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Towards a km^3 scale neutrino detector in the Mediterranean: NEMO and KM3NeT

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Neutrinos are promising probes for high energy astrophysics. According to present estimates, km^3 scale detectors are needed to detect high energy cosmic neutrinos. Deep water/ice Cherenkov technique was proposed to detect high energy neutrinos through the tracking of the secondary muons produced in neutrino interactions. The IceCube neutrino telescope is under construction at the South Pole. For a full sky observation, a second km^3 telescope is required in the Northern hemisphere. In this paper progress and latest results from the NEMO experiment as well as the status of the KM3NeT European consortium activities toward a km^3 telescope in the Mediterranean Sea are presented.

Key words: Neutrino detectors, underwater cabled observatories.

1. Introduction

Detecting high-energy neutrinos ($E_\nu > 1$ TeV) from astrophysical sources will represent a major step towards a more complete understanding of the non-thermal Universe. Neutrino telescopes can contribute to the study of Active Galactic Nuclei, Supernova Remnants, micro-Quasars, Gamma Ray Bursts, etc. Theoretical estimates (Kistler and Beacom, 2006; Kappes *et al.*, 2007) indicate that cosmic neutrinos will only be detectable by instruments with size of about one km^3 or larger.

The most promising method to achieve the ambitious goal of realizing a km^3 scale Neutrino Telescope is based on the use of large volumes of natural optically transparent media (water or ice). The detection technique is based on the tracking of secondary muons produced in neutrino interactions occurring in the volume close to the telescope. The Cherenkov light emitted along the muon track can be detected by a sparse array of optical sensors, deployed in deep sea or ice (2000–4000 m depth) and arranged in a geometry that allows the reconstruction of the track direction by measuring the arrival times of Cherenkov photons on the optical sensors.

A first generation of small scale detectors has been built (AMANDA (Andres *et al.*, 2000) at the South Pole and NT-200 (Belolaptikov *et al.*, 1997) in the Baikal lake) proving the feasibility of the detction technique and allowing to set limits on neutrino fluxes.

The IceCube (Spencer, 2008) telescope, currently being built at the South Pole, will have an instrumented volume of ice of one km^3. Due to the intense atmospheric muon background, neutrino telescopes are mostly downward looking detectors, and as a result the IceCube detector will explore mostly sources located in the Northern sky. To allow full sky coverage, a second km^3 neutrino telescope in the Northern hemisphere is required. Due to its location, such a detector will allow to survey a large fraction of the Galactic plane including the Galactic centre.

An optimal location for the installation of a km^3 size neutrino telescope is the Mediterranean Sea. Three international collaborations are presently active in the Mediterranean Sea: ANTARES, NEMO and NESTOR. ANTARES (Aslanides *et al.*, 1999) has built a 0.1 km^2 demonstrator detector at a site off the south coast of France near Toulon; this is presently the largest neutrino telescope in the Northern hemisphere. The NESTOR collaboration (Tzamarias, 2003) is working at a site near Pilos off the coast of Greece, where in 2003 a prototype of detection structure was operated. NEMO (Migneco *et al.*, 2008) is active since 1998 with R&D activities carried out on two sites off shore the eastern coast of Sicily.

Moreover the ANTARES, NESTOR and NEMO collaborations joined their efforts in the KM3NeT consortium (De Wolf, 2008). Aim of KM3NeT is to unify experiences of the three pilot experiments toward the realization of a km^3 telescope in the Mediterranean Sea.

2. NEMO

Since 1998 the NEMO Collaboration carried out R&D activities aimed at developing and validating key technologies for a deep-sea cubic-kilometre scale neutrino telescope. Search and characterization of an optimal site for the km^3 detector installation and on the development of key technologies for the km^3 underwater telescope have been the main activities of the collaboration.

A deep sea site with optimal features in terms of depth and water optical properties has been identified at a depth of 3500 m about 80 km off shore Capo Passero and a long term study of the site has been carried out (Capone *et al.*, 2002; Riccobene *et al.*, 2007).

