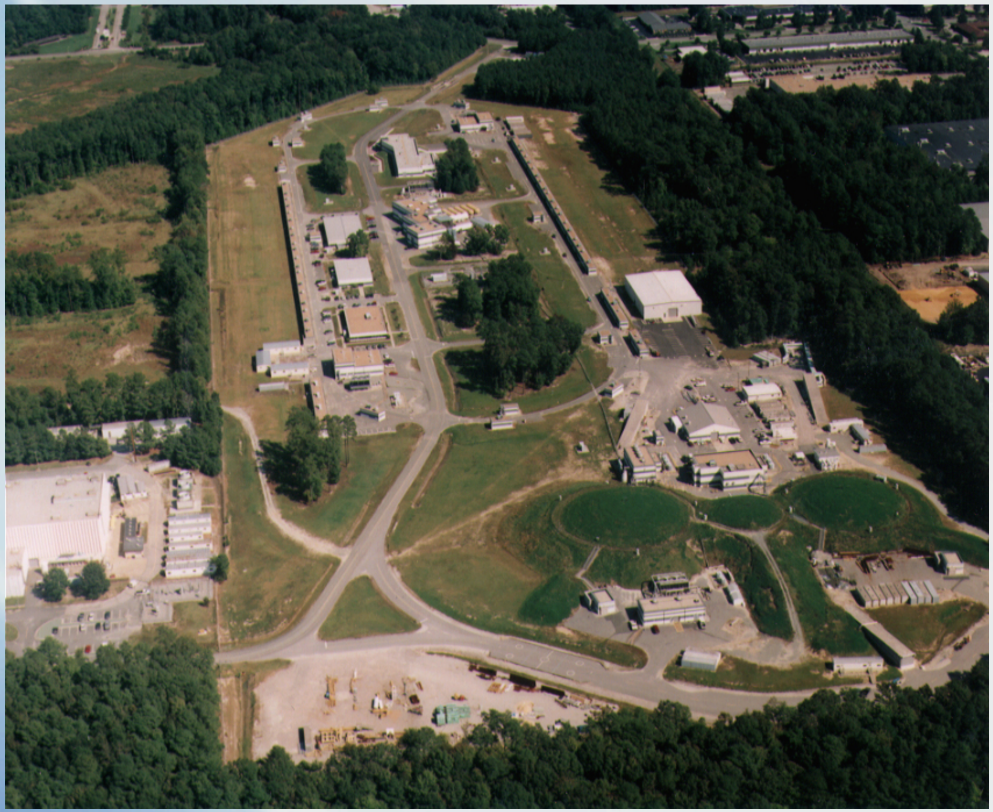
Applying Nuclear Physics Research Detector Technology to Biomedical Applications



Drew Weisenberger

Detector and Imaging Group

Thomas Jefferson National Accelerator Facility

Newport News, Virginia

Jefferson Lab
Thomas Jefferson National Accelerator Facility

U.S. DEPARTMENT OF ENERGY

"Beside the comfort of knowledge, every science is auxiliary to every other."

Thomas Jefferson

August 26, 1786

JLab Detector and Imaging Group

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

Stan Majewski (Group Leader) - detector concepts/design applications

Brian Kross - mechanical design and construction / gas systems

John McKisson- software / data acquisition / electronics

James Proffitt - high speed electronics

Sasha Stolin - medical physics post doc

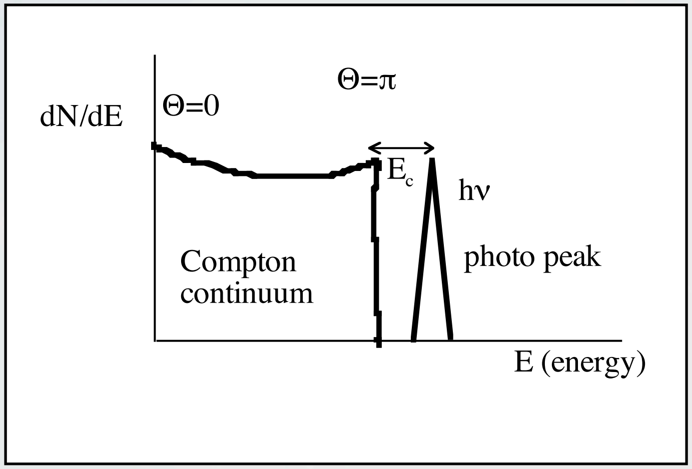
Drew Weisenberger - data acquisition / applications / photo multipliers

Carl Zorn - scintillators / photo multipliers / optics

Detector Physics

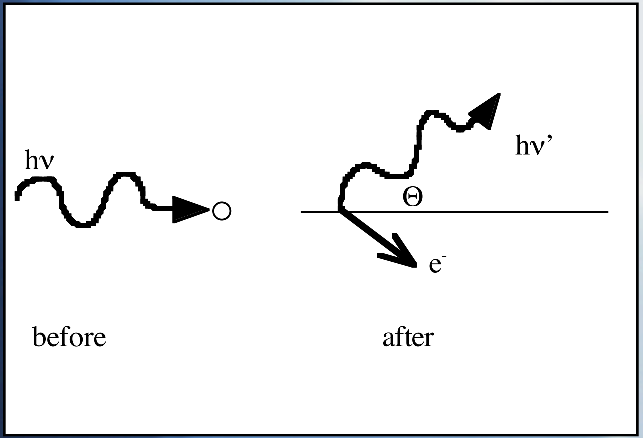
Detecting and Imaging Radioactive Decay (a nuclear process)

Scintillator: transparent material for detecting high energy photons (i.e. x-rays, gamma -rays)

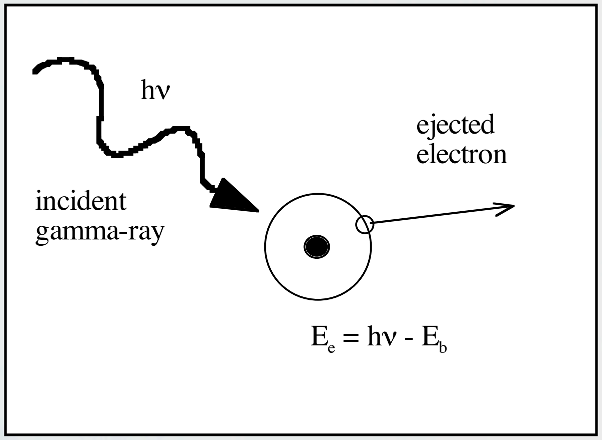


A high energy photon deposits energy in the atoms of the scintillator resulting in the release of lower energy photons that can then be converted to an electrical signal by devices called photomultiplier tubes (PMTs).

Compton Scattering



Photoelectric Absorption



Nuclear Medicine

Medical Imaging Modalities

Structural

Functional

Somatostatin receptors (neuroendocrine tumors)

Nuclear Medicine Imaging Basics

Functional imaging (vs structural): patient injected with a radiopharmaceutical that has a biological function in the body i.e. metabolism.

Radiopharmaceutical: radioactive isotope + bioactive tag

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)
Coincident radiation detection through positron-electron interaction
fluorine-18 (positron emitter, 110 minute half-life) two 511 kev annihilation photons

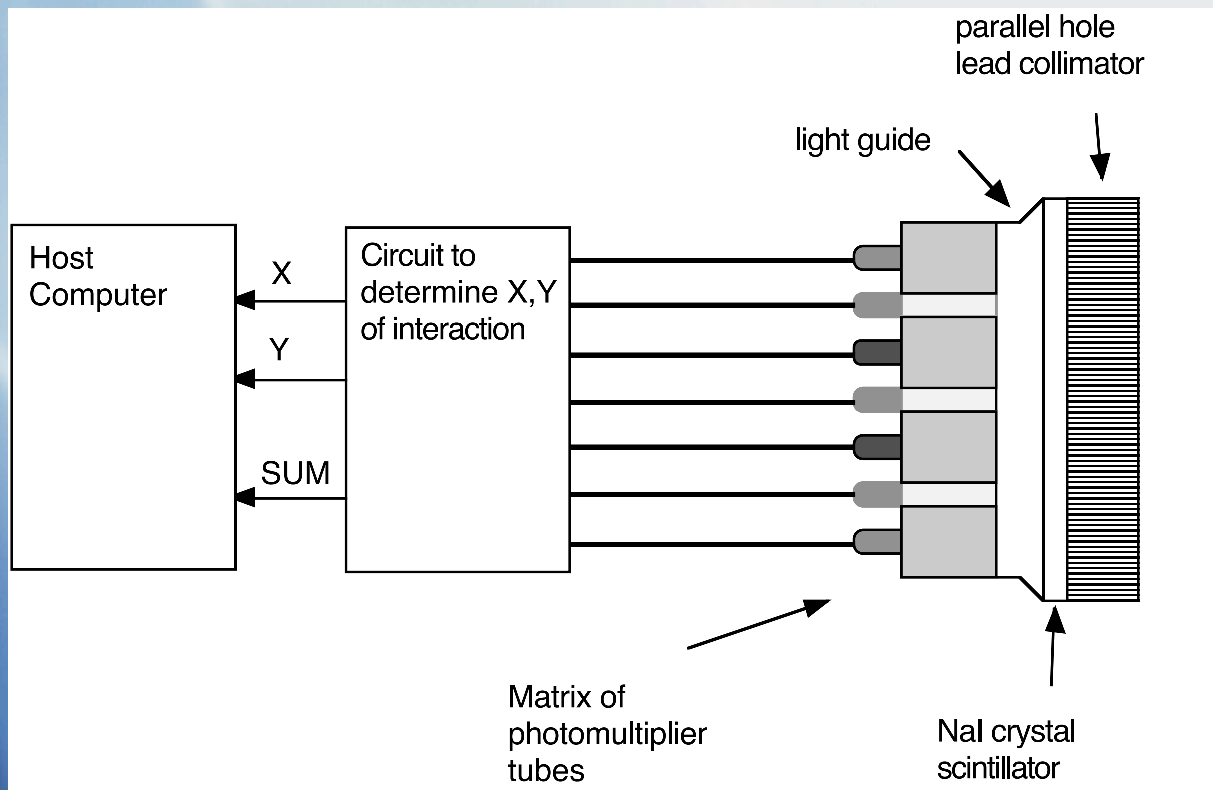
Isotope	Half-live	Photon energies (keV) (photon abundance)
technetium-99m (^{99m}Tc)	6.02 hours	140 (89%)
indium-111 (^{111}I)	2.83 days	170 (94%), 240 (90%)
gallium-67 (^{67}Ga)	3.25 days	93 (37%), 185 (20%), 300 (17%), and 394 (4%)
iodine-123 (^{123}I)	13.3 hours	159 (84%)

