

Medical Imaging Applications and Demonstrators: Challenges in PET Imaging

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PET fundamentals

System design

Imaging artifacts

Image reconstruction

Demonstrators



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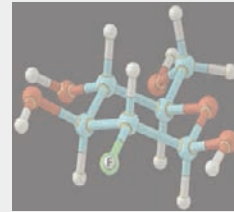
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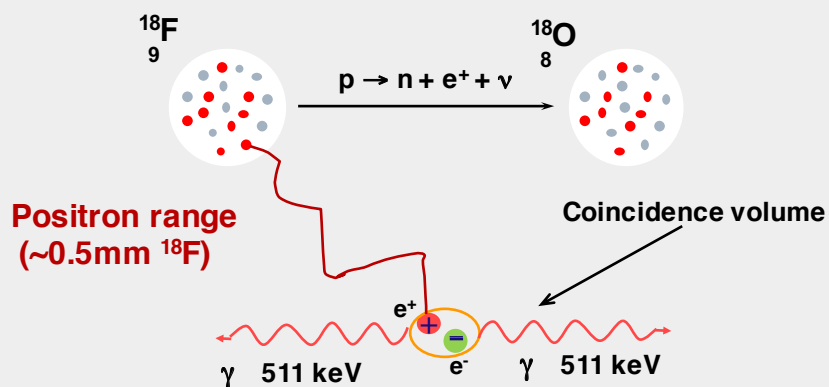
Image reconstruction

Demonstrators



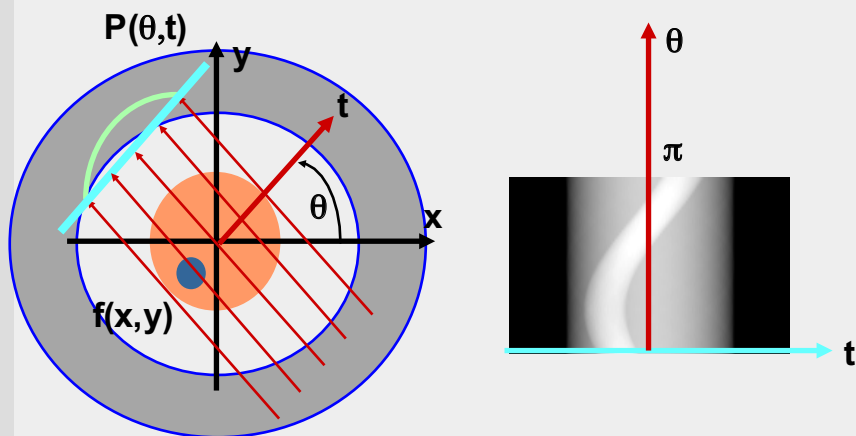
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β^+ decay



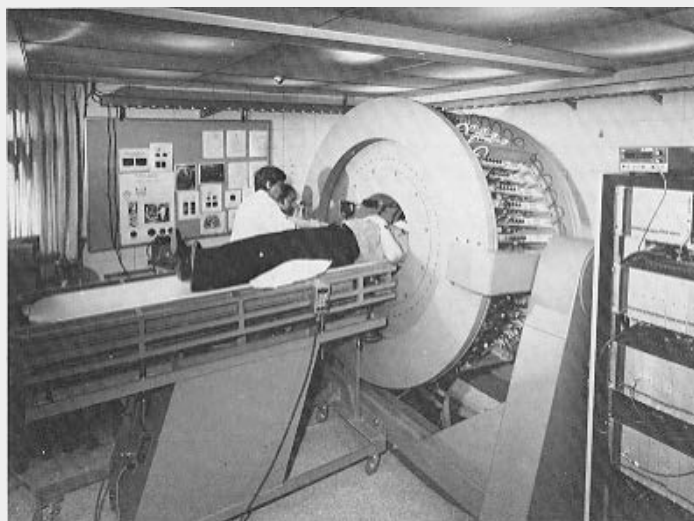
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Projections and sinogram



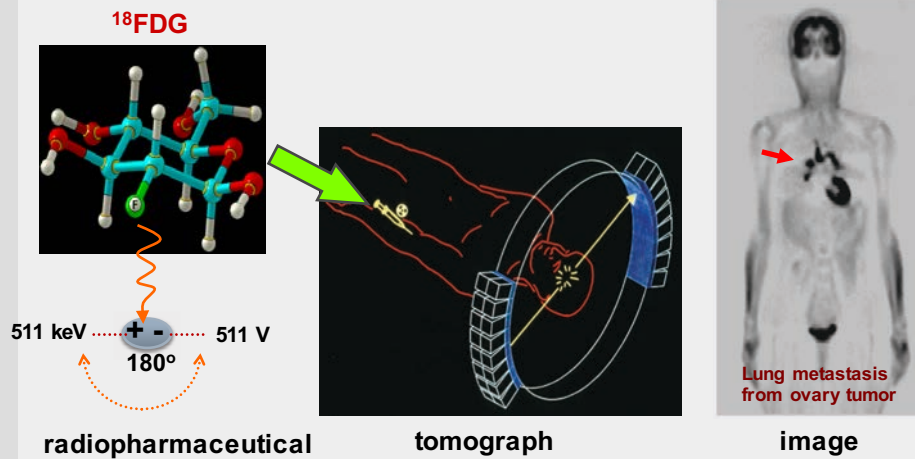
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PET tomograph



