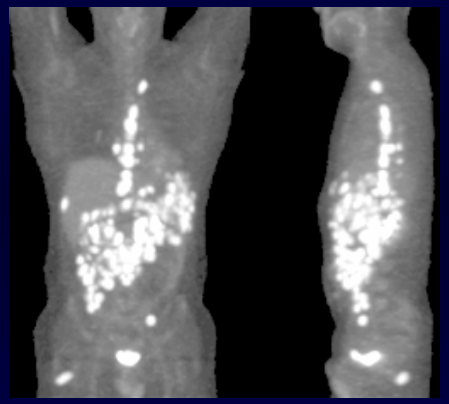
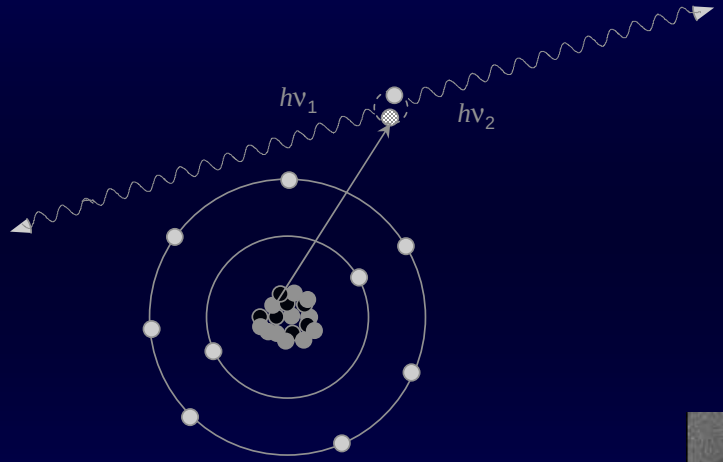
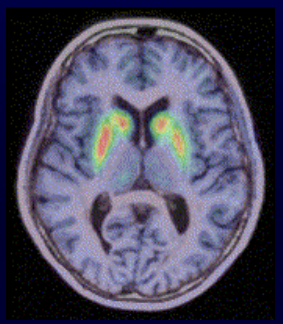
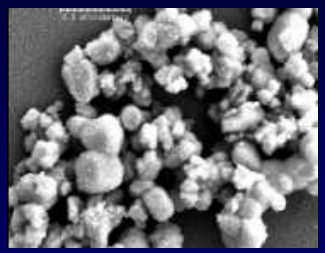
CURRENT STATE-OF-THE-ART IN PET INSTRUMENTATION









Dale Bailey *PhD*

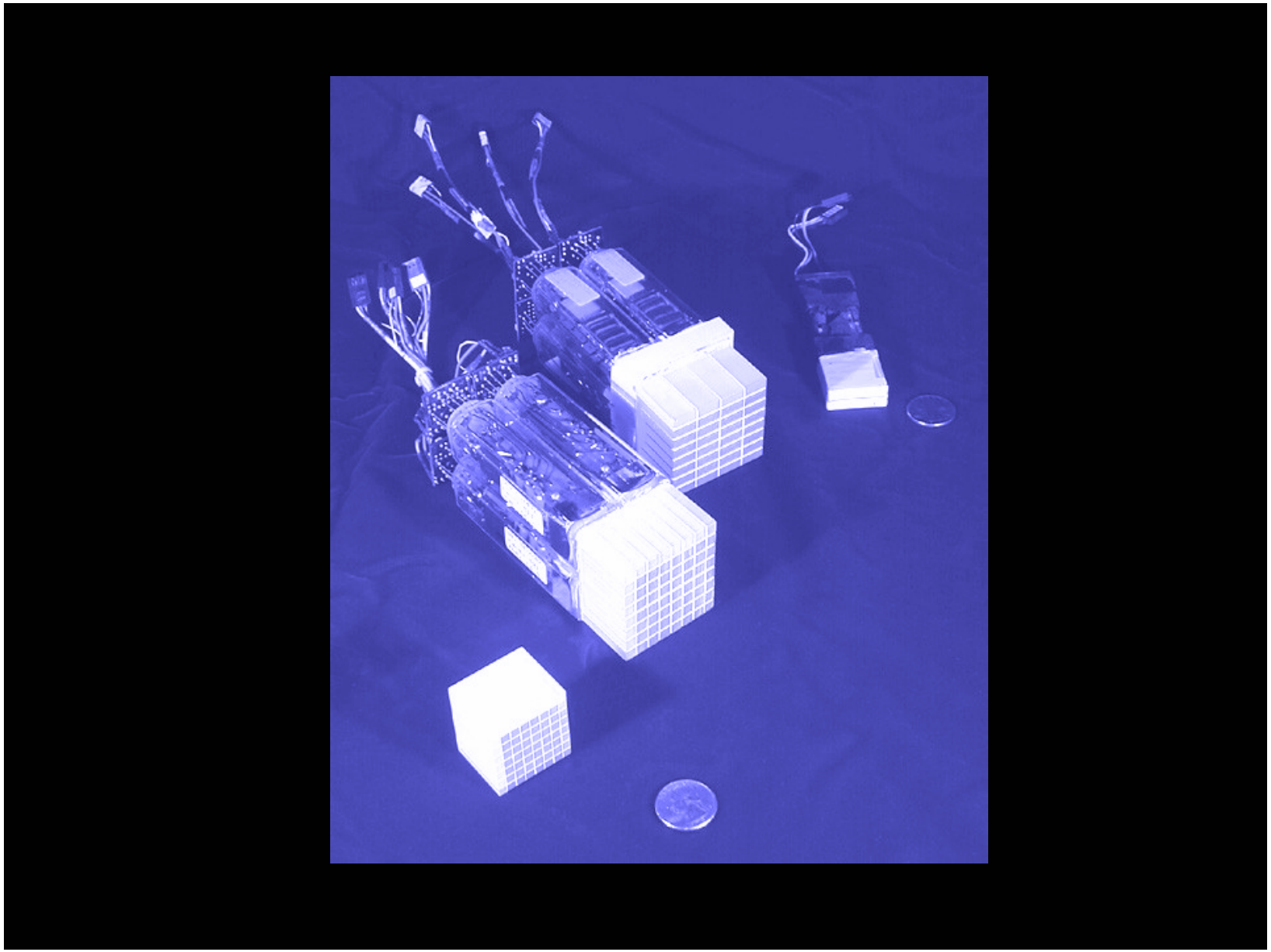
Northern Sydney Health
better health: from the Harbour to the Hawkesbury
ROYAL NORTH SHORE HOSPITAL

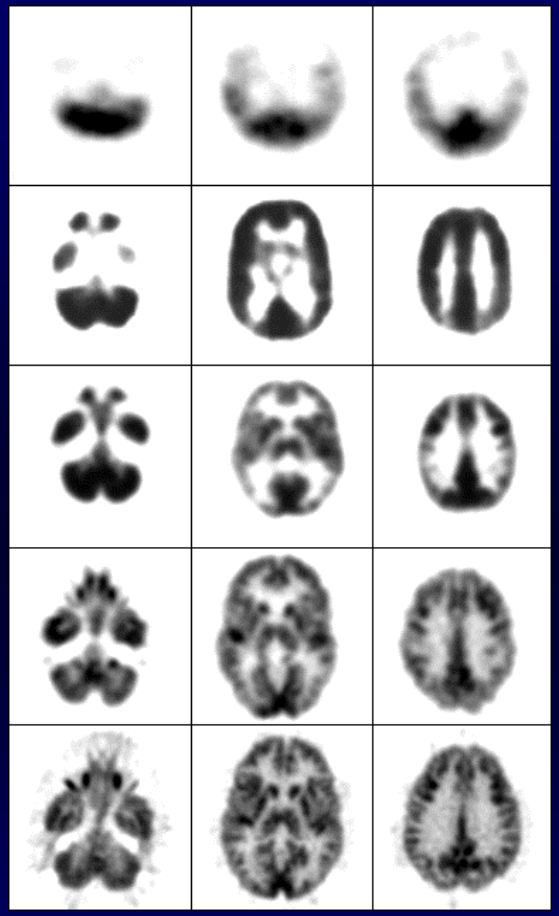
Landmarks in PET Instrumentation

- 1945: [^{11}C]-CO (Tobias)
- 1948: NaI(Tl) - 1st inorganic scintillator (Hofstadter)
- 1951: ^{74}As in brain tumour (Brownell & Sweet)
- 1955: 1st medical cyclotron (Hammersmith)
- 1957: [^{15}O]-O_2 autoradiography (Ter-Pogossian)
- 1973: 1st β^+ tomographic images (Chesler, MGH)
- 1975: PETT - NaI(Tl) (St Louis)

Landmarks in PET Instrumentation

- 1977: BGO for PET suggested (Cho)
- 1986: BGO block detector (Casey & Nutt, CTI)
- 1989: 3D PET (Hammersmith, UCLA)
- 1992: LSO (Melcher)
- 1994: PET/CT (Townsend)
- 2001: 1st commercial LSO PET camera (CTI)
- 2002: GE - BGO, CTI - LSO, Philips - GSO





PETT III (1975)

ECAT II (1977)

NeuroECAT (1978)

ECAT 931 (1985)

ECAT EXACT HR+ (current)

