TIPP for Medical Applications

Chin-Tu Chen, Ph.D.

The University of Chicago

&

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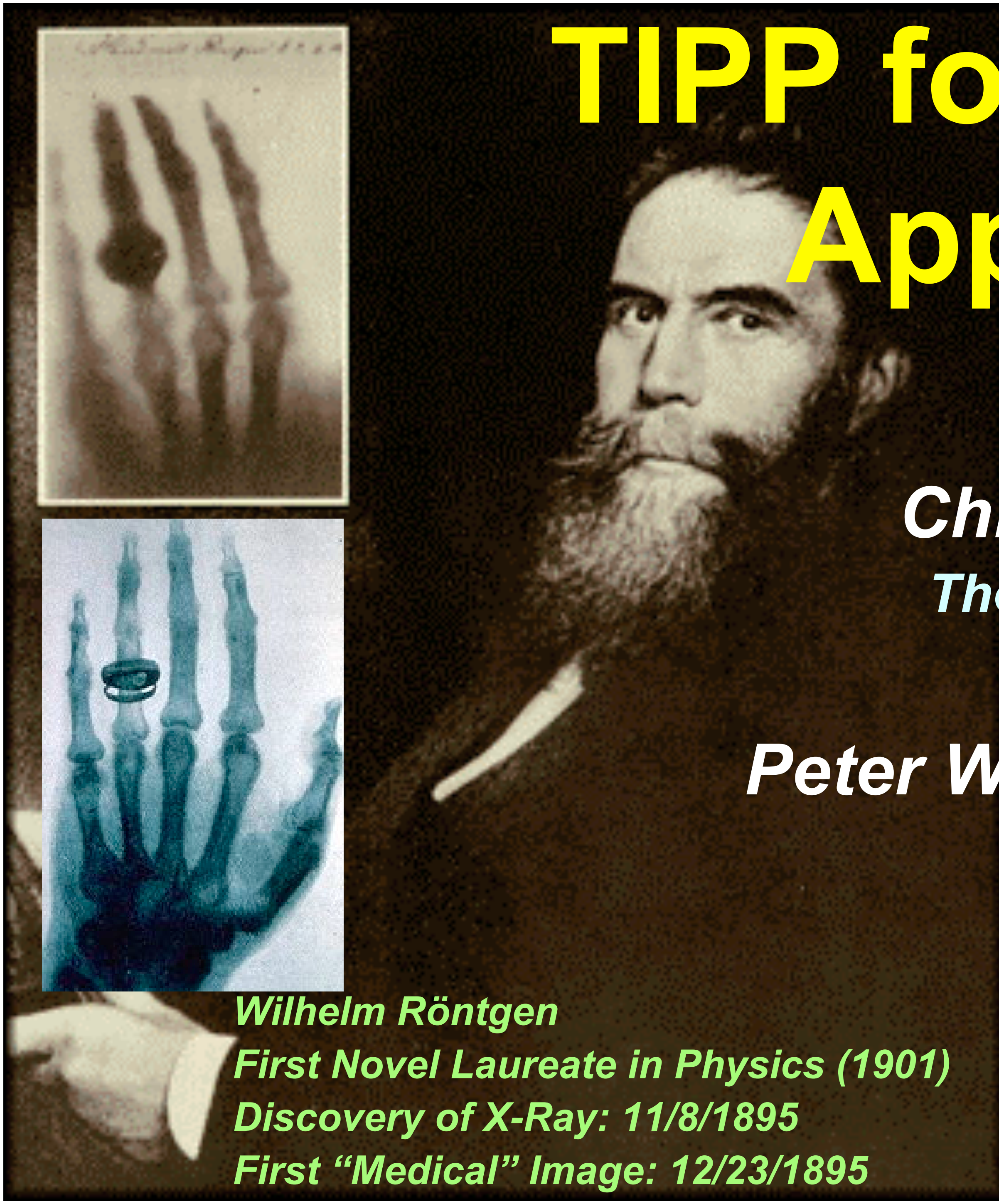
CERN



Wilhelm Röntgen
First Novel Laureate in Physics (1901)
Discovery of X-Ray: 11/8/1895
First “Medical” Image: 12/23/1895

June 10, 2011, TIPP 2011, Chicago

This Overview

- **Only a limited selection of medical applications**
- **TIPP 2011 papers largely not included**
- **Emphasis on**
  - **- PP/HEP connections**
  - **- Emerging, forward-looking, next-generation**
  - **- Potentials for routine and wide-spread use (commercialization)**
  - **- Impacts to medicine & health-care**

More on Medical Applications:

- TIPP 2011 Tuesday 6/14/2011, 10:30am
Patrick Le Du: "Application Outside HEP"

- TIPP 2009, Peter Weilhammer: "Particle Physics Instrumentation and Its Impact on Medical Imaging"

Common Ground of PP/HEP & Medicine

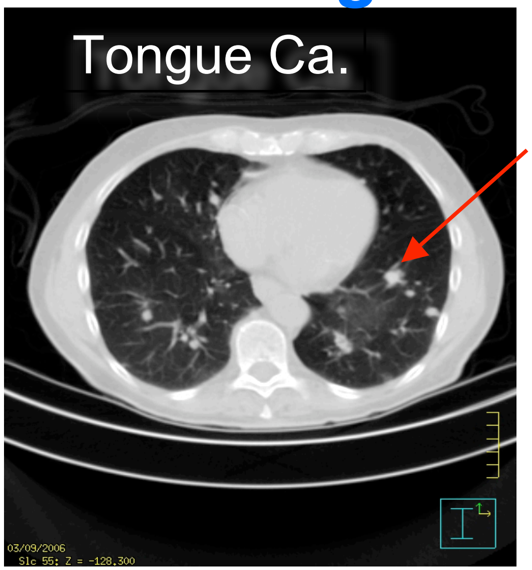
- **Diagnostic Imaging**
- **"Radiation" & "Particle" Therapy**
- ***"Thera[g]nostics"* (Diagnostics + Therapeutics)**

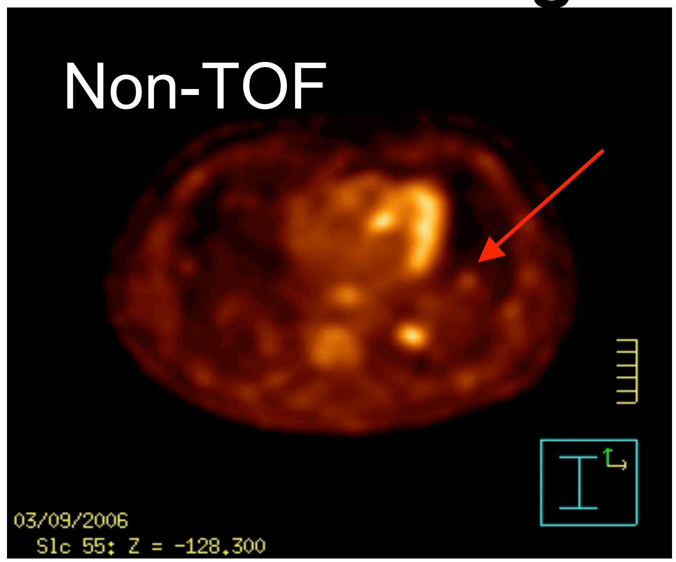
"……Medical Applications serve as ideal 'prototyping' test and validation platforms of realistically feasible small-scale for PP/HEP Technology and Instrumentation……"

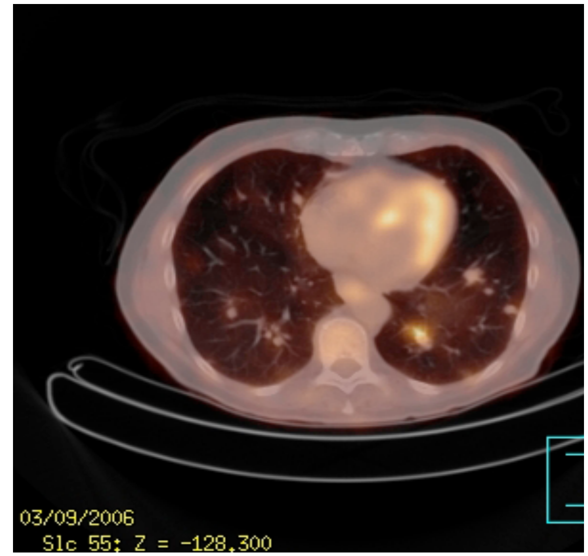
- In Discussion with Marcel Demarteau

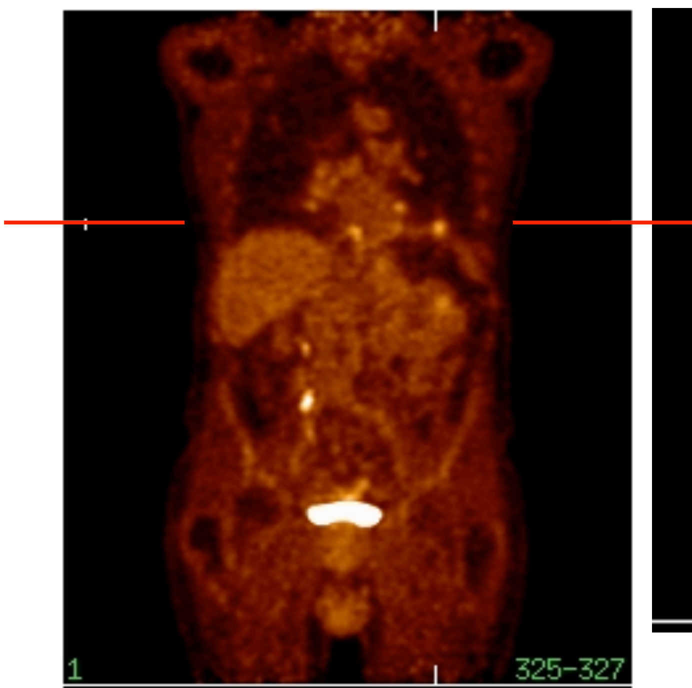
PHILIPS

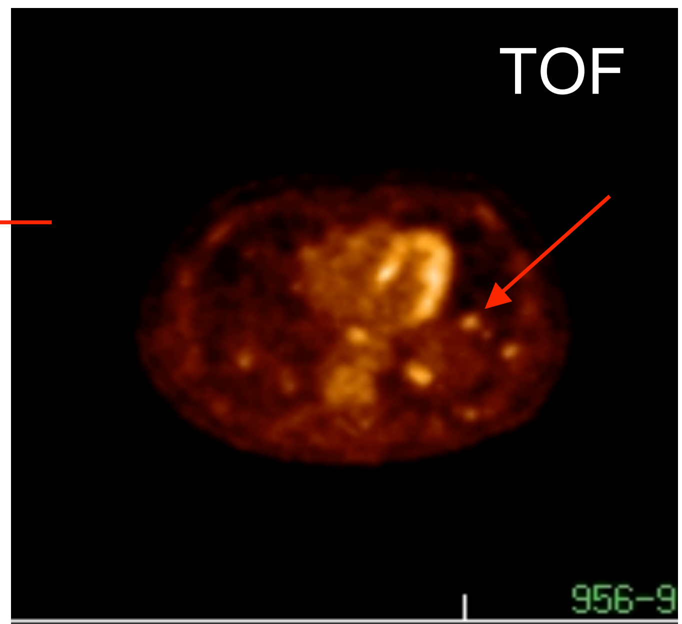
TruFlight™: Enhanced Diagnostic Confidence









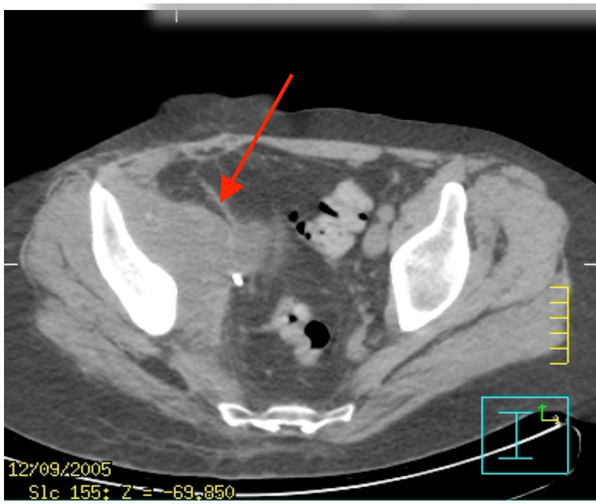


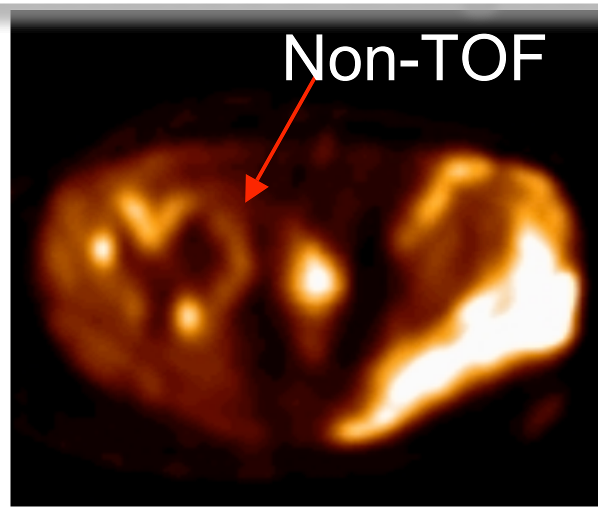
improved detectability of sma
mets in lung

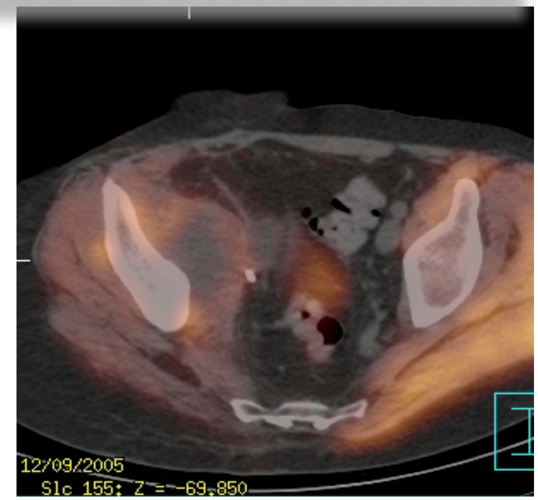
67 kg; BMI = 29.0
9.8 mCi; 1 hr post-
(2min/bed)

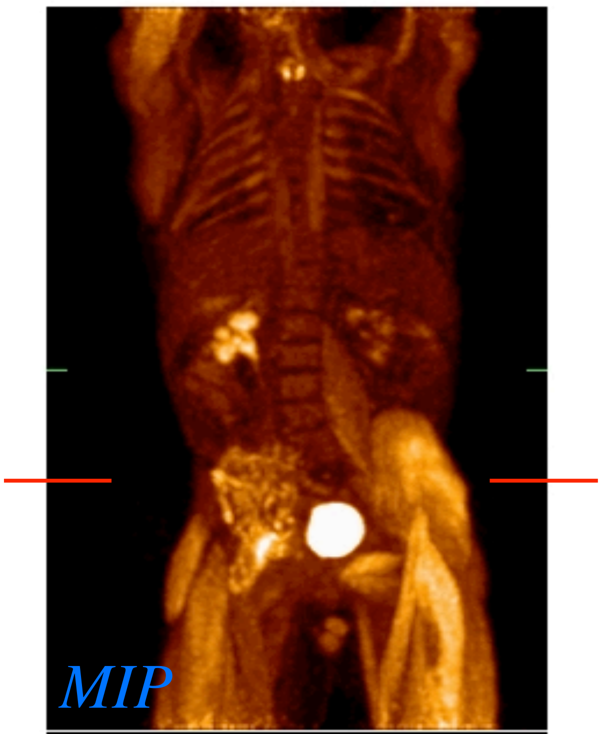
Data courtesy of J. Karp, University of Pennsylvani

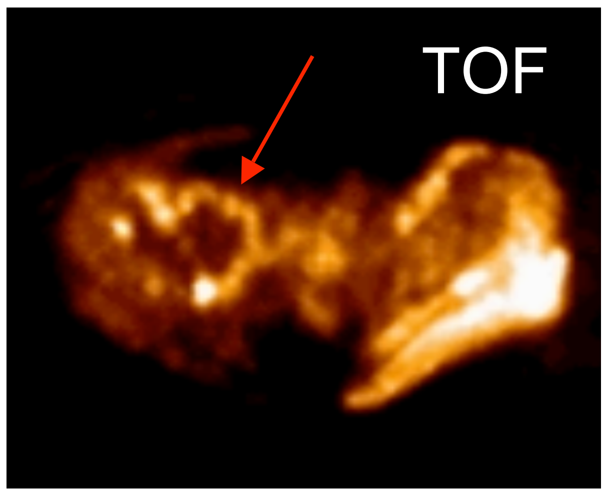
TruFlight™: Enhanced Diagnostic Confidence











