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New Compact Gamma Camera for Prostate Cancer Imaging

Yonggang Cui

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Brookhaven National Laboratory

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USDOE National Nuclear Security Administration (NNSA)
Office of Nonproliferation and Verification Research and Development (NA22)

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2016 IEEE Long Island Systems, Applications and Technology Conference

New compact gamma camera for prostate cancer imaging

Yonggang Cui

Brookhaven National Laboratory

Why do we care about prostate cancer?

- Very common cancer in men in North America
- One of the major cause of cancer death
- Tumors can be aggressive
- Low early detection rate
- Best treatment of today is surgical intervention
- New diagnosis methods highly demanded

source: www.pcf.org

Outline

- Prostate and prostate cancer
- Diagnosis and today’s limitation
- Novel imaging technique
- Path to the future

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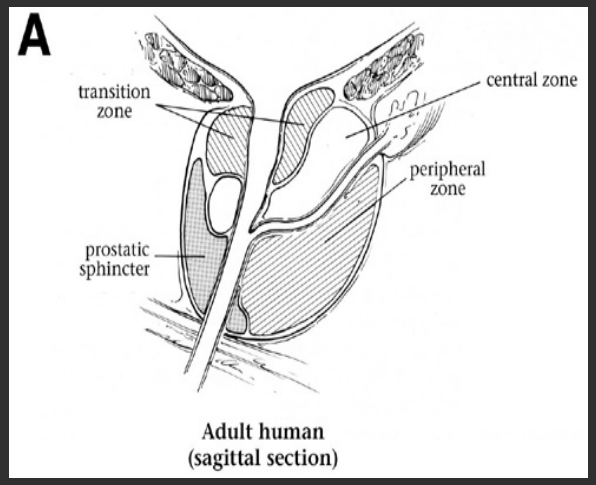
American Cancer Society®

PROSTATE CANCER FOUNDATION

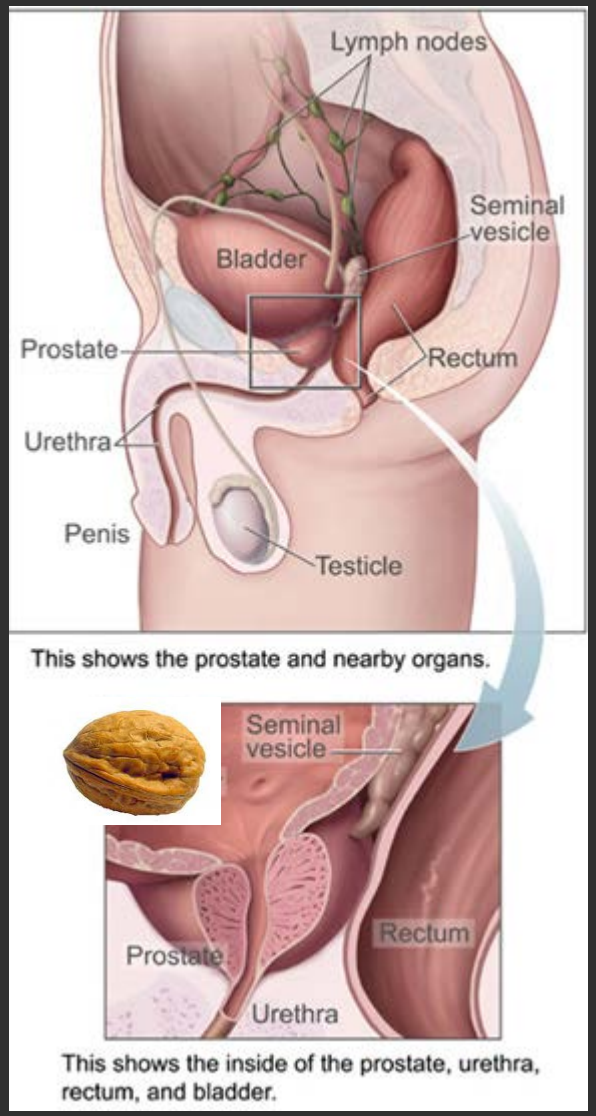
Accelerating the world's most promising research

What is the prostate?

- A gland – part of the reproductive system in men
- Located in front of the rectum and under the bladder
- A healthy prostate gland is about the size of a walnut



source: tvmouse.ucdavis.edu



en.wikipedia.org

Basics of prostate cancer

- Very common cancer in men in North America
- One of the major cause of cancer death
- Prostate cancer starts in the gland cells of prostate
- Causes unknown and prevention not possible
- Early detection is important for prostate cancer treatment, but limited by current technology
- Tumors can be aggressive
- Best treatment of today is surgical intervention
- New diagnosis methods highly demanded

Outline

- Prostate and prostate cancer
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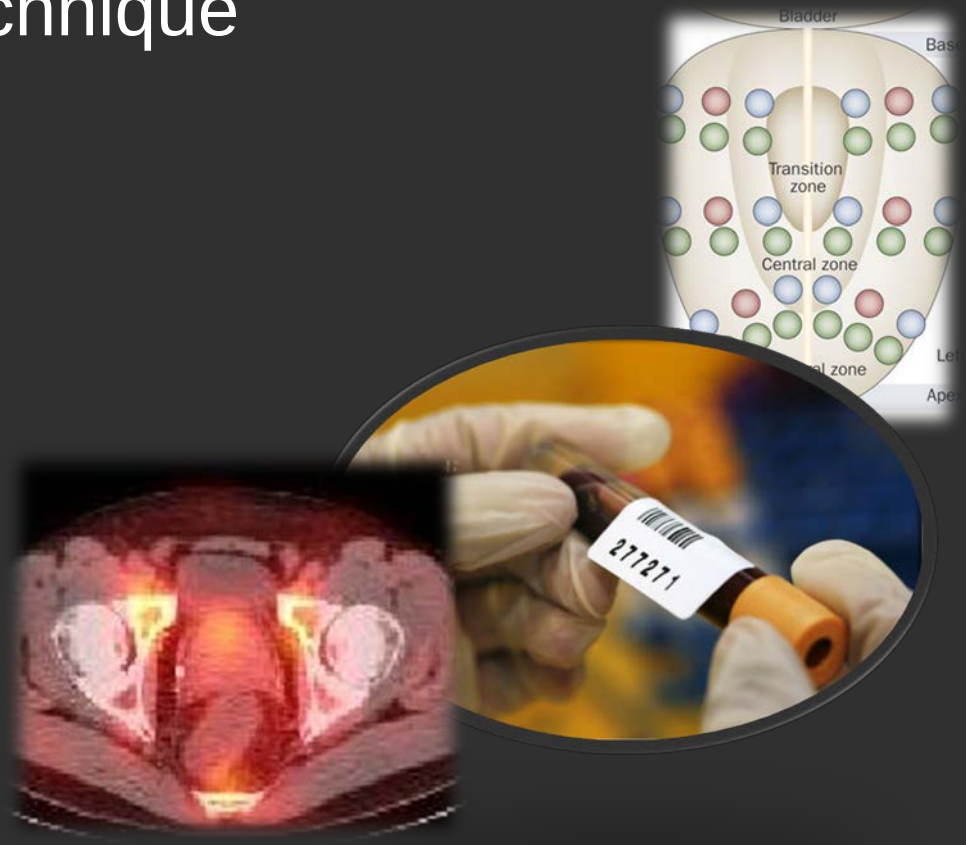


Cancer screening

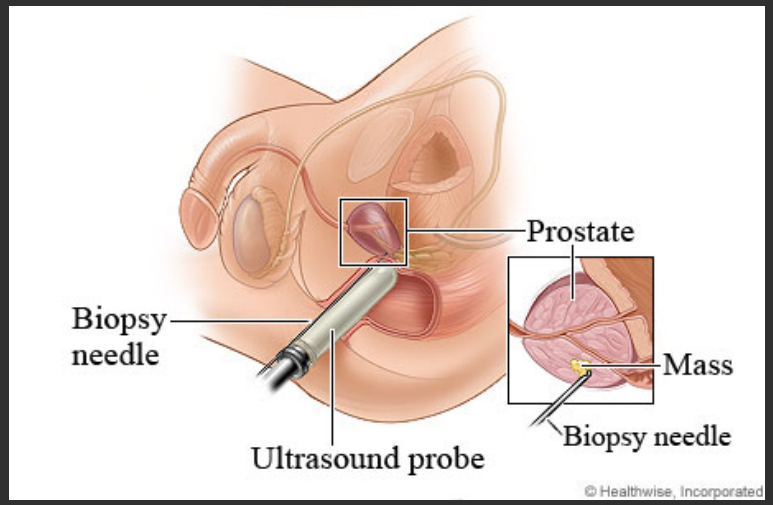
- Prostate-specific antigen (PSA) test
- Digital rectal exam (DRE)
- Neither is accurate
  - PSA – 30% false positive
    15% false negative
  - DRE doesn't work well for all zones

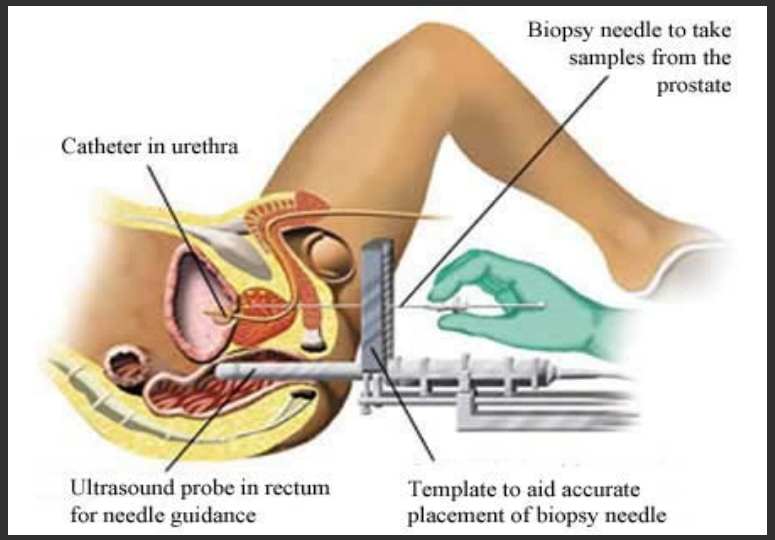
- Further tests to confirm disease

medicinenet.com

Gold standard - biopsy

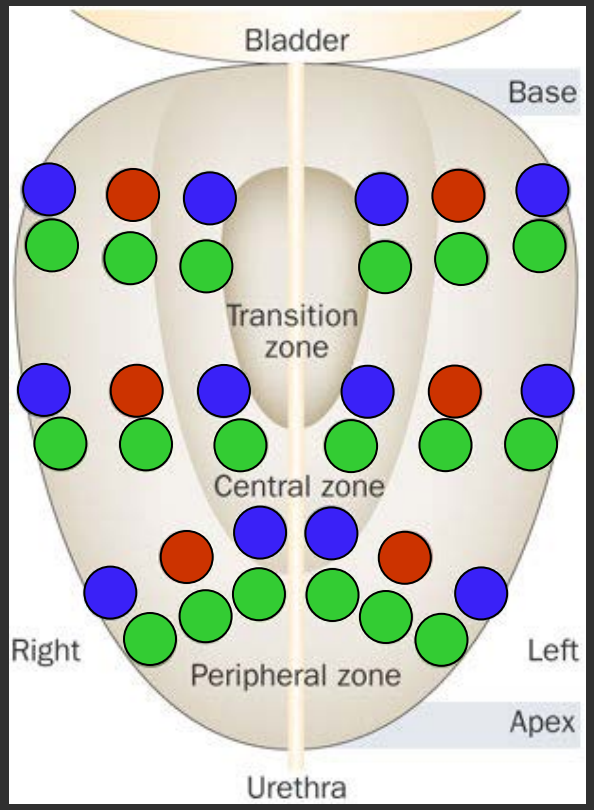
- Transrectal ultrasound imaging (TRUS)
  - Using sound waves to sense tissue
  - Cannot distinguish benign and malignant tumors
- TRUS-guided biopsy
  - Determines boundaries
  - Guides biopsy needles into the right area
    - Transrectal
    - Transperineal





