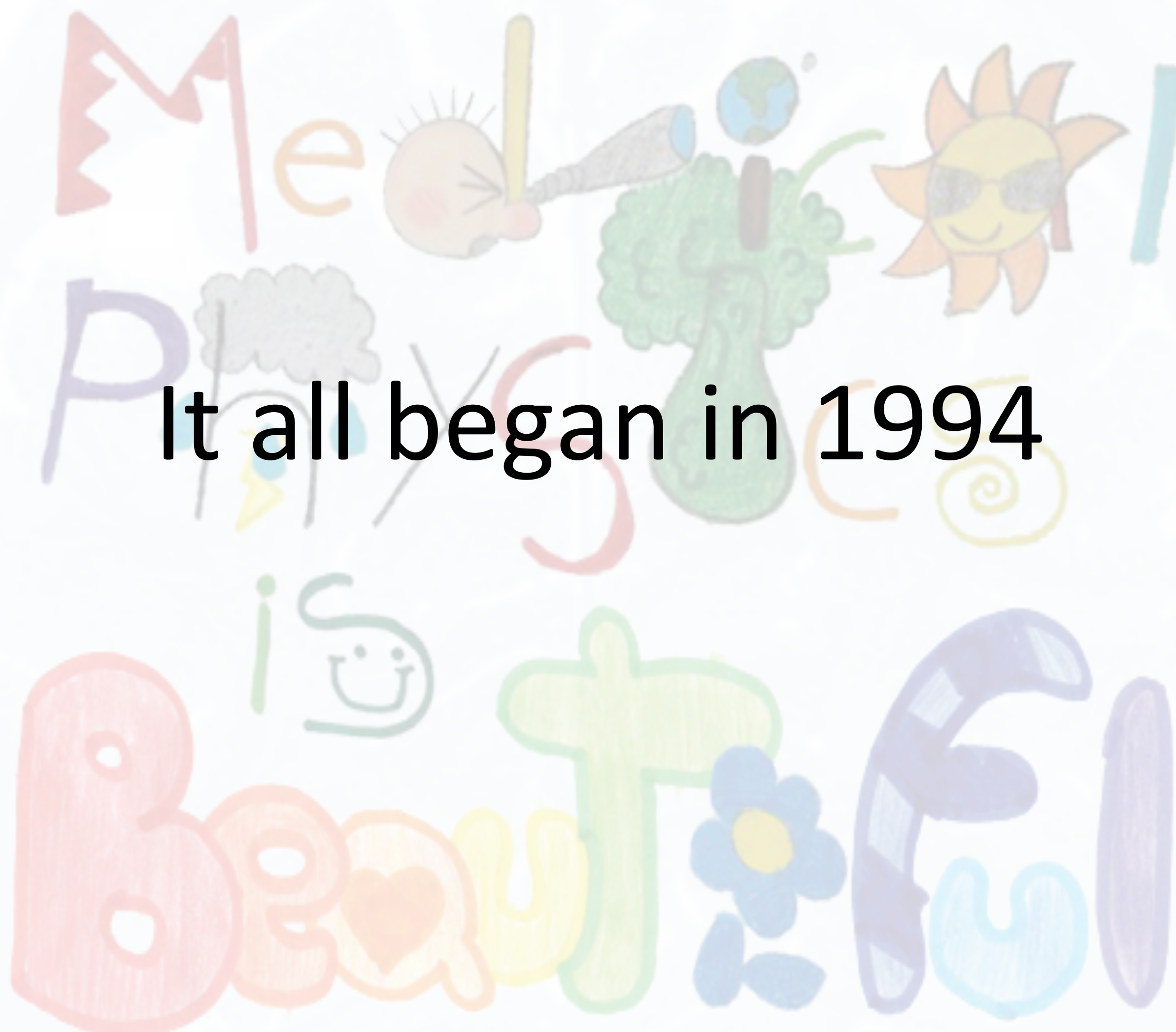
Small Animal PET/SPECT with YAP:Ce scintillator and beyond

Guido Zavattini



It all began in 1994

YAP:Ce

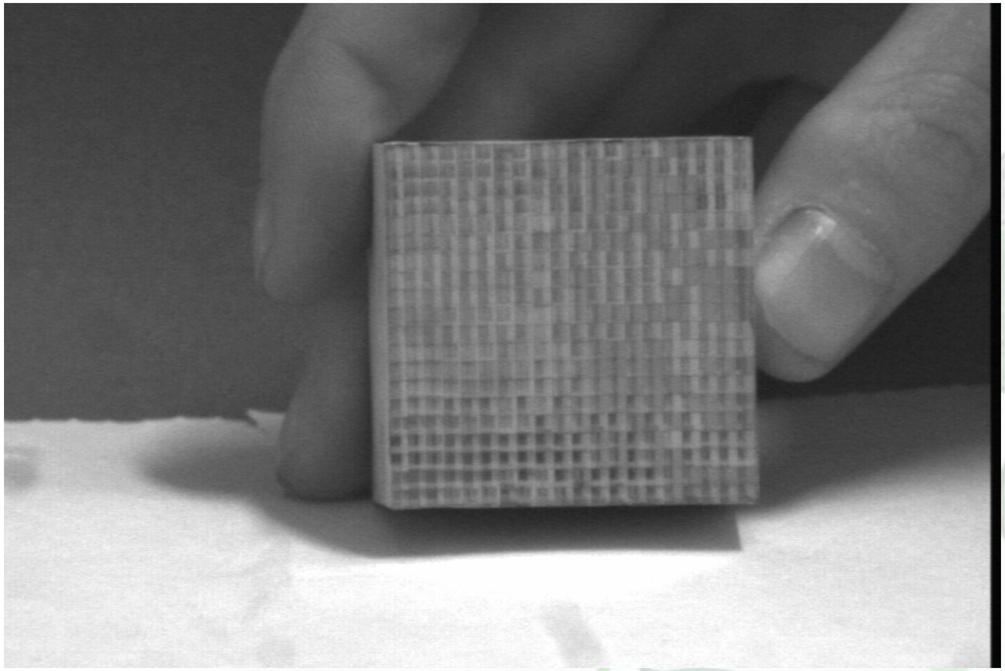


Photo of YAP:Ce matrix (4 cm x 4 cm). Each pixel crystal is 2 x 2 x 30mm^3.

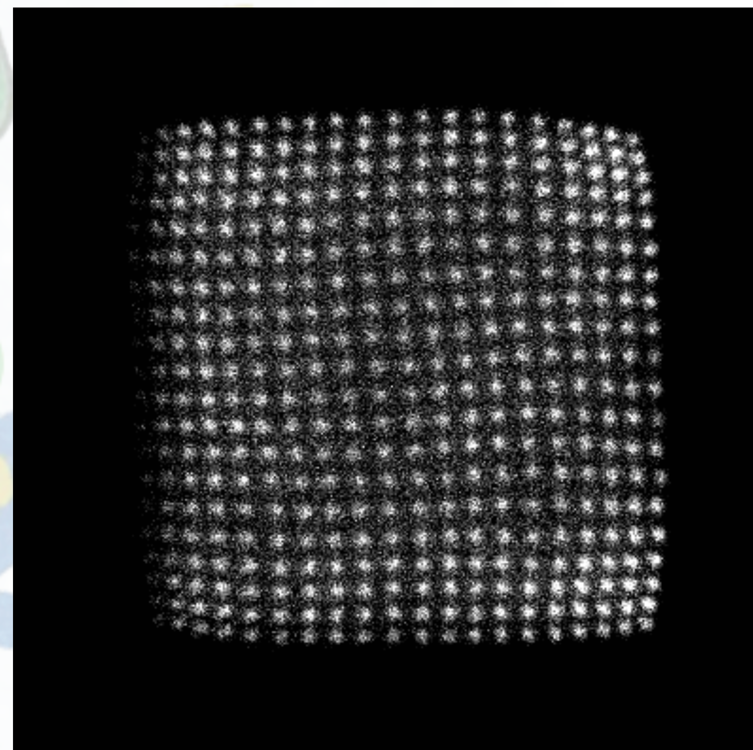
Pixels are separated by a 5 μm reflective layer

- Density 5.37 g/cm^3
- Atomic numbers 39,13,8
- Light yield > 50% of NaI
- Scintillation decay time 27 ns
- Peak wavelength em. 370 nm
- Refractive index 1.95
- Very high packing fraction
- Small pixel
- Non radioactive
- Photofraction
  50% @ 140keV
  4% @ 511 keV

YAP:Ce properties

- **Diameter: 3 inch**
- **effective area ø = 55mm**
- **Mesh dynode structure**

Photo of Hamamatsu position sensitive phototube mod. R2486-06.

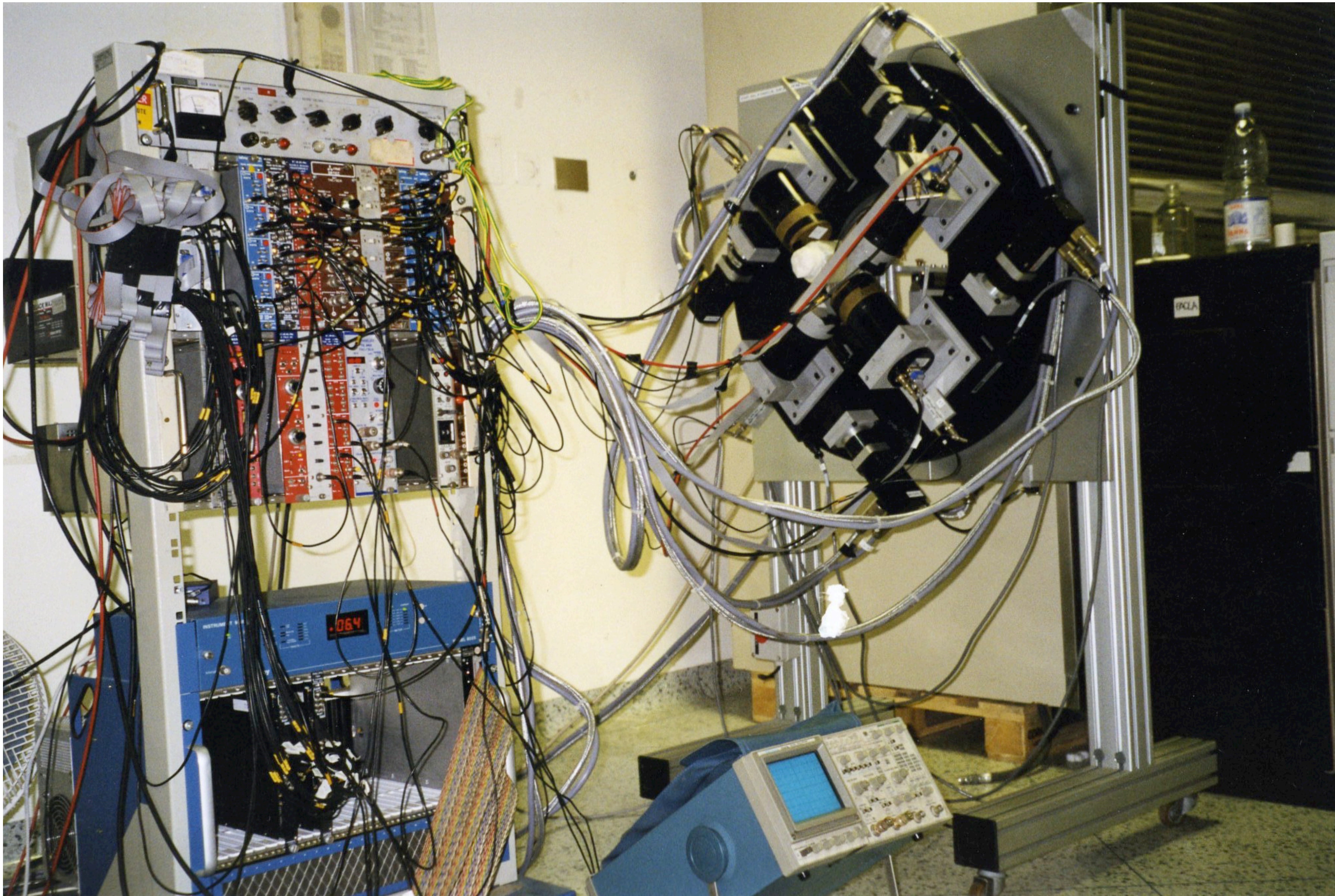


- **Quantum efficiency η ≈ 15%**
- **Anode: 16X + 16Y wires, pitch 3.75 mm**
- **4 output position signals**
- **1 last dynode timing signal**

