

Étude et construction tomographe TEP/TDM pour petits animaux
combinant détecteurs à pixels hybrides et modules phoswich à scintillation

Stan Nicol
Groupe imXgam
Dirigé par Christian Morel

Imagerie multimodale TEP/TDM

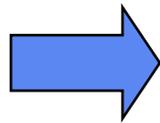


Tomodensitométrie (**TDM**)

Imagerie anatomique

Lieu A

t_1 ($\Delta t_1=30$ s)



**Recalage
Fusion**

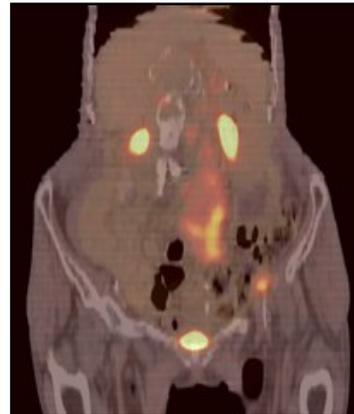
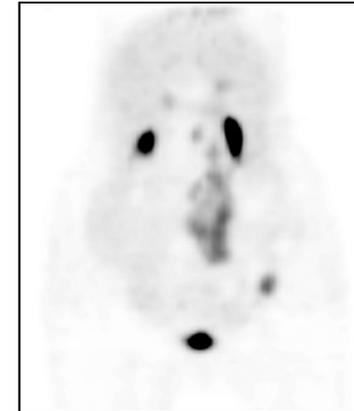


Image recalée et fusionnée

Informations anatomique & fonctionnelle



Tomographie à émission de positons (**TEP**)

Imagerie fonctionnelle

Lieu B

t_2 ($\Delta t_2=15$ min)

[Imagerie multimodale - Problématique



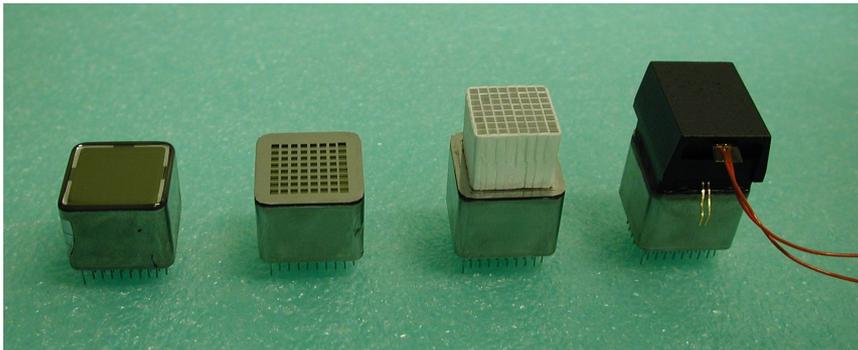
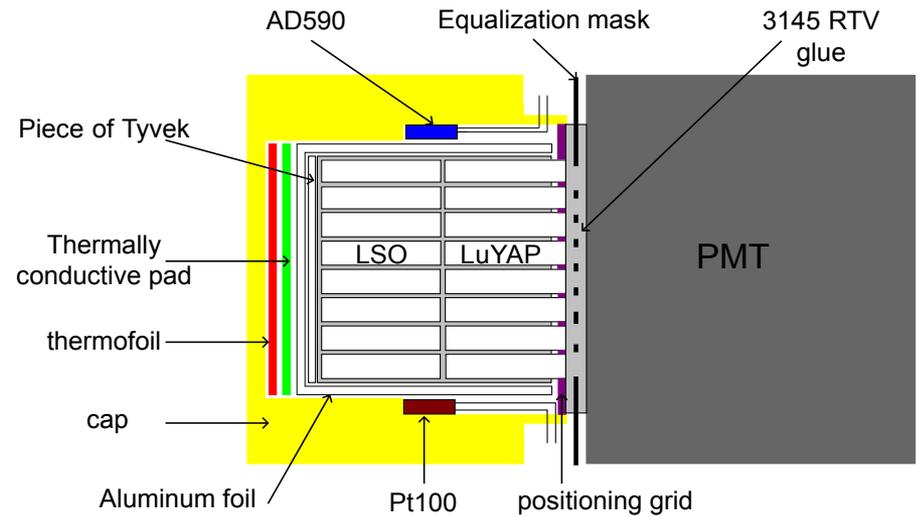
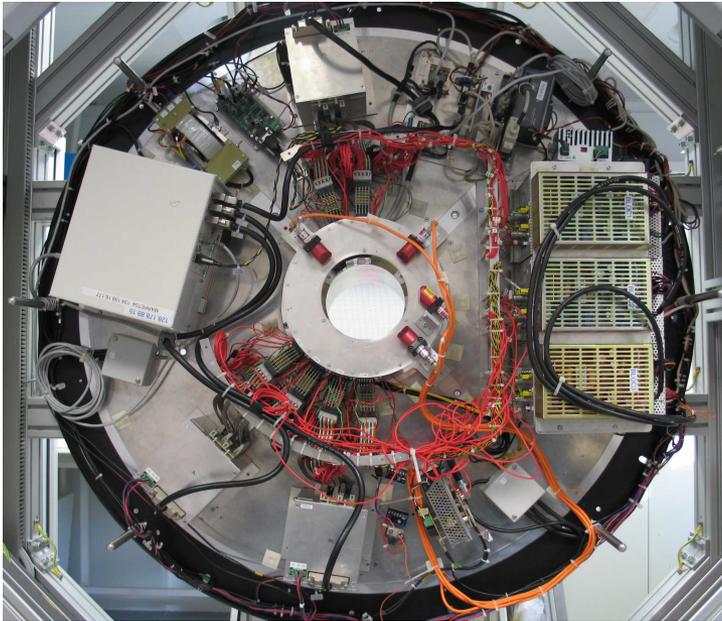
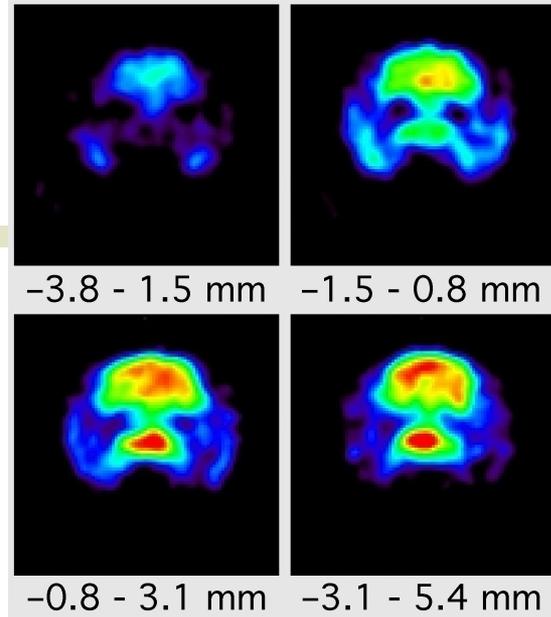
- Les acquisitions TEP et TDM du volume à imager ne sont pas simultanées

Solution : Concevoir un système d'acquisition TEP/TDM simultanée partageant un champ de vue commun

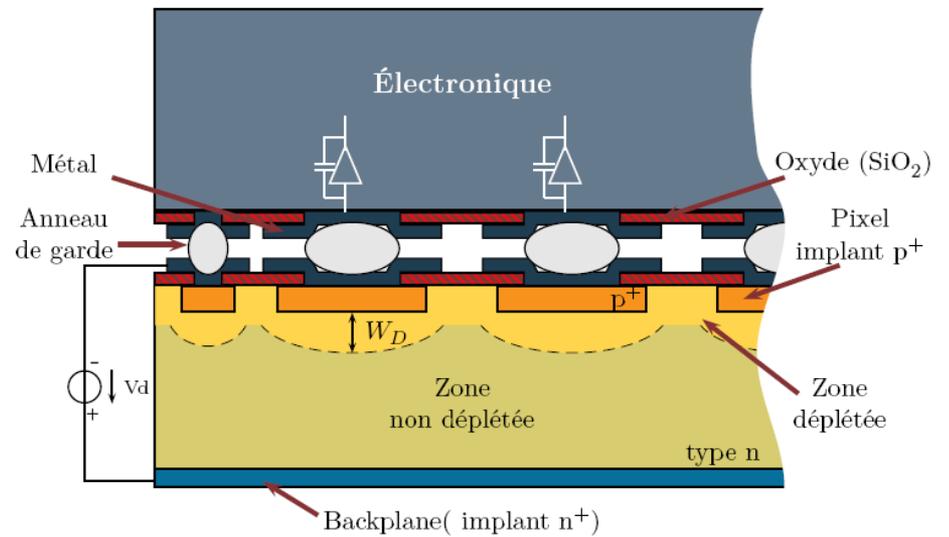
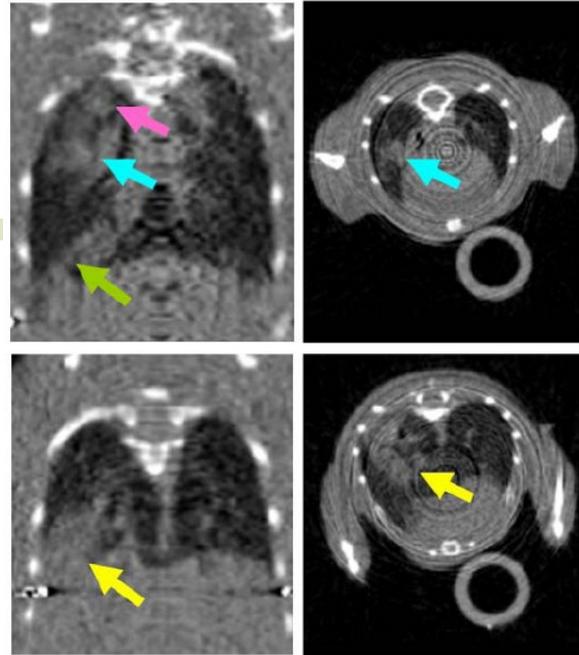
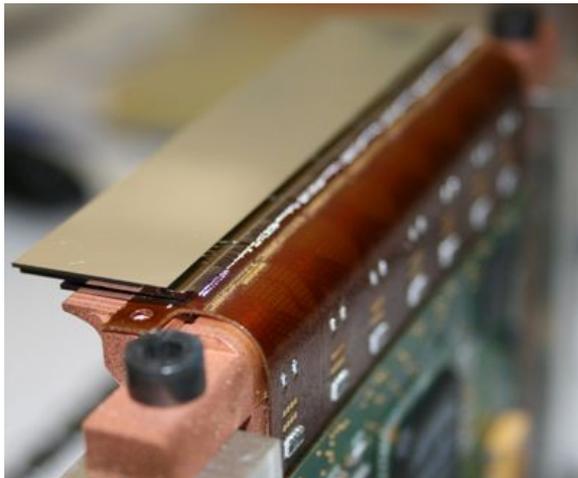
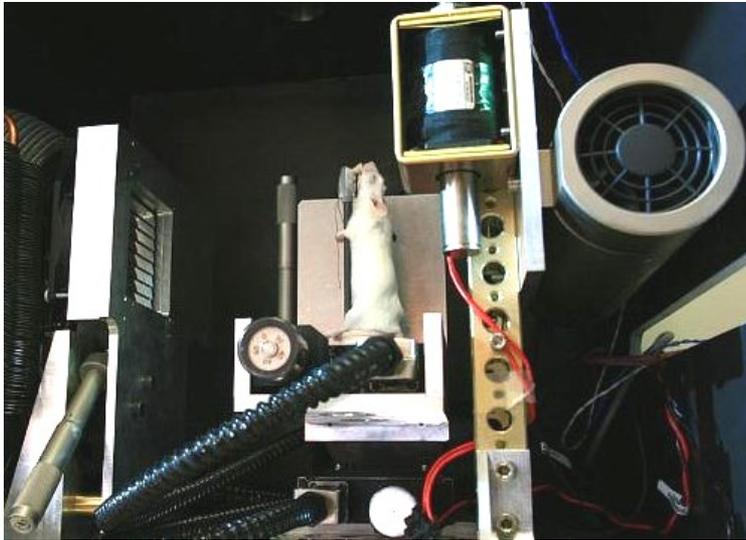
- Les acquisitions TEP sont entachées d'un flou cinétique dû aux mouvements physiologiques

