Aging Studies of SensL C-series SiPMs

Stuart Mufson, Brice Adams
DUNE Photon Detector Review
August 2, 2016

Continuing work reported in DUNE docdb #904, #905, & #1380

- note well: SiPMs will be sitting in a very benign environment – cold, dark, exposed to the occasional passing muon and ^{39}Ar decays
- heating devices doesn't work – every heating cycle requires a thermal cycle, and separating the two effects is impossible

1. Infant Mortality

- SiPMs could fail mechanically through mechanical issues from CTE mismatches during cool-down or warm-up
- Electronic components could fail at cryogenic temperatures

Test with limited sample size:

In the two most recent TallBo experiment at PAB at Fermilab, 80 SensL SiPMs (B and C series) were used that were never thermally cycled and had only been tested electrically for functionality at room temperature

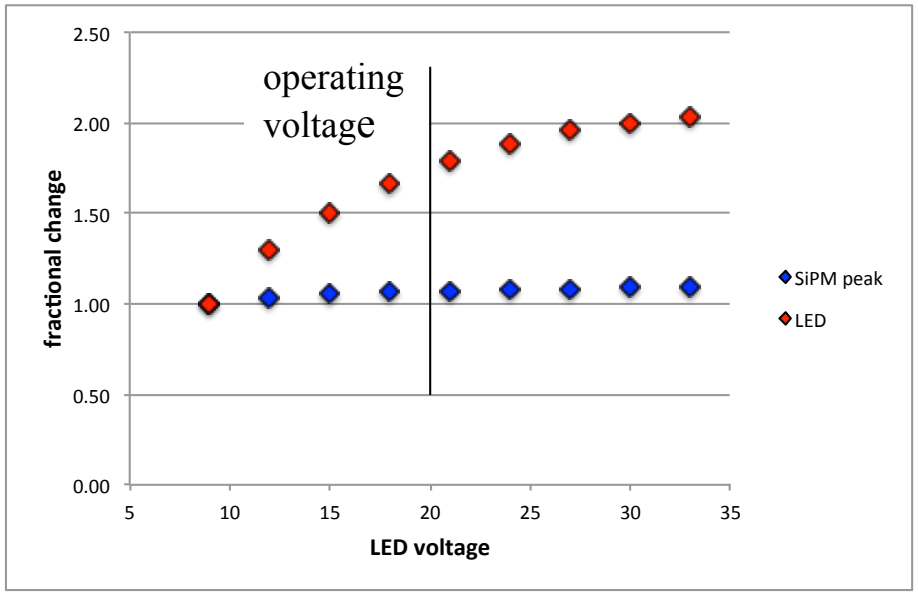
All 80 that tested as working at IU survived the fill and the experiment

This is an encouraging result but not definitive

2. SiPM aging – Pulsing Tests

- continuously stress all 18,960 microcells on each of 6 SensL C series SiPMs by subjecting them to a continuous stream of LED pulses
  - test in LN2
  - 25.5 V bias
  - LED pulse width 750 ns, pulse rate 1kHz

By saturating the SiPM, all microcells have avalanched



LED output increases with voltage

SiPM response remains constant – SiPM saturated

SiPM/LED ratio decreases

- Pulse Test Age Estimate
  - noise rate ~ 15 Hz (underground cosmic rate significantly lower)
  - ^{39}Ar decays @ 100x noise rate
  - SiPM sees 15 Hz x 100 x 3.16x10^{7} s/yr ≈ 5x10^{10} avalanches/yr
  - event triggers 1.5 microcells on average (conservative, cross talk prob 30%) out of ~18,960 microcells
  - typical microcell sees:

    5x10^{10}/(18,960/1.5) ~ 4x10^{6} avalanches/yr
  - **Test**: hit each microcell with 10^{9} pulses (~2 weeks of running @ 1 kHz)

    10^{9}/4x10^{6} ≈ 250 yrs of simulated exposure

- The ongoing testing program so far includes 53 SensL SiPMs
- So far no failures have been found
- An additional 6 (=59) are currently being tested and have not shown problems midway through the test
- Sample: 720 needed for protoDUNE

  53/720 = 7.4%

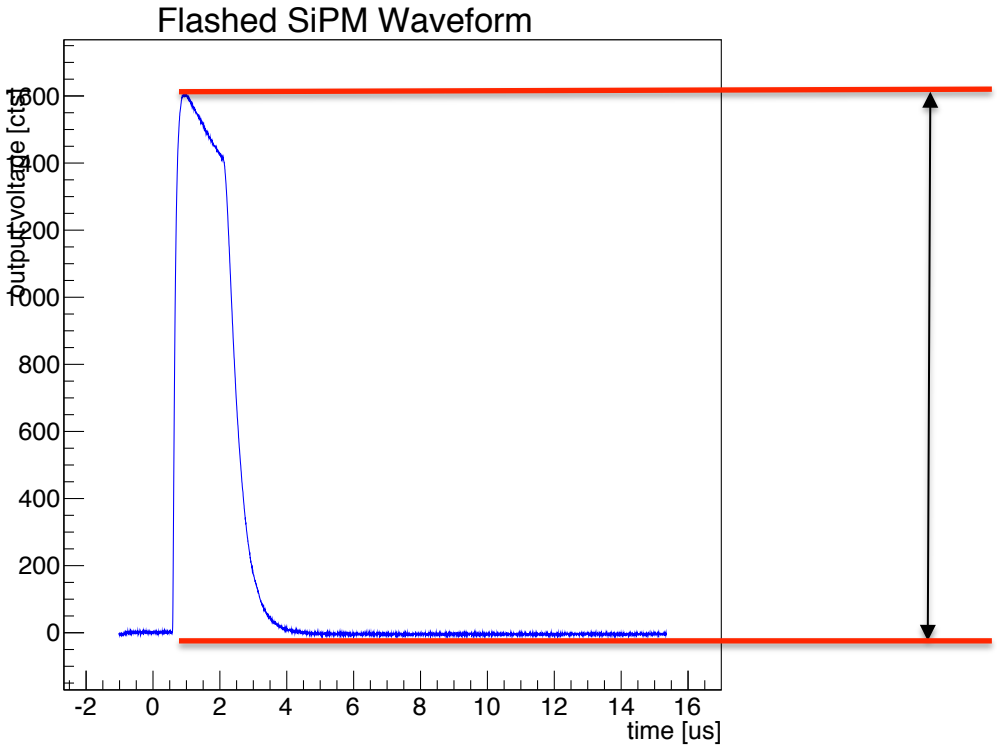
<u>Mean time to failure</u>

- Assuming a Poisson model for failures, Monte Carlo simulation shows that for 0 failures in 53 trials

  mean time to failure > 1,000 yr

  for this failure mode

SiPM response – output voltage for an event proportional to (# functional microcells x output of single microcell)

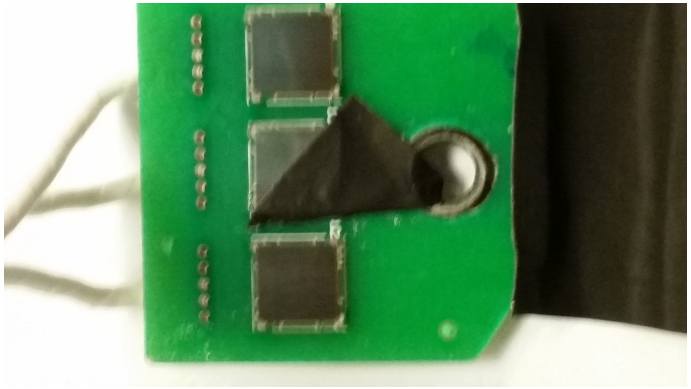


output voltage from fully functional SiPM = 18,960 microcells x output of single microcell

