PET Research at UC Davis

都军伟

Department of Biomedical Engineering
University of California at Davis
Where is UCD?
Where is UCD?
Where is UCD?
Where is UCD?
Positron Emission Tomography (PET)

Courtesy of Wiki
Outlines

PET Groups at UCD

Center for Molecular and Genomic Imaging (CMGI)

A 0.5 mm Resolution Small-animal PET

The 2nd PET Insert at UCD

Explore PET

SiPM (Silicon Photomultiplier)
PET Groups

- Professors: 3 (Simon R. Cherry, Jinyi Qi, Ramsey D. Badawi)
- Assistant Professors: 1
- Scientists: 6
- Specialists: 5
- Postdocs: 5+
- Students: 12 (?)
PET Groups

Cherry’s Lab

Qi’s Lab

Badawi’s Lab
Cherry’s Lab

- Prof. Simon R. Cherry
- Scientists: 4
- Specialists: 3
- Postdocs: 2
- Students: 5 (?)
Center for Molecular and Genomic Imaging

- Mission: To provide state-of-the-art instrumentation and expertise for in vivo imaging and biospecimen imaging
- Dedicated facility in Genome & Biomedical Sciences Building, and satellite facility at California National Primate Research Center (CNPRC)
- Over $10M in state-of-the-art imaging instrumentation
- Expert staff and faculty directors to assist users
- All major imaging modalities available
- Also operates a biomedical cyclotron and radiochemistry research facility
- …
Center for Molecular and Genomic Imaging

- **Optical Imaging**
  - IVIS Spectrum (Perkin Elmer)
  - Maestro 2 (Perkin Elmer)
  - Fluorescence Cryomicrotome (Barlow)

- **Nuclear Imaging (PET/SPECT)**
  - microPET Focus 120 (Siemens)
  - microPET P4 (Siemens)
  - Inveon SPECT/CT (Siemens)
  - Discovery PET/CT (GE)
  - MicroPET II

- **Magnetic Resonance Imaging**
  - Biospec 7T/30 (Bruker)

- **MicroCT (X-ray)**
  - XCT-200 (Xradia)

- **Radiochemistry**
  - RDS 111 Biomedical Cyclotron (Siemens)
  - Hot Cells (Von Gahlen)
  - TracerLAB (GE Healthcare)

~$10M capital equipment in dedicated imaging space adjacent to vivarium
A 0.5 mm Resolution Small-animal PET

(led by Dr. Yongfeng Yang)
Prototype Scanner Geometry

Crystal Array: 14x14 elements, LSO

Crystal size:
Front: 0.44 × 0.44 mm²
Back: 0.80 × 0.44 mm²
Length: 13 mm

16 dual-ended readout tapered detectors

Field of view:
axial 7 mm
transaxial 40 mm

Electronics:
NIM electronics + multiplexer

PSAPDs
Front: 10 × 10 mm²
Back: 10 × 15 mm²
Detector Performance

Flood Histogram:

Energy Resolution:
20-25% for central crystals

Timing Resolution:
40 ns

DOI Resolution:
1.7 mm
Value includes ~ 1 mm collimation beam width

\[ x = \frac{(C+D)-(A+B)}{A+B+C+D}, \quad y = \frac{(A+D)-(B+C)}{A+B+C+D} \]

DOI ratio = \[ \frac{E_1}{E_1 + E_2} \]
Phantom Image

Prototype scanner

Rod to rod distance is twice rod diameter

2D ML-EM reconstruction

0.5 mm rods can be resolved

Siemens Inveon D-PET

OSEM reconstruction

Spatial resolution ~ 1.5 mm
In Vivo Animal Images

Prototype scanner

12.6 gram mouse
220 μCi $^{18}$F-fluoride
Scan time: 1 hour
3D list mode OSEM

Siemens Inveon D-PET

11.9 gram mouse
260 μCi $^{18}$F-fluoride
Scan time: 0.5 hour
2D OSEM reconstruction
2nd PET Insert
(led by Dr. Martin Judenhofer)
2nd PET Insert

- Preamplifiers are located at the axial ends of the insert
- Flex boards are used to connect the PSAPDs to HV and preamplifiers (~150 mm)
- Mini coaxial cables are used to transfer signals outside MRI room
2nd PET Insert- Phantom Measurements

- PET acquisitions at high resolution with and without MRI
- MRI images at 7T can be acquired and fused to MRI
Small Animal PET/MRI Systems so far...

