New development in DDS and RVS integration. The SIG experience

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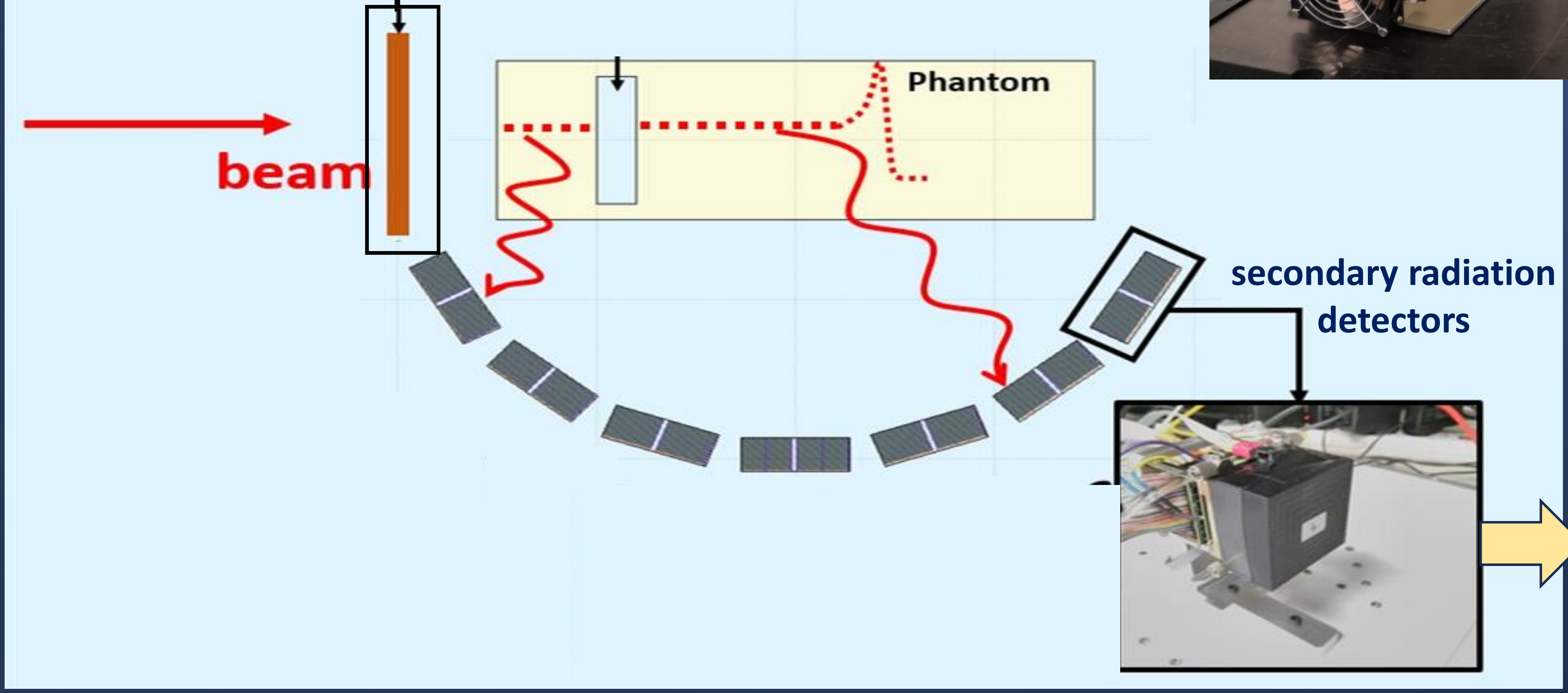
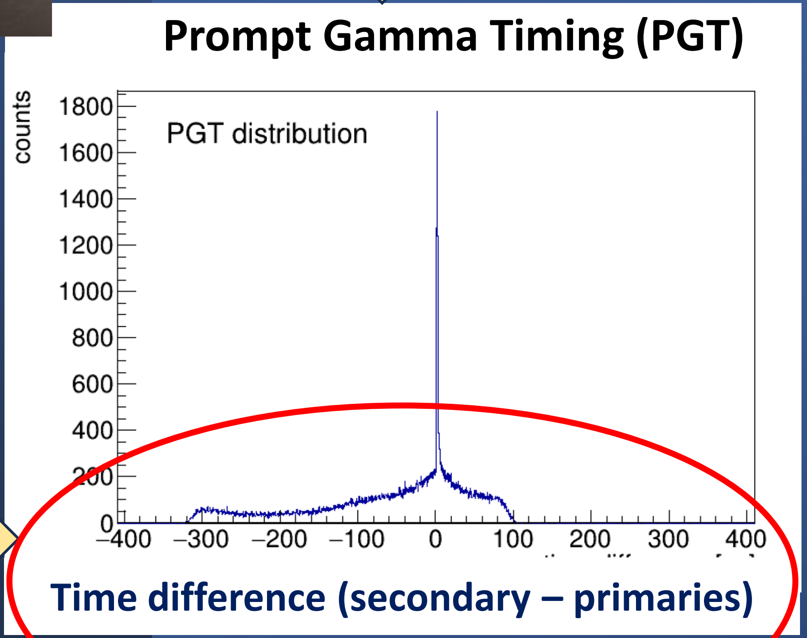
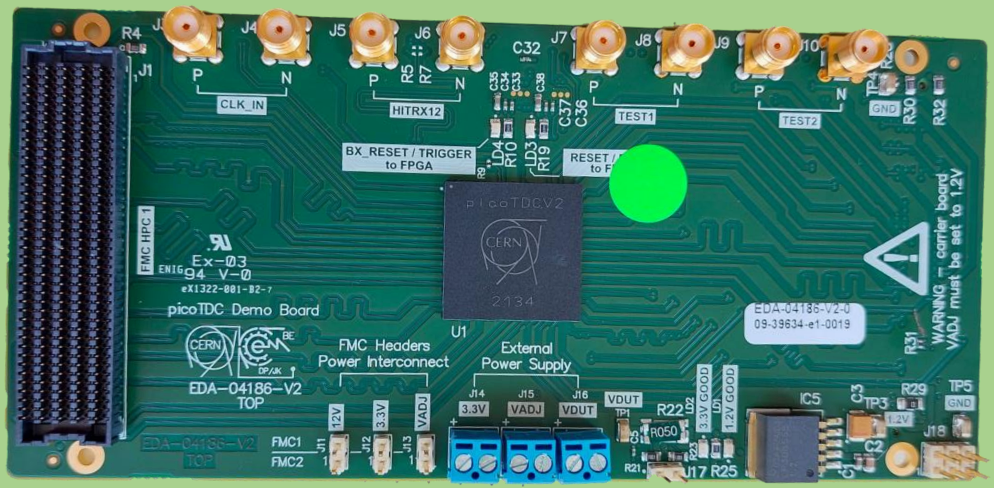
Integration of novel Dose Delivery and in-vivo Range Verification Systems

beam monitoring system
MOVEIT project





Integration of novel Dose Delivery and in-vivo Range Verification Systems

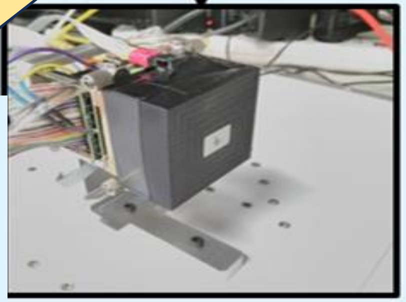


PicoTDC

- Bin size = 3.05 ps
- 64 channels

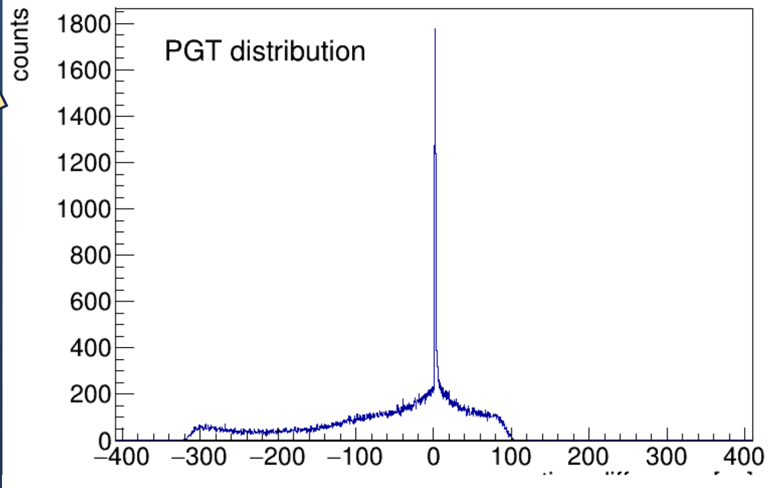
beam monitoring system
MOVEIT project

secondary radiation detectors



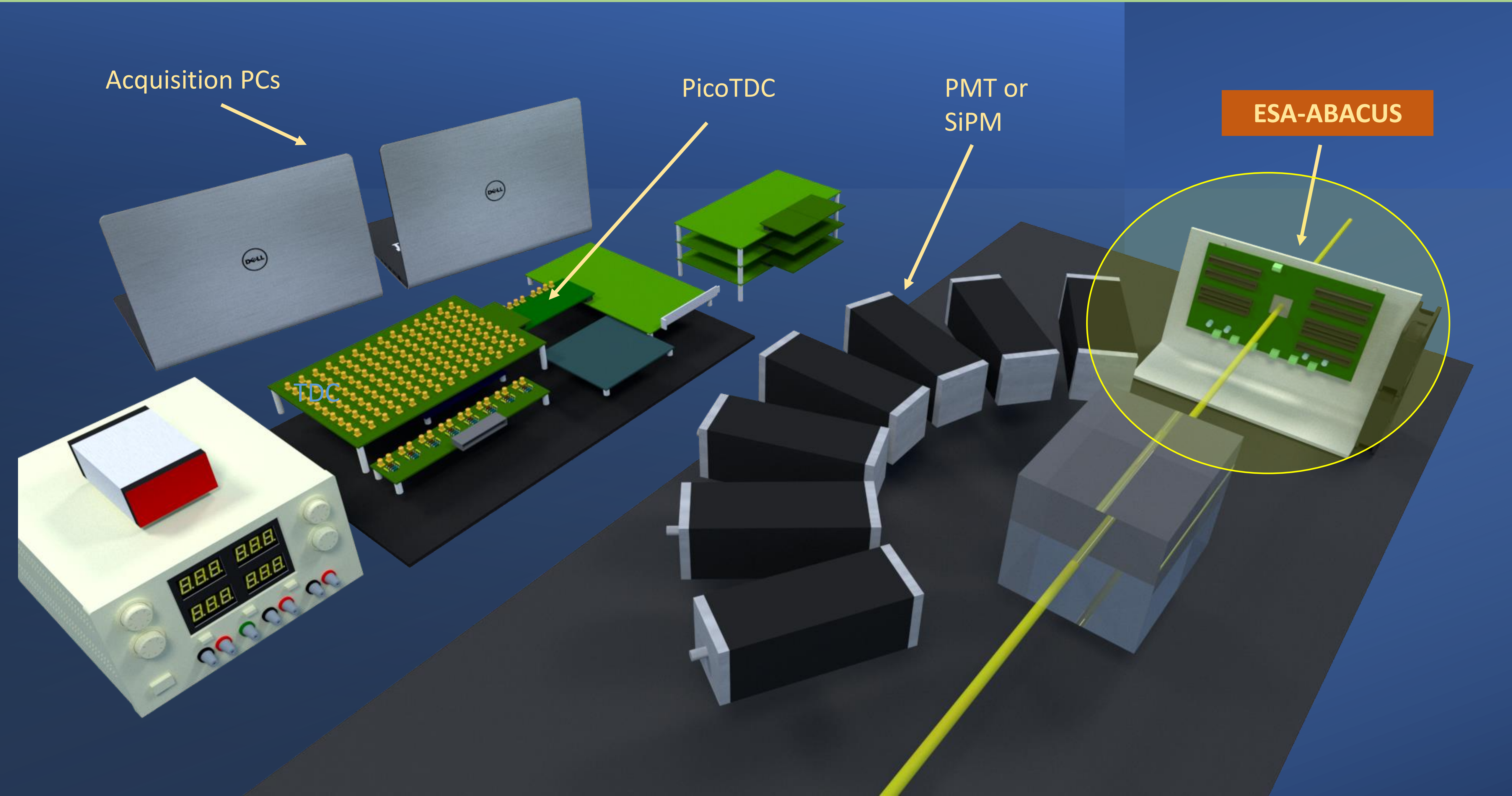
I3PET detectors

Prompt Gamma Timing (PGT)



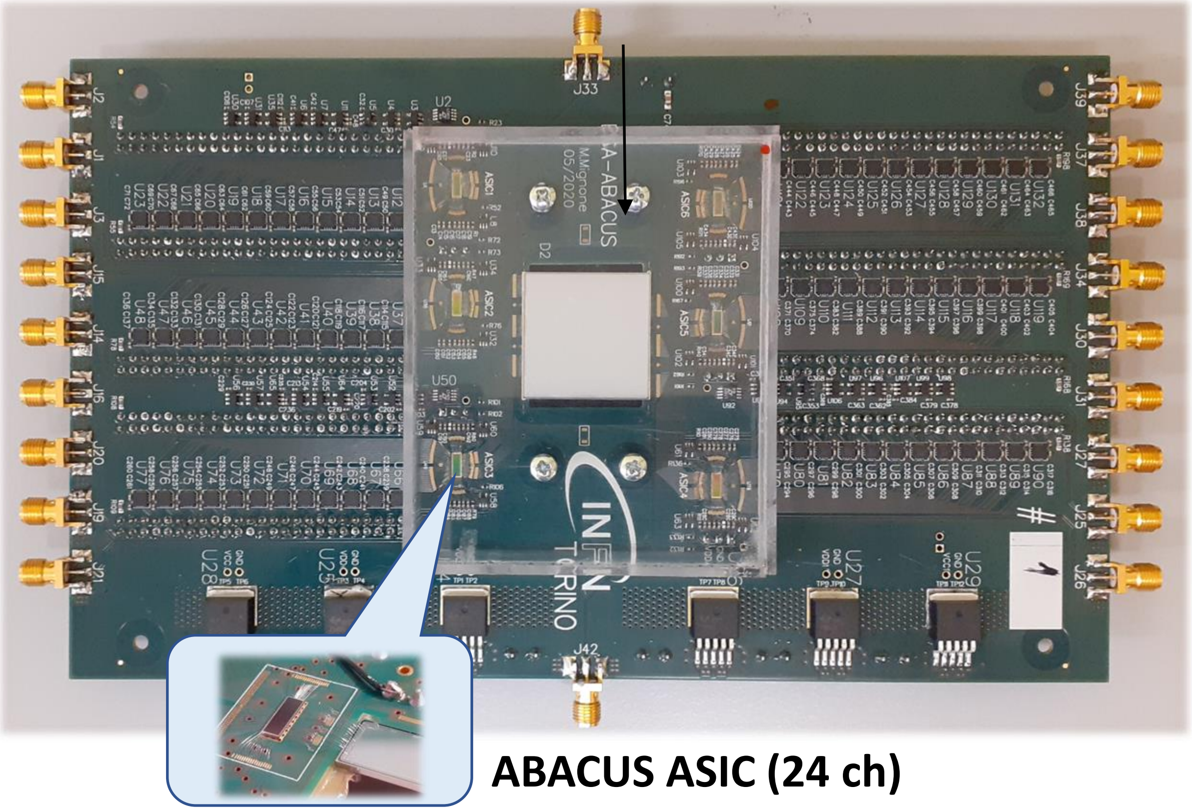
Time difference (secondary – primaries)

