Towards the Development of an Iterative Algorithm for Positronium Lifetime Imaging Using ^{44}Sc with the Modular J-PET

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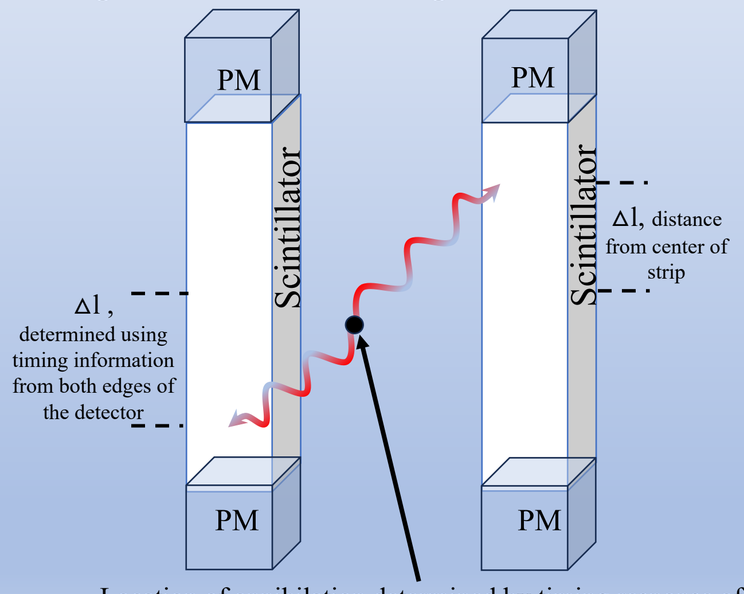
Positron Lifetime Imaging

Positronium Lifetime Imaging (PLI) represents an emerging imaging modality which enhances PET capabilities through its ability to map the spatial distribution of mean lifetimes of positronium (Ps) atoms [1,2,3]. However, an efficient reconstruction method is extremely crucial to obtain quality lifetime images. The aim of the present study is to develop such a PLI method and to validate it using the real data. For this purpose, we have used data from the recent experiment carried out with the ^{44}Sc on a NEMA Image Quality phantom using the modular J-PET scanner [4]. The radionuclide ^{44}Sc was selected for this study, having a clinically suitable half-life (4.04 hours) emitting 1157 keV prompt gamma in 100% cases.

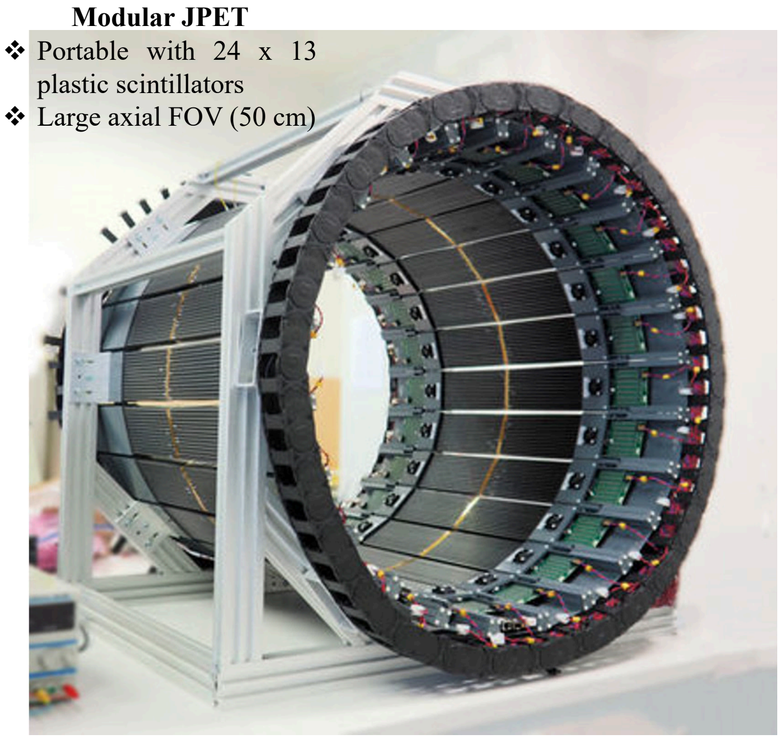
Image Reconstruction using Scintillator Detectors

