

The design of the optical modules of the KM3NeT-Italia project towers

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Abstract. The KM3NeT-Italia project aims to construct a large volume underwater neutrino telescope, to be installed in the depths of the Mediterranean Sea. The R&D and mass production phases of the detection elements of the telescope, the optical modules, were entirely performed in the INFN-LNS site in the harbour of Catania. In November 2014 a first tower of 14 storeys equipped with 84 optical modules was successfully deployed in the Mediterranean Sea site. The design of the optical modules and their main components are described in this paper.

1. Introduction

The main goal of an high-energy neutrino telescopes is the study of the Universe by observing extremely high-energy neutrinos (10^{11} – 10^{16} eV). The most suitable technique to perform such measurement is to instrument large volumes of water in order to detect the Cherenkov radiation emitted by the secondary muons and hadrons produced in the neutrino interactions with the matter surrounding the detector. This faint light can be detected by means of a three-dimensional array of optical modules (OMs), systems composed by high-sensitive photodetectors integrated into transparent pressure-resistant vessels. The KM3NeT-Italia project, PON 2007–2013 by the Italian Ministry of Education, University and Research (MIUR), aims to deploy a deep sea neutrino detector off shore the Mediterranean coast of Sicily at about 3500 m of depth, connected to the ground station in the harbour of Capo Passero through a 100-km electro-optical cable. The detector will be composed of 8 towers spaced by a mean distance of 120 m. Each tower has 14 storeys, 8m-long, interleaved vertically by 20 m plus a tower base module. In each storey will be hosted 6 optical modules, tilted vertically and horizontally at each extremity and in its centre 45° downwards. In November 2014 a first tower of 14 storeys equipped with 84 OMs was successfully deployed in the Mediterranean Sea site, at a depth of over 3500 meter, and now it is running in data taking. The optical modules R&D and production phases were entirely performed in the INFN-LNS site in the harbour of Catania. The design and the main components of the optical modules are described in this paper.

2. The optical module main components

The key detection element of an underwater Cherenkov detector is then the “optical module”. The mean intensity of the Cherenkov light signal, which arrives at each OM in water, could

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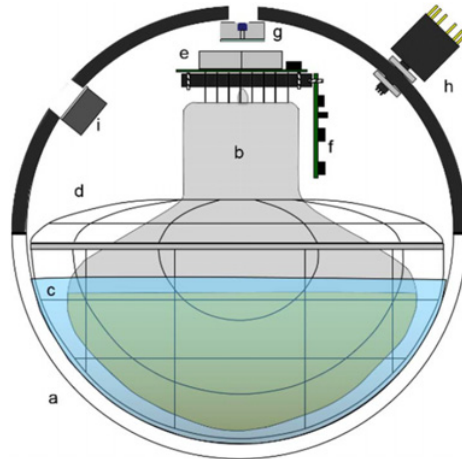


Figure 1. A schematic drawing of the optical module components: (a) 13-inch glass sphere; (b) 10-inch photomultiplier; (c) optical gel; (d) mu-metal cage; (e) base voltage supply; (f) Front End Module (FEM) board; (g) LED beacon system; (h) 8-pin connector; (i) manometer.

be low as few photons, and so optimization of the photon sensitive is therefore mandatory. Among the main requirements, the optical coupling between the water and the photodetector has to be optimized, the influence of the Earth's magnetic field must be minimized, the electronic power supply board and the electronic front-end must be installed inside the OM vessel and all the components must be highly reliable. Indeed, the neutrino telescope lifetime must be higher than 10 years.

Figure 1 shows schematically the main components of the optical module, designed following the experience of the successfully phase 1 and phase 2 of the NEMO project [1, 2].