Lymphoma within iliopsoas muscle w central area of nec

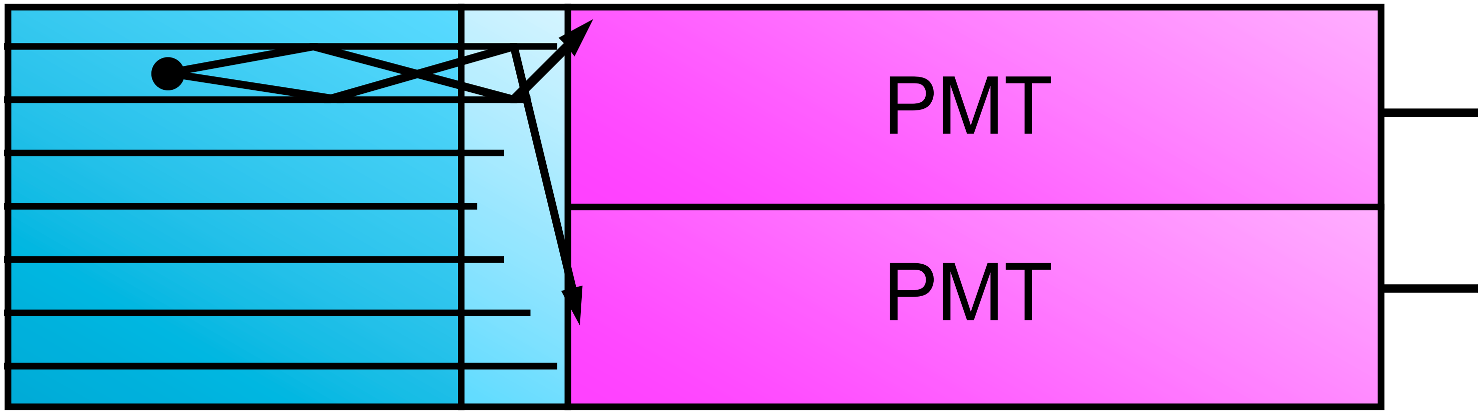
improved delineation of lymphoma activity

116 kg; BMI = 31.2
14 mCi; 2 hr post-inj

Data courtesy of J. Karp, University of Pennsylvania

What Timing Can An LSO Module Achiev

Crystal Geometry

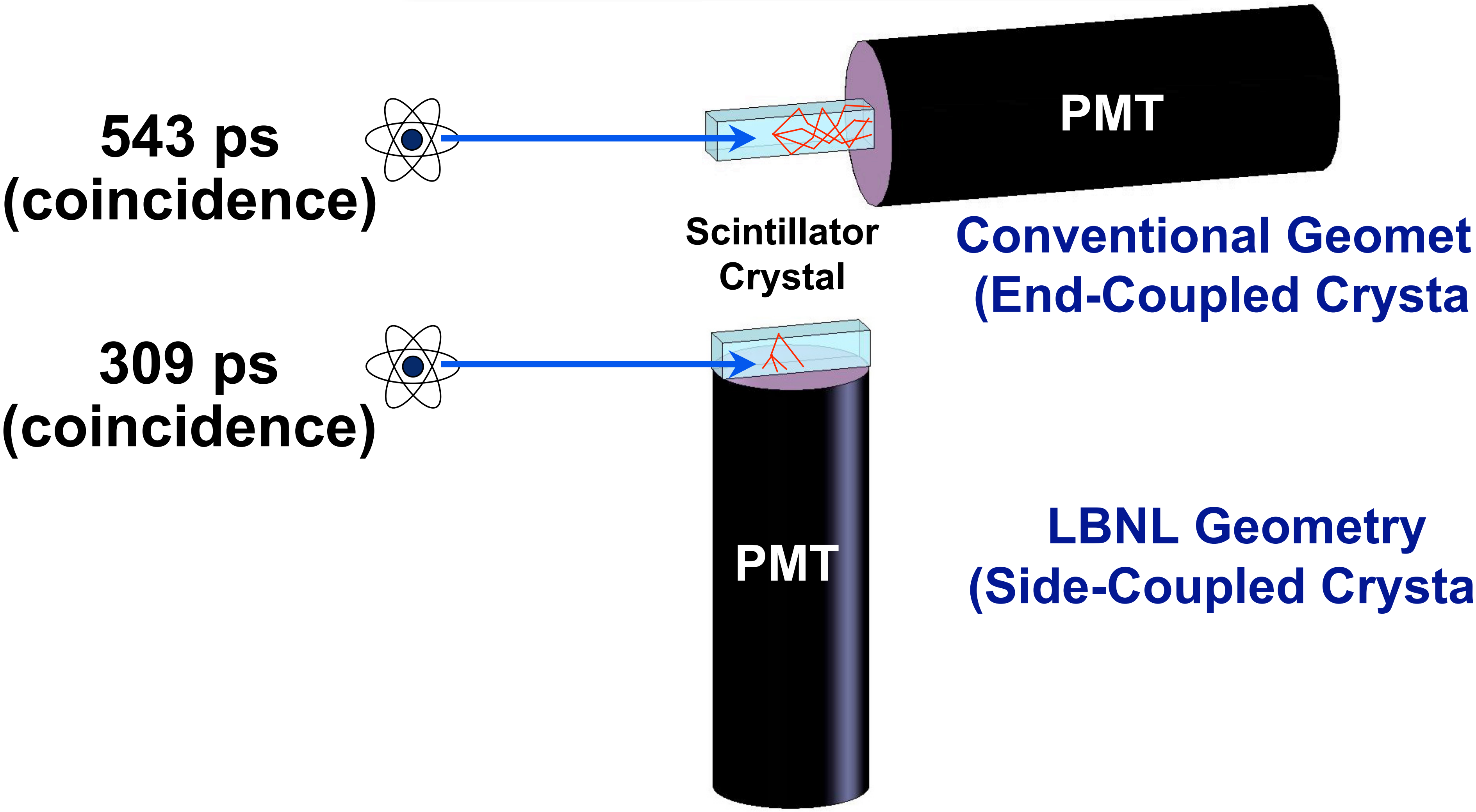


Light Sharing | **PMT Quality** | **Multiple PMTs**

Predicted Limit	550 ps
Measured Value	575 ps

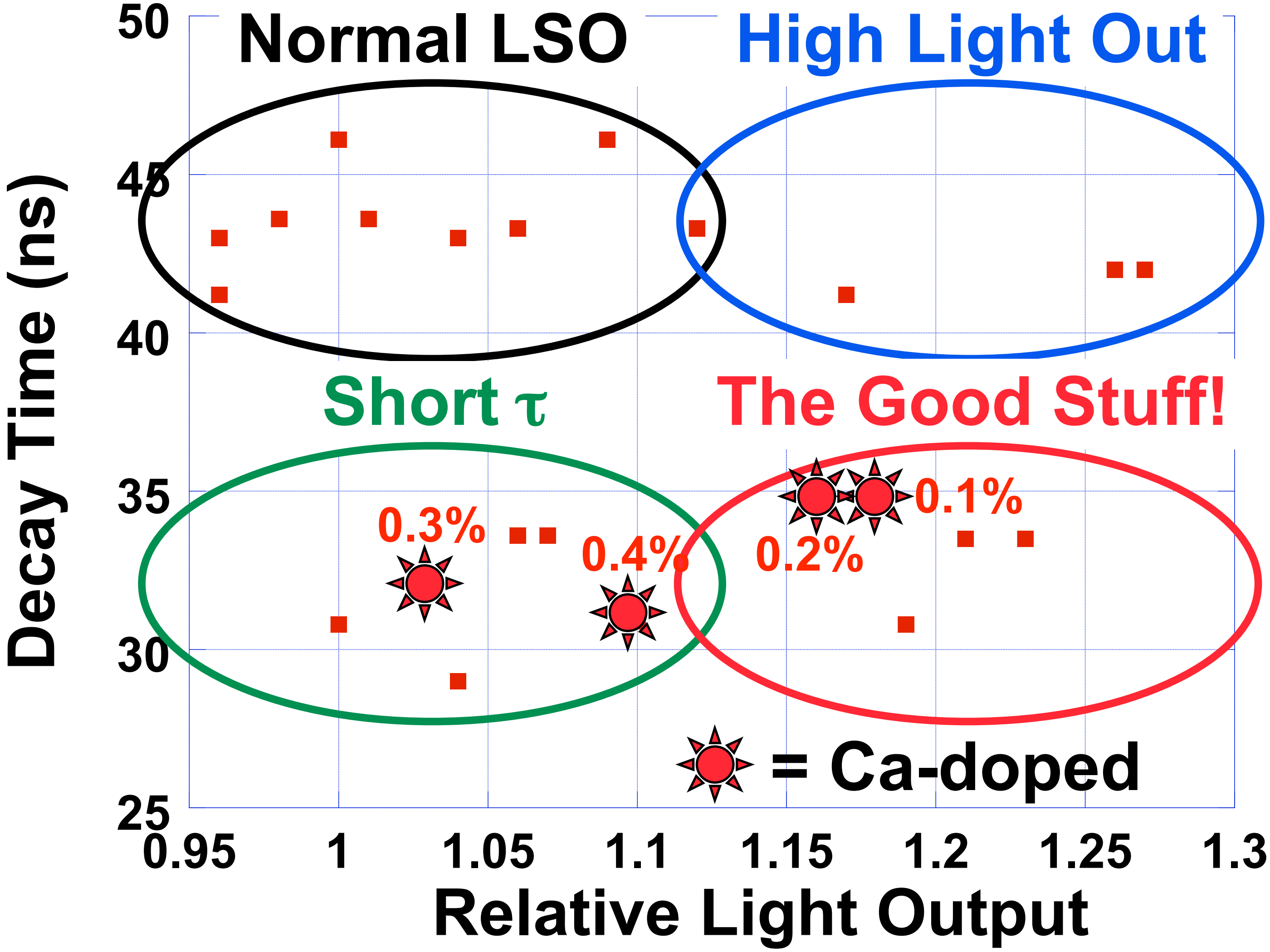
Already Near LSO Block Detector Theoretical L

Side-Coupled Design



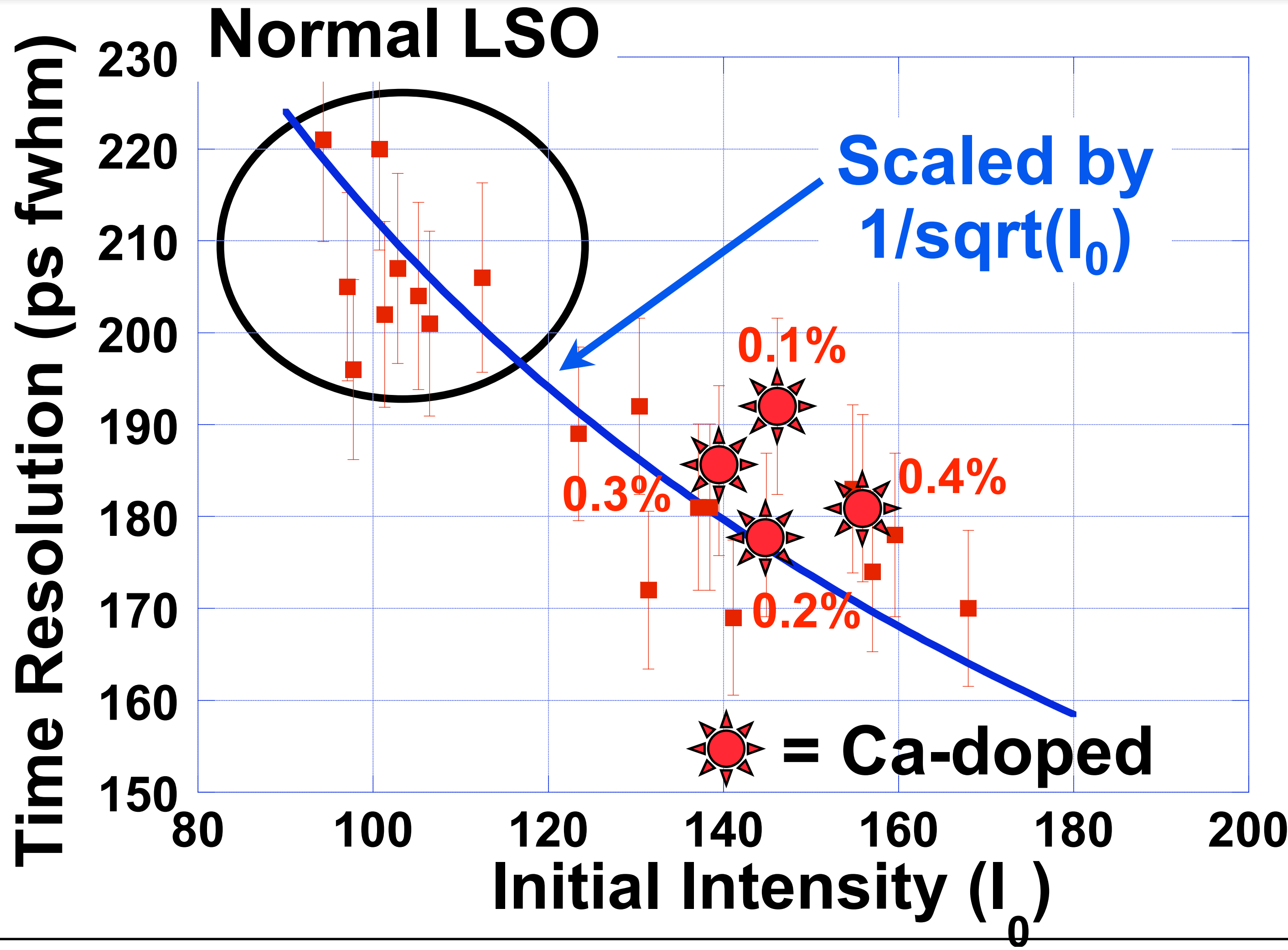
Shorter Optical Path Length & Fewer Reflections

Optimization: LSO Composition



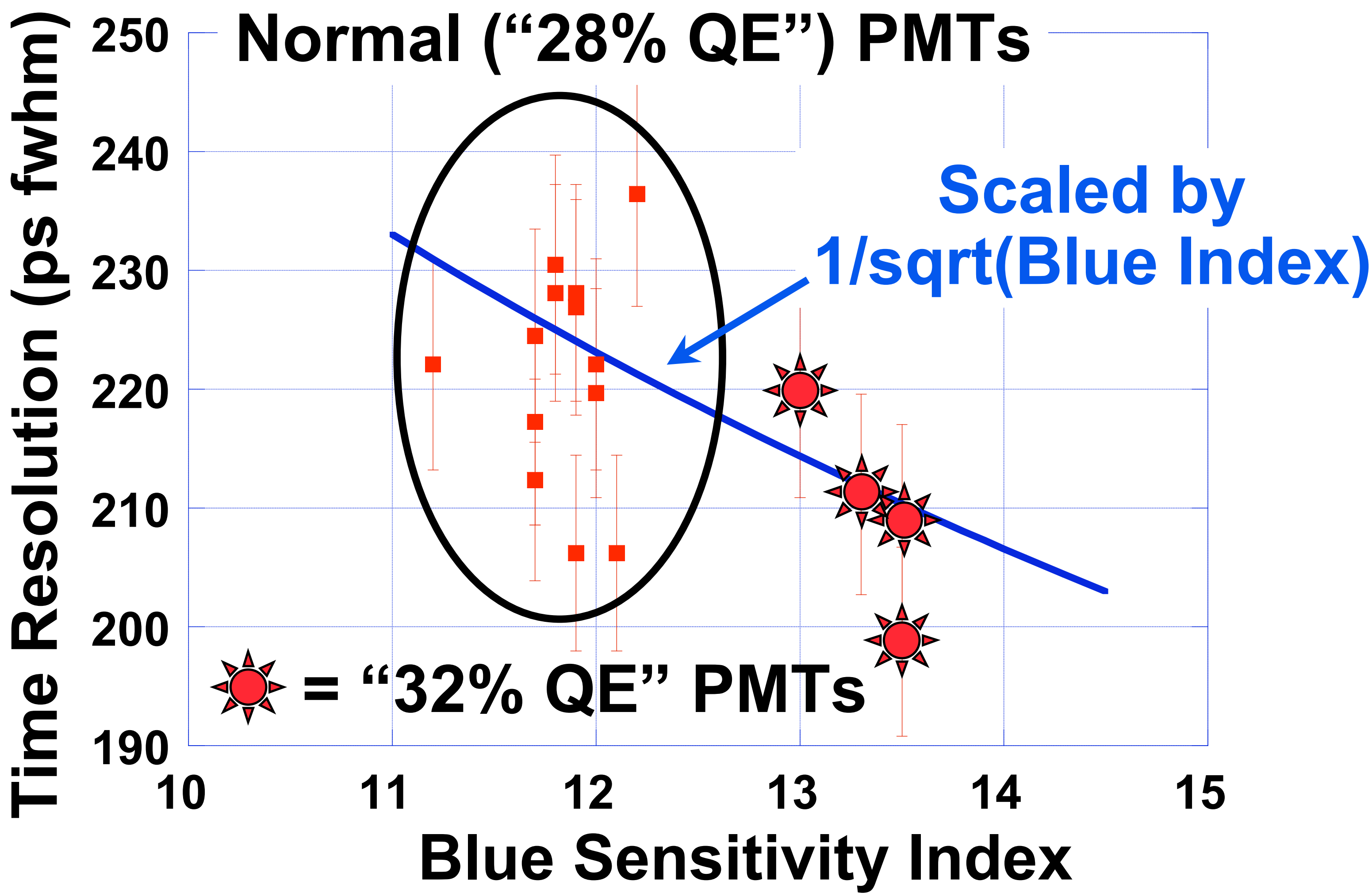
Ca-Doping Gives High Light Output & Short

