GRID applied to simulation of Positron Emission Tomographic (PET) Systems using GATE

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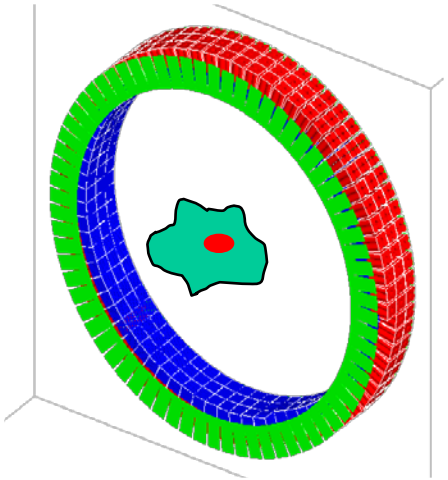
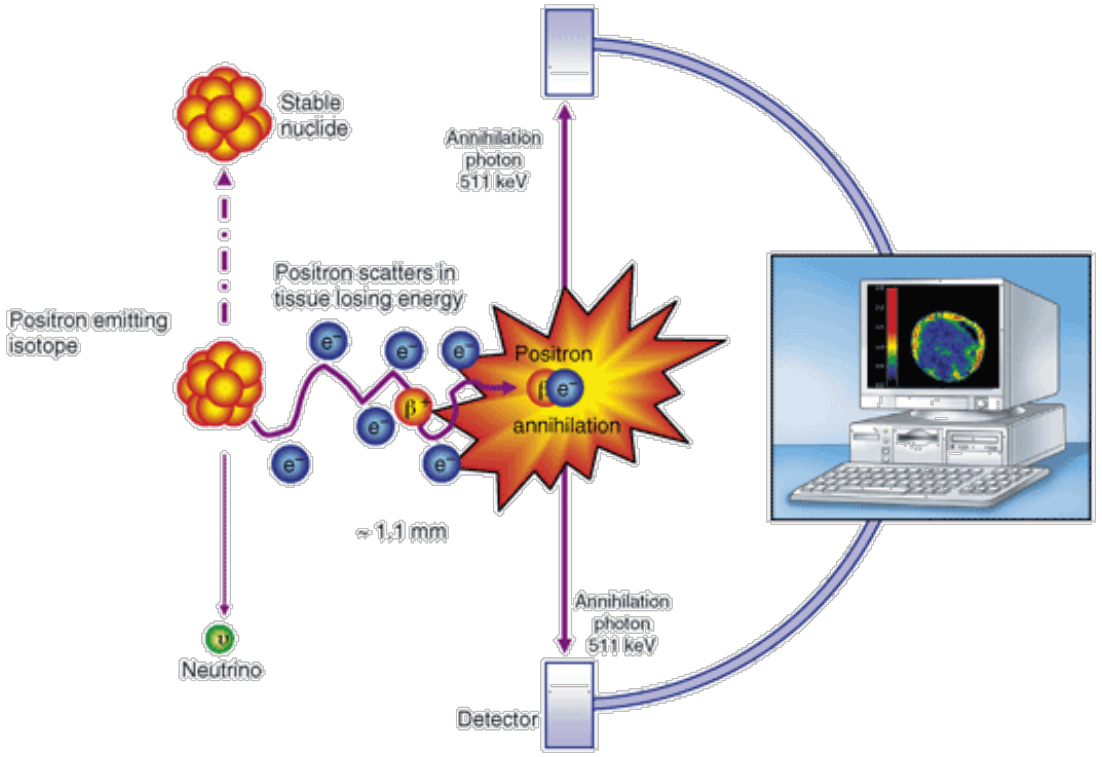
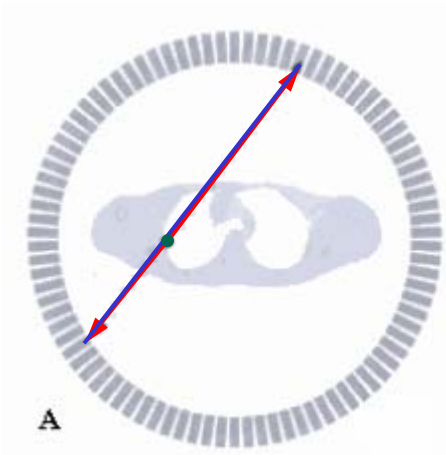
PCI-2011 Workshop, Rabat, 27-28 June 2012

Basics of the Positron Emition Tomography (PET) System

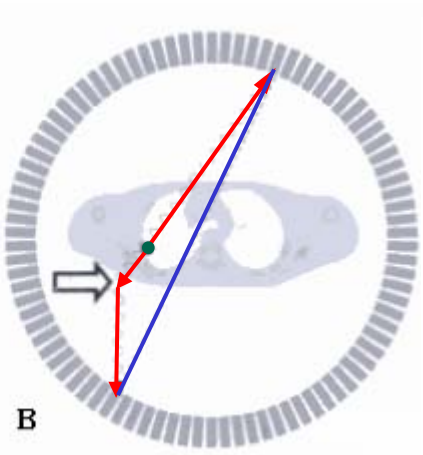




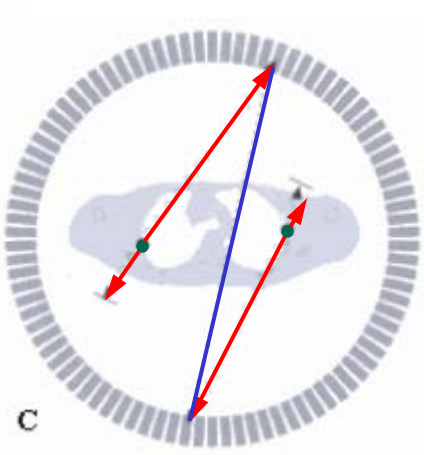
Line of Response (**LOR**)



