Tissue-Equivalent Radiation Dosimeter-on-a-chip

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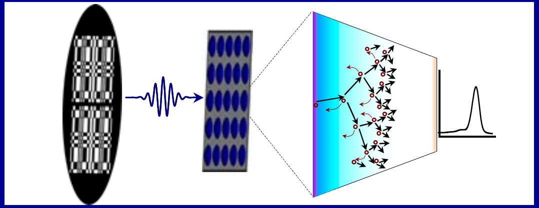
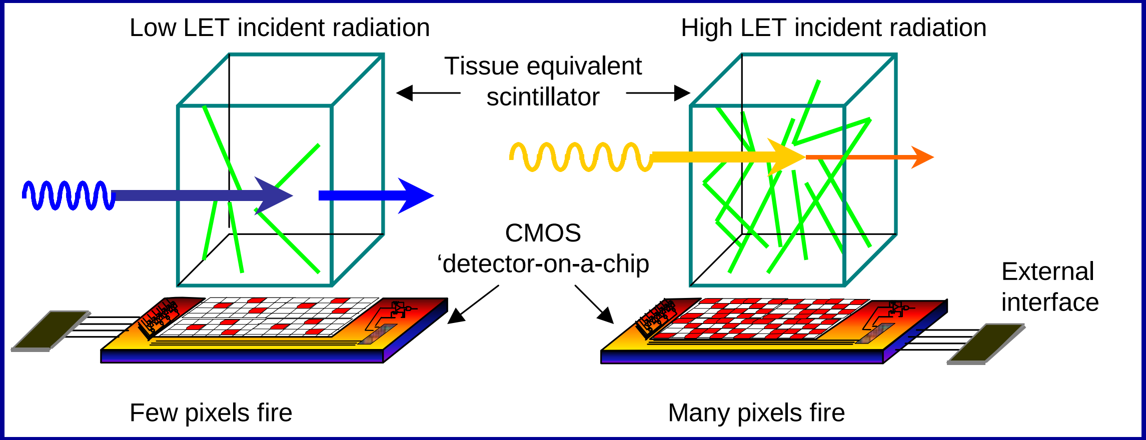
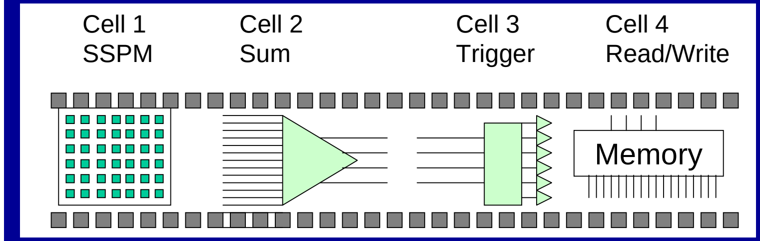


Dosimeter-on-a-chip

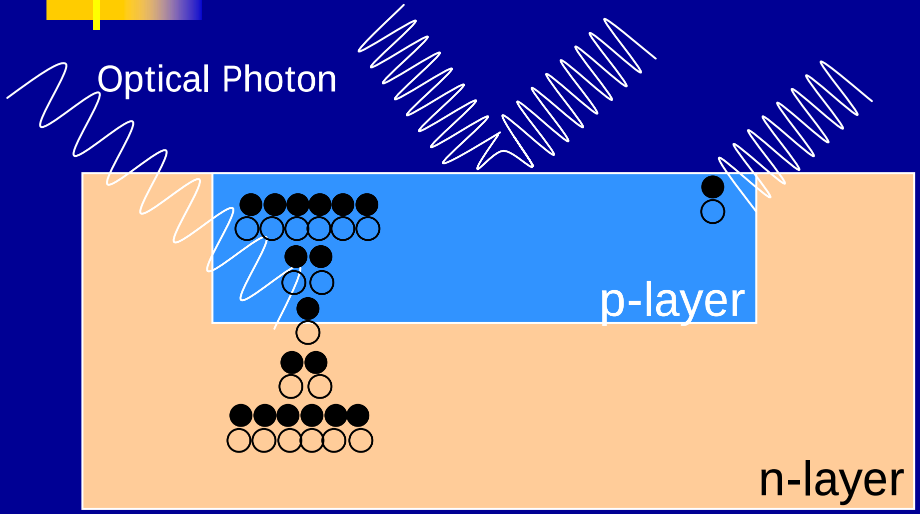
Compact, light-weight dosimeter-on-a-chip using tissue-equivalent scintillator.

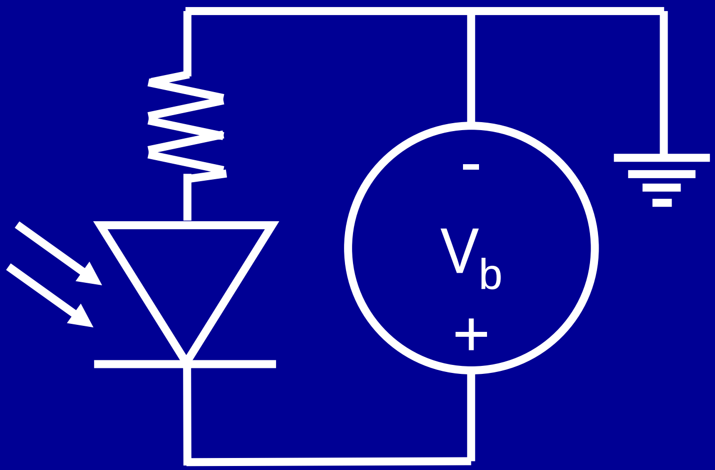




- Use a tissue-equivalent scintillating material.
- Use CMOS technology for optical device and readout.
- The scintillator is the limiting factor for the dosimeter size.
- Compact, low-power, low-mass.
- Provides rates, accumulated dose and spectra.