Measured Results: LSO Composition



- Ca-Doping Gives Good Timing Resolution
- ~15% Improvement Over Normal LSO

Measured Results: High QE PMTs



- Increased QE Improves Timing Resolution by
  - Expect 10% Improvement with 35% SBA PM

Additional Improvements

Hardware	Coinc. (ps fwhm)	TOF Gain
End-Coupled Crystal	543	4.3
Side-Coupled Crystal	309	7.6
Co-Doped LSO	258	9.1
32% QE PMT	219	10.6

- TOF PET with *Significantly* Better Timing is Possib
- To Achieve, We Must "Think Outside the Block Detec

Detector Module Design

Two LSO Crystals

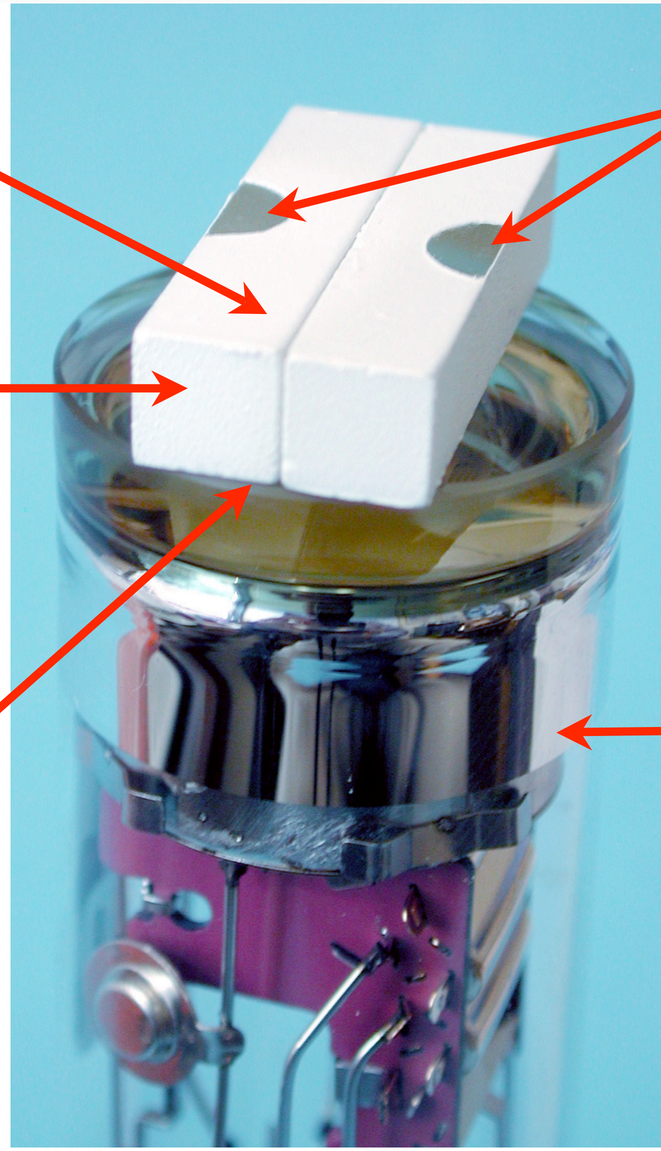
(each 6.15 x 6.15 x 25 mm^3)

Reflector

(on all five faces of each crystal, including the face between the two crystals)

Optical Glue

(between lower crystal faces and PMT)



Hole in Reflec
On Top Face
Crystals

PMT

(Hamamatsu R-9800)

Two Side-Coupled Scintillator Crystals per PMT

How Far Can TOF PET Go?

- **100 ps Timing Resolution**
- **23x Effective Efficiency Increase**
- ***Very* Fast Reconstruction**

Acquire & Reconstruct Image in <1 Minu

Conclusions

Benefits of TOF are *HUGE*:

- 5x effective efficiency gain w/ 500 ps timing
- Greatest improvement in large patients
- Faster reconstruction algorithm convergence

Rebirth of TOF PET Due To New Scintillators:

- 575 ps for LSO, 350 ps for $LaBr_3$

Still *LOTS* To Do:

- Electronics
- Module Design
- Reconstruction
- Photodetectors
- Scintillators
- Evaluation

***Much* More Improvement To Come!**

UChicago, Argonne, Fermi, +……

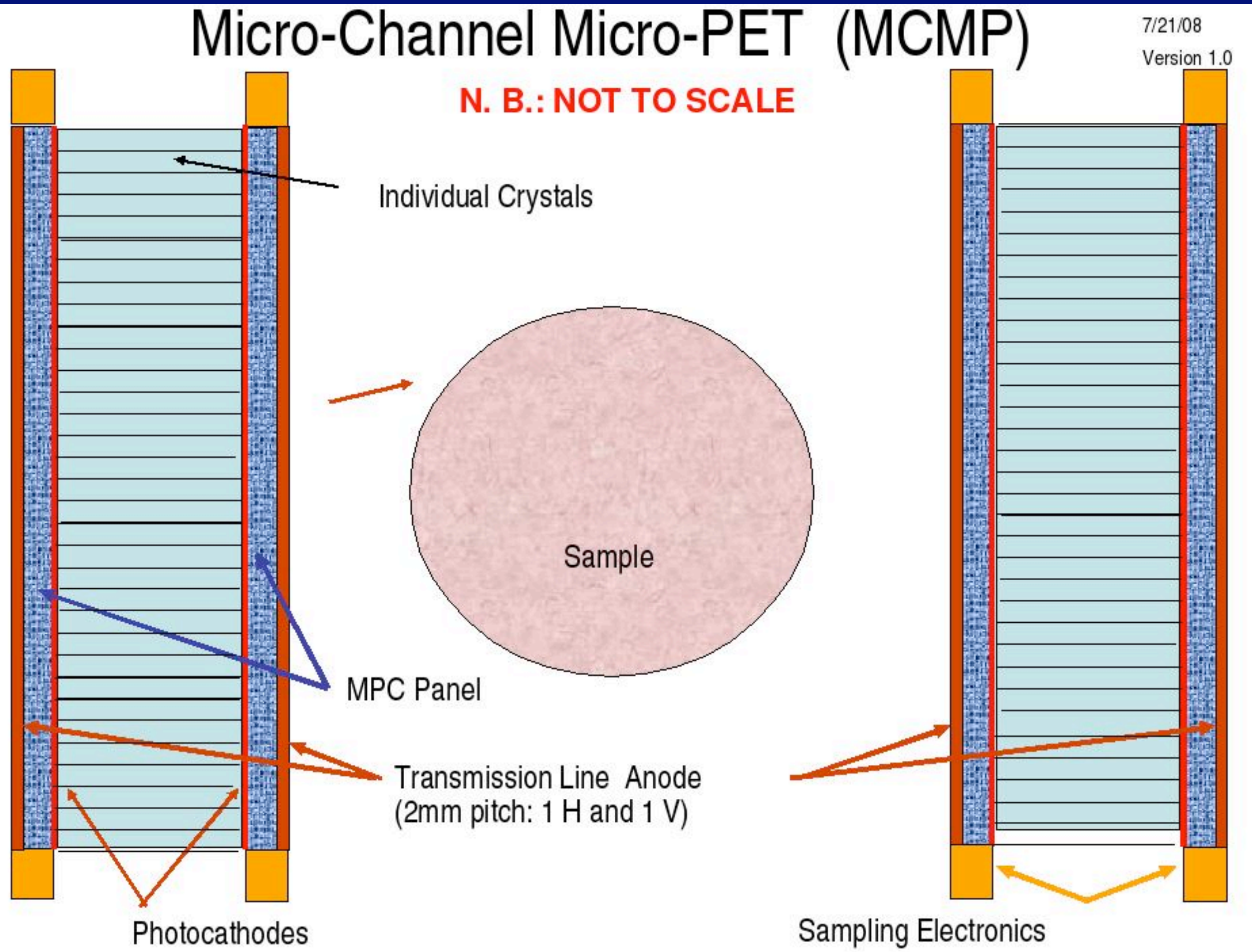
Large-Area Picosecond Photo-Detector (LAPPD) Project

Next-Generation MCP-PMT

<u>*Project with 4 primary goals:*</u>

1. Low-Cost LAPPD with good timing and spatial resolution (~$10/sq-in area cost)
2. Large-Area TOF particle/photon detectors with picosecond time resolution
3. Understanding photo-cathodes so that high QE cathodes can be reliably made with tailored spectral response, and new materials & geometries can be developed
4. Produce commercializable modules within 3 years & transfer technology to industry

Panel-Based DOI-Coded TOF PET



Potential Applications:

(DOI+TOF)-PET/CT

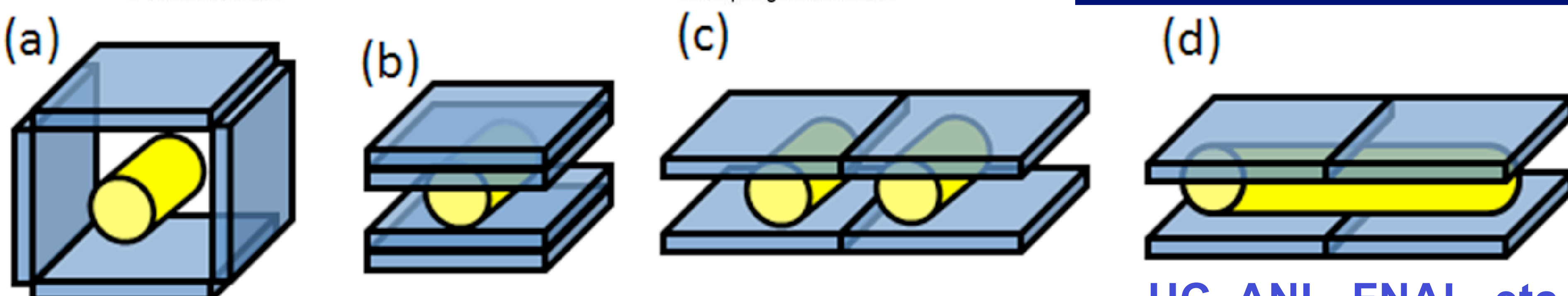
Reconfigurable, Integrative, Modular "Super-Modules"

[a] High-Resolution "Cube"

[b] High-Sensitivity "Multi-Layer"

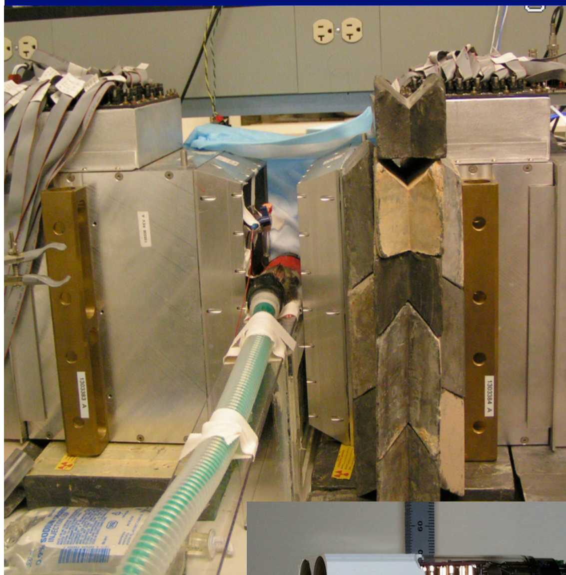
[c] High-Throughput "Multi-Object"

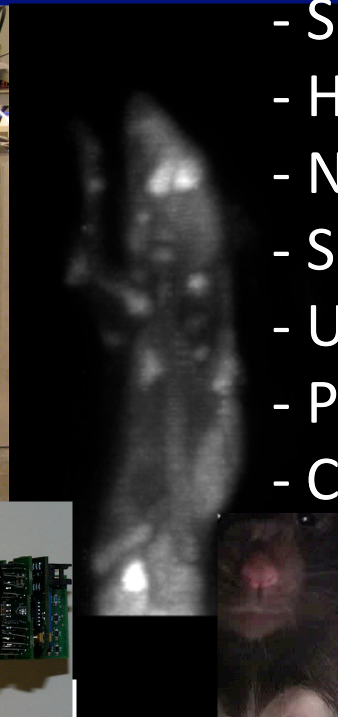
[d] Whole-Body



UC, ANL, FNAL, etc.

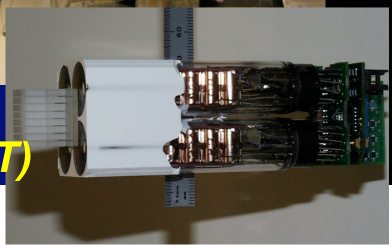
High-Sensitivity Dual-Panel DOI-PET

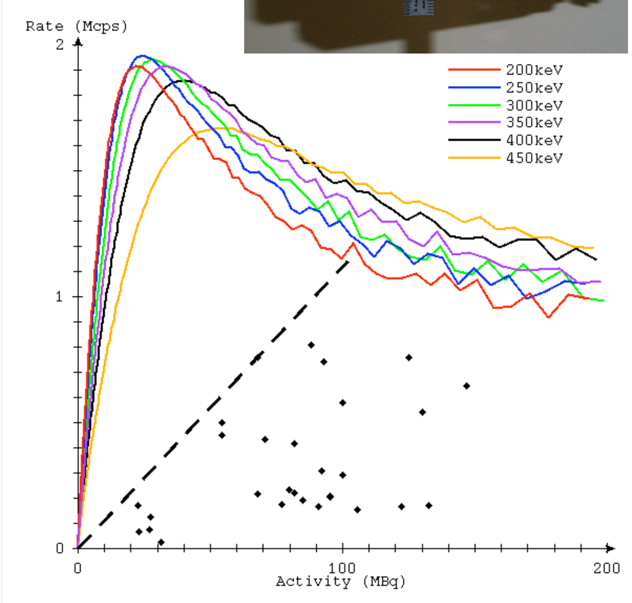




- Sensitivity 25-30% (3-10 folds increase)
- High-throughput, multi-object
- Novel reconstruction/no rotation
- Super-resolution recovery
- Uniform resolution within large FOV
- Pre-clinical drug development
- Clinical or research brain imaging

Q-Sharing PMT (HRRT)

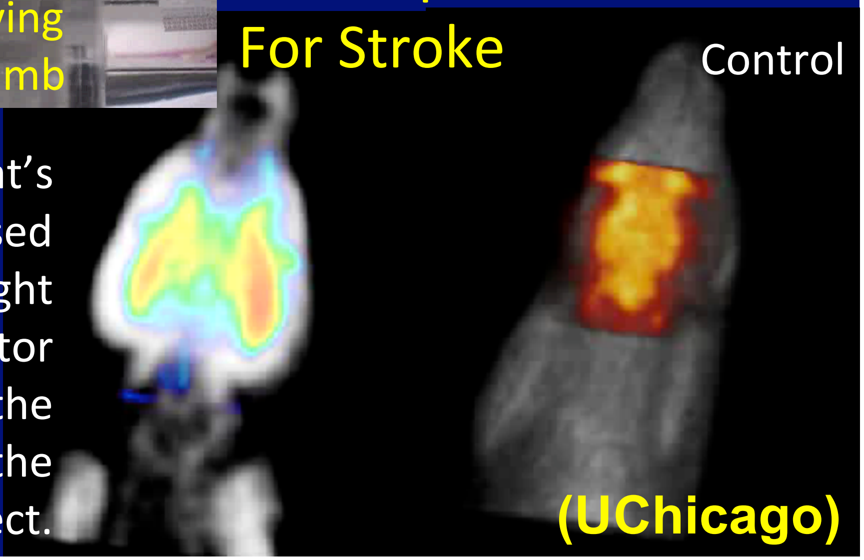




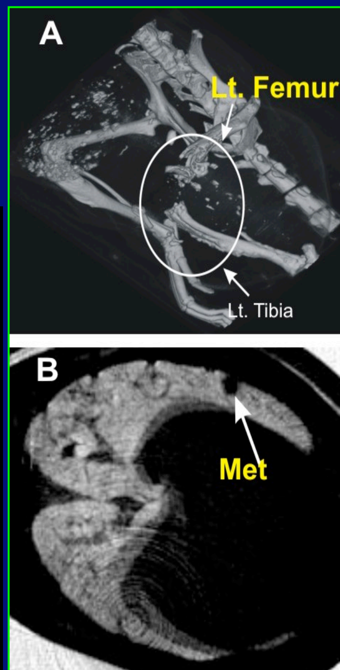
Reaching task involving the left forelimb

