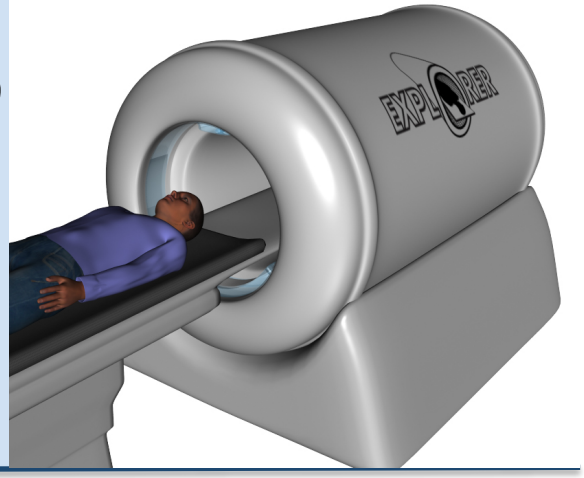
EXPLORER An Ultra-Sensitive Total Body PET Scanner for Biomedical Research



Simon Cherry, Joel Karp, Bill Moses, Jinyi Qi,
Julien Bec, Eric Berg, Woon-Seng Choong,
Jennifer Huber, Srilalan Krishnamoorthy,
Qiyi Peng, Jonathan Poon,
Suleman Surti, Xuezhu Zhang, Jian Zhou,
Terry Jones, Ramsey Badawi

UC DAVIS
UNIVERSITY OF CALIFORNIA

Penn
University of Pennsylvania

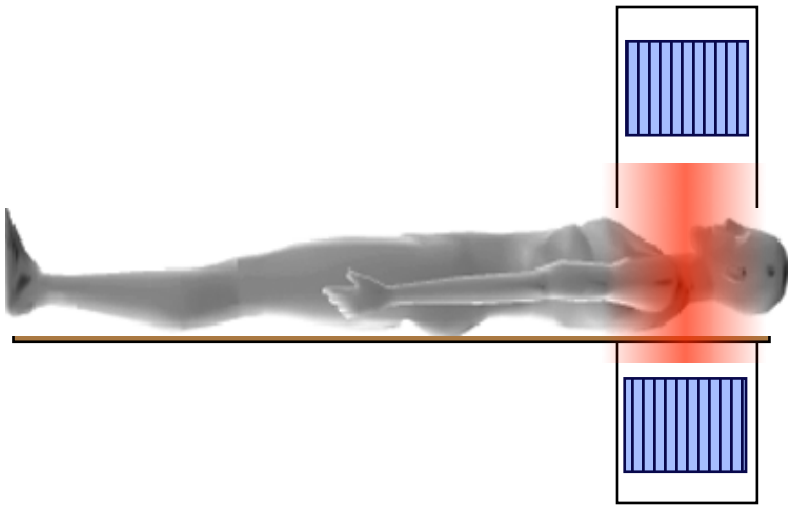
Berkeley Lab

Acknowledgments

- **Funding**
  - **NIH grant R01 CA170874 (Badawi)**
  - **UC Davis RISE award (Cherry)**
  - NIH grant R01 EB016104 (Choong - OpenPET Electronics)
  - NIH grants R01 EB009056 (Surti) and R01 CA113941 (Karp)
- ***Medical Advisory Board:***
  - Dave Mankoff, Richard Wahl, Michael Graham, Bill Jagust
- ***Senior Advisors:***
  - Tom Budinger and Michael Phelps
- ***For useful discussions:***
  - Roger Gunn, Jan Passchier, Illan Rabiner (Imanova, London)
  - Pat Price (Imperial College)
  - Yun Zhou (Johns Hopkins)

EXPLORER

Sensitivity – Every Count Counts



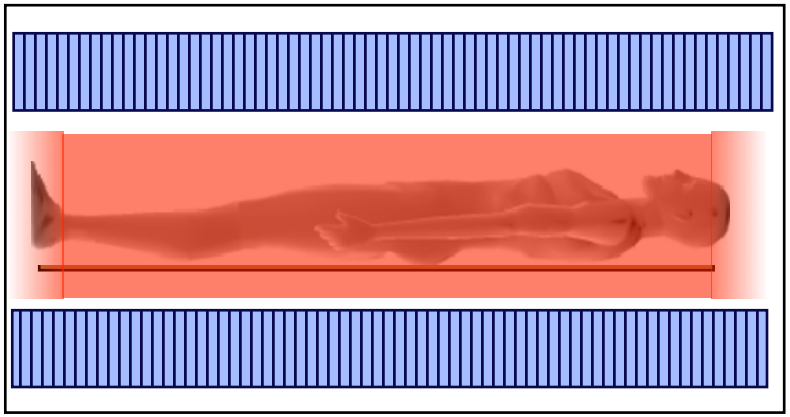
- PET provides the most sensitive non-invasive molecular assay of the human body
- All PET studies are limited by statistics, radiation dose, or both

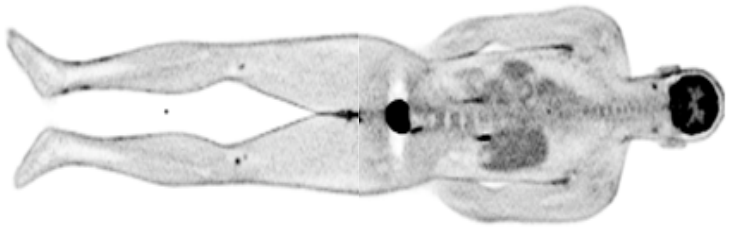
Current scanners do not maximize the sensitivity for whole-body imaging

