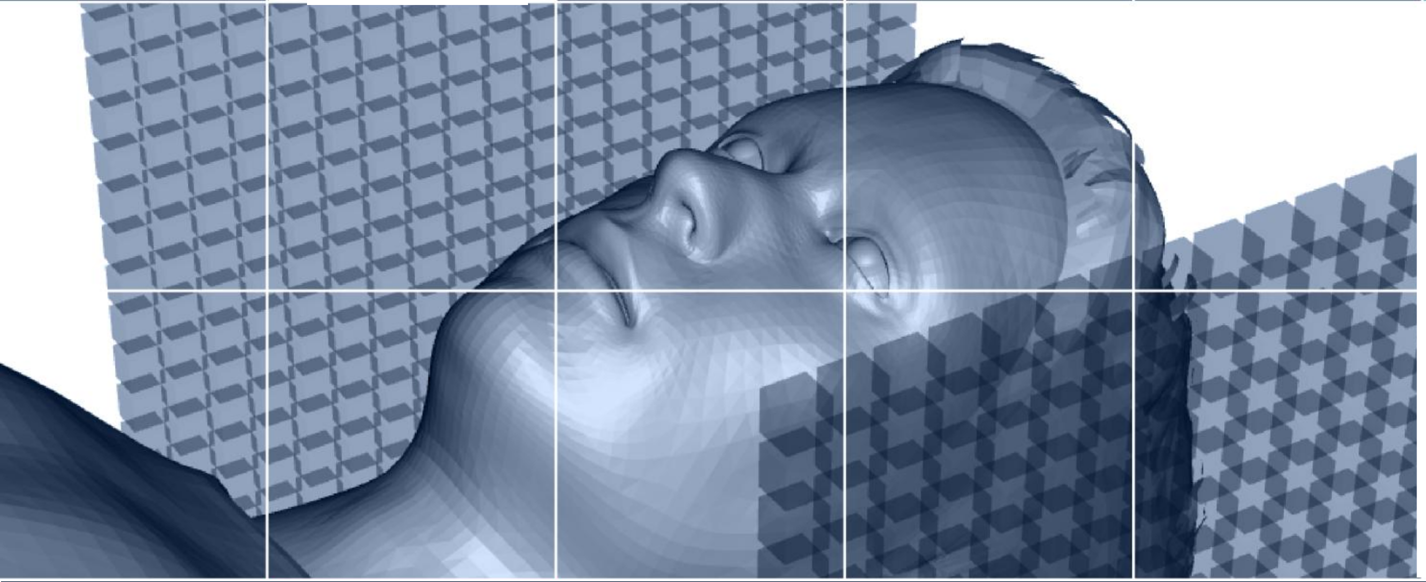
Follow PetVision project on LinkedIn



PetVision & ARIS PET

Gašper Razdevšek

Institut "Jožef Stefan" Ljubljana, Slovenija

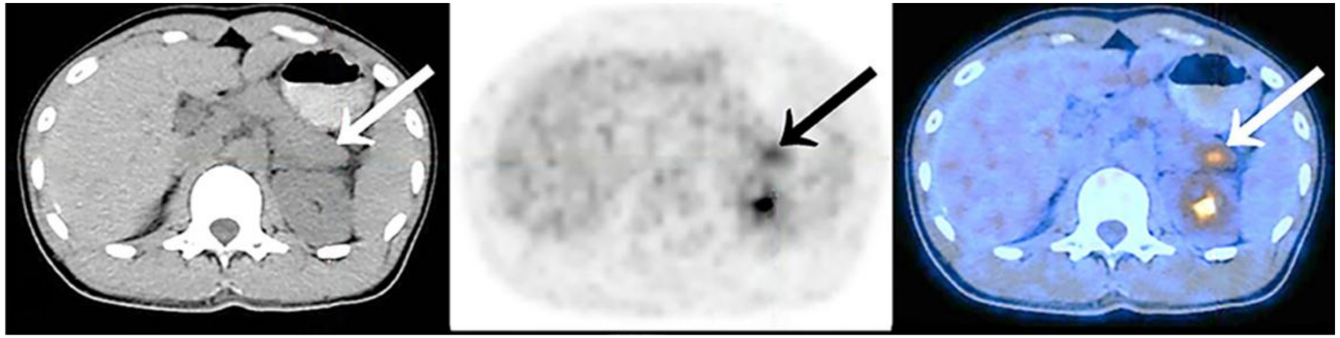
PET VISION

F9 Strategic meeting, Krvavec, September 28-30 2026

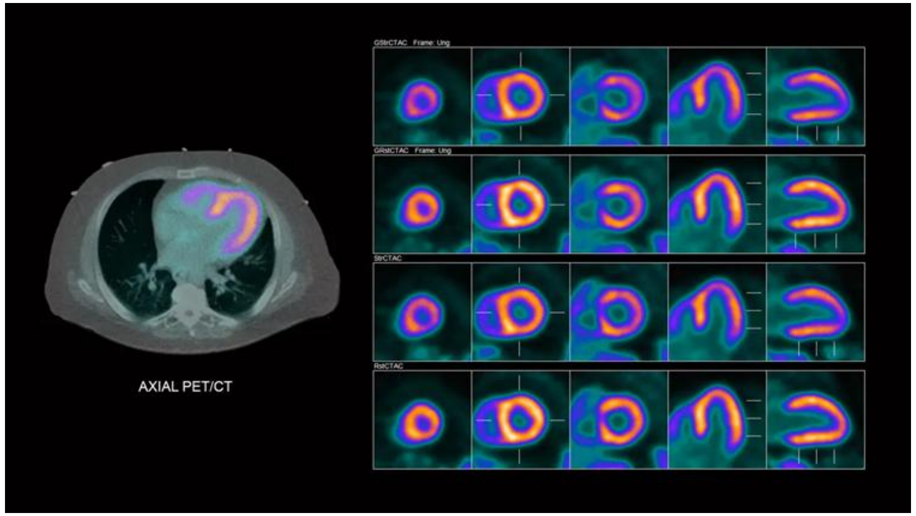
Positron emission tomography (PET)

- Medical imaging technique that uses radioactive tracers to produce **3D images of functional processes in the body**
- PET/CT imaging:
  - PET → **functional** information
  - Computed tomography (CT) → **anatomical** information

  complementary information
- Oncology, Cardiology, Neurology

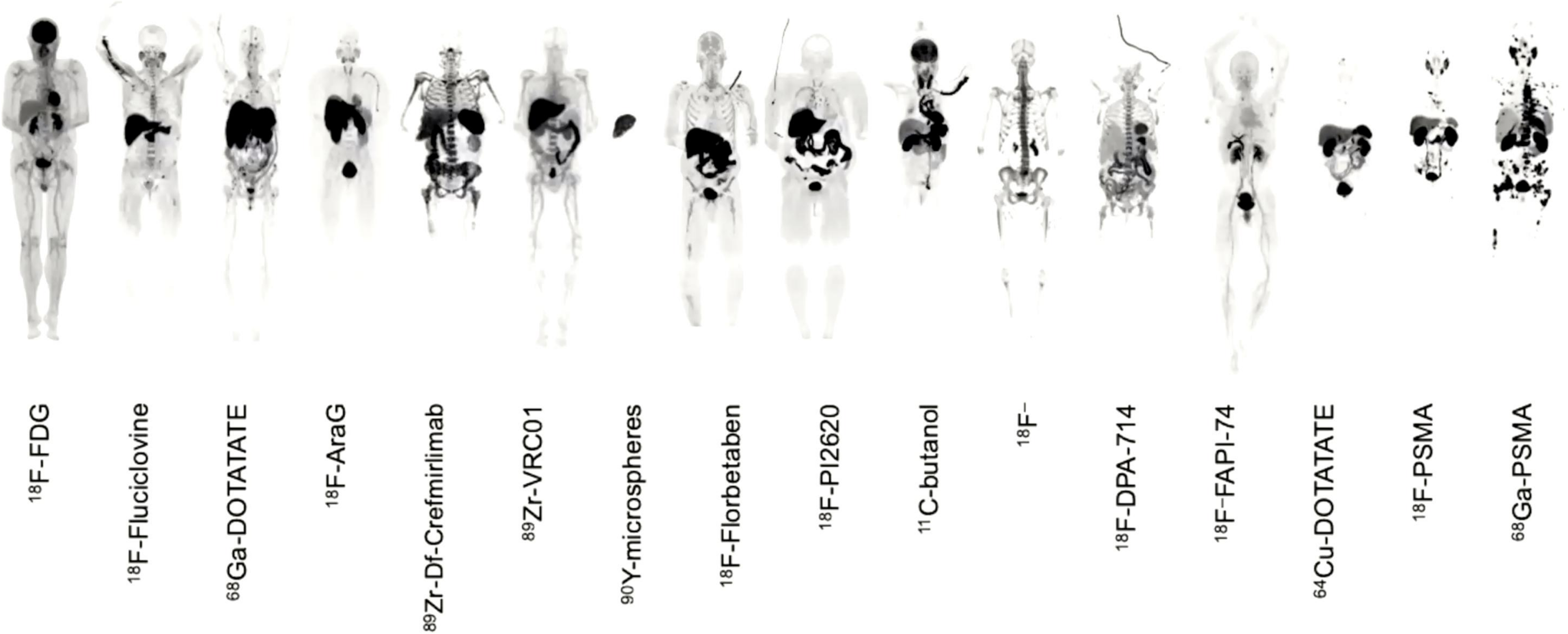


CT PET PET + CT



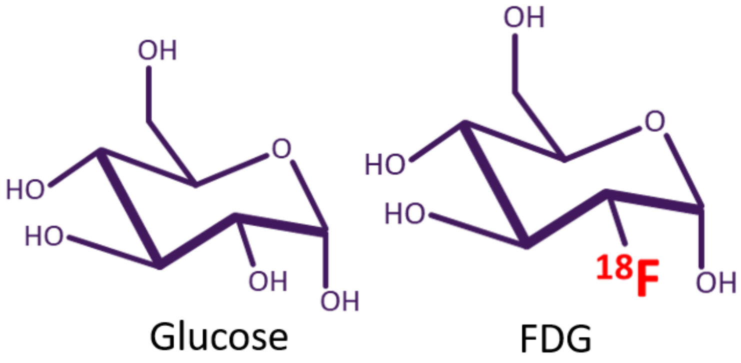
PET radiotracers

- Different radiotracers → different distributions in the body



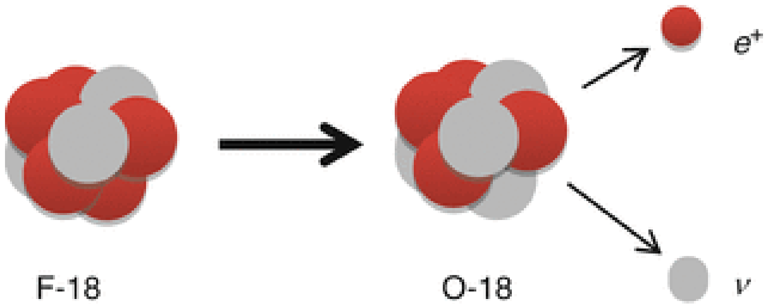
PET – basic principle

1) Injection of radiotracer into the patient



Injector

2) Radionuclide undergoes β+ decay → emitted positron (e^+)



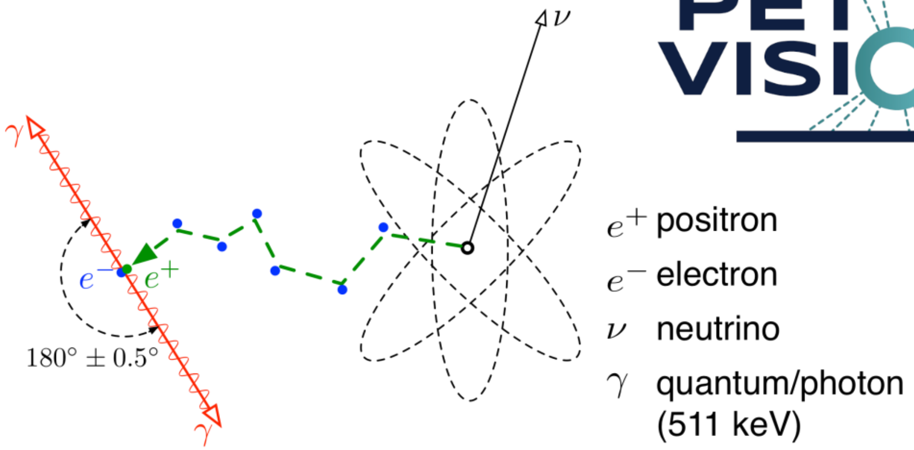
PET – basic principle

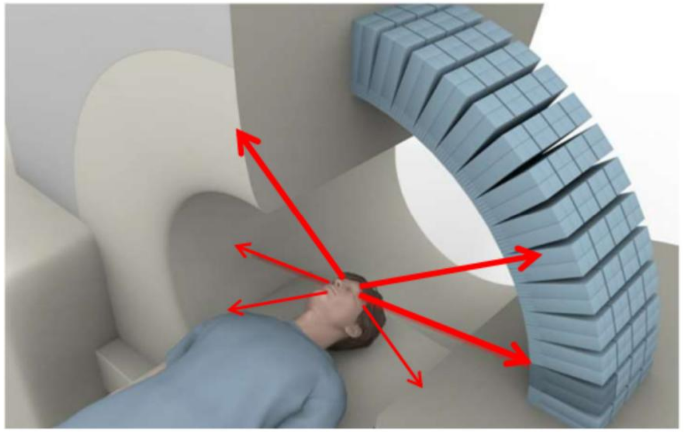
3) e^+e^- annihilation → 2 gamma rays

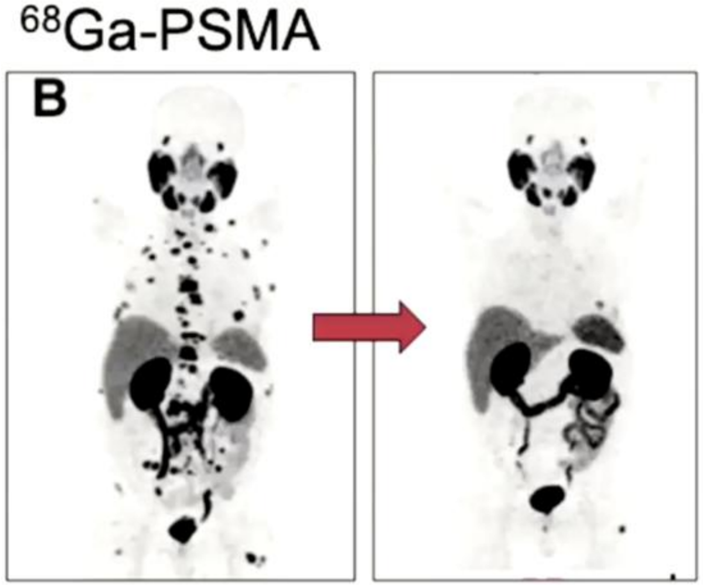
$$(E_\gamma = 511\,\mathrm{keV})$$

4) Detection of both gammas → coincidence event → line-of-response (LOR)

5) Image reconstruction → 3D image showing the distribution of the radiotracer in the body



