Temperature Dependence of MPPC Parameters

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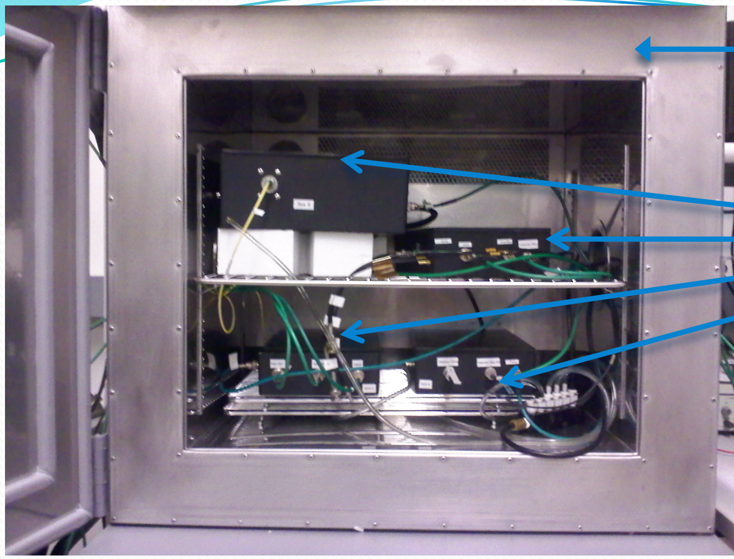
Outline of Goals

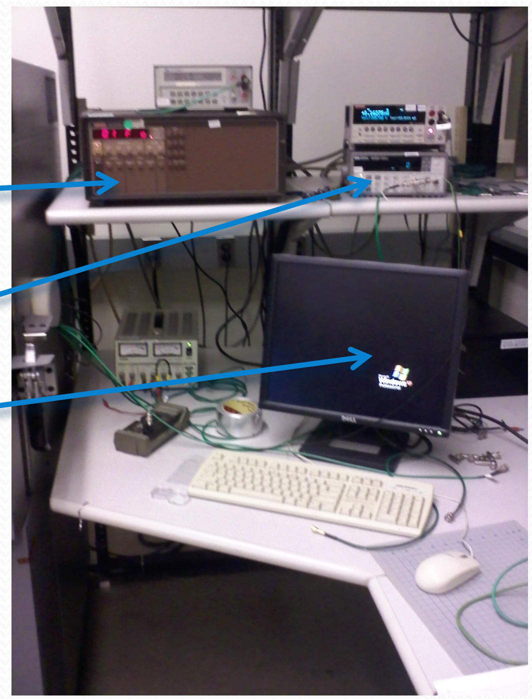
- Develop an experiment for the study of the temperature dependence of Silicon Photo-Multiplier (SiPM) characteristics
  - Setup a laboratory with sufficient hardware
  - Create acquisition and analysis software
- Determine from the findings the the optimal operational conditions for the use of SiPM technology is future detector experiments

Instrumentation

- Space acquired at the Silicon Detector Center (SiDET) at Fermilab
- Hardware and Equipment
  - MPPC SiPM devices from Hamamatsu Photonics
    - 25μm, 50μm, 100μm micro-pixel sizes
  - Miteq Amplifier AM-4a-000110
  - Dark Boxes
  - Keithly 2400 Source Meter
  - HP 53131A counter
  - Test Equity Temperature Chamber
  - LabView software version 8.4
  - 680 nm Laser



- Temperature Chamber (Test Equity)
- 4 Dark Boxes allows 4 simultaneous experiments



