MULTIPURPOSE J-PET DETECTOR FOR TESTS OF DISCRETE SYMMETRIES AND MEDICAL IMAGING

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on behalf of the J-PET Collaboration

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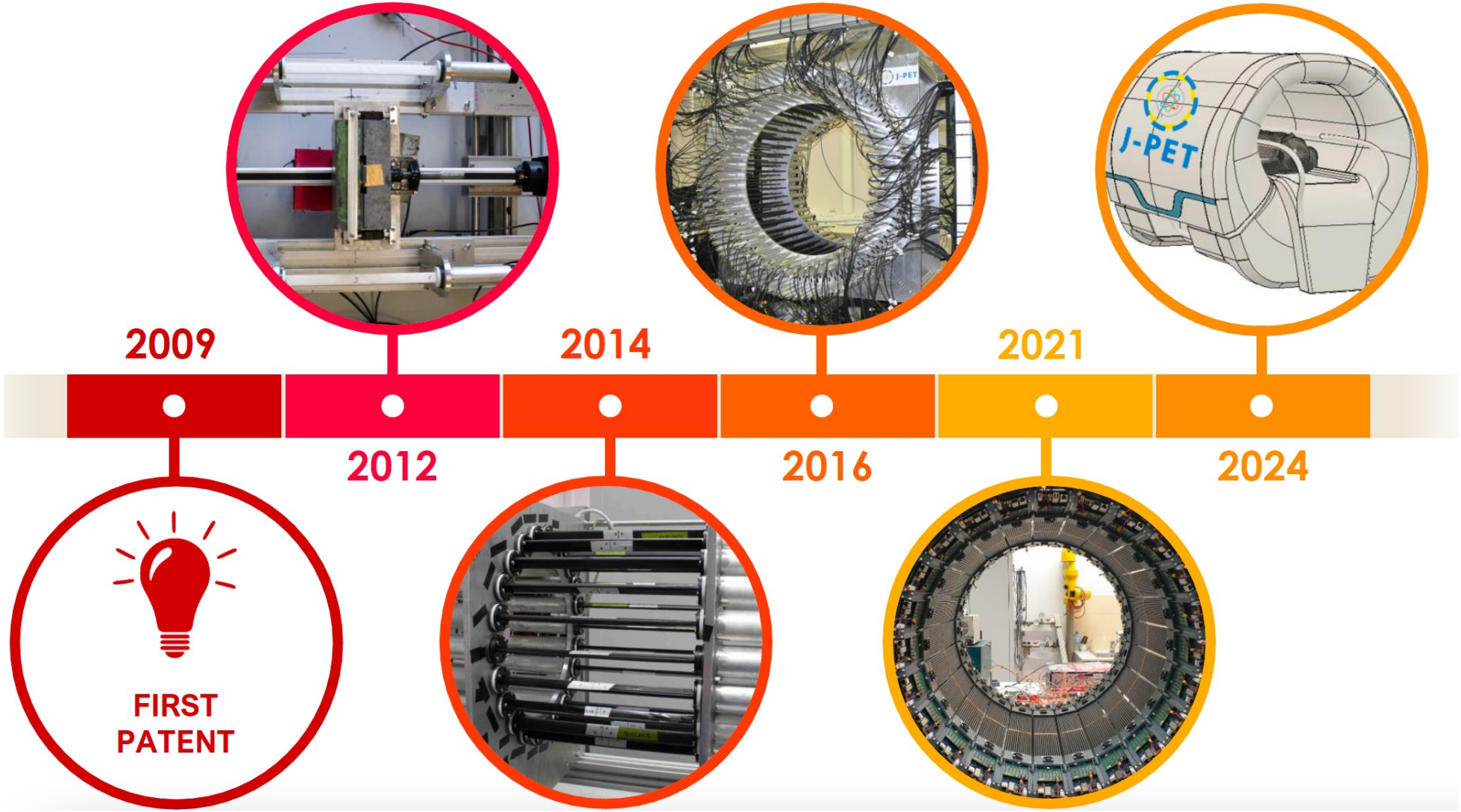
MOTIVATION

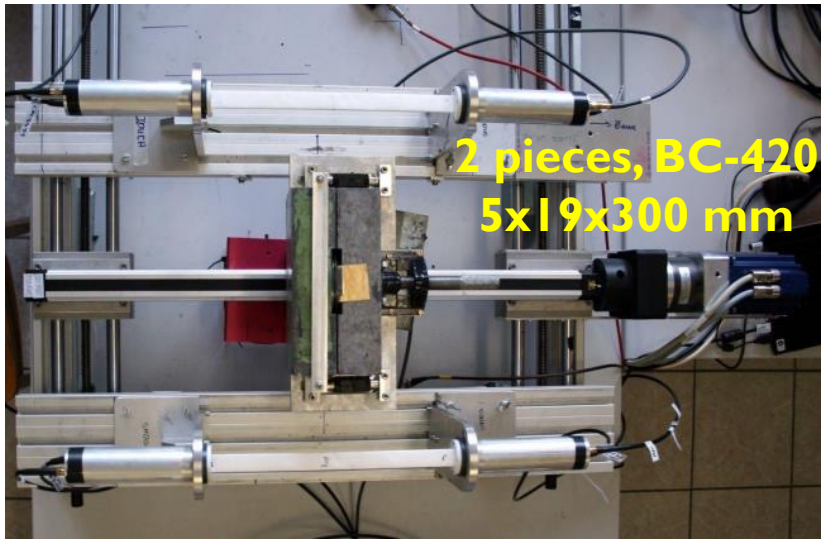
The primary aim of the group is to elaborate a technology for:

- **The cost-effective total-body PET scanner based on plastic scintillators;**
- **PET scanner with positronium and multiphoton imaging capabilities;**
- **Modular and transportable PET scanner with the field of view adjustable to the patient size.**
- **Study of discrete symmetry :** Aleksander Gajos talk on 8/07/2022 **(**Beyond the Standard Model at 15:45**)**



