Fast, Low Noise Photodetectors for Nuclear Physics

Presented by:

Mickel McClish

Principal Investigator

Kanai S. Shah

DOE Contract Number

DE-FG02-08ER84988

Outline

- Motivation for SSPM development
- SSPM introduction
- Overview of SSPM performance properties
  - Discrete
  - Position sensitive
- RMD corporate background

Motivation to Replace PMTs

PMTs possess high gain (10^6) and low noise (ENF ~ 1) but…

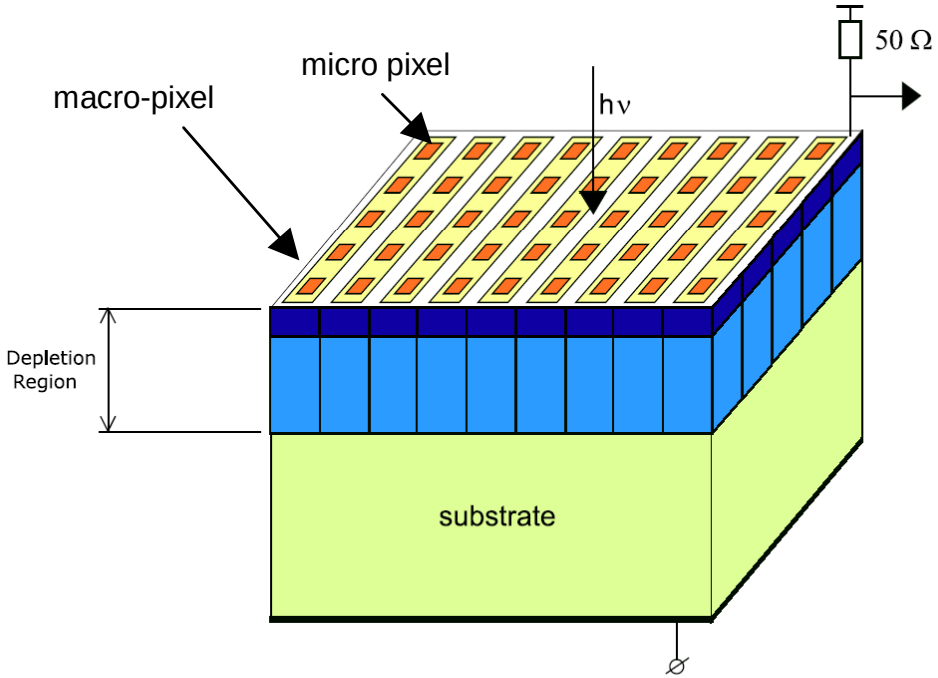
- **PMTs are bulky and fragile**
- **PMTs are sensitive to magnetic fields**
- **PMTs require high bias (~1000 V)**
- **PMTs have low quantum efficiency**
- **Spectral response of PMTs is narrow**

Solid-State Photomultipliers

General SSPM main features

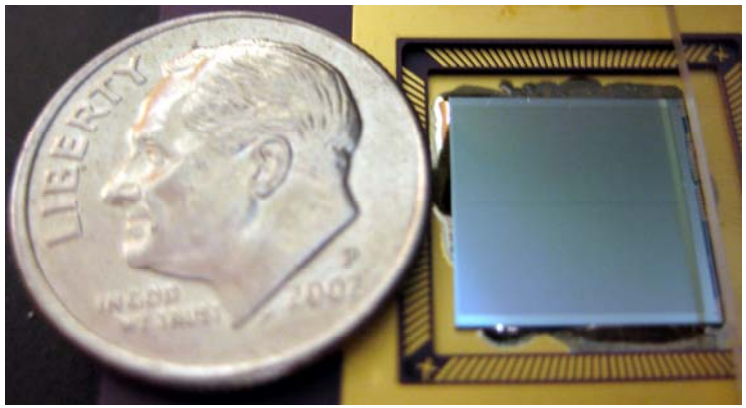
- Very high gain (>10^5), very simple electronic readout
- Low bias operation (~30 V)
- Fast response (sub-ns rise time)
- Very low excess and electronic noise (<1 electron level)
  - ❖ Dark noise a problem at very low light levels
- Insensitive to magnetic fields
- Position sensitive structures possible
- RMD fabricates these devices by CMOS process, hence cost should be very low upon mass production.
- On-chip integration of readout electronics possible

