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Site characterization for a km^3 scale deep underwater astrophysical Neutrino observatory in the Mediterranean Sea

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Abstract

In the next decade the construction of a kilometer-scale Astrophysical Neutrino Observatory in the Mediterranean Sea could become a reality. NEMO Collaboration has been funded both to study the characteristics of some deep sea Mediterranean sites, close to the Italian coast, where the kilometer-scale Cerenkov Detector could be located, and to develop technologies relevant for its design and optimization. Results obtained so far and the program of work for the near future will be described.

1 Introduction.

One of the open problems in Astro-Particle Physics is the origin of very high-energy particles in cosmic rays. Cosmic ray spectrum shows events with energy in excess of 10^{20} eV (ref. N.N. Efimov et al., 1991, D.J. Bird et al., 1993). Gamma Ray Astronomy has been able to identify few extra-galactic accelerators able to produce high-energy photons. If high-energy photons are generated through the production and decay of neutral pions it is reasonable to expect, from the same sources, an associated high-energy neutrino flux through the production and decay of charged pions. Neutrinos, as well as photons, being not deflected by intergalactic magnetic fields, offer the possibility to identify their sources through the "source tracking back", i.e. the "neutrino astronomy". Neutrino astronomy will complement and extend the traditional gamma rays astronomy. High-energy gamma-rays fluxes are reduced, in intergalactic space, by the interaction with the background infrared light. Weekly interacting neutrinos will escape these interactions and will allow to explore regions of the universe invisible with the photon detection. More than 20 years ago V. S. Berezinskii and G. T. Zatsepin (ref. V. S. Berezinskii and G. T. Zatsepin, 1977) proposed to build an underwater Neutrino Telescope based on the detection on Cerenkov light generated by neutrino induced high energy muons. It is clear today that the identification of neutrino fluxes expected from astrophysical sources requires a detector with an effective area close to 10^6 m^2 instrumented along a distance comparable to the range, in water, of the high energy (~1000 TeV) muons. A detector of such dimensions, usually called a "Km^3 Neutrino Telescope", is one of the main goals of the Astro-Particle Physics today. Mediterranean Sea offers optimal conditions, on a worldwide scale, for locating an underwater neutrino telescope. Along the Italian coasts there are several places, at depths beyond 3000m, potentially interesting to host an undersea neutrino telescope. The choice of the Km^3 scale neutrino telescope location is such an important task that careful studies of candidate sites must be carried out in order to identify the most suitable one. NEMO Collaboration has started a two years program to characterize deep-sea Italian sites that could be appropriate for the construction of a deep-sea high-energy neutrino detector. We will study deep-sea water optical properties (absorption and diffusion) and the sites environmental properties: water temperature, biological activity, water current, salinity and sedimentation.

2 Selecting a deep-sea site for Km^3 size Neutrino Telescope.

The selection of the site where the Km^3 detector can be located implies several requirements.

a) the site has to be deep enough to filter out the down-going atmospheric muon background to allow the selection capability of up-going tracks (originated from up-going neutrino interactions in the Earth below the detector). The needed background rejection is function of the muon angle, of the muon energy and depends also on the capability of the muon reconstruction program to correctly distinguish up-going tracks from down-going ones. At 3500m depth under the Sea level the atmospheric muon flux is reduced by 5 order of magnitudes. If the probability of reconstructing as up-going a genuine down-going muon is lower than 10^{-5} we will be able to isolate events due to up-going neutrinos.

b) the site has to be close to the coast. The data transmission to the on-shore laboratory, as well as the transmission of power from the laboratory to the off-shore detector, will be obtained via an electro-optical multi-fibre cable. These kind of cables, generally used for communication and data transmission, are expensive and require special care in their deployment. The transmission of data over distances less than 100 km is possible, with DFB laser, without any signal amplifier. We have also to consider that being too close to the coasts could give origin to some difficulties related to the eventual presence of "turbidity" and "density" currents on the continental shelf boundary.

c) the site has to show good optical underwater properties. The detector effective area is 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 about 50m distance from the detector can be easily observed since the emitted photons have a non vanishing probability to reach the Optical Sensors. 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 tracks reconstruction (based on the measurement of the photon arrival time on the Photon Detectors).

d) the "sedimentation" 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 the sensitive part of Photon Detectors reduces the global detector efficiency.

