CAEN
Tools for Discovery

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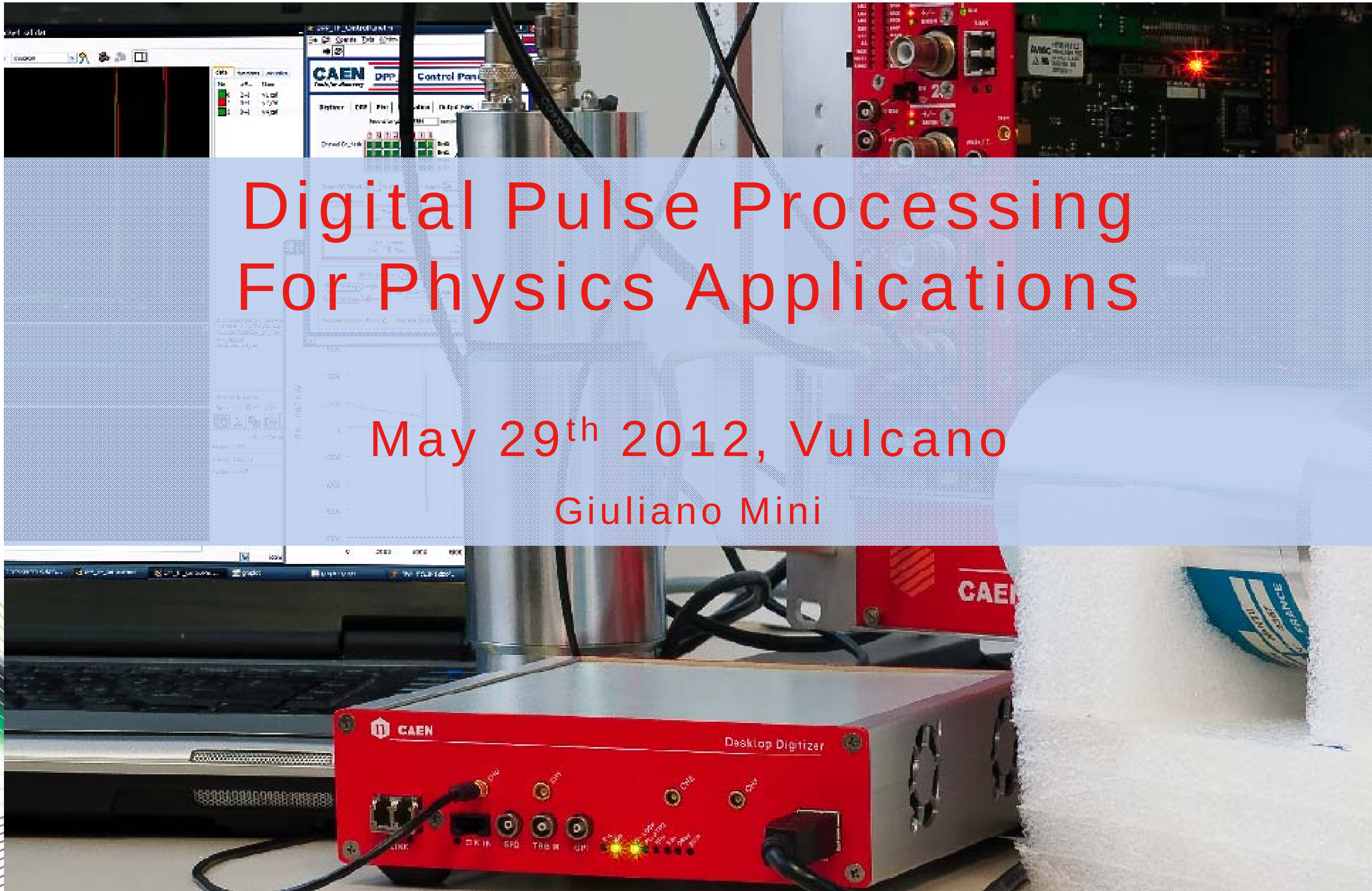


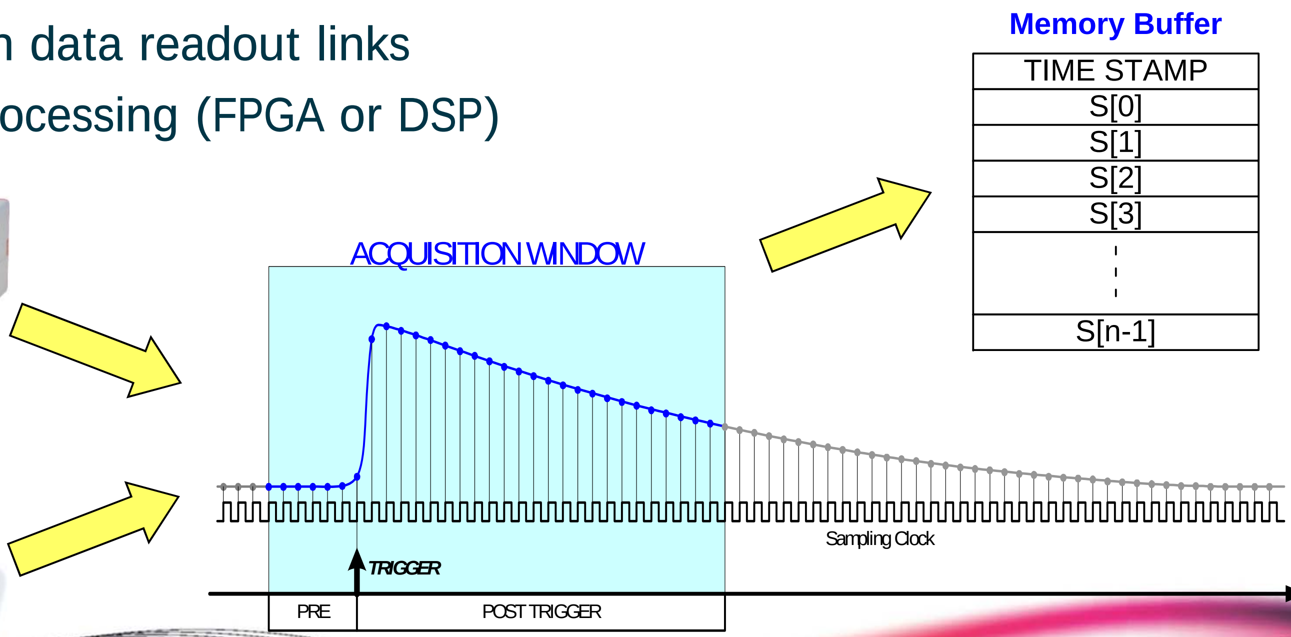
Digital Pulse Processing For Physics Applications

May 29th 2012, Vulcano

Giuliano Mini

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
- However, 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)



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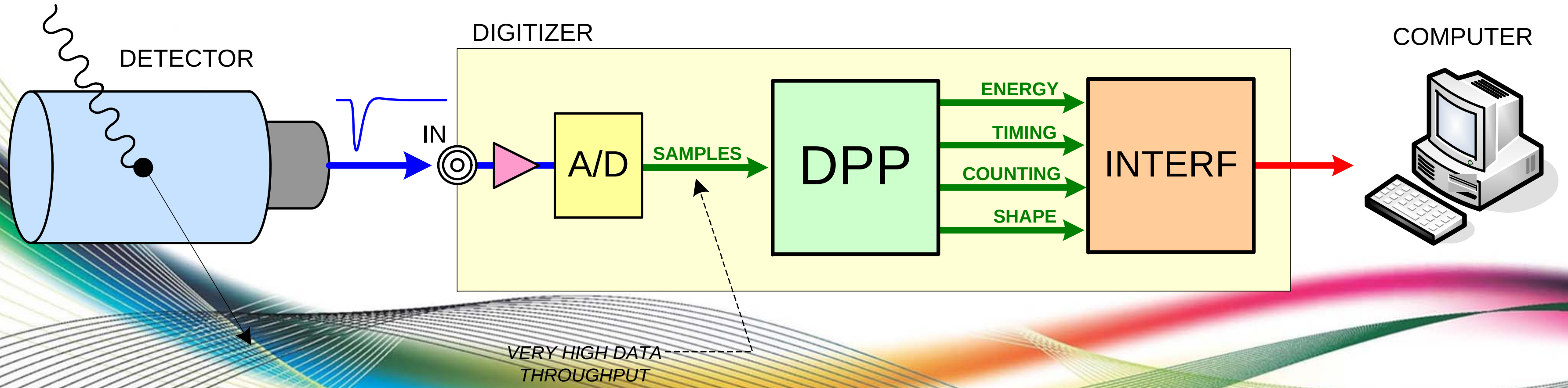
CAEN Digitizers Highlights

- VME, NIM, Desktop form factors
- VME64X, Optical Link (CONET), USB 2.0
- Memory buffer: up to 10MB/ch (max. 1024 events)
- Multi-board synchronization and trigger distribution
- Programmable PLL for clock synthesis
- Programmable digital I/Os
- Analog output with majority or linear sum
- FPGA firmware for Digital Pulse Processing
- Software for Windows and Linux

- **From 2 to 64 channels**
- **Up to 5 GS/s sampling rate - Up to 14 bit**
- **FPGA firmware for Digital Pulse Processing**

Benefits of the digital approach

- One single board can do the job of several analog modules
- Full information preserved: *A/D conversion as early as possible, data reduction as late as possible*
- Reduction in size, cabling, power consumption and cost per channel
- High reliability and reproducibility
- Flexibility (different digital algorithms can be designed and loaded at any time into the same hardware)



Raw waveform mode: Limits

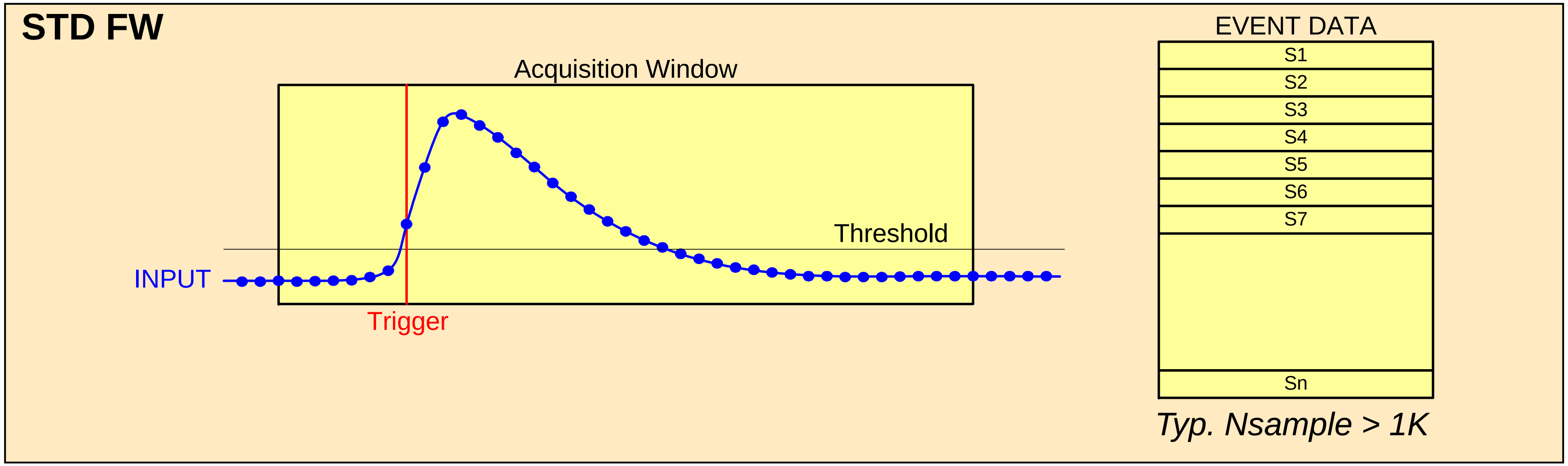
- Using digitizers as waveform recorders can produce a large amount of data to be transferred from the acquisition board to a mass storage devices
- The data throughput can be extremely high: it may be no possible to transfer raw data to computers and make the analysis off-line!
- On-line Digital Pulse Processing is needed to extract only the information of interest reducing the data throughput
- The aim of the DPP is to provide FPGA algorithms able to make in digital the same functions of analog modules such as Shaping Amplifiers, Discriminators, QDCs, etc.
- Three main DPP firmware have been developed so far:

