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A km^3 detector in the Mediterranean: status of NEMO

Piera Sapienza[a] for the NEMO collaboration

[a]Laboratori Nazionali del Sud, INFN - Via S. Sofia 62, 95123, Catania, ITALY

The status of the NEMO project, which aims at characterizing and monitoring the Capo Passero (Sicily, Italy) candidate site for the km^3 underwater Mediterranean detector and developing and testing the related key technological solutions, is described. NEMO Phase 1, which is a technological demonstrator aiming towards the Mediterranean km^3 telescope, is under realization and is reported.

1. Introduction

The astrophysical neutrino astronomy is considered today one of the most important scientific challenges to be addressed in the next decade. Conservative flux estimates based on the cosmic ray observations indicate that to inaugurate high energy neutrino astronomy, neutrino telescopes with muon effective areas of the order of one km^2 are needed. 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. In the South Pole, following the AMANDA experience, the km^3 underice detector ICECUBE is already under construction. There are strong scientific motivations for an underwater km^3 detector in the Northen hemisphere which would allow, together with ICECUBE [5], to have the full sky coverage for the neutrino astronomy. In particular, from the Northern Hemisphere, one could detect upgoing neutrino signal from the Galactic Center, a region where high energy photons (TeV) have been recently measured with a rather hard spectrum [6]. The Mediterranean Sea, where the ANTARES, NEMO and NESTOR collaborations are operating, offers optimal conditions vicinity to infrastructures, good water quality and good weather conditions for sea operations. Moreover, such an installation (at a 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 aiming at carrying out the necessary R&D towards the km^3 neutrino detector [7]. The activity has been mainly focused on the search and characterization of an optimal site for the installation and on the development and test of key technologies for the km^3 underwater detector via the realization of a small scale technological demonstrator (the NEMO Phase 1 project).

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. In particular, the NEMO collaboration has performed, since 1998, a long term research program to select and characterise an optimal deep-sea site close to the italian coasts. 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 at about 3400 m in a wide abyssal plateau at about 40 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. Water transparency was measured *in situ* using a set-up based on a transmissometer and the measured value of the absorption length, averaged over the range of depths where the telescope should be placed, is about 70 m in

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the blue region (440 nm), close to the value of optically pure sea water [8].

Another feature 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, where the detector should be installed. The very low optical background due to bioluminescence represents a very appealing feature of the Capo Passero site at 3400 m, since high optical rates can have a severe impact on the detector performances.

3. Proposed architecture for the km^3

The design of the mechanics and electronics of an underwater telescope should fulfill several specification. It should allow the deployment of the detector structures and permit the recovery of structures for maintenance and/or detector reconfiguration; 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 which is roughly the expected detector life time. An optimization of the spatial arrangement of sensors and of the detector architecture must be done in order to achieve the requirements mentioned above. Preliminary computer simulations show that by filling up a volume of about 1 km^3 with about 5000 optical sensors one can reach, for muon energies higher than ≈1 TeV, an effective area of the order of 1 km^2.

Following these indications, and taking into account some constraints suggested by a preliminary feasibility study, we have proposed an architecture composed by a square array of structures, called *towers* [7] that will be described in more detail in section 4. 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 deeper feasibility study.

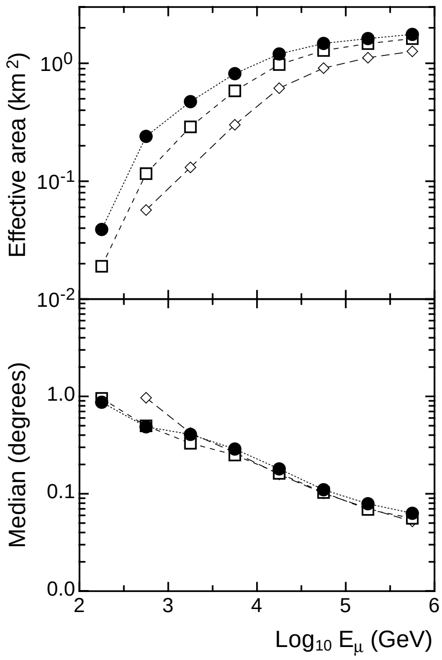

Figure 1. Effective areas and median angles between true and reconstructed muon tracks as a function of muon energy for a 9 × 9 array of “NEMO towers” (5832 OM in total) with different background rates: 20 kHz (full dots), 60 kHz (open squares) and 120 kHz (open diamonds). Quality cuts were applied in order to achieve similar angular resolutions.

Computer simulations performed using the software package developed by the ANTARES collaboration [9] were undertaken. An important issue that was addressed is the investigation of the impact of the site properties on detector performance. For this purposes the simulations have been carried out generating up-going muons with a E_μ^{-1} spectrum at the surface of a cylinder surrounding the detector that represents the detector horizon.

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) for different background rates. The resolving power of a neutrino telescope is intrinsically limited by the angle between the neutrino and the muon. Quality cuts are 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). With increasing background rate from 20 kHz to 120 kHz, when appropriate quality cuts are applied to obtain a good angular resolution, a large reduction in the effective area is observed.

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 [7].

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 ones) and two towers. This will allow to test the mechanical characteristics of both towers as well as the data transmission and power distribution system of the whole apparatus. The completion of this project is foreseen for the beginning of 2007.

Due to the number of junction boxes that will be needed in a km^3 detector, an alternative design to the standard Titanium pressure vessels has been developed, to reduce costs and increase the reliability. The proposed junction box will have a pressure resistant steel vessel hosted inside an oil filled fibreglass container, thus decoupling the two problems of pressure and corrosion resistance.

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 minitower made of 4 storeys and 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. An experimental 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.

A data transmission system, that uses fibre optics transmission with Wavelength Division Multiplex (WDM) techniques, is also being developed. This system uses totally passive components with the only exception of the electro-optical transceivers. The great advantages in terms of power consumption, reliability, and simplicity makes it a very good candidate for the

km^3 detector. 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, has been chosen.

Several solutions for the power 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, and a three phase AC system has been chosen since it presents some advantages in terms of voltage drops and reliability.

5. NEMO Phase Two

Moreover, it has become evident that a continuous on-line monitoring of the Capo Passero site is needed. For these reasons, a phase two project, which plans the installation of a 100 km electro-optical cable linking the selected deep sea site to shore, has been started. This infrastructure will also allow to test and compare different detector structures and technology in a 3500 m environment.

6. 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 the Capo Passero site, at 3400 m depth and 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 for the beginning of 2007. Moreover, an underwater station at the Capo Passero site, 3500 m depth, is underway.

The design, construction and operation of the km^3 neutrino telescope will be hopefully pursued by the KM3NeT collaboration [10] formed around the European institutes currently involved in neutrino astronomy projects.

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