^{99m}Tc-sestamibi

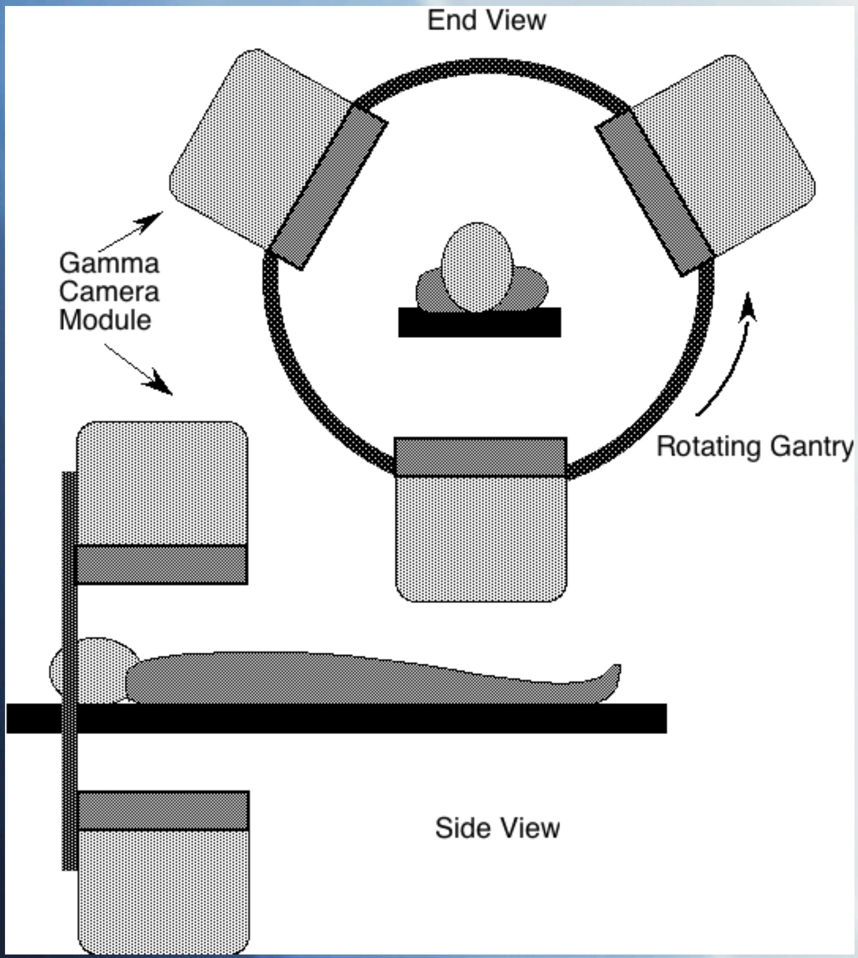
Positron Emitting Isotope	Half-life (minutes)	Positron E_{max} (MeV)
oxygen-15 (^{15}O)	2.07	1.72
nitrogen-13 (^{13}N)	9.96	1.19
carbon-11 (^{11}C)	20.4	0.96
fluorine-18 (^{18}F)	109.7	0.64

