Overview of RMD Silicon Semiconductor Detector Activities

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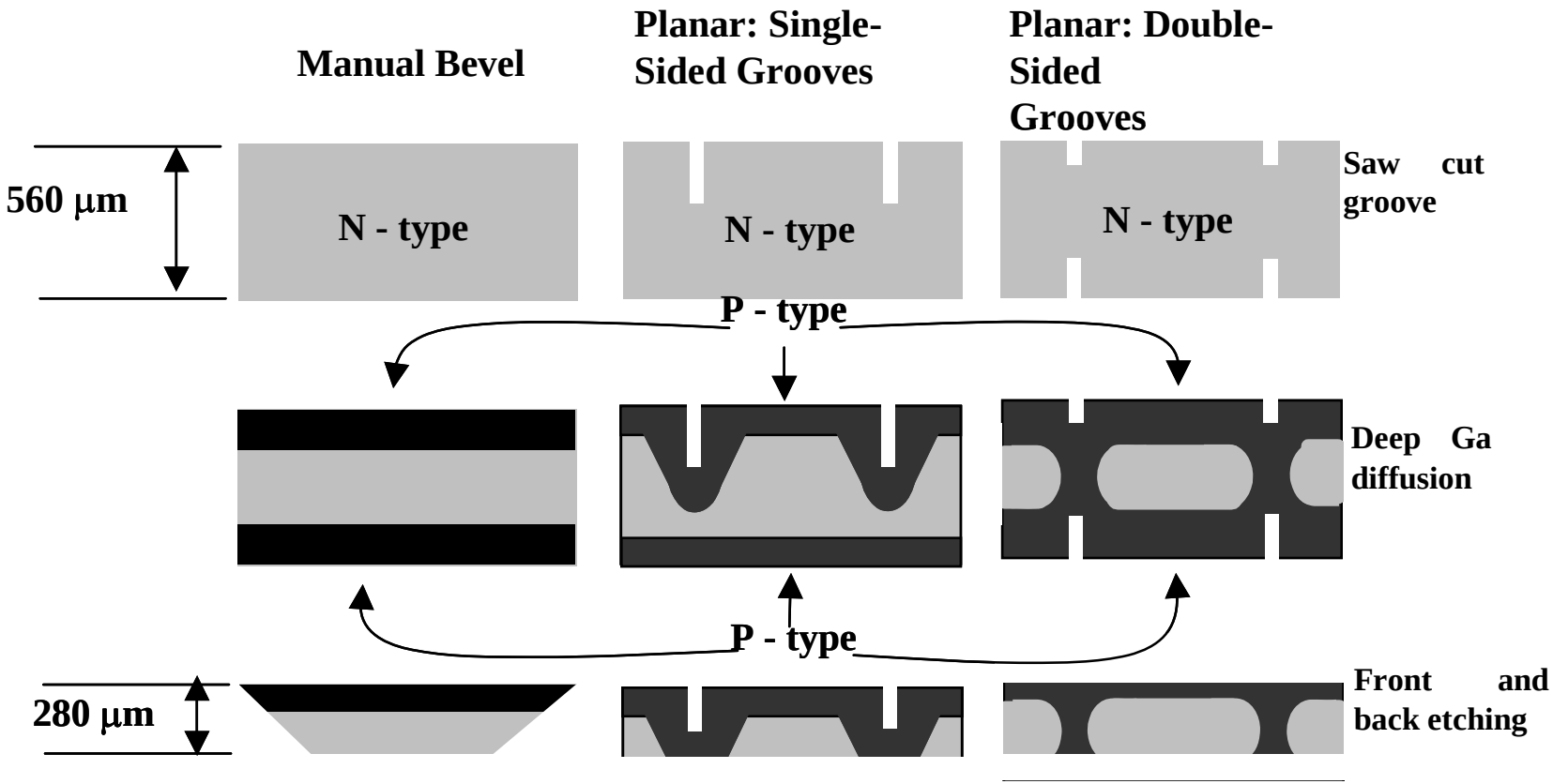
LIGHT07

Workshop on the Latest Developments of Photon Detectors 2007

OVERVIEW

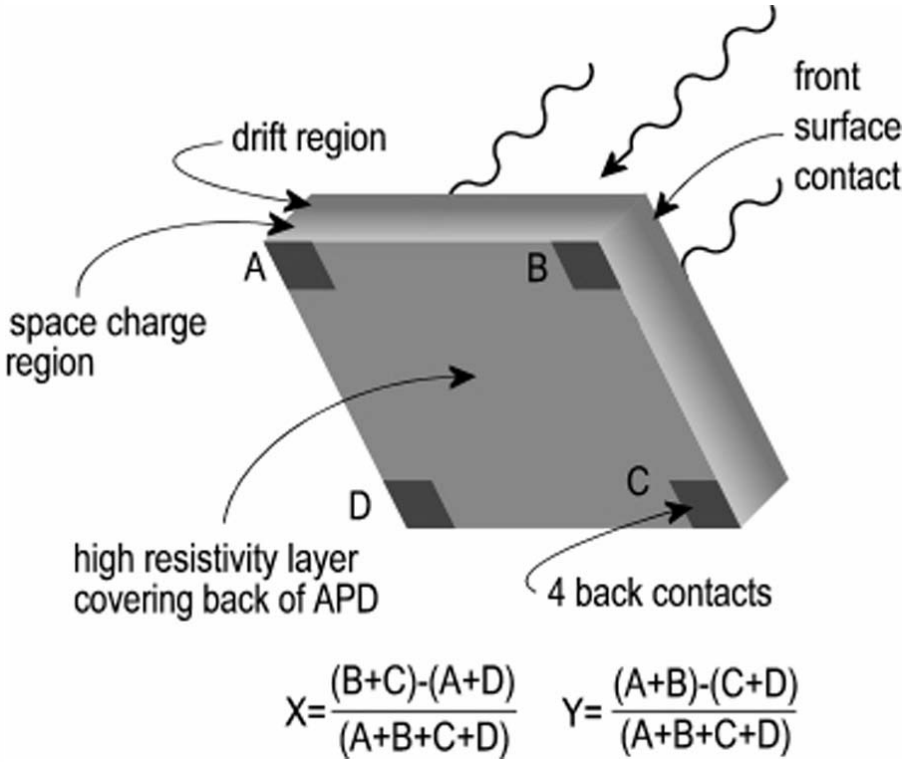
- Planar Process for Deep Diffused Silicon APDs and Position Sensitive APDs (PSAPDs)
- Characteristics of Planar APDs and PSAPDs.
- Detector Applications
  - Positron Emission Tomography (PET)
  - High-Energy Physics Experiments (LXe)
  - Homeland Security
- SSPM Development
- Summary

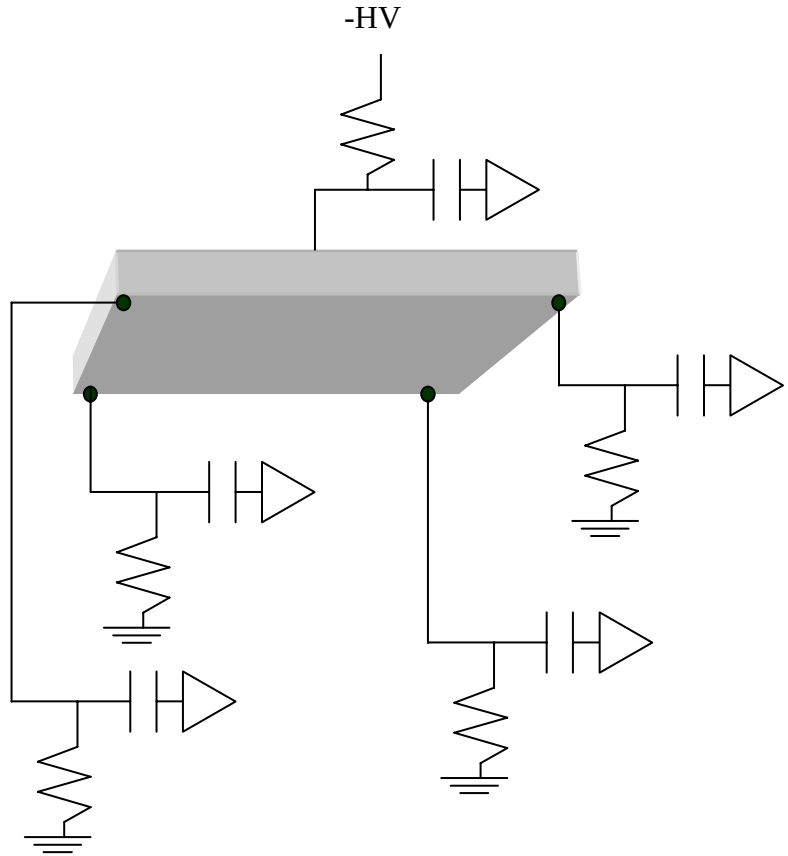
Planar Process for APD Fabrication



R Farrell, K.S. Shah, K. Vanderpuye, R. Grazioso, R. Myers, G. Entine, "APD arrays and large-area APDs via a new planar process," *Nuc. Inst. Meth. Phys. Res. A*, vol. 442, pg. 171, 2000.