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PET procedure

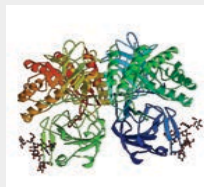


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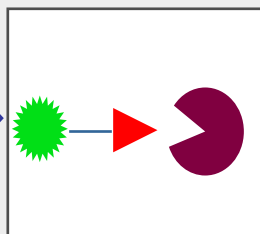
Courtesy of J. Clark, U. Cambridge

Tracer imaging

Biomarkers
biomarkers identified from
studies of the Human
Genome & Proteome



Targeted Chemistry
Add targeted chemistry that
selectively binds to them and
amplifies their imaging signal

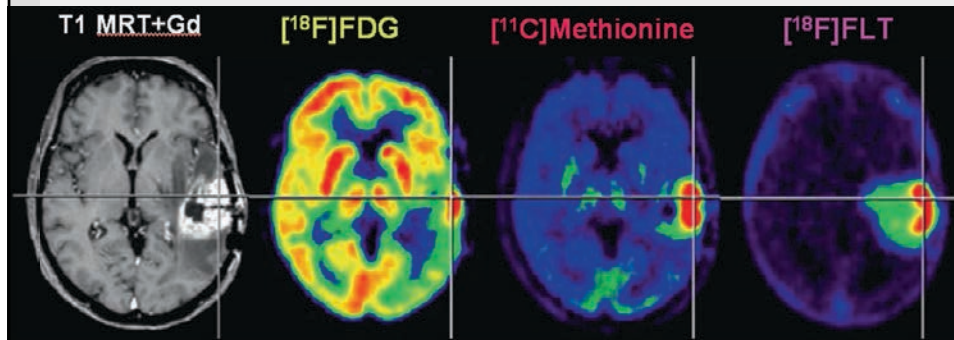


Diagnostic Technology
Using high-sensitivity, high-
resolution imagers



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Contrast



MRI detects morphological changes; 18FDG shows glucose metabolism; 18FLT y [11C]MET depict cellular proliferation (Jacobs 2005)



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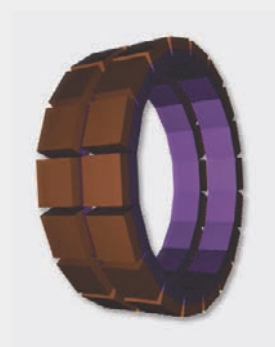
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Resolution vs. Sensitivity

"Resolution is more important than sensitivity for quantitation task performance, while sensitivity is a more significant issue for detection."

Lee, Kinahan, Miyaoka et al., IEEE TNS vol 5, no 1, pp 22, Feb 2004

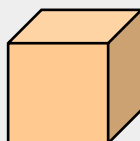


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Scale problem



human
70,000 g



rat
250 g



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Image equivalence

Image equivalence implies that the human and the animal voxel have the same statistics

$$S_r \cdot C_r \cdot D_r \cdot V_r \cdot F_r \cdot e^{-u \cdot X_r} = S_h \cdot C_h \cdot D_h \cdot V_h \cdot F_h \cdot e^{-u \cdot X_h}$$

S: specific activity (uCi/g)

C: concentration (g/g)

D: tissue density (g/cc)

V: voxel volume (cc)

F: sensitivity del detector

e^{-uX} : attenuation (u: 1/cm, X: cm)



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How to achieve equivalence?

$$S_r \cdot C_r \cdot D_r \cdot V_r \cdot F_r \cdot e^{-u \cdot X_r} = S_h \cdot C_h \cdot D_h \cdot V_h \cdot F_h \cdot e^{-u \cdot X_h}$$

$$C_r = 84 \cdot C_h$$

$$\text{activity}_r = 30\% \text{ activity}_h$$

$$F_r \cdot S_r = 84 \cdot F_h \cdot S_h$$

↑F: detector sensibility (x5 max)



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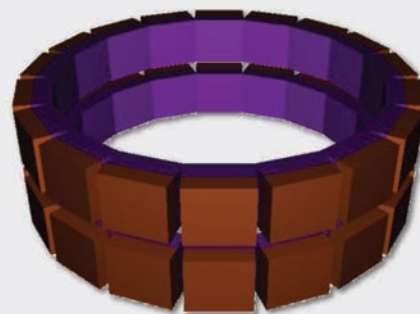
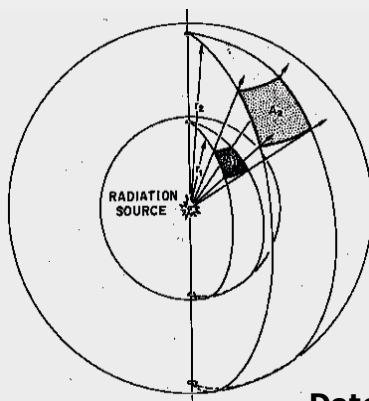
Key technological solutions

- Optimized geometry:
 - Increased solid angle
 - Use of Depth of interaction
- High performance detector
- Optimized image reconstruction
- Optimized workflow:
 - Fully integrated PET/CT acq. protocols



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System geometry



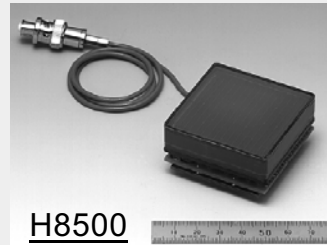
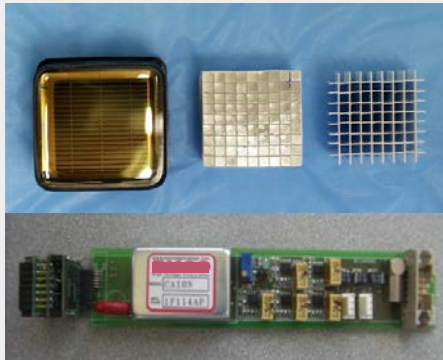
- Detectors:**
- High granularity
 - High sensitivity
 - High resolution