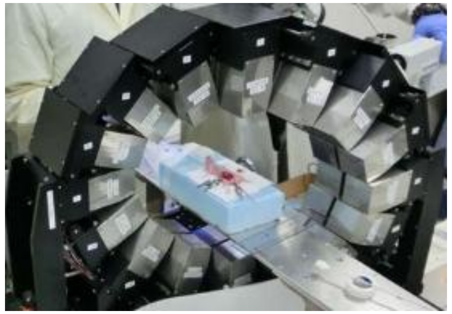




Shagera et al, J Nucl Med 63: 1191-98 (2022)

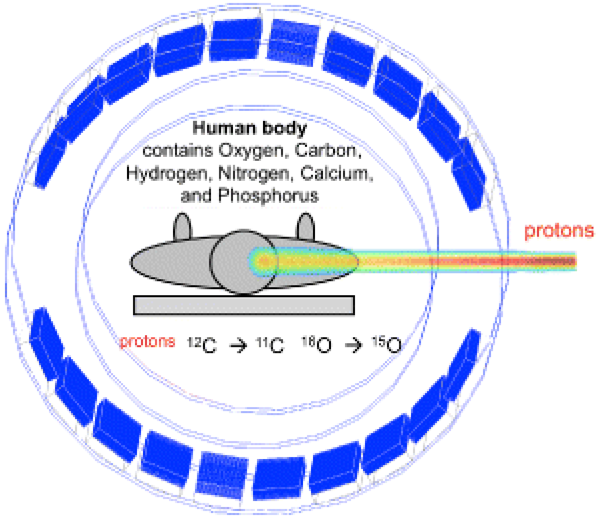
PET scanners

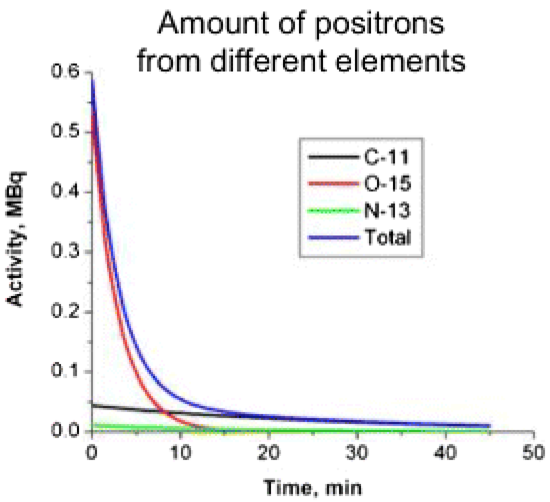
- Full-ring PET is the clinical standard.
- Ring systems are not ideal for every clinical or research scenario.
- Can we make the geometry more flexible without sacrificing image quality?



Yoshii et al., Oncotarget 9, 28935–28950 (2018), doi:10.18632/oncotarget.25649

The Walk-Through PET (https://www.wt-pet.org/)

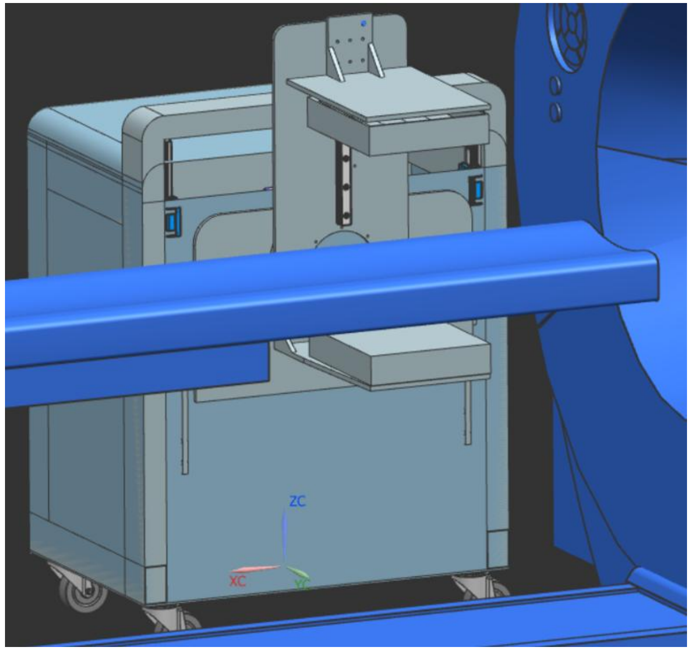


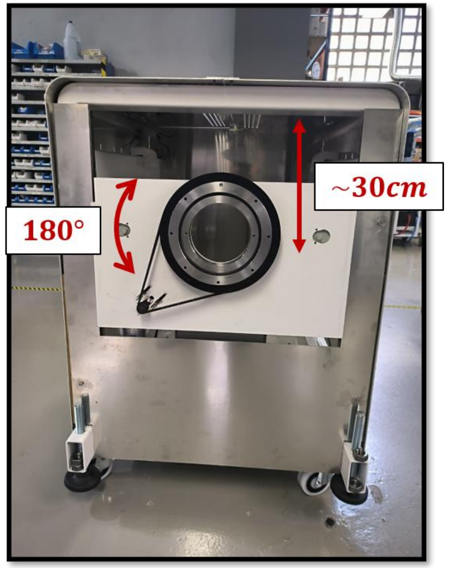


Vandenberghe et al., EJNMMI Physics 3, 3 (2016), doi:10.1186/s40658-016-0138-3

PetVision project

- Develop a flexible, modular and cost-effective PET scanner based on **two opposing planar detector panels** with **excellent TOF resolution**.





Rok Pestotnik
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David Gascon
Chip design
Universitat de Barcelona

Alberto Gola
Photo sensors
2D integration
Fondazione Bruno Kessler — Future built on knowledge

Georges El Fakhri
Associated P. Hospital: Design & Validation
Yale

Rafael Ballabriga
Chip design
CERN

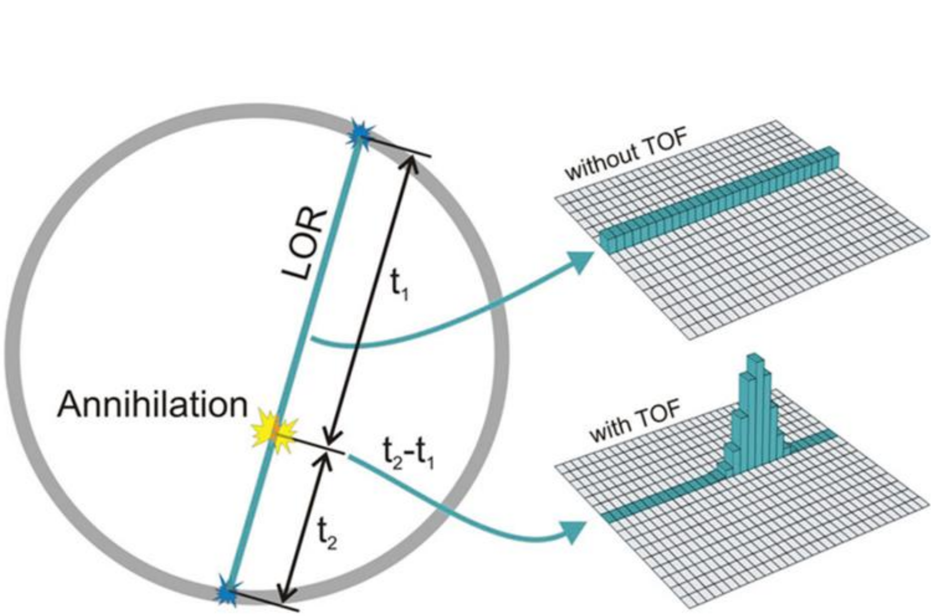
Wolfgang Weber
Hospital: Validation
MRI Klinikum rechts der Isar Technische Universität München
TUM

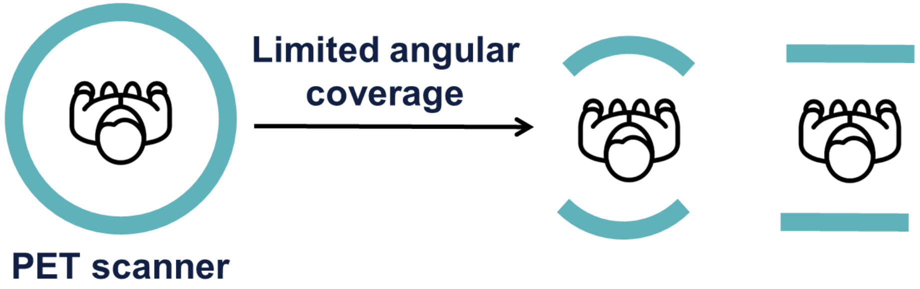
Jose Benlloch
Readout Electronics
Data Acquisition
i3M

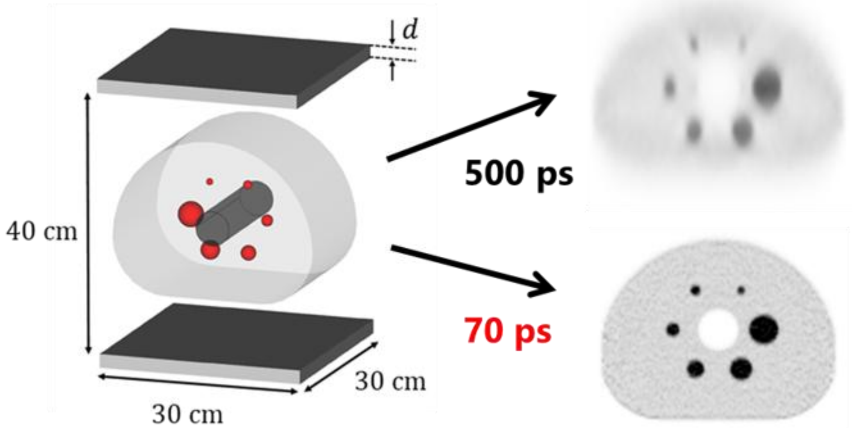
David Sanchez
SME: Mechanics & Software
Onco Vision

Time-of-flight (TOF) information

- Improves localization of the annihilation event, reduces noise correlations, and increases image signal-to-noise ratio (SNR) → **sensitivity amplifier**
- TOF also **enables reduced angular sampling** → open-PET geometry







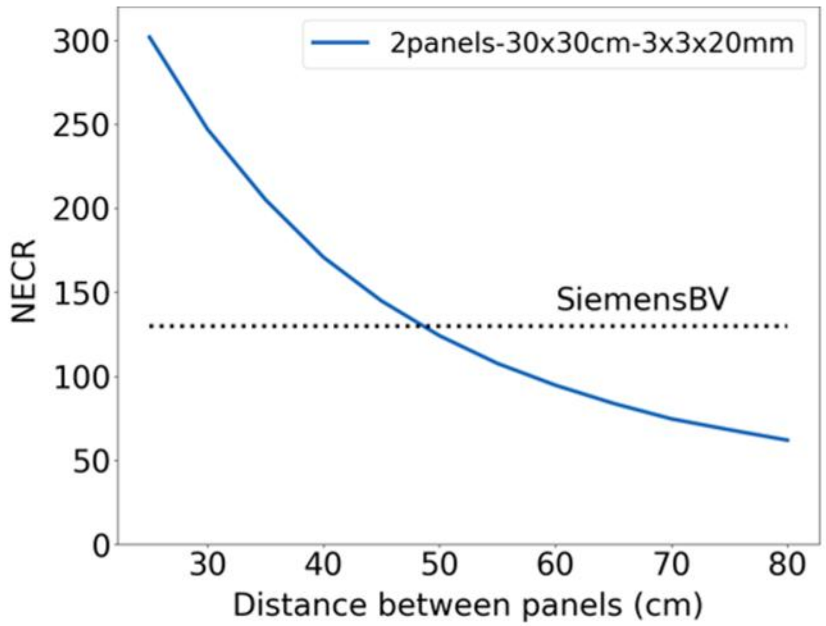
Advantages of panel detectors

Flexibility → adjustable FOV and sensitivity

Mobility → portable or bedside PET imaging

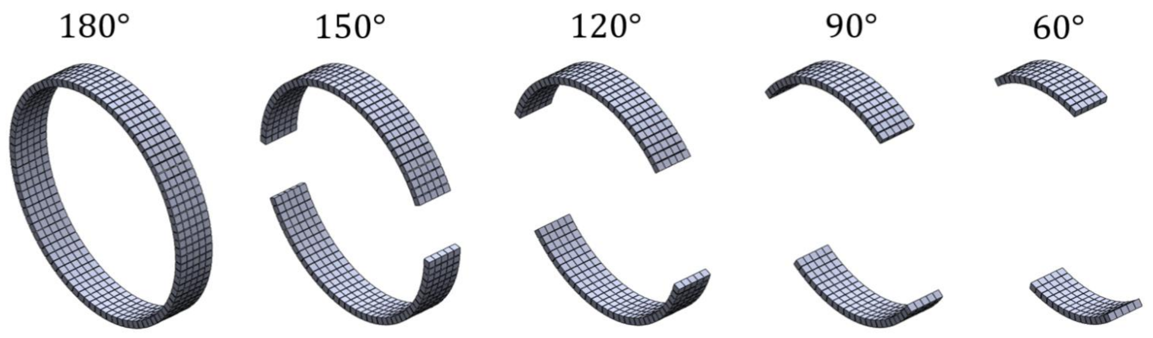
Modularity → multi-organ/total-body PET scanner

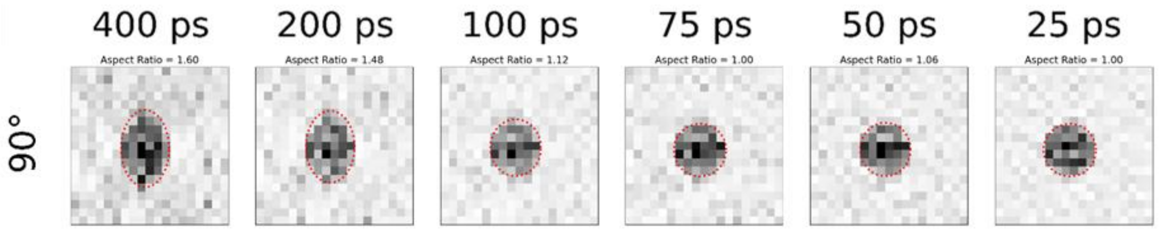
Accessibility → reduced manufacturing cost and complexity

