Recent Advances in PET and PET/CT Scanners

Frederic H. Fahey, D.Sc.
Children's Hospital
Boston, MA

Children's Hospital Boston frederic.fahey@childrens.harvard.edu

PET: Back in the day…

PET III
BNL - 1980

- Research Device
- Single Slice
- Run by the research team
- Neuroscience

Children's Hospital Boston

PET Imaging Today

- Recent Growth
  - Oncology
  - Regional Distribution of ^{18}F FDG
  - Reimbursement
- Development
  - Simpler to run
  - More robust
  - Multi-Slice (15 cm volume)
  - Multi-Modality (PET-CT)

Children's Hospital Boston

Outline

- Basics of PET Scanner Design
- Review of Current PET Instrumentation

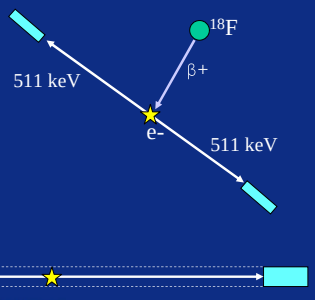
Children's Hospital Boston

Basics of PET Scanner Design

- Annihilation coincidence detection
- Detector designs
- Scintillation materials
- 2D vs 3D
- Performance Parameters

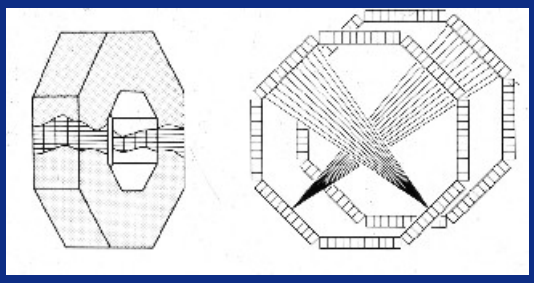
Children's Hospital Boston

Positron Emission



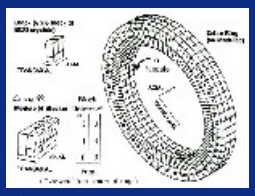
Children's Hospital Boston

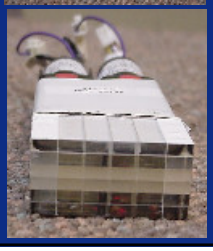
Detector Ring



Children's Hospital Boston

Detector Bocks (GE Advance NXi)

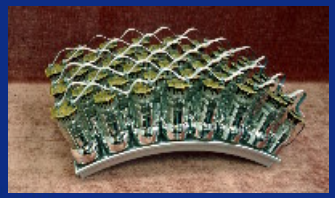




Children's Hospital Boston

Large Crystal Designs

- Large NaI detectors, PMT array
- 25x50 cm, 1" thick
- Hexagonal array



Children's Hospital Boston

New Detector Materials

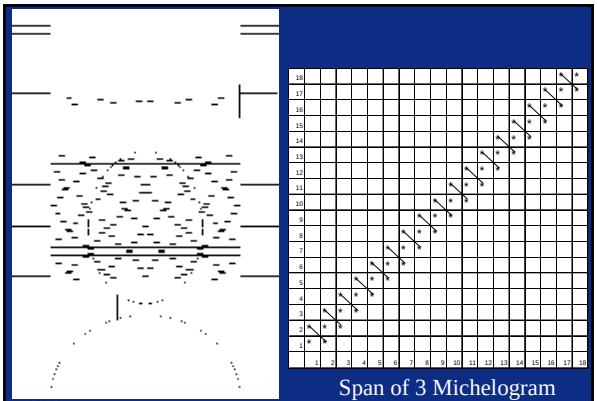
SCINTILLATOR	NaI(Tl)	BGO	LSO	GSO
Rel. Light Yield	100	15-20	75	20-25
Peak Wavelength (nm)	410	480	420	440
Decay Constant (ns)	230	300	12,42	30-60
Density (g/cc)	3.67	7.13	7.40	6.71
Effective Z	51	75	66	59
Index of Refraction	1.85	2.15	1.82	1.85
Hygroscopic ?	Yes	No	No	No