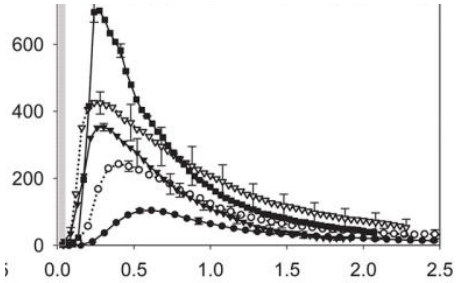
EXPLORER

Total-Body PET: Maximizing Sensitivity

- x40 gain NEC!
- Higher statistics
  - Support higher spatial resolution
- Lower radiation dose
  - Whole body scans at ~ 100 μSv
- Higher dynamic range
  - Late imaging, 5 more $T_{1/2}$
- Whole-body kinetics
  - Better temporal resolution
  - All tissues/organs simultaneously

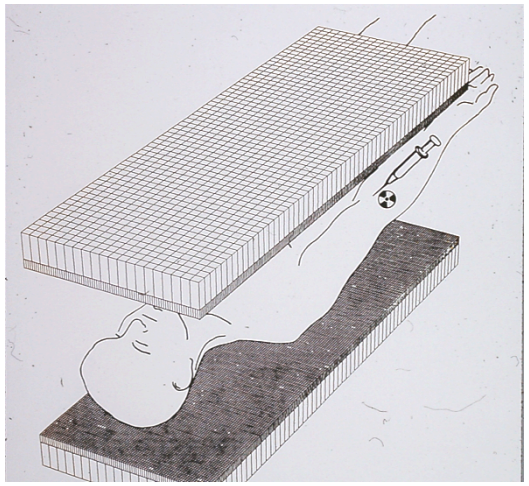




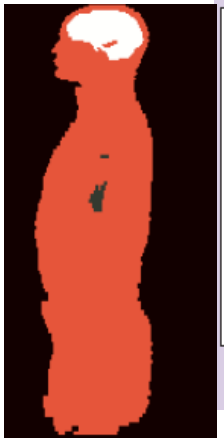


EXPLORER

Not a New Idea!



Terry Jones, circa 1990



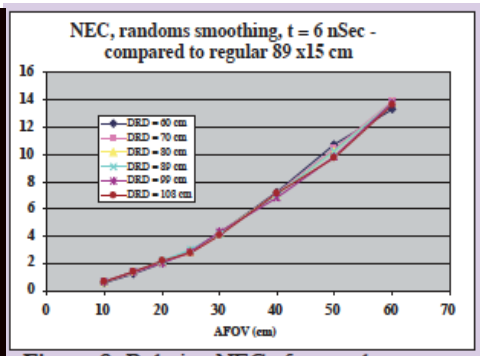
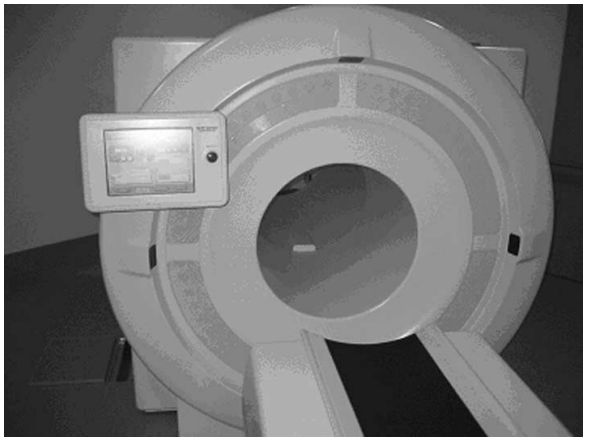
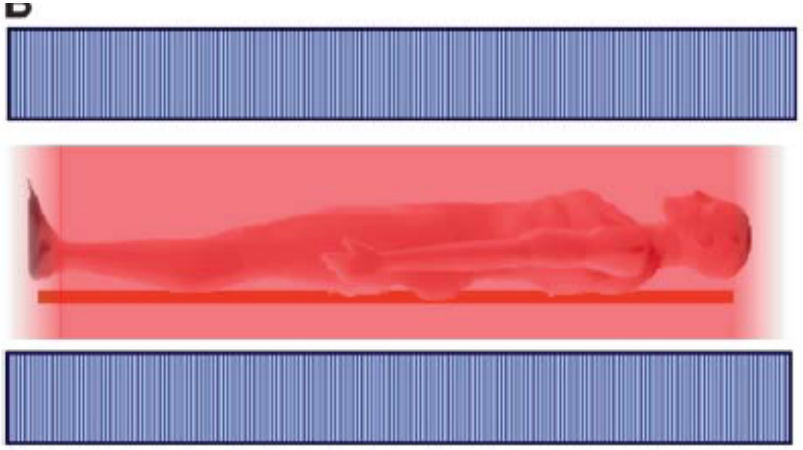


Figure 8: Relative NEC after randoms smoothing and a 6 nSec time window.

Badawi et al, *IEEE Trans Nucl Sci* 2000;47:1228–32



Watanabe et al, *IEEE Trans Nucl Sci* 2004;51:796–800.



Cherry, *J Nucl Med* 2006;47:1735–45.

Eriksson et al.
IEEE Nucl Sci Symp Conf Rec 2008:1632–6.

