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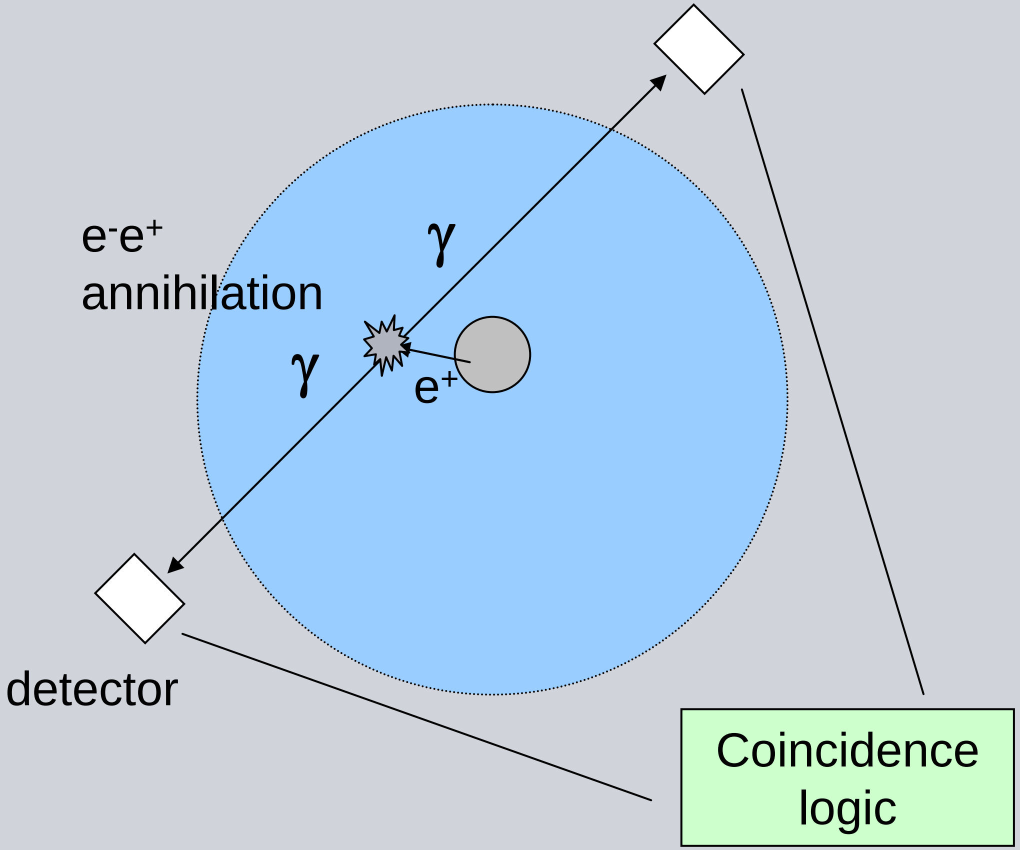
Positron Emission Tomography:
Principles, Detectors and Imaging Performance

Dr. Debora Henseler, Siemens MED, Forchheim

PET – Basic Principle



- positron emitters used as tracer molecules
- positrons annihilate with surrounding electrons:
  → two γ photons emitted in opposite directions:
  2 x 511 keV
- 180° emission enables „electronic collimation“

Positron Emission Tracers

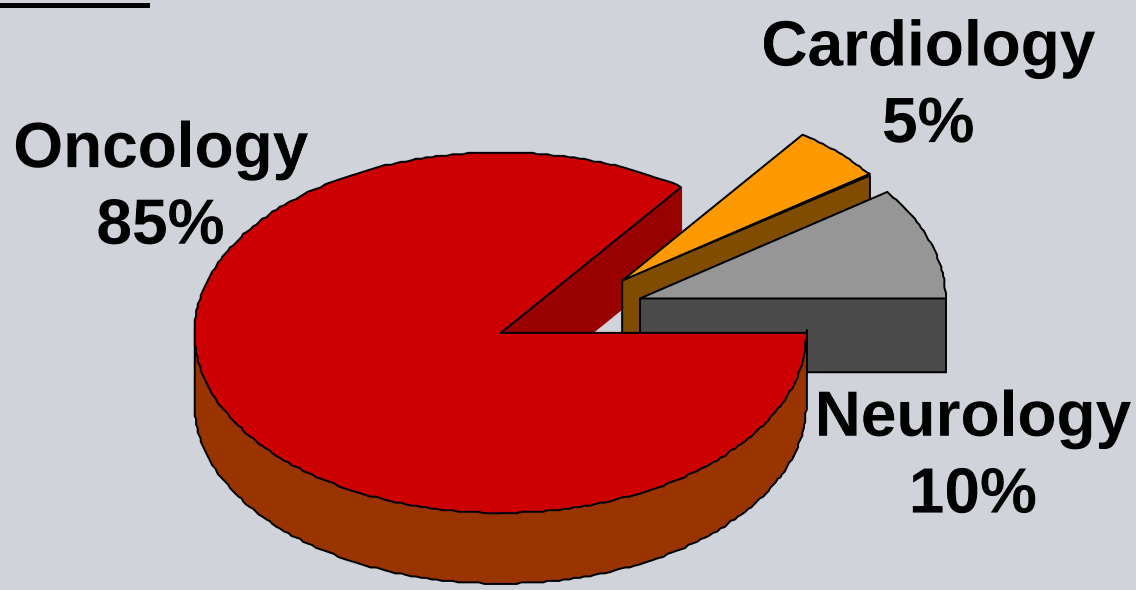
tracer = positron emitter + biomolecule

Positron emitter	half-life [min]	mean absorption length [mm]
^{11}C	20.4	~0.3
^{13}N	9.9	~0.4
^{15}O	2.9	~1.5
^{18}F	**110**	**~0.2**

- most common PET tracer is **FDG**: ^{18}F labelled fluoro-deoxy-glucose
- requires cyclotron for production
- PET tracers provide **functional imaging**, in this case showing **metabolic activity**

Application of PET Imaging

Clinical PET Procedures:



- **Clinical PET Systems:**

  combined PET/CT scanners provide anatomical + functional imaging

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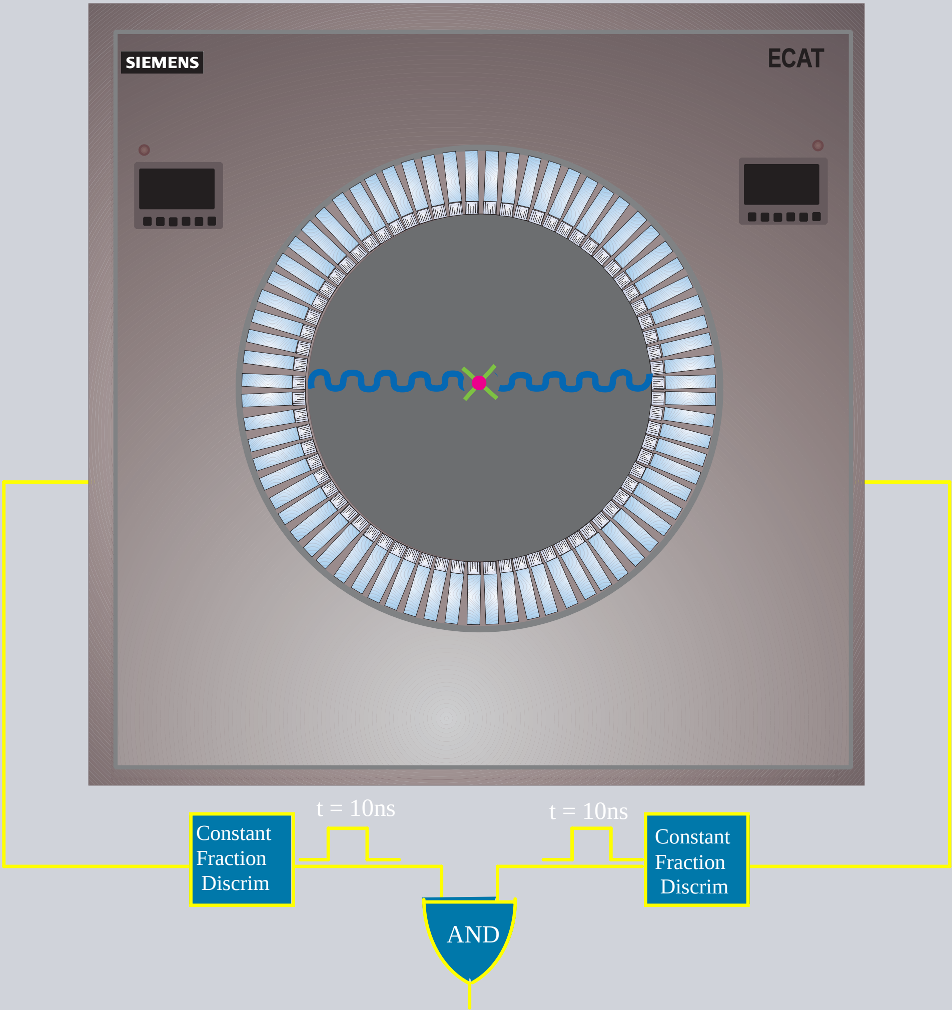
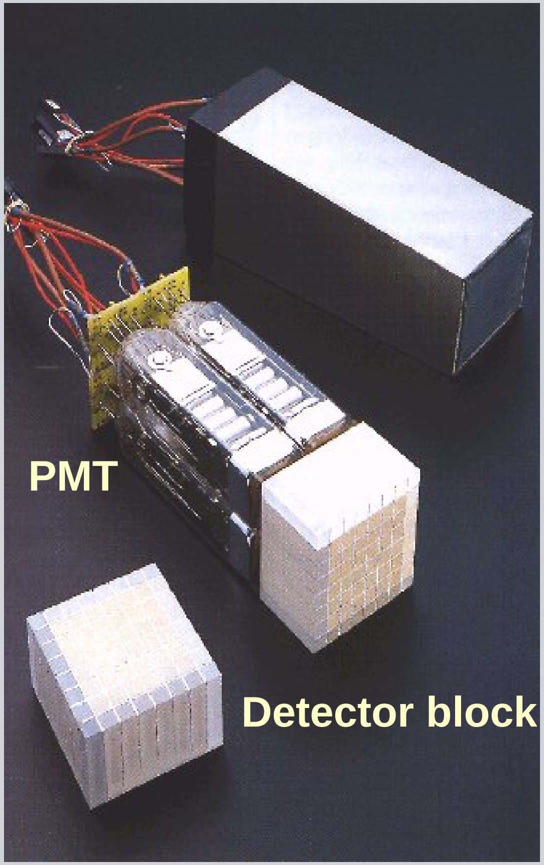
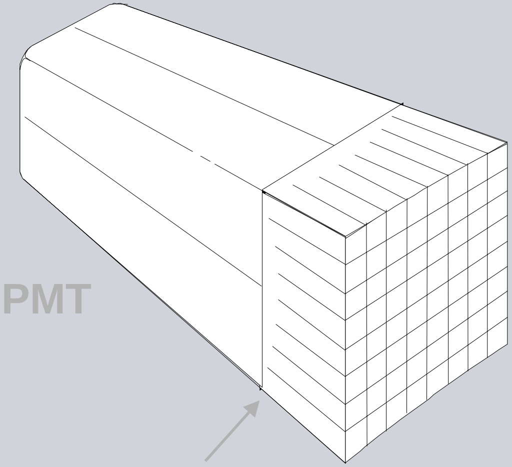
Clinical PET Systems

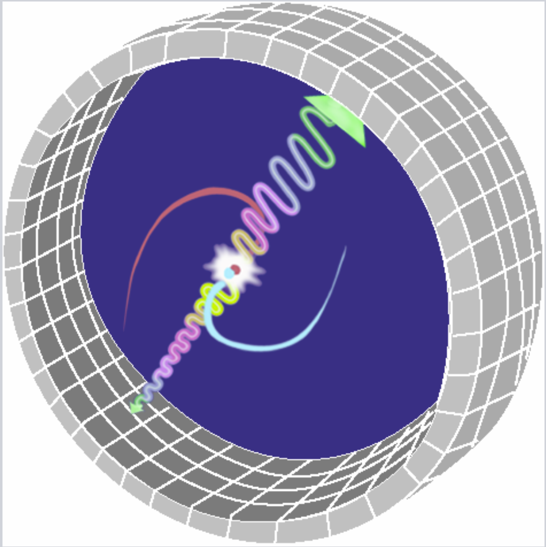


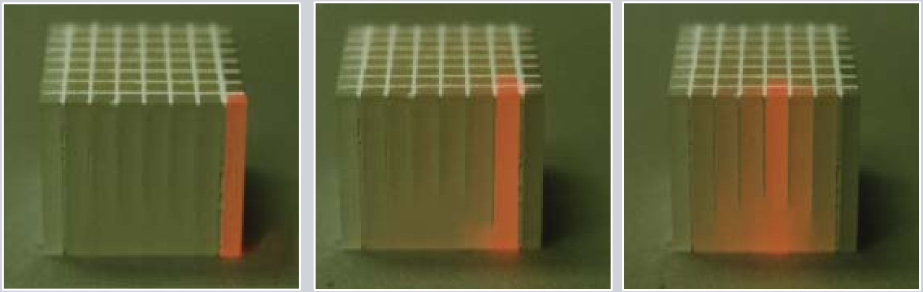
- non-rotating gantry
- circular arrangement of detector blocks
- coincidence time window of few ns
- line of response determined for each coincidence event

PET Block Detectors









Channeled scintillation light

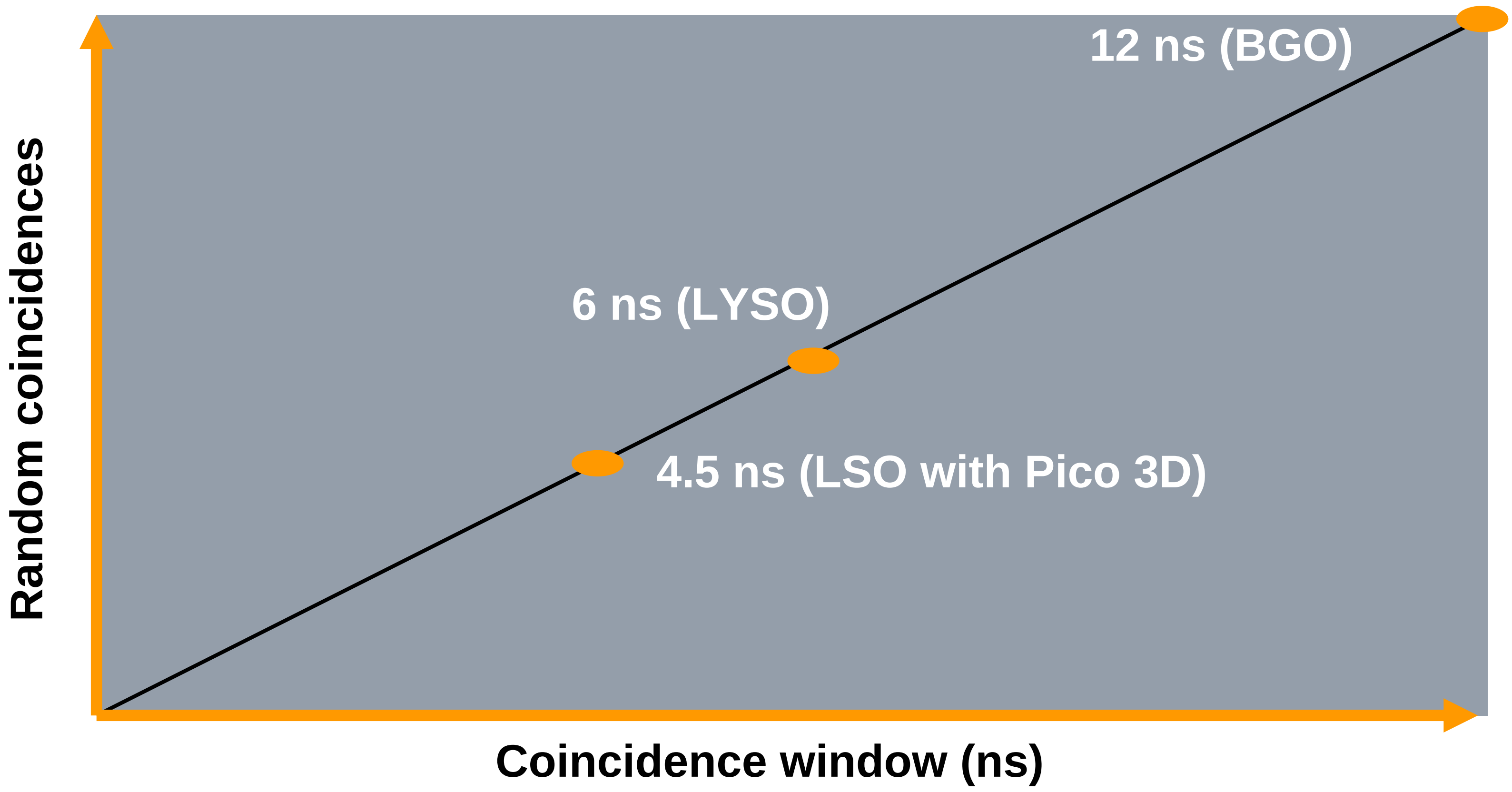
PET Scintillators

	NaI	BGO	GSO	LSO
Mean Free Path (cm)	2.88	1.05	1.43	1.16
Decay Time (nsec)	230	300	60; 600	40
Relative Light Output	100	15	25	75
Hygroscopic?	yes	no	no	no