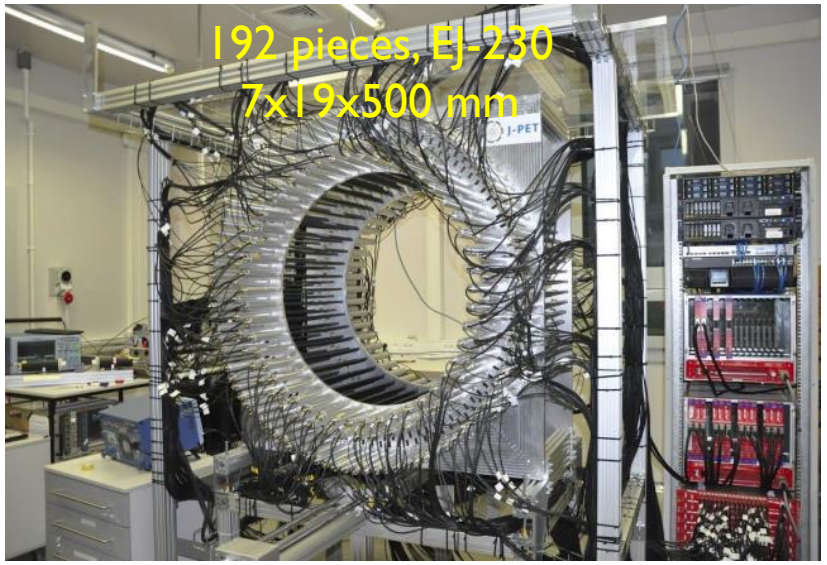
J-PET scanner prototypes : timeline

J-PET scanner prototypes

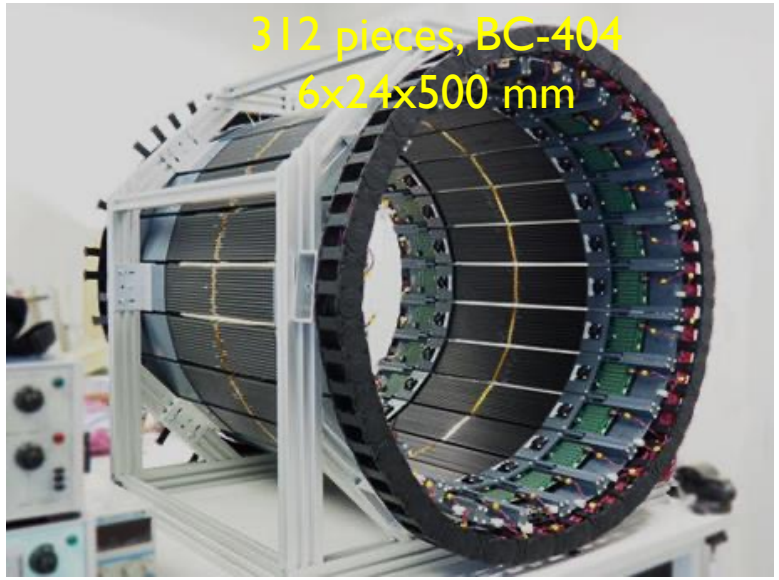


Two detector modules

Mini J-PET



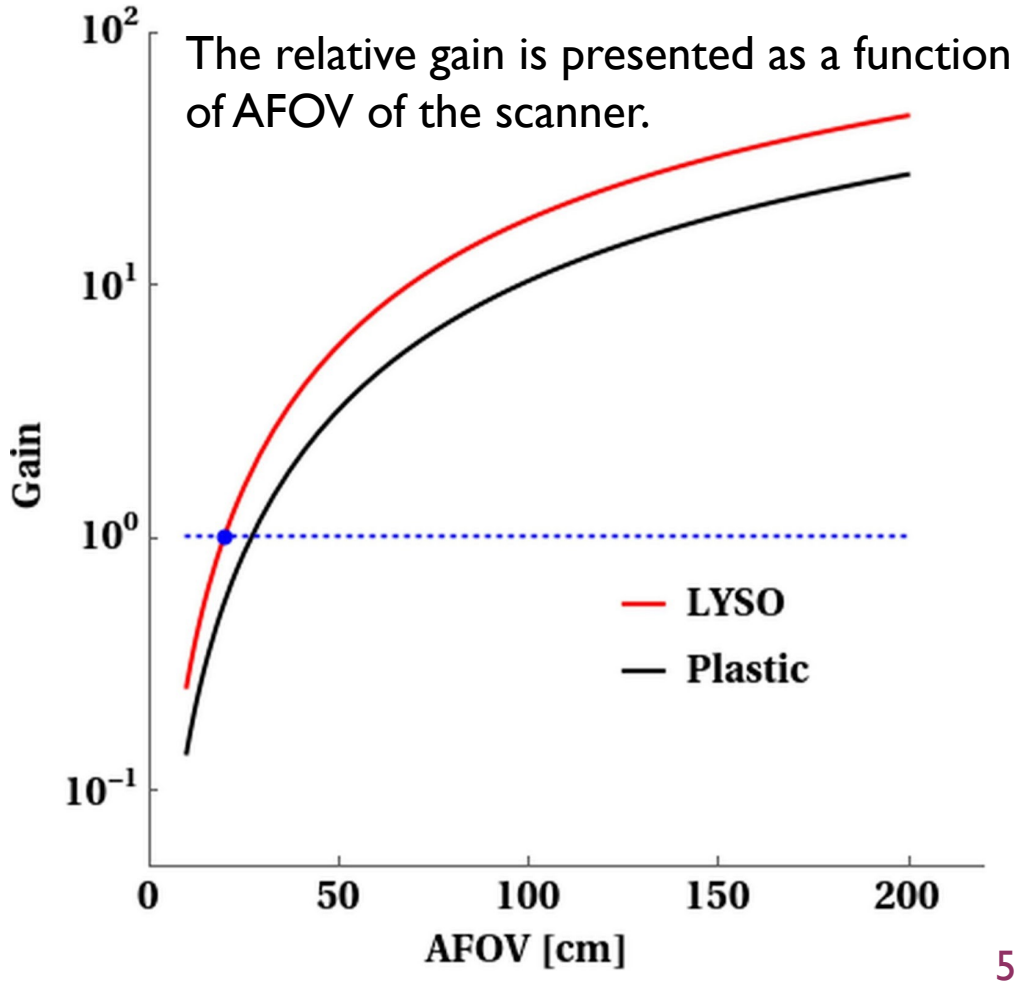
3 layers J-PET



Modular J-PET

DIFFERENCES BETWEEN TRADITIONAL PET AND NOVEL STRIP J-PET SCANNERS

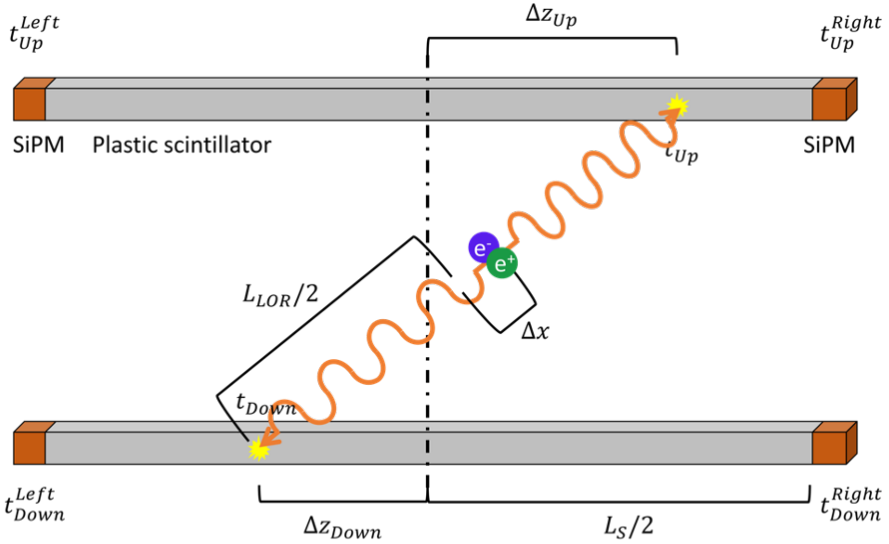
Parameters	Traditional PET	Strip J-PET
Type of scintillator	crystals LSO, LYSO, BGO	plastics BC-404, BC-420, EJ-230
Physical phenomenon	photoelectric effect	Compton scattering
Measured property	energy of gamma photon + time of flight	time of flight
Granularity of detector	high	low
Number of scintillators	13,824 to 32,444 crystals	192 strips
Scintillator size [mm³]	e.g. 4x4x20; 6.3x6.3x30	e.g. 6x24x500; 5x19x300
Photo-detector	PMT, SiPM, dSiPM, APD	PMT, SiPM
Number of PMTs	256 to 768	384
Detection efficiency	high	low
Detector's acceptance	low	high
Axial length [mm]	157 to 260	500
Used electronics	analog	digital
Signal triggering	triggering	triggerless data acquisition
TOF resolution* [ps]	345 to 550	320
Simultaneous imaging of the whole human body	no	yes
Simultaneous imaging of PET-MRI	yes	yes
Simultaneous imaging of PET-CT	no	yes



S. Vandenberghe, P. Moskal, J. Karp, State of the art in total body PET, EJNMMI Physics (2020) 7:35

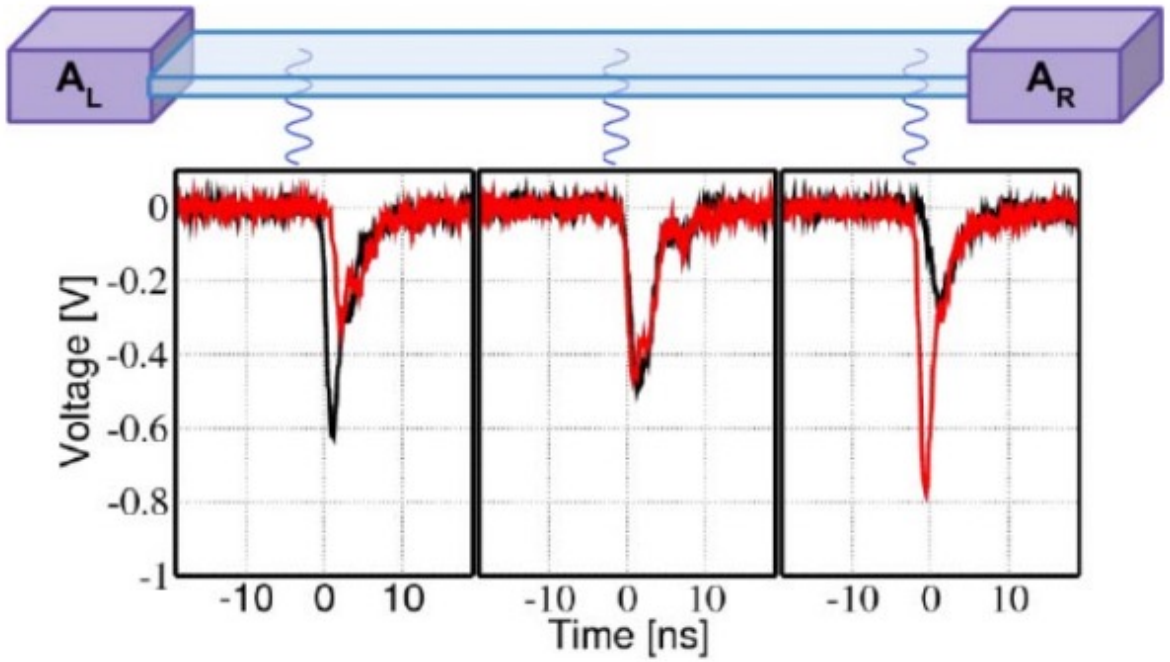
HIT RECONSTRUCTION ALONG THE STRIP

Hit along the strip → Annihilation Point → 3D image



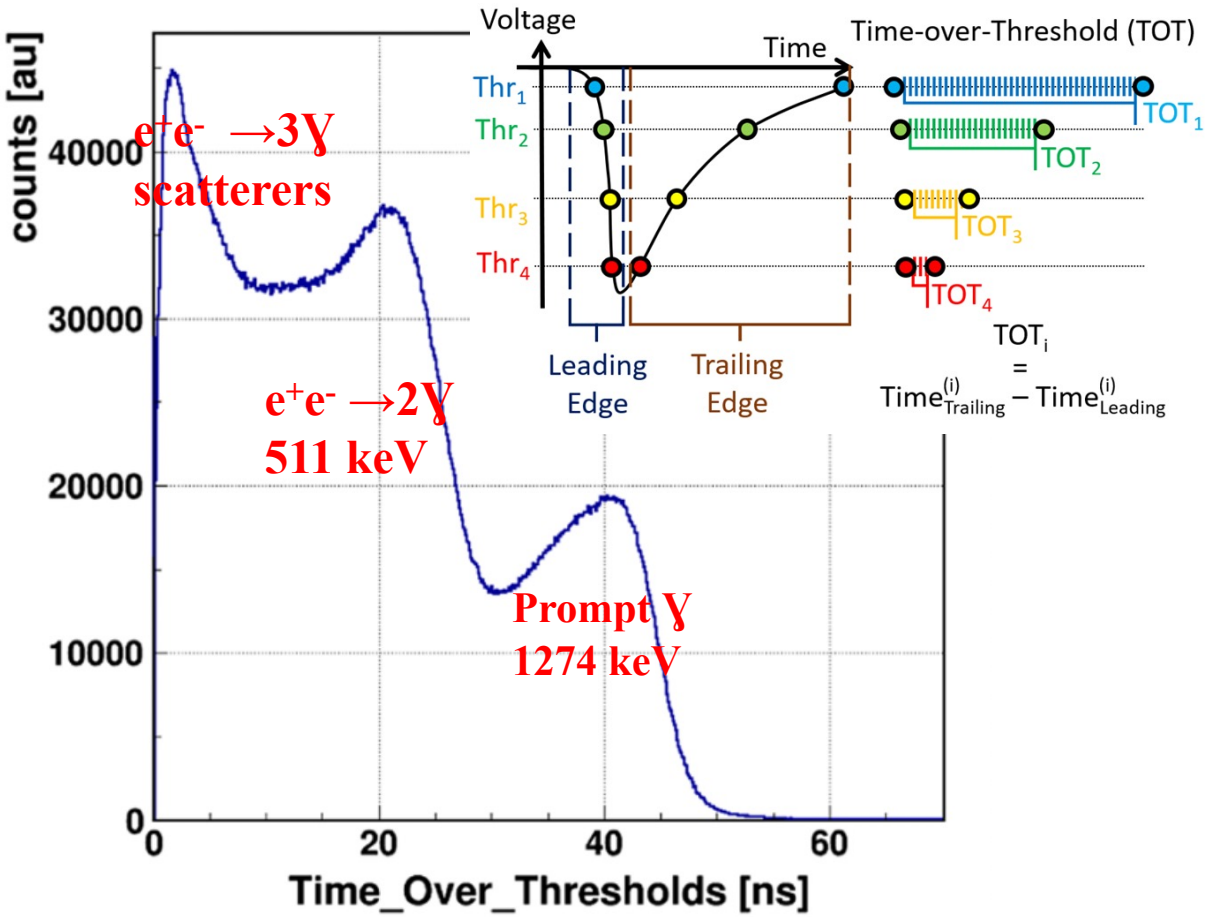
$$\Delta z_{Up/Down} = \frac{\left(t_{Up/Down}^{Left} - t_{Up/Down}^{Right}\right) v_S}{2} \qquad t_{Up/Down} = \frac{t_{Up/Down}^{Left} + t_{Up/Down}^{Right}}{2}$$