Integration of novel Dose Delivery and in-vivo Range Verification Systems

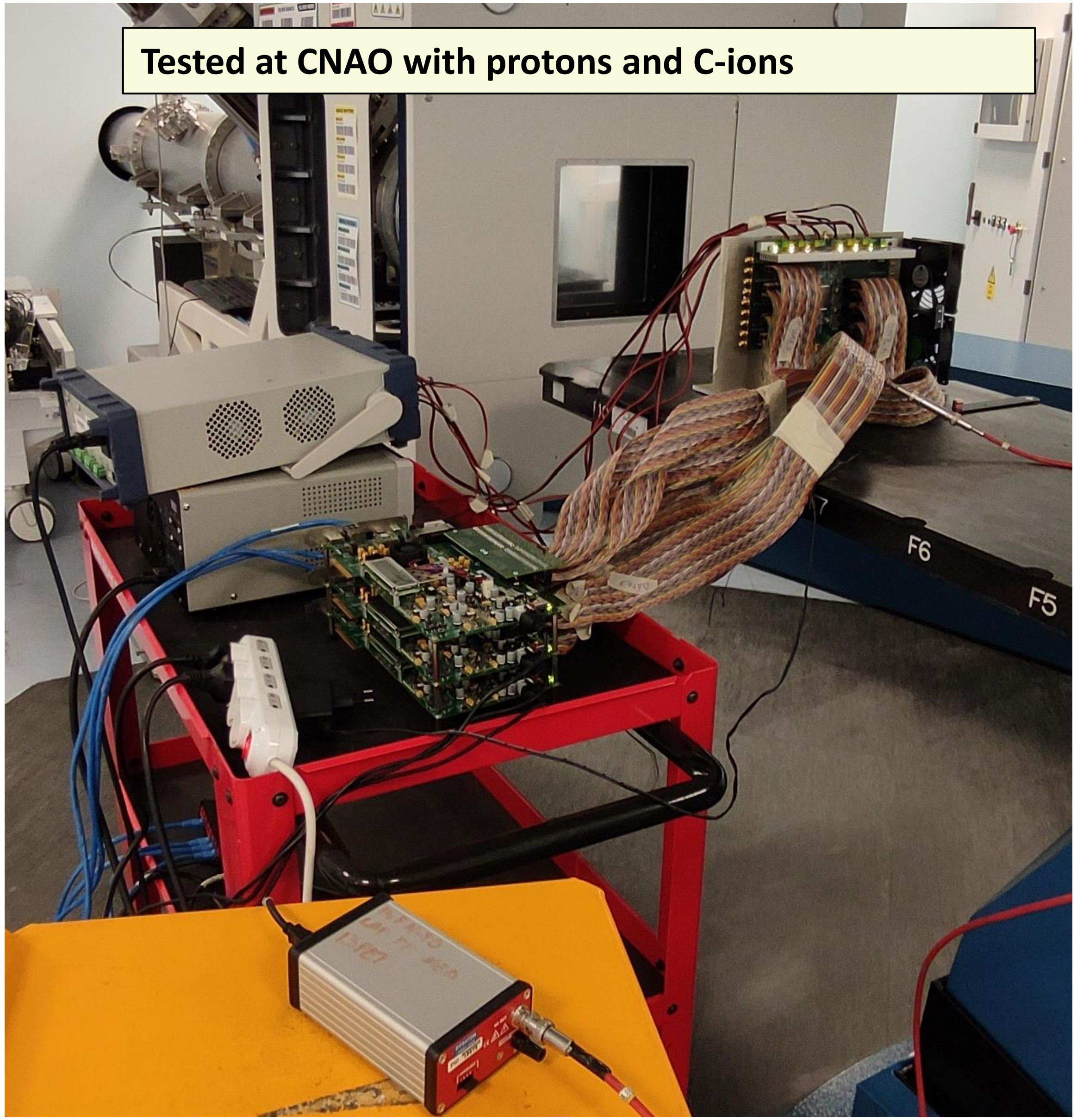


Beam monitoring. ESA-ABACUS 144-channel beam particle counter

Silicon sensor 2.7×2.7 cm^2 active area (144 strips)
Pitch → 180 μm, active Thickness → 60 μm , Capacitance → 7 pF



ABACUS ASIC (24 ch)

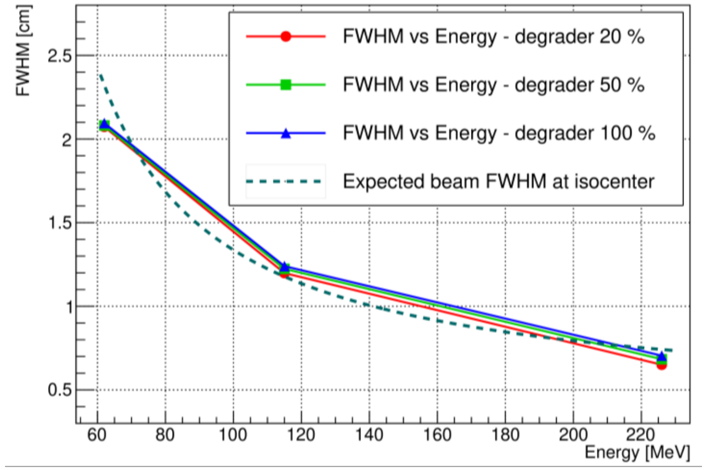


Tested at CNAO with protons and C-ions

- Six ABACUS front-end ASIC -> 3 FPGA boards
- Counting rate up to 100 MHz with < 2% pileup inefficiency
- For larger rates, inefficiency measurement implemented in FPGA

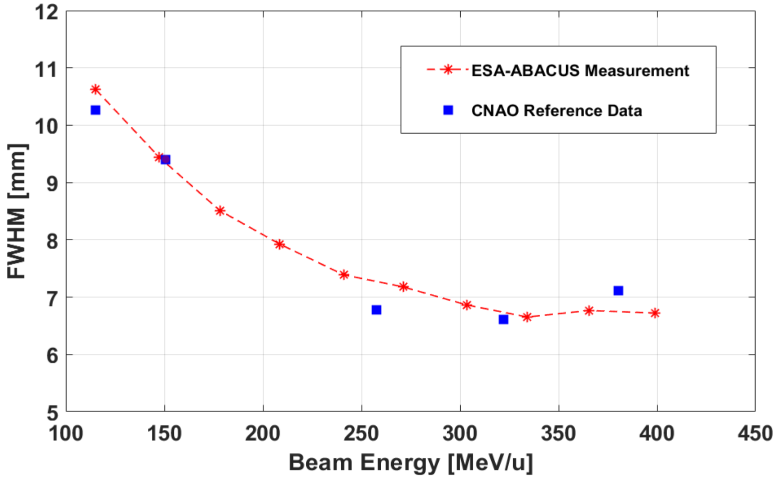
Beam monitoring. ESA-ABACUS 144-channel beam particle counter

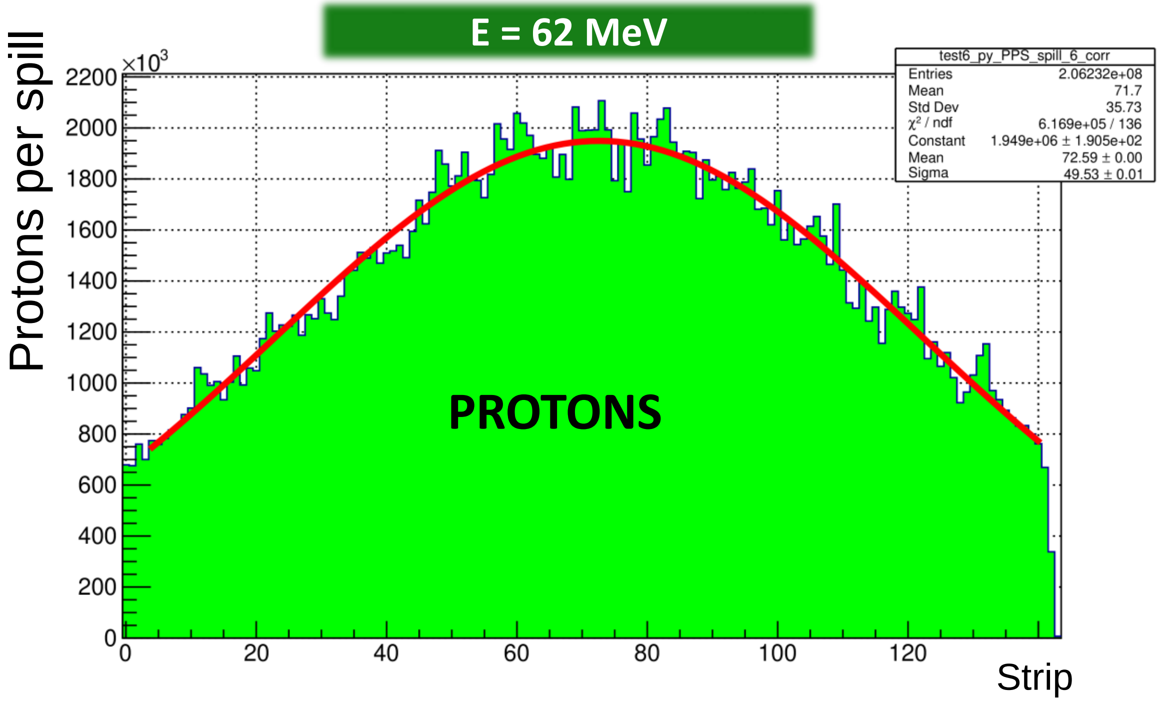
FWHM vs Energy for protons

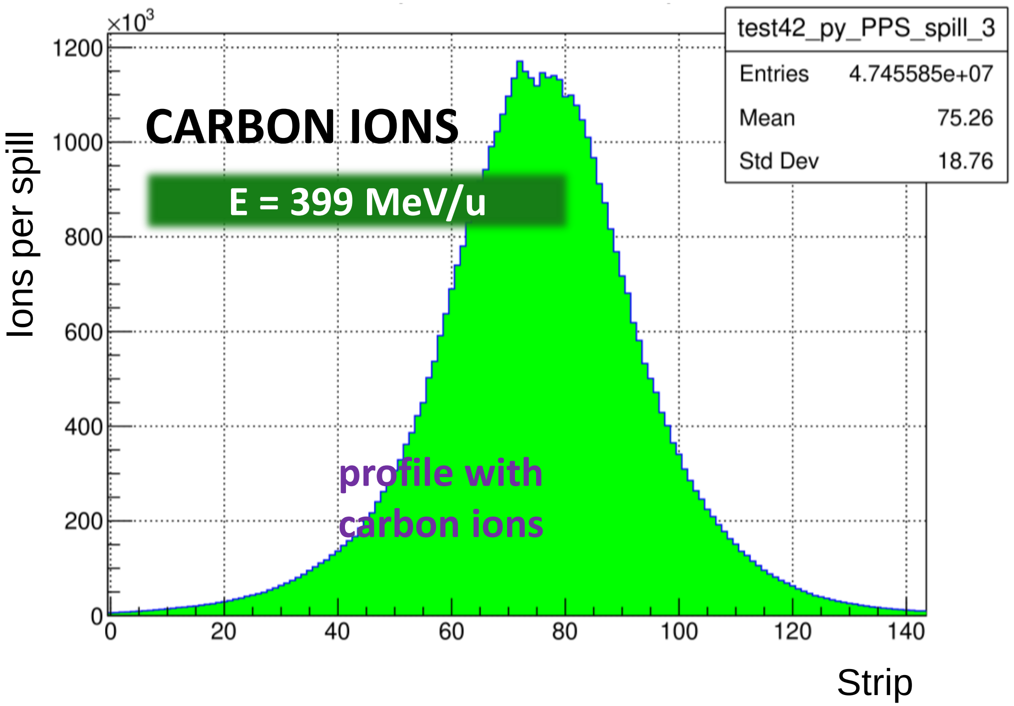


- Examples of proton and carbon ion beam profiles (**intensity = 100 %)**
- **Red curve** → Gaussian fit