The average waveform for 10 sets of 50 pulses from an array of 430 nm LEDs for SiPM

sanity check:

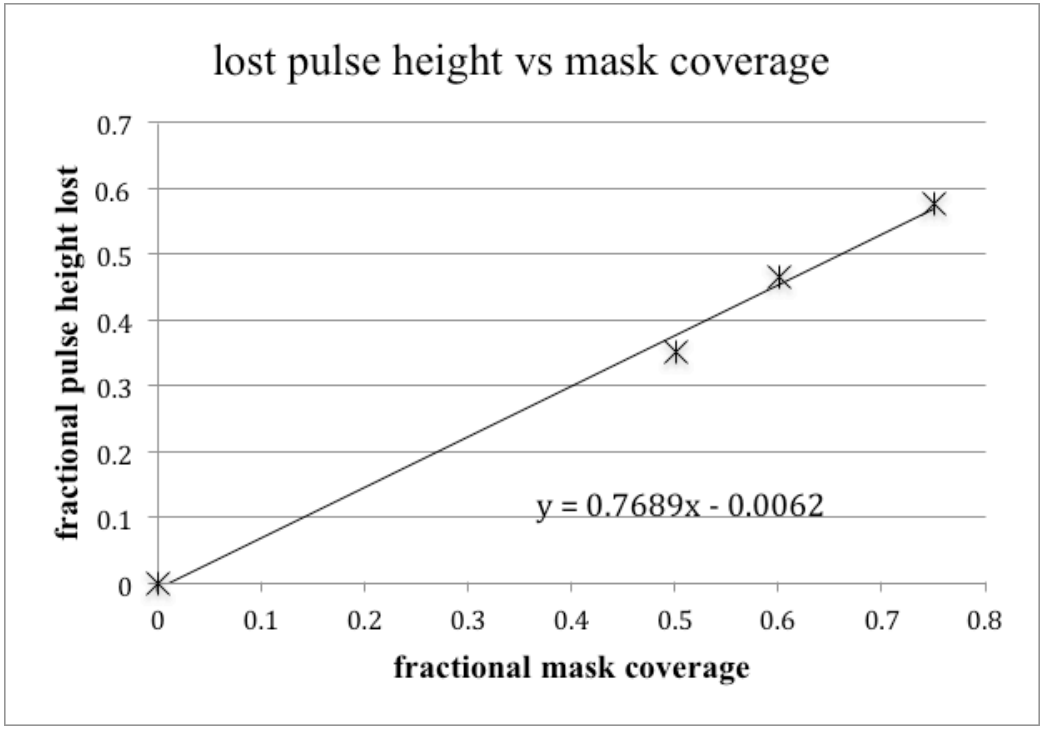
mask cells



50% mask

look for linear decrease in SiPM output with fractional mask coverage

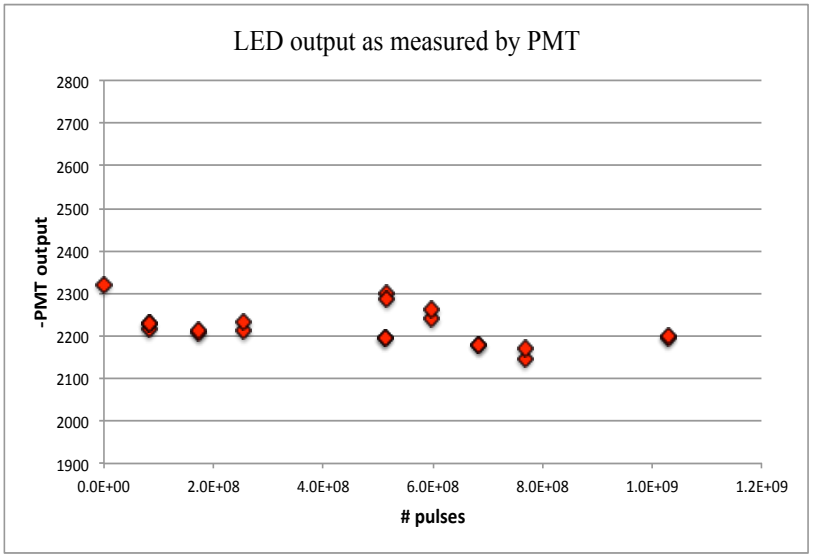
(Slope <1 – extra light from cross talk since masked microcells are not failed)



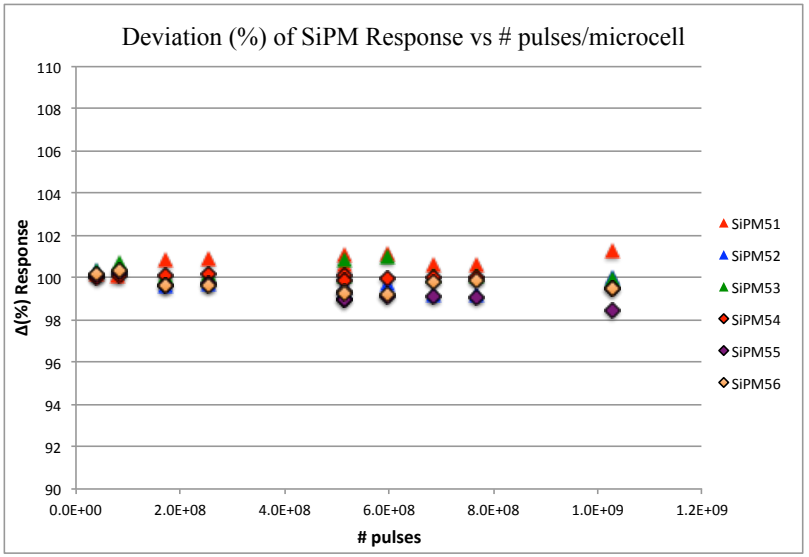
- 53 SiPMs tested in runs of 6 SiPMs

Results from a typical run:

