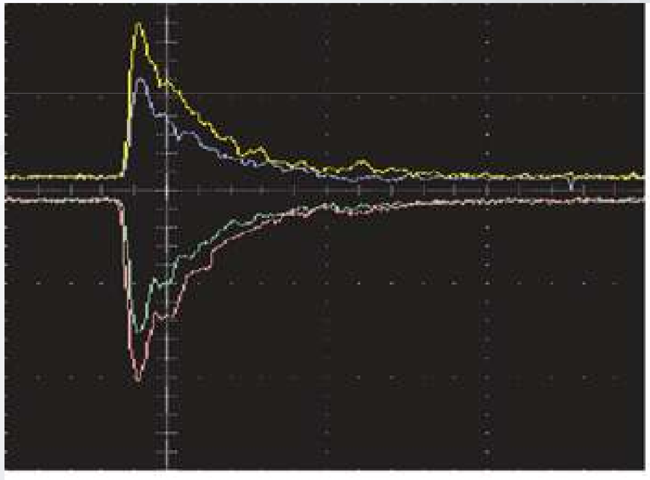
Digital strategies for time and energy measurement for ultra fast inorganic scintillators



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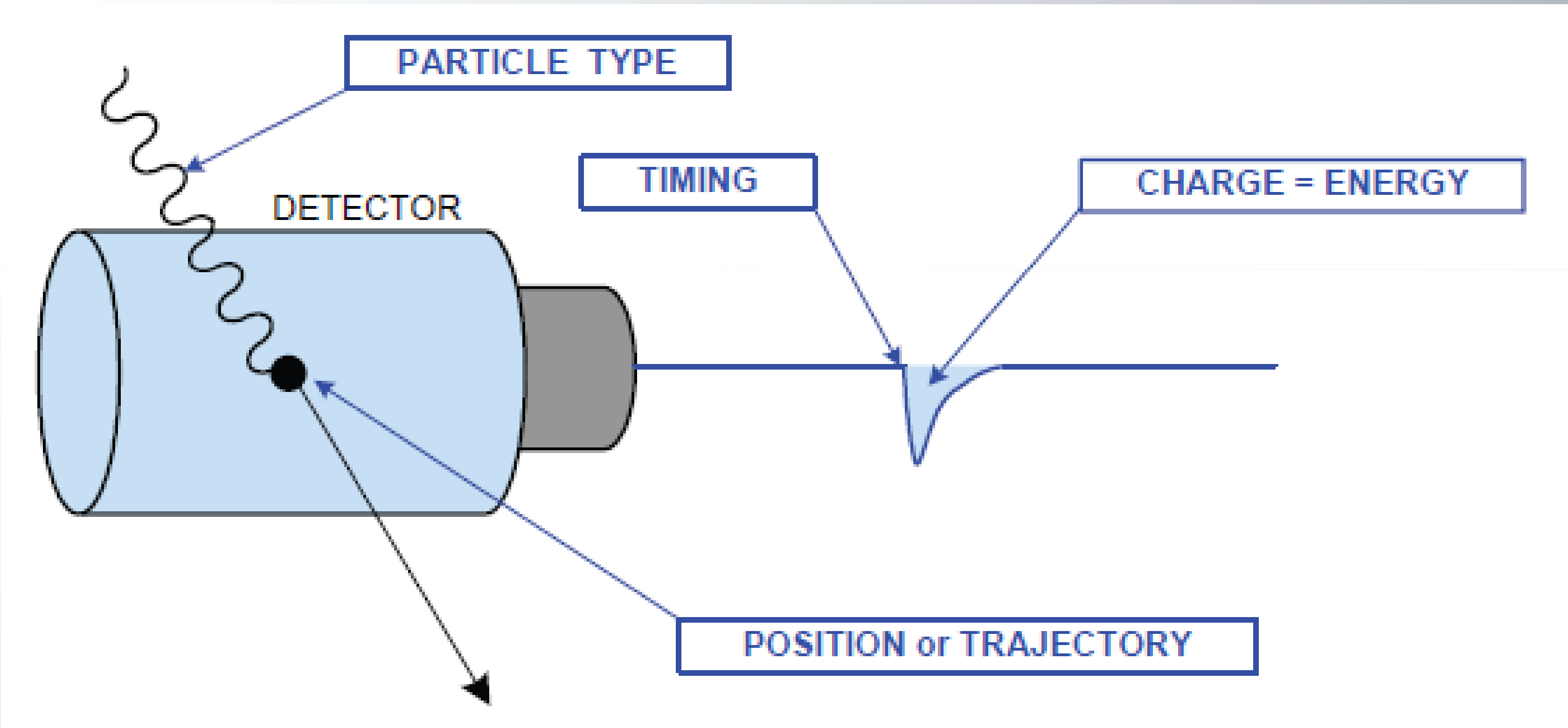
Fully digital (FD-DAQ) nuclear pulse processing for (from) the layman

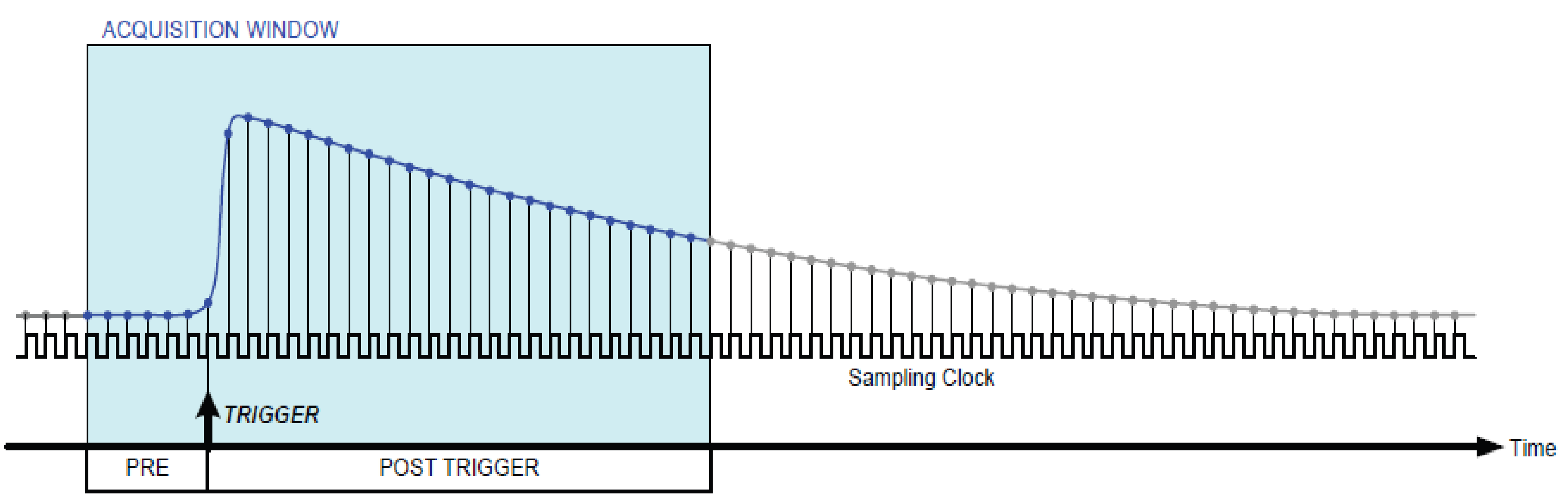
JM Udias NUSPIN-2017

What and why?


