

Operation, Performance and Measurements with the NESTOR Test Detector

G. Aggouras^j, E. G. Anassontzis^{a*}, A. E. Ball^d, G. Bourlis^f, W. Chinowsky^h, E. Fahr^g, G. Grammatikakis^c, C. Green^g, P. Grieder^b, P. Katrivanosⁱ, P. Koske^g, A. Leisos^{j,f}, E. Markopoulos^j, P. Minkowsky^c, D. Nygren^h, K. Papageorgiou^j, G. Przybylski^h, L. K. Resvanis^{a,j}, I. Siotisⁱ, J. Sopher^h, A. Staveris-Polikalas^j, V. Tsagli^j, A. Tsirigotis^{j,f} and V. A. Zhukov^k

(a) *Physics Dept. University of Athens, Greece*

(b) *Physikalisches Institut, University of Bern, Switzerland*

(c) *Institute for Theoretical Physics, University of Bern*

(d) *CERN (European Organization for Nuclear Research) Geneva, Switzerland*

(e) *Physics Dept. University of Crete, Greece*

(f) *Hellenic Open University, School of Science and Technology, Patra, Greece*

(g) *Inst. Of Experimental and Applied Physics, University of Kiel, Germany*

(h) *Lawrence Berkeley National Laboratory, Berkeley, CA, USA*

(i) *NCSR Demokritos, Athens, Greece*

(j) *NESTOR Inst. for Deep Sea Research, Technology and Neutrino Astroparticle Physics, Pylos, Greece*

(k) *Institute for Nuclear Research, Russian Academy of Science, Moscow, Russia*

Presenter: P.K.F. Grieder (peter.grieder@phim.unibe.ch) swi-grieder-P-abs1-og25-poster

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 location¹ 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 °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: $36^{\circ} 37.5'$ N, $21^{\circ} 34.6'$ 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:

$$\alpha = 4.7 \pm 0.5(\text{stat}) \pm 0.2(\text{syst})$$

$$I_0 = 9.0 \cdot 10^{-9} \pm 0.7 \cdot 10^{-9}(\text{stat}) \pm 0.4 \cdot 10^{-9}(\text{syst}) \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{sr}^{-1} \quad (1)$$

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 $I_0 = 9.8 \cdot 10^{-9} \pm 4.0 \cdot 10^{-9} \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{sr}^{-1}$ 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 $I_0 = 1.31 \cdot 10^{-8} \pm 0.4 \cdot 10^{-8} \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{sr}^{-1}$ at a depth of 3707m.w.e. [17] and $\alpha = 6_{-1}^{+7}$ 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 $8.8 \cdot 10^{-9} \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{sr}^{-1}$, whilst the model of Bugaev et al. [19,20] predicts, $I_0 = 9 \cdot 10^{-9} \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{sr}^{-1}$ (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.

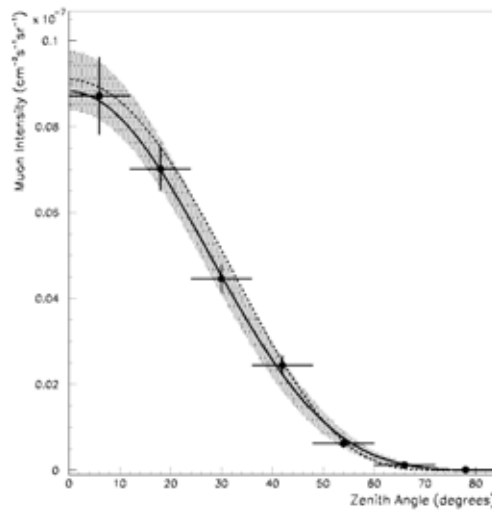


Figure 1: Comparison of the measured atmospheric muon fluxes with results of fits. The solid points represent the data corrected for (pseudo) efficiencies in reconstructing tracks, as evaluated by a Blind Fit. The gray band represents the results of the fit within one sigma, the solid line represents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

