weeroc

High-end Microelectronics Design

Weeroc Progress Report

AIDA INNOVA – Progress Meeting 3

Annual Meeting 2

24/04/2023

J. Fleury

5 design taped-out

- Time of flight measurement for all kind of photodetector, 64 channels
  - Radioroc2 : SiPM dual modality (photon counting + charge integration)
  - Psiroc : low gain detector dual modality dual polarity
  - Poproc : PMT, MCP read-out, photon counting
  - Liroc2 : SiPM photon counting (collaboration Omega)
  - Temporoc2 : SiPM read-out, internal ADC and TDCs
- Presentation of only few of them today

RADIOROC schematic

Trigger :

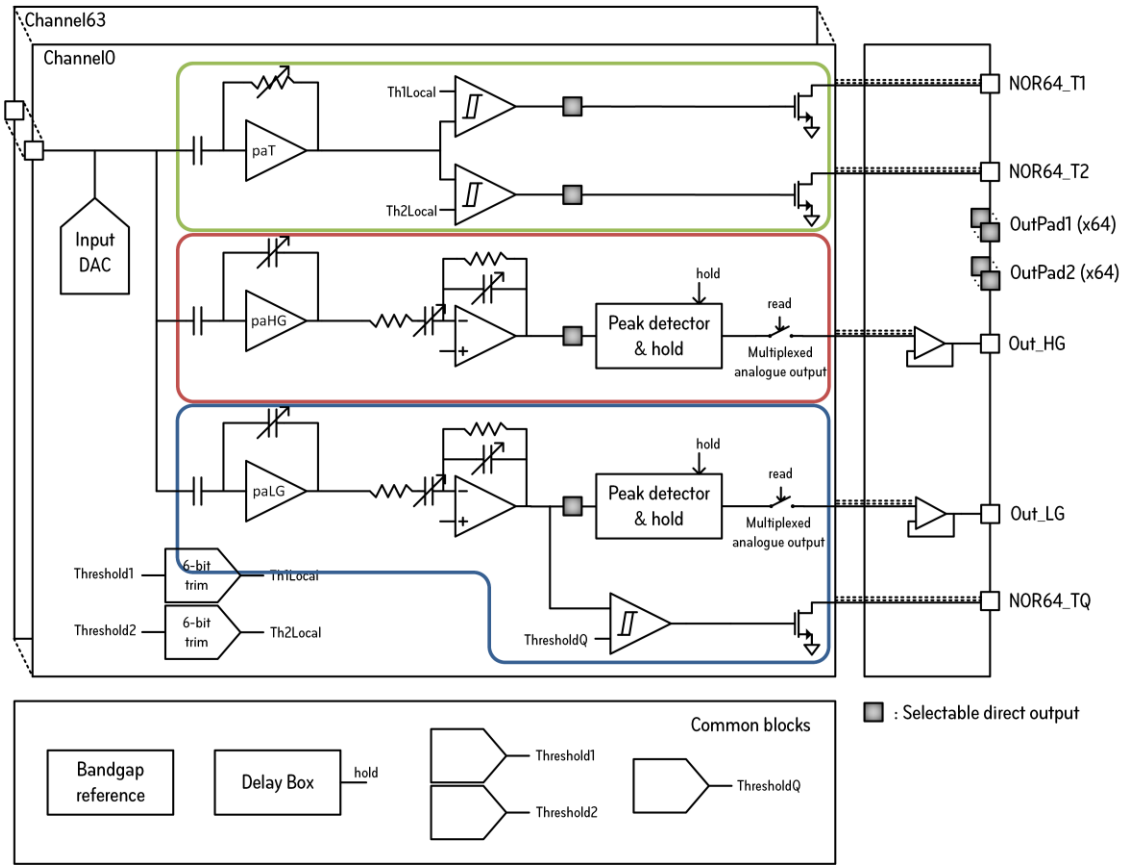
- Dual threshold
- Time resolution of 55 ps FWHM on a single pe (160 fC);
- Photocounting over 200 MHz ;
- TOT.

High gain charge measurement :

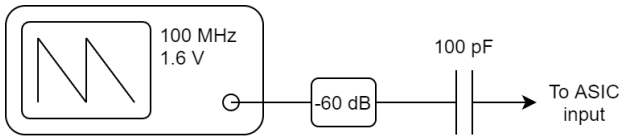
- SNR > 10 ;
- 1% linearity up to few hundreds of photo-electrons ;
- Gain 5 to 80 ;
- Shaping time 20 ns – 300 ns.

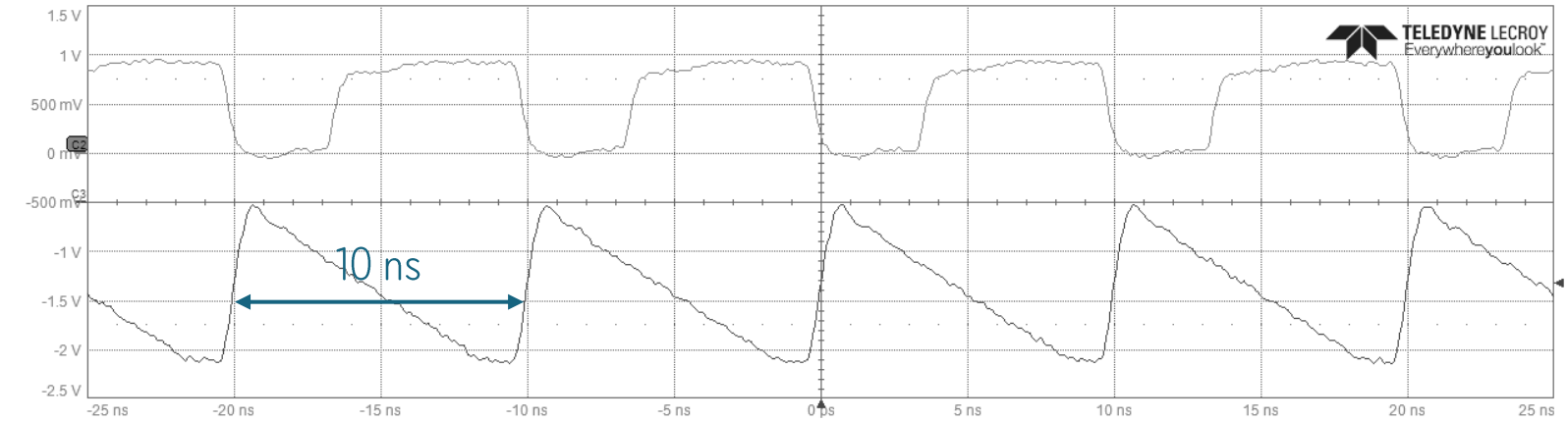
Low gain charge measurement :

- Charge veto ;
- 1% linearity up to few thousands of photo-electrons ;
- Gain 0.5 to 8 ;
- Shaping time 20 ns – 300 ns.



Photocounting



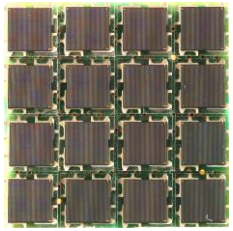


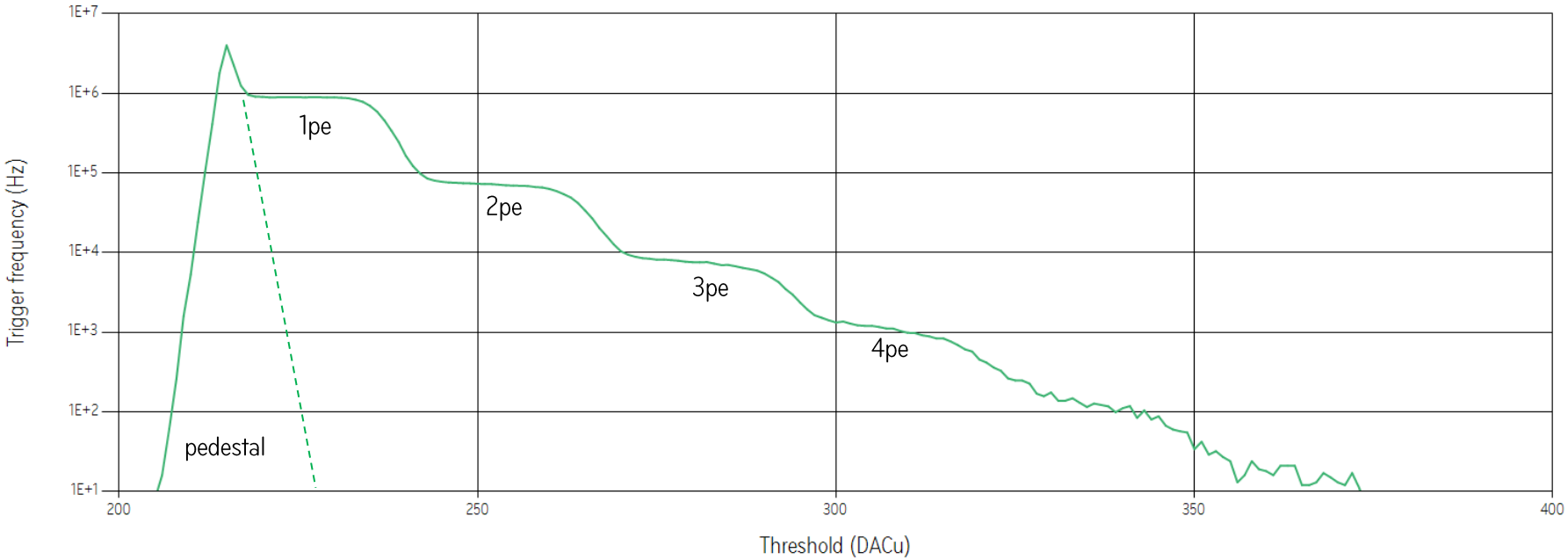
Measure	P1:E2E(C2,C3)	P2:rise(C3)	P3:- - -	P4:- - -	P5:- - -	P6:- - -	P7:- - -	P8:- - -
value		720 ps						
mean		692.85 ps						
min		371 ps						
max		788 ps						
sdev		63.50 ps						
num		16.950e+3						
status		.n.						

