Le Projet ClearPET

Etude et développement d'un tomographe à positons de haute résolution pour petits animaux

Christian MOREL

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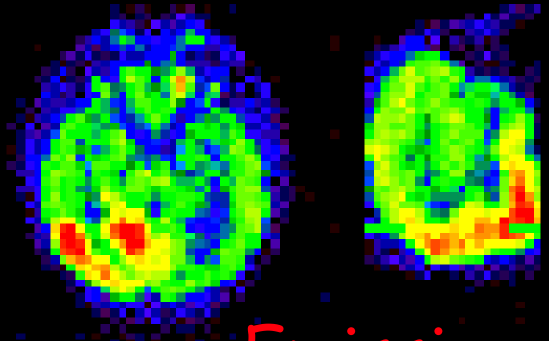
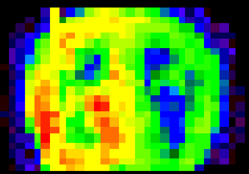
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Crystal Clear ClearPET Project



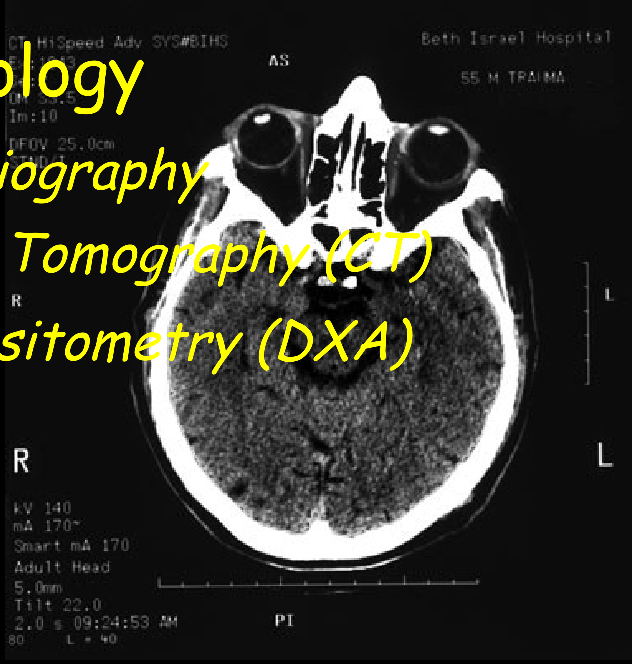


X-ray radiology

X-ray Radiography

Computed Tomography (CT)

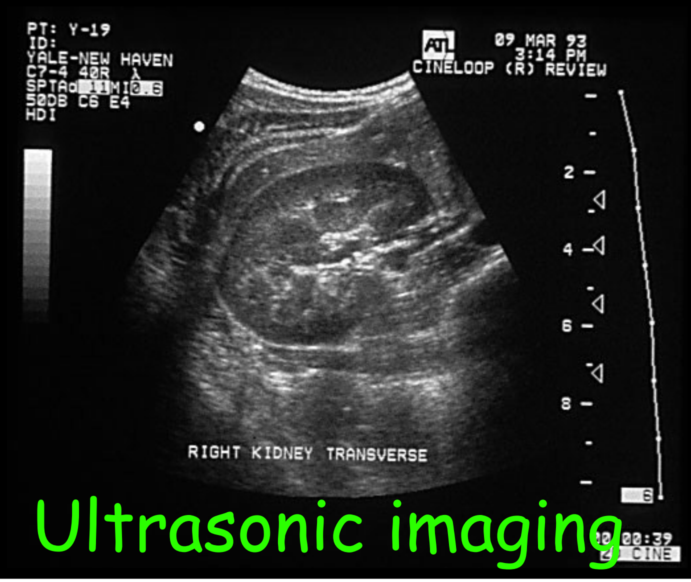
Tomo-Densitometry (DXA)



Emission tomography

Single Photon Emission Computerized Tomography (SPECT)

Positron Emission Tomography (PET)

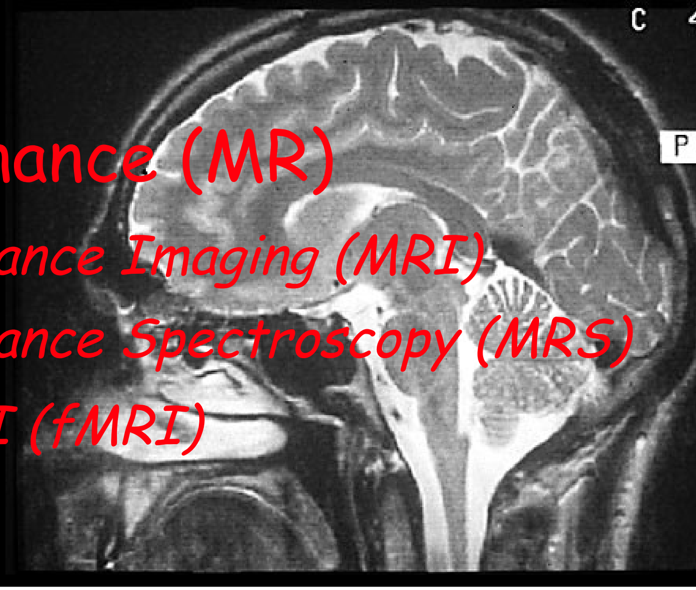


Magnetic Resonance (MR)

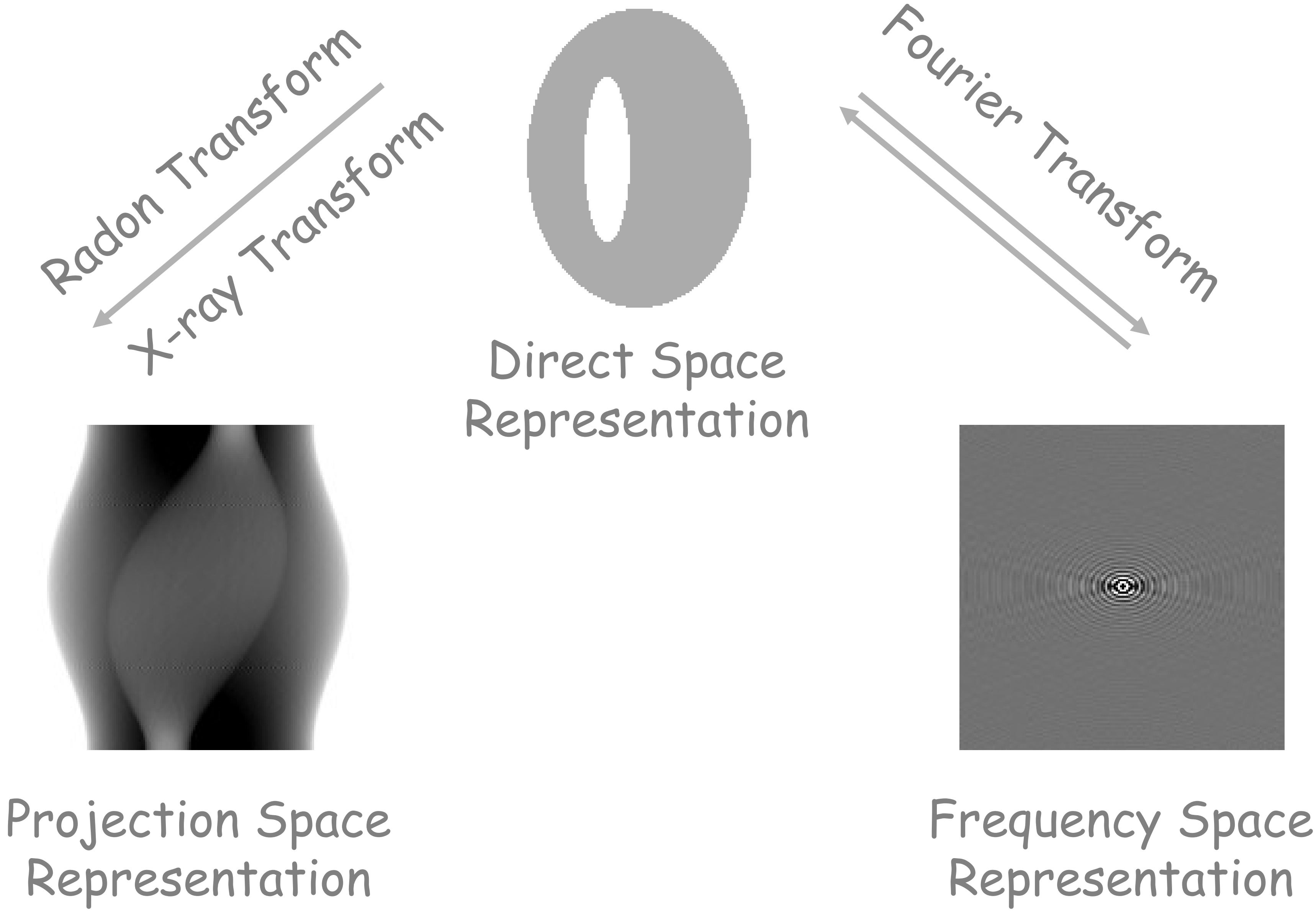
Magnetic Resonance Imaging (MRI)

Magnetic Resonance Spectroscopy (MRS)

Functionnal MRI (fMRI)



Ultrasonic imaging


Radon Transform
X-ray Transform
Fourier Transform
Direct Space Representation
Projection Space Representation
Frequency Space Representation