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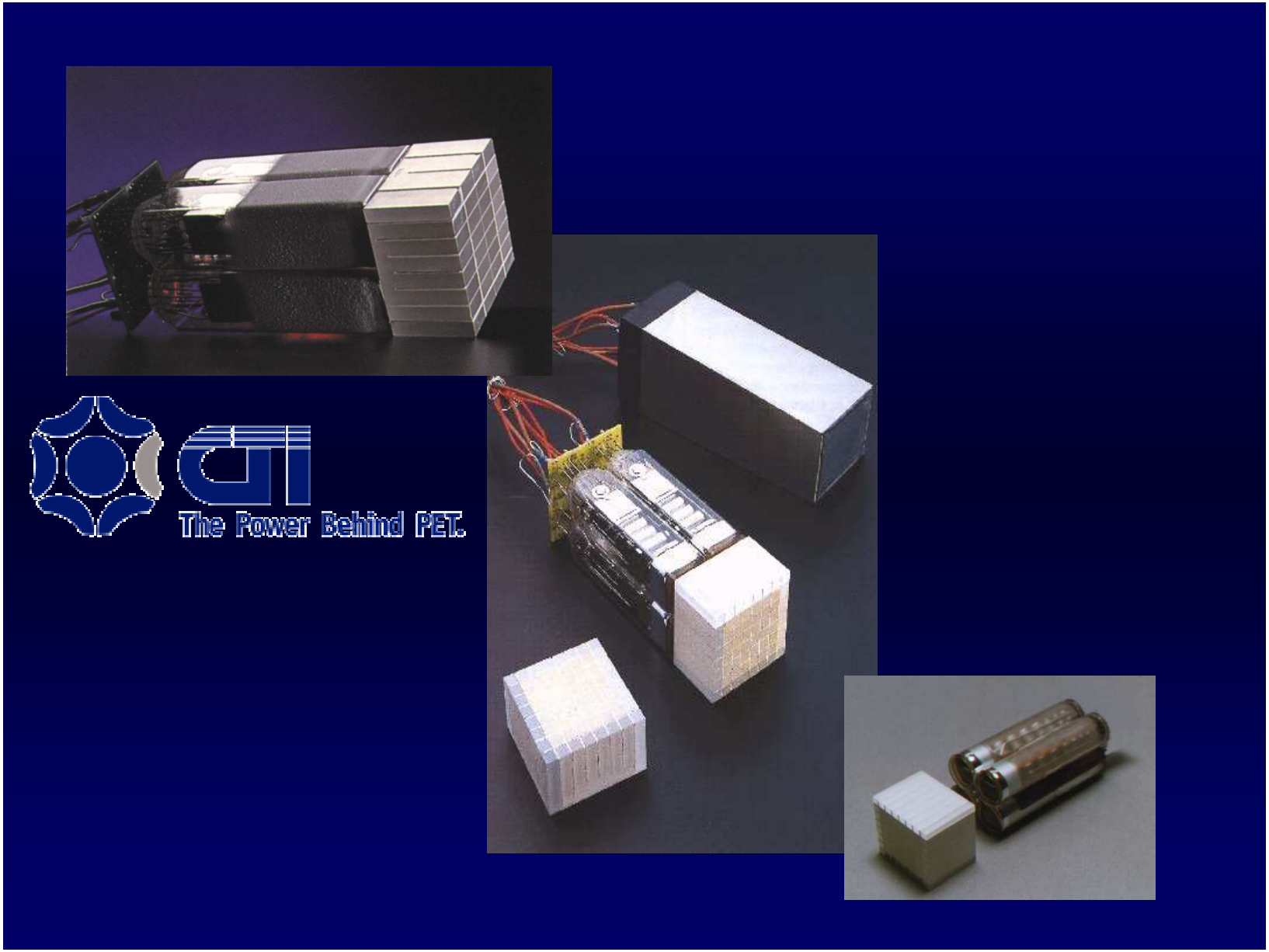
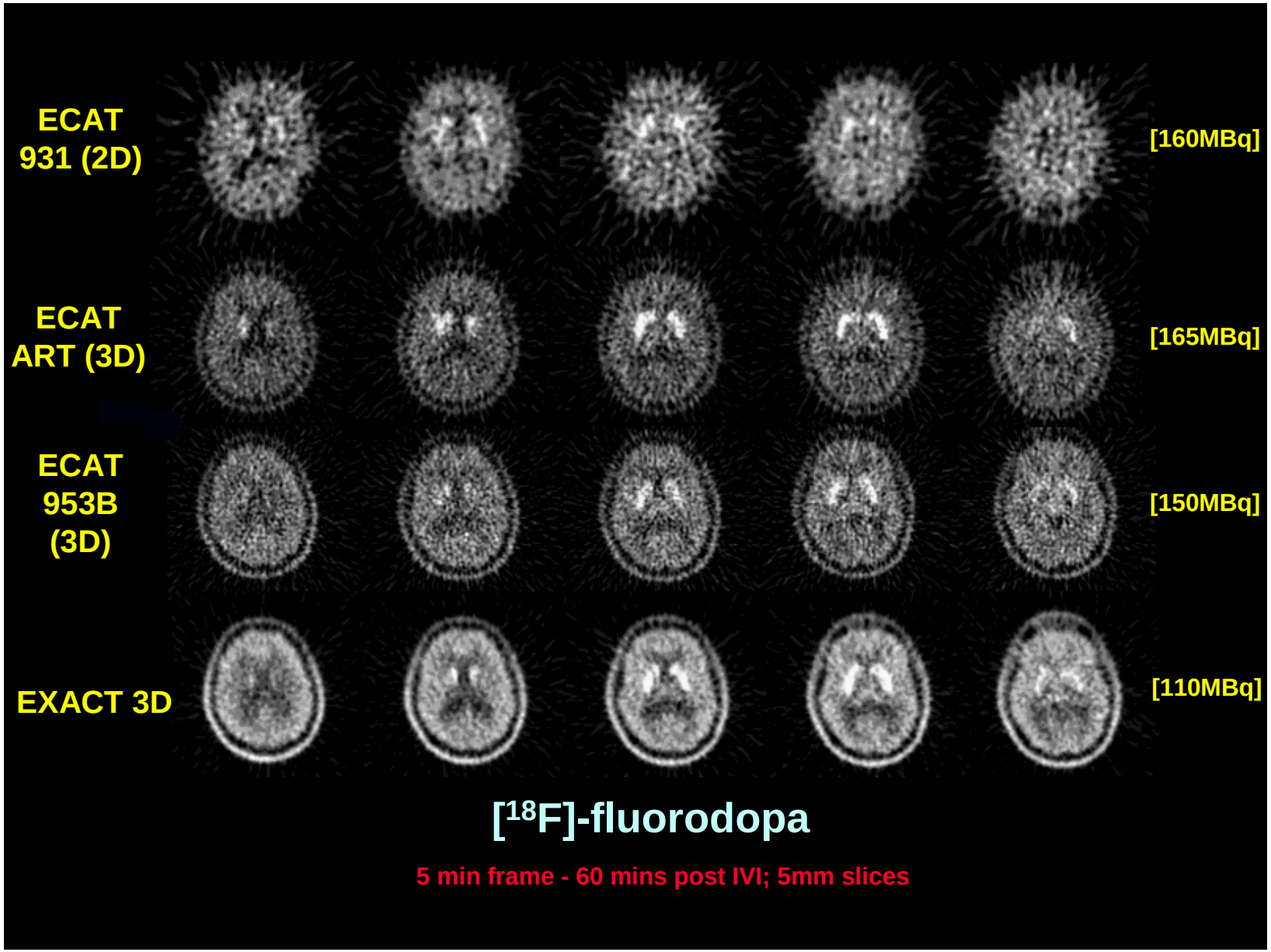

The Power Behind PET.

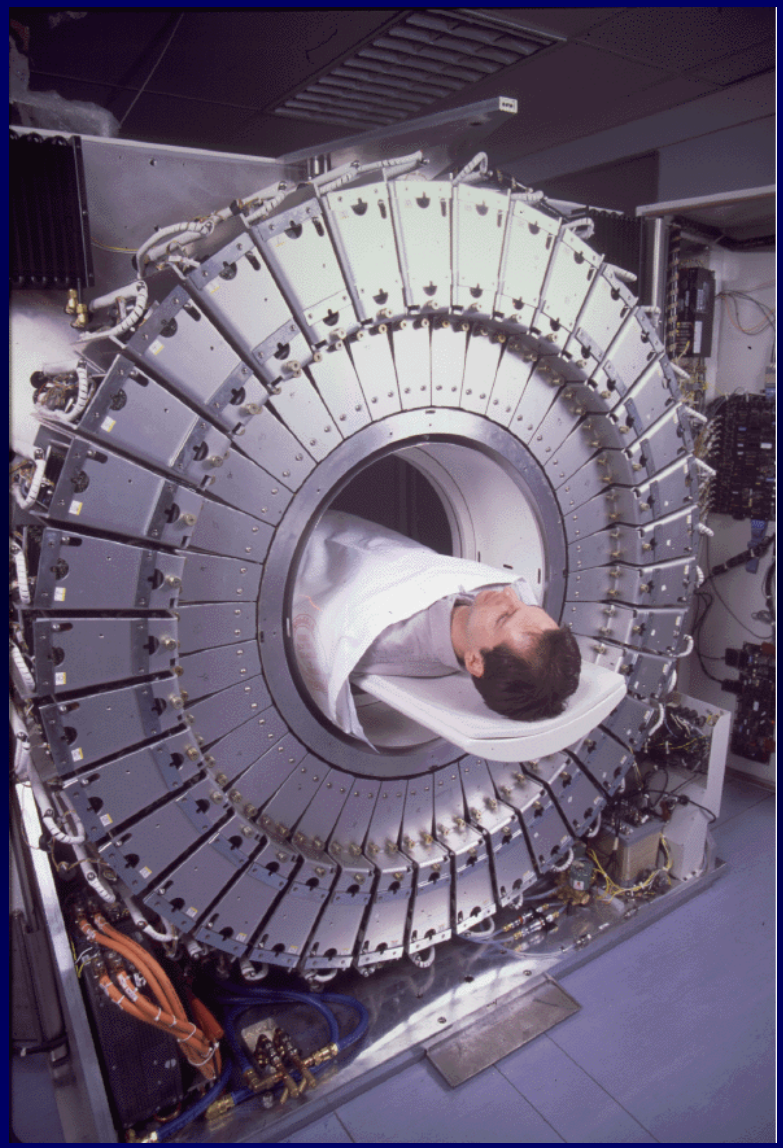

ECAT
931 (2D)
[160MBq]
ECAT
ART (3D)
[165MBq]
ECAT
953B
(3D)
[150MBq]
EXACT 3D
[110MBq]
[18F]-fluorodopa
5 min frame - 60 mins post IVI; 5mm slices

