PROCEEDINGS OF SCIENCE

The KM3NeT project: Towards a km^3-scale neutrino telescope in the Mediterranean Sea

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In recent decades we have gained a tremendous amount of knowledge on our Universe. However, up to now astronomical observations have been restricted to the electromagnetic spectrum. The detection of cosmic high-energy neutrinos ($\gtrsim$ 1 TeV) will complement the information from these observations and at the same time provide completely new insights. The low interaction probability, which renders neutrinos perfect cosmic messengers, also poses a large challenge for their detection. Calculations indicate that neutrino telescopes of km^3-scale are necessary to detect neutrino fluxes from Galactic or extra-Galactic objects such as supernova remnants or gamma-ray bursts which are thought to produce neutrinos up to the PeV scale. KM3NeT, which is currently in the design phase, targets to instrument at least one km^3 of deep-sea water in the Mediterranean Sea, its field of view complementing the IceCube neutrino telescope at the South Pole and exceeding it in sensitivity by a substantial factor. We report on the current status of the KM3NeT project and on possible solutions for the various technical challenges encountered when building an off-shore detector in water depths of several kilometers.

European Physical Society Europhysics Conference on High Energy Physics
July 16-22, 2009
Krakow, Poland

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PoS(EPS-HEP 2009)102

1. Introduction

The detection of high energy neutrinos from astrophysical sources would be a major breakthrough in our understanding of origin and production mechanisms of cosmic rays and would open a completely new window to our universe. However, despite intense search for these neutrinos during recent years, no such neutrino has been identified up to now. Calculations [1, 2] indicate that detectors with at least a km^3 of instrumented volume are required for this task where detectors of the first generation like AMANDA or ANTARES have typical volumes of 0.01 km^3. At the South Pole the IceCube detector with an instrumented volume of 1 km^3 is currently being build as the successor to the AMANDA neutrino telescope. However, due to the large atmospheric muon background for upward observations with neutrino telescopes, the sensitivity of the detector to sources in the southern sky which includes most of the Galactic Plane and the Galactic Centre is greatly reduced. These regions harbour many potential high energy neutrino sources like supernova remnants, pulsar wind nebulae, microquasars and other binary systems, but also unidentified sites of high energy gamma-ray emissions. In order to be able to observe these sources, a km^3-scale neutrino telescope in the Northern Hemisphere is required.

Building on the experience gained in the pilot projects ANTARES, NEMO and NESTOR, the three collaborations have joined forces to develop, construct and operate such a km^3-scale neutrino telescope, KM3NeT, in the Mediterranean Sea at the beginning of the next decade. KM3NeT is envisioned as a multidisciplinary research infrastructure with a permanent deep-sea access for marine sciences (such as oceanology, marine biology, environmental sciences, geology and geophysics) through an *associated science node*. Evaluating the experience gained with the pilot projects it became clear that a simple scale-up of these detectors to km^3 size is technically not feasible and/or too expensive. Therefore, a research and development phase was initiated which is conducted within the framework of a Design Study funded by the EU in FP6. It started in February 2006 and will end in 2009. The main goal of the Design Study is the compilation of a technical design report (TDR) that subsequently allows for a timely construction of the detector and its concurrent operation with IceCube. As an intermediate step, a conceptual design report [3] has been released at the beginning of 2008 that describes options for the solution of the various technical challenges. KM3NeT is recognised by ESFRI (European Strategy Forum on Research Infrastructures) as *a research infrastructure of pan-European interest* and is listed on the ESFRI roadmap [4] for future large scale infrastructures. This entitled the consortium to be funded in the framework of a *Preparatory Phase* in the EU FP7 program which addresses the political, financial, governance, strategic and remaining technical issues. This process will also lead to a decision concerning the choice of the site for the construction of KM3NeT. KM3NeT is also supported by both the astronomy and astroparticle communities and entered the ASTRONET and ASPERA roadmaps as a high priority project.

2. Detector performance studies

The aim of the Design Study is to deliver the design specifications for a detector which yields the best physics performance for a given budget. Therefore, a large number of basic detector configurations have been simulated and their performance with respect to astrophysical benchmark fluxes has been evaluated. The performance objectives are a sensitivity which is larger than that of

IceCube by a substantial factor with an angular resolution of 0.1° for muons with energies above 10 TeV.