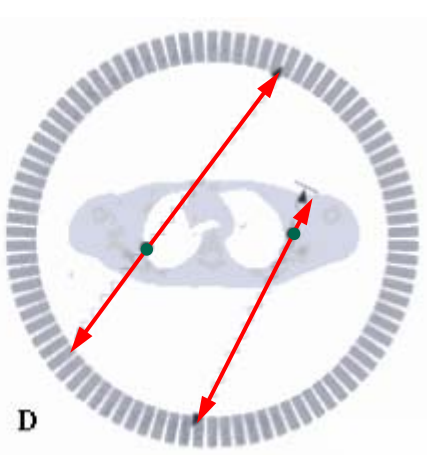
True



Scattered



Random



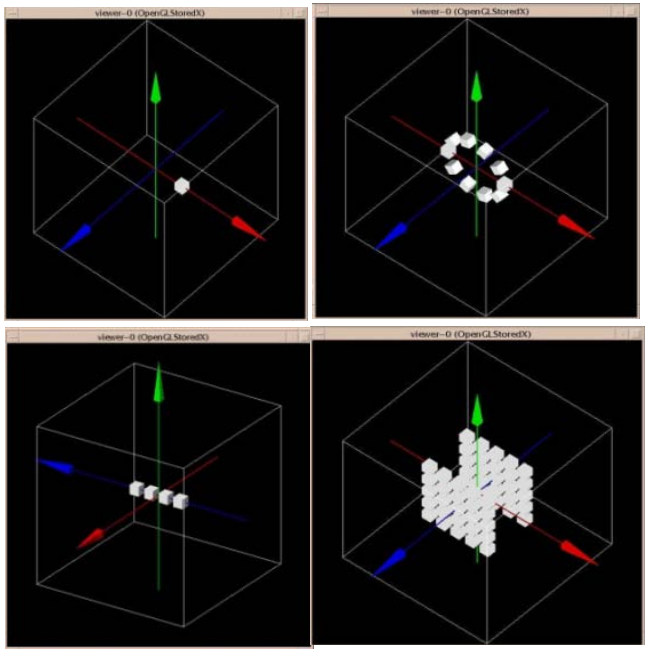
Multiple

GATE: Geant4 Application for Tomographic Emission

GATE is a Geant4-based simulation platform for emission tomography

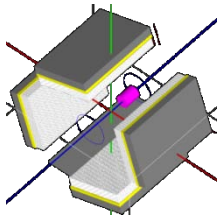
Geant4 is used as the basis layer for Monte Carlo simulations of nuclear medicine acquisition systems in Gate.

Gate allows the user to realistically model experiments using accurate physics models and time synchronization for detector movement trough a script language contained in a macro file.

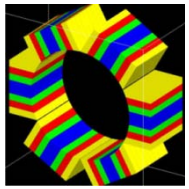


```
#WORLD
/gate/world/geometry/setXLength 400. cm
/gate/world/geometry/setYLength 400. cm
/gate/world/geometry/setZLength 400. cm

#ECATEXACTHR+PETSCANNER
/gate/world/daughters/name ecat
/gate/world/daughters/insert cylinder
/gate/ecat/setMaterial Air

#REPEATPMT
/gate/PMT/repeaters/insert cubicArray
/gate/PMT/cubicArray/setRepeatNumberX 1
/gate/PMT/cubicArray/setRepeatNumberY 2
/gate/PMT/cubicArray/setRepeatNumberZ 2
```

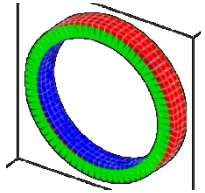
Simulate various system :



