A simulation study to evaluate NEMA characteristics of Modular J-PET

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Abstract

Modular Jagiellonian Positron Emission Tomograph (J-PET) is latest prototype of the J-PET Collaboration (Fig. 1) [1-3]. The modularity of prototype allows for simple construction and deconstruction, portability, and the possibility of assembly with different numbers of panels depending on the patient size and clinical needs [4]. The main aim of this simulation study is to estimate the performance of the Modular J-PET by GATE software [5] according to the NEMA NU 2-2018 standards.

Materials and methods

The presented study was carried out by the GATE software which is a validated simulation toolkit for a medical imaging application. Modular J-PET Consists of 24 Modules which are arranged in regular 24-sided polygon circumscribing a circle with the diameter of 73.9 cm [6-7]. Each module is built out of 13 scintillator strips placed next to each other, read out on both ends by SiPM.

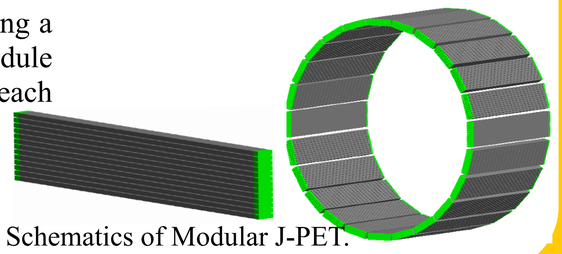


Fig 2: (Left) Schematic of one Module with 13 plastics scintillator(gray color) and SiPM (green color), (Right) Schematics of Modular J-PET.

Scatter Fraction

The Scatter Fraction was calculated based on SSRB algorithms. True, scatter, and random coincidence rates were extracted from the re-binned sinograms.

Source Distribution:

- Line source
- Diameter of source is 3.2 mm
- Position of source (mm) is (0, -45, 0)
- The activity of source is 1 MBq
- Back to back gamma photons

Phantom simulation:

- Cylinder phantom composed of polyethylene with specific gravity of 0.96 ± 0.01 g/cm^3
- Diameter of source is 203 ± 3 mm
- Length of source is 700 ± 5 mm
- Position of source (mm) is (0, -45, 0)

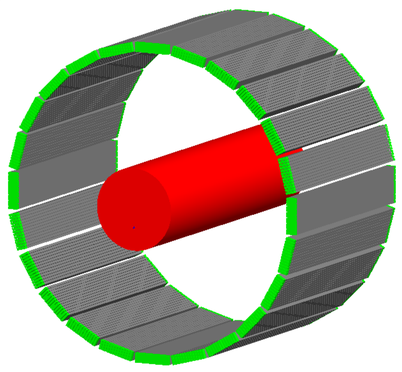
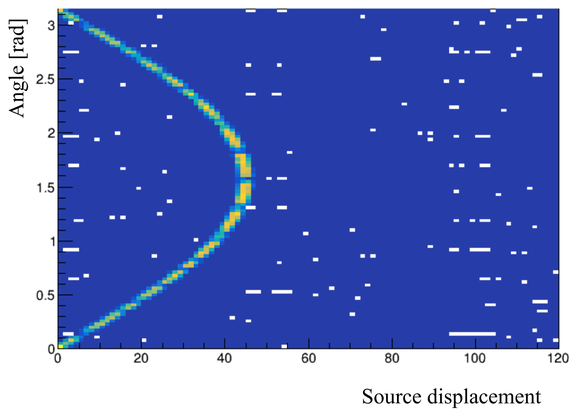


Fig 3: Schematics of 24 Modular J-PET with the simulated scatter phantom inside detector.



.Fig 4: The sinogram for a whole scanner .

