TOF MLEM for Total-Body J-PET with Analytical System Response and Resolution Modelling

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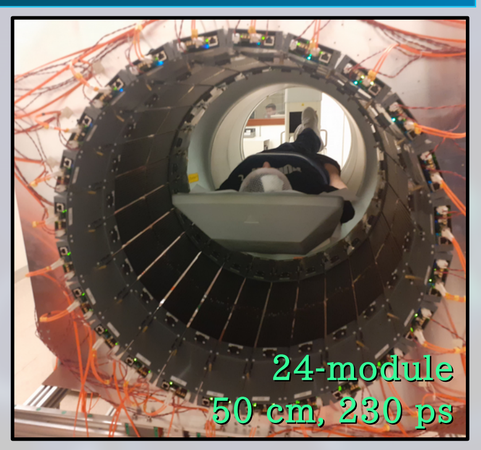
Objective

Develop the iterative time-of-flight (TOF) image reconstruction algorithm with a realistic resolution modelling (RM) employed to define the system response matrix (SRM) for the multi-layer total-body Jagiellonian PET (J-PET) scanner.

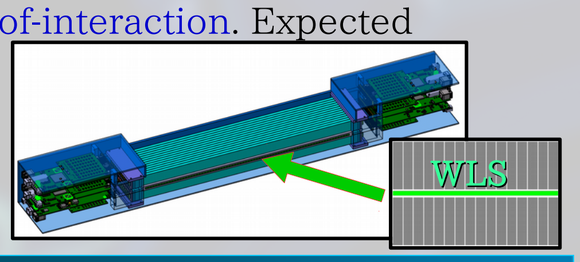
Total-body Jagiellonian PET

J-PET: Compton scattering of e^-e^+ annihilation photons in EJ-230 plastic detectors[1,2], TOF available, total body scale (50–200 cm).

Signal readout: silicon PM (**SiPM**) & FPGA electronics[3].



Future prototype: ~2 m, 2-layer (×15 sensitivity) + wavelength shifters (**WLS**)[4]: improves axial resolution, potentially – depth-of-interaction. Expected **resolutions**: 5 mm (spatial), 190 ps (temporal).



Complex geometry – how to calculate SRM?

TOF MLEM with realistic SRM

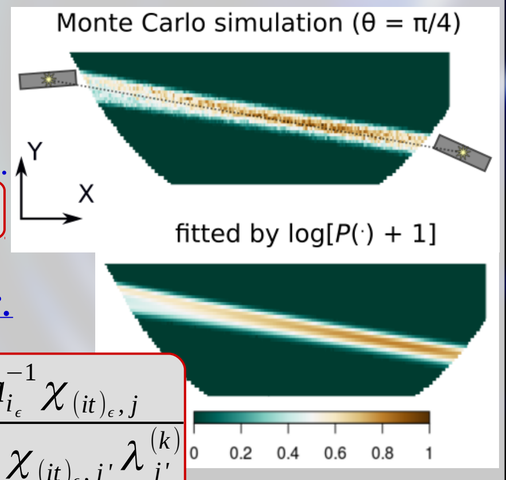
Maximum likelihood expectation maximisation (MLEM) – iterative algorithm which uses SRM – probabilities m_{ij} for i-th bin detecting the emission from j - th voxel λ_j [5].

Decompose SRM elements $m_{it,j}$ (t – TOF bin) as $m_{it,j} = n_i a_i \chi_{it,j}$ (normalisation, attenuation and geom./shift-variant RM)

List-mode, with attenuation and normalisation[6]:

$$\lambda_j^{(k+1)} = \frac{\lambda_j^{(k)}}{\sum_{i\in I} a_i n_i \chi_{ij}} \sum_{\epsilon\in E} \frac{\chi_{(it)_\epsilon,j}}{\sum_{j'\in J} \chi_{(it)_\epsilon,j'} \lambda_{j'}^{(k)}}$$

The idea – replace χ-elements by analytical *fitting functions* per bin applied to the *simulated* emissions in 2D for several obliquenesses θ [7].