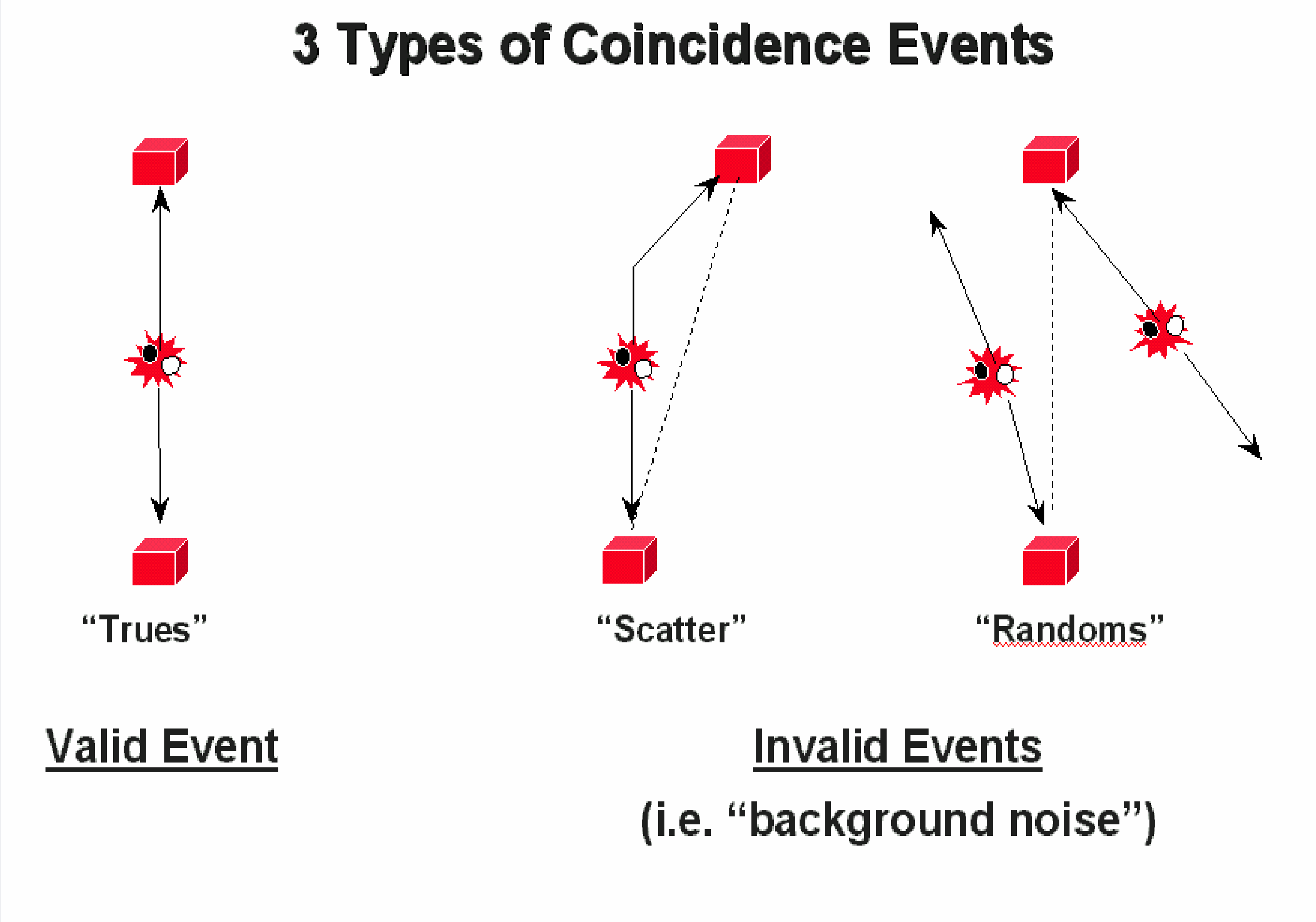
- high density and atomic number needed for 511 keV absorption
- fast decay time for coincidence timing
- high light output for good energy resolution

LSO crystal

Imaging Performance: 1) Coincidence Timing



Imaging Performance: 2) Scatter



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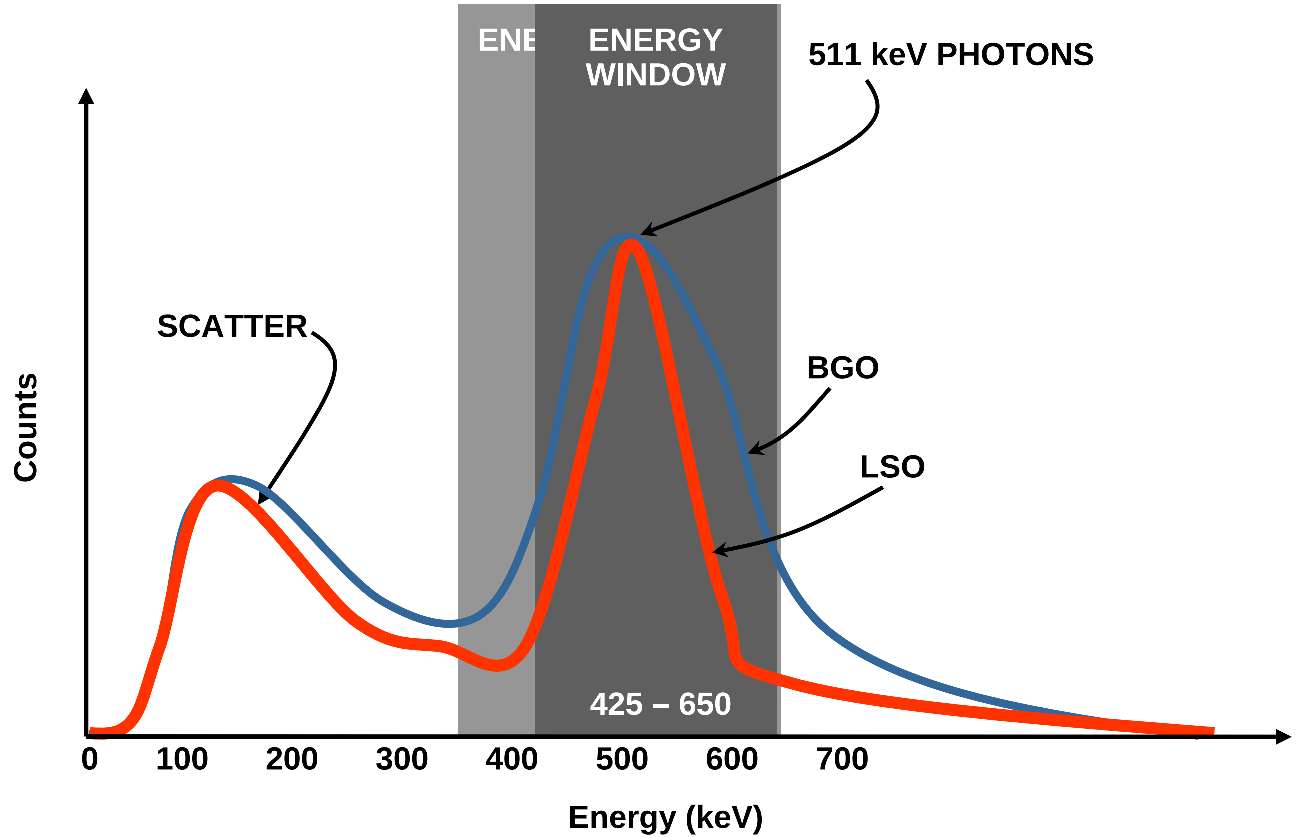
Imaging Performance: 2) Scatter

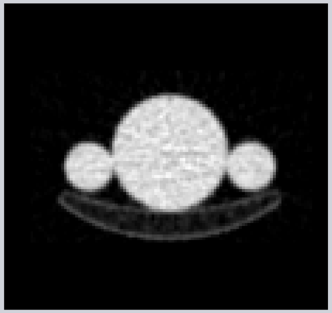
PET events are distributed across a range of energy, not only in the 511 keV range. **An energy window is employed to reject scatter.**



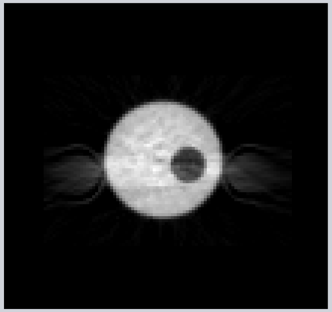
Imaging Performance: 2) Scatter

Scatter Correction:

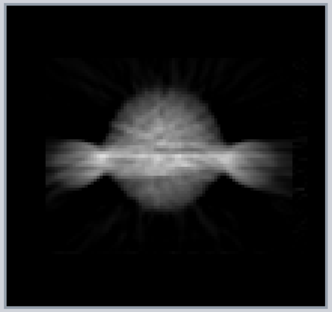
- Transmission map provides physical scatter boundaries
- Emission map provides distribution of activity, including scatter
- Scatter map determined from transmission and emission images
- Intrinsically accounts for varying patient geometry
- Corrects scatter for quantitative accuracy



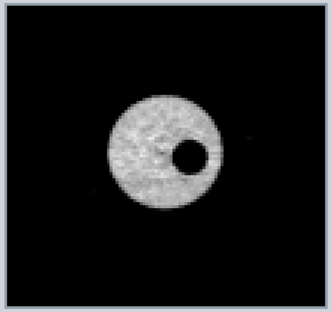
Transmission



Emission



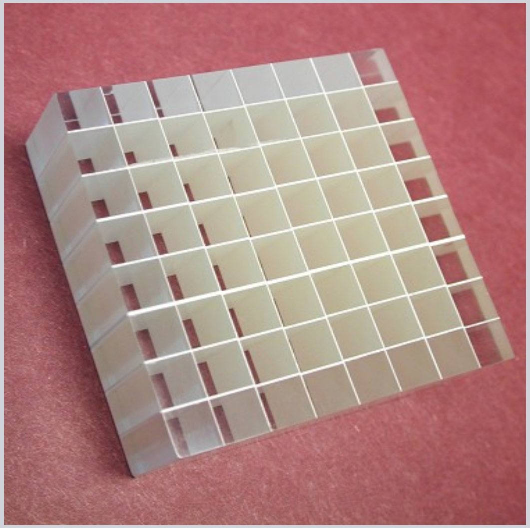
Scatter



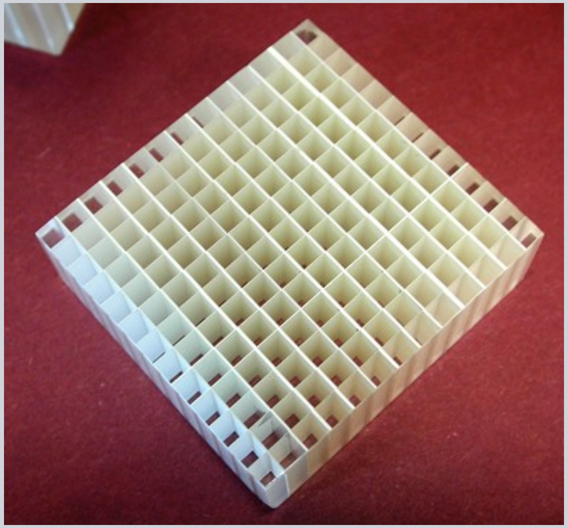
Corrected

Imaging Performance: 3) Spatial Resolution

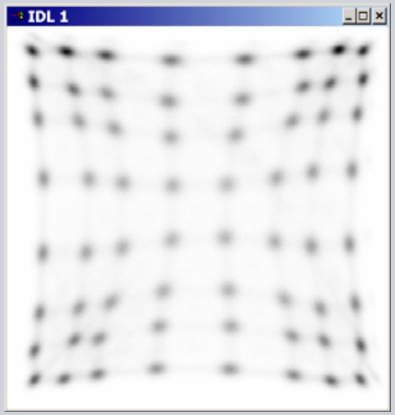
LSO block: 64 x (6.4 x 6.4 mm^2) pixels

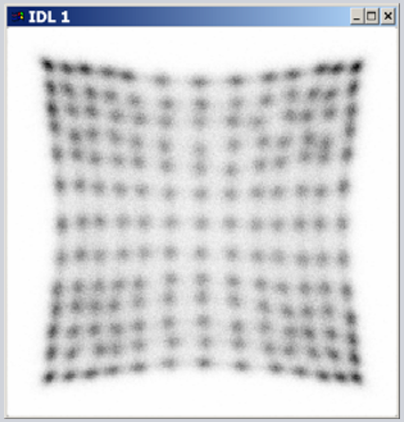


HI-REZ LSO block: 196 x (4 x 4 mm^2) pixels



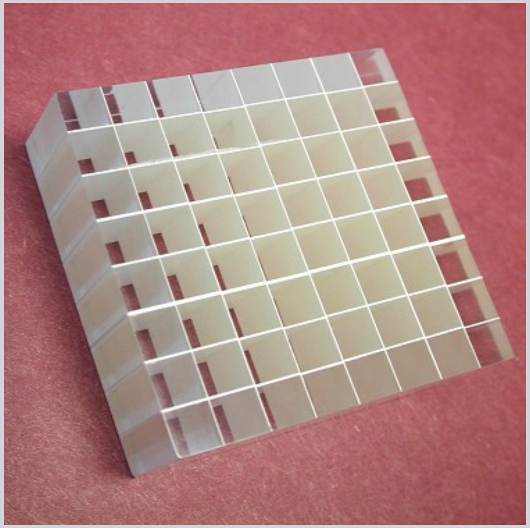
spatial resolution determined by pixel maps:



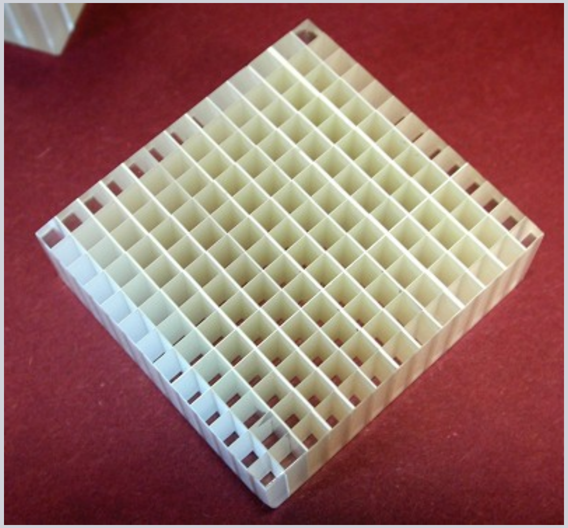


Imaging Performance: 3) Spatial Resolution

LSO block: 64 x (6.4 x 6.4 mm^2) pixels



HI-REZ LSO block: 196 x (4 x 4 mm^2) pixels

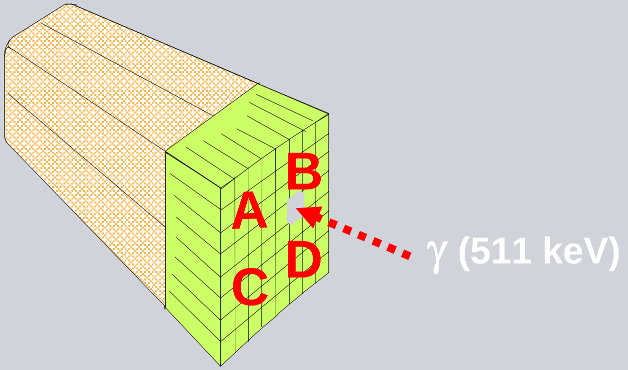


Imaging Performance: 4) Sensitivity

- *thicker crystals*

  20 mm to 30 mm

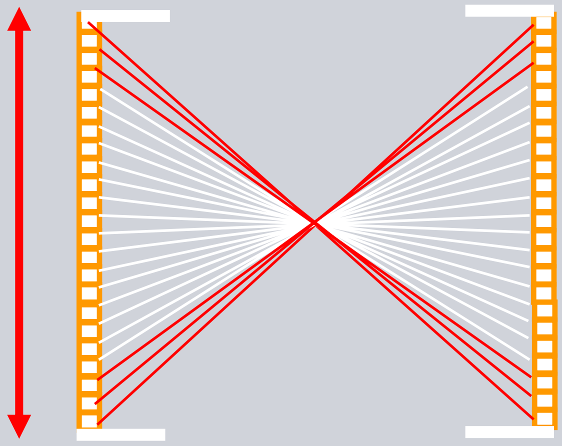
  sensitivity increase: 40%



- *extended axial FOV*

  16.2 cm to 21.6 cm

  sensitivity increase: 77%



3D (no septa)

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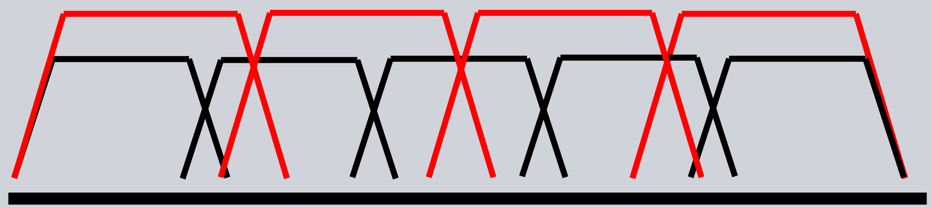
Imaging Performance: 4) Sensitivity

bed # 



Standard:	**5**	**15 min**
Extended FOV:	**4**	**8 min**

- **higher sensitivity = shorter imaging per bed (or more counts)**
- **larger axial FOV = fewer bed positions for same axial coverage**

