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The NEMO Status Report

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Abstract: The NEMO (NEutrino Mediterranean Observatory) Project aims at the construction of a km^3-scale neutrino telescope in the Mediterranean Sea. After extensive deep-sea surveys performed in several sites in the Mediterranean, an optimal installation site for the apparatus has been identified at a depth of 3500 m, about 80 km off Capo Passero, at the SE corner of Sicily, Italy. In this talk, we illustrate the apparatus design and discuss its simulated capabilities. We then show the results of our long-lasting R&D efforts toward the construction of the apparatus. Specifically the NEMO Project has recently completed the Phase 1, consisting in the construction, deployment and operation of a subsystem which includes all the key elements of the apparatus at a test site located at a depth of 2000 m, about 25 km off the coast of Catania. The system is presently fully operating and results are presented in this talk. The NEMO Collaboration activity is now dedicated to the instrumentation of the Capo Passero site including the deployment by the end of 2007 of a 100 km electro-optical cable connecting the site to the Porto Palo shore station and in 2008 the deployment of a full-size Tower.

Introduction

High-energy neutrinos are expected to be very promising probes to investigate the most energetic phenomena in the Universe. Neutrinos may easily escape even from thick sources, are hardly absorbed during their propagation and are not deflected in magnetic fields. They are therefore the ideal candidate particles to point back to the sources of high-energy cosmic rays.

However the expected low fluxes, estimated mainly from the measured cosmic ray fluxes and from theoretical model for several high energy sources (GRB, AGN, GZK, ...)[1] require a detector with a sensitive volume in the km^3-scale. A first generation of small scale detector instrumentation with photomultipliers (PMT) have been realized (AMANDA[2] in the South Pole and BAIKAL[3] in the Baikal lake) demonstrating the viability of the detection in deep water or ice of the Cherenkov light emitted by neutrino induced muons.

Following the success of AMANDA the km^3 ICECUBE[4] is presently under construction at the South Pole. A similar detector located in the northen emisphere would provide the full sky coverage, including the investigation of the Galactic Centre that has raised interest after the recent impressive results from HESS on the detection of TeV gamma rays[5]. The Mediterranean Sea offers optimal conditions to locate the telescope and three collaborations are currently operating: the ANTARES[6] Collaboration is building an underwater detector demonstrator of about 0.1 km^2 at about 2400 m depth, 40 km offshore Toulon; the NESTOR[7] Collaboration aims at the deployment of the first NESTOR tower with 10^4 m^2 effective area for $E_\mu \geq 10$ TeV and the NEMO[8] Collaboration whose activity is the topic of this presentation. The three collaborations are presently participating in the KM3net Design Study[9].

The NEMO Collaboration was formed in 1998 with the aim to carry out the necessary R&D towards the km^3 neutrino detector. In the beginning the activity has been mainly focused on the search and characterization of an optimal site for the km^3 installation and on the development of a feasibility study of the detector. Very recently the realization of a small scale technological demonstrator, the so called NEMO Phase 1 project, has been succesfully completed.

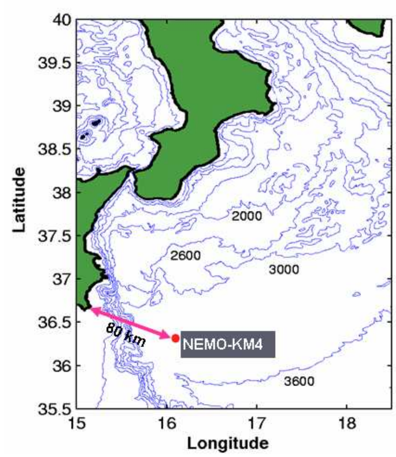

Figure 1: The south Ionian Sea, showing the location of the site selected and characterized by the NEMO Collaboration.

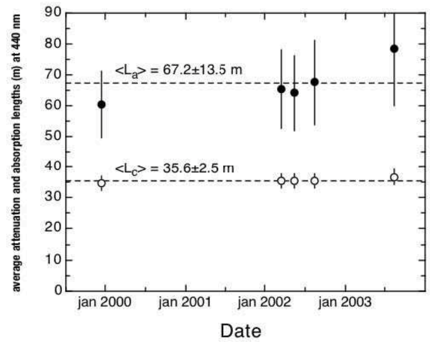

Figure 2: Values of the absorption (full symbols) and attenuation (open symbols) lengths at 440 nm measured during five different campaigns. The reported values are the average in the depth region 2850-3250 m. Dashed lines are the average over the five campaigns.