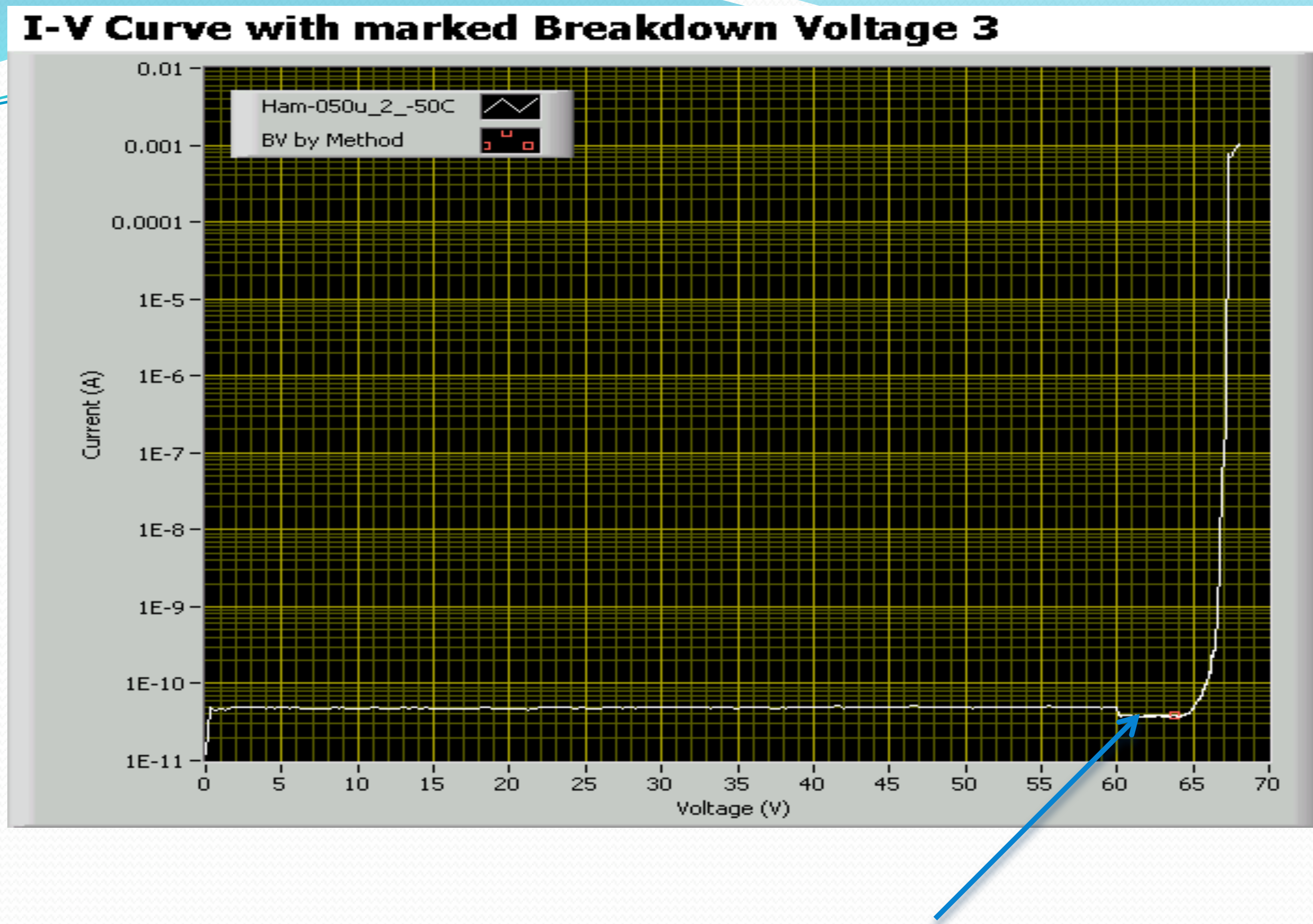
- HP Counter
- Keithly Source meter
- Control PC

Experimental Tests

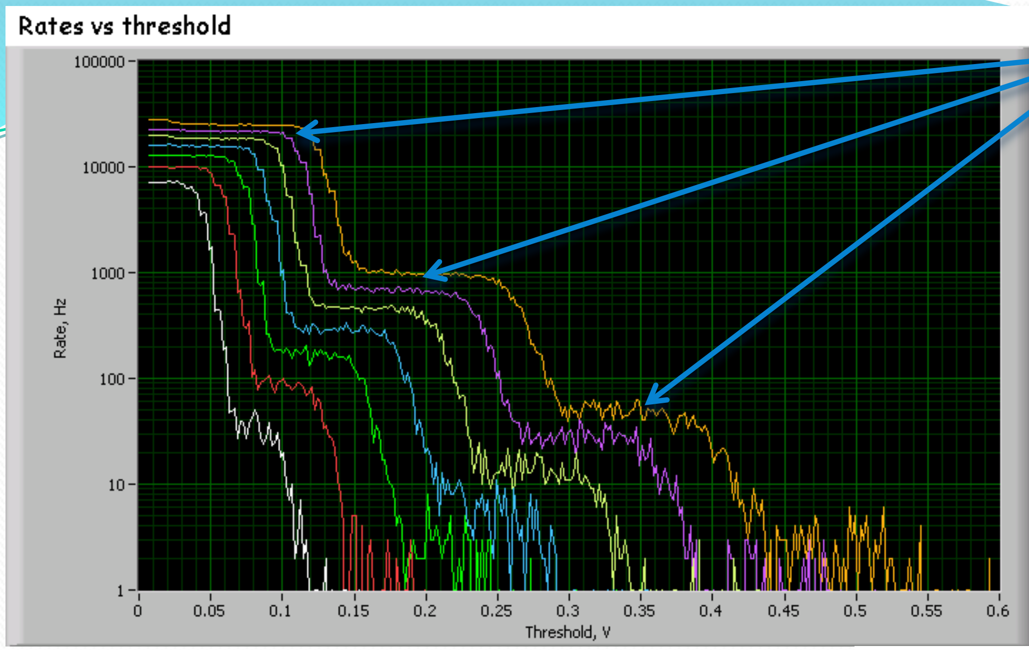
- Conducted with a temperature range from -60 to 50 Celsius
  - Dark Rates
  - Breakdown Voltage
  - Crosstalk
  - Carrier Density
  - Gain
  - Pulse Shape
- In all cases tests over several bias voltages are conducted at each temperature

Dark Rates and Breakdown Voltage

- Alternative method based on dark pulse amplitude
  - Dark Rate measurements taken at several operational voltages with increasing peak threshold values
    - Dark rates range over the temperatures from ~10 Hz to ~10^6 Hz
  - Average height of first photoelectron peak is found
  - Amplitudes are used to extrapolate to an operational voltage with zero pulse height
  - This returns our definition of Breakdown Voltage at a Given Temperature
  - Repeated process over temperature range shows linear dependence of ~55 mV/^{o}C

