NEMO: NEutrino Mediterranean Observatory

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Abstract. The NEMO (NEutrino Mediterranean Observatory) Collaboration aims at R&D for the construction of an underwater Čerenkov neutrino detector. Great attention is dedicated to projects for the apparatus electronics and mechanical structures. At this stage the main effort of the collaboration is devoted to the selection and characterization of a marine site suitable for the detector deployment. Several sites near the Italian coast have been investigated. In addition, during year 2001, the collaboration will install a test site at 2000 m depth near the Sicilian coast. The facility will be fundamental to study the deep sea environment and to test the reliability of submersed structures.

1. Underwater Telescopes for Neutrino Astronomy

In the last decade, the observation of cosmic rays of Very High Energy, Ultra High Energy, and even with energy greater than 10^{20} eV, has attracted the attention of the scientific community (Cronin et al., 1997). The sources of such events are supposed to be the most luminous and energetic objects observed in the universe such as Gamma Ray Bursters and Active Galactic Nuclei. The detection of intense extra galactic gamma ray sources with energy ~ 10 TeV seems to confirm this hypothesis. If these high energy photons are generated through the production and decay of neutral pions, it is reasonable to expect, from the same sources, an associated flux of high energy neutrinos, generated through the production and decay of charged pions.

It has been demonstrated that the GZK mechanism (Greisen, 1966) does not allow the observation of photons with energy > 10 TeV and protons with energy $> 10^{18}$ eV from sources located at cosmological distance. On the contrary, weakly interacting neutrinos are not significantly absorbed in the universe and are not deflected by the intergalactic magnetic fields: the identification of neutrino events will allow trace back to the source. This is the goal of the new exciting field of neutrino astronomy (for a complete review, see (Gaisser, Halzen, Stanev, 1995)). Already in 1960, Markov proposed to use seawater and the rocks of seabed as a huge target to detect UHE neutrinos, and to look at charged current (CC) weak interactions between neutrinos and water or rock nuclei. If one looks at outgoing muons (and anti muons), those particles carry $\sim 50\% \div 60\%$ of the neutrino energy and preserve the neutrino direction. The neutrino-induced muon propagates in seawater for several km ($\sim$ 10 km at 10 TeV) and generates, along its path, Čerenkov light that can be detected by a lattice of optical sensors (e.g. large area photo multiplier tubes, PMTs). In order to identify faint neutrino fluxes from astrophysical sources the detector should have an effective area $\geq 10^6$ m^2. Several calculations show that the reconstruction of neutrino energy and direction, is affordable with a detector instrumented with limited number ($\sim$ 7000) of PMTs displaced over a volume of ~ 1 km^3. Such detectors are usually named km^3 neutrino telescopes. Underwater telescopes may allow the reconstruction of the neutrino direction within a few tenths of degree and the reconstruction of neutrino energy, within an order of magnitude. The expected angular resolution will allow a catalogue of the expected neutrino sources in the sky to produce a map and search for correlations with the known gamma sources to be made. The previous statements make the construction of the km^3 neutrino telescope one of the main goals of the astro-particle physics today.

2. The NEMO Project

Several collaborations are involved in neutrino astronomy. The major effort in this field has been conducted up to now by AMANDA-ICECUBE at the South Pole (Spiering, 2000) and BAIKAL-NT, located in lake Baikal (Russia) (Spiering, 2000), the first undewater-ice detectors which observed neutrino events. In the Mediterranean Sea, a region which offers optimal conditions over a worldwide scale for locating the detector, three collaboration are active: NESTOR (Resvanis, 1993) which, since 1990, aims for the construction of a 10^4 m^2 demonstrator detector near the Greek coast at 3800m depth; ANTARES collaboration[1] which is working to build a 0.1 km^2 demonstrator in the vicinity of Toulon (France) at 2500 m depth; and NEMO. The realisation of the ANTARES demonstrator will be a fundamnetal step to acquire experience in submarine technology and to start the activity of neutrino astronomy in the Mediterranean area. ANTARES and NEMO collaborations are also developing new technologies for the realization of the km^3 detector in the Mediterranean Sea. In particular NEMO is an R&D is project funded by INFN which concerns: *i*) a complete characterisation of several deep sea sites in the Mediterranean area; *ii*) Monte Carlo simulation studies of the detector capabilities; *iii*) design of low power consumption, high rate and high reliability electronics for

[1] see ANTARES Collaboration web page: *http:antares2.in2p3.fr*

data acquisition and transmission to shore; *iv*) design of mechanical and connection layout of the detector.