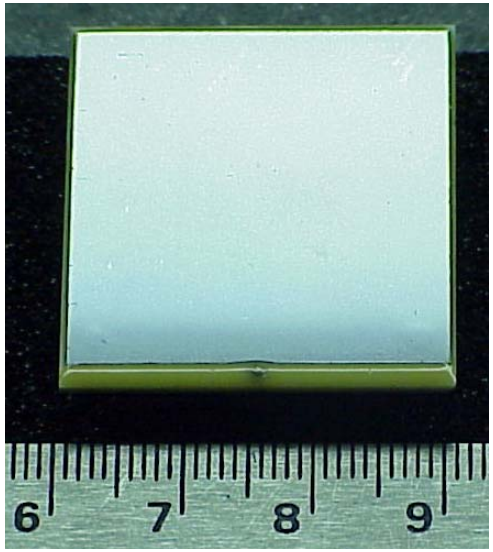
Fabrication for Position Sensitivity

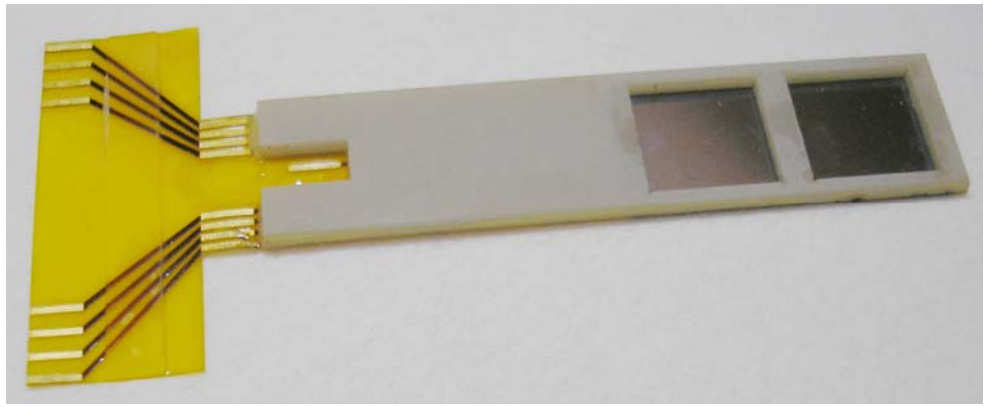


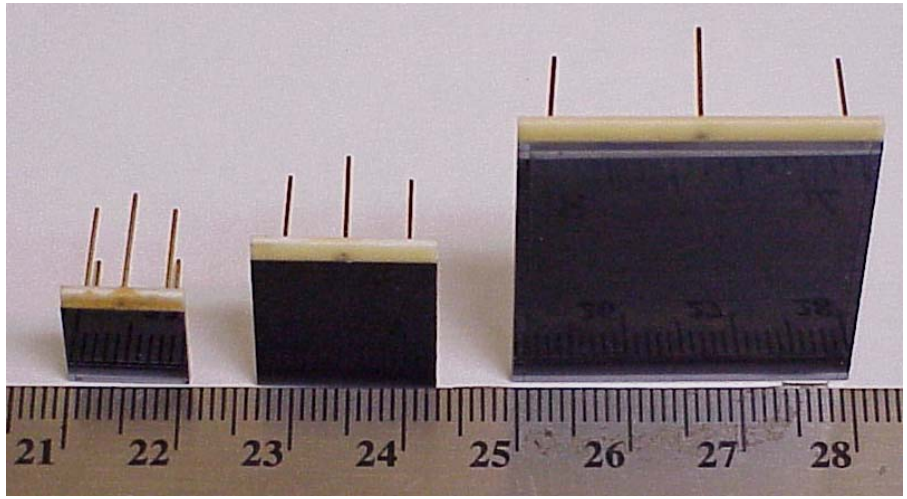


K.S. Shah, R. Farrell, R. Grazioso, E. Harmon, E. Karplus, "Position-sensitive avalanche photodiodes for gamma-ray imaging," *IEEE Trans. Nuc. Sci.*, vol. 49, no. 4, August 2002

Various APDs and PSAPDs

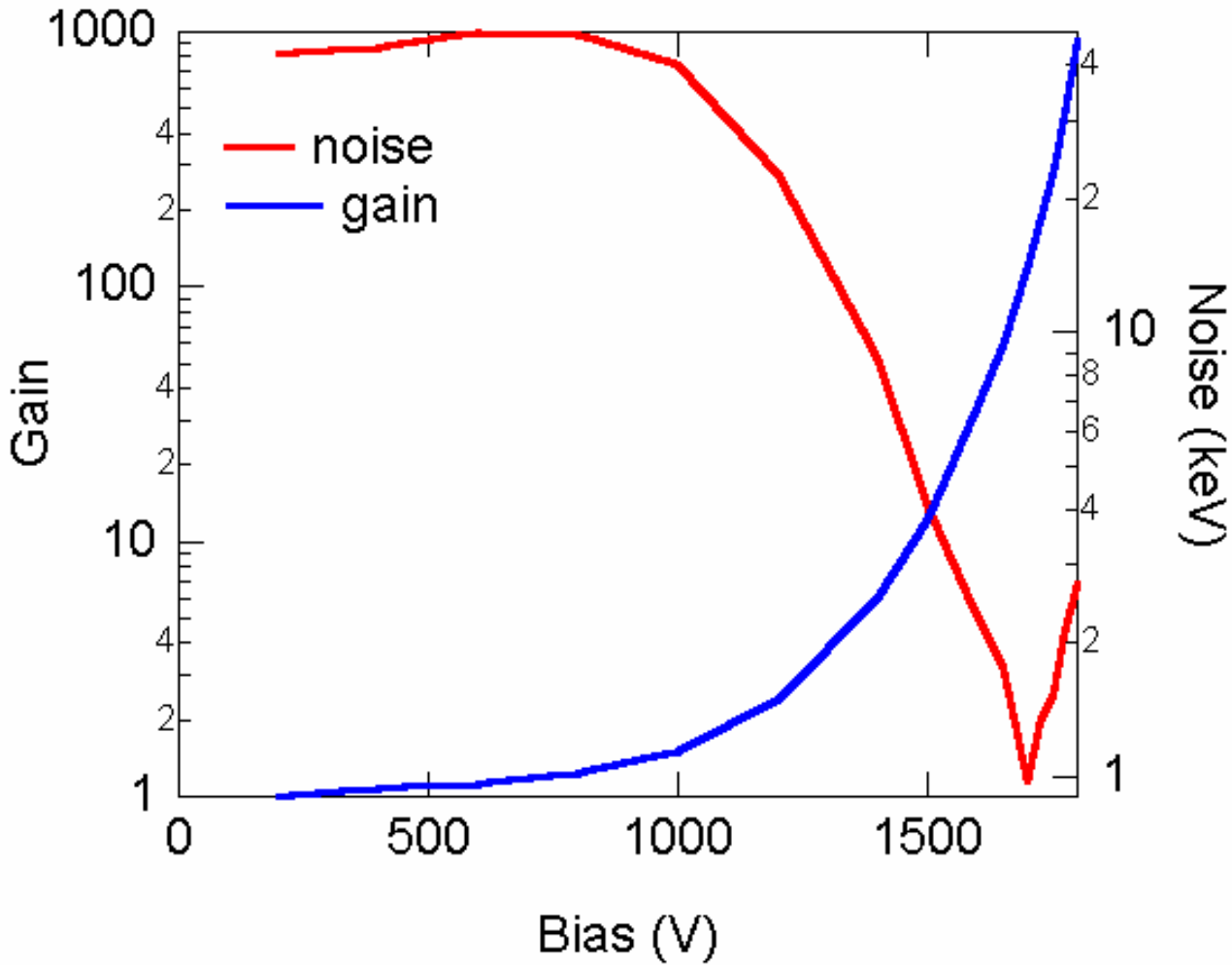




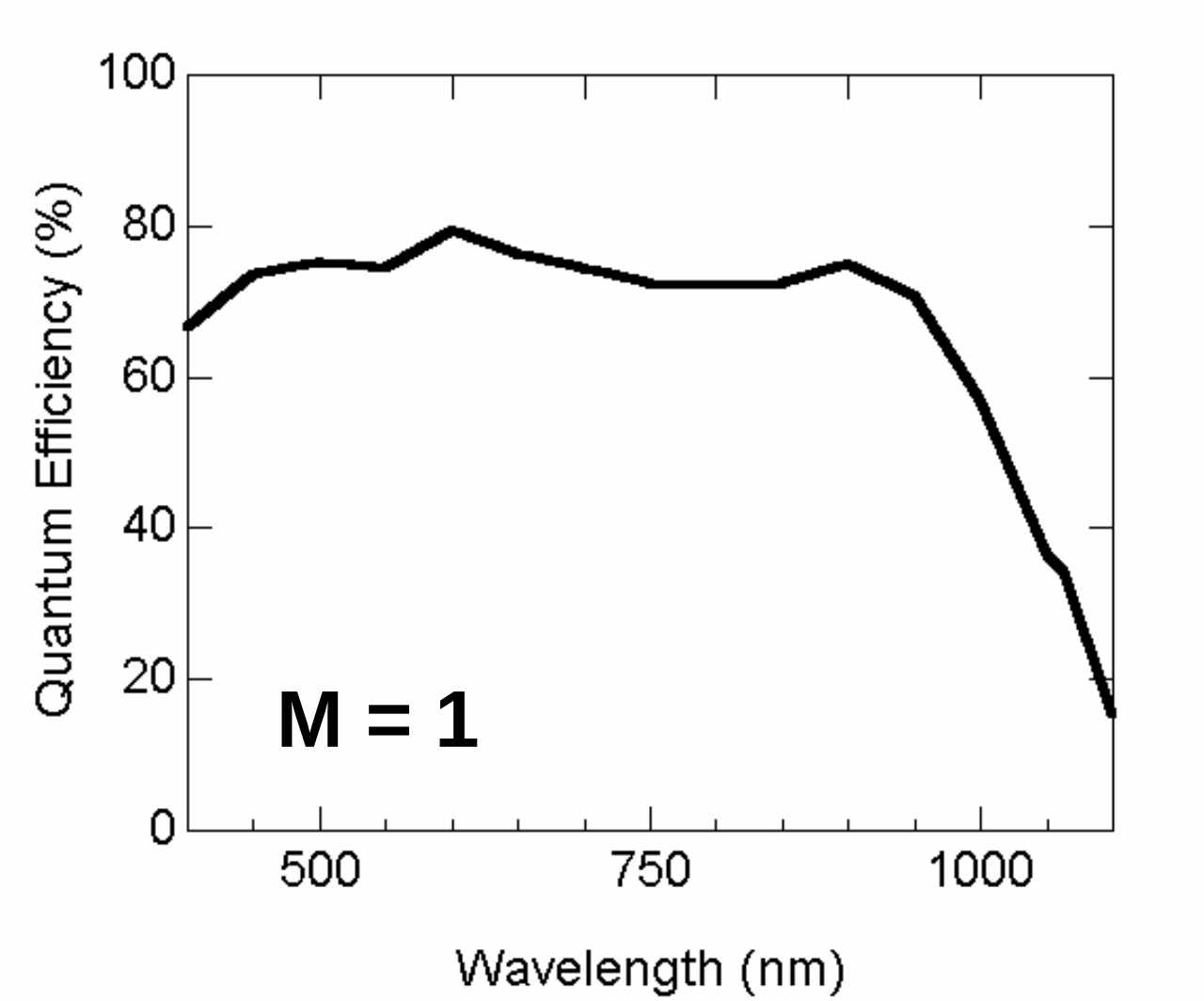


APD/PSAPD Gain and Noise

8 x 8 mm² APD at room temperature (24 °C)



