The Consortium for Enabling Technologies and Innovation

Virtual Summer Meeting for Young Researchers

Characterizing the Temperature Dependence of Silicon Photomultipliers and Scintillators

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ETI

NNSA National Nuclear Security Administration

Biography

- B.S.E. and M.S.E. from the University of Michigan in Nuclear Engineering
- Ph.D. from North Carolina State University in Nuclear Engineering on neutron scatter camera imaging
- Four internships at Sandia National Laboratories during undergraduate and graduate school
- Postdoctoral researcher at Sandia National Laboratories in Livermore, CA

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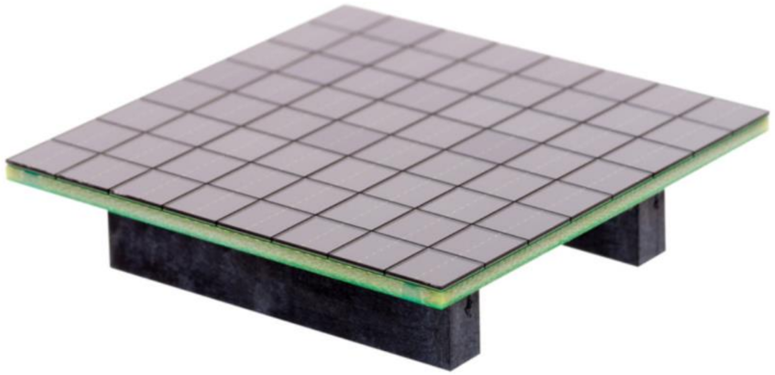
Why silicon photomultipliers?

- Compared to traditional photomultiplier tubes (PMTs)
  - Small form factor
  - Low operating voltage
  - Magnetic field insensitivity
  - Negligible cost differences for comparable photo-sensitive area
  - Gain and dark current
  - Higher photon detection efficiency
- Temperature affects the amount of dark current from thermal production of charge carriers and the breakdown voltage

ON Semiconductor ArrayJ Series SiPMs



Why silicon photomultipliers?

- How does temperature affect
  - Resolution
  - Pulse shape discrimination (PSD) figure-of-merit (FOM)
  - Dark current
  - Others…
- Primary interest in summed response of the 8x8 SiPM array coupled to a 2” x 2” cylinder scintillator
- Investigate individual pixel response to help understand summed array response

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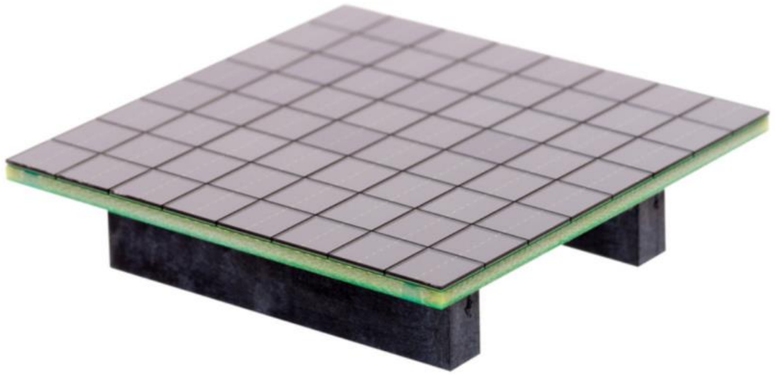