Small animal PET initial design

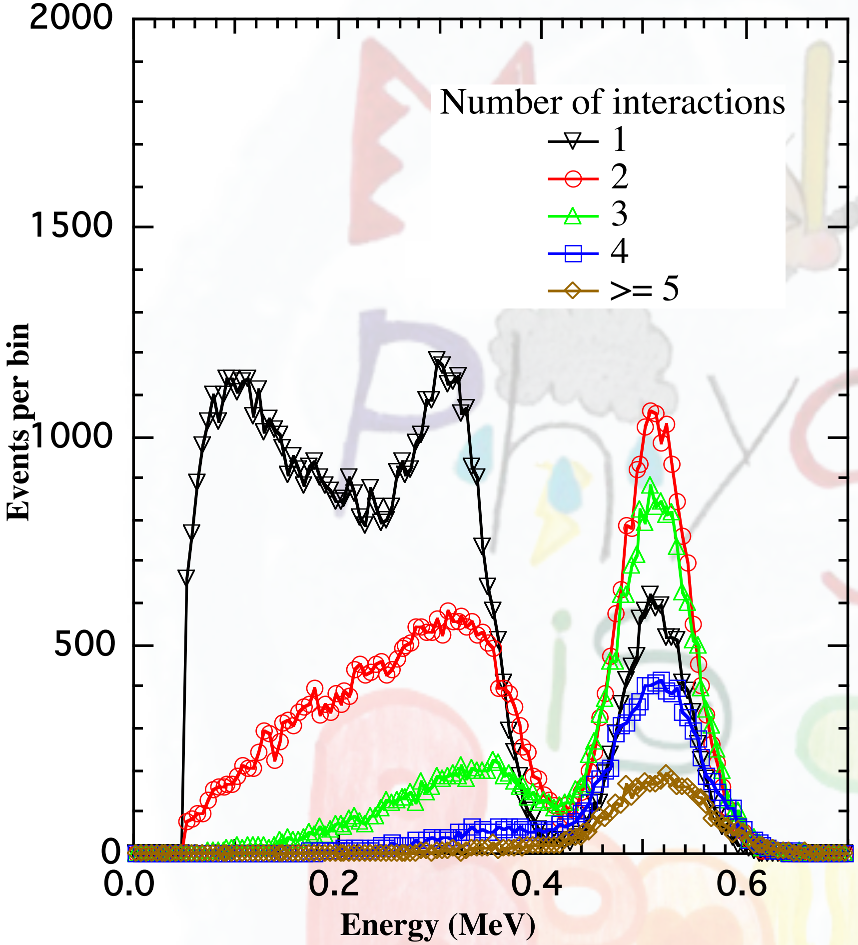
- ‘large’ planar detectors
- Rotating gantry
- Radial shift to increase sensitivity
- ... or tangential shift for oversampling and increased FOV
- Interesting choice for implemetation of planar collimators for SPECT and co-rotating CT

Small animal PET

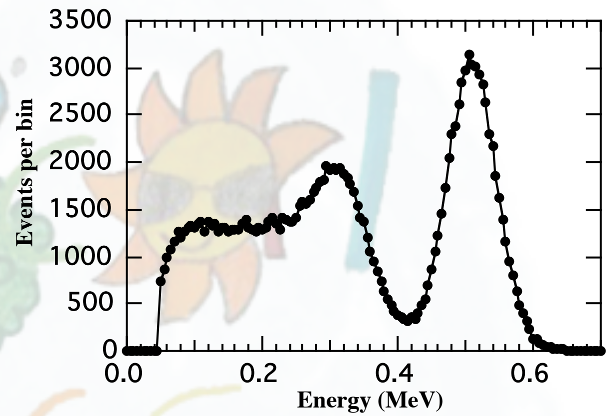


Why low Z scintillator

Energy deposit in YAP:Ce Vs number of interactions



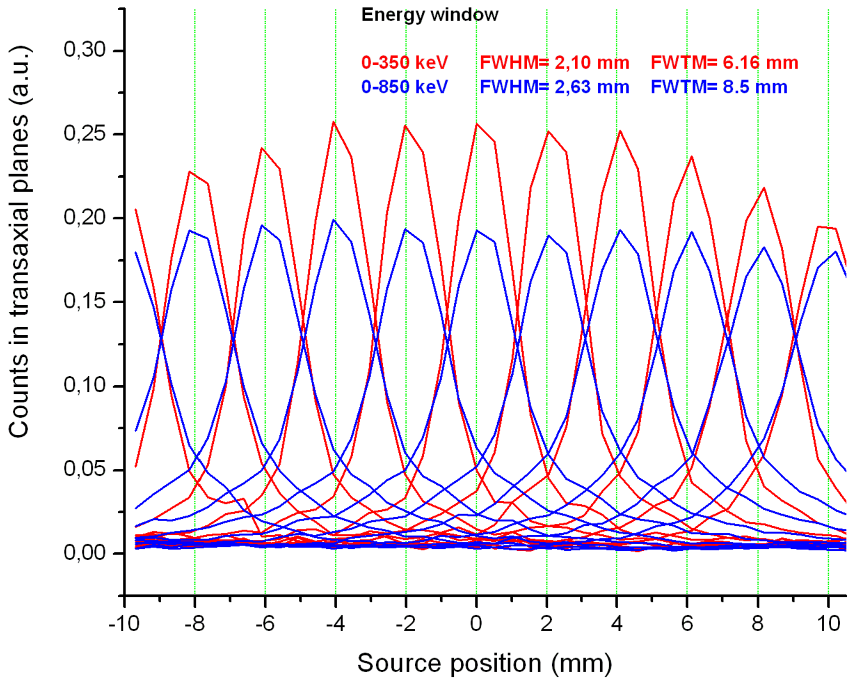
Deposited energy in function of the number of interactions



# interactions	% photons detected	fraction detected in 50-415 keV
1	46.05	0.86
2	28.74	0.58
3	15.46	0.29
4	6.79	0.14
≥ 5	2.96	0.08

By applying an upper energy threshold one eliminates many multiple interactions

YAP-(S)PET performance: Intrinsic resolution (PET)



By selecting the high resolution energy window (50–350 keV) the intrinsic resolution is improved with respect the high sensitivity mode (50–850 keV).

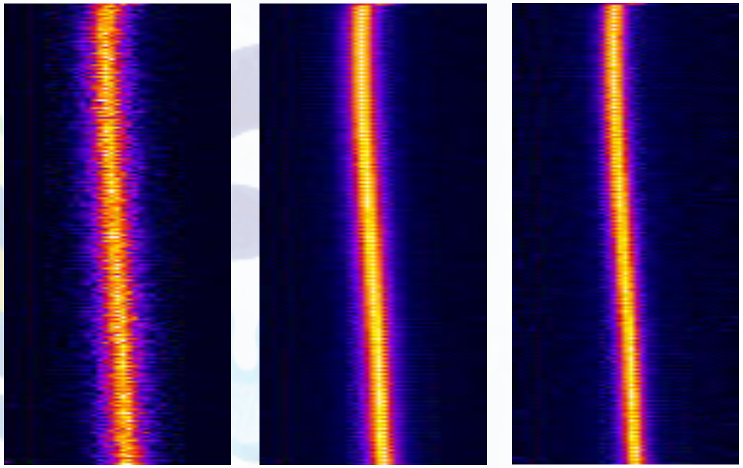
Measured intrinsic resolution

High resolution energy window:

2.10 mm FWHM (50-350 keV)
6.16 mm FWTM (")

High sensitivity energy window:

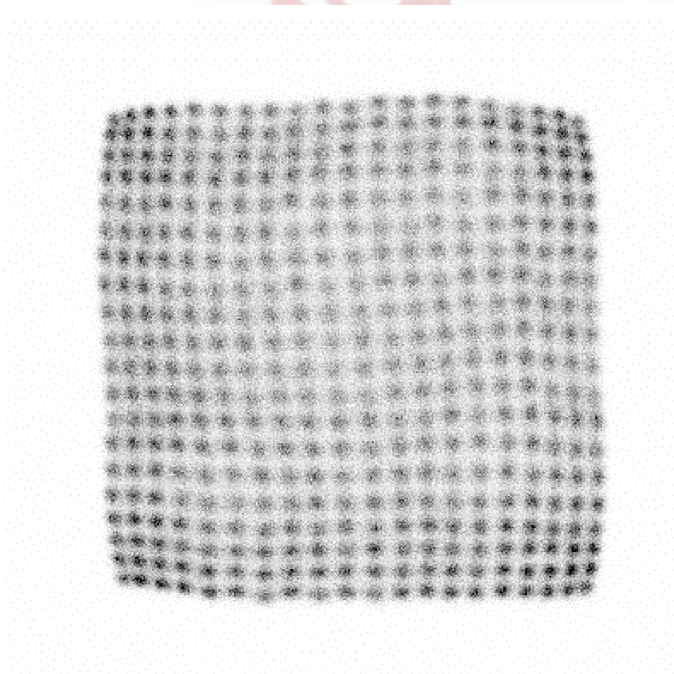
2.63 mm FWHM (50-850 keV)
8.50 mm FWTM (")

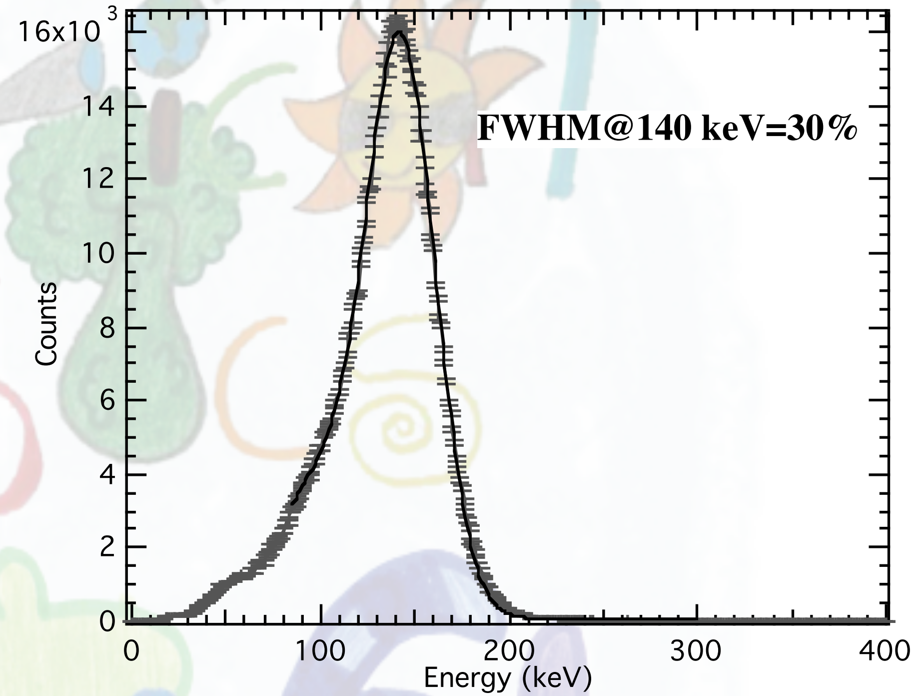


Photopeak all Compton

Small animal SPECT

Performances of detector to 140 keV





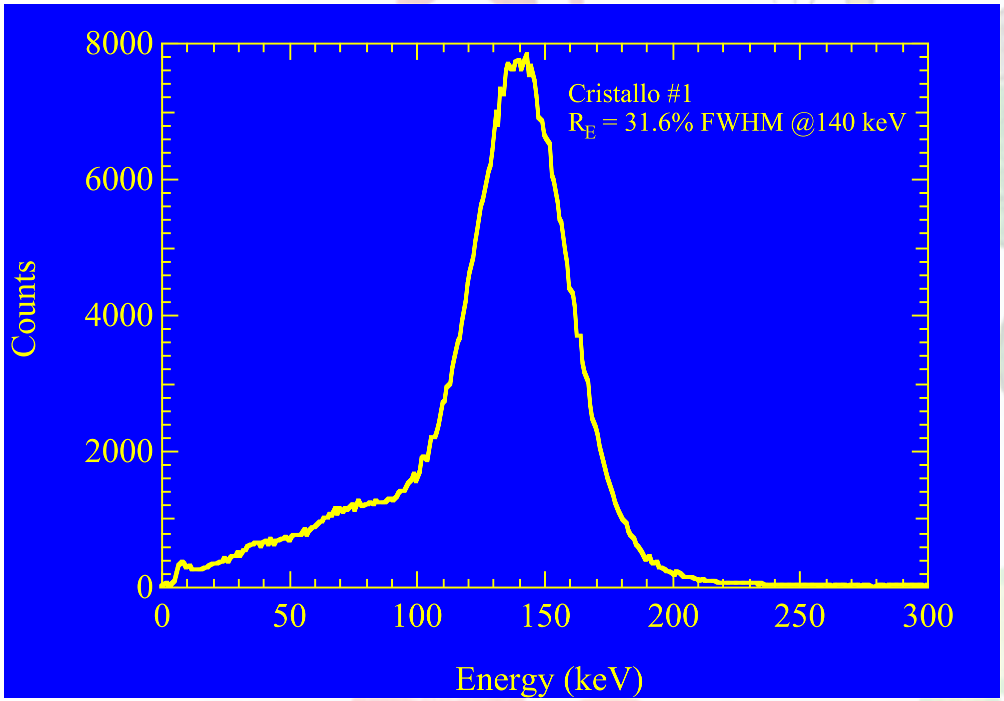
Flat field at 140 keV. YAP:Ce matrix as seen by the Hamamatsu PSPMT