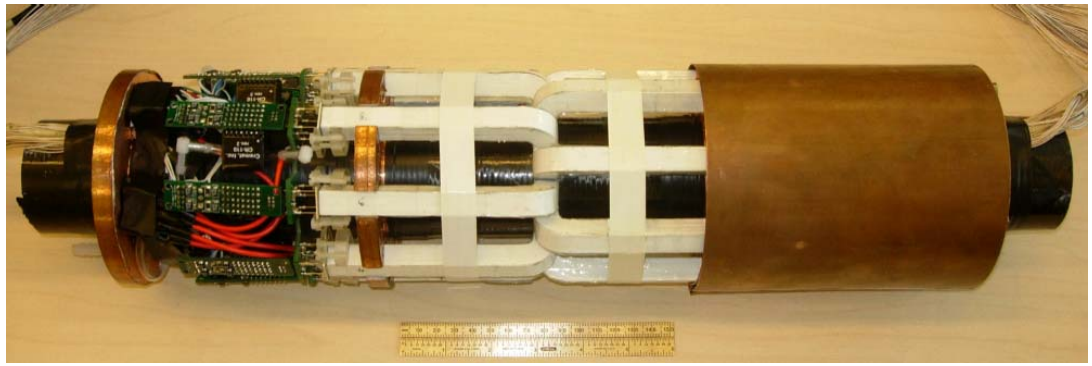
APD/PSAPD Quantum Efficiency



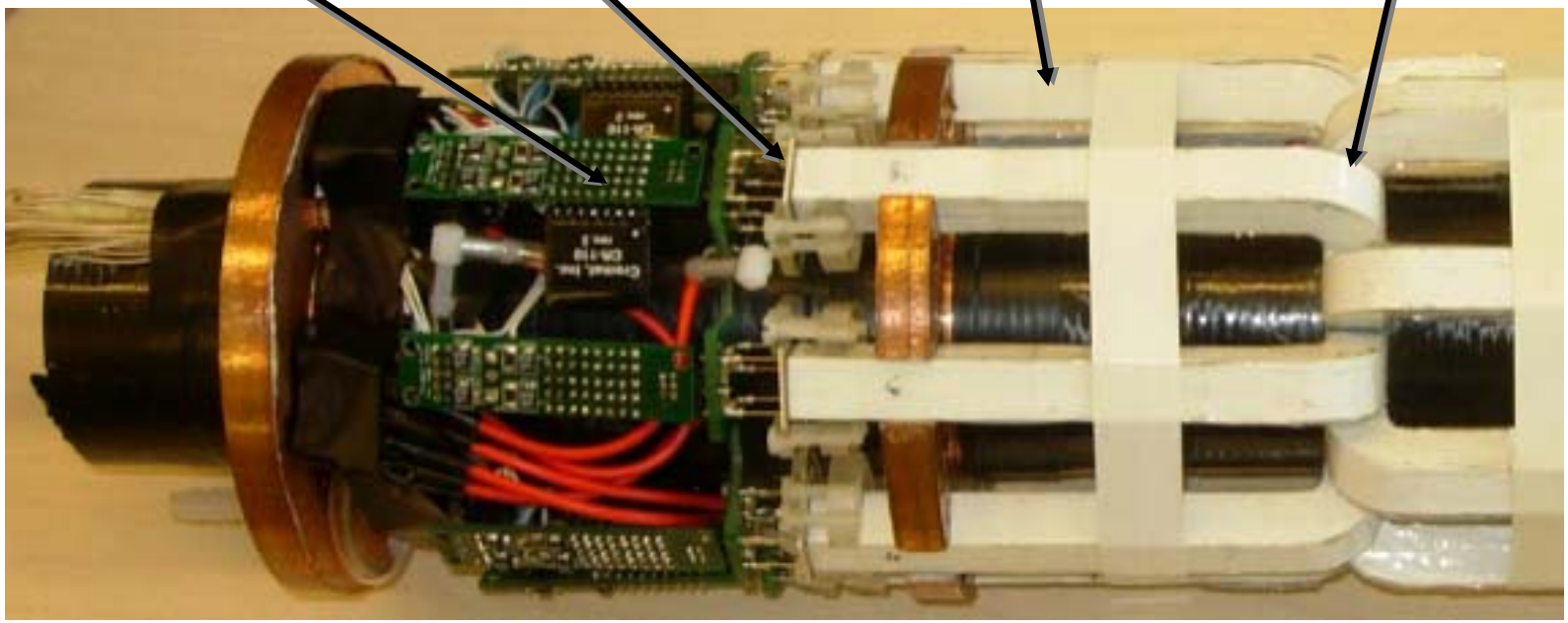
Current Major APD/PSAPD Projects

- **Medical Imaging**
  - **Small Animal PET**
    - **UC-Davis (Simon Cherry)**
    - **Stanford University (Craig Levin)**
    - **UC-SF (Bruce Hasegawa)**
- **High-energy physics experiments**
  - **LXe studies at Rice (Uwe Oberlack) and Brown Universities (Rick Gaitskell)**
- **Homeland Security**

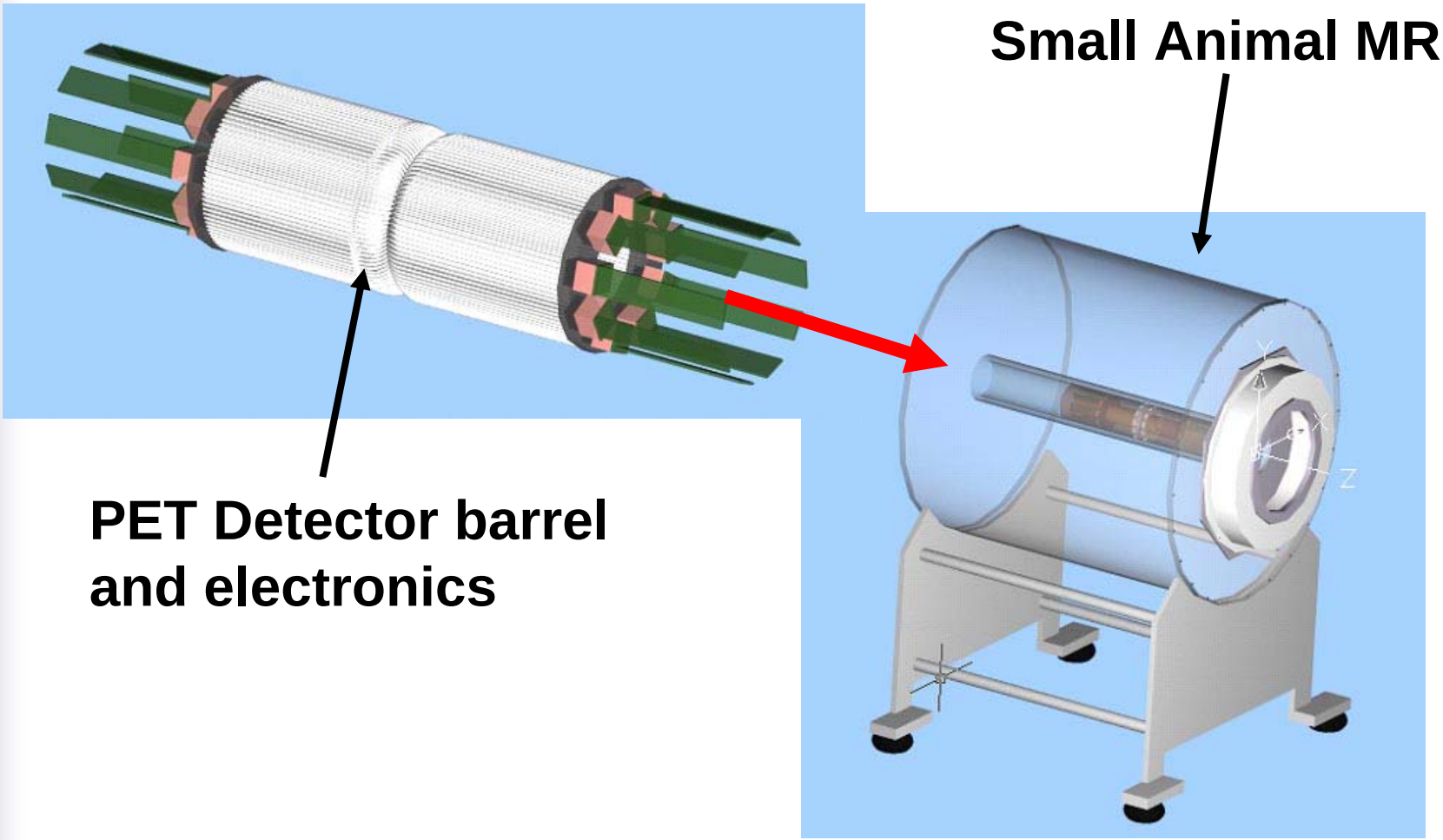
UC-Davis PET/MRI Prototype



preamplifiers PSAPDs optical fibers scintillator ring



PET/MRI Prototype

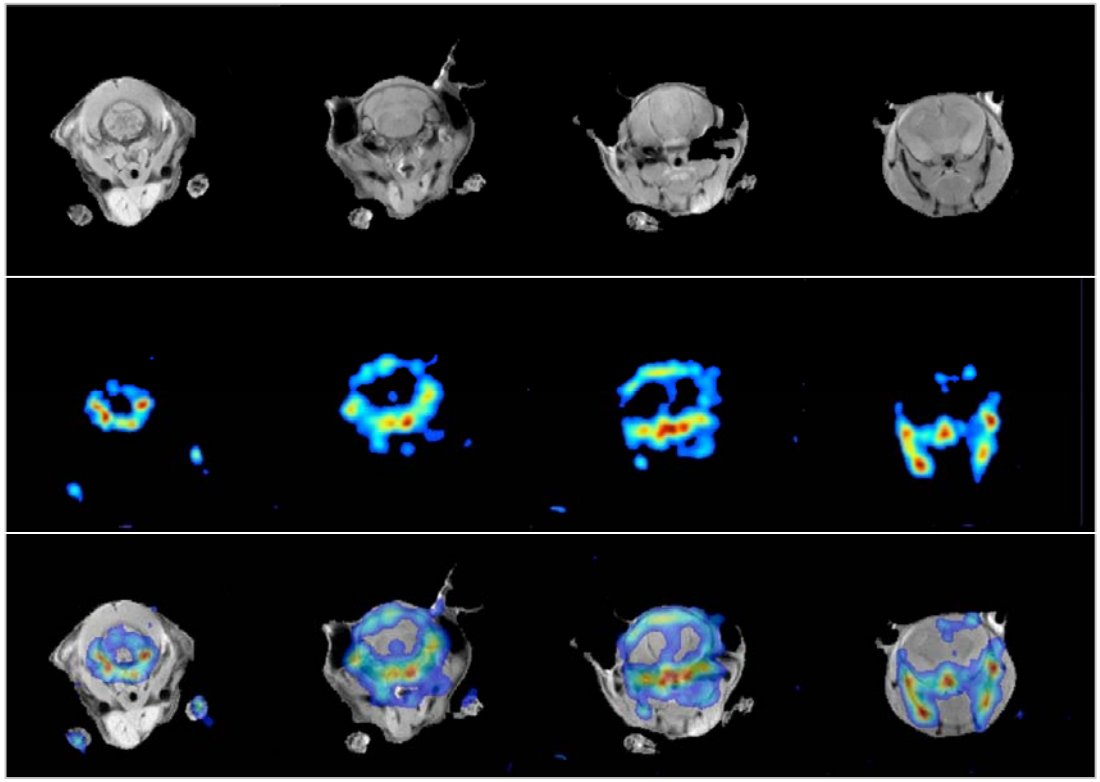


PET/MRI Prototype Phantom Images

MRI

PET (^{18}F)

