Position-sensitive Solid-state Photomultiplier Devices

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Instrument Research & Development

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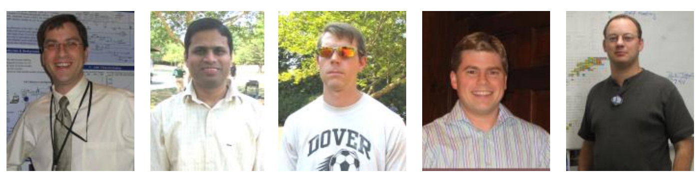
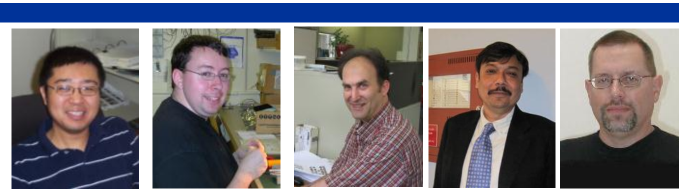




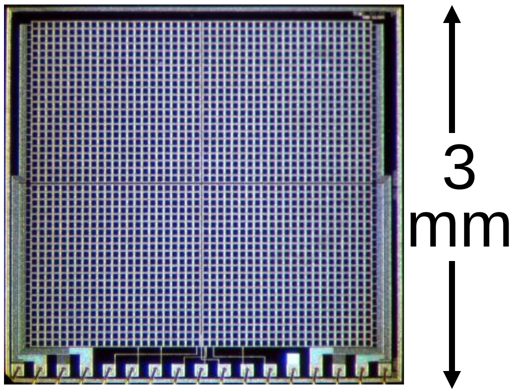
www.rmdinc.com

a Dynasil member company

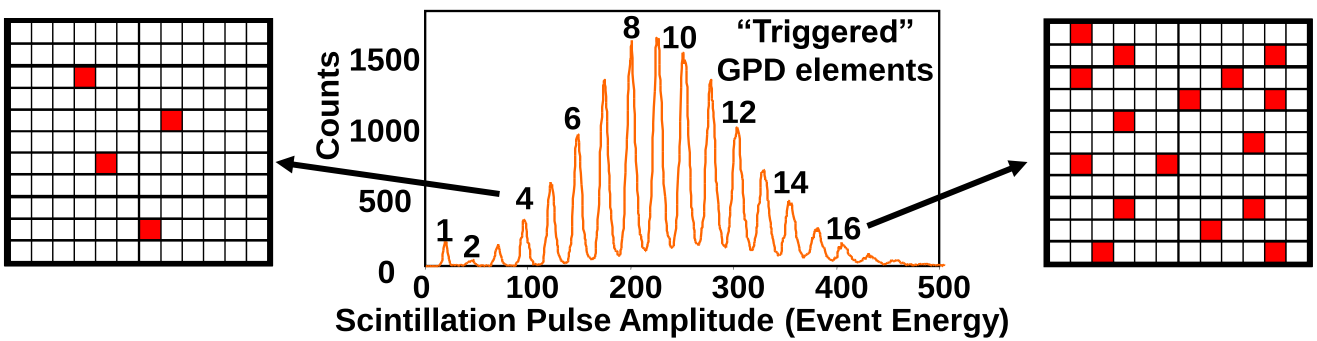
Radiation Monitoring Devices, Inc.

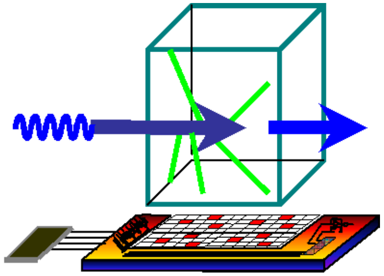
Solid-state photomultiplier

- Photodetector - Detects optical (200-700 nm) photons
  - Parallel Array of Geiger photodiodes (GPDs)
    - Avalanche photodiode operated above breakdown
  - Very high gain ~10^6



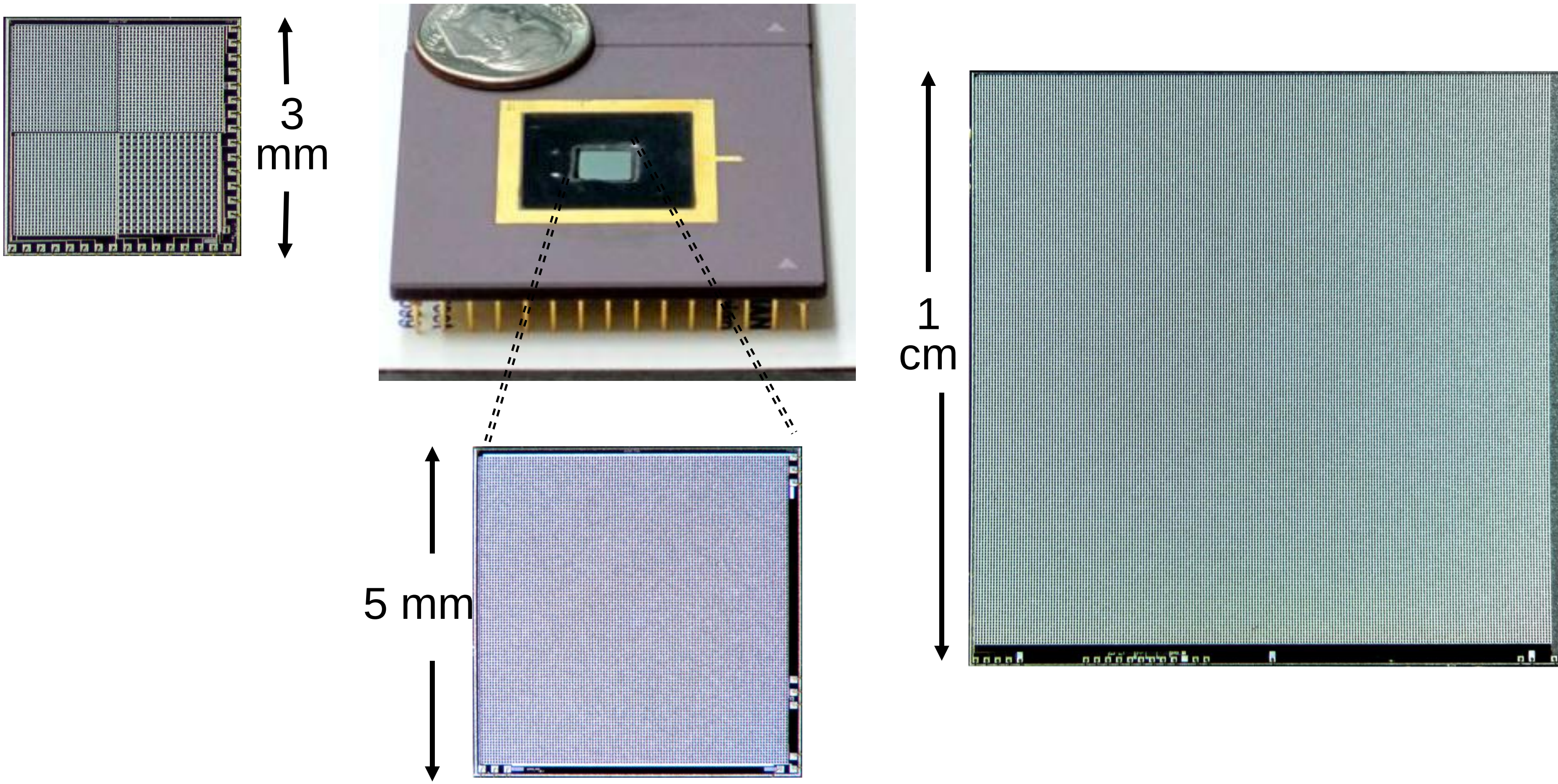
- Uniform illumination of GPD array
  - **Number of triggered pixels proportional to light amplitude**
  - Effective digitization of pulse amplitude





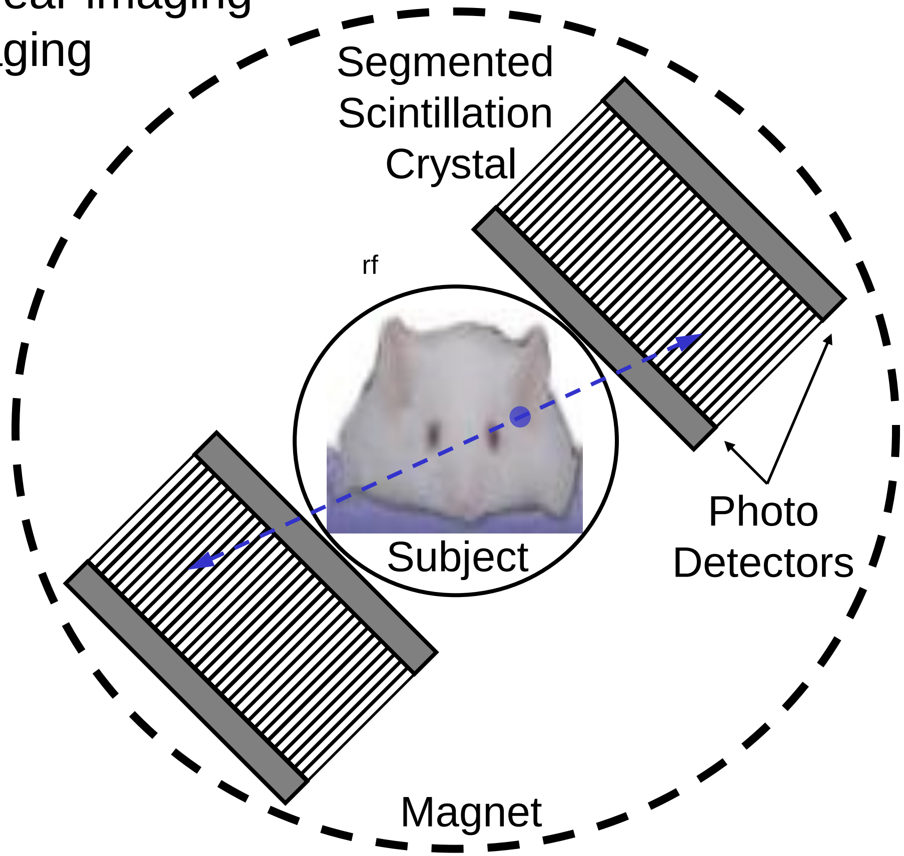
RMD PS-SSPMs

- PS-SSPM: Position-sensitive (PS) Solid-state Photomultiplier (SSPM)
- Four channel readout of position, reduces channels and complexity



