PetVision spatial and time resolution

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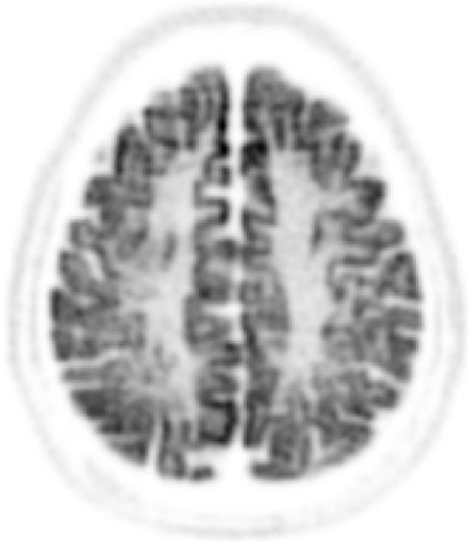
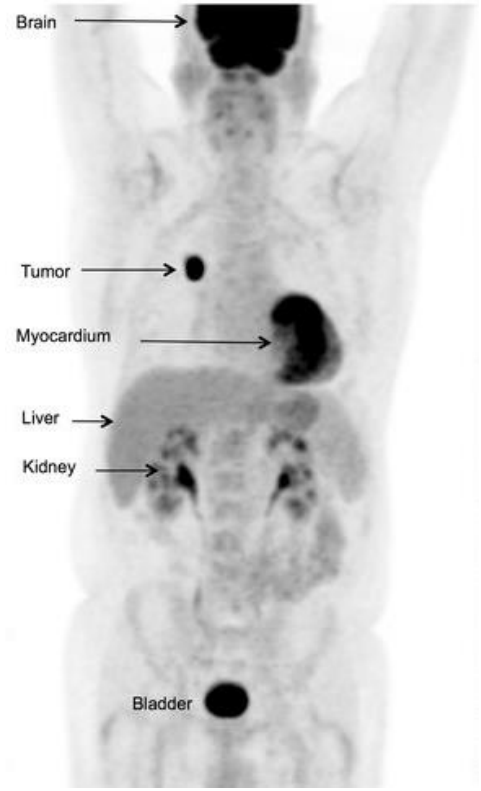
Positron emission tomography (PET)

- Tomographic imaging technique used in nuclear medicine
- Functional imaging (imaging physiological processes)
- Radiopharmaceuticals injected into the body



[1] *Orehar M et al. 2024*

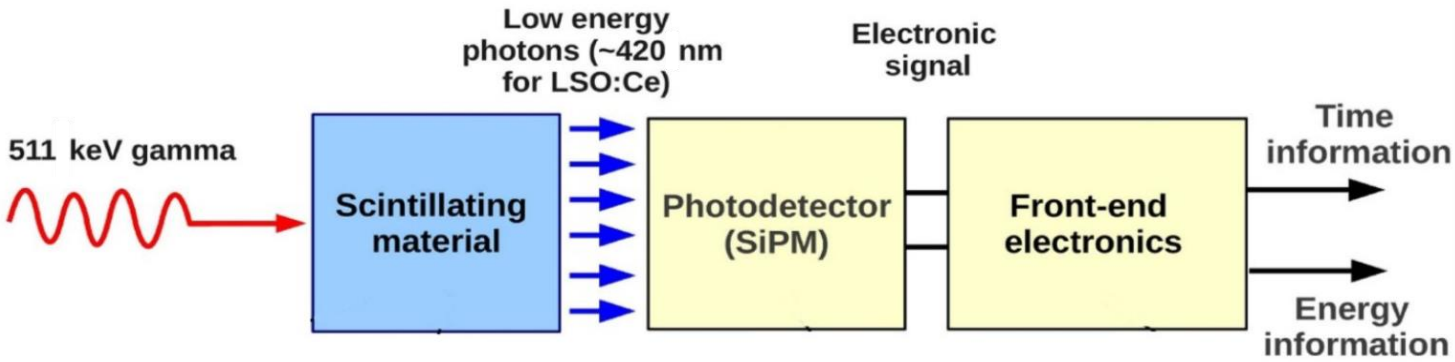


[2] *Nair V S et al. 2013*

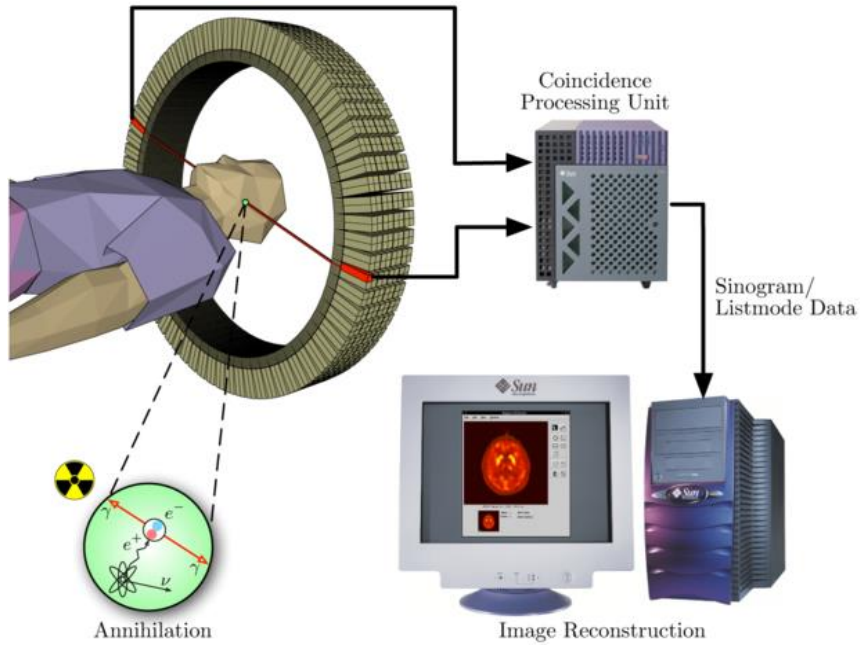
[3] *Casey M E et al. 2020*

PET Detectors

- Scintillators convert gamma rays to visible photons
- Photodetectors convert photons to an electrical signal
- Electronics read out and process the signal



[1] *Acerbi F et al. 2019*



[2] *Langner J 2003*

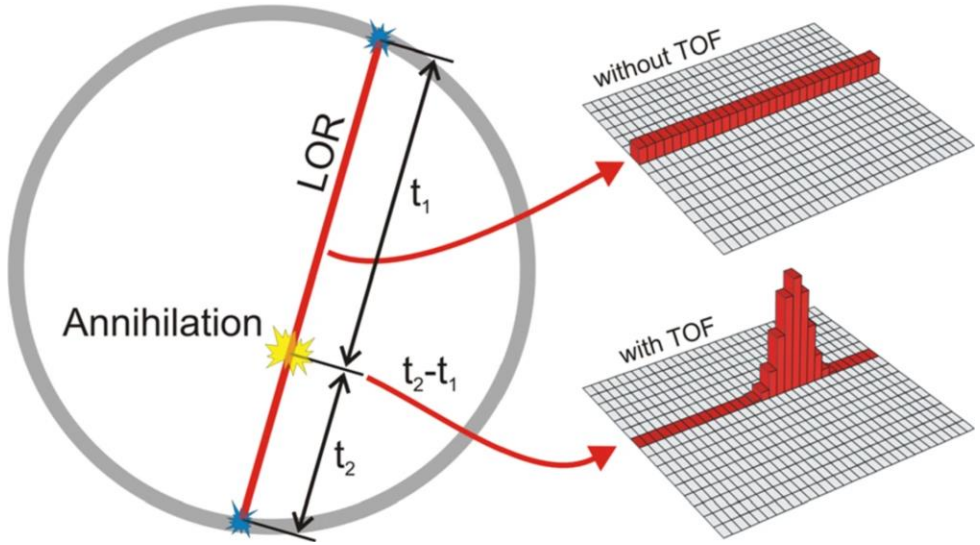
Time-of-flight (TOF)

