A CONVERSATION BETWEEN INDUSTRY AND ACADEMIA: RADIATION DETECTION FOR MEDICAL IMAGING

Cameron Clarke, Eric Christy, Seung Joon Lee

Radiation Detector & Imaging Group, Nuclear Physics, Jefferson Lab

Academic Basic Research

Industrial Products
Industry and Academia in Conversation: Radiation Detection for Medical Imaging

- Industry/Academia: Interactions
- Industry/Academia: Research similarities and differences
- Industry/Academia: Careers
- JLab Biomedical Research and Innovation Center (BRIC) medical imaging applications
HOW DO INDUSTRY AND ACADEMIA INTERACT?

Technology transfer from academic basic research to industry can take many forms

➢ SBIR Small Business Innovation Research (tech-transfer small businesses, 3.2% of agency budgets)
➢ STTR Small Business Technology Transfer (academic partnership start-up, 0.45% of agency budgets)
➢ Start-ups – other than SBIR

SBIR tech transfer research funding across federal agencies

3.2% of each agency's total budget, by law

Billions of $ per year
Technology transfer from academic basic research to industry can take many forms

- SBIR
- STTR
- Start-ups
- CRADAs - Cooperative Research and Development Agreement
  - DOE partnerships between national labs and industry or academic partners
  - Share resources between partners involved to accomplish a shared goal
  - Arranges for intellectual property and profit sharing between partners
  - Managed by Research and Technology Partnerships Office at JLab (Marla Schuchman)
HOW DO INDUSTRY AND ACADEMIA INTERACT?

Technology transfer from academic basic research to industry can take many forms

➢ SBIR
➢ STTR
➢ Start-ups
➢ CRADAs
➢ Pre-clinical – System capability development, testing phantoms or animals, before human studies
➢ Clinical – Medical system development or human biology science studies using advanced systems
➢ Institutes – Private research institutes perform medical research with industry funding
➢ Development – Private companies performing system and product research and development
HOW DO INDUSTRY AND ACADEMIA INTERACT?

Technology transfer from academic basic research to industry can take many forms

- SBIR
- STTR
- Start-ups
- CRADAs
- Pre-clinical
- Clinical
- Institutes
- Development
- Internships – Many companies will hire students to work on short term projects, or partner with profs
- Post-docs – Federal academic funding can go to pay post-doc researchers stationed at companies
- Collaborations – Companies can join academic collaborations to help and advance market share

EXPLORER Total-Body PET prototype development collaboration between UC Davis, UPenn, Philips and United Imaging, among others
OVERLAPS: HOW ARE INDUSTRY AND ACADEMIA SIMILAR AND DIFFERENT?

Industry Research model for Developing and Deploying Products

➢ Research:
  • Identify and test candidate technology for new applications
  • Identify a need and explore opportunities to address it

➢ Develop:
  • Engineering and system development to accomplish goals

➢ Market:
  • Advertise, support with ongoing updates, compete with companies

https://thehealthsciencesacademy.org/health-tips/how-to-conduct-an-effective-self-experiment/
OVERLAPS: HOW ARE INDUSTRY AND ACADEMIA SIMILAR AND DIFFERENT?

Industry Research model for Developing and Deploying Products

➢ Research:
  • Identify and test candidate technology for new applications
  • Identify a need and explore opportunities to address it

➢ Develop:
  • Engineering and system development to accomplish goals

➢ Market:
  • Advertise, support with ongoing updates, compete with companies

Academic Research model for Posing and Answering Basic Science Questions

➢ Theory:
  • Identify interesting problems, explore needed measurements, propose experiments

➢ Experiment:
  • Develop measurement apparatus, test capabilities, build experiment, and take data

➢ Interpretation:
  • Analyze results, compare with theory, evaluate impacts on the field, publish and present

https://thehealthsciencesacademy.org/health-tips/how-to-conduct-an-effective-self-experiment/
Technology Readiness Levels (TRLs): DOE terminology for stages of application R&D

- 9 Tier list, mapped on to various concept/examples, labelled as
  1) Basic science questions posed, studied, and answered – ready for application
  2) Application concept is formulated, applied research develops analytical and simulation tools
  3) Demonstration application prototyping, useful for parametrized study of system capabilities
  4) Component validation studies in an idealized laboratory environment
  5) Component validation studies in a realistic end-goal environment
  6) Beta-testing, prototype model and system demonstration in a realistic environment
  7) Pilot-testing, engineering scale prototype demonstration in an operational environment
  8) Pre-commercial, final product fully functions and integrated in an operational environment
  9) Commercial, final product, fully operational

