Status of the NEMO project

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Abstract. The NEMO (NEutrino Mediterranean Observatory) collaboration is conducting an intense activity to develop technical solutions for the deployment of km^3 scale neutrino detector in the Mediterranean Sea. The study of underwater networks of electro optical cables and connectors, mechanical layout and data transmission, is conducted together with leading companies in the field of submarine operations. The collaboration has also selected and characterised an optimal marine site in the region of Capo Passero at 3300 m depth, near the Sicilian Coasts. In addition, during year 2001, the collaboration has equipped a *Test Site* facility 28 km offshore the town of Catania. The facility will be fundamental for prototyping mechanical structures and data transmission systems.

1 The challenge for a Mediterranean km^3 telescope

At present the major effort in the field of neutrino telescopes has been conducted by two collaborations: AMANDA (Andres *et al.*, 2000), that already deployed a small scale detector at the South Pole, and BAIKAL, the pioneer underwater detector deployed in the Siberian lake Baikal (Domogatsky *et al.*, 2001). The ICECUBE collaboration (see ICECUBE proposal) is going to extend the dimensions and capabilities of AMANDA aiming at a km^3 neutrino telescope in the Southern hemisphere. In the Mediterranean Sea, a region which offers optimal conditions over a worldwide scale to locate the km^3 detector, three collaborations are active: NESTOR (Resvanis *et al.*, 1993); ANTARES (see ANTARES proposal) and the NEMO group of INFN. The ANTARES collaboration (which includes several researchers from NEMO) is going to deploy a 0.1 km^2 detector in the vicinity of Toulon (France) at ∼2400 m depth starting from year 2002.

The contemporary operation of ICECUBE together with a future Mediterranean km^3 will offer the optimal conditions for neutrino astronomy providing the full coverage of the sky. The two detectors will also have complementary characteristics: the long light absorption length of the Antarctic ice will permit good energy resolution, the long light scattering length of the Mediterranean abyssal seawater will permit excellent angular resolution.

The main work towards the underwater km^3-scale detector is a matter of developing submarine technology. In deep sea, indeed, the lifetime of most materials used for surface applications is strongly reduced; new materials and techniques are indispensable together with long term tests. The construction and operation of ANTARES 0.1 km^2 will provide the first real test for such apparatuses. In the same time NEMO is acquiring technologies and support for the construction of the km^3 telescope. After three years of activity the NEMO collaboration has presented: *i*) an optimal deep sea site for the deployment of the telescope, selected and characterised as a function of seasonal variations; *ii*) a preliminary design of the detector mechanical structure and submarine connections; *iii*) Montecarlo simulations of the detector efficiency as a function of the geometry and environmental parameters; *iv*) a preliminary design of data and power transmission system to/from the shore. This work has been conducted together with industrial partners leader in the field of submarine operations (*SAIPEM-SASP-SONSUB* groups of the Italian *Ente Nazionale Idrocarburi*, *Ocean Design*), telecommunication technology (*ALCATEL*, *NEXANS*), scientific institutions (*Istituto Nazionale di Oceanografia e Geofisica Sperimentale* - OGS, *Istituto Nazionale di Geofisica e Vulcanologia* - INGV, *Consiglio Nazionale delle Ricerche* - CNR) and with the support of the *Italian Military Navy* and *NATO-SACLANTCen*.

2 Site selection and characterisation

The choice of the location for the km^3 scale neutrino telescope is such an important task that careful studies in candidate sites must be performed in order to identify the most suitable one. The site has to be deep enough to filter out a large part of the down-going atmospheric muons. At 3500 m

