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AIDAinnova

Advancement and Innovation for Detectors at Accelerators

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MILESTONE REPORT

LARGE-SCALE WLS SURFACES AND SIPMS TESTED

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Abstract:

This task focuses on innovation in scintillation light readout in large liquid argon detectors, covering the development of light collection readout methods: photo-sensors and electronics, new wavelength shifting methods and light calibration. The goals of this task are the characterisation of the new photon detection methods, calibration devices and readout electronics in dedicated test-stands; the implementation and characterisation of a more efficient light collection system in large liquid-argon detectors (based on Xe doping and WLS coated reflective foils); the dissemination of R&D results and light-collection performance. This document reports on tests performed using facilities at INFN-MiB, CIEMAT and the 50 l facility at the CERN Neutrino Platform.

For more information on AIDAinnova, its partners and contributors please see http://aidainnova.web.cern.ch/

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Table of Contents

1. INTRODUCTION 4

2. ACTIVITIES AND RESULTS 4

2.1. SIPM DEVELOPMENT AND TESTS 4
2.2. ENHANCED WLS AND X-ARAPUCA SYSTEM 7
2.3. LARGE AREA WLS-REFLECTOR TESTS 8

3. REFERENCES 9

ANNEX: GLOSSARY 10

Executive summary

Task 9.4 focuses on innovation in scintillation light readout in large liquid argon detectors, covering the development of light collection readout methods: photo-sensors and electronics, new wavelength shifting methods and light calibration. This milestone reports on the tests of Silicon Photo-Multipliers (SiPMs) performed for the ProtoDUNE II detector at CERN in dedicated facilities at INFN-MiB and CIEMAT. In addition, we report on tests of large area WLS components used to enhance light collection inside of the large-area X-ARAPUCA light traps (INFN-MiB), as well as a large area s WLS surfaces to enhance passive light collection efficiency using the CERN Neutrino Platform 50l prototype.

1. INTRODUCTION

The cryogenic neutrino detector WP focuses on innovative developments of readout technologies, both in terms of charge readout, with pixels or in dual-phase detectors as well as readout of scintillation light. The main applications are in the near and far DUNE LAr detectors, but the results will also be of general interest for dark matter experiments and other applications of noble liquefied gas detectors. Task 9.4 focuses on innovation in scintillation light readout in large liquid argon detectors. The task will cover the development of light collection readout methods: photosensors and electronics, new wavelength shifting methods, and light calibration. The goals of this task are the characterization of the new photon detection methods, calibration devices, and readout electronics in a CERN test stand; the implementation and characterization of a more efficient light collection system in ProtoDUNE phase II; the dissemination of R&D results and ProtoDUNE II light-collection performance.

Scintillation light is an important part of the development of liquid-argon neutrino detectors. It enhances the capability of detecting low-energy astrophysical neutrinos, such as coming from supernovae and the Sun, enhances the calorimetric reconstruction and improves cosmic-ray background rejection in detectors placed on the surface. To perform these tasks the light collection in the detectors must be as good as possible, however taking into account the needs in terms of size, electronic channel numbers, power consumption, and functioning at low temperatures of large-scale liquid argon detectors such as DUNE. This has led to the choice of using silicon Photomultipliers (SiPMs) together with light collector traps called X-ARAPUCAs. Similarly, an important component of large liquid argon detectors are the wavelength-shifting compounds needed to change the liquid argon light emitted at 128 nm to visible wavelengths detectable by most SiPM detectors. Milestone MS40 reports on to the development and characterization of SiPMs in liquid argon to be installed in the ProtoDUNE II detector at CERN, together with the development of novel WLS materials to enhance light collection both inside of the light collectors as well as passive detector components.

2. ACTIVITIES AND RESULTS

2.1. SIPM DEVELOPMENT AND TESTS

The development of novel SiPMs is a complex task, which is performed in collaboration with foundries and research centres. AIDAinnova leverages the investment and efforts of the DUNE collaboration with two major SiPMs producers: Hamamatsu Photonics and Fondazione Bruno Kessler. This common effort has brought to two new cryogenic sensors (HPK S16517 and FBK NUV-

HD-CRYO-TT) that have been designed for use in liquid argon. In the first two years of the project, CIEMAT and INFN-MIB have demonstrated:

- That the custom sensors fulfill the main specification for operation in liquid argon
- That these sensors are appropriate for use in cryogenic light trapping systems like the X-ARAPUCA system to be implemented in ProtoDUNE II

