First experimental demonstration of positronium lifetime imaging with ^{44}Sc using the J-PET Scanner

Manish Das[1,2,*], Sushil Sharma[1,2], Ewa Stępień[1,2], Pawel Moskal[1,2]

On behalf of the J-PET collaboration

[1]Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, S. Łojasiewicza 11, 30-348 Kraków, Poland

[2]Center for Theranostics, Jagiellonian University, Kopernika 40 St, 31-501 Krakow, Poland

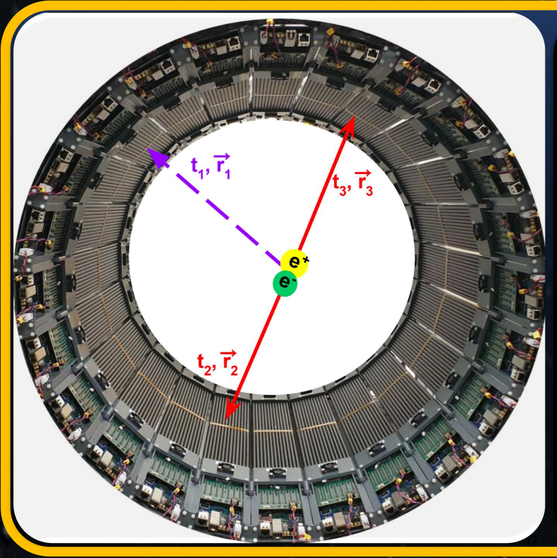
*manish.das@doctoral.uj.edu.pl

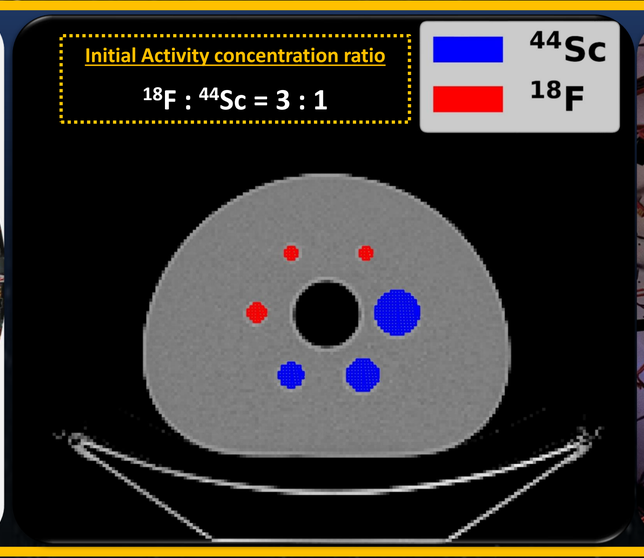
Positronium imaging with ^{44}Sc

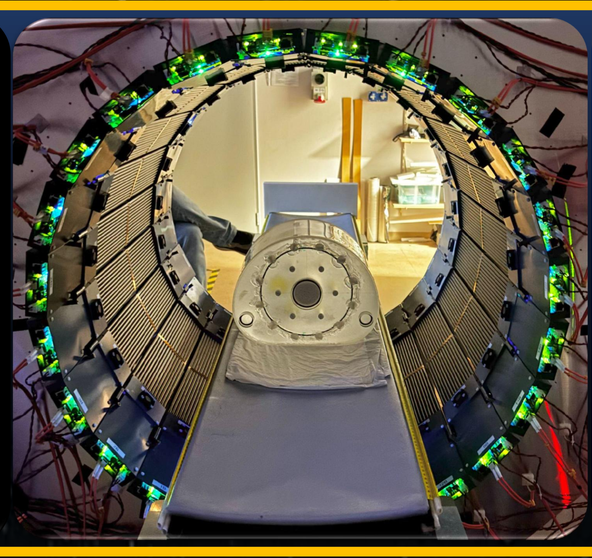
Positronium Lifetime Imaging (PLI) is a novel technique with potential applications in cancer assessment[1,2,3,4]. Recently, the first PLI of a human brain was demonstrated using the modular J-PET detector with the ^{68}Ga isotope[3]. This study revealed limitations associated with isotopes that exhibits a low yield of de-excitation photons (for ^{68}Ga it is ~1.3 %) for positronium lifetime estimation. In contrast, ^{44}Sc emerges as a more suitable candidate for PLI due to its favorable properties[6,7]: it has a clinically relevant half-life of 4.04 hours, and 100% of its decays result in the emission of a high-intensity prompt photon with an energy of 1157 keV. This study reports the first experimental demonstration of PLI using **Scandium-44** with the Modular J-PET scanner, utilizing a NEMA-IQ phantom.

