

GATE simulations of a multi-detector geometry: combining the total body J-PET with a brain insert

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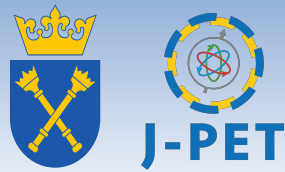
²Centre for Theranostics, Jagiellonian University, Kopernika 40, 31-501 Kraków, Poland



GATE Scientific meeting 2025

April 1st - 3rd 2025

Outline



1. Background & Motivation
2. Multi-detector geometries in GATE
3. CASToR reconstructions
4. Conclusions

1.

Background & Motivation

Total body PET scanners

First large field of view scanners commercially available:

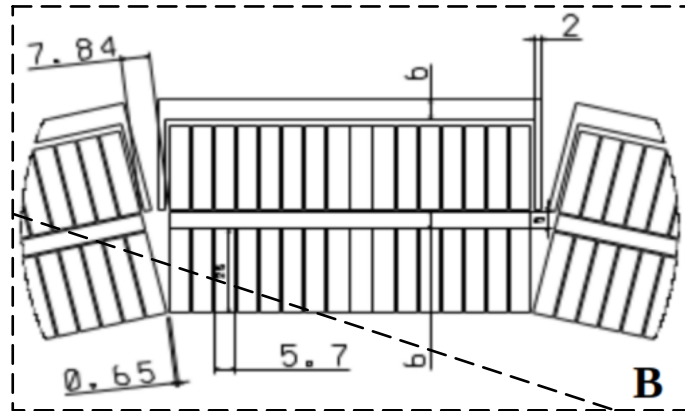


Enabling: low dose imaging, short scan times, dynamic imaging, ...

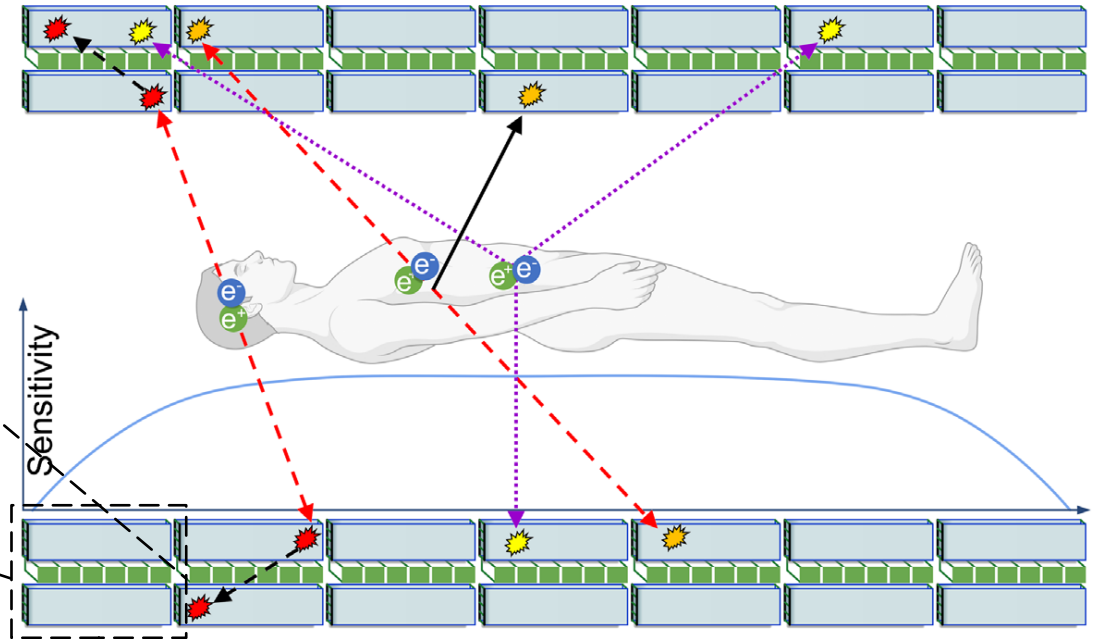
But also: very expensive ...

Total body J-PET scanner

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



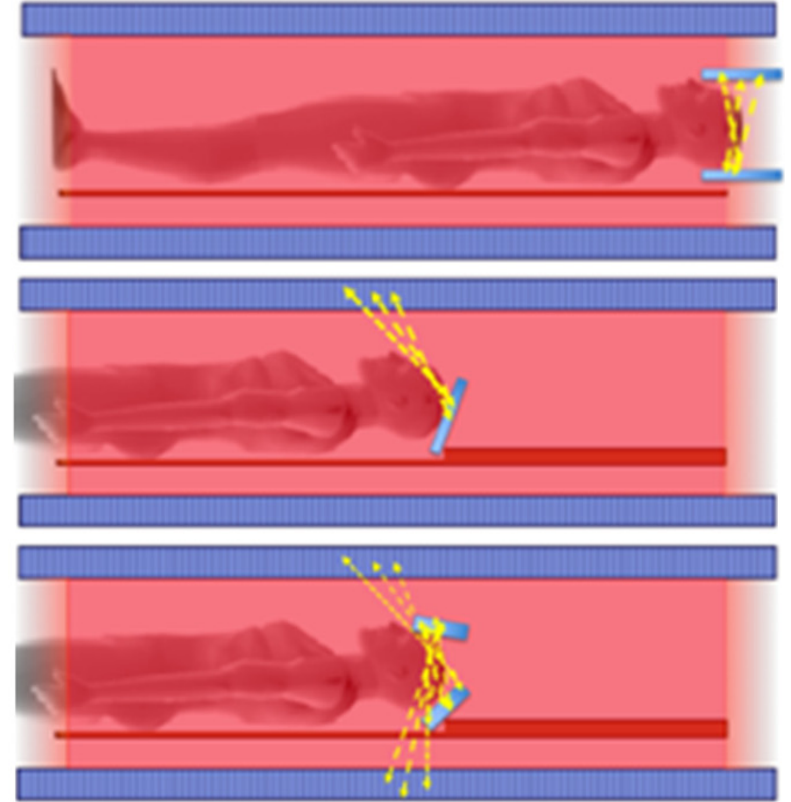
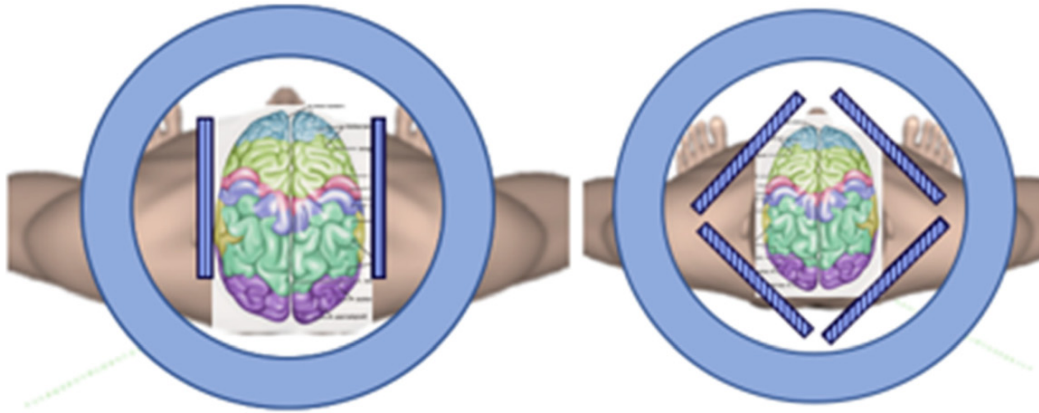
Baran et al.: "Realistic Total-Body J-PET Geometry Optimization: Monte Carlo Study" *Med Phys.* 1–15 (2025)



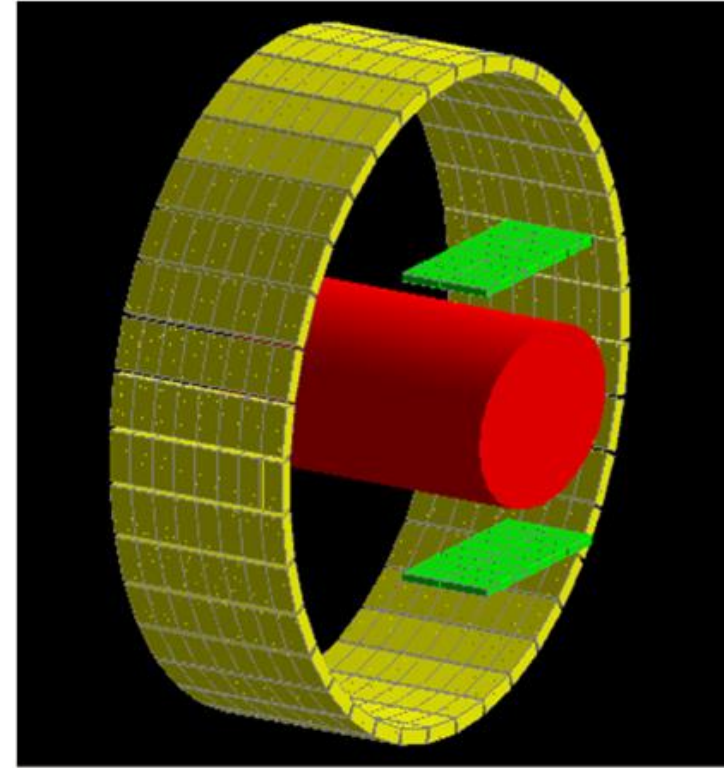
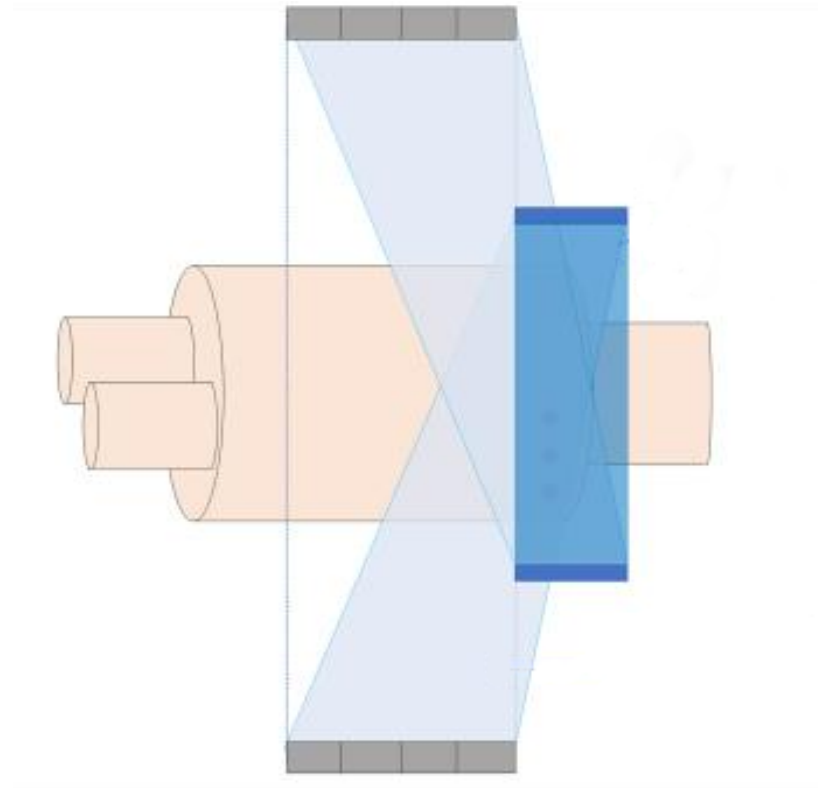
Bass et al.: "Colloquium: Positronium physics and biomedical applications" *Rev. Mod. Phys.* 95, 021002 (2023)

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.”

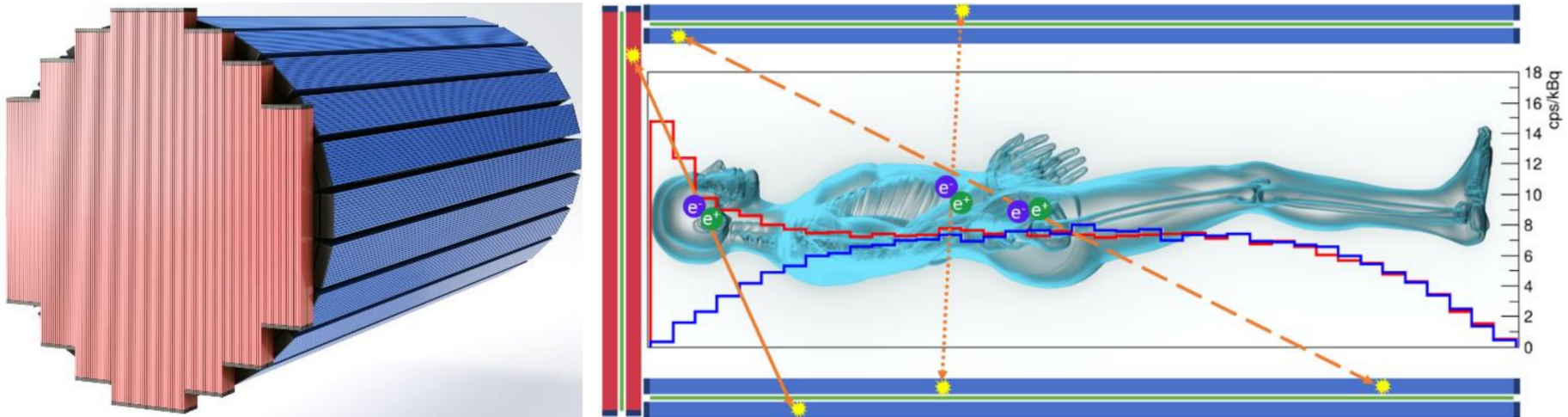


Magnification “outsert”



Preliminary work

- Preliminary study of a frontal detector combined with the TB-J-PET using **Gate 9.0**
- Coincidence sorting was carried out in post-processing



National Science Centre of Poland grant no. 2021/42/A/ST2/00423 (PI: Paweł Moskal)
Simulations conducted by S. Parzych

2.

Multi-detector geometries in GATE

GATE v9.3 and onwards ...