Application: Small-animal PET, PET-MRI

- PET – functional, or physiological, nuclear imaging
- MRI – structural, or morphological, imaging



Photodetector characteristics

- Readout scintillation segments
  - Small, fast scintillation pulses
  - Can provide DOI information: improved image
- Insensitive to magnetic fields
- Compact, minimize connections
- Commercial CMOs process allows integration of components on chip

- Additional applications include High energy physics, Cherenkov detectors, space dosimetry telescopes

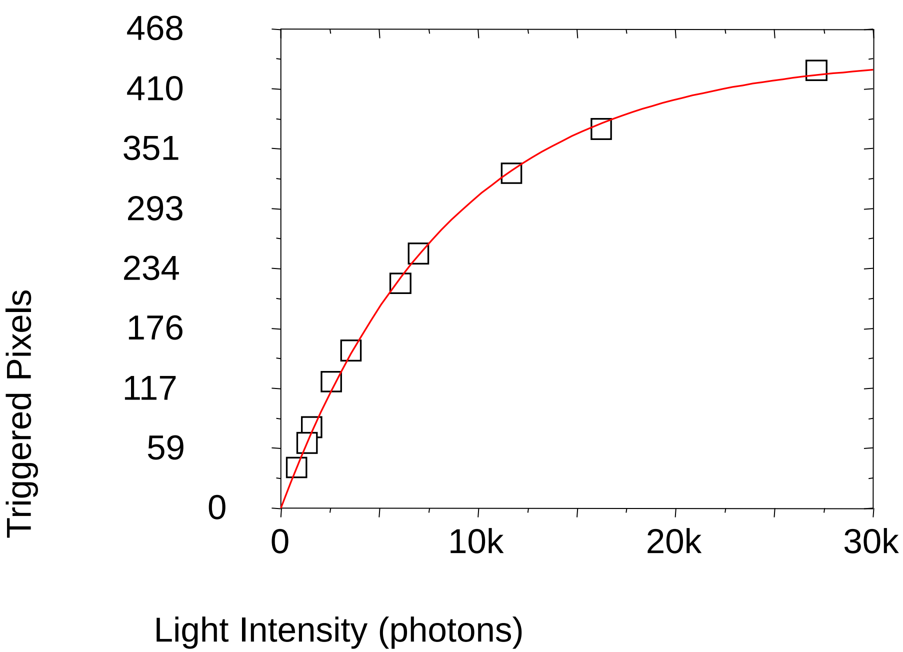
RMD PS-SSPMs

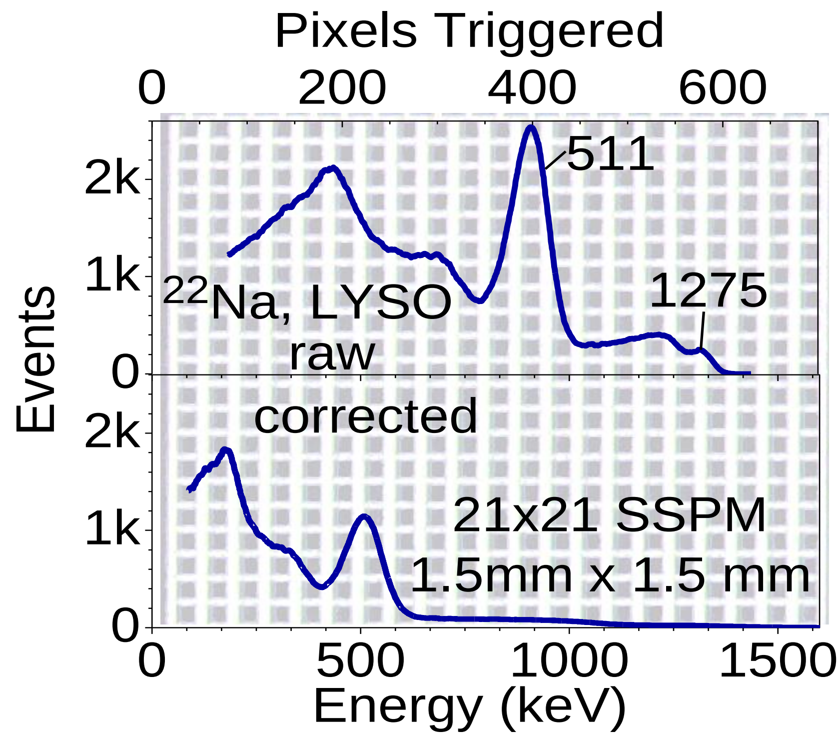
- Non-uniform illumination: Readout scintillation segments
- Charge sharing network

$$\left(\frac{\sigma_E}{E}\right)^2_{\mathrm{det}} = \frac{F_{SSPM}\left[\langle n_t\rangle\left(1-\frac{\langle n_t\rangle}{n_{ttl}}\right)+\langle n_{dark}\rangle\right]}{\left(-\ln\left(1-\frac{\langle n_t\rangle}{n_{ttl}}\right)\cdot\left(n_{ttl}-\langle n_t\rangle\right)\right)^2}$$

<u>Binomial Statistics and Saturation</u>

- Finite number of pixels leads to saturation



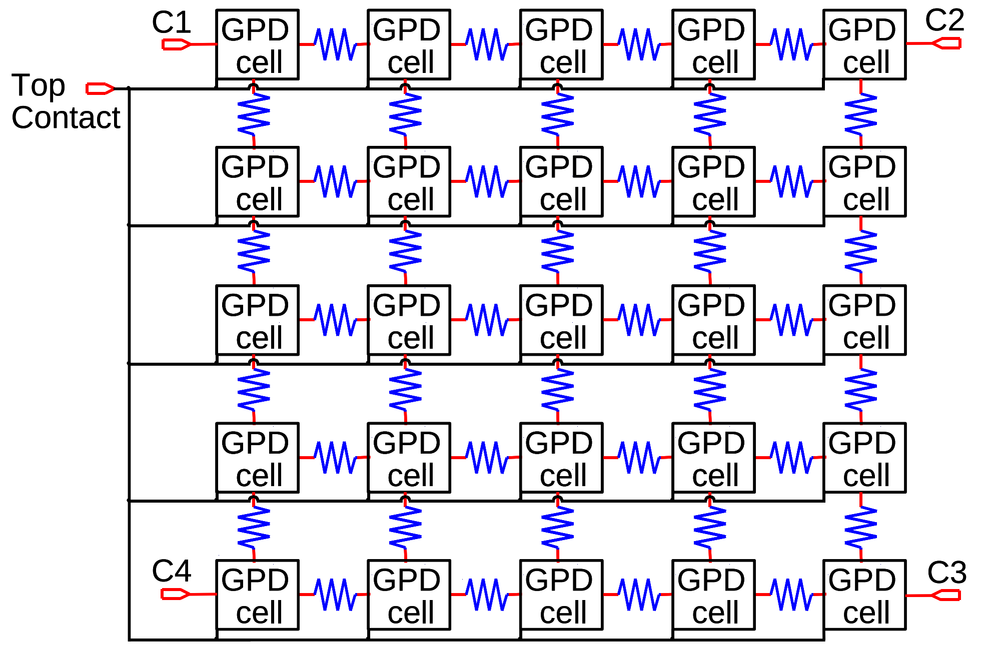


Position-sensitive SSPMs - Simulation

Resistor network to 4 contacts:

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

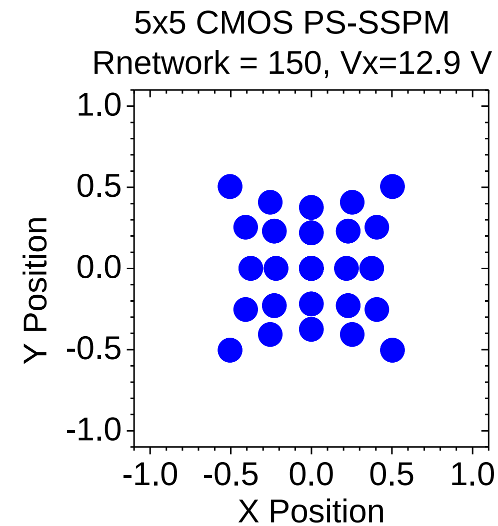
$$Y = -\frac{C1 - C3}{C1 + C3} - \frac{C2 - C4}{C2 + C4}$$