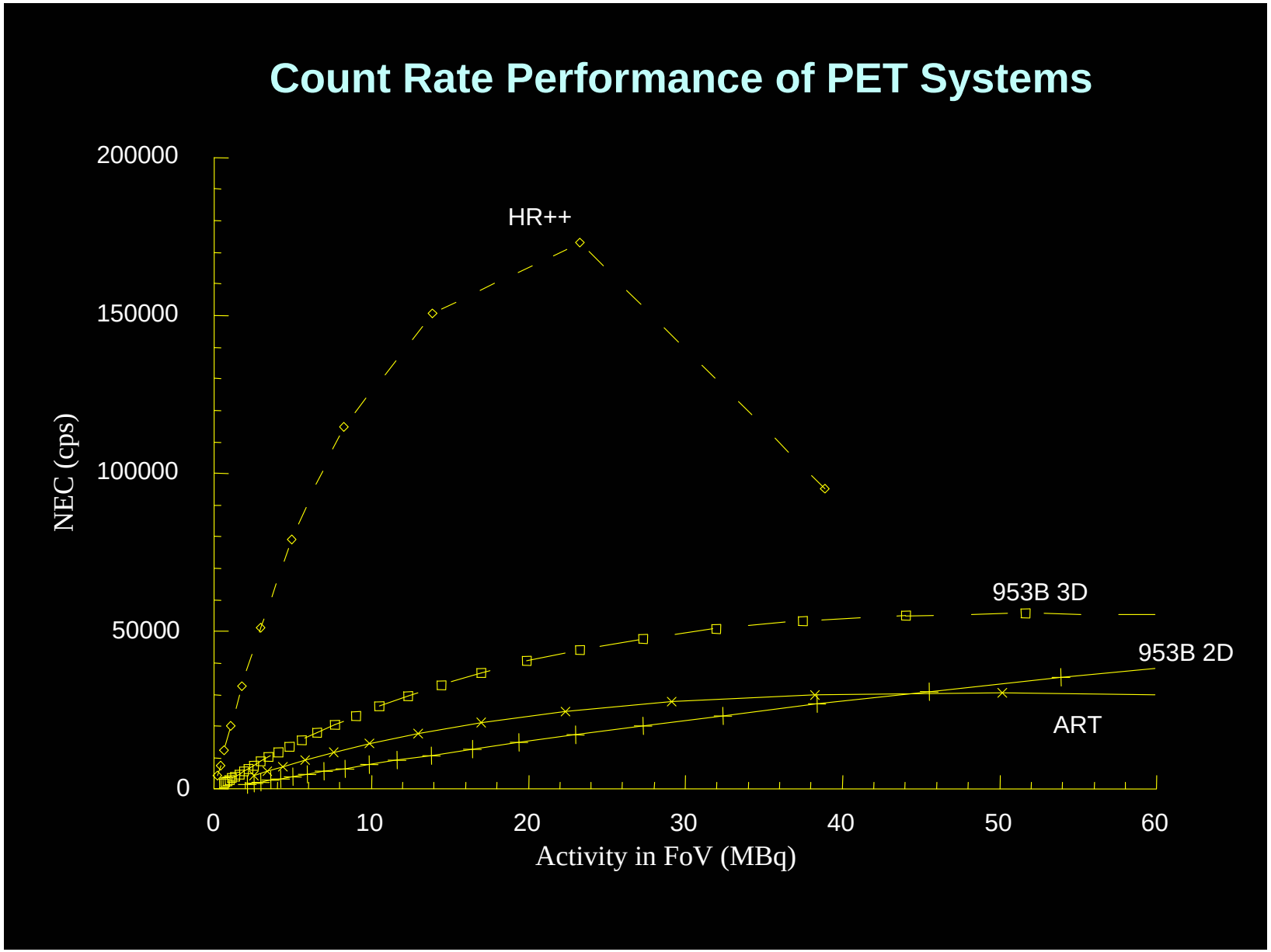
What are the characteristics of today's PET camera?

- **Spatial Resolution**
  - Reconstructed Resolution 4-6 mm FWH — OK
- **Sensitivity**
  - Need dense (>5g/cc) detectors — *x*
  - Very high in 3D mode — ü
- **Energy Resolution**
  - ~10% FWHM at 511 keV — *x*
- **Survey area**
  - Small (<20 cm axial FoV) — *x*
- **Count rate performance**
  - Poor randoms discrimination and dead time (3D mode) — *x*

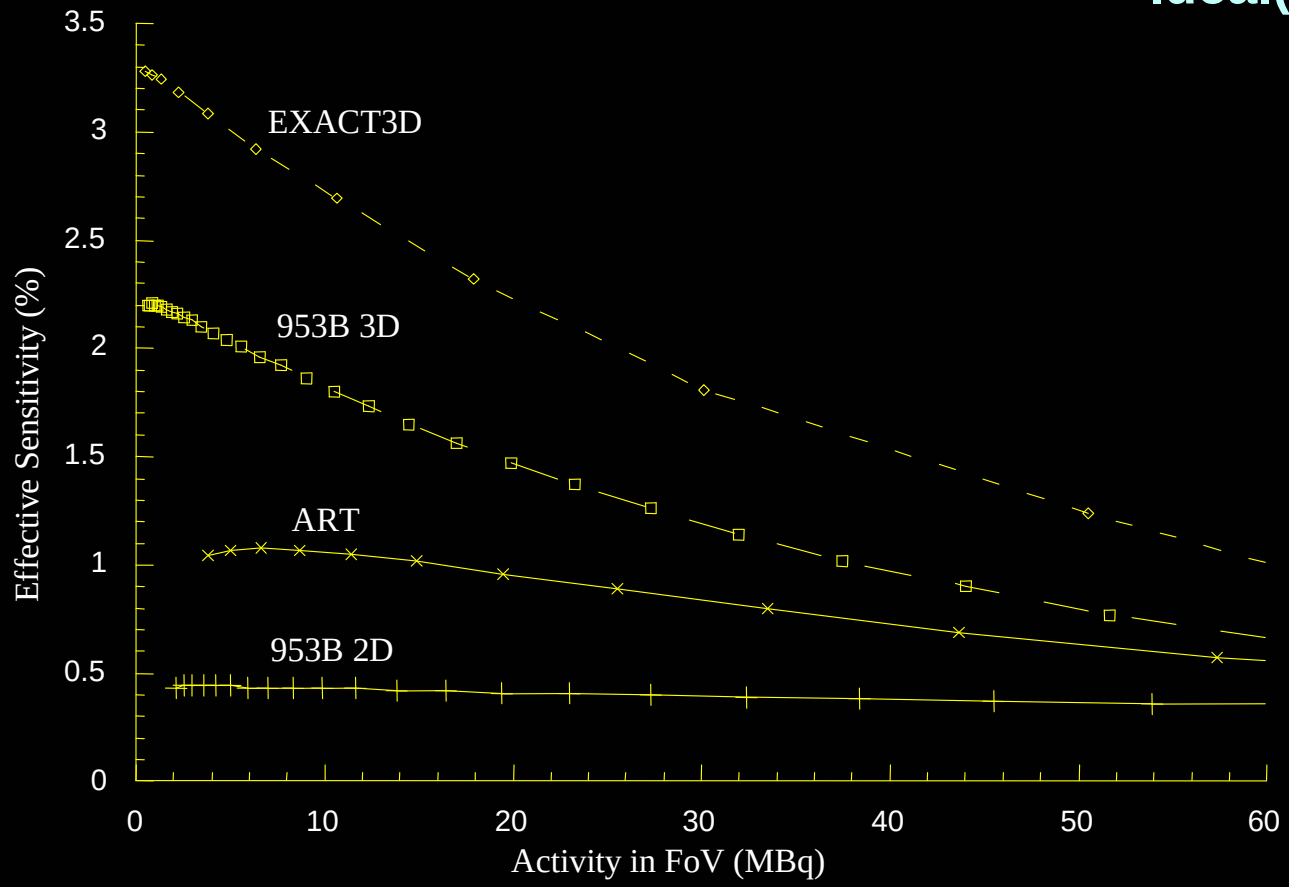
What is the Impact of a 'Slow' Scintillator?

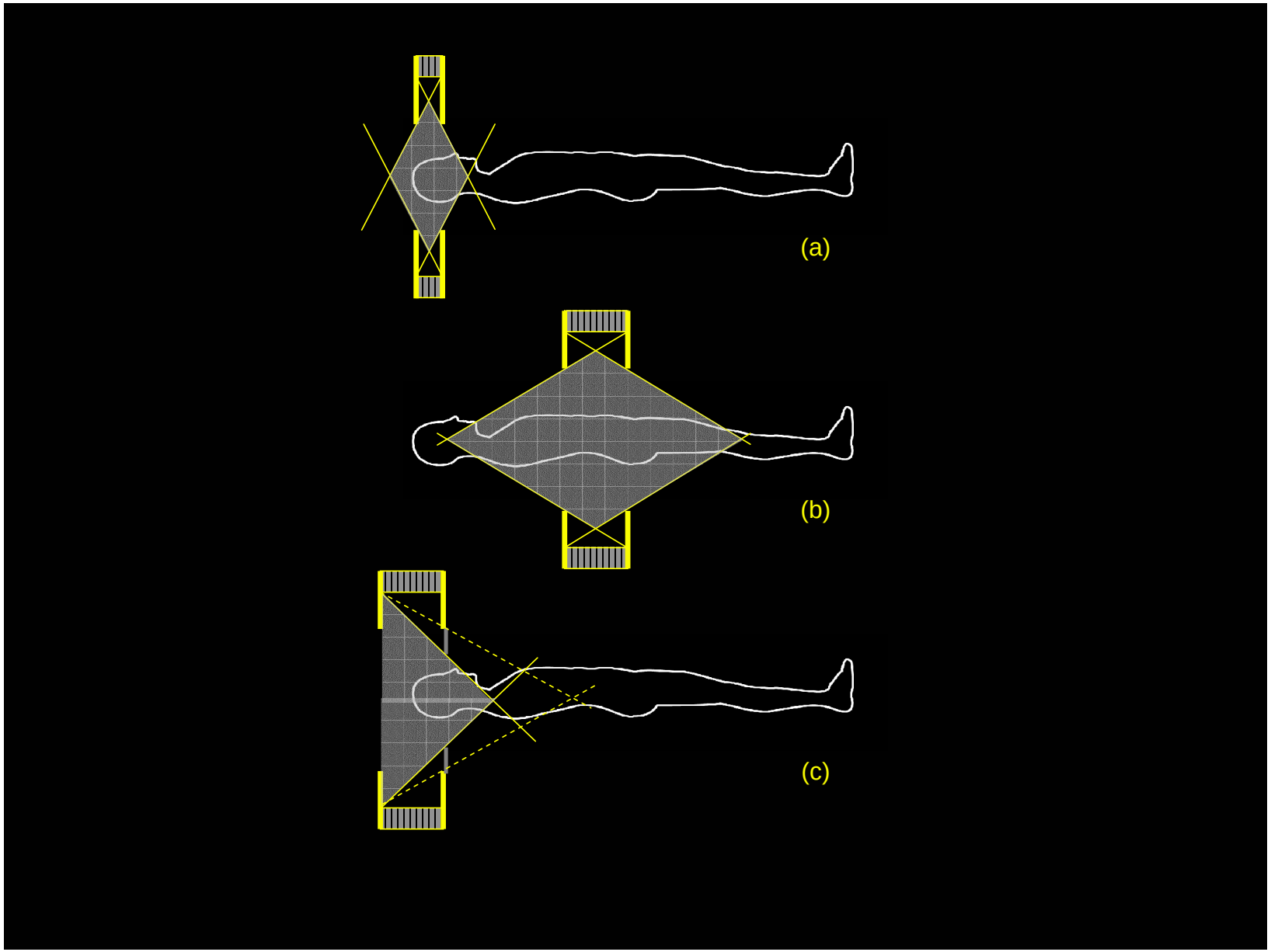
- **Reasonably long coincidence timing windows**
  - →**High random coincidence rates**
  - →**High electronic dead time**
- **Limited dynamic range**
- **Decreased effective sensitivity**
- **Ultimately…..smoother reconstruction filters**
  - →**Poorer resolution**