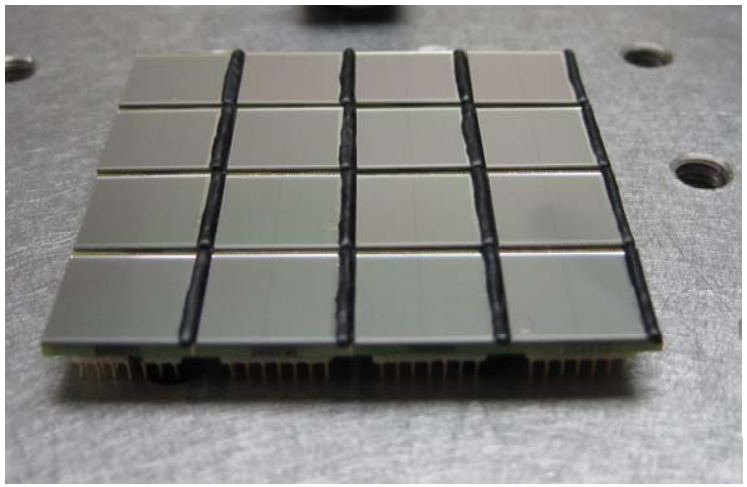
Silicon Photomultiplier Introduction

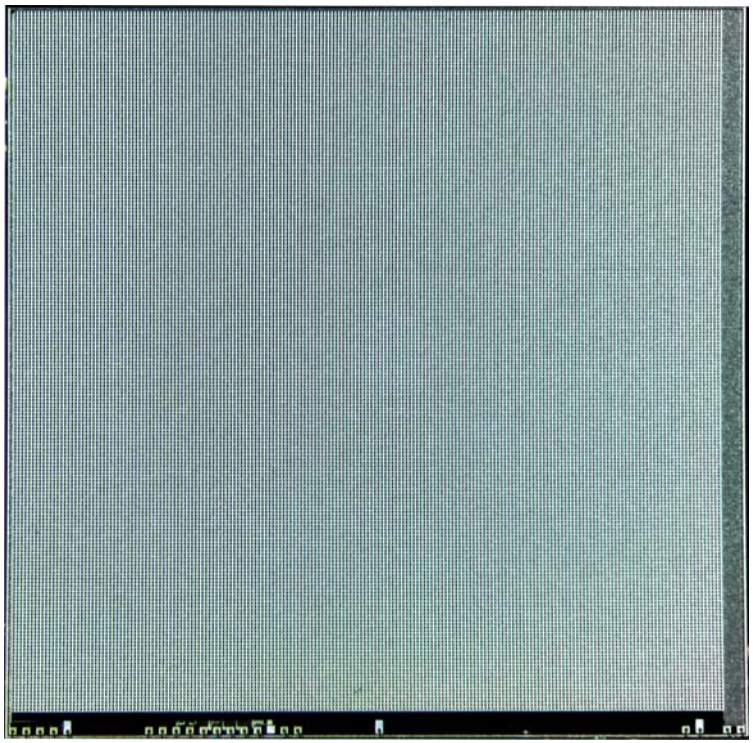


- Independent Geiger Mode Micro-APDs (~ 30 μm)
- Passively quenched
- Binary output, constant amplitude
- Common substrate, signals are summed
- Single macro analog output