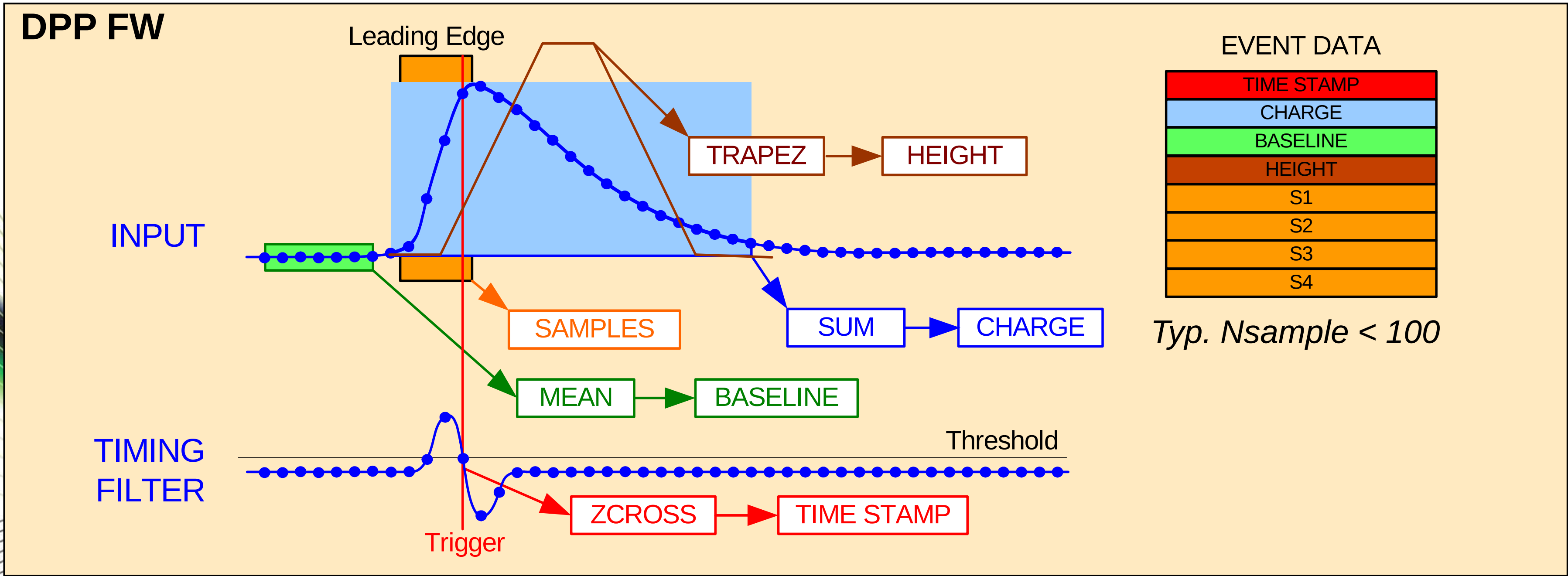
DPP-PHA (Pulse Height Analysis)

DPP-CI (Charge Integration)

DPP-PSD (Pulse Shape Discrimination)

Acquisition mode: raw waveform vs DPP





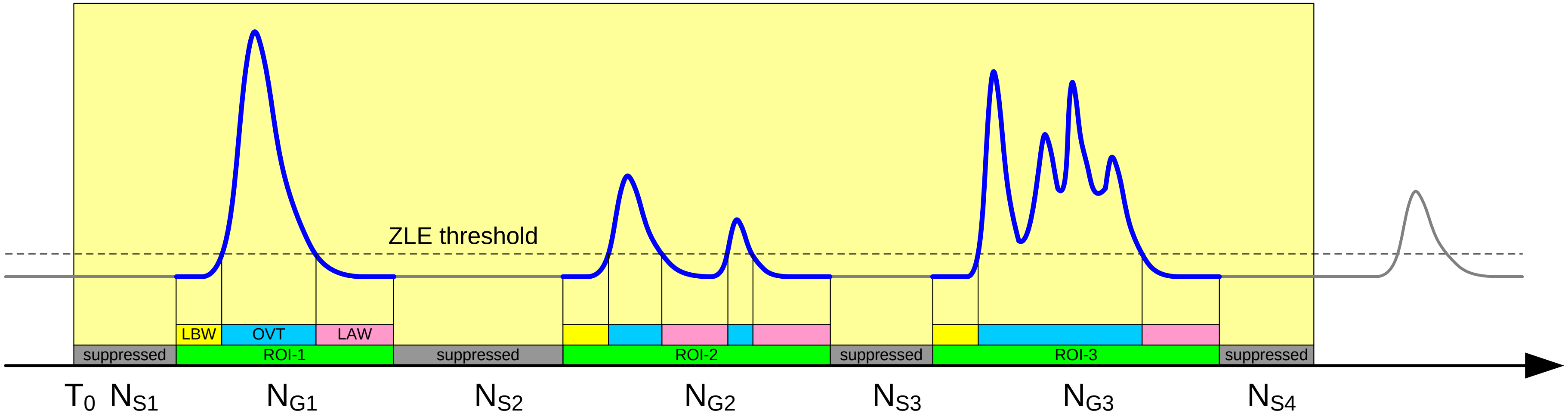
ZERO SUPPRESSION

ZLE topics

- The zero suppression (**Zero Length Encoding**) in a waveform digitizer consists in removing from the acquisition window the parts or the waveform that don’t contain useful information
- DPP only used for the pulse identification (Region Of Interest) and not to extract relevant quantities from the waveforms
- Typically used in beam experiments where the trigger is common to all channels, but only few of them contains events
- Available in the standard firmware of the x724, x720, x721 and x731; current version of the ZLE suffers from a readout bandwidth reduction
- A new ZLE algorithm that guarantees the best readout performances is under development for the x720 and x751

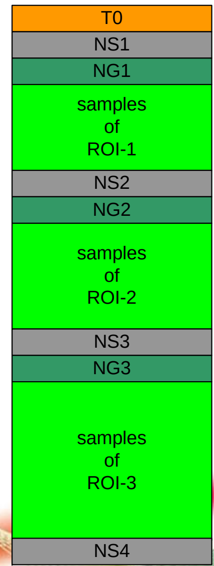
ZLE example

Acquisition Window (programmable size with pre and post trigger)



LBW	***Look Back Window***: programmable size
OVT	***OverThreshold***: lasts as long as the signal is over threshold
LAW	***Look Ahead Window***: programmable size; can be retriggered
T_0	Time Stamp of the first sample of the Acquisition Window
N_S	Number of skipped samples belonging to the suppressed region
N_G	Number of good samples belonging to the ROI