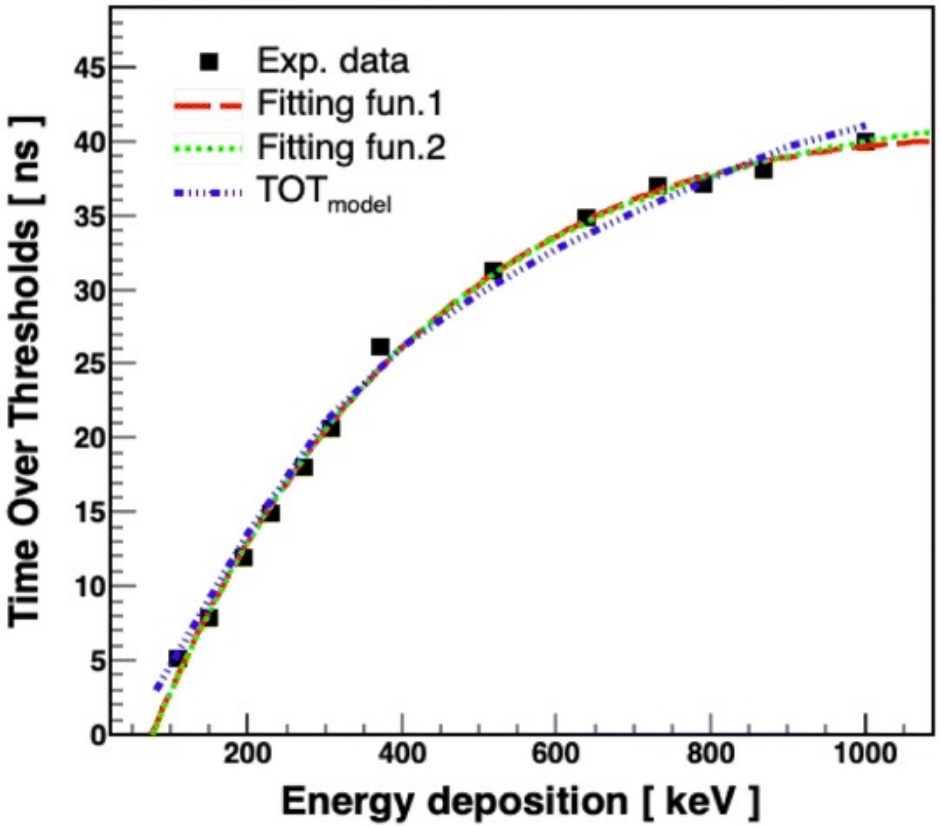
$$\Delta x = \frac{\left(t_{Up} - t_{Down}\right) v}{2}$$



N. Gupta et al., IEEE Trans on Rad and Med. Sci(2020) 4:528

TIME OVER THRESHOLD

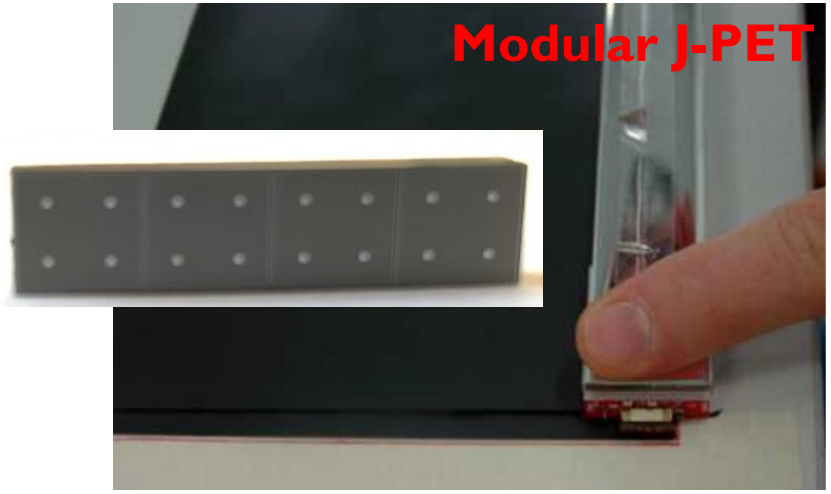




Estimating relationship between the Time Over Threshold and energy loss by photons in plastic scintillators used in the J-PET scanner

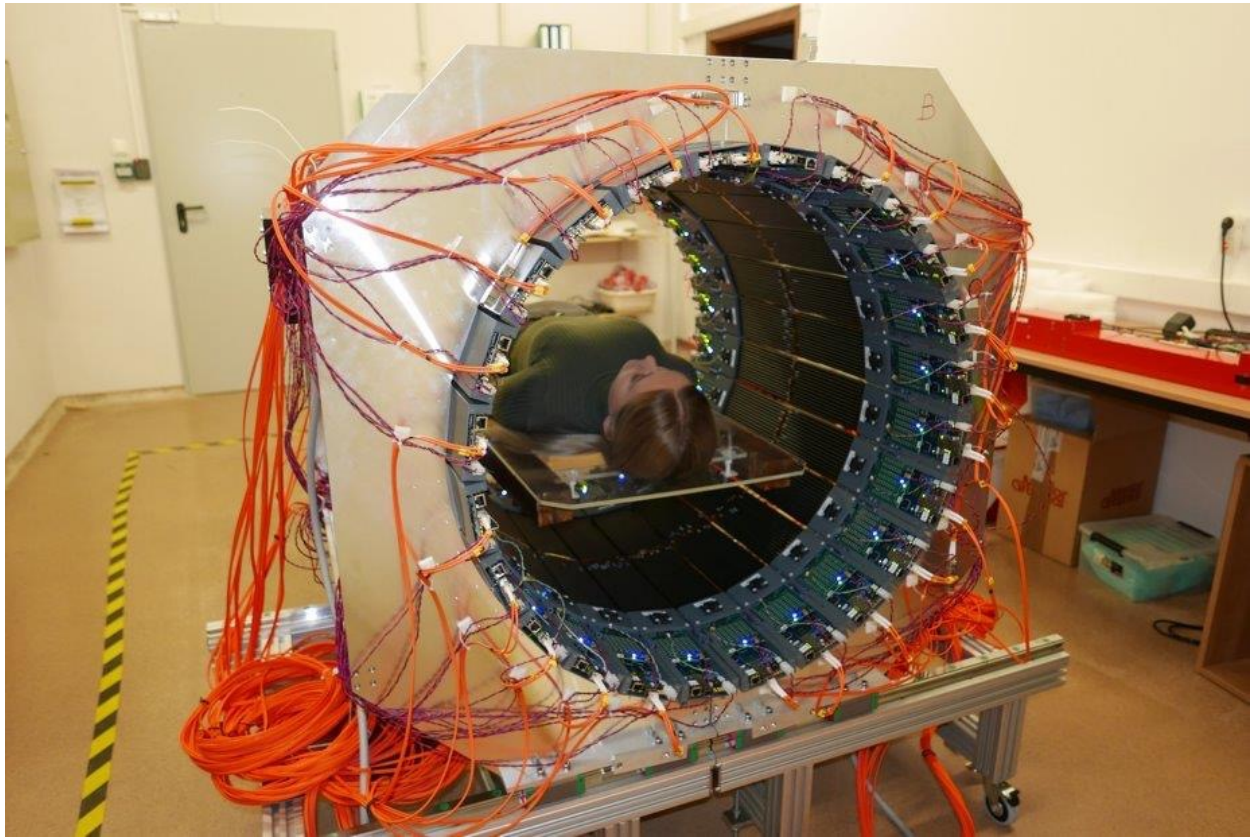
S. Sharma et al., EJNMMI Physics(2020) 7:39

