Basic studies with Silicon Photomultiplier

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OUTLINE

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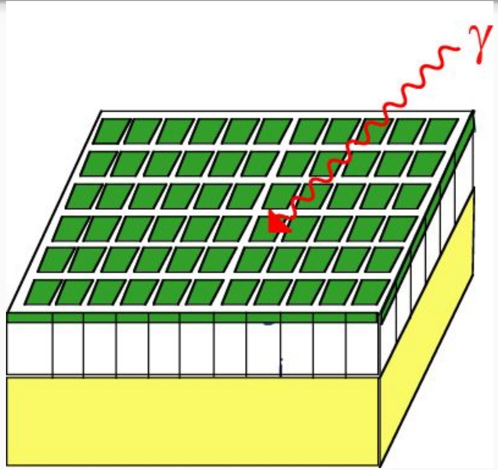
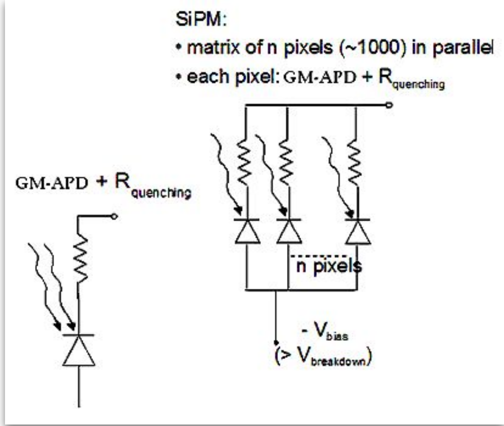
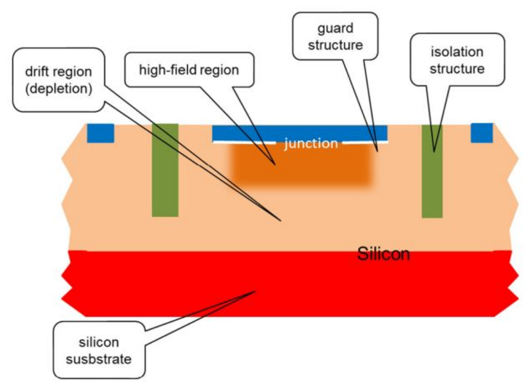
Introduction

- A silicon photomultiplier is a matrix of Single Photon Avalanche Diodes (SPAD)
- The SiPMs are designed to operate above breakdown voltage (V_{br}) in reverse bias mode.
- All the microcells are electrically and optically isolated from each other and give signal when fired by a photon.



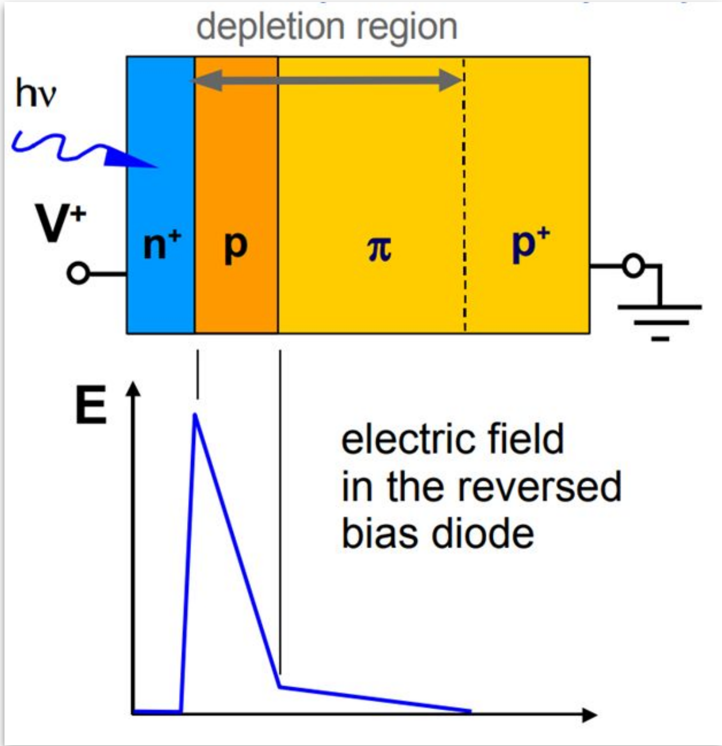


- The microcells in SiPM are connected in parallel with each other and hence share a common bias.