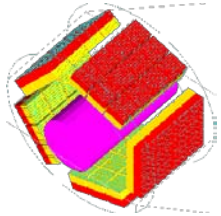
SPECT



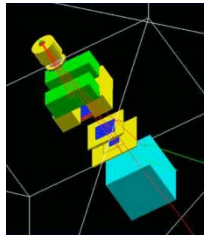
OPET scanner



Ecat PET



CylindricalPET



Radiotherapy

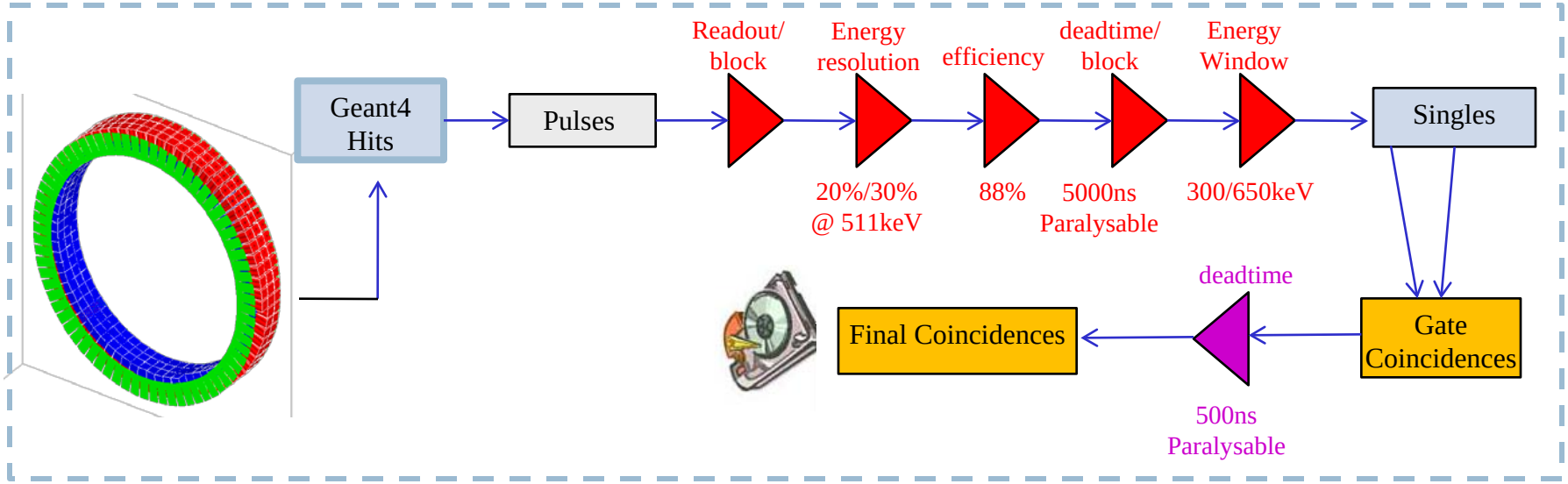
GATE: Simulation Conditions for a PET system

Parameters

- ✓ Lowenergy models for Compton and Rayleigh
- ✓ Energy cuts: delta-ray 10 keV, X-rays 10 keV,
- ✓ Electron range cut 2 mm

- ✓ Coincidence time window 12 nsec
- ✓ Energy window (in spectra) 300-650 keV

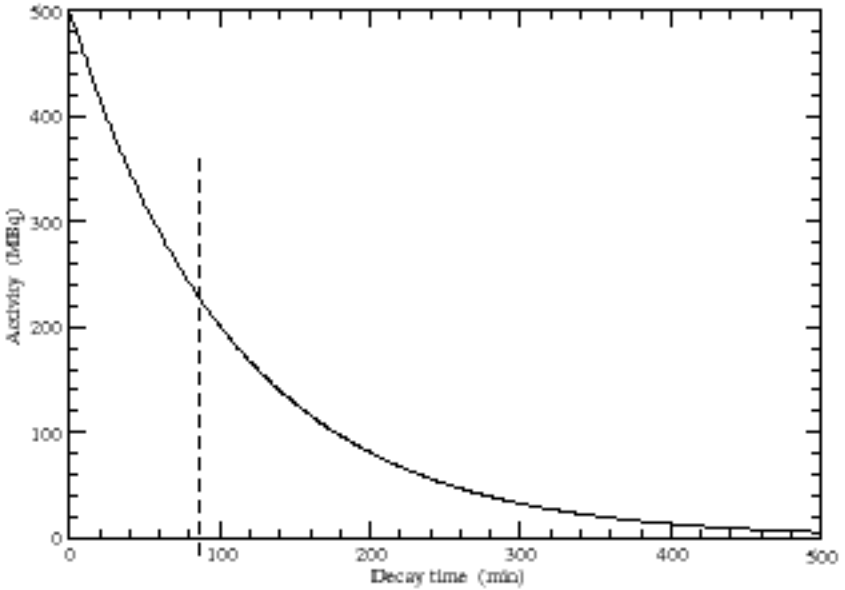
Signal processor chain



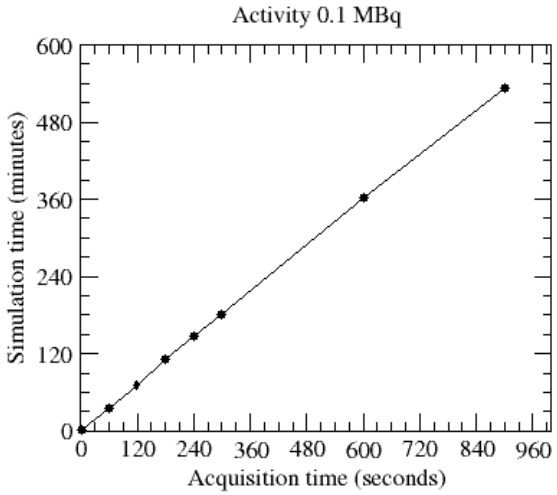
GATE: Simulation of realistic model of an experiment

In a real experiment :

500 MBq initial FDG (18F),
acquisition during 20 min,
Pause during 15 – 20 min,
do this untill reaching between 10 - 20 times the half-live of the isotope.