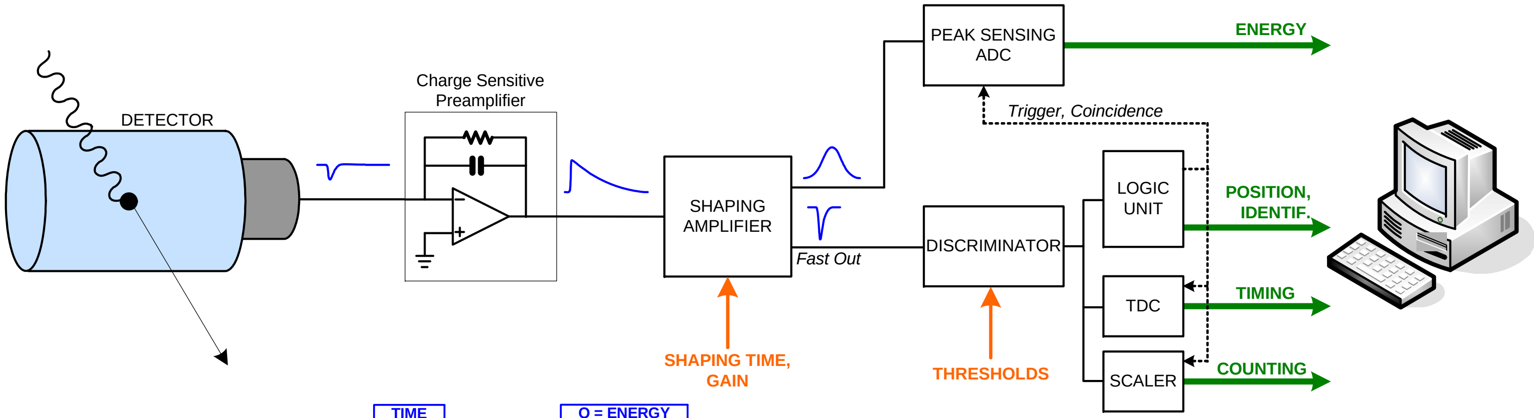
Readout Data

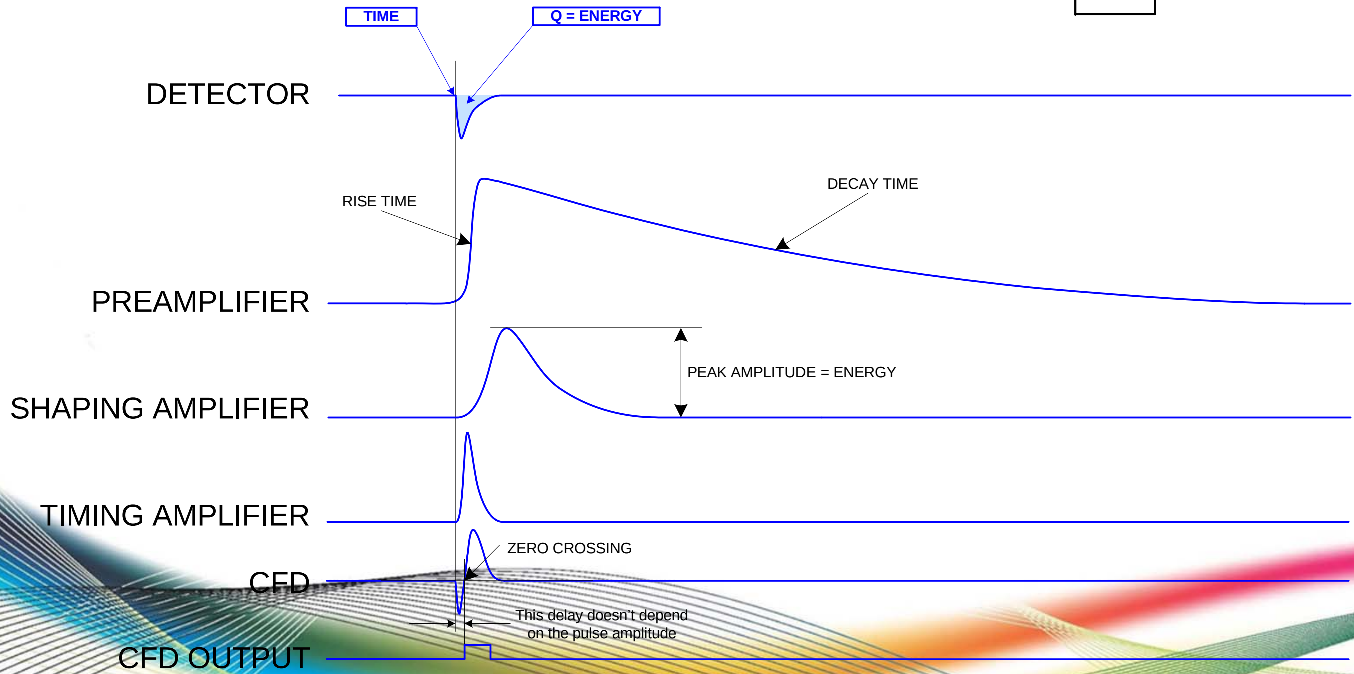


DPP-PHA
PULSE HEIGHT ANALYSIS

Traditional chain: example 1

charge sensitive preamplifiers

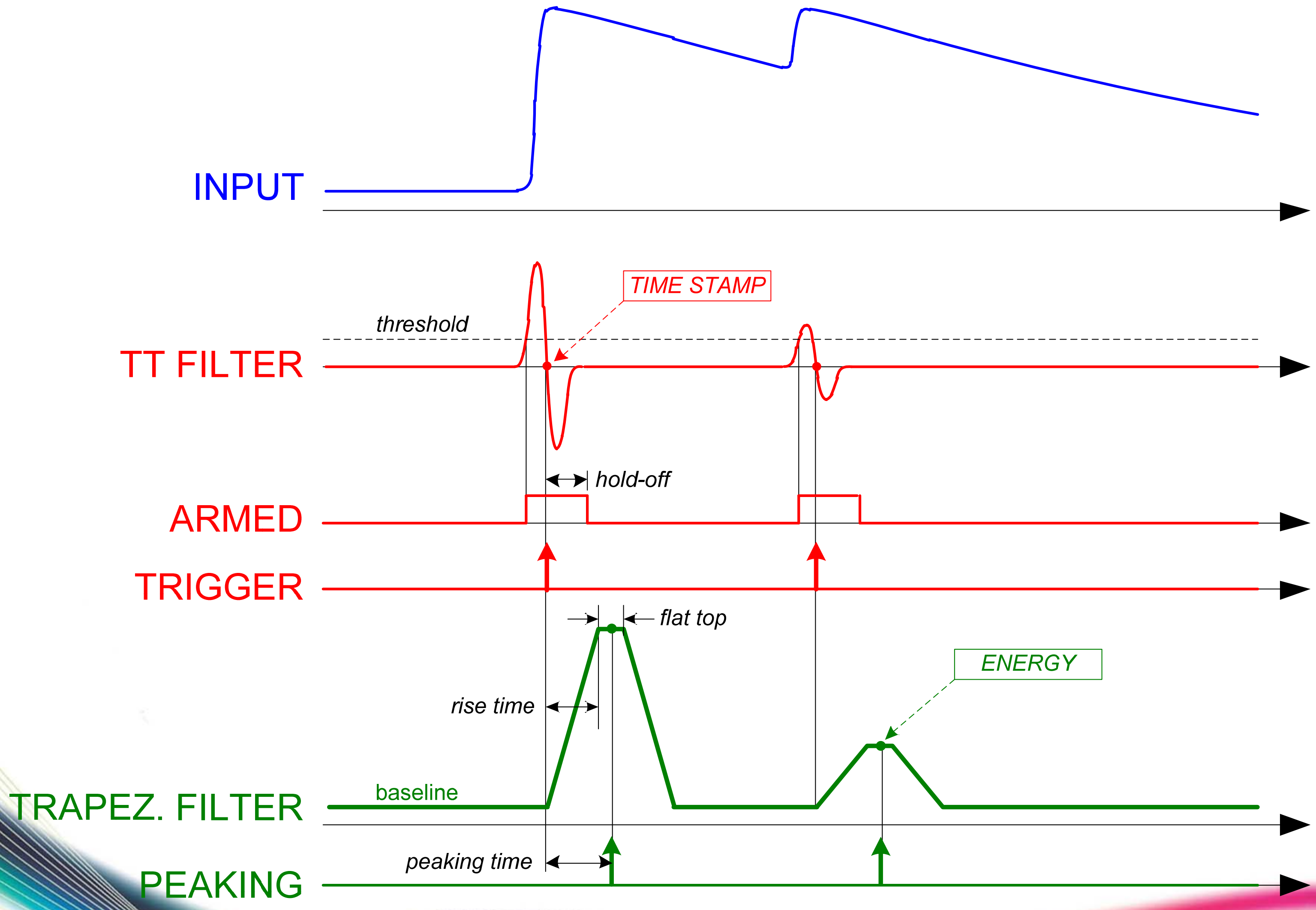




DPP for Pulse Height Analysis (DPP-PHA)

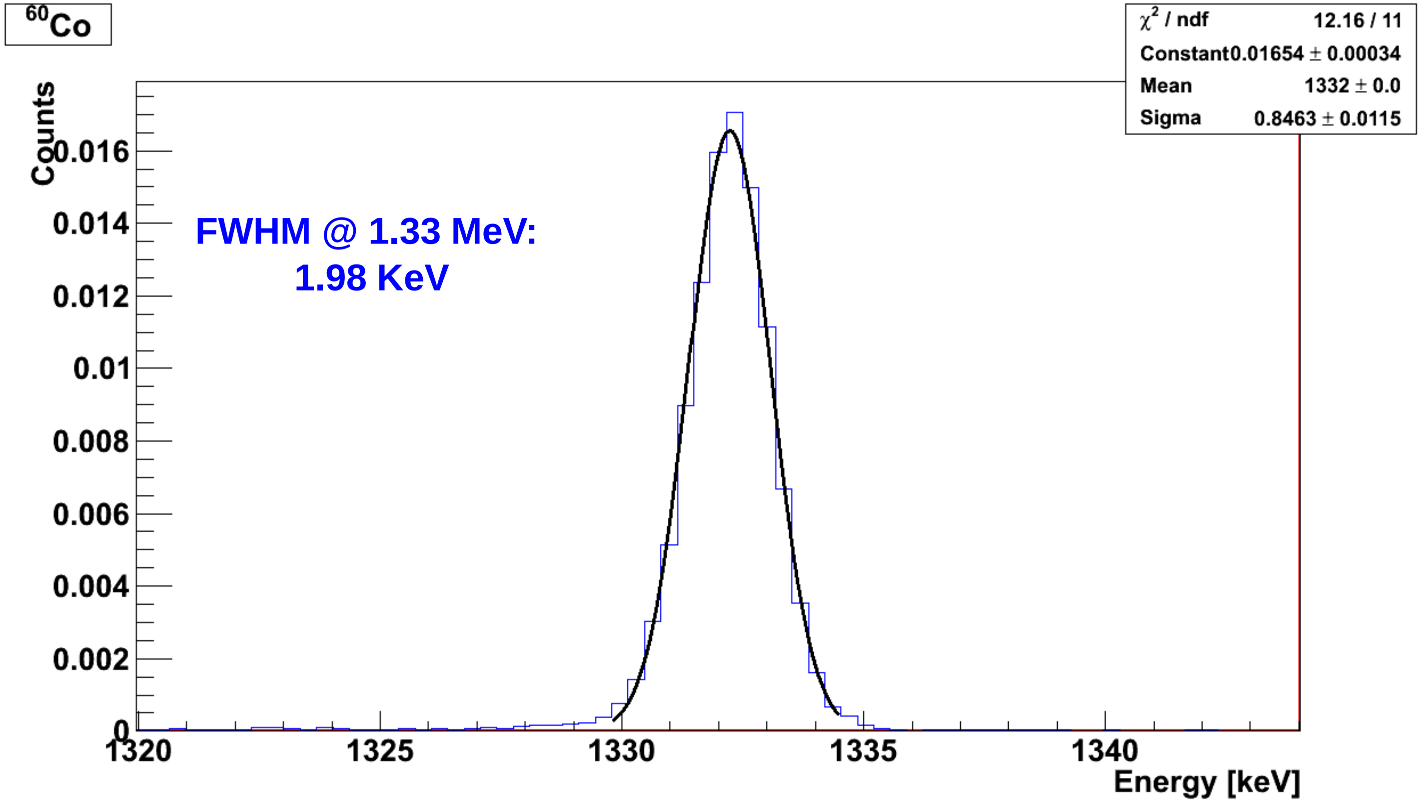
- Digital implementation of the shaping amplifier + peak sensing ADC (Multi-Channel Analyzer)
- Charge Sensitive Preamplifier directly connected to the digitizer
- Implemented in the 14 bit, 100MSps digitizers (mod. 724)
- Provides Pulse Height, Time Stamp (10ns) and optionally raw data
- Pile-up rejection, Baseline restoration, ballistic deficit correction
- Low dead time => high counting rate (up to 1Mcps)
- Best suited for high resolution spectroscopy (HPGe and Si detectors)
- Also suitable for homeland security and biomedical applications
- Can work with segmented detectors (synchronizations, coincidences and neighbour triggering)

DPP-PHA signals

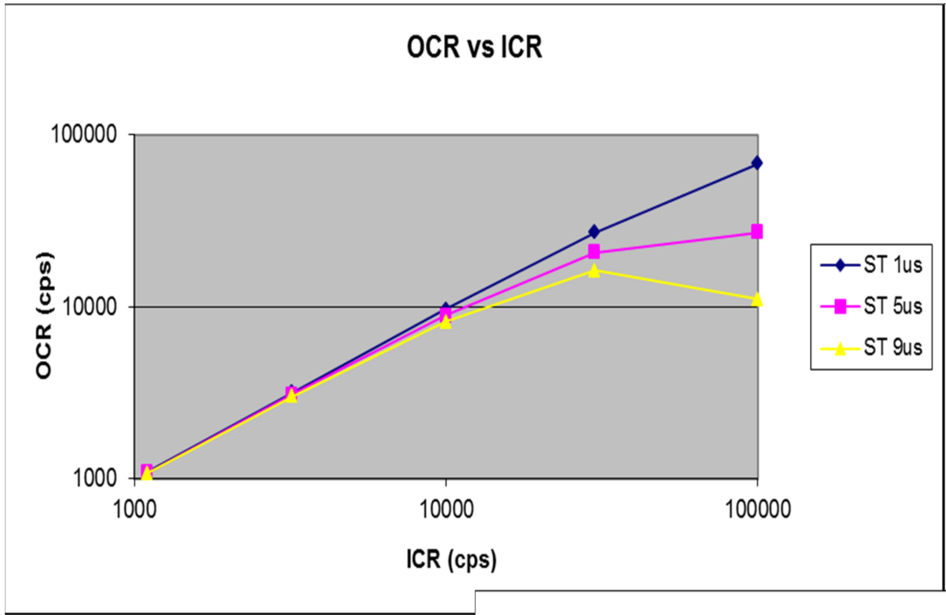


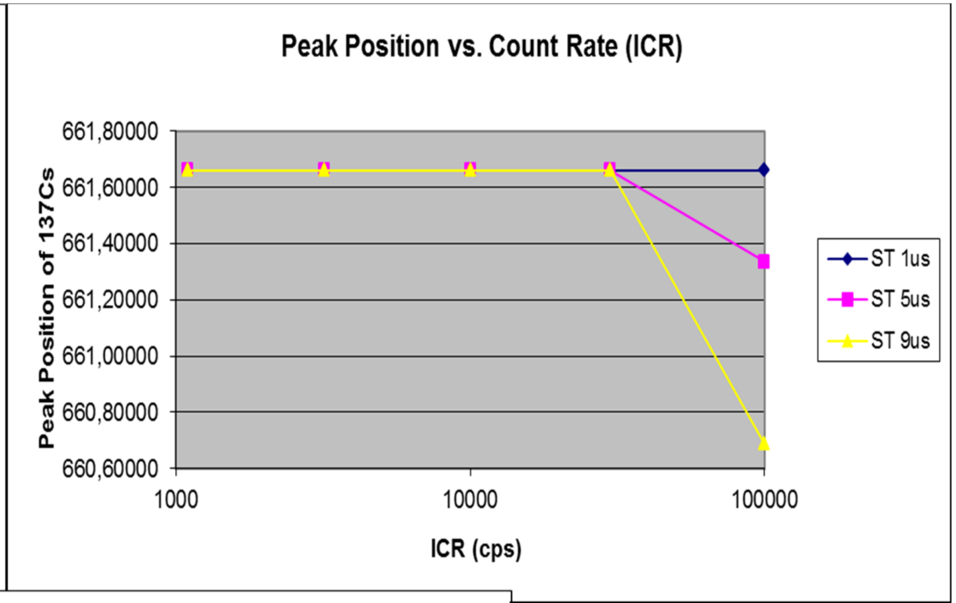
Test Results with HPGe detectors

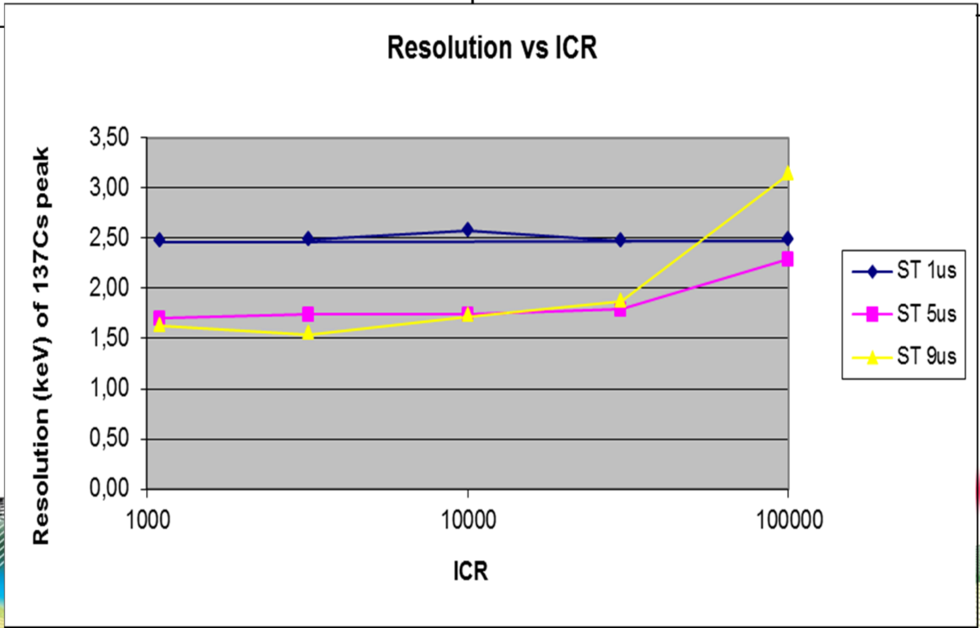
- Preliminary tests performed at LNL (Legnaro - Italy) on Nov-2008 and Feb-2009
- Duke University on Jul-2010
- University of Palermo (Dep. Of Phisycs) on Jan 2011. Detector: Ortec HP-Ge mod. GEM40P4 cooled with an X-cooler (Peltier). Preamp: A257P (time constant = 100μs).
- Saclay (France), lab of radiochemistry on March 2011. Different types of detectors and sources.