PARTICLE TYPE
TIMING
CHARGE = ENERGY
DETECTOR
POSITION or TRAJECTORY

Fully digital

- Digitize the raw (or as raw as convenient) signal (ADC) with adequate resolution and number of samples per second. Process the pulse to get time and/or energy numerically, i.e., with a program

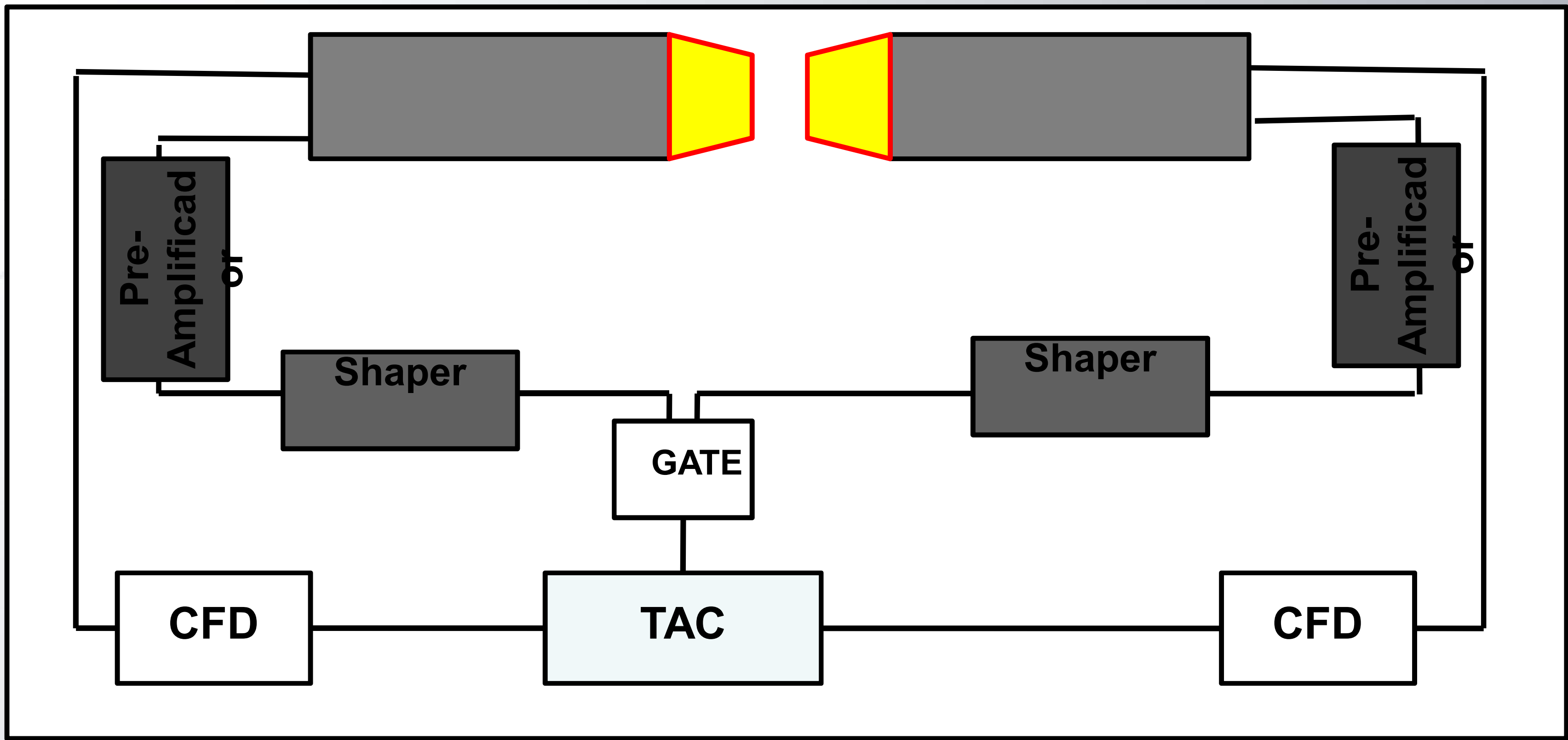


Why?

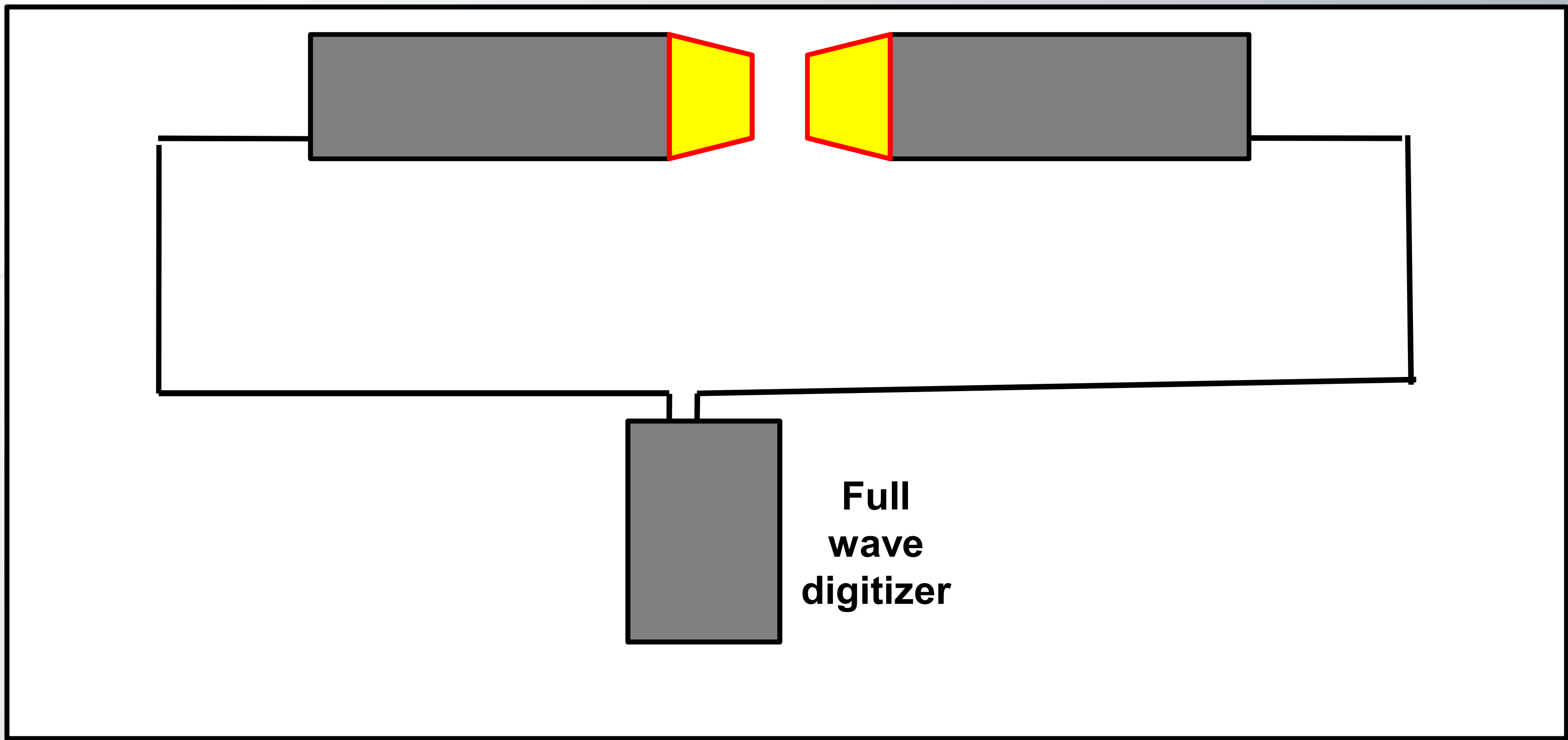
- Simplicity: the same board can acquire and digitize data for energy and time coincidences. Preserve pulse properties.
- Flexibility. Any kind of processing and filter is possible, median filter, recursive filters, FFT and frequency based filters. It is not limited to the ones implemented in analog circuits
- Stability and noiseless: digitized data are further inmune to noise, temperature changes, etc