1 cm^2 Large Area CMOS SSPMs

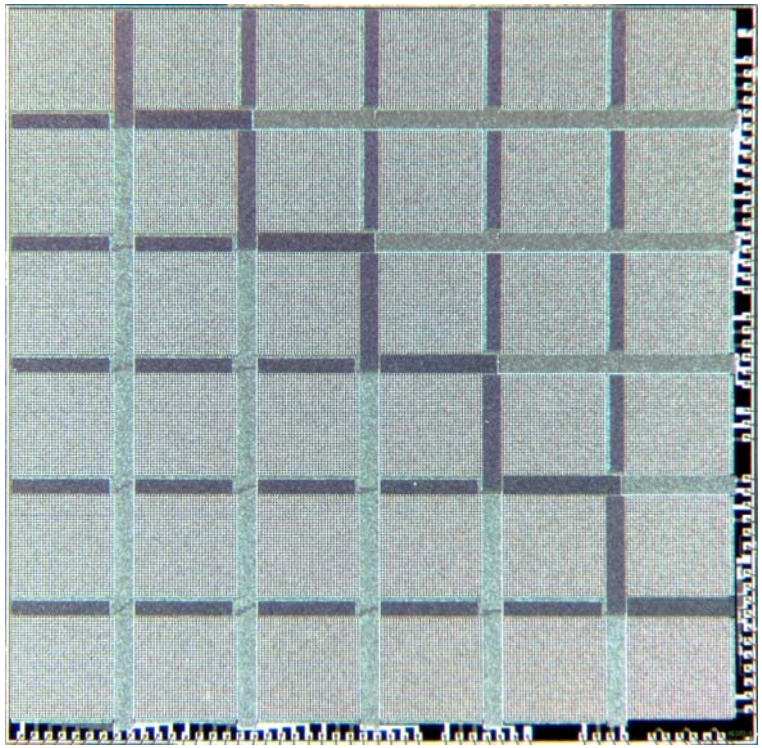


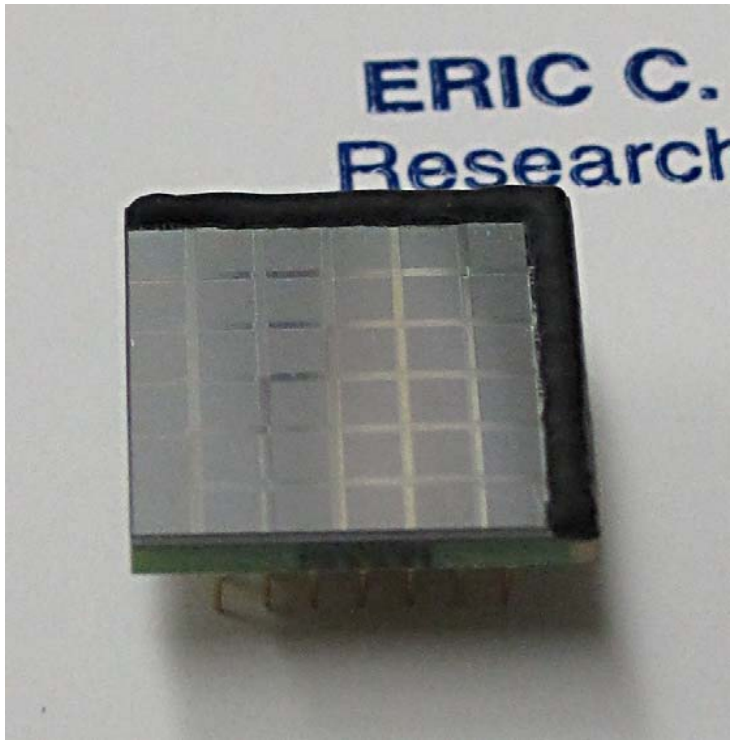




1 cm^2 monolithic SSPM

CMOS SSPM Arrays

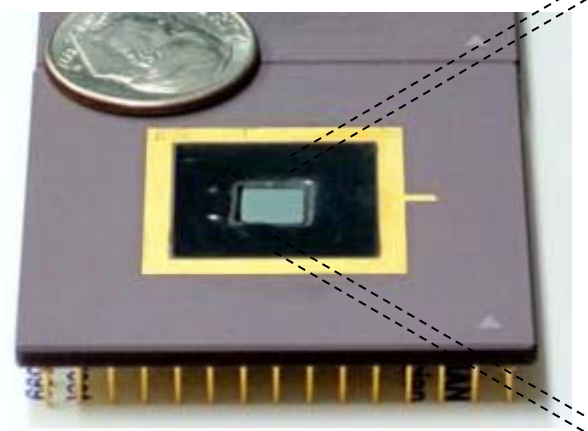


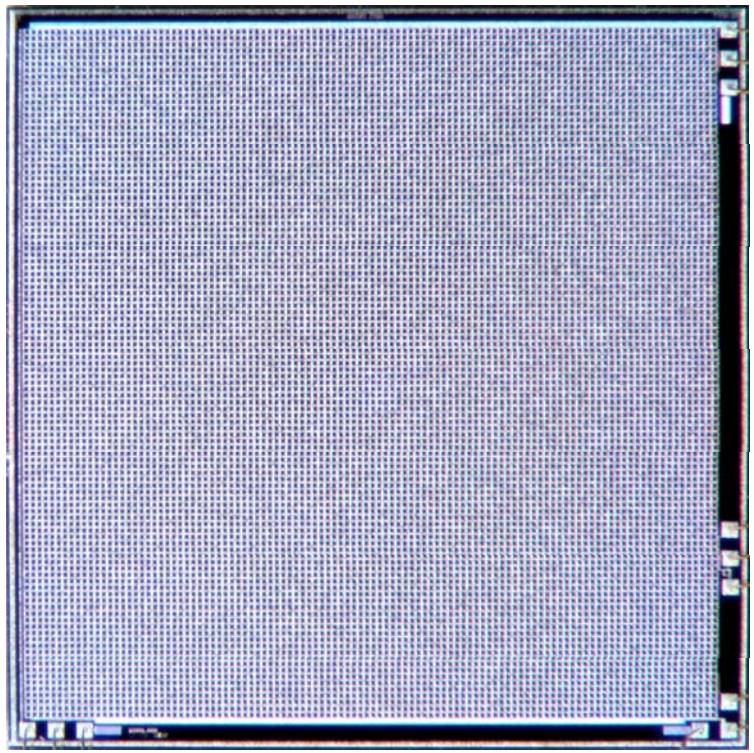


- 1.5 x 1.5 mm^2 each element
- Each element composed of 34 x 34 micro-pixels
- Fill factor is 49%