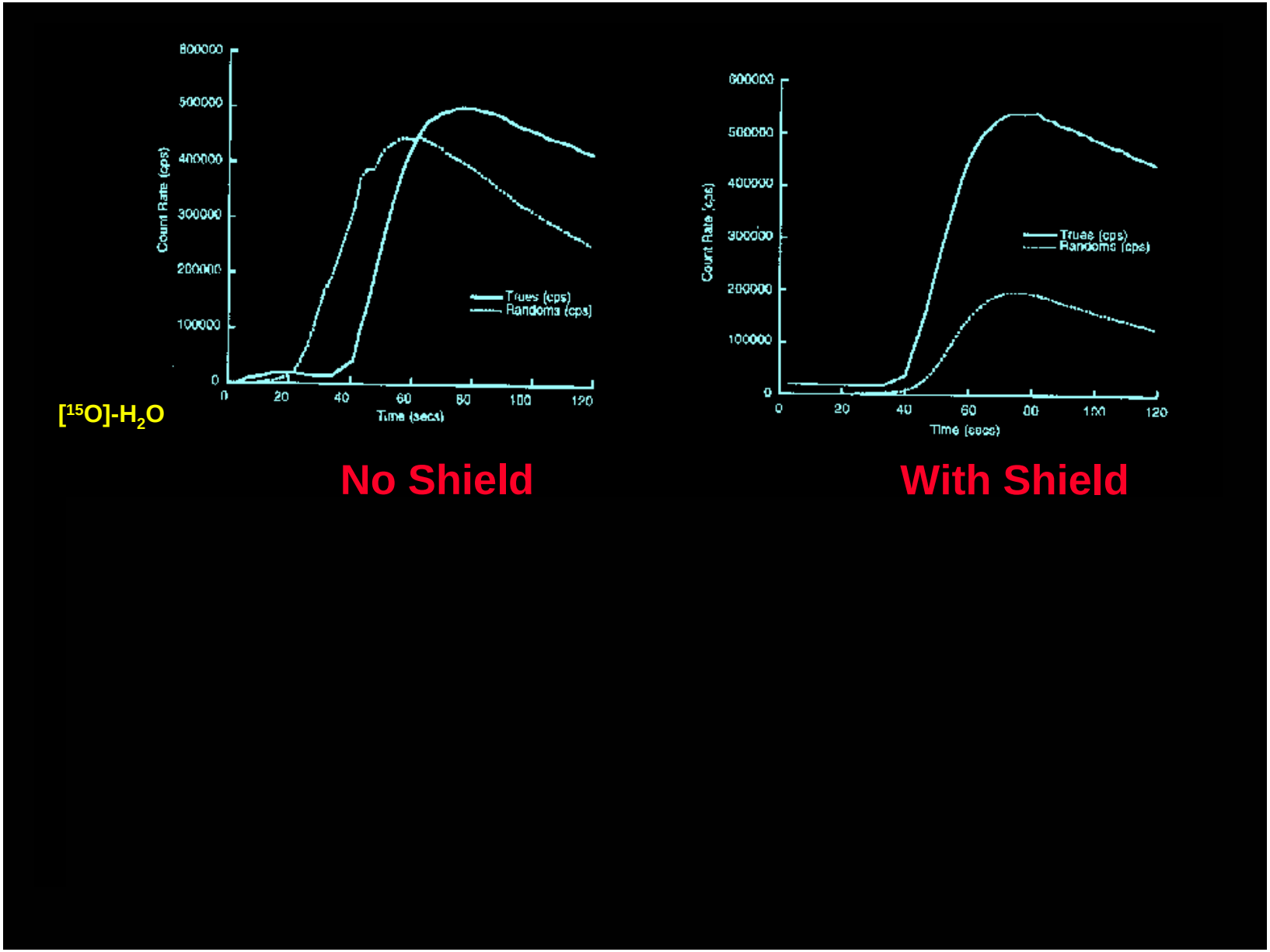


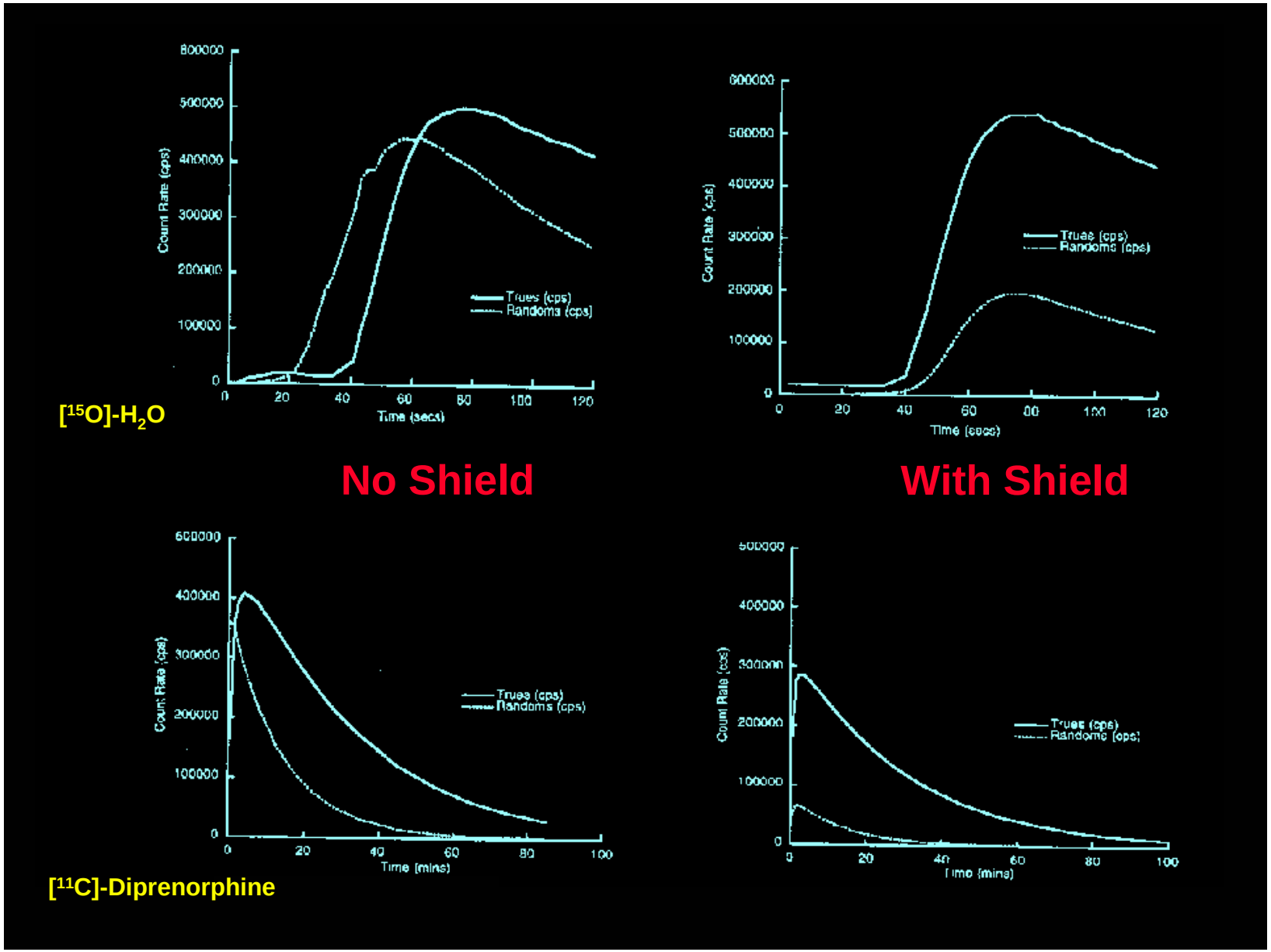

Count Rate Performance of PET Systems
200000
150000
100000
50000
0
NEC (cps)
HR++
953B 3D
953B 2D
ART
0
10
20
30
40
50
60
Activity in FoV (MBq)

Effective Sensitivity = Absolute Sensitivity *x* NEC(a) / Ideal(a)




(a)
(b)
(c)


[15O]-H2O
Count Rate (cps)
Time (secs)
Trues (cps)
Randoms (cps)
No Shield
With Shield


[15O]-H2O
No Shield
With Shield
[11C]-Diprenorphine
Count Rate (cps)
Time (secs)
Time (mins)
Trues (cps)
Randoms (cps)

PET Must Go 3D

- **Maximise sensitivity**
- **Increase throughput &/or decrease dose**

CONCLUSION

PET using detectors with 200-300 ns decay times has reached its limit

PET Scintillators

Property	NaI(Tl)	BGO	LSO	YSO	GSO	BaF_2
Density (g/cm^3)	3.67	7.13	7.4	4.53	6.71	4.89
Effective Z	50.6	74.2	65.5	34.2	58.6	52.2
Attenuation Length	2.88	1.05	1.16	2.58	1.43	2.2
Decay Constant (ns)	230	300	40	70	60	0.6
Light Output (photons/keV)	38	6	29	46	10	2
Relative Light Output	100%	15%	75%	118%	25%	5%
Wavelength λ (nm)	410	480	420	420	440	220
Intrinsic $\Delta E/E$ (%)	5.8	3.1	9.1	7.5	4.6	4.3
$\Delta E/E$ (%)	6.6	10.2	10	12.5	8.5	11.4
Index of Refraction	1.85	2.15	1.82	1.8	1.91	1.56
Hygroscopic?	Yes	No	No	No	No	No
Rugged?	No	Yes	Yes	Yes	No	Yes
μ (cm^{-1})	0.3411	0.9496	0.8658	0.3875	0.6978	0.4545
μ/ρ(cm^2/gm)	0.0948	0.1332	0.117	.0853	0.104	0.0929

Physical properties of commonly used scintillators in PET. The energy resolution and attenuation coefficients (linear (μ) and mass (μ/ρ)) are measured at 511 keV.