[Diagram showing Technology Development, Commissioning, and Operations phases with TRLs 1 to 9]
Collaborations between Academia and Industry

➢ Hugo Thienpont – Professor of Engineering – Director of Brussels Photonics – University Group
  • SPIE Photonics Focus article in this month’s issue: [link]
  • Initially tried sharing his optical fabrication techniques with companies
  • Eventually developed a massive 70+ person research group housed off-campus
  • "I learned the hard way that technology push doesn't work"
  • "I realized that helping [companies] with [their] problems ... was the opportunity I had been looking for"
  • This approach is called 'flipped tech transfer'

Brussels Photonics (B-PHOT) research facility at Vrije Universiteit Brussel (VUB) in Belgium
Basic Research can lead to Developed Applications

Grid of Basic Research, Engineering/Development, Applications

➢ My heuristic diagram – useful to see basic instrumentation research alongside system development

### Capability and Scale of Development

<table>
<thead>
<tr>
<th>Basic Research</th>
<th>Engineering</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic RnD</td>
<td>Application research</td>
<td>Opportunistic research</td>
</tr>
<tr>
<td>Prototype/Pre-clinical research</td>
<td>Capability development</td>
<td>Product/technique development</td>
</tr>
<tr>
<td>Pilot/Clinical research</td>
<td>Product/technique deployment and adoption</td>
<td>Final technique/product/clinical care</td>
</tr>
</tbody>
</table>
**BASIC RESEARCH CAN LEAD TO DEVELOPED APPLICATIONS**

Grid of Basic Research, Engineering/Development, Applications

<table>
<thead>
<tr>
<th>Technology</th>
<th>Research</th>
<th>Engineering</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Basic Research</strong></td>
<td>Ex) JLab Radiation Detector and Imaging Group doing basic detector development research at Hampton University Proton Cancer Institute's Proton Therapy accelerator</td>
<td></td>
<td>Opportunistic research</td>
</tr>
<tr>
<td><strong>Engineering</strong></td>
<td></td>
<td>Ex) Using CEBAF beam dumps for detector or beamline component test-beams</td>
<td></td>
</tr>
</tbody>
</table>

Proton beam nozzle

Ex) Proton beam nozzle
**Basic Research can lead to Developed Applications**

Grid of Basic Research, Engineering/Development, Applications

<table>
<thead>
<tr>
<th>Basic Research</th>
<th>Engineering</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex) JLab Radiation Detector and Imaging Group PET system deployment assisting UC Santa Cruz research group with plant-biology studies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pilot/Clinical research</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Basic Research can lead to Developed Applications

Grid of Basic Research, Engineering/Development, Applications

<table>
<thead>
<tr>
<th>Technology</th>
<th>Engineering</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prototype/Pre-clinical research</td>
<td>Ex) JLab accelerator scientists using UITF e-beam to test compact accelerators' suitability for commercial waste-water sterilization and PFAS neutralization treatments</td>
</tr>
</tbody>
</table>

Regarding the Capability and Scale of Development:
**Basic Research can lead to Developed Applications**

Grid of Basic Research, Engineering/Development, Applications

<table>
<thead>
<tr>
<th>Engineering</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capability development</td>
<td></td>
</tr>
<tr>
<td>Ex) Medical imaging system capability and engineering development – such as Canon Medical Research USA in Illinois, designing next-gen PET and X-ray CT scanners</td>
<td></td>
</tr>
</tbody>
</table>
### Basic Research Can Lead to Developed Applications

<table>
<thead>
<tr>
<th>Basic Research</th>
<th>Engineering</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ex)</strong> University of Pennsylvania and UC Davis research groups collaborating with Philips and United Imaging to develop Total-Body PET scanners (~$10^4$ detector arrays, ~$10^6$ pixel ASIC readout and real-time processing)</td>
<td>Product/technique development</td>
<td></td>
</tr>
</tbody>
</table>

![Image of medical equipment](image-url)
Basic Research can lead to Developed Applications