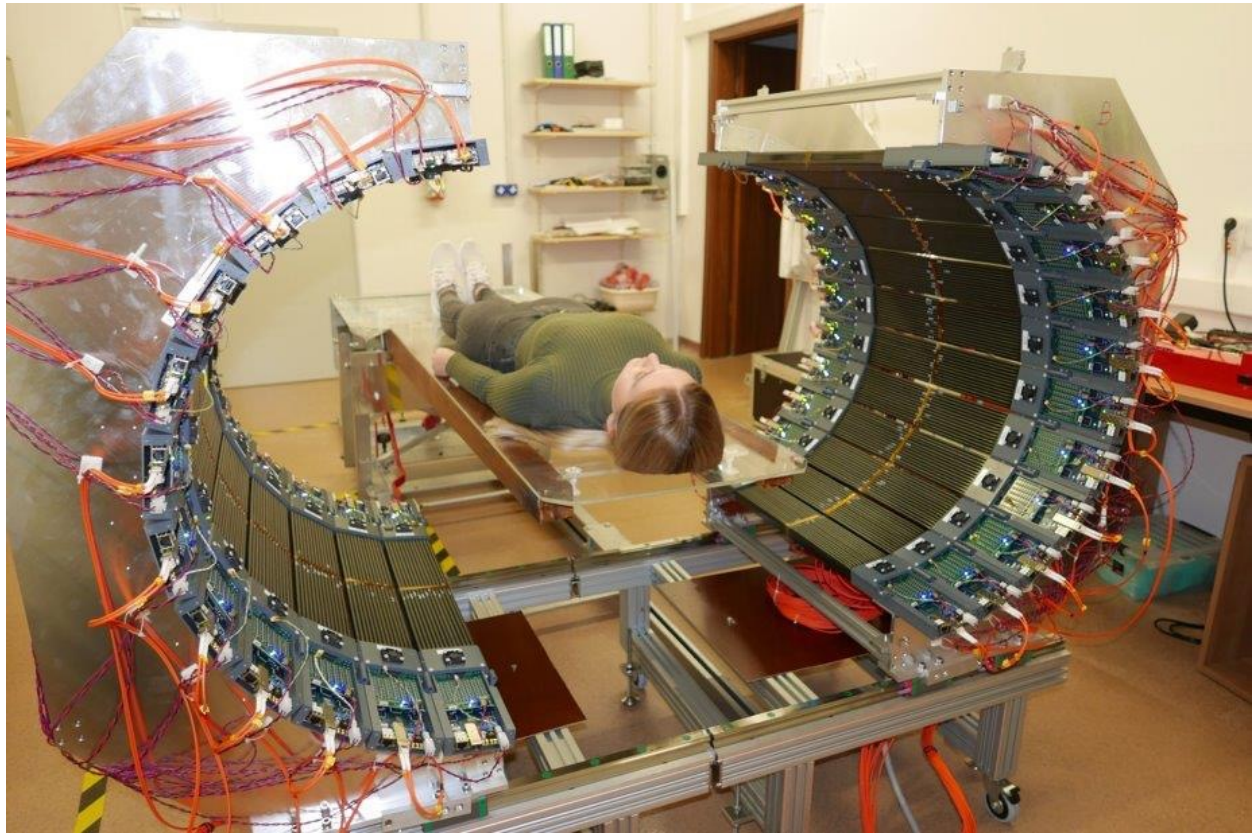
READOUT : LIGHT DETECTORS FOR J-PET



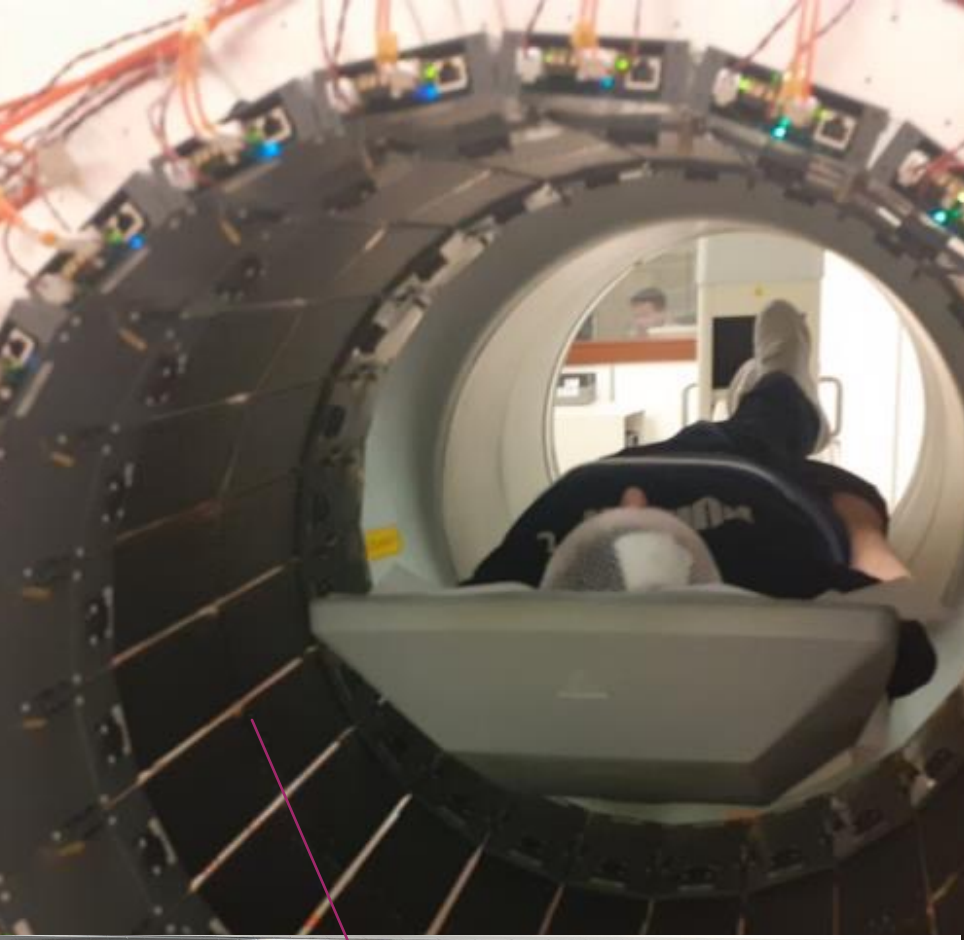
Parameter	PMT R4998	SiPM S13361
Effective photosensitive area (mm)	**20 diameter**	**6 x 6**
Spectral response range (nm)	**300 -650**	**320 -900**
Peak sensitivity wavelength (nm)	**420**	**450**
Gain	**5.0 * 10^6**	**1.7 * 10^6**
Photon detection efficiency(%)	**25**	**40**
Supply voltage(V)	**2500**	**60**