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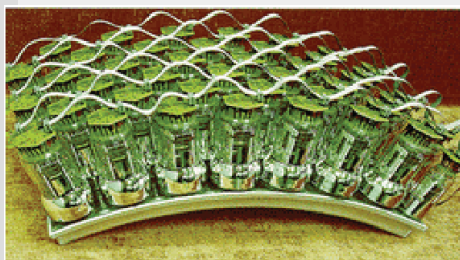
Detectors

- Segmented crystals
- Photodetectors

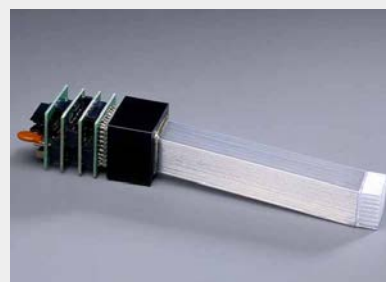


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Detectors



C-PET (NaI) Module Anger camera
(G. Muehllehner - UGM/ADAC)



S.Cherry



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Scintillators



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New Scintillators

Att. Coef. \Rightarrow detector sensitivity

Light output \Rightarrow energy resolution

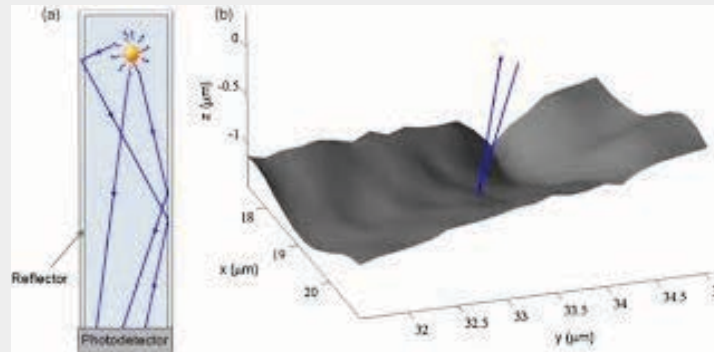
Decay time \Rightarrow count rate, coin. window

	NaI	BGO	GSO	LSO	LYSO	LPS	LuYAP
Luminosity (ph/MeV)	38	8,2	10	28	37	26	12.5
Energy Resol.	7	12	9	10	8	10	8
Effective Z	51	75	59	66	64.5	63.8	64.9
Decay Time (ns)	230	300	30~60	35~45	45~60	38	25, 200
Density (g/cc)	3.67	7.13	6.7	7.4	7.3	6.2	7.4
Atten. Length (mm)	25.6	11.2	13.8	11.4	12	15	13
Photofraction	0.17	0.43	0.25	0.34		0.31	0.27
Wavelength (nm)	410	480	440	420	400	385	390
Refractive index	1.85	2.15	1.85	1.82	1.82		1.94
Natural Radioactivity?	No	No	No	Yes	Yes	Yes	Yes
Hygroscopic?	Yes	No	No	No	No	No	No



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Guiding the scintillator light

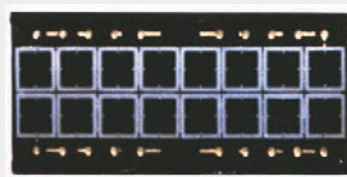


- We need to guide all the scintillator light towards the photodetector
- The type of reflection depends on the reflector surface
- We want maximum lambertian reflection
- Current methods are paint, plastic reflectors (Lumirror, Vikuiti), surface treatments with acids...

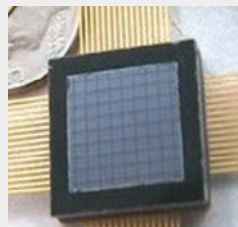


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APDs (Avalanche PhotoDiodes)



Hamamatsu



RMD, Inc.

Advantages:

- Energy resolution
- Spatial resolution
- Compact
- 'Magnetic field proof'

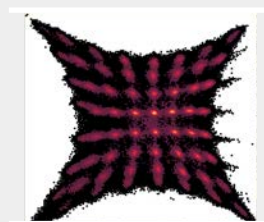
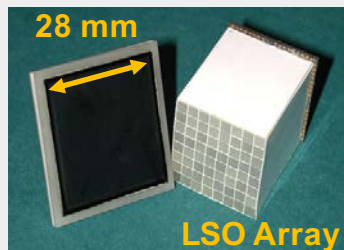
Limitations:

- Large dead area
- Signal to Noise Ratio
- Availability and cost
- Needs individual amps

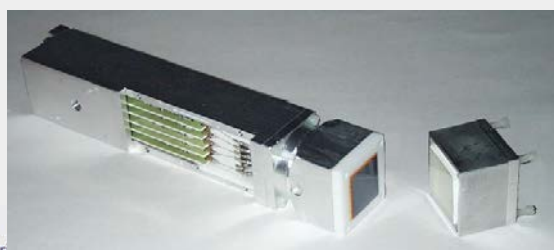


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Position-Sensitive APD



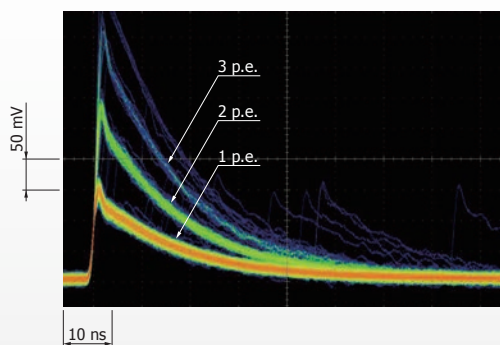
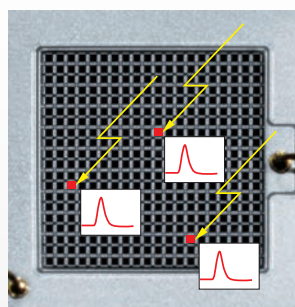
15% FWHM energy resolution, 3 ns FWHM timing resolution



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RMD, Inc.

