Progress and latest results from Baikal, Nestor, NEMO and KM3NeT

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Abstract.
Neutrinos are considered promising probes for high energy astrophysics. Deep water/ice Čerenkov technique was proposed to detect high energy neutrinos. According to present estimates, km^3 scale detectors are needed to detect high energy neutrinos from cosmos. IceCube neutrino telescope is under construction in the South Pole. For a full sky observation, a second km^3 telescope is required. In this paper progress and latest results from Baikal, NESTOR and NEMO experiments, operating in the Northern hemisphere are reviewed. KM3NeT status and activities toward a km^3 telescope in the Mediterranean Sea is also presented.

1. Introduction

Detecting high-energy neutrinos ($E_\nu \geq 1$ TeV) from astrophysical sources will be a major step towards a more complete understanding of the non-thermal Universe. These neutrinos can be detected by under-water/ice Cherenkov telescopes. Neutrino telescopes can contribute to the study of active galactic nuclei, supernova remnants, micro-quasars, gamma ray bursts, etc. Estimates indicate [1] that cosmic neutrinos will only be detectable by instruments with size of about one km3 or larger.

The IceCube [2] telescope being built at the South Pole will have an instrumented volume of ice of a km^3. Due to the intense atmospheric muon background, neutrino telescopes are mostly downward looking detectors, and as a result the IceCube device will explore mostly sources in the Northern sky. To allow the full sky observability, a second km^3 neutrino telescope in the Northern hemisphere that will survey a large fraction of the Galactic plane including the Galactic centre, is required.

In this paper we review the present status of the Baikal, NESTOR and NEMO underwater neutrino telescopes, operating in the Northern hemisphere. We present their latest results and the progress in R&D activities toward a km^3 scale neutrino telescope. Moreover the ANTARES (see proc. by J. Carr [3]), NESTOR and NEMO collaborations joined their efforts in the KM3NeT consortium. Aim of KM3NeT is to unify experiences of the three pilot experiments toward the realization of a km^3 telescope in the Mediterranean Sea. The present status of the KM3NeT consortium is also reported.

2. Status of the under-water high energy neutrino experiments in the northern hemisphere

2.1. Baikal

The Baikal Neutrino Telescope is operated in Lake Baikal, Siberia, at a depth of 1.1 km and it was the first installed underwater neutrino detector. The first telescope, NT-200, started full operation in spring 1998 and contained 192 Optical Modules (OMs). It is a high granularity detector with a threshold $E_\mu \simeq 10$ GeV and an effective detection area $\leq 10^5$ m^2 for TeV muons. With NT-200, the Baikal Collaboration measured the atmospheric neutrino flux and set the first 90% c.l. upper limit for diffuse astrophysical neutrino fluxes $(\nu_e + \nu_\mu + \nu_\tau)$ of $E_\nu^2 \Phi_\nu < 8.1 \times 10^{-7}$ cm^{-2} s^{-1} sr^{-1} GeV [4].

An upgrade of the telescope, NT200+, was commissioned in April 2005 by adding three additional external strings (see fig.1). The external strings of NT200+ are 200 m long (140 m instrumented) and are placed at 100 m distance from the center of NT200. Each string contains 6 pairs of OMs. Recently, the Baikal collaboration proposed the construction of a sparse Gigaton detector based on detection units made of 4 strings with 12-16 OMs each arranged in a geometry similar to NT-200+ where the central high granularity detector is replaced by one string.

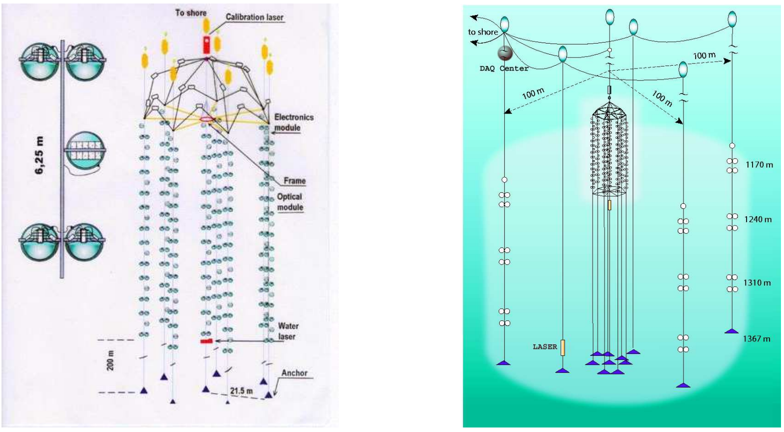

Figure 1. Sketch of the Baikal Telescope NT200 (left) and NT200+ (right).

