



weeroc

High-end Microelectronics Design

Temporoc 3 for monolithic PET: From readout characterisation towards a full PET system

Vsevolod Yeroshenko

vsevolod.yeroshenko@weeroc.com



Bruno Mazoyer - LAL Orsay

French-Ukrainian W O R K S H O P

**Instrumentation developments
for high energy physics**

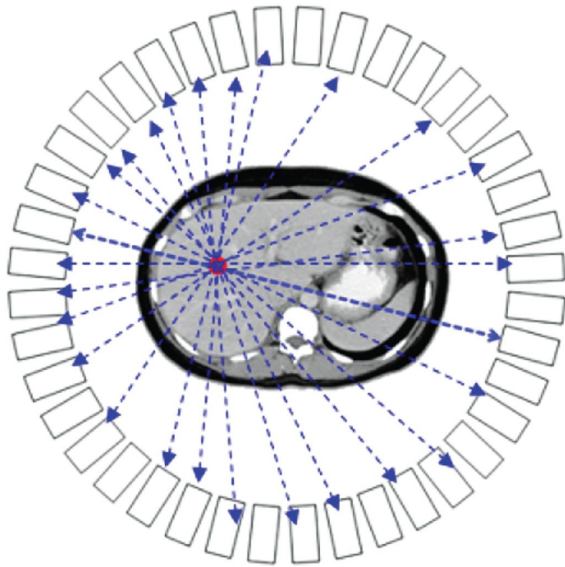


October 12-14, 2026

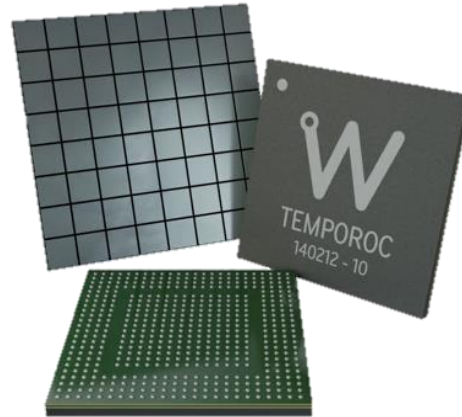
IJCLab, Orsay - France

Overview

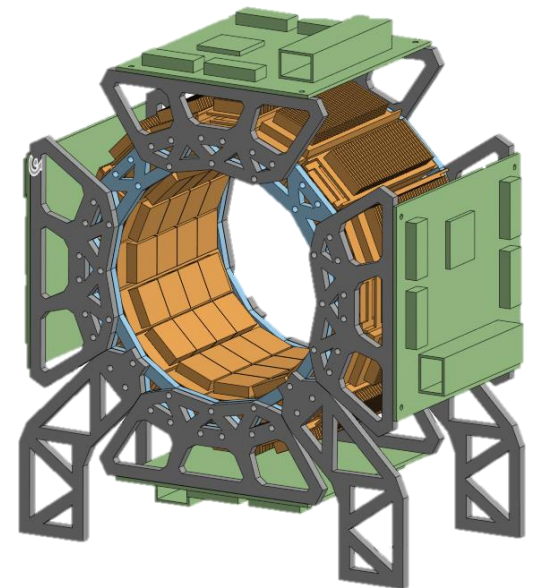
Introduction



Temporoc 3 ASIC

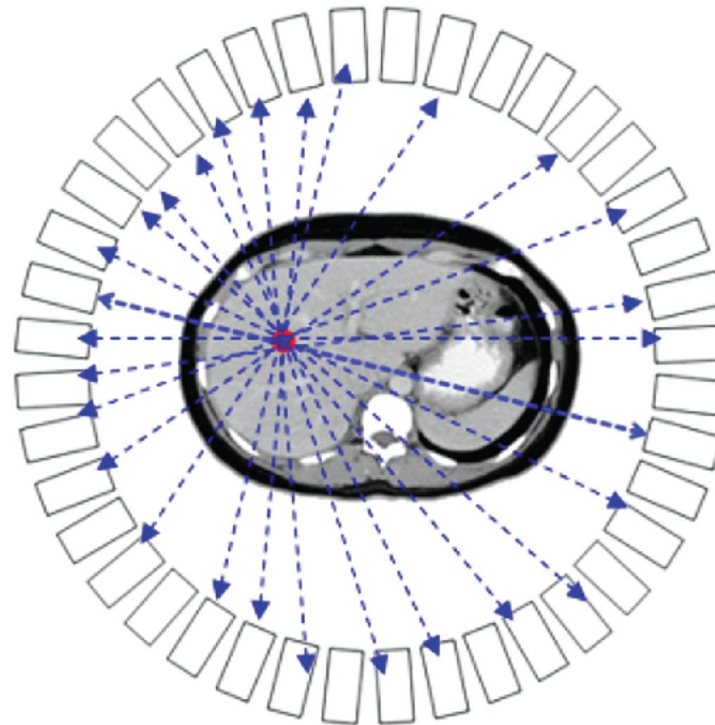
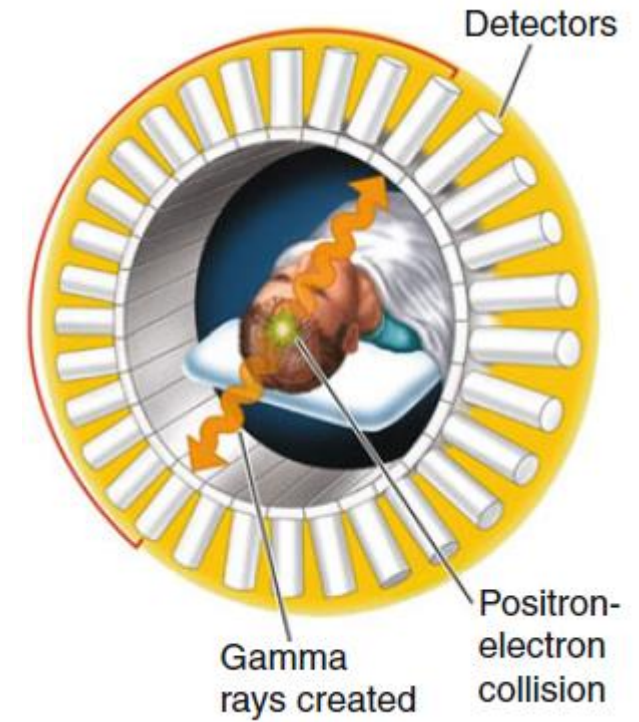
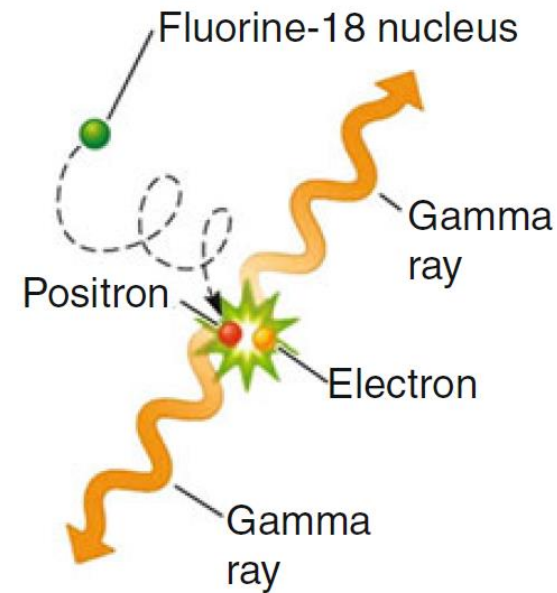


Demonstrator system



What is PET?

Imaging the (β^+)radioactive agent density distribution via detection of pairs of annihilation photons



Connecting lines
(Lines of Response, LoR)

What makes a good PET scanner?

Spatial resolution

- **Reduce blur** and separate nearby features
- **Sharper** tumor contour
- Use DOI to maintain **resolution across FOV**

Timing resolution

- **Use TOF** to constrain ROI
- **Reduce random coincidences** through tighter windowing

Sensitivity

- Detect **weaker activity**
- **Reduce patient dose**
- Reach a **quality image faster**

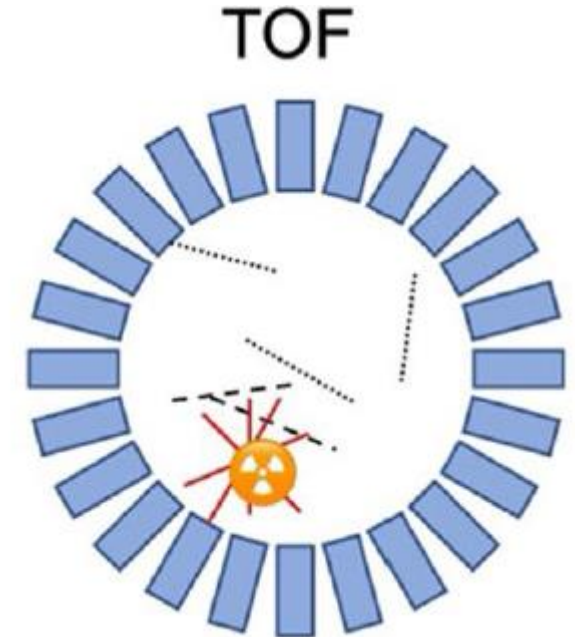
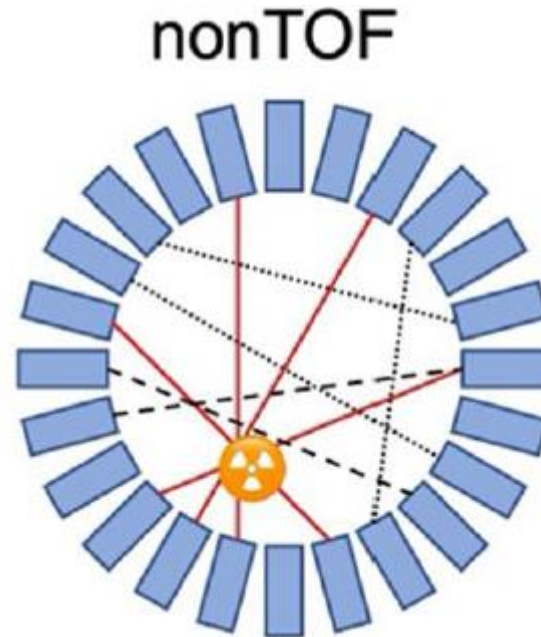
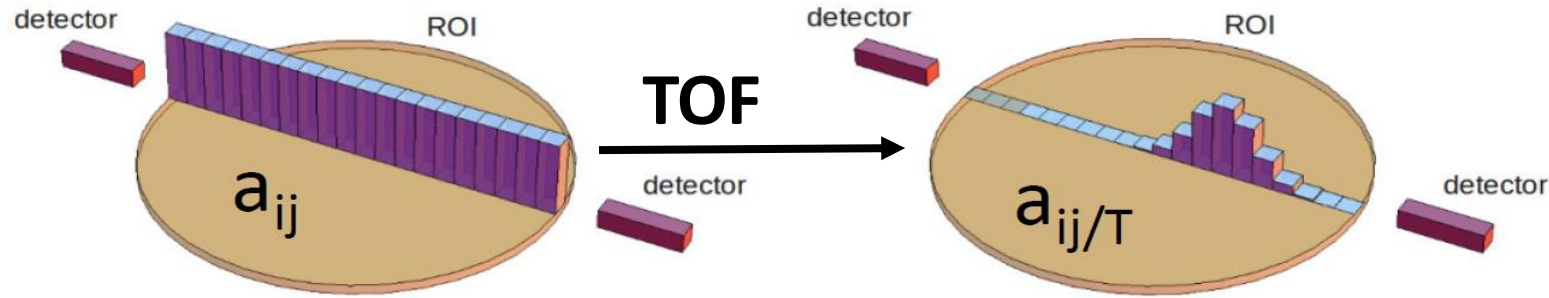
(Price)

Smaller detectable features -> reliable quantification -> Shorter acquisitions or lower injected activity

Shorter acquisitions -> motion compensation, reduce tracer kinetics effects

Timing in PET

- Narrow coincidence window
 - Low multiple rate
- Reduced ROI (**Region of interest**)
 - Faster convergence
 - Reduced scattered noise
- Real-time functional imaging

