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GRBNeT – A prototype for an autonomous underwater neutrino detector

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Abstract. GRBNeT is a project aiming at the detection of ultra–high energy neutrinos, for example neutrinos originating from Gamma Ray Bursts. The goal is to design, construct and deploy a prototype unit of an autonomous (data/energy–wise) neutrino detector. Being autonomous is crucial since for the detection of ultra–high energy neutrinos a very large volume of water is required. Large scale facilities such as IceCube and KM3NeT are designed to be more sensitive to galactic and diffuse flux neutrinos rather than extragalactic ultra–high energy neutrinos. However, their sensitivity to such neutrinos could be increased by placing around and at larger distances detectors such as the one of the GRBNeT project. This extension would increase the instrumented volume of neutrino telescopes to several cubic kilometres. In addition to that, as no cable connection to the shore is required, GRBNeT detection units cost significantly less than regular detection units and can become a cost effective extension of large scale facilities. For the GRBNeT prototype unit ultra low power electronics have been developed. The response to high energy neutrinos from GRBs and to the atmospheric muon background has been simulated.

1. Introduction

The Gamma Ray Burst Neutrino Telescope (GRBNeT) is a project funded by the Greek National Strategic Reference Frame Work (THALES Initiative 2011–2015). It is a collaboration between the Institute of Nuclear and Particle Physics of N.C.S.R. Demokritos, the University of Athens and the Hellenic Center for Marine Research, consisting of more than 15 scientists and engineers. GRBNeT has been conceived and proposed in the spirit of earlier autonomous detector proposals [1–3].

Gamma Ray Bursts are short duration emissions of γ–rays associated with extremely violent explosions in distant galaxies, characterized by the largest luminous energy emissions known to date.

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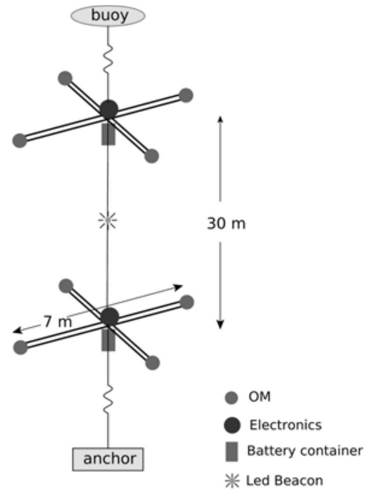

Figure 1. A schematic representation of the GRBNeT prototype detector.

It is predicted that during these explosions charged pions are produced through photon–hadron reactions, which in turn decay to ultra–high energy (PeV energies) neutrinos.

GRBNeT detection units can be placed independently from other infrastructure, creating a large neutrino detector. Using a multimessenger approach it is possible to pinpoint interesting astrophysical events in space and time that emit high energy neutrinos and then combine those in the offline analysis. GRBs are ideal candidates for this kind of analysis since their location in the sky and their exact time are precisely known by (γ–ray, x–ray, etc.) telescope observations. GRBNeT detection units can also be placed around large scale neutrino telescopes like KM3NeT/ARCA [4]. Since GRBNeT detection units do not depend on cables they can be deployed in various distances around existing underwater telescopes, the outcome would be the increase of the sensitivity in ultra–high energies of the said telescope in a very cost effective way.

2. Prototype design

The prototype unit consists of two cross–shaped titanium floors each with four Optical Modules (OMs) facing outwards. All four OMs are connected to the Control Board of their floor which is located in a separate sphere at the center of each cross. This sphere houses all the electronics necessary for the digitization, trigger and data acquisition. Each OM consists of a single 13″ Hamamatsu R8055 photomultiplier (PM), surrounded by a mu–metal mesh and placed in a 17″ glass sphere. Studies have been made to optimise the detection of ultra-high energy neutrinos (E_ν > 1 PeV) with respect to the OMs' orientation. It was found that OMs facing the horizontal perform better, as compared to any other direction. In addition, having a detection unit in the Mediterranean Sea with the PMs facing horizontally gives a full sky coverage during the day.

