Sensitivity to the standard metabolic imaging and positronium imaging using J-PET design

Szymon Parzych

On behalf of the J-PET Collaboration

J-PET

UNIWERSYTET JAGIELLOŃSKI W KRAKOWIE

Metabolic and Positronium Imaging

Metabolic Imaging

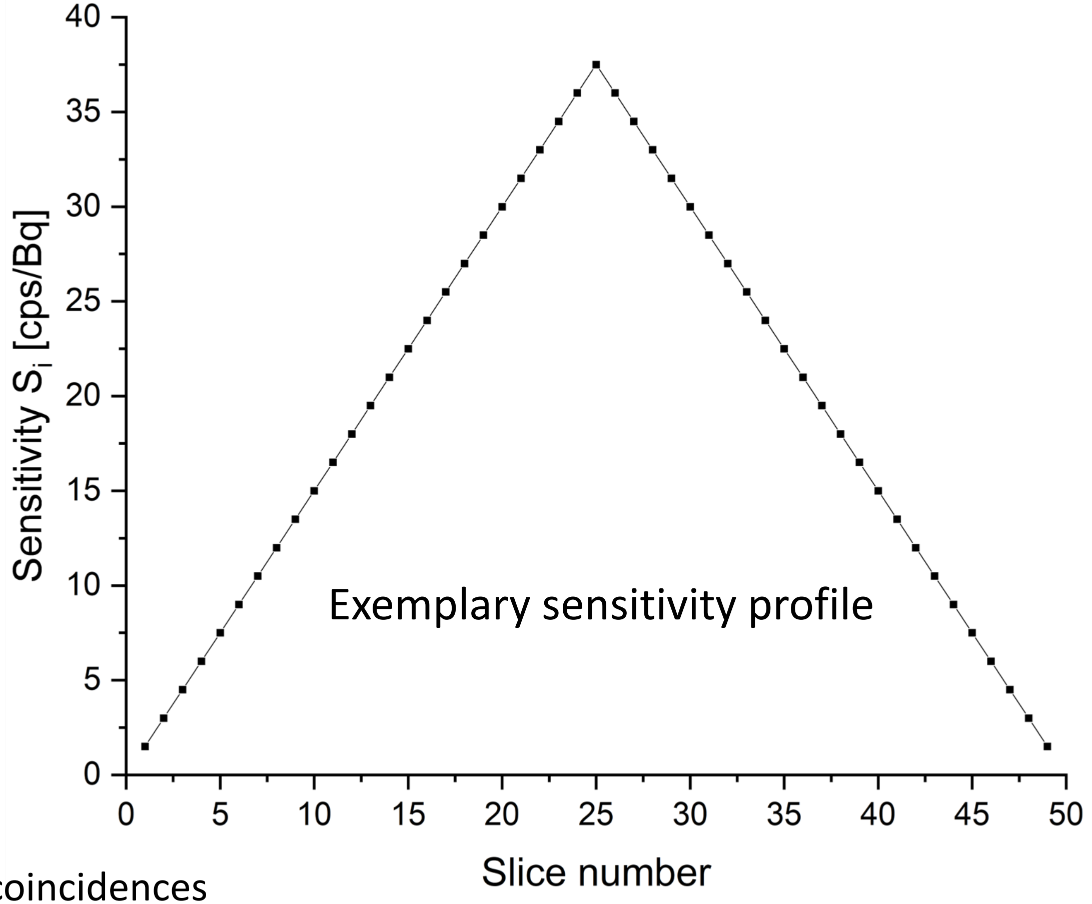
- Standard imaging in PET systems
- Based on the back-to-back annihilation photons
- Enables diagnosis of the uptake of radiopharmaceuticals in cells (SUV)

Positronium Imaging

- Complementary to Metabolic
- Based on the back-to-back annihilation photons and deexcitation gamma
- Ortho-Positronium mean lifetime instead of SUV parameter
- Enables imaging of the inner structure of tissues
- Additional diagnostic indicator

Sensitivity

- The sensitivity of a PET tomograph is expressed as the true coincidence events rate normalized to the total activity of the source
- According to “NEMA Standards Publication NU 2-2018” guidelines it can be reported as:
  - System (total) sensitivity $S_{tot} = {}^{R}/_{A}$
  - Sensitivity profile, where $S_i = {}^{R_i}/_{A_i}$



R_i - rate of registered true coincidences originating within the i^{th} slice
A_i - fraction of activity located in i^{th} slice

Geometries

Tomographs designed with J-PET technology:

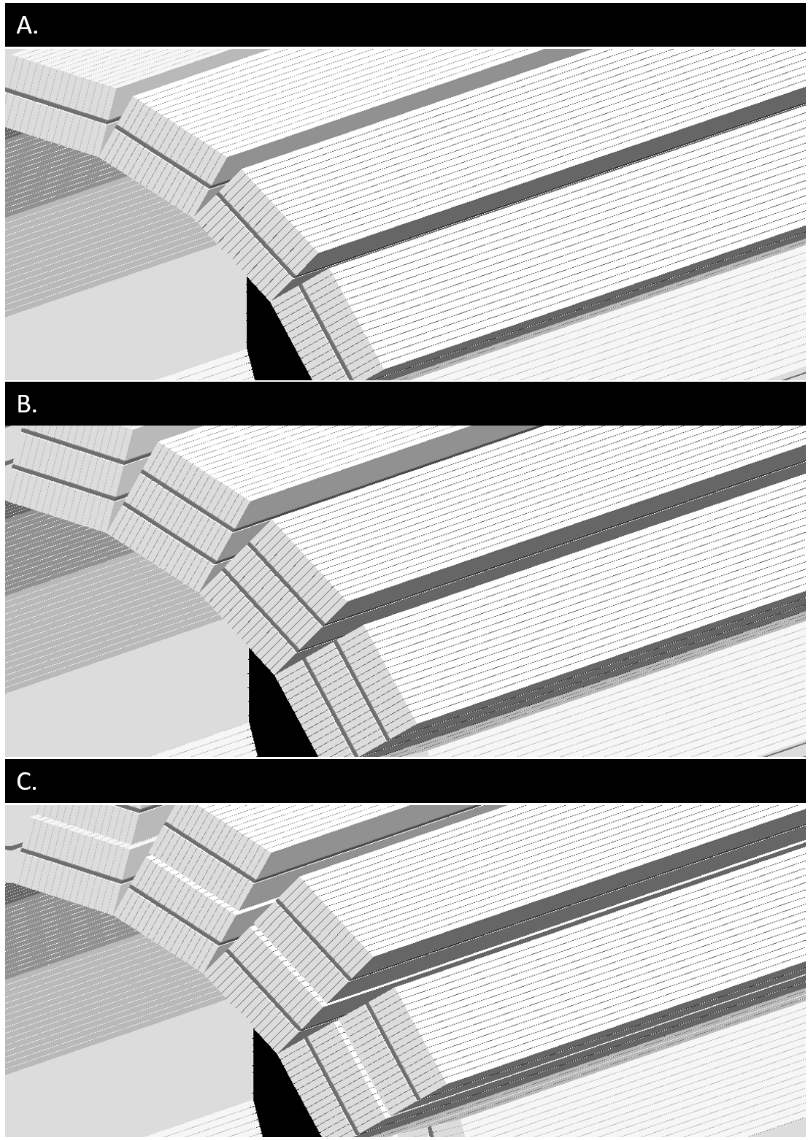
- Scintillator material – plastic (EJ230, Eljen Technology)
- Axial arrangement
- Silicon photomultiplier (SiPM) readout at both ends

Three designs were taken into account:

A. 2 panels × 16 scintillators

B. 3 panels × 16 scintillators

C. 4 panels × 16 scintillators



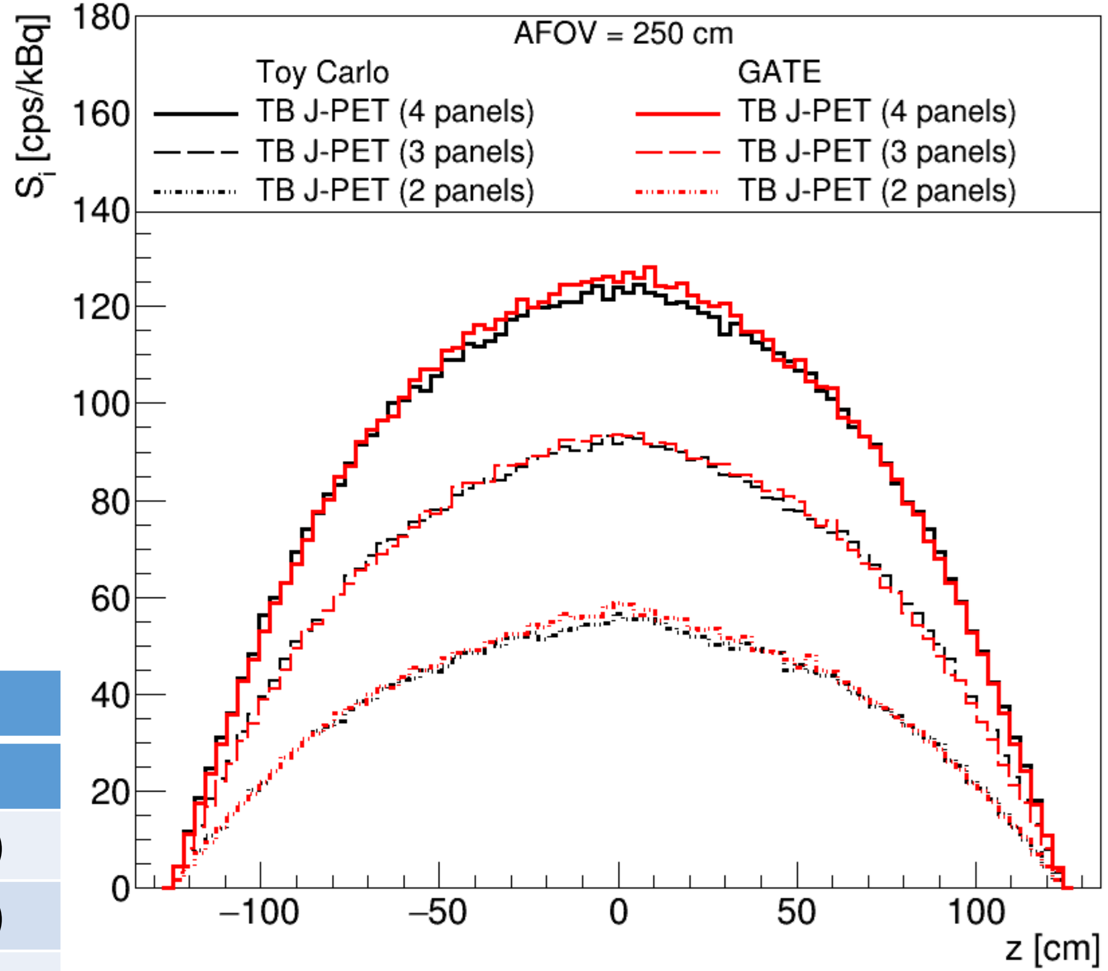
Simulation software

Presented study was conducted with a use of a dedicated Toy Monte-Carlo model:

- event-by-event basis
- true coincidence registration
- Metabolic and Positronium Imaging

Validation was performed as a comparison with the standard GATE software

Design	S_{tot} [cps/kBq]	
	Toy Carlo	GATE
A.	37.14(06)	36.46(06±07)
B.	62.12(08)	62.21(08±08)
C.	85.47(09)	84.7(0.9±1.1)



Simulation parameters

Utilized sources:

- 1 cm long linear source of 1MBq activity (point-like, small lesion)
- 70 cm long linear source of 1MBq activity (NEMA)
- 183 cm long linear source of 1MBq activity (human-size)
- 250 cm long linear source of 1MBq activity (full-scanner)

Results

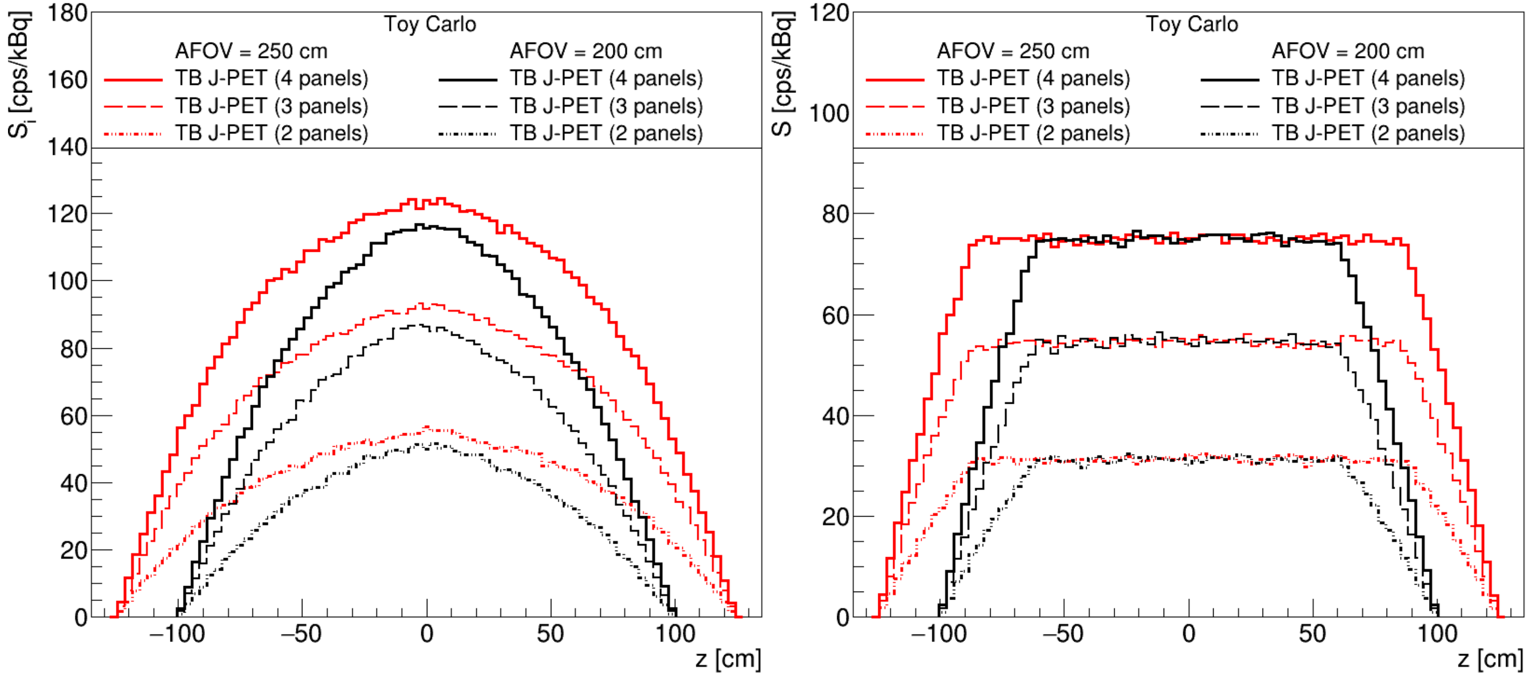
Metabolic Imaging sensitivity

250cm source

Sensitivity profiles of the 200 cm and 250 cm long (AFOV) Total Body J-PET tomographs:

a. without any conditions

b. with imposed angular acceptance criterion on 45° angle

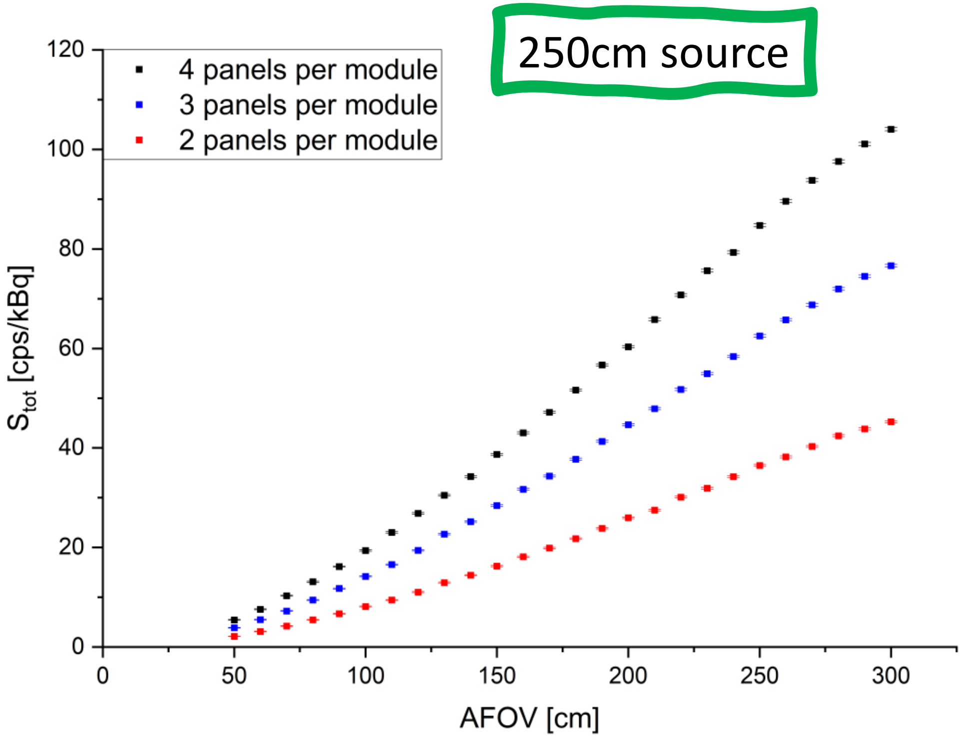


a. b.

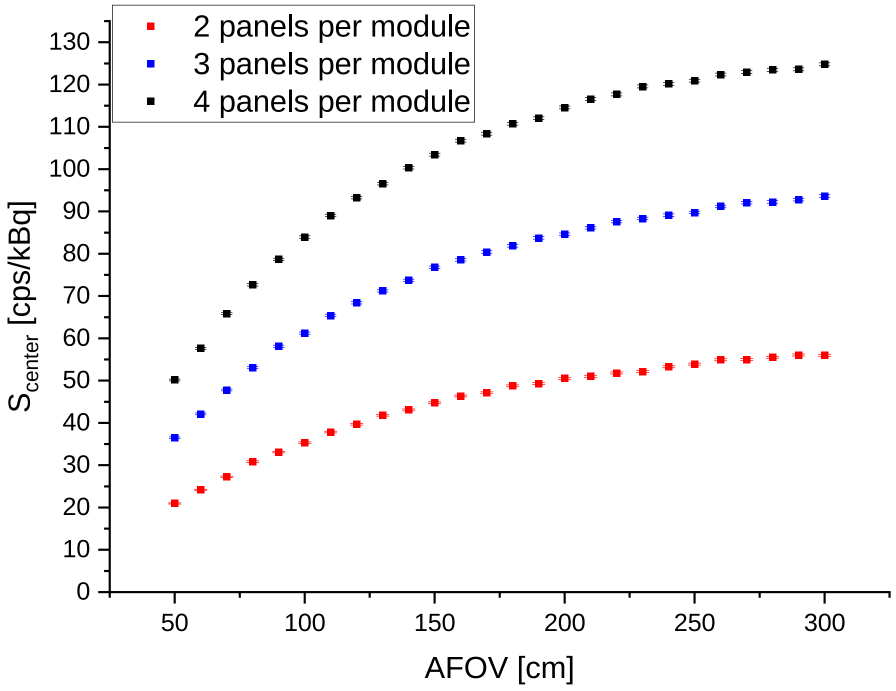
Results

Metabolic Imaging sensitivity

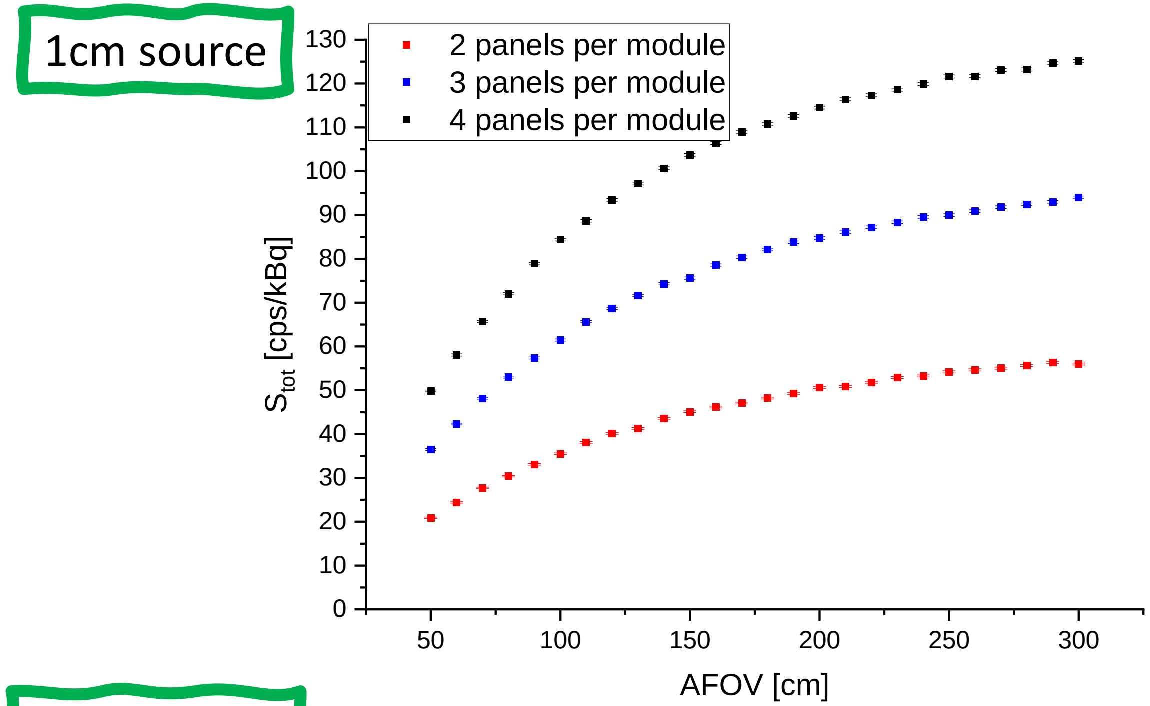
Dependence of the sensitivity on the PET scanner’s length

