

KM3NeT: R&D and technical solutions for the next generation underwater neutrino telescope

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Abstract

In this proceedings we report on the technical solutions adopted for the realization of the KM3NeT neutrino telescope, an underwater detector to be installed at different abyssal sites in the Mediterranean Sea. We present the detection and calibration elements and their deployment techniques and arrangement over kilometers in the submarine locations. Finally we review the KM3NeT data acquisition model, suitable for such a largely distributed setup, and designed to be scalable and allow the experiment to continuously run in *all data to shore* mode.

Keywords: neutrino telescopes, submarine infrastructure, data acquisition

1. Introduction

The KM3NeT Collaboration [1] aims at constructing a multi-km³ neutrino telescope in the Mediterranean Sea, exploiting the Cherenkov emission of relativistic charged particles in water [2]. The detector will consist of a three-dimensional array of large-diameter pressure-resistant multi-PMTs Digital Optical Modules (DOMs). The DOMs are attached to vertical structures called detection units (DU).

Providing an adequate density of sensors in the instrumented volume, DOM's technology is suitable for both measurements of astrophysical neutrinos and searches for neutrino mass hierarchy [3].

The KM3NeT project will be implemented in three subsequent phases, increasing the instrumented volume of the telescope from about 0.1 km³ (Phase 1) to 1–2 km³ depending on the DOM spacing (Phase 1.5) and finally to several km³ (Phase 2). Construction in Phase 1 will start at two installation sites (40 km offshore Toulon, France at a depth of 2500 m; 80 km offshore CapoPassero in Sicily, at a depth of 3500m); a third site offshore Pylos, Greece is expected to join in the next phase.

2. The Digital Optical Module (DOM)

The innovative DOM [4] is a stand alone sensor module with 31×3 PMTs in a 17 inch glass sphere (see figure 1). The front of each PMT is surrounded by a light concentrator ring to further increase the light collection area. The DOM also contains calibration sensors for the determination of its position (the acoustic piezo sensor), its orientation (the compass and tilt meters) and its timing (the nano-beacon). The readout electronics are confined inside the glass sphere of the DOM: the Central Logic Board (CLB) handles the digitized signals from all the sensors in a DOM; 2 Octopus Boards connect two groups of 19 +12 PMTs to the CLB; 31 Bases Boards provide the PMT signal amplification and discrimination and the PMT high-voltage (1500 V) with the very low power consumption of 45 mW; finally the Power Conversion Board (PCB), which supplies power to the DOM with a maximum consumption of about 10 W. The CLB is the core processing unit of the DOM. It is based on a Xilinx Kintex-7 FPGA. It implements two LatticeMico32 (LM32) processors: one LM32 processor serves the White Rabbit [5] implementation for sub-nanosecond time synchronization of the DOM and the IPv4 connectivity for data distribution. The sec-

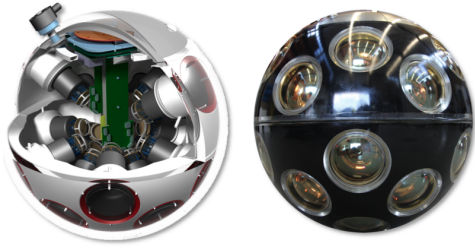


Figure 1: The Digital Optical Module in a cut-view (left) and as it looks after the full assembly (right).

and LM32 processor serves the control interfaces to all sensors. The digitized signals from the 31 PMTs are processed by dedicated TDCs, also implemented in the FPGA, measuring the occurring time and the time over threshold (ToT) for each detected pulse with a precision of $1/\sqrt{12}$ ns. The CLB is equipped with an optical interface for long-range transmission to shore in a DWDM technique.

Three different models of 3 inch PMTs passed the quality and performance requirements necessary to be integrated in the DOM [6, 7] *a*: ETEL D792, *b*: Hamamatsu 12199; and *c*: HZC XP53B20. The general characteristics are: standard bialkali photocathode with a maximal quantum efficiency of 30%, transition time spread (TTS) ≤ 5 ns, high gain of $\sim 5 \cdot 10^6$, low dark current rates (below 500 Hz) and low contamination of afterpulses (less than 3-5%).

3. Detection and Calibration Units

The Detection Unit is the vertical support for a string of 18 DOMs (see figure 2, right). It consists of two vertical Dyneema[®] ropes (4 mm diameter) with a length of about 600 m. The DOMs are spaced by 36 meters. The lowest optical module is at ~ 100 m above the seabed. The backbone connections of all the DOMs and of the base container at the DU foot is obtained by the vertical electro-optical cable (VEOC), a pressure balanced oil filled cable, providing the fiber-optic readout and electrical power distribution along the DU. The VEOC contains 18 optical fibres (+ spares), one per DOM, with a global optical attenuation ≤ 0.8 dB at 1550 nm over the entire VEOC length, and 2 copper conductors distributing the 12 V DC to all the DOMs. Using only one penetrator, each DOM is connected to the VEOC with a dedicated break-out electro-optical cable (BEOC).

The Calibration Unit is formed by two elements: the Calibration Base (CB) and the Instrumented Unit (IU). The CB consists of a module with one laser beacon and

two acoustic devices, an emitter and a receiver, operated by a dedicated CLB to ensure data communication and synchronization with the shore station. Multiple CBs are intended for calibrating the surrounding DUs. The IU consists of a line mooring a set of environmental sensors, such as the current meter, sound velocimeter, oxygen sensor, light transmissometer and fouling devices. It exploits the inductive technology [10] to transmit data along the line, eliminating the need for additional cables. CB and IU are connected physically or through an acoustic modem. A more detailed discussion about Detection and Calibration Units can be found in [9].