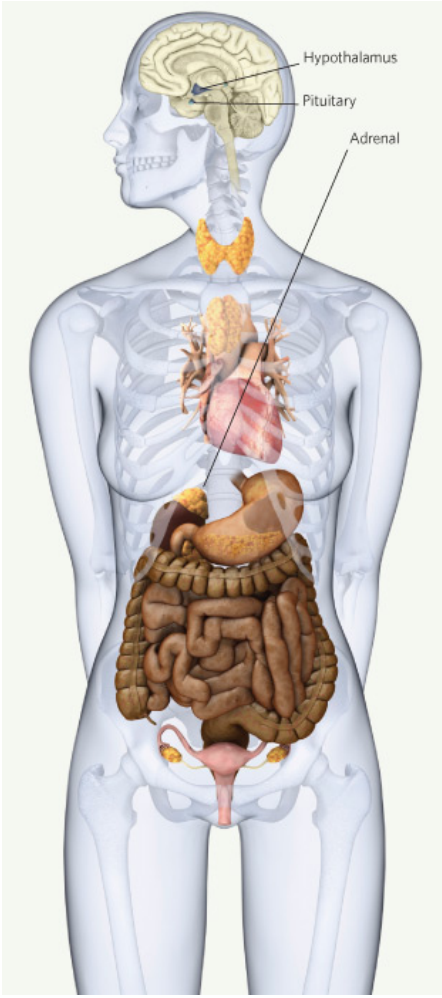
Borasi et al.
Eur J Nucl Med Mol Imaging 2010; 37:1629–32.

Crosetto
IEEE Nucl Sci Symp Conf Rec 2003; 2415–19.

EXPLORER

Applications

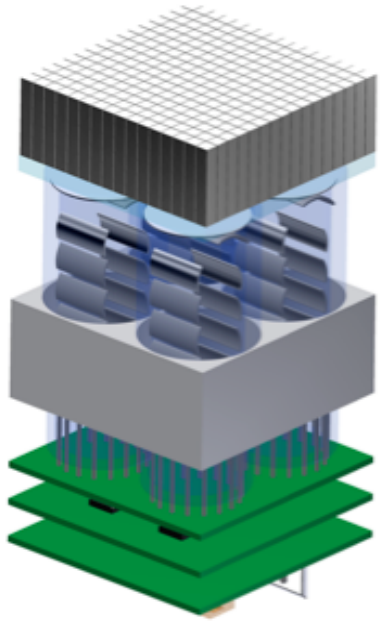
- **Systemic disease and therapies:**
  - Cancer: Ultra-staging and micrometastasis
  - Inflammation
  - Infection
  - Cellular therapy and trafficking
  - Mind-body interactions
- **Total body pharmacokinetics**
  - Drug development
  - Toxicology
  - Biomarker discovery
- **Low Dose may enable:**
  - Expanded use in pediatrics
  - Use in chronic disease
  - Studies of normal biology

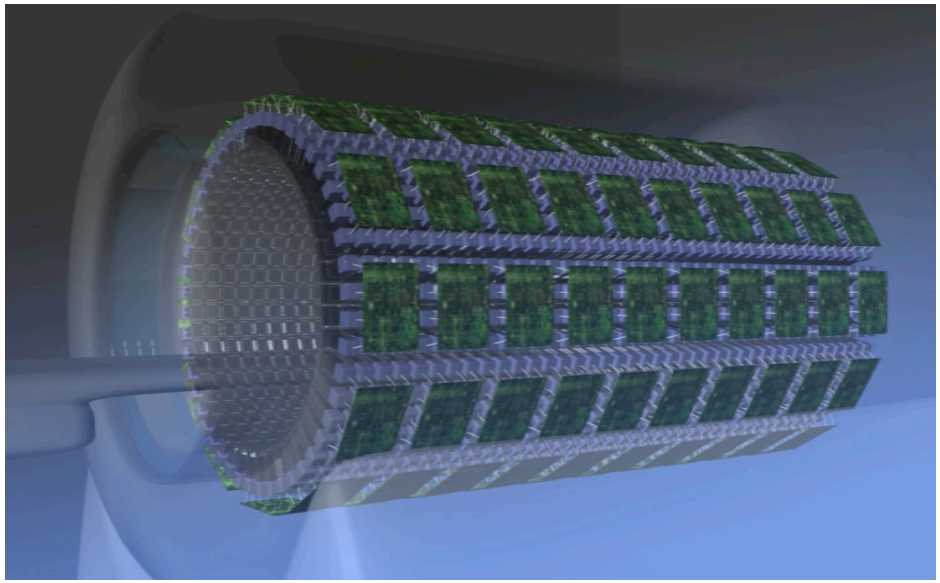


EXPLORER

Working Design

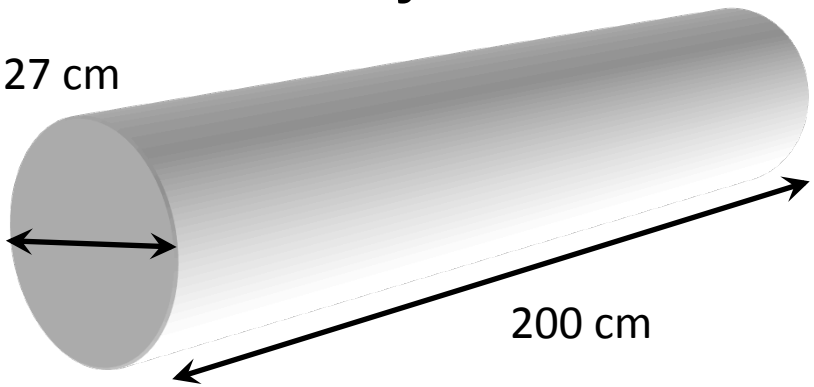
- Modular “Block” Detectors
- ~3.1 x 3.1 x 20 mm L(Y)SO (16 x16)
- PMT (possibly SiPM) readout
- Time of flight and 1-bit DOI
- 40 rings, 48 detectors/ring
- ~78.6 cm ring diameter
- 215 cm axial FOV
- OpenPET electronics