Children's Hospital Boston

Michelogram

- Graphical description of the axial sampling of a PET scanner
- Plot of detector rings on one side of the scanner versus those on the other side
- Can be used to illustrate the differences in axial sampling between various PET data acquisition approaches (e.g. 2D vs 3D PET)

Children's Hospital Boston



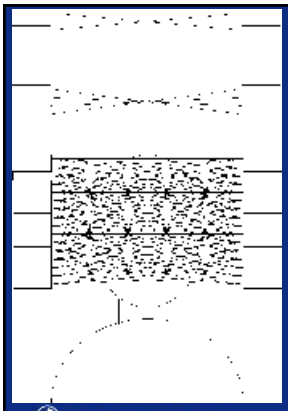
Span of 3 Michelogram

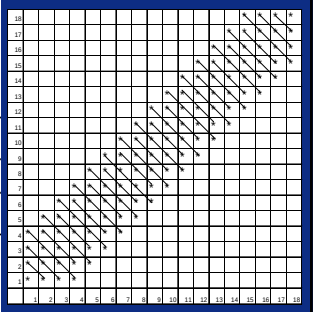
Children's Hospital Boston

"Span" is the sum of axial lines of response combined in an odd slice and those for an even slice.

For example, if the odd slices include direct coincidences only and the even slices combine two crossed coincidences (e.g. from Ring 2 to 3 and from Ring 3 to 2), then this would be described as a Span of 3 (1 direct + 2 crossed coincidences).