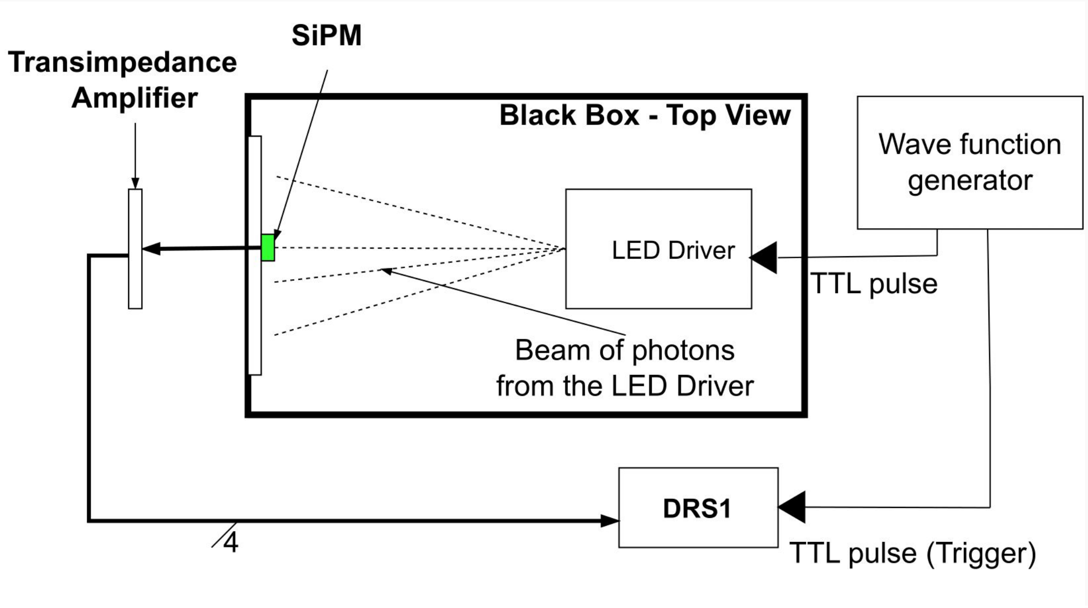


Working Principle of SiPM

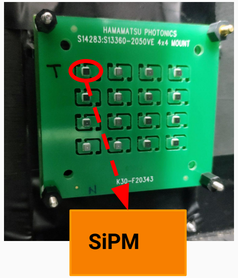
- When a photon hits a microcell, it creates an e-h pair. The e− start drifted towards the high field region and on the way it gains enough kinetic energy to knockout a secondary e-h pair.
- The secondary e− further creates an additional e-h pair and this process continues to an avalanche (e− multiplication) in the high field region.
- The signal due to the avalanche in a microcell is called as one photoelectron signal and often referred as “one microcell is fired”.
- The sum of signals from all the microcells is proportional to the number of microcells fired.



Experimental Setup



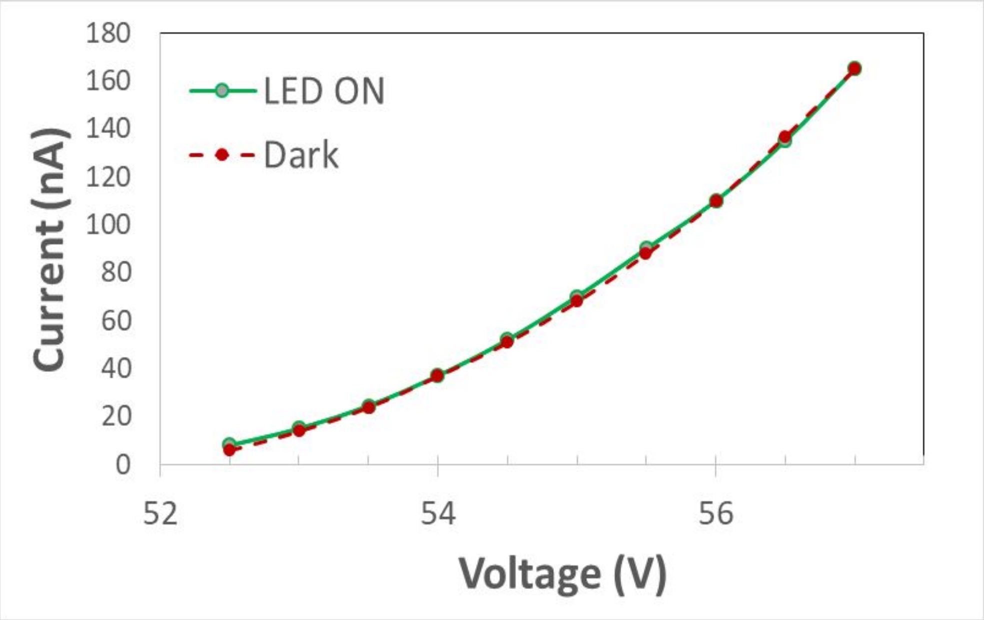
- **Each Cell - 2 mm×2 mm**
- **1584 sq. microcells**
- **microcell pitch: 50 µm**



