Aging Studies of SensL Series C SiPMs

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October 8, 2015

Work reported in DUNE docdb #457

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

I. 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 most recent TallBo experiment at PAB at Fermilab (June, 2015 through August, 2015), 53 SensL SiPMs (B and C series) were used that were never thermally cycled and had only been tested electrically for functionality at room temperature

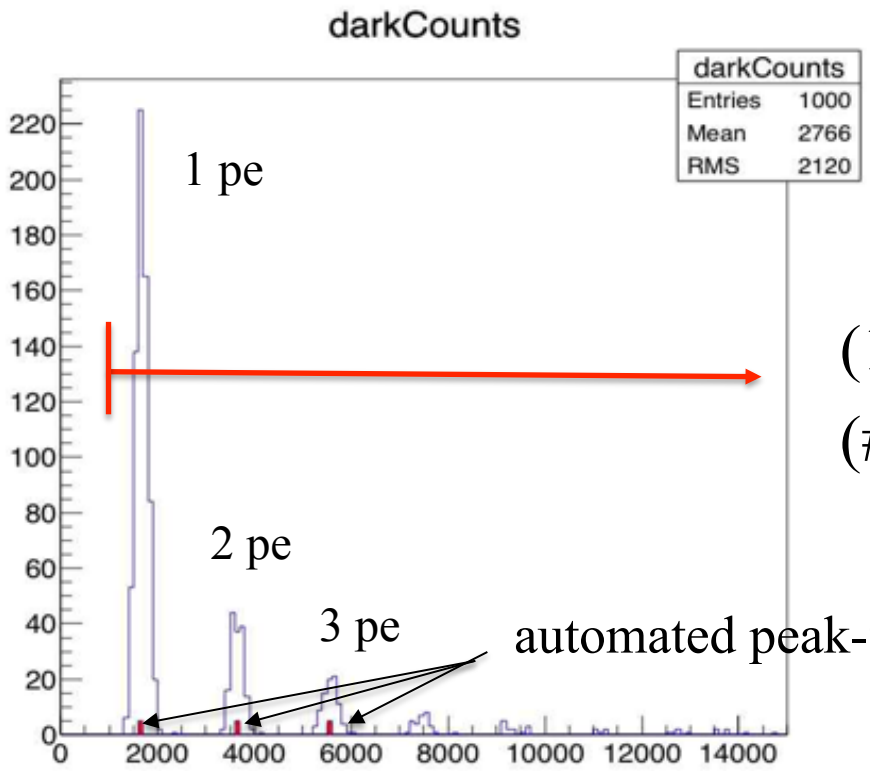
All 53 survived the fill and the experiment

This is an encouraging result but the test should be repeated with a larger sample size

II. Dark Tests

- 6 SiPMs continuously in LN2 at 77K since March, 2015 (> 200 days)
- 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)
- hypothesis: aging normally at 30.5 V because ^{39}Ar decays are also ~50x the dark rate
- 4 properties monitored:
  - dark noise rate
  - cross talk probability
  - breakdown voltage
  - gain slope

- 1,000 dark noise triggers at 15 bias voltages between 24.0 V and 31.0 V in 0.5 V intervals
- trigger threshold ~0.5 pe

