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Evaluation of triggering schemes for KM3NeT

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ABSTRACT

The future neutrino telescope KM3NeT, to be built in the Mediterranean Sea, will be the largest of its kind. It will include nearly two hundred thousand photomultiplier tubes (PMT) mounted in multi-PMT digital optical modules (DOM). The dominant source of the PMT signals is decays of ^{40}K and marine fauna bioluminescence. Selection of neutrino and muon events from this continuous optical background signals requires the implementation of fast and efficient triggers. Various schemes for the filtering of background data and the selection of neutrino and muon events were evaluated for the KM3NeT telescope using Monte Carlo simulations.

1. Introduction

The future Mediterranean deep-sea neutrino telescope KM3NeT is designed for the detection of high energy cosmic neutrinos [1]. The telescope is essentially a 3-dimensional array of PMTs, which detect Cherenkov photons from relativistic charged particles. The vast majority of these particles are down-going atmospheric muons (μ), while the characteristic signature of a neutrino (ν) event is an up-going muon produced by CC interactions.

The atmospheric muon and neutrino events in KM3NeT have to be reconstructed from temporally and spatially correlated PMT signals. However, before reconstruction, these events have to be separated and selected from the continuous deep sea optical background, coming mainly from Cherenkov photons induced by radioactive Potassium (^{40}K) present in sea water. This selection is made with software filters (triggers).

Triggering in KM3NeT will be based on the "all data to shore" concept, which is successfully used in the first Mediterranean neutrino telescope ANTARES [2]. In this concept different triggering schemes, which can also be applied simultaneously, are used for event selection from the continuous detector data stream. The flexible triggering creates the possibility for event selection with high efficiency and purity. The trigger efficiency is defined as the ratio of selected physics events over all events which are giving at least one signal hit in the KM3NeT detector. The trigger purity is defined as the ratio of the number of selected physics (muon and neutrino) events to the total number of events selected by the trigger.

One possibility for the KM3NeT triggering is an adaptation of algorithms from the ANTARES DAQ software [3]. However, the use of these algorithms in KM3NeT is complicated by the large number of PMTs and the corresponding increase of background hits. These changes will lead to a significant increase of the computer resources required for the triggering and makes the use of new triggering schemes necessary. The goal is to find a trigger combining a high efficiency with a low rate of background events.

A new optical module, proposed for KM3NeT, the multi-PMT DOM, allows for new triggering algorithms, based on local time coincidences between the signals in the DOM. The spatial structure of the KM3NeT configuration can be further explored in new triggering algorithms.

This paper is organised in the following way: the structure of the KM3NeT detector, which is relevant for the triggering is discussed in the next section. The optical background rates induced by ^{40}K decays and different hit levels are discussed in Section 3. The simulated muon and neutrino event samples and triggering software for the study of triggering schemes and corresponding results are discussed in Section 4.

2. The KM3NeT configuration

The configuration of the KM3NeT detector, used in this study, includes 6160 multi-PMT DOMs which are distributed among 154 detection units (DU). The KM3NeT DU is a vertical structure with

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[1] http://www.km3net.org

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20 storeys, where the first storey is mounted at 100 m above the seabed. The KM3NeT storey is a bar of 6 m length holding two multi-PMT DOMs. Adjacent storeys are perpendicular to each other in a horizontal plane and the vertical distance between them is 40 m. The average distance between DUs in this configuration is about 150 m. The instrumented volume of this configuration exceeds 3 km^3.

A multi-PMT DOM includes 31 PMTs with 3 in. diameter mounted in a 17 in. glass sphere. Nineteen PMTs in the DOM are "down-looking" and are mounted in the lower hemisphere; 12 "up-looking" PMTs are mounted in the upper hemisphere. The use of this innovative DOM has several advantages in comparison to ANTARES and IceCube optical modules, where a single large 10 in. PMT is used. This includes a larger photocathode area per OM surface, better quantum efficiency and timing characteristics, enhanced photon counting capability and directional sensitivity of the DOM.

