TOFPET: Past, present, and musing on the future

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The beginnings

- 1980 - articles published on the potential improvements in SNR if TOF utilized (Ter-Pogossian, Snyder, etc)

The candidate scintillators at the time were BGO, NaI, CsF, BaF:

Crystal	NaI(Tl)	BGO	LSO	GSO	CsF	BaF_2
Density (g/cm^3)	3.67	7.13	7.4	6.71	4.61	4.89
Photoelectric Linear Attenuation (cm^{-1})	0.06	0.39	0.23	0.18	0.087	0.085
Compton Linear Attenuation (cm^{-1})	0.28	0.52	0.56	0.46	0.334	0.35
Total Linear Attenuation (cm^{-1})	0.34	0.91	0.79	0.72	0.42	0.44
Relative Light Yield - fast component	100	15	75	40	6	5
- slow component	-	-	-	-	-	16
Decay Constant (ns) - fast component	230	300	40	50	2.5	0.6
- slow component	-	-	-	-	-	620
Peak Light Emission (nm) - fast	415	480	420	430	390	210
- slow	-	-	-	-	-	310
Index of Refraction at peak emission	1.85	2.15	1.82	1.85	1.48	1.56

First TOF scanners

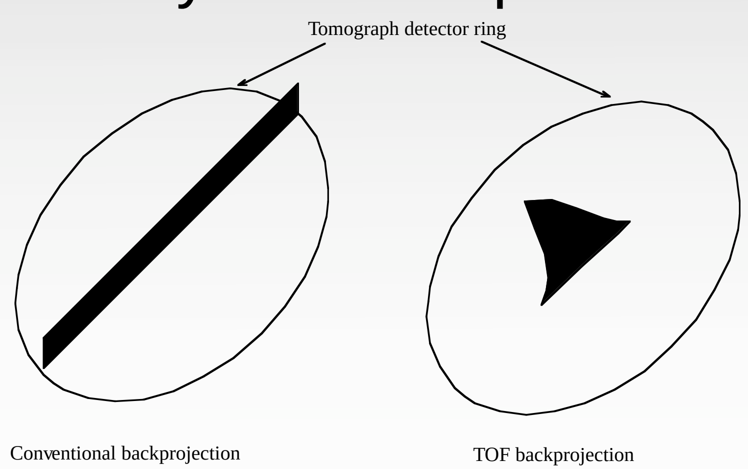
- 1982-83: Groups at Washington U. and CEA-LETI and U. Texas were building the first scanners.

		System		
Parameters	SuperPet I [1]	SuperPet3K[2]	LETI TOF [3]	TTV03[4]
Scintillator	CsF	BaF_2	CsF and BaF_2	BaF_2
Crystals/PMT	1/1	8/5	1/1	1/1
Number rings	4	4	3 CsF, 1 BaF_2	4
Detectors/ring	96	320	96	324
Ring diameter	85 cm	90 cm	92 cm	89 cm
Wobble motion	yes	yes	yes	
Transaxial resolution†	8 mm /12 mm (high res./low res.)	7 mm	7 mm/11 mm (high res./low res.)	5.7 mm
Axial resolution‡	11.4 mm	7.3 mm/9 mm (high res./low res.)	15.5 mm	7.7 mm
TOF resolution	500 ps	540 ps	470 ps	750 ps
Sensitivity* (entire FOV)	121 kcps/µCi/cc	65 kcps/µCi/cc	100 kcps/µCi/cc	82 kcps/µCi/cc

1. Ter-Pogossian M.M., Ficke D.C., Yamamoto M., Hood Sr. J.T., Super PETT I: a positron emission tomograph utilizing photon time-of-flight information. IEEE Trans Med Imag. 1982; MI-1(3):179-186.
2. Lewellen T.K., Bice A.N., Harrison R.L., Pencke M.D., Link J.M., Performance measurements of the SP3000/UW time-of-flight positron emission tomograph. IEEE Trans Nuc Sci. 1988; 35(1):665-669.
3. Gariod R., Allemand R., Cormoreche E., Laval M., Moszynski M. The "LETI" Positron Tomograph Architecture and Time of Flight Improvements. Workshop on Time-of-Flight Tomography: 1982: 25-29.
4. Mazoyer B., Trebossen R., Schoukroun C., Verrey B., Syrota A., Physical Characteristics of TTV03, a New High Spatial Resolution Time-of-Flight Positron Tomograph. *IEEE Trans. Nucl. Sci.* 1990; 37:783-788.