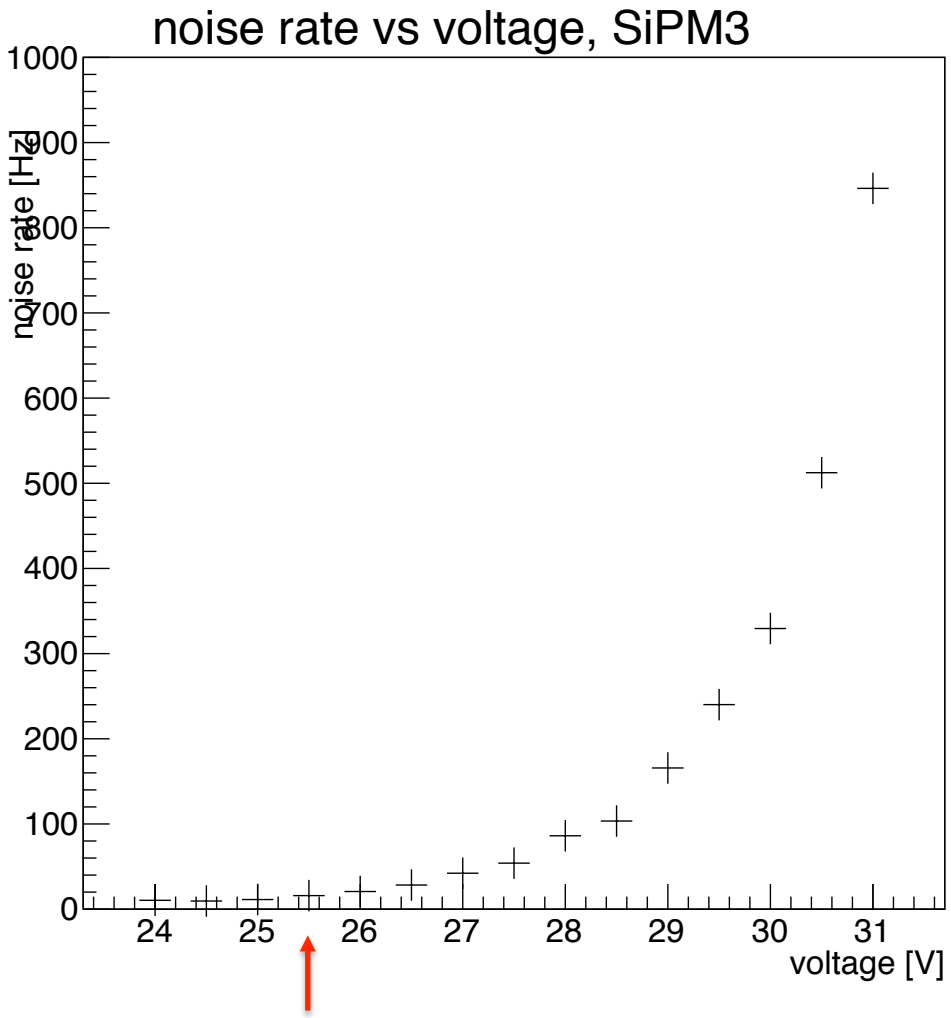


(1) noise:

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

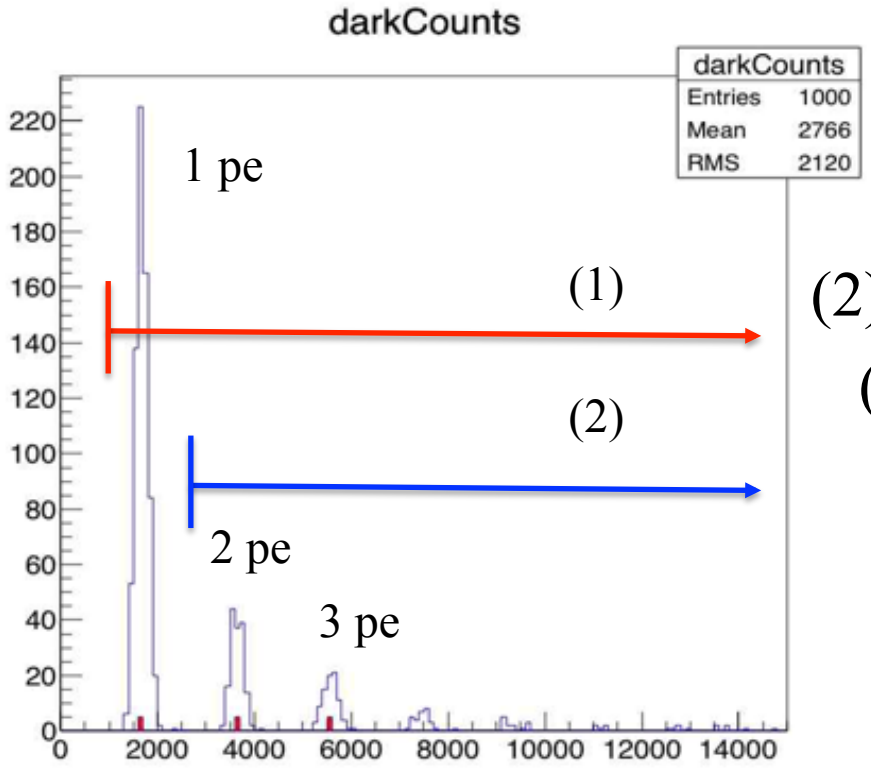
histogram of #ADC cts in integrated waveform for 1000 triggers

Typical noise vs bias voltage curve from 9/28/2015, SiPM 3



operating bias voltage 25.5 V

- 1,000 dark noise triggers at 15 bias voltages between 24.0 V and 31.0 V in 0.5 V intervals
- trigger threshold ~0.5 pe

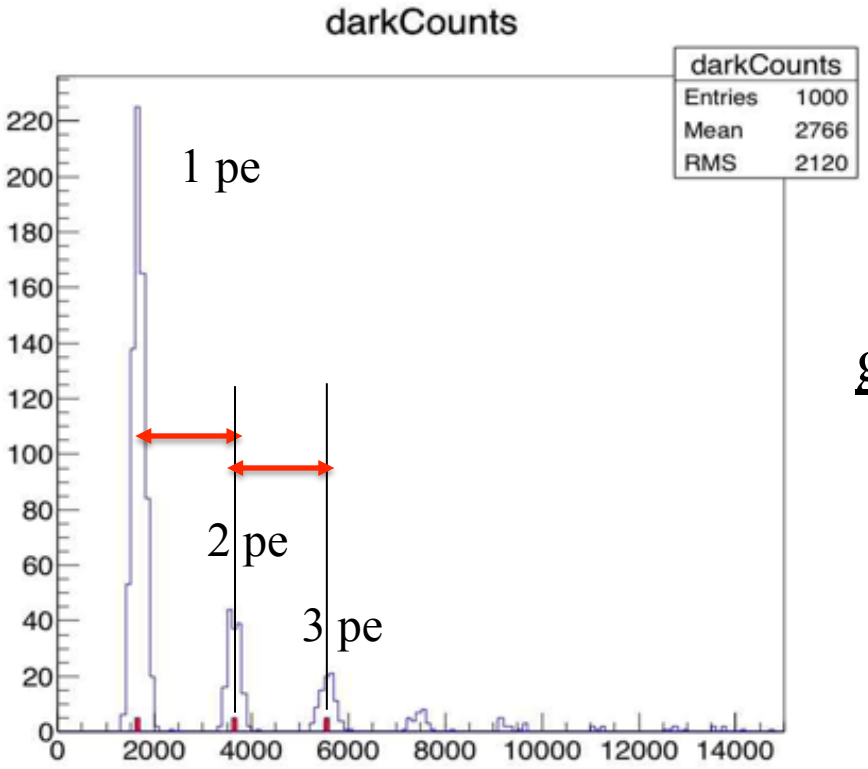


(2) <u>cross talk probability</u>:

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

cross talk prob = (2)/(1)

- 1,000 dark noise triggers at 15 bias voltages between 24.0 V and 31.0 V in 0.5 V intervals
- trigger threshold ~0.5 pe



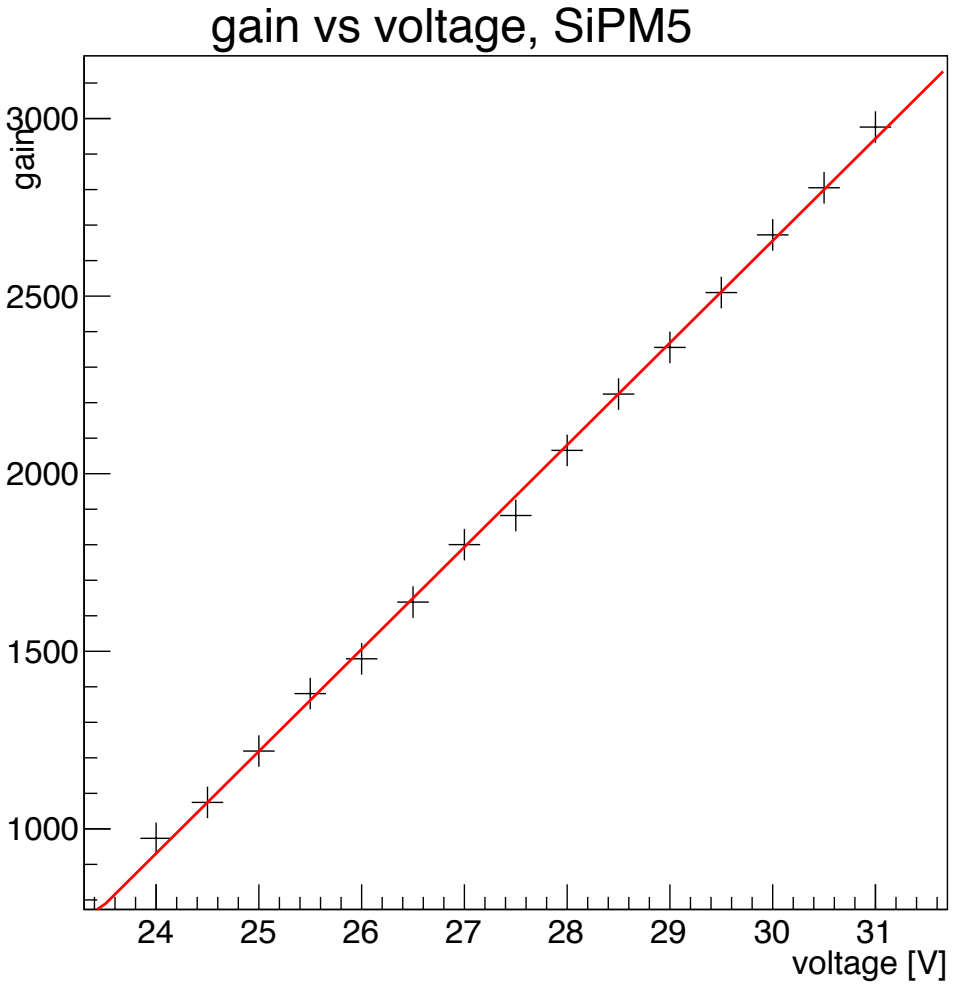
gain:

difference in ADC cts between peaks proportional to gain

linear devices

histogram of #ADC cts in integrated waveform for 1000 triggers

Typical "gain" vs bias voltage curve from 9/28/2015, SiPM 5

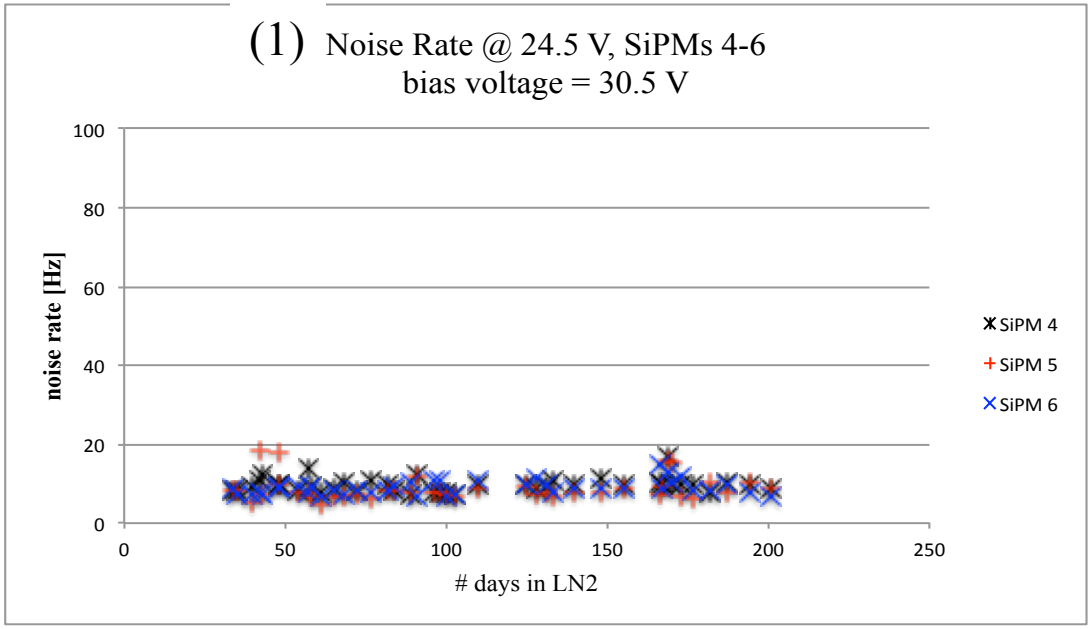


(3) gain slope:

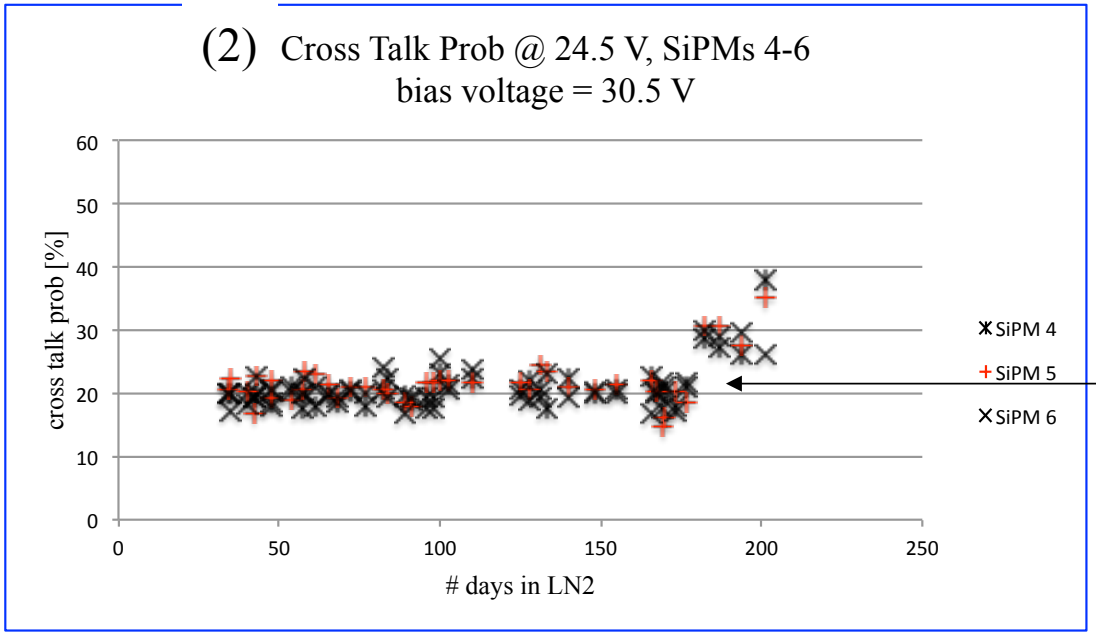
least squares fit to gain vs bias voltage

(4) breakdown voltage:

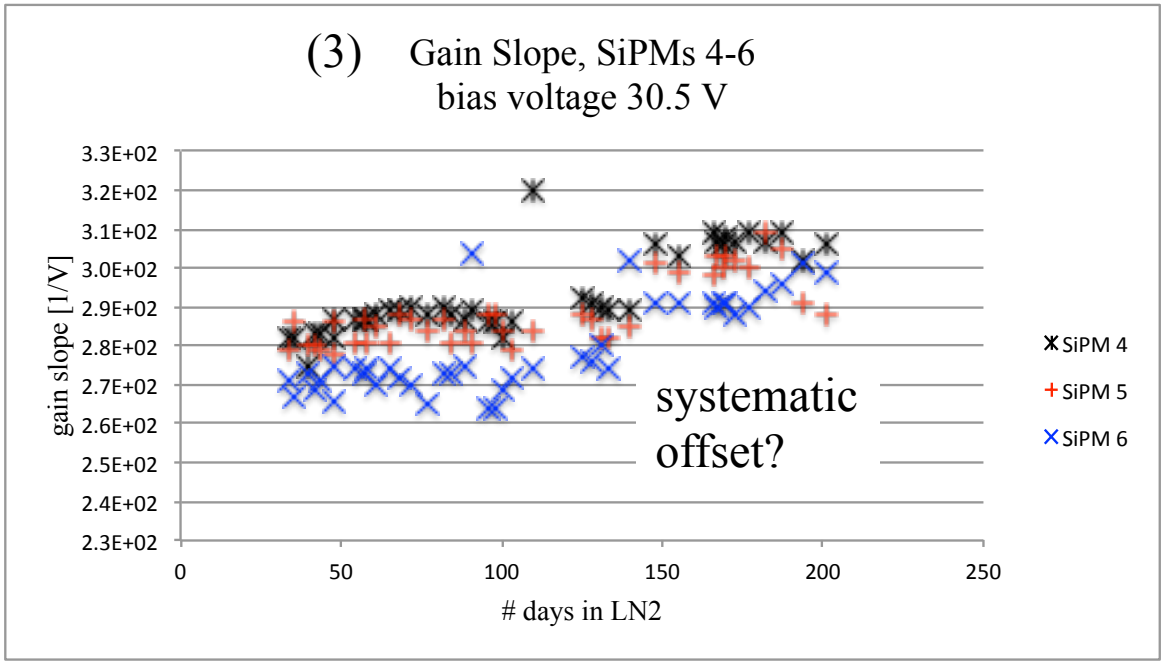
voltage at gain = 0

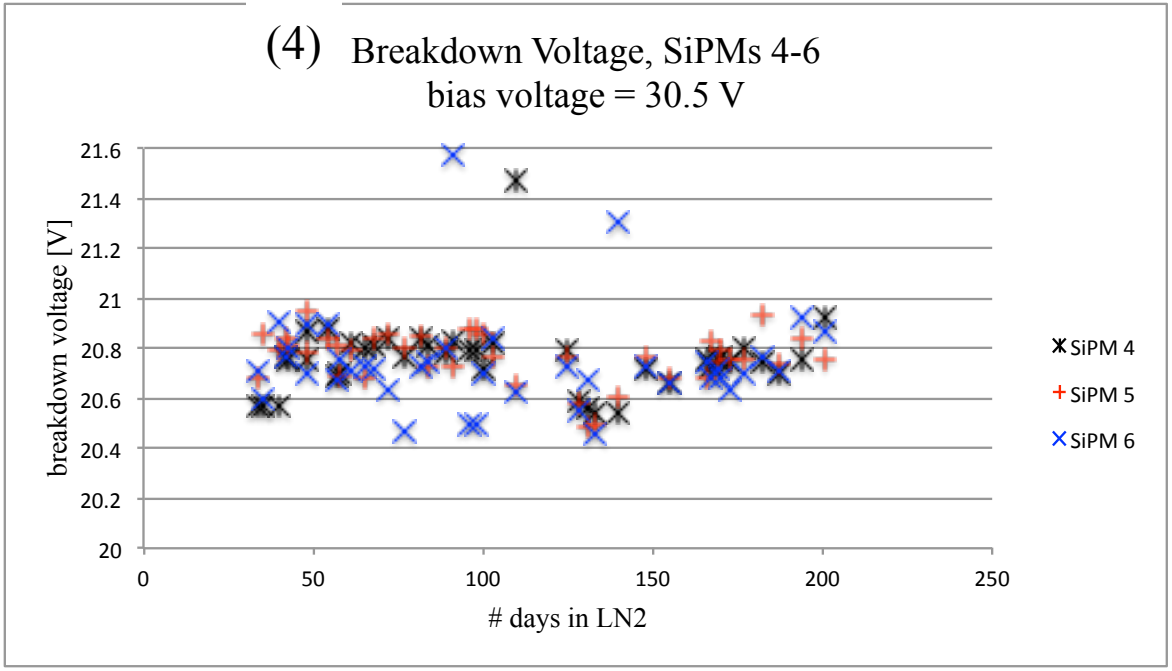


In March, 2015, the nominal bias voltage was 24.5 V.
It's now 25.5 V.
For this experiment, the bias voltage remains 24.5 V.