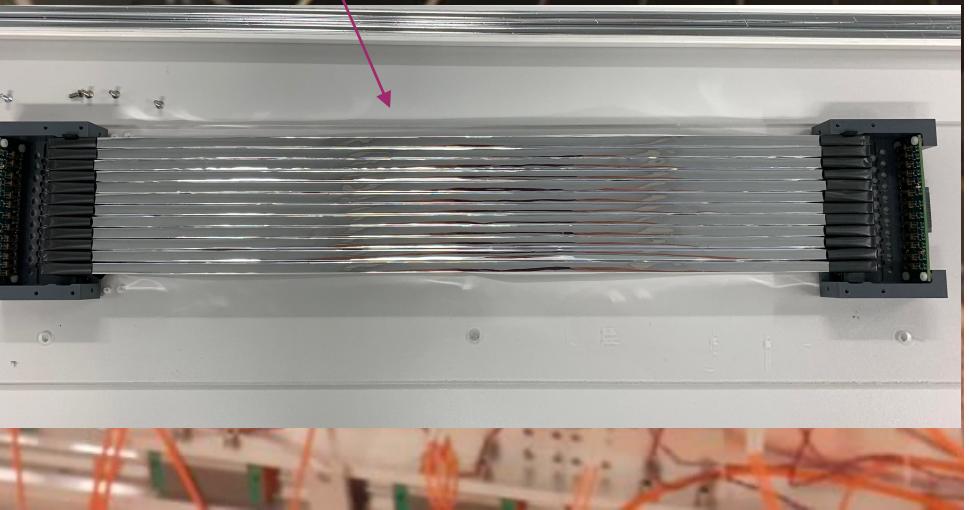
THE WORLD'S FIRST MODULAR AND PORTABLE POSITRON EMISSION TOMOGRAPHY SCANNER

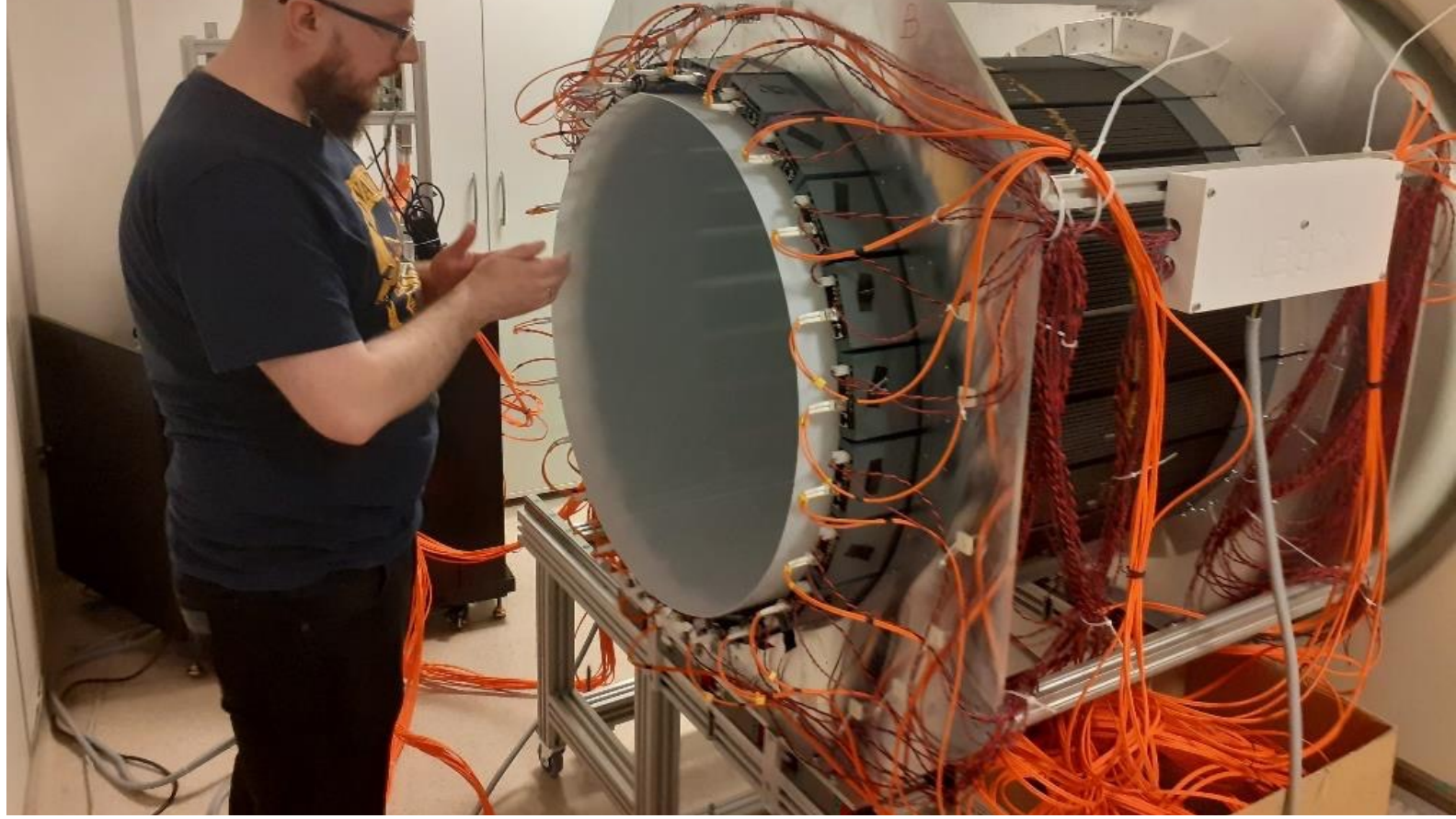




Total-Body Jagiellonian-PET Laboratory, Krakow

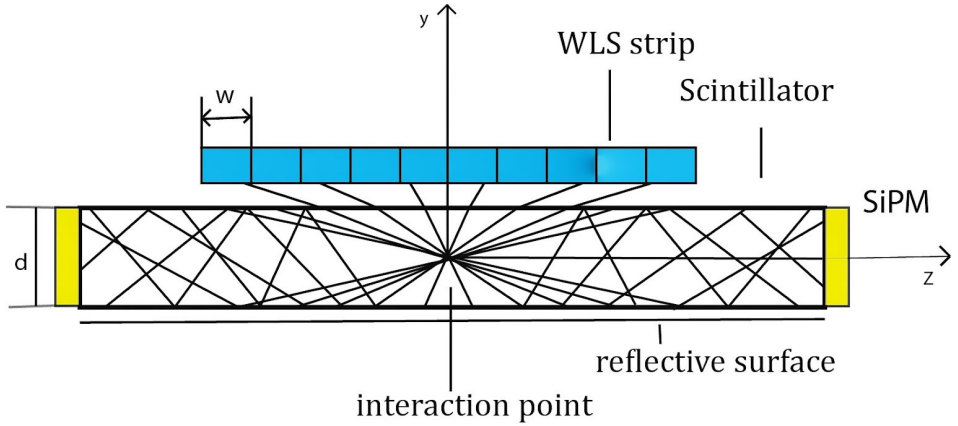


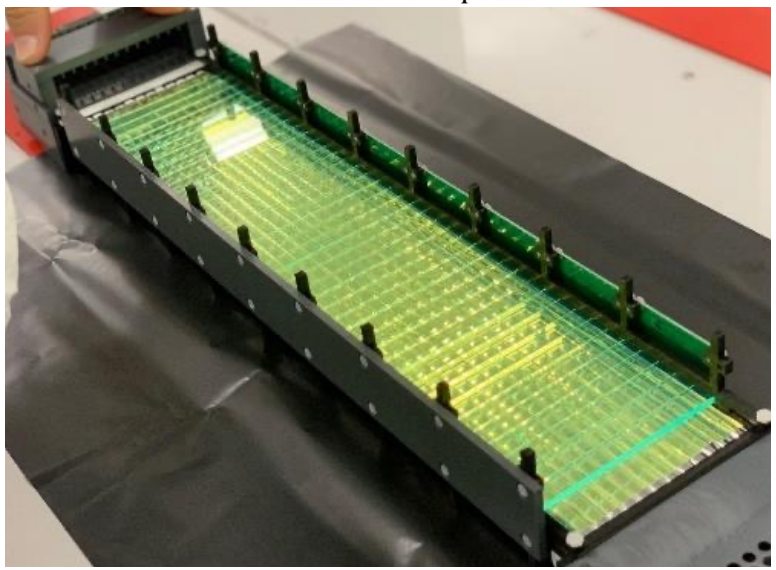


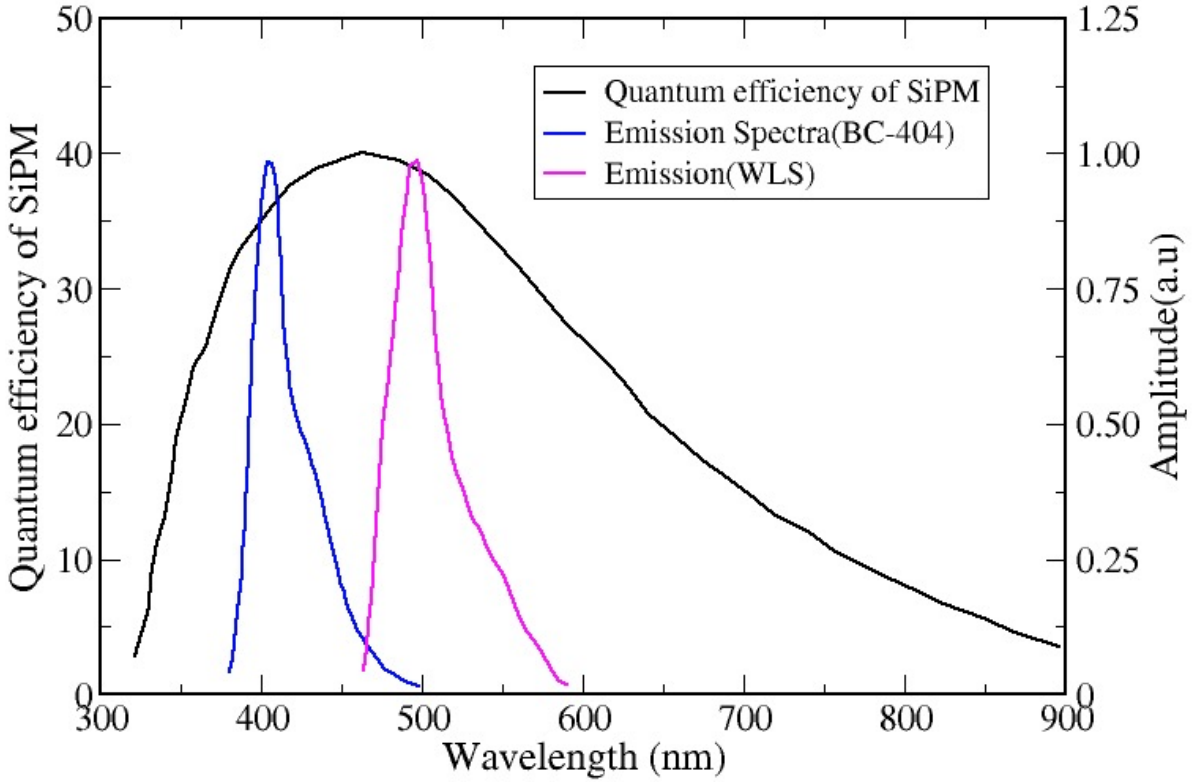


FIRST IMAGING OF PATIENTS WITH MODULAR J-PET IN MEDICAL UNIVERSITY OF WARSAW

TOTAL-BODY J-PET: DESIGN

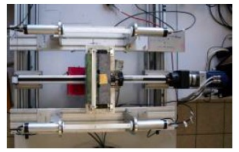


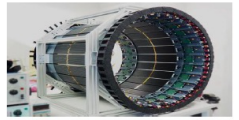
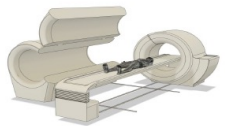




J. Smyrski et al, Nucl Instr and Meth in Phys Res A 851 (2017) 39–42

J-PET SCANNER PROTOTYPES: PROPERTIES

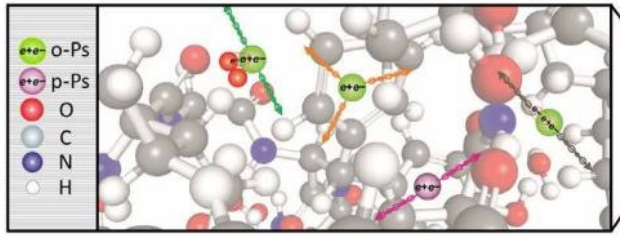


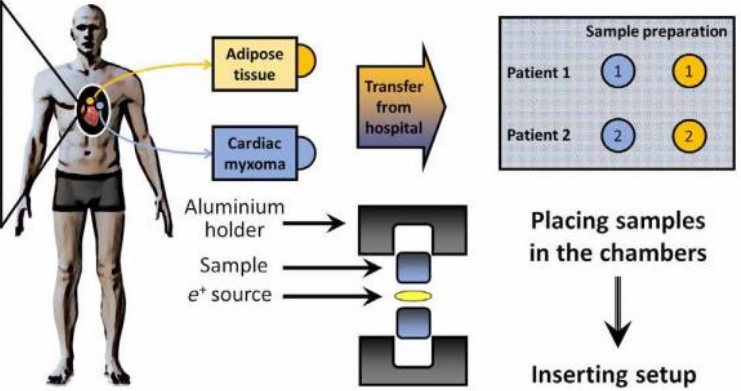




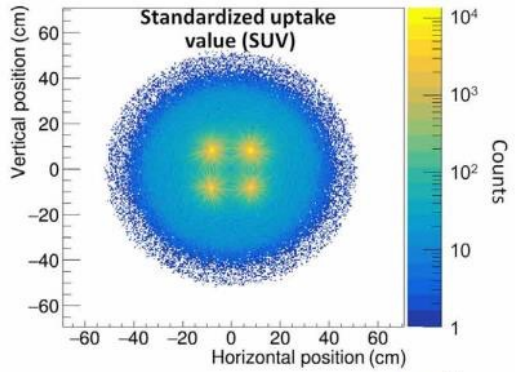
Prototype	Plastric Scintillator	Light Detector	Spatial resolution (FWHM,mm)	CRT (sigma,ps)	
Two detector modules	2 pieces, BC-420 5x19x300	4 pieces PMT R5320	6.7 MLEM	280	Doctoral dissertation, Szymon Witold Niedzwiecki, UJ, 2019
Mini J-PET	24 pieces, BC-420 5x19x300	48 pieces PMT R4998	27 MLEM	490	Doctoral dissertation, *Tomasz Bednarski, UJ, 2016*
3 layrers J-PET	192 pieces, EJ-230 7x19x500	384 pieces PMT R9800	11.4 3D MLEM	220	M. Pawlik-Niedźwiecka et al. 10.12693/APhysPolA.132.1645
Modular J-PET	312 pieces, BC-404 6x24x500	2496 pieces SiPMS13361-5797	5.4 QETIR	230	
Total-Body J-PET	5400 pieces,EJ-200 / BC-408, 6x30x330	43 000 pieces SiPMS14	4.9 MLEM	240	P. Moskal, Phys. Med. Biol. 66 (2021) 175015

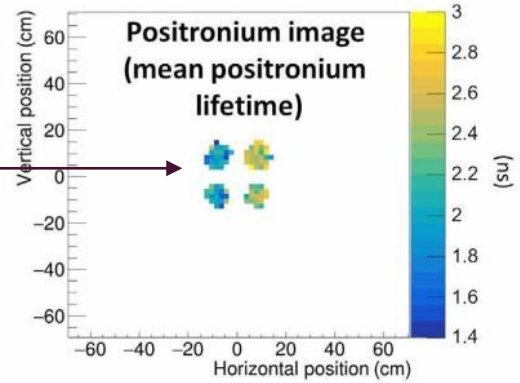
IN-VITRO POSITRONIUM IMAGING

- In 40 % cases it happen via formation of positron-electron bound state, known as positronium.
- In tissue, this lifetime is significantly shorter (roughly 1.8 to 4 ns).
- Mean o-Ps lifetime highly sensitive to the size of inter- and intramolecular voids and the concentration of biomolecules within them.
- To create a positronium image, the system examines triple coincidence events corresponding to the registration of two annihilation photons and one prompt gamma photon.
- SUV image reflects the geometrical configuration of the tissue samples and the activity of the ^{22}Na sources.



