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The NESTOR neutrino telescope(*)

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Summary. — We present a short overview and status report of the NESTOR deep sea high energy muon and neutrino telescope now under construction in Pylos, Greece.

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1. – Introduction

The NESTOR project is a deep sea high energy muon and neutrino telescope now under construction at the NESTOR Institute and Laboratory in Pylos, Southern Greece. Its configuration consists of a *tower* of 12 hexagonal *floors* of 32 m diameter positioned at vertical intervals of 20 m. It is equipped with two highly sensitive 15 inch photomultiplier tubes (PMT) at the corner points of the hexagonal floor structures and in the center, totaling 168 units for phase 1.

The PMTs are arranged in pairs, one above the other, one facing up the other down, to insure uniform spherical response [1, 2]. The basic tower concept can be extended arbitrarily to an array of towers forming a large 3-dimensional matrix of optical sensors.

2. – Mode of operation

Like similar earlier projects, such as the pioneering but discontinued DUMAND string matrix of detectors or the currently operating arrays in Lake Baikal or in the antarctic ice cap (AMANDA), NESTOR will detect the Cherenkov radiation produced by muons (and electrons for electron-neutrino–induced reactions) in a large volume of very clear water. The muons recorded by the optical detector modules of the NESTOR matrix are either of atmospheric origin, produced by cosmic rays in interactions with atmospheric target nuclei and are therefore downward directed, or they are the result of neutrino

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reactions in the water within the detector matrix, its immediate surroundings or in the sea floor below the tower.

Neutrino-induced muons manifest an omnidirectional distribution because the flux of muon neutrinos (and antineutrinos) is predominantly of atmospheric origin and therefore omnidirectional, too. However, neutrino-induced muons can only be identified as such within the zenith angular range that is inaccessible for atmospherically produced muons. The latter depends on the overburden of water and therefore on the depth below the surface at which the detector matrix is being operated. Relatively shallow detectors are therefore restricted to upward going muons only as a safe signature for neutrino-induced muons.

On the other hand, deep detectors such as NESTOR whose prospective site is located at a depth of ~ 4000 m, approximately 20 km off shore of the town of Pylos in Southern Greece, will be able to use almost 3π steradian of its 4πsr field of view for the neutrino work, excluding only a zenith angular cone about the vertical upward direction of $\simeq 70°$ to eliminate downward-going atmospheric muons subtending zenith angles of $\leq 70°$.

3. – Scientific goals

The scientific goals of NESTOR had been outlined in several papers [1, 3]. They are essentially the same as those discussed initially and very extensively in numerous papers of the early DUMAND workshops, where neutrino astronomy was initiated. They can be summarized as follows.

3˙1. *High energy ν-astronomy.* – Search for high energy (TeV) neutrino point sources in an attempt to locate potential sources of high energy cosmic rays, and search for high energy diffuse neutrinos from unresolved AGNs and similar objects.

3˙2. *Muon and neutrino physics.* – Explore the muon spectrum, muon multiplicities and decoherence. Investigate the atmospheric neutrino flux, study neutrino oscillations using either atmospheric or accelerator neutrinos.

3˙3. *Search for dark matter.* – Nestor can also search for certain forms of dark matter, such as neutralinos which, if captured by the Sun (or less likely by the Earth) can annihilate in pairs, producing a detectable neutrino source in the host body.

4. – Effective area and minimum detectable flux

The effective area and volume of a NESTOR-type detector is energy dependent because of the energy dependence of the muon range. The effective area is approximately 20000 m^2 for TeV muons, for a single tower as described above. The minimum detectable flux (MDF), too, is energy dependent. In addition it is angular resolution dependent because it is an interplay between signal and noise. The signal-to-noise ratio increases with increasing angular-resolution for point sources. For a single NESTOR tower it amounts to $\sim 10^{-10}$ $cm^{-2}s^{-1}$ for muon neutrinos from point sources with energy > 1 TeV and a one degree square resolution. Detectors of this kind are in general signal and not background limited.