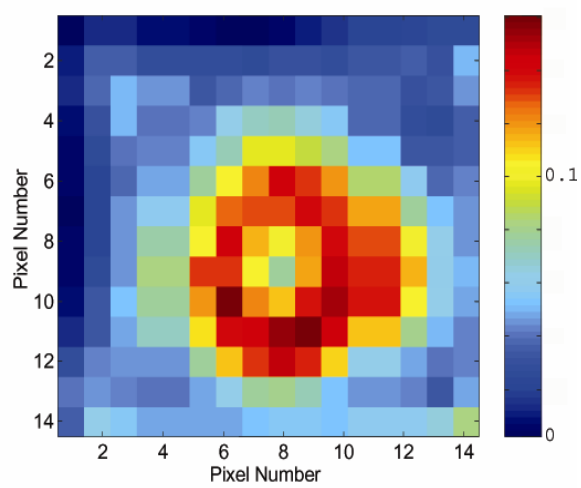
Combined

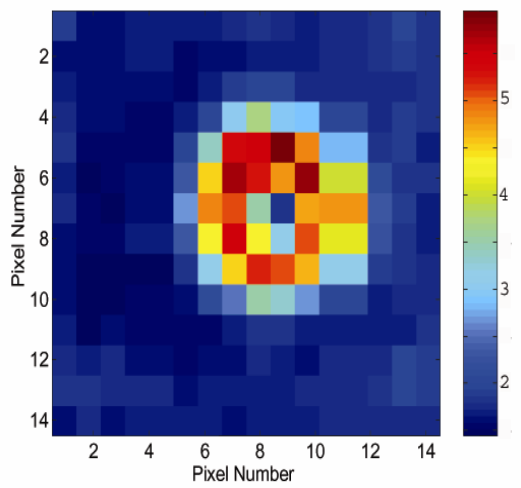


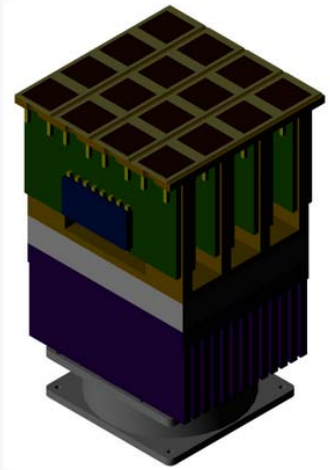
C. Cantan, Y. Wu, M.S. Judenhofer, J. Qi, B.J. Pichler, S.R. Cherry, “Simultaneous acquisition of multi-slice PET and MR images: initial results with a MR-compatible PET scanner,” *J. Nucl. Med.,* vol. 47, no. 12, pp. 1968-1976, Dec. 2006.

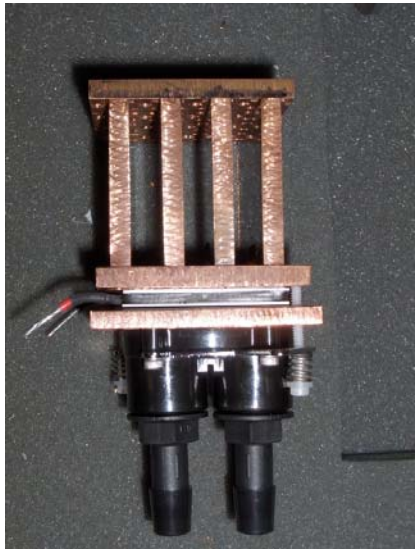
Small Animal SPECT

Mouse heart phantom images







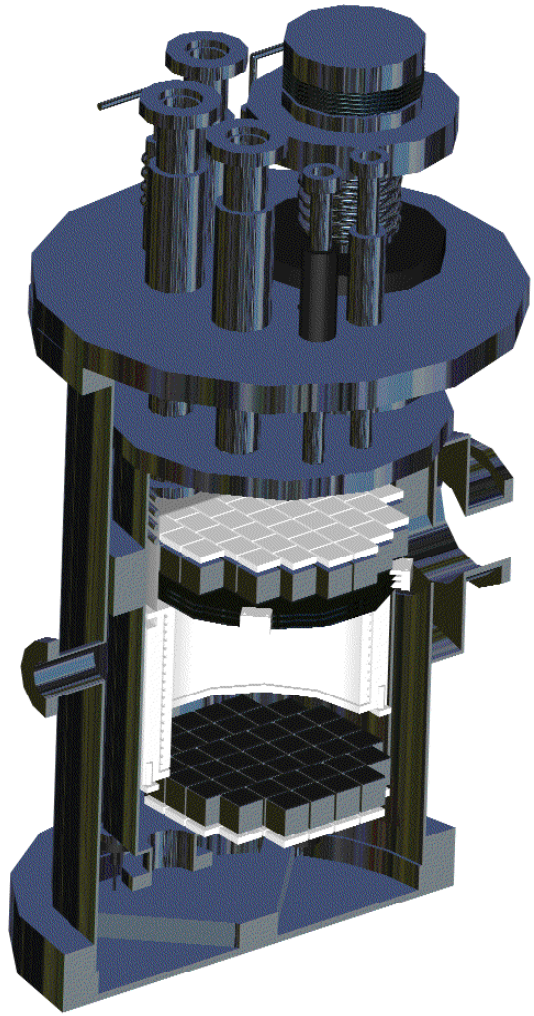


SPECT module comprised of 4 x 4 array of 8 mm PSAPDs.

Still under construction.

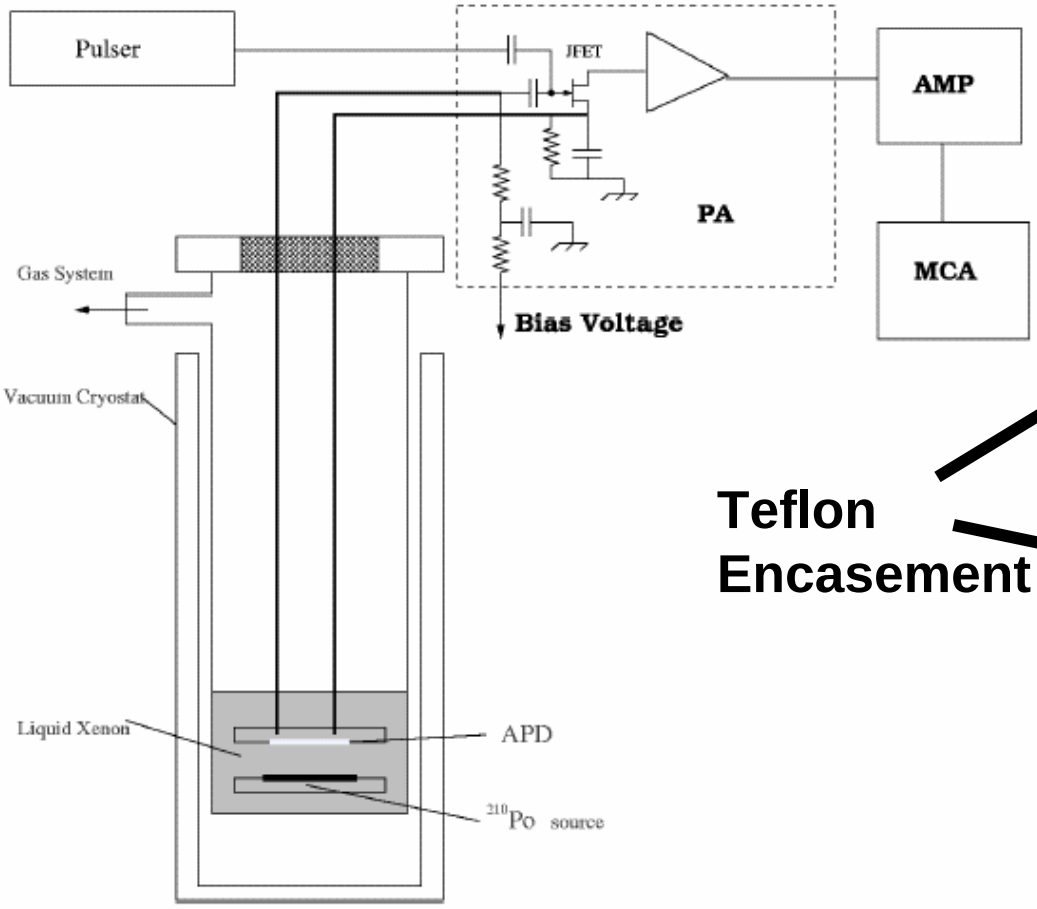
Detector for dark matter search?