Geiger Photodiodes

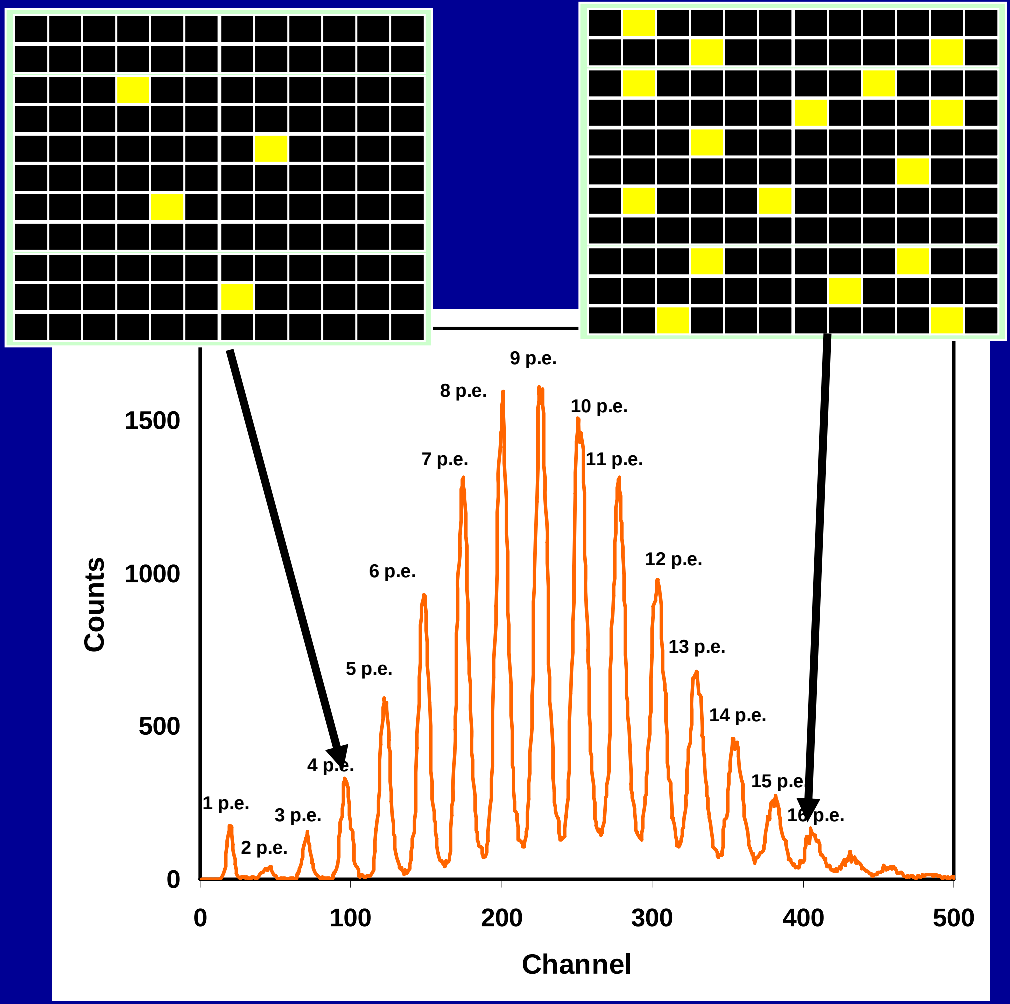


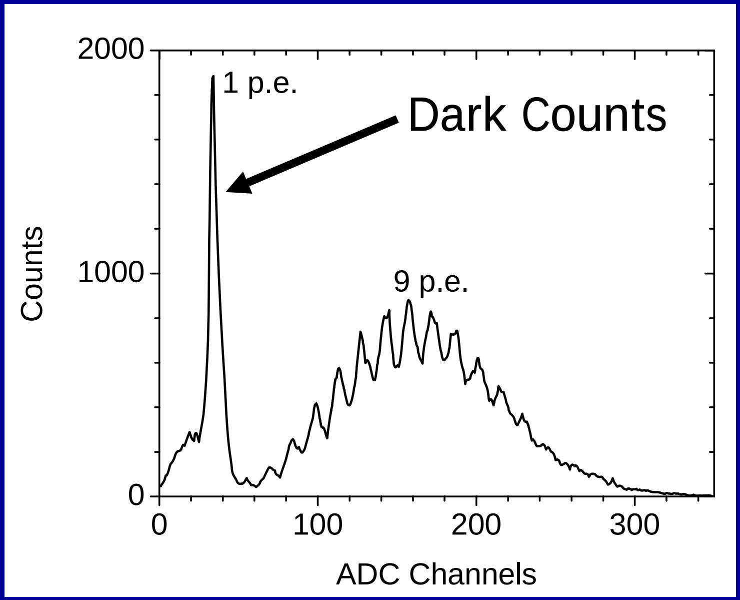


- SSPMs are built as an array of Geiger Photo-Diodes (GPD).
- GPD is a reversed biased photodiode operated beyond the diode breakdown voltage.
- Single pixel detection efficiency = Quantum Efficiency•Geiger Probability
- Quantum Efficiency is the potential for incident light to generate electron-hole pairs in the silicon.
- Geiger Probability is the potential of an electron-hole pair to generate a self-sustained avalanche.
- Avalanche is quenched using a voltage sensing resistor.

