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# Recent results and perspectives of the NEMO project

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**Abstract**

The latest results and the activities towards the realization of a km$^3$ Cherenkov neutrino detector carried out by the NEMO Collaboration are described. The realization of a Phase-1 project, has validated all relevant technologies proposed for the realization of the km$^3$ detector on a Test Site at 2000 m depth. The realization of a new infrastructure on the candidate Capo Passero site (for Phase-2 project) will provide the possibility to test detector components at 3500 m dept.



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## 1. Introduction

In spite of the tremendous efforts spent in the last decades by several collaborations High Energy Neutrinos, from galactic and/or extragalactic sources have not yet been observed. Several models [1] predict their fluxes, on the basis of measured cosmic ray fluxes; all agree that the opening of the high-energy neutrino astronomy era cannot be afforded without a detector with at least a km$^3$ scale.

Smaller scale detectors have been realized (AMANDA [2] at the South Pole, NT-200 [3] in the

Baikal lake, ANTARES [4] close to Toulon in the Mediterranean Sea) and have set limits on neutrino fluxes, others are at different stage of realization (NESTOR [5]). Following the success of AMANDA the realization of the IceCube km$^3$ detector [6] is now progressing at the South Pole. On the other hand, many issues, as the full sky coverage, strongly support the construction of a large detector in the North Hemisphere: the consortium KM3NeT [7], funded by the EU 6th Framework Program, aims at the definition of a complete project for km$^3$-scale Cherenkov Neutrino Telescope in Mediterranean Sea.

The activity of the NEMO collaboration has been mainly focused, in the period 1998-2004, on the search and characterization of an optimal site for the detector installation and on the development of key technologies for the km$^3$ underwater telescope.

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 monitoring of the site has been carried out. Results of these measurements have been previously reported [8], [9], [10].

NEMO collaboration has also carried out a feasibility study of the km$^3$ Cherenkov Neutrino detector, which included the analysis of all the construction and installation issues and the optimization of the detector geometry by means of numerical simulations. A validation program of the proposed technologies is going on; all the proposed technical solutions have to be validated in deep-sea environment: this is the aim of the two intermediate projects NEMO Phase-1 and Phase-2.

## 2. The NEMO km$^3$ detector layout

The considerations leading to the definition of a proposed architecture for the km$^3$ detector have been described elsewhere [11]. We will here briefly recall the main characteristics of the detector.

The proposed NEMO architecture is a modular array of detection units, called “towers”, arranged in a $9 \times 9$ square lattice. Performances of this detector, like effective area, angular resolution and sensitivity to point-like neutrino sources were evaluated by means of numerical simulations [11]. These simulations were carried out using the software [12] developed by the ANTARES collaboration and adapted to km$^3$ scale detectors [13]. In the simulation site dependent parameters such as depth, optical background, absorption and scattering length, have been set accordingly with the values measured in Capo Passero at a depth of about 3500 m [9].

## 3. The NEMO-Phase1 project

The NEMO Phase-1 project, carried out in the period 2004-2007, has allowed a first validation of the technological solutions proposed for the km$^3$ detector. The apparatus, built and tested in deep sea, included prototypes of the critical elements of km$^3$ detector: the junction box and the tower.

The apparatus has been installed at 2000 m depth at the Underwater Test Site of the Laboratori Nazionali del Sud in Catania, connected to the shore by means of a 28 km electro optical cable and operated for few months.

### *3.1. The Junction Box*

The Junction Box (JB) (fig. 1) is a key element of the detector. It provides connection between the main electro-optical cable and the detector structures and

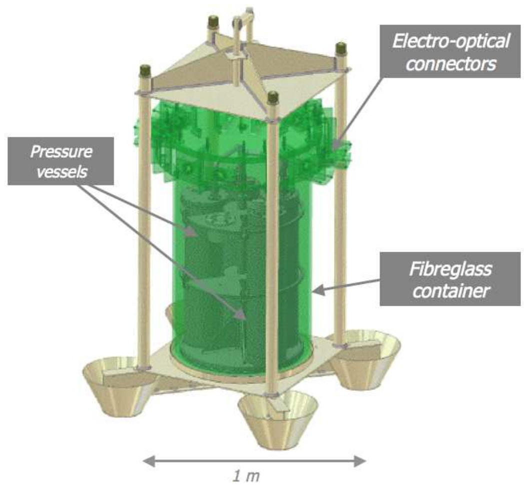


Fig. 1. The NEMO Phase-1 Junction Box.

hosts and protects 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.