Solution : Asservir ce système d'acquisition simultanée à un signal physiologique

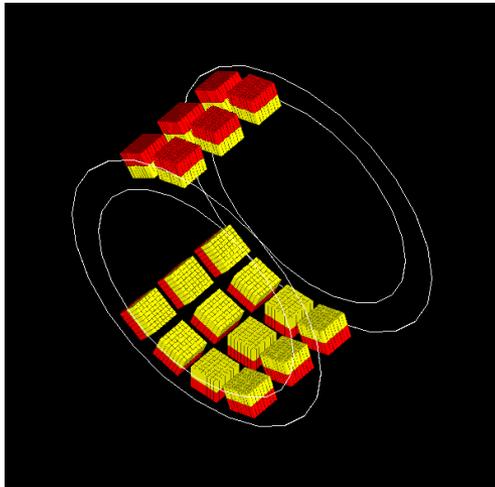
Démonstrateur ClearPET



Démonstrateur PIXSCAN



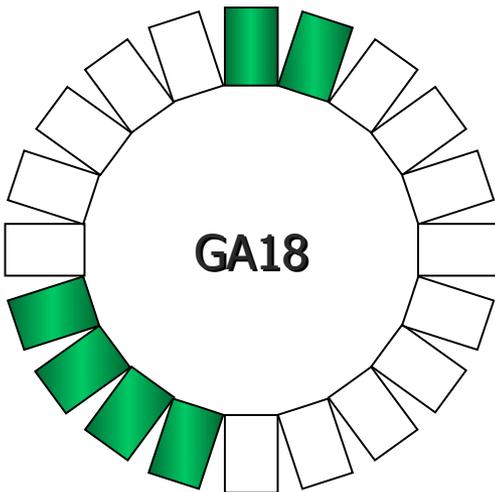
ClearPET - Géométrie initiale



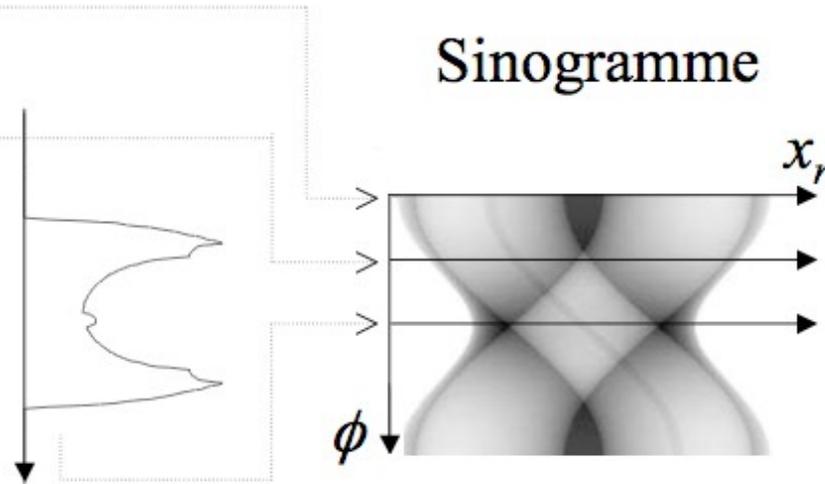
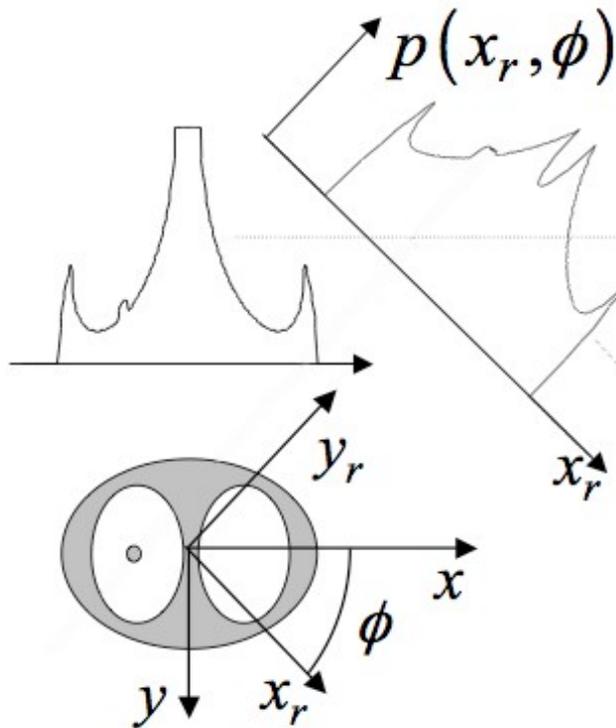
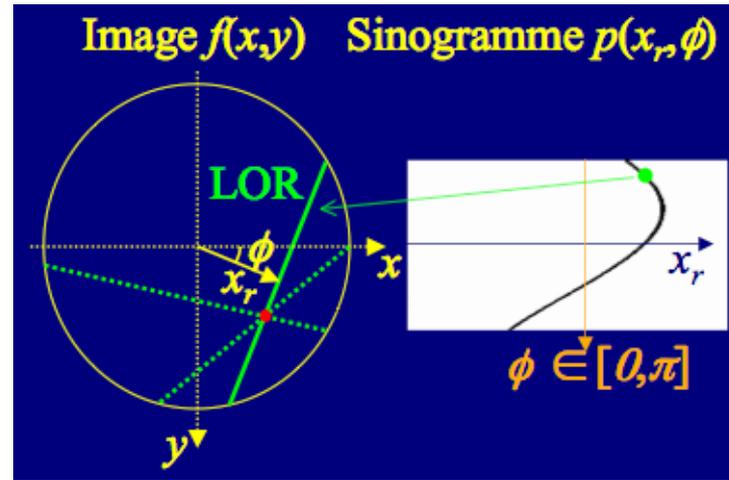
- Géométrie partielle
- Diamètre 142 mm
- 3 anneaux - 20 secteurs
- 18 modules phoswich LSO/LuYAP (3x6)
- Rotation continue sur 360° (1 tour.min⁻¹)
- FOV axial : 78 mm
- FOV transverse : 96 mm

A partir de cette géométrie initiale, on souhaite :

- Eliminer axialement l'espace mort entre chaque anneau
- Remplir l'intégralité des sinogrammes
- Améliorer la sensibilité de détection des évènements
- Rendre la sensibilité axiale homogène
- Pouvoir intégrer le micro-TDM PIXSCAN
(source RX + caméra à pixels hybrides XPAD)

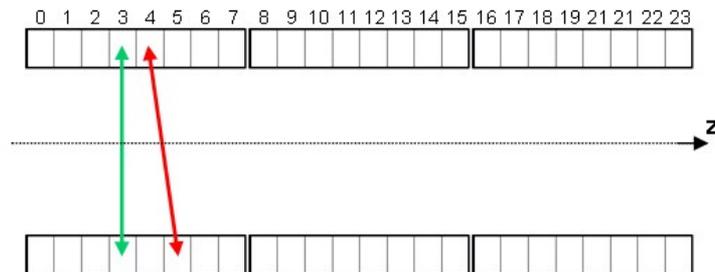
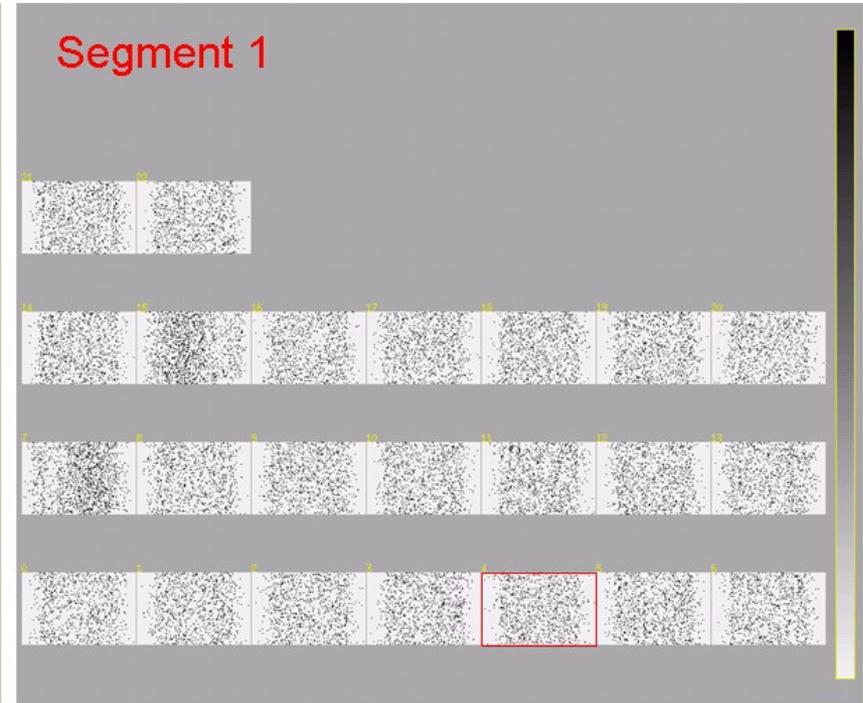
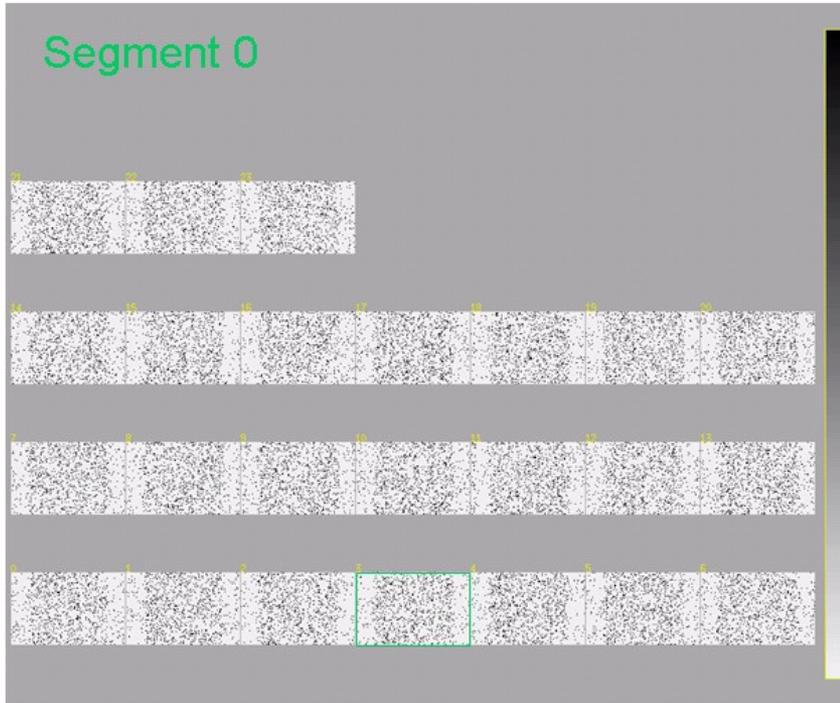


