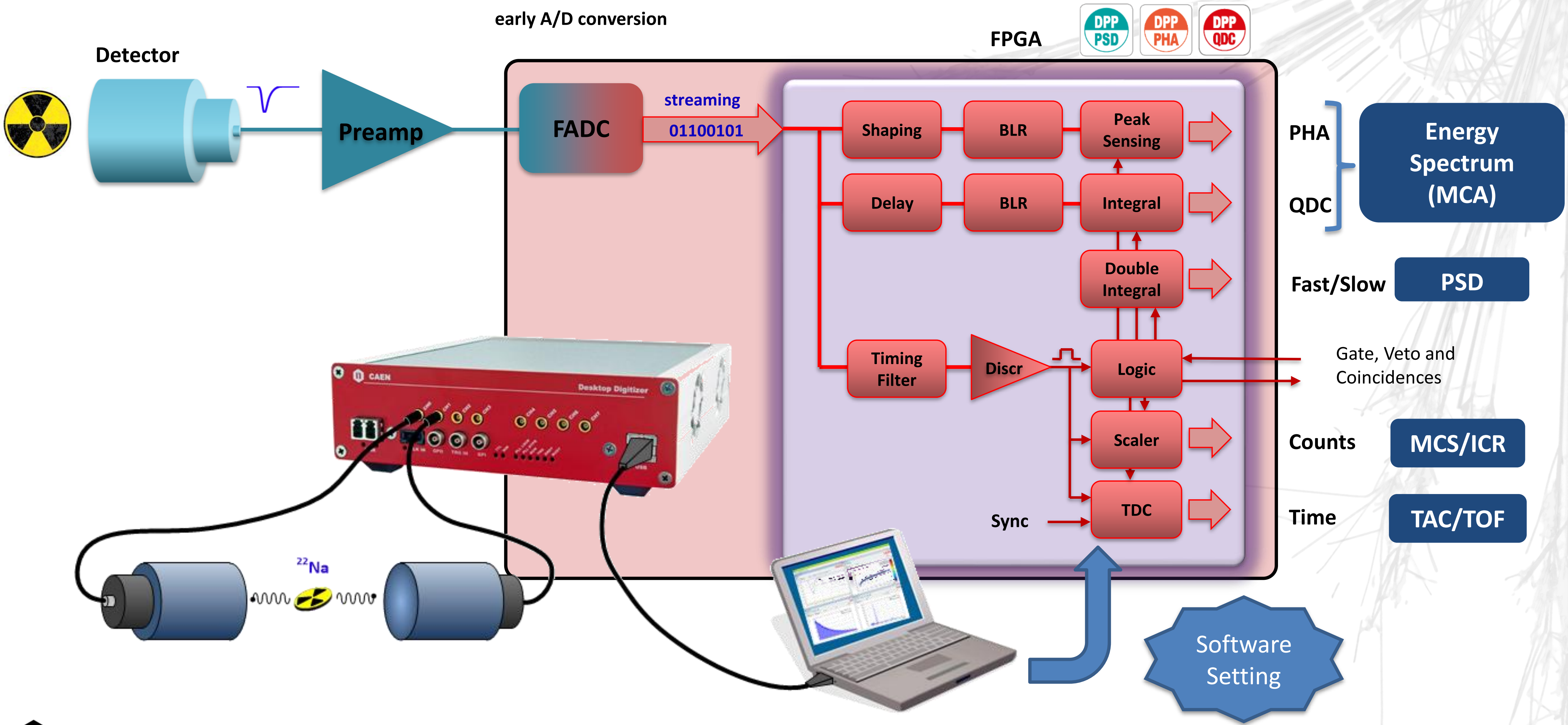
Traditional Spectroscopic/Multiparametric Analog Chain



The Digital Approach: All in one



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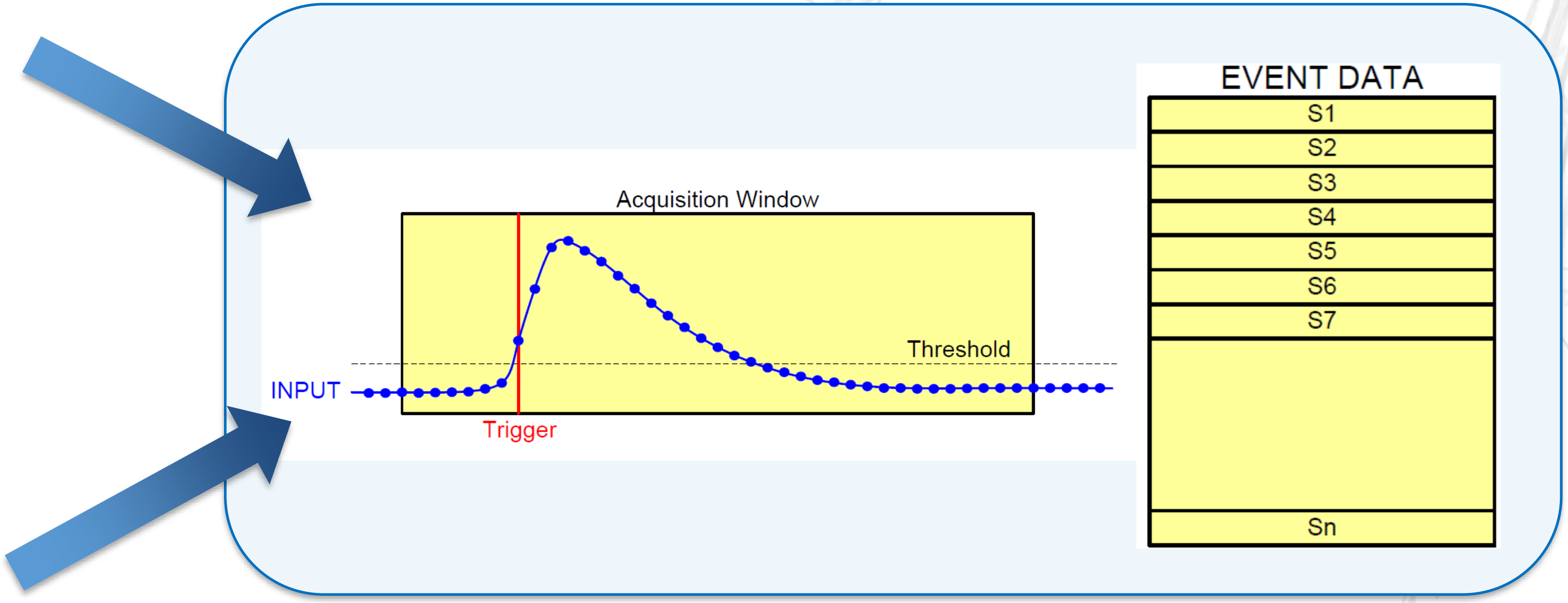
Digitizers vs Oscilloscopes

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



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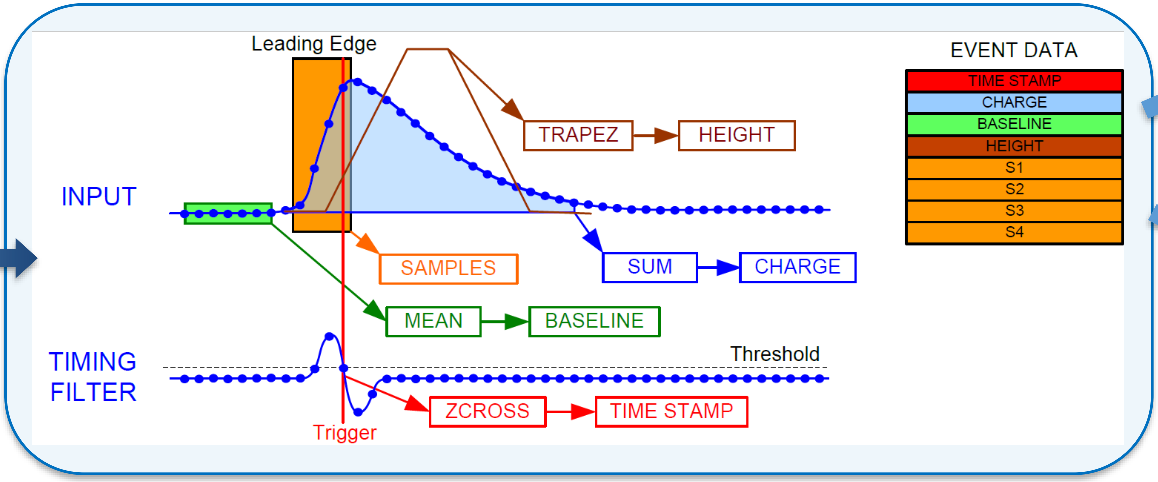
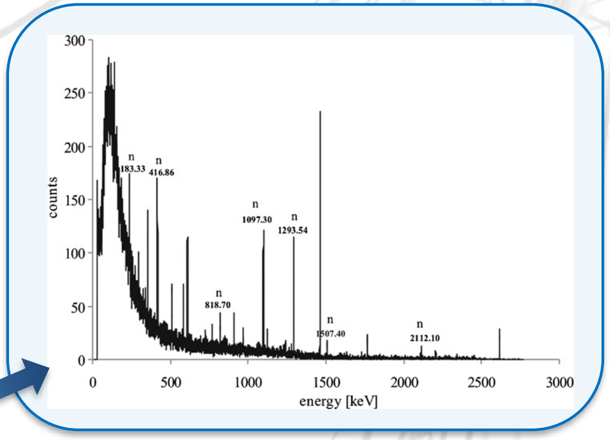
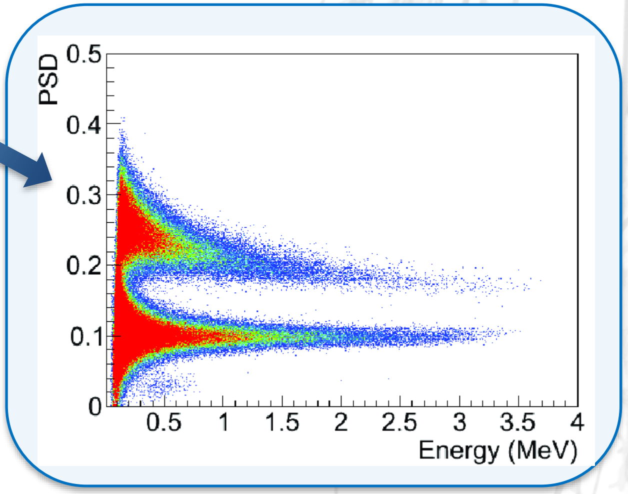
Digitizers vs Oscilloscopes

There are important differences:

