NESTOR Participation to the KM3NeT

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Abstract

The NESTOR Collaboration is a leading participant in the Design Study of the KM3NeT, the European Deep Sea Neutrino Telescope. In this report we describe briefly the KM3NeT and the NESTOR experience and contribution towards this objective; the 4500m deep NESTOR site, the star-like detector, the deployment and recovery of telescope modules and the "DELTA-BERENIKE", the specially constructed deployment ship.

I. Introduction

In the dawn of science, Man looked up the black night sky of the Fertile Crescent, to the stars and made the first scientific observation. He was looking into the Cosmos using the first optical detector, his eyes, detecting what thousands years later called by the physicists, the photon. And up to now, our knowledge of the Universe is based on the photon, this singular information messenger from the depth of Time and Space. From this vast collection of information, astronomy and astrophysics have evolved to the present date knowledge.

Photons or γ (gamma rays) can be produced in hadronic and electromagnetic processes, they are electromagnetic radiation and are recognised as visible photons, UV, IR, long wavelength, short wavelength, x-rays and gamma rays, photons, all travelling in straight lines, thus astronomy, i.e. pointing to a particular source, is possible. Each photon differ in their wavelength, thus, the photons of those fields, require different detectors and the evolution of those detectors has followed the advance of the scientific knowledge and technology.

Photons though have a drawback; they are absorbed by the interstellar matter and they interact with UV and infrared ambient starlight and with the 3K photon background, relic of the Bing Bang. Scientists have looked for others messengers, hadrons and charged leptons, to be used in order to probe deeper into the physical processes of the stars. But particles, travelling through space, are attenuated by the interstellar matter AND, if they are charged, are bent by the magnetic fields thus pointing to a source is not possible.

About fifty years ago the neutrino was discovered. Neutrinos are a unique tracer of energetic hadron acceleration in astrophysical sources and can be produced as the decay product of particles produced in hadronic interactions. They not only go through interstellar space without suffering any attenuation or direction alteration but they also escape their progenitor's acceleration and target sites without suffering any absorption. Thus we do believe that neutrino is a unique messenger of Universe and that with neutrinos we can see “further out” and “deeper into” the Cosmos than with any other particle known to date [1].

II. The Neutrino History

In 1920s physicists were puzzled with the β-decay (beta decay); the conservation laws of energy and momentum seemed not to apply. In 1930, Wolfgang Pauli proposed the hypothesis of the existence of a massless and neutral particle, having the "missing energy and momentum"; Enrico Fermi proposed its name: "neutrino", the small neutral one.

There are three types of neutrino, ν, (and their corresponding antiparticles), each named after the particle they produce in the rare case of interaction with matter;

- the electron neutrino, ν_e, discovered by Reines and Cowan in 1956
- the muon neutrino, ν_μ, discovered by Lederman, Schwartz, and Steinberger in 1962, at Brookhaven
- the tau neutrino, ν_t, discovered at Fermilab, 2000

Neutrinos are tracers of energetic hadron acceleration in astrophysical sources since they can only be produced from hadronic interactions. They have tiny mass and are neutral, so they interact extremely feebly with matter (energy) and they can travel exceptionally long distances before interacting; those attributes make the neutrino a unique messenger of the mighty powers that rule the Universe. But those attributes make also the neutrino extremely hard to detect.

Their interaction probability is energy dependant. For neutrinos with energy up to a few TeV, the Earth is transparent (to neutrinos) but for energies more than a hundred TeV, Earth is opaque [2]. For energies roughly ranging between 1 TeV to 1 PeV, neutrino may pass through Earth and interact just before they emerge; those are the best candidates for detection.

Neutrinos are detected tracing their interactions' products (electrons, muons and taus) in a transparent medium using Cherenkov radiation.

III. The Neutrino Astronomy

On 24.2.1987 astronomers had observed a supernova, 1.6×10^5 ly away, in the Large Magellan Cloud. And IMB and Kamiokande discovered that on the same date, an unexpected burst of 19 neutrinos was detected [3]. Neutrino astronomy was born.

