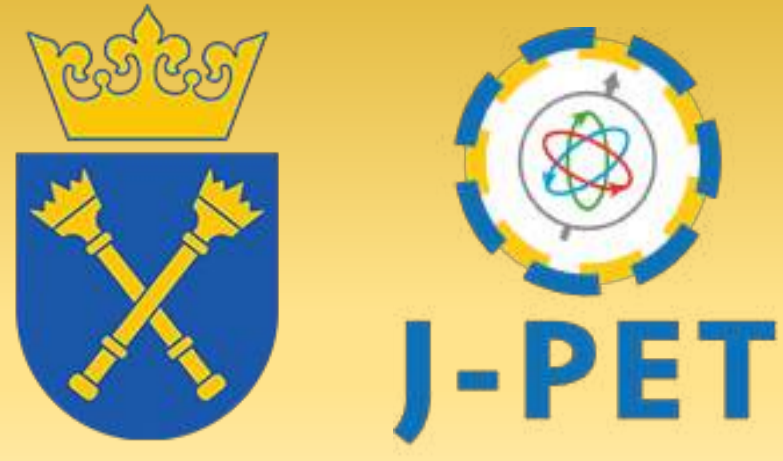


Development and validation of iterative reconstruction method for positron lifetime imaging using ^{44}Sc with the modular J-PET



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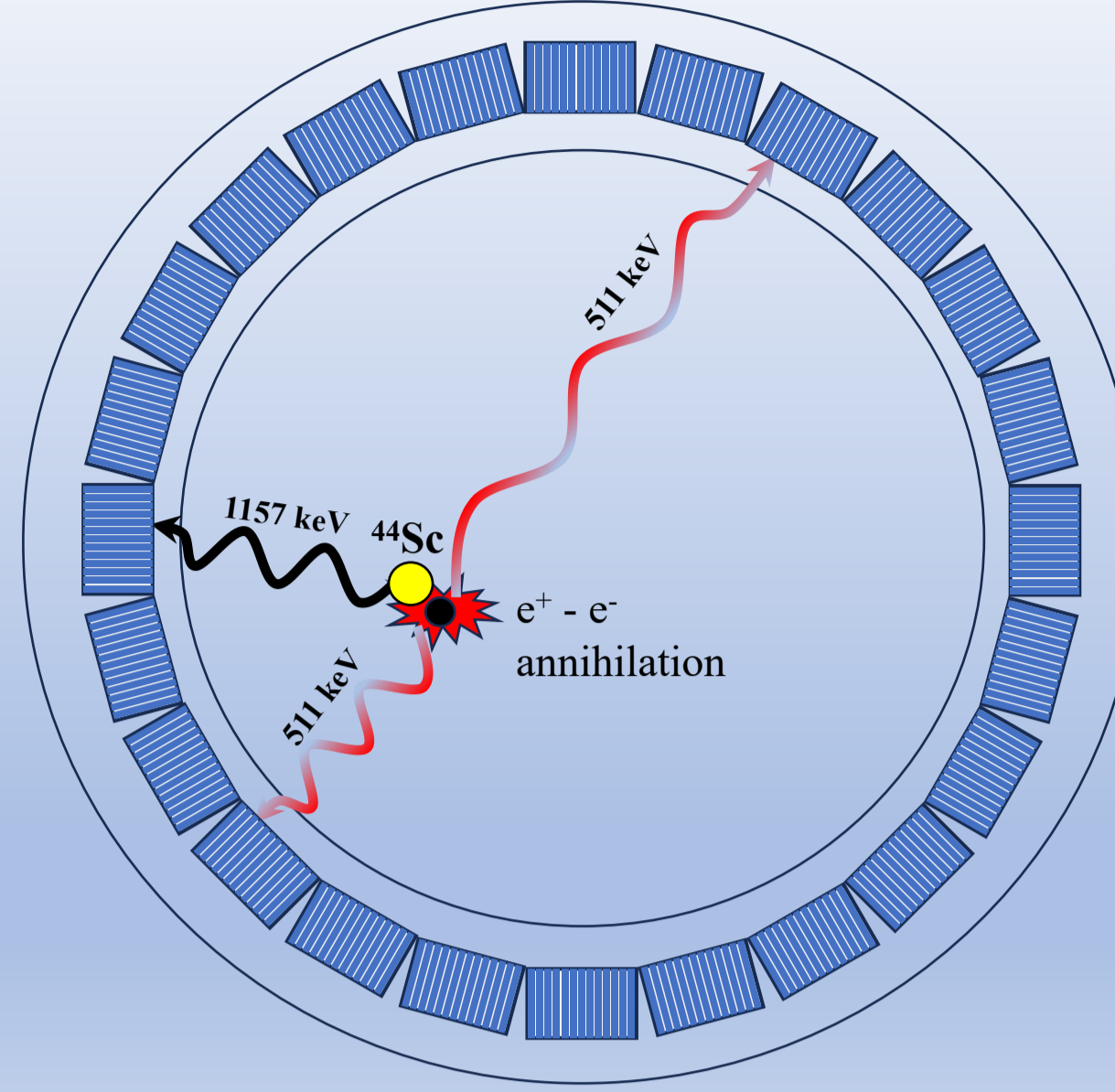
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Introduction