C2 DSQ DC50 500 mV/div 500 mV ofst | C3 INV DC50 500 mV/div 0 mV offset

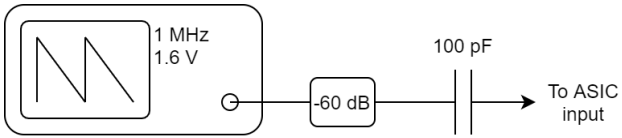
Timebase 0.0 ns 5.00 ns/div 1 kS 20 GS/s | Trigger C3 DC Stop 815 mV Edge Neg

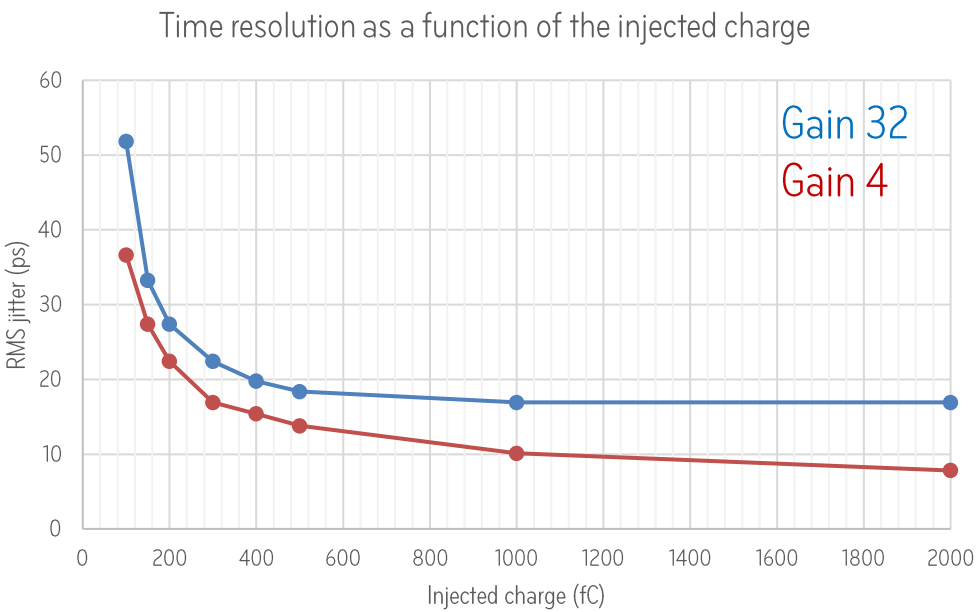
Staircase (SensL arrayC 30035, 3x3mm^2 16 channels)

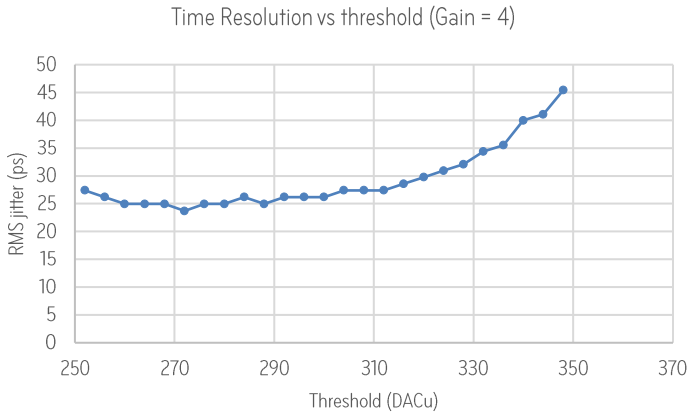


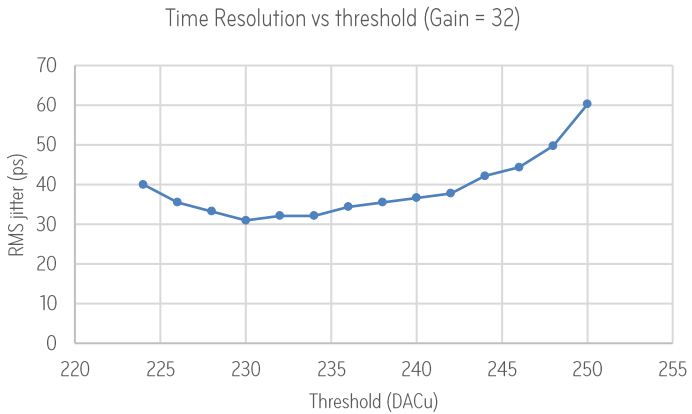


Time resolution



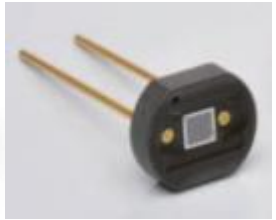


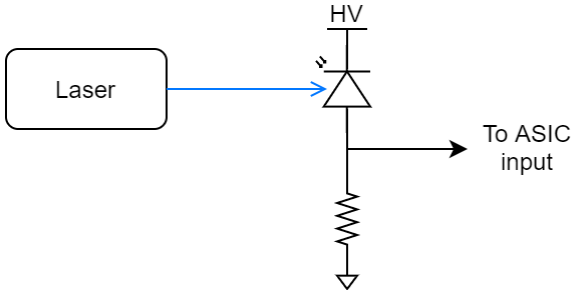




1 DACu = 250 µV

Single Photon Time Resolution measurements

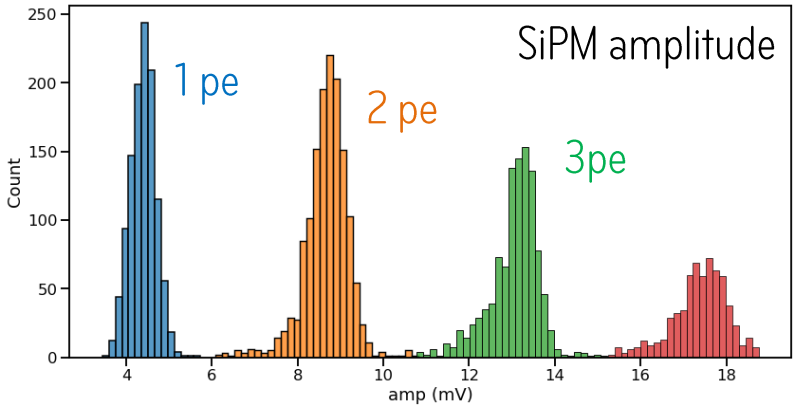


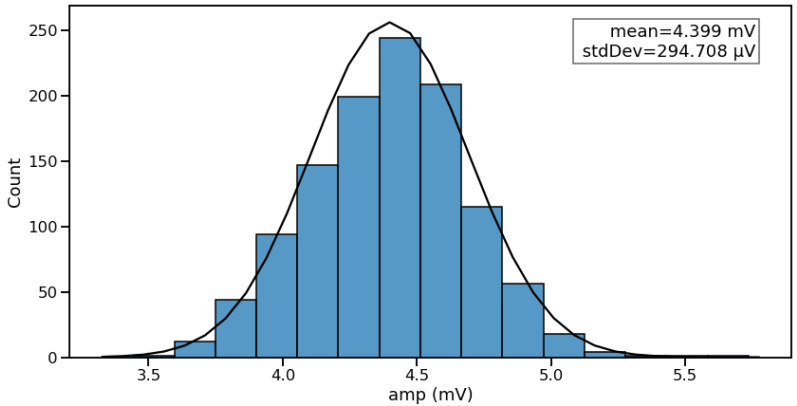


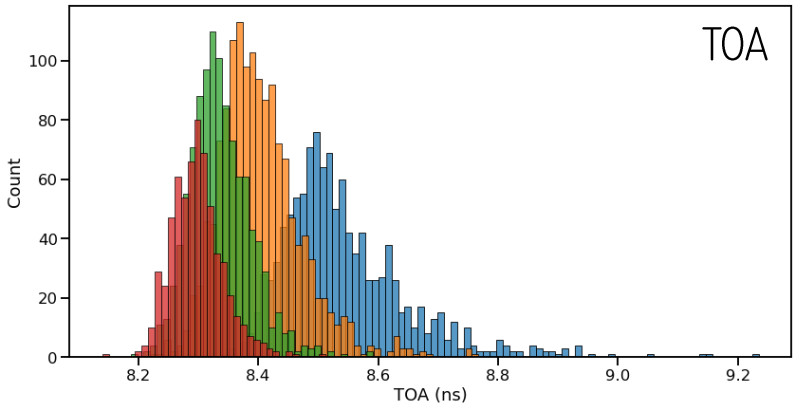
- MKT photonics picosecond laser (PiLas DX PIL1-040-40)
- 1.3x1.3 mm^2 Hamamatsu SiPM S13360-1350CS
- High voltage = 58.6 V with Vbr = 53 V, gain $3 \cdot 10^6$
- Lecroy WaveRunner 8254, bandwidth of 2.5 GHz, 20 GS/s

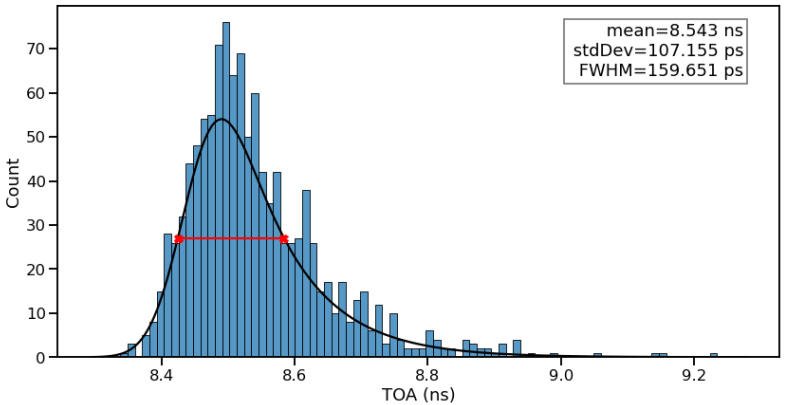
Measurement of the Time Of Arrival (TOA) defined as the delay between the LASER synchronisation trigger and the ASIC output trigger

SPTR (Hamamatsu 1.3 mm^2 S13360-1350CS)