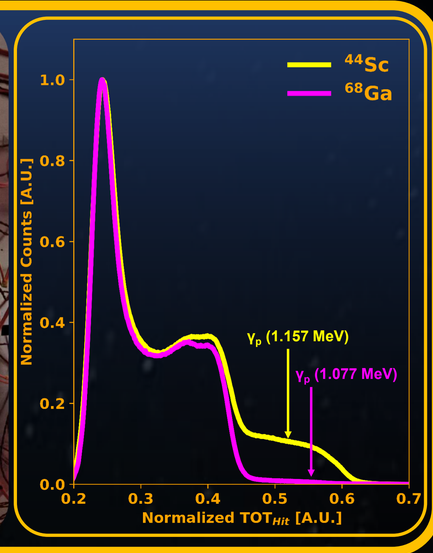
Key features

- 312 Plastic scintillators (24 modules)
- FPGA based DAQ[5]
- Multiphoton PET[6,8]

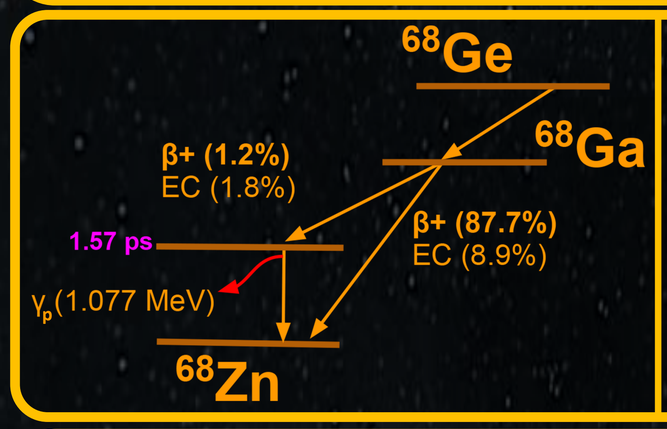


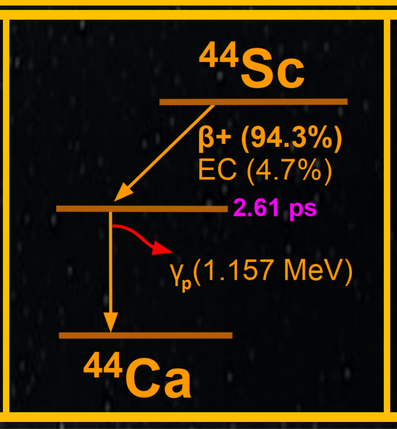


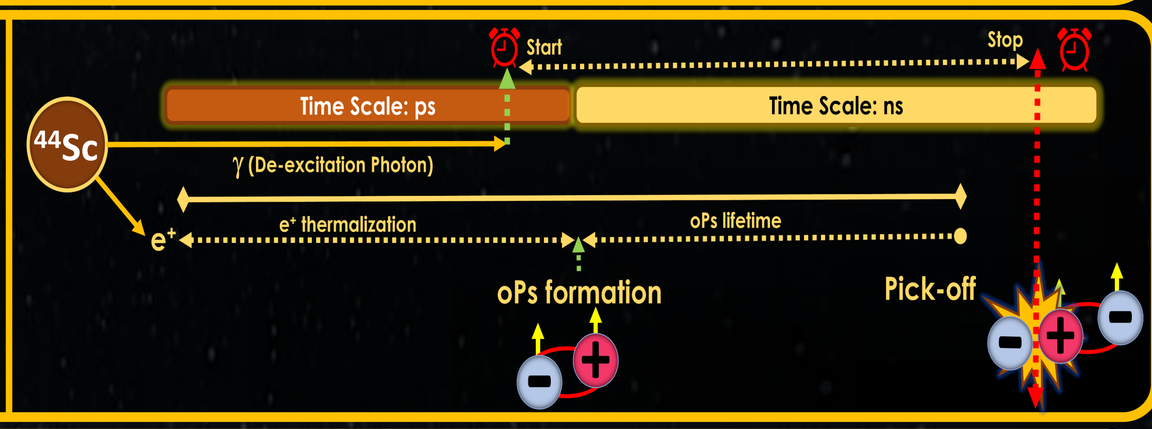




Positronium formation and lifetime estimation[9]



