

Simulation studies of a brain PET insert for the total body J-PET tomograph

M Rädler^{1,2} and P Moskal^{1,2} on behalf of the J-PET Collaboration

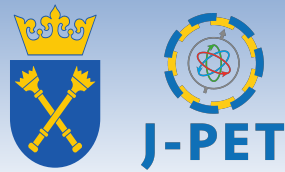
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²Centre for Theranostics, Jagiellonian University, Kopernika 40, 31-501 Kraków, Poland

5th Jagiellonian Symposium
on Advances in Particle Physics and Medicine

Kraków, June 29 – July 7 2024
Collegium Novodvorscianum

Outline



1. Total body PET & brain PET scanners
2. Design considerations
3. Monte Carlo simulations: sensitivity
4. Image reconstructions: spatial resolution
5. Conclusions

1.

Total body PET & brain PET scanners

Total body PET scanners

First large field of view scanners commercially available:

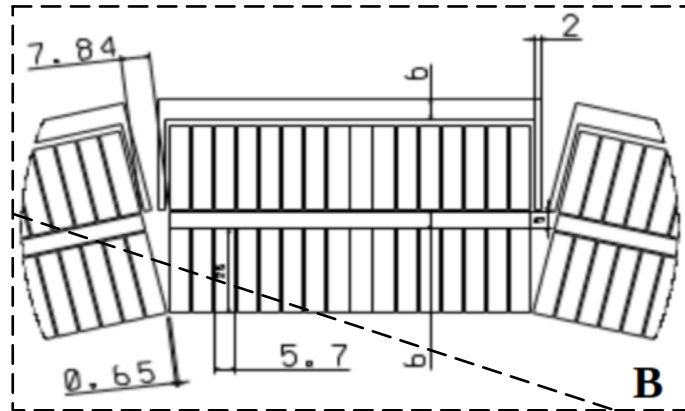


Enabling: low dose imaging, short scan times, dynamic imaging, ...

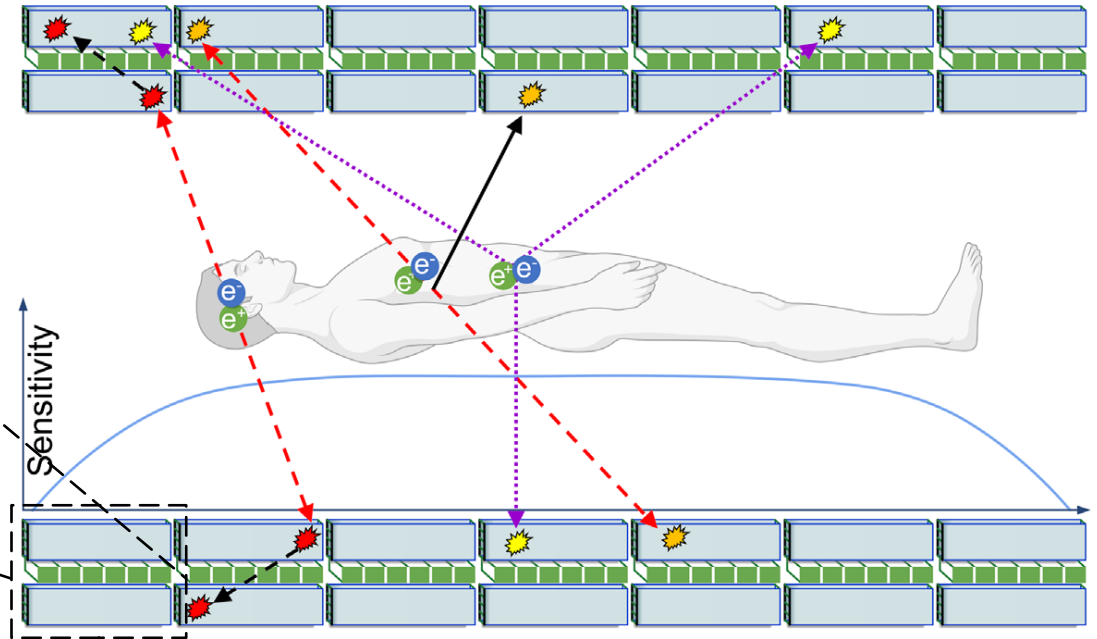
But also: very expensive ...

Total body J-PET scanner

Cost-effective plastic scintillator based total body J-PET under development at UJ



Baran et al.: "Realistic Total-Body J-PET Geometry Optimization – Monte Carlo Study" *arXiv:2212.02285* (2022)



Bass et al.: "Colloquium: Positronium physics and biomedical applications" *Rev. Mod. Phys.* (2023)

Not optimized for brain imaging ...

Rationale of brain PET

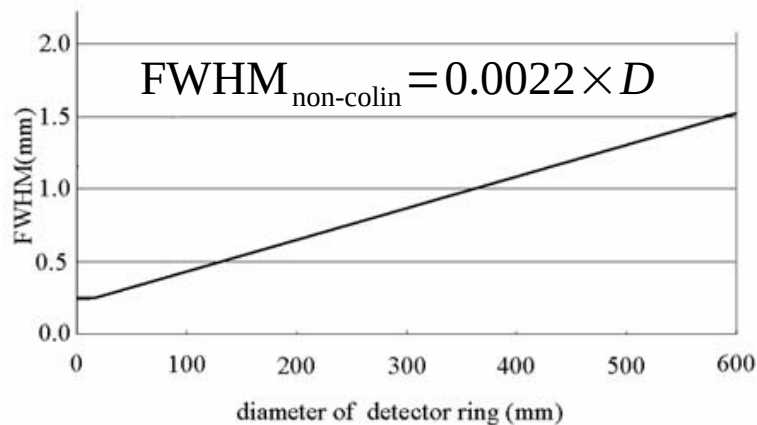
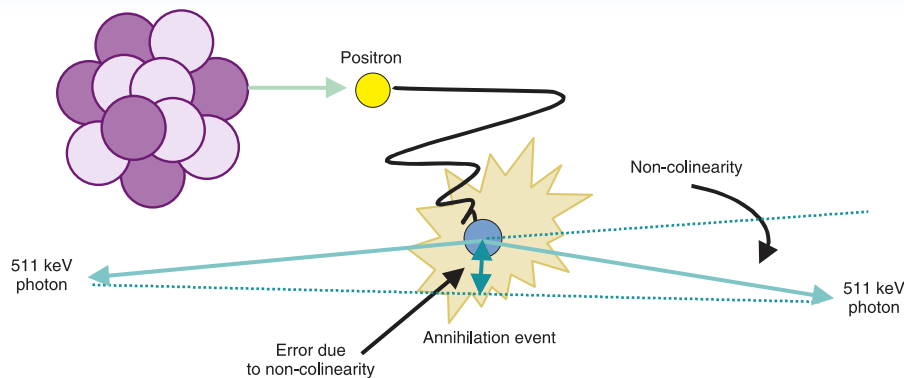
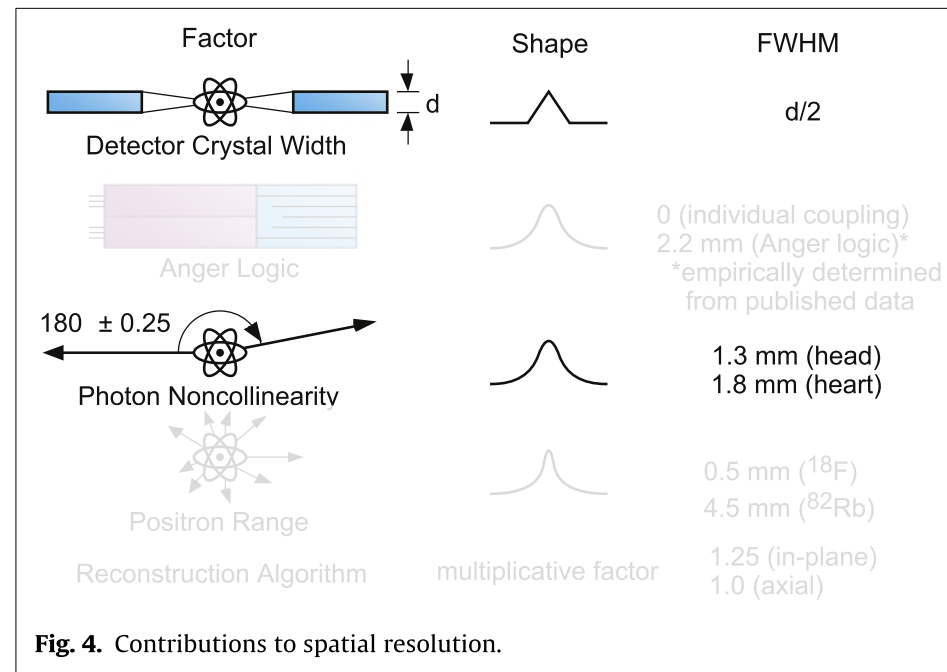


Fig. 1. Spatial resolution of PET using ^{18}F as a function of diameter of detector ring.

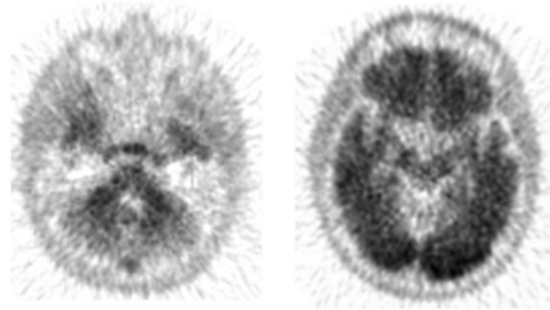


Moses. Nucl. Instrum. Methods Phys. Res. A 648 (2011)

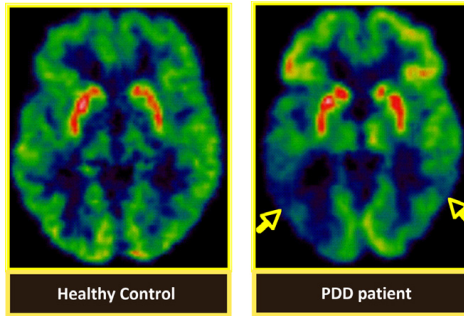
Rationale of brain PET

PET enables imaging of

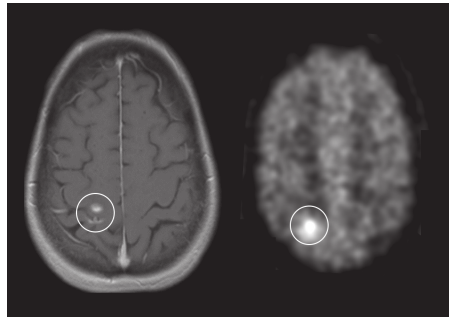
- Metabolism
- Neurochemistry
- Connectivity
- ...