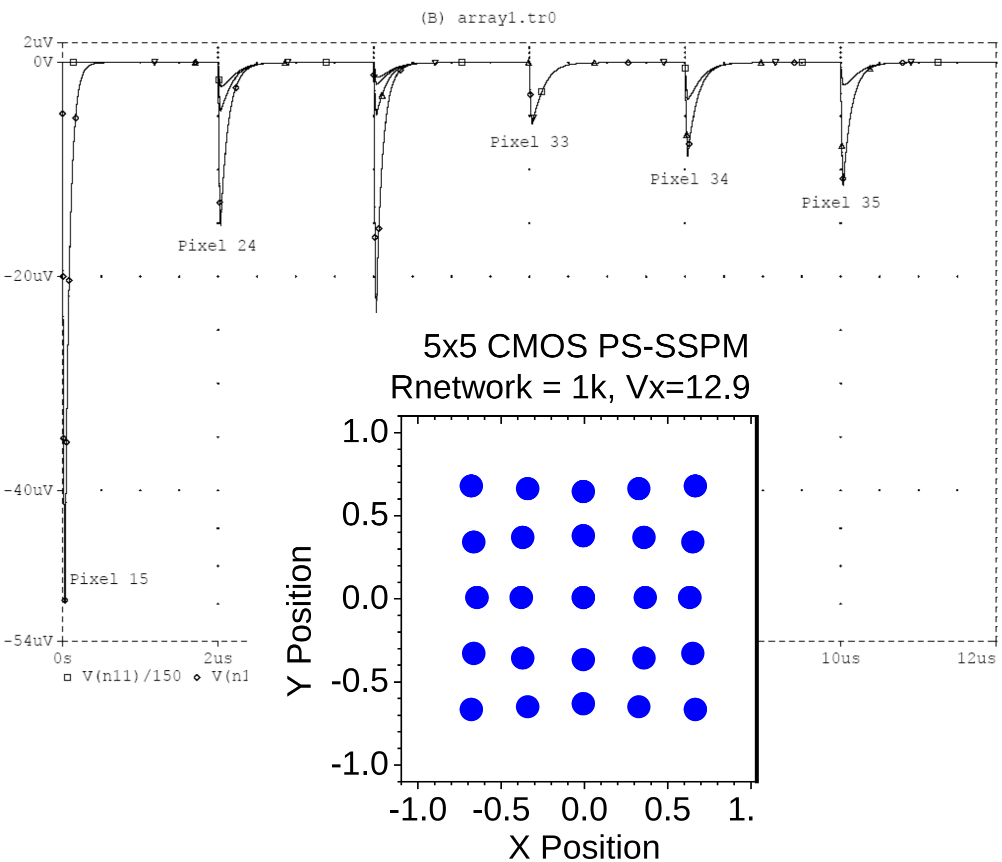


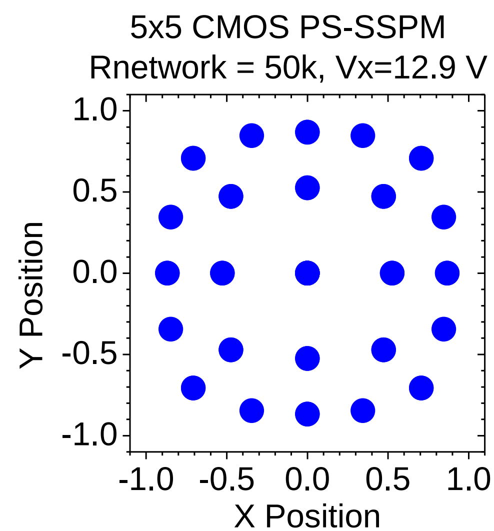
Zhang, Levin *et al.*, IEEE NSS/MIC Proc. p. 2478 (M11-126), (2005)