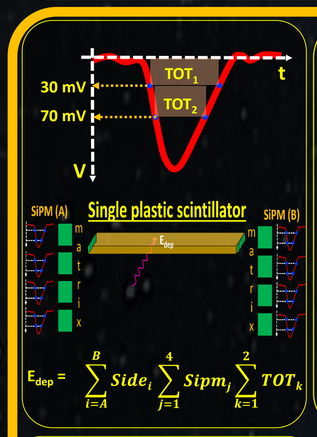




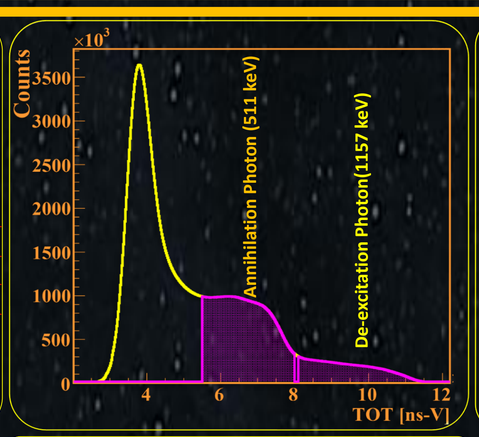
Registration of annihilation photons and prompt gamma[10]

Selection criteria :

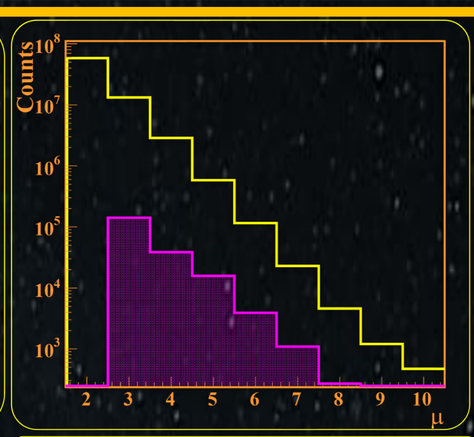
- ✓ Annihilation and prompt selection based on TOT[11]. (measure of energy dep.)
- ✓ Events with 3 hits ($2\gamma_a + \gamma_p$)
- ✓ Angular correlation b/w hits



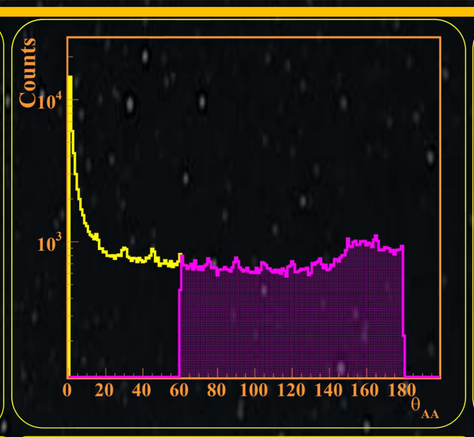
Time-Over-Threshold (TOT) as a measure of energy deposition[11].



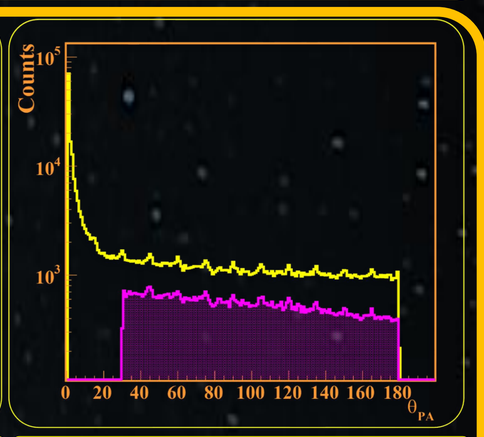
In this context, the measure of energy deposition is represented by the TOT values, which serves for photon identification. Pink shadowed regions denotes the respective ranges of TOT values utilized for selecting annihilation (511 keV) and de-excitation photons[7,13].



