



## General Electric Signa PET-MR simulations: validation with GATE

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FACULTÉ  
DE MÉDECINE



Context & applications

Validations

Corrections

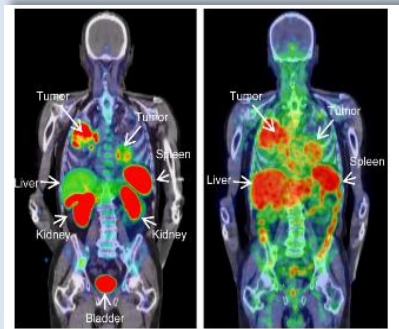
Clinical imaging

Conclusion & perspectives

# Context & applications

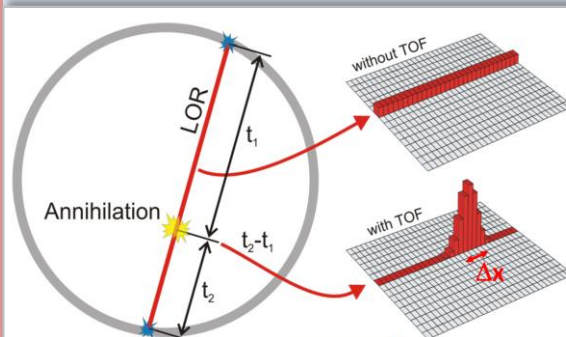
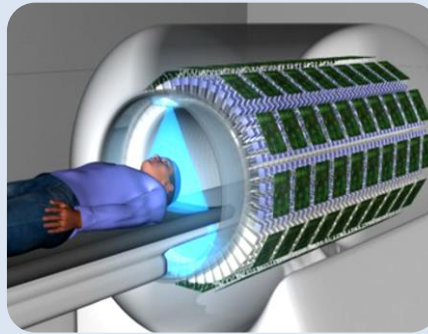
## PET imaging

- Dynamic total-body imaging
- Pharmacology & drugs development



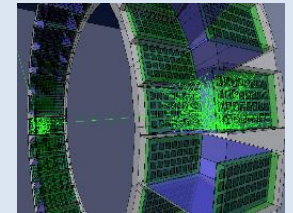
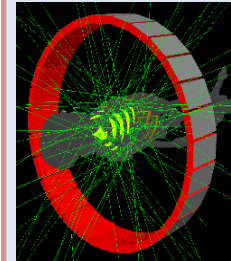
## New PET generation

- Total body
- « Embedded » machine learning
- Ultra high TOF resolution ( $10ps < TOF < 100ps$ )

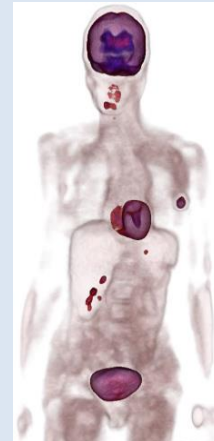


## Numerical twin

- Instrumentation development
- Data correction
- Image reconstruction algorithm
- Data analysis



+



# Gate simulation

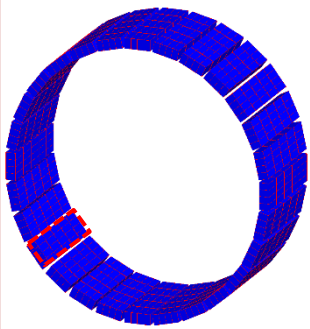
25mm Scintillator (LBS) Crystal Array  
with Light Guides and Enhanced  
Spectral Reflectors (ESR)

SiPM - Silicon Photomultiplier  
with Circuit Boards/ASICs



Digitizer module :

- Adder « centroïd »
- Readout « winner take all »
- Spatial blurring : 1 mm [FWHM]
- Time blurring : 270ps FWHM
- Paralyzable dead time : 750 ns
- Crystal quantum efficiency : 93%



=

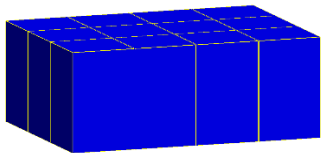


25 mm (LYSO) crystal array

1 detection unit:

= 5 matrices

= 720 crystals



Simulations : Gate 9.1

Image reconstruction : Castor 3.1.1

Context & applications

**Validations**

Corrections

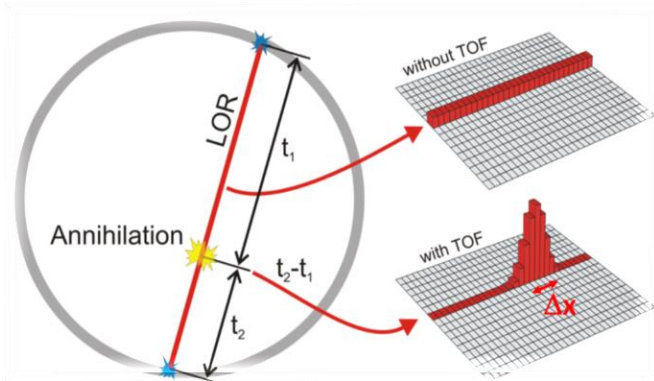
Clinical imaging

Conclusion & perspectives

# CTR : time blurring validation

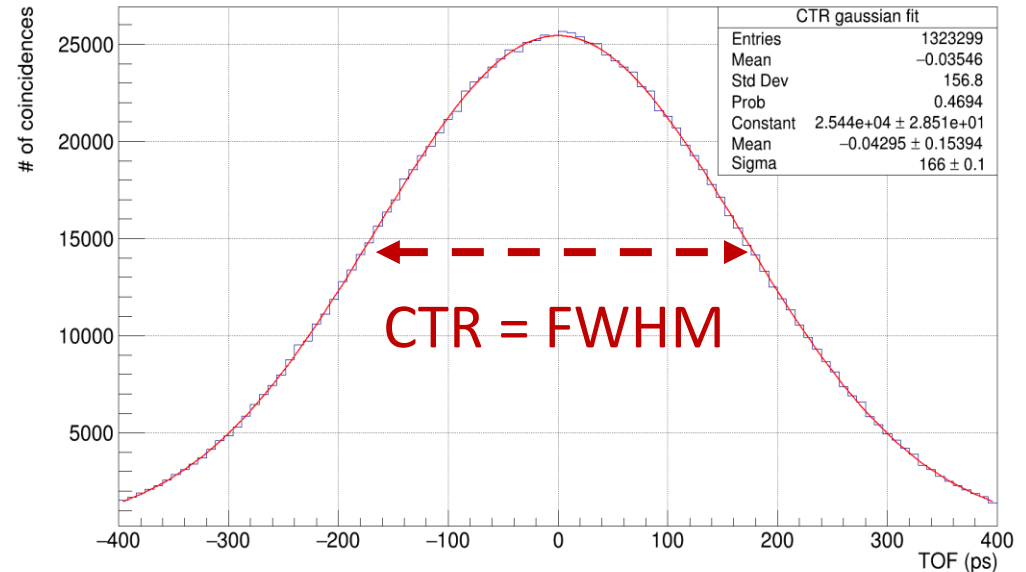
CTR : minimal measurable TOF (*Coincidence Time Resolution*)

TOF : difference between arrival times of two gammas (*Time Of Flight*)



TOF = *added* information about the annihilation location

Gate TOF measure (GE) with 270ps blurring



Histogram of TOF from Gate output fitted using Root

- PET CTR simulated **without** blurring : 87 ps (*physical boundary of this technology*)
- CTR SIGNA : 390 ps
- = CTR simulated **with** 270ps blurring