The rate of atmospheric (down-going) muons in the deep sea telescope depends on the depth of installation. Three potential Mediterranean sites are under consideration for KM3NeT: the site near Toulon, France in the western Mediterranean, close to the ANTARES telescope at a depth of about 2500 m, a site near Capo Passero (Sicily) with a depth of 3500 m and an eastern Mediterranean site near Pylos, Greece with a depth of about 4500 m.

3. Hit levels and corresponding background rates

The basic signal collected from the KM3NeT detector is a PMT hit with two parameters: time and charge. A hit amplitude is usually measured in photon-electrons (p.e.) and should exceed an initial threshold level. We assume that in the KM3NeT telescope the hit threshold will be set at 0.3 p.e., the value used in the ANTARES telescope. This basic signal is usually referred as a level-0 (L0) hit. The vast majority of L0 signals in the KM3NeT data will be single p.e. hits from the deep sea optical background. The L0 rate depends on the PMT properties (photocathode area, quantum efficiency, and angular acceptance) and the optical parameters of the site (attenuation length of the optical photons). These parameters were set for the so called "KM3NeT reference detector", the configuration described in the previous section. The PMT quantum efficiency is 30% for photons with wavelengths $\lambda = 370-390$ nm, the maximum absorption length is 67.5 m at $\lambda = 440$ nm (same for all sites).

The data rate to shore and the bandwidth of the communication line are defined by the L0 rate. However, this rate is too high to be used directly in the software triggers. Therefore, it is necessary to define higher level hits with significantly lower rates. The multi-level organisation of the KM3NeT detection system (PMT → DOM → storey) gives the possibility to construct high level hits based on a time coincidence of the local L0 hits. The level-1 hit (L1), which is defined in a single multi-PMT DOM, requires at least two PMTs with L0 signals in a time interval of 10 ns. The T0 and T1 hits are based on a time correlation of L0 and L1 hits on the same storey. Here a T0 hit is defined as both a L0 and a L1 signal on a single storey within a time interval of 50 ns and the T1 hit requires 2 L1 hits.

The L0 and L1 rates induced by hits from ^{40}K optical background have been studied with the help of GEANT-4 based Monte Carlo (MC) simulations [4]. The L0 rate, which corresponds to an activity rate of 13.0 kBq/m^3 of sea water is about 4 kHz. For the L1 rate about 700 Hz was obtained from simulations, which includes two components, an uncorrelated signal from two L0 hits from different ^{40}K decays and a 600 Hz rate from a single ^{40}K decay, which takes place in close proximity of the DOM. The uncorrelated L1, T0 and T1 rates for the corresponding L0 rates can be obtained from calculations assuming random statistics. MC studies indicate that T0 and T1 rates from single ^{40}K decays are very low.

A physics event in the KM3NeT neutrino telescope is a collection of all hits in a predefined time interval t_{ev}. The t_{ev} time interval is centered on the first triggered hit, and extended in both directions by the time a muon needs to traverse the KM3NeT detector, about 10 μs. The minimal requirement for the reconstruction of a muon track with five parameters is at least five causally connected hits. To reduce the number of background hit combinations in the software filters, ANTARES is using only L1 hits in the trigger. For a large number n of background L1 hits the number of all 5L1 combinations is close to n^5, which makes the trigger search very time consuming. In our study we have considered trigger schemes based on L1, T0 and T1 hits.

The expected background rates for the L0, L1, T0 and T1 single hits, together with their mean multiplicity expected in the time interval of 20 μs is given in Table 1. The multiplicities for high level L1, T0 and T1 hits are 84.3, 2.3 and 3.1×10^{-3}, respectively.