Sinogramme

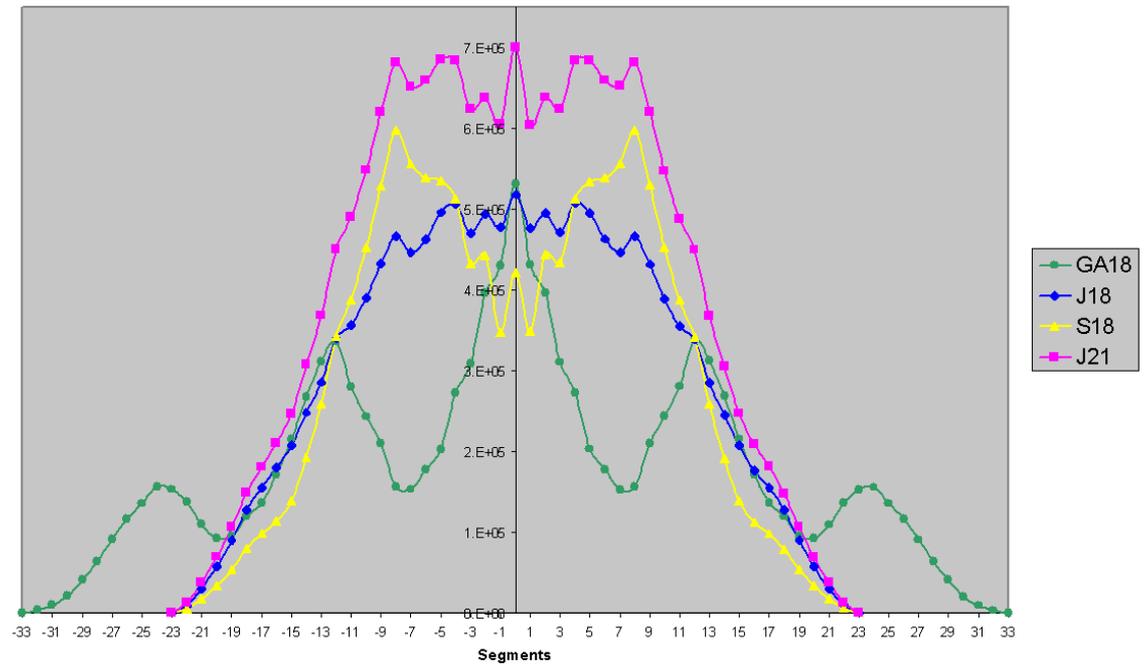
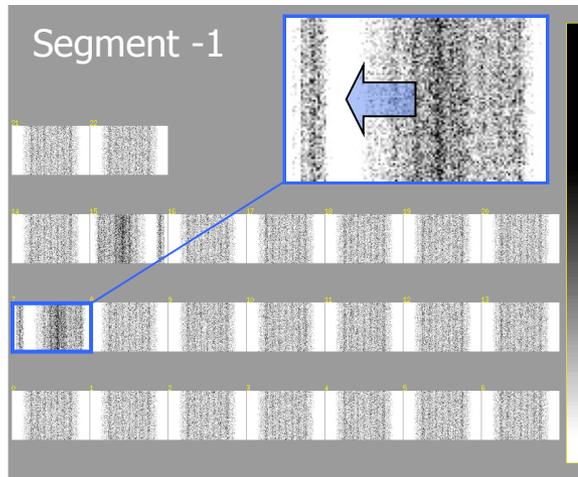
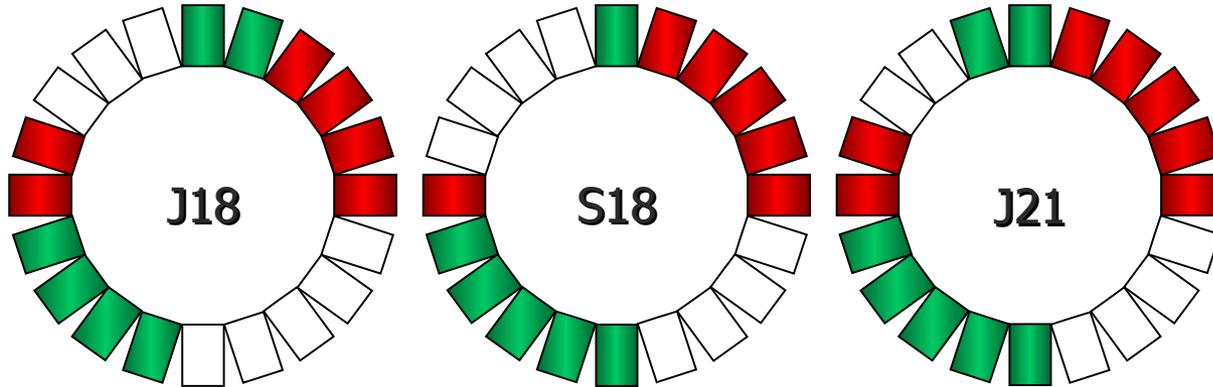


Sinogramme

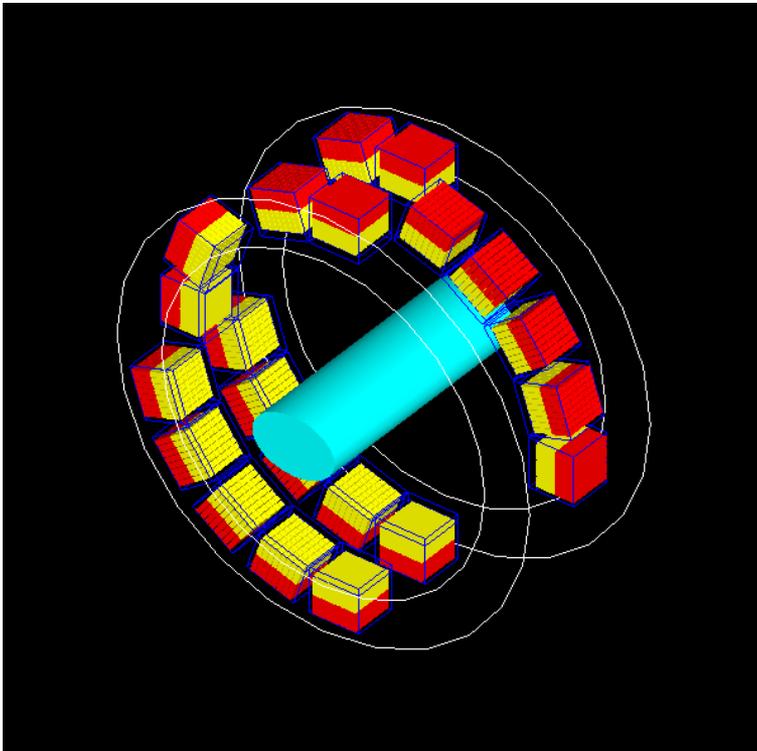
Source cylindrique homogène :
 $D=100$ mm, $L=150$ mm, $A=10$ MBq



GATE - Etude de design



ClearPET - Nouvelle géométrie



- Géométrie partielle
- 21 modules phoswich LSO/LuYAP (3x7)
- FOV axial : 55 mm
- FOV transverse : 112 mm

Critères rempli par cette nouvelle géométrie :

- Détecteur continu axialement
- Champ de vue correctement échantillonné
- Gain relatif en sensibilité : 71%
- Sensibilité homogène axialement
- Intégration du micro-TDM PIXSCAN possible