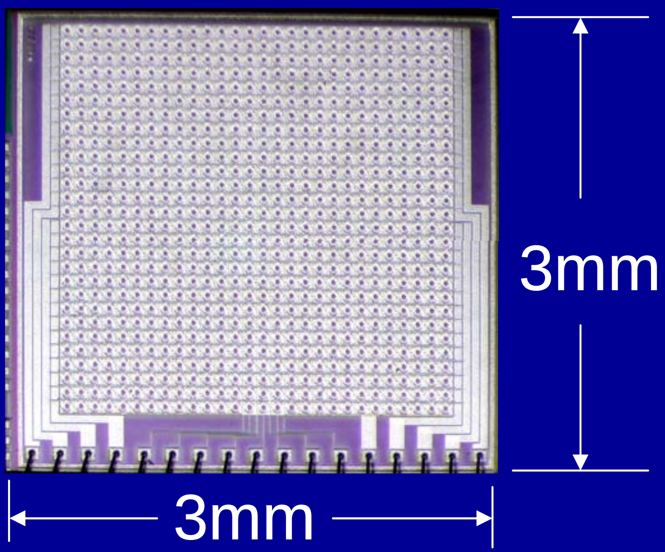
Solid-State Photomultipliers

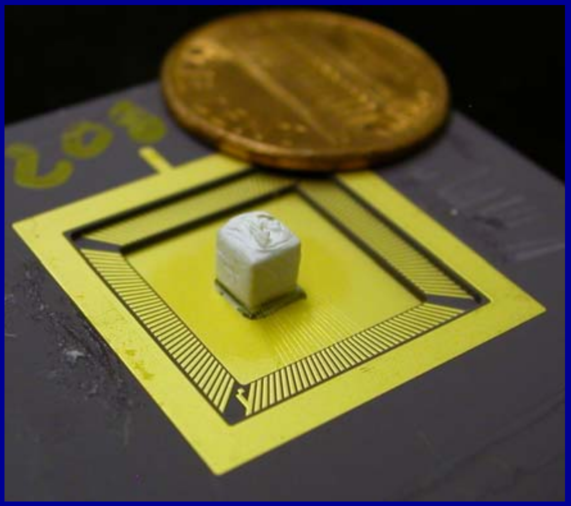
- Dark Counts
  - Equivalent to dark current
  - Uncorrelated random events
- Resolution
  - Light intensity distribution: sqrt(N)
  - Single pixel: sqrt(N)*σ_{pixel}