Overview of Current Small Animal PET and PET/MRI Systems

Most current preclinical prototypes lack sufficient FOV, spatial resolution and sensitivity.

Next generation of systems targeted towards larger FOV, higher sensitivity and better spatial resolution.
Explore PET
Explore PET
Explore PET

- 2 m long
- Time of Flight (TOF)
- Depth of Interaction (DOI)
- ~ 2,000 Blocks
- > 4 Channels / Block
Silicon Photomultiplier (SiPM)
SiPM

- SiPM, GAPD, MPPC, SSPM
  - SiPM: Silicon Photomultipliers
  - SSPM: Solid-State Photomultiplier
  - GAPD: Geiger-mode avalanche photodiode
  - MPPC: multi-pixel photon counters (Hamamatsu)
SiPM

A novel MR compatible PET detector

- Each cell is operated above breakdown
- Output signal is sum of all cells
- Each cell provides maximum-gain signal on single photon interaction
## SiPM

<table>
<thead>
<tr>
<th></th>
<th>PMT</th>
<th>APD</th>
<th>SiPM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gain</strong></td>
<td>$10^6$</td>
<td>$10^2$</td>
<td>$10^6$</td>
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<tr>
<td><strong>Magnetic Field</strong></td>
<td>Sensitive</td>
<td>Not sensitive</td>
<td>Not sensitive</td>
</tr>
<tr>
<td><strong>Bias Voltage</strong></td>
<td>1000V</td>
<td>350-2000V</td>
<td>20-70V</td>
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<tr>
<td><strong>Signal / Noise Ratio</strong></td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Dynamic Range</strong></td>
<td>High</td>
<td>High</td>
<td>Small</td>
</tr>
<tr>
<td><strong>Timing Properties</strong></td>
<td>&lt; 1ns</td>
<td>2-4ns</td>
<td>&lt;1ns</td>
</tr>
<tr>
<td><strong>Electronic Readout</strong></td>
<td>Voltage Amplifier</td>
<td>Charge sensitive pre-amplifier</td>
<td>Voltage Amplifier</td>
</tr>
</tbody>
</table>
SiPM

• SiPM, GAPD, MPPC, SSPM
  – SiPM: Silicon Photomultipliers
  – SSPM: Solid-State Photomultiplier
  – GAPD: Geiger-mode avalanche photodiode
  – MPPC: multi-pixel photon counters (Hamamatsu)

• Position-Sensitive SiPM
• Non Position-Sensitive SiPM (Pixel)

• Analog SiPM
  – Hamamatsu, FBK, RMD, SensL …

• Digital SiPM
  – Philip
PS-SSPM vs. Non PS-SSPM

\[ x = \frac{(C+D)-(A+B)}{A+B+C+D}, \quad y = \frac{(A+D)-(B+C)}{A+B+C+D} \]
### PS-SSPM

**Parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>5 mm × 5 mm PS-SSPM</th>
<th>10 mm × 10 mm PS-SSPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon detection efficiency @ 420 nm</td>
<td>~10%</td>
<td>~10%</td>
</tr>
<tr>
<td>Micro-pixel area</td>
<td>30 μm × 30 μm</td>
<td>30 μm × 30 μm</td>
</tr>
<tr>
<td>Micro-pixel pitch</td>
<td>44.3 μm × 44.3 μm</td>
<td>44.3 μm × 44.3 μm</td>
</tr>
<tr>
<td>Geometrical fill factor</td>
<td>0.46</td>
<td>0.46</td>
</tr>
<tr>
<td>Total number of micro-pixels</td>
<td>11 664 (108 × 108)</td>
<td>40 000 (200 × 200)</td>
</tr>
<tr>
<td>Dark current at 2V (nA)</td>
<td>10 509</td>
<td>198 120</td>
</tr>
<tr>
<td>Dark count rate (Hz)</td>
<td>1.21 × 10^8</td>
<td>6.18 × 10^8</td>
</tr>
<tr>
<td>Network resistors (Ω)</td>
<td>246.5</td>
<td>90</td>
</tr>
<tr>
<td>Quench resistors (kΩ)</td>
<td>143</td>
<td>143</td>
</tr>
<tr>
<td>Capacitance (fF/pixel)</td>
<td>220</td>
<td>220</td>
</tr>
</tbody>
</table>

- Signal to noise Ratio
- Energy resolution
- Timing resolution
- Flood histogram