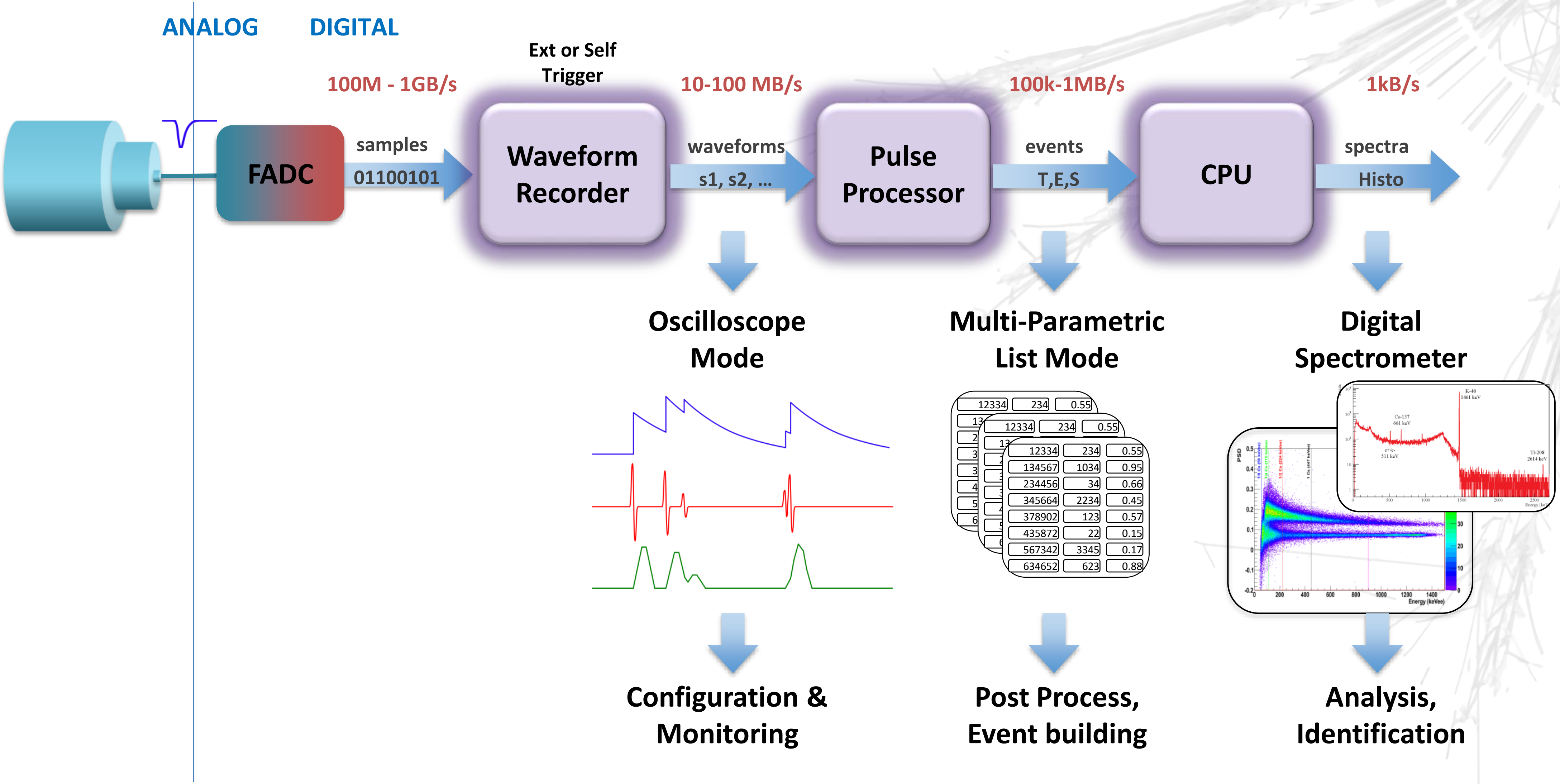
- no dead-time between triggers (Multi Event Memory)
- multi-board synchronization for system scalability
- high bandwidth data readout links
- on-line data processing (FPGA or DSP)







The Digital Approach: Digital Acquisition Chain



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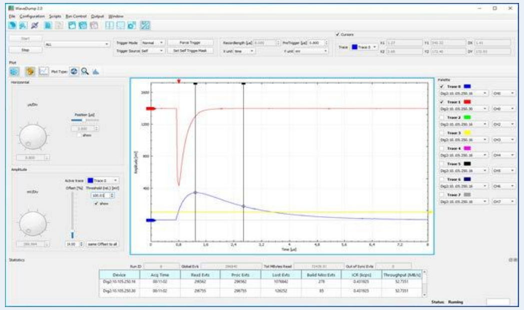
Trigger scenarios

1 Common Trigger

OSCILLOSCOPE MODE · Waveform acquisition

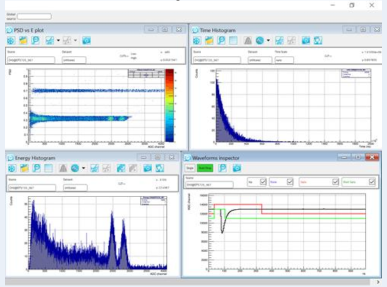
All channels receive the common trigger and save a set number of samples around it in a local memory buffer.



2 Self Trigger / Trigger-less

DPP MODE · List acquisition

Each channel self-triggers independently. Only characteristic parameters (pulse height, charge, time stamp) are needed — FPGA algorithms extract them from the pulse.



3 Global Trigger from DPP

INTERMEDIATE · Waveforms on validation

DPP algorithms identify pulses and generate triggers (coincidences, multiplicities…) to open a common acquisition window, saving waveforms on all channels simultaneously.

4 Validated List Mode

INTERMEDIATE · List + common gate

List-mode DPP with independent self-triggers plus a common validation signal — list data saved only within a defined time interval. Enables coincidence, veto logic, etc.

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Pulse Processing Algorithms

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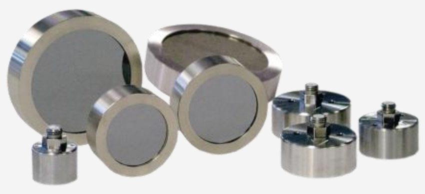
DPP-PHA

Pulse Height Analysis

The DPP-PHA

DETECTOR



Silicon detectors

HPGe

Scintillator + PMT

CZT

CAEN DIGITIZERS

Typical DPP-PHA signal
Rise time ≈ 100 ns
Decay time ≈ μs to tens of μs

x780 / x781
14 bit · 100 MS/s · Dual/Quad MCA

Hexagon
16 bit · 100 MS/s · Single/Dual MCA

V1782
16 bit · 100 MS/s · Octal MCA

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Analog spectroscopy chain

N14xx HV

Radioactive source → **Ge / Si** detector → **A1422** C.S. preamplifier → **N968** Shaping amplifier → **N957** Peak-sensing ADC → **Energy**

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The DPP-PHA Algorithms and Block Diagram

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DPP-QDC/PSD

Charge Integration and Pulse Shape Discrimination

The DPP-PSD

DETECTORS

BaF2

Plastic scintillator

NaI / LaBr3 / CeBr3

Liquid Scintillator

Diamond detectors

CAEN DIGITIZERS

Typical signal for DPP-PSD
Rise time ≈ few ns
Decay time ≈ few ns to few μs

x725 / x730
14 bit · 250/500 MS/s

x751
10/14 bit · 1 GS/s

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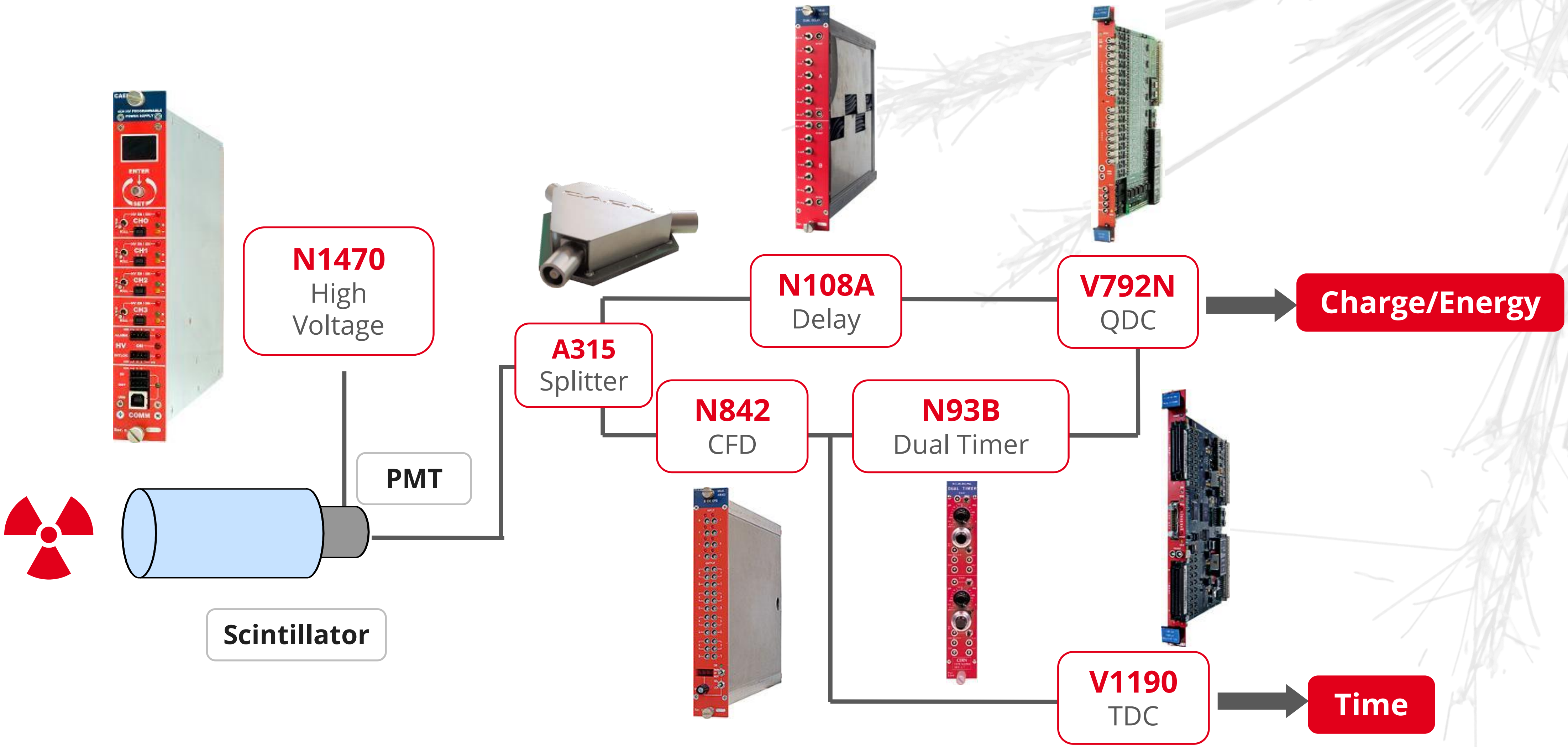
Analog QDC Chain



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The DPP-PSD/QDC Algorithm and Block Diagram

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Timing Analysis

Conventional TDCs vs Digitizers

Conventional TDCs

V1190
128 channels · 100 ps · Multi-Hit TDC

V1290
32 channels · 25 ps · Multi-Hit TDC

V775
32 channels · 35 ps · Start-Stop TDC

External CFD required!