Marcus et al.: "Brain PET in the Diagnosis of Alzheimer's Disease" *Clinical nuclear medicine* (2014)

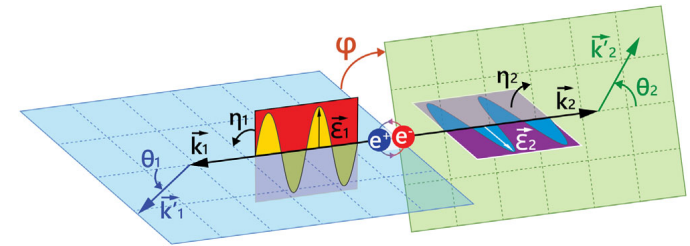
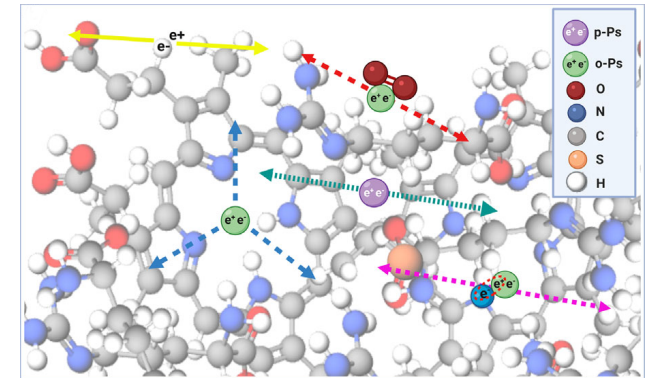


Pavese: "PET studies in Parkinson's disease motor and cognitive dysfunction" *Parkinsonism & related disorders* (2012)



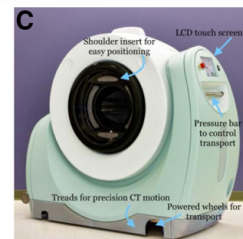
Galldiks et al.: "PET imaging in patients with brain metastasis – "report of the RANO/PET group" *Neuro-Oncology* (2019)

Novel contrast mechanisms based on positronium imaging:

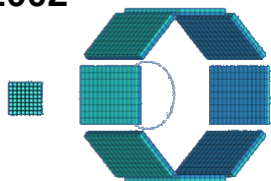


Bass et al.: "Colloquium: Positronium physics and biomedical applications" *Rev. Mod. Phys.* (2023)

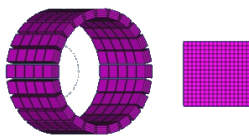
Horizontal brain PET scanners



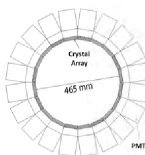
2002



2006



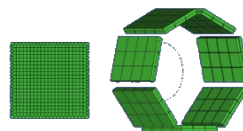
2013



2015



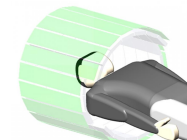
2016



2022



2024



	HRRT	jPET-D4	Rainbow VHD	CerePET	NeuroPET/CT	BresTome	NX
Crystal	LSO:Ce	GSO	LYSO	LYSO	LYSO	LSGO	LYSO
Layers	2	4	1	1	2	1	1
Sens.	1.04%	11%	-	-	~1%	7-8%	4.6%
Res.	2.5 mm	< 3 mm	~ 3 mm	2.1 mm	~ 3 mm	~ 2.5 mm	< 2 mm

Catana: "Development of dedicated brain PET imaging devices: recent advances and future perspectives" *Journal of Nuclear Medicine* (2019)

Majewski: "Perspectives of brain imaging with PET systems" *Bio-Algorithms and Med-Systems* (2021)

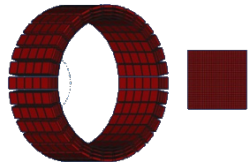
Allen et al.: "New Horizons on Brain PET Instrumentation" *PET clinics* (2024)

July 5th 2024

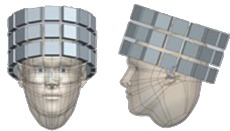
Upright brain PET scanners



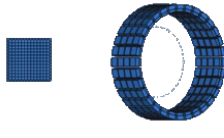
2017



2019



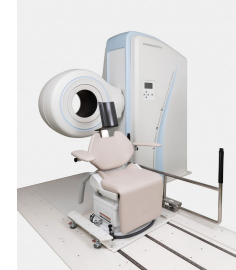
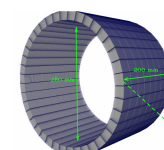
2021



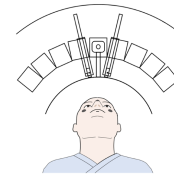
2022



2022



2022



2023



Brain PET

CareMiBrain

BBX-PET

NeuroLF

4D-PET

HIAS-29000

Pharos

Crystal

LYSO

LYSO

LYSO

LGSO/LYSO

LYSO

LFS

Lut.-based

Layers

4

1

1

2

1

1

1

Sens.

2.14%

10%

2.59%

3.5 %

16.2%

~2.2%

6%

Res.

2 mm

~ 1.5 mm

~ 2.6 mm

< 2 mm

~ 1 mm

~ 2 mm

< 2 mm

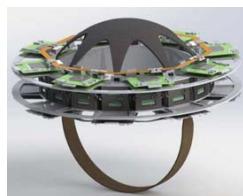
Catana: "Development of dedicated brain PET imaging devices: recent advances and future perspectives" *Journal of Nuclear Medicine* (2019)

Majewski: "Perspectives of brain imaging with PET systems" *Bio-Algorithms and Med-Systems* (2021)

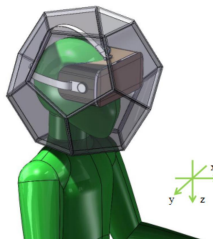
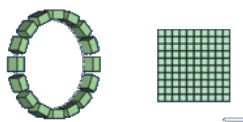
Allen et al.: "New Horizons on Brain PET Instrumentation" *PET clinics* (2024)

July 5th 2024

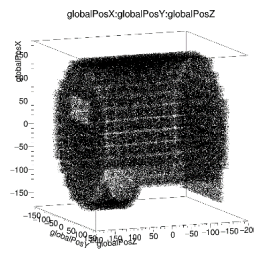
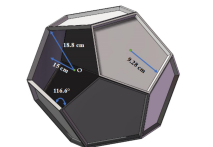
Unconv. brain PET scanners



2017



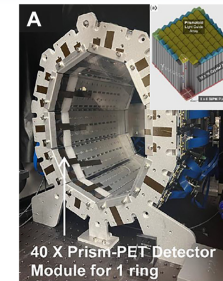
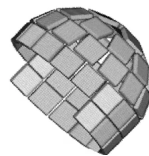
2018



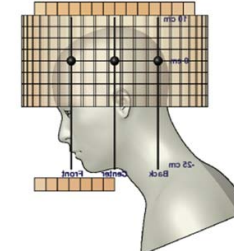
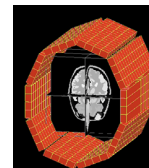
2020



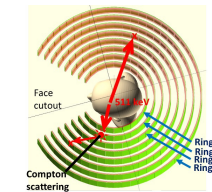
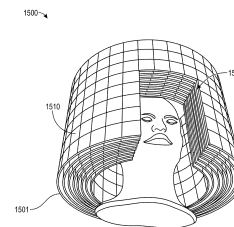
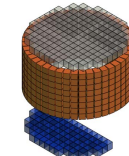
2022



2022



2022



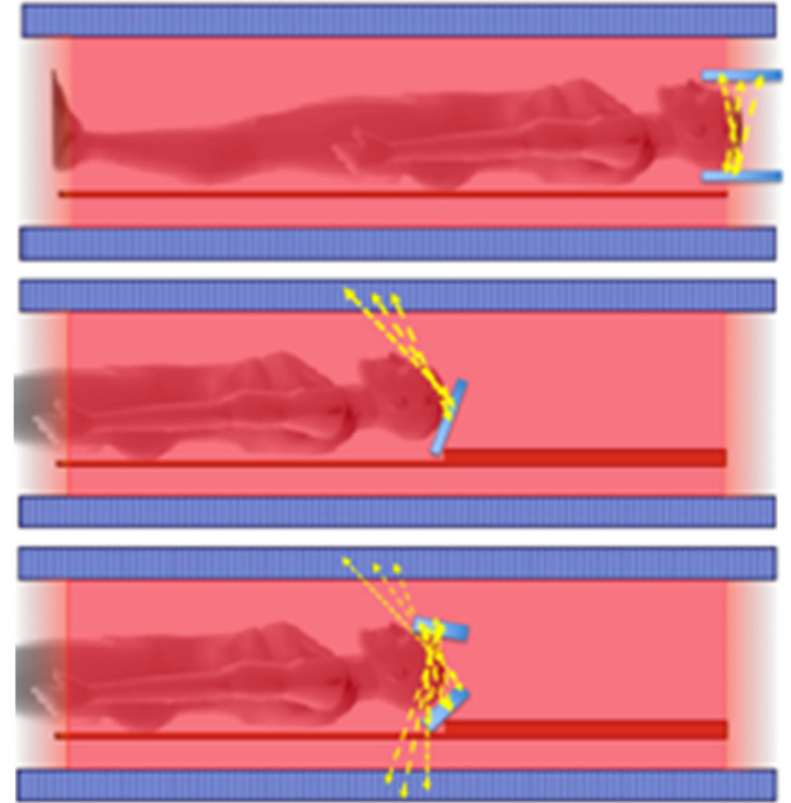
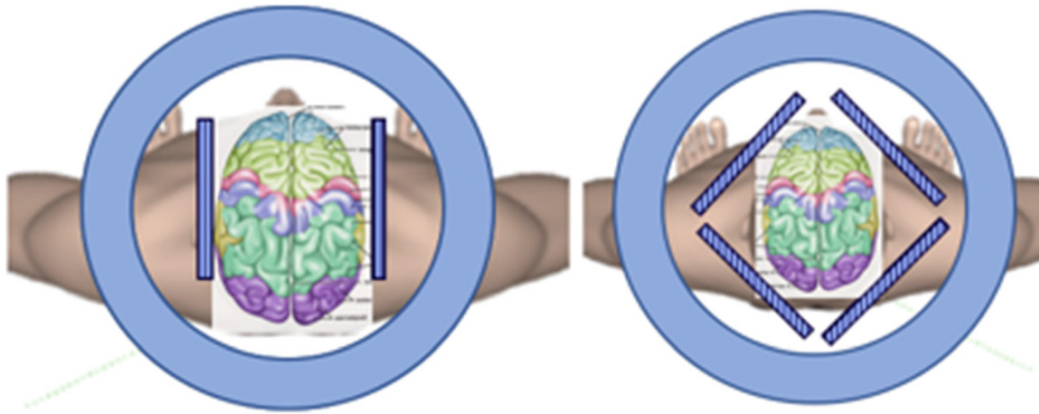
	Mind-tracker	Dodecahedron	Head shaped	VRAIN	Prism PET	Top hat PET	Br. PET Expl.
Crystal	LYSO	LYSO	LYSO	LFS	LYSO	LYSO:Ce	LYSO
Layers	1	1	3	4	1	1	8
Sens.	-	6.15%	16%	2.5%	5.2%	17%	~24%
Res.	1.5-3 mm	1.98 mm	1.5 mm	2.2 mm	1.35 mm	~ 3 mm	0.9 mm

2.