Gold standard of today - TRUS

- 6-18 samples
- Sampling is random
  - Small tumors missed easily
  - Size of tumor underestimated
- Painful – bleeding, infection



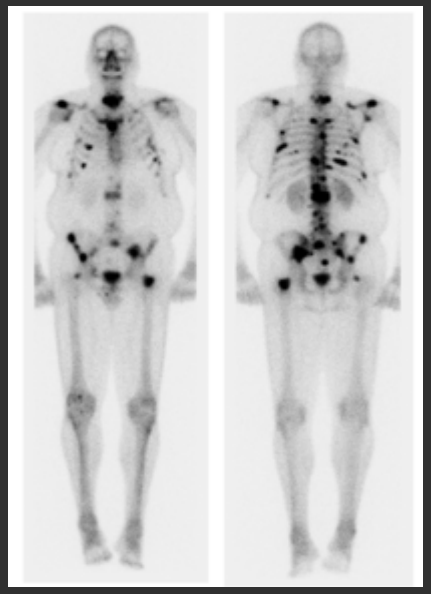
G. L. Andriole
Nature Reviews Urology 6, 188-189

Better imaging guidance is needed to improve accuracy of biopsy!

How about imaging techniques?

- CT – not specific to soft tissues
- MRI – no differentiation between tumor and inflammation
- Traditional SPECT – modest spatial resolution
- Bone scan – detects metastasis in bone
- PET – tumors are not glucose dependent for ^{18}F-FDG

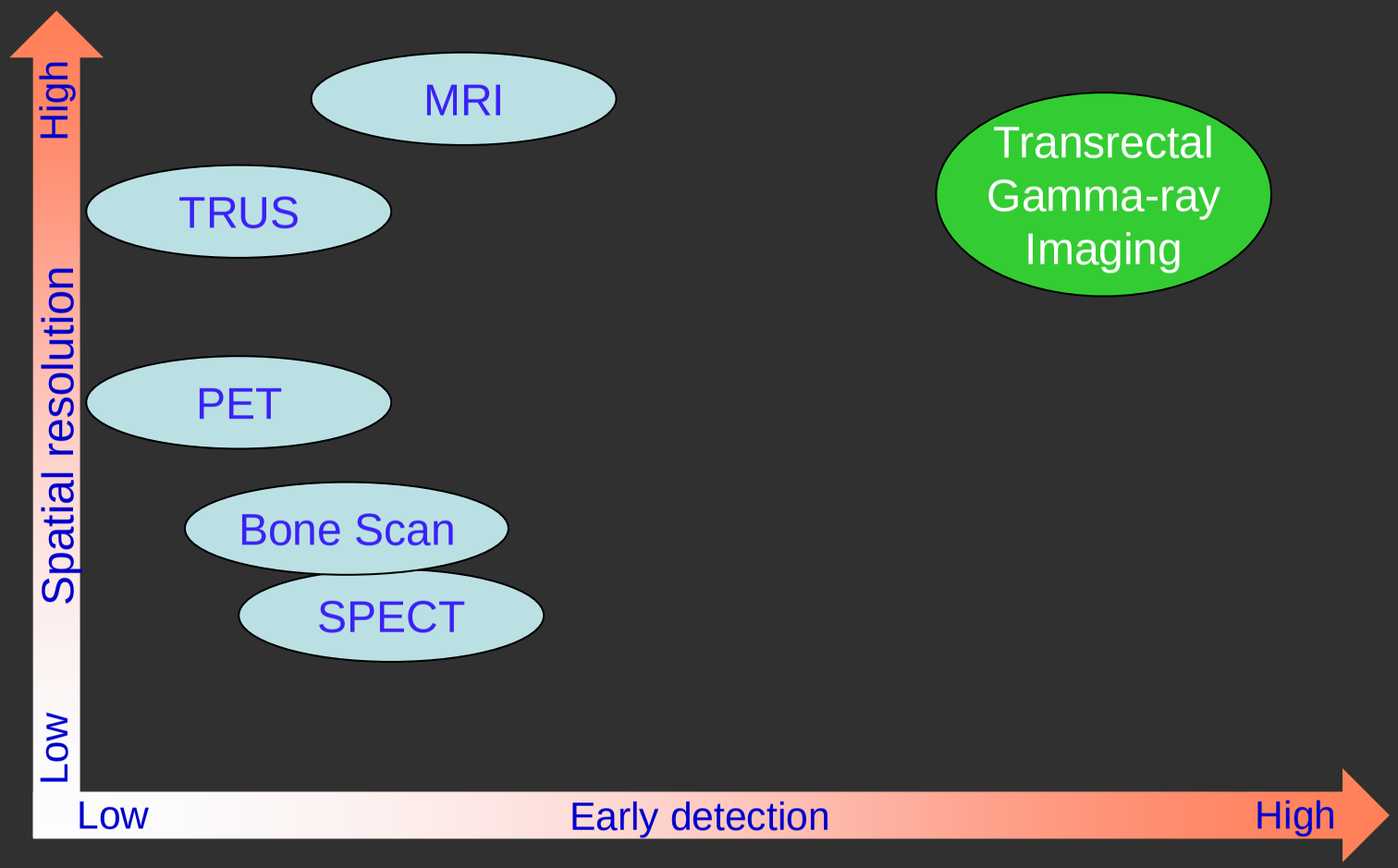
Discovery NM/CT 670
Source: gehealthcare.com



P. J. Saylor, et al. J Nucl Med, 2012 v.53, no.11, pp1670-1675

A. Abdellaoui, et al. Future Oncol. 2011;7(5):679-691

Issue and solution



- Problem – Instruments available today cannot accurately image intra-prostatic cancer, and early detection of disease is disappointingly low

Outline

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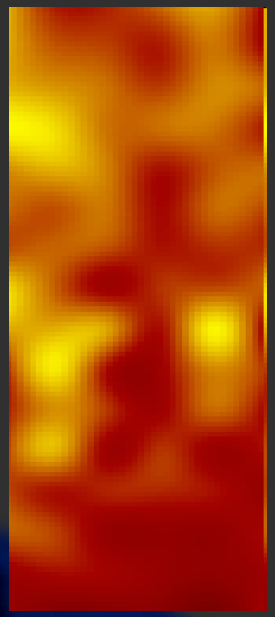
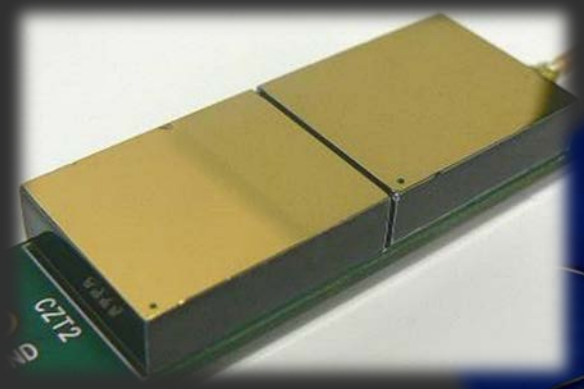




Expected features of new tools

Concept

A compact digital gamma camera capable of insertion into the rectum as a probe, bringing it directly adjacent to the prostate gland for high-resolution localization and imaging of prostate cancer

Features

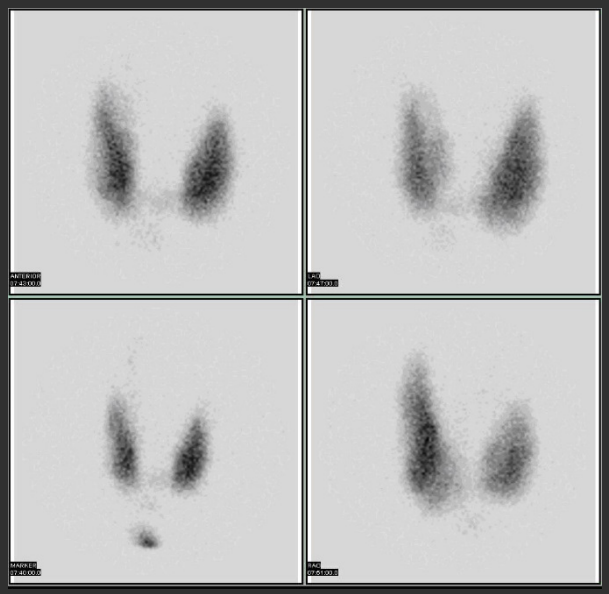
- Nuclear medical imaging device
- Compact and trans-rectal probe
- High spatial resolution
- High sensitivity
- Low cost

Key components

- Radiation detector
- Application specific integrated circuits (ASIC)

