Advances in PET Technology
New Crystals and Detector Designs

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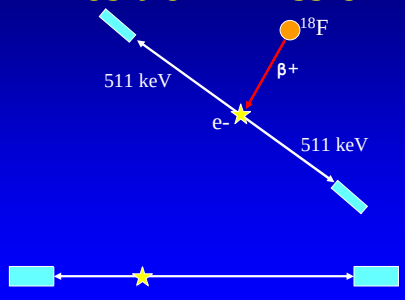
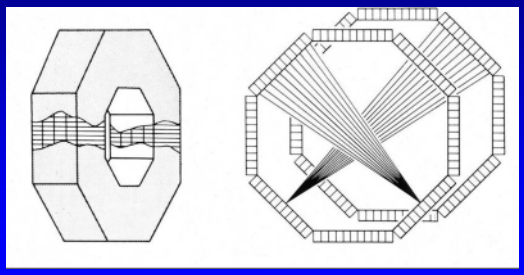
Outline

- Basics of PET Scanner Design
- Data Acquisition
- Review of Scintillation Materials
- PET/CT
- Time-of-Flight (TOF) PET
- MicroPET

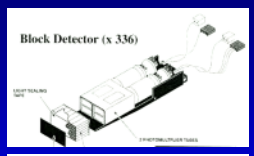
Positron Emission

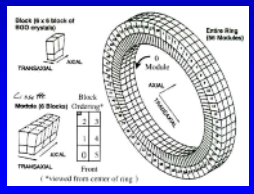


Detector Ring

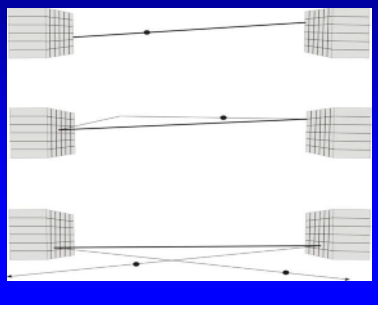


Detector Blocks (GE Advance NXi)





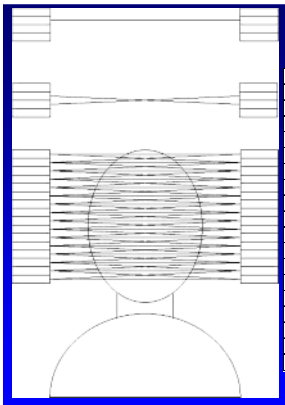
True, Scatter and Random Coincidence Detections

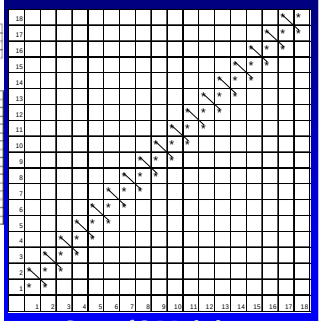


True

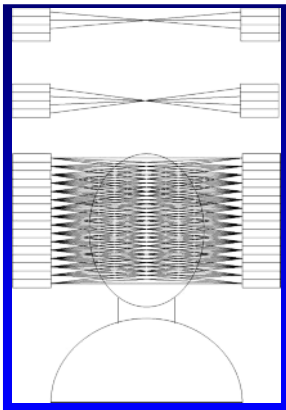
Scatter

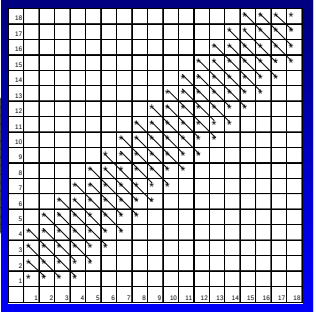
Random
(R = 2 τ N1 N2)