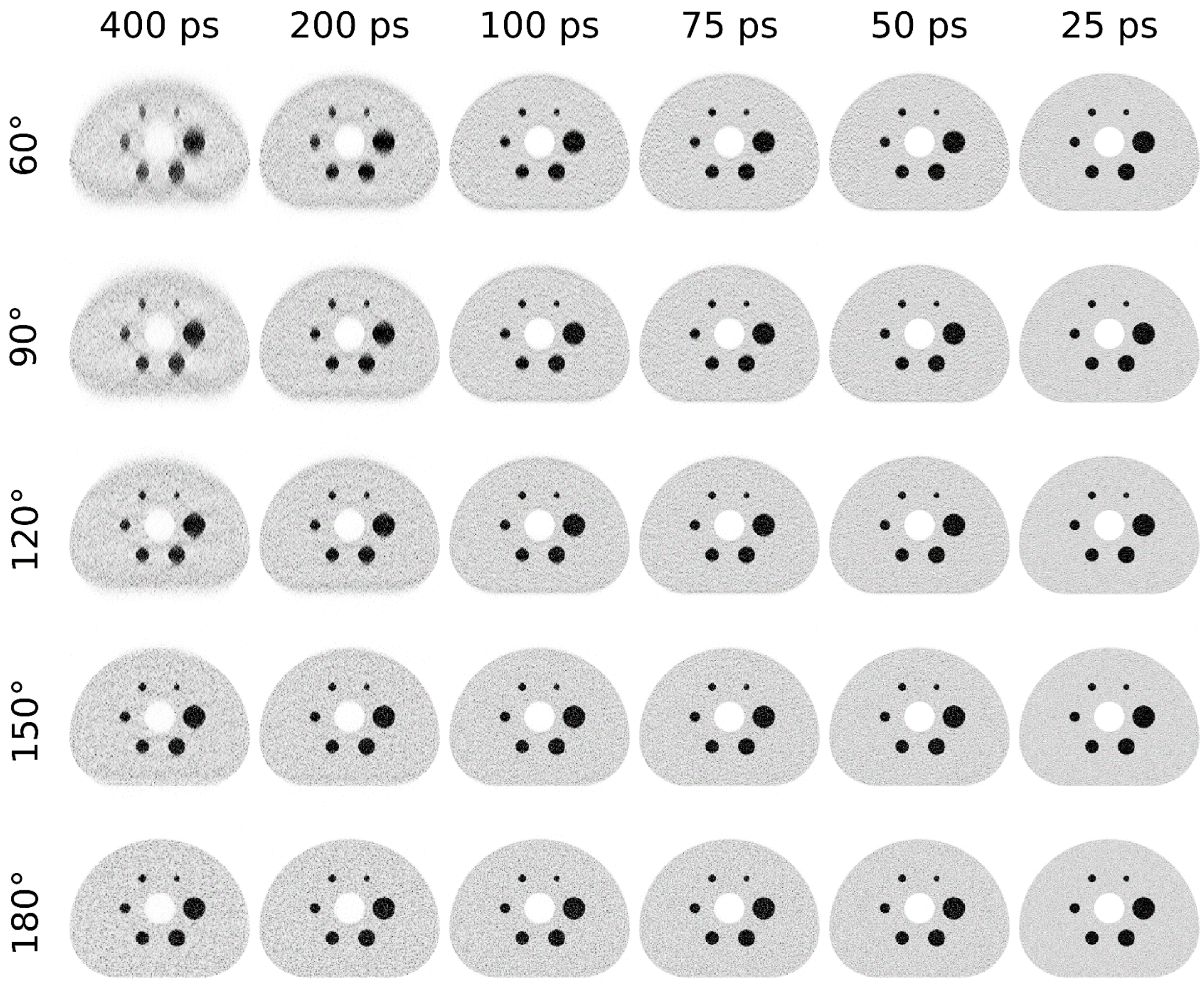


Razdevšek G, et al. Flexible and modular PET: Evaluating the potential of TOF-DOI panel detectors. Med Phys. 2025; 52: 2845–2860. https://doi.org/10.1002/mp.17741

TOF Requirements for Artifact-Free Open-Geometry PET



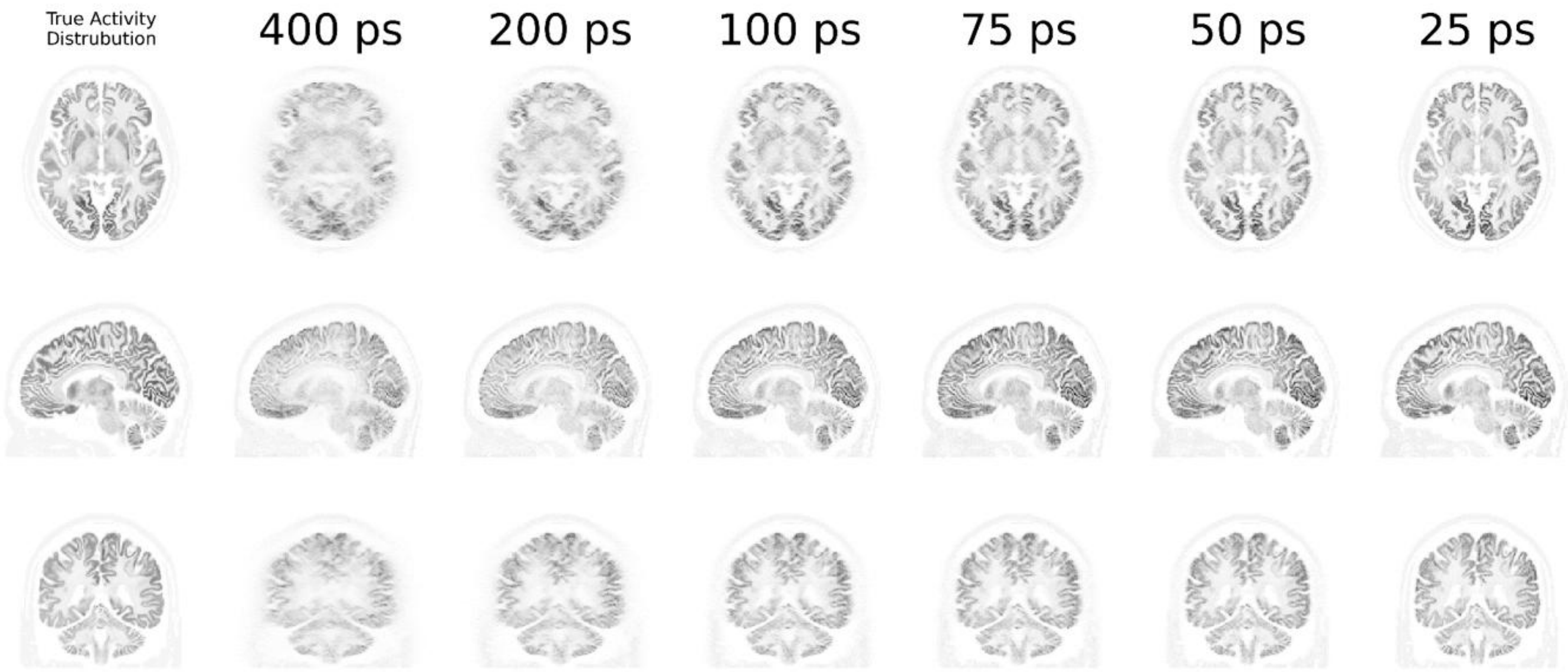


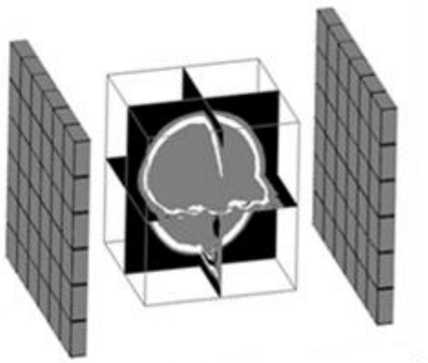


TOF ≤ 100 ps → the key to unlocking the full potential of open-geometry PET imaging

2-Panel System: Monte Carlo simulation

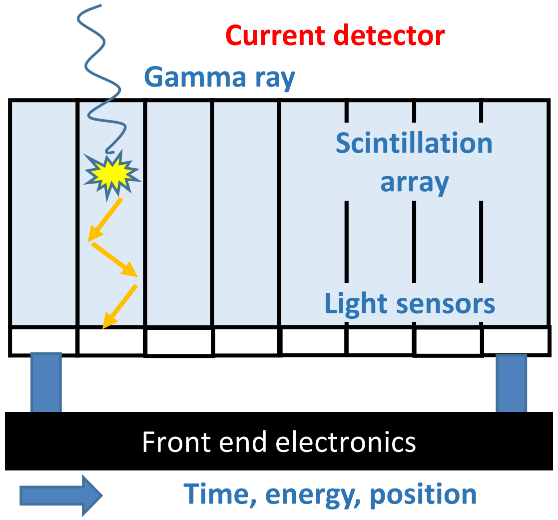
- 2 panels: 30 x 30 cm, panel separation: 30 cm (90° angular coverage)
- High-resolution brain phantom [18F]FDG, 100 M true events

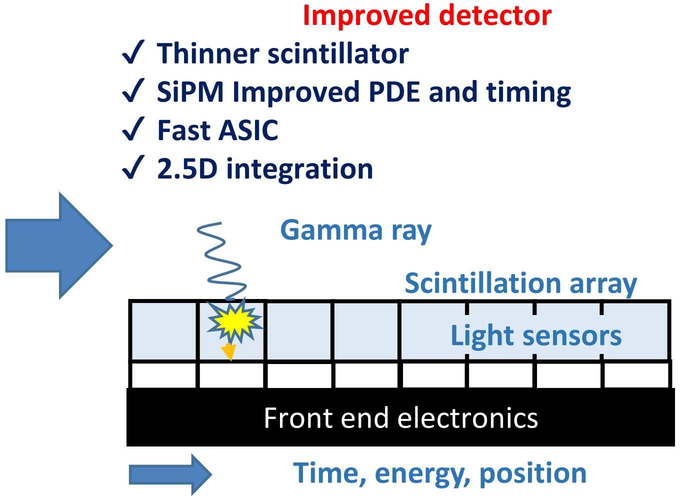


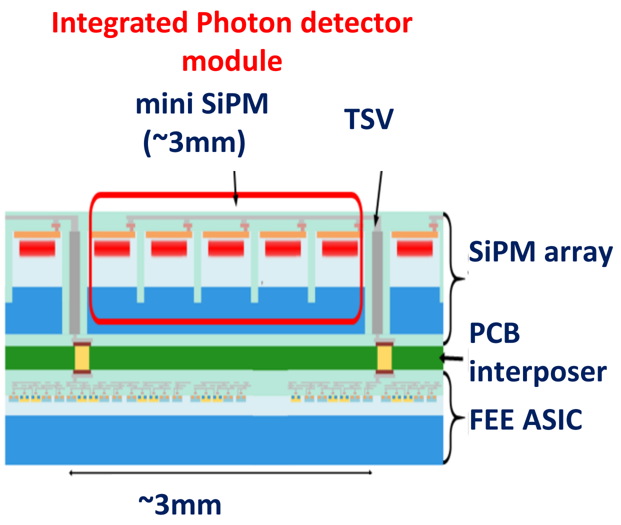


How do we plan to achieve sub-100 ps TOF resolution?

- Shorter crystals → 10 mm (3×3×10 mm + 100 ps ≈ 3×3×20 mm + 200 ps)
- High-PDE SiPMs → Sensor based on NUV-HD-MT + TSV technology
- Fast ASICs → PoETIC, a highly configurable pixelated ASIC for fast-timing applications based on FastIC
- Minimized-capacitance interconnects → 2.5D integration





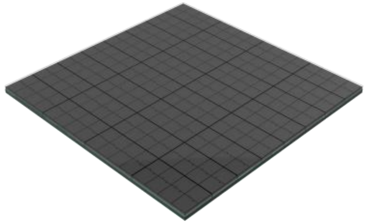


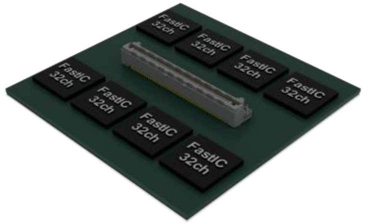
Timeline

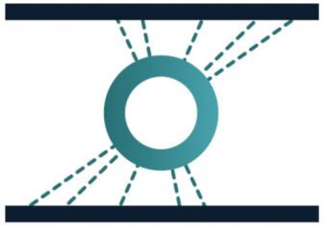
2026

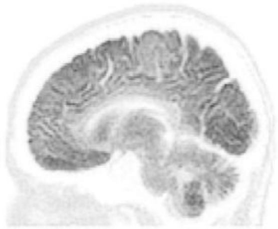
PetVision

Year 2	Year 3	Year 4	Year 5	Year 6-7
3x3 mm^2 Photo Sensor with improved performance	**PoETIC ASIC and integration into a digital module**	**Integration of the prototype: 2 panels 30x30 cm^2**	**Validation in two hospitals**	**Further developments & exploitation**









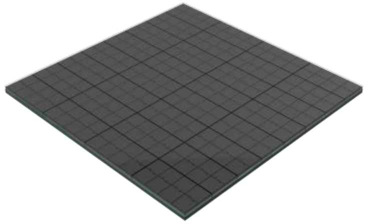
Further funding

On the way and beyond PetVision

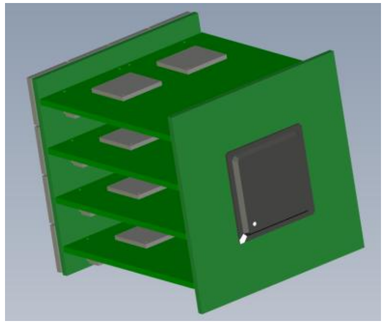
2026

ARIS-PET

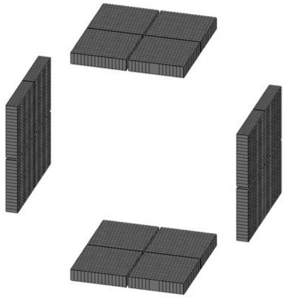
Year 1: 3x3mm^2 Photo Sensor with improved performance



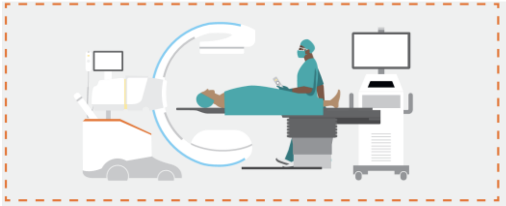
Year 2: FastIC+ ASICs on the plugin cards



