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# Validation of the CAEN DT5730 digitizer for the TDCR measurement and perspective for the SIRTI

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Romain Coulon – Workshop on RMO SIRTI – 6 June 2022

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# Test of digitizer in the framework of the ESIR

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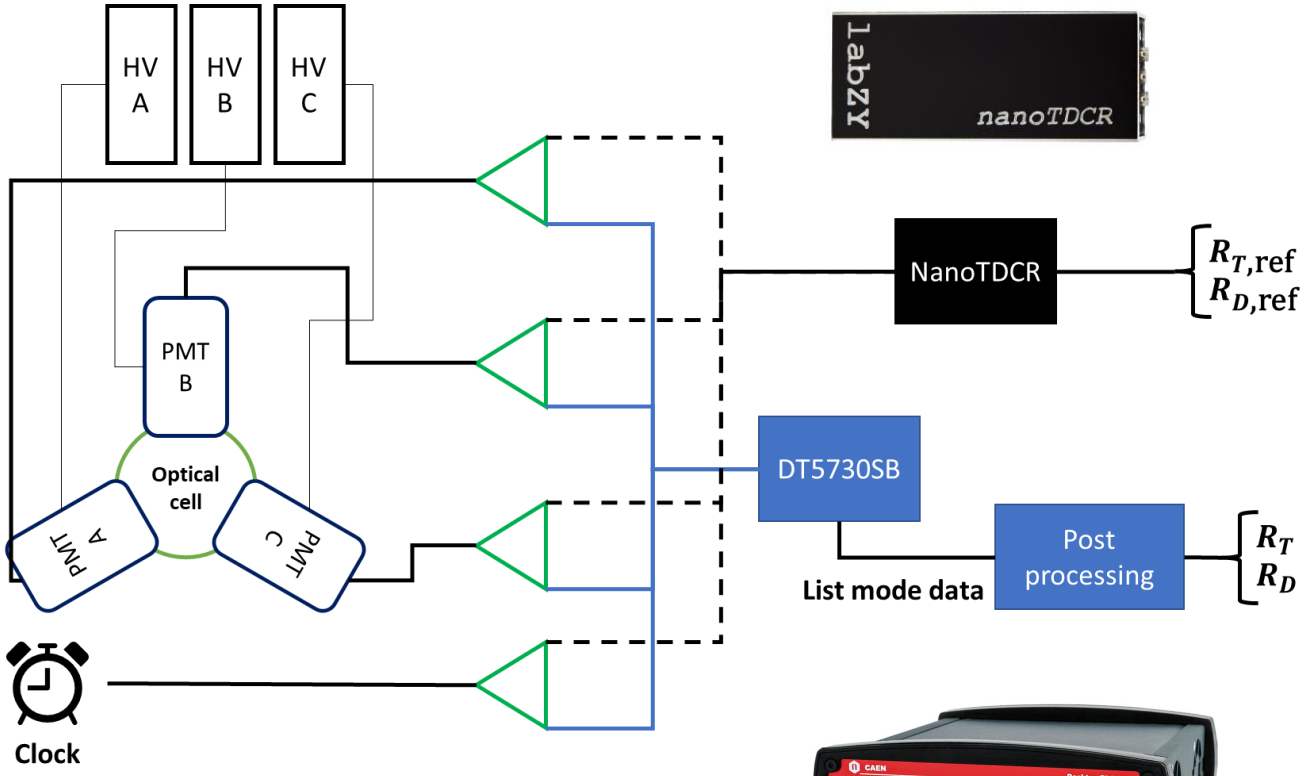
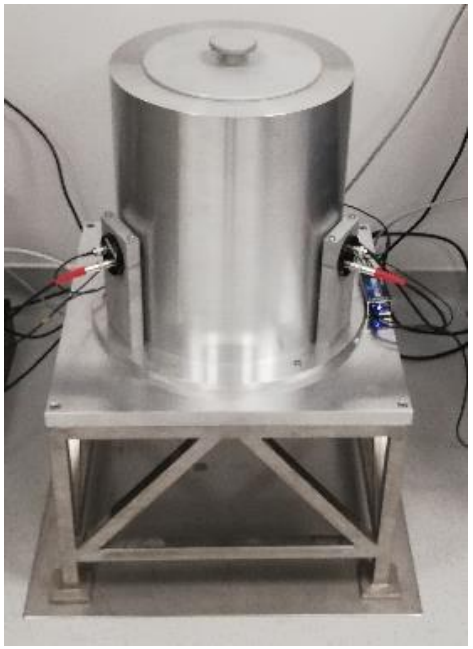
# Digitizer implementation at BIPM