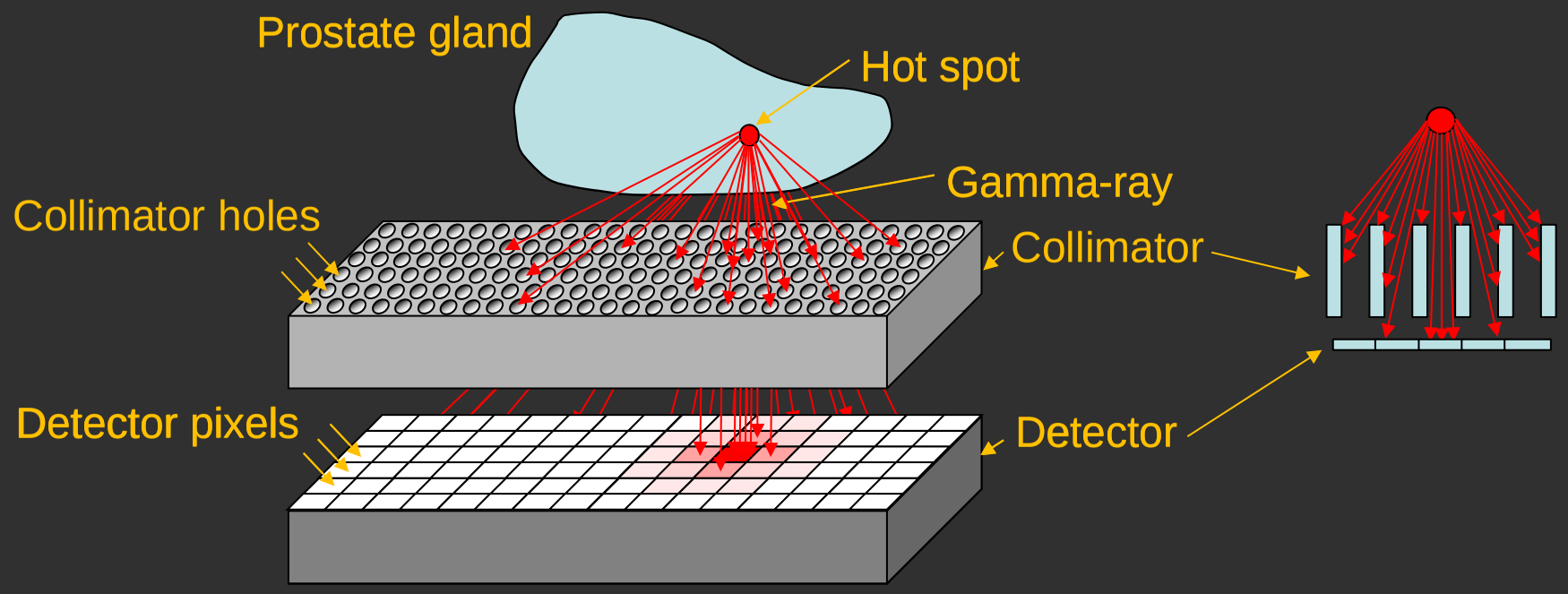
Nuclear medical imaging

- Radioactive tracer
  - Chemical compound
  - Participates in specific metabolic process
  - Concentrates in specific organ or tissue
    - Iodine in production of thyroid hormone and concentrates in thyroid
  - One or more elements replaced by radioactive isotope
    - Iodine-123 emits gamma rays
- Functional imaging
- Many tracers developed for different applications



Thyroid imaging using I-123
Source: Wikipedia.org

Concept of gamma camera

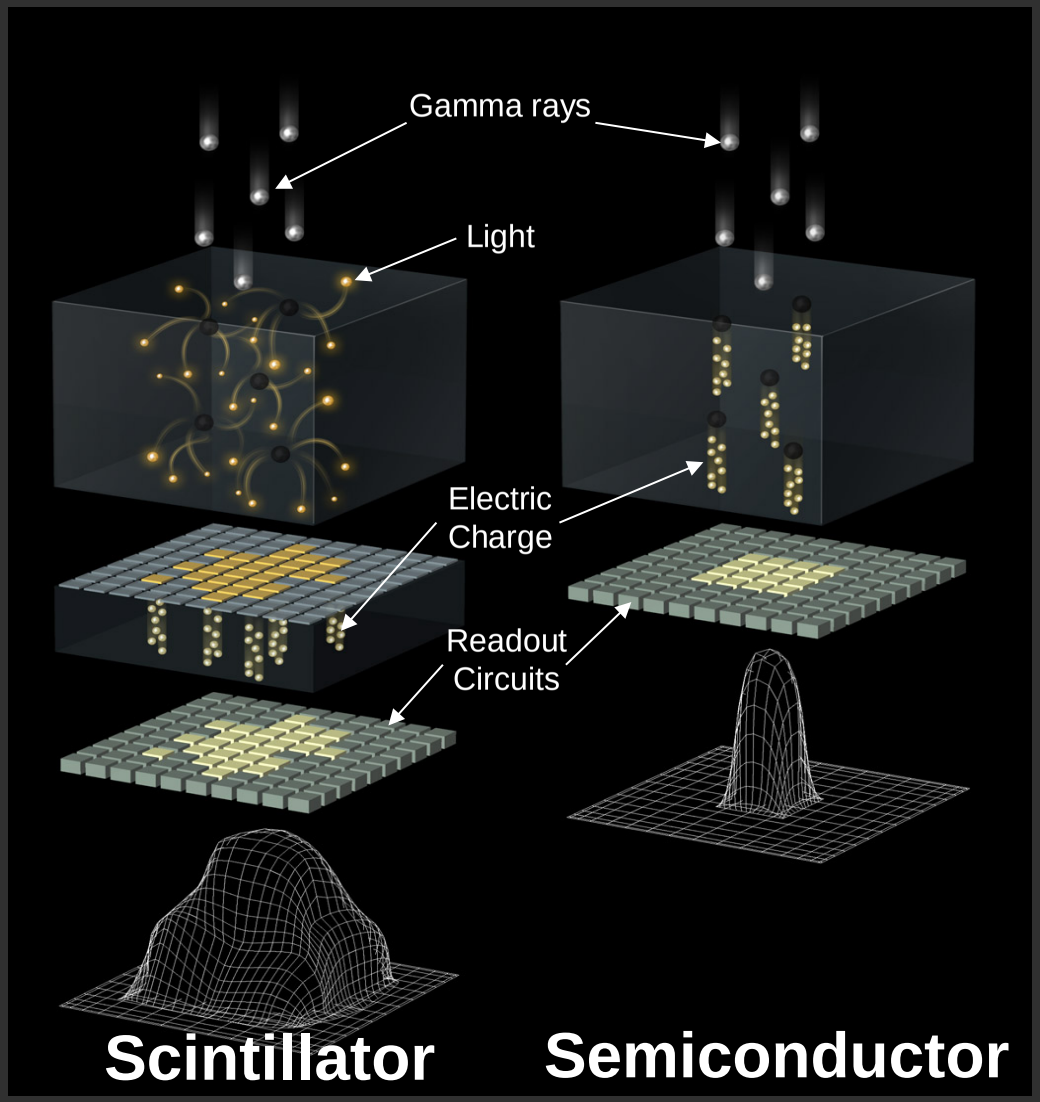


Scintillator vs semiconductor detectors

***Indirect* Conversion of Gammas to Electrons**

Spread of light reduces spatial resolution

Reduced detected light degrades energy resolution



***Direct* Conversion of Gammas to Electrons**

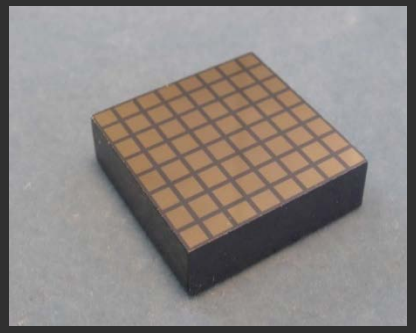
Compactness of electric charge enhances spatial resolution

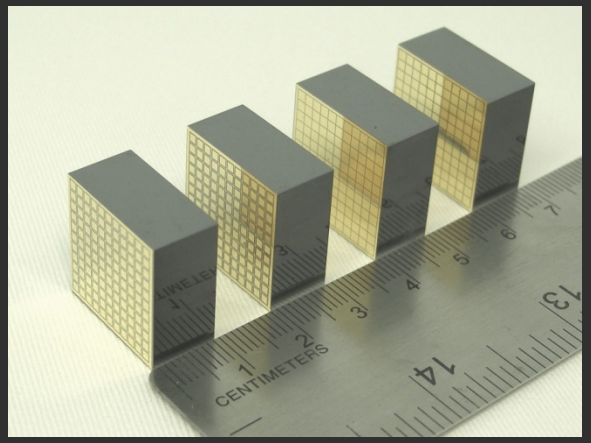
Enhanced signal collection increases energy resolution

Energy and spatial resolution are improved.

Cadmium Zinc Telluride (CZT) Detector

- Radiation Detector R&D Group
- Developed for national security
- Good material properties for medical imaging
  - High density and atomic number
  - High resistivity
  - High energy- and spatial-resolution



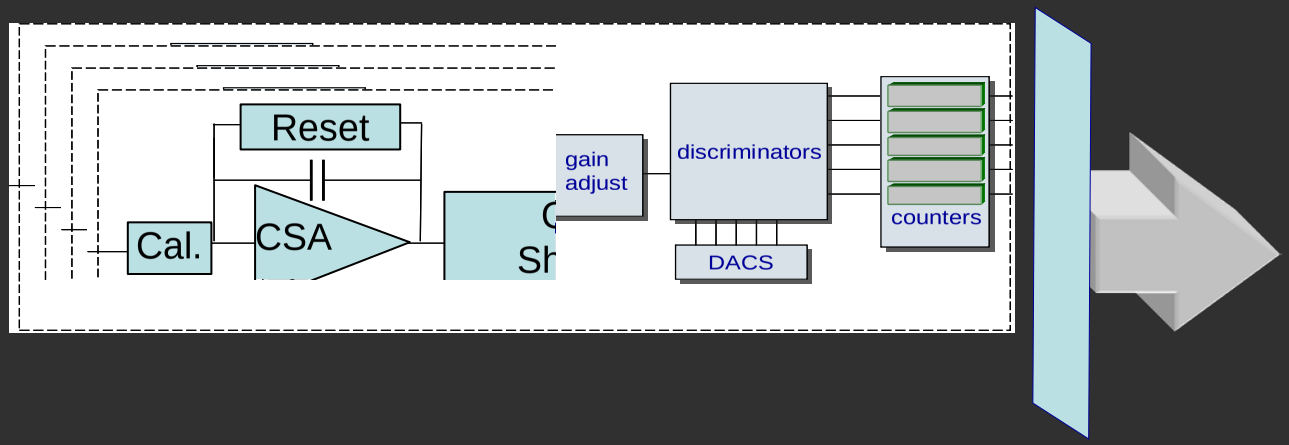


Courtesy of Redlen, Acrorad and Yinnel Tech

Application-specific-integrated circuits (ASIC)

