The Development of Biomedical Applications of Nuclear Physics Detector Technology at the Thomas Jefferson National Accelerator Facility

Drew Weisenberger

JLab Program Focuses on Unique Expertise/Capabilities

Jefferson Lab has four primary program elements

Nuclear physics: world leading user facility for hadronic physics

- **6 GeV program based on worldwide unique accelerator**
- **Planning for 12 GeV upgrade**
- **Lattice QCD initiative**

Support for construction projects involving srf technology within DOE national lab system

- **SNS , ~ $21M program in FY '01**

Application of core competencies in support of "photon science"

- **FEL**
- **bio-medical detector development**

Advanced accelerator R&D

Jefferson Lab Detector Group

Stan Majewski (Group Leader)

Brian Kross
Vladimir Popov
Tim Tran
Mark Smith
Drew Weisenberger
Ben Welch
Carl Zorn

- Support design and construction of new detector systems
- Technical consultants for the lab scientists and users
- Development and use of radiation detection systems
- Expertise in nuclear particle detection
  - gas based detectors
  - scintillation and light guide techniques
  - standard and position-sensitive photomultiplier tubes (PSPMTs)
  - fast analog readout electronics and data acquisition
  - on-line image formation and analysis
  - image reconstruction algorithms

Medical Imaging

Functional Imaging vs Structural

Ultra sound

MRI

X-ray CT

Nuclear Imaging

- SPECT
- PET

Nuclear medicine imaging basics

Functional imaging (vs structural): patient injected with radio- pharmaceutical, shows function i.e. metabolism via ligands labeled with radio isotopes.

- Gamma Camera
  - planar nuclear medicine images (also known as scintigraphy)
  - single-photon emission computed tomography (SPECT)
  - technetium-99m (140 keV gamma-ray, 6 hour half-life),
- Positron Emission Tomography (PET)
  - fluorine-18 (positron emitter, 110 minute half-life) two 511 kev annihilation photons

Isotope	Half-live	Photon energies (keV) (photon abundance)
technetium-99m (^{99m}Tc)	6.02 hours	140 (89%)
indium-111 (^{111}I)	2.83 days	170 (94%), 240 (90%)
gallium-67 (^{67}Ga)	3.25 days	93 (37%), 185 (20%), 300 (17%), and 394 (4%)
iodine-123 (^{123}I)	13.3 hours	159 (84%)

^{99m}Tc-sestamibi

Positron Emitting Isotope	Half-life (minutes)	Positron E_{max} (MeV)
oxygen-15 (^{15}O)	2.07	1.72
nitrogen-13 (^{13}N)	9.96	1.19
carbon-11 (^{11}C)	20.4	0.96
fluorine-18 (^{18}F)	109.7	0.64

^{18}F -fluoro-2- deoxyglucose (FDG)

Scintillators

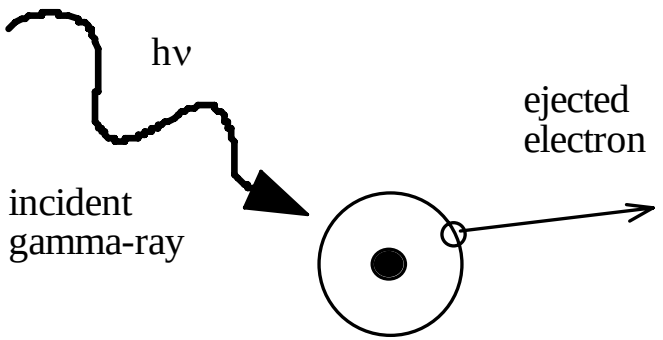
Transparent material that generates a light pulse by converting energy lost by ionizing radiation. Intensity of pulse of light directly proportional to absorbed energy ($E = h\nu$). Inorganic used in nuclear medicine.

Energy transferred to material in three ways:

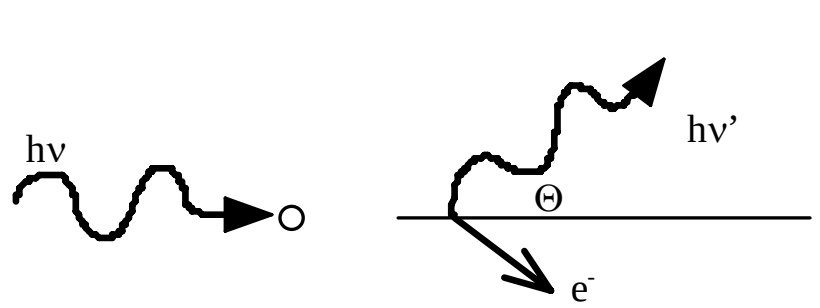
- **photoelectric absorption**
- **Compton scattering**
- **pair production (E > 1.022 MeV)**

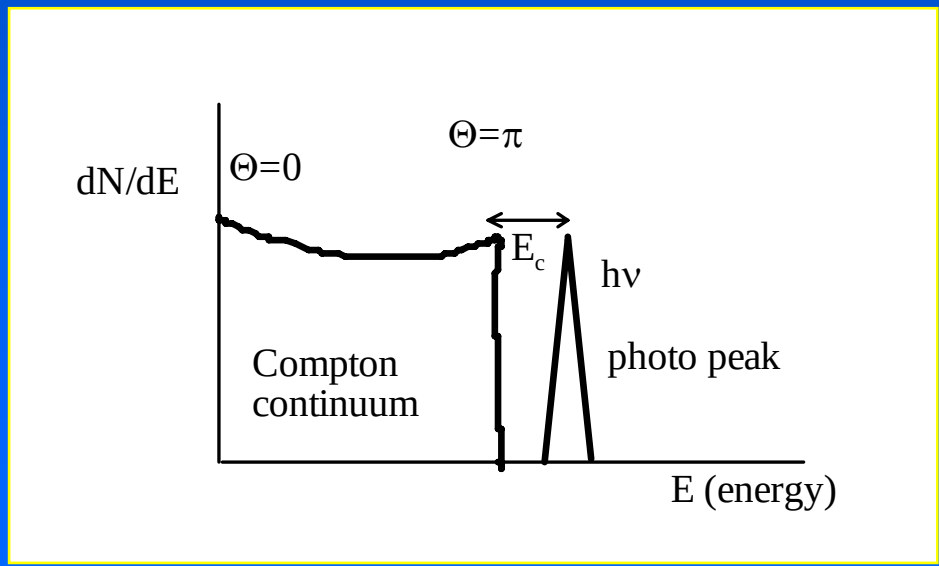
For nuclear medicine imaging only photoelectric absorption and Compton scattering.