Year 3: Integration of the smaller prototype 10 x 10 cm^2



Year 4: Validation in a hospital



Slovenian Research and Innovation Agency

Jožef Stefan Institute, Ljubljana, Slovenia

UNIVERZA V LJUBLJANI
University of Ljubljana

univerzitetni klinični center ljubljana
University Medical Centre Ljubljana

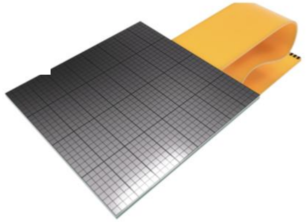
Project no. J7-50229

Year 1 | Year 2 | Year 3 | Year 4 | Year 5

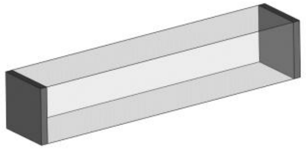
Fastsight

Year 1: DOI - Dual-sided readout of the light from longer crystals

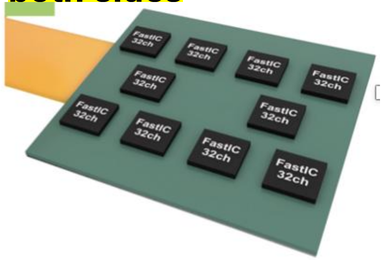
Year 2: 1.5x1.5 mm^2 Photo Sensor



Year 3: Crystals: 1.5x1.5x 20 mm^3



Year 4: PoETIC ASICs to combine info from both sides



Year 5: Integration and validation in a hospital

National Institutes of Health
Turning Discovery Into Health

R01 EB036642

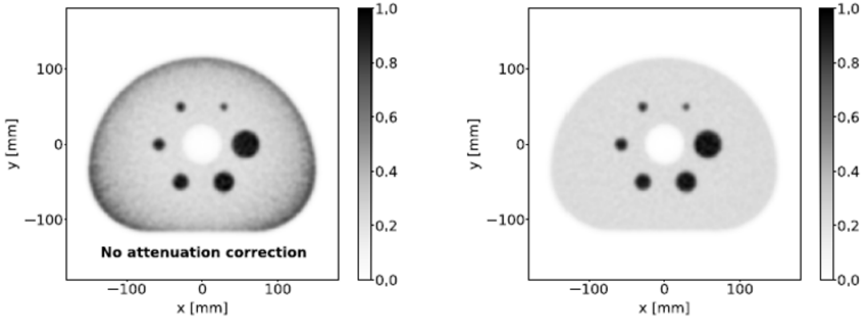
Yale

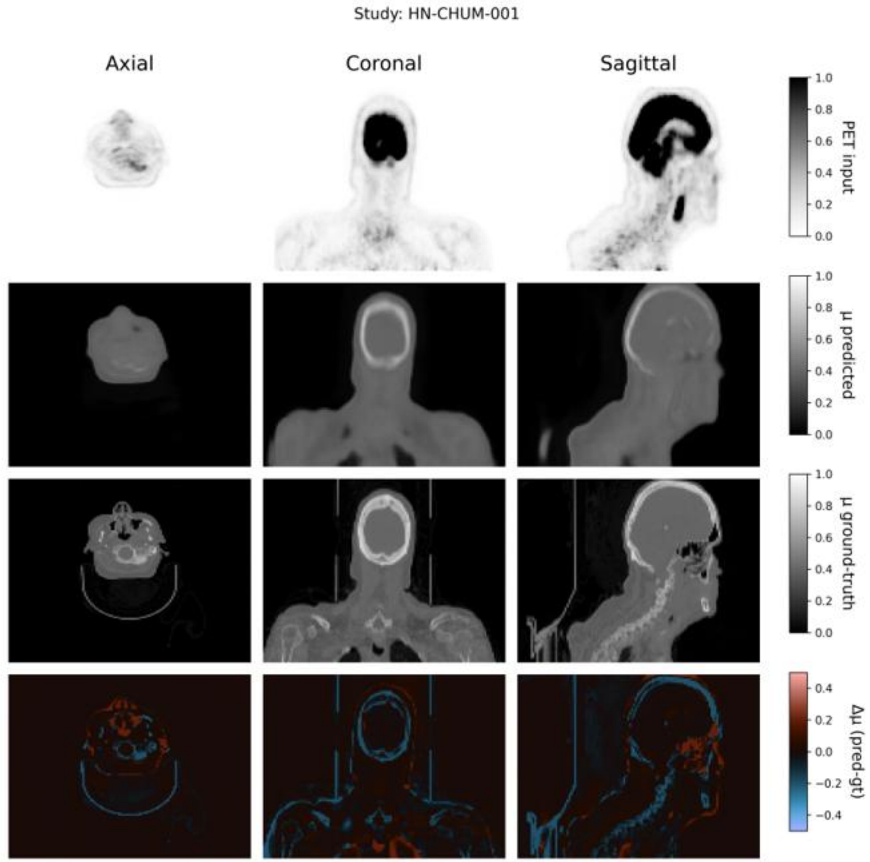
FBK, I3M, JSI, ICCUB

2026

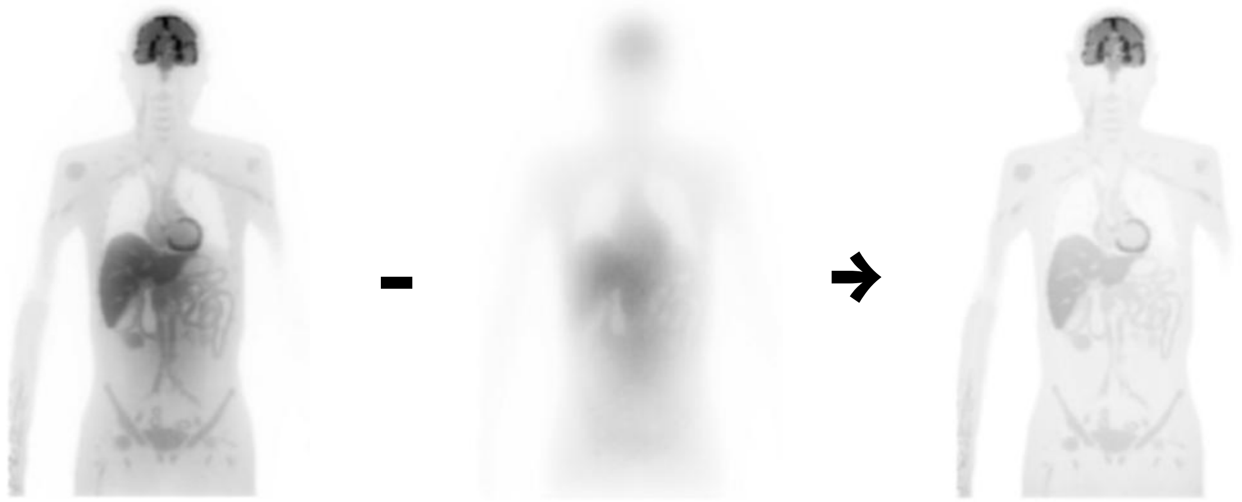
CT-Free PET: A Deep Learning Approach for Attenuation and Scatter Correction in High Time-Resolution PET Scanners

- ARIS Postdoctoral Research Project (Z1-70006)
- 1.3.2026 - 29.2.2028 Z1-70006

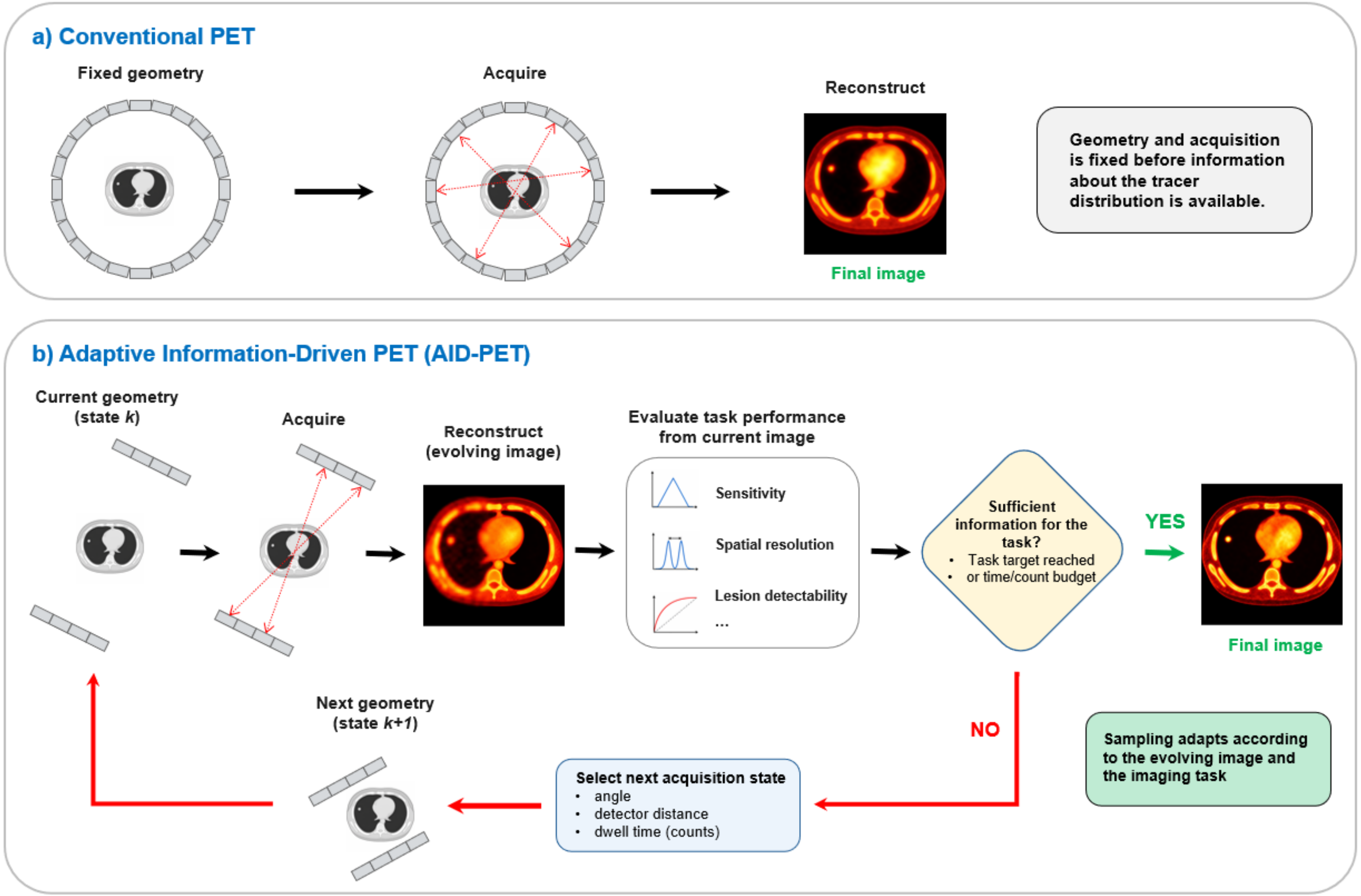




True + scatter - Scatter → True



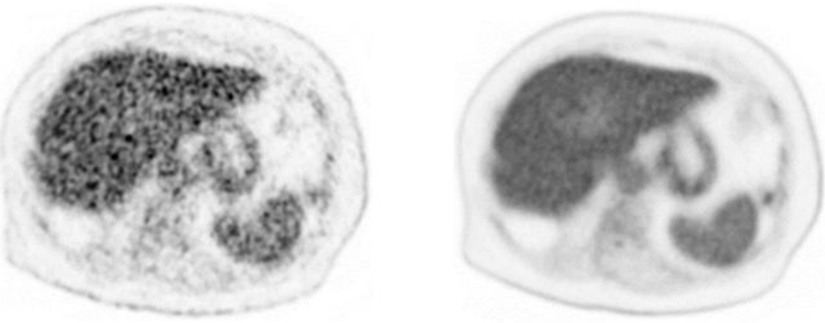
ERC Starting Grant - preparing an application



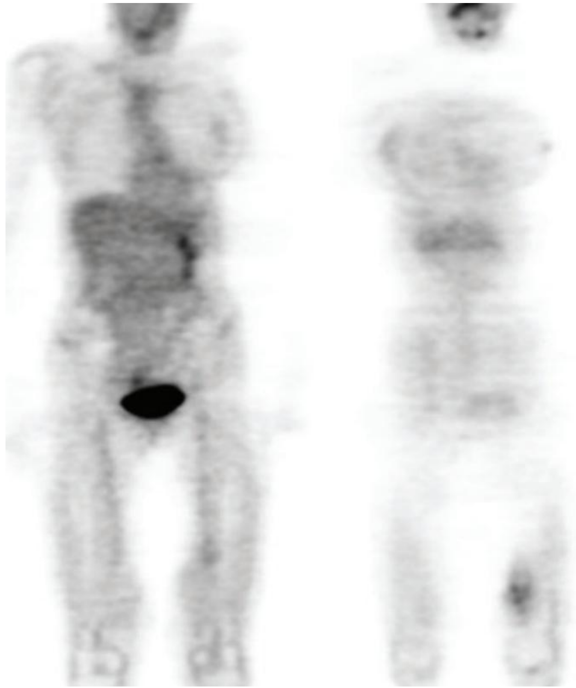
Backup slides

Image quality

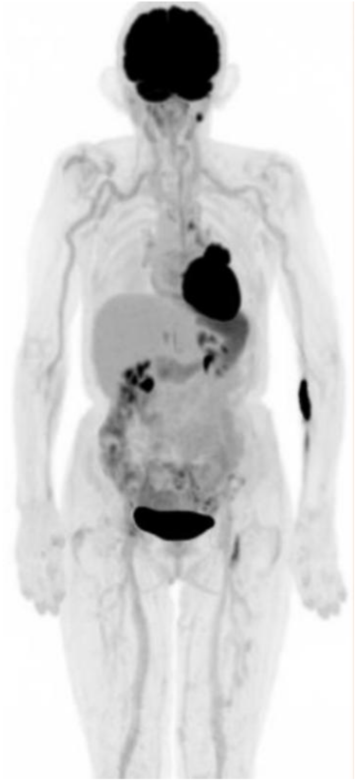
- Accuracy with which an image represents the imaged object
- Basic characteristics:
  - Contrast
  - Spatial resolution
  - Noise