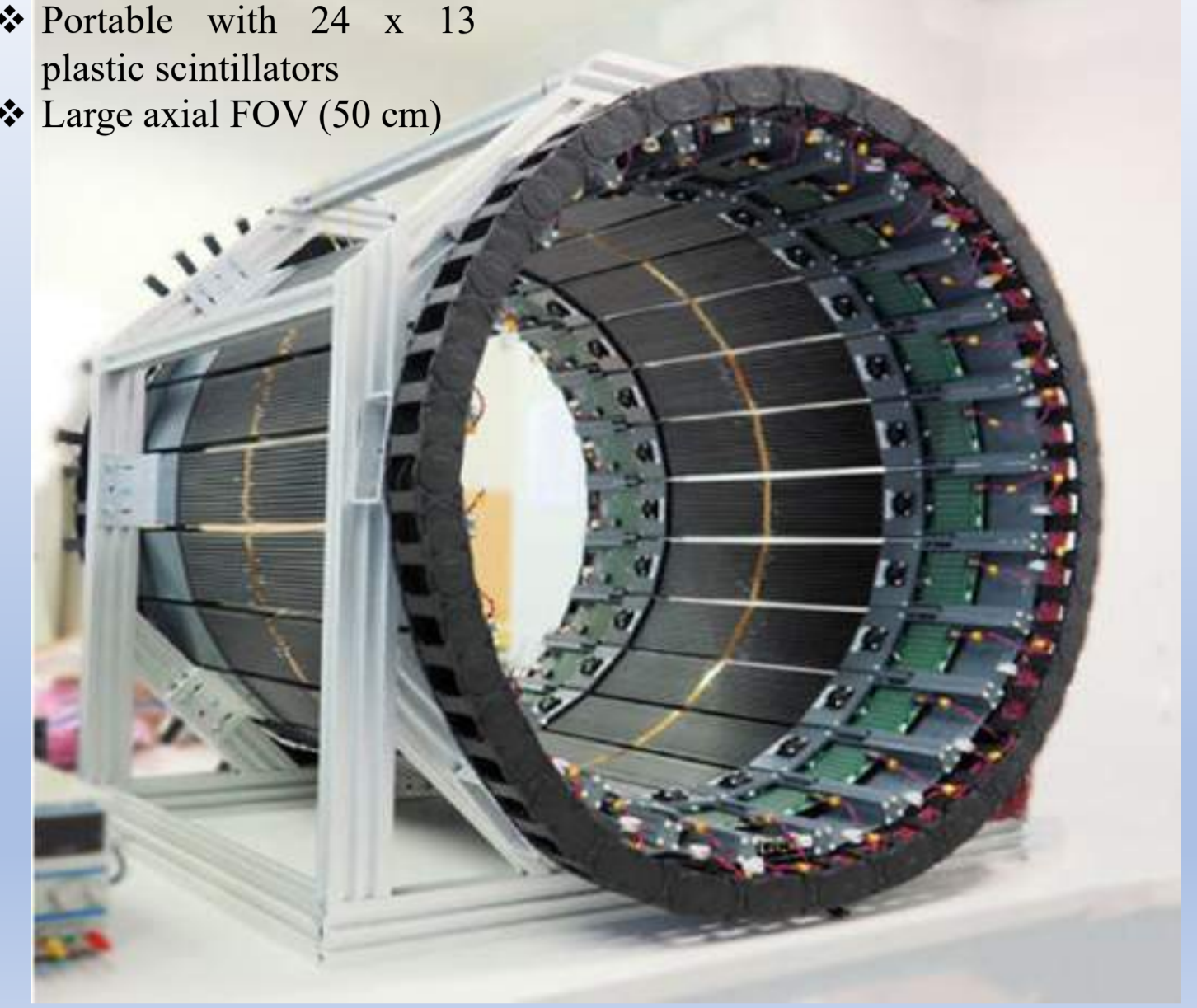
- Positron Lifetime Imaging (PLI) is an imaging technique built on the principles of Positron emission tomography (PET) with the ability to map spatial distribution of positronium (Ps) lifetimes [1].
- The nanoscale sensitivity of o-Ps lifetimes enables PLI to detect tissue microstructure beyond standard PET [2].
- Recently JPET group demonstrated that ^{44}Sc , with a 4.04 h half-life, ~94.3% positron branching ratio, and 1157 keV gamma, has the potential to be used for PLI [3].
- So far, we have been using conventional reconstruction technique to produce activity and lifetime images.
- This work aims to address this challenge: to develop iterative reconstruction algorithm for the PLI using JPET.

Positronium Lifetime Imaging (PLI)