Photoelectric Absorption

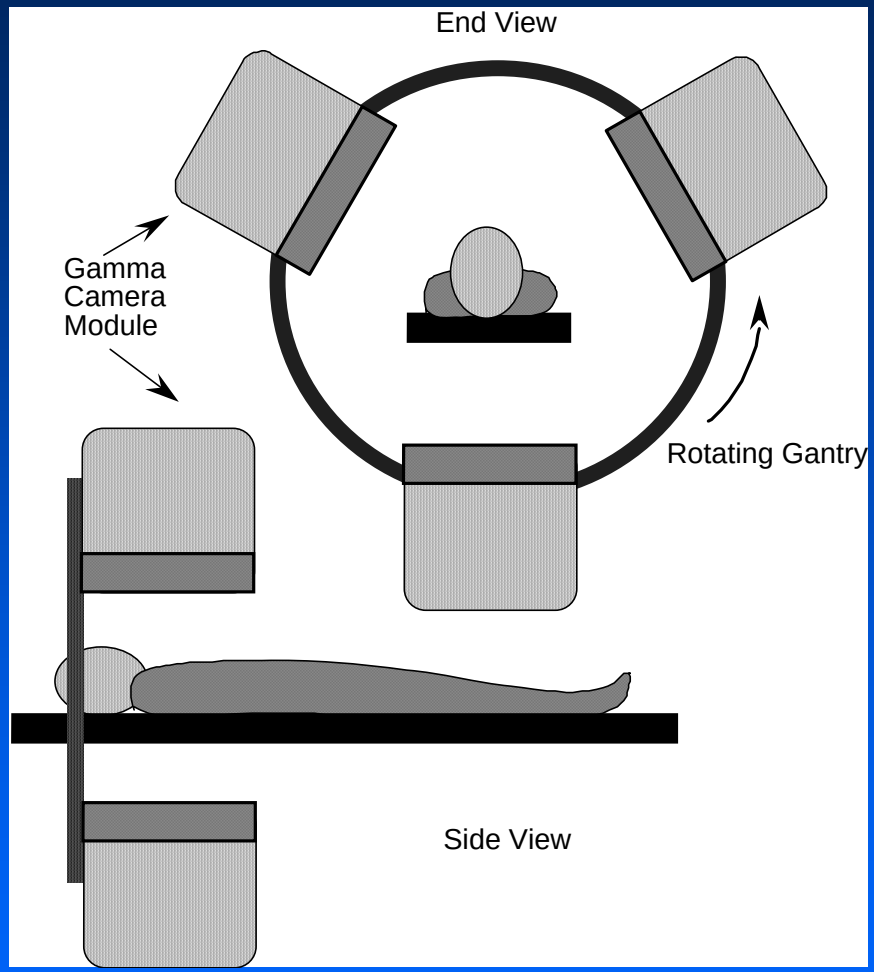


Compton Scattering

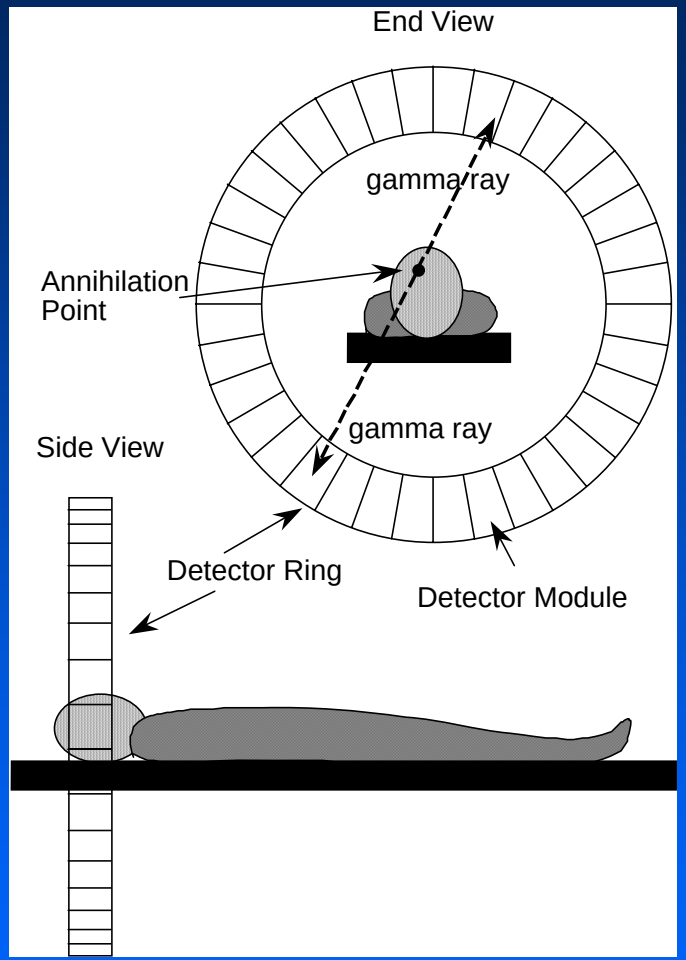




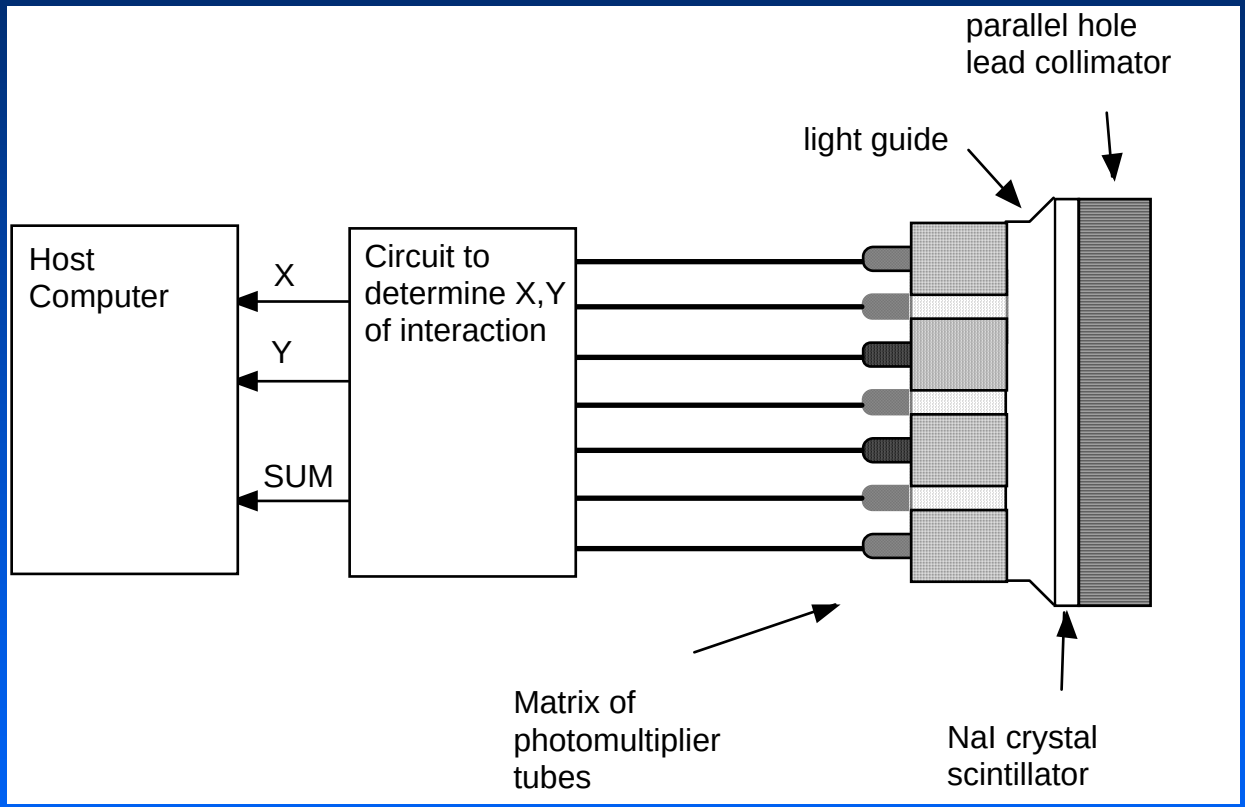
Clinical SPECT System



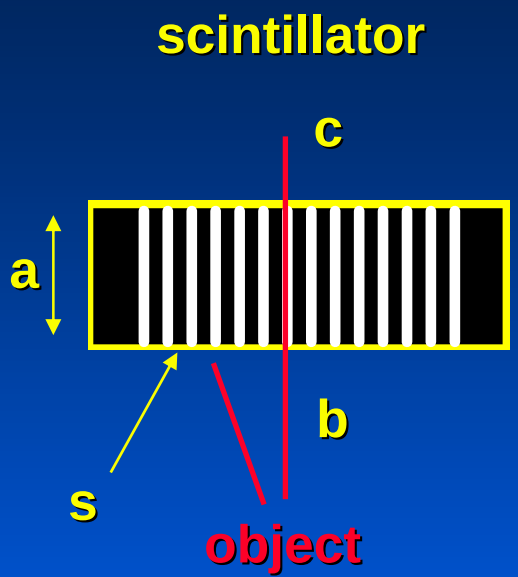
Clinical PET System

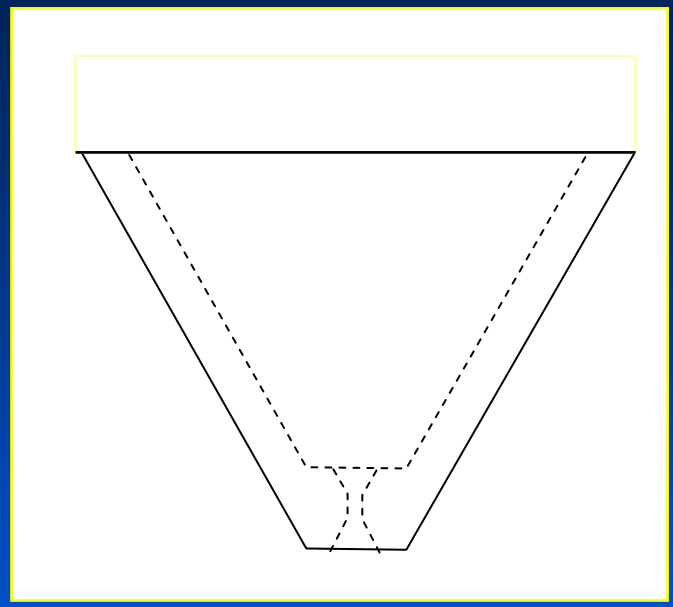


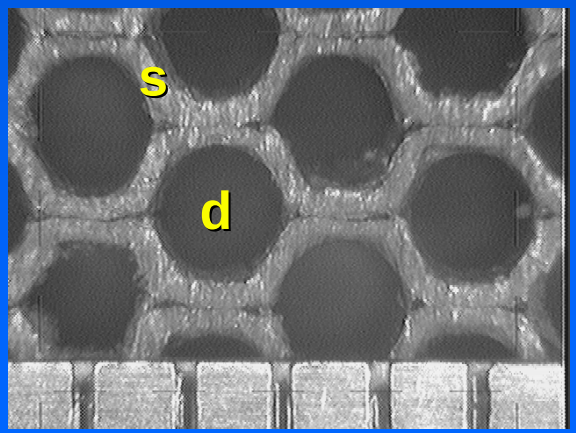
Typical Clinical Gamma Camera



Collimator Design







1 cm thick

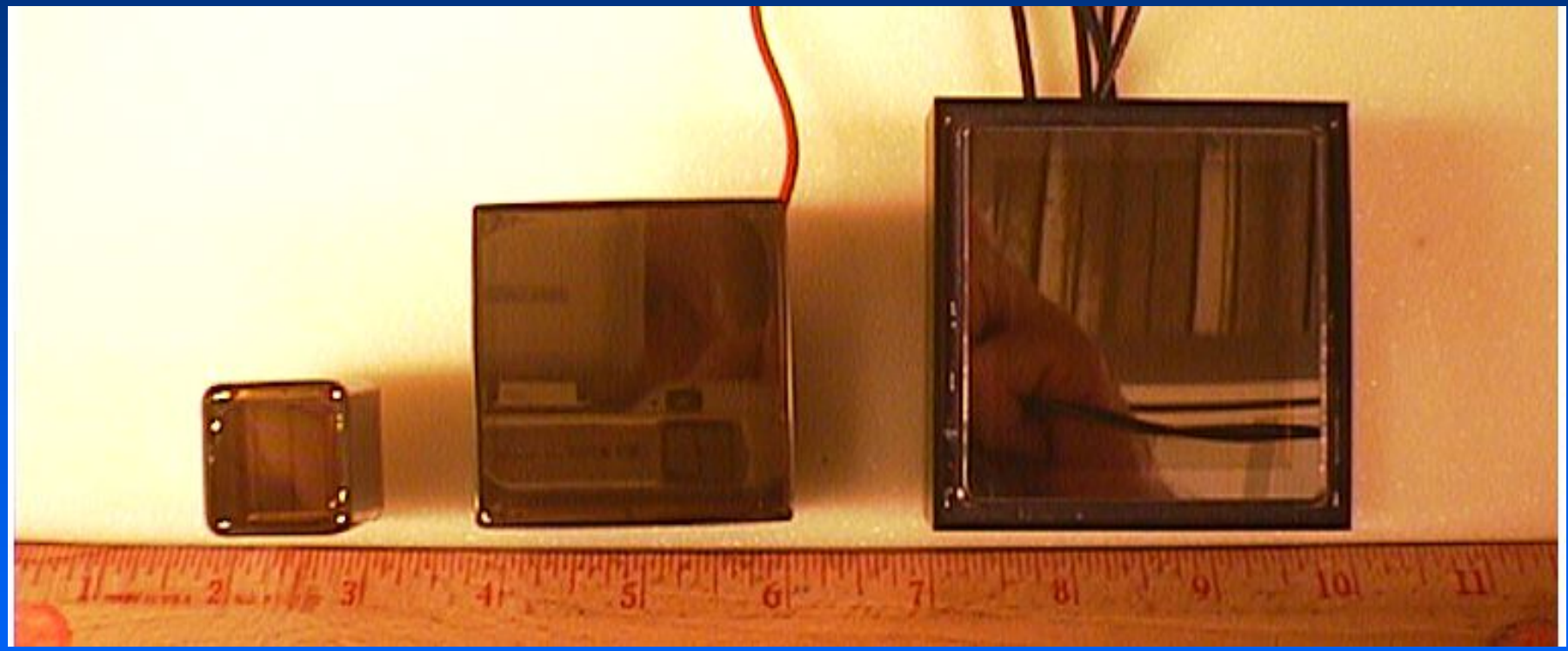
1.27 mm openings

0.15 mm septa