# Sensitivity

*Global* detection efficiency  
= activity measured / activity in  
the FOV

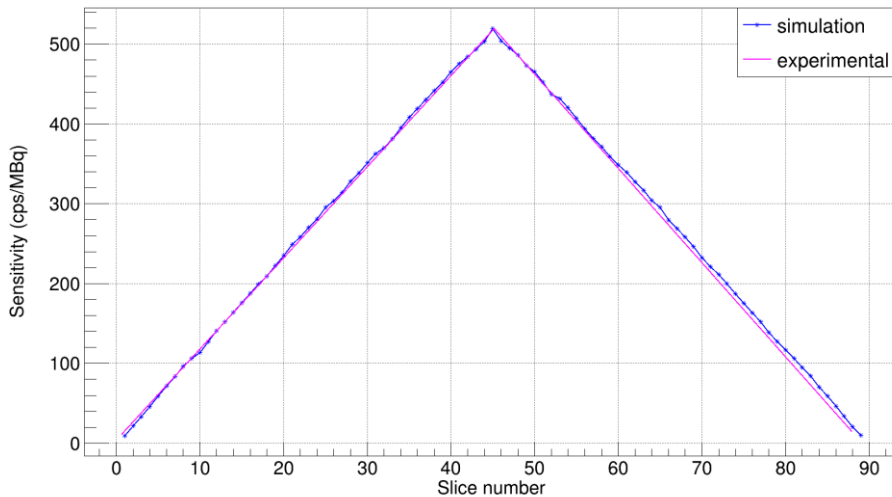
**20cps/kBq -> 2%**

Simulation : A (shifted) line source in the FOV

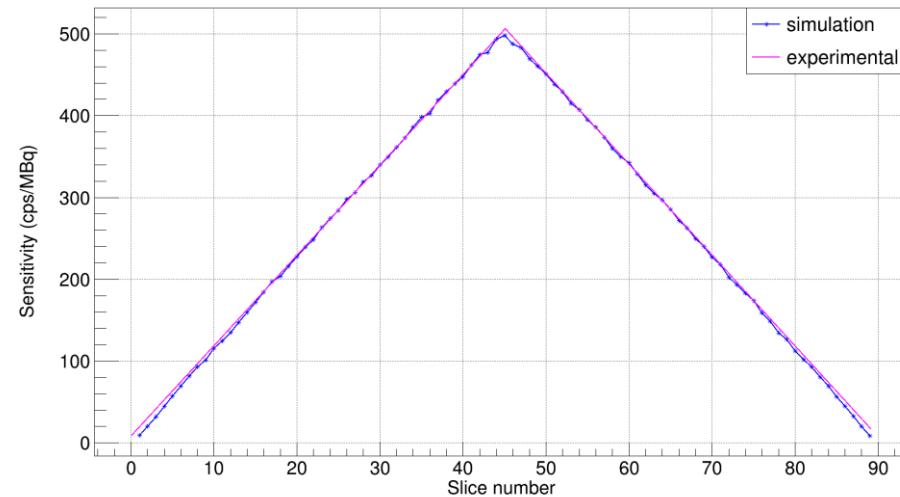
Count *per slice* for axial profile  
using SSRB  
= activity *per slice* / activity in the  
FOV

*Good agreement  
with experimental  
data*

sensitivity vs axial position



sensitivity vs axial position (10cm vertical shift)

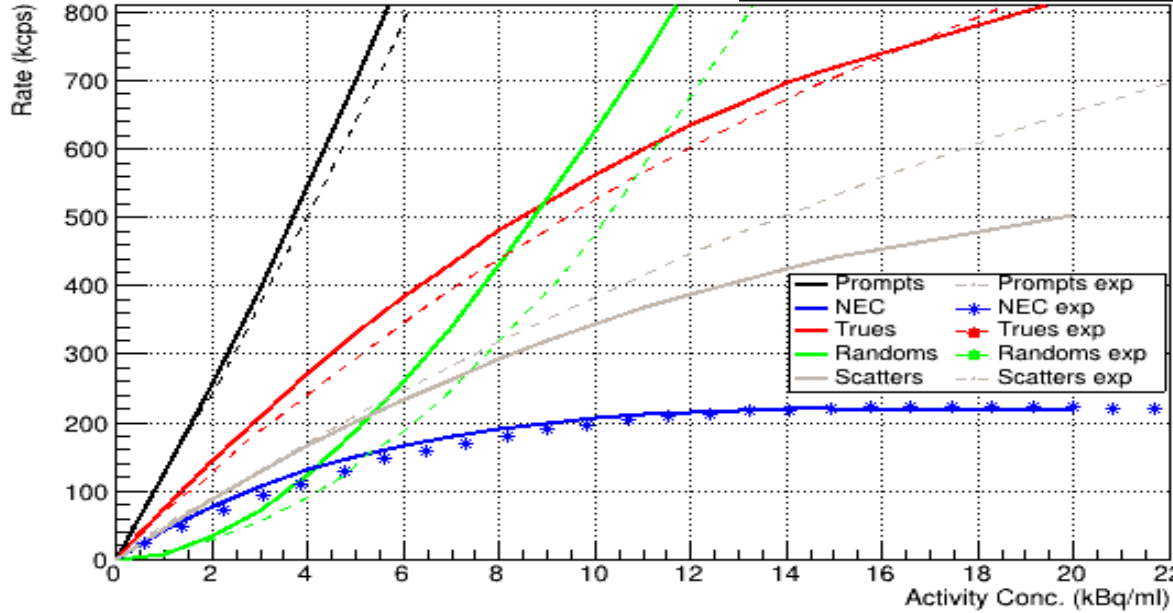
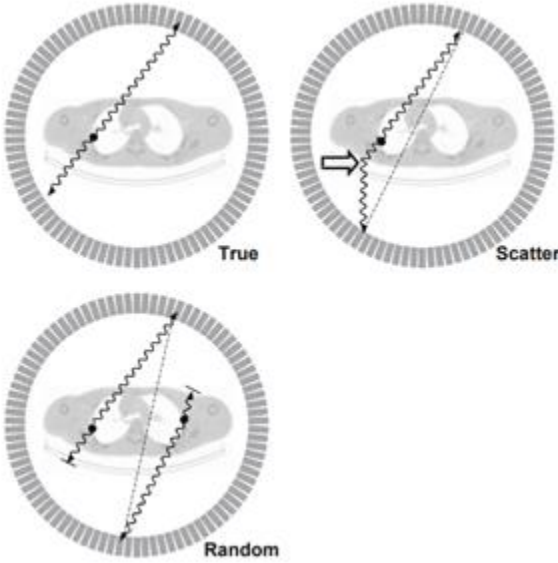


# NECR : Noise Equivalent Count Rate

$$\text{NECR} = \frac{T^2}{T+S+R}$$

Good agreement with experimental data

« Signal-to-noise » ratio about coincidences



**True** : as expected (« signal »)

**Scatter** : Compton & Rayleigh interaction

**Random** : different annihilations

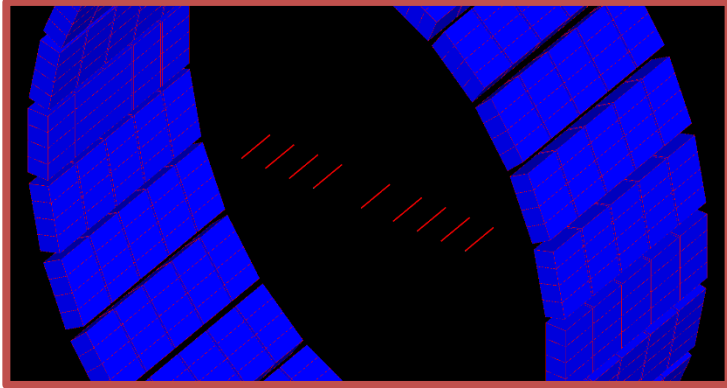
« noise »

**Prompt** : any coincidence

Image adapted from Bailey, Dale L., ed. *Positron Emission Tomography: Basic Sciences*. New York: Springer, 2005.