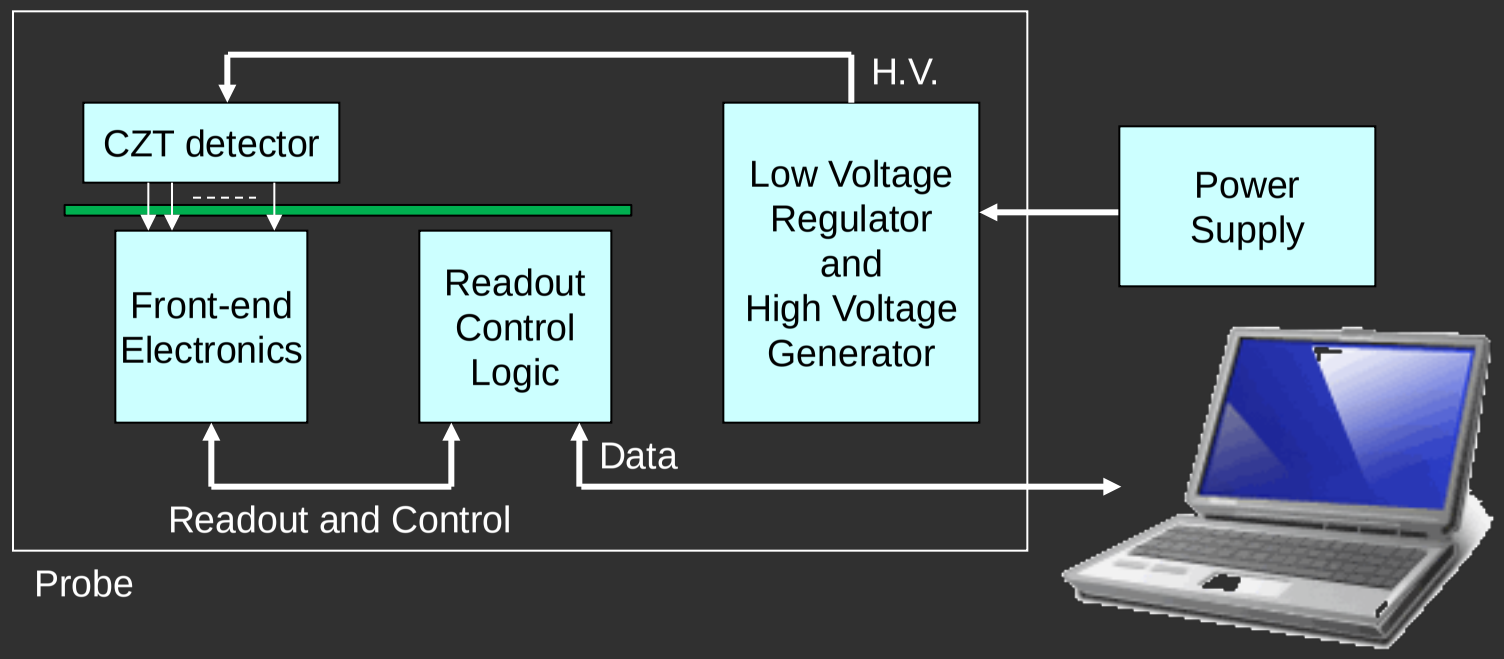
- State-of-the-art integrated circuits (IC)

- ASIC uses the same technology, but for specific application
  - Radiation detector readout
  - Designed by Instrumentation Division



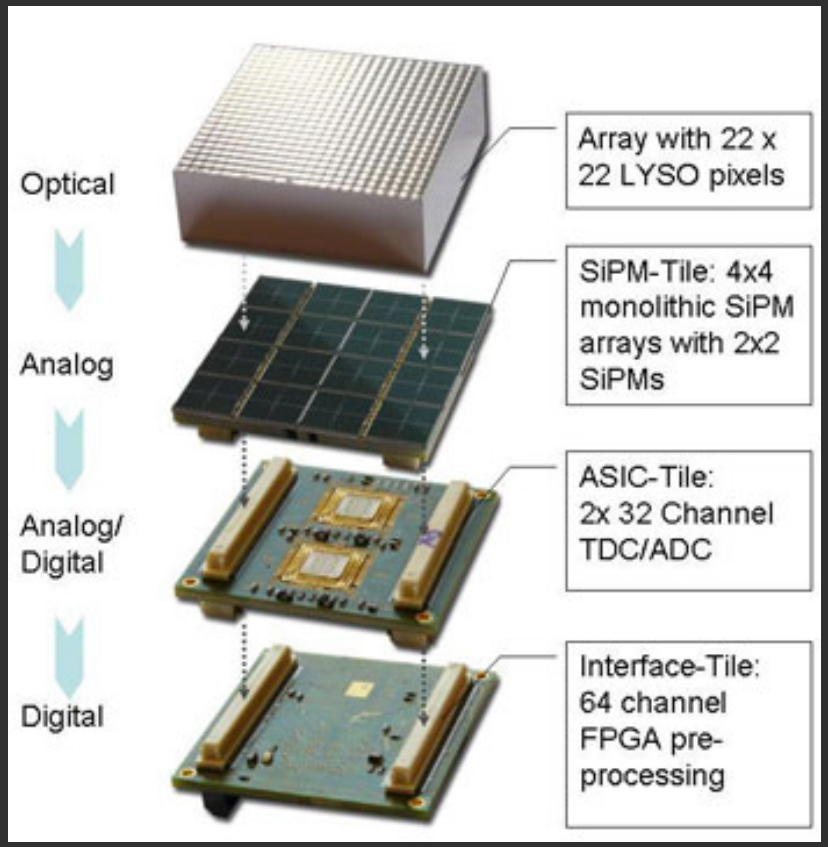
System Design - Data Acquisition System

- Highly integrated design
- USB communication
- Low power consumption: ~600 mW



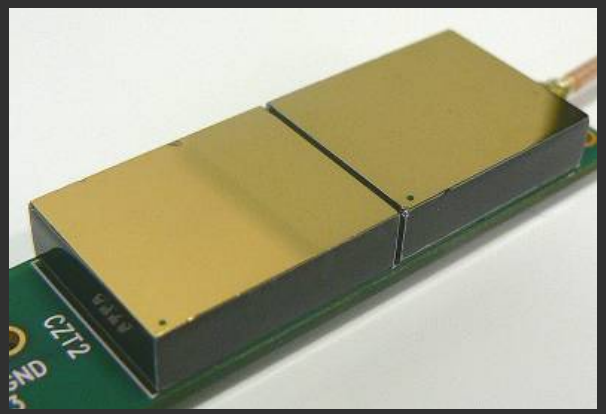
Compact detector modules

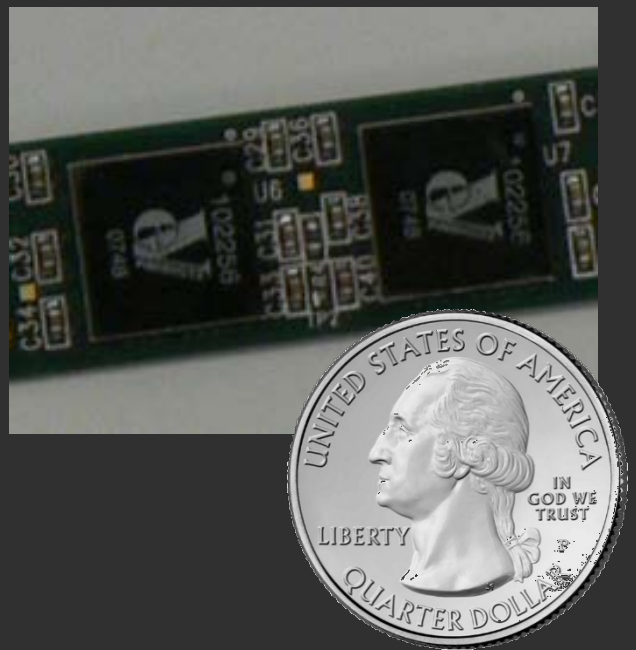
Scintillator



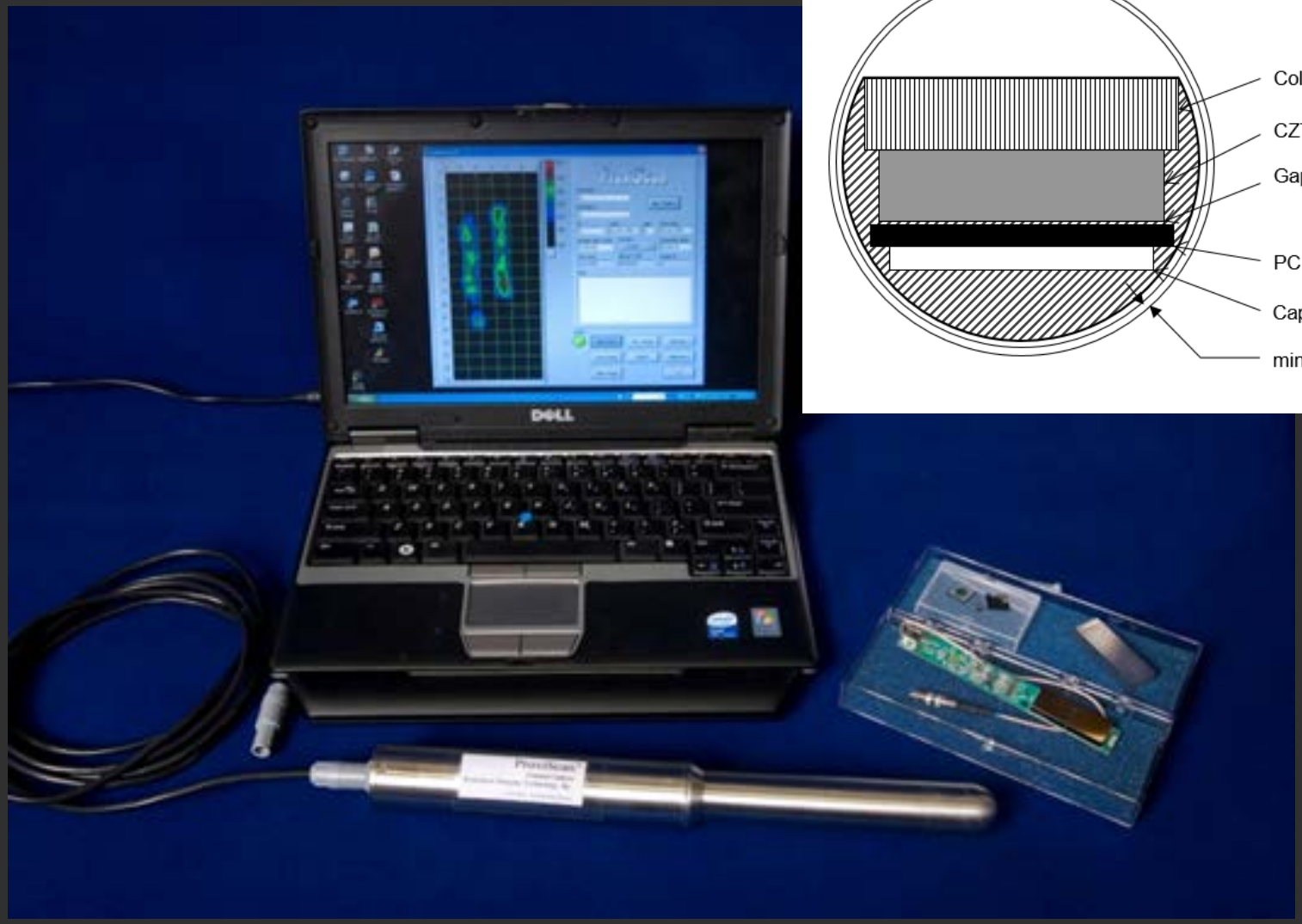
Digital PET detector. V. Schulz, et al. WMIC Annual Congress. 2010