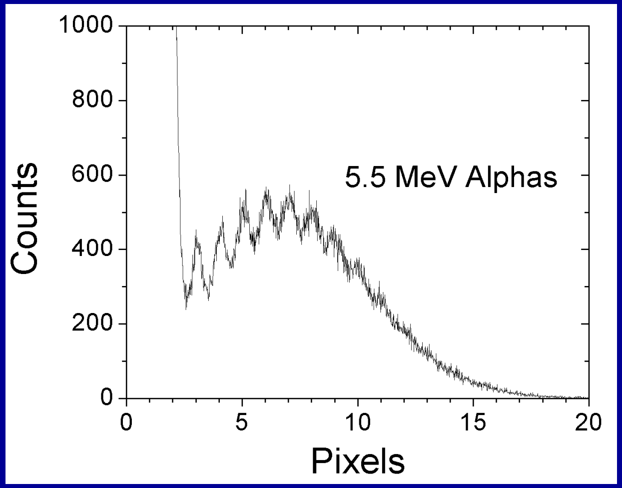




SSPM Dosimeter

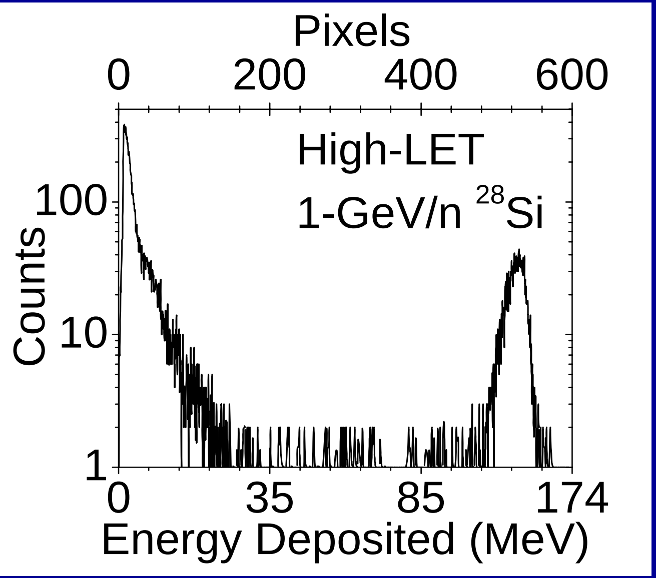


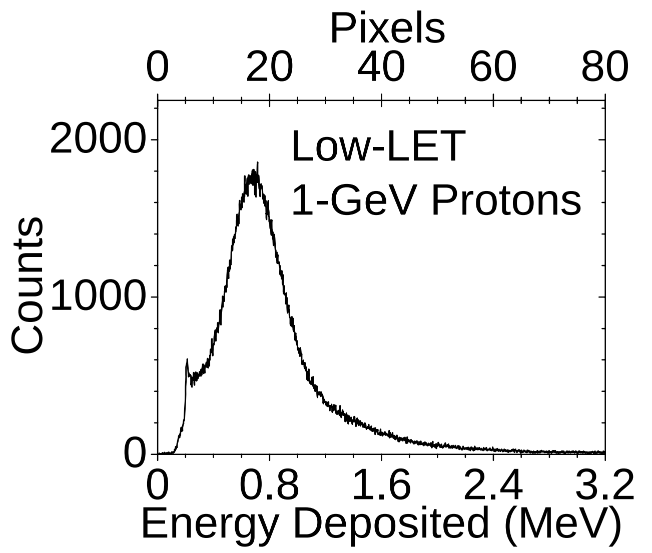




- Prototype device to evaluate at the NSRL at Brookhaven.
- 780 pixel device is coupled to a plastic scintillator covered in Teflon.
- Responded to alpha particles
- Mounted in plastic box for NSRL tests.

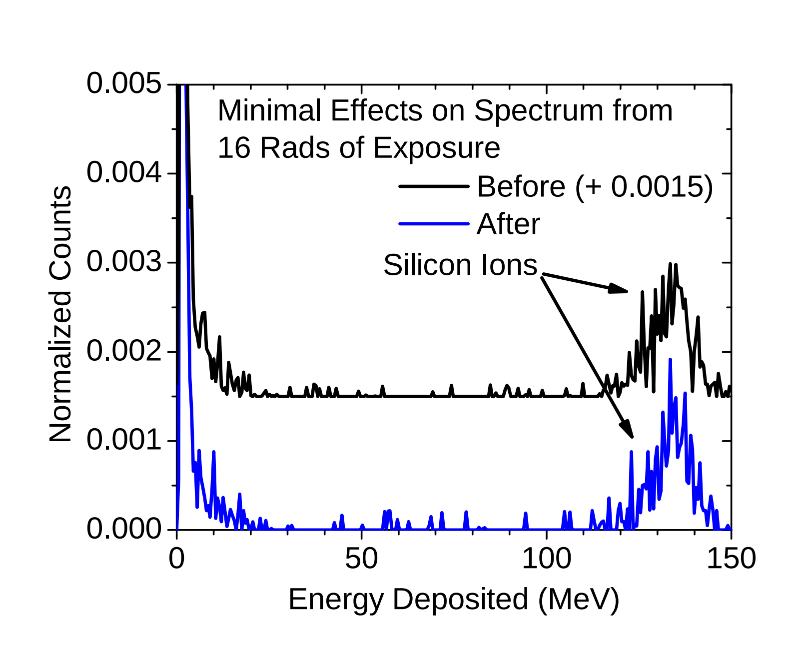
NSRL Spectral Results





- Spectra obtained for low-LET and high-LET particles.
- Large dynamic range demonstrated.
- Thermal background (dark counts) do not obscure the 1-GeV protons (minimum ionizing).

Radiation Damage



$$Dose \propto \frac{\frac{dE}{dx} \cdot L}{\rho \cdot A \cdot L} = \frac{\frac{dE}{dx}}{\rho \cdot A}$$

$$\rho_{Si} \approx 2 \cdot \rho_{scint}$$

$$\left.\frac{dE}{dx}\right|_{Si} \approx 2 \cdot \left.\frac{dE}{dx}\right|_{scint}$$

$$A_{Si} = A_{scint}$$

$$Dose_{Si} \approx Dose_{scint}$$

- Dose in scintillator is approximately equal to dose in silicon.
- No effect on spectrum for this exposure.

26 rads	Exposed SSPM	Control SSPM
Before	1.6 MHz	1.6 MHz
After	2.3 MHz	1.6 MHz

High-Density SSPM

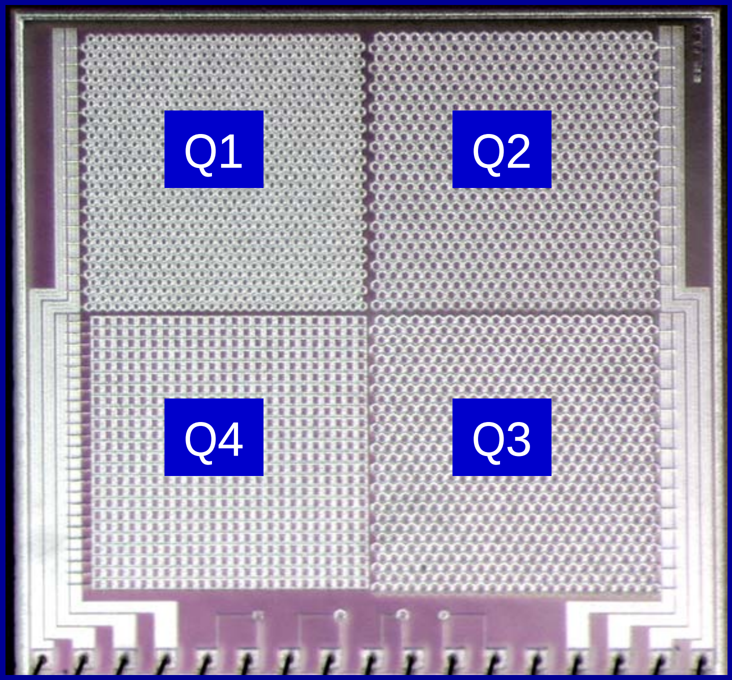
- Advantages of an SSPM with a high pixel density for spectral based dosimetry.
  - Better energy resolution
  - Larger dynamic range
  - Better separation between the baseline noise and the signal.