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.**”

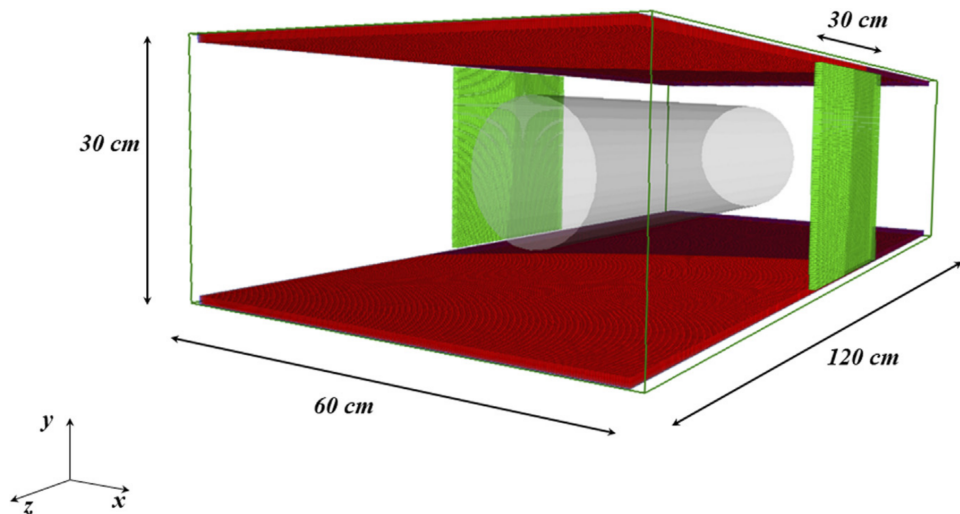
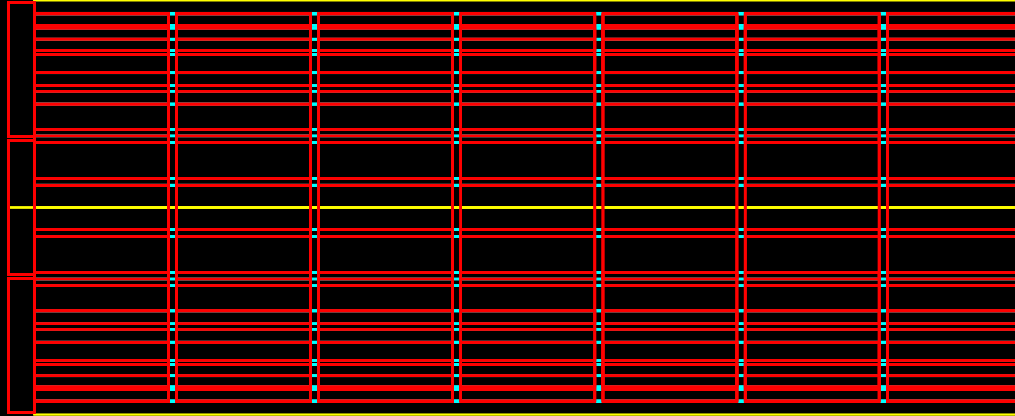
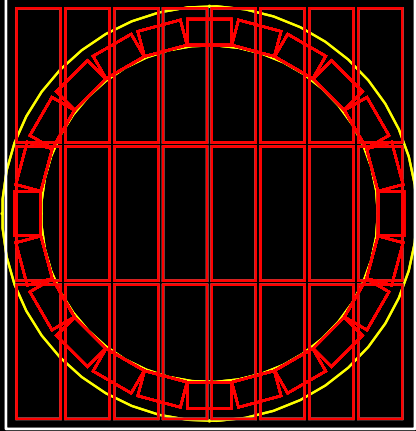


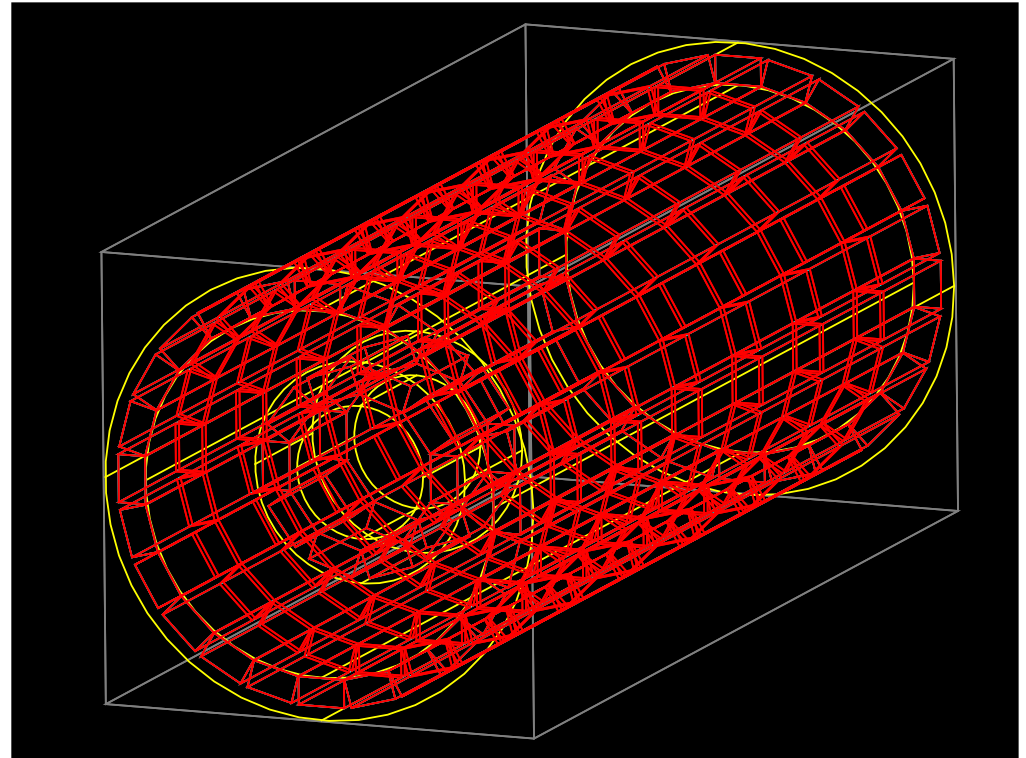
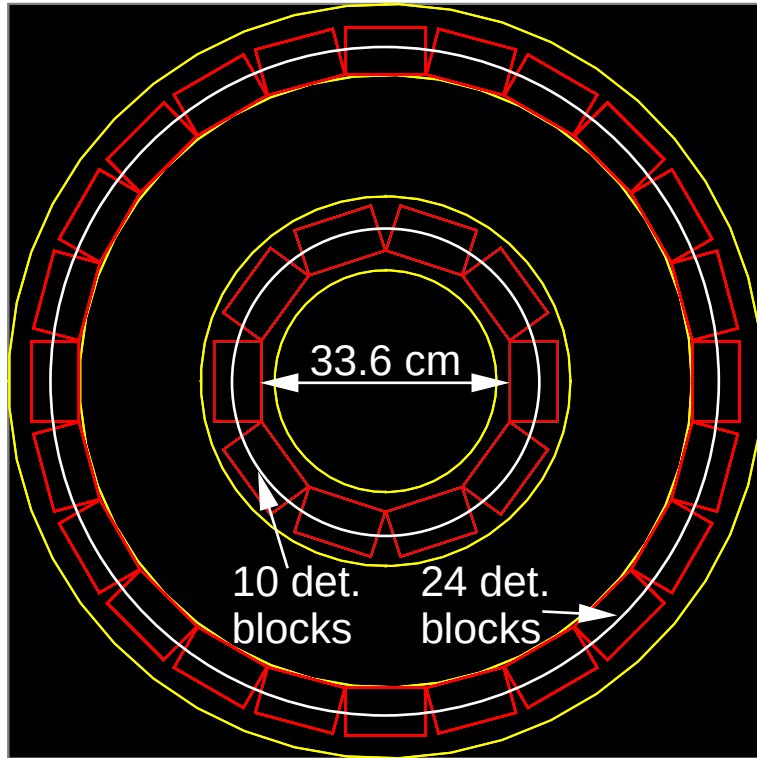
FIGURE 10
Multi-system example: multipanel limited angle PET system from [19] (red) with smaller side panels (green) added.

Frontal detector

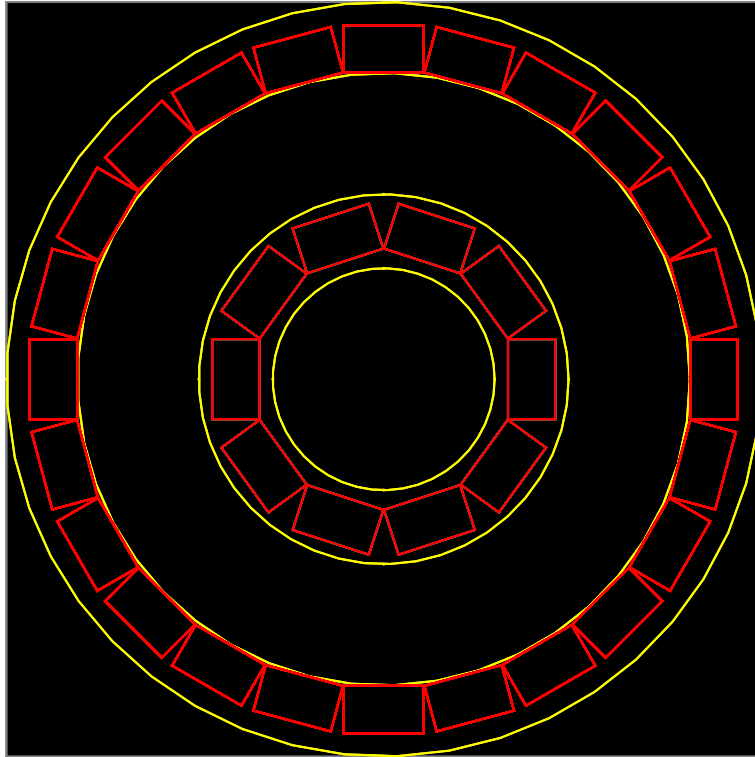
24 det.
blocks



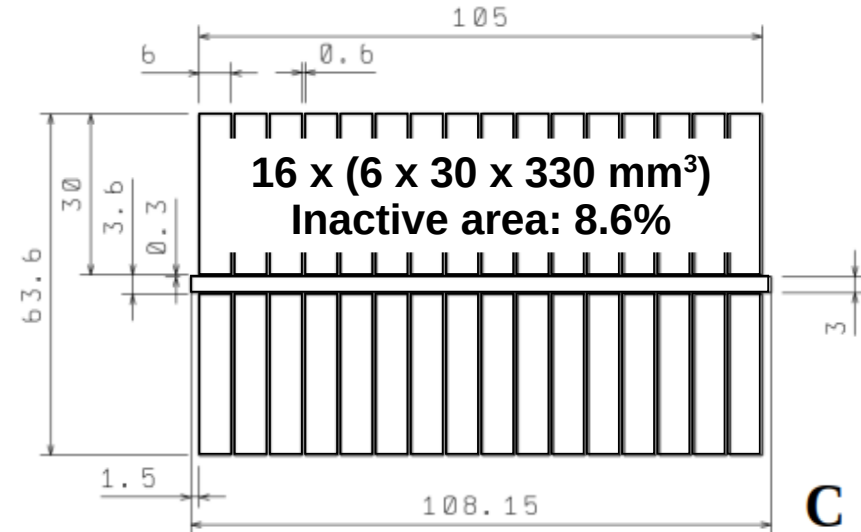
Brain insert



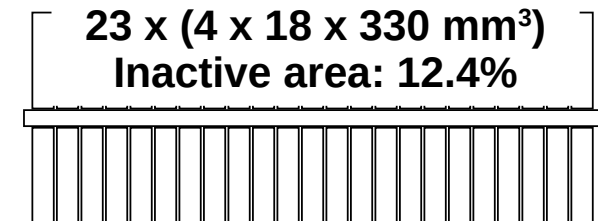
Brain insert variations



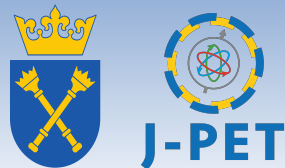
Total body
detector
block



Brain insert
detector
block
variation



Issue #1: Multiple GateCylindricalPETSystem's



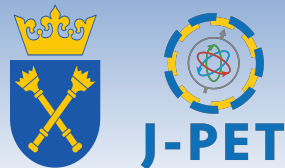
```
GateDigitizerMgr.cc (l.163): ***ERROR*** CoincidenceSorter *** The input collection
name is ambiguous as you have several Singles Collections/SinglesDigitizers!
Please, use /setInputCollection for your CoincidenceSorter to choose the correct one.

*** Break *** segmentation violation
```

The list of digitizer entries features only one CoincidenceSorter:

```
Idle> /gate/digitizerMgr/list
-----
DigitizerMgr summary
Table size 20
collID | DigitizerModule | DigiCollection | size
-----
0      | GateCoincidenceSorter | Coincidences | 0
1      | DigiInit | Singles_Blayer_1 | 0
...
```

Issue #1: Multiple GateCylindricalPETSystem's



Issue: When setting up a GateCylindricalPETSystem, a GateCoincidenceSorter called “Coincidences” is automatically generated, leading to the ambiguity

Patch: Comment the automatically generated GateCoincidenceSorter's called “Coincidences”

