KM3NeT: From the Cosmos to the Sea

Lizeth Morales-Gallegos[1,2,*] *On behalf of the* KM3NeT collaboration

[1]Università degli Studi della Campania "Luigi Vanvitelli", Viale Lincoln, 5, 81100 Caserta, Italy
[2]INFN - Sezione di Napoli, Complesso Univ. Monte S. Angelo, I-80126 Napoli, Italy

Abstract. Neutrinos are particles that can tell us much about our Universe. Due to their neutral, stable, and weakly interacting nature, neutrinos are valuable for studying various astrophysical phenomena including supernovae, Active Galactic Nuclei, the diffuse galactic neutrino flux and dark matter. However, neutrino fluxes at high energies are very low, which makes it indispensable to build very large detectors. The KM3NeT collaboration currently builds two large volume neutrino telescopes in the Mediterranean Sea to investigate phenomena from the with energies in the GeV to PeV range. These two detectors are called ARCA (Astroparticle Research with Cosmics in the Abyss) and ORCA (Oscillation Research with Cosmics in the Abyss). The ARCA detector is designed to detect high-energy astrophysical neutrinos, whereas the ORCA detector is optimised for less energetic neutrinos. The combination of these two detectors allows for a comprehensive understanding of cosmic-energy neutrino sources. ARCA and ORCA comprise multi-PMT optical modules that have been carefully designed and assembled in numerous integration sites across Europe and Morocco. This work aims to give an overview of the KM3NeT telescope technology, construction processes and deployment.

1 Introduction

Neutrino telescopes were conceptualized by Moisey Markov around 1960, addressing the inherent limitations of conventional telescopes [1]: absorption and scattering of photons, deflection by electromagnetic interactions, etc. To overcome these obstacles, Markov proposed the use of large volumes of transparent media (such as water or ice), equipped with three-dimensional arrays of detectors systematically arranged to optimise detection capabilities.

The detection principle of neutrino telescopes is straightforward: when neutrinos interact with the transparent medium surrounding the detectors, they produce secondary particles. These charged particles subsequently induce Cherenkov photons, which can be detected by the instruments integrated into the telescope (typically photomultiplier tubes). By analysing the timing, spatial distribution and amplitude of the detected photon pulses, both energy and direction of the incoming neutrinos can be inferred.

Building upon this foundational principle, the KM3NeT collaboration deploys two distinct neutrino telescopes situated off the coasts of France and Italy: ORCA (Oscillation Research with Cosmics in the Abyss) and ARCA (Astroparticle Research with Cosmics in the Abyss). The primary objectives of KM3NeT are twofold: firstly, to discover and observe

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[*] e-mail: moralesgallegos@na.infn.it

high-energy neutrino sources in the Universe through the ARCA telescope; and secondly, to determine the neutrino mass hierarchy via the ORCA detector [2].

Both ORCA and ARCA cover a broad spectrum of neutrino energies, ranging from supernova neutrinos (MeV range) and neutrino oscillations (GeV) to dark matter interactions (TeV) and very high-energy neutrinos (PeV). While each telescope has complementary scientific goals, they share a common detection principle and technological framework.

A simplified representation of the KM3NeT technology can be envisioned as a network where multiple photomultiplier tubes are housed within spherical modules that are interconnected to form larger detection units in a vertical string fashion, as sketched in figure 1. This innovative design facilitates effective monitoring of cosmic neutrinos while advancing our understanding of fundamental astrophysical processes.

In the following sections, KM3NeT technology is briefly described.