FWHM vs Energy for C-ions



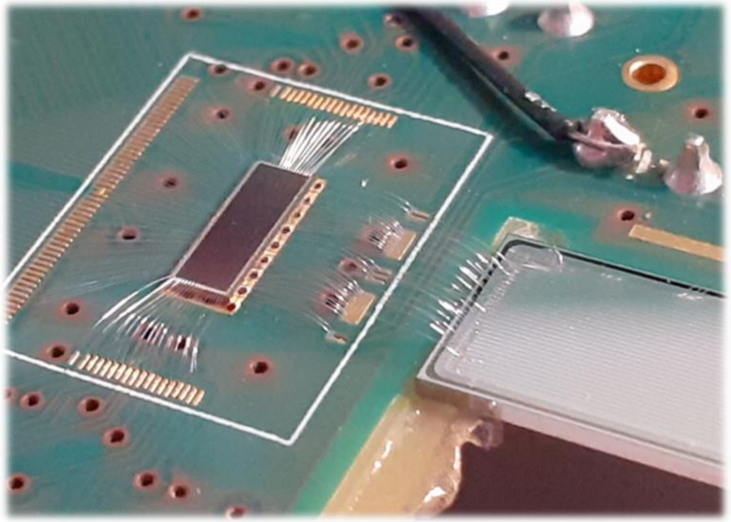


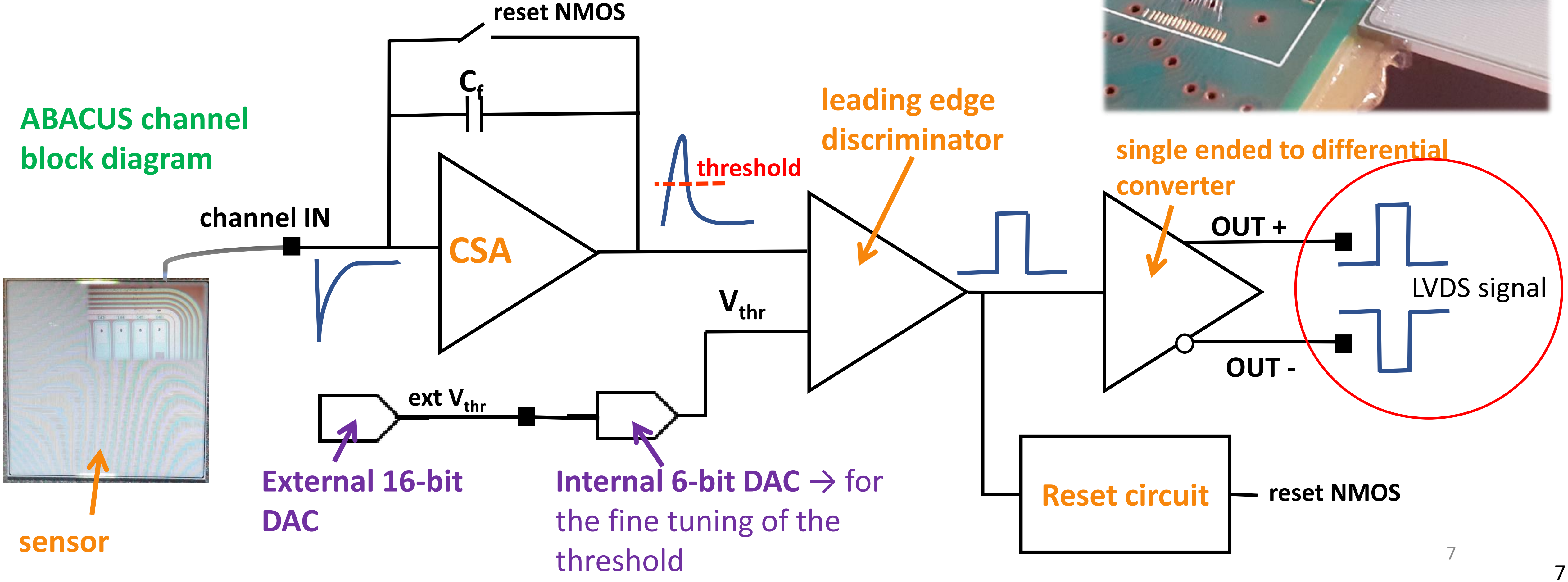


Beam monitoring. ESA-ABACUS 144-channel beam particle counter

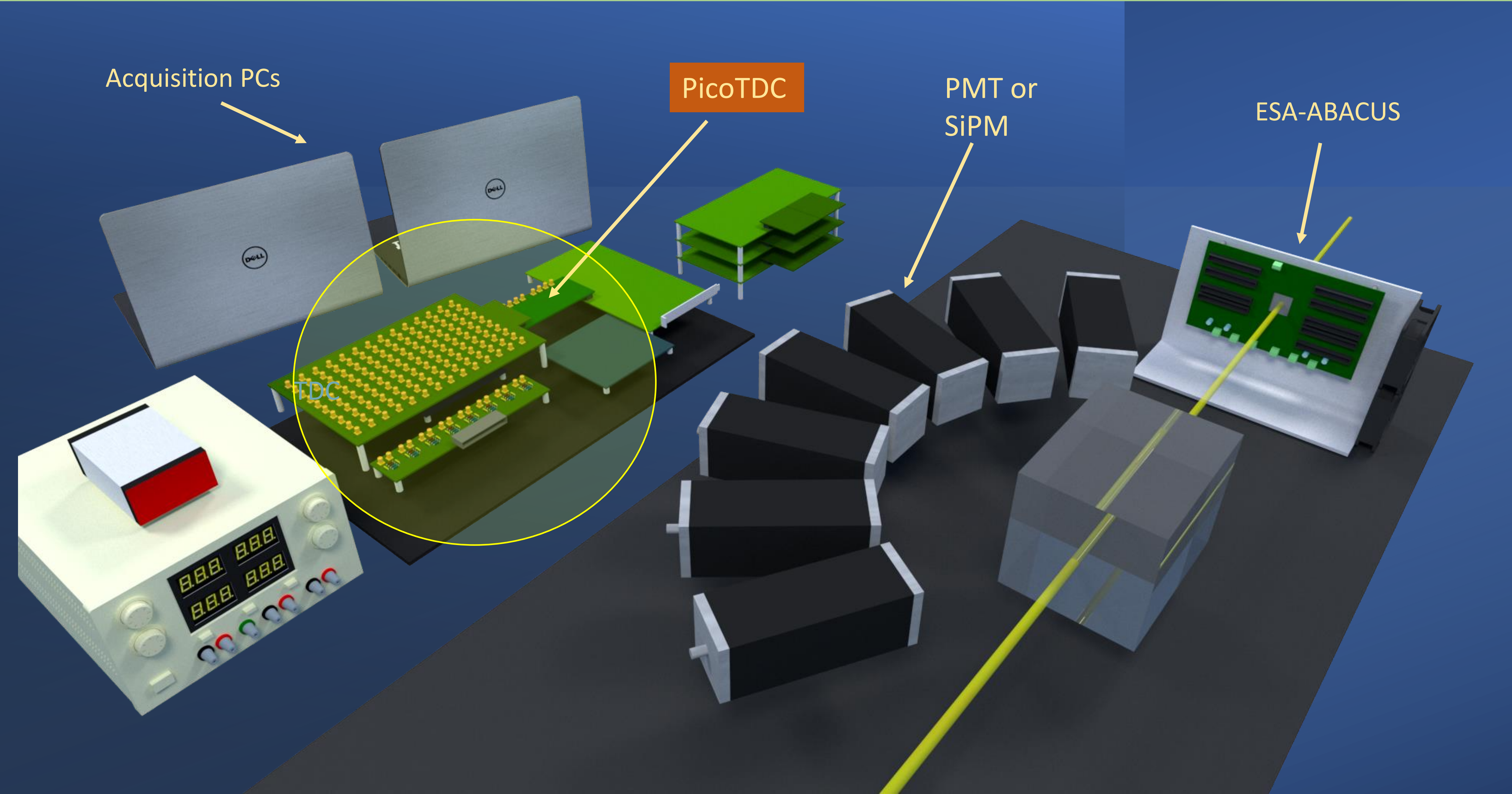
- 110 nm CMOS technology, 24 channels
- CSA dynamic range: 4 fC – 150 fC
- First characterization results:
- Dead time < 10 ns

Readout electronics: ABACUS chip



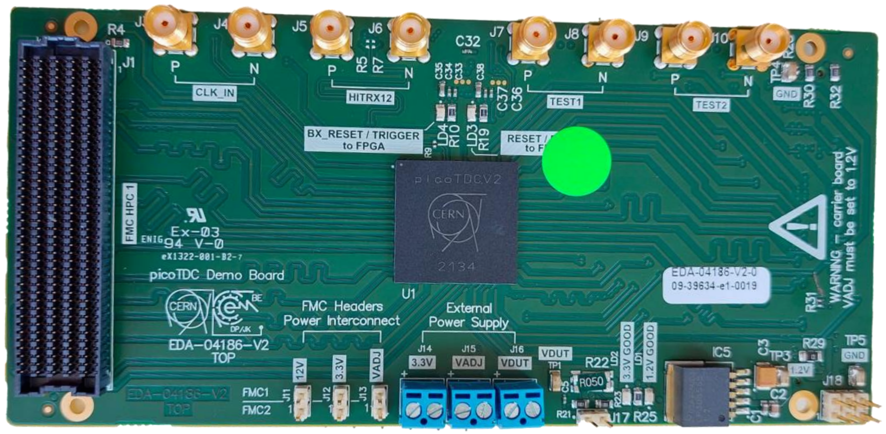


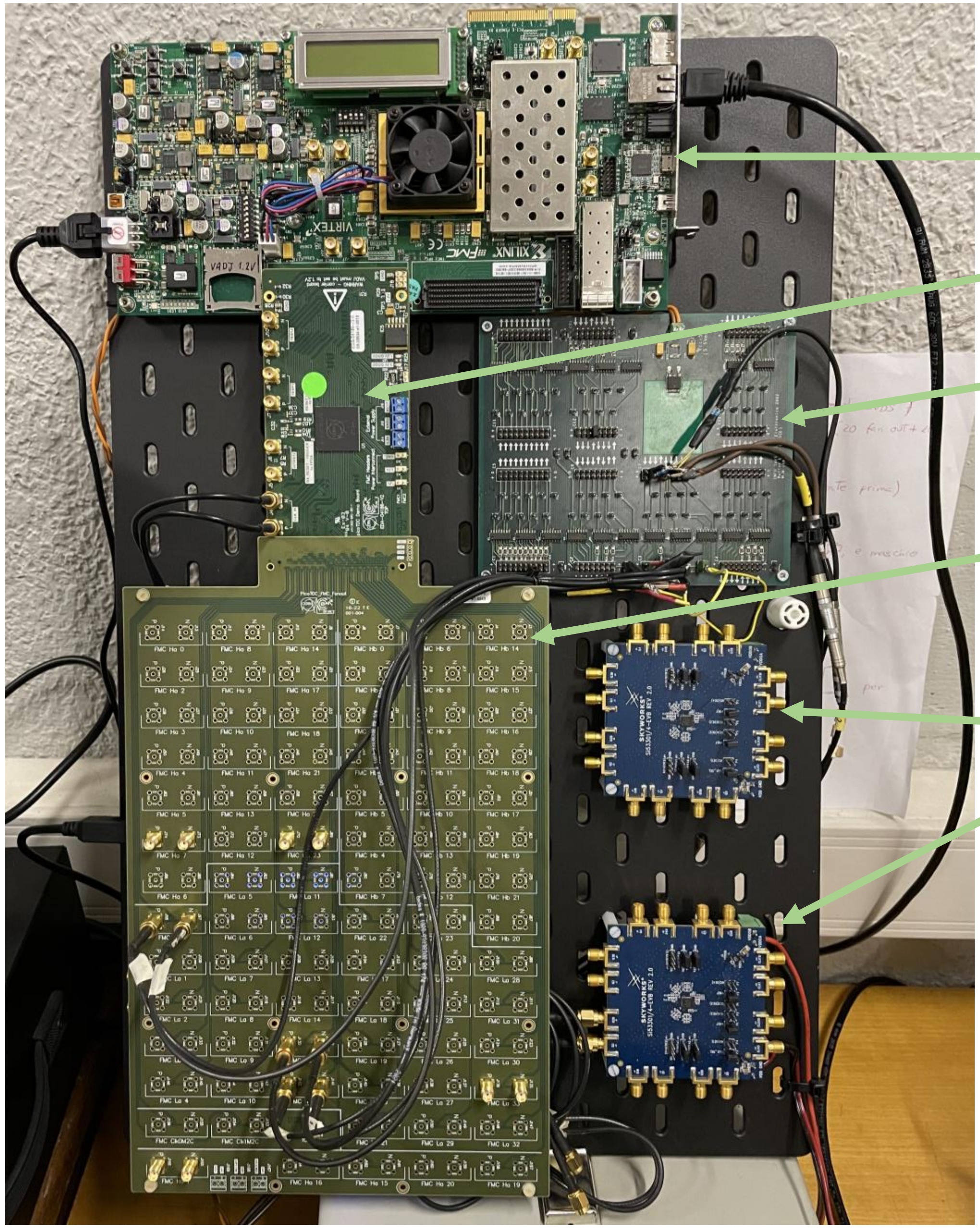
The PicoTDC setup



The PicoTDC setup

- 64 channels
- based on Delay Locked Loop with 64 delay element
- Bin size = 3.05 ps
- Dynamic range = 205 µs
- LVDS18 input signals