The NEMO Phase-1 JB has been built following the concept of double containment. Pressure resistant steel vessels are hosted inside a large fibreglass container. This last one is filled with silicone oil and pressure compensated. This solution has the advantage to decouple the two problems of pressure and corrosion resistance.

Moreover, all the electronics components that were proven able to withstand high pressure were installed directly in oil bath.

### *3.2. The detector tower*

The tower that hosts the optical modules and the instrumentation is a three dimensional flexible structure composed by a sequence of floors (that host the instrumentation) interlinked by cables and anchored on the seabed [14]. The structure is kept vertical by appropriate buoyancy on the top.

While the design of a complete tower for the $km^3$ foresees 16 floors, the prototype realized for the Phase-1 project is a “mini-tower” of 4 floors, each made with a 15 m long structure hosting two optical modules (one down-looking and one horizontally-looking) at each end (4 OM per storey). The floors are vertically spaced by 40 m. Each floor is connected to the following one by means of four ropes that are fastened in a way that forces each floor to take an orientation perpendicular with respect to the adjacent (top and bottom) ones. An additional spacing of 150 m is added at the base of the tower, between the tower base and the lowermost floor to allow for a sufficient water volume below the detector.

A scheme of the NEMO-Phase1 four floors tower is shown in fig. 2. In addition to the 16 Optical Modules the instrumentation installed includes several sensors for calibration and environmental monitoring. In particular two hydrophones are mounted on the tower base and at the extremities of each floor. These, together with an acoustic beacon placed on the tower base and other beacons installed on the seabed, are used for precise determination of the tower position by means of time delay measurements of acoustic signals.

The other environmental probes are: a Conductivity-Temperature-Depth (CTD) probe used for the monitoring of the water temperature and salinity, a light attenuation probe (C*) and an Acoustic Doppler Current Profile (ADCP) that will provide continuous monitoring of the deep-sea currents along the whole tower height.

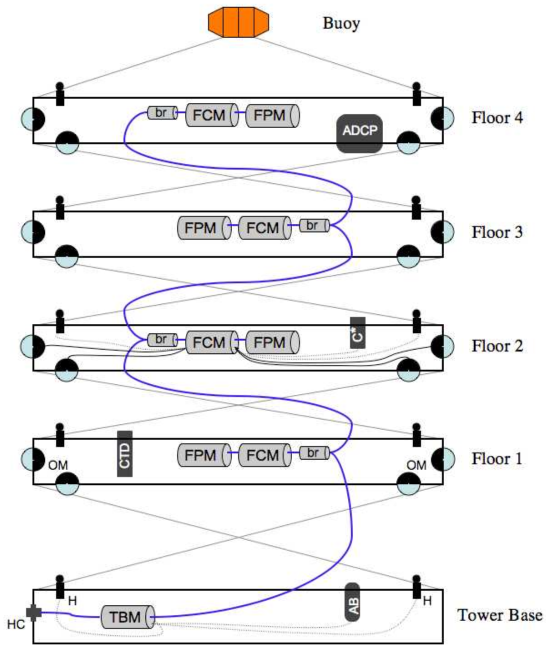


Fig. 2. Scheme of the four floors prototype tower of the NEMO Phase-1 project. The instrumentation mounted on it includes: 16 Optical Modules (OM); 10 Hydrophones (H); 1 Acoustic Beacon (AB) on the Tower Base; 1 Current-Temperature-Depth probe (CTD) on the first floor; 1 probe for light attenuation measurements (C*) on the second floor; 1 Acoustic Doppler Current Profiler (ADCP) on the fourth floor. The scheme of the backbone cabling including the Tower Base Module (TBM), the floor breakouts (br), the Floor Control Modules (FCM) and the Floor Power Modules (FPM) is shown. Connection to the Junction Box is provided through a wet mateable hybrid connector (HC) placed on the tower base. For clarity the layout of the floor internal cabling is drawn only for floor 2, with electro-optic connections as continuous lines and electric connection as dotted lines.