Grid of Basic Research, Engineering/Development, Applications

<table>
<thead>
<tr>
<th>Basic Research</th>
<th>Engineering</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application research</td>
<td></td>
<td>Ex) Canon Medical Systems Corporation (Japan) funding University at Buffalo Canon Stroke &amp; Vascular Research Center – basic medical capabilities research</td>
</tr>
</tbody>
</table>
**Basic Research can lead to Developed Applications**

Grid of Basic Research, Engineering/Development, Applications

- My heuristic diagram – useful to see basic instrumentation research alongside system development

### Capability and Scale of Development

<table>
<thead>
<tr>
<th>Basic Research</th>
<th>Engineering</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic RnD</td>
<td>Application research</td>
<td>Opportunistic research</td>
</tr>
<tr>
<td>Prototype/Pre-clinical research</td>
<td>Capability development</td>
<td>Product/technique development</td>
</tr>
<tr>
<td>Pilot/Clinical research</td>
<td>Product/technique deployment and adoption</td>
<td>Final technique/product/clinical care</td>
</tr>
</tbody>
</table>

- **Technology**
- **Basic Research**
- **Engineering**
- **Applications**

- **Academic** basic RnD
- **Industry** product RnD
- **Clinical care** RnD
Careers across Academia and Industry

➢ Industry targets different steps of development
➢ Academia/Industry interact and overlap
➢ Typical tasks of an industry researcher:
  • **Propose tests/experiments:** Work within a team to test ideas about system or component issues
  • **Work with engineers:** Set up and run experiments/simulation/data analysis approaches
  • **Analyze data:** Prioritize practical problem solving and resource saving approximations
  • **Present results:** Share results internally and seek feedback with trusted collaborators
  • **Submit patents:** Apply for intellectual property protection for calibrations or new developments
  • **Share results:** Attend academic and industry conferences after prototype deployment or product launch

➢ First three dominate
➢ Choice of tasks depends on team and project needs
➢ Infrequent self-directed research, but can be done
➢ Can be rewarding, well-managed, with real-world impacts
Industry research is well-funded:

➢ Majority of academically trained researchers leave academia
➢ Industry funds most applied and a third of basic research

A changing career landscape

Over the past 20 years, the portion of U.S. life and health sciences Ph.D.s employed as tenured and tenure track faculty has declined—while the number of Ph.D.s awarded in these fields has grown.

“Tenured” line for physical sciences is ~20% today

AAAS Career Survey results

https://www.science.org/content/article/first-us-private-sector-employs-nearly-many-phds-schools-do

Jefferson Lab
Why Consider a Career in Industry Research?

Pursuing careers in Industry R&D is natural for scientists

➢ Industry research groups hiring practices differ from academics
  • Typically hire based on transferrable technical skills, not domain knowledge
  • Value demonstrated achievements and results, goal-oriented mindset (Action+Problem+Result framing)
  • Seek interpersonal and communication skills
  • Programs exist to support career searches:
    o PhD Career Ladders Program at Stony Brook - https://www.stonybrook.edu/phd-career-ladder/
    o 7 Step process to hone goals, transferrable skills, networking, job applications, etc.

Tools exist to assist in navigating industry careers:

➢ Industry internships and postdocs – check company websites and aggressive networking
➢ Job boards – APS (FECS, FGSA, Forum on Industrial & Applied Physics), AAAS, SPIE, IEEE, etc.
➢ AAAS IDP program (https://myidp.sciencecareers.org/)
➢ APS Industry Days at March Meeting
➢ APS IMPact Industry Mentoring Program
  https://mentoring.aps.org/programs/impact/
BRIC is a clearinghouse for biomedical applications and technology transfer at JLab

- Supports JLab researchers seeking to apply their research
- Supports external interests in working with JLab
- Highlights and market work already going on at the lab

Eric Christy, and Cameron Clarke, Seung Joon Lee participate with BRIC

- **Eric:**
  - Academic Hall A/C physicist – working on applying GEM TPC technology to Proton Therapy
- **Seung Joon:**
  - PhD Biomedical Engineer – working on pre-clinical motion tracking and Phyto-PET scanners
- **Cameron:**
  - PhD on Hall A PVES – Shifted to medical imaging detector development at Canon, now BRIC
Eric Christy