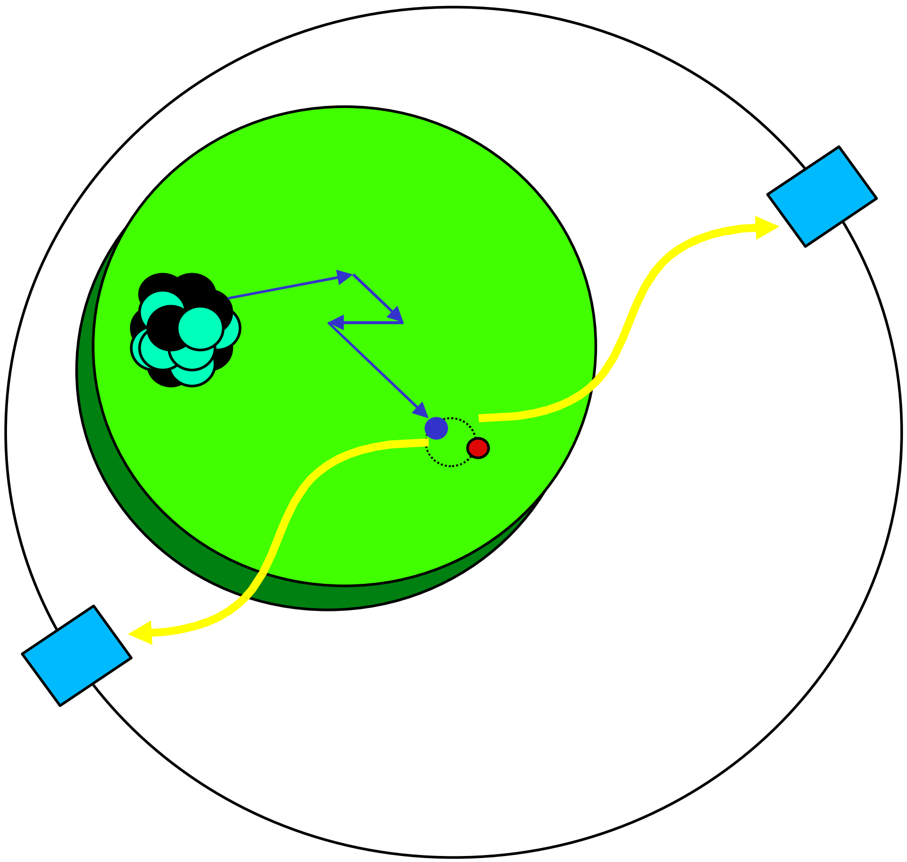
Positron Emission Tomography

^{18}F

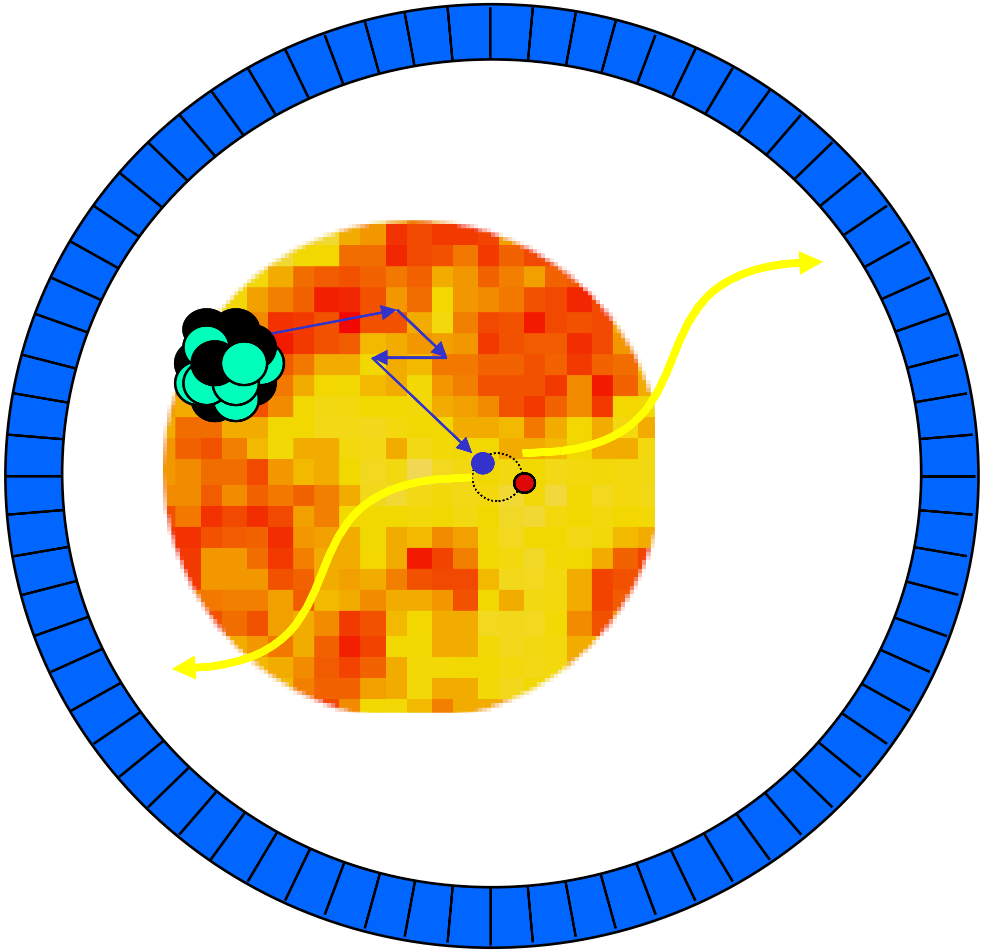
^{15}O

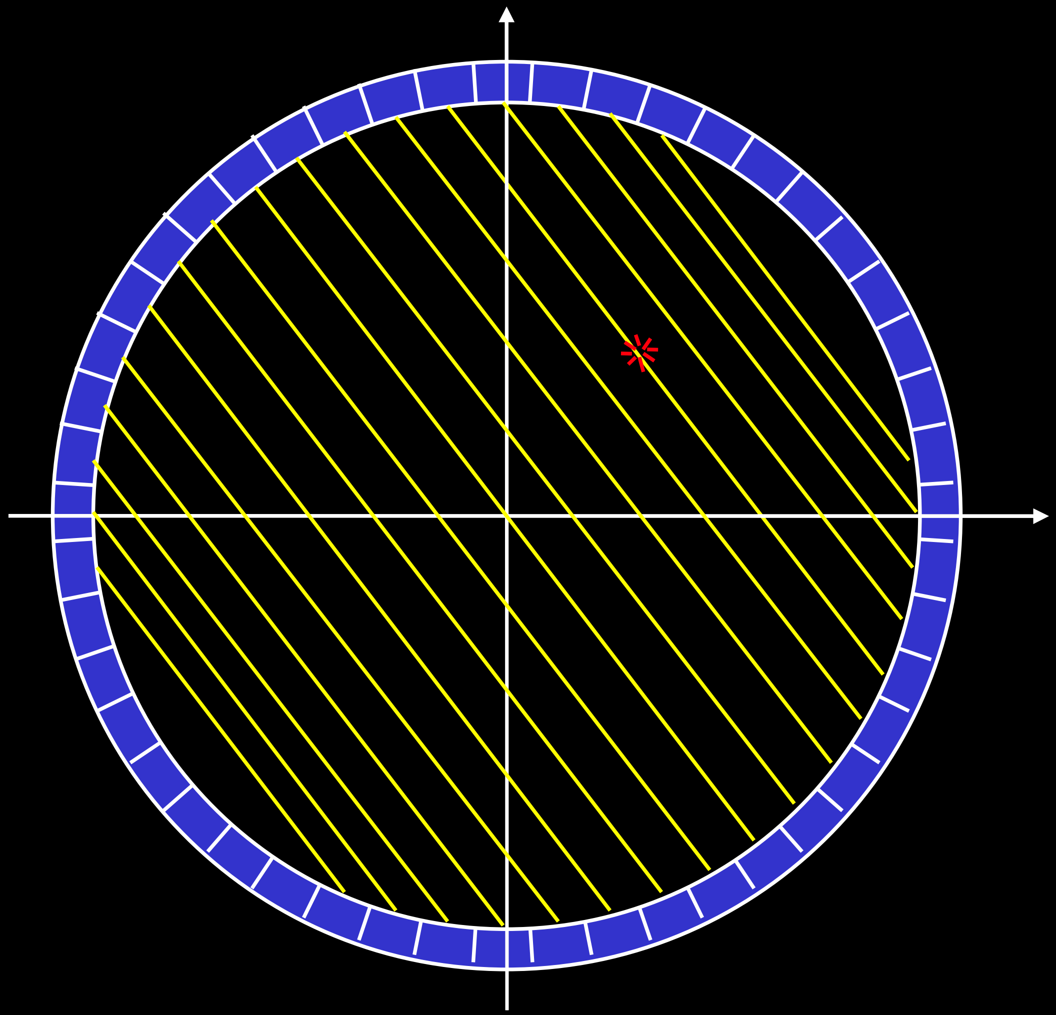
^{13}N

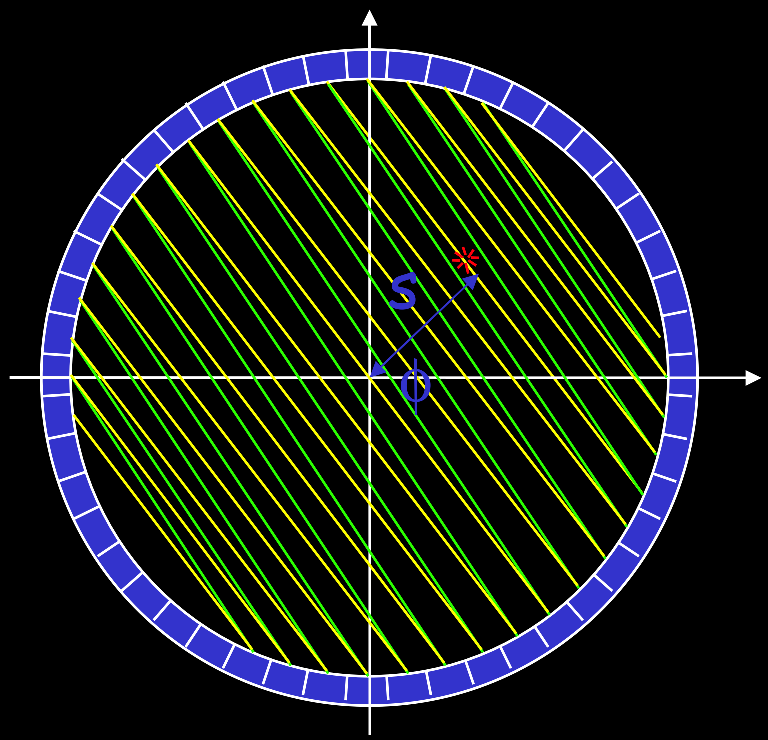
^{11}C



Positron Emission Tomography






s
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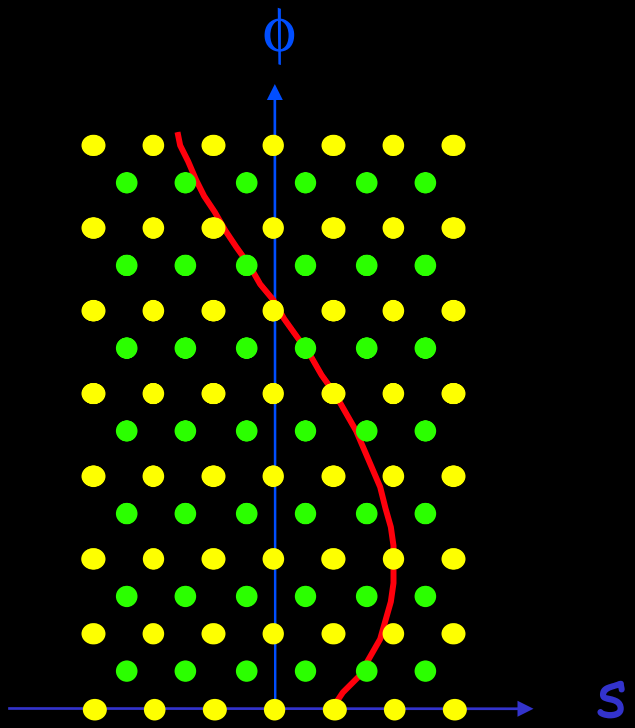
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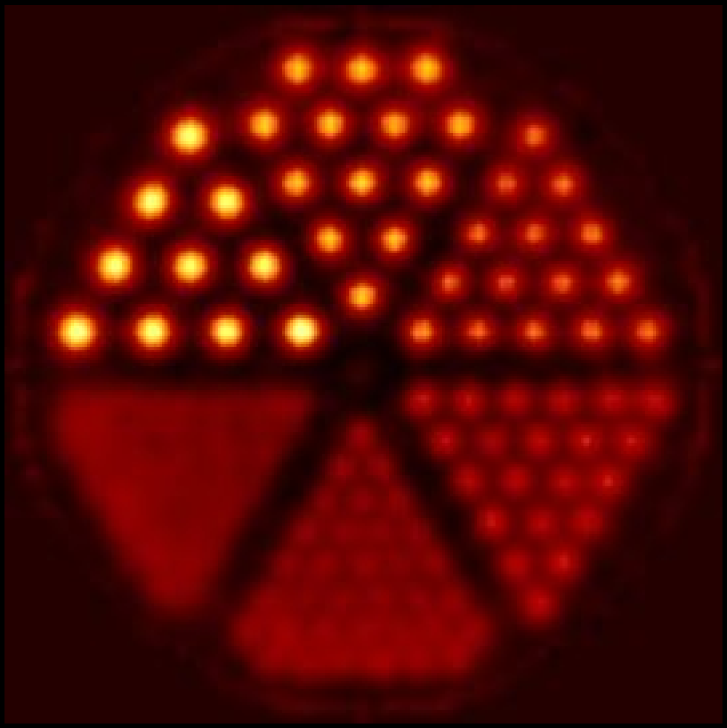
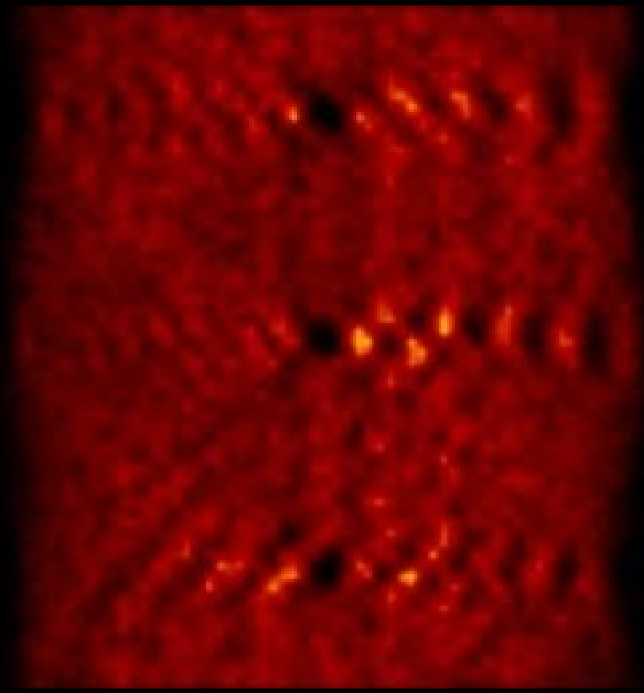
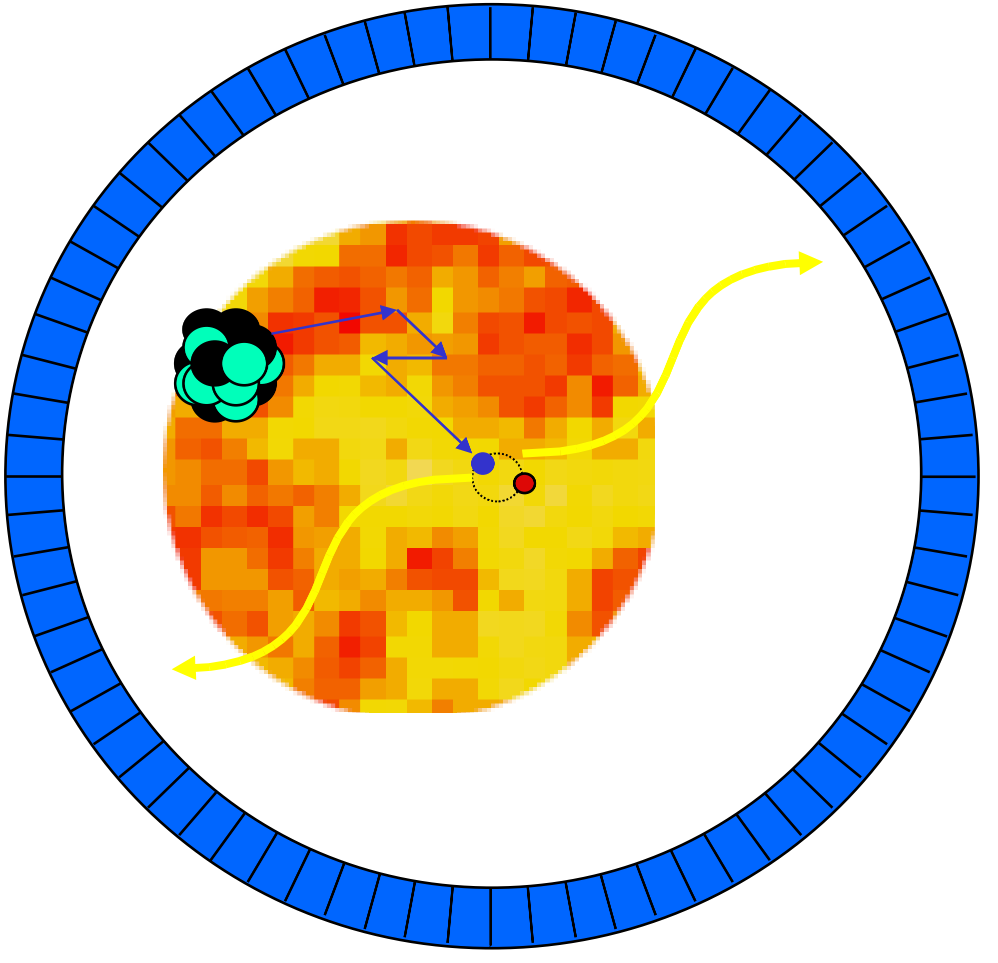
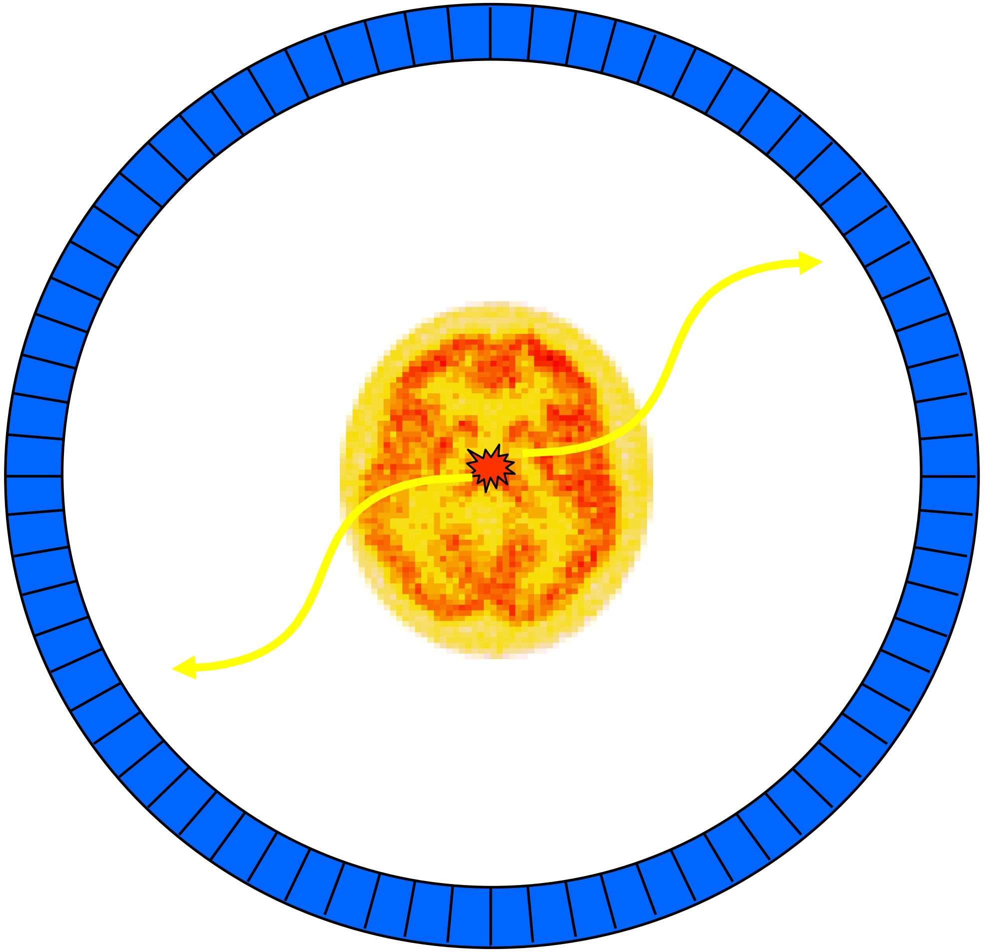


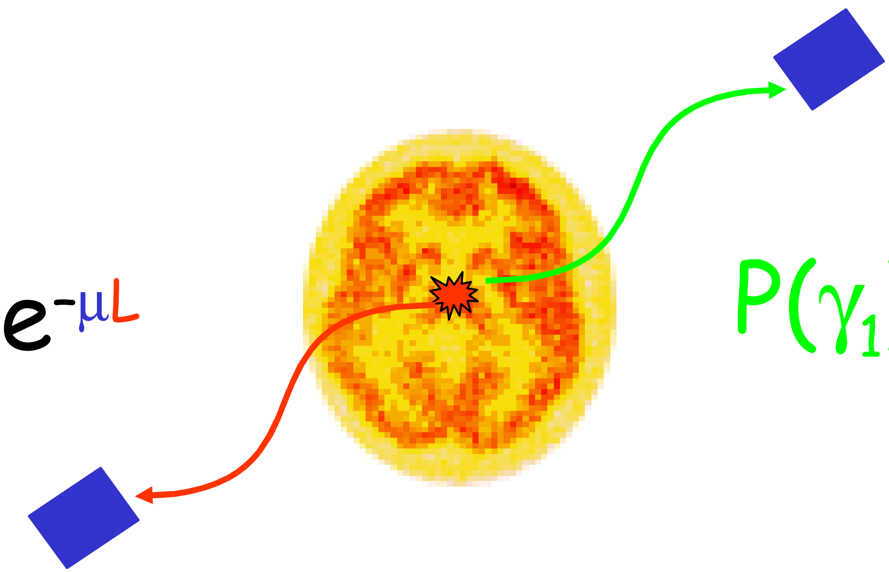






$$P(\gamma_1) \times P(\gamma_2) = \varepsilon^2 \, e^{-\mu(L+L)}$$

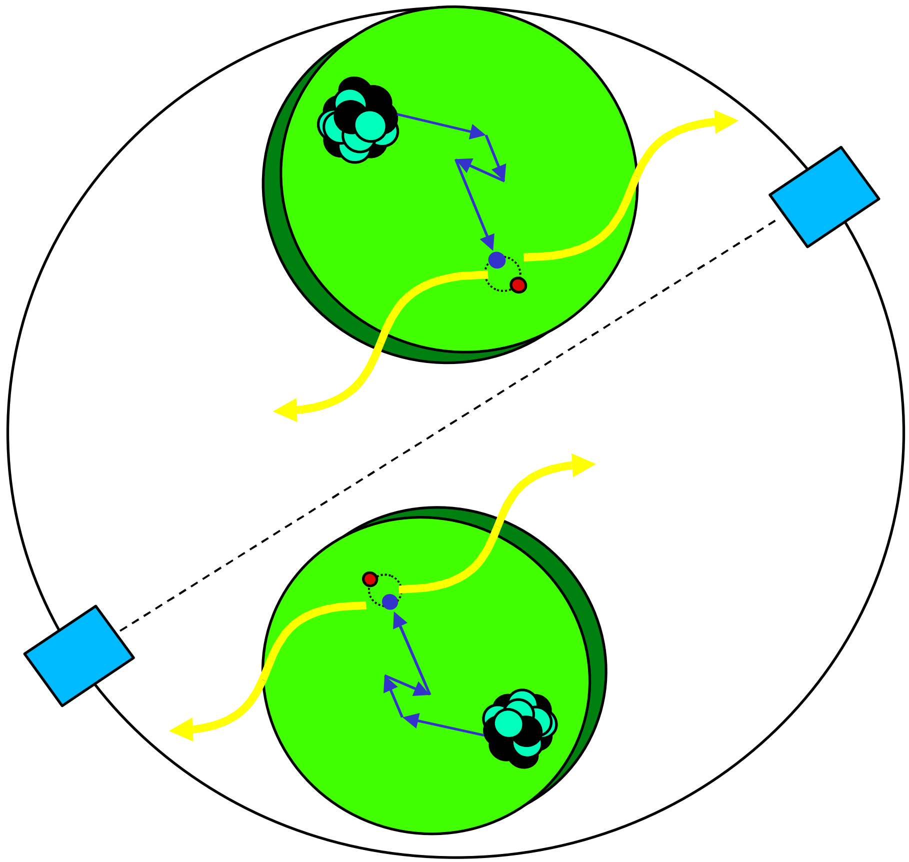
$$P(\gamma_2) = \varepsilon \times e^{-\mu L}$$



$$P(\gamma_1) = \varepsilon \times e^{-\mu L}$$

Quantitation

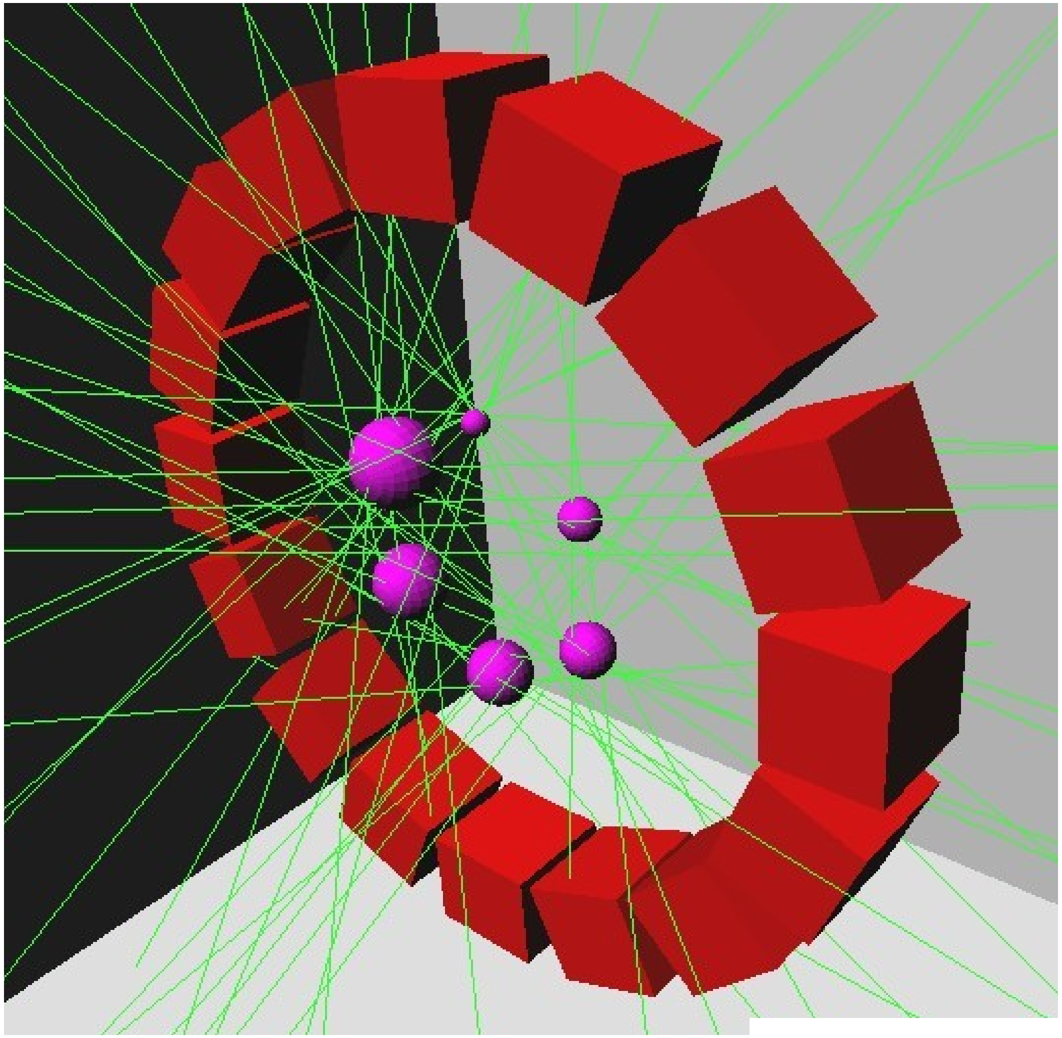
Detection of random coincidences



$N_1 = A\,\varepsilon\,\Omega$

$N_2 = A\,\varepsilon\,\Omega$

Monte Carlo simulation



Approaches for PET/SPECT simulation

HEP tools

EGS4
MCNP
Geant3/4

PET/SPECT tools

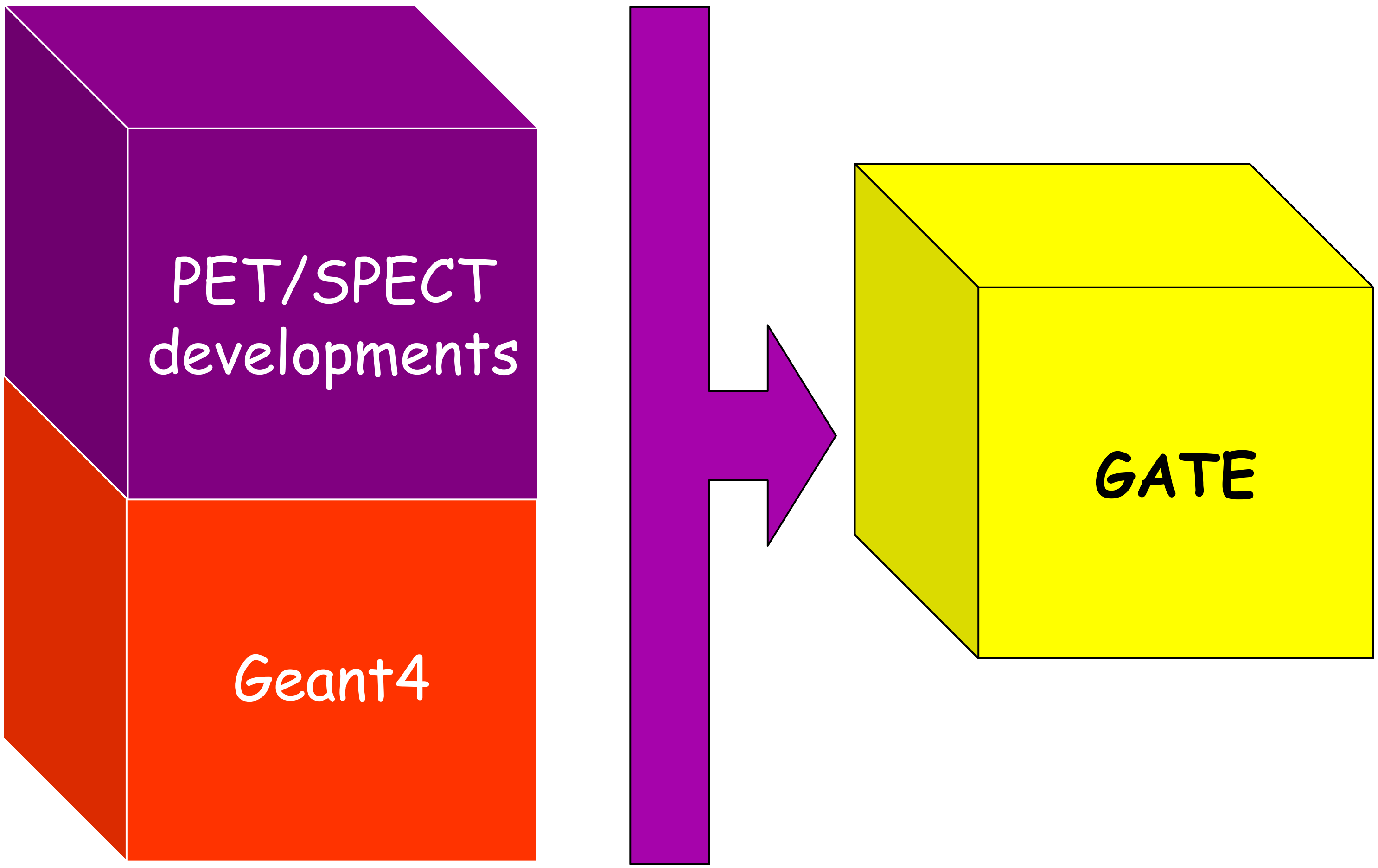
PETsim
SimSET
Eidolon

Complexity !
Speed ?

???

Features ?
Maintenance ?
Accuracy ?

Combining both approaches



- The main GATE features are :

✓ modelling of time
  - *decay kinetics, movement, randoms…*

✓ ease-of-use, interactivity
  - *use of a scripting language*

✓ versatility
  - *geometry and simulation fully scripted*

✓ modular design
  - *new extensions easily added*

✓ shared development
  - *long-term support*

QuickTimeª et un dŽcompresseur GIF sont requis pour visualiser cette image.