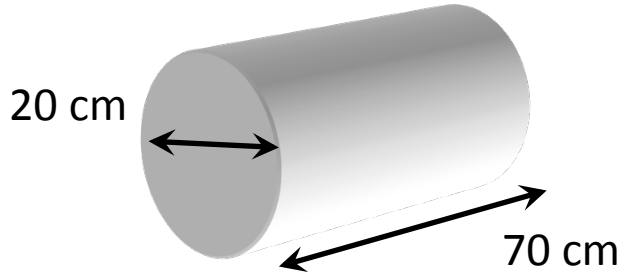
Predicted NEC_{TOF} Gains
versus Siemens Biograph mCT

Adult Total Body Phantom:



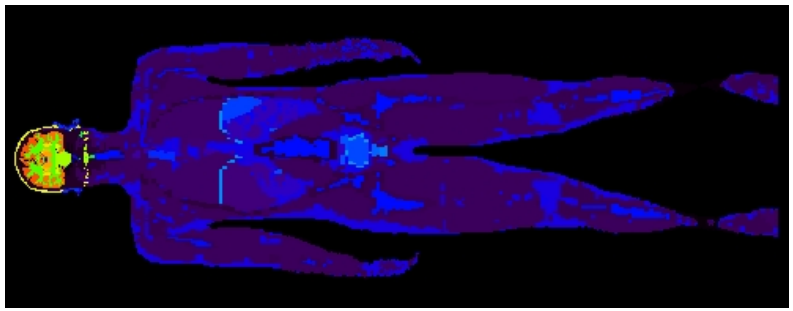
43.9 (10 mCi)

Pediatric Total Body Phantom:



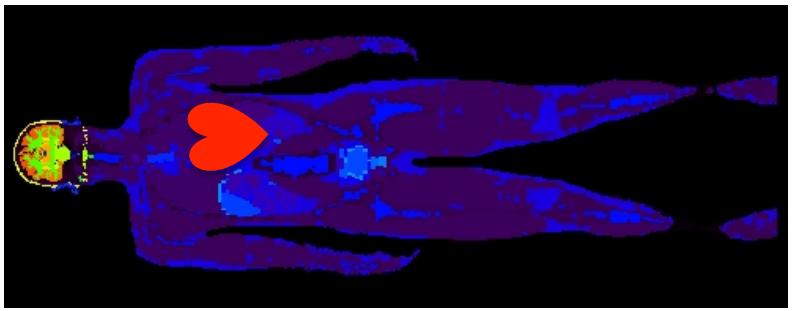
20.0 (0.3 mCi)

Brain: (Voxtiss 8, 6:1 brain to body)



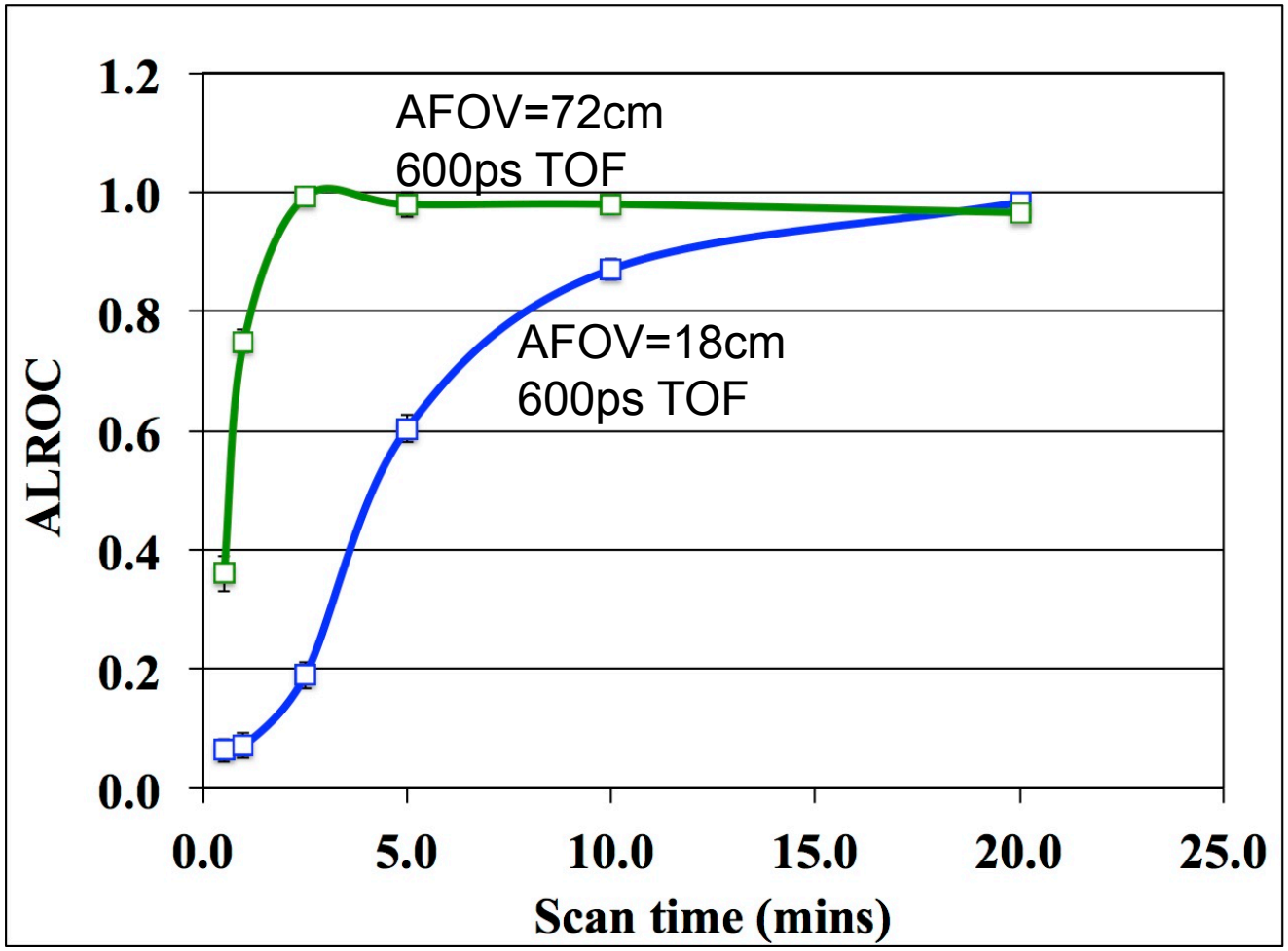
4.2 (10 mCi)