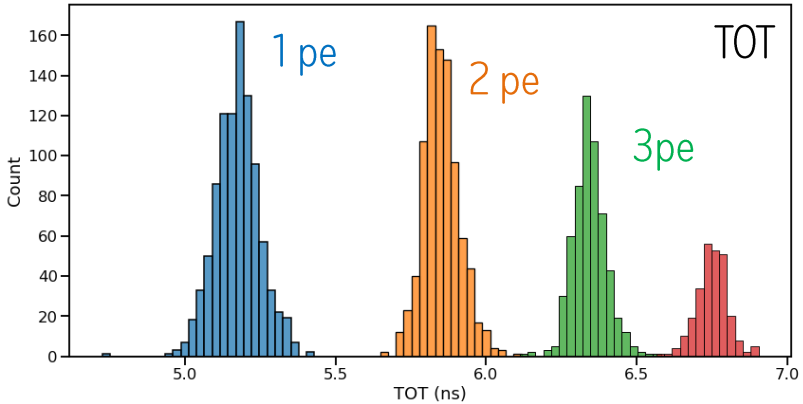


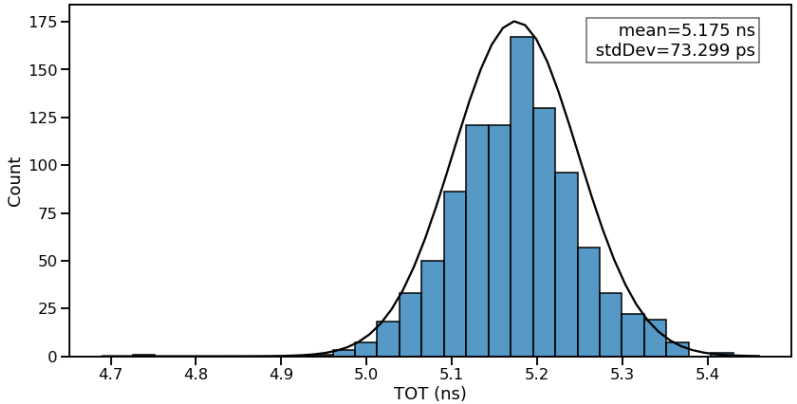


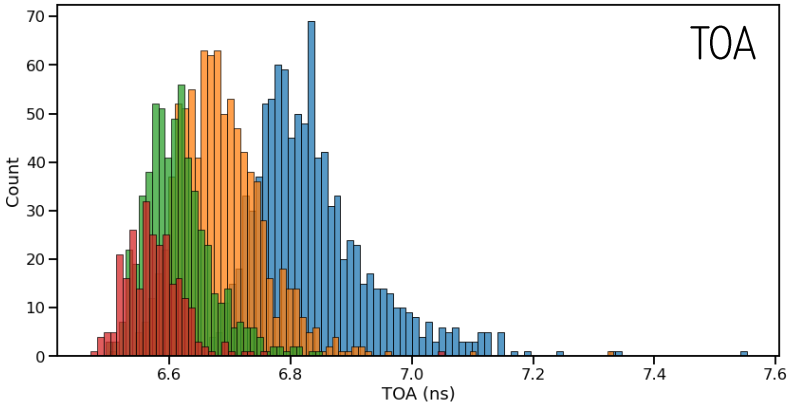
Fit equation from "Single photon time resolution of state of the art SiPMs", M. V. Nemallapudi et al 2016 JINST 11 P10016

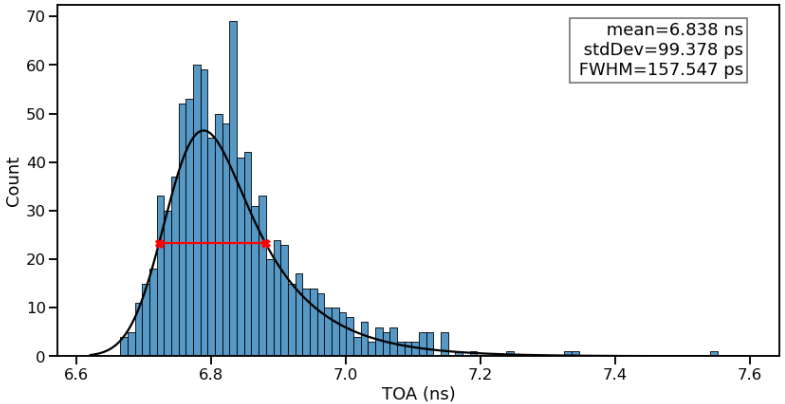
$$f(x;\mu,\sigma,\lambda,) = \frac{\lambda}{2} e^{\frac{\lambda}{2}(2\mu+\lambda\sigma^2-2x)} \left[1 - \mathrm{erf}\left(\frac{\mu+\lambda\sigma^2-x}{\sqrt{2}\sigma}\right)\right]$$

SPTR (SiPM + radioroc)





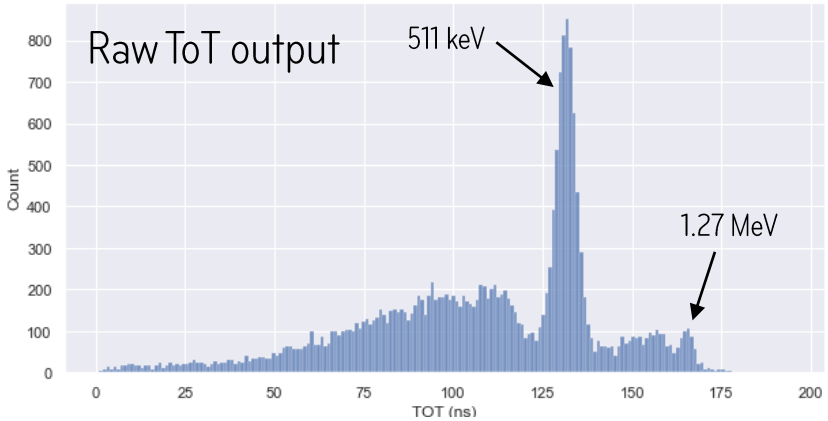


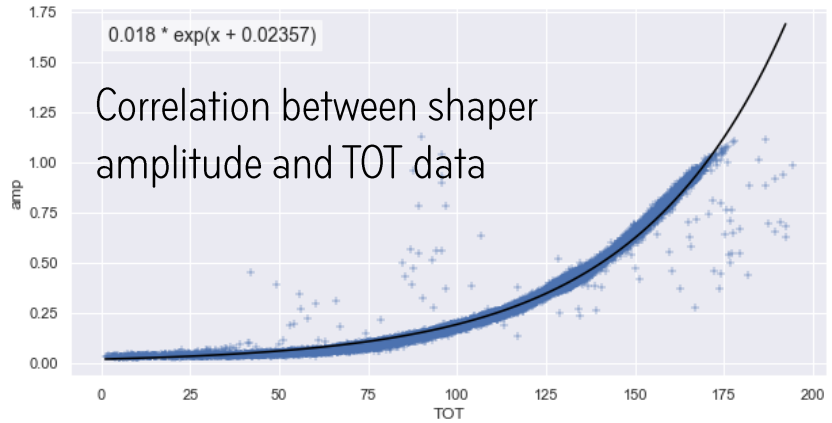


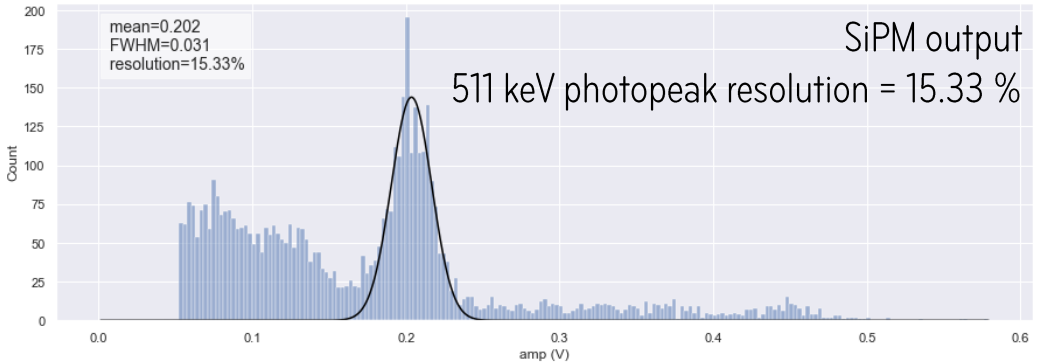
Electronics has a negligible effect, SiPM jitter is the limiting factor

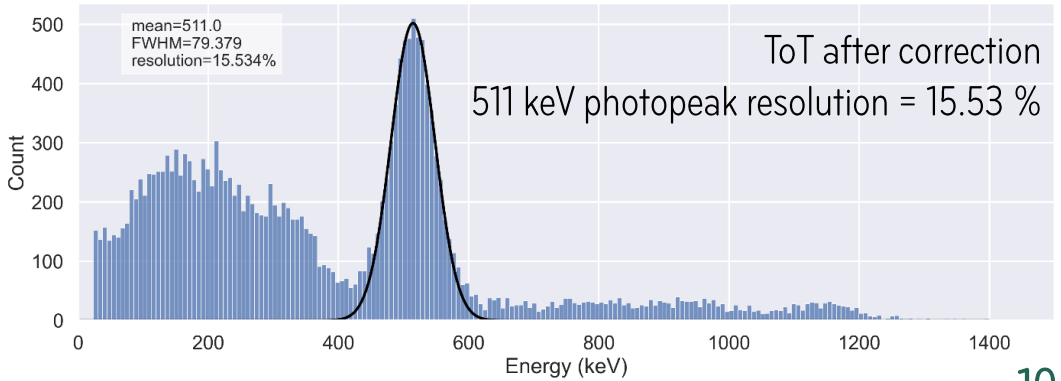
TOT

Na22 radioactive source, LYSO scintillator 3x3x20 mm^3 , SensL arrayC 30035-16p, HV = 28V