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

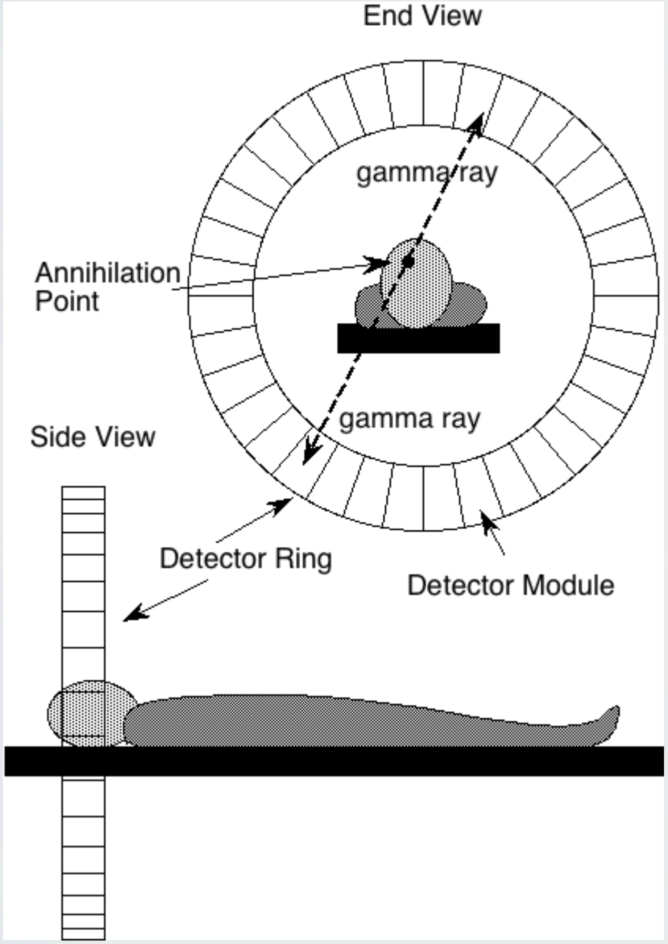
Typical Clinical Gamma Camera



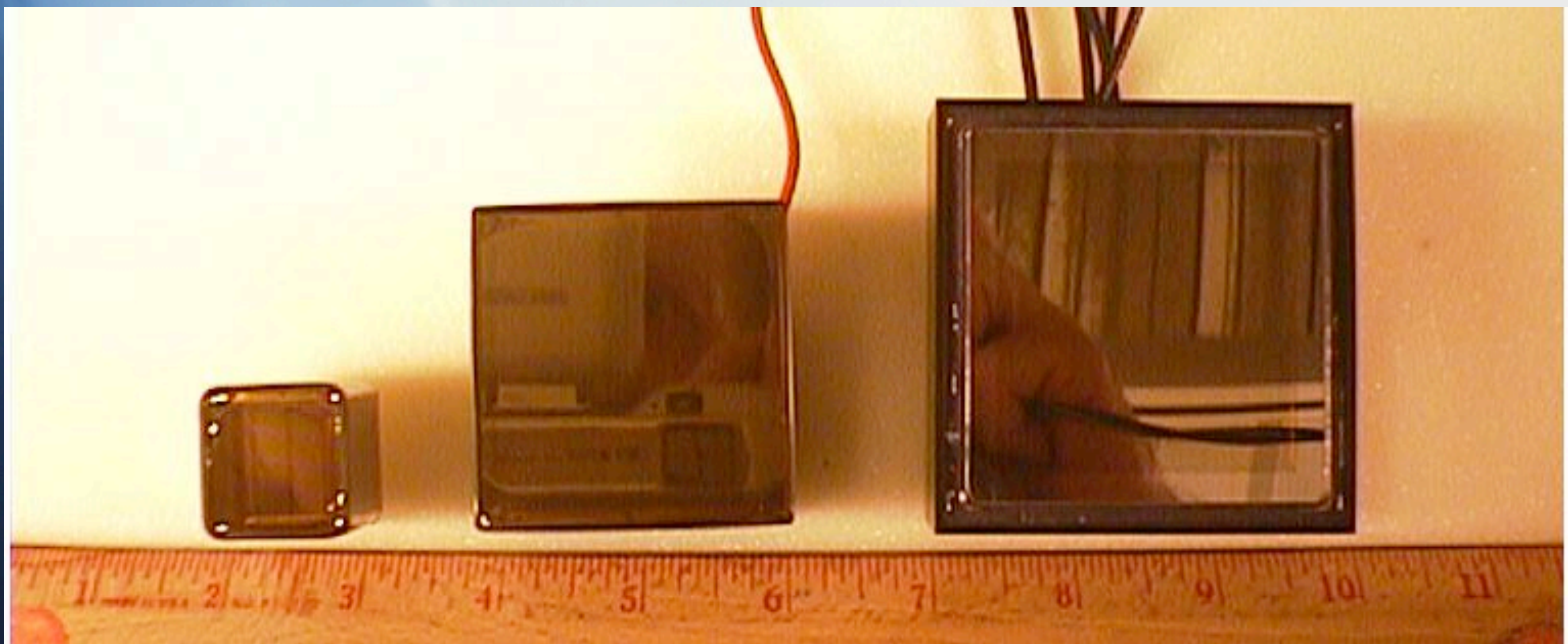
Clinical SPECT System



Clinical PET System



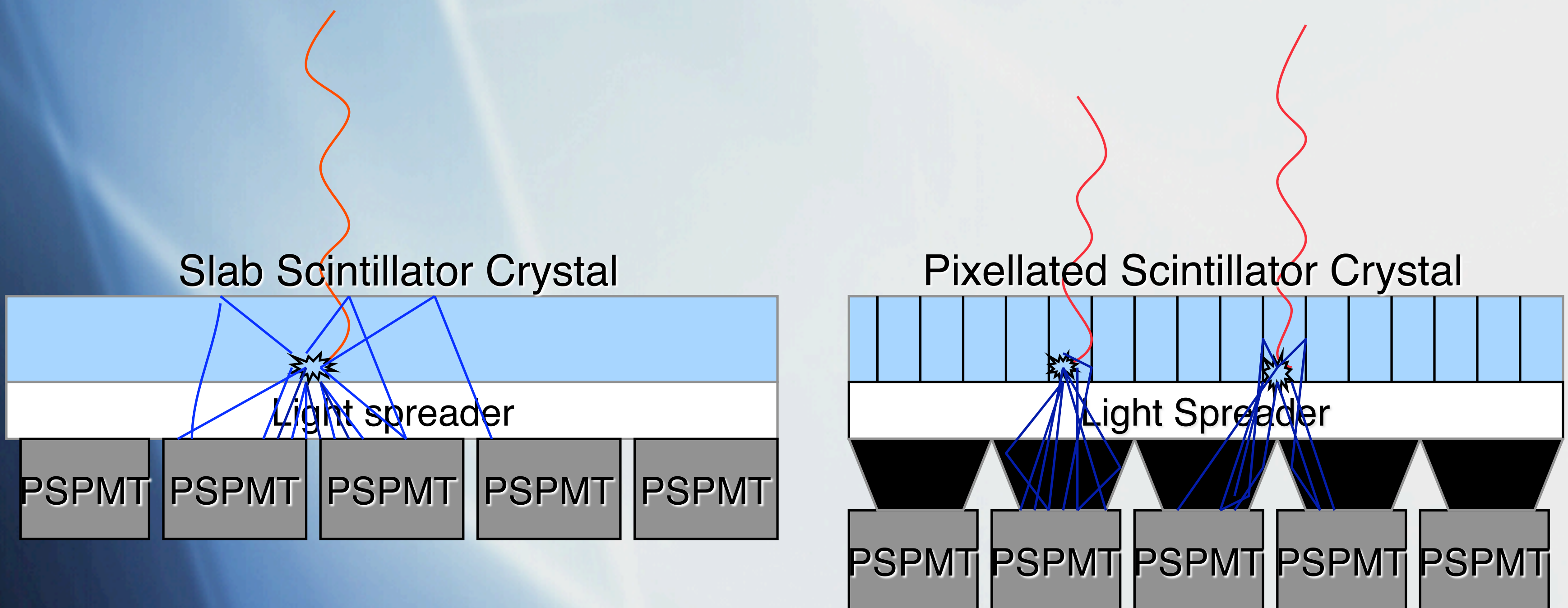
Latest photomultiplier tube technology allows modular detector construction



Compact position sensitive PMTs:

Hamamatsu's R7600, H8500/H8900, and Burle's 85001.