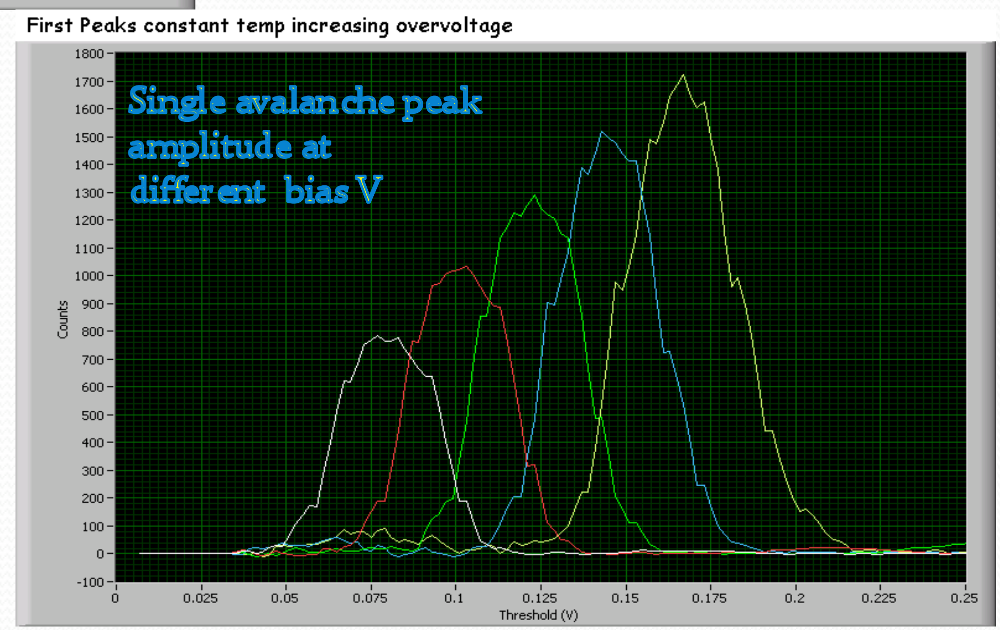


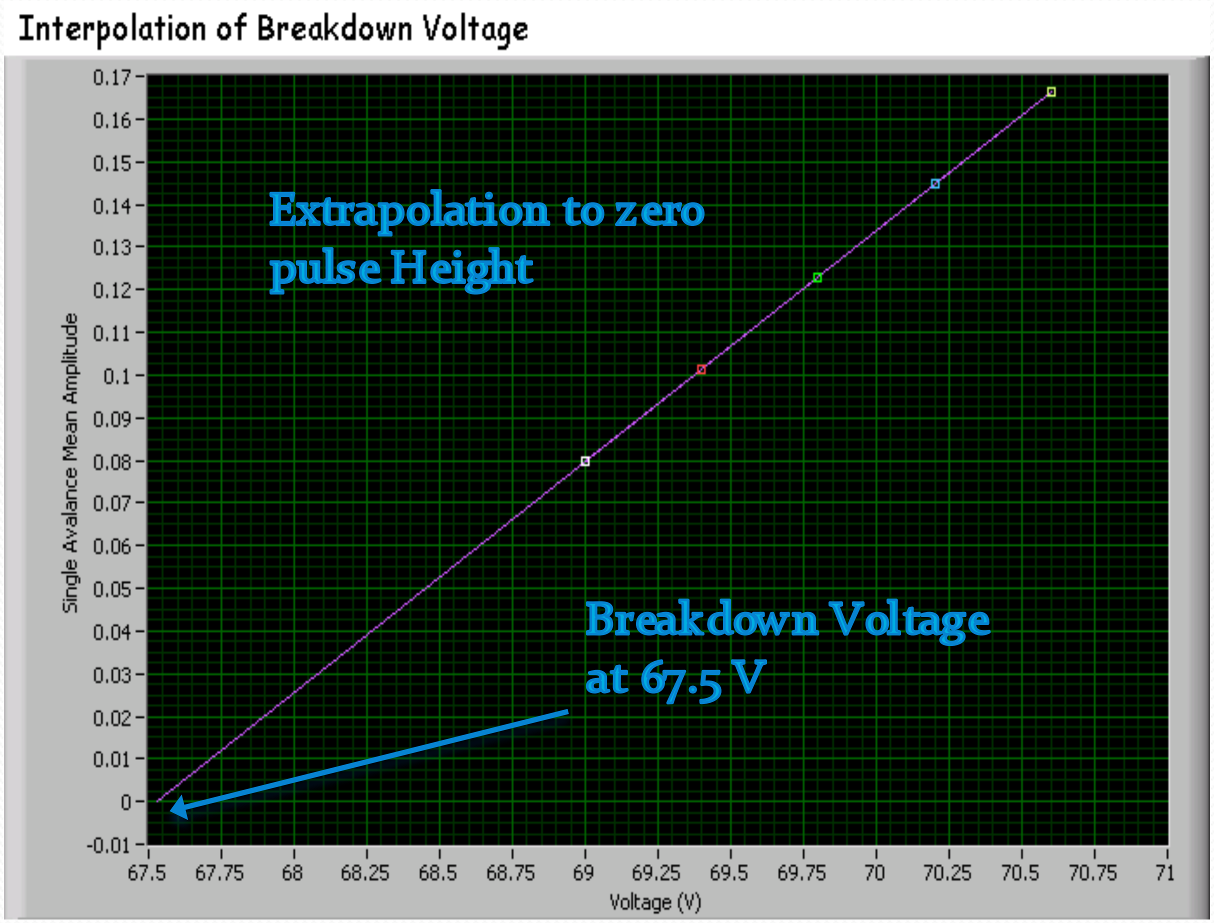
- Typical method for determining Breakdown Voltage is by examining the I-V curve to find the initial increase in current of the device
- We have an alternative method that examines the output pulse amplitude of the SiPM