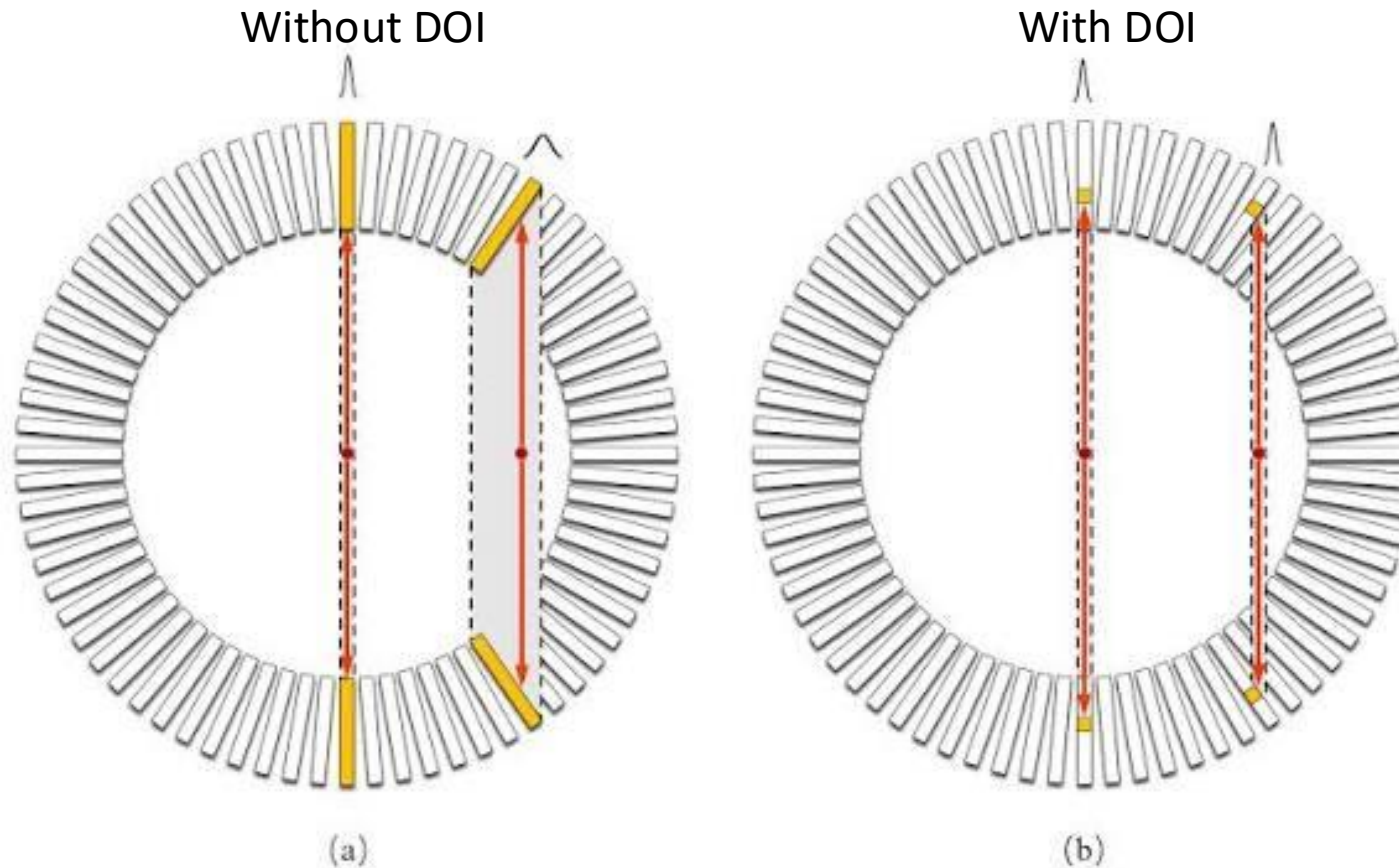


Less noise = better contrast with lower exposure

Why do we need DOI?

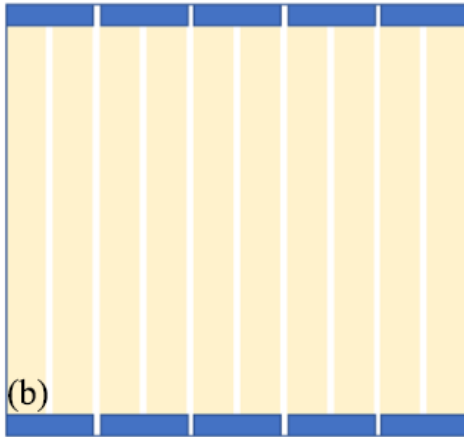
Depth of Interaction (DOI)

- Reduces uncertainty related to the depth of a crystal

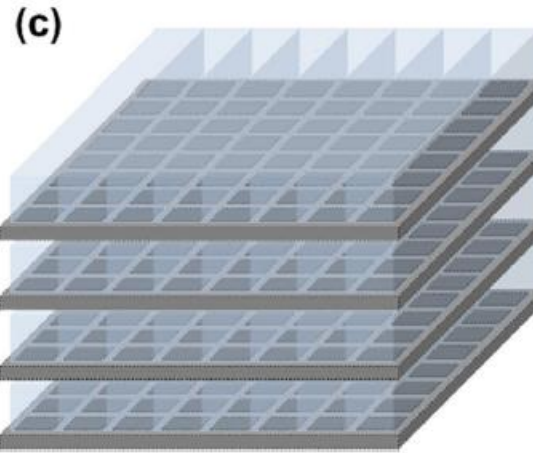


How to find DOI?

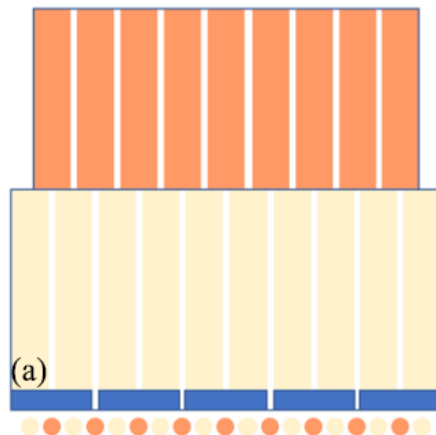
Dual-ended readout



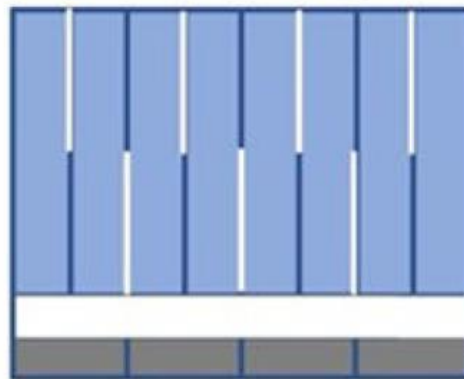
Independent layer readout



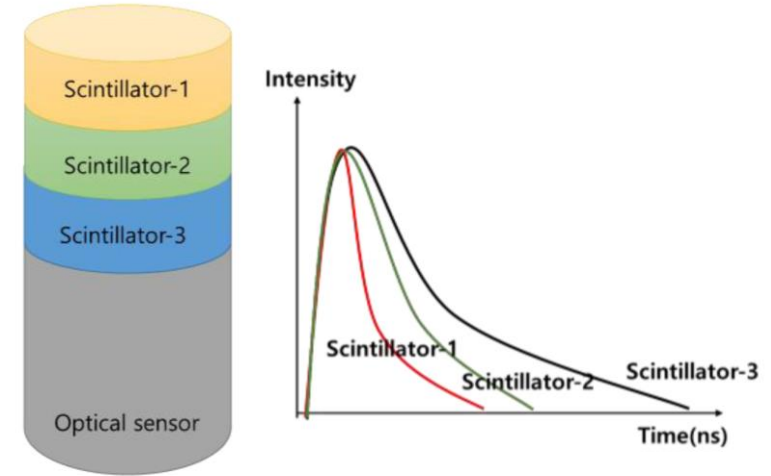
Offset layers



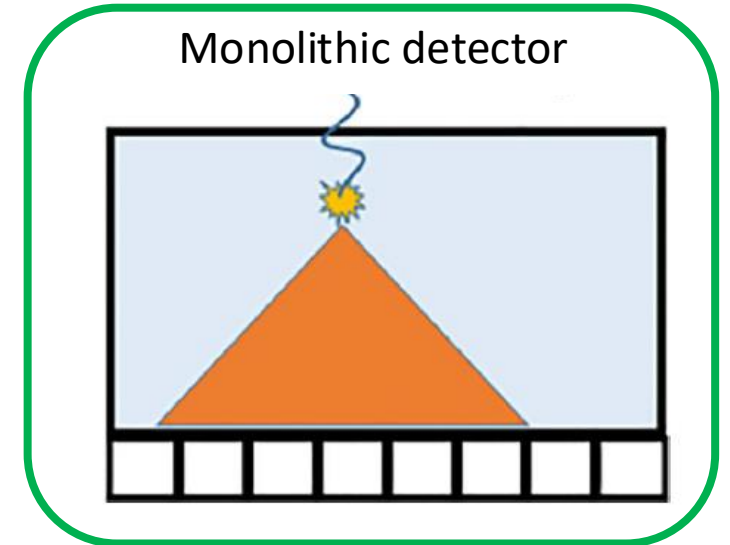
Reflector-based encoding



Phoswitch



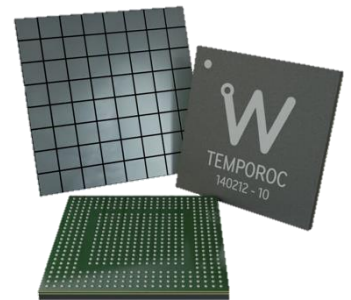
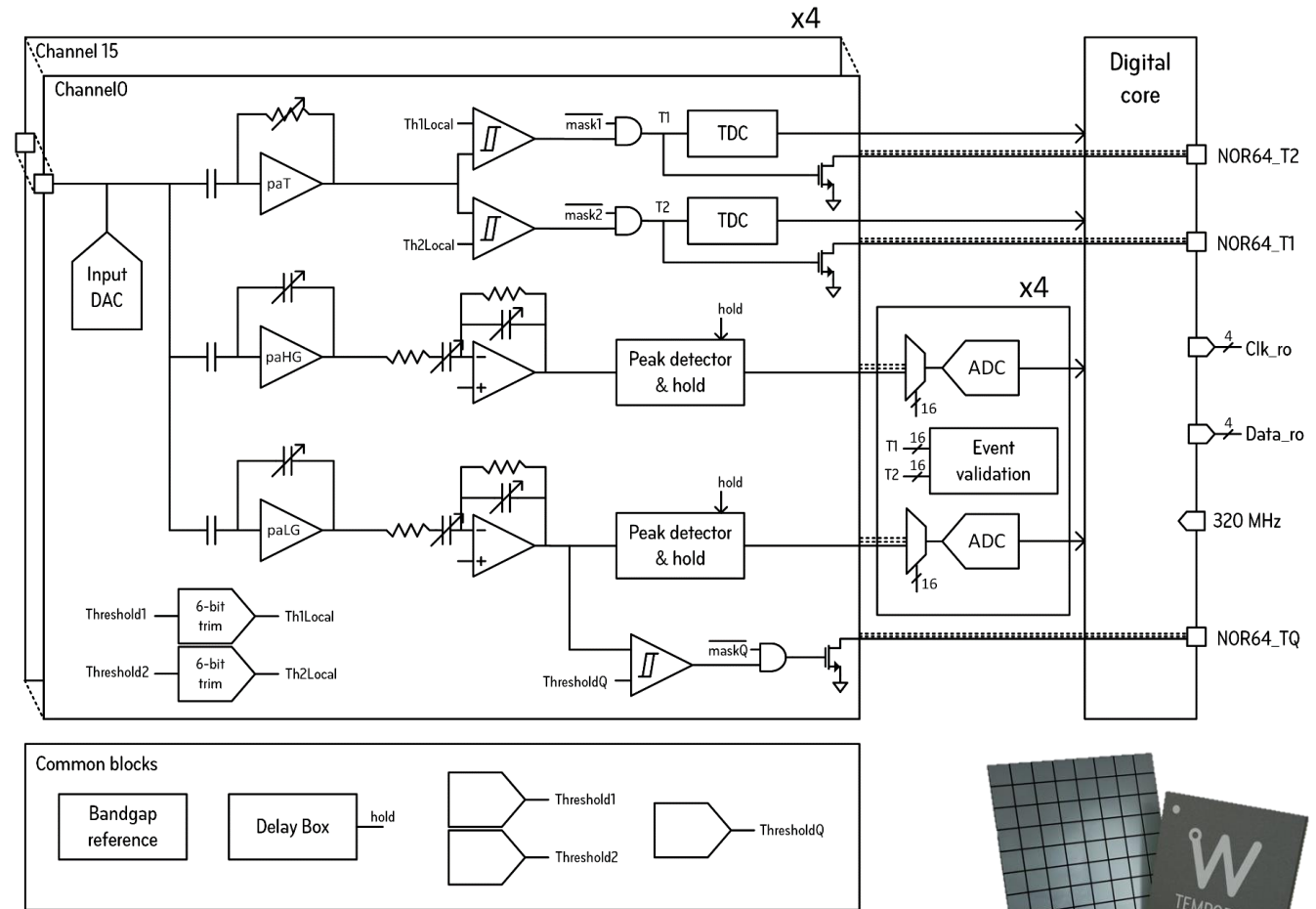
Monolithic detector