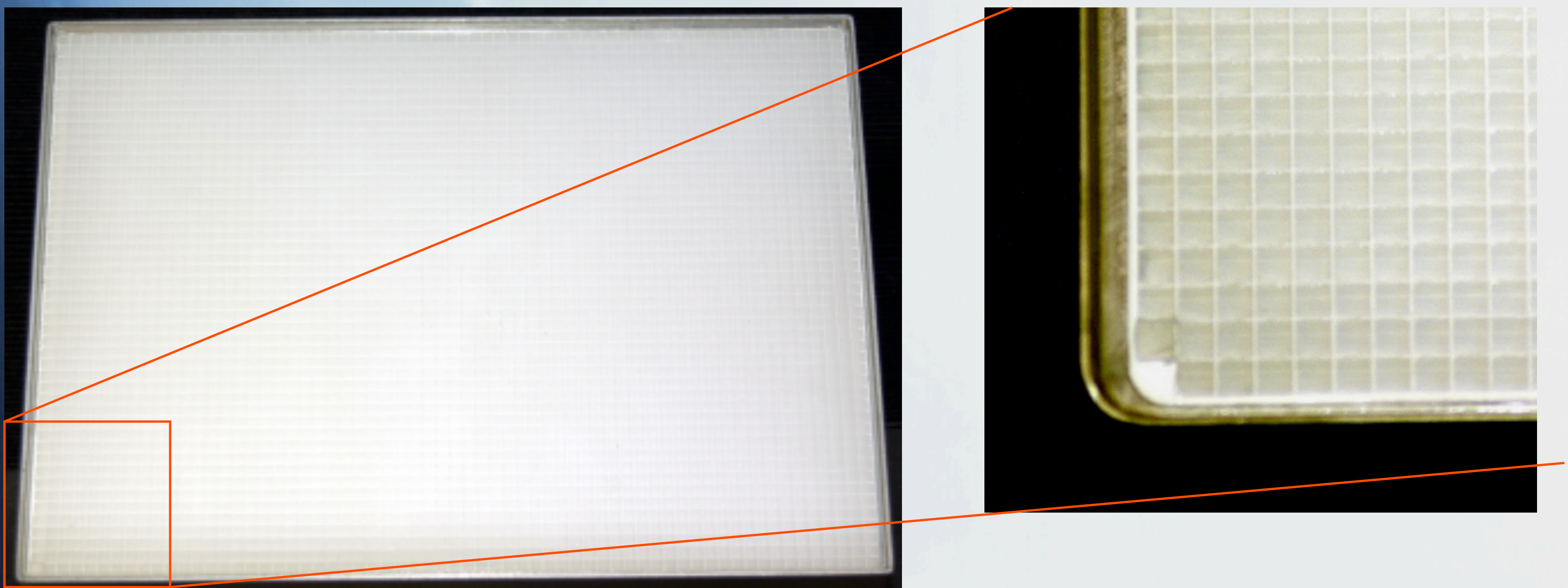
Light Distribution
Slab vs. Pixellated



Simple light guide light is sufficient to bypass the cracks

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

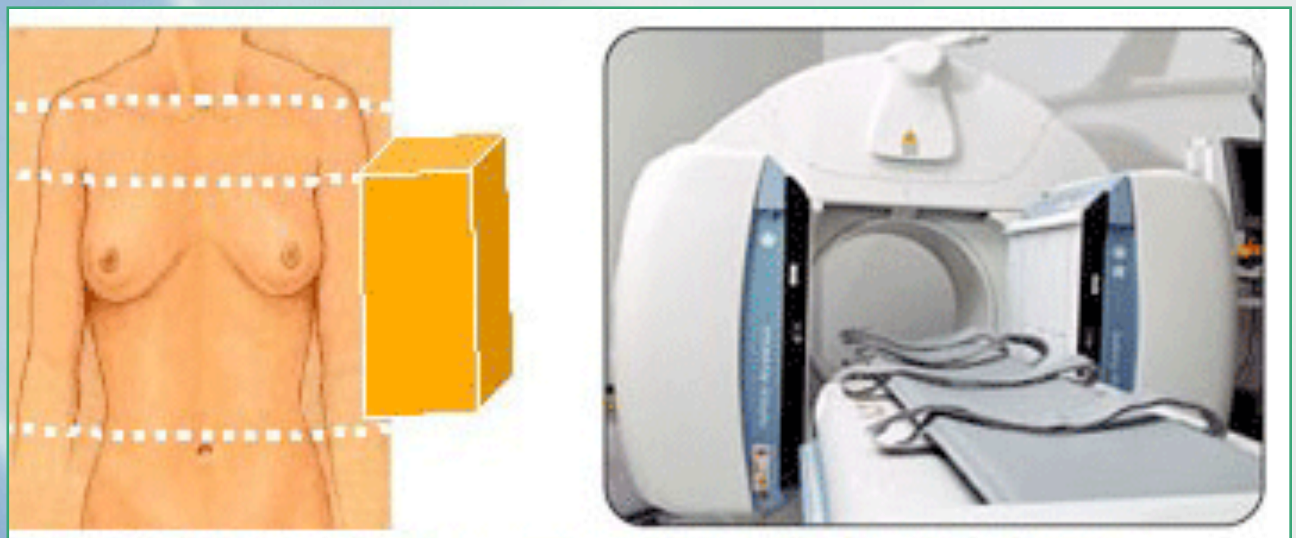
Scintillator Array



Breast Cancer Detection

Improving scintimammography

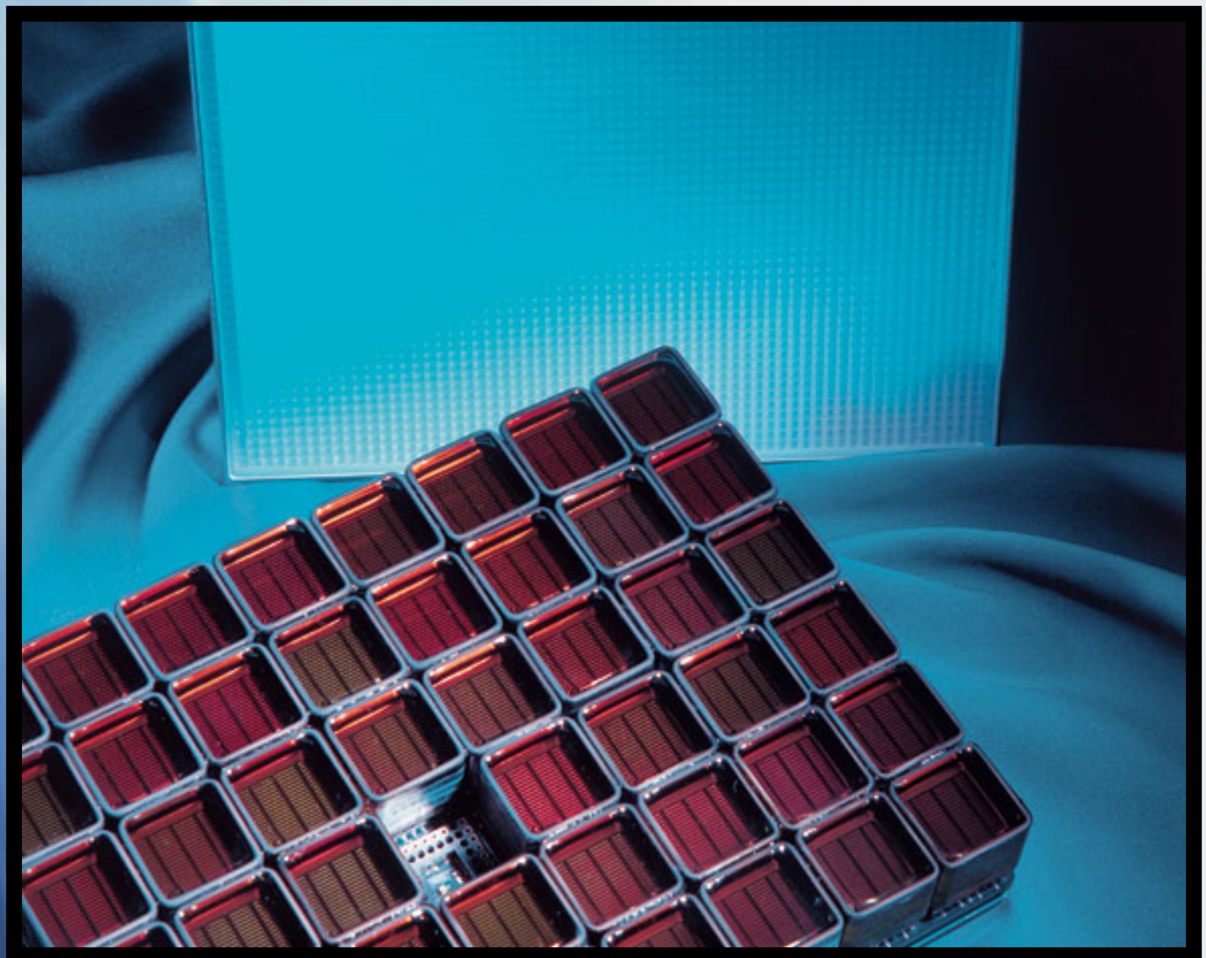
Need for a Detector Built for the Task



Breast-Specific Gamma Imaging (BSGI):

Functional imaging to complement mammography

Uses Tc99m-sestibibi



Compact Detector Allows for Improved Imaging

The Dilon 6800 Gamma Camera

Small High-Tech Company in Newport News, VA
Licensed patented technology from Jefferson Lab

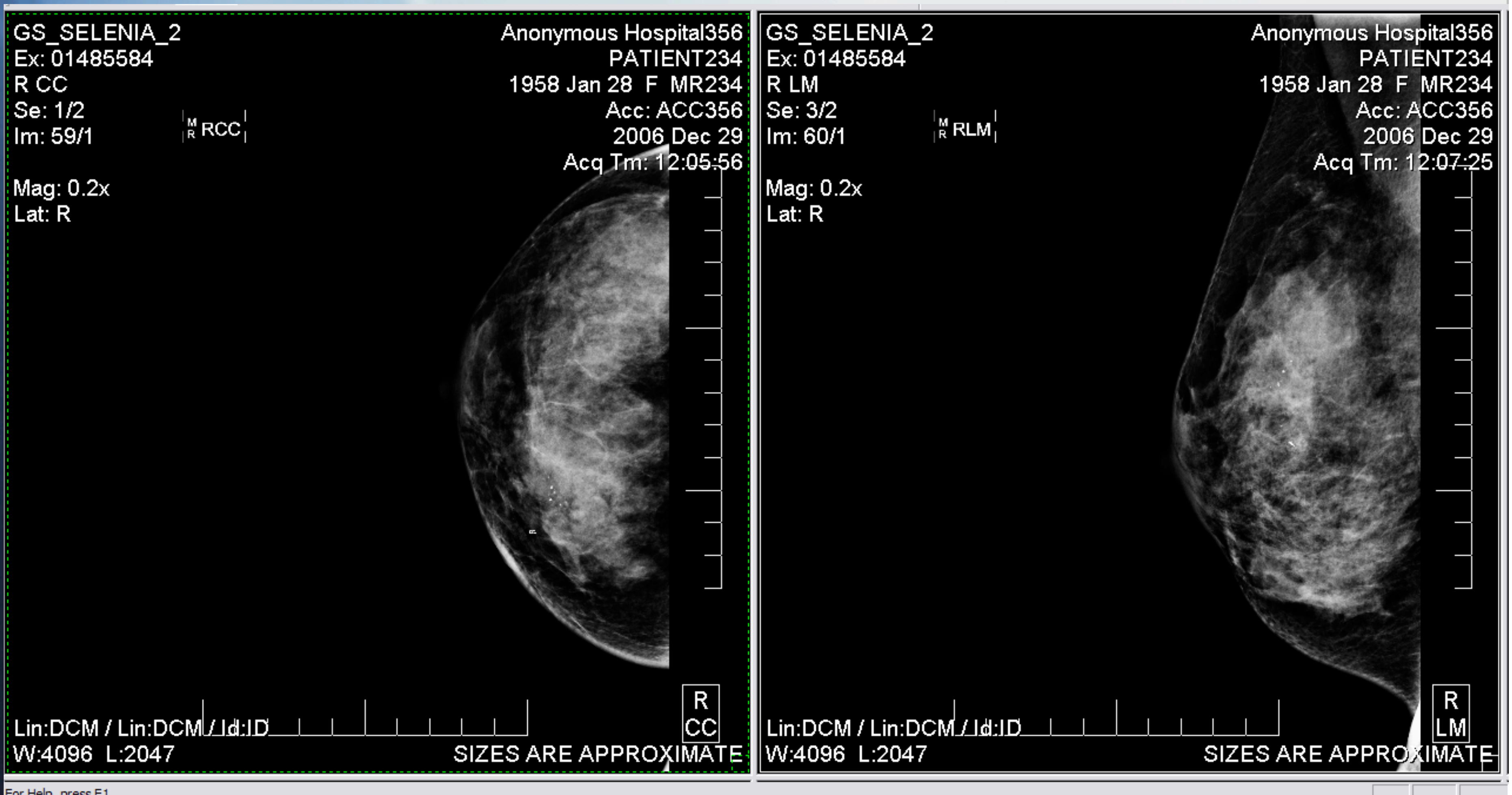
System is being used in centers all across the US, from Seattle to Houston, CA to FL, and there are many in the North & Eastern states/cities- such as in NYC, Philadelphia, Pittsburgh, Washington, DC, Boston, Newport News, Raleigh

Lahey Clinic in Burlington, MA

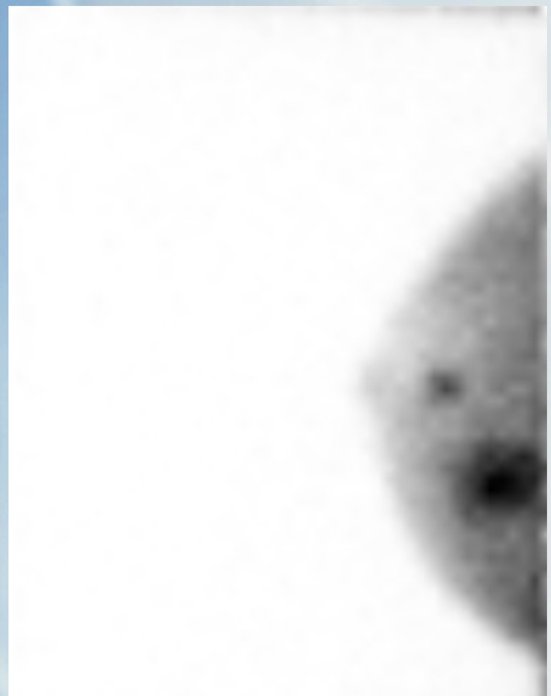
Since the first camera installation about 3 years ago, there have been about 60,000 patients imaged with the Dilon 6800

X-ray mammogram: The patient returned 8 weeks later reporting increased perception of dimpling. No palpable area noted in the clinical examination.

Follow-up Ultrasound: Right breast - fibrocystic change with a large number of cysts. No discrete mass is found.