Neutrino telescopes will eventually help us to understand and extend our knowledge in [1]:

- Galactic and extragalactic neutrino sources and cosmic accelerators, namely detecting neutrinos which are produced by galactic e.g. X-ray binaries or extragalactic sources, such as the active galactic nuclei (AGNs) ;
- The search for dark matter particles; their annihilation or decay will eventually give neutrinos e.g. neutralinos trapped in the Sun or the Earth.
- Study of the Ultra High Energy neutrinos, with energies more that 10 PeV since no terrestrial accelerator can produce these energies. If the neutrino telescope is large enough the limitation of low flux can be, in part, overcome and this might be the only way for High Energy Physics to reach these Ultra High Energies.
- Multiple W/Z production. Search for possible substructure of the elementary particles i.e. compositeness of quarks and leptons.
- Neutrino oscillations using neutrinos produced in the atmosphere and Long Base Line neutrino oscillations using one of the existing high-energy physics accelerators.
- Supernova detection.
- The Unexpected. A new observational window will open up with these neutrino telescopes. No one has ever viewed sites in the Universe shielded by more than a few hundreds grams of matter. One should keep in mind that every time a new brand of astronomy opened up, a new class of phenomena was discovered.

IV. THE NEUTRINO DETECTOR

High-energy neutrinos interact weakly with matter producing, as was stated before, electrons, muons or taus. The produced charged particle has essentially the direction of the parent neutrino.

M. Markov first proposed to use the sea as a neutrino Cherenkov detector [4, 5]. For neutrino energies of a GeV and above, up to the many PeV, the water Cherenkov technique seems to be the best technique, i.e., we can detect the Cherenkov light emitted by the muon of CC neutrino interactions. When such interactions occur in the sea water or seabed close to the detector, these charged particles can be observed by the Cherenkov photons that they emit transversing the water volume, using the neutrino detector; arrays of sensitive optical detectors, the so called Optical Modules. Electrons have a very short path and they produce a flash of light confided in a very small volume and tau has a very long track in water (several km long) but they are rare. Muons, depending on their energy, have a track of several tens of metres to few km long and produce a lot of Cherenkov photons; from the arrival time and intensity of the light pulses detected by the optical detectors, the direction of the muon, and hence that of the incident neutrino, can be reconstructed.

The above described neutrino detection is of course the Signal. Atmospheric muons are abundant and they also produce Cherenkov radiation that can easily blanket the neutrino-induced muons; they are the Noise (or to be exact, part of the noise, see below). In order to increase the signal/noise ratio (s/n) we should shield our detector from those atmospheric muons; in land detectors this shielding is provided by the rocks above the detector while in a water detector this shielding is provided by the water column, therefore the detector should be deployed as deep as possible.

Another source of noise is radioactivity in the sea and bioluminescence. In sea water the main source of radioactivity is Potassium-40. Moreover bioluminescence, produced by sea life, is a source of light in the detector that we have to take in account.

A sea neutrino detector has to fulfil several requirements:

- Wide area with a gentle slope; to be possible to increase the size of the detector thus to increase the sensitivity and angular resolution of the detector and determine the direction of the detected tracks with higher accuracy
- Short distance from the shore; to minimise the cost of the electro-optical connections between the detector and the shore station. This cable is required in order to transmit data to shore station and power the detector. Moreover short distance form the shore increase safety and easiness of operations
- Deep waters; to reduce the noise background from the down coming atmospheric muons and to reduce bioluminescence since biological activity diminishes with depth
- Clear waters; to reduce light attenuation and increase the active volume of the detector
- Low underwater currents speeds; to minimise mechanical stress on the detector components and movements of the optical modules and excitation of bioluminescence
- Low sedimentation and biofouling; to minimise the sedimentation covering on the Optical Modules and to increase the detector lifetime
- Low optical noise; in order to increase the s/n ratio

V. THE NESTOR SITE

All the requirements described above for a seawater neutrino detector could be found in the Ionian Sea off the south-western tip of the Peloponnesus (figure1). Extensive surveys in 1989, 1991 and 1992 [6, 7] have located a large flat abyssal plateau of 8x9km2 with a mean depth of 4500 m; the so-called NESTOR basin. Situated on the side of the Hellenic Trench that lies between the west coast of the Peloponnesus and the submarine East Mediterranean Ridge, the site is well protected from major deep-water perturbations. Moreover, if deeper waters are required, the Oinousse Pit, the deepest part of the Mediterranean with a 5200 m depth, is located a few km away from the NESTOR basin. The typical coordinates of the, so-called, NESTOR site are 36^0 37’ N and 21^0 35’E. The location has a mean depth of 4000 m, is 7.5 nautical miles from the island of Sapienza, where there are two small harbours, and 11 nautical miles from the port of Methoni, while substantial port facilities are available 17 nautical miles away in the bay of Navarino where the town of Pylos is located. The sea bottom of NESTOR site has a clay deposit