GATE : Geant4 Application for Tomographic Emission

- The main GATE features are :

✓ modelling of time
  - *decay kinetics, movement, randoms…*

✓ ease-of-use, interactivity
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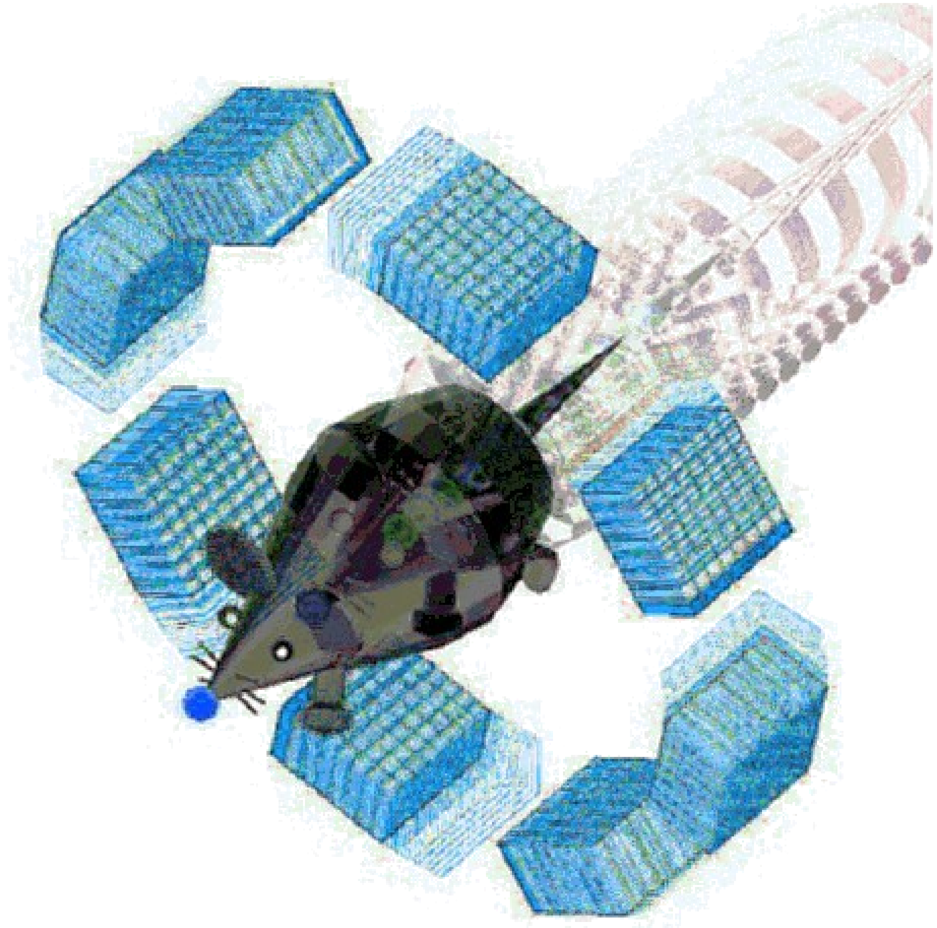

OpenGATE Collaboration

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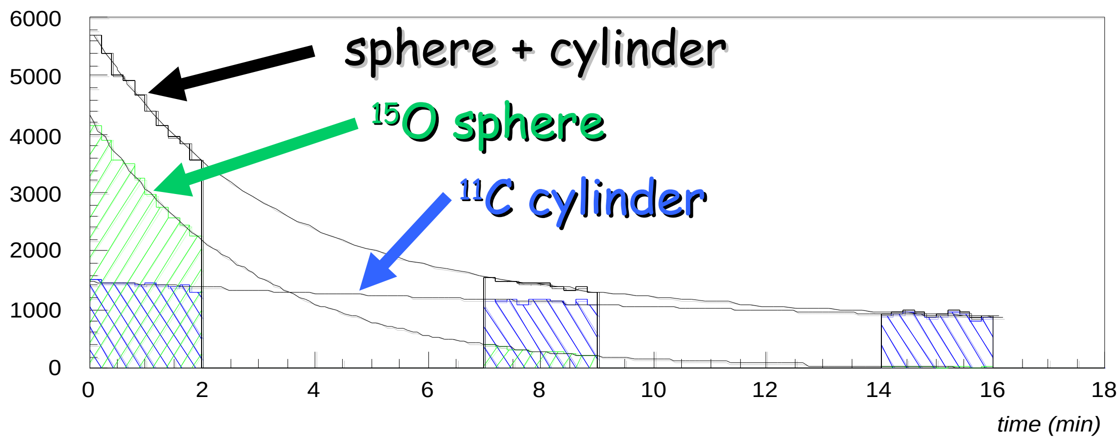
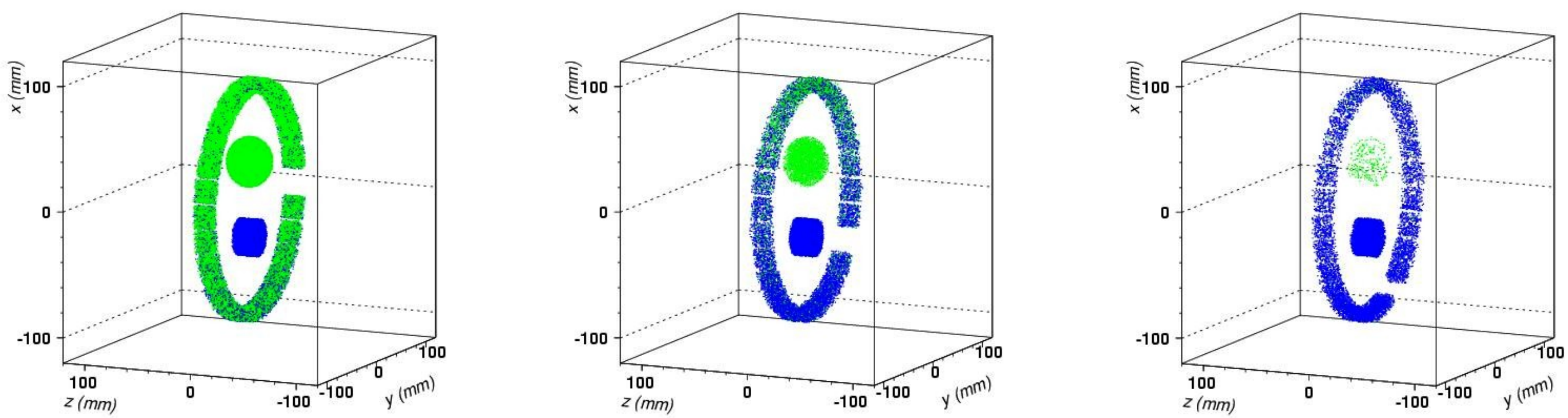
Crystal Clear ClearPET Project

Simulation of decaying sources



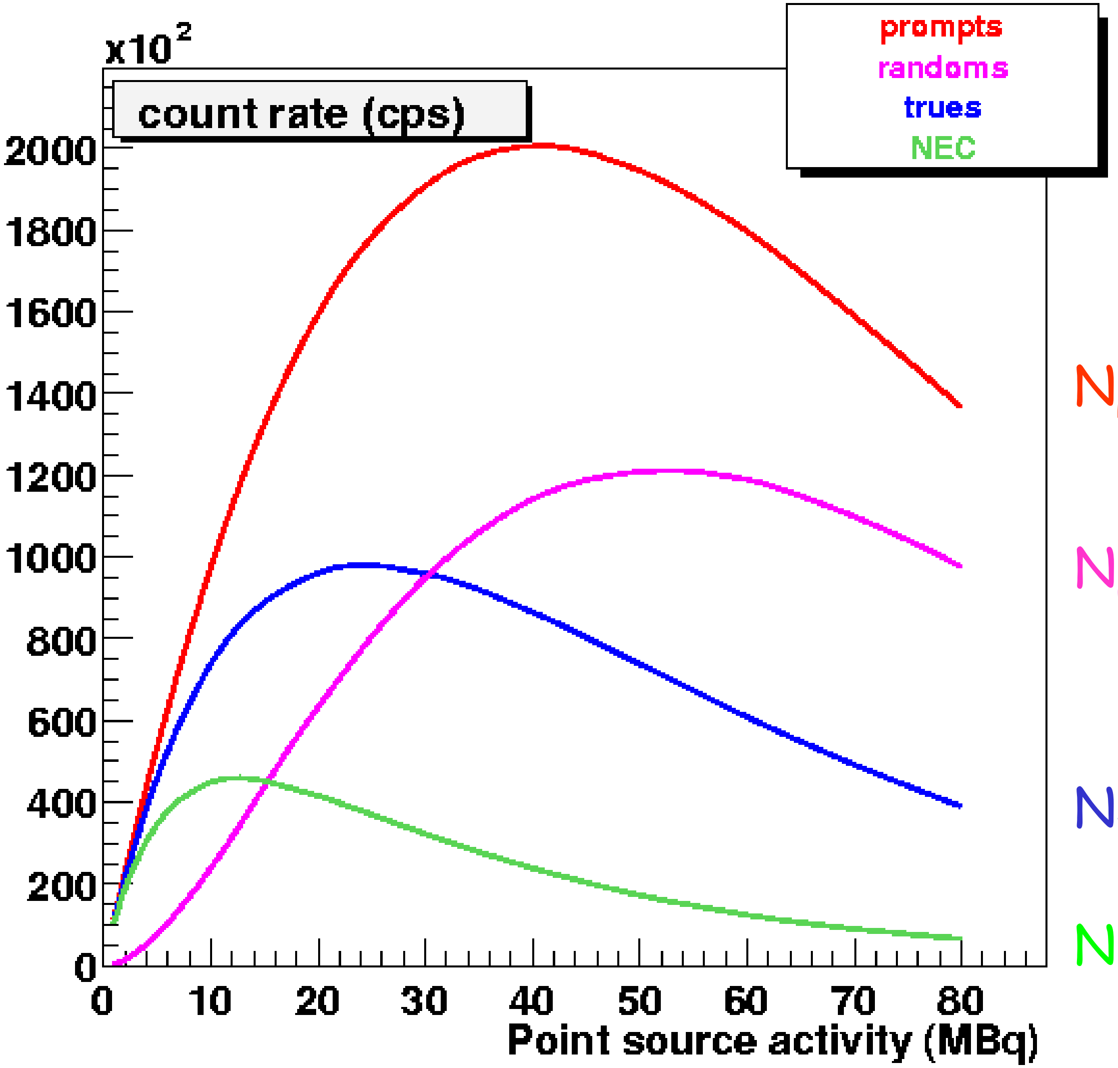
^{15}O (2 min)

^{11}C (20 min)



Crystal Clear ClearPET Project

Detection of random coincidences



$N_{Prompts} = N_{Trues} + N_R$

$N_R = (2\,w)\,A^2\,\varepsilon^2\,\Omega^2$

$N_{Trues} = A\,\varepsilon^2\,\Omega$

$NEC = N_{Trues}^2/(N_{Trues} + 2\,N_R)$

High Resolution in 3D PET

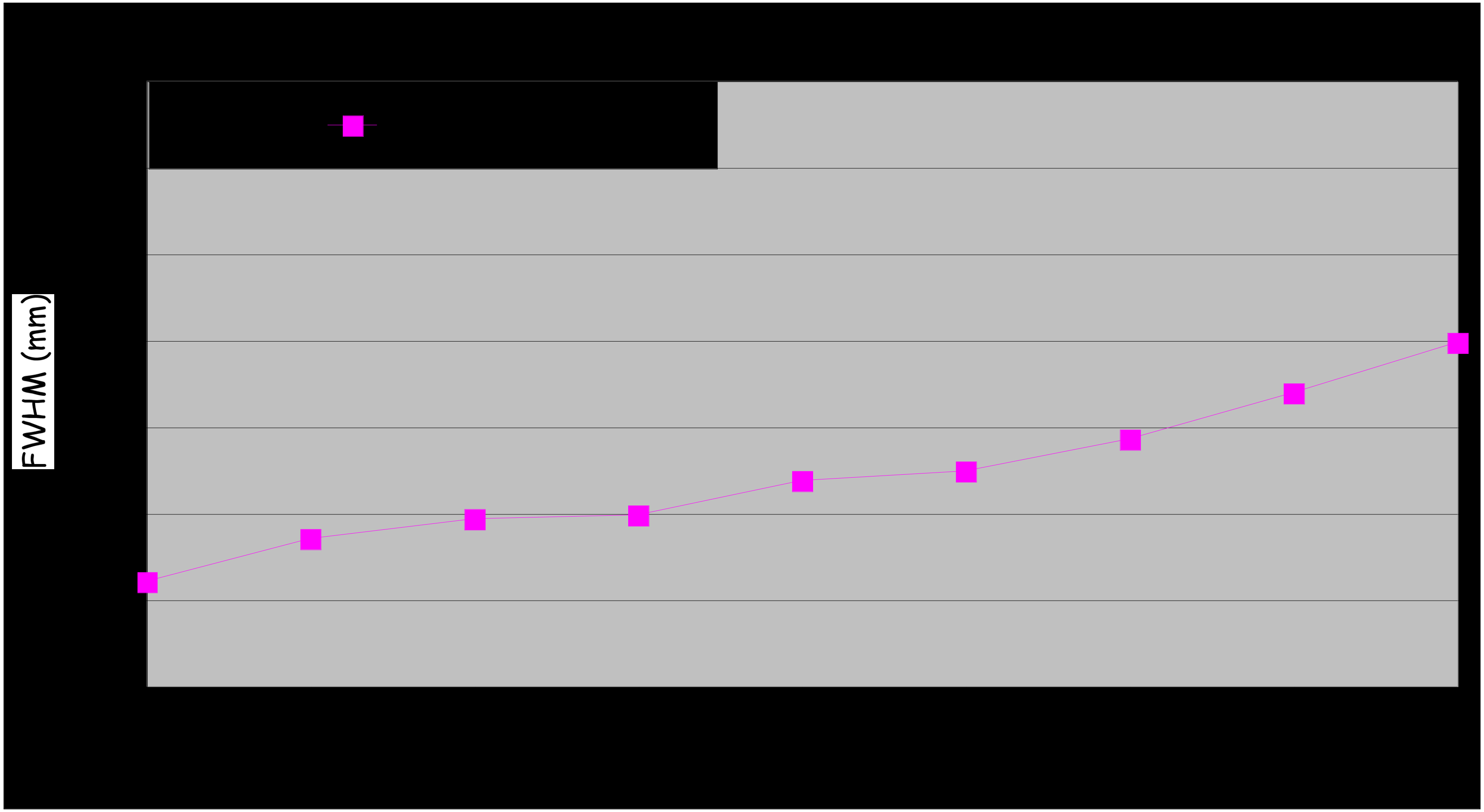
High spatial resolution & High signal-to-noise ratio

Noise Equivalent Count (*NEC*)

Inorganic scintillators for PET

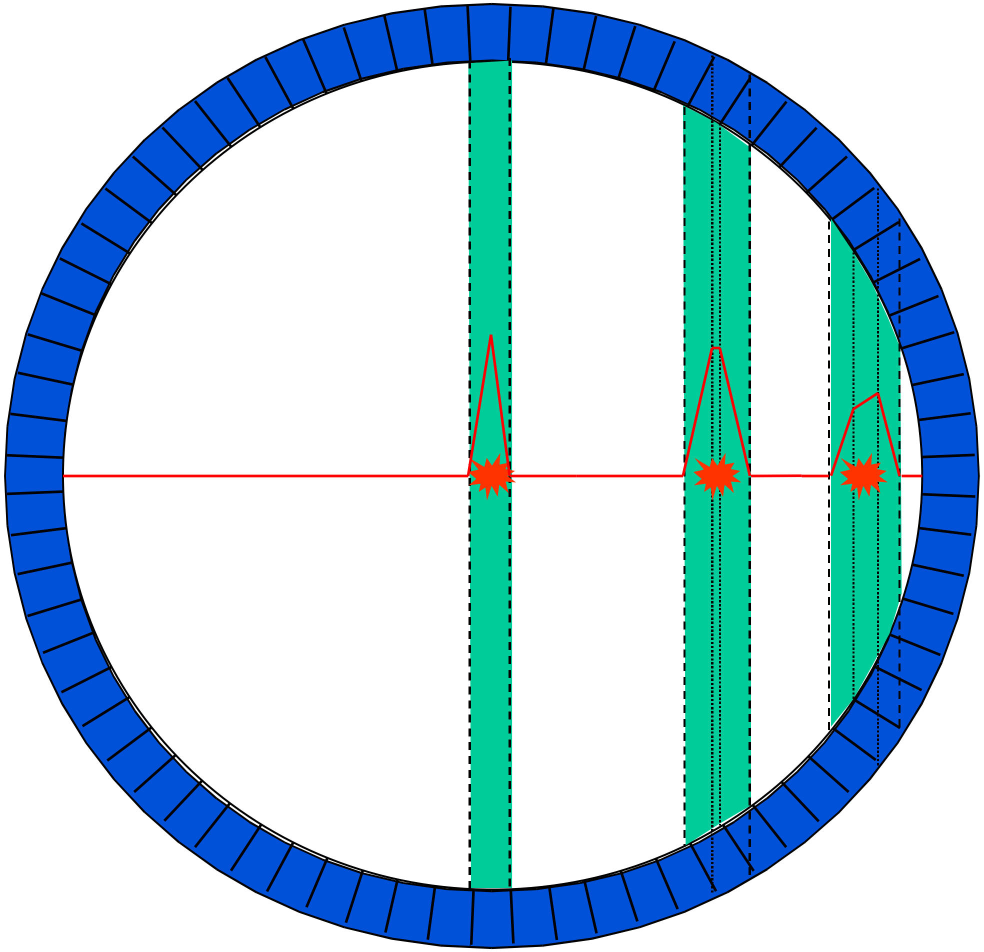
	NaI	BGO	GSO:Ce	LSO:Ce	LuAP:Ce
Density (g/cm^3)	3.67	7.13	6.71	7.40	8.34
Atomic number	51	75	59	66	65
Photofraction	0.17	0.35	0.25	0.32	0.30
Decay time (ns)	230	300	30-60	35-45	17
Light output ($h\nu$/MeV)	43000	8200	12500	27000	11400
Peak emission (nm)	415	480	430	420	365
Refraction index	1.85	2.15	1.85	1.82	1.97

Radial resolution of a line source

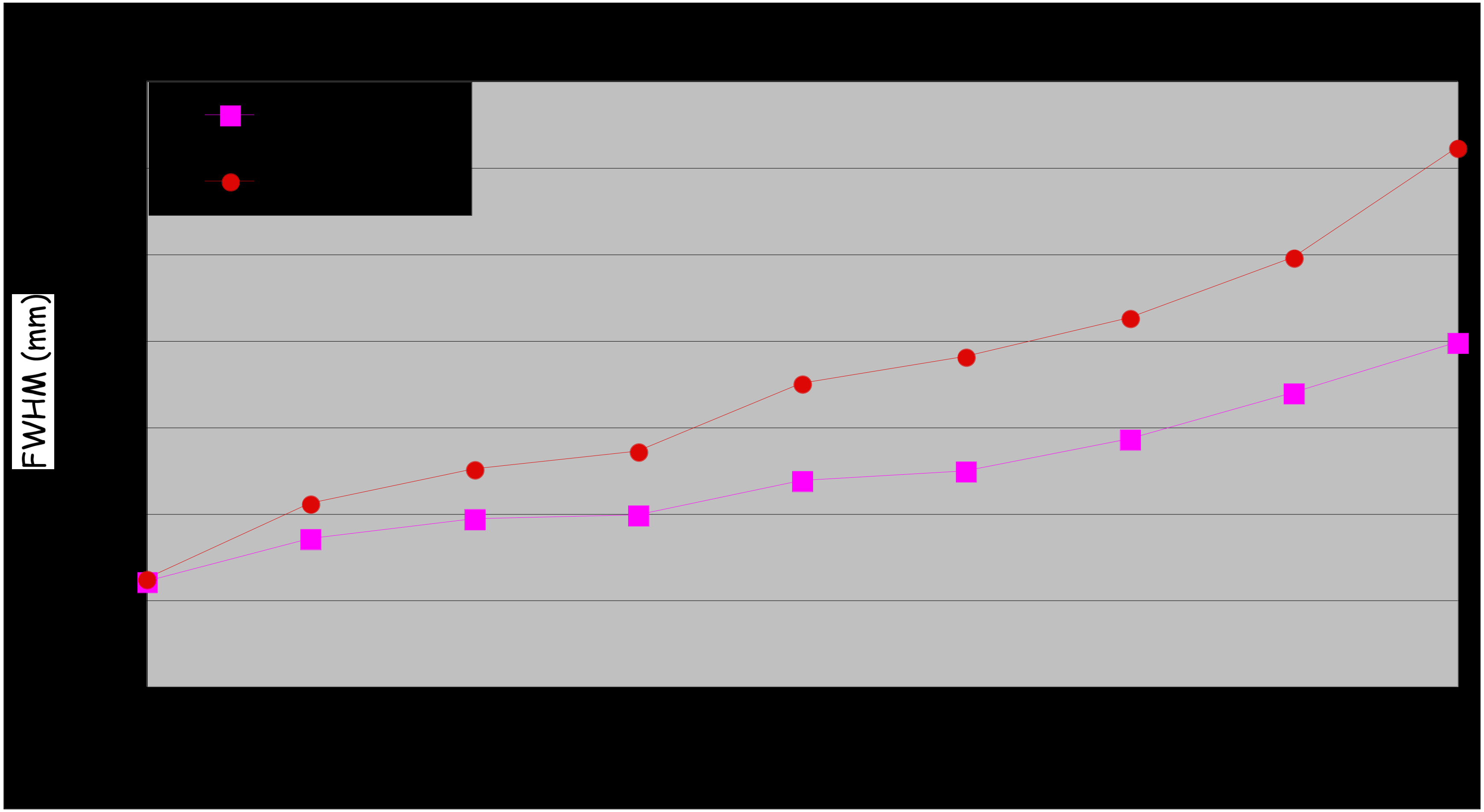


Crystal Clear ClearPET Project

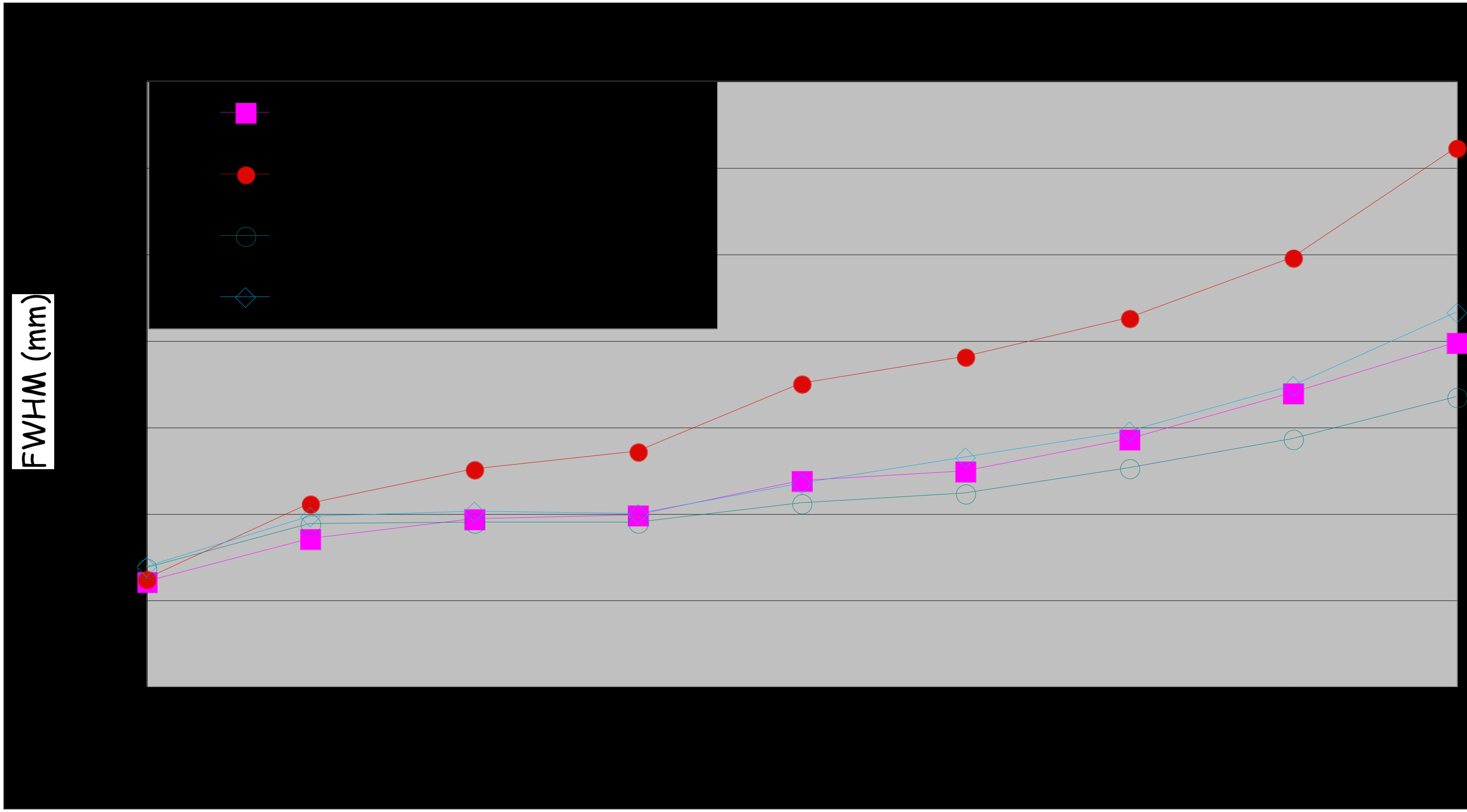
Line Spread Function (LSF)