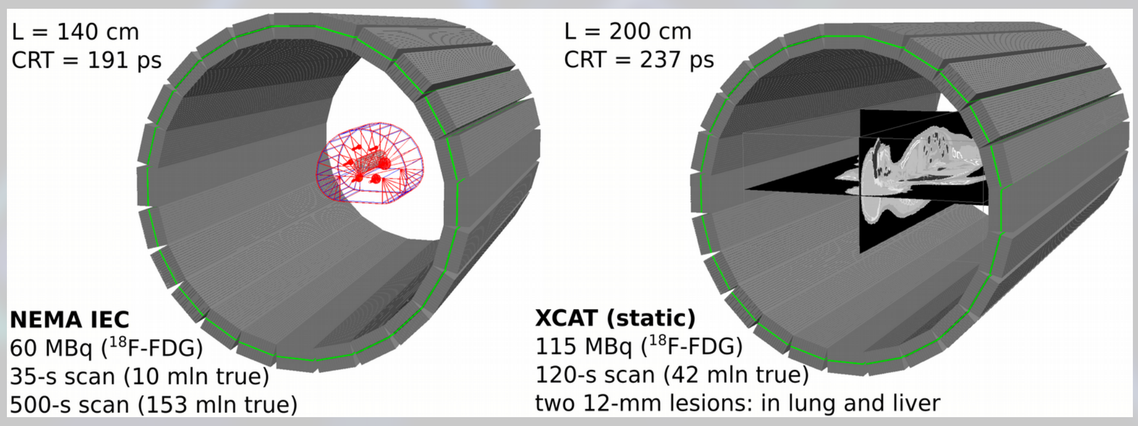


Each function $\chi_{i_\epsilon}(x_j, y_j, z_j, \Delta t_\epsilon, \theta)$ accounts for: TOF, Z-error of hit, parallax correction, detector blur.

Simplified attenuation correction (AC):

$$\lambda_j^{(k+1)} = \frac{\lambda_j^{(k)}}{\sum_{i\in I} n_i \chi_{ij}} \sum_{\epsilon\in E} \frac{a_{i_\epsilon}^{-1} \chi_{(it)_\epsilon,j}}{\sum_{j'\in J} \chi_{(it)_\epsilon,j'} \lambda_{j'}^{(k)}}$$

Simulated setup in GATE[8]



NEMA IEC
60 MBq (^{18}F-FDG)
35-s scan (10 mln true)
500-s scan (153 mln true)

XCAT (static)
115 MBq (^{18}F-FDG)
120-s scan (42 mln true)
two 12-mm lesions: in lung and liver

Results

Two ACs tested for predefined μ-maps.