- Test of the CAEN DT5730SB digitizer in the ESIR framework

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# The CAEN DT5730SB

- Characteristics of the ADC:
  - 8 channels
  - Sampling rate = 500 MS $s^{-1}$
  - Bandwidth = 250 MHz
  - Resolution = 14 bits
  - Voltage range = 2 Vpp
- FPGA = Arria V GX
- Firmware = DPP-PSD


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# FPGA online processing

- Signal from 3 channels are processed
- Pulse are detected using **digital CFDs** parametrized by a threshold express in lbs (least significant bit)
- The **trigger time** (timestamp) is measured using the ADC sampling clock (500 MHz) stabilized with an external 10 MHz clock liked the BIPM atomic clock
- The **energy** is estimated by summation of the pulse over two gates
- The digitizer provides a **list mode data** file including the two information that are used for TDCR metrology

$$\{\text{Channel}, \text{Timestamp}\}$$

| BOARD | CHANNEL | TIMETAG | ENERGY | ENERGYSHORT | FLAGS |
|---|---|---|---|---|---|
| 0 | 0 | 7.9E+11 | 1410 | 0 | 0x4400 |
| 0 | 0 | 1.55E+12 | 295 | 4095 | 0x4480 |
| 0 | 0 | 1.62E+12 | 1283 | 67 | 0x4000 |
| 0 | 0 | 1.73E+12 | 1319 | 3 | 0x4400 |
| 0 | 1 | 1.79E+12 | 1423 | 51 | 0x4400 |
| 0 | 0 | 2.18E+12 | 1438 | 11 | 0x4400 |
| 0 | 0 | 2.58E+12 | 1411 | 41 | 0x4400 |
| 0 | 0 | 2.92E+12 | 1305 | 182 | 0x4400 |
| 0 | 0 | 3.86E+12 | 1147 | 1 | 0x4000 |

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# Offline processing

- The TDCR approach requires to implement
  - the live-time measurement,
  - the extended dead-time,
  - the coincidence detection among channels.
- A TDCR processing software has been developed (Python code)

Algorithm. 1. Speudo-code of the TDCR post processing.

```
| V = (0,0,0); θ = 0;  S = 0;  D = 0;  T = 0; lt = 0
|Until end of file, read next row of the list mode file:
|   |μ, c ←                                  /# read the timestamp and the channel #/
|   |if μ > t0 + δ:                          /# detection when the system is idle #/
|   |   |if ∑V ≥ 1:              S+= 1       /# increment single event counter #/
|   |   |   |if ∑V ≥ 2:          D+= 1       /# increment double event counter #/
|   |   |   |   |If ∑V = 3:      T+= 1       /# increment triple event counter #/
|   |   |lt = μ − (t0 + δ)                   /# update the live time #/
|   |   | V = (0,0,0)                        /# reinitialize the triplet vector #/
|   |   |t0 = μ                              /# initialize the trigger reference time #/
|   |   |V[c] = 1                            /# record the new event in the triplet vector #/
|   |   |δ = φ                               /# set the extended paralyzing time #/
|   |else:                                   /# detection when the system is busy #/
|   |   |if μ <t0 + τ:                       /# detection within the resolving time #/
|   |   |   |V[c] = 1                        /# record the event in the triplet vector #/
|   |   |   |δ:= δ + μ − t0                  /# extend the paralyzing time #/
|   |   |else:                               /# detection after the resolving time #/
|   |   |   | δ = μ − t0 + φ                 /# extend the paralyzing time #/
|RS = S/lt ; RD = D/lt ; RT = T/lt →         /# send the count rates #/
```

