Characterisation of Hamamatsu SiPM for cosmic muon veto detector at IICHEP

Mamta Jangra[1,2], Mandar N Saraf[2], Gobinda Majumder[2], B. Satyanarayana[2] and Suresh S Upadhya[2]

[1] Homi Bhabha National Institute, Mumbai, Maharashtra.
[2] Tata Institute of Fundamental Research, Mumbai, Maharashtra.

E-mail: mamta.jangra@tifr.res.in

Abstract. A test setup is built to characterise the SiPM and to measure muon detection efficiency of an extruded plastic scintillator detector. In the setup, light from the scintillator is readout by SiPMs using two embedded Wavelength Shifting Fibres (WLS) fibres. The SiPM was calibrated using LED source, but alternate calibration procedures using radio-active source as well as noise data were also established. The SiPM is studied at various over voltages (V_{ov}) and determined the operating V_{ov} by optimising the muon detection efficiency and noise rate. The muon position along the length of the scintillator is measured using timing information from both sides of the fibres. Results from our characterisation studies of SiPM ($2mm \times 2mm$, Model S1330-2050VE), e.g. after pulse, cross-talk, recovery time etc. will be discussed in this paper.

1. Introduction

The cosmic ray muon flux on earth's surface is $\sim$ 1 muon/cm^2/s[1] and thus constitutes a huge background for experiments looking for rare event phenomena. Setting up an experiment underground at a depth of $\sim$ 1 km will reduce cosmic muon background by a factor of 10^6 and a shallow depth of $\sim$ 100 m will give a suppression factor of 10^2. In order to attain a suppression factor of 10^6 at shallow depth of 100 m, an active cosmic muon veto detector is needed with veto efficiency >99.99%. A miniature version of the Iron CALorimeter (ICAL) experiment at the India-based Neutrino Observatory, mini-ICAL is operational at Madurai, India. Mini-ICAL consists of an 85-ton magnet built using 11 layers of 5.6 cm thick soft iron plates and 10 layers of $2\,m \times 2\,m$ glass Resistive Plate Chambers (RPCs). A Cosmic Muon Veto (CMV) detector on top of mini-ICAL is going to be made with extruded plastic scintillators with embedded WLS fibres to propagate light and SiPM as photon transducers.

2. Experimental setup

The tests discussed in this paper are performed using a ($60\,cm \times 5\,cm \times 2\,cm$) extruded scintillator strip with 60 cm long WLS fibre inserted into the holes throughout the length of scintillator. To mount the Counter Mother Board (CMB), an acrylic fibre guide bar is glued on both sides of the extruded scintillator strip. A total of 4 SiPMs are used to readout on both sides as shown in Fig. 1. SiPMs are powered using a Keithley sourcemeter (Model 2400) with a common bias of 51 to 57 V. Output is taken out via coaxial cables to oscilloscope as shown in Fig. 2.

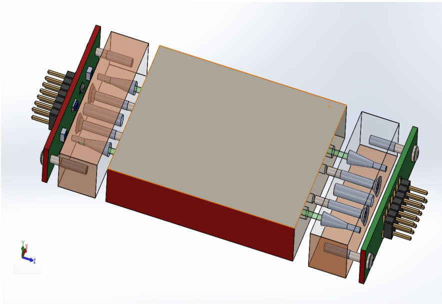

Figure 1. Scintillator counter schematic.

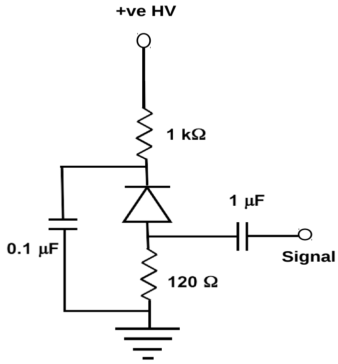

Figure 2. SiPM circuit diagram.