Position Sensitive CMOS SSPMs

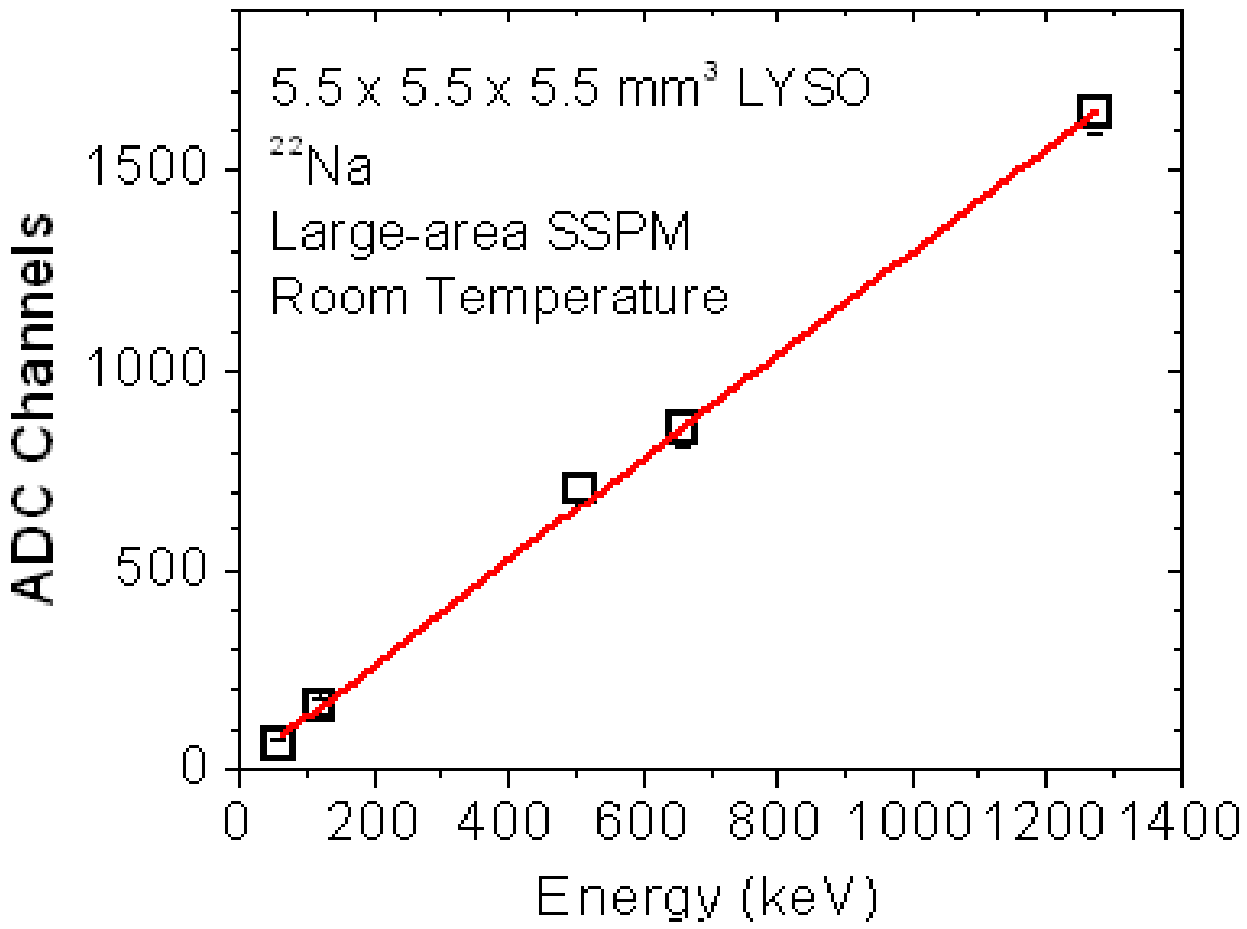
Sensitivity on micro-pixel level



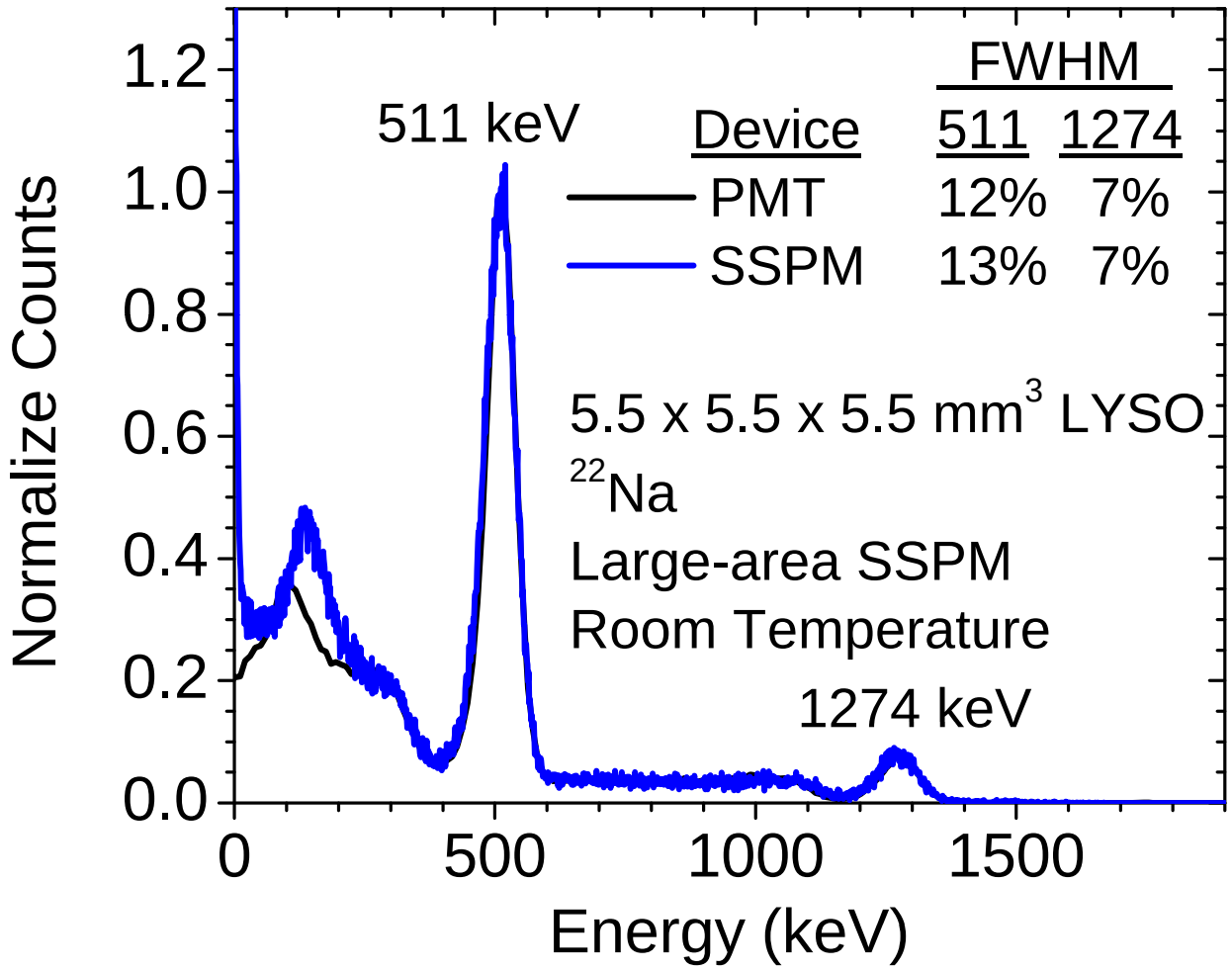


5 x 5 mm^2 PS-SSPM

1 cm² SSPM Linearity