Energy spectrum with 140 keV photons. FWHM@140 keV = 30%

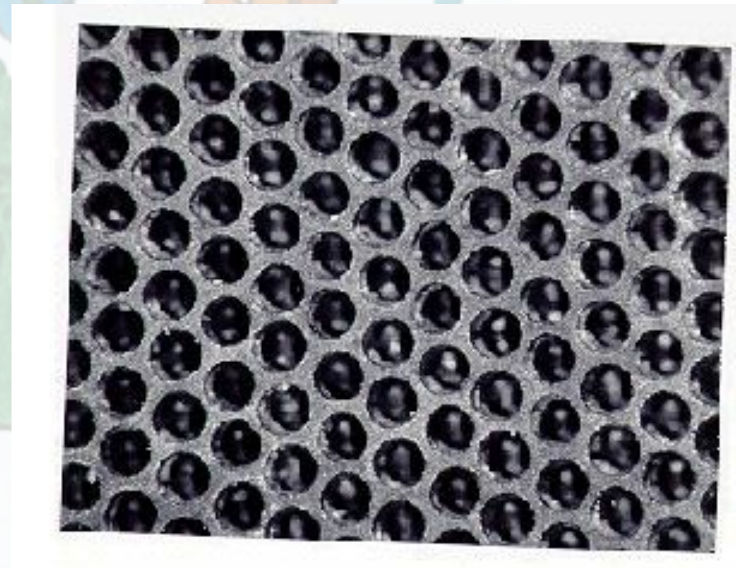
YAP:Ce is not radioactive

Small animal SPECT

Collimator



Energy spectra of one of the YAP:Ce matrices (<u>with collimator</u>) after having applied energy corrections to each single crystal pixel.

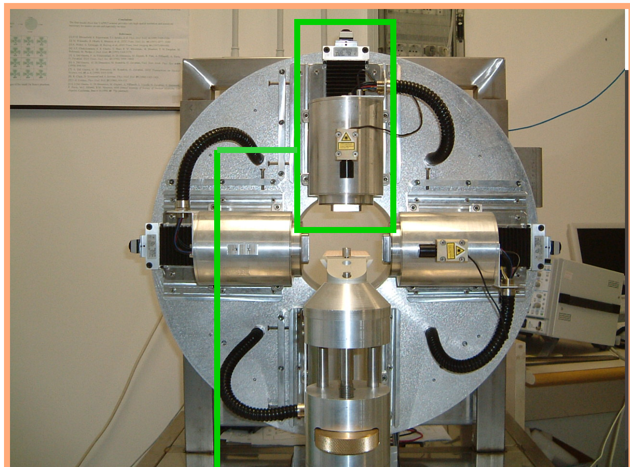


Lead collimator photo: hole diameter 0.6 mm, septa 0.15 mm, height 20 mm.

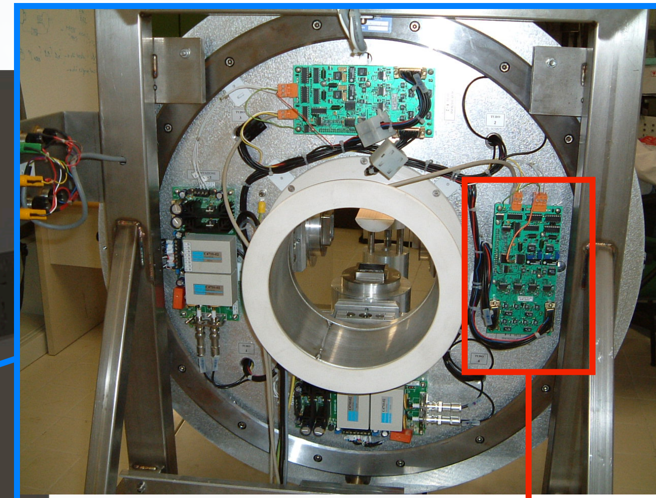
Geometric efficiency $5.0\ 10^{-5}$

Sensitivity of one detector head 2.1 cps/μCi

YAP-(S)PET design

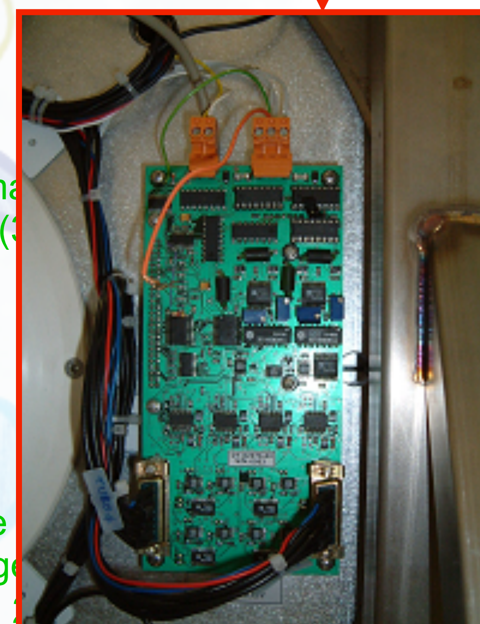


The four heads are mounted on a rotating gantry and the detector spacing can be varied in the 10 cm – 25 cm range (only in our unit).

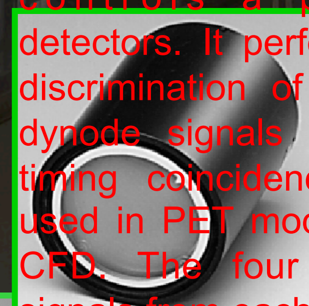


The acquisition boards and the four HV units are mounted on the back of the gantry

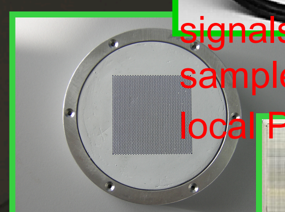
The detector head are equipped with the laser pointer.



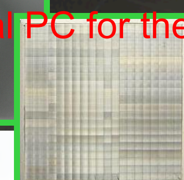
Each acquisition board controls a pair of detectors. It performs the discrimination of the last dynode signals (and the timing coincidence when used in PET mode) using CFD. The four position signals from each tube are sampled and sent to a local PC for the acquisition



Hamama
R2486 (



Parallel hole lead collimator 2 cm thick.
Holes: 600 mm ∅, 150 mm septa



YAP:Ce
400 finge
2 mm ×

YAP-(S)PET small animal scanner

Scanner configuration

Configuration: Four rotating heads

Scintillator: $YAlO_3$:Ce (YAP:Ce)

Crystal size: 20 x 20 (2.0 x 2.0 x 25 mm^3 each)

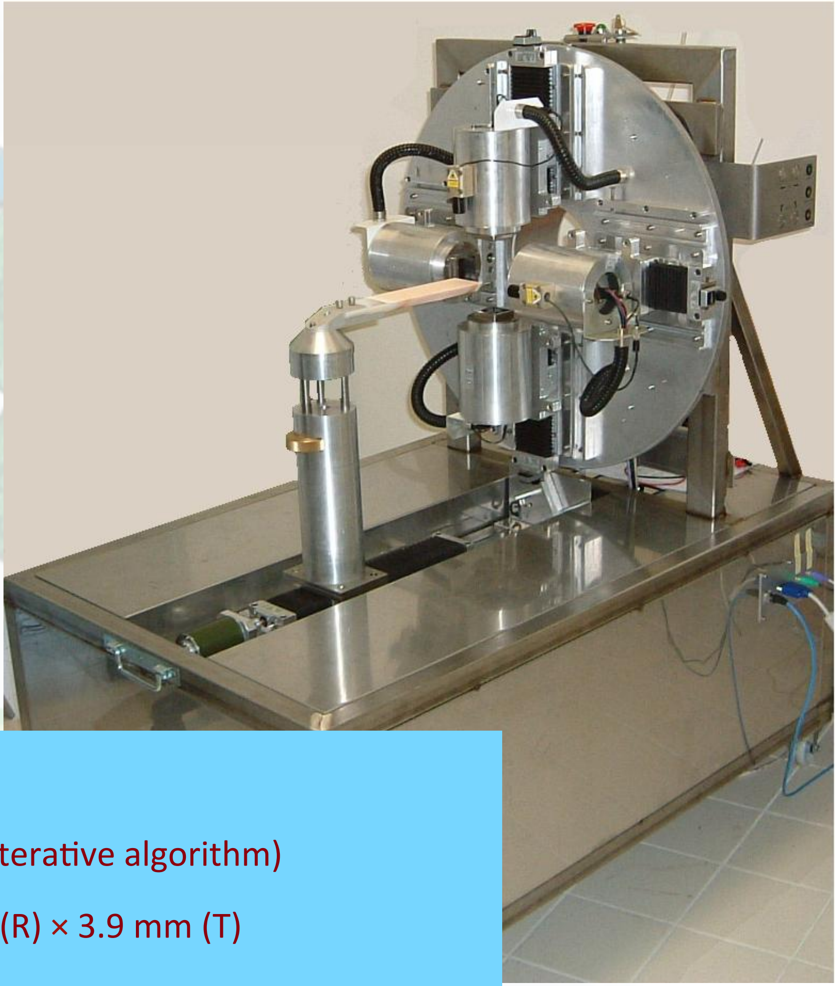
Photodetector: Position Sensitive PMT

Readout method: Resistive chain (4 channels)

FoV size: 4 cm axial × 4 cm Ø

Collimators: (SPECT) Lead (parallel holes)