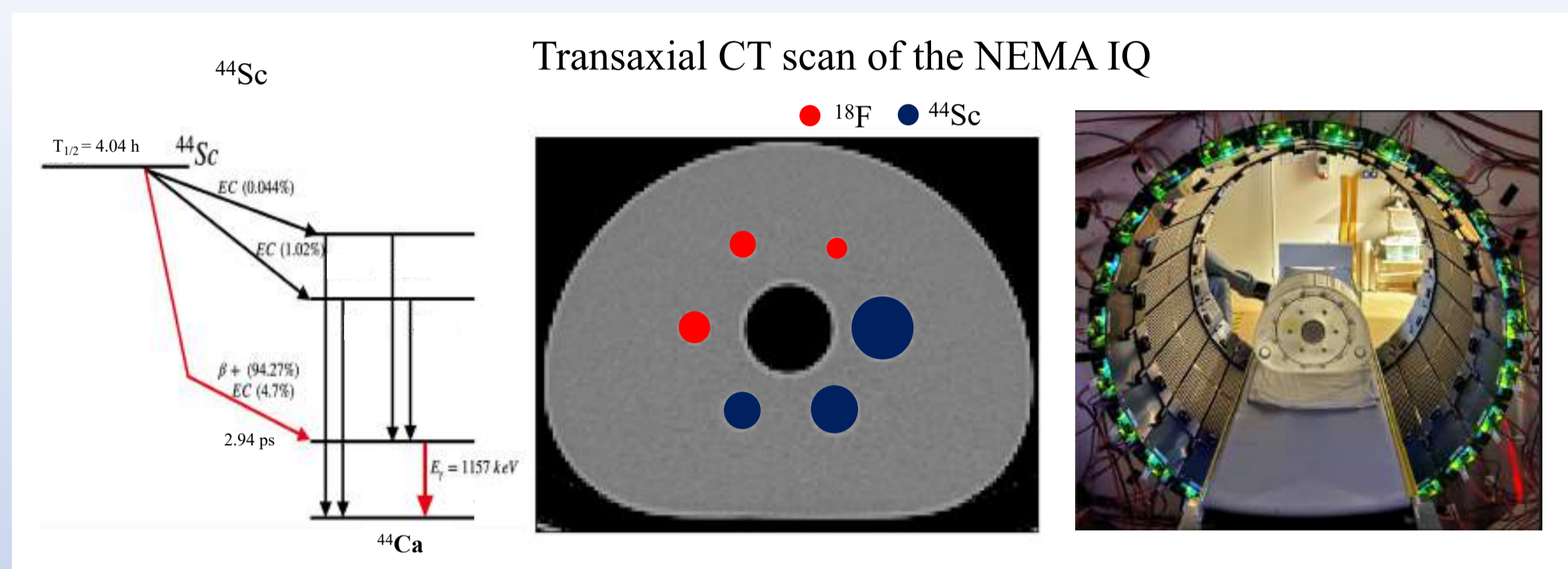


Modular JPET

- ❖ Portable with 24 x 13 plastic scintillators
- ❖ Large axial FOV (50 cm)



Experimental Details and Data Analysis using JPET Framework



Event Selection

Selection criteria for filtering the events:

- ❖ Annihilation and prompt selection based on TOT [4].
- ❖ Events with multiplicity ≥ 3
- ❖ Time difference between the annihilation hits
- ❖ Angular correlation between annihilation hits
- ❖ Scatter Test:

$$|t_{ann2} - t_{ann1}| - \frac{|r_{ann2} - r_{ann1}|}{c}$$

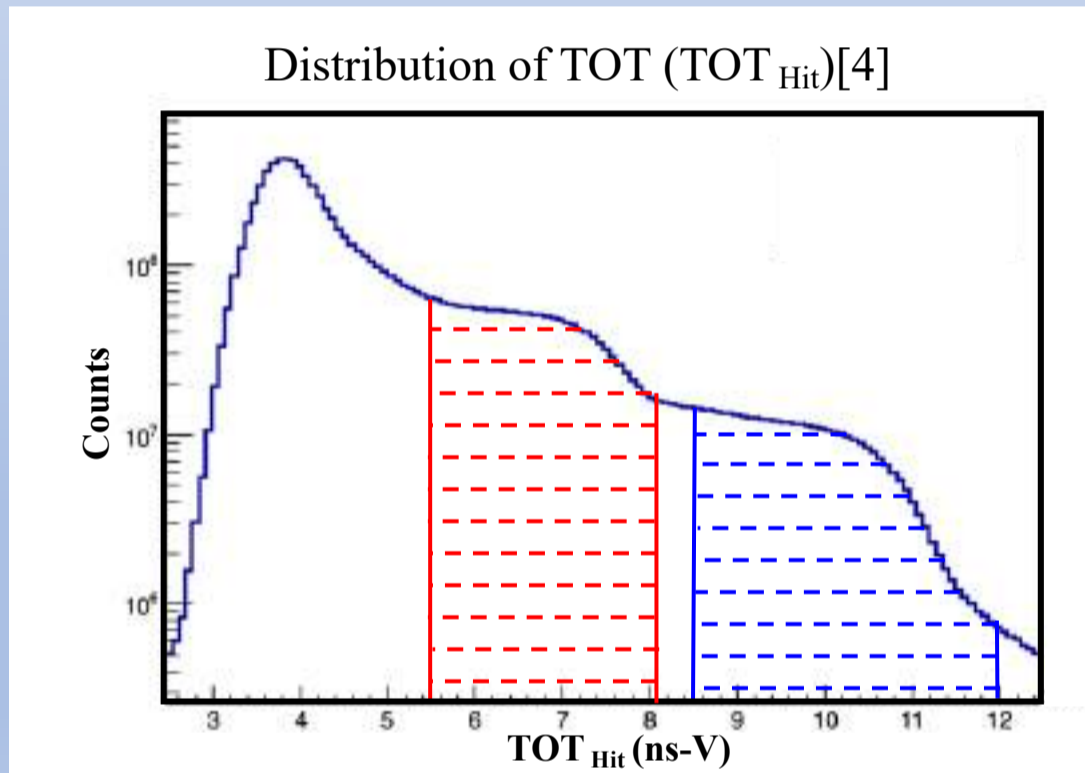
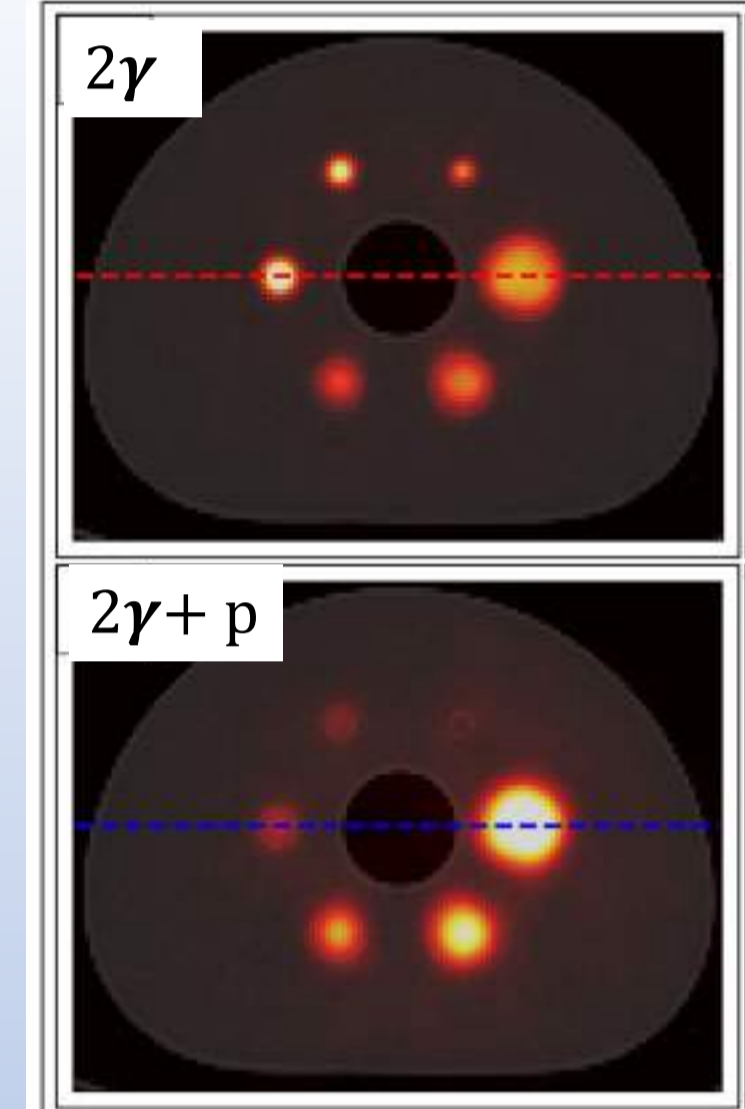
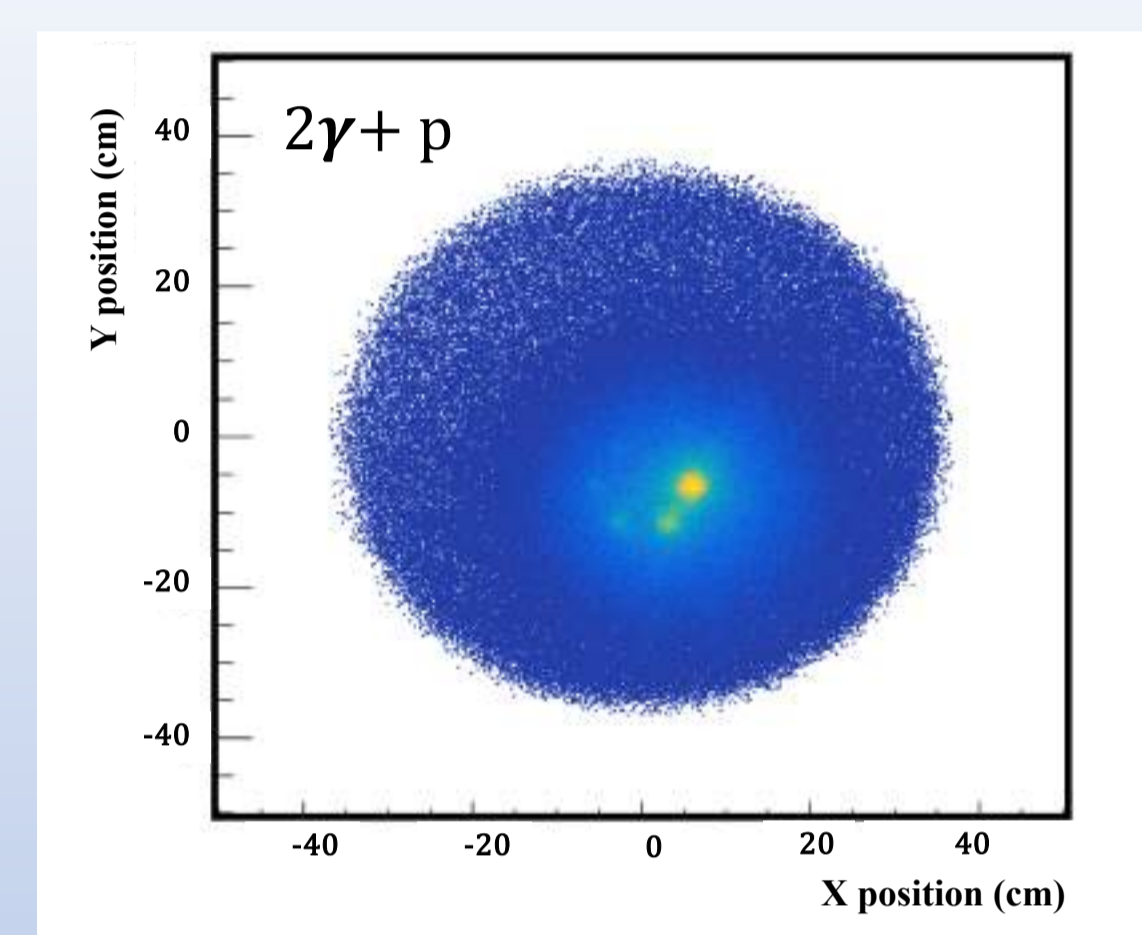


