PROCEEDINGS OF SCIENCE

The KM3NeT Neutrino Telescope and Prospects for Dark Matter Detection

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KM3NeT is a future deep sea research infrastructure located in the Mediterranean Sea. It will include a km^3-scale neutrino telescope, optimized for the search of high-energy neutrinos produced by astrophysical neutrino sources and/or via self-annihilation of Dark-Matter particles. The detection principle relies on the observation of Cerenkov light emitted by muons resulting from charged current neutrino interactions in the sea water or sea floor surrounding the detector. Based on, minimal Supergravity (mSugra) and Kaluza-Klein models, predictions for the flux of high energy neutrino flux originating from dark matter annihilation in the Sun, are presented. The expected sensitivity of KM3NET to dark matter is discussed.

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1. Introduction

The scientific goal of neutrino telescopy is the detection of high energy neutrinos from energetic astrophysical sources. The detection of such neutrinos will yield invaluable information on the acceleration mechanisms operating in these extreme environments and in particular will help understand the relative importance of hadronic versus leptonic acceleration. Another important physics topic, the subject of this paper, is the indirect search for dark matter. Dark matter can accumulate in massive bodies such as the Sun and be detectable via their co-annihilation into Standard Model particles which subsequently decay to energetic neutrinos.

Neutrino telescopes are constructed from large arrays of photo multiplier tubes buried deep in transparent media such as ice or water and are designed to detect the Cherenkov light emitted by secondary particles produced in neutrino reactions. Currently, three such installations are taking data: The Baikal experiment [1] in a large freshwater lake in Siberia, ANTARES [2] in the Mediterranean Sea and IceCube [3] at the South Pole. Whereas the first two are first-generation projects with typical instrumented volumes of the order 0.01 km^3, IceCube will comprise roughly 1 km^3 after its completion in 2011. There are many good reasons to assume that this is the minimum size required to exploit the scientific potential of neutrino astronomy. The future KM3NeT neutrino telescope aims to exceed the IceCube sensitivity by a substantial factor, exploiting the superior optical properties of sea water as compared to the Antarctic ice as well as an increased over all photocathode area.

2. KM3NeT

The technical design of the KM3NeT infrastructure is the subject of the ongoing KM3NeT Design Study. The major challenge is to find cost effective solutions to efficiently instrument a km^3-scale detector volume. A Conceptual Design Report (CDR) [4] is already available and the final design will be described in a Technical Design Report by the end of 2009. The KM3NeT infrastructure will also provide an undersea platform for associated sciences such as marine oceanography, seismology etc. The KM3NeT consortium includes all institutes involved in the three ongoing Mediterranean projects (ANTARES, NEMO, NESTOR) as well as a number of marine research institutes. In parallel to the design study, since March 2008, a 3-year KM3NeT Preparatory Phase project (KM3NeT-PP, EU FP7) addresses the political, funding, governance and strategic issues that need to be settled before the start of construction. Three suitable candidate sites for KM3NeT have been extensively explored by the pilot projects: off the French Mediterranean coast near Toulon (depth 2500m); off the Sicilian coast near Capo Passero (3500m) and off the west coast of the Peloponnesus near Pylos (4500-5200m).

Being located in the Mediterranean Sea, the KM3NeT infrastructure will study the region of the galaxy not observable by the southern hemisphere ICECUBE detector, including the important region of the galactic centre. Being water based it will allow a significantly improved angular resolution; preliminary studies indicate that an angular resolution better than 0.1 degrees should be achievable for energies above 10 TeV.

Although KM3NeT is optimized for the energy range 1-100 TeV, it has significant sensitivity for the lower energies relevant for dark matter detection albeit with less precise angular resolution (1.5 degrees at 1 TeV) due to the kinematic smearing from the neutrino-muon interaction.

