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NESTOR Deep Sea Neutrino Telescope
Deployment and results

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Abstracts

One module of NESTOR, the Mediterranean deep-sea neutrino telescope, was deployed at a depth of 4000m, 14km off the Sapienza Island, off the South West coast of Greece. The deployment site provides excellent environmental characteristics.

The deployed NESTOR module is constructed as a hexagonal star like latticed titanium star with 12 Optical Modules and an one-meter diameter titanium sphere which houses the electronics. Power and data were transferred through a 30km electro-optical cable to the shore laboratory.

In this report we describe briefly the detector and the detector electronics and discuss the first physics data acquired and give the zenith angular distribution of the reconstructed muons.

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1. Introduction

Neutrinos are only involved in weak interactions and have an extremely small cross-section with nucleons (~ 10^{-38} cm^2 at 1 GeV energy). Therefore very large masses of target matter are needed in order to detect them. The standard technique of observing neutrinos is to detect the Cherenkov radiation generated by relativistic muons produced in charged current neutrino–nucleon interactions, therefore large volumes of transparent matter are required. M. Markov in the early sixties, proposed to use water as the detector medium for neutrinos.

The present paper describes the NESTOR basic element deployed in March 2003 as part of the NESTOR telescope, the deployment and the data analysis of the recorded data from a depth of 4000m.

2. Site description

After some intensive site-specific investigations [1,..,6] (bottom topography, currents, light attenuation of the sea water body, sediment properties, sedimentation, biological activity and bioluminescence) an excellent site for a deep-sea neutrino telescope installation was located in the deepest part of the Mediterranean, in the Ionian Sea, close to the south-west corner of the Peloponnese in Greece. This site, at a distance of about 30 km Southwest of the small harbor of Methoni and at a water depth of 4.000 to 5.000 m, on a smooth plateau, the NESTOR basin (Figure 1), with clear water (i.e. water with small light attenuation coefficient), without considerable sedimentation, and currents below 10 cm/s; has very favorable conditions for the operation of an optical detector system.

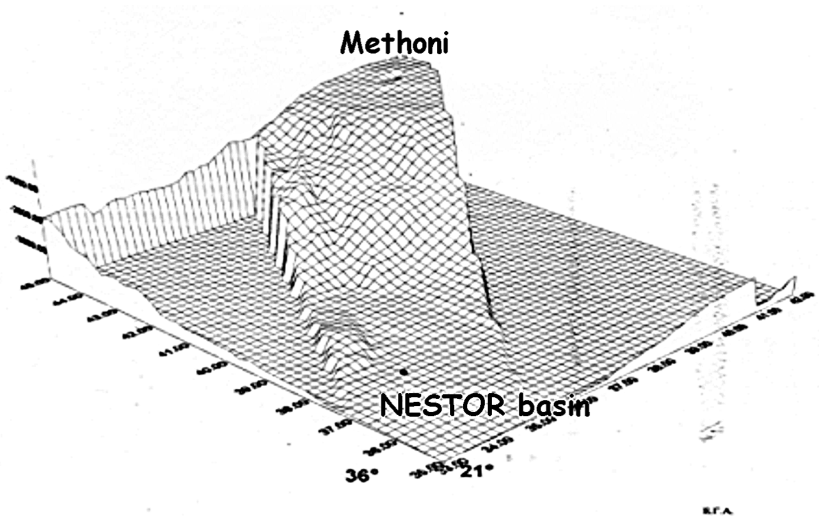

Figure 1. 3D display of the NESTOR site and the electro-optical cable land and sea end points.

It was decided to establish a deep-sea station around the coordinates $\varphi = 36^0\ 35{,}9'$ N, $\lambda = 21^0\ 34{,}1'$ E at a water depth of about 4.000 m.

3. The detector

The schematic of the basic module of the NESTOR telescope detector schematic, as deployed in March 2003, is shown in figure 2. The system consists of a hexagonal floor, an anchor with the junction box, and the main buoy. The detector is connected to the shore for power and data transmission with an electro-optical cable. The deployment depth is 4000m. The floor is located 80m above the sea floor and the main buoy is located 30m above the floor. Two blue LED Calibration Units were attached 30m above and below the floor, pulsing very short calibration light pulses as required. The floor is attached on the Pyramid, which is also the Anchor base, with ropes. The main electro-optical cable is attached on the junction box with a dry mating connector with 18 fibers plus one conductor hybrid electro-optical connector. The MARO, a long buoyant rope (more than 5km), is used for the deployment and the recovery of the detector and it is equipped with a release/buoy system at its free end for the recovery of the detector[7].