J. Schmall, J. Du et al., PMB, 2012.
PS-SSPM: Signal-to-noise Ratio

J. Schmall, J. Du et al., PMB, 2012.
PS-SSPM: Energy Resolution

J. Schmall, J. Du et al., PMB, 2012.

5 mm device

10 mm device
Timing resolution for an individual center, edge, and corner crystal on the surface of 5 mm PS-SSPM (left) and 10 mm PS-SSPM (right). The $6 \times 6$ array of 1.3 mm crystals was used.
Flood histograms from the 10 mm PS-SSPM (left) and 2 × 2 array of 5 mm PS-SSPMs (right). The bias voltages are 31 V and 30.5 V for the 10 mm PS-SSPM and 5 mm PS-SSPMs respectively. The crystal is 1.3 mm LSO scintillation array.

J. Schmall, J. Du et al., PMB, 2012.
Flood histogram analysis with the $2 \times 2$ PS-SSPM array and 0.5 mm LSO scintillation array at bias voltage 30.5 V and 0 °C.

J. Schmall, J. Du et al., PMB, 2012.
Nice Detector to resolve 0.5 mm scintillation array
20 Channels readout
Simple readout to reduce the electronics complexity
Five channels is the best.
A Simple Capacitive Charge-Division Readout for Position-Sensitive Solid-State Photomultiplier Arrays

\[ A = A_1 + (B_1 + C_1 + D_1 + A_2 + A_3 + A_4)/2 \]
\[ B = B_2 + (A_2 + C_2 + D_2 + B_1 + B_3 + B_4)/2 \]
\[ C = C_3 + (A_3 + B_3 + D_3 + C_1 + C_2 + C_4)/2 \]
\[ D = D_4 + (A_4 + B_4 + C_4 + D_1 + D_2 + D_3)/2 \]

\[ x = \frac{(C + D) - (A + B)}{A + B + C + D} \]
\[ y = \frac{(A + D) - (B + C)}{A + B + C + D} \]

J. Du, J. Schmall et al., TNS.
A Simple Capacitive Charge-Division Readout for Position-Sensitive Solid-State Photomultiplier Arrays

- Capacitor Value (n2): 51 pf, 100 pf, 200 pf, 510 pf, 1 nf, 2 nf, 5.1 nf, 10 nf.
- Capacitor Value (n1): n1 = 2 * n2.
- Bias voltage: 28 V to 32 V, in 0.5 V interval.
- Temperature: 0 °C.
- Source: $^{68}$Ge.

*J. Du, J. Schmall et al., TNS.*
Signal - to - Noise Ratio

Noise

Bias Voltage (V)

Noise (ADC Channel)

0.051nf
0.1nf
0.2nf
0.51nf
1nf
2nf
5.1nf
10nf

Signal

Bias Voltage (V)

Signal (ADC Channel)

0.051nf
0.1nf
0.2nf
0.51nf
1nf
2nf
5.1nf
10nf

SNR

Bias Voltage (V)

Signal to Noise Ratio

0.051nf
0.1nf
0.2nf
0.51nf
1nf
2nf
5.1nf
10nf

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CMG
Energy Resolution

![Graph showing energy resolution vs bias voltage](image-url)
Timing Resolution

- Capacitor Value of n1 (nf)
- Timing Resolution (ns)
- 200 keV & Calibration
- 400-650 keV & Calibration
Flood Histogram Quality

\[ k = \frac{1}{12} \left( \frac{x_2 - x_1}{(w_{x1} + w_{x2})/2} + \frac{x_3 - x_2}{(w_{x2} + w_{x3})/2} + \frac{x_5 - x_4}{(w_{x4} + w_{x5})/2} + \frac{x_6 - x_5}{(w_{x5} + w_{x6})/2} + \frac{x_8 - x_7}{(w_{x7} + w_{x8})/2} + \frac{x_9 - x_8}{(w_{x8} + w_{x9})/2} \right) \]

\[ + \frac{y_1 - y_4}{(w_{y1} + w_{y4})/2} + \frac{y_4 - y_7}{(w_{y4} + w_{y7})/2} + \frac{y_2 - y_5}{(w_{y2} + w_{y5})/2} + \frac{y_5 - y_8}{(w_{y5} + w_{y8})/2} + \frac{y_3 - y_6}{(w_{y3} + w_{y6})/2} + \frac{y_9 - y_6}{(w_{y6} + w_{y9})/2} \]
Flood Histogram Quality