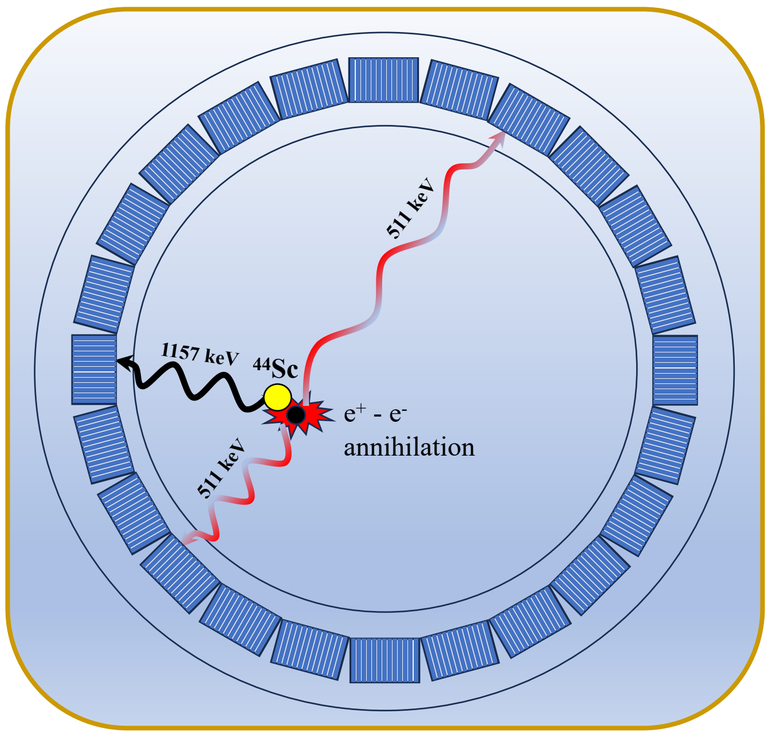


Location of annihilation determined by timing response of two detectors by constructing Line of response b/w two interaction points

Modular JPET

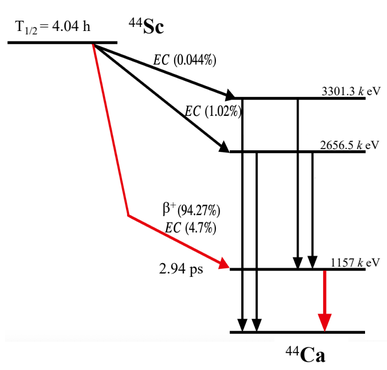
- Portable with 24 x 13 plastic scintillators
- Large axial FOV (50 cm)



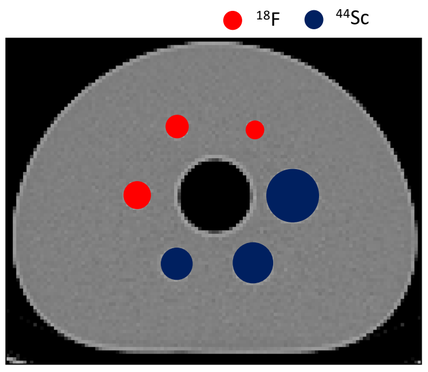


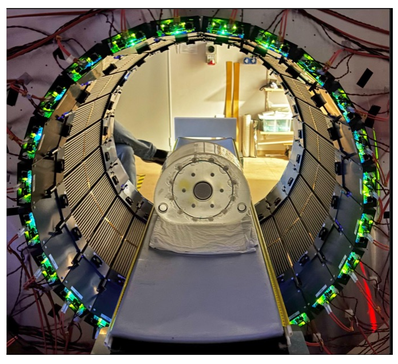
Experimental Details

^{44}Sc decay



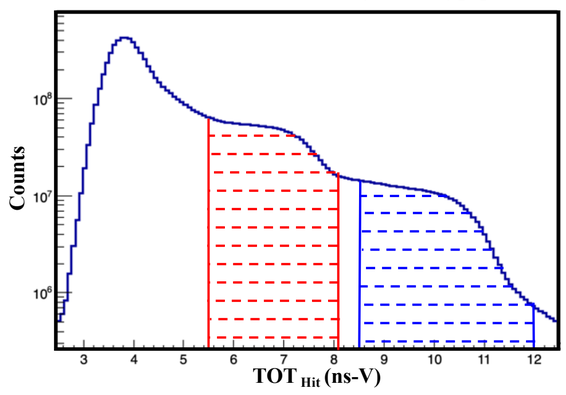
Transaxial CT scan of the NEMA IQ [4]





Data Analysis using JPET Framework

Distribution of TOT (TOT $_{Hit}$)[5]



Annihilation points plot

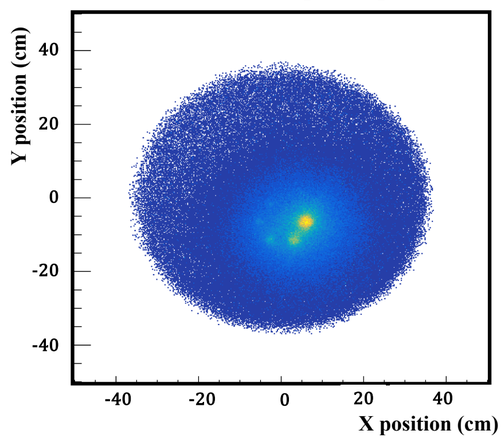


Figure: Range of TOT$_{Hit}$ values for selecting annihilation (Red) and deexcitation photons (Blue)