List mode input data

Coïncidence revolving time

Extended dead-time

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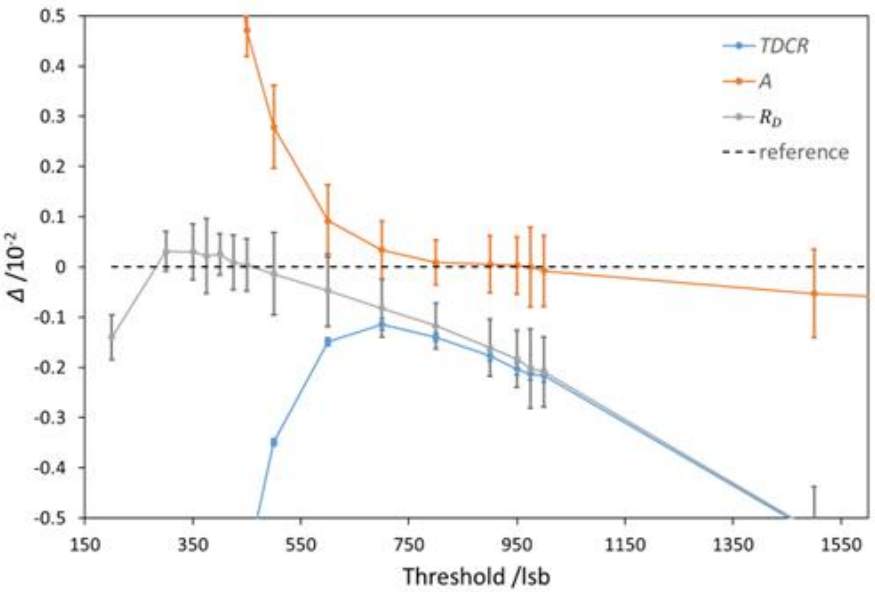
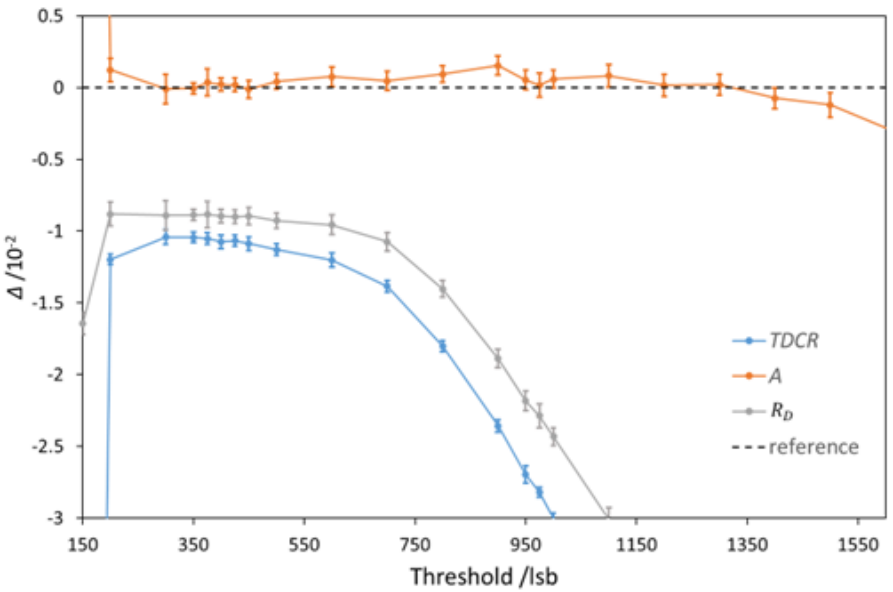
# Validation against the Yantel nanoTDCR

$^{14}C$ source




$^{3}H$ source




- The detection efficiency is lower when compared the analog front-end nanoTDCR device
  - ~0.15% for $^{14}C$ and ~1% for $^{3}H$,
- However, the TDCR metrology is robust against this loss of count rate.