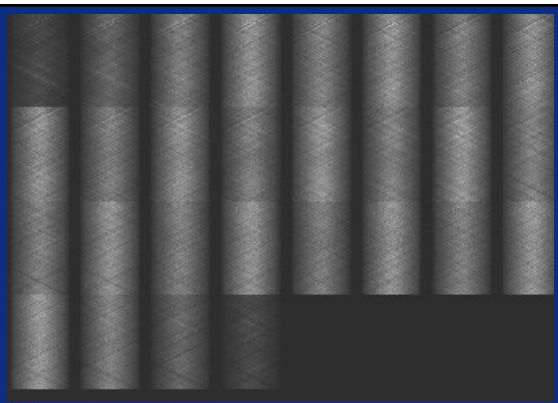
Children's Hospital Boston





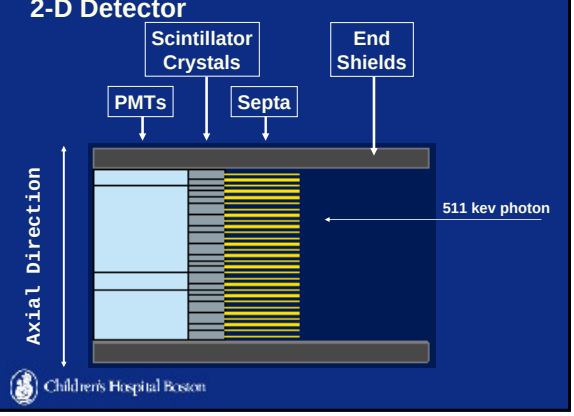
Span of 7 Michelogram

Children's Hospital Boston

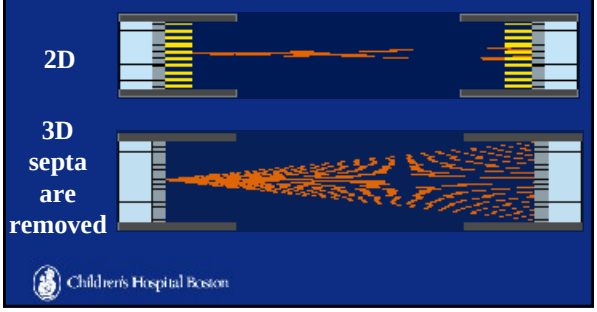


Children's Hospital Boston

2-D Detector



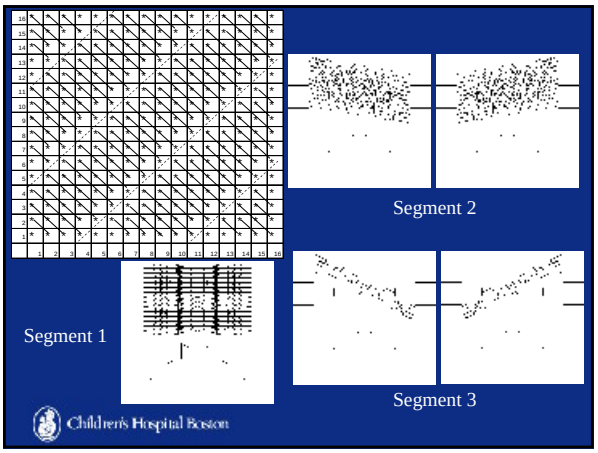
Acquisition Modes



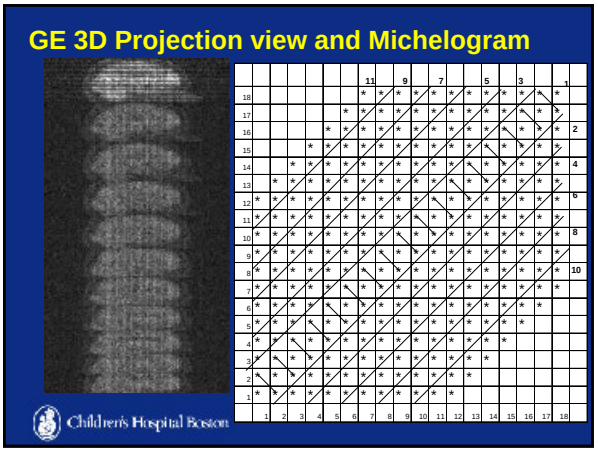
"Ring difference" describes the maximum allowable range of axial coincidences within a 3D acquisition.

For example, if Ring 1 is allowed to be in coincidence with Rings 1 through 12, but not with Rings 13 through 18, then this would be a Ring Difference of 11 (RD = 12 – 1 = 11).

Children's Hospital Boston



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

Children's Hospital Boston

Performance Parameters for PET Systems

- NEMA NU-2 1994 and 2001
- 2D and 3D
- PET parameters
  - Spatial resolution (transverse and axial)
  - Sensitivity
  - Scatter fraction
  - Count rate (Noise equivalent count rate)

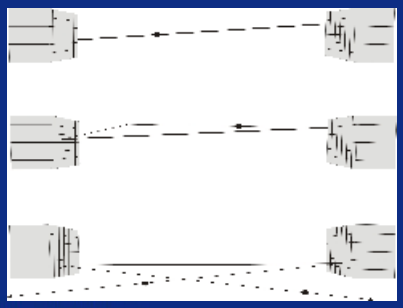
Children's Hospital Boston

Sensitivity

- 1994: 20 cm cylindrical phantom with known activity concentration (µCi/mL) in gantry center. Results reported in kcps/µCi/mL. OK for 2D and small axial FOV.
- 2001: 70 cm line source filled with known activity and 5 sleeves of various diameter sleeves assure annihilation. Fit to exponential model and reported counts at zero thickness as cps/kBq

Children's Hospital Boston

True, Scatter and Random Coincidence Detections



Children's Hospital Boston

Random Coincidences

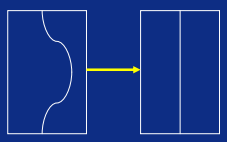
$$R = 2 \tau N_1 N_2$$

- Increases as the square of activity concentration
- More an issue at high count rates
- 2D septa help reduce the random coincidences from activity that is out of the FOV
- So more an issue with whole body 3D

Children's Hospital Boston

Scatter Fraction

Image line source



Align rows of sinogram

Profile across sinogram

Integral = T

Integral = S

Children's Hospital Boston

Scatter Fraction = S/T

Noise Equivalent Counts (NEC)

•Not all coincidences are created equal. We must correct for random and scatter coincidences.
•The "Noise Equivalent Count" is the number of counts from a Poisson distribution (SD estimated by SQRT{N}) that will yield the same noise level as in the data at hand.
•This allows one to compare counts acquired on different machines or using different acquisition schemes.