Coincidence experiment

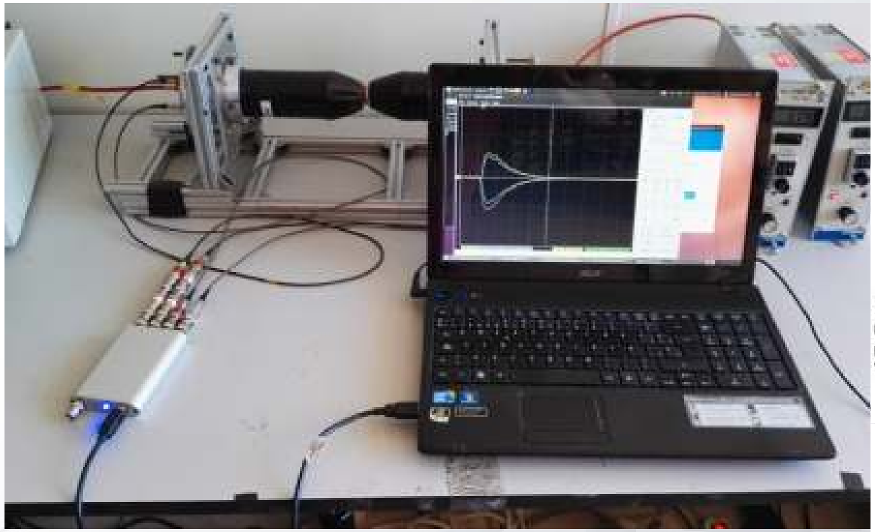
Conventional DAQ

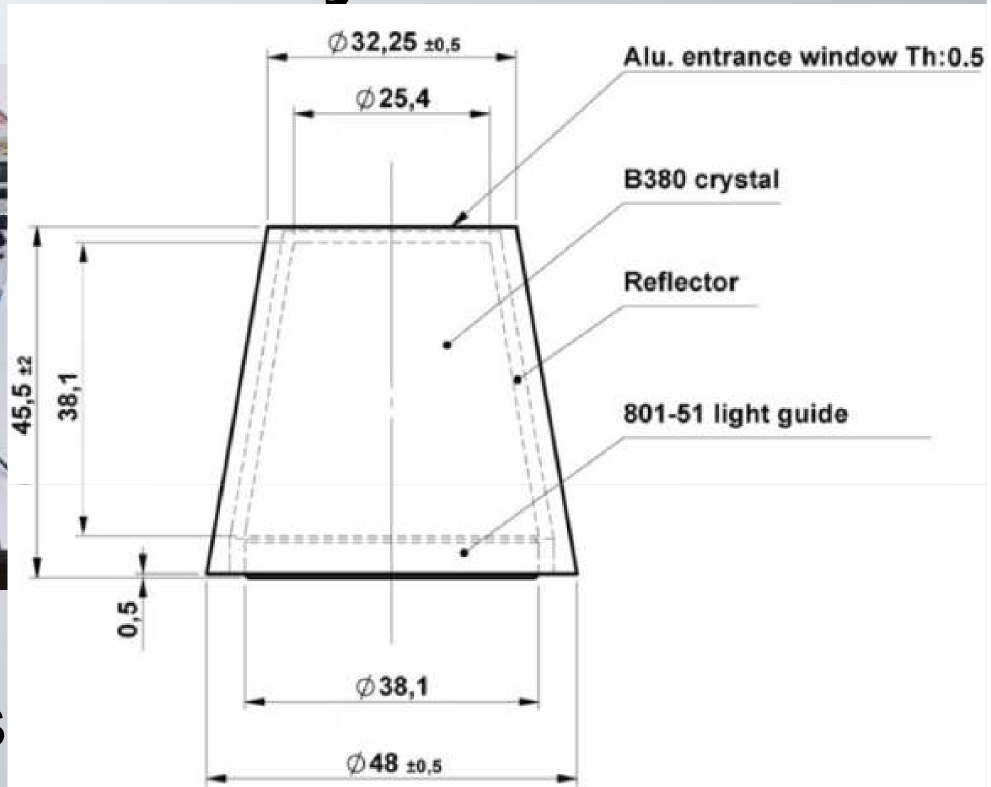


FD-DAQ



Actual FD-DAQ system





Truncated conical crystals
1x1.5x1.5" $LaBr_3$(Ce)

PMT Hamamatsu R9779

FATIMA http://nuclear.fis.ucm.es/fasttiming

Performance evaluation of novel LaBr3 (Ce) scintillator geometries for fast-timing applications, V. Vedia, M. Carmona-Gallardo , L.M. Fraile , H. Mach, , J.M. Udías, https://doi.org/10.1016/j.nima.2017.03.030

- Disadvantages: quite a different world from the one of analog electronics designers. Different expertise and equipment. Extremely fast evolving technologies, difficult to keep up with progress

- A lot on information on continuous D-DAQ and Digital Signal Proccesing (DSP) (audio, video), but much less on Digital Pulse Procesing (DPP)

Resolution, speed, price

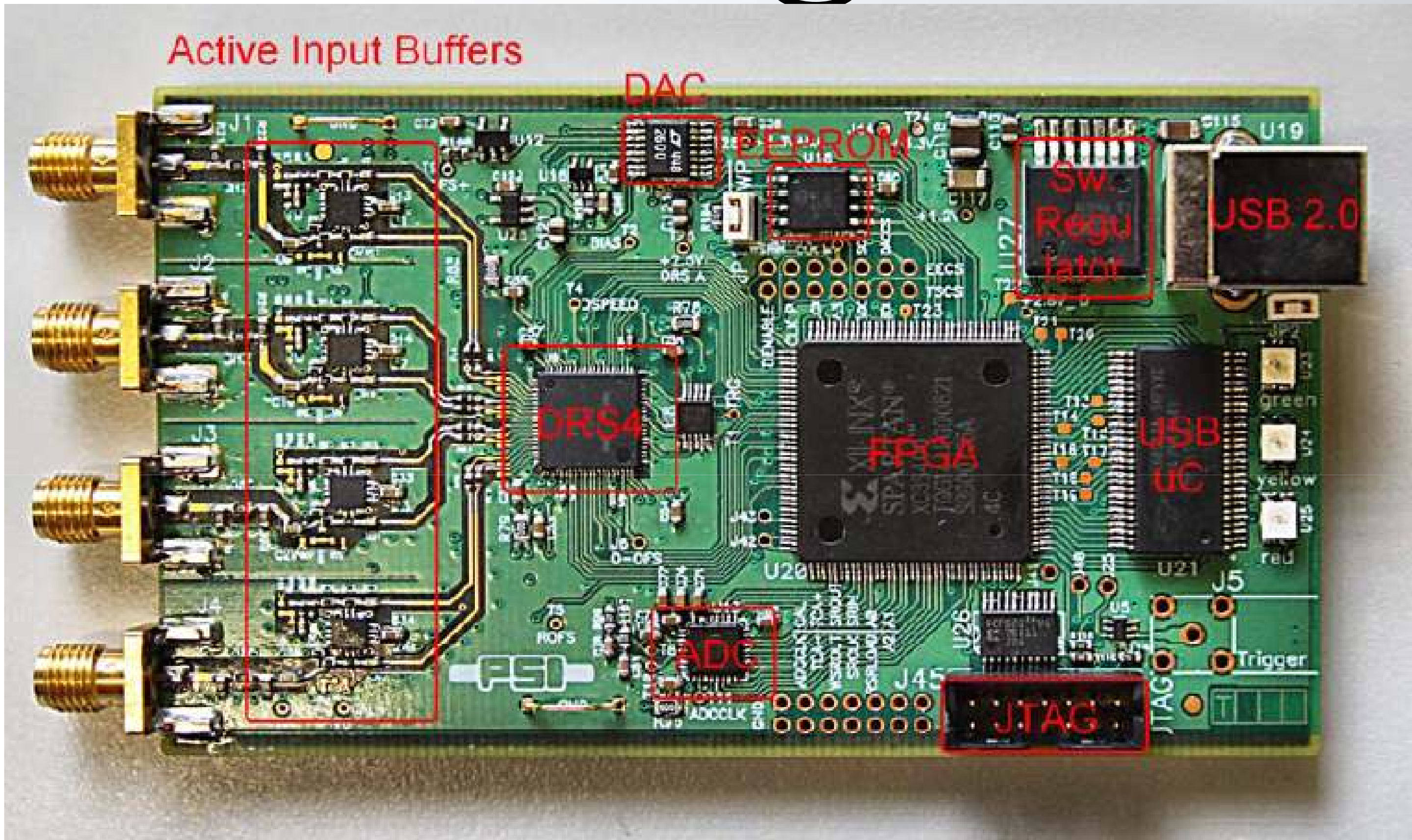
- High speed, high resolution, continuous (free-running) ADC exist, Acquitek digitizers, >20 Gs/s, >10 GHz bandwidth, continuous. Expect them in the 50 keuro range

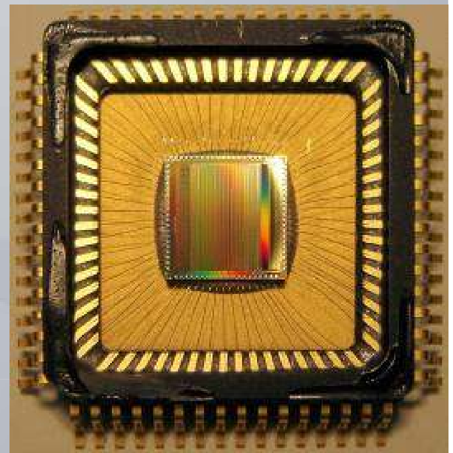
- We have pulses, do we need continuous digitizing capabilities? Not really