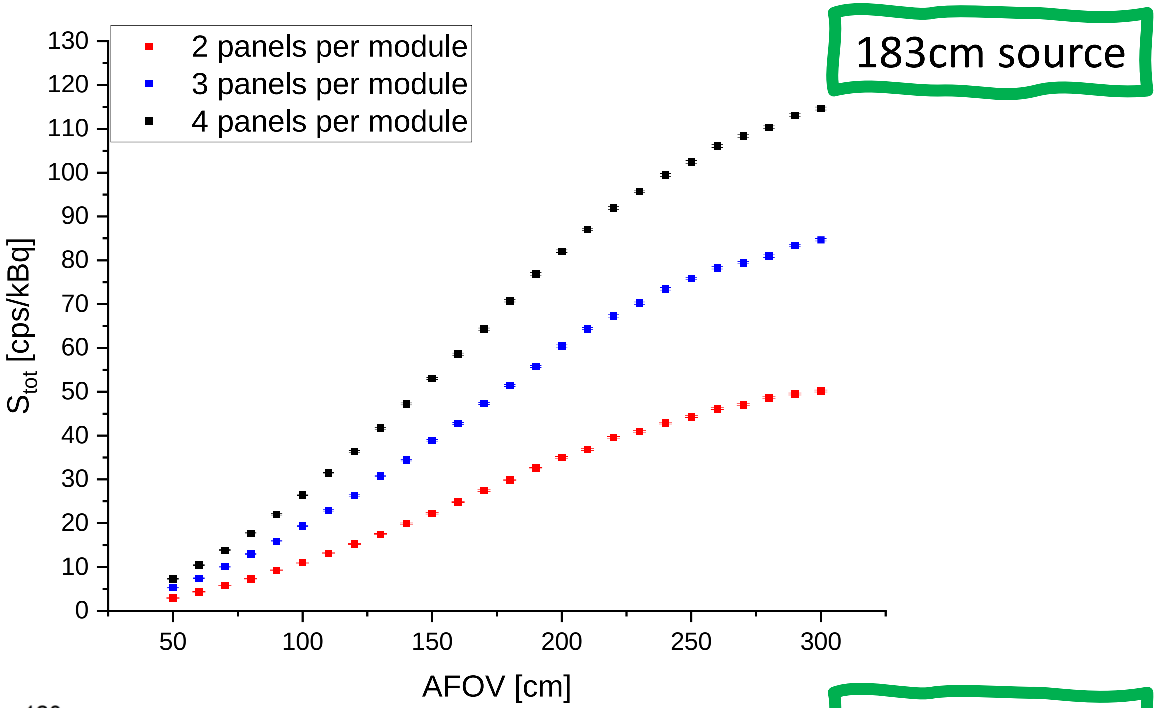


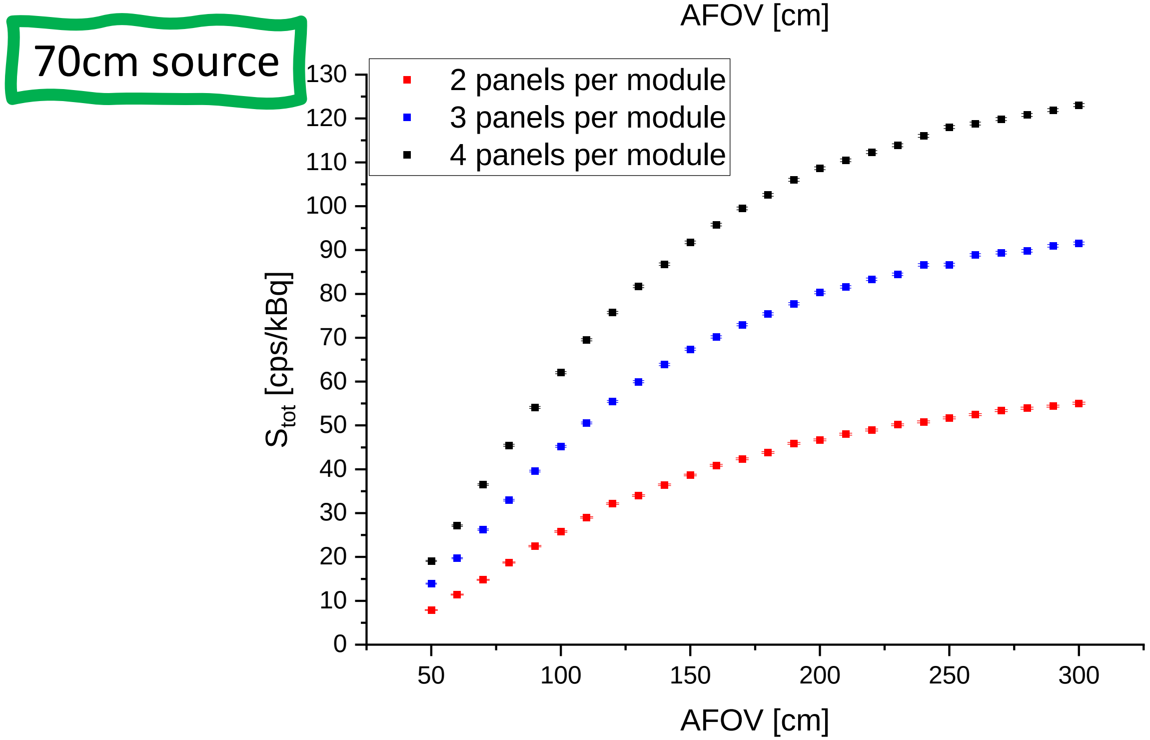
System (total) sensitivity

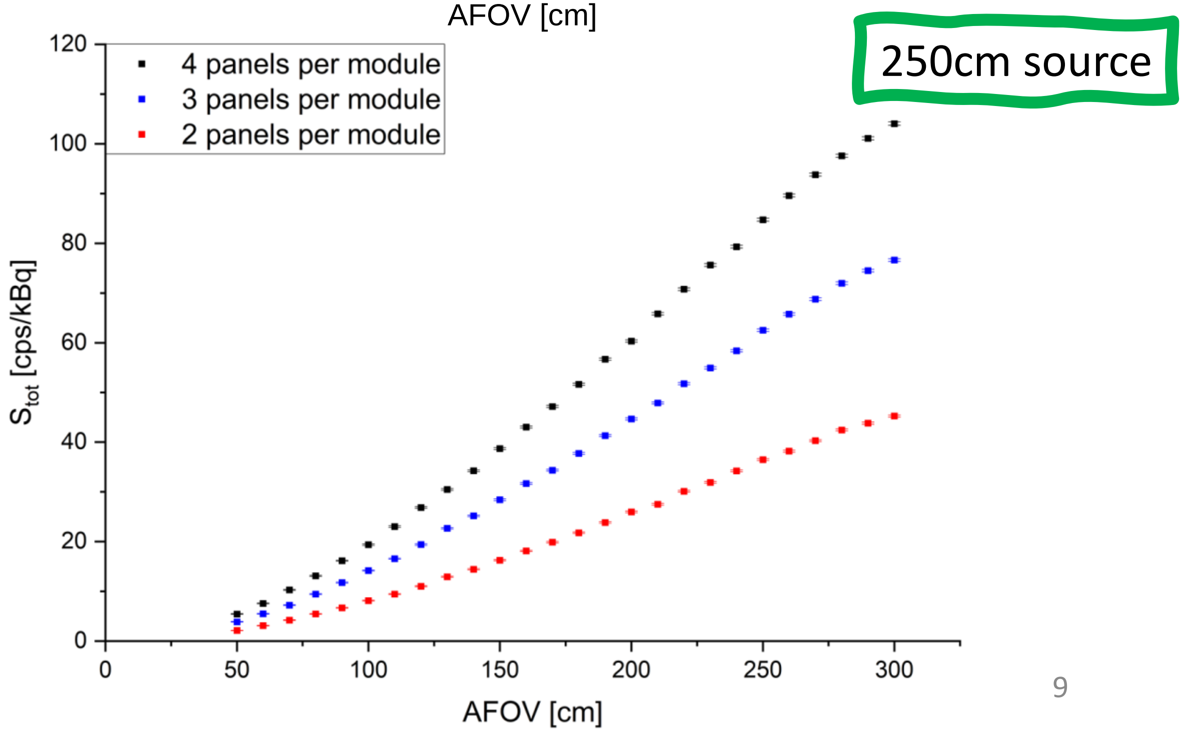


Sensitivity in the center of PET scanner


1cm source
2 panels per module
3 panels per module
4 panels per module
S_{tot} [cps/kBq]
AFOV [cm]