The tower is designed such that it can be assembled in a compact configuration (see fig. 3). This configuration is also maintained during the transport and the deployment, which is performed from a suitable surface vessel by means of a winch.

In December 2006, after the correct positioning on the seabed (25 km East off-shore Catania at 2100m depth) and the connection to the undersea cable network, the tower has been unfurled, with a procedure actuated remotely, using the pull provided by the buoy.

Fig. 3. The NEMO prototype tower fully assembled before its deployment.

### *3.3. Tower cabling system*

The tower cabling system has been already reported elsewhere [15]. Nevertheless it's worth to provide a short description of it.

At the base of the tower there is a Tower Base Module (TBM). The TBM is connected by means of a hybrid penetrator to the backbone cabling and by means of a hybrid connector to a jumper cable terminated with a wet mateable bulkhead that allows the interconnection of the tower to the Junction box by means of a ROV.

A lightweight electro-optical backbone cabling system distributes the power and the data transmission signals to and from the tower floors. The splitting of the cable is performed by means of breakouts positioned at each floor level. The breakouts are realized with pressure vessels each one containing two passive optical devices that perform the Add/Drop functions for the optical data transmission signals of the outgoing and incoming data flows.

Inside each floor structure two containers are installed: a Floor Power Module (FPM) and a Floor Control Module (FCM). This last one is the core of the system since it hosts all the floor electronics for data transmission. This module is realized with an analogous solution to that adopted for the Junction Box: a metallic pressure resistant vessel placed inside an external plastic container filled with silicone oil and pressure compensated. The FPM is silicone oil filled plastic container, since all the power supply subsystem that is hosted inside has been tested to operate under pressure [16]. The FCM is interfaced to the floor instrumentation by means of four electro-optical (for the OMs) and three electrical (for the additional instrumentation) penetrators.

In this cabling system connectors are positioned only at the subsystems interfaces, to allow for testing of each single subsystem and for an ease of assembly, and at users interfaces. This allows reducing their number thus reducing the cost of the system and increasing its reliability. Moreover, the use of penetrators instead of connectors minimizes the optical losses allowing for a higher budget for the data transmission system.

### *3.4. The Optical Module*

The optical module is essentially composed by a photo-multiplier (PMT) enclosed in a 17" pressure resistant sphere of thick glass.

The used PMT is a 10" Hamamatsu R7081Sel with 10 stages. In spite of its large photocathode area, this PMT has a good time resolution of about 3 ns FWHM for single photoelectron pulses with a charge resolution of 35%.

Mechanical and optical contact between the PMT and the internal glass surface is ensured by an optical silicone gel. A $\mu$-metal cage shields the PMT from the Earth's magnetic field.

The base card circuit for the high voltage distribution (Iseg PHQ 7081SEL) requires only a low voltage supply (+5 V) and generates all necessary voltages for cathode, grid and dynodes with a power consumption of less than 150 mW.

A front-end electronics board, built with discrete components, has been designed, realized and tested [17]. This 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 which classifies (according to a remotely programmable threshold) the signal as valid or not; stores it with an event time stamp in an internal 12 kbit FIFO; packs OM data and local slow control information; and codes everything into a bit stream frame ready to be transmitted on a differential pair at 20 Mbit/s rate.

### *3.5. Data transmission system*

The design of the data transport system for NEMO Phase-1 has been based on technical choices that allow scalability to a much bigger apparatus [18],[18]. Owing to synchronization purposes, a common timing is provided to the whole apparatus at the level of detection device to allow correlation in time of events. For this reason a synchronous and fixed latency protocol, which embeds data, synchronism and clock timing in the same serial bit stream, and allows an easy distribution of the clock signal to the whole apparatus, has been chosen. At the physical layer of communication the technology adopted relies on Dense Wavelength Division Multiplex (DWDM) techniques, using totally passive components with the only exception of the line termination devices, i.e. electro-optical transceivers. The great advantages in terms of power consumption, reliability, and simplicity recommend this technique as a perfect candidate for the final $km^3$ detector.