- TOF information can be used in image reconstruction to increase Signal to noise ratio (SNR)
- State of the art time resolution (CTR) **FWHM 189 ps** (*Li G et al. 2024*)
  - Experimental measurements as low as 58 ps (*Gundacker S et al. 2019*)
- Every part of the detector contributes to the CTR
- Scintillators
  - Material properties
    - Rise and decay time, Light yield
  - Crystal length

[1] *Budinger T F 1983*

$$\mathrm{SNR}_{\mathrm{TOF}} = \sqrt{\frac{D}{\Delta d}}\mathrm{SNR}$$

[2] *Lecoq P et al. 2021*



$$\mathrm{CTR} \propto \sqrt{\frac{\tau_r \tau_d}{n}}$$

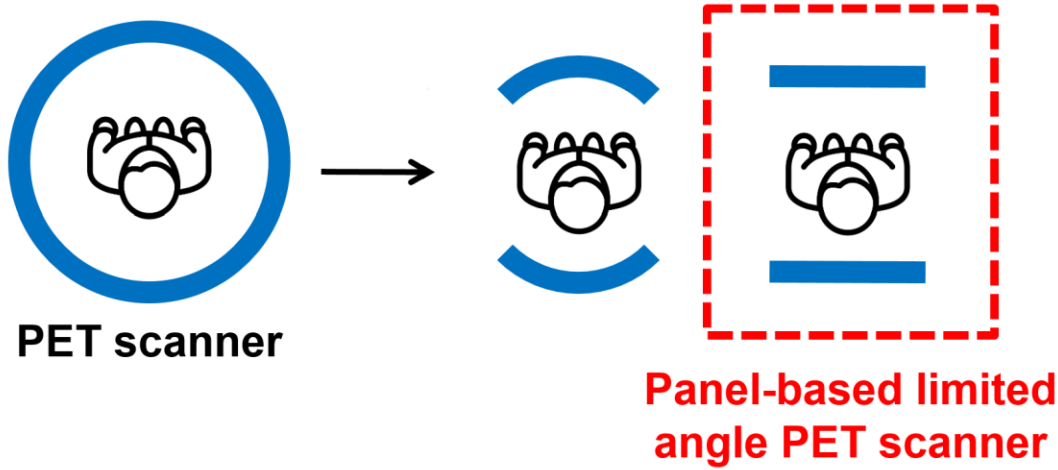
[3] *Gundacker S 2014*

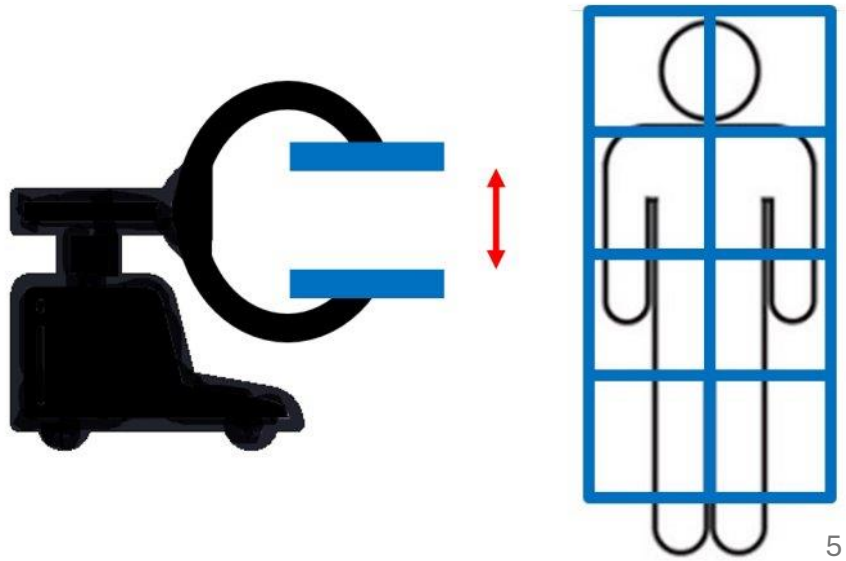
[4] *Orehar M 2026*

$$\Delta d = \frac{\Delta t \cdot c}{2}$$

Flat Panel Scanner Geometry

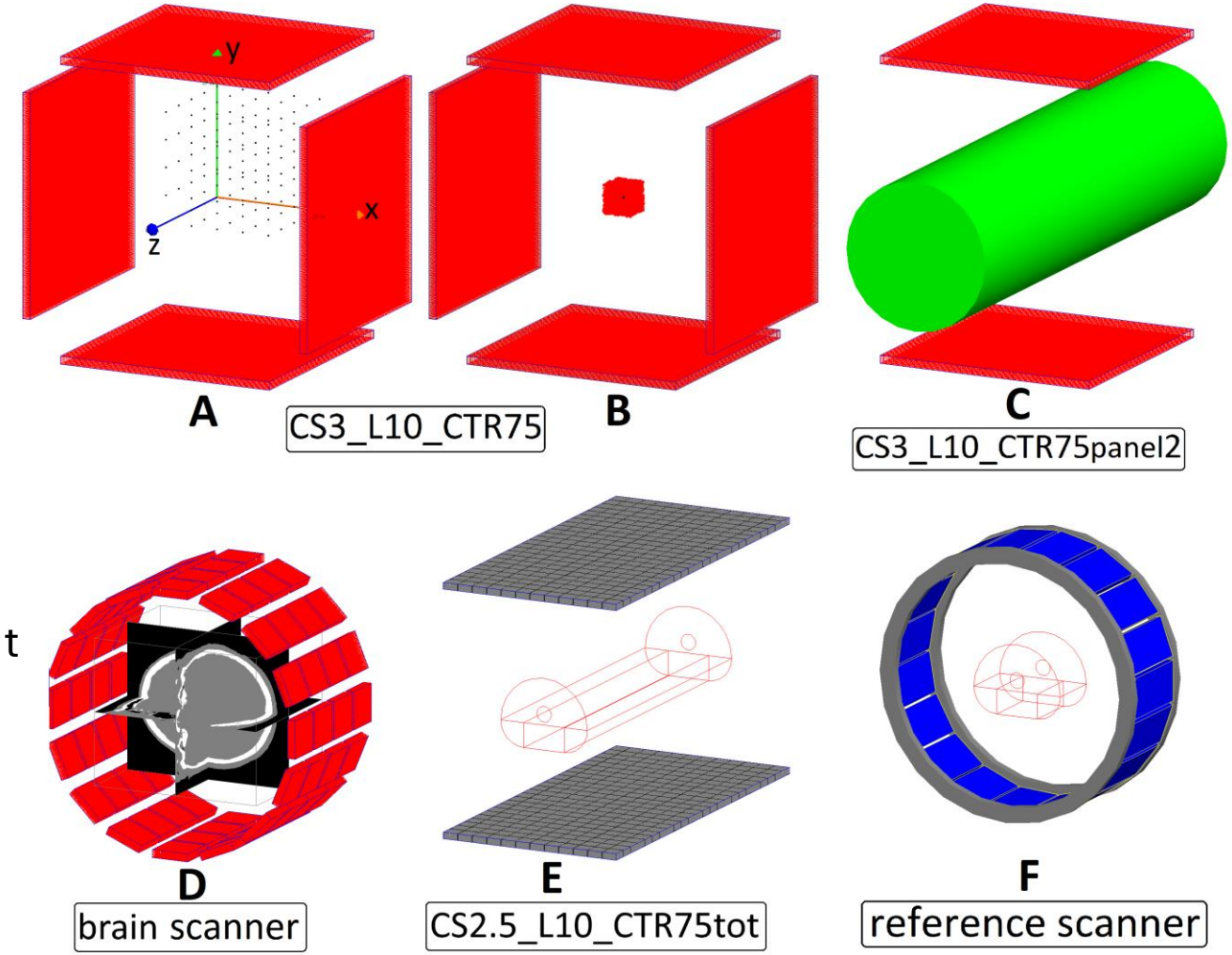
- Problems addressed with flat panel scanners:
  - **Open geometry** enables access to the patient
    - Particle Therapy monitoring (*Fuentes C et al. 2025*)
    - Surgery (*Sajedi S et al. 2021*)
  - Material **cost reduction**
    - Over 70 % scintillator material reduction and 30 % to 60 % reduction in number of detector elements (*Orehar M et al. 2024*)