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depth, the atmospheric muon flux is reduced by ∼5 orders of magnitude compared with surface; this would dramatically reduce the number of downgoing muons eventually reconstructed as *fake* upgoing events by the track reconstruction algorithms. At this depth, there will be also an enhancement of the capabilities of the telescope to detect horizontal tracks, which are expected to overcome upgoing events at energy $\geq$ 10 PeV (Klein and Mann, 1999). The site has to be close enough to the coast. The data and power transmission to/from shore, are performed via electro-optical multi-fiber cables. At distances closer than 100 km from the coast, commercial systems allow data and power transmission without special hardware requirements (e.g. amplifiers) which would increase the cost and reduce the reliability of the project. Moreover, the proximity of the detector location to the coast and to existing infrastructures (well equipped ports and international laboratories) will reduce the time and the cost of sea operations. On the other hand, one should also consider the possible occurrence of catastrophic submarine events such as *turbidity* and *density* currents that may occur near the continental shelf boundary. This suggests to locate the detector far enough ($\geq$ 30 km) from shelf breaks and canyons. The collaboration has preliminary selected three sites in the Tyrrhenian Sea (named Ustica, Alicudi and Ponza) and Capo Passero in the Ionian Sea . In these sites we measured light attenuation and absorption as a function of depth over nine wavelengths, see map and details in (Capone, Riccobene *et al.*, 2002). Results suggest that a large region located ∼ 80 km SE of Capo Passero (Sicily) is excellent for the construction of the detector. The bathymetric profile of the region is extremely flat over hundreds km^2, with an average depth of 3350 m. Blue light (412 nm) attenuation length value exceeds 35 m and absorption length is close to 70 m; we observed seasonal changes of the order of 20% (in March 2000 we measured an attenuation length of 42 m). In this region the collaboration has been monitoring submarine currents since August 1998. Data show that the average currents value is ∼ 3 cm/sec with maximum intensity of about 10 cm/sec (Capone *et al.*, 1999). The sedimentation rate measured in the period August-December 2000 is ∼ 20 mg m^{-2} day^{-1}, about hundred times less than the values measured during summer in the Northern Tyrrhenian Sea. A short term measurement (40 days in the period January-February 2000) has shown a negligible effect of bio-fouling on optical surfaces. At present several measurements are going on and they will continue during 2002 and 2003. The characterisation programme will be implemented with: new optical measurements made with the *AC9* trasmissometer, as described in (Capone, Riccobene *et al.*, 2002), and two new detectors: an attenuation meter called NERONE (Cordelli *et al.*, 2001) and a light scattering meter called DEWAS (Pappalardo *et al.*, 2000); measurements of optical background: bioluminescence and Čerenkov light produced by β-radioisotopes dissolved in seawater (e.g.^{40}K); measurements of dissolved compounds and particulate; measurements of deep sea currents, sedimentation rate and fouling.

3 Detector Layout

The km^3 neutrino telescope under design by the NEMO collaboration contains ∼ 4000 PMTs, has (for TeV muons) an effective area greater than 2km^2, an height of ∼ 600 m and is located at ∼ 3500 m depth. The mechanical structures, the deployment procedure, the data transmission system, the electronics are under design to fulfill the following criteria: allow an easy and fast deployment of the detector (to be completed within ∼ 4 years); transmit, without data reduction, all PMT signals and slow controls to the shore; permit the recovery of structures for maintenance; reduce the costs. The neutrino telescope complex will consist of:

- a shore laboratory, located in the village of Porto Palo (Sicily), hosting the power suppliers, and part of the slow control and data transmission systems;

- the underwater detector itself consisting of an array of 64 vertical structures (called *towers*, hosting 64 PMTs each) arranged in a 8 × 8 square lattice with a spacing of about 200 m (see figure 1);

- a network of underwater cables consisting of a main electro optical cable, from the shore to the proximity of the detector, and several secondary cables connecting the main cable to the the *towers*.

The spacing of about 200 meters between towers has been selected as a good compromise between the large distances required by *ROV* (Remote Operating Vehicles) during the deployment/maintenance operations and the expected detection efficiency of the apparatus.

3.1 Electro optical cables

NEXANS and INFN have proposed to use an armoured electro-optical cable of about 100 km length with 48 optical fibres (OF) plus 3 or 4 electrical conductors, capable to transport ∼80 kW power load. This number of optical fibers permits the data transmission rate and the level of redundancy described in section 3.3. The number of electrical conductors to be used is still not defined; the collaboration is evaluating different technical solutions (AC Voltage, DC Voltage with sea return, DC Voltage with cable return): simulation of the complete system (including cable transformer, AC/DC and/or DC/DC converters, sensors and power suppliers) are running.