Figure: Range of TOT_{Hit} values for selecting annihilation (Red) and deexcitation photons (Blue)

Annihilation points plot



Manish Das et al., arXiv:2506.07230 [5]

Positronium Lifetime Estimation (ΔT)

- ❖ Annihilation time t_a is calculated from the time and position of the annihilation hits ($(t_{ann1}, \vec{r}_{ann1})$ and $(t_{ann2}, \vec{r}_{ann2})$):

$$t_a = \frac{t_{ann1} + t_{ann2}}{2} - \frac{|r_{ann2} - r_{ann1}|}{2c}$$

- ❖ The prompt gamma emission time (t_p) is calculated as:

$$t_p = t_{prompt} - \frac{|r_{prompt} - r_{ann}|}{c}$$

$$\Delta T = t_a - t_p$$

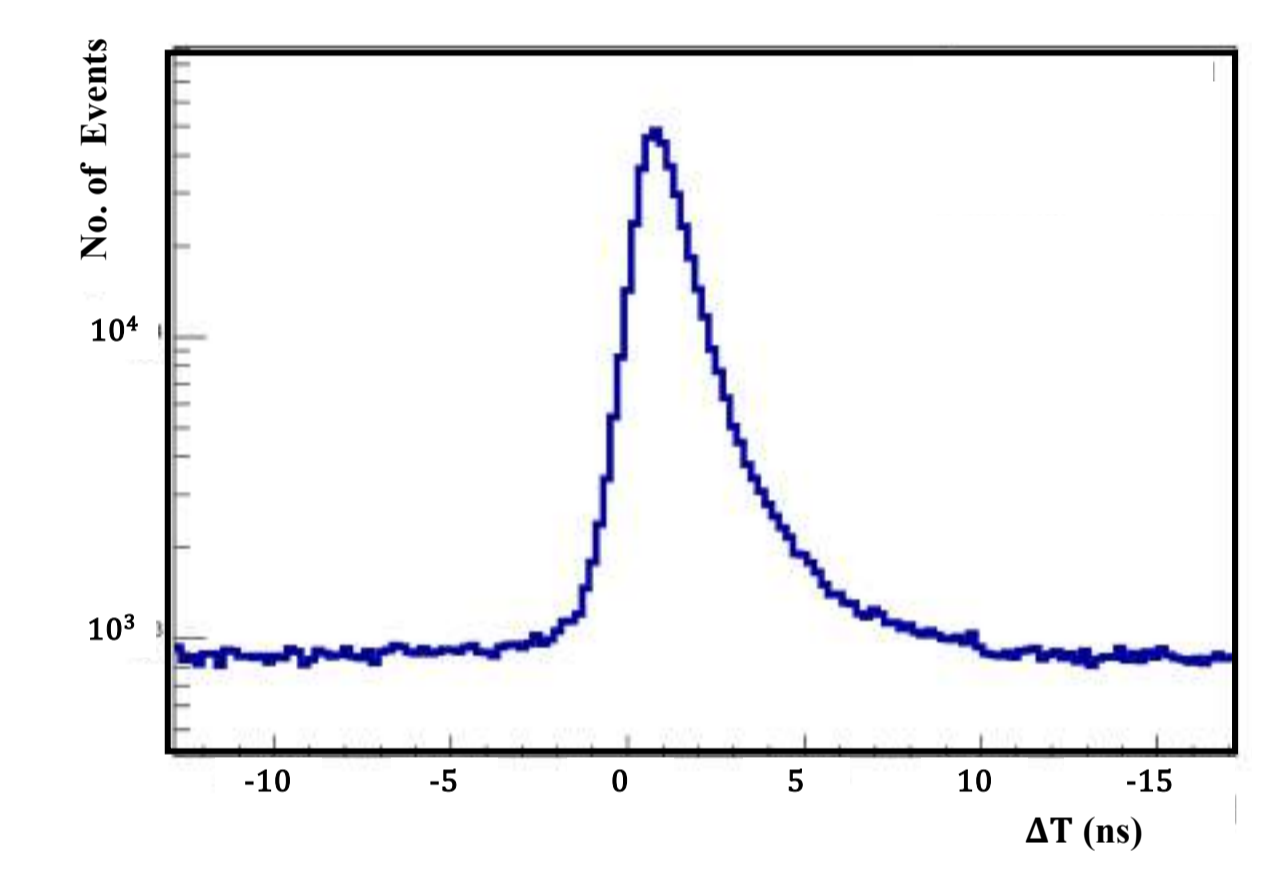


Image Reconstruction using List Mode Data

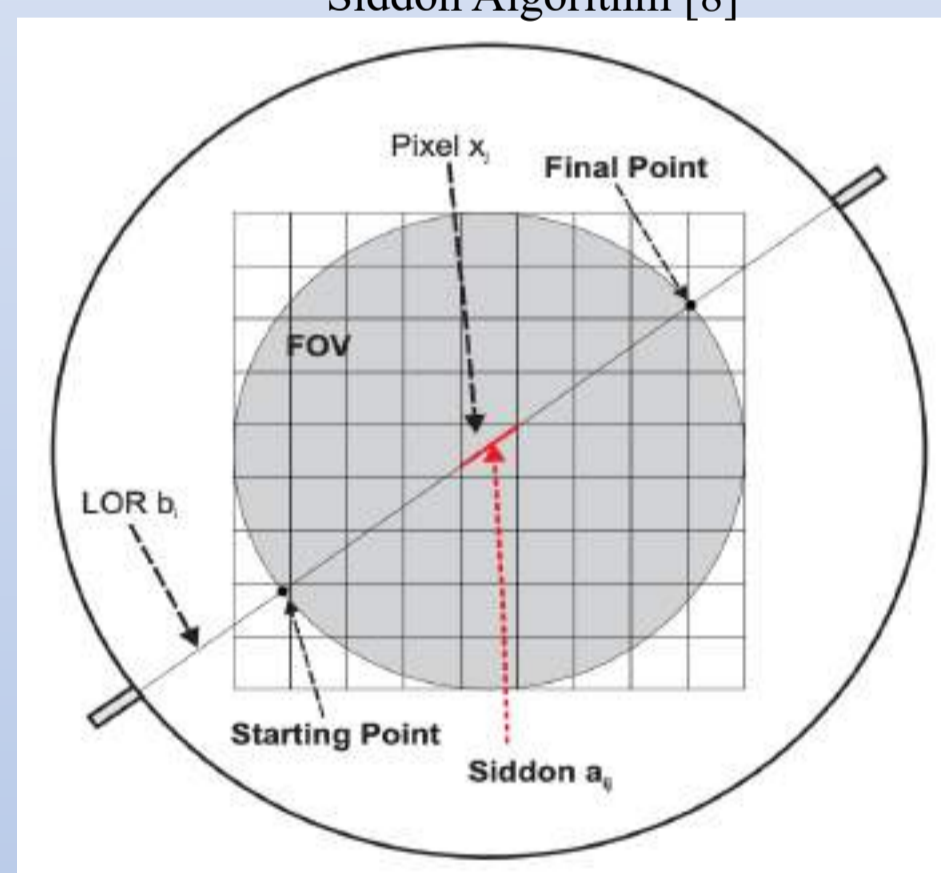
Activity Conc. Image