The histogram displays the distribution of hit multiplicities, with the pink shadow indicating observations in events consisting one prompt and two annihilation photons.



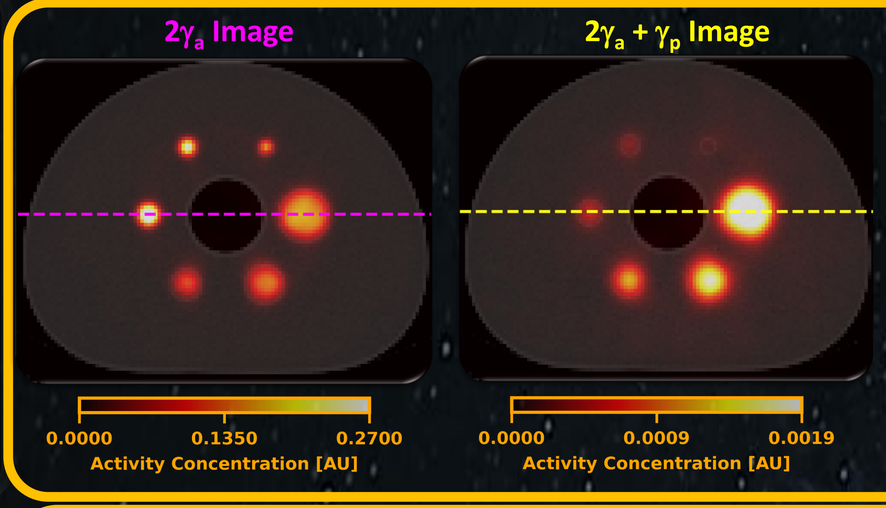
In the analysis, the relative angle between annihilation photons is transaxially restricted to the pink range ($\theta_{AA} \geq 60°$), to constrain the FOV of the detector and suppress unwanted events.

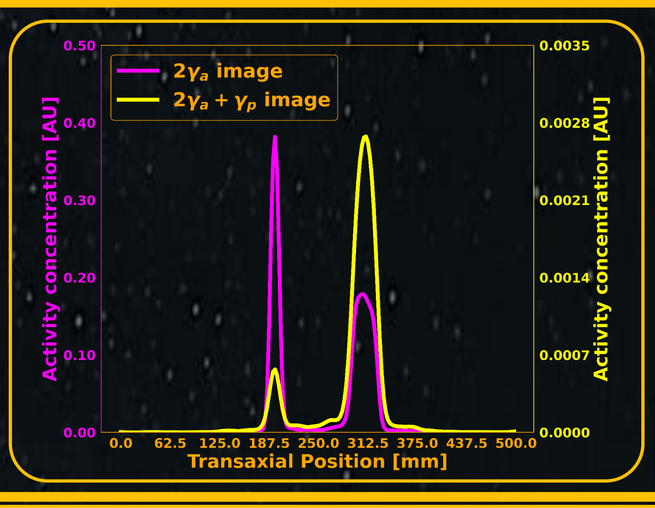


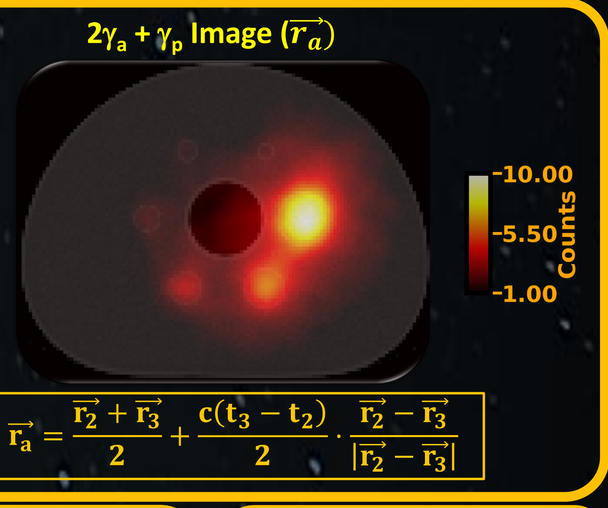
Distribution of the relative angle (θ_{PA}) between prompt gamma vector and annihilation photon vectors, with $\theta_{PA} \geq 30°$ as the restriction. The observed distribution of the angle between the annihilation photons and prompt gamma is peaked for small angles.
Additionally, a Scatter Test (ST) was applied to filter out detector scattered and accidental events (details for ST can be found in [13]).