CANDIDATE 1

LSO

FOR

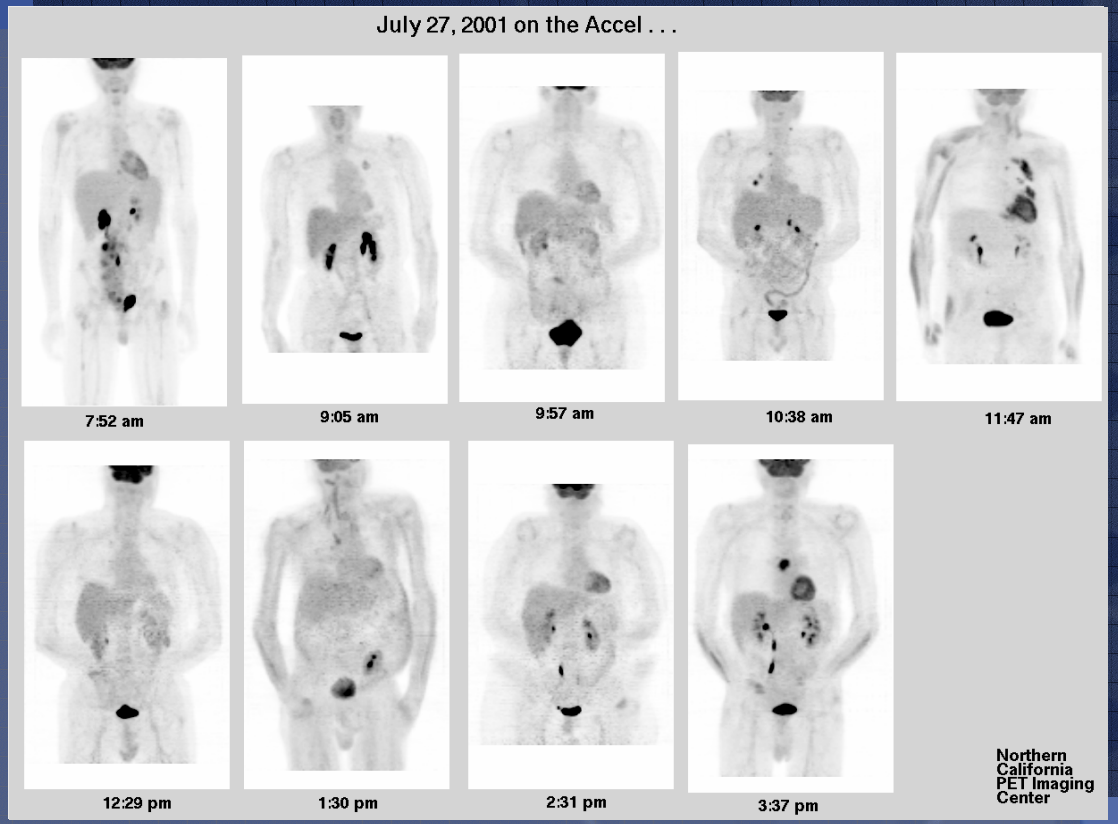
- **High density**
- **Good light output**
- **Fast**

AGAINST

- **Intrinsic radioactivity (^{176}Lu)**
- **Cost ?**

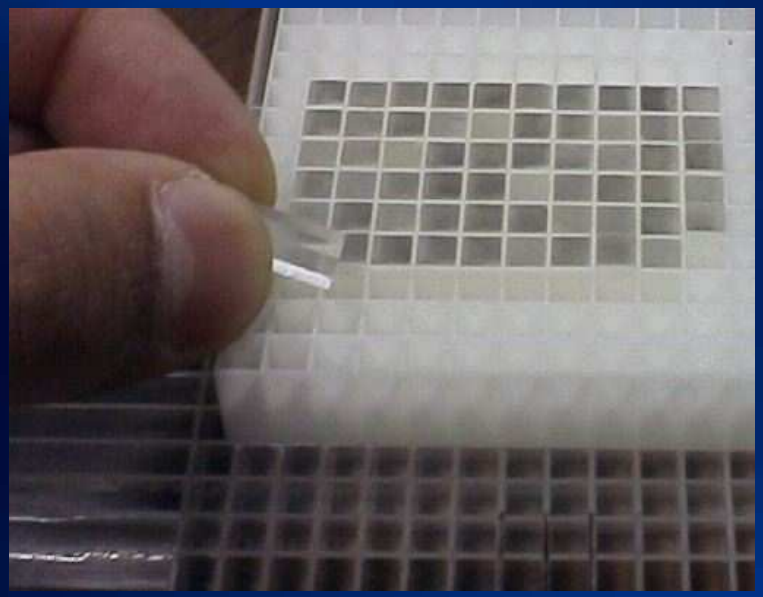
The Power Behind PET.

ECAT ACCEL— All in a day's work



CANDIDATE 2

GSO



FOR

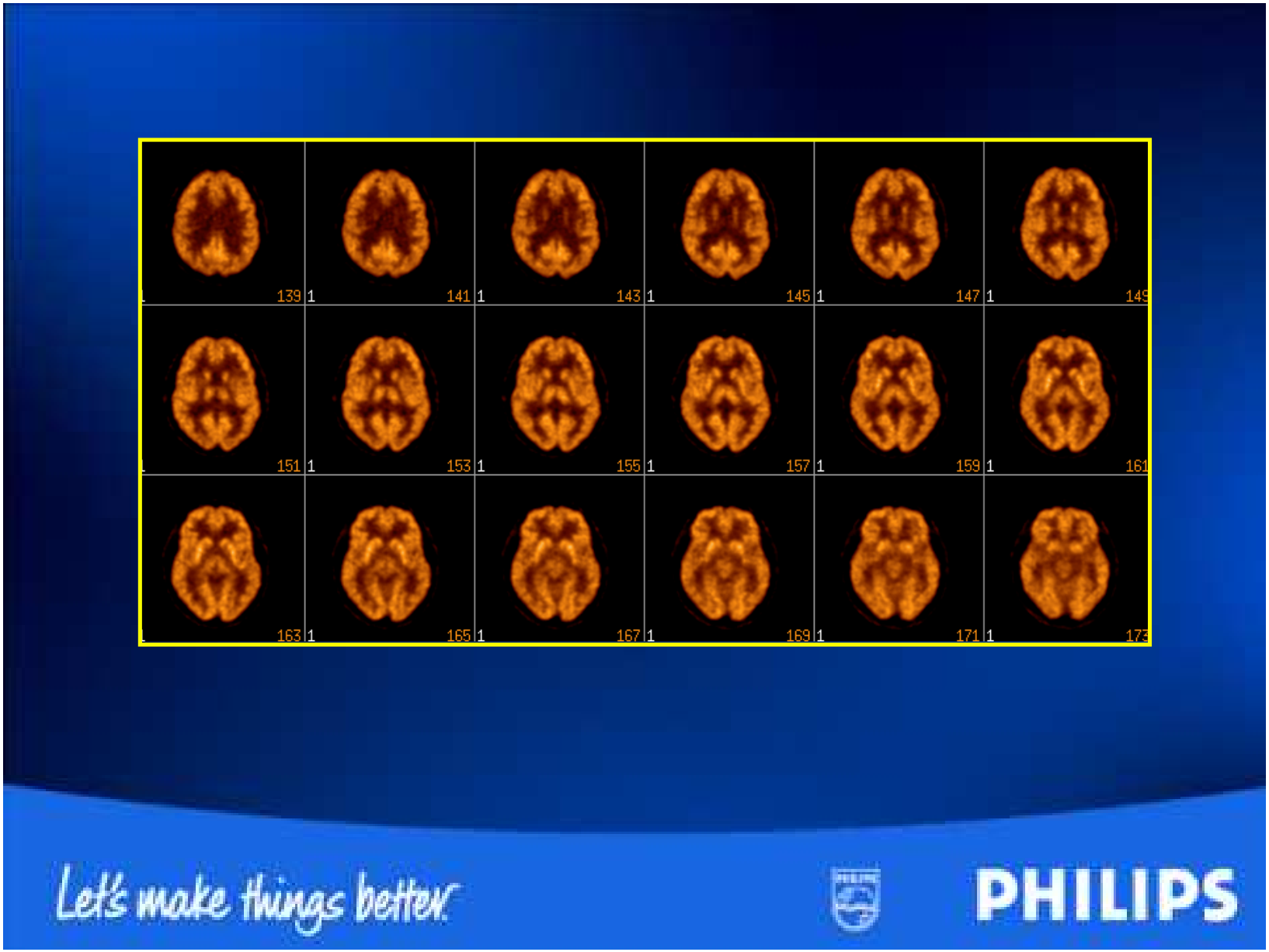
- Relatively high density
- Good intrinsic ΔE/E
- Fast

AGAINST

- Poor light output
- Cost

Let's make things better.