LED output during run as monitored by a PMT vs # pulses

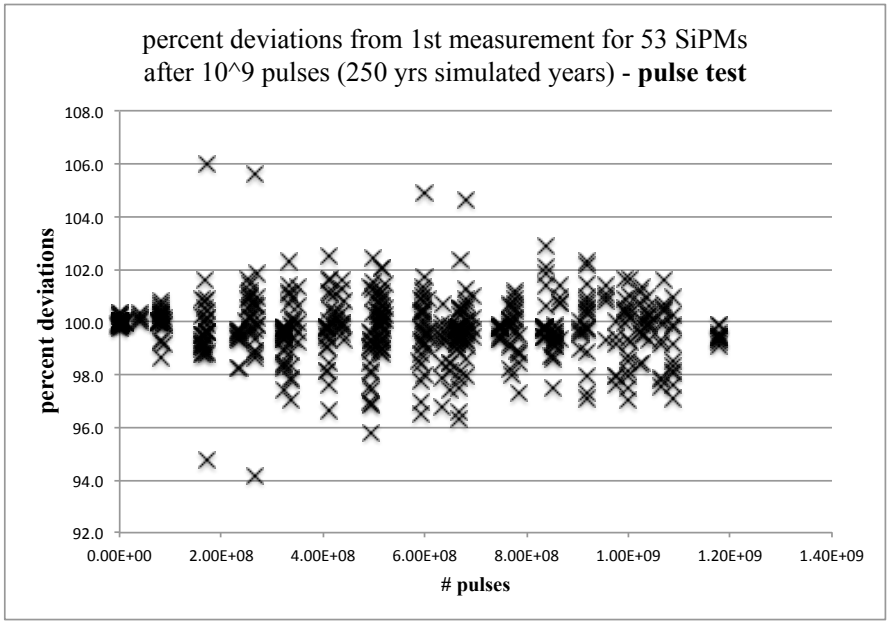


percent deviations from 1st measurement vs # pulses

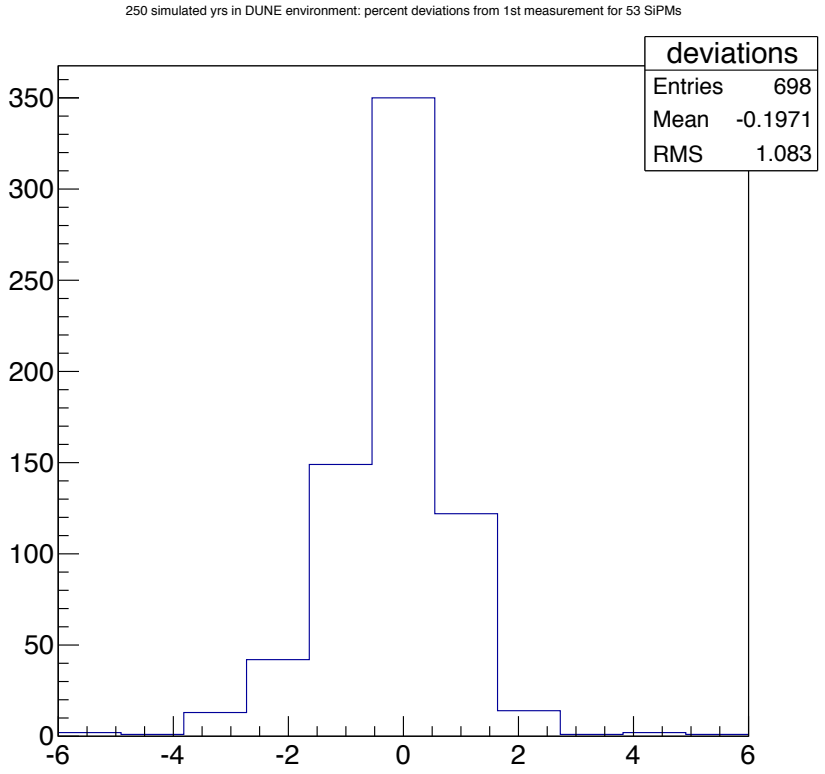


SiPM response: Results for all 53 SiPMs

percent deviations from 1st measurement vs # pulses



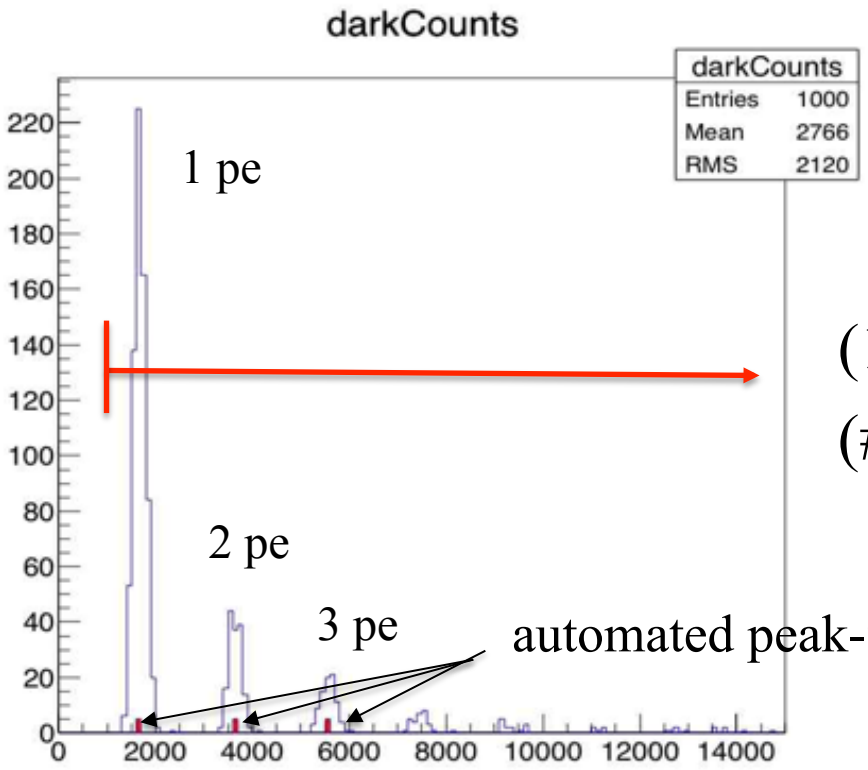
percent deviations from 1st measurement



(spike at 0 – first measurements in histo)

Dark noise

- 1,000 dark noise triggers with trigger threshold ~0.5 pe
- noise rate calculated from acquisition time



(1) noise:

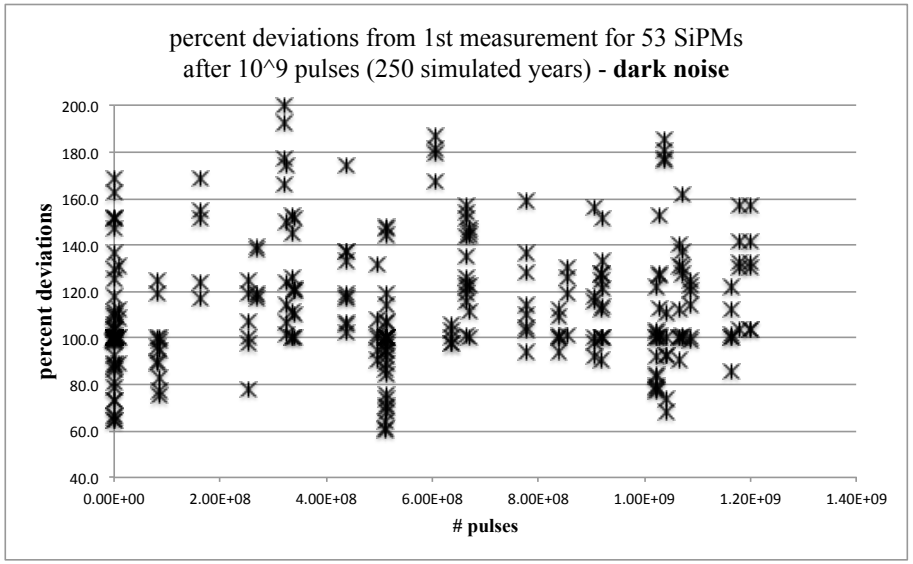
(# ADC cts > 0.5 pe)/(acquisition time)