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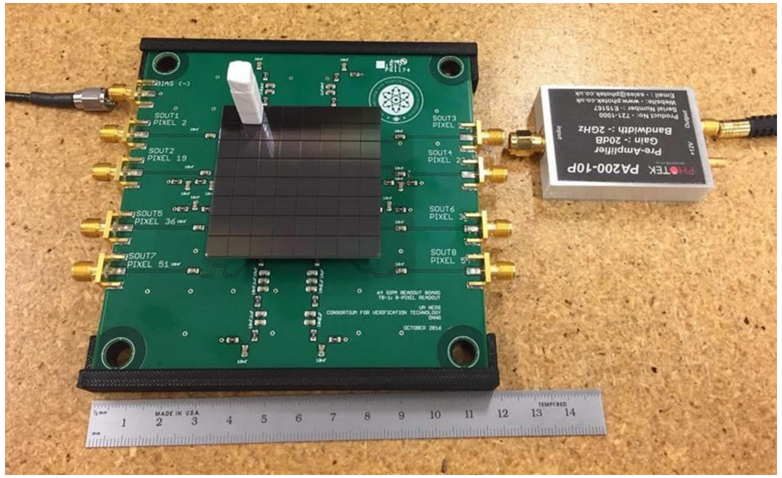
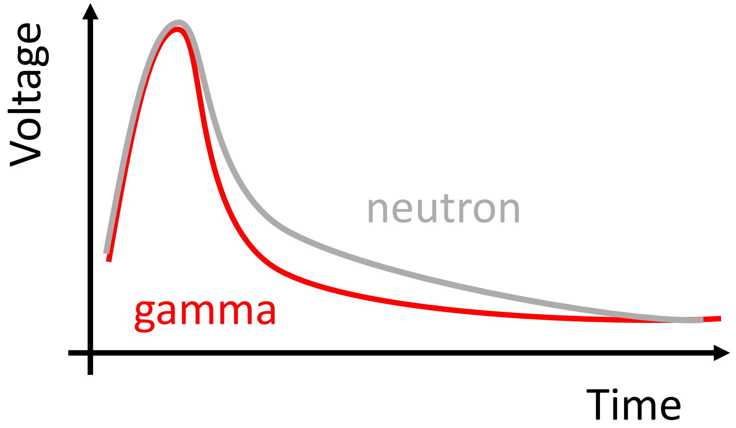
Single SiPM Pixel Experimental Setup

- J-series SiPM array
- CAEN DT5730 500 MHz, 14-bit digitizer
- Digitized four channels
  - Two channels with coupled to organic EJ-299 scintillator pillars
  - Two uncoupled channels with 10x amplification
- Temperature chamber
- Sources: AmBe, Cs-137