The underwater termination of the main cable, called *backbone*, is equipped with 8 branching units (BU). Each BU connects the *backbone* to a junction box (JB) that serves 8 towers. The junction boxes are connected one to each other forming a safety control loop. The distance between a branching unit and its neighbour junction box is about 40 meters, the distance between neighbour junction boxes is 200 meters.

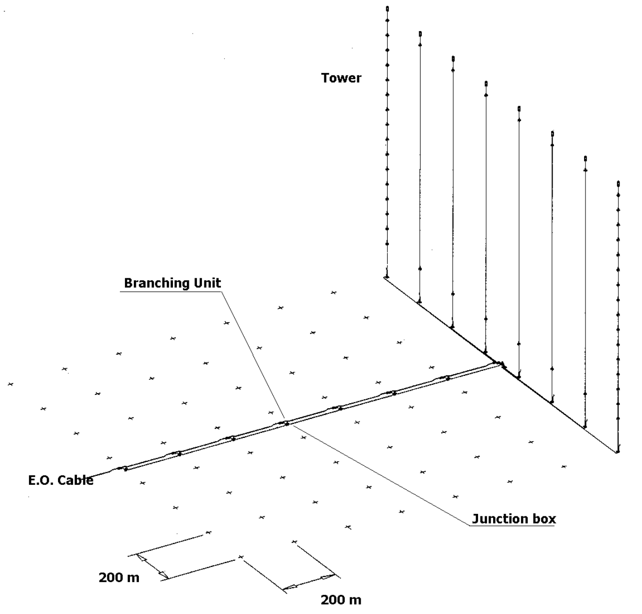

Fig. 1. The layout of cabling: the *backbone* cable comes through the 64 towers. The main cable is spliced by means of 8 branching units and 8 junction boxes, each BU-JB pair serves 8 towers.

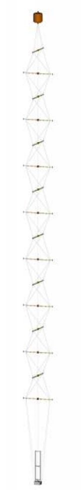

Fig. 2. The NEMO tower is designed for easy deployment and recovery. It has 16 arms, in glass fibres, connected through cables and it is pulled up by a buoy. The structure carries 64 OMs (four per beam) upward and downward looking.

3.2 Mechanical structures

The NEMO tower (see figure 2) has an innovative structure, 750 m high, composed by: a base, which acts as an anchor and hosts the tower optical communication system; 16 beams (or *arms*) vertically spaced by 40 meters one from each other, displaced between 150 m and 600 m from the seabed; a buoy, located above the highest beam, that pulls the whole structure. The arms of the NEMO tower have a tubular shape and are fabricated in composite material (glass fibers) to prevent corrosion during underwater lifetime. The use of composite material is also preferable for: lightness, stiffness, resistance, acoustic neutrality in water (important for the acoustic positioning system). Each beam is kept in tension by four cables connected to the higher and to the lower neighbours: this configuration ensures both flexural and torsional rigidity during deployment and underwater lifetime.

The optical modules (one OM contains one PMT and its digitizing front-end) are displaced four per beam, two looking upwards and two downwards; foreseeing 64 OMs per tower, the total number of PMTs in the telescope should be 4096 (see figure 3). The beams are also equipped with instrumentation for oceanographic (and optical properties) monitoring and slow control sensors.

3.3 Data and power transmission

The electro-optical connections described above distribute the power from the shore laboratory to all the OMs, to the slow control and to the oceanographic instrumentations, these connections also allow the data transmission between the telescope and the shore laboratory. The data/power transmission system has been designed considering: reliability, flexibility, possibility of expansion and easiness of maintenance. *ALCATEL* proposed a commercial telecommunication system, according to the specifications of NEMO. This implies the use of standard communication protocols, allowing high redundancy level, auto re-configuration of the system in case of malfunctions or breaks, high MTBF, high transmission rates (8 output lines at 20 Gbps) and low power consumption ($<$ 500 W per tower).