Siddon ray tracing method [6] is used as projector to give the contribution from the voxels and Maximum Likelihood expectation maximization (MLEM) is used to update the image iteratively

The MLEM reconstruction is given as [7]:

$$image_j^{k+1} = \frac{image_j^k * \sum_i C_{ij}}{N * \sum_j C_{ij} * image_j^k}$$

$image_j^k$ = value of reconstructed image at the voxel j for the k -th iteration,
 k – iteration number,
 j – voxel number,
 i – the event number,
 C_{ij} – coefficient giving the probability that event i is the result of an emission from voxel j
 N – Normalization



Preliminary Results

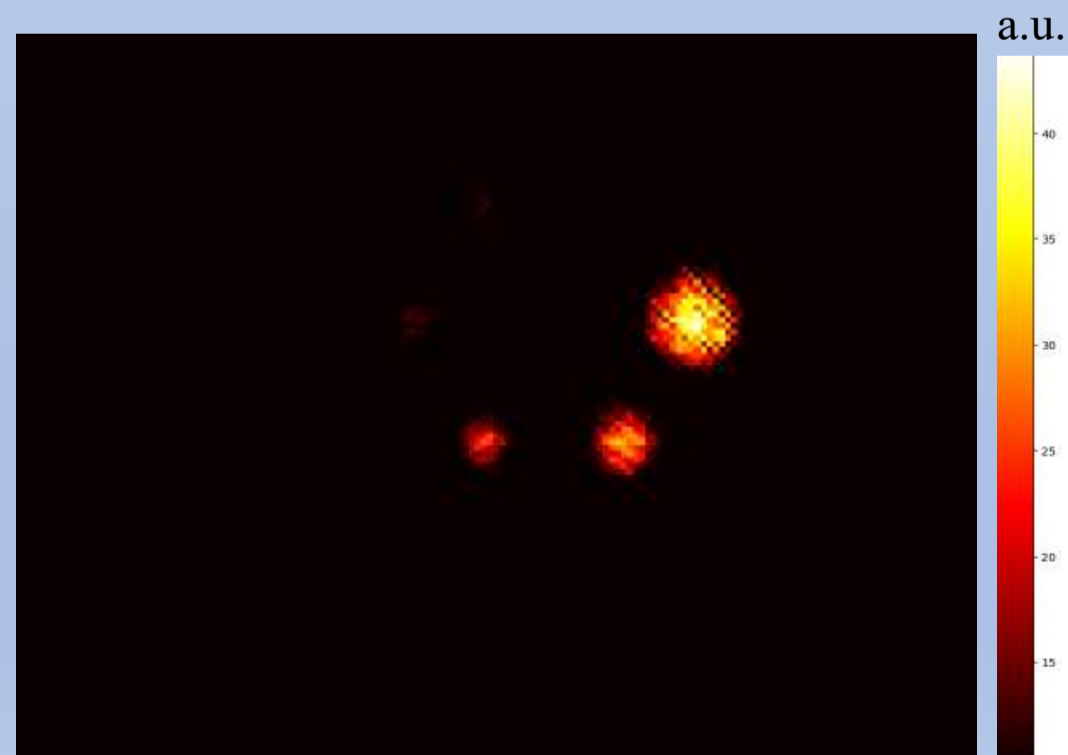


Figure: Transaxial view of the $2\gamma_s$ PET image obtained from the $2\gamma_s + \gamma_p$ events with modular J-PET, reconstructed using the iterative algorithm.