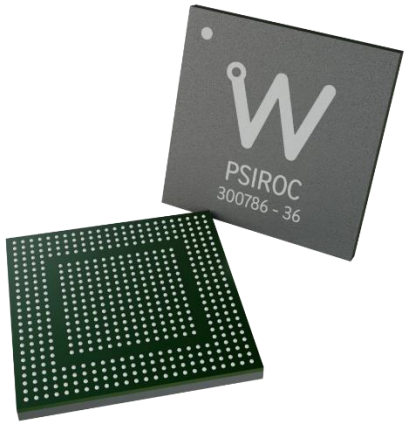


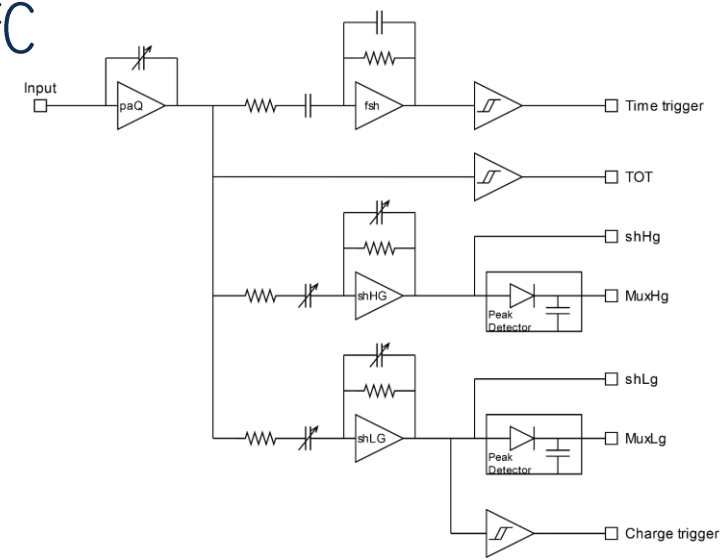


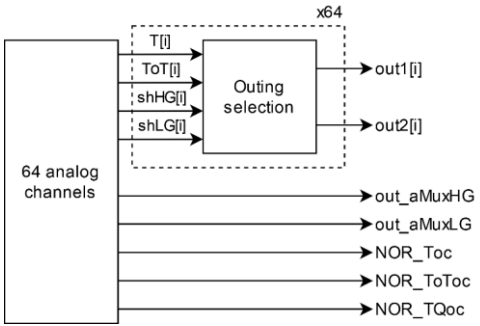


Psiroc – read-out low gain detector

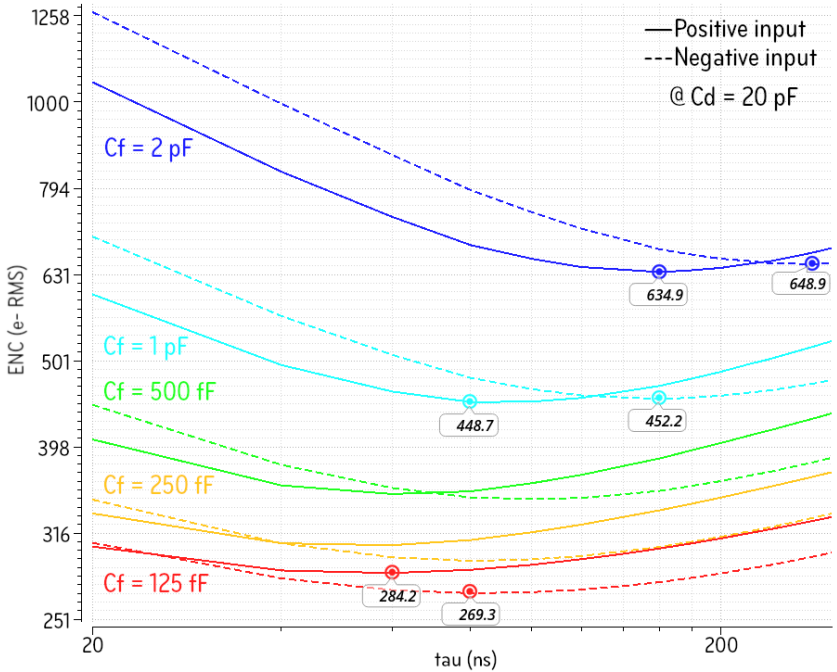
- Psiroc =radioroc + charge preamplifier + dual polarity
- APD / GEMs / Si strips, etc…
- Trigger on 0,5fC

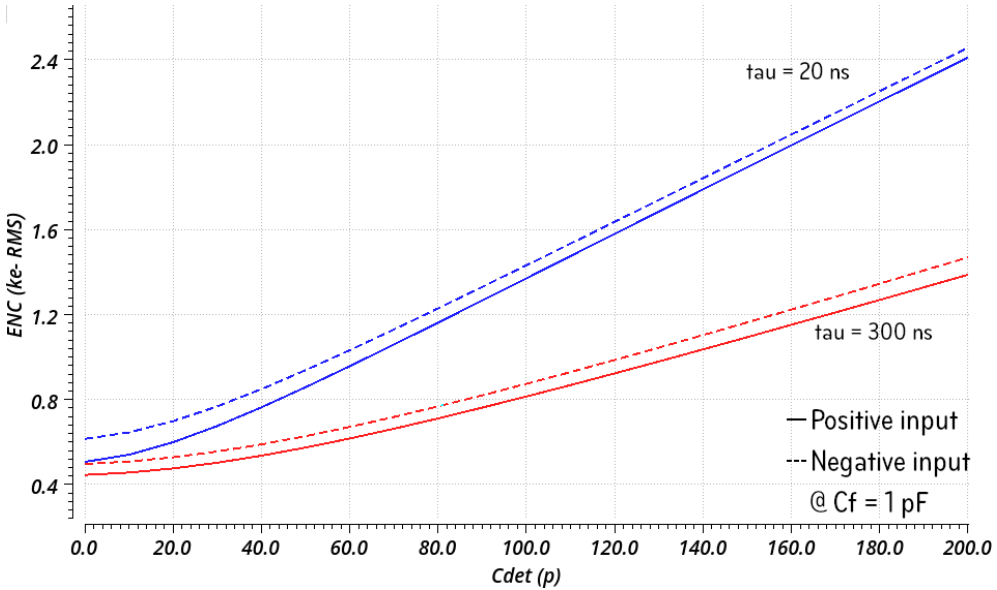




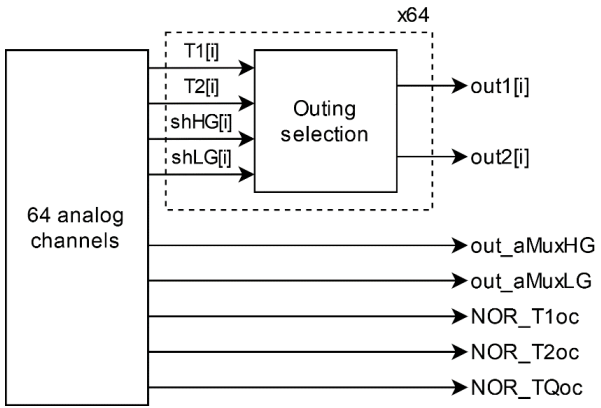


Psiroc - simulations





Programmable outputs Radioroc / Psiroc



The following values are available for *lvdsOut* I²C parameter:

- `00` = Differential output disabled, refer to *outPad1* and *outPad2* I²C settings;
- `01` = Differential output for Trigger T1;
- `10` = Differential output for Trigger T2;
- `11` = disable all outputs.

The following settings are available for *outPad1* and *outPad2* I²C parameters :

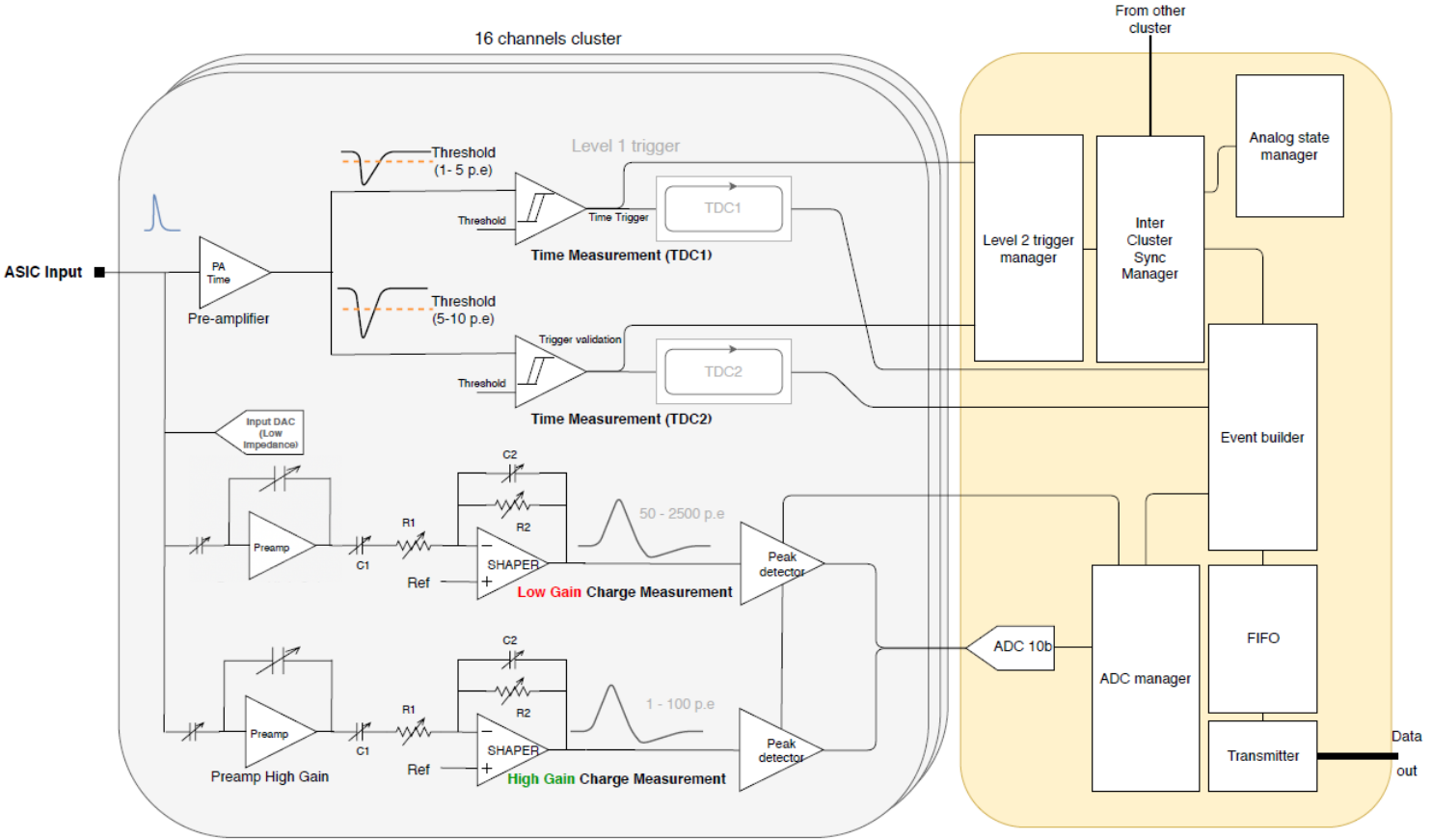
- `00` = single-ended output for Trigger T1;
- `01` = single-ended output for Trigger T2;
- `10` = High gain slow shaper output;
- `11` = Low gain slow shaper output.