  - Modular (number and placement of panels)
  - Flexible configuration per patient
  - Compact, mobile devices
- New challenges:
  - Sensitivity loss
  - Incomplete angular coverage
  - Parallax error
- Solutions:
  - Use of TOF information
  - Rotation of detectors
  - Smaller crystal dimensions
  - DOI encoding





Simulated scanner parameters

- Various simulated configurations and phantoms
- Tested parameters include crystal dimensions and time resolution
- All results compared to the reference scanner based on a clinical scanner (Siemens Biograph Vision)



Crystal cross-section

Crystal Length

Time resolution

Suffix for additional information (readout level, crystal pitch, extended scanners)

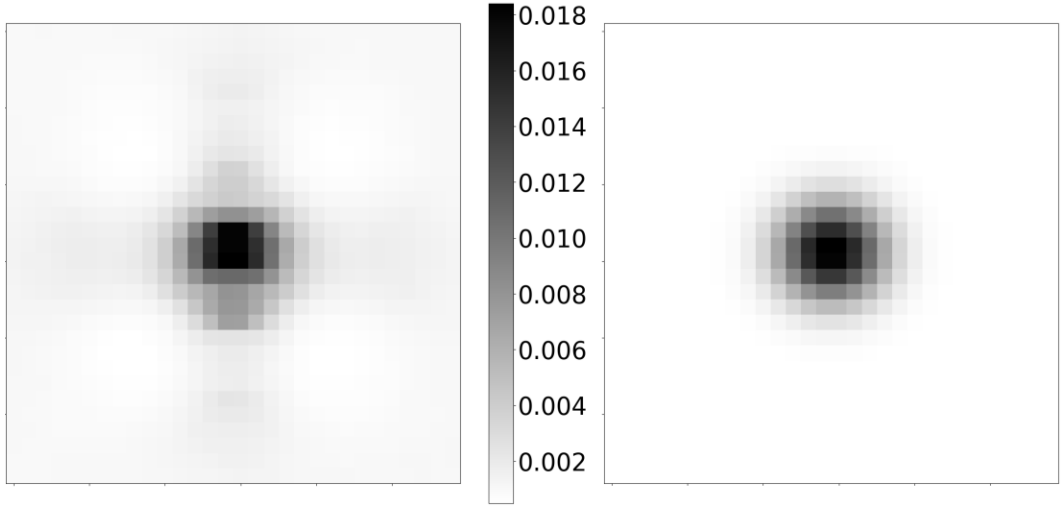
CS3_L10_CTR75submod

[1] *Orehar M 2026*

Spatial resolution

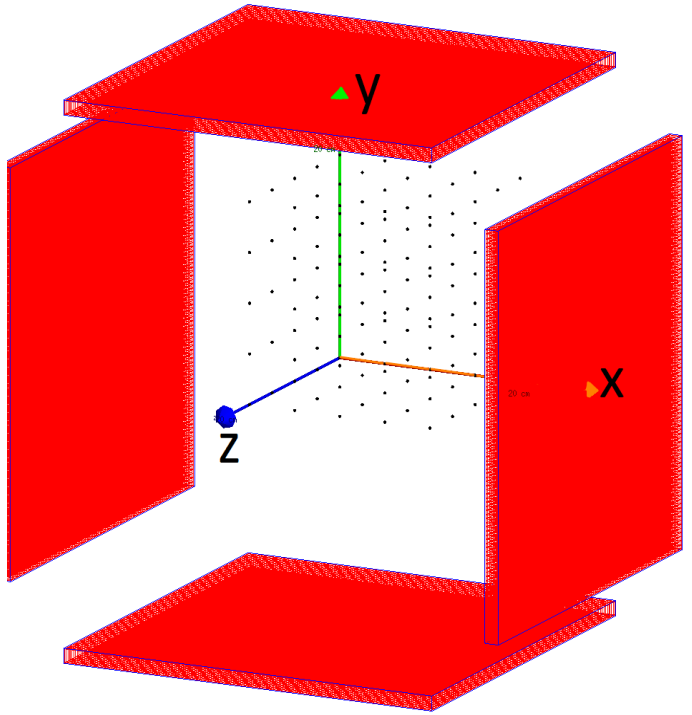
- Simulations of point sources in a rectangular grid (5x5x5) in the first octant
- Gaussian fitting of reconstructed images

$$f(x,y,z) = A \cdot e^{-\left(\frac{(z-z_0)^2}{2\sigma_z^2}+\frac{(y-y_0)^2}{2\sigma_y^2}+\frac{(x-x_0)^2}{2\sigma_x^2}\right)} + C$$