Less noise



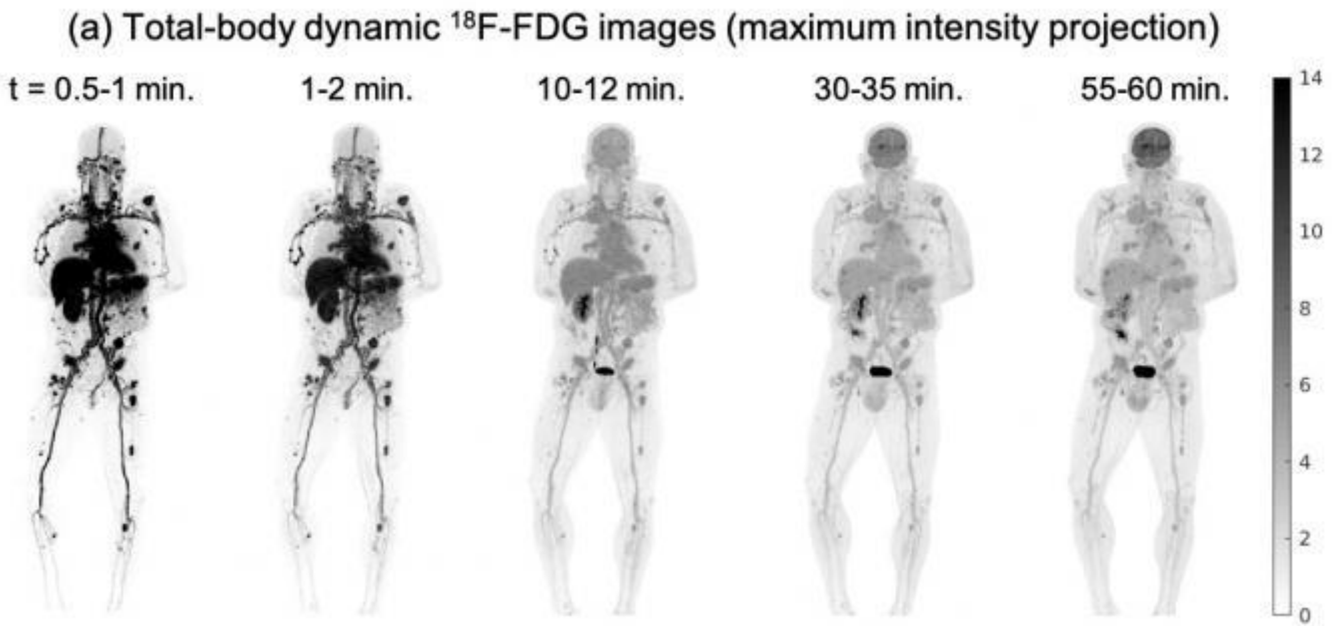
Siemens PET (ECAT 951R), **1992**

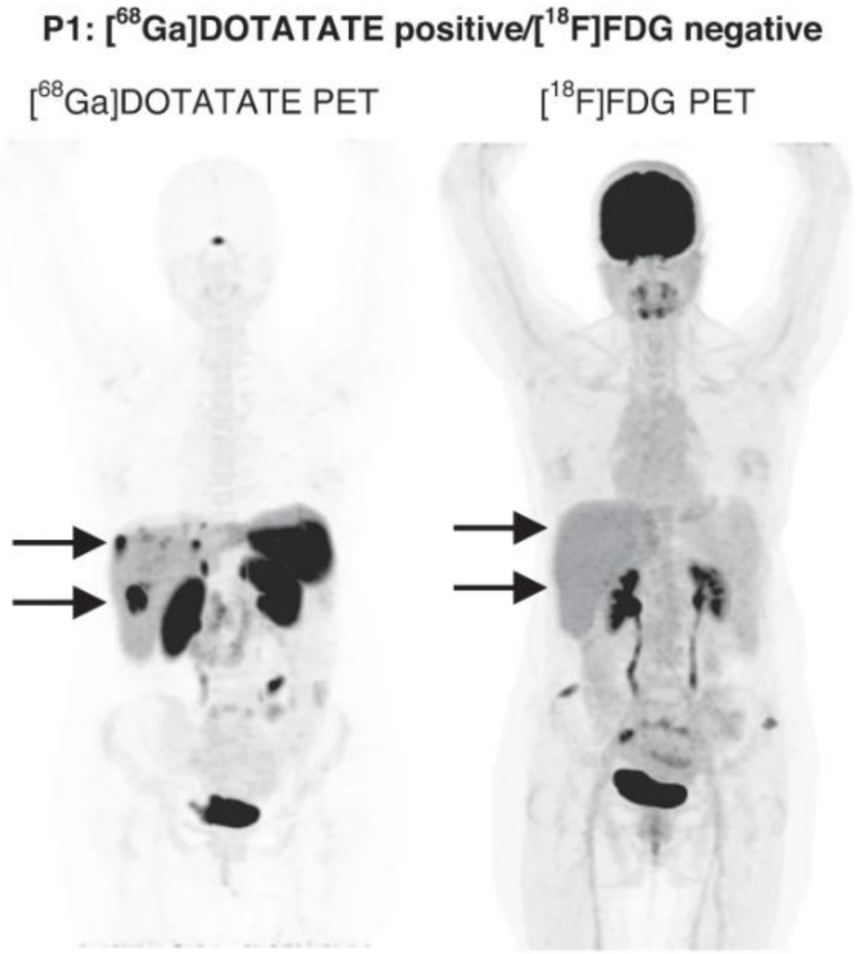


Siemens Biograph Vision Quadra, **2021**

Contrast

- Ability to differentiate between areas of varying radioactivity concentration within the imaged region
- Significantly impacted by the properties of the radiotracer



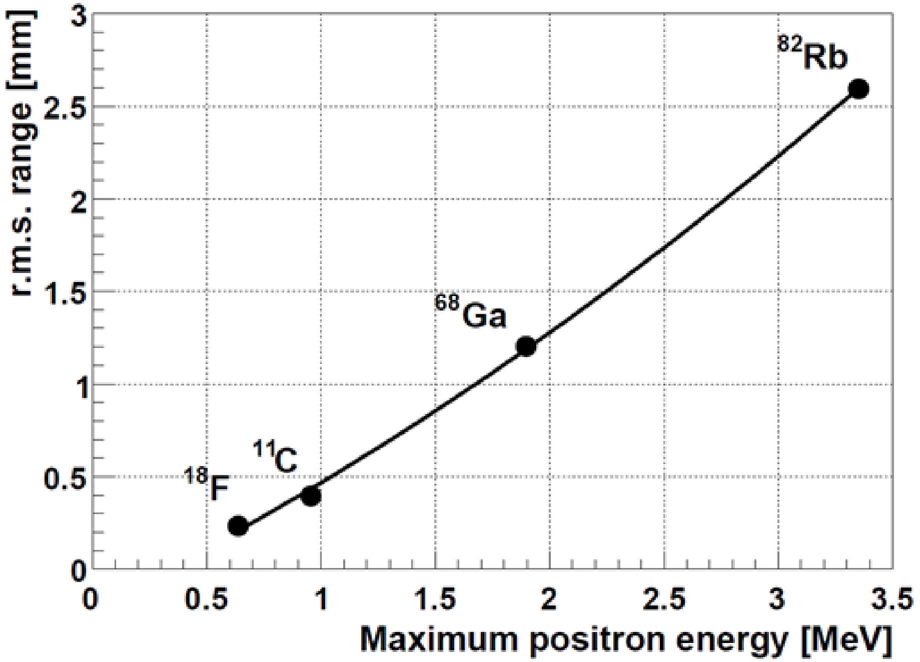


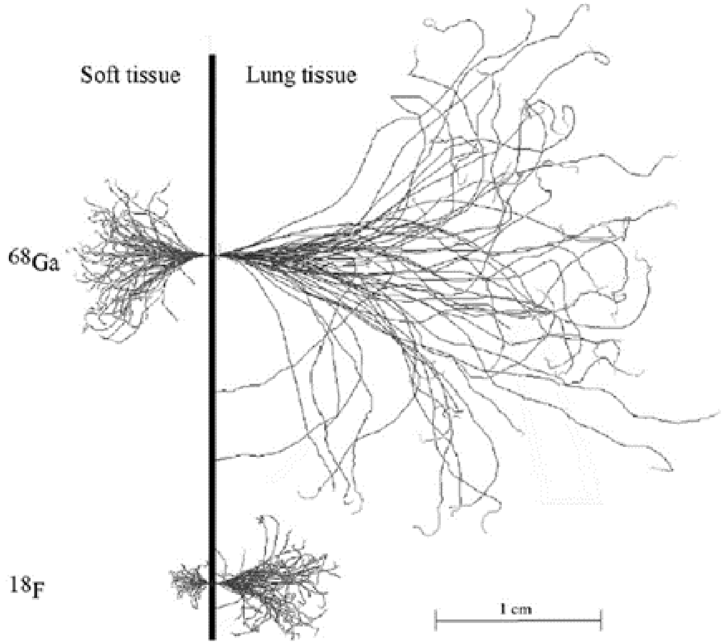
A. Iagaru *et al.*, JNM, 2022

Spatial resolution

- Physical limitation ~ 2 mm
- State-of-the-art ~ 3-4 mm

$$R_{sys} = k\sqrt{R_{det}^2 + R_{DOI}^2 + R_{e^+}^2 + R_{180°}^2 + R_b^2}$$





Spatial resolution

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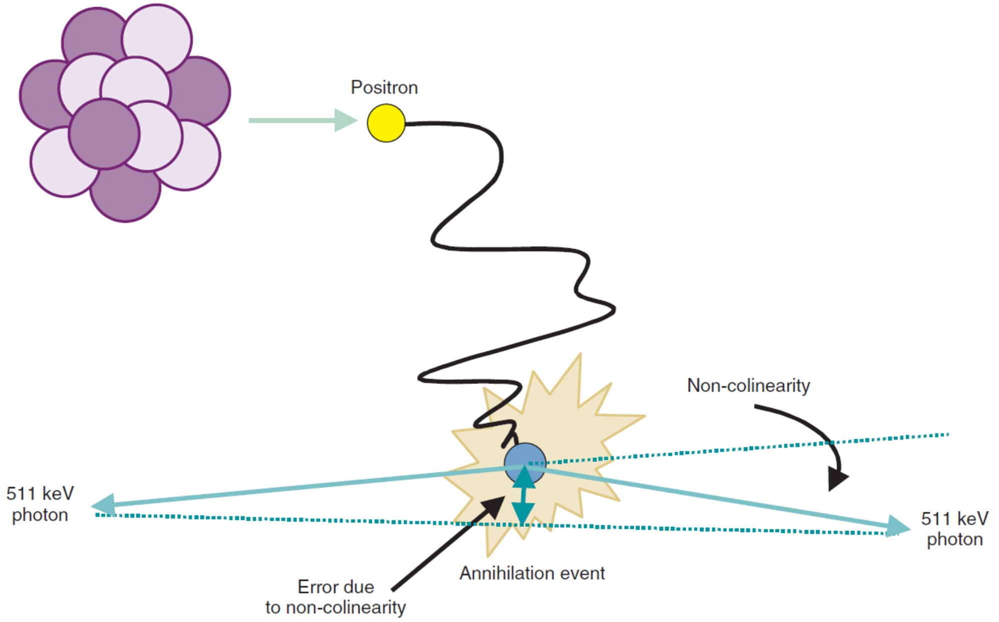
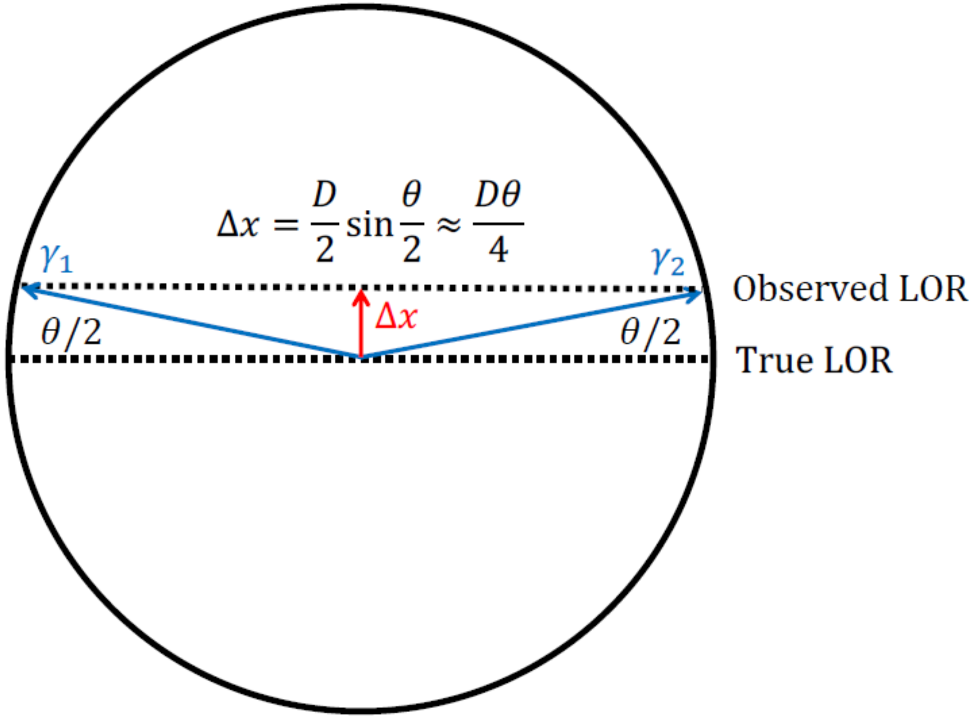


$\text{FWHM} \approx 0.5^{\text{o}}$



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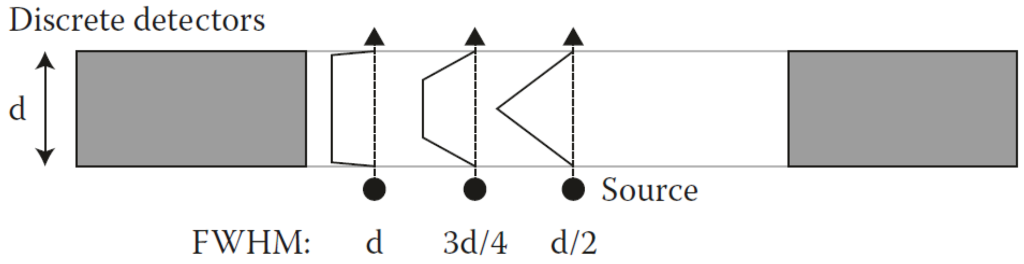
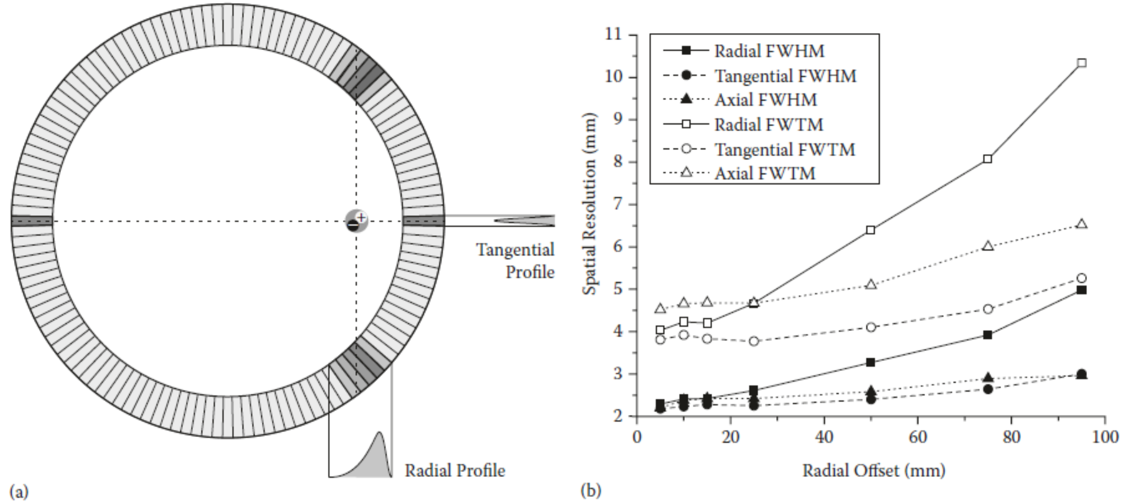
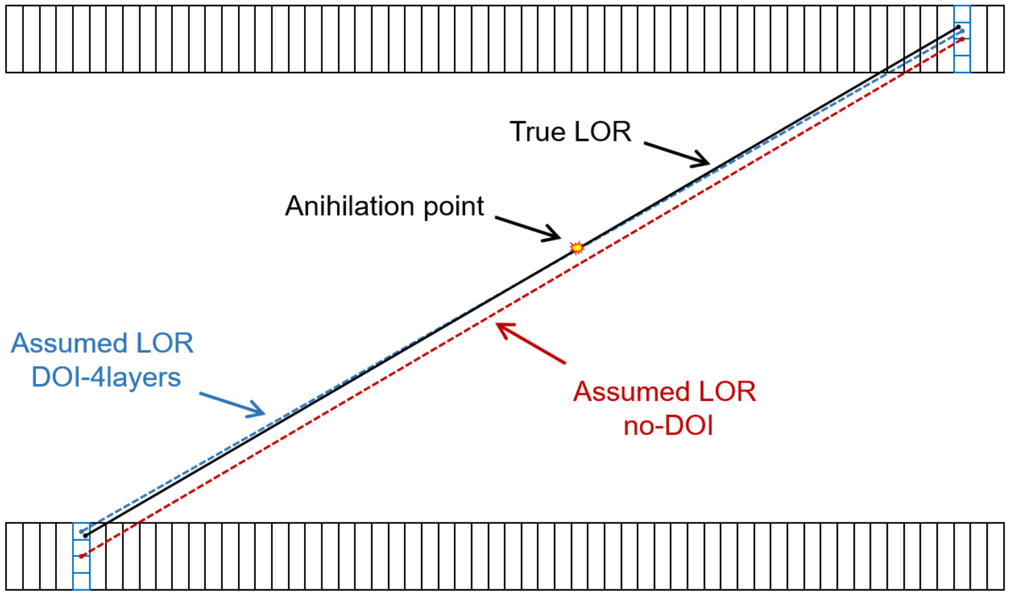