Position-sensitive SSPMs - Simulation

- Determined best network resistor with SPICE
- 4 peaks for each trig. location

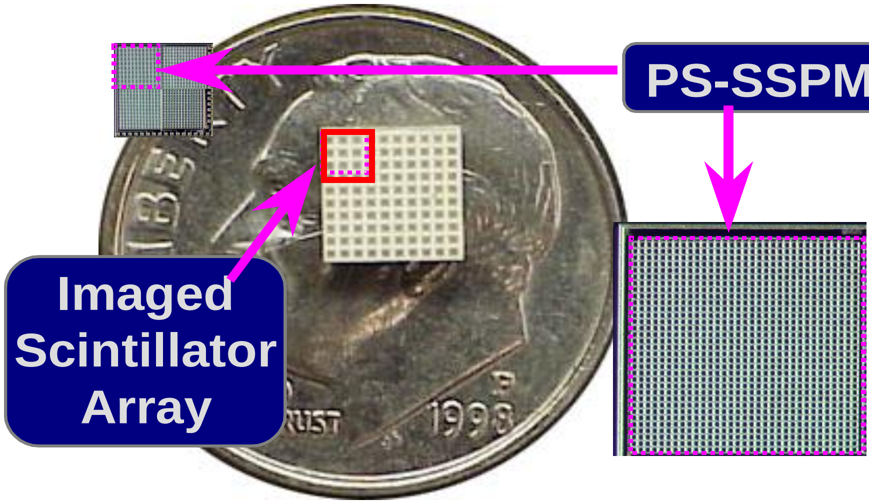


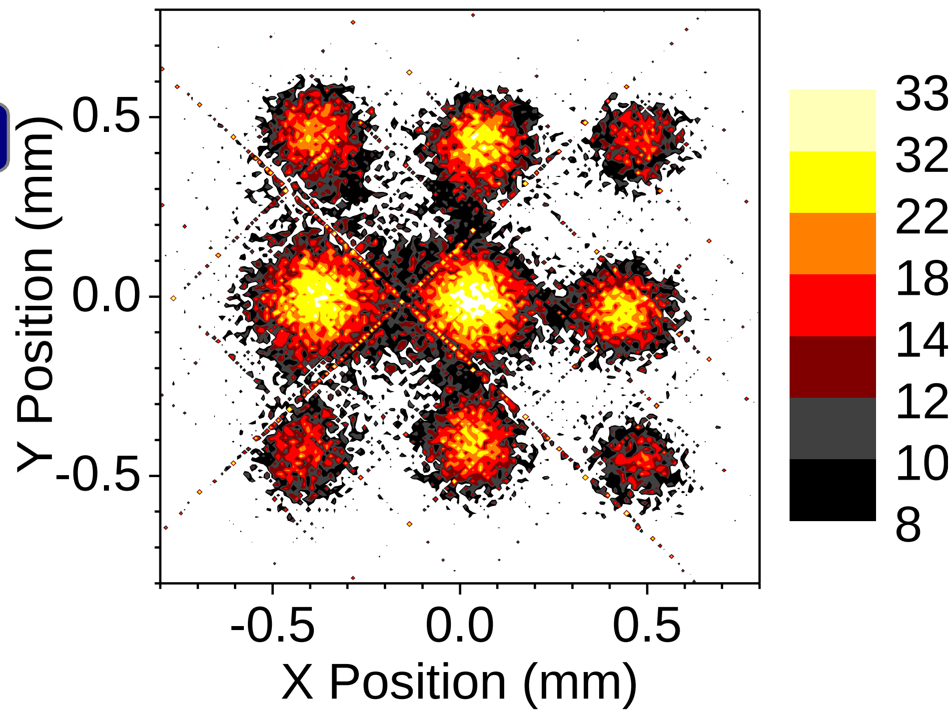




1.5 mm Position-sensitive SSPM

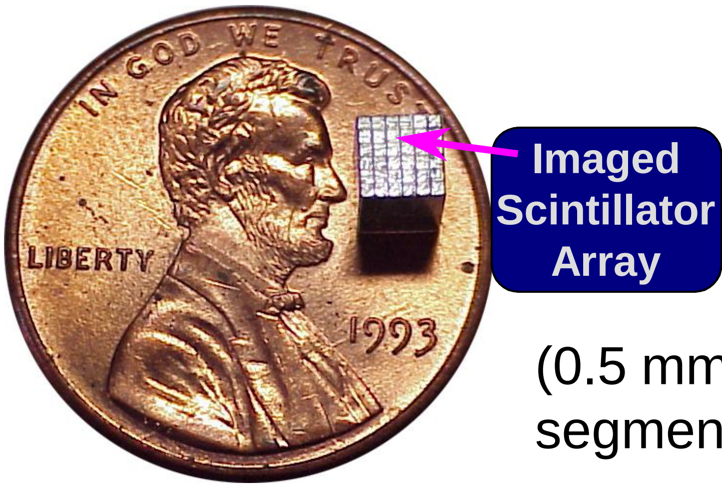
Scintillator imaging results



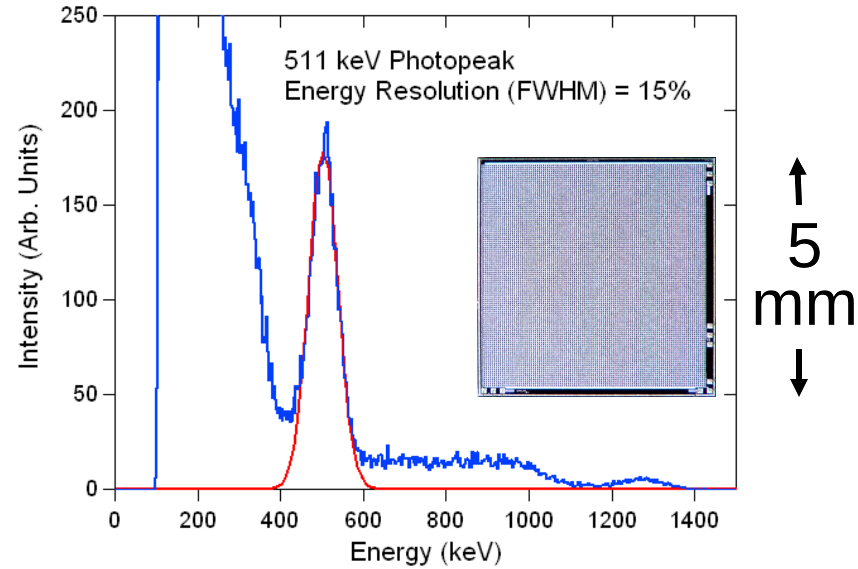


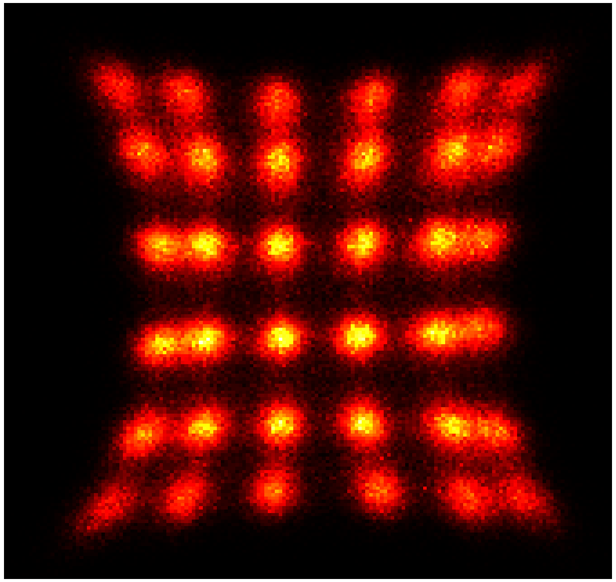
- ♦ CsI(Tl) array
- ♦ Small device works

$(5mm)^2$ Position-sensitive



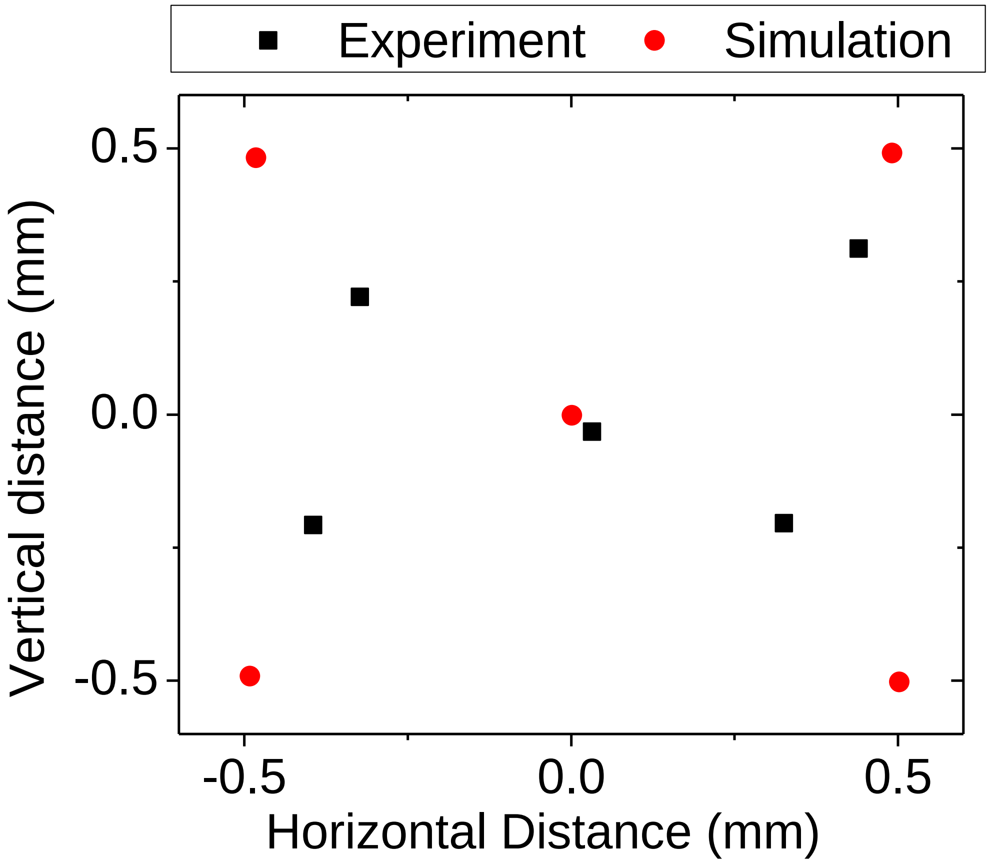
$(0.5\ mm)^2$ segments

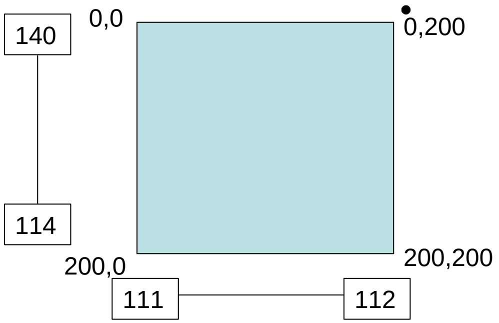




- PS-SSPM ~x2 bigger than Scintillator Array
- Distortions from Anger logic
- Scale-up successful
- 4 Channel readout

Modeling of 1-cm^2 Large-area devices



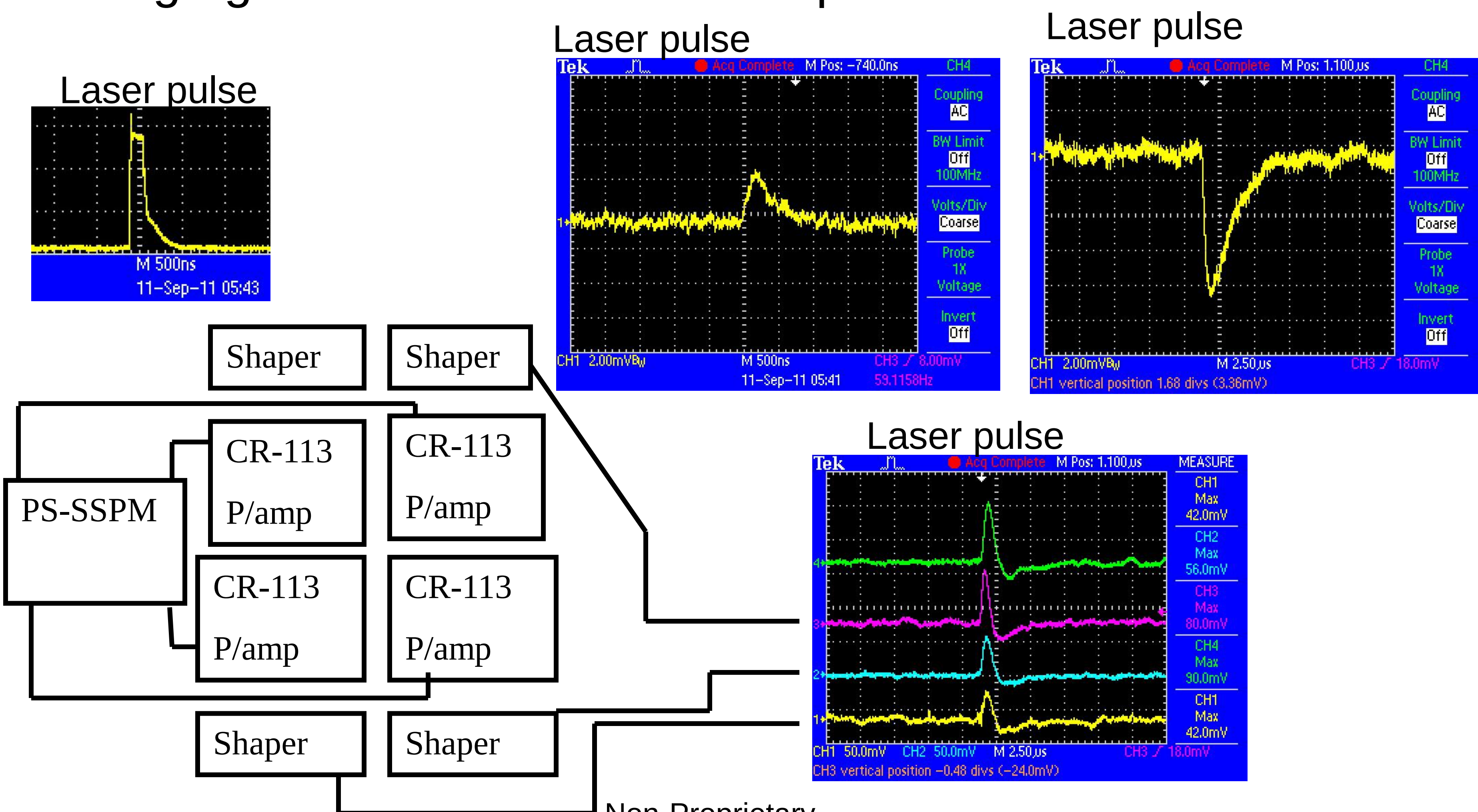


Facing Active Area: top view

- Fabricated devices based on small-area parameters
- Initial results: “worked, but not as expected”
- More modeling to “fix”