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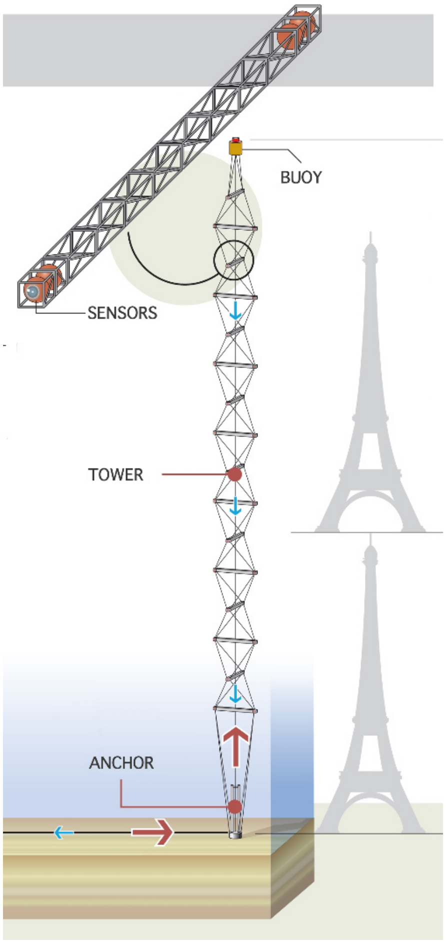

Fig. 1. Artist view of the NEMO detection structure.

One of the efforts undertaken by the NEMO collaboration has also been the definition of a feasibility study of the km^3 detector, which included the analysis of all the construction and installation issues and the optimization of the detector geometry by means of numerical simulations.

The NEMO detector concept is based on semirigid vertical structures (NEMO towers) (Fig. 1) composed of a sequence of 12 m long horizontal beams made of marine grade aluminum. Each of these has two optical modules at either end, one looking vertically downwards and the other horizontally outwards and hosts instrumentation for positioning and environmental parameter monitoring. A tower, which consists of 16 floors interlinked by a system of ropes is anchored to the seabed and kept vertical by appropriate buoyancy on the top. The spacing between floors is 40 m, while the distance between the anchor and the lowermost floor is 150 m. The structure is designed to be assembled and deployed in a compact configuration, and unfurled on the sea bottom under the pull provided by the buoy. Once unfurled the floors assume an orthogonal orientation with respect to their vertical neighbors.

2.1 NEMO Phase-1

To validate the key technologies proposed for the km^3 detector a demonstrator has been built and installed at a 2100 m deep TestSite located 25 km off-shore Catania. This apparatus, called NEMO Phase-1, included a junction box and a prototype detection structure (Fig. 2).

The JB is a key element of the detector. It must provide connection between the main electrooptical cable and the detector structures and has been designed to host and protect from the effects of corrosion and pressure, the optoelectronic boards dedicated to the distribution and the control of the power supply and digitized signals. It was design following an innovative concept. Pressure resistant steel vessels are hosted inside a large fiberglass container. This last one is filled with silicone oil and pressure compensated. This solution offers the advantage to decouple the two problems of pressure and corrosion resistance increasing the system reliability.

The detection structure is a four floor prototype tower designed following the concept outlined above. The tower hosts 16 optical modules (four on each storey), each one containing a 10″ PMT. In addition, several sensors for calibration and environmental monitoring are also present.

Phase-1 was installed in December 2006 and successfully took data for 5 months allowing the test and validation of all the key components of an underwater neutrino detector: optical and environmental sensors, power supply, front-end electronics and data acquisition, time and position calibration, slow control systems, on-shore data processing.

Down-going muon events were detected and tracks reconstructed allowing the measure of the atmospheric muon angular distribution. A set of data, corresponding to a livetime of 11.3 hours, was fully analyzed. A total number of 3049 atmospheric muon events were reconstructed, corresponding to a mean reconstruction rate of 0.075 Hz. The muon angular distribution was measured and compared with Monte Carlo simulations of the detector response to atmospheric muons. The comparison is shown in Fig. 3.