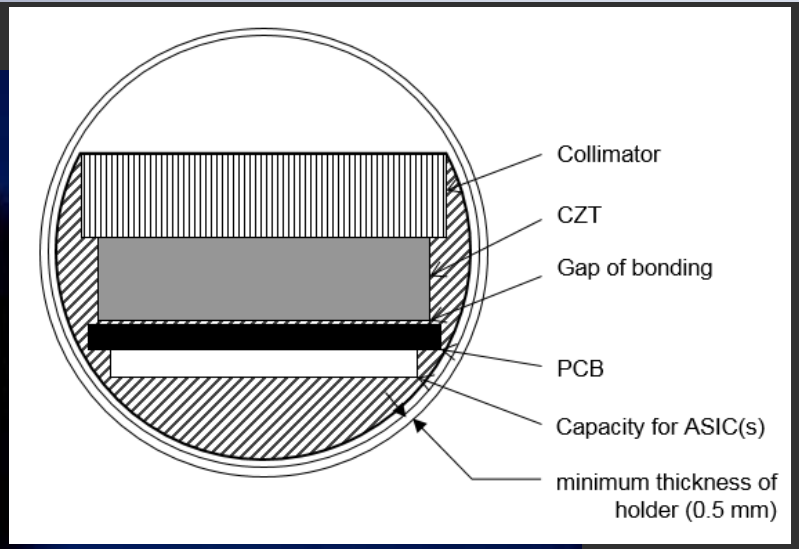
CZT



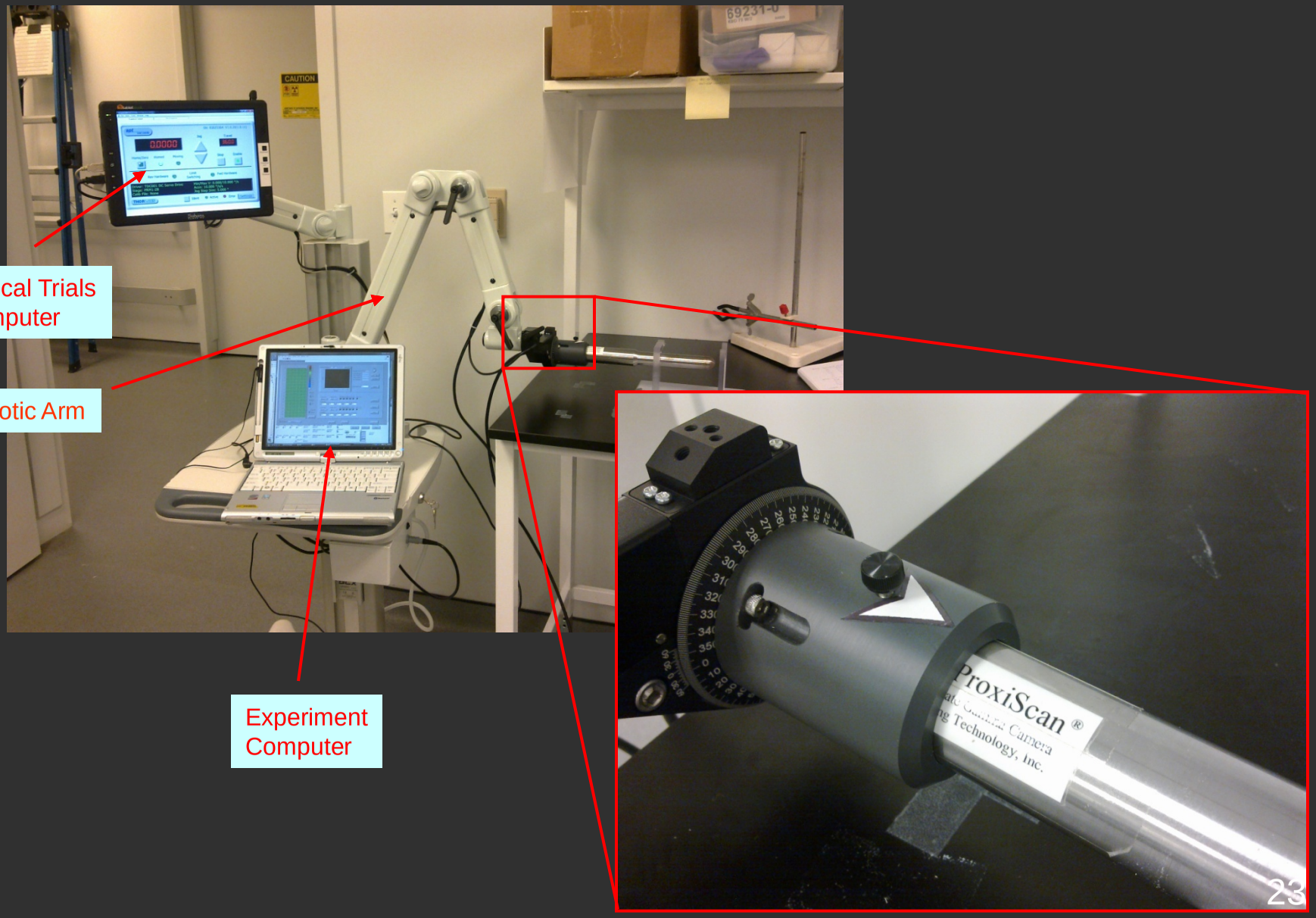


We made it! - ProxiScan™



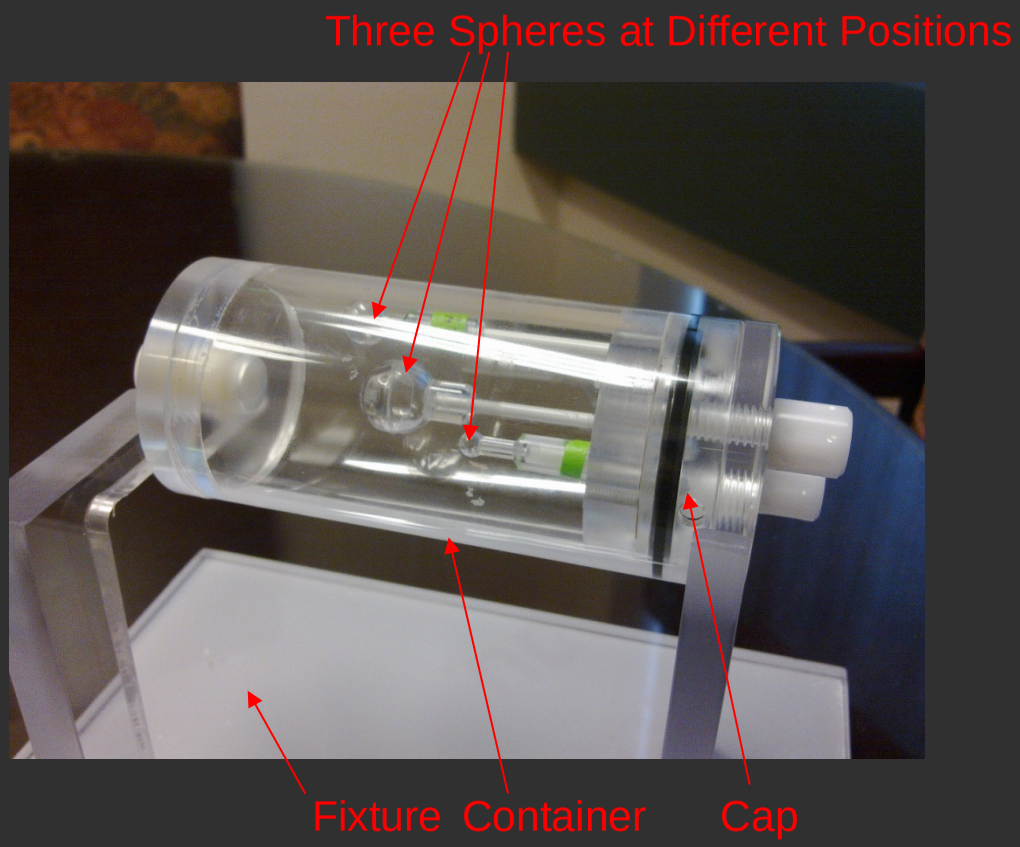


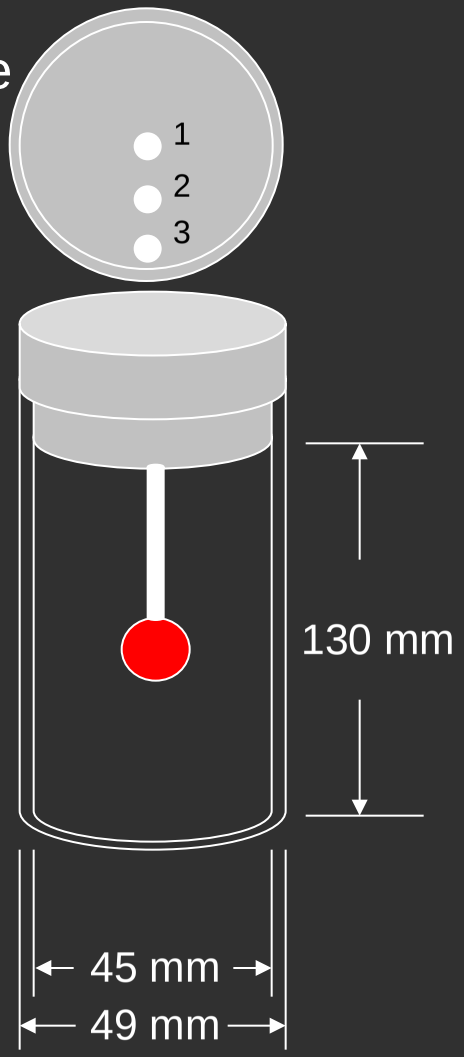
System Photo



Prostate Phantom

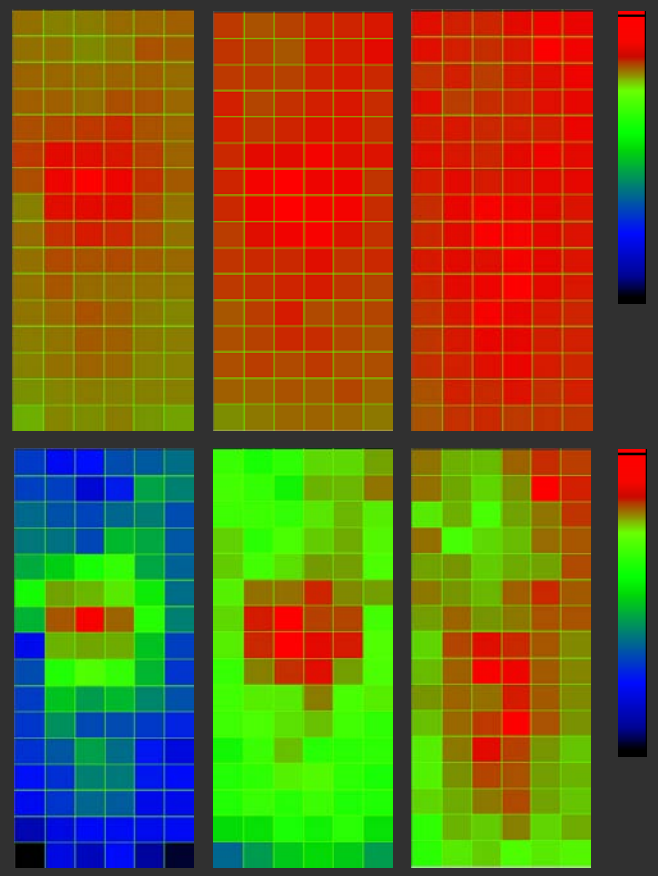
- Built at Johns Hopkins University
- Emulate the uptake of radioactive tracer in prostate
  - Container: uptake in gland and surrounding tissues
  - Spheres: uptake in tumors