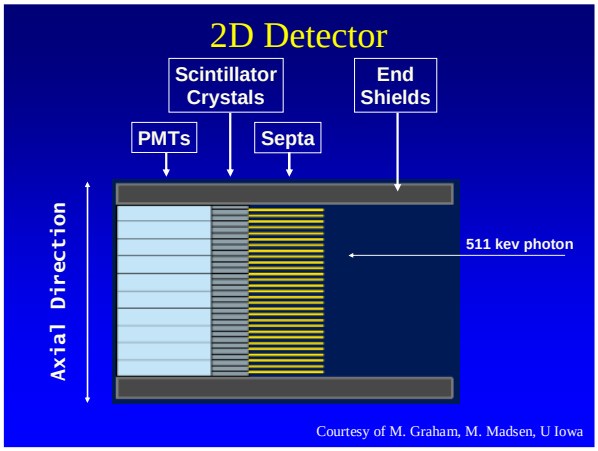


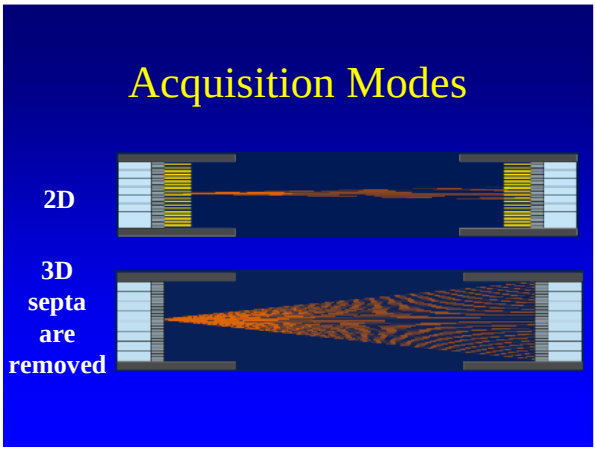
Span of 3 Michelogram

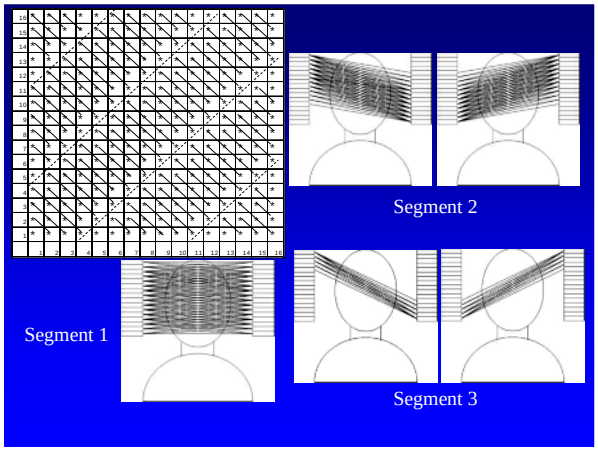


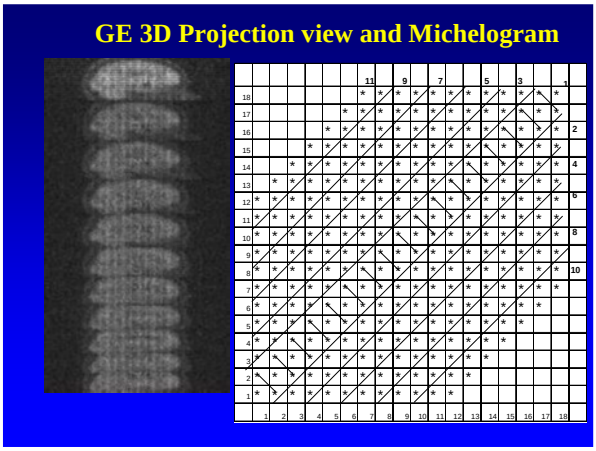


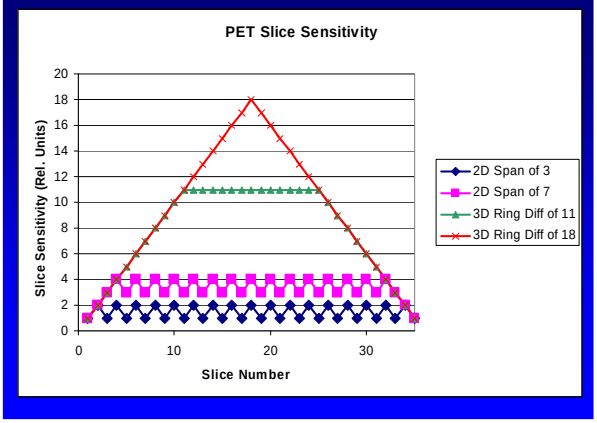
Span of 7 Michelogram


2D Detector
Scintillator Crystals
End Shields
PMTs
Septa
Axial Direction
511 kev photon
Courtesy of M. Graham, M. Madsen, U Iowa


