2022 YIWS Young Investigators' Workshop Multi-Gamma Imaging

Positronium Imaging - a multi-gamma imaging technique investigated with the J-PET tomograph

Szymon Parzych

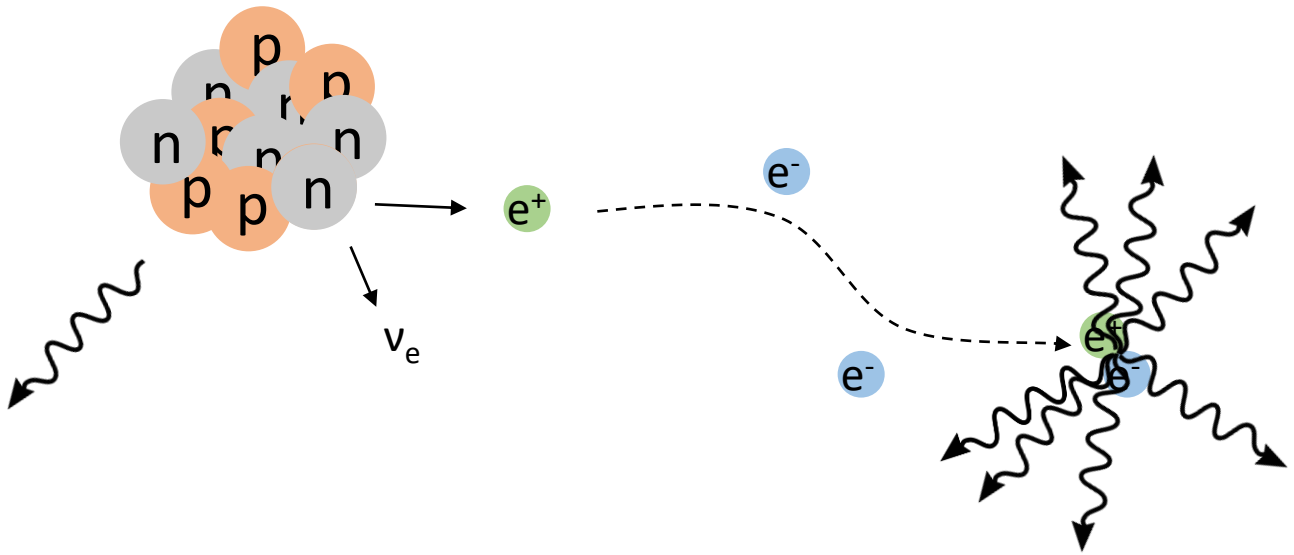
On behalf of the J-PET Collaboration

Faculty of Physics, Astronomy and Applied Computer Science
Jagiellonian University, 30-348 Kraków, Poland

J-PET

UNIWERSYTET JAGIELLOŃSKI W KRAKOWIE

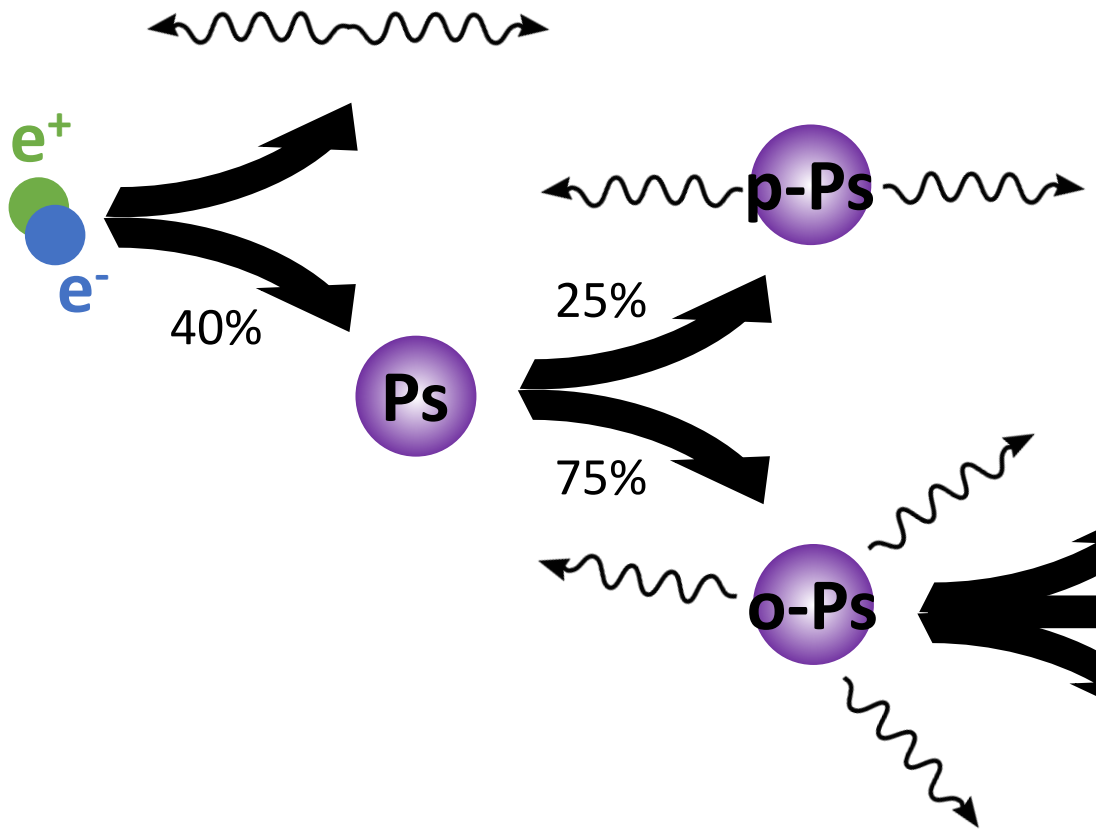
Positron Emission Tomography PET

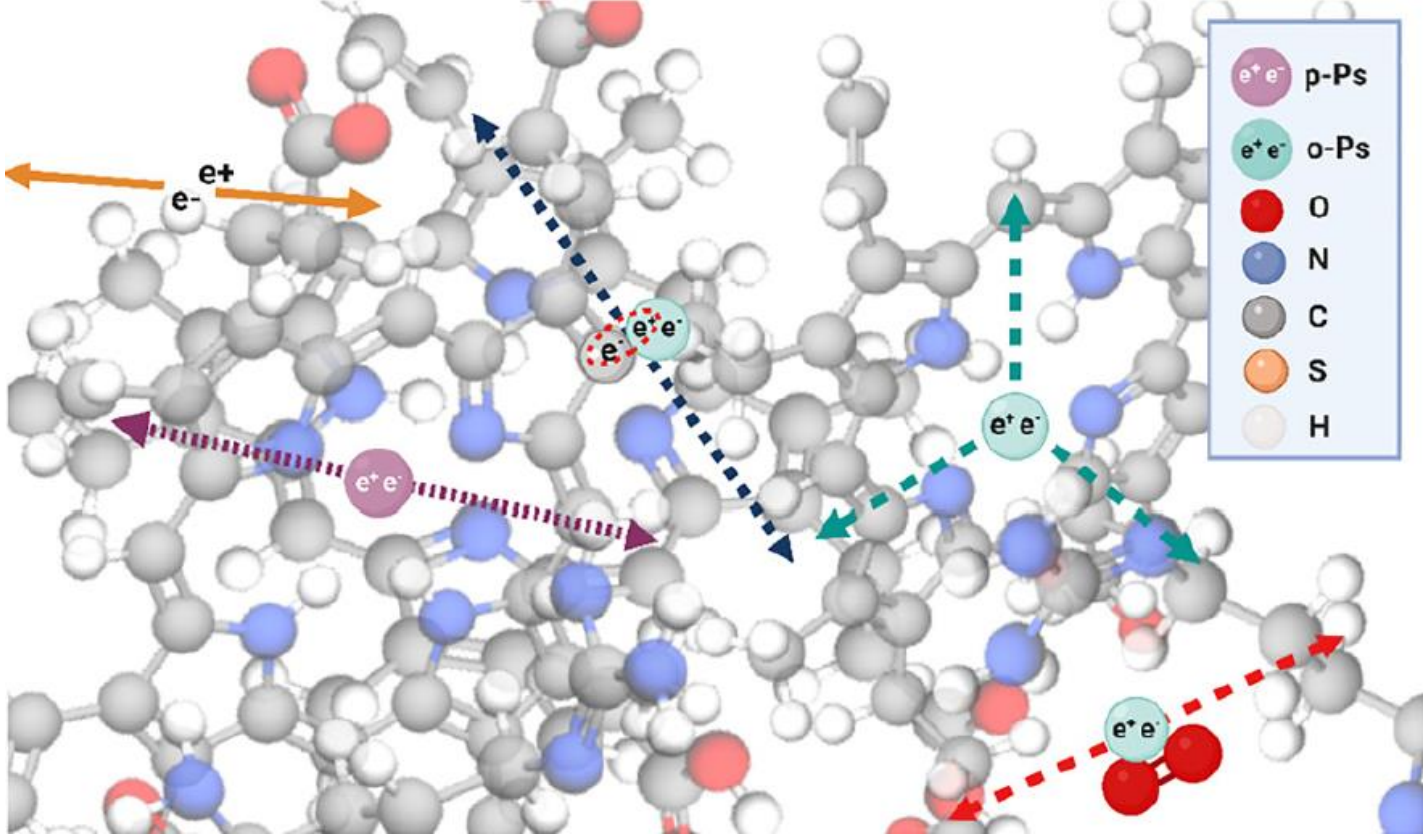


Positronium (Ps)

- Para-positronium p-Ps
  Spin: ↑↓
  $\tau \approx 0.125$ ns
- Ortho-positronium o-Ps
  Spin: ↑↑
  $\tau \approx 142$ ns

Positronium (Ps)