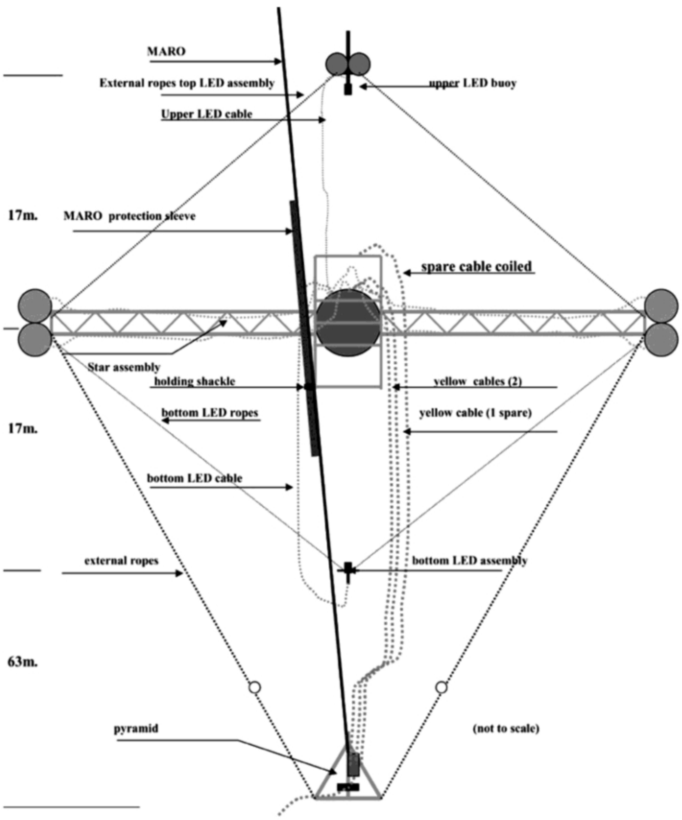

Figure 2. The NESTOR telescope detector, as deployed in March 2003 (not in scale)

The floor is a 6 arms titanium star. Each arm has a length of 5m and it is constructed as a latticed Ti tube construction (45cm x 45cm) connected to a central Ti tube-frame. At the end of each arm, two Optical Modules [8], OM, (OM = one 15” R2018-03 HAMAMATSU photomultiplier inside a 17” BENTHOS glass housing) are mounted. A Ti Sphere, (1m diameter) housing the necessary floor digitization, housekeeping and control electronics is installed within the Central Frame, in the middle of the star. Electrical cables connect each OM to the Ti sphere and 2fibre/2conductor hybrid electro-optical cable the Ti sphere to the Junction Box that is attached on the Pyramid.

The detector was deployed successfully in March 2003 to a depth of 4000m using the cableship RAYMOND CROZE (figure 3). On the 30th of March the first deep-sea muon data were transmitted to shore; through the 30km long electro-optical cable to the Methoni counting room.

Figure 3. The NESTOR star during deployment, just below the seas surface. Inset: The "Raymond Croze" of FranceTelecom

4. Electronics and Data Acquisition

Relativistic muons produced in charged current neutrino–nucleon interactions by neutrinos (or by cosmic ray interactions) moving in a transparent medium, in our case seawater, produce photons by Cherenkov radiation. A number of those photons per muon track are detected by the photomultipliers of the Optical Modules. The purpose of the electronics and the data acquisition is to digitize those pulses and transmit the digitized information to the shore.

The NESTOR electronics are divided to the Sea or Ti-sphere Electronics, kept inside the Ti sphere, and to the Shore Electronics [9,10]. The two sets of electronics communicate in real time through the monomode fibbers of the electro-optical cable. The Ti-sphere electronics are divided into two interconnected units, the Housekeeping Board that handles the system monitoring and control functions, and the Floor Board that handles the Data Acquisition signal treatment and communications. Both are mounted on an aluminum sub-frame that also carries the local sensors and dc-dc converters and it is electrically isolated from the sphere (figure 4).

The Housekeeping Board controls the power setting of the PMTs, monitors the PMT's high voltage supply as well as environmental sensors and operates the LED Calibration Units.

The Floor Board administers the PMT signal waveform capture, digitization, majority logic event triggering, event packag formation and the communications with the shore board; the 'up-link' data sending to shore and the 'down-link' receiving of the clock signal, commands and operational parameters. The heart of the Floor Board is a novel ASIC developed at the Lawrence Berkeley National Laboratory, the "Analog Transient Waveform Digitizer" (ATWD) [11]. Each ATWD has four channels with 128 common-ramp, 10-bit, Wilkinson ADCs that, after activation, digitize all 128 samples of a selected channel. A sampling speed of 273M samples/s was selected in order to capture the PMT signals and to recognize overlapping pulses, giving a sampling period of 3.66ns. There are five ATWDs on the Floor Board, providing twenty digitization channels mainly for the PMT pulses and a 40MHz clock signal broadcasted from the shore.

