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An instrument to measure the scattering effect on the Cherenkov light for a neutrino underwater telescope

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The relevant parameters for the site choice of an underwater neutrino telescope are discussed. The *in-situ* measurement of the scattering distribution of the Cherenkov light requires a suitable experimental setup. Its main features are described here.

1. NEMO UNDERWATER TELESCOPE FOR NEUTRINO DETECTION

1.1. The choice of the optimal site

Ultra-high energy neutrino detection is possible by detecting Cherenkov light coming from the rare secondary high energy charged leptons over a suitable km^3 scale underwater telescope[1]. A very thick sea-water substrate acts both as detector and shield of cosmic charged radiation. The choice of its location is such an important task that much effort has been and is currently spent in the characterization campaign of several sites in the Mediterranean Sea, in order to identify the most suitable one. Following are the main requirements the optimum site has to fulfil: high depth (ca. 3500 m); optimal underwater optical properties; low environmental background noise rates (^{40}K and bioluminescence); low sedimentation and bio-fouling, both corrupting track reconstruction resolution and detection efficiency; stability of hydrodynamical conditions (small seasonal variations of water currents, absence of turbidity); close coastal infrastructures. A test program has been planned and partially completed with a set of short/long term deep-sea measurements. Both the oceanographic parameters (sea currents, temperature, salinity, etc.), and the optical ones (light attenuation and absorption vs. wavelength and depth) are measured by using commercially available instrumentation. To measure the other parameters, such as the angular distribution of scattered light, the optical noise, the sedimentation and bio-fouling rates, customized experimental setups are required. The measurement program aims to characterize four Italian sites, whose co-ordinates are summarized in Table 1. Currently, the most promising site seems to be Capo Passero, where relatively large absorption and attenuation lengths (ca. respectively 70 m and 40 m @ 440 nm, very good if compared with ca. 100 and 80 m for pure fresh water at the same wavelength) couple with low deep sea current, very small seasonal variations of current velocity and direction and very small sedimentation rates ($7.62 \cdot 10^{-3}$ mm^3/dm^3 per year @ 2310 m depth) [2].

1.2. Deep-sea optical properties

Light traversing a water thickness x undergoes an attenuation given by:

$$I(x) = I_0 \cdot \exp(-x/L) \qquad (1)$$

where L is the water attenuation length; its value depends on wavelength and characterizes the site. Its maximum value is that of pure water attenuation length L_w [3]. In ocean water, the attenuation length is reduced by the presence of organic and inorganic particulate (L_p), chlorophyll and phytoplancton (L_c) and dissolved yellowish organic matter (L_y) [4]. At 3000 m depth the contribution of chlorophyll and phytoplancton seems to be negligible. Scattering is due to the medium inhomogeneities. We consider coherent and independent scattering, in which wavelength does not change and the particles are sufficiently far from

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Table 1
Italian sites candidate to NEMO deployment.

Site	*Coordinates*	*Depth(m)*
Alicudi (Tyrrhenian Sea)	39° 05′ N, 14° 20′ E	3400
Capo Passero (Ionic Sea)	36° 30′ N, 15° 50′ E	3600
Ponza (Tyrrhenian Sea)	40° 40′ N, 12° 45′ E	3400
Ustica (Tyrrhenian Sea)	39° 05′ N, 13° 20′ E	3400

each other (3 times the particle radius). The net effect is that intensities scattered by each particle must be added without regard to the phase. Moreover, if multiple scattering is allowed, we are facing with the radiative transfer problem. For unpolarized incident radiation and isotropic particles (scalar polarizability) we have the well-known Rayleigh scattered light intensity:

$$I(\vartheta) = \frac{2\pi[n(\lambda) - 1]^2}{\nu \cdot \lambda^4} \cdot [1 + \cos(\vartheta)^2] \qquad (2)$$

where n is the refractive index of water and ν the molecular concentration. The Rayleigh distribution fits quite well the experimental data for light scattering in pure or salt water (molecular scattering). The particulate presence in water makes more difficult and not ever analytically solvable the problem of the light absorption and scattering. A first-order description can be given by the Mie theory, concerning the problem of a diffusing sphere of arbitrary radius and refractive index. Even in this case, when an exact analytical solution can be established, its effective evaluation can require the use of complex and heavy computation.

2. THE SCATTER-METER

Because of the hostile environment the apparatus must be very robust, compact and low power consuming. Moreover, if the measurement of the scattering distribution both at small and large angles (Mie and Rayleigh components) is required, the detecting system must have a high dynamic range ($10^4 \div 10^5$) and a very good signal to noise ratio. These constraints strongly dictate the experimental setup scheme. The apparatus is contained inside a suitably reinforced stainless steel torus-like shaped container ($\phi \sim 60$ cm, $h \sim 25$ cm). In the surface of the central hole suitable optical windows allow the passage of an incident beam into the water and the collection of the scattered light. The wall is made by a borosilicate glass tube (internal diameter 115 mm, thickness 13 mm) lined by a stainless steel tube.

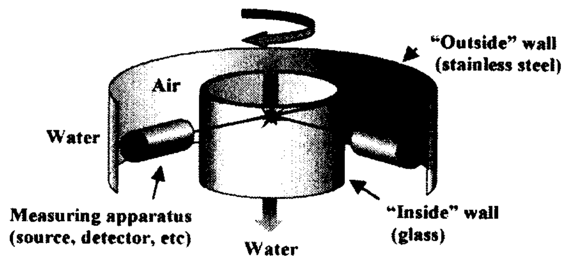

Figure 1. Schematic structure of the apparatus.

The source is a blue light emitting diode (λ_{LED}= 470 nm) followed by an appropriate optical system. The diffused light is collected by a collimator (a converging lens and a pinhole) and it is sent onto the detector which can rotate around the system's symmetry axis, in order to measure the scattering distribution in almost the whole angular range.

The detector used is a miniature type (7 mm bialkali photocathode, gain $3 \cdot 10^5$) photomultiplier followed by a switched integrator which acts as a low noise amplifier and a synchronous detector controlled by the same low frequency signal generator which feeds the LED. A small photodiode on the transmitted light path acts as reference