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KM3NeT perspectives

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KM3NeT is an underwater Cherenkov telescope that in the complete configuration should instrument a total volume of about 3 km^3. One of the main physics objectives of KM3NeT is the search of neutrinos from galactic sources. In this contribution a brief description of the detector and the state of art on sensitivity and discovery potential for galactic sources and in particular the results for the Supernova Remnant RXJ1713 are presented. Further improvements on the reconstruction algorithm and detector optimization are in progress also in view of the recent IceCube observation of the first comic neutrinos.

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†A footnote may follow.

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1. Introduction

High energy neutrino astronomy [1] is a very important challenge of astroparticle physics. Several galactic and extra galactic objects have been proposed as potential sources of high energy neutrinos (E $\geq$ 1 TeV). Among the extragalactic objects Active Galactic Nuclei (AGN) and Gamma Ray Bursts (GRB) are considered as the most likely environment where proton and/or nuclei can be accelerated up to 10^{20}eV, i.e. the highest cosmic ray energy ever measured. Anyway, the major problem in the estimate of extragalactic neutrino fluxes either from AGNs and GRBs are the large uncertainties due to model assumptions and due to the intergalactic absorption of VHE γ-rays that strongly modifies the spectra measured at Earth. On the other hand, TeV γ-rays have been observed in galactic sources like shell type SuperNova Remnants (SNR), Pulsar Wind Nebulae, Star Formations Regions and the dense molecular clouds [2] related to them that are potential neutrino sources.

Eventually two high energy neutrino candidates have been detected in IceCube [3], that is the first km^3 high energy neutrino telescope operating at the South Pole [4], and 26 more events were found at lower energy (E $\geq$ 30 TeV) in the analysis of high energy starting events [5]. This signal includes upward- and downward-going events with neutrino energies from a few 10 TeV to above 1 PeV. Even though the signal is statistically very significant, the properties of the underlying neutrino flux (energy spectrum, directionality, flavor composition) are not yet clear. This signal is the first high-energy extraterrestrial neutrino signal ever observed and thus marks a major turning point in the history of neutrino astronomy.

2. The KM3NeT telescope

KM3NeT [6] is a new Research Infrastructure, consisting of a cabled network of deep-sea neutrino telescopes in the Mediterranean Sea. The main objective of KM3NeT is the discovery and subsequent observation of high-energy neutrino sources in the Universe. Anyway KM3NeT will also provide an integrated platform for Earth and deep sea sciences. The total cost for the complete Research Infrastructure is estimated at 220$-$250 Meuro. The building scheme of KM3NeT provides several large blocks that can be accommodated in a multi-site option. In underwater and underice detectors the neutrinos are detected indirectly by means of the Cherekov light produced by the lepton produced in the neutrino interaction. The KM3NeT neutrino telescopes consist of large three dimensional arrays (several cubic kilometers) of ultra-fast and very sensitive photo-sensors and various other instruments. The photon-sensors are Digital Optical Modules (DOM) hosted in mechanical structures about 1 km height, called detection units (DU). The Detection Units are made of a sequence of 20 storeys with one DOM made of 31 three inch PMTs. The full KM3NeT detector consists of 620 DUs.

The deep-sea sites are linked to shore with a network of cables for electrical power and high-bandwidth data communication. On site, shore stations are equipped to provide power, computing and a high-bandwidth internet connection to the central data repository. Three suitable deep-sea sites are identified, namely off-shore Toulon (France), Capo Passero (Italy) and Pylos (Greece). Due to the location and the size of the infrastructure, there is significant synergy with Earth and Sea sciences. Presently, the collaboration is committed to the realization of the first phase of the

KM3NeT Research Infrastructure which is being implemented at the Toulon and Capo Passero sites. In March 2013, a prototype DOM with a prototype readout electronics was incorporated on an ANTARES string and successfully deployed at a depth of 2500 m. This DOM has been operated continuously ever since. A preliminary analysis of the data from the DOM confirms the expected performance.

3. Simulation results

Due to its good angular resolution, 70% of selected events lie within 0.2° of the neutrino direction, and large size, about 3 km^3 of instrumented volume, this project will provide the scientific community with a very powerful instrument to study cosmic neutrino sources. In the Technical Design Report [7] the sensitivity to point-like cosmic sources of neutrinos was estimated for a flux spectrum with a E^{-2} dependence. Due to its location in the Northern hemisphere, the detection of Galactic sources is one of the main science goal of KM3NeT. In fact, it is in this region that KM3NeT can give significant contributions to neutrino astronomy. The E^{-2} spectrum for a point-like source represents a reasonable approximation for extra-galactic sources but could not be the case for galactic sources that are characterised by an energy cut-off and often also by a spatial extension. Therefore the detector design has to be optimised to increase the discovery potential for galactic sources. In the hypothesis of hadronic gamma emission, models for galactic neutrino sources are constrained by TeV γ-ray observations and allow to obtain realistic expectations on the detection perspectives [8] . Amongst the galactic objects, Fermi Bubbles and Super Nova Remnants are probably the most promising ones. In particular, the Super Nova Remnants RXJ1713, VelaX and Vela Junior that are at present between the best objects of this type in the high-energy gamma-ray band can be used to evaluate the KM3NeT performance.