SiPM

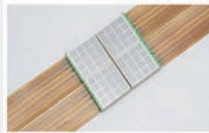


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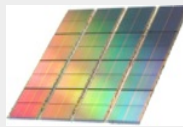
Courtesy of Hamamatsu Photonics K.K.

Analog and digital SiPM

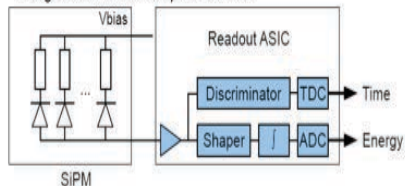
Analog SiPM



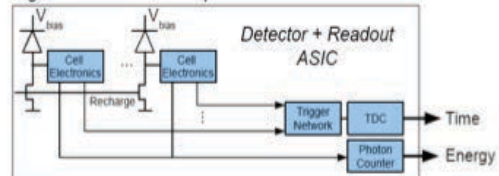
Digital Photon Counter



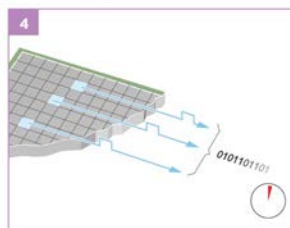
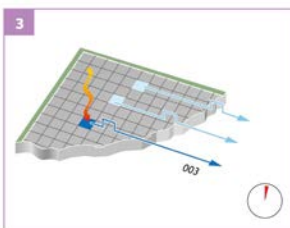
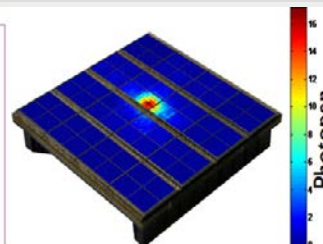
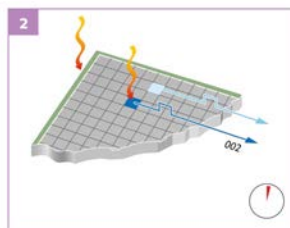
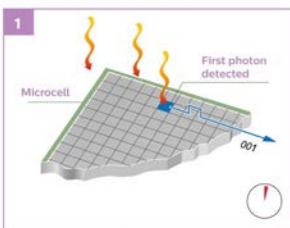
Analog Silicon Photomultiplier Detector



Digital Silicon Photomultiplier Detector



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Drawings courtesy of Philips GmbH

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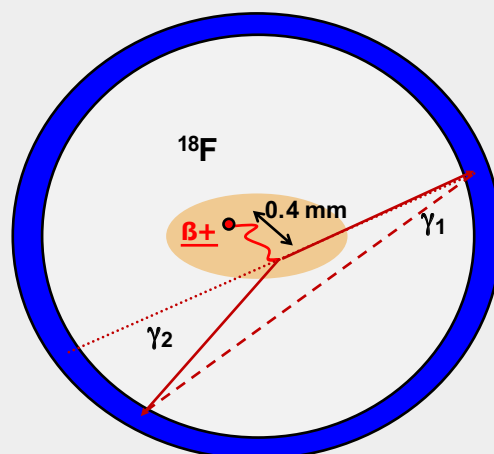
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Positron range a non-colinearity



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Positron annihilation physics

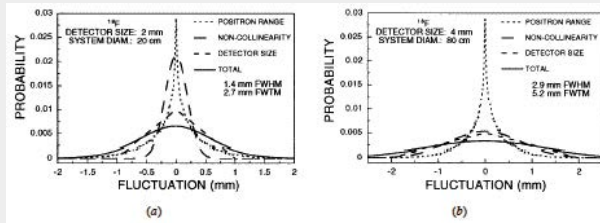


Figure 10. Calculated spatial resolution blurring factors and their combination for ^{18}F with (a) 20 cm system diameter and 2 mm wide detectors, and (b) 80 cm system diameter with 4 mm detectors.

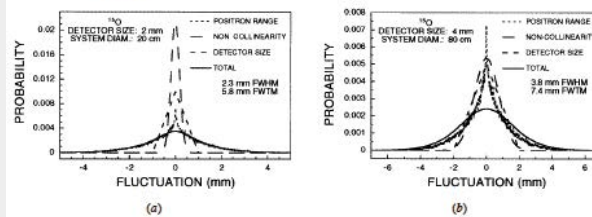


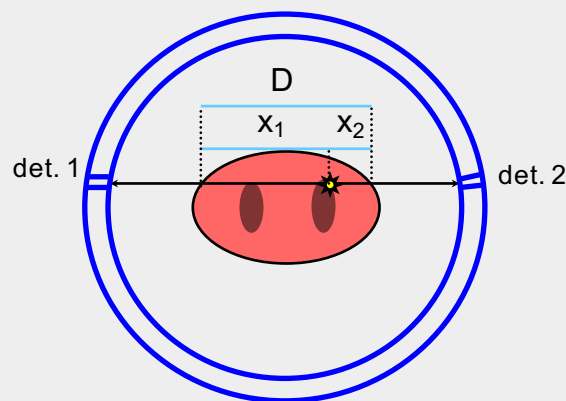
Figure 11. Calculated spatial resolution blurring factors and their combination for ^{15}O with (a) 20 cm system diameter and 2 mm wide detectors, and (b) 80 cm system diameter with 4 mm wide detectors.