Virtex 7 FPGA

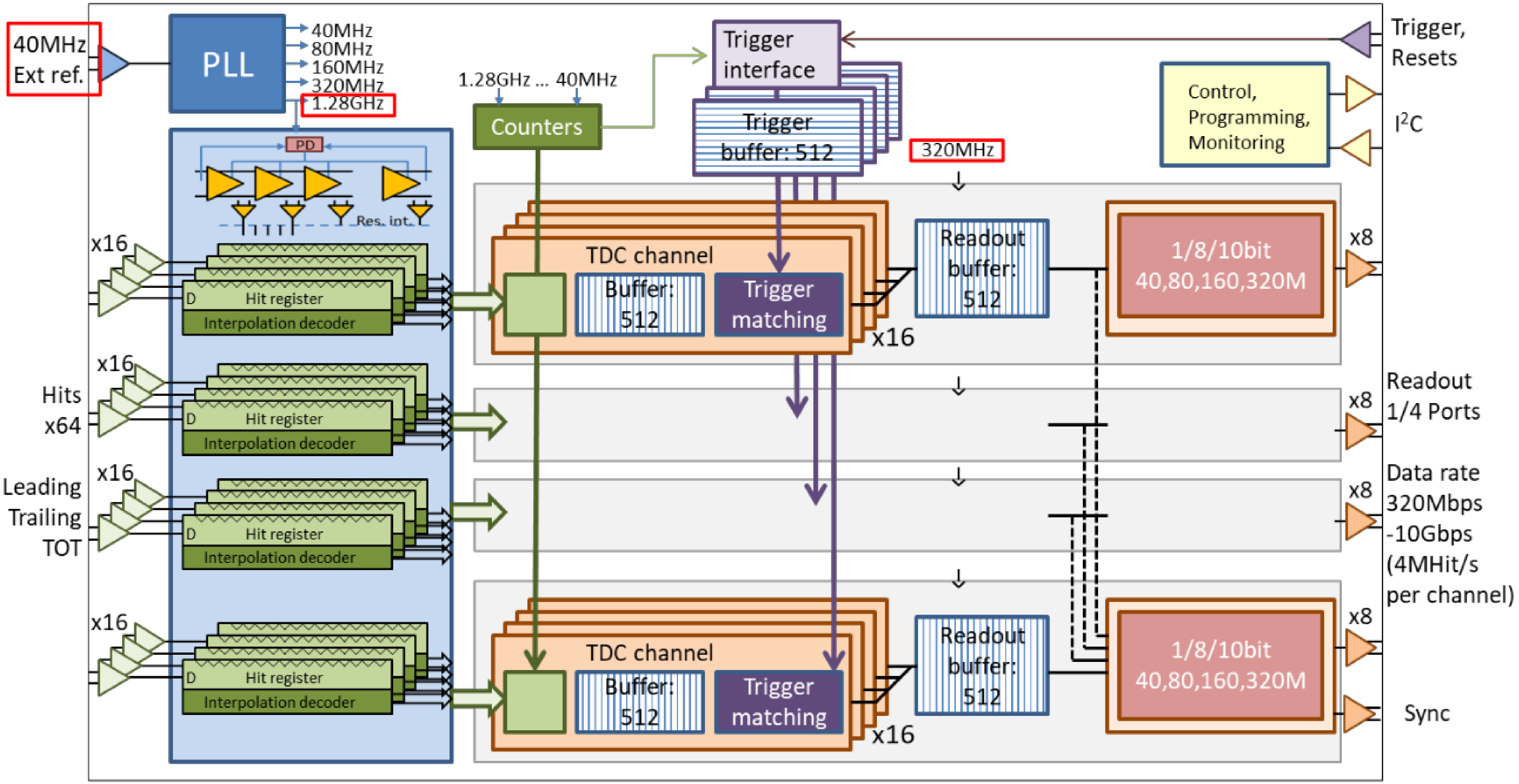
PicoTDC

TTL to LVDS board

Fan-In board

LVDS clock distribution boards

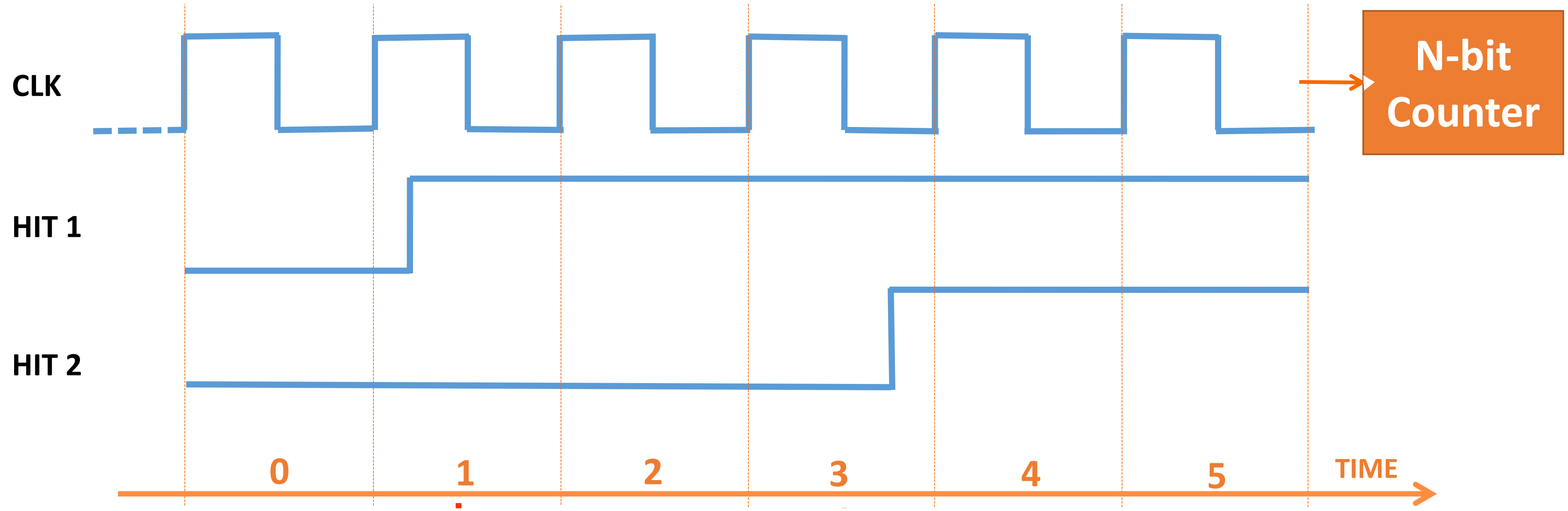
PicoTDC. Architecture



PicoTDC measurements modes

Single and triggered mode

- **Single mode**



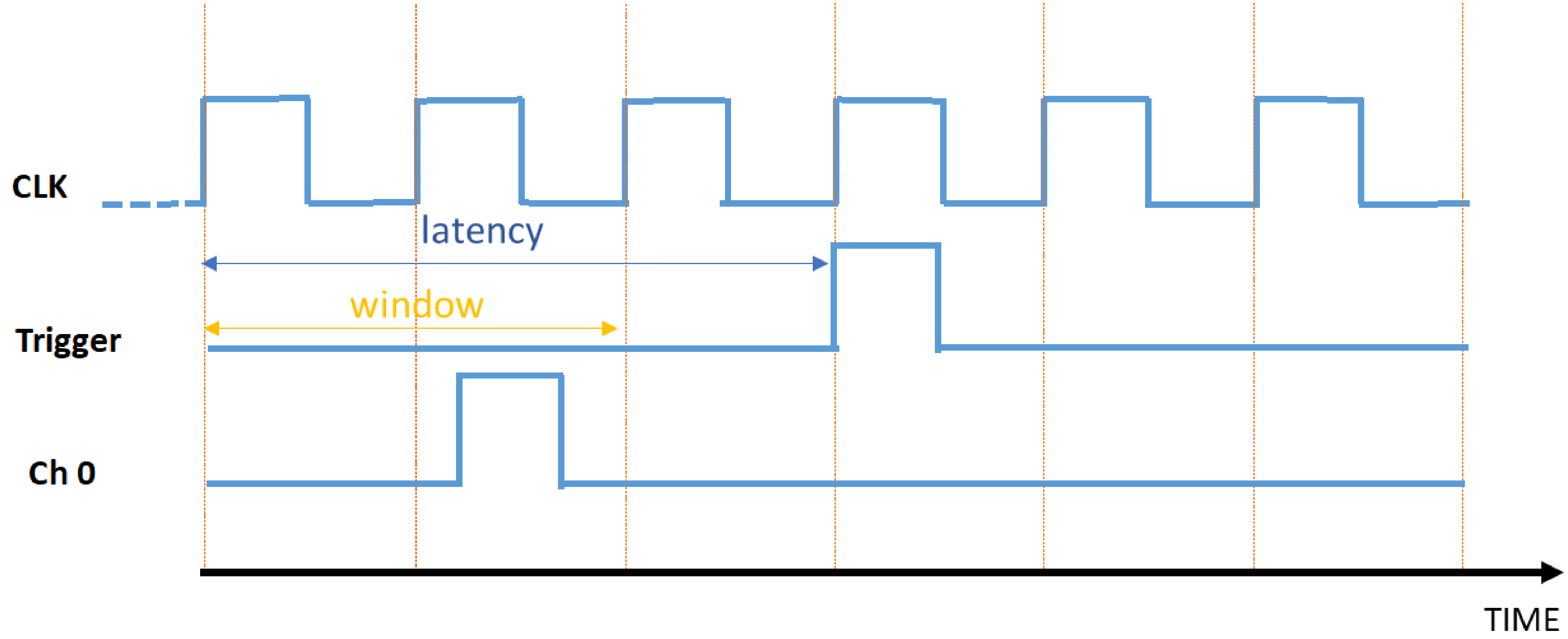
FULL TDC data, **DEFAULT FORMAT**

Type (1)	Channel (4)	Edge (1)	Coarse cnt (13)	Med. cnt (5)	DLL int (6)	Res int (2)

26 bits integer * 3ps

Single and triggered mode

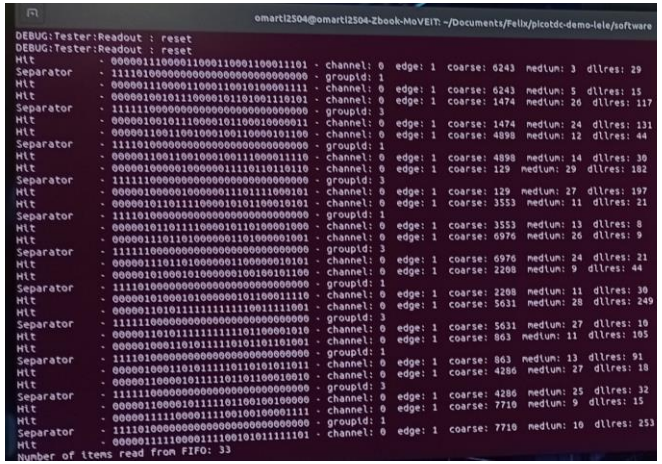
▪**triggered mode**



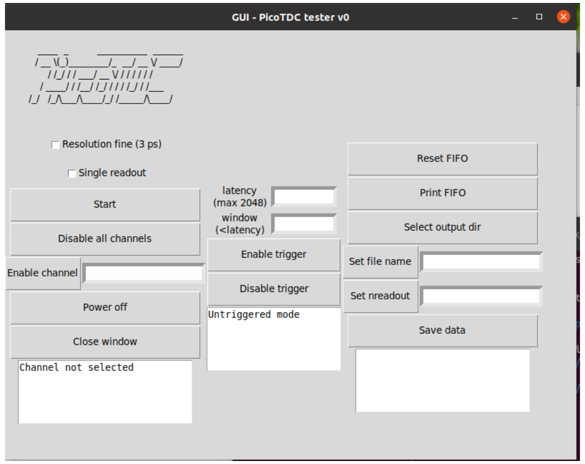
- A match between a trigger and a hit is detected within a programmable time window
- All hits from this trigger time until the trigger time plus the trigger matching window will be considered as matching the trigger
- “resolution” of the trigger matching is one clock cycle (25ns)
- the trigger window and latency are specified in steps of clock cycles

