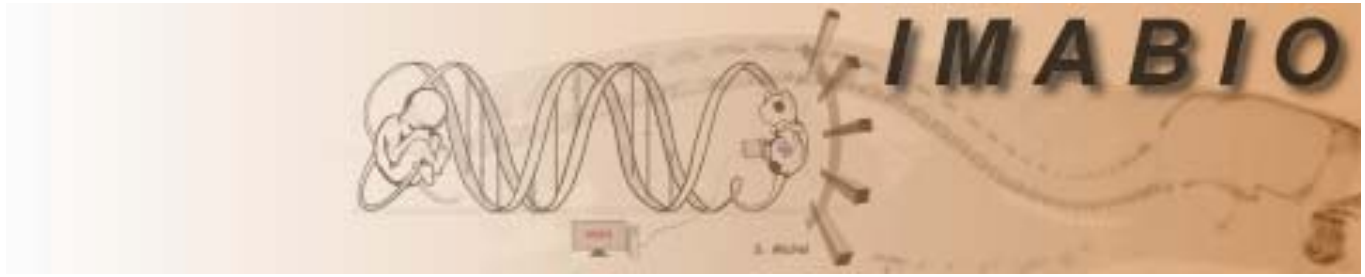


Study for the design of a multimodality imaging system dedicated to small animal

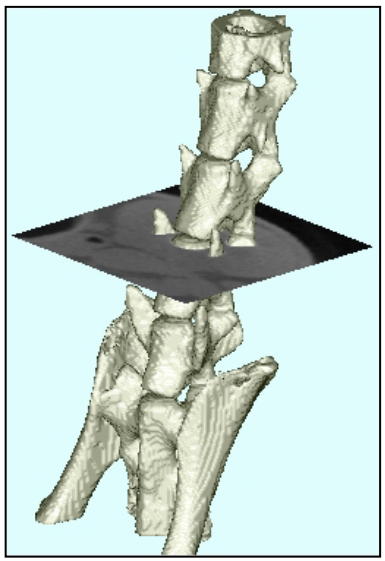
I. Piqueras, D. Brasse, V. Bekaert, K. Leroux, J-L. Guyonnet

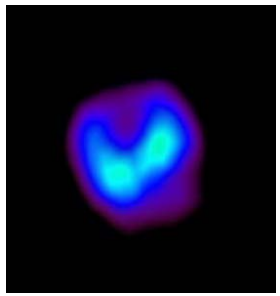
Institut de Recherches Subatomiques
CNRS-IN2P3-ULP Strasbourg

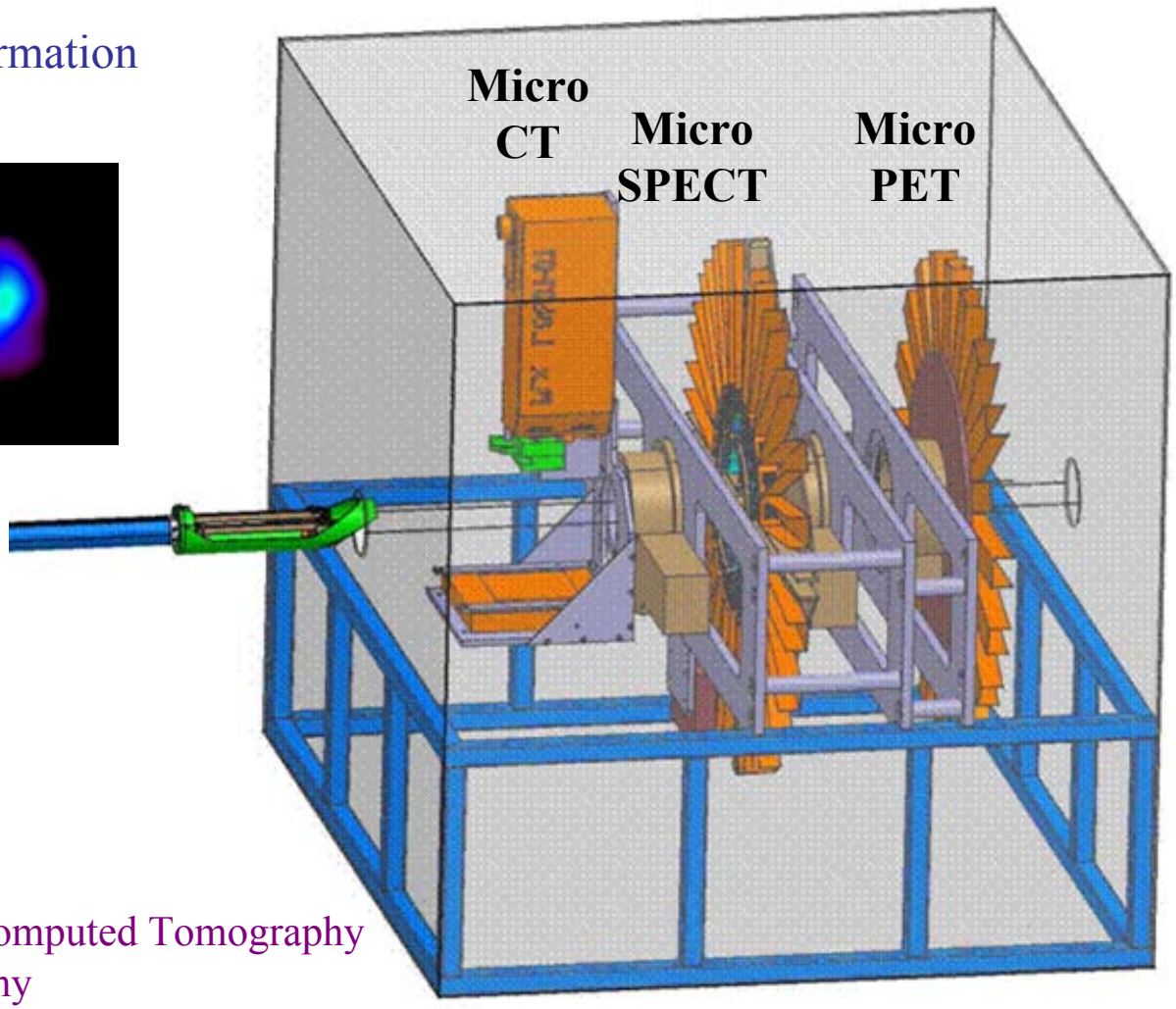
Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

Multimodality imaging system for small animal

Goal:
Anatomical + functional information





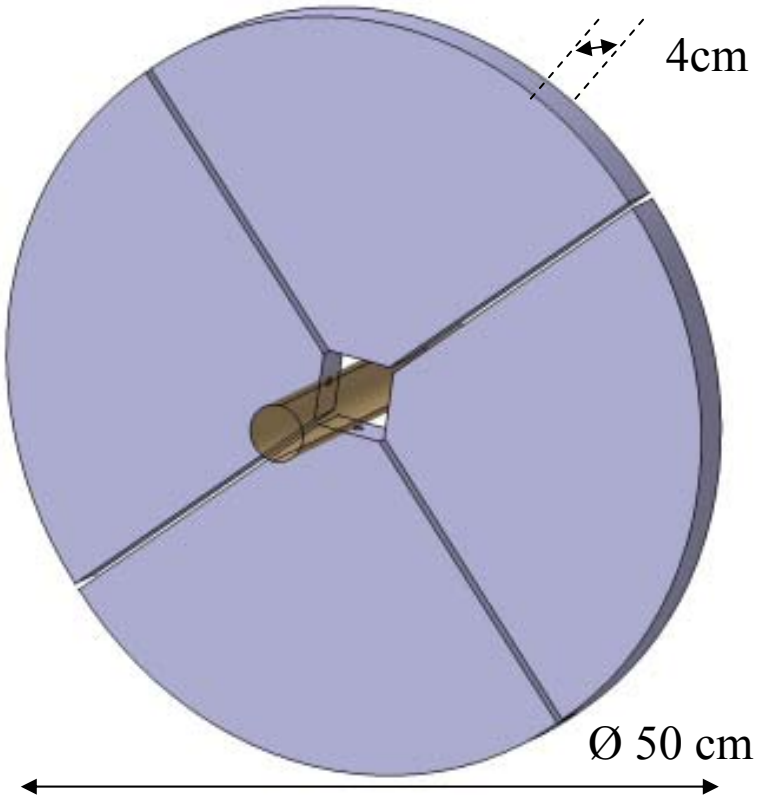


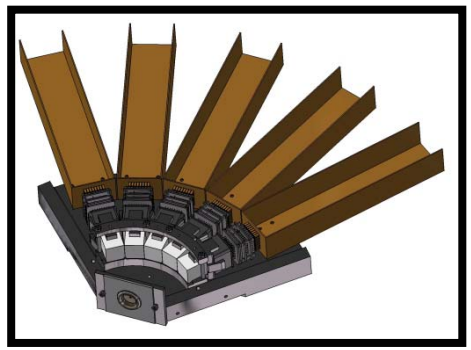
CT : Computed Tomography
SPECT : Single Photon Emission Computed Tomography
PET : Positron Emission Tomography