2.2 NEMO Phase-2

Although the Phase-1 project provided a fundamental test of the technologies proposed for the realization and installation of the detector, these must be finally validated at the depths needed for the km^3 detector. Following these motivations the realization of an infrastructure on the site of Capo Passero has been undertaken. It consists of a 100 km long cable, linking the 3500 m deep sea site to the shore, a shore station, located inside the harbor area of Portopalo of Capo Passero, and the underwater infrastructures needed to connect prototypes of the km^3 detector.

For the power distribution system a solution using DC power feeding has been chosen. The main electro-optical cable, manufactured by Alcatel, carries a single electrical conductor and 20 optical fibres. It has already been laid in 2007. An innovative DC/DC converter, specifically designed by Alcatel for deep-sea applications, will be installed. After the successful test of the final prototype the DC/DC converter is presently under realization; it will be deployed beginning of 2009.

A fully equipped 16 storey detection tower is presently under construction. It will be installed on the Capo Passero site and connected to the deep-sea infrastructure. The design will implement some improvements, following the experience gained with the Phase-1 project, aimed at simplifying the detector integration, increasing its reliability and reducing its costs.

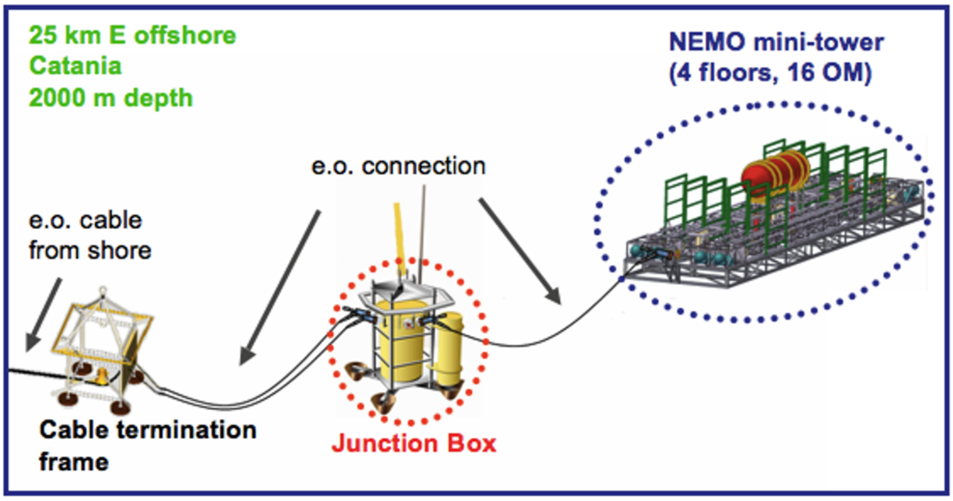

Fig. 2. Layout of the NEMO Phase-1 installation at the Catania Test Site.

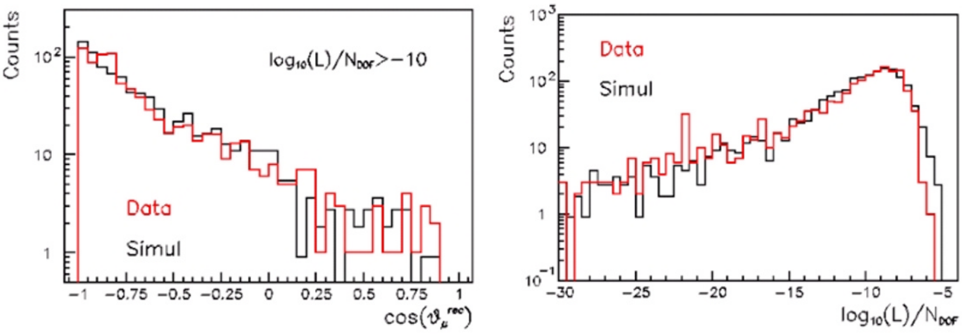

Fig. 3. Distributions of the cosine of the zenith angle of reconstructed muons tracks (left) and of the likelihood (right), compared with Monte Carlo simulations.