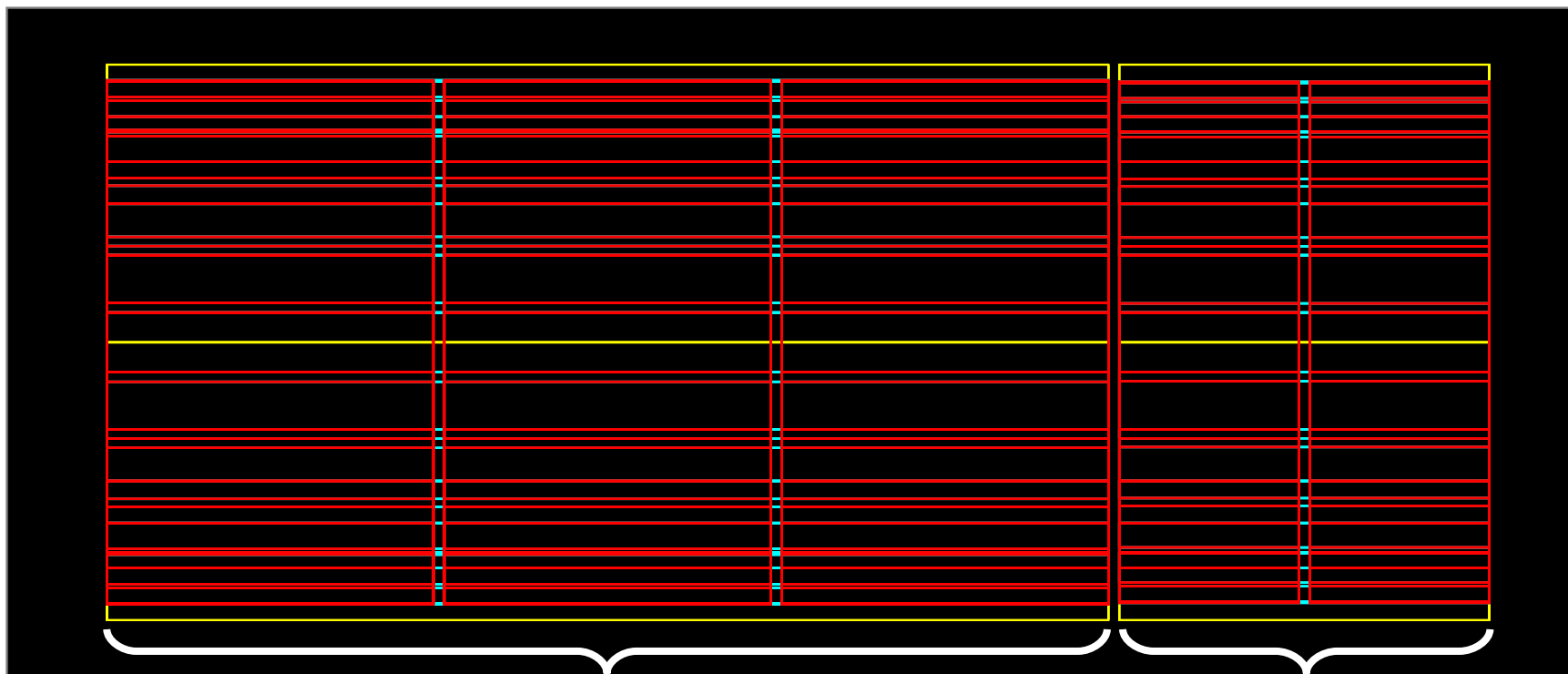
Gate/source/geometry/src/GateCylindricalPETSystem.cc:

```
53 // Integrate a coincidence sorter into the digitizer
54 //OK GND 2022
55 GateDigitizerMgr* digitizerMgr = GateDigitizerMgr::GetInstance();
56 GateCoincidenceSorter* coincidenceSorter = new GateCoincidenceSorter(
    digitizerMgr, "Coincidences");
57 digitizerMgr->AddNewCoincidenceSorter(coincidenceSorter);
```

Similar issue also for other PET geometries

Issue #1: Multiple GateCylindricalPETSystem's

Same issue for geometries that are not nested:

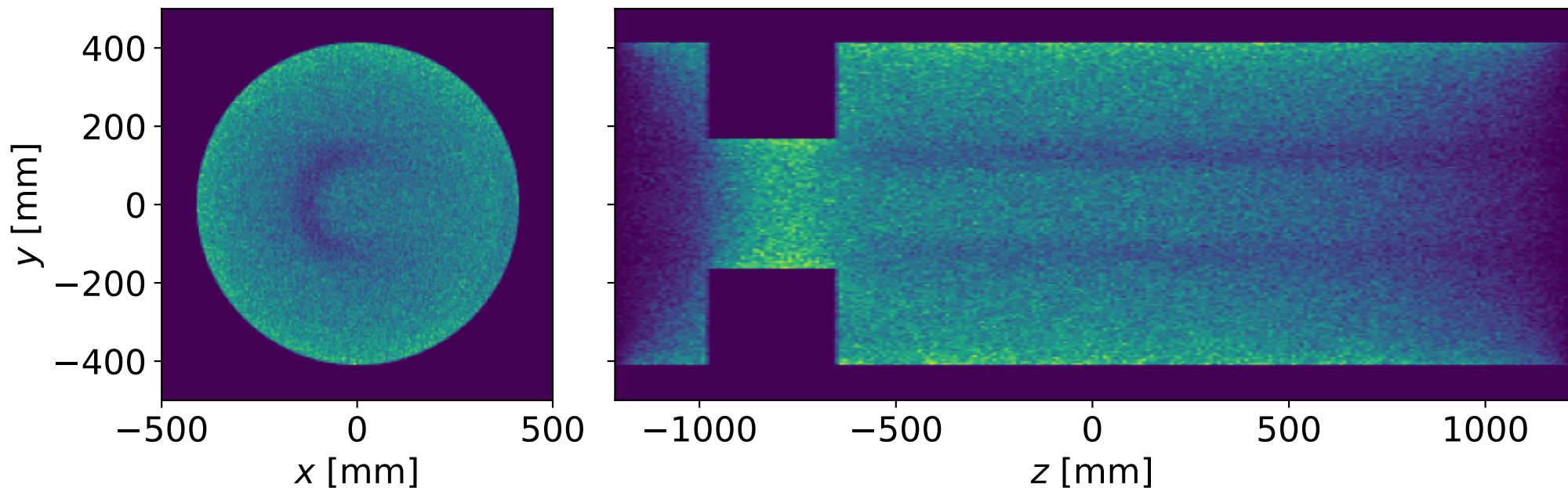


3 rings with each 60 cm

2 rings with each 33 cm

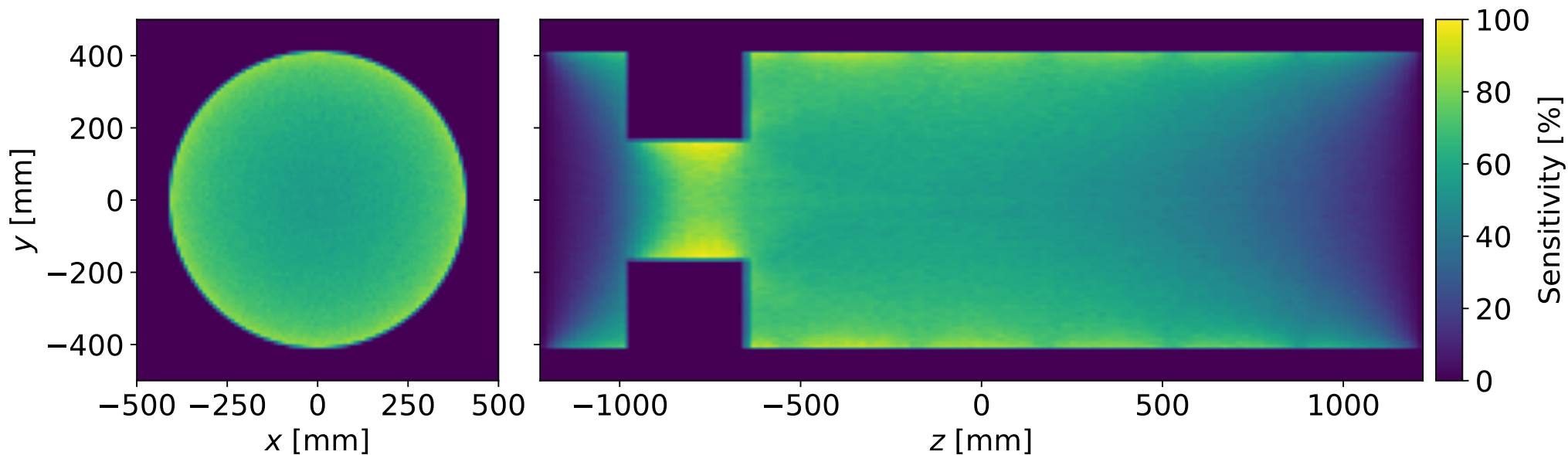
Issue #2: minSectorDifference

Issue: C-shaped artifact for the simulation of a sensitivity map

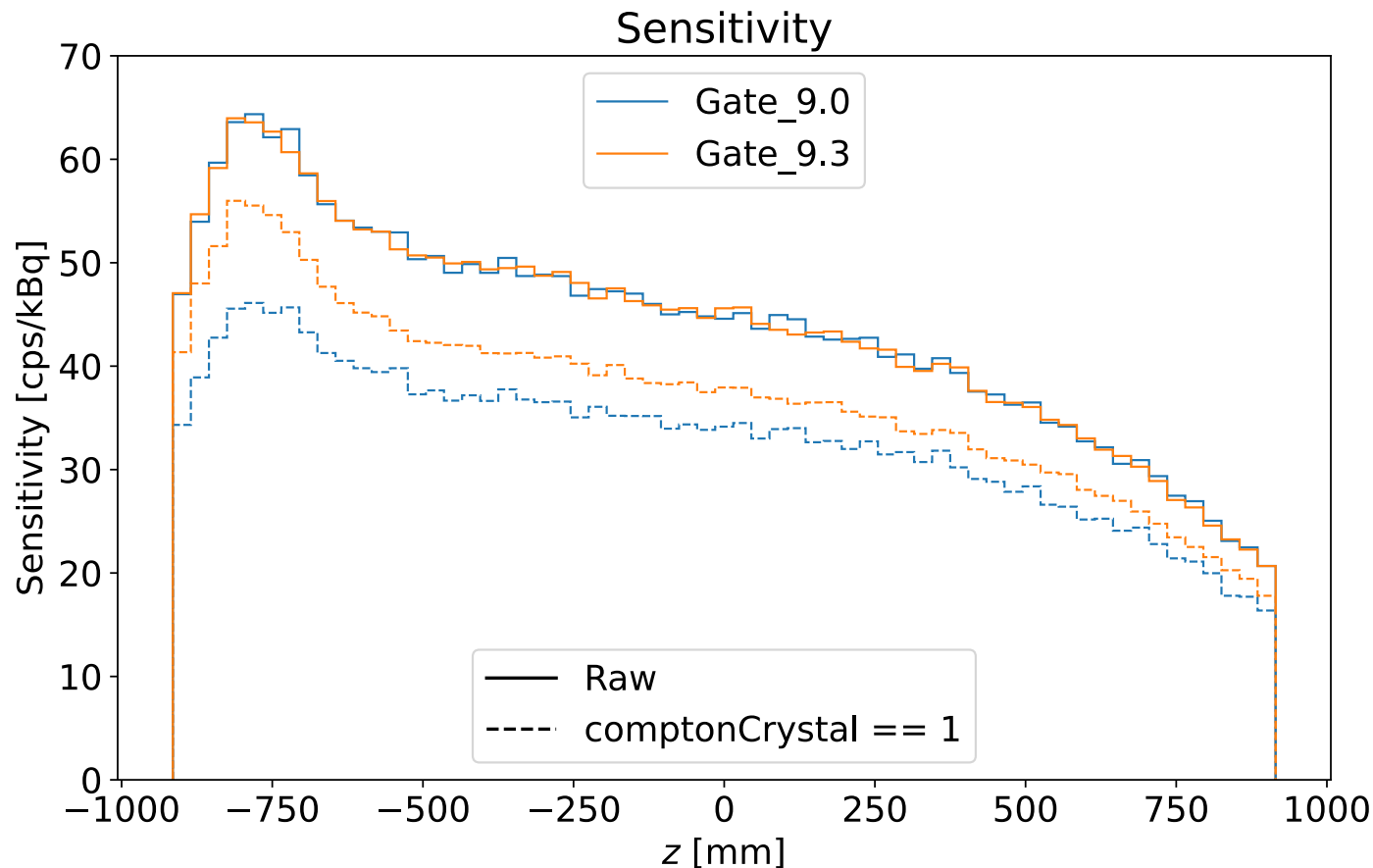


Issue #2: minSectorDifference

After setting
`minSectorDifference=0`



Issue #3: Compton counts



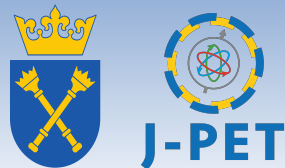
Issue #3: Compton counts

Issue: Since v9.3, Gate Hits are subdivided into layers and processed independently layer by layer. A Hit that occurred previously in a different layer is not taken into account

Gate/source/digits_hits/src/GateAnalysis.cc:

```
141 //OK GND 2022
142     std::vector<GateHitsCollection*> CHC_vector = GetOutputMgr()->
        GetHitCollections();
143
144     for (size_t i=0; i<CHC_vector.size();i++ )
145     {
146         GateHitsCollection* CHC = CHC_vector[i];
147         G4int NbHits = 0;
148         G4int NpHits = 0;
```

Issue #3: Compton counts



Patch:

- Before writing the Compton and Rayleigh counts, first extract the Compton and Rayleigh Hit times in the same order they are processed

```
t = [0.8, 0.1, 0.7]
```