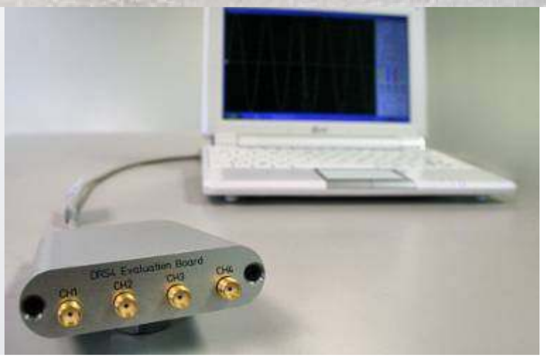
S. Ritt

DRS4 @ PSI

http://drs.web.psi.ch







DRS4 Evaluation Board

4 channels, 1024 samples per channel in a pulse

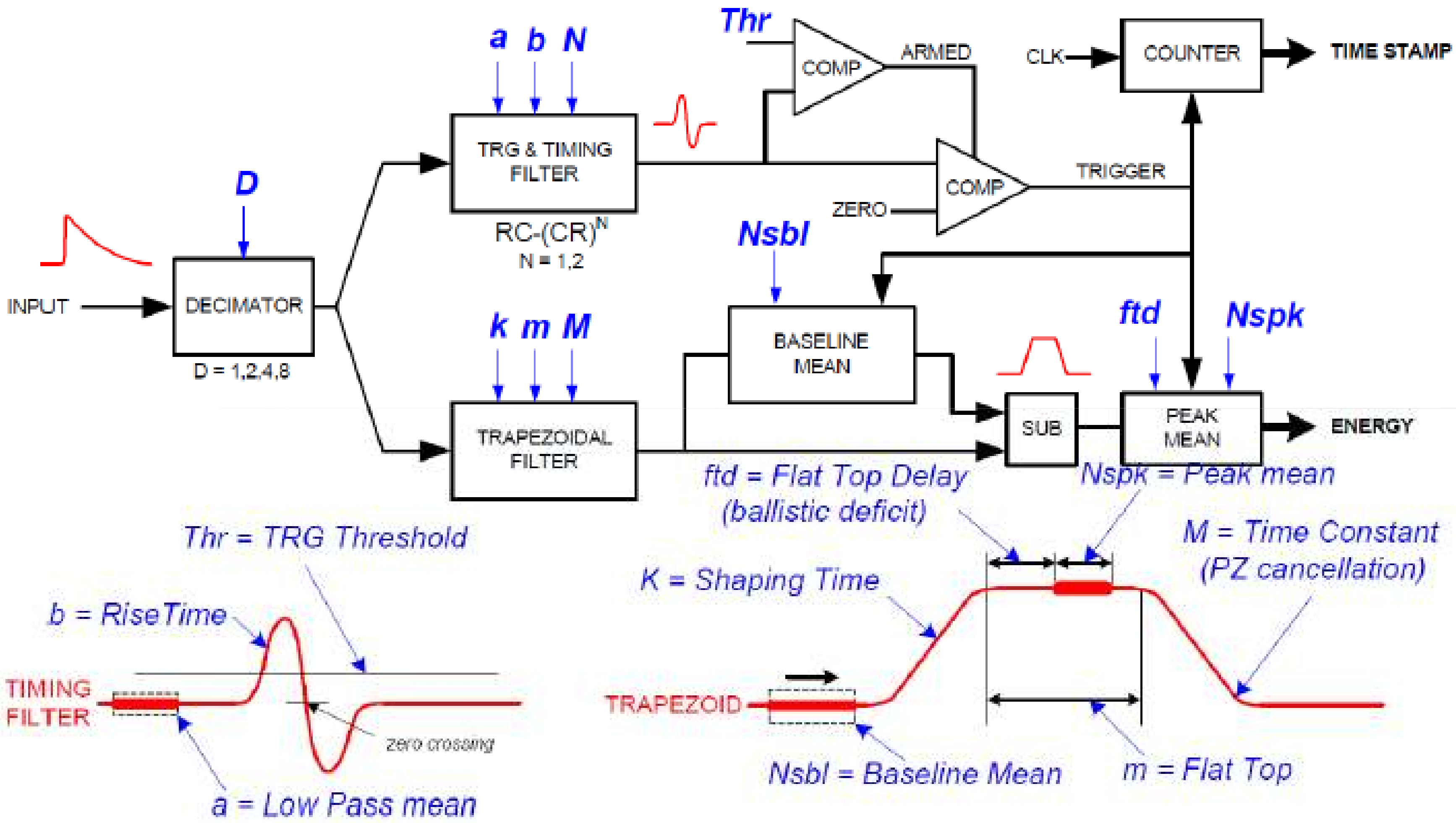
1-5 GS/s

12 bit

USB power

500 pulses / s in the PC, full 4 channels, 12 bits at 5 GS/s

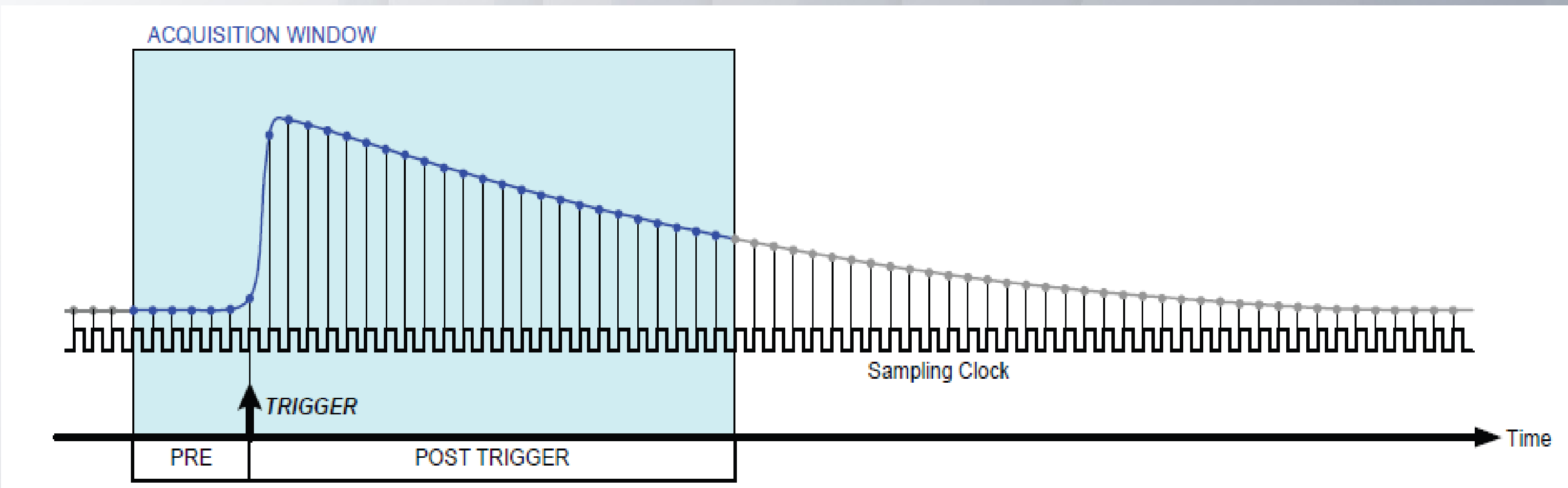
Digital Pulse Processing (DPP)