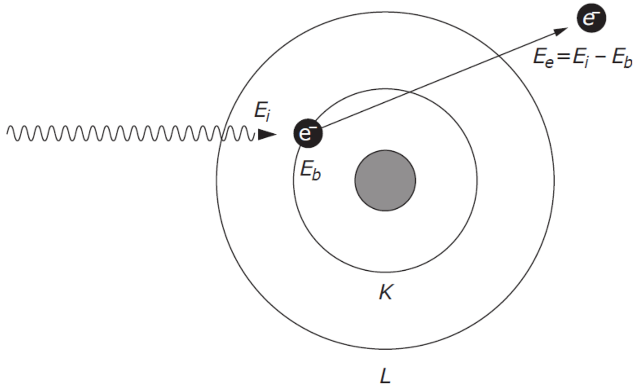




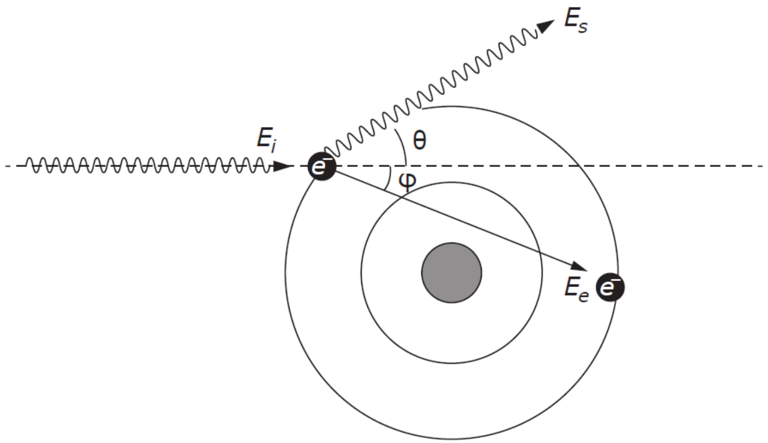
Parallax error

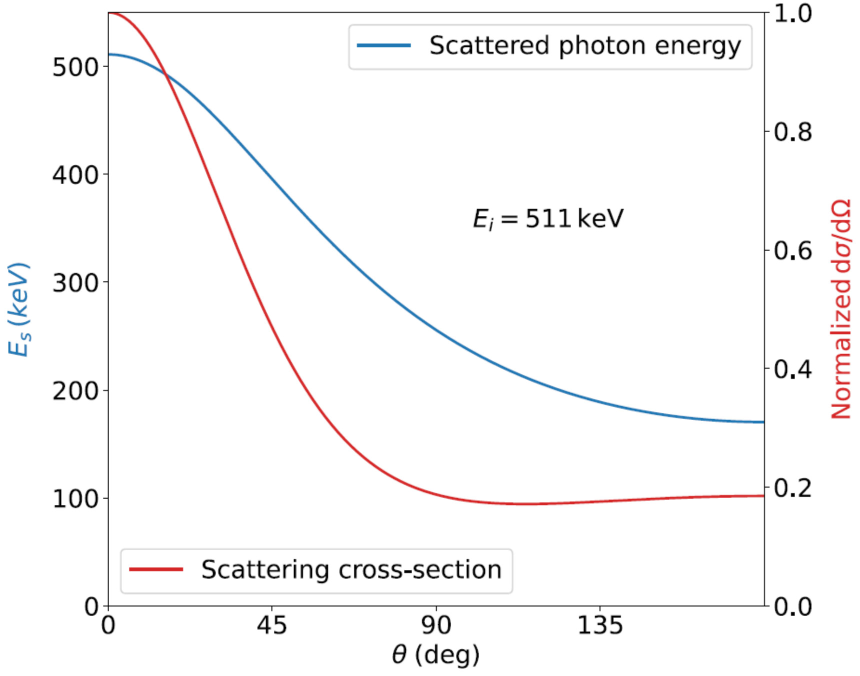
Main interactions in PET

Photoelectric effect



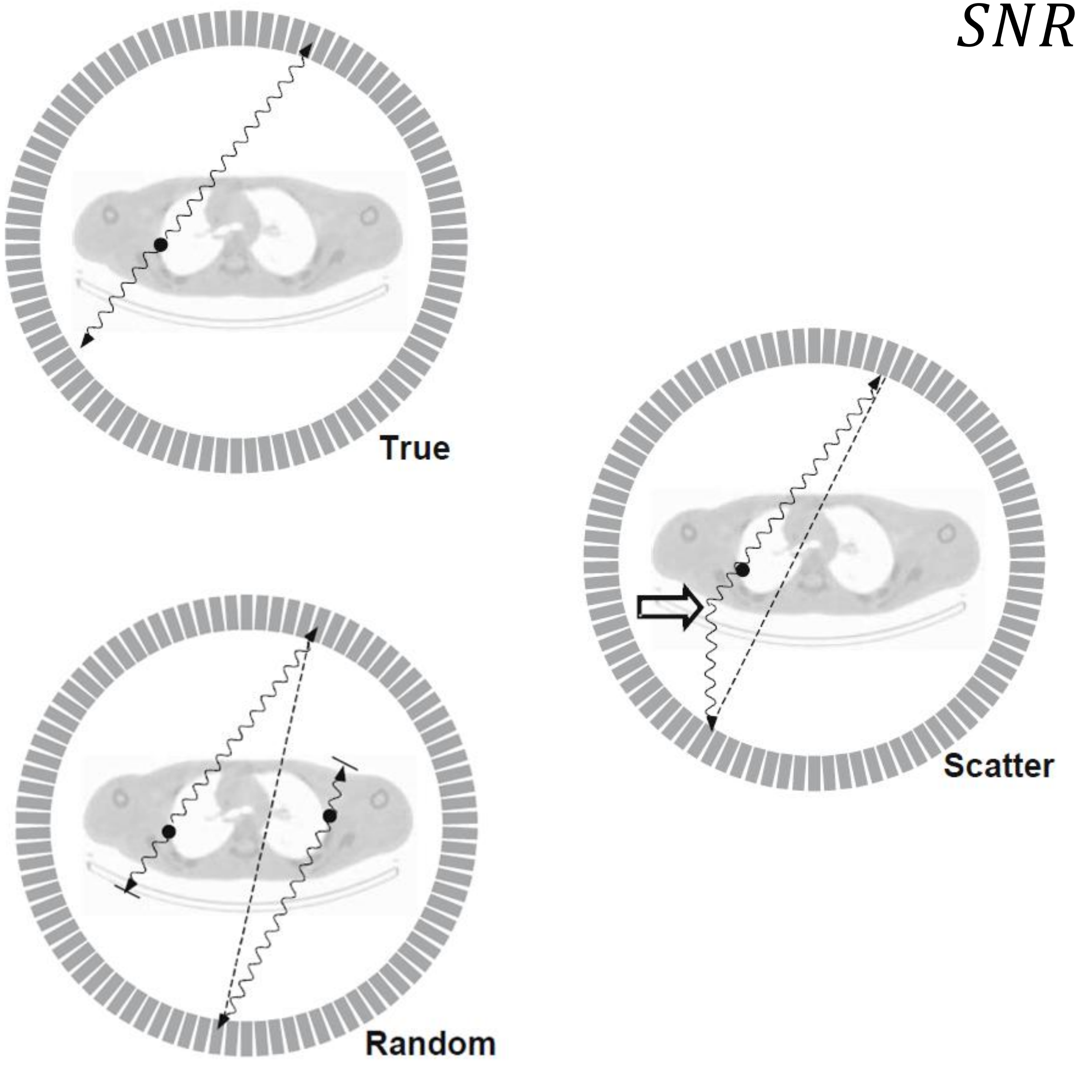
Compton Scattering





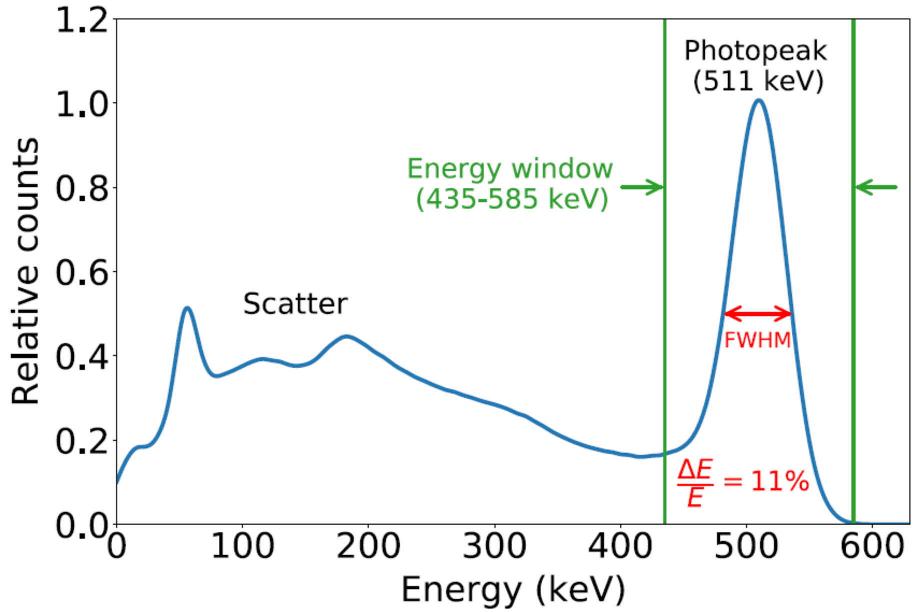
Material	Photofraction at 511 keV	μ_{511keV} (cm^{-1})	Attenuation length $1/\mu$ (cm)
Water (H_2O)	~0.02%	0.096	10.4
LSO (Lu_2SiO_5)	~32%	0.87	1.15

Coincidence events



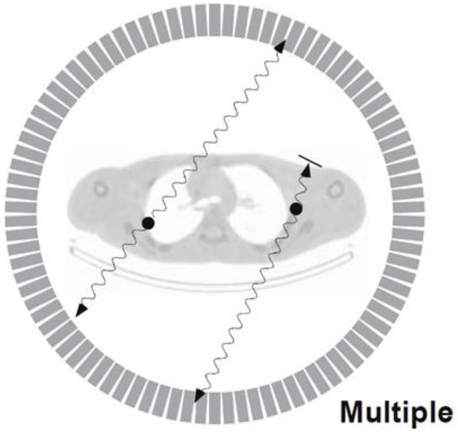
$$SNR \propto \sqrt{\frac{T^2}{T+S+R}} = \sqrt{NECR}$$

noise equivalent count rate

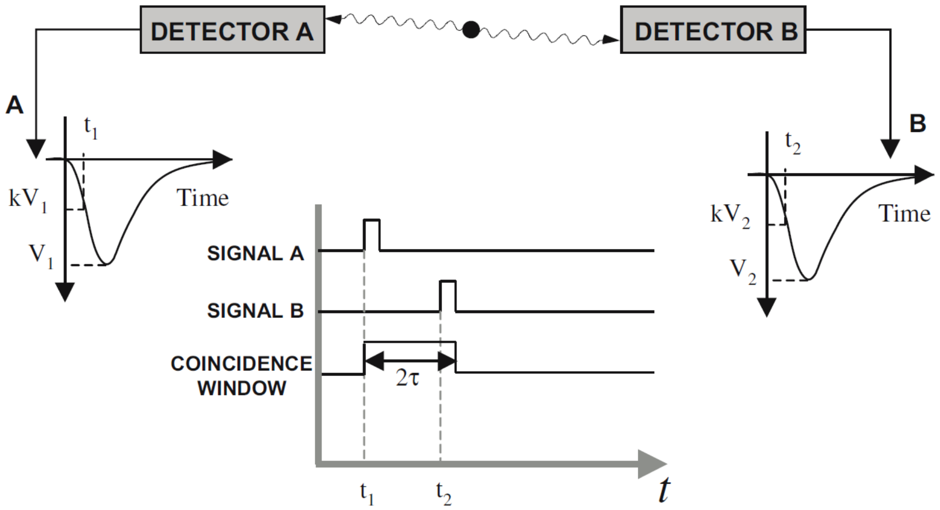


Multiple coincidences

- When more than two singles are found in coincide
- Coincidence time window: 2 – 6 ns
- Different sorting policies
- PetVision: keep all valid coincidences between opposite panels



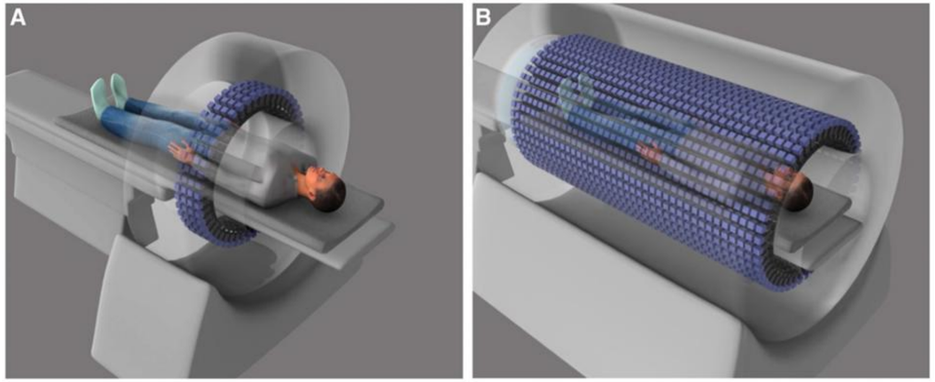
Policy name	Description
takeAllGoods	Each good pairs are considered
takeWinnerOfGoods	Only the good pair with the highest energy is considered
takeWinnerIfIsGood	If the pair with the highest energy is good, take it, otherwise, kill the event
takeWinnerIfAllAre-Goods	If all pairs are goods, take the one with the highest energy
takeWinnerIfOnlyOne-Good	If exactly one pair is good
killAllIfMultipleGoods	If more than one pairs is good, the event is seen as a real "multiple" and thus, all events are killed
killAll	No multiple coincidences are accepted, no matter how many good pairs are present