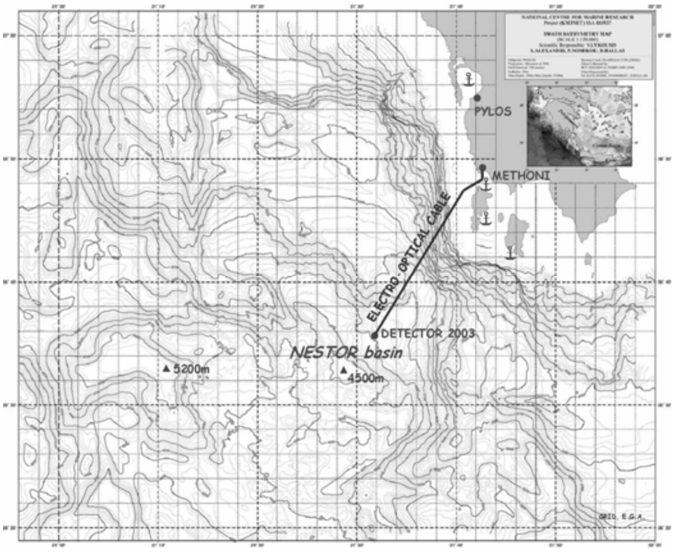

Figure1 The NESTOR basin. Sites with 4500 m and 5200 m depths are marked. Pylos and Methoni are shown. The site of the 2003 prototype deployment in 2003 is also shown. Charted by HCMR.

accumulated over some tens of thousands of years which provides good anchoring [8].

Measurements of water transparency, using *in-labo* spectrophotometric analysis of a large number of samples and deployment of open geometry photometers *in situ*, down to 4000 m of depth [9, 10], show transmission lengths of 55±10m at a wavelength of 460 nm, stable temperatures of 14.2ºC and water current velocities well below 10 cm/s [11, 12, 13, 14]. Typical underwater current at the NESTOR site, obtained within the KM3NeT framework, is shown in figure 2.

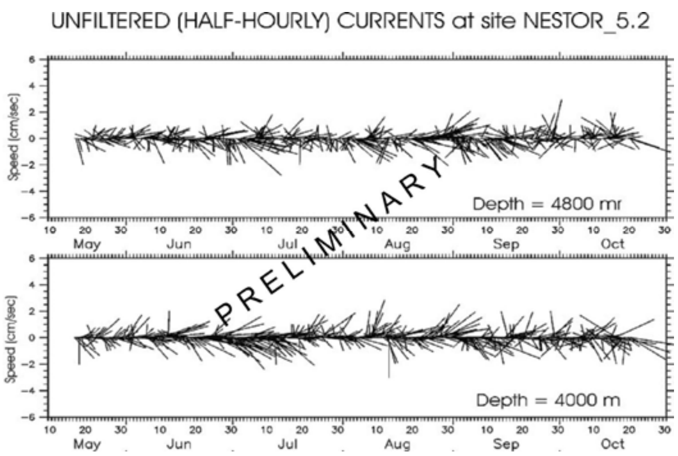

Figure2 Typical underwater current at the NESTOR site, obtained within the KM3NeT framework. Measurements taken with HCMR

Extensive studies of sedimentation [8] and biofouling are performed in the NESTOR site [15]. In particular, for sedimentation, several LIMS (Light Intensity Measuring System), each comprised of 32 photodiode, 2 mm^2 each, suitably distributed, oriented and located in a glass housing and illuminated by two LEDs located nearby and outside the glass sphere, were deployed (by NESTOR Institute and Hellenic Centre of Marine Research, HCMR) for long time series measurements of sedimentation rate. Results are still under study, but in figure 3a and 3b, a typical graph of the