4. The Launching vehicle of Optical Modules

For the deployment on the seabed, the DU is packed into the Launching vehicle of Optical Modules (LOM) [9]. It is a 2 m diameter spherical aluminum frame with cable trays running round its circumference, hosting both the backbone VEOC and Dyneema[®]. The LOM is remotely released and floats up to the surface, leaving the detection unit unfurled (see figure 2, left). This is a convenient approach for simplifying the operations at sea, and it makes possible to store on the same ship several DUs for multiple deployments during the same mission. This technique is also suited for building dense arrays of DOMs, such for the ORCA detector. Various qualification tests of the LOM were done since 2010, for optimizing the deployment technique with pure mechanical strings in the Mediterranean sea and in the Atlantic Ocean offshore Spain. In May 2014 a prototype DU, called Pre-Production Module-DU (PPM-DU), with 3 active DOMs, was deployed in the Capo Passero site with the latest release of the LOM. Installation of PPM-DU (included the connection to the Seafloor Network) took one night (between May 6th and 7th). The PPM-DU unfurled correctly and it is currently taking data [2].

5. KM3NeT Phases and Seafloor Networks

The three dimensional configuration of the KM3NeT detector was obtained with simulation studies. A building block is the smallest size KM3NeT telescope with an optimal detection efficiency. With 18 DOMs per DU, a building block corresponds to a grid of 115 DUs, horizontally spaced by ~ 90 m [9]. Phase 1 of the project, to be completed in 2016, consists of 24 DUs in the Capo Passero site and 7 DUs in the MEUST site [11]. Although this is only a first portion of one building block, the infrastructures in the two sites are designed to modularly expand with the detector size. Phase 1.5 foresees

the construction of 2 building blocks, for a size of $\sim 1 \text{ km}^3$. The envisaged size of the final KM3NeT detector is made of 6 building blocks (Phase 2) in multiple sites. Two concepts for the seafloor network of KM3NeT have been worked out.

KM3NeT-It (in the Capo Passero site): a 100 km long electro-optical cable (EOC), working in DC with a maximum voltage/current of 10 kV/8 A, and with 20 optical fibres, links the shore station of Portopalo to the submarine detector. Offshore, the EOC ends up with a Cable Termination Frame (CTF). The CTF includes a Medium Voltage Converter (MVC), reducing the distributed voltage to 375 V DC. The Phase 1 CTF provides electric power and optical links to 5 secondary junction box (SJB); each SJB can connect to 12 KM3NeT DUs in a star-center configuration. At each DU base container, a second DC/DC conversion provides the 12 V needed by the CLB. In Phase 1, two SJBs will be dedicated to the 24 strings one SJB will connect 8 Italian NEMO-like Towers [12].

KM3NeT-Fr (in the Toulon site): the seabed infrastructure comprises a modular open ring network for a building block. It is connected to shore with two 60 km long Main Electro-Optical Cables (MEOCs). Each MEOC provides electrical power (10 kV DC) and data (36 single mode optical fibres) links between the shore and the submarine infrastructure. The complete network comprises 6 nodes distributed at the periphery of an ellipse shape dimensioned about 600 m x 1200 m. Each node serves 20 DUs, grouped in five chains of 4-DUs plus one Earth and Sea Science instrument and Calibration Unit. The main functionality of the power system of a node is to provide 400V AC to the DU base container, which on its turn applies an AC/DC conversion to grant the 12 V for the CLBs.

6. The Data Acquisition System

The shore-based DAQ system, running on an HPC infrastructure, operates the KM3NeT telescope and online handles all the information from all the sensors of the submarine detector. No hardware triggers are implemented in the underwater detector; all the measured signals are sent to the shore station where they are filtered and recorded [13]. The PMTs optical background (due to the environmental sources such as ^{40}K decays and the bioluminescence bursts) is $\sim 7 \text{ kHz} / 3'' \text{ PMT}$, and determines a large throughput from the detector. Also the acoustic stream from the positioning system is relevant (from $\sim 1/4$ - $1/2$ of the optical stream). A $\sim 15 \text{ Gbps}$ throughput is expected from the Phase 1 detector; $\sim 60 \text{ Gbps}$ from one building block, and 400 Gbps from the

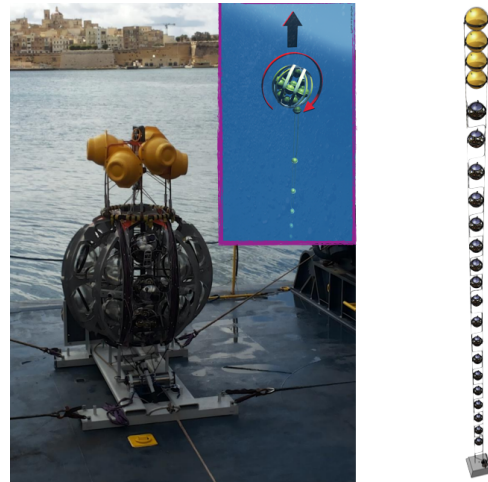


Figure 2: The KM3NeT Detection Unit. The LOM (left) used for the PPM-DU deployment and the unfurling procedure (pink box); the unfurled string with 18 DOMs and a group of buoys on top (right).

full Phase 2 detector. At the level of the DOMs, the continuum of time is counted as a succession of subsequent timeslices (TSs). Data from all the telescope occurred within the same TS are collected by the same filtering process on shore, the DataFilter (DF), which applies various trigger algorithms. The number of necessary DFs scales with the detector throughput and with the algorithms complexity without changing the DAQ design. The data reduction is more than a factor 10^3 with respect to the throughput from the detector.

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