The digital output produced by the 64 OMs of each tower are grouped and converted by electro-optic front-end modules, that are connected the tower base module (working at 2.5 Gbps). The signals coming from 8 towers are concentrated into one DWDM (Dense Wavelength Division Multiplexer) module installed inside each junction box. Eight specular modules are installed on the shore. The shore modules demultiplex the optical signals and permit to recover the digital outputs of the 4096 OMs.

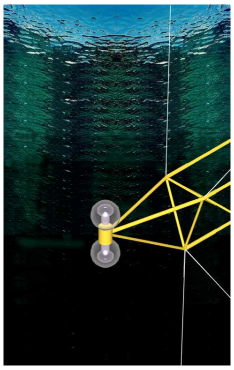

Fig. 3. Four PMTs (2 upward looking and 2 downward looking) will be positioned at the tips of each arm.

4 Detection Efficiency

The activity of the engineering team has been conducted in strong connection with physicists. NEMO has developed an extremely flexible Montecarlo code that allows frequent changes of the detector configuration, PMT resolution, PMT dimensions and seawater optical properties (De Marzo *et al.*, 2000). In order to reduce the CPU time the code extensively uses parametrisations for the muon propagation and Čerenkov light production. The software team has tested the performances of several configurations of phototubes, according to engineering constraints (deployment procedure, costs, reliability, etc.). The present status of simulations shows that the detector instrumented with $\sim$ 4000 PMTs described in section 3.2, located in a site with the optical parameters measured in Capo Passero, may achieve a trigger area larger than 2 km^2 for $E_\mu > 100$ TeV and an angular reconstruction resolution $< 0.5°$ (see figure 4).

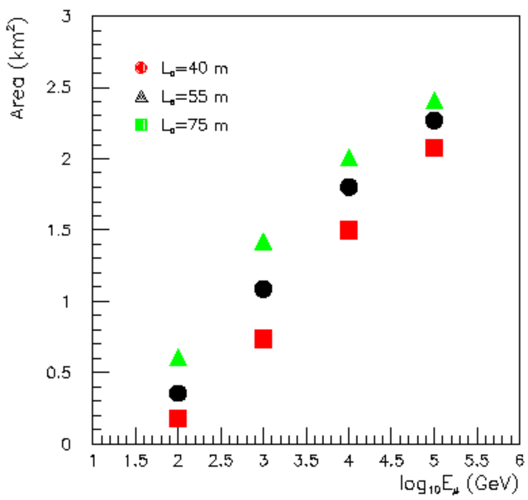

Fig. 4. Trigger area as a function of muon energy for the detector design (64 towers, 4096 OM) described in the text. The plot shows the influence of light absorption length in the detection efficiency.

5 The Test Site in Catania

In September 2001 NEMO has installed a *Test Site* at 2000 m depth, $\sim$25 km E offshore the town of Catania (where the INFN - *Laboratori Nazionali del Sud* are located). The shore laboratory, built inside the port of Catania, is connected to deep sea through an electro-optical cable consisting of 10 optical fibers (OF) and 6 electrical conductors (EC). A submarine splitter box divides the cable into two branches. One branch (6 OF, 4 EC) is devoted to NEMO and the other one (4 OF, 2 EC) to *GEOSTAR*, a seismologic monitoring station operated in collaboration with INGV (see GEOSTAR webpage). Within 2002 the station will be equipped with underwater ROV operated connectors. From that moment the station will be available to test prototypal structures of NEMO: optical modules, electronics, data/power transmission systems, underwater connectors and deployment procedures.

6 Conclusion

The Mediterranean neutrino telescope could have excellent capabilities to detect events with angular resolution of the order of few tenth of degree. This detector will look at sources located in the opposite hemisphere with respect to the proposed ICECUBE detector. The decisive effort for the underwater km^3 is still needed but close. NEMO is demonstrating, indeed, that the technological challenges could be overcome within few years. Moreover the collaboration has performed a careful long term study of oceanographic and optical properties in the region of Capo Passero, showing that the site is optimal to host the Mediterranean km^3 detector. It must be mentioned also that the installation of the km^3 underwater telescope will give to oceanographers a unique opportunity to study the mysterious world of deep-sea abysses.

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