Understanding the temperature dependence of SiPM characteristics

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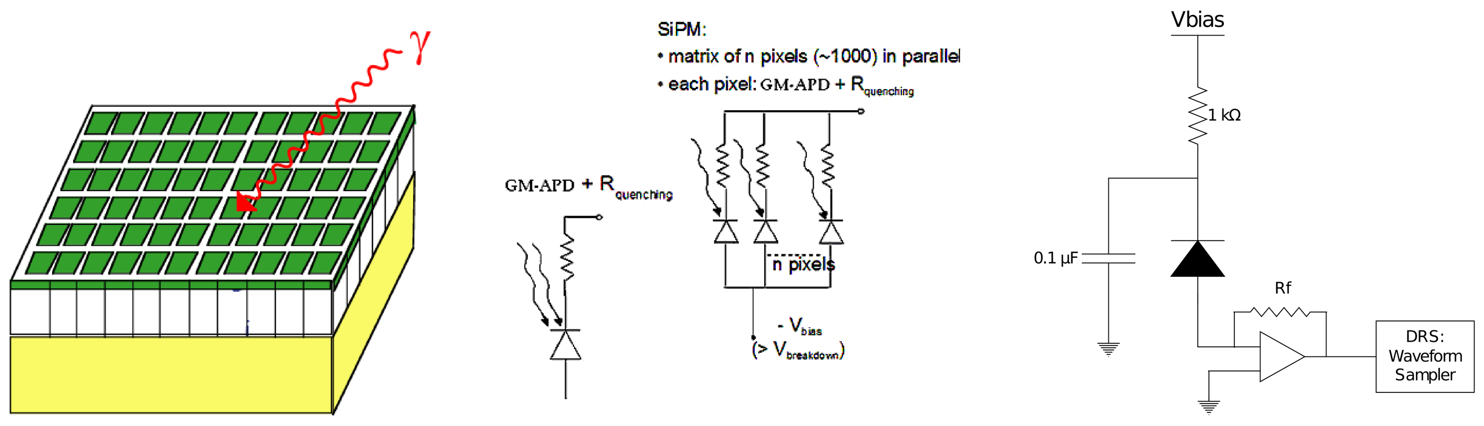
Abstract

The prototype detector of ICAL experiment at the India-based Neutrino Observatory i.e., mini-ICAL is in operation at the IICHEP, Madurai. A Cosmic Muon Veto detector around the mini-ICAL is being built using extruded plastic scintillators with embedded WLS fibers to propagate scintillator signal to SiPMs. The SiPMs will be calibrated using an ultrafast LED driver. An experimental setup was built using a thermal chamber to characterise the SiPMs in a temperature controlled environment. The readout electronics involves trans-impedance amplifiers to amplify the SiPM output pulses and a digital storage oscilloscope for the data collection. Along with the basic characterisation i.e. gain and breakdown point estimation of the SiPM, various other charateristics of the Hamamatsu SiPM (S13360-2050VE), e.g. signal shape, optically correlated and uncorrelated noise etc were studied as a function of the SiPM's overvoltage (V_{ov}), number of photoelectrons and the temperature.

About Silicon-photmultiplier and the electronic circuit

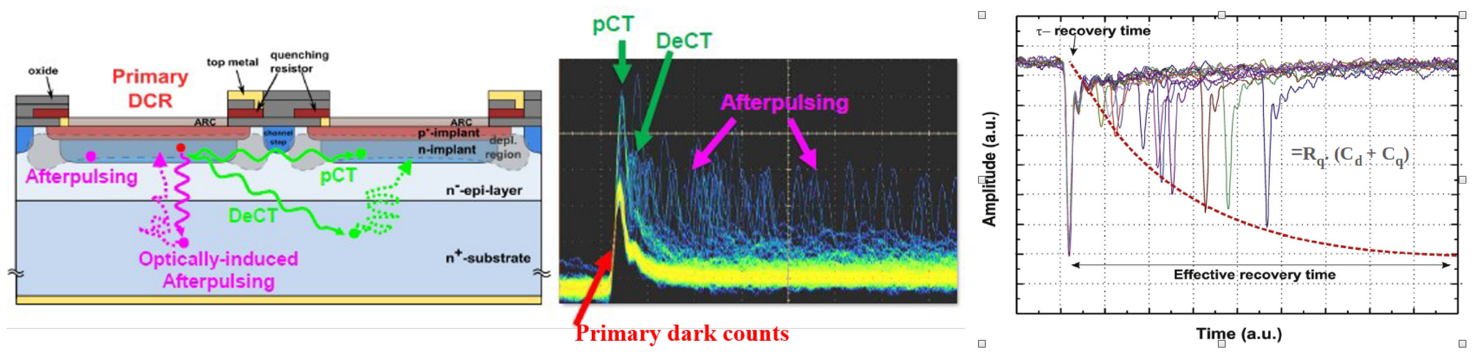
The SiPM under test is from Hamamatsu (S13360-2050VE) with a photosensitive area of 2 mm×2 mm and a pixel pitch of 25 μm, breakdown voltage of (53 ± 5) V + V_{ov} of 3 V and −dG/dT = 2% [1].