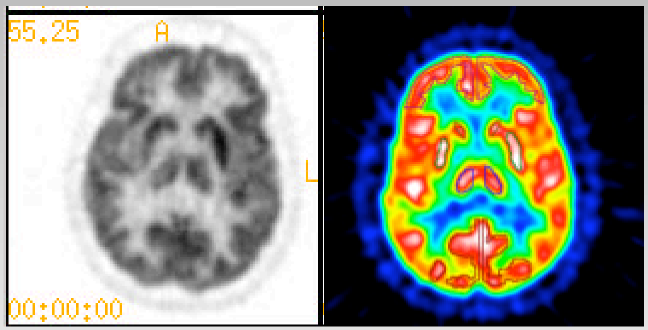
TOF reconstruction in 1980s

- In the 1980s, it was primarily Confidence Weighted Filtered Backprojection (Snyder, Pollitte, others)
- Scatter correction was not included or done the same as BGO systems (simple exponential models) or augmented with assumption that scattered events will have slightly longer TOF
- Basic recons done via list mode (not all that popular in 1980s due to relatively slow computational speeds available)



Why did they not prosper?

- Only four commercial versions of the SP3K were built
- In my opinion the problem was - stopping power and stability (UW had a SP3K system)



BGO BaF2

- The SNR boost in the TOF systems was negated by the higher stopping power (more counts/mCi) in the BGO systems
- The electronics of the time were not all that stable

Why now?

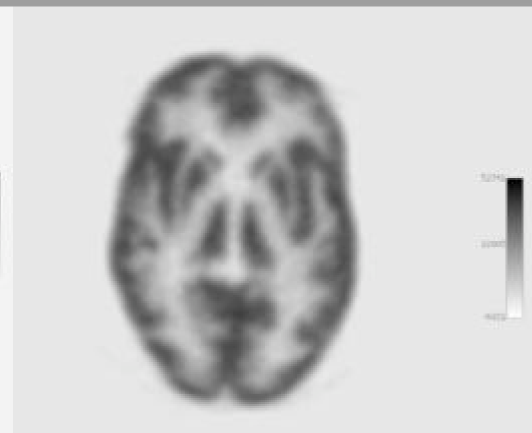
- Already seen from previous talks
  - » LSO, LYSO have sufficient stopping power relative to BGO
  - » Modern electronics more compact, more stable
  - » List mode much easier to handle (computer clusters, big disks, etc)
  - » Statistical recons can take full advantage of TOF information
- Current scanners limited in image quality for large objects and increasing sensitivity is either not worthwhile (already have good stopping power) or too expensive (making scanner longer to increase solid angle) => pursue TOF increase in SNR
- Some vendors see TOF as a strong selling point against the friendly competition.

Performance increase?

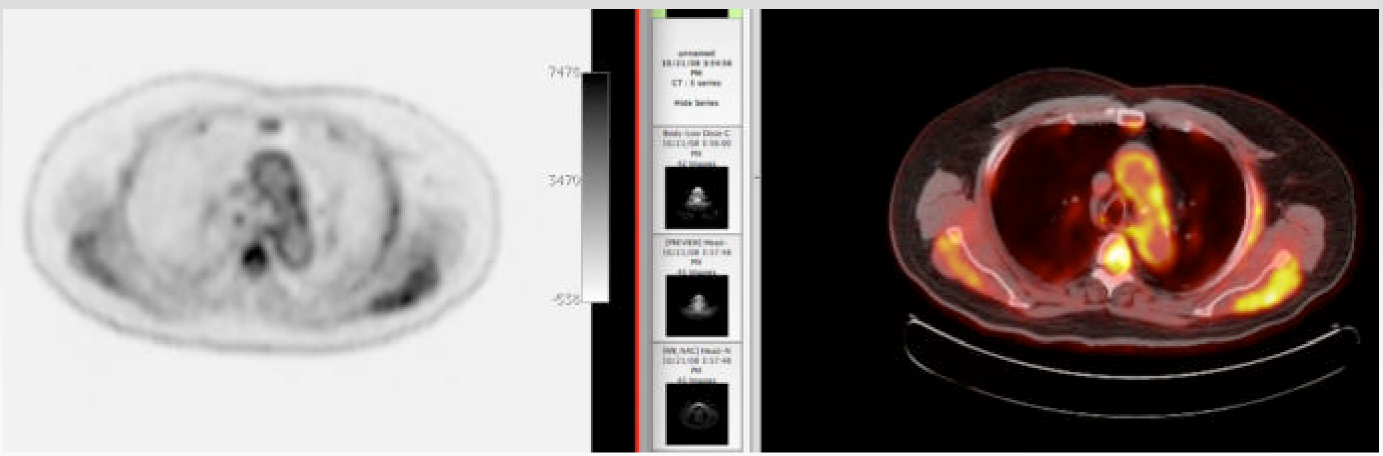
- Not in TOF resolution (commercial scanners). We got 580 ps in 1984 and have ~ 570 ps in 2009
- Yes in image quality due to SNR increase with modest loss of stopping power (comparing a BGO system to a LYSO system)and improved image reconstruction algorithms
- Yes in image reconstruction time thanks to modern computer power (e.g., clusters) and other computational advancements