resolution at 1.5 cm is 3.5 mm

366 cpm/μCi

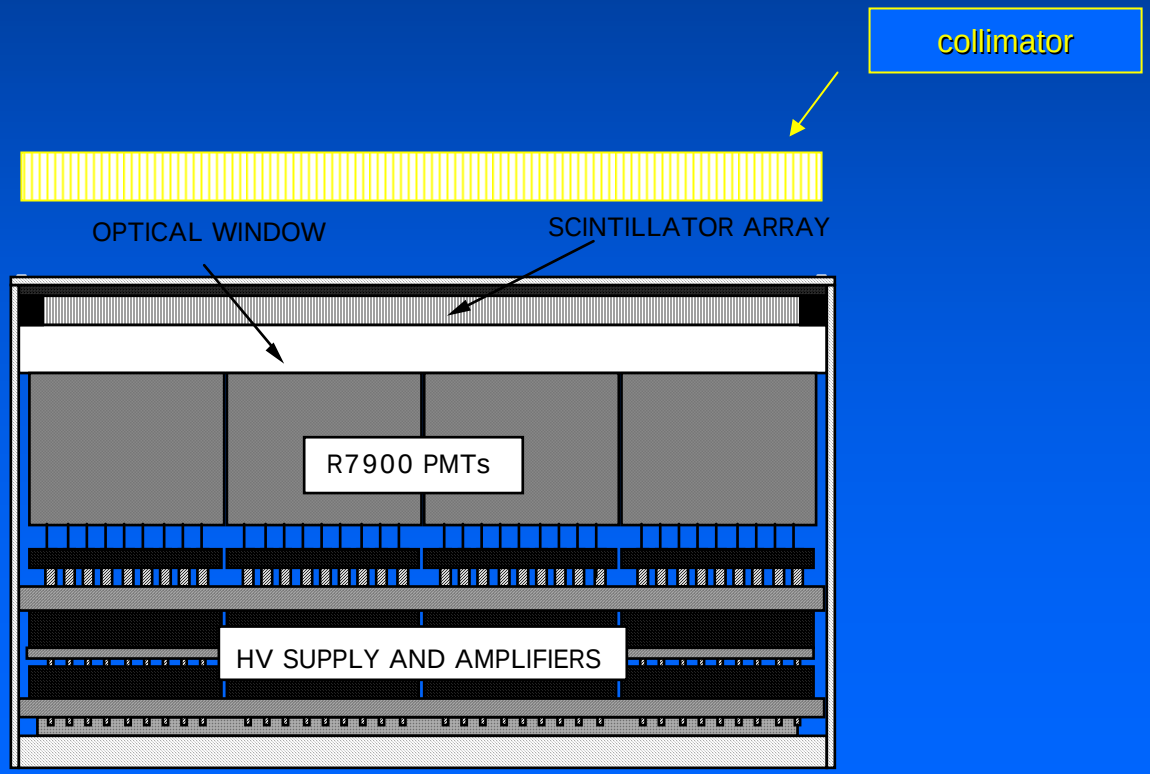
Latest PSPMT Technology allows modular detector construction



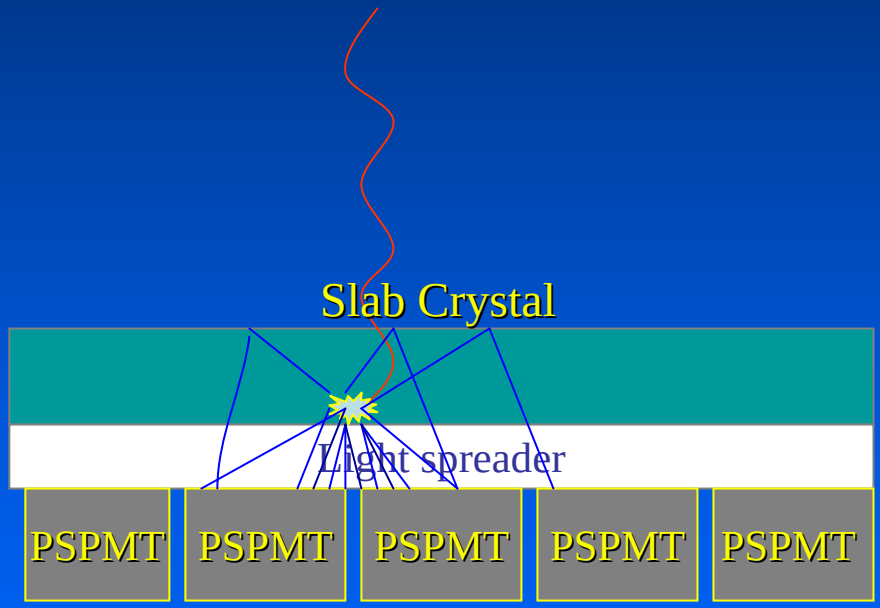
Compact position sensitive PMTs:

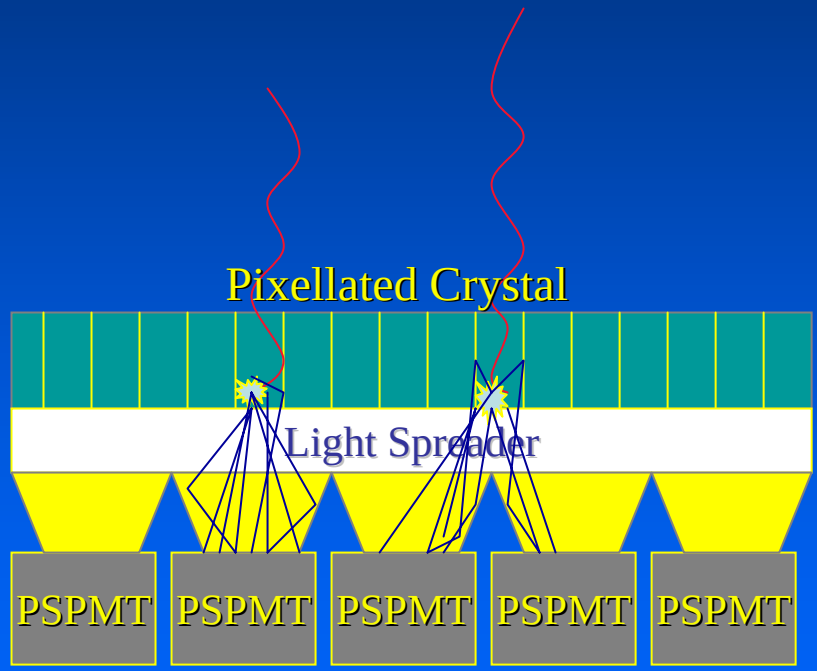
Hamamatsu's R7600, H8500, and Burle's 85001.

Schematic of an imaging detector head based on a 4 x 4 array of ~1” square R7900-C8 PSPMTs and a 10x10cm scintillating crystal array. The lead collimator is removed.