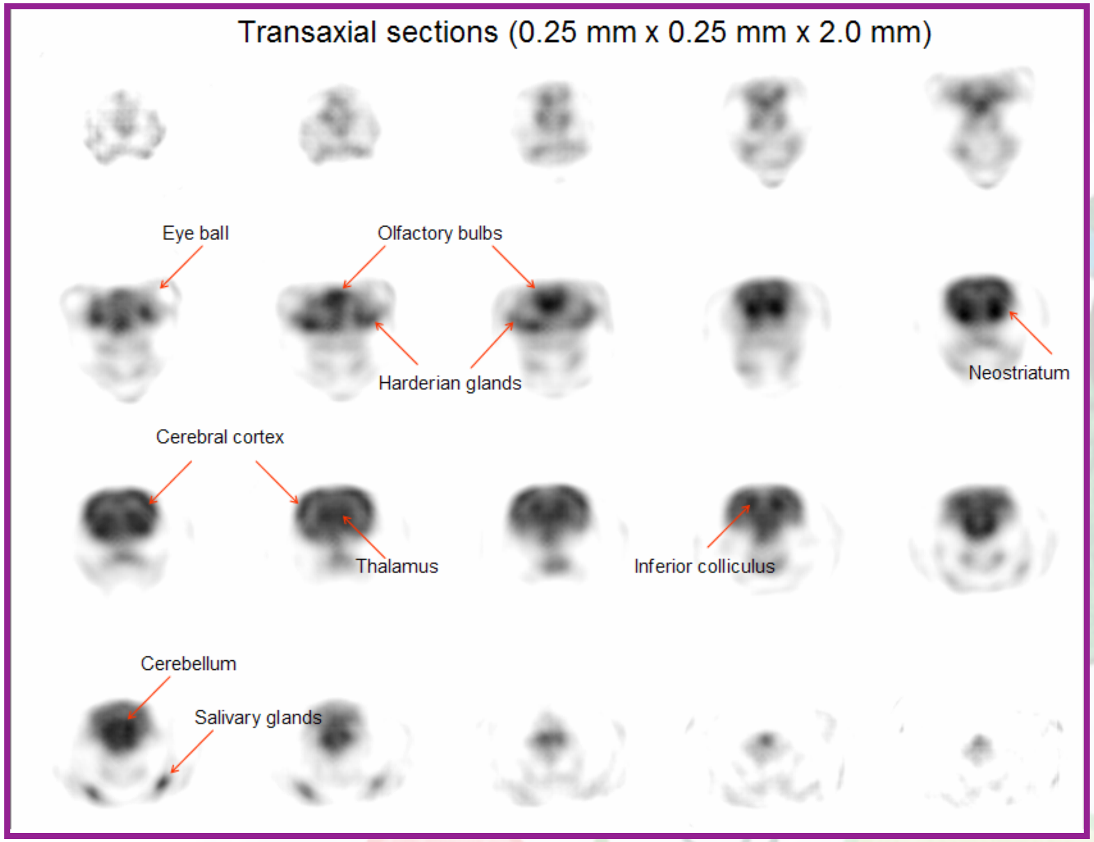
Head-to-head distance: 15 cm



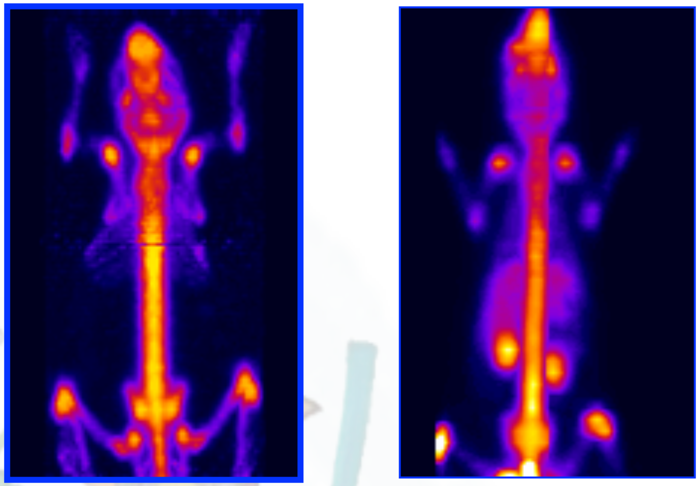
Present performance

PET mode:	**SPECT mode:**
Spatial resolution (iterative algorithm)	Spatial resolution (iterative algorithm)
Volume: 5.2 mm^3 (4.4 mm^3) @ CFOV	Transaxial: 3.1 mm (R) × 3.9 mm (T)
Sensitivity: 19 cps/kBq @ CFOV (50-850 keV)	Sensitivity: 30 cps/MBq (140-250 keV)

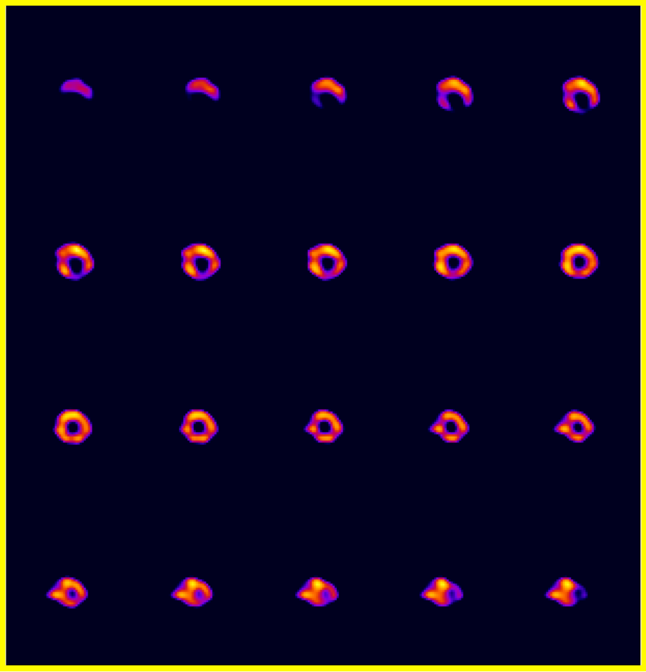
Animal imaging



Coronal section of a rat brain (0.5 x 0.5 x 0.2 mm)
Wistar male rat (250 g) injected with 37 MBq of ^{18} F-FDG.
Uptake time: 45 min., acqusition time: 60 min.

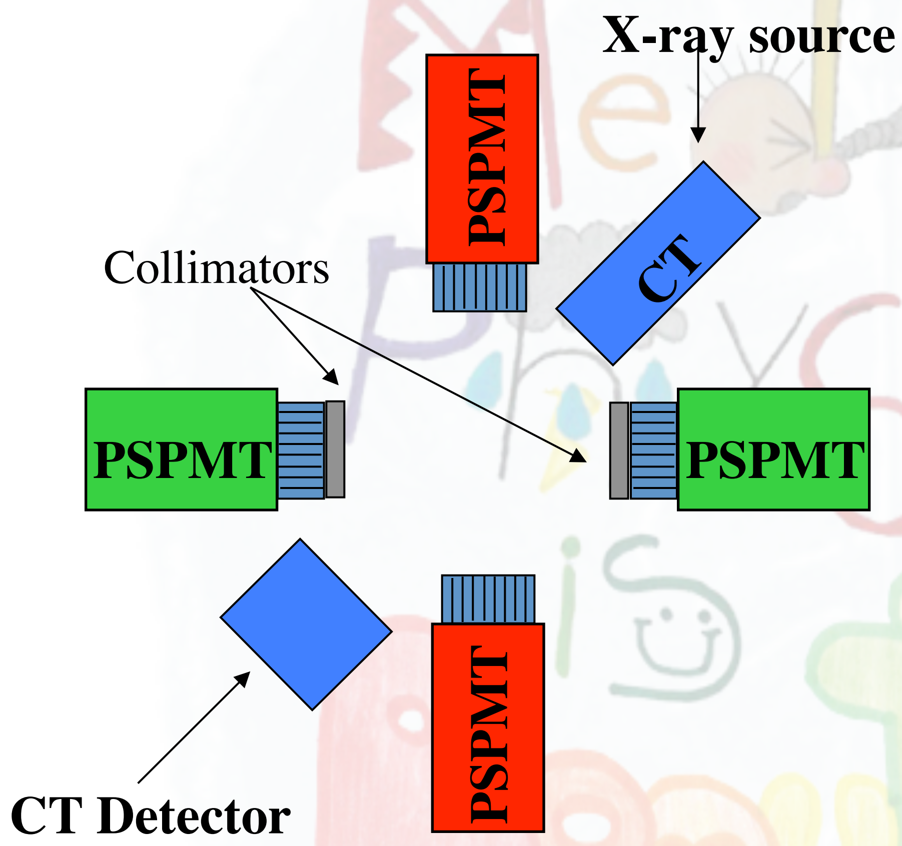


Skeleton of a mouse visualized in PET ($^{18}F^-$, left) and SPECT (^{99m}Tc-MDP, right)



Perfusion of the myocardium of a rat visualized in SPECT mode with ^{99m}Tc-Myoview (8 mCi)
Uptake time: 80 min., acquisition time:180 min.

Combined PET/SPECT/CT

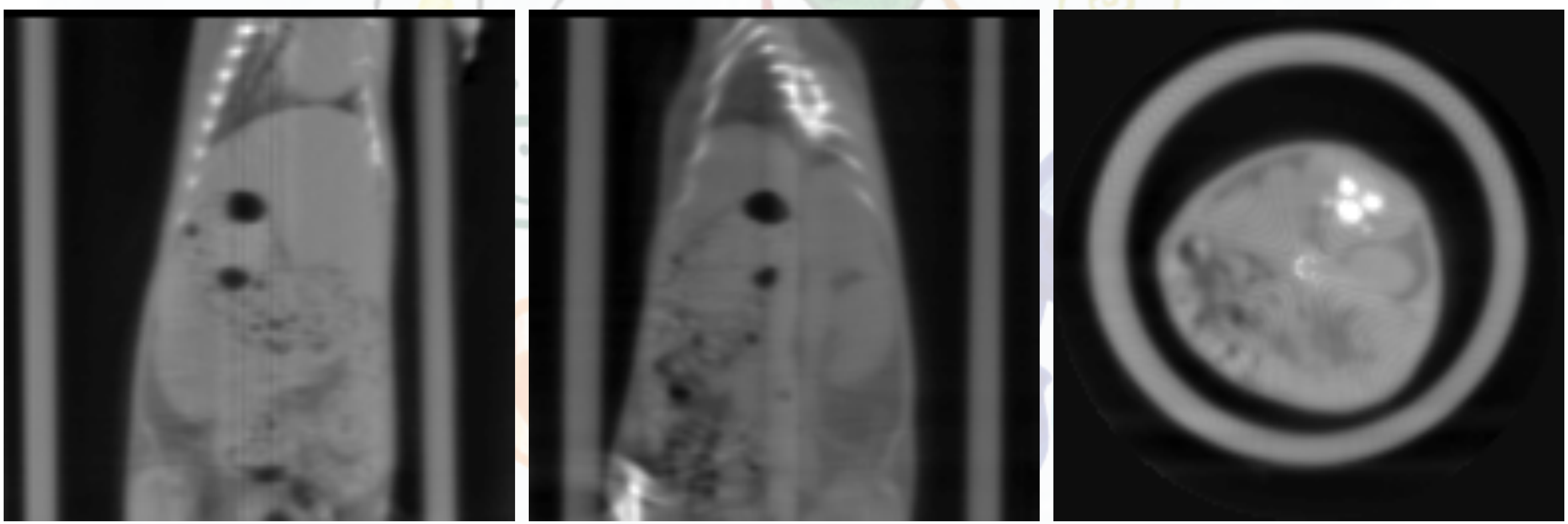


1. SPECT/CT
2. PET/CT
3. Simultaneous
   PET(2 head in coinc.) &
   SPECT (2 head in anticoinc.)

Ferrara YAP(S)PET scanner with CT

- Distance form x-ray source to rotation axis 40 cm
- Distance from rotation axis to detector 4 cm
- Tube H.V. 40 kVp, I=1.8 mA, Al filtration 1mm
- Acquisition time ≈ 15 min.