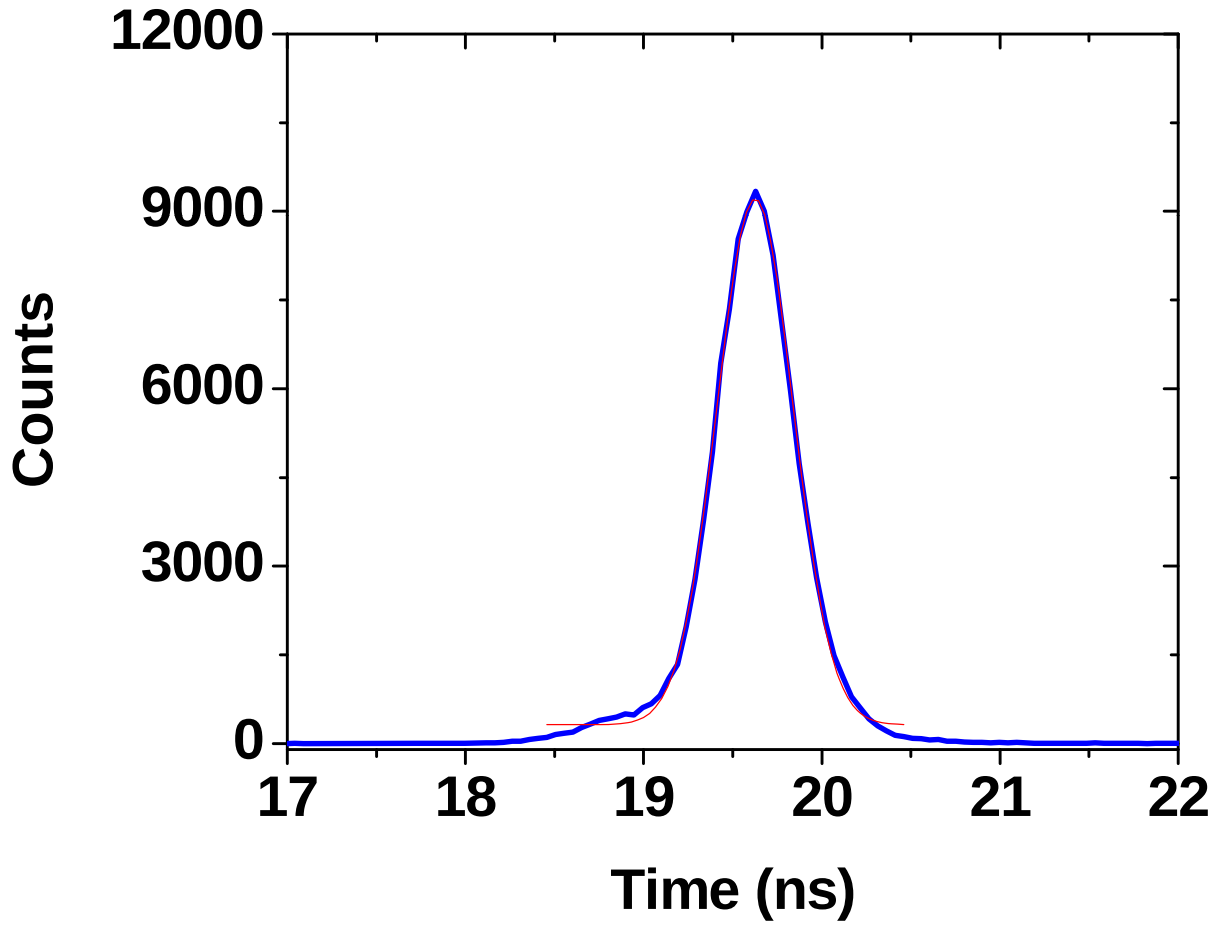
1 cm² SSPM Energy Resolution



RMD

SSPM Timing Resolution

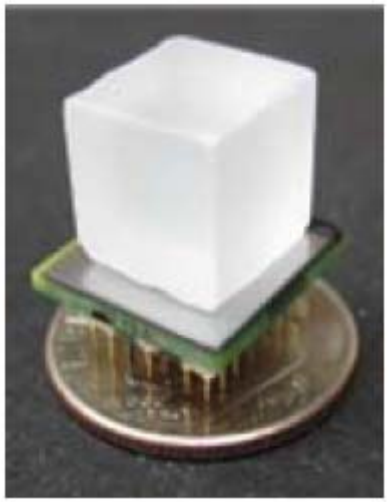
Timing Resolution FWHM = 425 ps at 511 keV
$LaBr_3$:Ce scintillator