Caractérisation source RX



RTW MCBM 65B-50Mo

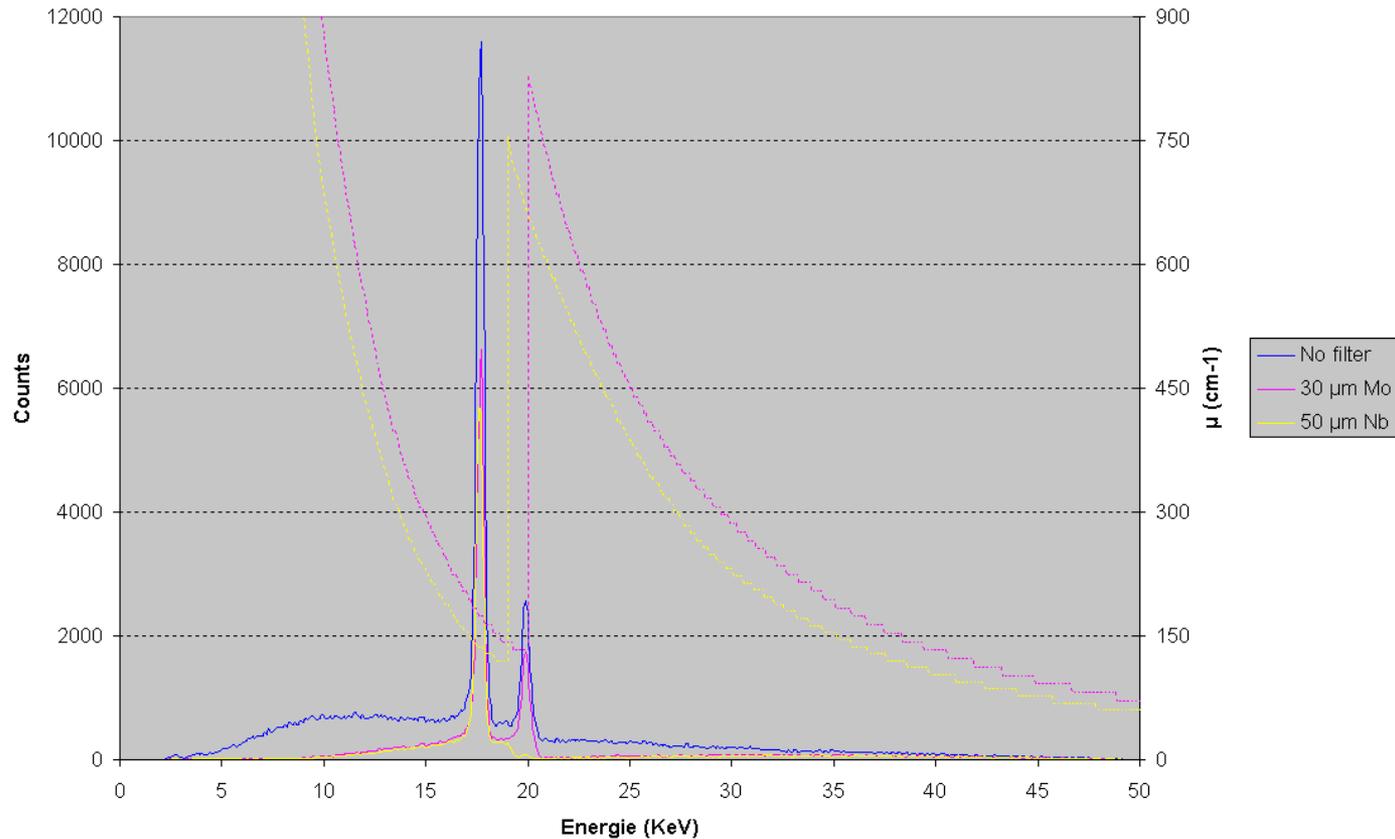
Anode Molybdène

65 kV, 0.8 mA, 50 W

Foyer 50x50 μm^2

Angle d'émission 25°

50 kV - 10 μA

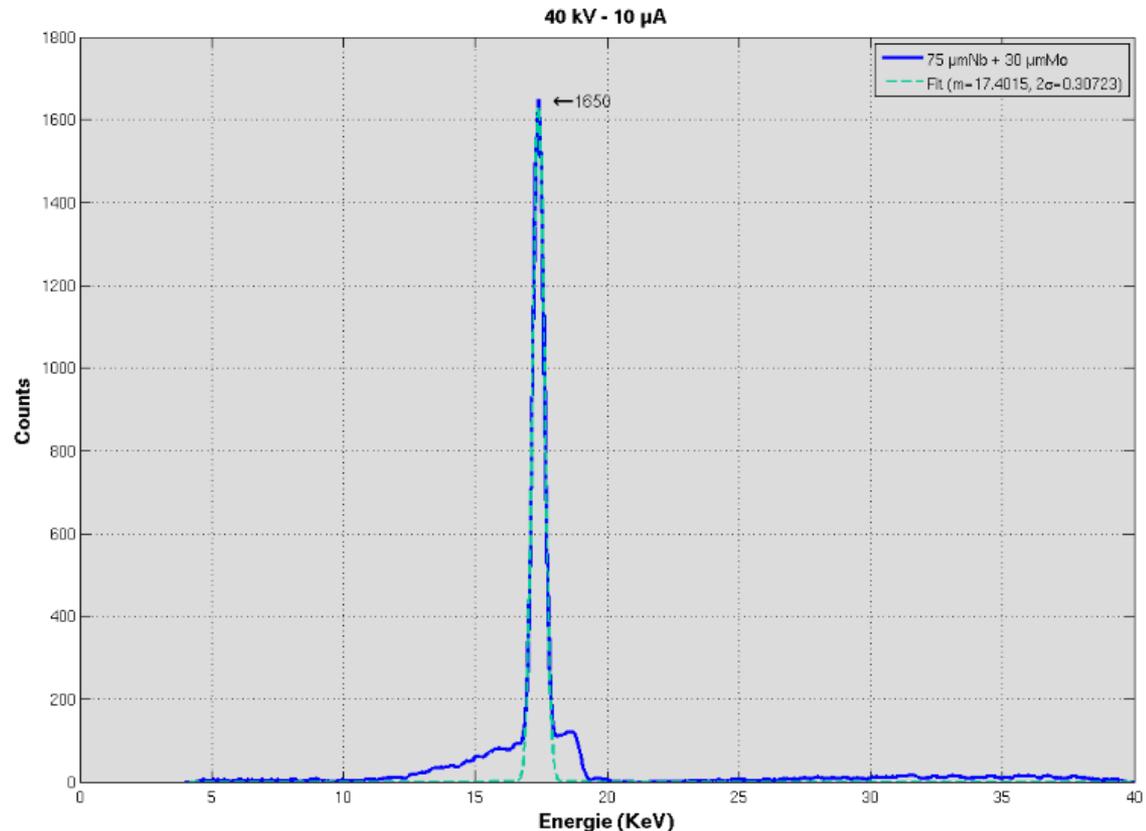


Caractérisation source RX

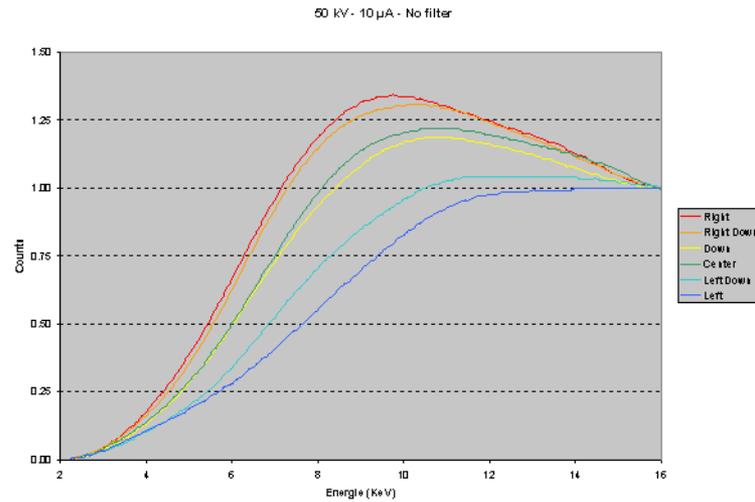
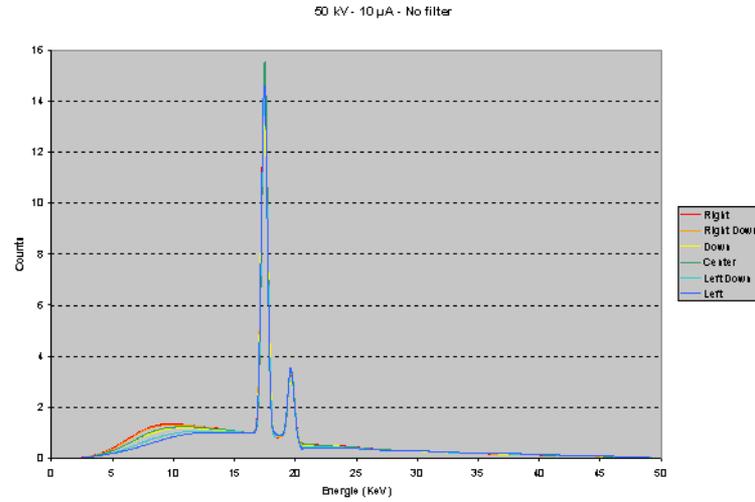
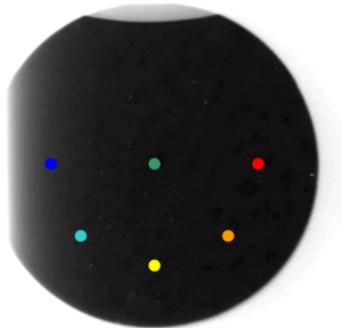
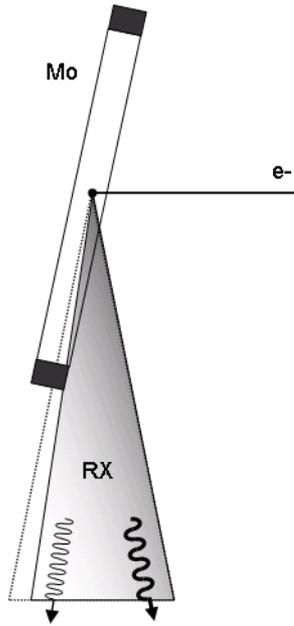


Acquisitions TEP/TDM simultanées :

- Paramètres d'acquisition : **40 kV, 100 μ A**
- Filtration : **75 μ mNb + 30 μ mMo**
Caractère monochromatique
(60% des photons dans le pic)
Correction atténuation TEP
- Débit de fluence :
 $4.8e5 \text{ ph.mm}^{-2}.\text{s}^{-1}$ @ 155 mm
- XPAD3-S/Si :
 $\text{Eff}_{500\mu\text{mSi}} = 51\% \gg 1000 \text{ ph.px}^{-1}.\text{s}^{-1}$
- Débit de dose absorbée dans l'air :
 0.13 mGy.s^{-1} @ 155 mm
15 min @ $1\text{tr.min}^{-1} \gg 120 \text{ mGy}$



Caractérisation source RX

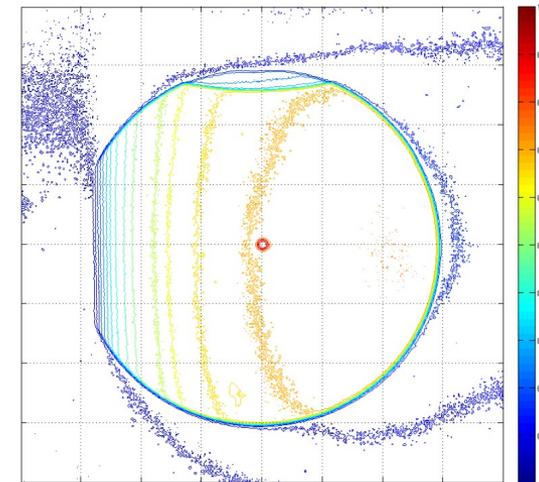
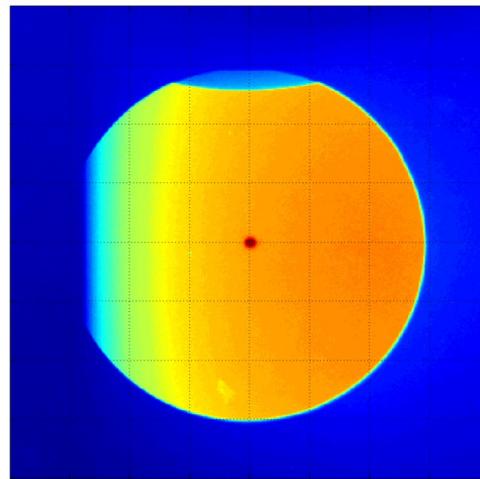


