FERMILAB-CONF-21-851-V
17th International Conference on Topics in Astroparticle and Underground Physics IOP Publishing
Journal of Physics: Conference Series **2156** (2022) 012242 doi:10.1088/1742-6596/2156/1/012242

Characterization of the DUNE photodetectors and study of the event burst phenomenon

Alessandro Minotti, for the DUNE collaboration
U2, Universit degli Studi di Milano-Bicocca, Piazza della Scienza, 3, 20126 Milano MI
E-mail: `alessandro.minotti@unimib.it`

Abstract. The Deep Underground Neutrino Experiment (DUNE) is an upcoming neutrino physics experiment that will answer some of the most compelling questions in particle physics and cosmology. The DUNE far detectors employ silicon photomultipliers (SiPMs) to detect light produced by charged particles interacting in a large liquid argon time projection chamber (LArTPC). The SiPMs are photosensors consisting of an array of single-photon avalanche diodes (SPAD) operating in Geiger mode. Their high sensitivity and dynamic range, as well as the possibility to fill large surfaces with high-granularity sensors, makes them an ideal choice for DUNE. An international consortium of research groups is currently engaged in a systematic comparison of the performances of the SiPM models that have been custom developed for DUNE by two manufacturers. Such detailed studies, which include gain measurements and a structure study of the dark count rate at 77 K, are meant to determine the best choice of the photodetection system for DUNE, as well as characterize the response of the chosen detectors for the DUNE simulation. Moreover, an investigation of a newly observed phenomenon, in which quick bursts of tens of events at close range are collected in individual SiPMs, is being carried out, which potentially impacts the design of future models and their implementation in particle physics experiments.

1. Introduction

A Silicon Photomultipliers (SiPM) is a photosensor consisting of a large matrix of the order of 10^4 single-photon avalanche diodes (SPADs). Each SPAD is a p-n junction polarised inversely, working above breakdown tension V_{bd}, that produces a macroscopic current when hit by a photon due to the avalanche effect (Fig. 1). The main advantages of SiPMs lay in their great robustness, and in their high sensitivity and dynamic range. Furthermore, the reduced costs allow for easy scalability, while the small size ($\sim$cm^2) for high granularity. On the other hand, dark signals due to thermal generation of carriers and tunnel effect, the latter being the main mechanism at cryogenic temperatures, must be monitored.

The Deep Underground Neutrino Experiment (DUNE) is an upcoming neutrino physics experiment, based in the United States, that will answer some of the most compelling questions in particle physics and cosmology. The DUNE far detectors, where the bulk of its scientific programme is pursued, employ SiPMs to detect light produced by charged particles interacting in a large liquid argon time projection chamber (LArTPC). The highly-granular SiPMs will be incorporated in the internal structure of the DUNEs far detector Anode Plane Assembly (APA) and operate at LAr temperature [1]. The basic unit of the DUNE photon detection system (PSD) is the X-ARAPUCA, a light trap containing up to 48 SiPMs that are connected to a

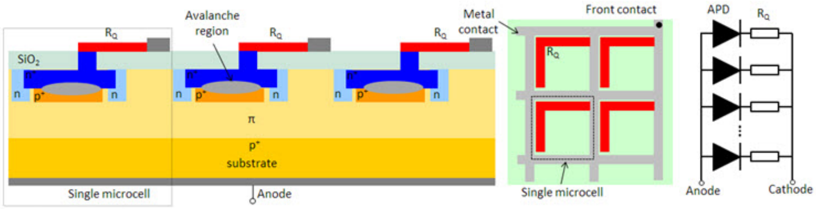

Figure 1. Operating principle of an SiPM.

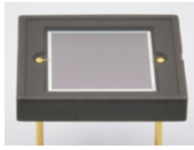

Figure 2. A ceramic packaging with lateral wire bonding SiPM.