Courtesy of Legacy Good Samaritan Hospital

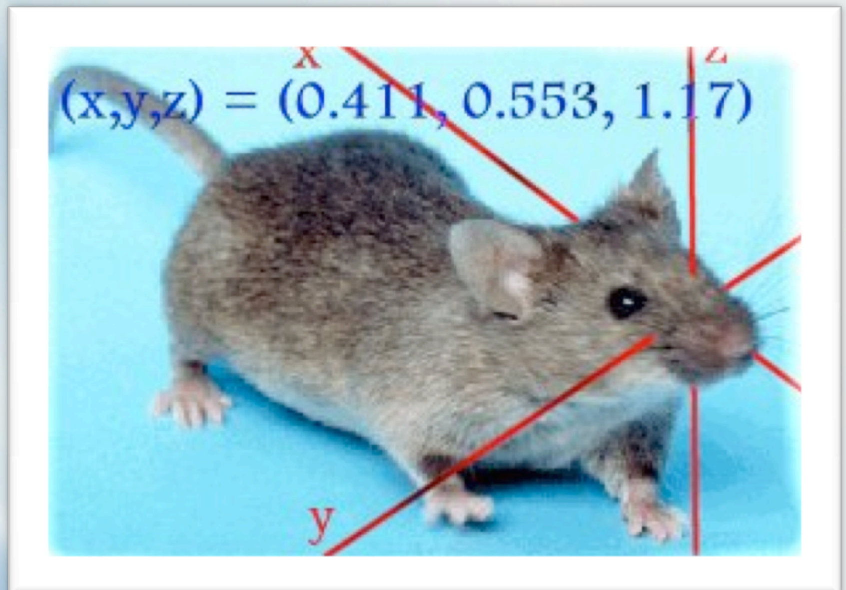


BSGI of right breast (two views)

BSGI: Left breast – normal uniform distribution. Right breast – a large area of asymmetric focal area of increased uptake in the upper-inner quadrant of the breast, measuring approximately 2 cm. A second, smaller and more intense focus located retroareolar, measuring about 1 cm at the 6 o'clock position. In addition, there are areas of increased activity in the right axilla which may be node activity. Multifocal positive in the right breast and possible positive findings in the right axilla.

Courtesy of Legacy Good Samaritan Hospital

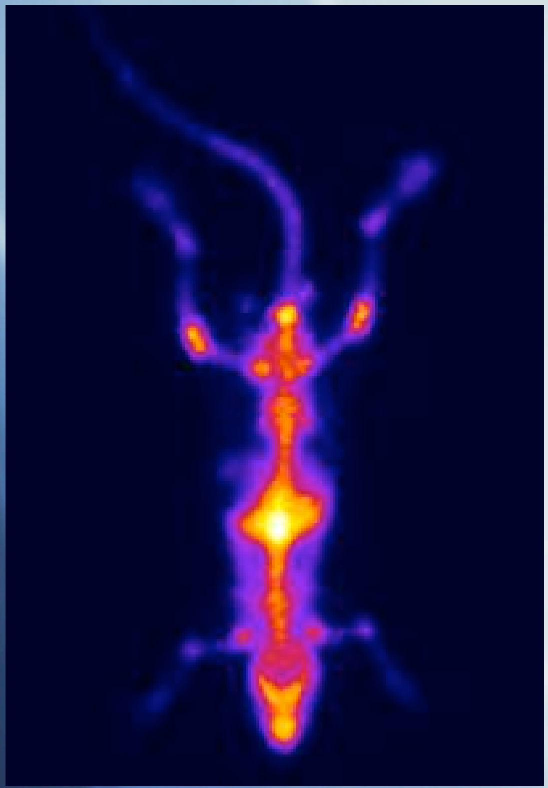
Awake Small Animal Imaging



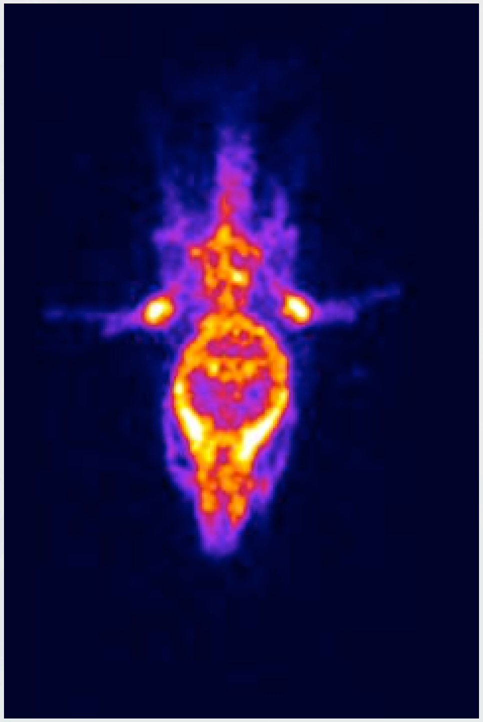
A new tool for biological research under development:

JLab, ORNL and JHU

Image of mouse injected with bone marker MDP-Tc99m



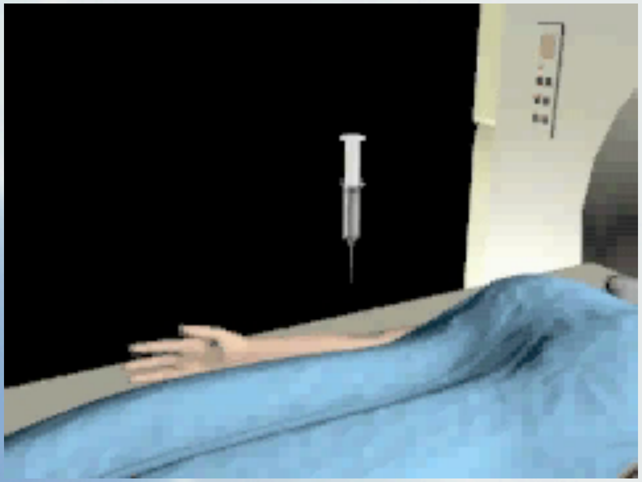
Using high resolution parallel hole collimator



Using 1mm pinhole ~2x magnification

Why anesthesia in Small Animal SPECT imaging?

Eliminate motion artifacts while taking multiple projections



Clinical SPECT

Effects of anesthesia on cerebral blood flow

anesthetic	*effect on CBF*
isoflurane	↑↑
chloral hydrate	=
α-chloralose	↓
propofol	↓
sevoflurane	↓
pentobarbital	↓↓

Indications for awake animal SPECT imaging

Addiction research

Neuro-degeneration:

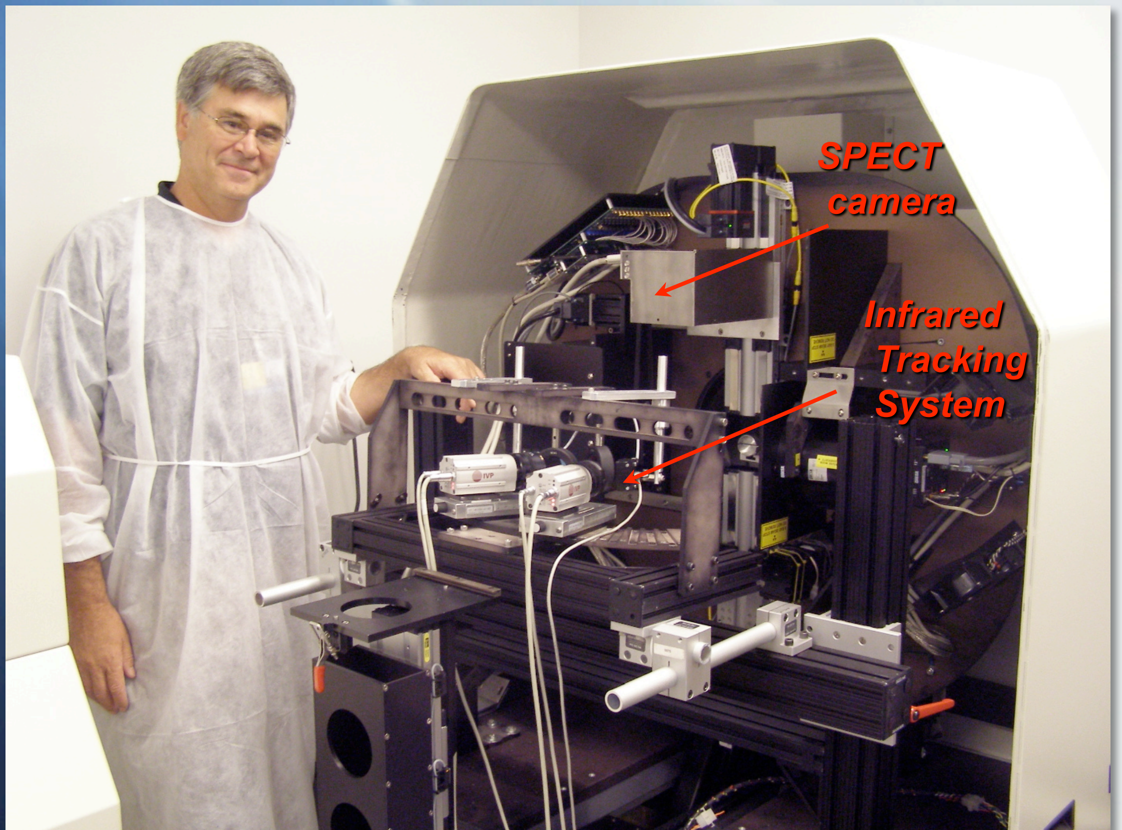
Alzheimer's Disease

Parkinson's Disease

Brain inflammation (i.e. HIV, MS).