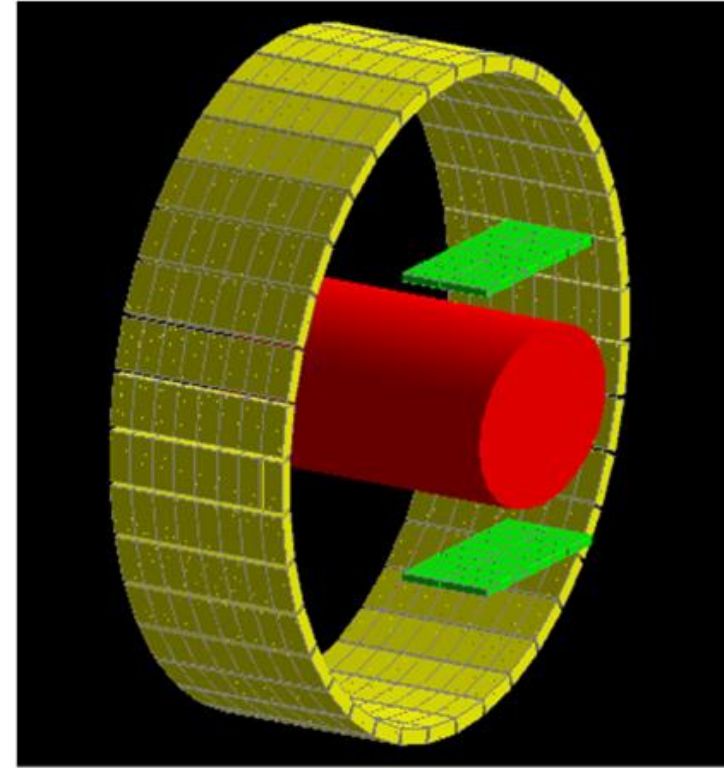
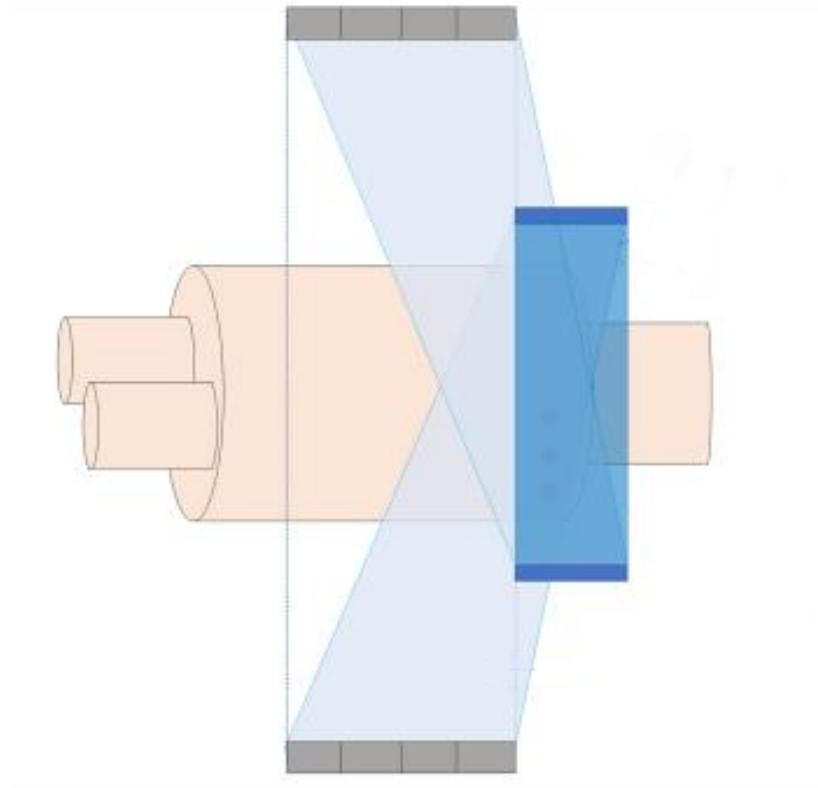
Design considerations

Magnification inserts

“[...] hybrid systems using a moderate-resolution **total body scanner** (such as J-PET) **combined with** a very high performing **brain imager** could be a very attractive approach.”



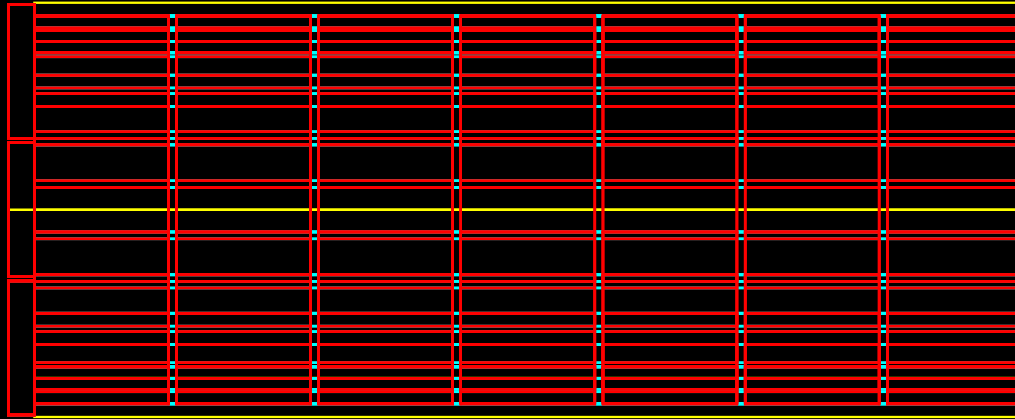
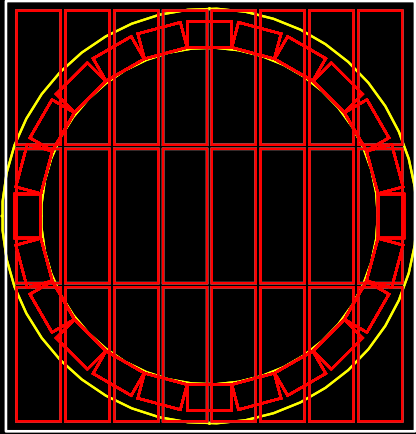
Magnification “outsert”



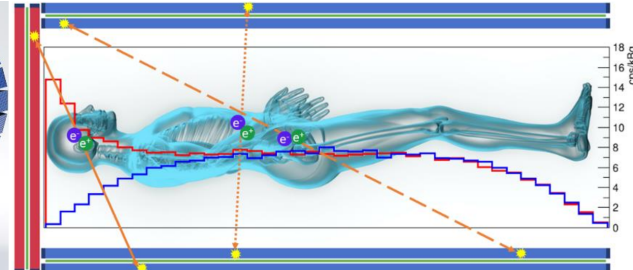
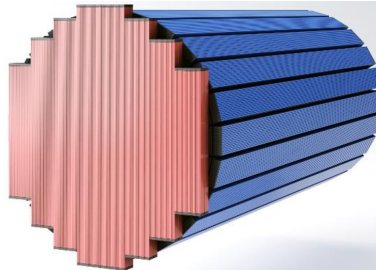
Frontal detector



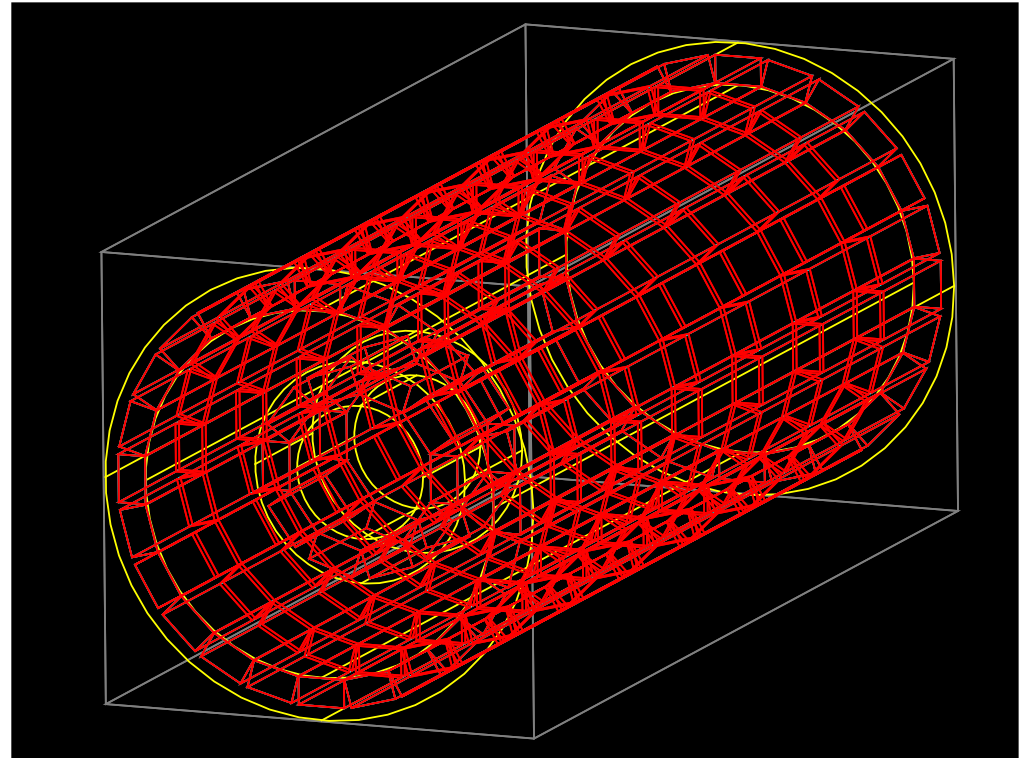
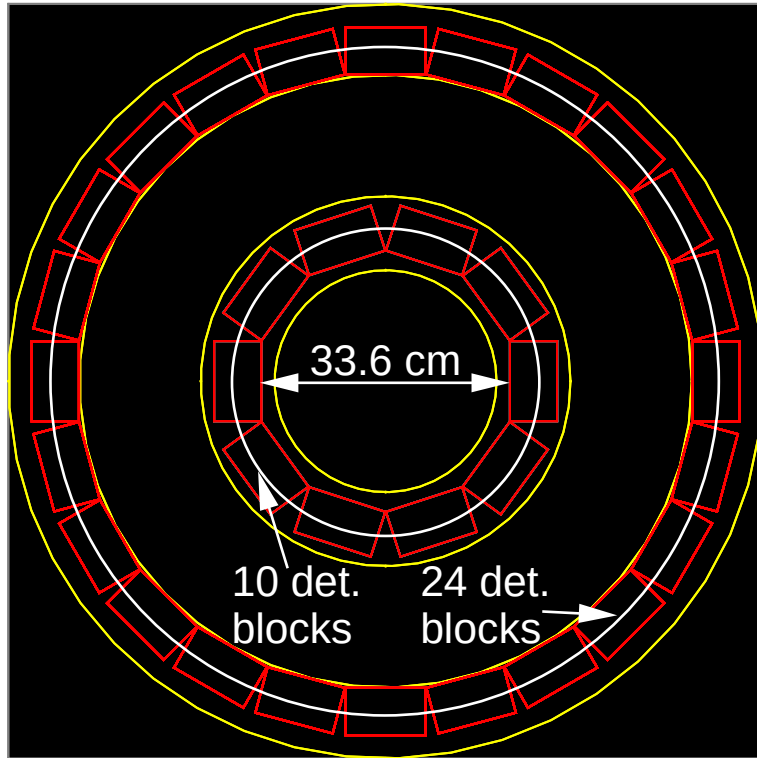
24 det.
blocks



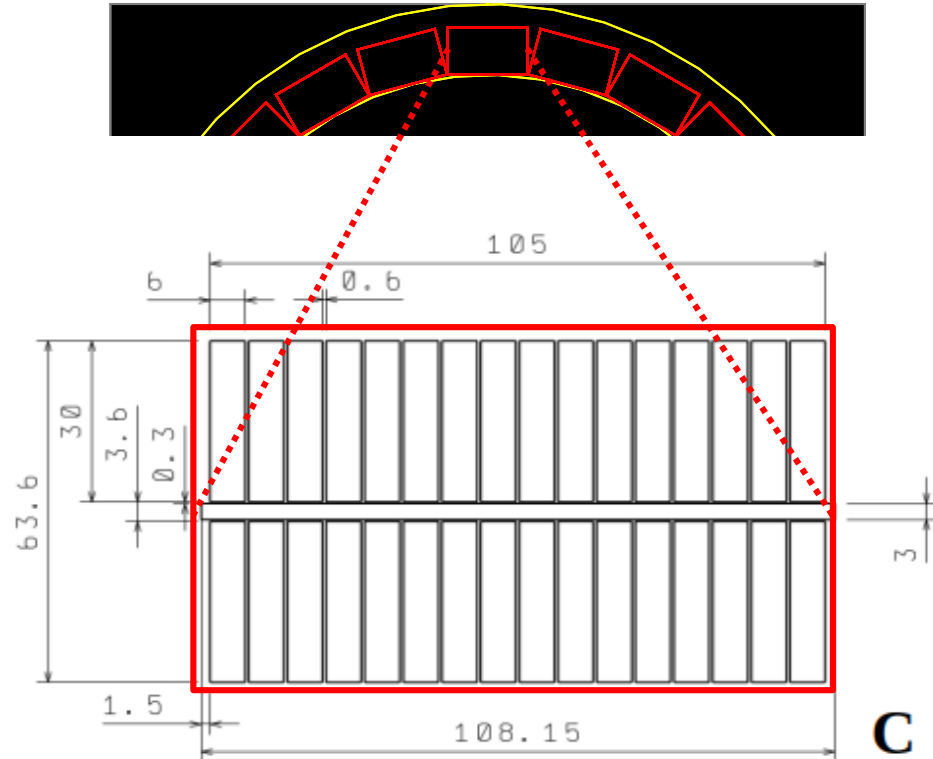
Initial concept:



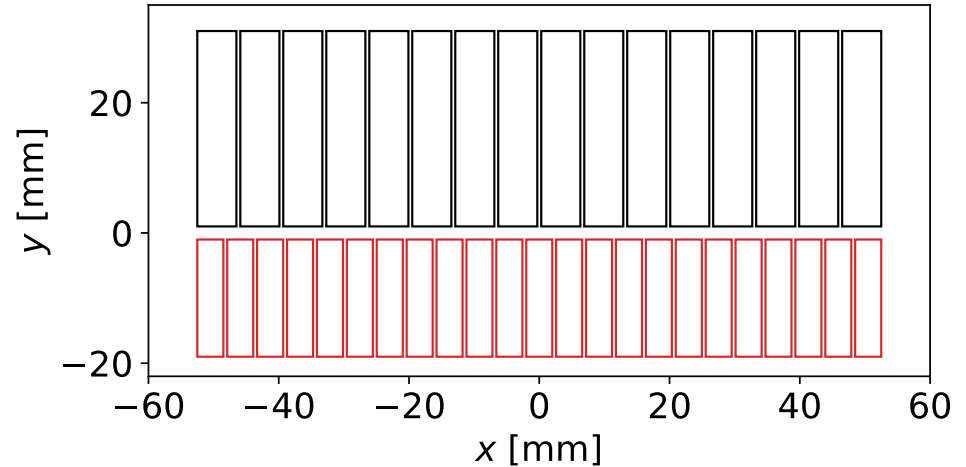
Brain insert



Brain insert variations



16 x (6 x 30 x 330 mm³)
Inactive area: 8.6%



23 x (4 x 18 x 330 mm³)
Inactive area: 12.4%

3.

Monte Carlo simulations: sensitivity

GATE v9.3 simulations

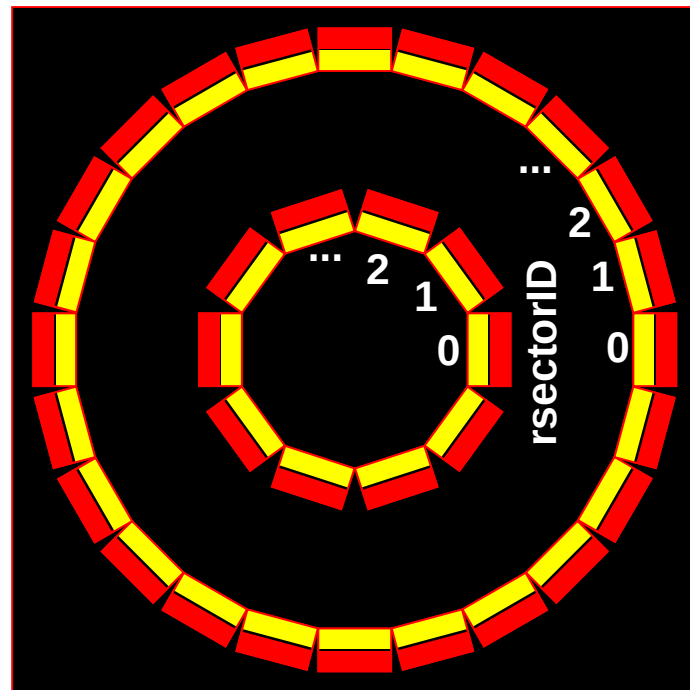
New GATE Digitizer Unit for versions post v9.3

Olga Kochebina^{1*}, Daniel A. B. Bonifacio^{2,3},
Georgios Konstantinou⁴, Adrien Paillet¹,
Christian M. Pommranz^{5,6}, Gašper Razdevšek⁷,
Viatcheslav Sharyy^{1,8}, Dominique Yvon^{1,8} and Sebastien Jan¹

“[...] possibility of GATE v9.3 to
**construct Coincidences coming from
several different GATE Systems.**”

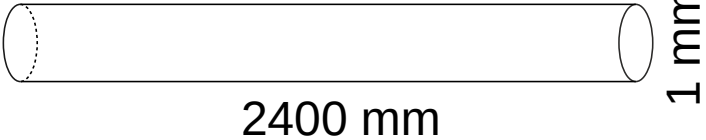
Adjustments

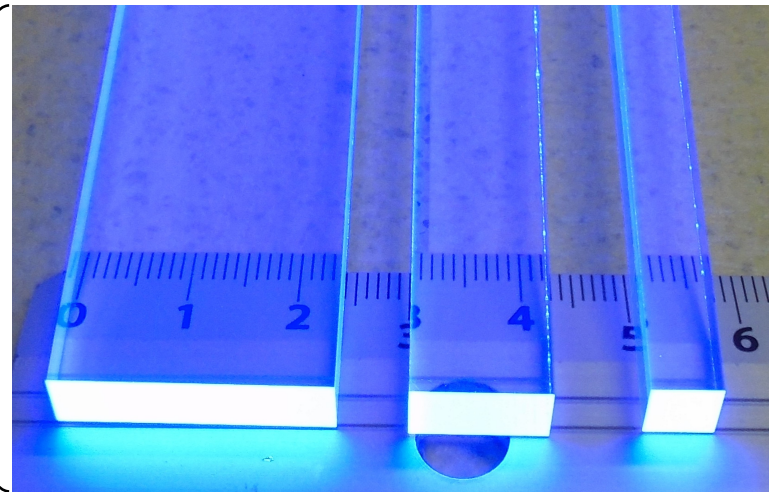
- Compton counts
- Minimum r-sector difference



GATE v9.3 simulations

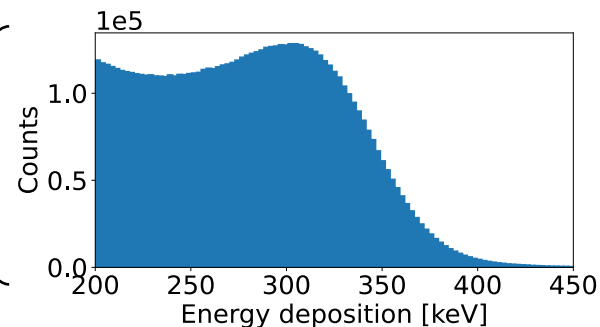
Simulation

Physics list	emlivermore_polar
Scintillator material	EJ-230
Source volume	
Source type	511 keV back-to-back photons
Source activity	1 MBq
Scan time	100 s