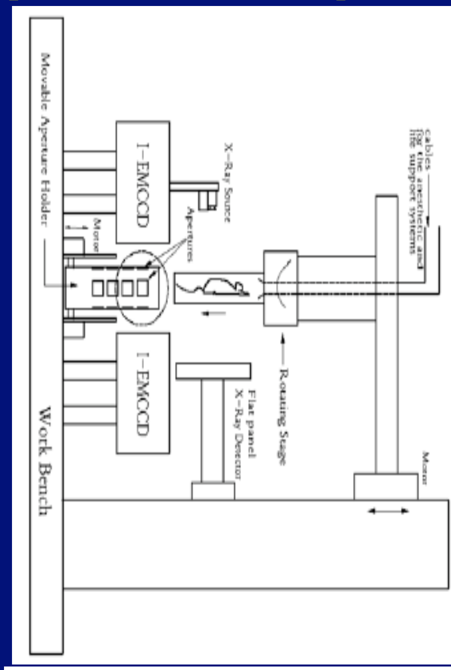
New CNS Drug Development For Stroke

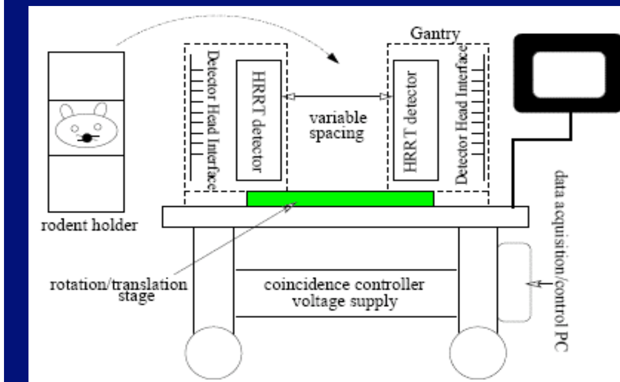
FDG imaging of a rat's brain shows increased FDG uptake in the right brain due to the motor task performed by the left forelimb of the subject.

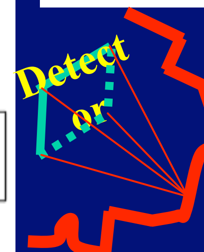


Modular, Re-Configurable, Integrative PET/SPECT/CT For Flexible Application-Specific Imaging





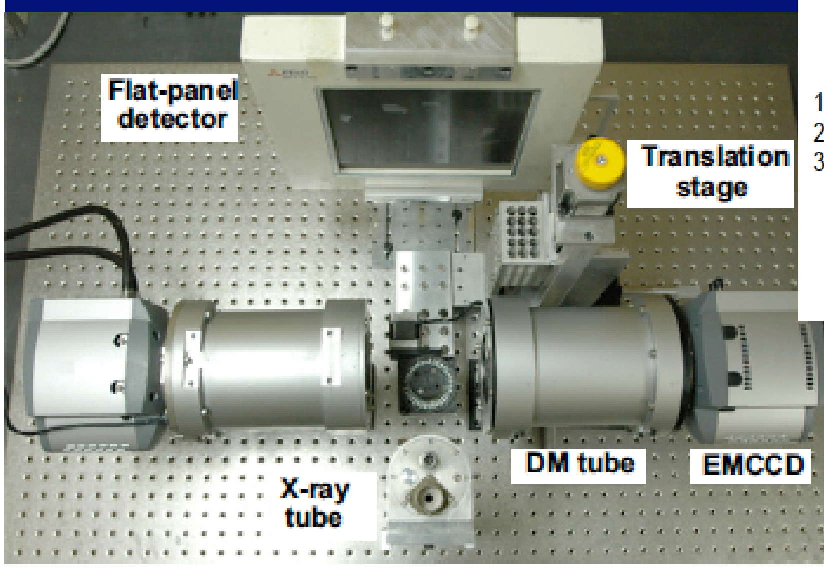


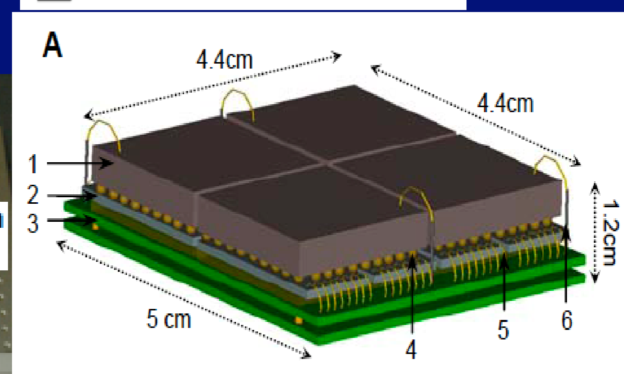


Integrative: *Assemble & dis-assemble based on application-specific needs.*

Flex-Configure: *Novel Recon for flexible scanning trajectories*

Multi-Modality: *PET/SPECT/CT*





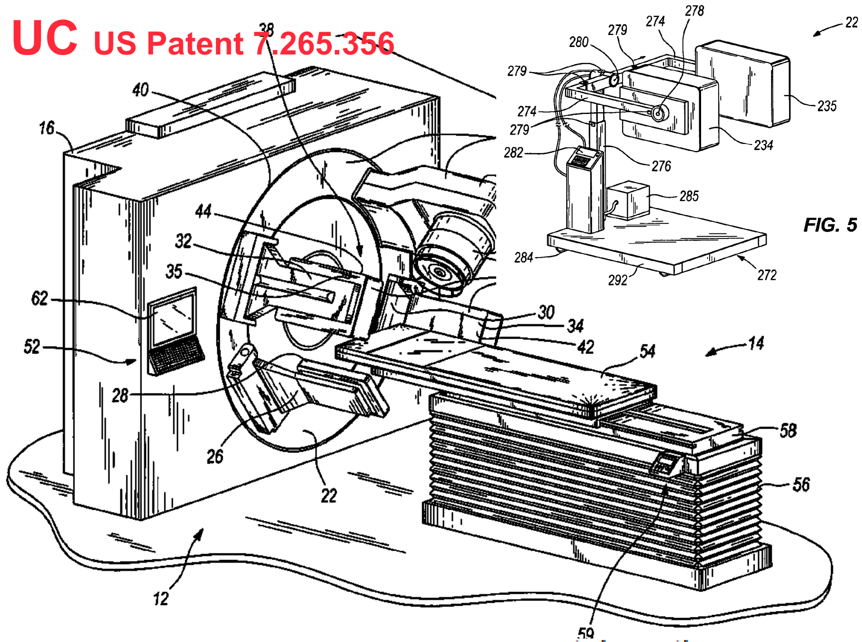
Semiconductor Detectors (CdTe/CZT)

Energy Resolved Photon Counting (ERPC)

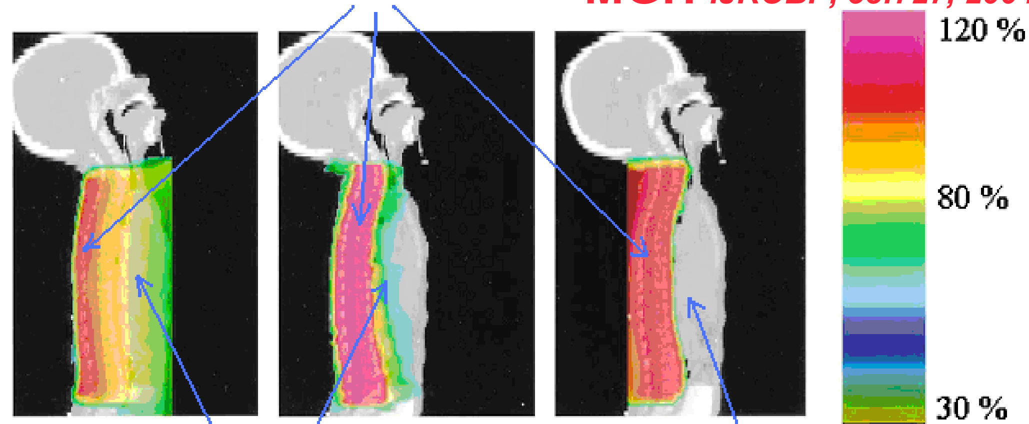
UIUC, WashU, UC

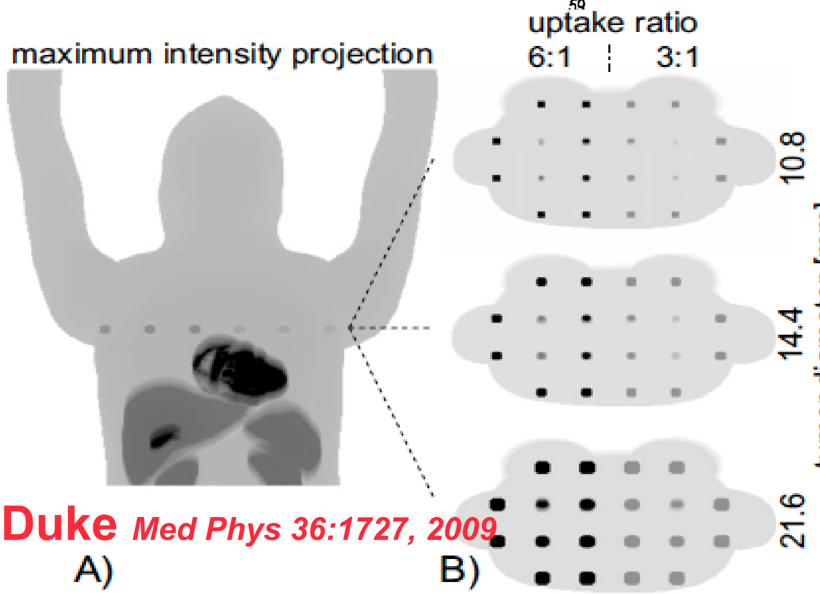
On-Board, In-Beam, In-Room CT, PET or SPECT for Radiation & Particle Therapy (Theranostics)