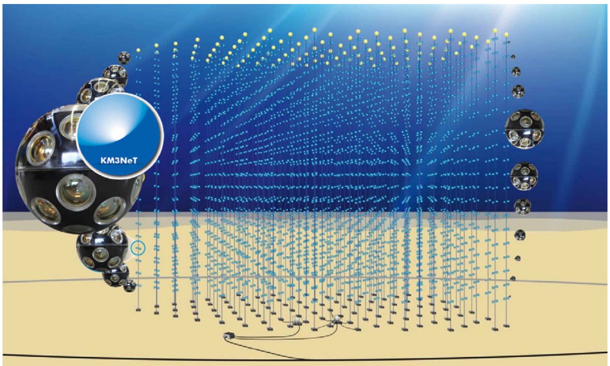

Figure 1. Artistic representation of the KM3NeT vertical strings configuration.

2 KM3NeT technology

2.1 Photomultipliers

KM3NeT employs advanced 8 cm diameter hemispherical photomultipliers manufactured by Hamamatsu Corp., which are integral to its detection capabilities [3]. These photomultipliers feature a sophisticated design comprising 10 dynode stages, allowing for enhanced amplification of the faint Cherenkov light produced during neutrino interactions. They are connected via a specialized base that efficiently dissipates only about 102 mW for high voltage generation, a remarkable achievement considering that commercially available state-of-the-art photomultiplier power supplies typically consume around 1.5 W. This innovative approach not only contributes to the overall energy efficiency of the KM3NeT infrastructure but also ensures high sensitivity and reliability in detecting low-light signals, which is crucial for accurately measuring the interactions of high-energy neutrinos in the deep-sea environment.

2.2 Digital Optical Modules

The KM3NeT project utilizes an innovative approach to PMT integration by incorporating 31 small PMTs into a Digital Optical Module (DOM). Each DOM is a robust 44 cm diameter pressure-resistant glass sphere, housing 12 PMTs in the upper hemisphere and 19 in the lower hemisphere [4]. This configuration not only enhances the sensitivity and directional accuracy of photon detection but also integrates essential read-out electronics, a nano beacon for auto-calibration, an acoustic sensor for position reconstruction, and a compass chip for comprehensive monitoring. The DOM electronics are capable of gathering gigabits of data per second, facilitated by optical fibre transmission [5] and synchronized using the White Rabbit protocol [6].

The choice of employing 31 small PMTs instead of a single large PMT, as utilized in other neutrino experiments, significantly enhances the sensitivity to the direction of incoming photons. By distributing the photocathode area across multiple sensors, the DOMs achieve improved angular coverage and photon counting performance. This design effectively reduces background noise from potassium decay and bioluminescence in seawater, allowing for more accurate measurements. In addition to these advantages, this multi-PMT configuration allows for uniformity in the most critical components of the detectors while minimizing the number of pressure housings and electronic systems required. This results in improved calibration of position and timing, as well as the ability to define local triggers within the detection units.

To date, more than 1566 DOMs have been successfully integrated across various collaboration sites, including Naples, Catania, Athens, Amsterdam, Erlangen, Strasbourg, Nantes, and Rabat. This extensive integration effort underscores the collaborative nature of KM3NeT and its commitment to advancing neutrino detection technology in deep-sea environments.

2.3 Base Module

After integrating the DOMs, 18 of them are assembled and connected via a Vertical Electro-Optical Cable (VEOC), which is a pressure-compensated, oil-filled polyethylene assembly designed to withstand the harsh conditions of the deep sea. Together, these 18 DOMs form a Detection Unit (DU). The VEOC facilitates both electrical power and glass fibre connections to each DOM within the DU. The VEOC is subsequently connected to a Base Module (BM), which is responsible for collecting data transmitted from the 18 DOMs through the VEOC, packaging this data, and transmitting it to the onshore station via the submarine infrastructure. Additionally, the BM distributes power and communication signals broadcast from shore to each DOM.