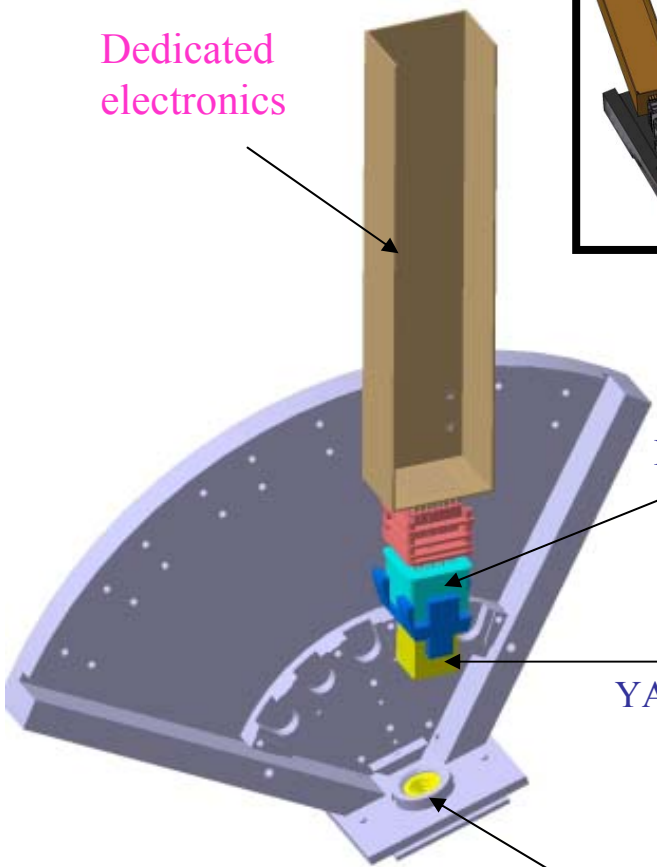
Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

Micro SPECT

Four cameras







Goals :

Resolution: 1 mm

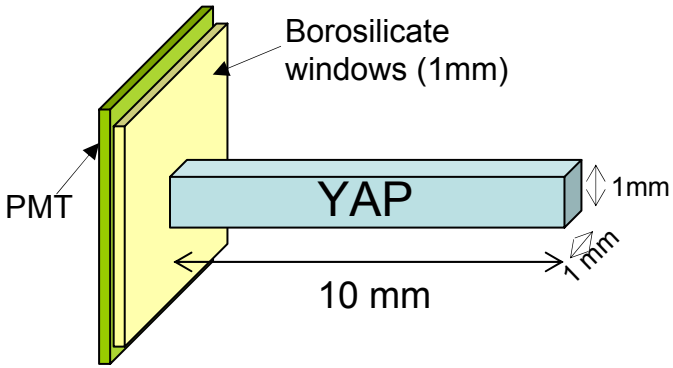
Geometrical efficiency : 40 cps/MBq/camera

Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

GEANT4 Simulations: scintillation process + light transport + light collection

Validation of simulation: comparison with references and measurements

Simulation of the scintillation in a YAP crystal 1 x 1 x 10 mm^3:



1. Scintillation Process:

In ExptPhysicsList:

#include "G4Scintillation.hh"

theScintillationProcess = new G4Scintillation("Scintillation");

theScintillationProcess->SetScintillationYieldFactor(1.);

theScintillationProcess->SetTrackSecondariesFirst(true);

2. Definition of the scintillator material and optical properties of the medium:

```
G4double PhotonEnergy[nEntries] ={ 2.90*eV,…… 3.6*eV };

G4double RefractiveIndex1[nEntries] ={ 1.90, …. 1.98};
G4double Absorption1[nEntries] ={14.35*cm, …15.0*cm};
G4MaterialPropertiesTable* myMPT1 = new G4MaterialPropertiesTable();
 myMPT1->AddProperty("RINDEX",       PhotonEnergy, RefractiveIndex1,nEntries);
 myMPT1->AddProperty("ABSLENGTH",    PhotonEnergy, Absorption1,     nEntries);
 myMPT1->AddConstProperty("SCINTILLATIONYIELD",18000./MeV);
 myMPT1->AddConstProperty("FASTTIMECONSTANT", 27.*ns);
 myMPT1->AddConstProperty("SLOWTIMECONSTANT",10.*ns);

 YAP->SetMaterialPropertiesTable(myMPT1);
```

Peak wavelength 370 nm

Refraction index

Absorption length in YAP = 14 cm

Light Yield

Decay Time

Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

GEANT4 Simulations: scintillation process + light transport + light collection

3. Boundary Process (between YAP and Air): "Al coating" simulation

Dielectric-Metal:

- Reflection = **0.95**
- Absorption = **0.01**

} **Aluminum coating**

```
G4OpticalSurface* OpAlSurface = new G4OpticalSurface("AlSurface");
OpAlSurface->SetType(dielectric_metal);
OpAlSurface->SetFinish(polished);     polished surface
OpAlSurface->SetModel(unified);       Model Unified

G4MaterialPropertiesTable *myST1 = new G4MaterialPropertiesTable();
```

4. Surface YAP- PMT window: two dielectric materials

- Photon transport defined by the materials and their refraction indexes

(**G4MaterialPropertiesTable**).

- Surface concept is no used

Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

GEANT4 Simulations : Comparison with references

1. Reference: S. Baccaro et al., NIM A 406 (1998), 479-485

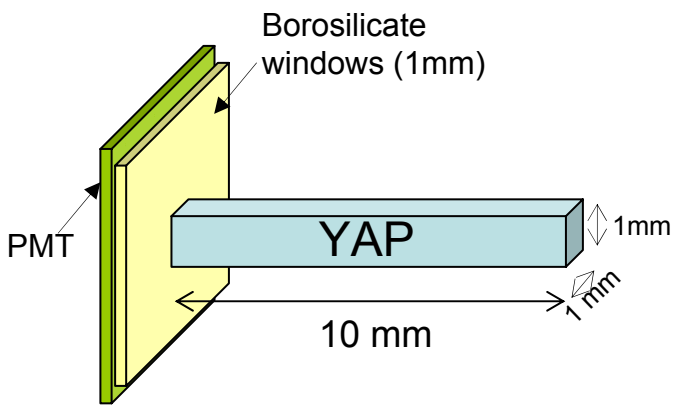
YAP crystal 1 x 1 x 10 mm^3

a. Calculated Maximum value ratio (Detected photons)/ (Emitted photons) (D/E) ~ **37%**
   Source located inside the YAP crystal
   Total Reflection (R=1) + Infinite absorption length of YAP

b. Monte Carlo Simulation D/E = **23%**
   (70% optical photons absorbed in the coat and 7% YAP crystal)

2. GEANT4 Simulation : D/E = **30 %**

(absorption in the surface YAP-Air (Al coating) = 1%, PMT surface 5x5 mm^2)



Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

GEANT4 Simulations : Crystal YAP

Comparison: Simulation – Measurement

• Measurement of a **10 x 10 x 10 mm³** YAP crystal.

Source 122 keV

Result = 0.6 photoelectron/keV

(quantum efficiency = 20%)

Ratio Detected Photons/Emitted photons (D/E) = **19%**

(Preliminary results)

• Simulation 10 x 10 x 10 mm³ YAP crystal

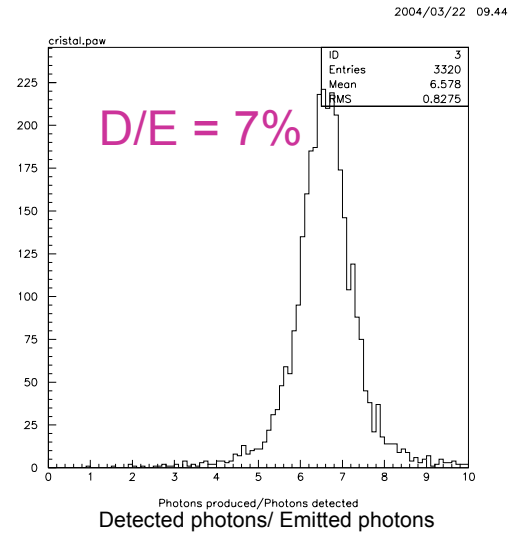
Borosilicate PMT window (1mm)