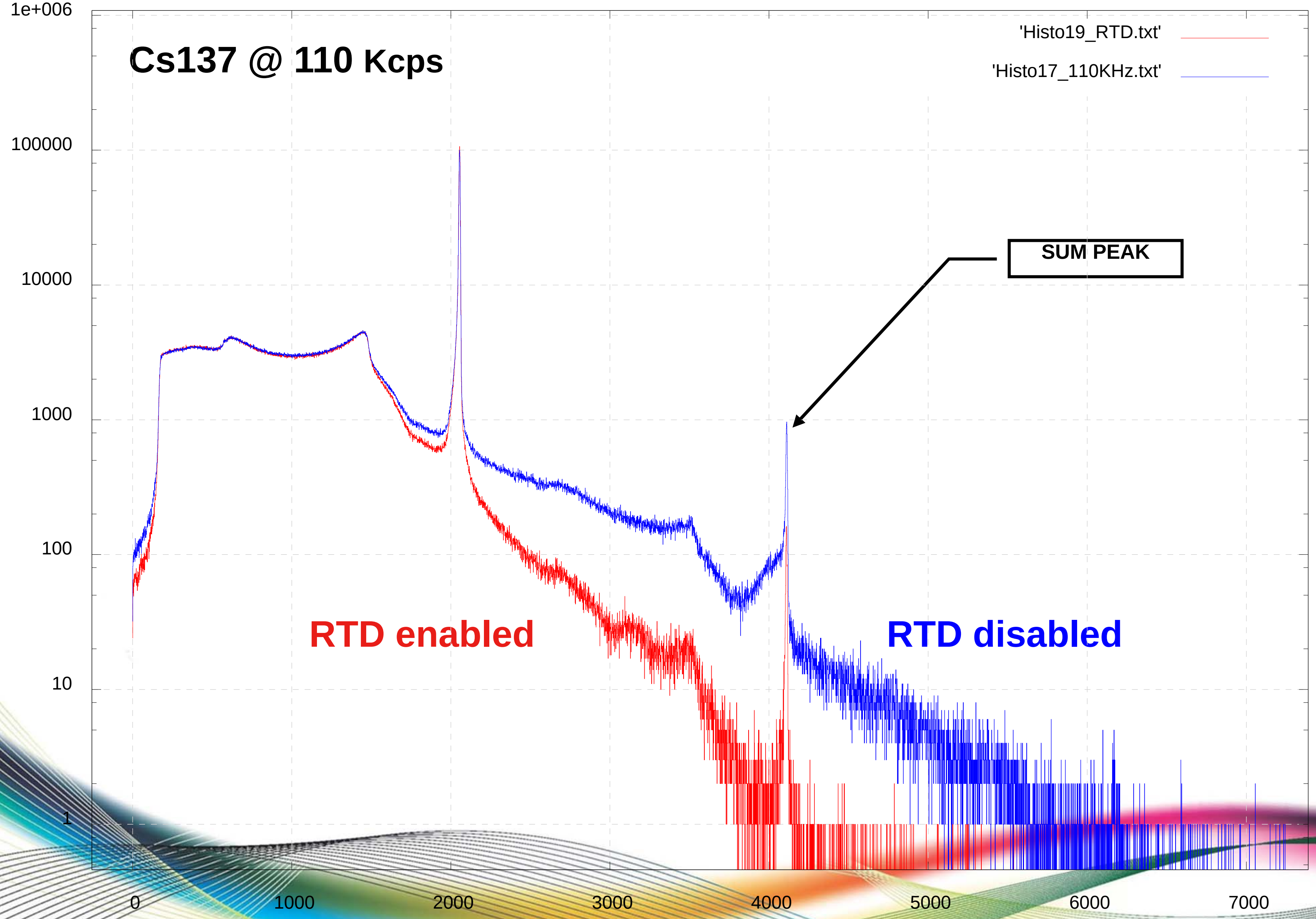
Test Results with HPGe (II)





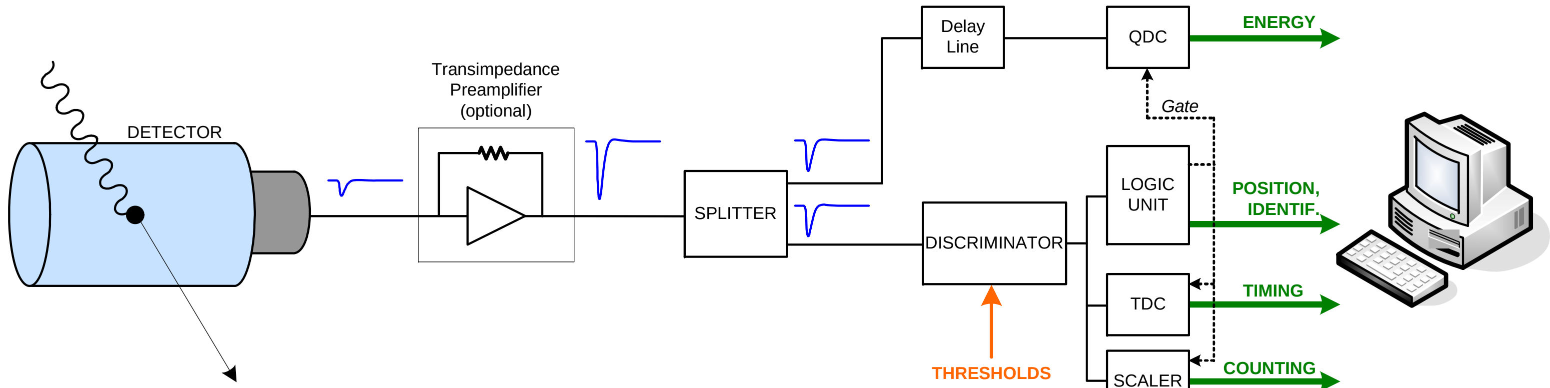


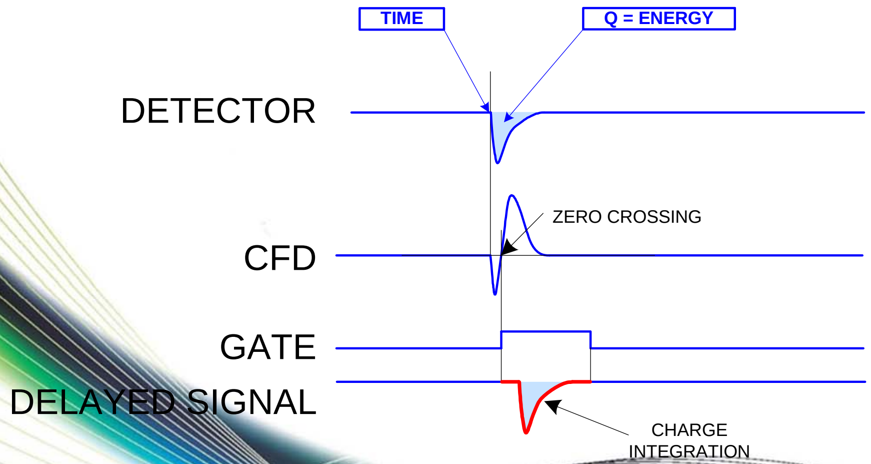
Test Results with HPGe (III)



DPP-CI
DIGITAL CHARGE INTEGRATION

Traditional chain: example 2
trans-impedance (current sensitive) preamplifier



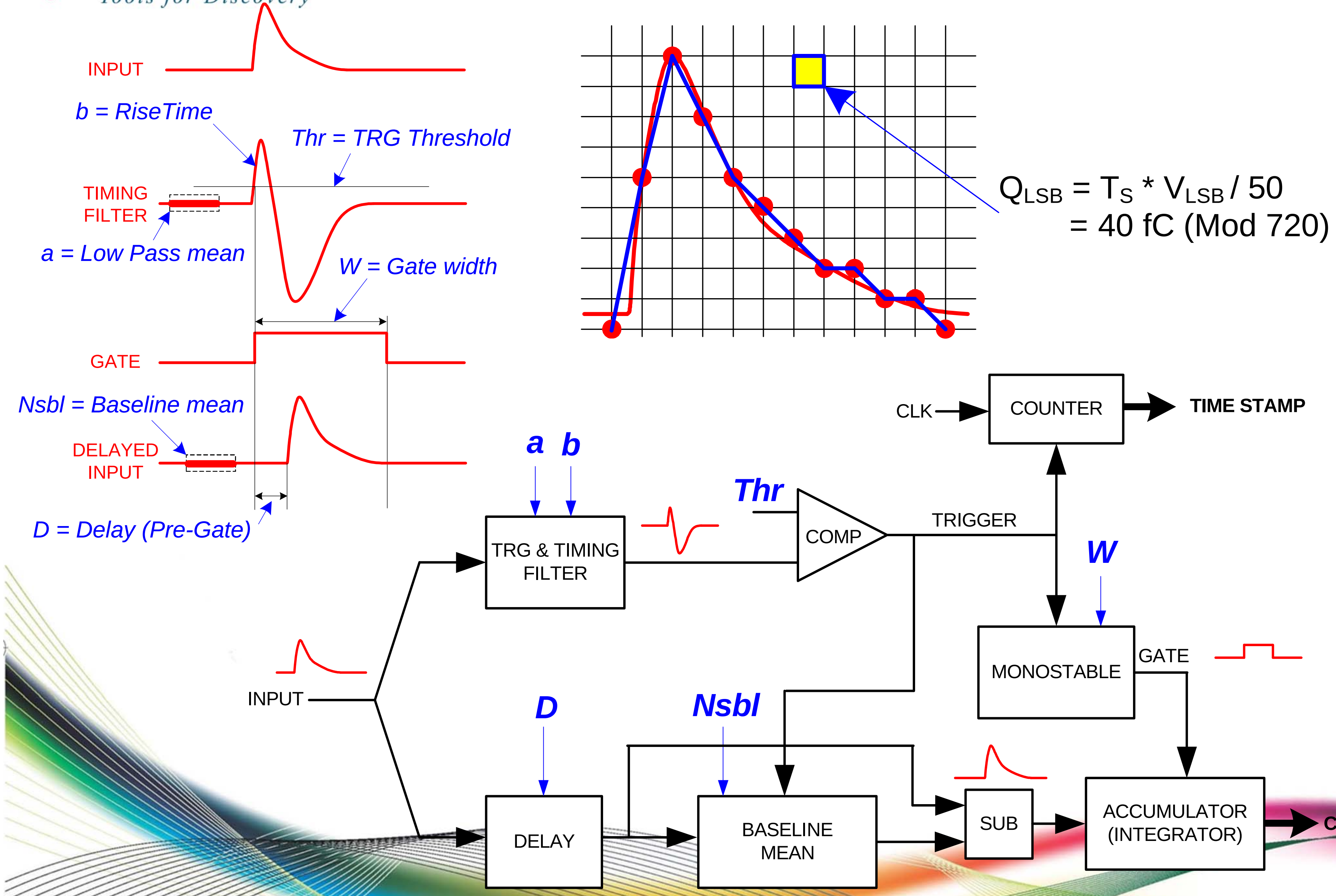


- The QDC is not self-triggering; need a gate generator
- need delay lines to compensate the delay of the gate logic