Caractérisation source RX

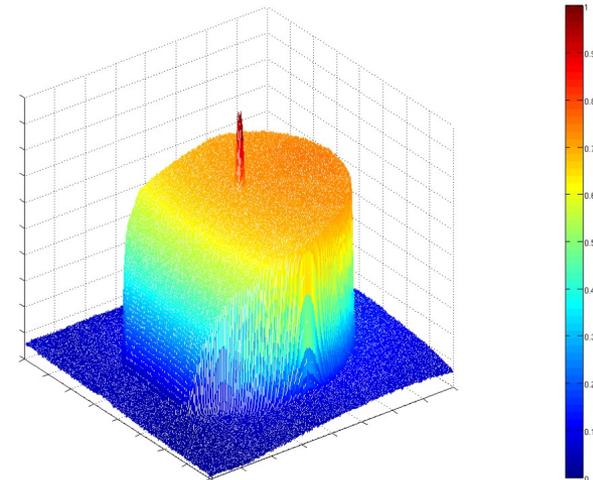


Film Kodak X-OMAT V

- Centrage :
Parfaitement centré
- Dimensions :
Délimitation floue
- Angle d'émission :
25°
- Homogénéité :
Effet Talon



Nécessité d'une collimation secondaire (20°)
et d'une filtration additionnelle

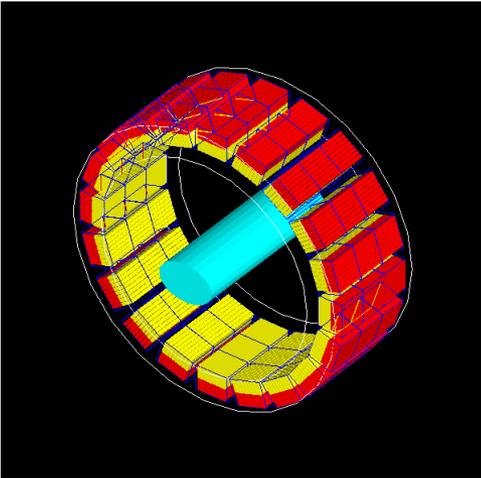


GATE - Nouvelle géométrie



1) Gate : version **standard**

Topologie axiale : 1 rsector, 3 modules / rsector

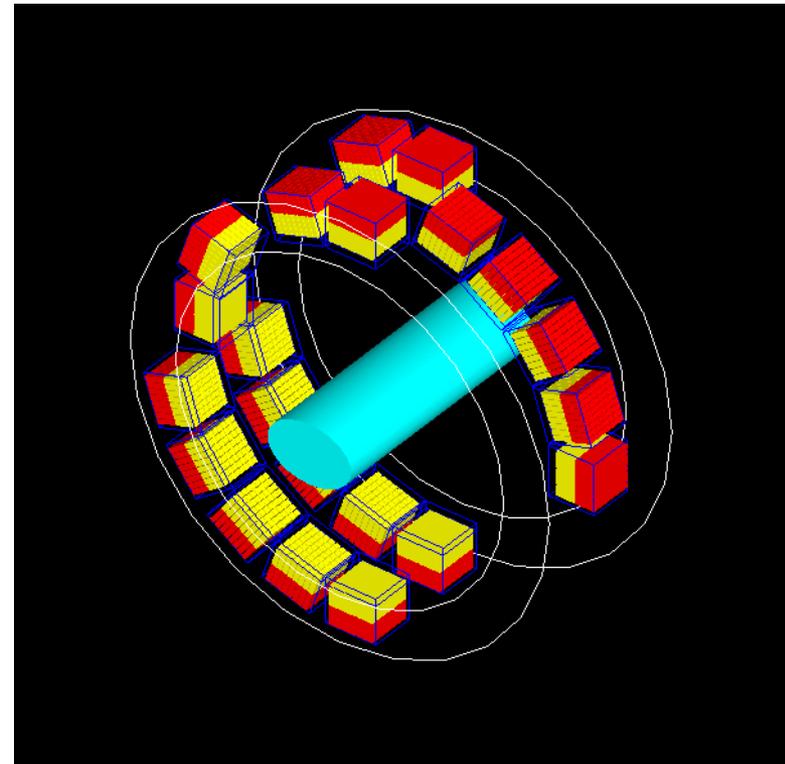


LMF
Selection des modules

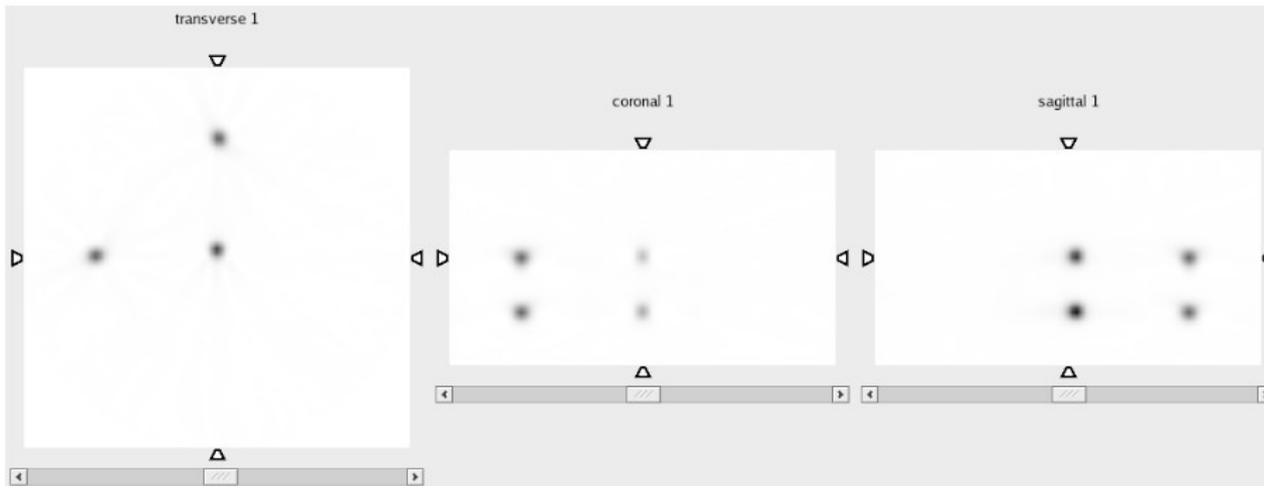


2) Gate : version **extendedCylindricalPETSystem**

Topologie axiale : 3 rsectors, 1 module / rsector



GATE - Nouvelle géométrie



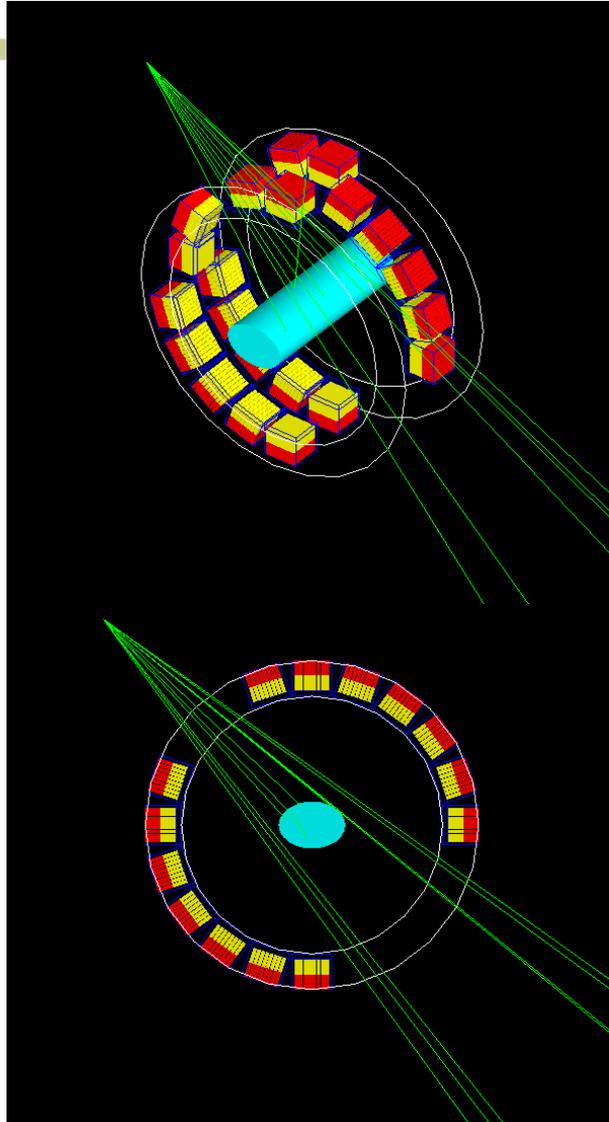
NEMA NU 2-2000

*1 MBq activity each
Rotation : 6 deg.s⁻¹
Acquisition time : 60 s*

		extended	standard
Singles		29 686 404	30 859 687
	Trues	1 203 267	1 344 681
Coincidences	Scatter	35 080	34 274
	Random	80 200	85 972

		Resolution (mm)	
		extended	standard
@ 2 mm radius	Transverse	2.88	2.89
	Axial	2.88	2.90
@ 30 mm radius	Transverse Radial	3.11	3.12
	Transverse Tangential	3.08	3.09
	Axial	2.98	3.01