183cm source
2 panels per module
3 panels per module
4 panels per module
S_{tot} [cps/kBq]
AFOV [cm]


70cm source
2 panels per module
3 panels per module
4 panels per module
S_{tot} [cps/kBq]
AFOV [cm]


250cm source
4 panels per module
3 panels per module
2 panels per module
S_{tot} [cps/kBq]
AFOV [cm]

Results
Metabolic Imaging sensitivity

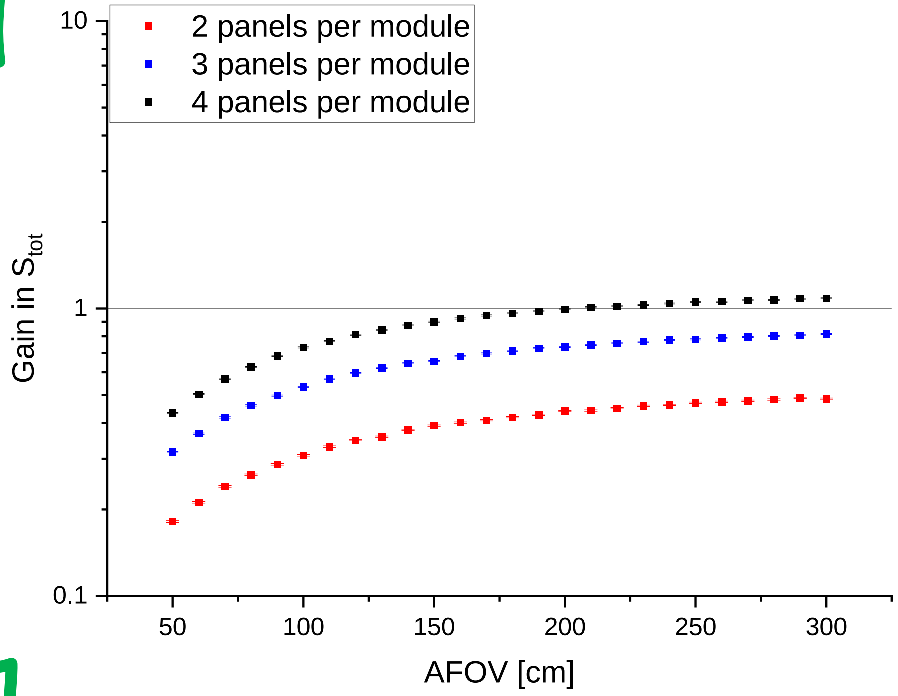
J-PET technology vs. state-of-the-art conventional short AFOV PET represented by the Biograph Vision

Gain is defined as a ratio:

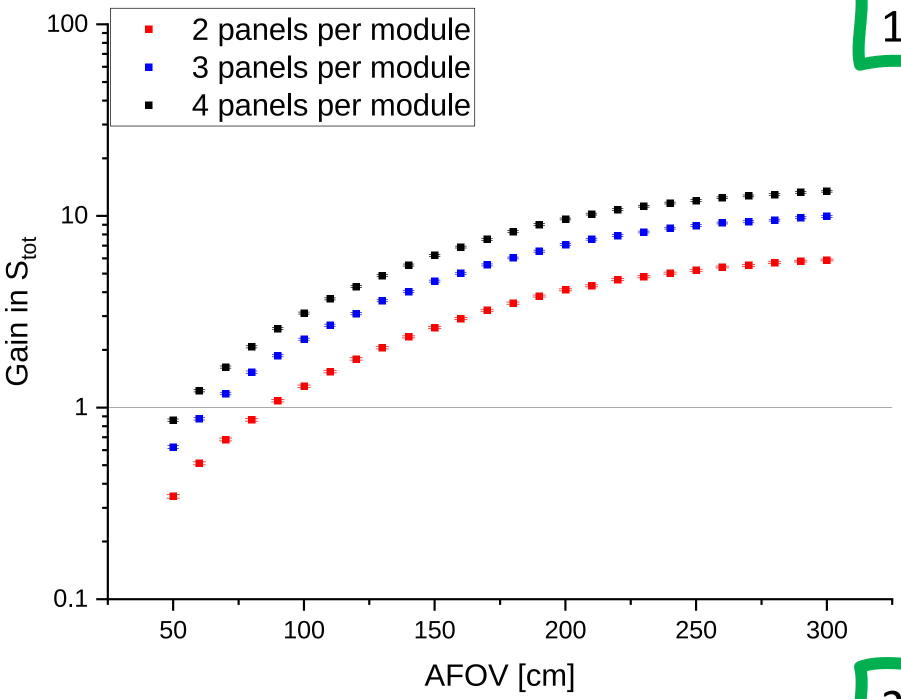
$$S_{tot}^{J-PET}(AFOV) \Big/ S_{tot}^{Biograph\,Vision}$$

Source [cm]	$S_{tot}^{Biograph\,Vision}$ [cps/kBq]
1	115.24(34)
70	22.31(15)
183	8.52(09)
250	5.81(08)