Selection criteria for filtering the events:

- Annihilation and prompt selection based on TOT [5].
- Events with multiplicity ≥ 3
- Time difference between the annihilation hits
- Angular correlation b/w annihilation hits
- Scatter Test:

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

$$\Delta T = \frac{t_{ann1}+t_{ann2}}{2} - t_{prompt}$$

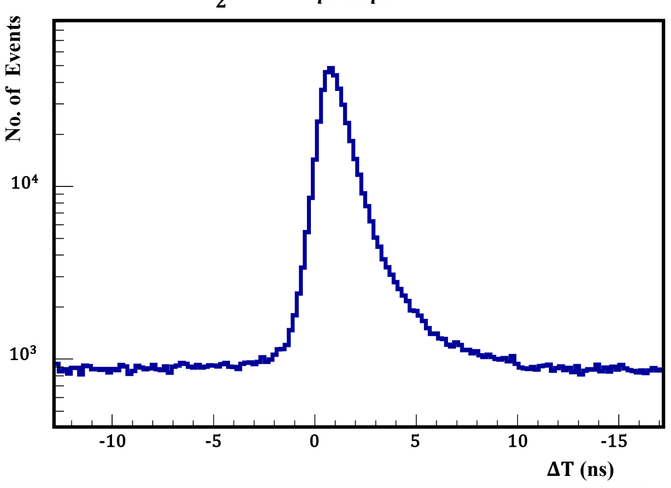


Image Reconstruction using List Mode Data

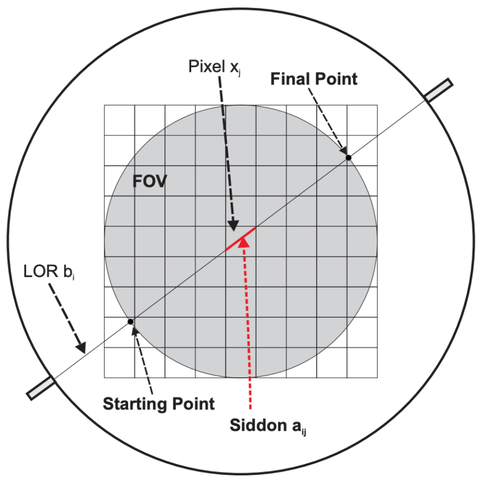
Siddon ray tracing method [6] is used as projector to give the contribution from the voxels and Maximum Likelihood expectation maximization (MLEM) is used to update the image iteratively

The MLEM reconstruction is given as [7]:

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

$image_j^k$ = 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 of event i is result of an emission from voxel j
N – Normalization

Siddon Algorithm [8]



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]:

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

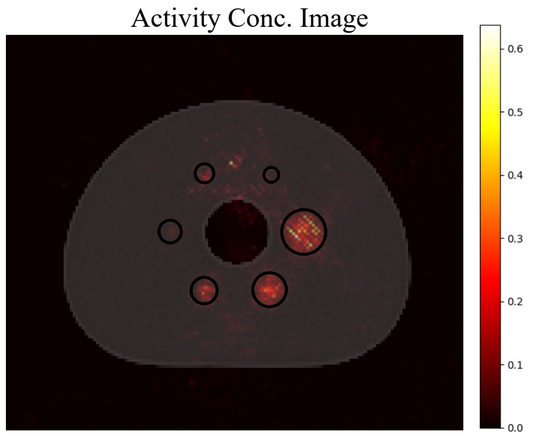
where w_{kj}^n is given by:

$$w_{kj}^n = \frac{C_{ij}\, image_j\, \lambda_j \exp(-\lambda_j^n \tau_k)}{\sum_{l=1}^J C_{il}\, image_l\, \lambda_l^n \exp(-\lambda_l^n \tau_k)},$$

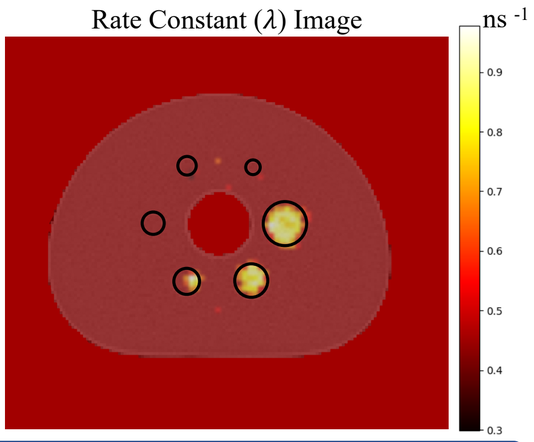
β = regularization term, η_j^n= penalty calculated from neighbours of pixel j

Preliminary Results

Activity Conc. Image



Rate Constant (λ) Image



Conclusion

- 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 real data measured using NEMA IQ phantom placed inside Modular J-PET
- We observed that the rate constant (lambda) images are of better quality

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Acknowledgements

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