Temporoc 3 – ASIC for SiPM readout for TOF PET

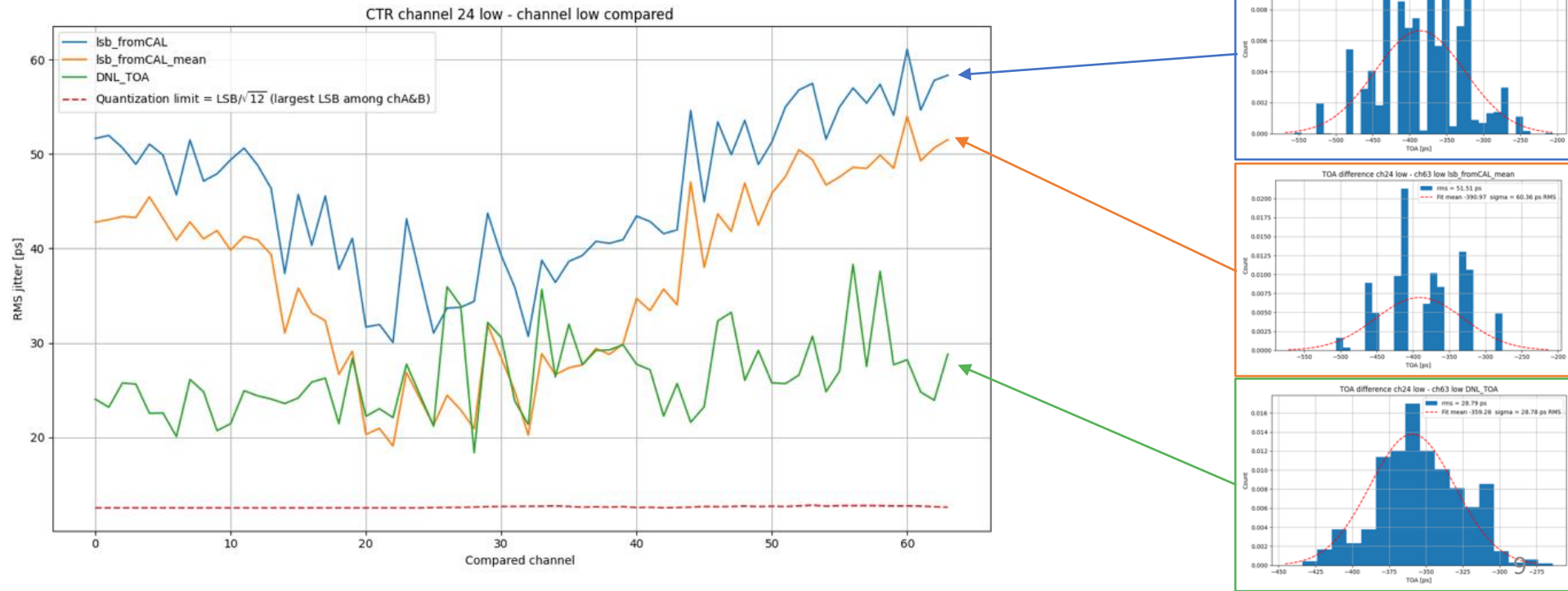
Readout ASIC for Monolithic PET

- **4 clusters x 16 channels**
 - Read out together or separately
- **Two TDC per channel**
 - Double threshold or ToT
 - 40ps TDC bin
- **Energy measurement (ADC)**
 - Two shapers (High and Low gain)
 - Tunable gain and shaping time
- **Charge trigger**
 - Veto if charge is < threshold
- 320 MHz clock
 - Up to 1.28 Gbps data rate
- Max rate ~300 kHz



Outputs digital data: time and charge

Channel to channel CTR

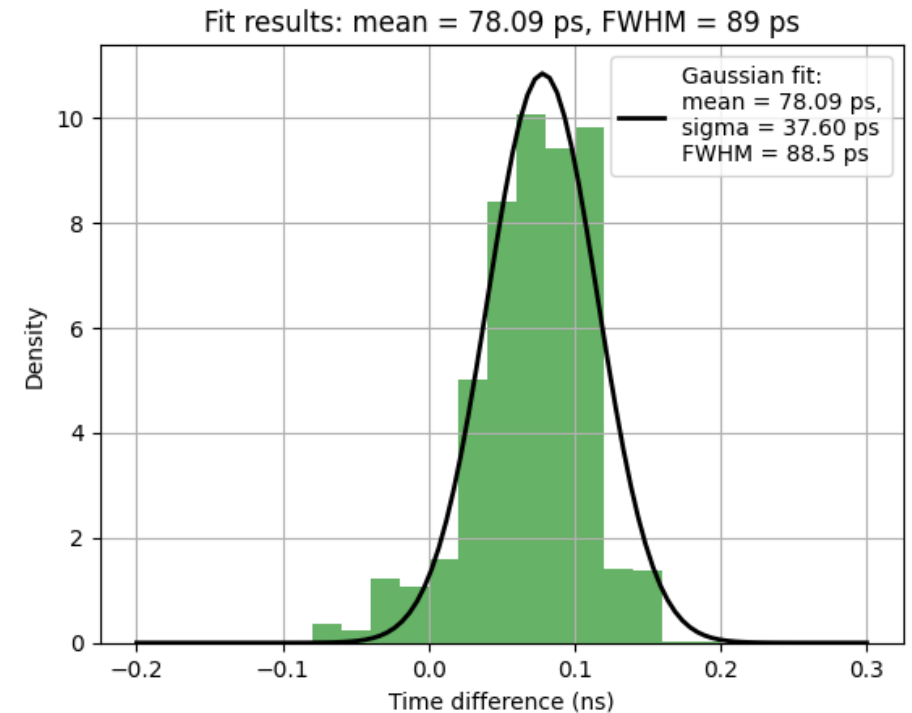
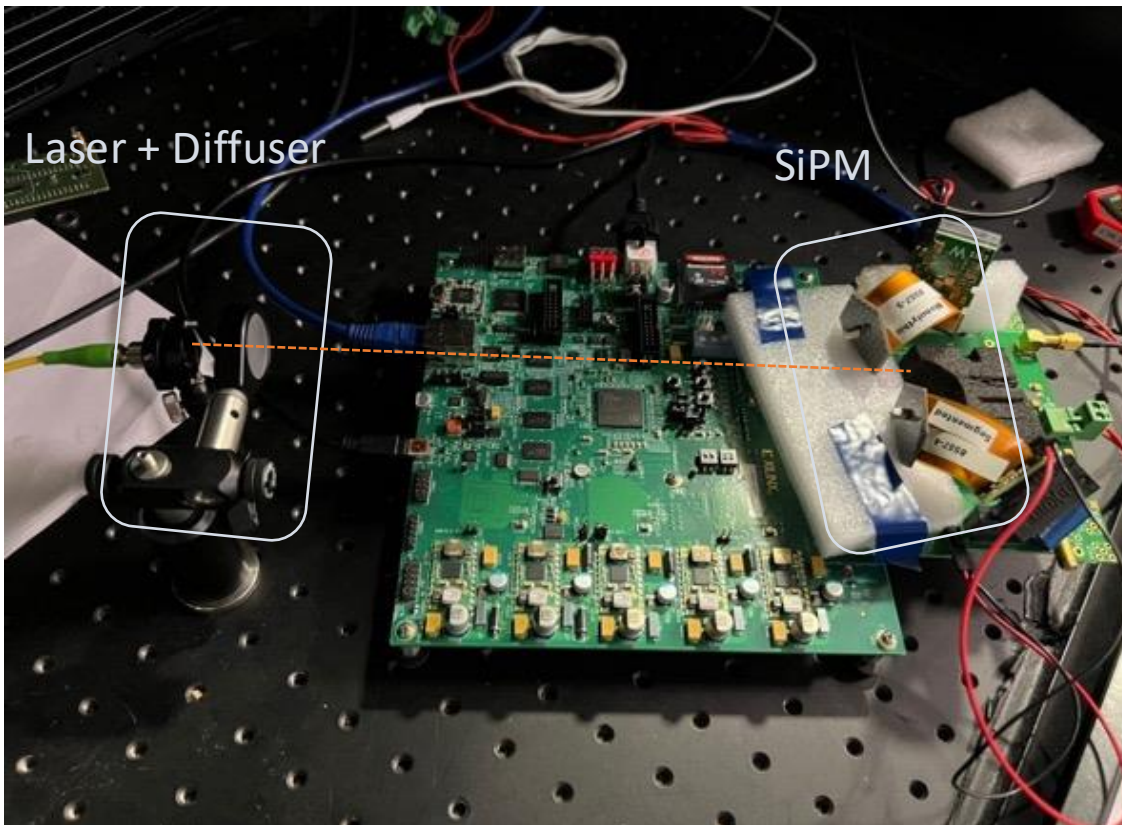


Coincidence time resolution with external trigger injected into all channels

- Differential non-linearity calibration: 28 ps RMS average
- Without calibration: on average **35ps RMS (82ps FWHM)**

Tests with laser (bright flash)

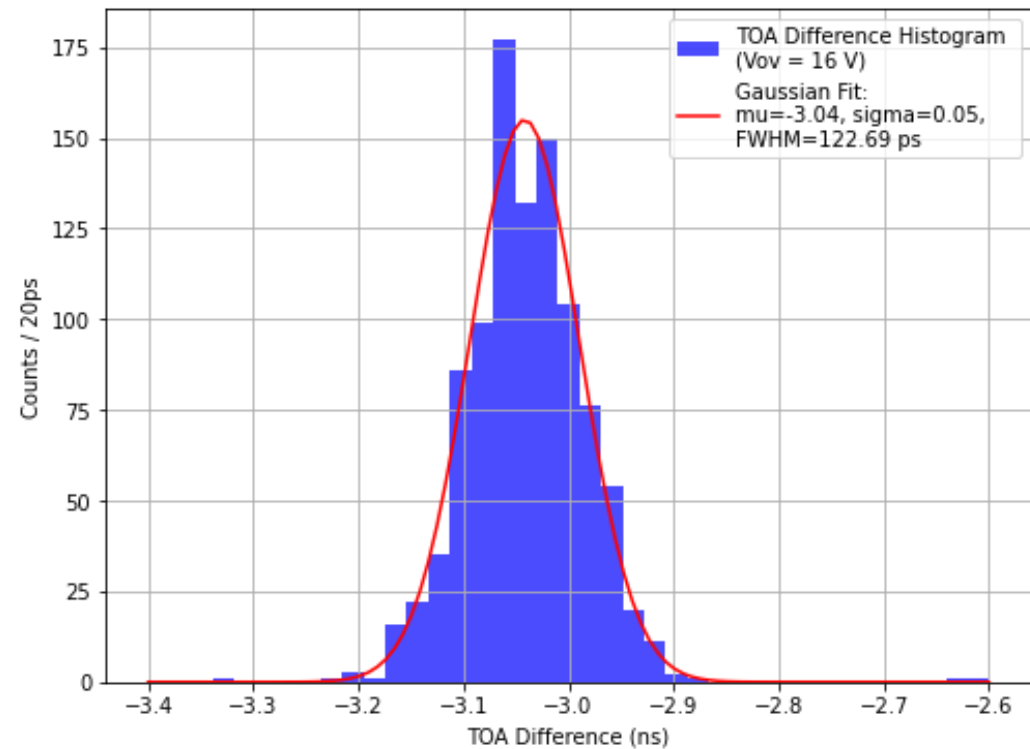
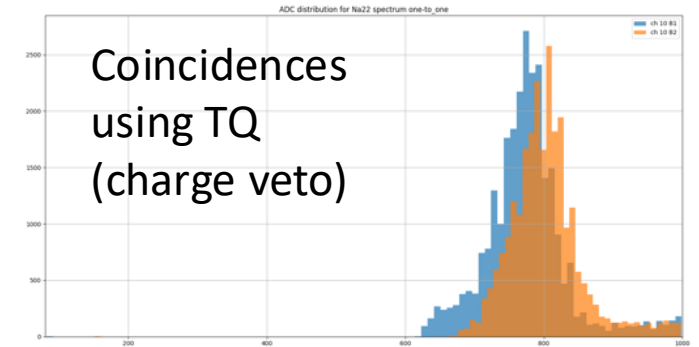
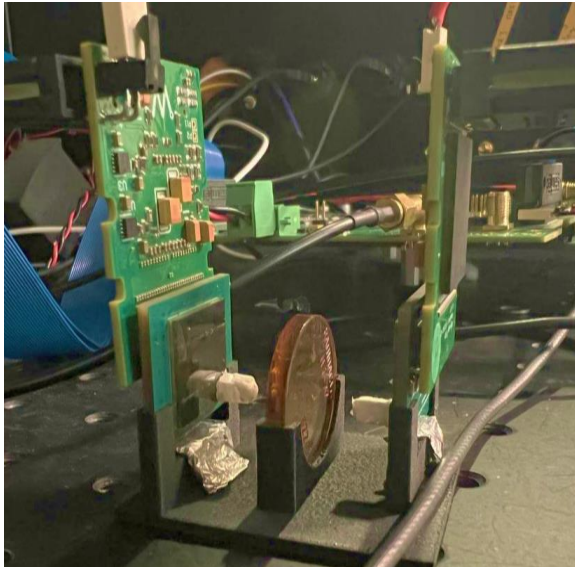
- Inter-ASIC test with picosecond laser pulse and AFBR-NUV-MT SiPM
- Average channel **~90 ps CTR (FWHM)**



