Neutrino Extended Submarine Telescope with Oceanographic Research

Status Report

• Neutrino Astronomy
galactic and extra-galactic neutrino sources

• Particle physics beyond the Standard Model
massive dark matter particles captured in the Earth, the Sun or galactic centre - multiple W, Z production etc.

• Neutrino Oscillations
atmospheric neutrino oscillations - long base-line neutrino oscillations

• Magnetic monopoles - Supernova detection

• The Unexpected
| Germany | Institute of Geophysics  
|         | University of Hamburg  
|         | Institute of Experimental and Applied Physics  
|         | Center of Applied Marine Sciences  
|         | Research and Technology Center West-Kueste (FTZ Buesum)  
|         | University of Kiel  |
| Greece  | Physics Dept.  
|         | University of Athens  
|         | Institute for Geodynamics  
|         | Athens Observatory  
|         | Physics Dept.  
|         | University of Crete  
|         | Institute for Informatics and Telecommunications  
|         | NCRS DEMOKRITOS  
|         | National Science Foundation  
|         | School of Science & Technology  
|         | Hellenic Open University  
|         | NESTOR Institute for Deep Sea Research, Technology and Neutrino Astroparticle Physics  
|         | Physics and Astronomy Dept.  
|         | University of Patras  
|         | Physics Dept.  
|         | University of Thessaloniki  |
| Russia  | Experimental Design Bureau of Oceanological Engineering  
|         | Institute For Nuclear Research  
|         | Russian Academy of Sciences  |
| Switzerland | Physics Dept.  
|         | University of Bern  |
| U.S.A.  | Dept. of Physics and Astronomy  
|         | University of Hawaii  
<p>|         | Lawrence Berkley National Laboratory  |</p>
<table>
<thead>
<tr>
<th>Country</th>
<th>Collaborators</th>
</tr>
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</table>
| Germany   | • ALU-BAU, Buedelsdorf  
• GeoPro mbH  
• GISMA GmbH                                                                                                                                   |
| Greece    | • Hellenic Telecommunications Organization (OTE)  
• Marine Technology Development Company (EANT)  
• National Centre Marine Research (NCMR)  
• Institute for Marine Biology of Crete  
• Kourtis Salvage Ltd  
• Naval Engineering Dept., Athens Technology University                                                                                      |
| U.S.A.    | • MAKAI Engineering, Hawaii  
• Scripps Institute of Oceanography, La Jolla, California                                                                                   |
Experimental Technique
The NESTOR Neutrino Telescope Site
Site characteristics

- **a broad plateau:** 8x9 km² in area, 7.5 nautical miles from shore
- **depth:** ~4000m
- **transmission length:** $55 \pm 10m$ at $\lambda=460 \text{ nm}$
- **underwater currents:** <10 cm/sec measured over the last 10 years
- **optical background:** 75 kHz/OM due to K40 decay, bioluminescence activity (1% of the experiment live time)
- **sedimentology tests:** flat clay surface on sea floor, good anchoring ground.
NESTOR TOWER

32 m diameter
30 m between floors

144 PMTs

Energy threshold as low as 4 GeV

20 000 m² Effective Area for E > 10 TeV
Effective Area
Geometrical acceptance \(\otimes\) Reconstruction Efficiency

Estimated by Monte Carlo Integration

\[
\text{(area)} \cdot \left( \frac{N_{\text{reconstructed}}}{N_{\text{generated}}} \right)
\]

- Energy depended
- Direction depended
NESTOR TOWER

32 m diameter
30 m between floors

144 PMTs

Energy threshold as low as 4 GeV

20 000 m²
Effective Area for E>10TeV
NEUTRINOS going through ONE EARTH DIAMETER

EARTH IS NO LONGER TRANSPARENT TO NEUTRINOS WITH ENERGY > A FEW HUNDREDS TeV !!!
The Optical Module

- Hamamatsu PMT R2018-03 (15”)
- Benthos spheres
- μ-metal cage
- power supply

Lab tests

FWHM = 5.5 ns

TTS at single p.e. conditions

Number of PMTs

Measured TTS (ns)