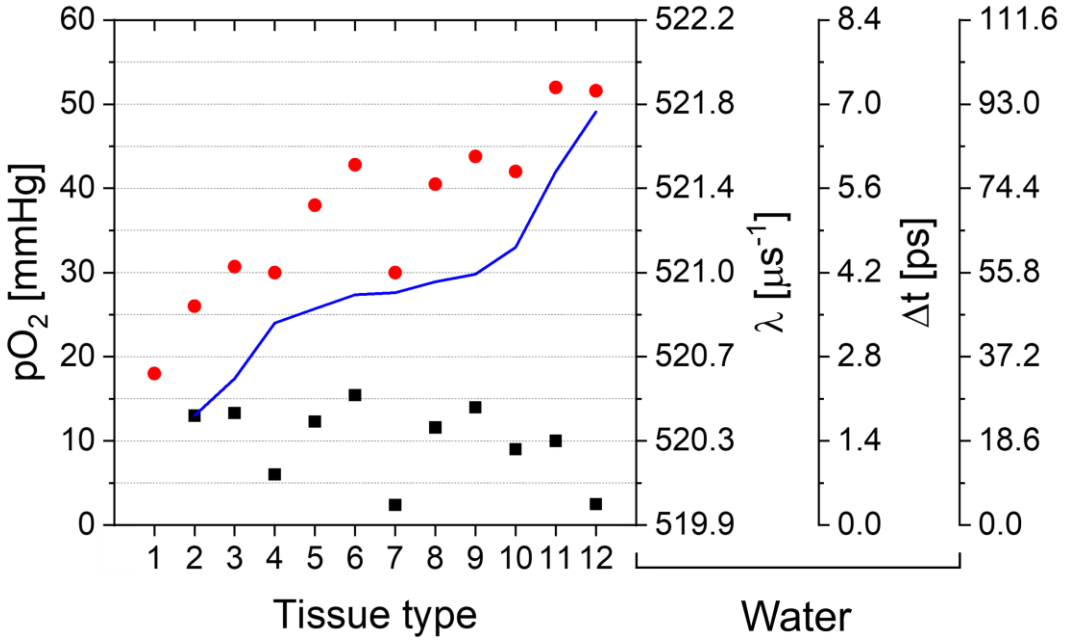


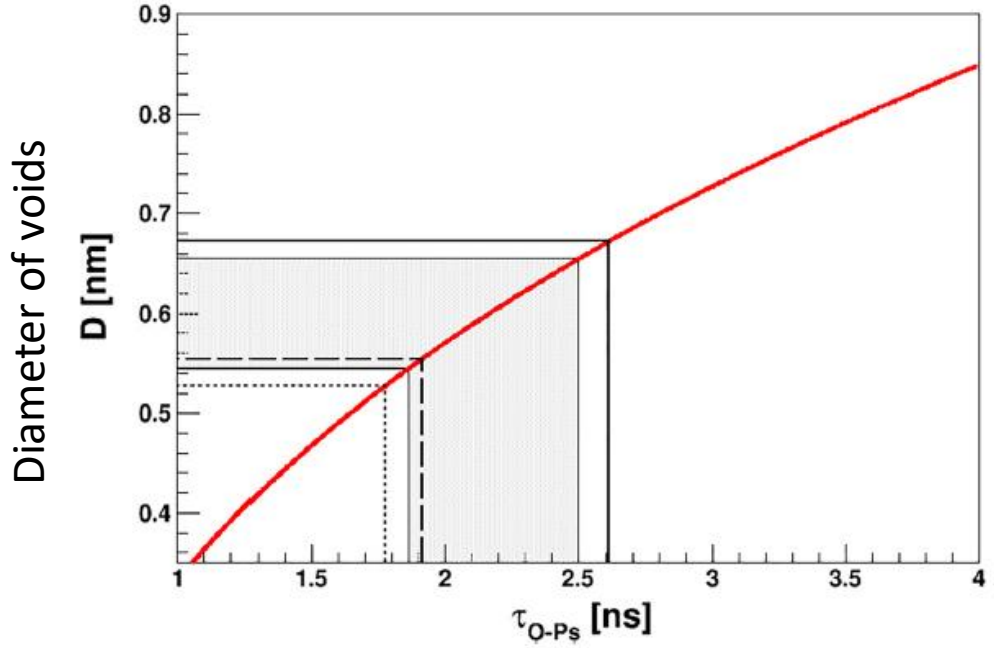


P. Moskal and E. Stępień,Bio-Algorithms and Med-Systems 17 (2021) 311-319

Positronium (Ps)

Because of the pick-off and conversion processes, the mean lifetime of o-Ps is highly sensitive to the size of inter- and intramolecular voids (free volume between the atoms) and to the concentration of biomolecules in them.





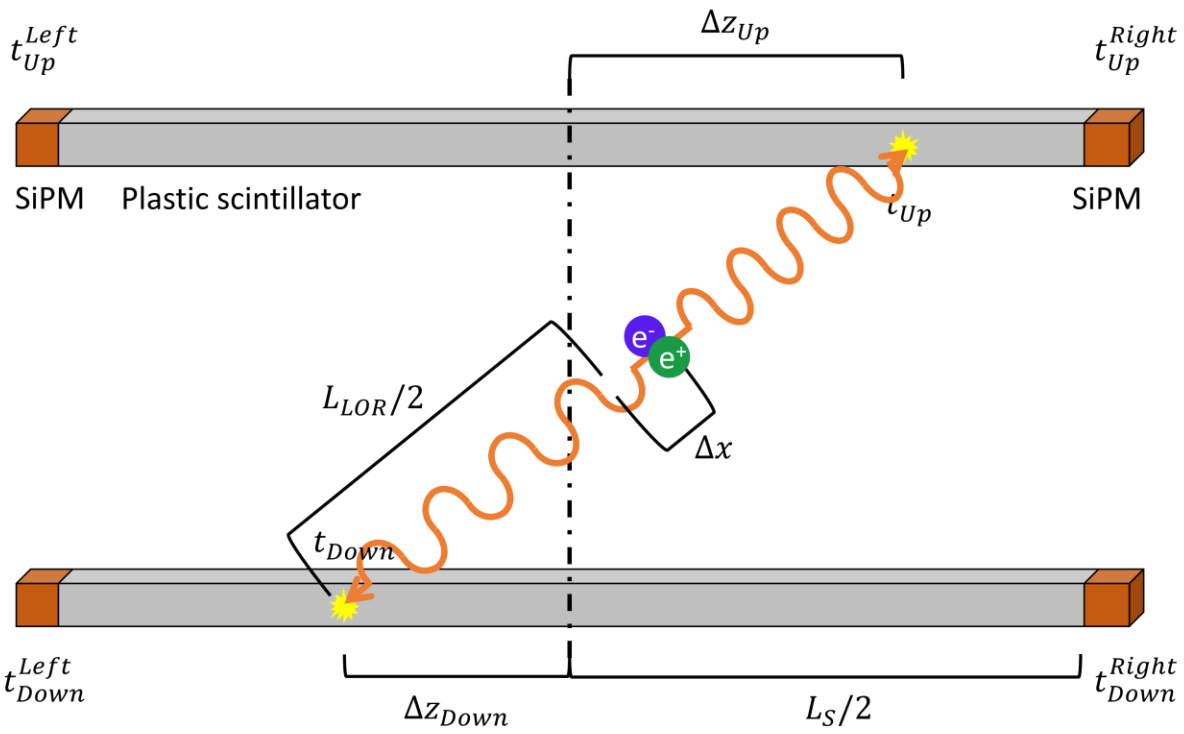
P. Moskal and E. Stępień,Bio-Algorithms and Med-Systems 17 (2021) 311-319

Jagiellonian-PET (J-PET) Collaboration

J-PET technology

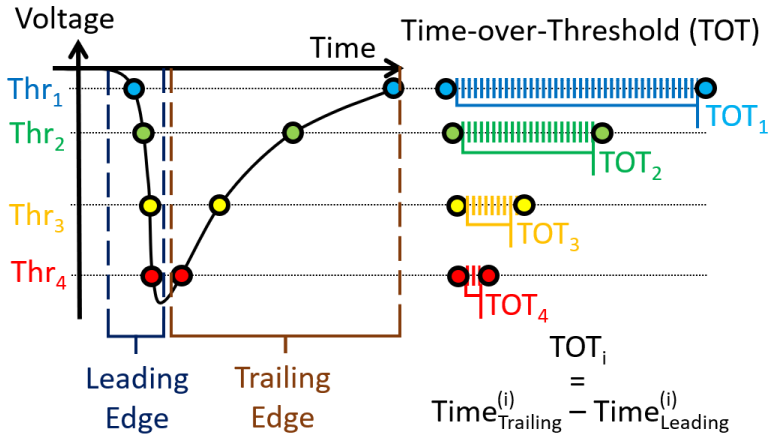
- Detection based on Compton effect in long plastic scintillators
- Energy estimated as a Time-over-Threshold value
- Both energy and position of the hit reconstructed based on the measured times (resolution ~350 ps in FWHM*)