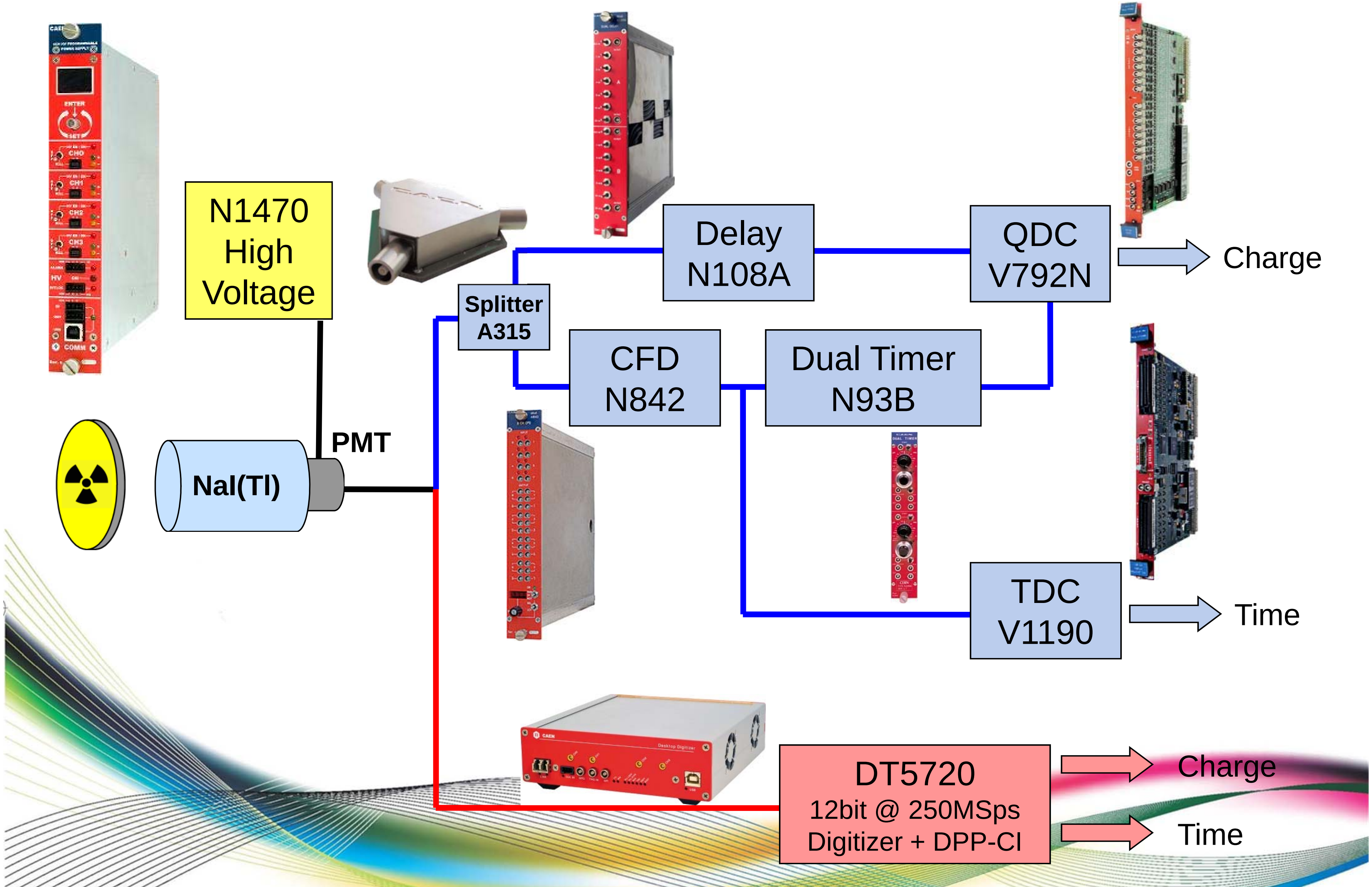
DPP for the Charge Integration (DPP-CI)

- Digital implementation of the QDC + discriminator and gate generator
- Implemented in the Mod. x720 - 12 bit, 250MS/s
- Self-gating integration; no delay line to fit the pulse within the gate
- Baseline restoration (pedestal cancellation)
- Extremely high dynamic range
- Dead-timeless acquisition (no conversion time)
- Energy and timing information can be combined
- Typically used for PMT or SiPM/MPPC readout

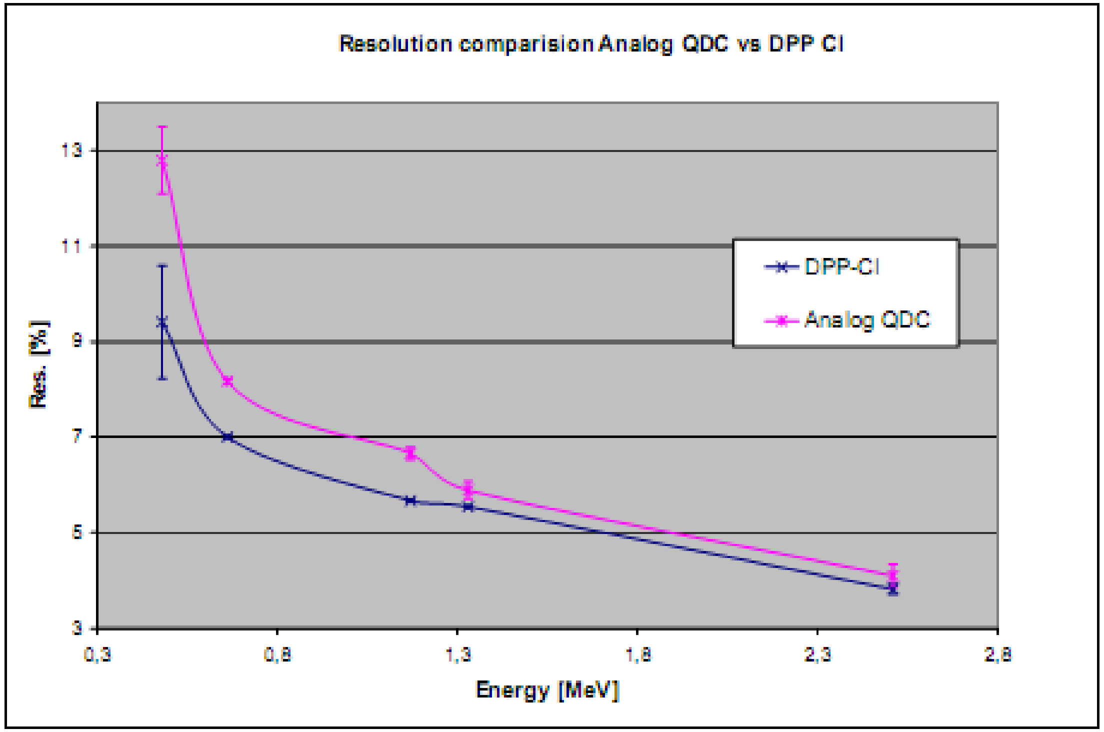
DPP-CI Block Diagram



DPP-CI / Analog Chain set-ups



DPP-CI: Test Results



NaI detector and PMT directly connected to the QDC or digitizer

	DPP-CI	***Analog QDC***
Energy (MeV)	Res (%)	Res (%)
0.481 (^{137}Cs Compton edge)	**9.41 ± 1.18**	**12.80 ± 0.70**
0.662 (^{137}Cs Photopeak)	**7.01 ± 0.04**	**8.17 ± 0.04**
1.33 (^{60}Co Photopeak)	**5.67 ± 0.03**	**6.66 ± 0.18**
1.17 (^{60}Co Photopeak)	**5.46 ± 0.02**	**5.89 ±0.13**
2.51 (^{60}Co Sum peak)	**3.82 ± 0.11**	**4.10 ± 0.24**

*Resolution = FWHM * 100 / Mean*

DPP-PSD
PULSE SHAPE DISCRIMINATION

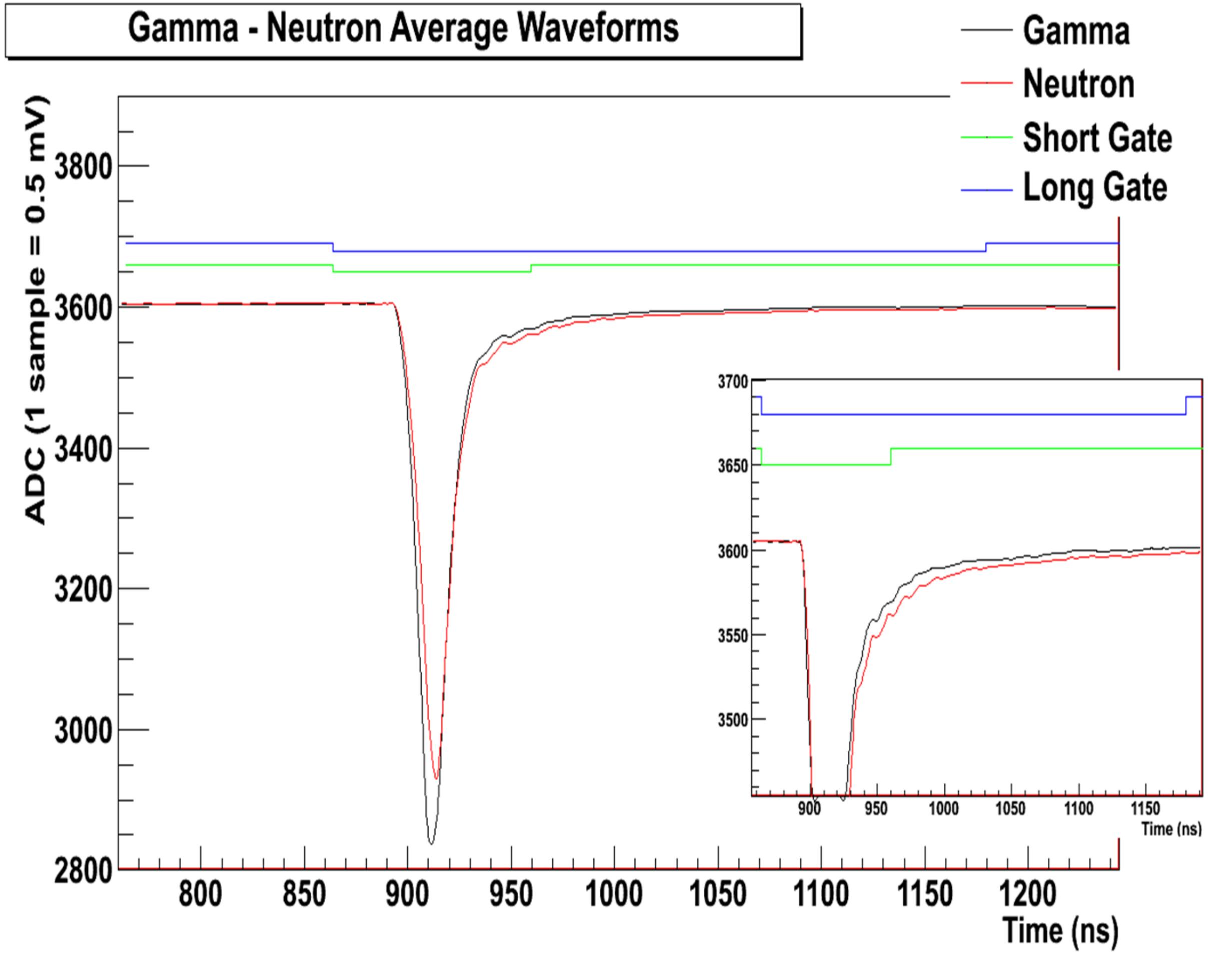
DPP-PSD topics

- Digital implementation of the ΔE/E analysis (double gate charge integration)
- Implemented in the Mod. x720 - 12 bit, 250MS/s and Mod x751 - 10 bit, 1GS/s or 2GS/s
- $PSD = (Q_{LONG} - Q_{SHORT}) / Q_{LONG}$
- Typically used with organic liquid scintillators (e.g. BC501)
- Dead-timeless acquisition (no conversion time)
- Alternative analysis (not implemented yet) based on the Rise Time Discrimination technique: ΔT in the Zero Crossing of two CFDs at 25% and 75%; applied to integrated output (either from C.S. preamp or digital integrator)