GATE: Simulation with low parameters value

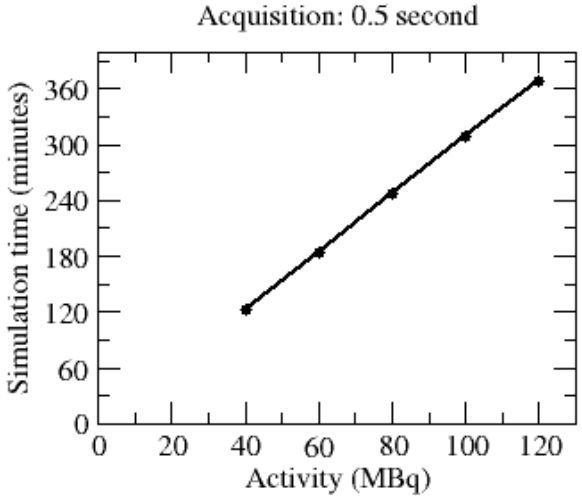


Simulation with low activity: **0.1 MBq**

Simulating 15 minutes of a real acquisition needs around 9 hours of computing time (83% of the source activity reached)

Simulating 1 MBq acquisition would need 10 times more time of Computing time : 90 hours !

…and we are still far from simulating the 500 MBq experiment…



Simulation with low acquisition time: **0.5 sec**

Simulating PET response for 120 MBq needs more than 6 hours

Simulating 500 MBq activity during 0.5 seconds acquisition time would need around 25 hours

…and we are still far from the 20 minutes of acquisition time…

Simulating with high accuracy a realistic model of an experiment using Gate is very time consuming !

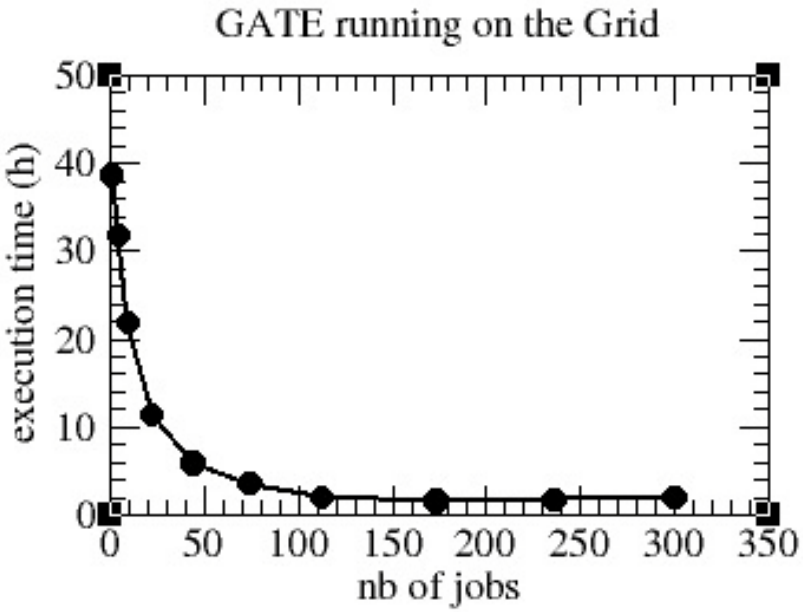
GRID applied to PET systems simulation using GATE

What do we measure by simulation for a PET system with GATE ?

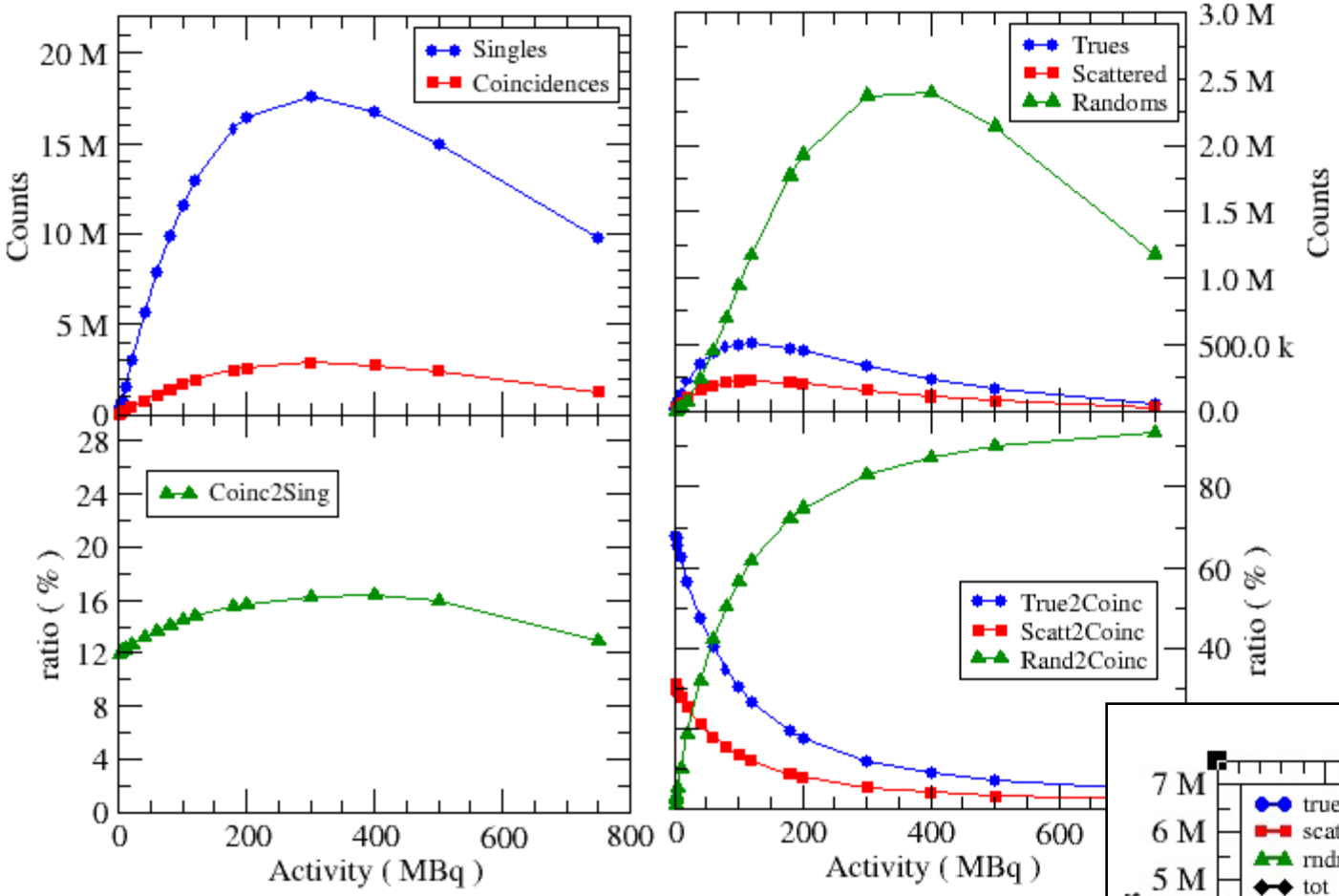
For a given PET system, to validate the simulation GATE code, few parameters are “calculated” and compared to measured ones obtained in a real experimental.