PMT surface: 2.5 x 2.5 cm²

Ratio Detected Photons/Emitted Photons (D/E) = 33%

1 crystal of the YAP matrix

2.3 x 2.3 x 28 mm³



Surface PMT
Edge effects

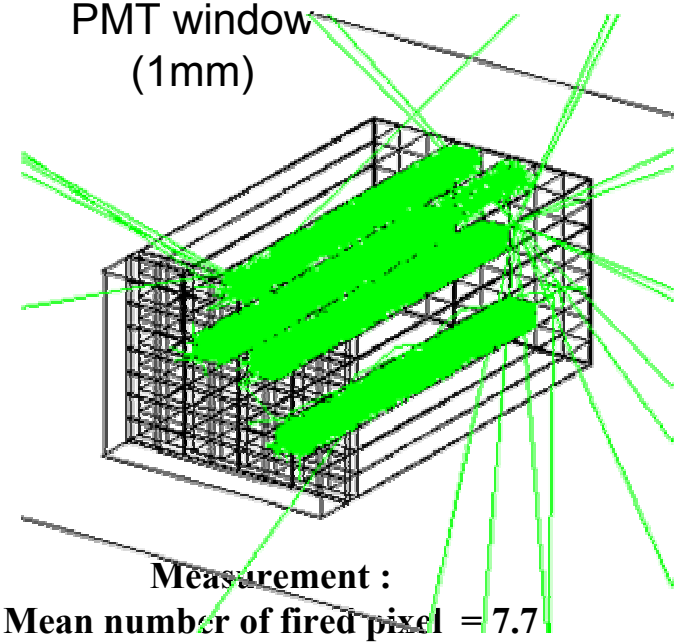
Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

GEANT4 Simulations : Matrix of 64 YAP crystals

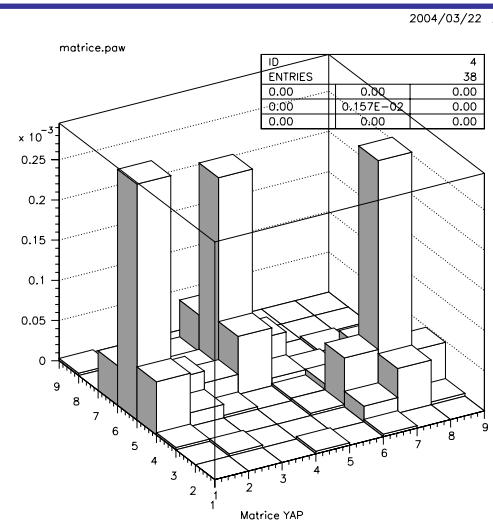
Matrix 8 x 8 crystals

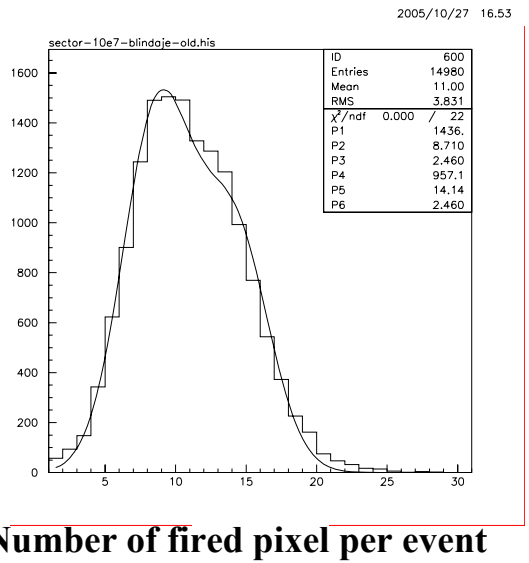
64 PMT channels

PMT window (1mm)



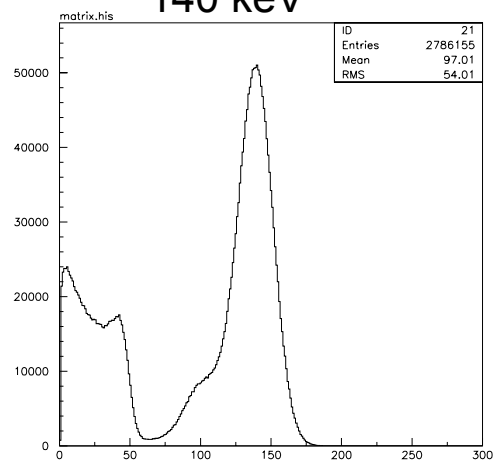
Measurement :
Mean number of fired pixel = 7.7 (cluster)



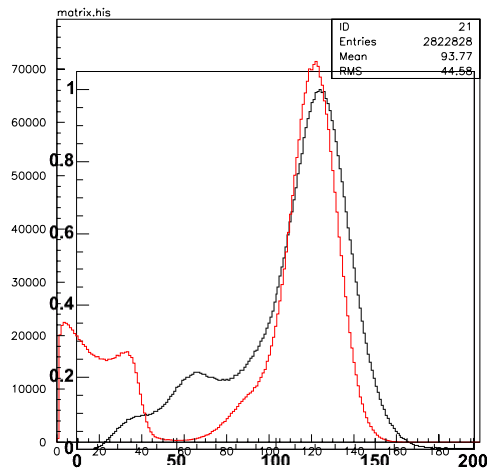


Number of fired pixel per event

Example of 3 events
140 keV



Energy (keV)



Measurement

Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

Energy distribution in the pixels: Matrix of 64 YAP crystals

Measurement

0.00	0.00	0.00
0.00	81.29	7.94
0.00	8.47	1.04

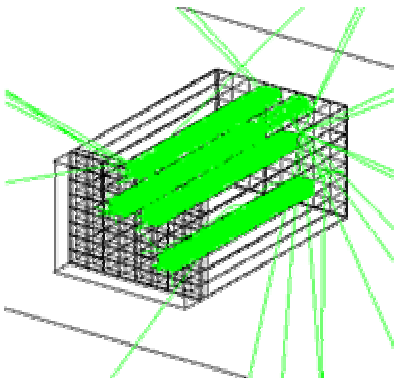
Pixel in the corner

0.00	10.75	1.26
0.00	67.74	7.17
0.00	9.78	1.04

Edge pixel

2.48	10.38	1.56
9.07	57.45	6.31
1.79	7.02	1.09

Central pixel



GEANT4

	80%	8.8%
	8.1%	3.1%

	9.6%	3.4%
	66%	6.8%
	10.5%	3.7%

2.4	9.8%	2.3%
9.1	54.5%	9.0%
2.0	8.3%	2.1%

Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

Simulation for the position correction Micro SPECT

Matrix of 8 x 8 crystals (2.3 x 2.3 x 28 mm^3)

Interaction probability for a 140 keV gamma in YAP:

- **50%** Photoelectric effect
- **50%** Scattering Compton

Simulation of the

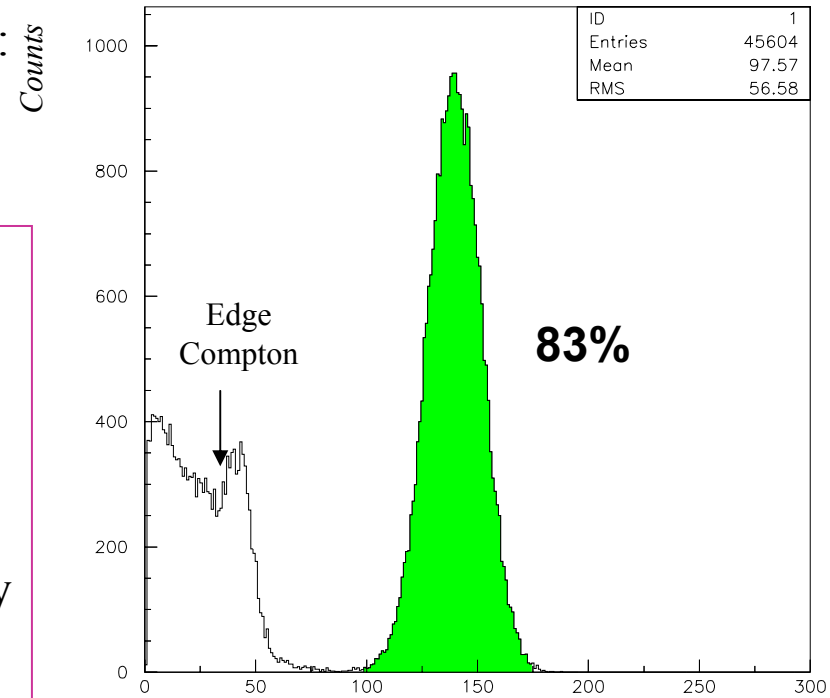
64 crystals matrix YAP (2.3 x 2.3 x 28 mm^3):

Total Photopeak Efficiency = **83%**

(total energy absorption in the matrix by photoelectric effect o multiple Compton scattering)

Photopeak efficiency (one single crystal fired) = 63 %

20% Resolution included in simulation



Experimental resolution R=29% @ 122 keV (matrix)

Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

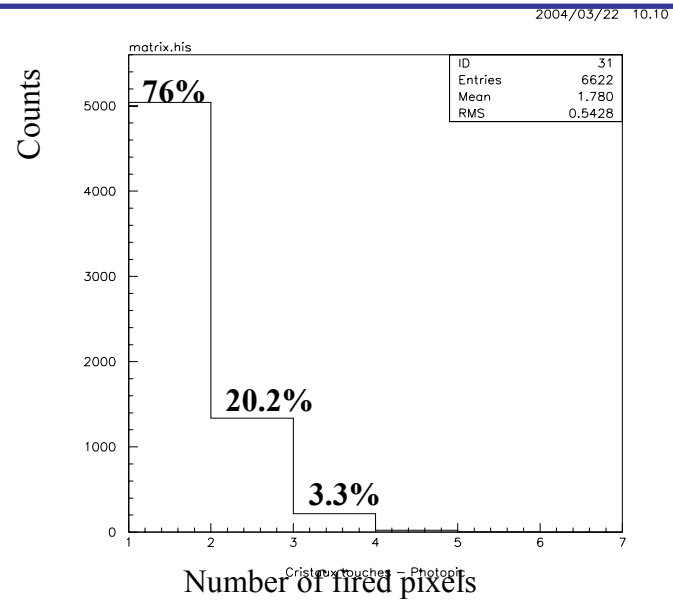
Simulation Energy distribution in the matrix