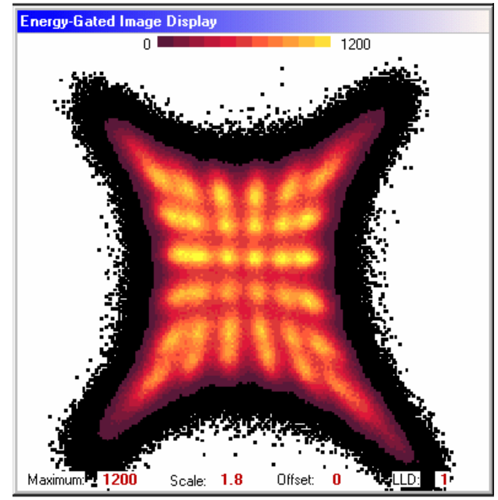
Signals

- Pulsed laser focused on PS SSPM
- Large gain in SSPM reduces amplifier constraints

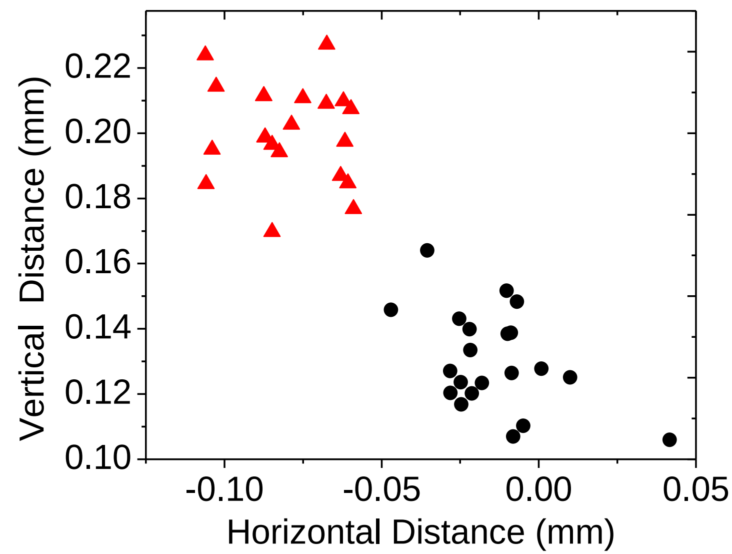


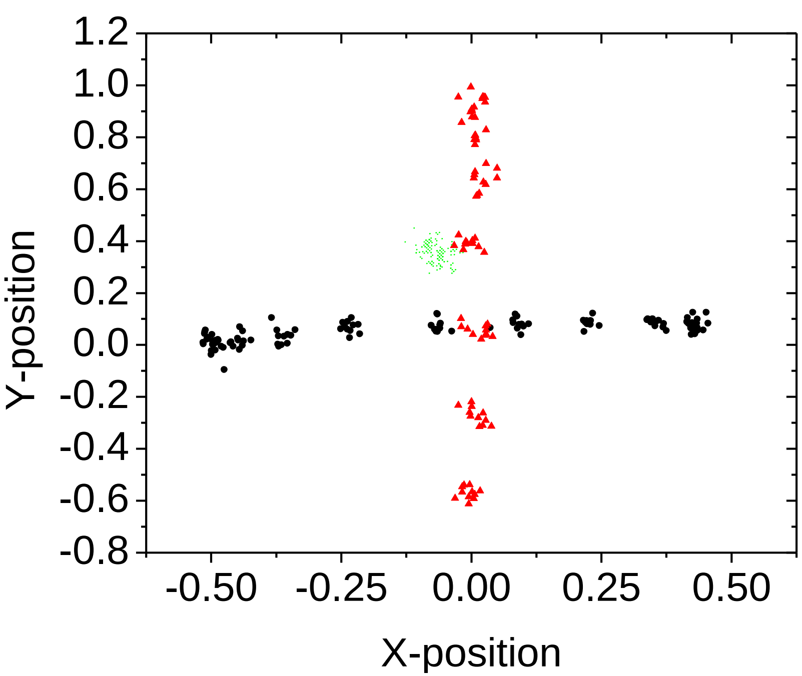
1cm PSSSPM images

- 3mm Laser spot dia. illuminating chip on translation stage
- Full 1 cm^2 area with 4 contacts
- LSO scintillator image (right)
- Pincushion results from anger algorithm for position calc.
- Est. 60 micron or better resolution



70 micron move

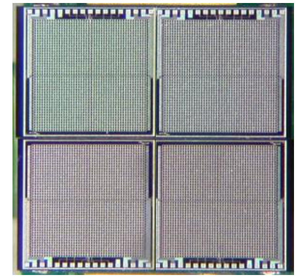


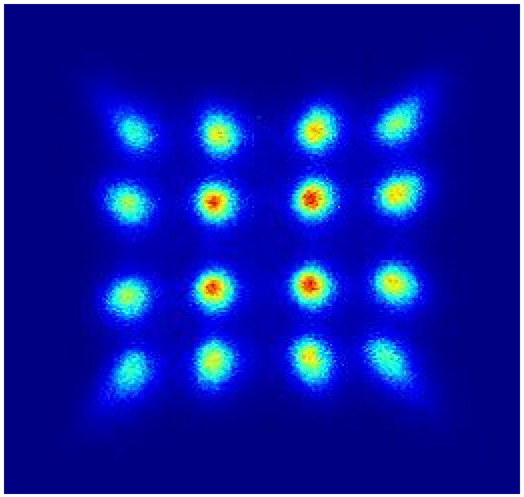


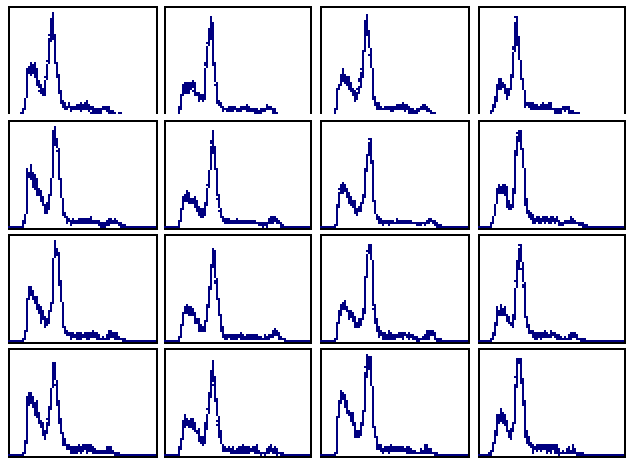
Segmented PS-SSPM

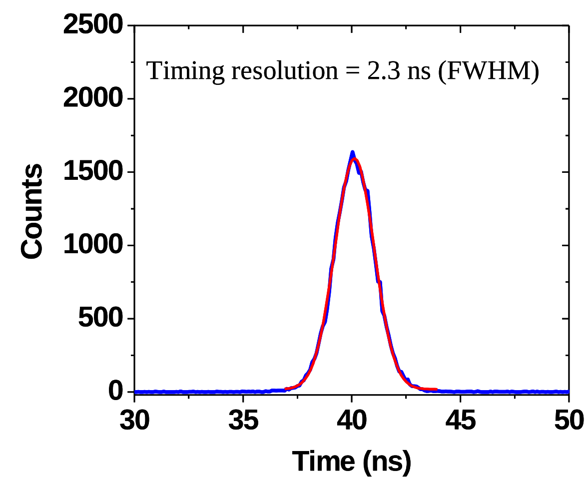
- ♦ Resistive network between detector segments