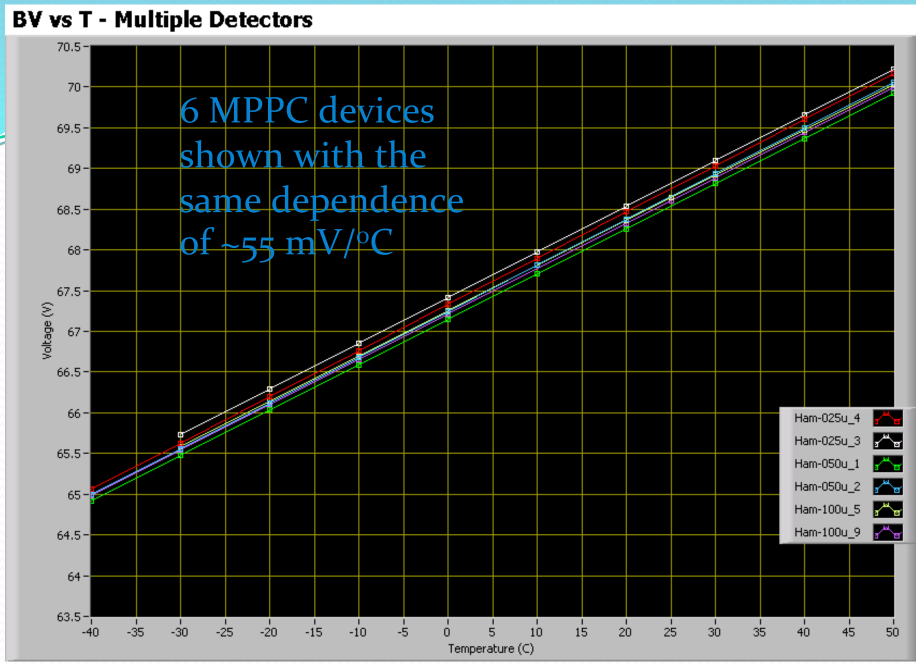
- Plateaus correspond to the photo electron peaks
- This is an integral plot of the rates at increasing threshold
- Each plot corresponds to an increase in bias voltage

- Differentiation recovers the photo electron spectrum
- Only the first peaks at each bias voltage are shown here



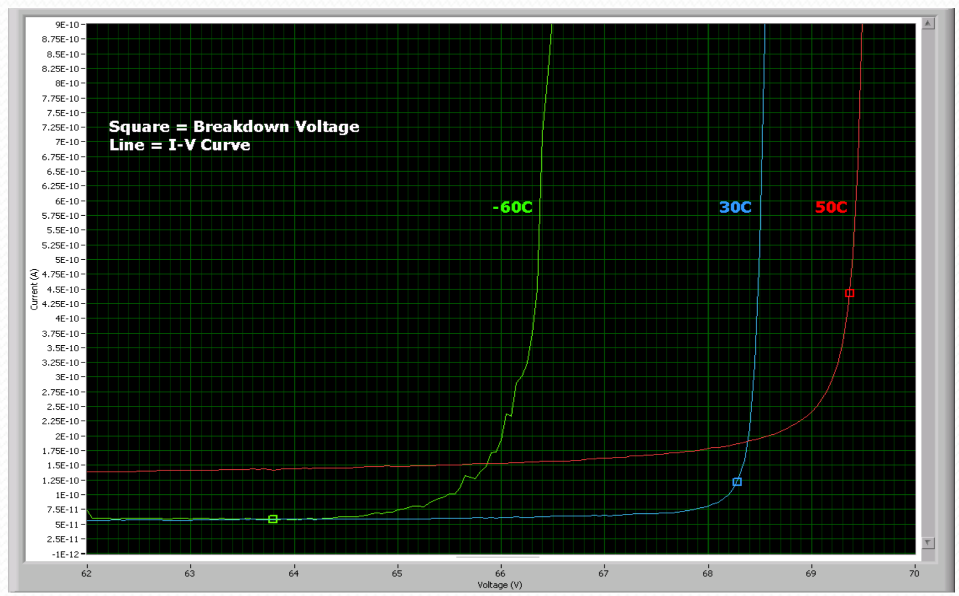


- The amplitude of the 1st p.e. pulse is linear with overvoltage
- Extrapolate to the X-intercept to find the breakdown voltage at this temperature