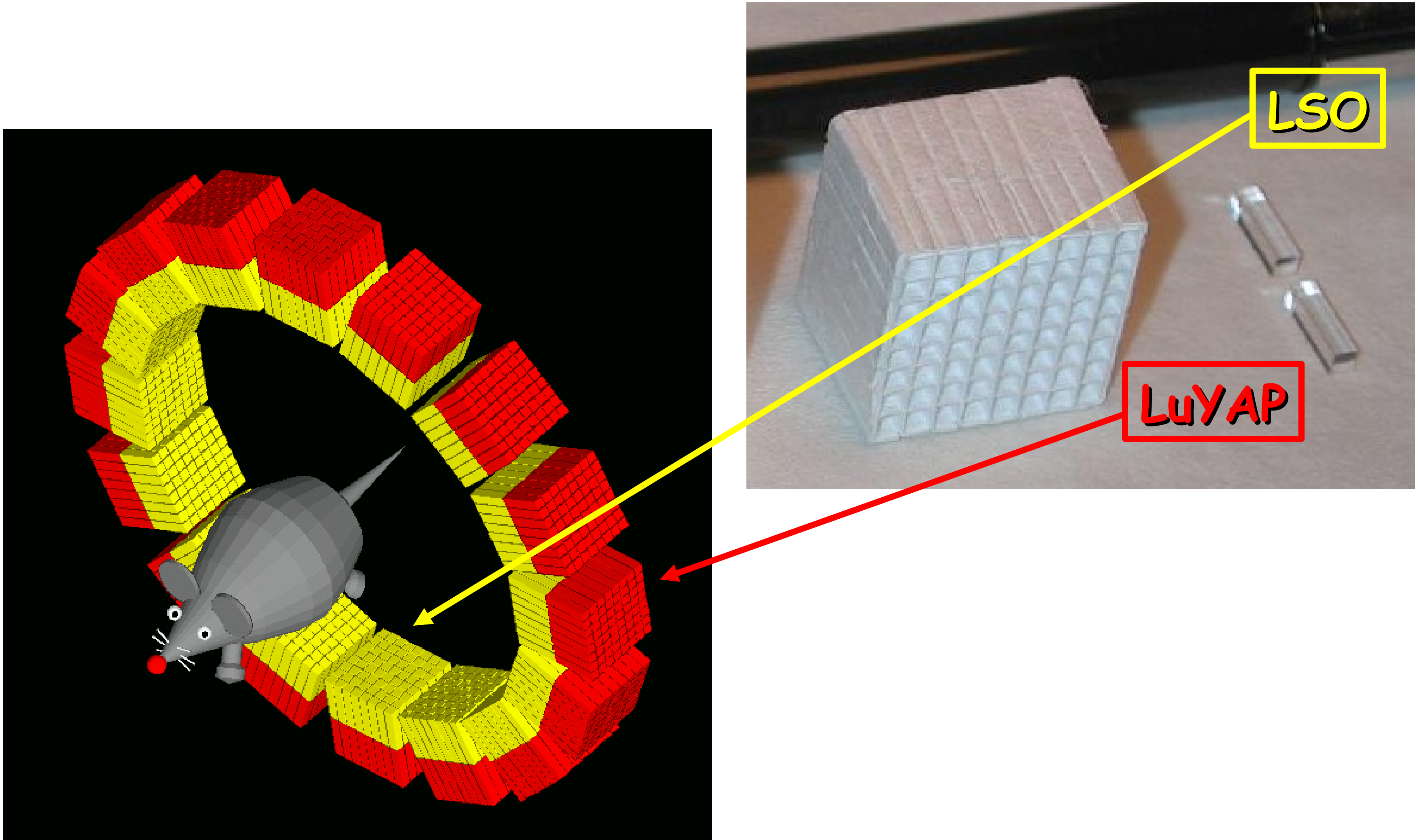
Radial resolution of a line source



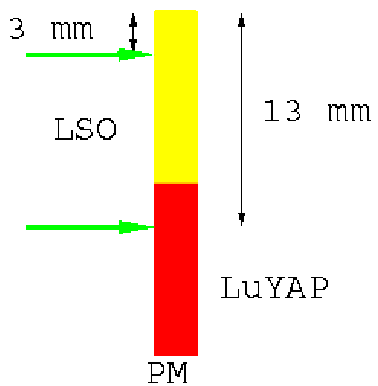
Radial resolution of a line source

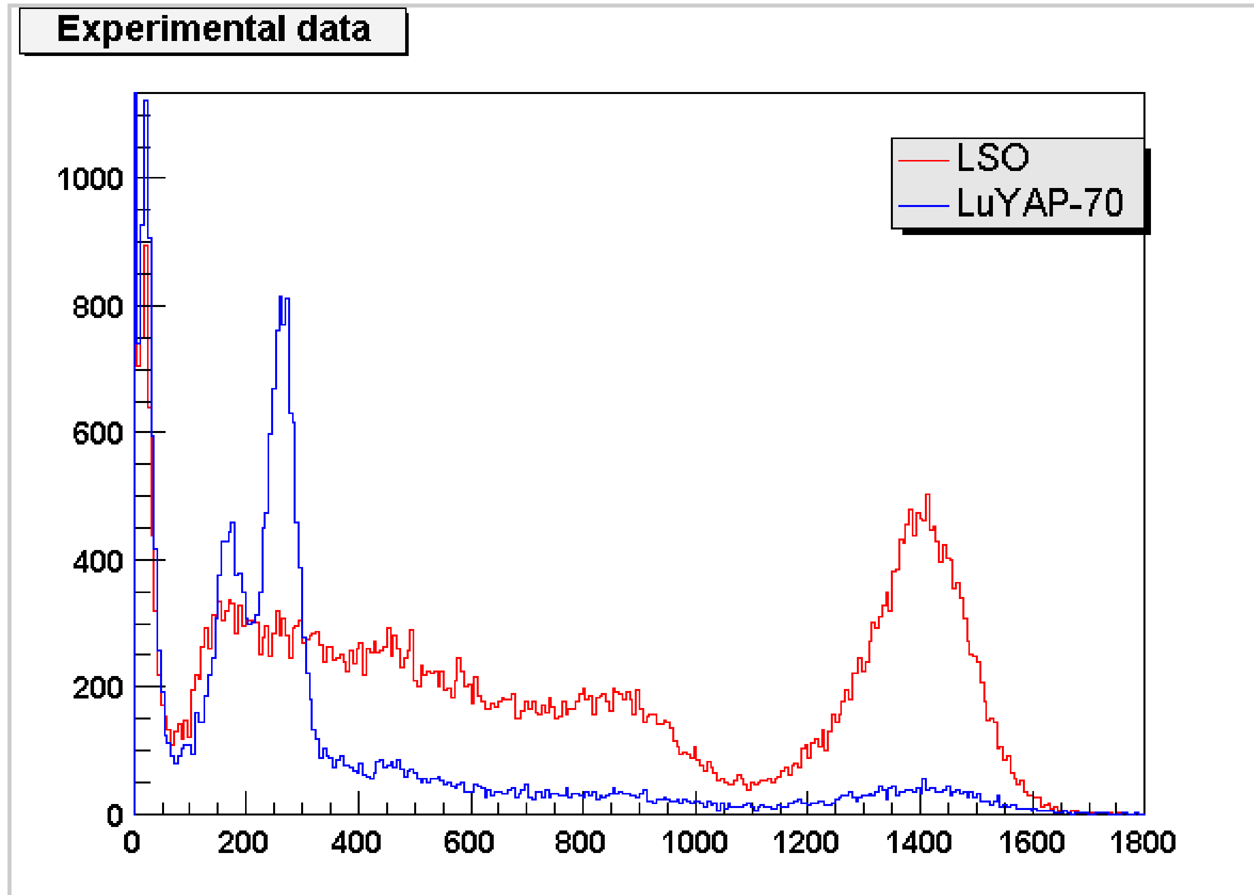


LSO/LuYAP phoswich detector head



LSO/LuYAP experimental spectra

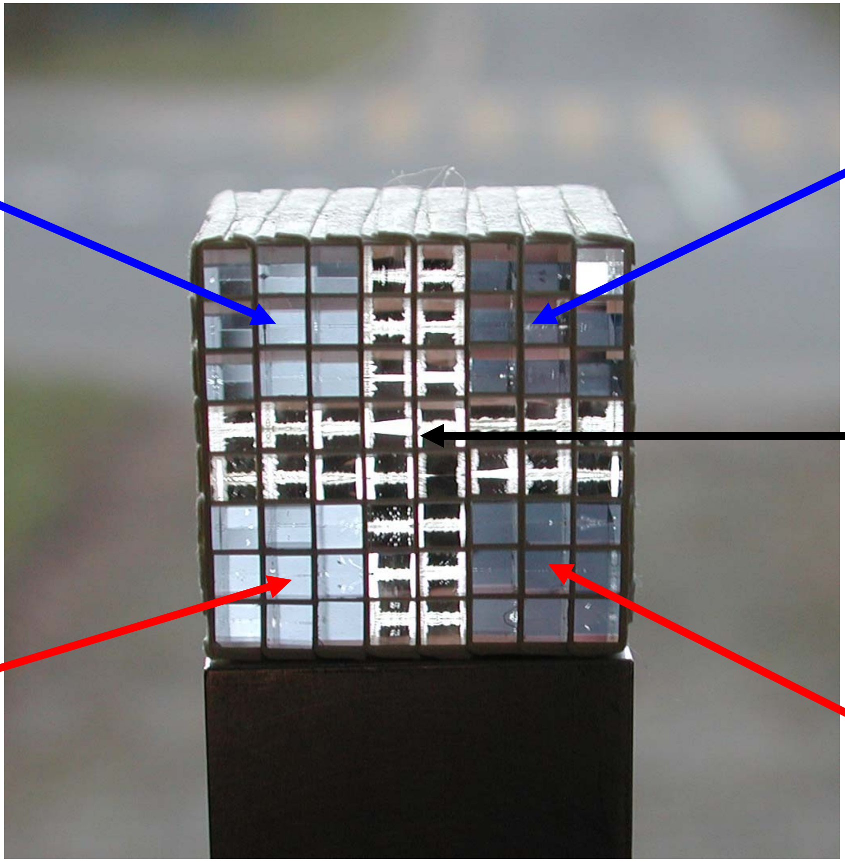




Test of aluminium deposition by evaporation

30 nm Al on LSO crystals

45 nm Al on LSO crystals

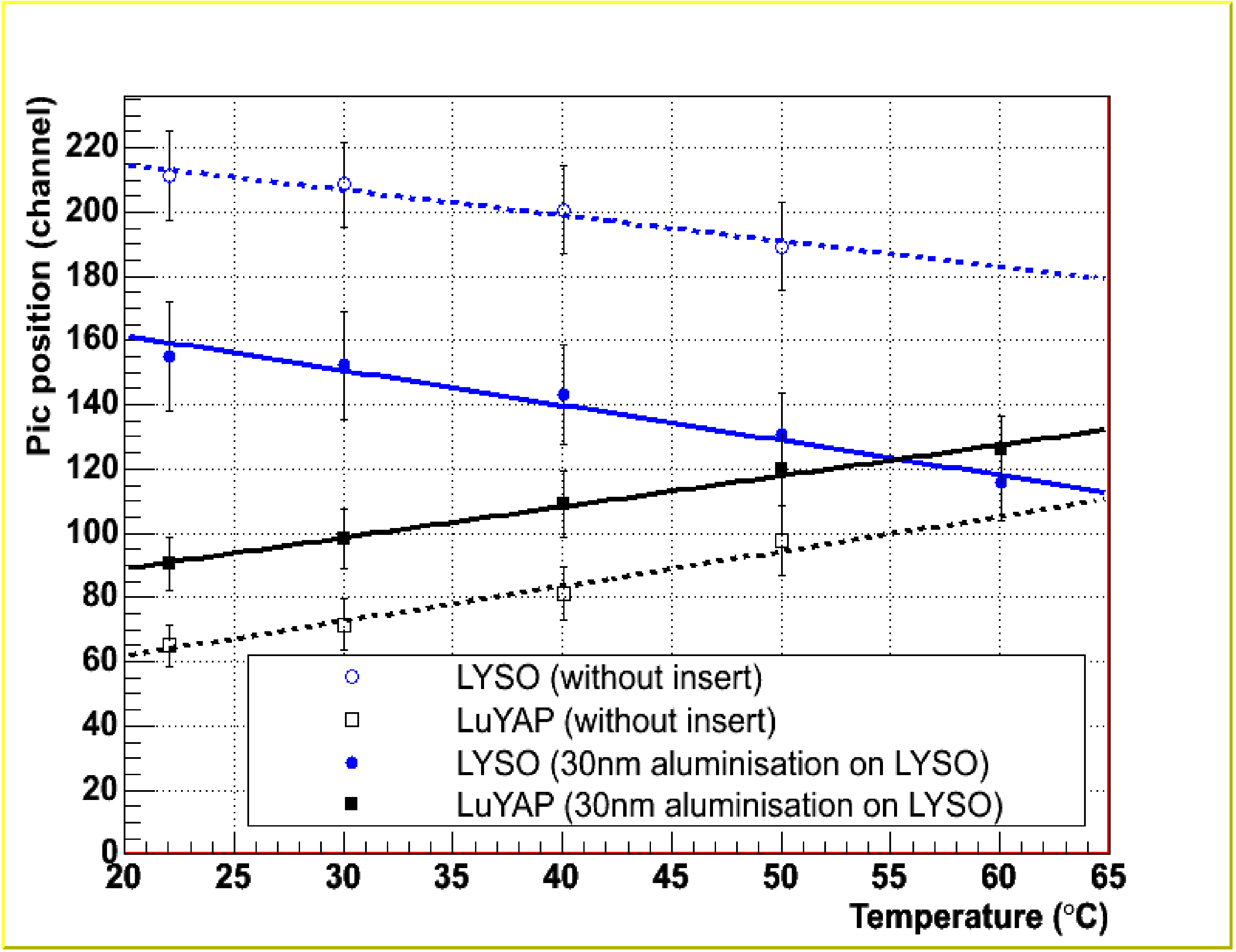


Aluminised Mylar cut up with a laser

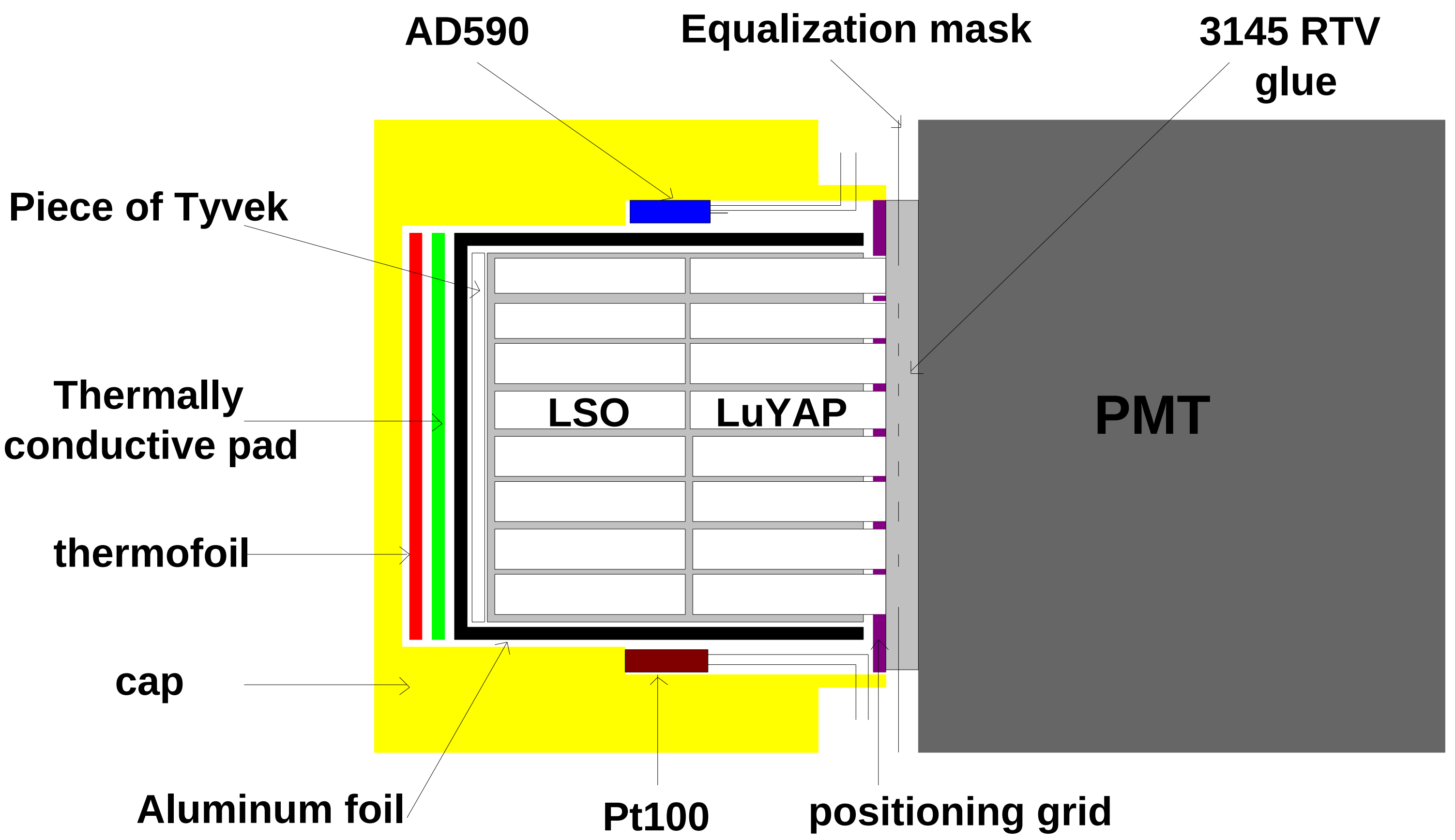
30 nm Al on LuYAP crystals

45 nm Al on LuYAP crystals

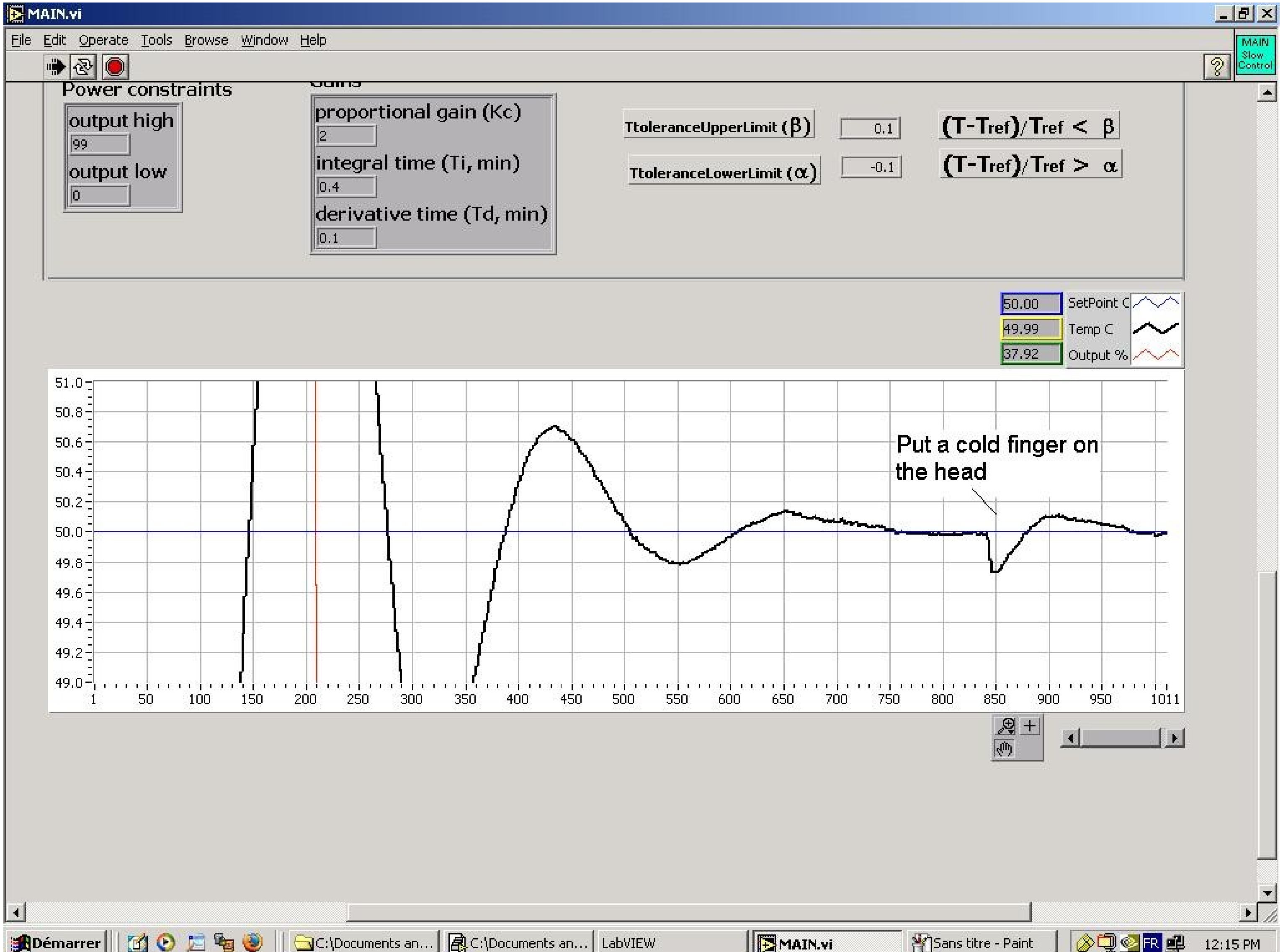
Phoswich head with 30 nm Al on LSO crystals