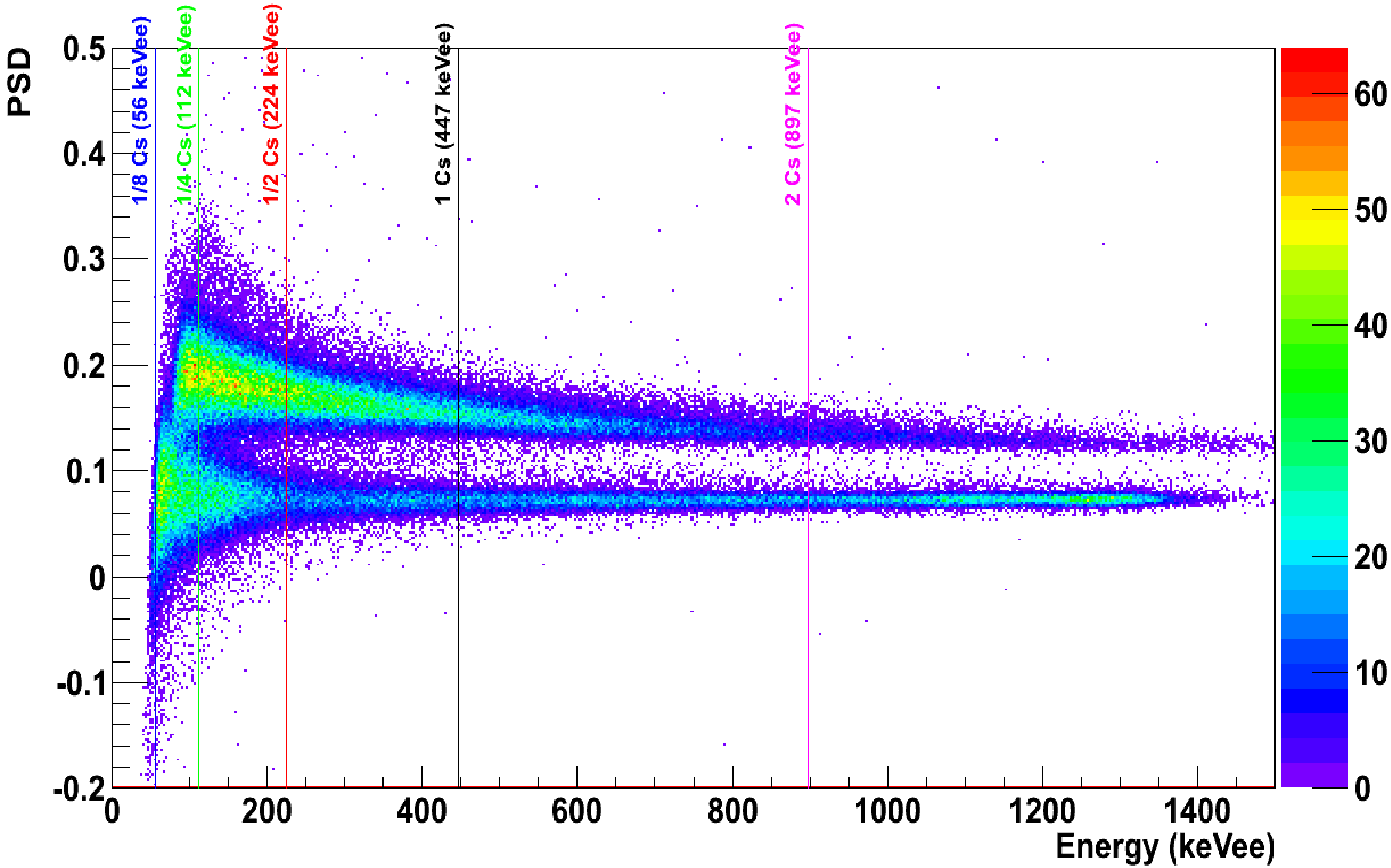
γ-n Discrimination: test results (I)

Detector: BC501A 5x2 inches,

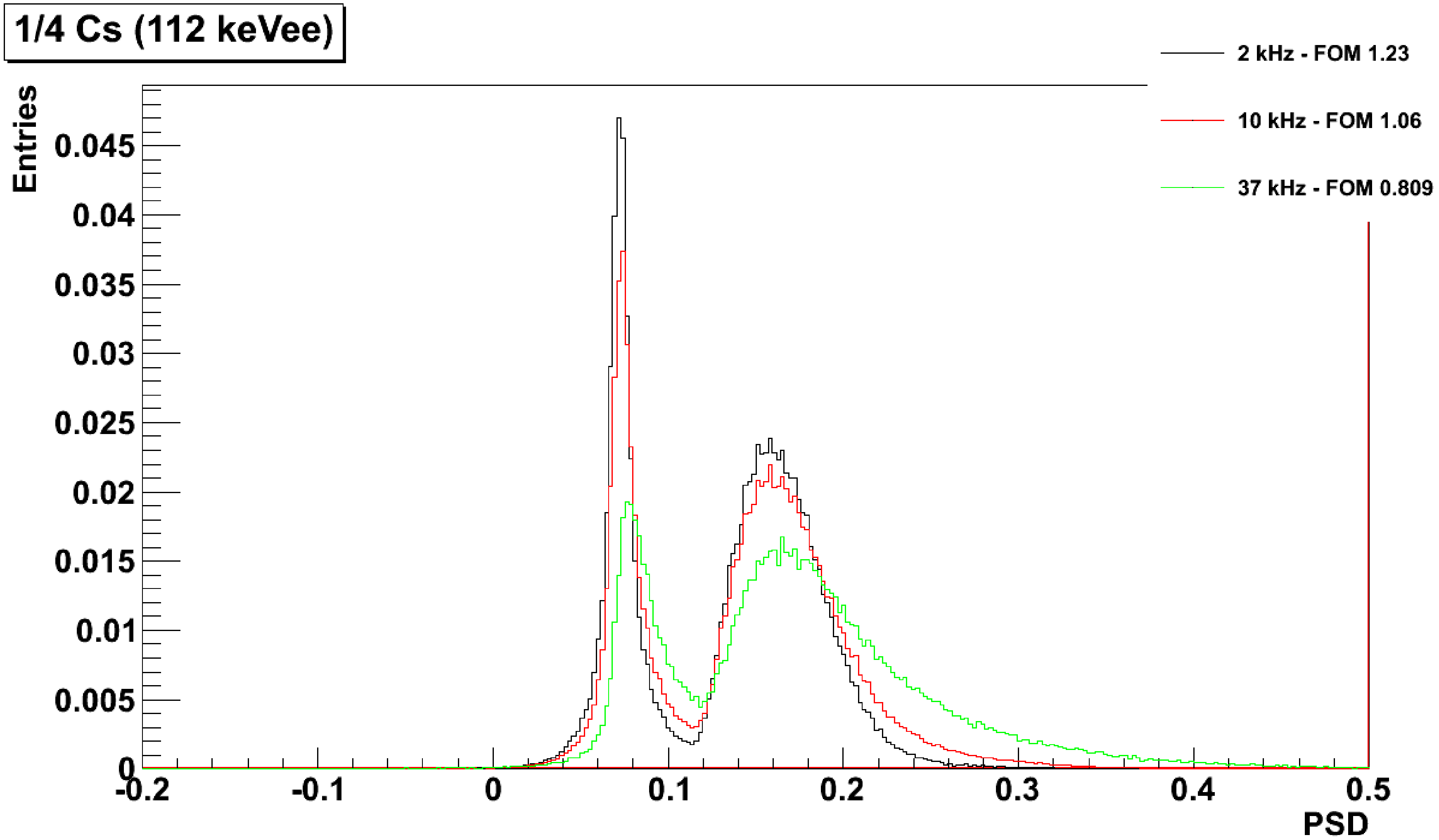
PMT: Hamamatsu R1250



γ-n Discrimination: test results (II)



γ-n Discrimination: test results (IV)



Some Real Applications

Synchronization

What does *synchronization* mean?

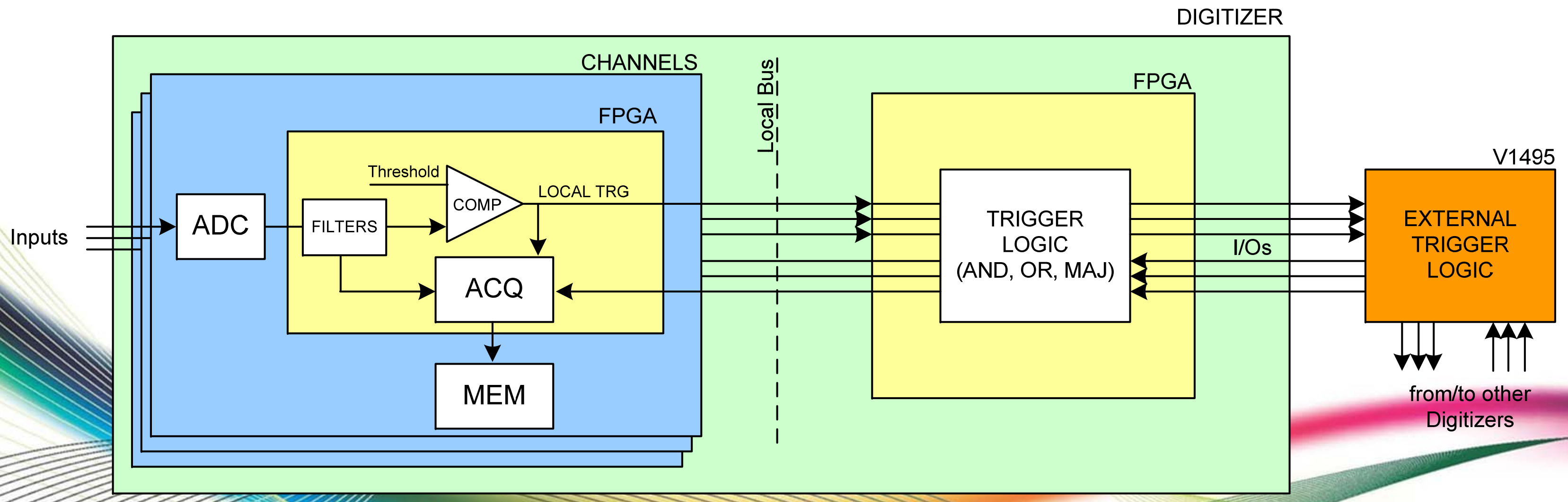
1. same sampling clock propagated to all flash ADCs:
   - ✓ External clock in/out(1); first board can act as a clock master and distributes the clock to many slaves in daisy chain
   - ✓ PLL for clock synthesis; lock to an external clock reference
   - ✓ Programmable Phase Adjust for cable delay compensation
2. same T zero for the time stamps:
   - ✓ Sync Input for a simultaneous start/stop of the acquisition and/or for time stamp reset
   - ✓ Sync Distribution through the boards in daisy-chain (via TrgOut)
   - ✓ Use of the first trigger to start the acquisition
3. trigger propagation and correlation:
   - ✓ External Trigger In/Out (NIM/TLL on LEMO connectors)
   - ✓ Global or individual Trigger propagation through LVDS GPIOs(1)
   - ✓ Neighbour triggering options for segmented and clove detectors

(1) for VME modules only

Coincidence and Event correlation (HW)

Hardware approach

- Propagate local triggers from each channel to the others within the board
- TR-TV mode: triggers from other channels (trigger requests) can be used as trigger validation
- Apply individual trigger masks and simple combinatorial logics on board (AND, OR, Majority)
- Use GPIOs on the front panel to propagate individual trigger inputs/outputs from/to external logic boards (e.g. V1495)



Coincidence and Event correlation (SW)

Software approach

- Read all events as long as you have enough bandwidth (i.e. make data suppression as late as you can): **preserve the information**!
- In list mode, the bandwidth requirement is very low (e.g. 8 bytes per event). Example: 8 channels at 100 KHz trigger rate gives 6.4 MB/s.
- In a modern multi-core computers, the readout process takes a small fraction of the CPU resources
- Time stamped events allow for easy and flexible software coincidence, anticoincidence, correlation, etc.