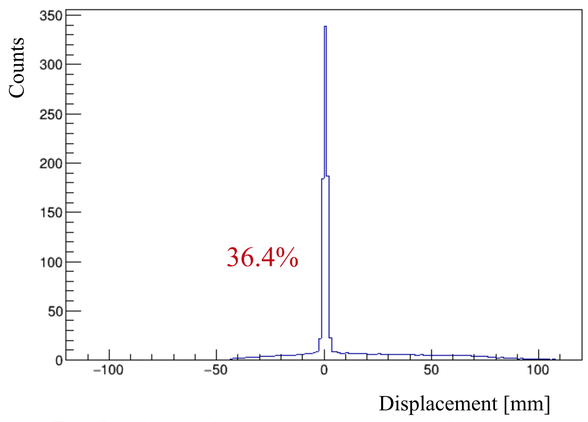


Fig 5: Alligned to zero and summed sinogram.

Sensitivity

The sensitivity of a PET scanner is defined as the number of counts per time unit detected by the detector for each unit of activity present in a source. The sensitivity of a scanner is highest at the center of the axial FOV and gradually decreases toward the periphery.

Source Distribution:

- 70 cm Line source
- Diameter of source is 1mm
- Source is in the center of scanner
- The activity of source is 1MBq
- Back-to-back gamma photons

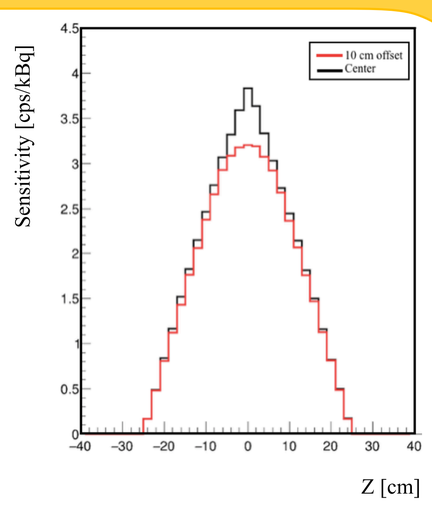


Fig 6: Axial sensitivity profile.

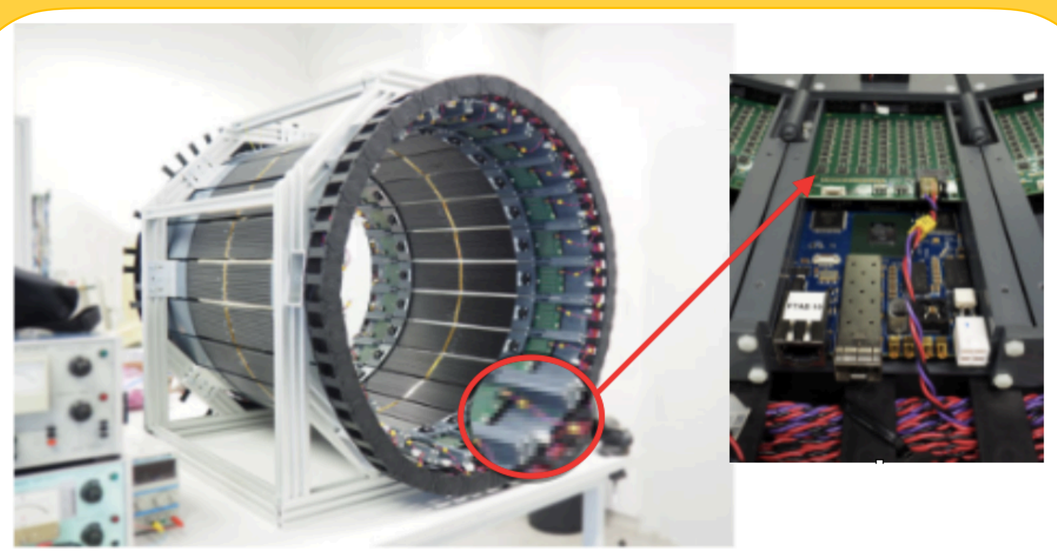


Fig 1: (Left) Modular J-PET after mechanical assembly, (Right) Power supply board (green) providing voltage to each SiPM separately and TDC board (blue) converting analog signals to digital ones, by measuring the Time of analog signal crossing at two selected constant thresholds.