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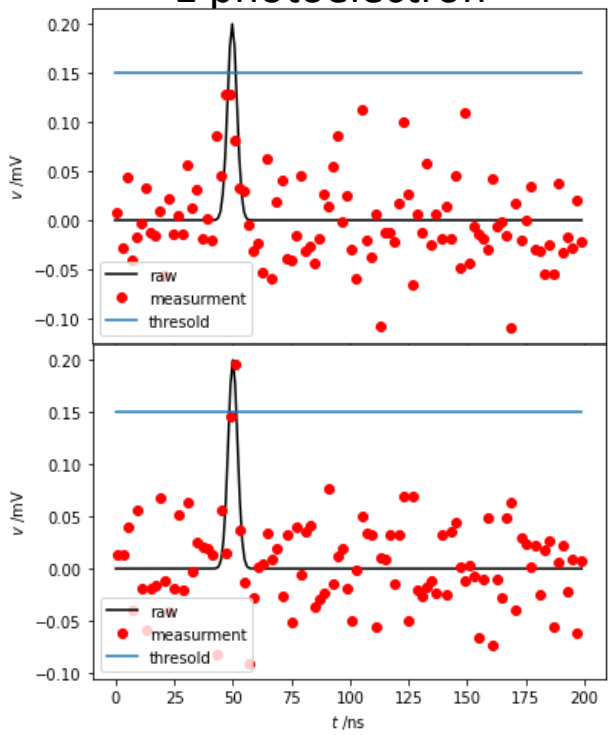
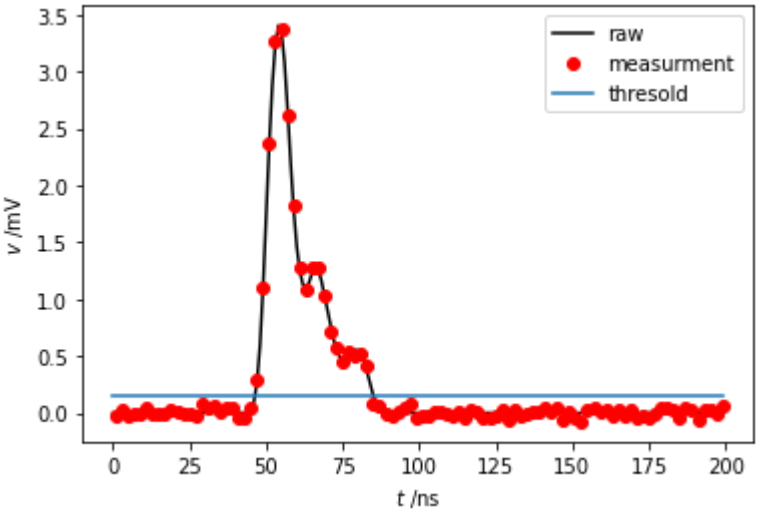
# About the loss of counts

- The loss increases with the decrease of the deposited energy per decay
- Tritium signal is mainly composed of single electron pluses thinner than the exponentially decaying pileup pulse observed at higher energy

1 photoelectron




100 photoelectrons

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# Perspective for the SIRTI

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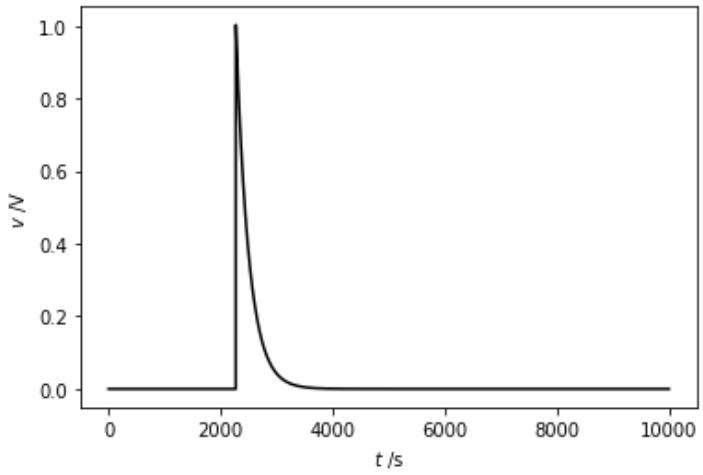
# Perspective for the SIRTI

- The loss of counts observed with the TDCR system would be dramatic for the SIRTI
- However, this should not happen because the NaI(Tl) signal has
  - Light yield = 38000 photons /MeV
  - Energy of Nb-93m = 16.6 keV
  - So, an average of 630 photons will be at least produced.
  - Considering an optical efficiency of 80% and a quantum efficiency of 20%,
  - 630*0.8*0.2 = **100 photoelectrons are expected to be produced by the photocathode during a scintillation decay period of 230 ns.**

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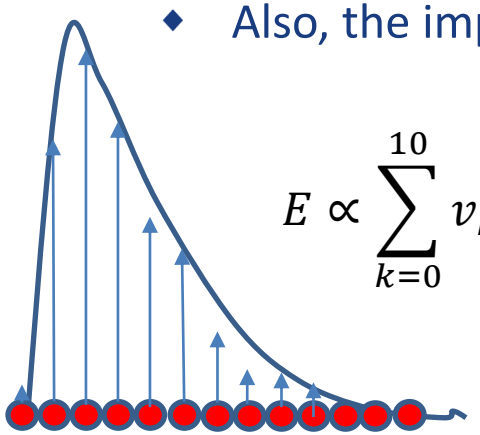
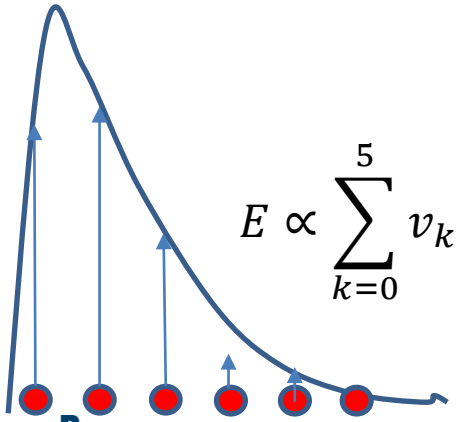
# Impact of the ADC on the energy resolution