- The sought number of Compton or Rayleigh is

```
n = [2, 0, 1]
```

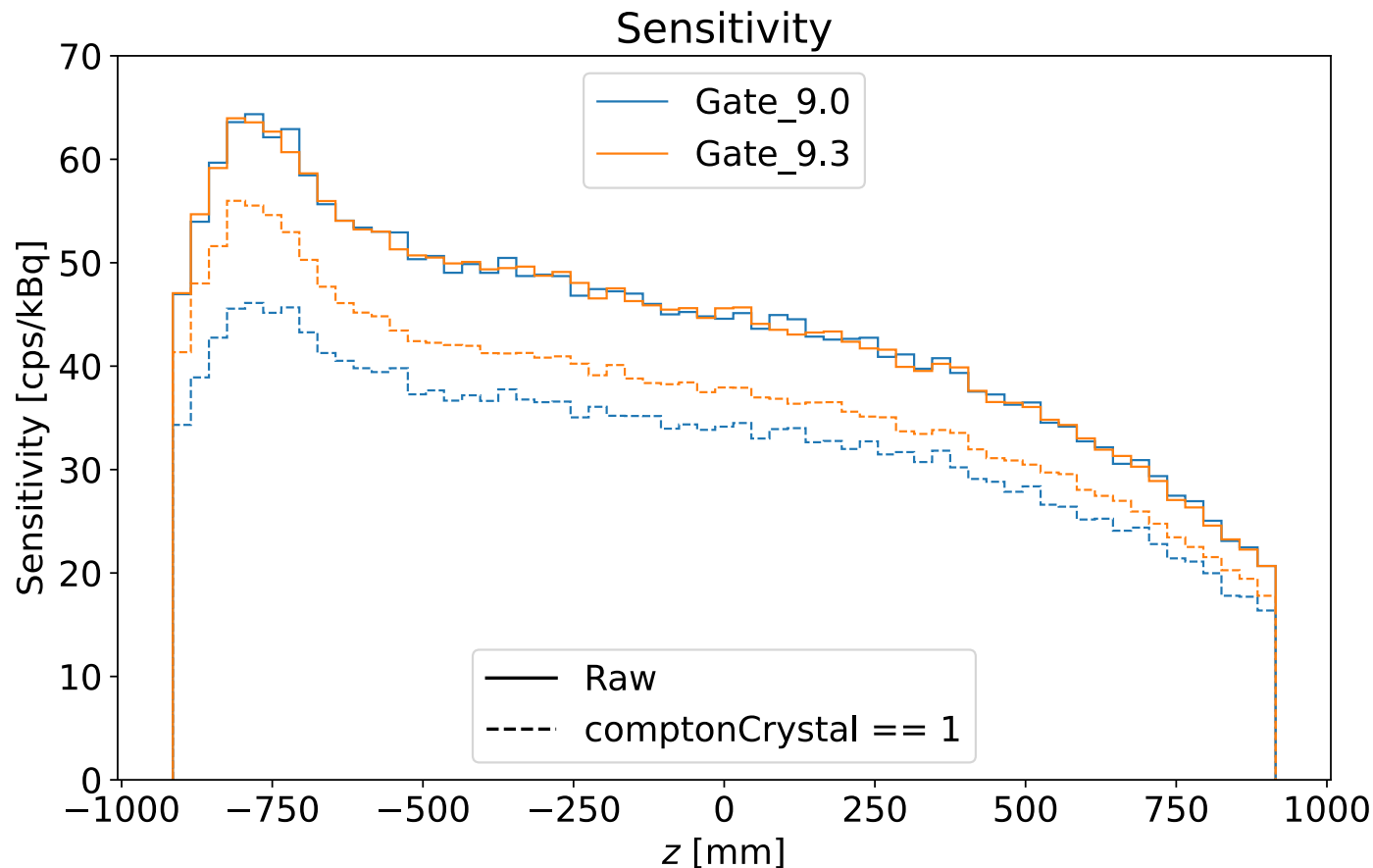
- Formally, n can be written as

```
sort(t)[n] = t
```

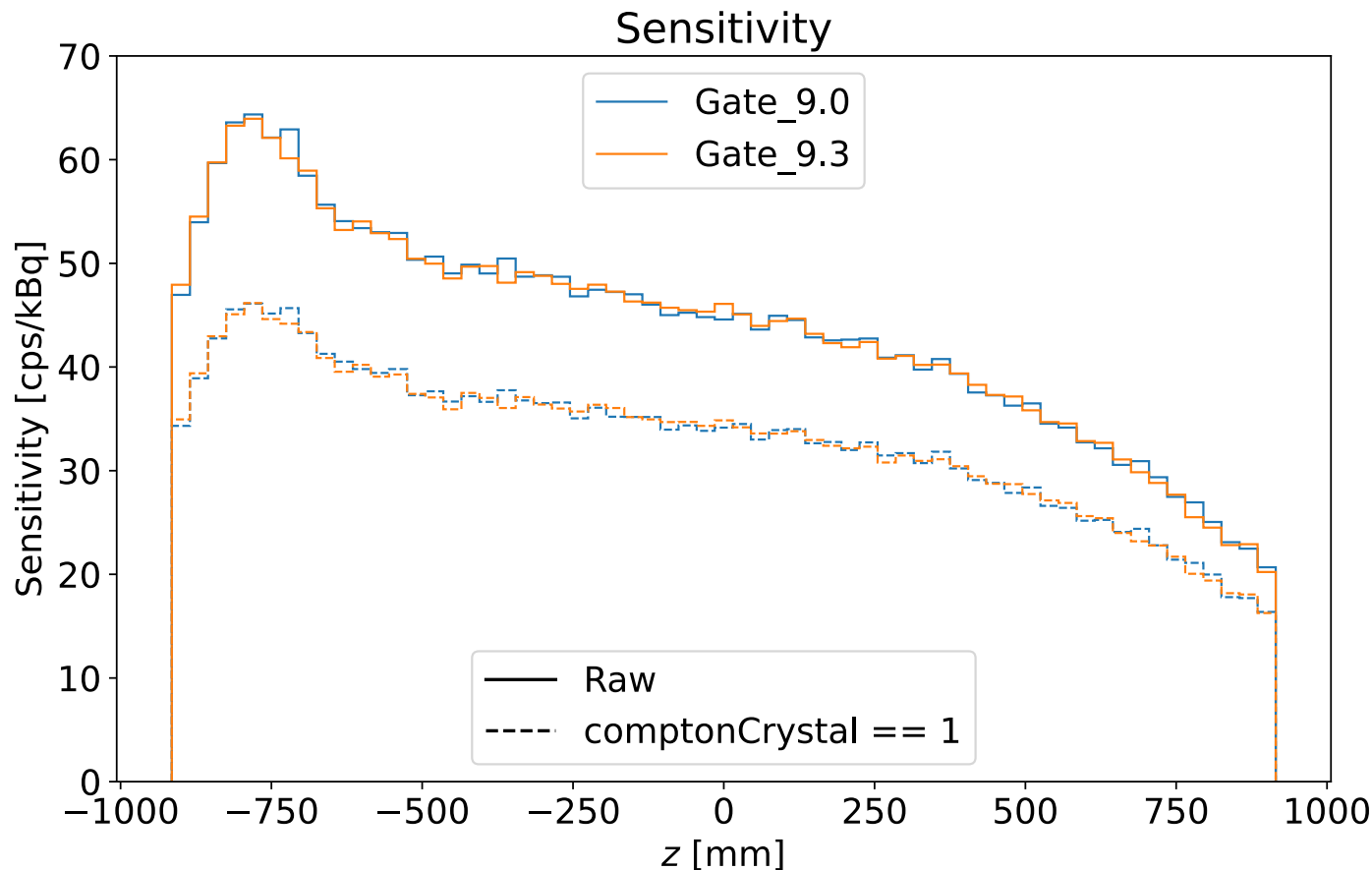
- In Python / numpy:

```
_, n = np.unique(t, return_inverse=True)
```

Issue #3: Compton counts

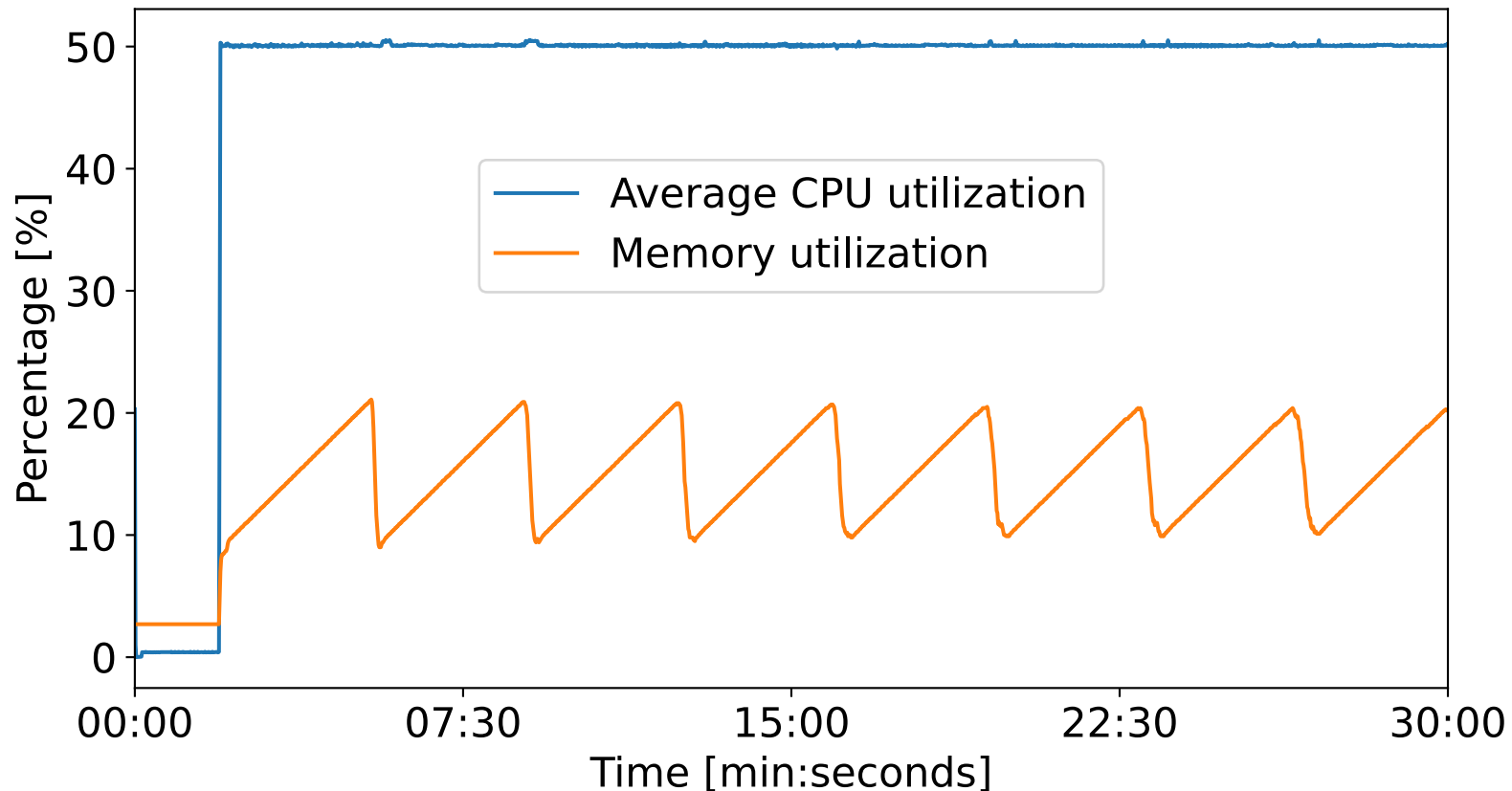


Issue #3: Compton counts



Issue #4: Memory leaks

- Gate v9.4.1
(without changes)
- TB-J-PET
(without insert)
- 1 MBq source
- Parallelized with
128 cores



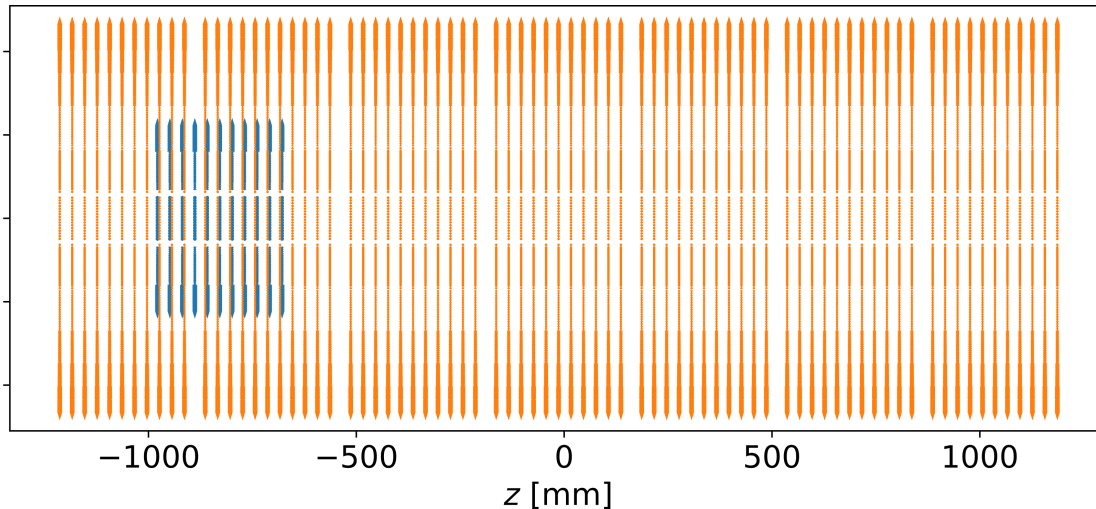
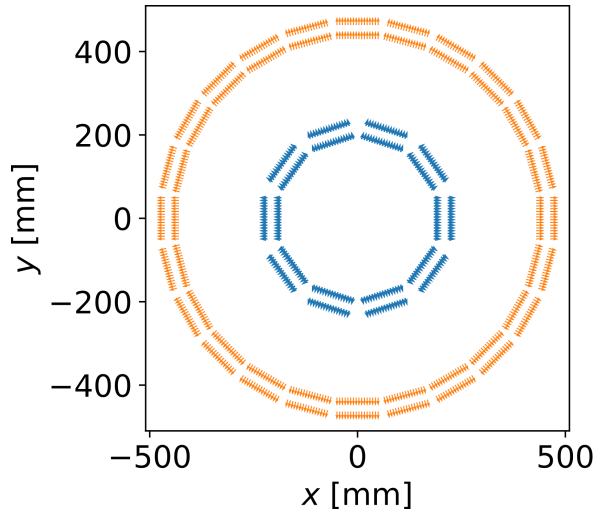
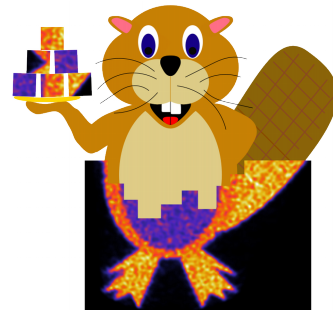
3.