Site Selection and Characterization

The Mediterranean Sea offers optimal conditions to locate the km^3 telescope. The seabed along the Italian coast can reach, at distances less that 100 km from the shore, depths beyond 3000 m. These features are very important because deep water helps to reduce the low energy component of the down-going atmospheric muons and the relatively short distance from the coast allows the data transfer between the on-shore station and the detector by means of standard electro-optical cables. The candidate site has been identified in the Ionian Sea (36° 19' N, 16° 05' E) after 30 sea campaigns started in July 1998. The site location, as shown in Figure 1, is a wide abyssal plateau with an average depth of about 3500 m, located at less than 80 km from the shore.

The transparency properties, such as the absorption, scattering and attenuation lenghts, of the water have been measured with the AC9 transmissometer at nine different wavelenghts ranging from 412 nm to 715 nm [10]. The measured values of the absorption lenght, as shown in Figure 2, are close to those of optically pure sea salt water (about 70 m at λ = 440 nm). Seasonal variations are negligible and compatible with the instrument experimental error.

The optical background has also been studied. It generates from the decay of ^{40}K, which is present in seawater, and from the light produced by biological organisms (bioluminescence). In Capo Passero an average rate of about 20-30 kHz of optical noise, compatible with what expected from pure ^{40}K background, with rare high rate spikes due to bioluminescence has been measured at a depth of 3000 m in several sea campaigns. This result is in agreement with the vertical distribution of bioluminescent bacteria measured in Capo Passero, that shows a very low concentration of these bacteria at depths greater than 2500 m.

Deep sea currents have been continuously monitored in Capo Passero since 1998. The analysis shows that the behaviour in the area is almost homogeneous along the part of the water column that has been monitored (at depths between roughly 2800 and 3400 m) with very low average values (around 3 cm/s) and peaks never exceeding 12 cm/s. The downward flux of sediments has also been analysed. The annual average value of material sedimenting at large depth in Capo Passero is about 60 mg m^{-2} day^{-1}, a rather small value as expected for an oligotrophic environment such as the Ionian Plateau.

The NEMO Detector Layout and Performance

The design of the mechanics and electronics of an underwater telescope should fulfil several specification: a) it should allow an "easy, fast and cost effective" deployment of the whole detector structures (to be completed within ≈ 5 years); b) permit both routine maintenance on the detector site as well as the recovery of the structures for special maintenance and/or reconfiguration; c) ensure the transmission to/from shore of slow controls and of all PMT signals, possibly without any data filtering. Moreover, all the elements must be reliable for a period of time of the order of ten years which is roughly the expected detector lifetime.

The NEMO Collaboration carried out the study of the technical feasibility of the km^3 detector, taking into account all of its components and their deployment, that eventually yielded a preliminary project of the detector. This study was carried out in close contact with leading companies in the field of deep sea operations.

The proposed detector is made by a square array of 9x9 structures ("Towers") hosting a total of 5832 optical modules (OM) each containing a 10" PMT. The Tower height is ≈ 1 km and the distance between Towers has been optimized to 140 m. The simulated effective area and the angular resolution are reported in Figure 3. For comparison the response of an "homogeneous" 10x10 detector made of strings spaced by 125 m and with 5600 OM is also reported. Quality cuts are applied in order to achieve an angular resolution for the reconstructed track comparable with the intrinsic one up to $E_\nu \approx 1$ TeV (note that the resolving power of a neutrino telescope is intrinsically limited by the angle between the neutrino and the muon). At 20 kHz, which is close to the measured value in Capo Passero, the effective area is comparable to the 125 m spaced lattice case.

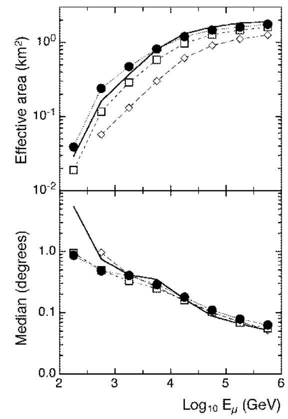

Figure 3: Effective areas and median angles between true and reconstructed muon tracks as a function of muon energy for different detector configurations. The solid line is for the 10x10 "homogeneous" detector with a 20 kHz background. Symbols are for a 9x9 array of "NEMO Towers" with different background rates: 20 kHz (full dots), 60 kHz (open squares) and 120 kHz (open diamonds).