Light Distribution
Slab vs. Pixellated

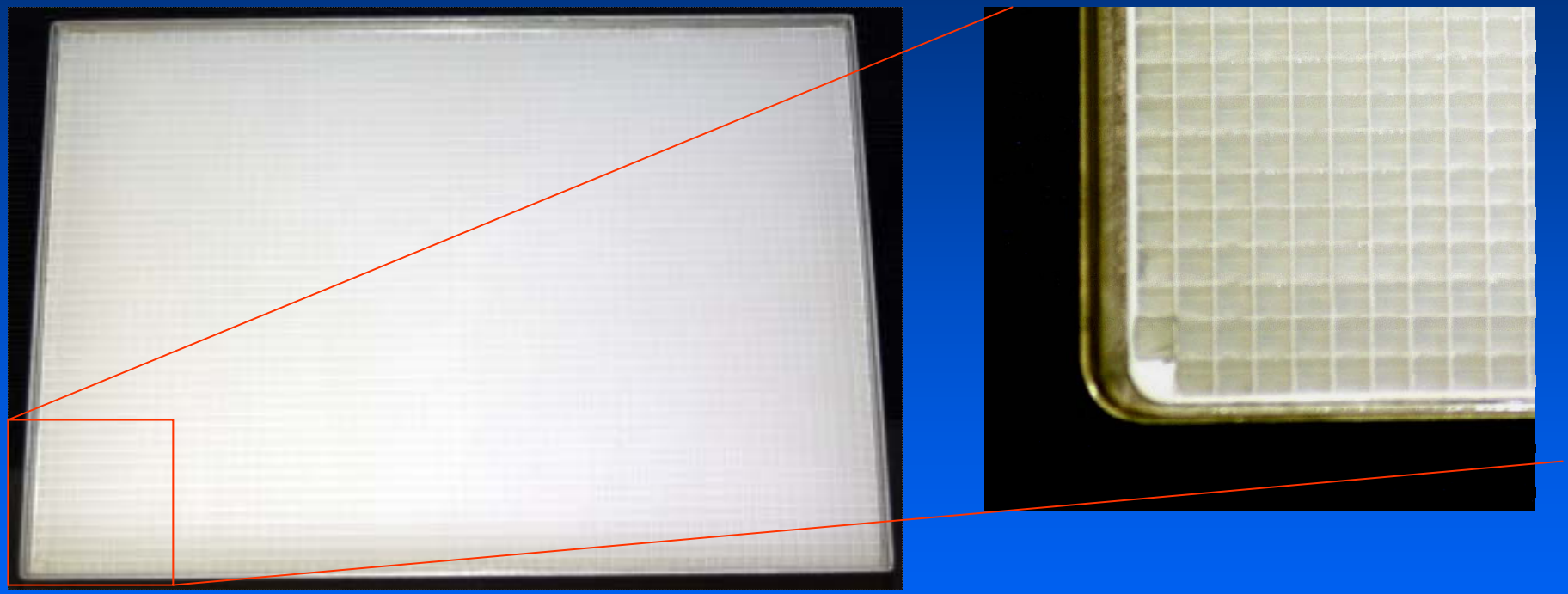




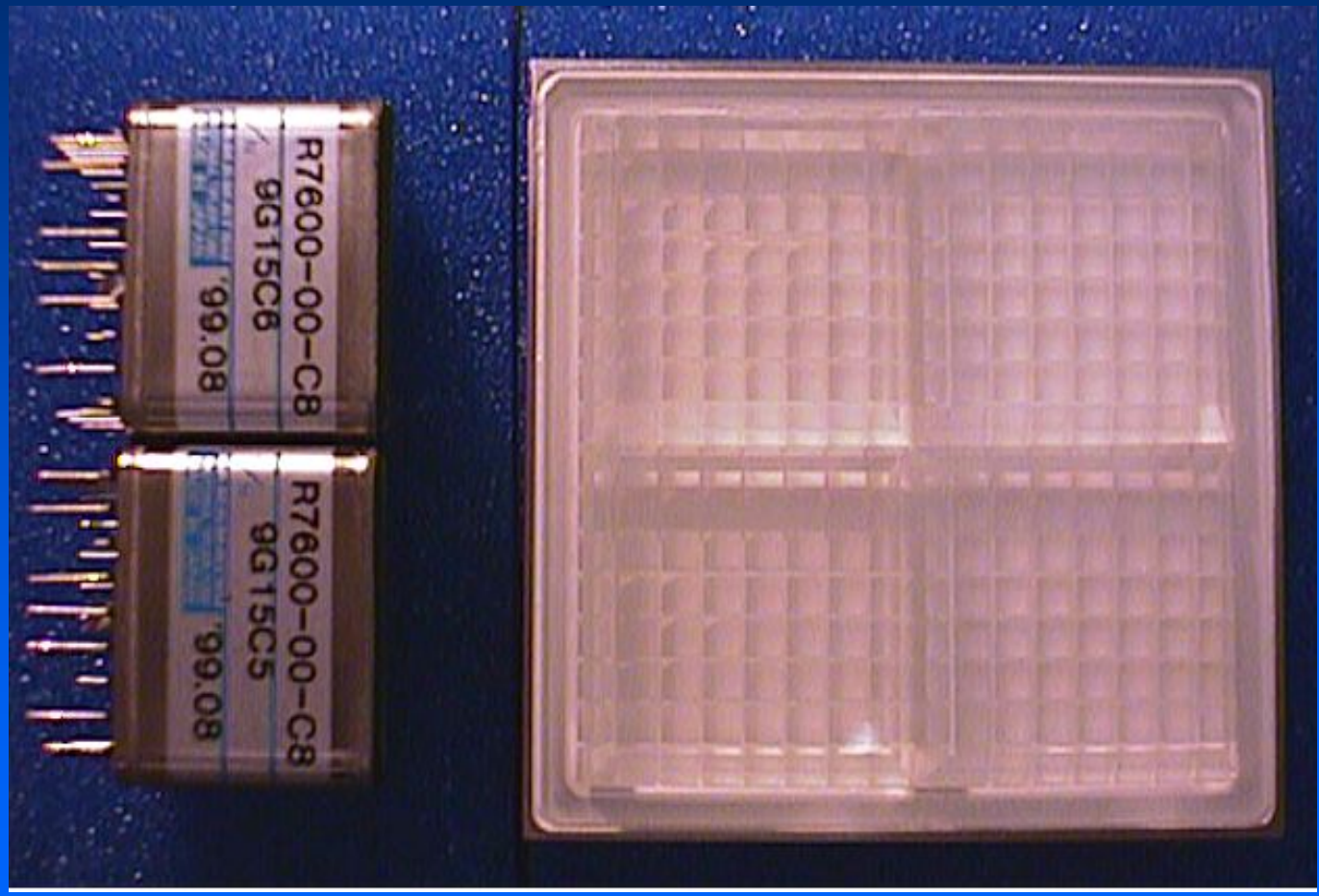
Simple light guide light is sufficient to bypass the cracks