Design of the phoswich detector module



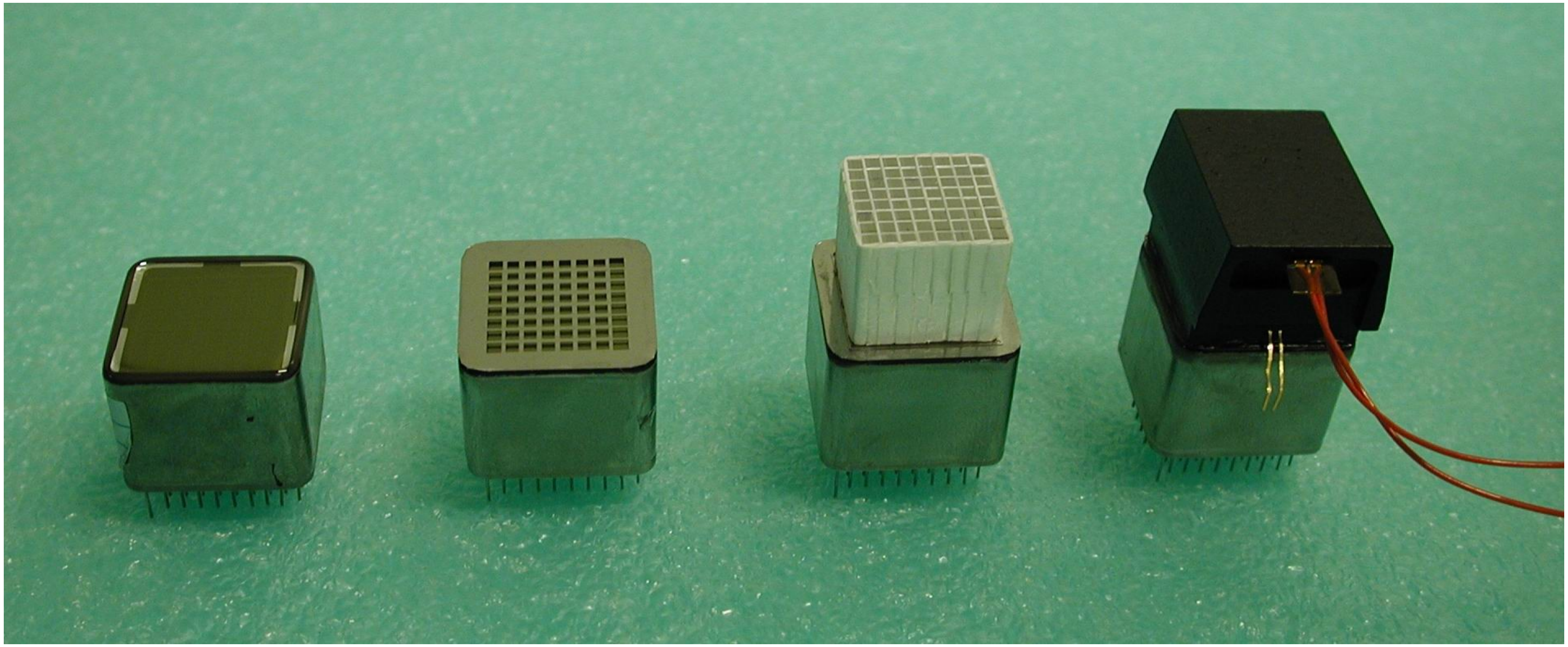
Temperature control



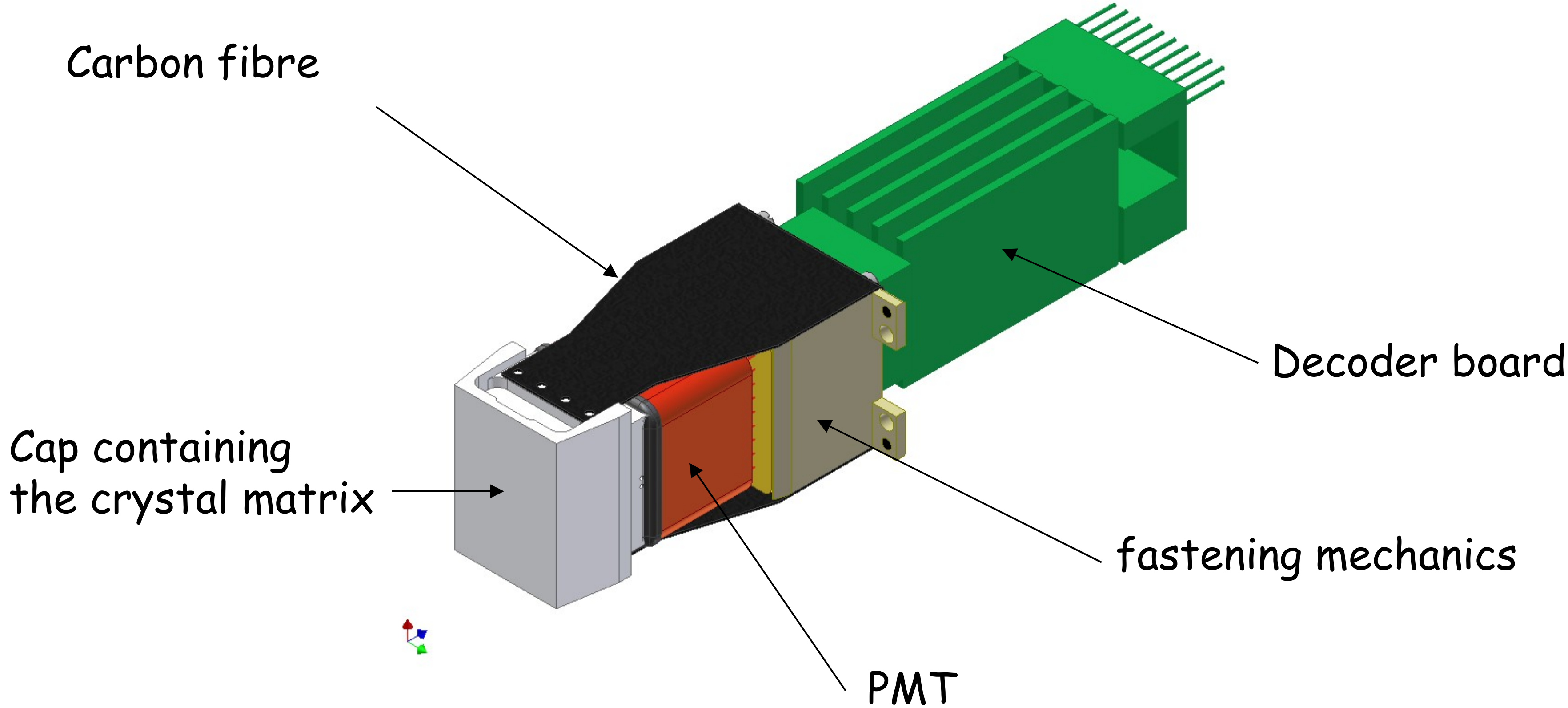
Crystal Clear ClearPET Project

Design of the phoswich detector module

- The crystal matrix is optically glued trough a grid
- The cap fits exactly in the grid
- The grid allows to positioned precisely the cap with regard to the crystals

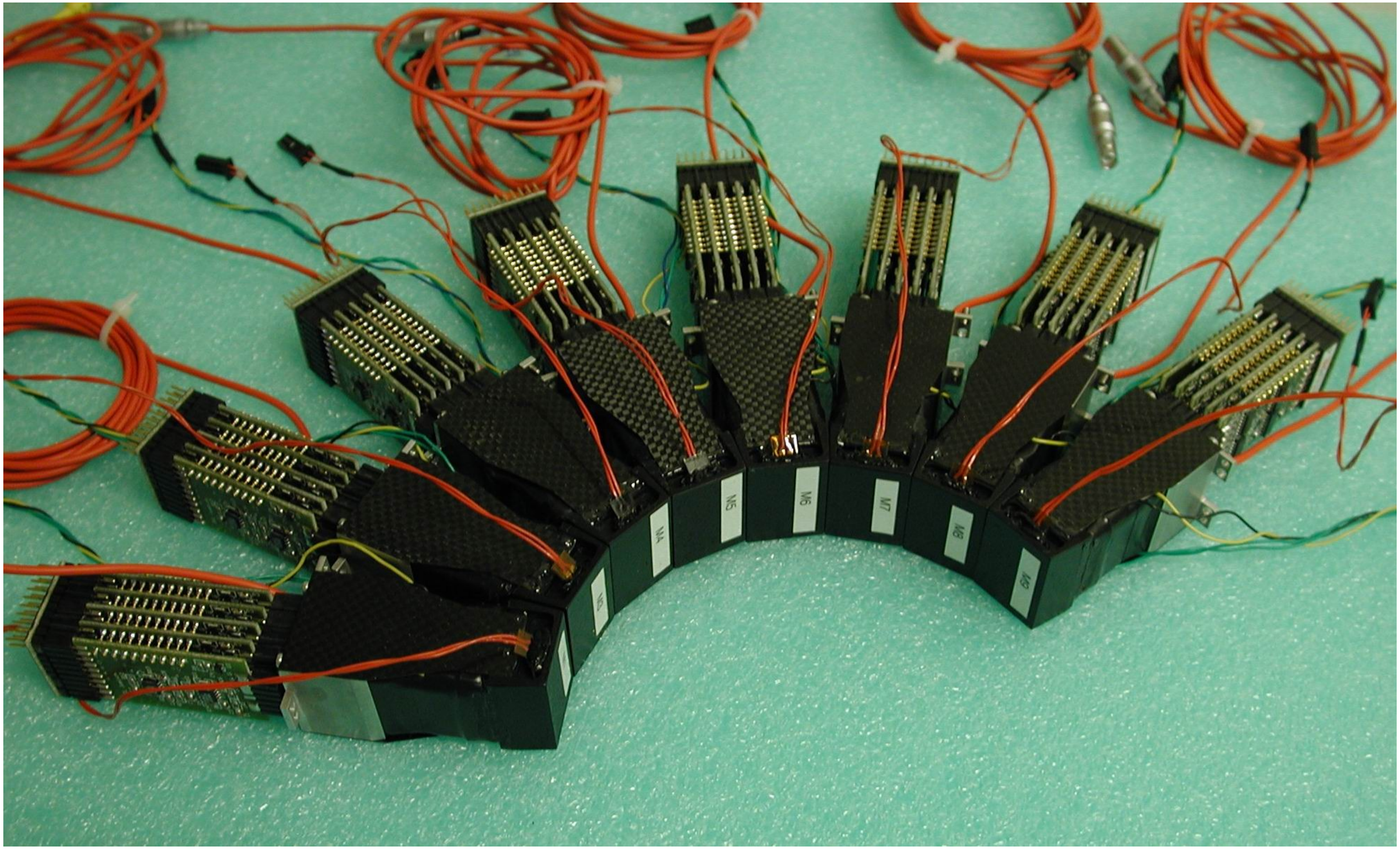


Design of the phoswich detector module

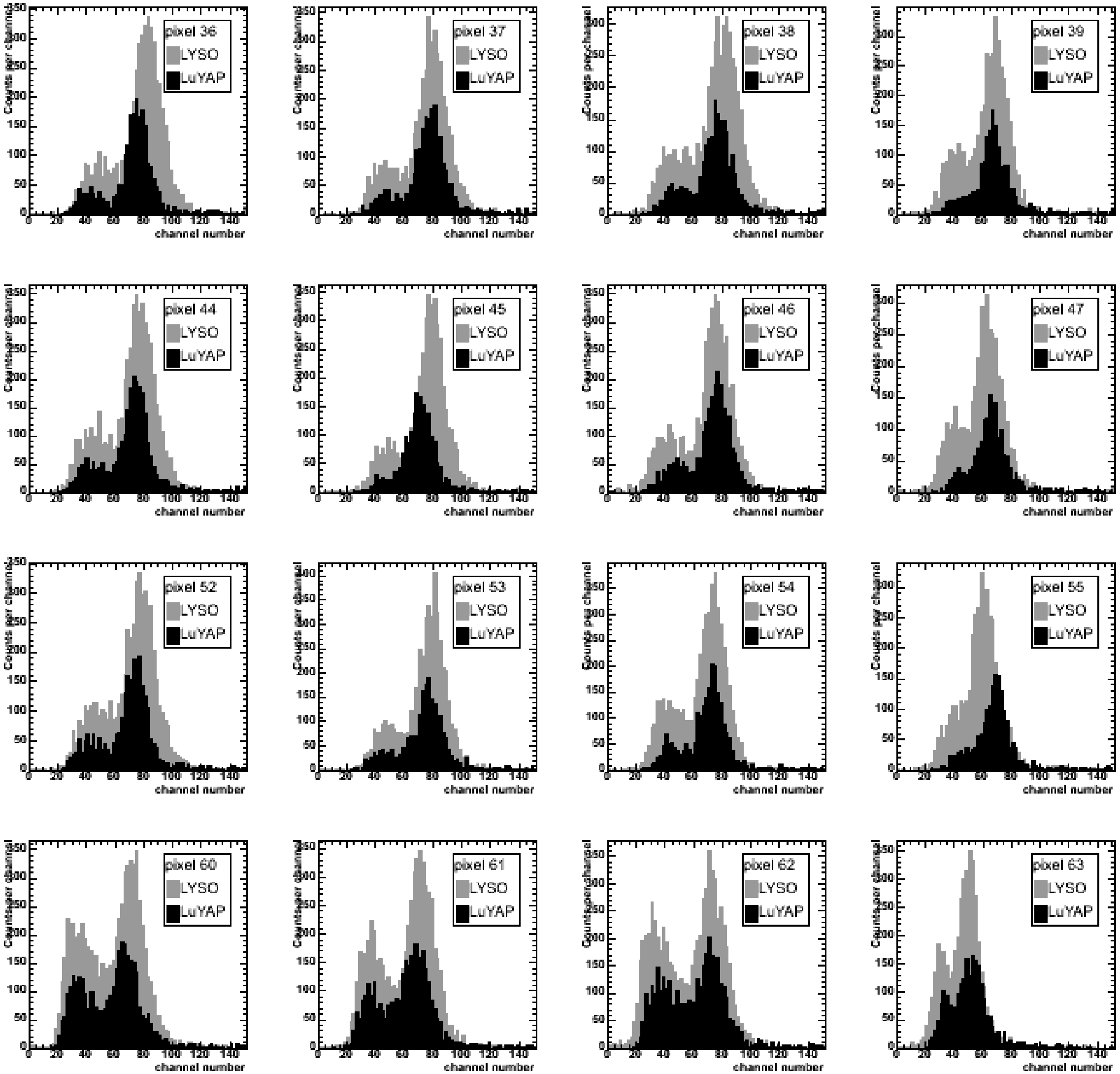


The phoswich module is positioned by the cap

Design of the phoswich detector module



LSO/LuYAP energy sprectra of 511 KeV γ-rays

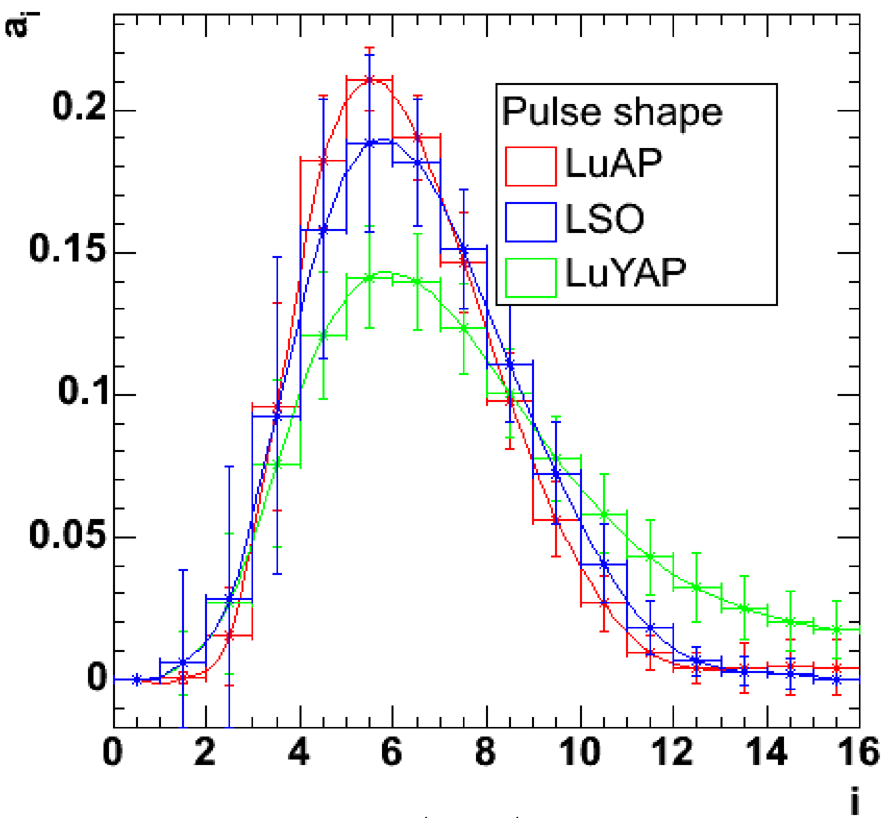


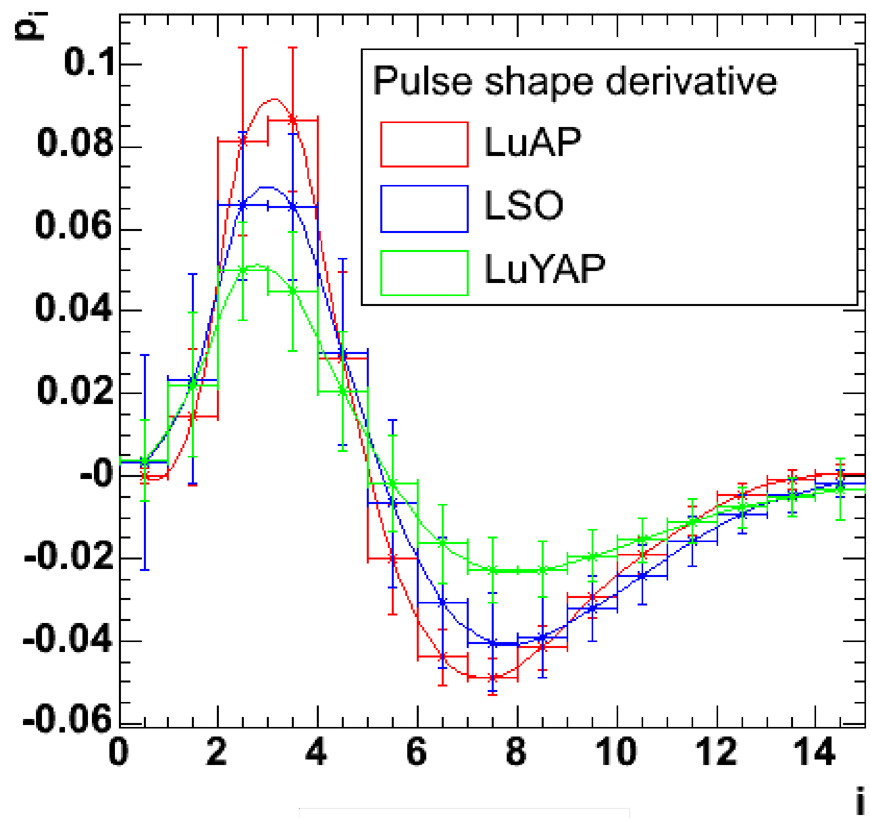
Module M1,
T= 48°C

The mean ratio
LSO/LuYAP is 1.03

At 28°C,
the mean ratio
LSO/LuYAP is 1.25

LSO, LuYAP and LuAP pulse comparison

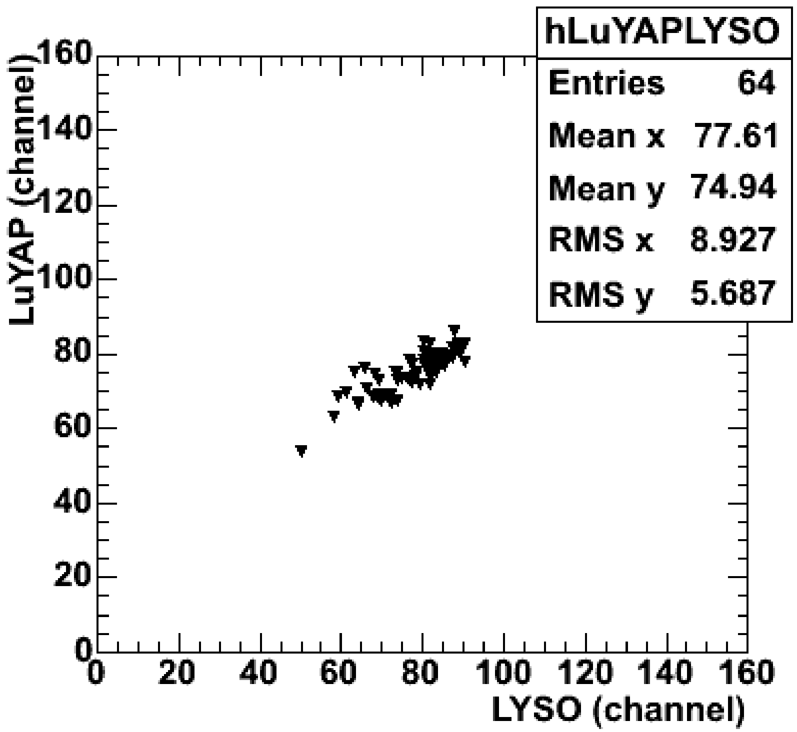




$$a_i = \frac{A_i - A_0}{\sum_{k=1}^{15} A_i - A_0}$$

Crystal Clear ClearPET Project

Dispersion of photopeak position

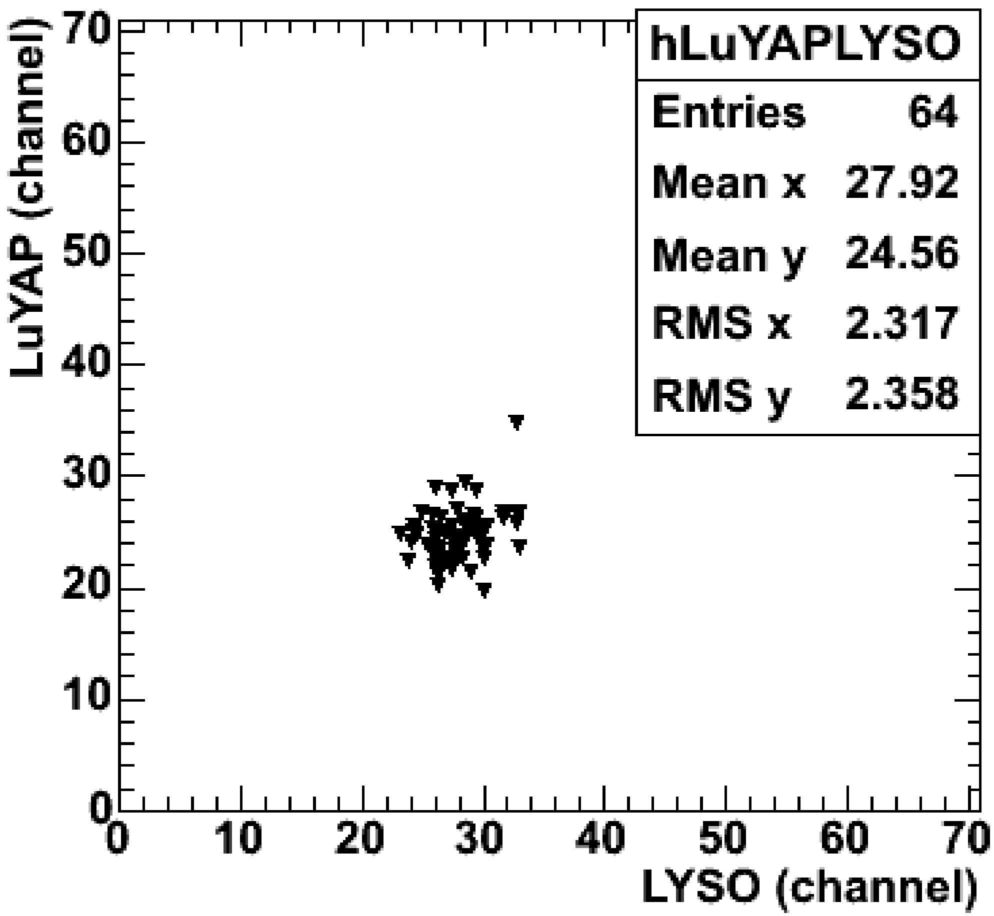


Module M1,
T= 48°C
Relative errors:
- LSO: 11.5%
- LuYAP: 7.6%

Relative errors before optical gluing and aluminisation:
- LSO: 8.3%
- LuYAP: 7.4%