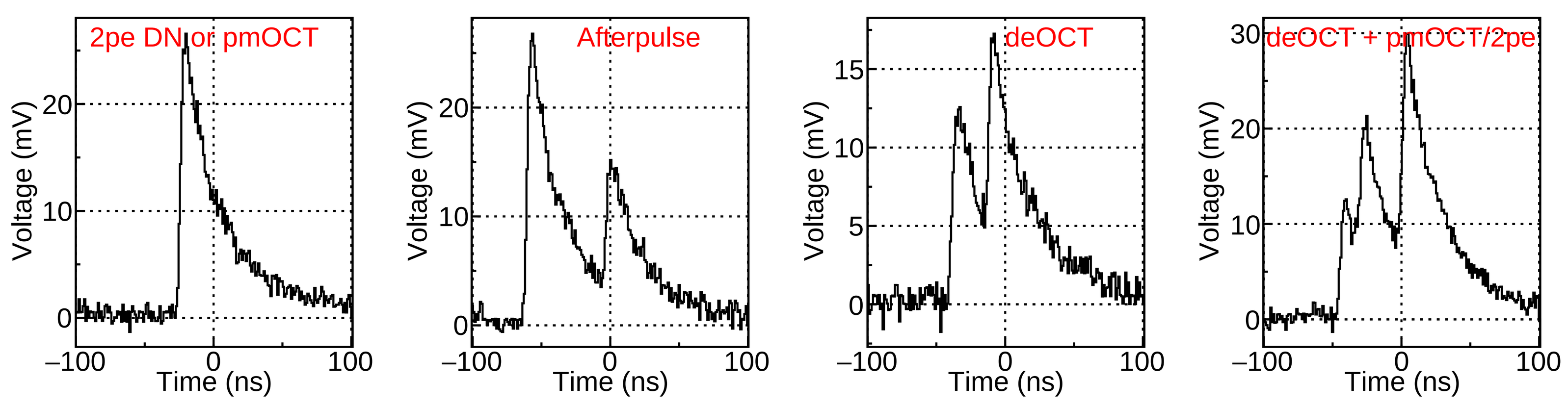


A picture to show the inside structure of the SiPM with pixels, the pixels connected in parallel with a series quenching resistor and the SiPM circuit diagram for the readout.

Correlated noise in SiPM

The noise in SiPM appears due to the avalanche triggered by the thermal electrons in the high field region. It could be primary noise or the secondary (correlated) noise. As the name suggests, correlated noise is related to the noise induced in the same or neigbouring pixel due to the primary noise. Correlated noise mainly categorised in the form of Afterpulsing (AP) and Optical Crosstalk (OCT).