Tapered light guides are required to recover light loss in the cracks

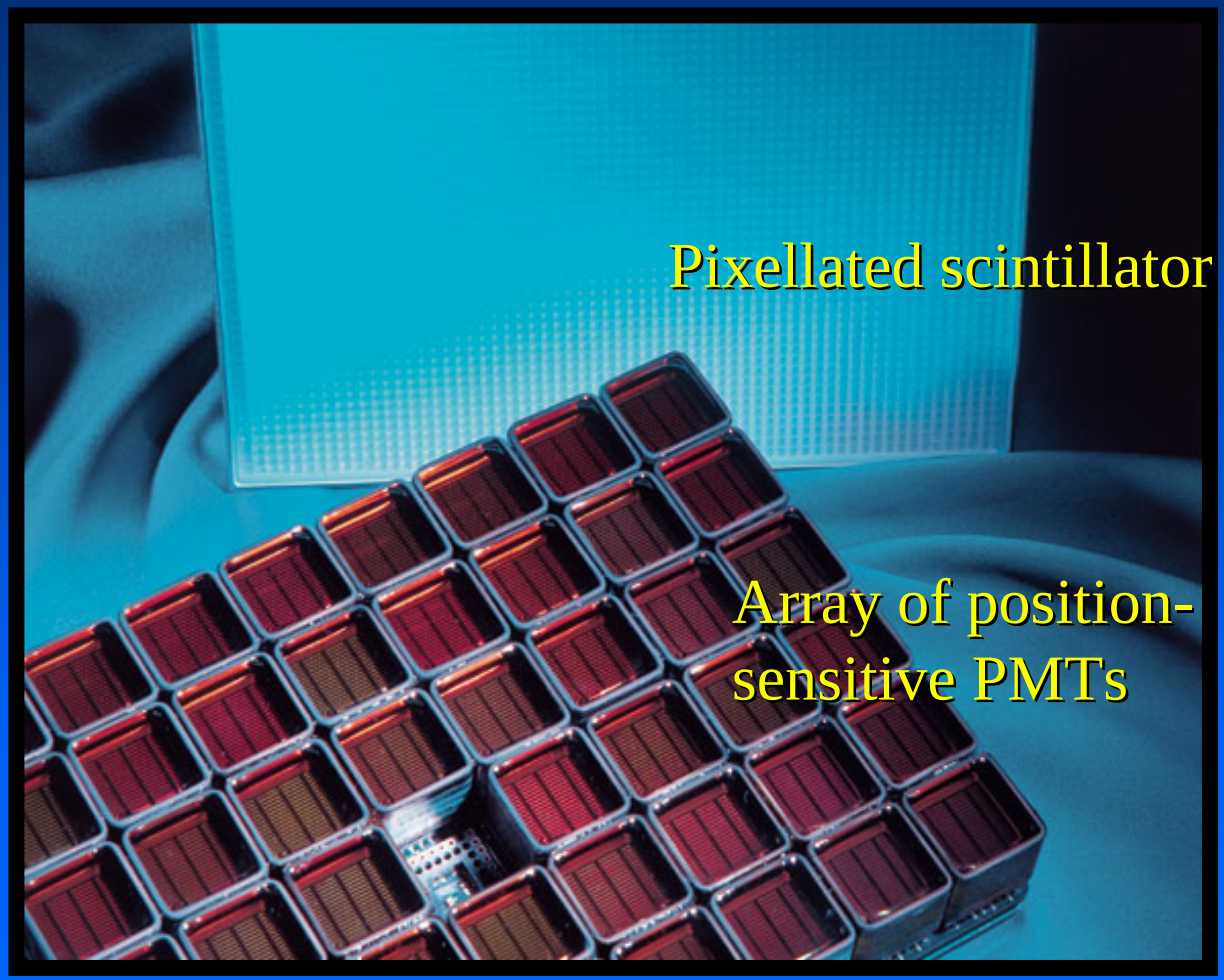
Scintillator Array



Key Technology Components

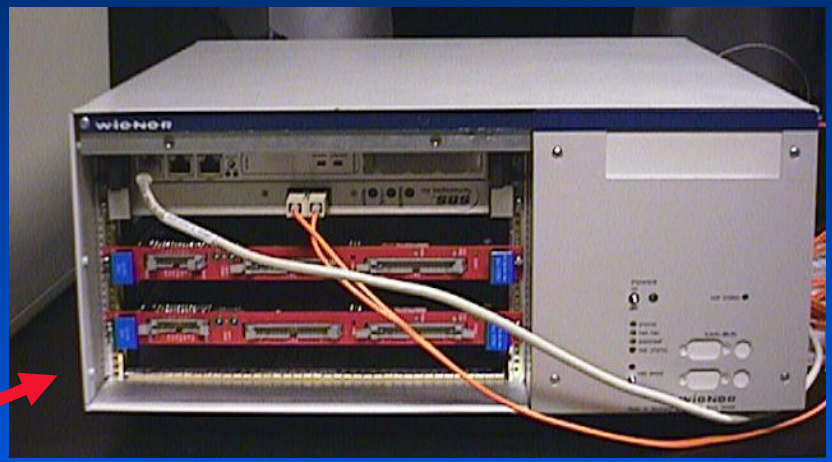


Hamamatsu R7600-C8 PSPMTs & Bicron Corp. NaI(Tl) array

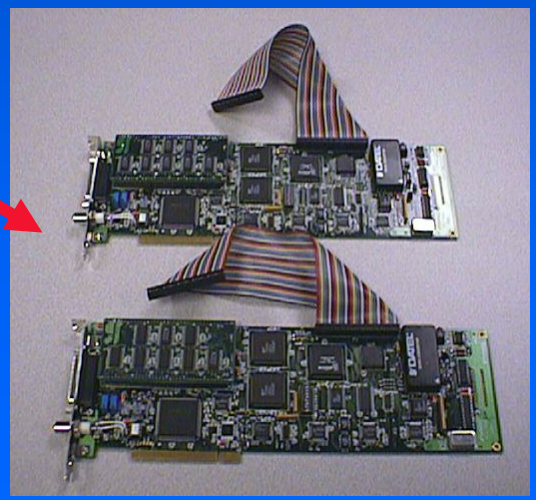

Pixellated scintillator
Array of position-sensitive PMTs

DAQ Readout Technology Evolution

CAMAC
LeCroy FERA ADCs

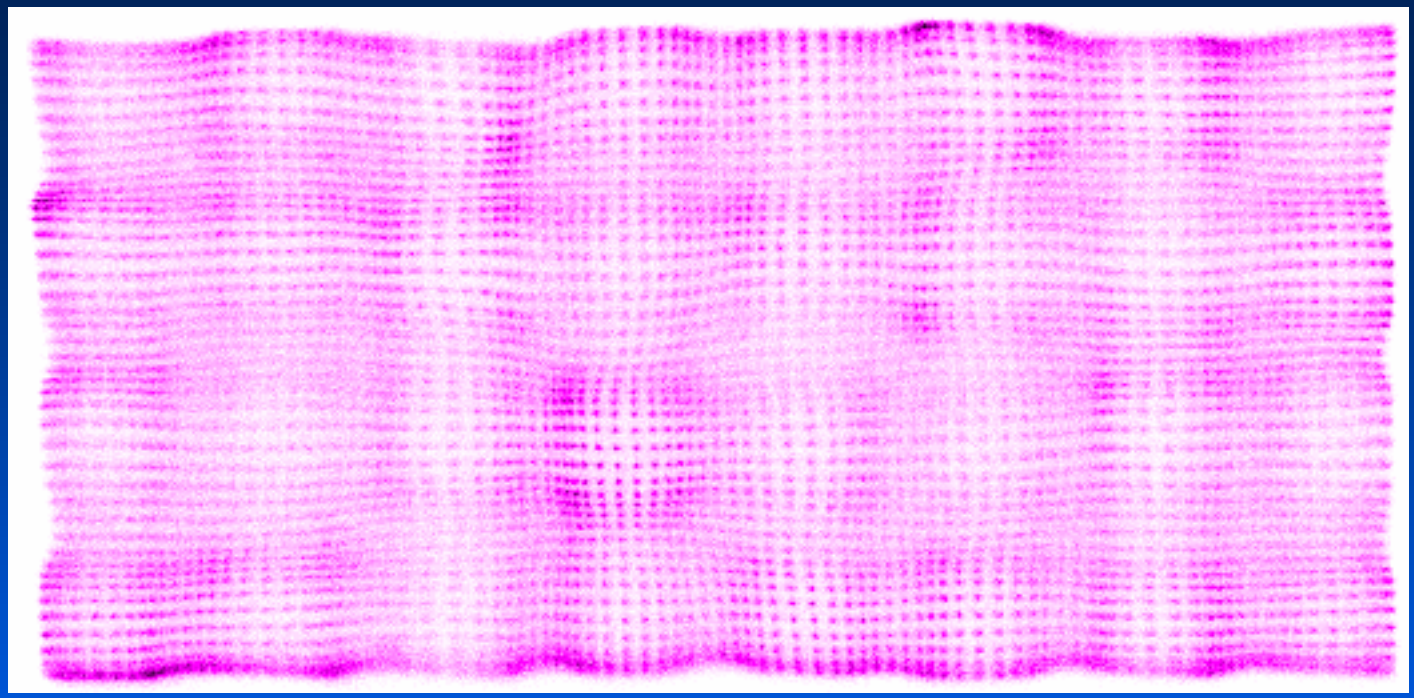


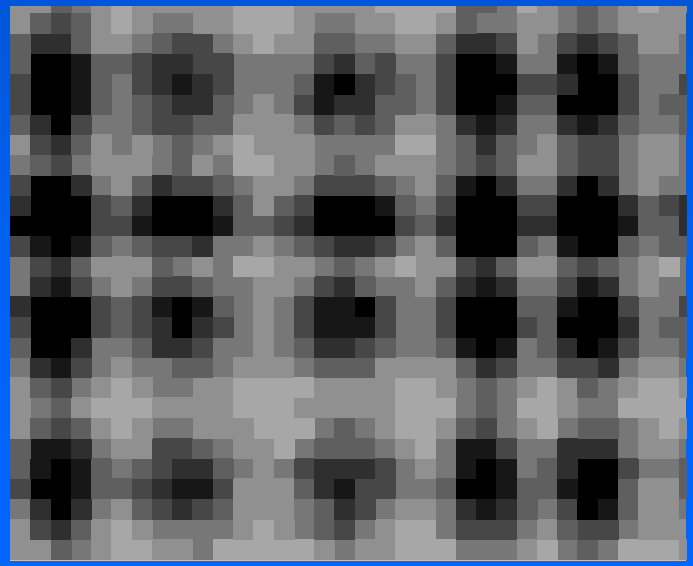
CAEN
VME
ADCs



DATEL (or
Nat. Instr.)
PCI ADCs

10 cm x 20 cm NaI(Tl) 2 mm x 2mm x 15 mm





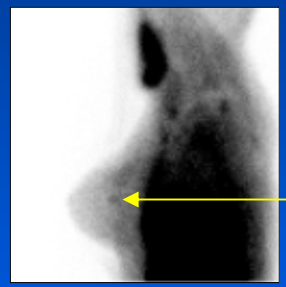
JEFFERSON LAB GAMMA-RAY IMAGING DETECTOR DEVELOPMENT FOR BIO-MEDICAL APPLICATIONS

Partners:

- Case Western Reserve University
- College of William and Mary
- Duke University
- George Washington University
- Hampton University
- Johns Hopkins University
- Medical College of Virginia
- Oak Ridge National Laboratory
- University of Virginia
- University of West Virginia
- Dilon Technologies, Inc.

