Evaluation of SiPMs for PET Imaging and Personal Radiation Safety

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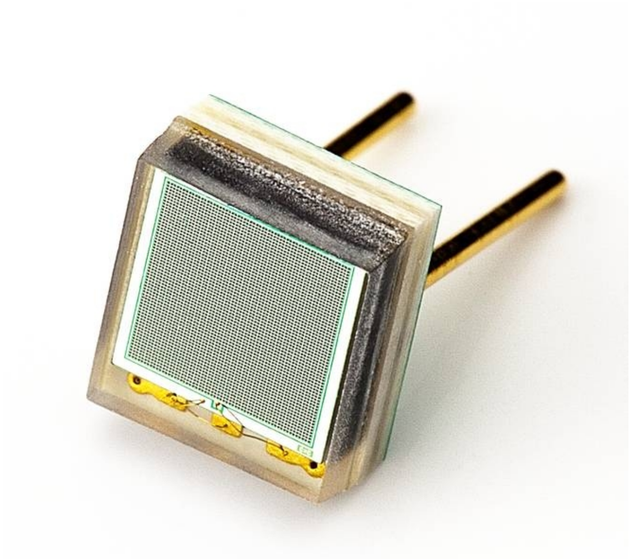
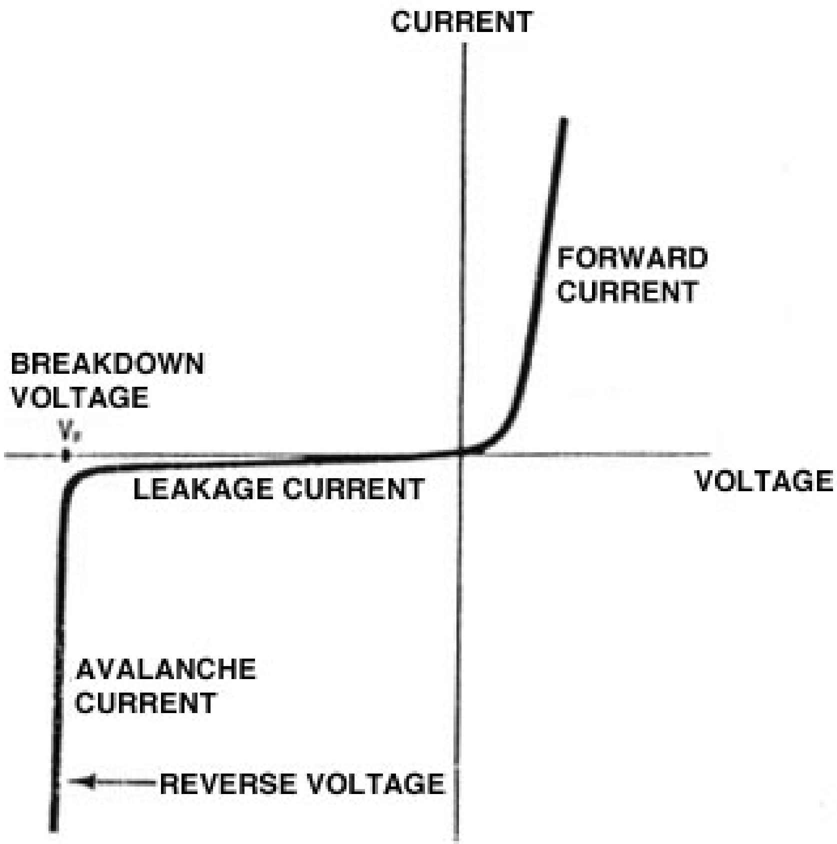
Silicon Photomultiplier (SiPM)