Test with laser reveals best resolution achievable with SiPMs

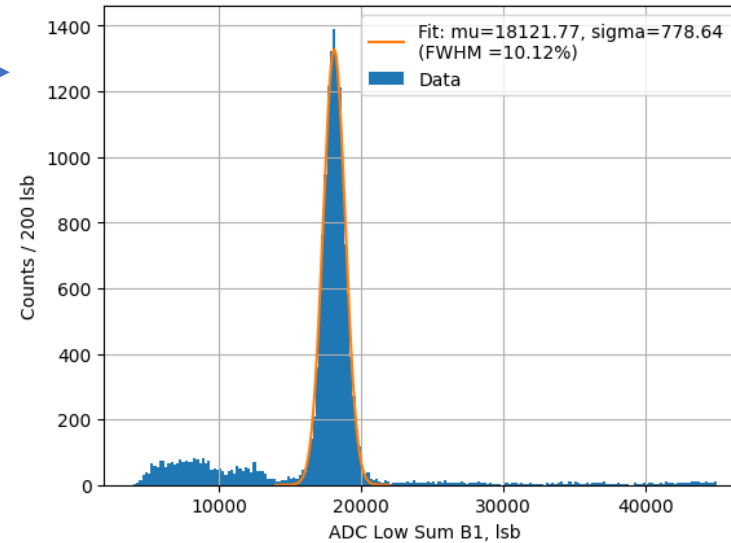
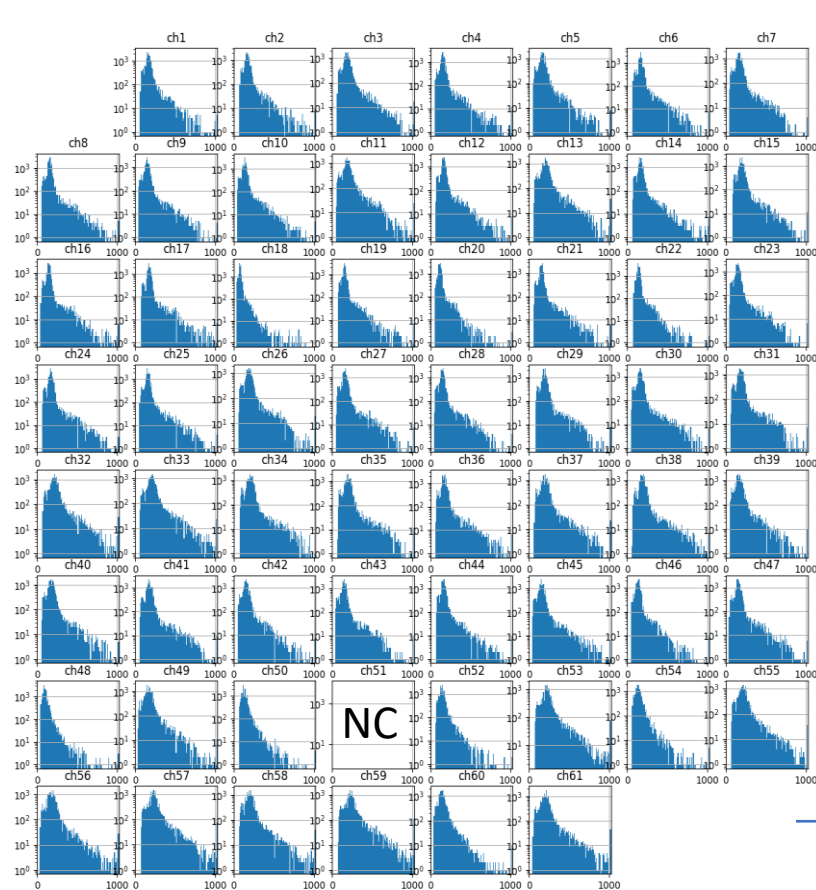
Single LYSO crystal test

- Small crystal coincidence (inter-ASIC)
 - LYSO(Ce) 3x3x5 mm³
 - ²²Na source
 - AFBR-NUV-MT SiPM
- CTR: **123 ps FWHM**
without calibration



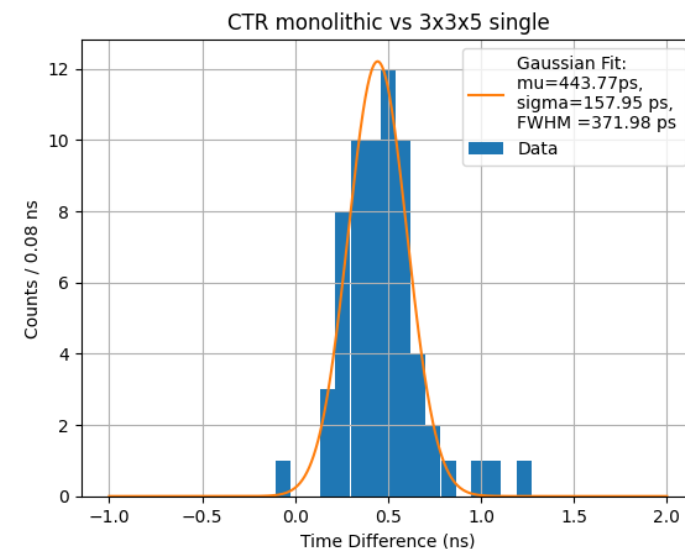
Entering 100 ps domain CTR

Monolithic readout with 60 channels LYSO(Ce) 32x32x20 mm³



**10% FWHM resolution
@ 511 keV with LYSO(Ce)**

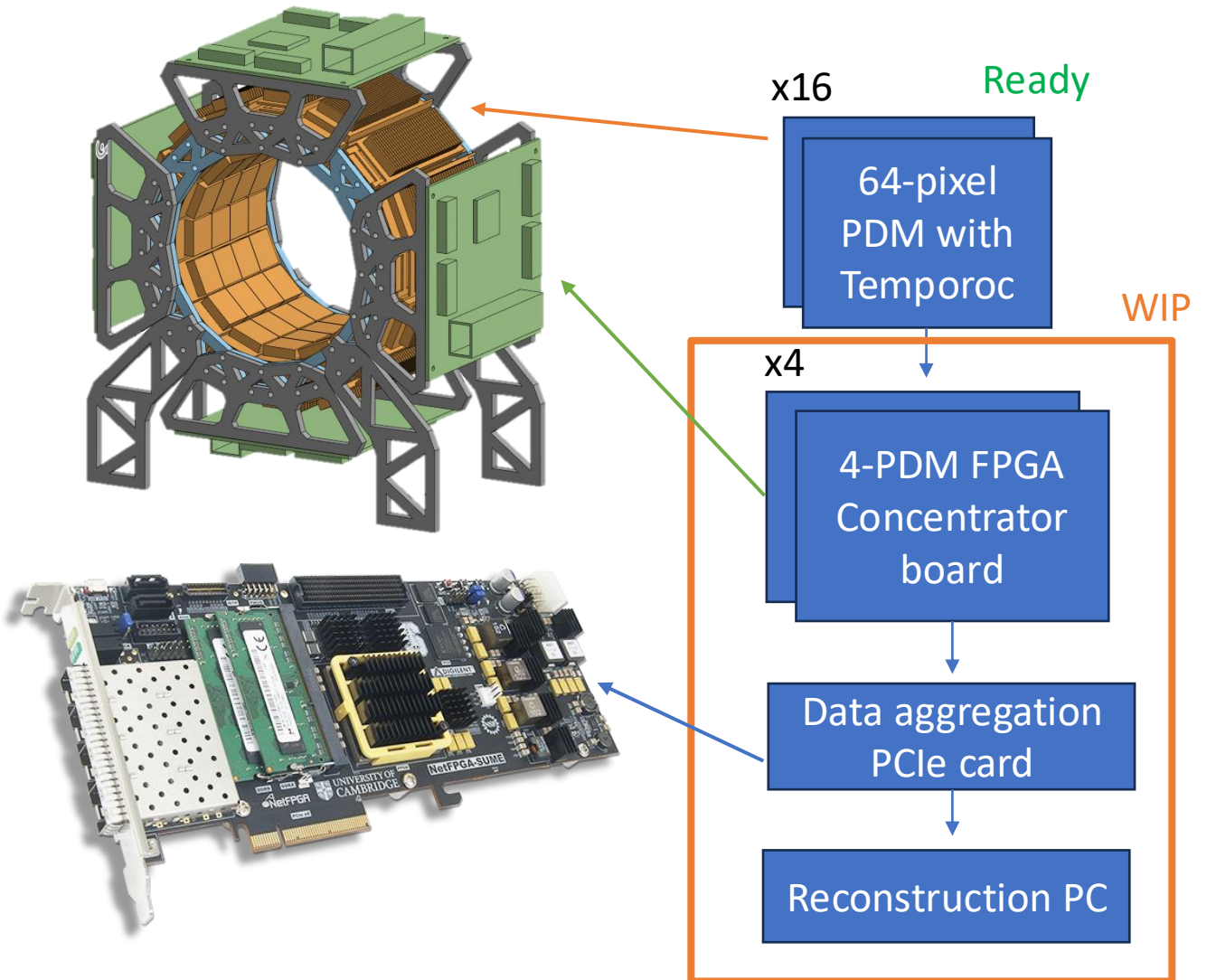
Time:
First signal among channels
with ADC > 800



372 ps FWHM – best achieved timing so far
Further investigation in progress

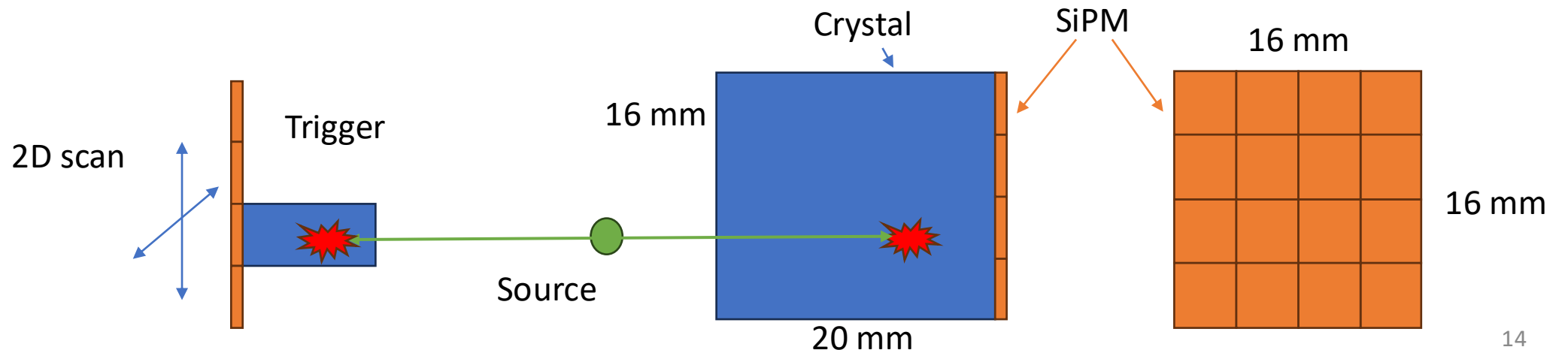
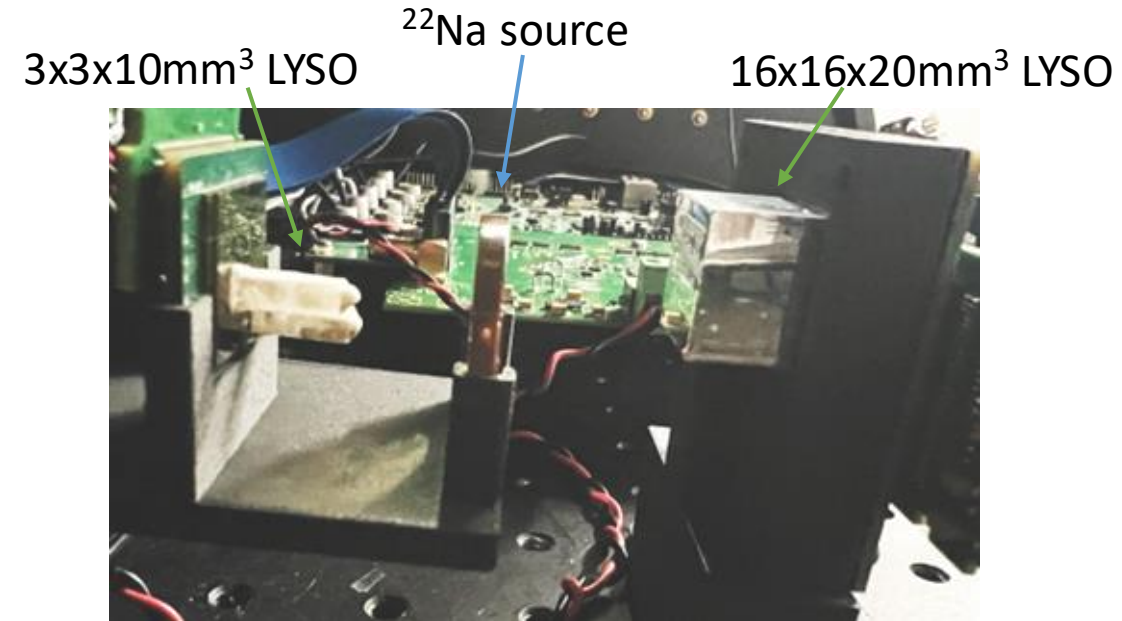
Small PET demonstrator system

- Demonstrate **ASIC** performance
- Develop **scalable open DAQ chain**
- R&D for **monolithic reconstruction**
- Current stage:
 - **Validating** with available coincidence system
 - **PDM design ready for fab**
 - **Concentrator** in development



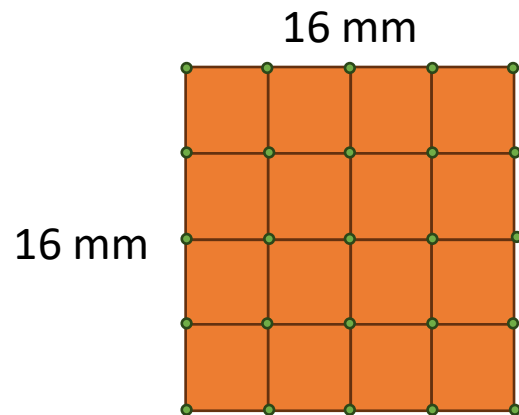
Monolithic reconstruction with 4x4 pixels