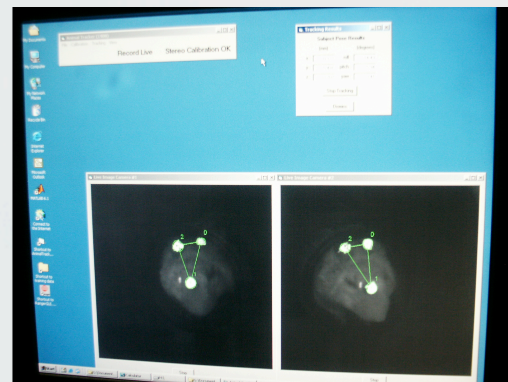
Stem cell trafficking

- ❑ avoid influence of anesthesia on: blood flow, metabolism, neural-vascular coupling
- ❑ elucidate disease pathophysiology
- ❑ drug/radiopharmaceutical development
- ❑ mimic the human state



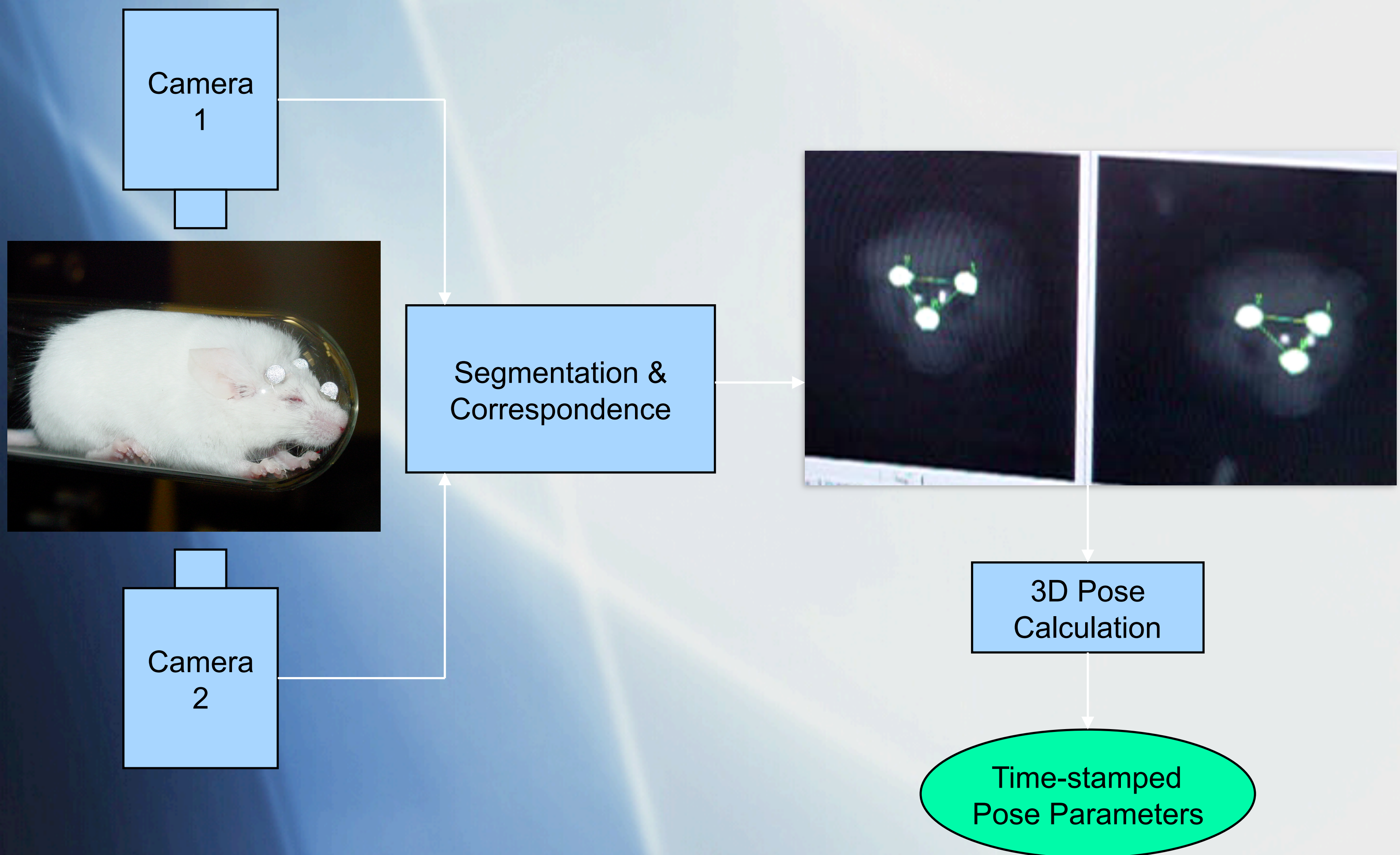
Modified SPECT/CT gantry with X-ray shield removed at JHU

An awake mouse with infrared reflectors for head tracking shown in imaging burrow.

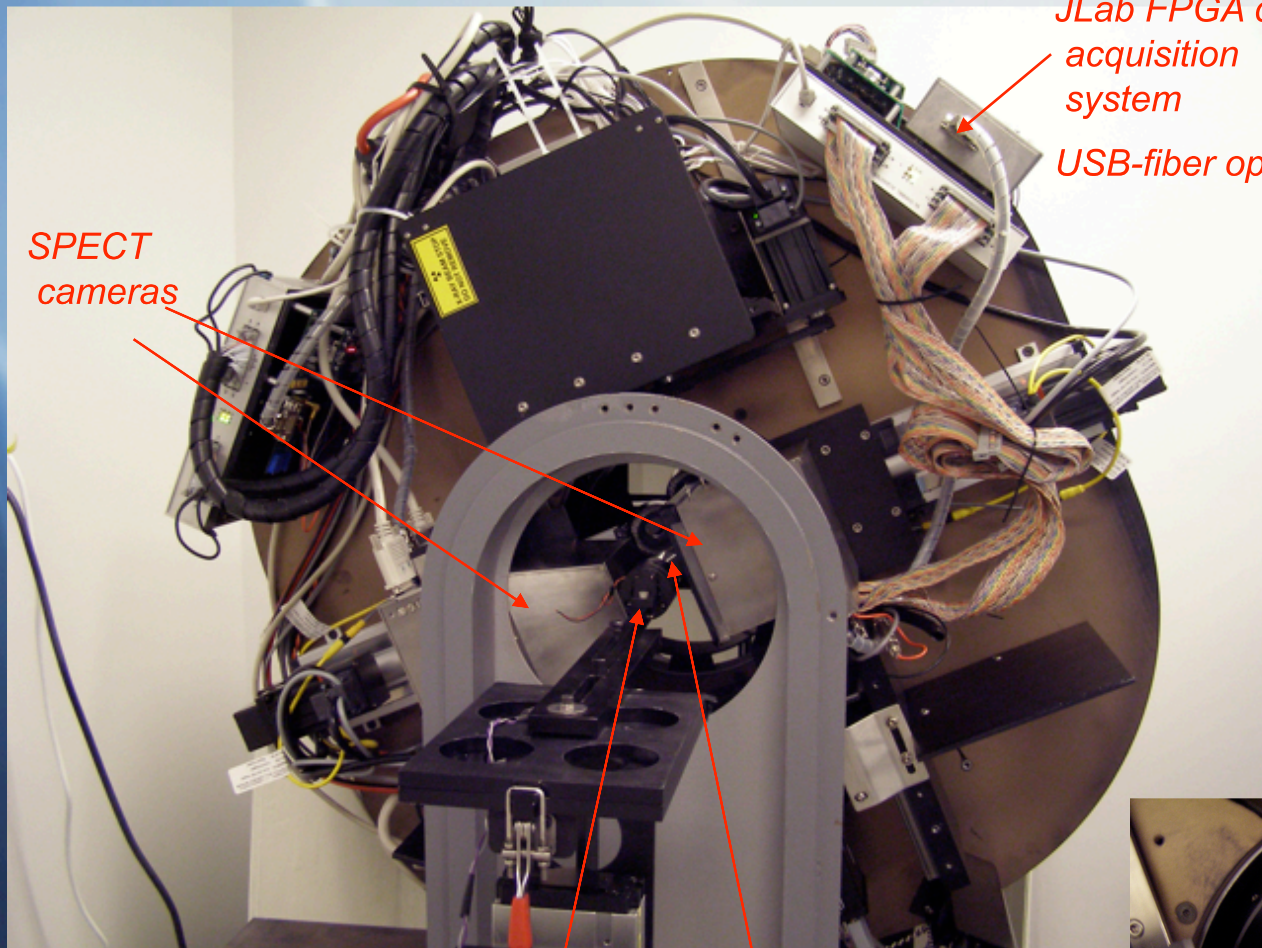


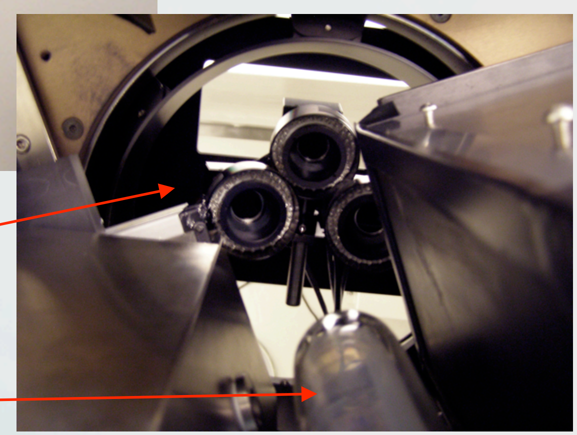
Computer display illustrating real-time pose tracking via the stereo infrared CCD cameras.

