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Operation, Performance and Measurements with the NESTOR Test Detector

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NESTOR is a deep-sea neutrino telescope that is currently under construction in the Ionian Sea, off the coast of Pylos, Southwestern Greece, at a depth of approximately 4000 m. We outline briefly the layout of the telescope and summarize the present status of the project. The results of a one month continuous operation of a test unit using our standard detector modules is discussed. Data of the cosmic ray muon flux acquired with the help of an electro-optical cable during this period is presented. The data are in good agreement with earlier experiments at comparable depth. In addition we discuss our results of bioluminescence measurements and other site and technical aspects.

1. Introduction

A number of reports and papers have described in detail the elements of the NESTOR detector and the techniques used for its deployment and recovery [1-6]. The main features are only briefly reviewed in this section.

The location[1] is 7.5 nautical miles from the island of Sapienza, where there are two small harbours, and 11 miles from the port of Methoni. Substantial port facilities are available 15 miles away in the town of Pylos on the bay of Navarino. Regular measurements [7, 8] of water quality show transmission lengths of 55±10 m at a wavelength of 460 nm, stable temperatures of 14.2 ^{0}C and water current velocities well below 10 cm/s [9]. Light bursts of 1-10s duration, consistent with bioluminescent activity, represent around 1% of the active time and there is little if any evidence of problems due to sedimentation or bio-fouling [10]. The sea bottom over the site has a clay deposit accumulated over some tens of thousands of years which provides for good anchoring.

[1] Site coordinates: 36^0 37.5' N, 21^0 34.6' E

A shore station has been established in Methoni where the land end of the 30 km long electro-optical cable is terminated. The main d-c power converter for the electrical supply, the monitoring and control systems and the land end of the data acquisition system are located in the Methoni building.

The basic element of the NESTOR detector is a hexagonal floor or star. Six arms, built from titanium tubes to form a lightweight lattice girder, are attached to a central casing. Two optical modules are attached at the end of each of the arms, one facing upwards, the other one downwards. The electronics for the floor is housed in a one-meter diameter titanium sphere within the central casing. The nominal floor diameter at the optical modules is 32 metres.

A full NESTOR tower would consist of 12 such floors stacked vertically with a spacing of 30 m between floors. This is tethered to a sea bottom unit (pyramid) that contains the anchor, the junction box, several environmental sensors and the sea electrode that provides the electrical power return path to shore. The junction box houses the termination of the sea-end of the electro-optical cable, the fan-outs for optical fibres and power to the floors etc., as well as monitoring and protection of the electrical system.

The optical module [11] consists of a 15” diameter photomultiplier tube (PMT) enclosed in a spherical glass housing which can withstand the hydrostatic pressure up to 630 atmospheres. To reduce the effect of the terrestrial magnetic field, the PMT is surrounded by a high magnetic permeability cage [12]. Optical coupling of the PMT to the glass sphere is made with glycerine, sealed by a transparent silicon gel gasket. The high voltage for each PMT is generated by a DC-DC converter within the glass sphere: the PMT signal, 24 V power, control and monitoring signals are connected through a single 7–pin connector and hybrid cable to the central titanium sphere with the floor electronics.

Other modules, above and below each floor, house LED flasher units that are used for calibration of the detector: these are controlled and triggered from the floor electronics.

Deployed equipment is brought to the surface, together with the sea end of the electro-optical cable, by means of a recovery rope, released from the sea bottom by an acoustic signal [6]. Modifications or additions to the experimental package are made at the surface and all connections are made in the air with dry-mating connectors. The cable and experiment systems are then re-deployed and the recovery rope, with its acoustic release laid on the seabed.

2. Measurement of the Zenith Angle Distribution of Atmospheric Muons.

From the total data sample collected with a 4-fold or higher coincidence trigger and 30mV PMT threshold, a subset containing 45800 events has been selected that have six or more PMT pulses (hits) within the 60 ns time window. These events have been analysed in order to reconstruct muon tracks. The arrival time of the digitized PMT pulses was used to estimate the muon track parameters by means of a χ^2 fit whilst the PMT pulse heights were used to reject ghost solutions and poorly reconstructed tracks. The details of the reconstruction strategy and the relevant studies are reported in another paper [13]. The results are summarized here.