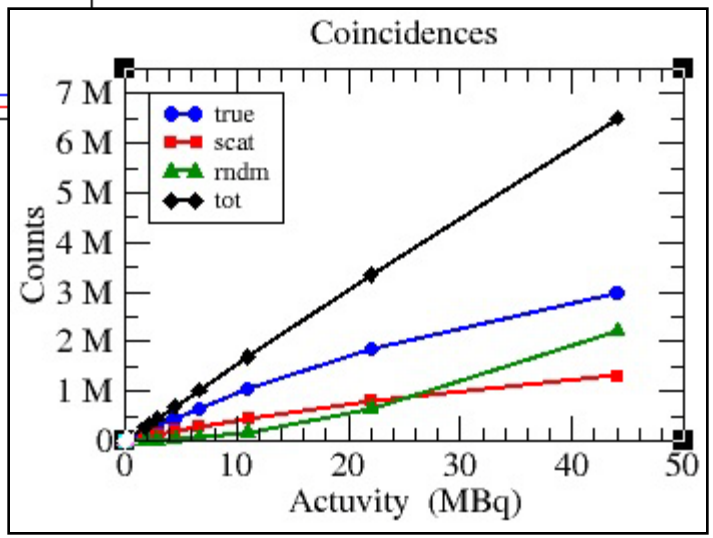
Counts of different type (singles, coincidences, noise,…)
Scatter Fraction
Sensitivity
Spatial resolution

GRID is also used to run simultaneously
several Monte Carlo simulations
with different input parameters.