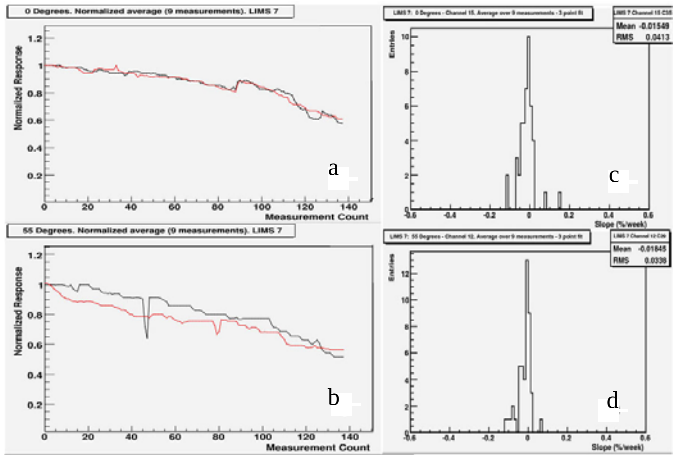

Figure3 Typical data from LIMS. In 3a and 3b, "measurement counts" correspond to a time period of about 6 months and are data from 4 photodiodes, a pair looking upwards (O° from the zenith) and the other looking at 55°. In 3b, it is obvious that something covered one photodiode of the pair and for a limited time.
In 3c and 3d the derivatives of two corresponding graphs are shown.

glass transparency (per % of initial transparency) versus time is shown for two photodiodes; one located at 0º and the second at 55º from the vertical. The distance between the photodiodes (in each pair) is less that 2 cm. In figure 3c and 3d, the derivatives of those graphs are shown with an indication of slight degradation of the glass housing transparency due to sedimentation and/or biofouling, independently of the orientation on the glass housing. Thus, preliminary analysis indicates that the "stick on" probability on the Optical Module is zenith independent. Moreover, from studying the recorded data from all photodiodes we have the indication that we have a recurrent localised degradation of glass sphere transparency that we attribute to "flying" small size residues that attach on the glass housing for a short period of time. The subject is still under study.

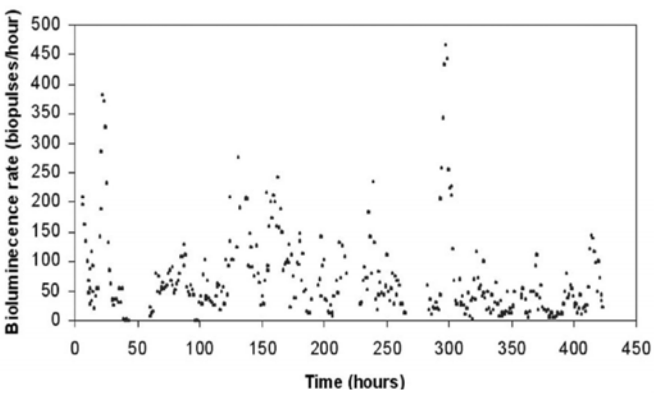

Figure 4 Bioluminescence rate versus time (2003 data, 4000 m depth)

Signal contamination by photons from radioactivity was studied. The only abundant radioactive source is the common in seawater potassium-40. Potassium-40 is well distributed in the seawater and is responsible to a noise on 15" photomultipliers of less than 50kHz. Other radioactive nuclei were not found (in excess concentrations of what it is typically found in seawater) [16].

Bioluminescence [17] activity is recorded as light bursts (biopulses) of a few seconds of duration and they represent about 1% of the active time as it was calculated during different expeditions in the NESTOR site. In figure 4 the rate of biopulses versus time is shown as registered during the 2003 deployment of a prototype of NESTOR star at a depth of about 4000m (see below). The same rate was measured several times in the past. It was established that there is a correlation between the underwater current speed and the rate of biopulses.

The prevailing weather condition in the area was studied looking the whether time series data from various sources. In figure 5, the per cent days year versus the wind state (in Beaufort scale) is shown. Since our experience indicates that deploying experimental instrumentation and working on the sea surface with dinghies is quite possible up to wind state of (including) 4 beaufort (about wind speed of 8m/s), it is quite obvious that at the NESTOR site, working at sea, is possible most of the time. For those graphs a ten years data recoded by the Hellenic National Meteorological Service were used [18].