Reconstructed image Fitting result

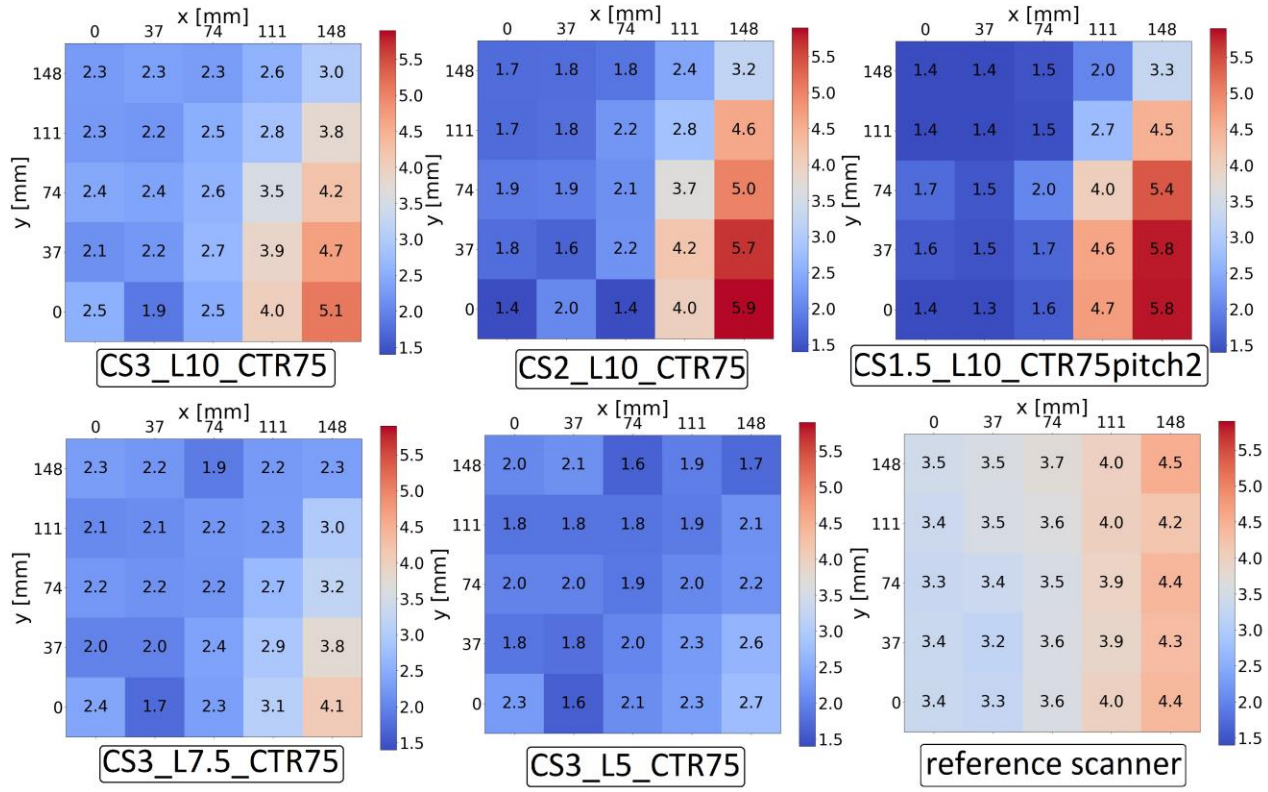
[2] *Orehar M 2026*



[1] *Orehar M et al. 2024*

Spatial resolution

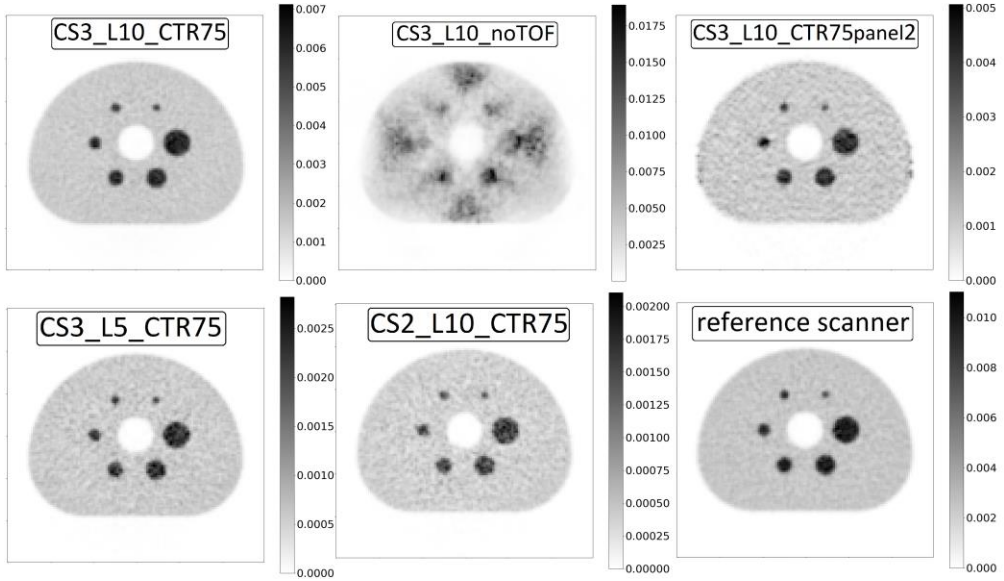
- Variability of resolution across the FOV (first quadrant)
- Effect of:
  - Crystal cross-section and pitch
  - Crystal length
- Optimisation between cost, CTR and sensitivity
- Compared to the reference scanner
  - Crystal dimensions 3.2x3.2x20 mm^3
  - Crystal pitch 3.21 mm
  - CTR 214 ps