3. LED calibration

SiPM characterisation is done using an ultrafast LED driver (CAEN SP5601). The integrated charge is calculated using the equation :

$$Q = \frac{1}{R}\int_0^T V(t)dt \tag{1}$$

where R = 120 ohm as shown in Fig. 2. The function used to fit total charge is :

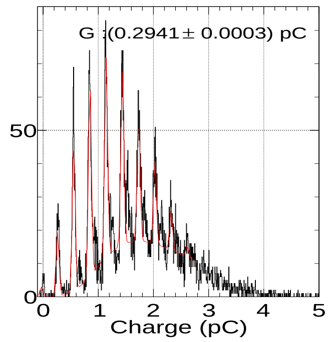

Figure 3. Photoelectron peaks at $V_{ov} = 3\,V$.

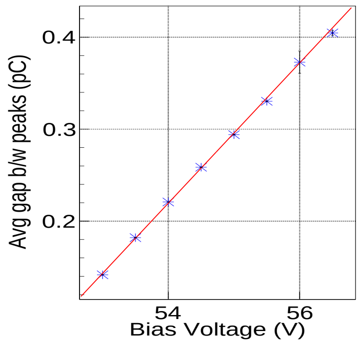

Figure 4. (a) Gain of SiPM as a function of bias voltage.

$$F(y) = Landau(y) + \sum_{a=0}^{N-1} R_a \times exp(-\frac{(y-a\mu)^2}{2\sigma^2}) \tag{2}$$

where N is the number of photoelectron (p.e.) peaks, R_a is the peak height, μ is the gain of SiPM and σ is the gaussian width of p.e. peak. There is a clear separation between p.e. peaks as shown in Fig. 3. Gain is calculated by determining the average gap between consecutive peaks from the fit which is shown in Fig. 4 as a function of bias voltage.

4. Calibration using noise data and radioactive source data

For noise data, a random trigger is generated using one of the SiPM channels and data from other SiPMs mounted on the extruded scintillator is collected. In case of radio-active source data, ^{22}Na is placed on top of the extruded scintillator. Trigger is generated in the same way as mentioned for noise data. Fig. 5 and Fig. 6 shows the total charge collected from noise data and radioactive source data respectively. Gain is calculated by noting the average gap between the consecutive peaks as it is done for LED data.

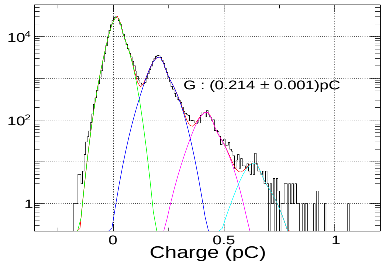

Figure 5. Photoelectron peaks at $V_{ov} = 3\,V$ from noise data.

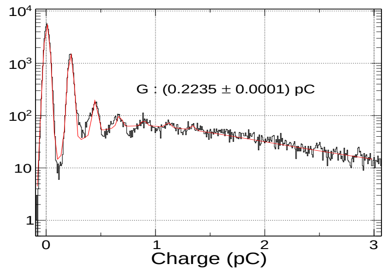

Figure 6. Photoelectron peaks at $V_{ov} = 3\,V$ from radio-active source data.

5. Optimisation of V_{ov} for SiPM operation

Noise data collection is done using random triggers as mentioned in the previous section. In the offline analysis, noise rates are calculated at different values of V_{ov} and at different charge thresholds. For cosmic data, coincidence technique is used to ensure that the muon has passed through the extruded scintillator strip. Cosmic muon efficiency is calculated at different values of V_{ov} and at different charge thresholds similar to noise rate calculation. By comparing noise rates and cosmic muon efficiency at different values of V_{ov}, it is decided to operate SiPMs at an overvoltage of (2-3) V for cosmic data.

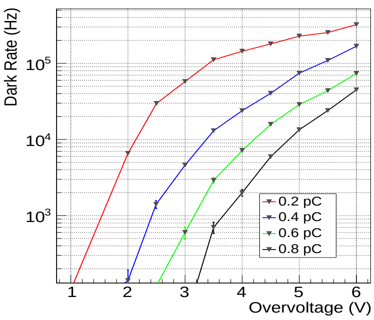

Figure 7. Noise rate in SiPM as a function of V_{ov}.

