Modular J-PET - a cost effective PET scanner prototype

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Abstract

Currently in the PET imaging community several Total-body PET systems are available, such as Quadra, Explorer and PennPET providing new imaging possibilities. Their cost and weight are holding back their application on a larger scale. J-PET group explores cost-effective and portable approach to Total-Body design, by employing plastic scintillators instead of crystals [1-4]. In this contribution prototype with 50 cm AFOV is presented, as a first step towards the Total-body PET based on plastic strips. Scanner resolutions alongside first J-PET in vivo images of patient's are presented.

Materials and methods

A portable, modular prototype of the J-PET detector was commissioned at the Jagiellonian University this year. The system is built out of 24 modules, composed of 50 cm long 13 scintillator strips, read out by a SiPMs (Fig. 1). Each module converts analogue signals to the digital data independently. Acquisition system is based on trigger-less FPGA technology, maintaining the modularity of the system: time to digital conversion based on multi-voltage thresholds by means of low-voltage differential signaling buffers [5], concentration of signals from each end of the module and final aggregation of data streams with possibility to produce initial image in real-time [6]. Modularity of system made imaging of patients in hospital possible without negative impact on ongoing PET diagnostics.

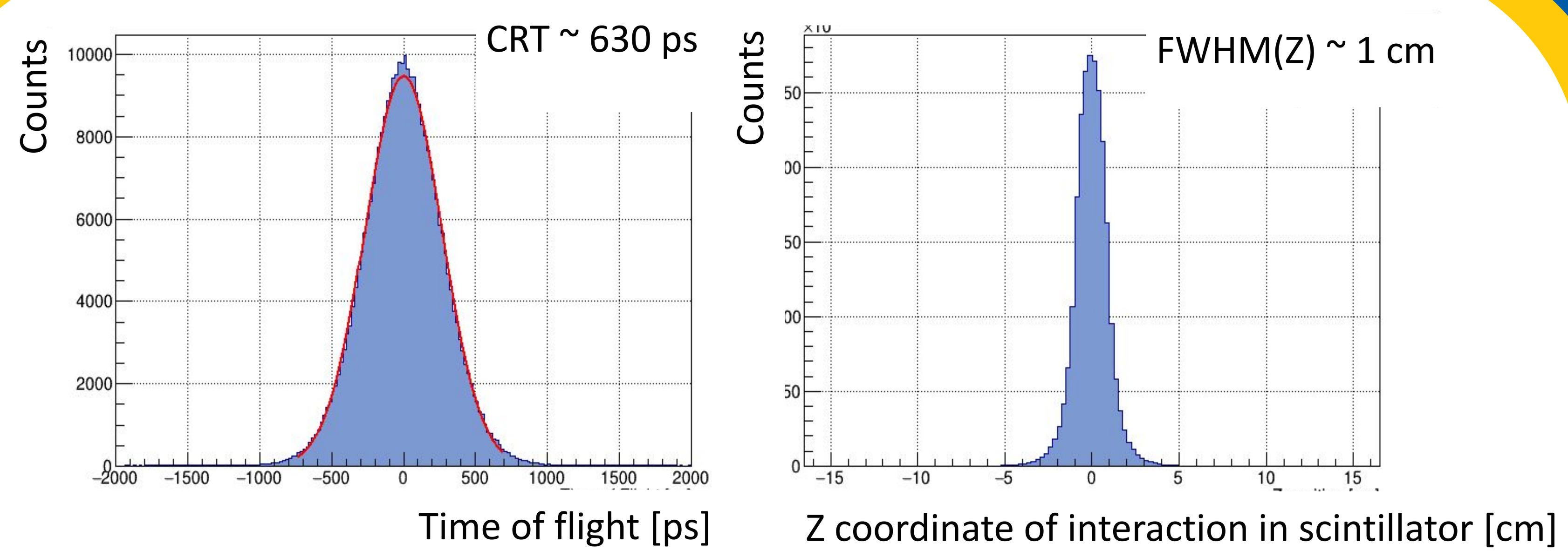

Fig 2. (left) Time of flight spectrum after first two iterative walk corrections. (right) Distribution of Z coordinates of interaction position inside scintillator.