Fig. 1 shows the background event rates as a function of T0 and T1 multiplicity in the event, calculated from Poisson statistics with the mean values given above. As indicated by the figure, the rates of multiple T1 background hits are very low and a single T1 hit (200 Hz rate) can be considered as a starting point for different triggering schemes in the KM3NeT telescope. For example the rate of a single T1 with an additional T0 is 100 Hz. The 2× T1 rate is below 1 Hz, which means that the purity of 2T1 trigger will be

Table 1
The expected singles rates of the L0, L1, T0 and T1 hits in the KM3NeT detector from ^{40}K optical background and corresponding mean multiplicities in events of 20 μs length.

Hit type	Logic	Time (ns)	Rate (Hz)	Mult. (20 μs)
L0	–	–	4×10^3	5×10^5
L1	L0&L0	10	700	86.2
T0	L1&L0	50	30.0	2.7
T1	L1&L1	50	5×10^{-2}	3.0×10^{-3}

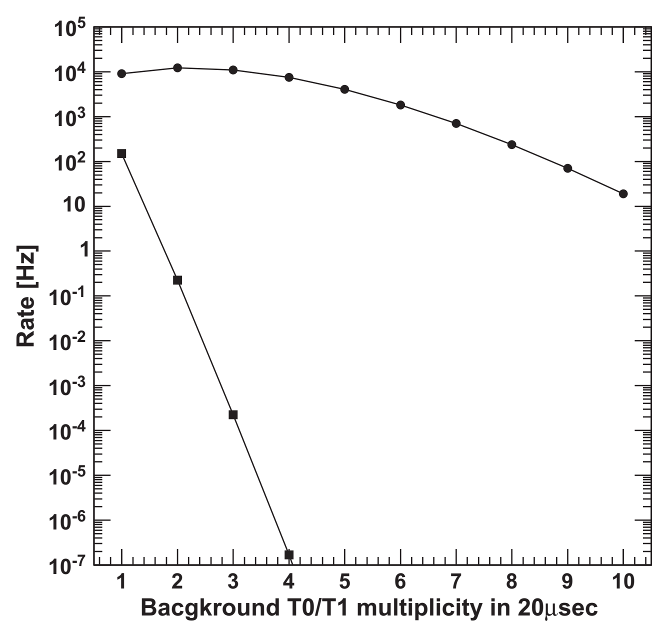

Fig. 1. The background event rates as a function of T0 (circles) and T1 (squares) hit multiplicities.

above 99% if the rate of muon and neutrino events selected with this trigger is above 100 Hz.

Additional optical background, including the PMT dark current and the marine fauna bioluminescence is not considered in this study. These background are supposed to be below the ^{40}K background rate for most of the time, excluding the periods of high bioluminescence (bursts).

4. Selection of the physics events

The triggering of physics events in the KM3NeT detector was studied with MC simulations using the modified ANTARES software [5]. Two different events samples have been simulated for these study—a muon neutrino events sample (charge current interactions) and an atmospheric muon sample.

The muon neutrino events sample corresponds to the energy (E) interval from 100 GeV to 100 PeV, follows an energy spectrum $E^{-1.4}$ and covers all zenith angles $-1 \leq \cos\Theta \leq 1$. The rate of atmospheric neutrinos or cosmic neutrinos with E^{-2} can be obtained from this sample by reweighting. 2×10^9 neutrino events have been simulated, from which 112,276 are giving at least one hit in the KM3NeT detector. These events were used for the study of different triggering schemes. The background has not been included in this study. Obviously the background hits do not affect the selection of triggered events, but may add additional ones.

The trigger efficiency for the neutrino events was studied with two different programmes. The first one is an adaptation of the ANTARES trigger software to KM3NeT, the second one was designed for the fast selection of simulated events with the simple triggering schemes. The trigger efficiencies for the neutrino events selected with T1, 5L1 and 2T1 hits/triggers as a function of neutrino energy and zenith angle ($\cos\Theta_\nu$) are shown in Figs. 2 and 3, respectively. As expected the T1 trigger will have the highest efficiency as it includes only 2L1 hits. The 2T1 efficiency is higher than 5L1 in the energy range below about 10 TeV. The trigger efficiency is also higher for up-going neutrino events as they encounter a larger photocathode area in the detector.

