KM3NeT: A second-generation neutrino telescope in the Mediterranean Sea

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Abstract: The KM3NeT Collaboration aims at the construction of a multi-km$^3$ neutrino telescope in the Mediterranean Sea, a convenient location to look for high-energy neutrino sources in the inner part of the Galaxy. The apparatus will also serve as a multidisciplinary science platform. The main design of the apparatus will be presented in this contribution. Three installation sites (40 km offshore Toulon, France at a depth of 2500 m; 80 km offshore Capo Passero in Sicily, at a depth of 3500 m; 20 km offshore Pylos, Greece at depths of 2500-5000 m) are being equipped for hosting part of the telescope. The detector will consist of a three-dimensional array of large diameter pressure-resistant spheres, the so-called DOMs (Digital Optical Modules), each equipped with 31 photomultipliers with 3” photocathode diameter. The DOMs will be arranged in detection units, vertical strings anchored on the sea floor, each equipped with up to 20 DOMs. The detection unit is packed into a launch vehicle, which has the shape of a sphere with 2 m diameter, for deployment on the sea bed; then the launch vehicle is remotely released and floats up to the surface, leaving the detection unit unfurled. A qualification campaign, comprising the operation in the deep sea of the first prototype DOM, is ongoing.

Keywords: neutrino, astronomy.

1 Introduction

Neutrinos are the perfect probe to explore the far Universe. They have no electrical charge, are insensitive to magnetic fields and interact only weakly. This means they can travel huge distances from their production sites before reaching a detector on the Earth, transporting direct information on mechanisms acting inside cosmic accelerators. The discovery of astrophysical neutrinos will open a new perspective of astronomy and astrophysics, complementing present gamma ray astronomy and cosmic ray studies.

However, because of the same properties that make them unique messengers of high-energy processes, there are severe limitations to detectability of high-energy neutrinos. Very large detection volumes, at least 1 km$^3$, are required in order to have an unambiguous signal due to astrophysical neutrinos together with an effective shield against the overwhelming background due to atmospheric muons, residuals of the high-energy cosmic ray showers.

KM3NeT is a second-generation neutrino telescope meant to be installed in the Mediterranean Sea, an ideal location for searching for high-energy neutrino sources in the inner part of the Galaxy. KM3NeT will thus ideally complement the field of view of Icecube, which is already taking data at the South Pole [1].

KM3NeT will be built with the experience gained with three pilot projects: ANTARES, the first undersea neutrino telescope, which is taking data at 2500 m depth offshore Toulon, France [2][3]; NEMO and NESTOR, two comprehensive R&D programs respectively in Italy and Greece. KM3NeT will be built in three modules at three installation sites in France, Italy and Greece. It will support real-time measurements for a variety of research fields, including environmental monitoring, seismology, oceanography and bioacoustics.

In this paper the design of the apparatus will be illustrated. A qualification campaign is ongoing, as illustrated in a separate presentation at this meeting [4]. The scientific program of KM3NeT will be illustrated in other presentations at this meeting [5][6][7][8].

2 Detection principle

The KM3NeT infrastructure will comprise a neutrino telescope and a network of nodes for marine and Earth science investigations. The main goal of the neutrino telescope is the detection of high-energy neutrinos of cosmic origin, though investigations are ongoing in an attempt to clarify to what extent it can contribute to measure the neutrino mass hierarchy from measurements of atmospheric neutrinos at low-energy.

The detection principle for neutrino searches is based on the collection of Cherenkov photons emitted along the trajectory of charged particles that are produced in the interactions of neutrinos with rock and water in proximity of the telescope. In the 1960s Markov suggested the use of large volumes of natural water provided by the oceans as a means to allow the detection of high-energy neutrino-induced events, where sea-water represents simultaneously the target, the shield and the active detection volume.

A lattice of very sensitive optical detectors needs to be deployed at a large depth for this reason. Time, position and charge information of signals due to Cherenkov photons are registered and processed with dedicated algorithms, allowing the reconstruction of the charge particle’s direction. Though the telescope is sensitive to all neutrino flavors, it is optimized to neutrino-induced muons. Identifying upward going tracks allows the rejection of the overwhelming background of atmospheric muons. The angle between the neutrino and the muon directions is less than 1 degree at energies larger than a few 100 GeV.
An excess of tracks over the expected background of atmospheric neutrinos would provide evidence for a cosmic source. The study of the energy spectrum of neutrinos reaching the detector can also provide indication of a diffuse flux of cosmic origin.

A network of underwater cables and junction boxes is necessary in order to collect all data from the telescope and send it to shore over a single long-distance cable. Data collection will be centralized.

3 The installation sites

Construction has started at the three sites which will host the telescope. The onshore facilities are under construction at La Seyne Sur Mer, France; the 40 km electro-optical cable needed to reach the depth of 2500 m is ready and awaits to be deployed.

The onshore control station is ready at Capo Passero, Italy and already connected to a 100 km electro-optical cable which reaches the depth of 3500 m. A prototype structure of KM3NeT, built with the so-called tower architecture, has been recently deployed and is providing high-quality real-time data useful for prototype qualification and site characterization. As a first step toward the construction of KM3NeT, a group of 8 more towers, for a total of 670 optical modules, are under construction for deployment at Capo Passero.

