SIMULATION OF THE PERFORMANCES OF THE km^3 UNDERWATER NEMO TELESCOPE FOR HIGH ENERGY NEUTRINOS

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Abstract

Preliminary simulation results for a detector made of "NEMO-towers" are presented. Effective areas and medians of the angle between true and reconstructed muon track are shown. The influence of the optical background rate is also investigated.

1 INTRODUCTION

The study of the response of a km^3-scale underwater Cherenkov neutrino telescope is a crucial point both for the design of detector and for the experiment analysis.
Indeed, in order to estimate the potential discovery for different neutrino sources, the effective detector area, the pointing (angular) resolution and the background rejection as a function of energy and angle must be evaluated.
The complete simulation of the detector response from the expected neutrino fluxes to the event reconstruction is a very hard and important task.
In this report, we present the expected performances of NEMO-dh140, which is a detector configuration understudy in the NEMO [1] Collaboration for the construction of a deep underwater km^3 Cherenkov detector to be deployed in the Mediterranean Sea, for high energy (100 GeV -1000 PeV) muon detection. In particular, the effect of the optical background rate has been investigated and the performances of the proposed detector lay-out, which is based on a modular "tower", is compared with a homogeneous detector, made up of strings arranged into a regular lattice pattern. The simulations have been performed using the software developed by the ANTARES Collaboration [2] as briefly described in section 3.
These simulations are part of a work in progress and represent a first attempt to guide a more refined design of the detector. Indeed, further efforts are needed in order to fully exploit the features of our detector for the definition of triggers, event selection and reconstruction.

2 THE DETECTOR LAY-OUT

One of the main concerns in the definition of the detector lay-out has been the feasibility in terms of technology within a reasonable budget and time construction schedule.
In this frame, we aim to design and optimize a km^3-scale detector made up of towers for high energy neutrino astronomy.
Constraints on the number of towers and PMTs, on the distance between towers and on their height arise from a feasibility study in terms of construction, deployment, operation and maintenance of the detector within reasonable costs.
The NEMO-dh140 configuration is made of 81 (9x9) towers with a height of 680 m, arranged in a square pattern with 140 m distance between towers. Each NEMO-tower consists of 18 bars 20 m long and 40 m spaced, consecutive storeys are orthogonal to each other. Each bar is equipped with 2 couples of PMTs at the two edges, each PMT couple consists of a down looking PMT and a horizontal one looking outside with respect to the tower center. In this configuration each tower hosts 72 PMTs, namely 5832 PMTs for the whole detector. The simulations on NEMO-dh140 represent a starting point for a detector design based on towers.

3 SIMULATION RESULTS

The simulation of the detector response to high energy neutrino fluxes consists of several different stages:

1. interaction of neutrinos in the media surrounding the instrumented volume;
2. propagation of the resulting particles until the detector horizon;
3. detector response to the Cherenkov light produced by the particles passing through the instrumented volume;
4. optical background and electronic simulation;
5. reconstruction track algorithms which allow to estimate the sensitivity of the detector to different sources.

These tasks are undertaken by different codes in the ANTARES Monte Carlo [3]. In the simulations shown in the following, we have used a modified version of the reconstruction code which allows to simulate large detectors of km^3 scale [ref.]. Our simulations aim to address the following two main questions:

- does a km^3 water Cherenkov detector based on towers fulfill the requirements for high energy neutrino astronomy?
- which is the effect of different environmental conditions (in terms of depth, optical water properties, …) on the detector performances?

The effect of the depth, which determines the shielding to atmospheric muons, is investigated in the previous report in this volume[4].

The optical properties are expected to affect the detector efficiency and angular resolution. In particular, the number of detectable photons and the spreading on their arrival time depend on the absorption and scattering length respectively, while the optical background induced by ^{40}K and bioluminescence tends to blur the muon signals thus requiring appropriate filters.

Detailed studies of the candidate sites for a deep underwater km^3 are in progress and also others characteristics, such as distance to coast, sea bed morphology, average and maximum currents, must be consistent with the technical feasibility requirements. In particular, an intense activity has been carried on for several years by the NEMO Collaboration to investigate the optical properties of some sites close to the Italian coast in view of the installationfor a km^3 water Cherenkov neutrino telescope. A site close to Capo Passero (KM4) has been proposed as candidate[5].

Moreover, a couple of campaigns have been done in the ANTARES (near Toulon) and NEMO (Capo Passero, KM4) sites with the same instrumentation in order to have a set of homogenous data for comparison.