Matrix of avalanche photodiodes (APDs) built on the same Si substrate

Reverse bias

Avalanche (Geiger) operation mode; Bias above breakdown voltage

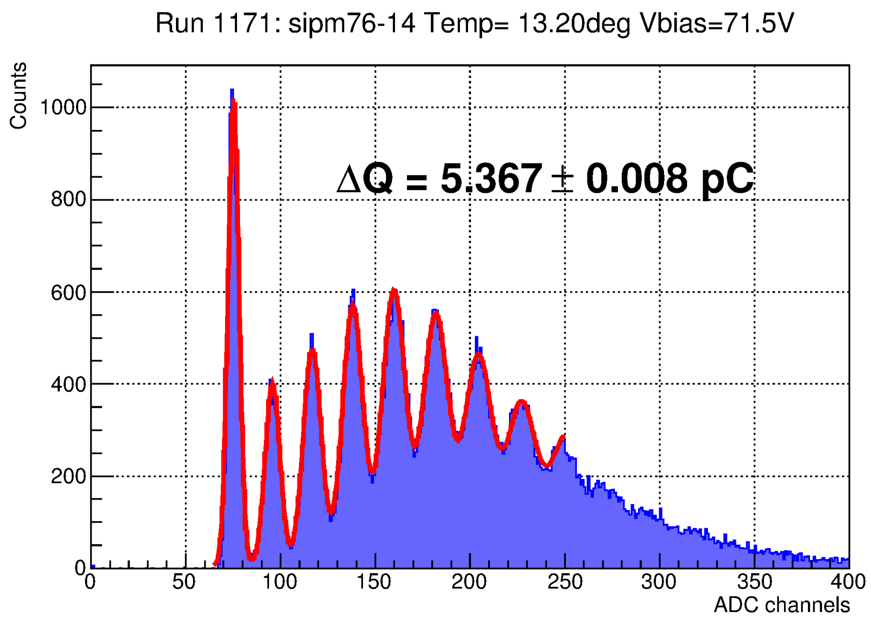
SiPM is few mm in size

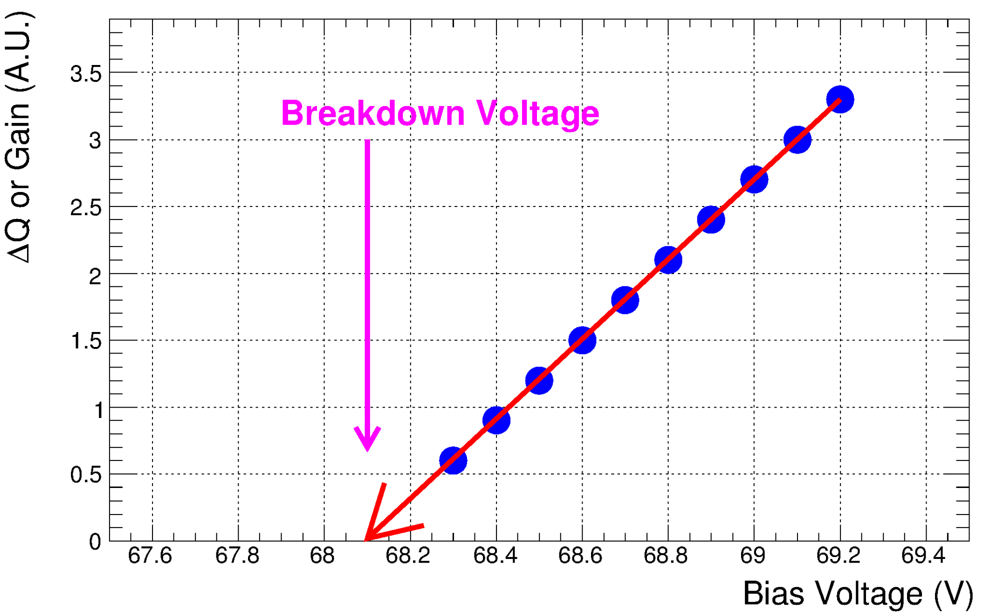
SiPM Properties

- ➔ **Single photon sensitive device (PDE~20-25%)**
- ➔ **Although each APD is a “digital” device, photon flux fire many APDs ⇒ “analog” SiPM signal**
- ➔ **Low bias voltage (20-70 V to be compared with 1.5-2 kV for PMTs; good for outdoor use.)**
- ➔ **A few μm-thick depletion layer ⇒ High electric field inside**
- ➔ **High gain (of $\approx 10^6$). Stable & fast signal**
- ➔ **No sensitivity for magnetic field. (A few Tesla field is no problem. Promising for PET/MRI hybrid.)**