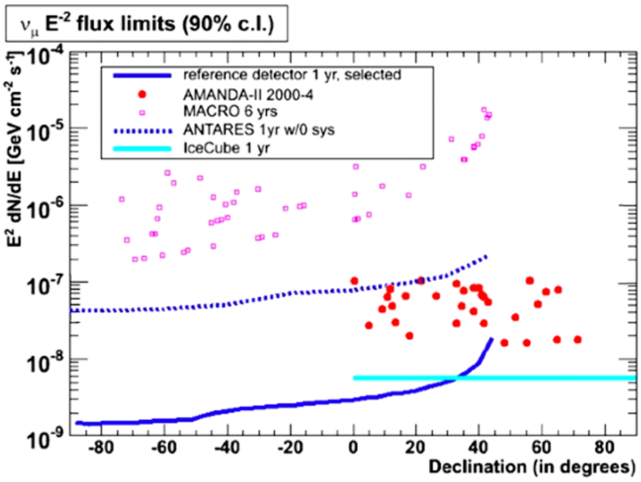

Fig. 4. Expected sensitivity of the KM3NeT neutrino telescope (blue line) compared with the other experiments. The Mediterranean km^3 telescope will complement IceCube in its field of view and exceed its sensitivity by a substantial factor.

With the completion of this project, foreseen by middle 2009, it will be possible to perform a full test at 3500 m of the deployment and connection procedures and at the same time set-up a continuous long term on-line monitoring of the site properties (light transparency, optical background, water currents, ...) whose knowledge is essential for the installation of the full km^3 detector.

3. KM3NeT: Towards a km^3 Scale Detector in the Mediterranean Sea

KM3NeT, acronym for KM3 Neutrino Telescope, will be the future deep-sea research infrastructure hosting a km^3 scale neutrino telescope and facilities for associate marine and earth sciences. KM3NeT is a consortium of institutes from 10 European countries including the three collaborations (ANTARES, NEMO and NESTOR) that develop pilot neutrino telescope projects in the Mediterranean Sea. KM3NeT is also part of the ESFRI (European Strategic Forum on Research Infrastructures) roadmap for future large scale infrastructures.

Activities started in February 2006 with the KM3NeT Design Study project co-founded by the EU. The project aims at developing a cost-effective design for the construction of a 1 km^3 neutrino telescope.

In this framework a Conceptual Design Report (available at http://www.km3net.org/CDR/CDR-KM3NeT.pdf), which describes the scientific objectives, and the concepts behind the design, construction, and operation of a large deep sea neutrino telescope in the Mediterranean Sea, has been published in 2008.

The KM3NeT project will end in October 2009 with the completion of the Technical Design Report, defining the technological solutions for the construction of the telescope.

Minimum requirements are an instrumented volume of at least 1 km^3, with angular resolution of about 0.1° for neutrino energies above 10 TeV, sensitivity to all neutrino flavors, and a lower energy threshold of a few hundreds of GeV. The impact of the various technical options on detector performance is being investigated with Monte Carlo simulations.

A Preparatory Phase project co-founded by EU started in March 2008. The Preparatory Phase will address political, governance, and financial issues of KM3NeT, including site issues. It will also include prototyping work, in view of the start of the telescope construction in 2011.

The KM3NeT detector in the Mediterranean Sea will complement IceCube in its field of view and exceed its sensitivity by a substantial factor (Fig. 4).

The KM3NeT research facility will also serve the cause of marine and geophysical sciences. The existence of dedicated and permanent sea to shore connections allows the operation of long term real-time monitoring stations serving these disciplines.

4. Conclusions

The present status of the NEMO underwater neutrino telescope activities was presented.

The activities of the NEMO collaboration have recently progressed with the realization and installation of the Phase-1 apparatus. With this apparatus it has been possible to test in deep sea the main technological solutions developed by the collaboration for the construction of a km^3 scale underwater neutrino telescope.

A Phase-2 project, which aims at the realization of a new infrastructure on the deep-sea site of Capo Passero at 3500 m depth, is presently progressing.

After the successful experience of the pilot projects operating in the Mediterranean Sea (ANTARES, NEMO and NESTOR), that have demonstrated the feasibility of an underwater neutrino detector, the three collaborations have founded the KM3NeT consortium with the aim of taking profit of the experiences of the three pilot experiments to step forward towards the realization of a km^3 telescope in the Mediterranean Sea.

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