Acquisition Modes
2D
3D septa are removed


Segment 1
Segment 2
Segment 3


GE 3D Projection view and Michelogram



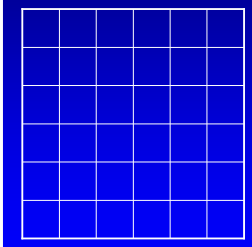
3D PET

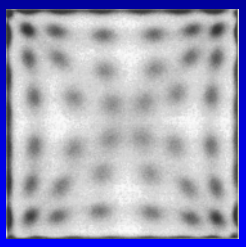
- Sensitivity drops off towards edges
- 4-5X increased sensitivity overall
- Increased scatter (15% to 40%)
- Increased randoms from out-of-field activity
- Rebinning algorithms to apply 2D reconstruction
- Some devices can acquire in 2D or 3D whereas some can only acquire in 3D
- 3D in Brain, 2D (or 3D) in Whole Body

Criteria for Scintillation Material

- Detection Efficiency (Stopping Power)
  - High Effective Z
  - High Density
- Light Output
  - Good energy resolution
  - Good crystal identification
- Decay Time
  - Reduction of random coincidences
  - Time-of-Flight PET

Crystal Identification





New Detector Materials

SCINTILLATOR	NaI(Tl)	BGO	LSO	GSO
Rel. Light Output	100	15-20	75	20-25
Peak Wavelength (nm)	410	480	420	440
Decay Constant (ns)	230	300	12,42	30-60
Density (g/mL)	3.67	7.13	7.40	6.71
Effective Z	51	75	66	59
Index of Refraction	1.85	2.15	1.82	1.85
Hygroscopic ?	Yes	No	No	No

PET/CT

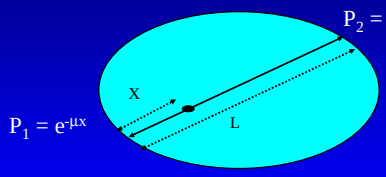
- State-of-the-art PET combined with state-of-the-art CT (up to 64 slice)
- Anatomical correlation
- CT-based attenuation correction

GE Discovery ST PET/CT

CT

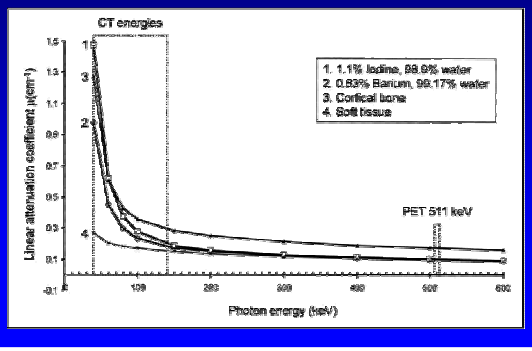
PET

PET Attenuation Correction

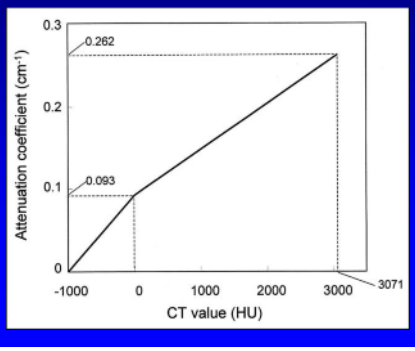


$P_{TOT} = P_1 \times P_2$
$= e^{-\mu L}$

PET-CT Attenuation Correction



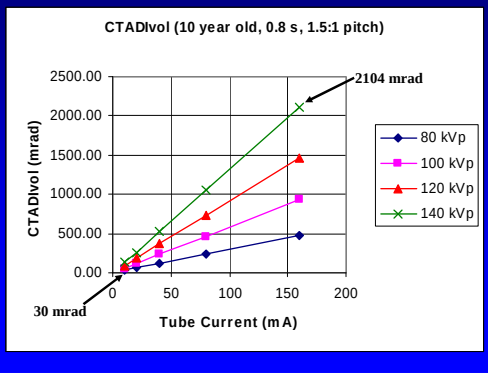
PET-CT Attenuation Correction



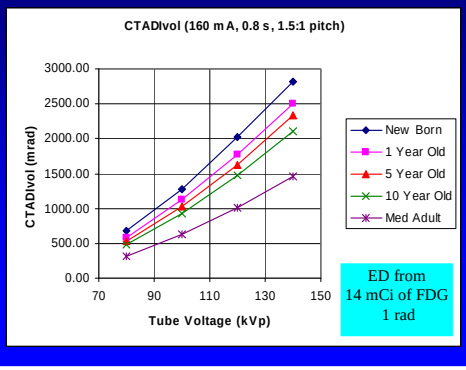
PET-CT Attenuation Correction

- Acquire CT Scan and reconstruct
- Apply energy transformation
- Reproject to generate correction matrix
- Smooth to resolution of PET
- Apply during reconstruction