C. Tintori (CAEN)
V. Jordanov *et al.*, NIM **A353**, 261 (1994)

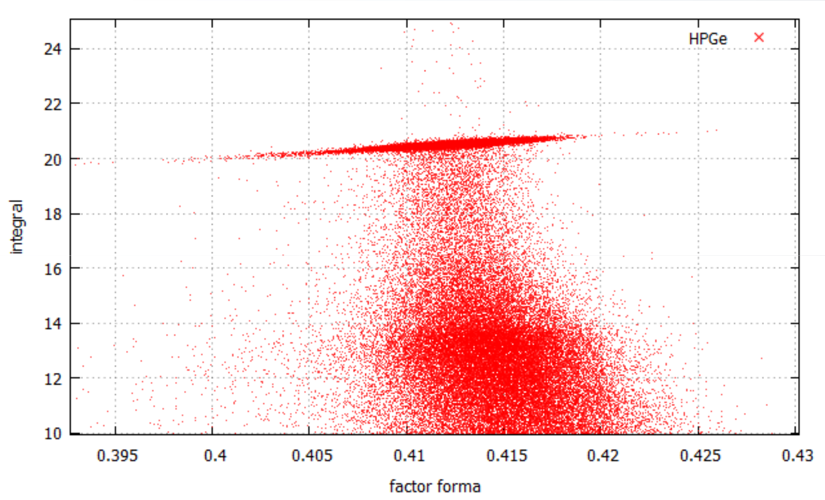
How to measure energy

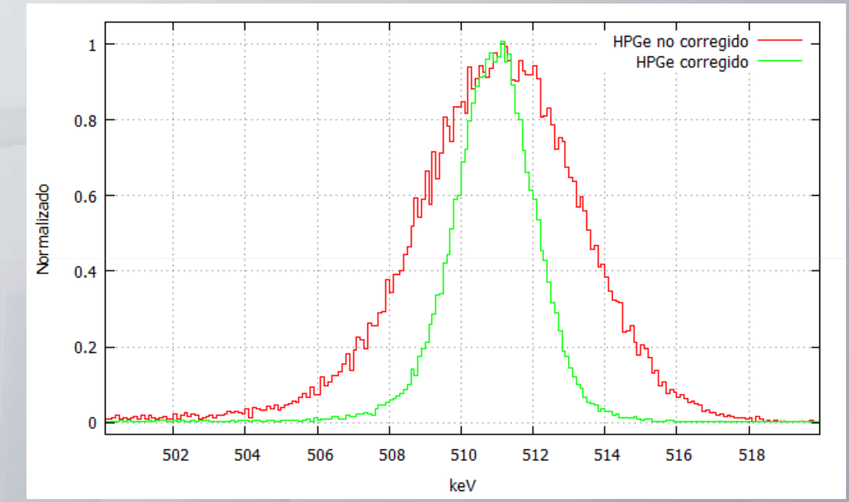
- All the algorithms commonly implemented in analog stages are available: semigaussian shaping plus peak detection, gated integrator, trapezoidal shaping
- But a simple Simpson or trapezoidal integration plus substraction of the baseline would do just as well. Pulse Shape correction / balistic deffect may be needed, but it is trivial with FD-DAQ



Energy

Balistic deffect / pulse shape correction



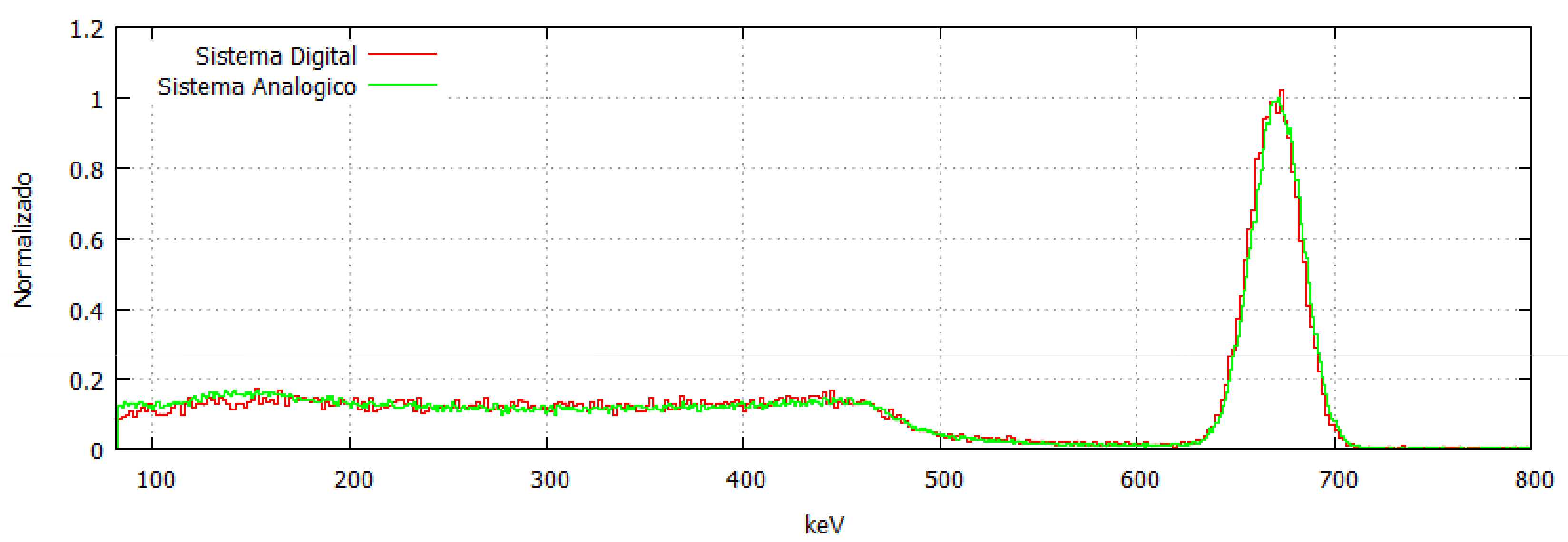


More conspicuous with HPGe detectors

0.3% (FWHM/E) – 662 keV* resolution

Same energy resolution is obtained with trapezoidal shaping, or by Pseudo-gaussian shaping plus peak height analysis

Back to LaBr results



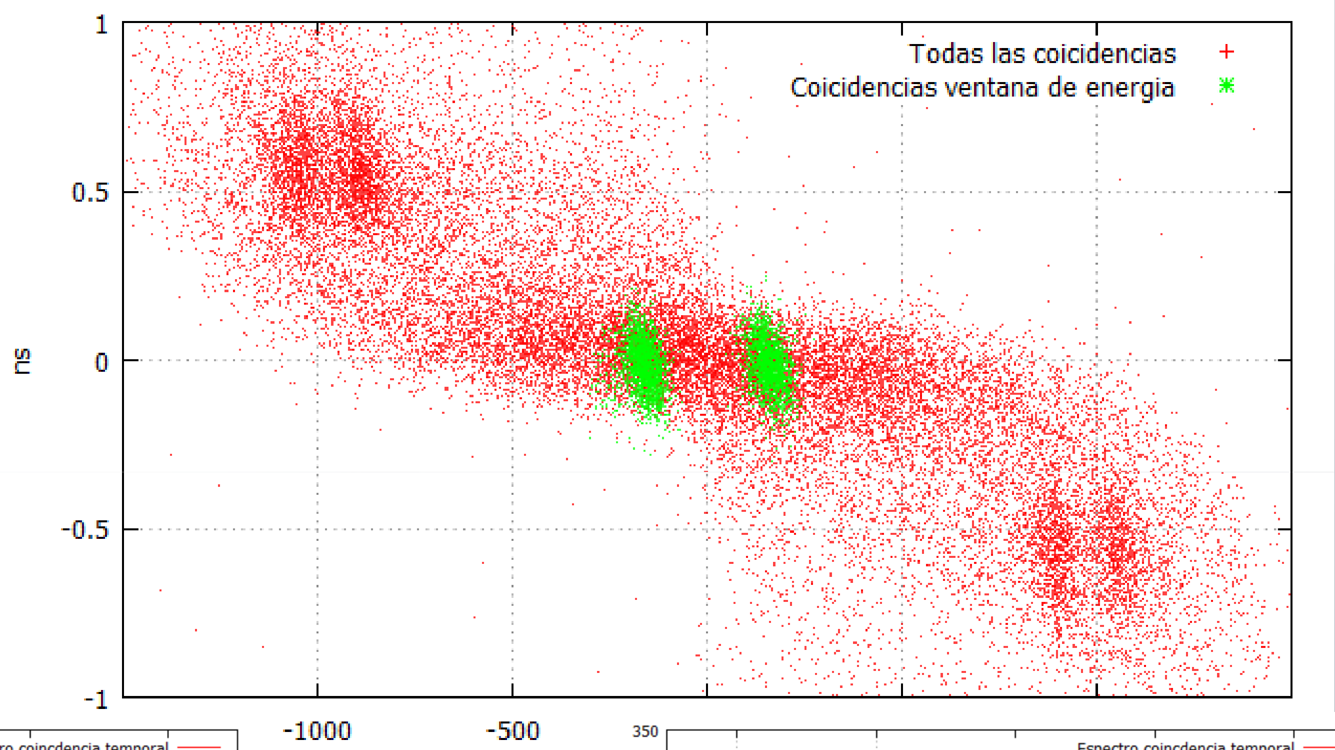
	Energy resolution (FWHM/E)		
Method	**511 keV**	**662 keV**	**1333 keV**
Conventional	5.4%	4.6%	3.4%
FD	5.3%	4.6%	3.3%