Contrast tests

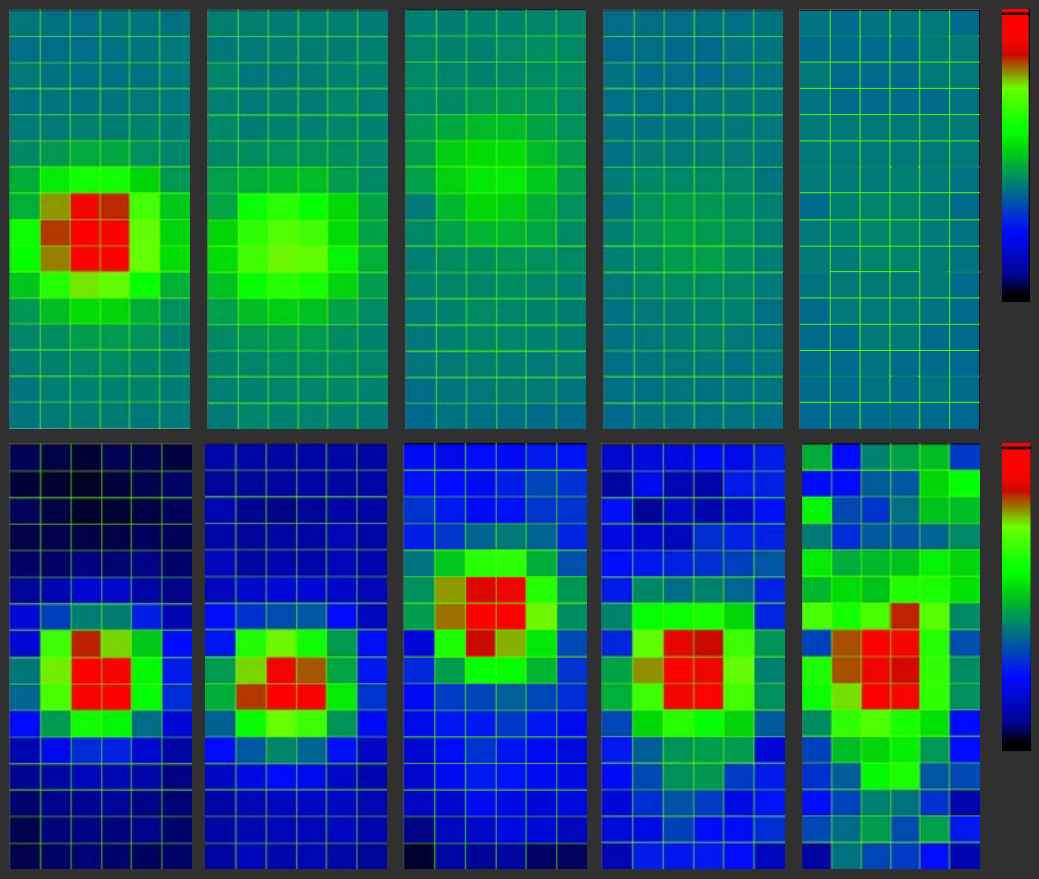
- Setup
  - Sphere ID: 4 mm
  - Contrast: 8:1, 4:1, 2:1
- Images
  - 1st row: raw images
  - 2nd row: processed images with background removed
- Results
  - Contrasts of 8:1 and 4:1 are resolved. 2:1 ratio is blurry



Ratio 8:1 4:1 2:1

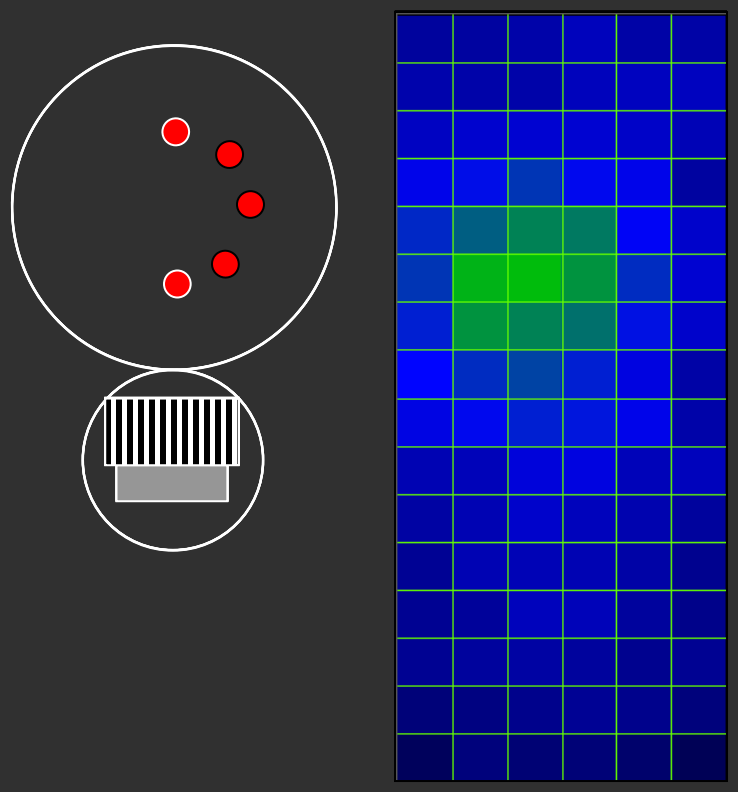
Contrast tests

- Setup
  - Sphere ID: 8 mm
  - Contrast: 2:1 up to 32:1
- Contrast 2:1 can be resolved as well