Dose from CT of PET-CT



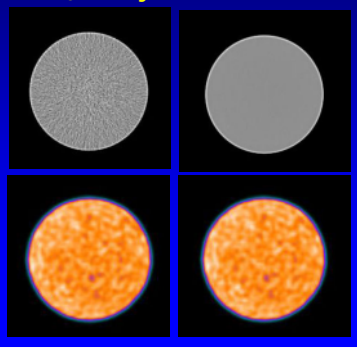
Dose from CT of PET-CT



ED from
14 mCi of FDG
1 rad

Quality of CTAC

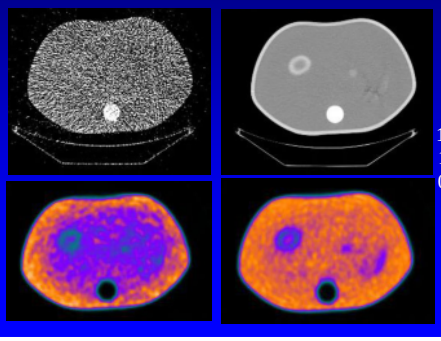
80 kVp
10 mA
0.5 s/rot
1.5:1



140 kVp
160 mA
0.8 s/rot
1.5:1

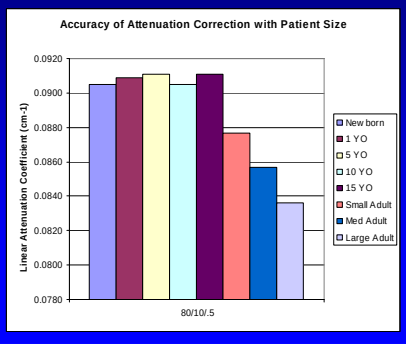
Quality of CTAC

80 kVp
10 mA
0.5 s/rot
1.5:1

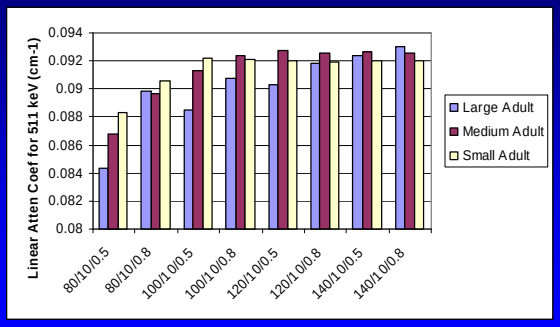


140 kVp
160 mA
0.8 s/rot
1.5:1

Effect of Patient Size
80 kVp, 10 mA, 0.5 s/rotation



Effect of Patient Size



PET-CT Scanners

- Siemens Biograph
- GE Discovery ST
- GE Discovery STE
- Philips Gemini

PET-CT Scanners

	GE Discovery STE	GE Discovery ST	Philips Gemini
Detector Dimension (mm)	4.7 x 6.3 x 30	6.2 x 6.2 x 30	4 x 6 x 20
# of PET Detectors	13,440	10,080	17,864
PET Detector Material	BGO	BGO	GSO
Spatial Resolution	5.0	6.1	4.9
2D/3D	2D/3D	2D/3D	3D
Atten Corr	CT	CT	CT&Cs-137

	Siemens Biograph LSO	Siemens Hi-Rez LSO
Detector Dimension (mm)	6.5 x 6.5 x 25	4 x 4 x 20
# of PET Detectors	9,216	23,336
PET Detector Material	LSO	LSO
Spatial Resolution	6.3	4.6
2D/3D	3D	3D
Atten Corr	CT	CT