*K. Dulski et al., NIM A 1008 (2021) 165452



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

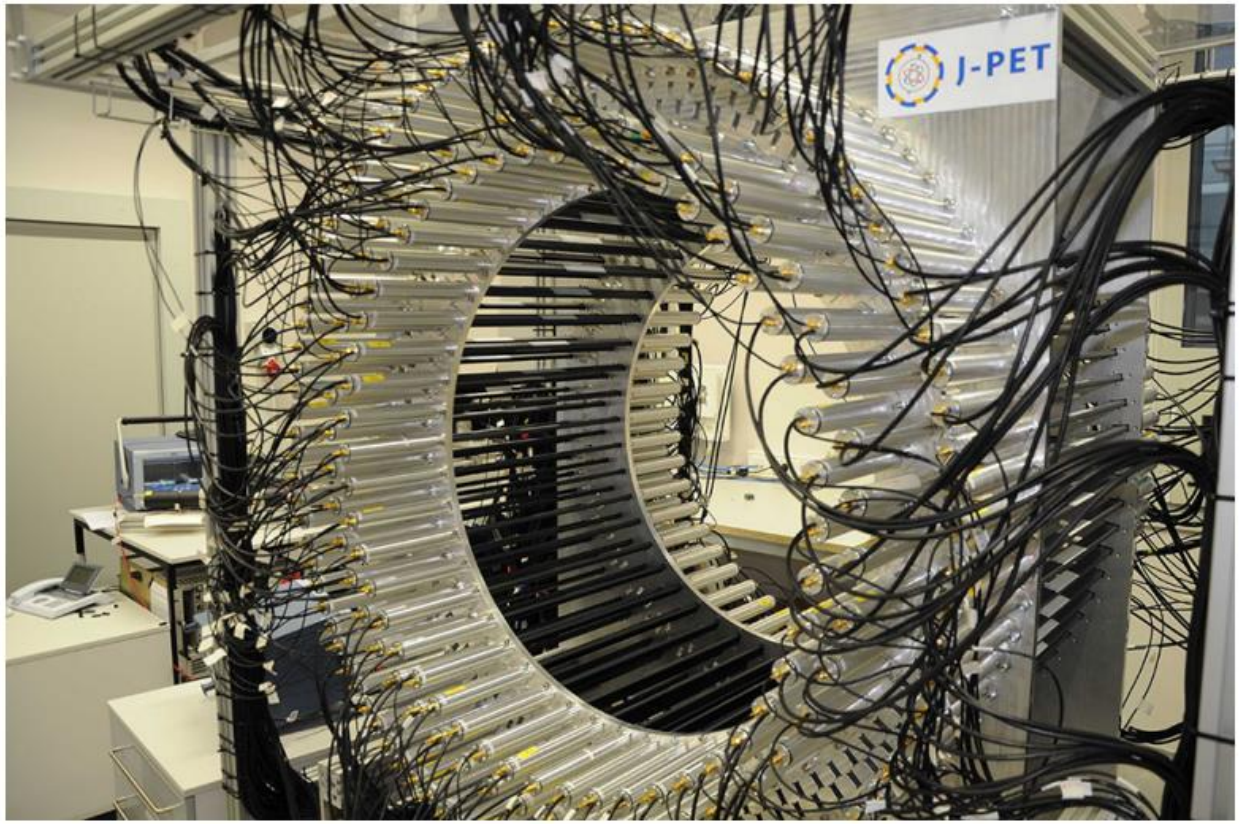
$$\Delta x = \frac{\left(t_{Up} - t_{Down}\right) v}{2}$$



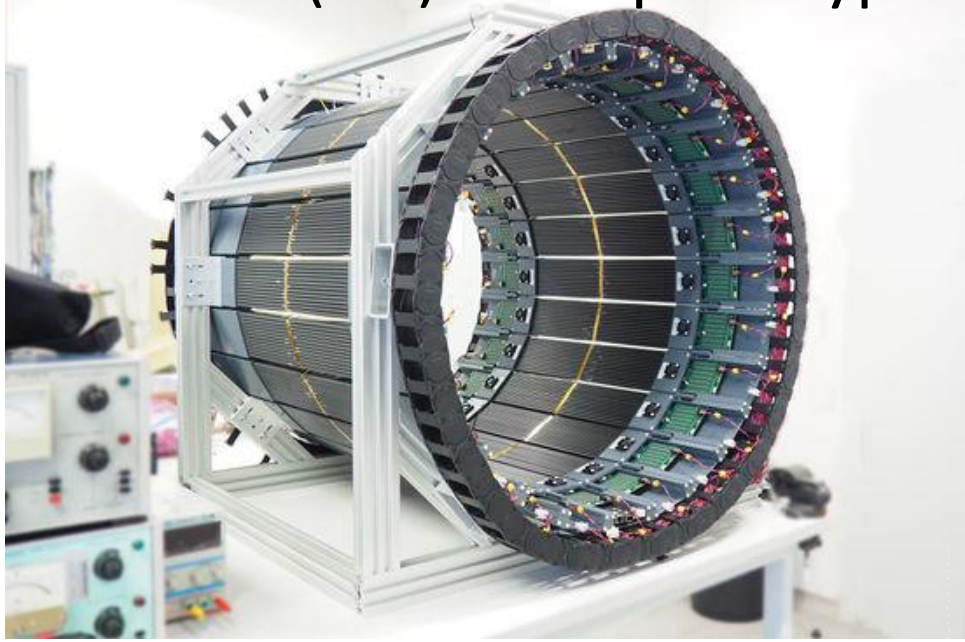
Detailed information will be presented during poster session by Szymon Niedźwiecki

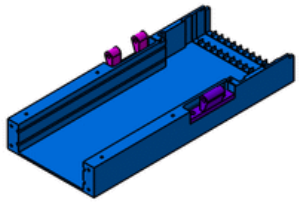
J-PET technology

1st J-PET prototype



Modular (2nd) J-PET prototype

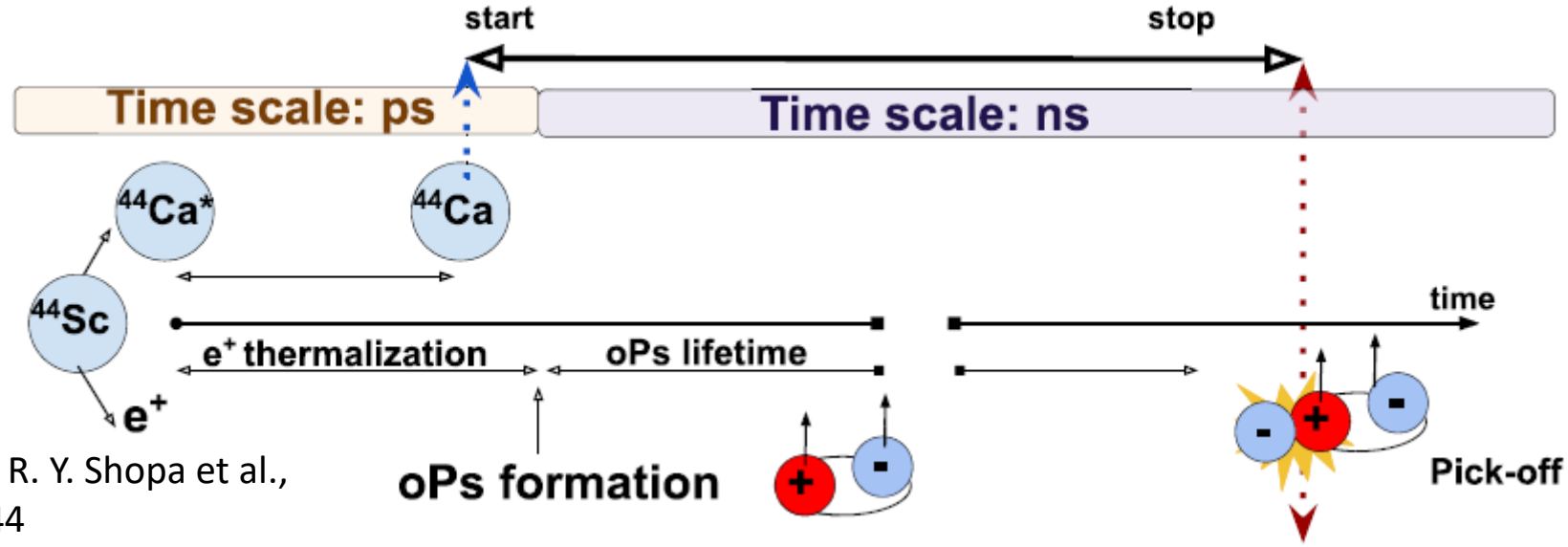




http://koza.if.uj.edu.pl/pet/

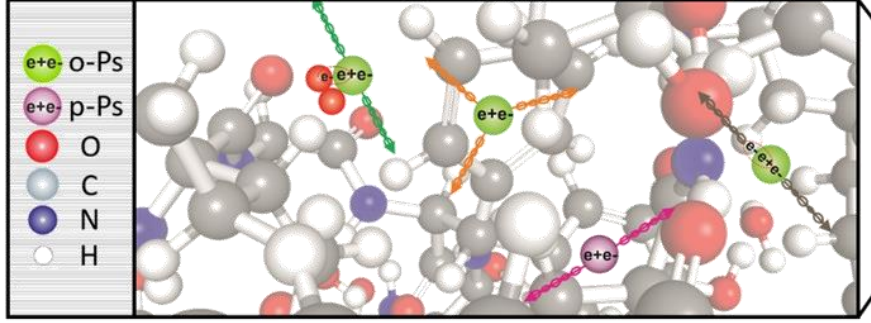
Positronium Imaging

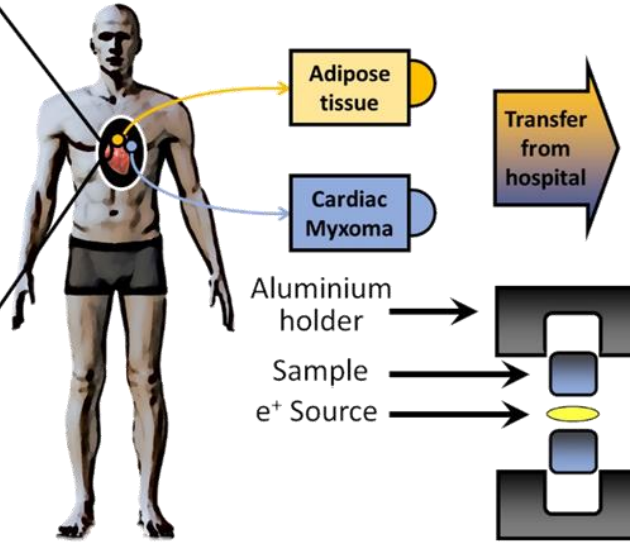
- Complementary to Metabolic
- Based on the back-to-back annihilation photons and deexcitation gamma
- Ortho-Positronium mean lifetime instead of SUV parameter
- Enables imaging of the inner structure of tissues
- Additional diagnostic indicator