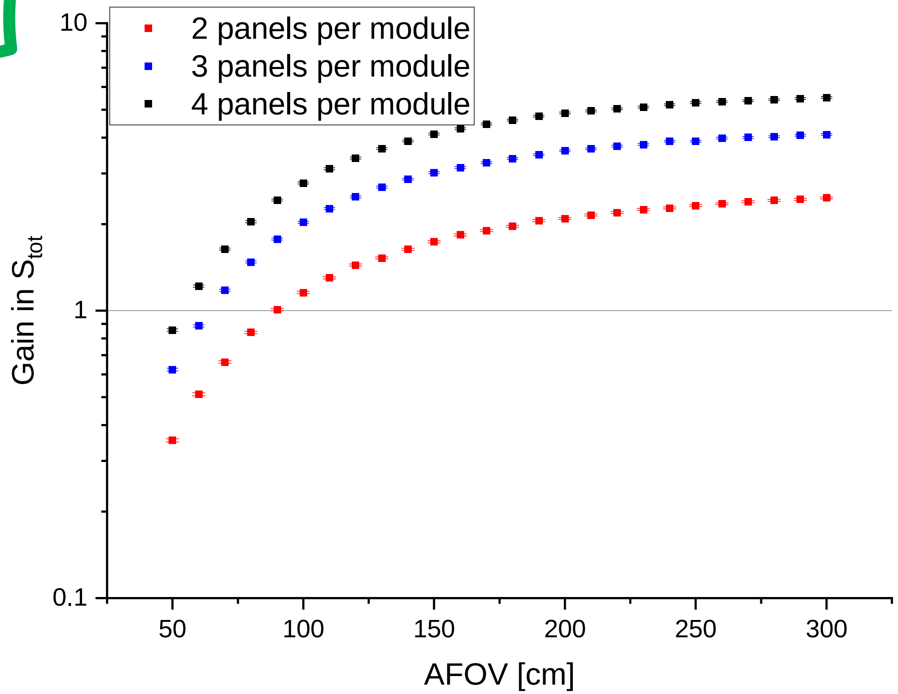
1cm source



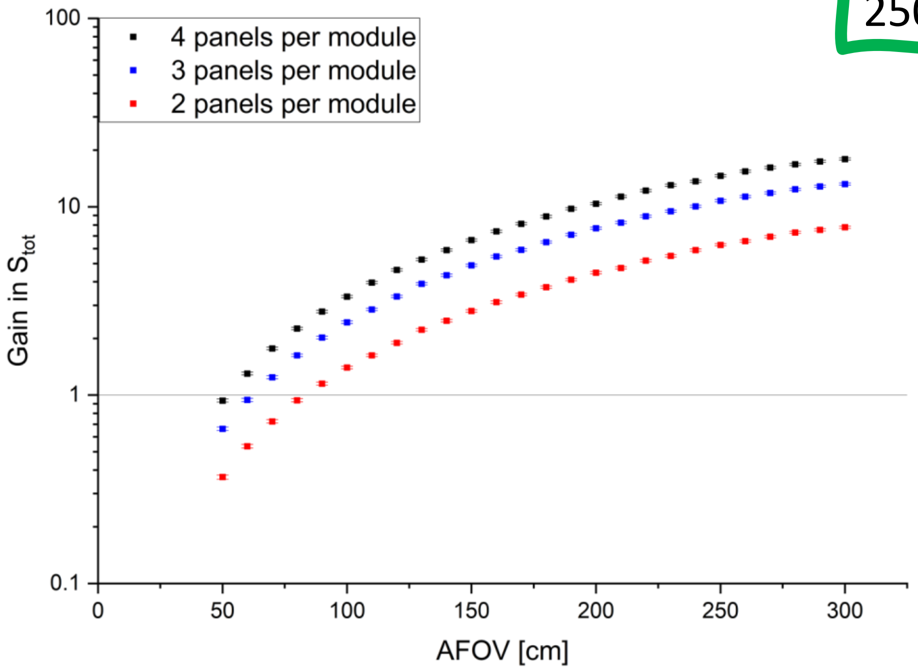
183cm source



70cm source



250cm source



Results

Positronium Imaging sensitivity

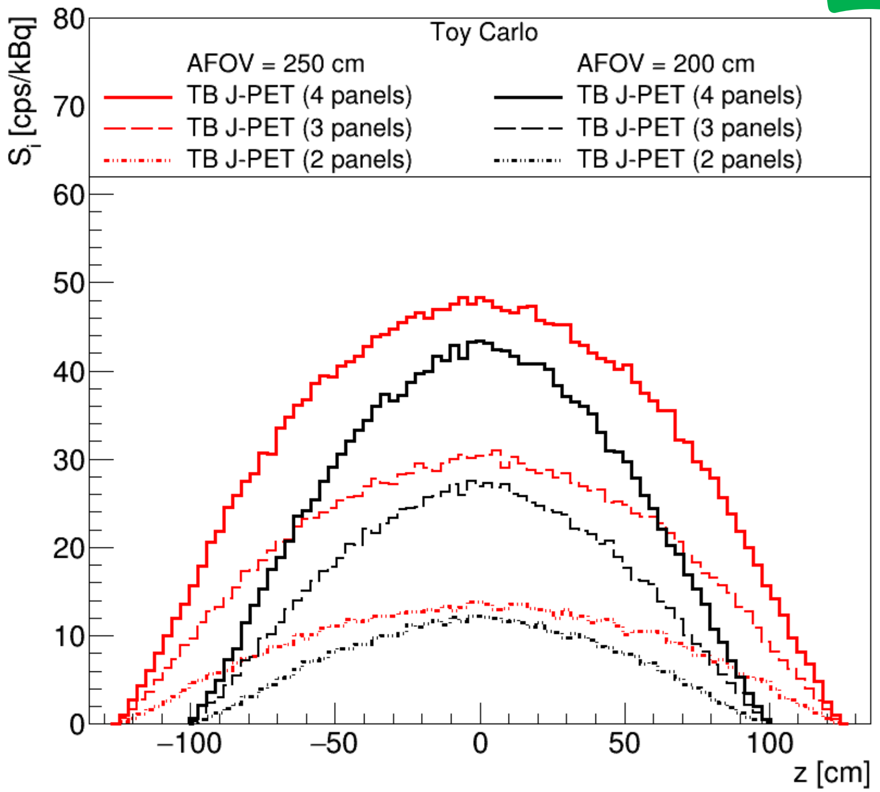
For the study of Positronium Imaging a ^{44}Sc isotope was chosen as a radioisotope. A corresponding reaction chain of β^+ decay:

$$^{44}Sc \rightarrow {}^{44}Ca^* + e^+ + \nu \rightarrow {}^{44}Ca + \gamma + e^+ + \nu$$

creates excited $^{44}Ca^*$ nucleus, which during the deexcitation process emits prompt photon of 1160 keV energy