GATE - Intégration source RX



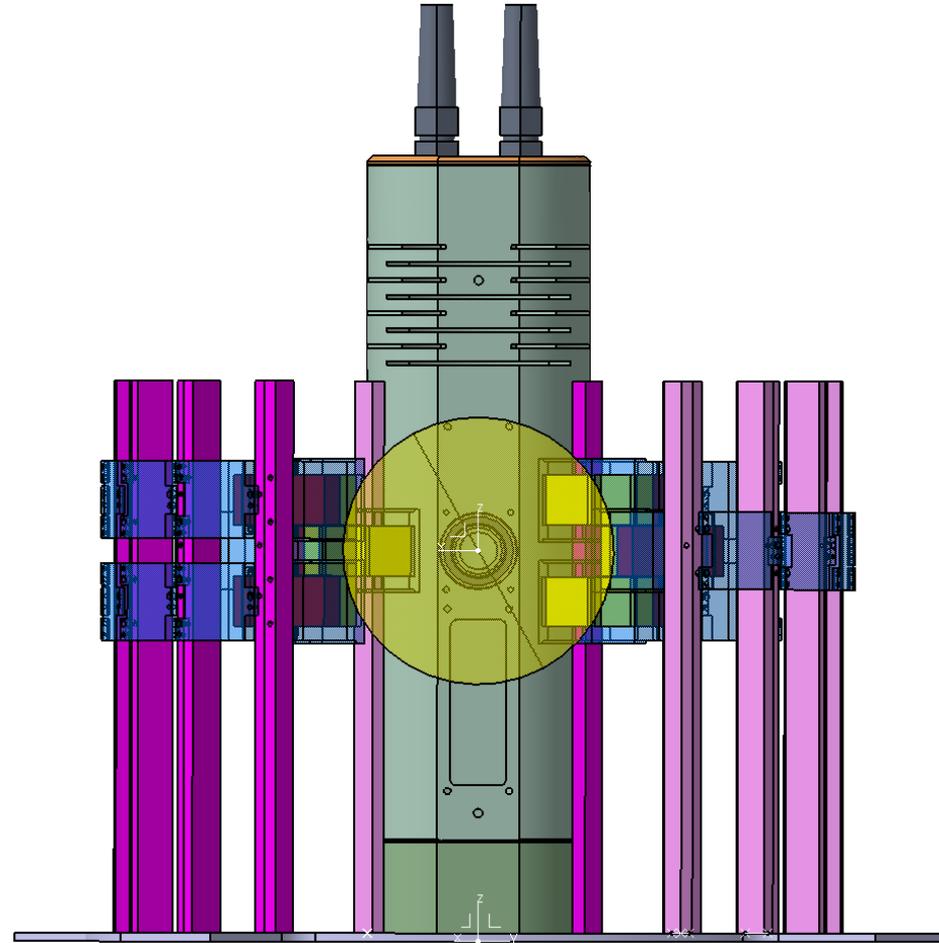
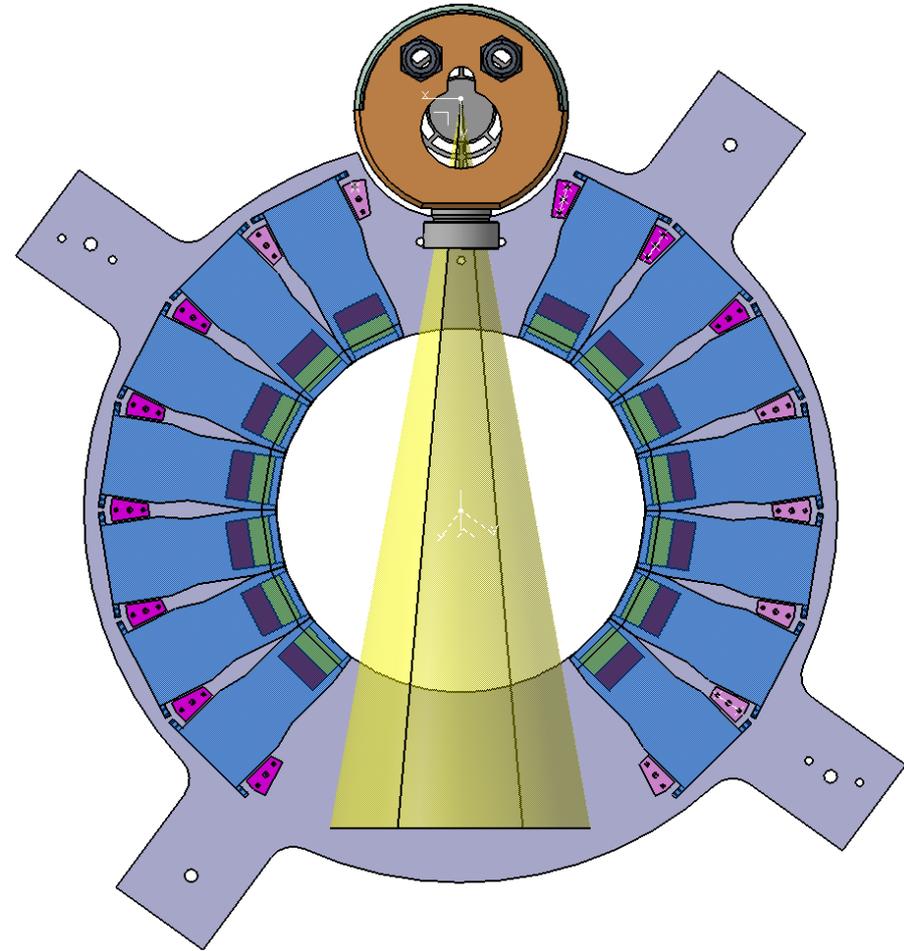
DSA = 155 mm
Foyer 50 μm
Angle d'émission 20°
Spectre 40 kV, 75 μmNb + 30 μmMo
100 μA \gg 4.8e5 ph.mm⁻².s⁻¹ @ 155 mm \gg A = 1 GBq

CCIN2P3 Lyon
A = 8 GBq (800 μA)

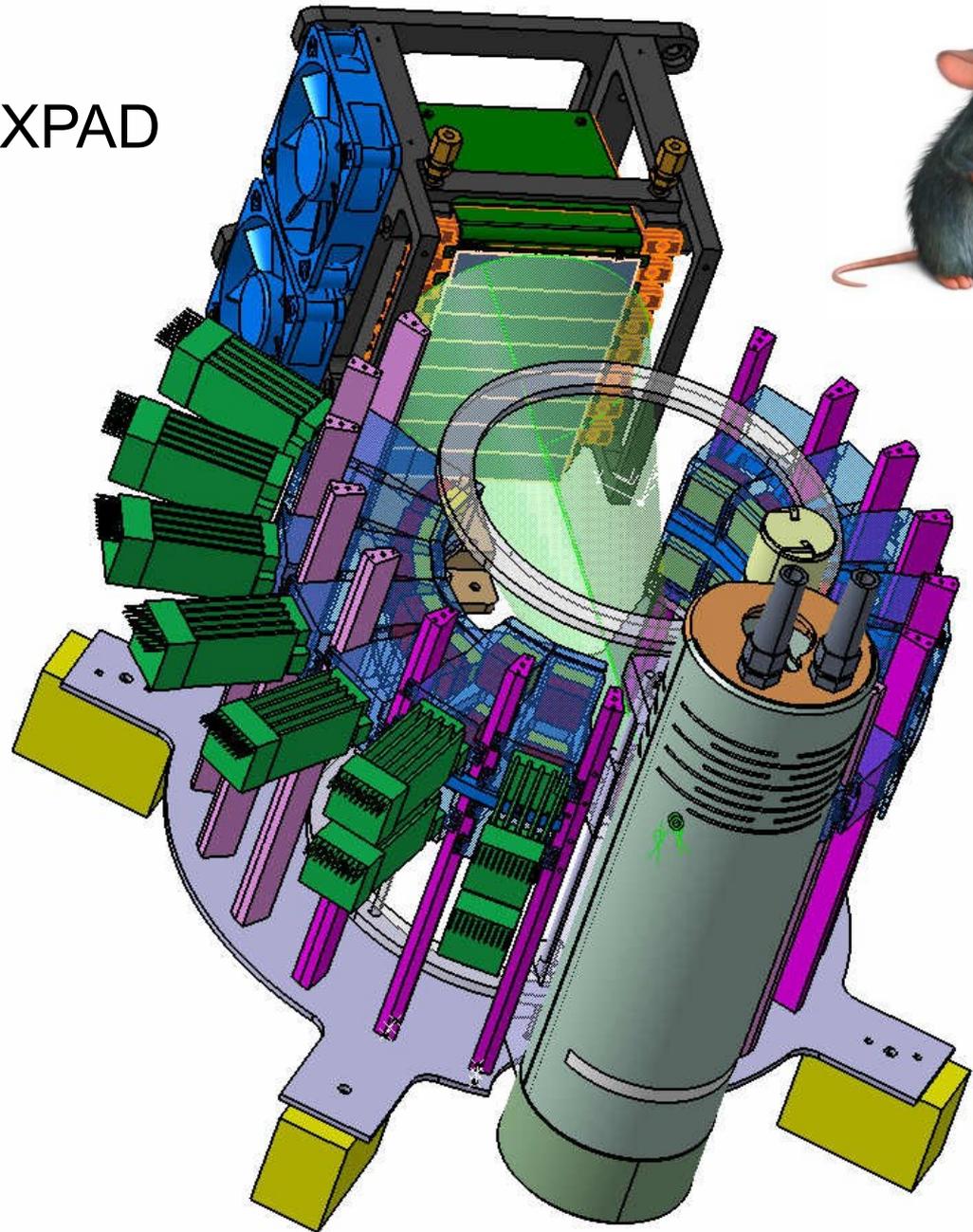
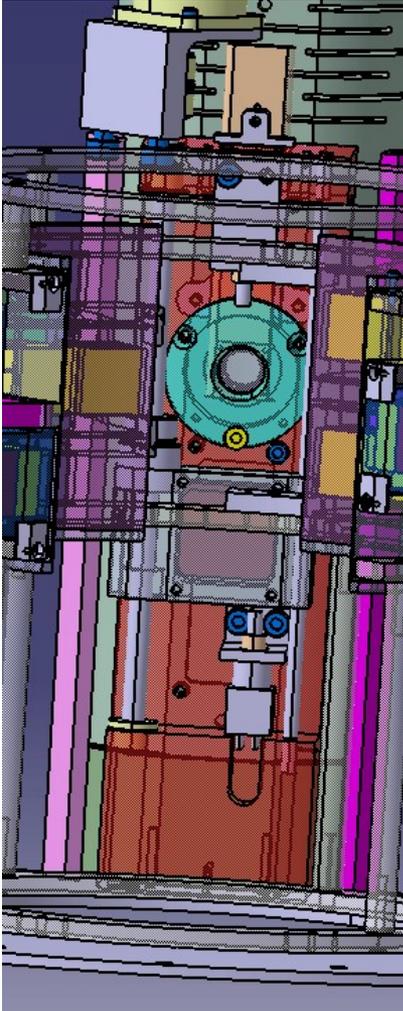
- 1 job :
 - run time : 0.041667 s
 - CPU time : 1.5e6 s (max 2e6 s)
 - Real time : 10 h
 - Output file : 100 MB