Head Pose Measurement Approach



Awake Animal SPECT-CT Imaging System Presently at JHU





JLab FPGA data acquisition system

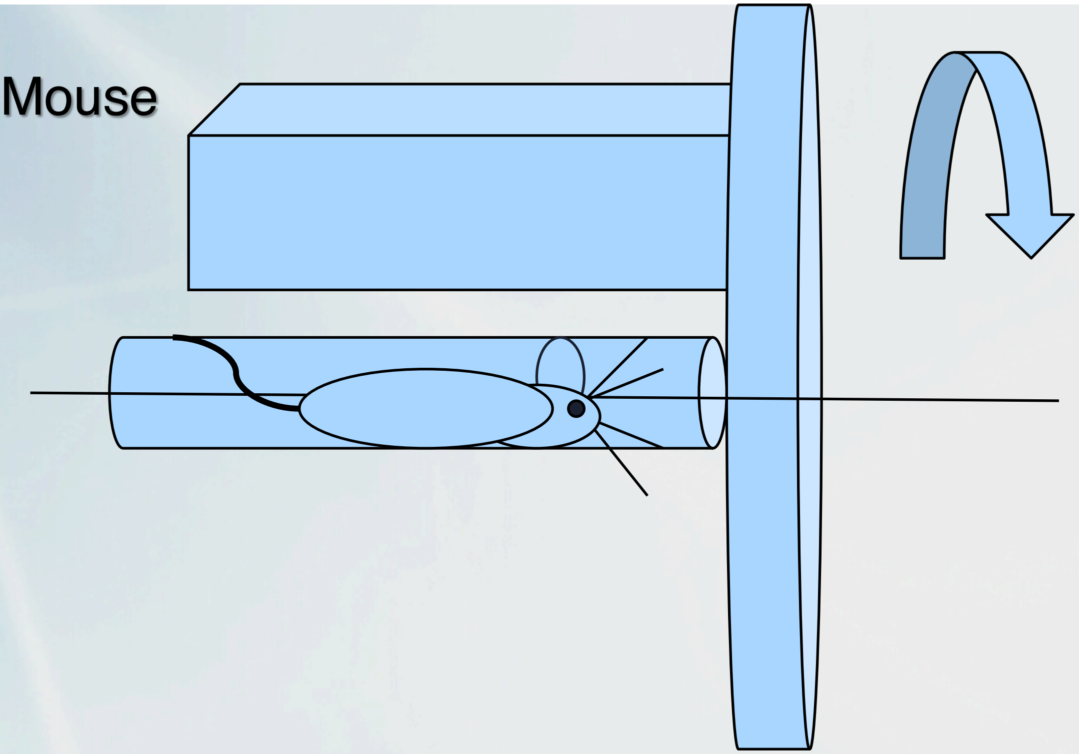
USB-fiber optic

SPECT cameras

Infrared Tracking System

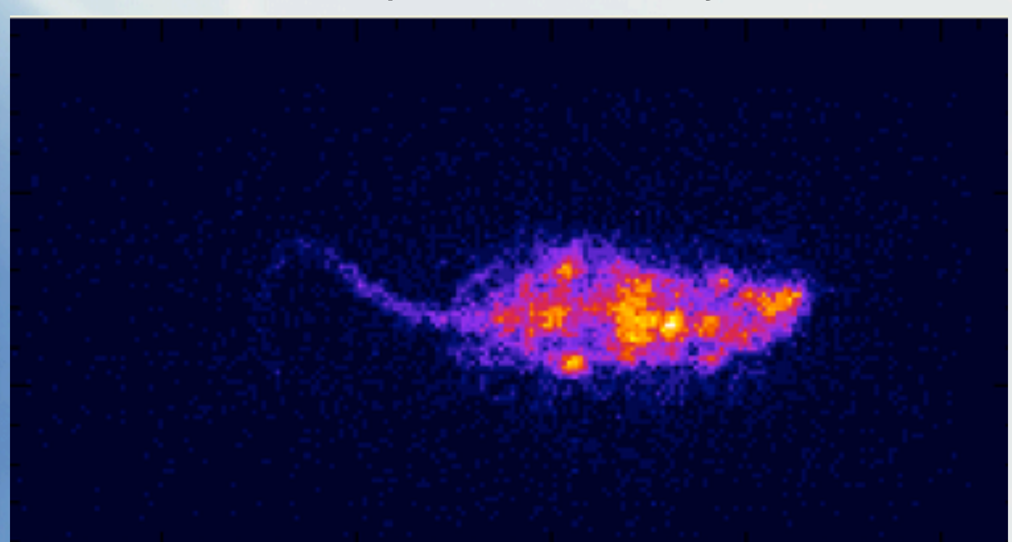
mouse in burrow

SPECT Scan of Awake Mouse

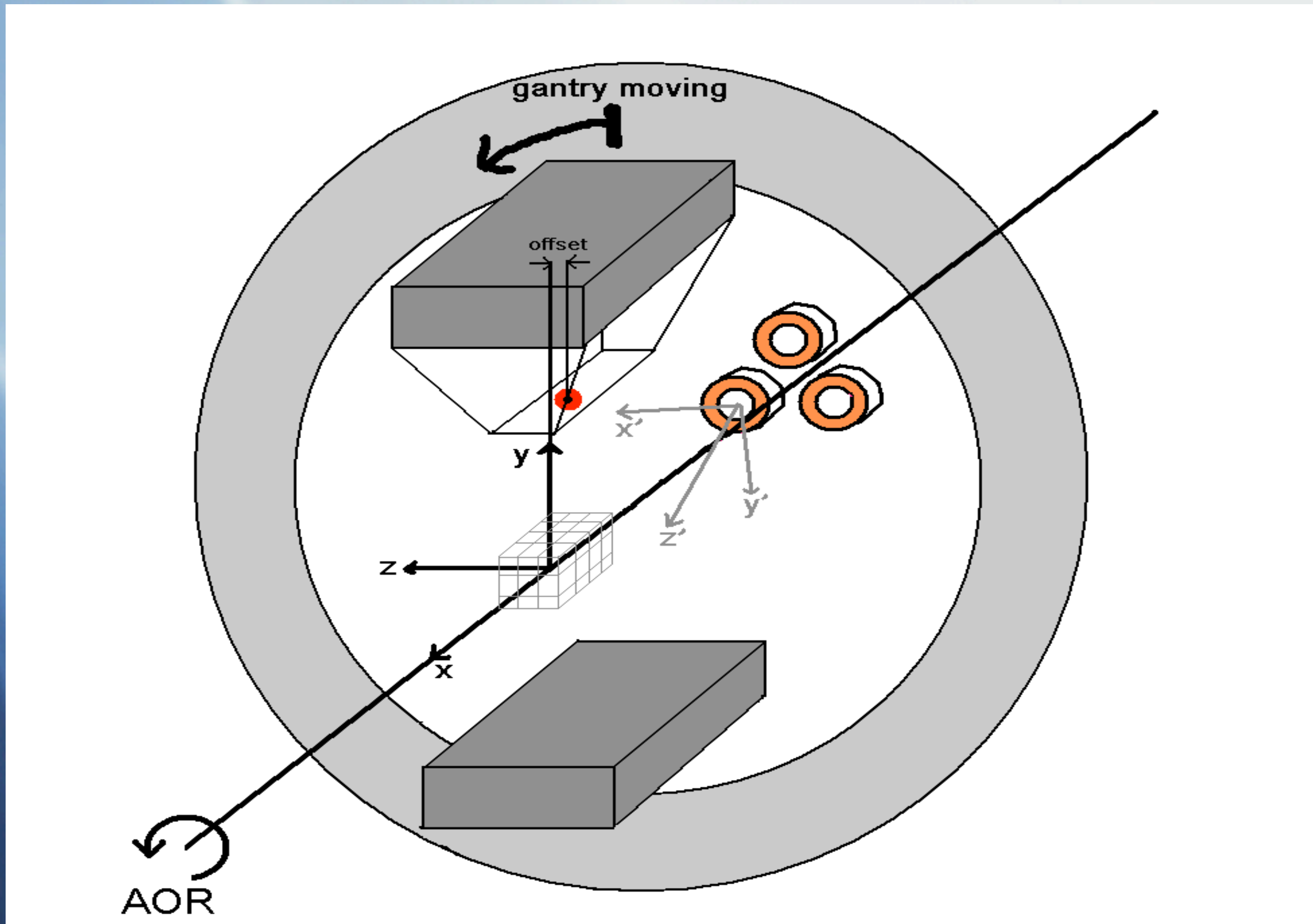


Tc99m-MDP

Movie of Multiple SPECT Projections



SPECT and Tracking Reference Frames



Motion Correction for 6 Degrees of Freedom

Three translations (t_p):

X

Y

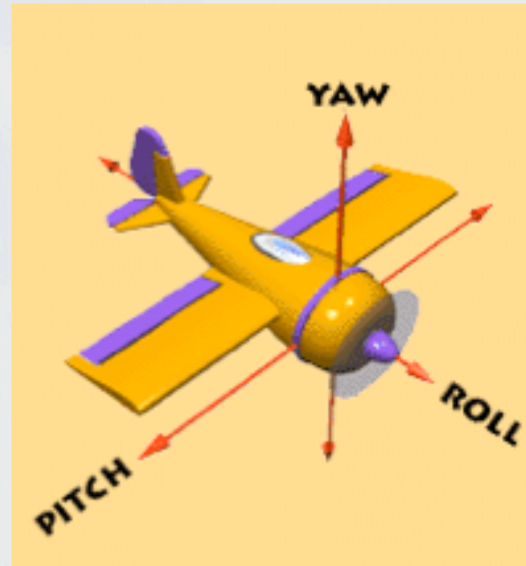
Z

Three rotations (R_p):