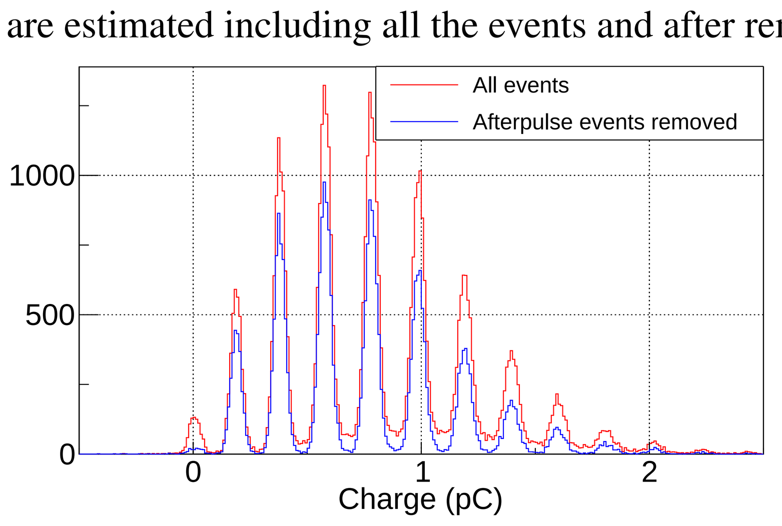




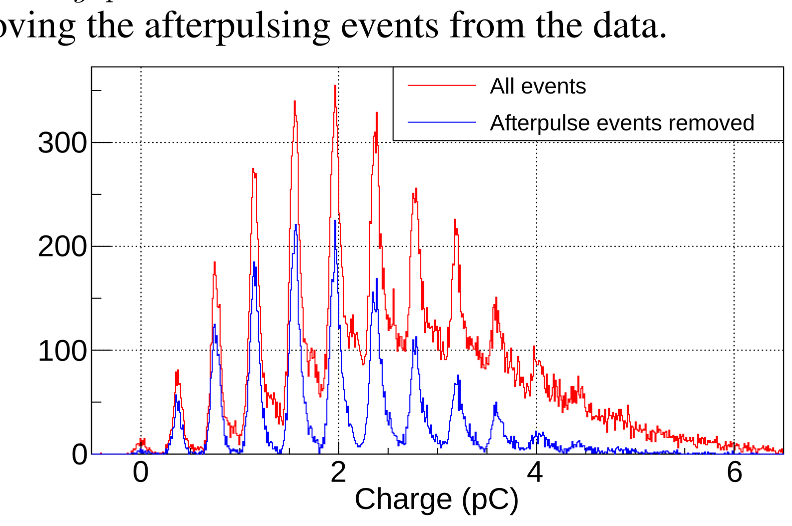
Some examples of different kinds of the correlated events from the experimental data.

Effect of the correlated noise on the gain estimation

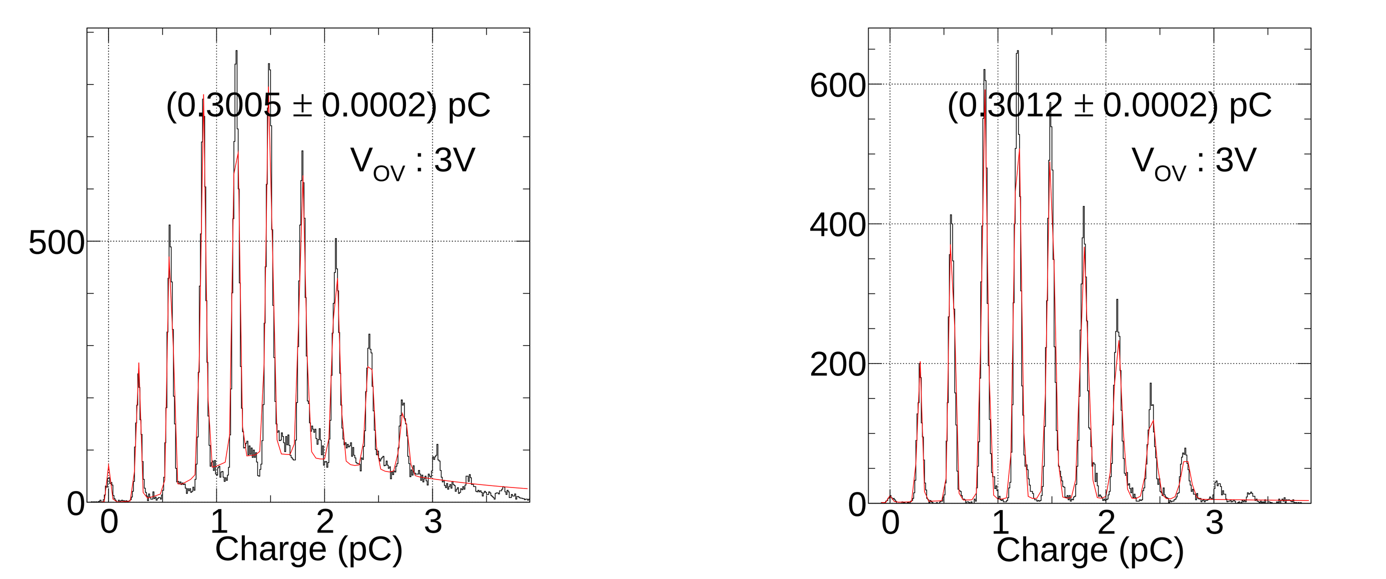
An ultrafast LED driver is used as a light source and the corrsponding waveforms from SiPM (in a black box) are collected via oscilloscope. The aim is to estimate the gain and the breakdown point of the SiPM. The gain of the SiPM is directly proportional to the average gap between the consecutive peaks (x_{gap}). The x_{gap} between any two consecutive peaks is expected to be the same, but the observations reveals that x_{gap} value increases as we go towards higher photelectrons peaks. Afterpulses could be suspected as one of the main sources of this increase in x_{gap} value. To confirm the same, the gain values are estimated including all the events and after removing the afterpulsing events from the data.