The two floors are seperated by a 30 m long rope and therefore their relative azimuthal position is varying. As there is no cable connection between the two floors, each of them is operated independently from the other; a led beacon is placed in equal distance between the two floors producing artificial events every seven hours for testing purposes, triggered by an autonomous timer. The detector is anchored on the sea bottom by an appropriate weight and held vertical by a top buoy. A schematic representation of the detector is shown in Fig. 1.

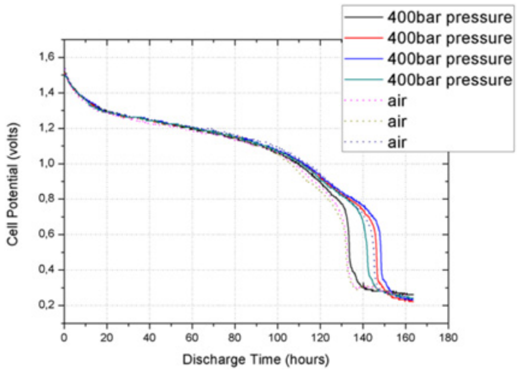

Figure 2. The voltage (V) of seven batteries versus the discharge time of each cell. Dotted/solid lines correspond to batteries discharging in air/under pressure of 400 bar respectively.

3. Power autonomy

The main idea behind the GRBNeT project is the autonomous character of the detector. By eliminating the dependence on cables, the detector is cost effective and easier to deploy. For this purpose, very low power electronics were designed and implemented. Power is provided by D type Varta alkaline batteries, arranged in clusters of 13 batteries in series. For each floor, 43 clusters in parallel provide enough power for at least six months. The batteries are contained in two plastic containers (one per floor) exposed to full depth pressure of 3000 m. The containers are filled with paraffin oil, which is an insulator and practically incompressible for that ambient pressure.

The behaviour of the batteries discharging under pressure has been studied in detail. Several tests were performed at pressures around 400 bar and no significant deviation has been observed. The discharge times of batteries on a 10Ω resistance at 1 and 400 bar are shown in Fig. 2, where the voltage drop of seven batteries is plotted against the discharge time of each cell.

4. Electronics – DAQ

The Data Acquisition and Slow Control are autonomous and all the data produced are written in SD–Cards. The DAQ has been designed with low power FPGA and the Slow Controls are implemented in custom made electronics [5]. They are both housed inside a glass sphere located at the center of each cross–shaped floor. The Control Board is the system that handles and distributes power (from the batteries) to the PMs and the other electronics (FPGA and Atomic clock), sets the high voltages on the PMs, reads the analog pulses produced by the PMs, digitizes them according to 4 thresholds and feeds the digital pulses to the FPGA for the coincidence logic to be applied. The four thresholds correspond to pulse charges of 1, 20, 30 and 50 photo–electrons (PEs), therefore from each analog pulse a maximum of four digital pulses are created. It also records the voltage of the PMs, the readings of a compass and a thermometer. All readings are recorded in SD–cards with a time stamp produced by an internal clock. The internal clock of each Control Board was synchronized with a GPS clock before deployment.

The FPGA implements the coincidence logic and records the single photoelectron rate. It stores the data produced in two separate SD–Cards, one for the single photoelectron rate and one for the events satisfying the trigger. For the single photoelectron rate, the number of pulses per second arriving from each PMT above the first threshold is being written. The coincidence thresholds were tuned in order to reduce the background and preserve battery energy, so a high threshold of 20 PEs was used. The trigger requires at least two pulses above threshold in different OMs within a time window of 200 ns.