UW examples

2009 TOF

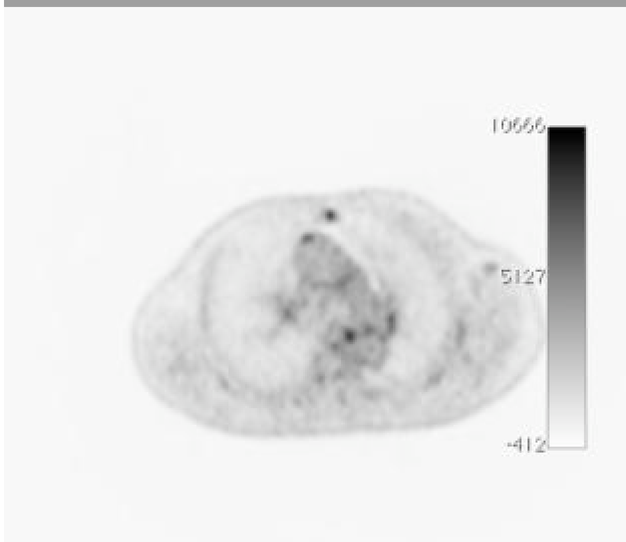


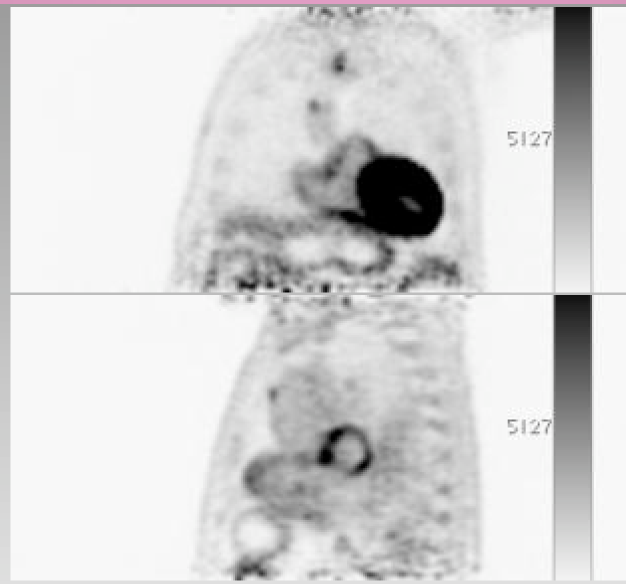
2004 BGO



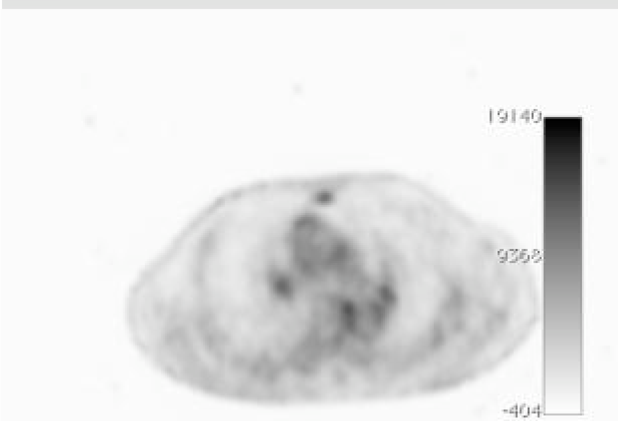
2009 TOF PET with fused CT

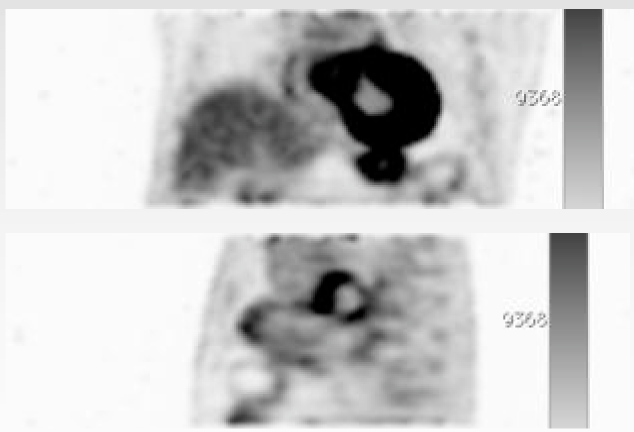
TOF and non-TOF recon from same data set





TOF (2 AFOV)





Non-TOF (1 AFOV)

Future musings….

- What we want is better TOF resolution without giving up any stopping power
  - » LaBr results show that factors of at least x2 in TOF resolution improvement feasible
  - » GM-APDs have the potential for optimal performance (one-on-one coupling with < 300 ps timing)
- Some thoughts of where we might go…
  - » Consider side coupling of GM-APDs to get maximum timing?
  - » Continue the hunt for the optimal scintillator
  - » Development of better methods for extracting timing from pulse data while finding ways to keep the electronics relatively cheap and low power consumption
  - » Start adding DOI - both to improve image resolution, but also to allow TOF improvements based on DOI.

Is TOFPET here to stay?

- Some vendors still skeptical, but the reality is that it is here and is helping to sell scanners
- It does provide a real benefit in image quality
- System costs continue to become more feasible - both form what the market well support and form the advancement in electronics and photosensors
- So yes, it is here to stay!

That's All Folks!

Not Chicago!