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Towards the Very Large Volume Mediterranean Neutrino Telescope, KM3NeT

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KM3NeT (km^3 Neutrino Telescope) will be one of the world's largest particle detectors, built at the bottom of the Mediterranean Sea, providing a window for the observation of the Universe through high energy neutrinos. KM3NeT will complement the South Polar IceCube neutrino telescope in its field of view and significantly surpass it in sensitivity and discovery potential. The underwater KM3NeT facilities will also provide continuous connectivity for long-term deep-sea scientific measurements in the geo- and biological sciences. We describe the major technical aspects of the KM3NeT design and we report on results concerning the evaluation of the sensitivity of the neutrino telescope to detect high energy astrophysical neutrinos.

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1. Introduction

KM3NeT is a deep-sea multidisciplinary observatory in the Mediterranean Sea that will provide innovative science opportunities spanning Astroparticle Physics and Earth and Sea Science [1]. This is possible through the synergy created by the use of a common infrastructure allowing for long term continuous operation of a neutrino telescope and marine instrumentation.

Neutrino astronomy opens a unique new window for the observation of the Universe. At the present time, the most sensitive neutrino telescope in the world is the IceCube detector at the South Pole which instruments a cubic kilometer of polar ice. Building on the experience gained with the ANTARES neutrino telescope and other projects in the Mediterranean Sea, the construction of the KM3NeT infrastructure is projected with a sensitivity exceeding that of IceCube by a substantial factor. KM3NeT will be an essential node in the global network of multimessenger instruments in astronomy.

2. Physics case

Various astrophysical sources are expected to produce high-energy neutrinos that may be detected with the KM3NeT. The information that can be gained by detecting just a handful of events emanating from a cosmic source cannot be underestimated. The existence of these neutrino sources will be proved and more importantly knowledge of their behavior, which cannot be acquired by other means, will be gained.

The observation of point-like sources of neutrinos would bring unique new insights on the nature of cosmic accelerators and resolve the enigma of the origin of cosmic rays. Observations by gamma ray telescopes have revealed many astrophysical objects, in which high-energy processes at and beyond the TeV level take place. However, measurements with gamma rays alone cannot clearly distinguish whether the accelerated particles are leptons or hadrons. Only the observation of neutrinos from a source can unambiguously establish the hadronic nature of that source.

Gamma Ray Bursts are also potential very high energy neutrino emitters according to the fireball model [2]. High energy neutrinos from prompt emission consistent with the detected gamma rays are expected to arrive within a short time window (2 - 1000 s)[3]. The narrow time window results in reduced background noise and with the combination of an appropriate cut on the reconstructed energy of the neutrino induced muon, the detection of down-going GRB neutrinos is feasible [4].

The ultra high energy neutrinos from: a) a multitude of objects such as Active Galactic Nuclei or GRBs, and b) from the interaction of cosmic rays with intergalactic matter and radiation or even with the cosmic microwave background, are expected to form an isotropic diffuse flux. Without the possibility of using a tight angular cut for reducing the background of atmospheric neutrinos, diffuse neutrino flux searches have to rely on a cut on the reconstructed muon energy.

3. KM3NeT Design

KM3NeT will consist of several hundreds of vertical structures (Detection Units - DUs), which carry photo-sensors and devices for calibration and environmental measurements, arranged vertically on Storeys. Each Storey will support two photo-sensors (see Figure 1). The photo-sensor unit

Figure 1: Artistic illustration of a DOMBAR Unit. The distance between the DOMs is 6 meters. A prototype of the Digital Optical Module is also shown.

is a digital optical module (DOM) consisting of a 17 inch diameter pressure resistant glass sphere housing 31 3-inch photomultiplier (PMT) tubes, their high-voltage bases and their interfaces to the data acquisition system with nanosecond timing precision [5]. The segmentation of the photocathode area in such a Multi-PMT Optical Module will aid in distinguishing single-photon from multi-photon hits, and thus provide a better optical background rejection and trigger efficiency.