4x4 SSPMs



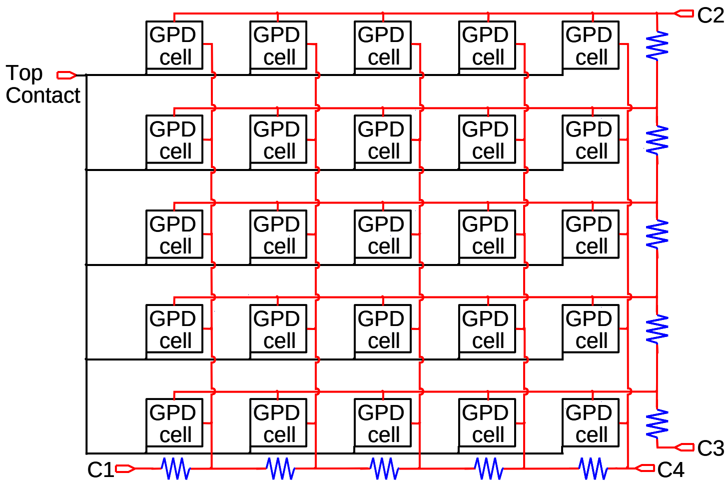


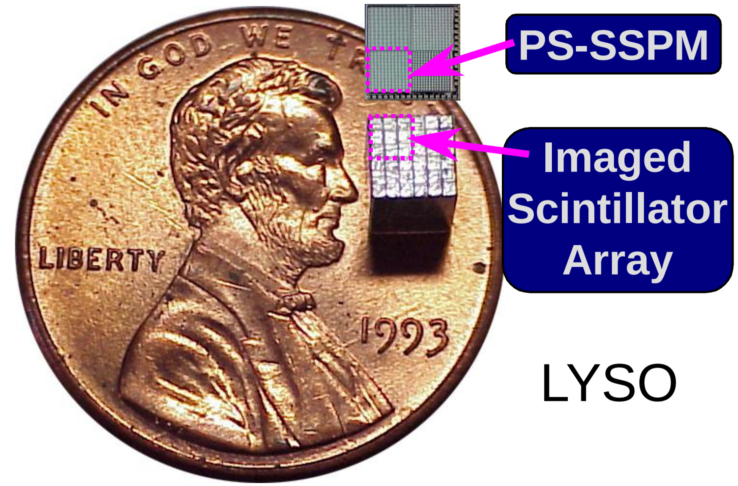


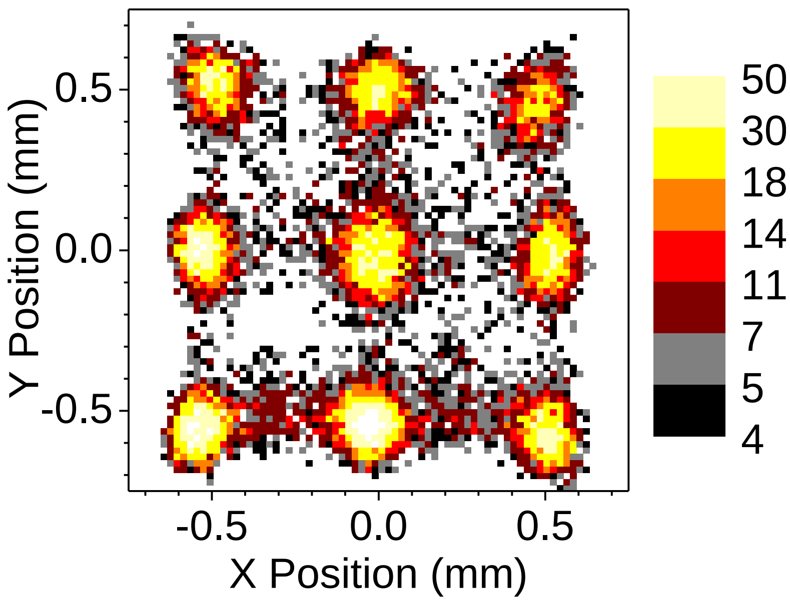


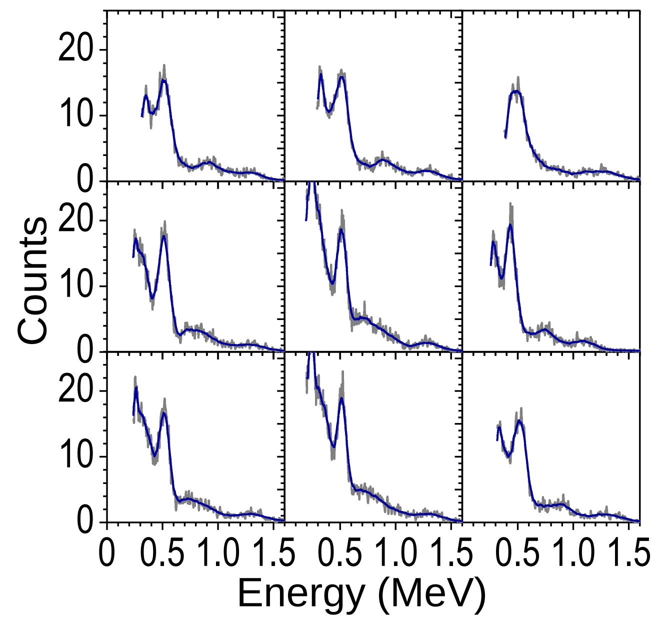
- ♦ Comparable energy performance, better timing
- ♦ ~2.7 mm DOI achieved

Other Configurations for PS-SSPM: Row-Col.



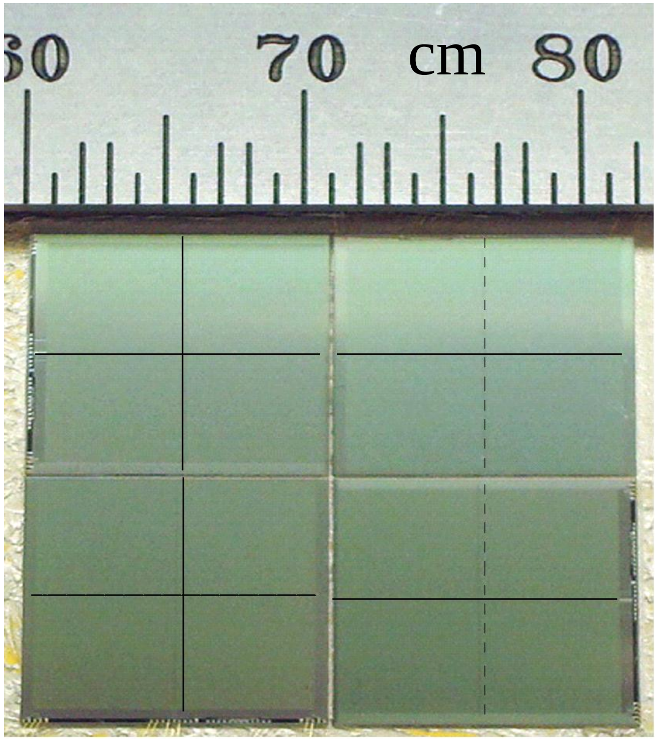


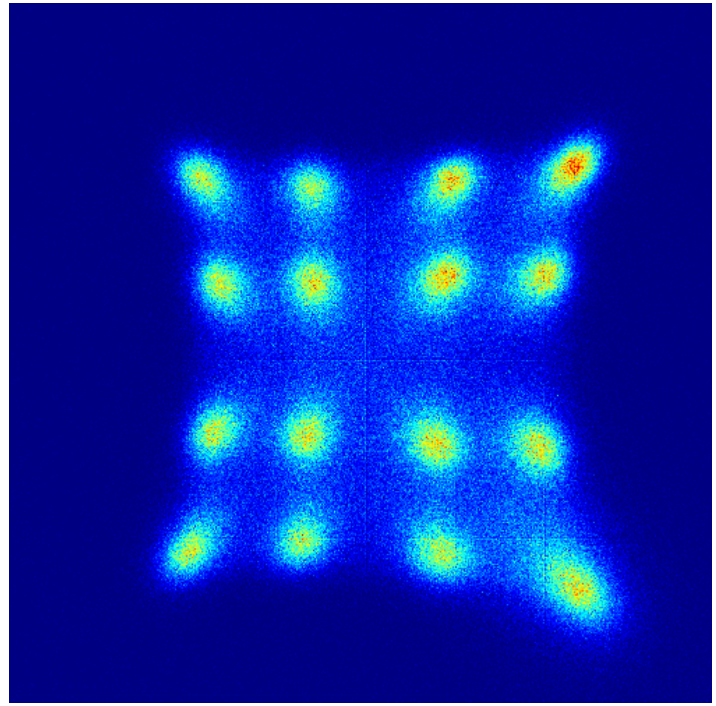




- Energy resolution
- Less internal resistance - large area

Larger area segments





4x4 LYSO array (5x5x20 mm^3 elements) and the resulting PET detector was irradiated with 511 keV γ-rays (^{22}Na source).