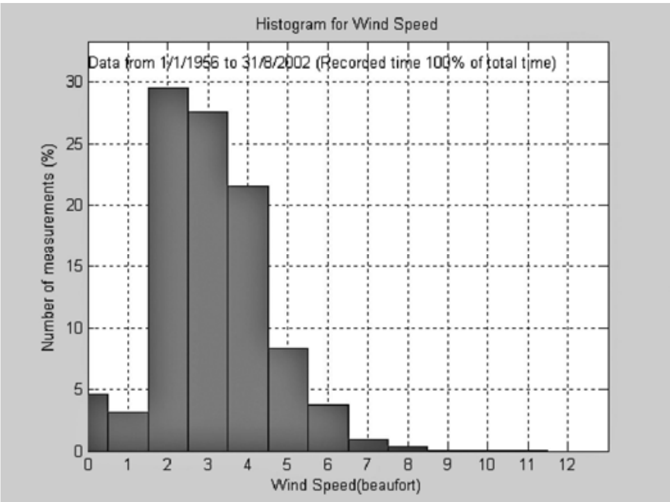

Figure 5. Per cent Time period of a particular wind state versus wind state in Beaufort. Wind state 4 beaufort correspond to a wind speed of about 8cm/s

The above described site features indicate the NESTOR site as most suitable site for the installation of a large deep-sea neutrino telescope.

VI. The KM3NeT

In 2006, a consortium of 40 Institutions and University from 10 European countries and the three Mediterranean neutrino telescopes pilot projects (ANTARES, NEMO and NESTOR), the KM3NeT Design Study consortium, was composed to study the How and Where to build a cubic-kilometre sized deep-sea infrastructure detector; a next-generation neutrino telescope, and to provide long-term terminal access for deep-sea research. The success of the prototypes of the three pilot projects demonstrates the feasibility of a deep-sea neutrino telescope. The KM3NeT consortium objectives are the building of a deep-sea neutrino telescope, the larger ever build detector, and to host facilities for marine and earth science research [19].

The main process than we expect to study is

$$\nu_{\mu} + N \rightarrow \mu + x$$

for neutrinos with energies larger than 100 GeV. The angular resolution of the detector is foreseen to be less than (or equal) 0.1°, the time resolution better than 2 ns and it will be optimized for neutrino energies in the range of 1 TeV – 1 PeV. We expect the overall sensitivity to be better than the sensitivity of ICECUBE [20]. The above require that we know the positions of the OMs with a resolution smaller than 0.4m.

The KM3NeT neutrino telescope (detector) will be highly modular; a large number of identical modules should be deployed on a very deep-sea bed. Those modules will be of complex construction but their final design is not finalised yet. Modules will be produced, deployed and connected to shore facilities in line production during 4 years and we expect to accomplish data acquisition and system calibration within the first year. To build the modules and the ancillary units, we will use inoxidizable material; titanium or aluminium, glass or stainless steel with rubber or plastic separators between dissimilar material. For deployment we should use mainly locally available transport vessels and non-highly specialised surface vessels while the maintenance should be minimum with an expected lifetime of the detector of 10 years at least.

Last but not least the design should incorporate as few electronics in the sea as possible. Ideally will be to have all the raw data on shore and triggering, data selection and event preselection to be performed in the shore terminal station.

The primary of the KM3NeT Design Study is the development of a cost-effective design for a cubic-kilometre sized deep-sea infrastructure housing a neutrino telescope with unprecedented physics sensitivity and providing long-term access for deep-sea research, the evaluation of procedures for the assembly and construction of the infrastructure and the preparation of models for its operation and maintenance. Extensive description of the KM3NeT and its aim could be found in the Conceptual Design Report (CDR) in www.km3net.org/cdr [21]

VII. The NESTOR prototype

The pioneer Mediterranean neutrino detector is the NESTOR neutrino telescope; a prototype was deployed in 2003. The basic element of the NESTOR detector is a hexagonal star (or floor) with Optical Modules. Each Optical Module comprise of a 15" photomultiplier (HAMAMATSU – R2018) inside a 17" diameter and 15mm thick glass housing sphere (BENTHOS) with the appropriate DC-DC high voltage converter (EMI) [22]. Six arms, built from titanium tubes to form a lightweight lattice girder, are attached to a central titanium latticed basket. At the end of each arm a pair of Optical Modules are attached, one with the photocathode facing upwards and the other downwards. The electronics for the floor is housed inside a 1m-diameter titanium sphere on special Al panels. The nominal floor diameter is 32 m; the prototype deployed has a diameter of 12m. A full NESTOR tower would consist of 12 such stars stacked vertically with a spacing of 30m between them.

