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NEMO – a km^3 Neutrino Telescope in the Mediterranean Sea

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The activities towards the realisation of a km^3 Cherenkov neutrino detector, carried out by the NEMO Collaboration, are described. A long-term survey of a 3500 m deep site close to the coast of Sicily 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 an underwater km^3 detector. An intense R&D activity finalized at the development of new solutions for the sensors and the acquisition electronics is also continuing. The realization of a technological demonstrator of the apparatus (the NEMO Phase 1 project) is under way.

1. Introduction

High-energy neutrino observations can provide a clue on the investigation of the most energetic phenomena in the Universe. High-energy neutrino sources are expected to exist over Galactic as well as over extra-Galactic distances. Neutrinos may easily escape even from thick sources, are hardly absorbed during their propagation and are not deflected in the magnetic fields. They are therefore the ideal candidate particles to point back to the sources of high-energy cosmic rays.

However, the detection of low fluxes of these very elusive particles requires a detector with a huge sensitive volume, which should be effectively shielded from the overwhelming background from charged cosmic rays. The only viable solution nowadays is to build a large array of light sensors in a transparent medium, such as water or ice. Photomultipliers can then detect the Cherenkov light emitted by the charged particles produced in charged-current interactions of neutrinos inside the apparatus or in its immediate surroundings.

An apparatus with an active surface of the order of one km^2 and a sensitive volume of the order of one km^3 is needed for neutrino astrophysics. So far, smaller scale detectors have been implemented or are under construction [1-4], demonstrating the feasibility of the technique of the Cherenkov detection of neutrino-induced muons in deep waters or ice. However, the realisation of a km^3 scale underwater 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 such a large detector scale.

2. The NEMO Project

The NEMO (NEutrino Mediterranean Observatory) Collaboration was set up in 1998 with the aim to carry out the necessary R&D towards a km^3 neutrino telescope in the Mediterranean Sea. The Mediterranean Sea seems the natural choice for detector installation, since from such latitudes the observation of the part of sky which is not accessible to ICECUBE [5], whose construction has started at the South Pole, is possible.

The NEMO Collaboration has initially focussed on the search and characterization of an optimal site for the apparatus installation (section 3) and on the definition of a general architecture of the detector which has been the subject of a detailed feasibility study. Then the activities have been directed to the complete design of the apparatus and to the implementation of all the necessary techniques for a full realisation.

Recently, a technological demonstrator campaign, NEMO Phase 1, has been launched, in an attempt to perform a field test of all the key solutions proposed for the km^3 apparatus, as will be illustrated in section 5.

3. Site selection and characterization

A careful selection of the site is the first step toward the installation of a km^3 neutrino telescope. The optimal site should be searched at a reasonable distance from the coast, at high depth, and should show low currents, a low level of sedimentation, good water quality as to light absorption and scattering. After an extended investigation of several promising sites in the Mediterranean, an optimal site was selected at about 80 km off the SE coast of Sicily, Italy in the Ionian Sea at a depth of 3500 m. More than 20 campaigns have been then performed in such site, in order to get a full characterization over a period of several years. These extensive surveys are illustrated in a dedicated presentation at this Conference [6]. This site is now being equipped with an electro-optical cable to the shore.

4. The detector architecture

The design of a large underwater neutrino telescope should fulfil several specifications: a) it should allow safe, relatively simple and cost effective deployment operations, so that the apparatus can be completely installed in a reasonable time and at an acceptable cost; b) it should allow routine maintenance of the detector as well as recovery of the structures which need refurbishment or reconfiguration; c) it should ensure a complete functionality of the apparatus, which requires a high-bandwidth data acquisition system, proper calibration systems to ensure that all accuracy specifications of the measurements are met and full remote-control of the sensors and electronics. Reliability is also a key point, as any upgrade of the already deployed structures is only possible at a large cost.

The design of the general detector architecture has been performed in an attempt to find a compromise between acceptable performance and technical feasibility of the detector. Such study has been therefore carried out in close contact with leading companies in the field of deep sea operations. As a result, a general layout of the apparatus was defined, which consists of a square array of structures called “towers”, described in more details in the next section, connected on the sea bed by means of a network of submarine cables and junction boxes.

The current design foresees 81 towers, spaced so that the whole apparatus covers a surface larger than 1 km^2, and connected by means of 10 junction boxes. The total number of photomultipliers will not exceed 6000.

Extensive computer simulations were performed in order to investigate the performance of the proposed detector. Such investigations were based on the ANTARES simulation package [7], which was adapted to the situation of a detector with a sensitive volume as large as 1 km^3 equipped with several thousands of photomultipliers. Remarkably, these simulations show that a “tower” implementation of the apparatus can achieve comparable performance as for a regular array of an equivalent number of photomultipliers distributed in the same volume.

Several different arrangements of photomultipliers were then simulated and compared, in order to optimize the apparatus geometry. Here we show only results for the configuration with 140 m distance between adjacent towers. In particular, Figure 1 shows the neutrino and muon effective area of the apparatus, as well as the angular resolution estimated for muon track reconstruction, as a function of the particle zenith angle in different energy ranges.