In this report, we present preliminary results on the response of NEMO-dh140 to up-going muons with energy between 100 GeV and 1000 PeV for different optical background rates. Upgoing muons, with a flat distribution in $\log_{10}(E)$, have been generated at the surface of a

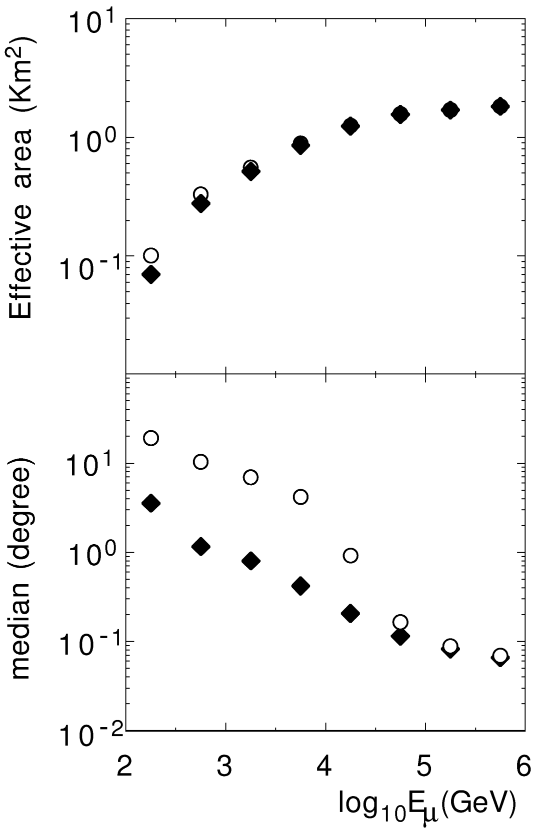

Fig. 1 – Effective areas (top) and median angles between true and reconstructed muon tracks (bottom) for 20 kHz (full diamonds) and 60kHz (open circles) for NEMO-dh140 detector.

cylindrical can which surrounds the detector and then step 3, step 4 and step 5 of the simulation have been run. The can dimensions have been chosen accordingly with the detector horizon, namely at distances where the Cherenkov light can be detected by the photomultipliers (PMT).

Two different values of the optical background have been considered (20 and 60 kHz). These values roughly correspond to the values in ANTARES and NEMO site respectively, where about a factor three in the background rates has been measured by the two collaborations [5]. The differences in the absorption and scattering length measured in the two sites have not been included yet in the simulation. Preliminary results are shown in fig. 1 where the effective areas (top) and medians (bottom) are reported as a function of energy for 20 kHz (full diamond) and 60 kHz (open circles) optical background rates for the reconstructed events.

Several reconstruction algorithms, based on different strategies can be implemented in the ANTARES simulation code. We have used the so-called Aart strategy [6].

Although very similar effective areas are obtained in the two cases of fig. 1, a remarkable deterioration of the angular resolution is observed increasing the optical background rate from 20 to 60 kHz. The effect is observed up to about 20 TeV, while no differences are observed at higher energies. The angular resolution achievable for high energy neutrino astronomy with Cherenkov muon detectors is intrinsically limited by the spreading angle between the incoming neutrino and the produced muon. This angle is expected to decrease from about one degree at 100 GeV to a few hundredths of degree at about 1 PeV. To improve the angular resolution, we have applied quality cuts on the reconstructed events. Moreover, the quality cuts are needed to eliminate the atmospheric muons badly reconstructed as upgoing muons. Since these muons represent the most dangerous source of background for the very low fluxes expected for high energy neutrino sources, very accurate simulations are needed. In particular, the generation of statistical significant samples of atmospheric muons is crucial to draw conclusions.

In fig. 2 the results obtained with quality cuts are shown. In order to achieve the same angular resolution for the 20 and 60 kHz case (top part of fig.2) different cuts must be applied. The obtained angular resolution is smaller or comparable with the expected angle between the neutrino and the muon up to about 10 TeV. At higher energy the angular resolution due to the reconstruction is larger than the angle between the neutrino and the muon. Preliminary results are shown in fig. 2 where the medians (top) and effective areas (bottom) are reported as a function of energy for 20 kHz (full diamond) and 60 kHz (open circles) for the reconstructed events which survive to the quality cuts. The achieved angular resolution is paid in terms of effective area which is reduced especially in the lower energy range; however, a much stronger reduction is observed for 60 kHz. Applying these cuts to the preliminary results of ref. 4