- Keithley sourcemeter was used to provide bias to the SiPM
- LED with peak wavelength 465 nm is connected to wave function generator (TTL pulse frequency : 450 Hz)
- SiPM signal is amplified by trans-impedance amplifier [gain: 909 Ω] and acquired by computer system

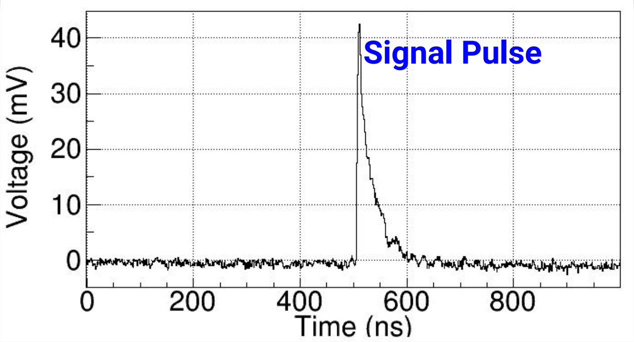
RESULTS : IV characteristics of SiPM

IV characteristics was performed in dark and under illumination LED



- Current increase exponentially as the bias voltage increases.
- Since the noise rate is much higher than the signal frequency, noise dominates the device current

Photoelectron spectrum of SiPM at different High Voltages



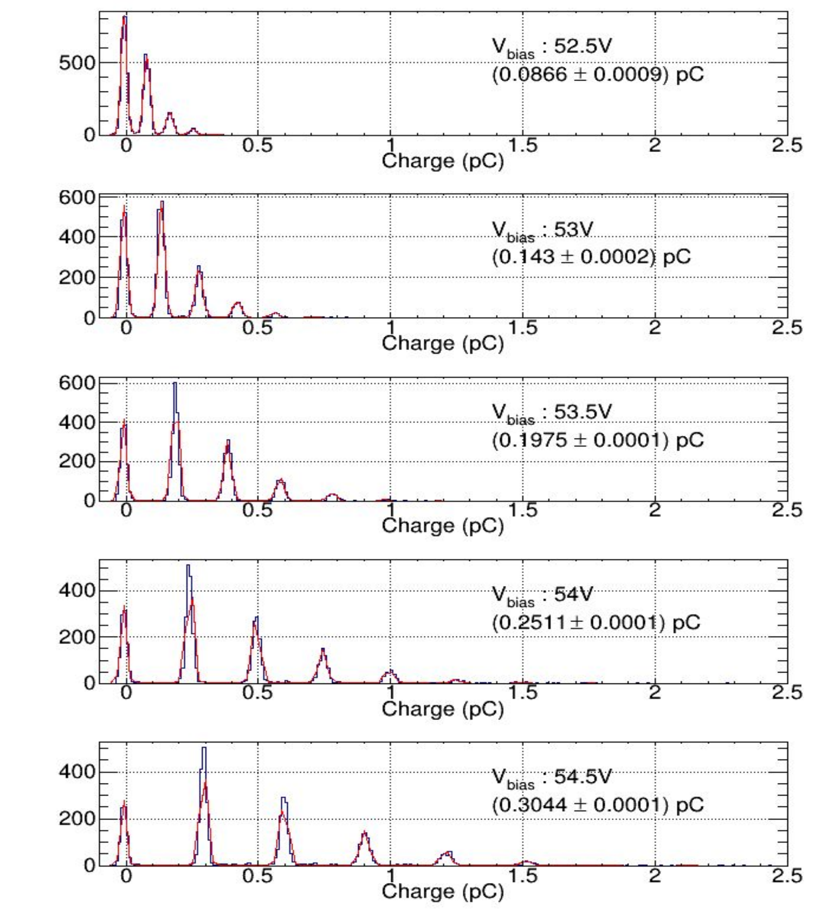
The charge generated by SiPM:

$$q = \frac{1}{R} \int_{to}^{t1} V(t)dt$$

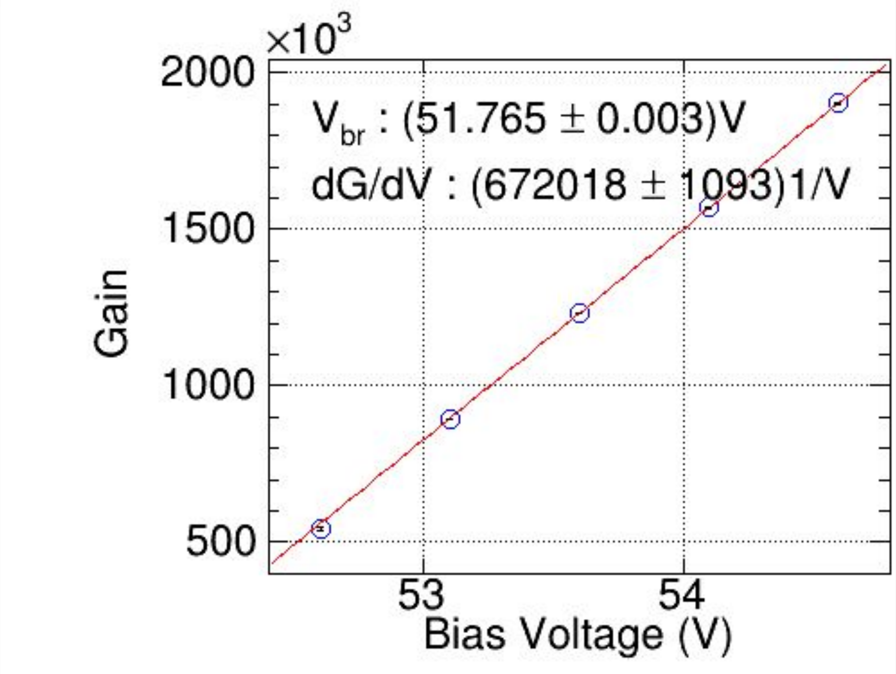
R = Input resistance of transimpedance amplifier

$$Gain(G) = \frac{\mu}{(1.6 \times 10^{-19})C}$$

μ - Average gap between the consecutive photoelectrons peaks



Estimating the breakdown point

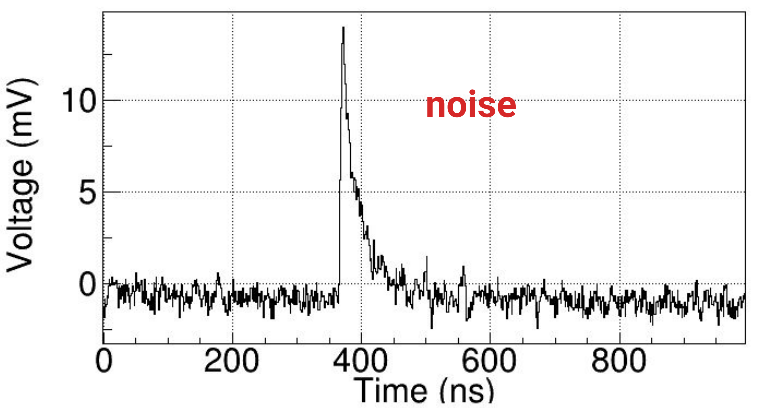


- The gain varies linearly with V_{bias}
- The voltage at which gain approaches zero will give the V_{br}

Noise rate of SiPM

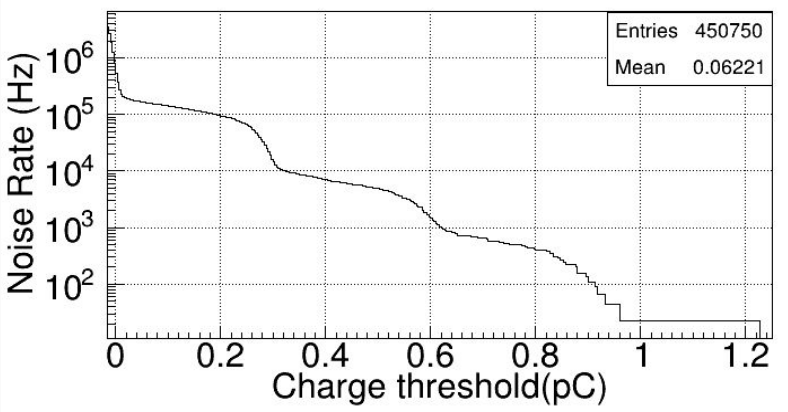
Sources of noise:

- **Dark count:** Signal corresponding to avalanche triggered by thermal electrons
- **Afterpulse:** Carriers can be trapped during an avalanche and then released triggering another avalanche.
- **Optical cross-talk:** Some of the discharged photons on avalanche can be absorbed in the adjacent cell and triggering new discharges



Noise rate calculation:

- Signals from the SiPM were collected in dark
- Estimated by the fraction of events crossing the charge threshold out of the total events.



Inference

- VI characteristics of SiPM was performed.
- Photoelectron spectrum of SiPM at different over voltages were obtained.
- Breakdown voltage was estimated from gain Vs bias voltage
- Noise rate of SiPM was estimated

Acknowledgement

BK, LM and SN acknowledge organizers of ICFA 2023 School, Lecturers, Instructors and all the Staff members of TIFR.

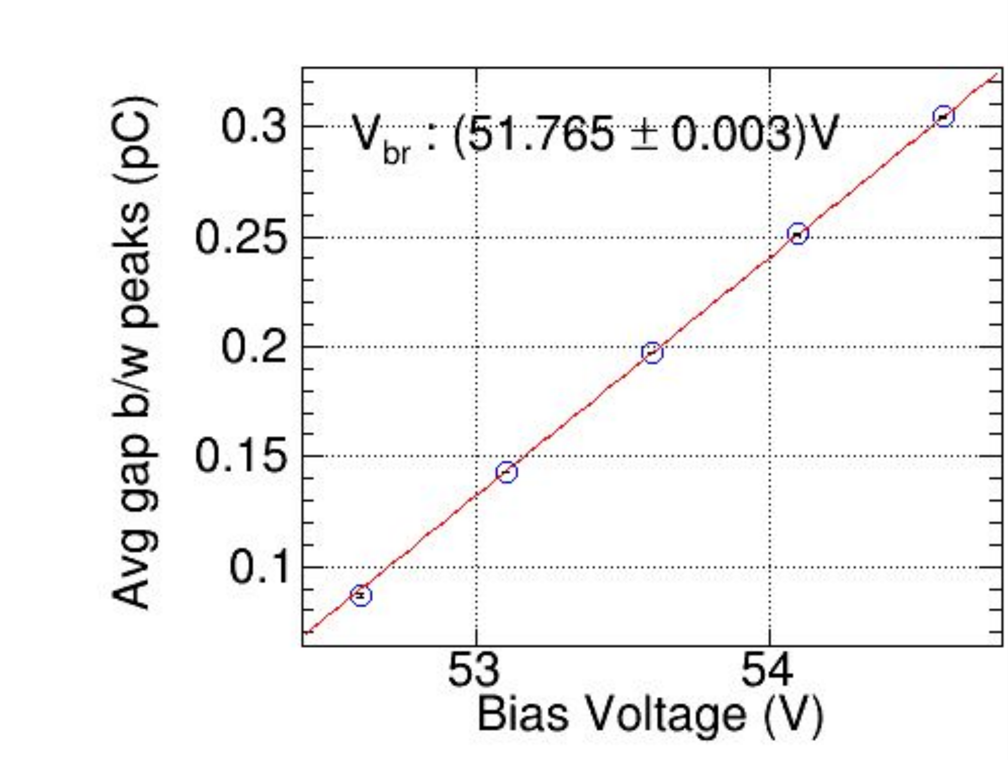
School was So Much Fun!!

Thank You!