- A resolution of 14 bits encodes the 2 V range with 16384 channels
- If the saturation is set at 2 MeV => 122 eV per bin.
- Also, the impact of the sampling rate on the energy estimation is negligeable

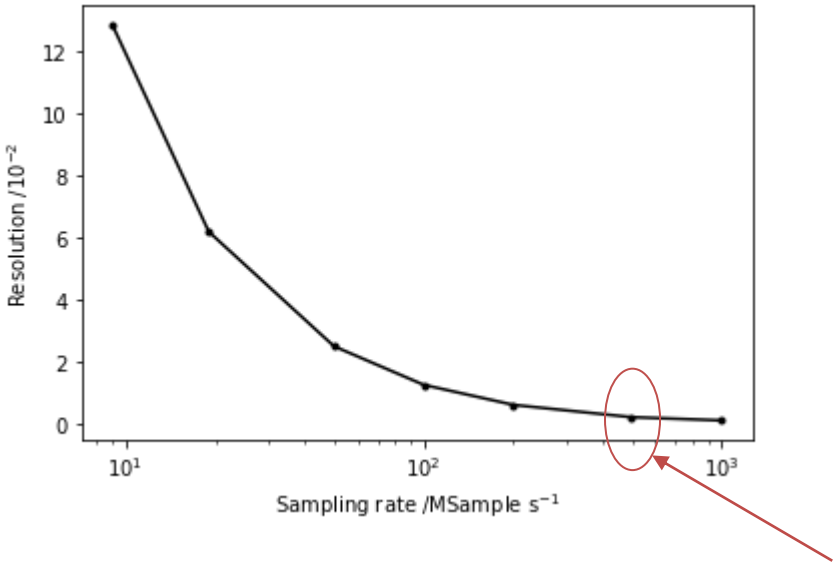


$$E \propto \sum_{k=0}^{10} v_k$$



$$E \propto \sum_{k=0}^{5} v_k$$

*Monte-Carlo estimation of the energy resolution from sampling at 16 keV*




500 MS/s
0.24%

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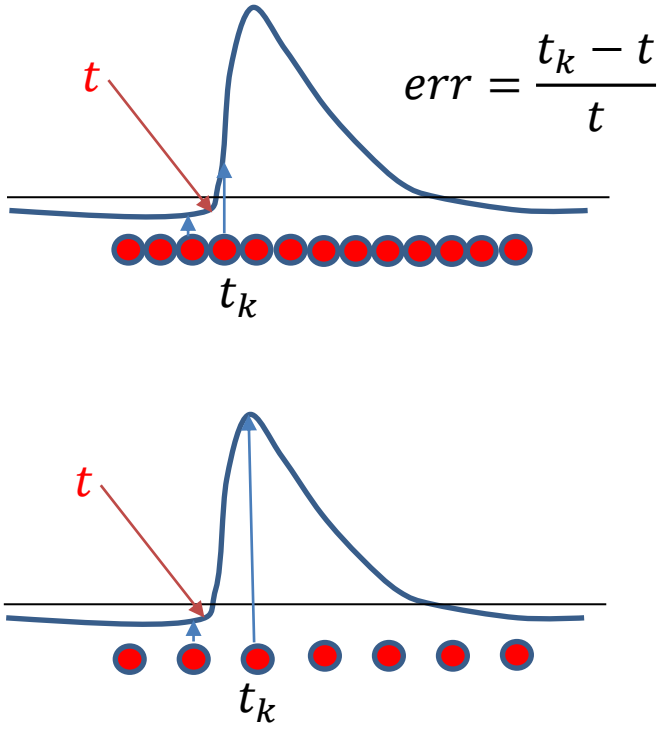
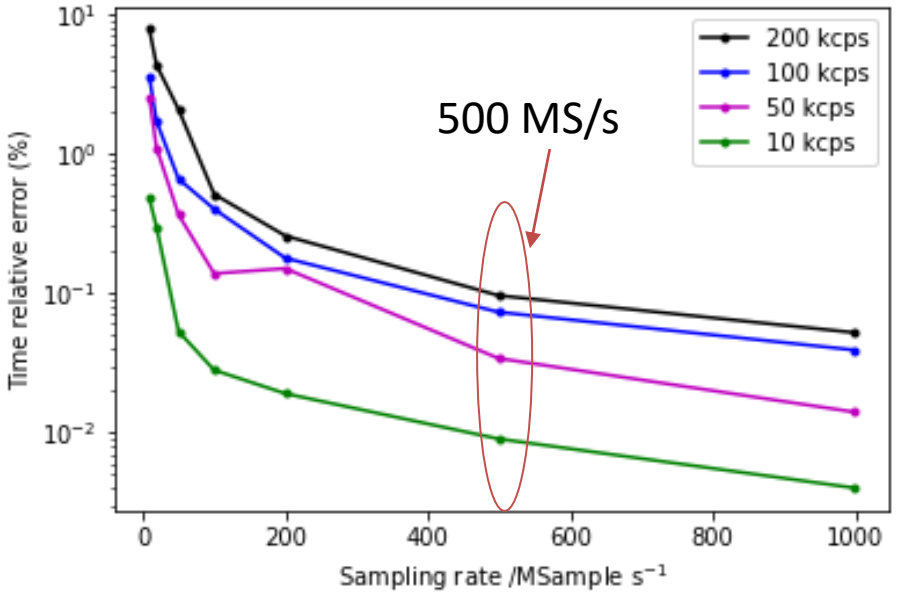
# Impact of the ADC on the live-time measurement