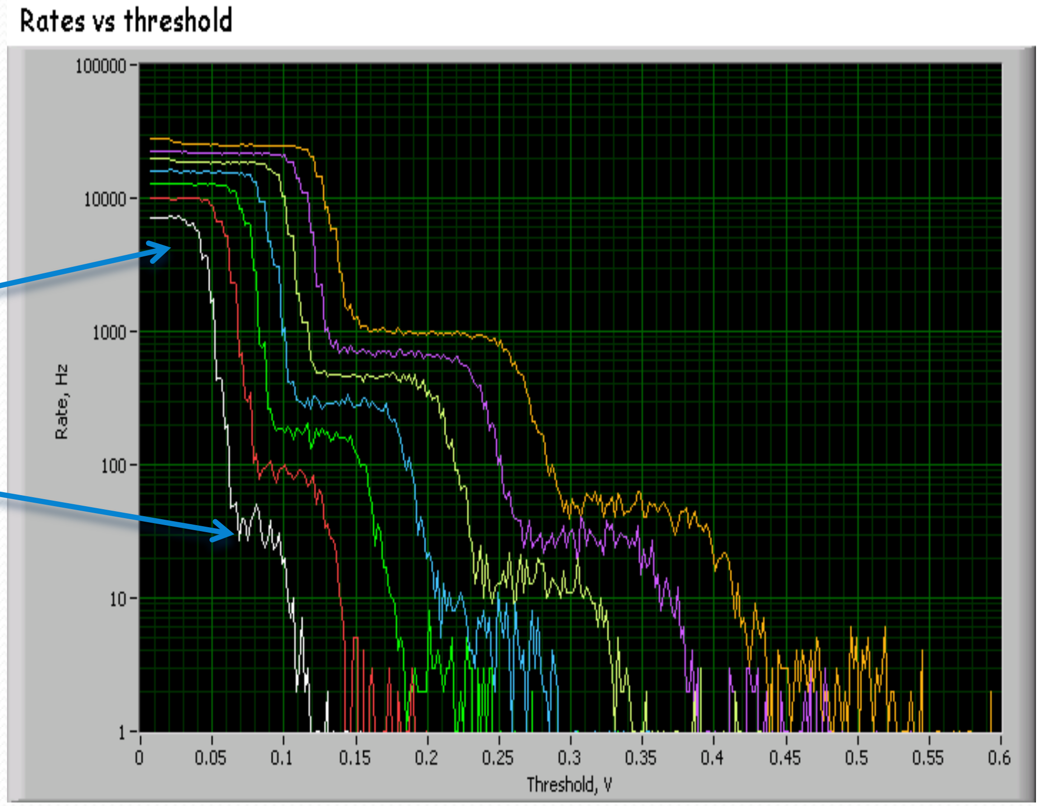
- Repeating the process at different temperatures reveals the linear dependence of the Breakdown voltage

- The advantage of our method is shown when comparing to the IV curves
- We know the true turn-on point of the device regardless of its position on the IV curve

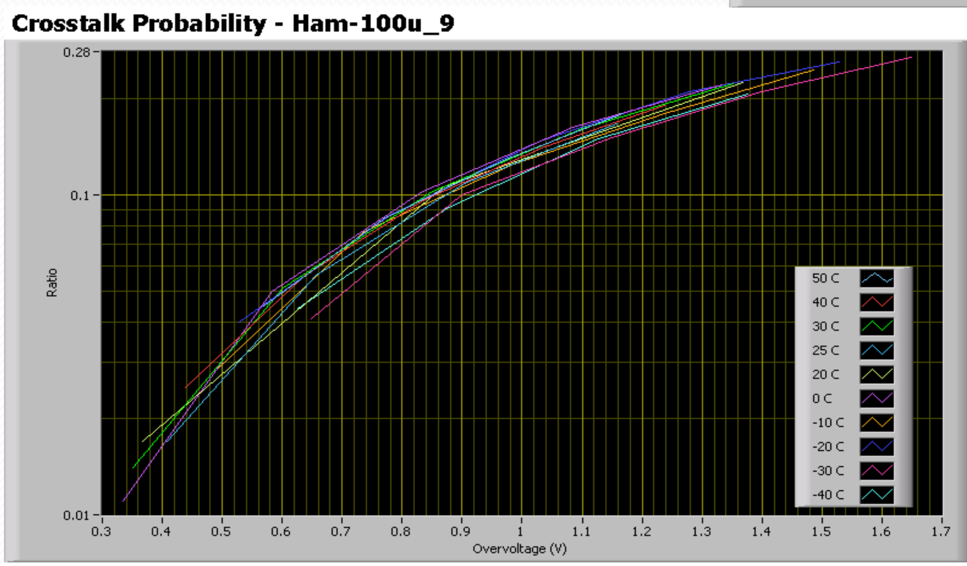


Crosstalk

- Ratio of the Average amplitude of n
  and n+1
  P.E. peaks produces the crosstalk probability



Crosstalk only ~1% for the 25μm device at the optimal operating voltage (1 V)