- **LXe scintillation signals can be very small for lower energy events, favoring a photodetector with higher QE than that available in PMTs**
- **PMTs can have relatively high background due to radioactivity**
- **PMTs can be fragile and break due to the thermal stresses experienced in the presence of cold xenon liquid or gas**
- **Tiled PMTs can possess significant dead space**



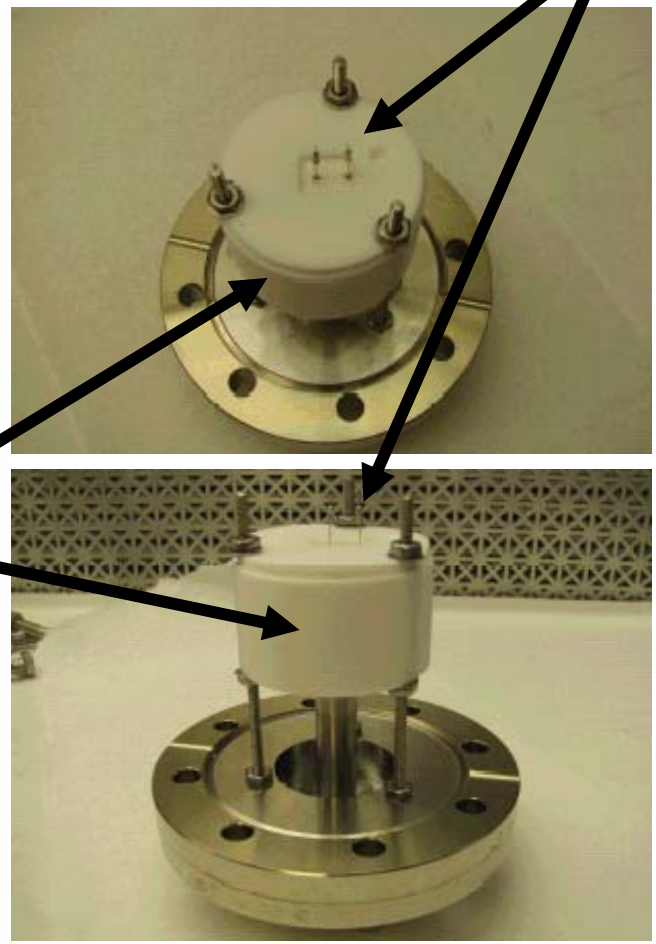
RMD

Liquid Xenon Studies



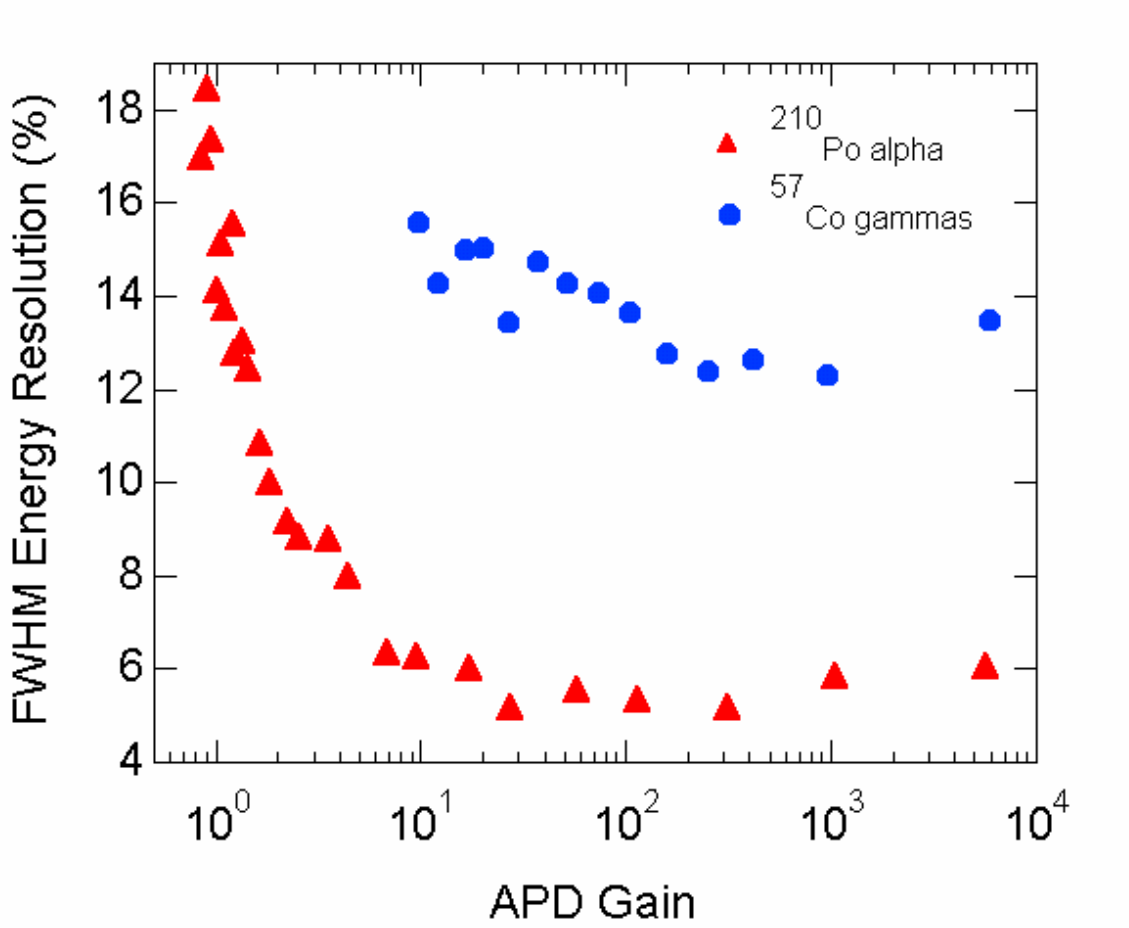
Biasing Pins

Teflon Encasement



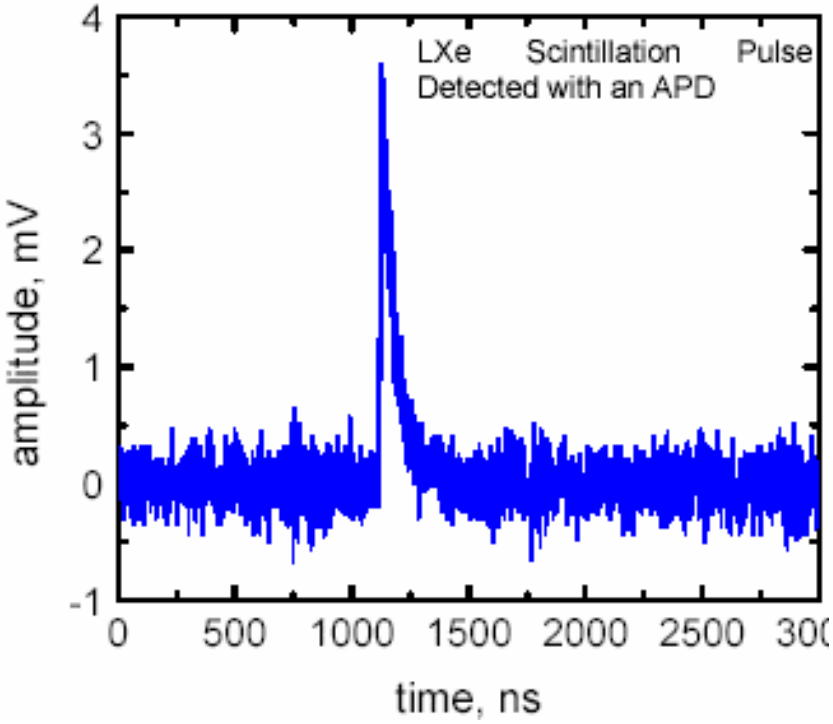
Basic Setup at Rice University

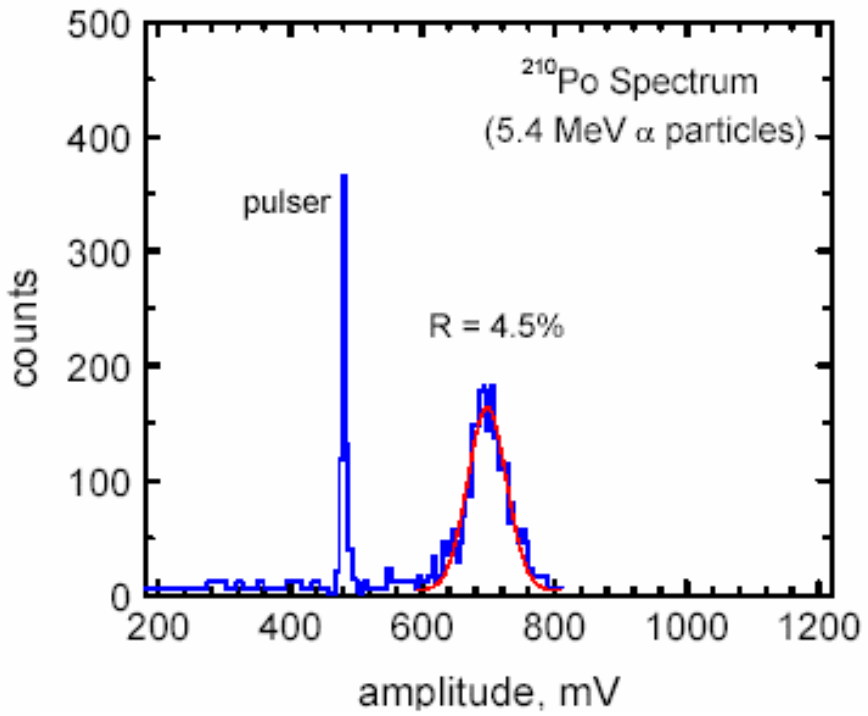
Liquid Xenon Studies



U. Oberlack, "Avalanche Photodiodes as Photosensors for Liquid Xenon Scintillation Light," IEEE Nuclear Science Symposium, San Diego, Oct. 30 2006

Liquid Xenon Studies

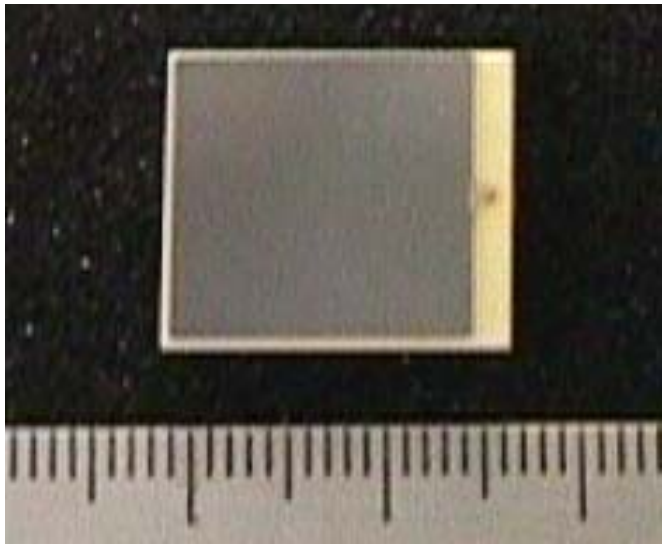




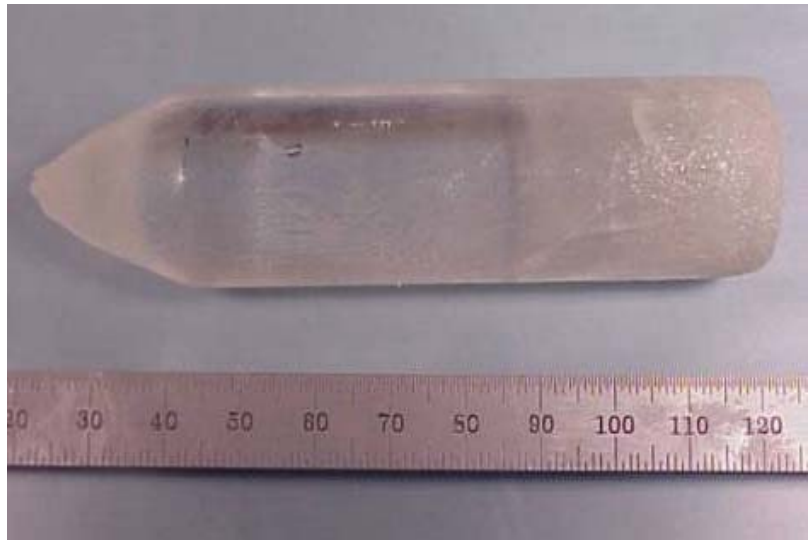
Measurements performed by Dr. Rick Gaitskell's group at Brown University.