CASToR reconstructions

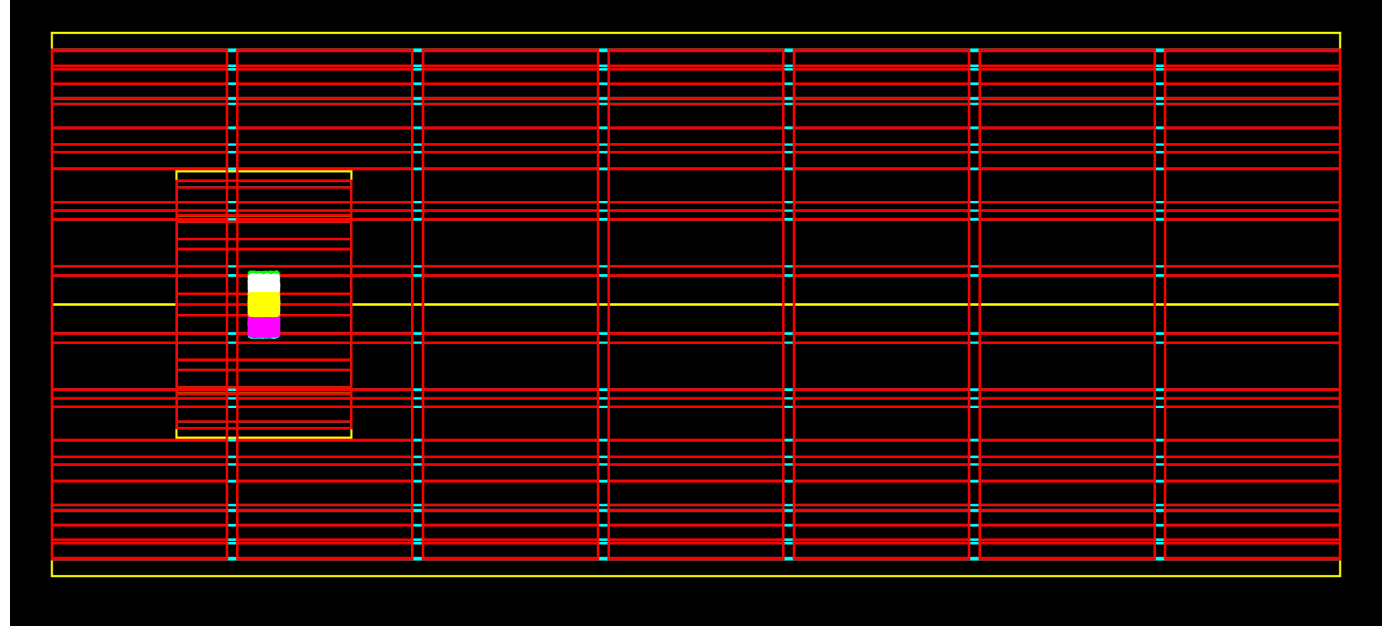
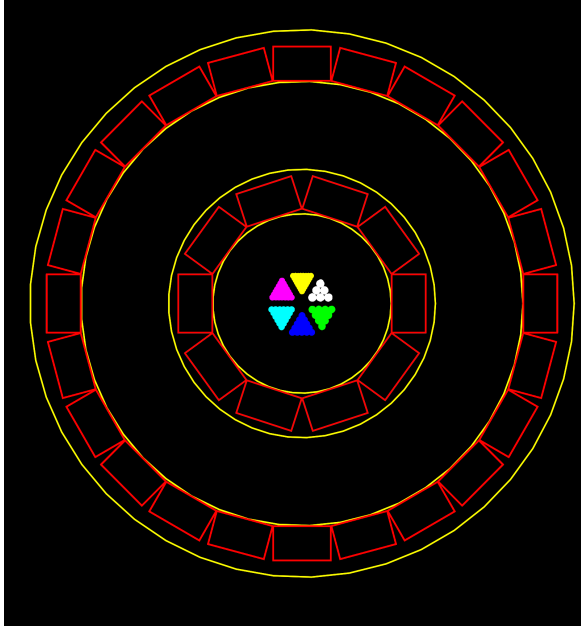
Reconstruction with CASToR



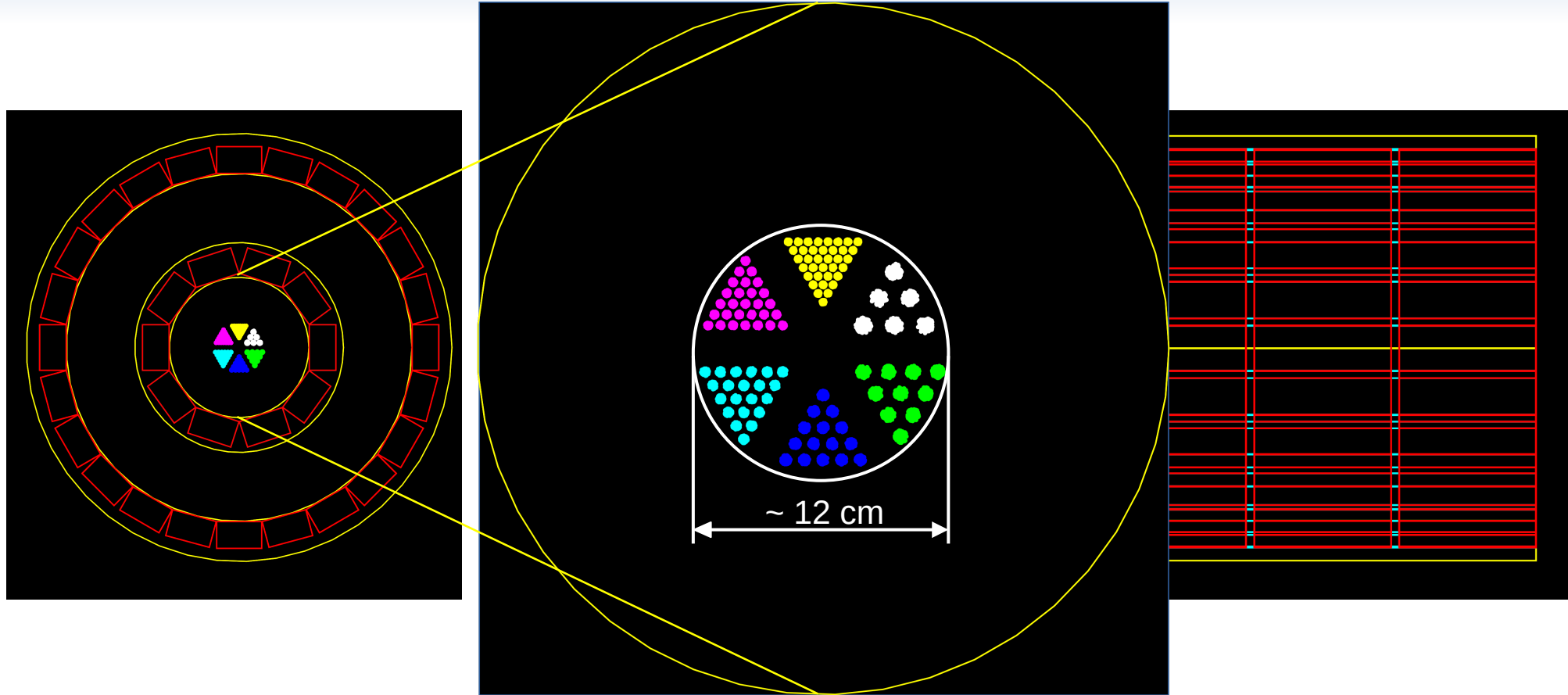
- Capable of handling unconventional geometries
- Using MLEM without TOF
- Multi-Siddon projector
- 1 mm image spacing



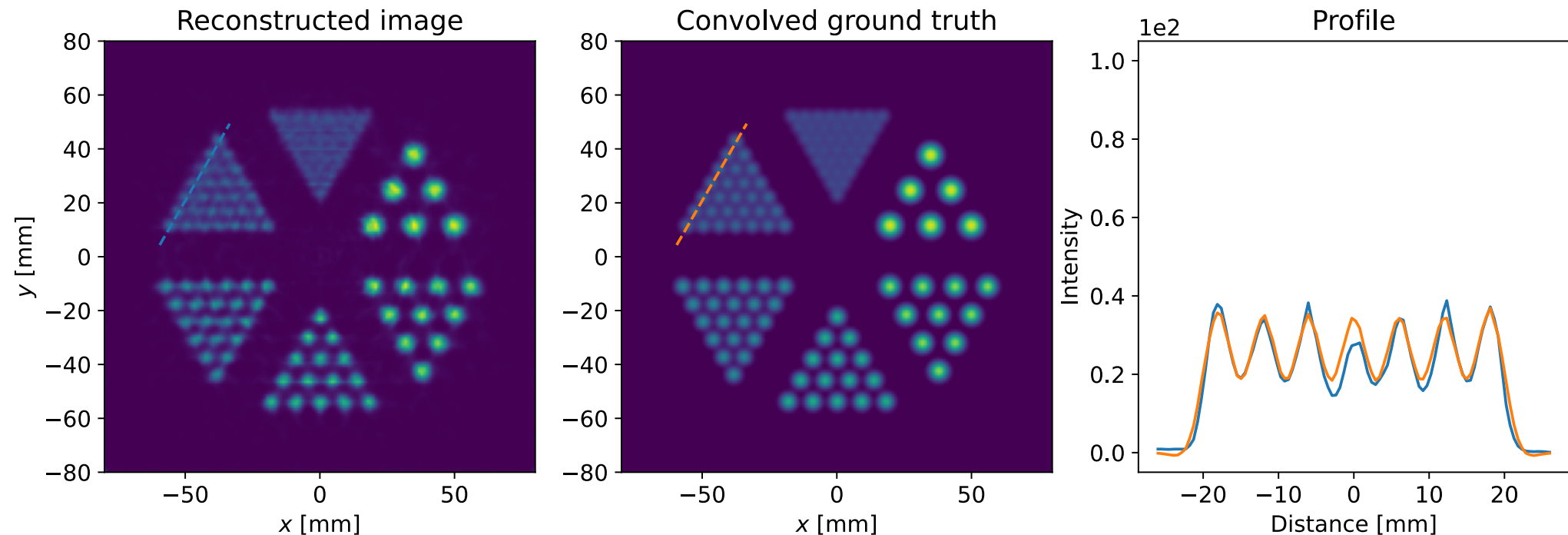
GATE: Derenzo phantom



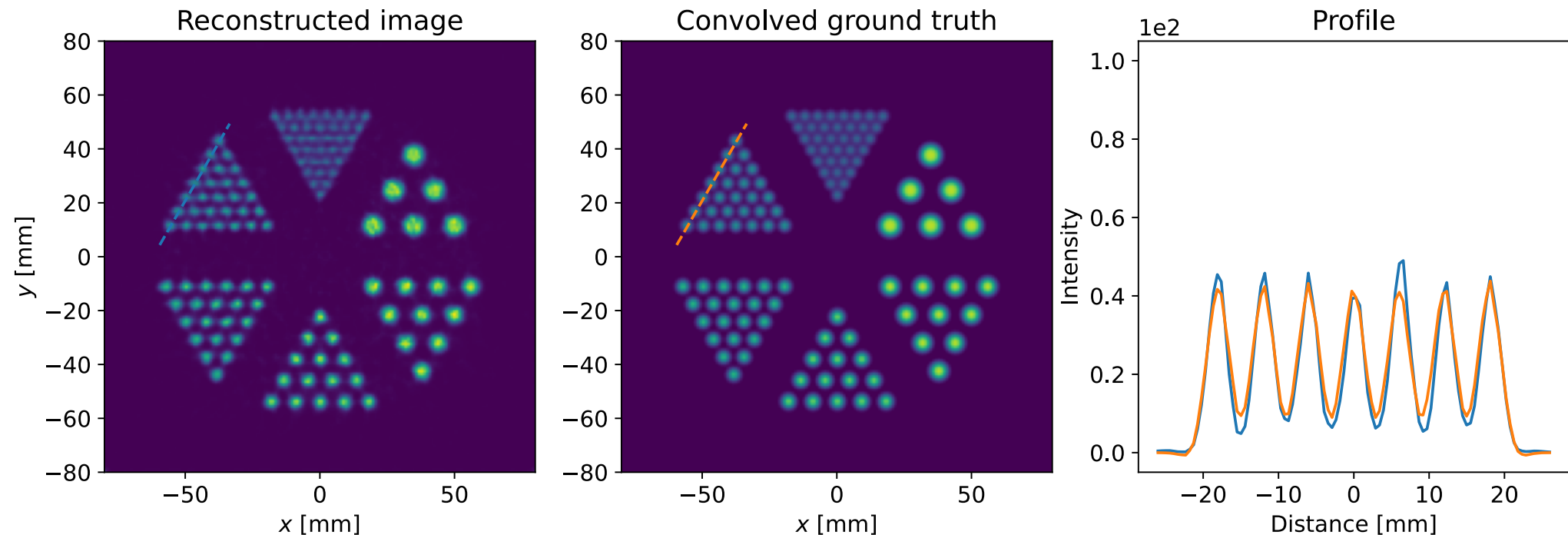
GATE: Derenzo phantom



6 x 30 x 3 mm³ insert crystals



4 x 18 x 3 mm³ insert crystals



4.