PHILIPS


139
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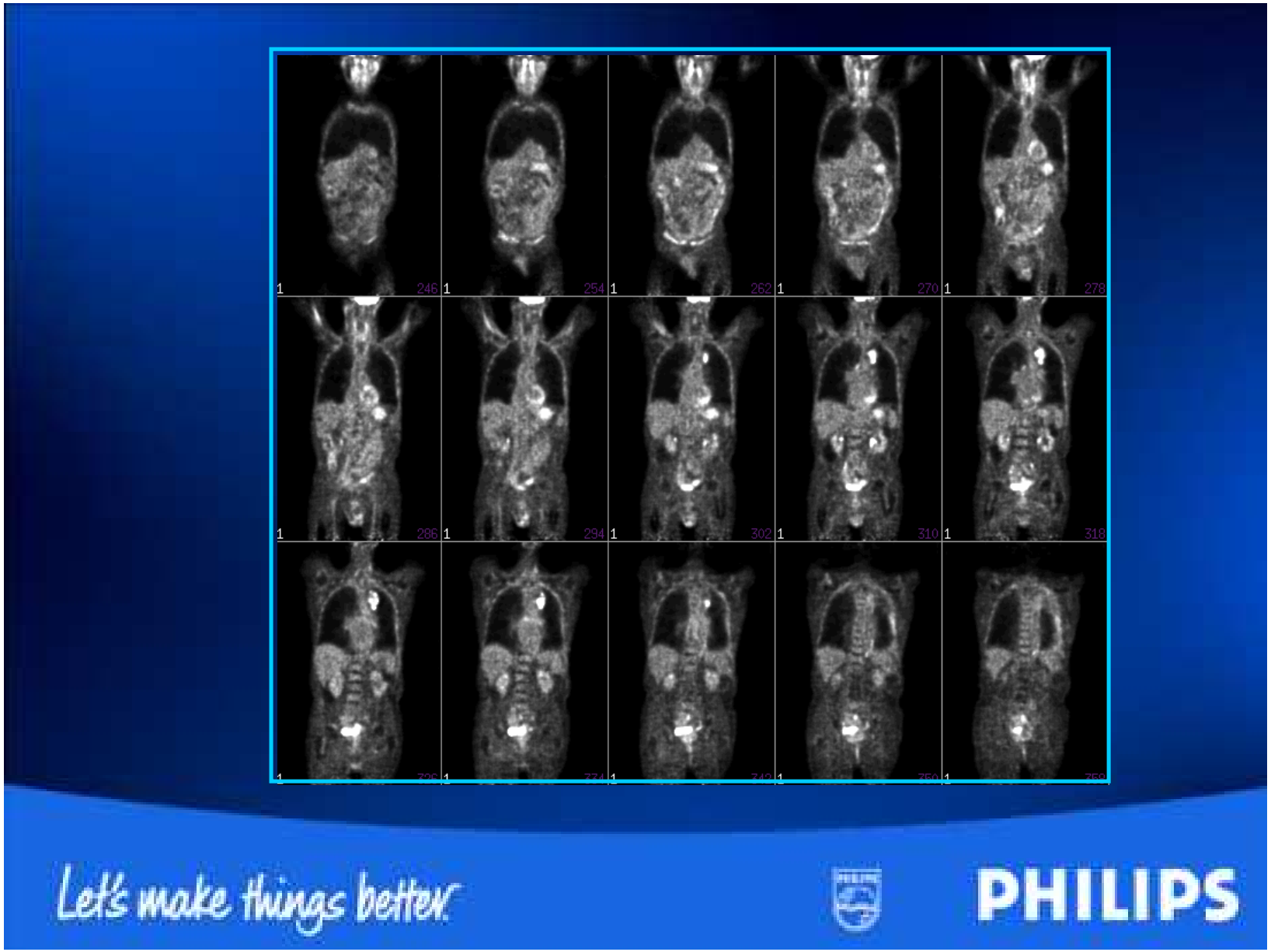
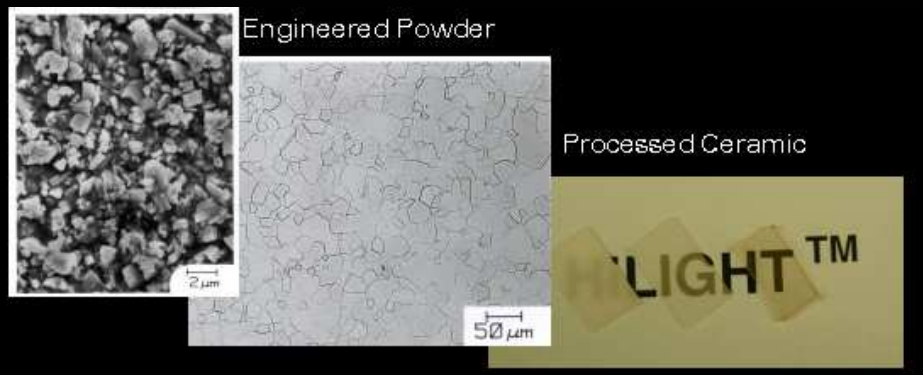
Let's make things better.
PHILIPS

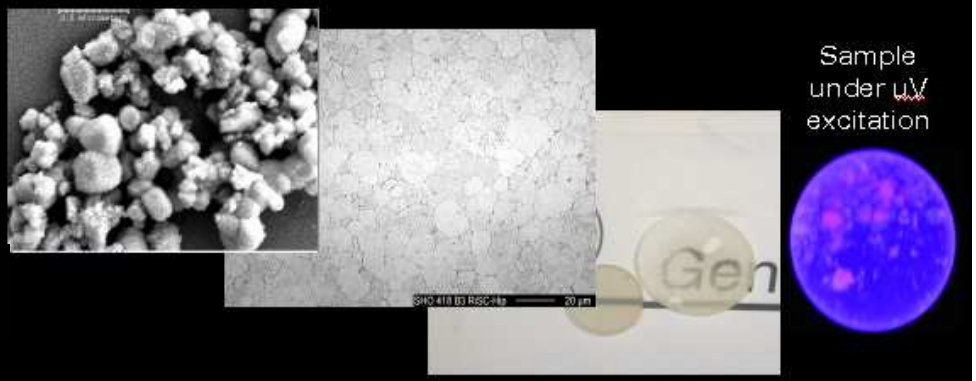

1 246
1 254
1 262
1 270
1 278
1 286
1 294
1 302
1 310
1 318
Let's make things better.
PHILIPS

CANDIDATE 3

Transparent Ceramics
Next Generation Detector Technology

- **Enables detector compounds which cannot be grown as single crystals.**
- **Provides better control of complex stoichiometry, for a more homogeneous detector.**
- **A high-yield, lower-cost detector synthesis process.**





Preliminary results from PET ceramic

Data courtesy of **GE Medical Systems**

HAFNATES COMPARED TO OTHER SCINTILLATORS

	NaI(Tl)[1]	BGO[2]	LSO[3]	GSO[4]	BaHfO[5]
Rel. Light Output	100%	22%	75%	35%	60%
Energy Resolution (in Scanner)	10%	20%	20%	15%	14%
Decay Constant (ns)	230	300	50	60	50
$\mu(cm^{-1})$	0.37	0.95	.89	.67	.95
Photofraction	~15%	~40%	~30%	~25%	~40%
Rel. Sensitivity (in Scanner)	15	100	80	50	105

1 - "in Scanner" from CPET datasheet
2 - "in Scanner" from HR+/Advantage datasheet
3 - "in Scanner" from Accel datasheet
4 - "in Scanner" from Allegro datasheet
5 - preliminary performance estimates based on small sample measurements