Optimization of Breast Imaging Procedure with Dedicated Compact Gamma Cameras

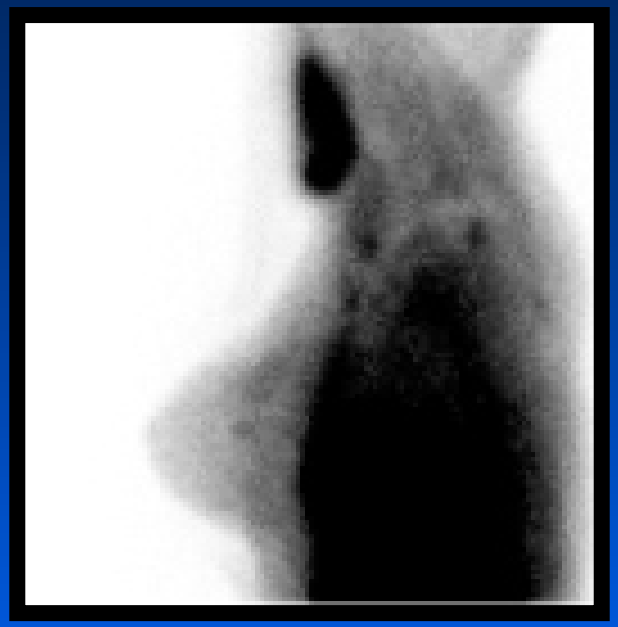
Clinical Trials at Johns Hopkins



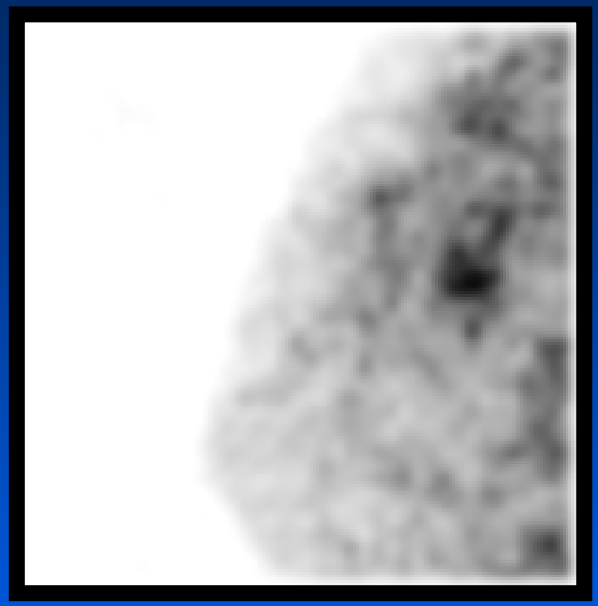
Standard gamma camera

Dilon imager

Clinical Performance 12.5cmx12.5cm Imager



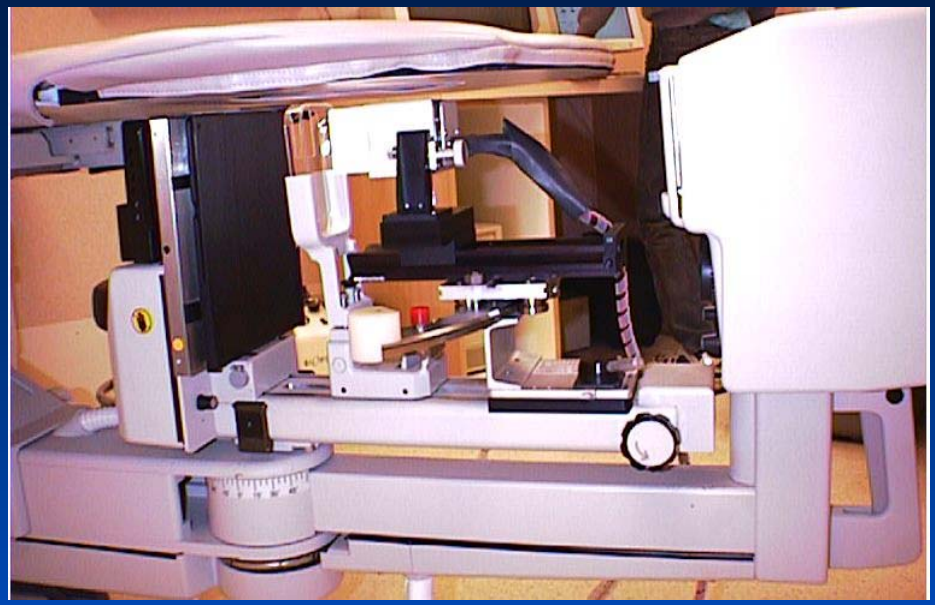
Siemens left lateral



Dilon left lateral

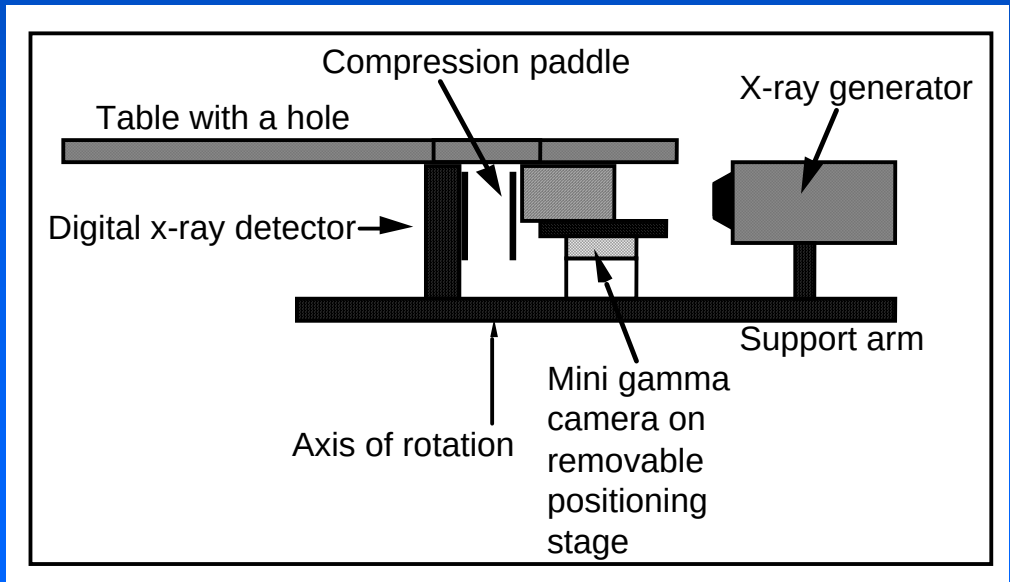
Dilon left cc

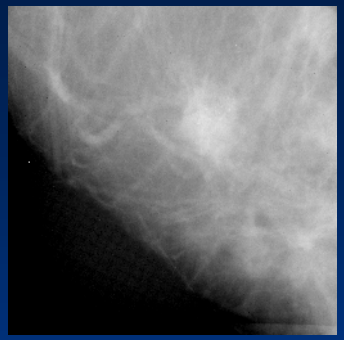
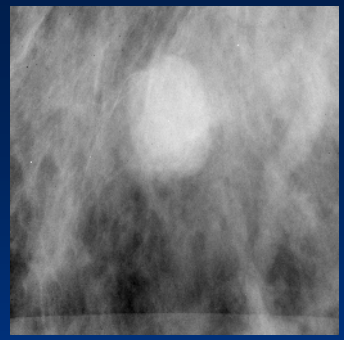
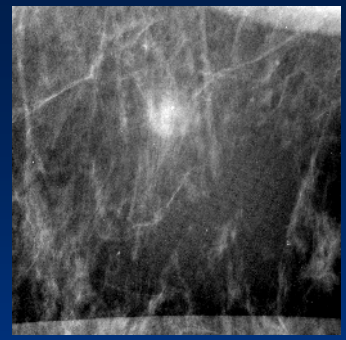
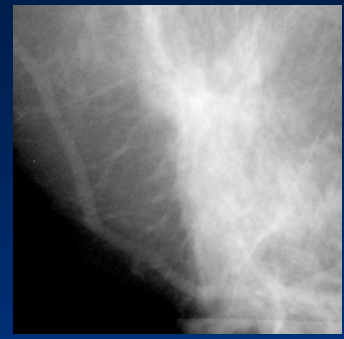
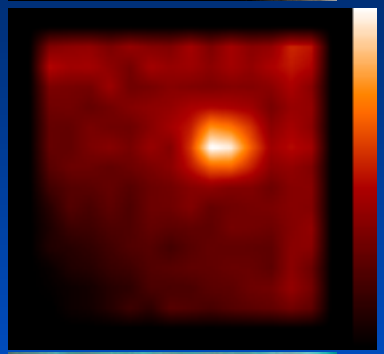
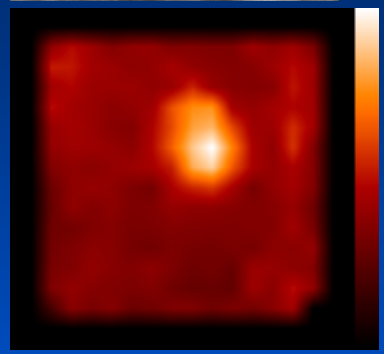
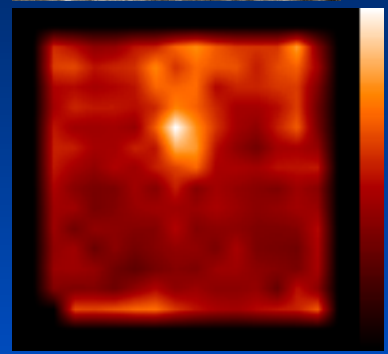
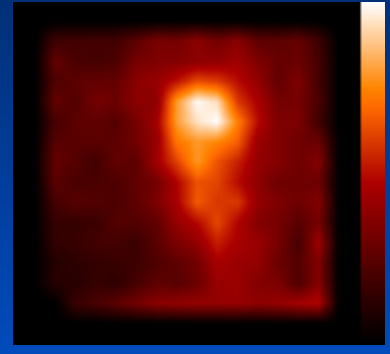
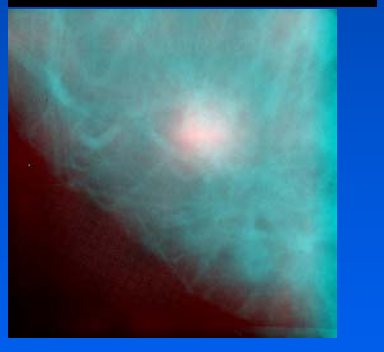
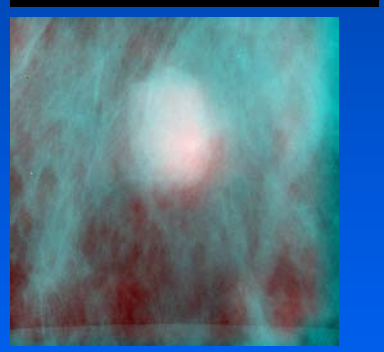
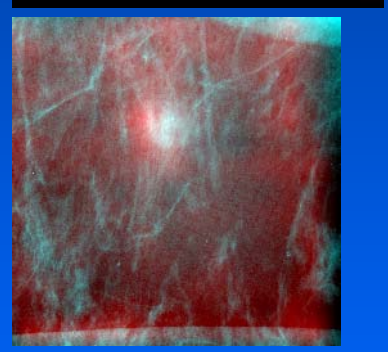
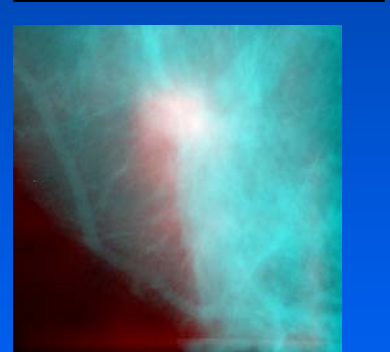
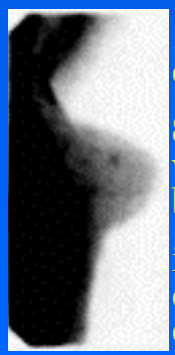
- Images obtained at Johns Hopkins University
- No abnormality on ultrasound or x-ray mammography

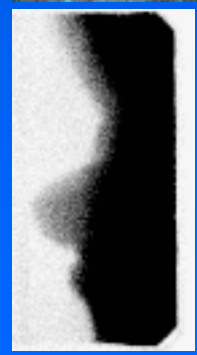
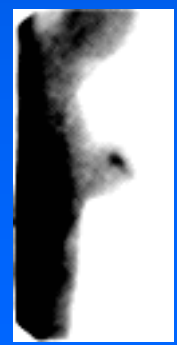


- Fischer Imaging Inc. stereotactic breast biopsy system
- Macintosh G3 desktop computer
- National Instruments Inc.: 4 channel ADC PCI card PCI-6110E controlled via Sparrow Inc. Kmax system
- Event files

- Hampton University
- Riverside Hospital
- Newport News, VA



175 lb., 68 year old patient

8 cm comp, CC view of right breast

intraductal carcinoma cribriform type

196 lb., 39 year old patient

7 cm comp, 60°MLO view of left breast

benign cellular fibroadenoma

180 lb., 77 year old patient

7 cm comp, CC view of the left breast

invasive ductal carcinoma

0.8 cm size

192 lb., 56 year old patient

6 cm comp, CC view of the right breast

infiltrating carcinoma, lobular

2.8 cm size

Clinical Breast Positron Imaging

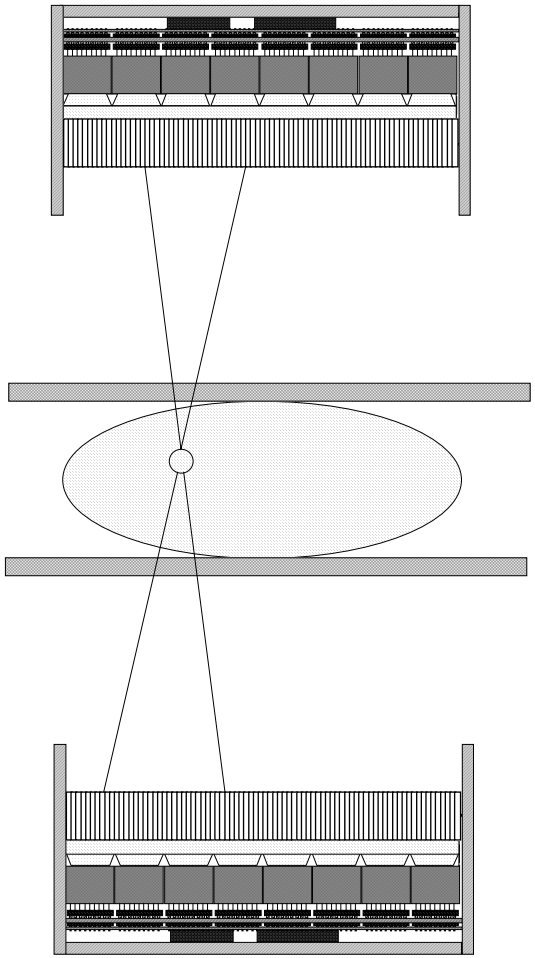
- ^{18}F-fluorodeoxyglucose (FDG) is used to image increased metabolism of breast tumors

- Imaging FDG uptake is useful in the detection, staging and treatment of breast cancer

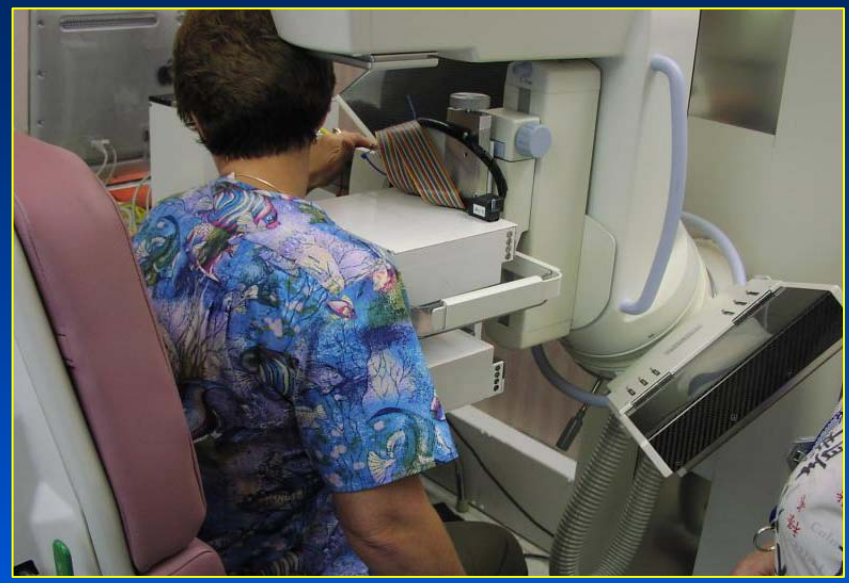
- No single factor is responsible for variation of FDG uptake in tumors

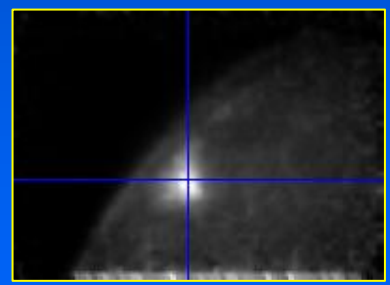
- Initial clinical evaluations of PEM systems
  - better resolution than in conventional PET scanners