- Scan with **2D motorized linear stage**
- Coincidence to **collimate the beam**
- Reconstruction using **simulation-trained models**
 - **Geant4 simulation** with full optics
 - Only **charge data** used (so far)

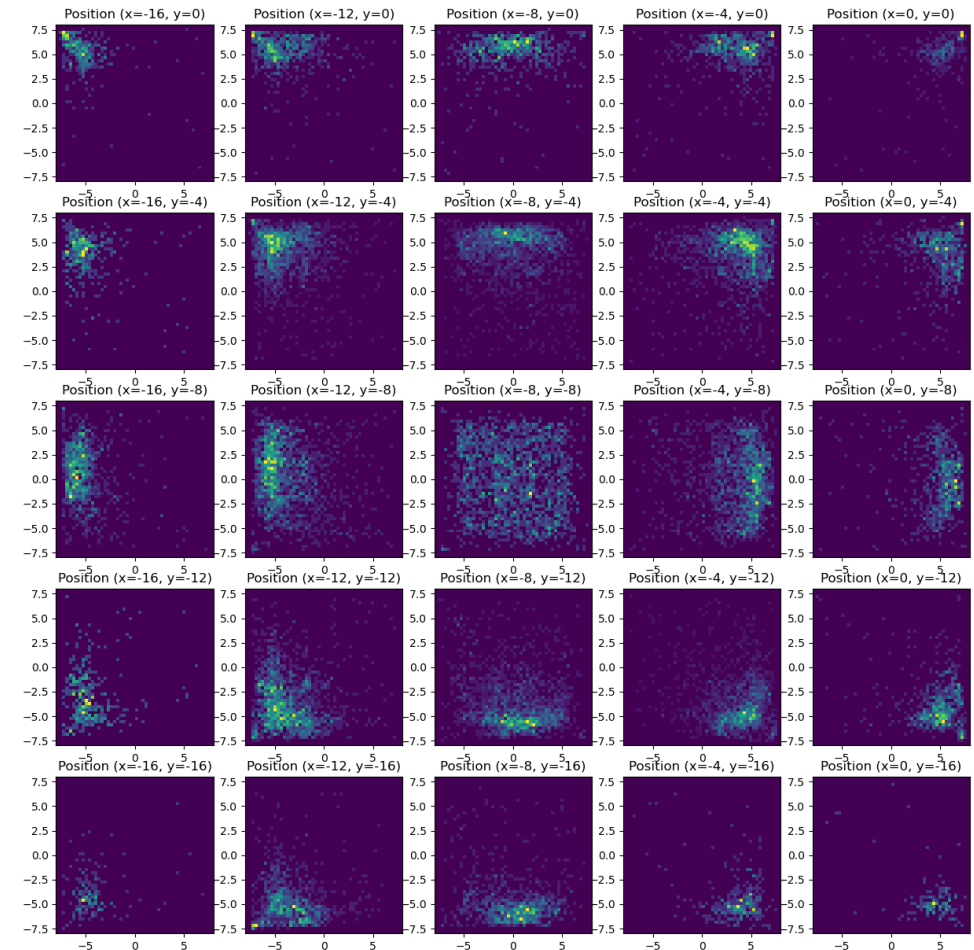


Reconstructed interaction position

- Scan with **5x5 stops**
- **Predicted gamma interaction position**
- Nearest Neighbors regression algorithm
 - Found working best on simulation
 - Studying other algorithms



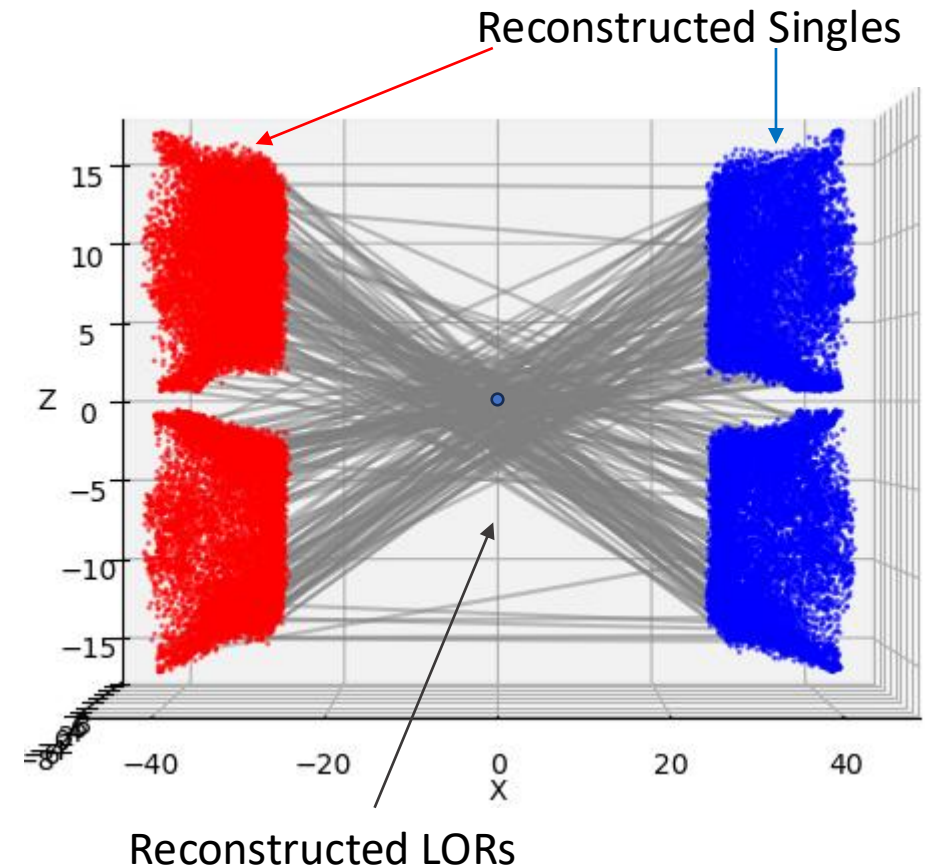
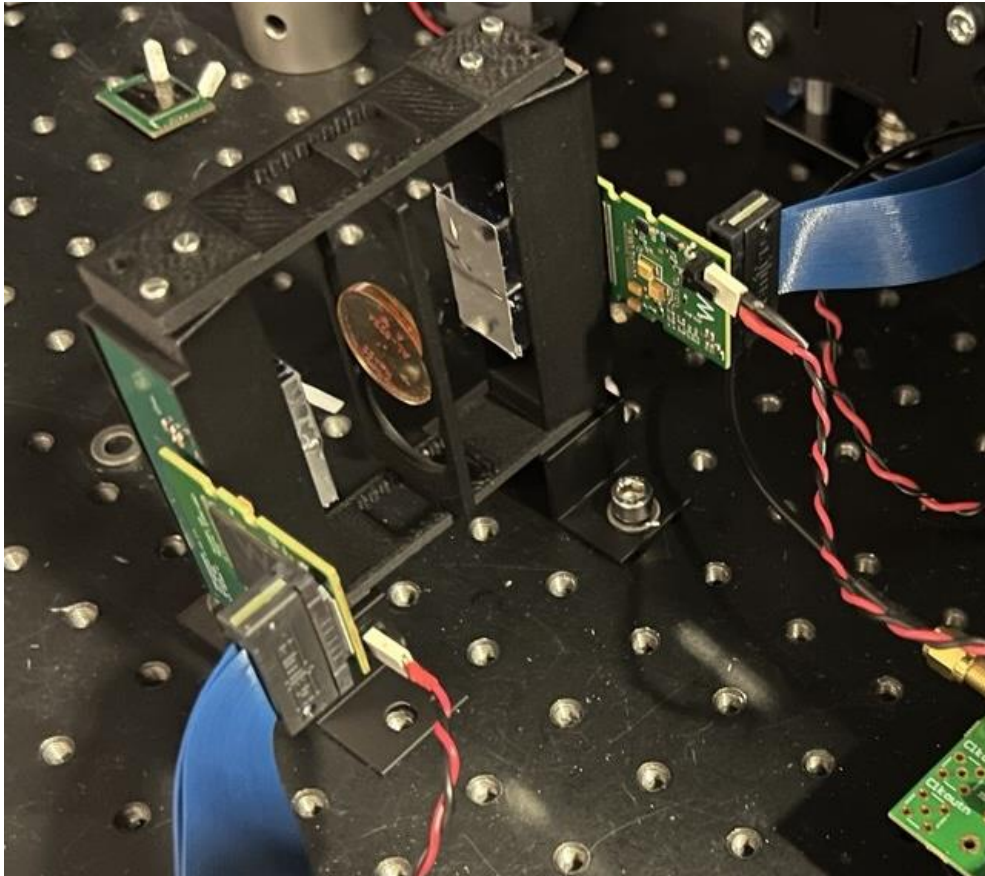
Scan grid



Data reconstruction works and matches the simulation

64-channel prototype

- 4 monolithic crystals with mirror coating, 4x4 SiPM pixels each
- **Reconstructed LORs**, image reconstruction in progress



Conclusions

- TempoROC 3 is a **powerful, highly customizable** ASIC for **monolithic PET** with **TOF**
- Achieved CTR **approaching state-of-the-art** level
- **Demonstrator PET** system is in development
- Promising **LoR reconstruction** with monolithic crystals



Thank you for your attention !

Questions ?

Previously on Temporoc



Temporoc 1
2020

Temporoc 3
2026

Temporoc 2
2023

Temporoc 1

Analogue Core OK
ADC OK
TDC KO ✖
Trigger schema KO ✖

Temporoc 2

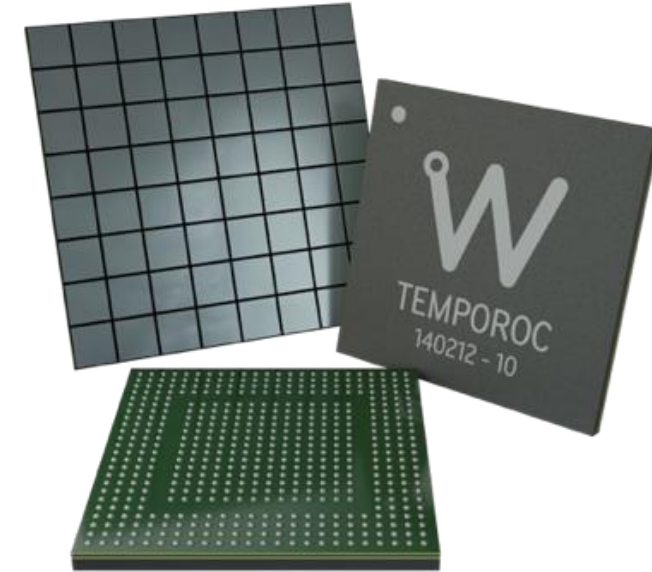
Analogue Core OK
ADC OK
TDC OK
Trigger schema KO ✖

Temporoc 3

Analogue Core OK ✓
ADC OK ✓
TDC OK ✓
Trigger schema OK ✓

TEMPOROC features

Detector Read-Out	SiPM (up to 64 channels)
Signal Polarity	Positive
Sensitivity	Trigger on first photo-electron
Timing Resolution	Self-calibrating TDC with a 40ps bin
Dynamic Range	3000 photo-electrons (10^6 SiPM gain) or ~ 500 pC Integral Non Linearity: 1% up to 2000 pe – shaping 20-300ns Charge Gain tunable from 0.5 (lowest low gain) to 78 (highest high gain)
Packaging & Dimension	BGA 20x20mm, 516 balls (silicon die : 11 x 5 mm), 130nm technology
Power Consumption	Power supply: 1.2V 540 mW at maximum serialization rate (8.5 mW per channel, 10.5mW in FR mode all on) 2/3 static for the analog + 1/3 dynamic for the digital readout
Inputs	64 voltage inputs with DC adjustment for SiPM HV tuning
Event validation	Per cluster trigger logic : Nb of trigger within a delay, energy validation, cluster sync for 64ch monolithic
Outputs	Digital output (dual ADC and dual TDC per channel) – selectable readout mode 1 multiplexed time trigger output 2 ASIC trigger OR outputs (64 channels, 2 levels)
Data rate	1.28 Gbps (4 x 320Mbps)
Internal Programmable Features	64 HV adjustment for SiPM (64x8bits), time trigger threshold adjustment (10bits), charge measurement tuning, ADC Peak Sensing, 64 trigger masks, channel by channel output enable, trigger latch



x4

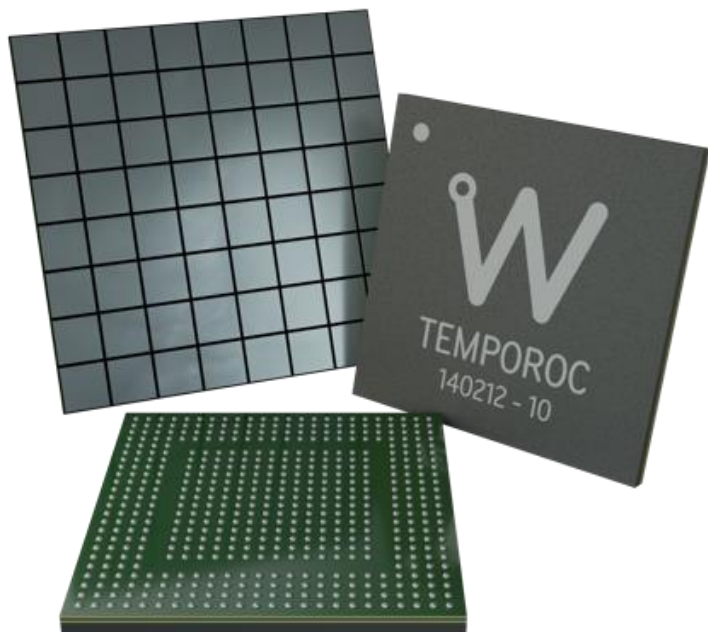


TEMPOROC programmability



- Temporoc does not embed zero-suppress and provide complete cluster information on each validated trigger
- Max rate is 1.28Gbps (4x320Mbps)
- More data outed → less rate
- Software Defined : Can be changed on the fly (calibration, compton mode, Timewalk estimate, etc...)
- Unused block or channel can be switched off individually. Max power consumption 8,5mW/ch all on. Free running mode rise power consumption up to 10.5mW/ch

Main readout modes	Frame rate per cluster [kHz]	Max Event Rate [kHz]
	Max Event Rate 64-monolithic	One to One or 16-monolithic Coupling
Single TDC	590	2360
Dual TDC (or TOA and TOT)	340	1360
Single ADC	470	1880
Dual ADC	460	1840
Single ADC and single TDC	450	1800
Single ADC and dual TDC	290	1160
Dual ADC and single TDC	330	1320
Dual ADC and Dual TDC	250	1000



Channel to channel CTR

Comparing 3 methods of timestamp conversion into picosecond time-of-arrival.