3. Results and Comparisons

The results of the fit have been shown to be free of statistical bias and to include a correctly estimated statistical error. The total systematic errors are evaluated as the quadratic sums of the contributions of the errors due to the track reconstruction, selection criteria and the energy dependence of the reconstruction efficiency. The re-weighting, the bin size definition and the functional parameterization of the zenith angle distribution do not produce measurable systematic effects.

The final results on the spectral index and the vertical atmospheric muon intensity can be quoted as follows:

$$\alpha = 4.7 \pm 0.5(stat) \pm 0.2(syst)$$
$$\mathrm{I_o} = 9.0 \cdot 10^{-9} \pm 0.7 \cdot 10^{-9}(stat) \pm 0.4 \cdot 10^{-9}(syst)\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1} \cdot \mathrm{sr}^{-1} \tag{1}$$

with an 86% of statistical correlation between the two estimated values.

These results are consistent with other measurements of the atmospheric muon flux at similar depths. It should be noted also that shallow experiments obtain this curve by looking at slant angles**.** Previous measurements [14], found the vertical intensity of atmospheric muons to be $\mathrm{I_o} = 9.8 \cdot 10^{-9} \pm 4.0 \cdot 10^{-9}\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1} \cdot \mathrm{sr}^{-1}$ at depths between 3700 and 3900m.w.e. The exponent in the angular distribution was found to be $\alpha = 4.5 \pm 0.8$ at a depth of 3697m.w.e. [15,16]. The DUMAND collaboration measured $\mathrm{I_o} = 1.31 \cdot 10^{-8} \pm 0.4 \cdot 10^{-8}\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1} \cdot \mathrm{sr}^{-1}$ at a depth of 3707m.w.e. [17] and $\alpha = 6^{+7}_{-1}$ for 4157m.w.e.

There is also good agreement between the present measurement of the vertical atmospheric muon intensity and existing phenomenological model parameterizations. The Okada model [18] predicts a vertical flux of $8.8 \cdot 10^{-9}\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1} \cdot \mathrm{sr}^{-1}$, whilst the model of Bugaev et al. [19,20] predicts, $\mathrm{I_o} = 9 \cdot 10^{-9}\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1} \cdot \mathrm{sr}^{-1}$ (see also [21]) for a depth of 3800 m.w.e..

The predicted shape of the zenith angle distribution by the Okada model [18] is found to be in agreement with these measurements [22]. Furthermore, using our parameterization, the exponent β for the zenith angle distribution has been estimated to be 3.7±0.5 whilst the Okada parameterization of the energy integrated flux corresponds to a value of β equal to 3.0.

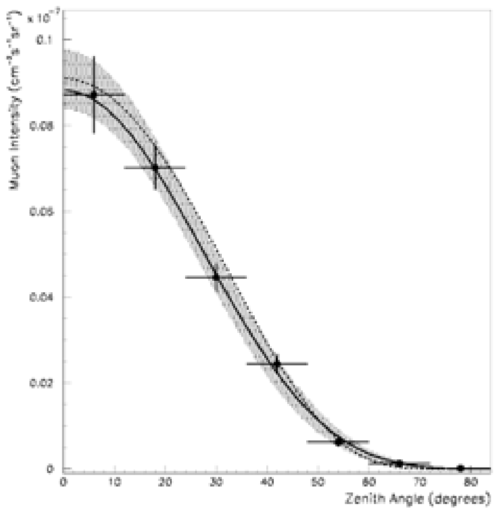

Figure 1: Comparison of the measured atmospheric muon fluxes with results of fits. The solid points represent the data corrected for (pseudo) efficiencies in reconstructing tracks, as evaluated by a Blind Fit. The gray band represents the results of the fit within one sigma, the solid line represents the results of the Blind Fit and the dotted curve represents the solution using a parametrization.

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