Waveform Digitizers

Can't match TDCs on density & cost — but they win when:

- **Excellent timing resolution (< 100 ps)**
  the conventional CFD+TDC chain shows its limits
- **Simultaneous Timing + Energy**
  multi-parametric analysis — T and E on a single board
- **Bursts of very close pulses**
  the digitizer operates without dead time
- **Direct detector-to-digitizer connection**
  no discriminators: fewer cables, less distortion, less cost

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Algorithms for the Time Measurements

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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

The problem

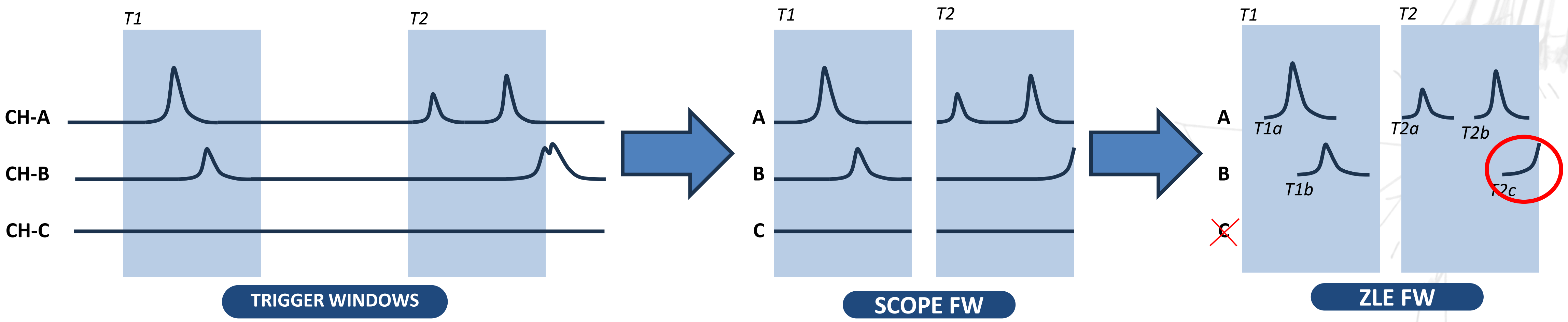
- Scope firmware (raw waveform readout) produces huge data volumes — reduction is often mandatory.
- Triggered acquisition: channels fire at different times, leaving long empty baseline.

ZLE firmware

- Suppresses the **empty channels**.
- Trims fired channels to keep only the **significant parts**.
- Each chunk is time-stamped within the window.

Trade-off

- Pulses across the trigger window are cut → possible loss of regions of interest.



Advanced Zero Suppression - 2: DAW firmware

The problem

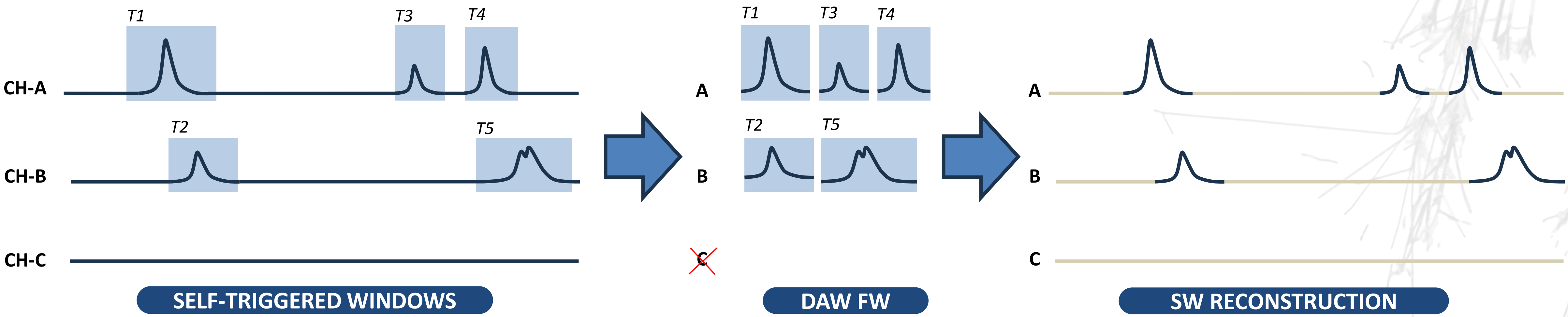
- Triggerless acquisition: no common window — each channel is self-triggered.
- Pulse width varies or pile-up → the acquisition window must **adapt dynamically**.

DAW firmware

- Channels run independently: a fired channel saves a waveform sized to fit the pulse, with its time stamp.
- **No pulse cutting.**

SW reconstruction

- Event building in software restores the correct position of each chunk using the time stamps.



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DPP-ZLE and DPP-DAW comparison

DPP-DAW

Advantages

- Dead-time free, no data loss (except at very high data throughput).

Limitations

- Less suitable for sparsely correlated events across different channels.
- Very small pulses below the trigger threshold may be lost.

DPP-ZLE

Advantages

- Global trigger enables a much lower suppression threshold than the trigger threshold.

Limitations

- Data loss in the case of cut-off events.

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Tools for Discovery

Digital vs Analog

PROs and CONs

Digital vs Analog: PROs and CONs

Flexibility

A waveform digitizer is a general-purpose instrument, reconfigured in firmware for different measurements. An analog chain is hard-wired and must be rebuilt to change setup.

Multi-parametric

From a single acquisition it extracts many parameters at once — amplitude, charge, timing, pulse shape. An analog setup needs a dedicated board for each quantity.

Dead-time

The Flash ADC samples continuously with no conversion dead-time, so it sustains higher trigger rates — unless the full waveform must be read out for every event.

Trigger Logic

Coincidence, anti-coincidence and multiplicity are handled inside the DPP firmware — no external units or cabling. Events are timestamped for offline correlation.

Complexity

Many configurable parameters mean a richer interface and a steeper learning curve. Once tuned, a setup is easy to save, replicate and maintain.

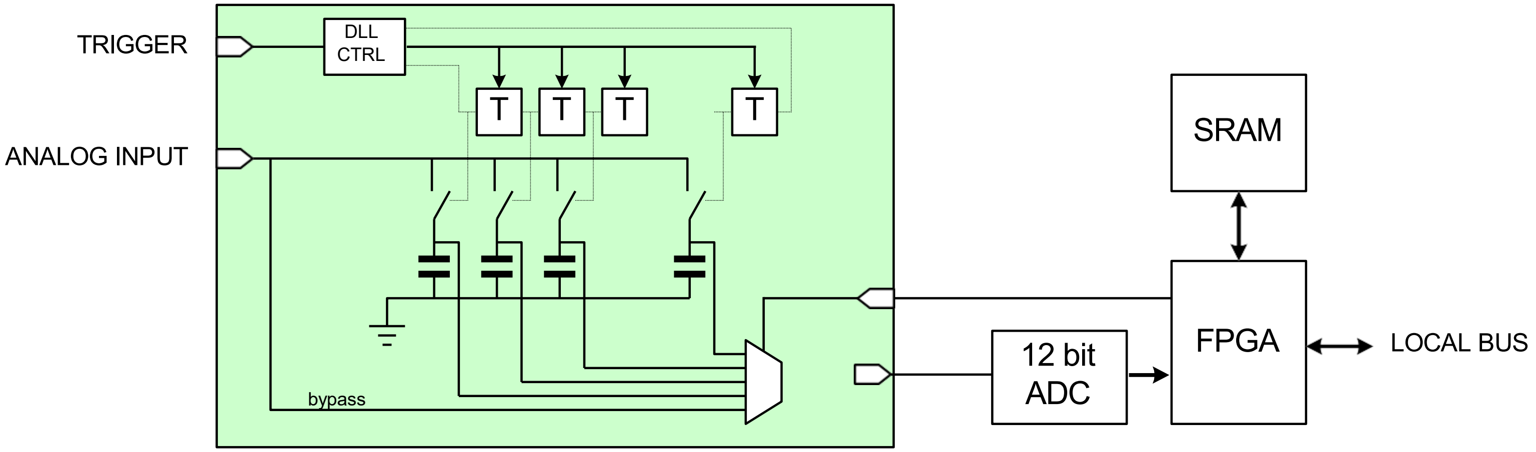
Cost

Digitizers are cheaper than analog chains for slow signals, but get expensive at very high sampling rates (≥1 GS/s), where fast analog electronics still competes.

Switched Capacitor Array Digitizers

Switched Capacitor Array Digitizer

Switched capacitor arrays can read very fast signals at low cost.



x742

32 + 2 ch · **5 GS/s** · 12 bit · 1024 pts · VME

x743

16 ch · **3.2 GS/s** · 12 bit · 1024 pts · VME

Two drawbacks

High dead-time · small, fixed acquisition window

CAEN Tools for Discovery

CAEN First Generation Digitizers

Digitizer 1.0: 15 years of success, still on the road

Model	# channels	MS/s	# bit	HV	LV	Wave	PHA	PSD	CFD	QDC	Notes
V1730 / DT5730	16 / 8	500	14	-	-	√	√	√	√	√	Waveform recorder + Pulse Processor
V1725 / DT5725	16 / 8	250	14	-	-	√	√	√	√	√	Waveform recorder + Pulse Processor
V1751 / DT5751	8 / 4	1000	10	-	-	√		√	√	√	Waveform recorder + Pulse Processor
V1724 / DT5724	8 / 4	100	14	-	-	√	√				Waveform recorder + Pulse Processor
V1720 / DT5720	8 / 4	250	12	-	-	√		√		√	Waveform recorder + Pulse Processor
V1740 / DT5740	64 / 32	62.5	12	-	-	√				√	Waveform recorder + Pulse Processor
V1742 / DT5742	32 / 16	5000 (1)	12	-	-	√					Waveform recorder (SCA)
V1743 / DT5743	16 / 8	3200 (1)	12	-	-	√					Waveform recorder (SCA)
DT5780	2	100	14	2	2	√	√				MCA (no histo memory, List readout)
DT5781	4	100	14	-	-	√	√				MCA (no histo memory, List readout)
DT5790	2	250	12	2	-	√		√		√	Pulse Processor