- 24 jobs :
 - 1 s d'acquisition
 - 10h de simulation
 - 2.4 GB de données

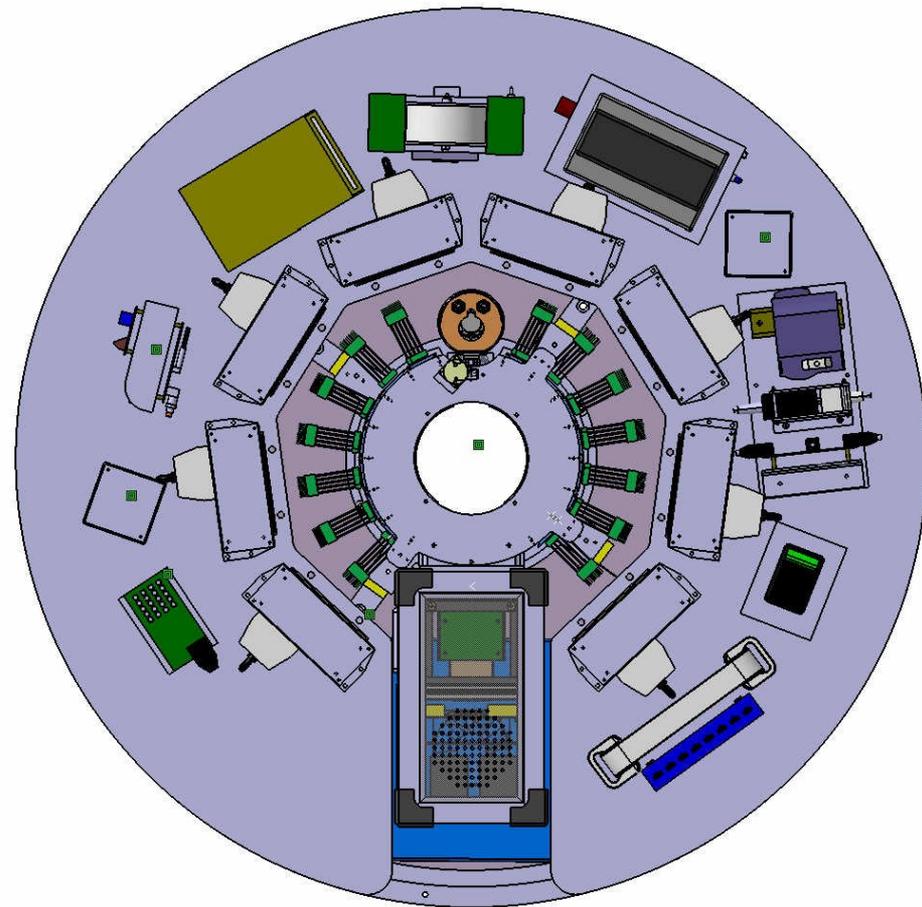
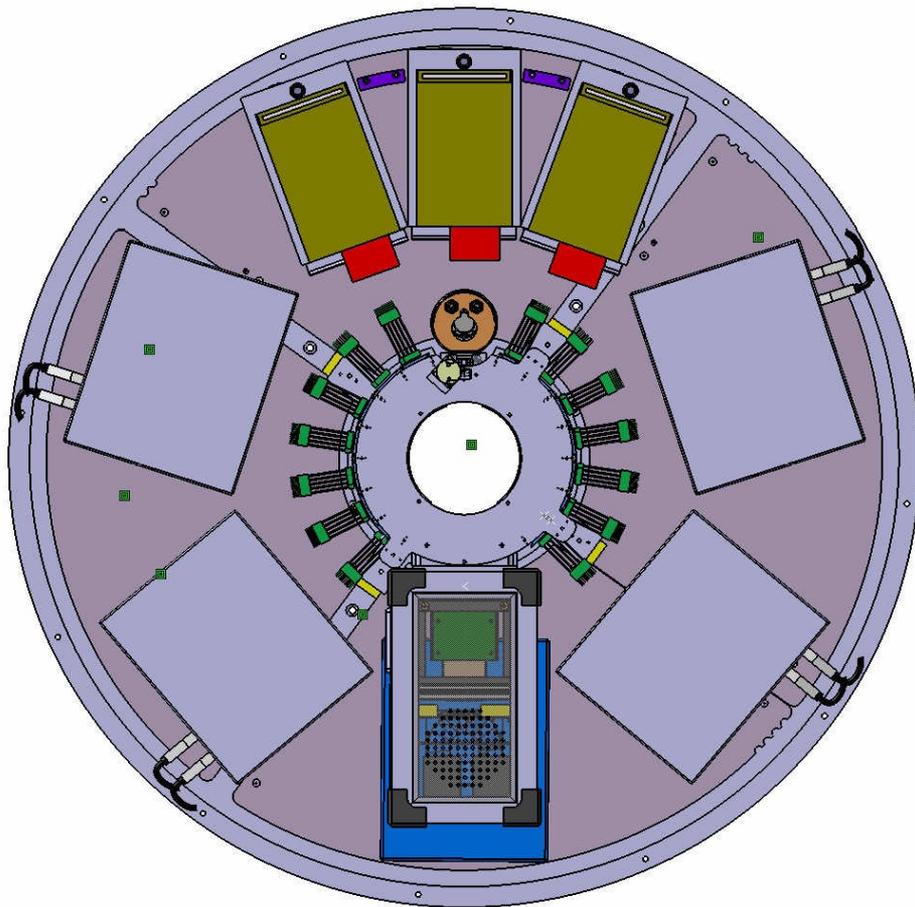
CAO - ClearPET/XPAD



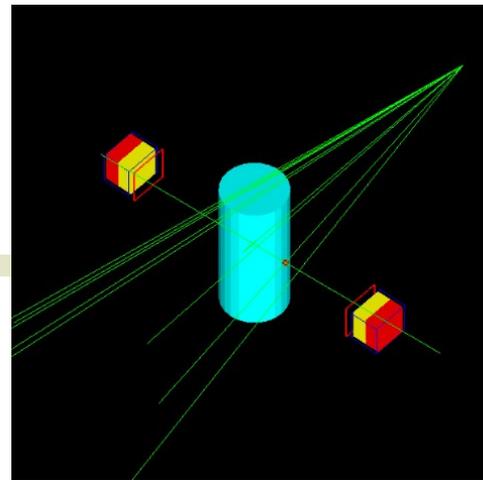
CAO - ClearPET/XPAD



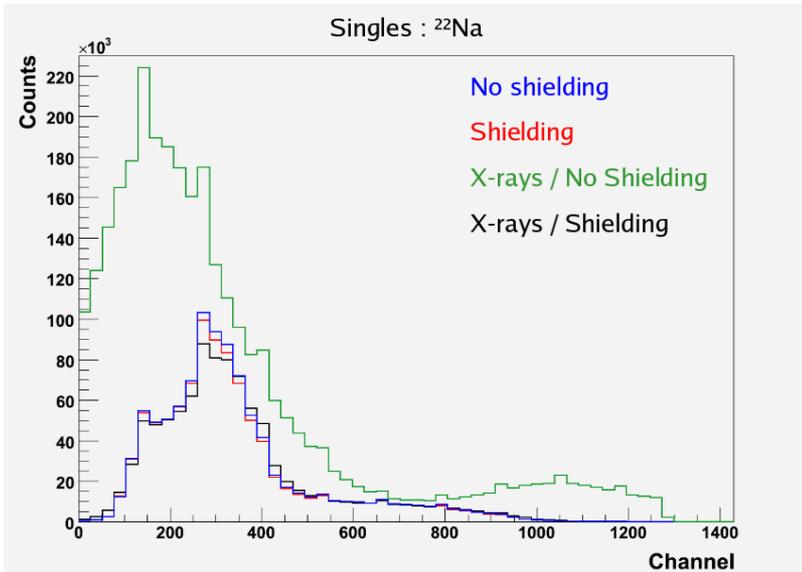
CAO - ClearPET/XPAD



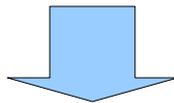
Acquisitions simultanées



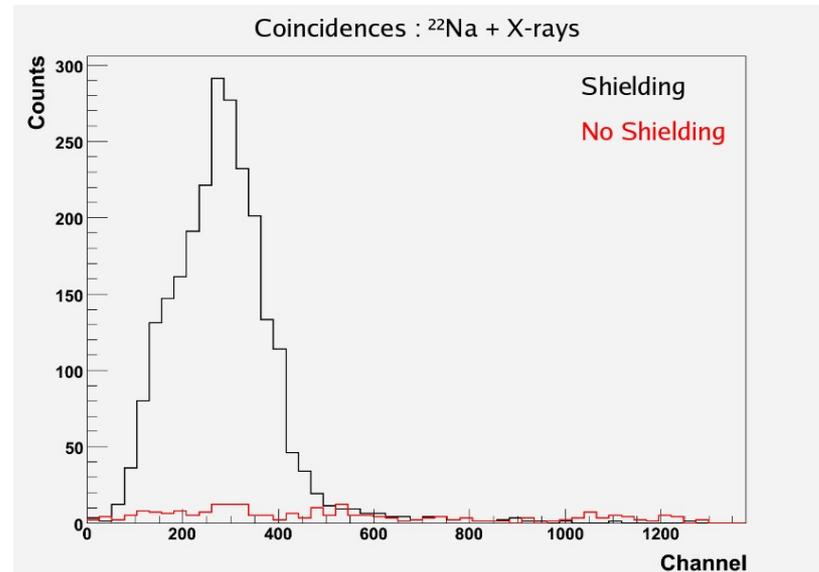
Shielding : 500 μm of brass



Important flux of scattered X-rays
(Rayleigh phantom scattering)



Saturation of the ClearPET detector modules
(complete loss of coincidences events)

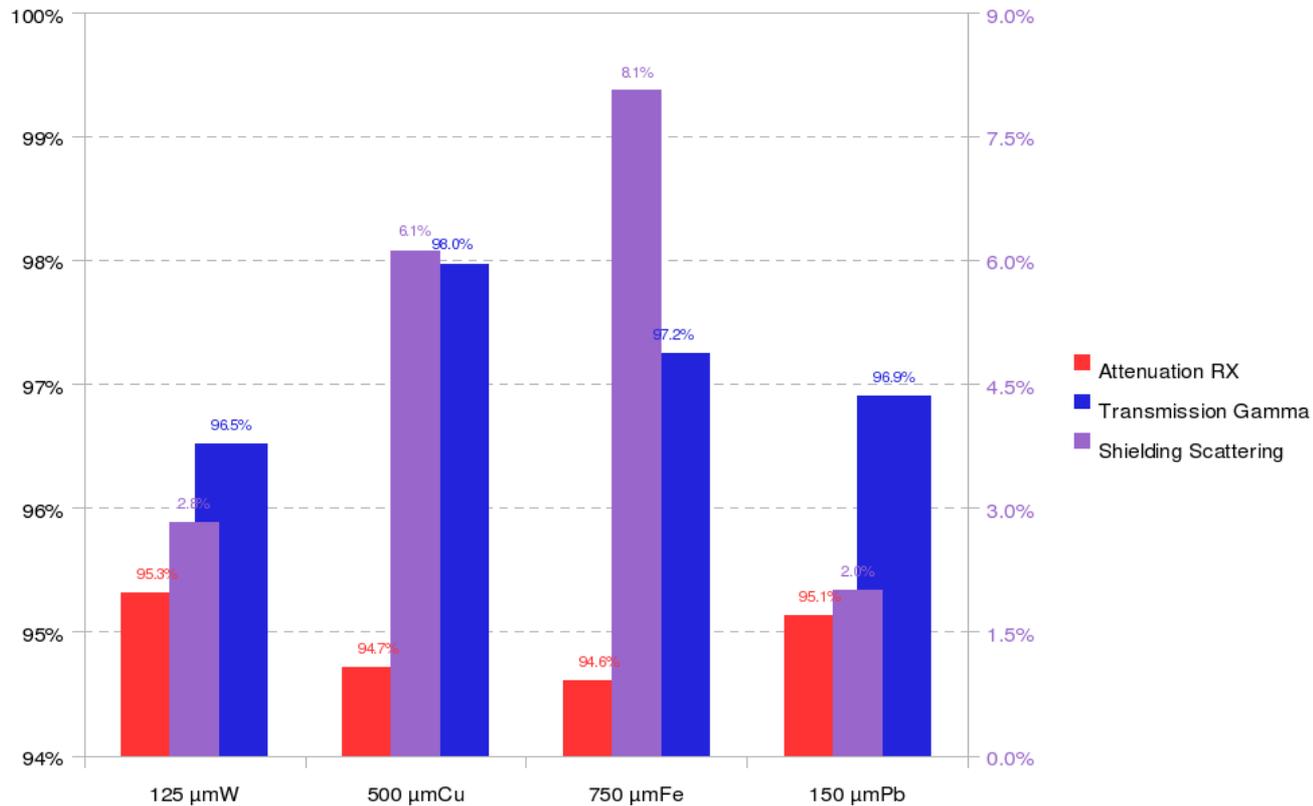
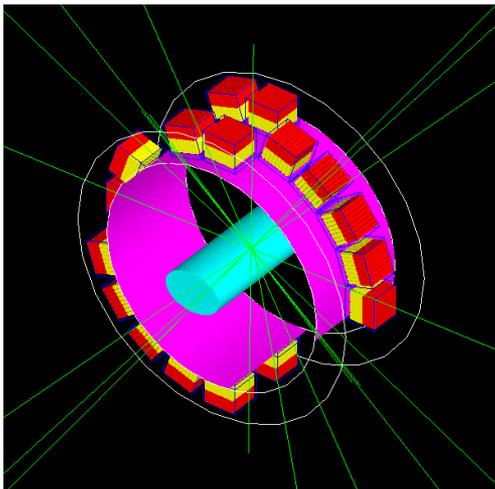
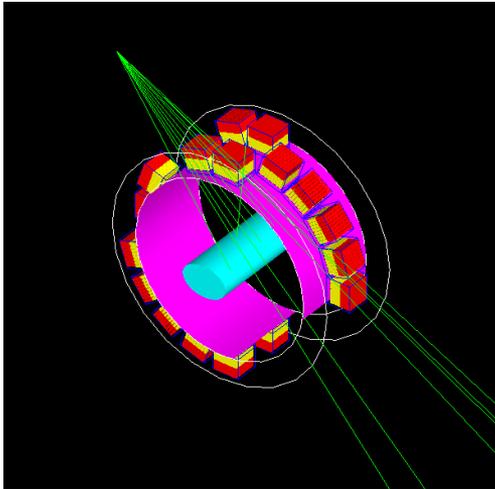