Children's Hospital Boston

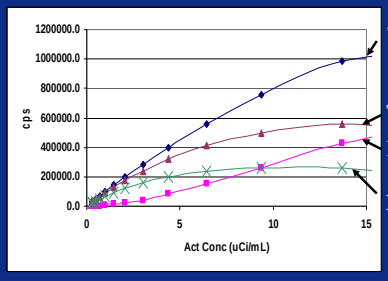
Noise Equivalent Counts (NEC)

$$NEC = \frac{T}{1 + 2R/T + S/T}$$

Where T is True counts
R is Random counts
S is Scattered counts

Children's Hospital Boston

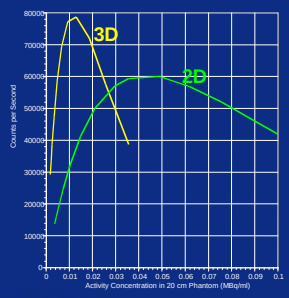
Scatter Fraction, Count Rate and Randoms Measurement (1994)



Total
True
Random
NEC

Children's Hospital Boston

NEC Rate: 2D vs 3D



Children's Hospital Boston

Review of Current PET Instrumentation

- High-End
- Mid-Range
- PET-CT
- Special Devices

Children's Hospital Boston

PET Instrumentation

- High-End
  - Siemens HR+
  - GE Advance
  - Philips Allegro
- Mid-Range
  - Siemens EXACT/ACCEL
  - Philips CPET+

Children's Hospital Boston

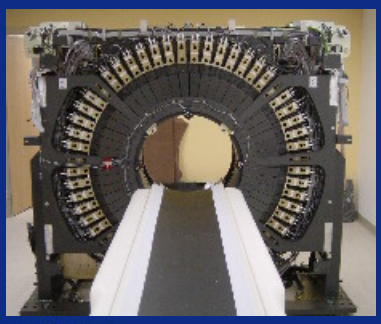
PET Instrumentation

	Siemens HR+	GE Advance	Philips Allegro
Detector Dimension (mm)	4.1 x 4.4 x 30	3.9 x 8.2 x 30	4 x 6 x 20
# of Detectors	18,432	12,096	17,864
Detector Material	BGO	BGO	GSO
Spatial Resolution (mm)	4.6	4.8	4.8
Sensitivity (kcps/uCi/mL)	200/900	200/1060	/800

	Siemens EXACT	Siemens Accel	Philips CPET+
Detector Dimension (mm)	6.8 x 6.8 x 20	6.8 x 6.8 x 20	500x300x25
# of Detectors	9,216	9,216	6
Detector Material	BGO	LSO	NaI
Spatial Resolution (mm)	6	6.2	5
Sensitivity (kcps/uCi/mL)	180/780	180/780	/450

Children's Hospital Boston

GE Advance NXi



Children's Hospital Boston

PET-CT Scanners

- Siemens Biograph (BGO or LSO)
- GE Discovery LS
- GE Discovery ST
- Philips Gemini

Children's Hospital Boston

PET-CT Scanners

	Siemens Biograph BGO	Siemens Biograph LSO	Philips Gemini
Detector Dimension (mm)	4.1 x 4.4 x 30	6.5 x 6.5 x 25	4 x 6 x 20
# of PET Detectors	18,432	9,216	17,864
PET Detector Material	BGO	LSO	GSO
Spatial Resolution	4.5	6.3	4.9
2D/3D	3D	3D	3D
Atten Corr	CT	CT	CT&Cs-137

	GE Discovery LS	GE Discovery ST
Detector Dimension (mm)	4 x 8 x 30	6.2 x 6.2 x 30
# of PET Detectors	12,096	10,080
PET Detector Material	BGO	BGO
Spatial Resolution	4.8	6.2
2D/3D	2D/3D	2D/3D
Atten Corr	CT&Ga-68	CT