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C.S. Levin and E.J. Hoffman Phys. Med. Biol. 44 (1999) 781–799

Attenuation

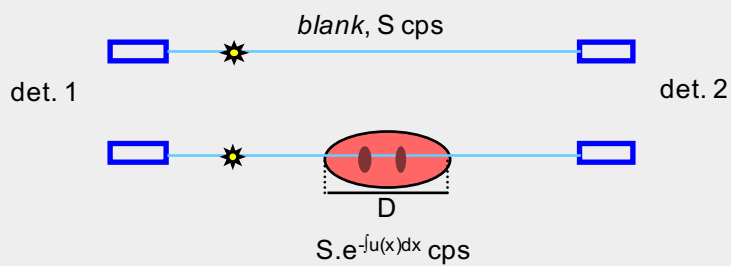


$$e^{-\int_{X_1} \mu(x) dx} \cdot e^{-\int_{X_2} \mu(x) dx} = e^{-\int_D \mu(x) dx}$$



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Attenuation correction

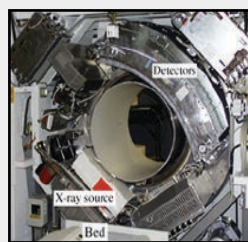


$$\text{corr.factor} = \frac{S}{S \cdot e^{-\int_D \mu(x)dx}} = e^{\int_D \mu(x)dx}$$

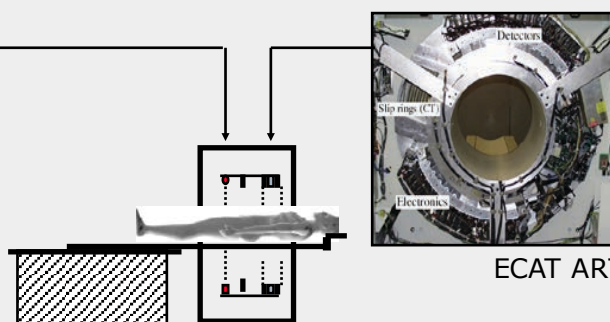


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PET/CT



Somatom AR.SP



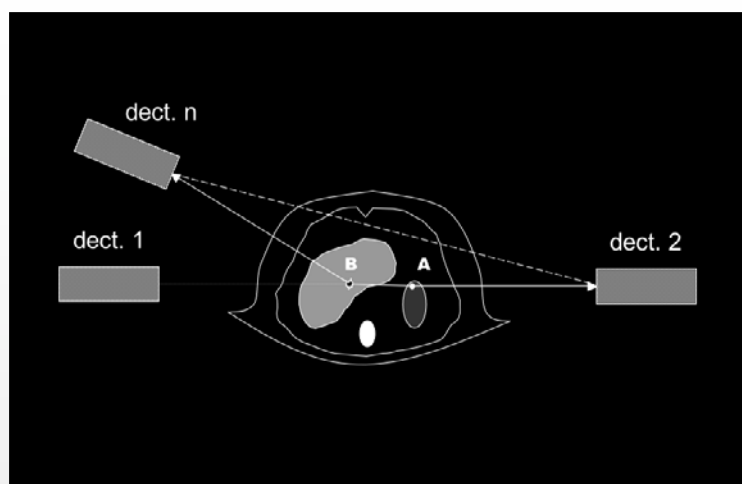
ECAT ART



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D. Townsend

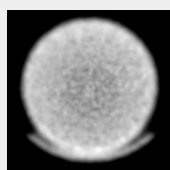
Scatter



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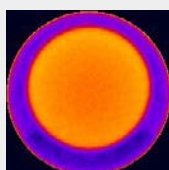
Scatter correction Rat Size Cylinder (5cm inner diameter)

Transmission



Note: Imaging bed visible; diameter of cylinder larger than in emission images

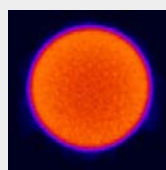
No correction



Note: background activity, edge artifact

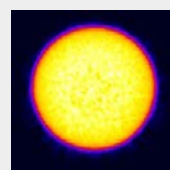
Emission Images

Scatter corrected



Note: background activity removed, edge artifact gone; central region faint

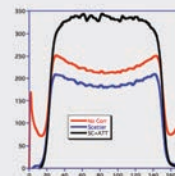
Scatter+Attenuation



Note: brightness now reasonably homogenous over cylinder area

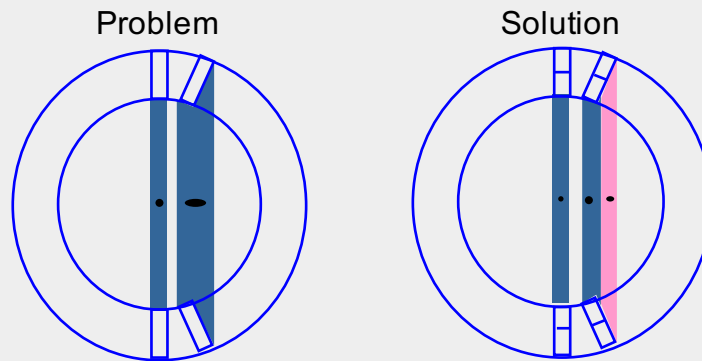
Emission scan: 2 hours, initial activity 567 μ Ci total or 1.93 μ Ci/ml, 250-700 keV energy window
Tx scan: 80 min with 450 μ Ci annulus, 250-700 keV window