J-Series SiPM Array

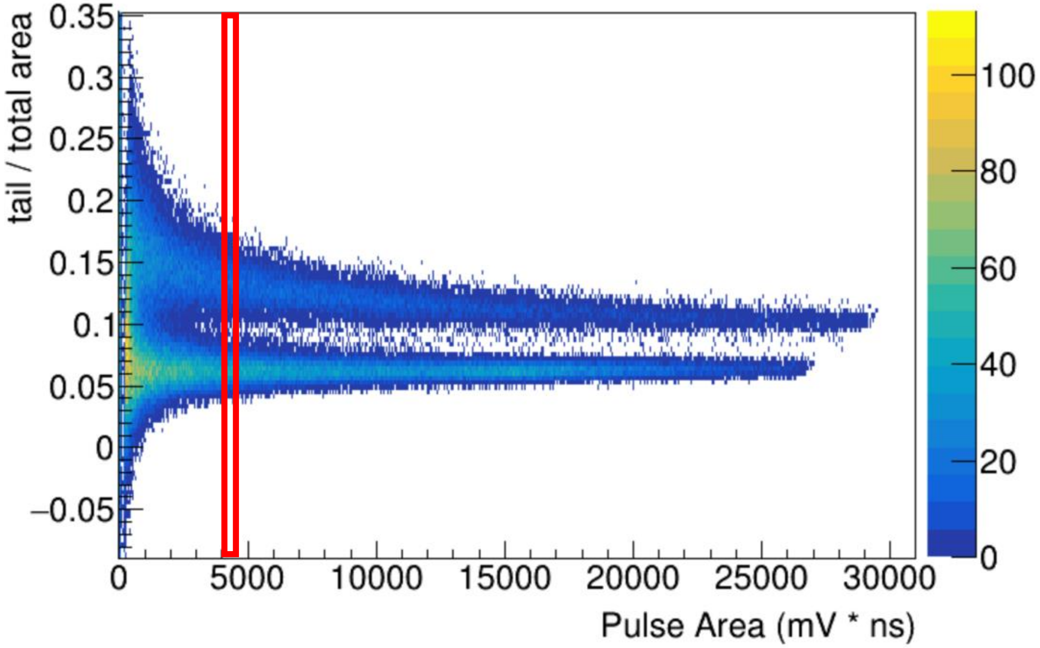




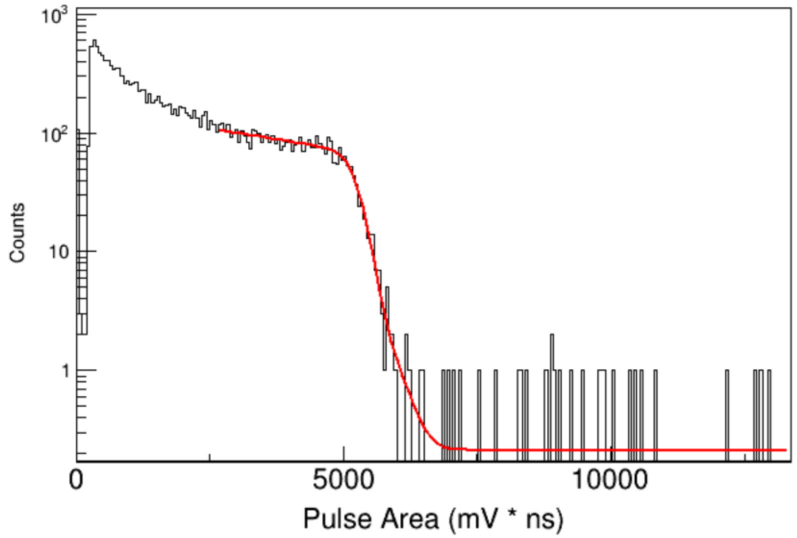
Pulse Shape Discrimination

- Estimate the Cs-137 Compton edge location
- Take a vertical slice on 2D PSD plot
- Fit slice with a double Gaussian to calculate FOM

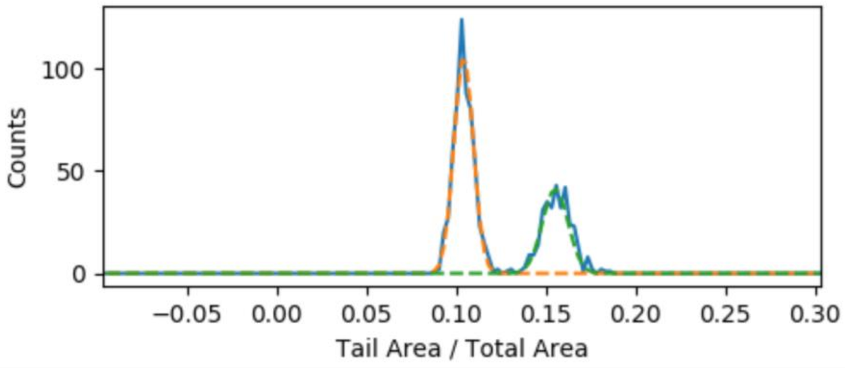
PSD



Cs-137 Compton Edge



FOM



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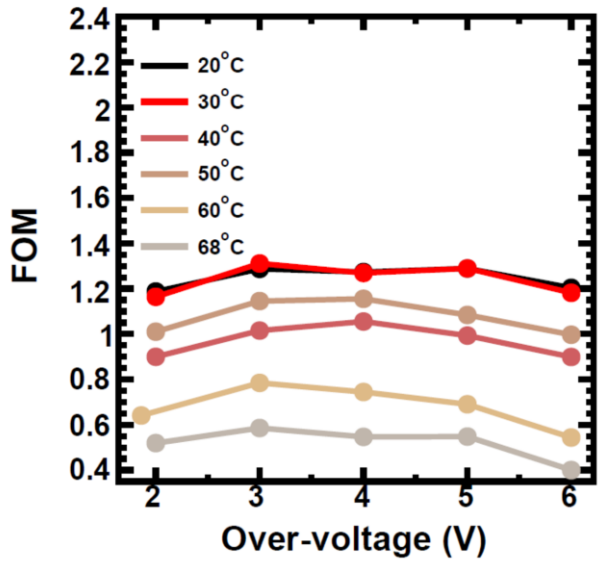
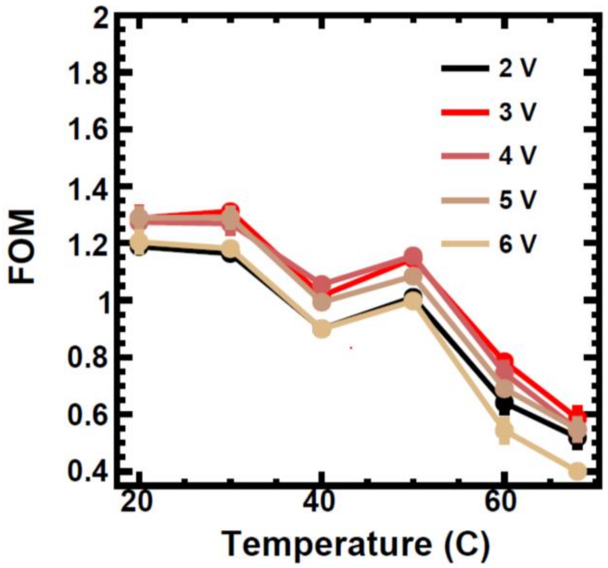
Temperature Response Results PSD and FOM