Clinical Examples: 1) Standard Update Values

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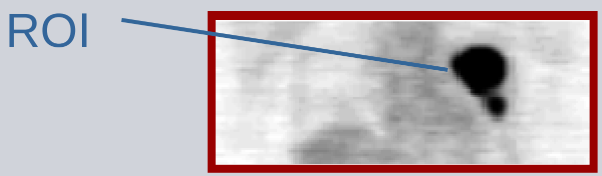
- Semiquantitative analysis, based on region of interest values
- Based on applying activity (µCi/cc) in the region of interest to patient weight and dose:

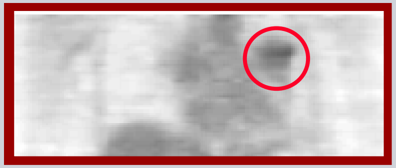
$$\textbf{SUV} = \frac{A_T}{V} \times \frac{Kg}{A}$$

where:

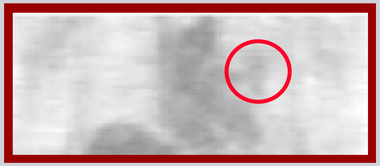
A_T = Activity in ROI
V = Volume of ROI
Kg= Patient Weight
A = Injected Activity



before chemotherapy
SUV = 17.2

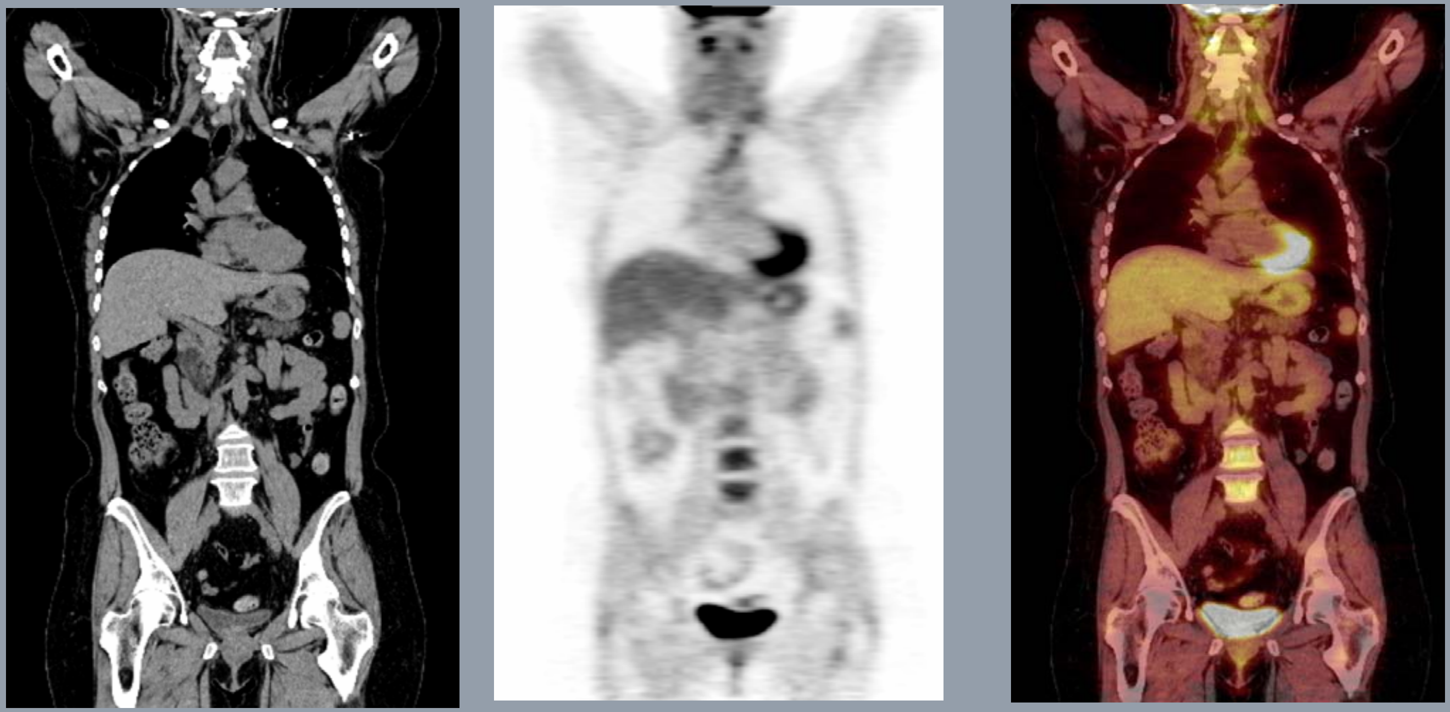


chemotherapy day 7
SUV = 3.9



chemotherapy day 42
SUV = 1.8

Clinical Examples: 2) PET / CT Scan



Melanoma

59 year old female (65 kg) with a history of metastatic melanoma, for assessment of possible recurrence near pancreas. No evidence of melanoma recurrence in the areas visualized.

Scan protocol: CT 140 mAs, 120 kV, 5 mm slices

PET 414 MBq FDG, 198 min p.i, 5 min/bed, 6 beds, 30 min scan time

Clinical Examples: 3) ^{18}F Fluoride Bone Scan

Normal study

Metastatic breast cancer

CT: 111 mAs, 120 kV, 5 mm slices
PET: 11.1 mCi ^{18}F-fluoride, 60 min p.i, 4 min/bed, 7 beds

CT: 157 mAs, 120 kV, 5 mm slices
PET: 11.8 mCi ^{18}F-fluoride, 110 min p.i, 4 min/bed, 9 beds

Current Topics: 1) HD•PET Technology

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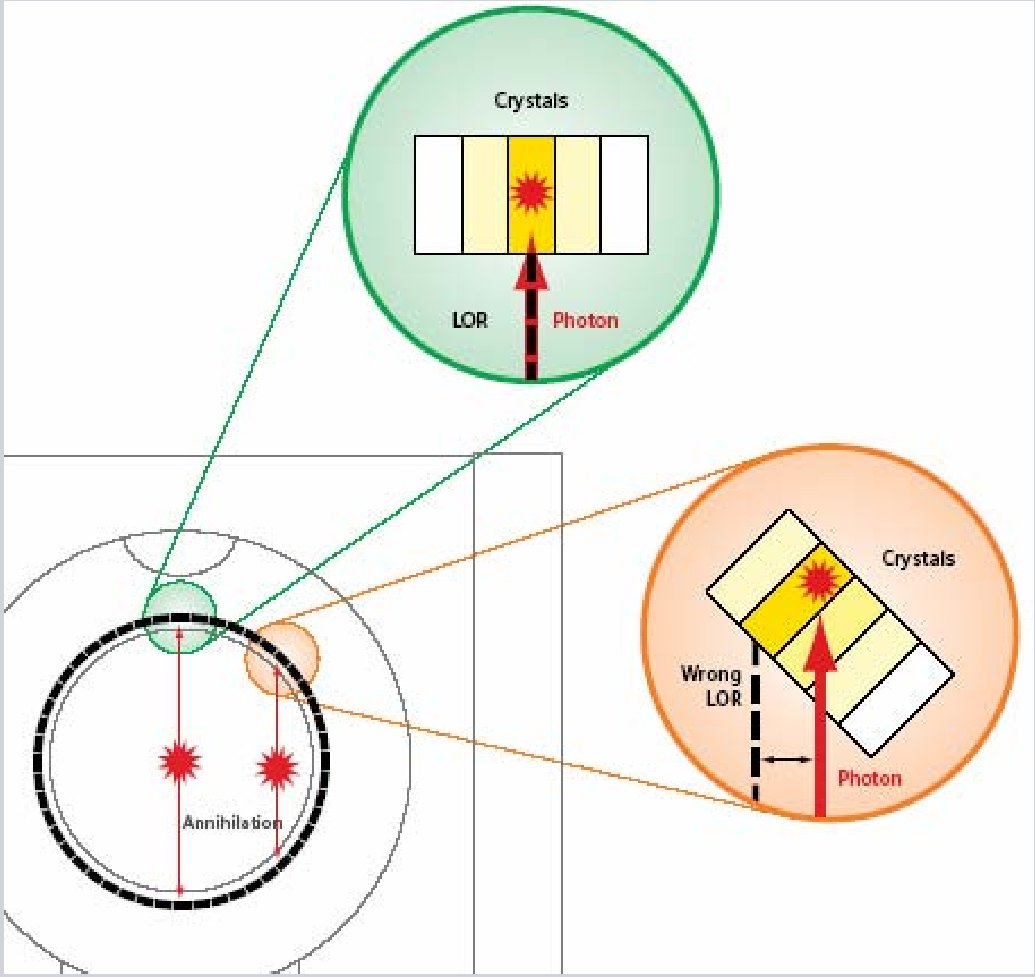
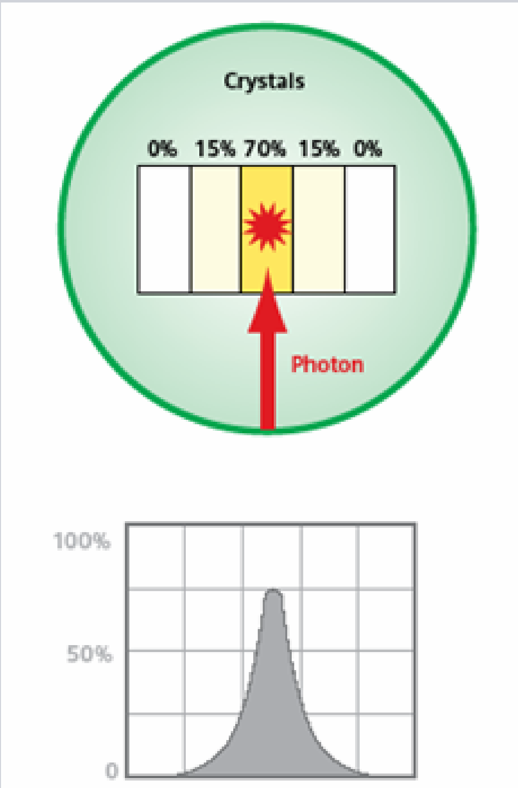


