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Characterization of SiPM for the photodetection system of DUNE far detector

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Summary. — Inside a Liquid Argon Time Projection Chamber the process which leads to the collection of scintillation light over a large area into a compact space is a challenging one. In this scenario, a Photon Detection System able to minimize its impact on the active volume of the Liquid Argon plays a crucial role. In the first module of the DUNE Far Detector, traditional photomultiplier tubes will not be used due to space reasons. Instead of them, sensors with reduced size are forseen: the Silicon Photomultipliers (SiPMs). These SiPMs will be placed in a cryogenic environment in extreme working condition. For this reason, a test campaign aimed to characterized and select them has been conducted. In this paper the preliminary results obtained during the first tests are reported.

1. – The DUNE experiment

The Deep Underground Neutrino Experiment (DUNE) is an international future project focused on studying neutrino physics, located in the U.S.. It will be designed as a long baseline experiment consisting of a Far Detector (FD) and a Near Detector (ND). While the ND will be housed at FermiLab, the FD will be located underground at the Sanford Lab in South Dakota, at a distance of $\sim$ 1300 km. Purpose of the experiment will be to study the still open questions of neutrino physics, as: i) determing a mass ordering, ii) studying a possible CP violation in the leptonic sector, iii) testing the three-flavour neutrino oscillation paradigm [1].

1·1. *The Far Detector*. – The FD will consist of four Liquid Argon Time Projection Chamber (LArTPC) detector modules. They will be installed at a depth of $\sim$1.5 km and have a mass of 17 kt. Each LArTPC will be inserted in a cryostat module filled with Liquid Argon and serves as a target for the neutrino interactions. The design of the first LArTPC module will use the Single Phase technology. Charged particles produced

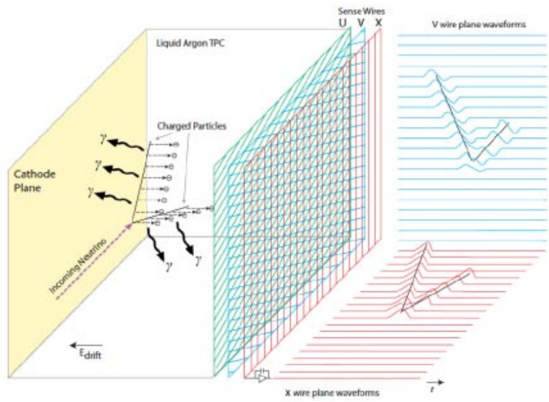

Fig. 1. – Neutrino interaction in a Single Phase LArTPC.

by neutrino interactions in liquid argon induce scintillation and ionization. In a Single Phase Time Projection Chamber (SP TPC), ionization electrons are drifted up through the detector volume under the influence of an electric field towards the anode, where they are read out (fig. 1). The process develops on a time scale of the milliseconds. The DUNE's SP LArTPC module will be instrumented with two cathode planes and three anode planes. The topology of neutrino interaction vertex is reconstructed in the SP LArTPC: two of the three spatial coordinates (y and z) are established from the position of the fired wires in the Anode walls, while the third one is obtained by the arrival time of the charge. The t_0 of the event is given by the scintillation light produced by the LAr excitation and collected by the PhotonDetection System (PDS).

2. – The Photon Detection System

The Photon Detection System of the first module of the FD will be embedded in the anode walls. Its modular unit is the Anode Plane Assembly (APA) in which, by means of slots, the Photon Detection modules will be located. The PD modules will make use of light collectors coupled with photomultipliers. In order to reduce the impact of the PD system on the active volume of LAr while maximizing the light collection efficiency, traditional large area photomultipliers tubes (PMT) will not be used. For the PD system of the DUNE Far Detector, the solution adopted will be to select sensors with small surface but high efficiency and mounting them inside the inactive space of the Anode Plane Assembly structure. The process which leads to the collection of scintillation light over a large area in a compact space is composed of different steps. First of all, the scintillation photons emitted by the LAr de-excitation are Vacuum-Ultra-Violet (VUV) photons with $\lambda \sim$127 nm, which implies the necessity of a conversion to longer wavelenghts to which the photonsensors are sensitive. This conversion occurs inside the light collector elements composing each PD module. The photons are then directed, as efficiently as possible, to photosensors able to convert the collected charge into electrical signal. Traditional photomultiplier will not be used because of space constraints reasons, while Silicon Photomultipliers (SiPMs) will be the best choice for the DUNE's PD system thanks to their dimensions of few millimiters. The specific design for the PD light collector module, is called X-ARAPUCA [3]. It consists of cells which act as light trap and captures photons