The FCM on each floor collects data from the floor OMs and the auxiliary instrumentation, creates a data stream with a payload of 640 Mbps, and sends data toward the shore laboratory. From the opposite direction, the FCM receives slow control data, commands and auxiliary information, and the clock and synchronizations signals needed for apparatus timing. Bidirectional data transport is realized by means of the backbone optical fibre cabling system already described in sec. 3.3.

The underwater structure has a mirrored on-shore counterpart, where all optical signals are reconverted into electrical signals. In the on-shore laboratory the Primary Reference Clock, which is used to give the same timing to all the towers of the apparatus, is also located.

### *3.6. Electrical power system*

For the Phase-1 project a three-phase AC system has been chosen in order to reduce voltage drops and increase the reliability. This system is used for the energy distribution up to the level of the local electronics module in each storey where a conversion to DC is made [16].

A control system has been realized to acquire all the relevant data such as currents, voltages and environmental parameters (temperature, humidity, etc…) inside the containers.

The system has been designed to have a large part of its components working under pressure inside an oil bath. Extensive tests performed on electric and electronics components have endorsed this choice.

### *3.7. Calibration and control systems*

A timing calibration system [20], embedded in the NEMO detector, allows to measure the offsets with which the local time counters inside the optical modules are reset on reception of the reset commands broadcasted from the shore, i.e. the time delays for such commands to reach the individual optical modules. All time measurements are in fact referred to the readout of such counters. The operation will be performed with a completely redundant system [19]: 1) a two-step procedure for measuring the offsets in the time measurements of the optical sensors; 2) an all-optical procedure for measuring the differences in the time offsets of the different optical modules.

In the first system the needed measurements are performed in two separate steps:

- using an ‘echo’ timing calibration;
- using an ‘optical’ timing calibration.

The former allowed us to measure the time delay for the signal propagation from the shore to the FCM of each floor; the latter, which is based on a network of optical fibres which distributes calibration signals from fast pulsers to the optical modules, allowed to determine the time offsets between the FCM and each optical module connected to it. The second system is an extension of the optical timing calibration system, which allows to simultaneously calibrate the optical modules of different floors of the tower.

The time calibration system was able to reconstruct the calibration signal with the accuracy requested (σ ≅ 1.5 ns), as shown in figure 4.

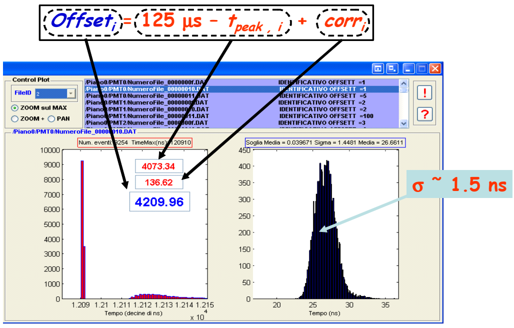


Fig. 4. Evaluation of the time offsets

An essential requirement for the muon tracking is the knowledge of each sensor position. While the position and orientation of the tower base is fixed and known from its installation, the rest of the structure can bend under the influence of the sea currents. A precise determination of the position of each tower floor is achieved by means of triangulation measurements performed by measuring time delays of acoustic signals between acoustic beacons placed on the sea floor and a couple of hydrophones installed on each tower floor. In addition to this the inclination and orientation of each tower floor is measured by a tilt meter and a compass placed inside the FCM.

The acoustic Long Base Line (LBL) is realized with four standalone battery-powered acoustic beacons and one additional beacon located on the tower base. The accuracy on the measure of the flight time is of the order of $10^{-4}$ s which yields an accuracy on the estimation of each hydrophone position of 15 cm.

To determine the position of the hydrophones the LBL must be synchronised to the master clock of the apparatus. This synchronisation takes place acoustically using a monitoring station placed in correspondence to the tower base.

Also the acoustic positioning system performed as expected. To test its performances the three dimensional measurements of the positions of the various hydrophones were taken simultaneously and then the 3D distance of couples of hydrophones was measured.

Figure 5 shows the results of this operation, carried out on the second floor of the tower. The mean length of the distance of the hydrophones was measured as 14.22 m and more than 80% of the data falls within 10 cm of the mean.