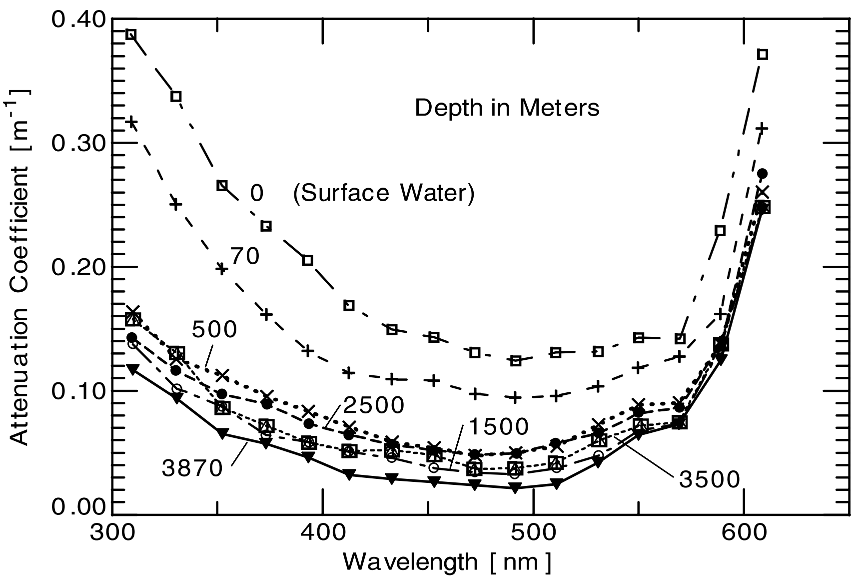

Fig. 1. – Typical optical attenuation coefficients *vs.* wavelength of water samples taken at different depth in the Mediterranean Sea at the NESTOR site [4].

5. – Project status

5·1. *The NESTOR institute.* – The laboratories in the new NESTOR institute building in Pylos are now fully equipped and operational and the construction of the NESTOR telescope is well under way.

5·2. *Site studies.* – The site studies including water transparency, water current and a variety of other environmental parameter measurements have been completed. A summary of the optical measurements is shown in fig. 1 and of the environmental parameters in fig. 2.

5·3. *Cable to site.* – The cable laying operation of the 31 km, 18-fiber electro-optical cable is currently in progress. Twenty-five km of this cable that follow the sea floor are armored, the remaining 6 km of the riser cable are torque balanced to avoid mechanical problems during deployment of the floors when assembling the tower.

5·4. *Exploratory tests.* – Various tests with a short exploratory string of six optical detector modules have been carried out some time ago. Depth-intensity measurements and zenith angle distributions of the muon intensity at different depths were determined. The results are shown in figs. 3 and 4, respectively.

5·5. *Shore station.* – The shore station where the cable terminates is situated in the Methoni Meteorological Station 10 km away from Pylos and is operational.

5·6. *Prototype tests.* – In the near future a small size test floor of 12 m diameter equipped with only 12 PMTs (not at the center) and the necessary support equipment, including environmental monitoring units, will be deployed, installed 85 m above the sea

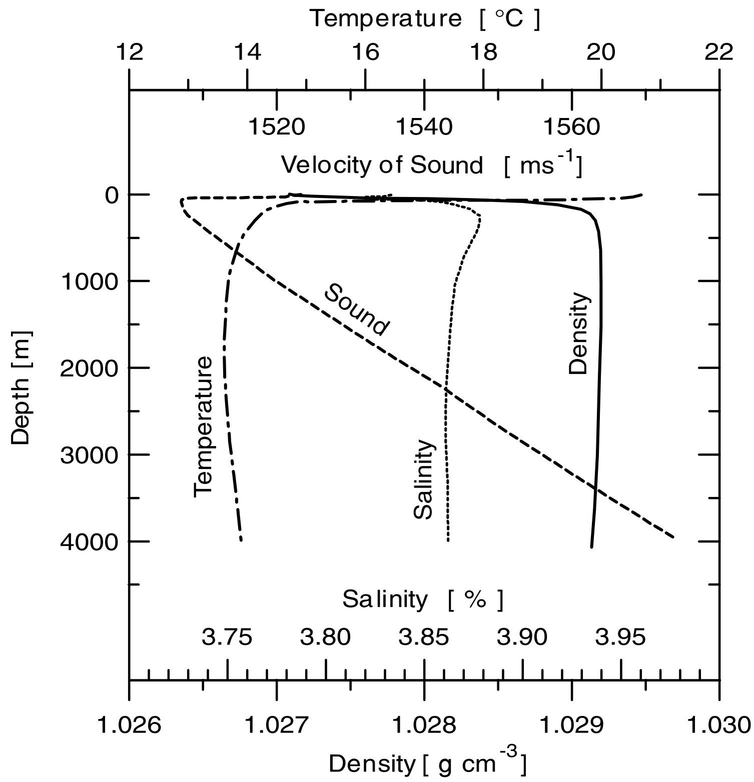

Fig. 2. – Environmental parameter profiles of the NESTOR detector site in the Mediterranean Sea [5].