UC US Patent 7.265.356

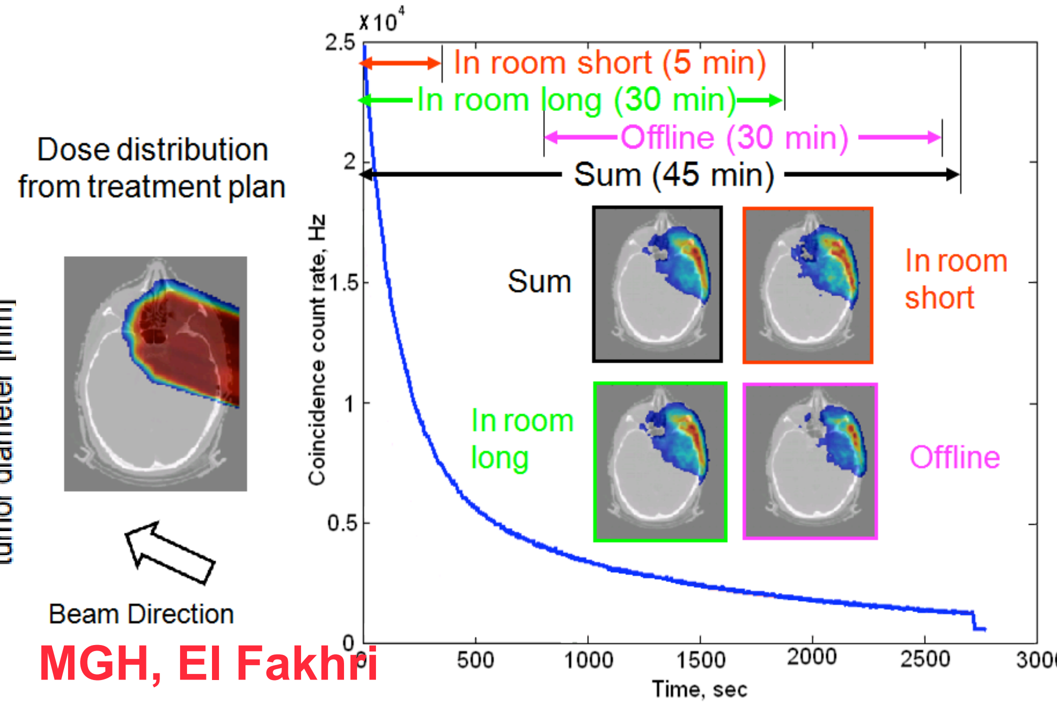


MGH *IJROBP, 58:727, 2004*



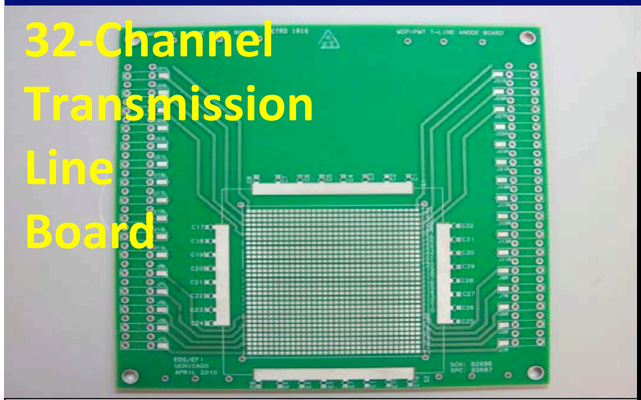


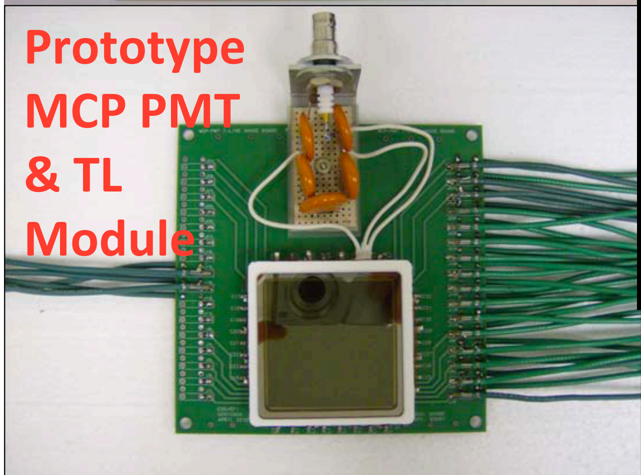
Duke *Med Phys 36:1727, 2009*

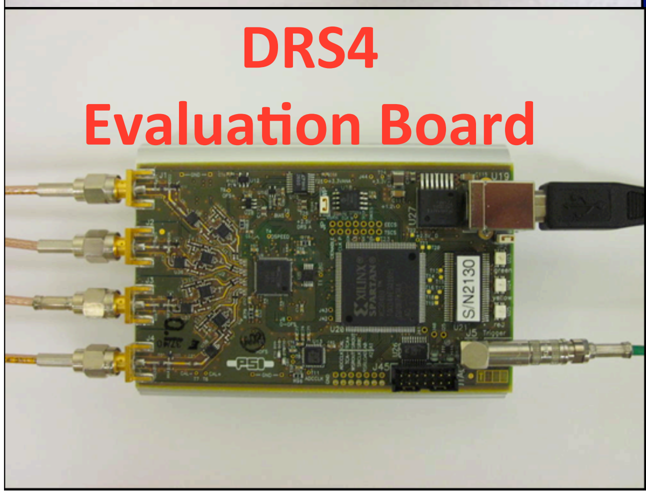


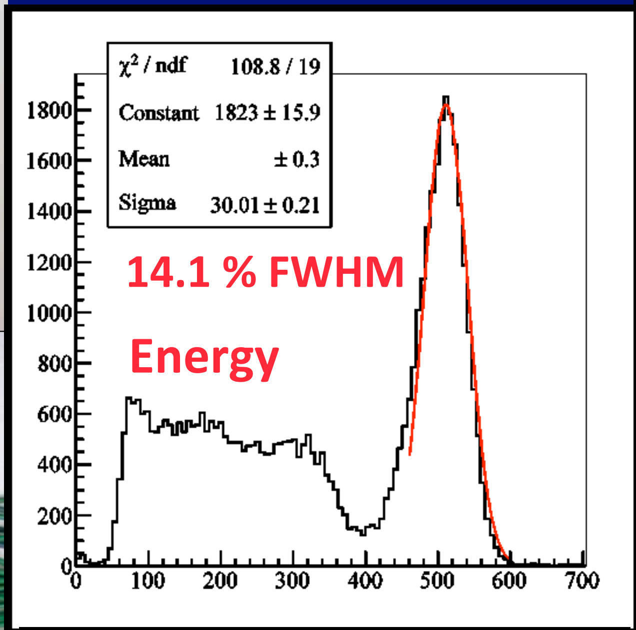
MGH, El Fakhri

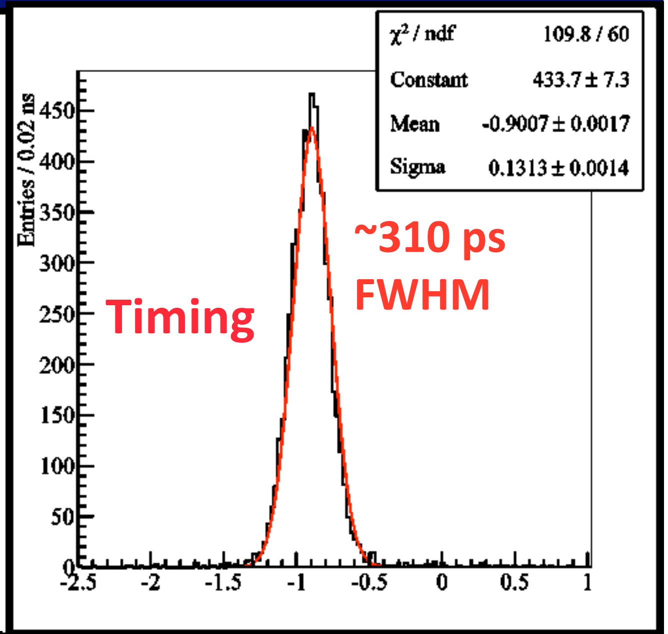
Fast Electronics and All Digital PET

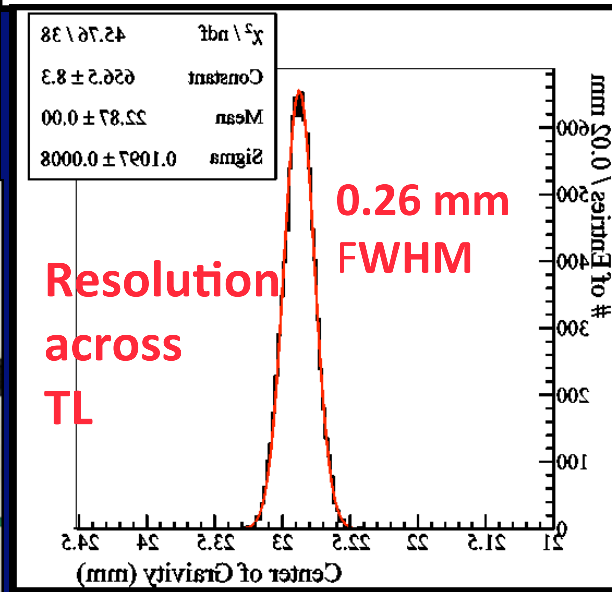


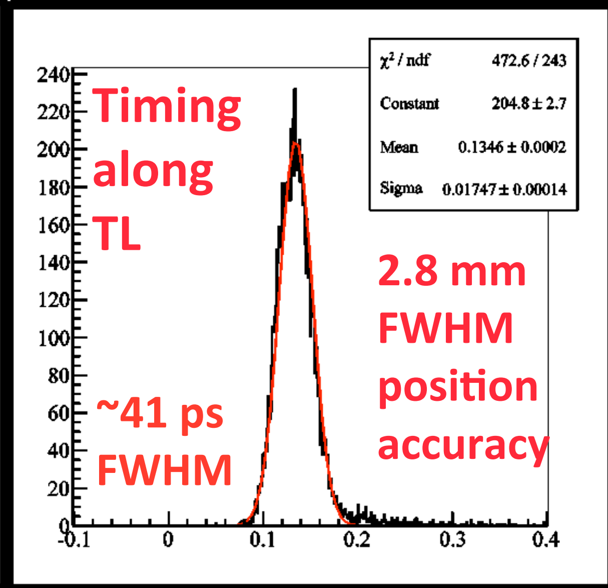






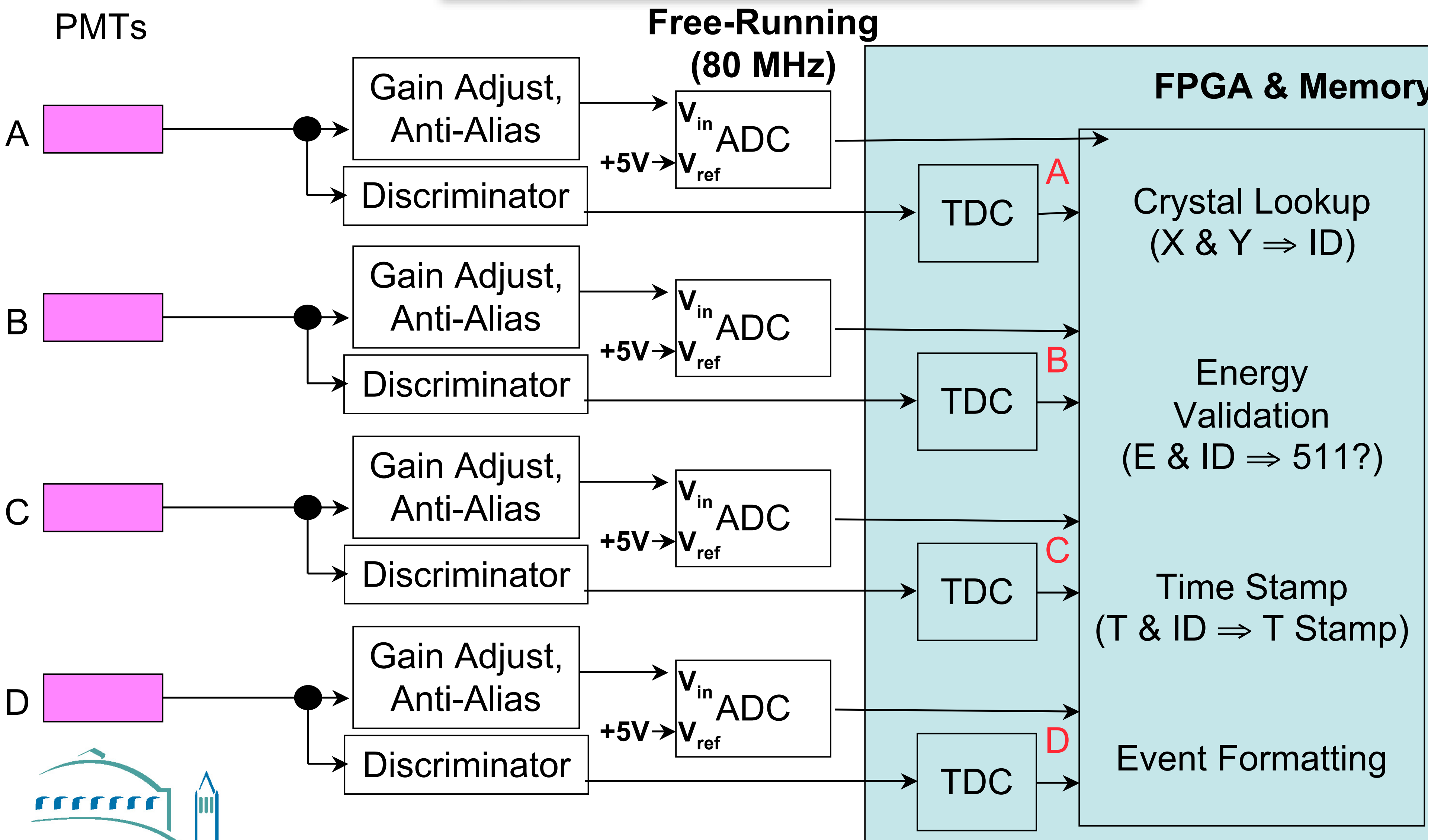






UC, ANL, etc.

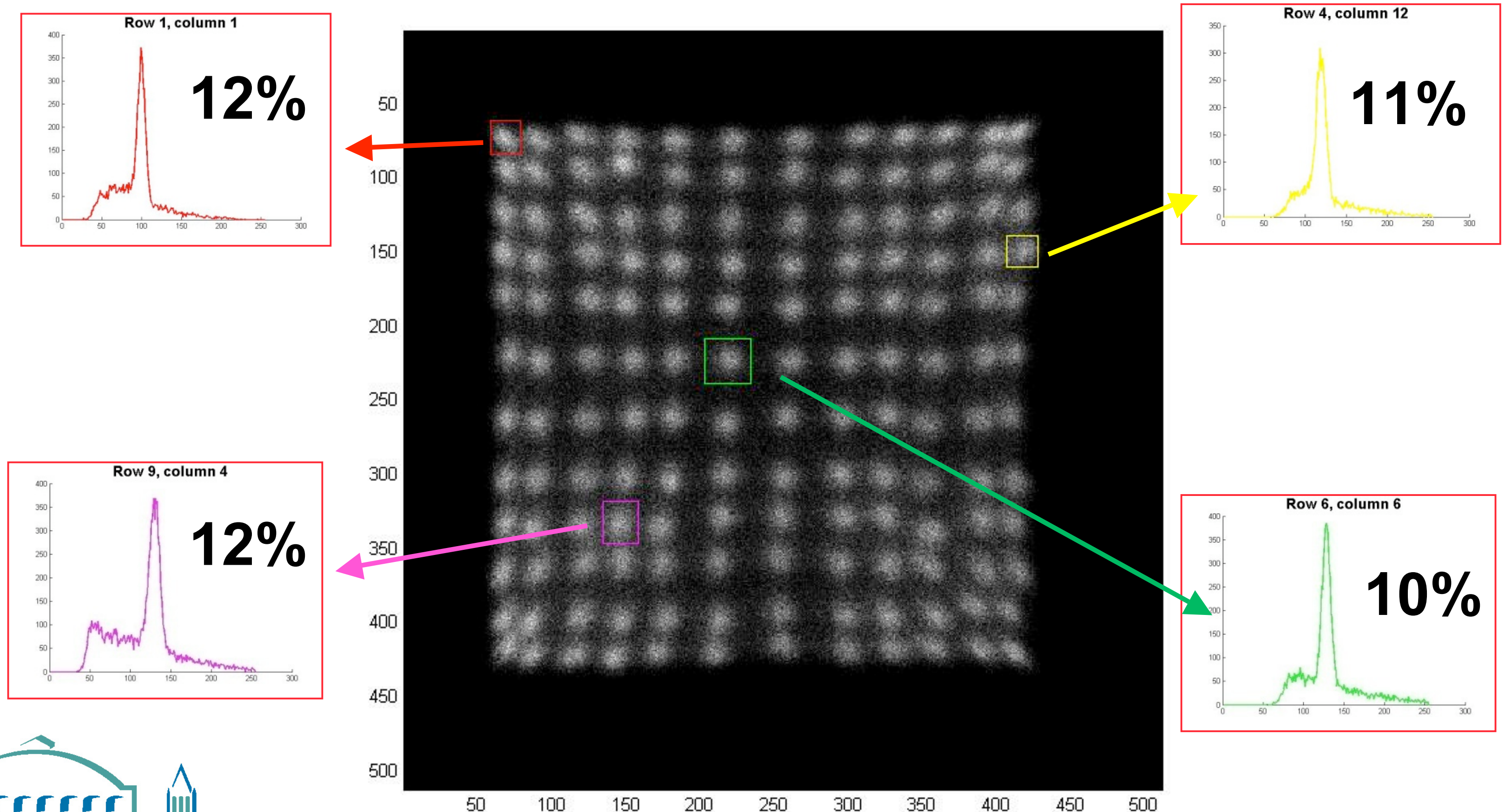
OpenPET Front End



Analog Done w/ Discrete, Digital Done w/ FPGA

Detector 1: Conventional Block Detector

12x12 array of 4x4x22 mm^3 LSO crystals
4 Hamamatsu R-9800 PMTs



- Pre-Prototype Circuit Boards
- Excellent Flood Map and Energy Resolution

Detector 2: SiPM Array

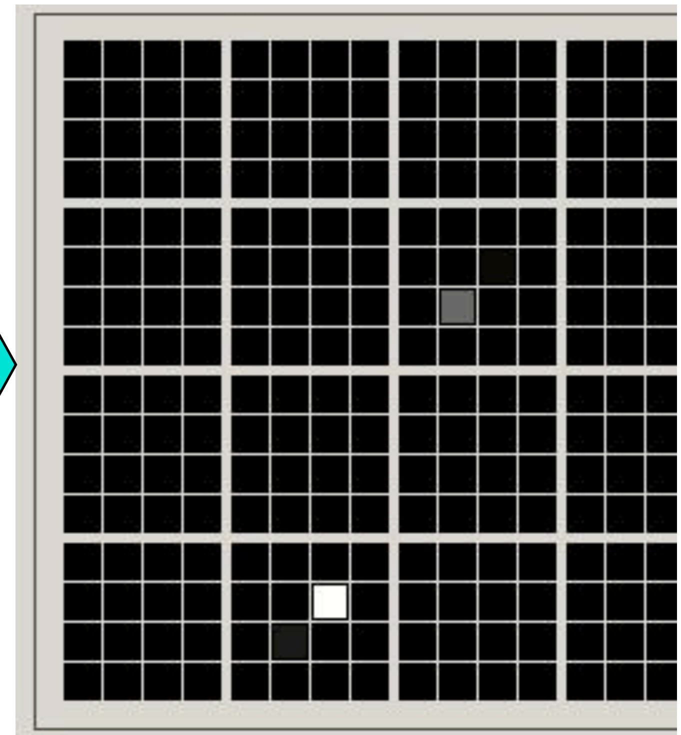
16x16 array
3x3 mm² SiPMs

3x3x20 mm³ &
3x3x30 mm³ LSO

Adapter Board

16x16 array
to
16 Row &
16 Column
Analog Sums

Natural LSO Activity



Pixel Intensity ∝
Energy x Count Rate

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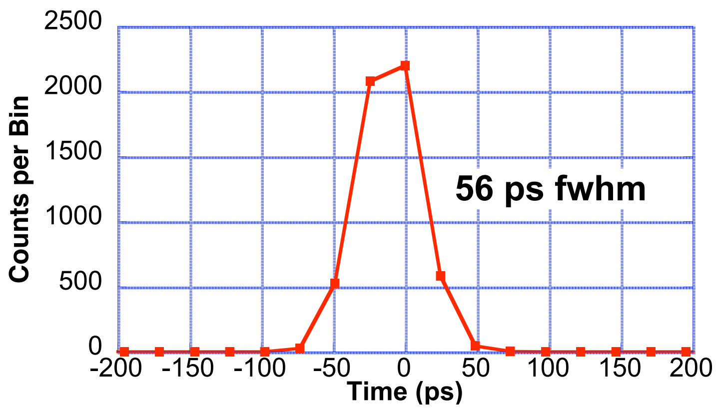
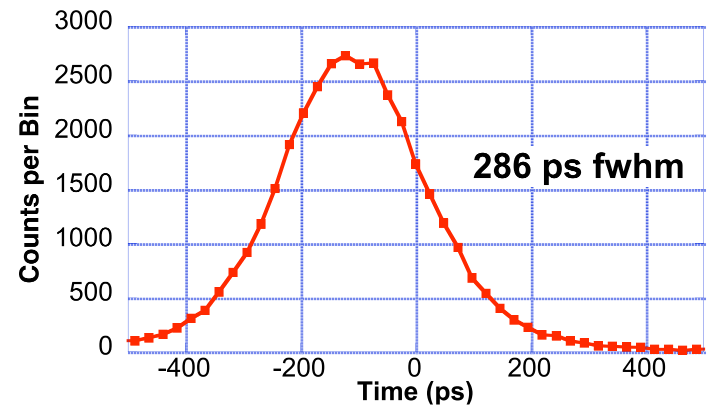
Same Electronics with *Very* Different Type of Detecto