All the Slow Control data (including data from all environmental sensors and the acoustic positioning system) are managed from shore by means of a dedicated Slow Control Management System [21].

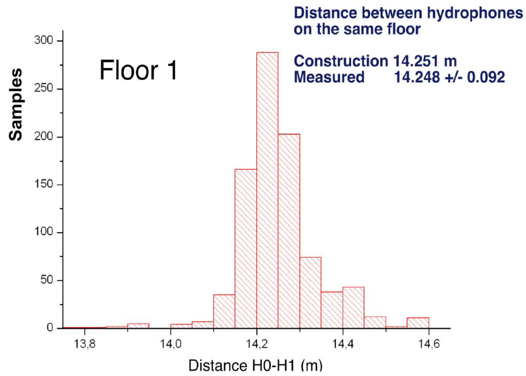


Fig. 5. Accuracy of the acoustic positioning system

## 4. NEMO-Phase1 operations

The NEMO Phase-1 system was successfully installed in December 2006: the Junction Box and the tower were deployed from the surface by means of a winch and positioned at 2100 m depth with an accuracy of a few metres with respect to the target positions. Prior to the connection of the system, the four acoustic beacons providing the LBL for the acoustic positioning system were deployed around the apparatus at an approximate distance of 500 m. Their relative position was determined with the desired accuracy of 10 cm with the help of the ROV equipped with a suitable calibration tool.

The JB was connected to the main cable termination frame and the tower to the JB with electro-optical links equipped with wet mateable hybrid connectors. Connection operations were performed with an underwater Remotely Operated Vehicle (ROV).

### 4.1. *First data and performance*

The data taking and analysis started soon after the deployment and the correct functioning of the system was verified.

The data transmission and acquisition system has been successfully tested, meeting its target performances [22].

As an example the time development of the average rate values of an OM is shown in figure 6: the shown data sample has been acquired during 18 hours starting from the 10th of January 2007 at 21 h. The thick plateau at about 73 kHz is the hit rate baseline, due to the contribution of both 40K and diffused bioluminescence; the high peaks emerging from the baseline and reaching values up to 5 MHz are caused by localized bioluminescence activity.

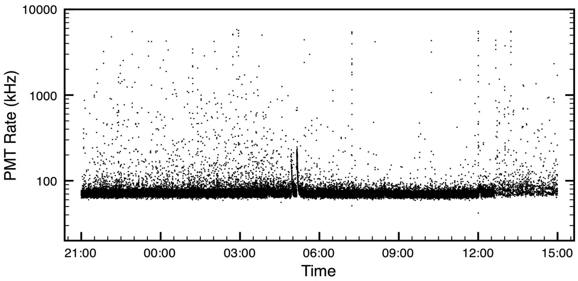


Fig. 6. Optical background during 18 hours.

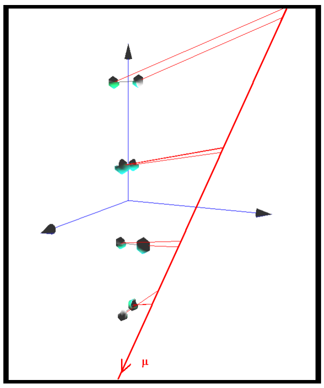

Fig. 7. Reconstruction of a downgoing atmospheric muon track.

Downgoing atmospheric muons have been observed, their tracks have been reconstructed; an example it is shown in figure 7.

The analysis of a small sample of collected data (23rd – 24th January 2007) has been reported to this Workshop [23] and elsewhere [24].

The selected sample, corresponding to 11.3 hours live time, allowed us to reconstruct 2260 atmospheric muon events yielding to a rate of 0.056 Hz, well in agreement with Monte Carlo expectations.

The angular distributions of reconstructed tracks are shown in figure 8 as a function of the cosine of the Zenith angle ($cos\ \theta_\mu^{rec}$) and of the Azimuth angle ($\phi_\mu^{rec}$). Distributions well agree with what is expected from Monte Carlo simulations.