Homeland Security

Monitoring the spread of nuclear materials requires scintillation based gamma-ray spectrometers to possess high sensitivity and high resolution.



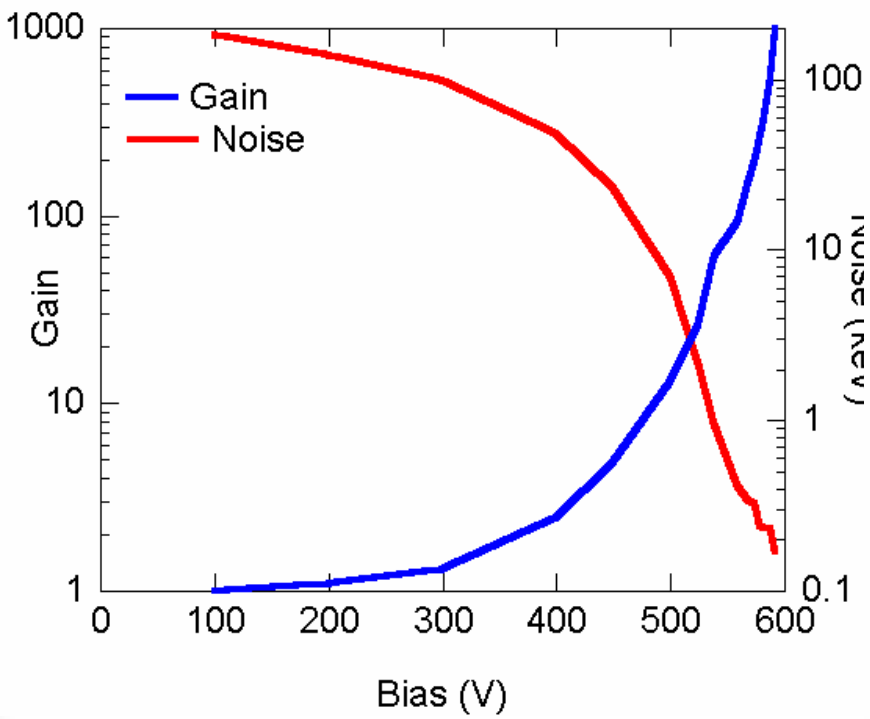
14 x 14 mm^2 blue-UV sensitive APD

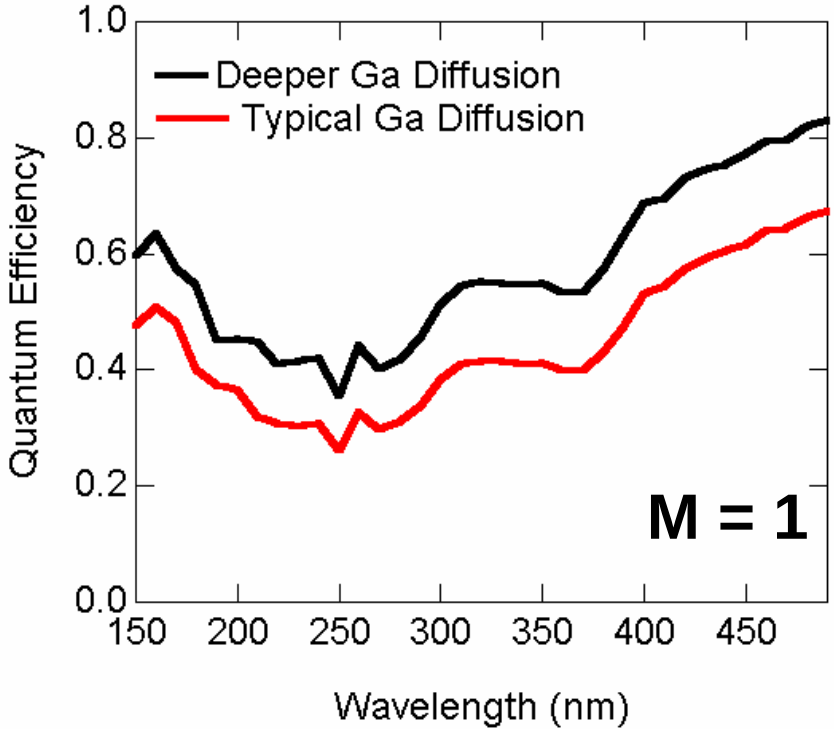


50 mm diameter $LaBr_3$:Ce

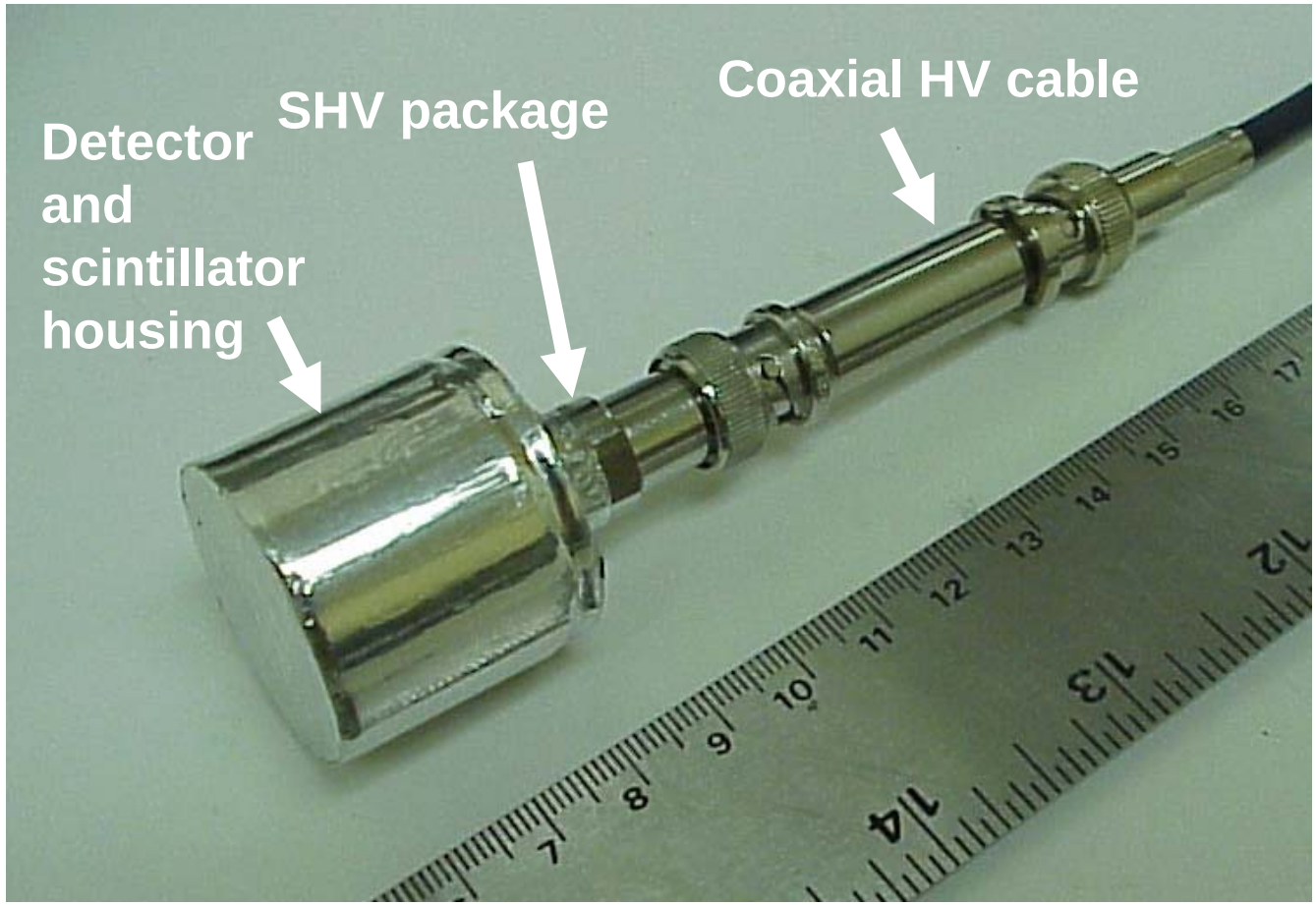
5 Ω-cm APD Gain, Noise, and QE

8 x 8 mm² APD at room temperature (24 °C)