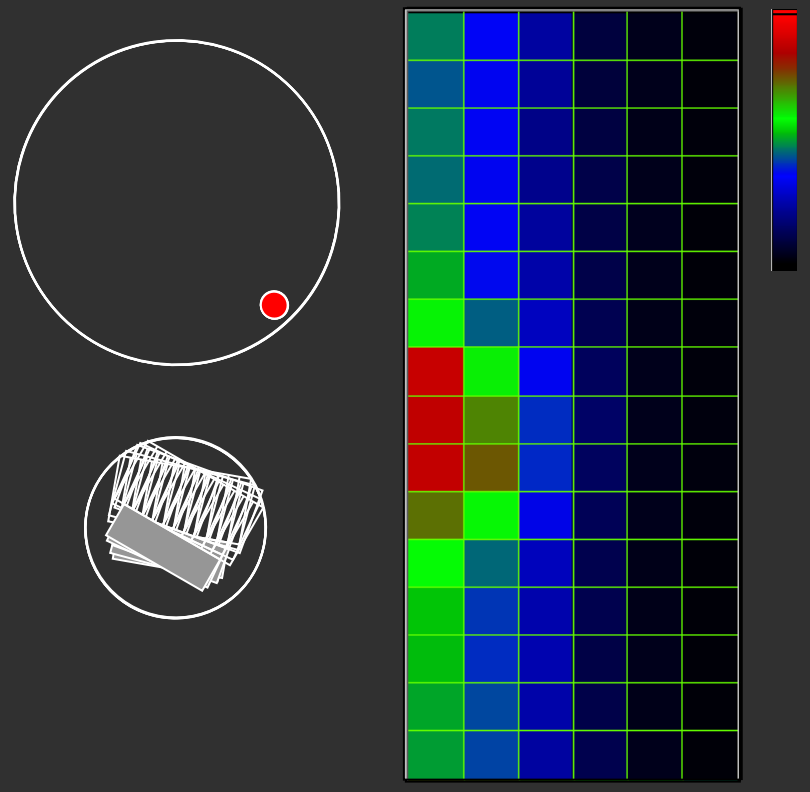


Contrast 32:1 16:1 8:1 4:1 2:1

Increasing field of view



Camera's response to hot spot in different regions



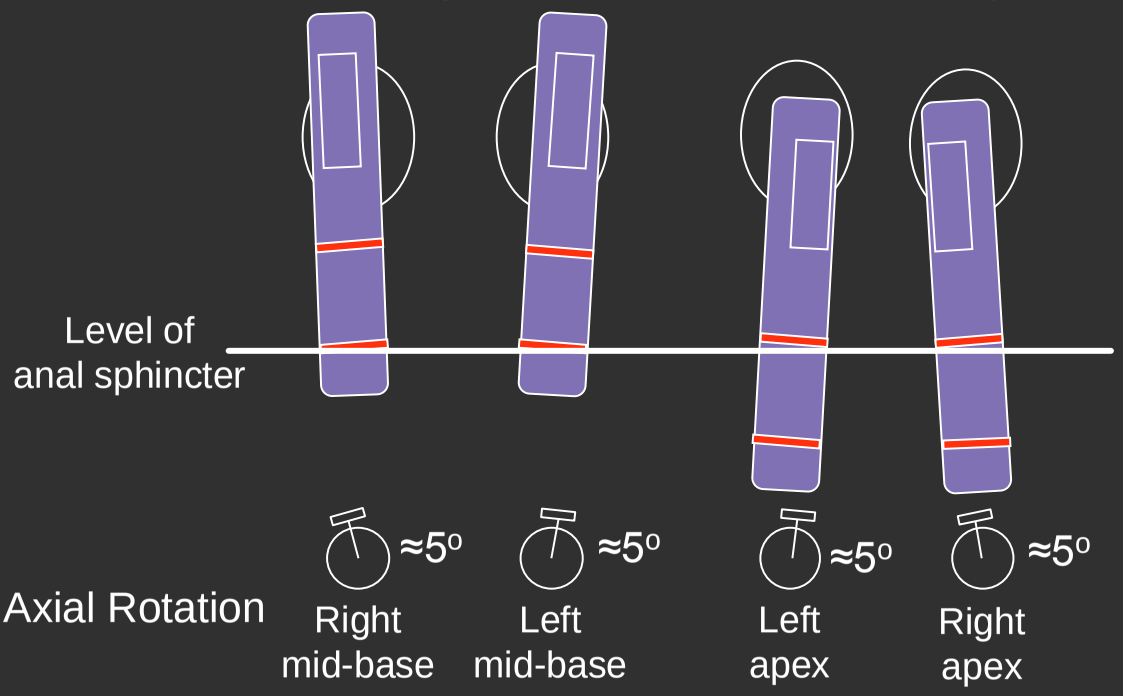
Rotating camera to cover whole prostate

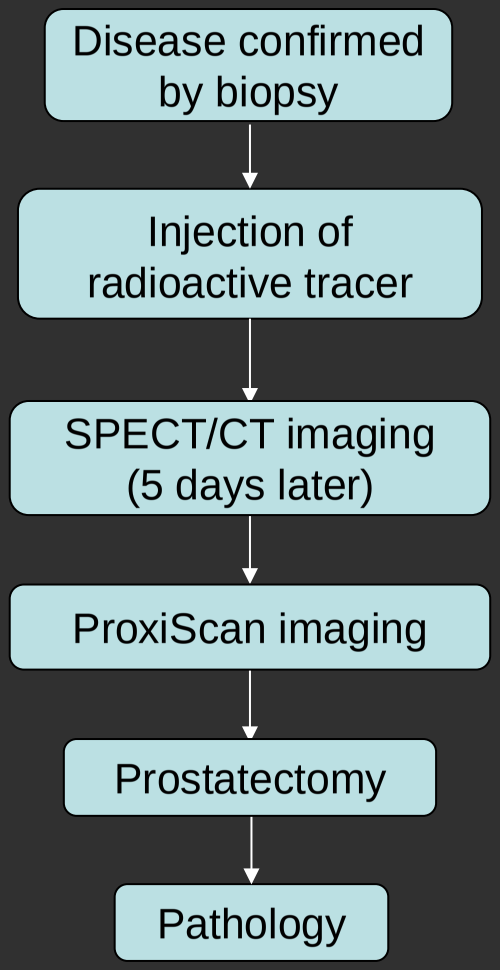
Clinical Trials of ProxiScan™

- FDA cleared
- First gamma camera authorized for endocavity imaging
- Clinical trial has been done
  - Johns Hopkins Hospital
  - Radiological Associates of Sacramento
- 14 patients in this study
  - 10 with confirmed disease

ProxiScan™ Imaging Procedure

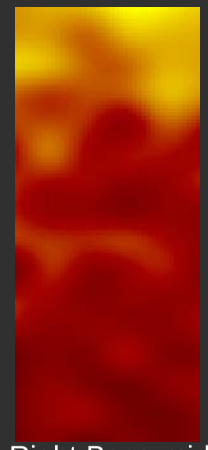
- Radioactive tracer - ProstaScint™
  - In-111 radioisotope
  - Sole tracer approved by FDA for prostate cancer imaging
- ProxiScan imaging
  - 4 images, 1 for each quadrant
  - 5-min acquisition time for each image



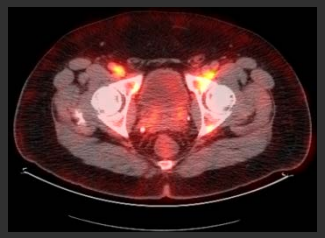


Patient image

- Biopsy results
  - Right base-mid: 8 mm
  - Left base-mid: focal high grade prostatic intraepithelial neoplasia (PIN)
- ProxiScan imaging
  - High uptake in both sides
  - Right base-mid:15 mm
  - Left base-mid: 5 mm
- Surgical pathology
  - Right base-mid: 18 mm
  - Left base-mid: 2 mm
- ProxiScan is closer to pathology data than biopsy
- ProxiScan agrees with SPECT/CT but with better spatial resolution

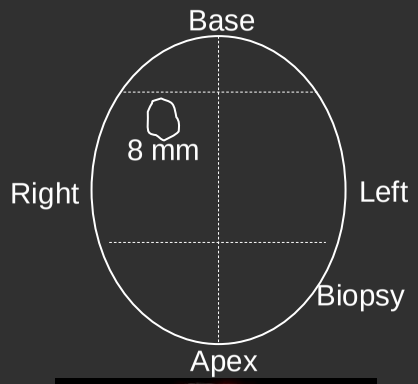


Right Base-mid



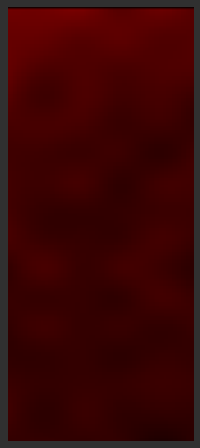
Transaxial view of mid-base region

Left Base-mid



Right Apex

Transaxial view of apex region



Left Apex

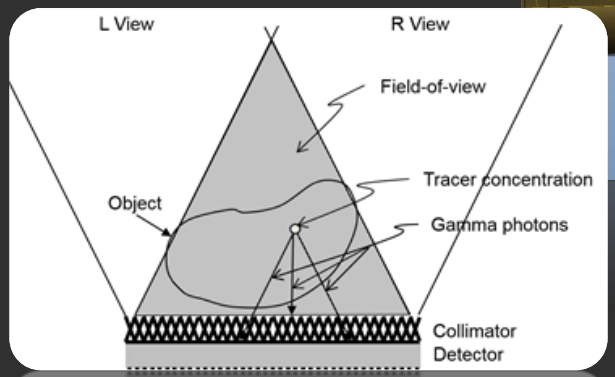
Clinical trials – summary

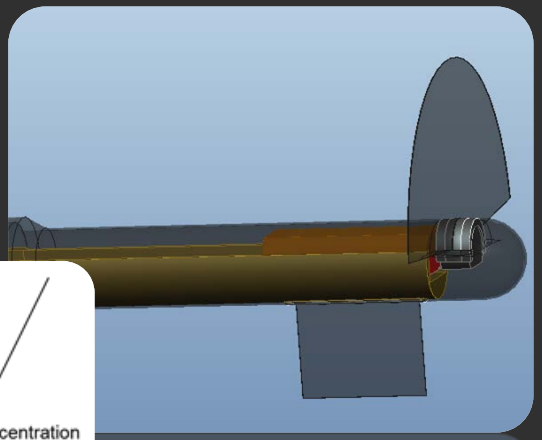
- Encouraging results
- ProxiScan can see small tumors
- ProxiScan is more accurate than biopsy
- ProxiScan has better spatial resolution than SPECT/CT
- Accepted by patients

More improvements?

Outline

- Prostate and prostate cancer
- Diagnosis and today's limitation
- Novel imaging technique
- Path to the future





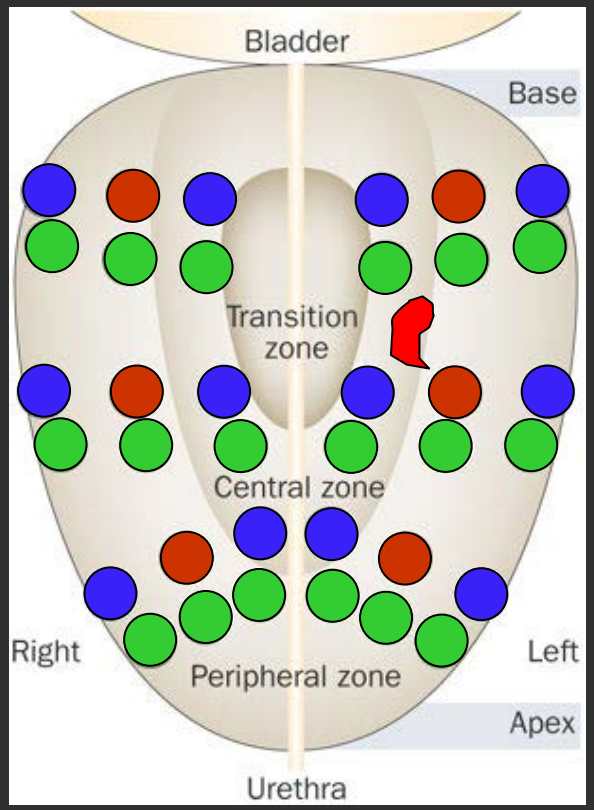
New demanded features

Final goal

Gamma-ray imaging guided biopsy

Demanded features

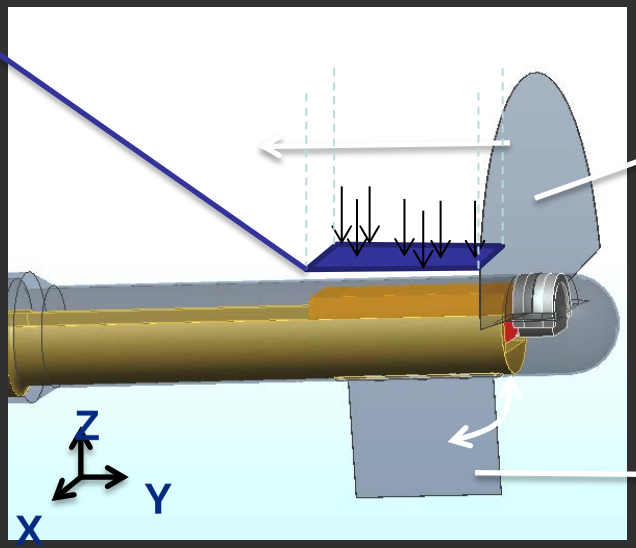
- Anatomical information
- 3D gamma-ray imaging
- Biopsy



Bi-modality imaging probe - GammaScout

- Co-register gamma image with ultrasound image
- Two ultrasound transducers by GE Healthcare

Nuclear Image is a projection of the Z paraxial photons



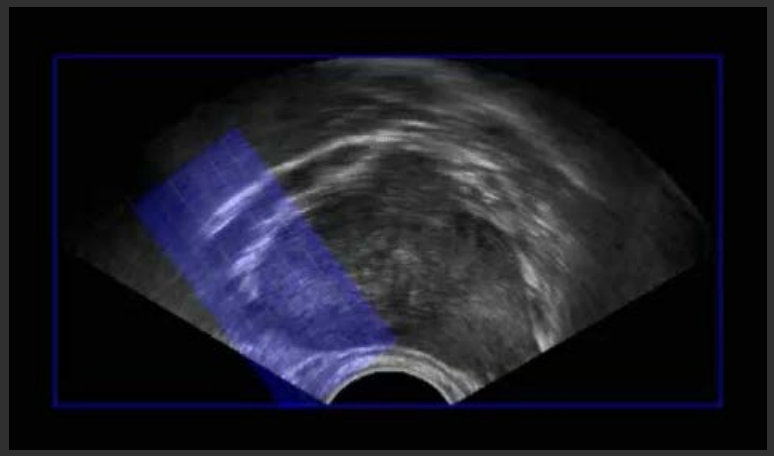
Microconvex 2D cut image (FOV plane X-Z).