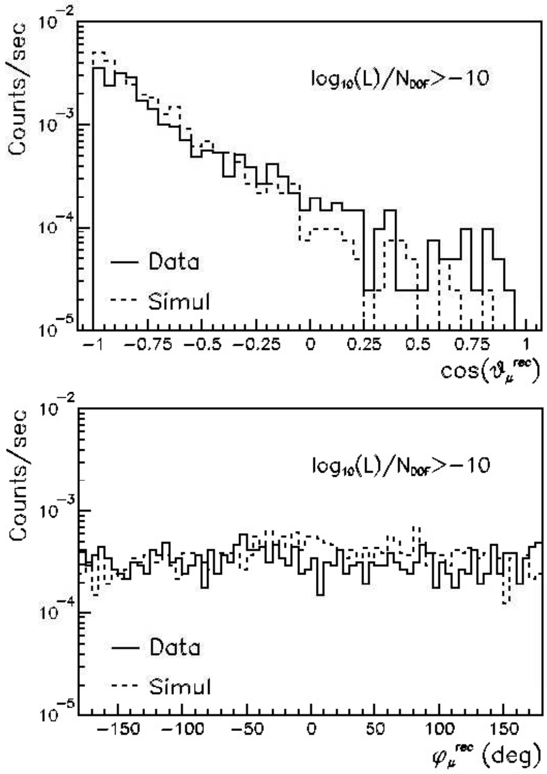


Fig. 8a,b. Distribution of reconstructed track directions as a function of the cosine of the Zenith angle ($cos\ \theta_\mu^{rec}$) (a: top panel) and the Azimuth angle ($\phi_\mu^{rec}$) (b: bottom panel).

The analysis of the whole data sample acquired by NEMO-Phase-1 detector (corresponding to ~3 months of live-time) is in progress.

Indeed some problems occurred after some months of functioning. The buoyancy of the tower decreased with the time, producing a lowering of the tower position.

The problem, originated in the construction process of the buoy, has been fully understood. This knowledge will improved the realization of the buoys for the tower in Capo Passero installation (Phase-2).

Another problem was related to a malfunction inside the JB that required its recovery for a full diagnosis. We recovered the JB on May 16$^{th}$, 2007. The accurate inspection of the JB gave very positive results: no water leak and no corrosion of the steel structure was present, the observed system malfunctioning could be attributed to a mechanical shock suffered by the JB during its deployment.

During data taking we also observed, for one optical fibre, an increase of the optical attenuation. The inspection of the JB allowed us to attribute this malfunctioning to the optical penetrator (ODI). This component has been modified, the JB has been refurbished and deployed again in NEMO-Phase1 test site on April 18$^{th}$ 2008. Once reconnected all JB components have been correctly operated.

On the basis of the experience made with the optical penetrator we decided to modify the design and the construction for the new tower of Phase-2 detector.

## 5. The NEMO-Phase2 project

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. For these motivations the realization of an infrastructure on the site of Capo Passero has been undertaken. It consist of a 100 km cable, linking the 3500 m deep sea site to the shore, a shore station, located inside the harbour area of Portopalo of Capo Passero, and the underwater infrastructures needed to connect prototypes of the km$^3$ detector.

At the same time a fully equipped 16 storeys detection tower is under construction and will be installed on the Capo Passero site. With the completion of this project, foreseen by the end of 2008, 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.

### *5.1. Phase-2 main electro-optical cable*

Due to the longer cable needed, with respect to the Phase-1 project, the DC solution was chosen for the electro-optical cable power feeding. The main cable, manufactured by Alcatel, carries a single electrical conductor, that can be operated at 10 kV DC allowing a power transport of more than 50 kW, and 20 single mode optical fibres for data transmission [25]. The DC/DC converter, realized by Alcatel, will convert the high voltage coming from the shore into 400 V.

The cable has been laid in July 2007. The cable deep sea termination, that includes the 10 kW DC/DC converter system, is presently under realization and will be deployed in the second half of 2008.

## 6. Conclusions and outlook

The activities of the NEMO collaboration have recently progressed with the achievement of a major milestone: 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. The realization of the deep-sea infrastructure has begun with the deployment of the long electro-optical cable while a shore station is under construction near the mole of Porto Palo harbour. After a careful revision of its design, following the experience gained with the Phase-1 project, the construction of a fully equipped 16 storeys tower is under way. The tower will be installed and connected by the end of 2008.