FORE/2D-FBP reconstruction, span=3, dmax=22, Hann filter, images shown are 50 slice averages (slice 6-55)



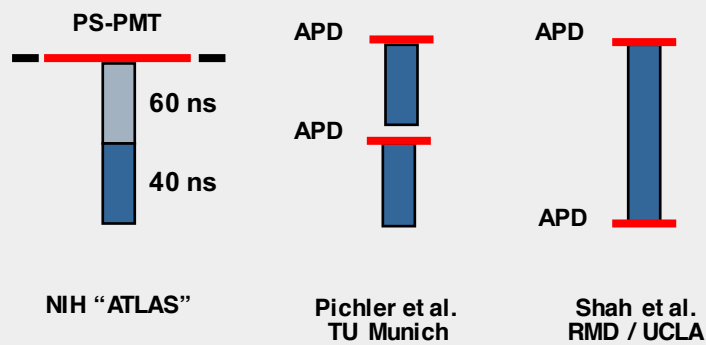
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Depth of interaction / parallax error



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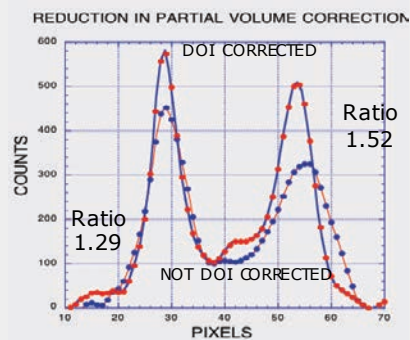
DOI Detectors



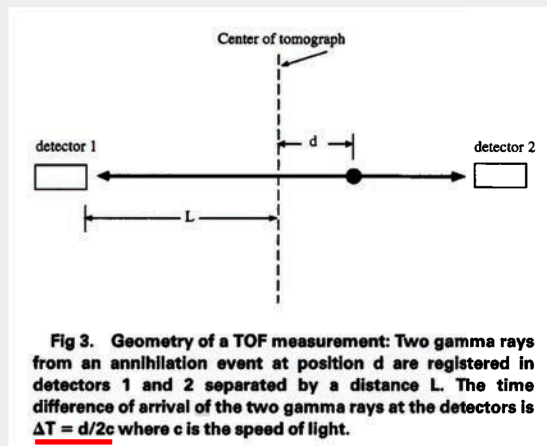
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Increasing Throughput:
Side-by-Side Mouse Imaging
32 g and 28 g Mice



TOF: Time of Flight



$\approx 3.3 \text{ ps/mm}$



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T. Lewellen SNM, 1998

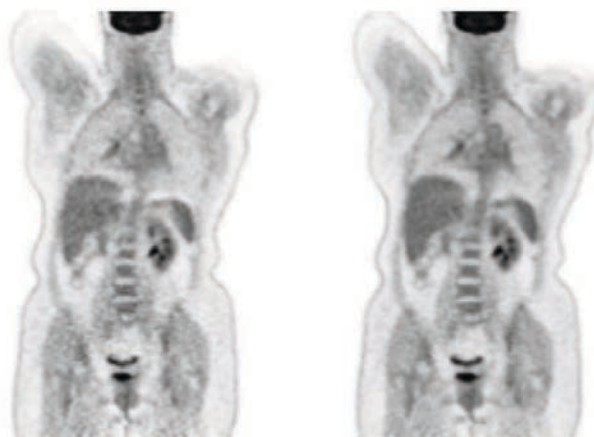


Figure 6.

A 79 kg patient (BMI 34.2) with lung cancer reconstructed (left) without TOF information and (right) with TOF. Note the almost complete disappearance of the photopenic artifact above the liver and the spleen in (right).