The spread of the photopeak position is meanly due to the non uniformity of the PMT responses

Dispersion of energy resolution at 511 keV



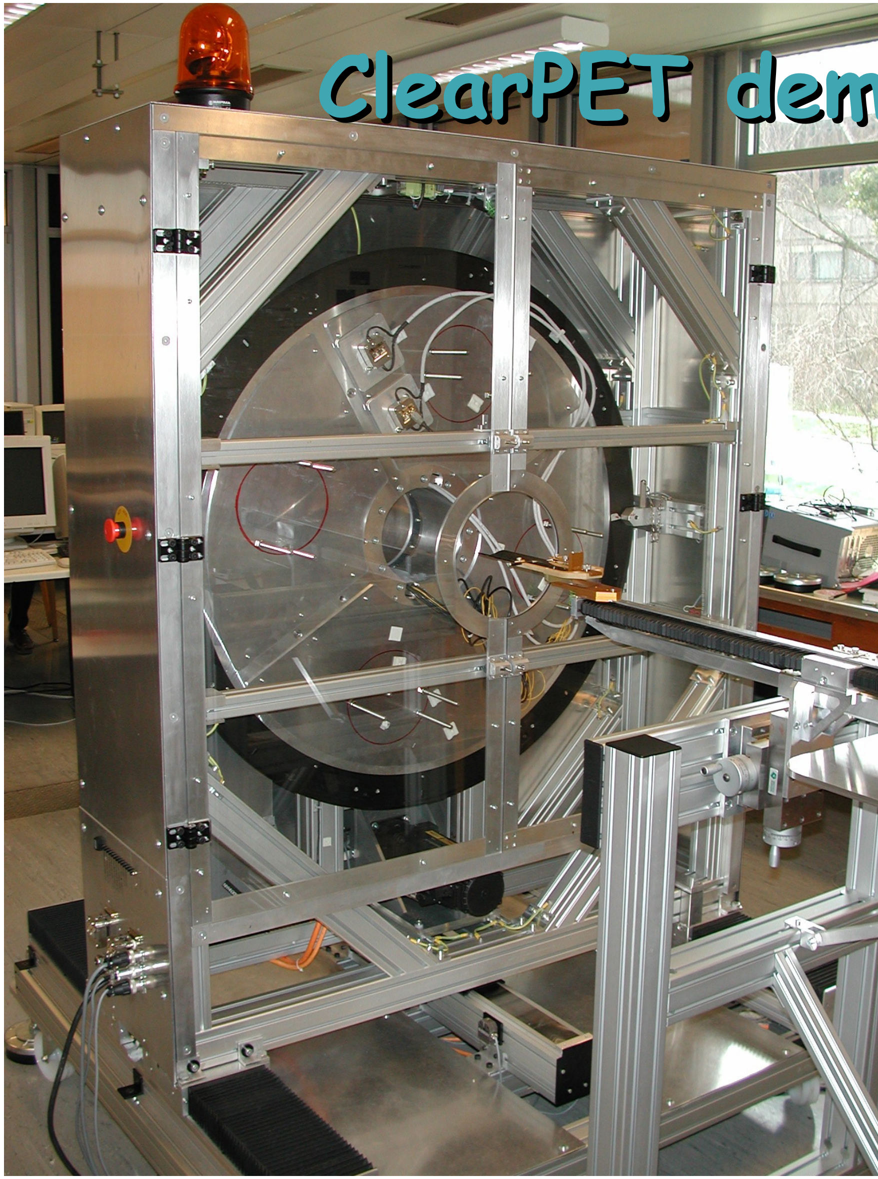
Module M1,

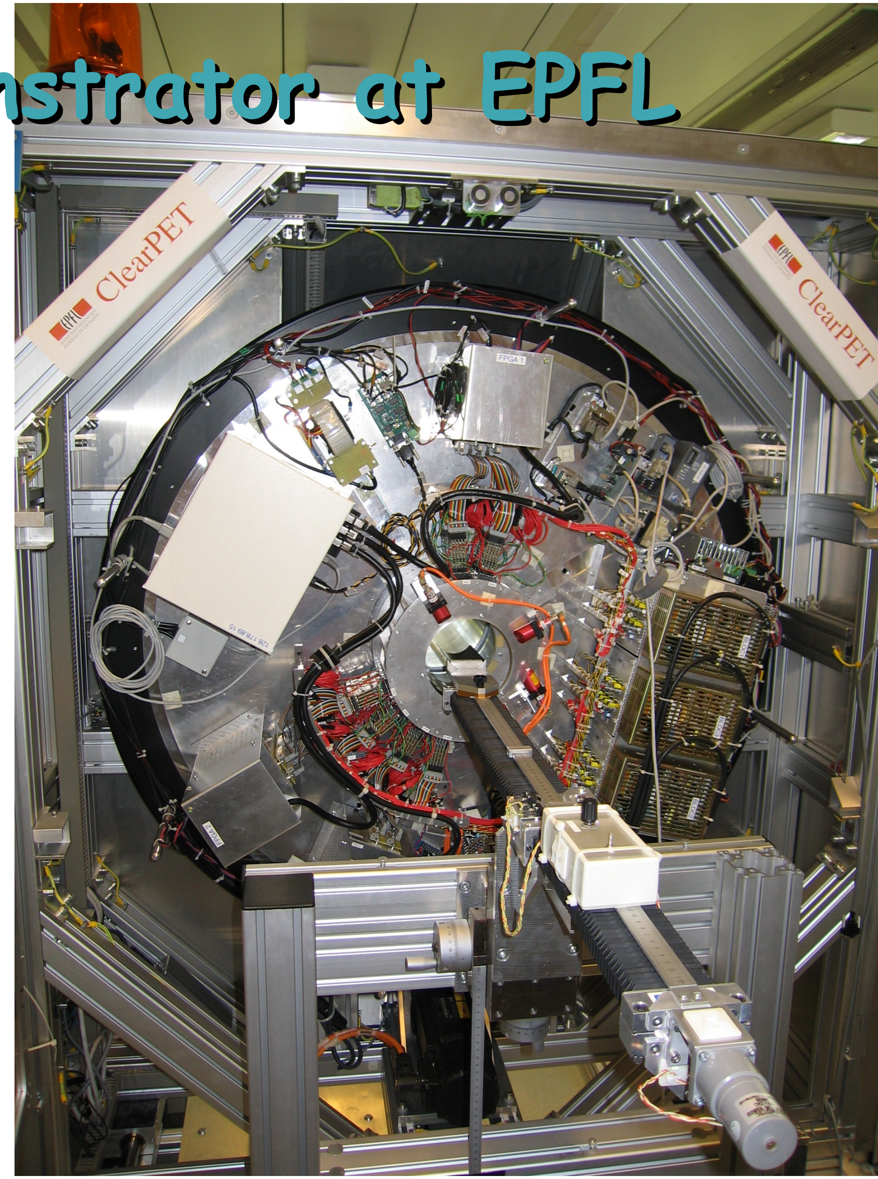
T= 48°C

Energy resolution:

- LSO: (27.9±2.3)%
- LuYAP: (24.6±2.4)%

ClearPET demonstrator at EPFL





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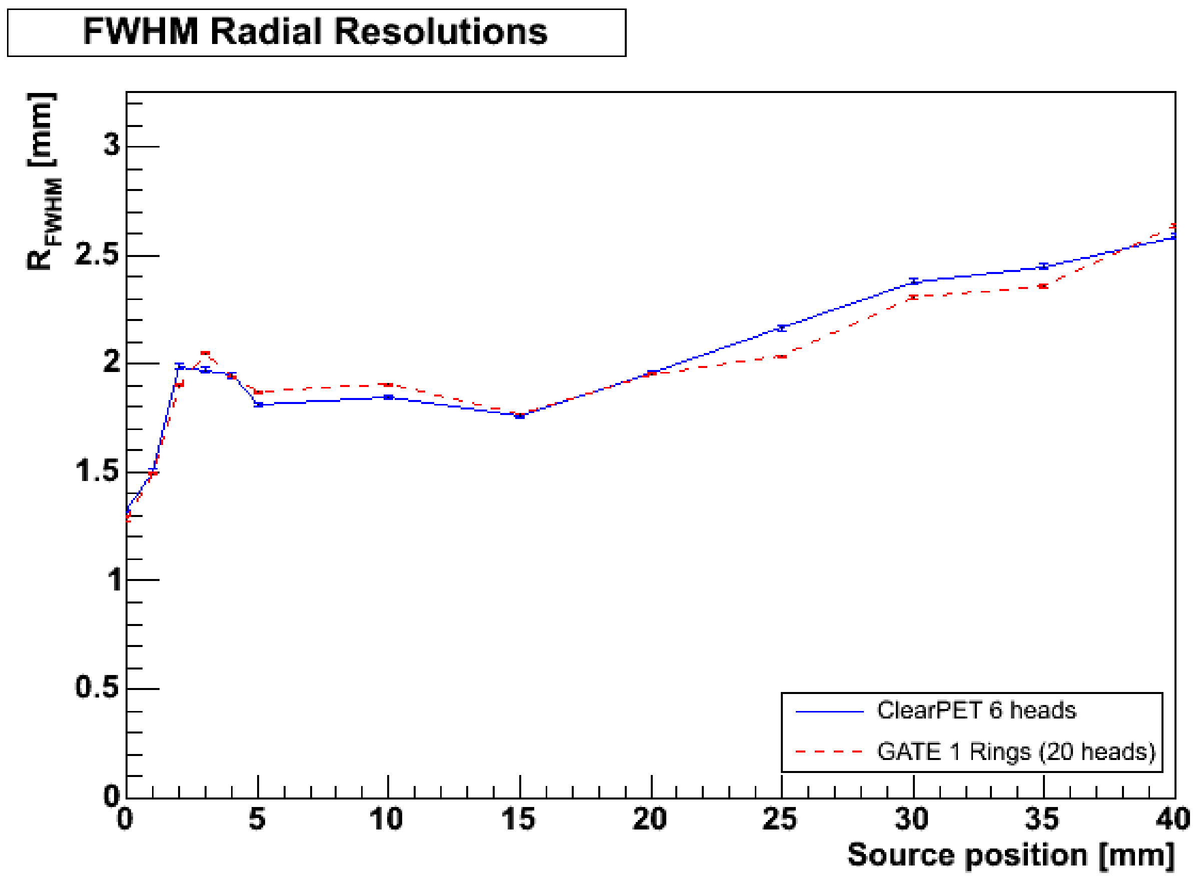
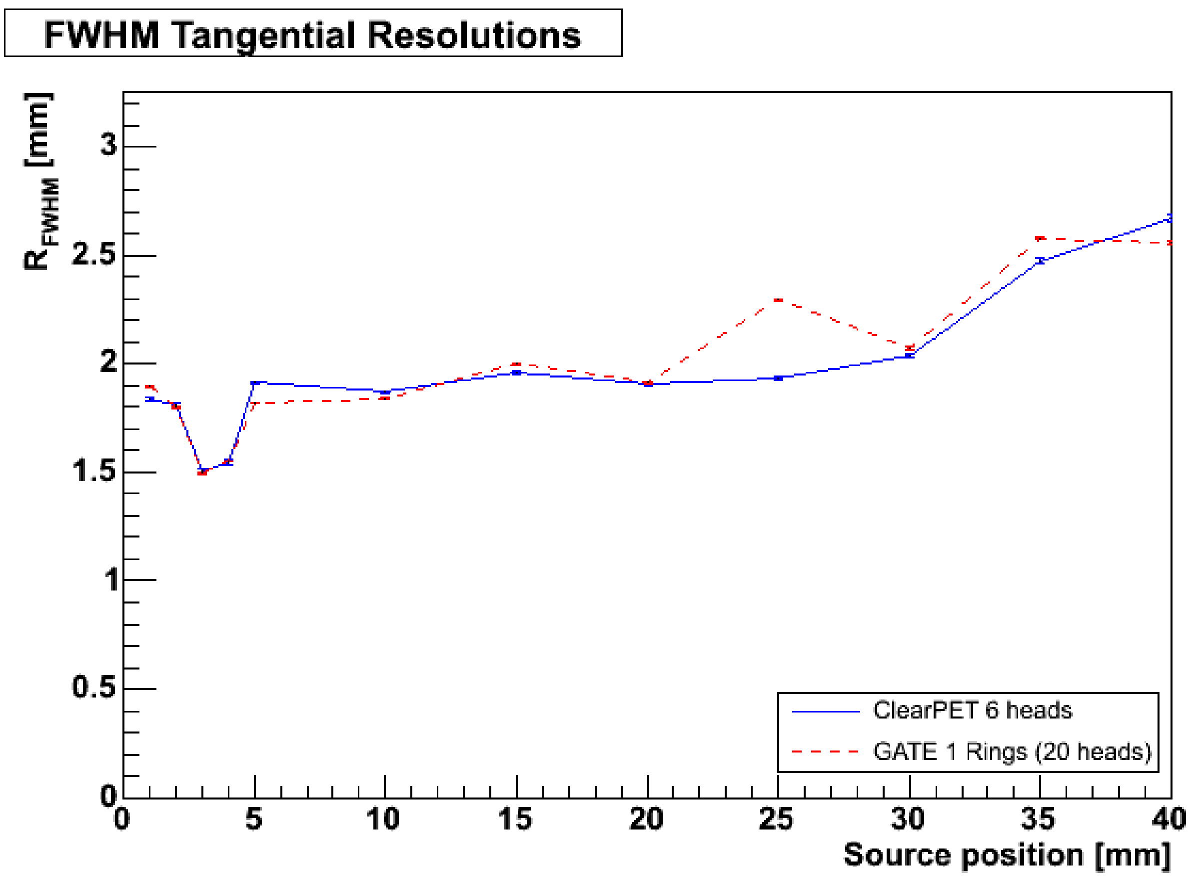
Measured and simulated radial resolutions



Measured and simulated tangential resolutions



Absolute point source sensitivity for two heads

Simulations with GATE

LuYAP density
7.1 g/cm^3 : 0.069%
6.6 g/cm^3 : 0.066%

Measurements
43.5 kBq ^{22}Na point source

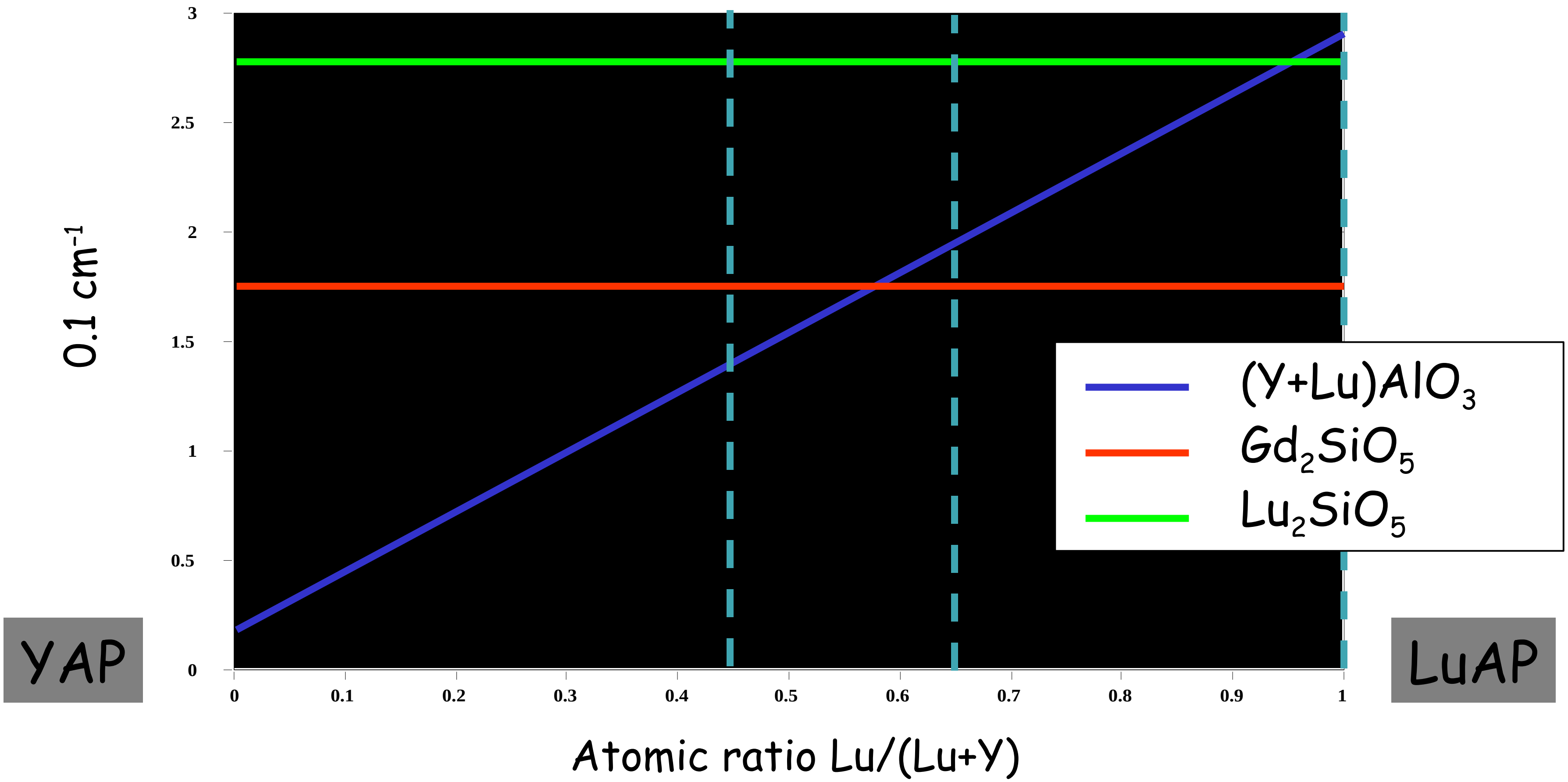
1 Head with high density (M1)
1 Head with low density (M3)
0.068%

Energy cut for both simulations and measurements : 350-750 keV

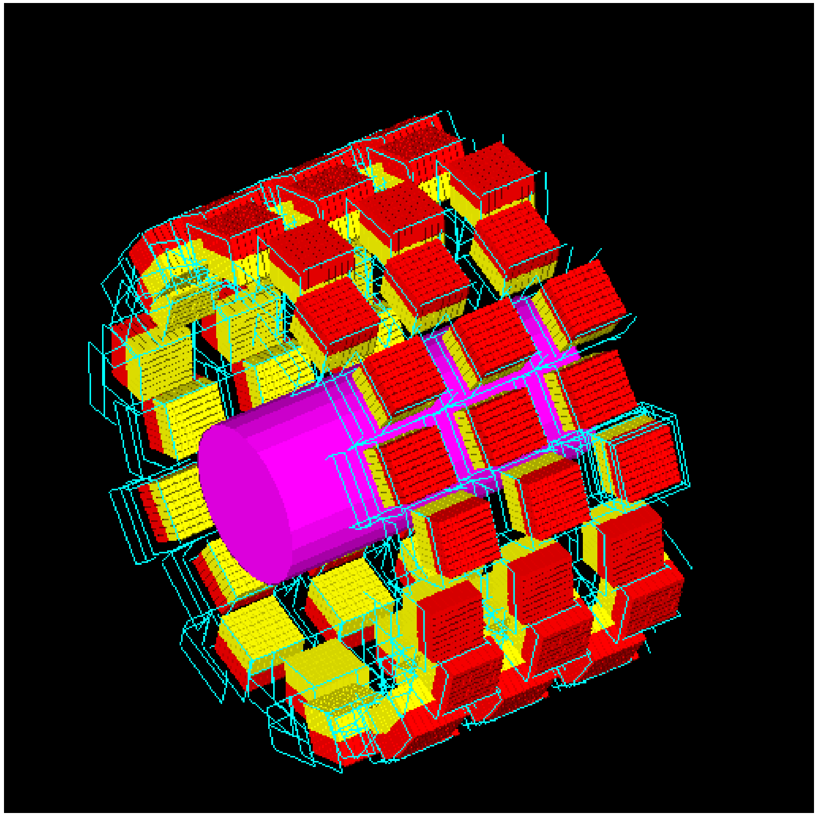
Extrapolation for a 4-ring ClearPET design
with shifts 3.1 ± 0.5 %
without shifts 4.4 ± 0.5 %