Data courtesy of GE Medical Systems


— 2ns window
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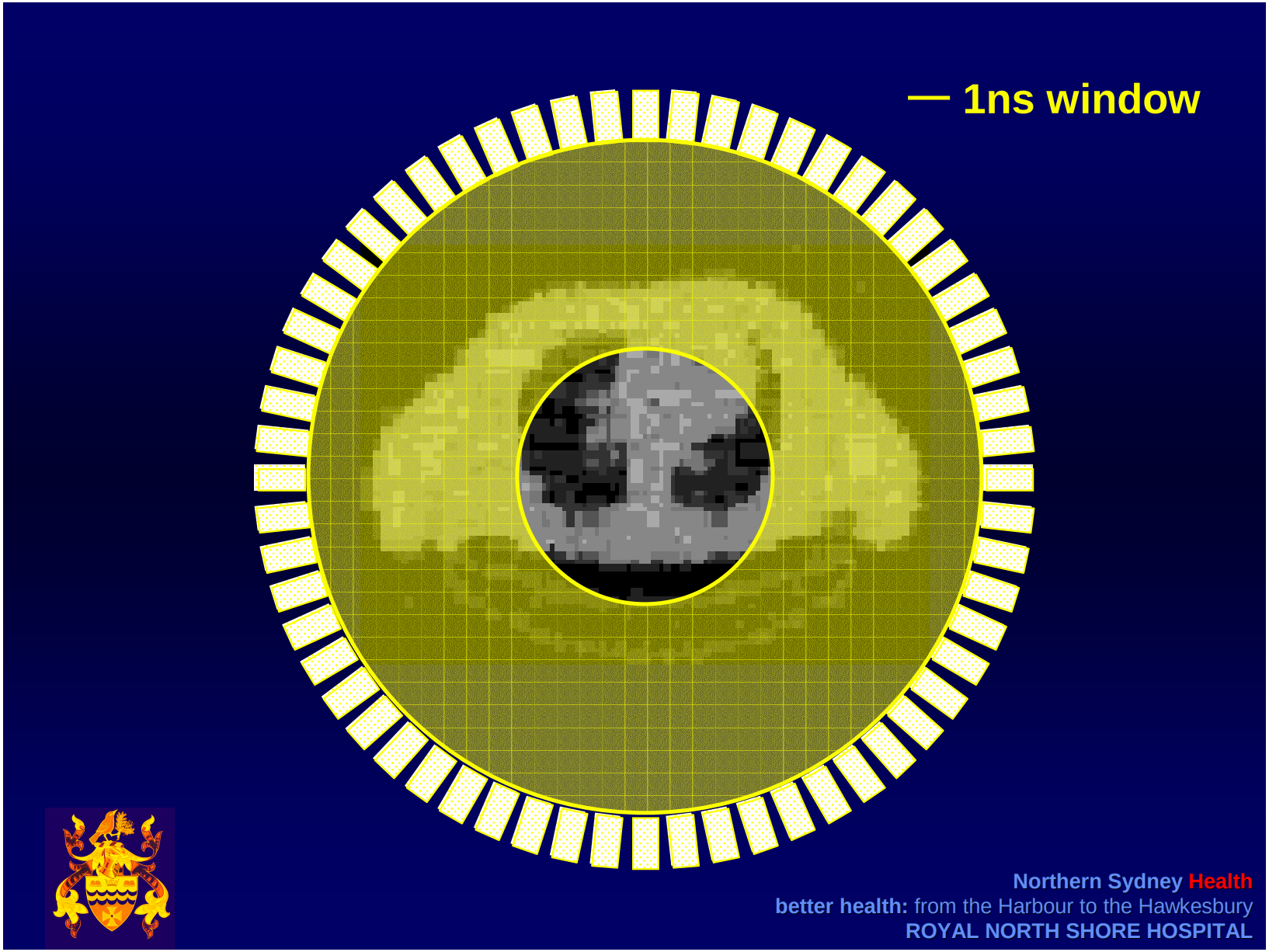
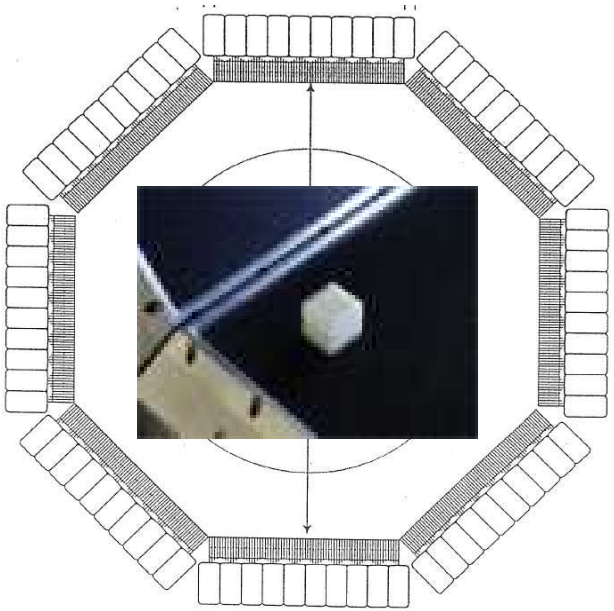
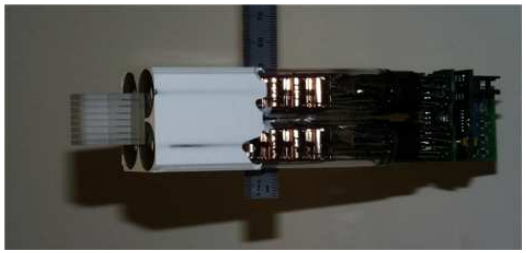

— 1ns window
Northern Sydney Health
better health: from the Harbour to the Hawkesbury
ROYAL NORTH SHORE HOSPITAL

The Koln HRRT prototype

Octagonal geometry with
117 LSO blocks per head.
936 blocks in total (9x13x8).
Two crystal layers per block for depth of interaction (DOI)
Block size 19 mm
64 crystals per layer
120,000 crystals 4.5 10^9 LOR's.
Every block is read by 4PMT's
Every PMT is shared by four neighbouring blocks.
9° gap (1.7 cm) between heads.
Axial FOV: 25.3 cm.
Transaxial FOV: 31.2 cm.

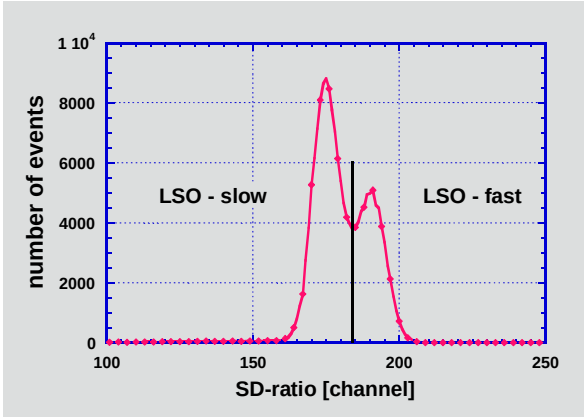


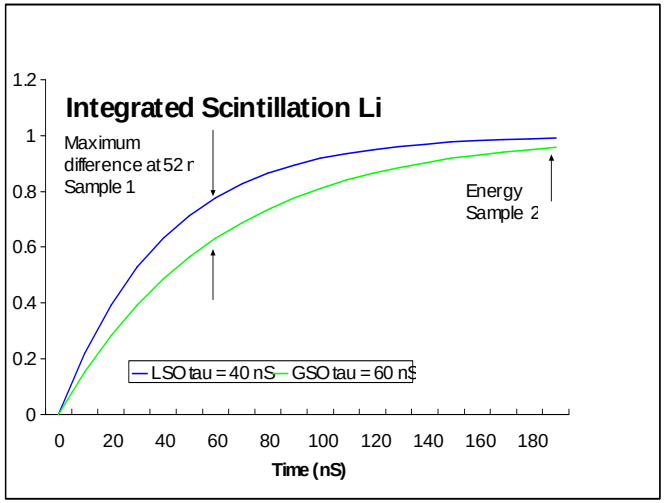


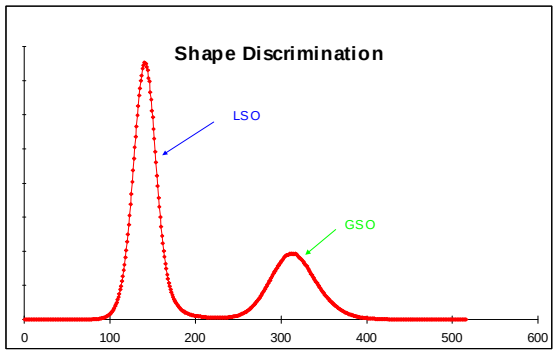
HRRT
CPS Innovations

DOI through Pulse Shape Discrimination

- Bi-layered block (2 x 7.5 mm) made from scintillators with two different decay times. LSO/LSO and LSO/GSO blocks used in the Koln prototype







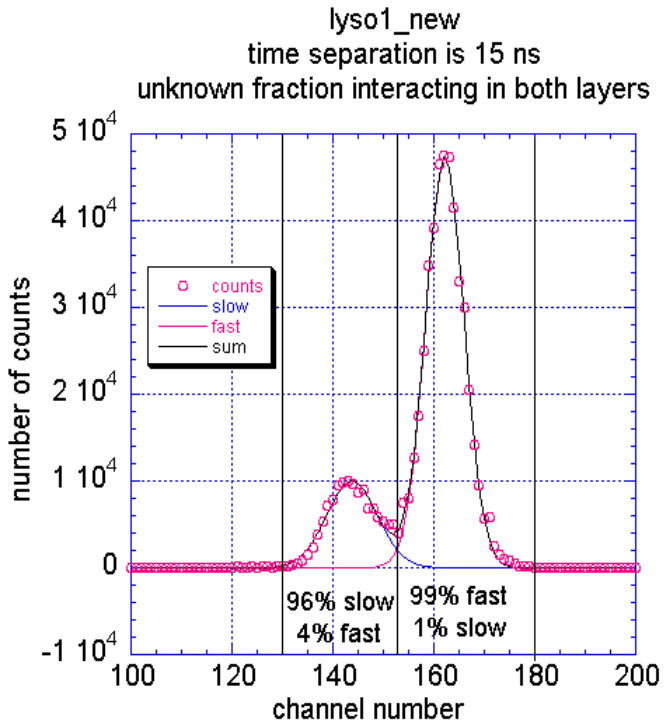
HRRT CPS Innovations

New LSO-LYSO detectors

The new HRRT generation uses LSO-LYSO blocks (2 x 10 mm). It improves sensitivity (by 20%) and DOI resolution when compared to LSO/LSO.

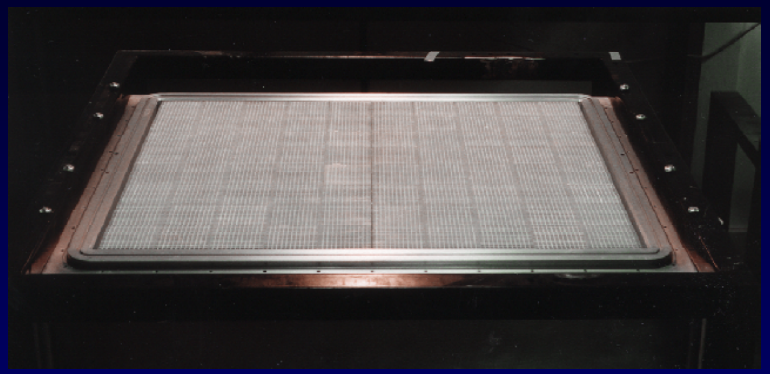
LSO decay time ¡ 40-45 ns
LYSO decay time ¡ 52-55 ns
Peak separation ¡ 10-15 ns

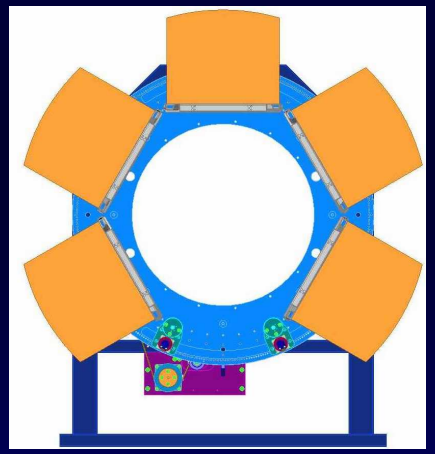
Reduction in LSO background singles (35 %) from 660 cps with LLD @ 350 keV
Block energy resolution: 16%



PROTOTYPE - ‘P39’

Five panels in a hexagonal array continuously revolve around the subject within a closed gantry with an aperture of *700 mm* and an axial coverage of *520 mm*. The sixth side holds the sources for transmission measurements.