Charge distribution at V_{ov}=2 V.



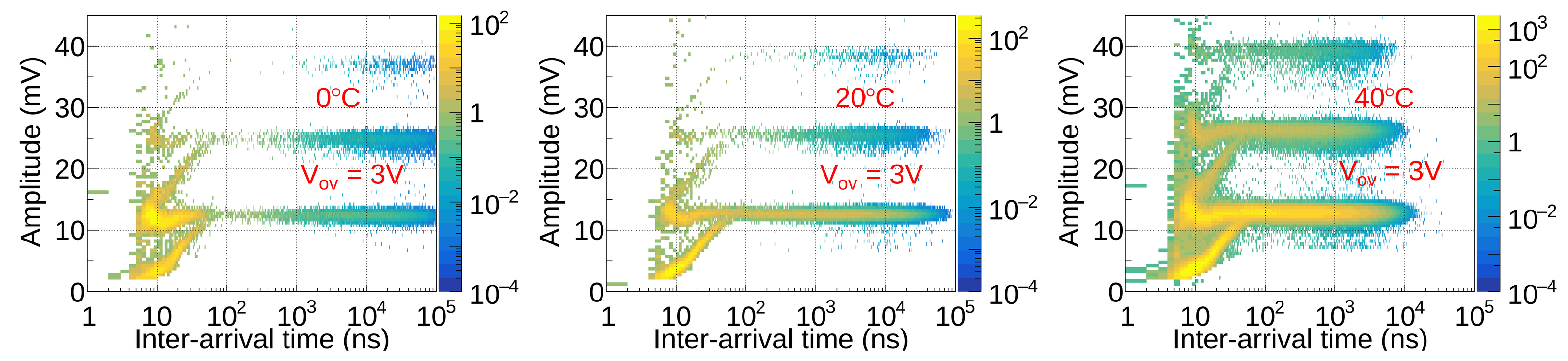
Charge distribution at V_{ov}=4 V.