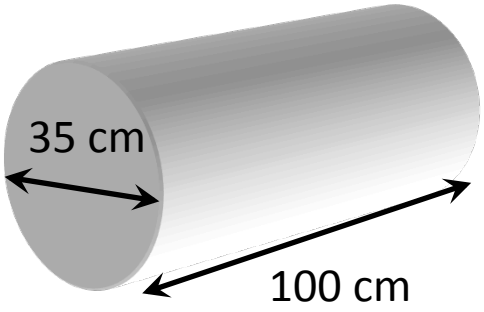
Heart: (Voxtiss 8, all in heart)

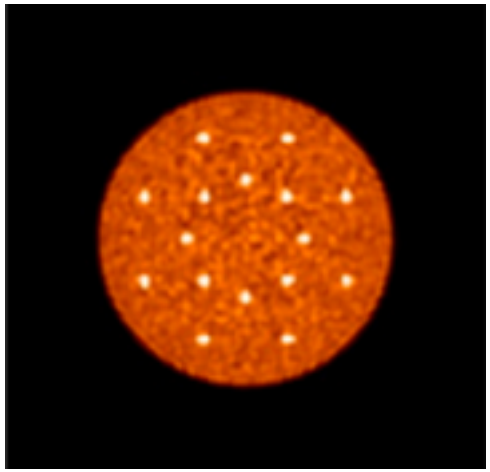


4.7 (20 mCi)

Lesion Detectability - ALROC





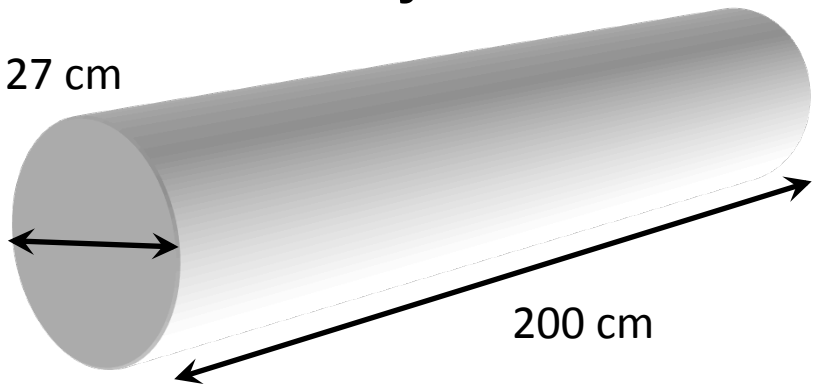


Scan times are total for imaging a 100 cm x 35cm dia. cylinder
Spheres are 1.0 cm diameter with 3:1 uptake ratio

EXPLORER

Expected Counting Rates

Adult Total Body Phantom:



10 mCi in phantom

Optimal ring difference:
284 (~40% axial FOV)

Singles:	164 Mcps
Prompts:	47 Mcps
Randoms:	34 Mcps

Singles:Prompts ratio: 3.5

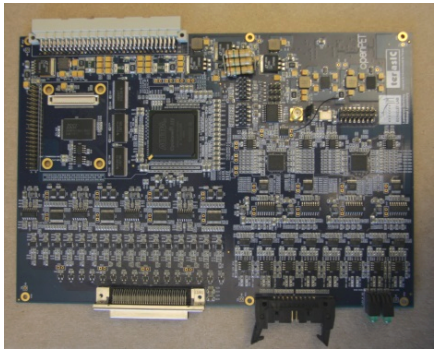
EXPLORER

Electronics

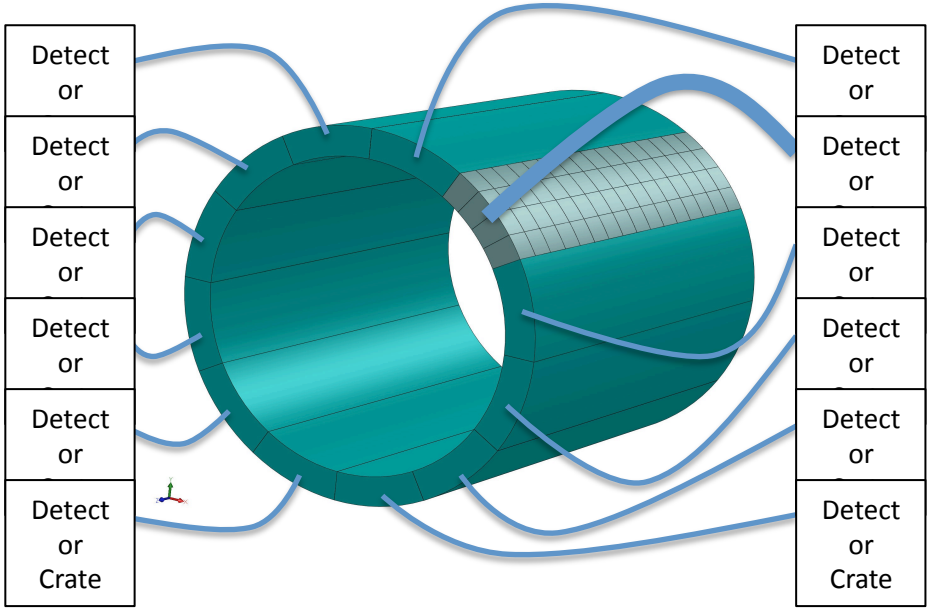
- Acquire singles
- Each detector crate writes singles to own disk
  - completely independent and scaleable
- Detector crates all synchronized in time
- Coincidences identified offline
  - complete flexibility in terms of energy window, timing windows etc…