# Spatial resolution



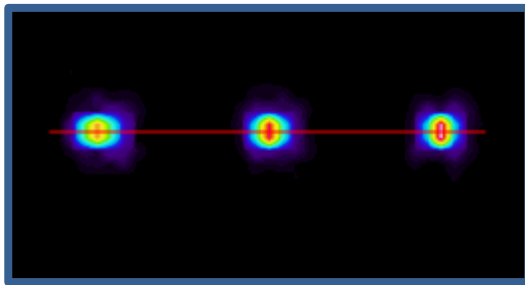
## Modification of Gate spatial blurring :

Before : pulses **stay** in original detection crystal

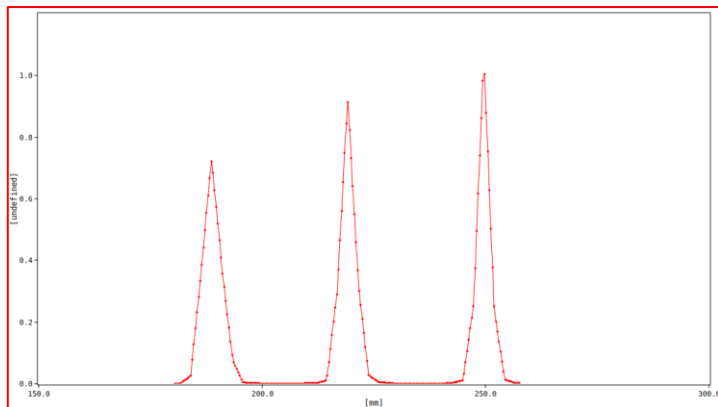
Pbm : Castor works with *crystal IDs*

After : pulses **may move** to another crystal

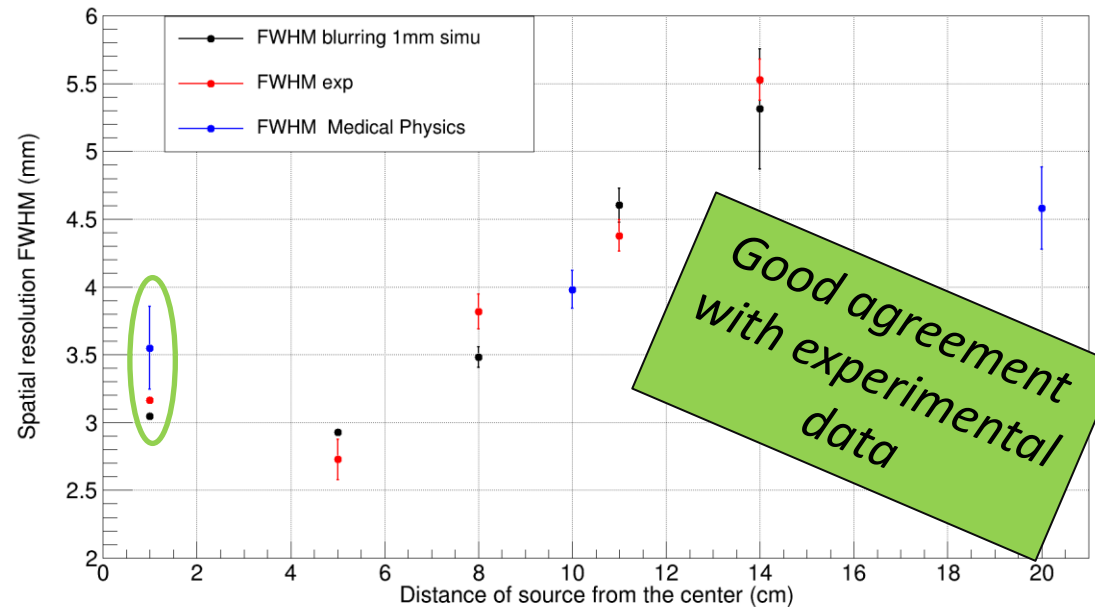
N.B. : works under certain conditions



Steps :  
Capillary tube source simulation  
Image reconstruction  
Study of *intensity profiles*

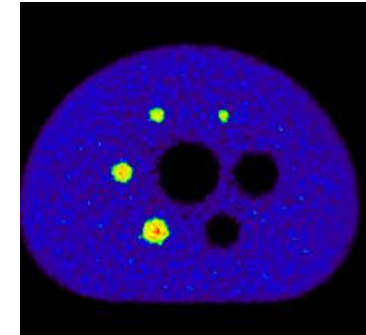
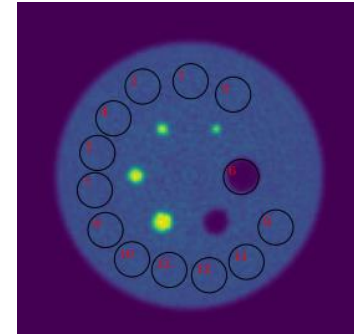
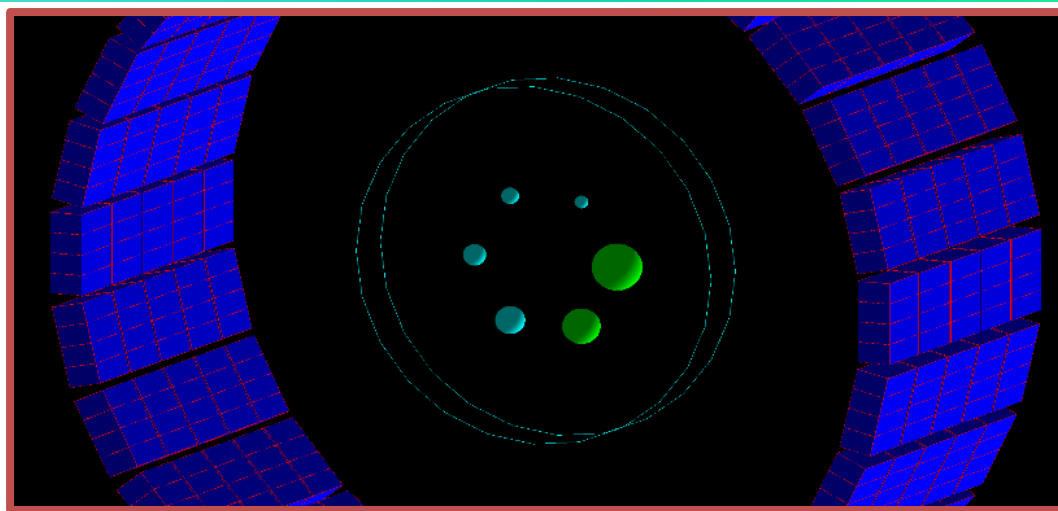


Spatial resolution



Good agreement  
with experimental  
data

# Image quality



- **Simulation** IQ NEMA 2012
- **4 hot spheres** 10, 13, 17, and 22 mm
- **2 cold spheres** 28 and 37 mm
- Attenuation **cylinder**

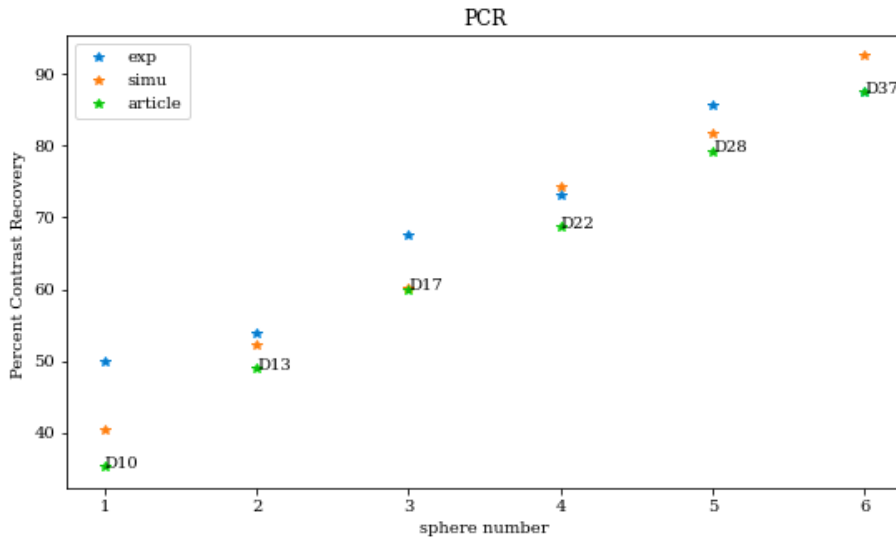
*Simulated reconstructed image (left) and experimental (right)*