Both CIEMAT and INFN-MiB have implemented a test stand (see Fig. 5) and a protocol to validate the cryo-reliability of the SiPMs. Accelerated aging tests were performed using thermal cycling by CIEMAT and INFN-MiB for >200 SiPMs of each type in 2022 (see Fig. 2 for example of setup and Fig. 1 for example single electron response spectrum used in signal/noise measurements). In 2021-22, INFN-MIB has carried out also accelerated aging tests of the front-end electronics that are employed to readout SIPMs in a group of 48 ("ganging mode") (see Fig. 3 for the testing set up). Both CIEMAT and INFN-MIB have tested SiPMs in standalone mode and embedded in ProtoDUNE II X-ARAPUCAs.   The system is now installed in ProtoDUNE II and ready for cooling.

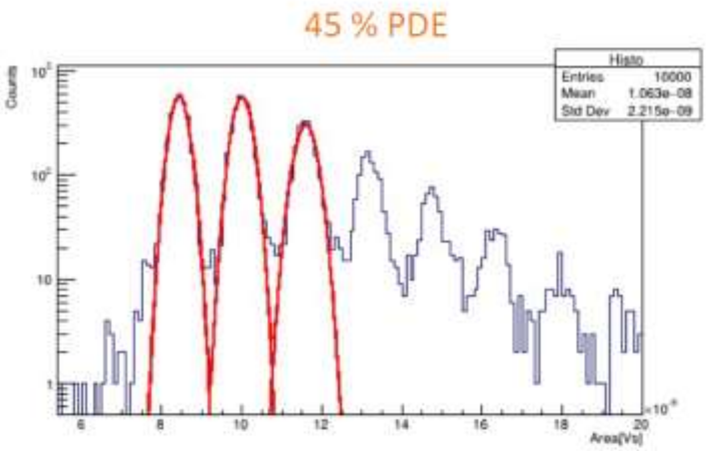

Figure 1 S/N measurements of FBK SiPMs at INFN-MiB

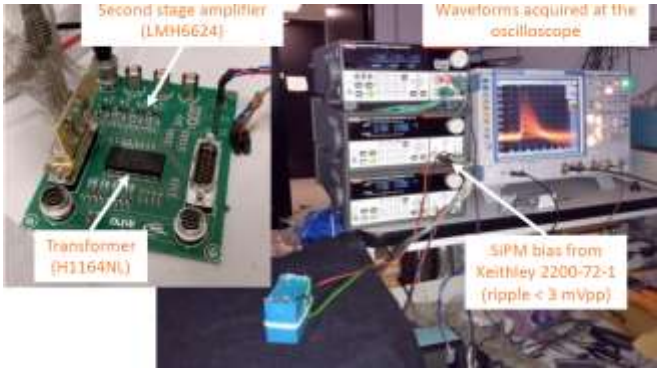

Figure 2 SiPM characterization at INFN-MIB

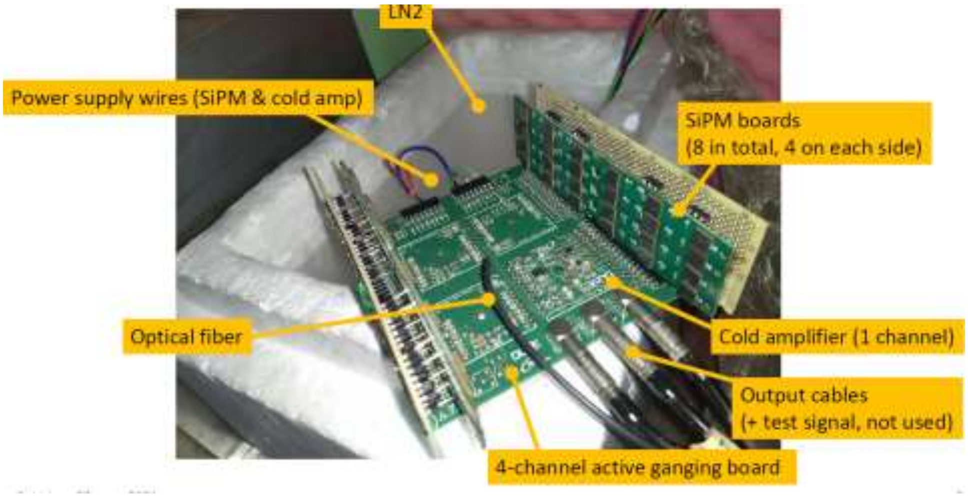

Figure 3 SiPM test setup in INFN-MiB to assess the ganging performance

In parallel INFN-MiB has pursued the functional tests at cold temperature and the characterization of the chosen HPK SiPMs mounted on flex Kapton circuits in term of cryo-resilience at about ten cooling/warming cycles, measuring signal-to-noise ratio and dark count rate. The two flex circuits equipped with 24 HPK-SiPMs have been embedded in an X-Arapuca device with a G2P-WLS with cylindrical dimples laser cut at the edges to host the SiPMs (see Fig. 4). They are ganged by the cold amplifier located at the top of the X-Arapuca supercell (not visible in the picture). The measured S/N is 7.6 at 45% of the SiPMs PDE and the DCR at the level of 1 kHz. This value is on the