4. Acknowledgements

The authors wish to acknowledge the help and support of all the members of the NESTOR collaboration. Our very sincere thanks are also due to the technical and support staff from the collaborating institutes, especially of the NESTOR Institute in Pylos and the “Institut für Angewandte Physik”, University of Kiel, for their unstinting efforts over several years. It is also a pleasure to acknowledge our many industrial partners for their essential contributions; in particular we express our gratitude to OTE S.A, the Greek Telecom Company for the substantial material support and for the sea and underwater operations that underpin the results presented here. Many thanks are due to the Masters, Crews and Cable Engineers on the THALES (OTE) and RAYMOND CROZE (France Telecom marine) and TENE0 (Tyco) as well as the support vessel DYNATOS, for their help and advice in sea operations and deployments.

References

- [1] Ball A. E. et al [NESTOR Collaboration], CERN Courier 43N9:23-25, 2003.
- [2] Peter K. F. Grieder [NESTOR Collaboration], Proceedings of the 28th International Cosmic Ray Conference (2003).
- [3] Tsirigotis A. G [NESTOR Collaboration], Proceedings of the International Europhysics Conference on High Energy Physics (EPS 2003, Aachen Germany), The European Physics Journal C, ISSN:1434-6044.
- [4] Tzamarias S. E. [NESTOR Collaboration], Proceedings of the VLVnT Workshop pp 11-16, NIKHEF, Amsterdam 5-8 October 2003.
- [5] Resvanis L. K., Proceedings of the 8th International Workshop on Topics in Astroparticle and Underground Physics (TAUP 2003) September 5 - 9, 2003, University of Washington, Seattle, Washington.
- [6] Anassontzis E. G. et al, Sea Technology 44-10, 2003.
- [7] S. A. Khanaev et al, Proceedings of the 2nd NESTOR International Workshop, page 253, L. K. Resvanis editor (1992).
- [8] E. G. Anassontzis et al, Nuclear Instruments and Methods A349:242-246 (1994).
- [9] T. A. Demidova et al, Proceedings of the 2nd NESTOR International Workshop, page 284, L. K. Resvanis editor (1992).
- [10] E. Trimonis et al, Proceedings of the 2nd NESTOR International Workshop, page 321, L. K. Resvanis editor (1992).
- [11] E. G. Anassontzis, et al, Nuclear Instruments and Methods A479, pp 439-455 (2002).
- [12] M. Barone, Proceedings of 5th International Conference on Advanced Technology and Particle Physics (COMO 96), Como, Italy, 7-11 Oct 1996, Published in Nucl.Phys.Proc.Suppl.61B:159-163,1998.
- [13] NESTOR Collaboration, “A measurement of the cosmic muon flux with a module of the NESTOR neutrino telescope”, to be published (2004).
- [14] I. F. Barinov et al, Proceedings of the 2nd NESTOR International Workshop, page 340, L. K. Resvanis editor (1992).
- [15] L. K. Resvanis, Proceedings of the 2nd NESTOR International Workshop, pp 1-19, L. K. Resvanis editor (1992).
- [16] L. K. Resvanis et al, “NESTOR: A Neutrino Particle Astrophysics Underwater Laboratory for the Mediterranean”, Proceedings of the High Energy Neutrino Astrophysics Workshop, V. J. Stenger, J. G. Learned, S. Paksava and X. Tata editors Hawaii (1992).
- [17] J. Babson et al, Physical Review D42, 3613 (1990).
- [18] A. Okada, Astroparticle Physics 2, 393 (1994)
- [19] Edgar V. Bugaev, et al, Proceedings of the 3rd NESTOR International Workshop, page 268, L. K. Resvanis editor (1993).
- [20] Edgar V. Bugaev, et al, Physics Review D58, 054001 (1998).
- [21] Peter K. F. Grieder, “Cosmic Rays at Earth”, Chapter 3, Elsevier, Amsterdam (2001).
- [22] Agouras G. et al, “Operation and Performance of a NESTOR test Detector”, to be published in NIMA (2005).