histogram of #ADC cts in integrated waveform for 1000 triggers

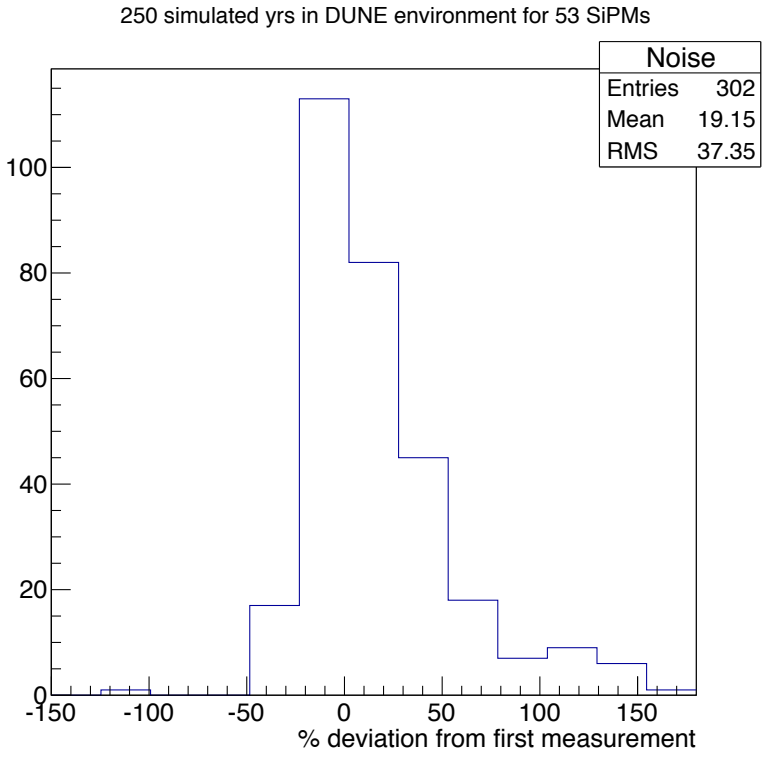
Dark Noise: Results for all 53 SiPMs

no evidence for aging in 250 simulated years

percent deviations from 1st measurement vs # pulses



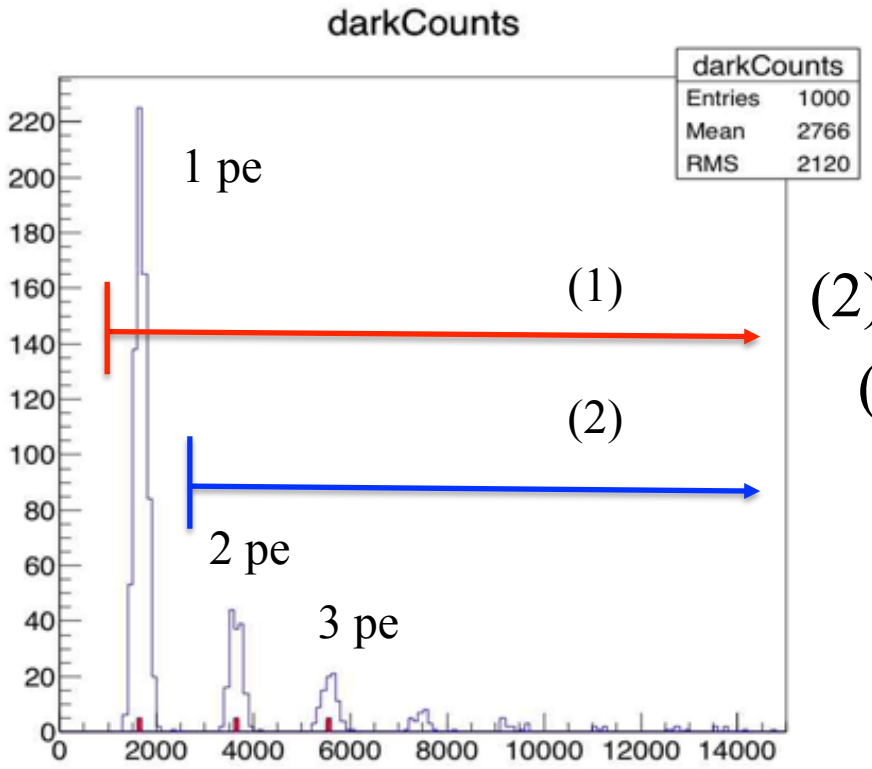
percent deviations from 1st measurement



(spike at 0 – first measurements in histo)

Cross talk

- 1,000 dark noise triggers with trigger threshold ~0.5 pe



(2) cross talk probability:

(ADC cts > 1.5 pe)/(ADC cts > 0.5 pe)

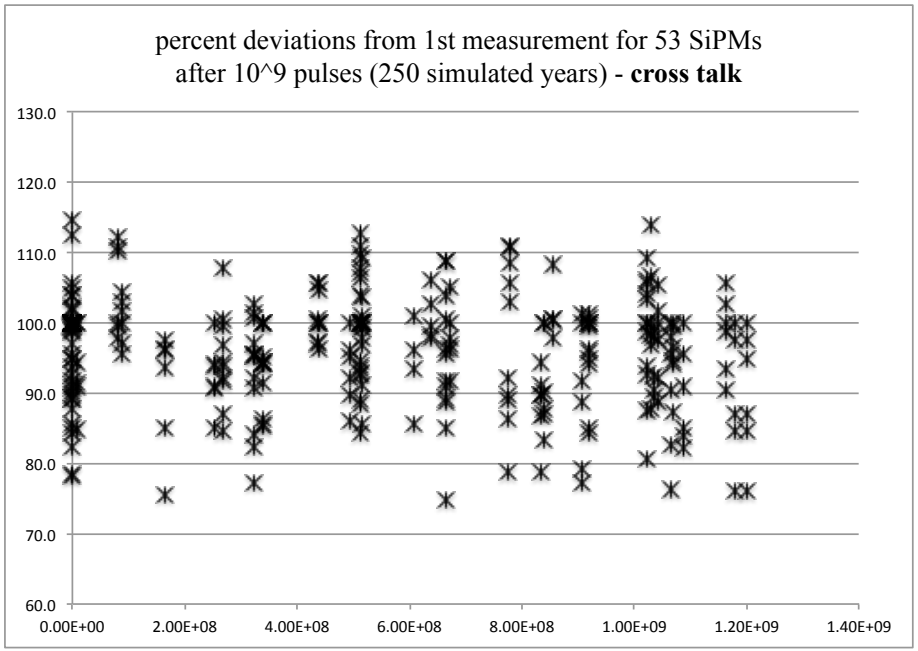
cross talk prob = (2)/(1)