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C. Lois JNM, 2010

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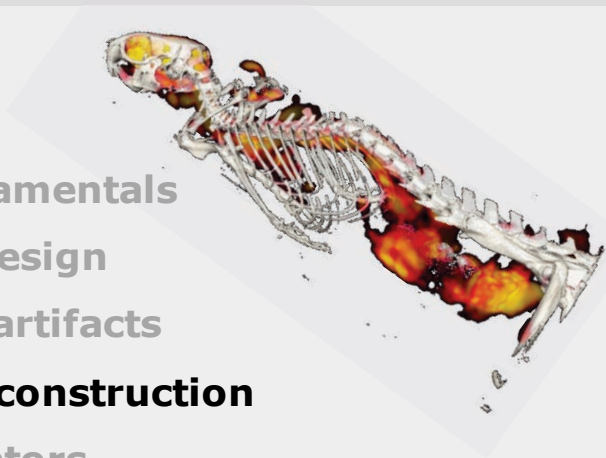
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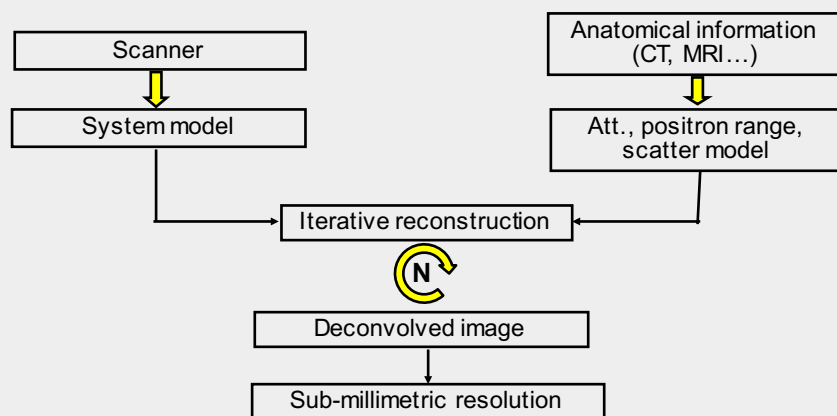
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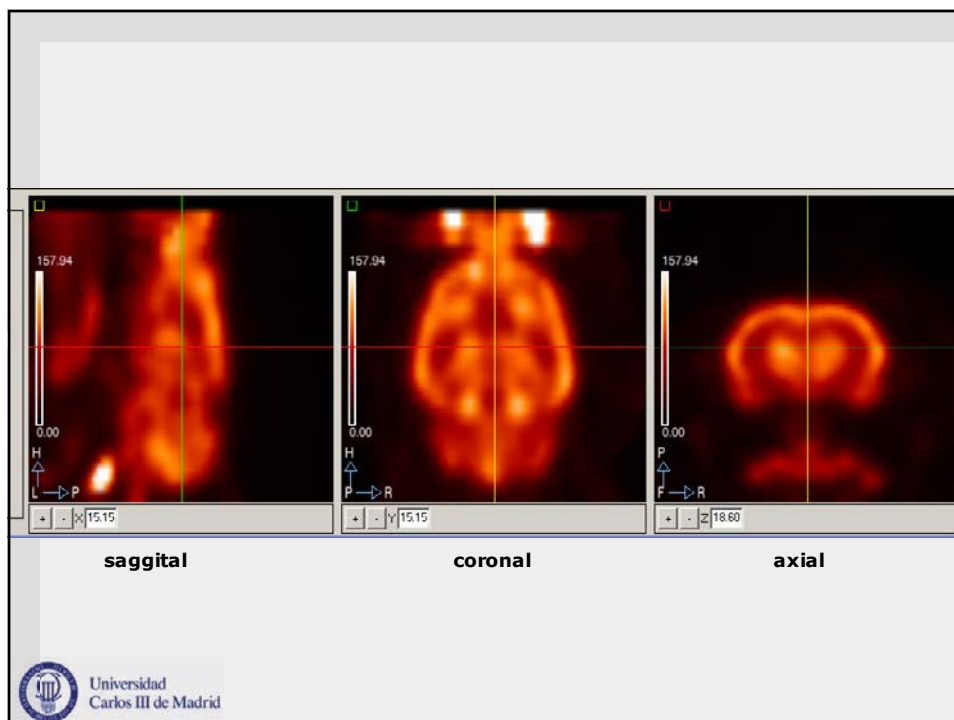
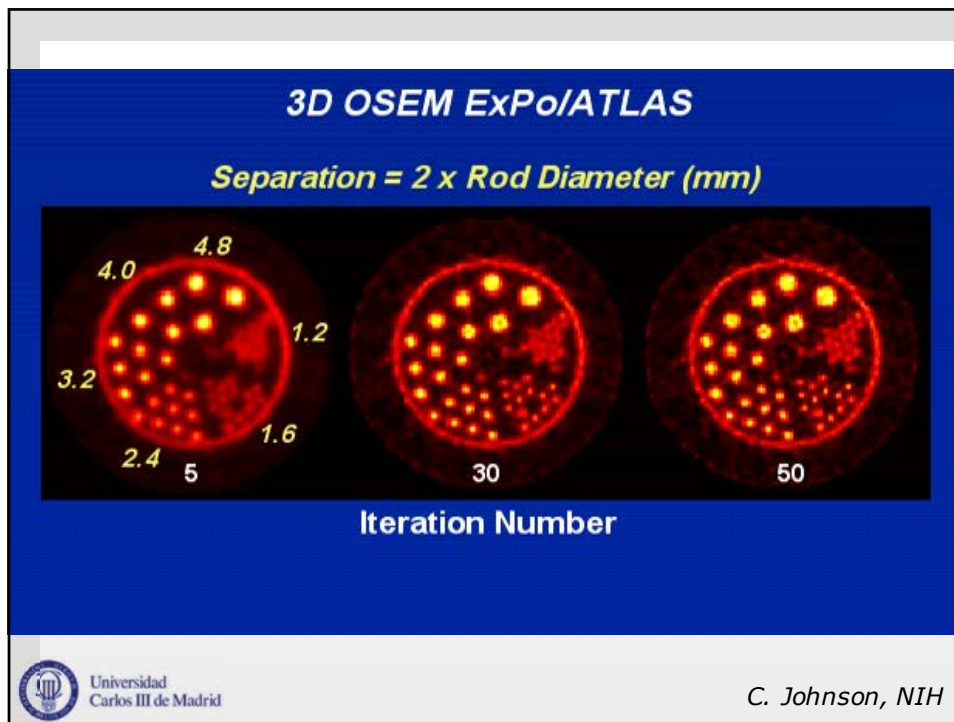
Image reconstruction



