Comparative studies of the selected issues of sparse and full geometries of Total-Body PET scanners

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Abstract

Despite of one of the main benefits of the Total-Body PET tomographs - their greatly enhanced sensitivity over the significantly extended field of view, their widespread use is being held back due to the construction expenses. The aim of this study is to inspect and compare simulation-based sensitivity of existing and presently developed scanners, while also focusing on their costs and scintillators characteristics.

Methods

The presented research has been carried out with the GATE software. In order to inspect sensitivity of the tomographs, a 250 cm long, centrally located linear source has been simulated with 1 MBq of activity. The data was acquired in the >200 keV, 430 – 645 keV and 435 – 650 keV energy windows for J-PET, uEXPLORER based and Biograph based scanners, respectively [1 - 5].

Sensitivity of slice

$$S_i = \frac{R_i \times L_{source}}{d \times A},$$

where d is the width of the slice

Total Body sensitivity

$$S_{TB} = \frac{\sum_{i=1}^{N} R_i}{A_{183cm} \times N},$$

where N is the number of slices within the 183 cm range and A_{183cm} its activity

Moreover, the examination of the angle- and ring-based acceptance criterion (analogous to 57° acceptance angle) was performed due to its utilization in oblique LOR elimination [4].

Results

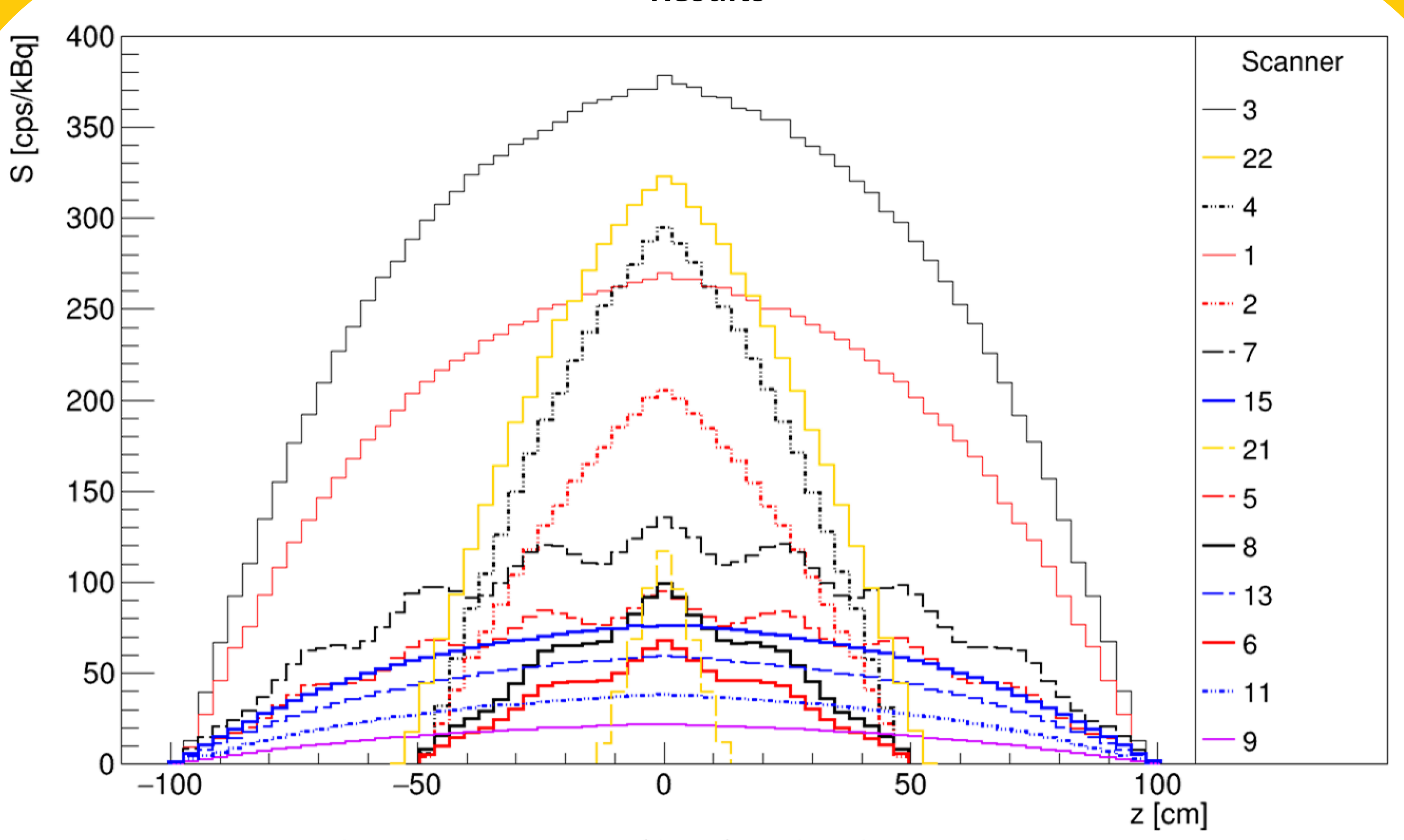


Figure I: Sensitivity profiles of Total-Body PET scanners.

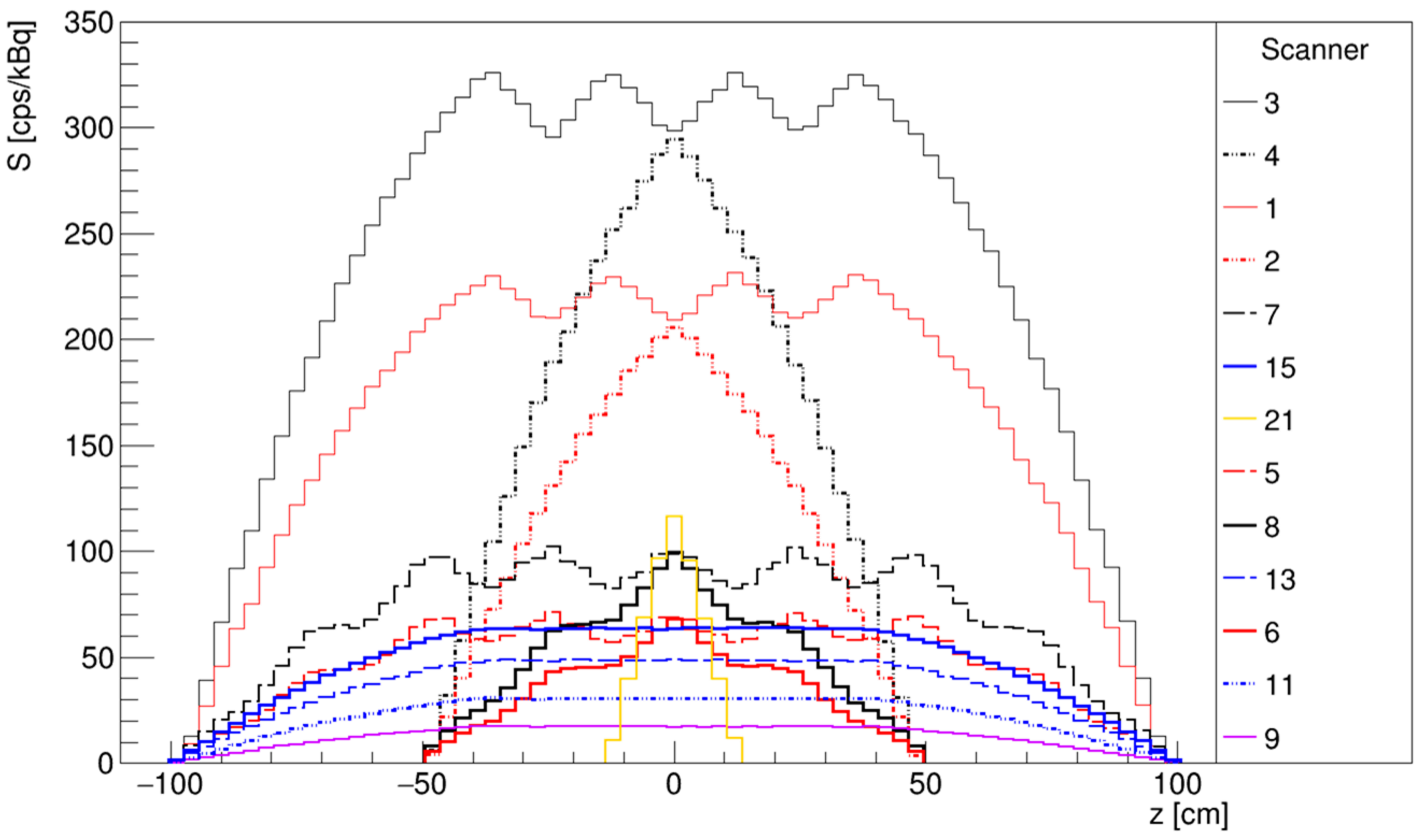


Figure II: Sensitivity profiles of Total-Body PET scanners after acceptance criterion.