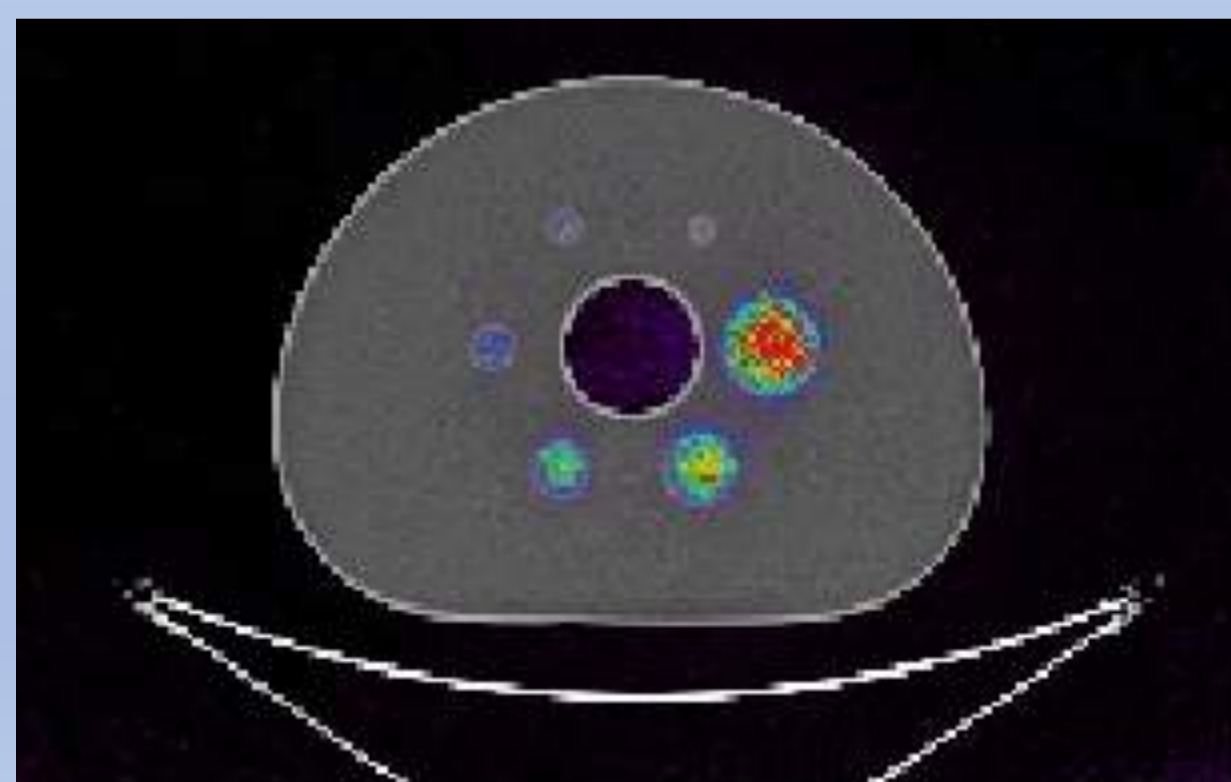


Figure: Transaxial view of the $2\gamma_s$ PET image obtained from the $2\gamma_s + \gamma_p$ events with modular J-PET, overlaid on the CT image of the NEMA IQ phantom

Activity Filtered Rate Constant (λ) Image

For describing the ΔT time difference, we have considered the exponential distribution:

$$f(\tau; \lambda) = \lambda e^{-\lambda\tau}$$

where λ , rate constant, is the inverse of the lifetime

Closed form equation for the ML estimation is given as [9]:

$$\lambda_j^{n+1} = \frac{\sum_{k=1}^n w_{kj}^n}{\eta_j^n \beta + \sum_{k=1}^n w_{kj}^n * \tau_k}$$

where w_{kj}^n is given by:

$$w_{kj}^n = \frac{C_{ij} image_j \lambda_j \exp(-\lambda_j^n \tau_k)}{\sum_{i=1}^I C_{ij} image_j \lambda_j^n \exp(-\lambda_j^n \tau_k)}$$