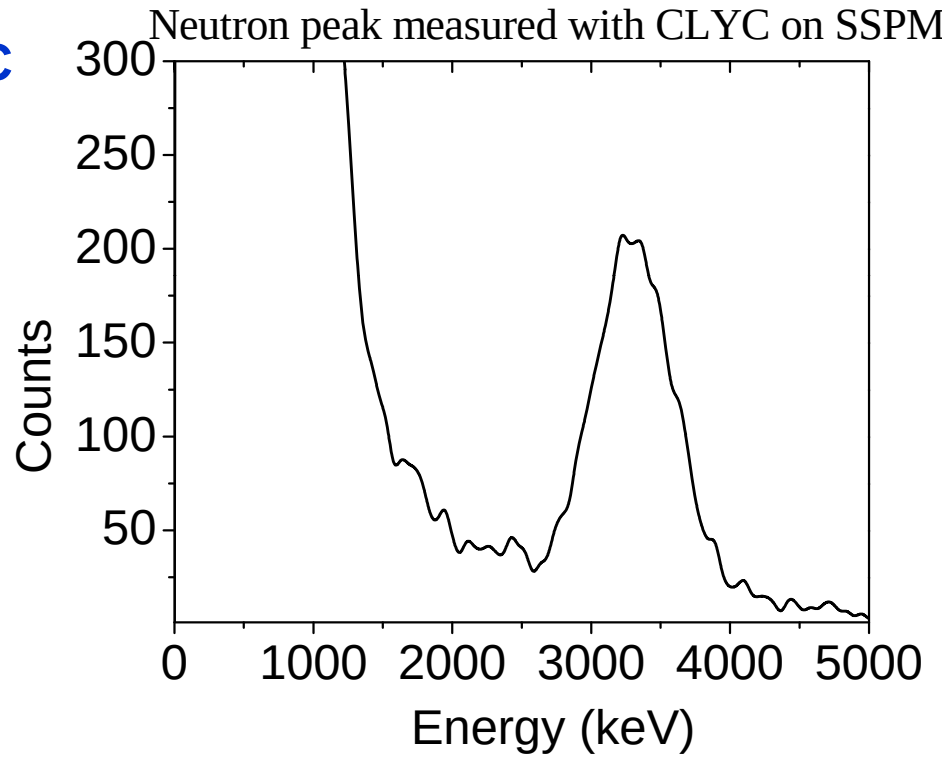


RMD

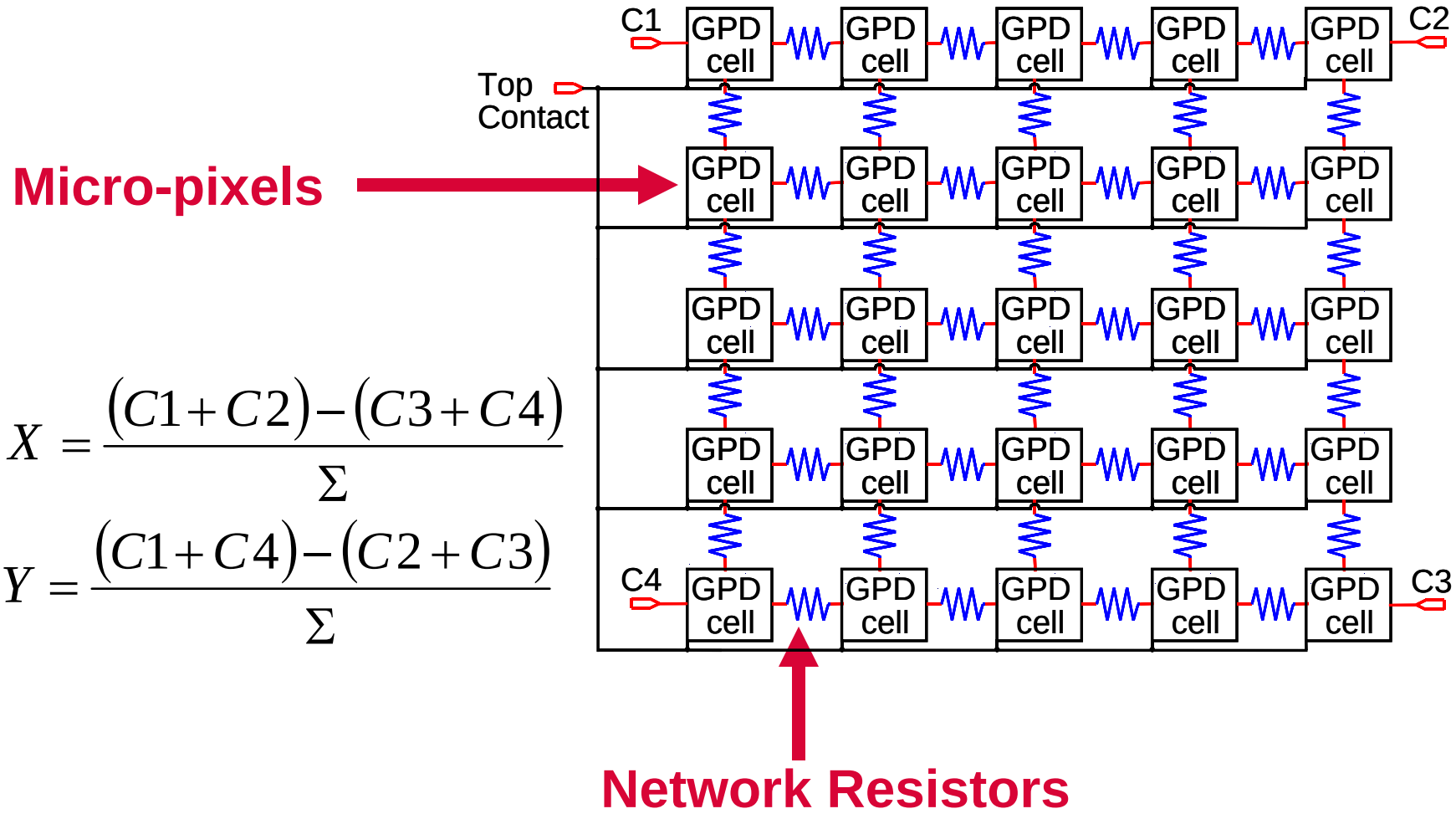
SSPM Neutron Detection

1 cm^2 SSPM coupled to CLYC





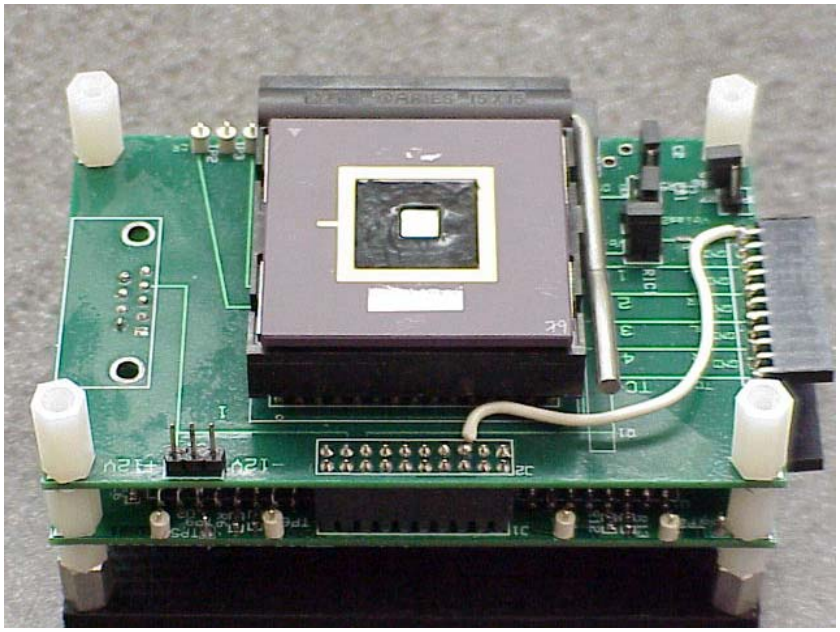
Position Sensitive SSPM Concept



$$X = \frac{(C1 + C2) - (C3 + C4)}{\Sigma}$$

$$Y = \frac{(C1 + C4) - (C2 + C3)}{\Sigma}$$

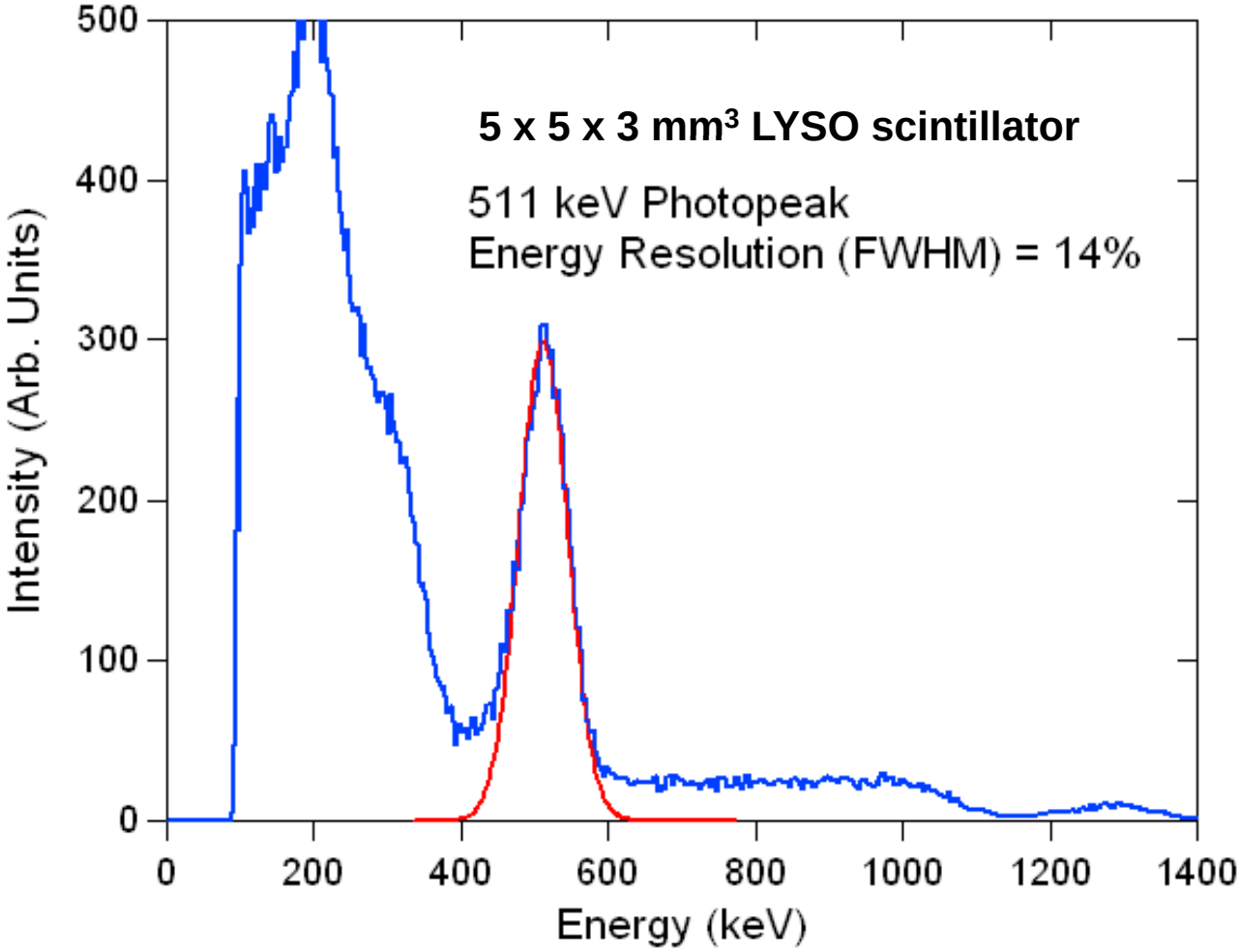
PS-SSPM & Readout PCB



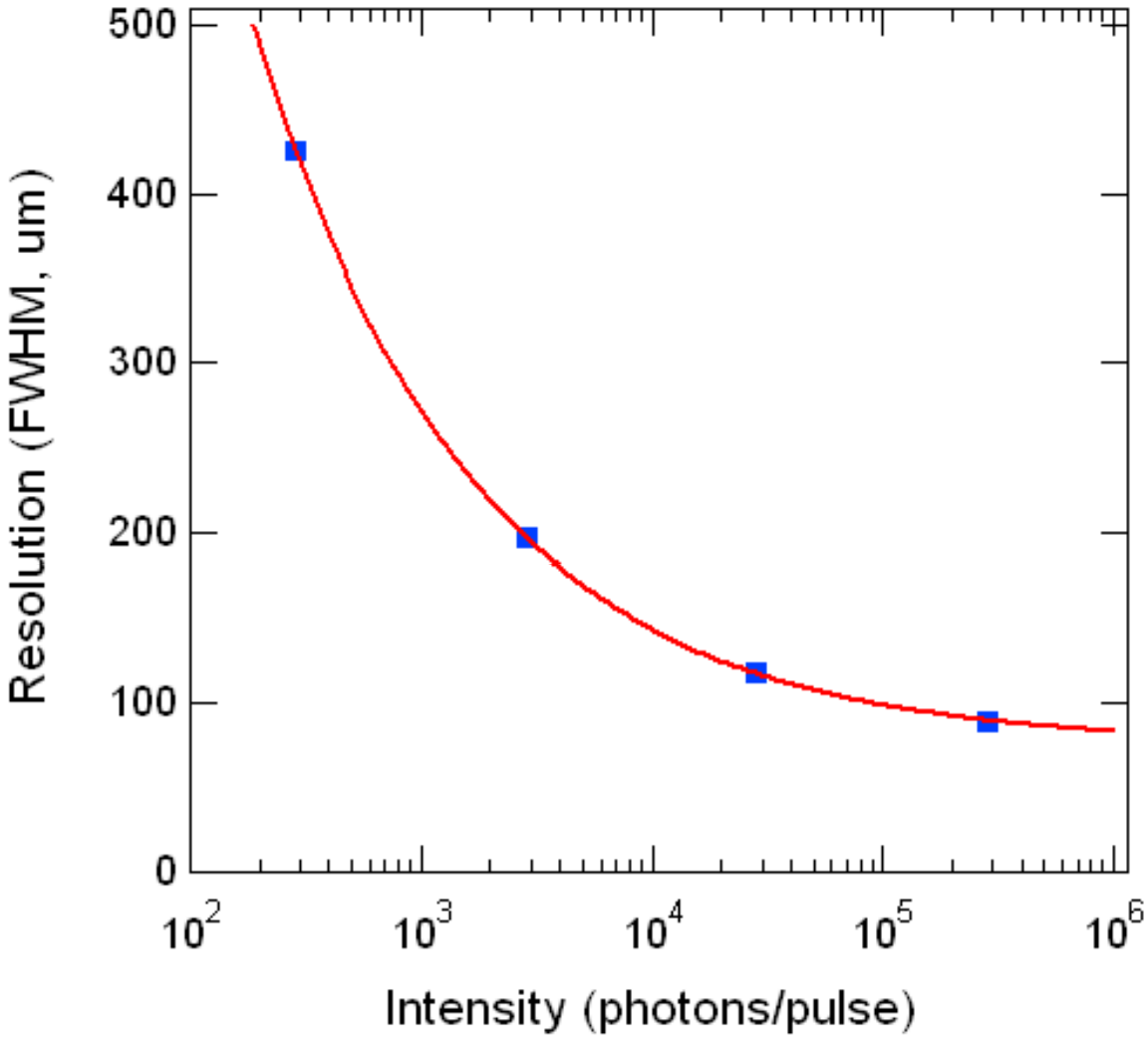
PS-SSPM Parameters	
Number of micro-pixels	11,664 (108 x 108)
Micro-pixel area	30 x 30 μm^2
Micro-pixel pitch	44.3 x 44.3 μm^2
Geometrical Fill Factor	46%
Quench Resistors	143.8 kΩ
Network Resistors	246.5 Ω
Detection efficiency @ 400 nm	~ 10%
Dark Current ($\mu A/mm^2$)	10
Dark Count Rate (kHz/pixel)	~ 117
Operating Bias	~ 32 V
Operating gain	~ 10^6
Excess Noise Factor	~ 1
Capacitance (fF/pixel)	150

- PS-SSPM chip was packaged on a ceramic 145 pin grid array
- Zero insertion force (ZIF) socket for easy removal