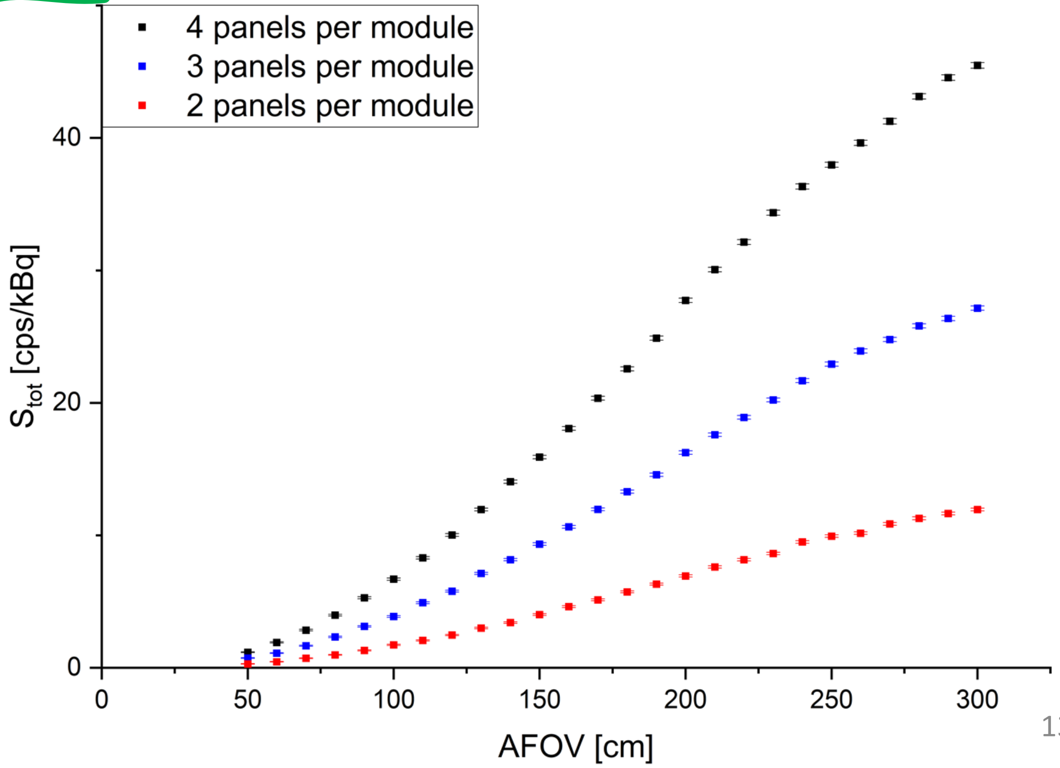
Results
Positronium Imaging sensitivity

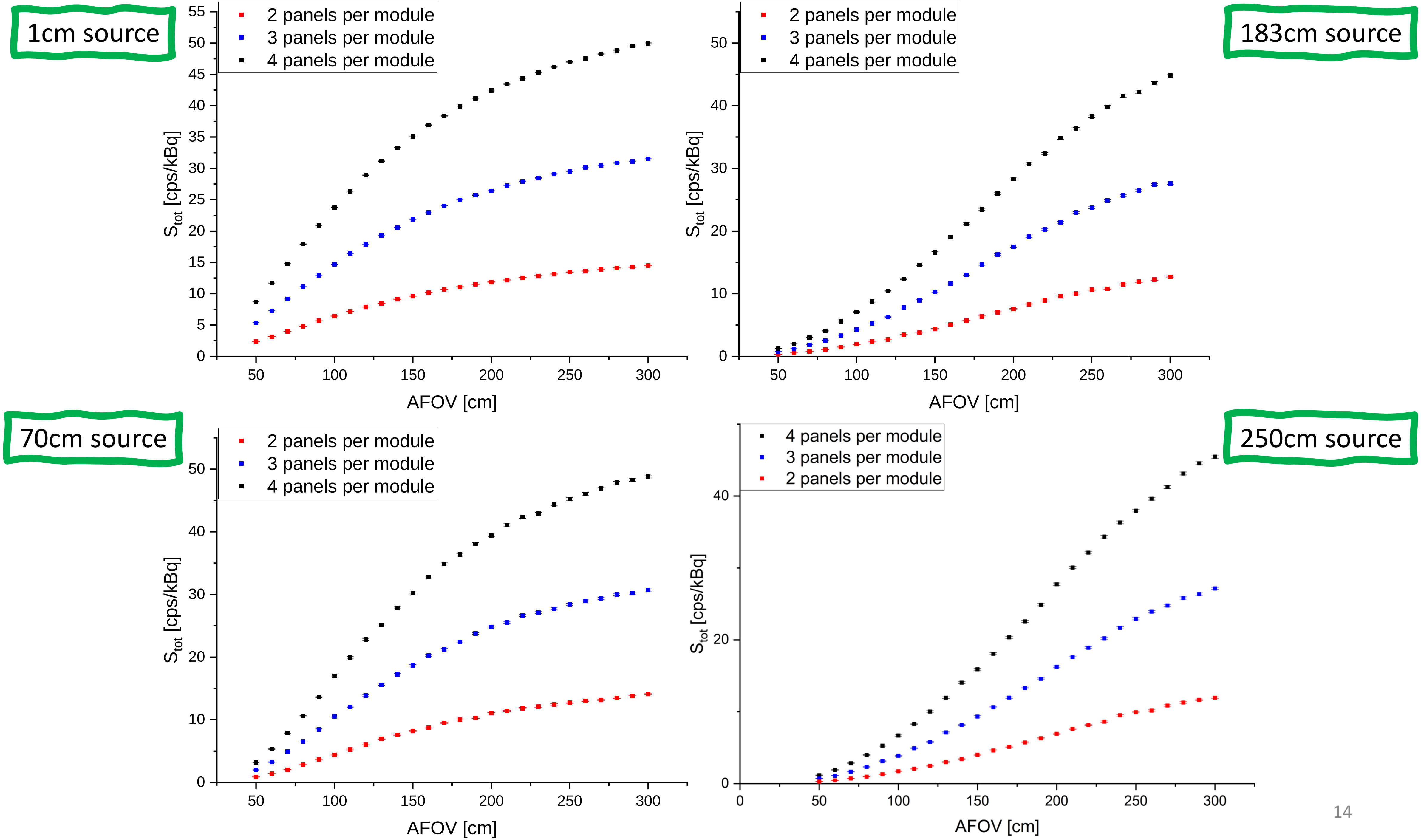
Sensitivity profiles of the 200 cm and 250 cm long (AFOV) Total Body J-PET tomographs



Dependence of the sensitivity on the PET scanner's length

250cm source

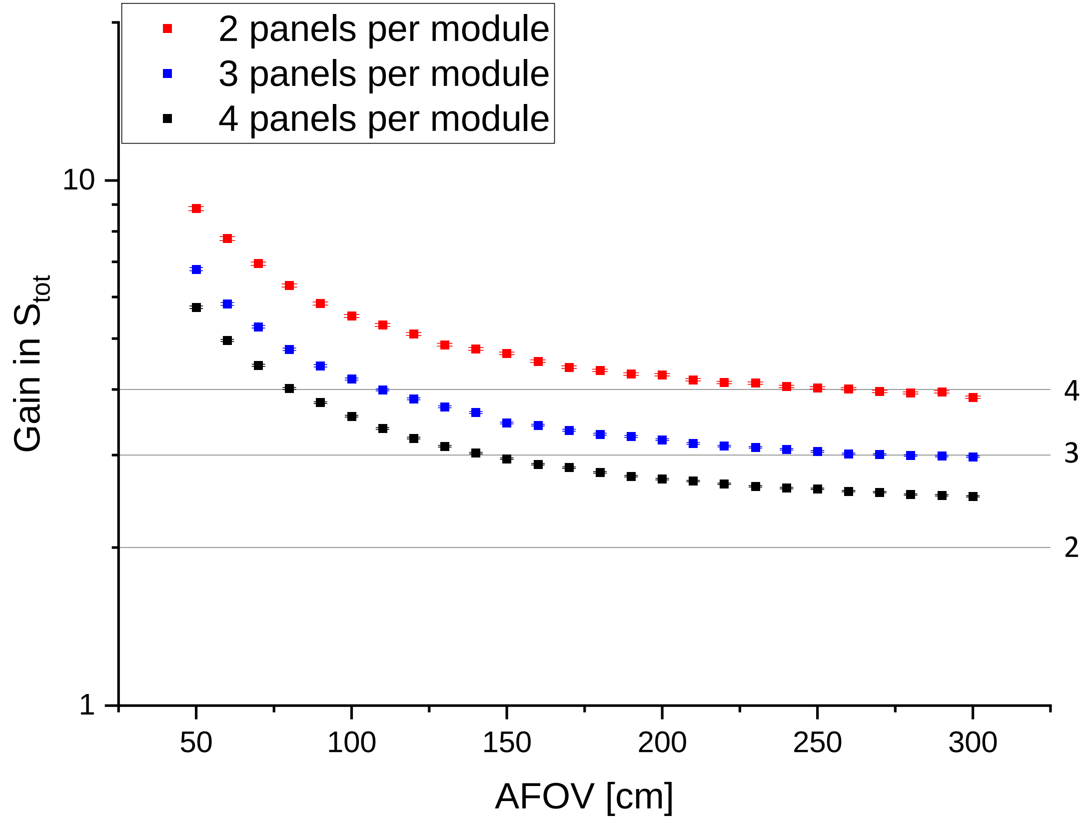



1cm source
2 panels per module
3 panels per module
4 panels per module
S_tot [cps/kBq]
AFOV [cm]
183cm source
2 panels per module
3 panels per module
4 panels per module
S_tot [cps/kBq]
AFOV [cm]
70cm source
2 panels per module
3 panels per module
4 panels per module
S_tot [cps/kBq]
AFOV [cm]
250cm source
4 panels per module
3 panels per module
2 panels per module
S_tot [cps/kBq]
AFOV [cm]

Results

Positronium Imaging sensitivity

Metabolic Imaging with J-PET technology vs. Positronium Imaging with J-PET technology



Gain is defined as a ratio:

$$S_{tot}^{Metabolic}(AFOV) \Big/ S_{tot}^{Positronium}(AFOV)$$

Results

Positronium Imaging sensitivity

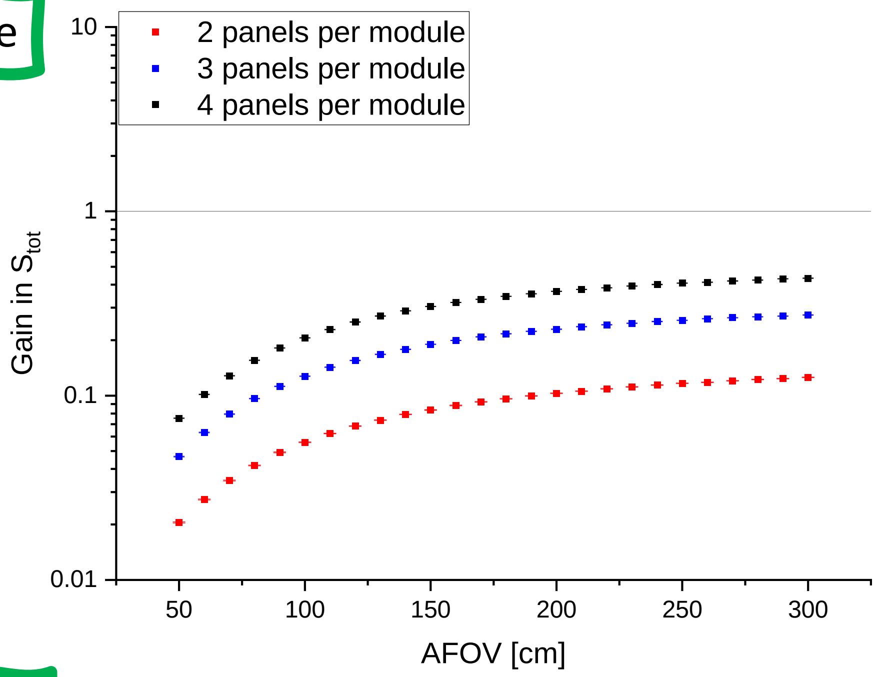
Positronium Imaging with J-PET technology vs. Metabolic Imaging with state-of-the-art conventional short AFOV PET represented by the Biograph Vision