- The sampling rate of 500 MS/s should ensure a live time measurement up to 100 000 $s^{-1}$ with an error below 1e-3.




*Monte-Carlo estimation of the live-time measurement error for different input count rates*




$$err(liveTime) = n^{-1} \sum_{i=1}^{n} \frac{t_k^{(i)} - t^{(i)}}{\Delta t^{(i)}} \text{ with } \Delta t^{(i)} \sim \varepsilon(R^{-1})$$

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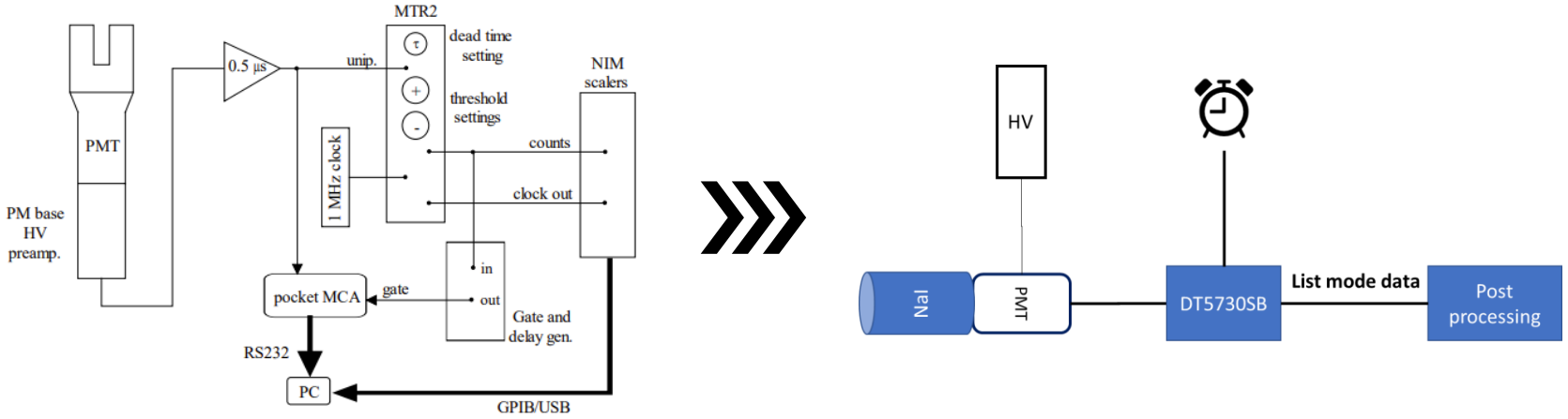
# Conclusion

- The CAEN DT5730 has been tested for TDCR measurement
- Although a significant loss of counts the TDCR method remains robust
- As the count rate loss seems to concern only the narrow SEPs, the SIRTI should not be impacted
- According to these tests and approximate calculations, it could be interesting to test our DT5730SB/DPP-PSD with the SIRTI




- If this build-in commercial solution fit the need, it is good news.
- Otherwise, “open-FPGA” solutions or “laboratory-developed” cards will be investigated.

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