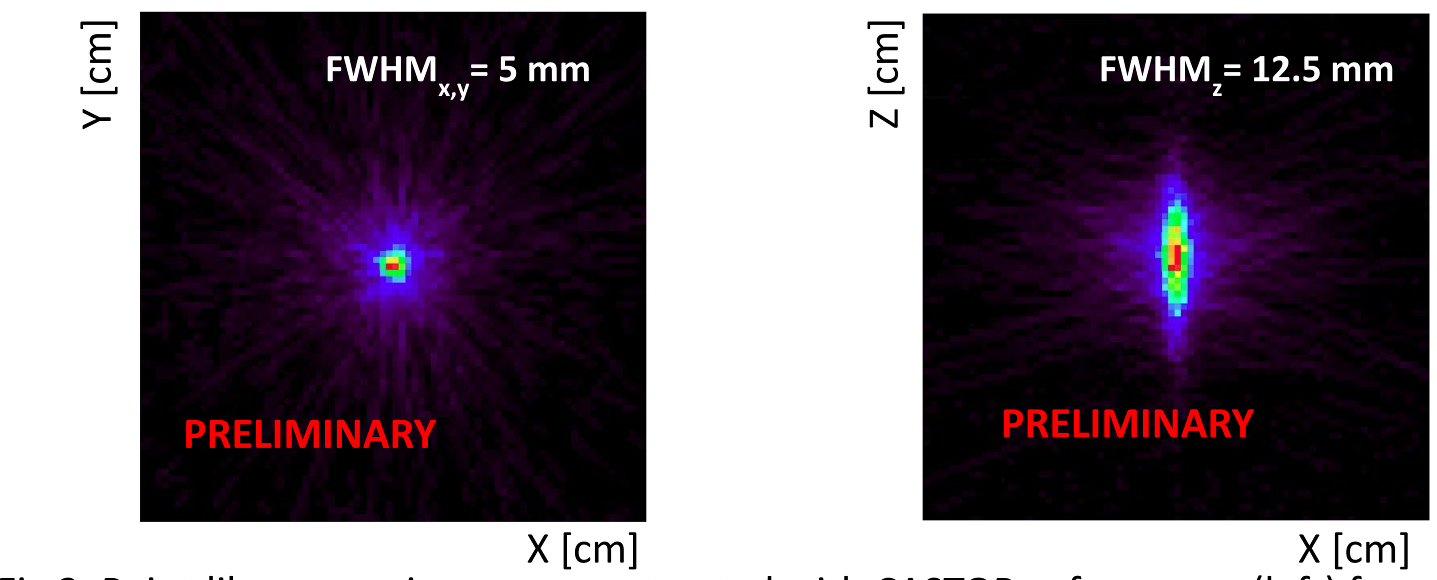

Fig 3. Point-like source image reconstructed with CASTOR software on (left) from the front view (XY plane) and (right) from the top (ZX plane).

System performance

Timing resolution of the system amounts to 630 ps (CRT) (see Fig. 2 and 3). Transaxial spatial resolution is at the level of 5 mm (FWHM), while axial one is equal to 12.5 mm (FWHM) and are presented in Fig 4. The worse axial resolution results from the method of determining gamma quantum interaction within scintillator material. In Fig. 4 an exemplary image reconstructed with CASTOR is presented for data gathered after standard PET/CT protocol. The image reconstruction takes into account only attenuation correction and scanner sensitivity, while normalization, random, and scatter corrections are still during development. Its quality is still not on par with commercial scanner yet, which is caused mainly by much lower statistics. The time for the measurement with patients was shorter than for standard protocol and the efficiency of the prototype was also not the best achievable.