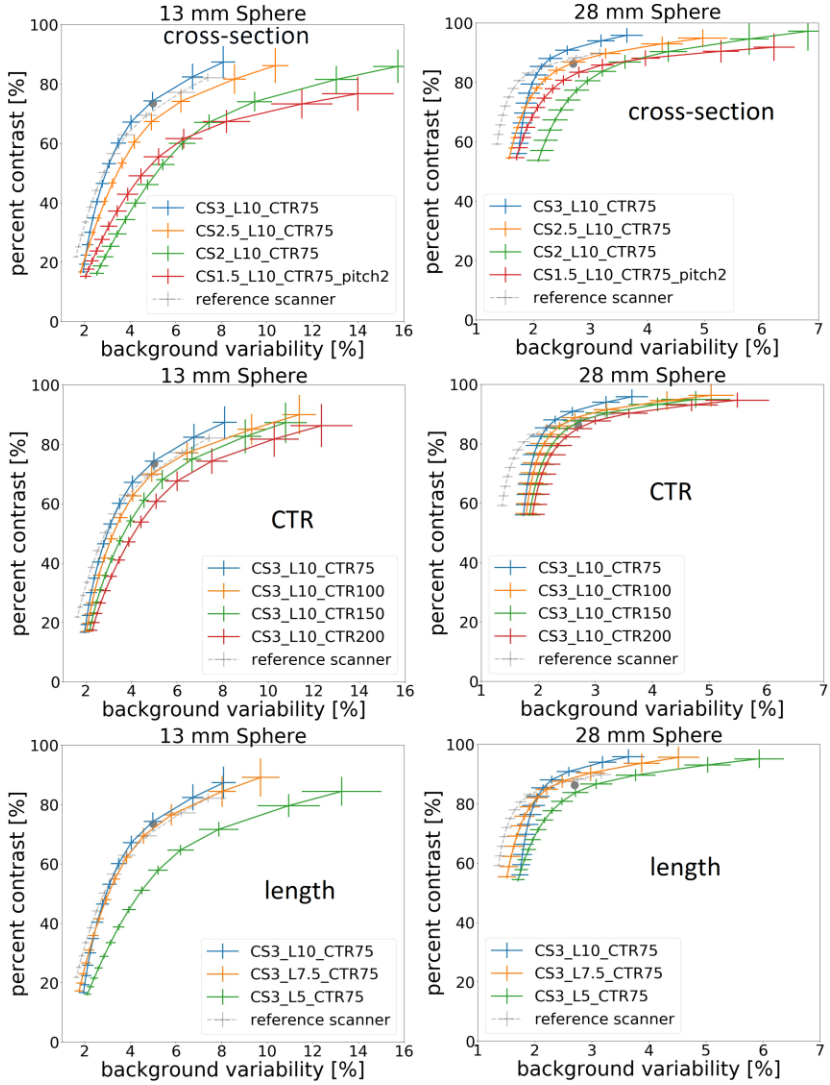
[1] *Orehar M et al. 2024*

Image Quality

- Performance of different scanner configurations and parameters
  - Crystal cross-section, length
  - CTR
- Gaussian filters of different widths applied to reconstructed images to get different metric values



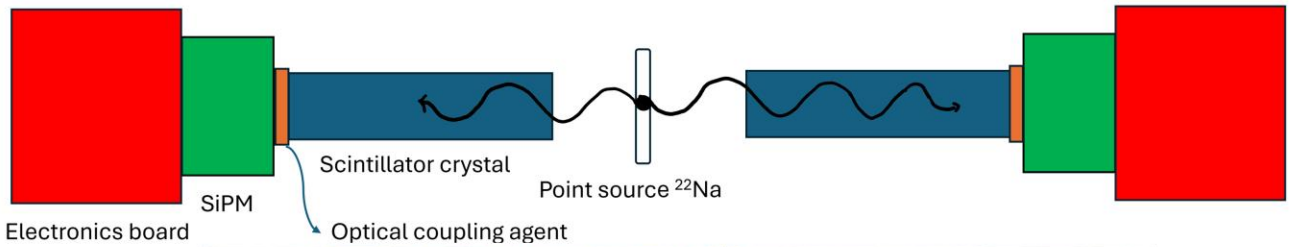
[1] *Orehar M 2026*

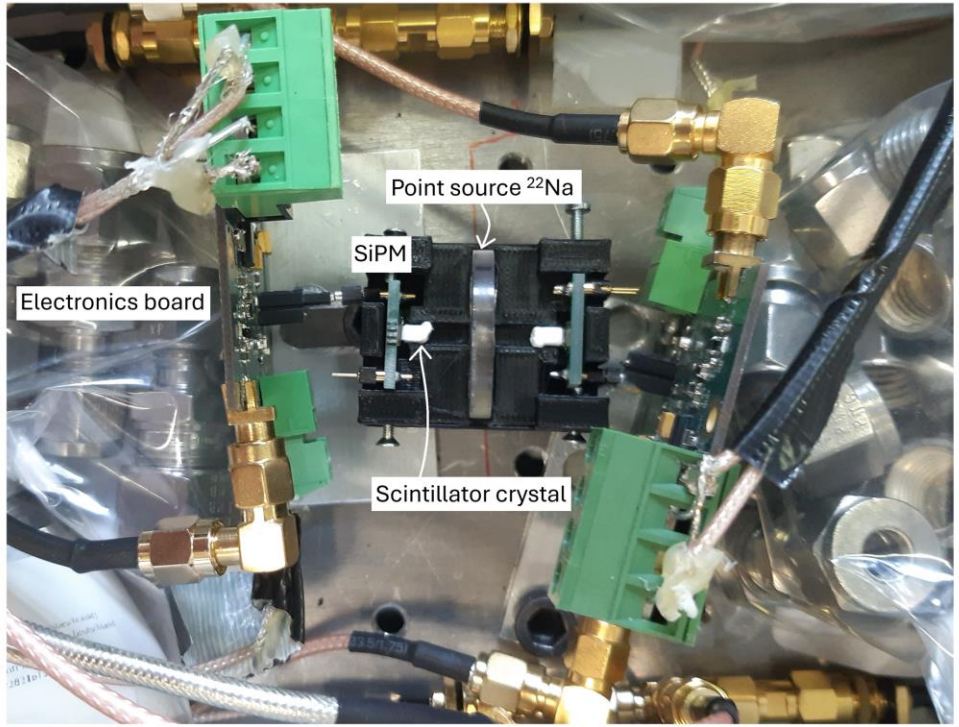


[2] *Orehar M et al. 2024*

Experimental setup for CTR measurements

- Minimal coincidence setup consisting of 2 detector elements
  - Scintillator crystal wrapped in Teflon tape, coupled to a SiPM (optical coupling gel)
- Signal from electronics board input directly into an oscilloscope
- Each detector produced a pair of waveforms per event
  - Time information (high level of amplification)
  - Energy information (low level of amplification)
- Waveforms saved to a computer for analysis