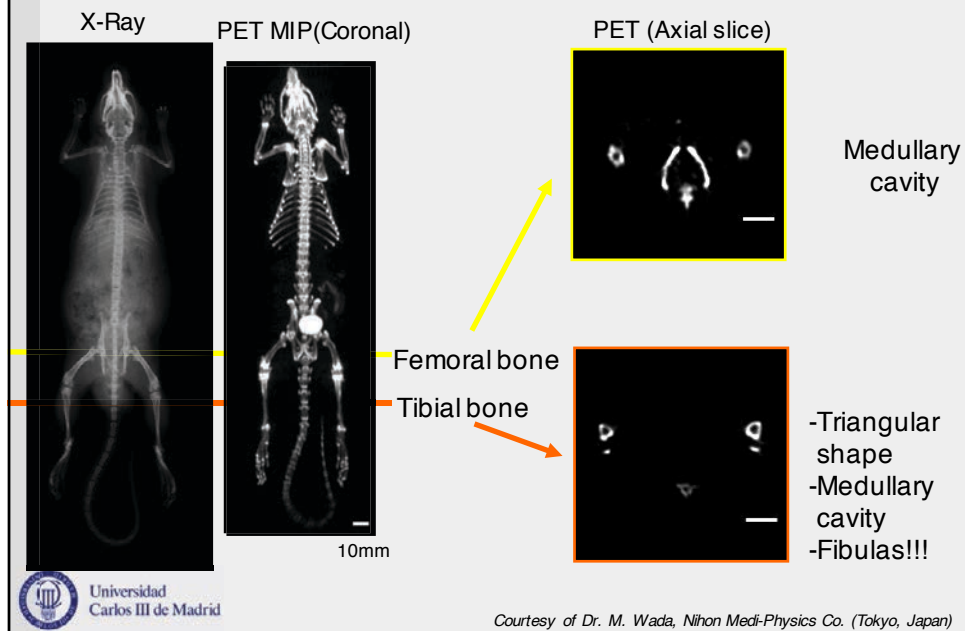
High sensitivity \rightarrow N high \rightarrow better resolution for the same SNR



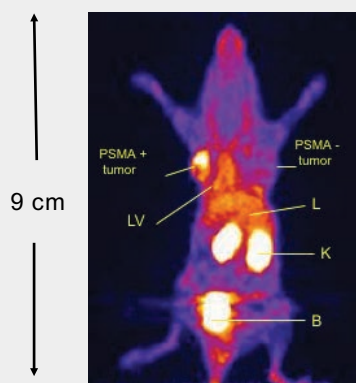
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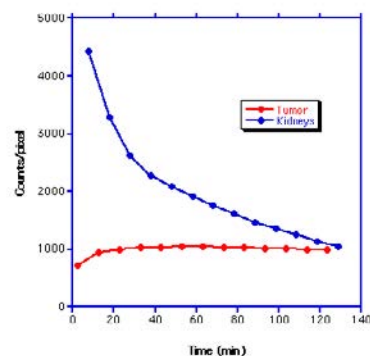
Exceptional Structural Resolution – 3D OSEM



Mouse Whole Body Dynamic Scan



Time-Activity-Curves



23 g mouse: 300 uCi ^{18}F FDG, active tumor on left side, inactive tumor right side
 Whole body scan: 2 bed @ 5 min each, 4 slices overlap, repeated multiple times
 Reconstruction: FORE/2D-OSEM with 2 iterations, 16 subsets

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ARGUS PET/CT family



Preclinical suites @ HGUGM



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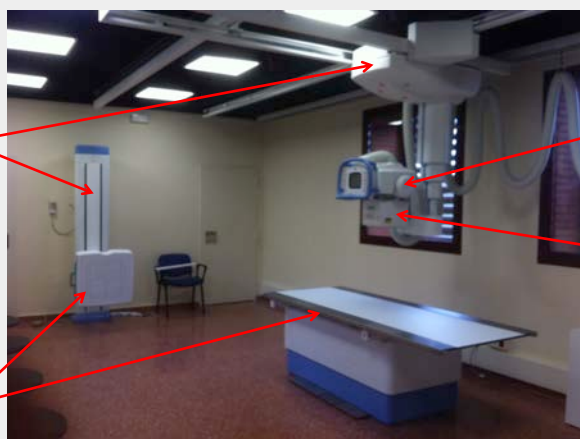
X-ray room @ UC3M

Motorized
stages

X-ray tube

colimator

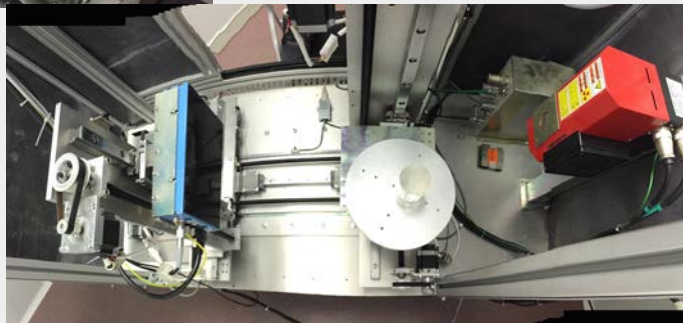
detectors



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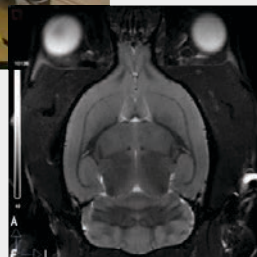
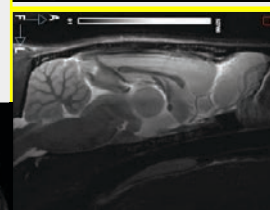


X-ray room mock-up @ UC3M



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Bruker 7T MRI suite



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