β = regularization term, η_j^n = penalty calculated from neighbours of pixel j

Preliminary Results

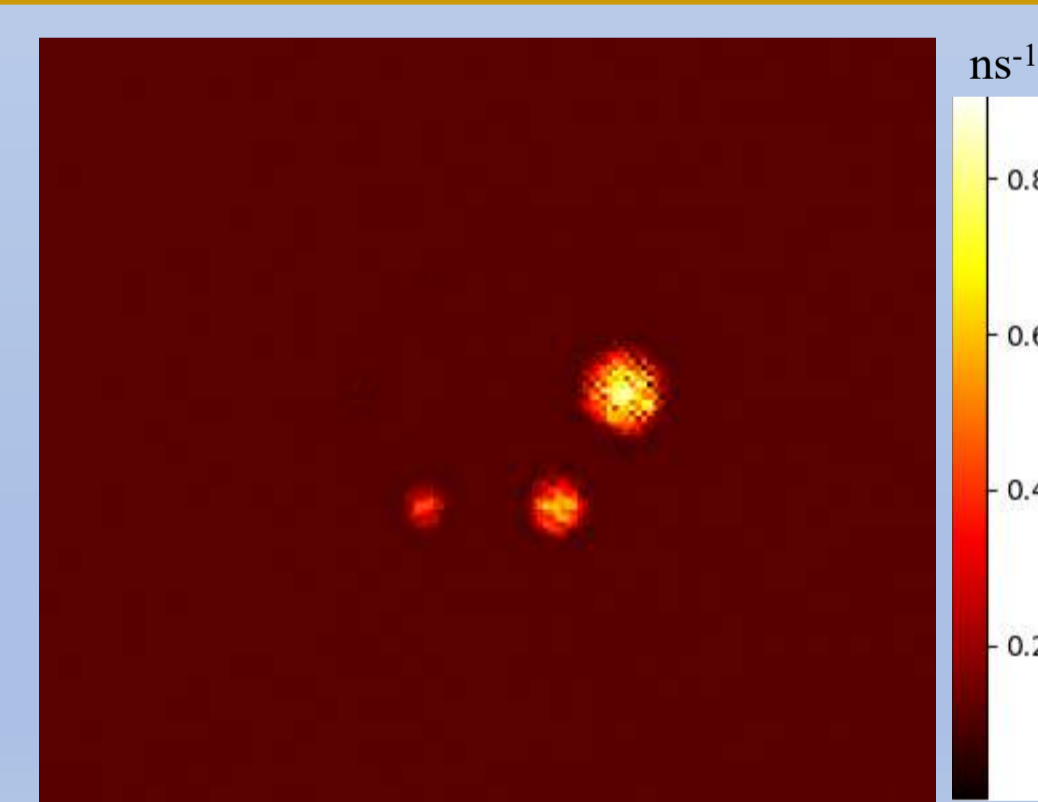


Figure: Transaxial view of the Activity Filtered Rate Constant (λ) image obtained from the modular J-PET, reconstructed using the penalized MLEM algorithm.

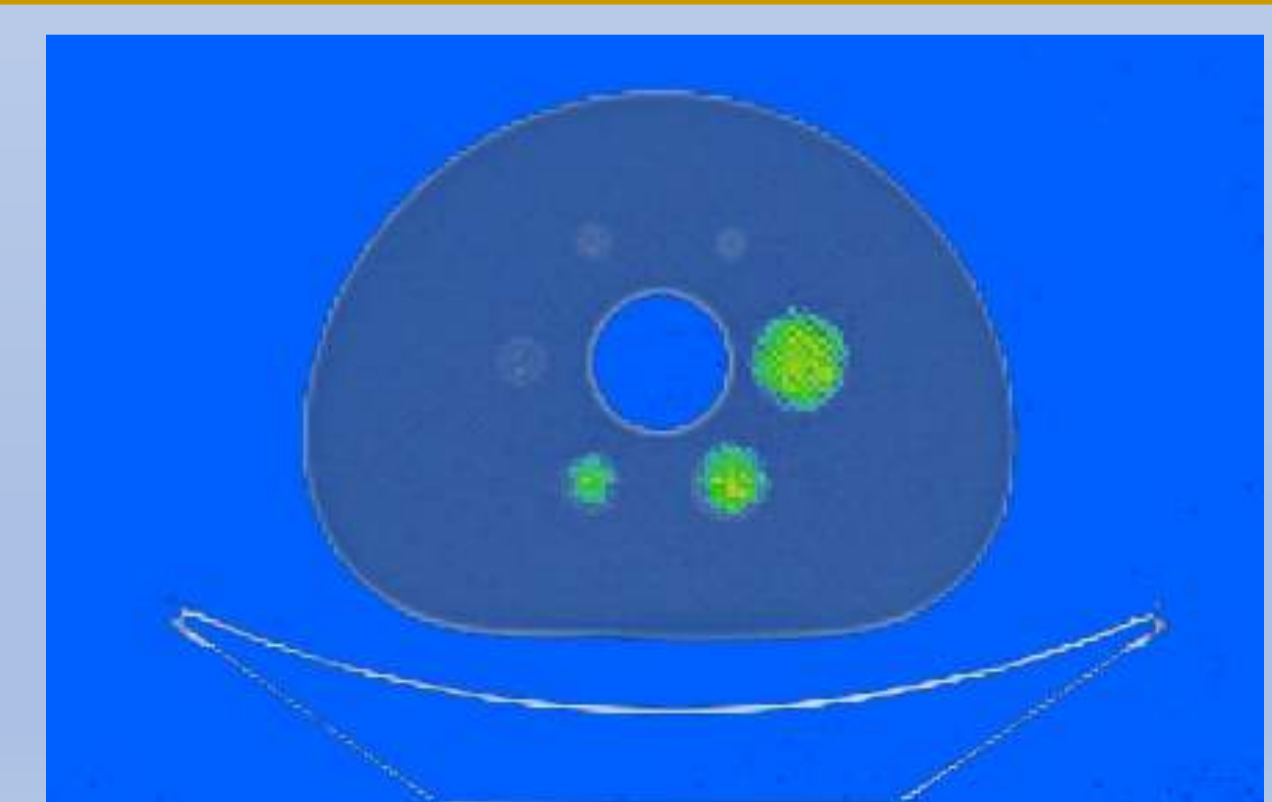


Figure: Transaxial view of the Activity Filtered Rate Constant (λ) image, overlaid on the CT image of the NEMA IQ phantom

Conclusion

- ❖ Present experimental studies demonstrate that the developed method can produce lifetime images with better resolution than that of the activity images generated by a JPET scanner with currently available time-of-flight resolution.
- ❖ In this work, we demonstrated positronium lifetime image reconstruction method using penalized MLEM.
- ❖ The preliminary validation of the reconstruction method has been conducted with the experimental data measured using NEMA IQ phantom placed inside Modular J-PET.

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