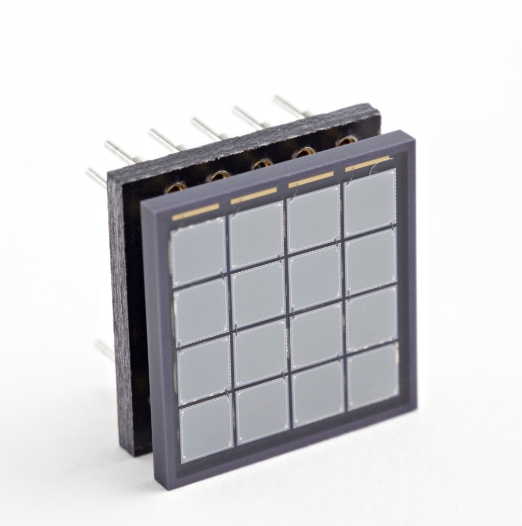
Gain Calibration with Photopeaks

$$Q_{out} = N_p \cdot C_p \cdot (V_{bias} - V_{break})$$



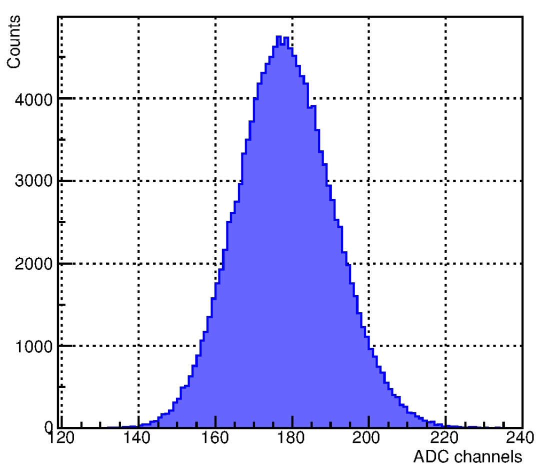


SiPM Array

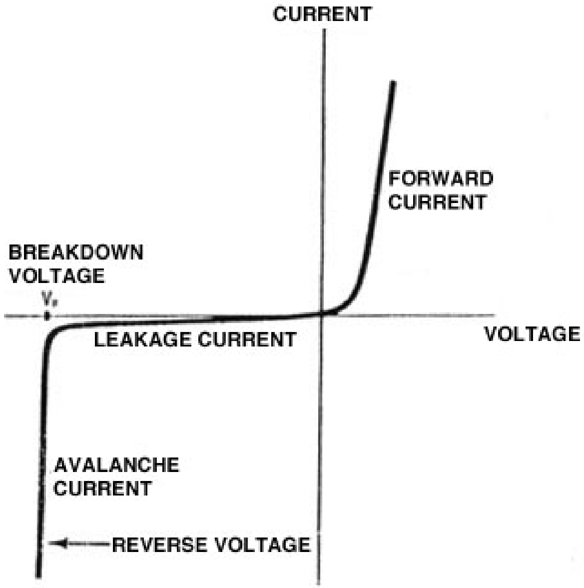


To provide a bigger-area photodetector, a few SiPMs (typically, 9-16) might be combined in the SiPM array.

Although each SiPM in the array might has individual output pin, producers often sell the detector with attached small-in-size pre-amplifier with one “summed” output.



Higher dark current (noise) from the summed SiPMs as well as some variations in the gain make the photopeaks wider and indistinguishable in the shape of ADC spectrum.



IV Curve

- **Measure the dark current as a function of bias voltage**
- **Fit the “Leakage Current” region with a linear function, and find the voltage where the deviation in avalanche region starts**

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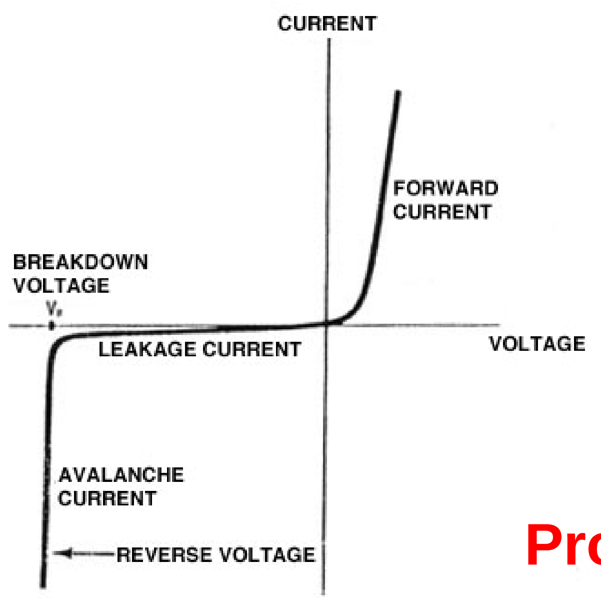