## **NEMA Image analysis :**

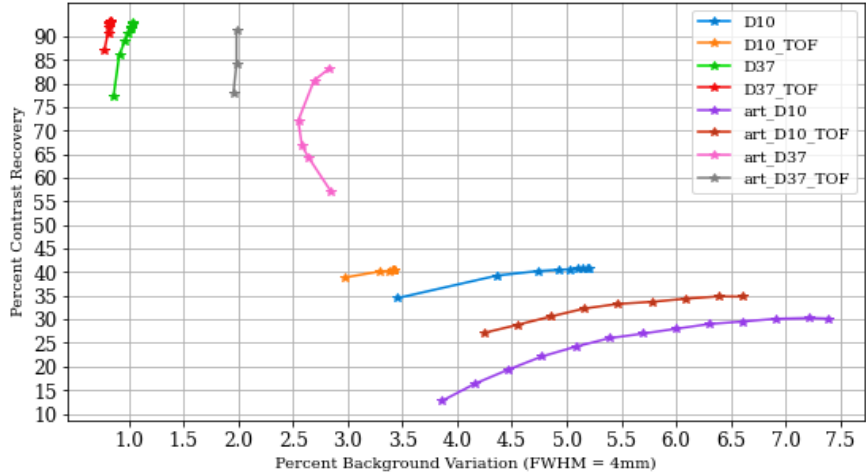
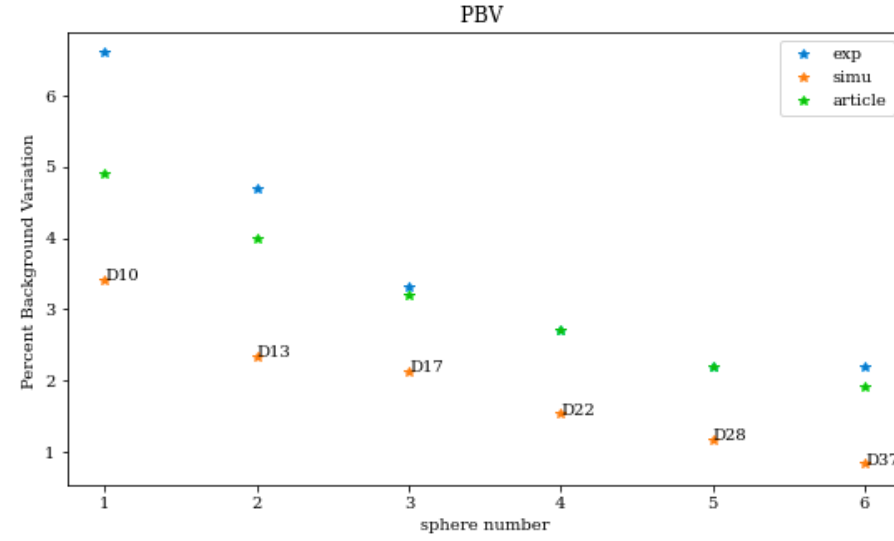
- Percent contrast recovery (PCR)
- Percent background variation (PBV)

# Image quality

*Good agreement between simulation and experimental data*



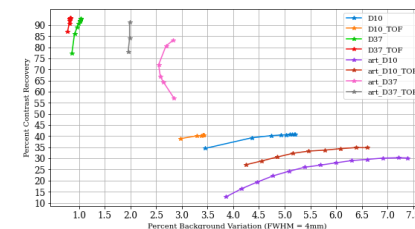
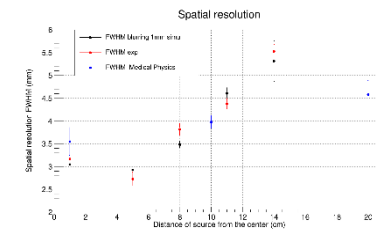
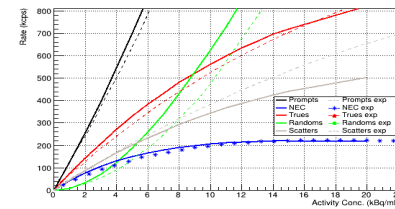
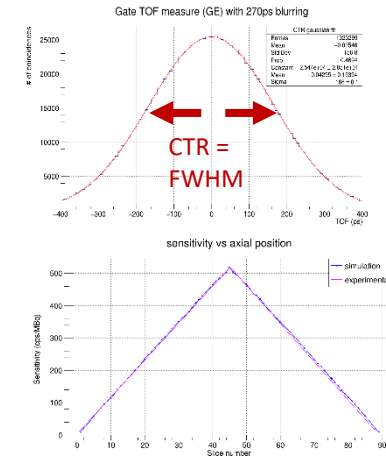
Trues only : noise is underestimated



- **PCR :**
- ✓ ↗ with iterations number
- ✓ ↗ with TOF
- **PBV :**
- X ↗ with iteration number
- ✓ ↘ with TOF

# Validation summary

- **CTR** is adaptable between 390 ps (real) and 87ps (physical limit)
- **Sensitivity** is almost exactly the same
- **NECR** : good agreement but digitizer still too simple
- **Spatial resolution** : good agreement, Gate spatial blurring could be adapted
- **Image quality** : PCR is ok but PBV is underestimated : need for a « realistic » scatter and random corection



Context & applications

Validations

**Corrections**

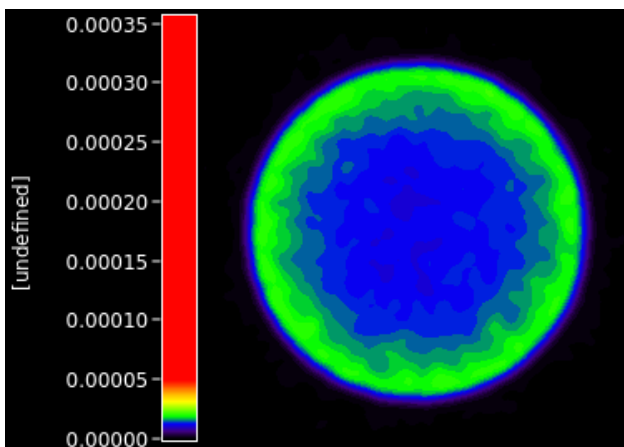
Clinical imaging

Conclusion & perspectives

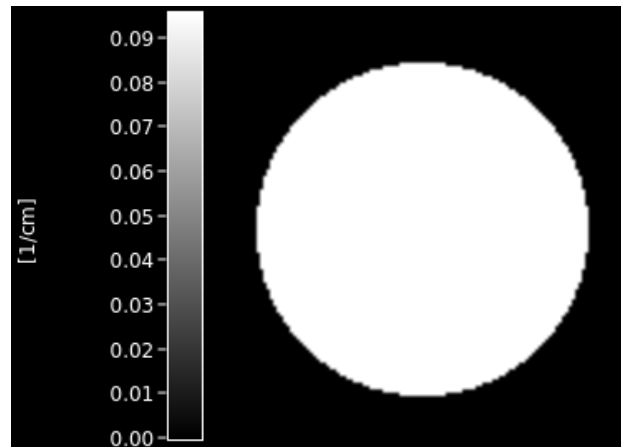
# Corrections

- Scatters & randoms : correction compensate for an excess of coincidences
  - Method : computation of scatter & randoms rates LOR by LOR
- Normalization : correction compensate for artefacts due to geometry
  - Method : « Direct », computed with analytic and Monte Carlo simulations
- Attenuation : correction compensate for a lack of coincidences due to phantom material
  - Method : voxelized map of attenuation coefficients (« mu-map »)