PicoTDC measurement and analysis chain

Python program



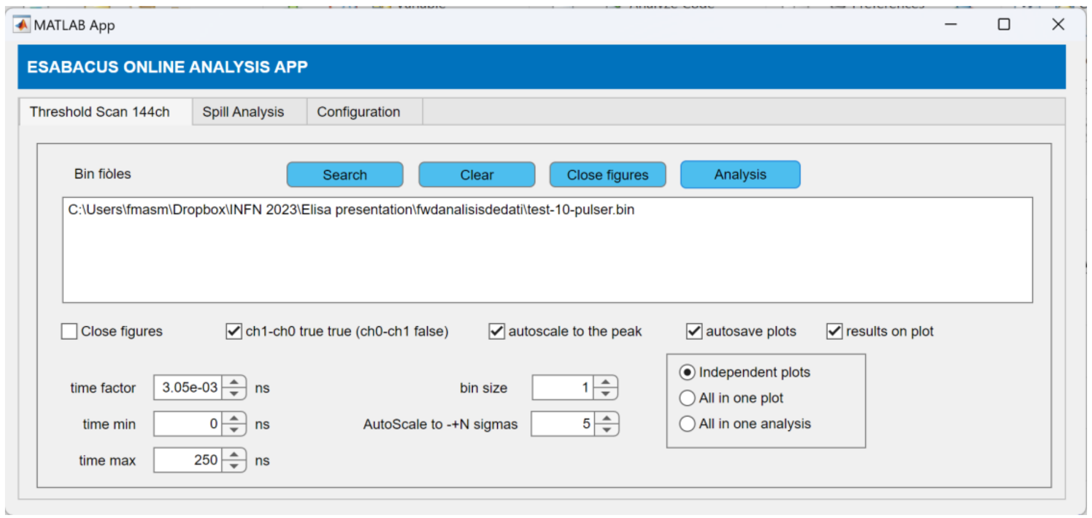
Python GUI



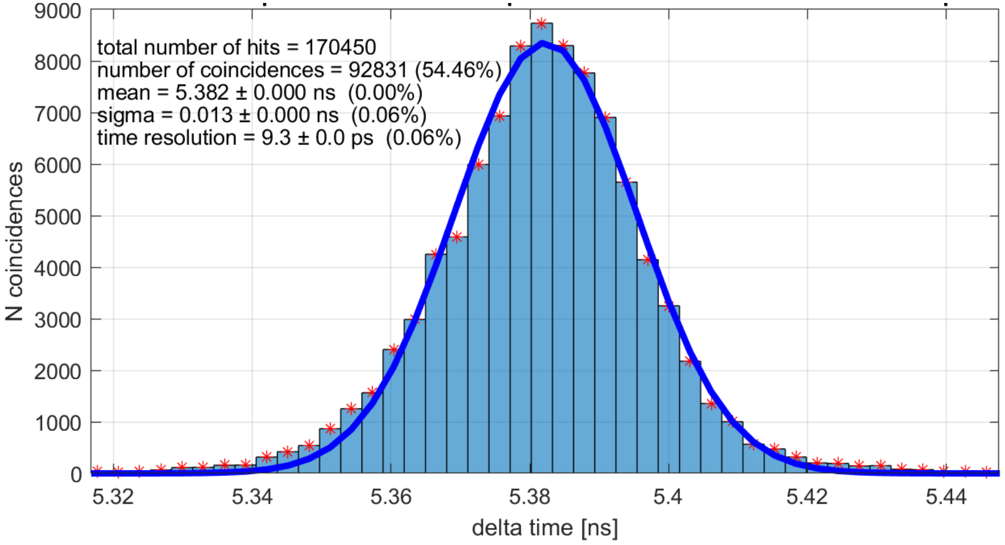
output

Binary files

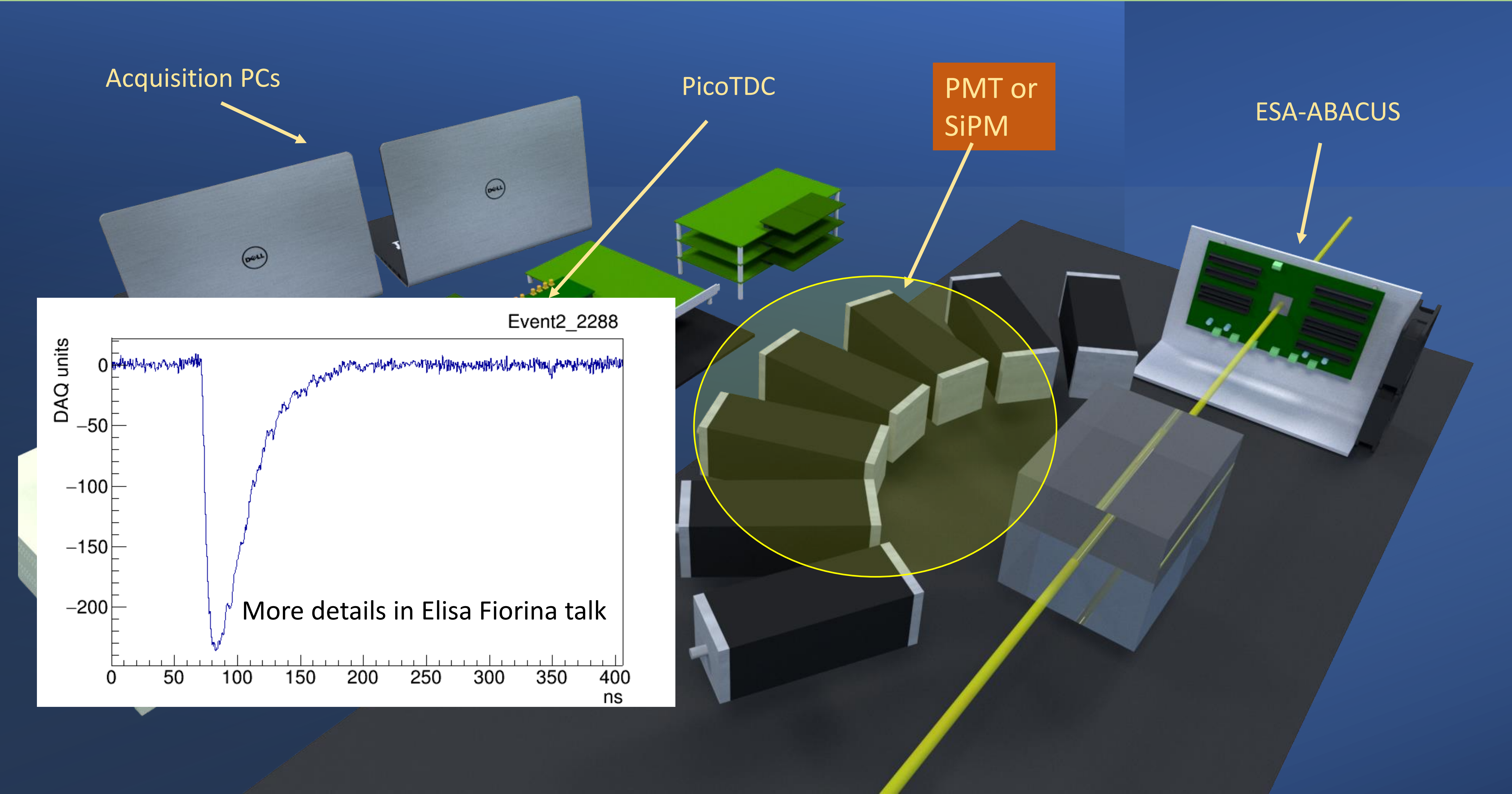
MATLAB App



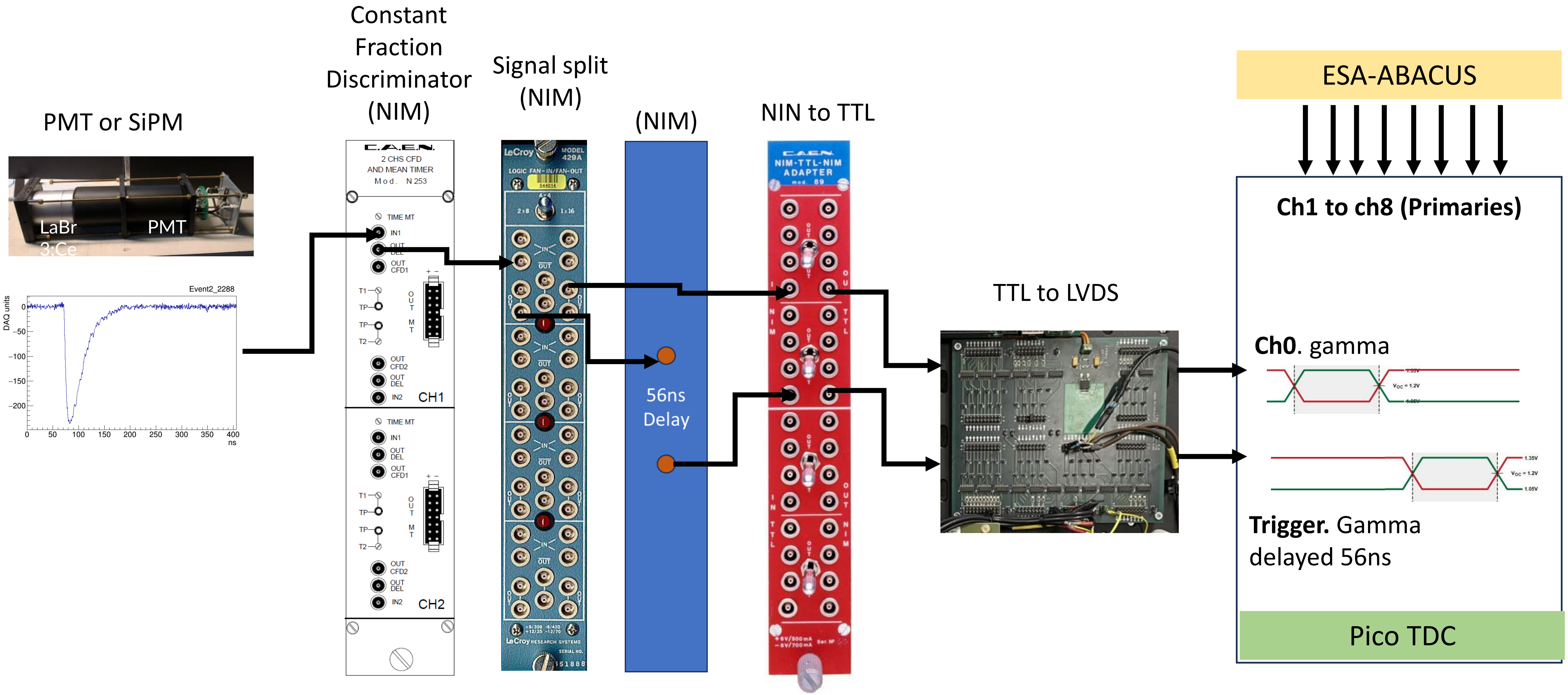
time difference



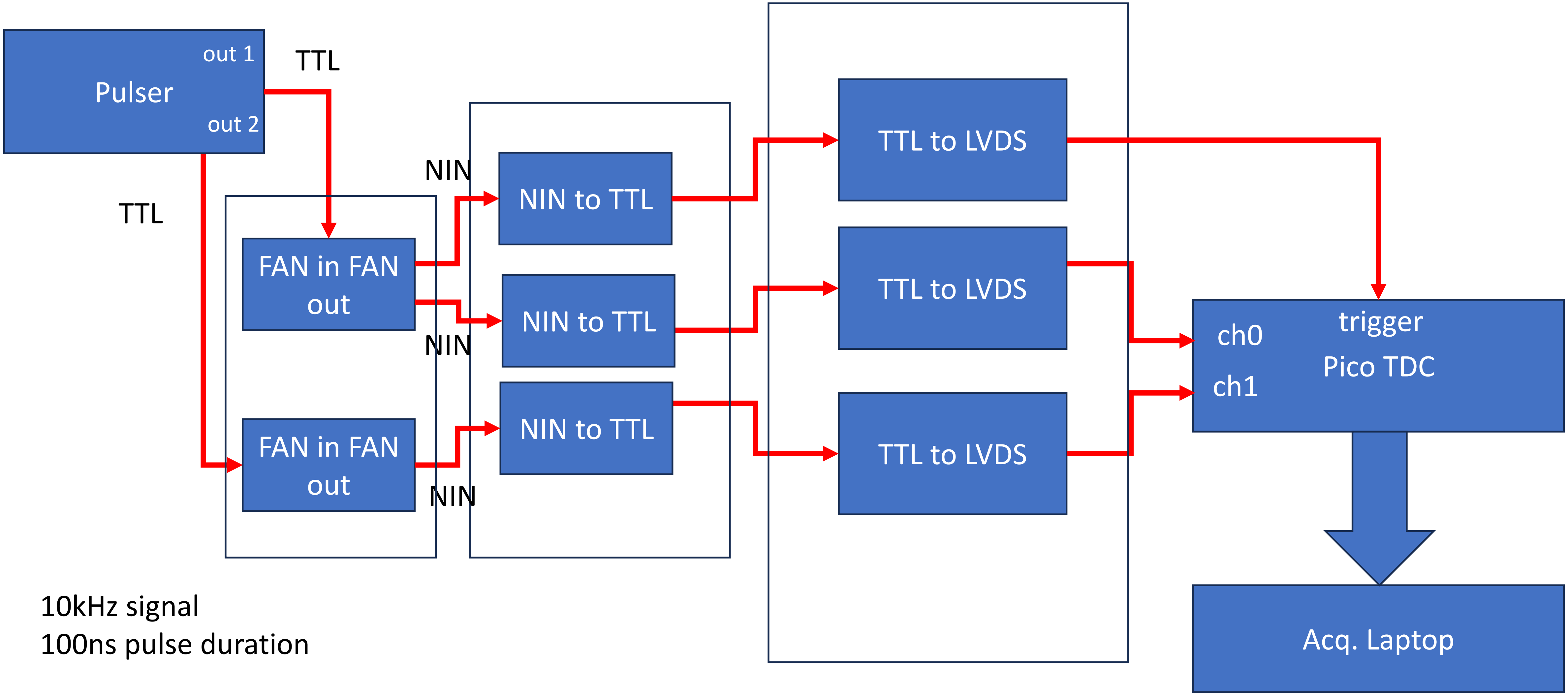
Detectors for secondaries signals



Integration. Preliminary setup

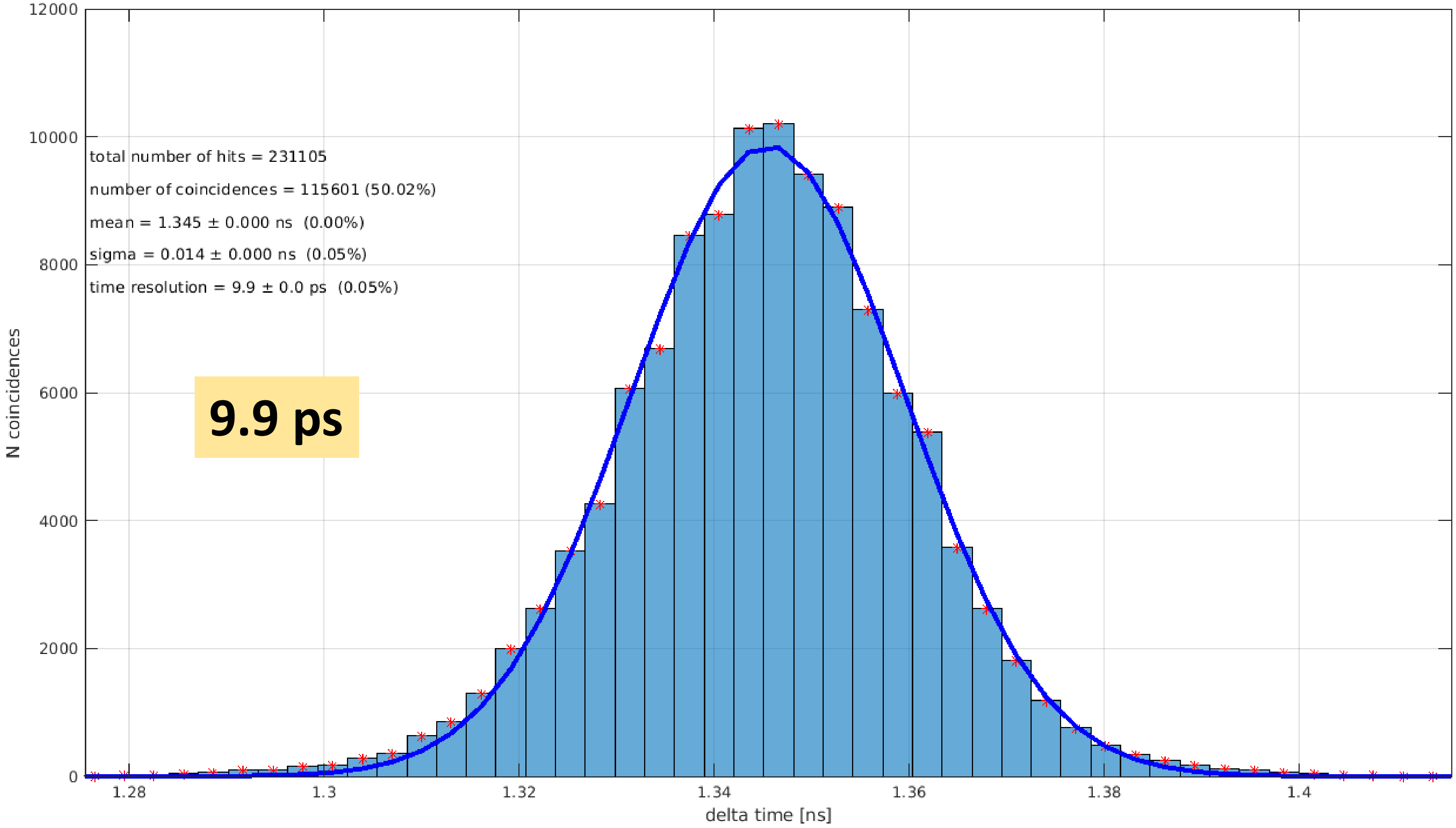


Laboratory measurements. Pico TDC time resolution

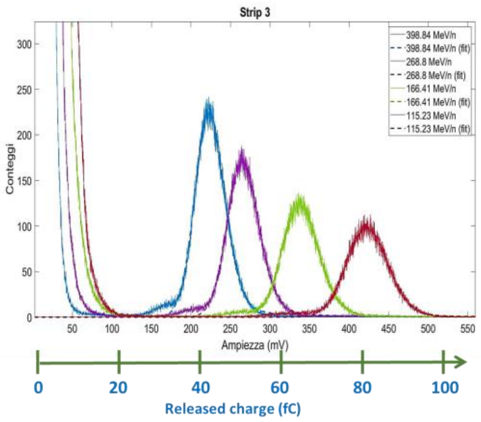


10kHz signal
100ns pulse duration

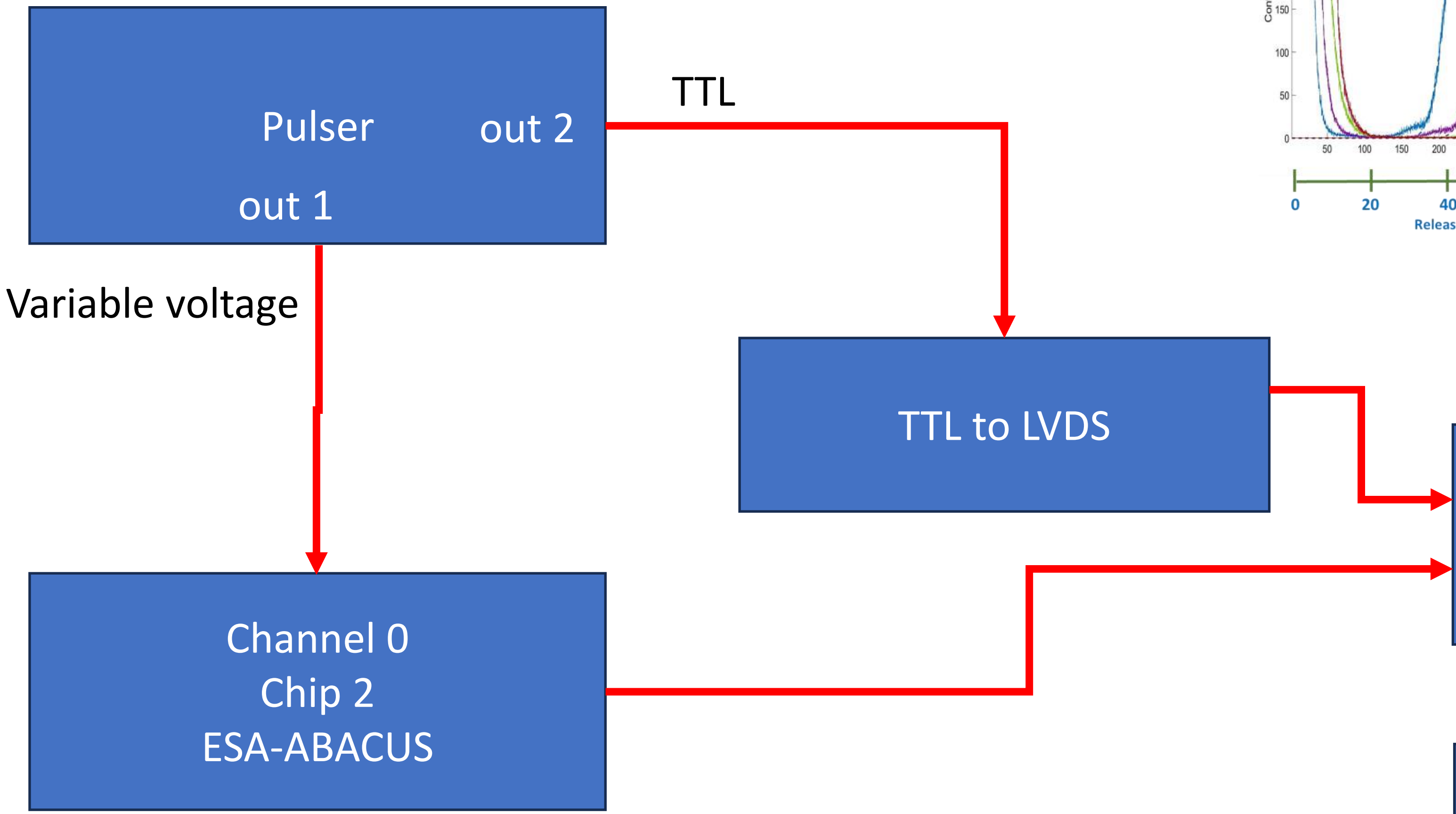
Laboratory measurements. Pico TDC time resolution

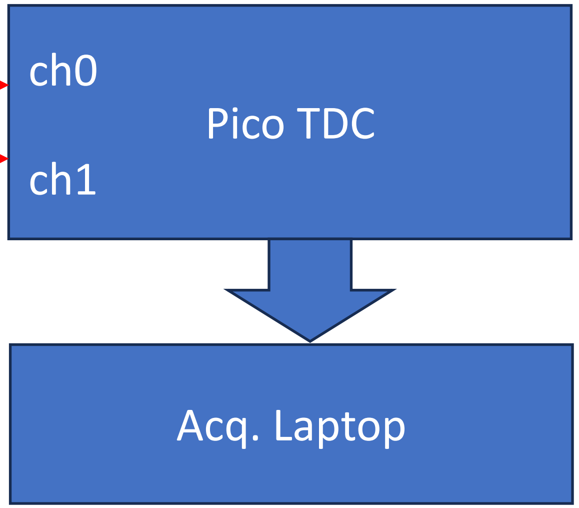


Laboratory measurements. ESA-ABACUS time resolution



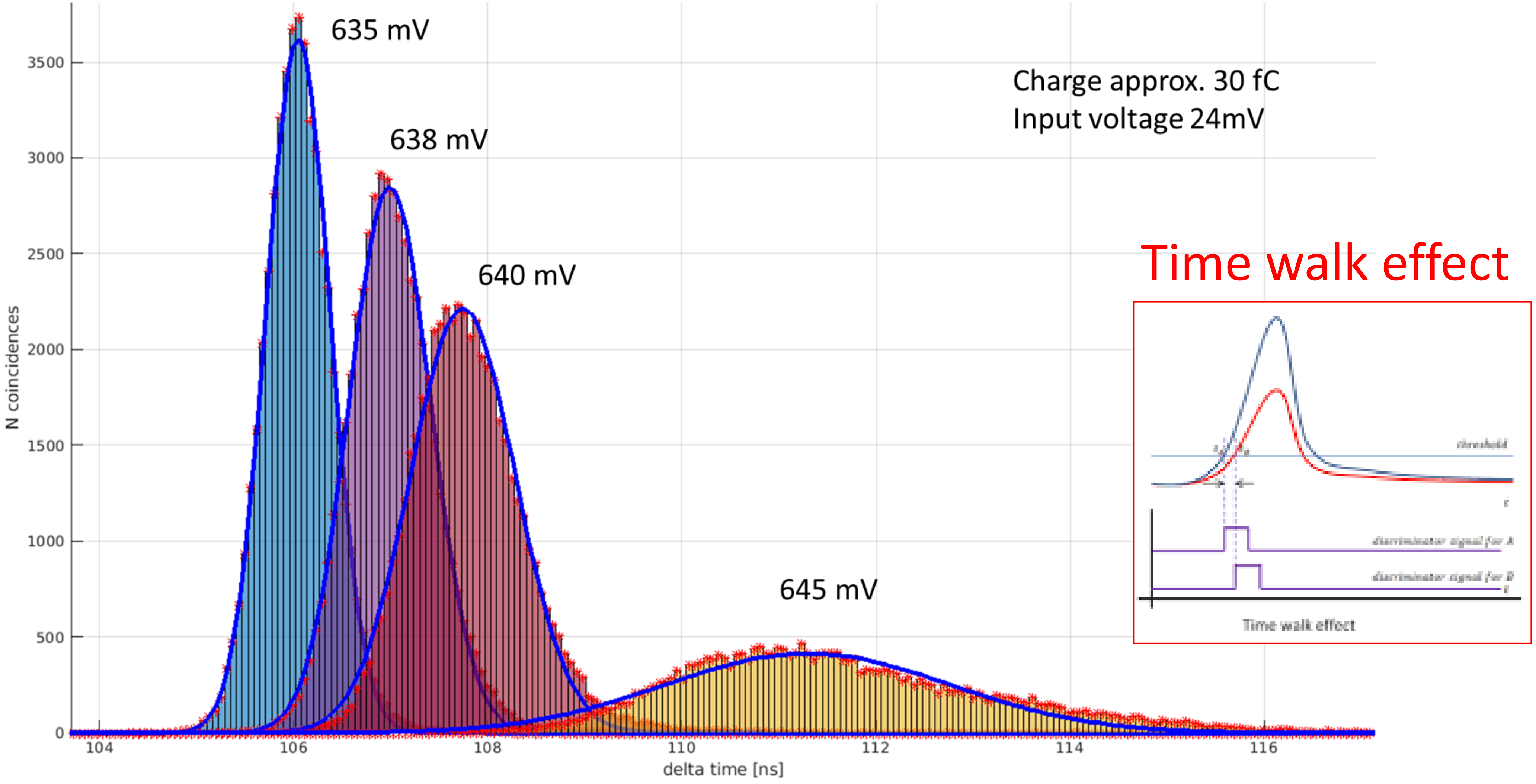
Expected deposited charged for C-ions: 30 fC to 100 fC.
Used voltages 24mV to 73mV (30fC to 90fC), and 12 Thresholds.