(1) switched capacitor array: fast sampling, slower A/D conversion (=> dead time)

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CAEN Second Generation Digitizers

Digitizer 2.0: what's new

More channels for denser systems

Variable gain amplifier to adapt the input dynamic range

Faster links: up to 10 Gbps communication

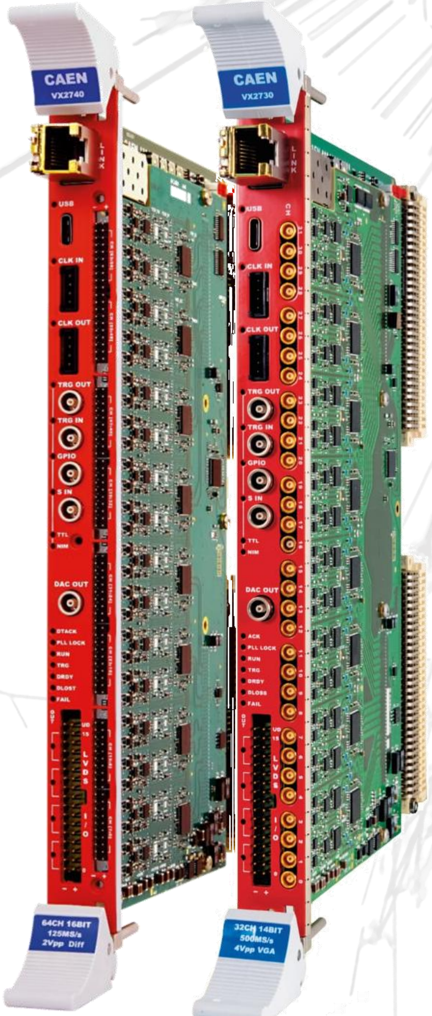
More on-board memory: MB → GB for longer recording

Scalability & sync: easier to expand across boards

Embedded Linux (ARM): Virtual Machine for user access

OpenFPGA + SciCompiler: design custom pulse processing

New Library & SDK: with demos for easy integration



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27XX — one platform, three models

COMMON PLATFORM — shared by all models

DC OFFSET
Adjustable over full dynamic range

READOUT
1 / 10 GbE · USB 3.1 · Optical Link

WAVEFORM
Max length ~84 ms

OPEN FPGA
SciCompiler + FDK · base FW: Scope / QDC / PSD / CFD

SOFTWARE
WaveDump2, Compass, Libs, Demos (Windows & Linux)

Spec	2740 / 2745	2730	2751
Channels	64	32 / 16	16
Sampling rate	125 MS/s	500 MS/s	1 GS/s
Resolution	16 bit	14 bit	14 bit
Inputs	SE / Diff, 2 mm header	SE, MCX	SE, MCX
Dynamic range	V2740: 2 Vpp fixed; V2745: 40 mV÷4 Vpp (x1–x100, 0.5 dB)	200 mV÷4 Vpp (x1–x20, 1 dB)	200 mV÷2 Vpp (x1,2,4,8,10)
Mem buffer	21 MS/ch	84 MS/ch	84 MS/ch
Firmware extra	+ PHA, ZLE; DAW planned	+ PHA; DAW, ZLE planned	DAW, ZLE planned
ENOB (typ.)	11.7	10.5	TBD
RMS noise	3.9 LSB (~120 µV)	2.8 LSB (~340 µV)	TBD
Best for	High-density spectroscopy (Si, HPGe), SiPM matrices	PSD, high timing resolution, fast detectors	Ultra-fast detectors, PSD, timing

2740
2745

2730

2751

What's coming

Low cost, low channel-density desktop line

DTL2730

Channels	**8**
Sampling	**500 MS/s**
Resolution	**14 bit**

DTL2751

Channels	**4**
Sampling	**1 GS/s**
Resolution	**14 bit**

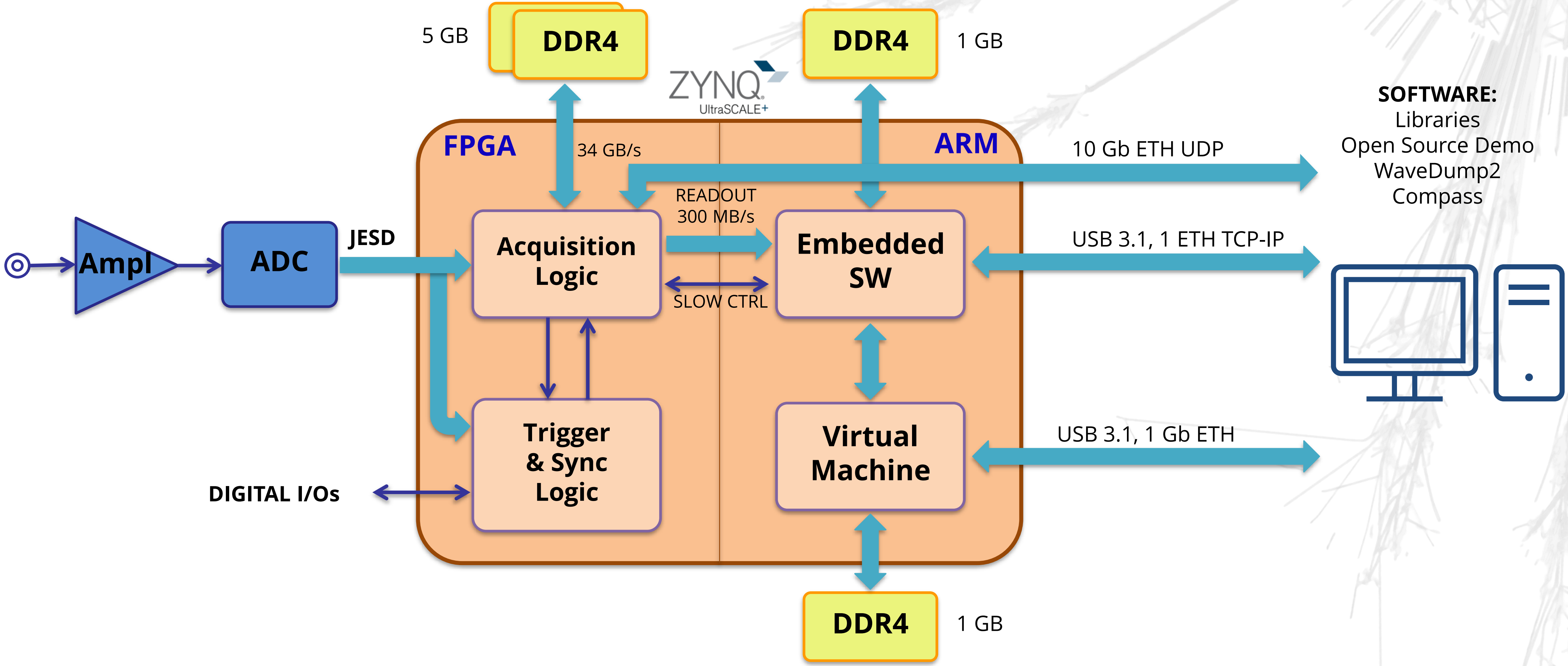
DTL2745

Channels	**8**
Sampling	**125 MS/s**
Resolution	**16 bit**

WHY IT MATTERS

- **Desktop form factor**
- **Same architecture & performance as the VME boards (fewer channels)**
- **Full compatibility with existing FW & SW**

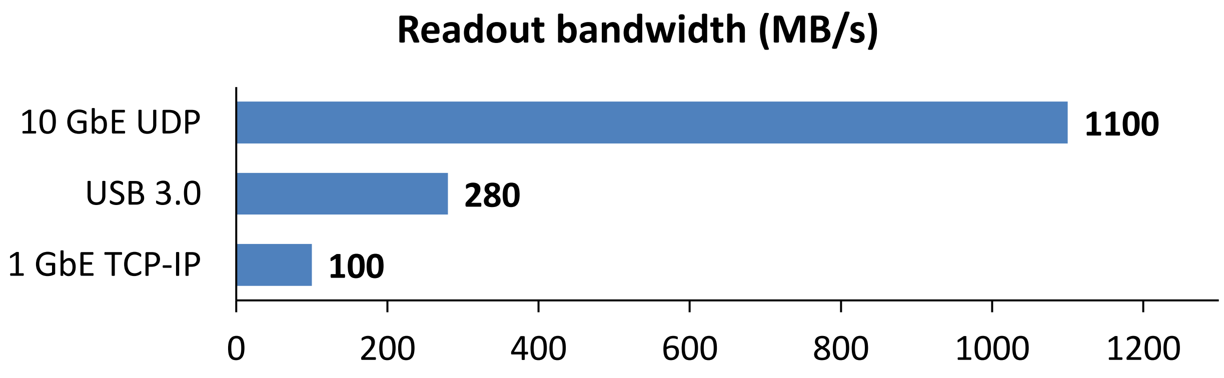
The Digitizer architecture



SOFTWARE:
Libraries
Open Source Demo
WaveDump2
Compass

Readout interfaces

- 1 Gb Ethernet TCP-IP: Bandwidth = **~100 MB/s**
- USB 3.0: Bandwidth = **~280 MB/s**
- **10 Gb Ethernet UDP** (bypass CPU) = **up to 1100 MB/s**
- *VME: legacy from the past… being dismissed (only used for power supply)*