Each optical module is hence composed by a transparent pressure-resistant vessel, which works as water and pressure protection ensuring a good light transmission. The vessel must have capability to withstand hydrostatic pressure, up to 400 atm, and a transparency to photons in the 350–600 nm wavelength range, with a refractive index that ensures a good optical matching between the sea water and the photodetector hosted inside. A 13-inch spherical deep-sea vessel made in borosilicate glass, produced by Benthos® [3] was selected. Each glass sphere is composed by one transparent hemi-spherical halve that hosts the photodetector, and by a second halve painted in black to stop the photons impinging from the back. Into the back black hemisphere a pressure gauge is glued to monitor the pressure inside the OM and a 8-pin SEACON® feedthrough is also mounted, which provides electrical connections (see Fig. 1). The selected photodetector was a Hamamatsu [4] large area photomultiplier (PMT) type R7081. It has 10-stages and a 10-inch bialkali photocathode with a typical surface around 500 cm² and a quantum efficiency of about 25% at 400 nm wavelength. This photomultiplier was selected for its low dark count rate, typically less than 3 kHz at a threshold 1/3 of single photoelectron threshold, good time resolution, with a transit time of about 3 ns as FWHM and for its good charge properties, such as the high gain, over 5×10^6 with a voltage less than 1800 volt, a peak to valley ratio over 2 and a charge resolution of about 40% as sigma.

The high voltage system is a PHQ7081-i-2m integrated active board produced by ISEG® [5]. Damping resistors properly designed were added to the last output stages to minimize the ringing effect on the anode signal. The Cockroft-Walton scheme requires only

a low voltage supply (+ 5 Volt), with the advantages of reducing power consumption and making very compact the design.

As confirmed by several studies [6], the performance of a large area PMT are significantly affected by its orientation with respect to the Earth's magnetic field. Therefore, the use of a magnetic shield is mandatory. The passive magnetic shield adopted is a cage made of 1 mm-diameter mu-metal wire, a nickel-iron alloy with high magnetic permeability. The cage, produced by ITEP [7], is composed of two parts. A hemispherical part of 30 cm-diameter and 14 cm-height that surrounds the entire photocathode area, and a flat part of a 30 cm-diameter disk with a hole in its centre through which the PMT neck could fit. The scale of the grid is $68 \times 68 \text{ mm}^2$, giving a shadow effect on the photocathode smaller than 4% and a reduction factor of the magnetic field inside the cage of about 4.

Into the transparent glass hemisphere, an optical silicon gel creates the optical coupling between the photocathode of the photomultiplier and the glass sphere, while ensuring the mechanical assembly of the PMT with the glass sphere and the mu-metal cage. The selected material is a two-component (A and B) silicone gel, WACKER® [8] SilGel 612. Taking into account the results obtained from measurements of the optical and the mechanical properties, the 60B/100A mixture was selected.

Inside the optical module, close to the PMT, is placed the Front End Module board (FEM). This is a $10 \times 10 \text{ cm}^2$ square printed circuit board that digitizes the PMT analog signals, encodes and transmits the data to the Floor Control Module that is located on each floor of the tower.

The time calibration of the detector is performed by means of a system of optical beacons, i.e. a series of pulsed light sources placed inside the optical modules and distributed throughout the detector to illuminate large groups of optical modules in the sea water. These well-controlled light pulses emitted in water allow the time response calibration of the optical modules as well as studying the sea water properties. To this aim, each of the two vertically downward-oriented optical modules on each storey of the towers hosts a so-called LED beacon system, which emits a series of light pulses outside the optical modules. The 470 nm LED and the pulse generator circuit, driven by the FEM board, are mounted vertically on a small black PVC structure, which is glued at the centre of the upper black hemisphere, directly on the inner surface of the glass, into a proper small window where the black paint was removed.

3. Conclusions

A 13-inch diameter optical module with a large 10-inch PMT was designed as the detection element of a large volume underwater neutrino telescope, to be installed in the depths of the Mediterranean Sea in the frame of the KM3NeT-Italia project. The whole optical module design, as well as each single component, was chosen after an intense R&D work on photomultipliers, high voltage supply circuit, optical gel, mechanical supports and effects of the Earth's magnetic field. Following a well-established production procedure, almost 700 optical modules were assembled at the INFN-LNS integration workshop located at the Harbour of Catania, and their functionality tested from electrical and mechanical point of view by using properly test-benches and a hyperbaric chamber.

References

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