Number of fired crystals (photopeak events):

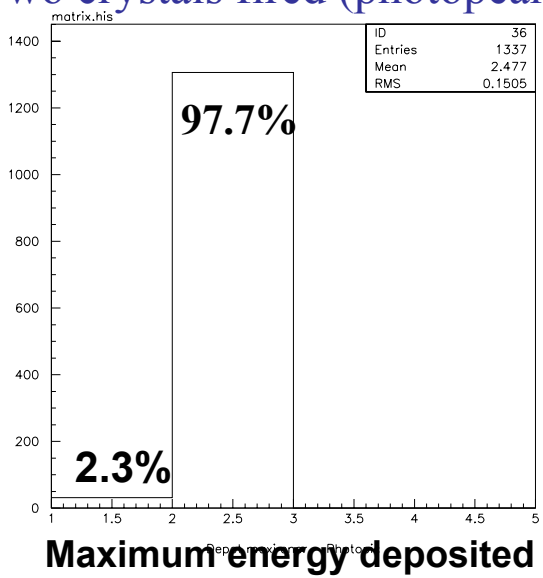
76% : One

20.2% : Two

3.3% : Three



Two crystals fired (photopeak events):

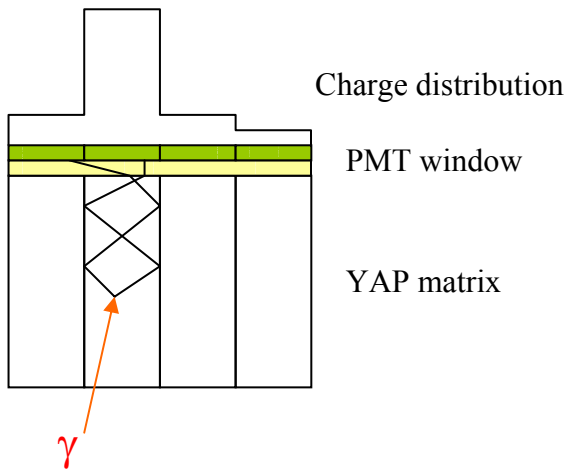


Maximum energy deposited:

Second crystal fired: 97.7%

Possible identification of the first crystal hit but …

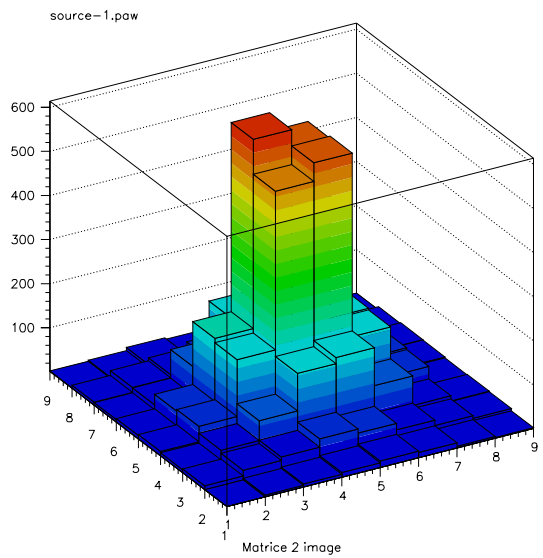
Energy range first hit [1, 49 keV]
Energy range second hit [91, 140 keV]

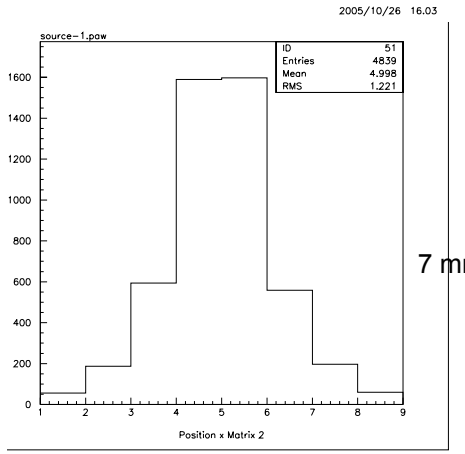


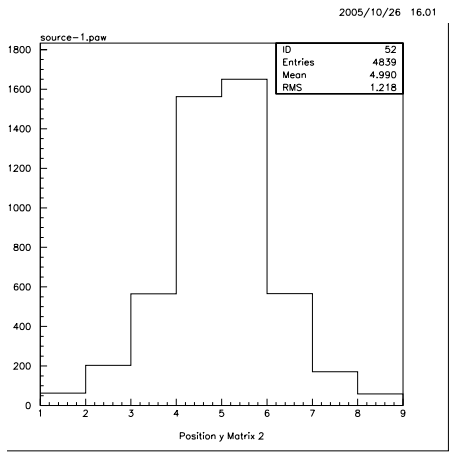
Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

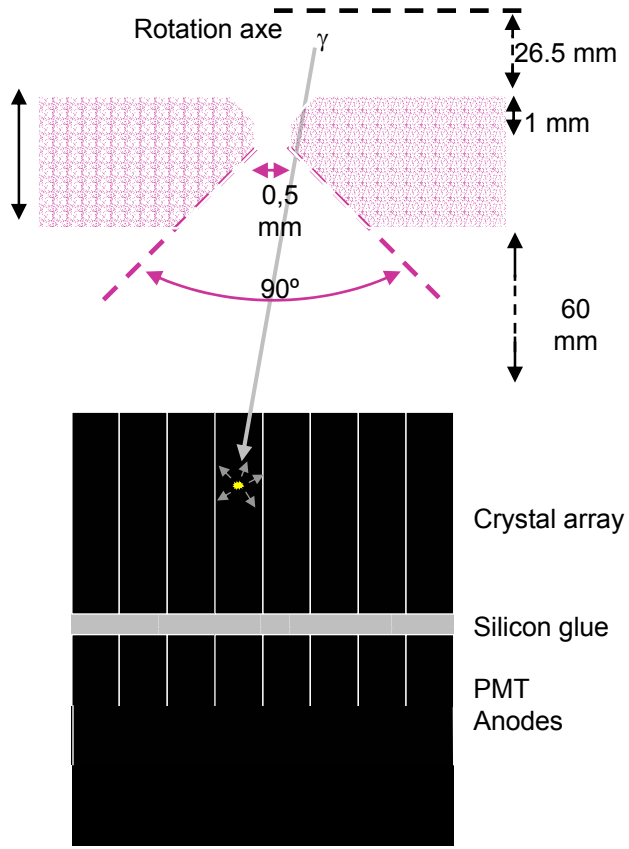
GEANT4 simulation – Detector response

Source at 2.5 cm of pin-hole
γ Ray emitted = $6x10^6$
Total Efficiency (Matrix 2)=6623cps/MBq
Photopeak efficiency =200cps/MBq/camera
ΔE (photons spectrum) =[400, 600 eV])



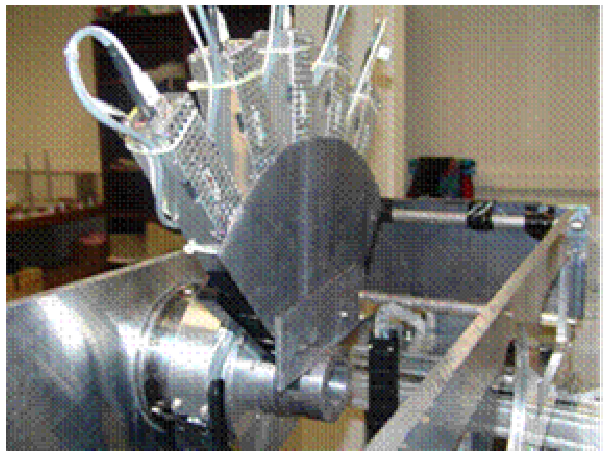




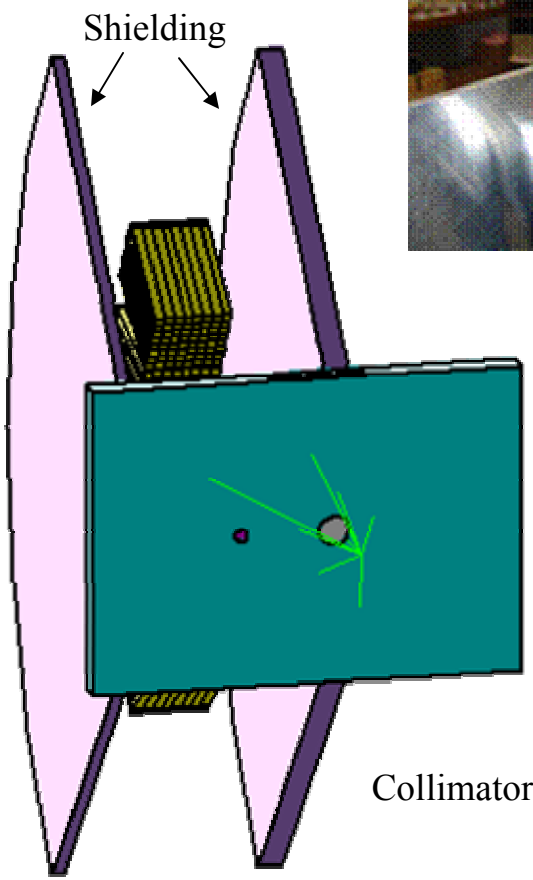


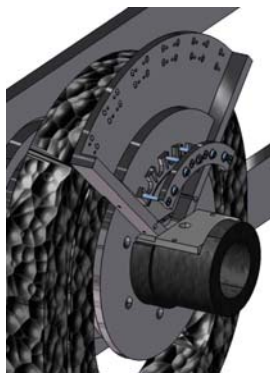
Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

