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KM3NeT: Toward a cubic kilometre volume neutrino telescope in the Mediterranean Sea

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ABSTRACT

High energy neutrino astronomy is emerging as one of the most exciting options for studying astrophysical processes. To establish neutrino detectability from specific sources, neutrino telescopes of km^3 scale are needed. In order to complement the IceCube detector currently under construction in the South Pole, a corresponding Northern Hemisphere detector is needed. The three neutrino telescope projects in the Mediterranean, ANTARES, NEMO and NESTOR have joined forces in order to develop, prepare, construct and operate such a research facility, KM3NeT. To this end, the EU is funding a 3-year design study. In the present paper, the status of the design study is presented and options for the various technical problems are discussed.

1. Introduction

Detecting high-energy neutrinos from specific astrophysical sources will be a major step towards understanding various particle physics related processes which occur in the universe. These neutrinos can be detected by water/ice Cherenkov telescopes. Such detectors can contribute to the study of Active Galactic Nuclei (AGN), Supernova Remnants (SR) or microquasars, Gamma Ray Bursts (GRB), etc. At the same time, questions like the search for neutrinos from the decay of dark matter particles (WIMPs), magnetic monopoles and other exotic particles can be addressed [1]. As recent studies indicate [2,3], these signatures will only be accessible through detectors of km^3 scale or even larger. Current telescopes like AMANDA [4] and ANTARES [5] are too small for this task.

The IceCube [6] telescope, under construction at the South Pole will have an instrumented volume of $1\,km^3$. Being a downward looking detector, the sensitivity to the southern sky will be limited. This limitation includes regions of the Galactic plane containing a multitude of possible high energy neutrino sources, like SR, microquasars, pulsar wind nebulae as well as several unassociated gamma-ray sources as reported by the H.E.S.S. telescope [7,8]. A logical conclusion is that a complementary detector in the Northern Hemisphere is needed to cover the whole sky.

In the Mediterranean Sea, three pilot projects, namely ANTARES [5], NEMO [9] and NESTOR [10] have joined forces in order to design, develop, construct and operate such a neutrino telescope, KM3NeT [11]. Apart from the accumulated expertise, the Mediterranean Sea offers some unique advantages for such an endeavor, namely, deep waters close to the shore, proximity of infrastructures, clean waters and large windows of good weather periods for the necessary sea operations. The KM3NeT collaboration currently consists of 37 Institutes from 10 European Countries (Cyprus, France, Germany, Greece, Ireland, Italy, Netherlands, Romania, Spain, UK). The KM3NeT facility is meant to be an interdisciplinary research infrastructure, serving, in addition, as a deep water facility for associated sciences, like marine biology, oceanography, geology, geophysics and environmental sciences.

2. Status of KM3NeT

Within FP6 the EU has initiated a 3-year research and development phase for KM3NeT. This design study started in February 2006, and will conclude in 2009 with the publication of the Technical Design Report (TDR) for KM3NeT. In early 2008, the Preparatory Phase (PP) of KM3NeT will start, overlapping for one year with the design study. The PP will be funded by FP7 and will address the political, governance, financial, strategic and socio-political issues of KM3NeT, including the site selection. The PP will also include prototyping work, in view of the start of the telescope construction in 2011. The time schedule of KM3NeT is such that the construction is expected to start early in the next decade,

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allowing the completion and operation of KM3NeT concurrently with IceCube. The overall cost of KM3NeT is estimated to be 220–250 MEuro.

KM3NeT is part of the ESFRI (European Strategic Forum on Research Infrastructures) roadmap [12] for future large scale infrastructures, being recognized as a *research infrastructure of pan-European interest*.

3. Detector optimization

The design study aims at providing design options for various components and detector configurations so as to deliver a detector with the best sensitivity for physics studies. The minimum requirements in terms of performance are an instrumented volume of at least 1 km^3, with angular resolution of about 0.1° for neutrino energies above 10 TeV, sensitivity to all neutrino flavors, and a lower energy threshold of a few hundreds GeV (and around 100 GeV for pointing sources).

Neutrino Cherenkov telescopes consist of a (usually) large number of photo-detection units, typically optical modules (OMs) containing one or more photomultiplier tubes (PMTs) for the detection of Cherenkov light. The OMs used in existing experiments, contain one large PMT (typically 10 in.) enclosed in a protective, pressure resistant, waterproof glass sphere. These OMs are arranged so as cover the instrumented volume, grouped in vertical structures with equal spacing between units. The specific choice of PMT size and arrangement in the OM as well as the layout of OMs in the instrumented volume have become the subject of detailed simulation, in order to optimize the sensitivity of the detector. In the context of the design study, various OM configurations and detector layouts have been simulated [13]. Examples of possible OMs can be seen in Fig. 1.

These include OMs with a single large PMT, double OMs, and OMs with many small PMTs inside. A large number of detector layouts have been evaluated, with the vertical strings arranged in cuboid, ring, hexagonal, clustered or mixed layouts (Fig. 2). In all cases the total instrumented volume has been kept constant to 1 km^3 and the total area of photocathode was kept constant.