Schematic Diagram of PEM Detector

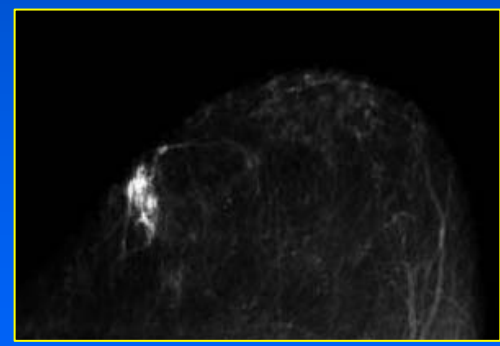


JLab Positron Emission Mammography (PEM) Imager Clinical Trials at Duke University Medical Center



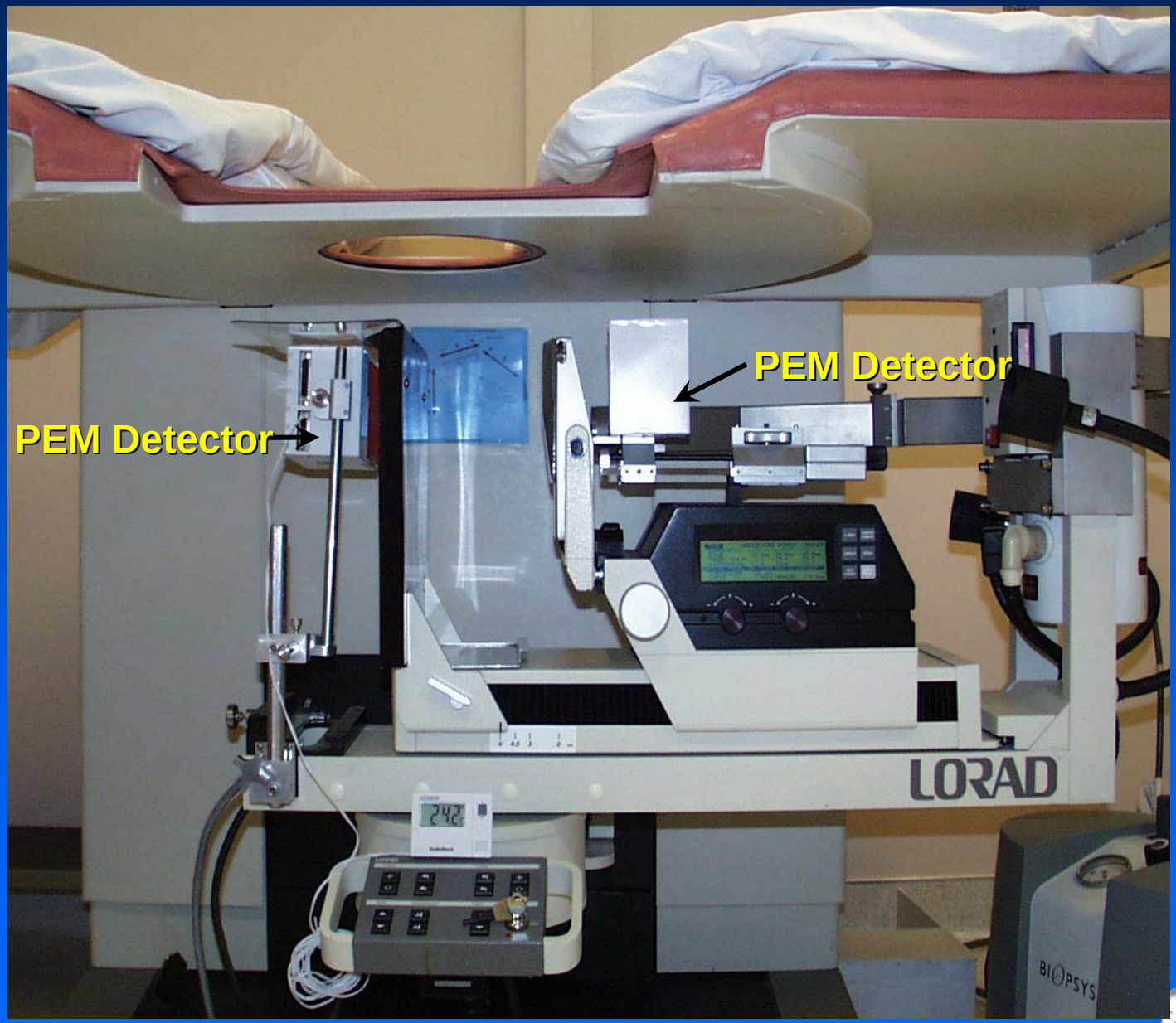


PEM
functional image of glucose metabolism

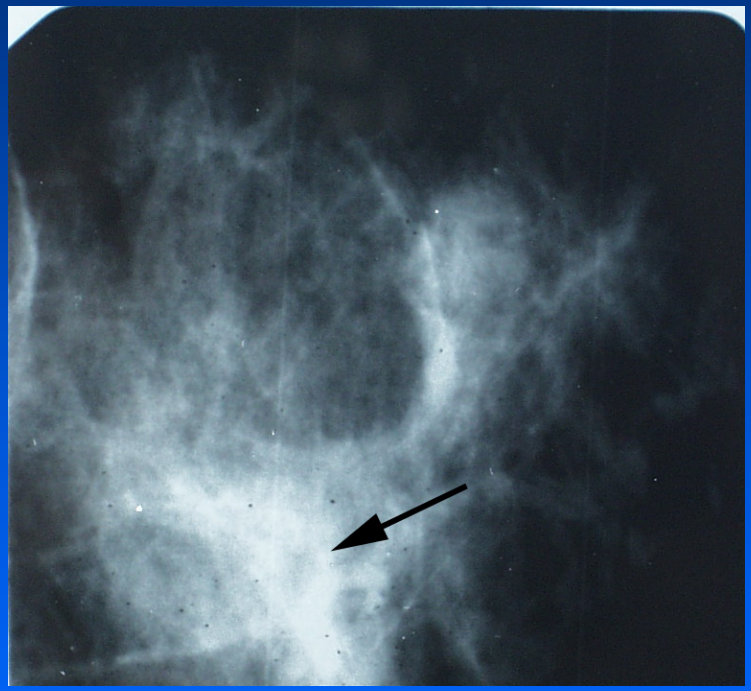


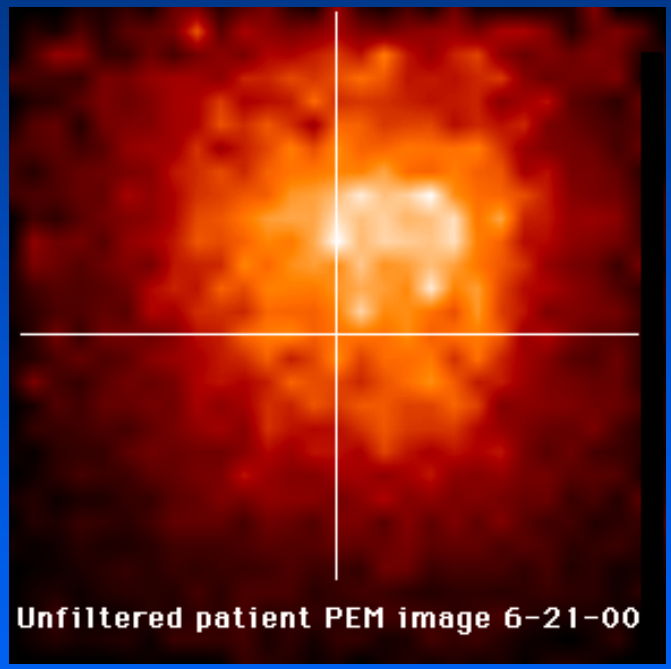
x-ray
anatomical image of x-ray attenuation

PEM-Biopsy Apparatus



The first clinical result





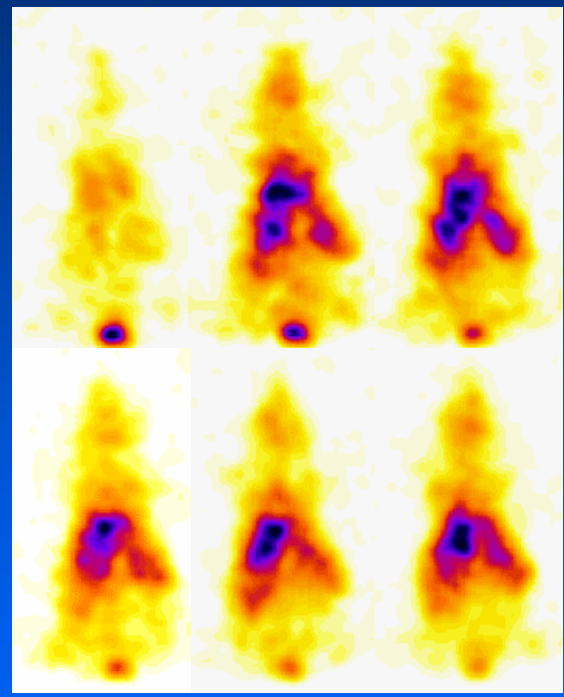
(source:Ray Raylman, Ph.D, West Virginia U.)