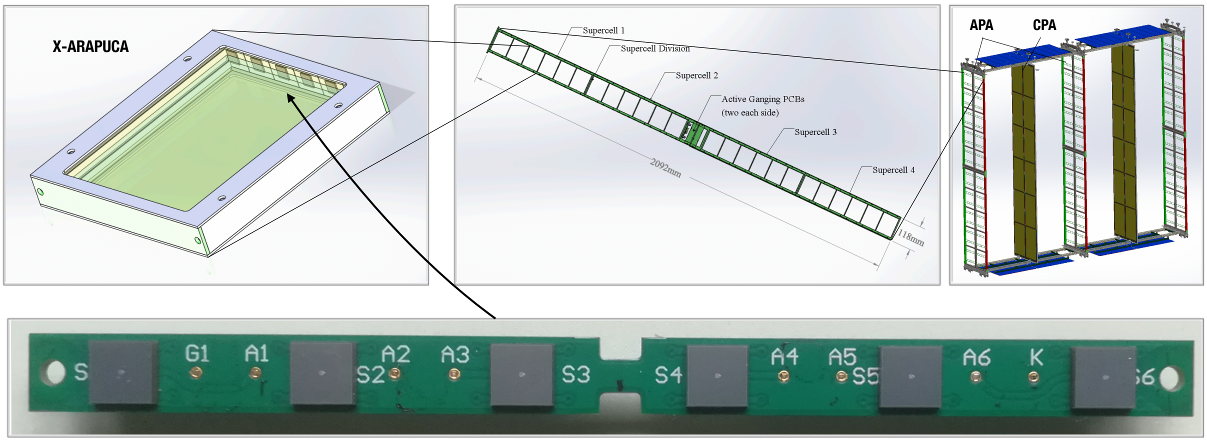

Figure 3. Photodetection system in the DUNE detector: 6 SiPMs are connected to the same electronic board; eight boards form the X-ARAPUCA light trap (the *supercell*, corresponding to one electronic channel); a PSD module consists of 4 supercells; the PSD modules are embedded in the DUNE Anode Plane Assembly (APA) structures.

common cathode (Fig. 3).

A consortium of laboratories from three different countries has been working on the characterisation of SiPMs that have been custom-made for DUNE by two vendors (Hamamatsu Photonics K.K. and Fondazione Bruno Kessler) in oder to select the best model for DUNE [2]. Main requirements for the photosensors are: high gain, large active area, sensitivity to single the single photoelectron (p.e.) in the UV region, resistance to thermal stress, and low dark current at cryogenic temperature ($< 100\,\mathrm{mHz/mm^2}$).

2. Characterization of the DUNE SiPMs

Two different setups are used to characterise the DUNE SiPMs (Fig. 4). In the first setup, the SiPM is placed in a dark box and connected to a SourceMeter to record the current-vs-voltage (IV) curves, both at room temperature and with the SiPM submerged in liquid nitrogen. From the IV curve recorded in reverse polarization we extract the breakdown tension V_{bd}, while the quenching resistance R_q is measured from the curve recorded in forward polarisation (Fig. 6).

The second setup consists of a power supply, a cryogenic amplifier, and an oscilloscope. The SiPM is in enclosed in a light-tight liquid nitrogen container together with the cold amplifier, and the dark events are recorded [3]. Three types of dark events can be observed (Fig. 5):

- dark current events, in which a single SPAD is firing, resulting in a 1p.e. amplitude peak;
- cross-talk events, in which more than 1 SPAD is firing, resulting in a 2 p.e. amplitude peak;

Journal of Physics: Conference Series **2156** (2022) 012242 doi:10.1088/1742-6596/2156/1/012242

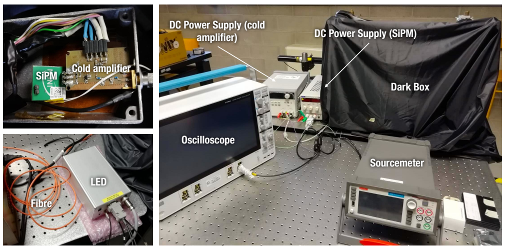

Figure 4. Setup used for the SiPM characterization. The SourceMeter is used to trace the IV curves, while the oscilloscope records dark signals.

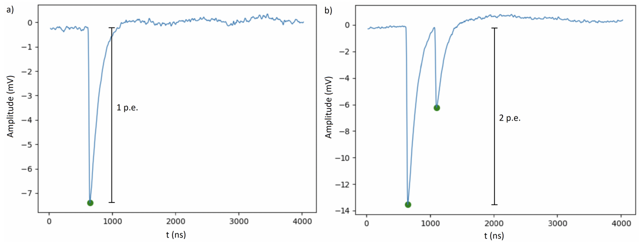

Figure 5. Typical signals recorded by an SiPM. On the left, a dark current event; on the right, a cross talk event (with double amplitude) followed by an after pulse.

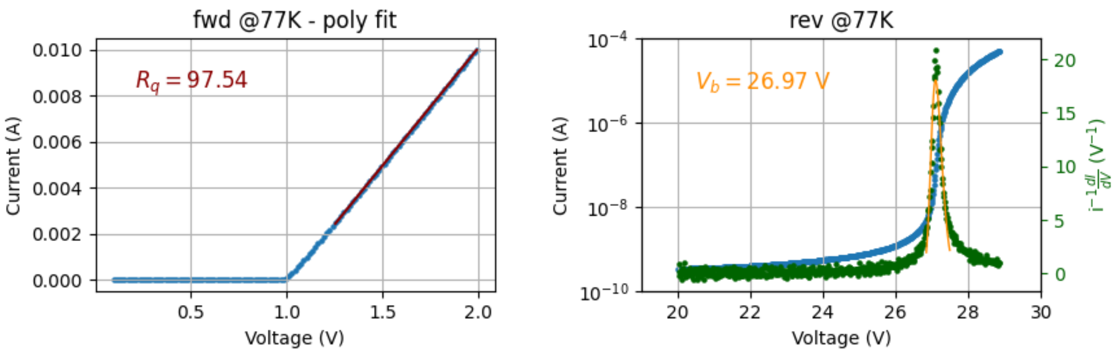

Figure 6. IV curves recorded in forward (left) and reverse (right) polarization. The R_q is extracted from the slope of the forward IV curve in the resistance region, while the V_{bd} corresponds to the saddle point of the forward IV curve.