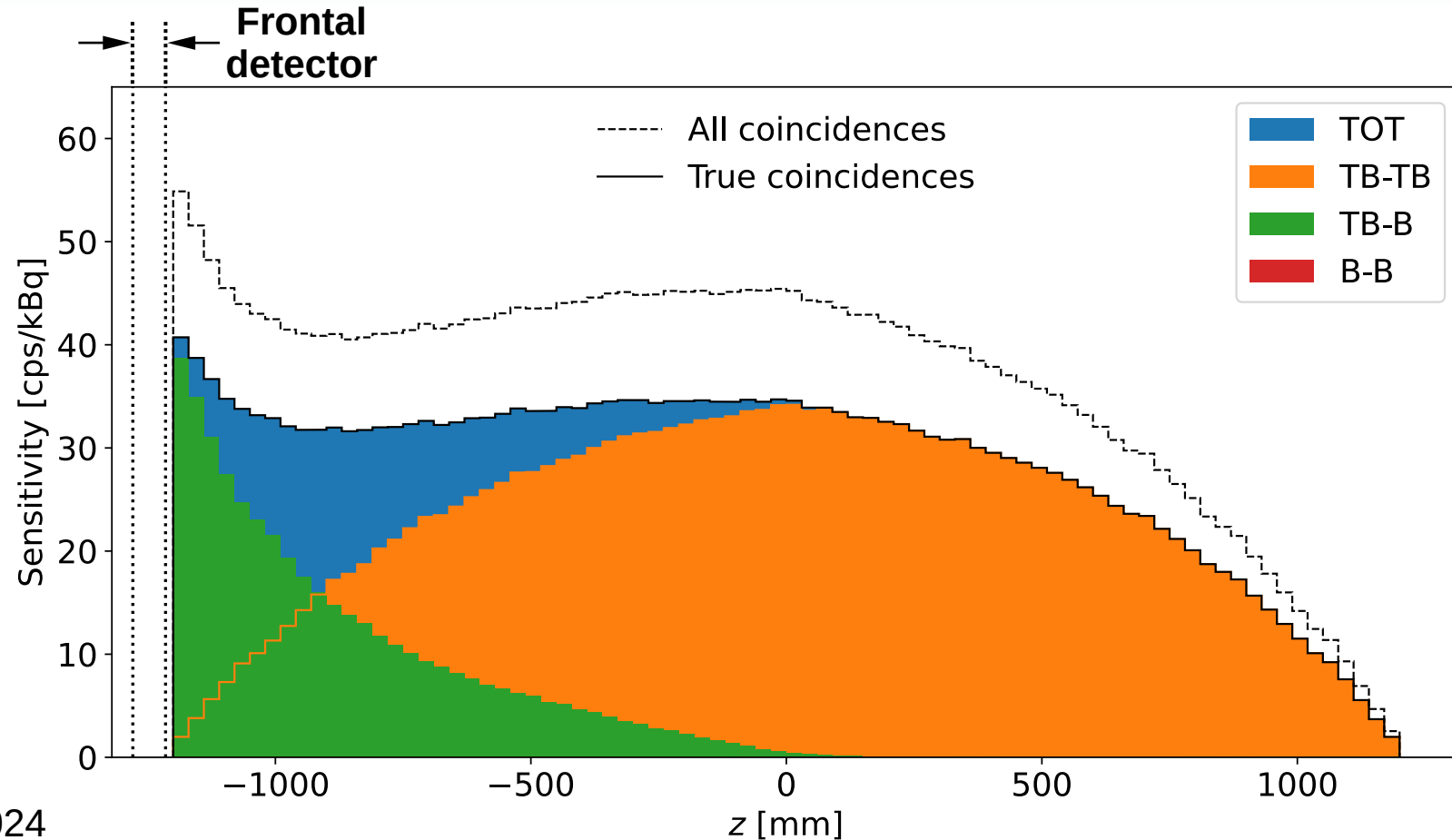


Event selection

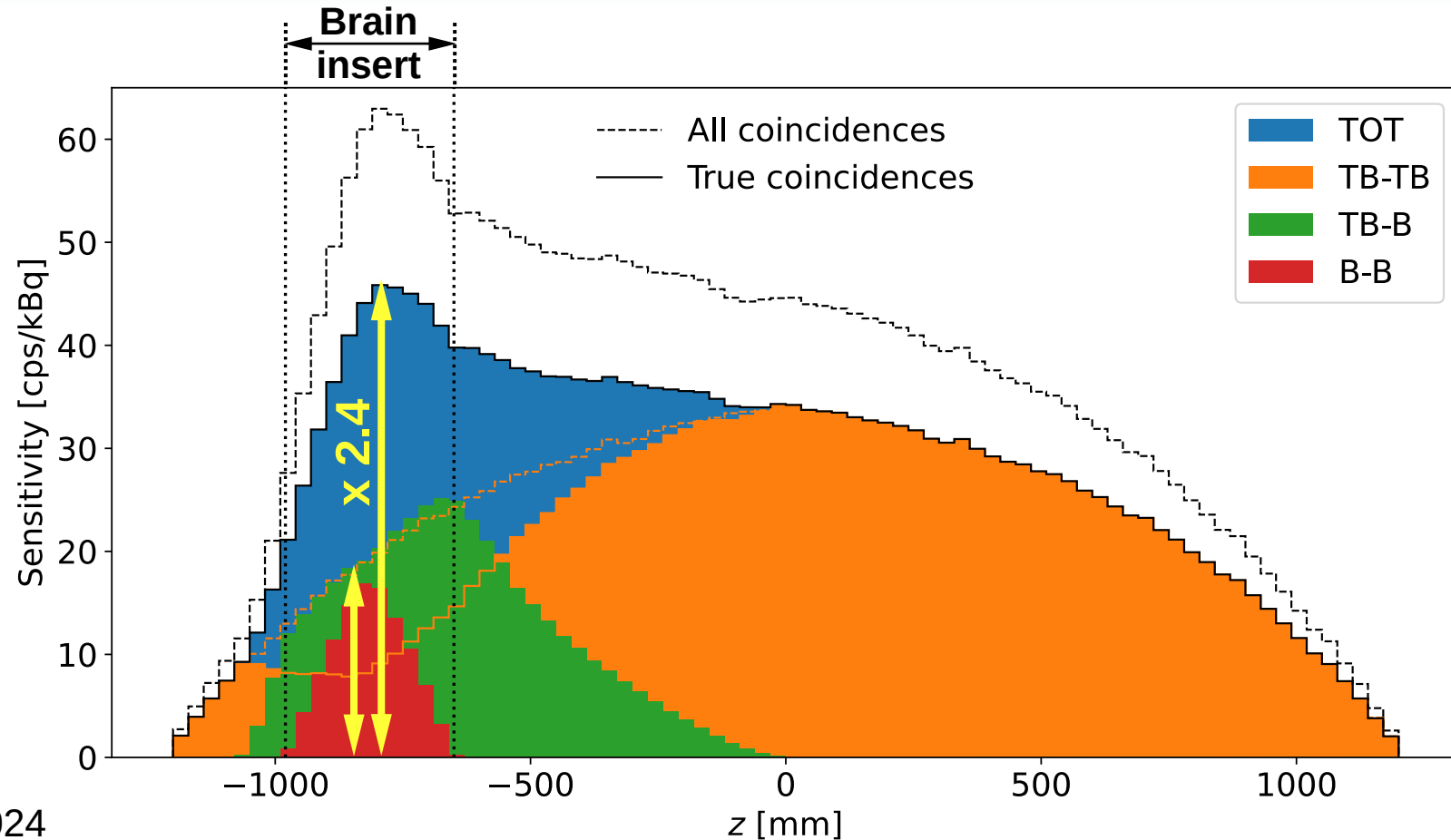
Lower threshold	200 keV
Coincidence window	3 ns



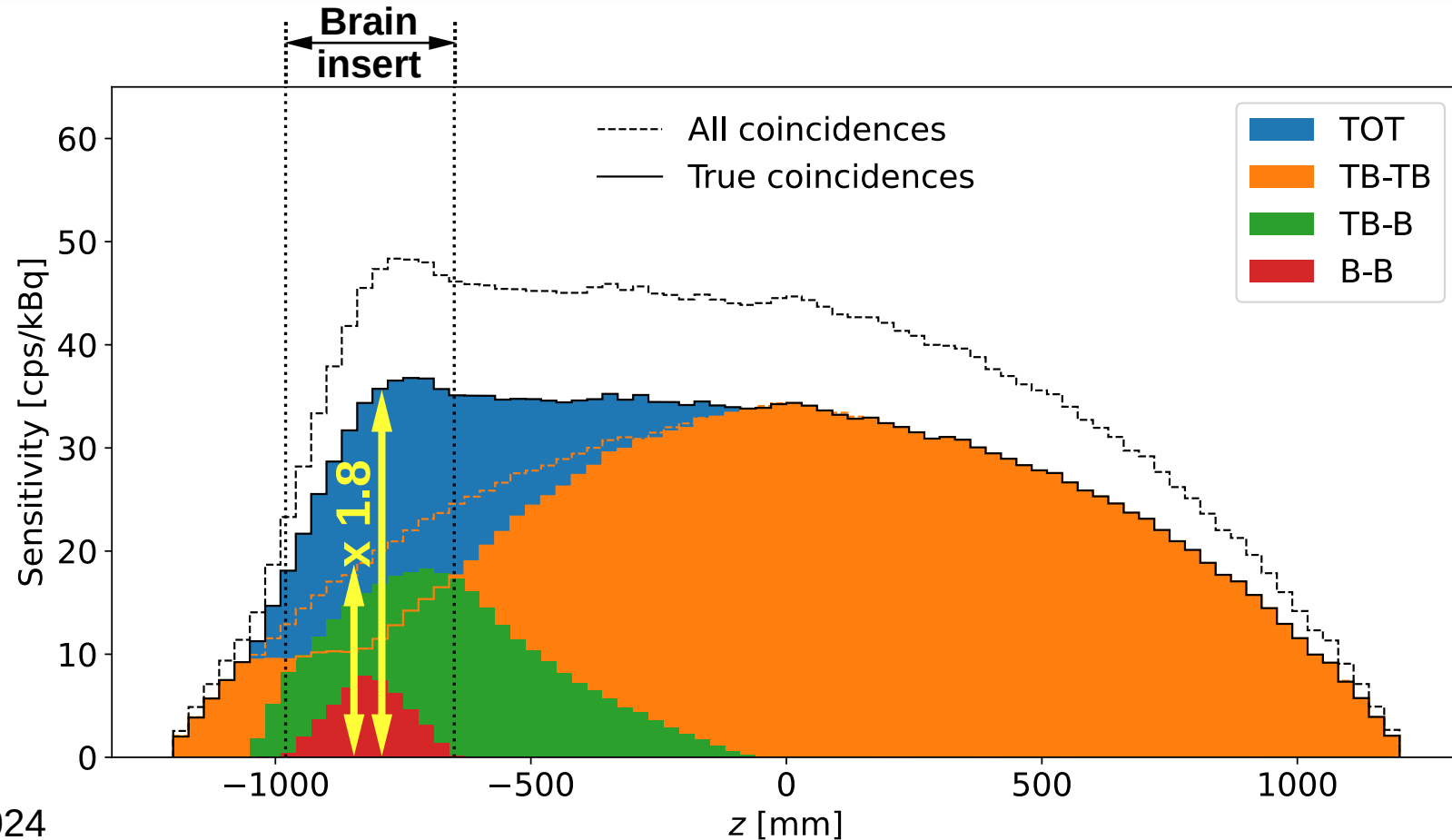
Sensitivity: Frontal detector



Sensitivity: TB & Brain insert

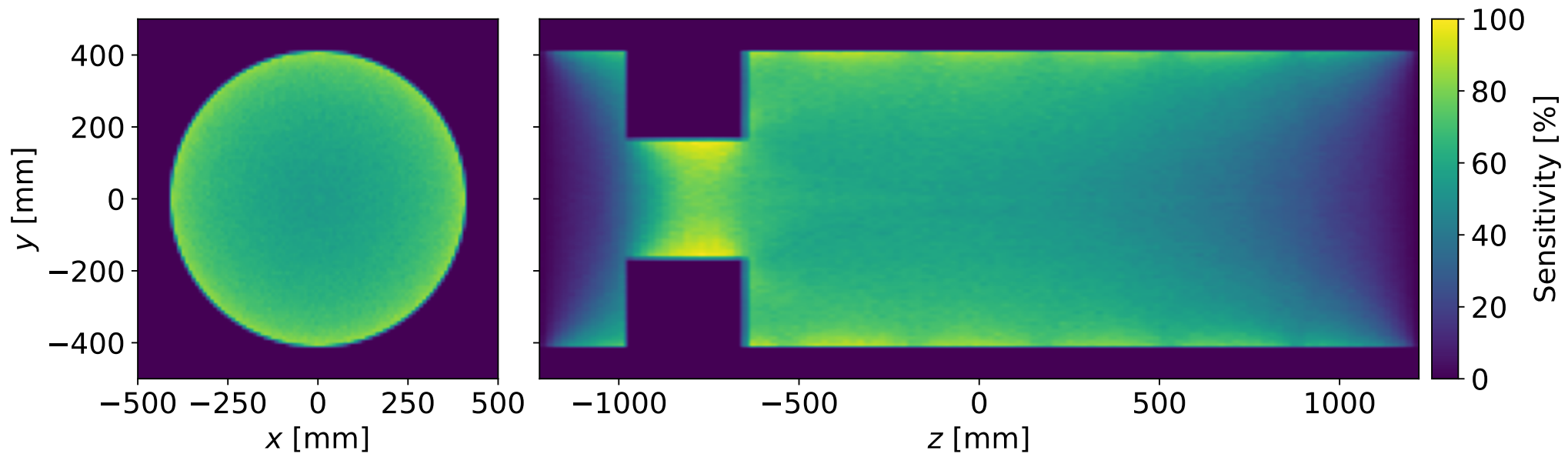


Sensitivity: TB & Brain insert



Complete sensitivity map

for the Brain insert



Resolution: 10 x 10 x 20 mm³

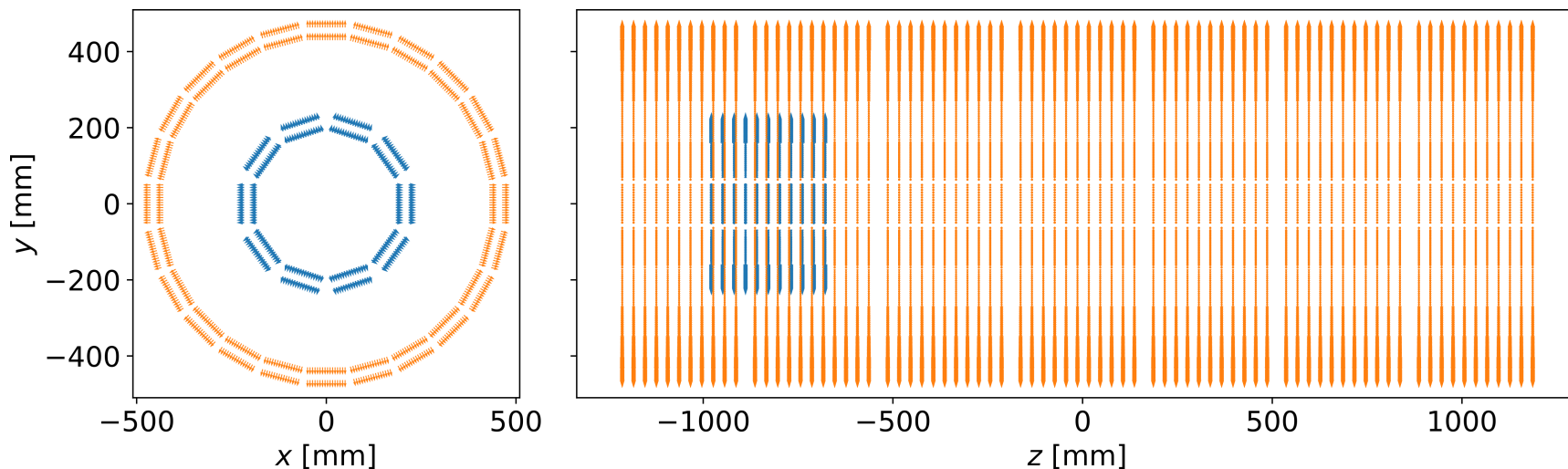
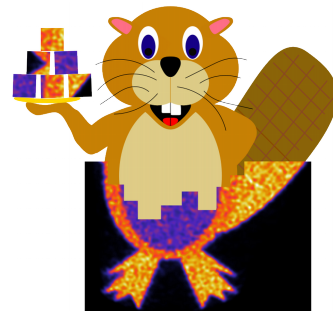
4.