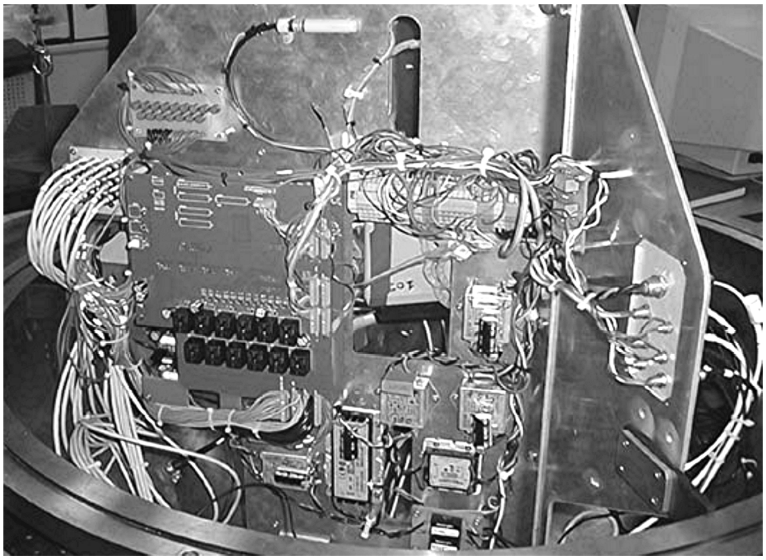

Figure 4. The Sea Electronics inside the opened Ti-sphere

The Shore Electronics consist mainly by a single PC EISA bus electronic board per floor, connected to the main server of the Data Acquisition (DAQ) computer cluster in the Shore Counting Room. It receives the event packages sends commands to set the run or calibration parameters and initiates functions to be executed by the Housekeeping board. The 'down-link' can also be used to re-program the FPGA/PLDs within the Floor Board and change the trigger logic parameters.

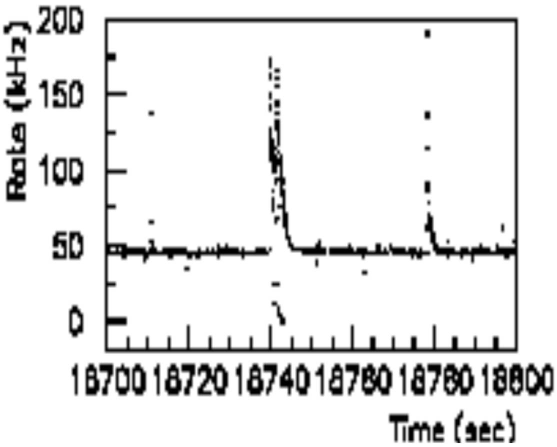

Figure 5: A typical pulse rate of a photomultiplier for a period of 100s. Bioluminescence pulses are shown also.

The selection trigger determines an Event when a majority coincidence requirement is satisfied. The trigger initiates waveform capture by the ATWDs, reading of the environmental parameters and data transmission to the shore. The leading edge of the majority logic signal (corresponding to the time when the last of the PMT pulses participating in the trigger crosses the threshold level) is used to define the absolute time of the trigger occurrence with respect to the 40MHz clock Details are reported in another paper [12].

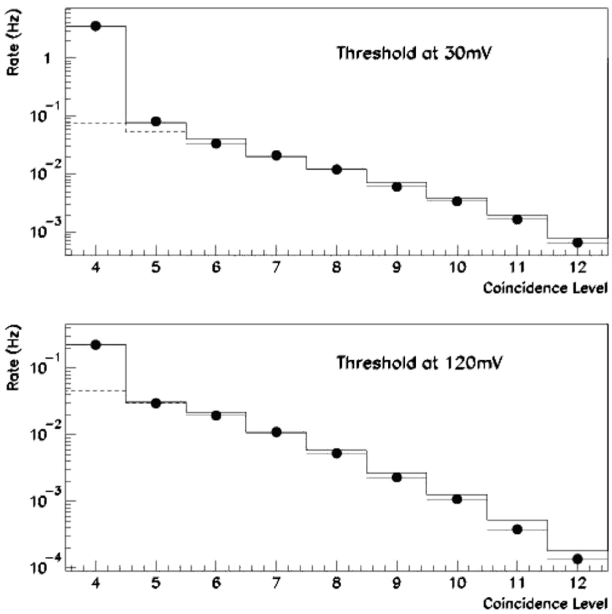

Figure 6: Trigger rates as a function of the coincidence level, for threshold settings at 30 and 120mV. Full circles represent data while the lines represent MonteCarlo estimation; the dashed line the contribution of the atmospheric muons and the solid line including background.