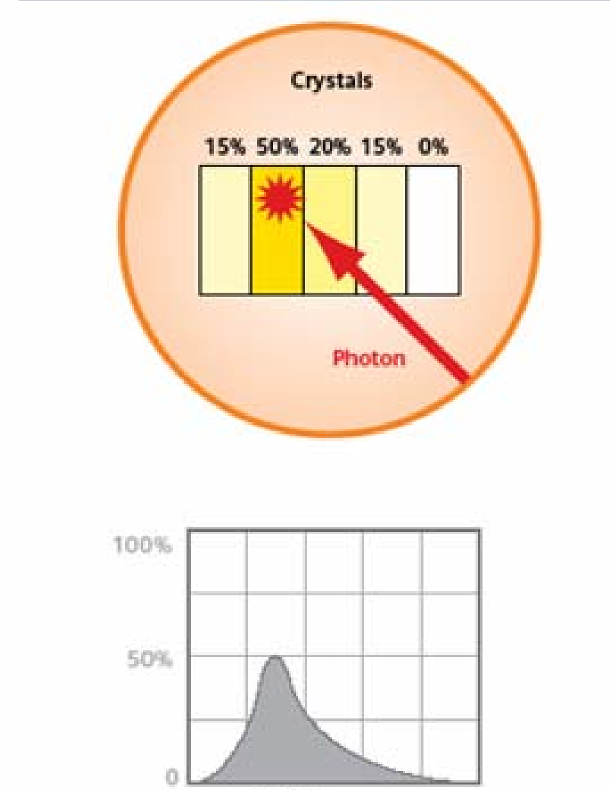
When a photon strikes a crystal, it travels a certain distance before its energy is converted into light. If the photon comes from the center of the field of view (FOV), the line of response (LOR) is likely to be correctly localized in the crystal in which the photon entered.

The further away from the center of the FOV, the less likely the LOR will be calculated correctly because the photon will hit the crystal on an angle and continue traveling to another crystal before it lights up.

Current Topics: 1) HD•PET Technology



PSF
(Center of FOV)



PSF
(Away from Center of FOV)

A Point Spread Function (PSF) describes the response of an imaging system to a point source or point object. A system that knows the response of a point source from everywhere in its field of view can use this information to recover the original shape and form of imaged objects.

PSFs are used in precision imaging instruments, such as microscopy, ophthalmology, and astronomy (e.g. the Hubble telescope) to make geometric corrections to the final image.

HD PET

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TrueX IMAGE RECONSTRUCTION

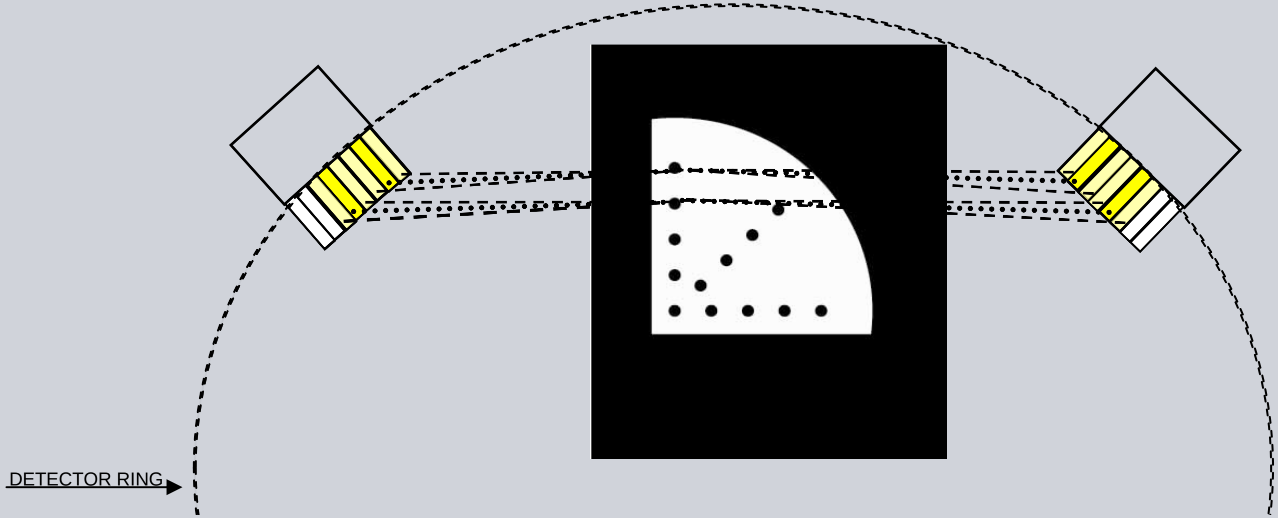
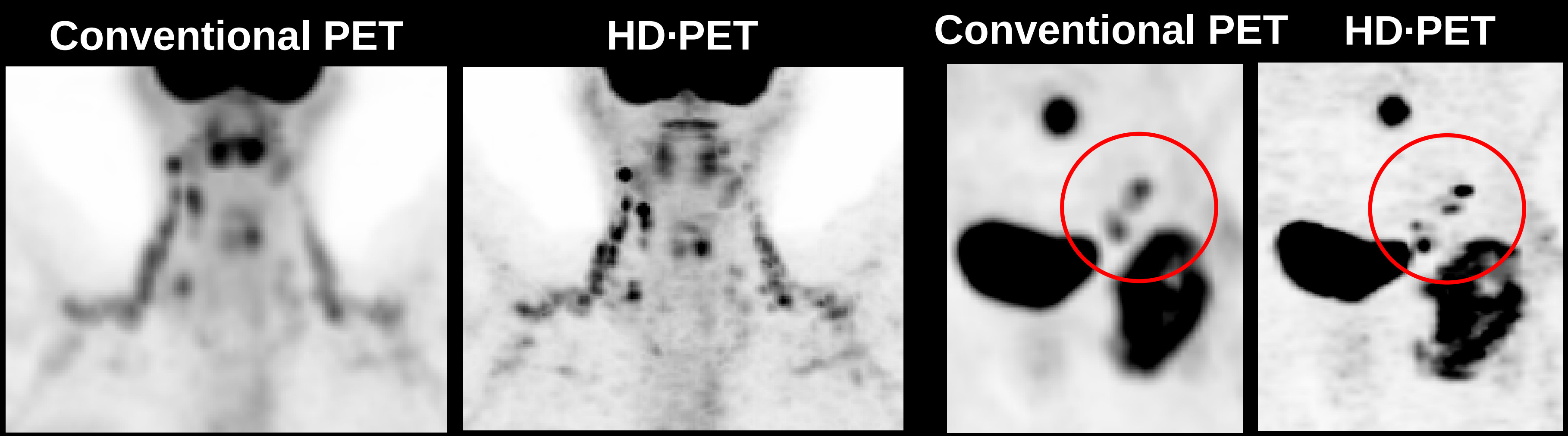


Image reconstruction in HD PET account for the PSF to restore a “de-blurred” image much closer to reality. As each PSF is variable for each LOR, millions of PSF were measured and incorporated in the reconstruction process.