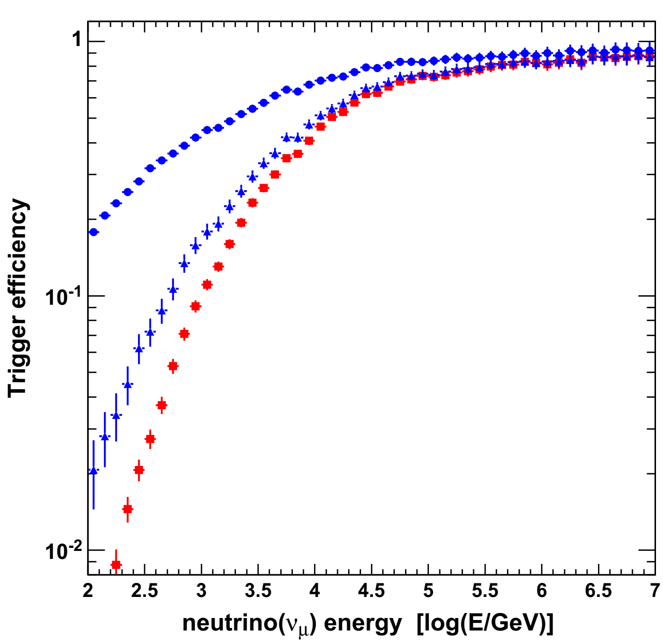

Fig. 2. Trigger efficiency for muon neutrino events with at least one signal hit in the detector as a function of neutrino energy. 5L1 hits/trigger (squares), T1 hits (circles) and 2T1 hits (triangles).

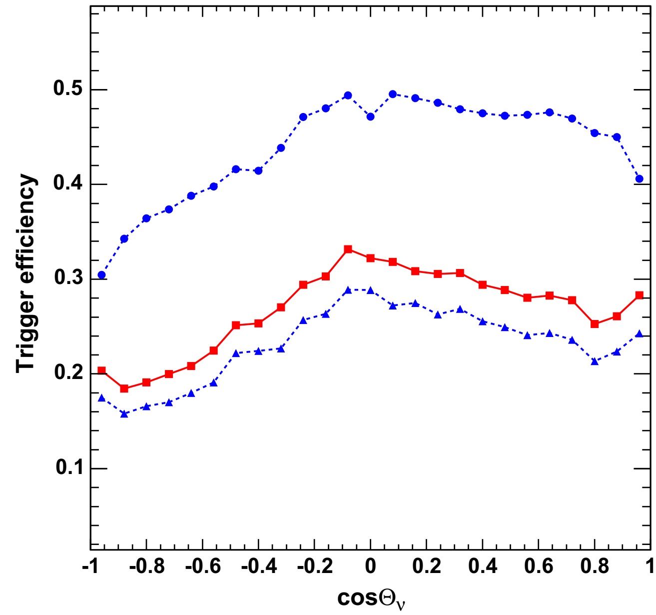

Fig. 3. Trigger efficiency for muon neutrino events, with at least one signal hit in the detector as a function of the neutrino zenith angle ($\cos\theta$). 5L1 hits/trigger (squares), T1 hits (circles) and 2T1 hit (triangles).