Concerning the detector design, the collaboration is simulating the performances of various arrays of phototubes. Several geometrical configurations, instrumented with different number of large area PMTs have been tested. The simulations show that a detector instrumented with $\sim$ 7000 PMTs arranged in a lattice of square towers (side =20 m, height= 300 m) placed at a distance $\sim$ 200 m one from the others, may achieve an effective volume greater than 3 km^3 for E>100 TeV muons, and an angular reconstruction resolution $< 0.5°$. At this stage the needed CPU time to run the simulation is a very important parameter to allow freqeuent change of the detector configuration. For this reason parametrisations have been used to describe muon propagation and Čerenkov light production (DeMarzo et al., 1999). INFN scientists are also collaborating with industrial partners, leaders in telecommunications (*ALCATEL*) and deep-sea operation (*SONSUB*) to design a mechanical layout and connection net which may allow easy and fast deployment (within few years) and the manteniance of the detector. Marine tests and R&D are also carried out with the helpful collaboration of Marina Militare Italiana and NATO-Saclantcen.

3. Deep Sea Site Selection

The choice of the km^3 scale neutrino telescope location is such an important task that careful studies in candidate sites must be performed in order to identify the most suitable one. The NEMO Collaboration is going to conclude a two year program to characterise selected deep-sea sites along the Italian Coast. The Collaboration has identified four areas corresponding approximately to the coordinates (figure 1):

- 35° 50 **N** 16° 10 **E** in the Jonian Sea, South-East of Capo Passero
- 39° 05 **N** 13° 20 **E** in the Tyrrhenian Sea, North-East of Ustica island
- 39° 05 **N** 14° 20 **E** in the Tyrrhenian Sea, North of Alicudi island
- 40° 40 **N** 12° 45 **E** in the Tyrrhenian Sea, South of Ponza island.

The characterisation programme includes measurements of deep sea water optical properties: absorption and diffusion; measurements of optical background: bioluminescence and Čerenkov light produced by β-radioisotopes dissolved in seawater (e.g. ^{40}K); measurements of site oceanographic properties: water temperature, water salinity, dissolved

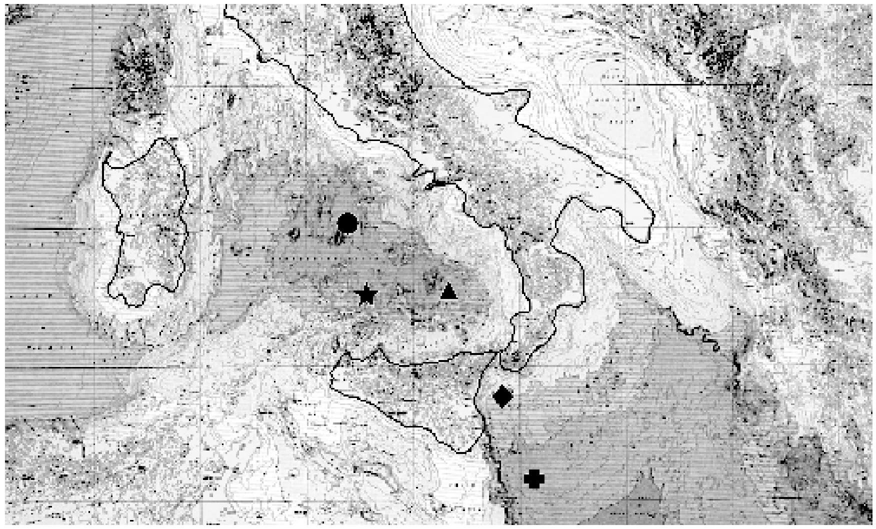

Figure 1. Location of the four sites selected by the NEMO collaboration as candidates for the km^3 deplyment. Alicudi (triangle), Ustica (star), Capo Passero (cross), Ponza (circle). The "Catania test site" location is also shown (diamond).

compounds and particulate; measuremnts of deep sea currents, sedimentation rate, fouling. This work is fundamental since the site must satisfy several requirements.

The site has to be deep enough to filter out the low energy downgoing atmospheric muons. At 3500 m depth, the atmospheric muon flux is reduced by 5 order of magnitude; this would dramatically reduce the number of downgoing muons 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 ≥ 10 PeV. The site has to be close enough to the coast. The data and power transmission to/from shore, are obtained via electro-optical multi-fiber cables. At distances closer than 100 km from the coast, commercial systems allow data and power transmission without particular requirements (amplifiers) which would increase costs and reduce the reliability of the project. Moreover, the proximity of the detector location to the coast and to existing infrastructures (well instrumented ports and laboratories) will reduce the time and the difficulties 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, and locate the detector far (≥ 30 km) from shelf breaks and canyons.