histogram of #ADC cts in integrated waveform for 1000 triggers

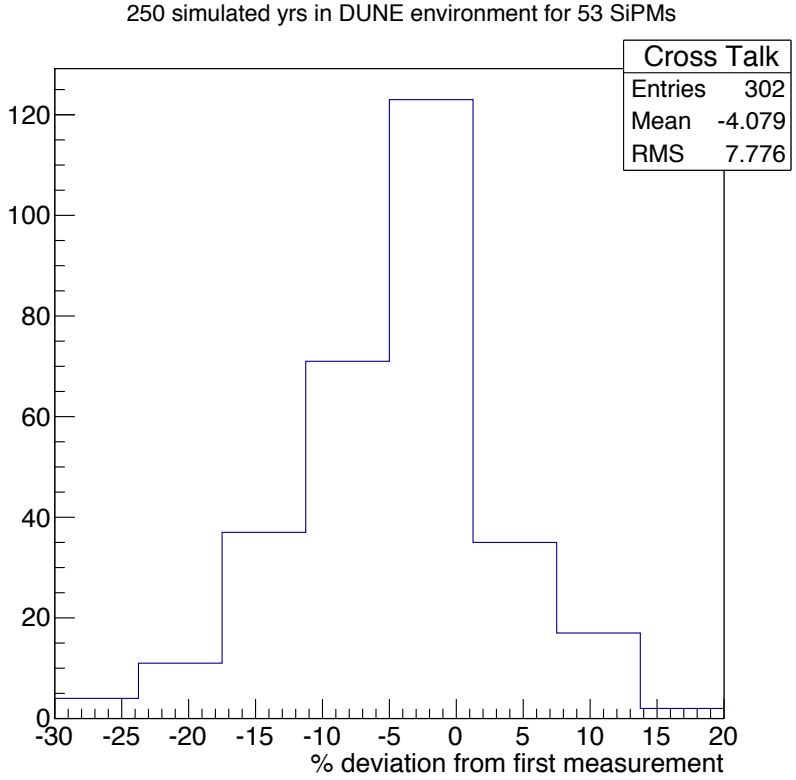
Cross Talk: Results for all 53 SiPMs

no evidence for aging in 250 simulated years

percent deviations from 1st measurement vs # pulses



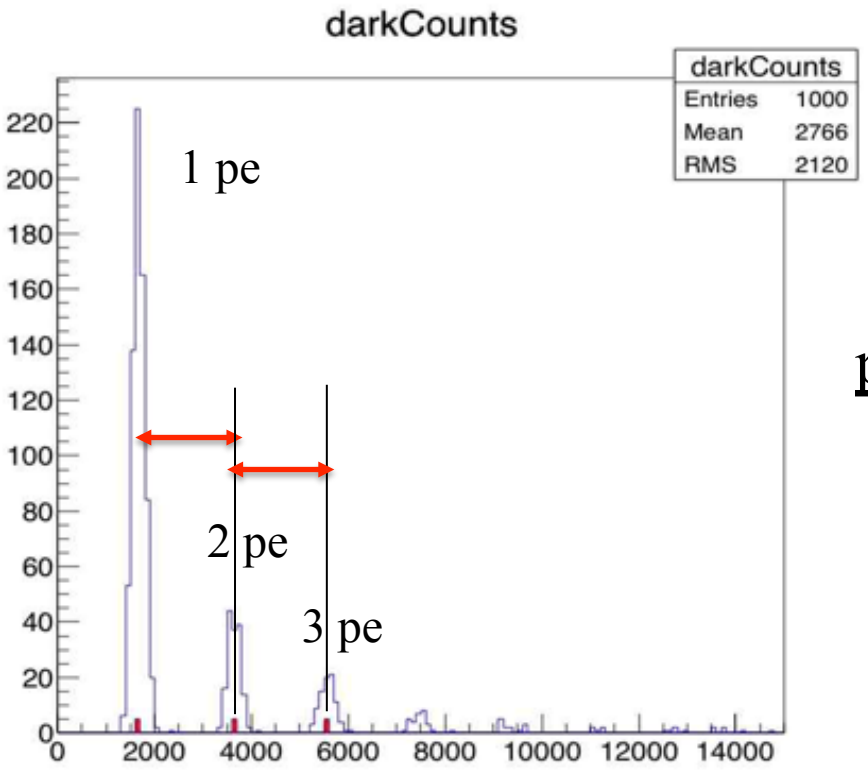
percent deviations from 1st measurement



(spike at 0 – first measurements in histo)

Pseudo gain

- 1,000 dark noise triggers with trigger threshold ~0.5 pe



pseudo-gain:

difference in ADC cts between peaks proportional to gain

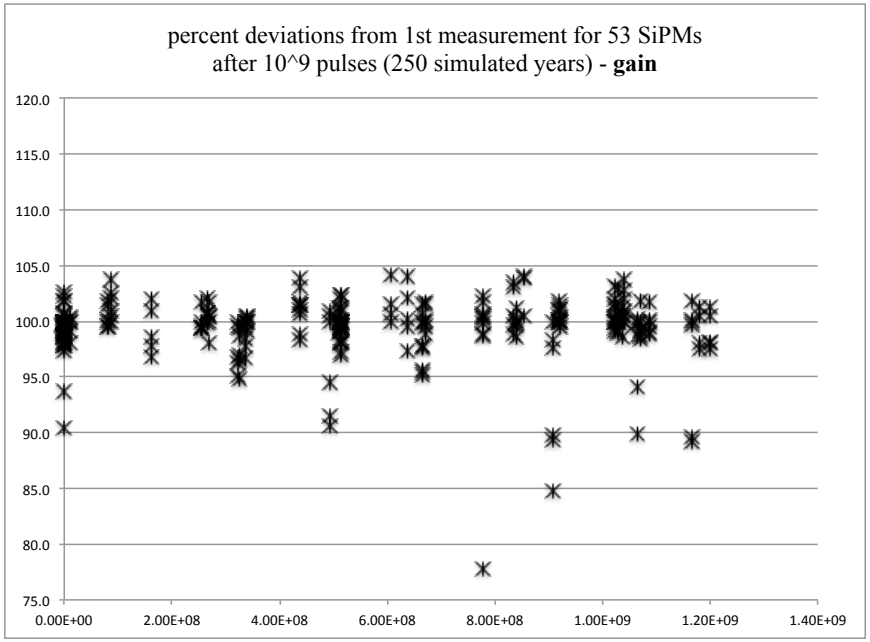
linear devices

histogram of #ADC cts in integrated waveform for 1000 triggers

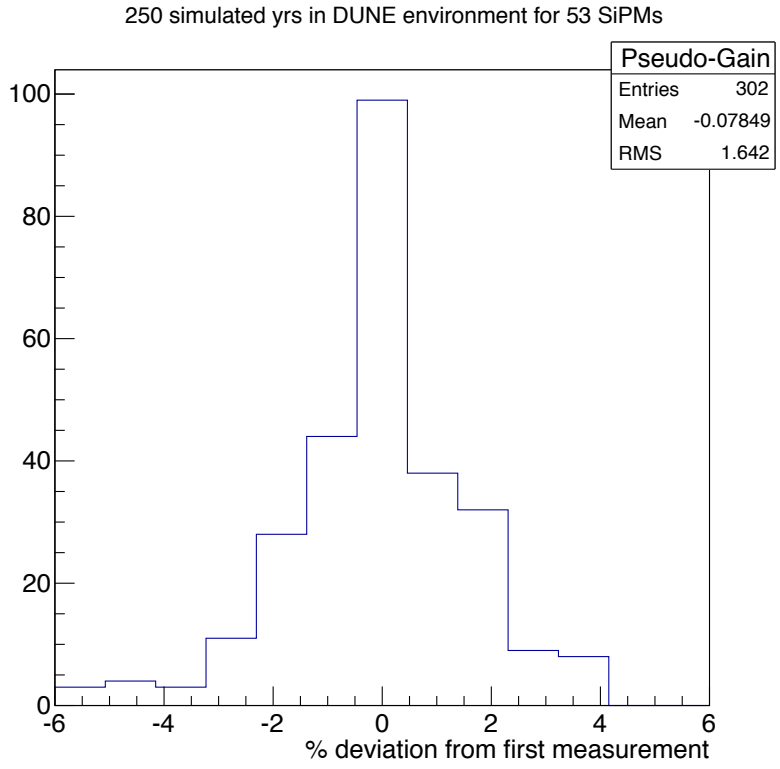
Pseudo GAIN: Results for all 53 SiPMs

no evidence for aging in 250 simulated years

percent deviations from 1st measurement vs # pulses



percent deviations from 1st measurement

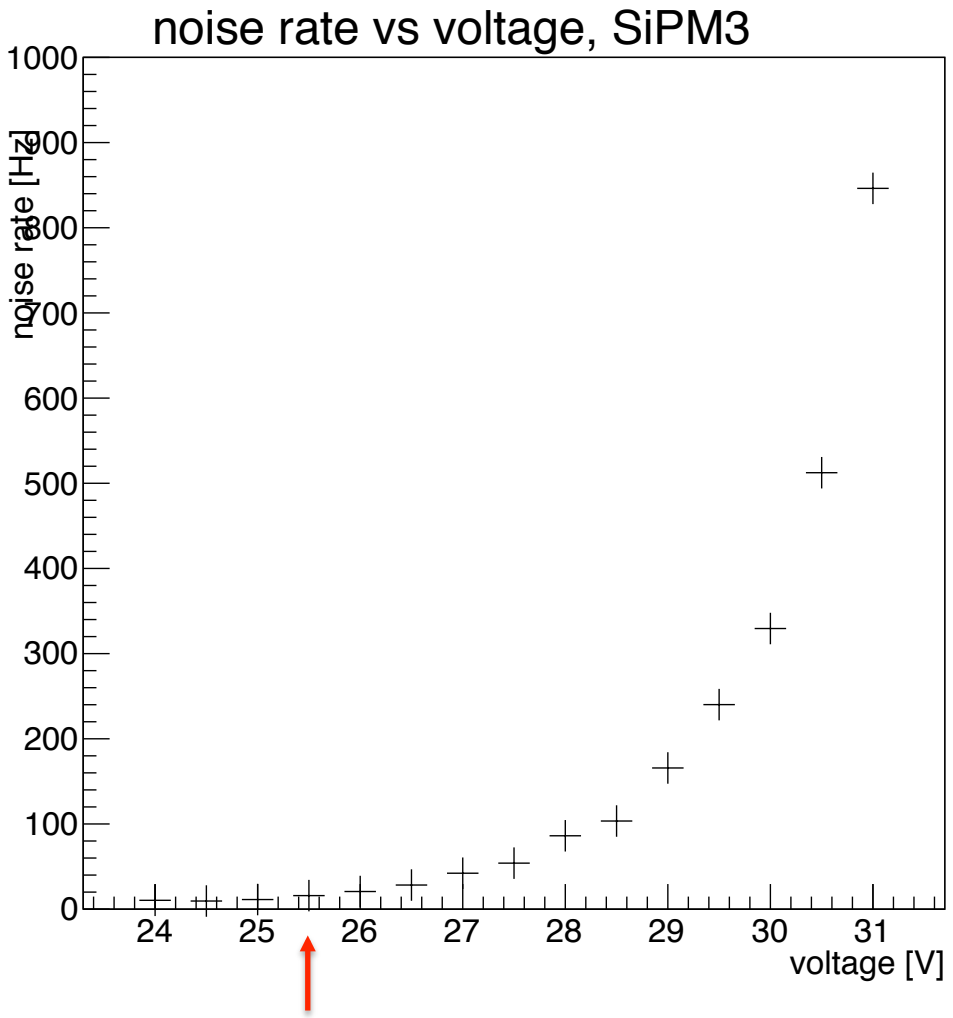


(spike at 0 – first measurements in histo)

3. SiPM aging – Dark Tests

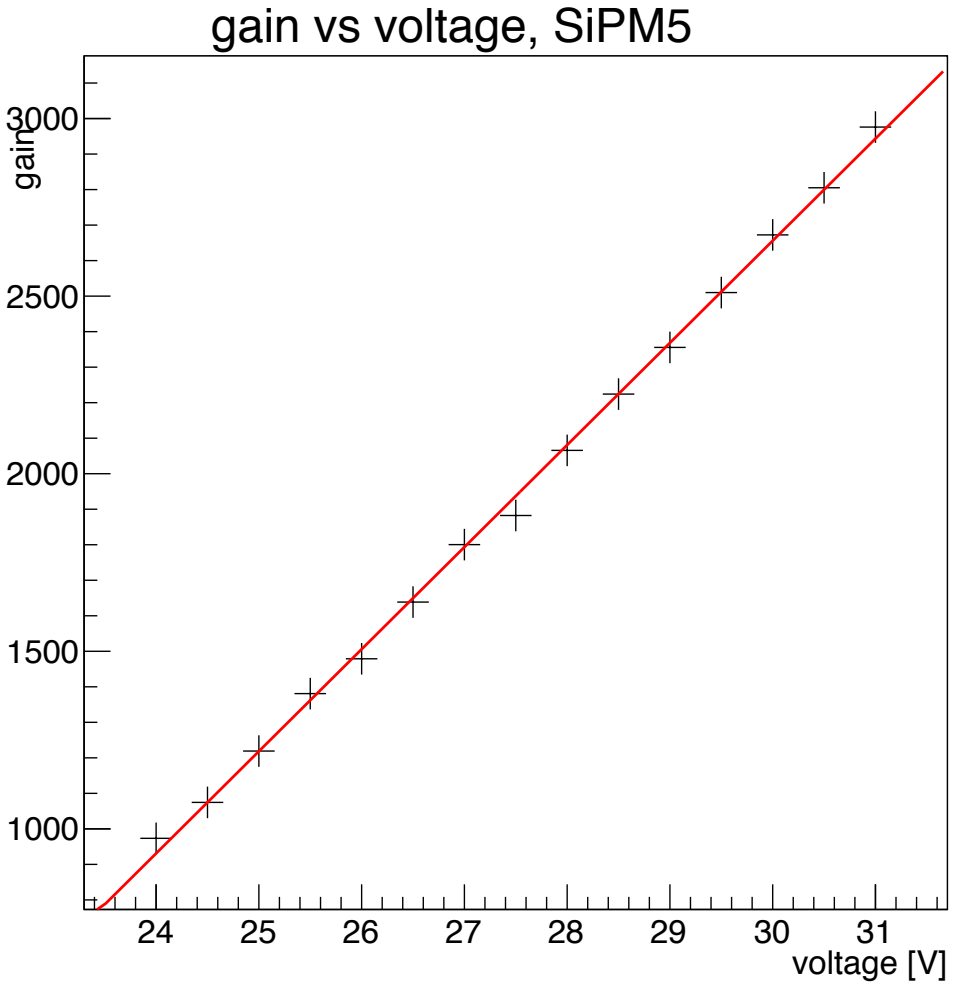
- 6 SiPMs continuously in LN2 at 77K for 488 days from March, 2015 through July 18, 2016
- Operating for 488 days in LN2is longer than the protoDUNE run
- 3 SiPMs biased at 24.5 V, the nominal bias voltage used at the time on the IU light guides
- 3 SiPMs were biased at 30.5 V (50x noise rate @ 24.5 V)
- hypothesis: aging "normally" at 30.5 V because ^{39}Ar decays are also ~50x the dark rate
- 4 properties monitored:
  - dark noise rate vs bias voltage
  - cross talk probability vs bias voltage
  - breakdown voltage vs bias voltage
  - gain slope vs bias voltage