Gain is defined as a ratio:

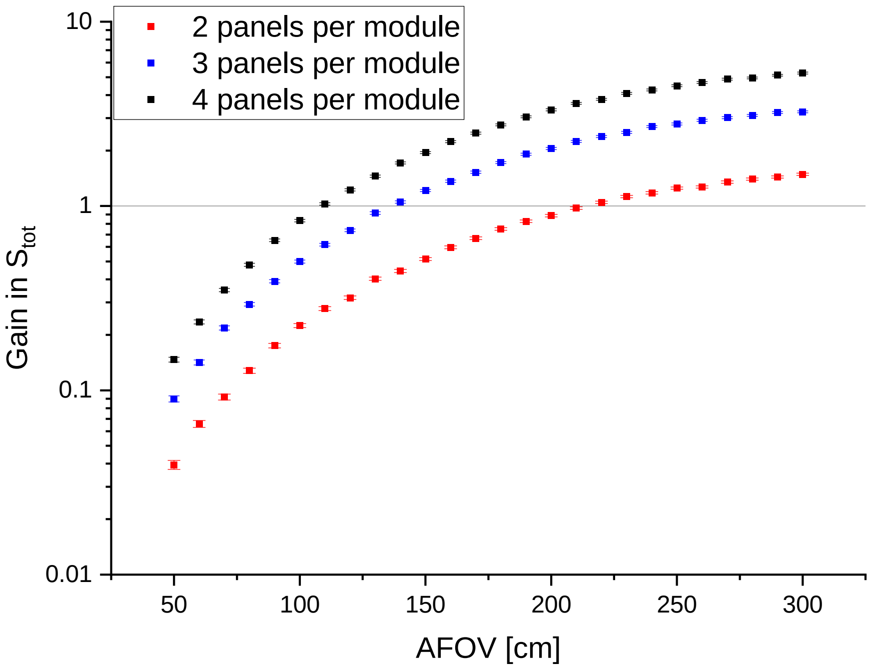
$$S_{tot}^{J-PET}(AFOV) \Big/ S_{tot}^{Biograph\,Vision}$$

Source [cm]	$S_{tot}^{Biograph\,Vision}$ [cps/kBq]
1	115.24(34)
70	22.31(15)
183	8.52(09)
250	5.81(08)

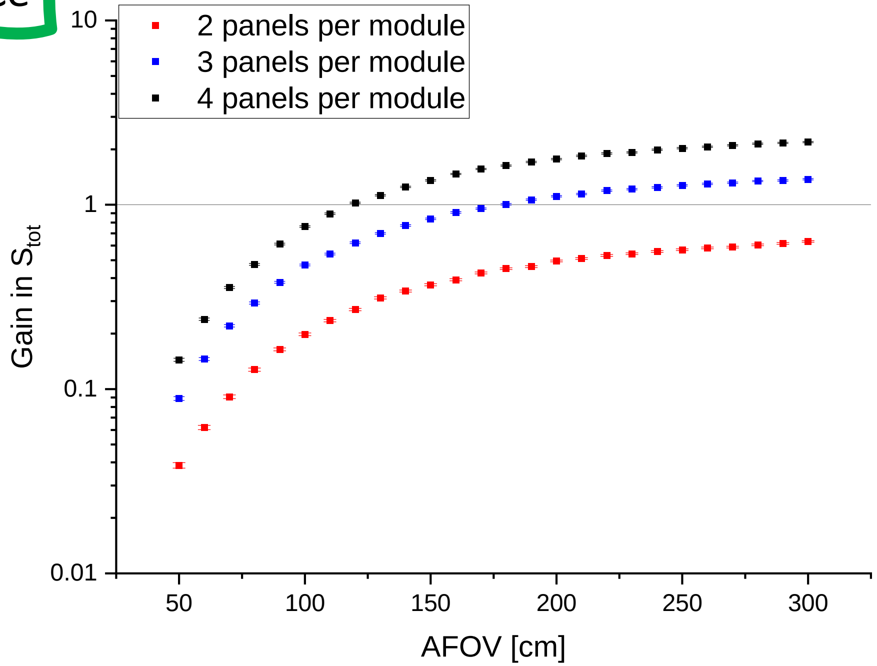
1cm source



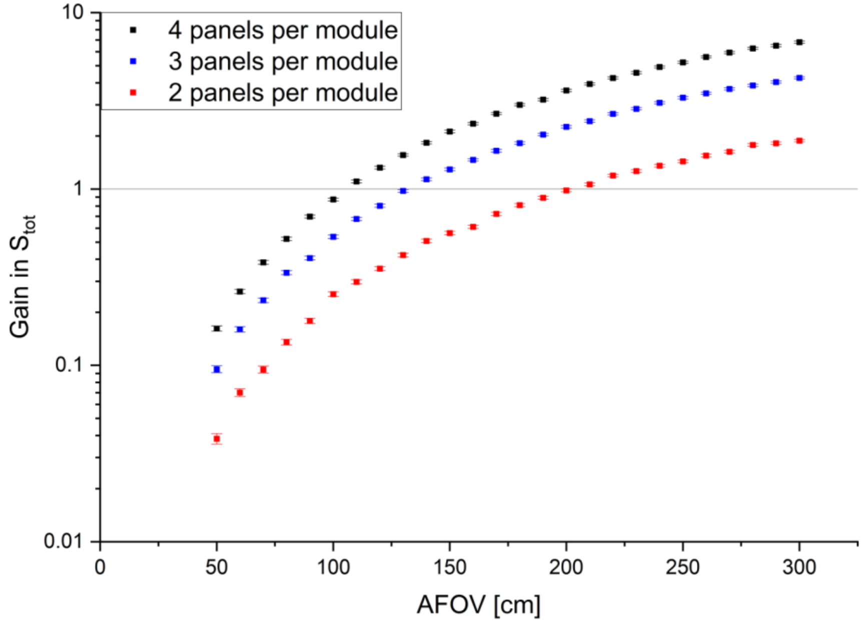
183cm source



70cm source



250cm source



Summary

Metabolic Imaging

- Sensitivity at scanner's center up to 124.1(1.0±1.1) [cps/kBq]
- Uniform simultaneous sensitivity over the patient's body
- Up to ~15 times improvement with respect to conventional short AFOV tomographs
- For NEMA up to ~5.3 times improvement over conventional system

Positronium Imaging

- Sensitivity at scanner's center up to 48.37(64±60) [cps/kBq]
- Only ~3 times worse than Metabolic Imaging
- Up to ~5 times improvement with respect to conventional short AFOV tomographs with Metabolic Imaging
- For NEMA up to ~2 times improvement over conventional system

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References

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Thank you for your attention