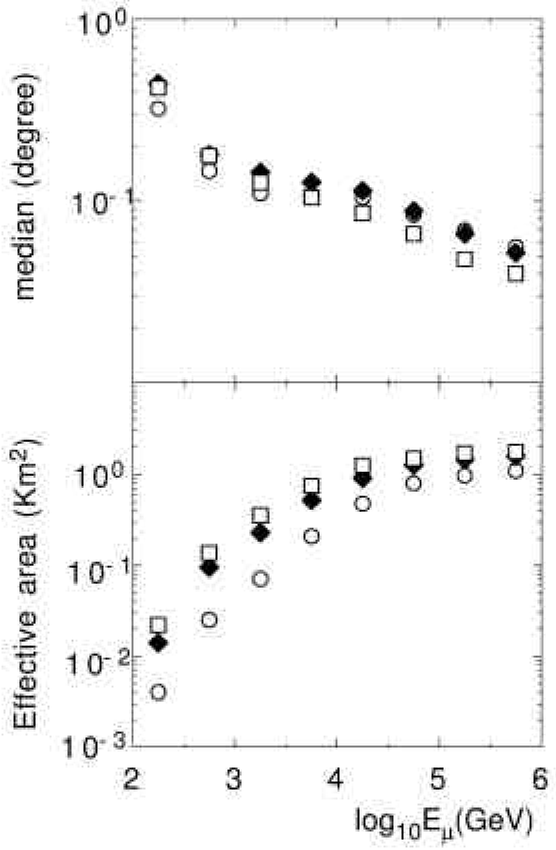

Fig. 2 – Median angles between true and reconstructed muon tracks (top) and effective areas (bottom) for 20 kHz (full diamonds) and 60kHz (open circles) after quality cuts for NEMO-dh140 detector. The open squares are the results obtained for a lattice detector with 20kHz (see text).

which represent about six minutes of data taking none of the atmospheric muons is reconstructed as up-going. Of course the lack of statistics doesn't allow to give conclusive answers.

In fig. 2 we have also reported the results of a simulation for a 5600 PMTs homogenous detector (open squares), made up of 400 strings in a lattice pattern 60 m spaced, with a height of 780 m. An optical background of 20 kHz has been considered, but no quality cuts have been applied in this case, due to the good angular response of the lattice detector. For the lattice detector the effective area as a function of muon energy (open squares of bottom of fig. 2) is close to NEMO-dh140 one at 20 kHz (full diamond), a similar angular resolution is observed. This comparison indicates that a km^3 detector based on NEMO-towers like NEMO-dh140 seems to fulfill the main requirements for high energy neutrino astronomy, especially for lower optical background rates. Moreover, it is important to point out that the homogenous detector, which has been derived from the Zaborov work [7], has to be considered only as an ideal detector which represents a reference for a given number of PMTs. Indeed, due to the very large number of strings (400) and to the small distance between them (60 m), a detector of this kind doesn't seem realistic for technical reasons and costs.

3 CONCLUSIONS

In summary, we have simulated the response of NEMO-dh140 detector with the ANTARES software tools and we have reported some preliminary results.

A rather strong deterioration of the angular response is observed increasing the optical background rate from 20 to 60 kHz. On the other hand, when quality cuts are applied we are able to obtain a good angular resolution in both cases with a consequent reduction in the effective areas especially at the lower energies. In particular, a much stronger reduction of the effective area is observed for 60 kHz, thus suggesting that a site with low optical background should be preferred for the installation of a km^3 detector.

The comparison with ideal detector, made of about the same number of PMTs arranged in a lattice pattern, confirms that a km^3 underwater detector based on NEMO-towers represents a promising approach to the high energy neutrino astronomy.

The results presented in this report are part of a work in progress which aims at the design and the optimisation of the NEMO detector.

4 REFERENCES

[1] C. De Marzo for the NEMO collaboration, Nucl. Phys. Proc. Supp. 87, 433 (2000) and http://nemoweb.lns.infn.it

[2] L. F. Thompson at al, Nucl. Phys. Proc. Supp. 91, 431 (2001) and documentation in www.antares2.in2p3.fr

[3] www.antares2.in2p3.fr ANTARES-soft Internal notes

[4] “Monte-Carlo simulation of the atmospheric muon background in a km^3 neutrino detector” R. Coniglione et al. for the NEMO collaboration, this volume.

[5] “Study and characterization of a deep sea site for a km3 underwater neutrino telescope” the NEMO collaboration, http://nemoweb.lns.infn.it/sitereport.

[6] “An algorithm for track reconstruction in ANTARES” Aart Heijboer ANTARES-soft/20002-002.

[7] “Simulation of cubic kilometer detectors” D.Zaborov ANTARES-soft/2002-008 www.antares.in2p3.fr. Internal note

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