Conclusions

Conclusions

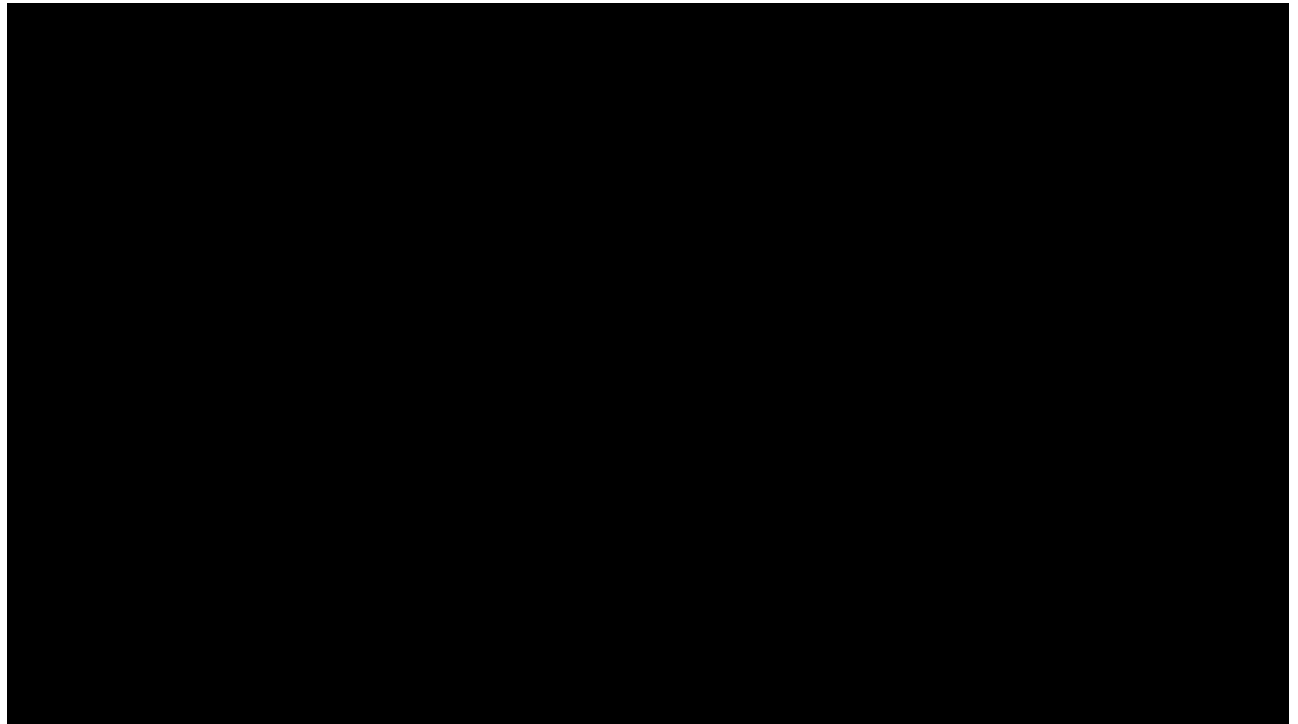
- Multi-detector geometries are possible (with simple patches) with Gate v9.3 and onwards
- For plastic scintillators (relying on Compton interactions) bigger adjustments were necessary
- Preferably fix or at least warn about the issues presented here to prevent others from finding & fixing the same ones
- Ideally, also make sure that the same does not happen with Gate 10

Thank You for Your attention!



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

Funding:



Backup slides

1.

Backup: Background & Motivation

Rationale of brain PET

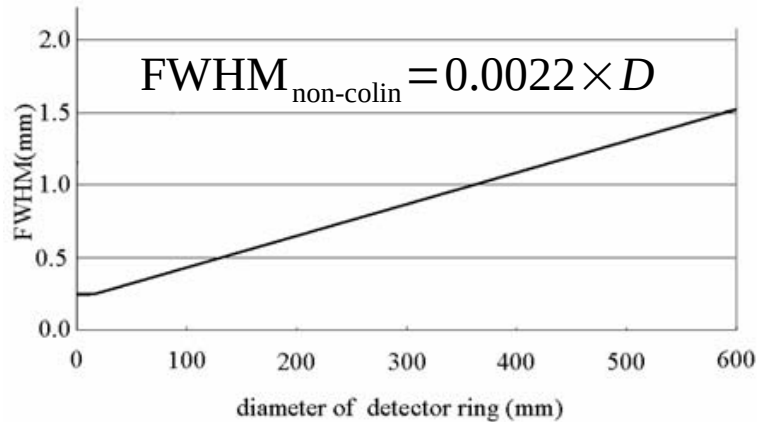
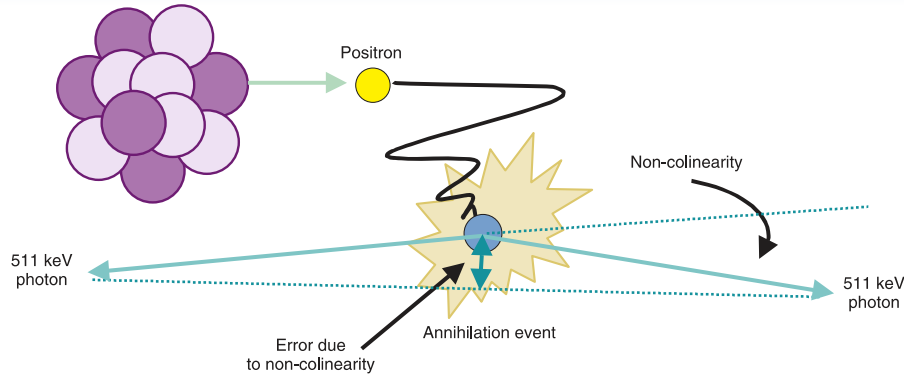
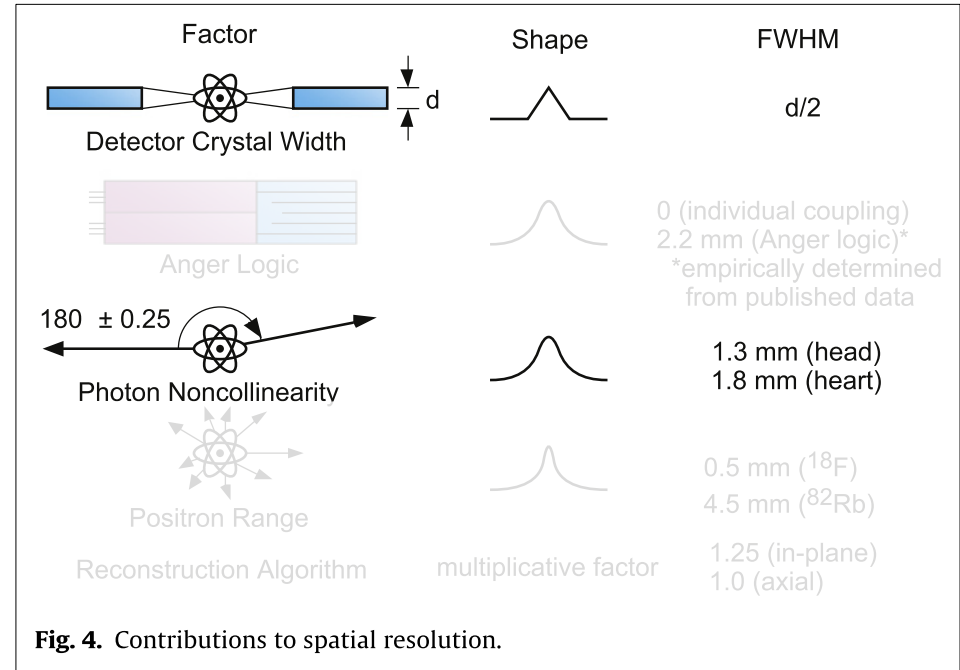


Fig. 1. Spatial resolution of PET using ^{18}F as a function of diameter of detector ring.

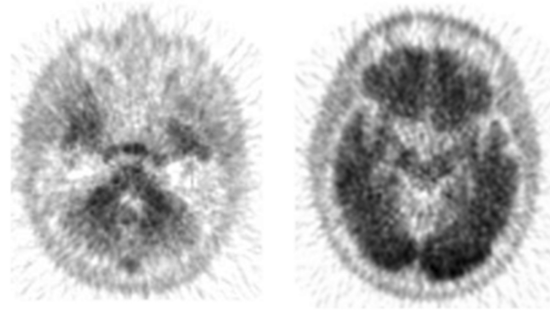


Moses. Nucl. Instrum. Methods Phys. Res. A 648 (2011)

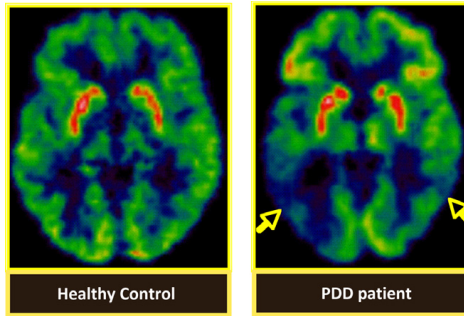
Rationale of brain PET

PET enables imaging of

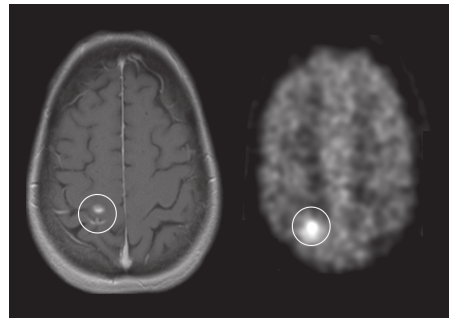
- Metabolism
- Neurochemistry
- Connectivity
- ...



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

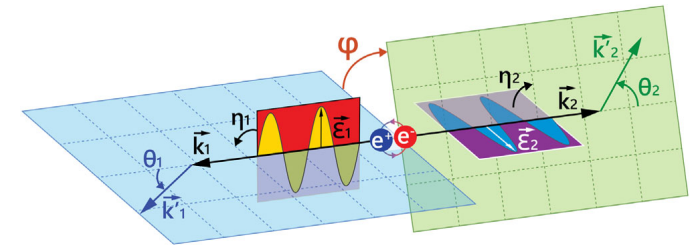
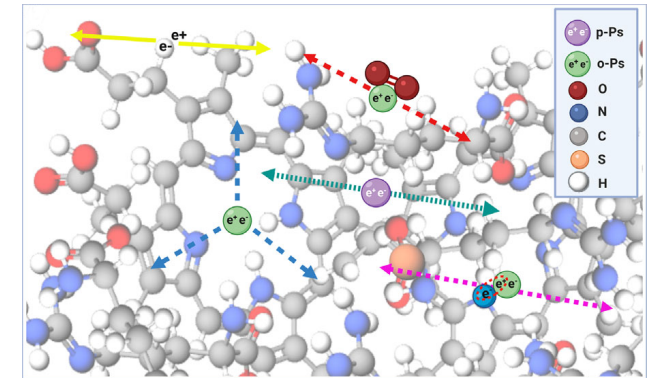


Pavese: "PET studies in Parkinson's disease motor and cognitive dysfunction" *Parkinsonism & related disorders* (2012)



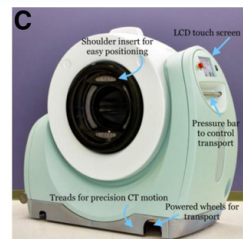
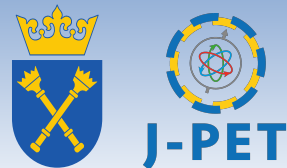
Galldiks et al.: "PET imaging in patients with brain metastasis – "report of the RANO/PET group" *Neuro-Oncology* (2019)

Novel contrast mechanisms based on positronium imaging:

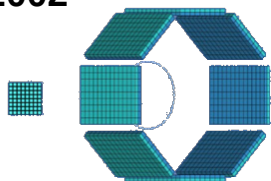


Bass et al.: "Colloquium: Positronium physics and biomedical applications" *Rev. Mod. Phys.* 95, 021002 (2023)

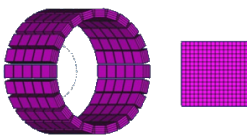
Horizontal brain PET scanners



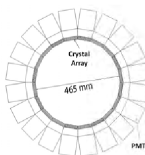
2002



2006



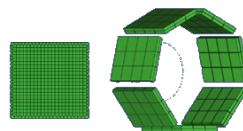
2013



2015



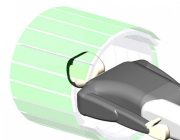
2016



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* 60 (8) 1044-1052 (2019)

April 1st 2025

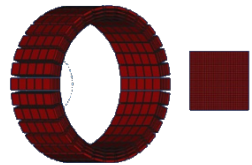
Majewski: "Perspectives of brain imaging with PET systems" *Bio-Algorithms and Med-Systems* 17(4): 269–291 (2021)

Allen et al.: "New Horizons on Brain PET Instrumentation" *PET clinics* 19(1):25-36(2024)

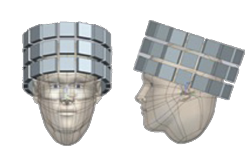
Upright brain PET scanners



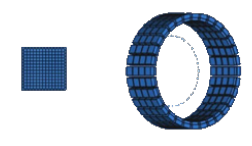
2017



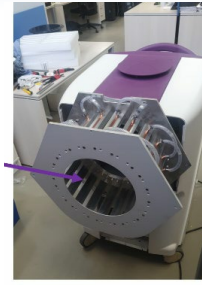
2019



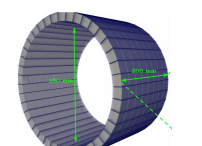
2021



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* 60 (8) 1044-1052 (2019)

Majewski: "Perspectives of brain imaging with PET systems" *Bio-Algorithms and Med-Systems* 17(4): 269–291 (2021)

Allen et al.: "New Horizons on Brain PET Instrumentation" *PET clinics* 19(1):25-36(2024)

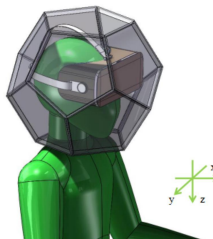
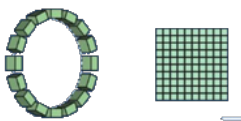
April 1st 2025

40

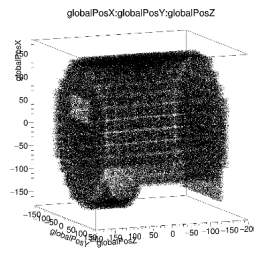
Unconv. brain PET scanners



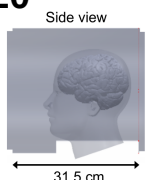
2017



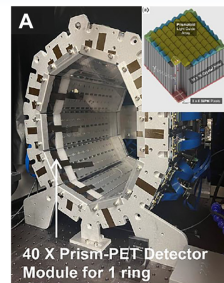
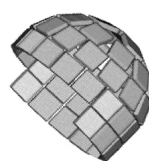
2018



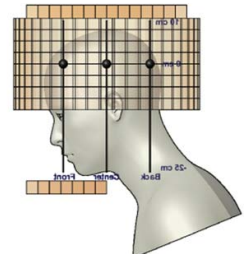
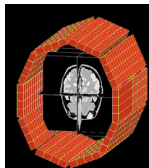
2020



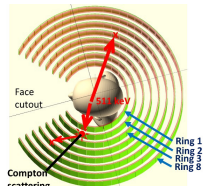
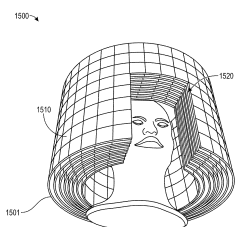
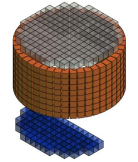
2022