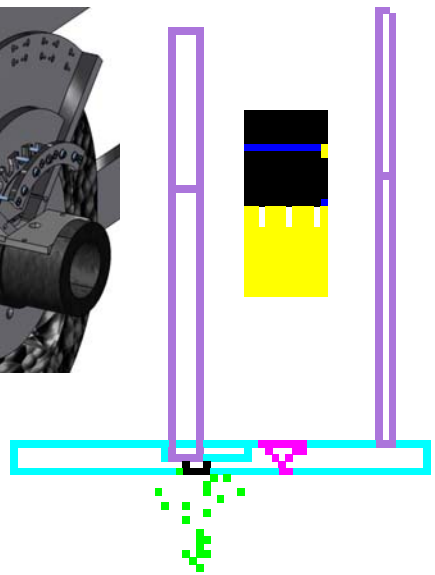
Simulations on the SPECT shielding

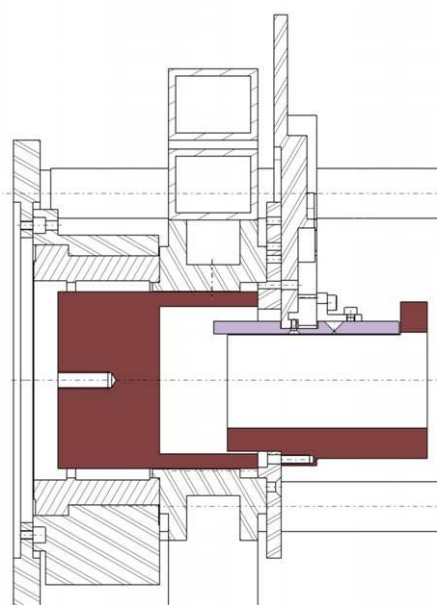


- Tungsten collimator
- Lateral shielding in Al (USIPLAN)
- steel screw in the collimator plate (Fe 86%)





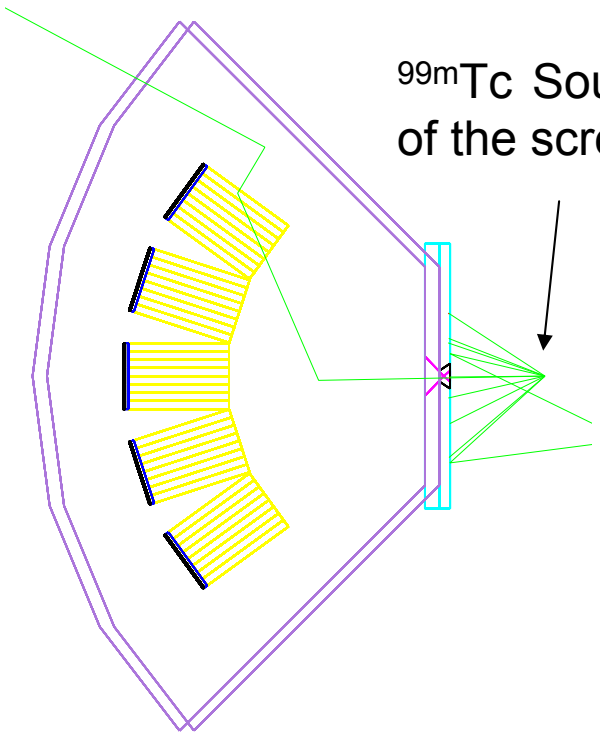




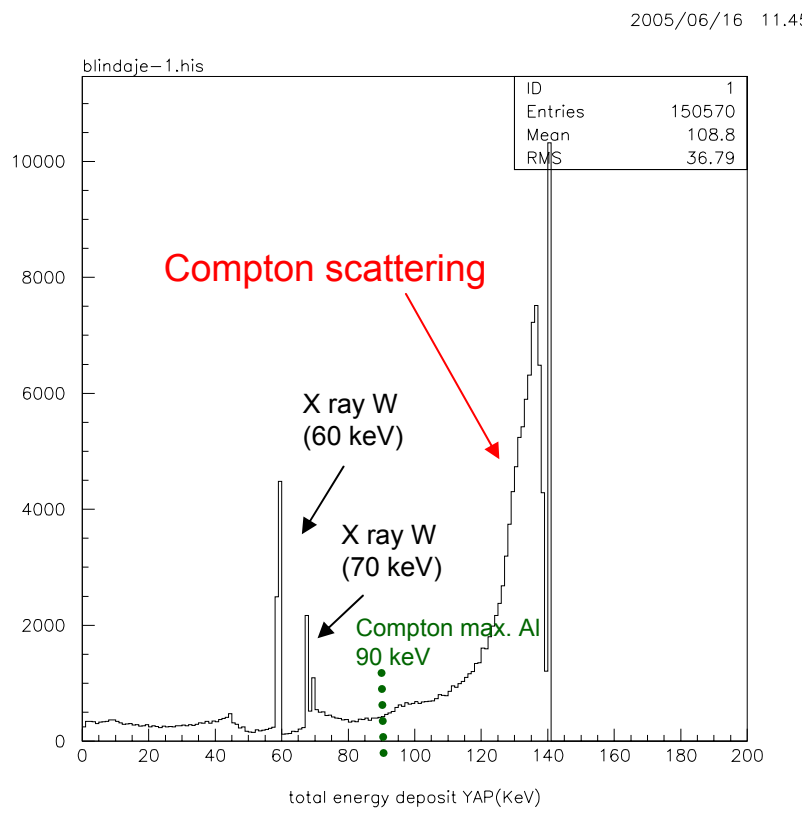
Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

Compton scattering and X fluorescence

Simulation of 5 YAP matrix (8x8 crystals of 2. 3 x 2.3 x 28 mm3):
Effect of the Compton scattering and the X fluorescence on the energy spectrum



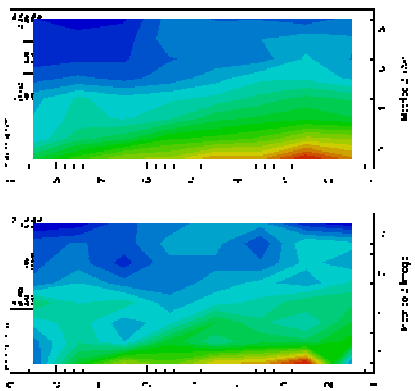
^{99m}Tc Source in front of the screw

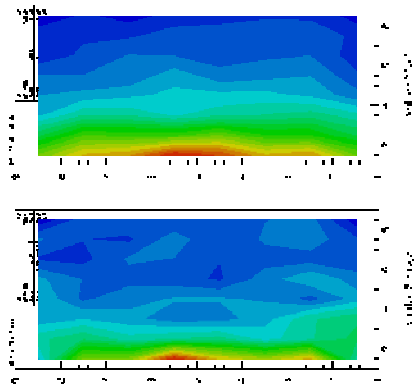


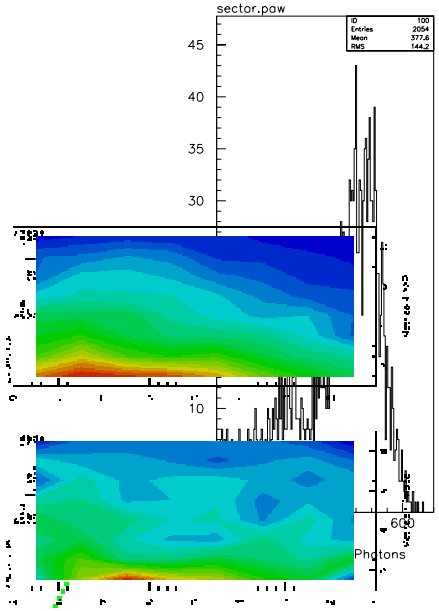
Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