The Gigaton detector will be made of 90-100 strings and 1300-1700 OMs, and a length of 300-350 m. Inter-string distance will be ≈100 m. The effective volume for cascades with energy above 100 TeV is 0.5-0.8 km^3.

2.2. NESTOR

NESTOR, the first Collaboration that operated in the Mediterranean Sea, proposes a site at 3800 m depth or more in the Ionian Sea, near the Peloponnese coast (Greece) for the installation of the km^3 telescope. A semi-rigid structure (*the NESTOR tower*), 360 m high and 32 m in diameter, equipped with 168 PMTs was designed. The basic element of the NESTOR tower is a hexagonal floor or star with two optical modules, one up-looking and the other down-looking, at the edge of each arm. The optical modules consists of a 15" diameter photomultiplier tube enclosed in a spherical glass housing which can withstand the hydrostatic pressure up to 630 bar.

In March 2003 NESTOR deployed one tower floor, with a reduced size of 12 m and equipped with 12 PMTs. The floor was deployed at a depth of 3800 m and was operational for about one month. Data analysis on atmospheric muons (745 events) allowed to compare the measured cosmic ray muon flux with simulation. A good agreement was found between distribution of the zenith angle of reconstructed tracks for the data and Monte Carlo event samples [5] (see Fig.2).

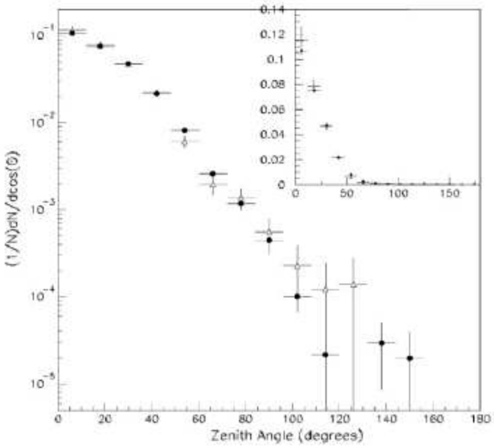

Figure 2. Distribution of the zenith angle of reconstructed tracks for the data (open triangles) and Monte Carlo (solid points) event samples. The insert shows the same distributions on a linear scale.

Recently the NESTOR Collaboration proposed an alternative solution to standard vessels for deployment of km3 modules. Delta-Berenike is a dedicated deployment vessel made of a triangular central-well, ballasted platform of 275 tons equipped with engines and thrusters for positioning (see Fig.3). Delta-Berenike is almost completed and should be delivered and launched in 2008.

Figure 3. Picture of the Delta-Berenike platform.

2.3. NEMO

Since 1998 the NEMO Collaboration carried out R&D activities aimed at developing and validating key technologies for a deep-sea cubic-kilometre scale neutrino telescope. The NEMO detector concept is based on semirigid vertical structures (NEMO towers) composed of a sequence of 12 m long horizontal beams made of marine grade aluminum. Each of these has two optical modules at either end, one looking vertically downwards and the other horizontally outwards and hosts instrumentation for positioning and environmental parameter monitoring. A tower, which consists of 16 floors interlinked by a system of ropes is anchored to the seabed and kept vertical by appropriate buoyancy on the top. The spacing between floors is 40 m, while the distance between the anchor and the lowermost floor is 150 m. The structure is designed to be assembled and deployed in a compact configuration, and unfurled on the sea bottom under the pull provided by the buoy. Once unfurled the floors assume an orthogonal orientation with respect to their vertical neighbors. The site proposed for the km^3 telescope installation is 100 km far from Capo Passero shore in Sicily, chosen for its optimal features to host the km^3 detector [6].