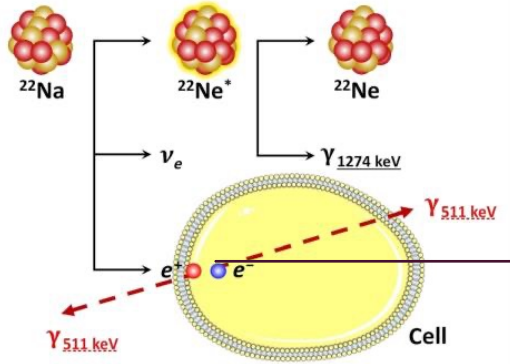


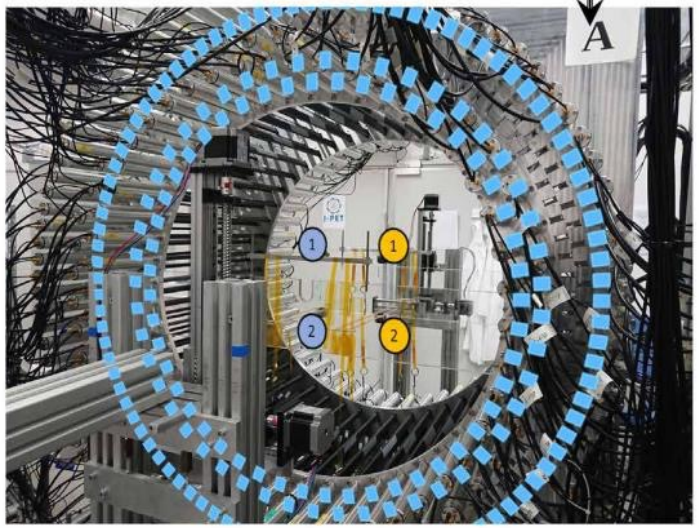




- For each voxel in the SUV image, the positron annihilation lifetime distribution is determined, in which the mean o-Ps lifetime is extracted by the PALS Avalanche software program.

- Visible and significant differences between the o-Ps lifetime in cancerous and healthy tissues, with mean lifetimes of approximately 1.9 ns in the tumour samples and 2.6 ns in the adipose tissues





P. Moskal et al., Science Advances7 (2021) eabh4394

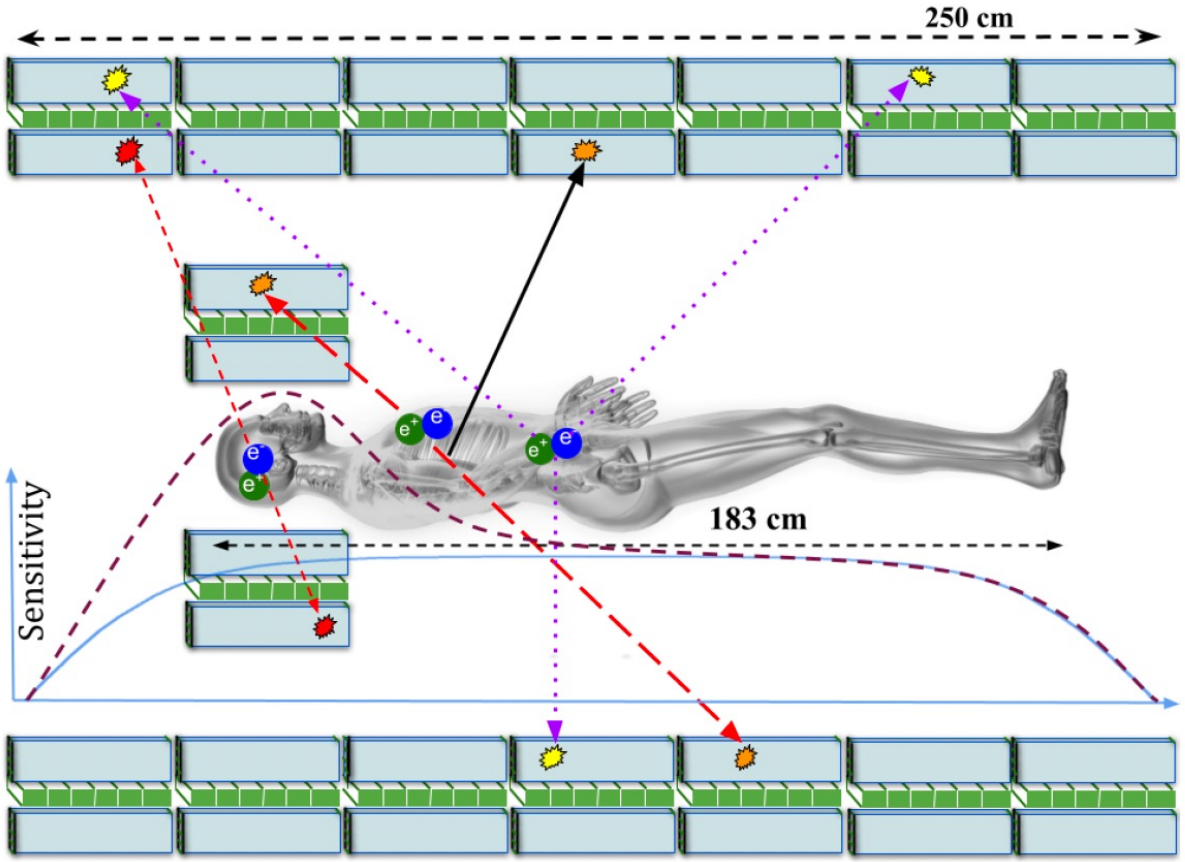
SUMMARY

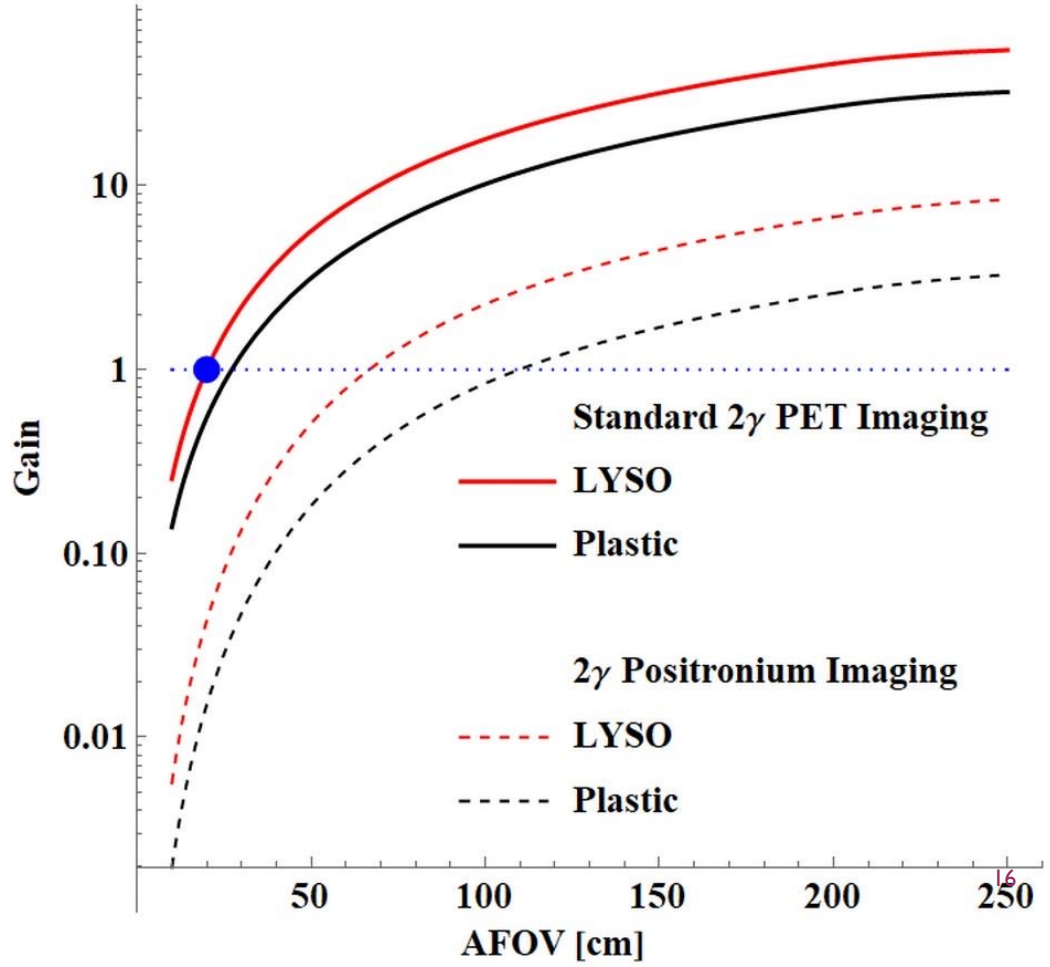
We are developing the Jagiellonian Positron Emission Tomography scanner based on plastic scintillators:

- ☐ **Modular and transportable,**
- ☐ **Field of view 50 cm (modular version) and will have 200 cm (total-body PET),**
- ☐ **Cost-effective in comparison with other total-body PET scanners,**
- ☐ **Image positronium and multi-photon isotopes labelled with biomolecules.**

Thank you so much for the attention!