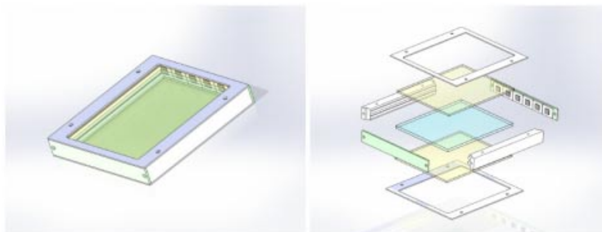

Fig. 2. – Design of the X-ARAPUCA cell.

inside boxes with highly reflective internal surfaces (fig. 2). The photons are then collected by Silicon Photomultipliers (SiPMs) located on the long side of each PD module. A PD module is composed of four X-ARAPUCA supercells, the SiPMs are mounted in group of six to PCBs, called "photosensor mounting boards". The arrays are installed on two of the narrow sides of the cell perpendicular to them. The total number of SiPMs which will be used for the Far Detector PD system will be of the order of ∼300000. Given this large number of sensors working at cryogenic temperature, an accurate selection and characterization of the SiPMs is envisaged. A massive test campaign has been started with this purpose.

3. – DUNE SiPMs

DUNE SiPMs need to satisfy some scientific requirements, such as: a good mechanical and electrical integrity in a cryogenic environment, single photoelectron sensitivity, a uniformity in their characteristics in order to ensure a uniformity in the response of the PDS and a design able to minimize the number of readout channel of the experiment. All the sensors for the first module of the Far Detector will be produced by two vendors: the Hamamatsu Photonics K. K. (HPK) and the italian Fondazione Bruno Kessler (FBK). A first preselection has been conducted at single SiPM level. In this phase, a first batch of 25 samples of different typology has been produced. The sensors were differing mainly in number of cells per SiPM and technology used [2]. Subsequently, a second batch of 250 samples has been produced. This time the SiPMs were ganged in arrays, in group of six on a same PCB with common cathode and ground but individual anode pins (fig. 3).

4. – Characterization protocol and setup

A campaign of tests for the validation of the arrays has been conducted following a protocol shared by the Photon Detection System Consortium. The measurements performed included: I-V curves at room and cryogenic temperature per each sensor of

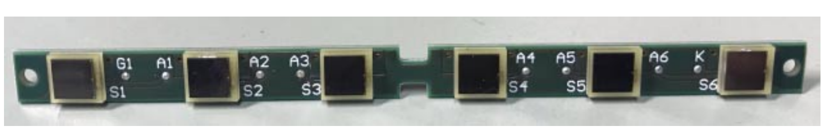

Fig. 3. – Array of SiPMs.

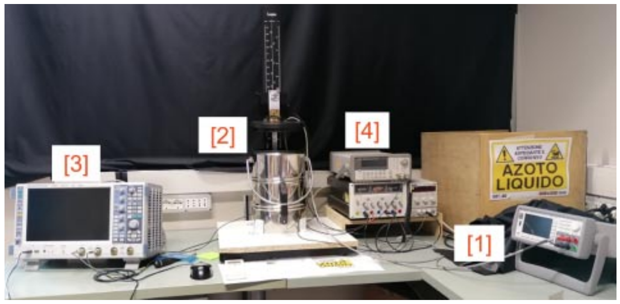

Fig. 4. – Setup used: 1) sourcemeter unit to obtain the I-V curves, 2) 6 liter dewar instrumented with a temperature sensor, 3) oscilloscope for the DCR measurements, 4) power supply.

the array, thermal stress tests to validate the robustness of the packaging in a cryogenic environment and measurements of Dark Count Rate (DCR) for 5% of the samples. A specific setup was developed (fig. 4).