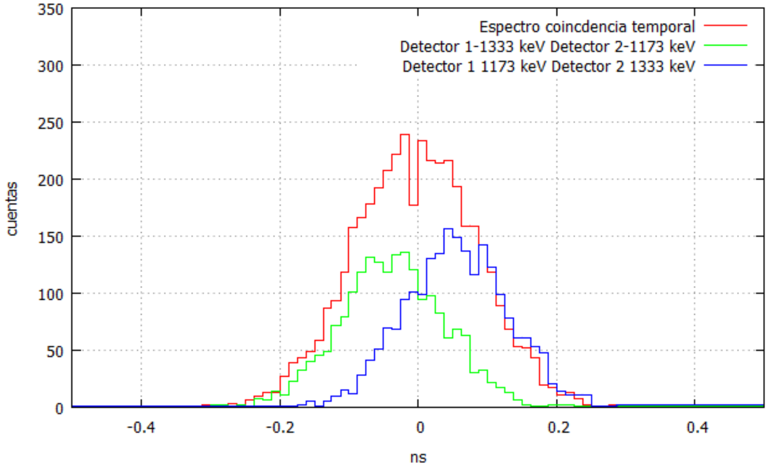
How to measure time

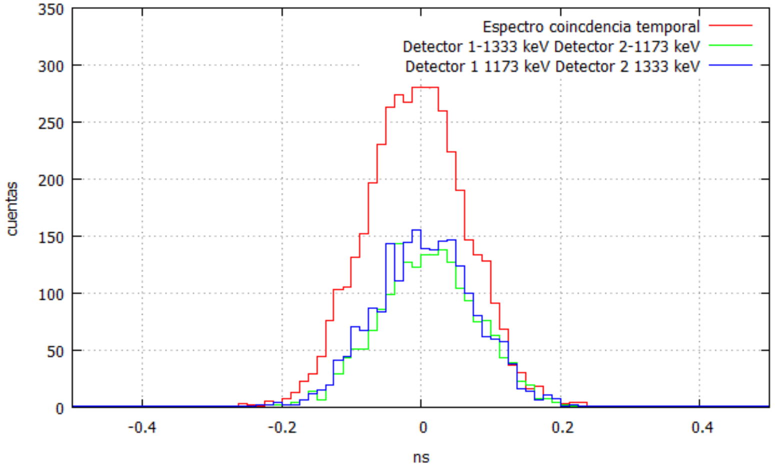
- We need to start/stop a clock based upon the arrival of the electronic signal (pulse).
- We can use the rise time part of the pulse (high slope), and a threshold (leading edge) to create a time stamp at the precise moment that the pulse crossed the level.
- Interpolation may be useful. We can set the crossing level at a given value, similar to analog leading edge discrimination.
- With this method significant time-energy walk will be expected. Larger pulses will cross sooner the level than smaller ones.

Time-energy walk can be corrected

truncated 1X1X1.5"
$LaBr_3$ Co-60
Absolute upper level discriminator time stamps

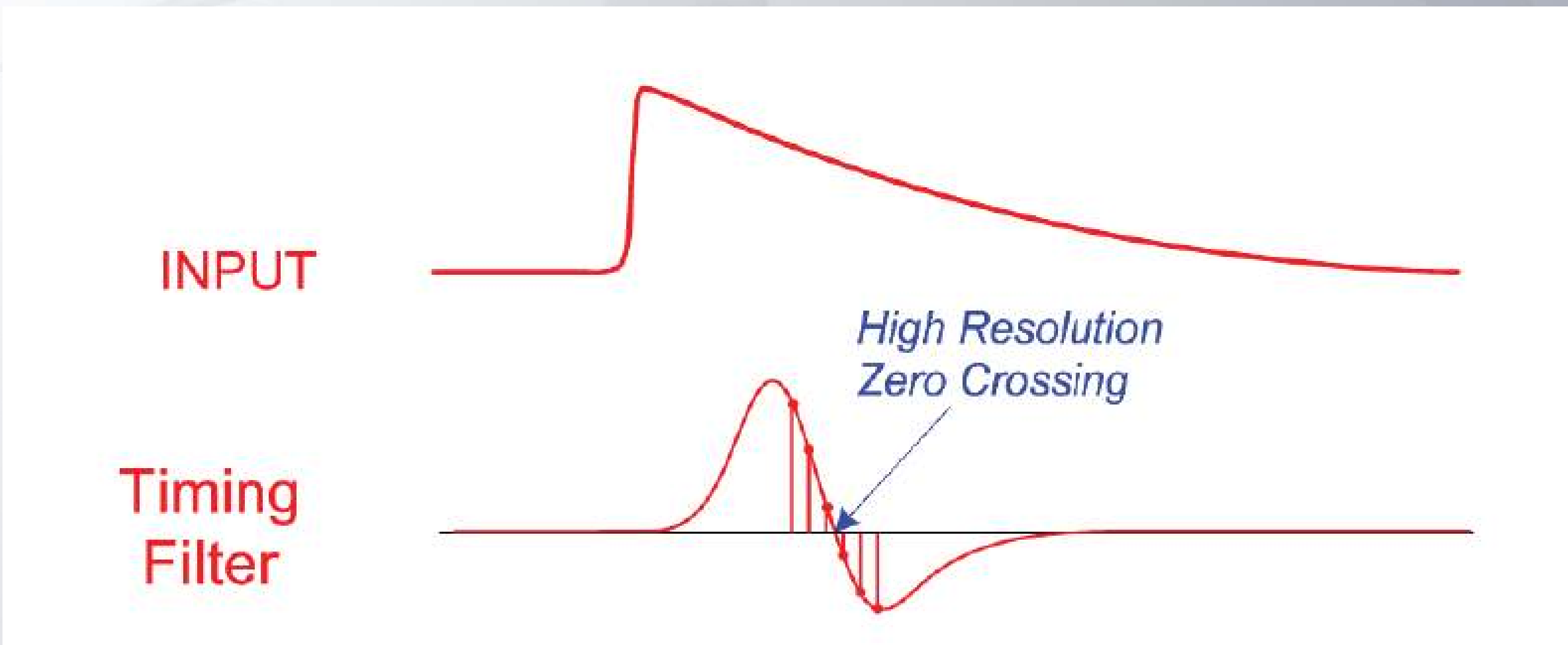






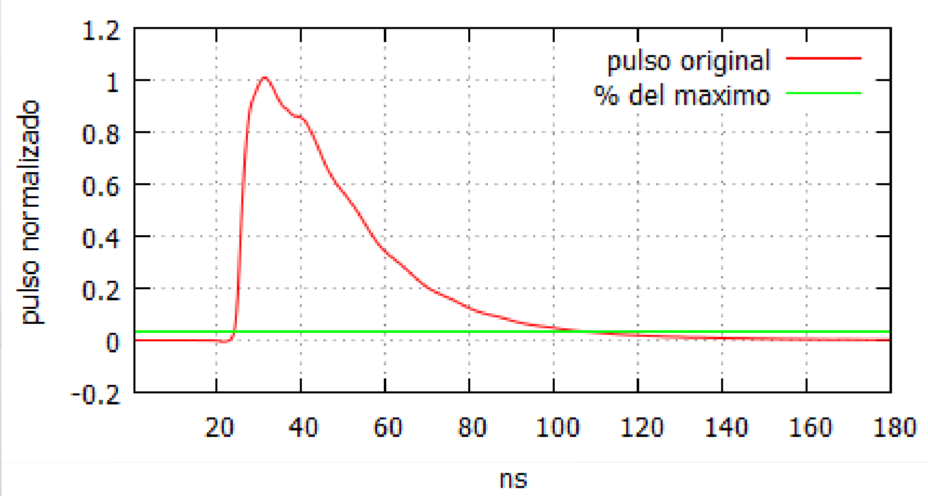
Solutions to the time energy walk problem