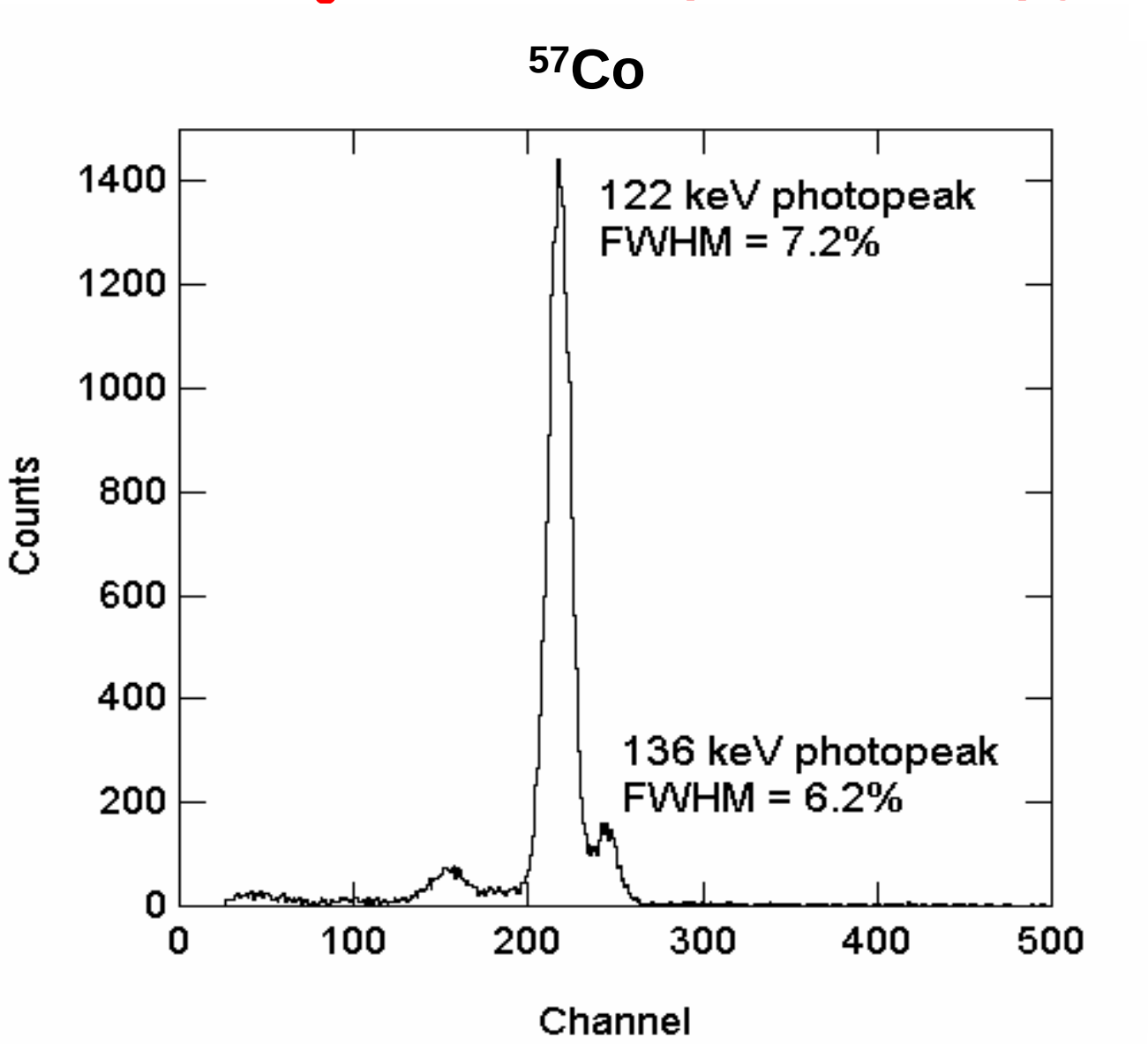




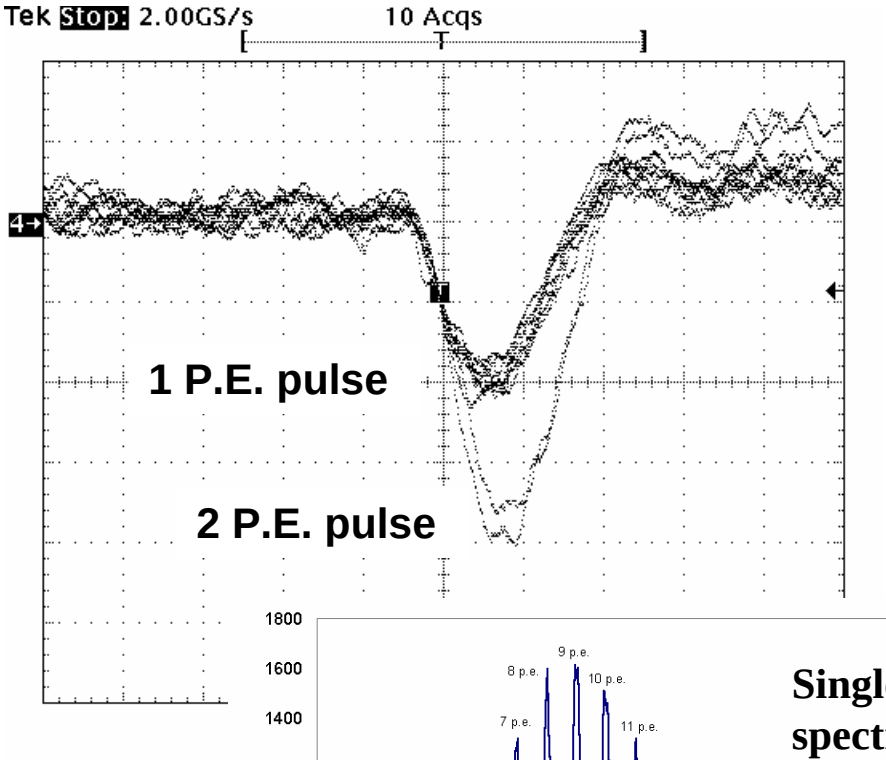
$LaBr_3$:Ce based APD Spectrometer Prototype

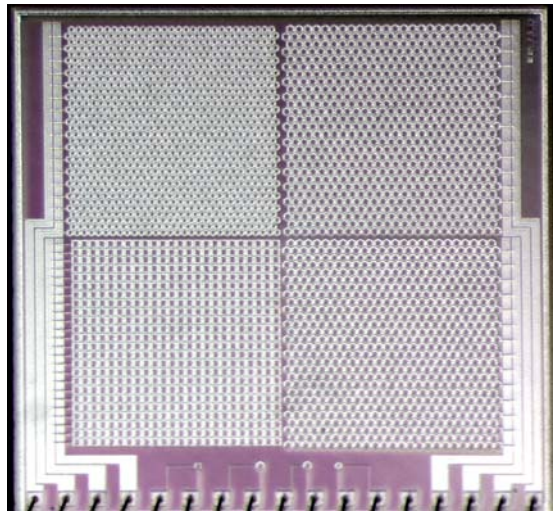


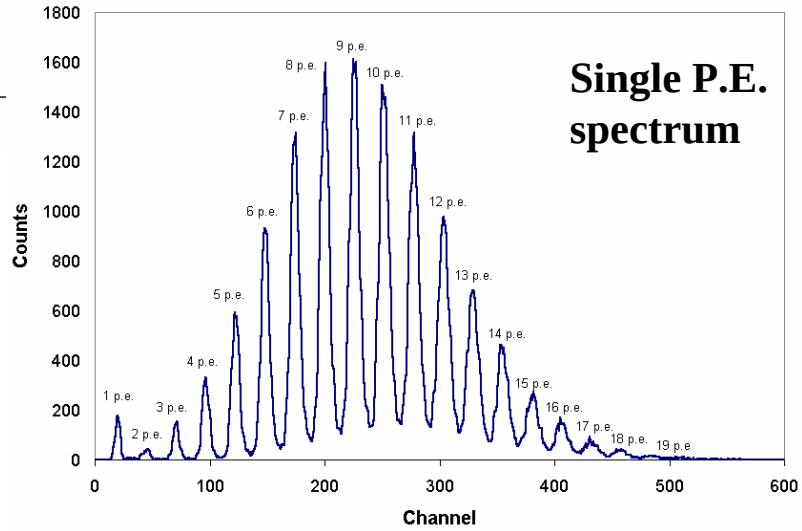
$LaBr_3$:Ce APD Spectroscopy



SSPM Development







2nd generation Research SSPMs

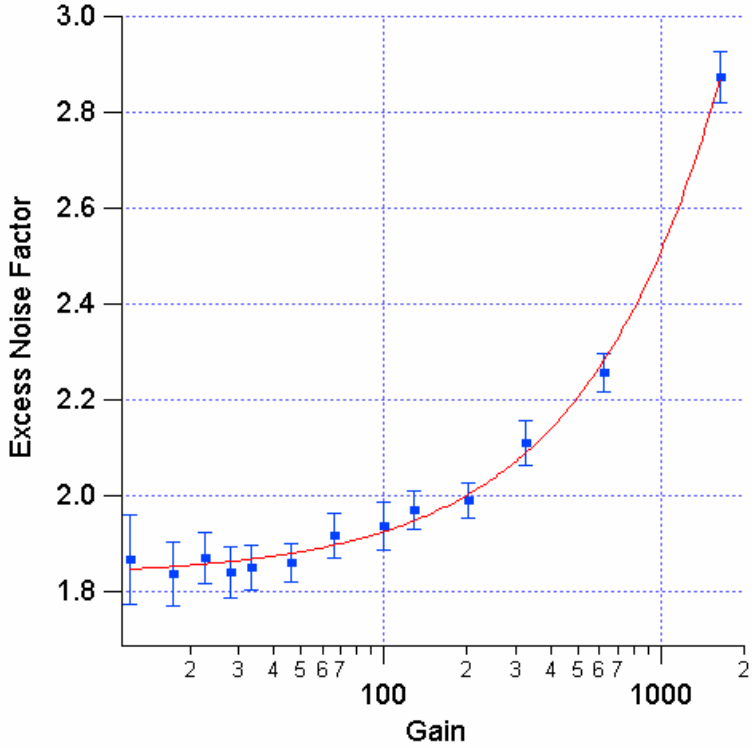
Four quadrants, each having different pixel geometries & fill factors. The CMOS chip is 3 x 3 mm^2, with each quadrant 1.5 x 1.5 mm^2

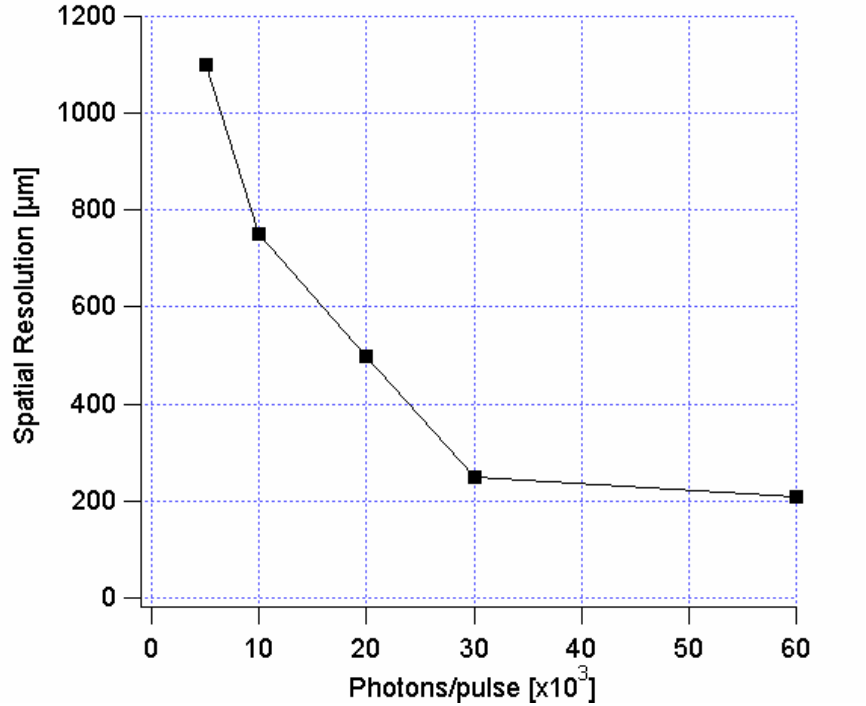
Summary

- **Silicon APD and PSAPD technology is advancing & improving. Development & application is proceeding in…**
  - **Medical Imaging (PET and SPECT)**
  - **Physics research (LXe based systems)**
  - **Homeland security**
- **CMOS SSPM technology is being actively researched at RMD. Our 2nd generation SSPM units are currently being characterized.**