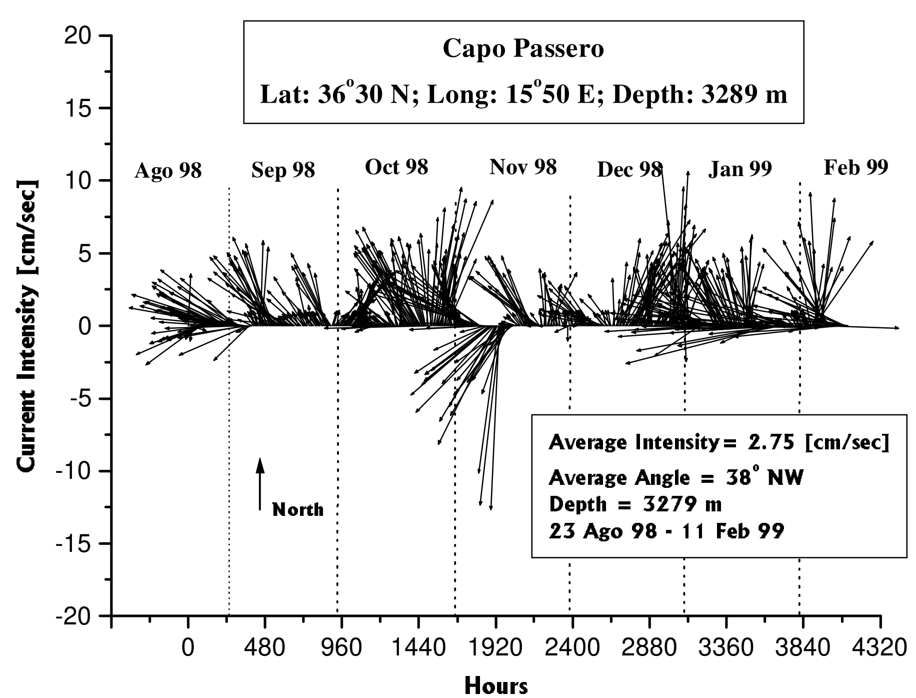

Figure 1 - Deep Sea current velocity in Capo Passero site over six months time

e) the site has to be "quiet", i.e. the water current has to show low intensity and stable direction. This is important for several reasons:

- it does not imply special requirements on 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

In the Mediterranean Sea we have identified four sites, close to the Italian coast, that could be appropriate for the construction of the Km^3 astrophysical neutrino detector. Approximately the co-ordinates of these sites are:

- 35° 50' N, 16° 10' E in the Ionic Sea, South-Est of Capo Passero in Sicily
- 39° 05' N, 13° 20' E in the Tyrrhenian Sea, North-Est of Ustica island (Sicily)
- 39° 05' N, 14° 20' E in the Tyrrhenian Sea, North of Alicudi island (Sicily)
- 40° 40' N, 12° 45' E in the central Tyrrhenian Sea, South of Ponza island (central Italy)

2.1 **Deep-Sea current measurements.** Since July 1998 we have started a campaign of study in the selected sites to obtain the information listed above. We have positioned in the region of Capo Passero, at about 3300m depth, a set-up made by two ANDERAA RCM8 current-meters positioned respectively 10m and 100m above the Sea bottom. The current velocities measured by the two instruments are in very good agreement. The deep-sea water current measured over six moths is quite stable in intensity (the average value is about 2.8 cm/s) and direction (the water flows from SE to NW and the average angle is 38° NW) as shown in Figure 1. The measurement is still going on. We plan to collect data over more than one year in order to observe, eventually, seasonal dependence of deep-sea currents.

2.2 **Deep-Sea water optical properties.** To characterize the deep-sea water optical properties we measured the absorption and attenuation coefficients, down to 3500m under the sea surface, at 9 different wavelengths in the range 412÷715 nm. The basic device for these optical measurements is an AC9 "transmissometer" by WetLabs. This instrument was connected to a CTD (Ocean MK317, by IDRONAUT) able to record data on Depth, water Temperature and Salinity. The setup was connected, in telemetry, to a data acquisition system on sea surface. With this setup during several cruises of the Italian Research Vessel URANIA we have been able to collect data in two sites close to Ponza island, in two sites close to Capo Passero and in the vicinity of Matapan Abyss (Eastern Ionian Sea). The AC9 transmissometer is able to measure, via dual path measurements, absorption and

