

# Results from NEMO and Km3Net

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**Abstract.** The status of the NEMO project is described: the activity on long term characterization of water optical and oceanographic parameters of the Capo Passero (Sicily, Italy), candidate for the installation of the Mediterranean  $\text{km}^3$  neutrino telescope; the feasibility study on physics performances and underwater technology for the  $\text{km}^3$ ; the activity on NEMO Phase 1, a technological demonstrator that is going to be deployed at 2000 m depth 20 km offshore Catania.

## 1. Introduction

The installation of detectors for high energy astrophysical neutrinos is considered today one of the main goals of astro-particle physics. The first generation of underwater/ice neutrino telescopes, BAIKAL [1] and AMANDA [2], despite their limited size have already set first constraints on astrophysical models of TeV neutrino production. The successful experience of AMANDA opened the way to IceCube [3], a  $\text{km}^3$ -size neutrino telescope which is now under construction at the South Pole. The scientific community is also supporting the construction of another  $\text{km}^3$  neutrino telescope in the Northern Earth Hemisphere, to allow contemporary observation of the full sky. The Mediterranean Sea offers optimal conditions to locate the telescope and, moreover, a Mediterranean  $\text{km}^3$  telescope should be able to observe neutrinos from the Galactic Centre region, not seen by IceCube. The NEMO collaboration is carrying out, since 1998, an *R&D* programme towards the construction of the Mediterranean high energy neutrino detector. The activities of the group have been mainly focused on three items: the search and long term monitoring of an optimal site for the installation of the  $\text{km}^3$  telescope; the development of a technical and scientific feasibility study of the detector; the realization of a technological demonstrator (the NEMO Phase 1 project), which is scheduled to be deployed and operated by the end of this year.

## 2. Site selection and characterization

The installation of the  $\text{km}^3$  detector needs a complete knowledge of the site physical and oceanographical characteristics over a long time period. Therefore, the NEMO collaboration has performed, since 1998, a long term research program to select and characterise an optimal deep sea site. After 30 sea campaigns a site located in the Ionian Sea ( $36^\circ 19' \text{ N}$ ,  $16^\circ 05' \text{ E}$ ), close to Capo Passero (South-East of Sicily), was identified as the best candidate. The site is a wide abyssal plateau with an average depth of about 3500 m, located at less than 80 km from the shore and about 50 km far from the shelf break (see Figure 1 Left). Water transparency was measured in situ using a set-up based on a transmissometer that allowed to measure light absorption and

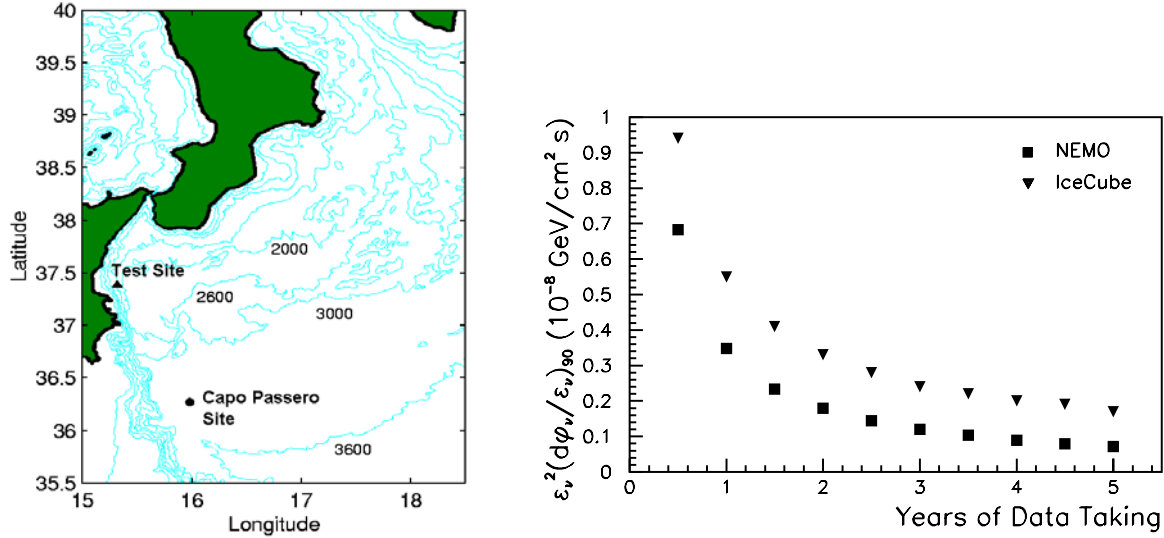
attenuation at nine different wavelengths ranging from 412 to 715 nm. The values of the light absorption length measured at depths of interest for the detector installation (more than 2500 m) are close to the one of optically pure sea water (about 70 m at  $\lambda = 440$  nm). Seasonal variations are compatible with the instrument experimental error [4]. Another characteristic of deep sea water that can affect the detector performance is the optical background, coming from  $^{40}\text{K}$  and bioluminescence. In Capo Passero an average rate of about 30 kHz of optical noise (measured with 10" PMTs at 0.3 single photoelectron threshold) has been measured at a depth of 3000 m in several sea campaigns. This value is compatible with what expected from  $^{40}\text{K}$  background, with rare high rate spikes due to bioluminescence, in agreement with the measured vertical distribution of bioluminescent bacteria, that shows a very low concentration of these bacteria at depths greater than 2500 m. The programme of site characterisation also includes long term measurements of water temperature and salinity, deep sea currents, sedimentation rate and bio-fouling. All data confirm the optimal characteristic of the selected site[5].