A further R&D program is also underway within the KM3NeT consortium [26] in which all the European institutes currently involved in the Mediterranean neutrino astronomy projects are participating. The project, partly supported by the European Union, has started in February 2006 a three year Design Study, which aims at producing a Technical Design Report for the realization of an underwater Cherenkov km$^3$-scale neutrino telescope.

This is presently followed by a Preparatory Phase project, started in 2008, that aims at defining all the aspects needed to bring the km$^3$ detector at the construction phase.

## References


[1] J.G. Learned and K. Mannheim, Ann. Rev. Nucl. Part. Sci., 50 (2000) 679.

[2] E. Andres et al., Astrop. Phys. 13 (2000) 1.

[3] I.A. Belolaptikov et al., Astrop. Phys. 7 (1997) 263; V. Aynudtinov, for the BAIKAL Collaboration, in these proceedings.

[4] E. Aslanides et al., ANTARES collaboration, *The ANTARES proposal*, <astro-ph/9907432>; M. Circella, for the NEMO collaboration, in these proceedings; ANTARES web page at http://antares.in2p3.fr.

[5] S.E. Tzamarias, Nucl. Instr. and Meth. A 502 (2002) 150; P. Rapidis in these proceedings; NESTOR web page at http://www.nestor.org.

[6] A. Achterberg et al., Astrop. Phys. 26 (2006) 155; E. Resconi in these proceedings; IceCube web page at http://icecube.wisc.edu.

[7] U. Katz in these proceedings; KM3NeT web page http://www.km3net.org.

[8] A. Capone et al., Nucl. Instr. and Meth. A487 (2002) 423.

[9] G. Riccobene et al., Astrop. Phys. 27 (2007) 1.

[10] P. Piattelli for the NEMO collaboration, Nucl. Phys. B Proc. Suppl. 165 (2007) 172.

[11] E. Migneco et al., Nucl. Instr. and Meth A 567 (2006) 444.

[12] D. Bailey, *MonteCarlo tools and analysis methods for understanding the ANTARES experiment*, Univ. of Oxford (2002).

[13] P. Sapienza, proceedings of the 1st VLVnT workshop, Amsterdam (2003), available at http://www.vlvnt.nl/proceedings; R. Coniglione, for the KM3NeT consortium, in these proceedings; P. Sapienza, for the KM3NeT consortium, in these proceedings.

[14] M. Musumeci for the NEMO collaboration, Nucl. Instr. and Meth A 567 (2006) 545.

[15] A. D'Amico for the NEMO collaboration, Nucl. Instr. and Meth A 567 (2006) 535; A. D'Amico, for the NEMO collaboration, in these proceedings.

[16] R. Cocimano for the NEMO collaboration, Nucl. Instr. and Meth A 567 (2006) 521; R. Cocimano, for the NEMO collaboration, in these proceedings.

[17] C.A. Nicolau for the NEMO collaboration, Nucl. Instr. and Meth A 567 (2006) 552.

[18] G. Bunkheila for the NEMO collaboration, Nucl. Instr. and Meth A 567 (2006) 559.

[19] F. Ameli et al., IEEE Trans. On Nucl. Science, Vol. 55, no. 1, (2008) 233.

[20] M. Ruppi for the NEMO collaboration, Nucl. Instr. and Meth A 567 (2006) 566; M. Circella, for the NEMO collaboration, in these proceedings.

[21] A. Rovelli for the NEMO collaboration, Nucl. Instr. and Meth A 567 (2006) 569

[22] F. Simeone for the NEMO collaboration, Nucl. Instr. and Meth A 588 (2008) 119.

[23] I. Amore for the NEMO collaboration, in these proceedings.

[24] I. Amore, Ph.D. thesis, University of Catania, Italy, 2008, http://nemoweb.lns.infn.it

[25] M. Sedita for the NEMO collaboration, Nucl. Instr. and Meth A 567 (2006) 531.

[26] U. Katz Nucl. Instr. and Meth A 567 (2006) 456; U. Katz, in these proceedings; the KM3NeT website is at http://www.km3net.org