- Majority of the figure of merit degradation occurs above at 50˚C
- Optical coupling issues may be the cause for a portion of the reduction in FOM
- FOM is relatively constant as over-voltage increases
- Discrimination of neutrons and gamma-rays becomes problematic at high temperatures
- FOM decreases as temperature increases

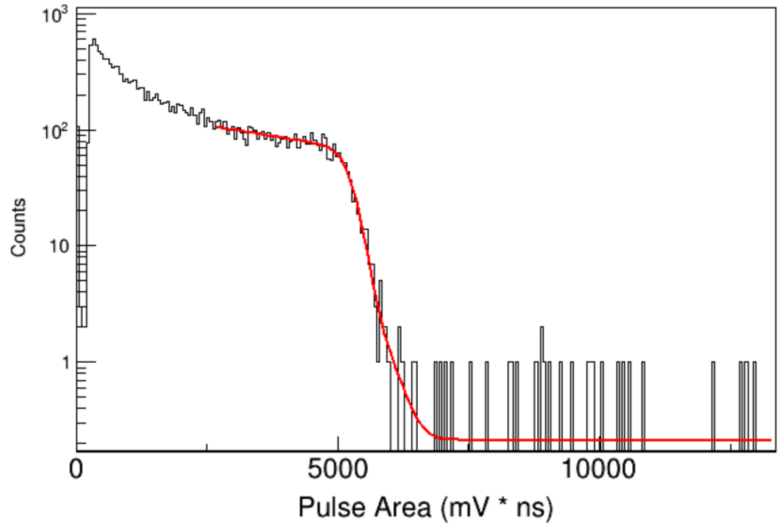


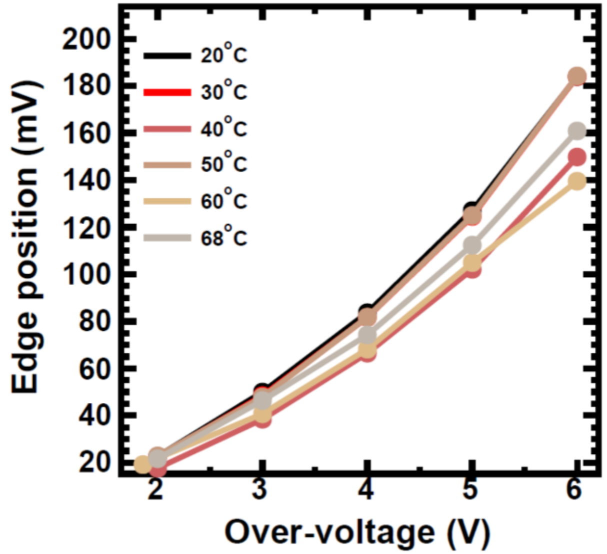


Compton Edge Position

- Fit the pulse height distribution with a convolved Gaussian and Heaviside step function to estimate the Compton edge position and
- Estimated edge position varies slightly at higher temperatures
- Edge position increases as expected at higher over-voltages due to increased gain