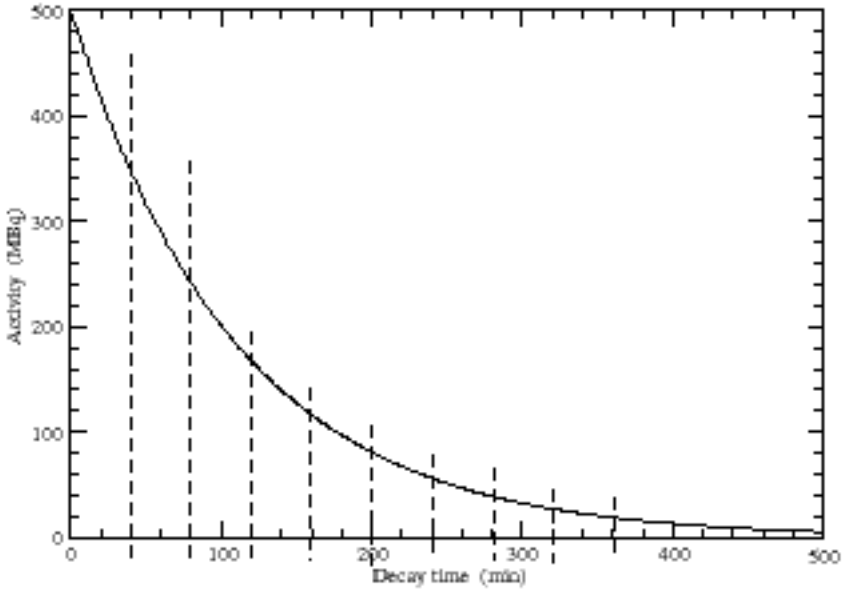


GRID applied to PET systems simulation using GATE : Example





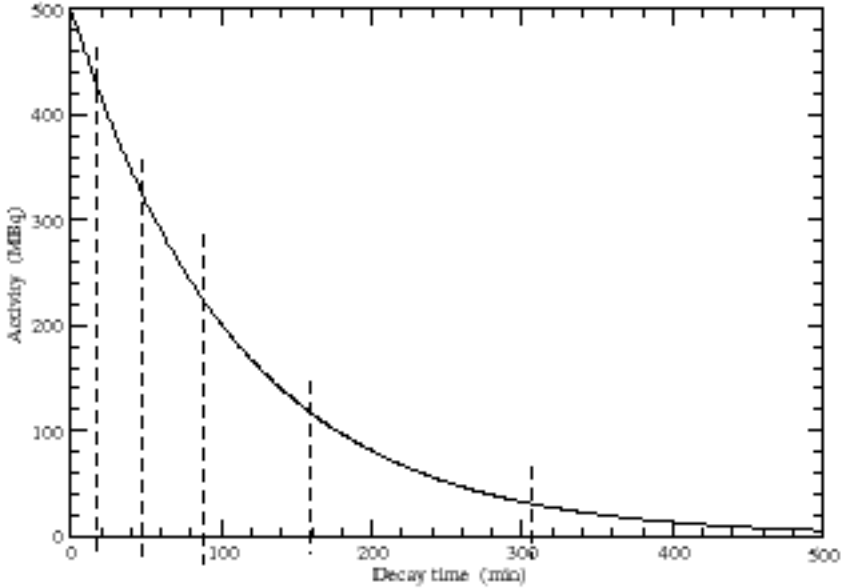
GRID applied to PET systems simulation using GATE : The Time-Domain Decomposition



Constant Time interval

The number of events to simulate is different for each time interval

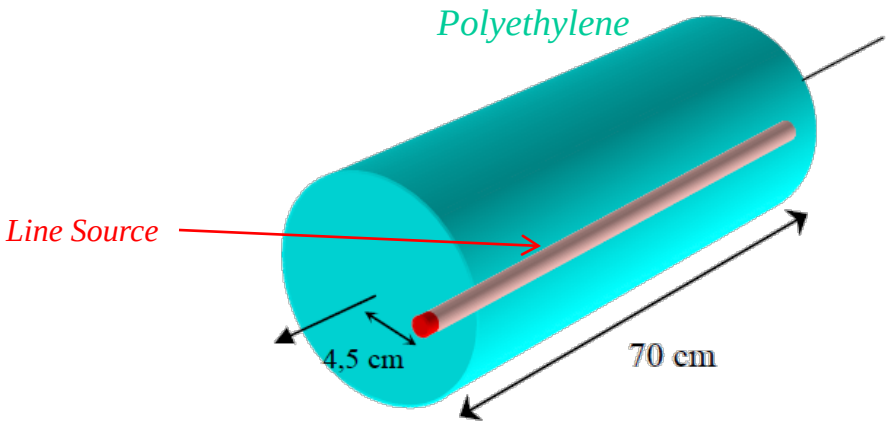
Time interval determined such as simulation is always performed on a constant number of events



Scatter fraction

is defined to be the ratio of scattered events to total events, which are measured at a sufficiently low counting rate that random coincidences, dead time effects are negligeble.

$$SF = \frac{\text{scattered events}}{\textit{total events}}$$

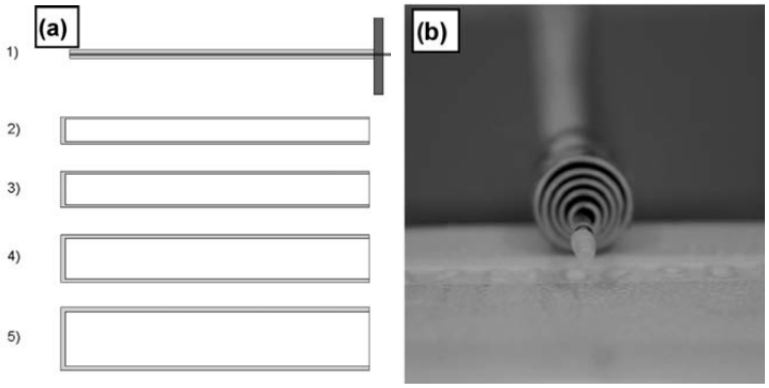


NEMA scatter fraction phantom

GATE: Phantom geometry used for Sensitivity simulation

Sensitivity

The sensitivity performance parameter of a scanner represents its ability to detect annihilation radiation.



A sensitivity measurement phantom: (a) schematic diagram, (b) actual phantom viewed end-on.