Signal-to-noise Ratio (SNR)

$$SNR \propto \sqrt{G\frac{\varepsilon^2}{\Delta t}kAt}$$

Geometric coverage of the scanner

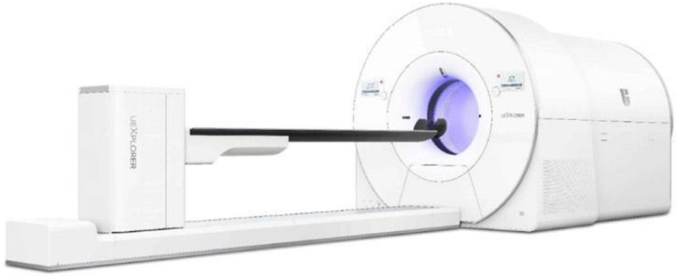


Total-body PET

k – patient (attenuation, scatter), reconstruction parameters

A – amount of activity in the scanner's field of view (FOV)

t - acquisition time (10-30 min)



uExplorer, 2018

Signal-to-noise Ratio (SNR)

$$SNR \propto \sqrt{G\frac{\varepsilon^2}{\Delta t}kAt}$$

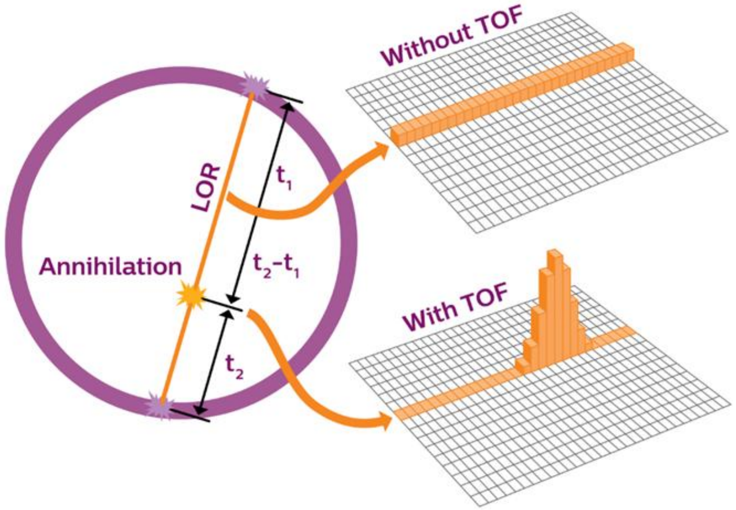
$\boldsymbol{\varepsilon}$ **-** detection efficiency

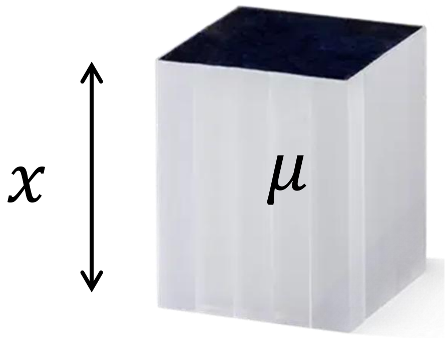
$$\varepsilon \propto 1 - e^{-\mu(\rho,Z,E)x}$$

Δt **-** coincidence timing resolution

Time-of-flight (TOF) information

→ better localization of the annihilation event

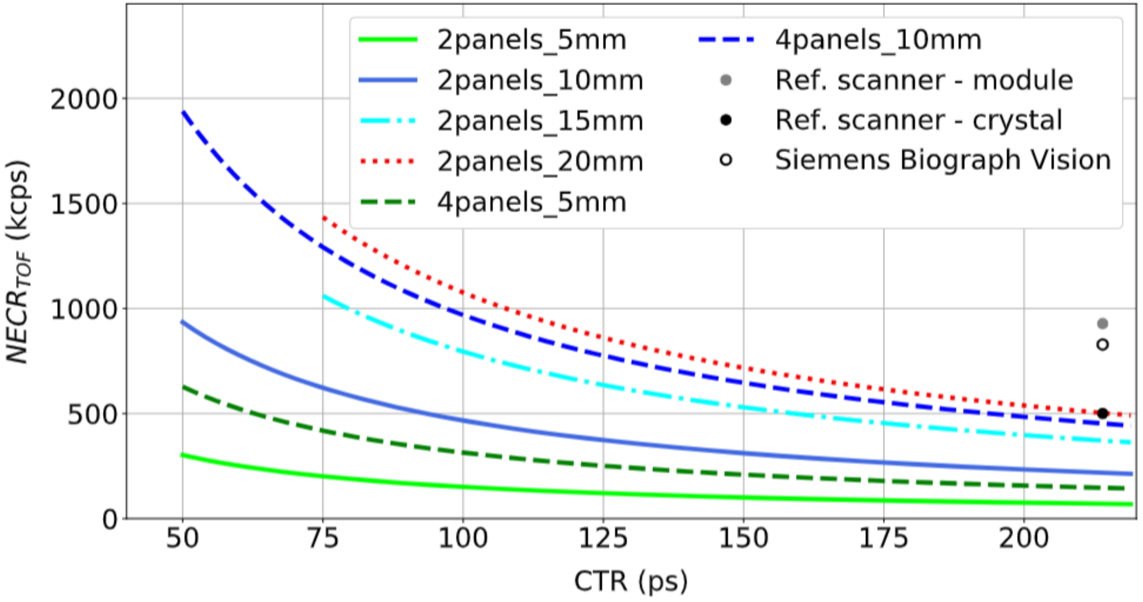




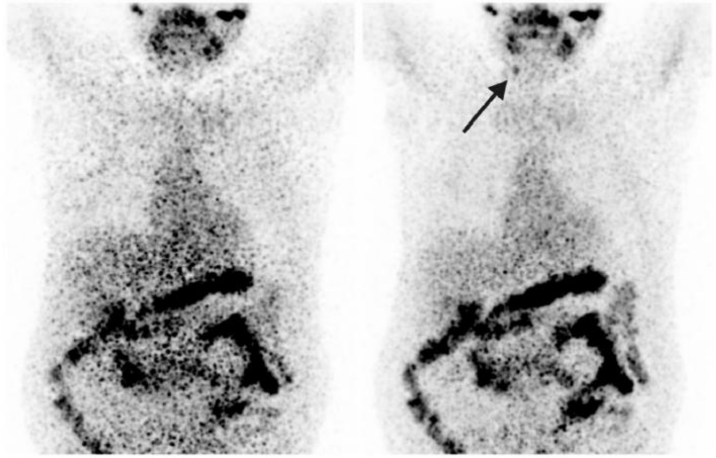
$x\uparrow$ → $SNR\uparrow$

$x\uparrow$ → $CTR\downarrow$, spatial resolution↓

TOF – sensitivity amplifier



$$\frac{SNR_{TOF}}{SNR_{non-TOF}} = \left(\frac{2\ln 2}{\pi}\right)^{\frac{1}{4}} \sqrt{\frac{D}{\Delta x}} = 0.815\sqrt{\frac{2D}{c\Delta t}}$$

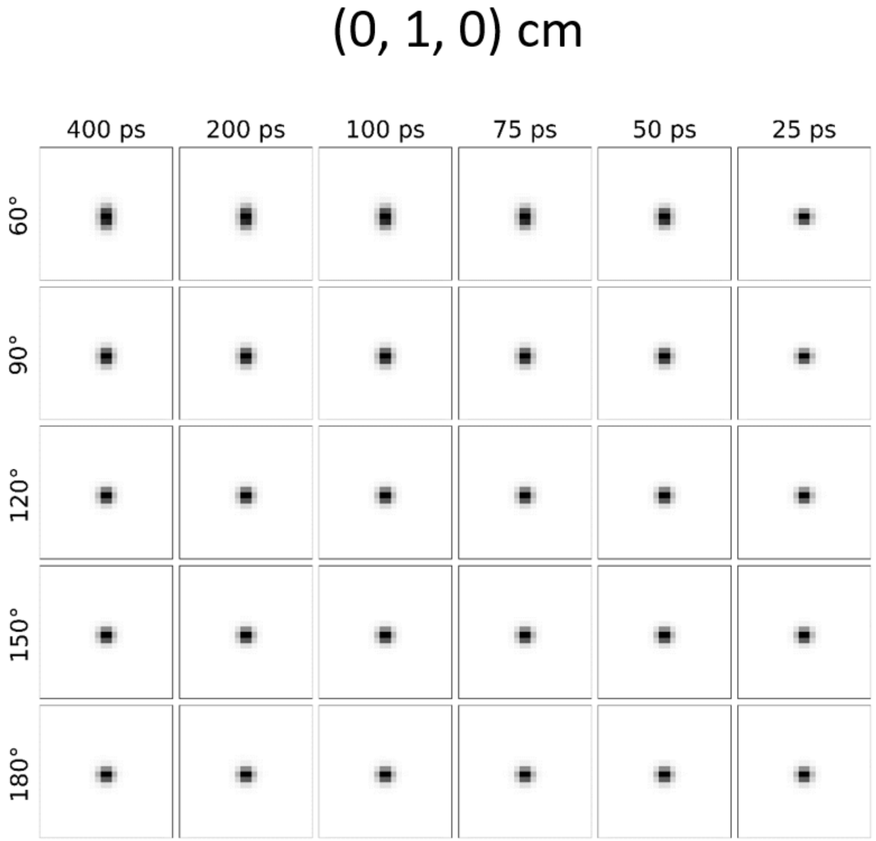


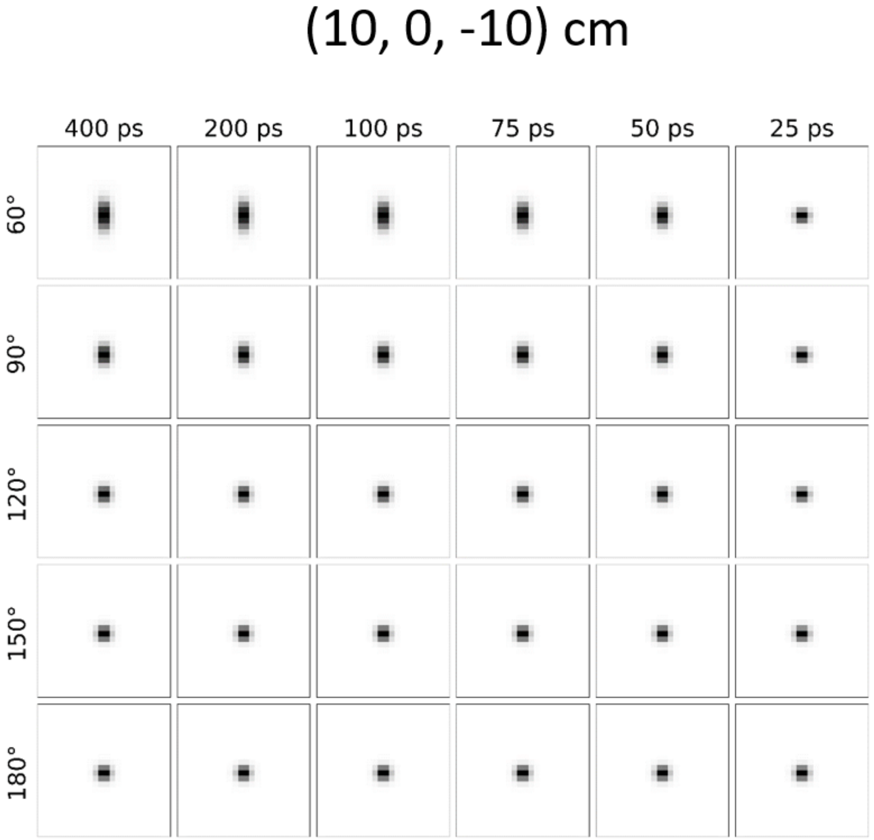
nonTOF TOF (214 ps)

- 3×3×10 mm + 100 ps ≈ 3×3×20 mm + 200 ps

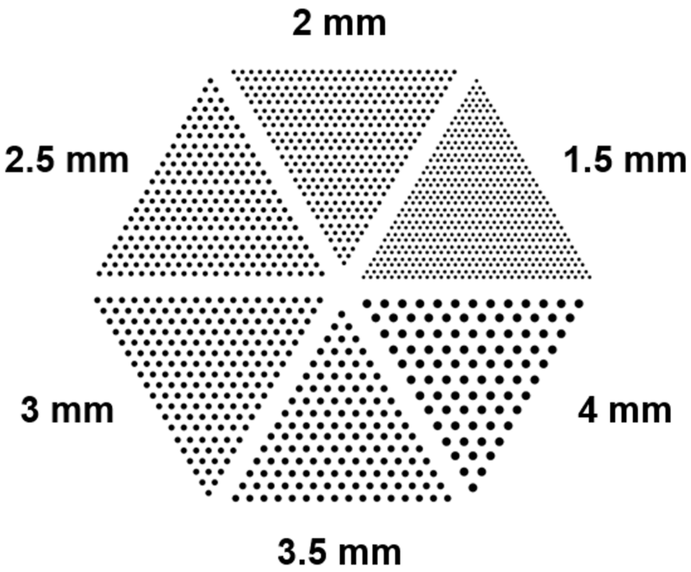
Spatial Resolution

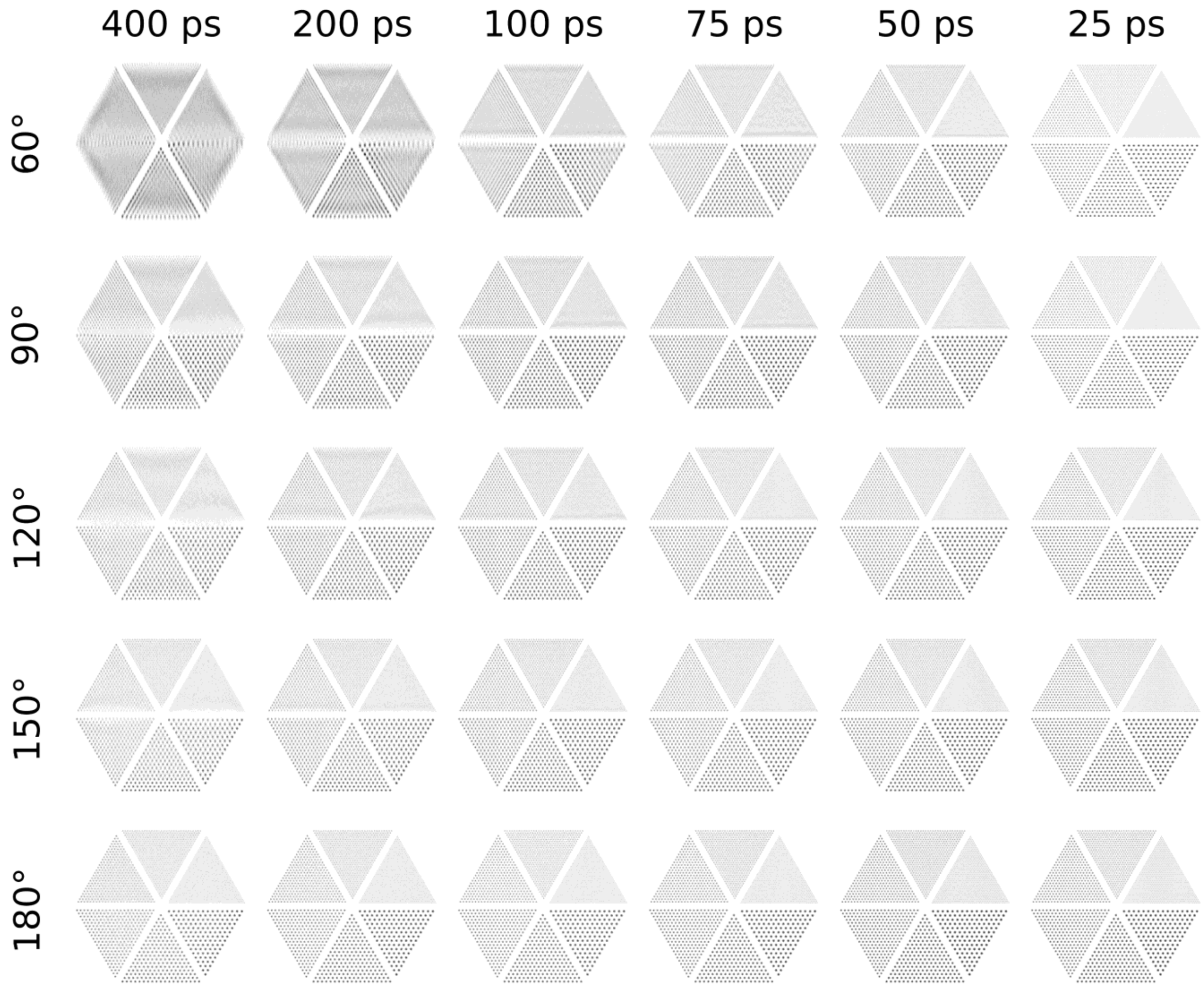
- Point sources (NEMA standard)
- Voxel size: 0.75 mm