2022



2022

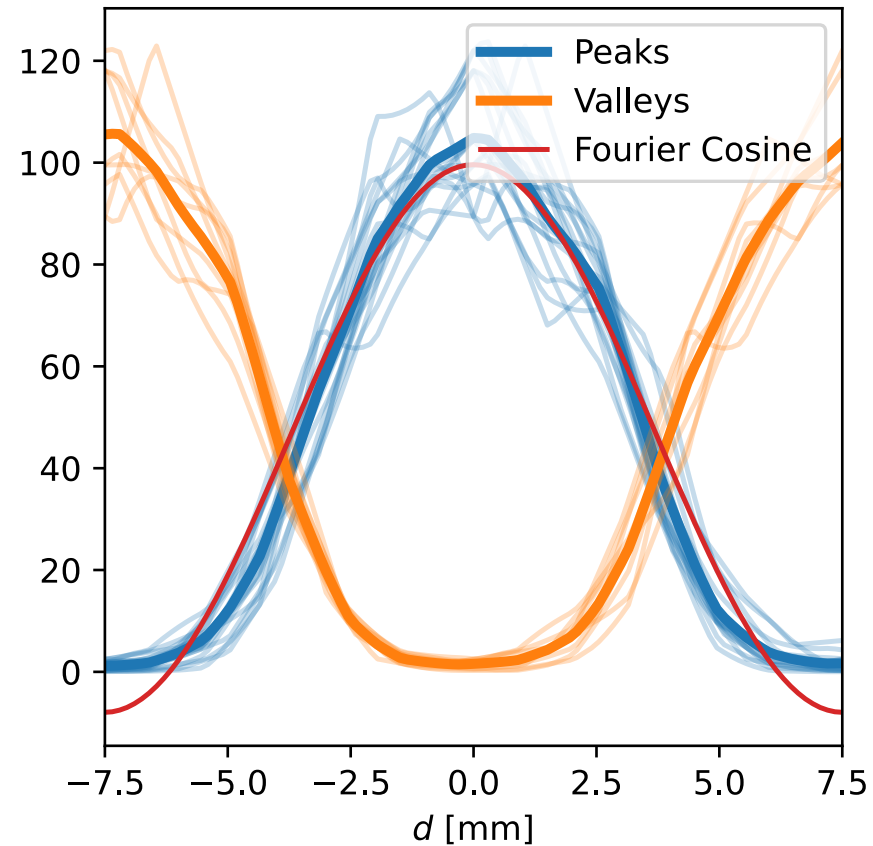
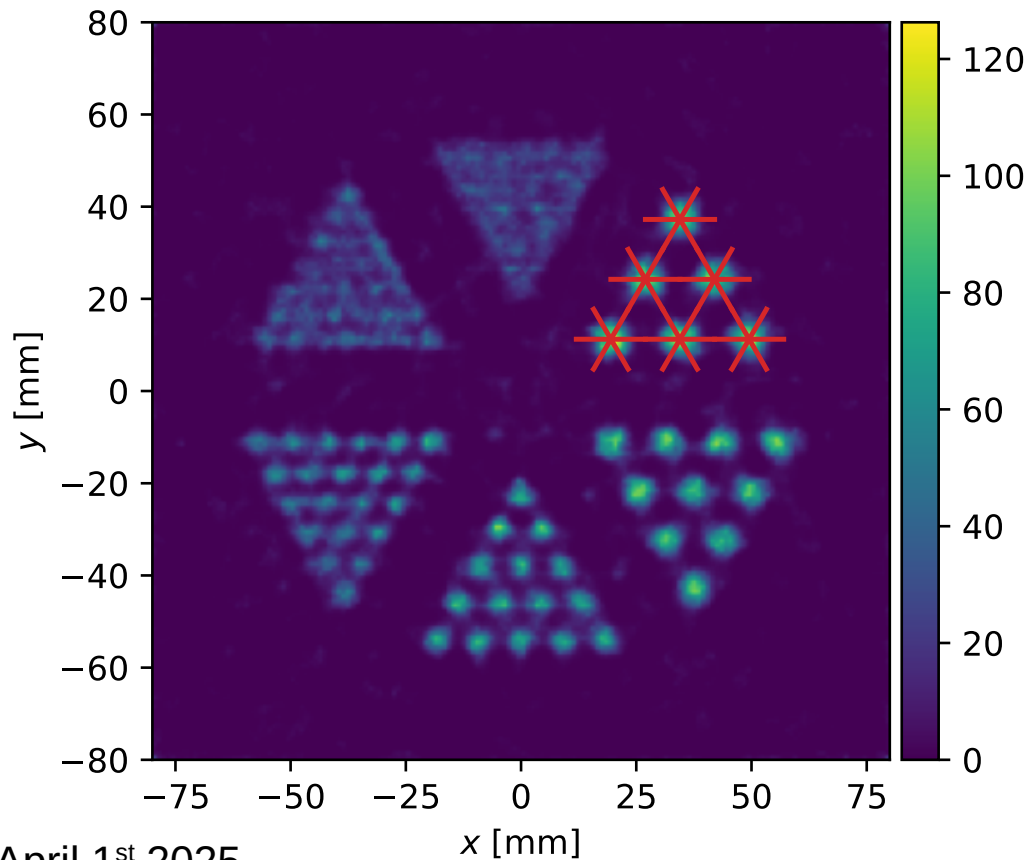


	Mind-tracker	Dodecahedron	Head shaped	VRAIN	Prism PET	Top hat PET	Br. PET Expl.
Crystal	LYSO	LYSO	LYSO	LFS	LYSO	LYSO:Ce	LYSO
Layers	1	1	3	4	1	1	8
Sens.	-	6.15%	16%	2.5%	5.2%	17%	~24%
Res.	1.5-3 mm	1.98 mm	1.5 mm	2.2 mm	1.35 mm	~ 3 mm	0.9 mm

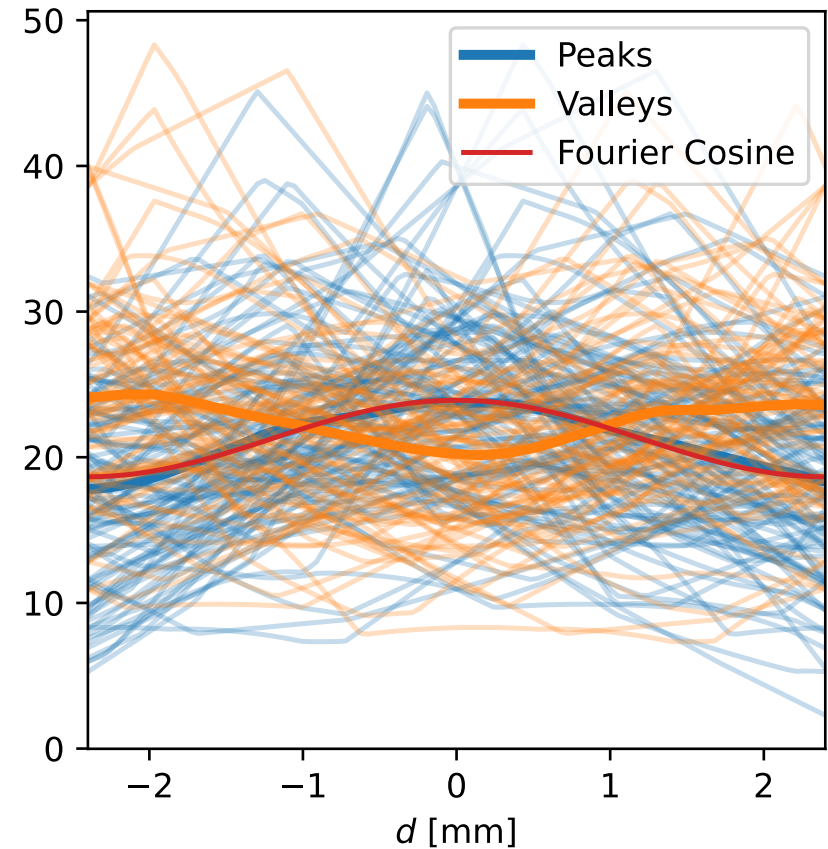
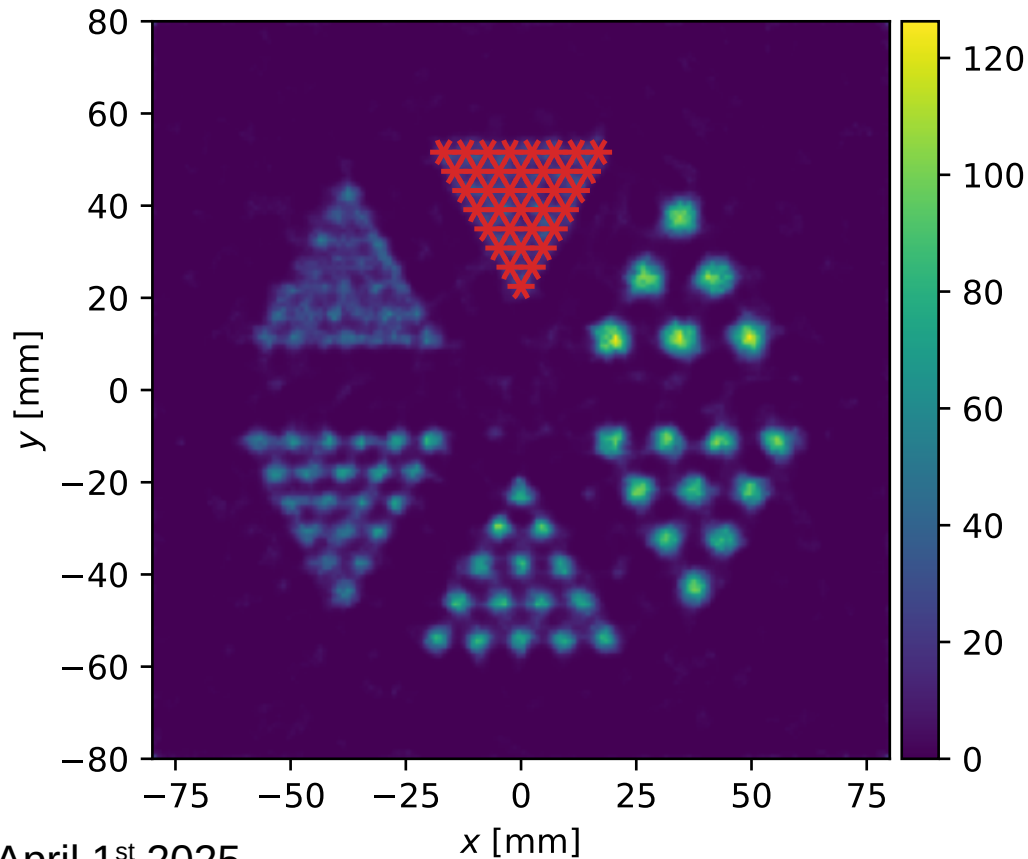
3.