lvdsOut[1:0]	outPad1[1:0]	outPad2[1:0]	out1	out2
00	00	01	T1	T2
01	XX	XX	CLPS T1_p	CLPS T1_n
00	00	10	T1	HG slow shaper

New family = pin to pin compatibility

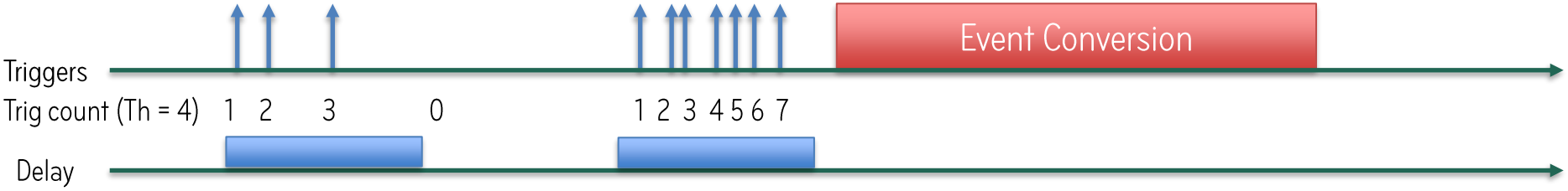
Radioroc2 / Liroc2 / Poproc / Psiroc are pin-to-pin compatible

Temporoc : Mixed signal ROC - General Block Scheme

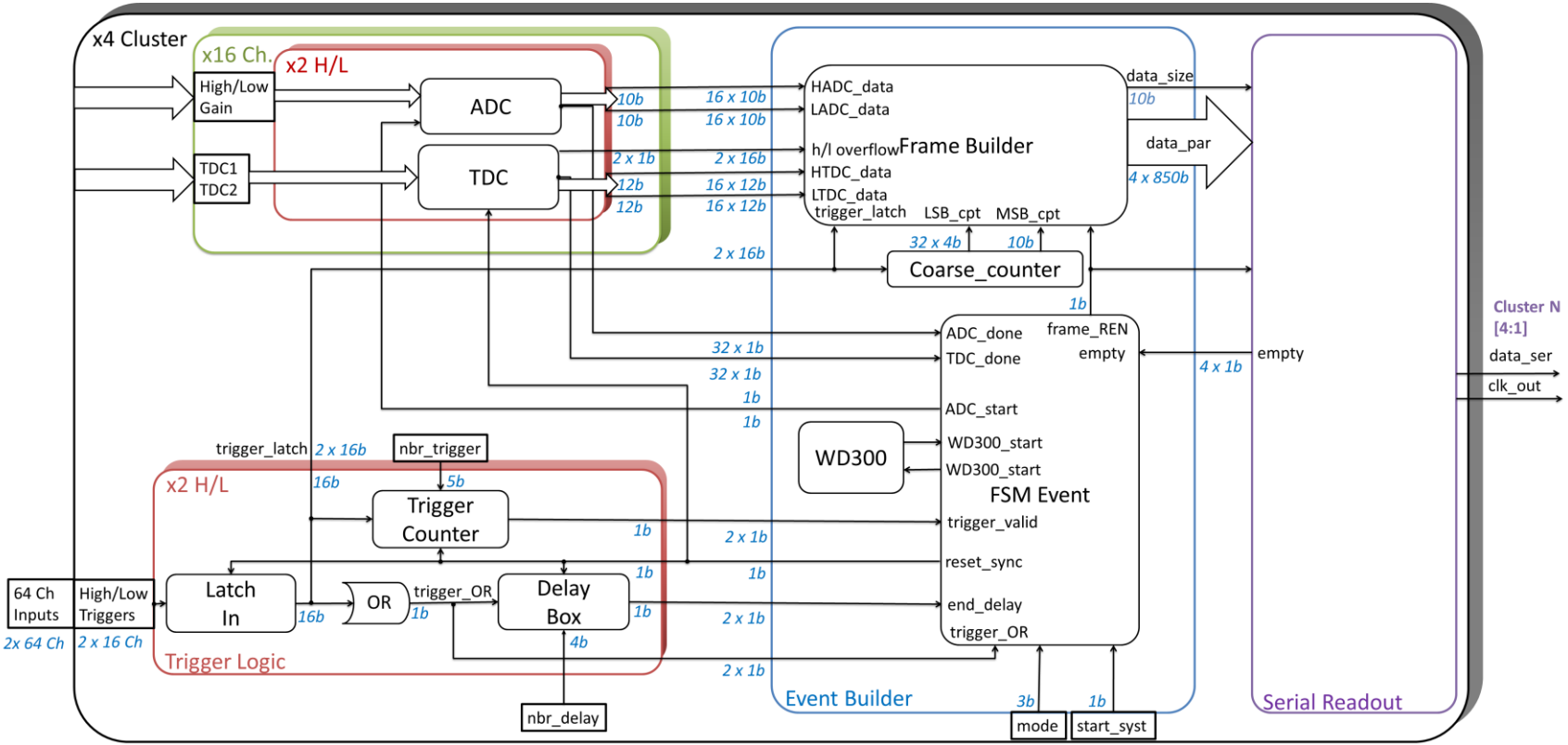


Requirement Specification for trigger

- Trigger scheme : monolithic crystal oriented
  - Temporoc shall trigger if a programmable number of channels (from 0 to 16) have triggered within a programmable delay (from 4ns to 40ns)
  - TDCs shall start upon trigger arrival independantly of general trigger validation
  - Temporoc shall self-reset if trigger scheme is not fulfilled

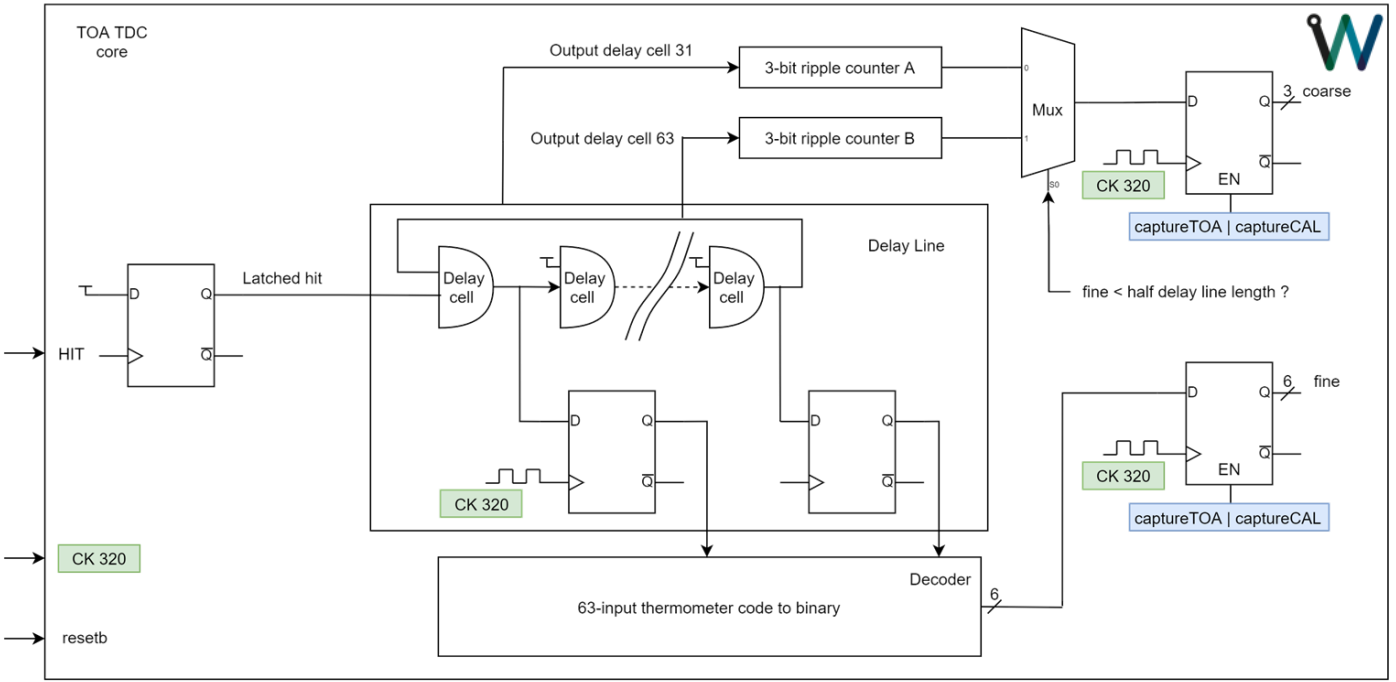


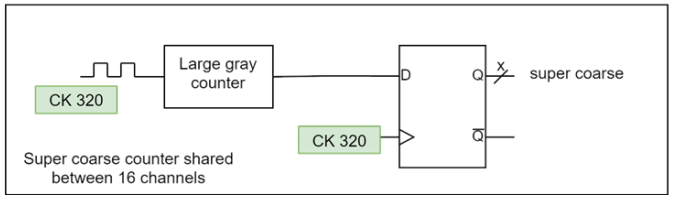
Digital Scheme



TDC archi

Fastest delay cell allowing closed delay line : NAND (not starved)

