The Neutrino Mediterranean Observatory Project

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Activities leading to the realization of a km^3 Cherenkov neutrino detector, carried out by the NEMO collaboration, are described. Long term exploration of a 3500 m deep site in the Mediterranean close to the Sicilian coast has shown that it is optimal for the installation of the detector. A complete feasibility study, that has considered all the components of the detector as well as its deployment, has been carried out demonstrating that technological solutions exist for the realization of the km^3 detector. The realization of a technological demonstrator (the NEMO Phase 1 project) is under way.

1. Introduction

The realisation of a km^3 scale detector for astrophysical neutrinos is considered today one of the most important aims of the next decade. Up to now only smaller scale detectors have been realized or are under construction [1–4], demonstrating the feasibility of the technique of Cherenkov detection of the neutrino induced muons in deep waters or ice. However, the realisation of a km^3 scale detector needs a further improvement of the technologies by means of appropriate R&D studies, since not all the technical solutions used for smaller scale detectors are scalable to a km^3 underwater detector.

The Mediterranean Sea offers optimal conditions to locate the telescope and, moreover, it has full complementarity, in terms of sky coverage, with the ICECUBE detector [5] that is under construction at the South Pole. Moreover, such an installation in the deep sea (at depth of more than 3000 m) is of extreme interest for deep sea sciences allowing a permanent monitoring of oceanographic parameters and many opportunities of multidisciplinary research (biology, seismology, ...).

The NEMO collaboration was formed in 1998 with the aim to carry out the necessary R&D towards the km^3 neutrino detector [6]. The activity has been mainly focused on the search and characterization of an optimal site for the installation and on the development of a feasibility study of the detector. More recently the realization of a small scale technological demonstrator (the NEMO Phase 1 project) has been started.

2. Site selection and characterization

The installation of the 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. This activity has demonstrated that the abyssal plateau in the Ionian Sea close to the southernmost cape of the coast of Sicily (Capo Passero) shows excellent characteristics to host the km^3 underwater neutrino detector.

The Capo Passero site is located in a wide abyssal plateau at about 50 km far from the Sicilian-Maltese shelf break. A geological survey of the area verified the flatness and the absence of any evidence of recent turbidity events. The nature and structure of the seabed was studied in detail in order to design the mooring structures of the neutrino detector.

Water transparency was measured *in situ* using a set-up based on a transmissometer (that allows to measure light absorption and attenuation at nine different wavelengths from 412 to 715 nm) [7]. The measured value of the absorption length, averaged over the range of depths where the telescope should be placed ($2850 \div 3250$), is about 70 m in the blue region (440 nm), close to the value of optically pure sea water. Seasonal variations were investigated with a series of campaigns and were shown to be negligible and compatible with the instrument experimental error.

Another characteristic of the deep sea water that can have severe impact on the detector performance is the optical background. This background comes from two natural causes: the decay of ^{40}K, which is present in seawater, and the so called *bioluminescence* that is the light produced by biological organisms. Of these two effects the first one shows up as a constant rate background noise on the optical modules, while the second one, when present, may induce large fluctuations (both in the baseline and as presence of high rate spikes) in the noise rate. 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 measured distribution of bioluminescent bacteria, 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 (bottom 500 m) with very low average values (around 3 cm/s) and peaks not 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.

3. Proposed architecture for the km^3

The design of the mechanics and electronics of an underwater telescope should fulfill 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 the recovery of structures for maintenance; c) ensure the transmission to/from shore of slow controls and of all PMT signals, possibly without any data filtering. All the elements must be reliable for a period of time of the order of ten years.

Following these indications, and taking into account some constraints on the distance between structures (larger than about 120 m) and on their height (smaller than 1 km) suggested by a preliminary feasibility study, we have proposed an architecture composed by a square array of structures, called *towers*, which will be described in more detail in sec 4.2. The proposed architecture is "modular", in the sense that it is expandable with the addition of extra towers, and configurable with different sea floor layouts. At present it should only been considered as a reference for a more complete feasibility study.

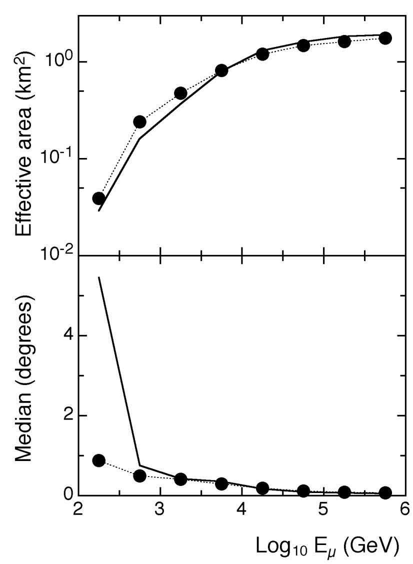

Figure 1. *Comparison of effective areas and median angles between true and reconstructed muon tracks as a function of muon energy for the "NEMO tower" (full symbols) and the "125 m spaced lattice" (solid line) configurations. See text for details.*

Computer simulations, performed using the software package developed by the ANTARES collaboration [8], were undertaken in order to investigate the performance of this detector. The performance in terms of effective area and angular resolution (median angles between true and reconstructed muon tracks) are reported in fig. 1 for a 9×9 array of 81 "NEMO towers" (5832 PMT) and for a 10×10 detector made of strings spaced by 125 m (each string including 56 downlooking Optical Modules vertically spaced by 16 m, for a total of 5600 PMT). A 20 kHz background was considered. Quality cuts were applied in order to achieve an angular resolution for the reconstructed track comparable with the intrinsic one up to about 1 TeV (see median angles in fig.1). The effective area in the two cases is comparable. However, lower energy muons are better reconstructed in a tower based detector with respect to a string based detector [9].