Translation along Y axis to acquire volume

Linear Array 2D cut image (FOV plane Z-Y)

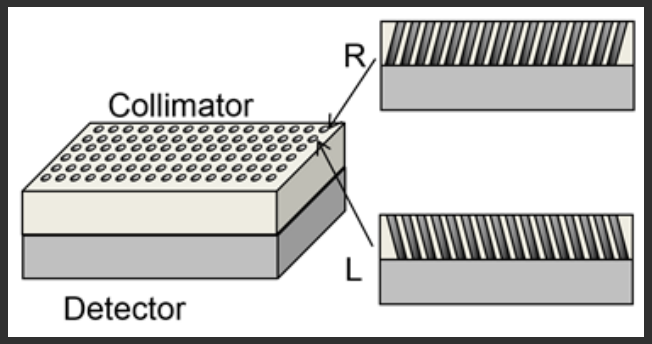
Rotation around Y axis to generate 3D visualization image

Prototyping, FDA 510(k) and clinical trials

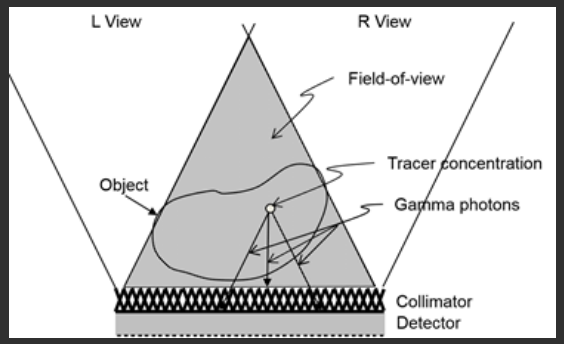


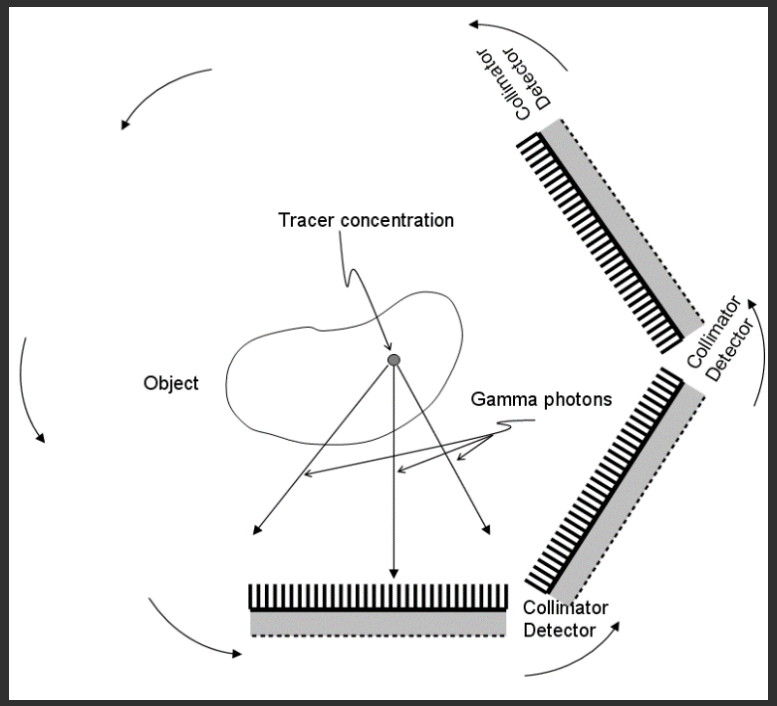
- Two prototype probes were built and tested
- Ultrasound modality was tested with B-K Medical systems
- Application of FDA clearance is being prepared
- Clinical trials of GammaScout is being discussed with several medical centers

3D imaging – interwoven collimator

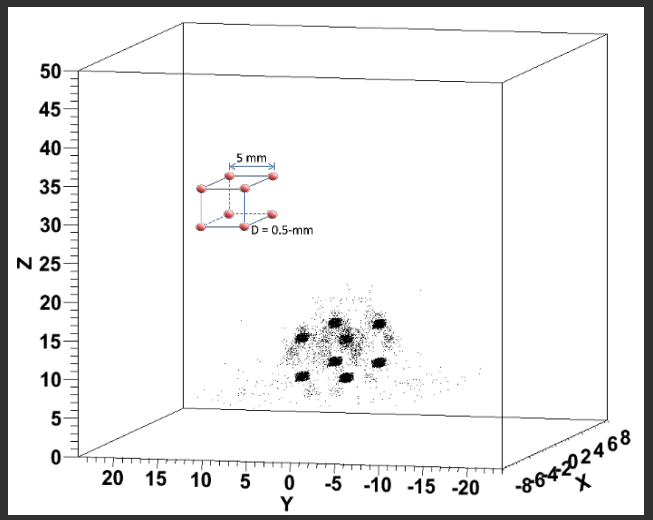


Interwoven collimator





Conventional 3D imaging scheme

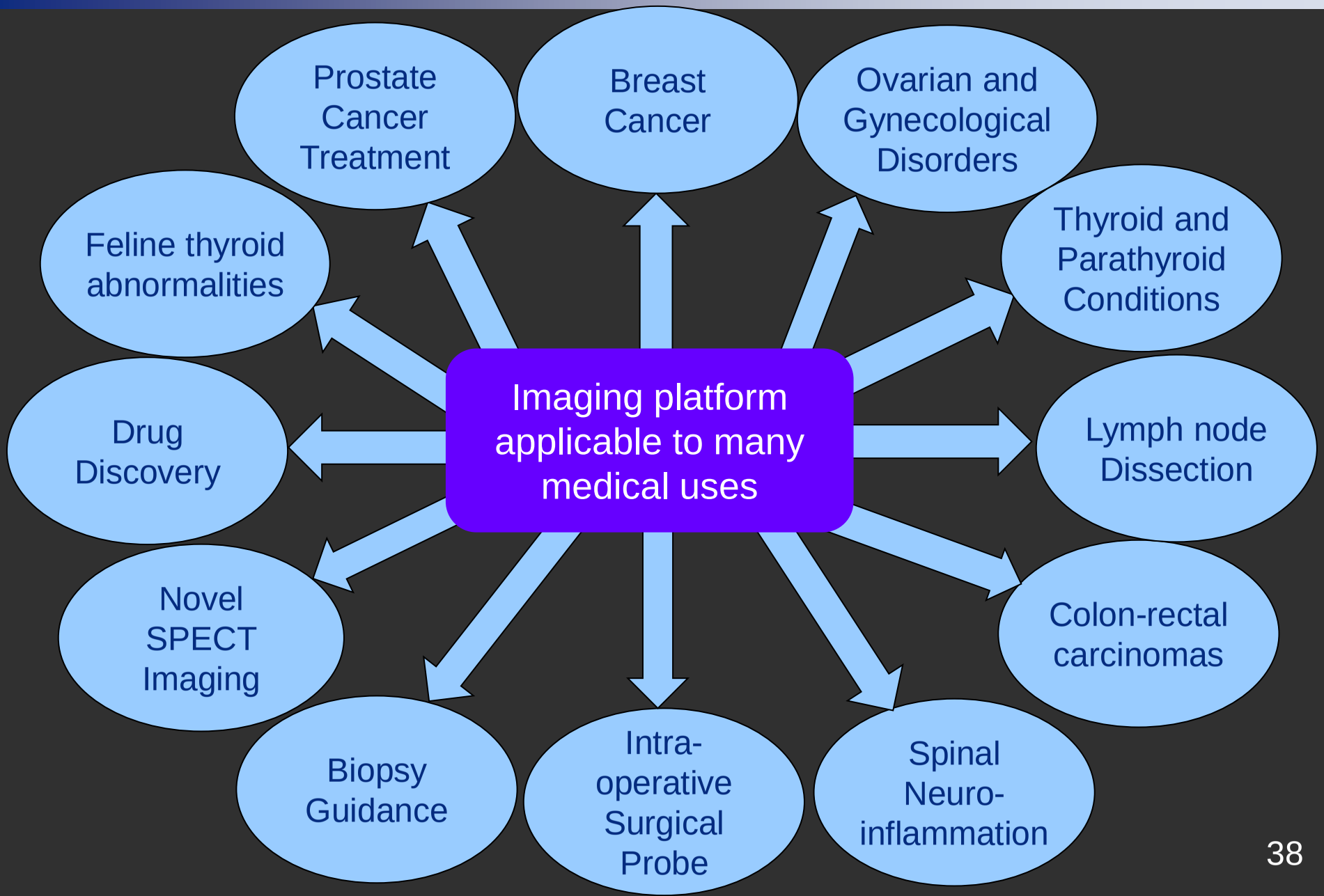


Simulation results

Imaging-guided biopsy

Source:www.bkmed.com

Potential applications of imaging platform



Take-away messages

- Advanced technology that redefines prostate imaging
  - Molecular imaging based on novel detector technology and state-of-the-art ASIC design
  - Targeting intra-prostatic tumors for early detection of disease
  - Addresses major shortcomings of conventional imaging methods
  - High sensitivity and spatial resolution
  - Low cost and compact
  - FDA 510(k) cleared

Take-away messages

- Huge potential impact
  - Over 1.7 million prostate biopsies performed annually in the U.S.
- 4 patents (1 granted, 3 pending)
- Award-winning invention
  - R&D 100 Award, Frost & Sullivan Innovation of the Year in prostate cancer, Battelle Award for Technological Impact, Long Island Men of the Year in science
- Expanding to new medical imaging uses

Thanks for your attention!