To validate the key technologies proposed for the km^3 detector, the Collaboration constructed a demonstrator at the NEMO TestSite (2100 m undersea located 25 km off-shore Catania port). The NEMO Phase-1 project started in 2002 and was completed in December 2006 with the deployment and connection of the junction box and a 4-floors prototype NEMO tower. All key components of an underwater neutrino detector are included: optical and environmental sensors, power supply, front-end electronics and data acquisition, time and position calibration, slow control systems, on-shore data processing [7].

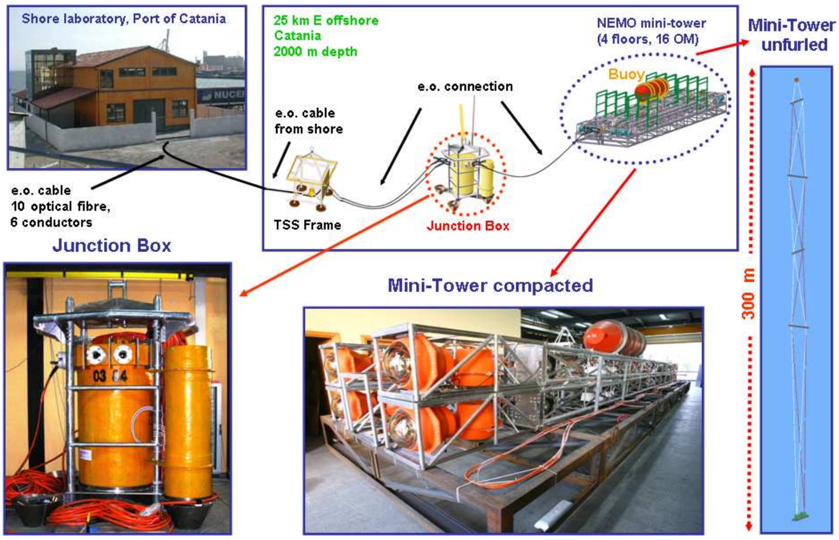

Figure 4. Sketch of the NEMO Phase-1 detector.

Down-going muon events were detected by the NEMO tower and tracks have been reconstructed thus allowing the measure of the atmospheric muon angular distribution. The comparison with Monte Carlo simulations is reported in fig. 5) [8].

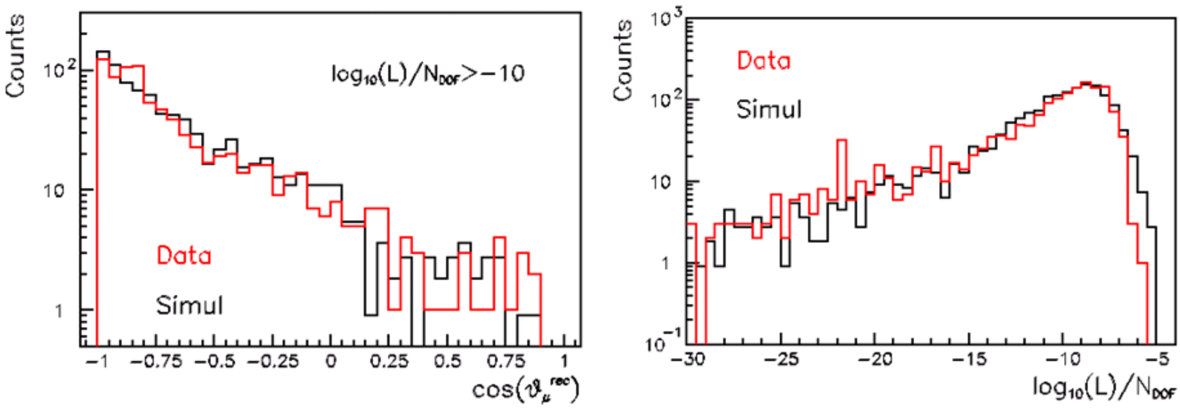

Figure 5. Angular distribution of reconstructed muon tracks in terms of the Zenith angle cosine and their likelihood spectrum compared with Monte Carlo simulations.

The next step is the NEMO Phase-2 project: an underwater infrastructure on the Capo Passero site and a complete tower structure with 16 storeys will be constructed at a depth of

3500 m. The NEMO Phase-2 deep-sea infrastructure includes a 100 km long electro-optical cable, laid in July 2007, which links a shore station, located in the harbour area of Portopalo di Capo Passero to an underwater infrastructure needed to connect detector prototypes. The experience gained with the Phase-1 tower led to a revision of the design aimed at simplifying the tower integration and reducing construction costs. The completion of Phase-2, expected in April 2009, will allow for a full validation of the deployment and connection techniques and of the functionality of the system at a depth of 3500 m.