Typical noise vs bias voltage curve, SiPM 3



current operating bias voltage 25.5 V

Typical "gain" vs bias voltage curve, SiPM 5



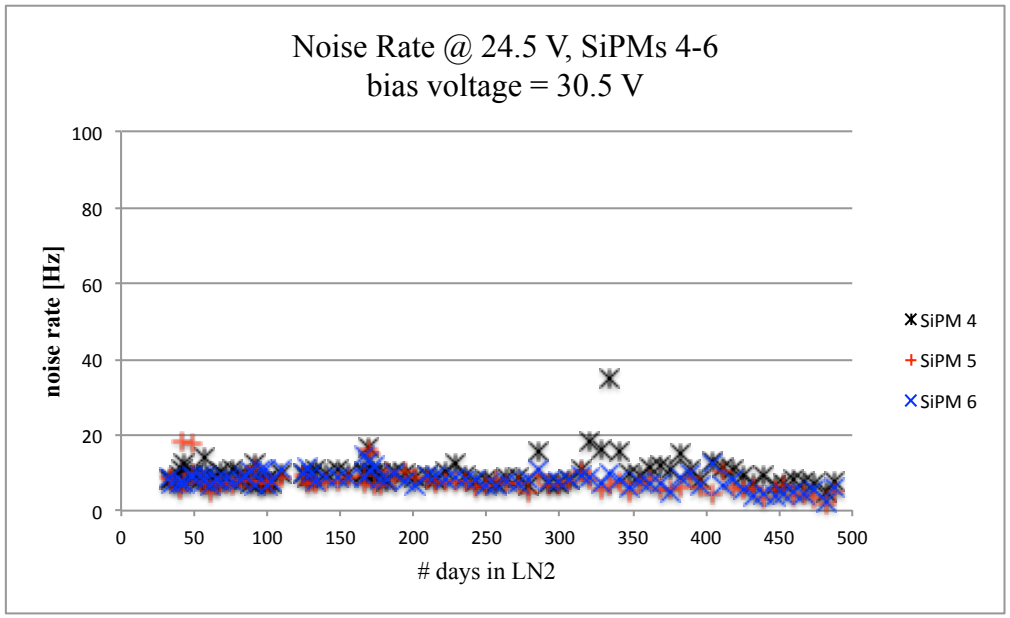
(3) gain slope:

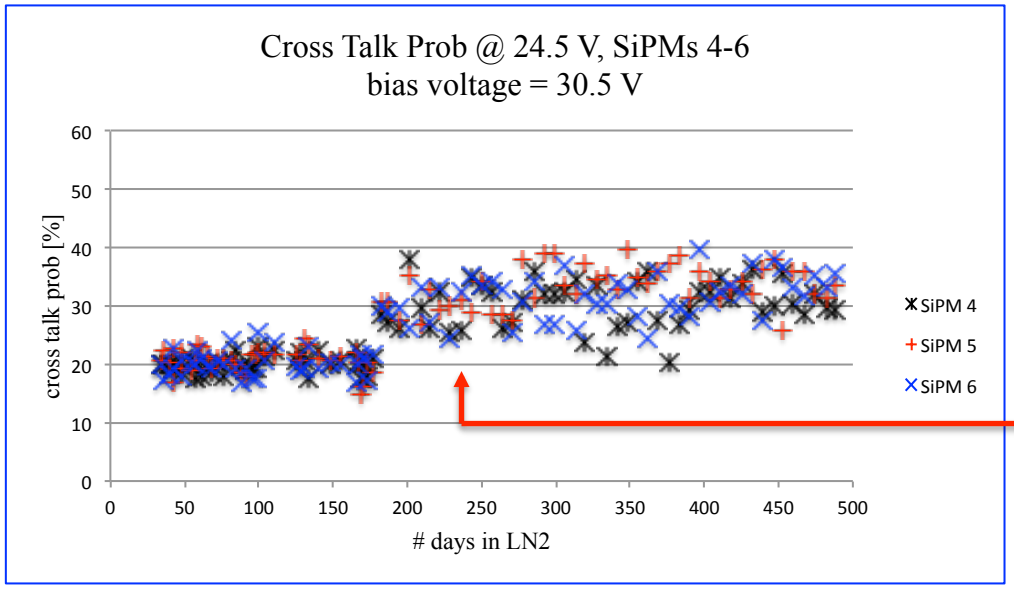
least squares fit to gain vs bias voltage

(4) breakdown voltage:

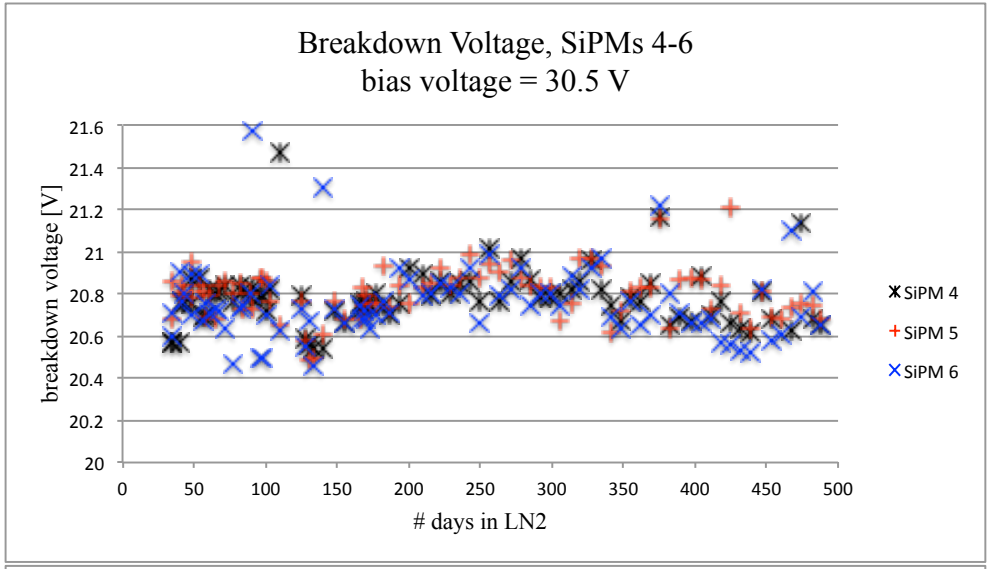
voltage at gain = 0

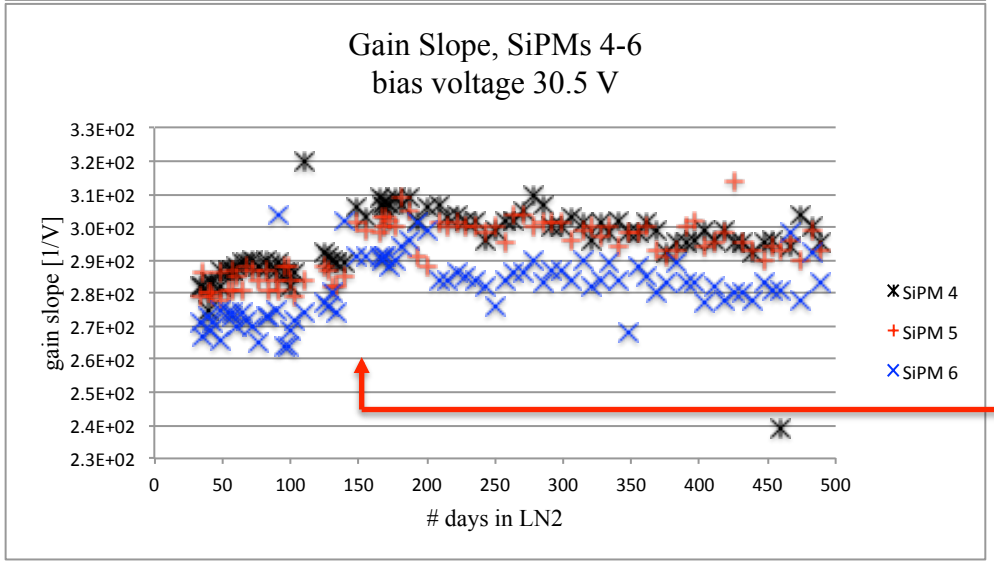
No evidence for aging in noise or cross talk in 488 days in LN2