Timing Resolution

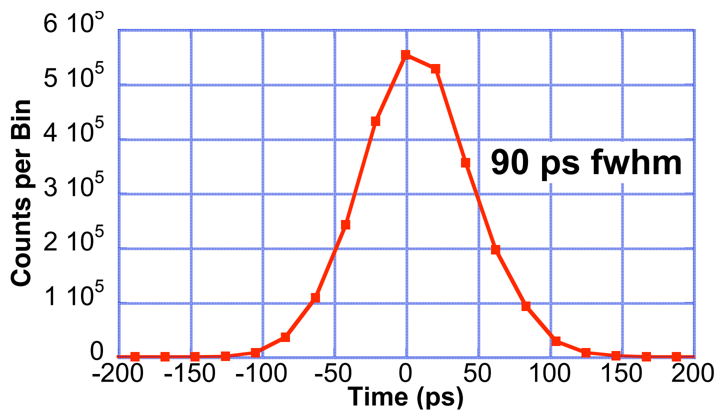
Test Pulse | TOF Module Pair

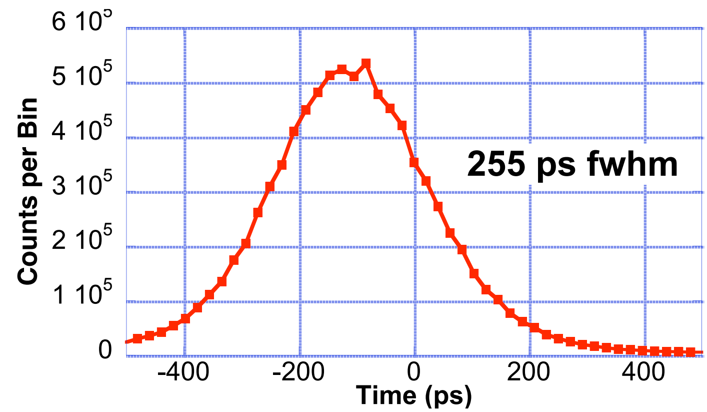
HPTDC (CERN)





FPGA





BERKELEY LAB

- 16 Channel TDC in Cyclone II FPGA
- Performance Good Enough for Time-of-Flight PET

OpenPET Vision

Open Source

- Hardware, Firmware, and Software
- Schematics, Gerbers, BOM,…

Active User Community

- Share Software and Expertise
- Module, Calibration, DAQ, Display,…

Fall, 2011

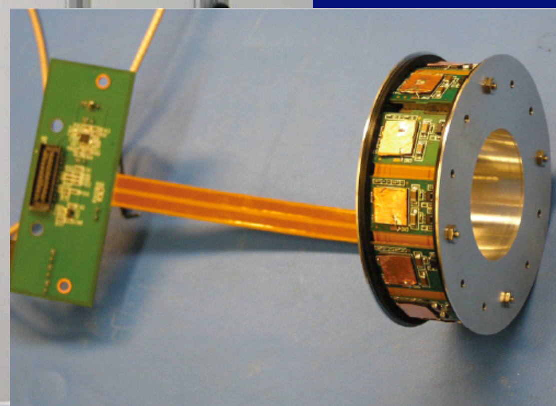
- Detector & Support Boards Available
- Work on Coincidence Board Begins

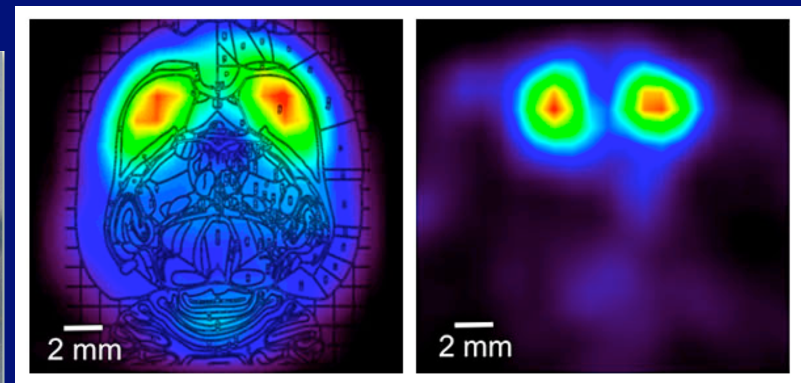
BERKELEY LAB

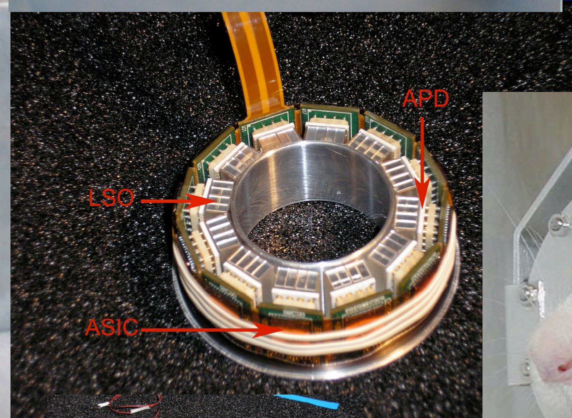
http://OpenPET.LBL.gov

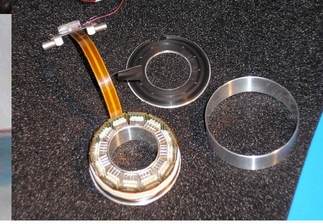
RatCAP for PET Imaging of Awake Animals

LSO + APD





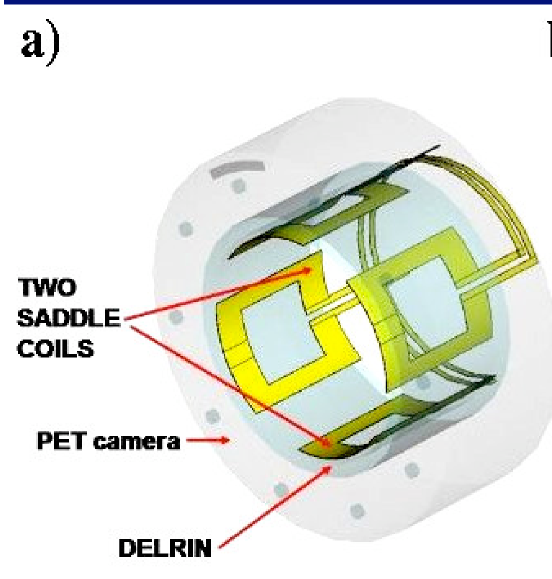




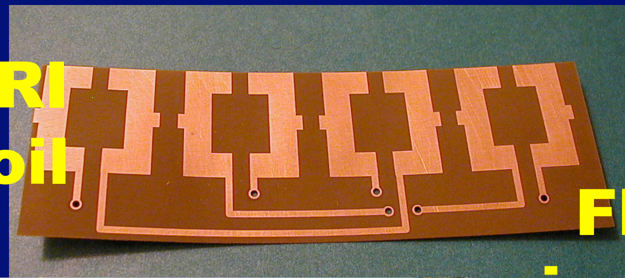
BROOKHAVEN
NATIONAL LABORATORY

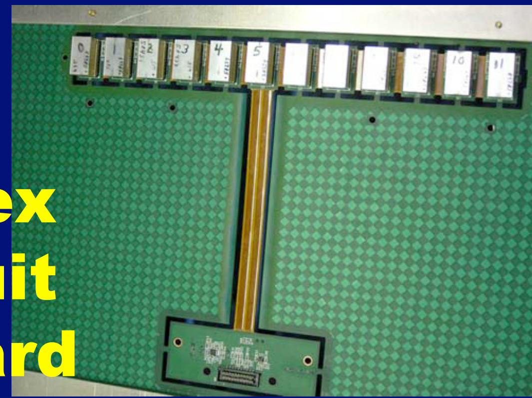
Simultaneous PET/MRI Based on RatCAP in Small Animals & for Breast Imaging

BROOKHAVEN NATIONAL LABORATORY

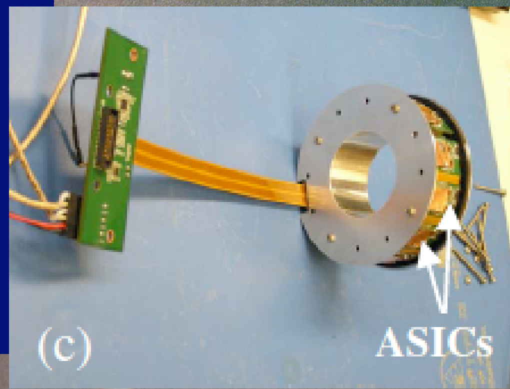


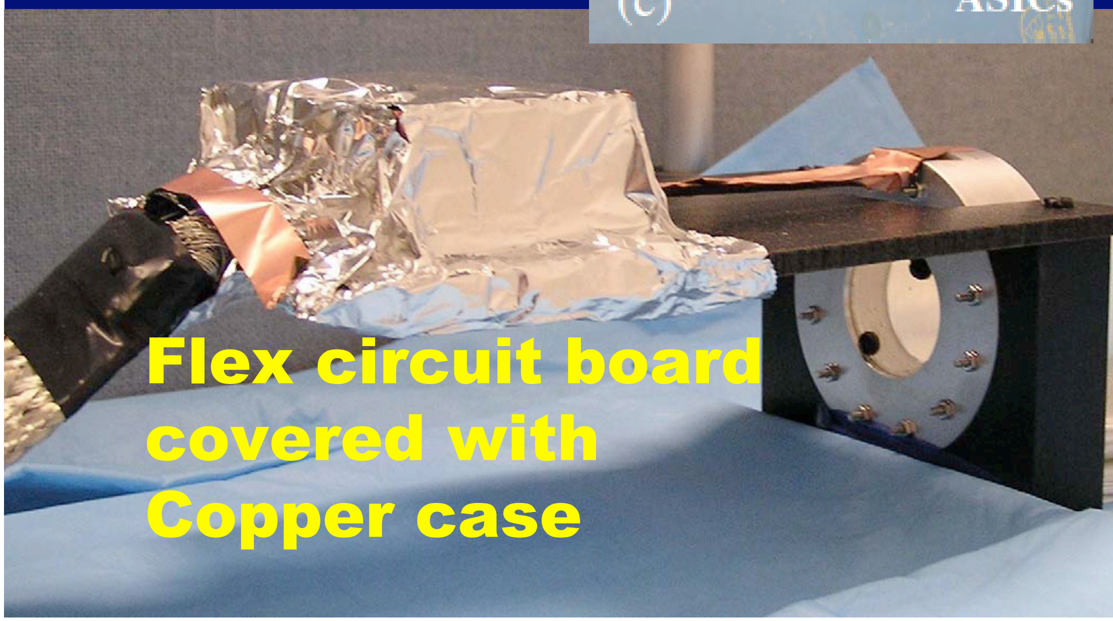
MRI Coil

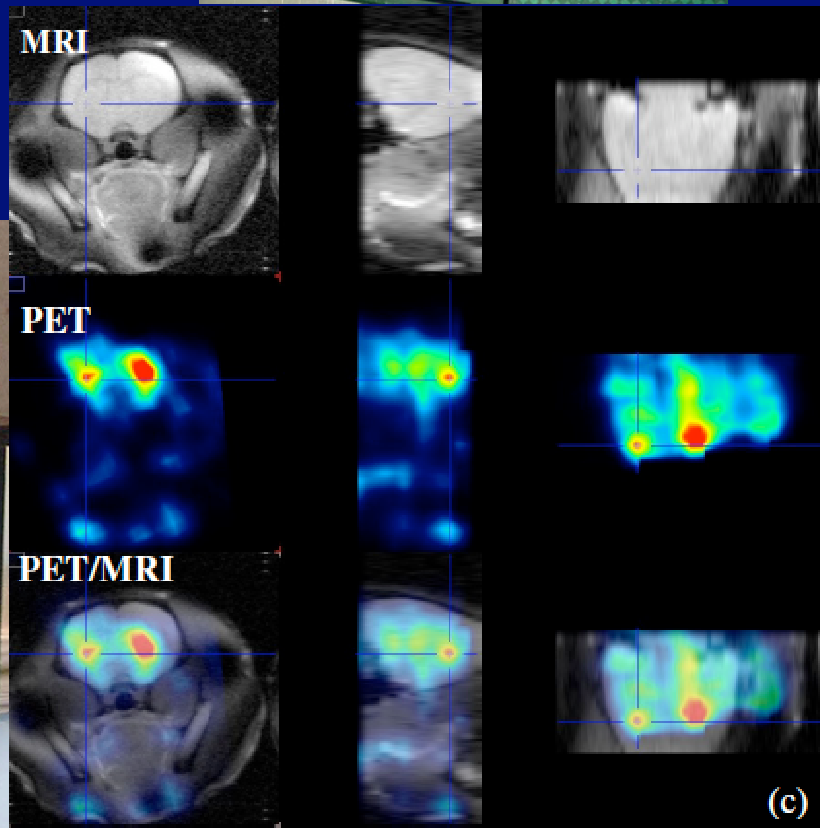




Flex circuit board

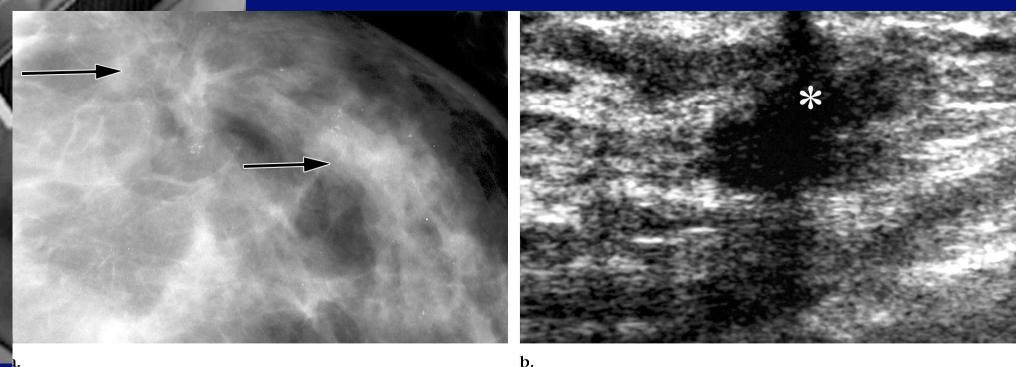




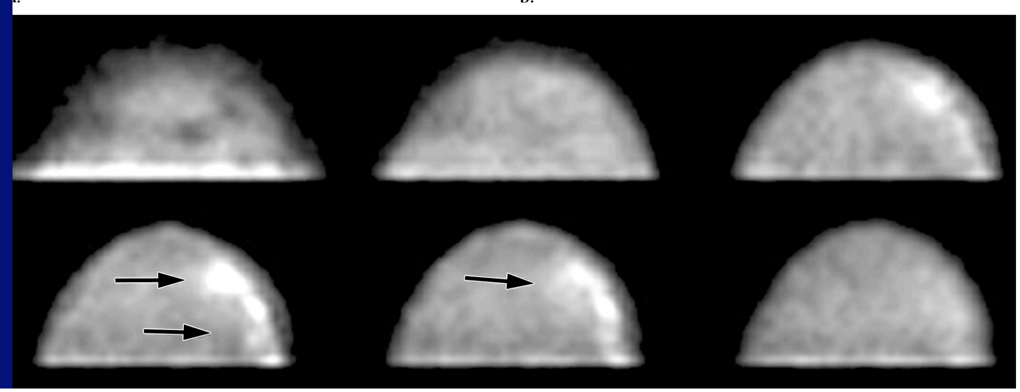


Large-FOV Positron Emission Mammography

- A large field-of-view (15 cm x 20 cm) PEM
- Two-Panel pixelated LGSO/LYSO
- Coupled to an array of PSPMTs



DOD & NIH Funded large-scale clinical trials Conducted at Duke Univ.