![Flood Histogram Quality Graph](image-url)
- Flood histogram of 1 mm LSO scintillation array (left) and position profile for one crystal row (right).
• Flood histogram of 0.75 mm LSO scintillation array (left) and position profile for one crystal row (right)
The capacitive charge-division analog signal processing method can significantly reduce the number of electronic channels, from 20 to 5, while retaining the excellent performance of the detector.
SiPM – Matrix 9

Photograph of Matrix9 detector head (left) and dimensions in mm (right)

J. Du, J. Schmall et al., MIC 2012.
Photograph of Matrix9 detector head (left) and 8 x 8 array of 1.5 x 1.5 x 6 mm³ crystal (right)
Positioning Methods

\[ x = \frac{\sum_{i=1}^{16} x_i s_i}{\sum_{i=1}^{16} s_i} \quad y = \frac{\sum_{i=1}^{16} y_i s_i}{\sum_{i=1}^{16} s_i} \]

- M1) All energies method
- M2) All energies method with offset calibration
- M3) Region of interest (ROI) method
- M4) ROI method with offset calibration
Positioning Methods

\[ x = \frac{\sum_{i=1}^{9} x_i S_i}{\sum_{i=1}^{9} S_i} \quad y = \frac{\sum_{i=1}^{9} x_i S_i}{\sum_{i=1}^{9} S_i} \]

- M1) All energies method
- M2) All energies method with offset calibration
- M3) Region of interest (ROI) method
- M4) ROI method with offset calibration
# Flood Histogram

<table>
<thead>
<tr>
<th></th>
<th>28.0 V</th>
<th>29.0 V</th>
<th>30.0 V</th>
<th>31.0 V</th>
<th>32.0 V</th>
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<tbody>
<tr>
<td>M1</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
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<tr>
<td>M2</td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
<tr>
<td>M3</td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
<td><img src="image15.png" alt="Image" /></td>
</tr>
<tr>
<td>M4</td>
<td><img src="image16.png" alt="Image" /></td>
<td><img src="image17.png" alt="Image" /></td>
<td><img src="image18.png" alt="Image" /></td>
<td><img src="image19.png" alt="Image" /></td>
<td><img src="image20.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Flood Histogram Quality

\[ k_i = \frac{1}{4} \left( \frac{x_2 - x_1}{(w_{x2} + w_{x1})/2} + \frac{x_4 - x_3}{(w_{x4} + w_{x3})/2} + \frac{y_1 - y_3}{(w_{y1} + w_{y3})/2} + \frac{y_2 - y_4}{(w_{y2} + w_{y4})/2} \right) \]

\[ k = \sum_{i=1}^{16} k_i \quad \text{and} \quad k_{\text{error}} = \text{std}(k_i) \]
Flood Histogram Quality

Using different positioning methods at different bias voltages and at 5 °C
“ROI with offset calibration” method at different bias voltages and different temperatures
Crystal Identification Ability

- 8 x 8 array of 1.5 x 1.5 x 12 mm³
- 9 x 9 array of 1.35 x 1.35 x 12 mm³
- 10 x 10 array of 1.0 x 1.0 x 10 mm³
Timing Resolution

Timing resolution:
- Raw data: 16.5 +/- 0.5 ns
- LED Cal.: 5.2 +/- 0.1 ns
Timing Resolution

![Graph showing the relationship between temperature (°C) and timing resolution (ns). The graph includes data for Raw data, Raw data & 400 - 650 keV EW, LED Cal., and LED Cal. & 400 - 650 keV EW. The data points show an increase in timing resolution with increasing temperature.]
SiPM – Matrix 9

Photograph of Matrix9 detector head (left) and dimensions in mm (right)

J. Du, J. Schmall et al., MIC 2012.
SiPM – 12 x 12 Array

J. Du, J. Schmall et al., MIC 2013.
Flood Histogram

10 x 10 array of 1.0 x 1.0 x 10 mm$^3$ polished LYSO crystals
Conclusions

• PET is still a “hot” topic
• Physics, electronics, computer science, biology, …
Thanks !
UC Davis & Davis

- Largest city in Yolo County (woodland), and the 122nd largest in CA, by population
- UCD: 7,309 acres
- 32,290 of 65,622 are students (6,395 Chinese Americans)
- Land of UCD: Yolo and Solano Counties.
- Liberal politics, bicycles and bike paths (a haven for bicyclists), and UCD
- Second most educated city in the US (CNN Money Magazine) after Arlington, Virginia
- Weather: Dry, hot summers and cool, rainy, winters
UC Davis & Davis