5. Analysis

The K^{40} background has been used to monitor the gain stability of the detector and the pulse rate of each PMT was registered during the running period. In figure 5 this rate is shown for 100s period of time, while short time (up to 10s duration) excess of this rate is attributed to bioluminescence; these pulses represent a total 1.1% of the active experimental time.

The average experimental trigger rate was determined by the coincidence of four or more PMT pulses above 30mV and 120mV amplitude (Figure 6) representing ¼ and 1 photoelectron correspondingly and show an agreement with the MonteCarlo prediction. For example at 30mV threshold the coincidence of “four or more” rate was 3.76Hz compared to an estimated rate of 3.79Hz derived from the Monte Carlo simulations, while the estimated rate fraction rate of atmospheric muons passing close to the detector is about 0,21Hz.

A data subset with six or more PMT’s in coincidence has been analyzed 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]. As an example, in figure 7 a reconstructed event with 7 PMTs in the trigger has two solutions, i.e. two possible tracks are shown. Measuring the photon-likelihood one of the two are chosen; the one coming from the horizon having zenith angle of 101°±10° and azimuth angle 33°±29°. Summarizing the fit strategy we select hits inside the trigger window then we perform χ^2 fit of the pulse arrival time and run a second pass to improve fit. Then for each minimum we examine if a mirror track solution exists and we calculate the photon likelihood function to select the fitted track.

Finally in figure 8 the Zenith Angle Distribution of the reconstructed tracks from atmospheric muons is shown and compared with MonteCarlo predicted tracks.

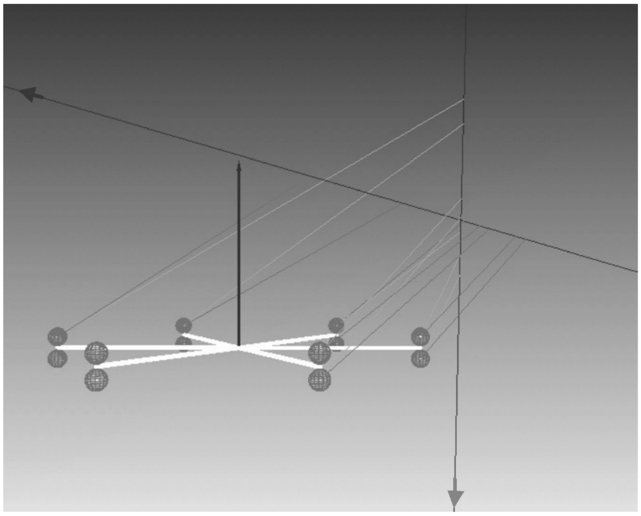

Figure 7. An event with 7 PMT hits and two solutions. Calculating the Photon-likelihood the "correct" track is the almost horizontal one.

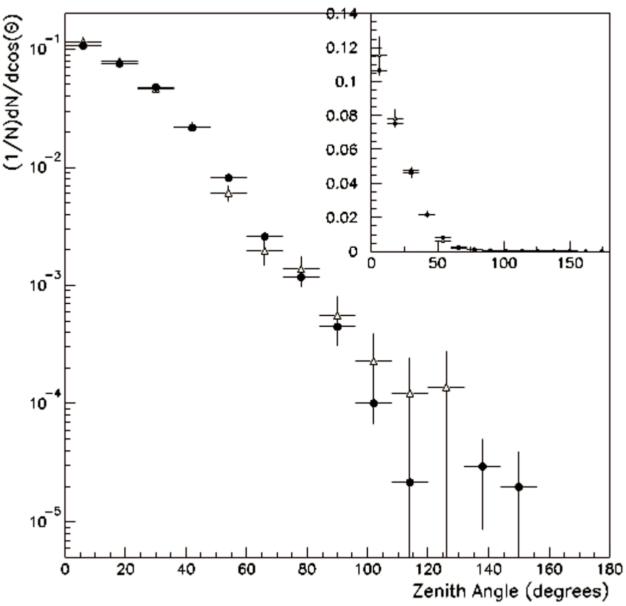

Figure 8: The Zenith Angle Distribution of the reconstructed tracks from atmospheric muons (triangles) compared to MonteCarlo prediction (full circles). Inset: Same plot on a linear vertical axis.

6. Conclusions

The objectives for the deployment of a NESTOR floor test detector concerning a thorough test of:

- the electrical supply and distribution systems
- the monitoring and control systems
- the full data acquisition and transmission chain from the sea to the shore station
- the demonstration of the ability of the proposed neutrino telescope to reconstruct muon trajectories,

were met successfully.

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