Images

- ❑ $2\gamma_a$ Image and $2\gamma_a + \gamma_p$ Image reconstructed using MLEM.
  (Note – only two 511 keV photons were used for the reconstruction)
- ❑ Annihilation point distribution ($\vec{r_a}$) for the $2\gamma_a + \gamma_p$ events, from which the lifetime values were extracted for each sphere.
  (Note – only two 511 keV photons were used for the calculation)



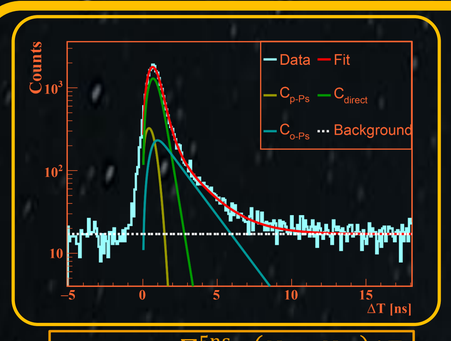




$$\vec{r_a} = \frac{\vec{r_2} + \vec{r_3}}{2} + \frac{c(t_3 - t_2)}{2} \cdot \frac{\vec{r_2} - \vec{r_3}}{|\vec{r_2} - \vec{r_3}|}$$

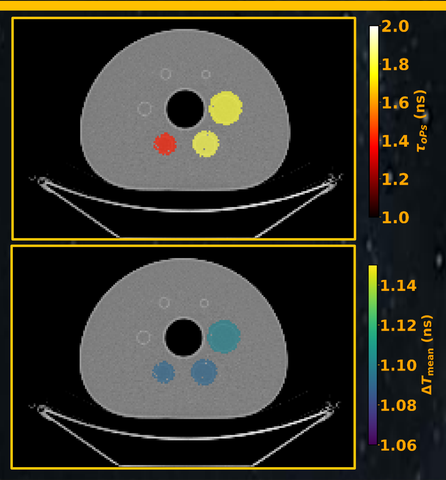
Results

- ❑ Positron lifetime spectra from the 37 mm diameter sphere and the deconvolution of their lifetime components.
- ❑ The results show that the mean oPs lifetime (τ_{oPs}) from the two largest spheres is consistent with the reference value for water, and the mean positron lifetime (ΔT_{mean}) is consistent across all spheres.



$$\Delta T_{mean} = \frac{\sum_{i=0ns}^{5ns} (N_i - N_{bg}) \Delta T_i}{\sum_{i=0ns}^{5ns} (N_i - N_{bg})}$$

N_i = Number of events for ΔT_i
N_{bg} = number of background events estimated by averaging the bin counts in the range of -10 to -5 ns.



Reference mean oPs lifetime (τ_{oPs}) in water [12]
1.839 ± 0.015 ns

D [mm]	t_{oPs} [ns]	I_{oPs} [%]	I_{direct} [%]	I_{pPs} [%]	ΔT_{mean} [ns]
22.00	1.413(70)	28.46(126)	61.11(143)	10.43(120)	1.099(13)
28.00	1.821(61)	25.55(74)	63.41(89)	11.04(73)	1.099(8)
37.00	1.804(42)	25.84(52)	62.05(63)	12.10(52)	1.102(5)

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Acknowledgements

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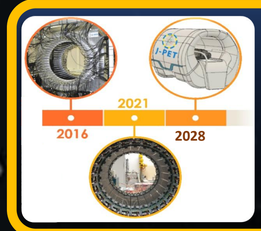

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