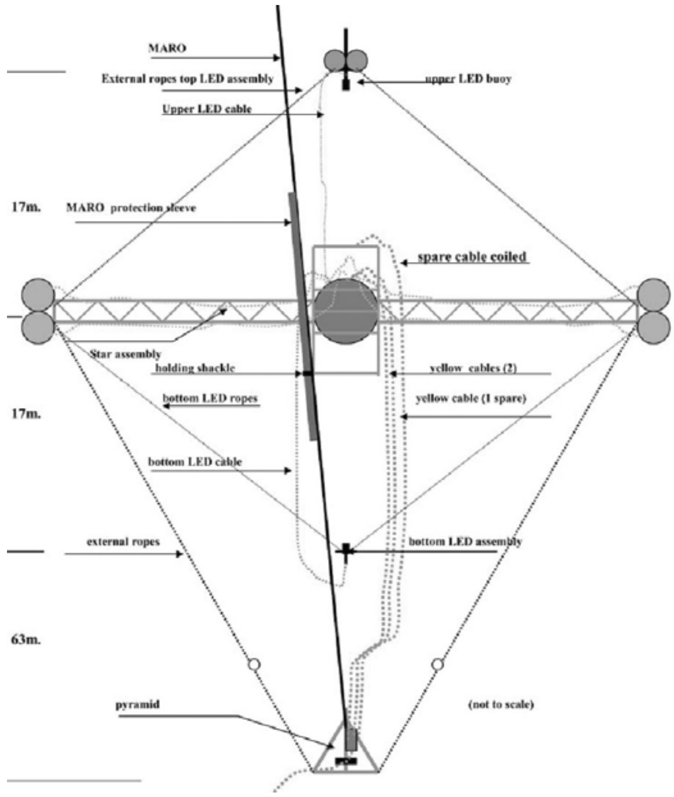

Figure 6 Schematic diagram of the NESTOR prototype, deployed in 2003 at a depth of 4000 m.

Every star (in the prototype, one star) is flexibly attached to the Anchor Unit, a sea bottom unit, pyramidal construction with Al tubing, that contains the anchor, the junction box, several environmental sensors and the sea electrode that provides the electrical power return path to shore, figure 6. A standard deep-sea electro-optical cable connects the "junction box" to the shore while light electro-optical cables connect the junction box to the stars. 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, power smart fuses and a small monitoring system. Calibration modules, above and below each floor, house LED flasher units that are used for calibration of the detector and they are controlled and triggered from the floor electronics.

The floor electronics consist of several electronics boards, the required DC-DC converters and environmental sensors housed inside the one-metre diameter titanium sphere and mounted on aluminium frames, electrically isolated from the sphere (and the sea). Special deep-sea cables connect the Optical Modules to the titanium sphere through GISMA deep-sea connectors to the floor electronics, while the deep-sea electro-optical cable is 30km long and has 18 fibres and a conductor that connects the floor electronics, through the junction box, to the "ShoreBoard" located in the Shore Station.

There are two main DAQ boards: The "FloorBoard", a multilayered board that manage signal reception, procession, trigger and communications and the "Housekeeping Board", a pair of multilayered "piggyback" boards that manage system monitoring and controlling functions.

The FloorBoard is the main board equipped with FPGAs and LPDs for computing power [23]. It receives the PMT signals, resolve the majority logic triggering and perform waveform capture, digitization and event formatting [24]. Moreover, it handles the communications with the ShoreBoard; sending the data to shore and receiving the clock signal, commands and operational parameters.

The heart of the FloorBoard (figure 7) is an ASIC developed at LBNL, the “Analog Transient Waveform Digitizer” (ATWD) [25]. Each ATWD has four channels with 128 common-ramp, 10-bit, Wilkinson ADCs that, after activation, digitize all 128 samples of a selected channel. The sampling rate is controlled and may be varied from 0.2 to 2.0 Gsamples/s. There are five ATWDs on the Floor Board, providing twenty digitization channels. Three channels per IC are used to digitize PMT signals while the forth is used to digitize the 40MHz clock signal sent from the shore in order to check the sampling rate stability. A sampling rate of 273M samples/s was used giving a sampling period of 3.66ns. This gives a dynamical range (active time window) for each ATWD channel of 465ns.