Time-of-Flight PET

Speed of Light $c = 3 \times 10^{10}$ cm/s

Time (ns)	0.1	0.5	1.0	5.0
Distance (cm)	3	15	30	150

Time-of-Flight PET

Speed of Light $c = 3 \times 10^{10}$ cm/s

Time (ns)	0.1	0.5	1.0	5.0
Distance (cm)	3	15	30	150

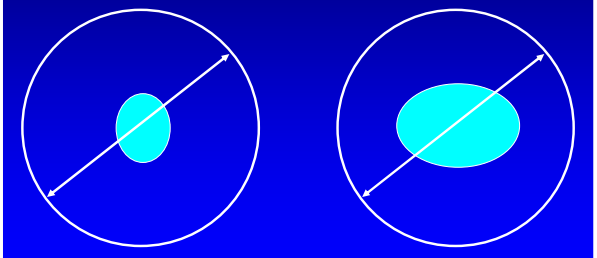
Time-of-Flight PET

$\Delta x = c\,\Delta t/2$

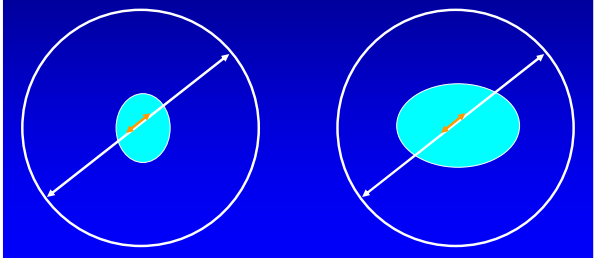
Where Δx is the time-of-flight spatial uncertainty and Δt is the timing resolution.