- Largest city in Yolo County (woodland), and the 122nd largest in CA, by population
- 32,290 of 65,622 are students
- Its liberal politics, many bicycles and bike paths (a haven for bicyclists), and UCD
- Second most educated city in the US (CNN Money Magazine) after Arlington, Virginia
- Weather: Dry, hot summers and cool, rainy, winters

### Climate data for Davis, California (1981–2010 normals)

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average high °F (°C)</strong></td>
<td>54  (12)</td>
<td>60  (16)</td>
<td>66  (19)</td>
<td>73  (23)</td>
<td>81  (27)</td>
<td>89  (32)</td>
<td>93  (34)</td>
<td>93  (34)</td>
<td>89  (32)</td>
<td>79  (26)</td>
<td>65  (18)</td>
<td>54  (12)</td>
<td>74.7 (23.8)</td>
</tr>
<tr>
<td><strong>Average low °F (°C)</strong></td>
<td>38  (3)</td>
<td>41  (5)</td>
<td>44  (7)</td>
<td>46  (8)</td>
<td>52  (11)</td>
<td>56  (13)</td>
<td>57  (14)</td>
<td>56  (13)</td>
<td>54  (12)</td>
<td>49  (9)</td>
<td>43  (6)</td>
<td>38  (3)</td>
<td>47.8 (8.7)</td>
</tr>
<tr>
<td><strong>Precipitation inches (mm)</strong></td>
<td>3.92 (99.6)</td>
<td>3.87 (98.3)</td>
<td>2.77 (70.4)</td>
<td>1.17 (29.7)</td>
<td>.56 (14.2)</td>
<td>.20 (5.1)</td>
<td>0  (0)</td>
<td>.05 (1.3)</td>
<td>.26 (6.6)</td>
<td>.90 (22.9)</td>
<td>2.36 (59.9)</td>
<td>3.54 (89.9)</td>
<td>19.60 (497.8)</td>
</tr>
</tbody>
</table>
Prof. Simon R. Cherry

- University College London, B.Sc. (Hons) 1986
- University of London, Ph.D. 1989

- 2001 – present, Professor, Dept. of Biomedical Engineering, University of California, Davis
- 2003 – present Director, Center for Molecular and Genomic Imaging, UC Davis

- 2008 Elected Fellow, Institute of Electrical and Electronic Engineers
- 2009 Elected Fellow, American Institute of Medical and Biological Engineers
- 2010 Elected Fellow, Biomedical Engineering Society
- 2012 Edward J Hoffman Medical Imaging Scientist Award

- 2001 – present Editorial Board, Molecular Imaging & Biology
- 2001 – present Editorial Board, Molecular Imaging
- 2011 – present Editorial in Chief, Physics in Medicine and Biology
Available Imaging Modalities (incomplete)

CT  MRI  Optical Imaging  PET/SPECT

Morphology  Morphology (Function)  Function  Function
## Modality Tools

<table>
<thead>
<tr>
<th>MODALITY</th>
<th>MODEL</th>
<th>MANUFACTURER</th>
<th>RESOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET</td>
<td>Inveon DPET</td>
<td>Siemens</td>
<td>~ 1.5 mm</td>
</tr>
<tr>
<td>PET</td>
<td>Focus 120</td>
<td>Siemens</td>
<td>~ 1.5 mm</td>
</tr>
<tr>
<td>PET</td>
<td>Primate 4</td>
<td>Siemens</td>
<td>~ 2.0 mm</td>
</tr>
<tr>
<td>PET/CT</td>
<td>Discovery 610</td>
<td>GE</td>
<td>~ 4 mm / 350 μm</td>
</tr>
<tr>
<td>SPECT</td>
<td>Inveon</td>
<td>Siemens</td>
<td>~ 0.5 – 3 mm</td>
</tr>
<tr>
<td>CT</td>
<td>Inveon</td>
<td>Siemens</td>
<td>~ 50 – 150 μm</td>
</tr>
<tr>
<td>High Resolution Specimen CT</td>
<td>MicroXCT-200</td>
<td>Xradia</td>
<td>~ 1 – 20 μm</td>
</tr>
<tr>
<td>MRI</td>
<td>Biospec 7T</td>
<td>Bruker</td>
<td>~ 100 – 250 μm</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>Sequoia</td>
<td>Siemens</td>
<td>~ 100 – 500 μm</td>
</tr>
<tr>
<td>Optical</td>
<td>Maestro 2</td>
<td>Perkin Elmer</td>
<td>~ 1 – 5 mm</td>
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<tr>
<td>Optical</td>
<td>IVIS Spectrum</td>
<td>Perkin Elmer</td>
<td>~ 20 μm – 5 mm</td>
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<tr>
<td>Optical</td>
<td>Optical Cyromicrotome</td>
<td>Barlow Instruments</td>
<td>~ 10 – 30 μm</td>
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<tr>
<td>Autoradiography</td>
<td>Storm 860</td>
<td>Amersham Biosciences</td>
<td>~ 50 – 100 μm</td>
</tr>
</tbody>
</table>
Spatial Resolution and Sensitivity Requirements for Small Animal PET