Inside a robust titanium cylinder, the Base Module houses several critical systems. It includes an optical system composed of band filters, transceivers, and splitters that manage light signals from the DOMs. The electronics consists of multiple circuit boards dedicated to power management and communications. Furthermore, the power system is equipped with various sensors that monitor temperature, humidity, optical power levels, voltages, and currents to ensure optimal operation under deep-sea conditions. The mechanical system within the BM provides cooling and protection for sensitive components, while connectors facilitate seamless interfaces with external systems. This comprehensive design ensures that the BM effectively supports data acquisition and transmission while maintaining reliable operations in the challenging underwater environment of the Mediterranean Sea.

2.4 Detection Unit

Once the 18 DOMs are assembled, they are systematically loaded into a Launcher Optical Module (LOM), which is a 2-meter diameter spherical structure weighing 450 kg and that is equipped with 12 flotation spheres for recovery purposes. This design ensures that the DOMs can be safely deployed and that the empty LOM can be retrieved again from the deep-sea environment. To date, approximately 75 DUs have been integrated across various collaboration sites, including Caserta, Catania, Genoa, Amsterdam, Marseille, and Caen.

After loading the DU into the LOM, it is essential to secure the string of DOMs to the seabed. To achieve this, each DU is placed on a robust anchor measuring 4 x 2 meters. This anchoring system is crucial for maintaining the stability and position of the DUs in the dynamic underwater environment. Furthermore, to facilitate communication between the DUs and the onshore control station, each DU must be connected to a communication Junction Box. Interlink cables are employed for this purpose, with lengths varying from 60 to 300 meters depending on the distance from the Junction Box to the anchor. This setup allows for efficient data transfer and power distribution, ensuring that all components of the KM3NeT infrastructure operate seamlessly together.

3 Sea Campaign

In order to deploy a complete DU, complex logistics planning and execution are undertaken. The transportation of multiple DUs from various integration sites is organised systematically. Detection Units are shipped to ports in Italy for ARCA DUs and to ports in France for ORCA DUs. Upon arrival at the ports, final optical, electrical and mechanical inspections are conducted on the DUs. Following these checks, the DUs are loaded onto a vessel, ensuring that each unit is assigned the correct coordinates for its deployment.

Once the DUs are accurately deployed into the sea and reach the seabed, a Remote Operated Vehicle (ROV) is employed to facilitate the release of the LOM and to unfurl the DU into its vertical configuration. LOMs are subsequently retrieved from the surface of the sea for reuse in further marine operations [7]. The same ROV is then utilized to connect the interlink cable to the appropriate port of a Junction Box, thereby initiating data collection activities.

References

[1] M. A. Markov, On high-energy neutrino physics. Proceedings of the 1960 Annual International Conference on High-Energy Physics **60**, 578-581 (1960).

[2] S. Adrián-Martínez *et al.*, Letter of intent for KM3NeT 2.0. Journal of Physics G: Nuclear and Particle Physics **43**, 084001 (2016). https://doi.org/10.1088/0954-3899/43/8/084001

[3] S. Aiello *et al.*, Characterisation of the Hamamatsu photomultipliers for the KM3NeT Neutrino Telescope. Journal of Instrumentation **13**, P05035 (2018). https://doi.org/10.1088/1748-0221/13/05/P05035

[4] S. Aiello *et al.*, The KM3NeT multi-PMT optical module. Journal of Instrumentation **17**, P07038 (2022). https://doi.org/10.1088/1748-0221/17/07/P07038

[5] S. Aiello *et al.*, KM3NeT Broadcast Optical Data Transport System. Journal of Instrumentation **18**, T02001 (2023). https://doi.org/10.1088/1748-0221/18/02/T02001

[6] D. Calvo *et al.*, Sub-nanosecond synchronization node for high-energy astrophysics: The KM3NeT White Rabbit Node. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **958**, 162777 (2020). https://doi.org/10.1016/j.nima.2019.162777

[7] S. Aiello *et al.*, Deep-sea deployment of the KM3NeT neutrino telescope detection units by self-unrolling. Journal of Instrumentation **15**, P11027 (2020). https://doi.org/10.1088/1748-0221/15/11/P11027