Simulation for KM3NeT using ANTARES-Software

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Abstract
The KM3NeT project is a common European effort for the design of a km$^3$-scale deep-sea neutrino telescope in the Mediterranean. For the upcoming Design Study simulations have been done using modified ANTARES software. Several concepts and ideas have been tested for their merits and feasibility.

Key words:
Neutrino telescope, Neutrino detection

1. Introduction
The European neutrino telescope experiments [1] have joined their efforts in the KM3NeT project [2] to design a km$^3$-scale deep-sea neutrino telescope in the Mediterranean. A neutrino telescope of these dimensions on the Northern hemisphere, complementary to IceCube [3], is necessary for high-energy neutrino astronomy.

As a first step for the KM3NeT project, a detailed simulation study of different detector models and photo-detectors is necessary. The software used by the ANTARES collaboration, with some modifications, is flexible enough for this task and was used for this study.

The modifications include the adaptation to a larger detector and a new causality filter for the event reconstruction [4]. In addition some changes were necessary to implement the different photodetection systems presented in this work.

Nonetheless the reconstruction and the selection cuts are optimized for ANTARES, and are therefore not necessarily optimal for different detector designs. However as the results show similar efficiencies for the detector models studied in this work and for the ANTARES detector, any reconstruction induced inefficiencies must be small.

The event sample used contained $10^9$ muon neutrinos with energies distributed between 10 and $10^7$ GeV and incident isotropically from the whole solid angle. Only charged-current $\nu N$ interactions were simulated, and the hadronic component of the final state was neglected. A $^{40}$K background rate of 91 Hz per cm$^2$ of photocathode area was used, corresponding to 40 kHz for a 10” Photomultiplier.

For comparison of different detector models the neutrino effective area was calculated as a function of the neutrino energy. The angular resolution, defined as the median angular deviation between reconstructed and true neutrino direction, was derived from the results, again as a function of energy.
2. The cylindrical storey

The different Photomultiplier (PM) configurations (storeys) considered in this work are depicted in fig.1.
- ANTARES storey with 3 10” PMs.
- Single Cylinder with 35 3” PMs, where each PM is read out individually.
- Three smaller cylinders with 12 3” PMs each, hits occurring in one of the sub-cylinders, within a predefined time window are added.

The overall Photocathode area of these structures is comparable. Small PMs generally have a higher quantum efficiency and a better Transit Time Spread (TTS). A disadvantage of the single cylinder structure lies in its vulnerability to mechanical stability problems. Additionally individual readout of 35 PMs within a very confined space might not be feasible. Therefore the triple cylinder variant was proposed. By adding hits in one sub-cylinder the amount of necessary readout electronics is reduced considerably.

3. Inhomogeneous geometries

The efficiency of a detector at low energies is correlated to the distance between the PMs. A possible way to combine low- and high-energy performance is to use clusters of densely instrumented strings as shown in fig.3. Low-energy muons have a high detection probability inside the clusters, while high-energy muons have a chance to hit several of the clusters, thus seeing a large instrumented volume.

As expected, effective area (fig.4), and angular resolution (fig.5) are significantly better than for the cube at energies below 20 TeV. At higher energies the performance is about 20% worse.
Above approximately 1 TeV the muon range in water exceeds the dimensions of the instrumented volume of a km$^3$-scale detector. Starting from this energy, most of the muons will enter the detector from the outside. Therefore the cross section area of the detector starts to become more important than a densely instrumented volume.

In order to exploit this effect the design of a ring-shaped detector with a densely instrumented boundary was studied. Examples of string layouts for such detectors are shown in fig.6.

Effective areas for the rings, as shown in fig.7, are slightly higher at low energies, due to the denser storey spacing in the ring. The angular resolution is very similar to the homogeneous case.

4. Conclusions

Several promising concepts of PM configurations and geometries for the design of the Mediterranean km$^3$ neutrino detector were considered.

Through simulations it was shown that the use of many small PMs in pressure cylinders can provide better performance as conventional large hemispherical PMs. Inhomogeneous geometries have been shown to increase efficiency at low energies with only small losses at high energies, while drastically reducing the number of necessary strings.

The simulations also demonstrated that ring geometries are a possible way to reduce the number of strings without any loss of performance.

The decision for a definite configuration has to depend on the physics priorities of the project, as the performance of the different detector concepts depends on the neutrino energy. Further studies with dedicated software for a km$^3$-scale detector are absolutely necessary to further clarify the results presented here, since the software used for this work is optimized for the ANTARES detector.

References

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