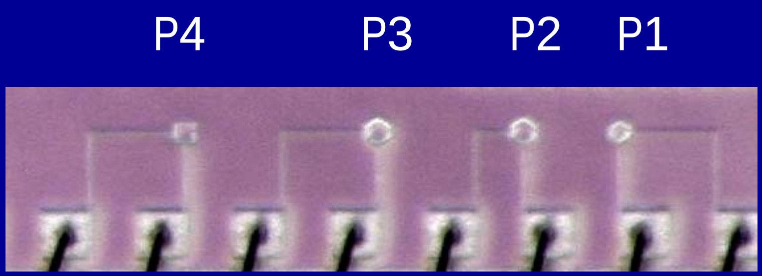
<u>Q1: Type 12</u>
Fill Factor = 19%
1020 pixels

<u>Q2: Type 12</u>
Fill Factor = 29%
700 pixels

<u>Q3: Type 4</u>
Fill Factor = 29%
700 pixels

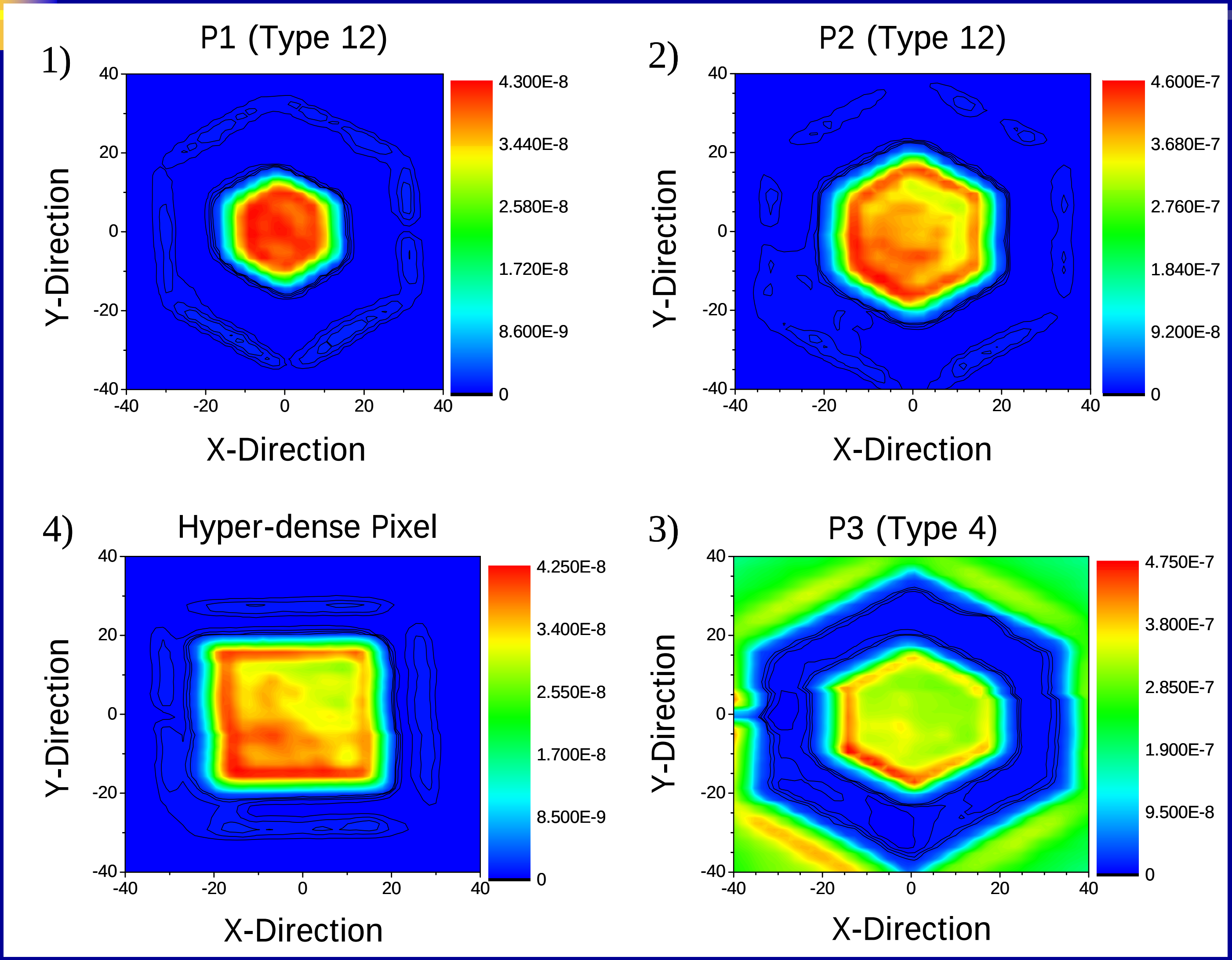
<u>Q4: Type 12</u>
Fill Factor = 29%
576 pixels