### 3. Feasibility Study for the $\text{km}^3$ telescope

The design of an underwater  $\text{km}^3$  neutrino telescope represents a challenging task that has to match the requirements of astro-particle physics discovery potentials, technical feasibility and budget. A  $\text{km}^3$  neutrino telescope is commonly defined as an array of about 5000 optical modules (OM) hosted on underwater structures. It is important to limit the total number of structures in order to reduce the number of underwater connections and sea operations, thus costs, and improve reliability. NEMO proposes innovative structures to host OMs: the NEMO *towers* (the lay out is discussed in the next section NEMO Phase 1) designed to deploy, during a single operation, a large number of OMs. Each floor of the tower hosts four optical modules equipped with 10" PMT. Floors are arranged in a 3-dimensional shape in order to locally allow event trigger and track reconstruction. The proposed detector geometry consists of a squared array of  $9 \times 9$  NEMO towers made of 18 floors each and with 5832 OMs. The distance between the towers is 140 m [7]. The Collaboration is evaluating detector performances by means of numerical simulations, using the software developed by the ANTARES collaboration and adapted to a  $\text{km}^3$  scale detectors [6]. Using the above geometry and the site parameters measured in Capo Passero, simulations show that the detector can reach an effective area  $>1 \text{ km}^2$  at muon energies of about 10 TeV, with an angular resolution of the order of few tenths of degrees. Results of simulations (see Figure 1 Right) also show that the expected sensitivity to a point like source at declination  $= -60^\circ$  is about  $1.2 \cdot 10^{-9} \text{ GeV cm}^{-2} \text{ s}^{-1}$  (the used spectrum is  $E_{\nu_\mu}^{-2}$ ), obtained for a search bin of 0.3 degrees [7]. These results indicate that such a detector may reach a better sensitivity and smaller search bin than IceCube, allowing a better identification of point-like sources. A simulations study of the Moon shadow effect, due to the absorption of primary cosmic rays by the Moon, has also been undertaken. Indeed, this effect can provide a direct measurement of both the detector angular resolution and pointing accuracy. Preliminary results show an angular resolution  $\sigma = 0.19^\circ \pm 0.02^\circ$  [8].

### 4. NEMO Phase 1 and Phase 2

In order to validate the characteristics of the mechanical, of the data transmission and of the power distribution systems, NEMO undertakes the realization of a technological demonstrator, called NEMO Phase 1, that includes prototypes of the critical elements of the proposed  $\text{km}^3$  detector. The project is under realization at the Test Site (Figure 1 Left) of the Laboratori Nazionali del Sud in Catania, where a 28 km electro optical cable, reaching the depth of 2000 m, allows the connection of deep sea instrumentation to a shore station, located inside the port of Catania. The shore laboratory hosts the power feeding system, the instrumentation control system, the landing station of the data transmission system and the data acquisition. NEMO Phase 1 schedules the deployment and operation of a Junction Box and of a "mini-tower" (Figure



**Figure 1.** Left: Bathymetric chart of Eastern Sicily. The location of the Capo Passero site and of the NEMO Phase 1 *Test Site* is shown. The seabed depth is about 3400 m for the *Capo Passero* sites and 2000 m for the *Test Site*. Right: Sensitivity to a neutrino spectrum with  $\alpha = 2$ , coming from a  $\delta = -60^\circ$  declination point-like source and comparison with the IceCube detector [3].