3. KM3NeT: towards a km3 scale detector in the Mediterranean Sea

KM3NeT [9], acronym for KM3 Neutrino Telescope, will be the future deep-sea research infrastructure hosting a km^3 scale neutrino telescope and facilities for associate marine and earth sciences. KM3NeT is part of the ESFRI (European Strategic Forum on Research Infrastructures) roadmap [10] for future large scale infrastructures. KM3NeT is a consortium of institutes from 10 European countries including the three collaborations (ANTARES, NEMO and NESTOR) that develop pilot neutrino telescope projects in the Mediterranean Sea.

Activities started in February 2006 with the KM3NeT Design Study projected co-founded by the EU. The project aims at developing a cost-effective design for the construction of a 1 km^3 neutrino telescope. In this framework, the consortium published the KM3NeT Conceptual Design Report at the beginning of this year. This document describes the scientific objectives, and the concepts behind the design, construction, and operation of the KM3NeT Research Infrastructure [11]. The project will end in October 2009 with the completion of the Technical Design Report, defining the technological solutions for the construction of a km^3 neutrino telescope in the Mediterranean Sea. Minimum requirements are an instrumented volume of at least 1 km3, 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 of GeV. The impact of the various technical options on detector performance will be investigated with MonteCarlo simulations. A Preparatory Phase (PP) project co-founded by EU started in March 2008. The PP will address political, governance, and financial issues of KM3NeT, including site issues. The PP will also include prototyping work, in view of the start of the telescope construction in 2011. The KM3NeT detector in the Mediterranean Sea will complement IceCube [2] in its field of view and exceed its sensitivity by a substantial factor. The KM3NeT research facility will also serve the cause of marine and geophysical sciences. The existence of dedicated and permanent sea to shore connections allows the operation of long term real-time monitoring stations serving these disciplines.

4. Conclusions and outlook

The present status of the Baikal, NESTOR and NEMO underwater neutrino telescopes, operating in the Northern hemisphere was presented. Their latest results and the progress in R&D activities toward a km^3 scale neutrino telescope were shown and discussed. In particular, the successful experience of the pilot projects operating in the Mediterranean Sea (ANTARES, NEMO and NESTOR) demonstrated the feasibility of the km3 underwater high energy neutrino telescope. The three collaborations founded the KM3NeT consortium. Aim of KM3NeT is to take profit of experiences of the three pilot experiments and step toward the realization of a km^3 telescope in the Mediterranean Sea.

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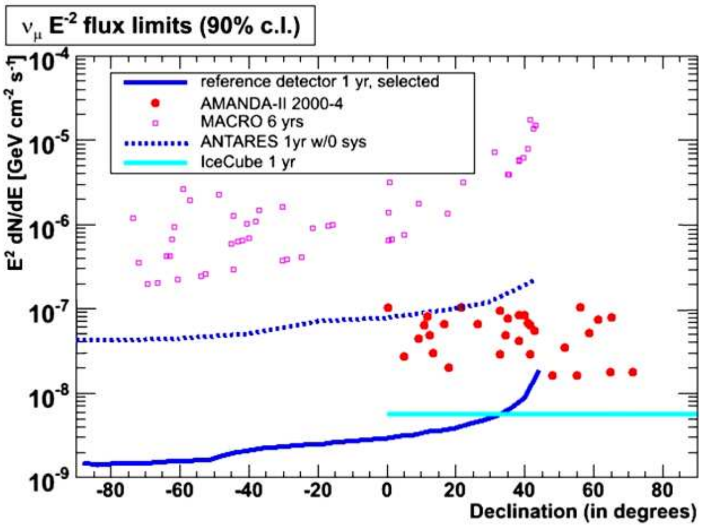

Figure 6. Expected sensitivity of the KM3NeT neutrino telescope (blue line) compared with the other experiments. The Mediterranean km^3 telescope will complement IceCube [2] in its field of view and exceed its sensitivity by a substantial factor.

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