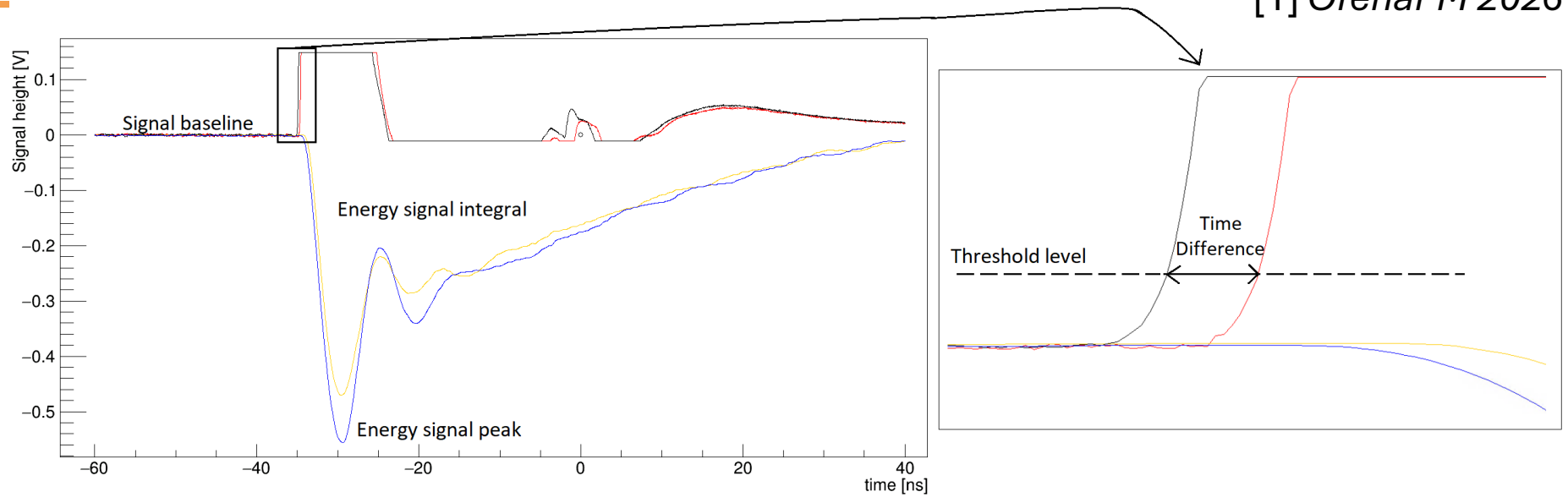


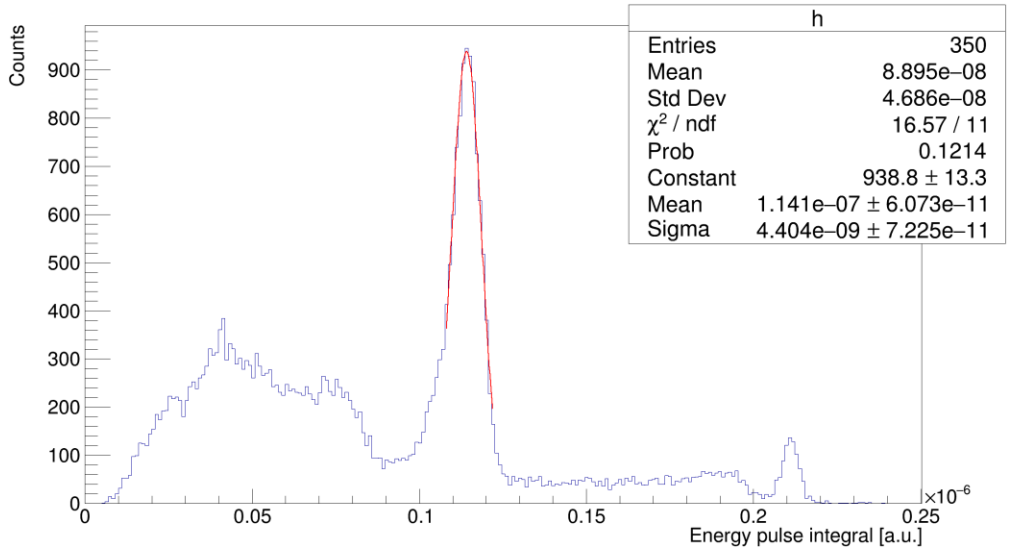


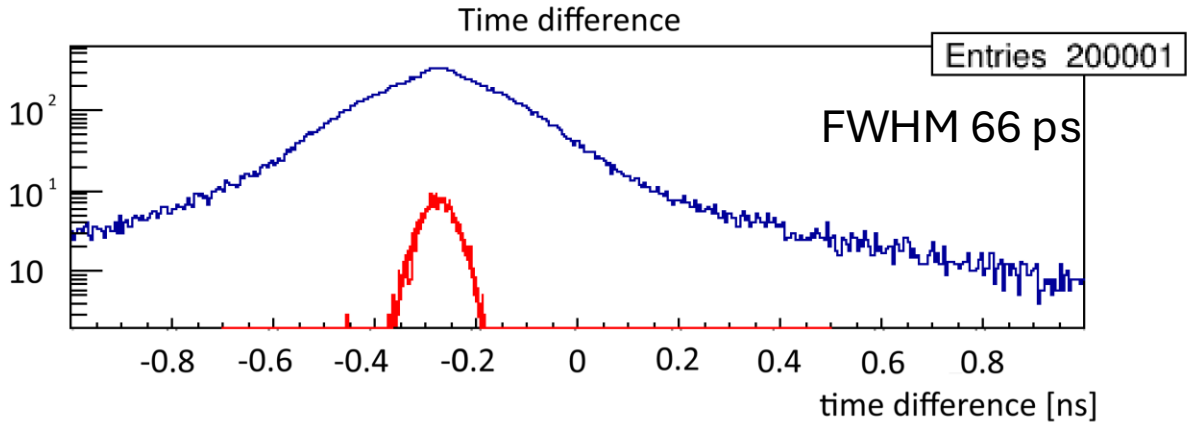
[1] *Orehar M 2026*

Waveform analysis

[1] *Orehar M 2026*

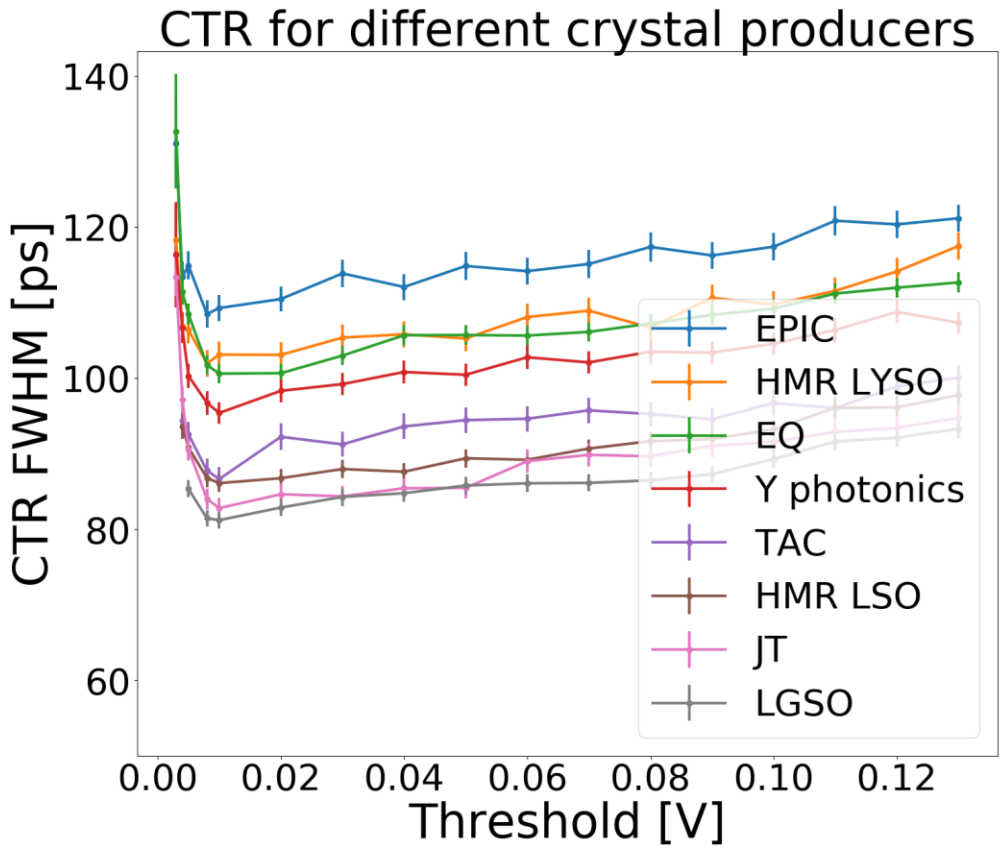






Coincidence Time Resolution Measurements

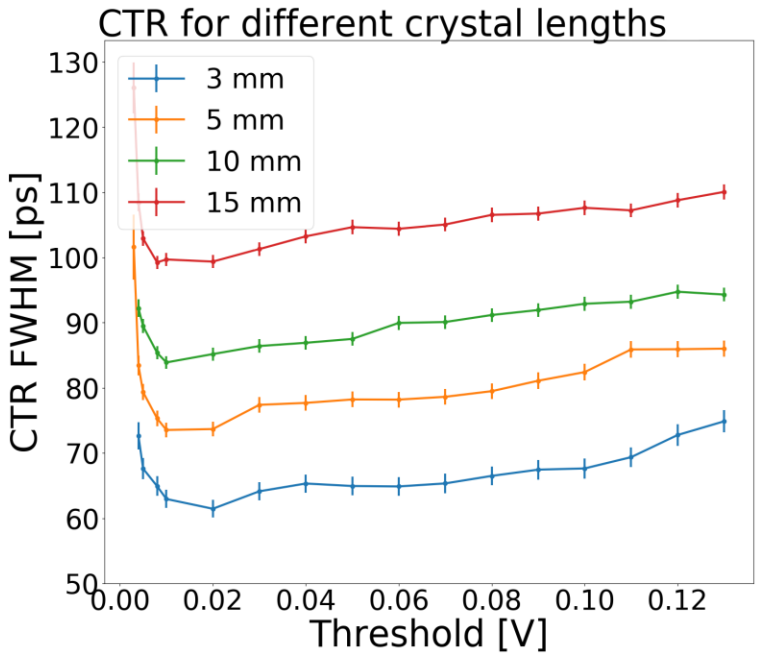
- Comparison of performance for crystal from different producers