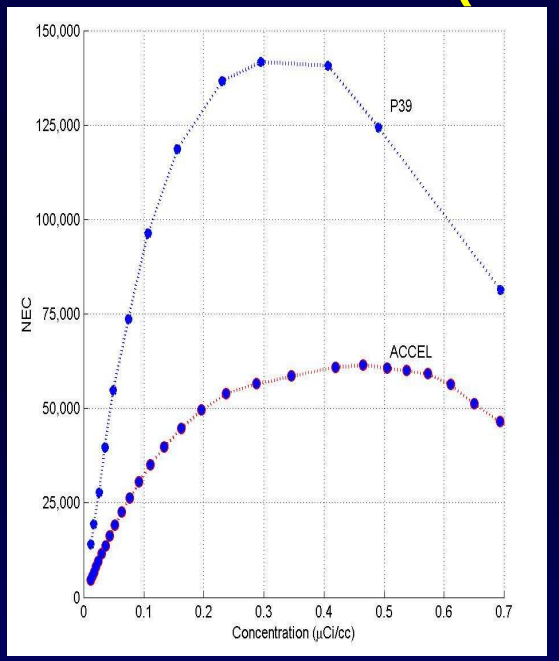




Each *detector element* is 4×4×20 mm³

PROTOTYPE - ‘P39’

- LSO
- 6 ns coincidence window
- Simultaneous em/tr (^{68}Ge)



1 hour post injection

EXACT

3 hours post injection

P39

MIPs

RAT $^{18}F^-$ SCAN

HIDAC PET scanner (Oxford Positron Systems)

Resolution ~0.75mm FWHM

Reconstructed with Regularised One-Pass List-Mode EM Algorithm (AJ Reader *et al*, UMIST, UK)

Scan Details:

30 min scan time

500g rat

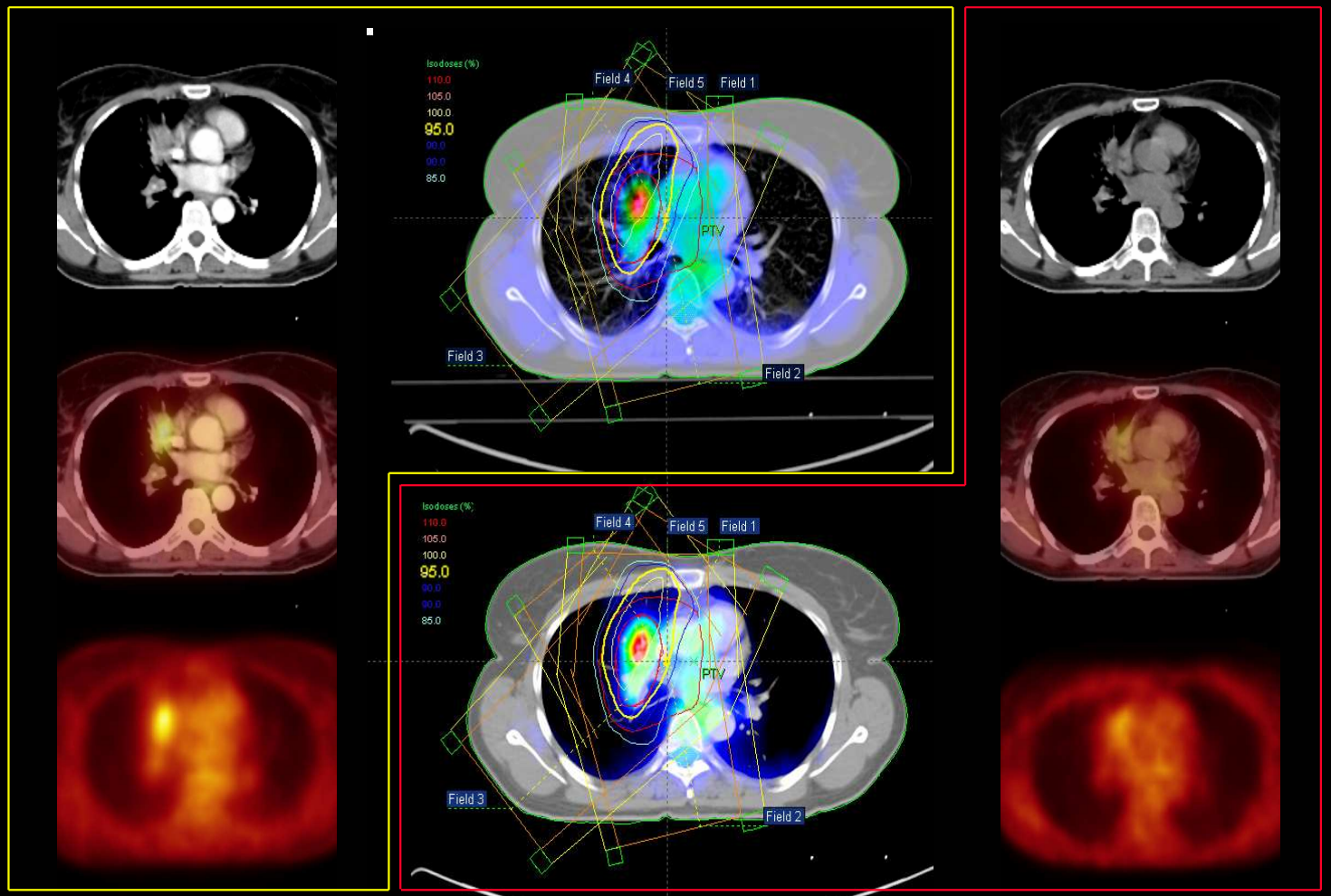
17 MBq

145 M events

The Power Behind PET.


Patient Edit Film Image Options Help
Viewing
Filming
3D
Copies
auto
Layout Images Camera
Camera
\\ADMIN1\CE_HPL
Status:
Film Size
Legal
1
2

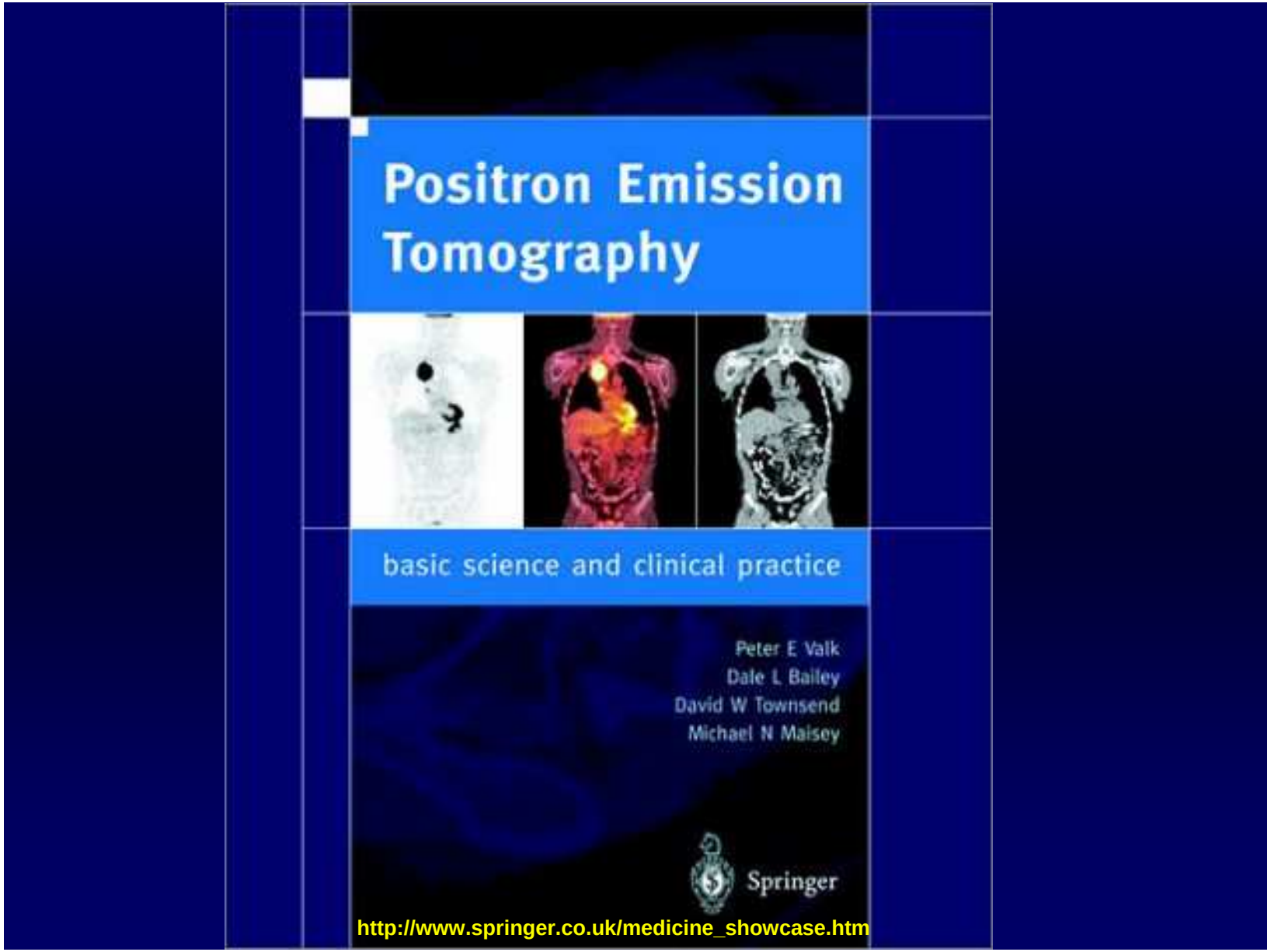
Treatment Planning and Response



Data Courtesy of Univesity of Pittsburgh Medical Center PET Facility

CHECKLIST FOR FUTURE PET CAMERA

- Fast dense detector (not necessarily inorganic scintillation crystal)
- 3D - no septa
- Time-of-Flight - new electronics
- CT as standard? - no transmission sources
- Extended axial field of view
- Motion detection/tracking/correction
- Little of no overhead for transmission/CT


Positron Emission Tomography
basic science and clinical practice
Peter E Valk
Dale L Bailey
David W Townsend
Michael N Maisey
Springer
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