Total Dose delivered
~ 5 mGy KERMA in air



CT-SPECT

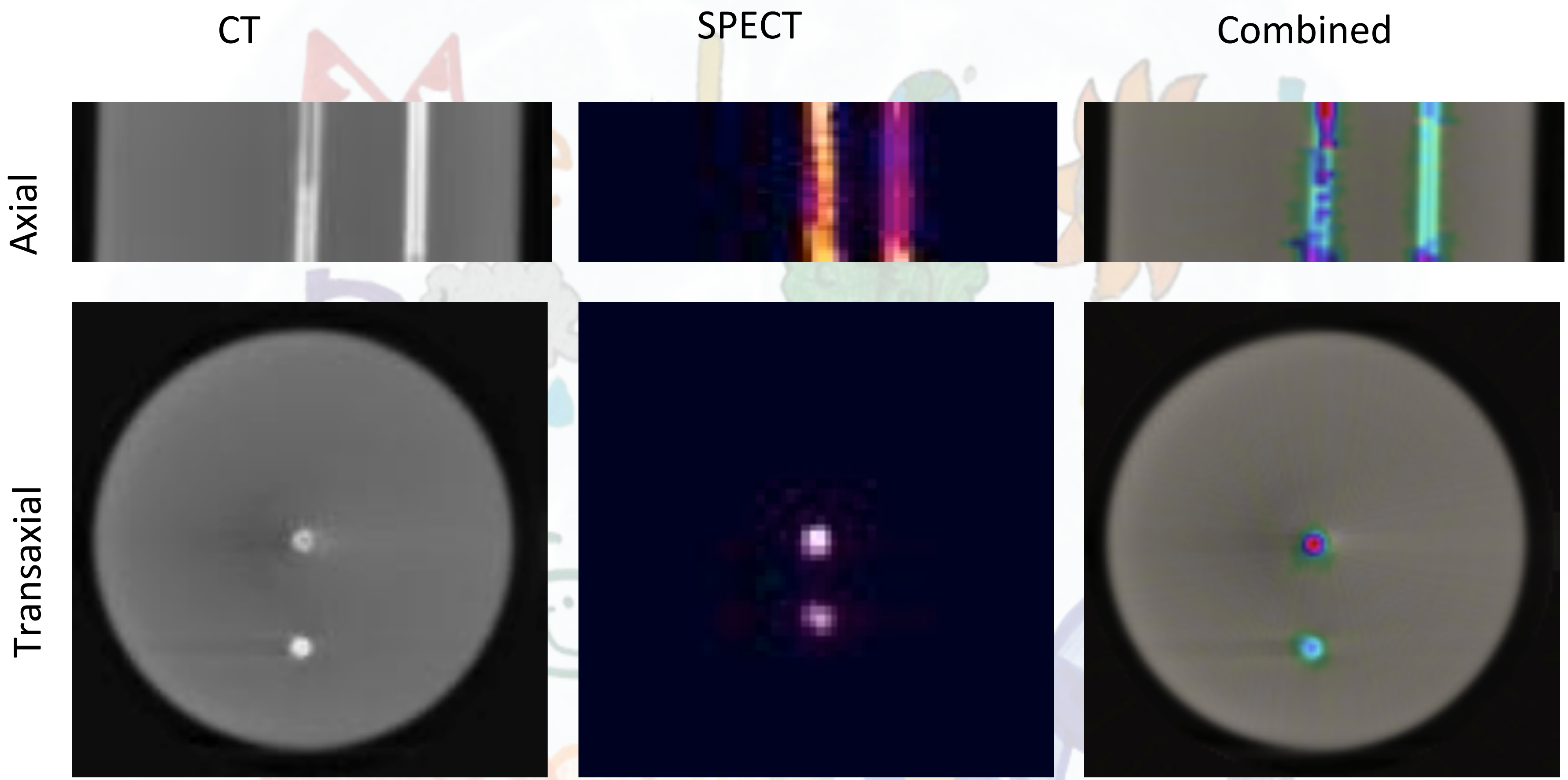
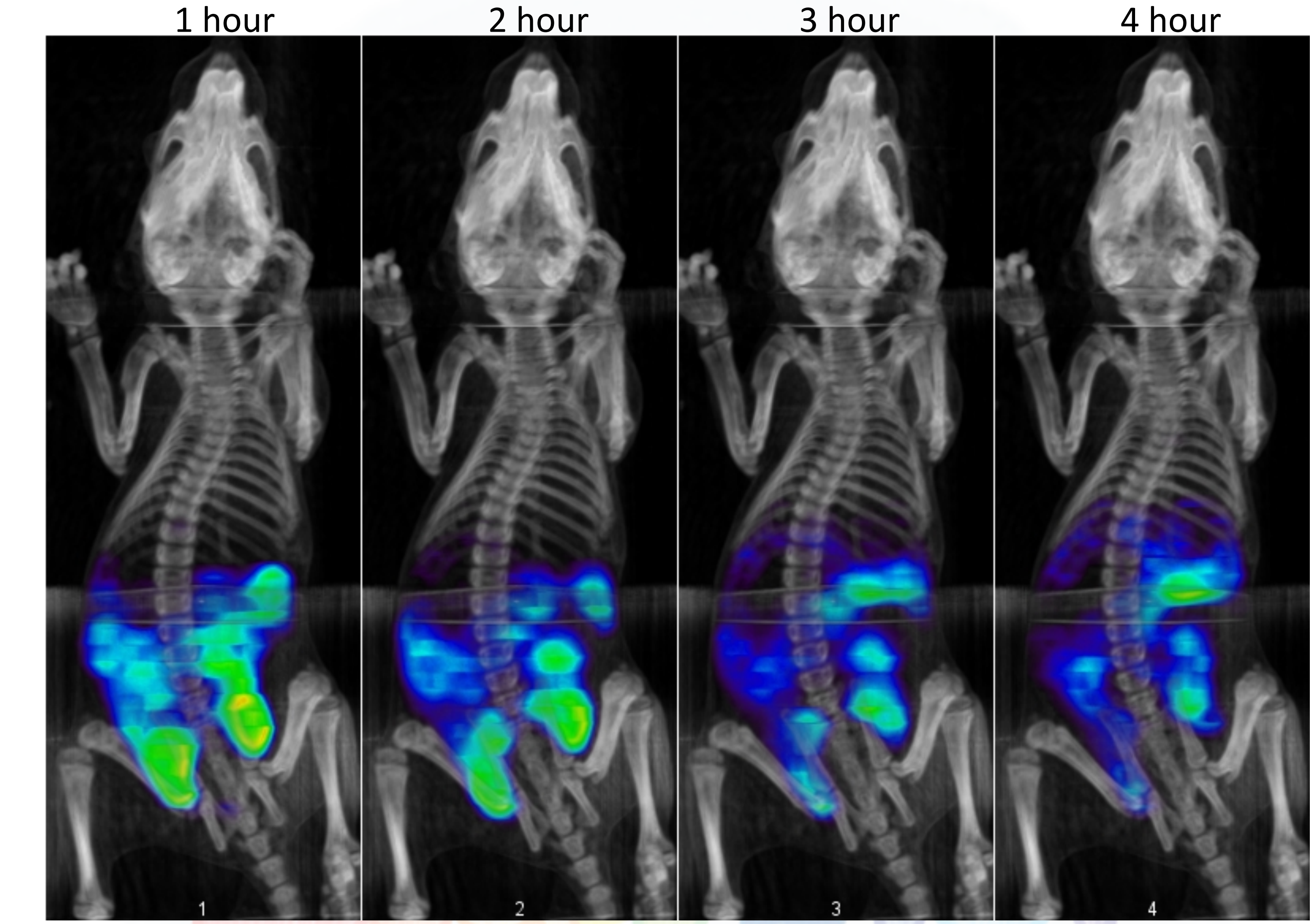
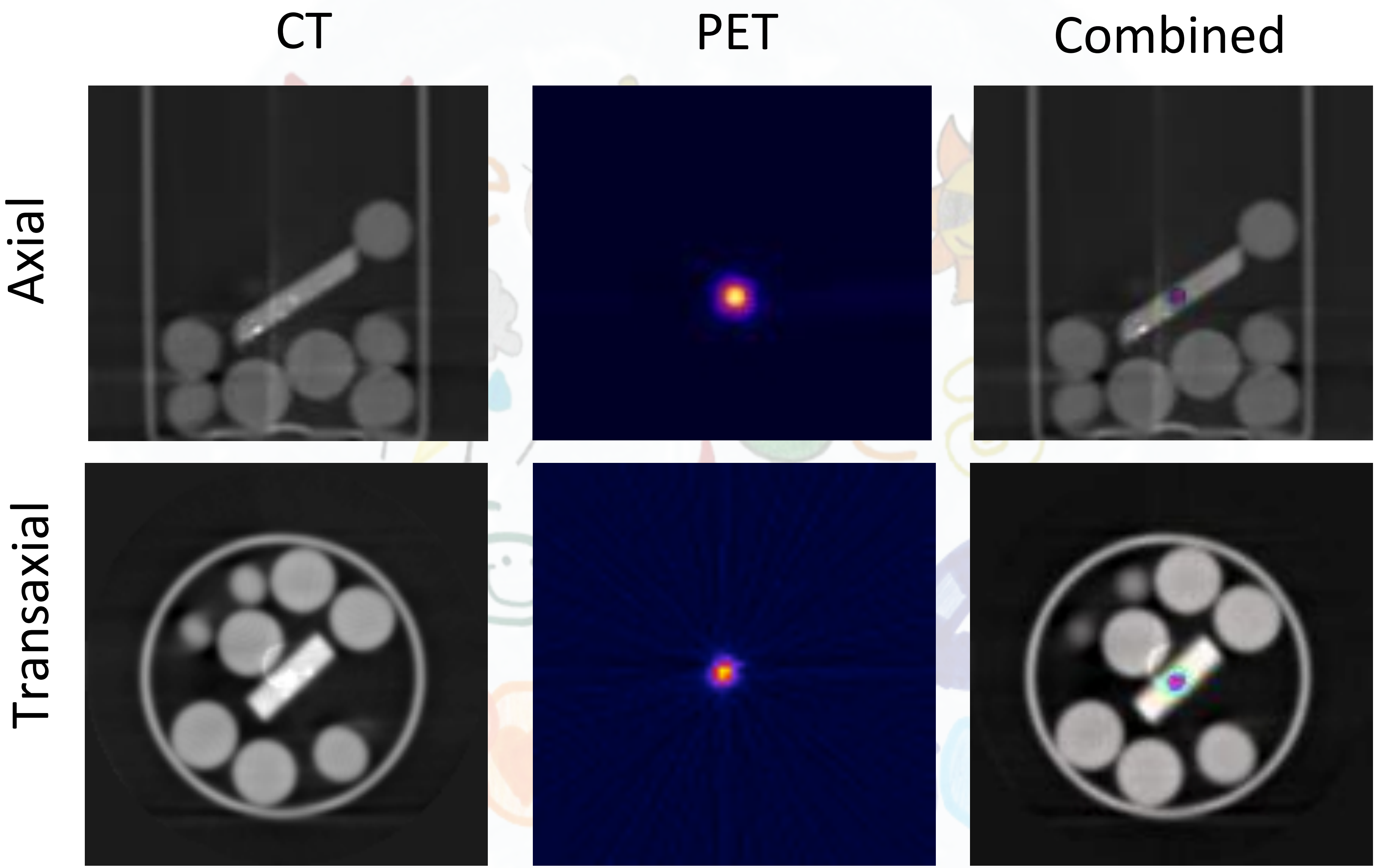


Image Fusion → ***ImageJ Plugins:*** TurboReg + HSB merge


1 hour
2 hour
3 hour
4 hour
1
2
3
4

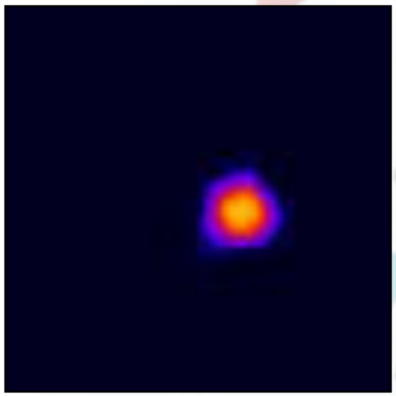
CT-PET



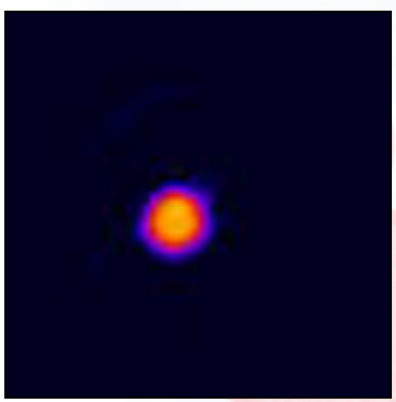
Simultaneous tomography

Two small ≈ 0.5cm diameter cylindrical bottles filled with ^{99m}Tc solution and FDG placed adjacently under the scanner.