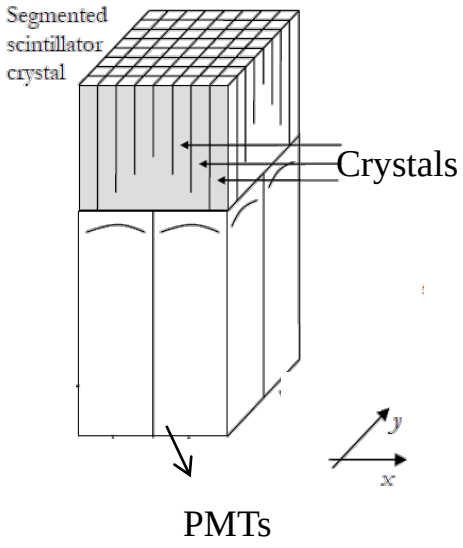
Tube No.	ID[a] (mm)	OD[b] (mm)	Thickness (mm)	Length (mm)
1	3.9	6.4	1.25	700
2	7.0	9.5	1.25	700
3	10.2	12.7	1.25	700
4	13.4	15.9	1.25	700
5	16.6	19.1	1.25	700

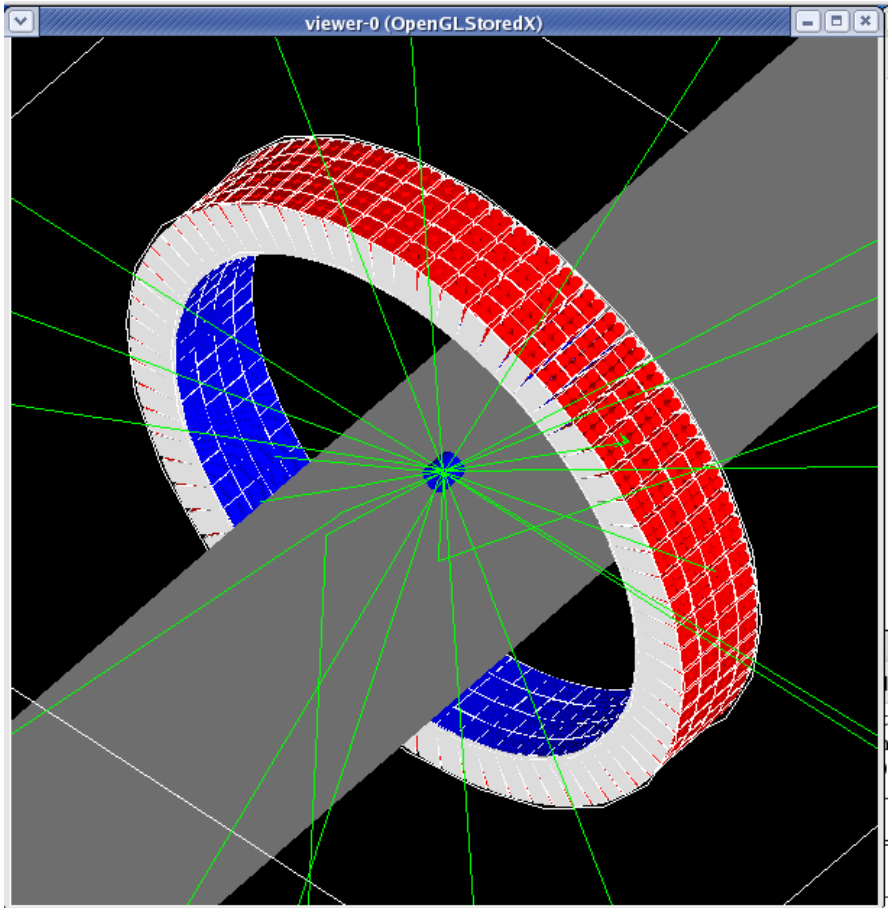
[a] ID: internal diameter.
[b] OD: outer diameter.

dimensions of the sensitivity measurement phantoms

GATE: Geometry for ECAT Exact HR+ Scanner system simulation

ECAT Exact HR+





Parameters	Ecat exact HR+
Detector Material	BGO
Crystal Dimension (mm^3)	4,05x4,39x30
Detector Ring Diameter (cm)	82,4
Transverse Field of View (cm)	58,3
Axial Field of View (mm)	155
Coincidence Time Windows (nsec)	12

GATE: ECAT Exact HR+ Scanner system simulation
Results:

The **SENSITIVITY** of a scanner represents its ability to detect annihilation radiations.

	MEASURED	SIMULATED
	SENSITIVITY	
T.O.P = 0 cm	6650 cps/MBq	6877 cps/MBq
T.O.P = 10 cm	7180 cps/MBq	7235 cps/MBq
Ratio (0 cm/10 cm)	0.926	0.95

T.O.P : Transaxial Offset Position

The **SCATTER FRACTION** is the ratio of scattered events to total events (at low counting rate).