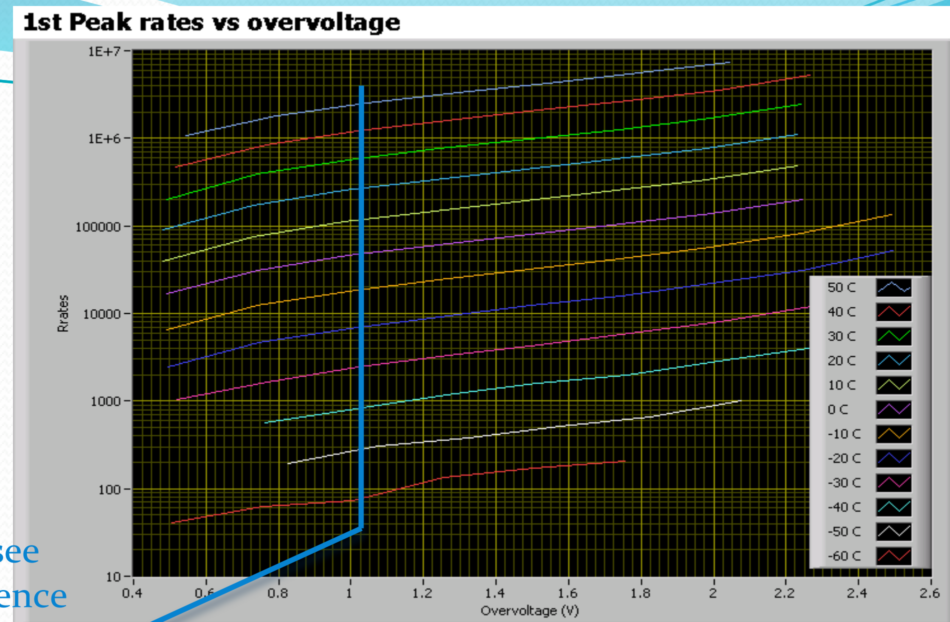


Crosstalk ~10% at over-voltage of 1 V for 100μm

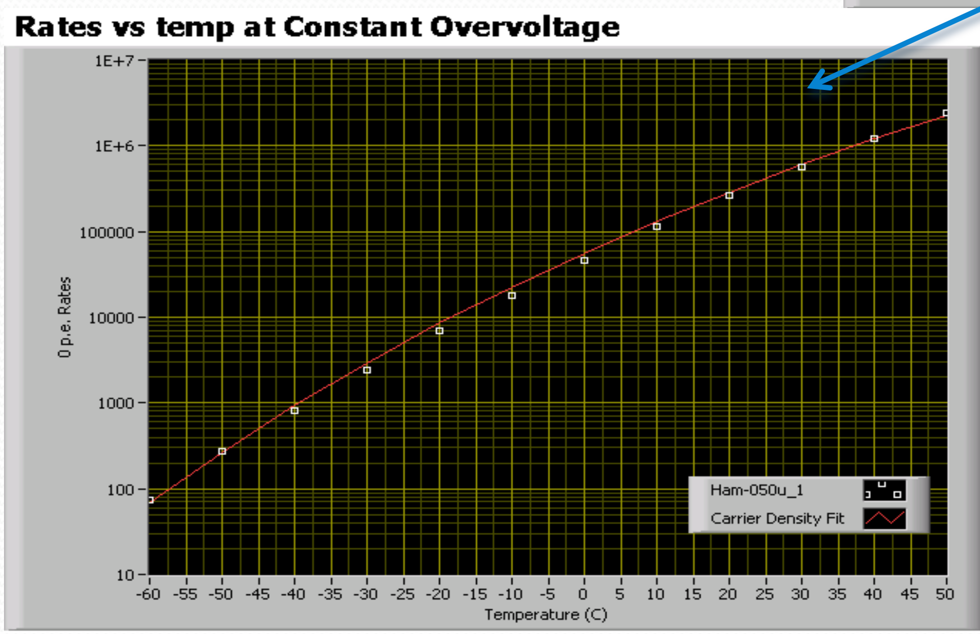
- Probability of crosstalk depends strongly on Voltage, weakly on temperature, and strongly on micro-pixel size

Carrier Density & Excitation Energy

Rate of the first avalanche peak increases nearly exponentially over the temperature range



Making the cut across constant overvoltage to see the temperature dependence



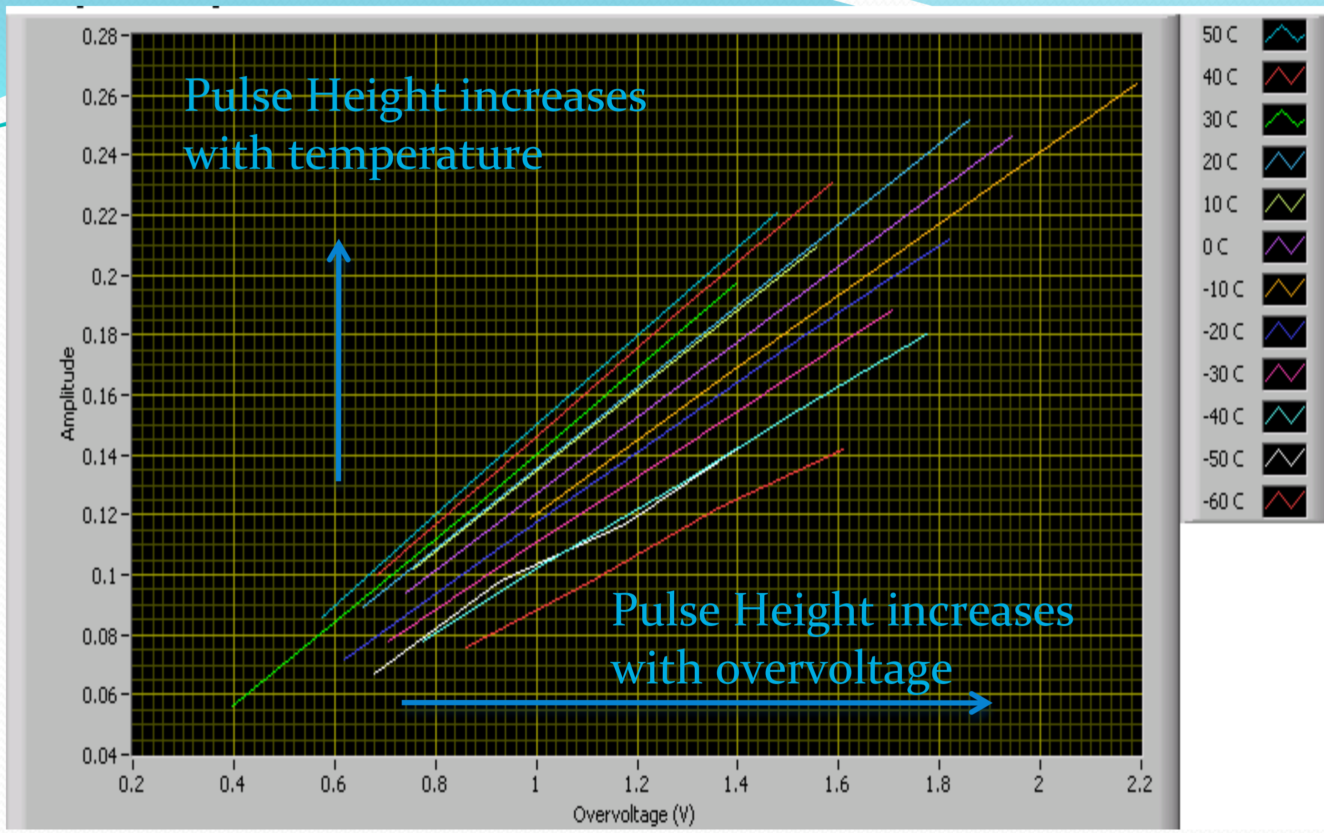
- Selecting the rates at a given over-voltage over this temperature range produces a curve proportional to the carrier density as:

$$n(T) \sim T^{3/2} e^{dE/kT}$$

- Under these conditions we find the excitation energy of our device to be 0.67 eV

Gain Variation in Temperature

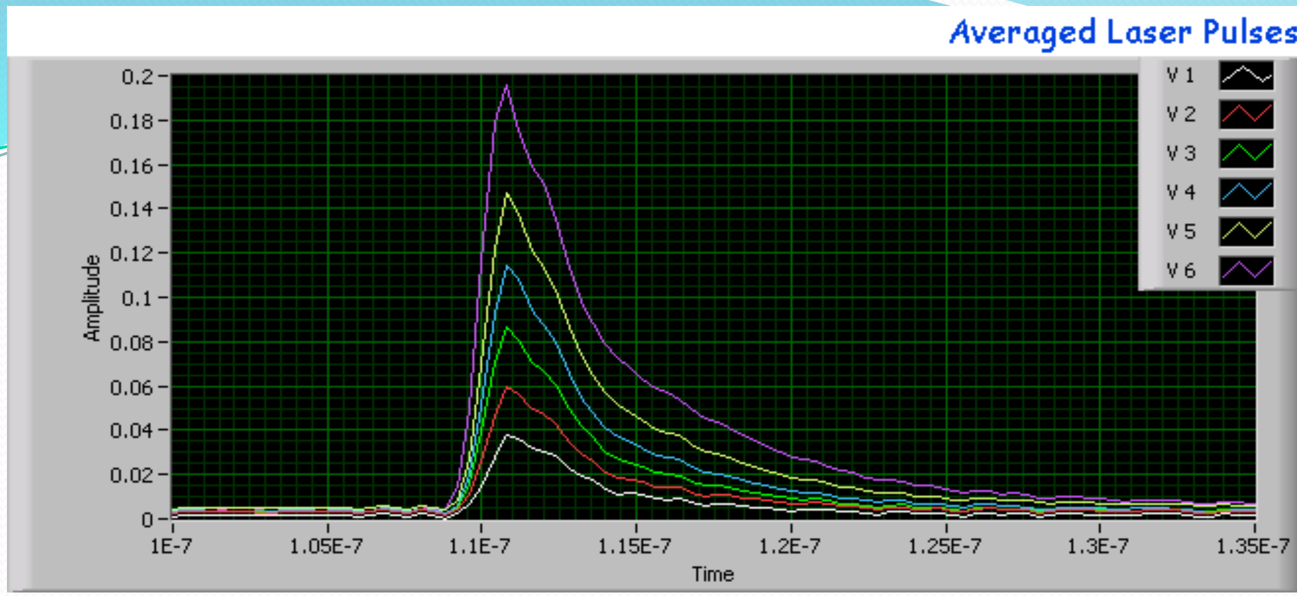
- Amplitude of a single avalanche peak is proportional to the gain of the detector.
- For a given over-voltage the gain of the detector increases with temperature by a factor of ~1.5% per ^{o}C
- In the following plot we see the dependence of the amplitude on overvoltage and the increase of this slope over temperature range