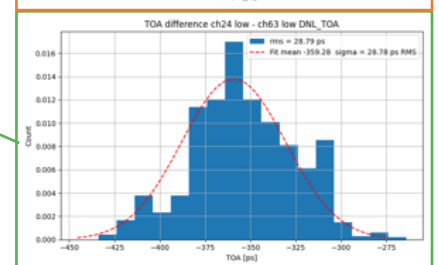
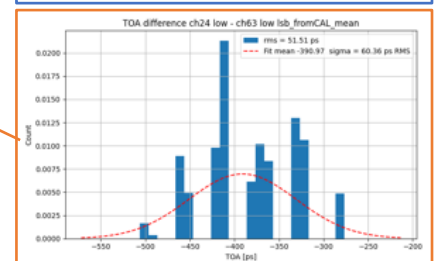
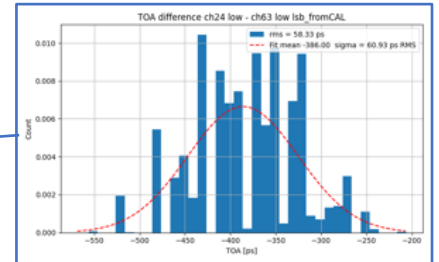
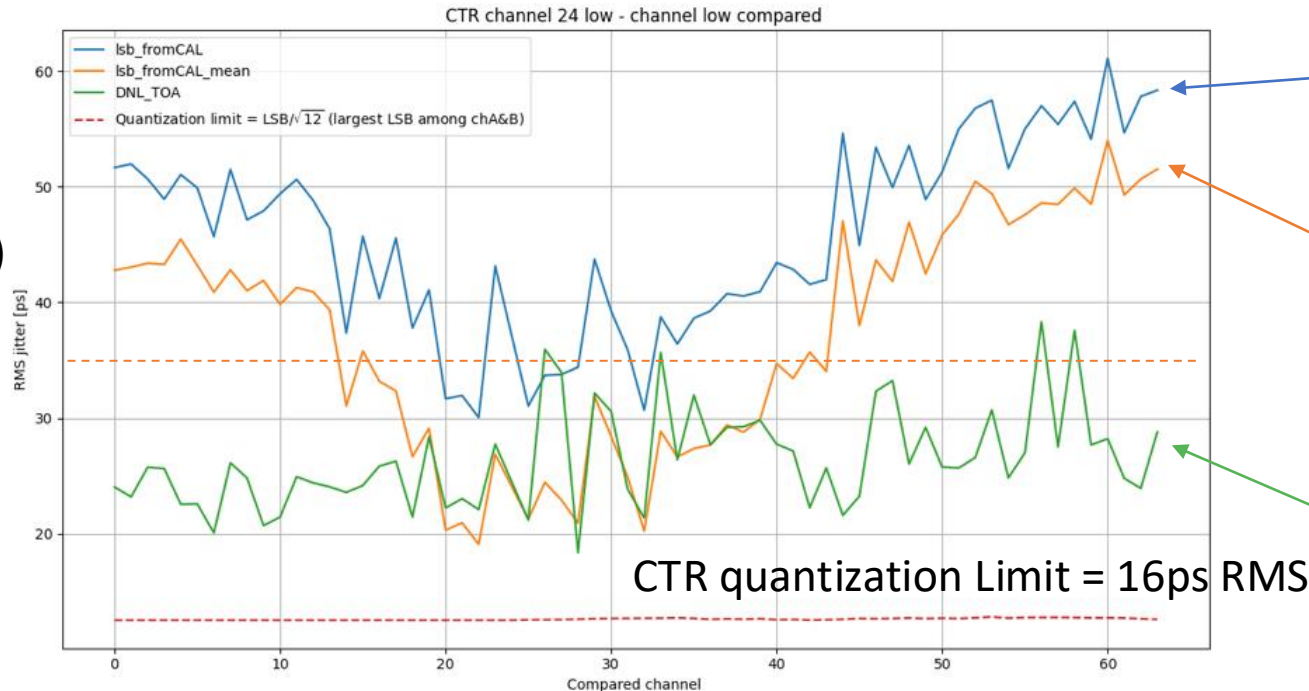
An external trigger is injected simultaneously into all 128 TDC and the time difference jitter between the TDC is computed.

The `lsb_fromCAL` method uses the CAL timestamp to compute a TDC LSB in [ps] for each event.

The `lsb_fromCAL_mean` method averages this computed LSB over all events acquired in this dataset, reducing the jitter on the LSB estimation, thus on the TOA difference.

The `DNL_TOA` method maps the TOA to a picosecond timestamp based on a calibration table previously acquired.

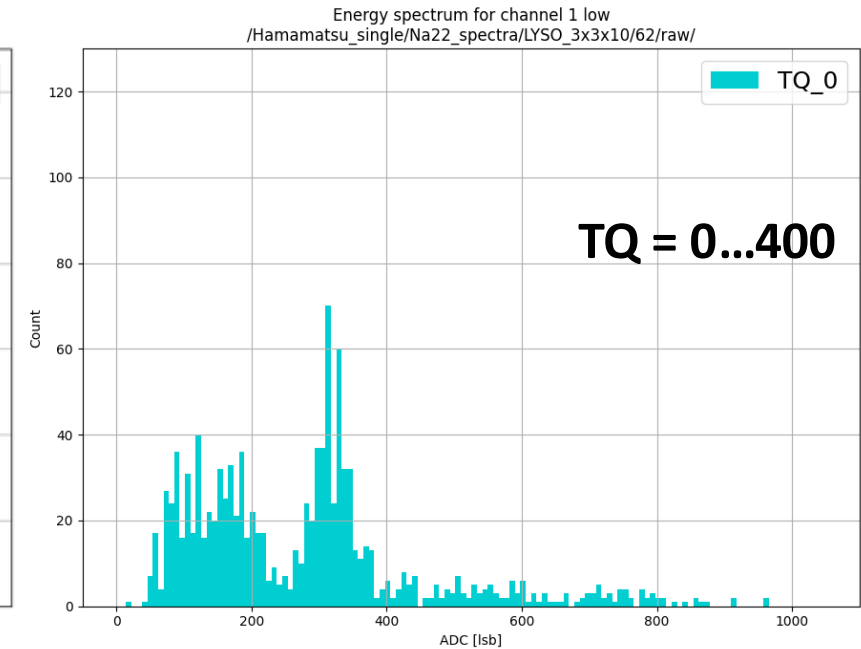
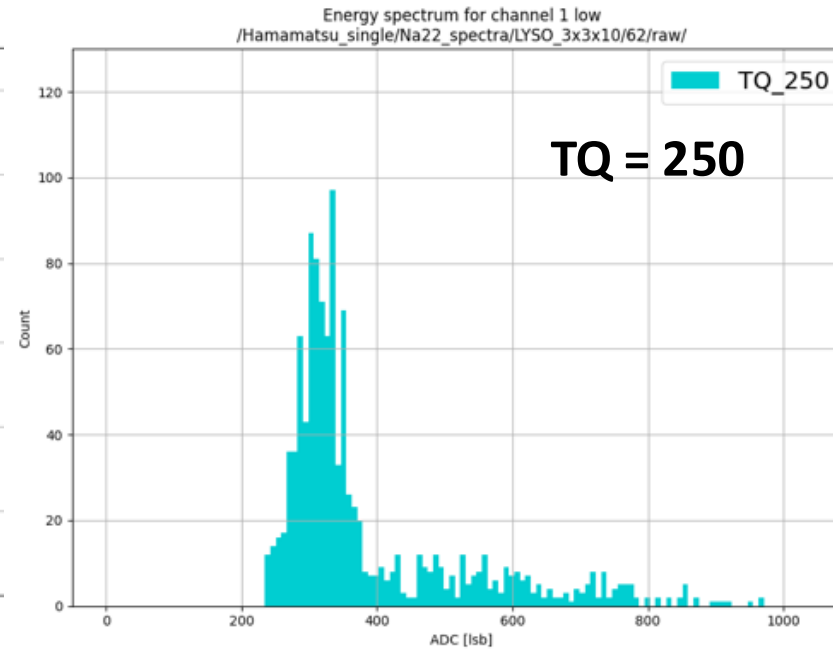
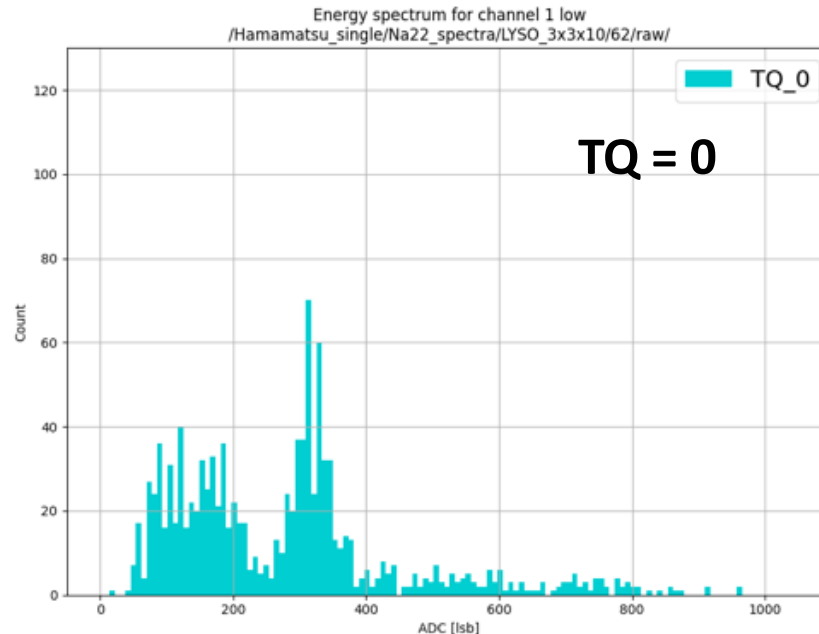
The jitter plotted on the y-axis corresponds to the standard deviation of the distribution (not the Gaussian fitted sigma).