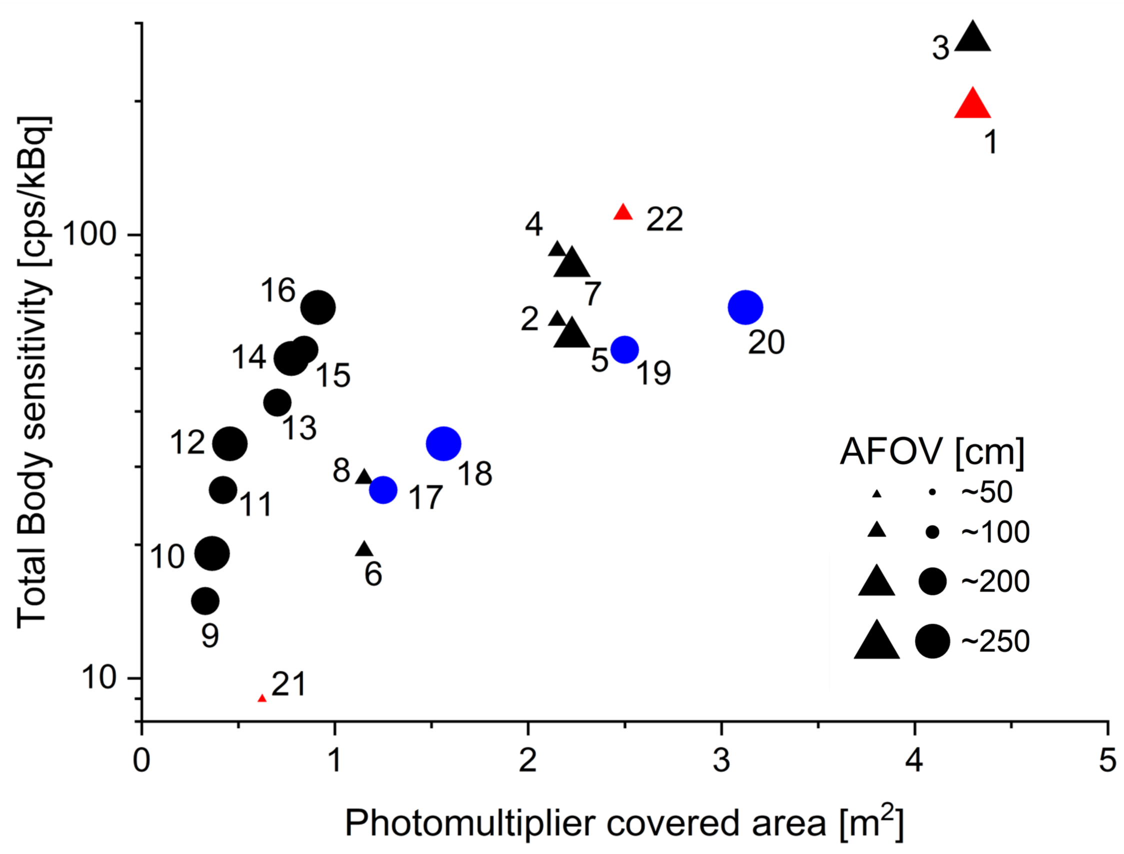


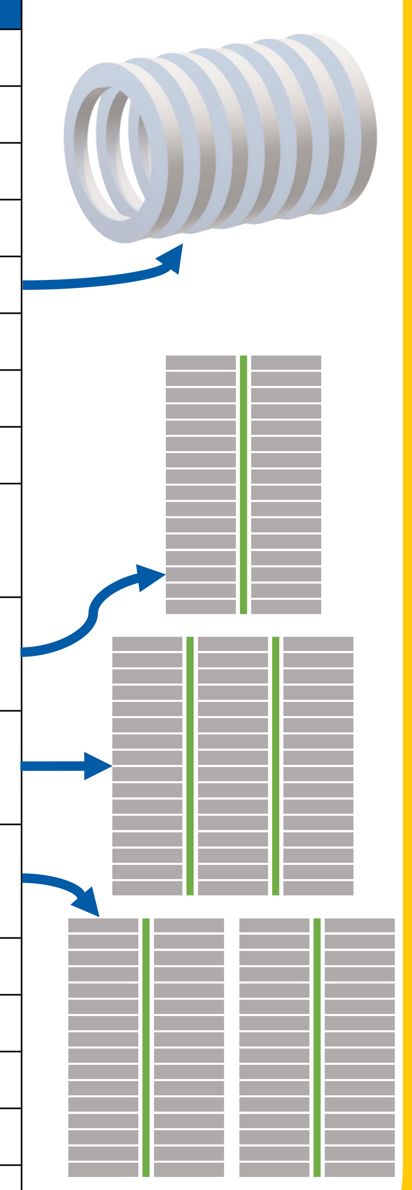
Figure III: Representation of the Total Body sensitivity of scanners as a function of the sum of the required photomultiplier covered area. The Total-Body PET systems based on the J-PET technology are marked with black circles. Four additional ring-based Total-Body J-PET geometries are marked with blue circles. The crystal-based geometries are marked in the plot with black triangles, while three of the existing systems have red colour.

Total-Body PET scanners

In the presented study, J-PET systems with different geometrical configurations, axial lengths, ring systems and scintillator cross-sections were studied. Moreover, PET scanners based on the uEXPLORER geometrical design were inspected, varying in parameters such as: scintillator material, axial length and detector configuration (full and sparse). In addition, the Biograph Vision based geometries were also investigated.

Table I: Geometrical configuration of Total-Body PET scanners [1 - 5].

No.	Scanner	AFOV [mm]	Scintillator dimension [mm]	Scintillators per ring	Number of rings
1	uEXPLORER (LYSO)	1948	2.76 × 2.76 × 18.1	70 560	8
2		974			4
3	uEXPLORER (BGO)	1948	2.76 × 2.76 × 18.1	70 560	8
4		974			4
5	Sparse uEXPLORER (LYSO)	1948	2.76 × 2.76 × 18.1	10 080	29
6		974			15
7	Sparse uEXPLORER (BGO)	1948	2.76 × 2.76 × 18.1	10 080	29
8		974			15
9	TB J-PET (2 modules)	2000	4 × 20 × 2000	1 152	1
10		2500	4 × 20 × 2500		
11	TB J-PET (2 modules)	2000	6 × 30 × 2000	768	1
12		2500	6 × 30 × 2500		
13	TB J-PET (3 modules)	2000	6 × 30 × 2000	1 152	1
14		2500	6 × 30 × 2500		