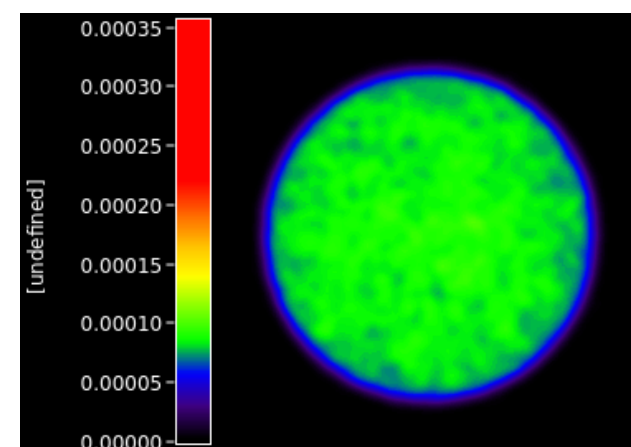
Without correction



Attenuation map



With correction



Context & applications

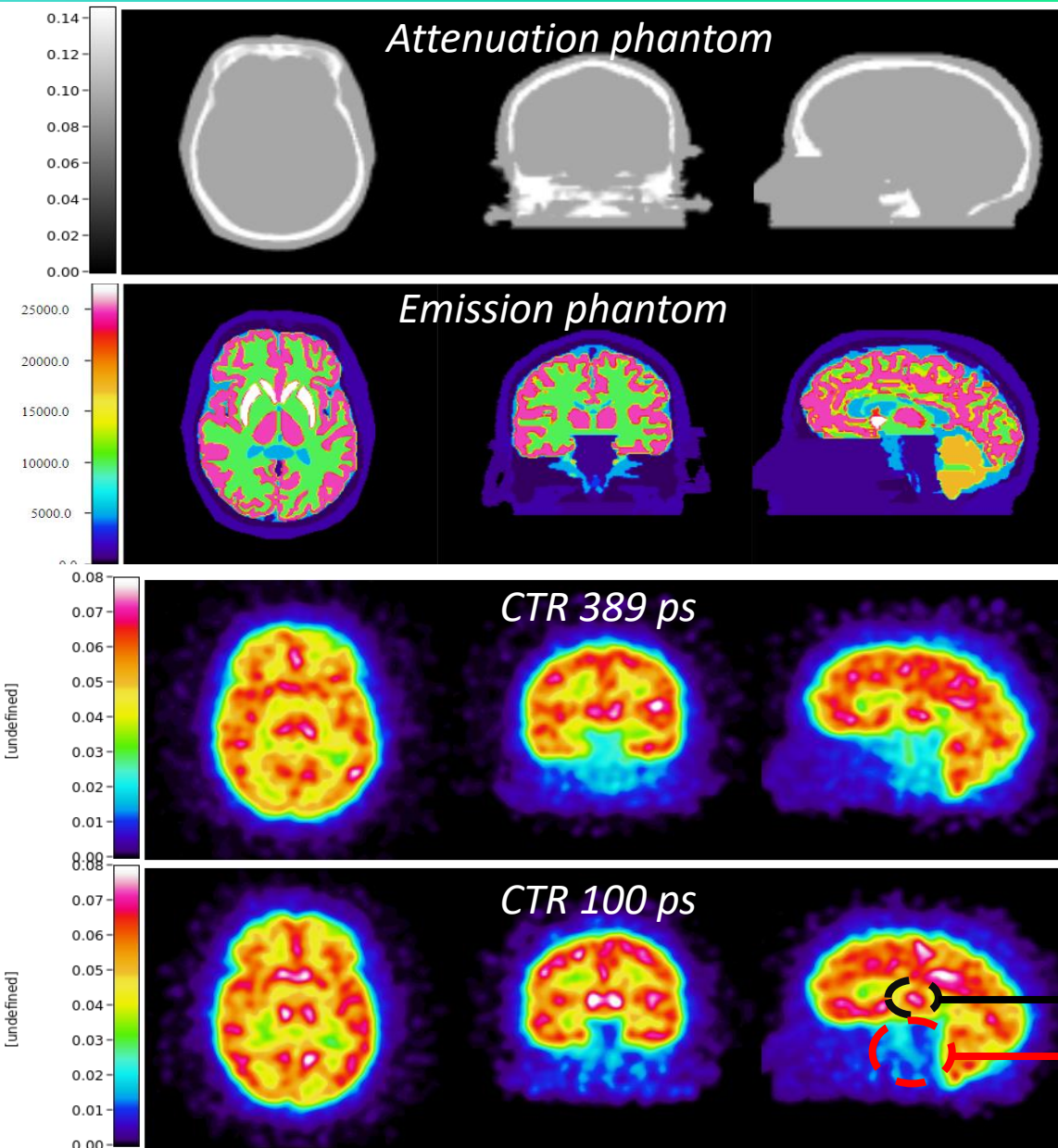
Validations

Corrections

Clinical imaging

Conclusion & perspectives

# Brain imaging



- 28 MBq in the brain at T0
- 2,5 M of trues for reconstruction
- Statistic : between 1/10<sup>th</sup> and 1/100<sup>th</sup> of a real exam

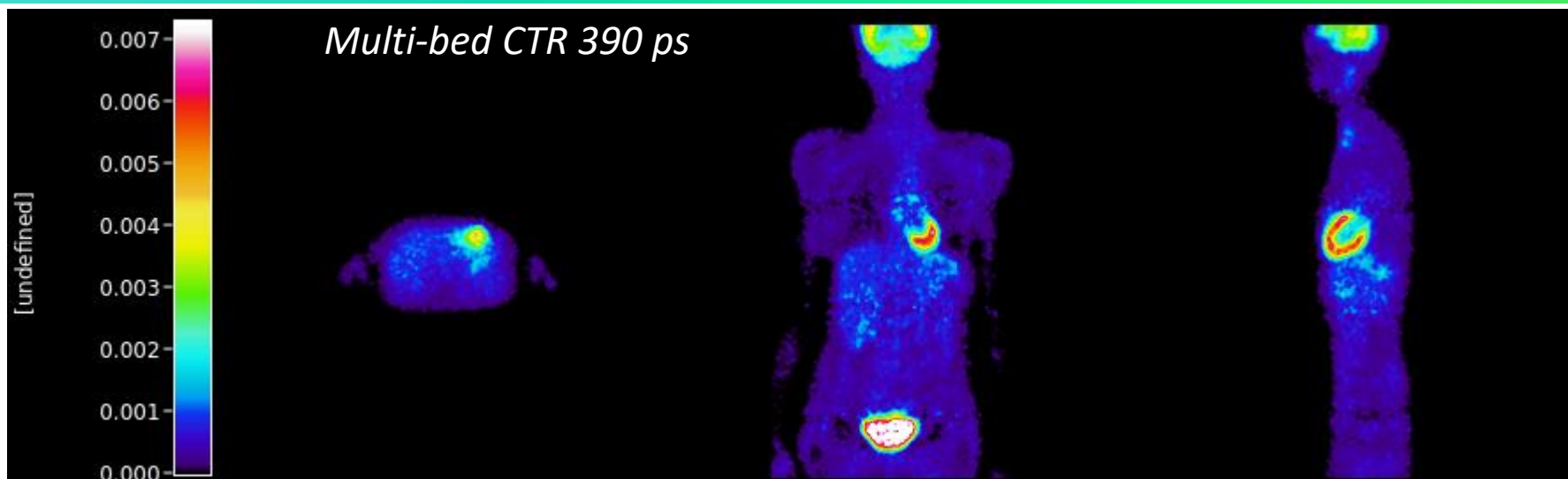
- Only Trues
- Normalized
- Corrected for attenuation