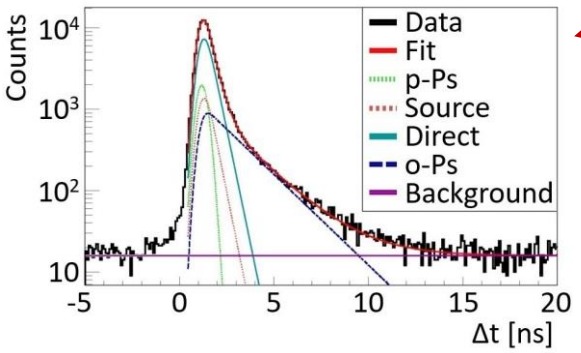


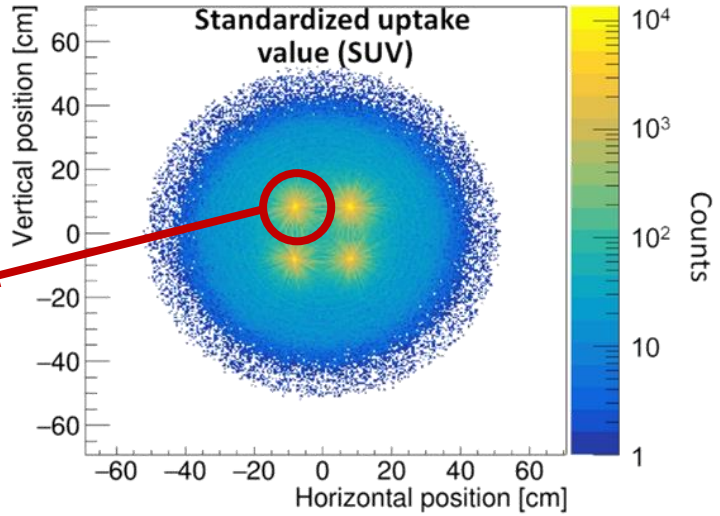
P. Moskal, D. Kisielewska, R. Y. Shopa et al., EJNMMI Phys., 7 (2020) 44

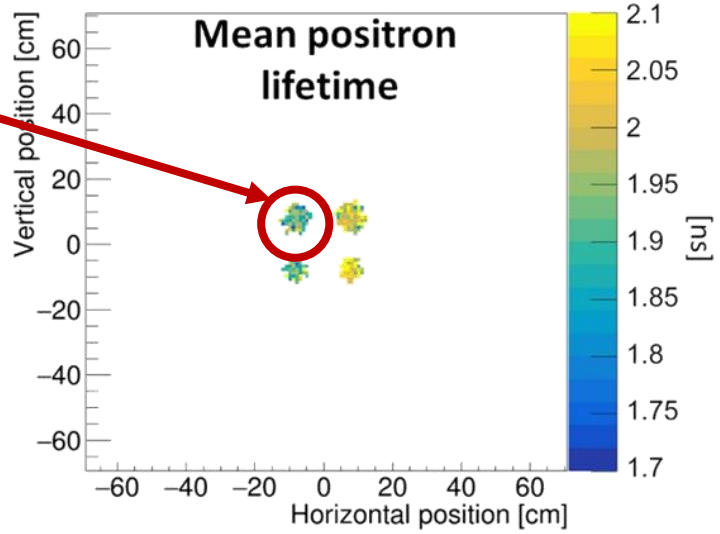
Detailed information will be presented during poster session by Kamil Dulski

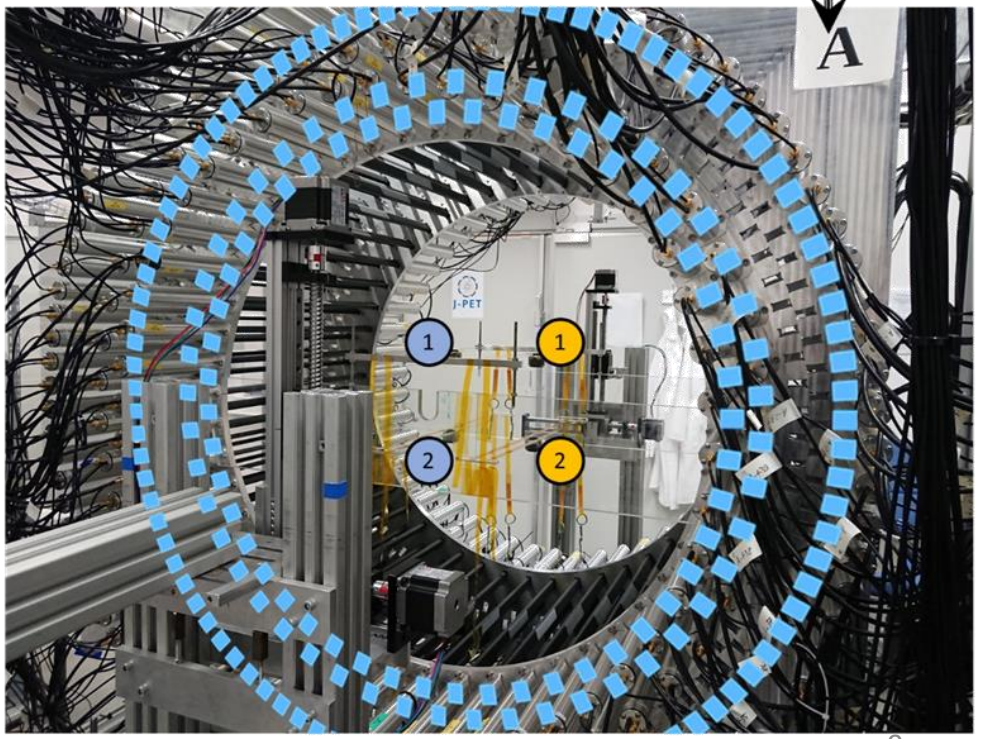








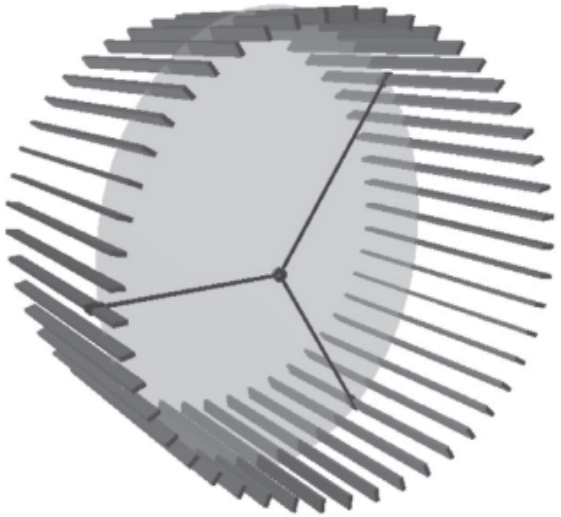


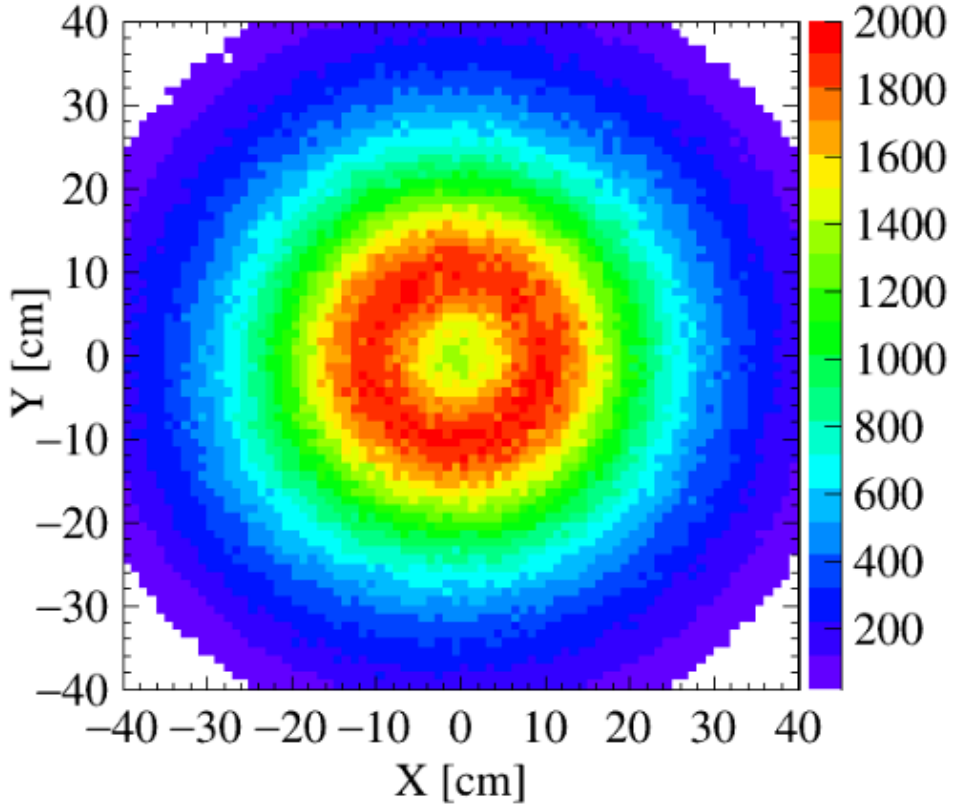


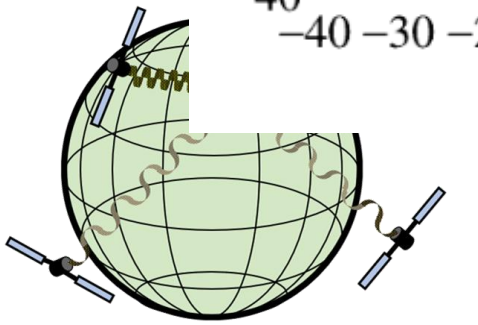
P. Moskal, K. Dulski et al., Science Advances 7 (2021) eabh4394