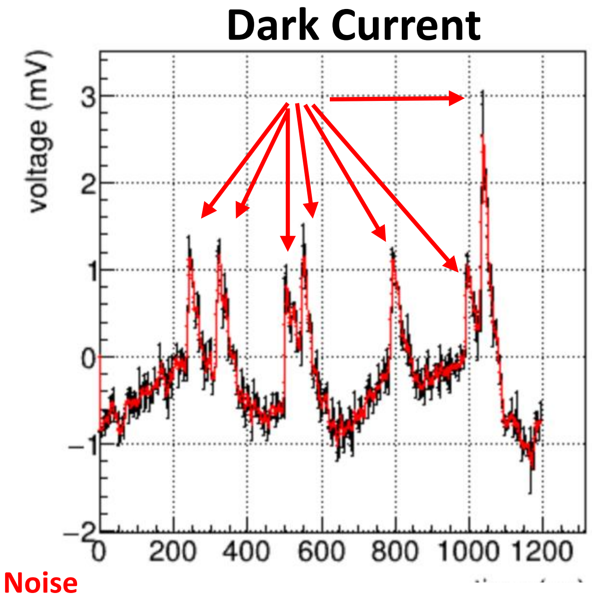
Cs-137 Compton Edge

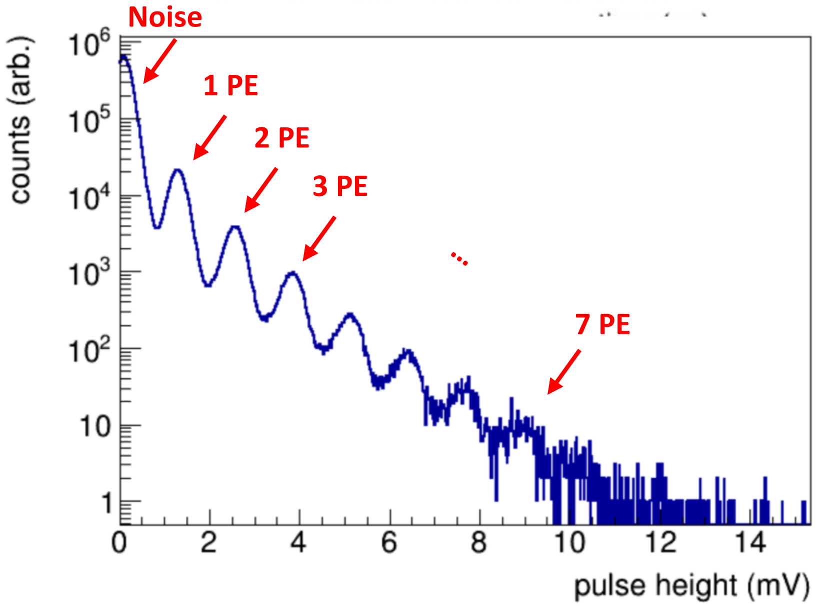




Dark Current

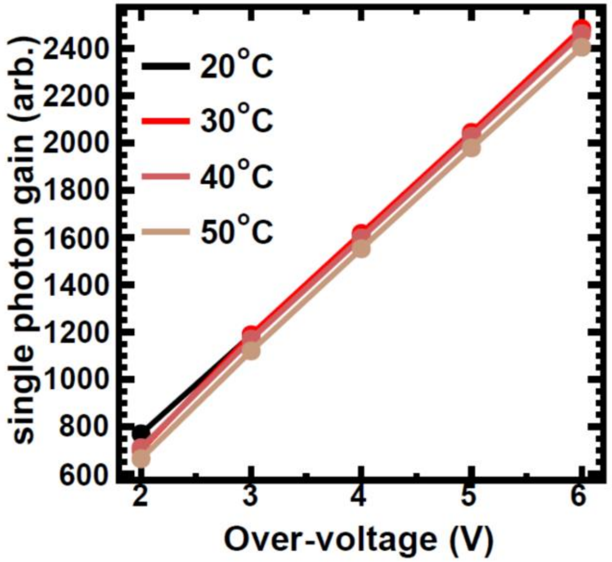
- Investigated dark current using the amplified uncoupled SiPM channels
- Estimated pulse height of dark current waveforms with a trapezoidal filter
- Subtracted noise peak by fitting a Gaussian to isolate single photo-electron peak