The remaining 4 channels are used to digitize the trigger majority logic signal, to provide information for the synchronization and timing checks and for internal calibration functions.

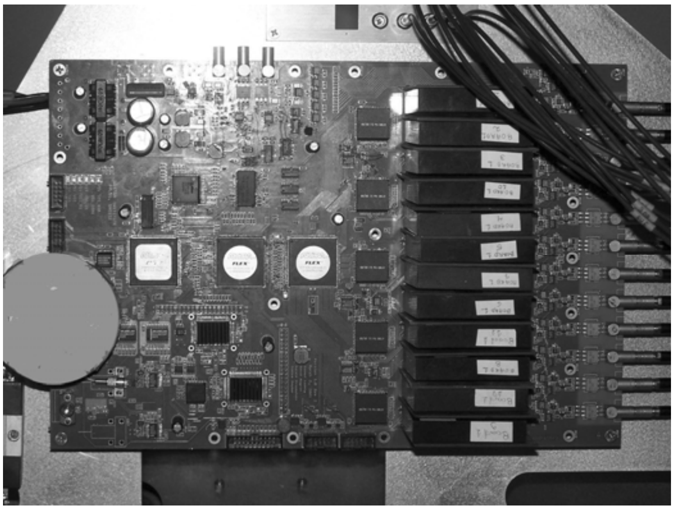

Figure 7 The "Floorboard"; PMT signal is coming from the right (LEMO cables) and data are sent to shore through optical fibres (protected inside the circular box, at left)

The event trigger is generated when the required number of PMT signals above a threshold is fulfilled (majority coincidence). The trigger window is adjustable; with the physical layout of the detector floor presently deployed, the trigger window was set at 60ns. The leading edge of the trigger signal is defining the trigger absolute time occurrence with respect to the 40MHz clock and initiates the PMT signal capture by the ATWDs, the reading of the environmental parameters and, after packaging, data transmission to the shore. Forced trigger on demand, by command from the shore control system, could also force data taking, without PMTs signal, for calibration purposes.

The Housekeeping Boards [24] regulate the powering of the PMTs and their high voltage and monitors the PMTs high voltage and data from the environmental sensors. Moreover it operates the LED calibration flashers suspended above and below the floor. In addition a Smart PMT Fuse board protects the system from shorts on any Optical Modules line.

The Shore electronics consist of ShoreBoard and several-networked computers. The Shore Board [24, 26], connected on the EISA bus of the Data Acquisition computer, performs all communication with the deployed detector floor, receiving data and sending commands to the FloorBoard through two fibres of the 30km long electro-optical cable. Event data packages received by the ShoreBoard are stored temporarily in local buffers. Then, every 13 events, the stored data are sent and stored in the computer's permanent storage facilities for keep, distribution and analysis. In addition of the above, the Shoreboard sends a 40MHz clock to the FloorBoard as well control commands, change of the trigger logic parameters and allow the reprogramming of the FloorBoard FPGA/PLDs within the Floor Board, if required.

The NESTOR prototype was deployed successfully March 2003 using the cable-ship RAYMOND CROZE (FranceTelecom). The first deep-sea muon data transmitted to shore, through a 30km long electro-optical cable to the Methoni counting room was achieved on the 30th of March 2003. Detailed analysis could be found elsewhere [14, 27].

VIII. The DELTA BERENIKE

For the construction of the KM3NeT, the km^3 neutrino telescope, specially constructed and dedicated vessel are preferred to minimize rocking, pitching and rolling motion during operations in the open sea. Moreover, in order to position the complex instrumentation package on exact position on the sea floor, precise navigation to the planed position is required and the ability to remain "stationary" for long hours at the deployment site, possibly with variable sea conditions. Actually, even in calm seas it is impossible to avoid the long wavelength – low frequencies waves which can be caused by storms hundreds of miles away or by nearby passing ships. This rocking, pitching and rolling motion may lead to catastrophic situations by exciting oscillations on the scientific payload in the sea underneath it.