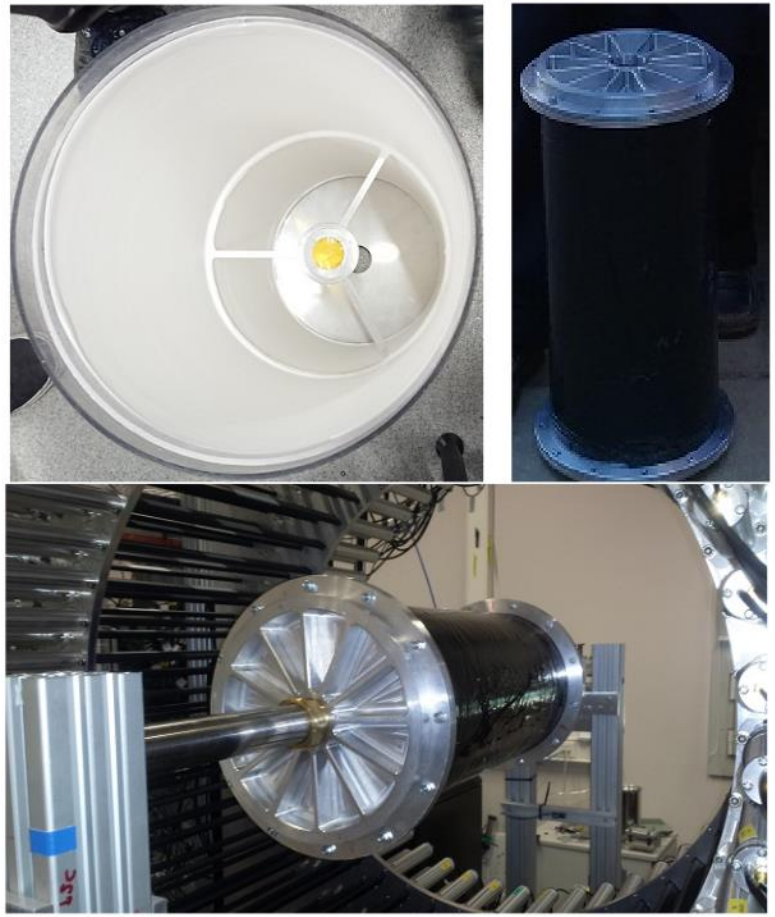
Three-photon o-Ps image

Trilatera









mber with walls coated
… mesoporous silica -> high
fraction of the o-Ps production

Detailed information will be presented during poster session by Aleksander Gajos

P. Moskal, A. Gajos et al., Nature Communications 12 (2021) 5658

Positronium Imaging sensitivity

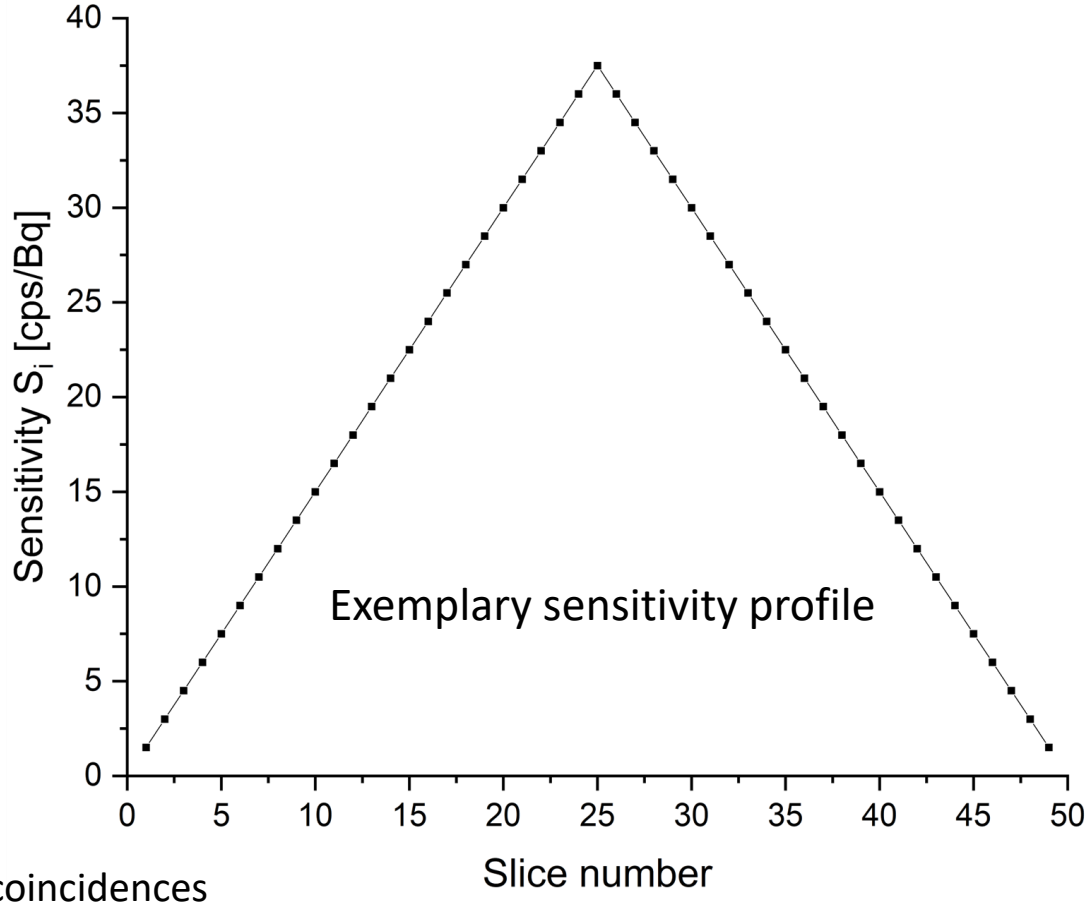
For the study of Positronium Imaging a ^{44}Sc isotope was chosen as a radioisotope. A corresponding reaction chain of β^+ decay:

$$^{44}Sc \rightarrow {}^{44}Ca^{*} + e^{+} + \nu \rightarrow {}^{44}Ca + \gamma + e^{+} + \nu$$

creates excited ^{44}Ca* nucleus, which during the deexcitation process emits prompt photon of 1160 keV energy

Sensitivity

- The sensitivity of a PET tomograph is expressed as the true coincidence events rate normalized to the total activity of the source
- According to “NEMA Standards Publication NU 2-2018” guidelines it can be reported as:
  - System (total) sensitivity $S_{tot} = {}^{R}/_{A}$
  - Sensitivity profile, where $S_i = {}^{R_i}/_{A_i}$



R_i - rate of registered true coincidences originating within the i^{th} slice
A_i - fraction of activity located in i^{th} slice

Geometries

Tomographs designed with Modular J-PET technology:

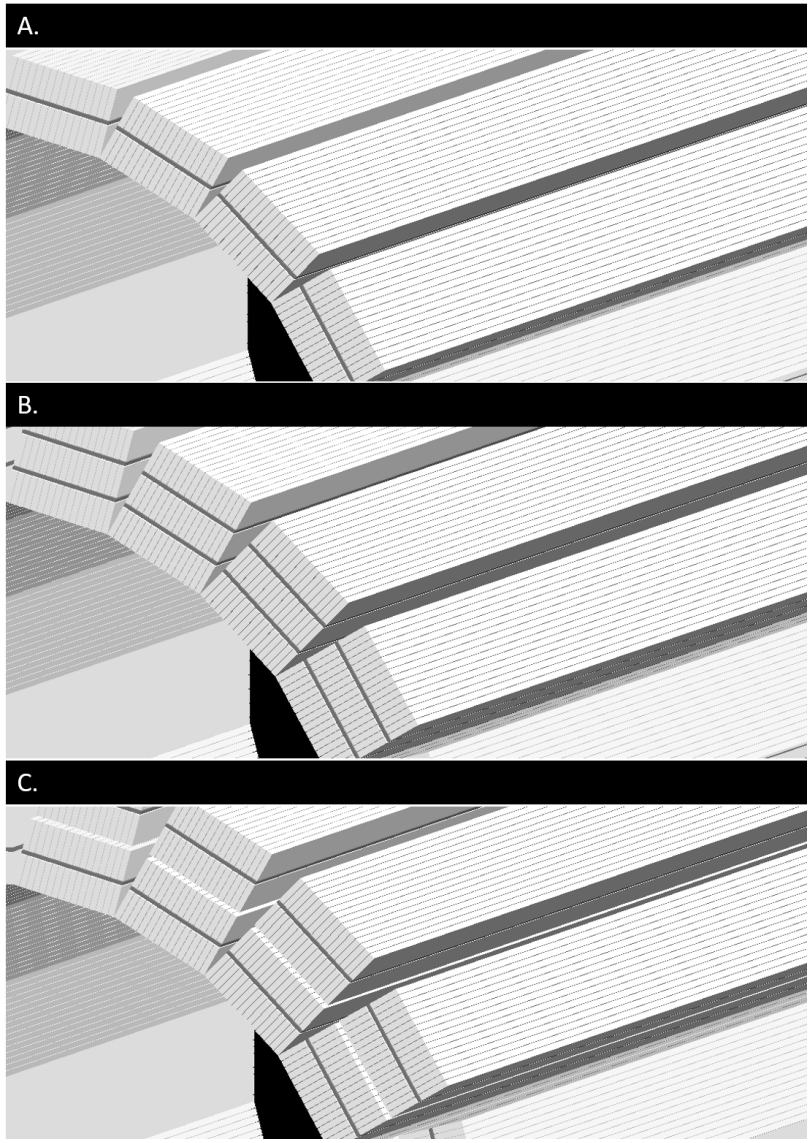
- Scintillator material – plastic (EJ230, Eljen Technology)
- Axial arrangement
- Silicon photomultiplier (SiPM) readout at both ends

Three designs were taken into account:

A. 2 panels × 16 scintillators

B. 3 panels × 16 scintillators

C. 4 panels × 16 scintillators



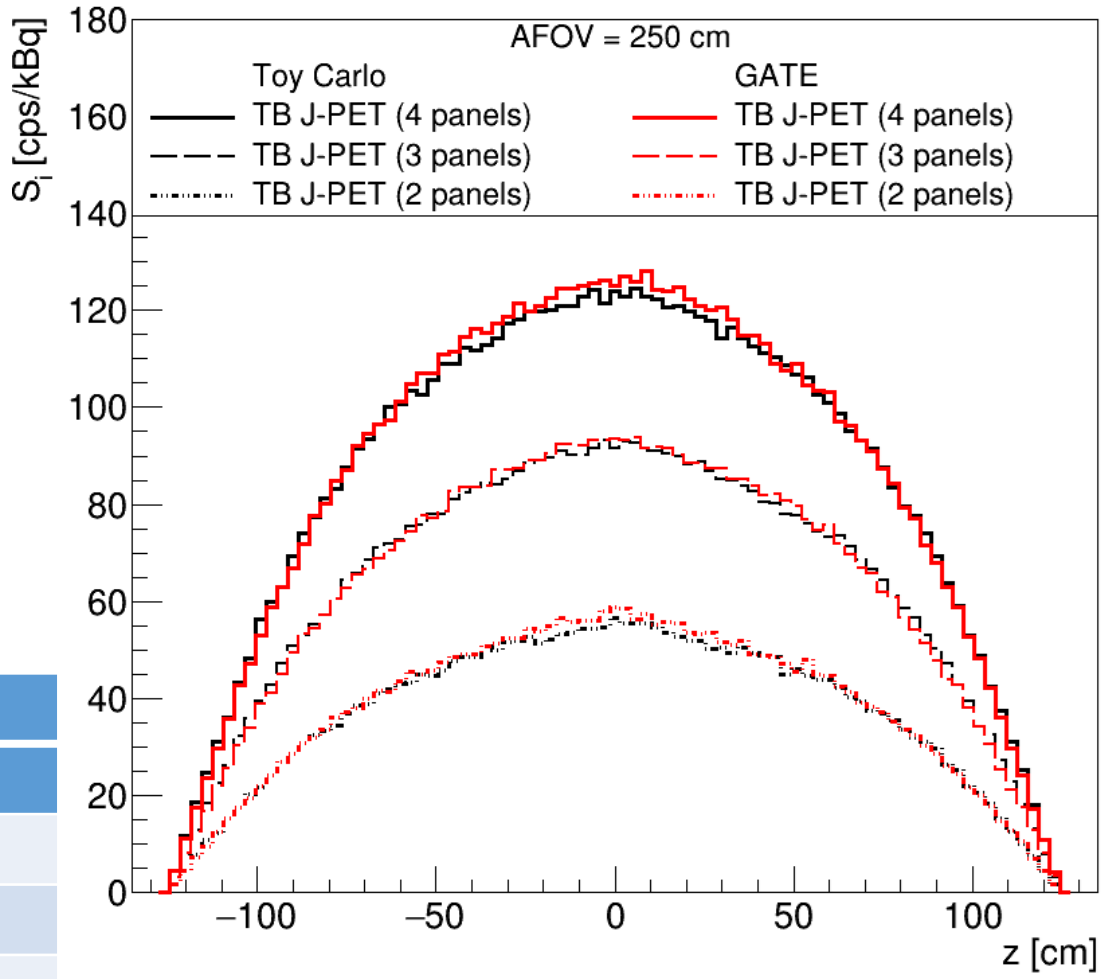
Simulation software

Presented study was conducted with a use of a dedicated Toy Monte-Carlo model:

- event-by-event basis
- true coincidence registration
- Metabolic and Positronium Imaging

Validation was performed as a comparison with the standard GATE software

Design	S_{tot} [cps/kBq]	
	Toy MC	GATE
A.	37.14(06±07)	36.46(06)
B.	62.12(08±08)	62.21(08)
C.	85.47(09±1.1)	84.7(0.9)



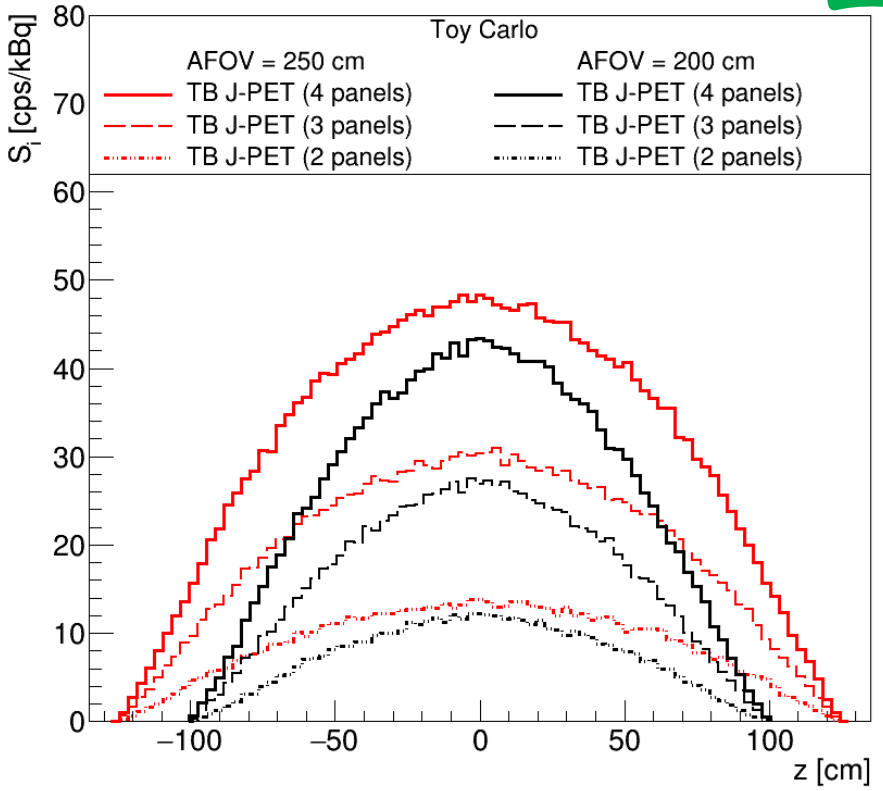
Simulation parameters

Utilized sources:

- 1 cm long linear source of 1 MBq activity
- 70 cm long linear source of 1 MBq activity
- 183 cm long linear source of 1 MBq activity
- 250 cm long linear source of 1 MBq activity

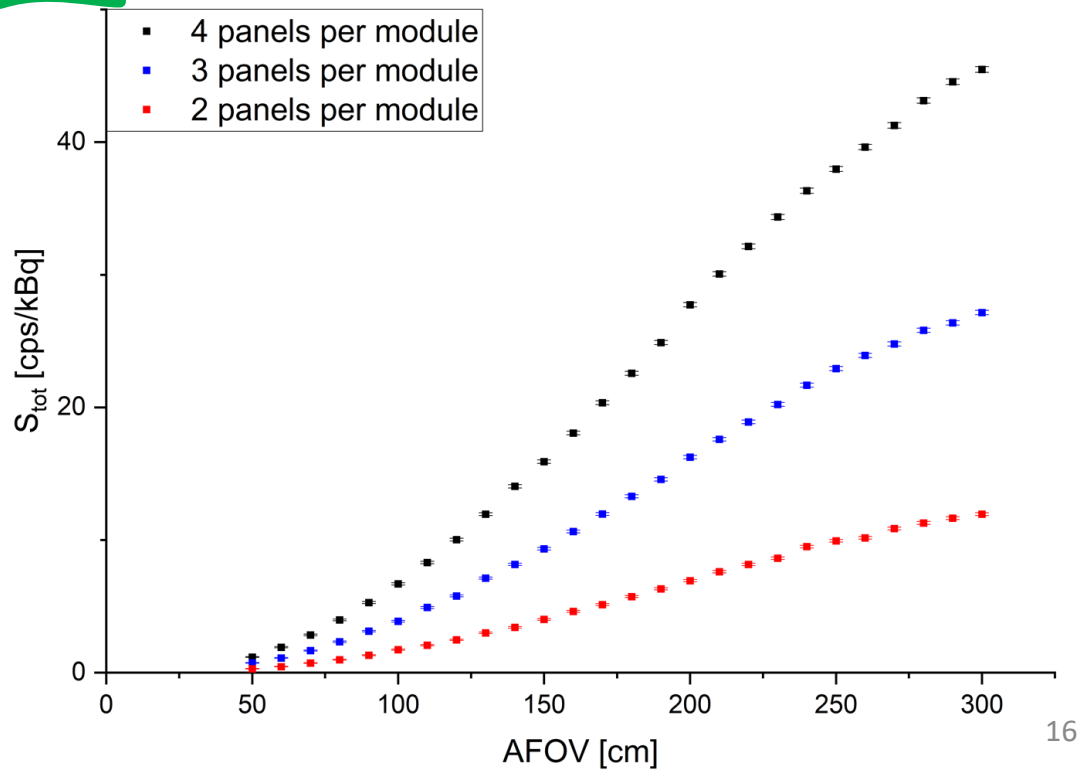
Positronium Imaging sensitivity

Sensitivity profiles of the 200 cm and 250 cm long (AFOV) Total Body J-PET tomographs