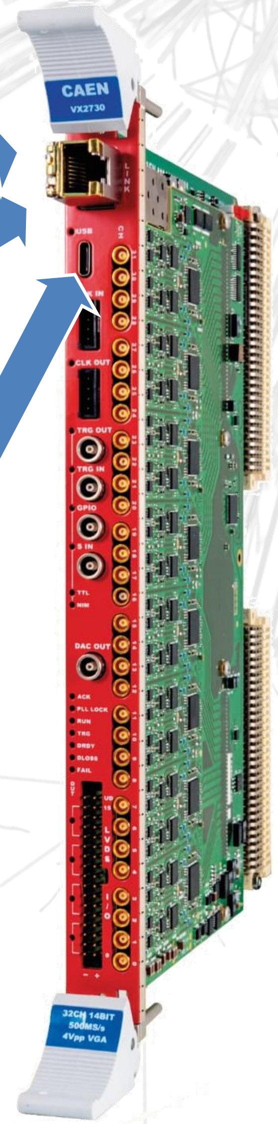


1 Gbps copper
(10 Gbps on request)

Exchangeable SFP+

1/10 Gbps optic

USB 3.0
Type C



No Backplane Protocols

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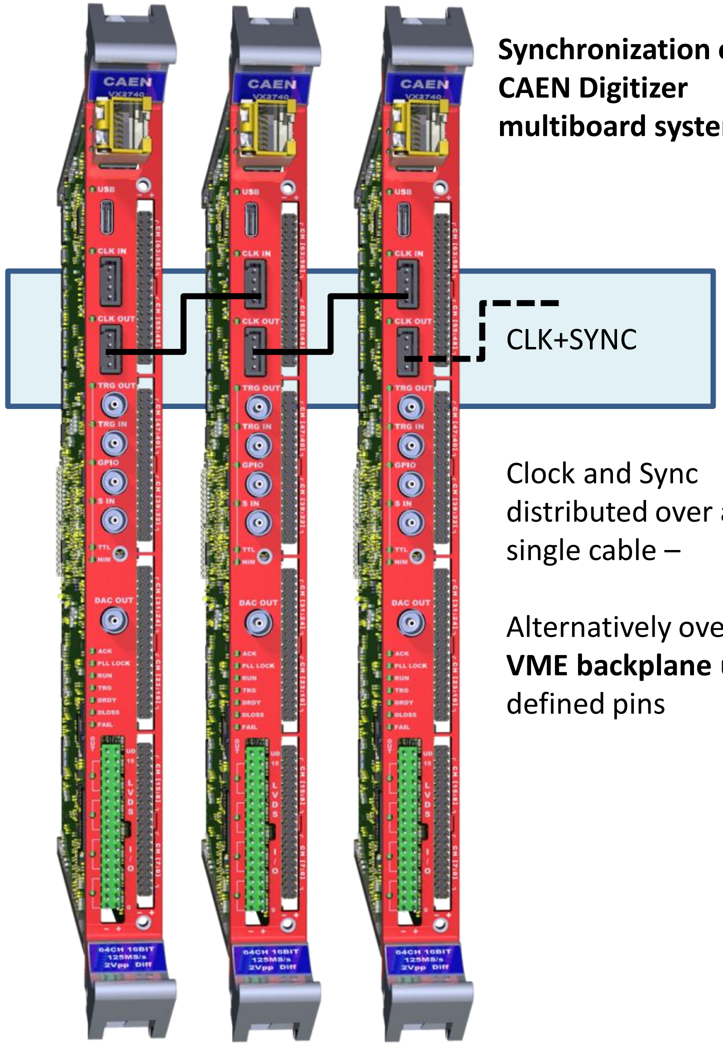
Digitizers Synchronization



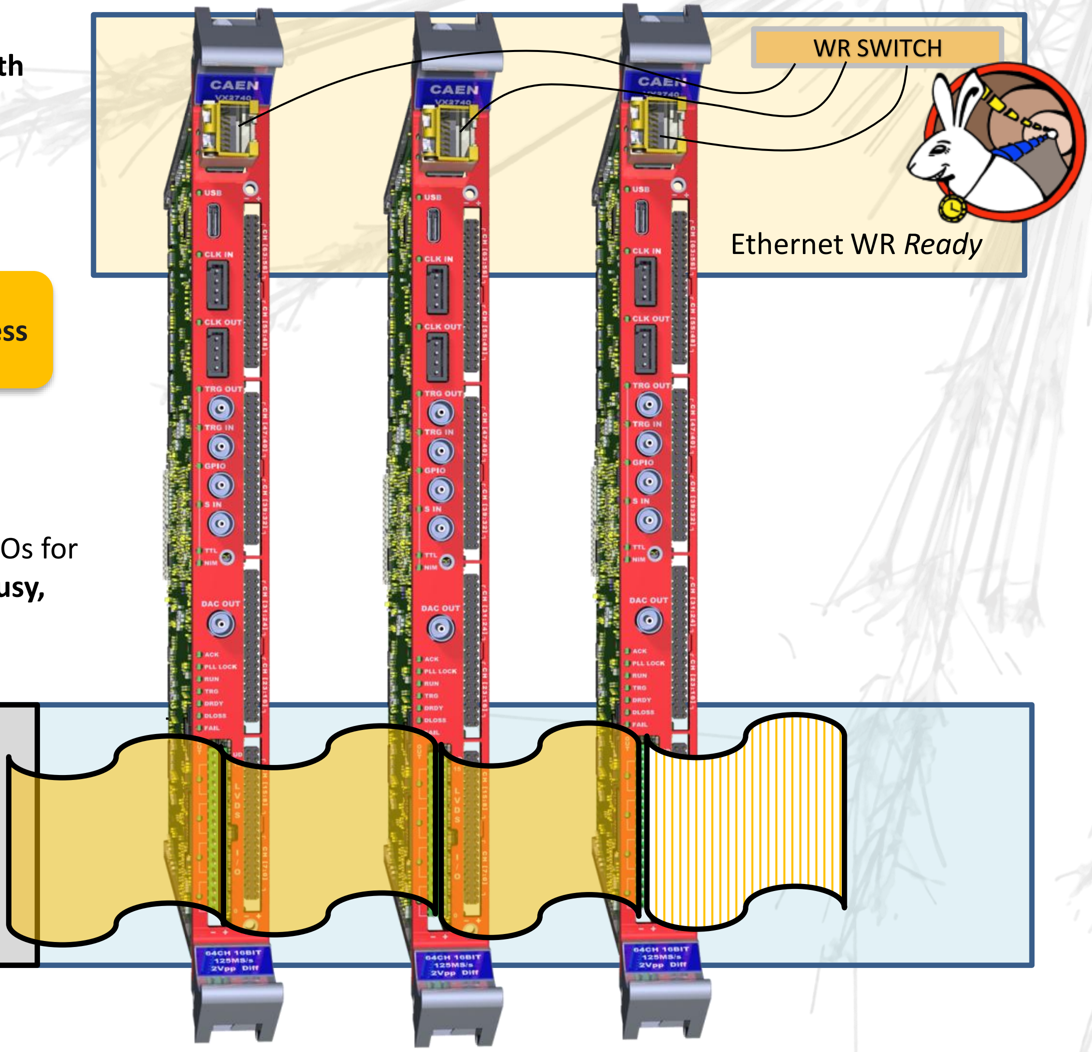
Synchronization of a CAEN Digitizer multiboard system

Clock and Sync distributed over a single cable –

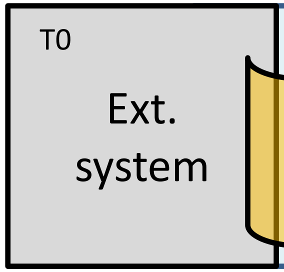
Alternatively over the **VME backplane** user-defined pins

Synchronization with external systems

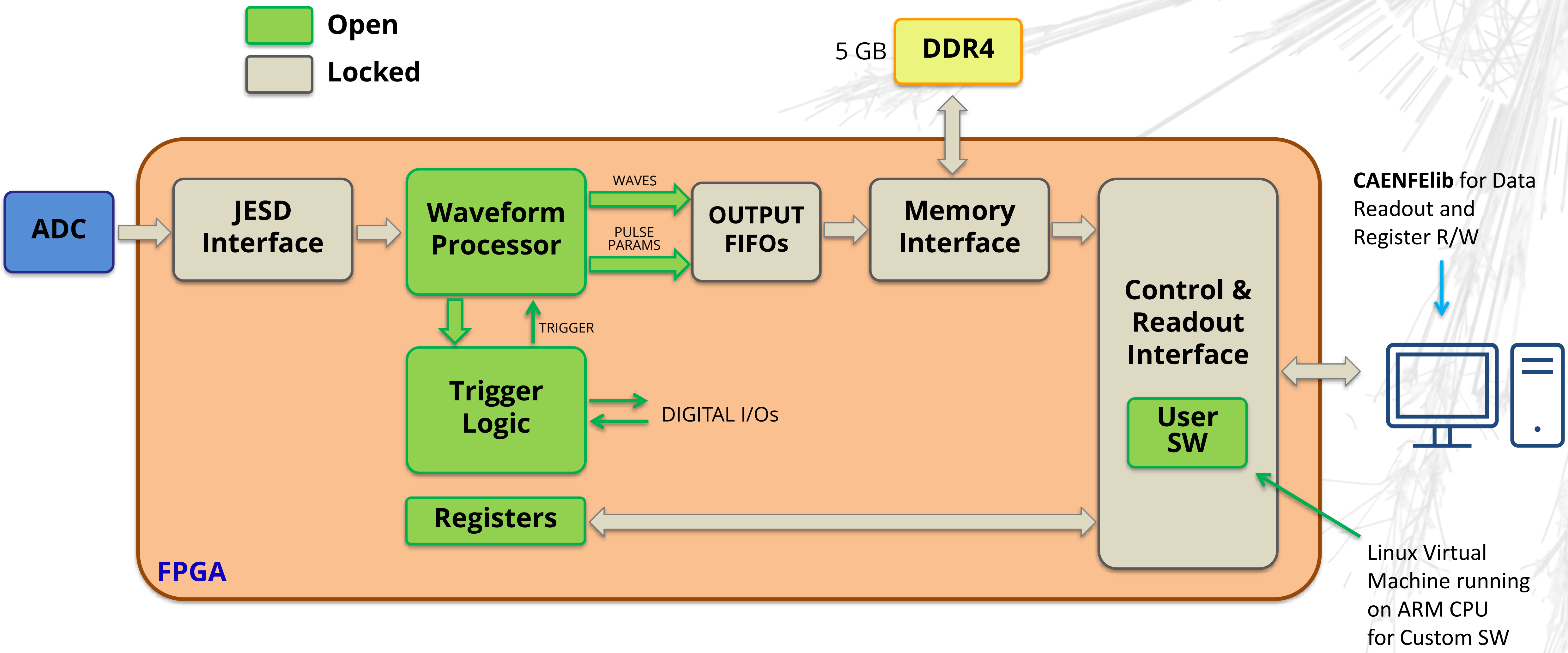
Work in progress



Additional LVDS I/Os for **trigger sharing, busy, veto** and **global timestamp**



Open FPGA: block diagram



Open FPGA: what you can or can't do

YOU CAN

- ✓ Implement custom Pulse Processing algorithms
- ✓ Implement custom trigger logic
- ✓ Implement user defined R/W registers
- ✓ Receive and transmit signals from/to the digital I/Os
- ✓ Manage acquisition, either triggered (simultaneous on all channels) or streaming (independent self-triggering channels)
- ✓ Acquire waveforms (raw or processed by custom algorithms) and/or synthetic meta-data (Energy, Time, PSD…)
- ✓ Push custom data into output FIFOs; the infrastructure will transfer data to the PC via USB or Ethernet

YOU CANNOT

- X Modify the infrastructure for the data transfer
- X Modify the readout protocol and interface
- X Direct access to the DDR memories
- X Modify clock, power and other sensitive parts of the digitizer

CAEN Tools for Discovery

ASICs based DAQ

Why ASICs

Application Specific Integrated Circuit

Many Channels	No power plug	Dedicated Measurements
• Large Experiments • High granularity • High integration	• Astrophysics Experiments • Space Applications	• Little data flow, but reduced information no waveform reconstruction
ASIC is low cost per channel when n. of channels gets very large	**ASIC is low power thus less cooling and power lines**	**ASIC is dedicated. Users know what they measure**

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- **ASICs:** research groups and spin-offs develop ASICs — and often the boards that house them — to read out multi-detector systems in NP and HEP.
- **Adaptation needed:** the same ASICs are attractive for other uses, but the electronics and software must be redesigned each time.
- **FERS (Front End Readout System):** versatile modules that integrate ASICs with full hardware and software support — usable both as an **evaluation board** and a **highly scalable solution**.