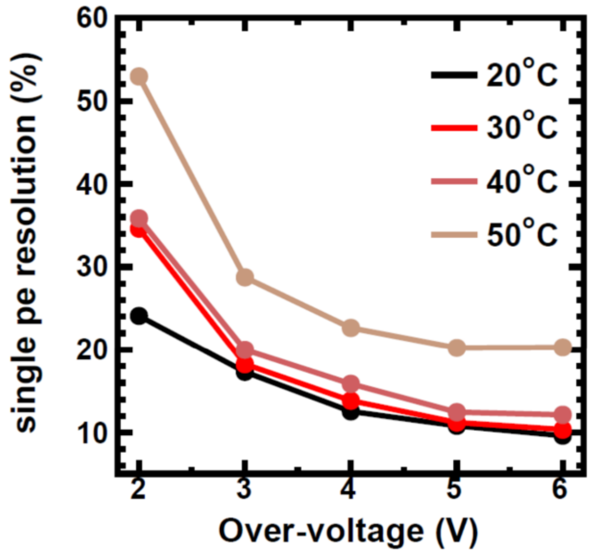




Single PE Gain and Resolution

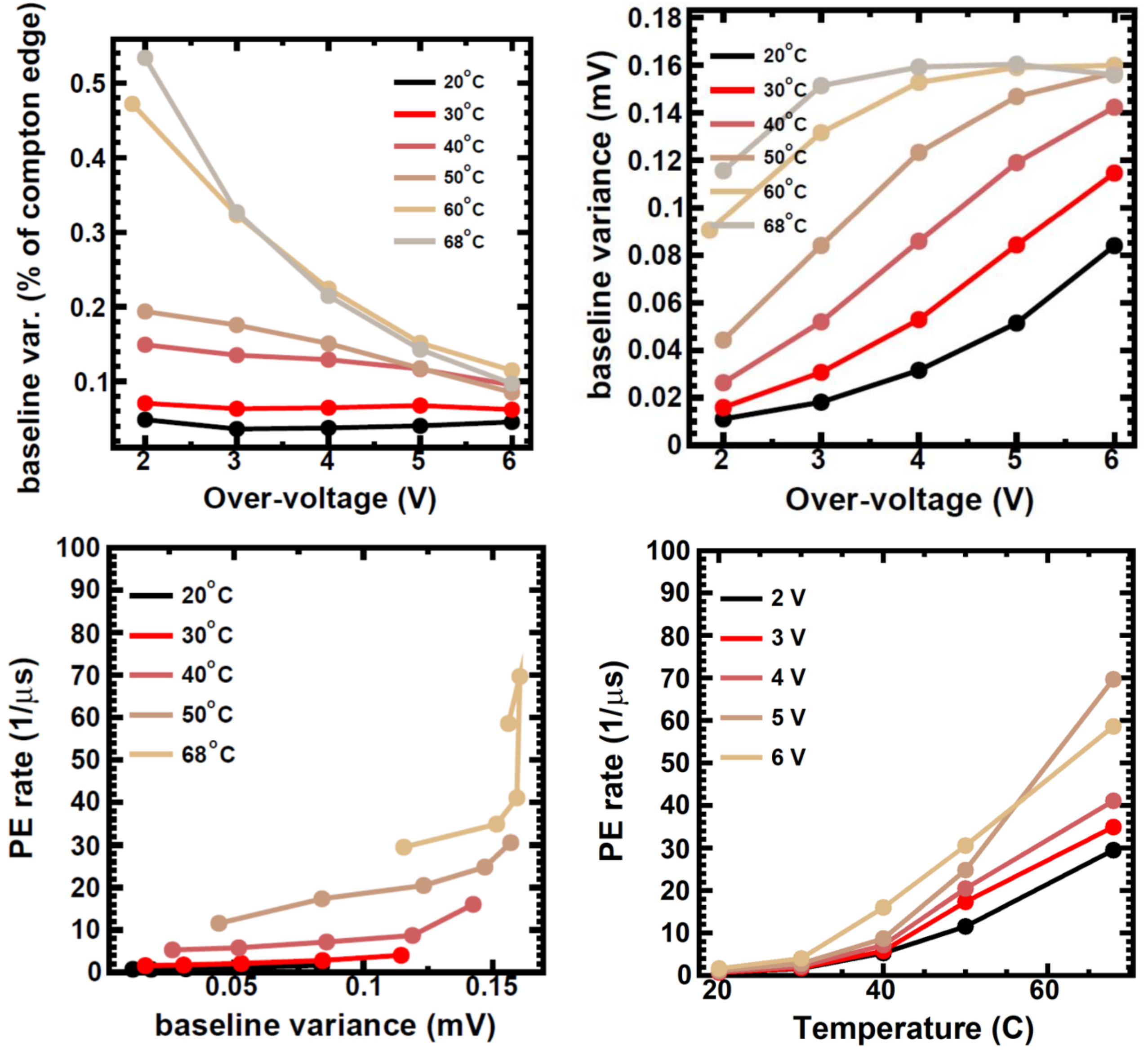
- Results at 60˚C and 68˚C not shown due to no observable single PE responses
- Single PE gain not dependent on temperature and behaves as expected
- Break-down voltage correction supplied by the manufacturer retained comparable gain for all temperatures measured
- Single PE resolution decreases as over-voltage increases due to higher gain and photon detection efficiency
- Higher temperatures result in worse single PE resolution





