THE KM3NeT PROJECT

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An international joint venture known as KM3NeT has been initiated to build a cubic-kilometre scale neutrino telescope in the Mediterranean Sea. The KM3NeT project is supported at the European level by the 6th and 7th framework programmes. Very high energy neutrinos are important messengers to study non-thermal phenomena in the Universe and their detection will help to answer astrophysical questions, such as those related to the origin of the cosmic rays and the mechanisms of particle acceleration. The pioneering ANTARES, NEMO and NESTOR underwater neutrino telescope projects comprise the extensive R&D knowledge base behind the KM3NeT project. The initial workload will culminate in a technical design report by 2009 and a Europe-wide funding model by 2010. A four year construction phase will follow immediately thereafter.

1 Introduction

There is a powerful scientific case for building a cubic-kilometre scale neutrino telescope in the Mediterranean Sea [1] (Section 1.2). In addition, the required infrastructure can easily be shared by a host of associated sciences, enabling long-term deep-sea measurements in oceanography, climatology, geophysics and biological marine sciences.

1.1 Logic and Feasibility of a Large Neutrino Telescope in the Mediterranean Sea

The interaction probability of neutrinos is small and they pass almost entirely unhindered through the cosmos. This small interaction probability makes them hard to detect on Earth. However, their interaction products do provide measurable signals through their Cherenkov light emissions in transparent media.

The Mediterranean Sea can provide the large mass necessary to enhance the neutrino detection rate and the transparency of its water makes it an ideal location to host a large array of light sensors, its geographic location also makes it an ideal place from which to observe that section of the sky which includes the centre of our own galaxy.

The feasibility of a deep sea neutrino telescope has been investigated in three pilot projects. In each of these, different configurations and techniques have been explored. These three projects, ANTARES, NEMO and NESTOR, have demonstrated the potential for detecting the interaction products of cosmogenic neutrinos by reconstructing the trajectories of atmospheric muons, and in the case of ANTARES by also reconstructing the trajectories of muons produced by upcoming atmospheric neutrinos.

1.2 Scientific Objectives of a Neutrino Telescope

Having no electric charge neutrinos are unperturbed by magnetic fields, and as weakly interacting paricles they can pass through any dense clouds of dust which may surround their sources, hence their arrival direction will point directly towards their origin.

One of the main objectives for a neutrino telescope is the discovery and study of the sites of high energy particle acceleration in the universe, i.e. the origin of the cosmic rays. The origins of the cosmic rays arriving at the Earth remains undetermined over a century after their descovery; neutrinos offer a unique possibility to trace their origins.

There are numerous candidate neutrino sources in the cosmos. There are possible galactic sources such as supernova remnants, pulsars and micro-quasars, and possible extragalactic sources including active galactic nuclei and gamma-ray bursts. For such sources the probable neutrino energy scale is 10^{12} to 10^{16} eV.

The search for dark matter in the form of WIMPs (Weakly Interacting Massive Particles) is another important objective of neutrino telescopes. As an example, in the case of supersymmetric theories with R-parity conservation, the relic *neutralinos* from the big-bang are predicted to concentrate in massive bodies such as the centres of the Earth, the Sun and the Galaxy. At these sites *neutralino* annihilations, and the subsequent decays of resulting particles, may yield neutrinos with energies above 10^{10} eV.

Additionally, the study of the diffuse neutrino flux originating from sources that cannot be individually resolved, or from interactions of cosmic rays with intergalactic matter or radiation, may yield important cosmological clues. Such measurements would be significant for neutrino energies in excess of 10^{15} eV.

Very large instrumented volumes, of the order of a cubic kilometre, are required to provide adequate sensitivity for the expected fluxes of neutrinos originating from these processes.

2 KM3NeT Design Goals

KM3NeT is planned as a long term observatory. A data taking period of at least ten years is required between major maintenance operations and a maximum period of four years is anticipated for the construction and deployment of the detector. The research infrastructure will be designed to survive for at least this long in the deep sea, under high pressure and in a chemically aggressive environment.

2.1 Effective Area

Neutrino telescopes have effective areas which increase with energy due to the physics of the neutrino interactions and the detection technique, while the energy spectra of most relevant neutrino fluxes are expected to fall with energy. This combination typically gives most of the detectable events in the energy range of 10^{12} to 10^{15} eV. Optimising the sensitivity in this range will also provide access to lower energies for searches for low-mass dark matter candidates and to higher energies for the investigation of diffuse cosmogenic neutrino fluxes.

2.2 Angular Acceptance

To avoid background from atmospheric muons, large scale neutrino telescopes focus on neutrino candidates that originate from below the horizon. However, the shielding by the deep sea water provides an effective mechanism for reducing this background and allows for focused observations of neutrinos above the horizon. Figure 1 shows the detector sky coverage in the Mediterranean Sea and is made assuming a 2π steradian acceptance of the detector.