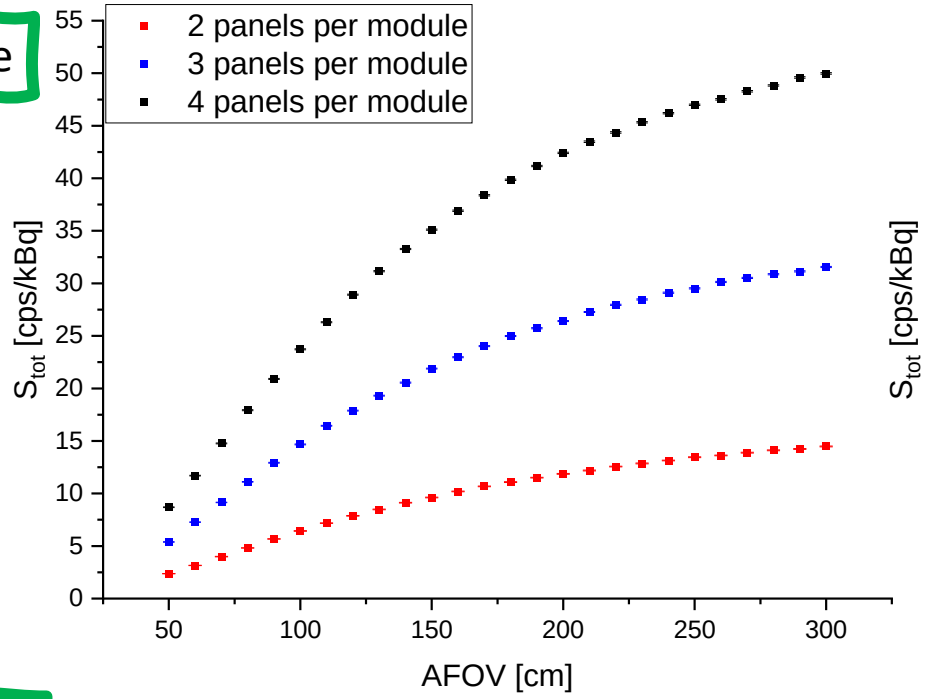


Dependence of the sensitivity on the PET scanner's length

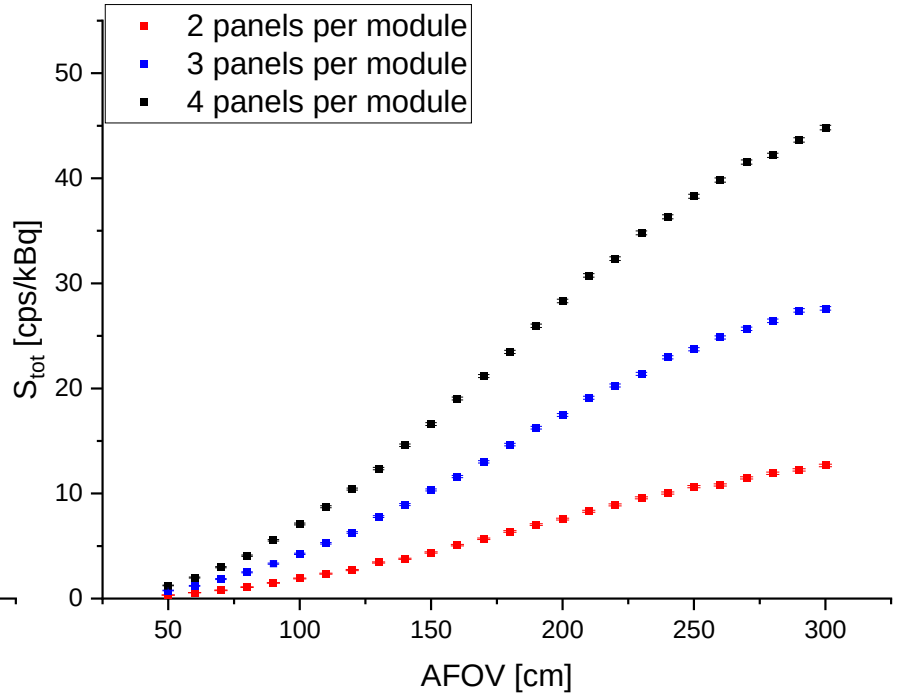
250 cm source



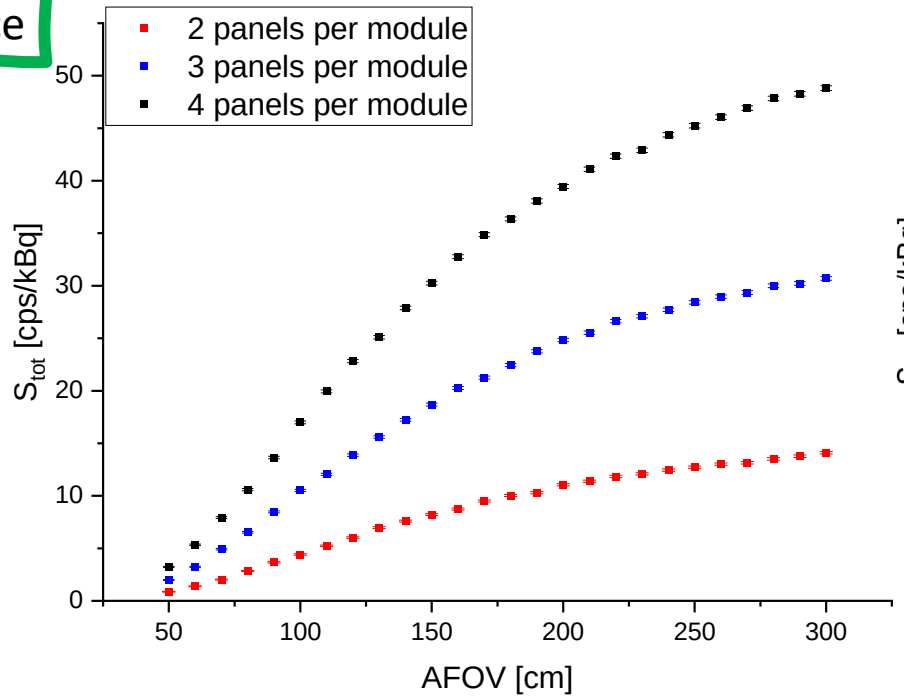
1 cm source



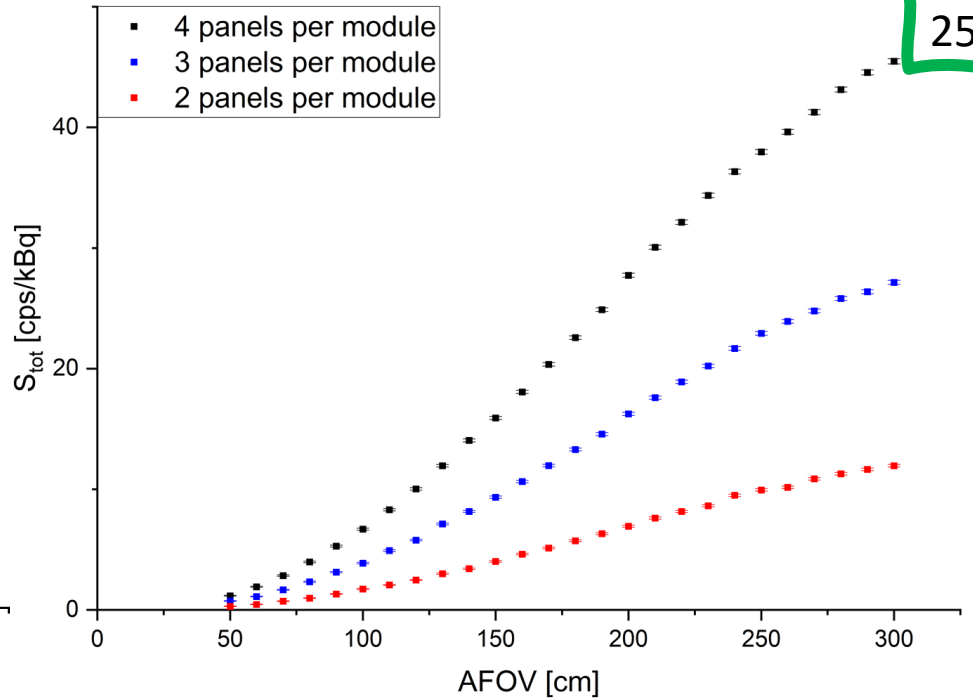
183 cm source



70 cm source



250 cm source

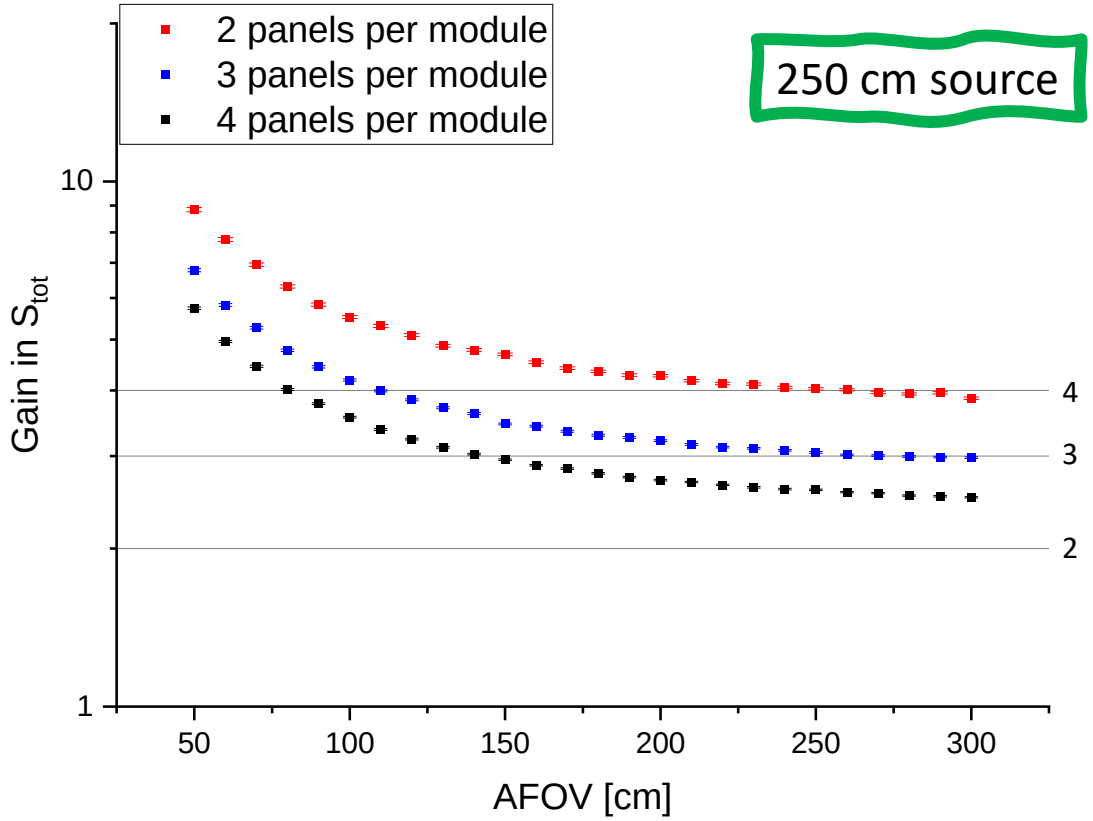


Positronium Imaging sensitivity

Metabolic Imaging with J-PET technology

vs.