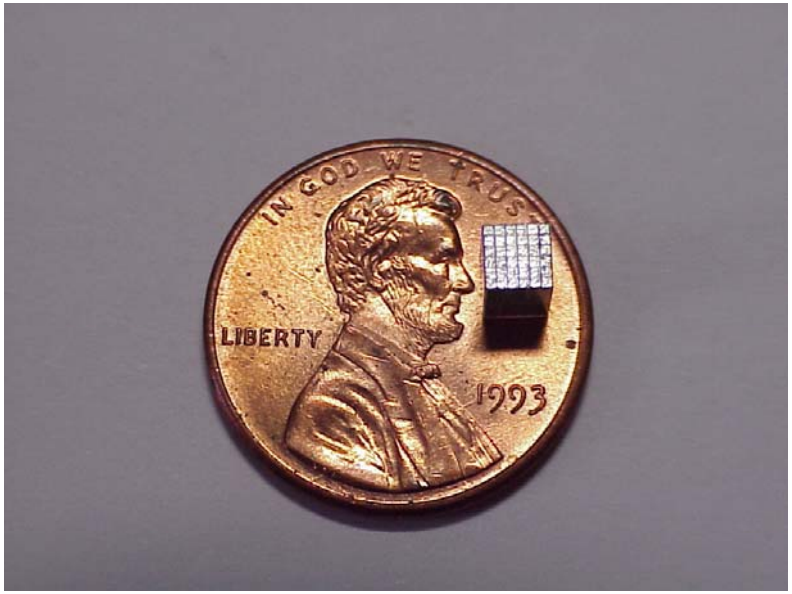
PS-SSPM Energy Resolution



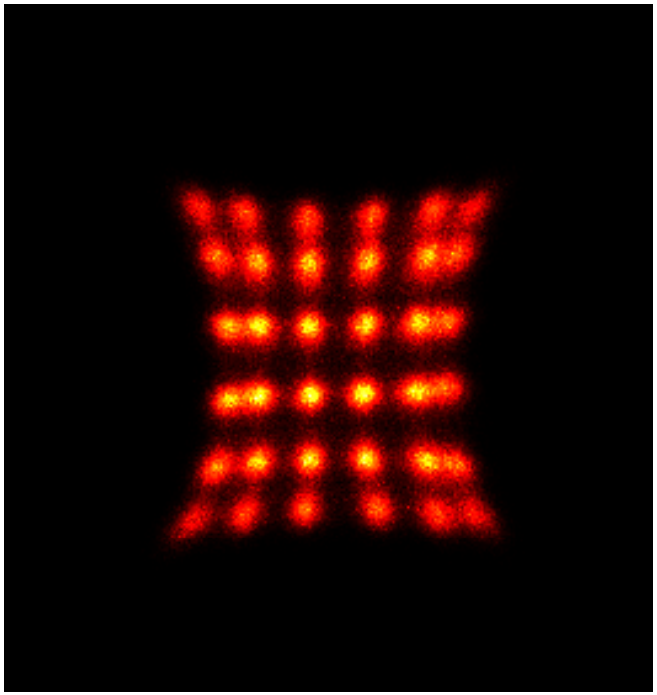
PS-SSPM Spatial Resolution



PS-SSPM Scintillator Images



6 x 6 LYSO array having 500 μm pixels



Uniform flood with ^{22}Na (511 keV)

NS Potential Applications

- Nuclear and particle physics research
  - Calorimeter
  - Fiber tracker
  - General charged particle or gamma-ray detector (with scintillator)

Other Potential Applications

- Nuclear medical imaging
- Astrophysics experiments
- Nuclear detection for non-proliferation
- Dosimetry

RMD Background

RMD Research Groups

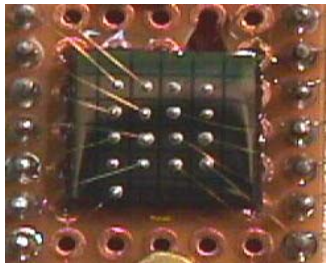
- **Biosensor Technology**
  - Microfluidic Channels
  - Quantum Dots
- **Instrumentation**
  - Magnetic Imaging
  - Portable defect detection and imaging
- **Instrumentation Research and Development**
  - SSPM Technology
  - Standoff radiation imager
- **Optics and Photonics**
  - LIDAR
  - Biomedical imaging
- **Imaging Technology**
  - Imaging screens and detectors
  - Fast imaging photodetectors
- **Material Science**
  - Scintillation Materials
  - Solid-state detectors (Si-APDs, TlBr)

RMD was founded in 1974
Located in Watertown MA, 5 miles from Boston
80 Research Staff

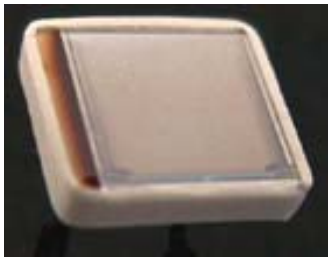
www.rmdinc.com

RMD

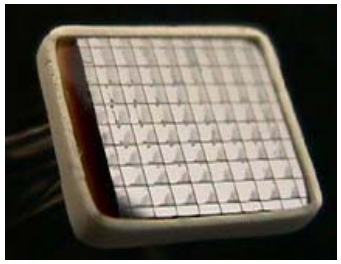
RMD Products



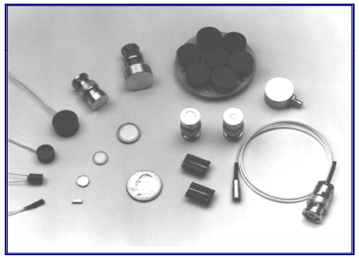
CZT Arrays



13mm x 13mm Si APD

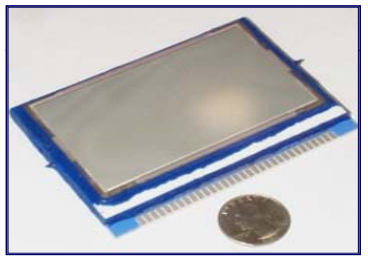


64-element APD Array



CdTe Detectors

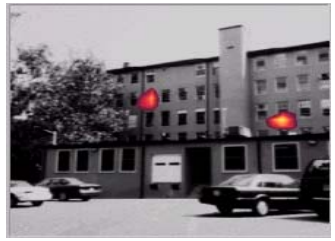
LPA-1 Lead-in-Paint Analyzer



CsI Imaging Screens

Navigator™ Surgical Probe

RadCam 2000™ Portable Gamma/Video Imager



RadCam 2000™ Image

Acknowledgement

We gratefully acknowledge the support provided by the US Department of Energy (DOE)