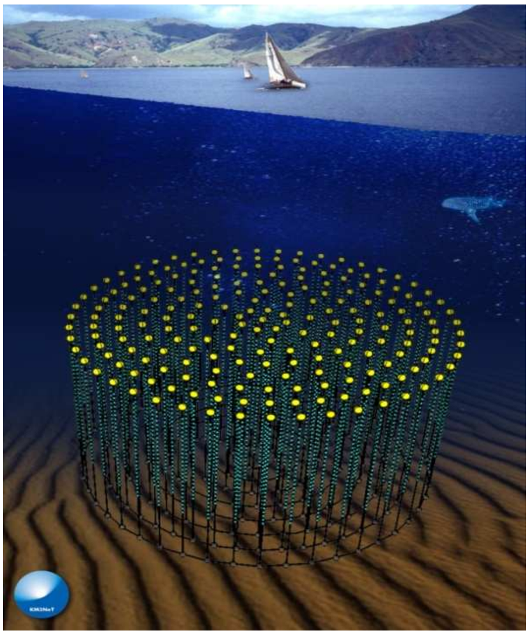

Figure 1: Artists view of a possible KM3NeT design

3. **Dark Matter**

In many theoretical models a Weakly Interacting Massive Particle (WIMP), a relic from the Big Bang, is proposed to explain the formation of structure in the universe and the discrepancy observed between the measured rotation curves of stars and the associated visible matter distribution in galaxies. The density of cold dark matter in the Universe is now well contrained by the WMAP experiment ($\Omega_{CDM}h^2$=0.11±0.006) [5]. A generic property of such WIMPs is that they gravitationally accumulate at the centre of massive bodies such as the Sun or the Earth, where they can self annihilate into normal matter. Only neutrinos, resulting from the decay of this matter, can escape from the body and be detected by a neutrino telescope.

In the following, the prospects for KM3NeT to detect energetic neutrinos produced via WIMP annihilation in the Sun for two well-motivated models, Supersymmetry and Universal Extra Dimensions, are evaluated. The simulations are based on the DARKSUSY Monte Carlo generator [6] and take into account the interactions of the neutrinos in the Sun medium as well as their oscillations in matter and vacuum before arrival at the earth. The search cone around the Sun direction is typically about three degrees and the irreducible backgrounds from atmospheric neutrinos are taken into account when calculating the expected 90% confidence level limits. Backgrounds produced by cosmic ray interactions in the Sun heliosphere are not considered.

3.1. Supersymmetry

Within Supersymmetric models with R-parity conservation, the lightest supersymmetric particle (LSP) is stable and is the WIMP candidate. In order to predict the expected solar neutrino fluxes the constrained phenomenological framework of the minimal Supergravity model (mSUGRA, computations using ISASUGRA[5]) has been adopted. The following model parameter ranges have been scanned: scalar mass m_0 in [0,8000] GeV, gaugino mass $m_{1/2}$ in [0,2000] GeV, tri-linear scalar coupling A_0 in [0,3m_0], sign of the Higgsino mixing parameter: μ>0, ratio of Higgs fields vacuum expectation values tanβ in [0,60], m_{top}=172.5 GeV. The local Dark Matter halo density (NFW-model) was set to ρ_0 = 0.3 GeV/cm^3.

Figure 2 (left) shows the predicted integrated neutrino fluxes above 10 GeV in KM3NET as a function of neutralino mass for the scan of the model parameters. A large fraction of the models which lead to relic densities favoured by WMAP can be excluded by KM3NeT. These models are in the so-called 'focus point' region, for which the decays are mainly via W^+W^- leading to a harder neutrino spectra. Figure 2 (right) shows for the same mSUGRA models, the corresponding spin-independent cross-section for interaction of the WIMP with protons. KM3NET will be competitive with planned direct detection experiments.