On average:
35ps rms (82ps FWHM)
Without calibration

One to one coupling : spectrum & veto

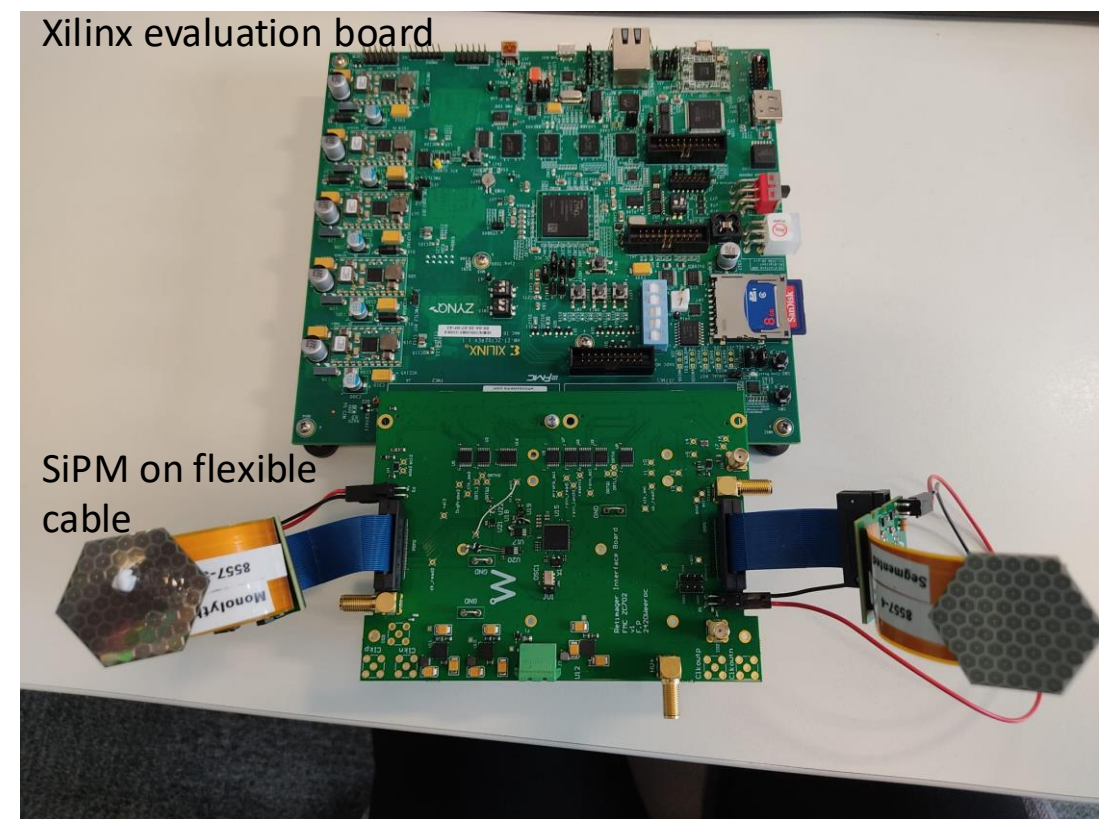
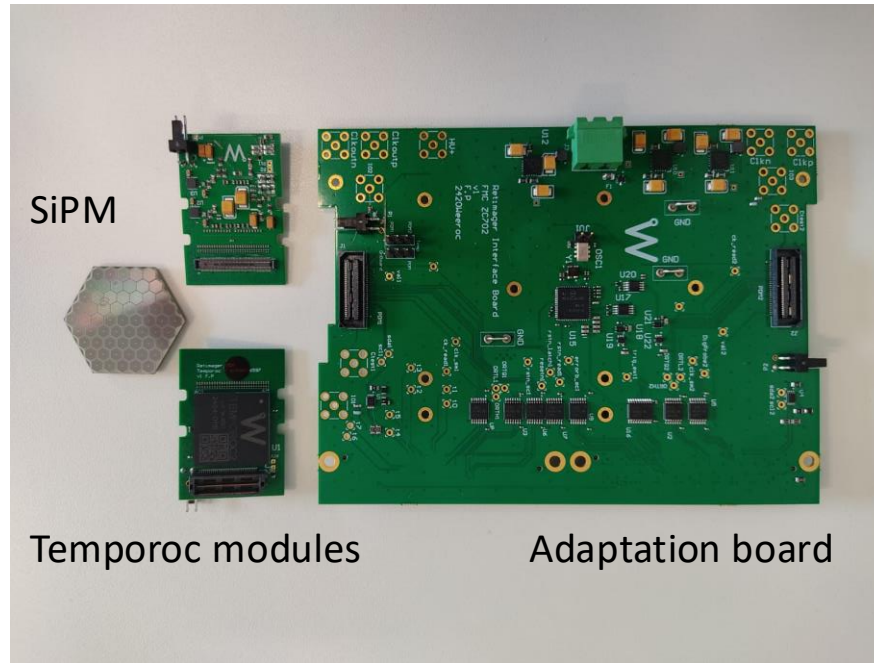
- Na22 source on single SiPM + 10mm LYSO
- Charge Veto (Trigger Q) threshold can be set to remove Compton



Shown very useful for data reduction

Evaluation system

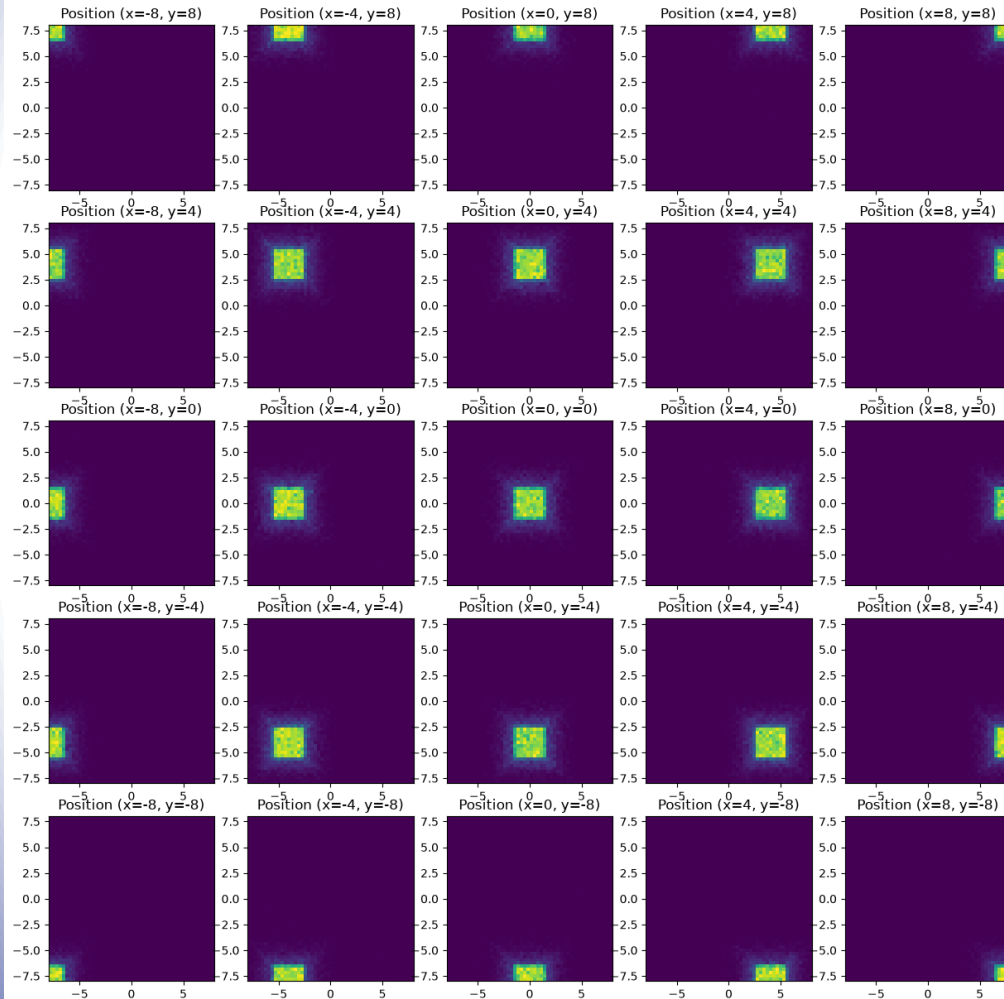
- **Temporoc2** soldered on the **adaptation board**
 - Coincidence between **two ASICs**
- **Flexible connection to the SiPM**
- **Xilinx FPGA Zync** operates the ASICs, ensures IO with PC software