CERN
weeroc
NALU SCIENTIFIC

- Off-the-shelf front-end ASICs for scientific instrumentation
- Readout of **SiPMs**, **Si strips**, **GEMs**, PIN diodes, microMegas, MA-PMTs
- Custom HEP solutions with **rad-hard** design

Synergies

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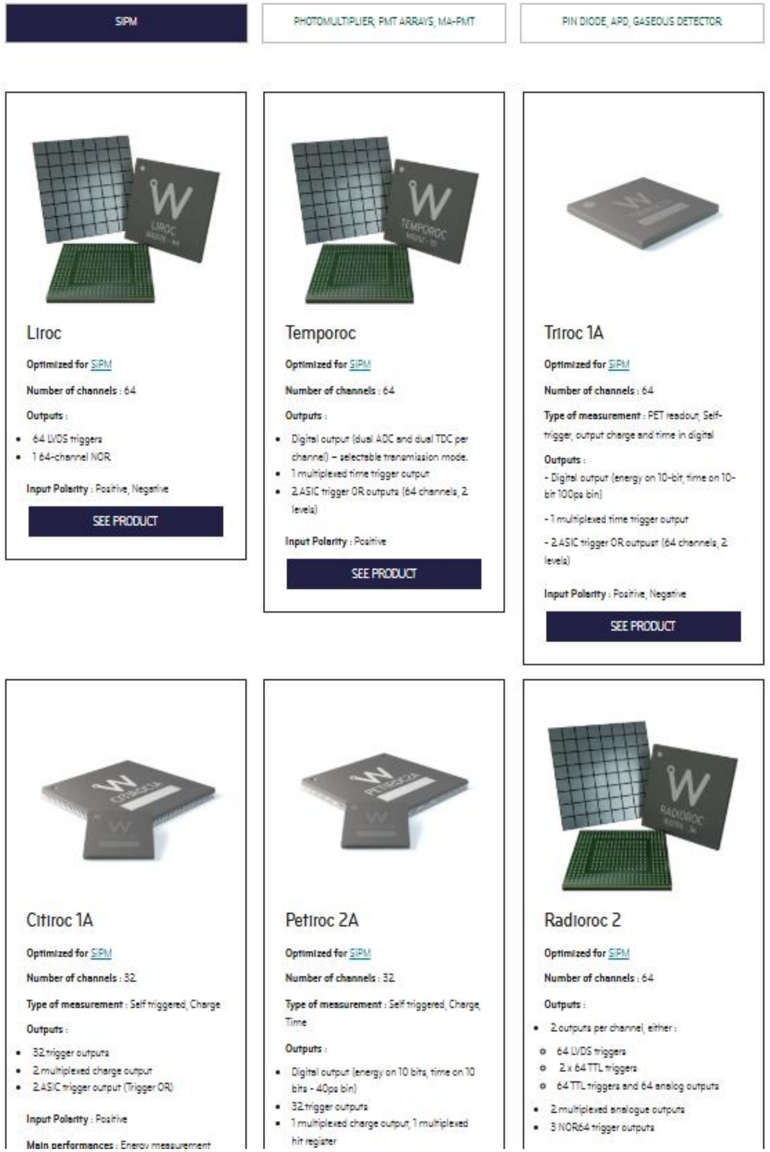
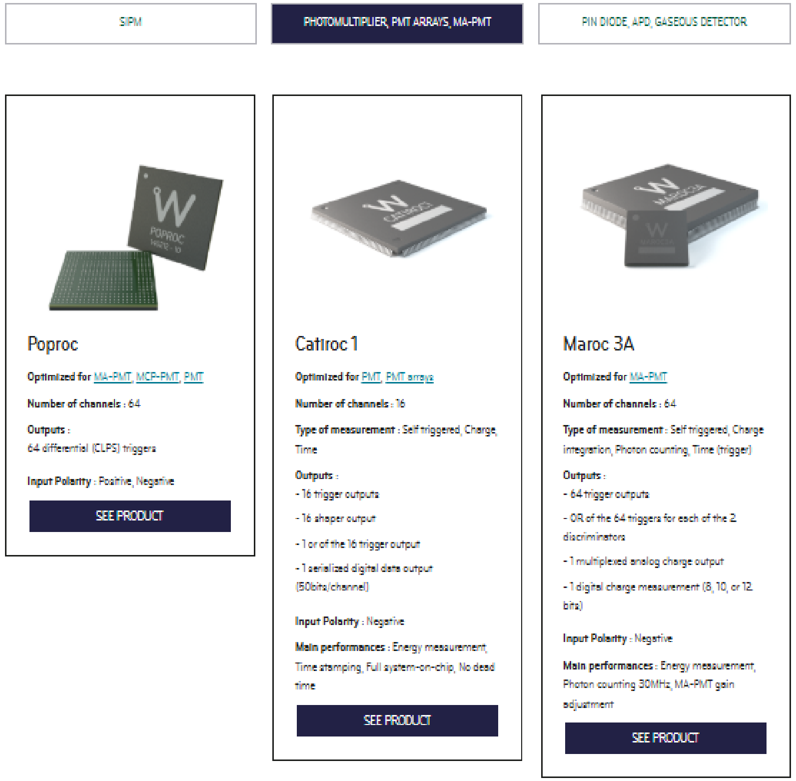
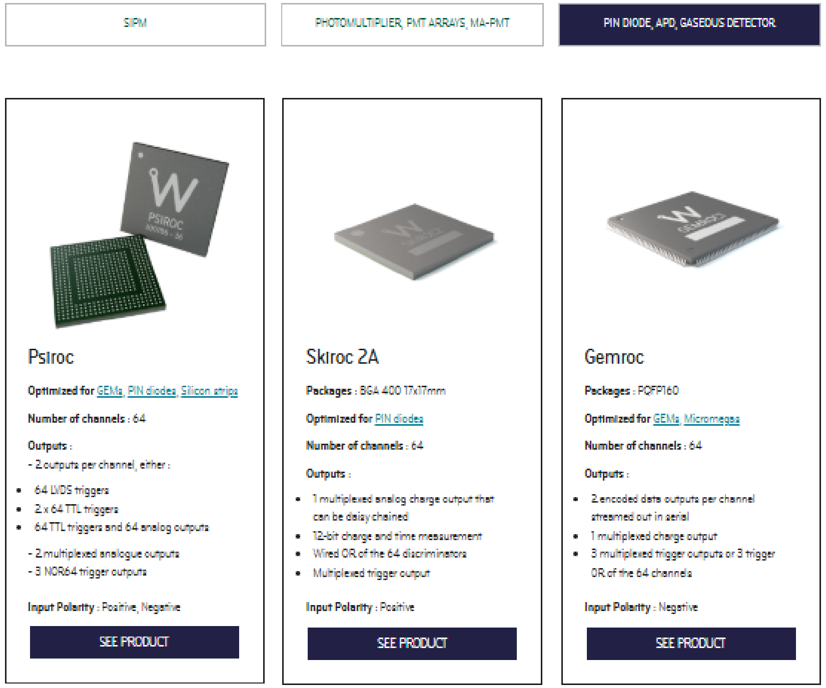
NI Nuclear Instruments

- Readout electronics for NP and HEP
- Power supply systems

ASICs selection from Weeroc







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 & Radiopharmacy

- 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

- Low and intermediate radioactive waste characterization

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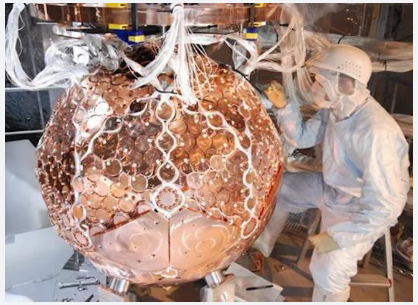
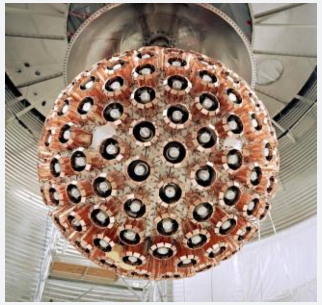
Multiparametric DAQ Applications: Experiments



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

XENON1T — LNGS, Italy

Dark Matter → **248** PMTs = 32 V1724s (100 MS/s, 14 bit) · **Trigger-less** DAQ with custom FW (**DAW**)

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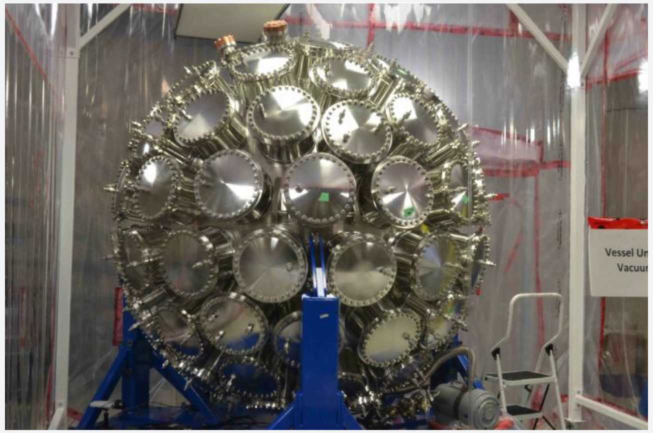
Multiparametric DAQ Applications: Experiments



Mini Clean — Snolab, Canada

Dark Matter · 150 kg fiducial volume of liquid argon or 85 kg of liquid neon · **92** sensitive photodetectors → **8** V1720 (12 bit, 250 MS/s) with Waveform Recording firmware