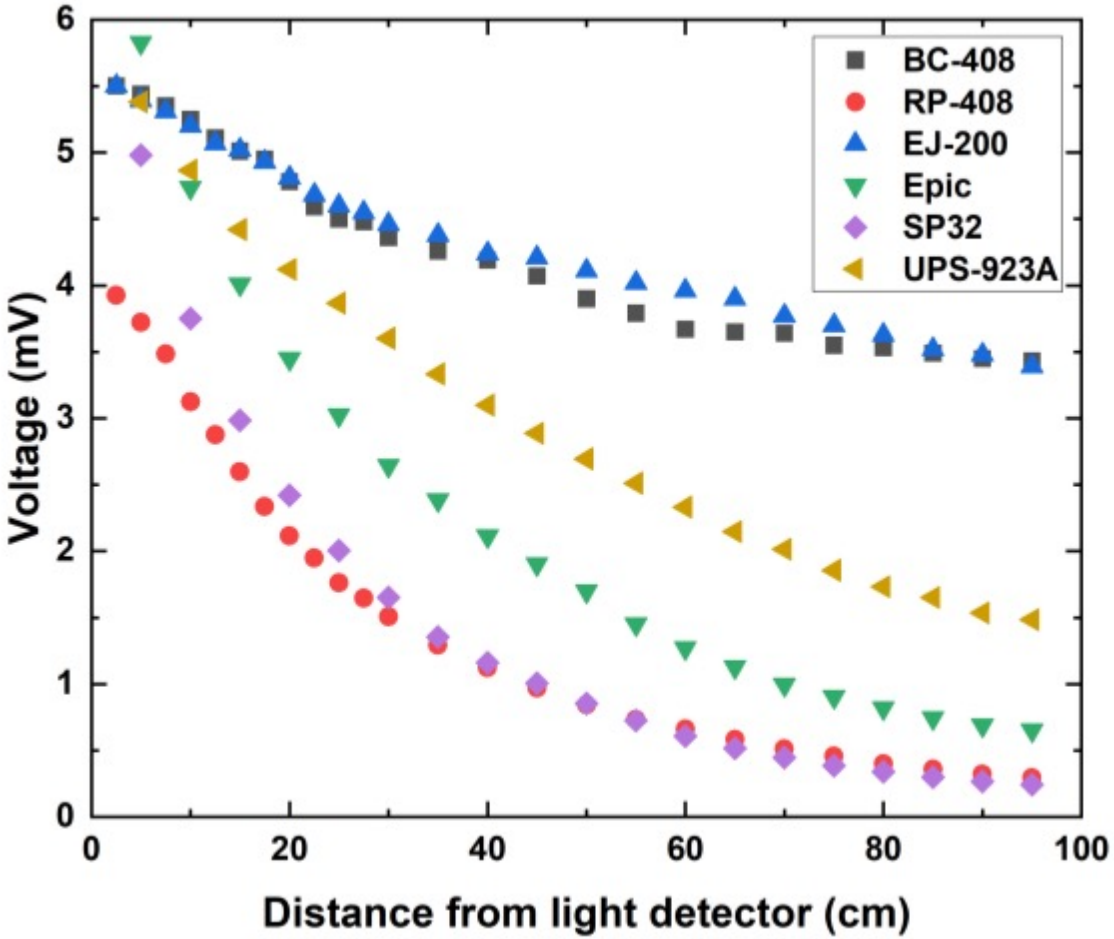
TOTAL-BODY J-PET: SENSITIVE GAIN

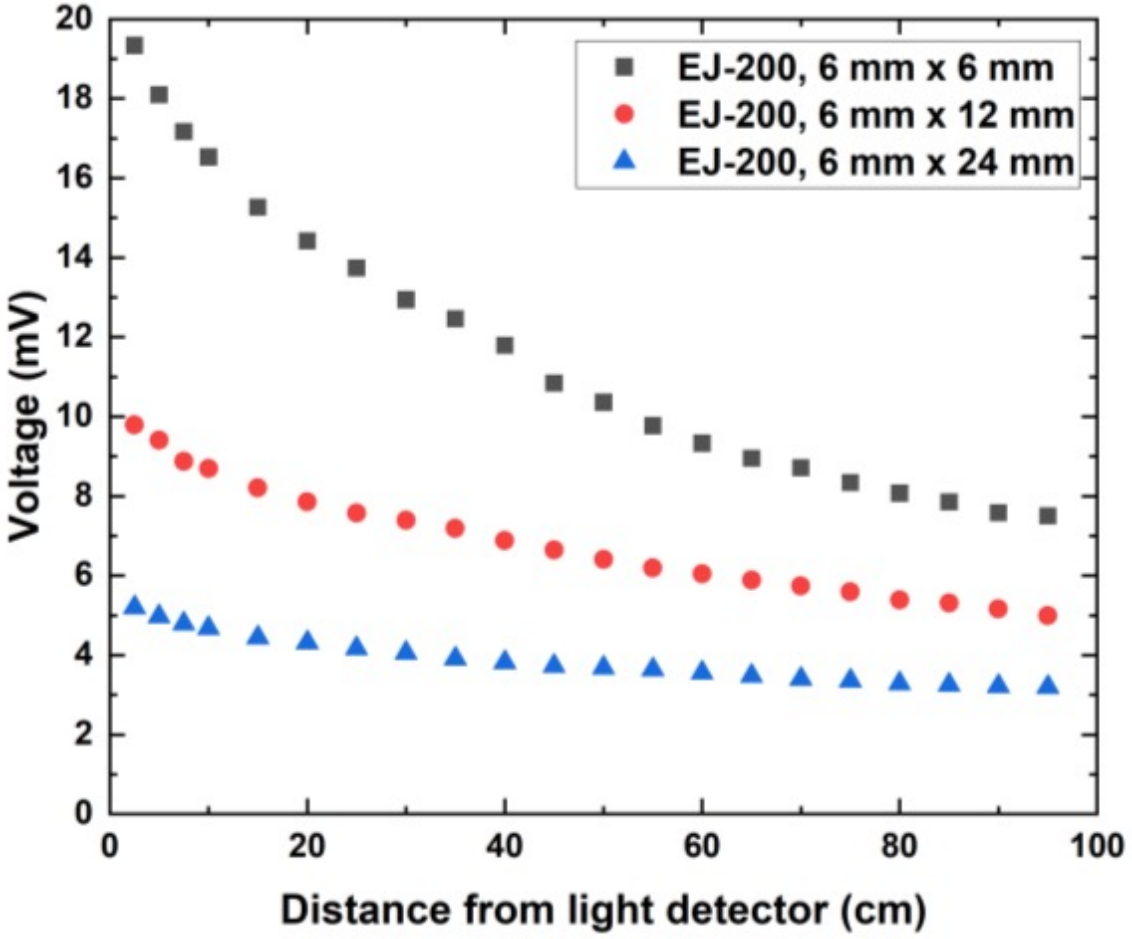




P. Moskal, E. Stępień, Prospects and clinical perspectives of total-body PET imaging using plastic scintillators, PET Clinics15 (2020) 439