Positronium Imaging with J-PET technology



Gain is defined as a ratio:

$$S_{tot}^{Metabolic}(AFOV) \Big/ S_{tot}^{Positronium}(AFOV)$$

Positronium Imaging sensitivity

Positronium Imaging with J-PET technology

vs.

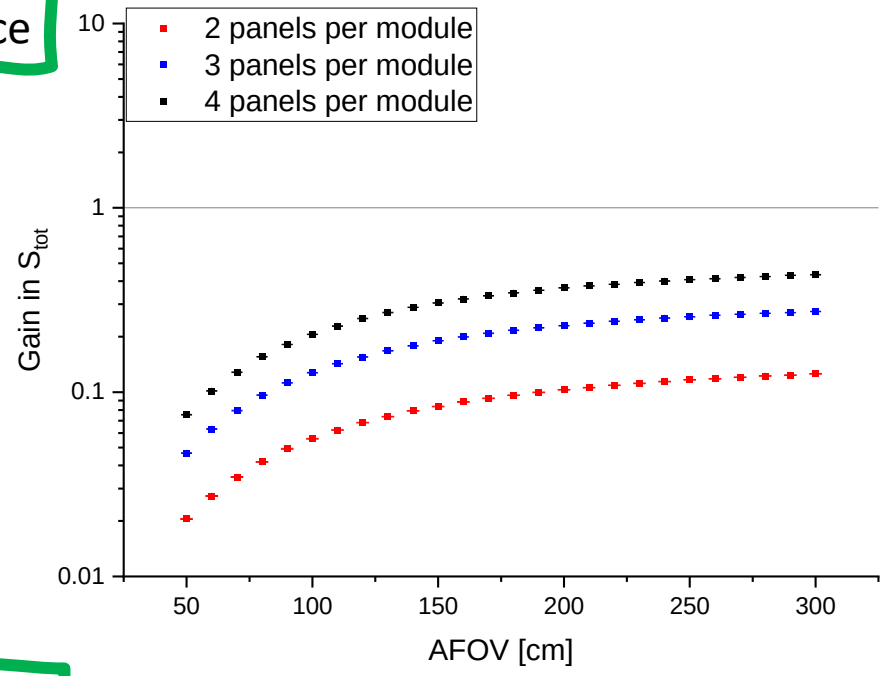
Metabolic Imaging with state-of-the-art conventional short AFOV PET represented by the Biograph Vision

Gain is defined as a ratio:

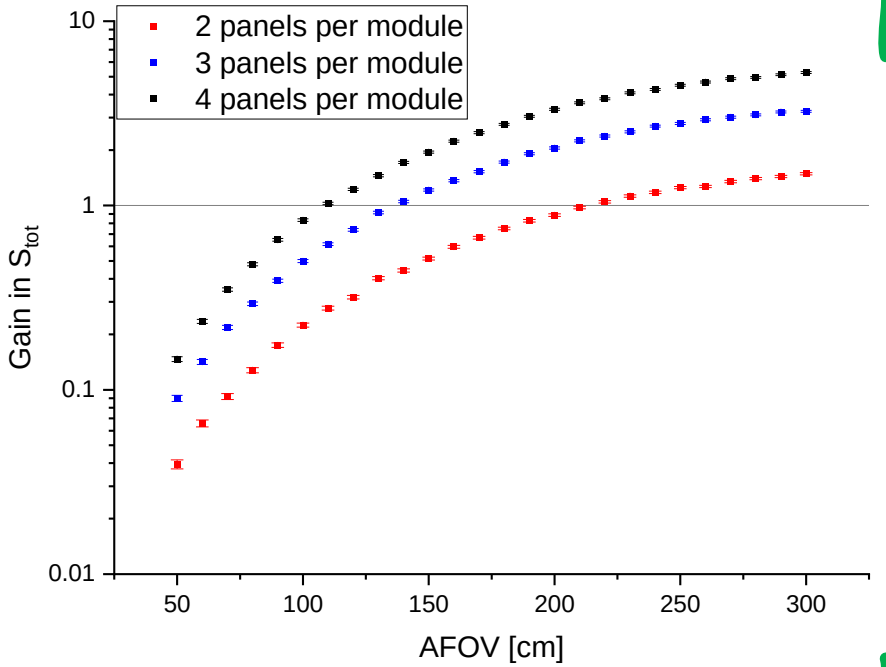
$$S_{tot}^{J-PET}(AFOV) \Big/ S_{tot}^{Biograph\ Vision}$$

Source [cm]	$S_{tot}^{Biograph\ Vision}$ [cps/kBq]
1	115.24(34)
70	22.31(15)
183	8.52(09)
250	5.81(08)

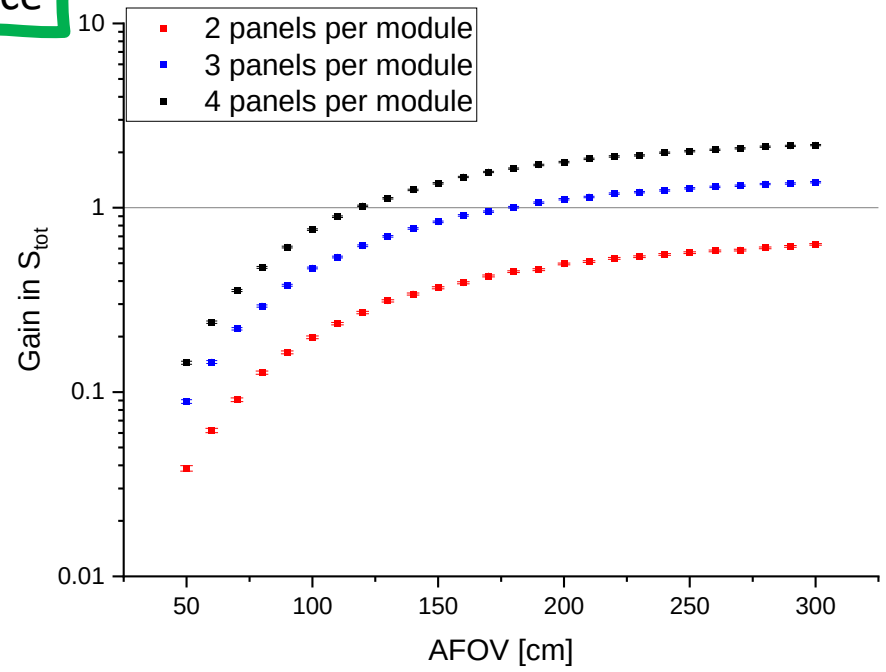
1 cm source



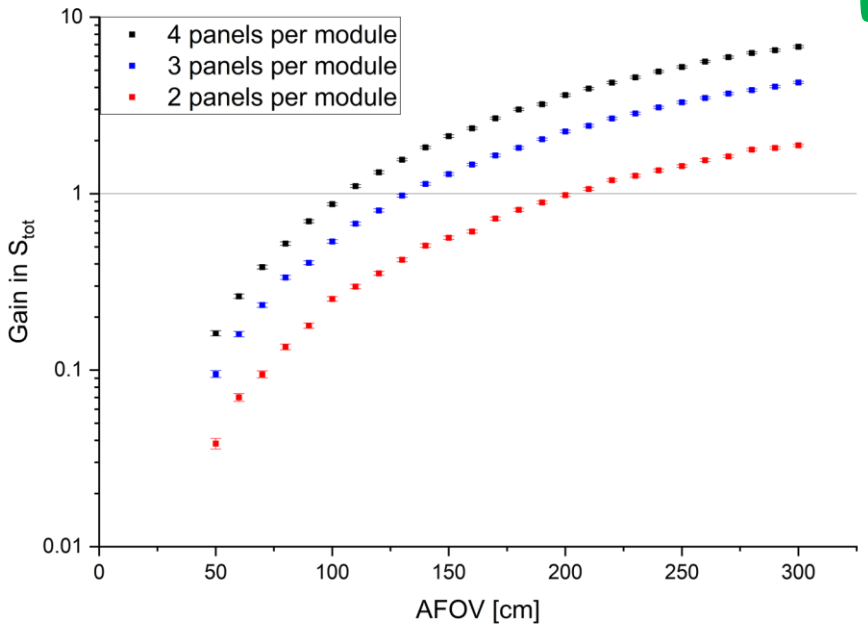
183 cm source



70 cm source



250 cm source



Summary

- Novel imaging method based on the multi-gamma detection has been developed
- It takes into consideration the non-used before positronium atoms created within the body after radiopharmaceutical administration
- Positronium Imaging proof of concept was presented by the J-PET detector. The first positronium image shown visible differences between two types of the tissues – Cardiac Myxoma and Adipose tissue.
- The first image of an object extensive in size was obtained using 3-photon annihilations of ortho-positronium.
- Achievable sensitivity to the Positronium Imaging reveal only ~3 times degradation with respect to the standard Metabolic Imaging for J-PET systems

Poster session

- For developed detector technology  Szymon Niedźwiecki poster
- For Positronium Imaging  Kamil Dulski poster
- For 3-gamma o-Ps imaging  Aleksander Gajos poster

Acknowledgements

This work is supported by the Foundation for Polish Science under Grant TEAM/2017-4/39

Thank you for your attention