- P1: Q1 pixels (Type 12)
- P2: Q2 pixels (Type 12)
- P3: Q3 pixels (Type 4)
- P4: Hyper-dense square pixel (Type 12)

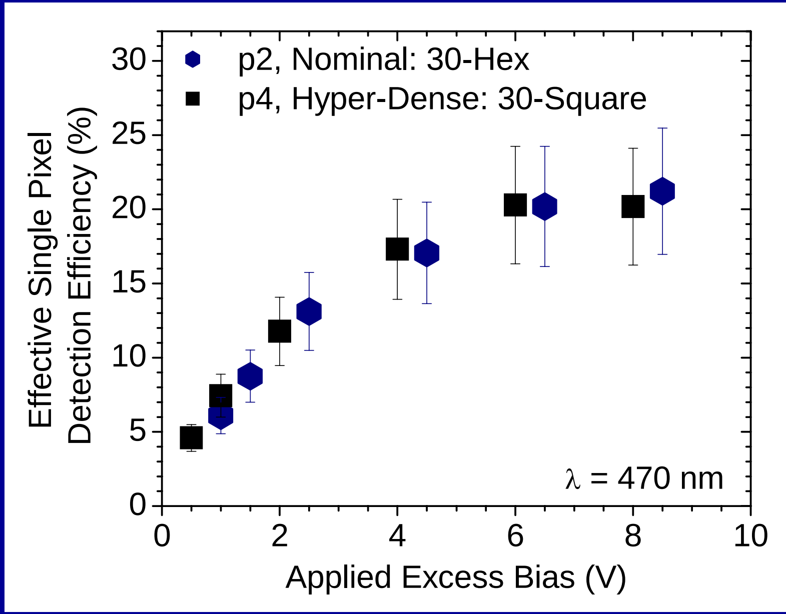
Imaging the Active Area



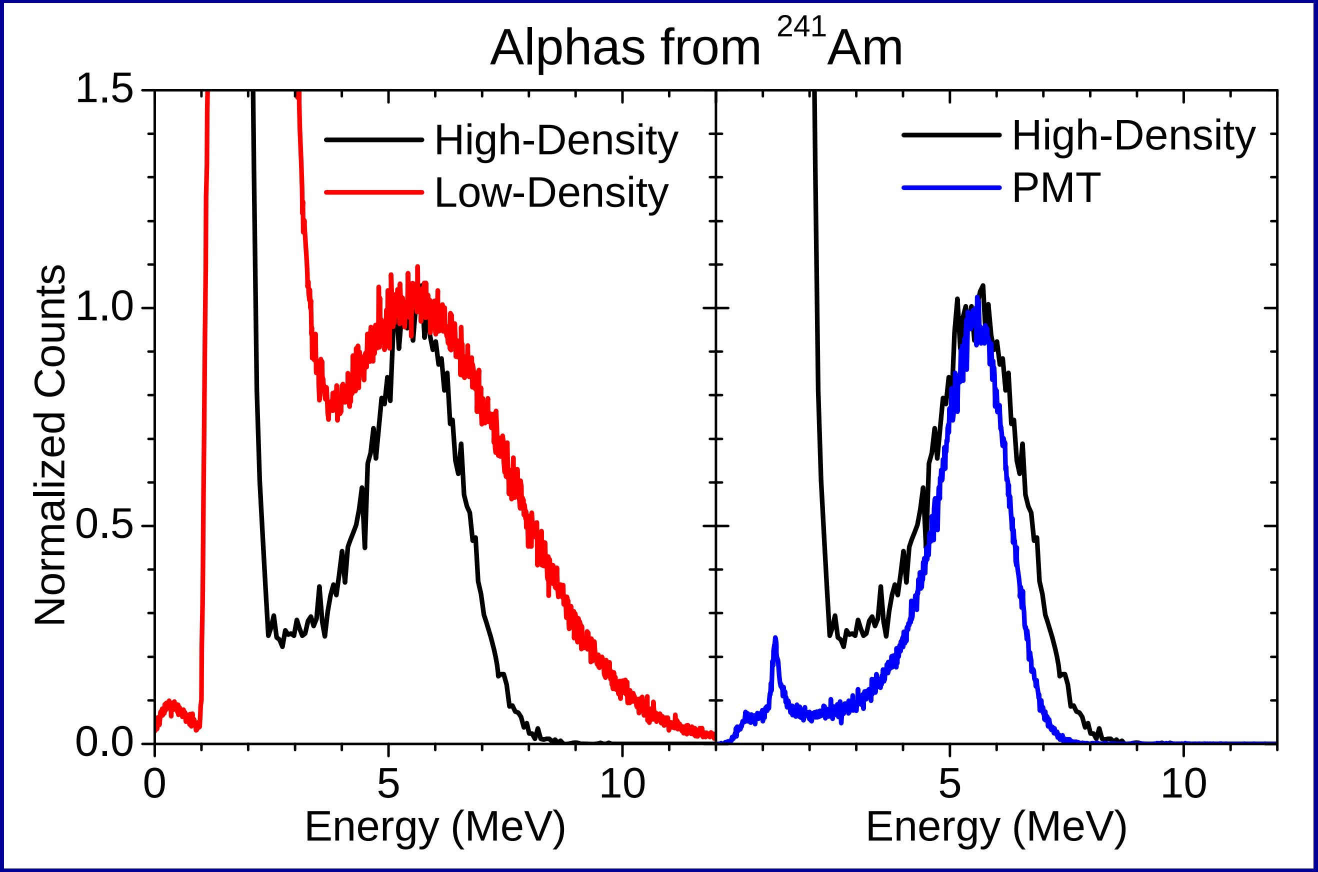
- Good quantum efficiency uniformity.