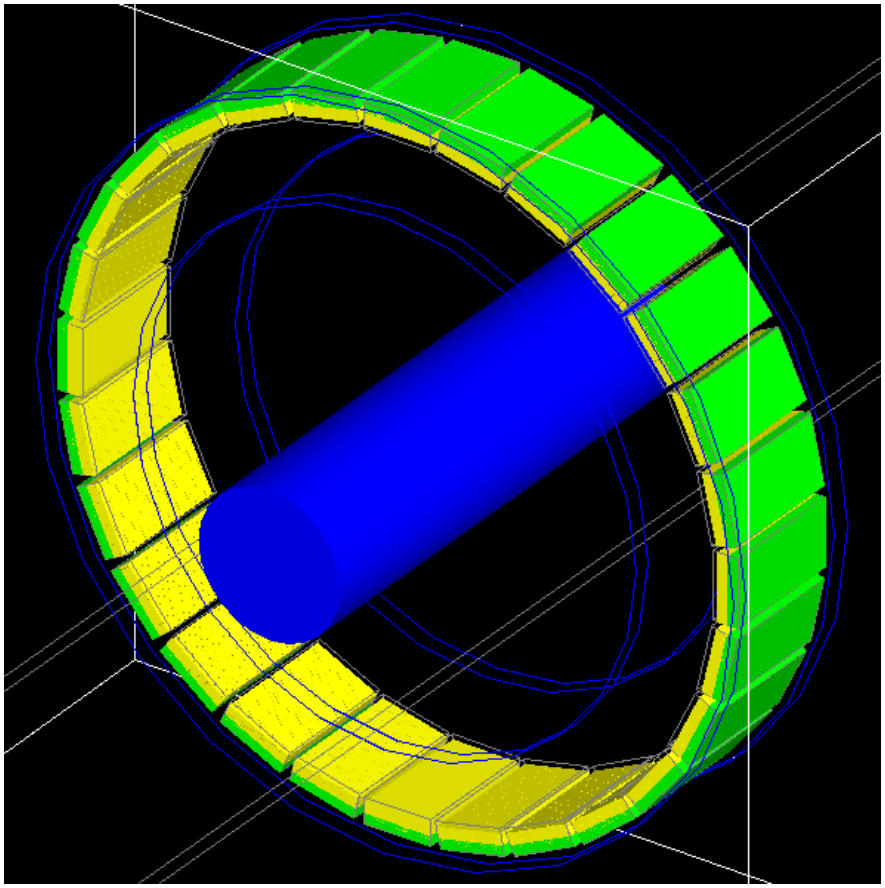
$$SF = \frac{\text{scattered events}}{\textit{total events}}$$

MEASURED	SIMULATED
SCATTER FRACTION	
46 %	44 %

Energy window (keV) 300 - 650

GATE: Geometry for PHILIPS Gemini TF Scanner system simulation

PHILIPS Gemini TF



Parameters	PHILIPS Gemini TF
Detector Material	LYSO
Crystal Dimension (mm^3)	4 x4x22
Detector Ring Diameter (cm)	90
Transverse Field of View (cm)	57,6
Axial Field of View (mm)	180
Coincidence Time Windows (nsec)	3,8

GATE: PHILIPS Gemini TF Scanner system simulation
Results:

The **SENSITIVITY** of a scanner represents its ability to detect annihilation radiations.

	MEASURED	SIMULATED
	SENSITIVITY	
T.O.P = 0 cm	6600 cps/MBq	6170 cps/MBq
T.O.P = 10 cm		5779 cps/MBq
Ratio (0 cm/10 cm)		0.94

T.O.P : Transaxial Offset Position

The **SCATTER FRACTION** is the ratio of scattered events to total events (at low counting rate).

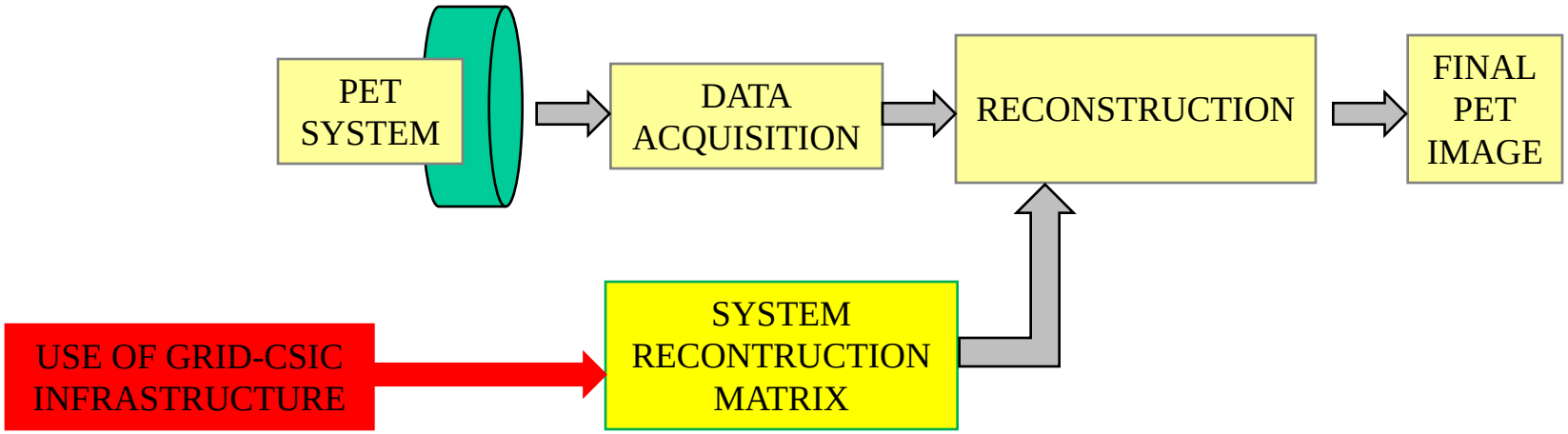
$$SF = \frac{\text{scattered events}}{\textit{total events}}$$

MEASURED	SIMULATED
SCATTER FRACTION	
27 %	26 %

Energy window (keV) 440 - 665

Using Grid for Image Reconstruction

IMAGE RECONSTRUCTION :



Matrix Size :

437 x 20 x 662976 = 5.8×10^9 elements

Calculation time :

- 2 months, with one CPU
- 12 hours, running 200 jobs simultaneously

THANK YOU