The NESTOR Institute has constructed a special purpose deployment platform named DELTA – BERENIKE (figure 8). The design of the DELTA – BERENIKE has been inspired by the off shore oil rigs of the North Atlantic. DELTA-BERENIKE is a Central Well Ballasted Platform of triangular structure with 51m long sides and 48m long base. At each apex of the structure, two concentric cylinders (4 and 6m diameter each) are located, providing the required buoyancy and housing the three (one in each apex) motive engine systems; a CATERPILLAR 322 BHP motor coupled to a SCHOTTEL 360° SPJ57RD jet, which can rotate a full 360°. Using the combinational power and thrust direction of those machines, DELTA-BERENIKE can sail to the required course, dock or hold position on the open sea. The opening in the middle of the triangular structure assures balanced access to the sea surface. The platform is equipped with assorted bridge crane, cranes, winches, etc to be used as required.

DELTA-BERENIKE is equipped with a Dynamic Positioning system that permits precise navigation and station holding in the open sea. This will extremely useful during deployment of NESTOR or KM3NeT instrumentation to exact positions on the seafloor.

It will be also valuable on measuring, with sub degree accuracy, the absolute angular resolution of the deployed neutrino telescope installing cosmic ray arrays on her deck and keeping position above the deployed neutrino telescope.

Figure8. DELTA-BERENIKE during upgrading

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IX. References

1 L. K. Resvanis, Nuclear Physics B (Proc. Suppl.) 122 (2003) 24-39

2 R.Gandhi, C.Quigg, et.al, AstroPart. Phys. 5, (1996), 81-110

3 John Learned, "An Introduction to Neutrino Astronomy", http://www.phys.hawaii.edu/~jgl/nuastron.html, 1999

4 M.A.Markov, Phys.Lett 10 (1964), 122-123

5.M.A.Markov, Proc.Int.Conf. on High Energy Physics, Rochester, EGG Tinlog et al, pp. 597 (1960)

6 L. K. Resvanis (1992), Proceedings of the 2nd NESTOR International Workshop, 1992, p. 1. Available from: /http://www.nestor.org.gr

7 L. K. Resvanis et al. High Energy NeutrinoAstrophysics (1992), V. J. Stenger, J. G.Learned, S. Pakvasa and X. Tata editor

8 E. Trimonis, et al., in: L.K. Resvanis (Ed.), Proceedings of the 2nd NESTOR International Workshop, 1992, p. 321. Available from: /http://www.nestor.org.gr

9 S.A. Khanaev, et al., in: L.K. Resvanis (Ed.), Proceedings of the 2nd NESTOR International Workshop, 1992, p. 253. Available from: http://www.nestor.org.gr

10 E. G. Anassontzis et al, Nuclear Instruments and Methods A349, (1994), 242

11 T.A. Demidova, et al., in: L.K. Resvanis (Ed.), in: Proceedings of the 2nd NESTOR International Workshop, 1992, p. 284. Available from: http://www.nestor.org.gr

12 E.G. Anassontzis, et al., Sea Technology. (2003) 10

13 HCMR, private communication

14 G. Aggouras et al, Nuclear Instruments and Methods in Physics Research A 567 (2006) 468–473

15 Bioluminescence variation in time, using data from 2003 run, nestor memo 2006, 95

16 Nuclei in NESTOR site, nestor memo 2007,103

17 G. Aggouras et al, Nuclear Instruments and Methods A 552 (2005) 420–439

18 Wheather conditions in NESTOR site, nestor memo 2008, 43

19 KM3NeT Consortium, www.km3net.org

20 ICECUBE, http://icecube.wisc.edu

21 CDR, http://www.km3net.org/CDR/CDR-KM3NeT.pdf

22 E.G. Anassontzis, et al., Nucl. Instr. and Meth. A479 (2002) 439

23 Joshua Sopher, “NESTOR FLOOR BOARD”, Technical Report, Internal NESTOR Publication 2002

24 D. Nygren, et al, “NESTOR Data Acquisition System – Based on Waveform Capture”, August 20, LBNL (1998).

25 Stuart Kleinfelder, “Analog Transient Waveform Digitizer”, LBNL 1998

26 P. Arragain, “NESTOR DAQ System on Shore”, LBNL (October 1999)

27 G. Aggouras et al, Astroparticle Physics 23 (2005) 377–392