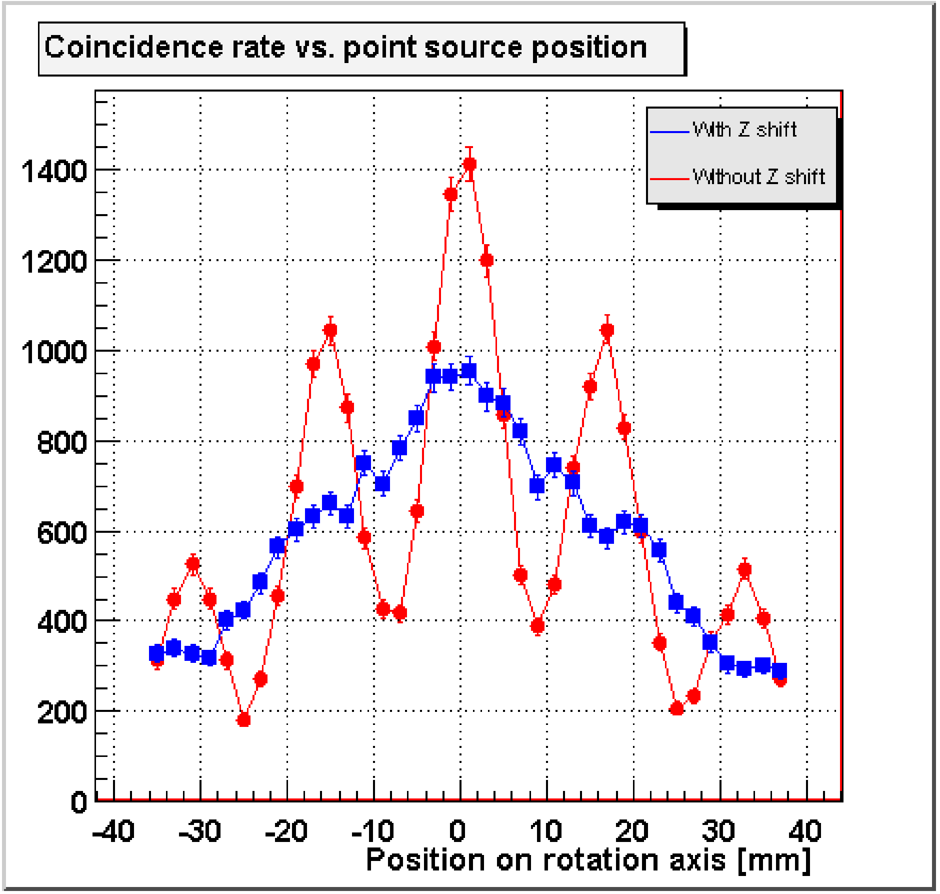
Growth of mixed LuYAP:Ce

Photoelectric absorption @ 511 keV for $(Lu+Y)AlO_3$ system



ClearPET design by GATE



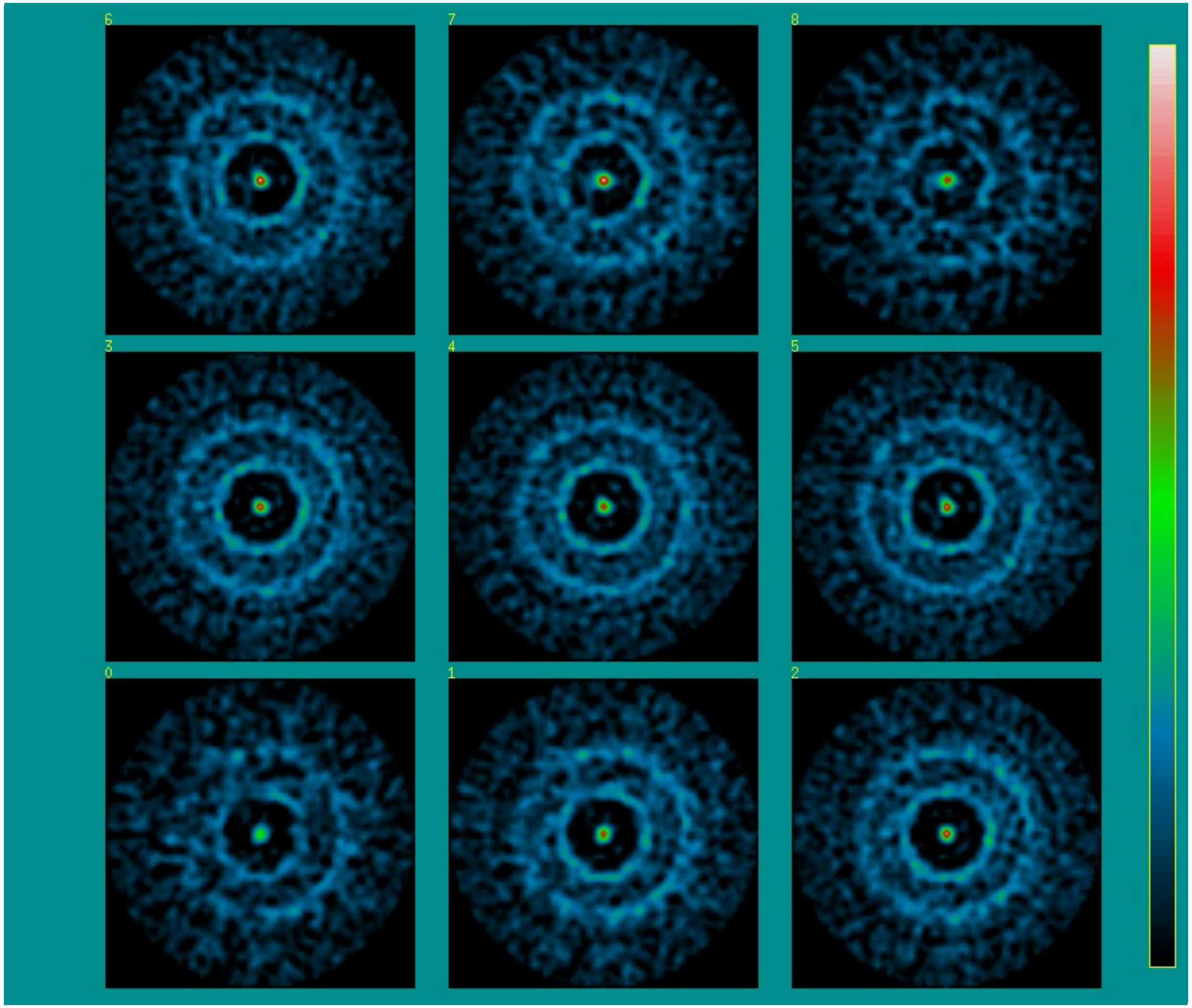


Crystal Clear ClearPET Project

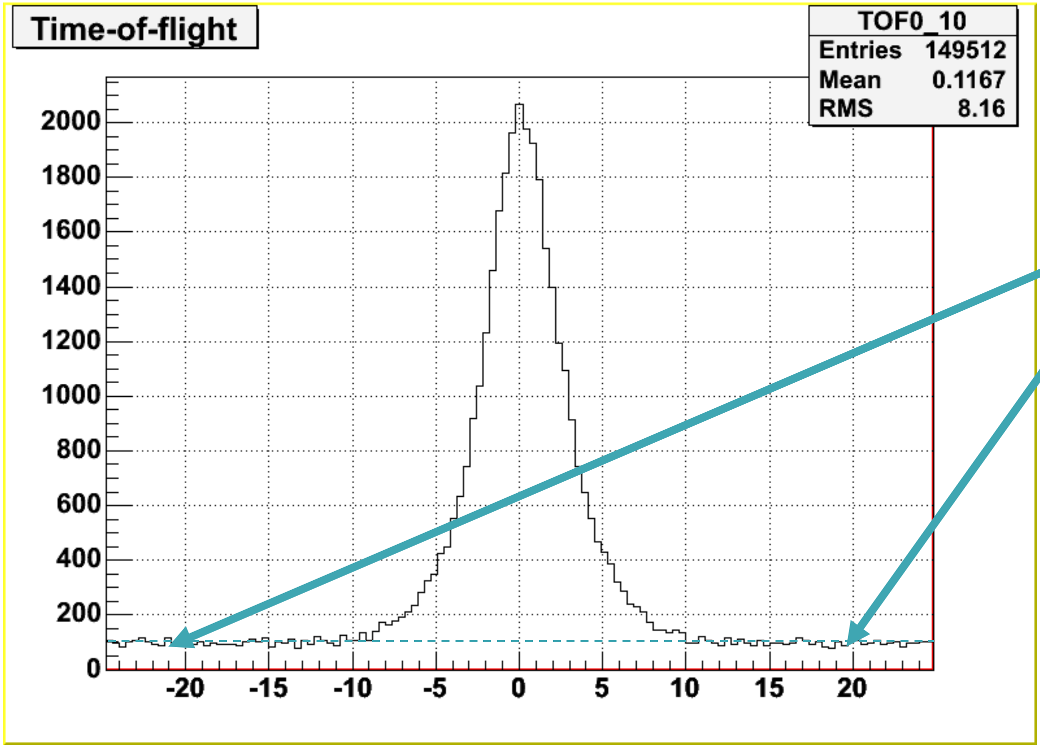
4-ring ClearPET scanner specifications

Scanner	ClearPET (CIBM)	MicroPET FOCUS 120 (Siemens)	Mosaïc (Philips)	eXplore VISTA DR (GE)
Crystal type	LSO/Lu(Y)AP	LSO	GSO	GSO/LYSO
crystals size [mm]	2x2x8	1.5x1.5x10	2x2x10	
Number of crystals	10'240	13'824	14'456	12'168
Ring diameter [mm]	141	148	210	118
Axial FOV [mm]	120	76	116	46
Energy res. (511 keV)	25-28%	15-40%	21%	
Time res. [ns]	5	3	1	
Spatial res on axis [mm]	1.3	1.2	2.2	1.6
Radial res. at 1 cm [mm]	1.9	1.8	2.7	1.9
Radial res. at 2 cm [mm]	2.0	2.2	2.6	2.2
Radial res. at 4 cm [mm]	2.6	3.3	3.1	
Absolute sensitivtiy	4.4 ± 0.5 %	5.4%	1.4%	4%
(energy window [keV])	(350-750)	(350-750)	(410-665)	(250-700)