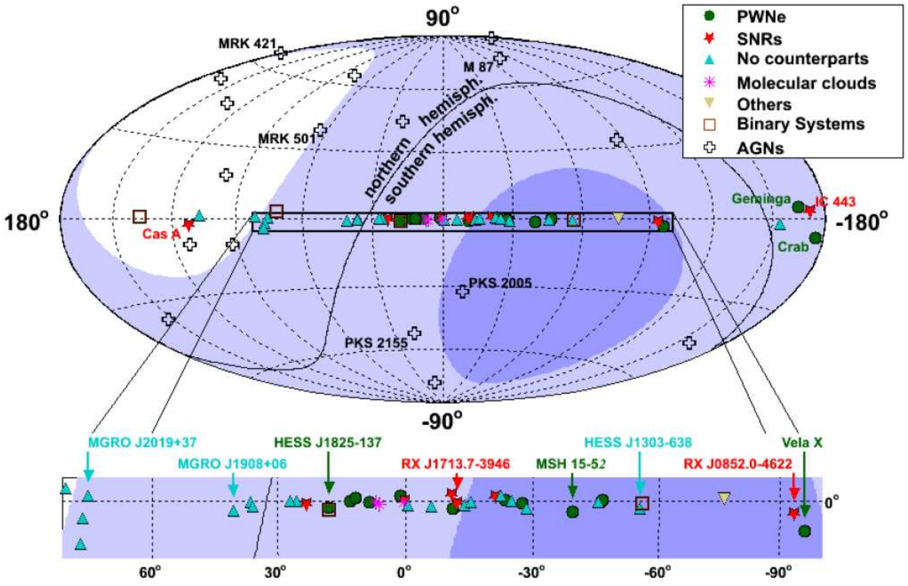

Figure 1: Sky coverage in Galactic coordinates for a detector located in the Mediterranean Sea. The shading indicates the visibility for a detector with 2π downward coverage; dark (light) shaded areas are visible at least 75% (25%) of the time. The locations of recently observed sources of high energy γ-rays are also indicated.

2.3 Angular Resolution

The contribution to the resolution from detector effects should not dominate the contribution from the kinematics of the neutrino interaction, over most of the relevant energy range. At around 30 TeV the kinematics induce a 0.1^o mean deviation between neutrino and muon directions which becomes larger at lower energies. For an E^{-2} energy spectrum the bulk of the detected events will be below 30 TeV, so an angular resolution of 0.1^o for muons is required. The systematic uncertainty in the direction reconstruction of muons must also be kept below this value.

2.4 Time and Position Resolution

The fundamental limit to the time resolution of a single photon is given by a combination of the chromatic dispersion and scattering of the sea water medium. The effective time resolution has a contribution from the position measurement as well as the timing measurement. Assuming equal contributions, and no correlation between position measurements, the time resolution should be better than 2 ns and positional precision should be better than 40 cm.

2.5 Failure Rate of Optical Modules

Monte Carlo studies have shown that the main effect of permanent optical module failures is to reduce the detector sensitivity at low energies. For example, a 10% *randomly distributed* failure rate results in the loss at the trigger level of 40% of muons with energies between 400-500 GeV, but only 10% for muons of 1 TeV. Above 30 TeV there is almost no effect. The effect on the angular resolution is small. For 10% failure, a 3% degradation in the angular resolution is observed for muon tracks. As a result, a permanent optical module failure rate of less than 10% is required over a 10-year period without major maintenance.

3 Configuration Studies

Different possible detector configurations for the neutrino telescope have been investigated in detailed simulation studies using a modified version of the Antares software [2]. The conclusions were confirmed by studies using independent simulation and reconstruction software [3].

A flux of muon neutrinos with an energy spectrum proportional to E^{-2} was considered in the energy range 10^{10} to 10^{16} eV. Only the muon emerging from charged-current reactions has been simulated and reconstructed. The random light background from potassium decays was included in the simulation at a rate of 100 Hz cm^{-2} of photocathode area, and a *typical* attenuation lenght of 50 m was used.

Two benchmark parameters have been considered for the comparison of simulated detector configurations: (*i*) the neutrino effective area, which defines the event rates in a neutrino telescope, and (*ii*) the angular resolution of the reconstructed muon, which defines the size of the search window for neutrino point sources and is crucial for the background rejection capability.

In order to normalise the different detector configurations to a common standard, the total effective photocathode area was kept constant, and the instrumented volume was in all cases chosen to be 1 km^3. Three main detector configurations have been investigated (Figure 2), all with a 15.5 m vertical distance between storeys.

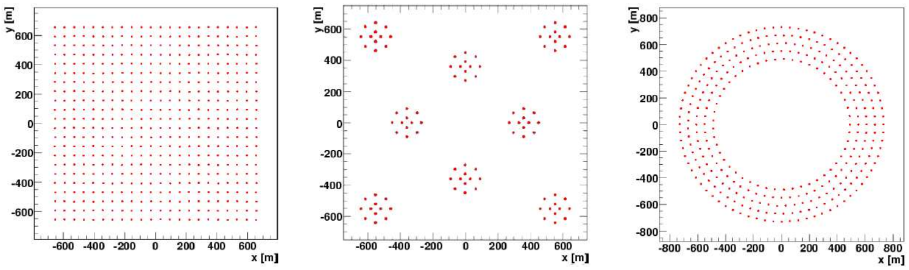

Figure 2: Sea-floor layouts of example neutrino telescope configurations of the type "Homogeneous", "Cluster" and "Ring" (left to right).

For given photocathode area per storey and fixed quantum efficiency the results for different configurations are rather similar. For each detector configuration, the muon neutrino effective area and the muon angular resolution have been calculated as bench-mark parameters.

It is found that none of the configurations is superior over the full energy range. It will therefore be crucial to define the physics priorities of the KM3NeT neutrino telescope before concluding on a final detector layout. It has been noted that configurations with densely instrumented regions (cluster and ring) are preferable for low neutrino energies, whereas homogeneous solutions yield the best efficiency for an intermediate energy range (10^{12} to 10^{14} eV).

Acknowledgments

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References

1. KM3NeT Conceptual Design Report 2008, http://www.km3net.org/public.php.
2. S. Kuch, PhD thesis 2007, University of Erlangen, Germany, FAU-PI1-DISS-07-001, www.slac.stanford.edu/spires/find/hep/www?irn=7232764.
3. J. Carr, et al. Proceedings of 30th Int. Cosmic Ray Conf. July 2007. Merida, Mexico.