Children's Hospital Boston

GE Discovery LS

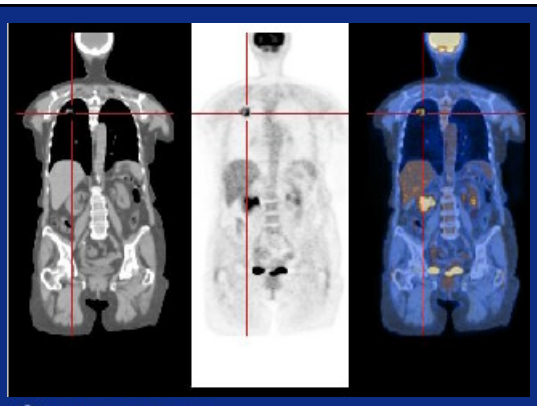
Advance NXi

LightSpeed Plus

- LightSpeed Plus CT (4-16 slice, 0.5sec gantry).
- Full-featured Advance NXi PET.
  - Retractable septa for 2D and 3D imaging.

Children's Hospital Boston

Courtesy of GE Medical Systems



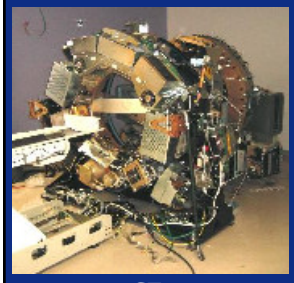
Children's Hospital Boston

Courtesy of GE Medical Systems

GE Discovery ST

Children's Hospital Boston

GE Discovery ST



CT

PET

Children's Hospital Boston

GE Discovery ST (vs LS)

- Larger Detectors (6 vs 4 mm)
- Lower Spatial Resolution (6.2 vs 4.9 mm)
- Shorter Septa (5 vs 10 cm)
- Higher Sensitivity (1.3/6.5 vs 2.1/9.5 cps/kBq)
- Larger patient bore (70 vs 50 cm)
- No rod sources
- 2D and 3D imaging

Children's Hospital Boston

Siemens Biograph Combining Anatomy & Physiology

- ECAT EXACT HR+: Highest performance PET scanner
- Siemens Somatom Emotion: High performance, spiral CT
- 70 cm patient port
- Optimized bed design

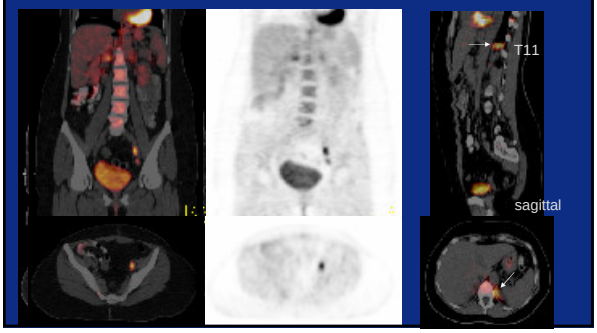
Courtesy of Siemens Medical Systems

Children's Hospital Boston

Cervical cancer

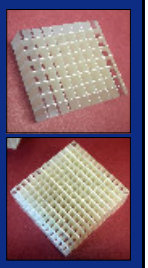
University of Pittsburgh

Case: 54 year old woman with history of cervical cancer. Referred for RT planning.
Finding: PET/CT: Focal uptake in two left pelvic sidewall nodes, not noted on recent clinical CT. Also, two foci of mild FDG uptake in para-aortic region (T-11 level)