Δt (ns)	0.1	0.3	0.5	1.0
Δx (cm)	1.5	4.5	7.5	15.0

Time-of-Flight PET



Time-of-Flight PET



Assume Δt of 0.5 ns => Δx of 7.5 cm

Time-of-Flight PET

SNR Gain from Time-of-Flight PET

$D/1.6\,\Delta x \approx 2\,D/\,1.6\,c\,\Delta t$

where D is the diameter of the object

D (cm)	20	30	40
SNR Gain	1.6	2.5	3.3

Philips Gemini TF

PET scanner

LYSO : 4 x 4 x 22 mm^3

28,338 crystals, 420 PMTs

70-cm bore, 18-cm axial FOV

CT scanner

Brilliance 16-slice

Installation at U.Penn Nov '05

Validation and research patient imaging

Nov '05 - Apr '06 *50 patients*

Beta testing and upgrade to production release software

May '06 - Jun '06 *40 patients (to date)*

Timing resolution = 600 ps

Courtesy of Joel Karp, PhD, Univ of Penn

Performance measurements

Intrinsic

Energy resolution: 11.5% fwhm, Timing resolution: 585 ps

NEMA NU-2

Spatial resolution: 4.8 mm at 1 cm, 5.2 mm at 10 cm

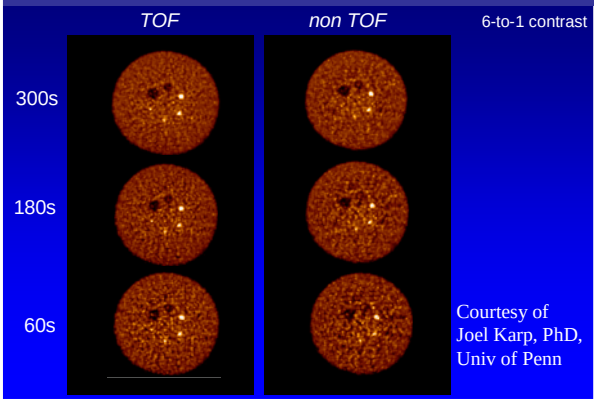
Sensitivity: 6.6 cps/kBq

Scatter fraction (at 440 keV): 27% for 20-cm x 70-cm

Peak NEC: 125 kcps @ 0.42μCi/ml

Courtesy of Joel Karp, PhD, Univ of Penn

Measurements: 35-cm lesion phantom

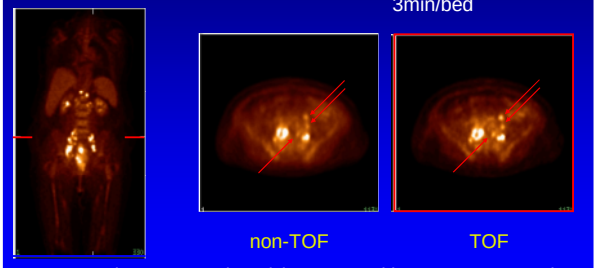


Courtesy of Joel Karp, PhD, Univ of Penn

Gemini TF - patient study

Rectal carcinoma metastases in mesentery and bilateral iliac chains

114 kg; BMI = 38.1
12 mCi; 2 hr post-inj
3min/bed



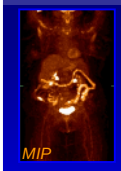
non-TOF TOF

Lesion contrast (SUV) improves with TOF reconstruction

Courtesy of Joel Karp, PhD, Univ of Penn

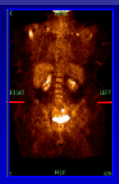
Gemini TF

Heavy-weight patient study

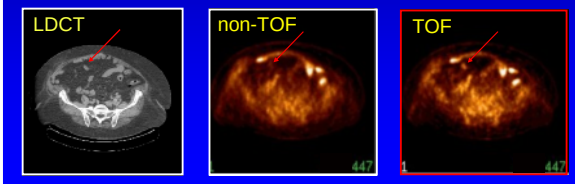


Colon cancer

119 kg
BMI = 46.5



13 mCi
2 hr post-inj
3 min/bed



Courtesy of Joel Karp, PhD, Univ of Penn

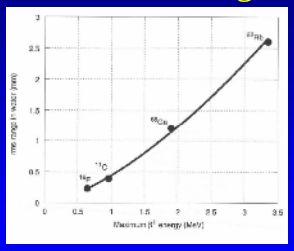
Design Criteria for MicroPET

- Image mice and rats
- Very high spatial resolution (~1-2 mm)
- High sensitivity (want to image with limited amounts of radioactivity)
- Reasonable size to fit into a laboratory
- Access to animal about the device

Spatial Resolution

- Positron range (related to positron energy)
- Non-collinearity (uncertainty depends on detector radius)
- Detector size

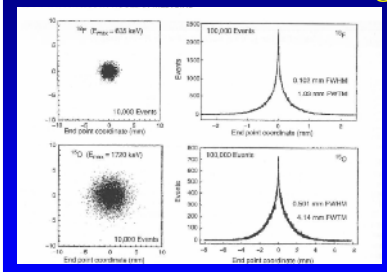
Positron Range



The rms range is proportional to positron energy.

From Cherry et al., Physics of Nuclear Medicine

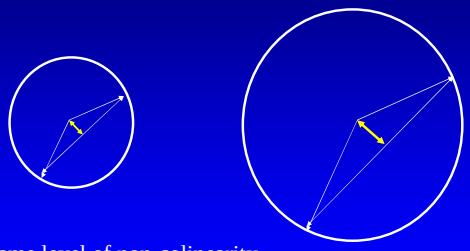
Positron Range



The distribution of rms range is exponential and not well characterized by FWHM.

From Cherry et al., Physics of Nuclear Medicine

Non-Colinearity



The same level of non-colinearity leads to a bigger uncertainty with a larger detector diameter.

$R_{180} \approx 0.002 \times D_R$

Limit on PET Spatial Resolution

(Regardless of detector size)

$R_{sys} = SQRT[R_{det}^2 + R_{range}^2 + R_{180}^2]$

Whole body scanner (100 cm diameter)	^{18}F ^{82}Rb	~2.0 mm ~3.3 mm
Small animal scanner (20 cm diameter)	^{18}F ^{82}Rb	~0.5 mm ~2.6 mm

Siemens MicroPET Focus 120 Scanner

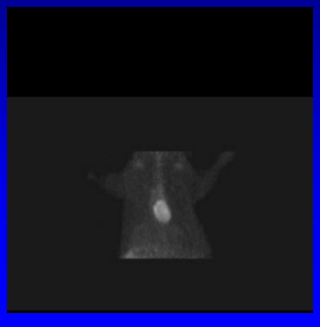
- Axial Field of View 7.6 cm
- Transaxial Field of View 10.0 cm
- Scintillating material LSO
- Number of Detectors 13,824
- Detector Size 1.5x1.5x10 mm
- Spatial Resolution (CFOV) 1.7 mm
- Sensitivity 6.5%

Siemens MicroPET Focus 120 Scanner

650g Rat
[^{18}F] Fluoride
4 bed positions
30 min each

Courtesy of Siemens Medical Systems

Siemens MicroPET Focus 120 Scanner



Gated rat study
with FDG

Imaging cholinergic receptors
in a mouse pancreas using microPET

Courtesy of Kathryn Morton MD
Wake Forest University

GE eXplore Vista Scanner

•Rodent system
•11.8 cm diameter
•4.6 cm axial FOV
•1.6 mm resolution in CFOV

Philips Mosaic

•16,680 GSO crystals
•2.1 mm resolution
•11.8 cm axial FOV
•^{137}Cs Transmission

Summary

- Modern scanners designed for oncologic imaging
- Practically all PET sales are PET/CT scanners
- New scintillation crystals combine excellent detection efficiency with short decay times
- Shorter decay times leads to possibility of time-of-flight PET.
- MicroPET scanners can provide very high spatial resolution with high sensitivity in a small foot print and easy access to the research animals.