Shielding needed !!!

GATE - Etude de blindage



	Z	ρ (g.cm ⁻³)
Fe	26	7.87
Cu	29	8.96
W	74	19.30
Pb	82	11.35



GATE - Source RX

Pile up resolution time τ
FWHM dynode shaped pulse

True event rate n
8x8 MAPMT channels

Counting rate m



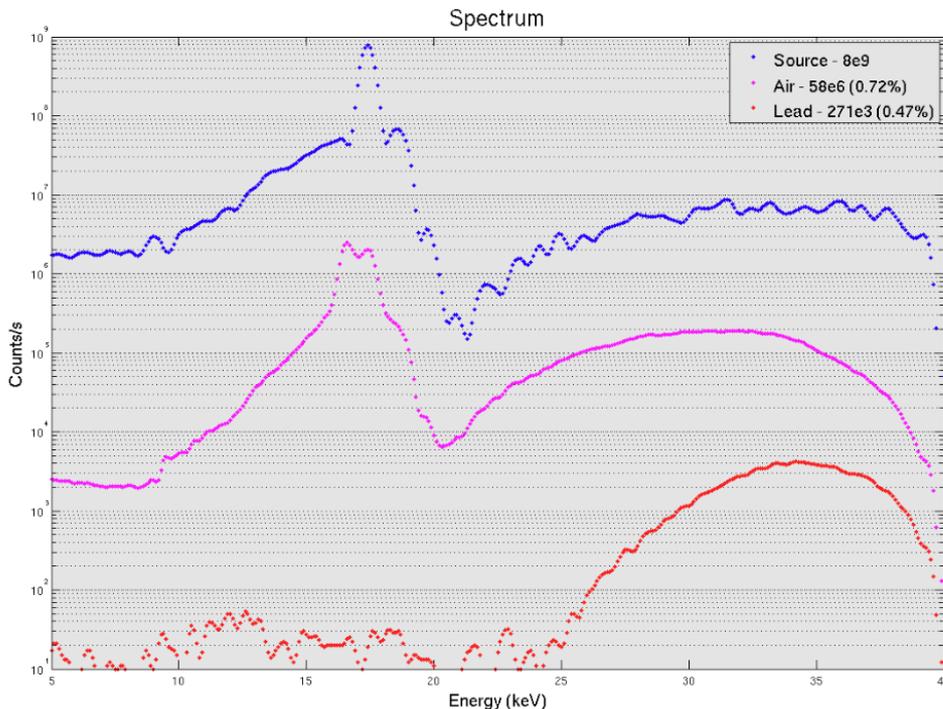
- Probability that k event occur over the following time tau :
- Probability that no event occur over the following time tau :
- Average number of true event per count (paralizable system) :
- Fraction of true event that escape pileup (recorded free of pileup) :

$$P(k) = e^{-n\tau} \frac{(n\tau)^k}{k!}$$

$$P(0) = e^{-n\tau}$$

$$m = n e^{-n\tau} \Leftrightarrow \langle x \rangle = \frac{n}{m} = e^{n\tau}$$

$$f_{FreeOfPileUp} = \frac{P(0)}{\langle x \rangle} = \frac{e^{-n\tau}}{e^{n\tau}} = e^{-2n\tau}$$



$$\tau = 150 \text{ ns}$$

$$n_{Air} = 58 \cdot 10^6 / 21 = 2,7 \text{ MHz}$$

$$n_{Pb} = 271 \cdot 10^3 / 21 = 12,9 \text{ KHz}$$

$$f_{FreeOfPileUp}^{Air} = 43,9 \%$$

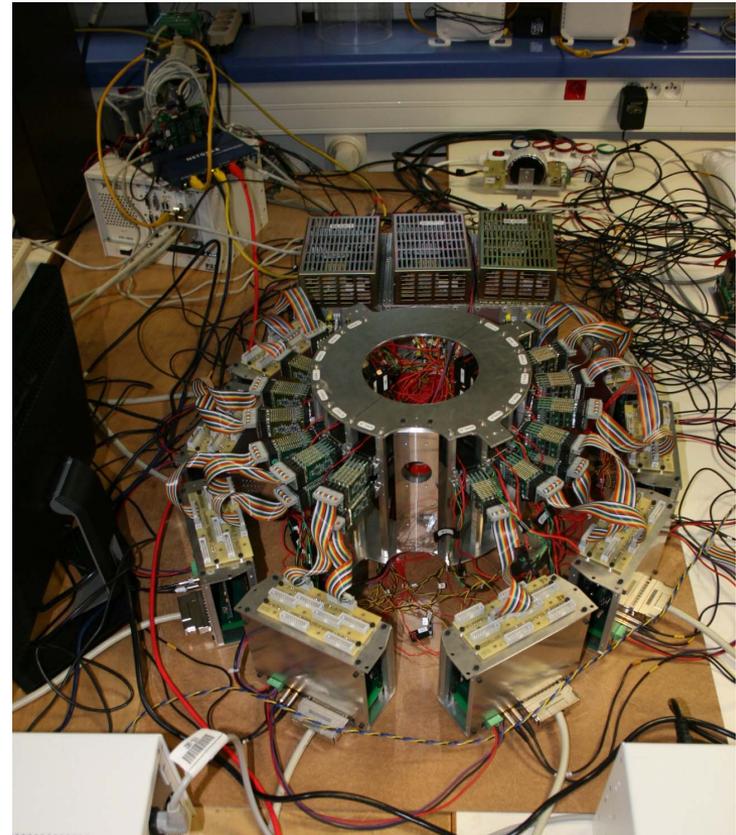
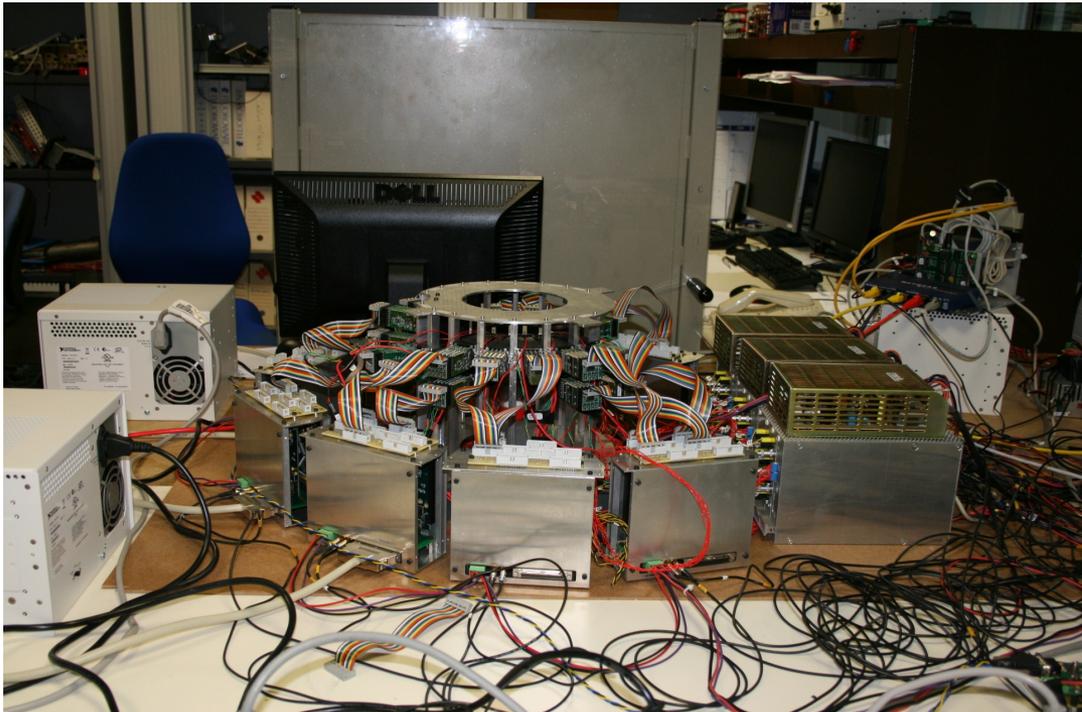
$$f_{FreeOfPileUp}^{150\mu\text{mPb}} = 99,6 \%$$

DAQ ClearPET



Refonte, optimisation et simplification du code (LabView) :

- Interface (contrôle par face avant distante)
- Communication (variables partagées)
- Management (LabView Project, subversion repository)
- Modularité, stabilité



Perspectives



■ Simulation

- Implémenter un modèle de pileup (energy, time measurements, DOI)
- Reproduire le comportement du ClearPET en mode acquisitions simultanées

■ DAQ

- Réglage individuel des modules TEP (tension, température, seuil, DOI)
- Validation des spectres mesurés
- Prise de donnée (singles & coïncidences)
- Intégration de la source RX

■ Mécanique

- Fabrication des pièces manquantes
- Montage