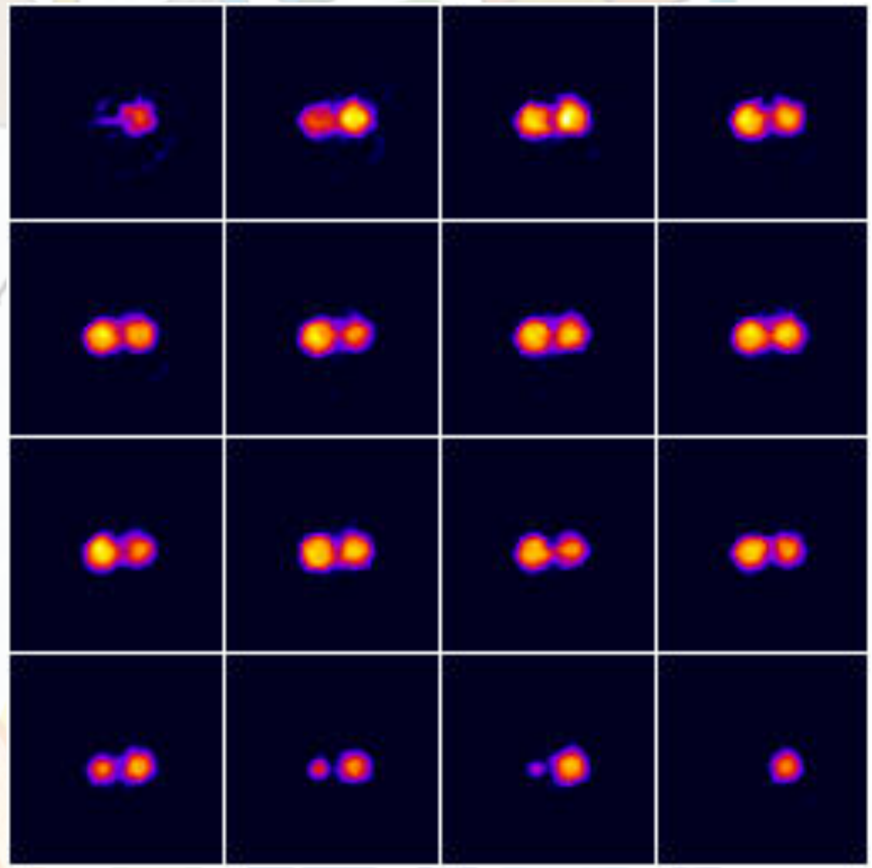
- 2 mm lead shields PET detectors from 140keV gamma
- SPECT detectors are in XOR
- Energy selection window for SPECT events



SPECT: 840μCi

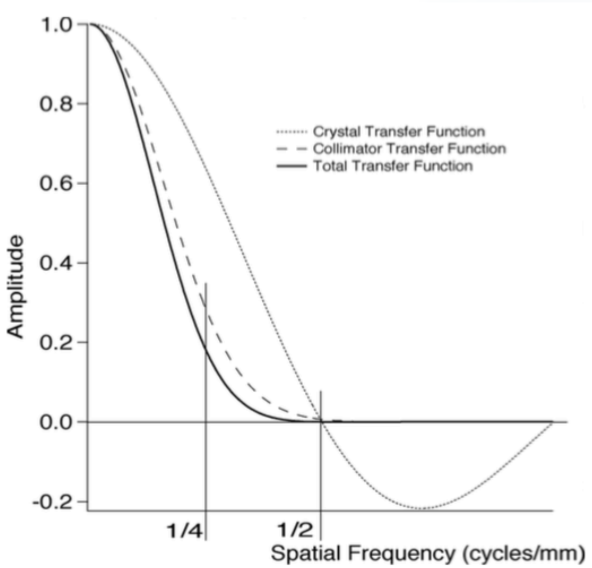


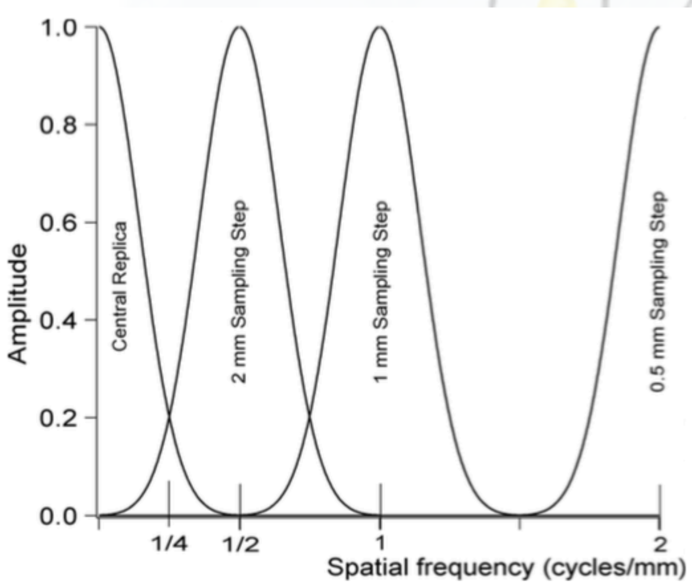
PET: 18μCi



PET and SPECT together

SPECT Oversampling - eliminate aliasing

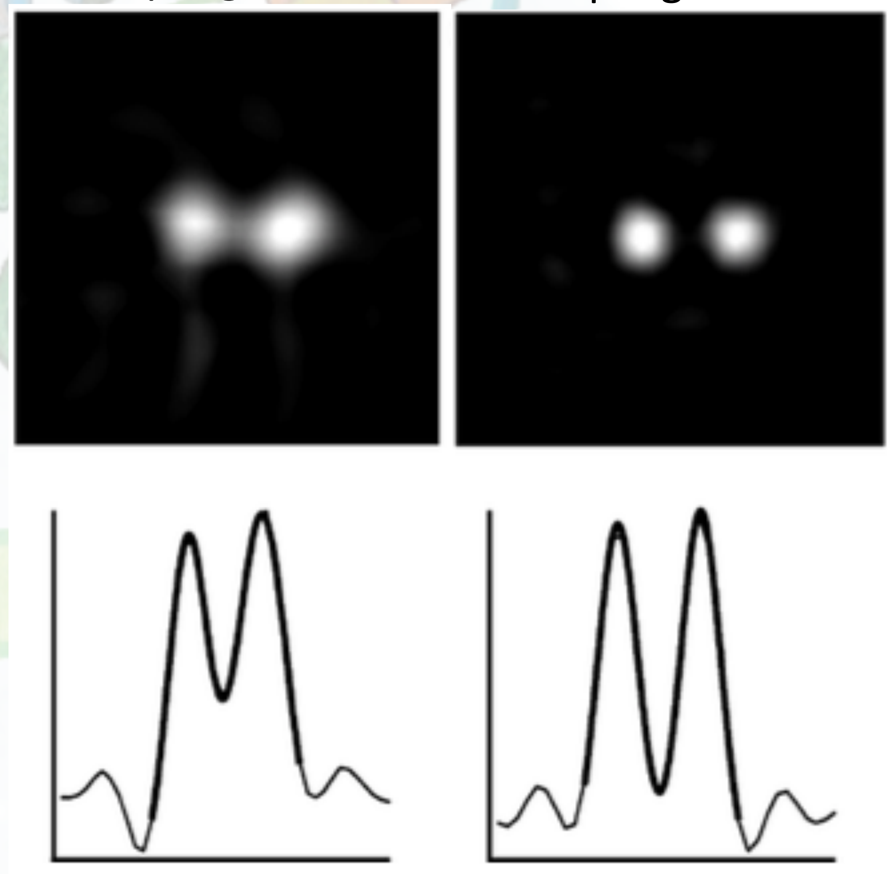




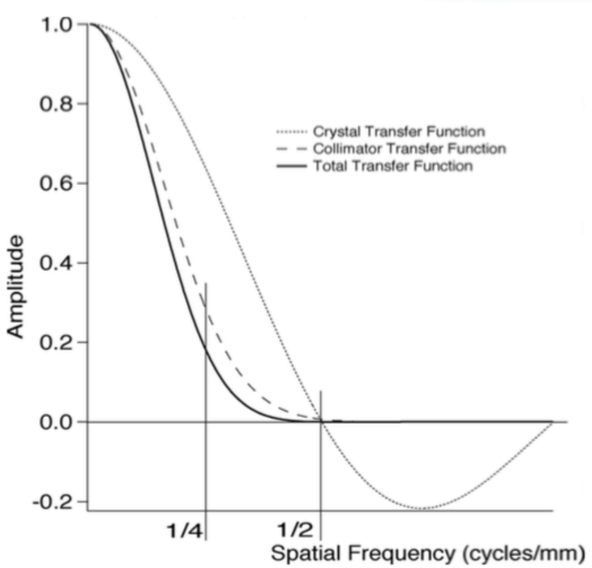
Two capillaries 4 mm apart (center to center)