Device Characterization

- Fill Factor: Ratio of active to dead area of an array
  - Low-density SSPM: 7%
  - High-density SSPM: 19% and 29%
  - Hyper-density SSPM: 50%
- Dark counts influences the spectral baseline.
  - Quadrants show similar behavior to low-density prototype used at NSRL.
  - Hyper-density pixel has similar DCR to nominal design.
- Detection efficiency is the product of the QE and Geiger probability.
  - Geiger probability is dependent on the excess reverse bias.
  - Excess bias is bias above breakdown.
- Hyper-dense pixel operates similar to the nominal pixel.



Energy Resolution



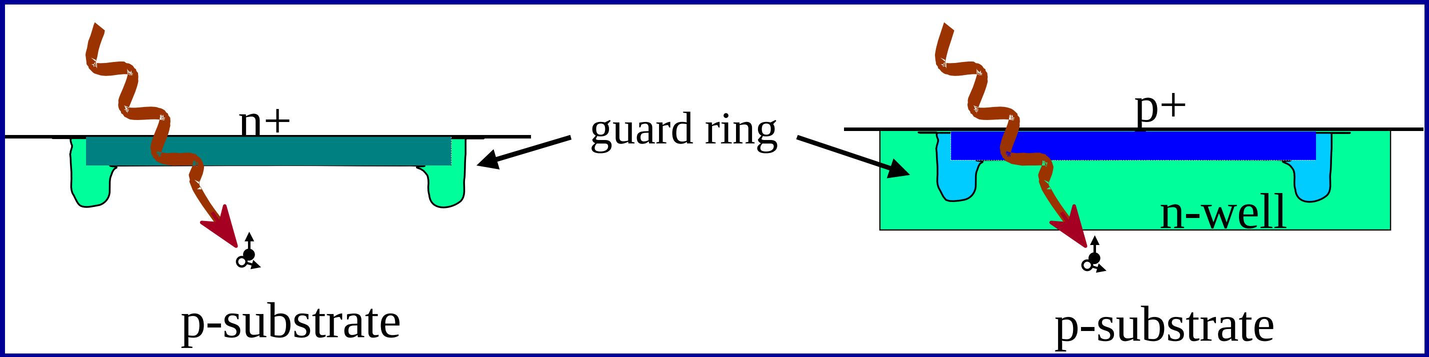
- Illustration of the strong dependence energy resolution has with DE.
- Equivalent performance to PMTs.

Summary

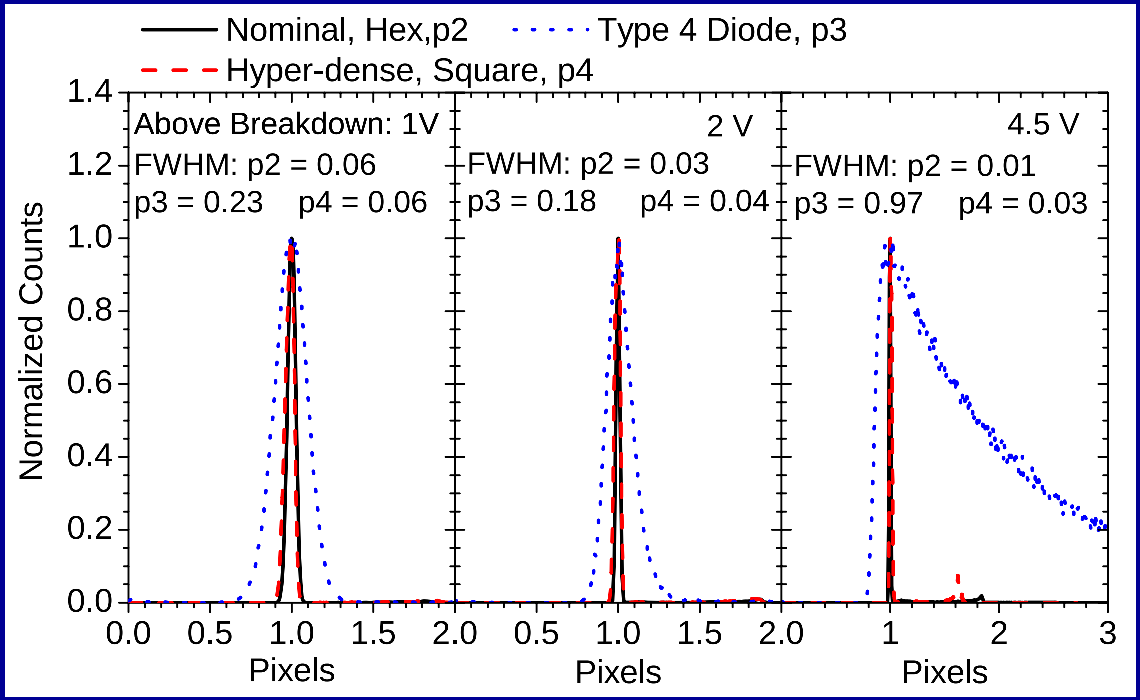
- Low-density array has an excellent response to protons and silicon ions for simulating space radiation.
- Radiation damage in the SSPM will have minimal effects on the spectrum for the high-density SSPM.
- High-density SSPM compared to the low-density array
  - Similar dark count rates.
  - Improved range of operation.
  - Improved energy resolution, close to PMT.
- Demonstrated feasibility of using an SSPM for a space radiation dosimeter-on-a-chip.
- Plan to develop chips with integrated readout.