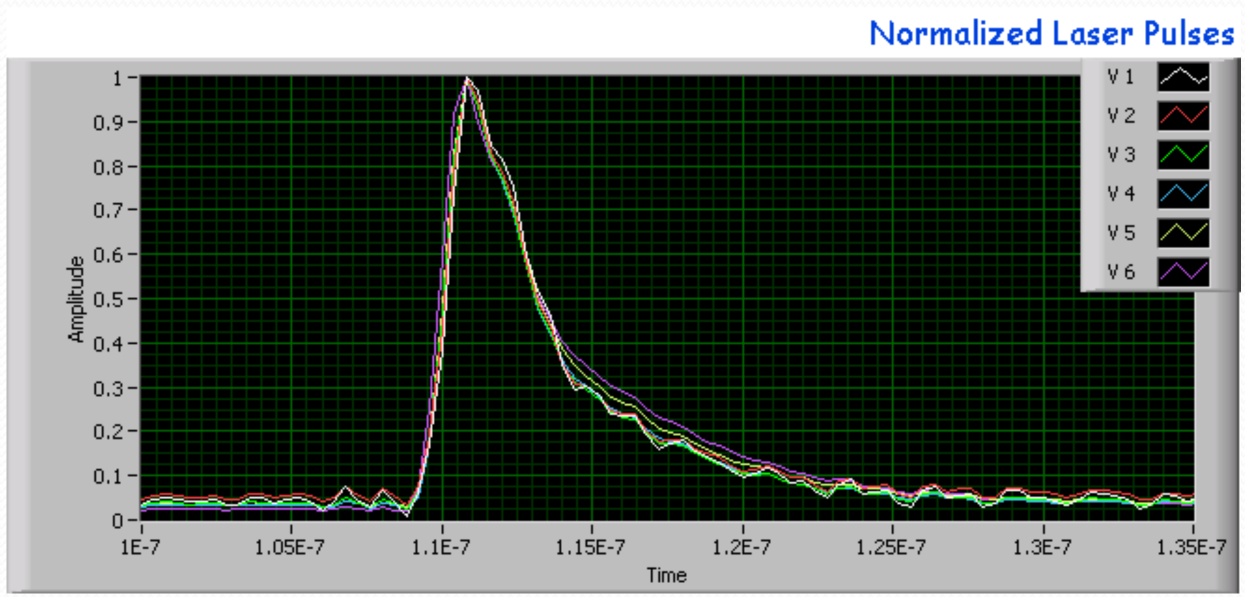
- With our method all plots are constrained to have a zero pulse height at zero overvoltage (the breakdown voltage)

Pulse Shape

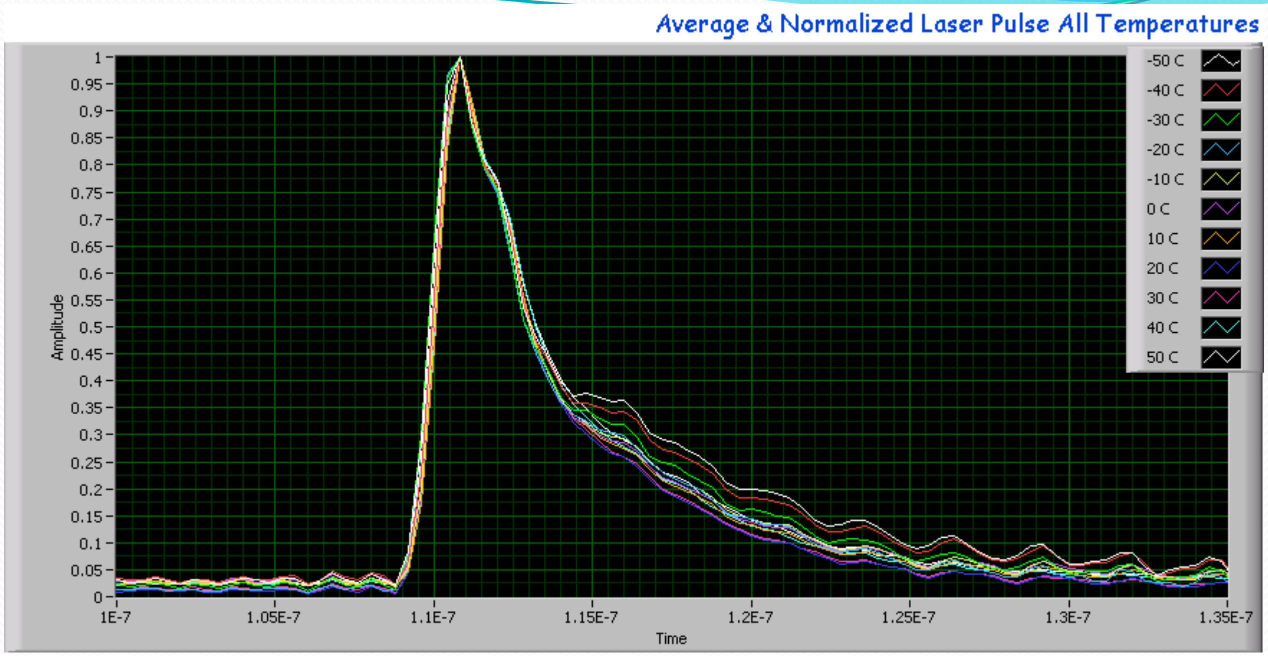
- The average response of the SiPM is recorded after the introduction of a few photons from our laser at over-voltages ranging from 0.5 V to 2 V
- The rise time and fall time of the diode is found to be constant
- The same is found to be true after repeating the experiment over the temperature range
- After normalization of the peak amplitude values we see the pulse shape is constant over both of these parameters



At constant temperature the pulse amplitude increases with bias voltage



After normalization of the peak values we find a constant pulse shape



- Comparing the normalized response over the temperature range reveals constant shape until we reach the tail
- Increase in the tail over temperature may be related to after-pulsing effects