Better contrast

Reduced noise



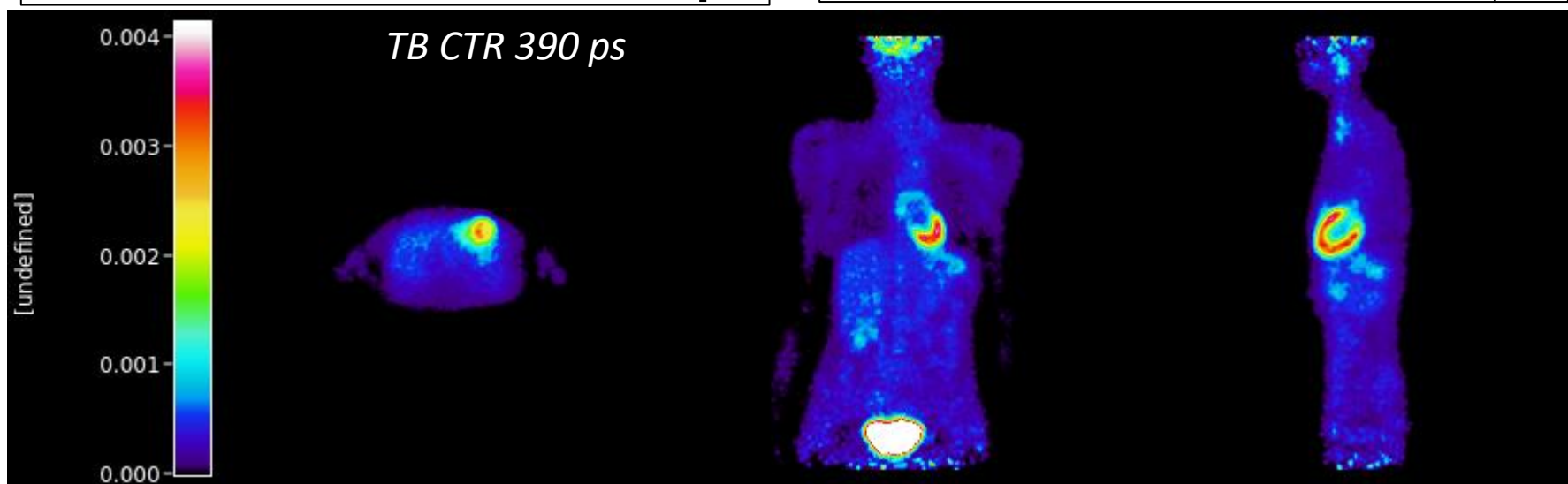
# Total body imaging



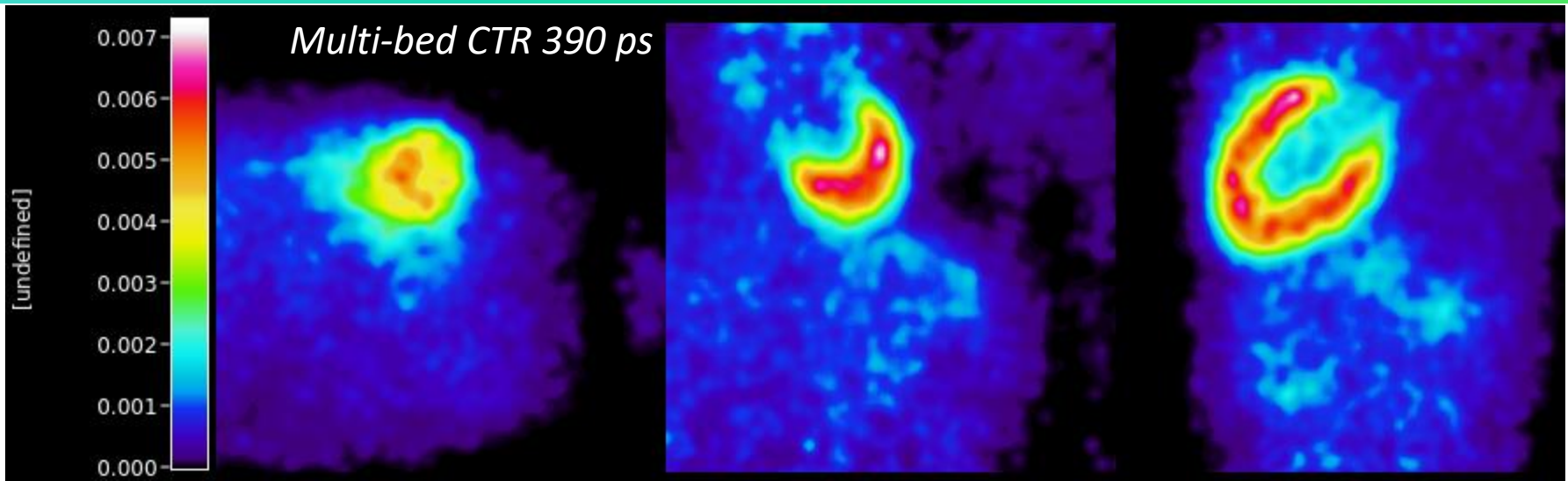
- $2 \cdot 10^7$  trues trues for reconstruction
- 3 bed steps
- 3D gaussian filter 6mm FWHM



- $2 \cdot 10^7$  trues trues for reconstruction
- TB geometry
- 3D gaussian filter 6mm FWHM