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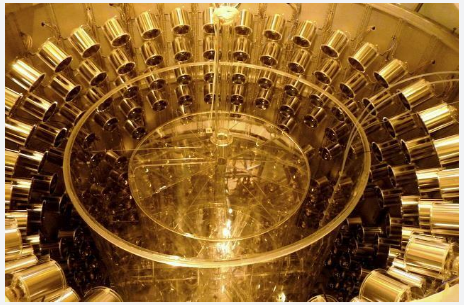
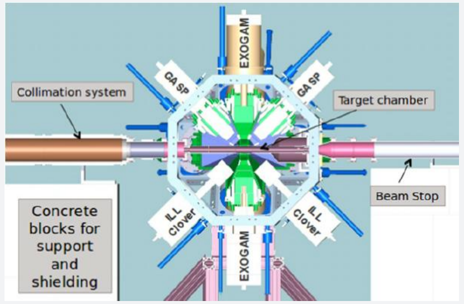
Multiparametric DAQ Applications: Experiments



Double-Chooz — Chooz Power Plant, France

Neutrino oscillation → **368** PMTs = 46 V1721s (500 MS/s, 8 bit)



Prospect — Yale/ORNL, USA

Oscillation signature of sterile neutrinos · **360** ^{6}Li doped liquid scintillator + PMTs = 22 × 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)

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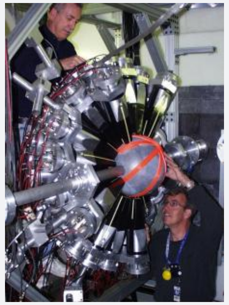
Multiparametric DAQ Applications: Experiments



Dance — Los Alamos, USA

Neutron capture · **162** segments (4 π BaF_2 crystals) = 12 V1730s (500 MS/s, 14 bit) with **DPP-PSD**

Eliade — ELI-NP, Romania

Photonuclear reactions at Extreme Light Infrastructure → **Clover**: 36 V1725 (250 MS/s, 14 bit + PHA) + **$LaBr_3$**: 2 V1730 (500 MS/s, 14 bit + QDC-PSD)

Durga — Dhruva reactor @ BARC, India

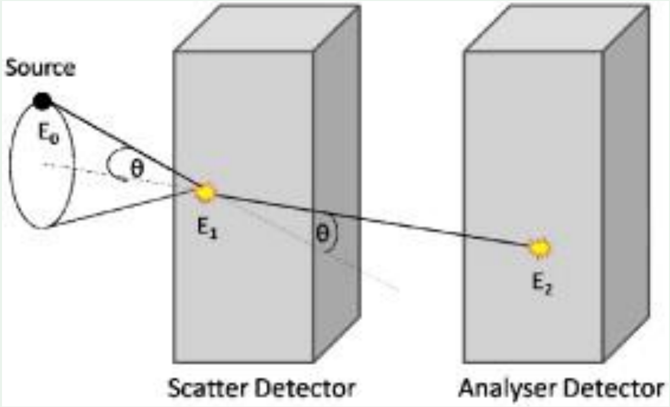
Gamma-ray spectroscopy of fission fragment nuclei · **8 Clover** detectors with ACS + 16 $LaBr_3$ => 4 V1724s (100 MS/s, 14 bit, **PHA**) + 1 V1720 (250 MS/s, 12 bit) + 1 V1730 (500 MS/s, 14 bit, **QDC-PSD**)

CAEN Tools for Discovery

Multiparametric DAQ Applications: Medicine and radiopharmacy production

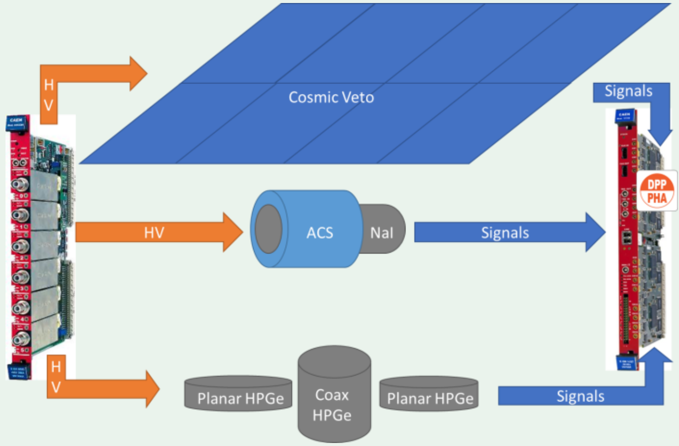
SPECT — Liverpool University, UK

Single Photon Emission Computed Tomography · Localization of a gamma-ray source via reconstruction of interaction sequences in position/energy-sensitive strip detectors → **4** V1724s + PHA



WBC — JRC, Italy

Whole Body Counter, measurement in very low background · Gamma spectroscopy with multi-input 16 k MCA and anticoincidence with plastic cosmic veto → **2** V1725s + PHA and PSD



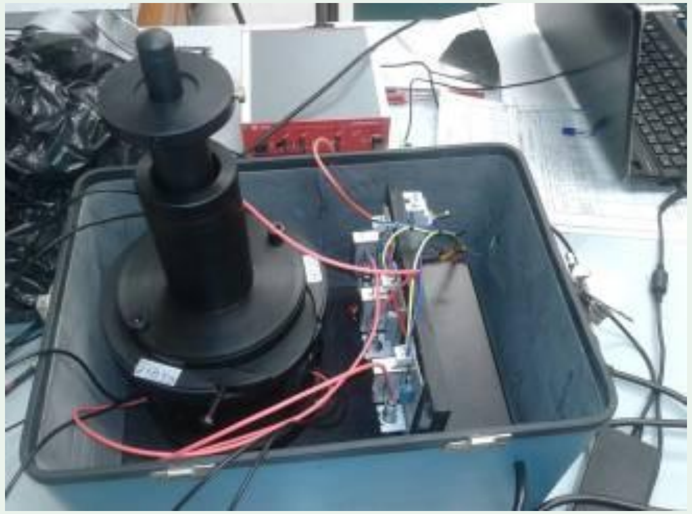
CAEN Tools for Discovery

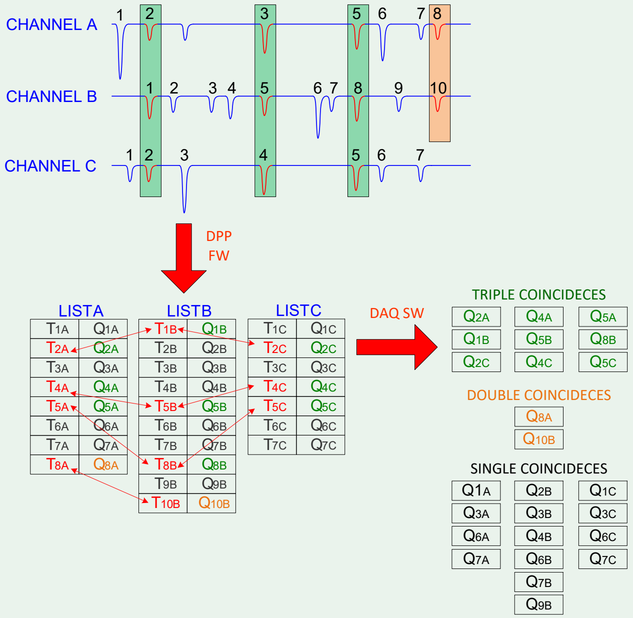
TDCR — ENEA, Italy

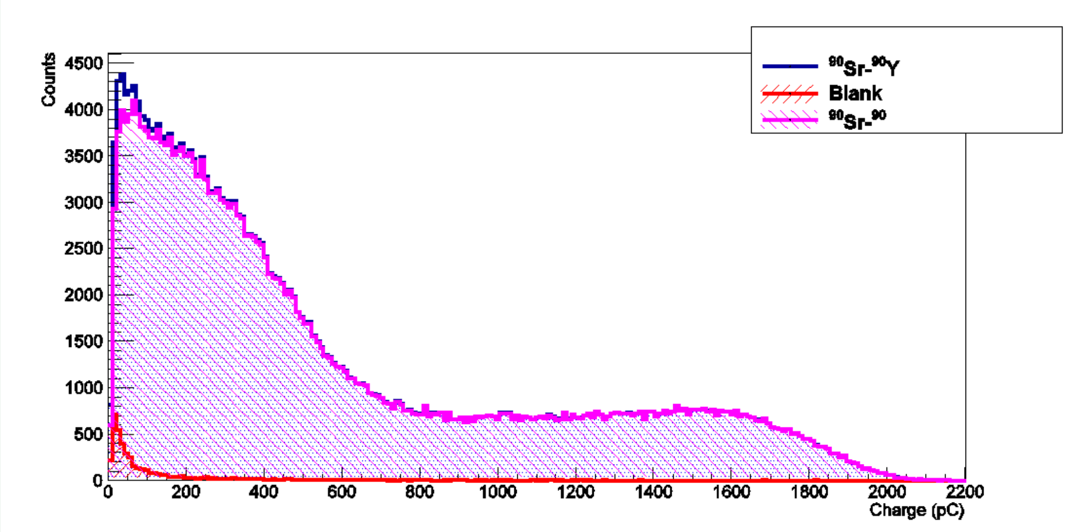
Evaluation of a radiosource activity via the Triple-to-Double Coincidence Ratio

Replaces the traditional analog chain (**MAC3** module) to read out and process 3 scintillators

→ DT5720/DT5725/DT5730/DT5751 + **DPP-PSD** firmware and dedicated TDCR analysis software

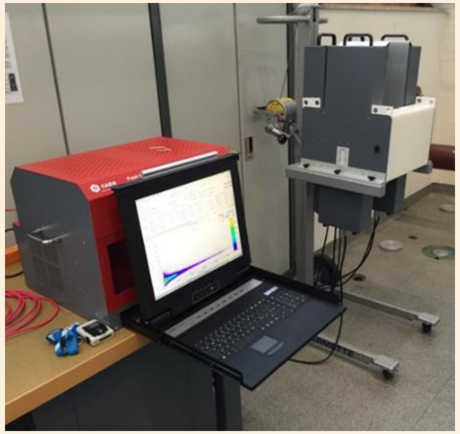






Fast Neutron Collar — IAEA, Austria

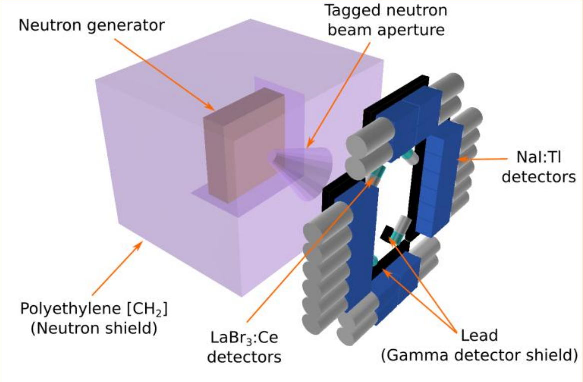
Non-destructive assay of NPP Fresh Fuel Rods → 4 V1730s (500 MS/s, 14 bit) with **fast waveform readout (300 MB/s)** and **PSD**