bug fixed in peak finding algorithm

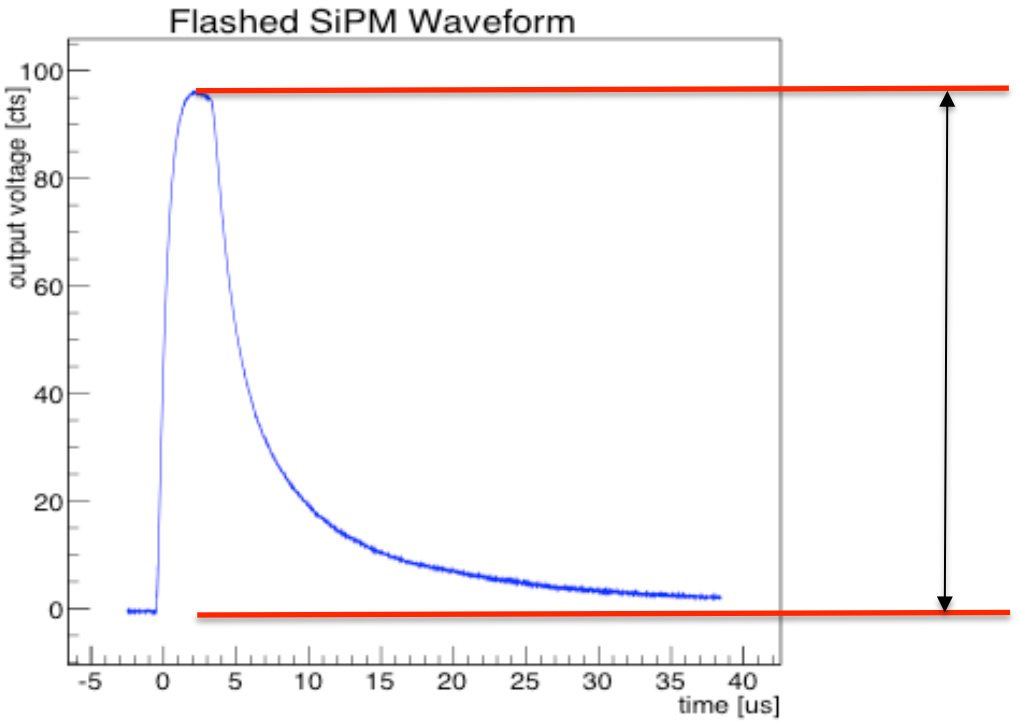

(3) Gain Slope, SiPMs 4-6
bias voltage 30.5 V
gain slope [1/V]
3.3E+02
3.2E+02
3.1E+02
3.0E+02
2.9E+02
2.8E+02
2.7E+02
2.6E+02
2.5E+02
2.4E+02
2.3E+02
0
50
100
150
200
250
days in LN2
systematic offset?
SiPM 4
SiPM 5
SiPM 6


(4) Breakdown Voltage, SiPMs 4-6
bias voltage = 30.5 V
breakdown voltage [V]
21.6
21.4
21.2
21
20.8
20.6
20.4
20.2
20
0
50
100
150
200
250
days in LN2
SiPM 4
SiPM 5
SiPM 6

III. Pulse test

- continuously stress each of the 18,960 microcells in 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 1.5 μs, pulse rate 1kHz
- Age estimate
  - noise rate ~ 10 Hz, ^{39}Ar decays @ 100x noise rate
  - SiPM sees 10 Hz x 100 x 3.16x10^{7} s/yr = 3x10^{10} avalanches/yr
  - event triggers 2 microcells (conservative, cross talk prob 30%) out of ~20,000 microcells
  - typical microcell sees 3x10^{10}/10^{4} ~ 3x10^{6} avalanches/yr
  - Test: hit each microcell with 1.64x10^{9} pulses > 100 yrs of hits (~month)

Metric for aging – output voltage for an event
= # functional microcells x output of single microcell

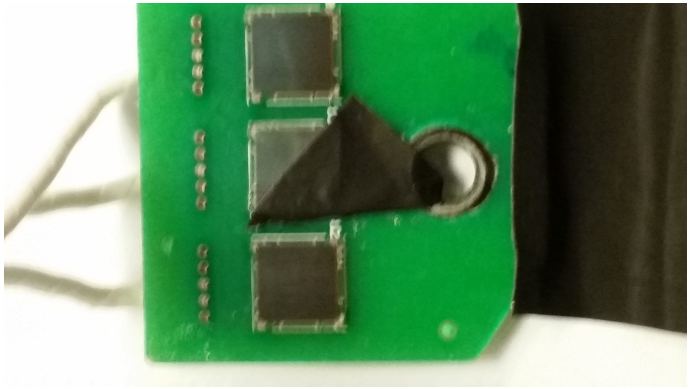


output voltage from fully functional SiPM = 18,960 microcells x output of single microcell

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

sanity check:

mask cells



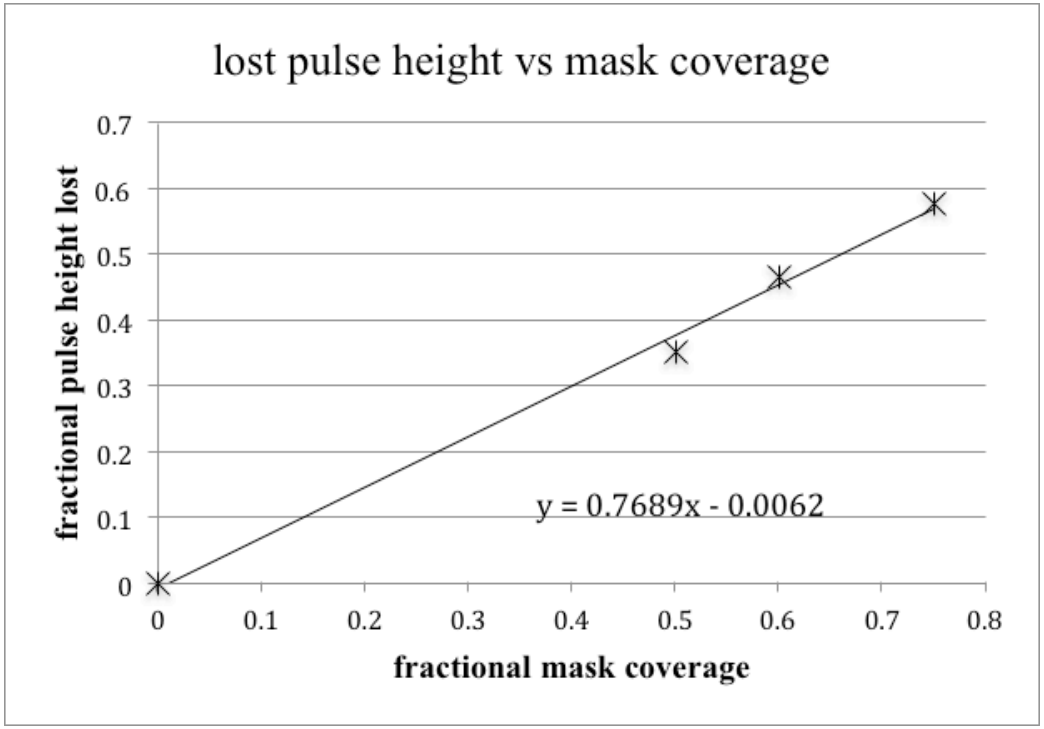
50% mask

look for proportional decrease in SiPM output

Slope = 1 if 50% of the signal lost when fractional mask coverage = 50%

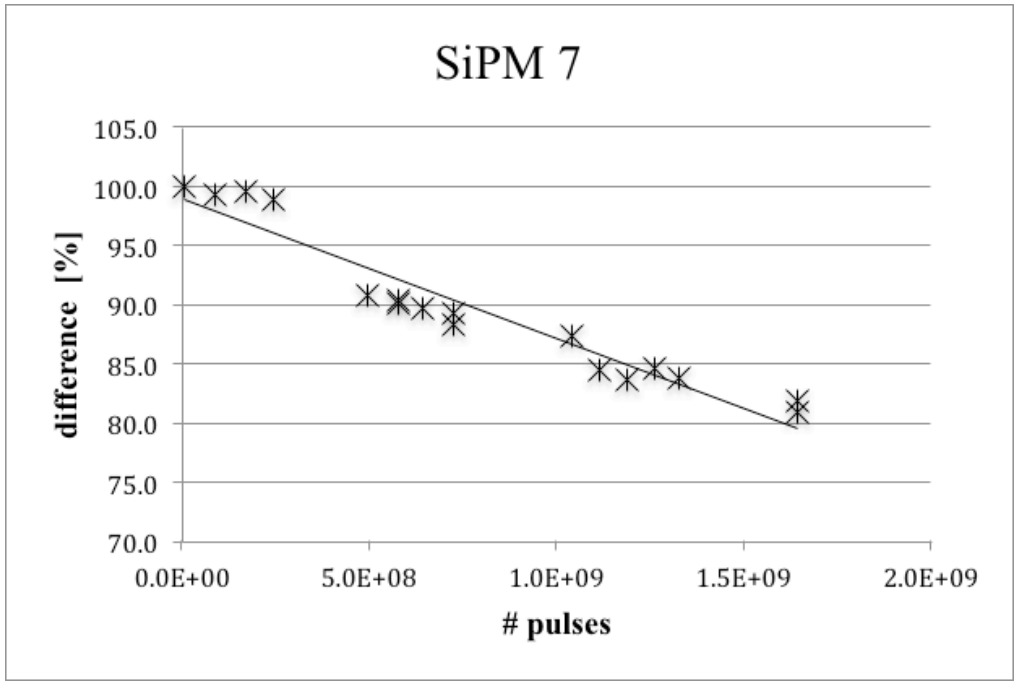
Slope <1, or less than 50% of the signal is lost when fractional mask coverage = 50%.