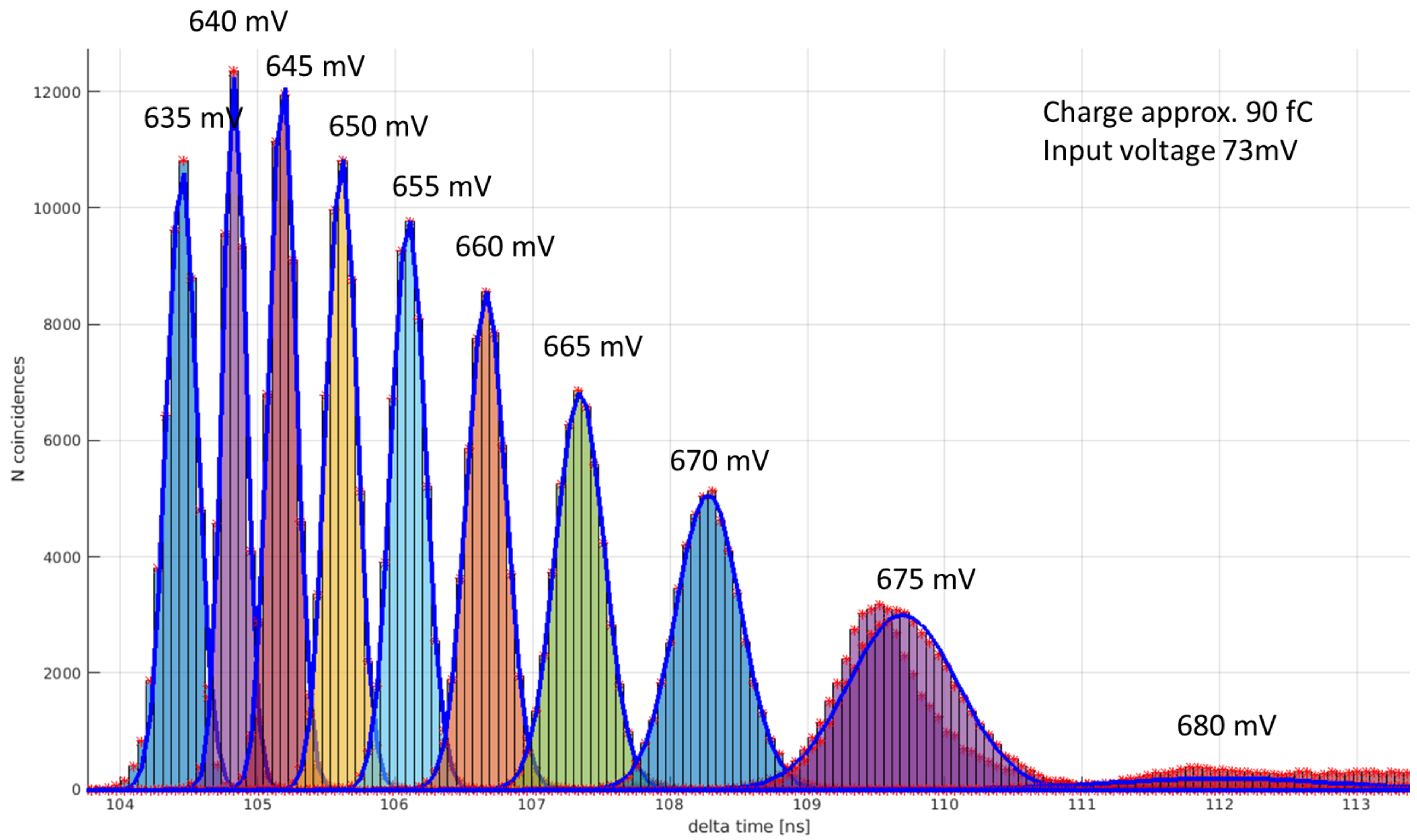


1MHz signal
100ns pulse duration

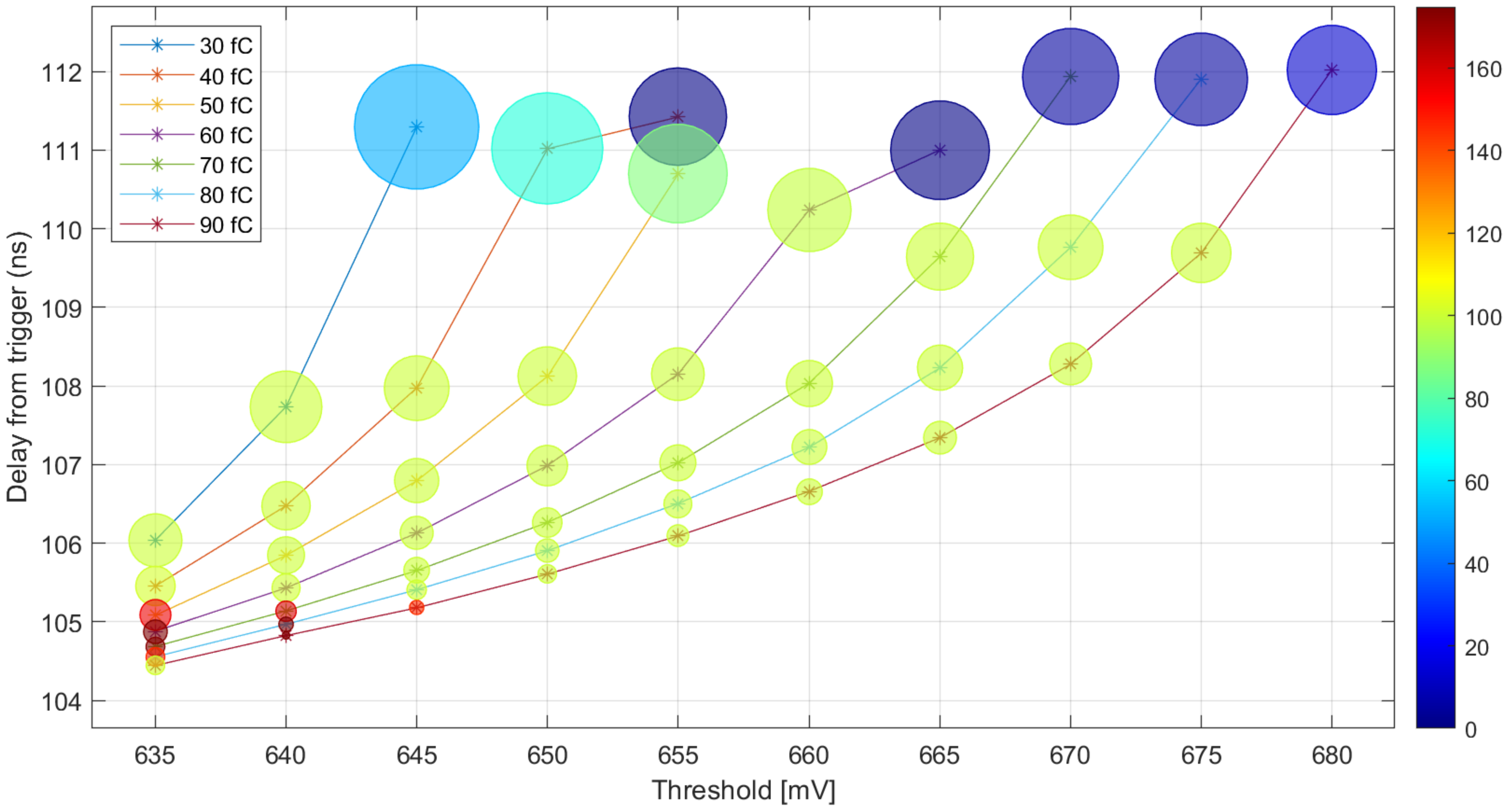
Laboratory measurements. ESA-ABACUS time resolution



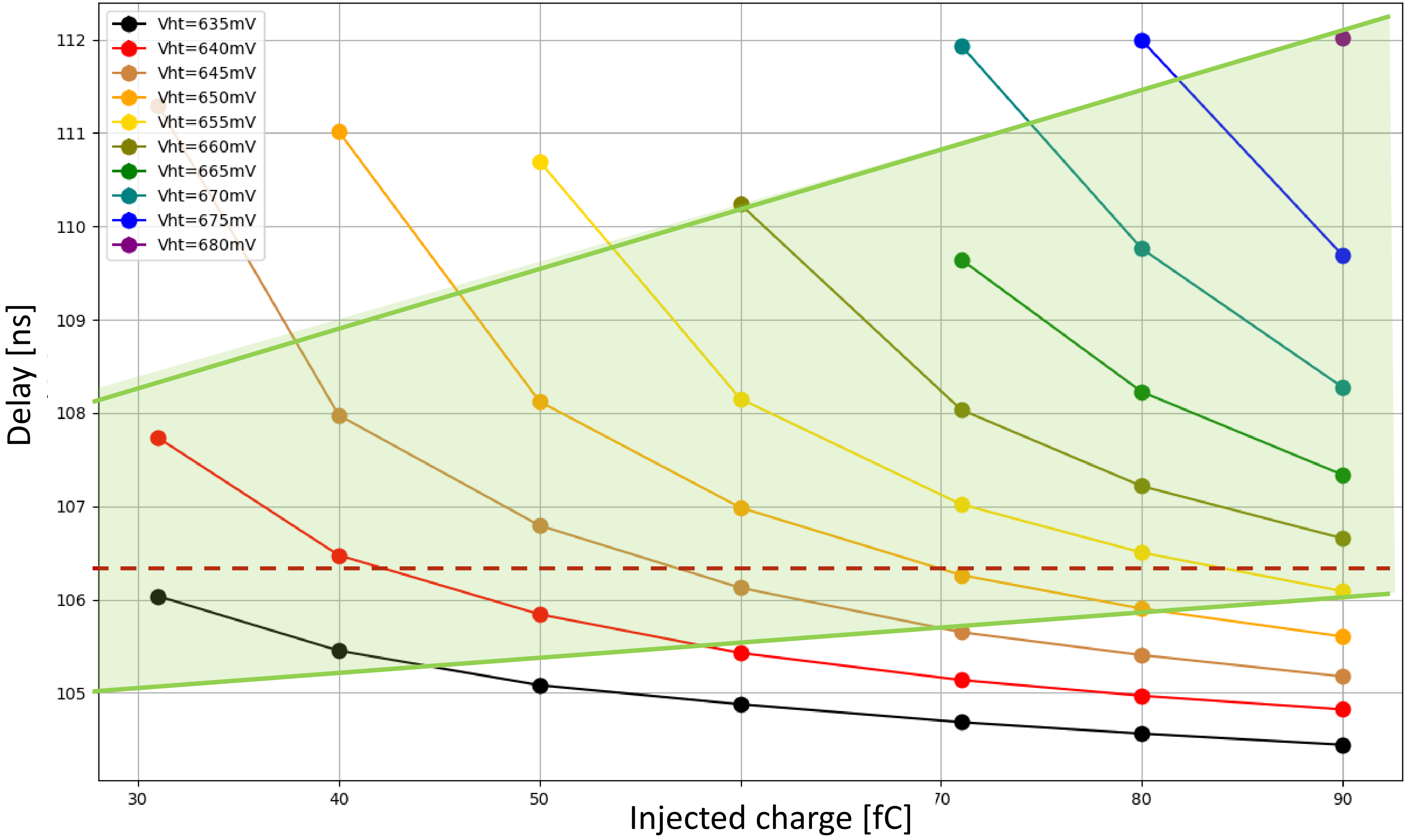
Laboratory measurements. ESA-ABACUS time resolution



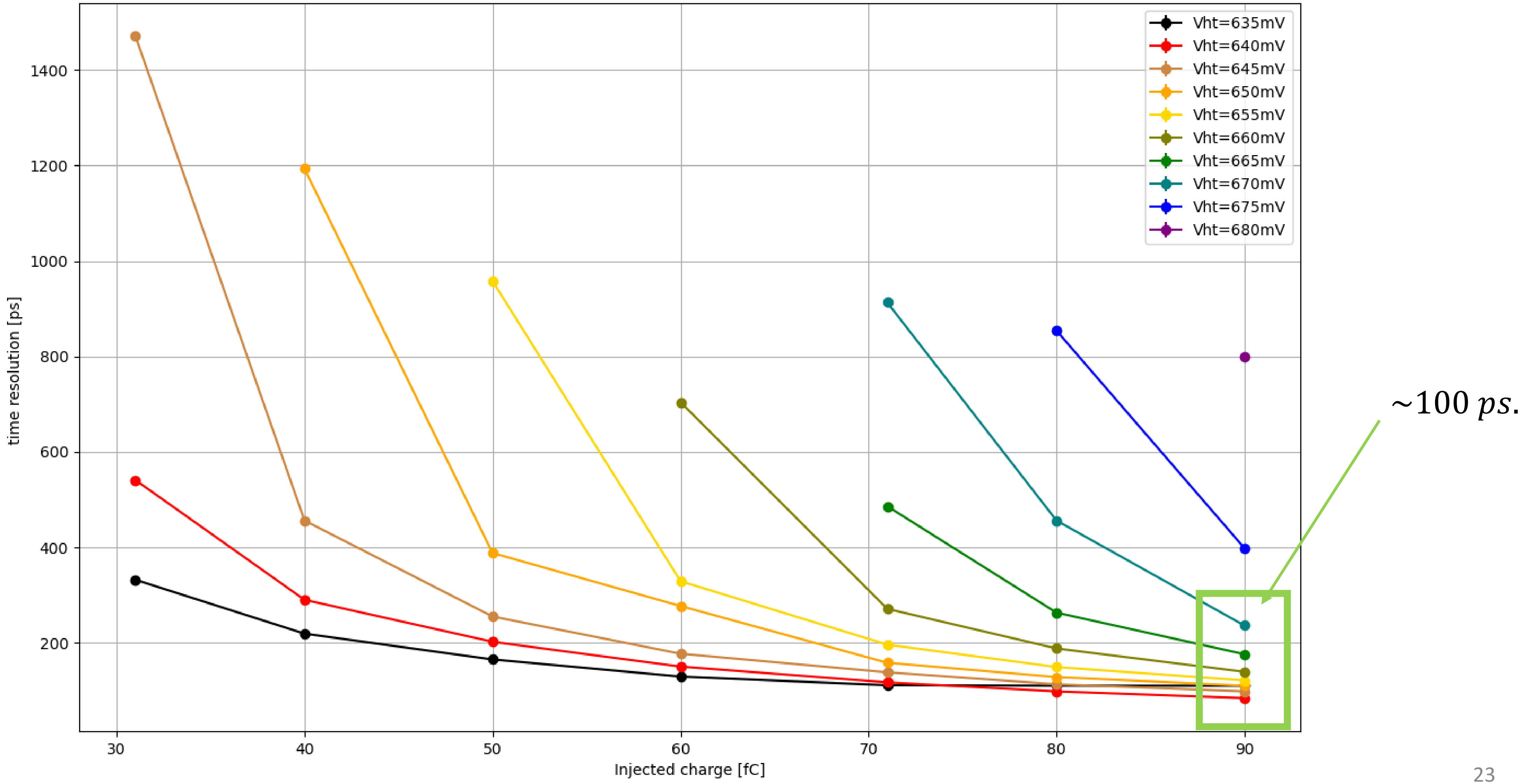
Laboratory measurements. ESA-ABACUS time resolution