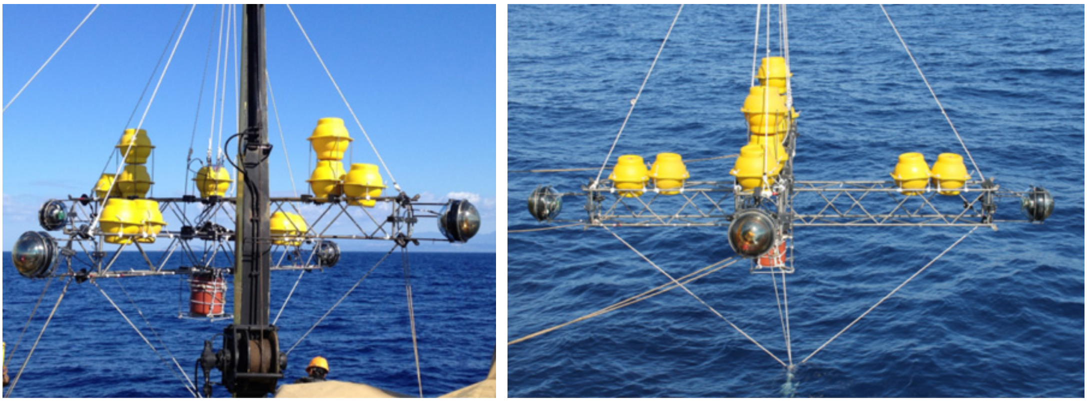

Figure 3. Left: A floor lifted from the deck of R/V AEGAEO. Right: A floor just before submersion.

When such a coincidence is detected, the time window opens for an additional 100 ns. In these 300 ns the rising times of the pulses that pass the second threshold, the ToTs of the pulses that pass each one of the three higher thresholds and the PM id are recorded. All the ToTs of the pulses passing each one of the three higher thresholds are recorded to better approximate the actual shape of the analog pulse. Each floor has its own FPGA recording coincidences independently from the other.

For the timing of the FPGAs two different techniques are applied. In the upper floor a low power atomic clock is attached to the FPGA. The atomic clock gives the actual time for the time stamps and also provides stable pulses per second used for the triggering by the FPGA. The time of the atomic clock was synchronized in the same way as the internal clocks of the Slow Controls before deployment. The lower floor does not have an atomic clock so the clock attached to the FPGA will be solely responsible for the time stamping and the timing needed for the coincidences. Thus, in the offline analysis, it will be possible to assess the performance of the embedded clock, and measure any potential long term drift, using the artificial events produced by the led beacons (placed in equal distance between the two floors) as time reference.

5. Simulations

Simulations studies have been made on the expected performance of the prototype to charge current muon neutrino and anti–neutrino events, and to atmospheric muon background events corresponding to a livetime of approximately 3 months, using the latest tools developed for KM3NeT [4]. The noise from the decay of the radioactive ^{40}K which is contained in sea water has also been added in both samples. For this prototype, given it's small effective volume, special focus is given on atmospheric muon events. This is done because the atmospheric muons triggered through the livetime of the prototype, can provide the statistics needed to validate its response. The trigger concept mentioned in Sect. 4 was also tested for neutrino events following an E^{-2} spectrum. It was found that more than 79% of the events that satisfy the trigger are high energy neutrino events ($E_\nu > 100$ TeV), which indicates that such a threshold setting for the prototype triggers high energy events.

6. Deployment

The deployment of the prototype took place on the 28th of October 2015 off the coast of Pylos in Peloponnese with the oceanographic ship "R/V AEGAEO" of the Hellenic Center for Marine Research. Figure 3 shows two photographs taken during deploymnet. Pylos site has ideal water properties for neutrino detection experiments, i.e. low velocity currents, low bioluminescence and low rate of sedimentation [6]. The prototype is deployed at a depth of 2960 m and the coordinates are lat: 36° 50.012′ and long: 21° 30.003′, and it will be retrieved shortly after the six month operational period. In future implementation the operational time is expected to be a factor of 2 or 3 larger.

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