The KM3NeT Project

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Abstract. The KM3NeT consortium has been carrying on R&D activities towards the construction of a km$^3$ scale deep sea neutrino telescope to detect high-energy astrophysical neutrinos. It will complement the IceCube detector, already in operation at the South Pole, and will have the Galactic centre and most of the Galactic plane in its field of view. Recently a technical design report has been released which contains the general description of the KM3NeT deep sea research infrastructure. This research facility will represent also a multidisciplinary marine and Earth science observatory, hosting a network of nodes for long term continuous monitoring of the deep sea environment. The objectives, status and plans of the KM3NeT project are presented.

1. Introduction
The multi-messenger astronomy can extend our knowledge of the Universe. In particular, neutrinos are unique messengers for the most energetic phenomena in our Galaxy and beyond. Electrically neutral and weakly interacting, neutrinos can carry information from the inner part of astrophysical objects and complement gamma ray astronomy and cosmic ray studies. The production of high energy neutrinos is expected to occur in objects where hadrons can be accelerated. Through the pion production in the astrophysical objects, it is possible to observe the MeV–TeV $\gamma$-ray spectrum of a source correlated with high energy neutrino events.

Several galactic objects are favoured as neutrino sources, such as supernova remnants, micro-quasars, unidentified TeV $\gamma$-ray sources; a diffuse flux could come from the galactic plane. Concerning the extragalactic objects, most violent phenomena like active galactic nuclei (AGN) and gamma-ray bursters (GRB) can produce an observable flux of $\nu$ [1]. Apart from point-like sources, collisions of cosmic rays with interstellar matter should generate a diffuse flux of neutrinos [2]. Some constraints on this diffuse flux have been established from the measured flux of cosmic rays of extragalactic origin [3]. The search for $\nu$ from dark matter decay in the Sun and the study of neutrino oscillations are also relevant topics in modern neutrino astrophysics. In Fig. 1 the visibility of a neutrino detector located in the Mediterranean Sea is shown.

The most efficient way to search for astrophysical neutrinos is through the detection of charged current interactions of muon neutrinos, with a muon in the final state [4]. The long range of the muon (about 1 km in water for a 200 GeV muon) allows the measurement of the direction of that particle through the detection of the Cherenkov light produced in a dense and transparent medium, such as sea water or ice. A lattice of photomultiplier tubes (PMT) can be used for the detection of the Cherenkov photons; from PMT positions and photon arrival times, dedicated algorithms can trace back the muon direction [5]. At high energies, the muon retains the original
direction of the neutrino; a detector measuring the muon direction can therefore be used to trace back to the emission source.

The main background in this kind of telescopes is represented by neutrinos and down-going muons produced by cosmic ray interactions in the upper atmosphere. Unlike traditional astronomy, neutrino astronomy examines the antipodal sky, looking for upward-going events. The background of atmospheric neutrinos is irreducible.

The experience gained with the ANTARES prototypal telescope [7] and with the pilot projects NESTOR [8] and NEMO [9] will help the construction of the KM3NeT underwater infrastructure. The KM3NeT consortium is composed by 40 European institutes from 10 countries and in 2006 was selected as one of 35 priority research infrastructures by the ESFRI panel. A preparatory phase was funded for the period March 2008-February 2012 and now the technical design has converged [10]. Building a deep-sea research infrastructure in the Mediterranean Sea hosting a km$^3$-scale neutrino telescope is a scientific priority in order to exploit the scientific potential of neutrino astronomy and complement the measurements performed by the IceCube detector [11] located at the South Pole.

2. Technical design

The KM3NeT neutrino telescope will consist of vertical structures (Detection Units, DU) anchored on the sea bed and kept under tension by submerged buoys (Fig. 2). An array of photomultiplier tubes contained in pressure-resistant glass spheres (Digital Optical Modules, DOM) will be installed on the DUs. The DUs are connected to shore via a sea-bottom network of electro-optical cables and junction boxes (Fig. 3). Following the strategy adopted by ANTARES [12], all data collected by PMTs are sent to shore where they are filtered according to trigger algorithms; no underwater data filtering is implemented.