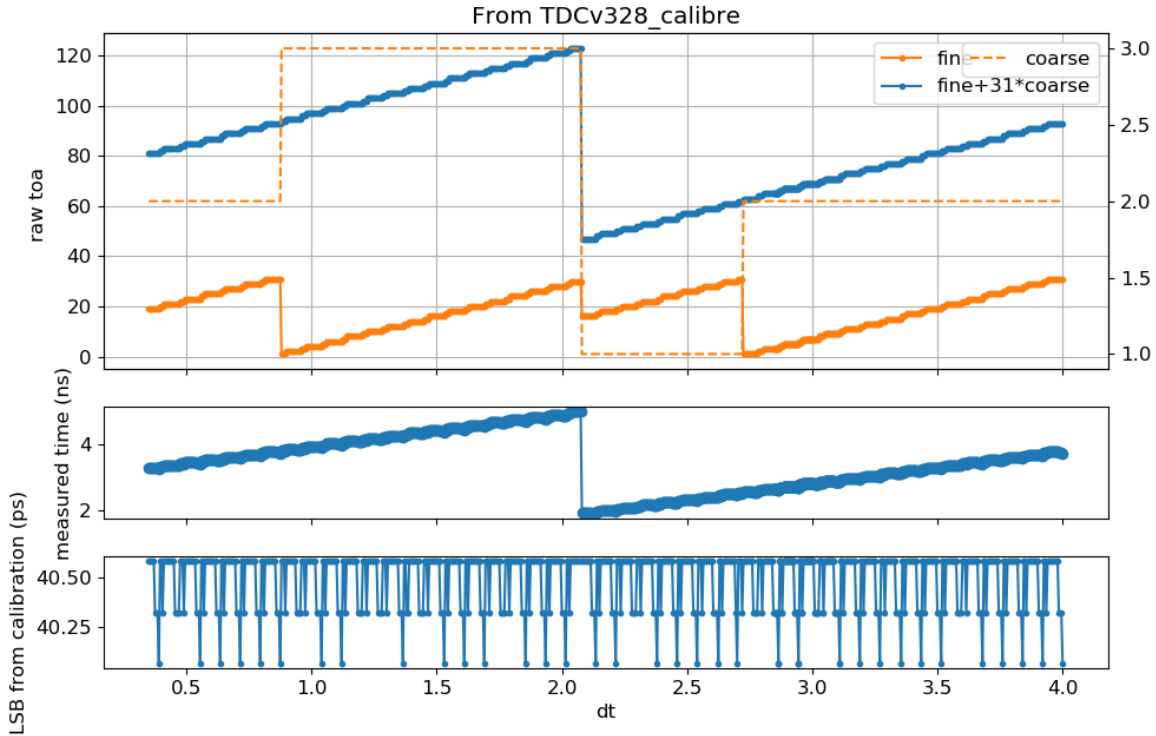




- Delay line length limited by the decoder critical path propagation time and area (hence the channel area), the 320 MHz clock distribution.
- Loop delay line needed to cover at least 2 clock periods (320 MHz = 3,125 ns) for calibration purposes

TDC transfer function in extracted view

- Periodic transfer function : a prerequisite for code density tests
- LSB ~ 40 ps



Estimation error on LSB from calibration: ~ 0,5 ps

Conclusion

- 5 new ASIC taped-out, all with time-of-flight capabilities
- Covering many application for many kind of detectors
- Pin to pin compatible for analog ASIC, PicoTDC compatibility for all of them (licence pending to be done)
- Evaluation board design started
- I am available to discuss more in detail each ASIC

Thank you

Thank you

Thank you

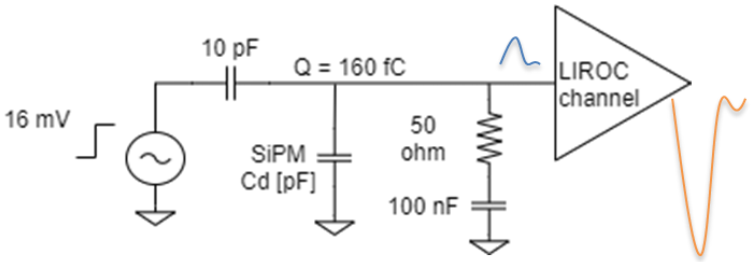
Thank you

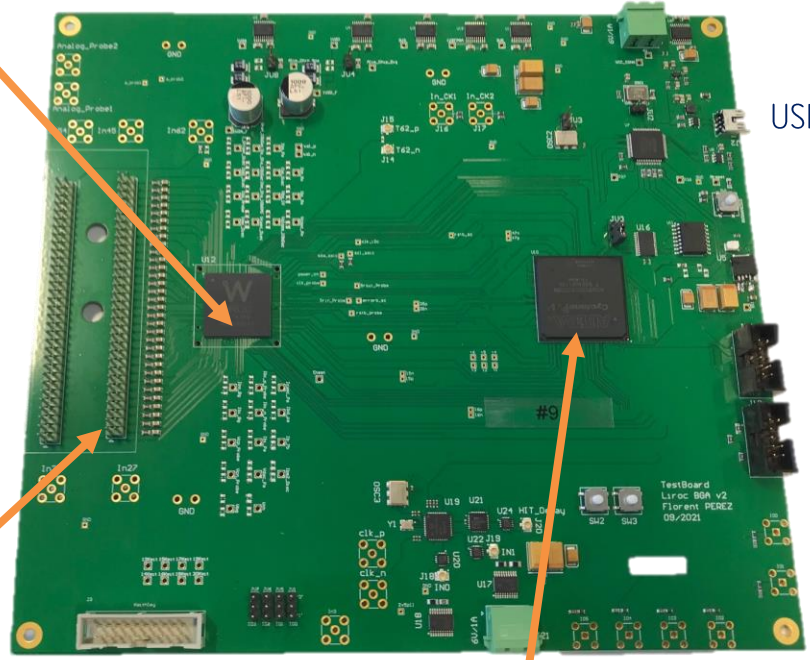
BACKUP SLIDES

LIROC : Parameters & Performances

Detector Read-Out	SiPM, SiPM array
Number of Channels	64
Signal Polarity	Positive or Negative (selectable ASIC-wise)
Sensitivity	Trigger on 1/3 of photo-electron
Timing Resolution	Better than 20 ps RMS on single photo-electron Better than 3 ns double-peak separation on single photo-electron
Dynamic Range	Over 300 MHz photon counting rate
Packaging & Dimension	BGA 20x20 mm^2 Flip-Chip low inductance packaging technology
Power Consumption	180 mW (2,9 mW per channel) – Supply voltage : 1.2 V
Inputs	64 analogue inputs with independent SiPM HV adjustments
Outputs	64 low-common-mode LVDS triggers (CLPS) – compatible with CERN picoTDC and all LVDS FPGA I/Os
Internal Programmable Features (I^2C)	64 HV adjustment for SiPM (64 x 6 bit), trigger threshold programming (10bits), 64 x 7 bit channel-wise threshold adjustment, ASIC-wise polarity selector, preamp pole-zero cancellation adjustment, individual trigger masking and cell powering.
Radiation Hardness	Rely on TSMC 130nm MS-RF technology, « CERN qualified » for irradiation, as ASIC design blocs are used for LHC and have been tested up to 300 Mrad