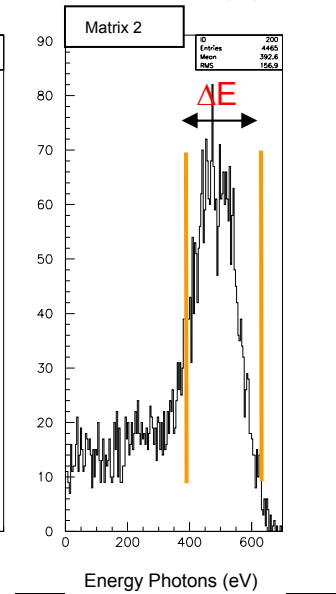
GEANT 4 Simulations : SPECT

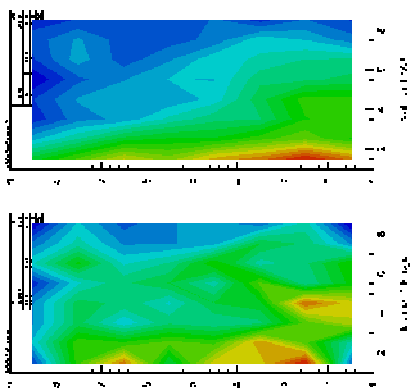
$6x10^8$ γ rays 140 keV
(solid angle of the sector : π/8)

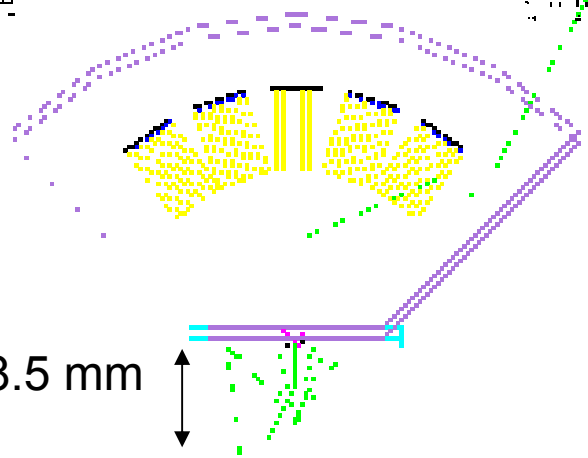


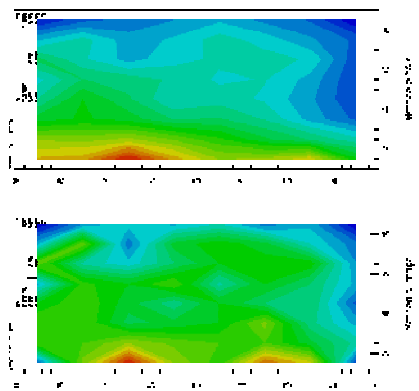






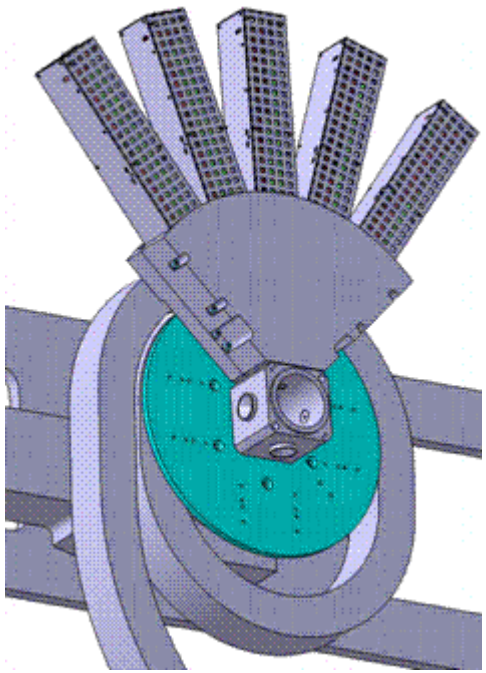


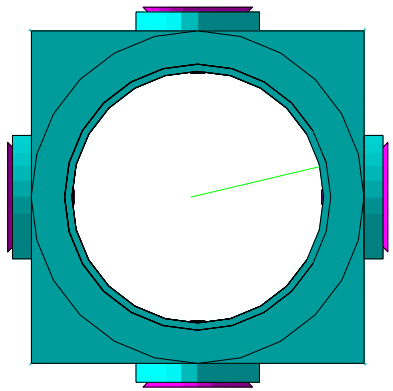


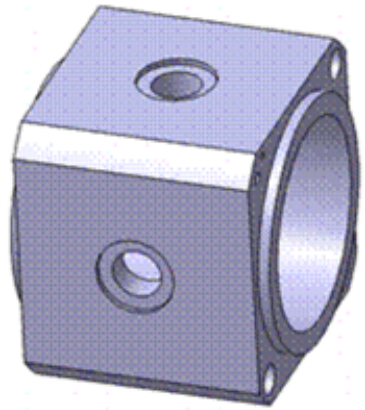


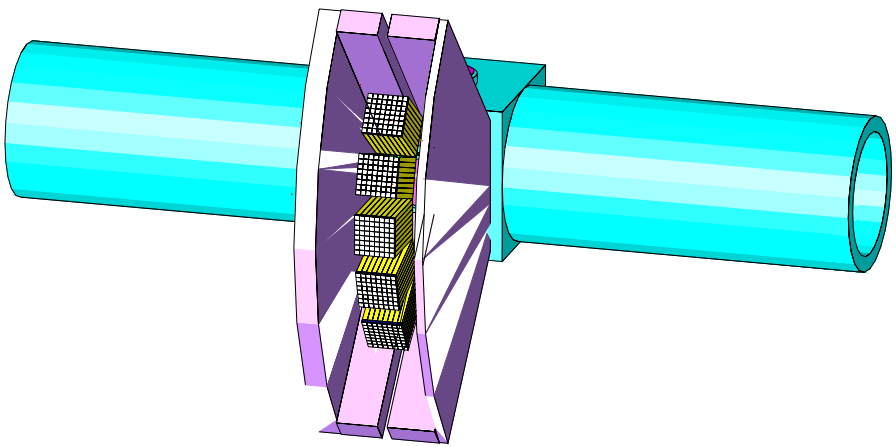
Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