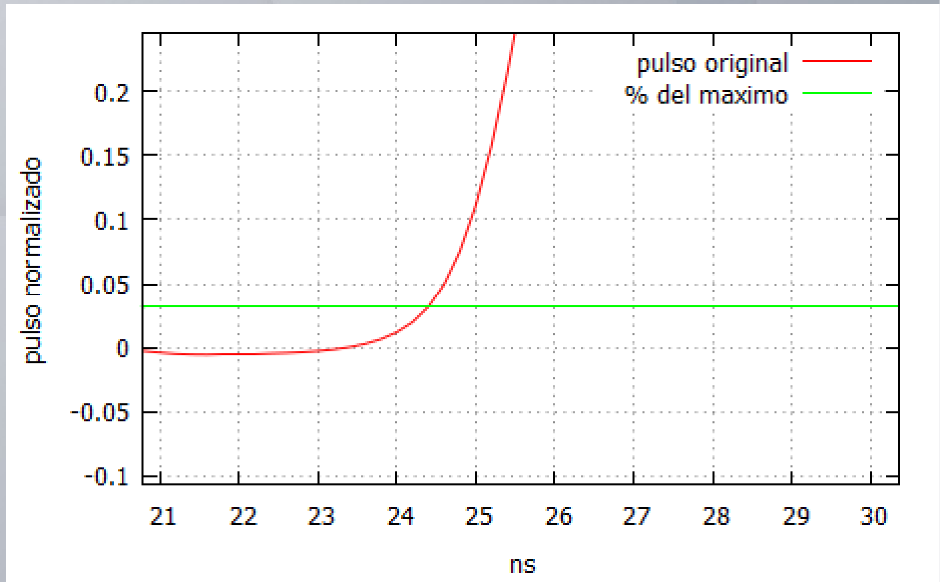
1.) The **traditiona**l way, turn the pulse into a bipolar one, use the crossing point as time stamp. Should be more independent on the amplitude of the peak. Use a timing filter: CR, Constant fraction discrimination (CFD) or similar strategies. Valid both for digital or analog pulse processing



Solutions to the time energy walk problem

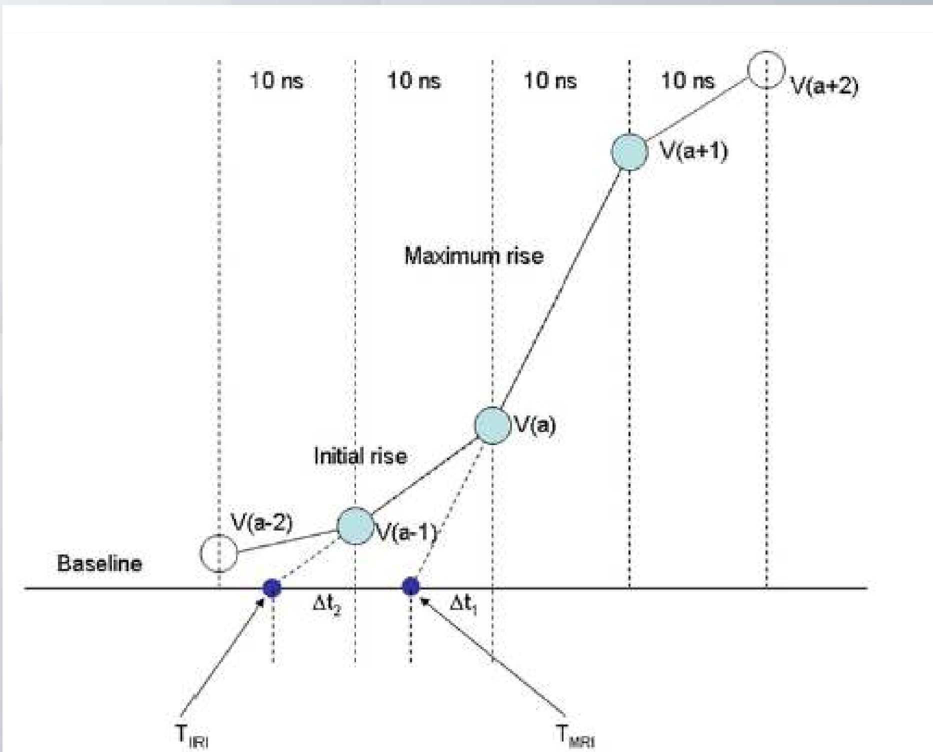
2.) A simple procedure, use crossing of ***relative*** thresholds for time stamping, instead of absolute ones: provides independence on the amplitude of the pulse. Easier implemented in digital world than in analog one





Solutions to the time energy walk problem

4.) FD-DAQ opens the way to sophisticated algorithms to produce accurate time stamp for each pulse. Machine-learning algorithms are being employed succesfully.



Solutions to the time energy walk problem

Time filters depend on several parameters: threshold levels in both detectors, delay and amplitude of inverted signal (CFD), time filter parameters, etc.

We have the pulses digitized, let’s have a machine optimization algorithm to look for the best combination of parameters. We use a Genetic Algorithm to pick the parameters

Promote this to a more general strategy: optimize all the parameters of an ‘arbitrary’ digital filter

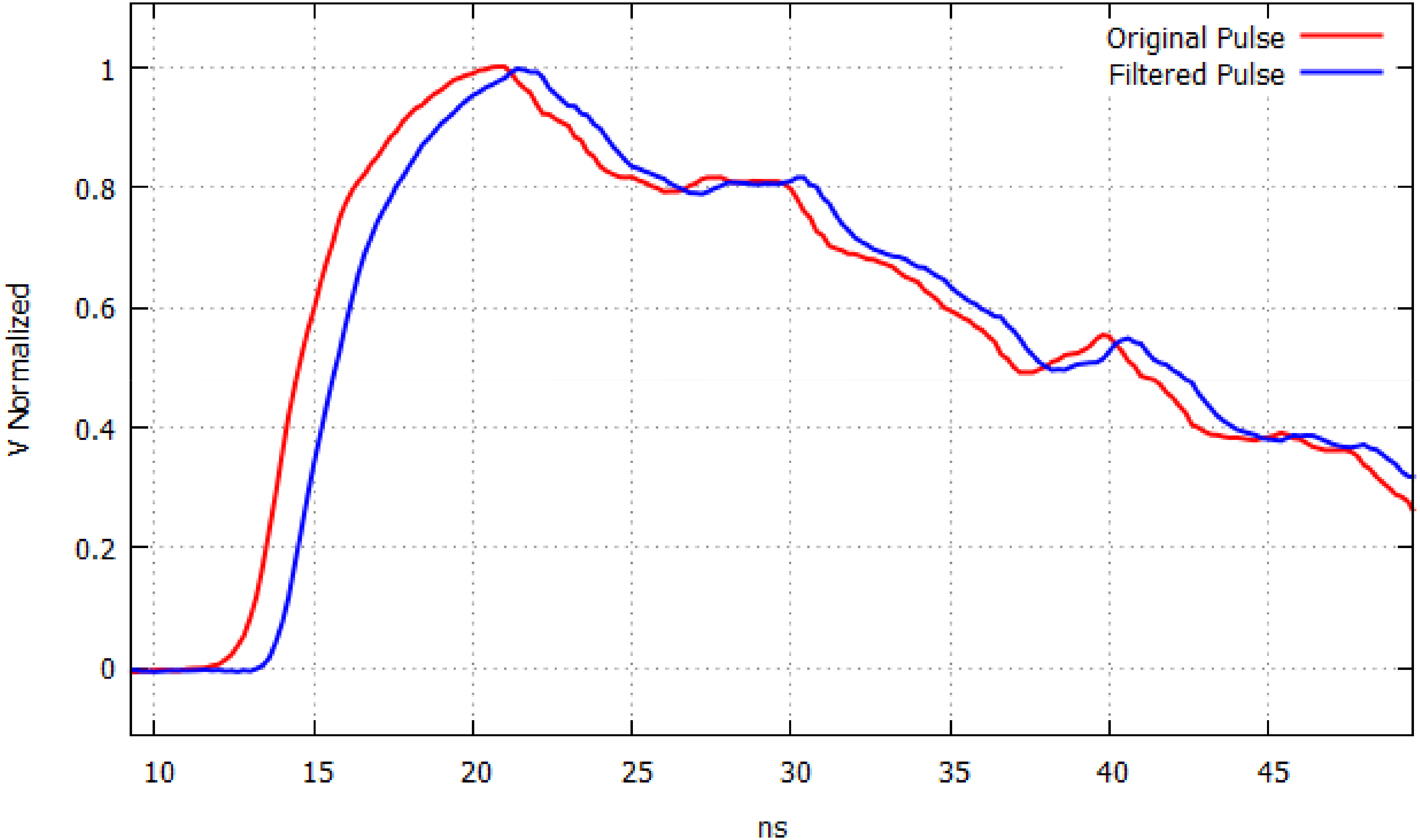
Solutions to the time energy walk problem