2 Left). The Junction Box (JB) provides connection between the main electro-optical cable and the tower. It is designed to host and protect, from the effects of corrosion and pressure, the opto-electronic boards dedicated to the distribution and the control of the power supply and digitized signals. A jumper cable will connect the JB to the mini-tower, a small size NEMO tower made of four floors. Each floor is a rigid aluminum structure, 15 m long, that hosts 4 OMs, environmental and control sensors, the front end electronics. Floors are interlinked by a system of cables and anchored on the seabed; the structure is kept vertical by a buoyancy on the top. In its working position each floor will be rotated by  $90^\circ$ , with respect to the up and down adjacent ones, around the vertical axis of the tower. The vertical distance between floors is 40 m. One of the advantages of this structure is represented by the fact that it can be compacted, by piling each storey upon the other, to allow transport and deployment. After its deployment on the seabed, the structure is unfurled reaching its operating configuration. Inside each floor two vessels are installed: a Floor Power Module (FPM) and a Floor Control Module (FCM). The latter is the core of the system since it hosts all the floor electronics for data transmission. The FCM is interfaced to the OMs by means of four electro-optical cables, and to auxiliary instrumentation (oceanographic probes, hydrophones for the acoustic positioning system) via electrical cables. The optical modules are essentially composed by a photo-multiplier (PMT) enclosed in a 17" pressure resistant sphere of thick glass. The used PMT is an 10" Hamamatsu R7081Sel with 10 stages. In spite of its large photocathode area, the Hamamatsu PMT R7081Sel has a good time resolution of about 3 ns FWHM for single photoelectron pulses with a charge resolution of 35%. The base card circuit for the high voltage distribution (Iseg PHQ 7081SEL) has a power consumption of less than 150 mW. A front-end electronics board is also placed inside the OM. Sampling at 200 MHz is accomplished by two 100 MHz staggered Flash ADCs, whose outputs are captured by an FPGA and transmitted to the FCM at 20 Mbit/s rate. All the Phase 1 detector subsystems have undergone extensive qualification and pressure tests. Phase 1 is now integrated at the Test Site shore laboratory, final tests of the complete system are running, the deployment of Phase 1 is scheduled by the end of this year.

Although the Phase 1 project will provide an important 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<sup>3</sup> detector. For these motivations the collaboration undertake the Phase 2 of NEMO, i.e. the realization of a dedicated infrastructure in the Capo Passero site. It will consist of a 100 km underwater electro-optical cable (linking the 3500 m deep sea site to the shore), a shore laboratory, located inside the harbour area of Capo Passero, and underwater infrastructures (underwater connectors, power transformers,...). The completion of this project is expected by the end of 2007 and will allow the connection of prototypes of the detector and instrumentation for long term on-line monitoring of the site properties.



**Figure 2.** The Junction Box (Left) and the mini-tower (Right) under assembling.

## 5. Conclusions

The realization of the Mediterranean km<sup>3</sup> telescope for high energy astrophysical neutrinos is a challenging task and several collaborations in Europe are working on the realization of first generation demonstrators. More efforts are needed to develop a project for the km<sup>3</sup> detector; for this reason EU recently funded Km3Net [9], which is expected to provide a Design Study for the Mediterranean km<sup>3</sup> telescope within 2009. In its five years of activity the NEMO collaboration has contributed in this direction performing: an extensive study on site properties, demonstrating that Capo Passero has optimal characteristics for the telescope installation; a technical feasibility analysis for the km<sup>3</sup> detector, showing that a detector with effective area for TeV muons of  $\sim 1 \text{ km}^2$  is realizable at an affordable cost; the realization of a technological demonstrator that is being installed at the underwater Test Site of the LNS in Catania.

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