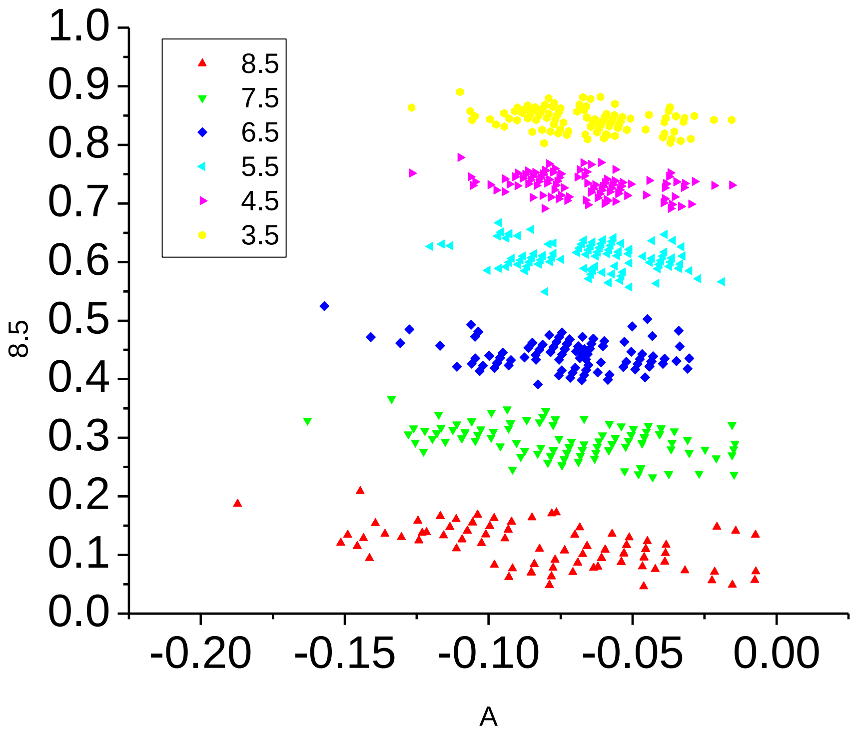
Summary

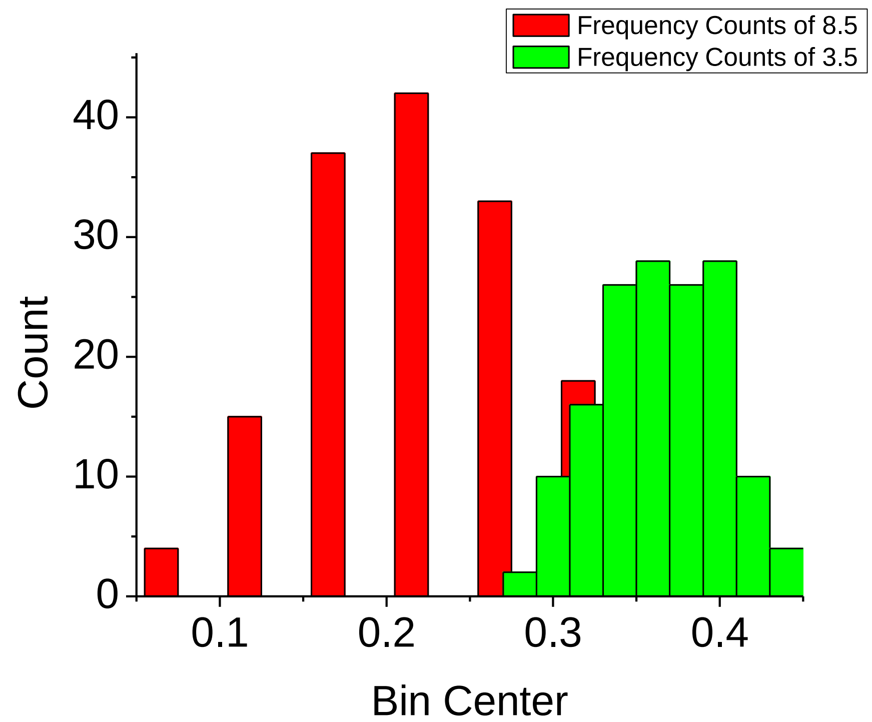
- ♦ SSPMs ideal for scintillation detector applications
  - Compact
  - Easy to read out
  - Low-cost
- ♦ Scale up to 1 cm PS devices is successful
- ♦ Integrated devices:
  - Additional capacitance in large devices
  - Better fill factor with monolithic devices
- ♦ Next steps include integration of components
- ♦ Sensor ASICs feasible

Acknowledgements

Funding agencies: US: DOE and DTRA

Saturation and position resolution





Radiation Monitoring Devices, Inc.

Contacts

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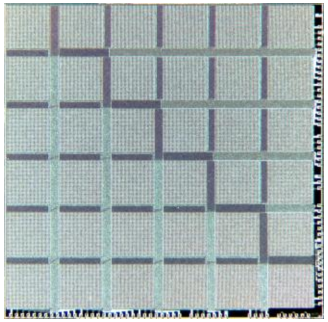
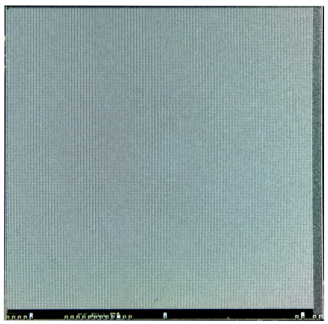
- ♦ Kanai Shah, Vice-president
  - phone: 617-668-6853

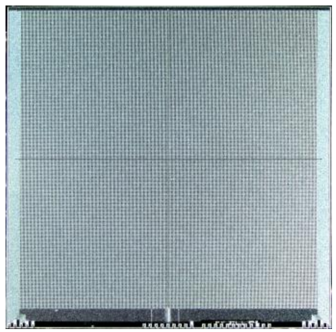
RMDs CMOS Solid-state photomultipliers



36 1.5x1.5 mm^2

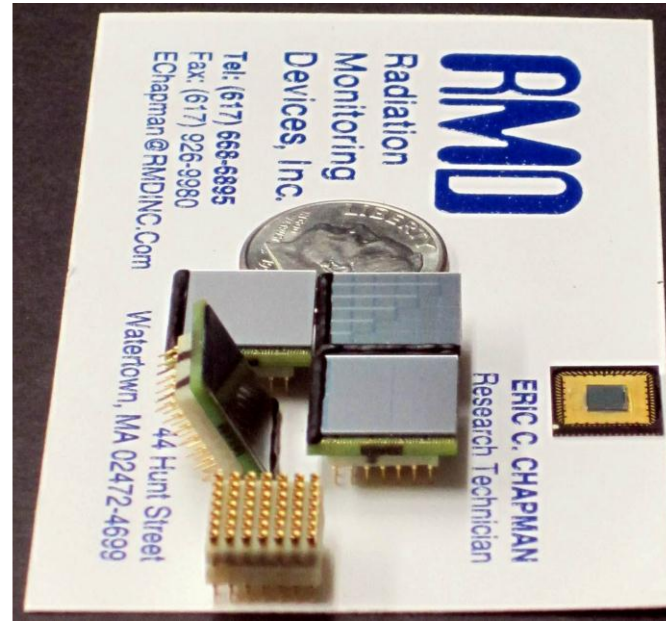


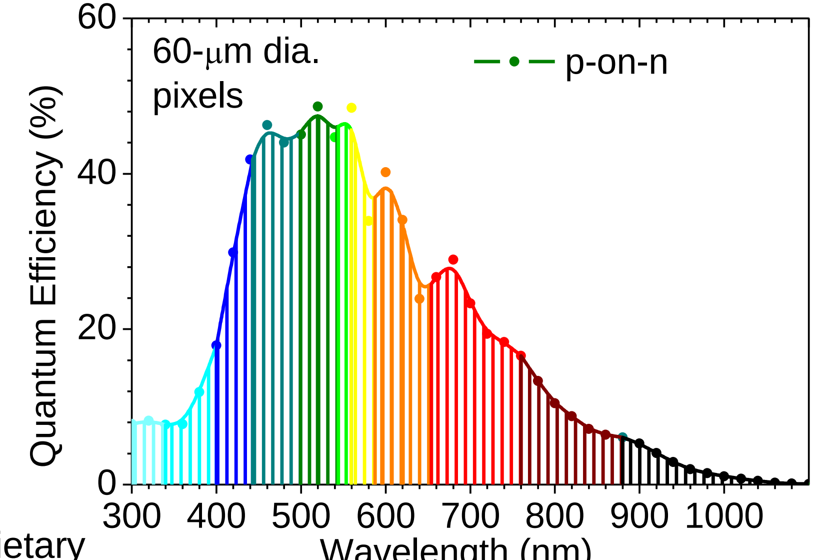
1 1x1-cm^2



1.1 cm

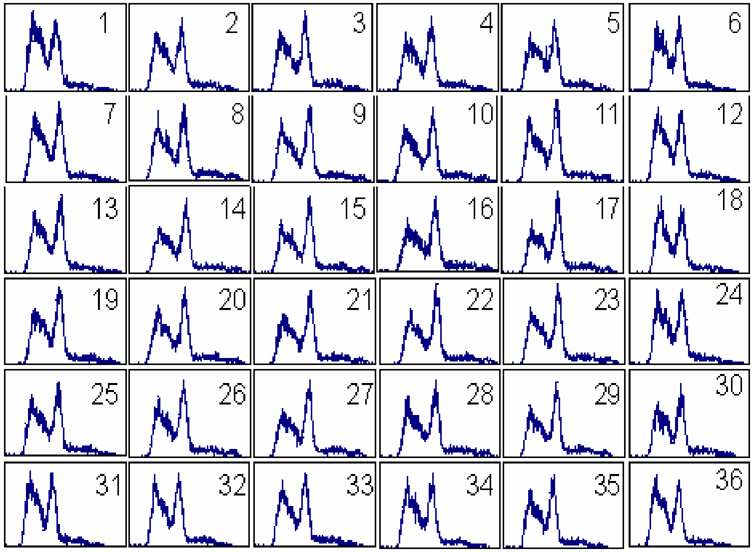
2x2, 5x5-mm^2 SSPM



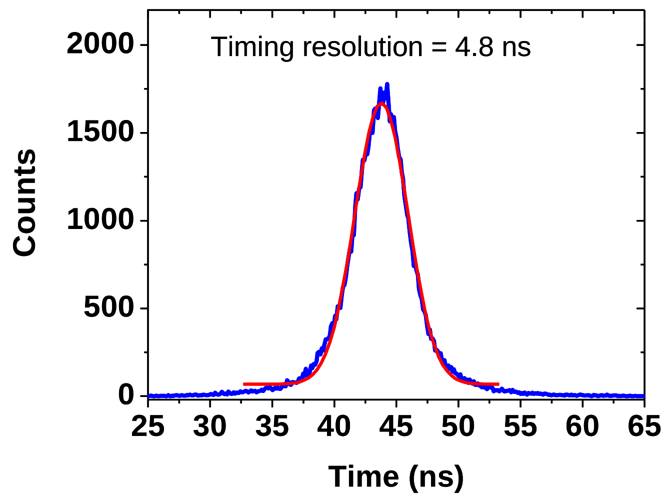


- Small footprint package:
  - PGA, Hirose, BGA
- Large-area, Quadrant, & Segmented devices