Image reconstructions: spatial resolution

Reconstruction with CASToR

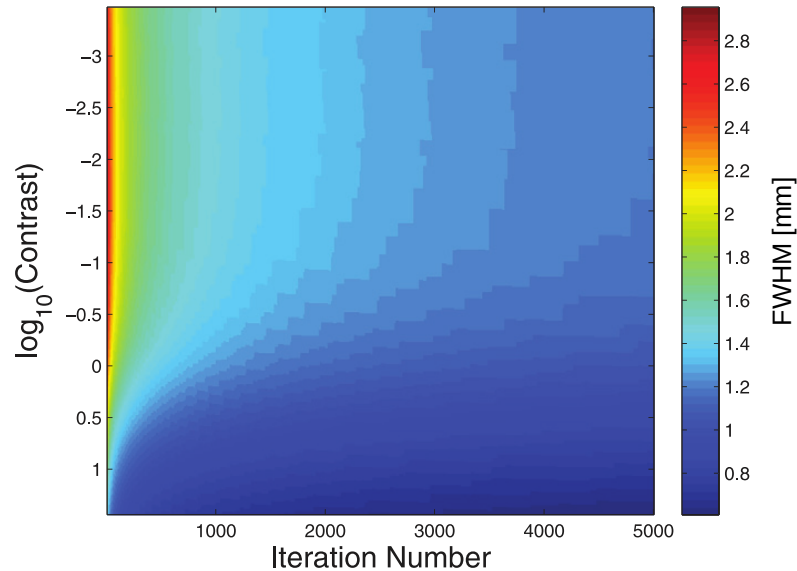


- Capable of handling unconventional geometries
- Using MLEM without TOF
- Multi-Siddon projector
- 1 mm image spacing



Relative spatial resolution

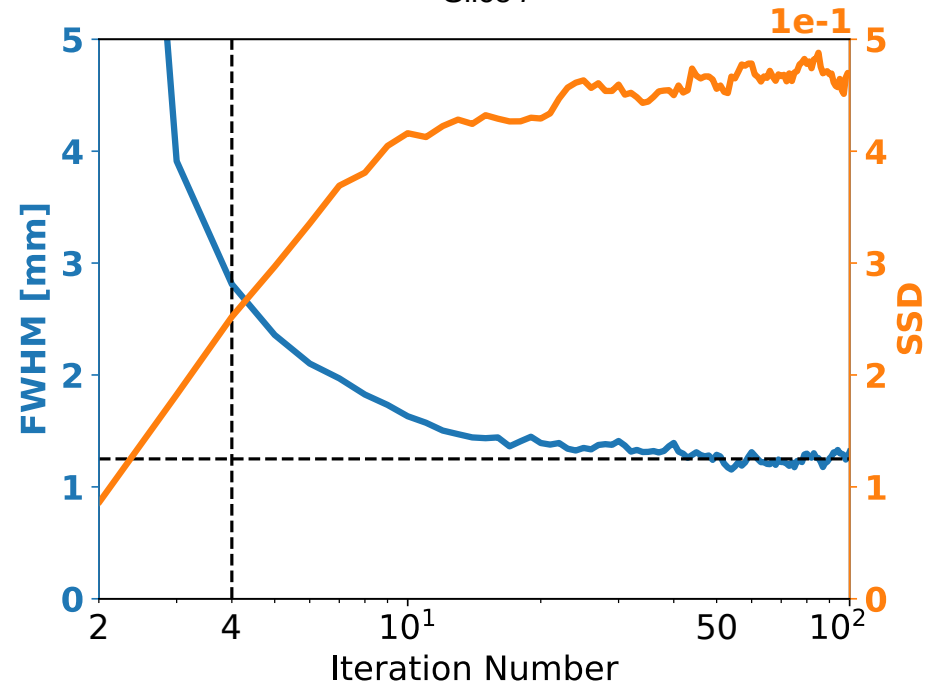
Emphasis on **relative** over absolute spatial resolution



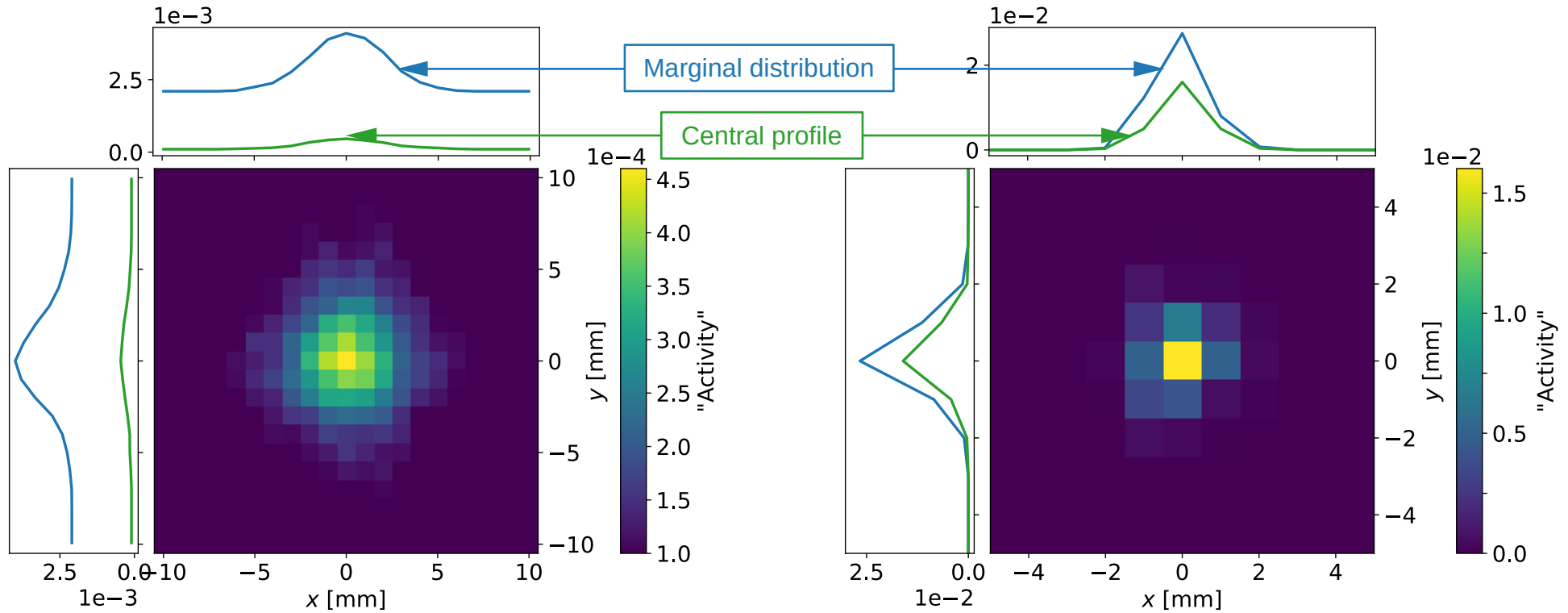
Gong et al.: "On the assessment of spatial resolution of PET systems with iterative image reconstruction" *Phys. Med. Biol.* **61** (2016)

$$\text{SSD} = \sqrt{\sum_i [F(z_{i+1}) - F(z_i)]^2} \quad F(z_i) = \int \overbrace{f(x, y, z_i)}^{\text{Reconstruction}} dx dy$$