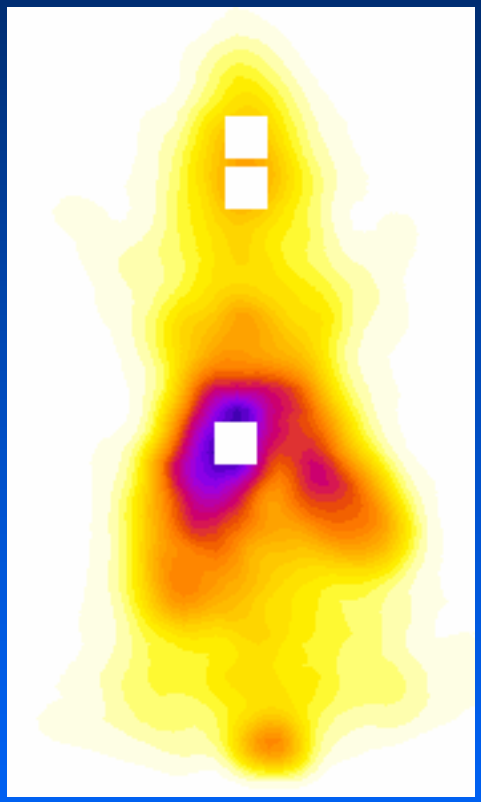
Animal Imaging

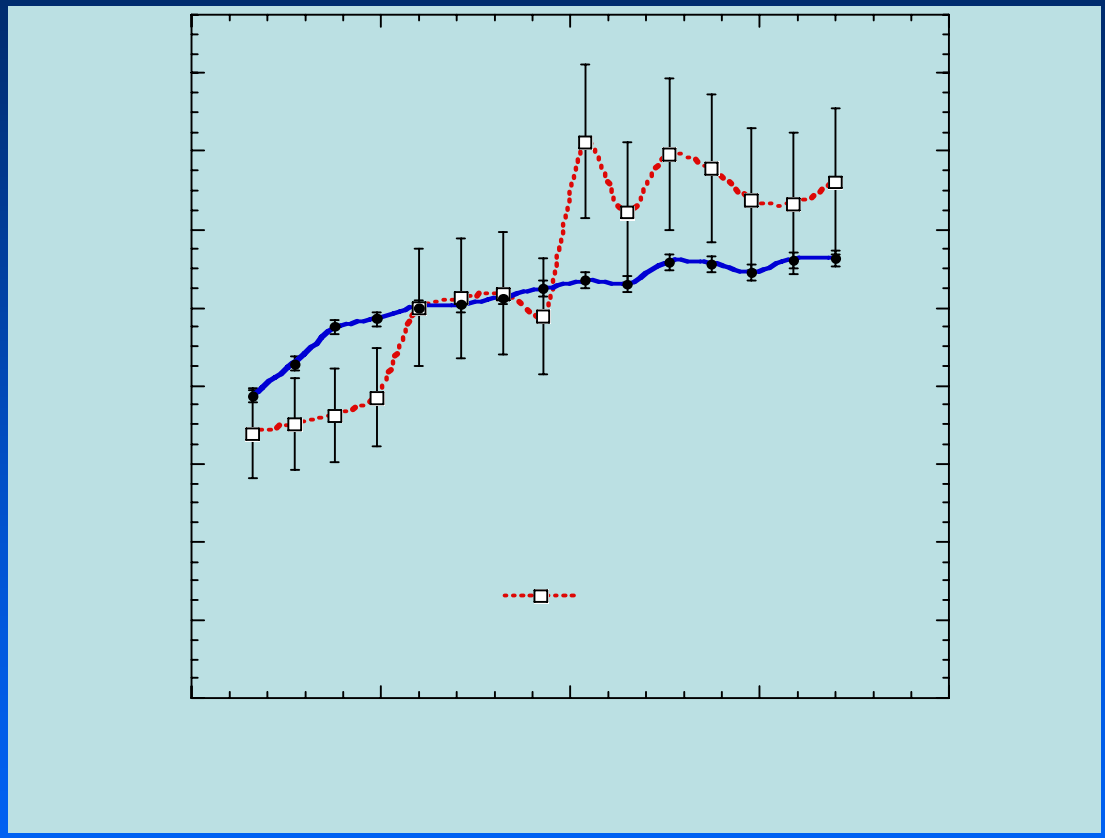
Imaging system capable of imaging in real time gene function in a live mouse. No need to sacrifice the animal and allows the same mouse to be used in follow-up research.

Applications:
- gene therapy development
- drug development

Change in distribution of genetic marker over time for a single live mouse.

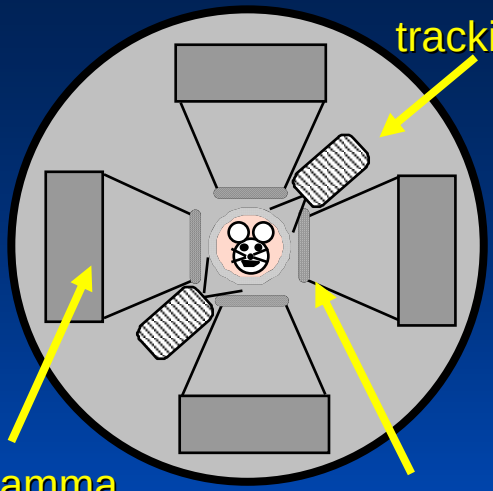


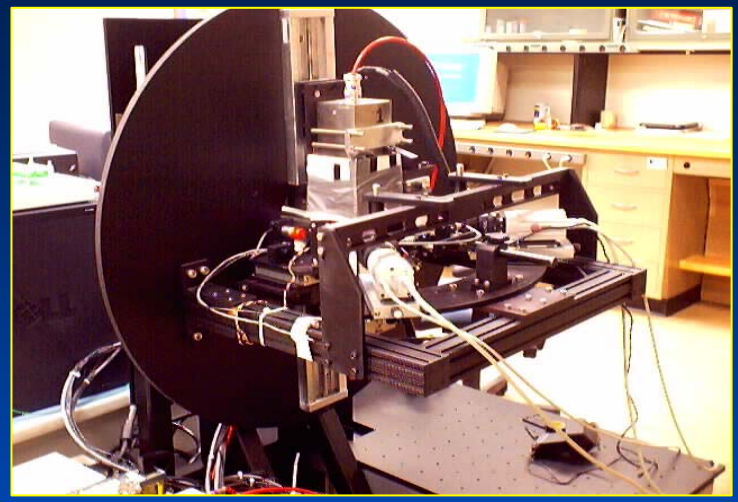




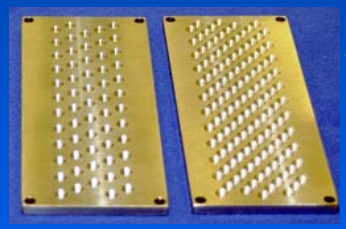
5 mm x 5 mm ROIs

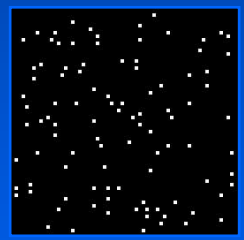
JLab-ORNL Restraint-Free Small Animal SPECT Imaging System

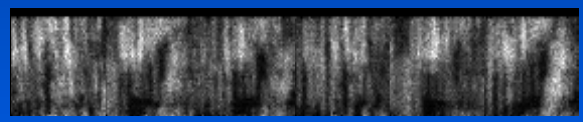




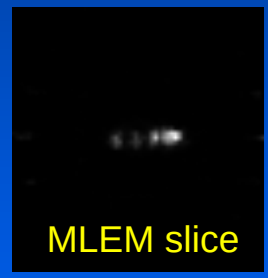
Detector/Tracking System

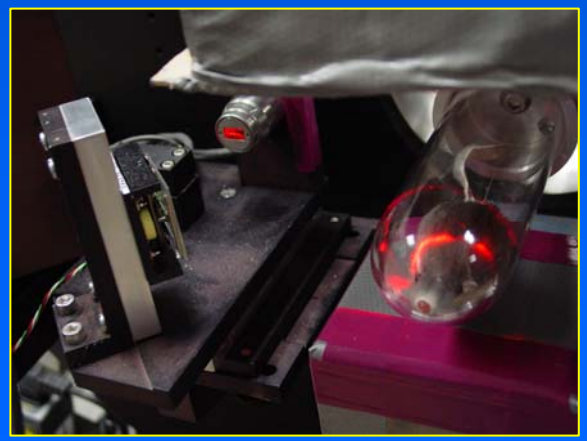




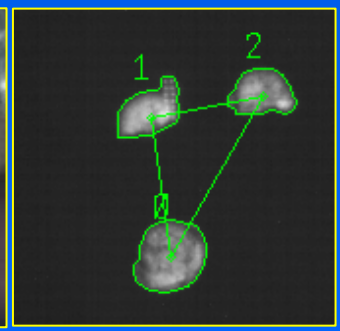


multipinhole projections at 6 angles





IR laser surface profiling

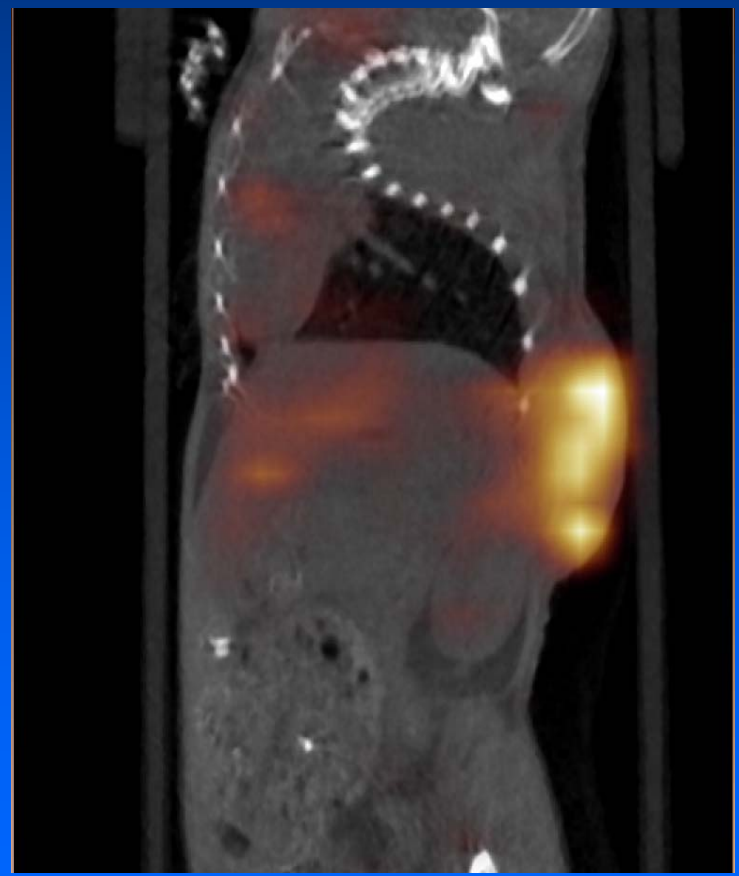


laser tracking of mouse motion

X-ray micro-CT and SPECT Imaging

- *Single Photon Emission CT* (SPECT) **used for functional imaging**
- **Dual Modality Example – Amyloid target labeled with I-125**

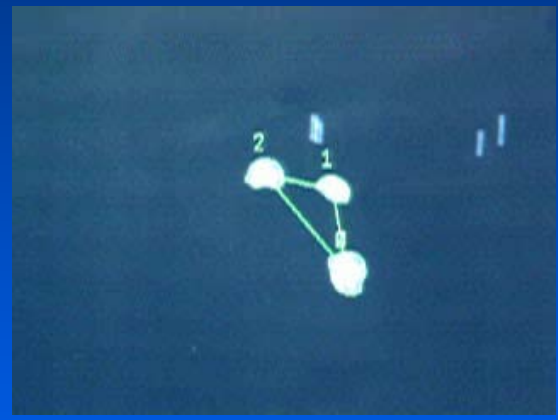
registered micro-SPECT and micro-CT volumes



registered micro-SPECT and micro-CT slices

IR Reflector Tracking:
First Live Mouse Experiment

Movie of sleeping animal



Movie of segmented image from camera #1

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