Technical attenuation length of plastic scintillators

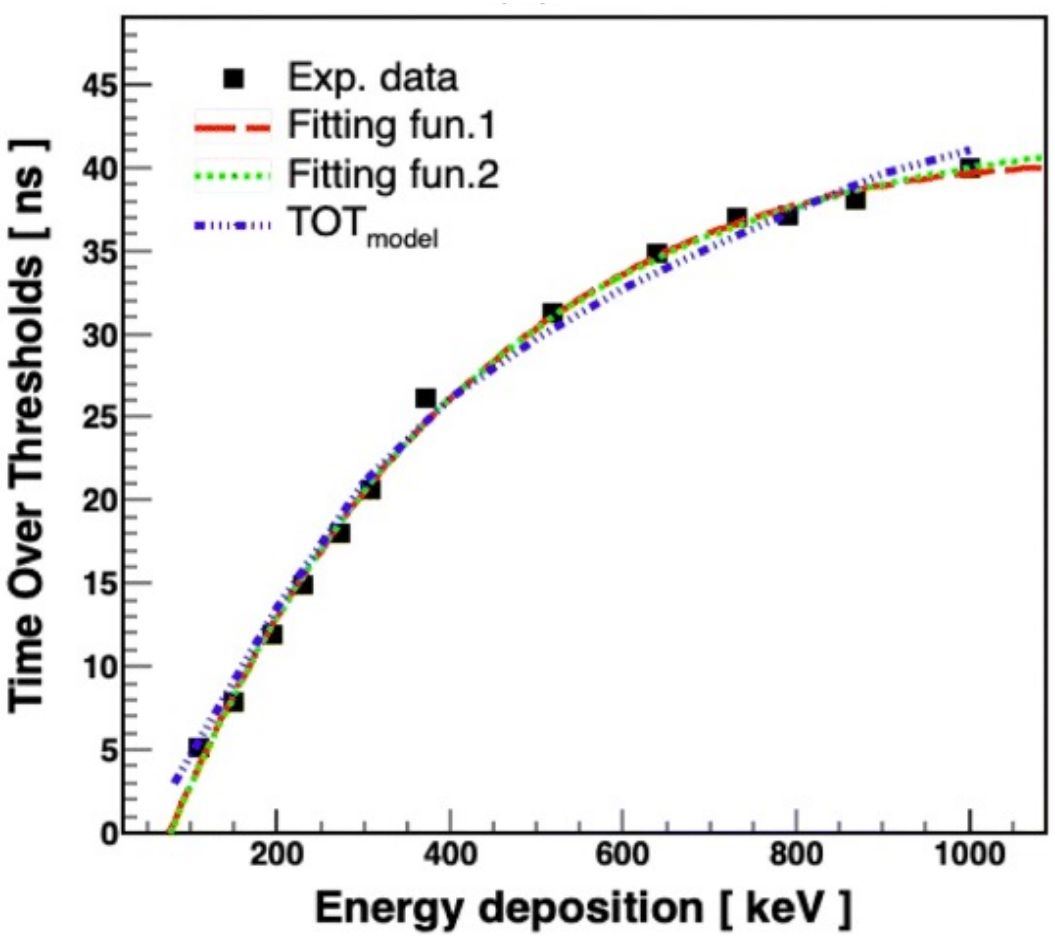


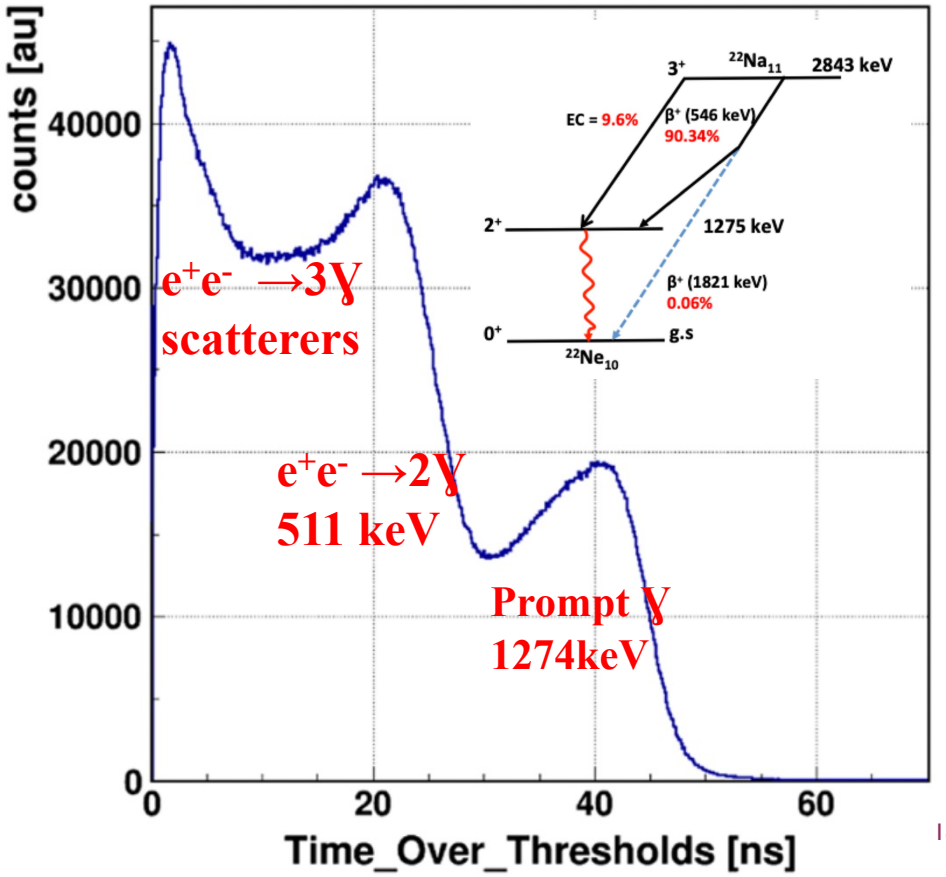


Results of the TAL measurements for four types of commercially available plastic scintillators. Two strips of each type were tested.

Ł. Kapłon, Technical attenuation length measurement of plastic scintillator strips for the total-body J-PET scanner, IEEE Trans. Nucl. Sci. 2020; 67:2286-2289

TIME OVER THRESHOLD



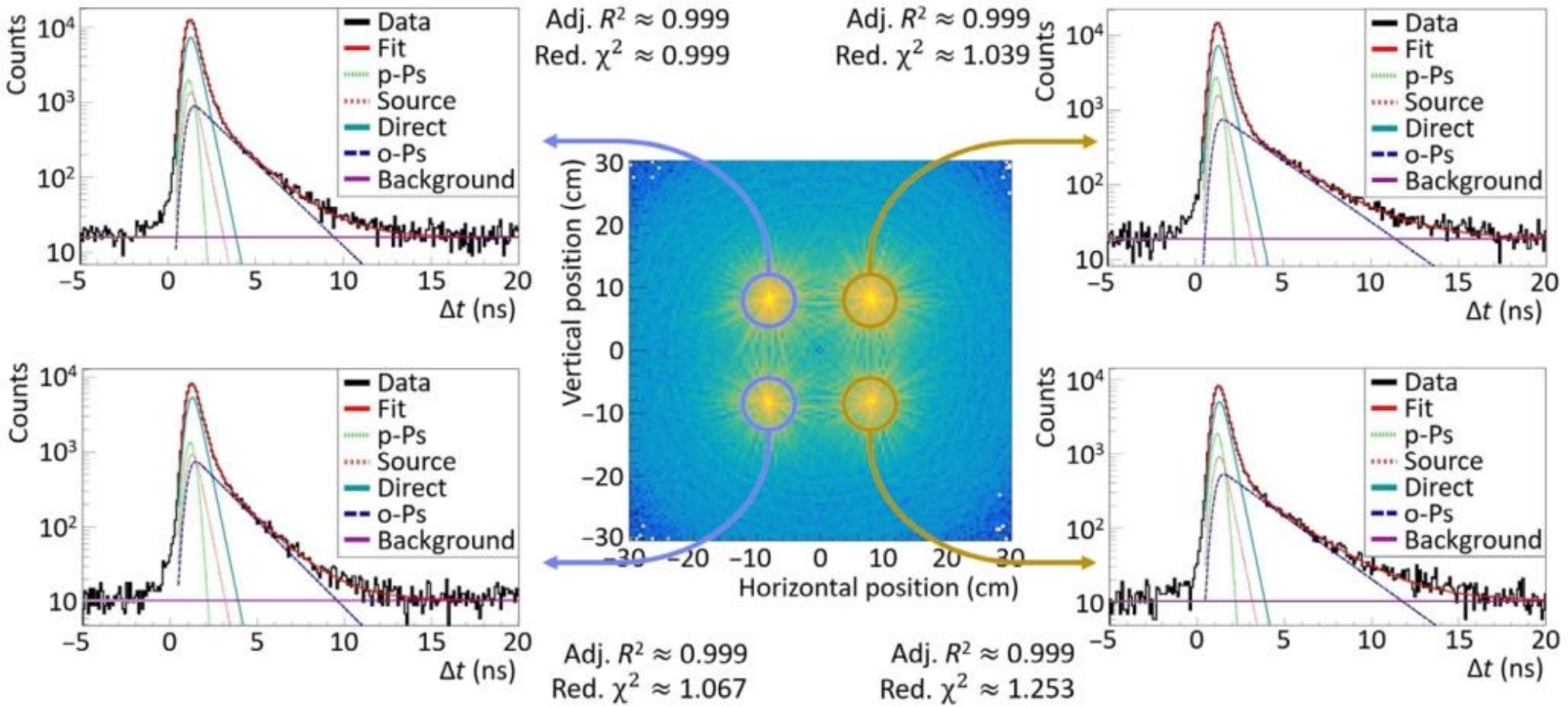


$$f(t|\Theta) = K \int_{\Theta}^{t} (e^{-\frac{t-\tau}{t_d}} - e^{-\frac{t-\tau}{t_r}}) \cdot e^{-\frac{(\tau-\Theta-2.5\sigma)^2}{2\sigma^2}} d\tau$$

The time distribution spectra of the emitted light in plastic scintillators EJ-230 (Eljen Technology) due to an incoming photon interaction at time theta can be estimated by the following equation

The equation is a convolution of Gaussian and exponential terms, where σ represents the rate of energy transfer to the primary solute, whereas tr and td denote the average time of the energy transfer to the wavelength shifter and decay time of the final light emission, respectively

K is the normalization factor to unity



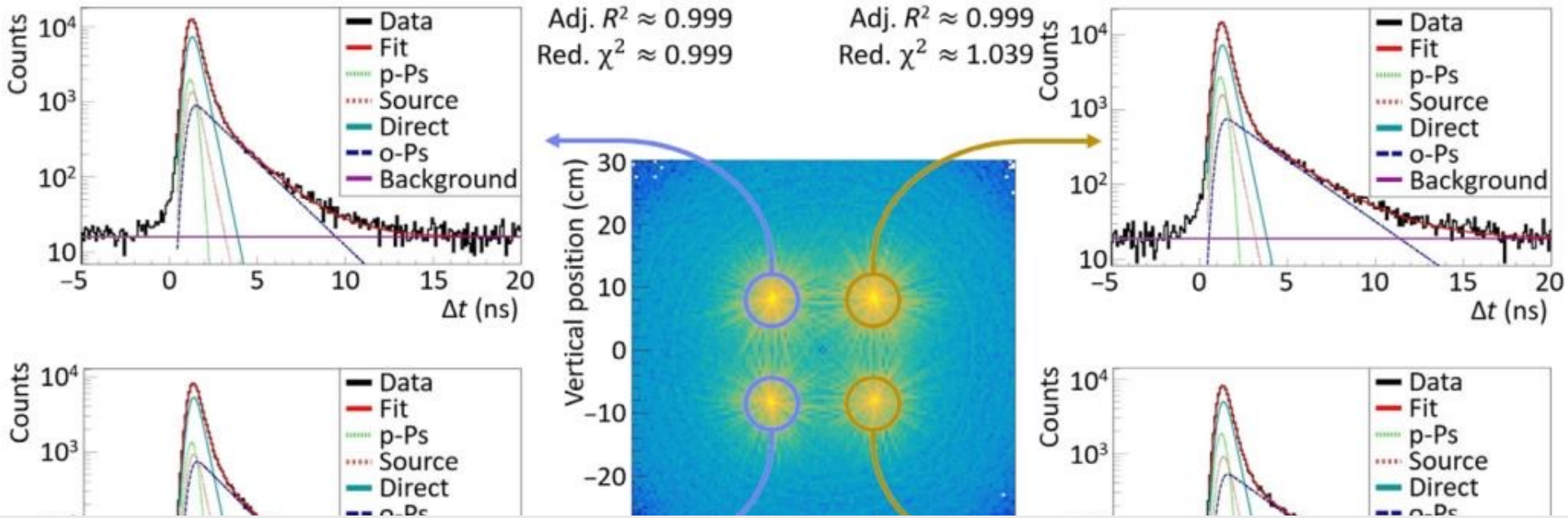
$$\mathrm{Fit}(\Delta t) = \sum_{i=1}^{4} I_i \left(\exp\left(-\frac{\Delta t}{\tau_i}\right) * \mathrm{Gaussian}\,(\Delta t, t_0, \sigma) \right) + \mathrm{Background}$$

I_i – Intensity of ith component,
τ_i – Mean lifetime of ith component

$$\sum_{i=1}^{4} I_i = 100\%$$

Positron annihilation lifetime spectra

P. Moskal et al., Positronium imaging with the novel multiphoton PET scanner, Science Advances7 (2021) eabh4394



Parameter name	Cardiac myxoma 1	Cardiac myxoma 2	Adipose tissue 1	Adipose tissue 2
Parapositronium mean lifetime (ns)		0.125 (fixed)		
Parapositronium intensity (%)	13.26 (18)	12.21 (21)	17.18 (16)	17.14 (20)
Direct annihilation mean lifetime (ns)		0.388 (fixed)		
Direct annihilation intensity (%)	65.35 (22)	64.52 (27)	61.34 (20)	61.31 (23)
o-Ps mean lifetime (ns)	1.950 (19)	1.874 (20)	2.645 (27)	2.581 (30)
o-Ps intensity (%)	21.39 (47)	23.27 (45)	21.49 (41)	21.56 (54)
Adjusted R^2	0.999	0.999	0.999	0.999
Reduced χ^2	0.999	1.067	1.039	1.253