Reference: TOF MLEM (CASToR)[9] only geom. SRM factors

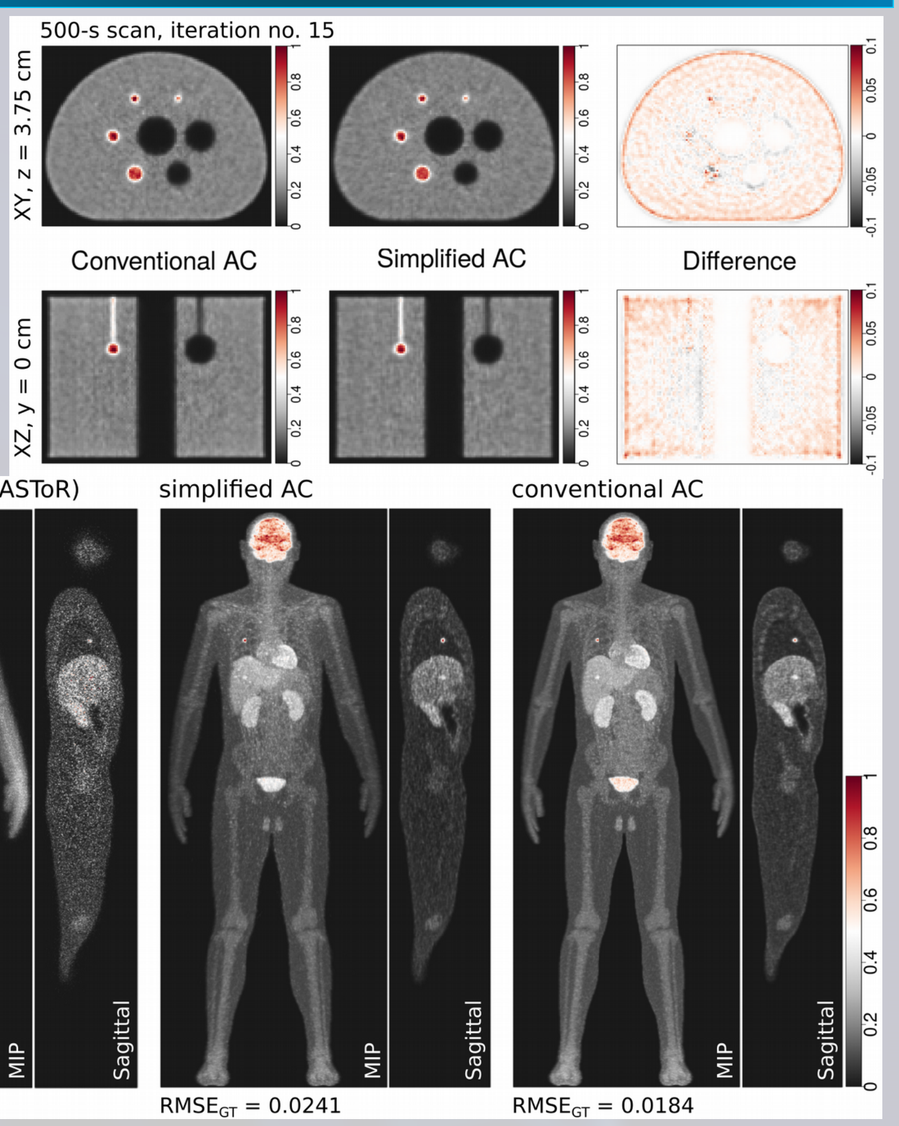
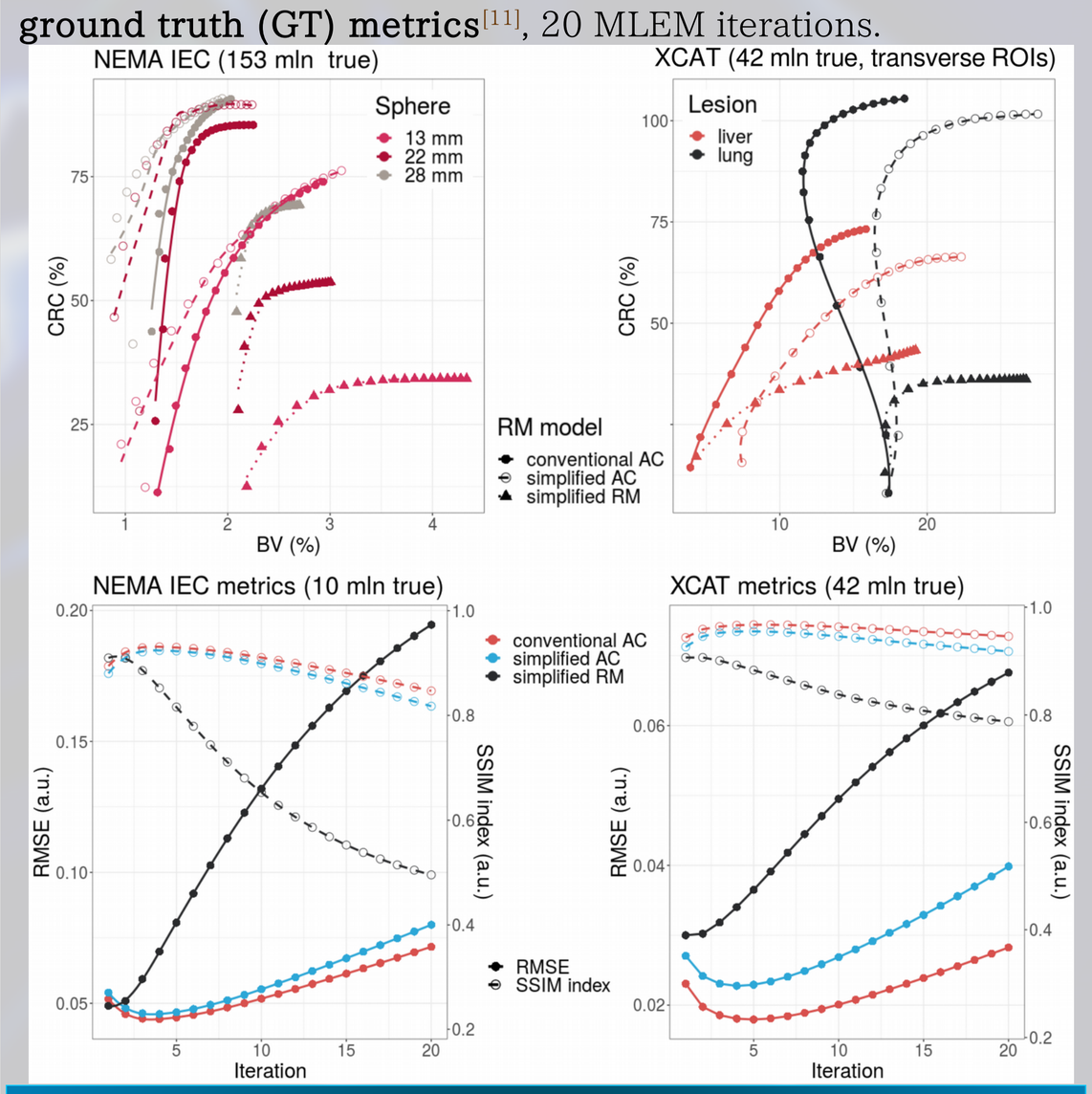


Image quality: contrast recovery vs background variability[10], **ground truth (GT) metrics**[11], 20 MLEM iterations.



Summary

The study of the proposed SRM model for J-PET proved to be rewarding for TOF MLEM. Image quality and GT metrics are superior to the reference. Sensitivity map is more accurate.

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