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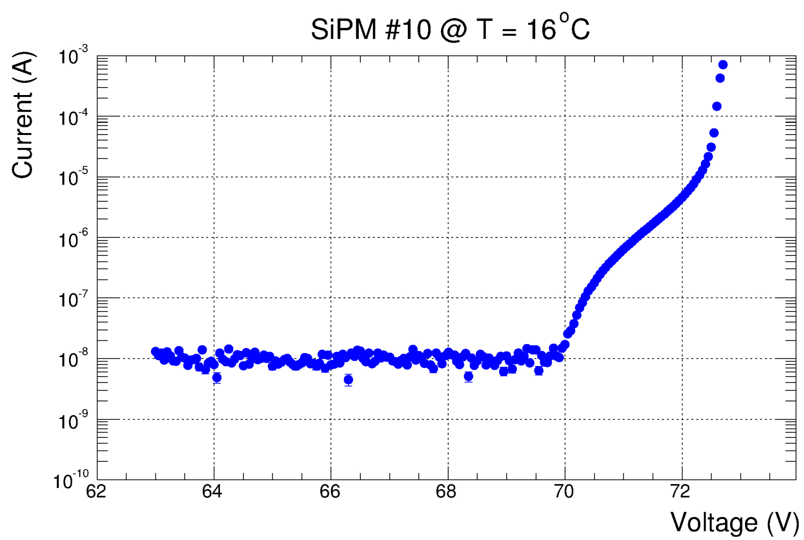
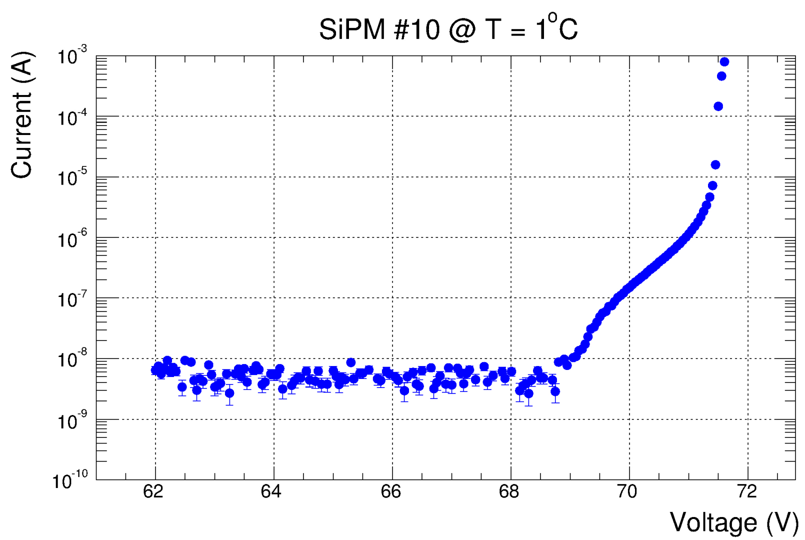
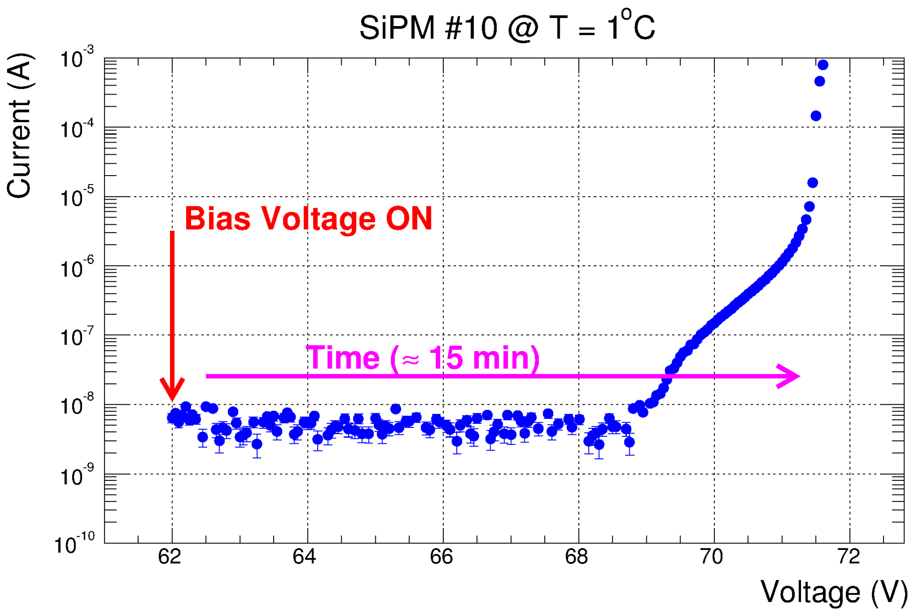
Problems: Fluctuations and No-Ohm's-Law Behaviour





IV Curve: SiPM Relaxation Time

Originally, the measurements were started right after the bias voltage was applied



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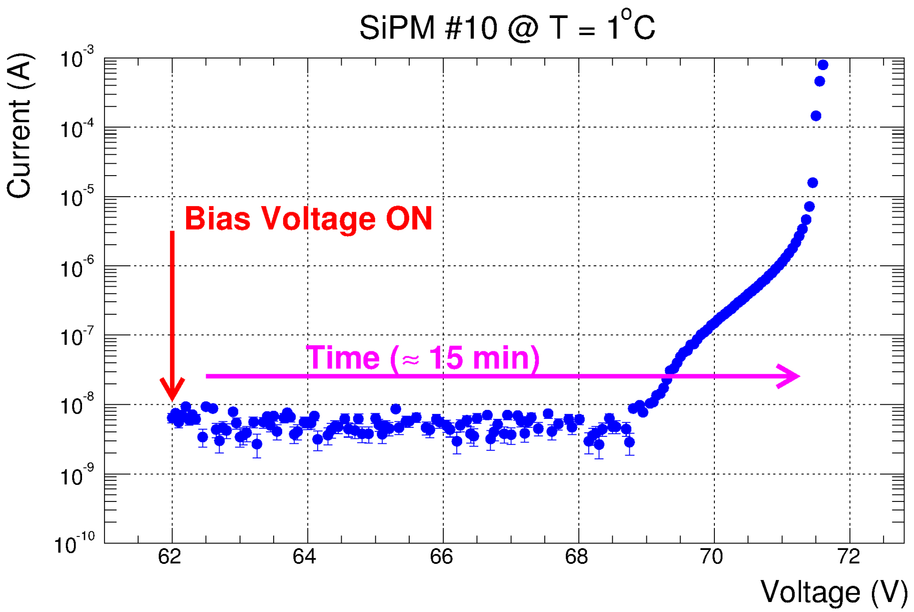