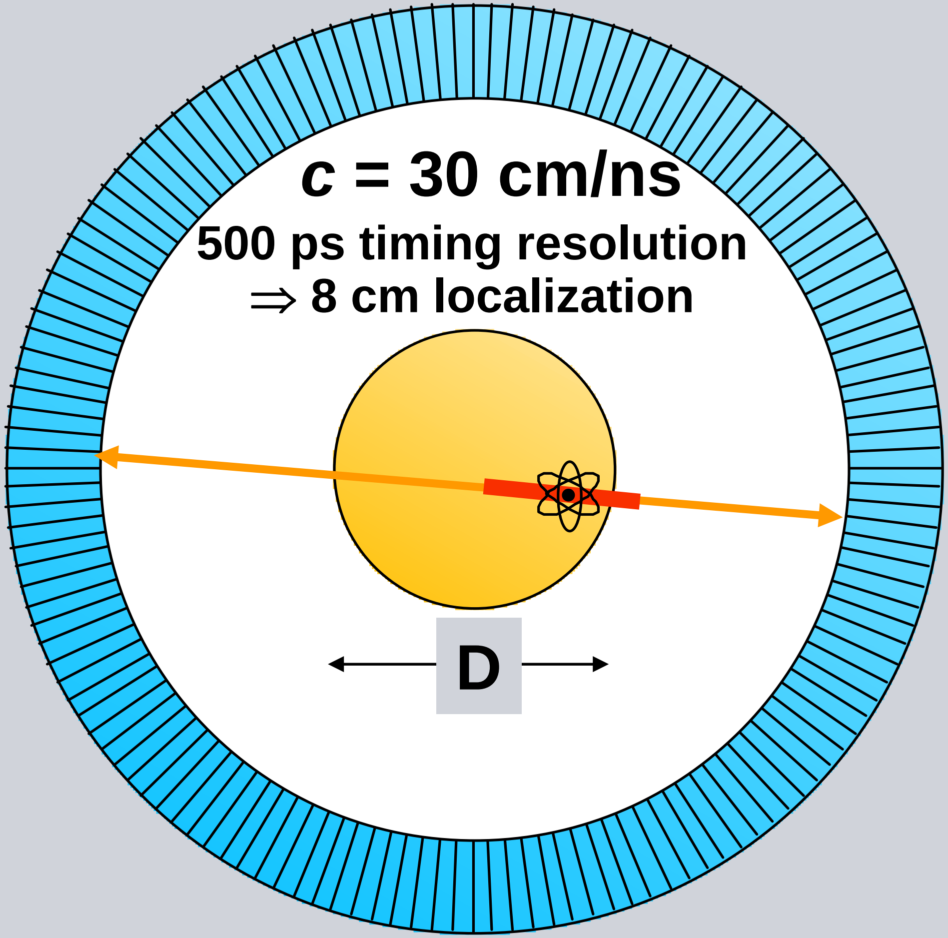
Current Topics: 1) HD•PET Technology



Source: Data Courtesy of University of Erlangen

Current Topics: 2) Time-of-flight PET

Motivation (Theory)



- Can localize source along line of flight.
- Time of flight information reduces noise in images.
- Variance Reduction Given by 2D/*c*Δt.
- 500 ps Timing Resolution
  ⇒ 5x Reduction in Variance!

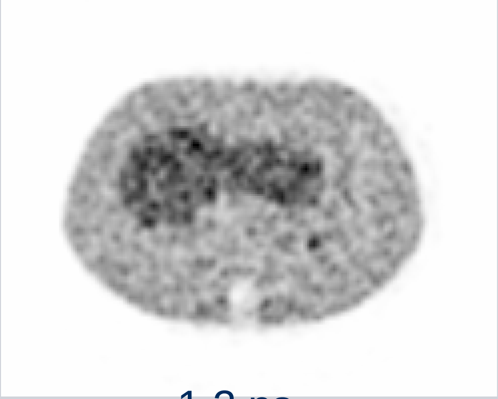
Moses W.W., IEEE Trans. On Nucl. Sci. vol 50(5):1325-1330

Current Topics: 2) Time-of-flight PET

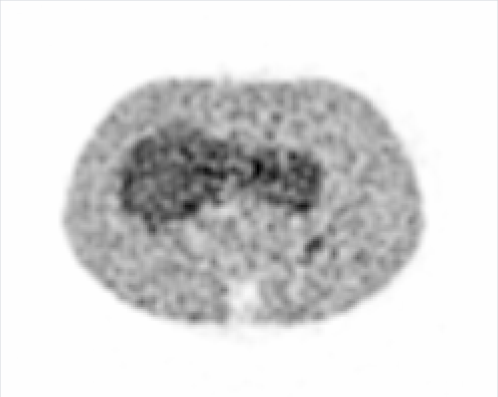
Motivation (Simulation)