Most of extra light from cross talk (masked microcells are not failed



Typical curve for SiPM 7 after 1.65 x 10^9 pulses > 100 yrs

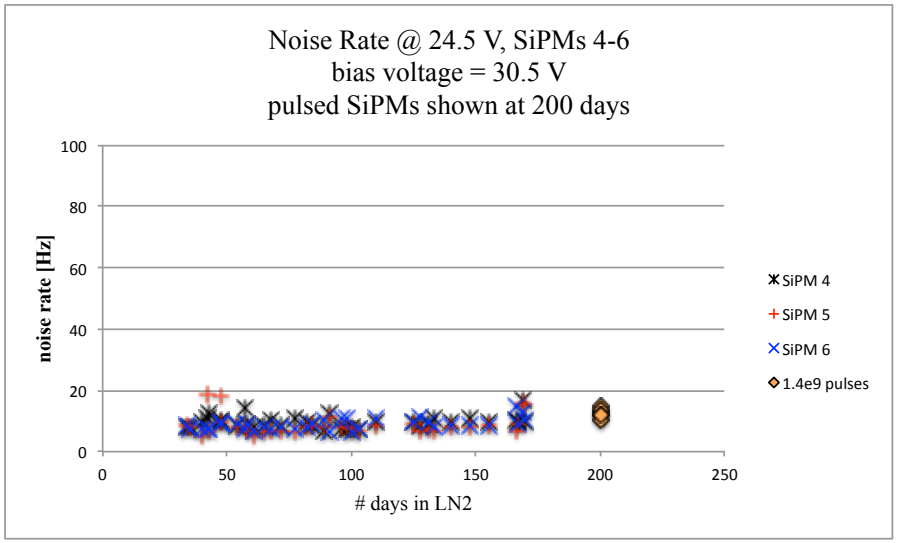
Other curves found in DUNE docdb #457

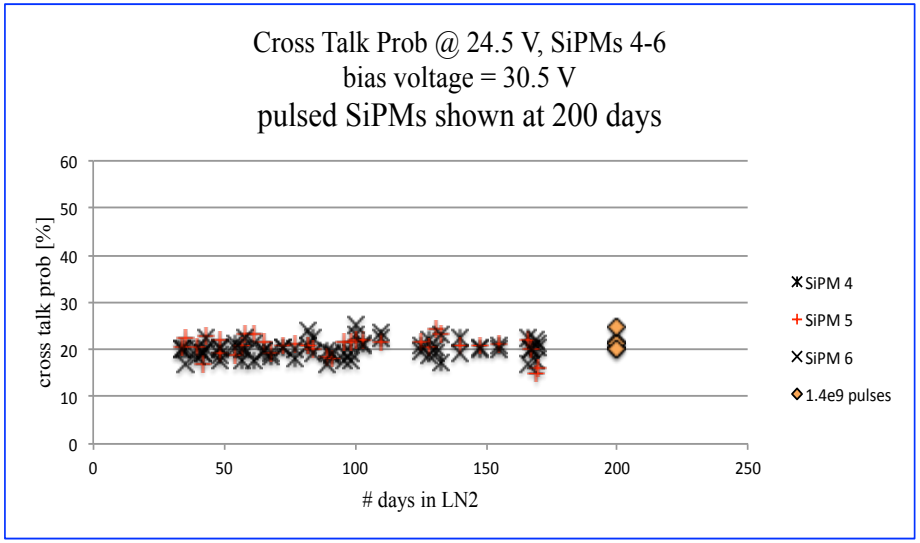


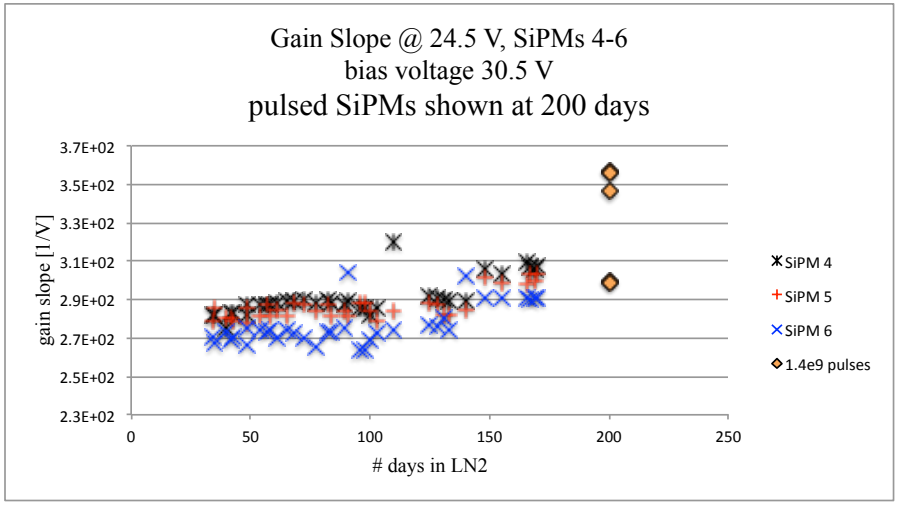
SiPM response falls by 20-25% after 1.64 x 10^9 pulses.

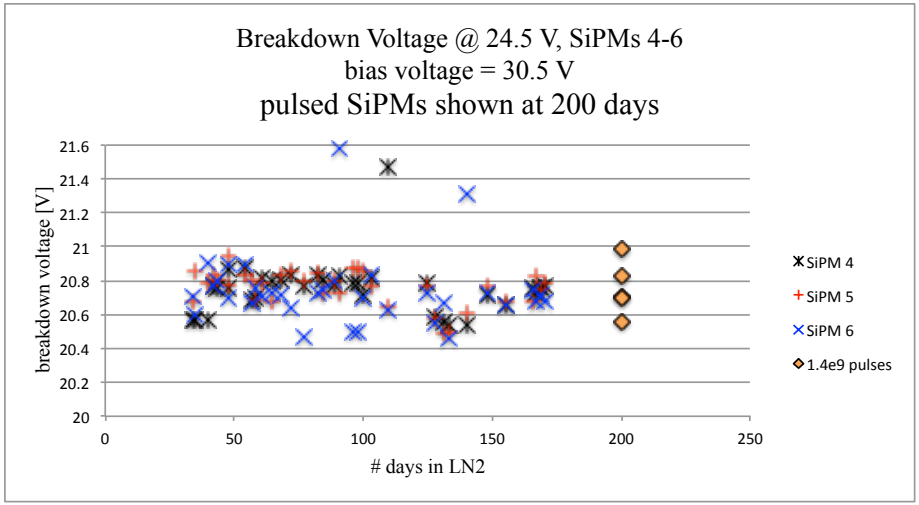
SiPM response falls (conservatively) by ~25%/100 yrs = 0.25%/yr

Properties of pulsed SiPMs after 1.65 x 10^9 pulses
No obvious evidence for aging









Future

- Test 27 additional SiPMs for infant mortality at next TallBo run, early 2016
- Continue dark test
- Initiated second pulse test with 6 new SiPMs