MONTE-CARLO SIMULATION OF THE ATMOSPHERIC MUON BACKGROUND IN A km^3 NEUTRINO DETECTOR

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Abstract

Preliminary simulation results on atmospheric muon background in deep undersea km^3 detector are shown for two different depths. A strong reduction in muon flux in an under-sea detector at 3400m depth respect to 2400m is observed especially near the horizontal plane.

1 INTRODUCTION

The presence in the measured cosmic ray spectrum of a high energy component (E>10^{19} eV) suggests the existence of cosmological sources that act as cosmic accelerators. These sources are expected to produce also high energy neutrinos [1]. Neutrinos, in contrast with high energy γ and cosmic rays, are weak interacting particles and can traverse the entire Universe essentially unaffected carrying information from regions of the cosmos inaccessible to ultra high energy cosmic rays. Predicted high energy neutrino fluxes are very low [1] and interaction cross section are small. Therefore very large detectors are required. A new generation of telescopes has been designed to detect high energy neutrinos in deep ice [2,3] and deep water environments [4,5] aiming at the detection of Cherenkov light emitted by up-going muons produced in neutrino charged current interactions with the Earth. Due to low neutrino fluxes a huge shield for down-going muons, produced in the interaction of cosmic rays with the atmosphere, is required. Down-going atmospheric muons can be mis-reconstructed as neutrino-induced up-going muons and can represent a dangerous background for neutrino source searches.

We have performed simulations to compare the response of a detector, proposed by the NEMO collaboration, to down-going atmospheric muons at two different depths. Some preliminary results will be shown in this work.

2 THE SIMULATION CODES

The intensity of the atmospheric muon strongly decreases below the sea surface as a function of depth and zenith angle [6]. Therefore, for a proper estimation of flux and muon event multiplicities a Monte-Carlo simulation is demanded. We performed a complete simulation that can be divided in three steps:

- Cosmic ray interaction in the atmosphere (simulation of atmospheric showers)
- Muon propagation in the seawater down to the detector
- Detector response simulation

2.1 Simulation of atmospheric shower

HEMAS (Hadronic, Electromagnetic and Muonic component in Air Shower) code (vrs7-02) [7] has been used to simulate atmospheric showers. HEMAS has been designed as a fast tool for the production of air showers initiated by hadron primaries. It allows the calculation of hadronic and muonic components of air showers above 500 GeV and electromagnetic showers above 500 keV. HEMAS takes into account the Earth curvature and therefore the simulation can be extended out to zenith angles of about 90°. The DPMJET hadronic interaction model has been used.

2.2 Muon propagation

Muons were propagate from the sea level to the detector using the MUSIC code [8]. MUSIC (MUon SImulation Code) is a three dimensional Monte-Carlo code that takes into account multiple scattering, bremsstrahlung, pair production and inelastic scattering.

2.3 Detector response simulation

In order to get a complete detector response simulation, Cherenkov light and electromagnetic and hadronic showers produced by muons have to be simulated. PMT's response as a function of light wavelength and incident angles is also simulated. Sea water light propagation (scattering and absorption of light), background from ^{40}K, electronic simulation and PMT's time indetermination have been taken into account. Eventually, from the arrival times and hit amplitudes in the PMT's and time-space characteristics of Cherenkov emission a muon track reconstruction is performed. The codes used to perform such simulation were developed in the ANTARES collaboration [9].

3 RESULTS

The simulations have been performed adopting a KM3 detector (NEMO-dh140) consisting of 81 towers located as a 9x9 matrix placed at a distance of 140m. Each tower consists of 18 bars, 40m distant, located along the tower. Each arm (20m length) is orthogonal to the previous one and supports 4 PMTs with a diameter of 10 inches. Two optical modules are down-looking and two horizontally looking. The total number of PMTs is 5832. The detector geometrical volume is 0.88 km^3. The active volume considered in the simulation is a "can" around the instrumented volume of the detector calculated taking the maximum extension of the detector plus 200m (about two times the attenuation length for each side $\lambda_{att} \approx 50$m).