upper side of the S/N values measured for the 17 HD X-ARAPUCA supercells equipped with G2P&HPK SiPMs, whose average S/N was 6.7: a total of 48 supercell equipped with FBK or HPK SIPMs and Eljin or G2P WLS have been tested at INFN-MiB in 2022 prior their installation in ProtoDUNE-II.

No SiPMs detached from the flex circuit Kapton PCB, and the circuits safely survived fast cooling and warming cycles.

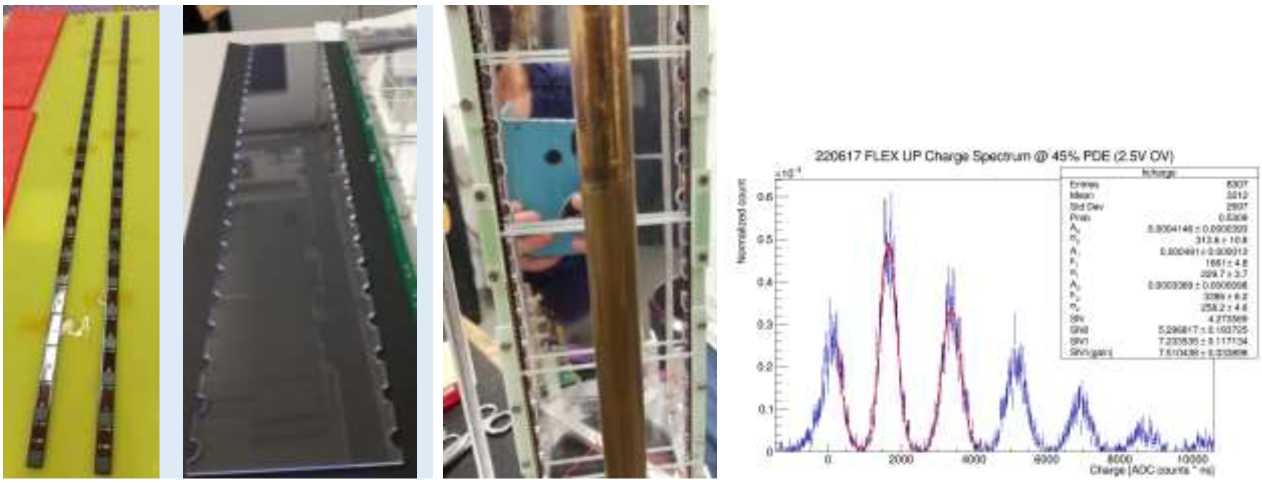

Figure 4: The two flex circuits populated with HPK SIPMs, the dimpled WLS, the X-Arapuca supercell equipped with these and the S/N plots achieved during a nitrogen test.

Figure 5 Test stand at CIEMAT and INFN-MIB for the X-ARAPUCA of ProtoDUNE II

2.2. ENHANCED WLS AND X-ARAPUCA SYSTEM

Another ongoing activity is geared towards enhancing the further development of the X-ARAPUCA light detection system of DUNE, with the aim of testing it in ProtoDUNE II. This activity exploits novel materials, with the aim of increasing the performance of the system to meet the increased specifications needed for application in the second DUNE module (FD2-Vertical Drift) and its demonstrator (ProtoDUNE-VD). INFN-MIB has engineered a new WLS material in a PMMA substrate with Glass-to-Power (G2P, Rovereto, Italy) (see Fig. 6) which can be produced in large area sheets needed by the DUNE-VD detectors. The G2P WLS bars were employed for half the modules of ProtoDUNE-II and tested in CIEMAT and INFN-MIB using a dedicated test stand. The bars have shown a significant increase in the light yield and in the photon detection efficiency (PDE) of an X-ARAPUCA device with respect to commercial products and have been chosen as the standard material for the ProtoDUNE-VD X-ARAPUCAs