~ 5 mm spatial resolution

~ 0.5 mm spatial resolution

High sensitivity is required for scanner with higher spatial resolution to achieve similar pixel based signal to noise ratio.
Spatial resolution of small animal PET scanners can still be improved by reducing crystal size.
Setup for DOI Measurement

5 depths of 1.5, 4, 6.5, 9 and 11.5 mm were selectively irradiated by electric collimation.
Depth of Interaction Error

DOI error:
• degrades both radial and axial spatial resolution.
• increases as the crystal length and axial FOV increases
• increases as scanner ring diameter decreases.

Detector with good depth encoding required to simultaneously achieve high sensitivity and high spatial resolution.
Factors Determining Spatial Resolution

\[ SR = k_{\text{reconstruction}} \sqrt{\left(\frac{\text{crystal}}{2}\right)^2 + (\text{positron \_ range})^2 + (0.0022D)^2 + (\text{decoding})^2 + (\text{DOI})^2} \]

Smaller crystal size (0.44 mm)
Smaller ring diameter (60 mm)
Position-sensitive APD
Dual-ended readout with \( \sim 1.5 \) mm DOI resolution
Iterative reconstruction with accurate system model

Goal: Develop a prototype small-animal PET scanner to assess the feasibility of achieving a reconstructed resolution of \( \sim 0.5 \) mm

WW Moses, *NIM A648*(2011)s236
In Vivo Animal Images

Prototype scanner
- 12.6 gram mouse
- 220 µCi $^{18}$F-fluoride
- Scan time: 1 hour
- 3D list mode OSEM

Siemens Inveon D-PET
- 11.9 gram mouse
- 260 µCi $^{18}$F-fluoride
- Scan time: 0.5 hour
- 2D OSEM reconstruction
Why PET/MRI?

- Large variety of PET tracers
- Sensitivity of PET is in the pico-molar range
- MR delivers high resolution and high soft tissue contrast images
- PET images may be complemented by additional functional imaging capabilities of MR (spectroscopy, fMRI, etc.)
- Simultaneous imaging of PET and MRI
  - Save total acquisition time
  - Image multiple dynamic processes
- Use MRI to correct for motion in PET data
- No additional radiation dose applied by MRI
Why PET/MRI?

1st PET Insert

University of Davis, California, USA

- Hybrid approach using short fibers and position sensitive APDs (provide intrinsic multiplexing)
- Operated inside a 7 T MRI
- Excellent MR performance due to absence of metallic materials at the center FOV

Position Profile

![Position Profile Graphs]

- **Horizontal**
- **Vertical**

*Graphs showing counts against flood pixel index for horizontal and vertical orientations.*
Noise and Signal

[Graphs showing the relationship between noise FWHM (Volts) and applied bias (Volts) at different temperatures and for different thicknesses.]
PS-SSPM

• Advantage
  – Simple electronics
  – Micro-cell level spatial resolution

• Disadvantage
  – Noise is large when the size is bigger
Scrambled crosswire readout

Schematic of “scrambled crosswire readout” technique
Flood Histogram

8 x 8 array of 1.5 x 1.5 x 12 mm³
ratio = \begin{cases} \frac{s \cdot R_d \cdot n_1}{s \cdot R_d (C_d + 2n_1) + 1} & \text{if signal is splitted} \\ \frac{2s \cdot R_d \cdot n_1}{s \cdot R_d (C_d + 2n_1) + 1} & \text{if signal is not splitted} \end{cases}