In our simulation $5{\cdot}10^6$ primaries with energies ranging from 20 TeV to 200 PeV have been simulated with a flat angular distribution in $\cos\theta_{zenith}$. Primary composition was based on ref. [10]. Only the following five different primaries have been taken into account: proton, helium, nitrogen, magnesium, and iron. With this primary composition cosmic ray spectrum is well reproduced up to 10^{17} eV. For a detector as NEMO-dh140 (effective area of $16.4{\cdot}10^6$ m^2sr) $5{\cdot}10^6$ primaries correspond to about 6 minutes of data taking.

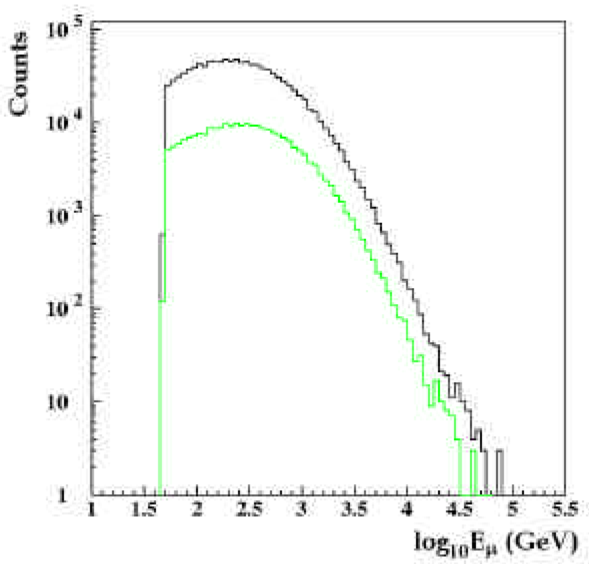

Fig.1 – Muon energy spectra at the "can surface" at different depths (2400m black line and 3400m gray line).

In Fig. 1 and 2 the muon energy spectra and the angular distributions at the "can surface" as a function of the zenith angle are reported. In the figures the calculations have been reported for two depths: 2400m (gray lines) and 3400m (black lines). These depths correspond to the two sites in the Mediterranean sea that have been intensively studied by the ANTARES (near the Toulon coast) and NEMO (near the Capo Passero Sicily coast) collaborations respectively. Deep-sea water optical properties (absorption and diffusion) and the sites environmental properties (water temperature, salinity, biological activity, optical background, water current and sedimentation) have been measured in these two site [11,12] that are candidates to locate an underwater telescope for high energy neutrinos. In Fig. 1 a major flux reduction is evident for 3400 m depth especially for energy E_μ<1 TeV. The ratio of the fluxes at 3400 and 2400m is 0.27. The reduction factor is much more important at angles near the horizontal where a factor 20 is observed at 15° over the horizontal (Fig. 2). This strong difference can be explained as due to the large difference in water thickness seen at angles near the horizontal by the same detector placed at different depths. The angles near the horizontal are particularly important for the high energy neutrino detection since neutrino over 10 PeV energy are strongly absorbed by the Earth [13] and consequently their best direction for detection is the horizontal plane.

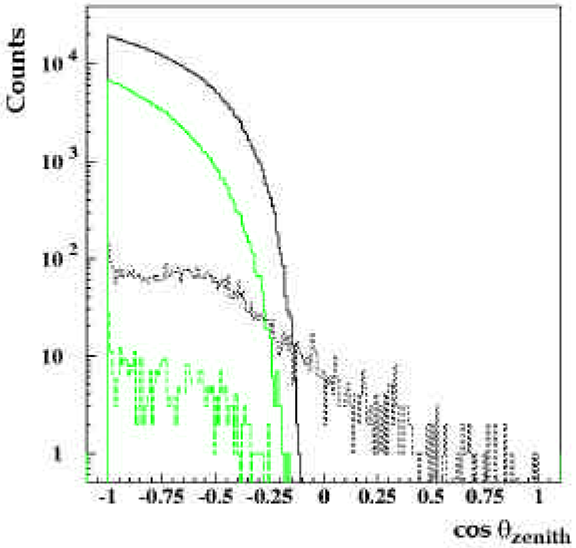

Fig. 2 - Muon angular distributions at the "can surface" at 2400m (black line) and 3400m (gray line). Reconstructed direction values are also reported (dashed lines) for the two depths (2400m black lines and 3400m gray lines) (see text).