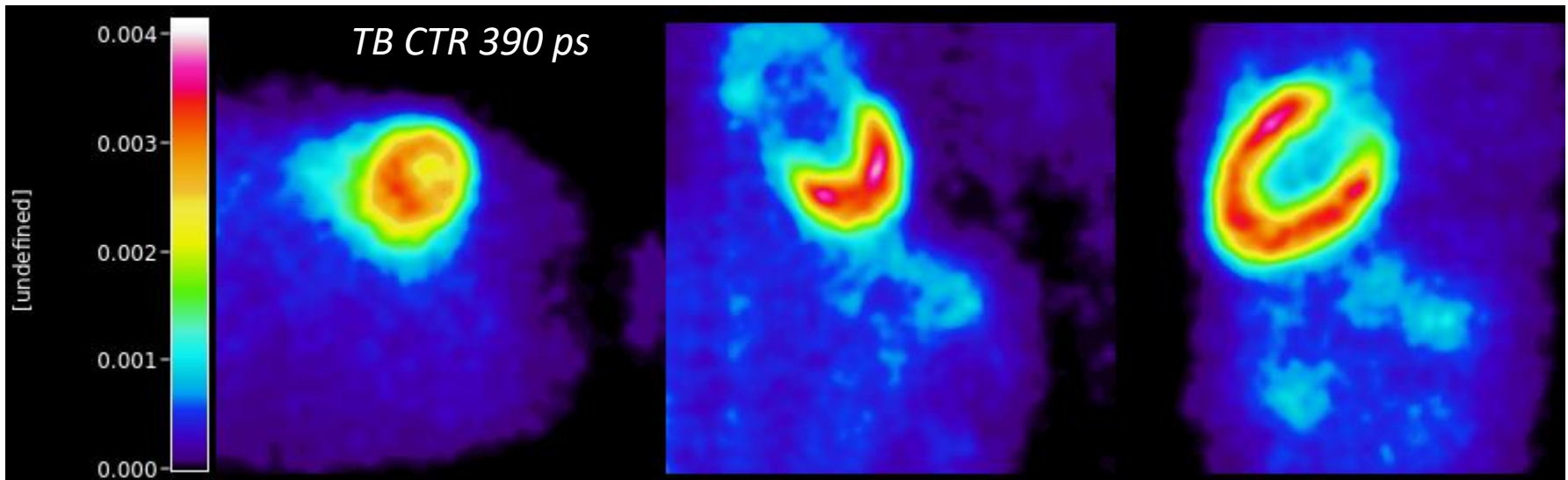


# Total body imaging

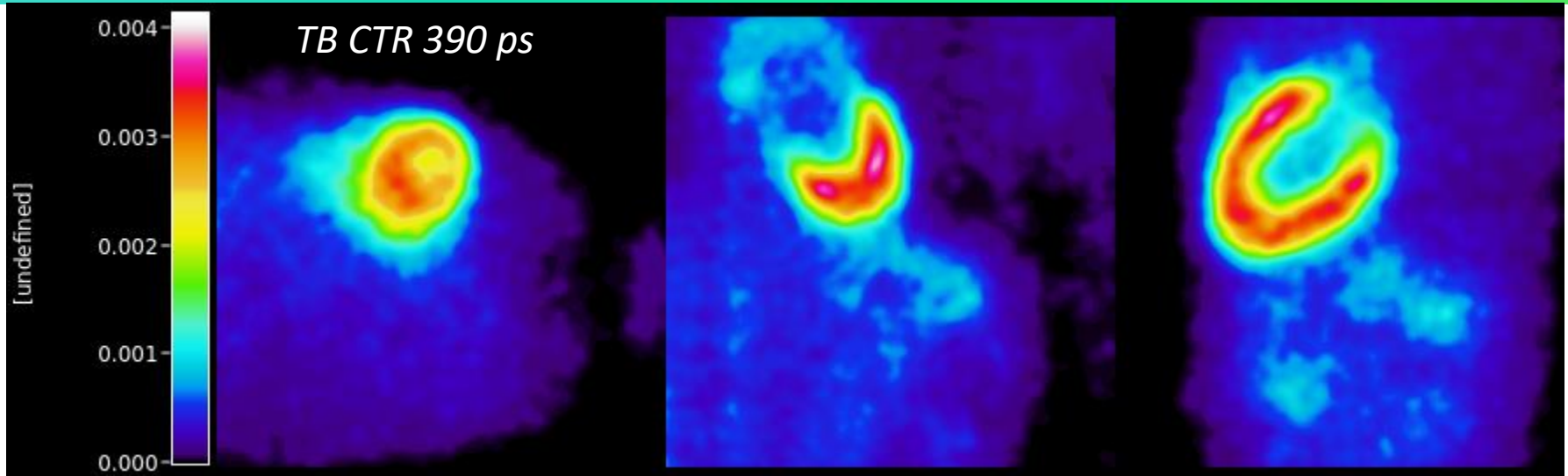


Reconstruction with trues only :

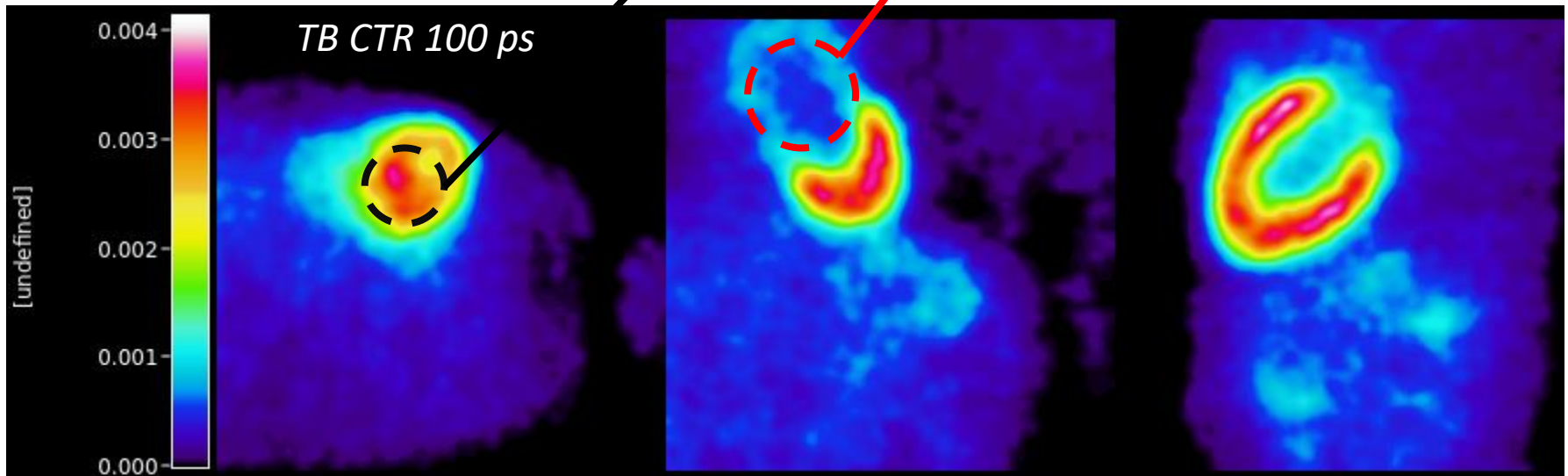
TB has slightly more events (500 000) : image is better overall, reduced scan time



# Total body imaging



Effect of CTR improvement : better contrast and reduced noise.



Context & applications

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# Conclusion & Perspectives

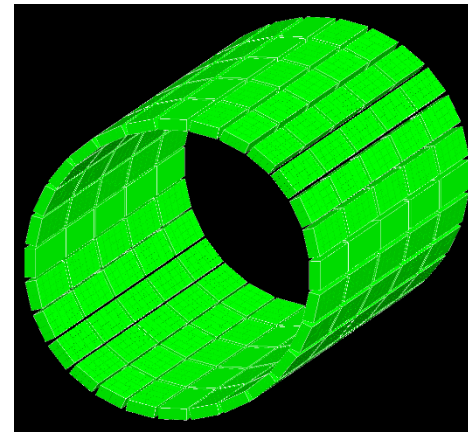
## **Conclusion :**

- **Validation** of the simulated SIGNA :
  - Spatial and time resolution
  - Sensitivity & NECR
  - Image quality
- Implementation of **image reconstruction** with Castor and custom **corrections**
- Conventional, TB & high CTR **static clinical exam**

## **Perspectives :**

- **Study** of **CTR <100ps** detectors with Geant4
- **Integration** of a **detector model** in GATE for a **total body structure**
- **Test** total body phantom & geometry + **CTR <100ps** in 4D clinical study

Total body geometry & (XCAT) phantom





*Thank you for your attention !*



# Image reconstruction

Sinogram :  $f(r,\theta)$

Image :  $f(x,y)$

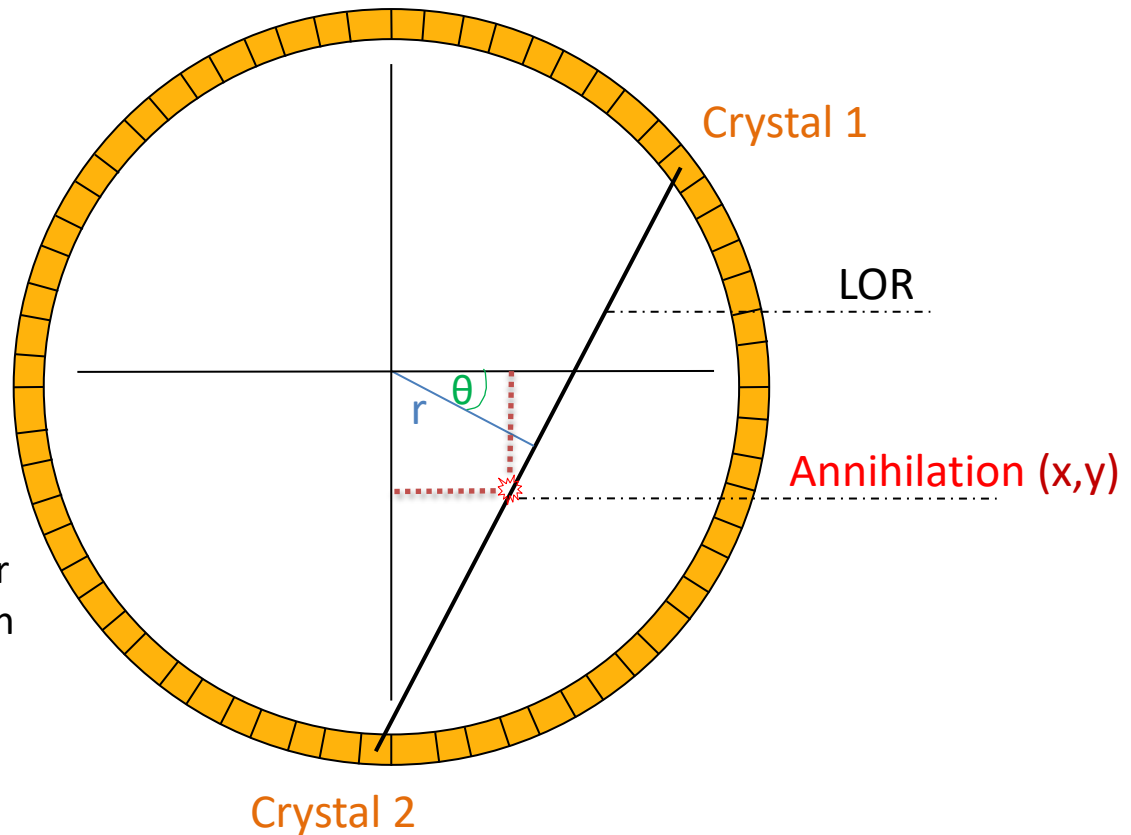
**Event** : detection in  
**crystal 1 & crystal 2**