roll

pitch

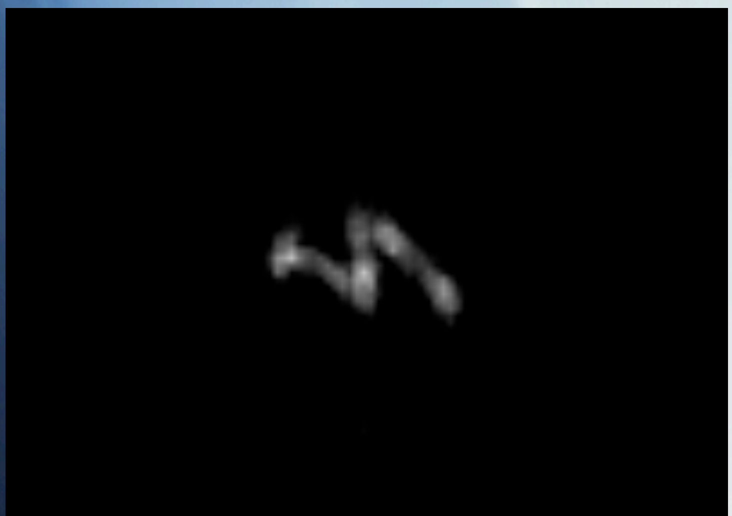
yaw

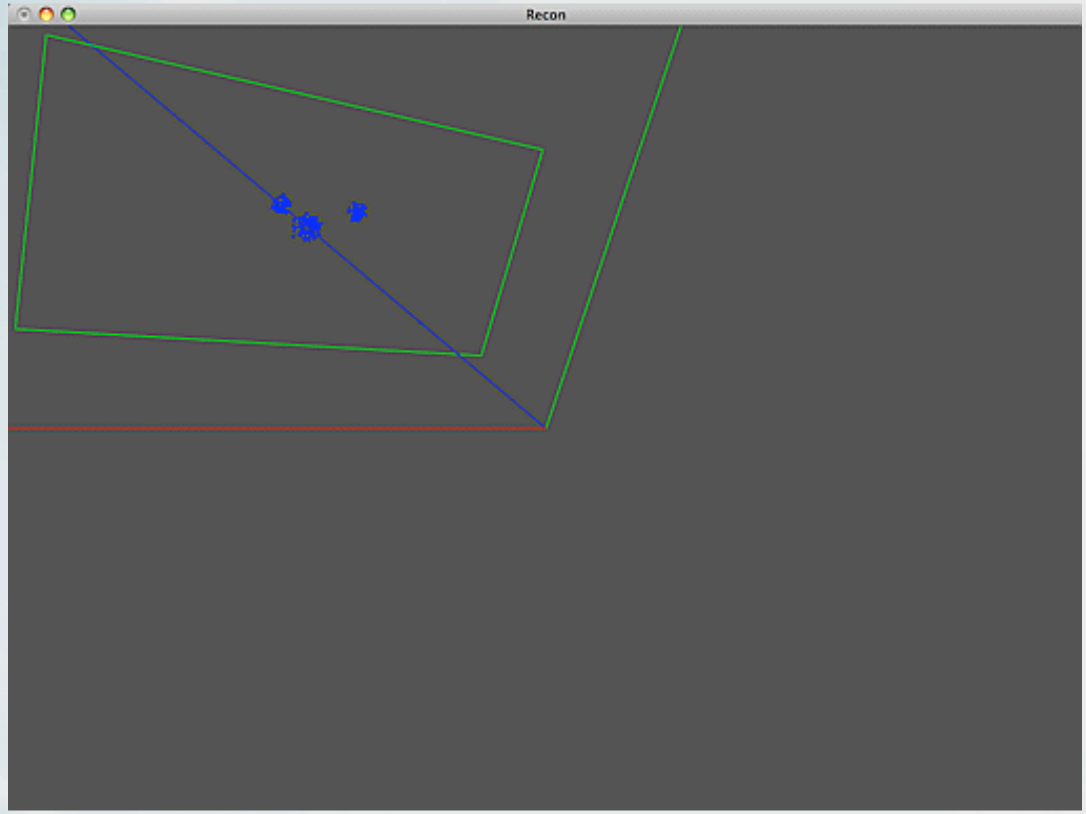


$$X(GRF;t) = R_{TG}\left[R_p(t)R_p^{-1}(t_0)\left\{R_{TG}^{-1}\left[X(GRF;t_0) - t_{TG}\right] - t_p(t_0)\right\} + t_p(t)\right] + t_{TG}$$

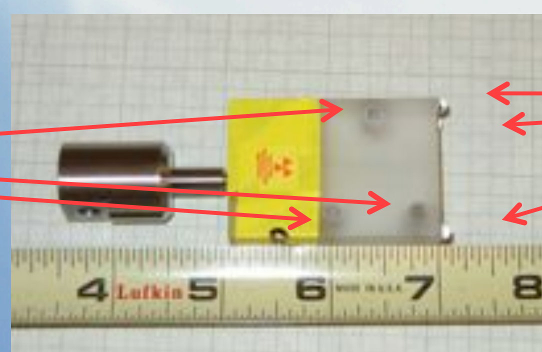
- Mouse head pose parameters:
  translation t_p, rotation $R_p = R_y R_x R_z$ (yaw, pitch, roll)
- Transformation from tracking coordinate system to gamma camera coordinate system R_{TG},t_{TG}
- Motion of a point in gamma camera reference frame

Computer Iterative Reconstruction of all 6 degrees of freedom on Simulated Data



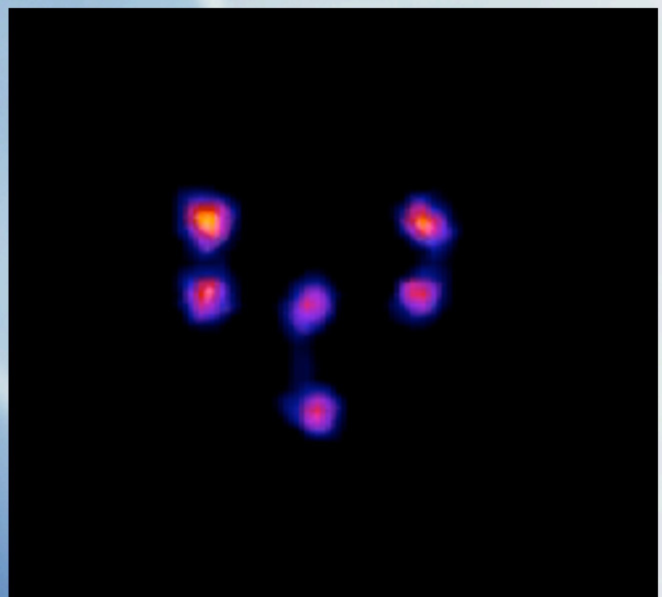


Co57

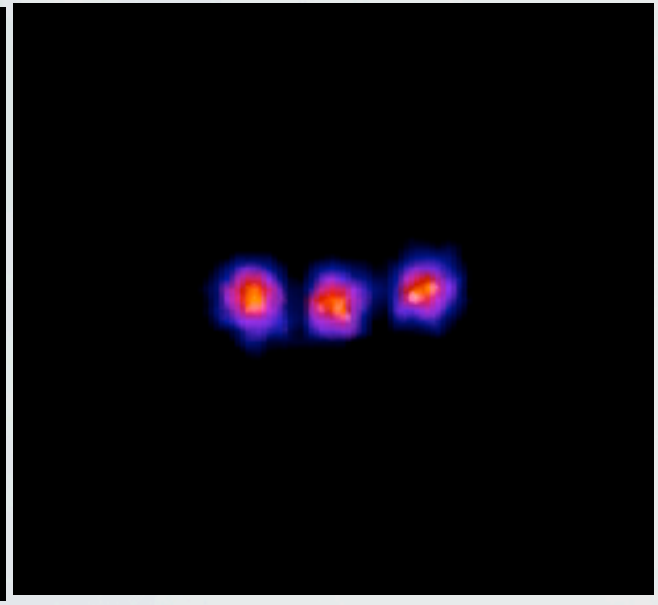


IR reflectors

SPECT Reconstruction of Moving Phantom with Roll Change

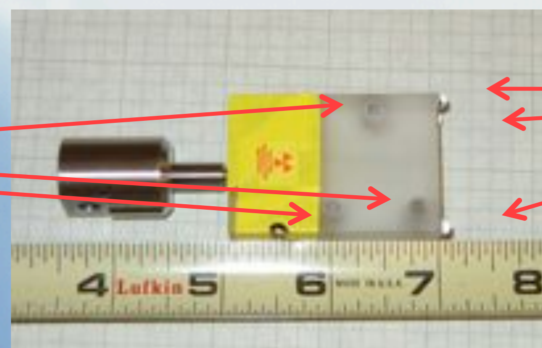


uncorrected



corrected

Co57



IR reflectors

phantom

Latest Results!

Final Words

- Radiation therapy monitoring
- Prostate cancer detection
- Brain imaging AD, PD

In 2004, federal funding of research in the physical sciences as a fraction of GDP was 54% less than in 1970. In engineering, it was 51% less.

…

In 2005, only four American companies were among the top 10 in receiving US patents.

…

Federal annual investment in research in the physical sciences, mathematics, and engineering combined is equal to the increase in US health care costs experienced every 6 weeks.

Is America Falling Off the Flat Earth?

Authors:

Norman R. Augustine, Chair, Rising Above the Gathering Storm Committee, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine of the National Academies

Acknowledgements

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"I have never heard before such support for the physical sciences from a President of the United States. But if the FY 09 enacted budget proves similar to FY 07 and FY 08 a "three-peat," the future of the physical sciences will be in jeopardy. Opportunities will be lost forever: for science, and our country."

Dr. Ray Orbach, Director of the Department of Energy Office of Science, and Under Secretary for Science commenting on the State of the Union Address.

The American Institute of Physics and two of its Member Societies, the American Physical Society and the American Association of Physicists in Medicine, have joined 50 scientific societies and associations, universities, and corporations in endorsing a letter requesting $300 million "to prevent serious damage to vital U.S. scientific efforts supported by the Department of Energy (DOE) Office of Science."

Letter sent January 28th by the Energy Sciences Coalition, to which AIP and several of its Member Societies belong, the President, DOE and select members of Congress requesting emergency funding.

System Architecture