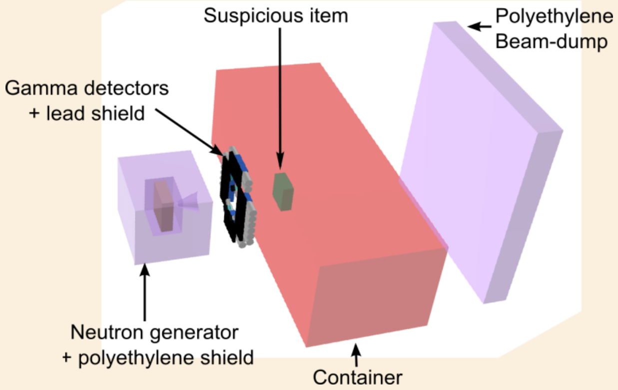


Statistical uncertainty on ^{235}U enrichment < 1% in 15 min acquisition · System immune to Gd mass variation

C-BORD — Rotterdam, Netherlands

Relocatable Tagged Neutron Inspection System · movable detection of illicit material via **TOF (alpha-gamma)** and energy correlation

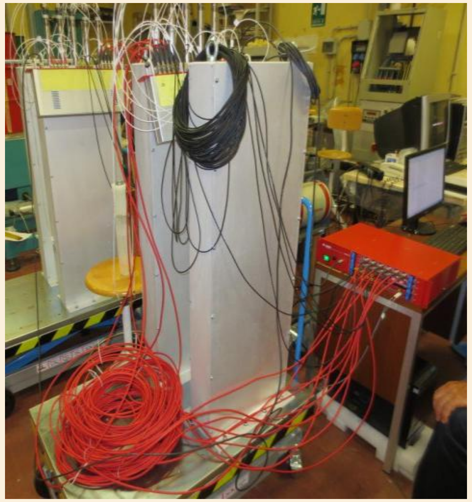




Multiparametric DAQ Applications: Safeguards and Security

EDEN — ENEA, Italy

Uncovers radioactive and nuclear threats, incl. IEDs (“dirty bombs”), via Neutron Active Interrogation (NAI) and Differential Die-Away Time Analysis → **He3 tubes + V1495 with custom coincidence & counting FW**



Tap Water Monitoring (Water-NET) — Warsaw, Poland

Mitigates radiological threats such as:

- Emergencies at nuclear facilities
- Transport accidents involving radioactive shipments
- Loss, theft or discovery of radioactive material (orphan sources)
- Terrorist attacks using radioactive materials (e.g. a “dirty bomb”)

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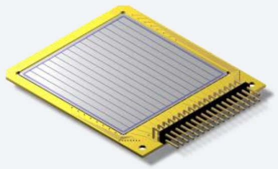
Tools for Discovery

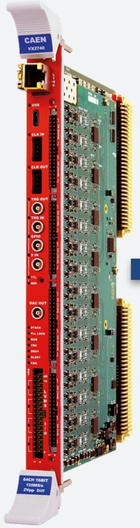
27xx Use Cases: Numen (SSD) & Dark Side (TPC)



SSD

A1429
64 ch Charge Sensitive Preamplifier

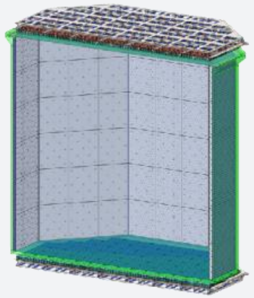
A372F
Cable Adapter

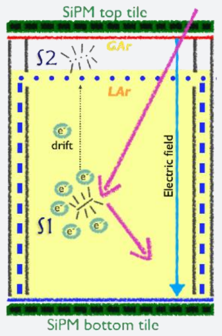


DPP PHA

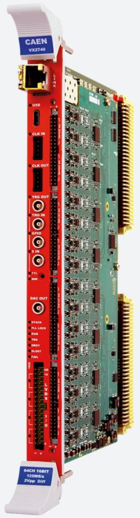
Numen — INFN-LNS, Italy

SSD Detector → A1429 (64-ch charge-sensitive preamp) → A372F cable adapter → **VX2745** (64 ch, 125 MS/s, 16 bit) → **DPP-PHA** → list-mode streaming readout





Dual Phase TPC
(SiPM based)



WAVEFORM RECORDING

Dark Side — INFN-LNGS, Italy

Dual-phase Time Projection Chamber with large-area SiPM arrays (Photo Detection Units, PDUs) → from V1720s (R&D) to **VX2745** with **Waveform Recording** firmware

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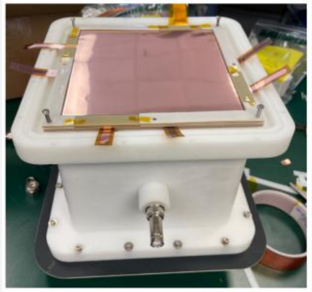
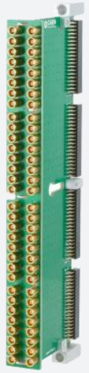
Tools for Discovery

27xx Use Cases: SREFT (LANL) & Tristan (Katrin-KIT)

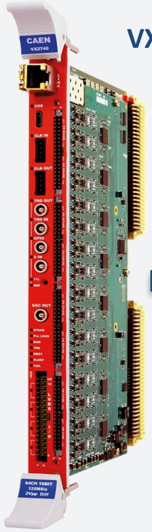


GEM-based TPC

A372M
Cable Adapter

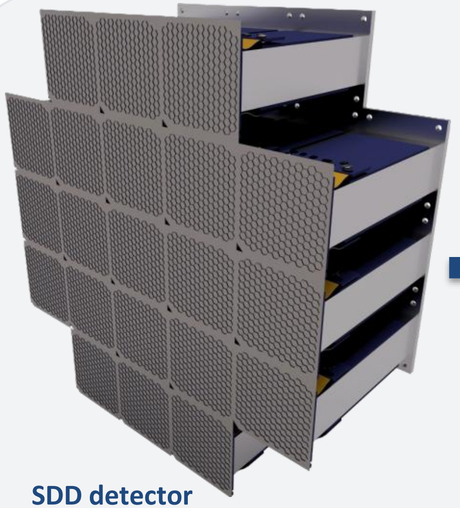


VX2745



SREFT (Spatially Resolved Fission Tracker) — LANL, USA

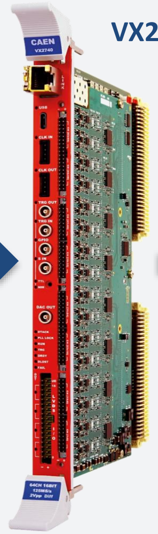
GEM-based TPC → A372M cable adapter → **VX2745** (64 ch, 125 MS/s, 16 bit) → **DPP-PHA** → list-mode streaming readout



SDD detector

A372F
Cable Adapter

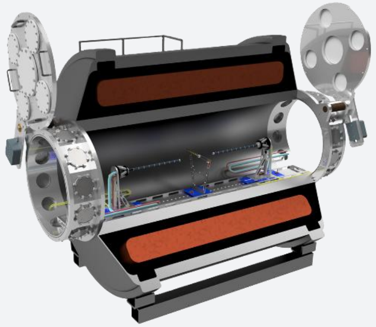
VX2745



Tristan — Katrin (KIT), Germany

SDD Detector → A372F cable adapter → **VX2745** (64 ch, 125 MS/s, 16 bit) → **DPP-PHA** → list-mode streaming readout

27xx Use Cases: Solaris (FRIB) & PI3SO (INFN-Energy)

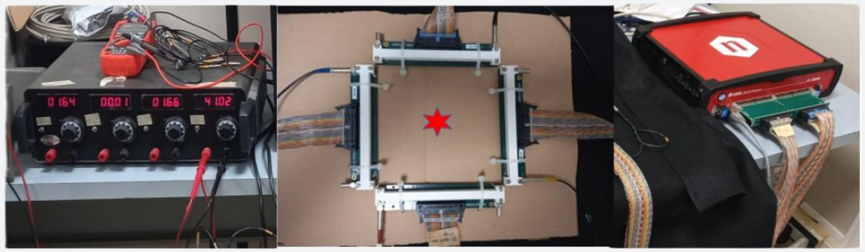


Solaris spectrometer

VX2745

Solaris — FRIB, MSU – USA

Solaris spectrometer → **VX2745** (64 ch, 125 MS/s, 16 bit) → **DPP-PHA** → list-mode streaming readout



128 CsI(Tl) + SiPM detectors

PI3SO – INFN-Energy project, Italy

Proximity Imaging System for Sort & Segregate Operations — classification, conditioning and characterization of low- and intermediate-level radioactive waste.

128 CsI(Tl) + SiPM gamma-ray detectors → A372F → **DT2745** (64 ch, 125 MS/s, 16 bit) → **DPP-PSD**

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27xx Use Cases: Venus (VECC – India) & Livermorium (Z=116) Production (LBNL – USA)

VENUS Setup

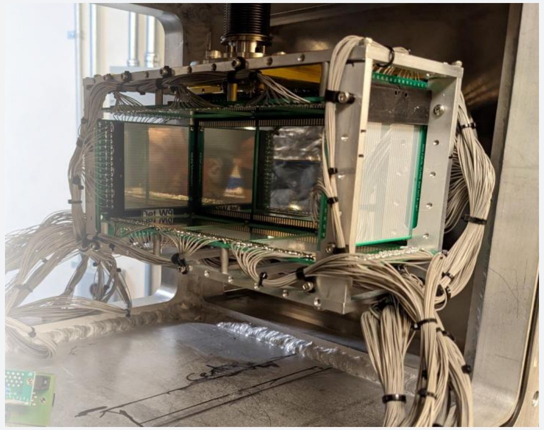
VX2730

A372M
Cable Adapter

VX2745 x 2

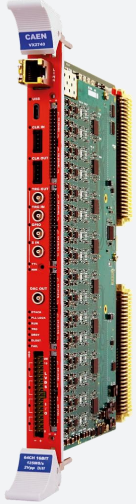
Venus – VECC, India

- 12 Clovers, 12 BGO, 4 LEPS, 2 seg. Clovers, 2 BGO → A372M → **VX2745** → **DPP-PHA**
- 16 fast scintillators → **VX2730** → **DPP-PSD**
- **Custom CoMPASS version**



SHREC – LBNL, USA

- SuperHeavy RECoil detector: three side-by-side double-sided silicon-strip detectors (**DSSDs**) by Lund University
- 64 ch DSSD readout → **VX2740** → **DPP-PHA** + **CoMPASS**



VX2740
64 ch, 125 MS/s
16 bit Digitizer

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Thank you for your attention!

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