Uniform cylinder phantom ø 6 cm

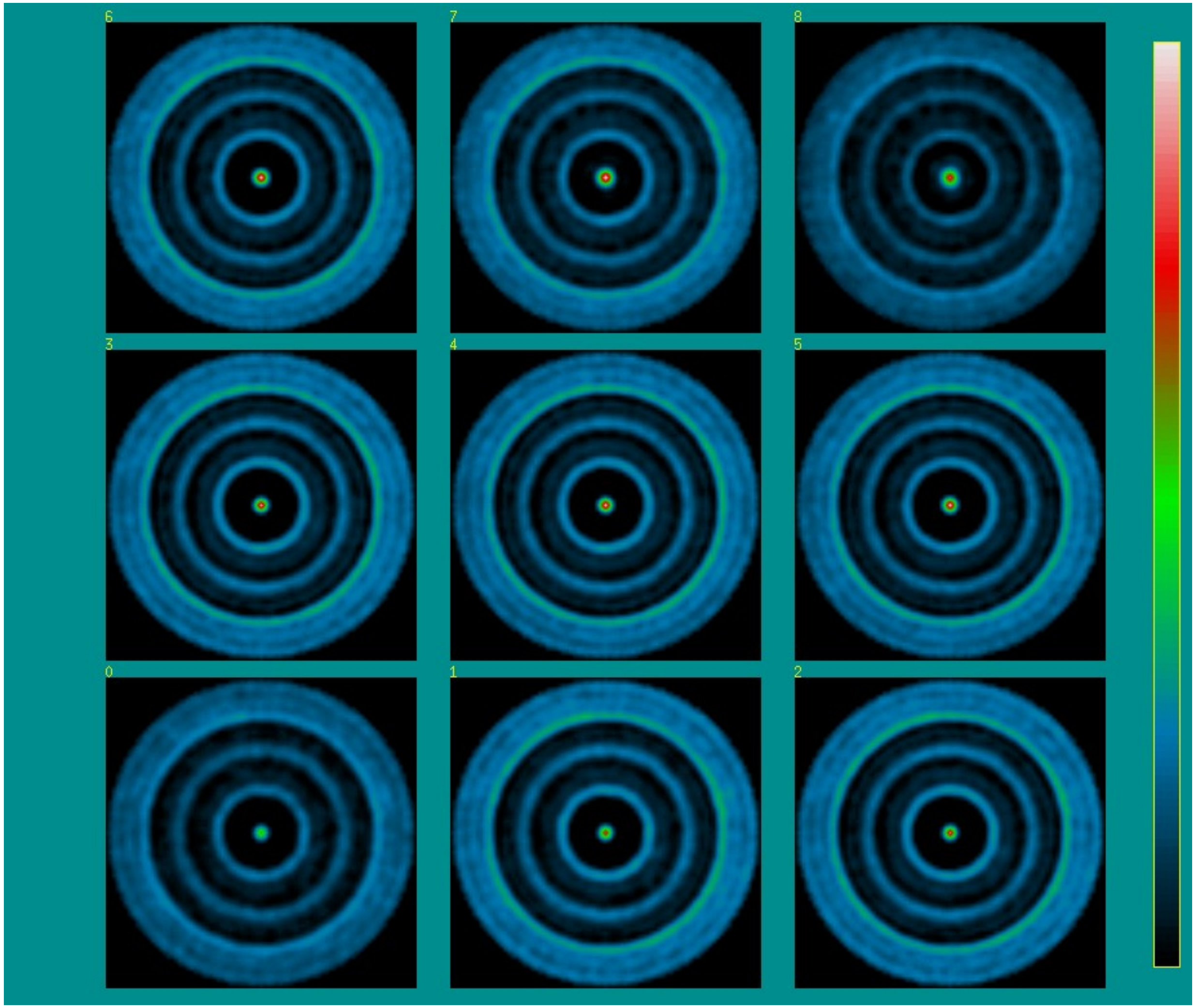


Trues and Randoms

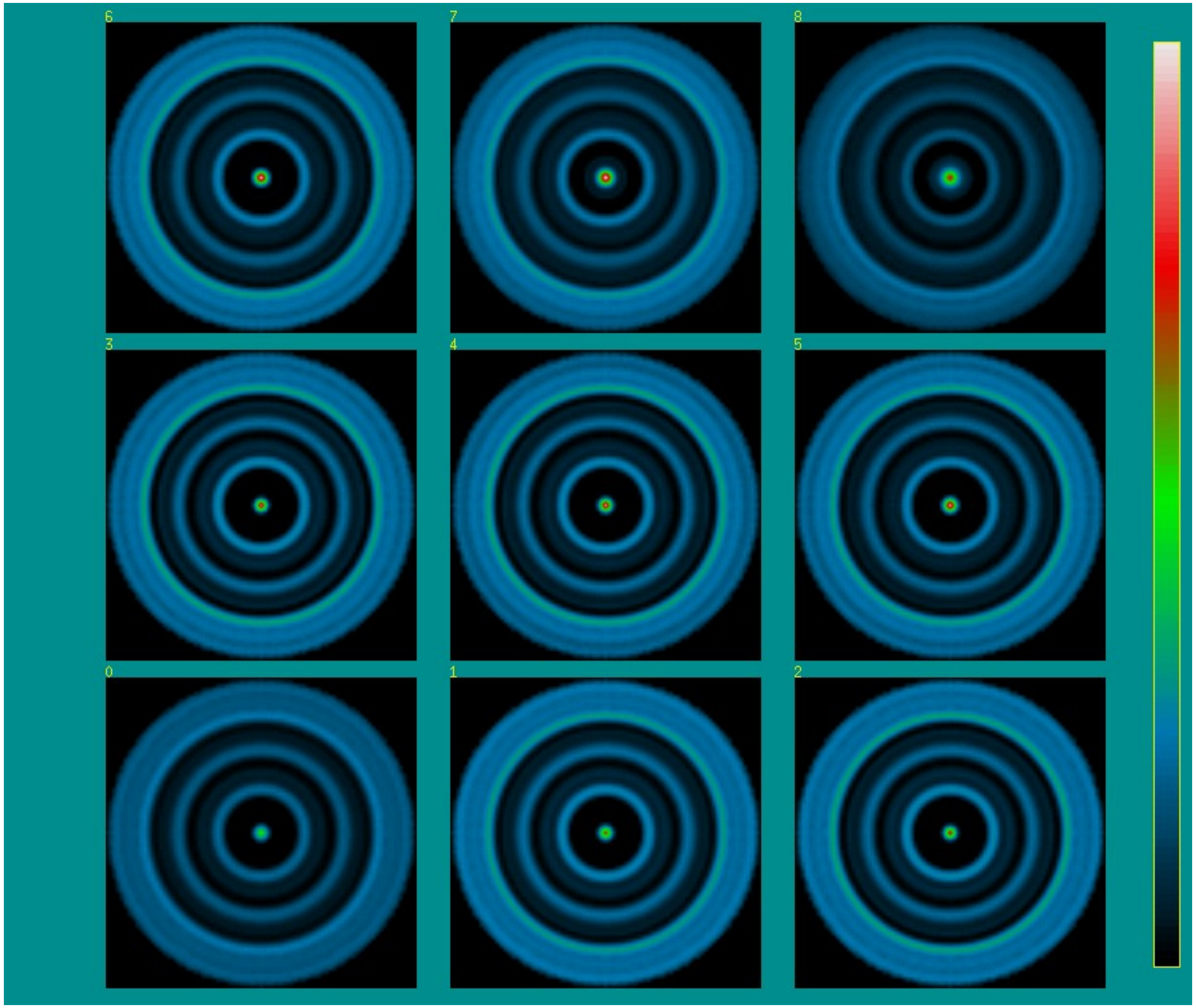


$\sim P_1 P_2 \; 2\,w$

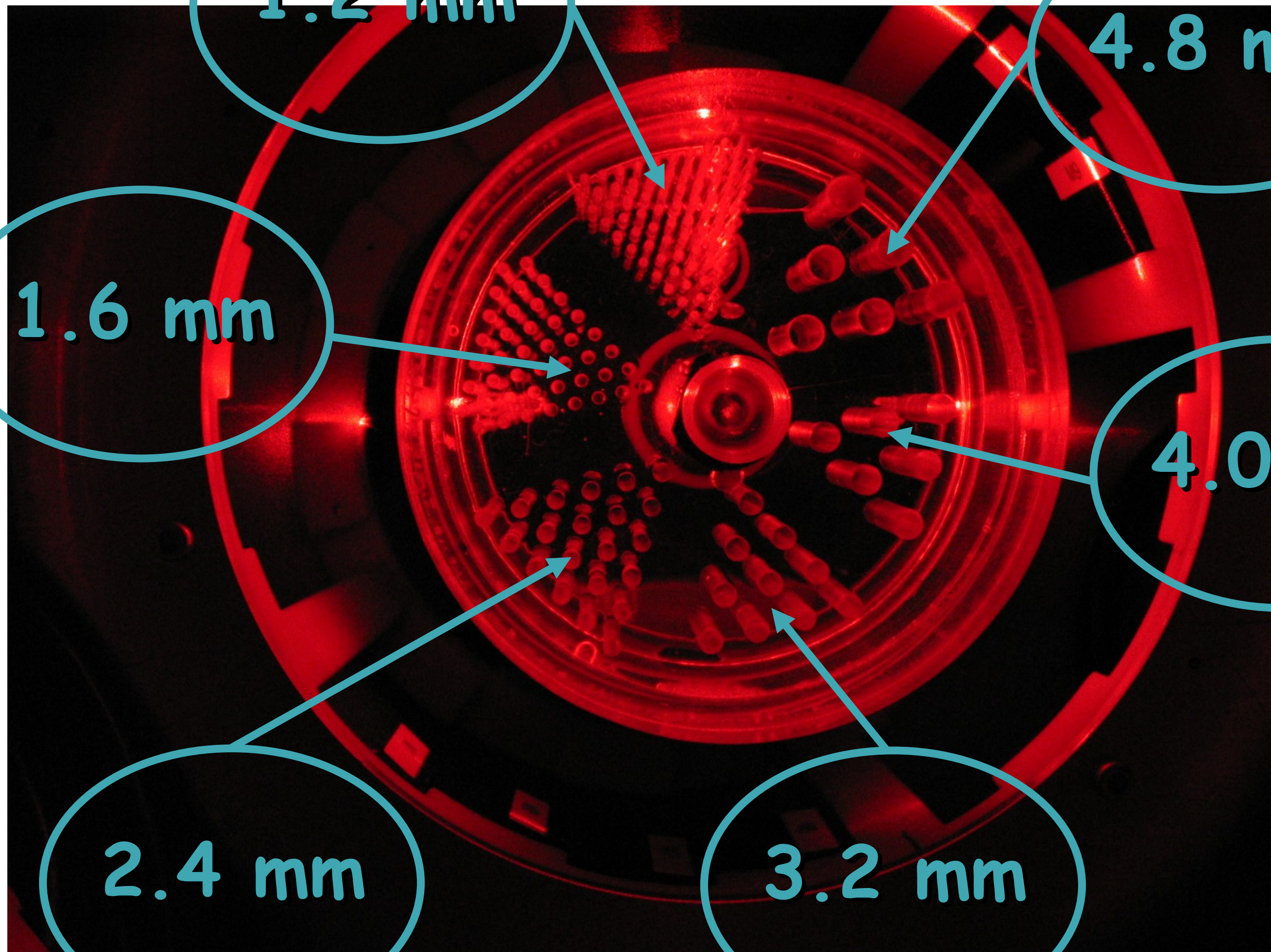
Sensitivity image estimated by randoms



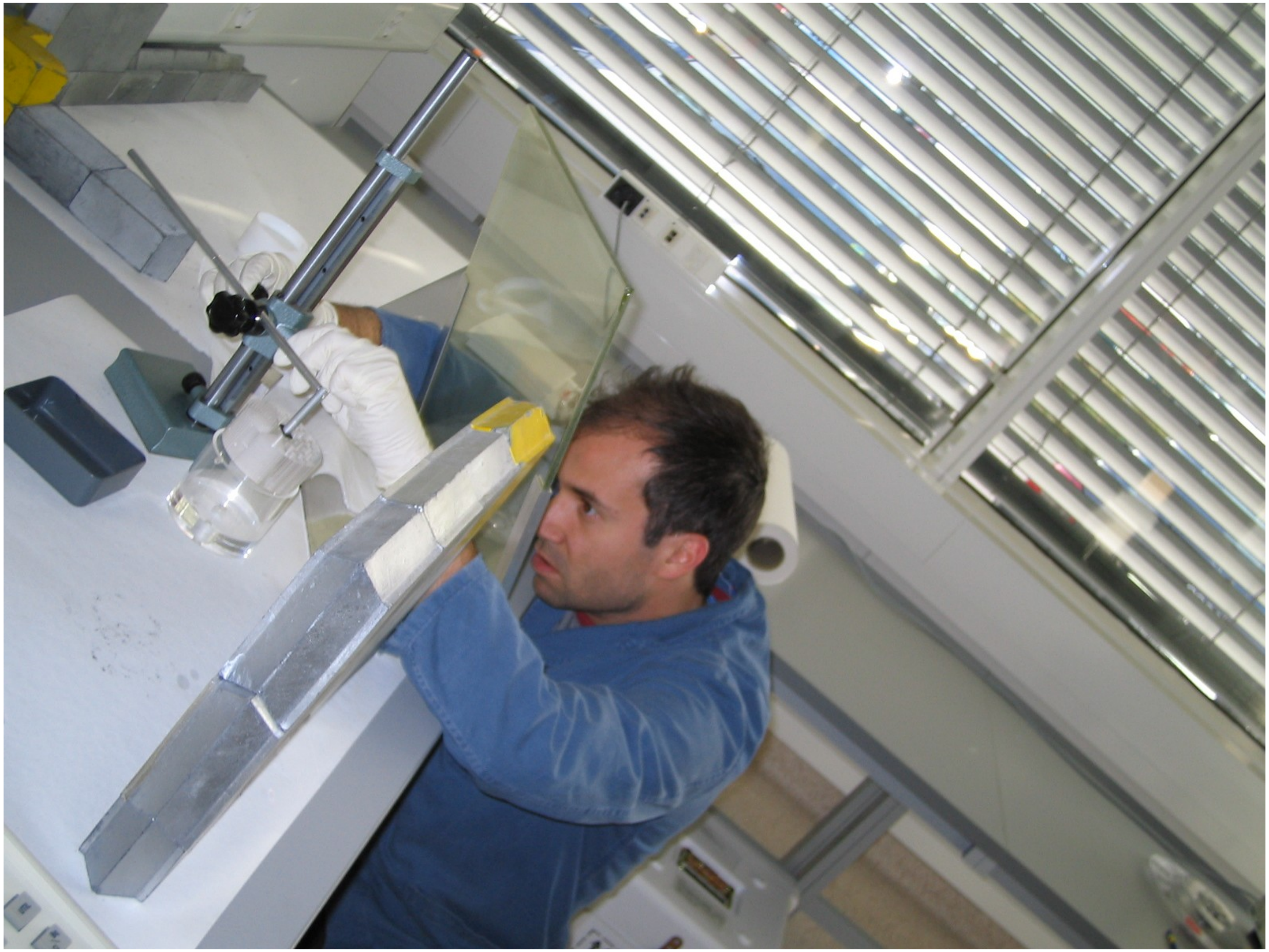
Symmetrised sensitivity image



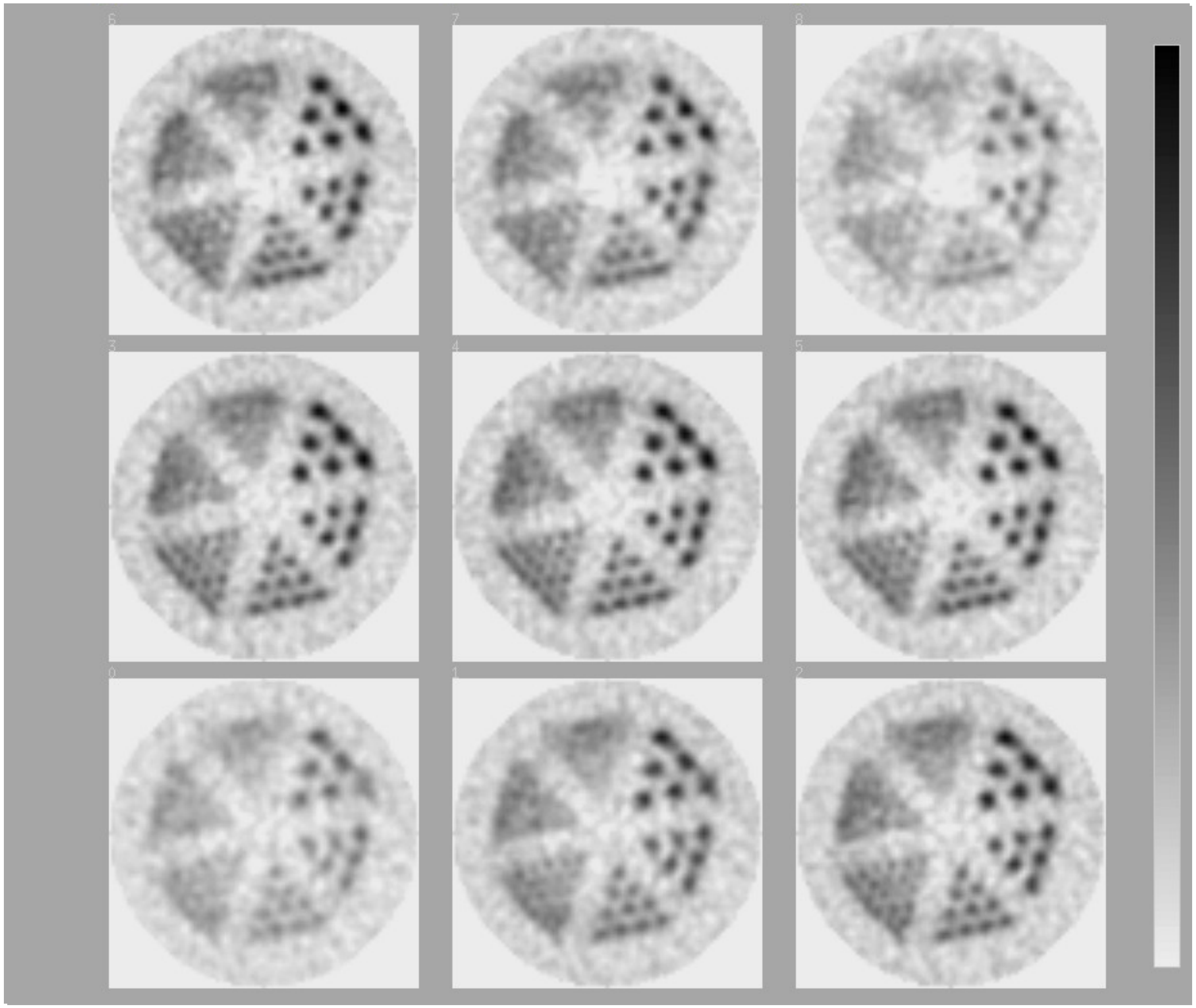
Mini-Derenzo phantom



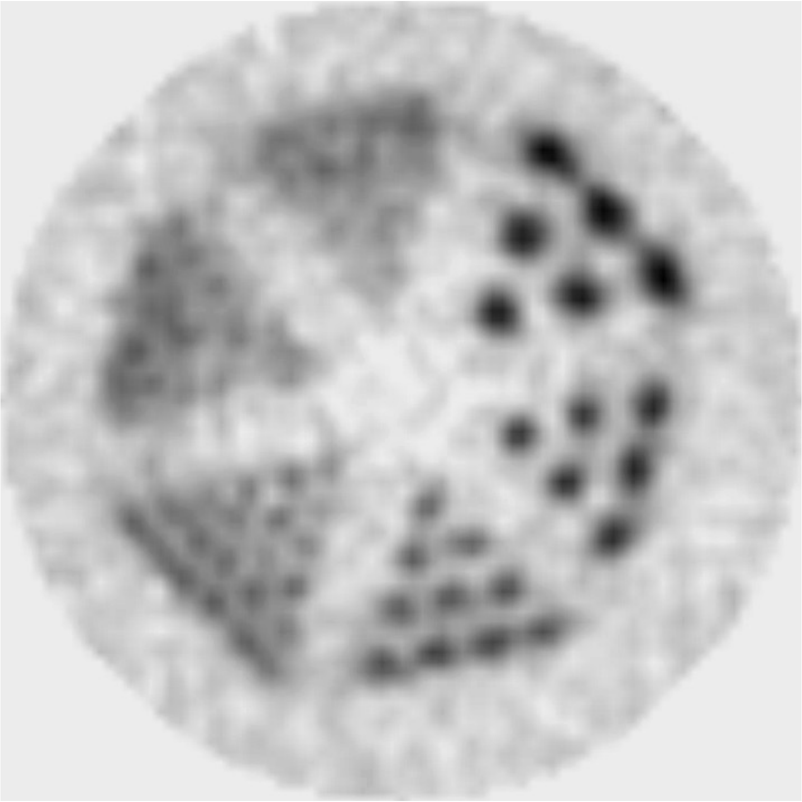
Preparation of the Mini-Derenzo phantom



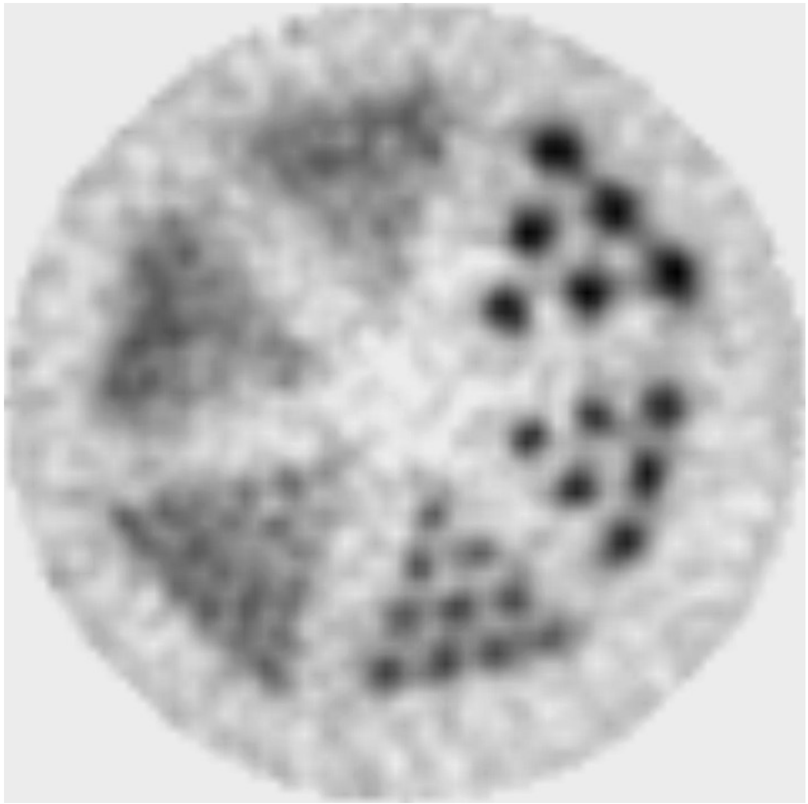
Mini-Derenzo phantom 2.5 mio events



Effect of DOI information



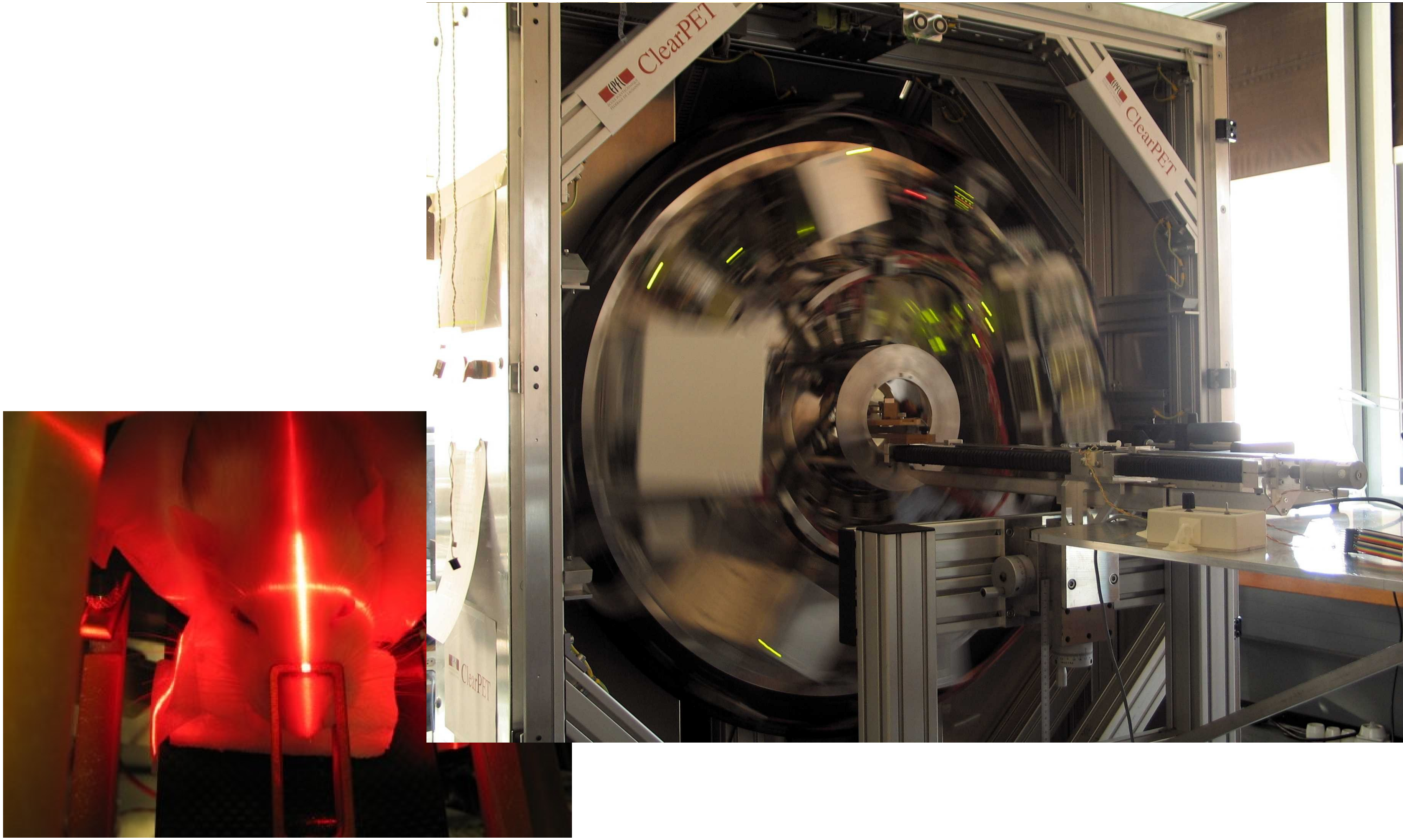
With DOI



Without DOI

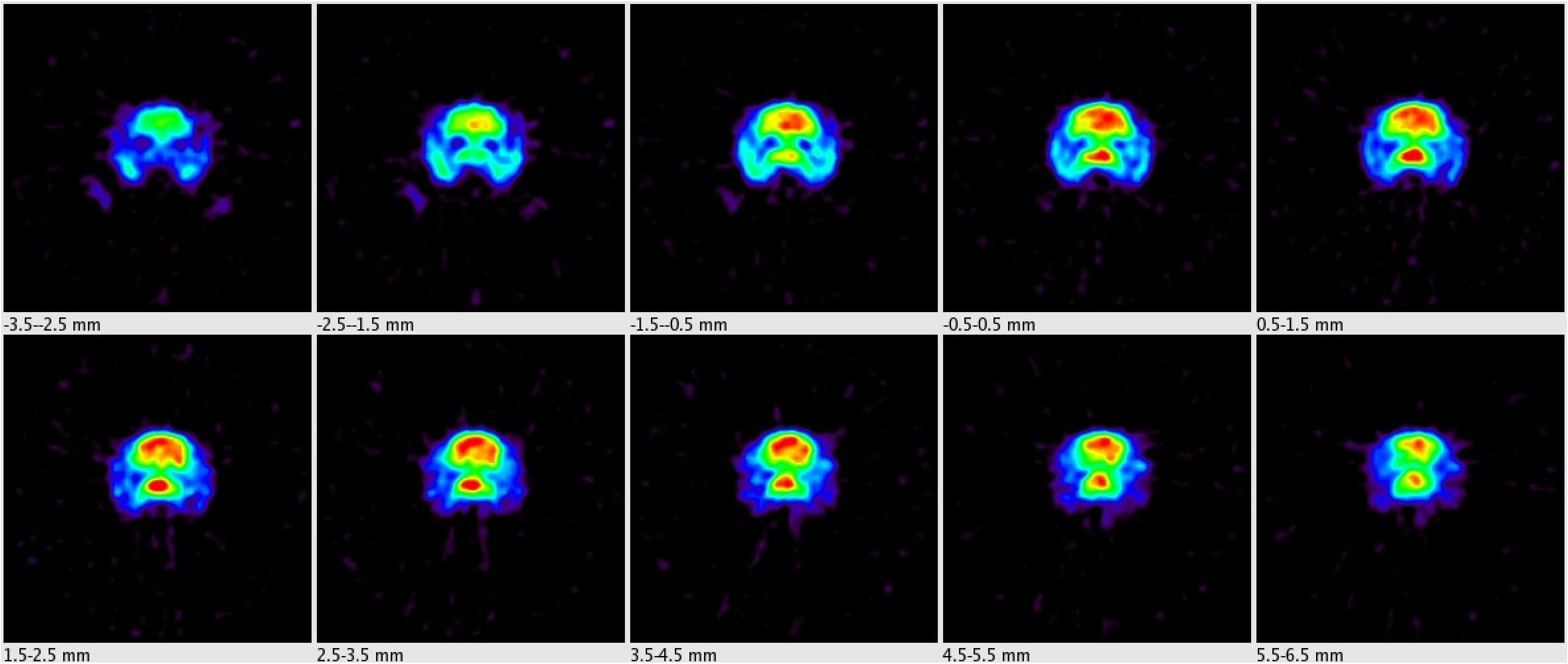
Crystal Clear ClearPET Project

First rat experiment on the ClearPET demonstrator




Waiting for an image !
Crystal Clear ClearPET Project

[^{18}F]FDG rat brain scan



- 240 g female rat
- 47.7 MBq [^{18}F]FDG
- 45 min post injection scan
- 16 min scan duration

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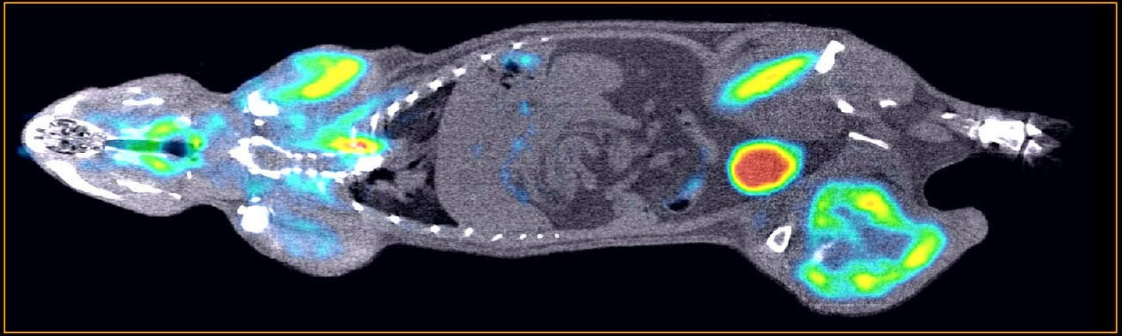
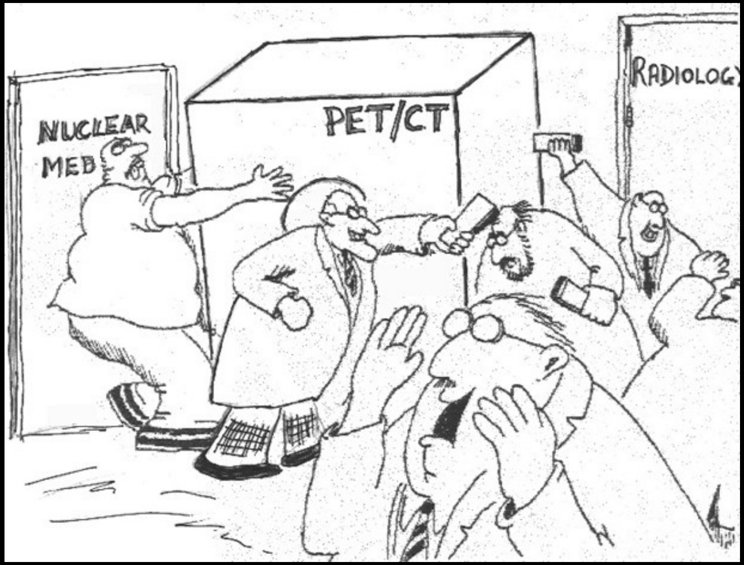
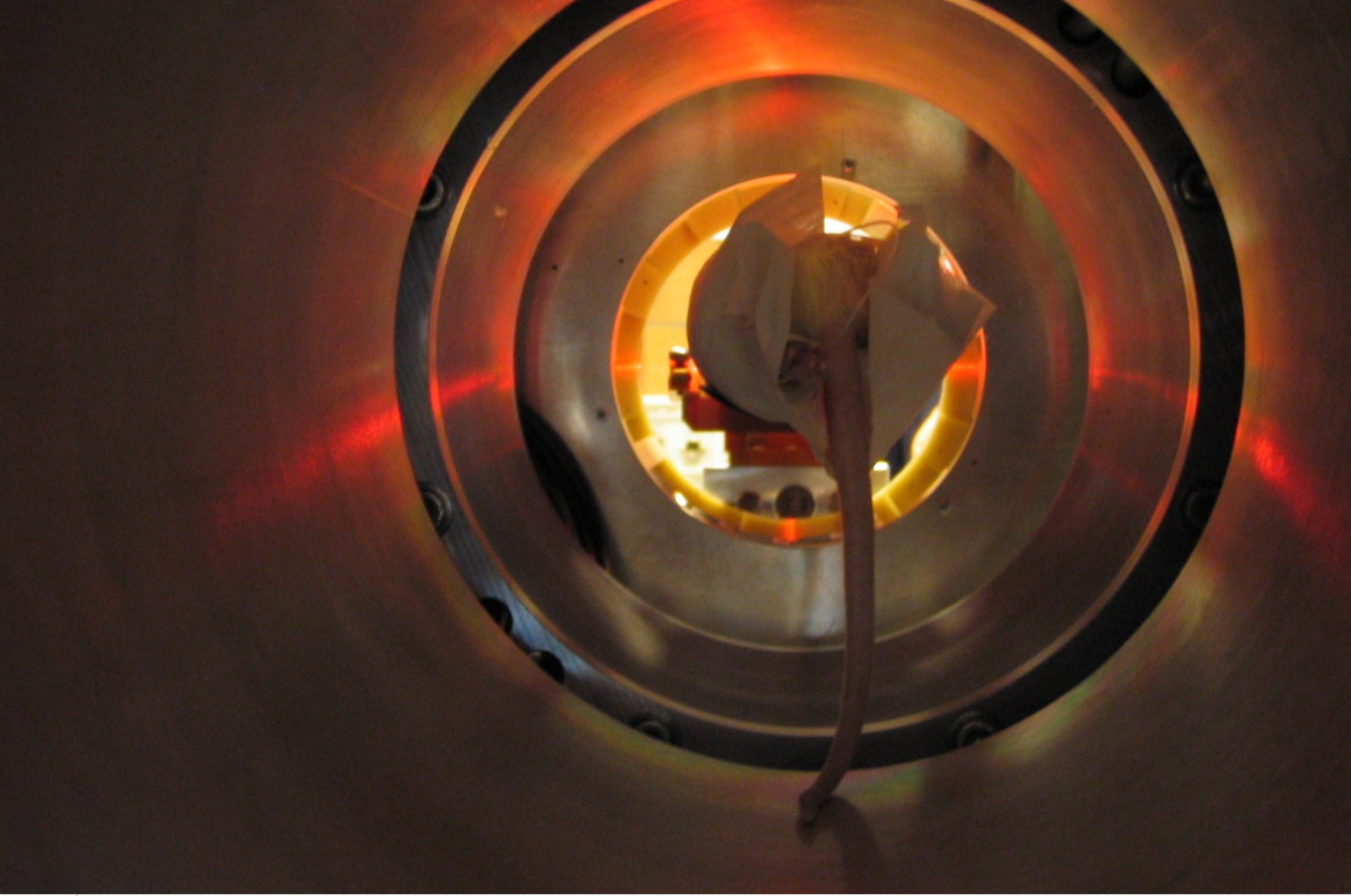
Hybrid imaging modalities







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