Figure 6 WLS prototypes for ProtoDUNE-VD

2.3. LARGE AREA WLS-REFLECTOR TESTS

WLS compounds can also be used to enhance light collection by using them to line the walls of the detector. In this case light can be wavelength-shifted and reflected to be detected by the Photon Detectors. This is a technique used in liquid noble gas detectors, but applications in large-scale detectors such as DUNE require methods to scale the WLS surfaces up. The compound most often used is tetra-phenyl butadiene (TPB), however it is difficult to deposit on large scale surfaces. A recently proposed alternative are polyethylene-naftalate (PEN) films, which can be produced at larger areas with much more ease. However, so far measurements of PEN have been performed in small scales and have shown lower conversion efficiency than TPB. In collaboration with groups from AstroCenT, University of Zurich, NiKHEF and Technisches Universitaet Munich, we have performed a test of large-scale PEN WLS sheets using the 50l facility at the neutrino platform at CERN. PEN has been shown to work at this large scale – the analysis of these results is in progress. Fig. 7 presents the prototype detector and one of the first light signals showing the performance of PEN in liquid argon.

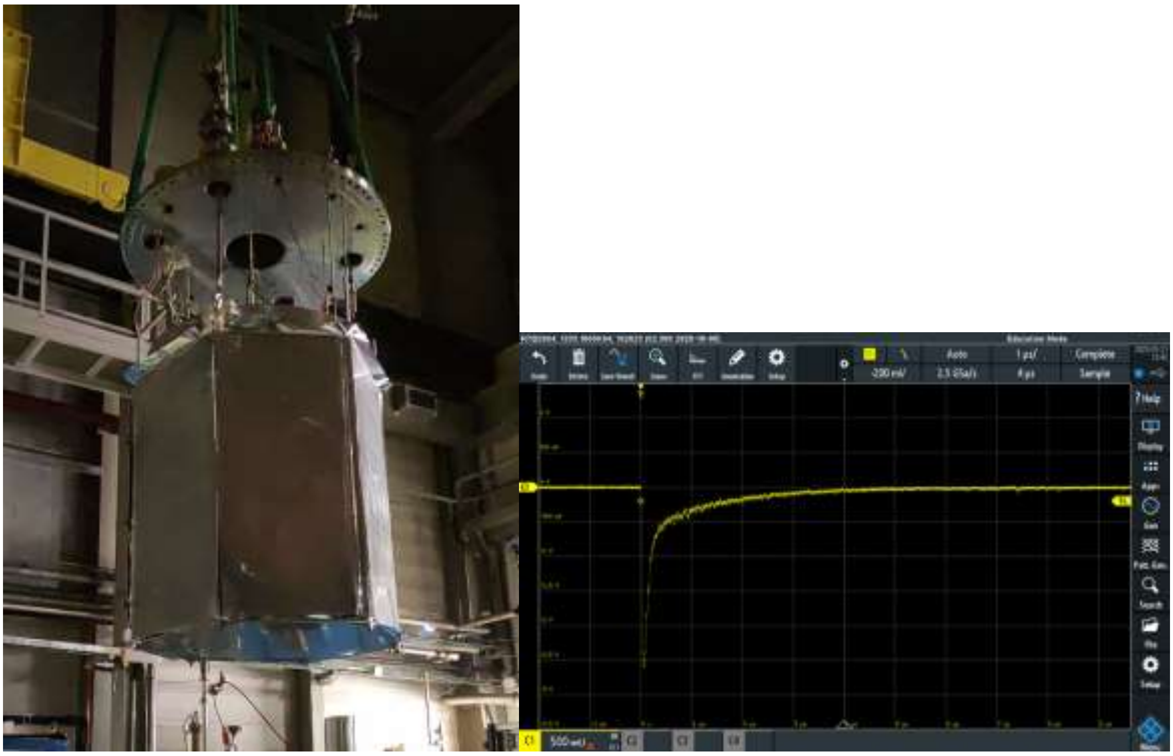

Figure 7 The large scale inner detector lined with PEN WLS foils. (right) one of the first signals registered by the detector PMTs.

3. REFERENCES

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ANNEX: GLOSSARY

Acronym	Definition
DUNE	Deep Underground Neutrino Experiment
FD-2	FD-2 Second DUNE Far Detector module (15 kton active LAr mass
LAr	Liquid Argon
PEN	Polyethylene Naphtalate
PDE	Photon Detection Efficiency
SiPM	Silicon Photomultiplier
TPB	Tetra Phenyl Butadiene
TPC	Time Projection Chamber
VD	Vertical Drift
WLS	wavelength-shifter