5. – Validation test and results

To test the resistance of the packaging in a cryogenic environment, all the sensors were subjected to thermal stress tests. Each array have been tested through cycles of submersion and emersion in Liquid Nitrogen (LN). A single thermal cycles, $\sim$ 27 minutes long, were divided into different phase (fig. 5). As requested from the protocol, a total sequence of 20 cycles ($\sim$ 8 hours) has been performed per each array. After the procedure, no mechanical or electrical damage has been reported for any of the sample tested. From the measurements of the I-V curves, it has been possible to obtain the value for the quenching resistance and breakdown voltage of each SiPM of the arrays.

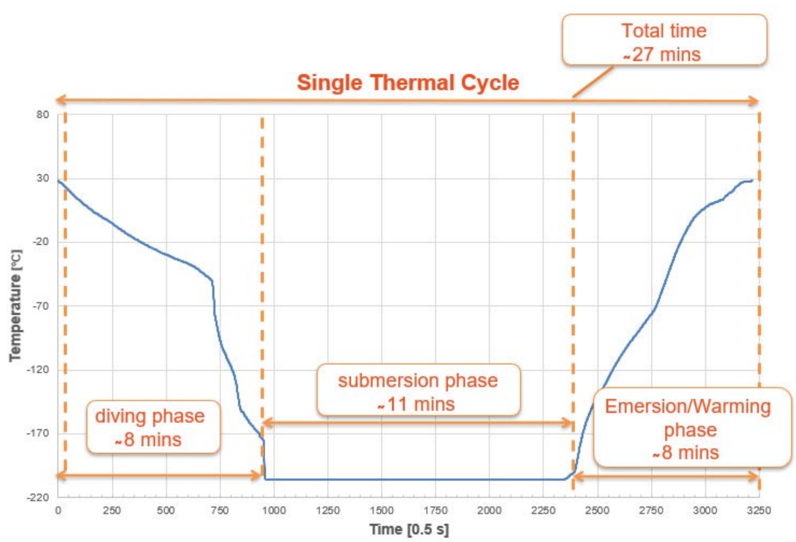

Fig. 5. – Thermal profile of a single cycle for the stress test.

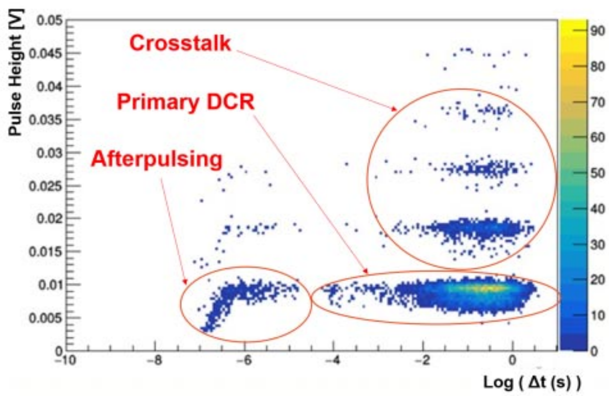

Fig. 6. – Bidimensional plot of the distribution of signal amplitudes as a function of their time difference.

This values have been obtained both before and after the thermal stress tests and, at a first analysis, it appears that the main characteristics of the samples did not change due to the procedure. Moreover, a general uniformity in the features of the sensors has been found over all the samples tested. The Dark Count Rate (DCR) has been measured in Liquid Nitrogen and absence of light. A trigger threshold of 0.5 p.e. was set and a preamplification stage for the SiPM signal output used. All the DCR values obtained resulted lower than 100 mHz/mm^2, satisfying some experiment requirements. From the DCR, a study of the correlated noise was conducted. The bidimensional plot shown in fig. 6, reports the distribution of signal amplitudes as a function of their time difference. In it, it is possible to identify different region of events, correspondent to different sources of noise.

6. – Conclusions

The characterization of SiPMs for the DUNE experiment has been conducted during a test campaign aimed to validate them. During this phase of tests a specific setup for the measurements requested has been developed. All the samples thermally tested showed a good mechanical integrity and unchanged features. A uniformity in their characteristics has been observed. These results are both in compliance with the experiment requirements. A next phase of tests foresees the production of $\sim$ 4000 SiPMs per vendor and a massive test validation campaign. A new semiautomated setup necessary is currently under development.

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