Slice i \nearrow



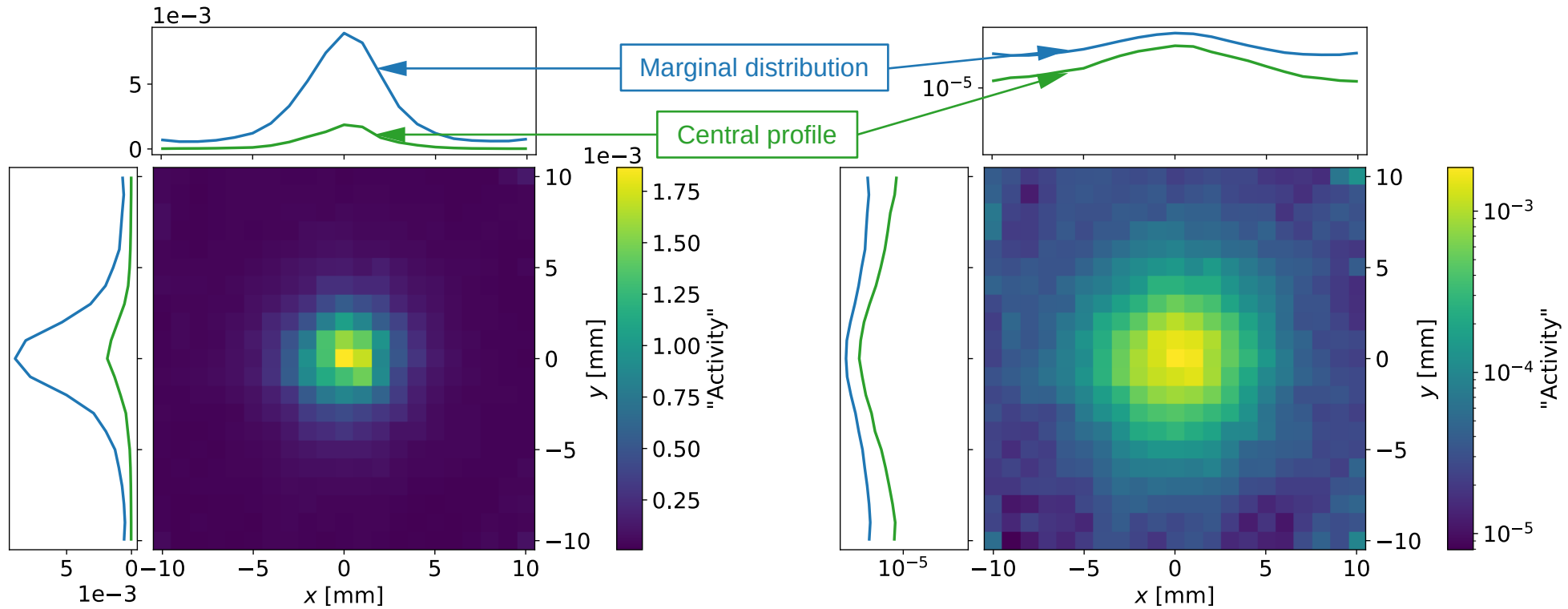
Relative spatial resolution



Iteration 2

Iteration 50

Relative spatial resolution

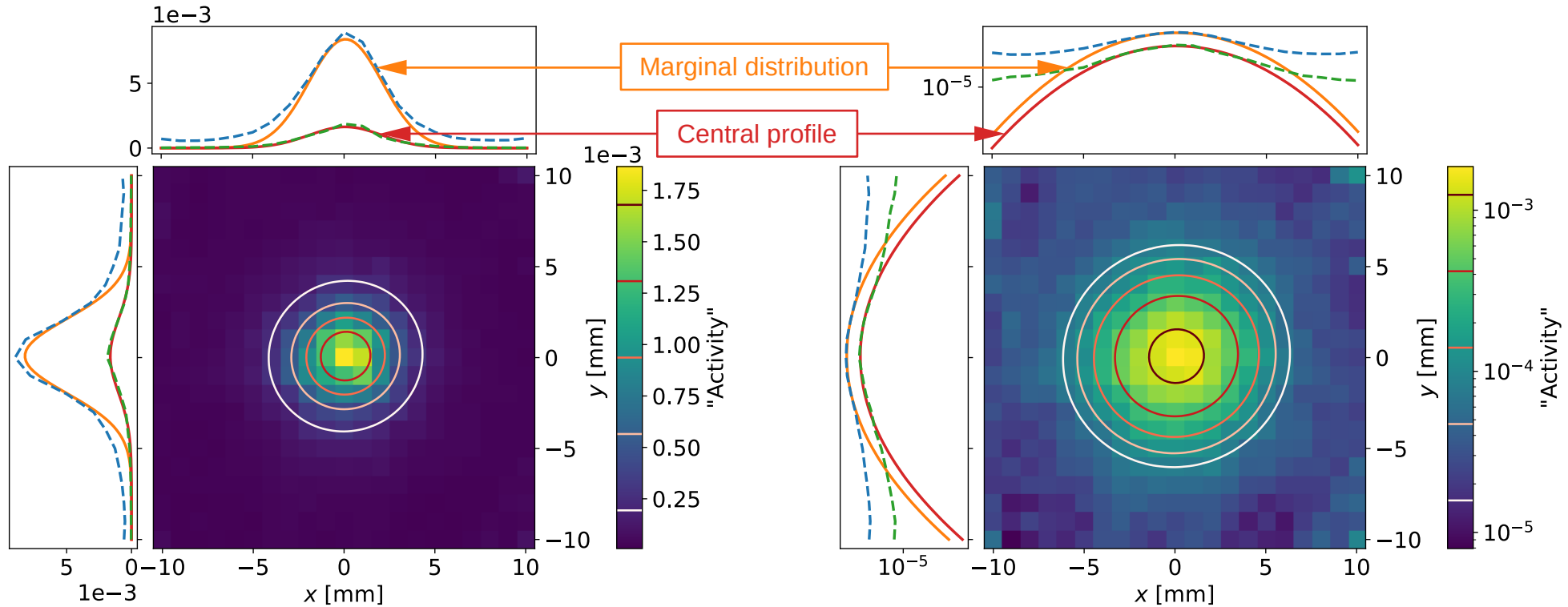


Iteration 4

Iteration 4

Relative spatial resolution

Gaussian fit

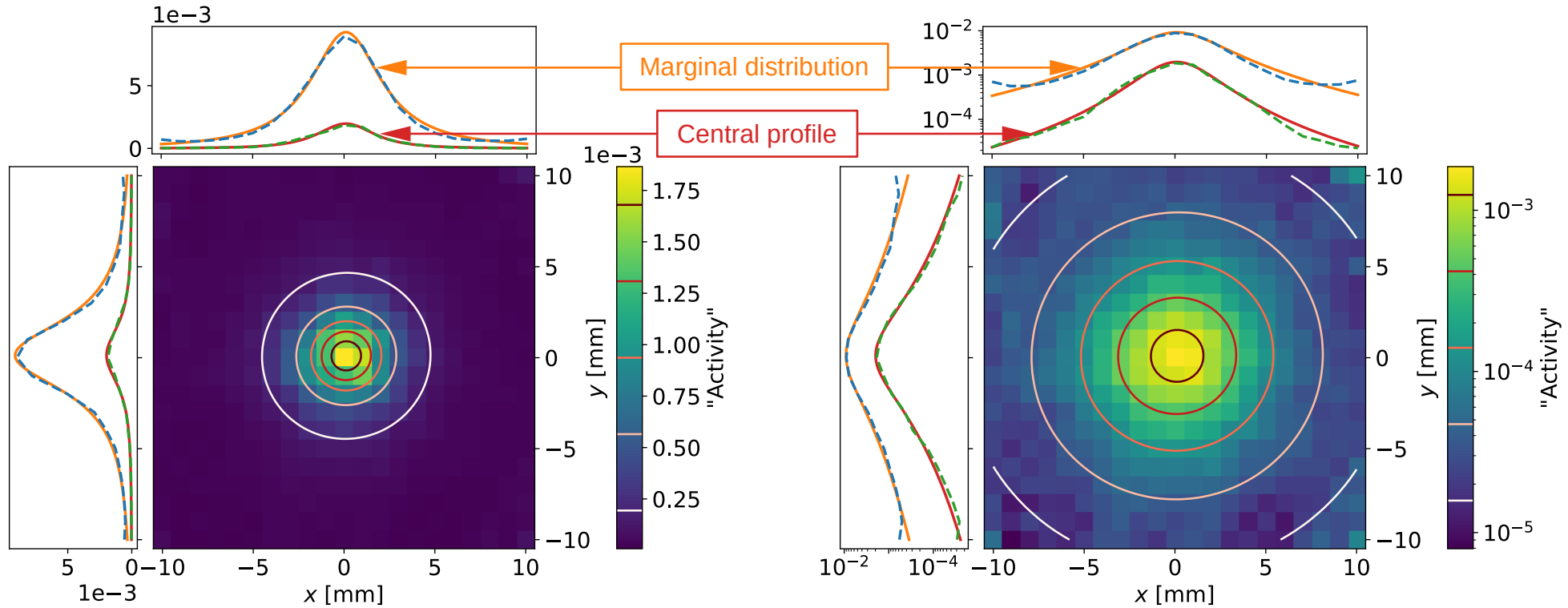


Iteration 4

Iteration 4

Relative spatial resolution

Lorentzian fit



Iteration 4

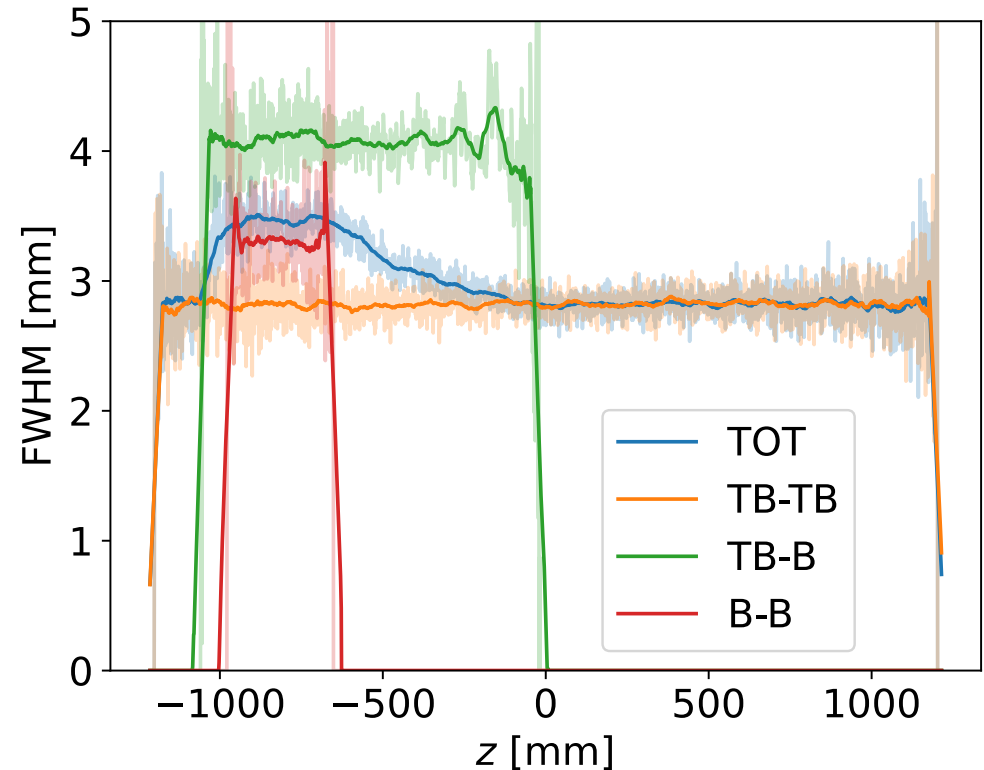
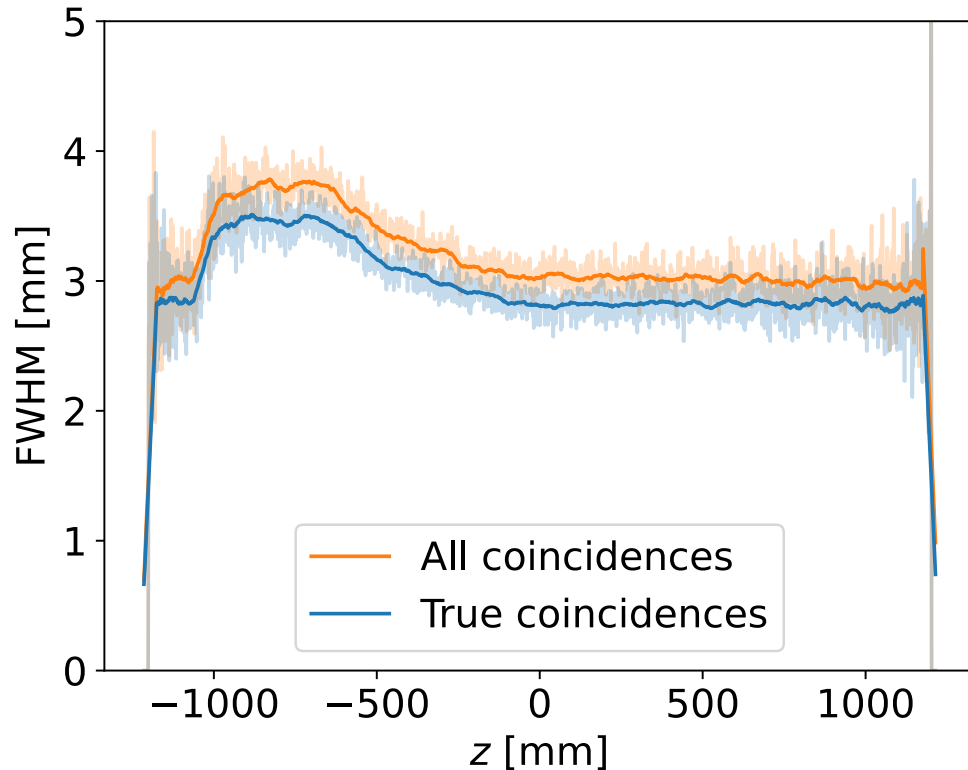
Iteration 4

Relative spatial resolution

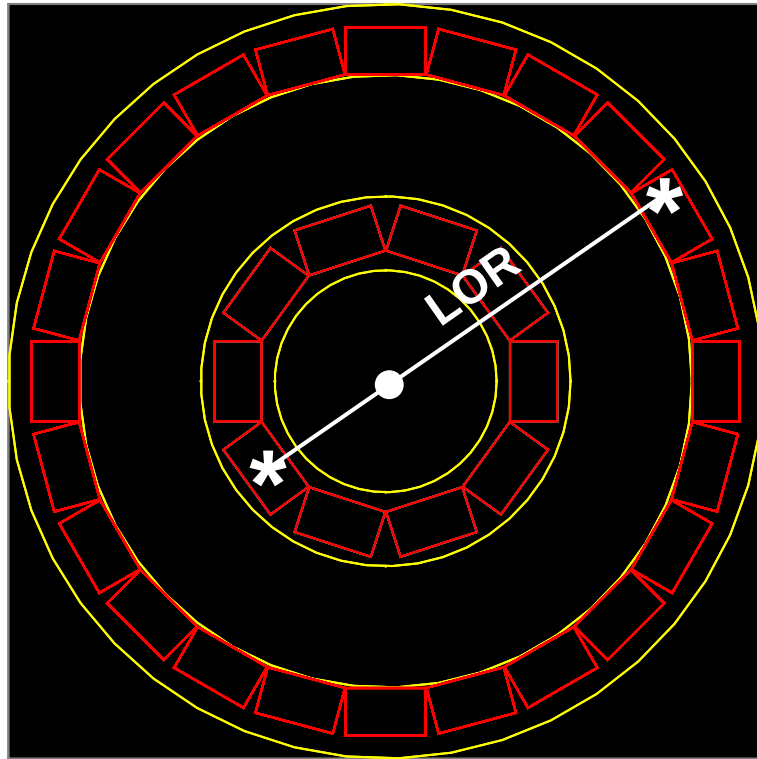
Data →  ← Moving average

16 x (6 x 30 x 330 mm³)

