

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

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GATE Scientific meeting 2025

April 1st - 3rd 2025





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



Background & Motivation

Total body PET scanners



~ 2 m

First large field of view scanners commercially available:



https://www.siemens-healthineers.com/molecular-imaging/pet-ct/biograph-vision-quadra

https://eu.united-imaging.com/en/product-service/products/mi/uexplorer

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

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

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But also: very expensive ...

Total body J-PET scanner



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



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

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Not optimized for brain imaging ...

Magnification inserts



"[...] hybrid systems using a moderateresolution **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

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Multi-detector geometries in GATE

GATE v9.3 and onwards ...



frontiers | Frontiers in Physics

TYPE Technology and Code PUBLISHED 21 March 2024 DOI 10.3389/fphy.2024.1294916

New GATE Digitizer Unit for versions post v9.3

Olga Kochebina¹*, 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





Brain insert







Brain insert variations







Brain insert detector block variation





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



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The list of digitizer entries features only one CoincidenceSorter:

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



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



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Patch: Comment the automatically generated GateCoincidenceSorter's called "Coincidences"

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

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



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Similar issue also for other PET geometries



Same issue for geometries that are not nested:



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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 😿



Issue: The minSectorDifference does not distinguish between scanners and has to be larger than 1



Issue #2: minSectorDifference 🟅



Issue: The minSectorDifference does not distinguish between scanners and has to be larger than 1

Patch: Set the minimum to zero:



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

50	<pre>cmdName = GetDirectoryName()+"minSectorDifference";</pre>
51	<pre>minSectorDiffCmd = new G4UIcmdWithAnInteger(cmdName.c_str(),this);</pre>
52	minSectorDiffCmd->SetGuidance("Set the minimum sector difference for
	<pre>valid coincidences.");</pre>
53	minSectorDiffCmd->SetParameterName("diff",false);
54	<pre>//minSectorDiffCmd ->SetRange("diff >=1");</pre>
55	minSectorDiffCmd->SetRange("diff>=0");

Issue #2: minSectorDifference 😿 🖉

After setting minSectorDifference=0









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 in the currently processed layer.

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;
```



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]



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• In Python / numpy:

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



Before





After



Issue #4: Memory leaks







CASToR reconstructions

Reconstruction with CASToR



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





Merlin et al.: "CASTOR: a generic data organization and processing code framework for multi-modal and multi-dimensional tomographic reconstruction" *Phys. Med. Biol.* **63** (2018)

GATE: Derenzo phantom





GATE: Derenzo phantom





6 x 30 x 3 mm³ insert crystals





4 x 18 x 3 mm³ insert crystals











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- 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



Backup: Background & Motivation

Rationale of brain PET







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)

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Horizontal brain PET scanners 😿 👰













	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





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)

40

Unconv. brain PET scanners





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)



Backup: CASToR reconstructions

Estimating the contrast





Estimating the contrast





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GATE v9.3 simulations



Simulation

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

Event selection

Lower threshold	200 keV	4
Coincidence window	3 ns	





Sensitivity: Frontal detector





Sensitivity: TB & Brain insert



Sensitivity: TB & Brain insert