The front end electronics is based on the use of the time over threshold (TOT) as main signal processing. The use of the amplitude information from thresholds and the time from sampled data allow for reconstruction of the original signal. The preferred solution for the readout system is one where all (digitized) data are sent to shore, to be processed in real-time. The data to shore can be accommodated on a modest number of optical fibers using dense wavelength division multiplexing (DWDM) techniques.

4. Telescope performance

The sensitivity of the detector to neutrino point sources, based on one year of data, is shown in Figure 2 as a function of the declination. The detector performance is presented as the flux that can be excluded at 90% CL (flux sensitivity) and the flux that can be detected at 5σ with 50% probability (discovery flux). This calculation assumes a neutrino energy spectrum proportional to E^{-2} with no energy cutoff. The detector layout has been optimized for the discovery of such sources.

Supernova remnants (SNR) of the shell type are the most probable sources of cosmic rays in the Galaxy. The material ejected during the explosion forms shock waves when it propagates into the interstellar matter. Particles are assumed to be accelerated in these shock waves, which can persist for several thousand years. The shell-type SNRs with the most intense gamma rays fluxes are RX J0852.0-4622 (Vela Junior) and RX J1713.7-3946. These sources have an angular size larger than the resolution of the neutrino telescope. Moreover, they are generally expected to have

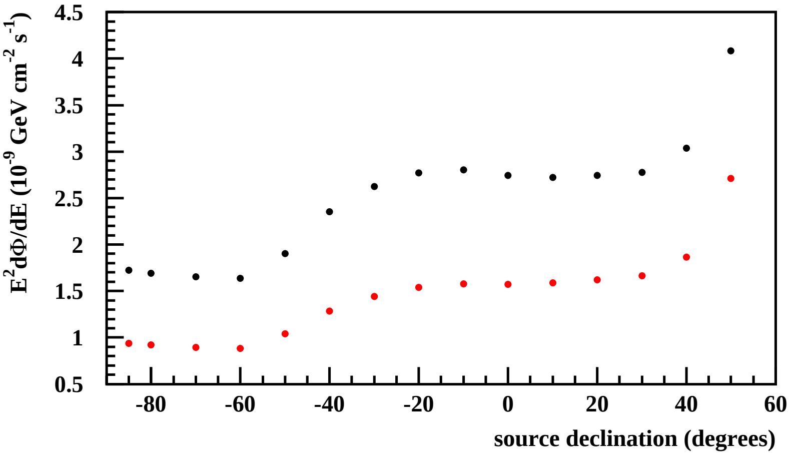

Figure 2: The KM3NeT flux sensitivity (red dots) and discovery flux (black dots).

a cut-off in their energy spectra in the range 1-10 TeV. However, the neutrino telescope layouts, optimized during the KM3NeT Design Study, exhibit optimal sensitivity in discovering astrophysical sources emitting neutrinos with an energy spectrum of E^{-2} and a high (or without any) energy cut-off [6]. Such detectors have lower sensitivity in detecting galactic neutrinos in the energy range of 1-10 TeV. Further studies have shown that, assuming that the dominating mechanism of gamma ray production is hadronic, the most luminous Galactic sources can be detected in less than 5 years of detector running time by reducing the distance between the DUs, and applying more sophisticated experimental and data analysis techniques, that take into account: (a) the track reconstruction resolution and the reconstructed energy of the neutrino induced muon on a track by track basis, (b) the known source direction, and (c) the source morphology.

5. Conclusions

In this work we described the major technical aspects of the Mediterranean very large volume neutrino telescope, KM3NeT, and reported on results concerning the evaluation of its sensitivity to detect high energy astrophysical neutrinos. KM3NeT will cover most of the sky with unprecedented sensitivity and in the first few years of operation will unambiguously discover neutrinos from many promising Galactic candidate sources.

Acknowledgments

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