OpenPET Meeting
18:30 Thursday ASEM 201

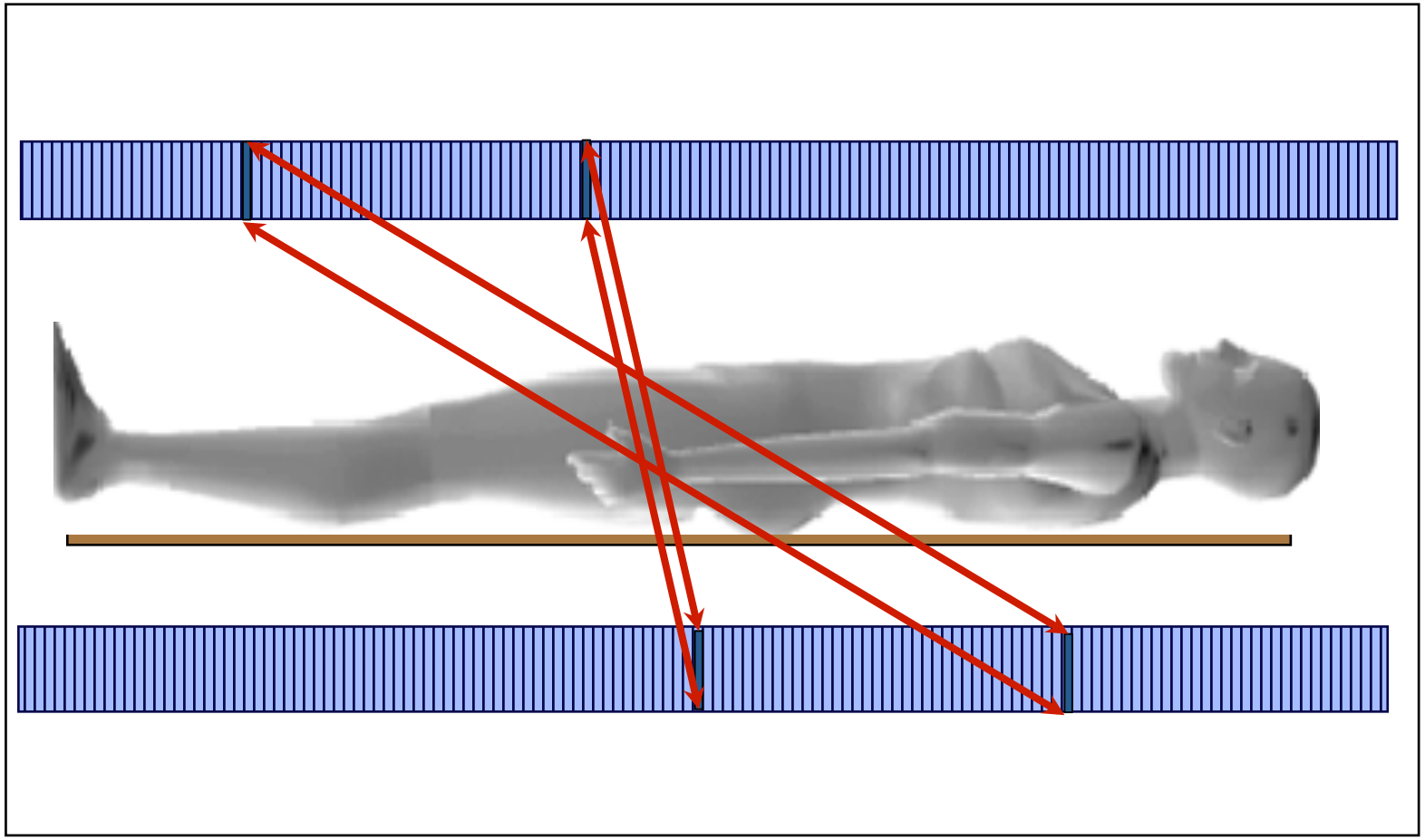
Detector Crate



16 Channel Detector Board



Why DOI-Encoding may be Necessary



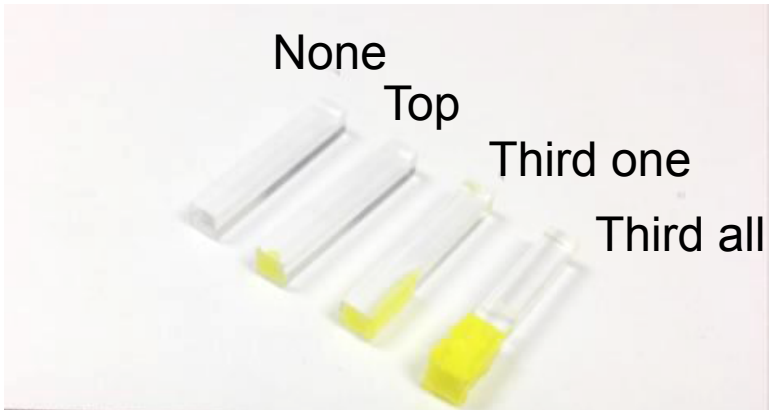
Detector Development

- **Goal:**

  < 400 ps timing resolution with 1-bit DOI

- **Approaches:**

  Phosphor-coating, two-layer, monolithic…



3 x 3 x 20 mm LYSO with