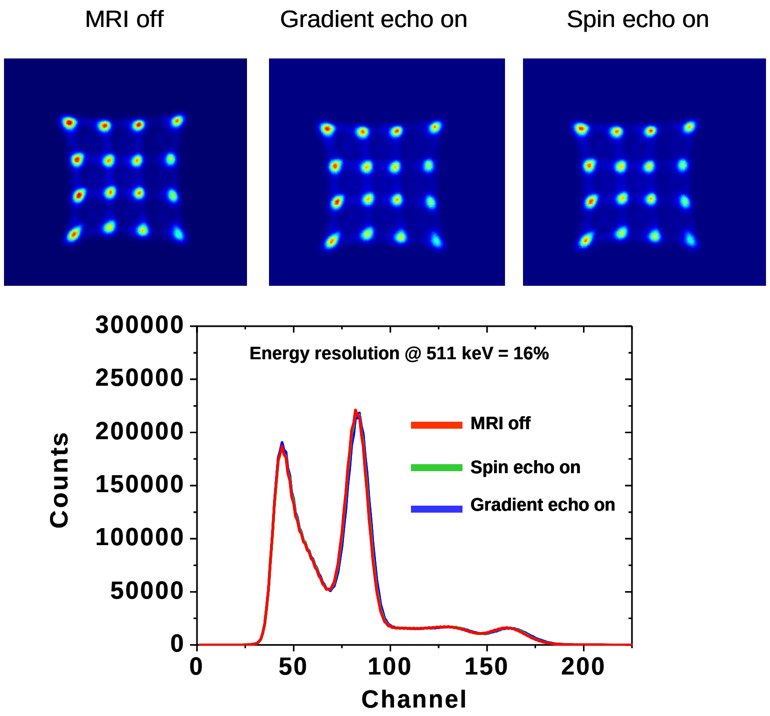
Consistency across channels



16	14.4	14.2	14.4	15.2	15.5
15.5	14.6	13.9	14.2	15.0	15.1
14.9	14.2	13.7	13.3	14.8	15.4
15.3	13.8	13.6	13.2	15.1	15.0
15.4	14.4	14.2	13.3	15	15.7
15.8	15.3	14.2	14.3	14.8	14.9



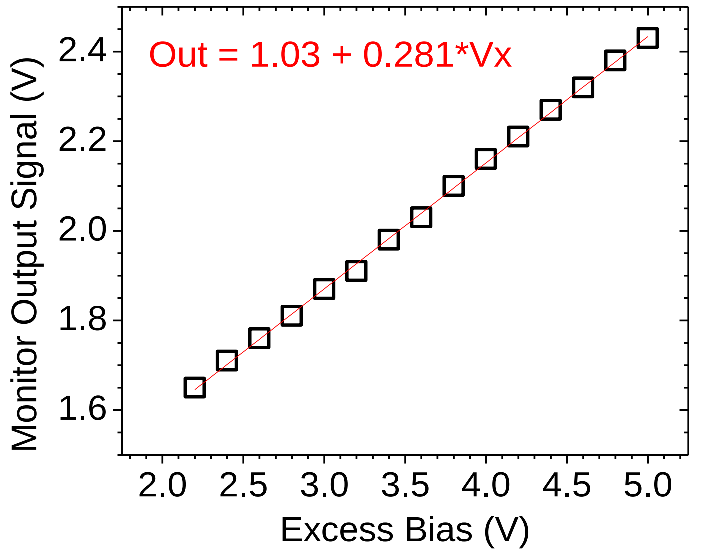
Extra

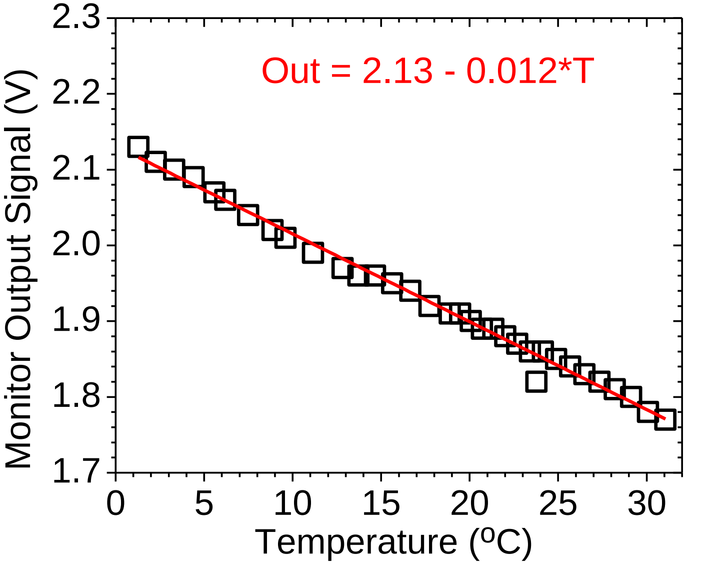


- Works in MRI (0.7x0.7 cm2)

Temperature dependence

- V_B depends on temperature (~50 mV/°C)
  - Gain proportional to ***excess bias*** <u>(% per °C)</u>
  - *DE* depends on excess bias (5%-10% per volt)
  - *"Other" temperature dependence small*

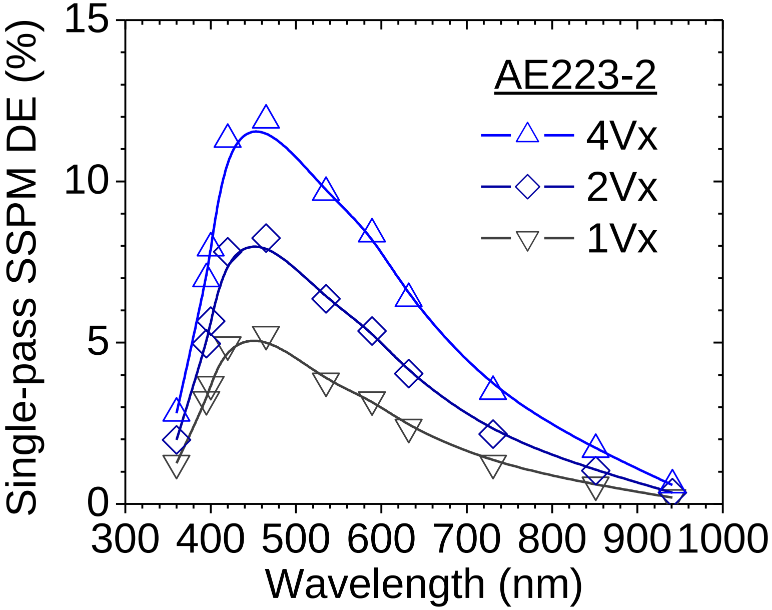


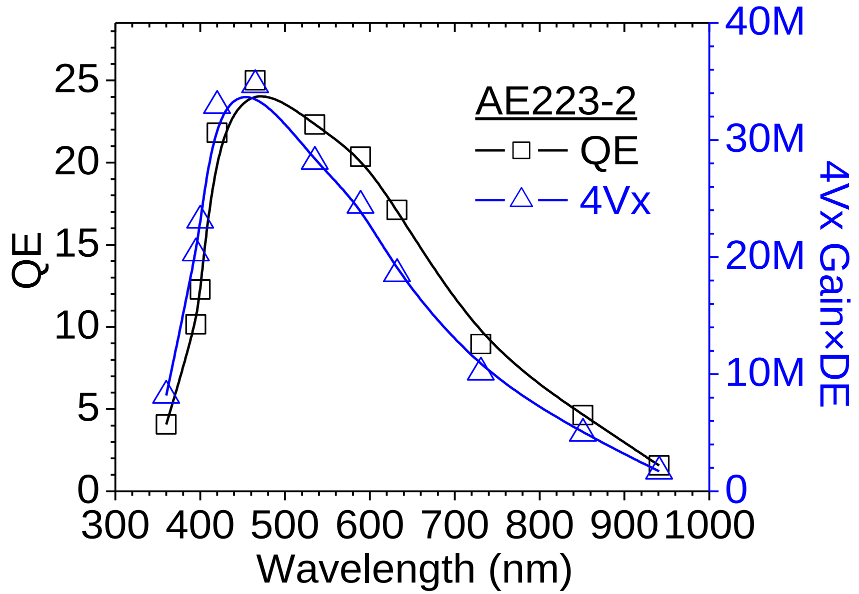


- Built-in temperature monitor
- Peak-hold: couple high bandwidth detector to low bandwidth readout

QE, DE, SSPM Gain, and Dark Current

1cm x 1cm SSPM: 50% fill factor





- Measure photocurrent - product of gain and DE
- Gain (q_{in}=1) : Collection of GPDs discharging

$$\sim n_{tr} \bullet C_j \bullet V_x \quad \sim \quad DE(V_x) \bullet n_{ph} \bullet C_j \bullet V_x \quad \left(+ \int_0^{\tau_q} i_{Rq}\, dt \right)$$

- Dark Current (output referenced): (5mm)^2 0.4 mA, ~5x10^6 gain @ 4Vx

Non-Proprietary