Simulation  
output

**Histogram** datafile :  
matrix of events  
sorted by **crystal ID**

**List-mode** datafile :  
List of events labelled  
with **crystal IDs**

File format for  
reconstruction

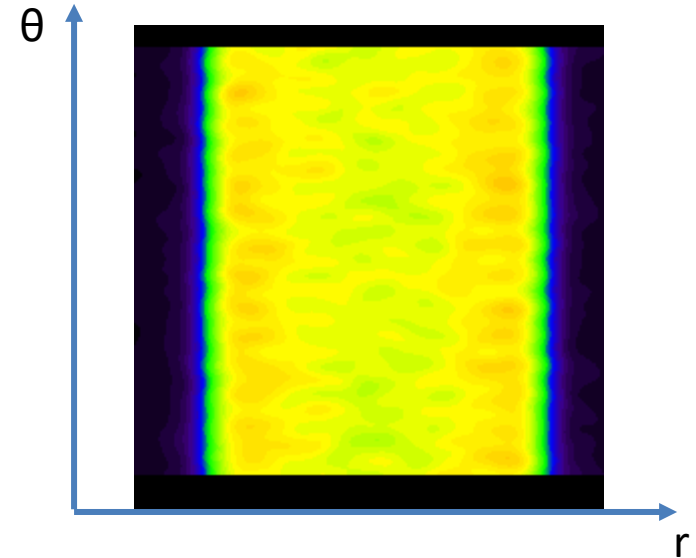
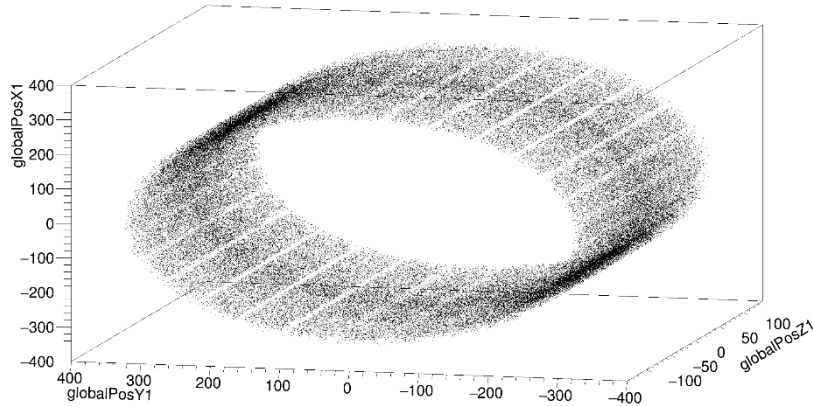


Gate Root output : **no** global **crystal ID** but *relative* localization in the geometry

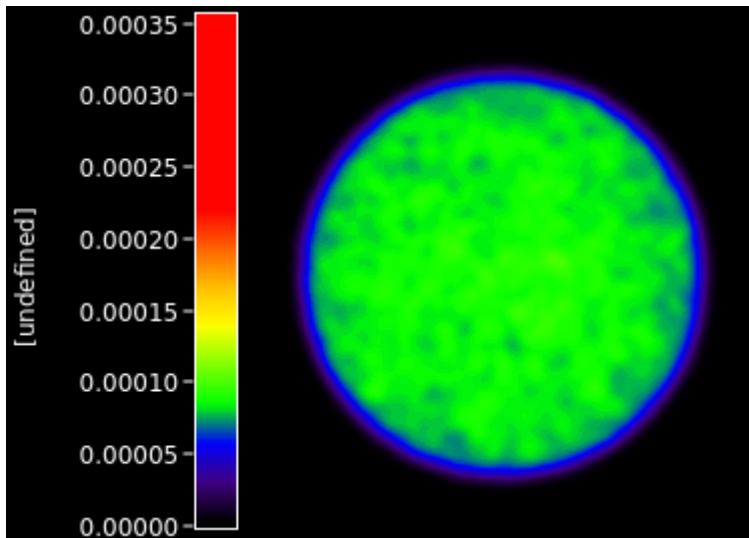
Castor : find the global **crystal ID**, file conversion then OSEM

# Image reconstruction

Position of events in the Gate simulation (xyz)



Reconstructed image (transaxial)



Transaxial sinogram  
same cylindrical source

Application of corrections  
on the datafile  
(attenuation correction  
here)



# Corrections

**Normalization** : Correction of the artefacts due to geometry\*

**Direct** : gold standard, but very costly

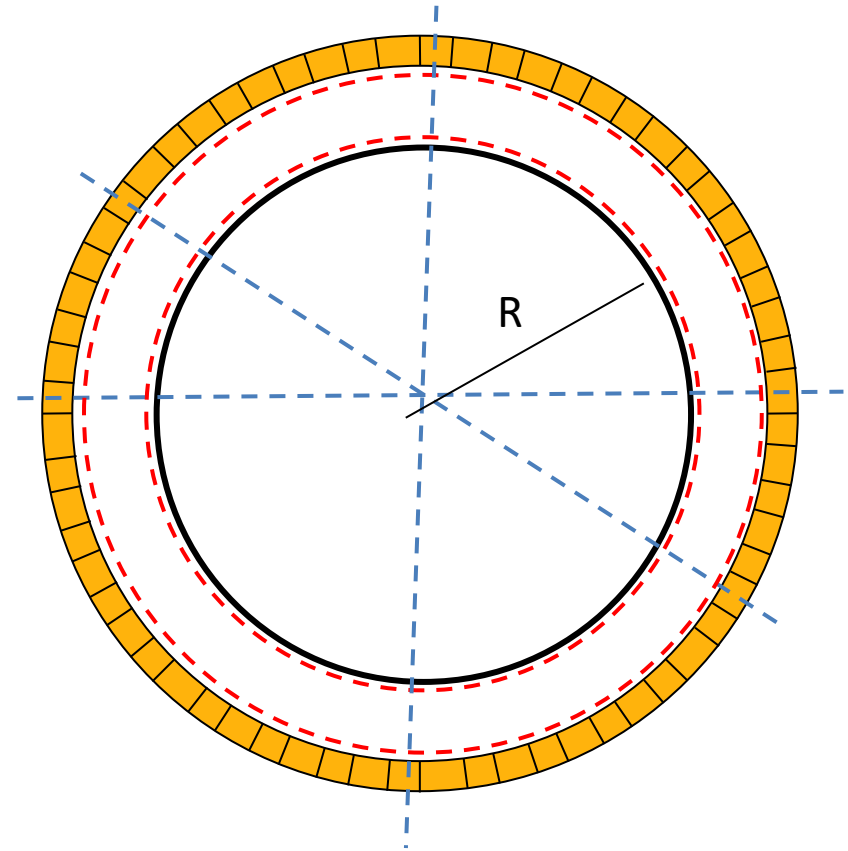
**Workaround** : use system **symmetries** & sinogram **radial cut**

**Symmetries** : One event in one LOR can be copied in symmetrical LORs

**Radial cut** : discard events in LORs where  $r < R$

Steps :

1. **Analytical** projection of an **annular source** that illuminates all LOR
2. **Monte Carlo simulation** of the **same source**
3. **Theoretical** number of events for a LOR : output of step 1
4. **Simulated** number of events for a LOR : output of step 2
5. **Normalization coefficient** for a LOR : ratio **analytical/simulated**



Still in development !

\*Pépin, Audrey, Simon Stute, Sébastien Jan, et Claude Comtat.  
« Normalization of Monte Carlo PET data using GATE ». In *2011 IEEE Nuclear Science Symposium Conference Record*, 4196-4200, 2011.  
<https://doi.org/10.1109/NSSMIC.2011.6153804>.