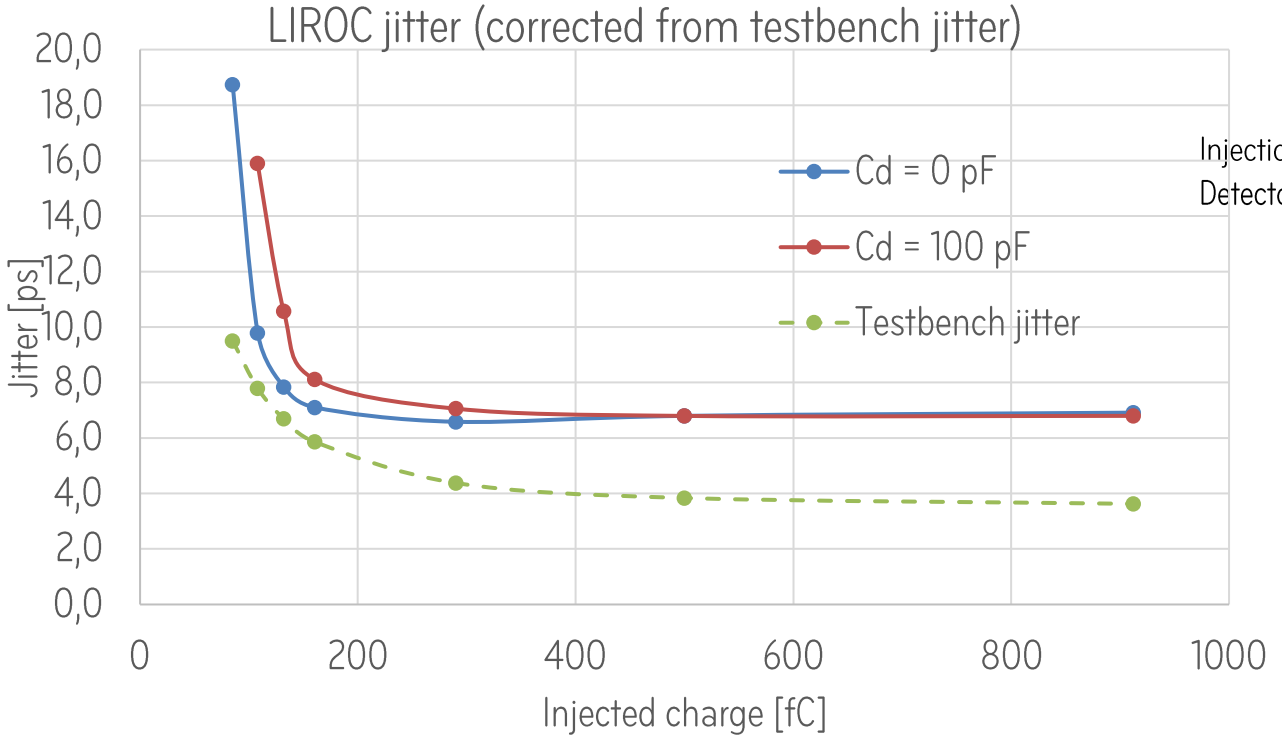
LIROC : Pulser testbench setup





LIROC : RMS jitter performance with input charge

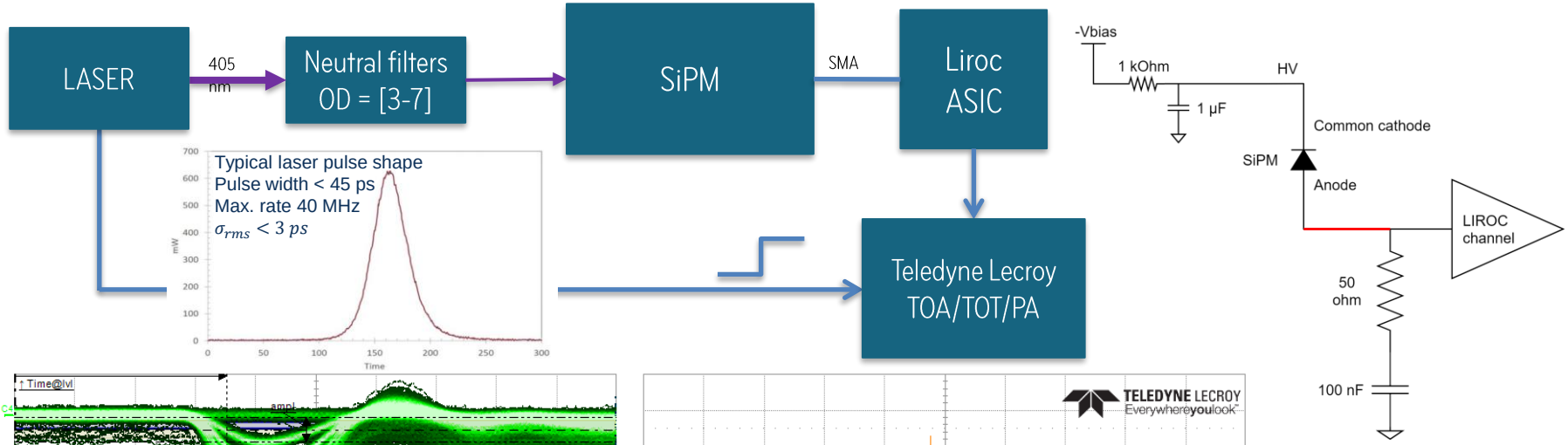
A fast-rising edge pulser is used to inject voltage steps into a capacitor to mimic charge deposited inside an SiPM.

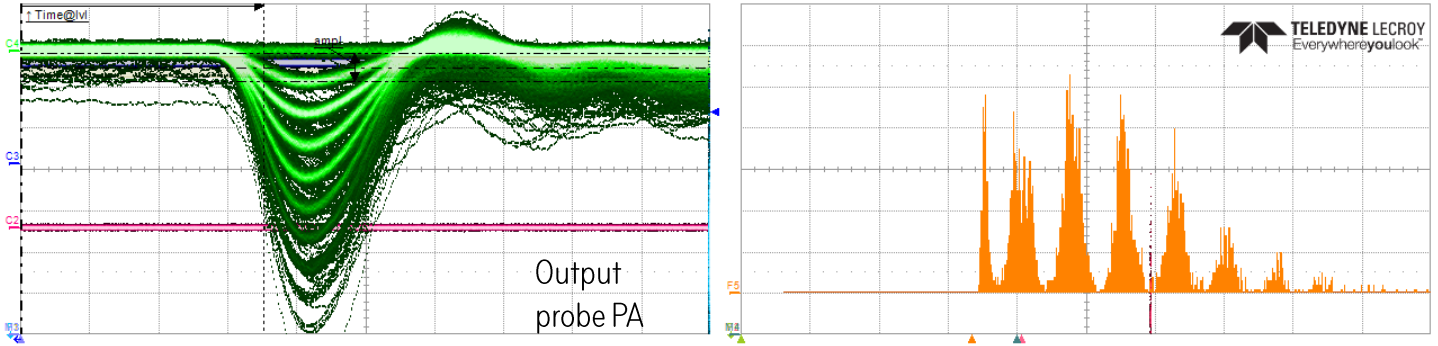


Injection capacitor = 10 pF
Detector capacitor = 0 pF and 100 pF

What should be the expected SPTR when coupled with an SiPM (Cd ~ 100 pF) ?
Assuming the collection of 1 single photoelectron delivers 160 fC : 8 ps rms.

LIROC : Laser testbench setup





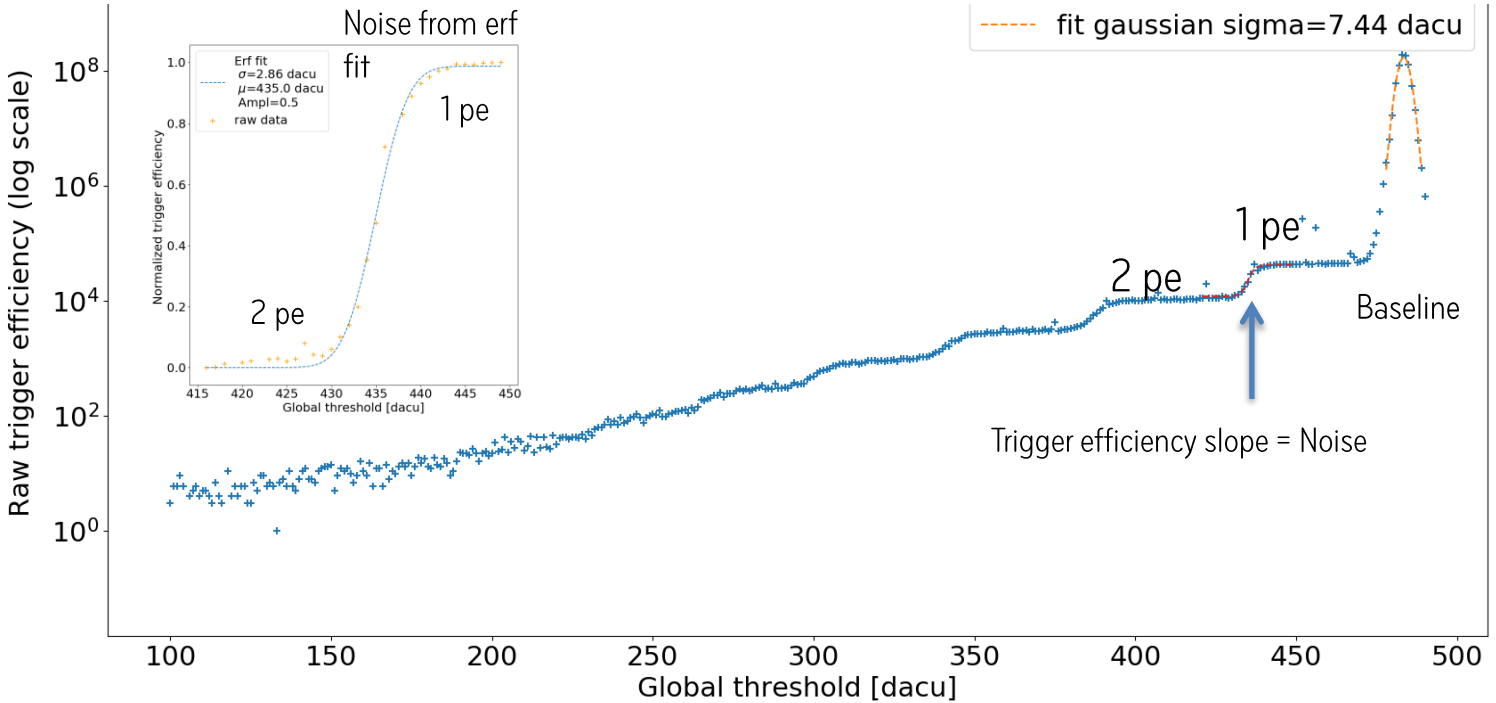
Measure	P1:time@lv(C4)	P2:ampl(C4)	P3:fall(C4)	P4:sdev(C2)	P5:time@lv(C3)	P6:max(C2)	P7:min(C2)	P8:edge@lv(C2)
value	44.224 ns	6.94 mV	4.810 ns	21 mV	---	75 mV	-51 mV	0
mean	42.9060 ns	> 19.29 mV	3.6175 ns	19.7571 mV	---	52.753 mV	-50.727 mV	0
min	41.518 ns	> 1.14 mV	374 ps	17 mV	---	28 mV	-93 mV	0
max	45.360 ns	> 71.52 mV	9.057 ns	22 mV	---	106 mV	-31 mV	0
sdev	762.5 ps	> 12.16 mV	717.4 ps	738.3 µV	---	9.778 mV	6.969 mV	0
num	2.584e+3	2.868e+3	2.779e+3	2.868e+3	0	2.868e+3	2.868e+3	2.868e+3
status	✔	✔	⎍	✔	⚠	✔	✔	✔

C2 1.00 V/div -1.405 V ofst | C3 1.00 V/div 125 mV ofst | C4 10.0 mV/div 28.60 mV | F1 trend(P1) 1.00 ns/div 100 k#/div | F2 trend(P2) 10.0 mV/div 530 k#/div | F3 trend(P3) 500 ps/div 100 k#/div | F4 trend(P5) 1.00 s/div 100 k#/div | F5 hist(P2) 10.0 #/div 10.0 mV/div | M3 No data available | M4 No data available | Tbase -51.6 ns 5.00 ns/div 500 S 10 GS/s | Trigger Stop 1.24 V Edge Positive

LIROC + FBK NUV UHD DA staircase on DCR

Liroc + Crystal PbF2 black painted 2x2x3 mm
+ SiPM FBK near UV & ultra high density (medium filling factor) + Na22 source