Jefferson Lab

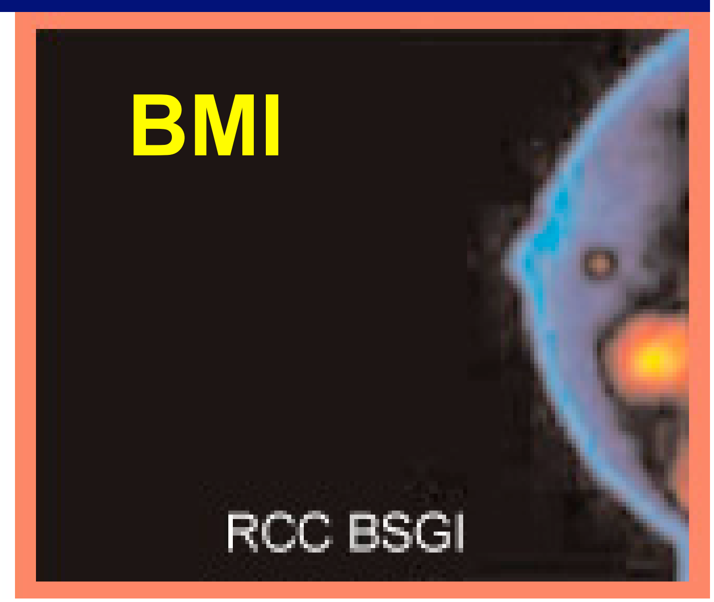
Molecular Breast Imaging (BMI)

Dilon 6800 Acella
Expanded FOV
20 cm X 25 cm

Dilon 6800
Gamma
Camera
15cmX20cm

Successful Technology Transfer to and commercialization by Dilon Diagnostics

BMI

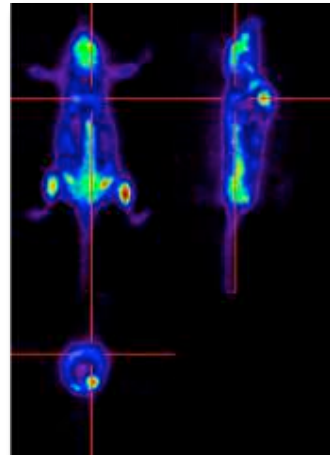


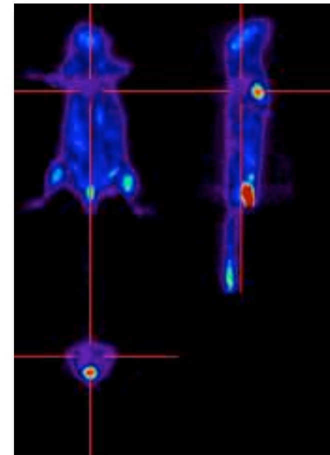
Jefferson Lab

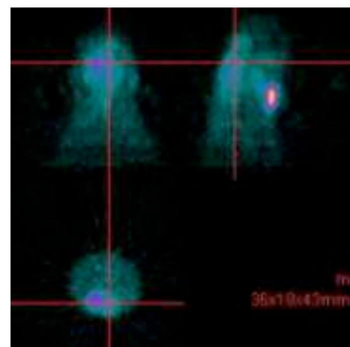
中国科学院高能物理研究所
Institute of High Energy Physics,Chinese Academy of Sciences

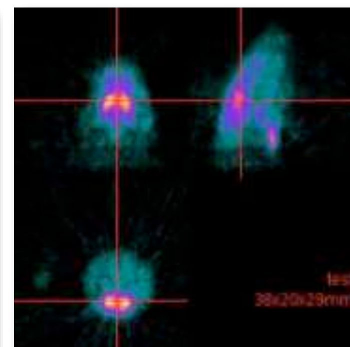
IHEP: Institute of High Energy Physics

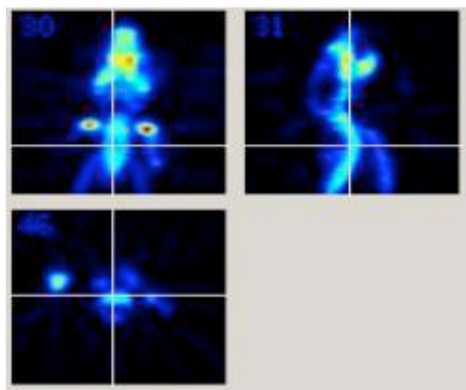
High resolution & high counting-rate animal PET scanner

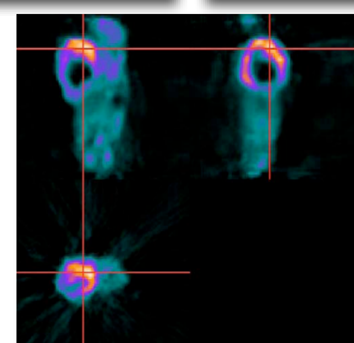


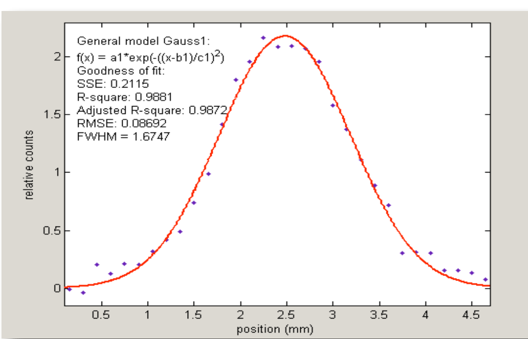












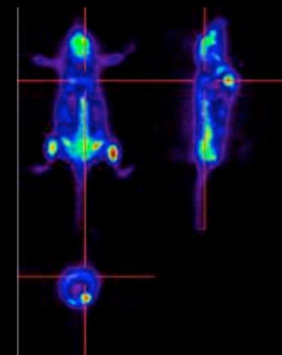
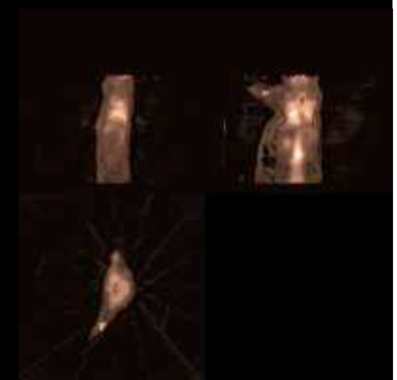
CFOV resolution: 1.67 mm

Scanners for Molecular Imaging

μPET、

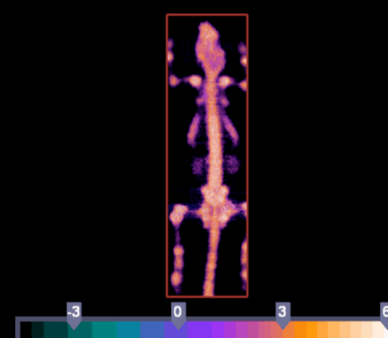
μPET/CT



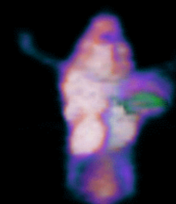
μSPECT/CT





Scanners for Molecular Imaging

Optical μPET

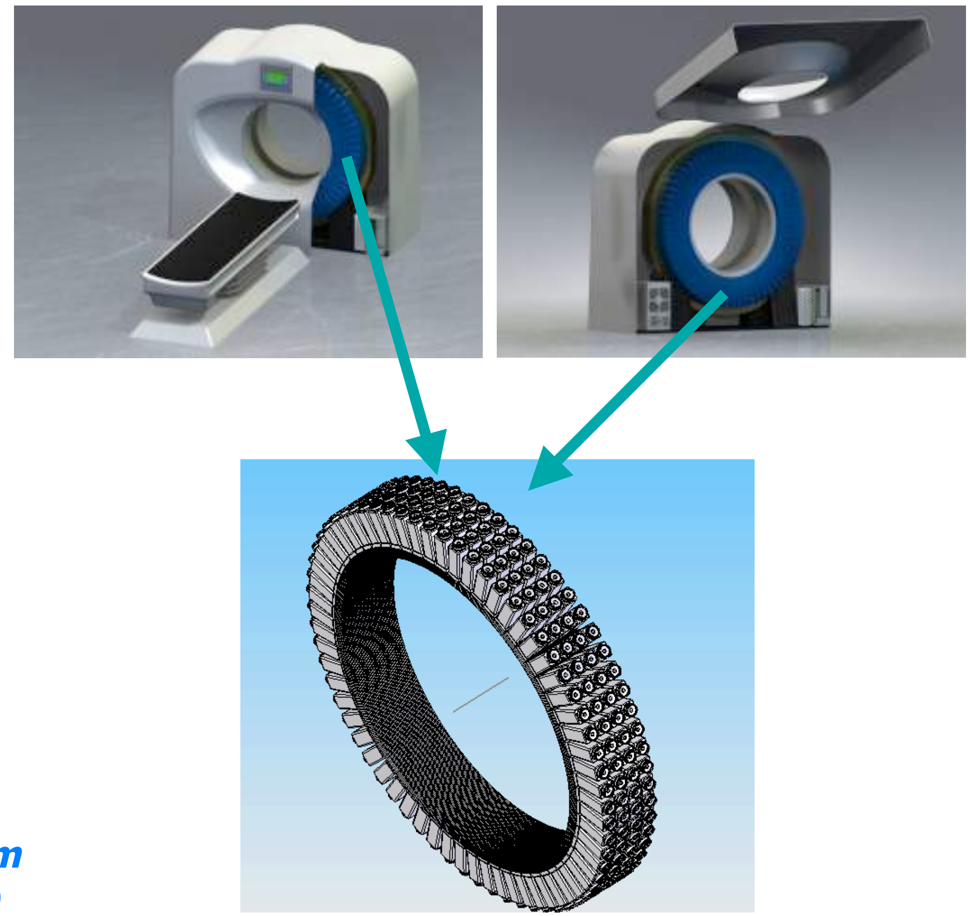


μCT

High Resolution whole-body PET Scanner (currently detector research)

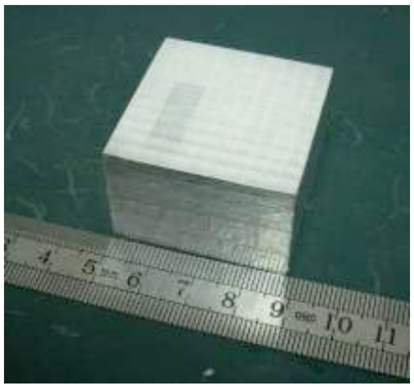
Designed Feathers:

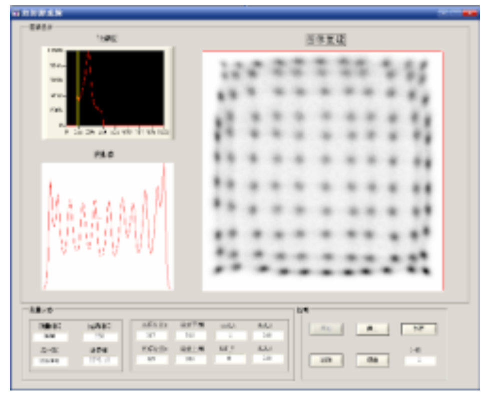
- Gantry aperture: >650 mm
- Axial FOV: >150mm
- Spacial Resolution: ~3.5mm
- Crystal material: LYSO
- Crystal number: 30976
- Detector number: 256
- Dia. of detector ring: 810mm



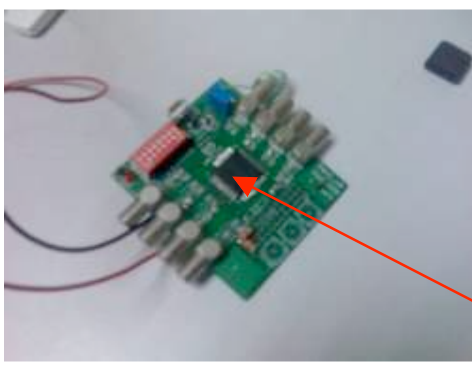
LYSO: an patent-free Cerium-doped Lutetium Yttrium Oxyorthosilicate ($Lu_{2(1-x)}Y2_xSiO_5$:Ce)

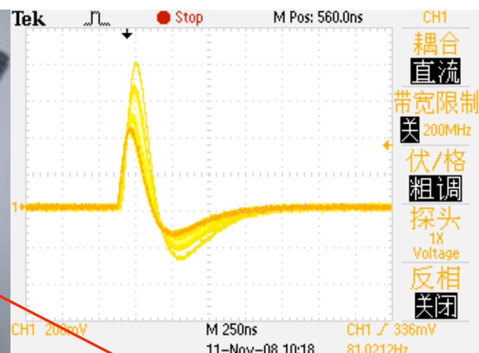
Performance of detector and electronics





Detectors and flood-histogram for 11×11 crystal array

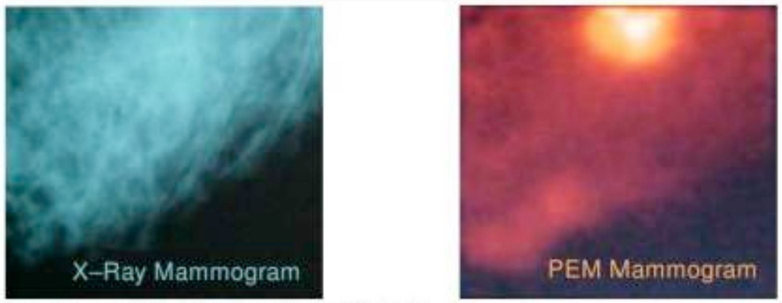




Front-end electronics (ASIC) and 32-Chanel digital board

PEM (Positron Emission Mammography)

Mammography is a morphological technique



Images courtesy of L.P. Adler, Cancer Center, Philadelphia

***A PEM system is a PET device dedicated to breast cancer detection, and has higher* gain and lower noise.**

Morphological
Sensitive to tissue density

Functional
Sensitive to metabolism

Sensitivity to small tumors (1-2 mm)

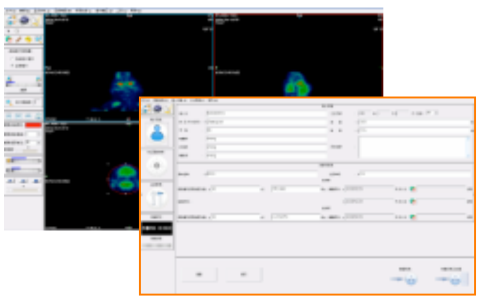
The PEM system we designed is prone-style, with annular detector structure.

IHEP in Beijing

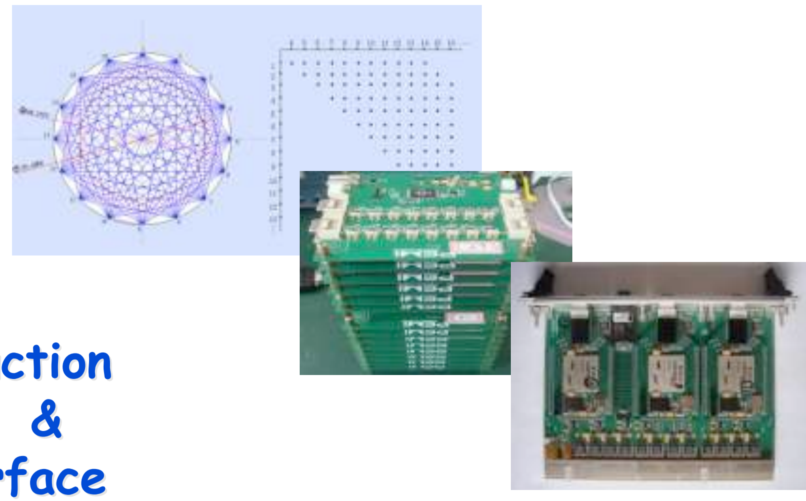
Medical systems

Design and production of PEM system have been completed. Performance testing is under way.