Promote this machine learning strategy. Let's try a rather general digital filter:

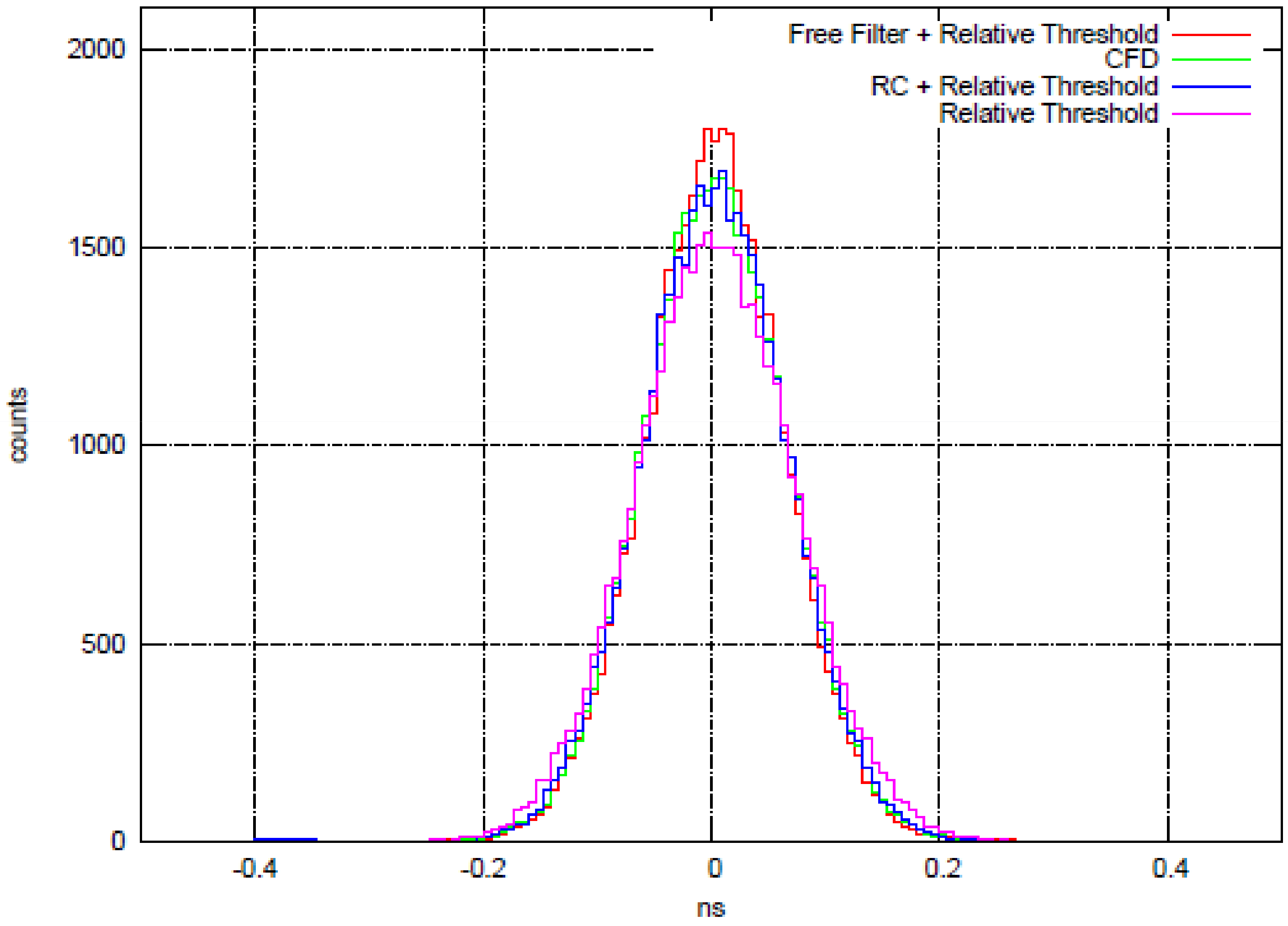
$$y[n] = A * y[n-1] + B * x[n] + C * x[n-1]$$

This is a recursive filter (0<A<1, -1<B,C<1) , let's allow for a machine learning algorithm to look for the best combination of parameters A, B; C. It is a generalization of a CR+R'C' digital filter.

To the resulting pulse we apply the relative upper level crossing time stamp. The GA choses the best relative thresholds for each detector.



Original Pulse
Filtered Pulse
V Normalized
ns
1
0.8
0.6
0.4
0.2
0
10
15
20
25
30
35
40
45


Free Filter + Relative Threshold
CFD
RC + Relative Threshold
Relative Threshold
2000
1500
1000
500
0
counts
-0.4
-0.2
0
0.2
0.4
ns

Results for CRT, FWHM, two BrLa(Ce) truncated cone+PMT Hamamatsu R9779 A -1300 V

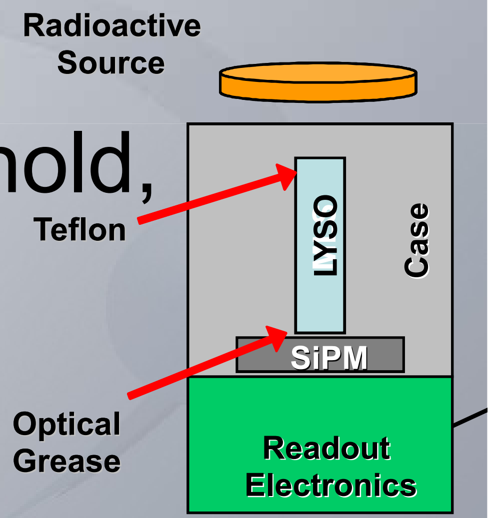
Method	Na22	Co60
Conventional CFD + TAC	226 +/- 4 ps	156 +/- 4 ps
*In silico*CFD	208.4 +/- 0.5 ps	143.1 +/- 0.6
Machine learned filter	193.7 +/- 0.6 ps	136.1 +/- 0.6

Performance evaluation of novel LaBr3 (Ce) scintillator geometries for fast-timing applications, V. Vedia, M. Carmona-Gallardo , L.M. Fraile , H. Mach, , J.M. Udías, https://doi.org/10.1016/j.nima.2017.03.030

Machine learning processing led to **15%** better time resolution than the conventional approach

SiPM FD, with DRS4

- 2x SensL FJ 30035, 3x3 mm2, 27 V bias
- SiPM with slow and fast output
- 2x 1.5x1.5x7 mm3 LYSO crystals
- CRT with FD-DAQ (relative threshold, manually chosen parameters)

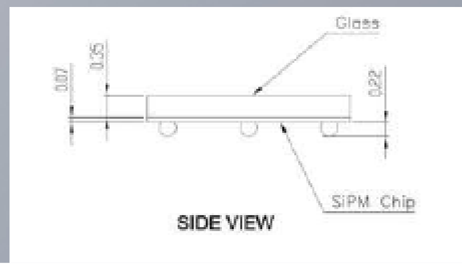


^{60}Co: 88 ps FWHM fast output,

103 ps slow output

^{22}Na: 103 ps FWHM fast output,

122 ps slow output



Conclusions

- FD-DAQ of pulses from very fast inorganic scintillators become possible with unexpensive digitizers
- FD procesing opens the way to machine learning algorithms to improve the performance of time pickup
- Up to a 15% better time resolution is obtained with the unguided machine learning algorithm
- Time resolutions smaller than 100 ps FWHM per detector is made possible on large detectors.