Heavy energetic hadrons in cosmic rays produce in the atmosphere very large showers with high multiplicity of muons. In Fig. 3 the muon multiplicities at the can for the two depths are reported. A higher number of multi-muon events is observed at 2400m. The ratio between the number of multi-muon events at 2400m and 3400m is 6.8. A proper track reconstruction of multi-muon events represents a difficult task to achieve**.**

Finally these simulated muons have been propagated in sea water and the PMT's response simulated. We add 20kHz of optical background (^{40}K and bioluminescence) for depth of 3400m and 60 kHz for 2400m. These background rates are consistent with the values measured by the NEMO and ANTARES collaborations [11]. From the simulated PMT's hits muon track reconstructions have been performed. Different reconstruction strategies can be adopted. "Aart" reconstruction strategy improved for km^3 detectors has been used [14,15] for our simulations. In this work a first level trigger based on hit amplitudes and local coincidences between couples at the edge of the bars is implemented. More sophisticated triggers, that

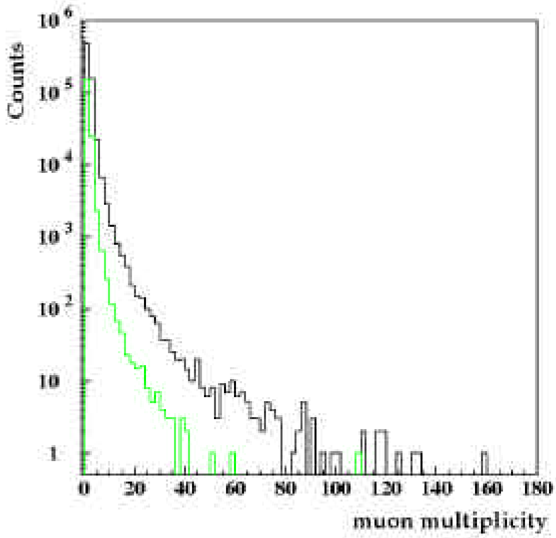

Fig. 3 – Muon event multiplicities at the "can surface" for two depths (2400m black line and 3400m gray

could strictly depend on the detector geometry, should be used. Work on this direction is still in progress. In order to avoid the presence of up-going reconstructed muons, quality cuts have been applied to the reconstructed tracks at 3400m. In Fig. 2 the reconstructed muon zenith angles for the two depths (dashed lines), with the same quality cuts applied, are reported. We have to mention that applying quality cuts we reduce the effective area of the detector that is one of the important parameter for a km^3 detector design (see following report in this volume [16]). From Fig. 2 it is clear that, with the same quality cuts applied at 2400m and 3400m data, the number of up-going reconstructed muons at 2400m is still large. In order to reject up-going reconstructed events at 2400m stronger cuts must be applied which further reduce the effective area (see following report [16]). The worse angular resolution at 2400m can be explained as mainly due to the higher optical background rate (60 kHz) simulated; the presence of a larger number of multi-muon events is also expected to affect the angular resolution. Much higher statistics is needed in order to draw definitive conclusions.

3 CONCLUSIONS

Simulation of background contributions in a neutrino telescope detector, also in a very low background environment as deep water, is an important task. The main background contribution in a high energy neutrino detector, based on Cherenkov light detection, is due to down-going atmospheric muon originated in the interaction of cosmic rays with the atmosphere. The atmospheric showers, the muon propagation in sea water and the detector response have been simulated as a function of depths (2400m with a ^{40}K rate of 60kHz and 3400m with a ^{40}K rate of 20kHz). Preliminary results, corresponding at about 6 minutes of data taking, show that a strong reduction in the atmospheric muon flux is observed at 3400m especially at angles near the horizontal plane. Reconstructed muon directions with quality cuts applied have been shown.

Work to significantly increase the number of atmospheric showers is in progress.

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