➢ BS (Physics and Mathematics) – Northern Kentucky University, 1991
➢ PhD (Nuclear Physics) – University of Kentucky, 1999
➢ Postdoc (JLab Physics) – Hampton University, 1999-2003
➢ Hampton U Physics Faculty – 2003-2021
  • Led Multiple detector development / construction efforts:
    1. One of two university factories for production of scintillator tracking detectors for MINERvA neutrino experiment at Fermilab
    2. Design and construction of SHMS tracking drift chambers
    3. Design and construction of BONuS12 radial time projection chamber based on gas electron multipliers (GEMs)
➢ Jefferson Lab Staff Scientist (Radiation Detector and Imaging Group), 2021-Present
  • Focus is on gaseous detector development for proton radiotherapy under BRIC
Eric Christy
Gas Electron Multiplier (GEM) detector development for hadron radiotherapy applications
(Collaboration with JLab, UVa, VUU, HUPTI)

Beam characterization / treatment QA
detector testing at HUPTI

Soft tissue equivalent and cortical bone
insert between beam nozzle and detector

Proton beam nozzle

Intensity map image of bone insert
in water phantom
– individual proton counting

Proton Computed Tomography (pCT) Device

Energy measurement TPC

GEM based vertical TPC with thin film
absorbers for range / dE/dx fitting

Fit residuals for simulated protons in
eTPC: 10-45 MeV

Energy Time projection Chamber (eTPC) detector dry fitting of parts.

Pre -Tracker

Post -Tracker

phantom

Standard GEM chambers

Energy degrader shutter box
(extends dynamic range)

Energy measurement TPC

$KE_{true} - KE_{meas}$ (MeV)

$KE_{meas} = 275$ keV

Energy Computed Tomography

Pre -Tracker

Post -Tracker

phantom

Standard GEM chambers

Energy degrader shutter box
(extends dynamic range)

Energy measurement TPC

Fit residuals for simulated protons in
eTPC: 10-45 MeV

Energy Time projection Chamber (eTPC) detector dry fitting of parts.

Pre -Tracker

Post -Tracker

phantom

Standard GEM chambers

Energy degrader shutter box
(extends dynamic range)

Energy measurement TPC

Fit residuals for simulated protons in
eTPC: 10-45 MeV

Energy Time projection Chamber (eTPC) detector dry fitting of parts.

Pre -Tracker

Post -Tracker

phantom

Standard GEM chambers

Energy degrader shutter box
(extends dynamic range)

Energy measurement TPC

Fit residuals for simulated protons in
eTPC: 10-45 MeV

Energy Time projection Chamber (eTPC) detector dry fitting of parts.
Cameron Clarke

- Mississippi State: Astronomy Undergrad – observational exoplanet astronomy
- SUNY Stony Brook: Nuclear physics PhD – DAQ, detector design, analysis for PREX2/CREX & MOLLER
- Canon Medical Research USA: Detector Scientist – Photon Counting CT semiconductor detectors

- Canon Medical Systems Corporation’s (Japan) pre-clinical prototype scanner
- Canon Medical Research USA’s science and engineering
- Uses Redlen’s detector modules
- Built with Redlen’s CZT semiconductor material
- Read out by [someone’s] ASIC frontend pre-amplifier/discriminator/digitizer

X-ray test-bench for Redlen company’s Cadmium Zinc Telluride (CZT) semiconductor-based CT detector (Right)
Cameron Clarke

- Mississippi State: Astronomy Undergrad – observational exoplanet astronomy
- SUNY Stony Brook: Nuclear physics PhD – DAQ, detector design, analysis for PREX2/CREX & MOLLER
- Canon Medical Research USA: Detector Scientist – Photon Counting CT semiconductor detectors

Traditional Energy Integrating Detector (EID): X-ray detection via scintillation + optical photo-detection + discrete electronics (left)

New Photon Counting Detector (PCD): X-ray detection via direct conversion + Ramo-Shockley induced charge readout + integrated electronics (right)
Cameron Clarke

- Mississippi State: Astronomy Undergrad – observational exoplanet astronomy
- SUNY Stony Brook: Nuclear physics PhD – DAQ, detector design, analysis for PREX2/CREX & MOLLER
- Canon Medical Research USA: Detector Scientist – Photon Counting CT semiconductor detectors
- JLab BRIC: Staff Scientist – Supporting BRIC mission, Streaming Readout PET project, etc.