floor at the NESTOR site and connected to the shore cable. The purpose of this operation is to test and explore the performance of a number of subsystems such as module control, data acquisition, data handling and transmission, as well as environmental parameter monitoring under realistic conditions for some time while assembling of the full size floor units continues.

5˙7. *Deployment platform.* – A special floating deployment platform of triangular shape measuring 60 m on the side is under construction. It will significantly facilitate deployment and installation of the NESTOR floors when assembling the tower and will also serve as servicing platform later on.

Table I.

Symbol	Depth (m)	m	Curve
○	3338	4.0 ± 0.8	A
●	3697	4.5 ± 0.8	B
△	4108	4.8 ± 0.8	C

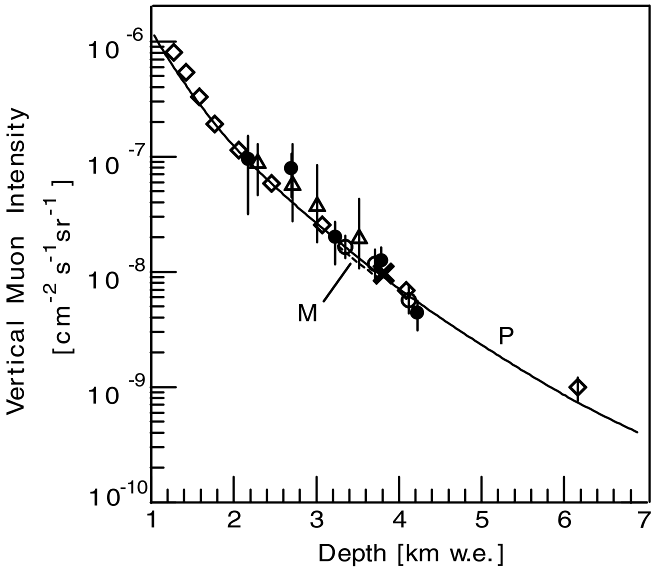

Fig. 3. – Muon intensity measurements *vs.* depth. The three sets of NESTOR data (∘, ×, △) apply to slightly different locations at the Pylos (Greece) site in the Mediterranean Sea [5] and were recorded at different dates. The solid curve labeled P is from the parametrization of Thron [6], the short dashed curve, M, represents a section obtained with the Miyake formula, adapted to sea water [7]. Also shown are data from other sites (⋄ Baikal [8], • DUMAND [9]).

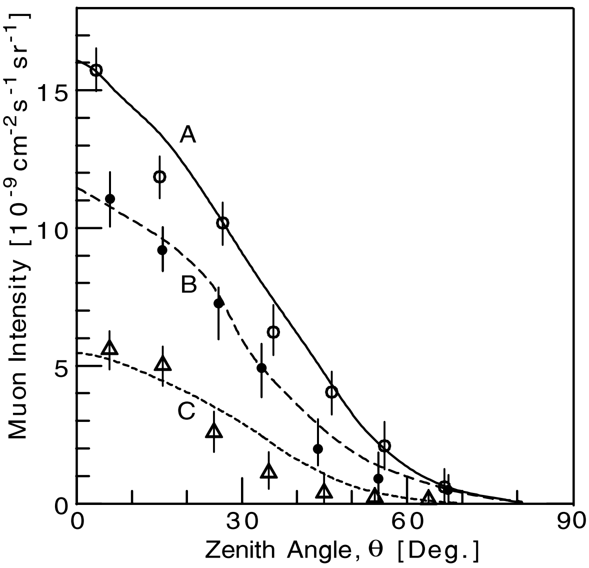

Fig. 4. – Zenith angle, θ, distribution of muons in the Mediterranean measured by the NESTOR Collaboration with six prototype optical detector modules at the NESTOR site, off the coast of Pylos (Greece) [1]. Shown are the actually measured intensities at depths as indicated in table I and fits to the data of the form $I(\theta) = I_0 \cdot \cos^m(\theta)$.

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