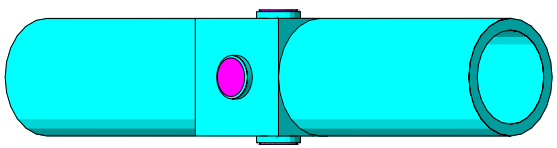
Future shielding





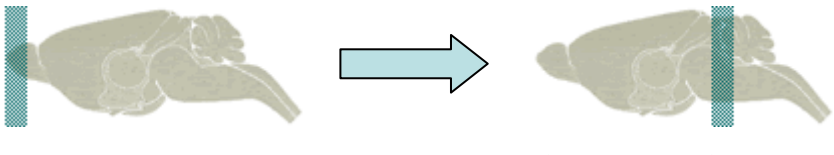




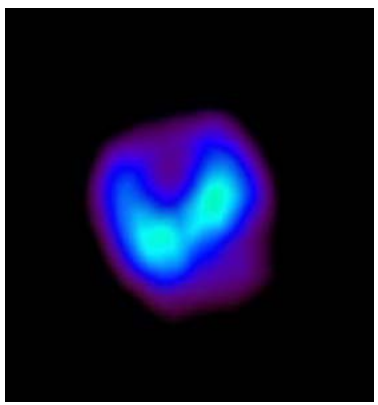


Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

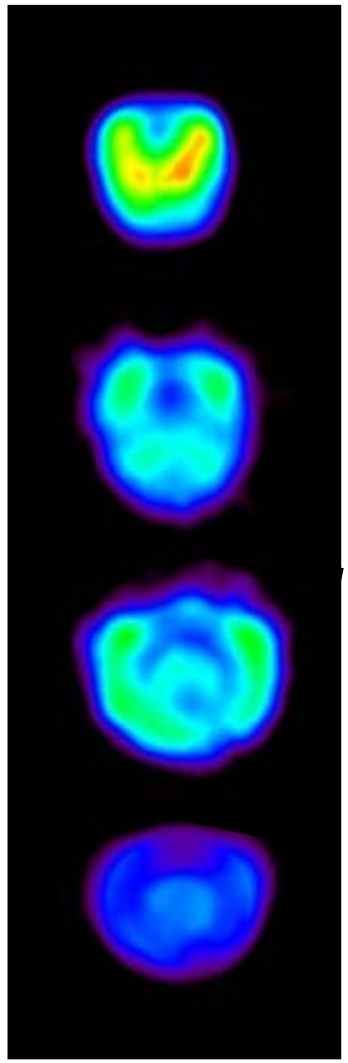
SPECT : first results



10 mm
Axial field of view



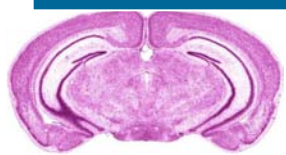
150 µm slide of the olfactory bulb



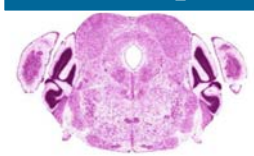
Olfactory bulb

Pyriform cortex

Diencephalon

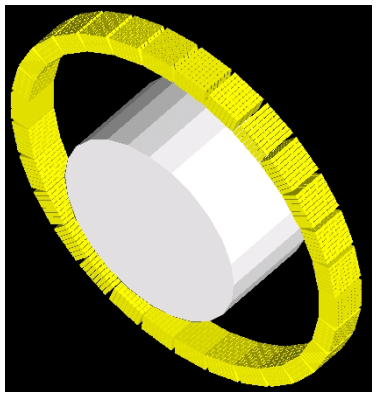


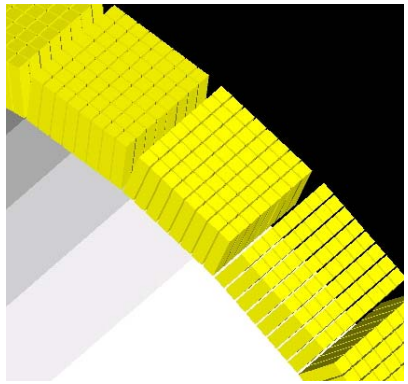
Mesencephalon



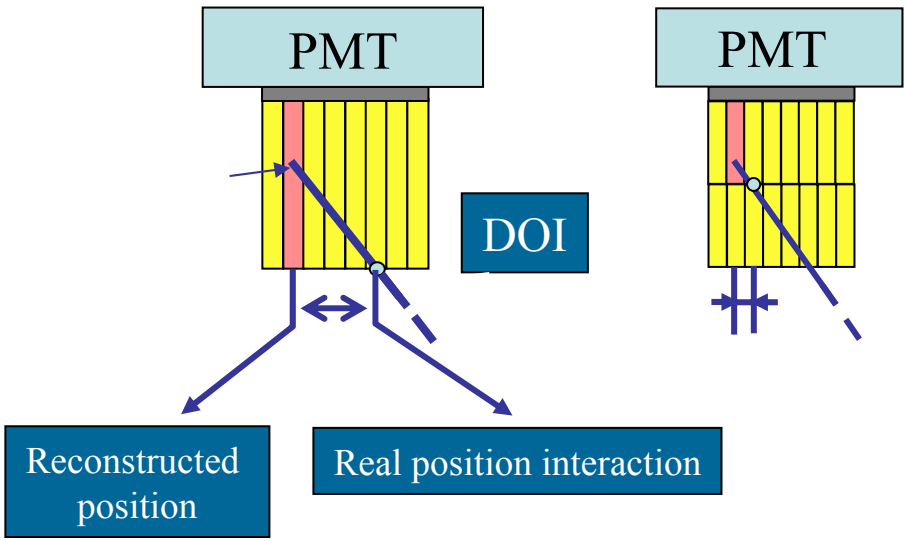
Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

GATE Simulation PET



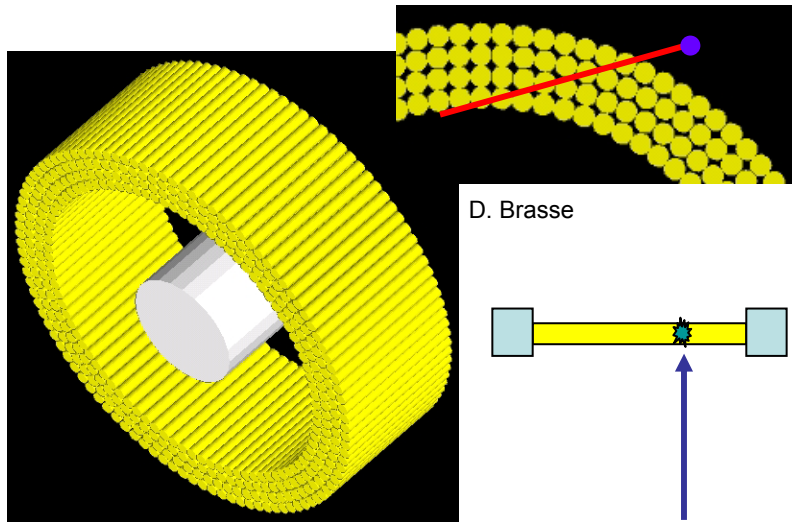


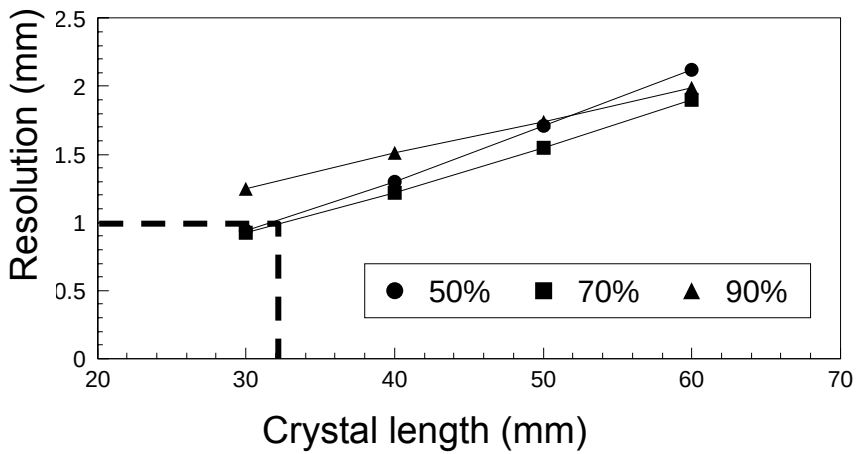
"Phoswich" system



Resolution : 1.5-2 mm

E_{ff} : < 10%





Resolution : 1mm

E_{ff} : > 25%

Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

GATE Simulation PET

Goal:

Spatial resolution :

1 mm^3

LYSO : Ce crystals

1.5 x 1.5 x 20 mm^3

Detection efficiency

>15 %

Time resolution

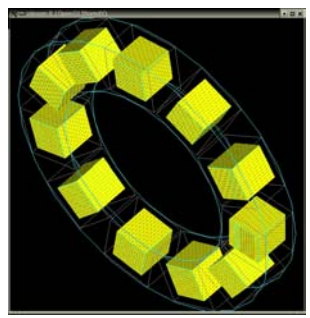
< 1 ns

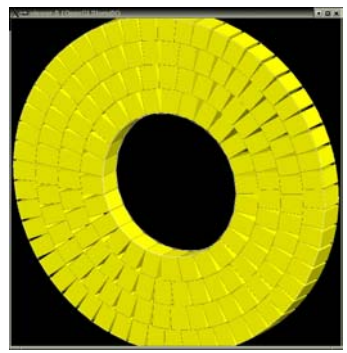
Timestamp

Dynamic 1 ~ 2000 pes

$$LMH_T = k\sqrt{\left(\frac{d}{2}\right)^2 + (0{,}0022D)^2 + r_p^2 + b^2}$$

Axial length





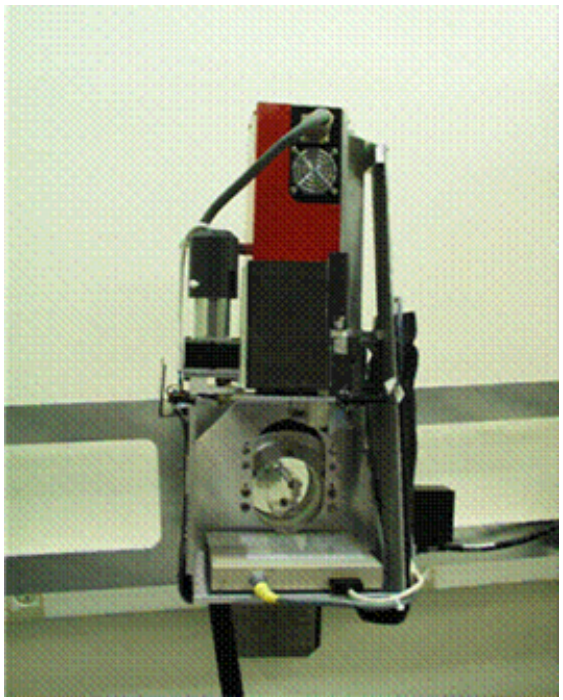
D. Brasse

Solid angle

Validation of the geometry
Simulation including physics effects

Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

Micro CT



Hamamatsu, C7942

CsI / photodiode
120 x 120 mm^2
2400 x 2400 pixels
Pixel de 50μm
470ms/projection
Mode binning:
- 2x2 (4 images/s)
- 4x4 (9 images/s)

Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

Micro CT Simulations

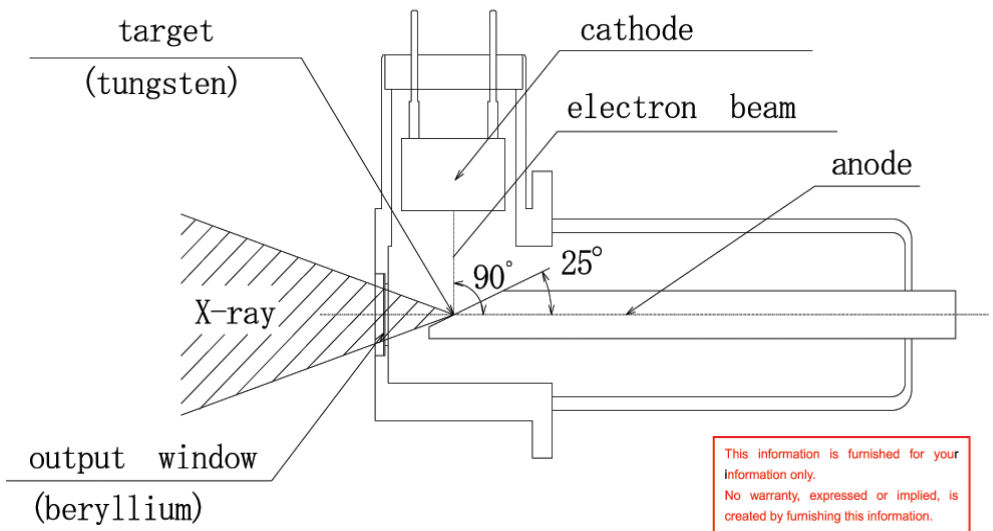
Goal : **Comparison of different models for generation of X-ray spectrum (optimization of filters for small animal radiology)**

- Semiempirical Model (Tucker-Barnes-Charckaborty)
- Monte Carlo ➡ Geant4
- Monte Carlo ➡ MCNP4C (Monte Carlo N-Particle)
- Measurements ➡ Detector Si(Li).

micro focus source (size = 5µm)
High voltage : 0 to 90kV
Current Intensity : 0 to 250µA
Max. Power: 10 W
Tungsten Anode and cathode
Beryllium Window(150µm)
Anode angle 25°

May. 19th, 2004

CONSTRUCTION of MICROFOCUS X-RAY TUBE



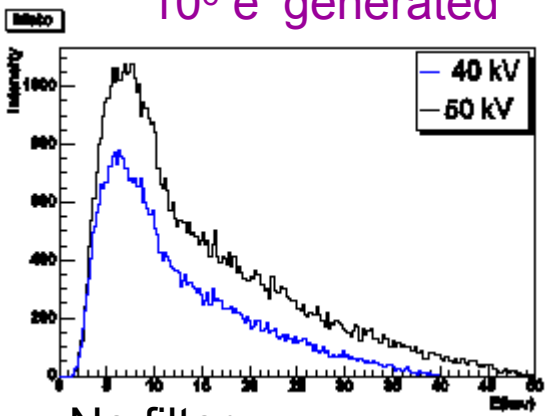
HAMAMATSU
HAMAMATSU PHOTONICS K.K. Electron Tube Division

Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

Micro CT Simulations

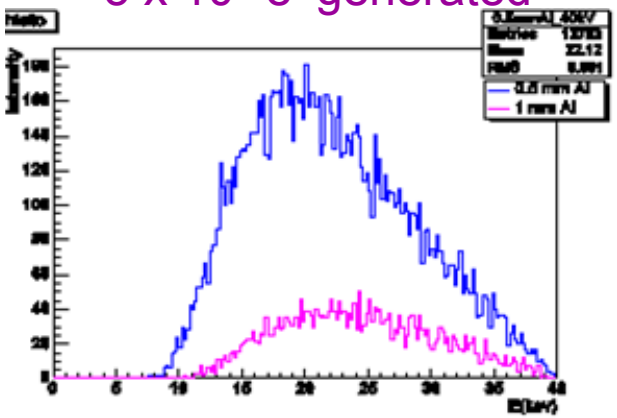
X ray spectrum – GEANT4

10^6 e$^-$ generated

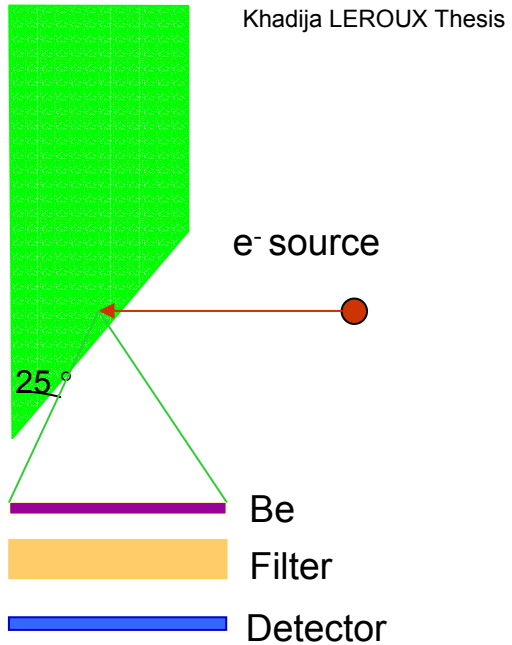


No filter

5 x 10^6 e$^-$ generated

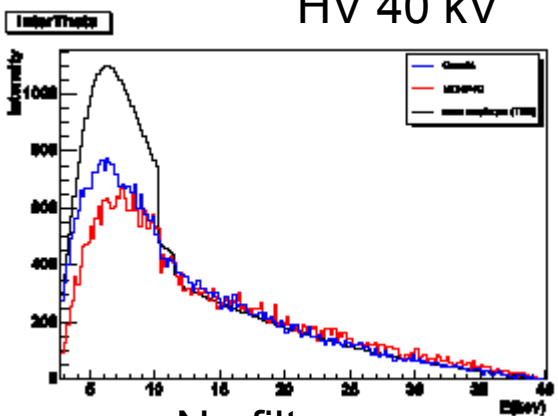


Al Filter

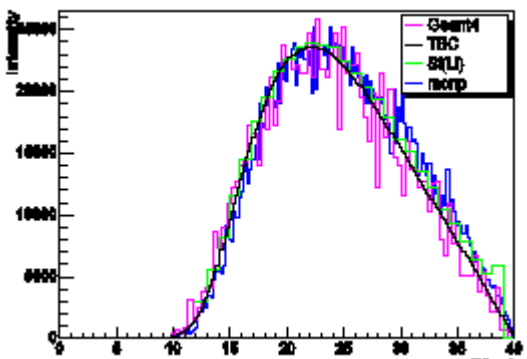


Comparison 3 models

HV 40 kV 175 μm de Be



No filter



1mm Al Filter

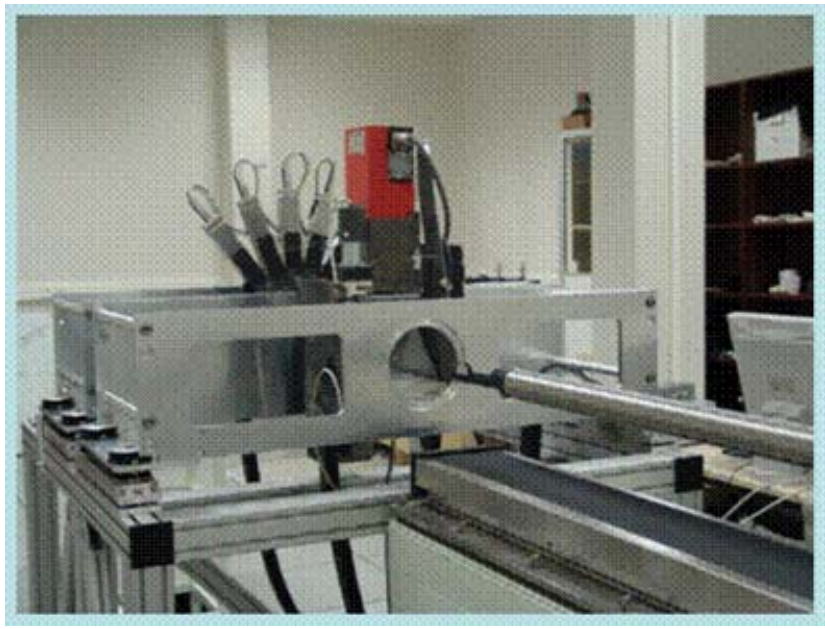
Conclusions

1. Good agreement at E>13 keV but not at low energy (E < 13 keV)
2. Optimization of the filters for Hardening the X ray spectrum : 10 μm Cu+ 0,6 mm Al
3. Future: Monte Carlo simulation to evaluate the physics effect in the image reconstruction

Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr

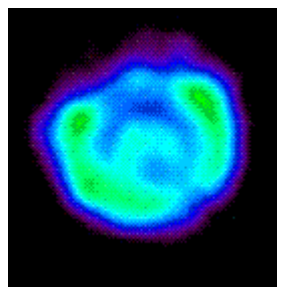
Conclusions

- Micro CT: working



- Micro SPECT: One camera working
  (3 cameras under construction)

  Spatial resolution 1.3 mm



- Micro PET: R&D

Inmaculada PIQUERAS Inmaculada.Piqueras@ires.in2p3.fr