Detector configuration (Ben Raydo and John McKisson)

Detector data streaming schematic (Ben Raydo and John McKisson)
Cameron Clarke

- Mississippi State: Astronomy Undergrad – observational exoplanet astronomy
- SUNY Stony Brook: Nuclear physics PhD – DAQ, detector design, analysis for PREX2/CREX & MOLLER
- Canon Medical Research USA: Detector Scientist – Photon Counting CT semiconductor detectors
- JLab BRIC: Staff Scientist – Supporting BRIC mission, Streaming Readout PET project, etc.

Test-set up at University of Maryland Baltimore School of Medicine nuclear medicine core imaging facility last month

4-point source configuration

3D image reconstruction (Seung Joon Lee)
Seung Joon Lee:
- Mechanical Engineering Undergrad
- Texas A&M: Biomedical Engineering PhD
- Oak Ridge National Lab: Postdoc, working on Awake Animal SPECT detectors and motion tracking
- JLab Radiation Detector and Imaging Group: Staff – SPECT, Dilon, leading Plant PET projects, etc.

Motion-corrected Awake Animal SPECT image

Dilon Gamma camera and VASH system development for nuclear medicine functional breast imaging
CONCLUSION

Takeaways:

• Applied research can multiply the value of basic research several-fold
• Academic/Industry applied research collaborations are possible, require intentionality
• Careers in Industry Research can be rewarding
• Transferrable scientific skills are highly valued on the job market
• JLab is a great place to get training, collaborate, and do applied research work
Technology Readiness Levels (TRLs): DOE terminology for stages of application R&D

➢ 9 Tier list, mapped on to various concept/examples, labelled as

1) Basic science questions posed, studied, and answered – ready for application
   • Bremsstrahlung charged particle "breaking" X-ray radiation discovery by Tesla in 1888-97


DOI: 10.13140/RG.2.2.16794.49600
Technology Readiness Levels (TRLs): DOE terminology for stages of application R&D

➢ 9 Tier list, mapped on to various concept/examples, labelled as

1) Basic science questions posed, studied, and answered – ready for application
2) Application concept is formulated, applied research develops analytical and simulation tools
   • Analytical description and simulations of Brem-radiation for medical X-ray sources

\[
- \left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2} \cdot \frac{n z^2}{\beta^2} \cdot \left( \frac{e^2}{4\pi\varepsilon_0} \right)^2 \cdot \left[ \ln \left( \frac{2m_e c^2 \beta^2}{I \cdot (1 - \beta^2)} \right) - \beta^2 \right]
\]

Bethe-Bloch

https://physicsopenlab.org/2017/08/02/bremsstrahlung-radiation/
Technology Readiness Levels (TRLs): DOE terminology for stages of application R&D

➢ 9 Tier list, mapped on to various concept/examples, labelled as

1) Basic science questions posed, studied, and answered – ready for application
2) Application concept is formulated, applied research develops analytical and simulation tools
3) Demonstration application prototyping, useful for parametrized study of system capabilities
   • Building a prototype X-ray gun with variable features and rudimentary controls
Technology Readiness Levels (TRLs): DOE terminology for stages of application R&D

- 9 Tier list, mapped on to various concept/examples, labelled as

  1) Basic science questions posed, studied, and answered – ready for application
  2) Application concept is formulated, applied research develops analytical and simulation tools
  3) Demonstration application prototyping, useful for parametrized study of system capabilities
  4) Component validation studies in an idealized laboratory environment
     - Testing the various features of the X-ray gun work as intended (power supplies, cooling, etc.)
Technology Readiness Levels (TRLs): DOE terminology for stages of application R&D

- 9 Tier list, mapped on to various concept/examples, labelled as

  1) Basic science questions posed, studied, and answered – ready for application
  2) Application concept is formulated, applied research develops analytical and simulation tools
  3) Demonstration application prototyping, useful for parametrized study of system capabilities
  4) Component validation studies in an idealized laboratory environment
  5) Component validation studies in a realistic end-goal environment
    - Similar studies as before, but in a hospital environment (commercial power, shielding, etc.)
  6) Beta-testing, prototype model and system demonstration in a realistic environment
    - Demonstrating that the entire X-ray gun system functions, beyond component testing
Technology Readiness Levels (TRLs): DOE terminology for stages of application R&D