The NEMO Phase 1 Project

As an intermediate step towards the underwater km^3 detector and in order to ensure an adequate process of validation of all the technical solutions proposed, a prototyping activity, called NEMO Phase 1, has been conducted in order to implement a reduced-scale demonstrator of the apparatus. The project is under realization at the underwater test site of the Laboratori Nazionali del Sud (LNS) of INFN. This site, which is located at 2000 m depth at a distance of about 25 km from Catania, is connected with an electro-optical cable connected to the shore station inside the Port of Catania (see Figure 4). In January 2005, the submarine termination panels were installed on the cable so that Remotely Operated Vehicles (ROV) can be used to plug underwater instrumentation. A prototype station for acoustic background measurements was also installed on the site during the same campaign, and it has been taking data continuously until December 2006 when the detector has been disconnected and replaced by the Junction Box and the Tower prototypes. The Junction Box is a key element of the detector. It provides connection between the main electro-optical cable and the detector structures, The NEMO Junction Box is made of pressure resistant steel vessel hosted in fibreglass container to avoid corrosion. The Tower is a three dimensional flexible structure composed by a sequence of storeys (see Figure 5) that host the in-

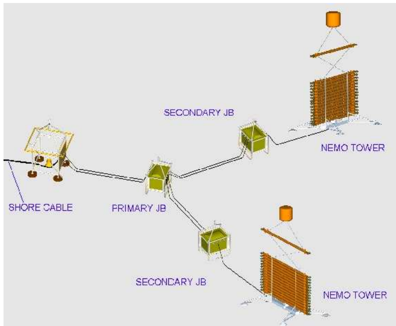

Figure 4: Schematic layout of the NEMO Phase-1 project. Components and distances are not to scale.

strumentation. The storeys are interlinked with cables, the Tower is anchored on the seabed and the structure is kept vertical by an appropriate buoyancy on the top. For the Tower of NEMO Phase 1 the number of storeys has been limited to 4, and the first storey is at about 150 m above the sea bottom. Each storey is made by a 15 m long structure hosting two optical modules at each end. Each OM is equipped with a 10" Hamamatsu R7081Sel with 10 stages. The PMT time calibration is provided by a LED system. The storeys host the read-out and transmission electronics as well as the acoustic positioning system, the compasses, tiltmeters and manometers necessary to control the storey position and orientation.

The PMT output is sampled at 200 MHz using two 100 MHz staggered Flash ADCs. A FPGA classifies the signal according ot a remotely programmable threshold and stores the values together the time stamp im an internal 12 kbit FIFO. Then the data are packed together with local slow control information and trasmitted on a differential pair at 20 Mbit/s rate to the Floor Control Module (FCM). From the FCM to the shore station, the data are transmitted along optic fibres at 155 Mbps rate.

At the beginning of December 2006 the Junction Box and the Tower have been deployed and connected. The Tower has been deployed with the 4 storeys packed as shown in Figure 4 and successfully unfolded operating with the ROV. Data have been taken until now and the analysis is in progress.

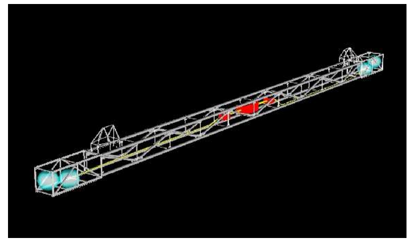

Figure 5: A NEMO Tower storey.

Conclusions and outlook

The NEMO Collaboration in the first seven years of activity identified a site close to the coast of Sicily optimal to install a km^3 neutrino telescope and successfully completed the NEMO Phase 1 aimed at testing technological solutions proposed for the km^3. A further R&D program will be developed within the KM3Net [9] Design Study in which all the European institutes currently involved in the Mediterranean neutrino astronomy projects are participating. The project has started in February 2006 and in three years will produce a Technical Design Report for the realization of an underwater Cherenkov km^3-scale neutrino telescope.

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