Default parameters
+ PZC 8
+ HV 45 V

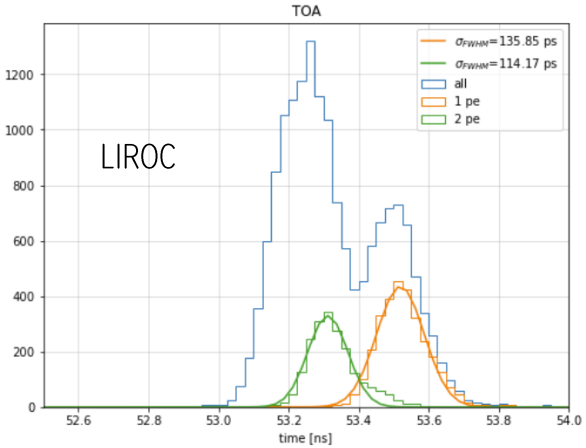


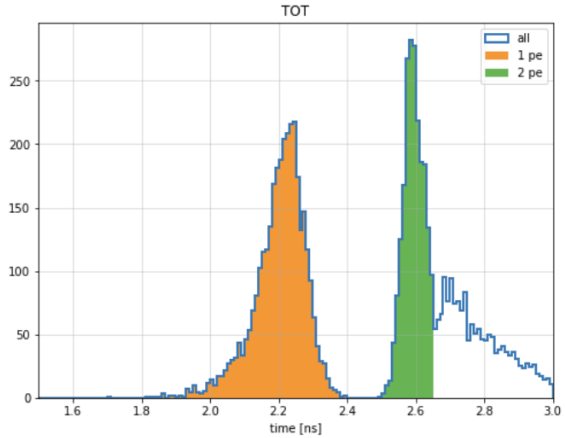
Noise = 2,86 dacu at 45 V

LIROC : Laser testbench results

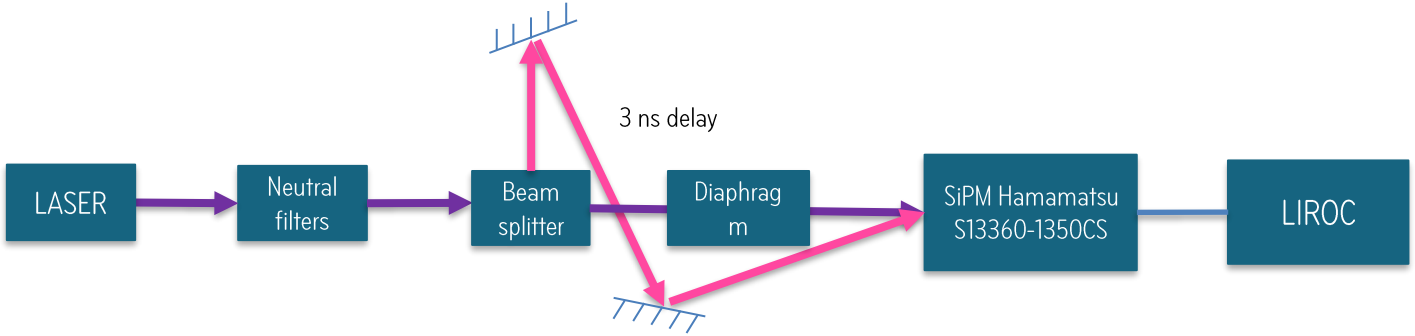
Compilation results from Roberta Pillera (INFN Bari)

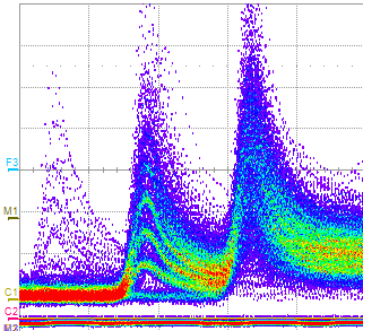
Device	HV - OV	Oscilloscope SPTR FWHM (ps) (measured)	Liroc SPTR FWHM (ps) (measured)	SiPM characteristics
Hamamatsu S13360-1350CS	58.6V - 6 ov	150.22	162.02	1,3 x 1,3 mm - 50 µm
Hamamatsu S14160-1315PS	46V - 8 ov	372.77	354.44	1,3 x 1,3 mm - 15 µm
Broadcom AFBR-S4N33C013	34.9V - 8 ov	304.41	300.02	3,14 x 3,14 mm - 30 µm
AdvanSiD ASD-NUV1S-P	32V - 6 ov	109.29	135.85	1 x 1 mm - 40 µm



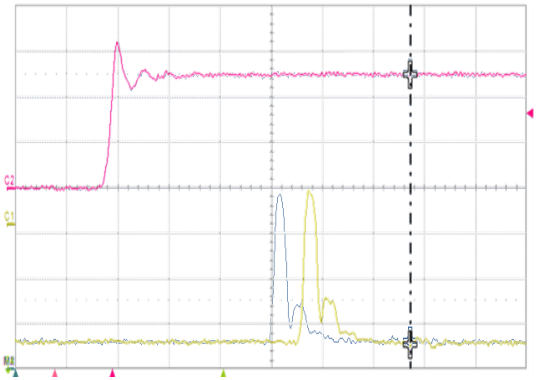


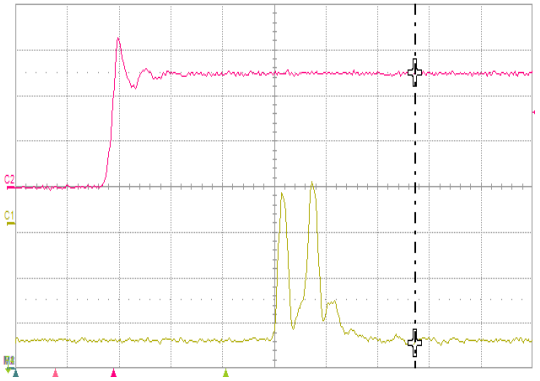
LIROC : Double pulse separation measured



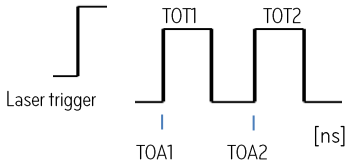


Direct to oscilloscope, 3 ns interval





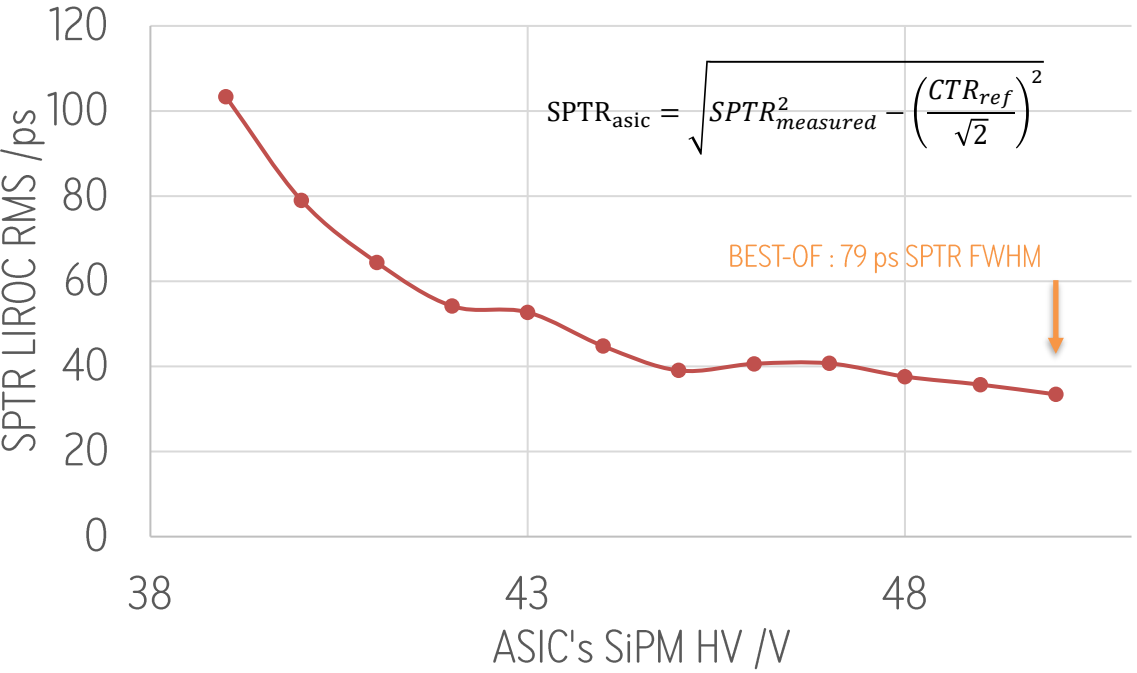
50 mV/div
5 ns /div

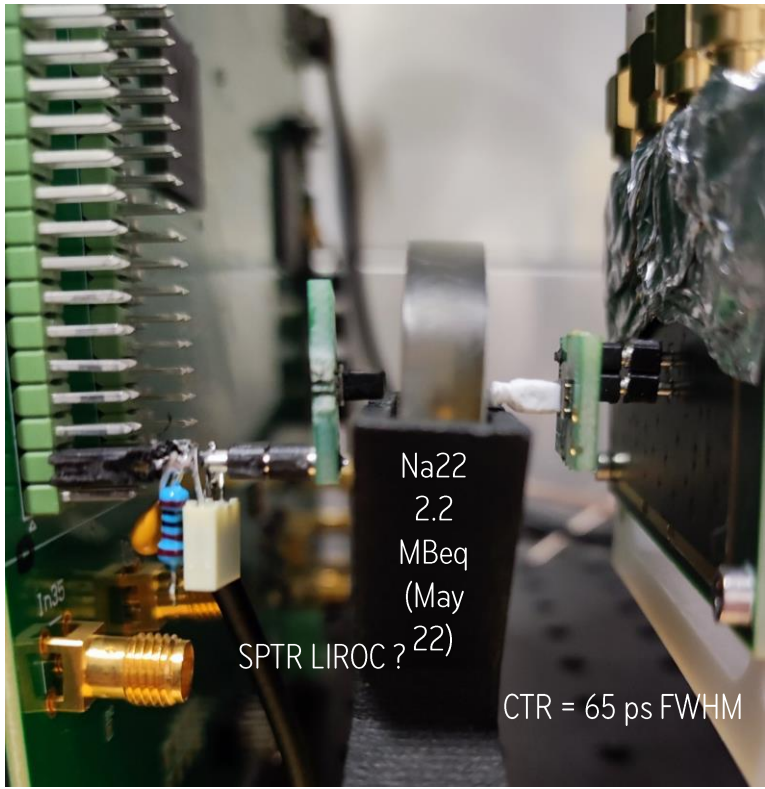


Conclusion : 3 ns double pulse well separated

LIROC + FBK NUV UHD DA SiPM

Crystal PbF2 black painted 2x2x3 mm





Thanks to Stefan Gundacker team (RTWH @Aachen)

LIROC	HF reference
EPIC 2x2x3 PbF2 black painted	TAC 2x2x3 mm LYSO CeCa
FBK NUV UHD DA	Broadcom