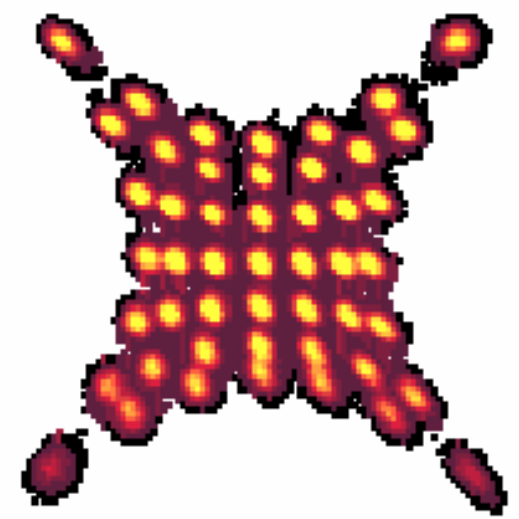
RMD

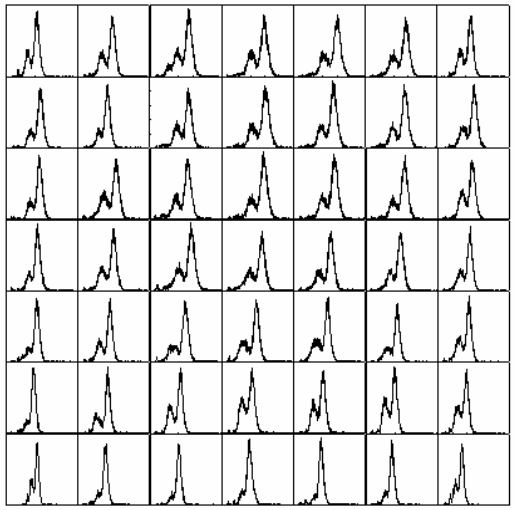
Extra Slide


Excess Noise Factor
3.0
2.8
2.6
2.4
2.2
2.0
1.8
2 3 4 5 6 7
100
2 3 4 5 6 7
1000
2
Gain

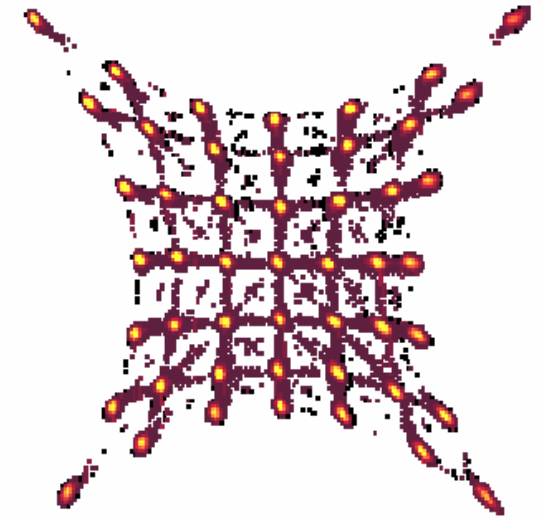

Spatial Resolution [µm]
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
Photons/pulse [x10^3]

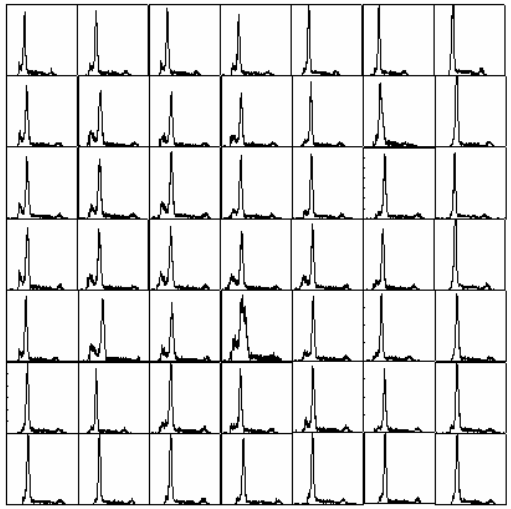
Extra Slide





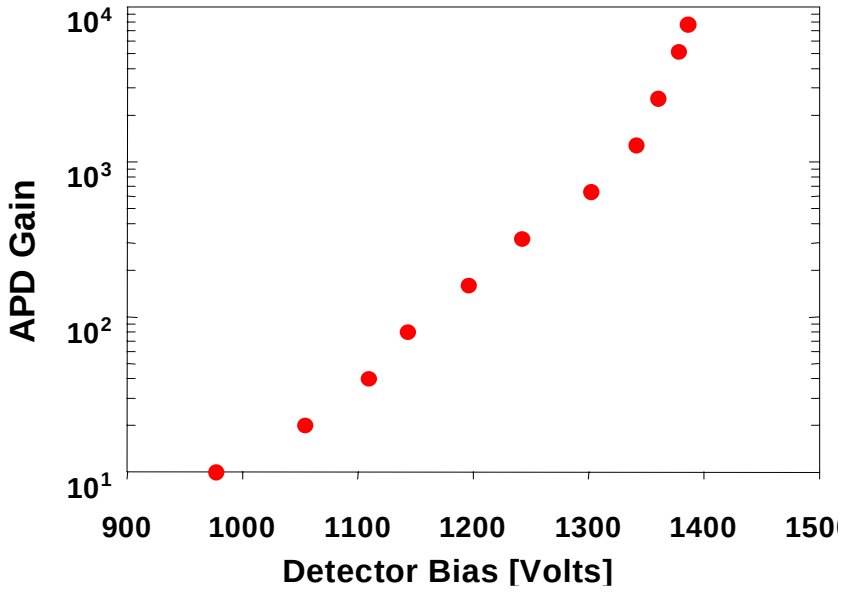
A uniform flood image and energy spectrum of a 7 x 7 CsI:Tl array with 3 mm pixels coupled to a 28 x 28 mm^2 PSAPD while cooled to -20°C and irradiated with ^{57}Co (122 keV)

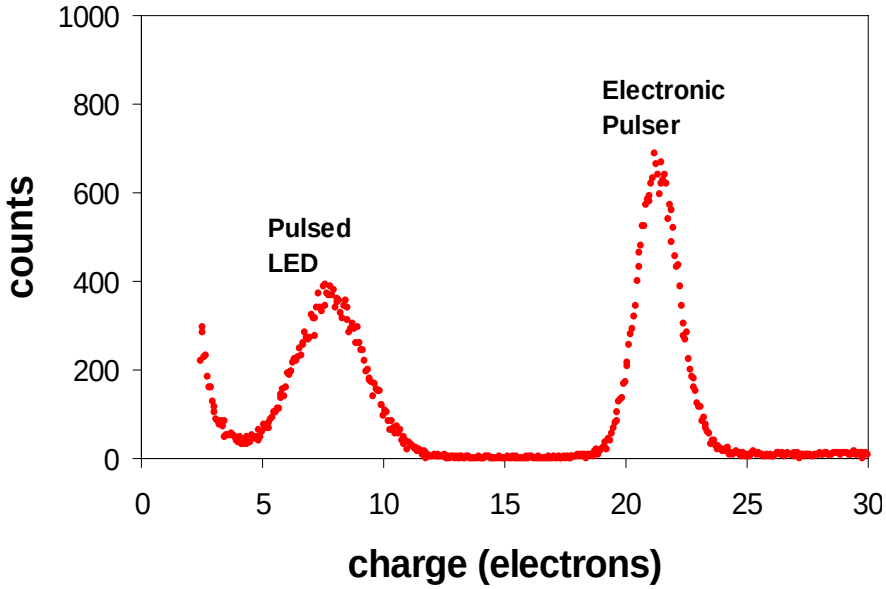




A uniform flood image and energy spectrum of a 7 x 7 LSO array with 3 mm pixels coupled to a 28 x 28 mm^2 PSAPD while cooled to - 20°C and irradiated with ^{22}Na (511 keV)

Extra Slide





45 cm^2 APD gain vs. bias at 77 °K.

45 cm^2 APD noise and optical detection at 77 °K. Noise = 0.8 electrons-RMS.

M. McClish, K.S. Shah, R. Farrell, F. Olschner, M. Squillante, "Characterization of very large silicon avalanche photodiodes," *IEEE NSS Conf. Rec.*, Oct. 16-24, 2004, Rome, Italy.

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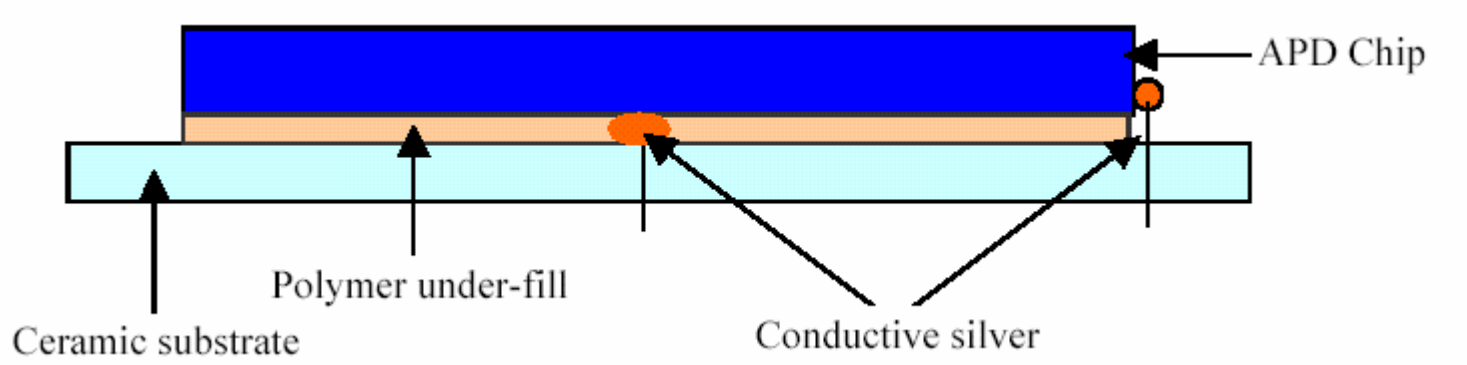
APD Chip
Polymer under-fill
Ceramic substrate
Conductive silver