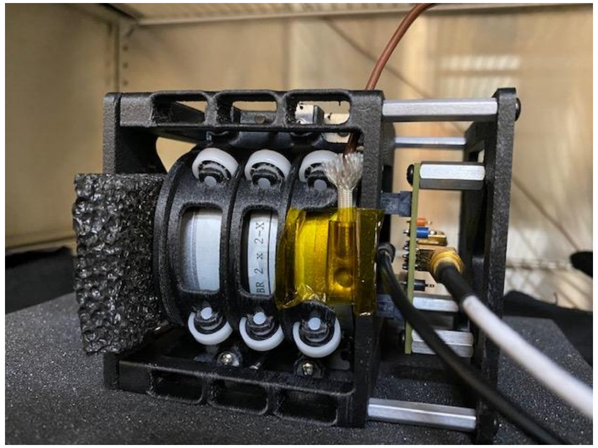
Experimental Setup

- Temperature and over-voltage both increase dark count rate as expected
- Baseline variance is based on the overall PE rate

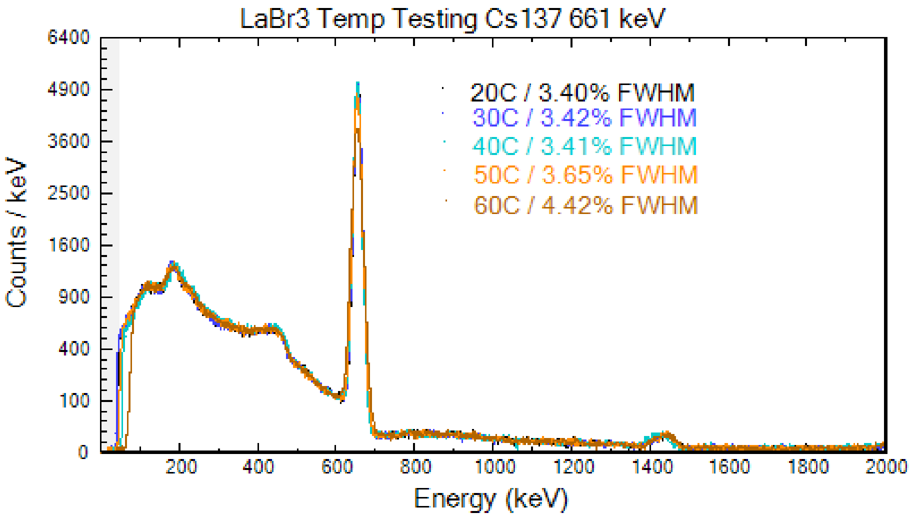


Current/Future Work

- Expand testing to a summed 8 x 8 SiPM array
- Use 2” x 2” cylindrical organic and inorganic scintillators
- Automate measurements for minimal human interaction needed
- Acquire detector response functions for each scintillator/SiPM combination for simulation campaign



$LaBr_3$ spectra using Cs-137



Conclusions

- Measured PSD capable plastic scintillator EJ-299 from 2V – 6V over-voltage and at temperatures from 20˚C to 68˚C
- Particle discrimination capability is possible at all temperatures tested
  - Degraded PSD above 50˚C
- Manufacturer recommended breakdown voltage corrections worked
- Possible loss of low energy events due to larger baseline variations at high temperatures
- Summed 8 x 8 arrays
  - Linear increase in PE rate
  - Quadrature increase of baseline variance

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