Backup: CASToR reconstructions

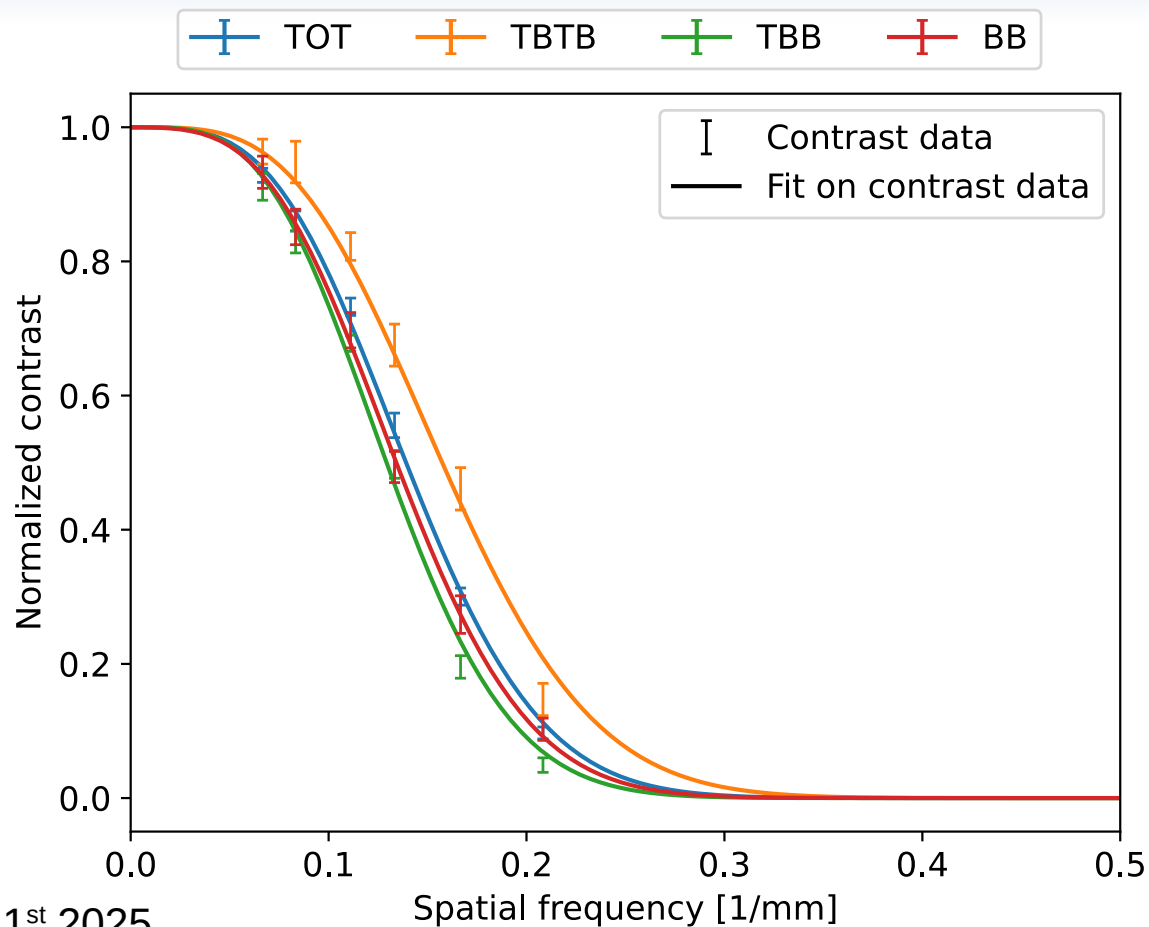
Estimating the contrast



Estimating the contrast



6 x 30 x 3 mm³ insert crystals



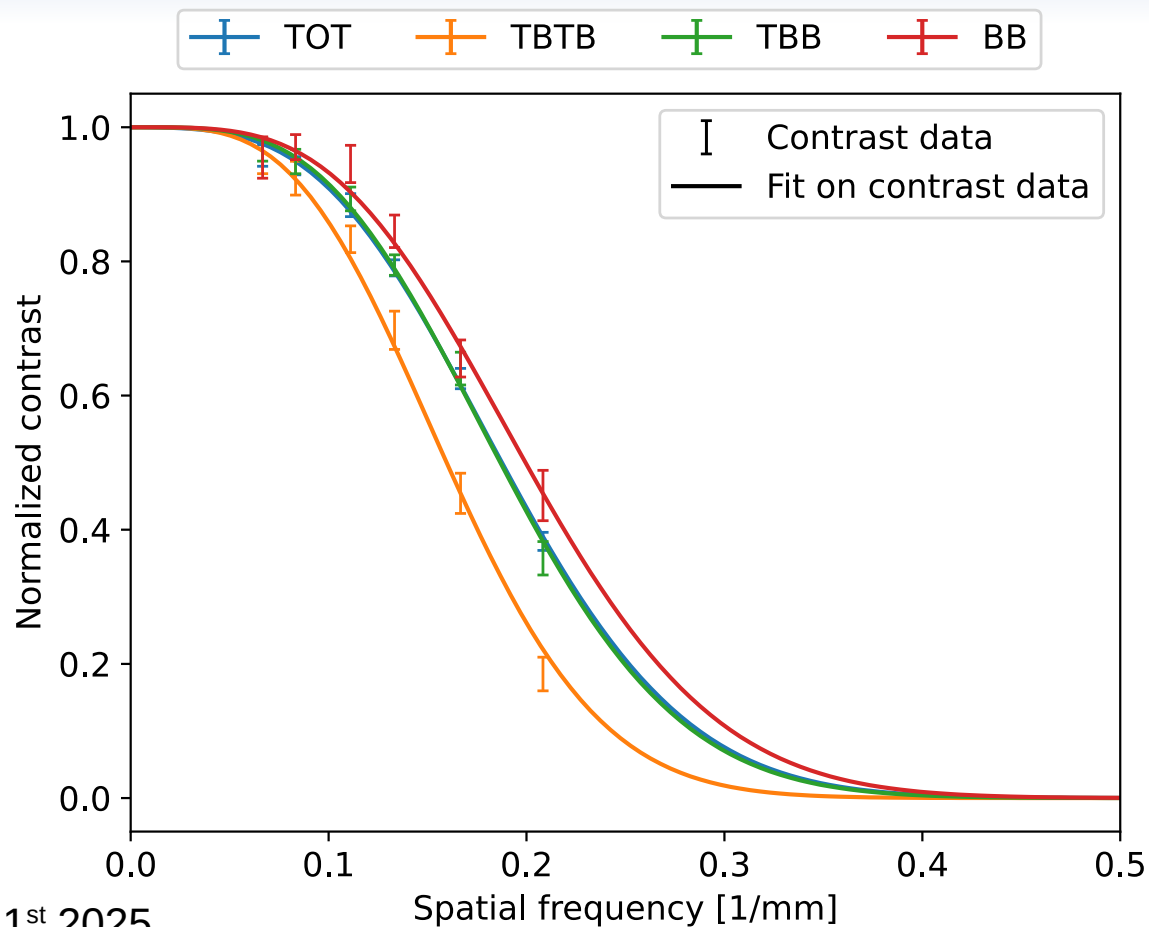
FWHM = 3.93(2) mm

FWHM = 3.49(4) mm

FWHM = 4.24(3) mm

FWHM = 4.06(3) mm

4 x 18 x 3 mm³ insert crystals



FWHM = 2.90(2) mm

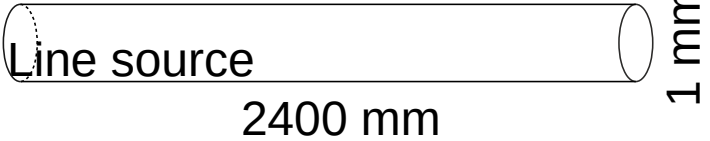
FWHM = 3.44(3) mm

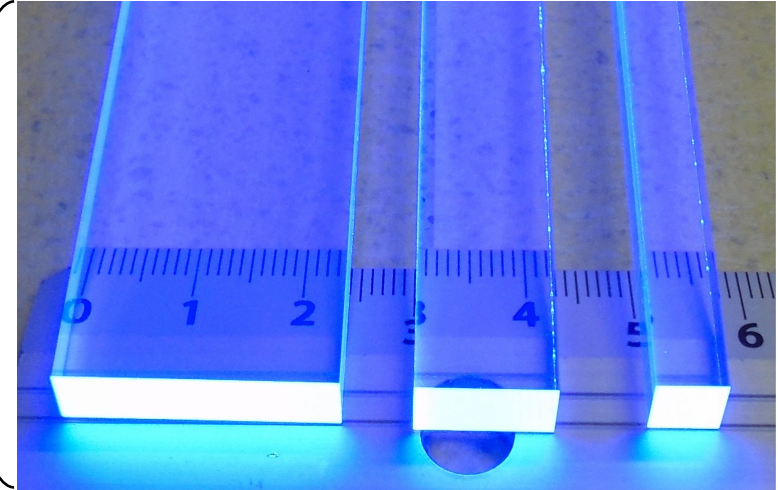
FWHM = 2.94(2) mm

FWHM = 2.75(4) mm

GATE v9.3 simulations

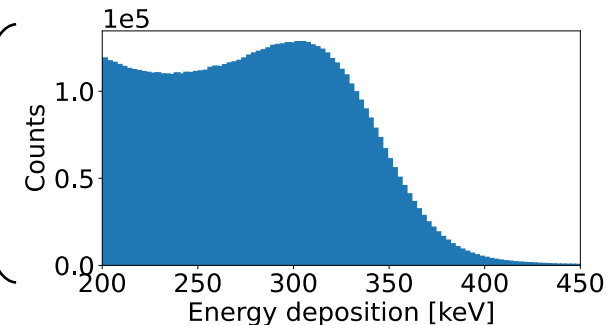
Simulation

Physics list	emlivermore_polar
Scintillator material	EJ-230
Source volume	 1 mm 2400 mm
Source type	511 keV back-to-back photons
Source activity	1 MBq
Scan time	100 s

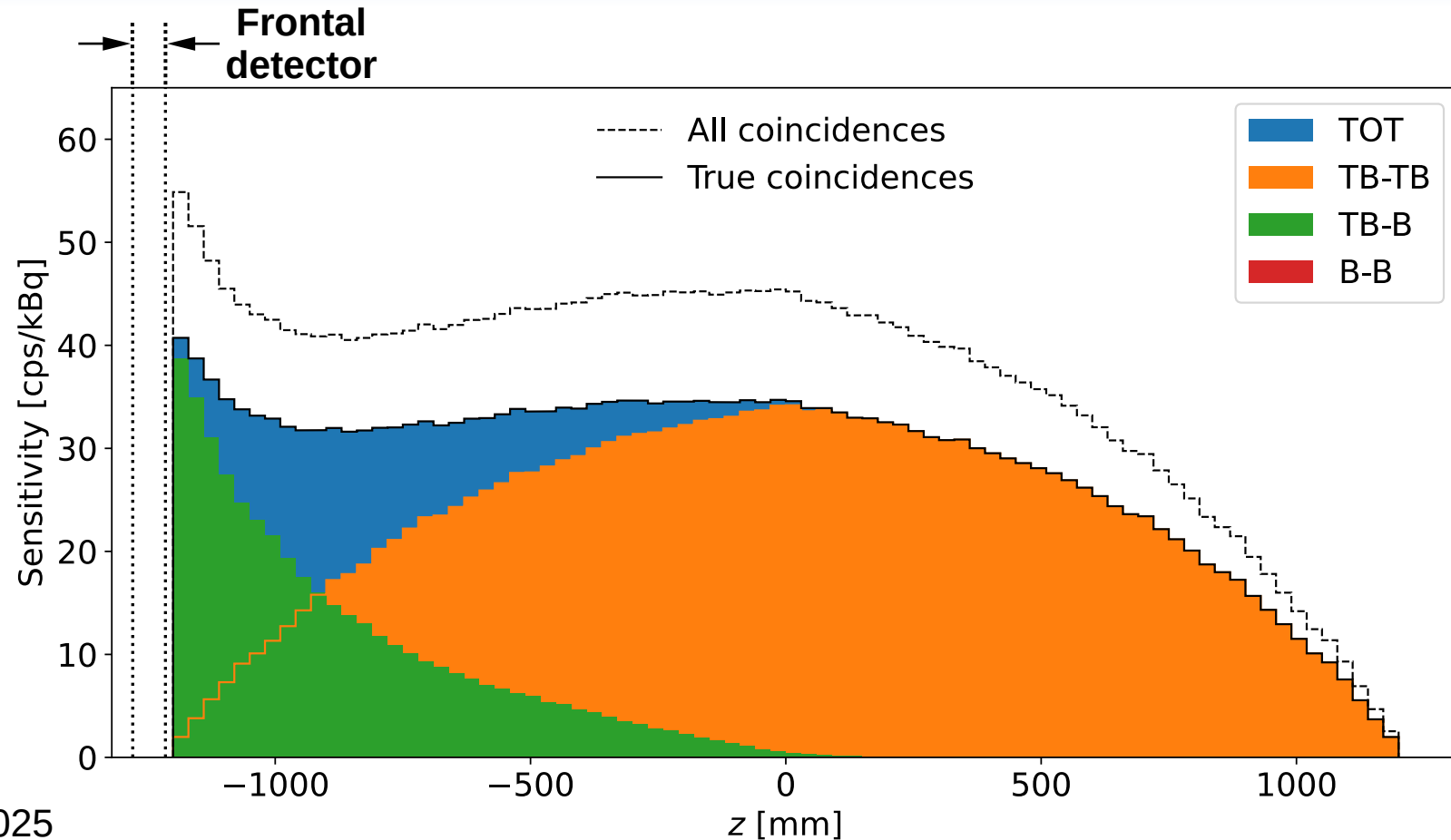


Event selection

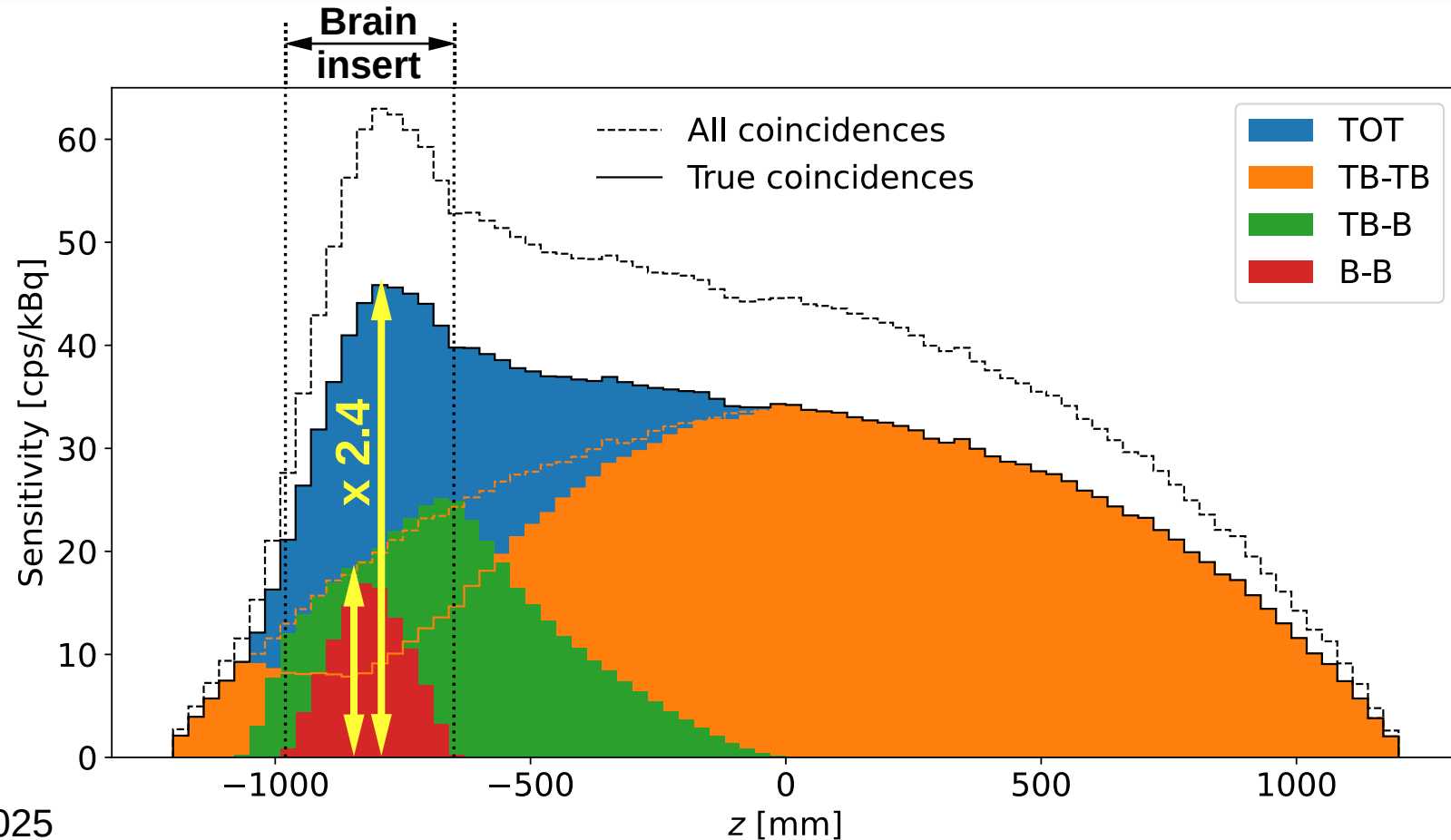
Lower threshold	200 keV
Coincidence window	3 ns



Sensitivity: Frontal detector



Sensitivity: TB & Brain insert



Sensitivity: TB & Brain insert