Spatial resolution

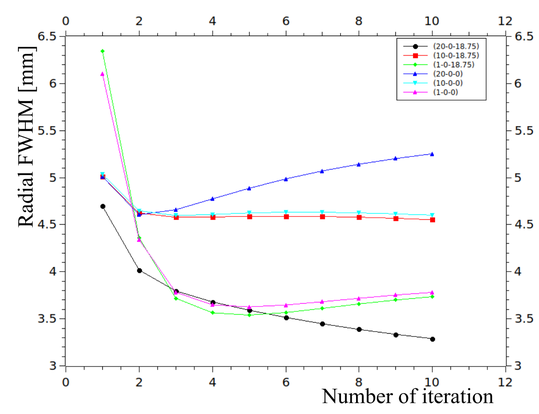
Spatial resolution is expressed as system ability to distinguish two points after image reconstruction. In this study, image reconstruction was by Quantitative Emission Tomography Iterative Reconstruction (QETIR) package.

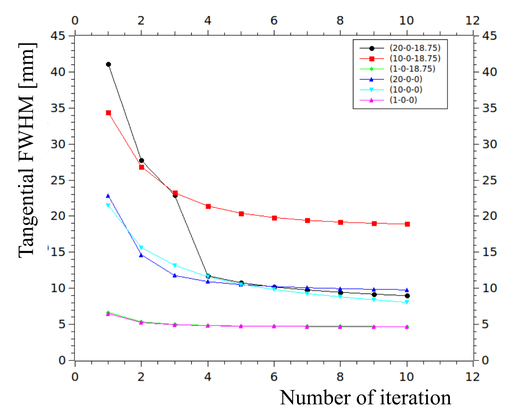
Source Distribution:

- Point like source
- Diameter of source is 1mm
- The activity of source is 370 kBq
- Back-to-back gamma photons
- Source is in the six position (unit of place of source is cm)

Image reconstruction parameters:

- Image size: $200 \times 200 \times 200$ mm^3
- Voxel size: $2.5 \times 2.5 \times 2.5$ mm^3
- Smearing data in Z direction is 2.12 mm
- TOF resolution is 630 ps





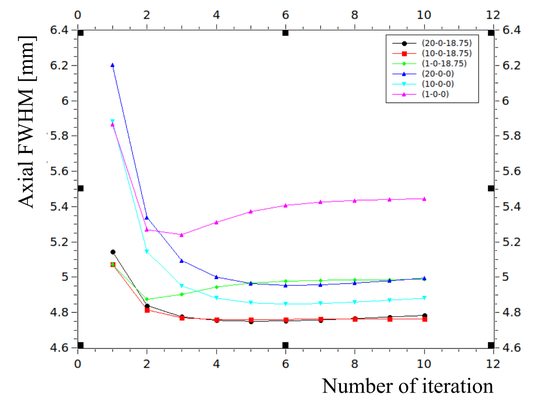


Fig 7: FWHM for three different direction as function of the number of iteration for six positions.

Conclusion

Performance characteristics of Modular J-PET based on the 50 cm FOV plastic scintillator were determined according to the NEMA NU 2-2018 by GATE simulation software and compared with other available crystal based PET devices [8-10].

Table 1: Results of Modular J-PET in comparison with traditional PET scan according to NEMA-NU2-2018.

Feature	First J-PET prototype	Modular J-PET	Philips Biograph mCT Flow	GE Discovery 710
Detector material	EJ 230	BC404	LSO	LYSO
AFOV [cm]	50	50	21.8	15.7
Scatter fraction [%]	35.8	36.4	40.2	33.5
Peak Sensitivity in the center (cps/kBq)	5	4	9.6	20.84
Transaxial resolution @ 1 cm (mm)	5	4.8	4.4	4.9
Axial resolution @ 1 cm (mm)	11.4	5.4	4.5	5.6
Time window [ns]	3	3	4.066	0.38
Energy window [keV]	200-380	>200	435-650	425-650

Acknowledgements

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