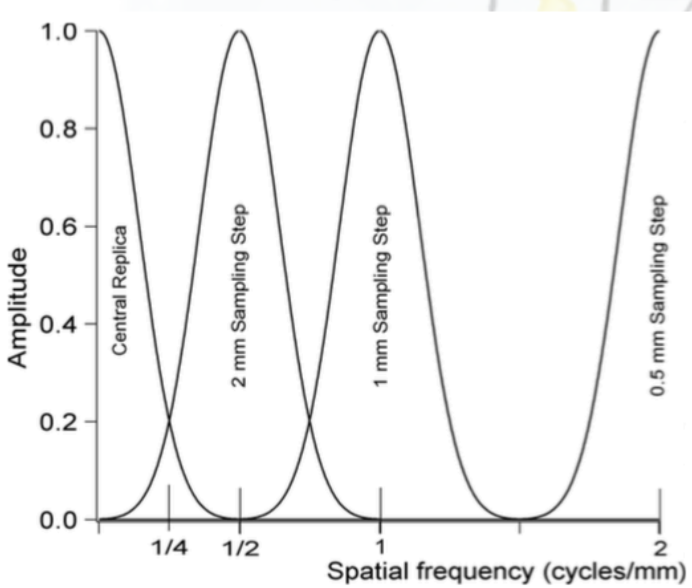
Sampling 2 mm

Sampling 1 mm

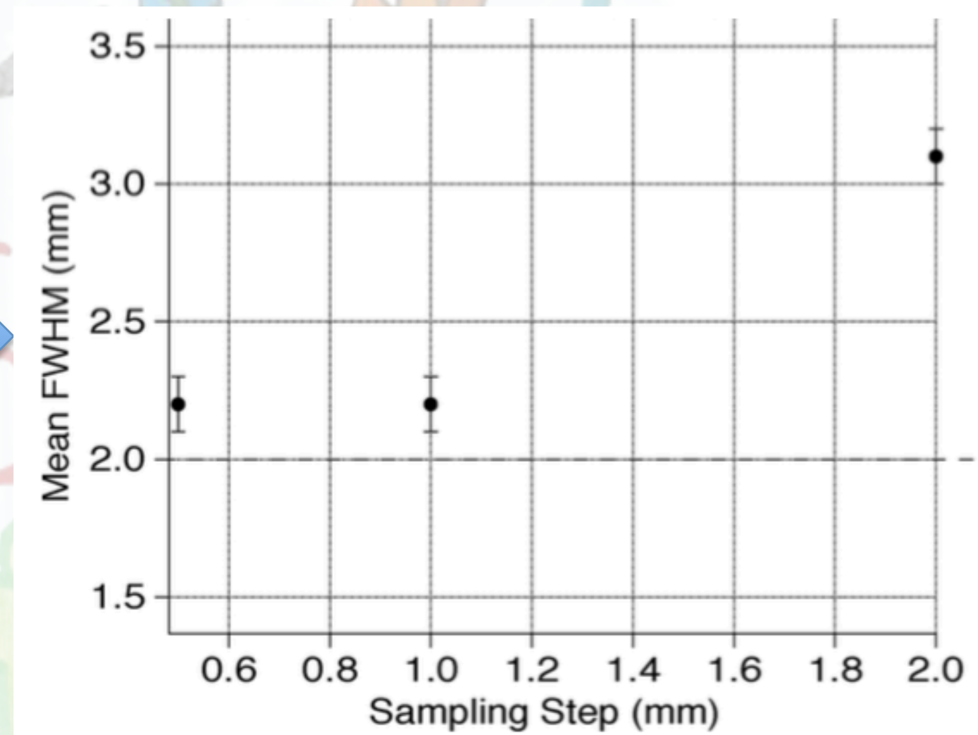


SPECT Oversampling - eliminate aliasing





SPECT resolution as a function of sampling step

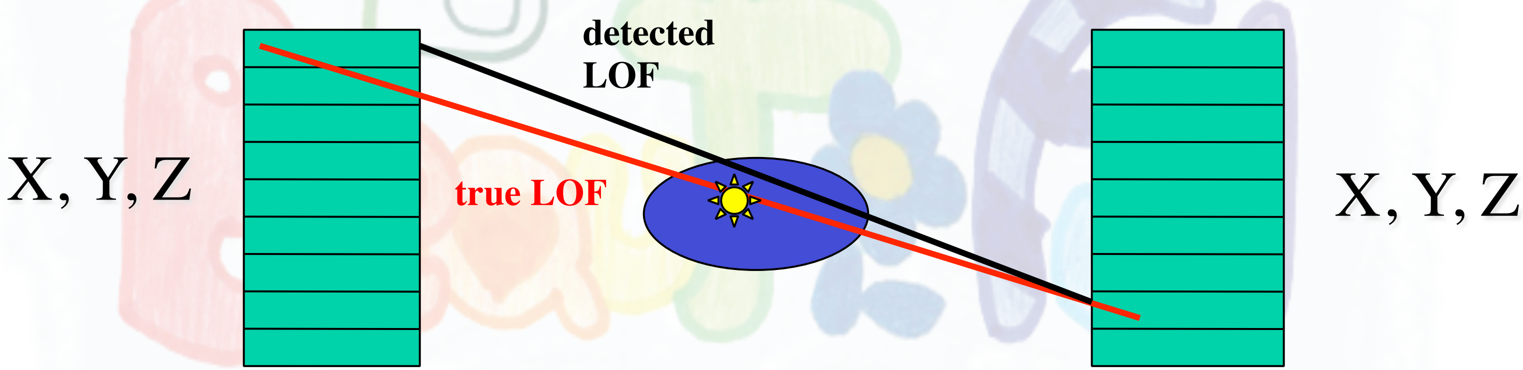


Going further - SiliPET

PROBLEMS

Thickness + Lack of Depth of Interaction measure
PARALLAX ERROR

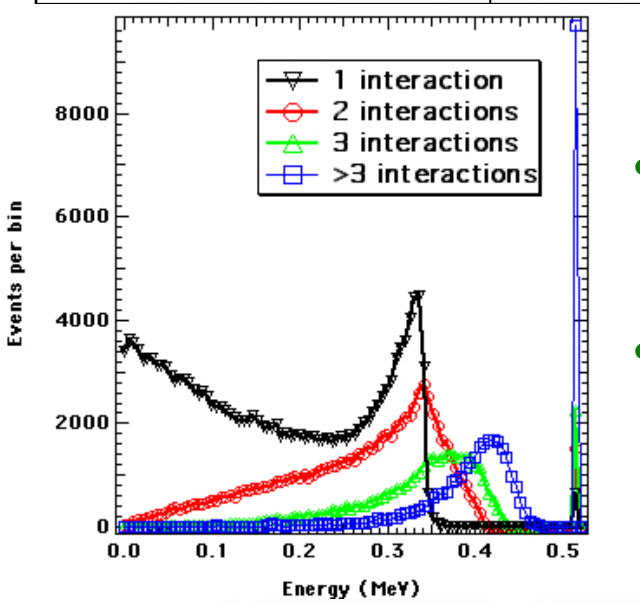
High Z materials
HIGH PHOTOFRACTION,
BUT ≈ 1/2 full energy events are multiple scattered events (1 GMFP)
Ideally single interactions are desired



Going further - SiliPET

In small animal imaging energy information is superfluous

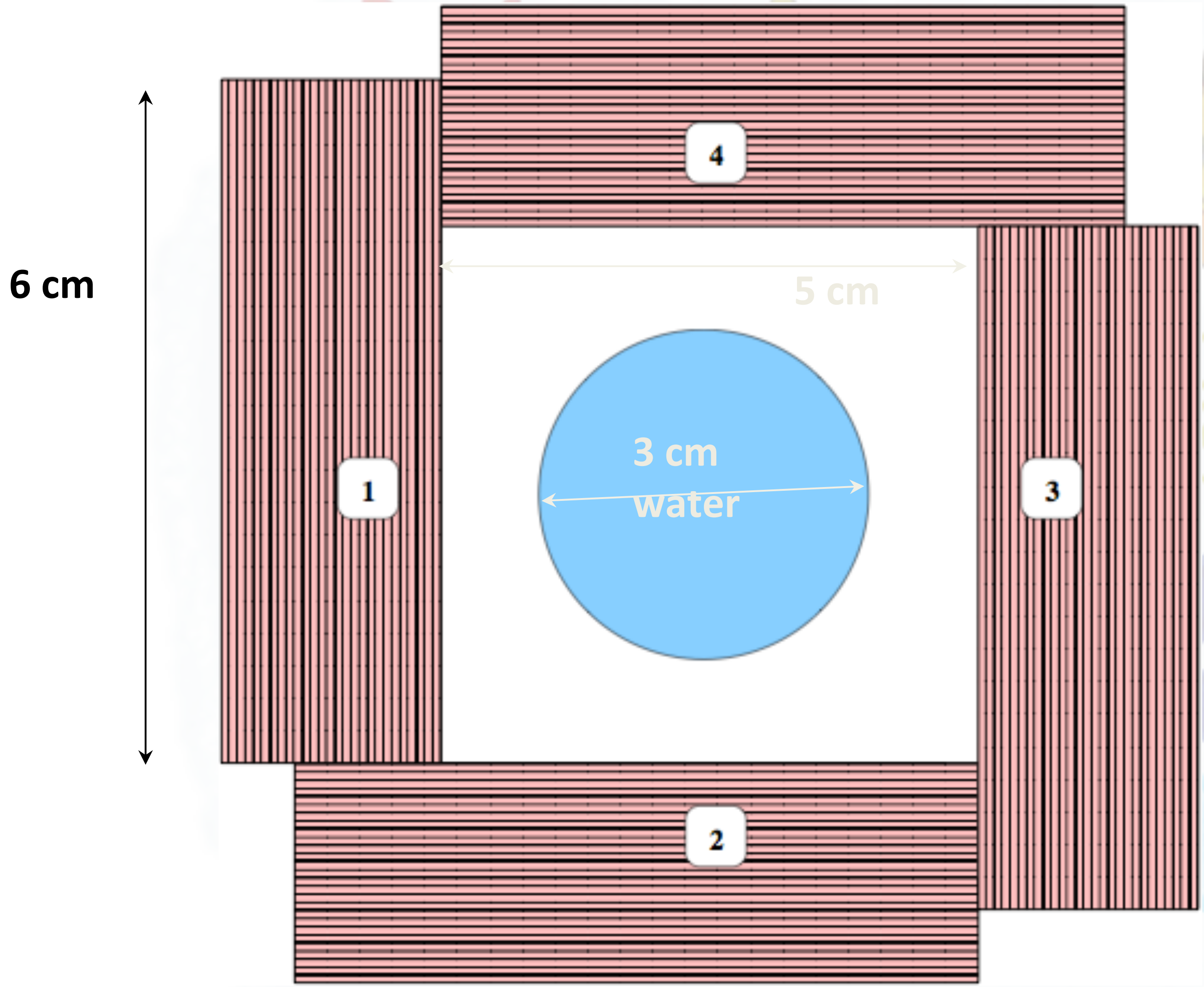
	% photons detected		
# interactions	***Si, 4cm thick***	***BGO, 1cm E>350keV***	***BGO, 1cm All***
1	51.8	50.3	56.3
2	24.9	35.1	31.4
3	11.7	11.6	9.8
>3	11.6	3.0	2.5



- High fraction of events are single Compton interactions
- Multiple interactions can be eliminated with multilayer detector

SIMULATED GEOMETRY

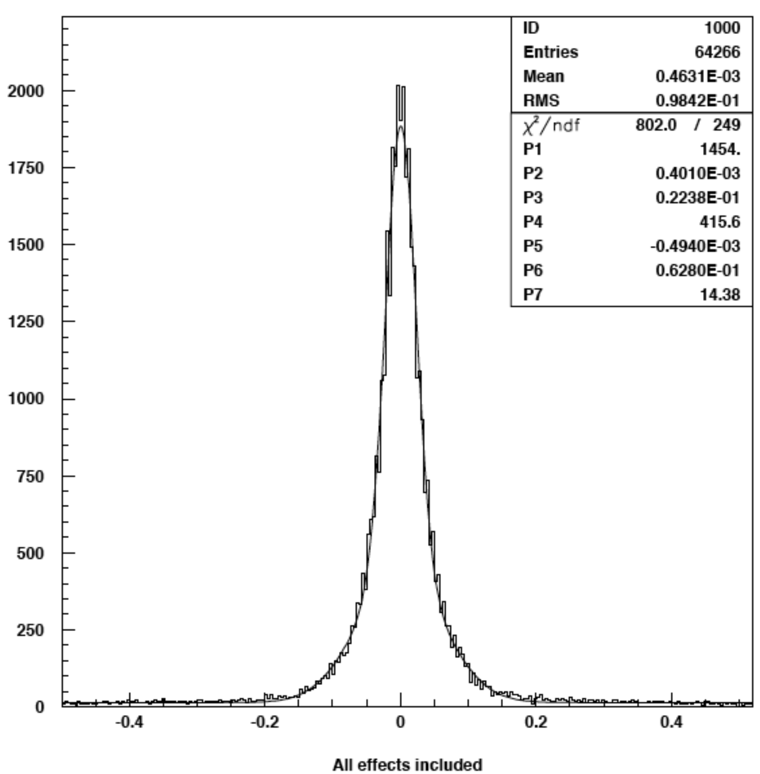
40 planes of 1 mm thick double sided silicon detectors.
Surface 6 x 6 cm^2. 128 channels per coordinate (470 μm pitch)



- Emitted positrons with ^{18}F spectrum.
- Included non collinearity of gamma rays.
- Each detector subdivided in cells
- Electron transport included