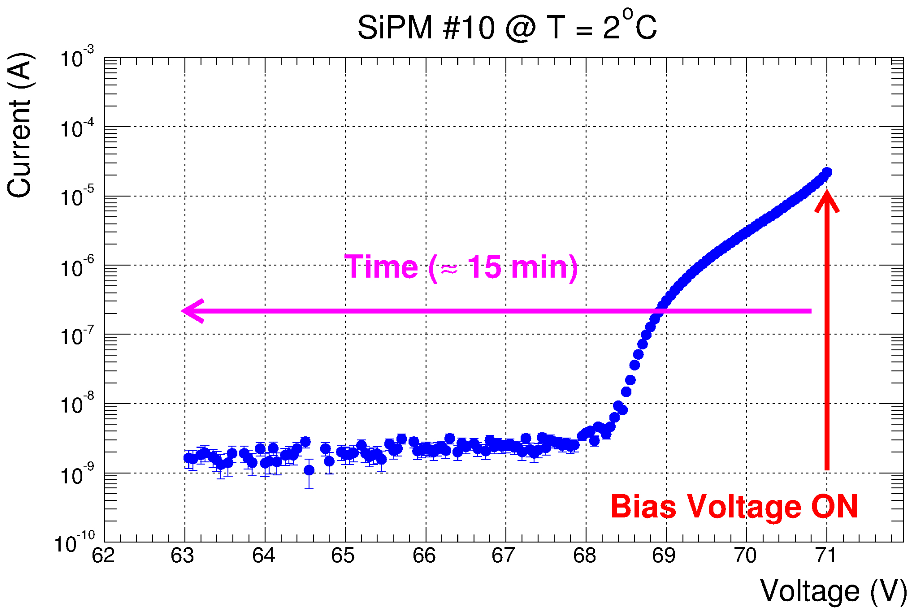

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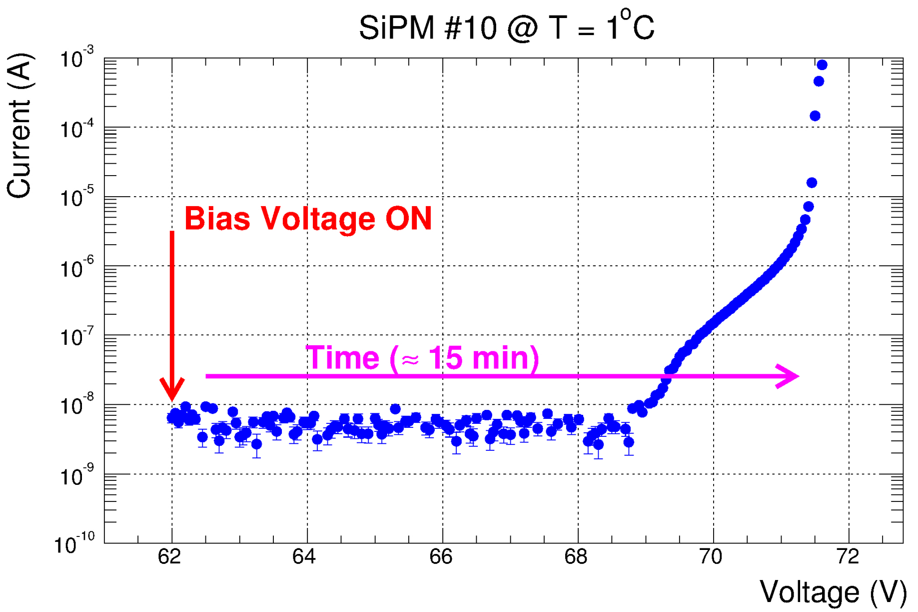
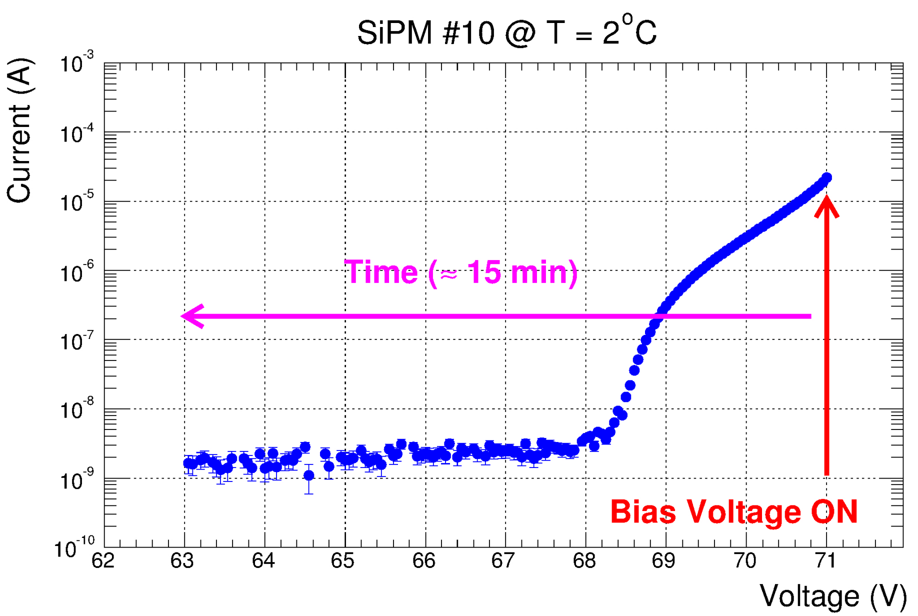
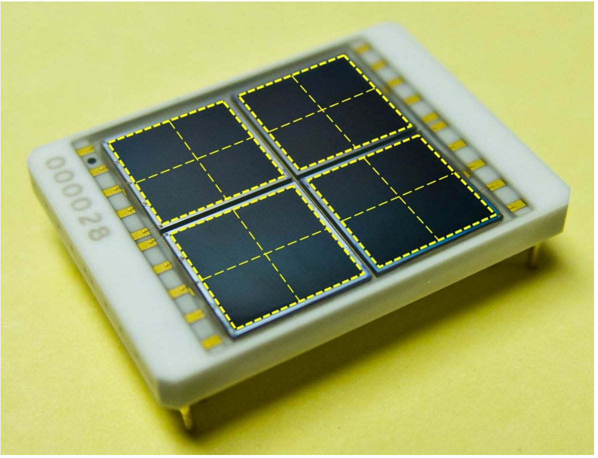