- Trues – 2e6
- Randoms – 1e6
- 2 iterations
- 14 subsets

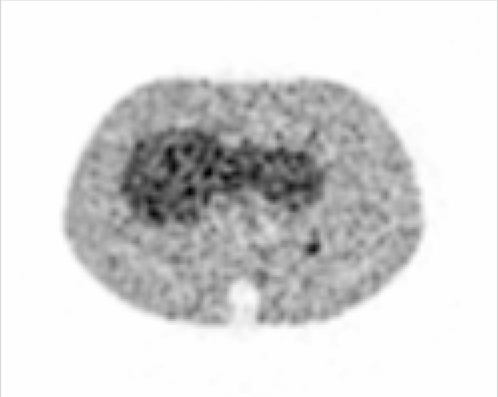
Conventional



1.2 ns



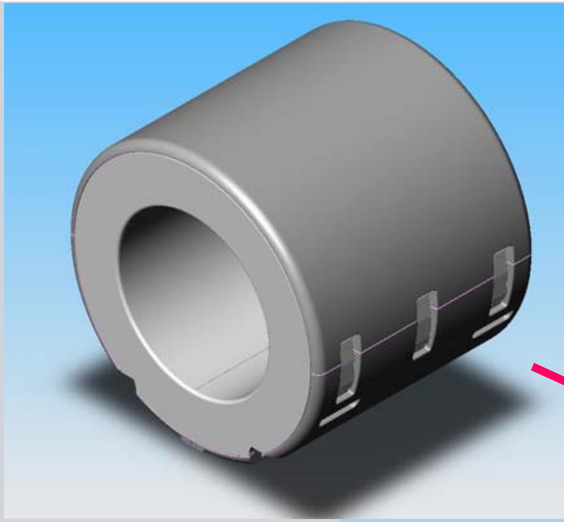
700 ps

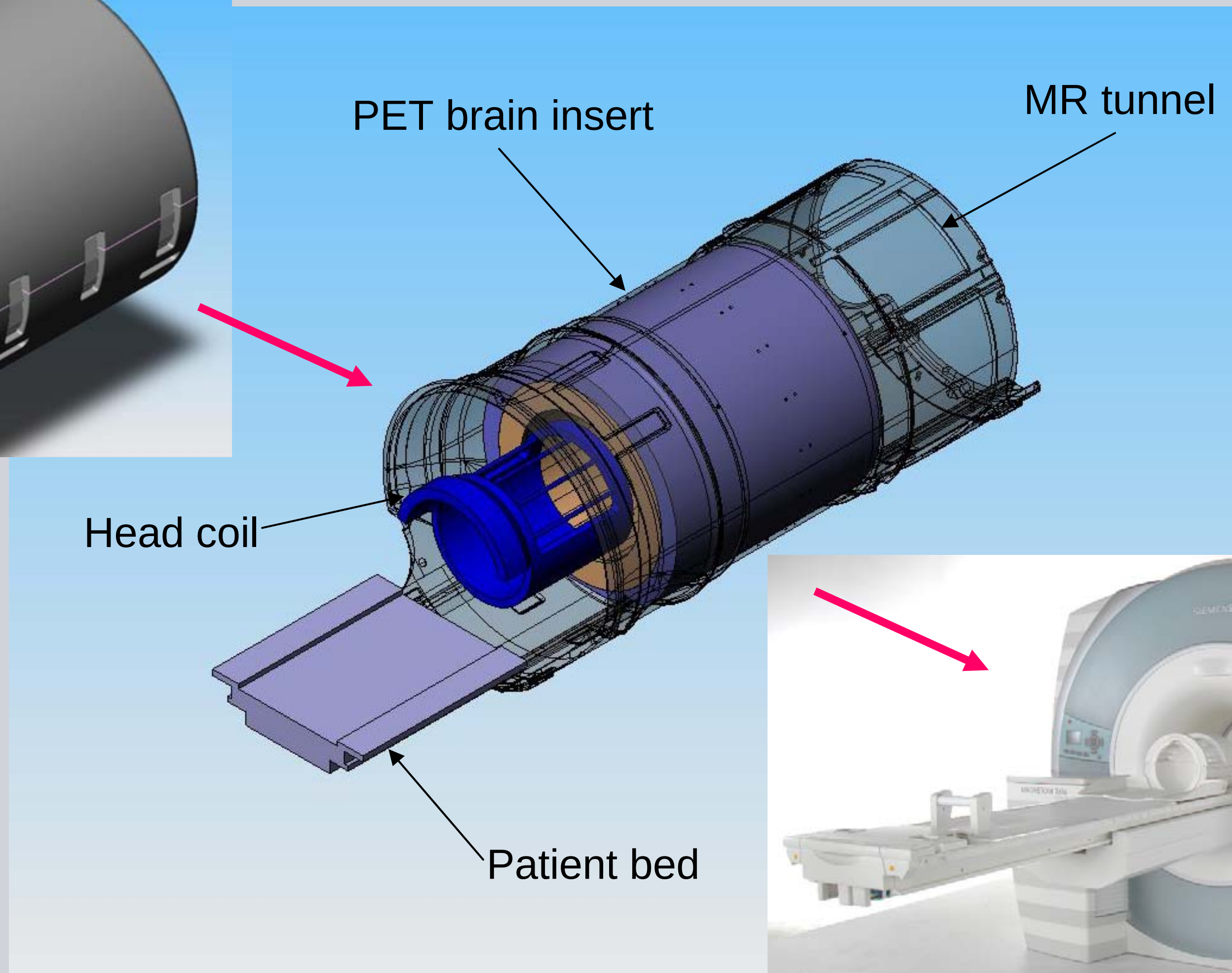


500 ps

From Mike Casey, SMI

Current Topics: 3) MR / PET Prototype Design

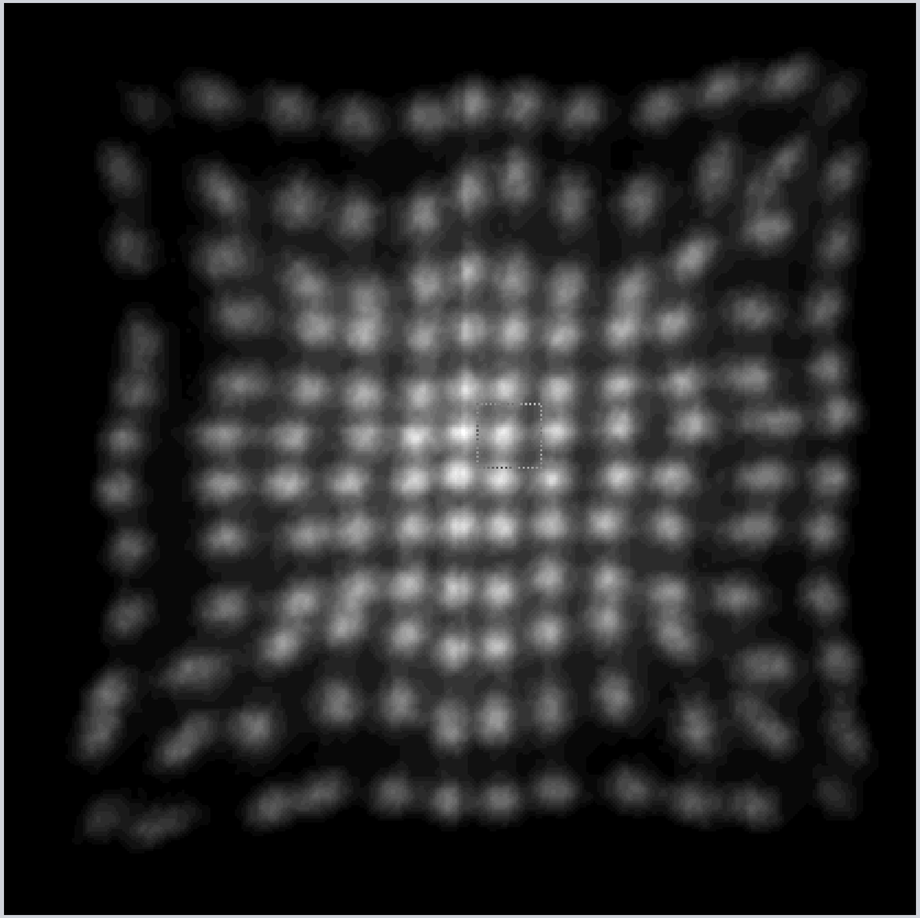




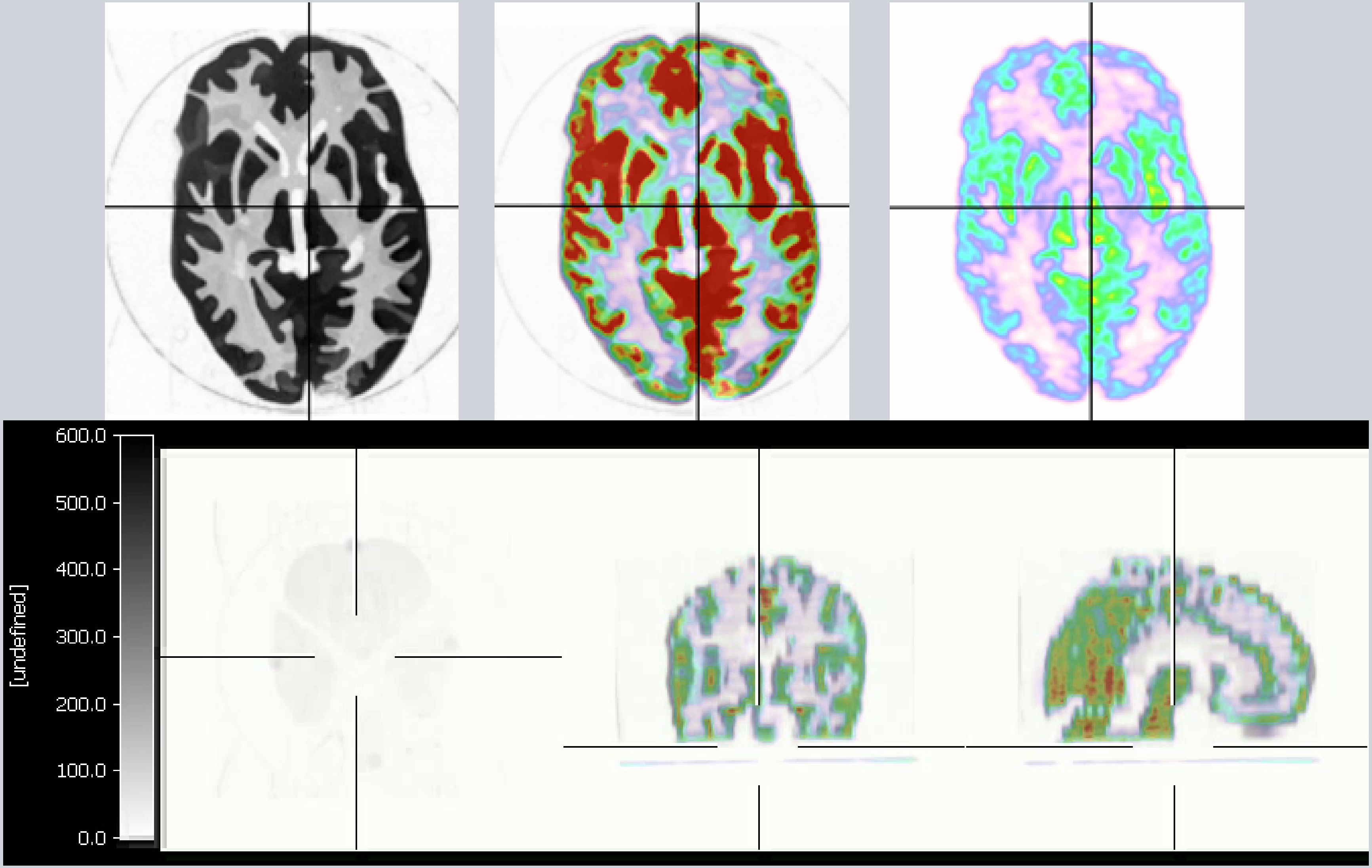
Current Topics: 3) MR / PET Prototype

Block detector performance:

- 12x12 array - 2.5 x 2.5 x 20mm^3 LSO
- 3x3 array - Hamamatsu APDs
- Avg. crystal energy resolution: ~15%
- Avg. crystal time resolution: ~ 5 ns
- Avg. peak-to-valley: 2.5



Hoffman 3D phantom – simultaneous MR/PET



Siemens Molecular Imaging

Innovation is in our genes.