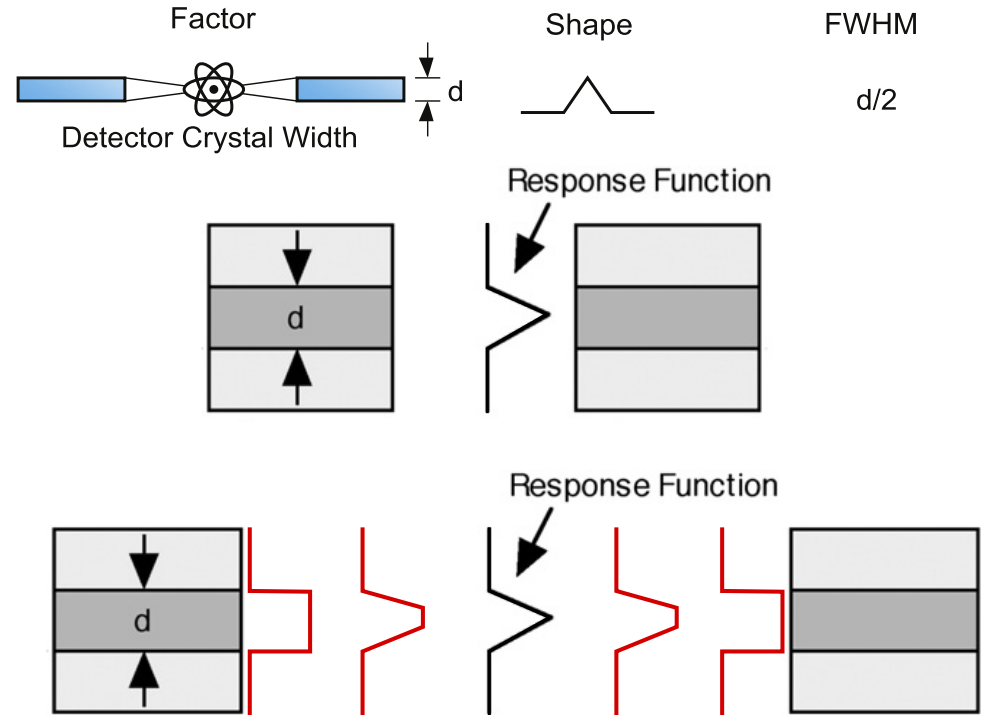
True coincidences only



Geometrical interpretation



Moses. Nucl. Instrum. Methods Phys. Res. A 648 (2011)

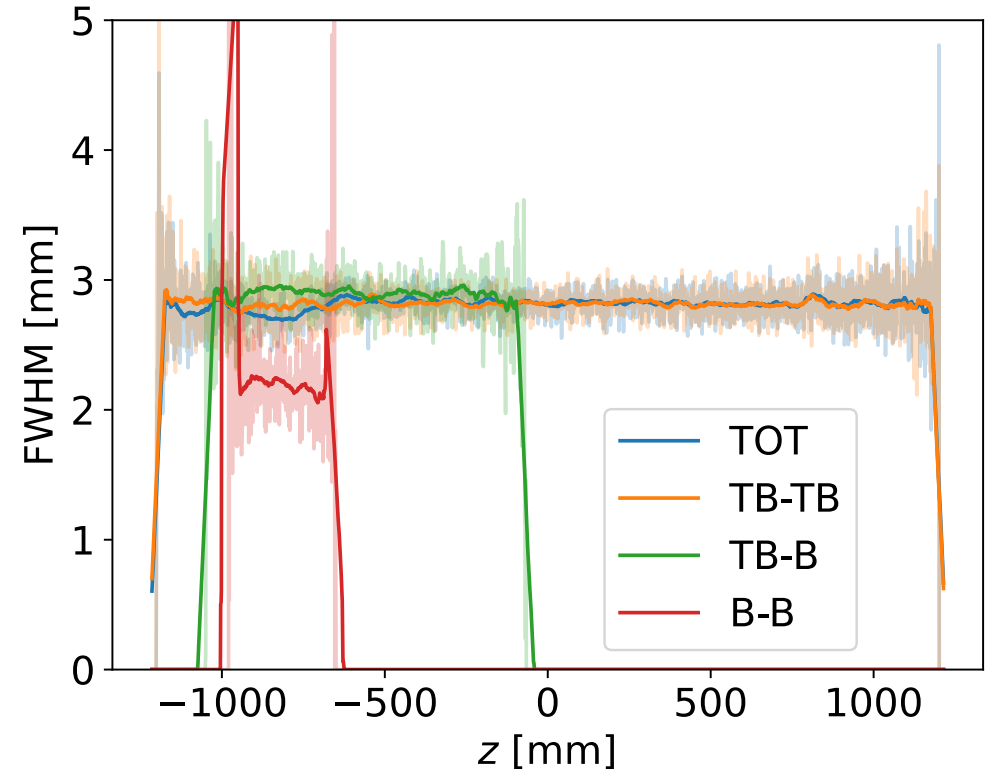
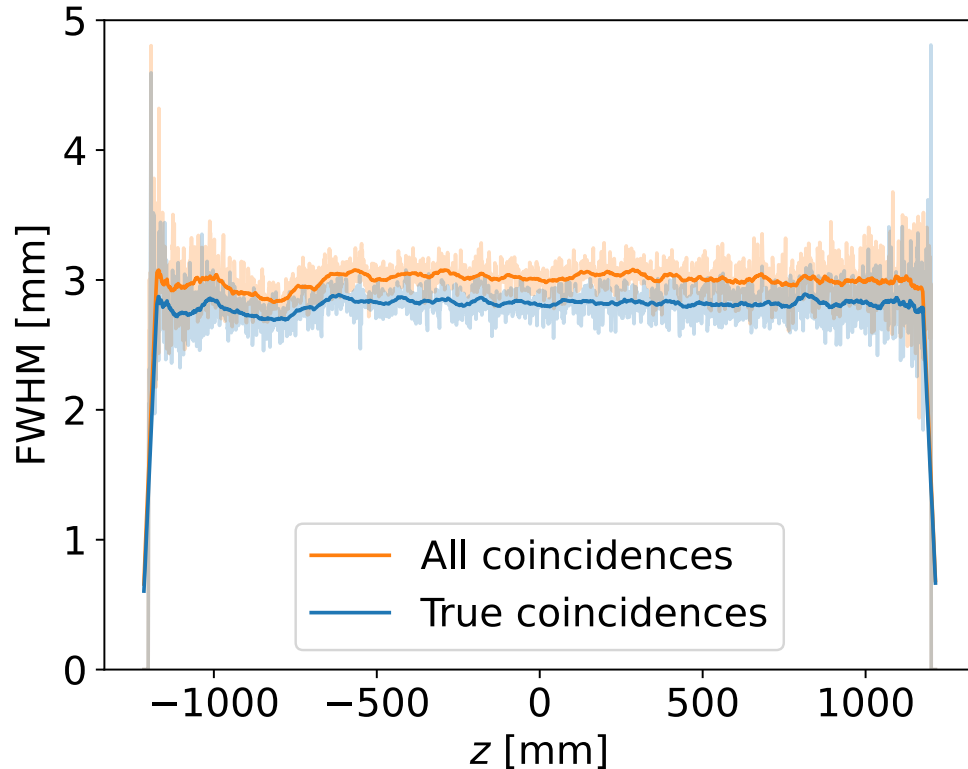


Relative spatial resolution

Data →  ← Moving average

23 x (4 x 18 x 330 mm³)

True coincidences only



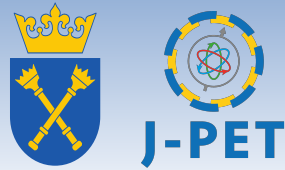
5.

Conclusions

Conclusions

- Brain PET insert under development at J-PET
- Simulation and reconstruction platform for nested geometries developed
- Based on sensitivity: Insert should be superior to the frontal detector
- The coincidences between inner and outer detectors have low resolution for geometrical reasons

Thank You for Your attention!



Thanks to the **J-PET** collaboration:

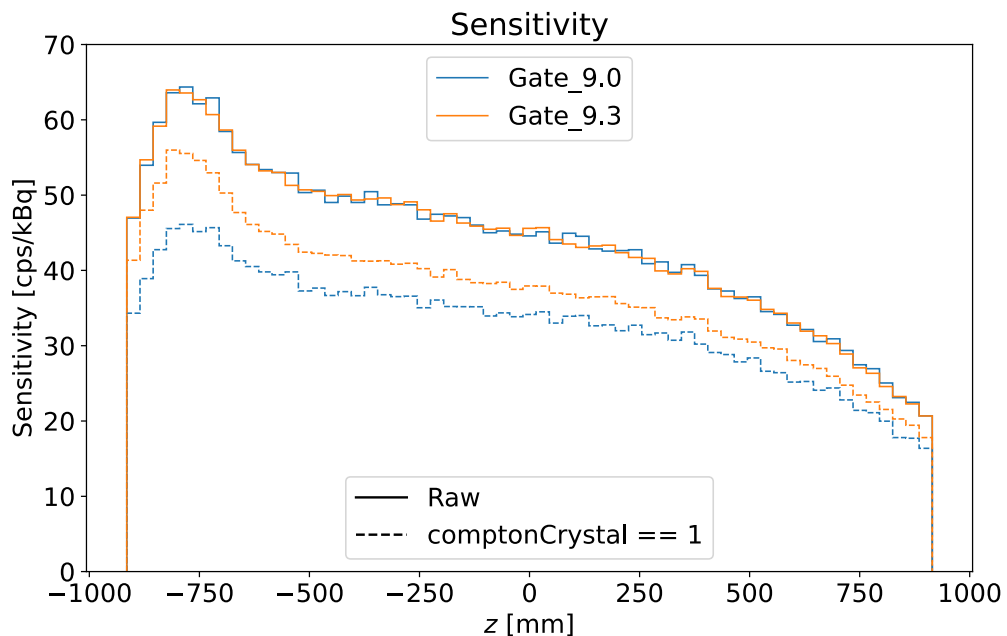
Supported by:



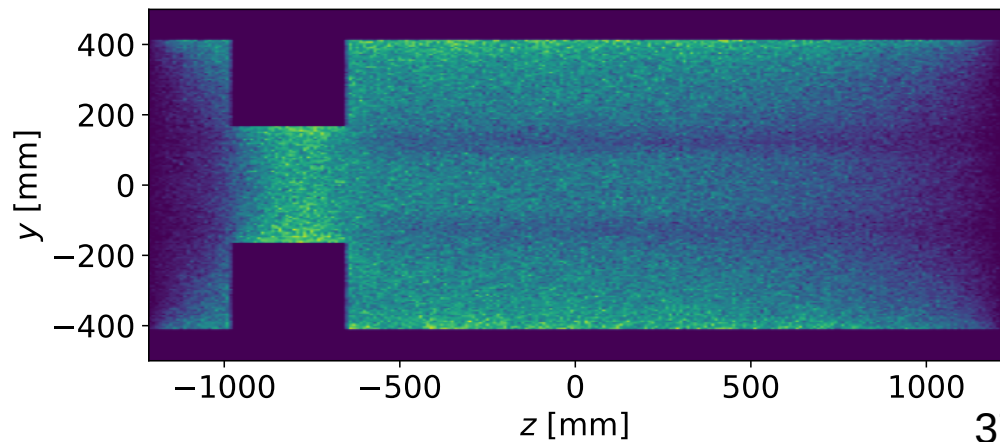
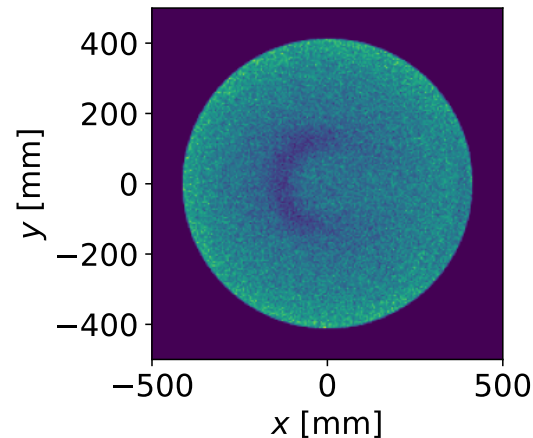
Backup

GATE v9.3 adjustments

Underestimation of Compton counts



Missing
coincidences
due to r-sector
difference > 1



CASToR sensitivity map