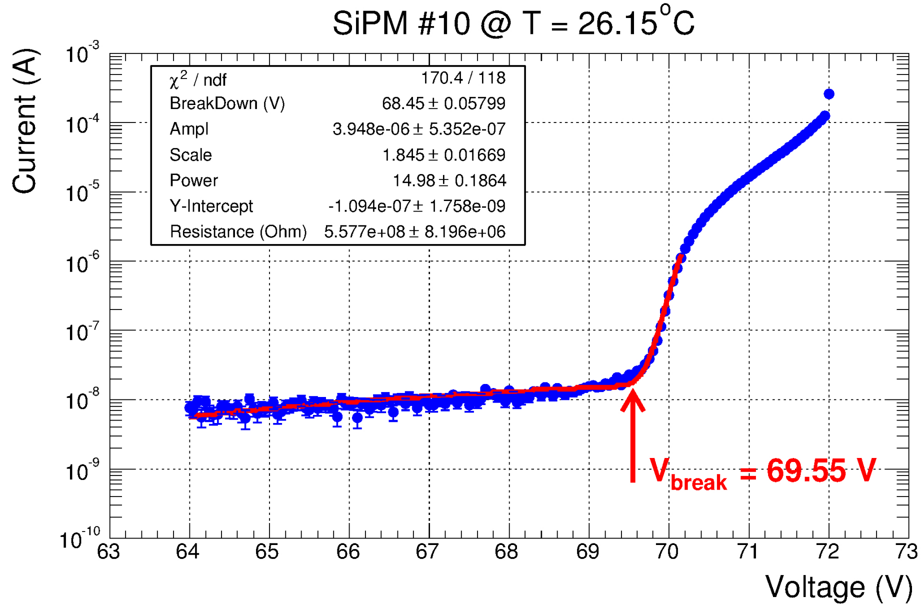


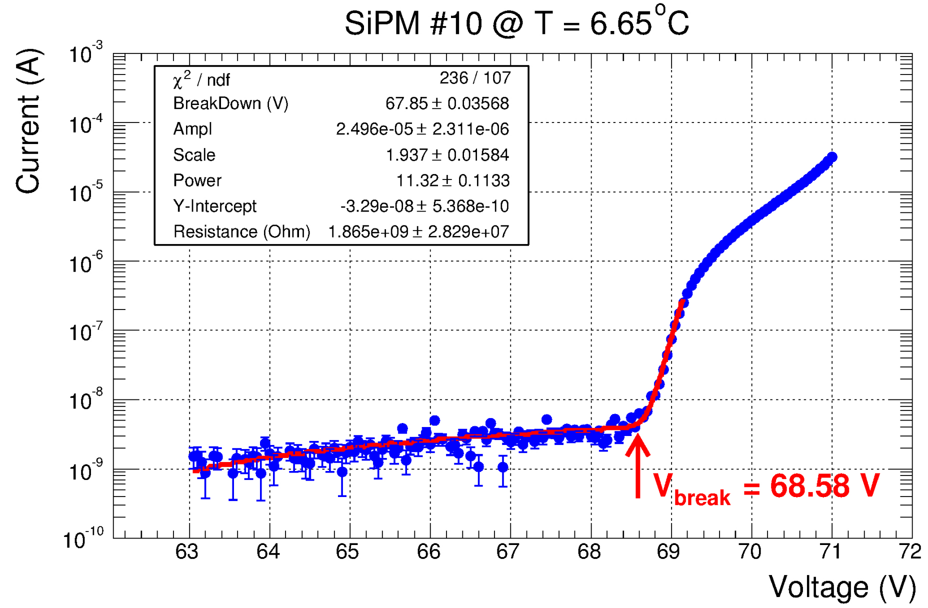
Measurements should be started only after 30-45 minutes of SiPM "warming"

Hamamatsu S12045(X) MPPC

(Multi Pixel Photon Counter)