Detector ring of our PEM

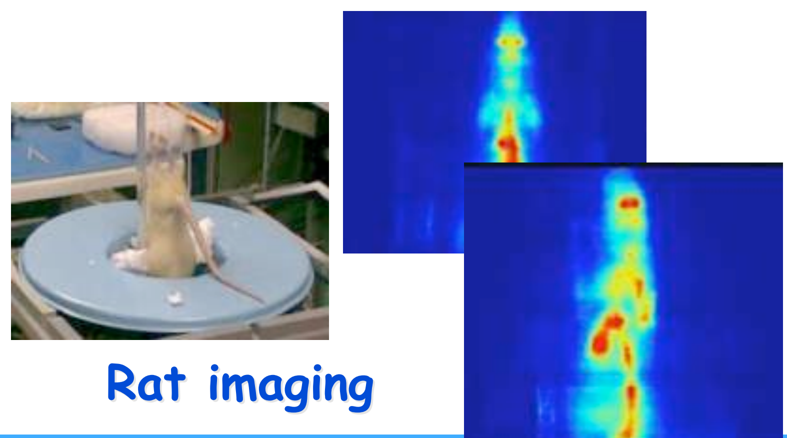


Reconstruction algorithm & user interface



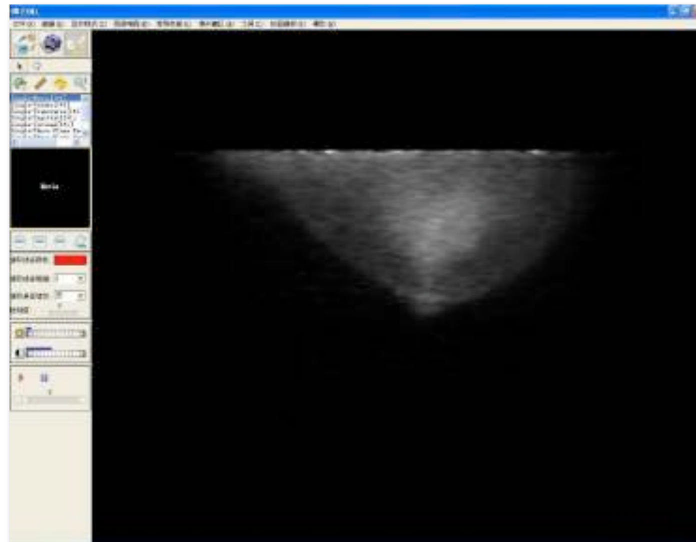
A/D & Coincidence system

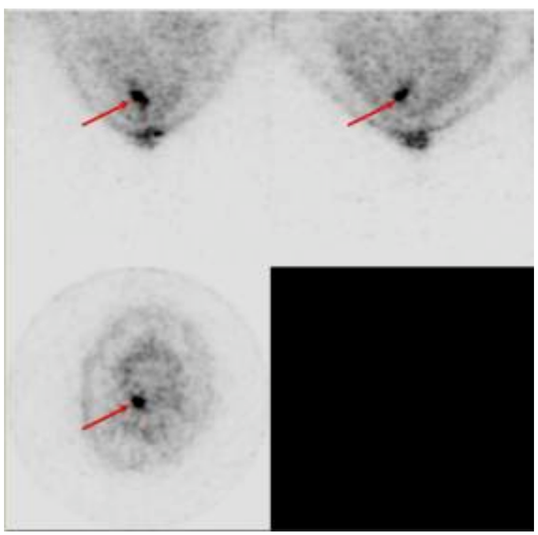
Initial imaging results

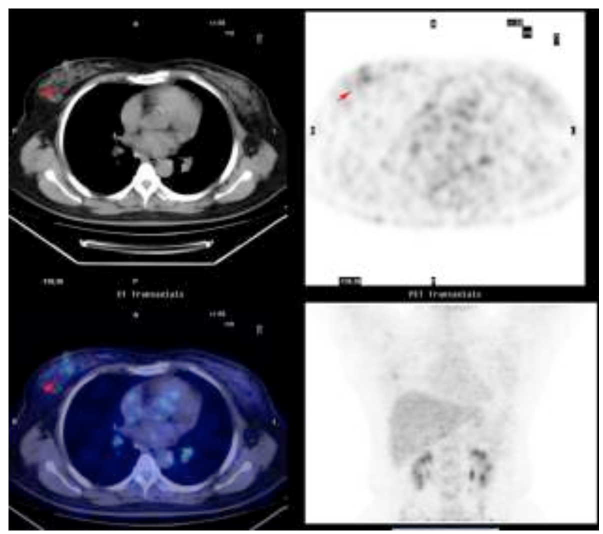


Rat imaging

PEM is in clinical trial stage for SFDA registration

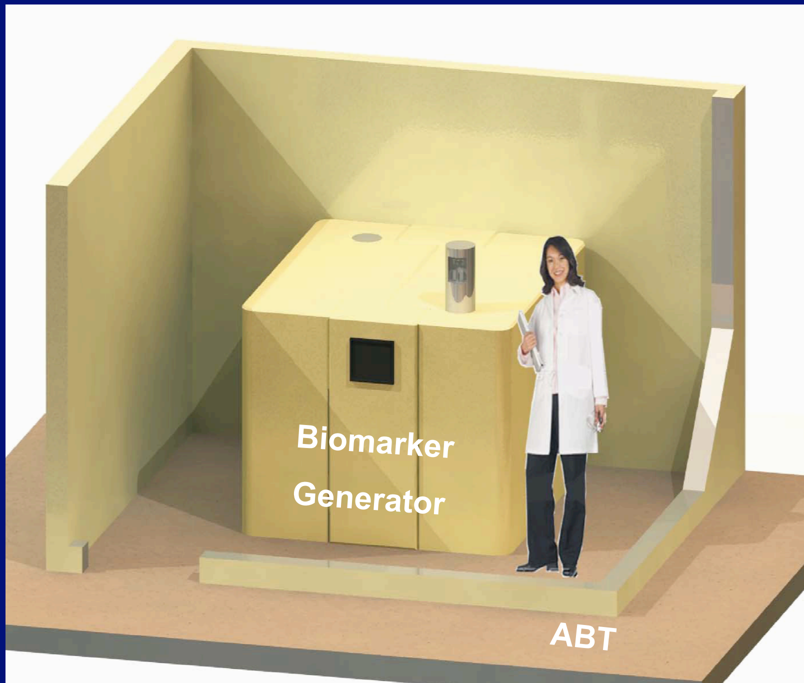




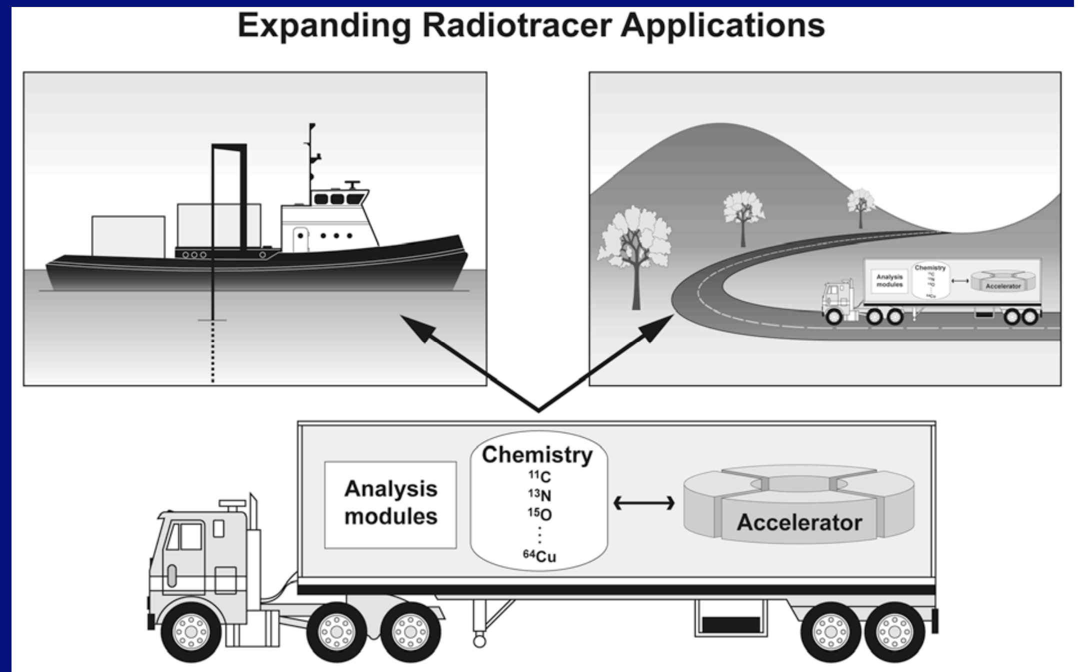


Radiotracer More Readily Available

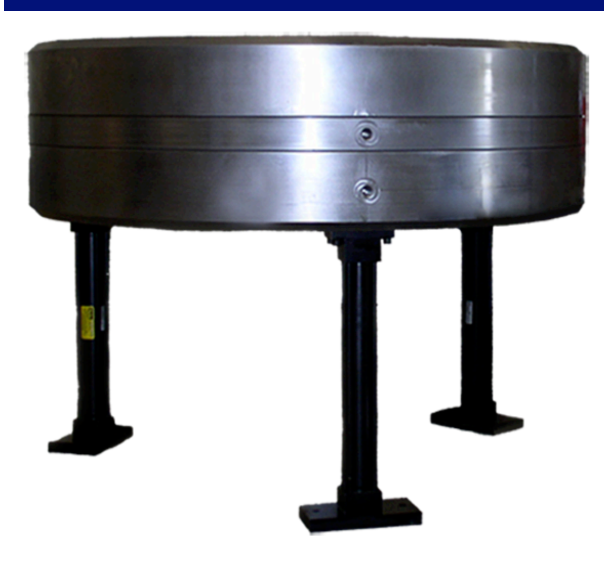
Mobile & Compact Biomarker Generator



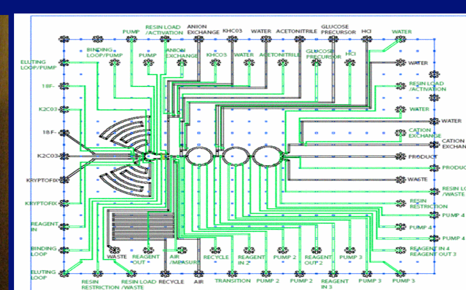
Micro Accelerator



DOE/LBL

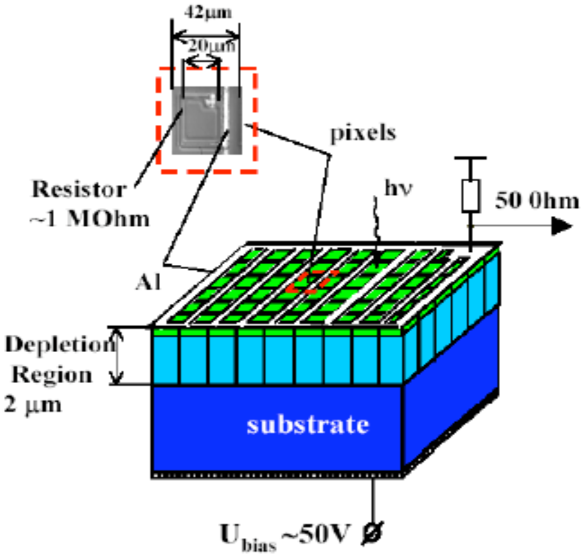


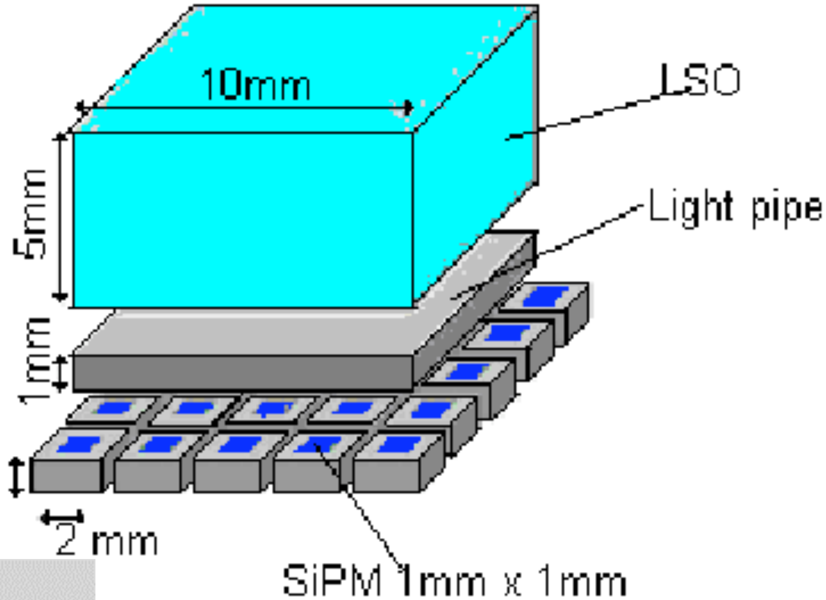
Microchemistry & Microfluidics

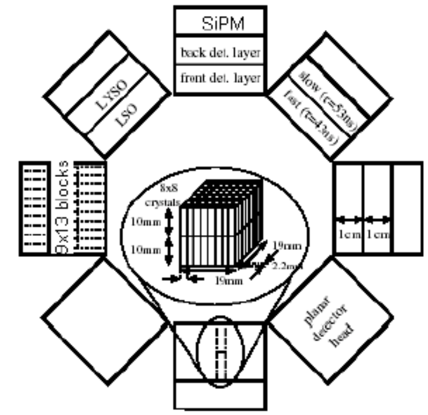


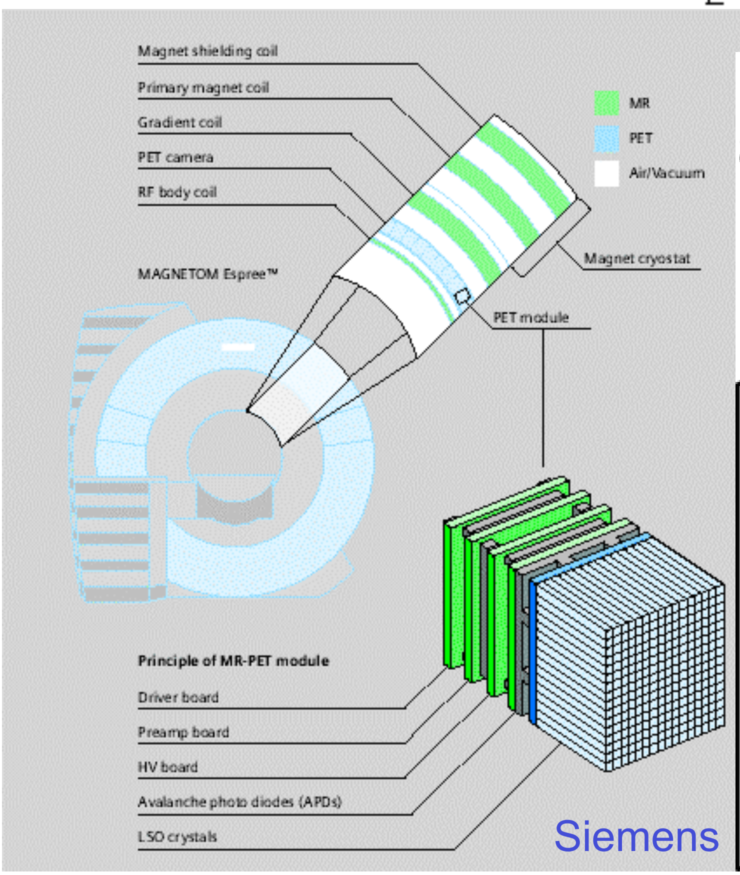
Courtesy of ABT

Oh, YES ! SiPM

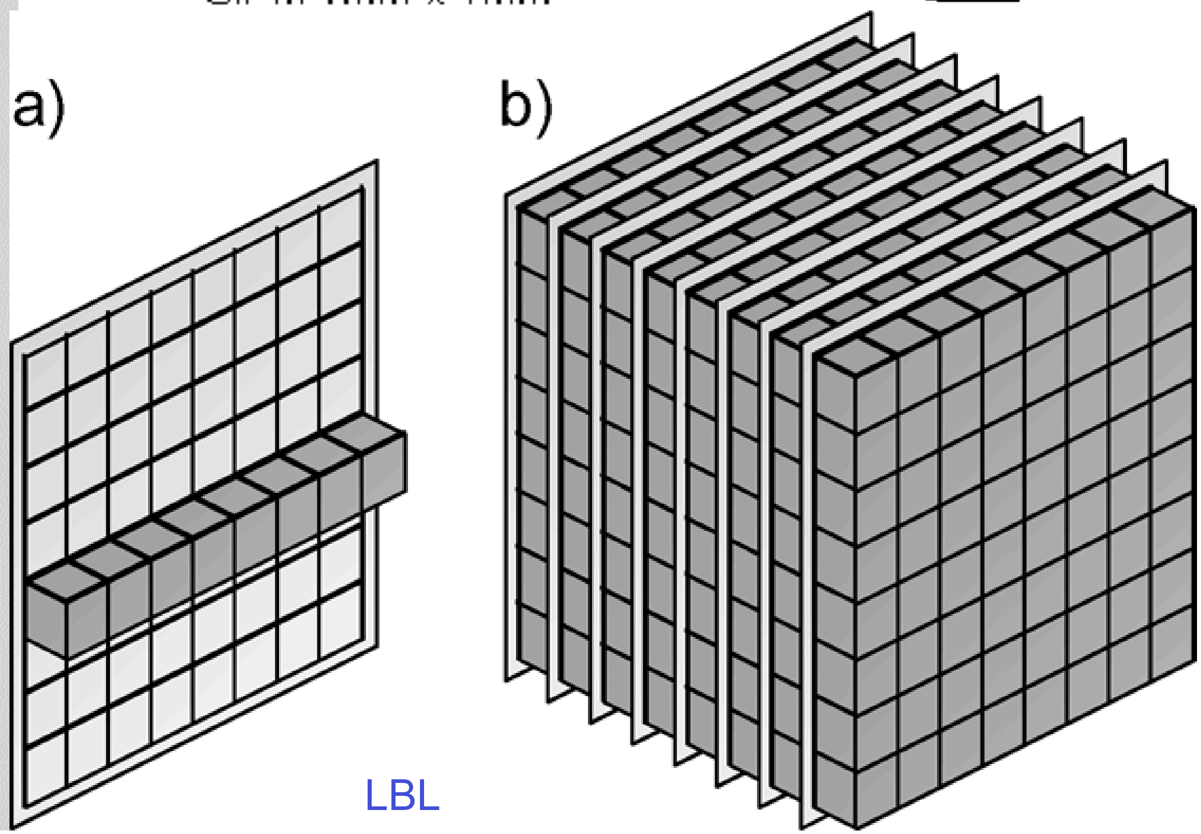








Siemens



LBL