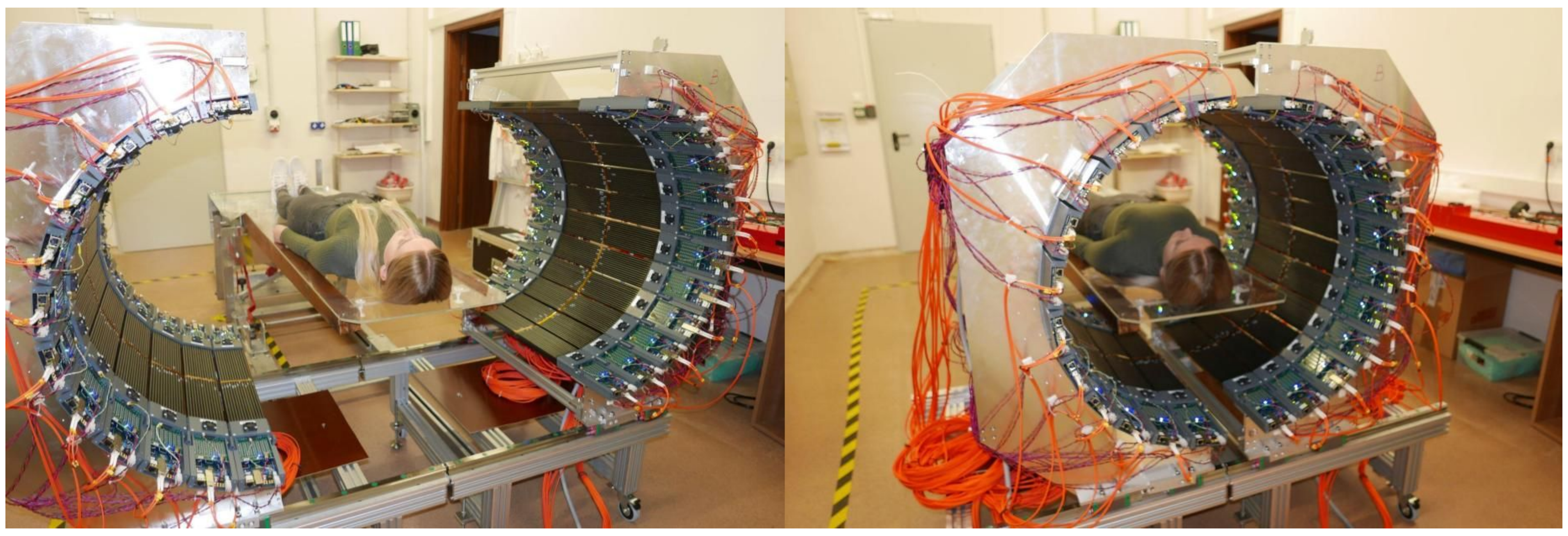

Fig 1. Mobile, modular J-PET prototype, built out of 24 modules during final tests of mechanical shift of two detection halves, before transfer to Warsaw University hospital. Modality of closing the system on the patient already laying on the table was necessary for performing measurements during standard PET/CT scan. Each module is composed of 13 scintillator strips, read out by a SiPM array from both sides. scintillators, converted to the electronic signal by SiPM, and processed with the FPGA electronics.