The effective area for muons as a function of muon energy is shown in Fig. 3 where the KM3NeT configuration-1 detector is a hexagonal array consisting of 127 vertical strings each with 25 OMs, 100 m horizontal spacing, 15 m vertical spacing between OMs and three large PMTs per OM, similar to the ANTARES configuration. In the same figure, the configuration-2 detector corresponds to a structure of 225 vertical strings arranged in a cuboid grid with inter-line spacing of 95 m, 36 stories, vertical spacing between OMs 16.5 m, with each OM containing 21 3 in. PMTs. The effective area calculation includes full simulation of the neutrino interaction, muon propagation, Cherenkov light transmission, track reconstruction and event selection. Optical noise including ^{40}K decays in sea water was added, as measured by NESTOR [14] and NEMO [15] in the respective sites. The higher effective area of the two KM3NeT detector configurations compared to IceCube can be explained partly in terms of the higher photo-cathode area and partly to the better angular resolution of the water detector. With similar configurations KM3NeT will have a sensitivity one order of magnitude higher than existing experiments.

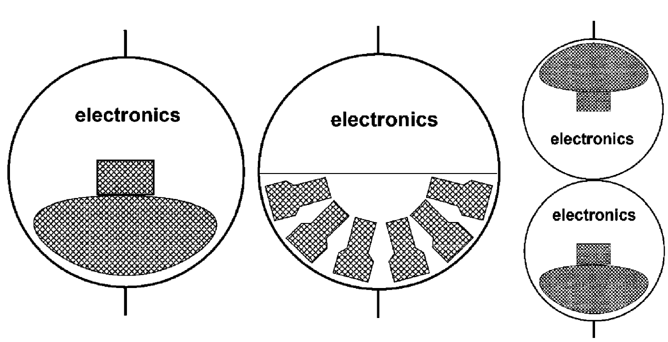

Fig. 1. Various options of optical module designs: (from left to right) single 10 in. PMT, multi-PMT OM, double PMT OM [13].

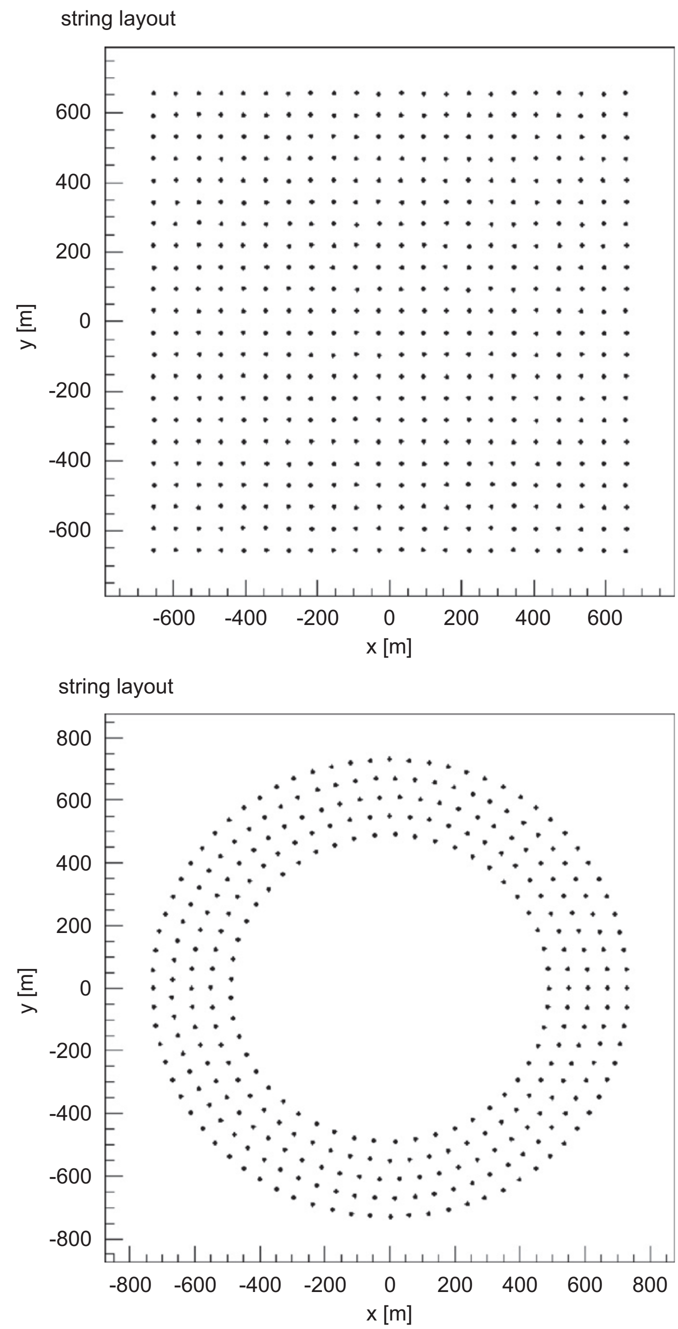

Fig. 2. Examples of the detector layout: cuboid (top), ring (bottom) [13].

4. Detector components and procedures

In designing the detector, the KM3NeT consortium can build upon the expertise of previous experiments, both in water (like DUMAND, Baikal, ANTARES, NEMO and NESTOR) and in ice