YAG phosphor

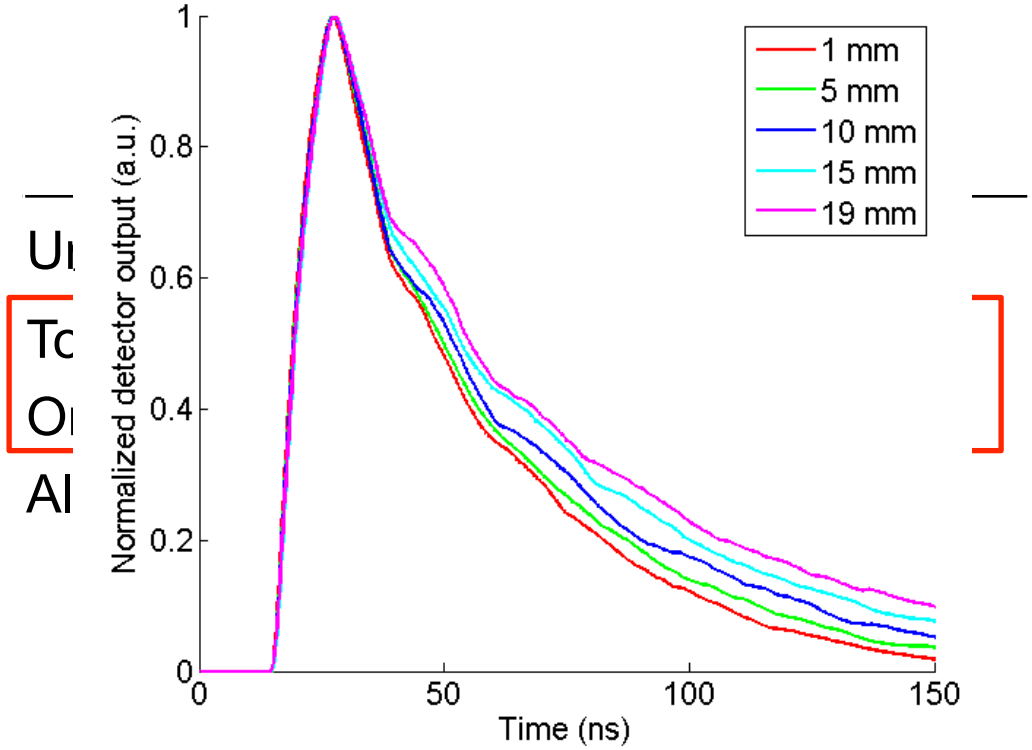
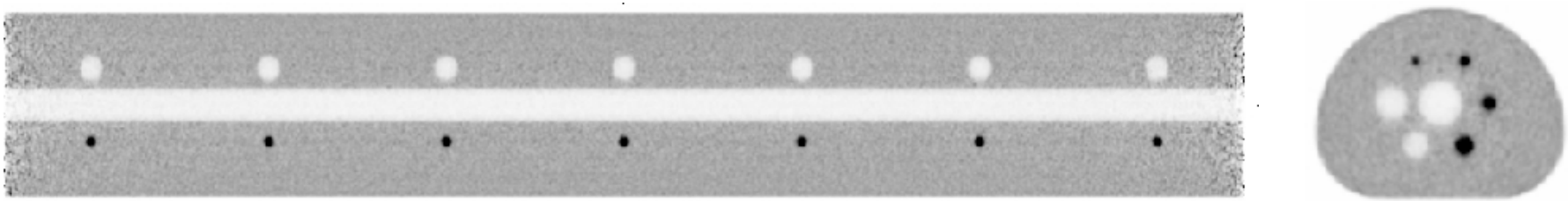


Image Reconstruction

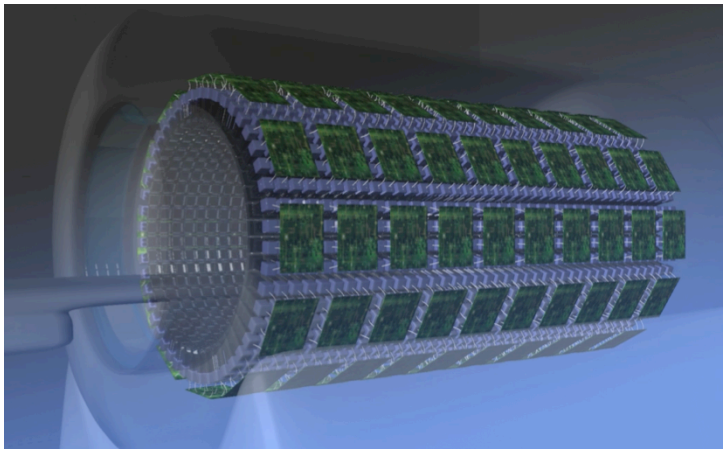
- 2 meter extended NEMA IQ phantom
- Reconstruction:
  - OSEM (5 iterations/2 subsets)
  - 2 mm voxels, 160 x 160 x 1000 image matrix
  - dual 8-core CPUs @ 2.0 GHz,
  - ~10 mins/iteration per 1 billion events