3.1. Water Optical Properties

The site has to show good optical underwater properties. The detector effective area is indeed not only directly determined by the extension of the instrumented volume but is strongly affected by the light transmission in the water. A muon track crossing the water at a certain distance from the detector can be easily observed since the emitted Čerenkov photons have a non vanishing probability to reach the PMTs. Mainly two microscopic processes affect the propagation of light in the water: absorption and scattering. Light absorption directly reduces the effective area of the detector; the scattering has a negative effect on track reconstruction (based on the measurement of the photon arrival time on the Photon Detectors). To characterise the deep-sea water optical properties, we measure the absorption and attenuation coefficients, down to 3500 m under the sea surface, over 9 different wavelengths in the range 412÷715 nm. The basic device for our optical measurements is an *AC9 transmissometer* by *WetLabs*. During several cruises aboard the Research Vessel *URANIA*, we carried out measurements in all the above mentioned sites and in the vicinity of Matapan Abyss, near the Greek coast, a few miles from the site selected by the NESTOR collaboration. A preliminary analysis of collected data shows that the optical properties of deep-sea water in the selcted sites are not very different from pure water (Smith and Baker, 1981). A preliminary estimation of the measured absorption coefficient for blue light ($\lambda = 440$ nm) close to Capo Passero site at 3300 m depth is equal to 0.014 ± 0.003 m^{-1}, while the value of attenuation coefficient at the same wavelength is 0.025 ± 0.003 m^{-1}. These values will allow us to evaluate the light transmission length in water when the diffused light angular distribution will be known. In deep-sea water, light transmission suffers both from Rayleigh and Mie scattering. Assuming for Mie scattering a conservative value of the average diffusion angle ($< cos\vartheta >\sim 0.9$) we can evaluate a transmission length for blue light close to 60 m.

3.2. Sedimentation and Fouling

Another requirement is that the sedimentation rate in the selected region must have very low values. The presence of sediments in the water can affect, seriously, the performances of the detector. Sediments increase the light scattering and so worsen the track reconstruction angular resolution. Moreover, a deposit on optical surfaces which host photon detectors reduces the global detector efficiency. Micro-organisms in submarine environment could also produce fouling, a thin organic film formed in submersed surfaces. Fouling can trap deposited sedimets and quickly reduce the transparency of optical surfaces. Starting from

August 1999, sedimentation rate was measured in Capo Passro. The first data (August-December 1999) show that sedimentation rate is extremly low when compared to other coastal regions. Data confirms the suspected low biological activity in the central regions of Mediterranean Sea. In order to measure the effect of sediments and fouling on optical surfaces, NEMO has constructed a deep sea station that was deployed in Capo Passero from December 1999 to March 2000. The station, moored at 3300 m depth, was composed of two blue LEDs that illuminated an array of 14 photodiodes (PDs). The photodiodes were positioned at different angles inside a pressure resistant transparent sphere (of the same type that will be used to contain the PMTs). As a function of mooring time, fouling formed on the surface of the sphere would reduce the light collected by the PDs. Data analysis of the first 40 days shows a constant value of the light collected for all the PD. Therefore, biofouling appears to be negligible over this time scale.

3.3. Deep Sea Currents

The site has to be *quiet*, i.e. the water current has to show low intensity and stable direction. This is important because it does not imply special requirements for the mechanical structure; the detector deployment and positioning is easier if the water current is limited; the *optical noise* due to bioluminescence, mainly excited by variation of the water currents, is reduced. Current metre chains have been moored in the region of Capo Passero since July 1998. The used lines carry current metres located within few hundreds meters from the seabed (in the range that can be covered by the km^3 structures). The deep-sea water current measured over 18 months is quite stable in direction and intensity: the average value is about 2.8 cm/s, and the maximum value is lower than 20 cm/s.

4. NEMO Deep Sea test Site

The collaboration is also installing a test site in proximity of Catania (Sicily). A 25 km long electro-optical cable will connect the structures moored at 2000m with a laboratory located in the port of Catania, and with the Laboratori Nazionali del Sud of INFN located in the town of Catania. The structure will be devoted to implement deployment, connection and recovery techniques in deepsea, and to perform long-term tests for the electronics. A branch of the electro-optical cable is assigned to other experiments: GEOSTAR and CREEP. The first is devoted to the survey of geoseismic and volcanic phenomena occurring in the Etna region; the second will perform long-term measurements to study the creeping of rocks under extreme pressure.

5. Conclusion

The construction of an underwater neutrino telescope seems to be feasible within the next ten years. However a strong technological effort is still needed. Careful and continuous survey of oceanographic and optical properties in few selected sites must be performed in order to choose the best location for the detector. A neutrino telecope located in a selected region of the Mediterranean Sea could have excellent capabilities to detect events with angular resolution of the order of $\sim 0.4°$. This detector could also look at sources located in the opposite hemisphere with respect to ICECUBE. Moreover, a detector moored at depth greater than 3000m could successfully search for E>10PeV horizontal events. It must be mentioned also that the installation of the km^3 underwater telescope will give other scientists a unique opportunity to study the mysterious world of deep-sea abysses.

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