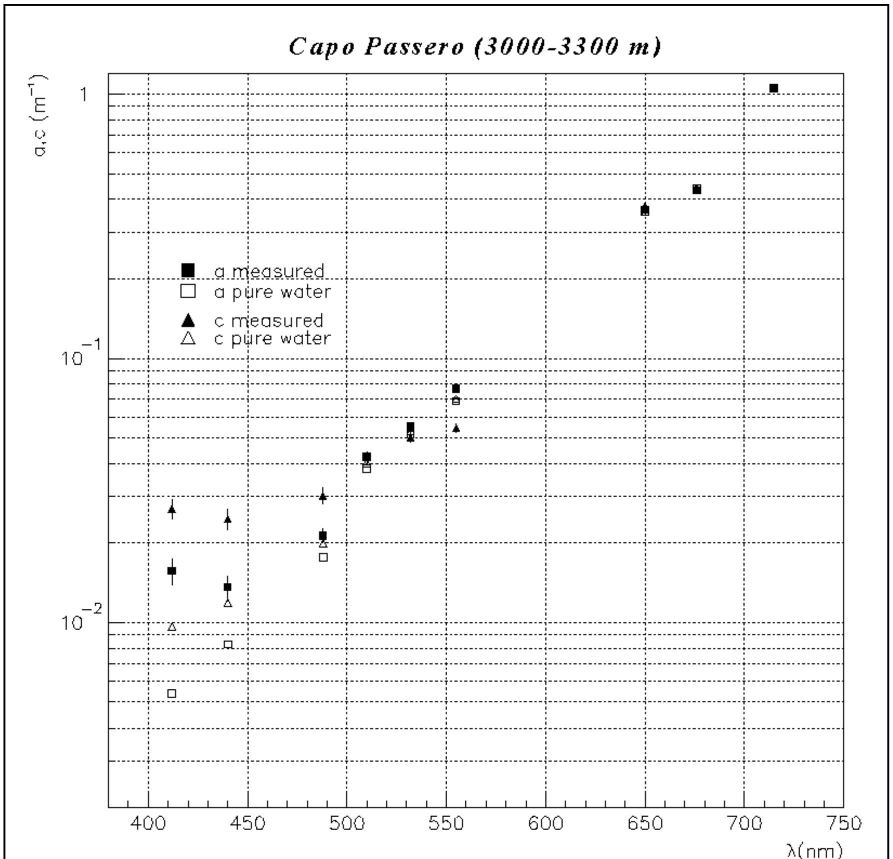

Figure 2 - Ligth absorption and attenuation coefficient in Capo Passero deep-sea water as function of wave-length

attenuation coefficients with good accuracy (~10^{-3} m^{-1}) once it is carefully calibrated. In Figure 2 we compare values of absorption ($a(\lambda)$) and attenuation ($c(\lambda)$) coefficients measured in the region of Capo Passero to the pure water coefficients (ref. Pope 1993, Bulteveld, et al.). A preliminary analysis of data collected in Ponza and in Capo Passero shows that the optical properties of deep-sea water in the two sites are close to the pure water ones. The measured absorption coefficient close to Capo Passero site at ~3300m depth) amounts to $a(440)= 0.014\pm0.003$ m^{-1}, while the value of attenuation coefficient in the same site is $c(440)= 0.025\pm0.003$ m^{-1}. These values will allow 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 for Rayleigh and Mie scattering. Assuming for Mie scattering a conservative value of the average diffusion angle ($\langle\cos\vartheta\rangle \sim 0.9$) we can evaluate a transmission length close to 60m.

3 Activity program for next future

3.1 **Diffused light angular distribution.** Absorption and attenuation coefficient values must be coupled to the knowledge of the scattered light angular distribution in order to estimate the effective attenuation in sea-water. An angular distribution characterized by a forward peak $\langle\cos\vartheta\rangle \sim 1$ will slightly affect photons trajectory even if scattering coefficient is big, on the contrary a wide angular distribution could affect seriously light transmission. We are building an apparatus devoted to such measurements. We plan to deploy it in the region of Capo Passero during 1999.

3.2 **Sedimentation rate and biofouling.** Bio-fouling and sedimentation are also relevant parameters in choosing the site for locating a Km^3 detector. ANTARES Collaboration has shown that biological growth on Optical Modules can reduce the transparency of glass surfaces, looking upwards, in few months and then light detection probability decreases significantly. We will deploy, in Capo Passero site during summer 1999, a deep-sea station to measure sedimentation and bio-fouling rate for a long term period (about one year). A standard sedimentation trap will acquire information on particulate density and dimension. Sedimentation information will be integrated over one month period. Bio-fouling rate will be evaluated measuring the transparency of a glass sphere containing an array of photodiodes and illuminated by a blue LED light. The deep-sea station will be also provided by a CTD and a current-meter in order to relate bio-fouling data to oceanographic parameters. An acoustic modem will allow us to download data up to the sea surface at any time. The station will provide data almost in real time.

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