Single p.e. conditions
Beam tests

248 Hamamatsu R2018-03 (15") PMT's

Deep water tests

450 Benthos spheres (3Al & 5Ti) floors

The optical module for the NESTOR neutrino telescope


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†NCRC "DEMOKritos", Greece
‡University of Crete, Greece
§CERN, Switzerland
University of Florence, Italy
University of Kiel, Germany
Institute for Nuclear Research, Russian Academy of Sciences, Russia
Institute of Oceanology, Russian Academy of Sciences, Russia
Experimental Design Bureau of Oceanographical Equipment, Russian Academy of Sciences, Russia
The NESTOR collaboration

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Abstract

NESTOR is a deep-sea water Cherenkov neutrino detector now under construction for deployment in the Mediterranean off Greece. Its key component is an optical module employing a photomultiplier tube with a 75 mm hemispherical photocathode in a transparent glass pressure housing. Extensive tests have been made on the sensitivity, uniformity, time resolution, noise rates and mechanical properties of the module; several test deployments have been made at sea. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Neutrino telescope; Cherenkov detector; Optical sensor
cosmic ray muon background
Ti floor

Hinged + Modular

32.5 m Diameter
14 PMTs Facing Up + Down

1m Ti Sphere Electronics Housing

Electronics Housing 1m Ti Sphere

PMTs facing up + down
Ti-Sphere Electronics

Floor Board
- PMT pulse sensing
- Majority logic event triggering
- Single & coincidence rate scaling
- Waveform capture & digitization
- Data formatting & transmission
- FPGA & PLD reprogramming

House Keeping Board
- PMT control
- Calibration Beacon control
- PMT HV monitor
- Power Supply monitors
- Environmental monitors

Shore Laboratory
- Power supply
- Signal transmission & Control

PMT signal transmission
- low voltage supply (24V)
- control and monitoring signal transmission
Floor Board

- PMT pulse sensing
- Majority logic event triggering
- Single & coincidence rate scaling
- Waveform capture & digitization
- Data formatting & transmission
- FPGA & PLD reprogramming

PMT Signal Capture & Digitization

5 ATWDs

Input: 12 PMT signals

Delay lines

Configuration parameters
PLD

Trigger Logic & Communication
FPGAs
Shore Board

- Downloads the FPGAs & PLD of the Floor Board
- Broadcasts the 40Mhz clock
- Receives Data from the Floor Board
- Transmits Data to the Run Control System
Real Time Monitor

Environmental
- Thermometers
- Hygrometers
- Compass
- Inclinometer/Accelerometer
- Pressure meter

Electrical
- PMT High Voltage etc

Digitization & DAQ Performance
- Digitized waveforms
- PMT rates
- Trigger rates
- DAQ status
Real Time Monitors

Sample

448 ns
Calibration

- Gain monitoring
- Timing
- Free running Calibration Trigger
- Adjustable Trigger frequency
- Adjustable LED’s light output
The LED Calibration System

Frequency
Duration
Light amplitude

Lab Tests

σ=9ns (including PMT time jitter)

off axis angle (degrees)

PMT time difference in ns

σ=9ns (including PMT time jitter)
Optical Module Preparation

- LED
- Reference
- Relative timing

Extensive Lab tests
On single p.e. conditions
- FWHM = 5.5 ns
- Measured TTS (ns)
- Number of hits

Electronic delay lines and amplifier
- Coaxial cable

Response
- Frequency (MHz)
- 0.0
- 0.2
- 0.4
- 0.6
- 0.8
- 1.0
- 1.2

Hamamatsu PMT inside the BENTHOS sphere
- Pressure gauges
- Al disk
- Filter
- Potentiometer
- PMT base
- dc/dc converter

Preparation
- L.E.D.
- Relative timing
- Reference

Reference waveform
Several Weeks of Bay Station Tests
ElectroOptical cable to shore (18 fibers +1 conductor)

Deployed in June 2000 by the cableship MAERSK-FIGHTER (ALCATEL- TELEDANMARK)

Cable was damaged during laying because of ship’s problems. ALCATEL accepted responsibility and will repair the cable.