- Crystal dimensions 2.8x2.8x10 mm3
- Bias voltage 50 V
- Best result achieved: 81 ps
- Repeatability difficulties
  - SiPM durability

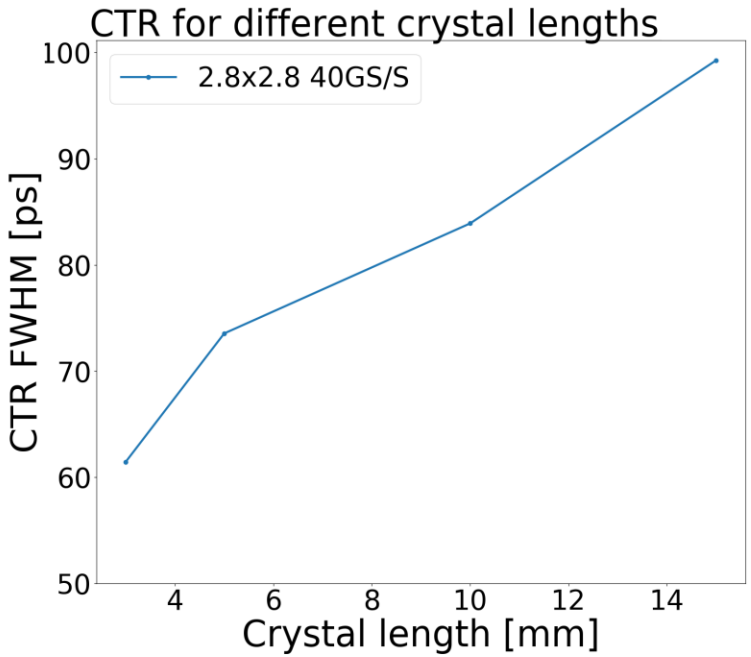


[1] *Orehar M 2026*

Coincidence Time Resolution Measurements

- All crystals from the same producer
- Crystal lengths from 3 mm to 15 mm
- Best result achieved: 61 ps