Time Frame Spectroscopic Imaging (I)

Need to get subsequent spectroscopic images of a sample
(1024 frames)

- For each frame multichannel spectra collection with coincidence capabilities is required
- Once a frame has been acquired, the system has to save the spectra, reset the histos and get ready to restart the measurement with no dead time between frames
- The frame change is synchronous with an external signal

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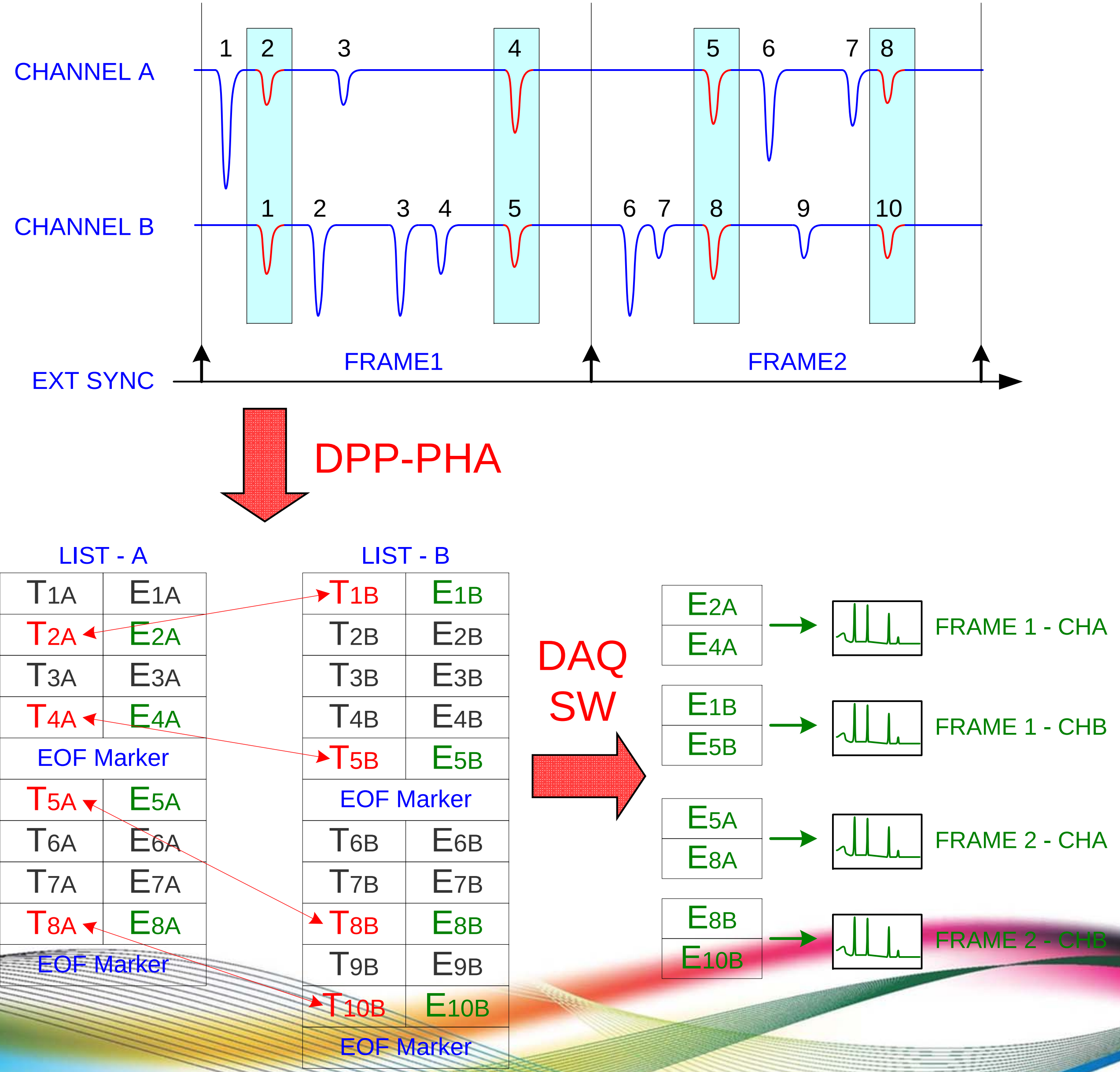
Time Frame Spectroscopic Imaging (II)

- On-board DPP-PHA processes the input pulses and produces a list of events (Energy & Timestamp)
- The DAQ software looks for coincidence using the timestamps and generates histos
- The External Sync signal forces the boards to produce a “End of Frame” marker in the data list
- The DAQ software recognizes the marker and closes the current frame opening the next one



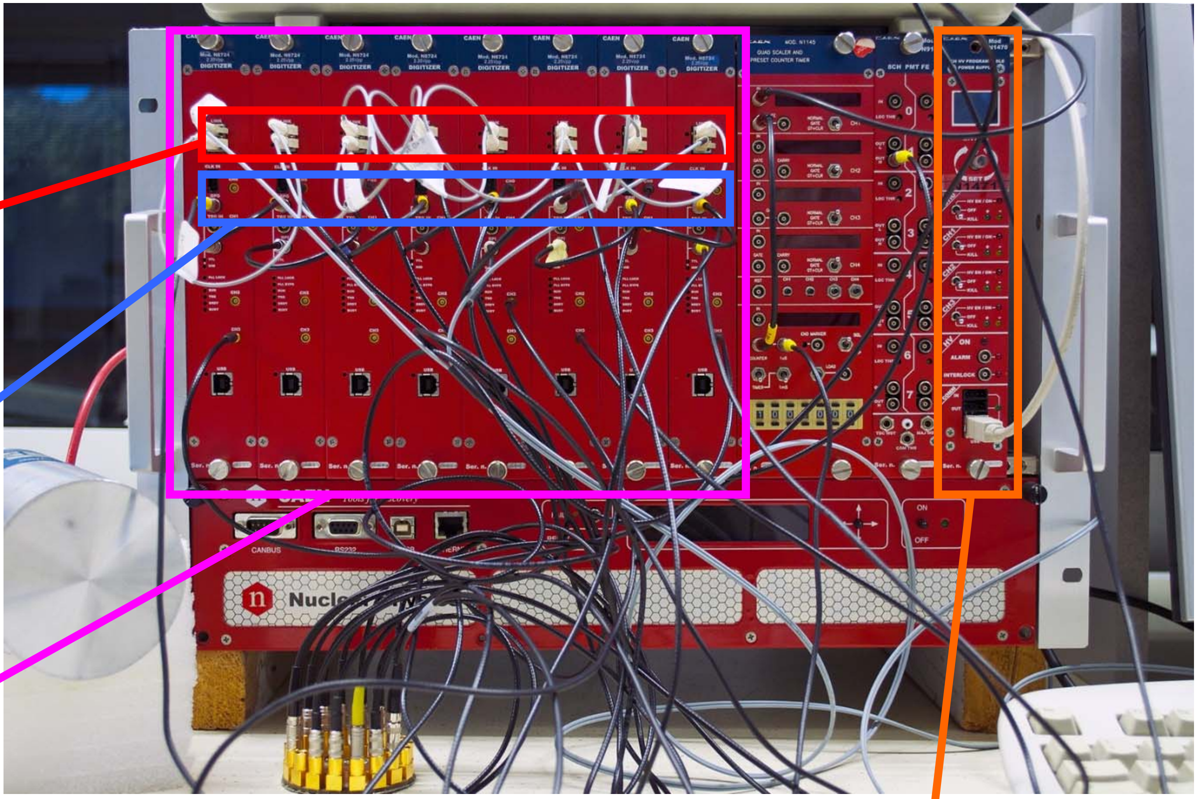
Time Frame Spectroscopic Imaging (III)

TEST SETUP

High-throughput readout via optical link (~300 kcps/ch)

Synchronous Histos collection and frame switch via daisy chain

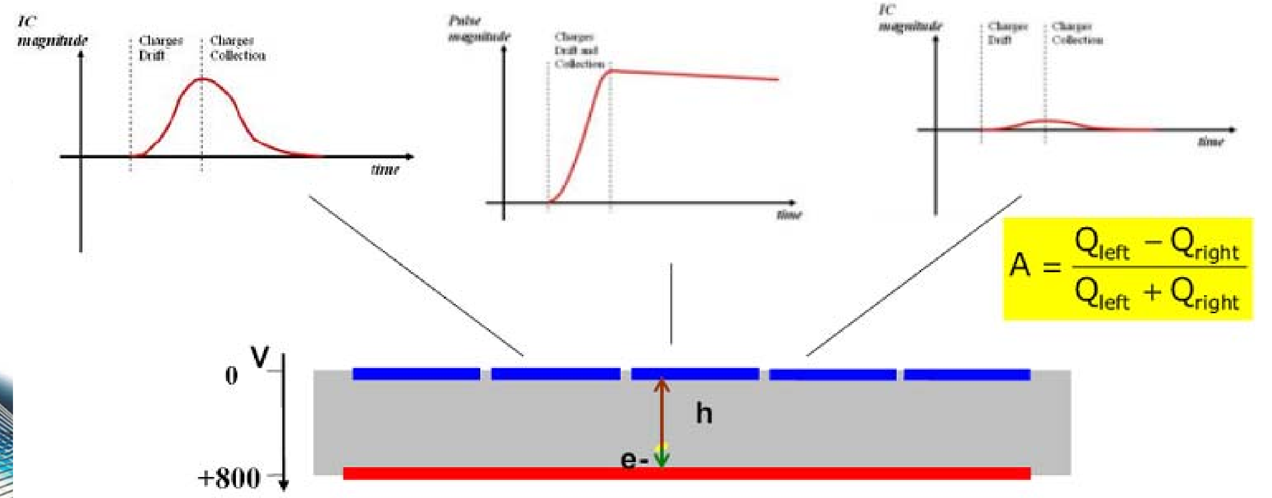
32 channels, 14 bit 100 MS/s with DPP-PHA (N6724)



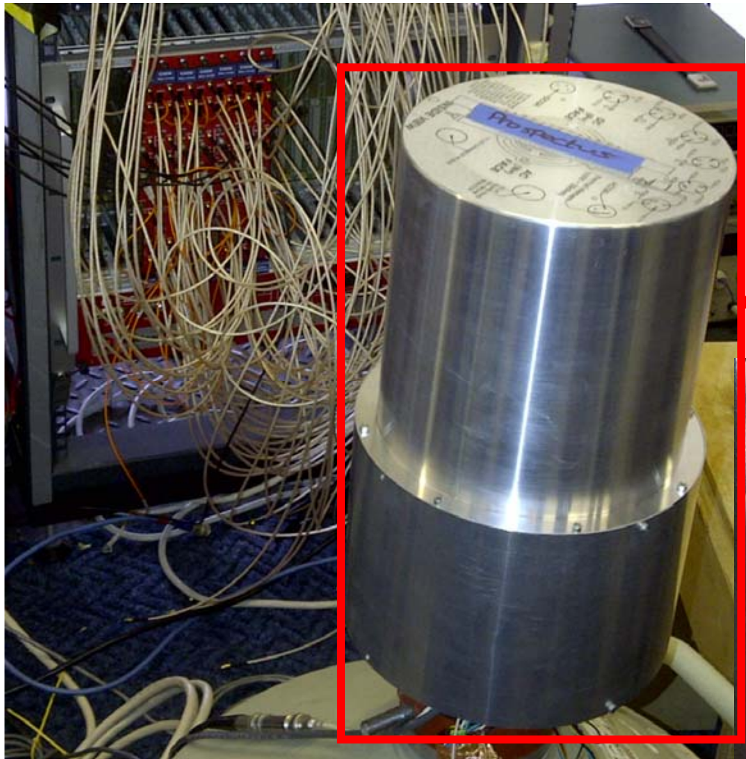
HV power supply

Individual inter-channel triggering (I)