bug fixed in peak-finding algorithm



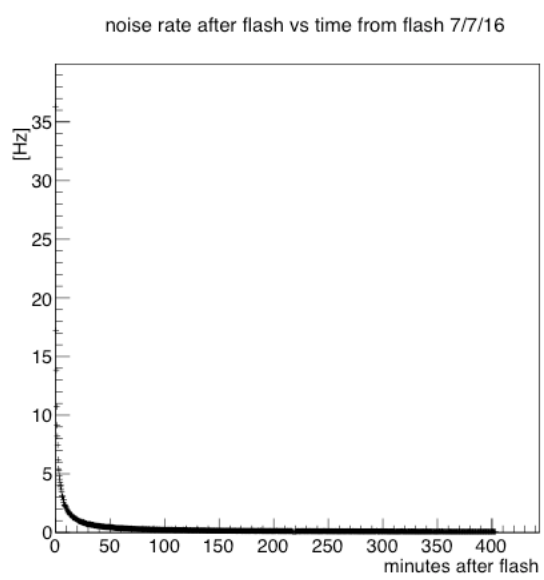


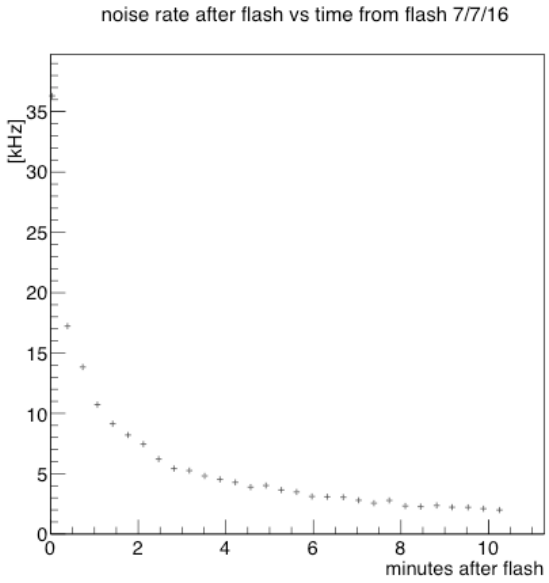
no evidence for aging

constant – fluctuation up – constant

4. Simulated voltage breakdown

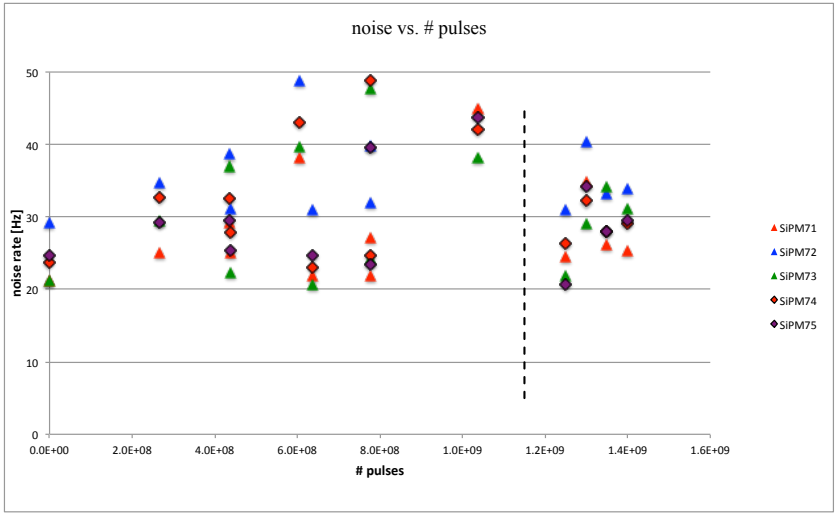
After 10^9 pulses, the SiPMs, still submerged in LN2,
were flashed with a bright halogen lamp. This test is intended
to simulate a voltage discharge in the cryostat.
The test consisted of 10 sets of 5 lamp flashes,
each set of flashes separated by a minute from the next.

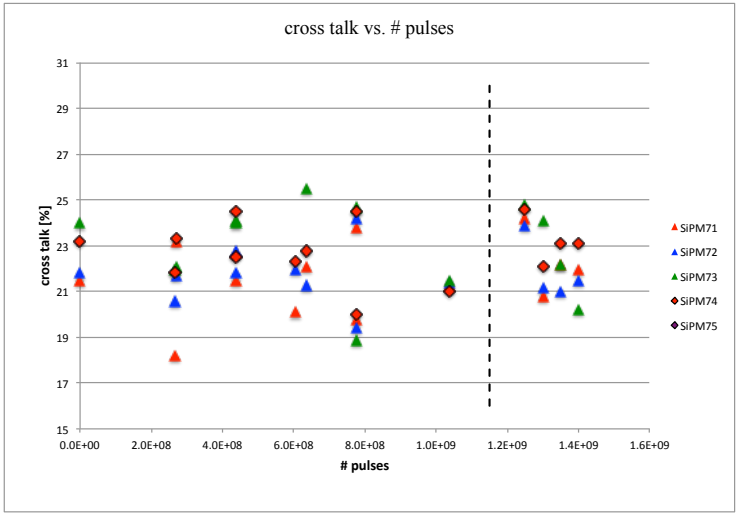


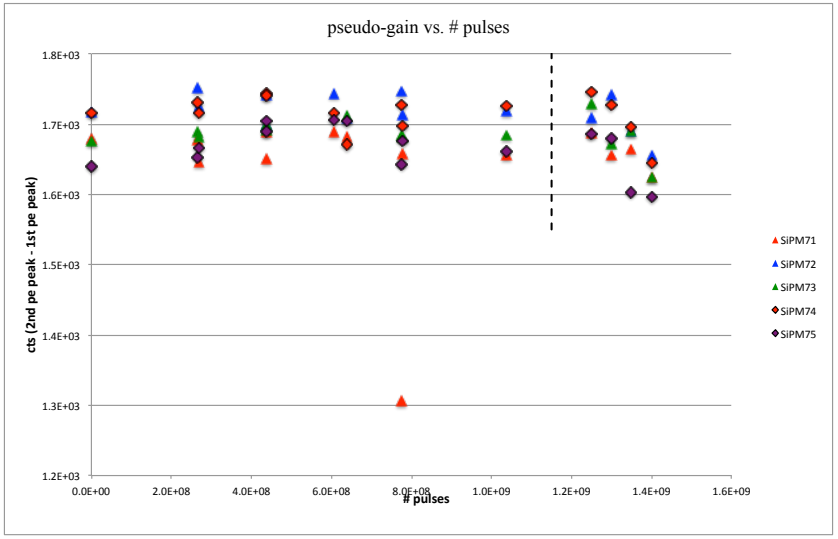


Noise initially spikes and then recovers

Dotted line marks onset of flashing for test in 6/16







SiPMs appear to recover their normal operating behavior after flashing

Conclusions

- Aging characteristics of SensL SiPMs in 4 ways
  - small sample size shows no evidence for infant mortality
  - pulse testing that simulates 250 years of exposure shows no evidence for aging for 53 SiPMs
  - long term aging study of 6 SensL SiPMs shows no evidence for aging in 488 days in LN2
  - after bright flashes from a halogen lamp to simulate discharge, SiPMs recover their normal operating behavior