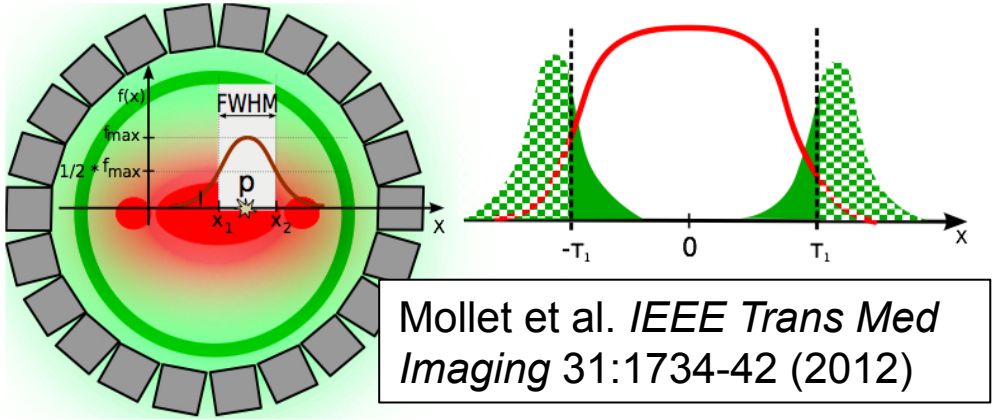
Reconstructed image corresponding to 4-minute scan, 10 mCi in phantom.

Other Considerations

- **Mechanical design**
  - Scale
    - 491,520 crystals
    - 880 kg of L(Y)SO!
  - Thermal management (~30-40 kW)
  - Highly reliable & easily serviced
  - Efficient fabrication scale-up



- **Attenuation correction**
  - Low-dose CT?
  - Static transmission rods?
  - LSO background?



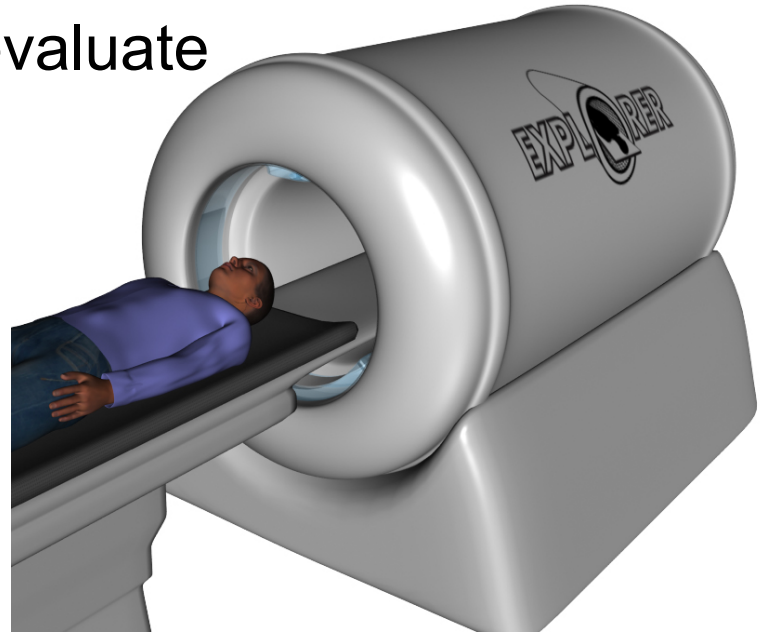
Mollet et al. *IEEE Trans Med Imaging* 31:1734-42 (2012)

- **Respiratory Gating**

EXPLORER

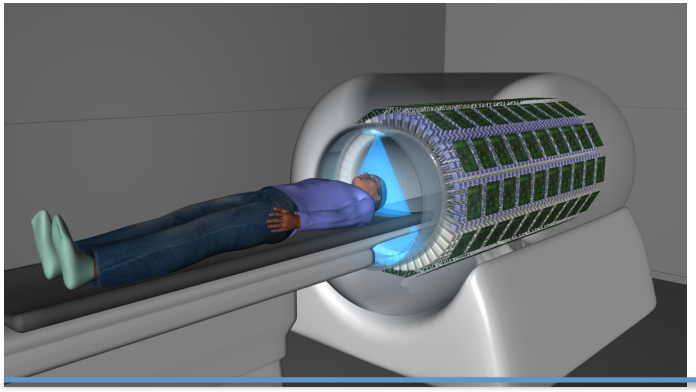
Current Status

- Project launched to build prototype total-body PET scanner with unprecedented sensitivity
  - Simulations are being used to evaluate design trade-offs
  - Initial design and feasibility studies underway
  - Conceptual applications in clinical medicine and research have been formulated



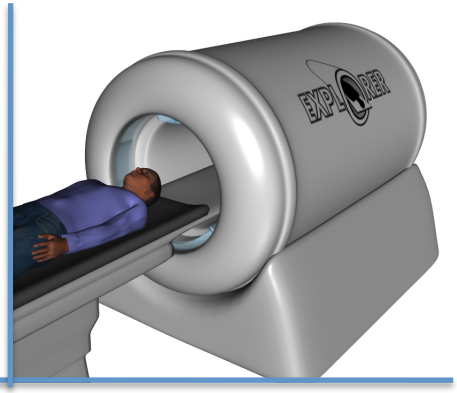
- Community input and participation encouraged

EXPLORER



EXPLORER

EXPLORER.ucdavis.edu



- **Greatly increased utilization of available signal**
  - Natural technical progression for the development of PET
  - Scans approaching background radiation dose, or,
  - High statistics scans at current radiation dose
- **Assured unique novel human applications**
- **The need for advances which embrace the skill base of the IEEE imaging community:**
  - Appropriate TOF/DOI detector technology
  - Optimal sorting and use of singles information
  - Accurate and fast detector normalization
  - Low dose attenuation correction
  - Efficient and accurate image reconstruction
  - …