- after pulse events, where the same SPAD is firing before being fully recharged, resulting in a < 1 p.e. peak following a ark current or a cross-talk event.

The dark events are studied in order to obtain a global dark count rate (DCR), which is compared with the goal specifications.

Finally, with the same setup, we use a LEP pulser to increase the signal and therefore measure the gain of the SiPM. All these measurements are repeated after the sensor is cycled between room and liquid nitrogen temperature for ~ 20 times, in order to test the SiPMs under thermal stress.

3. Results and Future Plans

The dark current plot (Fig. 7) shows the different signal recorded by a typical SiPM of the DUNE samples, tested in the darkness and cryogenic temperature. In addition to the expected dark current events due to tunnel effect, with $0.01 - 1$ Hz and 1 p.e. amplitude, the cross-talk events, with same frequency and higher amplitude, and the after pulse events, which immediately follow ($10^{-8} - 10^{-6}$ s) another event, we observe another distribution of correlated events with a $10 - 100$ mHz rate. These *bursts* of ~ 100 correlated events are typically triggered by a high-amplitude event (Fig. 8); they contribute to a fraction of the total DCR, which is still well within specifications for all studied models. Such novel phenomenon has been studied in details in [4]; further investigation is ongoing.

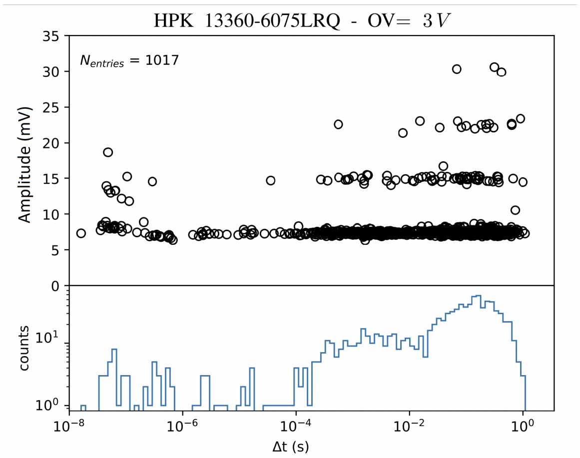

Figure 7. Events recorded in the dark at cryogenic temperature for an SiPM, in terms of amplitude vs time distance from the previous event.

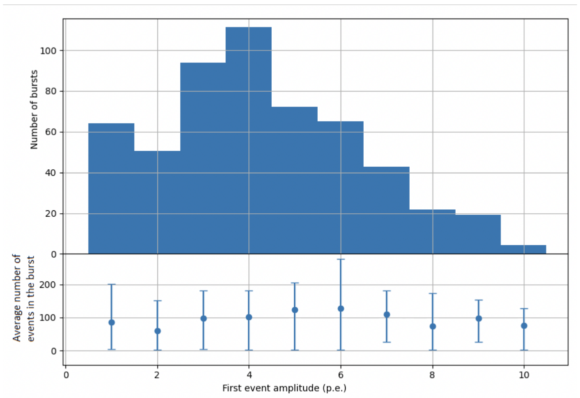

Figure 8. Number of observed bursts (top) and number of events per burst (bottom) as a function of the amplitude of the first event of the burst.

We studied different models of SiPM that were custom-made for the DUNE experiments, and concluded that all models fulfil the specifications in terms of gain, dark current ($\sim 10\,\mathrm{mHz/cm^2}$), and stability. The consortium succesfully down-selected one best model for each vendor. The down-selected sensors provide the best signal-to-noise at 1 p.e. once the SiPMs are connected in groups of 48. Currently, we are preparing for the mass test of the proto-DUNE phase-II SiPMs ($\sim$ 8000 photosensors) starting in late 2021 and, later, for the DUNE production ($\sim$ 288000 photosensors), which will be performed by means of dedicated systems.

References

[1] B. Abi et al. [DUNE Collaboration], 2020 JINST 15 T08010
[2] A. Falcone et al 2021 Nucl. Instrum. Methods Phys. Res. A 985 164648
[3] P. Carniti et al. 2020 JINST 15 P01008
[4] M. Guarise et al 2021 JINST 16 T10006