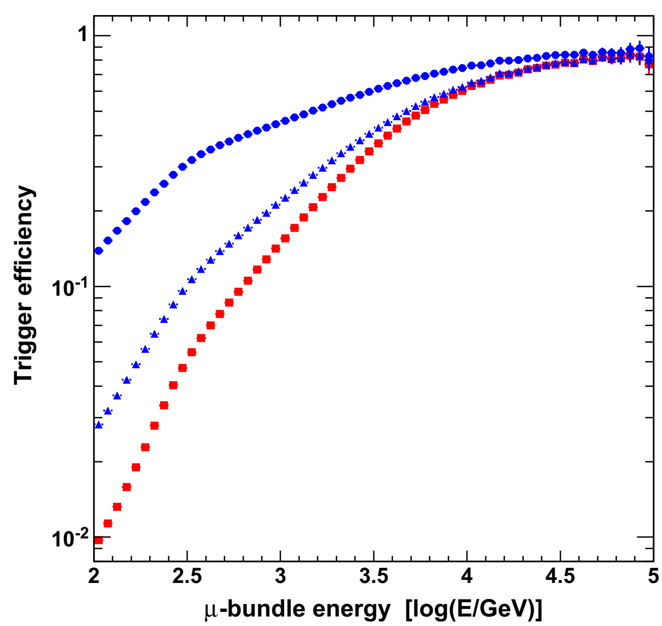

Fig. 4. The trigger efficiency for the atmospheric muon events as a function of μ-bundle energy for T1 (circles), 5L1 (squares) and 2T1 hits/triggers (triangles). The energy of the muon corresponds to its position on the CAN volume.

Atmospheric muon events were simulated with the fast Monte Carlo generator Mupage [6], which is based on parametric formulae obtained from a full simulation of cosmic ray showers. The programme generates muon bundles and propagates them in sea water. The maximum energy of muon bundles in these simulations is 100 TeV and the maximum zenith angle is 85°. The equivalent livetime available from the mupage simulation gives the possibility to evaluate the atmospheric muon event rate in KM3NeT. While the neutrino (up-going muon) event rates are the same at all KM3NeT sites the atmospheric muon rates depends on the depth of installation. In Fig. 4 the event selection efficiency is depicted for the atmospheric muon events selected with the same triggers as atmospheric neutrinos, T1, 5L1 and 2T1. For low energies the efficiency of 2T1 selection is higher than 5L1. This indicates that 4L1 hits which are included in the T1 are distributed on two adjacent storeys. For the energy range beyond 10 TeV the 5L1 signal is as effective as the 2T1, although the purity of 2T1 selection is expected to be much higher in comparison to 5L1 signals.

A clear difference in the event triggering efficiency is related to the fact that in mupage the muon energy in the bundle is defined on a surface of a virtual cylindrical volume that surrounds the detector (so called CAN volume). The height of this cylinder and its radius exceeds the size of the instrumented volume by about 150 m, which corresponds to three absorption lengths of the photons at 350 nm wave length. In the case of muon neutrino events the muon energy is defined at the interaction point, which may be far from the detector as the path length of the high energy muon in the deep sea can exceed several km.

5. Conclusions

The multi-level organisation of the KM3NeT detector elements allows the construction of high level hits with low background rates, which can be used in triggering schemes for the selection of neutrino and muon events. The triggering schemes based on L1, T0 and T1 hits have been evaluated for continuous ^{40}K background hits and physics events. Due to the high rate of expected accidental L1 hits in the KM3NeT telescope, the triggers based on 5L1 hits will require additional causality checks for the very large number of combinations, which will significantly increase the triggering time. The triggering schemes based on T0 and T1 hits are providing a necessary suppression level for the background events and a selection of neutrino and muon events with high efficiency and purity.

Acknowledgments

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References

[1] P. Koojman, Nuclear Instruments and Methods in Physics Research Section A, this issue.
[2] J.A. Aguilar, et al., ANTARES Collaboration, Nuclear Instruments and Methods in Physics Research Section A 570 (2007) 107.
[3] B. Bakker, Master Thesis, University of Amsterdam/Nikhef, 2011.
[4] B. Herold, T. Seitz, R. Shanidze, Nuclear Instruments and Methods in Physics Research Section A 626–627 (2011) S246.
[5] T. Seitz, R. Shanidze, Nuclear Instruments and Methods in Physics Research Section A 626–627 (2011) S208.
[6] G. Carminati, A. Margiotta, M. Spurio, Computer Physics Communications 179 (2008) 915 arXiv:0802.0562.