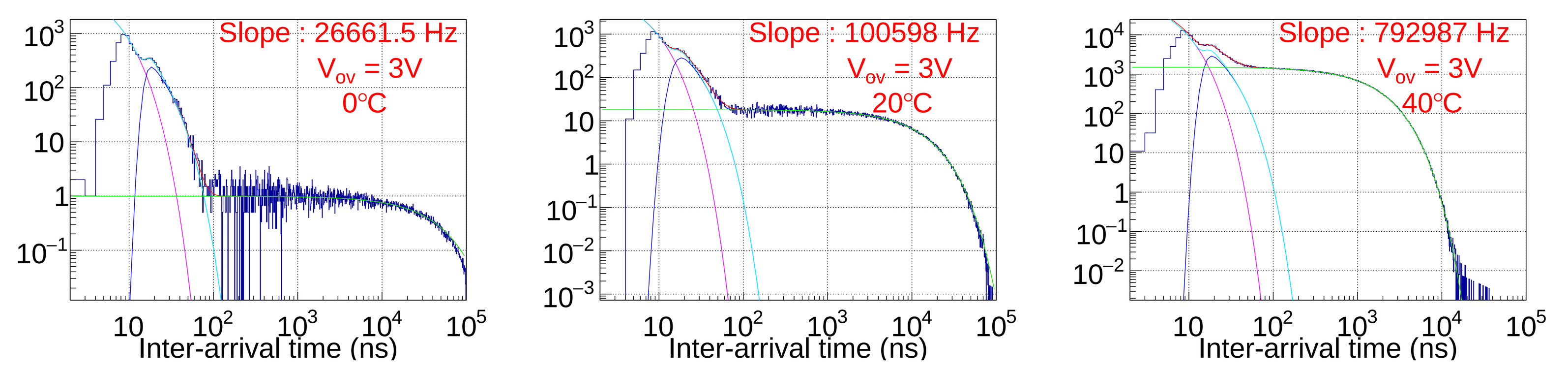
Fitted charge distribution at V_{ov}=3 V with all the events and after removing Afterpulse events.

Correlated signals

A double pulse trigger was generated within a 100 μs window to collect SiPM waveforms in a dark room. To differentiate between the correlated events, the time difference between the consecutive events (inter-arrival time) and their amplitudes are the crucial parameters.



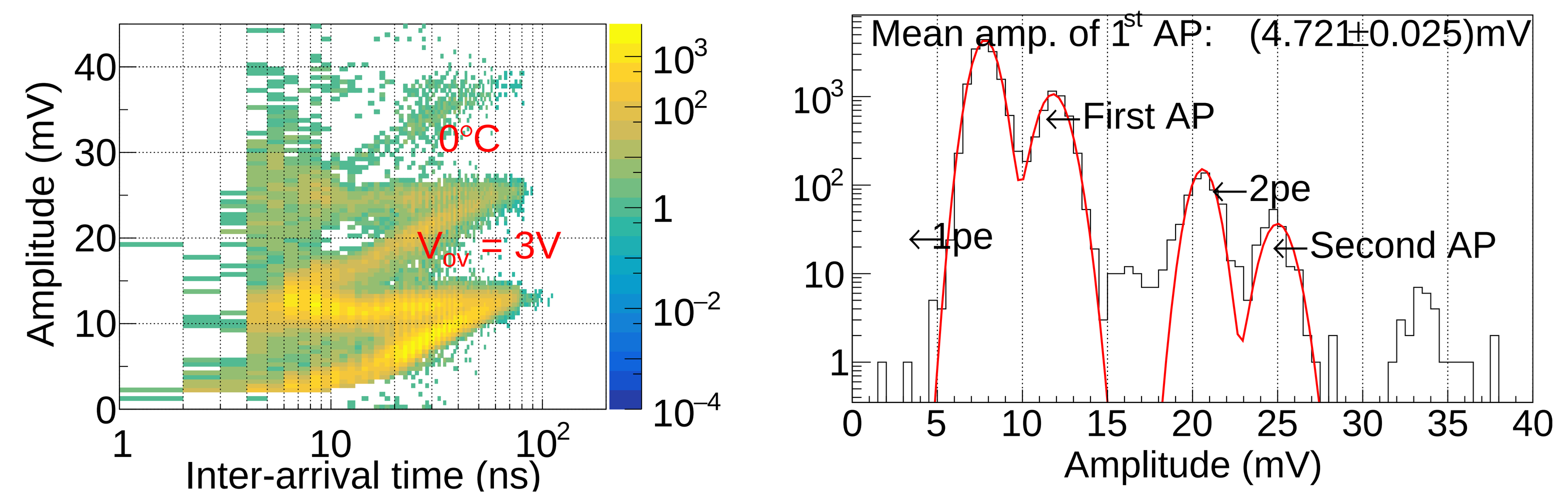
Amplitude of the second pulse versus the inter-arrival time plots for different temperature at V_{ov}=3 V.



Inter-arrival time distribution for different temperature at V_{ov}=3 V to estimate the rates of correlated and uncorrelated noise.