Onshore infrastructures are largely available at Pylos, Greece.

4 The Optical Modules

The active part of a neutrino telescope is the optical module. The solution chosen for KM3NeT is based on multi-PMT optical modules, built by means of a large number of small-size PMTs housed in a pressure-resistant glass sphere. This solution offers some advantages compared to more traditional designs based on large-area PMTs, such as a larger photocathode surface inside the optical module, insensitivity to the Earth’s magnetic field, directionality in photon detection. In addition, the segmentation of the detection area in the optical module helps for rejection of the environmental optical background.

The Digital Optical Module (DOM) of KM3NeT comprises 31 PMTs of 3-inch diameter housed in a sphere of 17-inch diameter (see figure 1). Electronics is located inside the sphere in order to digitize and send the data to shore. Long-range transmissions exploit DWDM techniques at 50 GHz spacing.

Active bases are mounted on the PMTs, which allow to have individual control from the shore of the HV and threshold settings for each tube. For each digitized hit, the threshold crossing time and the time-over-threshold are sent to shore.

All DOMs are synchronized to the sub-nanosecond level by means of a clock signal broadcast from shore. The time offsets of the individual PMTs will be calibrated onshore before deployment, and will be continuously monitored in situ by means of a system of light beacons meant to illuminate groups of DOMs at known times; this system comprises laser beacons located on the sea bottom and LED pulsers located inside the DOMs.

The instrumentation mounted in each DOM comprises a piezo-sensor for acoustic positioning purposes, a tiltmeter and a compass, as well as sensors of the temperature and humidity inside the DOM for monitoring purposes.

The internal structure of the DOM has been carefully designed so as to efficiently remove heat from the electronics and transfer it to the sea through the glass sphere.

5 The Detection Units

The Detection Units (DUs) of KM3NeT are built with a flexible structure, as shown in figure 2. Each DU is anchored on the sea floor and is kept taught by the buoyancy of the DOMs and by the additional buoyancy provided at the top of the structure. The DU is kept together by two dyneema ropes, while a backbone provides connections for each DOM on two conductors for power and two optical fibers for communications with shore. In order to protect the backbone from excessive tension, sufficient slack is provided, while integrating the DU, so as to accommodate for the elongation of the ropes once the DU is installed.

Figure 1: The Digital Optical Module (DOM) of KM3NeT.

Figure 2: Schematic view of a detection unit of KM3NeT.
In the reference configuration, there are 18 DOMs, spaced by 36 m, on each DU. The first DOM will be at a level of 100 m from the sea bottom. The total height of a DU will thus exceed 700 m.

![Figure 3: Unfurling a DU of KM3NeT.](image)

The DU is packed into a launch vehicle, which has the shape of a sphere with 2 m diameter, for deployment on the sea bed; then the launch vehicle is remotely released and floats up to the surface, leaving the detection unit unfurled, as sketched in figure 3. This is a convenient approach for simplifying the operations at sea. This technique is also suited for building dense arrays of detection units, if needed.

![Figure 4: The prototype DOM installed on the instrumentation line of ANTARES during deployment (16 April 2013).](image)

6 The Qualification Campaign

The KM3NeT Collaboration is pursuing an extensive qualification campaign for validating all technical choices for DU constructions. As a first step of this campaign, a prototype DOM has been mounted on the instrumentation line of ANTARES (see figure 4), which has been recently installed in the deep sea. The device is working nominally and is providing high-quality data. The analysis of the PMT coincidence rates shows signals due to muons (see figure 5).

![Figure 5: Multiplicity of hits detected in a 20 ns coincidence window by the PMTs of the prototype DOM. Data are compared to simulations, showing the different contributions expected from uncorrelated optical background, $^{40}$K decays and Cherenkov light induced by muons. This plot is preliminary.](image)

The next steps of the qualification project are the following:

- construction and installation at the Capo Passero site of a pre-production model of DU, consisting of a reduced-size DU equipped with 3 DOMs;

- the deployment of a mechanical model of a full-size DU. This will be a final test of the improved procedures and equipment, after an extensive campaign, comprising 5 deployment tests, performed in spring of this year offshore Malaga, Spain (see figure 6).

This qualification project is illustrated in more details elsewhere at this conference [4]. The installation of the first detection line is planned for 2014.

7 Conclusions

Based on the experience from the ANTARES, NEMO and NESTOR pilot projects, the KM3NeT Collaboration is preparing the construction of a multi-km$^3$ neutrino telescope in the Mediterranean Sea. Construction of the infrastructure at the three installation sites in France, Italy and Greece has started. As a first step of an ongoing, extensive qualification campaign, the first prototype DOM has been recently installed in the deep sea, where it performs nominally. As a next step in the qualification program, a small-size model of DU, equipped with 3 DOMs, will be built and installed at 3500 m depth. The construction of the DUs will start next year.
Figure 6: Mechanical model of a DU, arranged on the launcher vehicle, being deployed during a test campaign offshore Spain in spring 2013.

References
[3] A. Kouchner et al., these proceedings
[4] S. Henry, these proceedings
[5] M. de Jong, these proceedings
[6] A. Trovato, these proceedings
[7] R. Coniglione, these proceedings
[8] P. Koiijman, these proceedings