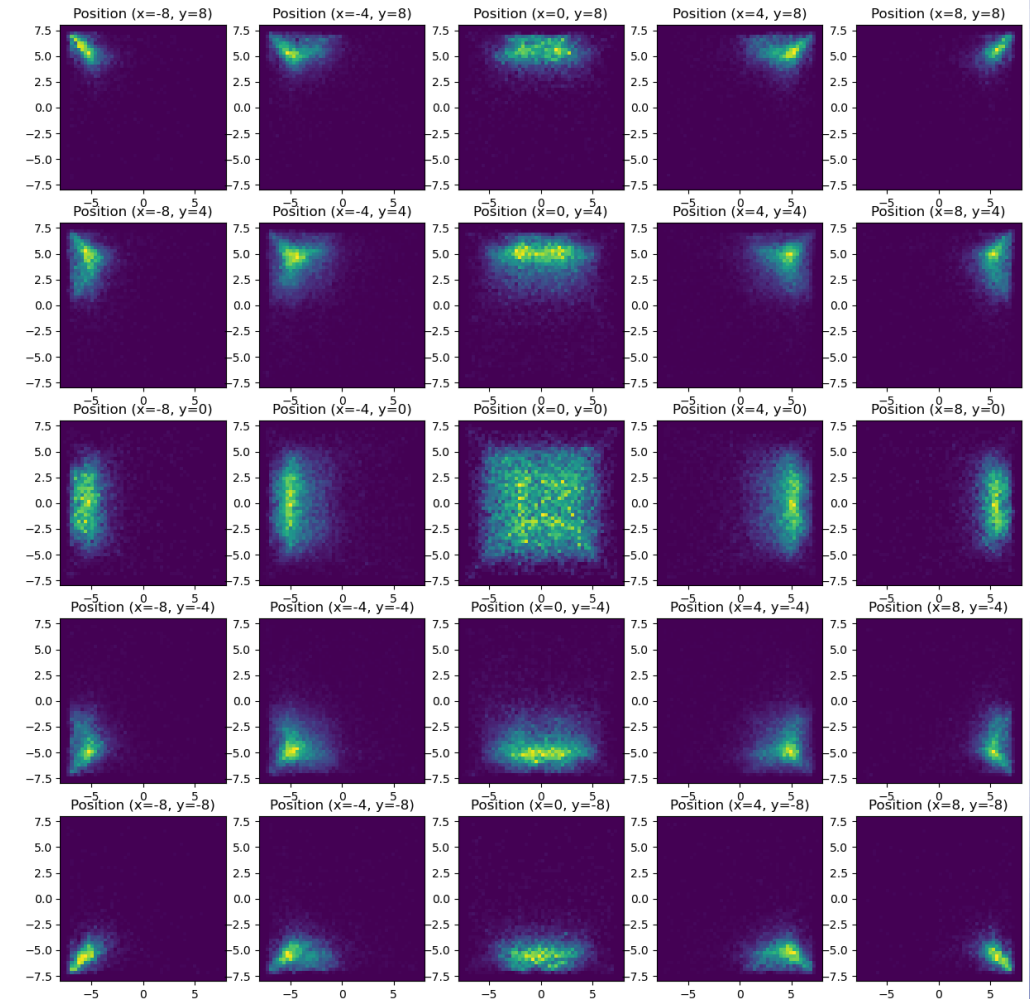
Reproduce scan in simulation

kNN reconstruction

True



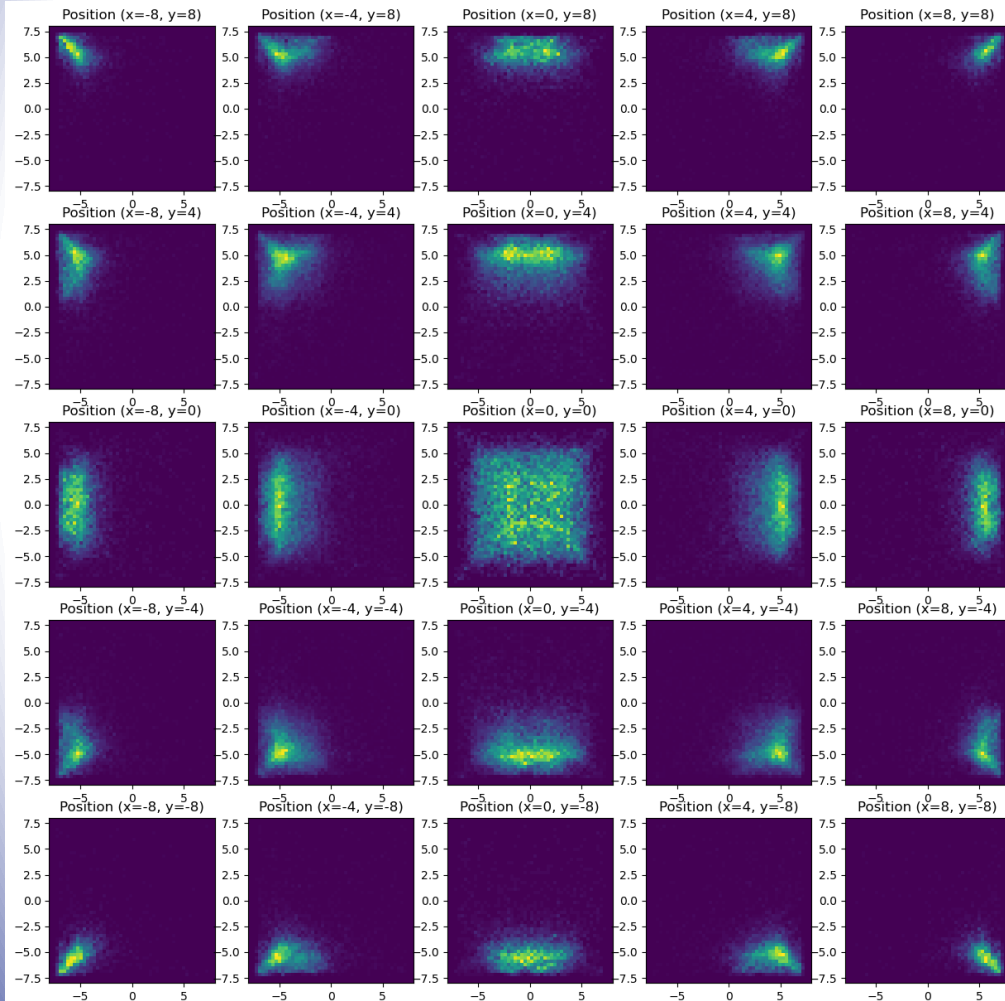
Reconstructed



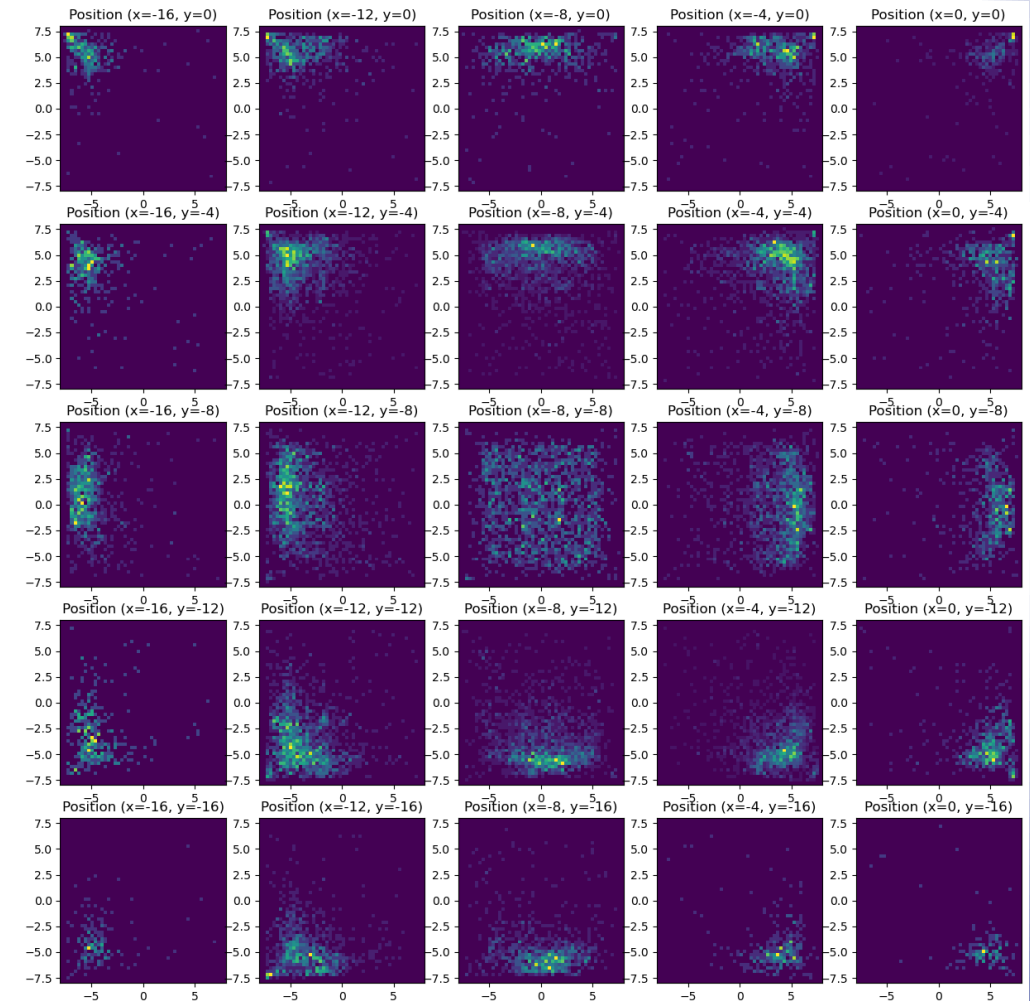
Reproduce scan in simulation

kNN reconstruction

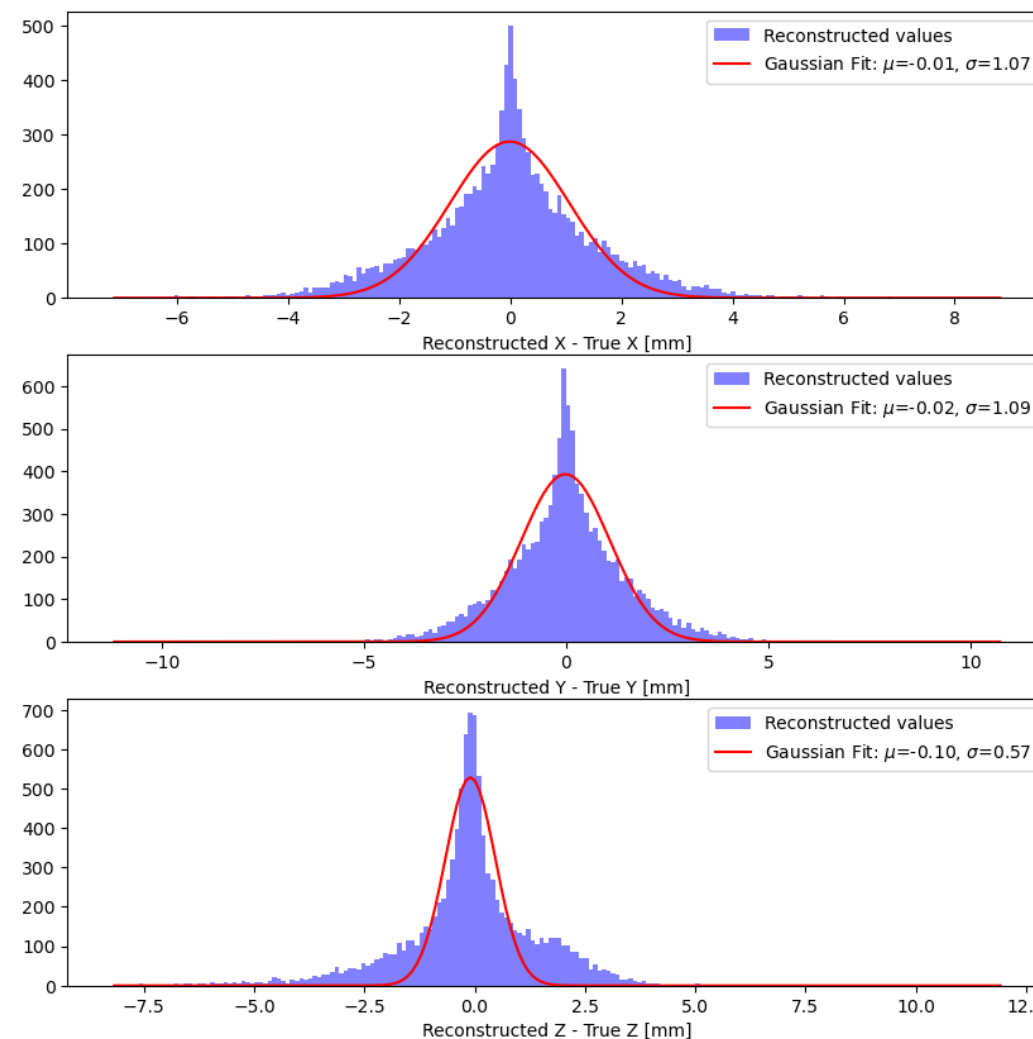
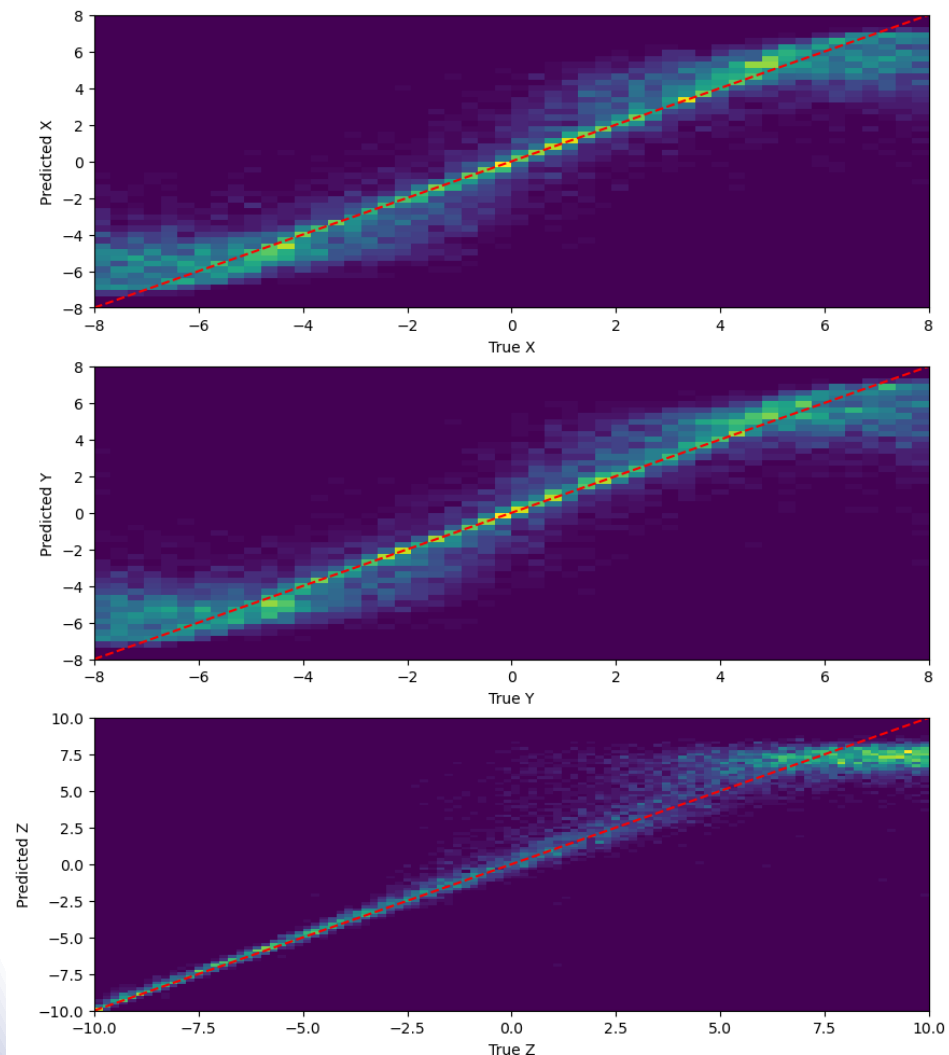
Simulation



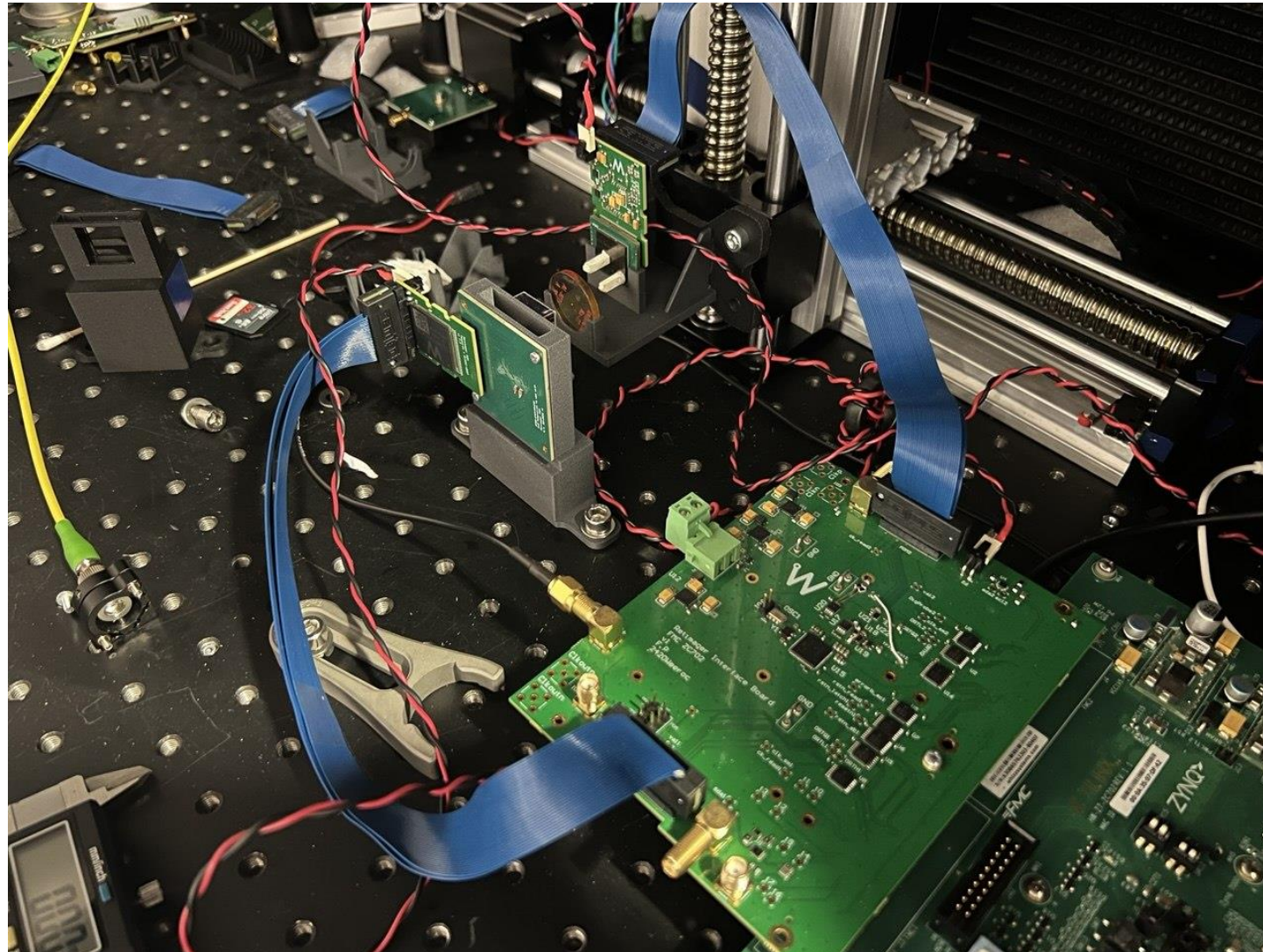
Measured



kNN resolution with simulation



Setup for scan



Prototype PET modules