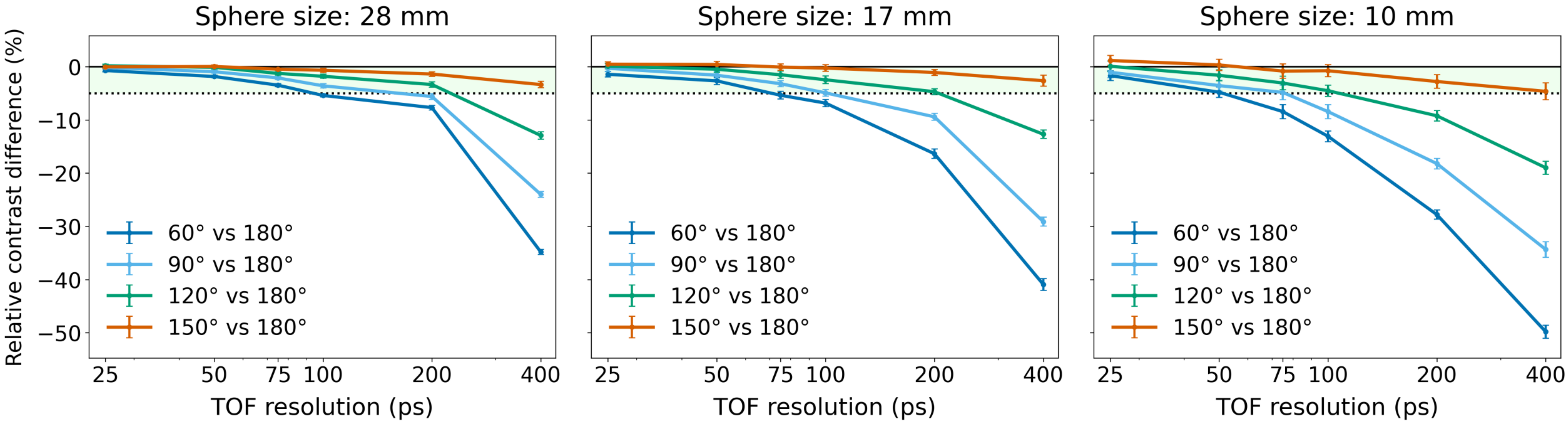


Spatial Resolution

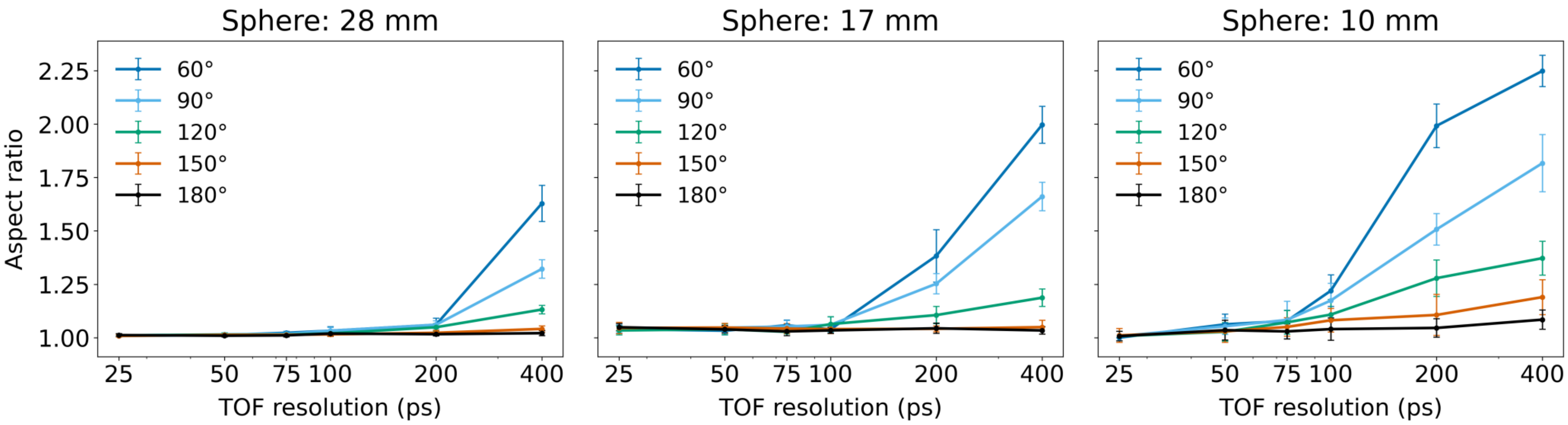


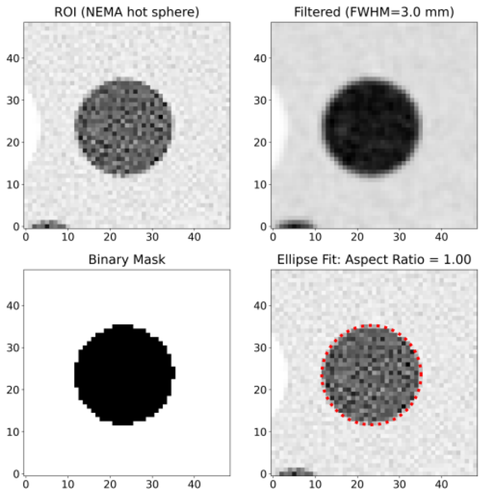


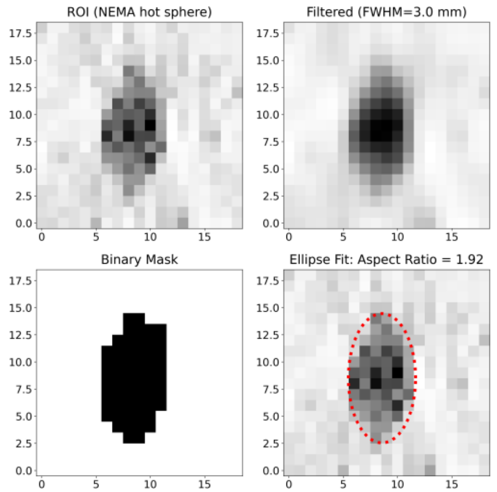
NEMA image quality phantom



Ellipse fitting to reconstructed hot spheres







Panel detectors

- Two-panel PET: back to the past? Not with excellent TOF resolution.

The PC-I, completed in 1969, used two planar arrays of crystals and was one of the first PET imaging devices.

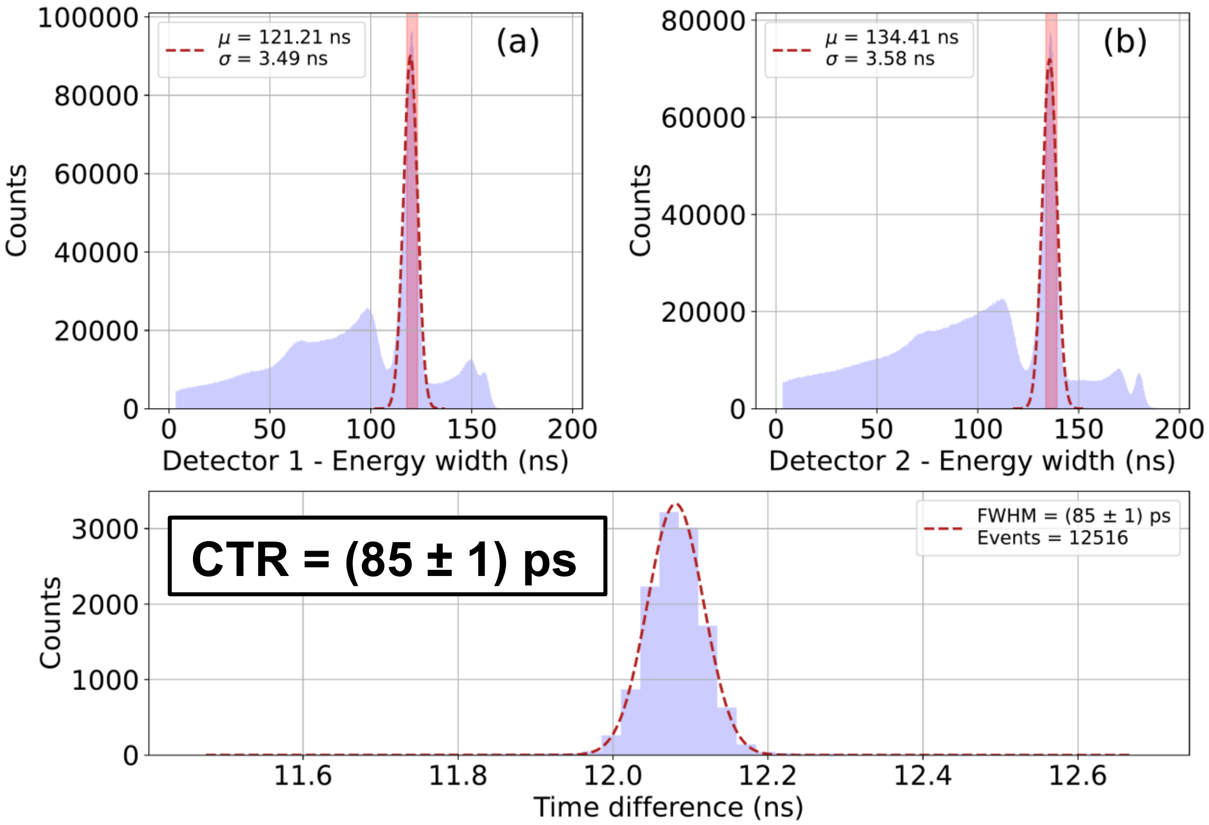
- PetVision aims for artifact-free open-geometry imaging without rotating the panels.

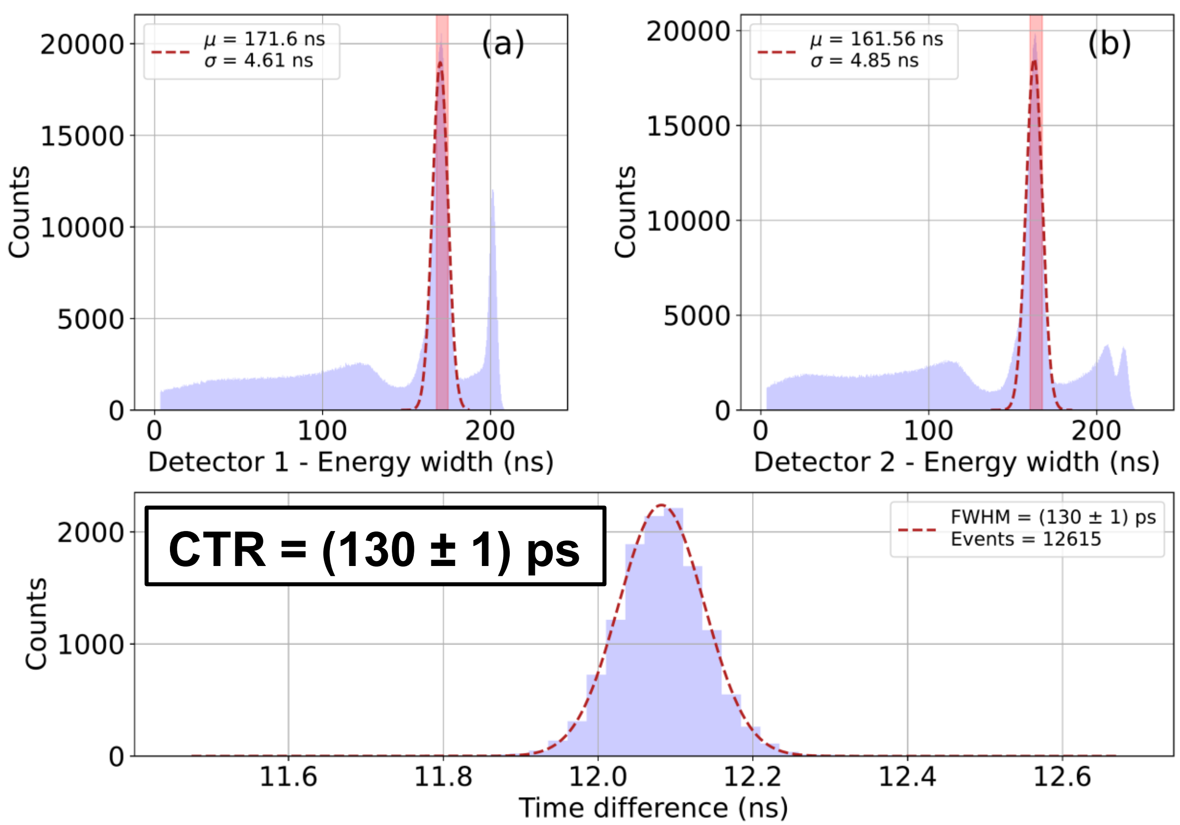
Proof of principle: FastIC+ CTR performance

Results with FastIC+ (the predecessor of the final chip) and without 2.5D integration

- **SiPM:** FBK NUV-HD-MT LFv2 M0 3x3 mm^2 50 µm SPAD
- **Over-Voltage:** ~10 V
- **Crystal**: Fast-LGSO (Oxide Corporation) – 2x2x3 mm^3

- **SiPM:** FBK NUV-HD-MT LF 4x4 M0 mm^2 40 µm SPAD
- **Over-Voltage:** ~10 V
- **Crystal:** LYSO:CeCa (Taiwan Applied Crystals) – 2.8x2.8x20 mm^3





Next generation ASICs based on FastIC family

- PoETIC - Highly configurable pixelated ASIC for Fast Timing applications based on FastIC

- Collaboration between the University of Barcelona and CERN
- Time Over Threshold
- Low power (~10 mW/ch),
- 25 ps bin TDC integration
- Packaged or direct 2.5D integration