- 9 Tier list, mapped on to various concept/examples, labelled as
  1) Basic science questions posed, studied, and answered – ready for application
  2) Application concept is formulated, applied research develops analytical and simulation tools
  3) Demonstration application prototyping, useful for parametrized study of system capabilities
  4) Component validation studies in an idealized laboratory environment
  5) Component validation studies in a realistic end-goal environment
  6) Beta-testing, prototype model and system demonstration in a realistic environment
  7) Pilot-testing, engineering scale prototype demonstration in an operational environment
      • Building and deploying a full system to an actual hospital, patient studies, evaluations
  8) Pre-commercial, final product fully functions and integrated in an operational environment
      • All product design and testing completed, available for purchase (FDA review first)
Technology Readiness Levels (TRLs): DOE terminology for stages of application R&D

- 9 Tier list, mapped on to various concept/examples, labelled as
  1) Basic science questions posed, studied, and answered – ready for application
  2) Application concept is formulated, applied research develops analytical and simulation tools
  3) Demonstration application prototyping, useful for parametrized study of system capabilities
  4) Component validation studies in an idealized laboratory environment
  5) Component validation studies in a realistic end-goal environment
  6) Beta-testing, prototype model and system demonstration in a realistic environment
  7) Pilot-testing, engineering scale prototype demonstration in an operational environment
  8) Pre-commercial, final product fully functions and integrated in an operational environment
  9) Commercial, final product, fully operational

Nuclear physics to medical imaging

• RADIATION DETECTOR AND IMAGING GROUP has been involved in numerous collaborations resulting in many application-specific radiation-imaging systems based on technology used in nuclear physics research. Examples are
  • Pre-Clinical Imaging: PET, SPECT (gamma ray imaging for small animal)
  • Clinical Imaging: Molecular imaging (gamma ray imaging for breast cancer detection)
  • Plant Biology Imaging: PhytoPET – PET system for imaging plant, especially underground
Awake animal SPECT

- Small animal imaging (mouse/rat) requires restraint or anesthesia to minimize motion artifact during the scan.
- Motion tracking system captures mouse head motion then compensate during image reconstruction.
- This system allows imaging without anesthesia that is known to affect brain physiology.

- **Jefferson Lab** – Developed Single Photon Emission Computed Tomography (SPECT) gamma camera and Image reconstruction algorithm
- **Oak Ridge National Laboratory** – Developed motion tracking system and SPECT gantry with X-ray CT
- **Johns Hopkins University** – Leads animal experiment
SPECT gamma cameras

Rotation Gantry

Live mouse in a glass burrow

Motion Tracking Cameras

Markers
Phantom Study

- 6 DOF data (30 frames/second)
- X,Y,Z,Roll,Pitch,Yaw
- In sub-mm / sub-degree accuracy
Animal Study

- Tc99m-MDP (bone scan agent)

- DaTscan (I-123) – binding to dopamine transporter
- Higher binding potential with Anesthesia
Variable Angle Slant-Hole Collimator for SPECT

- **X-ray Mammography**:
  - most common for breast cancer screening
  - low sensitivity, specificity in dense breasts
- **Scintimammography (BSGI, MBI)**:
  - functional imaging
  - potential to complement mammography
  - higher dose compare to X-ray
- **SPECT, PET, or MRI**:
  - expensive

We need 3D functional imaging with minimal dose and cost!
Molecular Breast Imaging (MBI)

- Inject radioactive tracer concentrated on fast growing cells
- Gamma detector with a parallel hole collimator
- No depth information, 2D image
**Slant-hole collimator system**

- Only two projections
- Limited depth information
- Reconstruction artifact
- **Wide space required** (limits scan area)

**Projection Images**
(capillary tube)

**Gamma Detector**

**Reconstruction Image**
Variable Angle Slant-Hole (VASH) Collimator

- Multi angle projections from stationary detector
  => 3D imaging without detector movement
- Less reconstruction artifact
- Less space requirement !!
Example of VASH collimator data

11 Projection images: bottom view (3 capillary tubes)

Reconstructed image (front view)

Reconstructed image 3D

blurry
PhytoPET

• A modular PET (Positron Emission Tomography) images plant
• Introduce C11 (radio-isotope) carbon dioxide -> Photosynthesis -> Glucose -> move to root (root imaging) -> sugar flow dynamics study
• Collaboration with Duke, Stanford, UC-Santa Cruz.