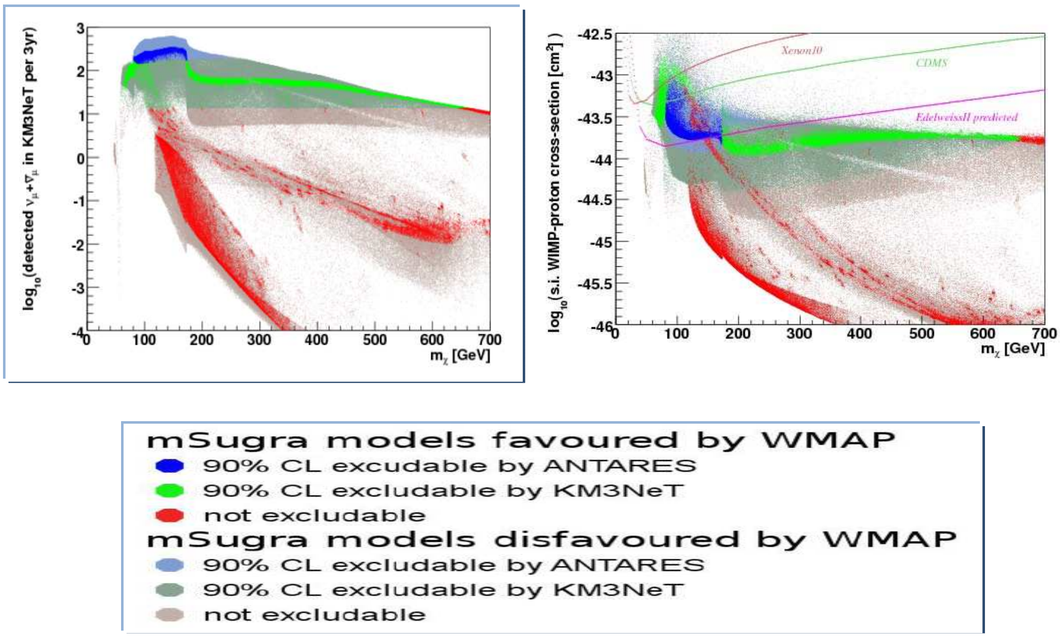

Figure 2 - KM3NeT mSUGRA exclusions: (left) sensitivity to the neutrino flux from the Sun . (right) comparison with direct detection experiments.

3.2. Extra Dimensions

Models with extra dimensions appear at or near the TeV scale have become popular in recent years. One class of these models are those in which all of the Standard Model fields propagate in 'universal' extra dimensions. In these models, Kaluza-Klein (KK) excitations appear as particles with masses of the scale of the extra dimension. Due to conservation of momentum in the higher dimensions, a symmetry called KK-parity can arise which, in some cases, make the lightest KK Particle (LKP) stable and a candidate for dark matter. The identity of the LKP depends on the mass spectrum of the first KK level and is most naturally the first KK excitation of the B^1. The relic density of the LKP can be calculated as a function of its mass. An appropriate density is predicted when the mass is moderately heavy (600- 1200 GeV), generally heavier than that favoured by SUSY models. The range of LKP mass depends on the details of the coannihilations of LKPs with heavier KK particles. In contrast to supersymmetric models, the bosonic nature of the LKP removes the chirality suppression in its annihilation to fermions, allowing direct production leptons pairs, including neutrinos. These models are therefore of particularly interest for neutrino telescopes.

The calculation of the expected neutrino flux, are performed using the WIMPSIM Monte-Carlo Dark Matter generator [7]. Figure 3 shows the calculated muon fluxes from UED models for various mass splitting between the LKP and the next-to LKP. The green shaded area indicates the masses leading to a relic density compatible with WMAP. The horizontal blue line indicates the expected sensitivity of KM3NeT after 5 years. KM3NeT should be able to exclude all UED models consistent with the WMAP relic density having a relative (NLKP-LKP)/LKP mass difference smaller than 20%.

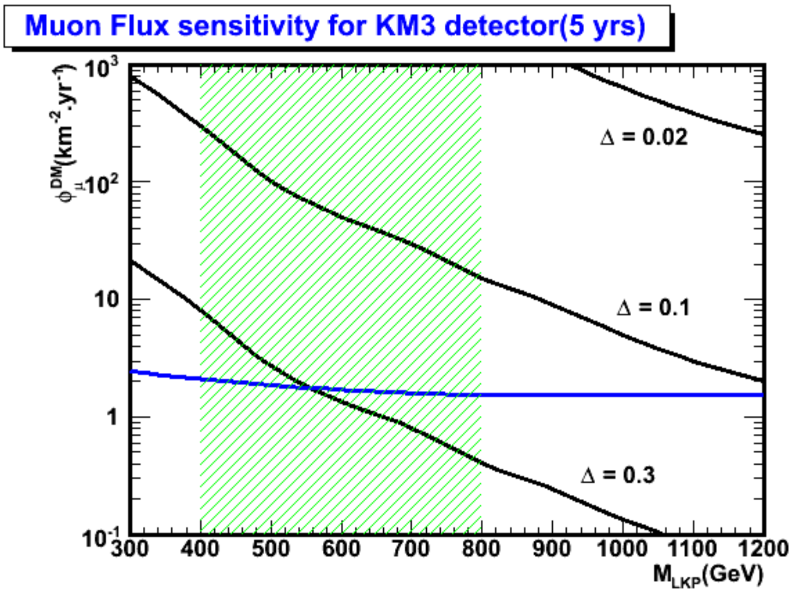

Figure 3 – Predicted muon fluxes from UED models for various mass splitting between the LKP and the next-to LKP. The green shaded area indicates the masses leading to a relic density compatible with WMAP. The horizontal blue line indicates the expected sensitivity of KM3NeT after 5 years.

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