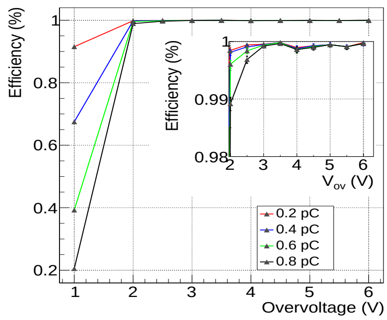

Figure 8. Cosmic muon efficiency as a function of V_{ov}.

6. Correlated noise

For measuring correlated noise rate i.e. afterpulse and crosstalk rates, amplified output waveforms from SiPM are stored using random triggers in a dark room[1, 2]. This measurement requires time difference between consecutive pulses and amplitude of second pulse as shown in Fig. 9. Correlated noise rates are measured by taking the difference between measured time values and extrapolated time values from fit as shown in Fig.10.

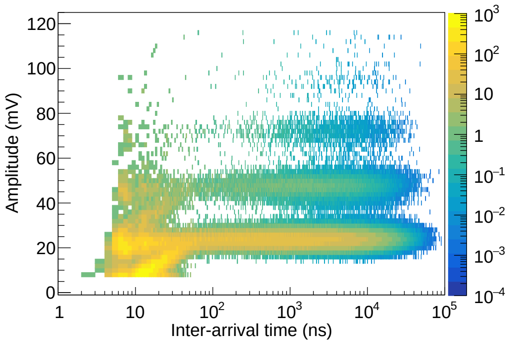

Figure 9. Amplitude versus time difference distribution at $V_{ov} = 3\,V$.

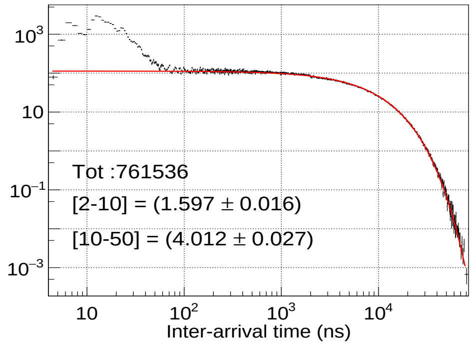

Figure 10. Correlated noise in log-log scale at $V_{ov} = 3\,V$.

7. Recovery time of SiPM

Recovery time is the time taken by SiPM to reset after an avalanche triggers. Data collection is done using a smart trigger on an oscilloscope at different values of V_{ov}. From the afterpulse slope as shown in Fig. 9, mean amplitude is measured for corresponding time values as shown in Fig.11 for V_{ov}=3.5 V. Variation in recovery time w.r.t V_{ov} is measured as shown Fig.12.

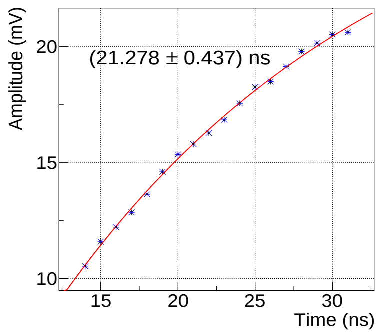

Figure 11. Amplitude versus time from afterpulse slope at $V_{ov} = 3.5\,V$.

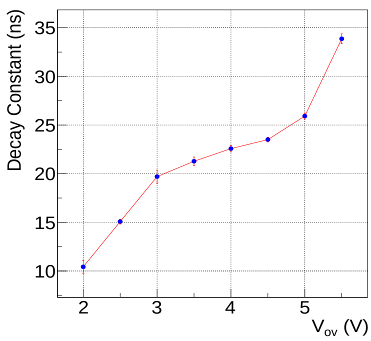

Figure 12. Variation in decay constant w.r.t. V_{ov}.

8. Conclusion

V_{ov} is a very crucial parameter for operating SiPM. Noise rate of SiPM and cosmic muon detection efficiency at different V_{ov} has been studied and an optimised value of V_{ov} is decided to be (2 - 3) V. Correlated noise is also studied and it is found to be (5 - 6)% of the total noise. Recovery time was found to vary between (10 - 35) ns for different V_{ov}.

Acknowledgements

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9. References

[1] Claudio Piemonte and Alberto Gola 2019 *Nuclear Inst. and Methods in Physics Research.* A **926** 2–15.
[2] Robert Klanner 2019 *Nuclear Inst. and Methods in Physics Research.* A **926** 36–56.