The basic building block of a detector is the optical module (OM) which contains the photomultiplier(s) (PMTs) for the detection of the Cherenkov light from charged particles. Up to now, neutrino telescopes have been using a single (typically 10”) PMT mounted in a pressure resistant glass sphere. In the course of detailed simulation studies, a large variety of possible OM configurations was investigated, among others a configuration that uses several small 3” PMTs. Small PMTs have a higher quantum efficiency, a better single photon resolution and a smaller transit time spread. Also, the usage of several PMTs in an OM can help to improve the single photon counting capability and yields directional sensitivity which can help in suppressing the optical background from bioluminescence. The OMs are positioned with equal spacing in a vertical structure (detection unit). Several of these units are then combined in different seafloor layouts. It turns out that a configuration of 225 detection units arranged in a cuboid grid with an inter-line spacing of 95 m a vertical OM distance of 16.5 m and 21 3” PMTs per OM yields a very good performance. This detector configuration was also used to obtain a first, preliminary sensitivity of KM3NeT to point sources. In Fig. 1 this is compared to the sensitivity of several other experiments. In this configuration KM3NeT would be able to search the southern sky with a sensitivity more than 10 times higher than current experiments.

3. R&D of detector components

A crucial parameter for the successful operation of the detector is the reliability of all offshore components. Although, in contrast to detectors frozen into the ice, it is possible to recover and repair deep-sea parts of the detector, this requires a large amount of time and resources. Also, due to the large number of components, even a moderate failure rate is unacceptable. Therefore, the reliability of all deep-sea components has been one of the prime guide lines in the design of the hardware from the begin of the Design Study.

As discussed in the previous section OMs equipped with several small PMTs show a very good performance and several further advantages. A prototype of such an OM is currently being built and tested at Nikhef [5]. As an individual readout is probably not feasible due to the required bandwidth, the idea would be to reduce the signal from the individual OMs to a digital pulse with a length equal to the time-over-threshold of the signal. The rectangular pulses of all PMTs inside an OM are then superimposed with their proper timing and sent to shore. In this way sufficient information can be retained afterwards.

4. Sea operations

A realistic detector configuration consists of 10 000 OMs on more than 100 detection units. The construction should not take longer than about 3 years in order to take data concurrently with IceCube over a long time period. The large number of detector units implies that new ways of detector deployment have to be developed. For example, in the case of ANTARES (12 lines) each line is deployed separately which takes typically 6 hours. Afterwards, in a separate campaign the lines are connected to a junction box with a submersible which again takes several hours. This

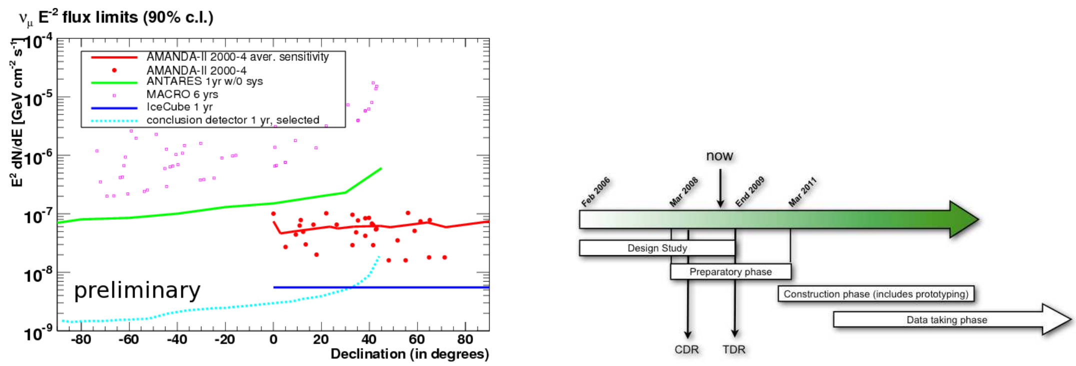

Figure 1: Left: Sensitivity of a possible KM3NeT configuration (blue dashed line labelled *conclusion detector*) to point-like sources as a function of declination. Also shown are the sensitivity of IceCube and other experiments (taken from [3]). Right: Anticipated timeline for KM3NeT (taken from [3]).

scheme is clearly impractical for a telescope with over 100 detection units. A possible solution is the deployment of "compacted" detector units similar to the NEMO scheme [6]. Here, the rolled-up detector unit resides in a container together with the buoy and a release mechanism. After deployment of the container on the sea floor the release mechanism is triggered by an acoustic signal and the buoyancy of the buoy unfolds the detector unit. The deployment of several containers already interconnected at the surface reduces the underwater operations and further speeds up the deployment process.

Acknowledgments

This work has been funded by the EU in the framework of the KM3NeT Design Study, FP6 contract 011937 and by the BMBF, project number 05CN5WE1/7. AK acknowledges support by the Marie-Curie OIF program, contract number MOIF-CT-2006-039706.

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