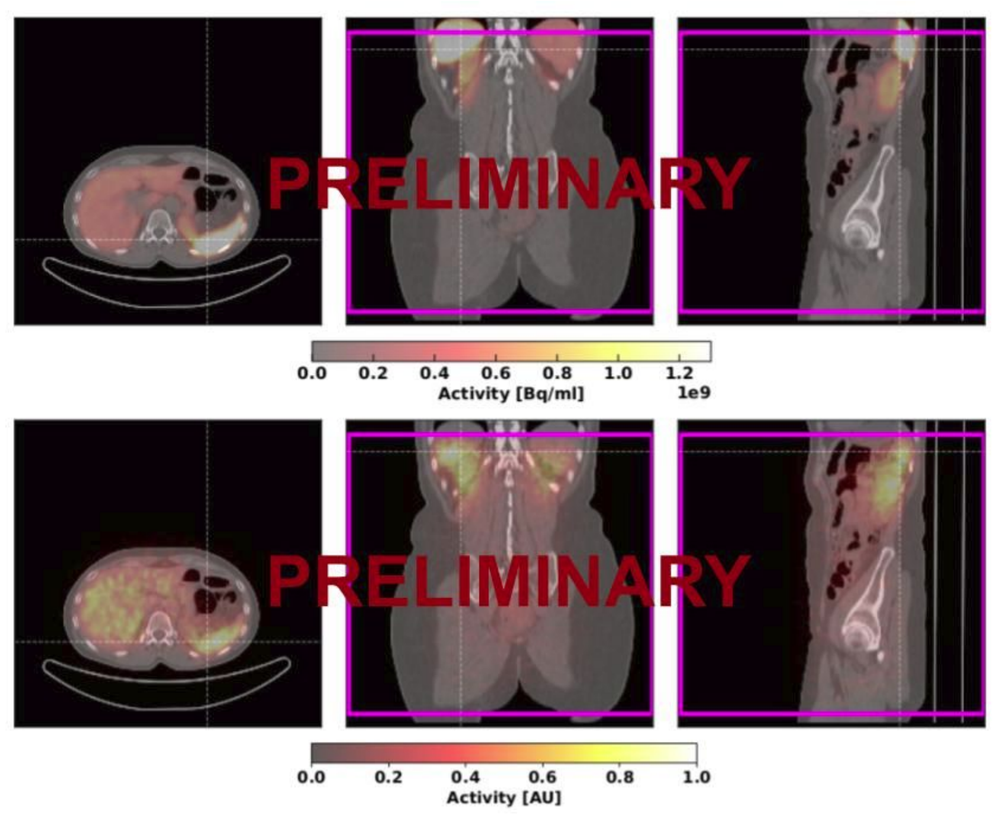

Fig. 4 Reconstructed standard 2 gamma PET from Siemens Biograph (top panel) 2 gamma J-PET (bottom panel) images superimposed on CT images for axial (left), coronal (center) and sagittal (right). The voxel sizes are 2.5 mm x 2.5 mm x 2.5 mm. Magenta rectangle indicates the J-PET axial FOV. Presented images are preliminary.

Conclusions and Perspectives for TB J-PET

First J-PET in-vivo patient's images obtained by means of the PET system built from plastic scintillators were demonstrated. Results present the modular J-PET as a possible cost-effective, portable and light-weight alternative to commercial scanners.

Comparison with other scanners, based on crystal scintillator readout as well as for the Total Body J-PET, currently in design phase is presented in Tab 1. The next J-PET prototype will possess high sensitivity and improved resolution along Z axis due to application of WLS readout [8] improving spatial resolution of the system to < 5 mm.

Tab 1. Comparison of selected features of Modular and Total Body J-PET scanners with other, crystal based PET devices [7].

Feature	Modular J-PET	Total Body J-PET	Philips Biograph mCT Flow	GE Discovery 710	uExplorer
Detector material	BC404	BC408	LSO	LYSO	LYSO
Transaxial resolution @ 1 cm [mm]	5 **PRELIMINARY**	5.5 **SIMULATION**	4.4	4.9	3.0
Axial resolution @ 1 cm [mm]	12.5 **PRELIMINARY**	4.5 **SIMULATION**	4.5	5.6	2.8
CRT [ps]	630 **PRELIMINARY**	140 **SIMULATION**	540	544	505
Energy resolution FWHM [%]	21	NA	NA	12	12
Energy window [keV]	200-380	200-380	435-650	425-650	430-645
AFOV [cm]	50	>200	21.8	15.7	194

References

[1] P. Moskal, et al. "Simulating NEMA characteristics of the modular total-body J-PET scanner - an economic total-body PET from plastic scintillators", Phys. Med. Biol. 66 (2021) 175015.
[2] S. Niedźwiecki, et al., "J-PET: A New Technology for the Whole-body PET Imaging", Acta Phys. Polon. 2017; B48 10: 1567-1576.
[3] P. Moskal, et al., "Positronium imaging with the novel multiphoton PET scanner", Science Advances 7 (2021) eabh4394.
[4] P. Moskal, et al., "Testing CPT symmetry in ortho-positronium decays with positronium annihilation tomography", Nature Communications 12 (2021) 5658.
[5] M. Pałka, et al., "Multichannel FPGA based MVT system for high precision time (20 ps RMS) and charge measurement", JINST; 2017: 12 P08001.
[6] G. Korcyl, et al. "Evaluation of Single-Chip, Real-Time Tomographic Data Processing on FPGA -SoC Devices", IEEE Transactions On Medical Imaging, 2018; Vol. 37, No. 11: 2526 - 2535.
[7] Vandenberghe, et al. "State of the art in total body PET", EJNMMI Phys 7, 35 (2020).
[8] J. Smyrski, et al. "Measurement of gamma quantum interaction point in plastic scintillator with WLS strips", NIM. in Physics Research A 851 (2017) 39-42.

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