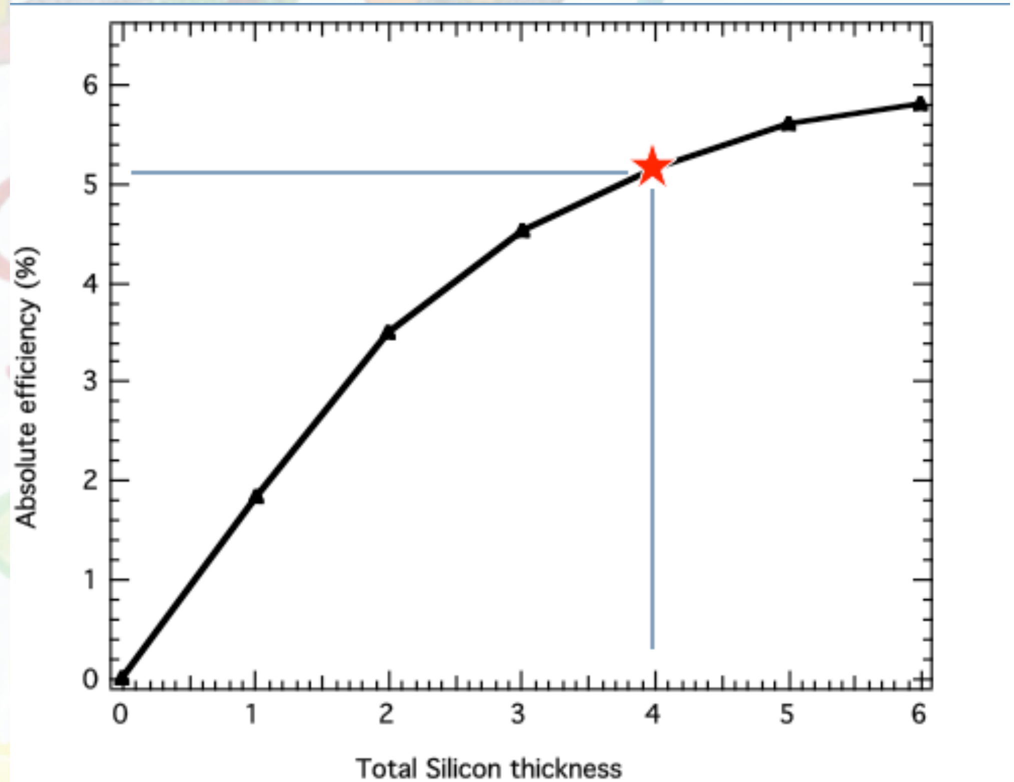
Simulated performances

Spatial resolution



Including positron range, FWHM = 0.52 mm

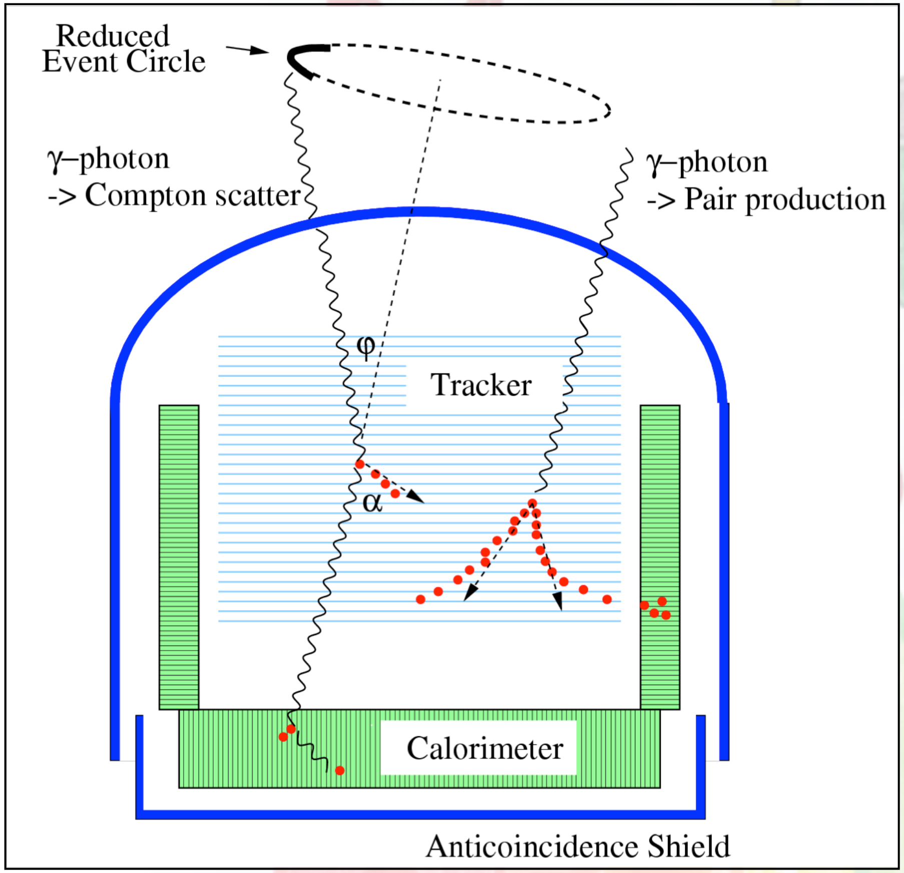
Absolute efficiency



Single interactions with 50 keV threshold

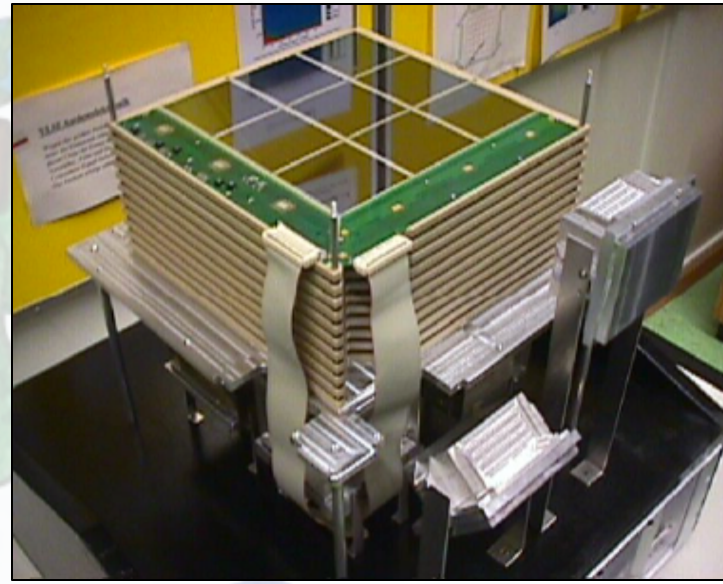
Proof of principle: MEGA prototype

Medium Energy Gamma-ray Astronomy (MEGA)



Energy range 0.4 – 50 MeV

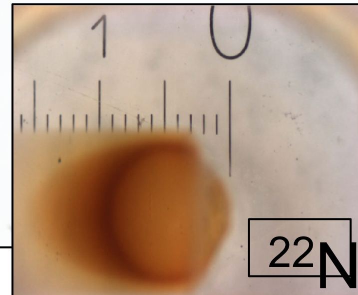
MEGA prototype

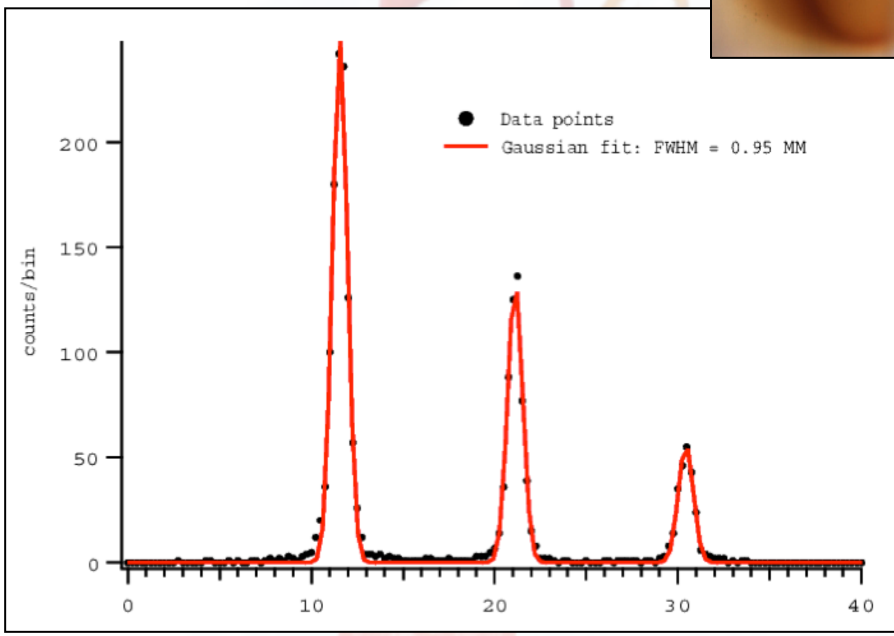


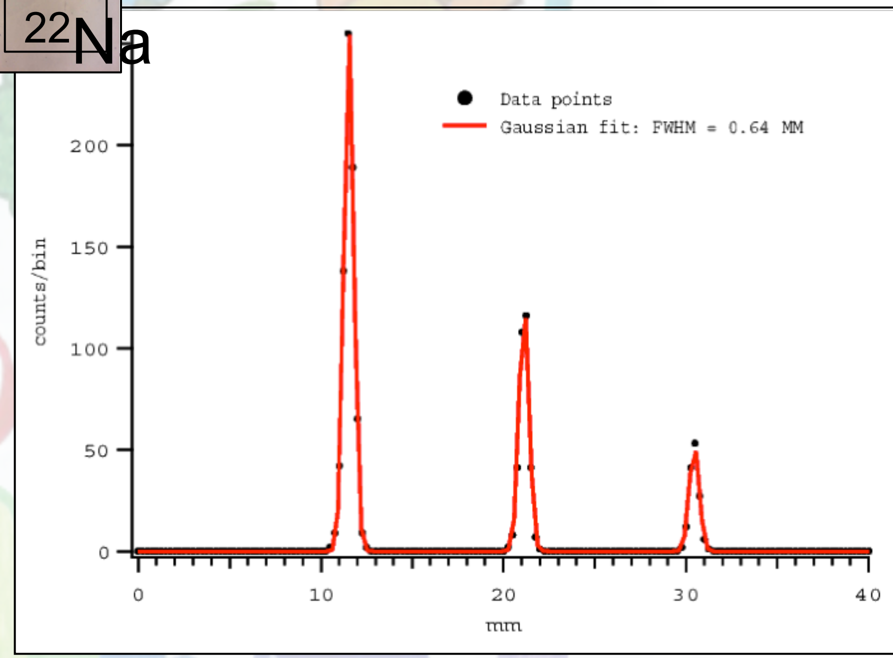
11 planes x 9 detectors, 6x6 cm^2
128x128 strip, 470 μm pitch
thickness 500 μm

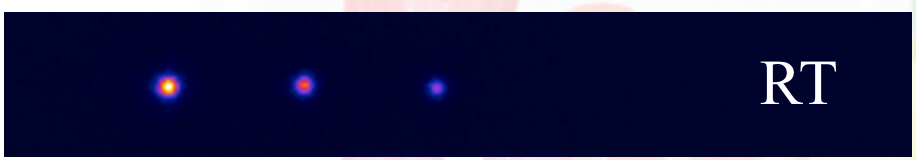
temporal resolution 1μs

Results – 0.63 mm ^{22}Na source









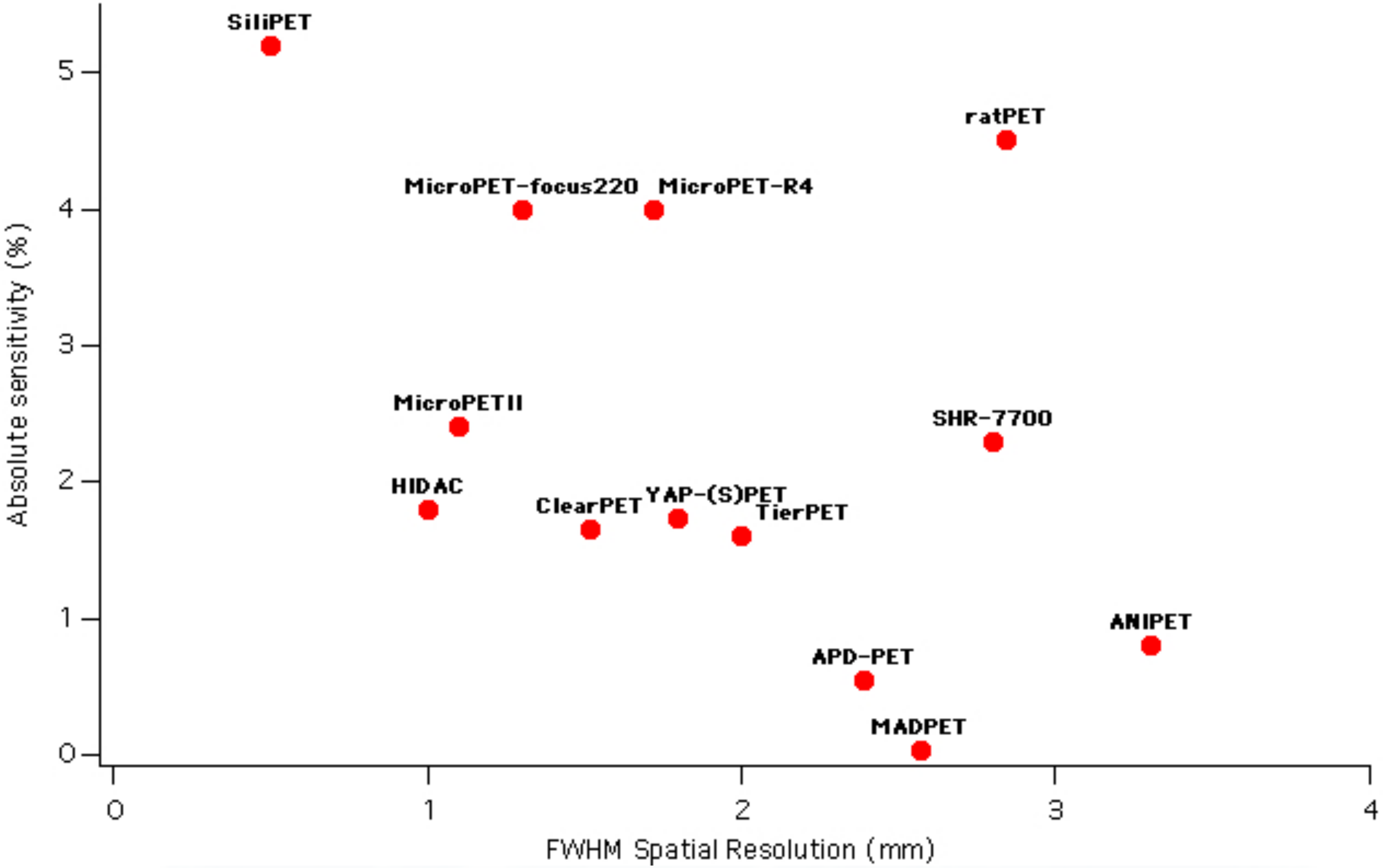
250x250 mm

250x250 mm

0.95 mm FWHM

0.64 mm FWHM

Small animal PET comparison



Medical Physics is Beautiful, Pisa, 31 October 2014