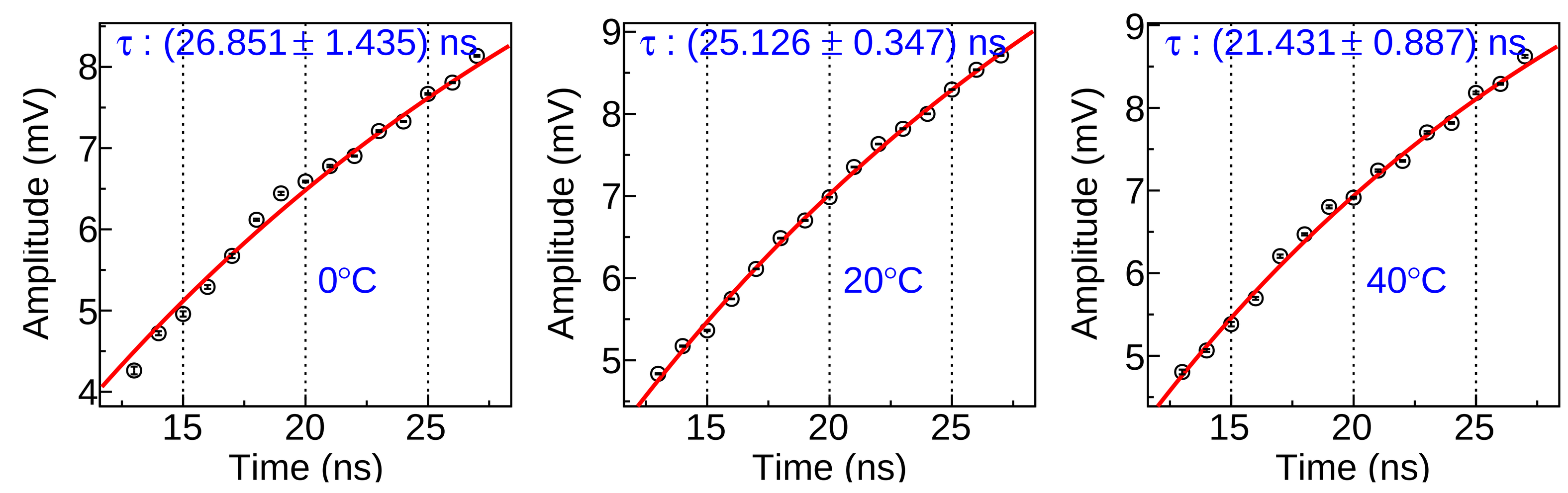
Recovery time w.r.t. temperature

A double pulse trigger was generated within a 80 ns window to collect the correlated events specifically. The recovery time depends on the quenching resistor and the junction capacitance. The variation in recovery time with temperature tells the effect of temperature variation on the quenching resistor and the junction capacitance.



Amplitude plot from the projection of 2D plots on the amplitude axis for Δt = (26 - 27) ns.

The mean and sigma of the first peak (1pe) and the third peak (2pe) are fixed and the four peaks are fitted with sum of gaussian functions. The mean value of the first afterpulse is estimated from the fit for different time bins.



Measurement of recovery time at V_{ov} = 3 OV for different temperature.

To estimate the decay constant, the distribution is fitted with the following function [2] :

$$f(\Delta t) = A \times \left[1 - exp\left(-\frac{(\Delta t - t_0)}{\tau}\right)\right]$$

where τ is the recovery time of the SiPM.

Conclusion

The overall increase in the x_{gap} values with increasing number of photoelectrons is yet to be understood. The recovery time varies from (21 - 27) ns with 40 degrees of variation in the temperature. To conclude, the temperature variation does not have any significant effect on the recovery time of the SiPM. We are simulating the signals for the better understanding of these observations by comparing the simulated events with the real data.

References

[1] HAMAMATSU MPPC (Multi-Pixel Photon Counter) datasheet, https://www.hamamatsu.com/eu/en/product/type/S13360-2050VE/index.html

[2] Mamta Jangra et al., Characterization of Silicon-Photomultipliers for a Cosmic Muon Veto detector, Journal of Instrumentation, 10.1088/1748-0221/16/11/P11029 **16** (2021) P11029.

Acknowledgements

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