Laboratory measurements. ESA-ABACUS time resolution



Laboratory measurements. ESA-ABACUS time resolution



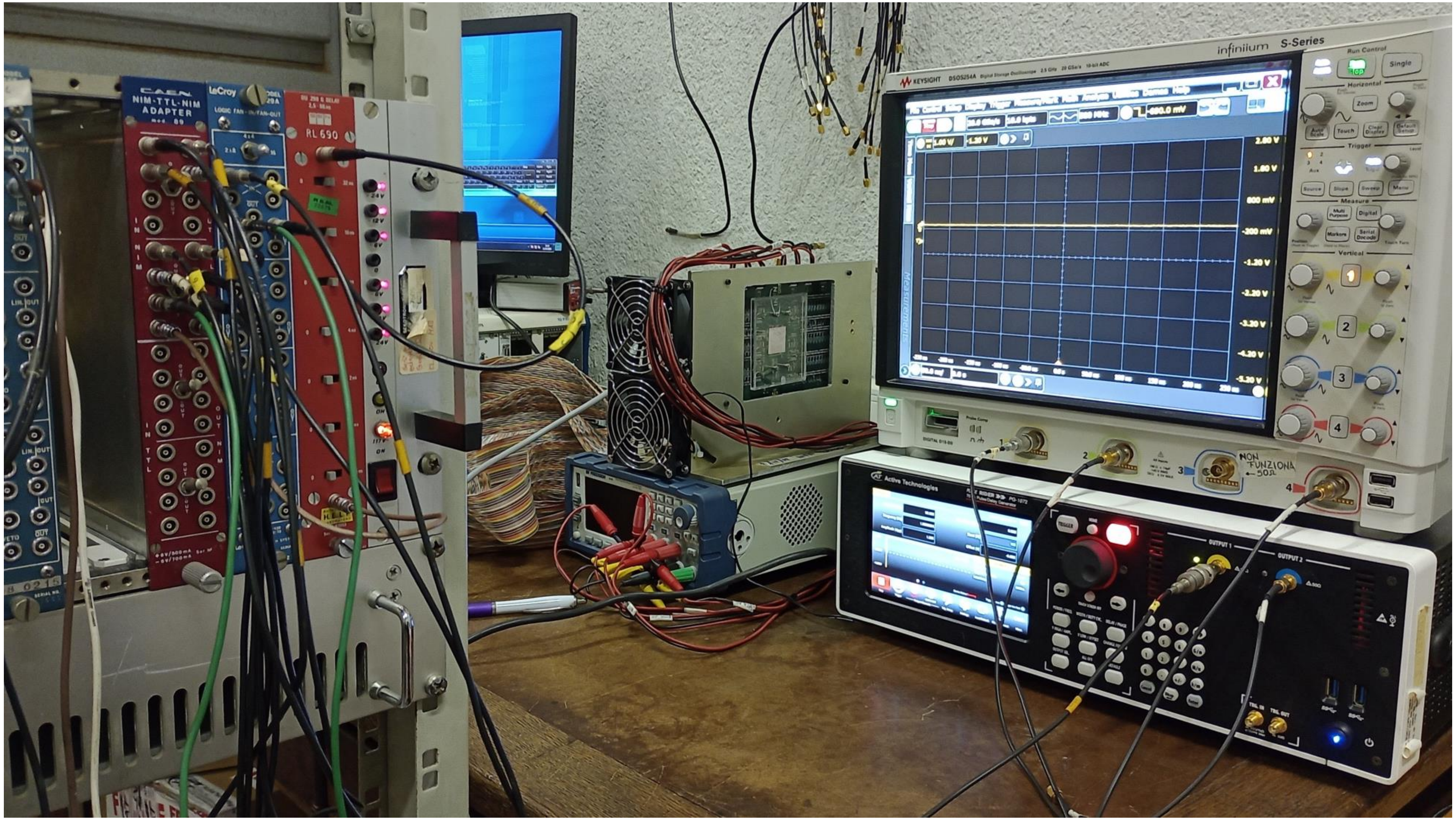
Conclusions

- A preliminary integration setup for primaries + secondaries detectors using the PicoTDC was done and tested in laboratory.
- We found the best time resolution for PicoTDC + ESA-ABACUS system equal to 100 ps.

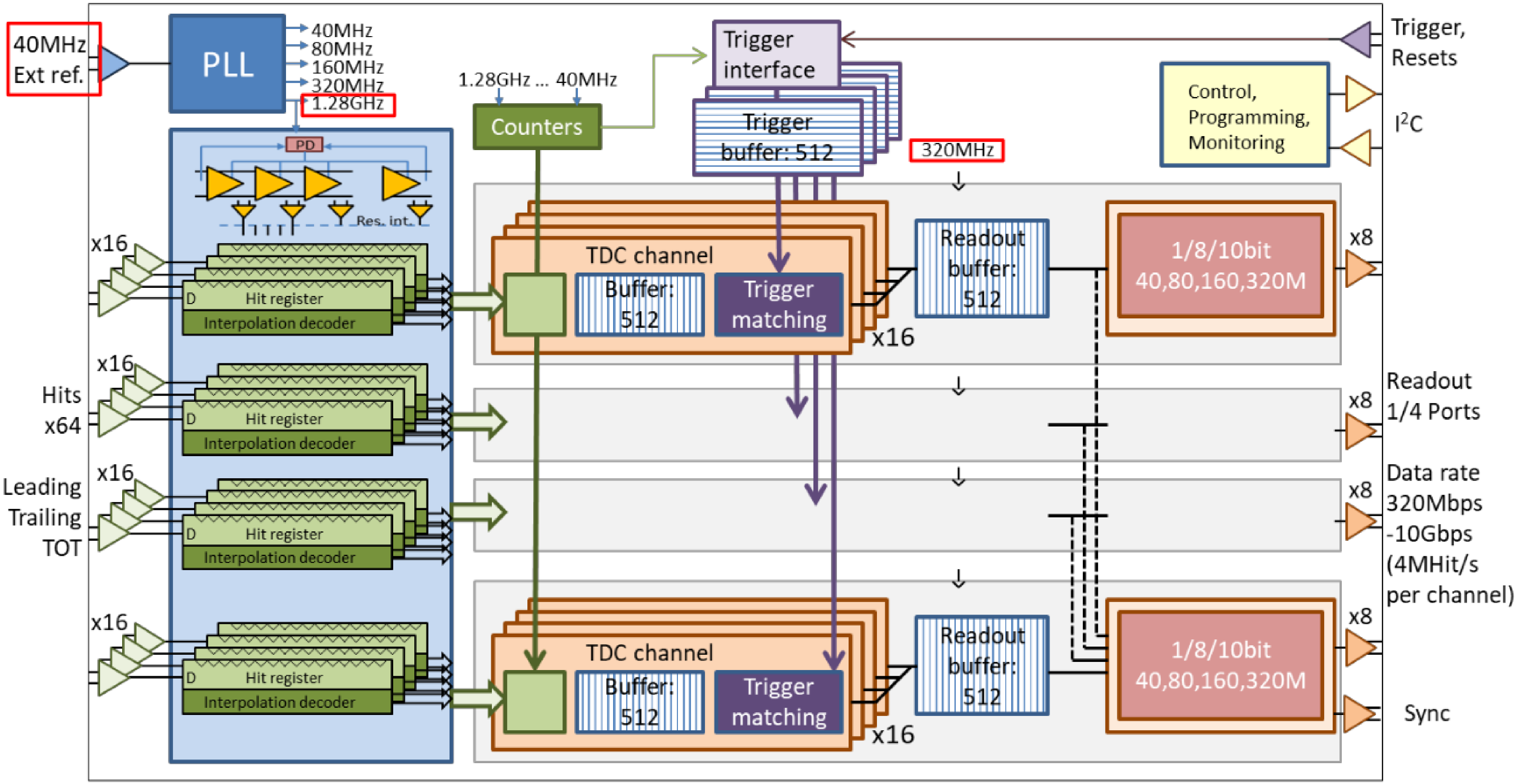
On going works

- Find the time resolution for PM + PicoTDC, and SiPM + PicoTDC using radioactive sources.
- Repeat the characterization in time resolution and time delay for 8 channels to be used for the next beam test.
- Find the corrections factors for each channels in function of the threshold.
- Improve the analysis software for online time difference calculation
- Find the final time resolution for all the system

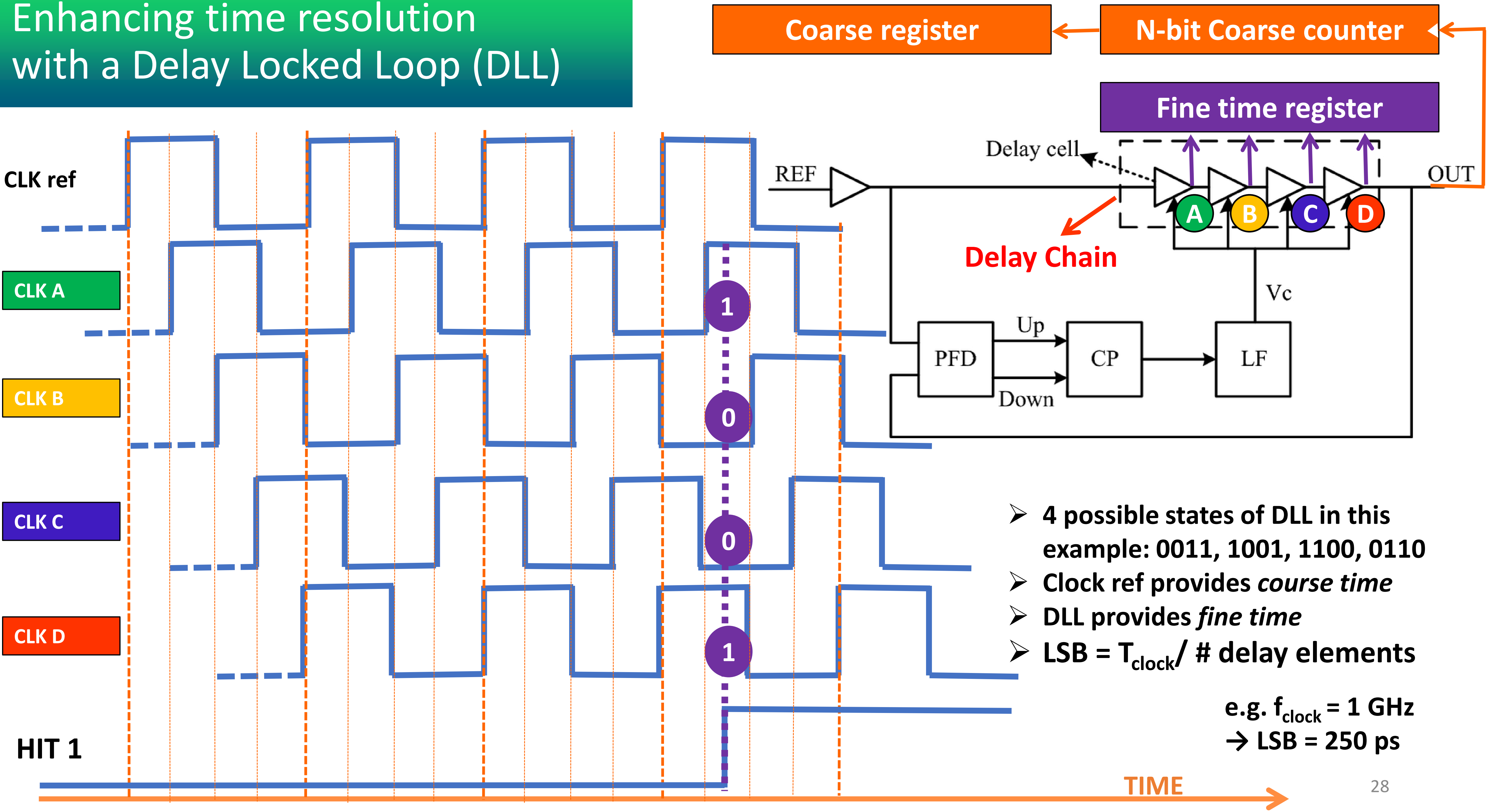
Thanks for your attention



PicoTDC architecture (1)



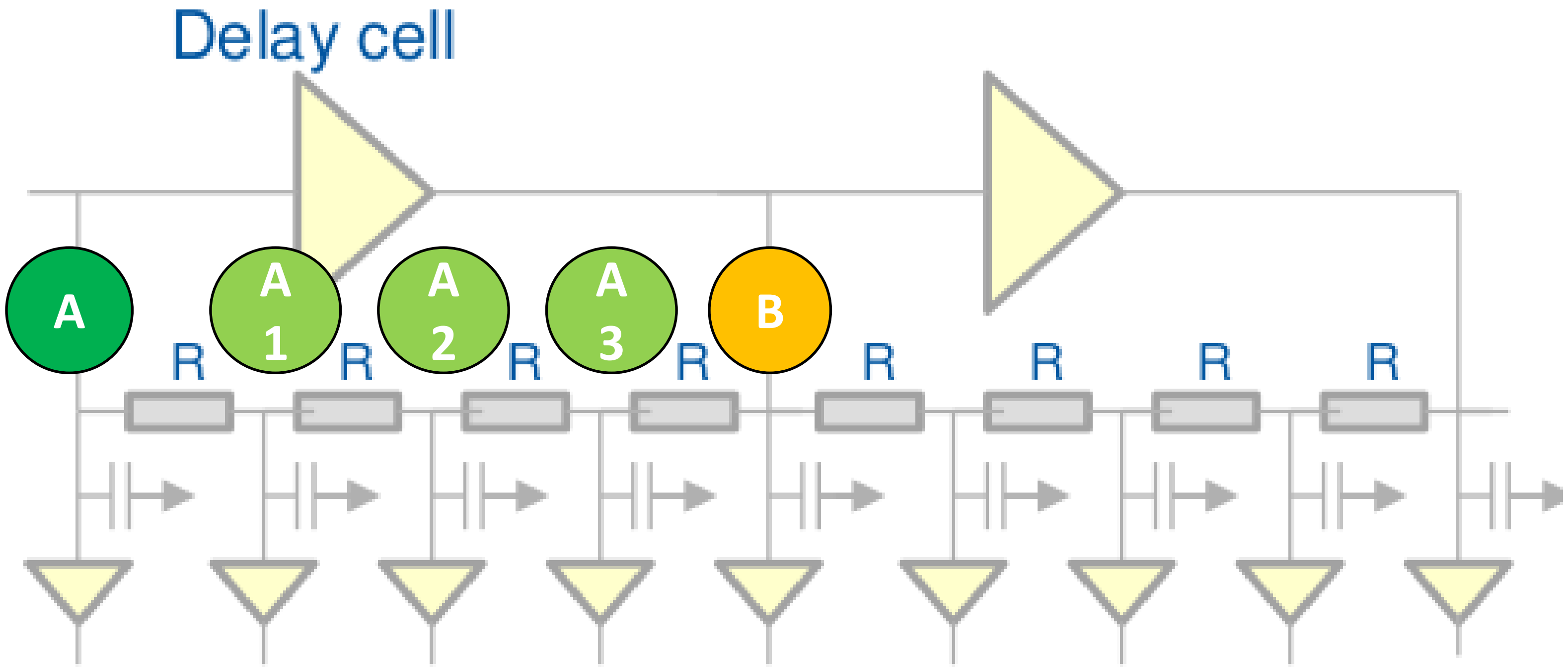
Enhancing time resolution with a Delay Locked Loop (DLL)