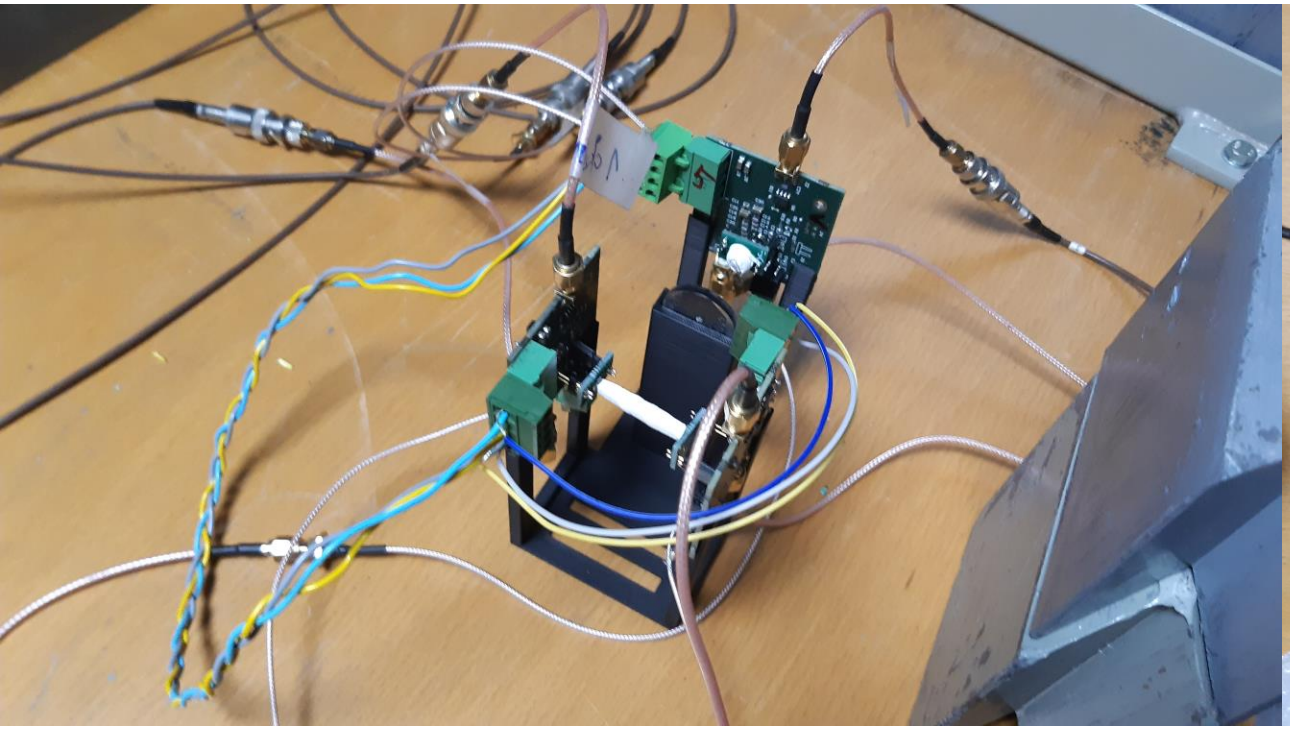


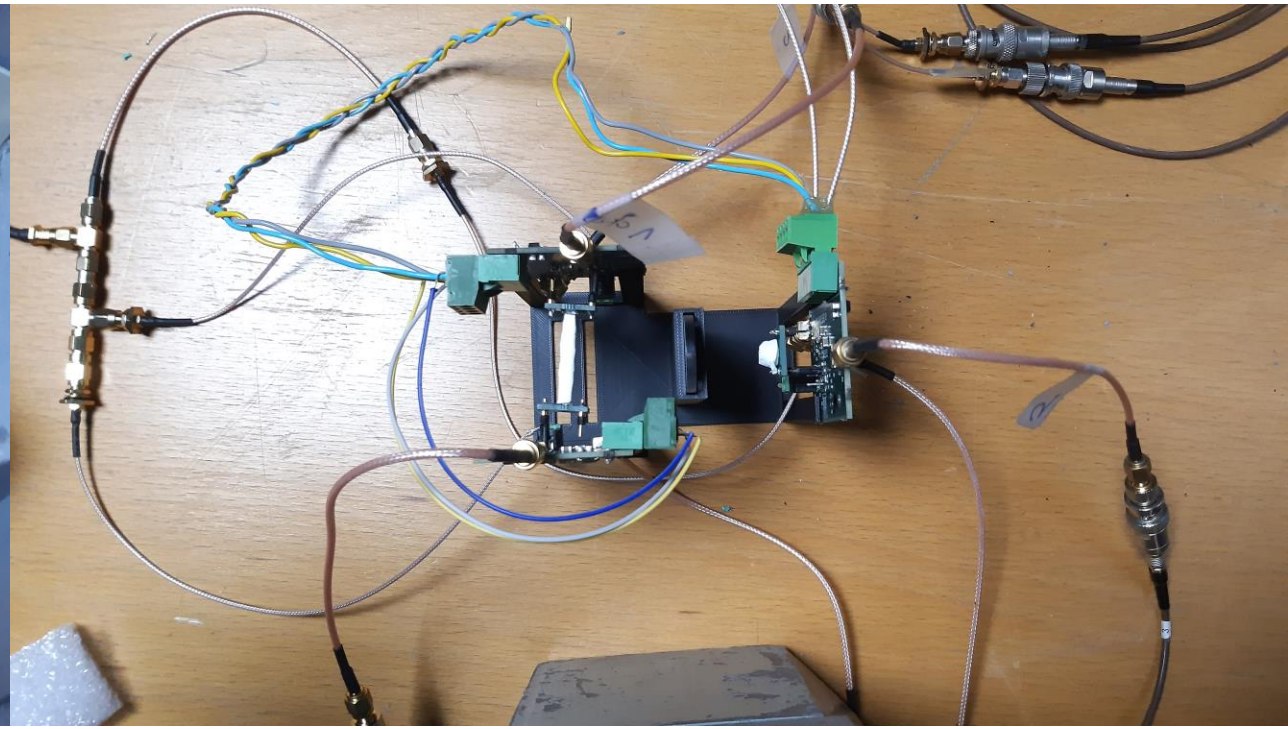


[1] *Orehar M 2026*

Double sided readout setup

- Depth of interaction (DOI) measurements – currently in progress

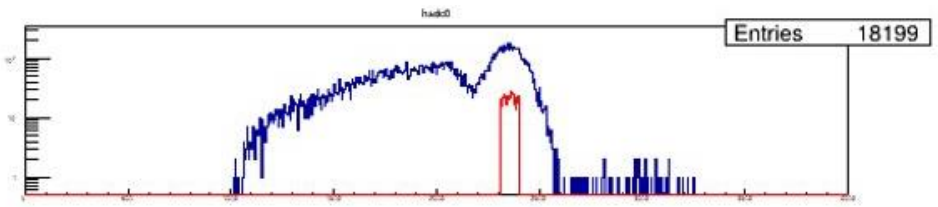




Redone analysis

- DOI position 68% of length
- DOI error 21% of length

ADC



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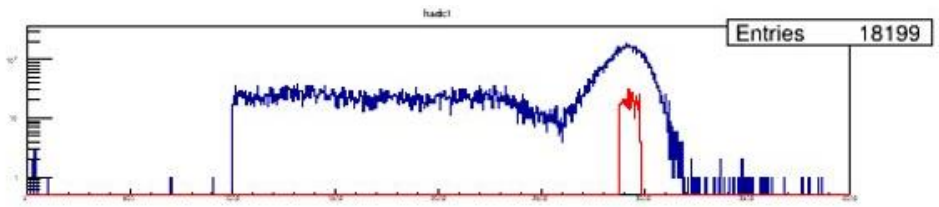
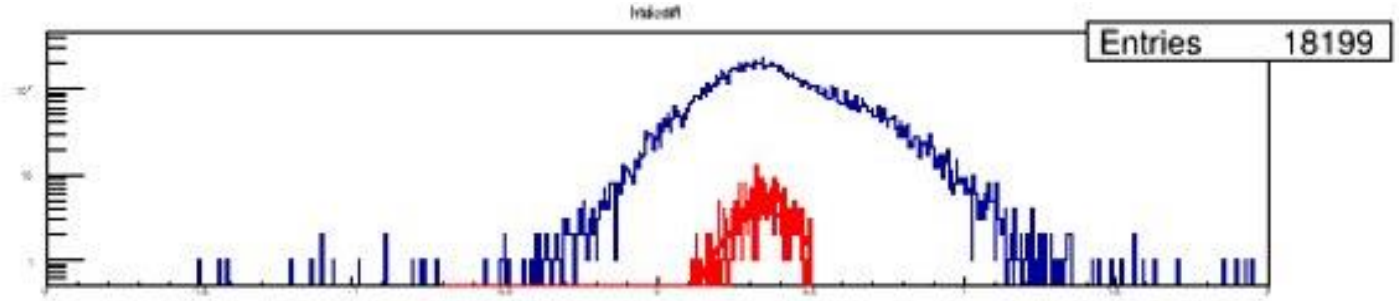
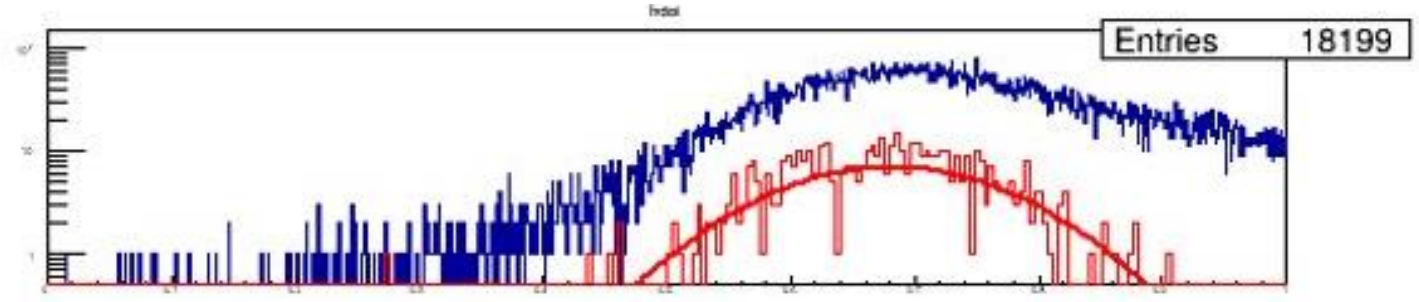


CTR



DOI



Q & A