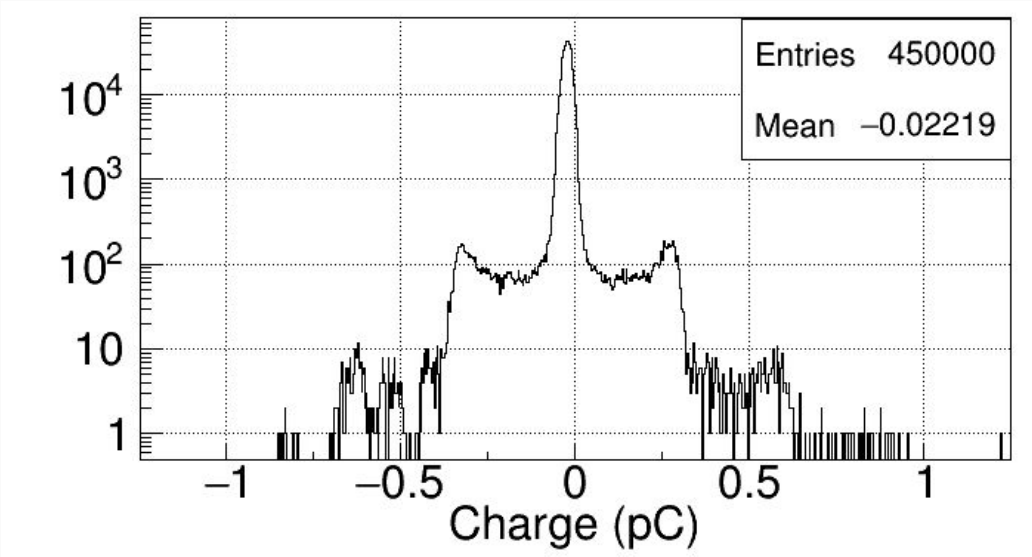
pc @dazz

Backup slides

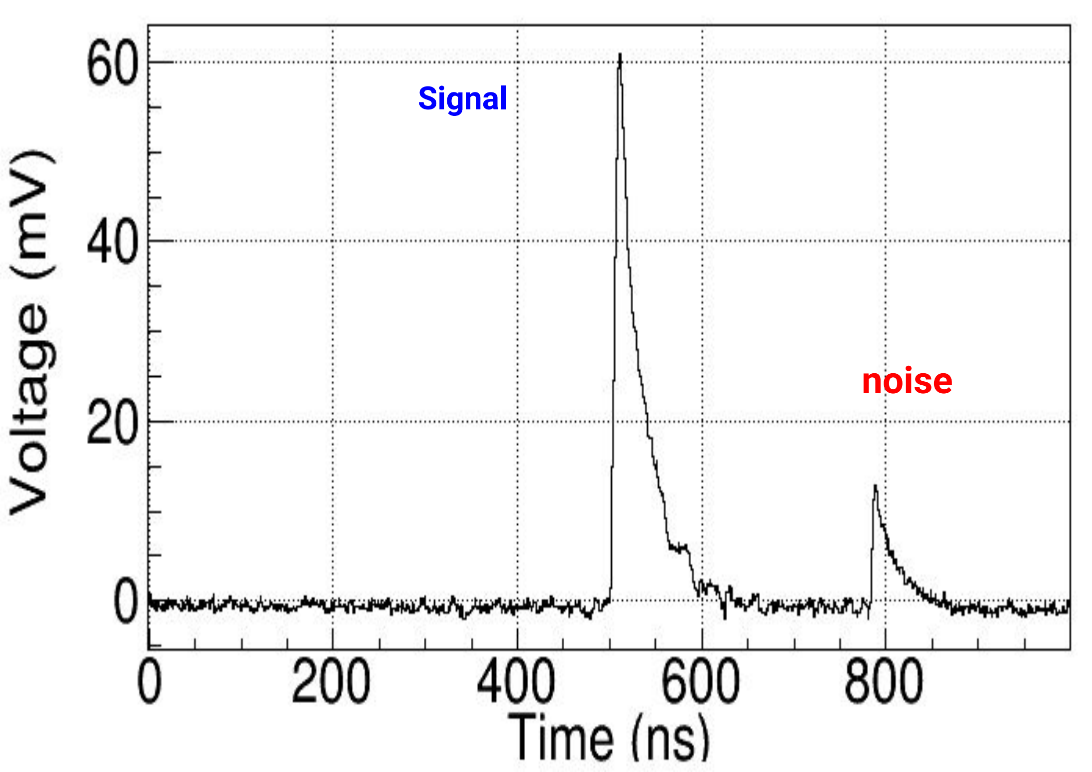
The Keithley sourcemeter (max. current limit 105 μA, (0 - 90) V)



- Signals from the SiPM were collected in dark at over voltage =3 v



The raw signals are integrated within a 100 ns time window around the peak, the pedestal subtraction is done to calculate the charge value from each event and the charge distributions.



Signal
noise
Voltage (mV)
Time (ns)
0
20
40
60
0
200
400
600
800