The KM3NeT consortium will use small PMTs grouped within a single digital optical module. A DOM is a 17” glass sphere which contains 31 PMTs with 3” diameter and the front-end electronics (Fig. 4); the total photocathode surface is 1260 cm$^2$. High voltage bases with a power consumption as low as 140 mW for a complete optical module have been designed for this application.

The multi-PMT design provides a large photocathode area, very good separation between single-photon and multiple-photon hits and some informations on the photon direction. In

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1 The average deflection angle is less than 0.1$^\circ$ for a 1 TeV neutrino.
2 European Strategy Forum of Research Infrastructures
addition, a single PMT loss minimally degrades the performance. These features improve the track reconstruction performance in a cost-effective way with respect to the use of single-PMTs. The detection unit is a self-unfurling flexible tower composed by 20 horizontal bars (DOMBAR) of 6 m length. DOMBARs are spaced vertically by 40 m and equipped with two DOM, one at each end. Adjacent bars are connected by a tetrahedral set of ropes, to be orthogonally orientated to each other. A full-size mechanical prototype has been successfully deployed and unfurled in February 2010.

3. Expected detector performances
Detailed detector simulations have been performed; to determine the sensitivity to point sources an unbroken $E^{-2}$ neutrino spectrum has been assumed. Software packages developed in the ANTARES collaboration have been used to produce neutrino induced events and down-going atmospheric muons [13, 14]. Then particles are tracked through the Earth and sea water and the light produced by muons and their secondary particles is generated and propagated to the detector [15]. At the end, the PMT response and the readout electronics is simulated taking into account the PMT photocathode area, quantum efficiency and angular acceptance.

The detector sensitivity and discovery potential were studied using a binned analysis method [10], injecting signal and background spectra to evaluate events rates. For each zenith bin (assuming uniform distribution of events in azimuth), cuts on track quality parameters, energy proxies and cone sizes around assumed sources can be optimised to get either best sensitivity or discovery. Fig. 5 shows the $E^{-2}$ flux that can be excluded with 90\% C.L. (i.e. the “sensitivity”) versus declination after 1 year. The discovery potential is assumed equal to a 5\sigma excess in 50\% of experiments. The sensitivity is compared to that of IceCube for a wide range of declinations, including a large part of the Galactic plane. The differences in shape of the sensitivity curve is caused by the different geographic location, being IceCube located at the South Pole with an almost constant view of the sky, while the view of KM3NeT is constantly changing with the Earth rotation.

4. Prospects and plans
The KM3NeT infrastructure represents a deep-sea multi-disciplinary observatory in the Mediterranean Sea that will provide innovative science opportunities and long term continuous...
The multi-PMT optical module consists in a 17” glass sphere housing 31 3” photomultipliers and the readout electronics.

Sensitivity and discovery potential of the KM3NeT telescope to a $E^{-2}$ spectrum as a function of the declination angle compared with IceCube.

operation also for Earth and Sea Sciences. The final decisions for specific technical solutions will be the result of the Preparatory Phase project running until March 2012. Three sites (near Toulon, at the east coast of Sicily and at the west coast of the Peloponnesus) have been proposed. All sites have been characterised by long term measurement of optical, geophysical and oceanographic properties [16, 17]. The opportunity for a network of neutrino telescopes remotely controlled (the multi-site option) has been also considered.

The consortium is strongly engaged in the construction of a pre-production model of the detection unit. One mechanically complete DU with some active OMs and related electronics is planned to be deployed in 2012. Data taking will start as soon as the first DUs are operational. A Memorandum of Understanding (MoU) is in preparation. Data from the KM3NeT neutrino telescope will offer unique quality and statistics giving a strong impact on neutrino astronomy.

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