15	TB J-PET (4 modules)	2000	6 × 30 × 2000	1 536	1
16		2500	6 × 30 × 2500		
17	TB J-PET (2 modules)	2000	6 × 30 × 500	768	4
18		2500	6 × 30 × 500		5
19	TB J-PET (4 modules)	2000	6 × 30 × 500	1 536	4
20		2500	6 × 30 × 500		5
21	Biograph Vision	263	3.2 × 3.2 × 20	7 600	8
22	Biograph Vision Quadra	1060	3.2 × 3.2 × 20		4 × 8



Properties of scintillators

Table II: Selected properties of scintillators [6 - 9].

Scintillator	Light output [photons/MeV]	Decay time [ns]	Density [g/cm³]	511 keV linear attenuation coefficient [cm⁻¹]	Price reduction
LYSO	32 000	41	7.1	0.82	1
LSO	31 000	43	7.4	0.88	~1
BGO	8 500	300	7.13	0.96	2-3
BC-408 (plastic)	11 000	2.1	1.023	0.096	80

Summary

The presented simulation-based study took into consideration advantages (in a form of sensitivity) and drawbacks (in a form of costs and materials performance) of the existing and presently developed Total-Body PET scanners in the issue of their widespread usage. The best sensitivity-wise performance can be achieved with the BGO crystals, however performance of this material is a drawback to its exploitation. The utilization of the sparse geometrical configuration has a direct impact on the construction costs; however it highly degrades the system's sensitivity over the discontinuous field of view. The atypical geometrical design provided with plastic scintillators in J-PET scanners gives an alternative approach to lower the expenses, while maintaining an almost continuous field of view. Nevertheless, it suffers from the relatively low efficiency performance.

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