Cable landing has been completed and first three km have been buried 2 m inside the bottom sand.

Methoni counting room is fully operational.
The Real Game: January 2002

ElectroOptical cable to shore (18 fibers +1 conductor)
Cable repaired in January 2002 by the cableship TENEo (TyCom)

Successful deployment of the anchor unit with environmental sensors to 4000m
A NESTOR floor deployment was postponed due to the bad weather conditions

15th of January: The first environmental data transmitted through the 35km ElectroOptical cable to the Methoni counting room

Geodynamic activity

21.02.2002
**Typical Current meter Data**

transmitted from the NESTOR site (4000m depth) through the 35km electrooptical cable

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**Horizontal Speed**

![Graph of Horizontal Speed](image)

**Current Direction**

![Graph of Current Direction](image)
Data Analysis Flow

Raw Data

Interface

Software Monitor Histograms

Database
(gains, baselines, attenuation etc)

Muon track generation
Muon propagation & γ shower generation
Cherenkov photon emission and propagation
PMT response simulation
Digitization
ATWD & Trigger simulation

Waveform Reconstruction
Hit Definition
DST Production

Data Quality Histograms

Calibration Data Analysis

Calibration Database Quality Histograms

MiniDST Ntuples & Histograms

Track Reconstruction

Calibration Database

background noise
Simulation and Analysis Effort

BEOWULF CLUSTER

32 PCs, each one with:
- dual processor INTEL III @ 500 MHz.
- 128 MB of RAM, 13 GB HD
- 2 FAST-Ethernet Cards.
- Interconnection via Fast-ethernet switches

Monte Carlo Production (studies)
Transition to C++
Waveform Reconstruction

Before the F.F.T. and the attenuation corrections

After the F.F.T. and the attenuation corrections

Rise Time
16 ns
9 ns

Double pulse separation

Sample Offset (ADC counts)

Offset (ADC counts)
Waveform Reconstruction
Hit Definition
DST Production

Data Quality Histograms

40 MHz Clock Waveform Capture

Event by Event Sampling Interval Variation (Constant Temperature)

RMS=0.006 ns

Software to Hardware Trigger Time Difference (arbitrary time offset)

σ=0.7ns
LED Calibration Data
Time Difference in PMTs Response

[Graphs showing time difference in PMTs response with pulse height in mV on the y-axis and time in ns on the x-axis]

LED Calibration Data
Gain Monitors

[Histograms showing pulse height distribution with categories for pulse height in mV and time in ns]
Track Reconstruction

- Software event building
- Hit filtering for noise (K\(^{40}\) and PM noise) reduction
- Reform Trigger Conditions
- Track Fit & background photons (showers) reduction
- Quality criteria
Time Scale

Electronics tests in Lab & Bay Test Station
*(done Autumn 2001)*

Cable rectification & acceptance tests
*(done January 2002)*

Environmental data acquisition

Summer 2002
Deep-sea deployment & run up to 2-floors
Engineering and Physics Run

Spring 2003
Recovery & re-deployment with 4-floors
Physics Run

2004
Full tower deployment in deep sea
Physics Data Taking

2005
Deployments of more towers
  e.g. 7 towers (1176 PMT's)
  • 1.8 Megatons of DENSILY instrumented mass
     within the 7 towers (i.e. few GeV threshold)
  • 25 Megatons of enclosed mass
Track Reconstruction

Pointing Accuracy (Degrees)

mean accuracy=17°
220 reconstructed tracks/day

mean accuracy=10°
70 reconstructed tracks/day

Event selection based on the PMT charge measurement

One NESTOR floor
Time Scale

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*(done Autumn 2001)*

Cable rectification & acceptance tests
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  - 1.8 Megatons of DENSILY instrumented mass
    within the 7 towers (i.e. few GeV threshold)
  - 25 Megatons of enclosed mass
4 NESTOR Floors

10000 m$^2$ effective area for E>10TeV

NESTOR Tower
(12 Floors)

20000 m$^2$ effective area for E>10TeV