Pixel Types

Type 4 | Type 12



Effects on Energy Resolution



Energy Resolution

$$\sigma_E \approx \sqrt{\frac{1}{N} + \frac{1}{N}\sigma_{pixel}^2 + \sigma_{scint}^2}$$

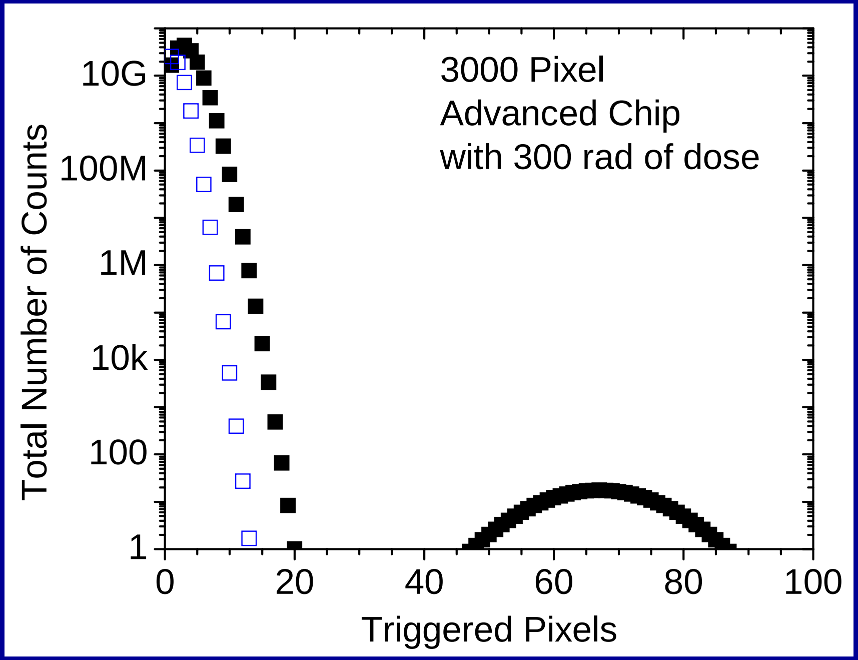
σ_{pixel} = single pixel resolution

σ_{scint} = scintillator resolution

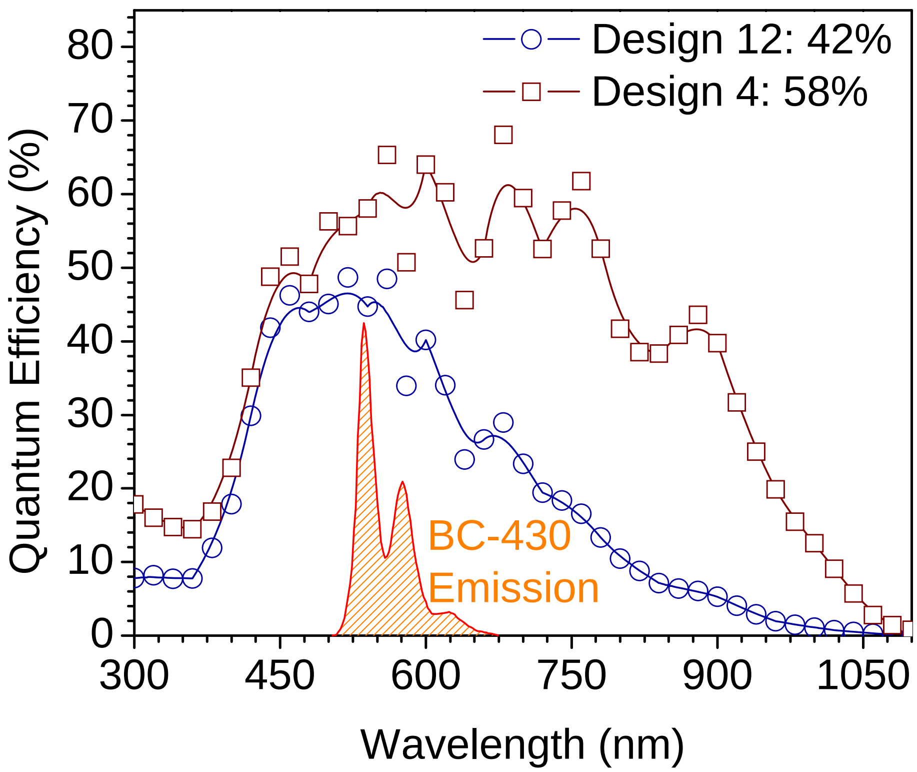
- Energy resolution depends on the number of triggered pixels.
- There will be no noticeable effects in the energy resolution until the single pixel pulse height width is greater than one.

Radiation Damage Simulation

- Assume damage (dark count rate) increases linearly with exposure.
- Simulate 300 rad of dose in SSPM.
- DCR increases from 5 kHz/pixel to 10.4 kHz/pixel.
- For the high-density chip, 1-GeV protons will still be sufficiently above the noise floor.



Quantum Efficiency



High-Density SSPM Quadrant Energy Resolution