4. NEMO Phase One

As an intermediate step towards the realization of an underwater km^3 detector we have decided to realize a technological demonstrator including most of the critical elements of the proposed km^3 detector to ensure an adequate process of validation. This project is called NEMO Phase 1 [6].

The project is under realization at the Underwater Test Site 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 intrumentation to a shore station. The NEMO Phase 1 system is composed by a network of Junction Boxes (a main one and two secondary) and two towers. This will allow to test the mechanical characteristics of both as well as the data transmission and power distribution system of the whole apparatus. The completion of this project is foreseen by the end of 2006.

4.1. Junction boxes

An alternative design to the standard Titanium pressure vessels used for junction boxes operating in seawater for a long lifetime has been developed. The approach is to decouple the pressure and the corrosion problems. Therefore, the proposed JB will be made of a pressure resistant steel vessel hosted in a fibreglass container to avoid direct contact between steel and sea water. The fibreglass container will be filled with oil to compensate the external pressure. This solution should improve the reliability and also reduce costs by avoiding the use of expensive alloys.

4.2. Mechanical structures

The tower that will host the optical modules and the instrumentation is a three dimensional flexible structure composed by a sequence of storeys (that host the instrumentation) interlinked by a system of cables and anchored on the seabed. The structure is kept vertical by an appropriate buoyancy on the top.

The final features of the tower (number and length of storeys, number of optical modules per storey, distance between the storeys) has to be optimized following the results of numerical simulations. However, the modular structure of the tower will permit to adjust these parameters to the experimental needs. For the Phase-1 project we have considered a 16 storey tower, where each storey is a 15 m long structure hosting two optical modules (one downlooking and one looking horizontally) at each end (4 OM per storey). In its working position each storey will be rotated by 90^o, with respect to the up and down adjacent ones, around the vertical axis of the tower.

One of the advantages of this structure, which represents an alternative solution to the ANTARES string or the NESTOR rigid tower, is represented by the fact that it can be compacted, by piling each storey upon the other, to allow transport and deployment. The structure is unfurled, reaching its operating configuration, only after its deployment on the seabed. A proof of concept of this design has been successfully carried out using a 1:5 scale four storey model of the tower deployed in shallow waters and operated with a small ROV throughout a complete unfurling/furling sequence.

4.3. Electronics and data transmission

An electronic board, built with discrete components, has been designed, realized and tested as the front-end electronics for the Optical Modules (OM). The board has embedded electronics, analog and digital, in order to control the OM power supply. This board will be used in the NEMO Phase 1 project, but, as a further improvement towards the km^3, a full custom VLSI ASIC to be used as the front-end electronics for the OM, designed in AMS 0.35μm CMOS technology, is under development.

For a 5000-6000 OM neutrino telescope with an expected overall rate of 20-30 Gbps, and a distance over which the data have to be transmitted in the order of 100 km, we have chosen the Synchronous Digital Hierarchy (SDH) 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. The technology adopted relies on Wavelength Division Multiplex (WDM) techniques, using totally passive components with the only exception of the electro-optical transceivers. The great advantages in terms of power consumption, reliability, and simplicity recommend this technique as a perfect candidate for the km^3 detector. All the required electronics for data collection and supervision is accomplished by a Floor Control Module (FCM) located at the center of each floor of the tower. The FCM creates an STM-1/SDH data stream at about 155 Mbps, and send data toward the land side 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 a backbone optical fiber connected to each FCM module on an Add & Drop basis at different wavelength for both directions. Such backbone links each tower directly to the on shore side. The underwater structure will have a mirrored on-shore counterpart, where all optical signals are reconverted into electrical signals.

4.4. Electrical power system

Several solutions for the energy distribution system have been analyzed: in direct current, in alternate current mono phase and alternate current three phase. These solutions have been compared in terms of voltage drops and Joule losses.

For the Phase 1 project a three phase AC system has been chosen since it presents some advantages in terms of voltage drops and 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.

5. Conclusion

The realization of a km^3 telescope for high energy astrophysical neutrinos is a challenging task and several collaboration in Europe are already working on the realization of first generation demonstrators. More efforts are needed to develop a project for the km^3 detector. In its five years of activity the NEMO collaboration has contributed in this direction by performing an intense R&D activity.

An extensive study on a site close to the coast of Sicily has demonstrated that it has optimal characteristics for the telescope installation. A complete study has been performed to analyse all the detector components both in terms of their technical feasibility and installation, showing that a detector with effective area over 1 km^2 is realizable at an affordable cost.

The realization of a demonstrator of some of the technological solutions proposed for the km^3 detector has been started at the underwater Test Site of the LNS in Catania. Its completion is foreseen by the end of 2006.

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