- Feature developed for the project *ProSPECTus* (Compton camera)
- Mainly needed in segmented or clove detectors
- One channel triggers itself and also neighbour channels (also from board to board)
- Individual TRG-IN and TRG-OUT lines from each channel to the Front Panel GPIO connector (8 inputs + 8 outputs)
- External trigger unit (V1495) for the coincidence matrix implementation

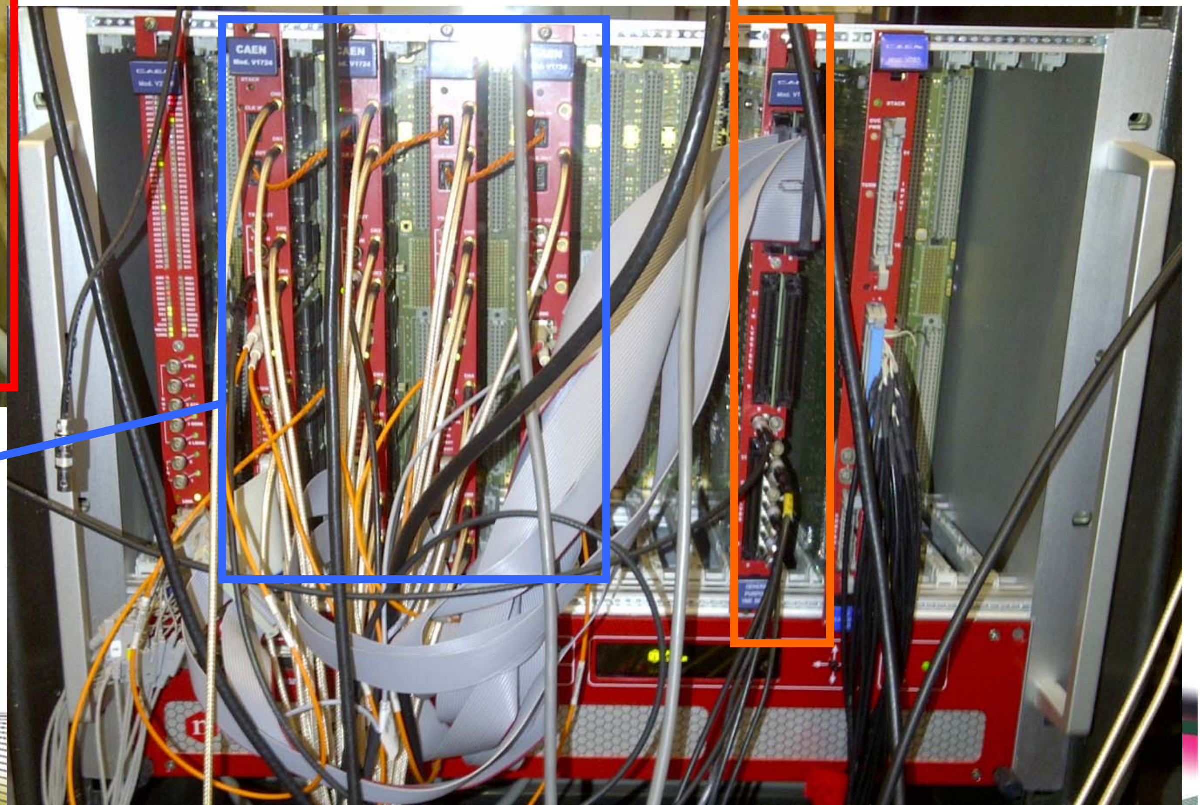


Individual inter-channel triggering (II)



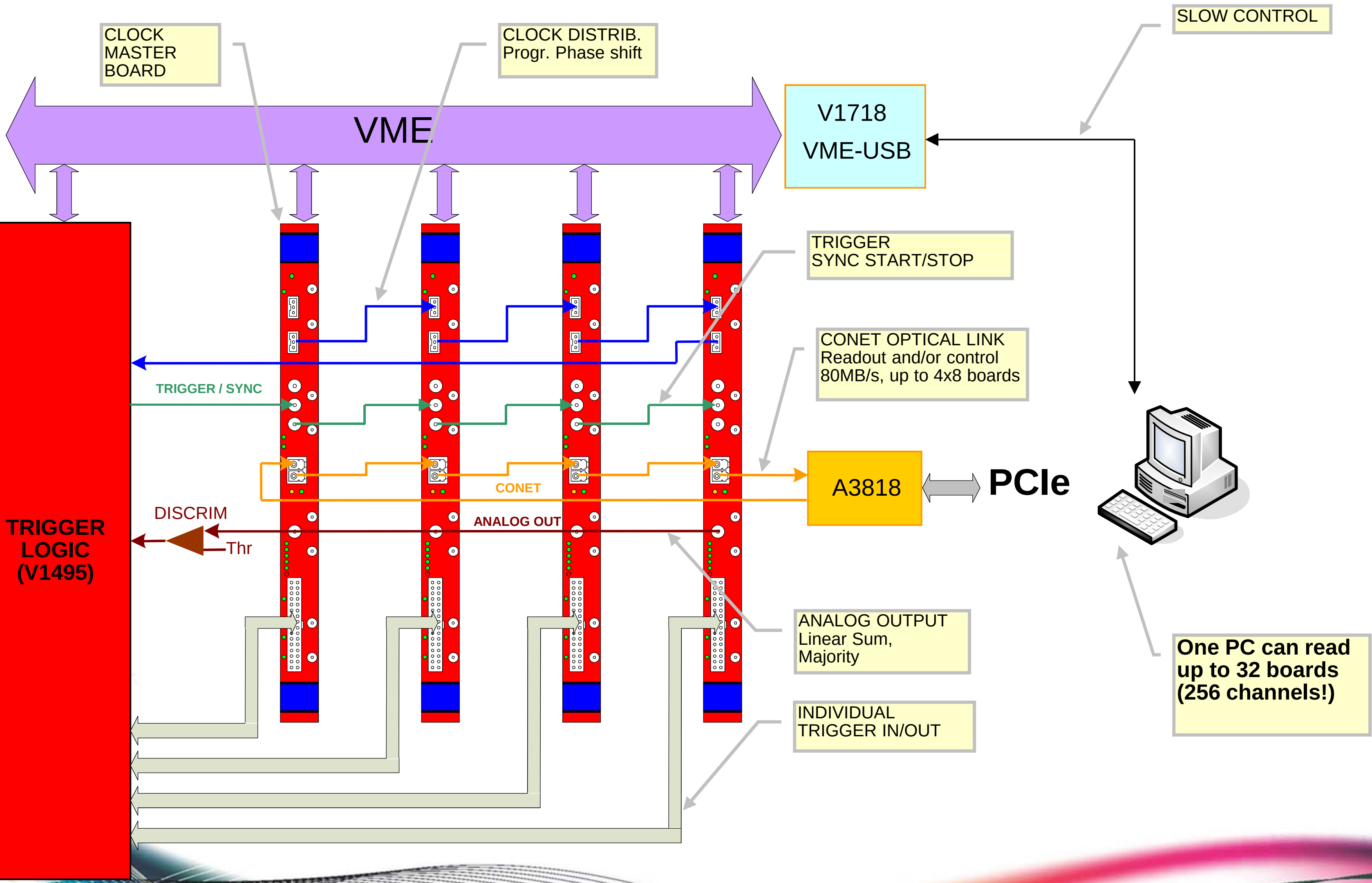
Segmented HPGe

V1495 with ad-hoc Trigger Logic



V1724 digitizers with DPP-PHA

Individual inter-channel triggering(III)

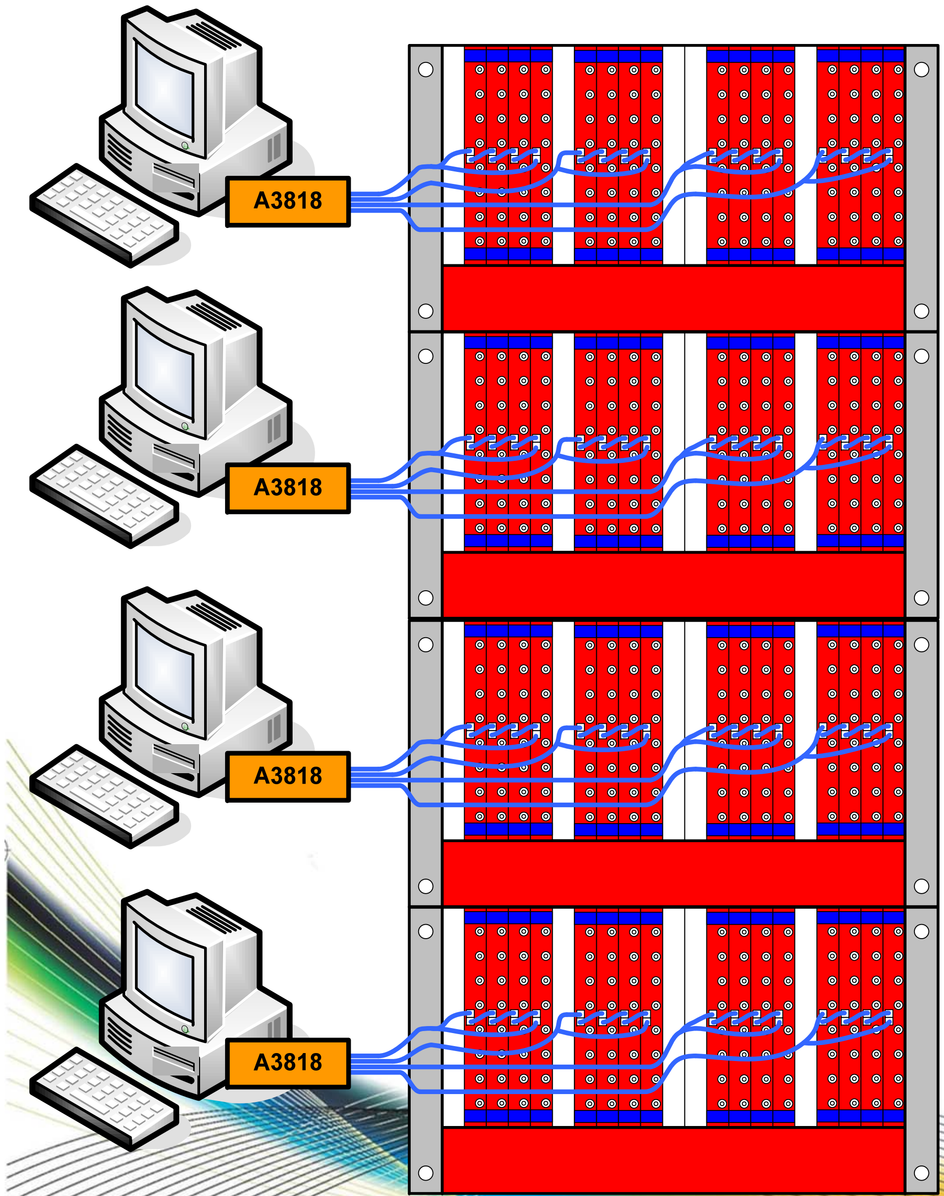


XMASS Experiment

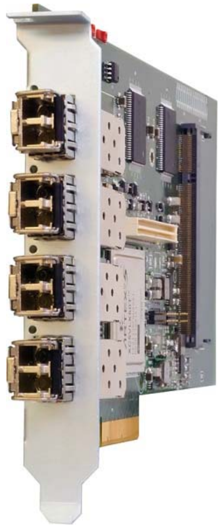
Multi purpose low-background experiment with LXe.

- **Xenon MASSive detector for Solar neutrino (pp/^{7}Be)**
- **Xenon neutrino MASS detector (double beta decay)**
- **Xenon detector for Weakly Interacting MASSive Particles (DM)**

XMASS Experiment (II)



- 80 V1751 modules in 5 VME crates
- ZLE
- 640 channels (10 bit @ 1GHz)
- 5 A3818s 4 link PCIe cards
- 20 parallel CONET links
- 4 digitizers daisy chained
- Readout Bandwidth = ~2 MB/s/ch
- Total aggregate throughput = ~ 1GB/s



A3818
PCIe 8x
CONET Controller

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Thank you!

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