Siemens Hi-Rez Detectors

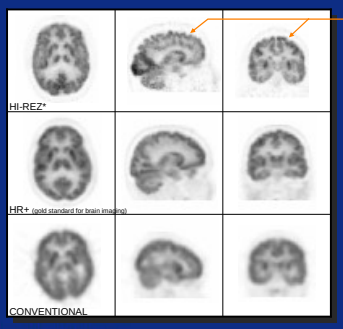
	CURRENT	HI-REZ
Detector material	LSO	LSO
Block matrix	8 x 8	**13 x 13**
Crystal size	6.4 mm x 6.4 mm	**4.0 mm x 4.0 mm**
Crystal thickness	25 mm	20 mm
Number of blocks	144	144
Total number of crystals	9,216	**24,336**
Axial field of view	16.2 cm	16.2 cm
Number of crystal rings	24	**39**
Number of image planes	47	**81**
Plane spacing	3.4 mm	**2.0 mm**
Ring diameter	83 cm	83 cm
Spatial resolution	6.3 mm	**4.6 mm**
Volumetric resolution	250 mm^3	**98 mm^3**



Children's Hospital Boston

Courtesy of Siemens

Siemens Biograph with LSO HI-REZ detectors



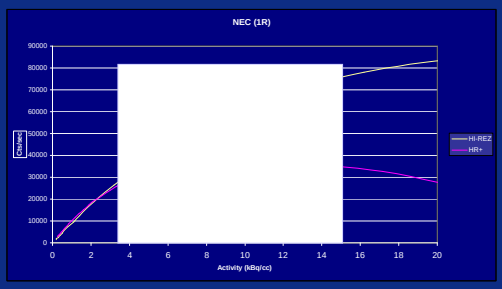
Note definition of sulcus and gyrus!

Children's Hospital Boston

Courtesy of Siemens

*510(k) pending, not for sale in the US

Siemens Pico-3D noise equivalent count rate for LSO



Children's Hospital Boston

Courtesy of Siemens

Philips Gemini

Allegro PET Scanner and
Mx8000 16 slice CT scanner

Children's Hospital Boston

Courtesy of Philips Medical Systems

Philips Gemini

Children's Hospital Boston

Courtesy of Philips Medical Systems

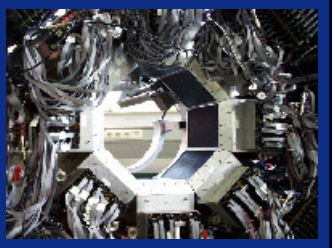
Special PET Devices

- Brain
- Breast
- Small Animal

Children's Hospital Boston

CTI ECAT HRRT

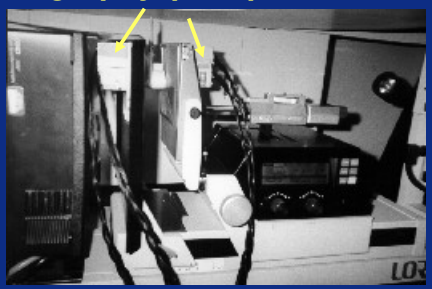
- Max Planck Institute in Cologne
- Dual LSO Phoswich for DOI Determination
- Octagonal Design
- 936 blocks with 128 2.1x2.1 dual detectors each
- 120,000 crystals
- Reconstructed resolution of less than 2.5 mm



Children's Hospital Boston

Courtesy of CTI

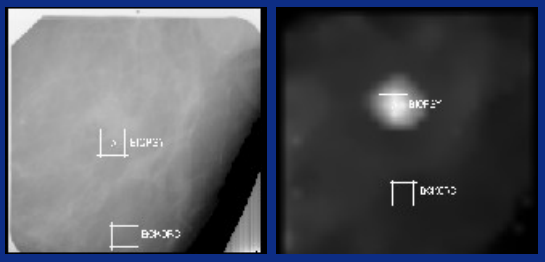
Positron Emission Mammography (PEM)



Children's Hospital Boston

Courtesy of Wake Forest University and PEM Technologies

Positron Emission Mammography (PEM)



Courtesy of Wake Forest University and PEM Technologies

Children's Hospital Boston

Concorde MicroPET Scanner

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

Courtesy of Concorde MicroSystems

Children's Hospital Boston

GE eXplore Vista Scanner

Children's Hospital Boston

Summary

- Scanners have become more clinically oriented
- New scintillation materials
- 3D vs 2D scanners
- PET-CT Scanners
- Special purpose scanners

Children's Hospital Boston