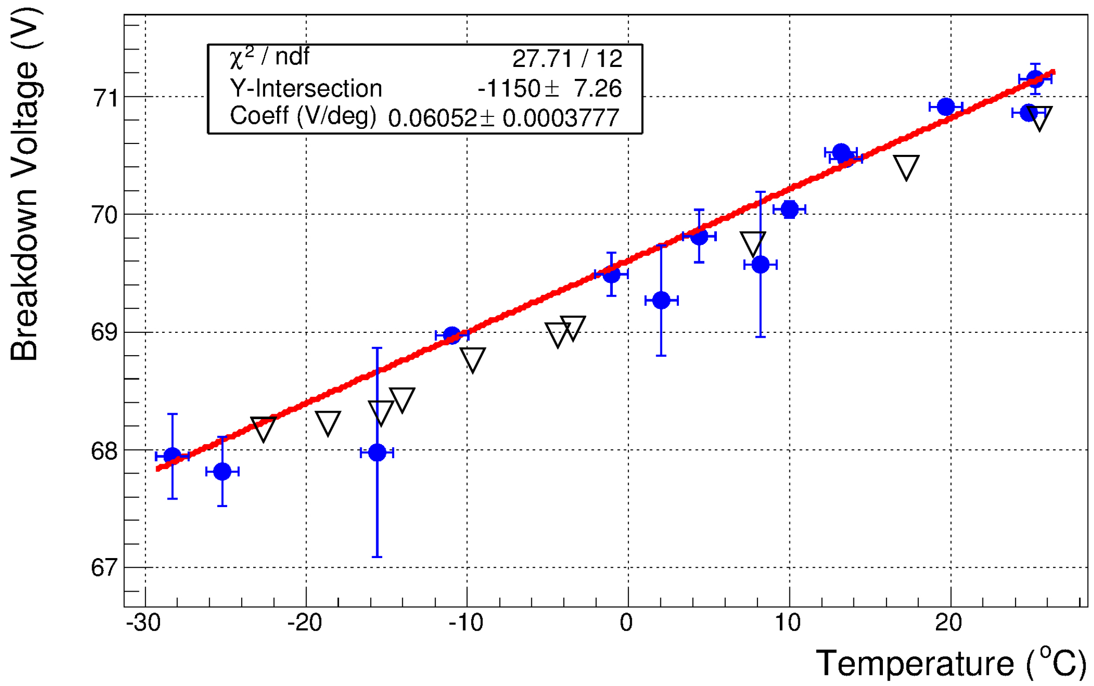






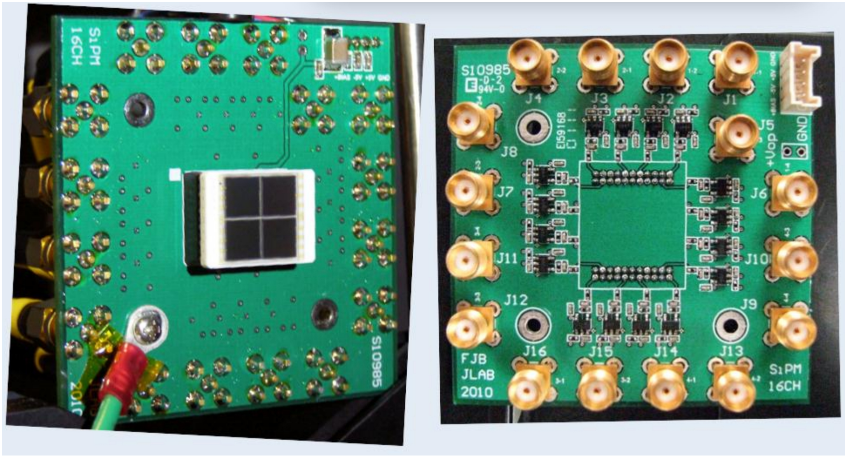
Measurements were done with Keithley 6471 picoammeter/voltage source

IV-Curves and Photopeaks Comparison



Blue circles for IV-Curve method

Empty triangles for photopeak method (cross-check on one cell using 16-output testing board from Jefferson Lab)



Slope of about 60 mV/deg

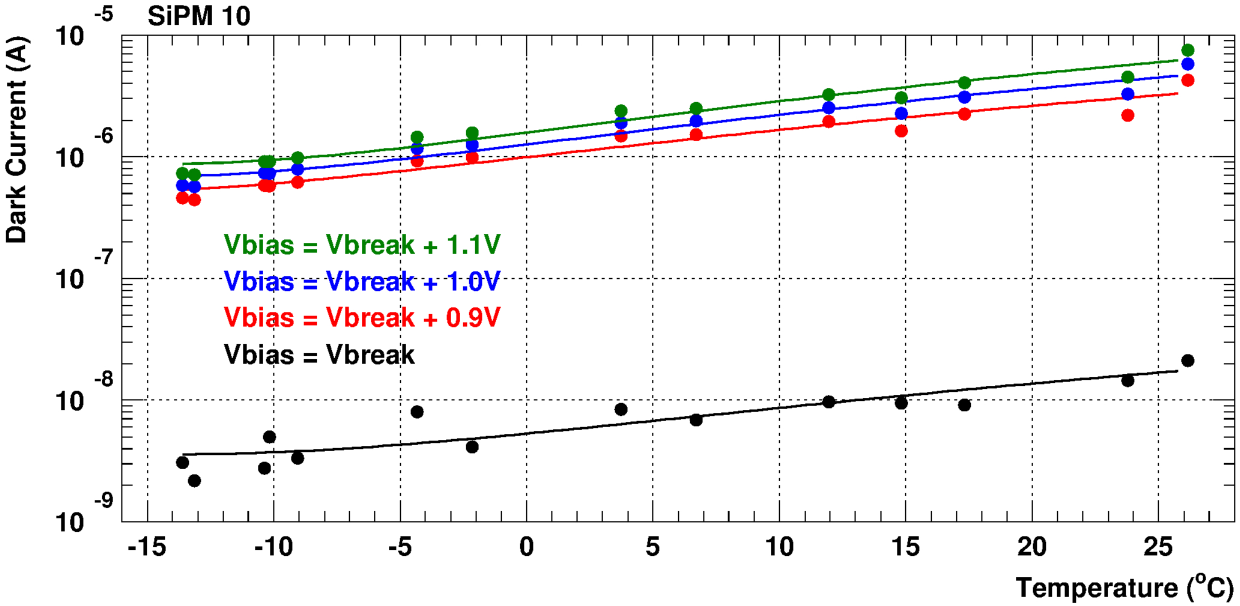
(good agreement for both methods)

Why Evaluate SiPMs?