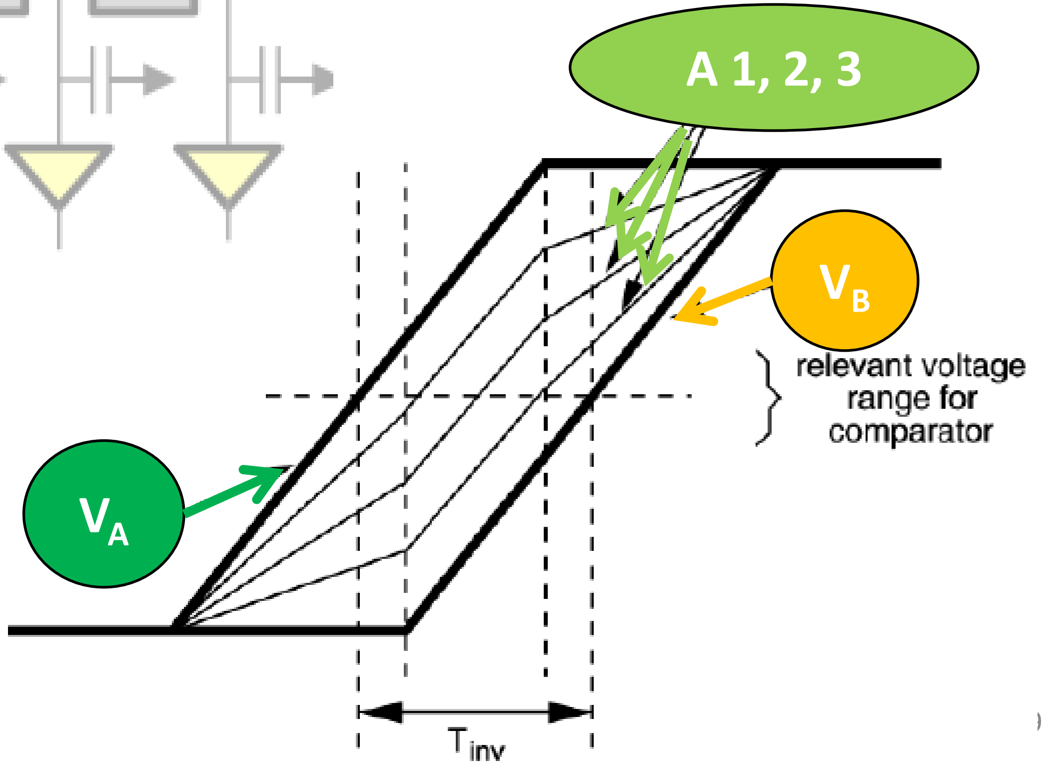
- 4 possible states of DLL in this example: 0011, 1001, 1100, 0110
- Clock ref provides *course time*
- DLL provides *fine time*
- LSB = T_{clock}/ # delay elements

e.g. f_{clock} = 1 GHz
→ LSB = 250 ps

Improving even more time resolution with *resistive interpolation*



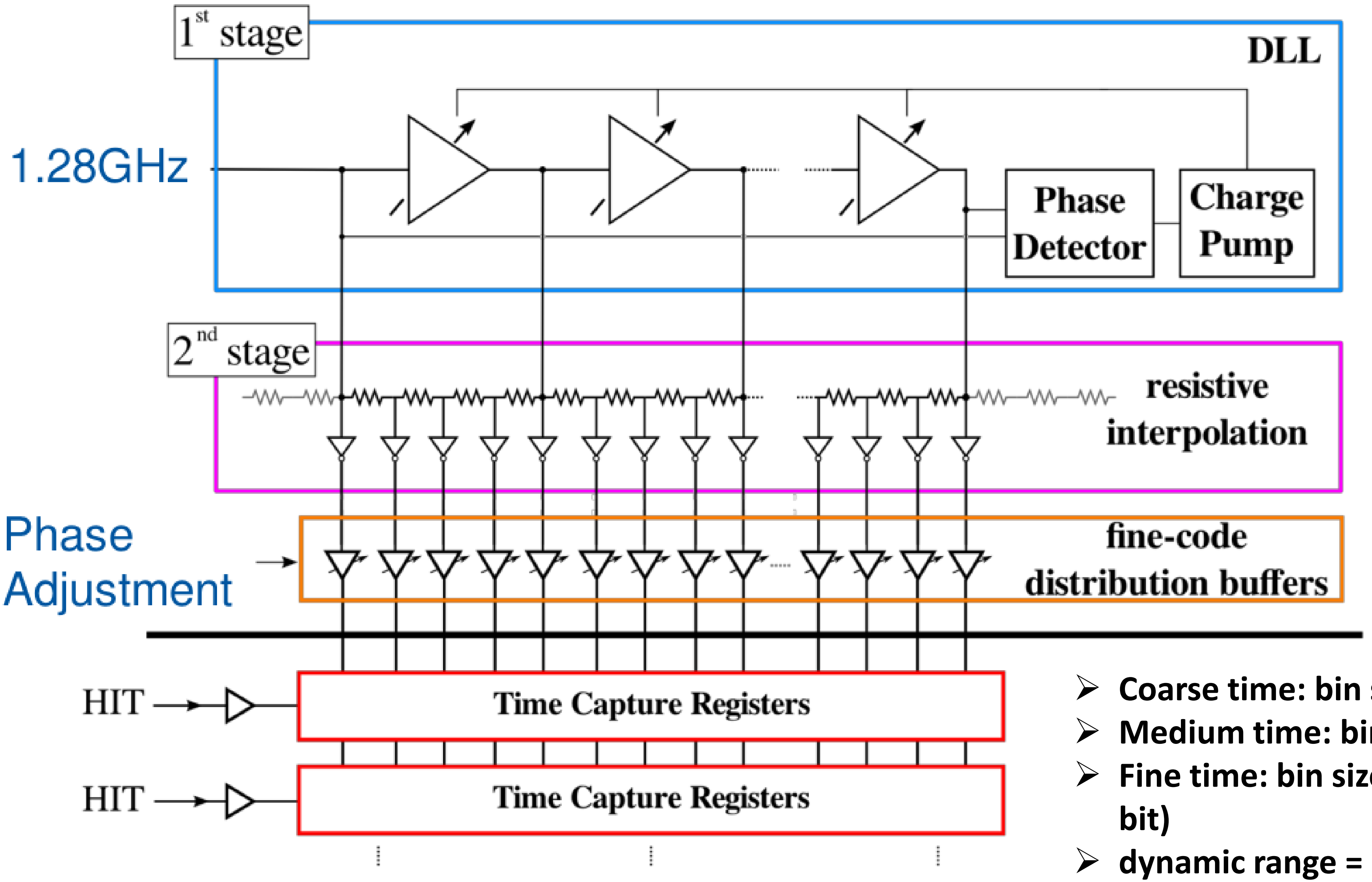
- Resistive voltage division across neighbor delay cells
- Rise times in delay chain longer than dealy of cell



- N_d = # of delay cells
- N_R = # of resistors for interpolation
- → LSB = T_{clock} / ($N_d \cdot N_R$)

e.g. f_{clock} = 1 GHz
N_d = 4, N_R = 4→ LSB = 62.5 ps

PicoTDC architecture (2)

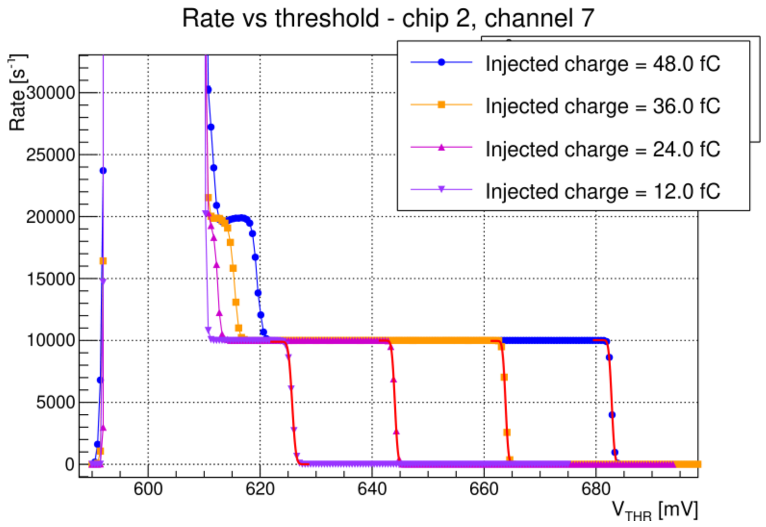


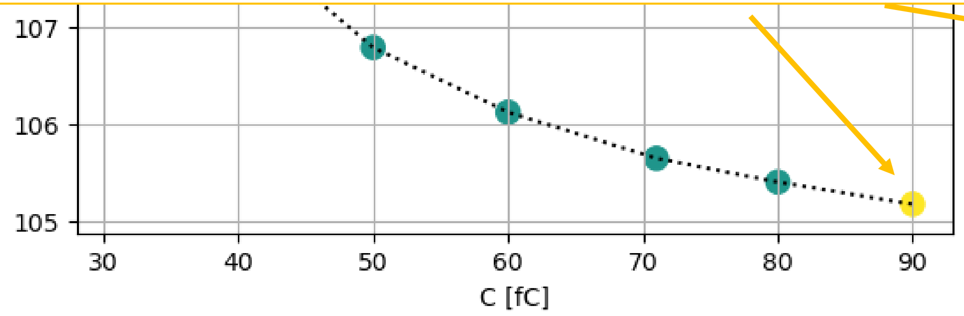
1st stage interpolation:
- DLL with reference clock frequency = 1.28 GHz → T = 781.25 ps
- 64 delay elements

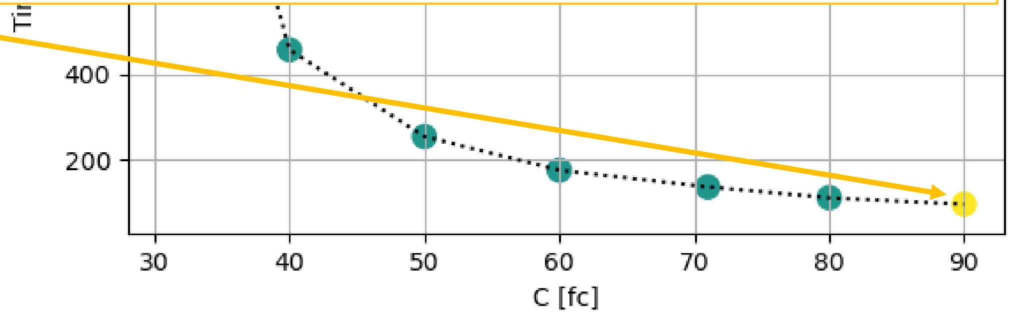
2st stage interpolation:
- interpolator with 4 resistors for each delay cell

- Coarse time: bin size = 25 ns (13 bit)
- Medium time: bin size = 781 ps (5 bit)
- Fine time: bin size = 12.2 ps (6 bit) or 3.05 ps (8 bit)
- dynamic range = 205 us

Il double counting è un effetto che deriva dal tempo prolungato di scarica del condensatore: al reset del circuito rimane della carica nel condensatore che viene individuata come un nuovo segnale dal’amplificatore.

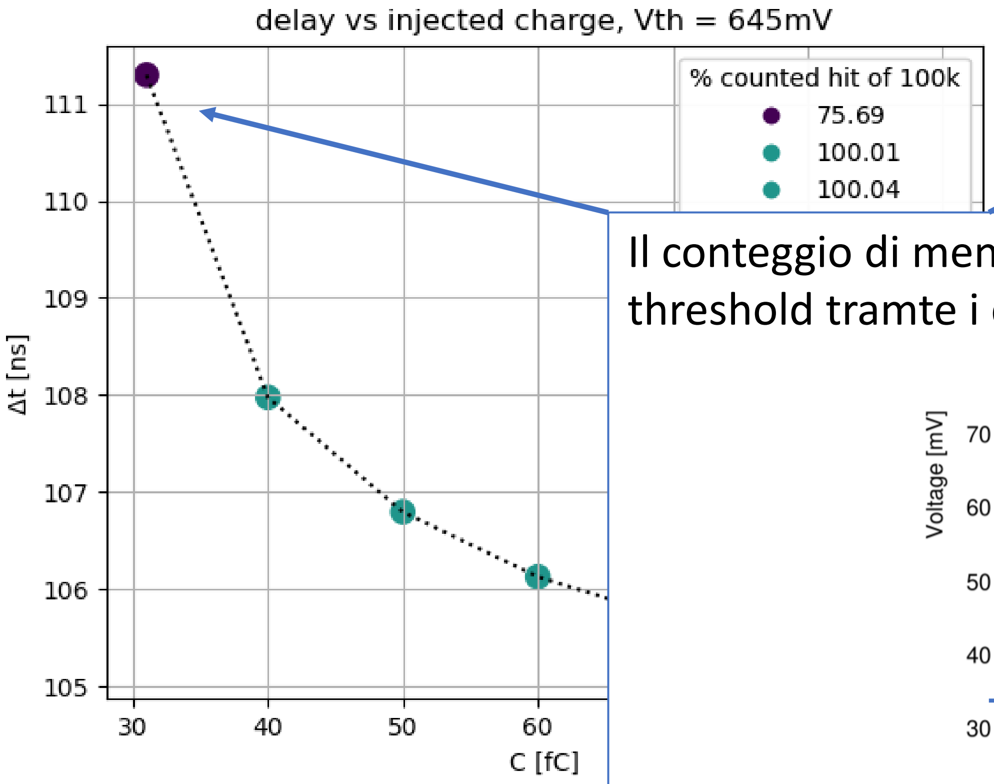


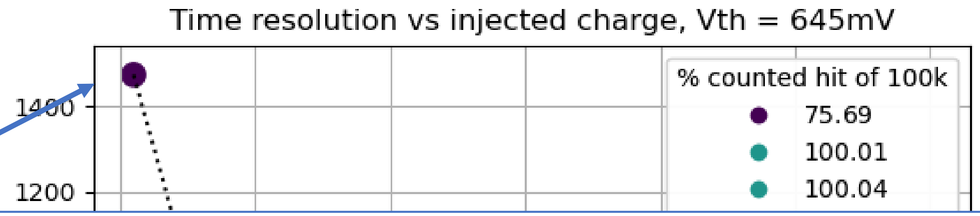




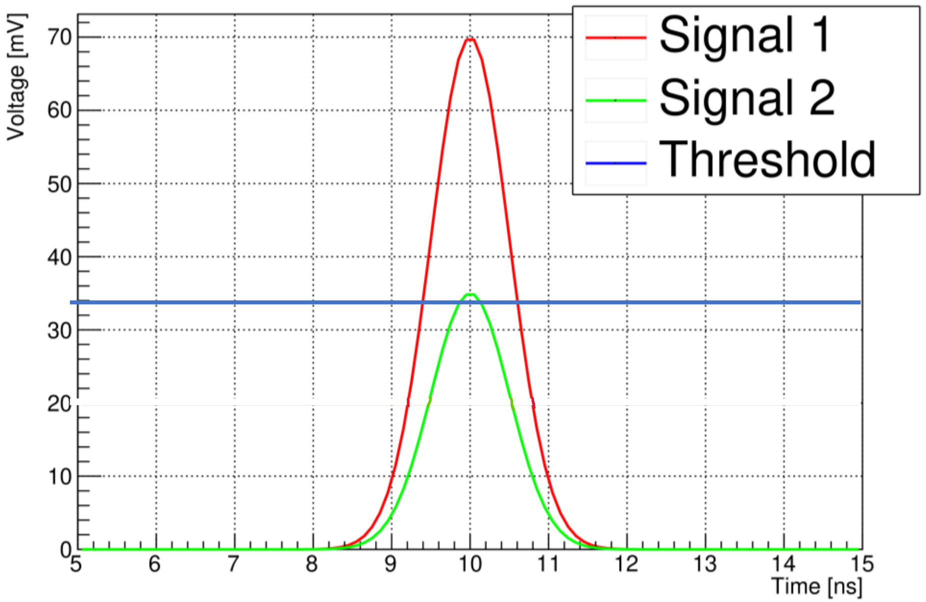
Per ogni threshold scelta si è effettuata un’analisi come riportato sopra, in cui con il codice colore si è riportata l’efficienza dello strumento: la regione di funzionamento è identificata dai punti riportati in verde.
I punti in giallo individuano la regione in cui si manifesta il *double counting*, mentre in viola i dti per cui il valore di threshold è troppo alto per permettere il conteggio di tutti i segnali

Una volta effettuata la calibrazione che ha permesso di determinare la corrispondenza tra il segnale in ingresso ad ESA_ABACUS e la corrispondente carica iniettata, si sono presi dati variando il valore di carica in ingresso e il valore di threshold del canale 0.





Il conteggio di meno segnali di quelli che vengono inviati è dovuto a valori di threshold tramte i quali non è più possibile distinguere con precisione i segnali



Per ogni threshold scelta si è eff
l'efficienza dello strumento: la re
I punti in giallo individuano la re
threshold è troppo alto per perm