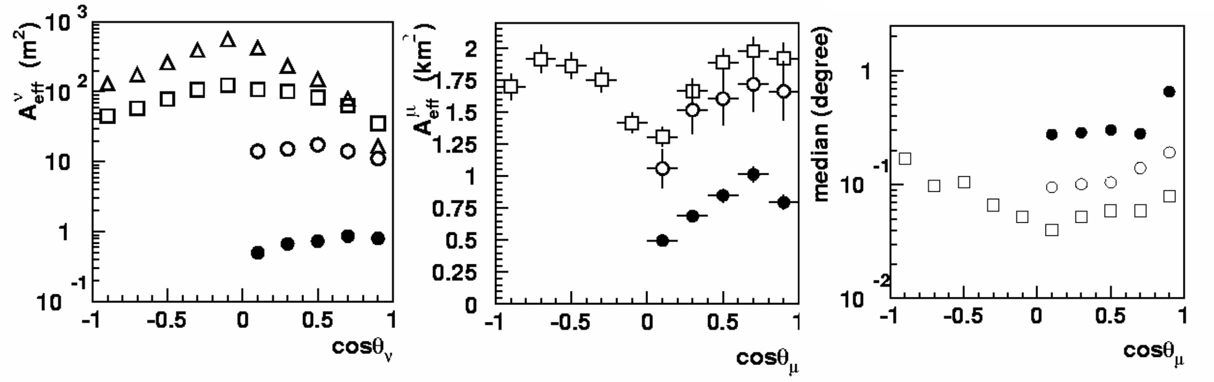

Figure 1. Effective neutrino area A^{ν}_{eff} (left), effective muon area A^{μ}_{eff} (center) and median angle between the simulated and reconstructed muon directions (right), as a function of the particle zenith angle for different energy ranges of the neutrinos or muons (for all panels, full circles: $10^3\div10^4$ GeV; open circles: $10^4\div10^5$ GeV; open squares: $10^5\div10^6$ GeV; open triangles: $10^6\div10^7$ GeV). The muon energy is defined as the particle energy at the point of closest approach to the center of the apparatus.

The very good values of angular resolution shown in Figure 1 become smaller than 0.1° at energy larger than 100 TeV. It turns out therefore that the proposed apparatus layout looks like a very promising solution for high-energy neutrino astronomy. The sensitivity to neutrino fluxes from point-like sources for such an apparatus has been also estimated [8].

5. NEMO Phase 1

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 has been launched in order to implement a reduced-scale demonstrator of the apparatus. This project is called NEMO Phase 1.

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 the coasts of Sicily, is already equipped with an electro-optical cable connected to a shore station inside the Port of Catania. In January 2005, 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 since then [9].

The NEMO Phase 1 apparatus comprises two instrumented towers connected by a network of underwater cables and junction boxes, so as to reproduce the typical connection layout foreseen for the full km^3 apparatus.

The towers consist of three-dimensional semi-rigid structures composed by a sequence of storeys, which host the optical modules and the instrumentation, interlinked by a system of cables and anchored on the seabed. Such a structure is kept vertical by appropriate buoyancy on the top. In the layout proposed for the km^3, each tower will comprise 18 storeys spaced vertically by 40 m. For the first prototype tower of NEMO Phase 1 the number of storeys will be limited to 4, while the second one will be equipped with 16. In any case, the first storey will be at about 150 m above the sea bottom.

Each storey, which is 15 m long, will host two optical modules at each edge. Such modules consist of pressure-resistant glass spheres which contain a large (10”) hemispheric photomoltiplier and its front-end electronics. The optical modules will be arranged such that one photomultiplier is oriented downward and the second one is oriented horizontally at each edge of each storey. In its working position, each storey will be arranged perpendicularly with respect to the adjacent ones. This solution ensures a certain degree of rigidity to the whole tower.

An innovative design has been exploited for the junction boxes, which will be built as two containers inserted one into the other: a pressure-resistant steel vessel inserted inside a corrosion-resistant fibreglass container filled with mineral oil. This solution will allow to build components which are well suited to work in the severe conditions of high-depth salted water, but with a sensible cost decrease if compared to more standard titanium containers.

The data communication system exploits a standard, synchronous telecommunication protocol (SDH). A Dense Wavelength Division Multiplexing (DWDM) system has been designed to allow high-bandwidth point-to-point bidirectional communications between the shore and each single storey of the towers, with a reasonable number of optical fibres. The towers will also feature: a redundant positioning system, which includes compasses, inclinometers and acoustic triangulation devices; a timing calibration system, which can illuminate the optical modules with calibration pulses delivered on a dedicated network of optical fibres; and several environmental sensors.

6. Conclusions

The realization of a km^3 telescope for high-energy astrophysical neutrinos is a challenging task which requires new solutions for the detector implementation and the deployment operations.

The NEMO Collaboration has performed a very extensive activity toward the realization of a km^3 Cherenkov detector in the Mediterranean Sea. An optimal site has been found close to the coast of Sicily and has been extensively explored. This site is now being equipped with an electro-optical cable to the shore.

The complete layout of the apparatus has been defined. Innovative solutions for the main mechanical structures, the towers and the junction boxes, have been designed. The power system, the data acquisition system, the positioning and timing calibration systems have been also defined and developed at a prototype level. All these investigations show that a km^3 apparatus is technically feasible at a reasonable cost.

The NEMO Phase 1 project is under way at a test site at a depth of 2000 m close to the coast of Catania, Italy. The aim of this activity is to test all the key solutions proposed for the implementation of the km^3 detector. This program is announced to be completed by the end of 2006.

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