Typical (V_{bias}-V_{break}) ≈ 1 V. If we want to control the gain better than 10%, we need control for V_{break} better than 100 mV. Without temperature correction, we can operate in the range of 1-2 degrees of temperature change only. Any outdoor operation will require temperature control and bias/gain correction.

Also, cooling is an effective way to reduce dark current (that is highly desired for imaging).

Decrease of the temperature by 40-50°C causes the decrease in the dark current by factor 10.



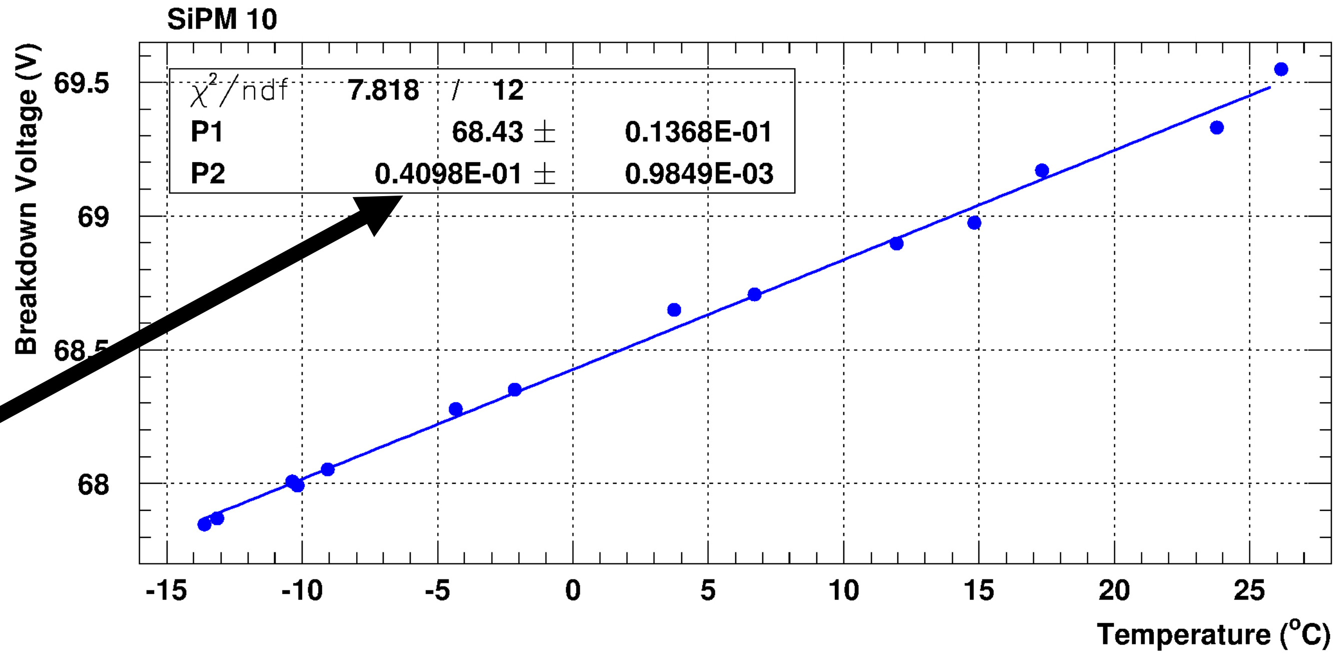
Variations in Temperature Response

SiPM producer may provide the "universal" temperature coefficient. (For example, Hamamatsu provides 56 mV/deg for S12045(x) MPPCs.)

Nevertheless, sensor-to-sensor variation is significant.

For example, another SiPM array...

≈41 mV/deg



Without evaluation of each individual SiPM array, the 10%-accurate operation is possible in the temperature range of few degrees only.

Summary:

● **Operation of SiPM-based detectors for personal radiation safety (viz., outdoor use) and imaging (viz., gain stability as well as a possible desire to decrease the noise via cooling) requires temperature control and bias/voltage correction.**

● **Sensor-to-sensor variation of the dependence on temperature suggests evaluation of each SiPM array.**

● **We have developed the technique for measurement of the breakdown voltage without using ADC photopeaks that are unavailable for SiPM arrays with output summed over all cells. Cross-check of this technique against the traditional photopeak method demonstrates a good agreement between these two methods.**

Acknowledgements

- Fedoruk Centre
- Jefferson Lab partners
- NSERC, DOE infrastructure
- Regina GlueX Team