In this section we report on the status of simulation activities with emphasis on performance w.r.t. point-like galactic sources. This task concerns both the development of specific algorithms for the track reconstruction and the study of the impact of the detector lay-out and geometry. In particular, one of the main parameters that affects the telescope performance is the distance between optical modules, namely the detector granularity.

The Monte Carlo code used for the simulations has been developed by the Antares collaboration [9] and consists of several codes with specific tasks: neutrino generation and interaction, propagation through the detector volume and light generation, detector response. In this work a depth of 3500 m and a wavelength dependent absorption length of 67.5 m at 440 nm [7] were considered. An additional 5kHz single photon rate per PMT due to ^{40}K decay has been also taken into account. The track reconstruction algorithm has been adapted to km^3-scale detector size [10]. The peculiar features of the multi-PMT DOMs have been also exploited both at the trigger and reconstruction level. In particular only hits within a PMT field of view, defined by an appropriate cut on the PMT angular acceptance, are selected. The hit multiplicity within the DOM replaces the charge used in the case of large (8-10 inches) PMTs. A scanning procedure is performed with a grid of 3° by 3°, from these directions the fit proceeds via several steps of optimization and at the last step the track with the best value of the likelihood is chosen.

The figures of merit of the telescope are sensitivity and discovery potential that are estimated by the signal to background ratio. The optimization of the signal to background ratio is strongly dependent on the source features (energy spectrum, angular extension, ...). The atmospheric neutrinos, that constitute the irreducible background in high neutrino telescopes, were simulated according to the Bartol flux [11] and for prompt component due to the charm decay the RQPM [12] that is the highest flux prediction was considered. Atmospheric muons were not considered in this work, however previous simulations made for another detector configuration at 3500 m depth show a worsening of the sensitivity for a source at -60° (fully visible) of about 3% [13] when the muon atmospheric background is included.

The sensitivities and discoveries have been obtained applying a binned method where the sky is divided in bins of declination and right ascension and the numbers of events detected per bin are analyzed. The parameters that are optimized in order to minimize the sensitivity and discovery [14] [15].

The reference source is the RXJ1713 that has a radial extension of about 0.5° with a rather complex shell type morphology with hot spots and an energy gamma spectrum extending up to about 100 TeV and suppressed significantly at energies above 10 TeV[16]. The RXJ1713-398.46 has been simulated with the neutrino energy spectrum calculated by Kernel et al [17] and parametrised as:

$$\Phi(E) = 16.8 \times 10^{-15}\,[ETeV]^{-1.72}\,e^{-\sqrt{E/2.1TeV}}\,GeV^{-1}s^{-1}cm^{-2} \tag{3.1}$$

and an extension reproduced by a flat disk with 0.6° radius centered on the source position. This last assumption is rather conservative and has a negative impact on the discovery potential.

The detector performance as a function of the DU distance was studied and the minima of sensitivity, and more evidently of discovery potential, correspond to a distance between DUs of 100 m, therefore in the following this distance between DU was chosen. The trend of the discovery potential for the RXJ1713 is shown in fig. 1.

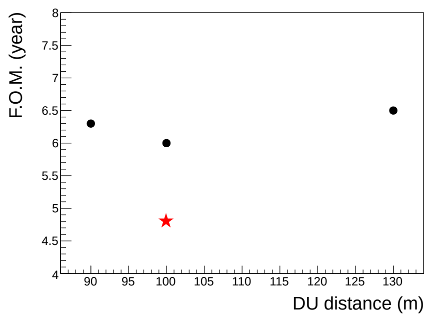

Figure 1: Years for discovery at 5σ, 50% probability as a function of the DU distance for the RXJ1713. The black dots are the values calculated with the binned method and the red star is the unbinned value extrapolated from one year flux.

A preliminary estimate of the detection capability of KM3NeT for the Vela X has been performed. Vela X was measured by HESS in several observation campaigns, in particular the results based on the first observations[18] has been recently updated[19] with data from the 2005-2007 and 2008-2009 observation campaigns and a more accurate method for the background subtraction has been used. The new data are characterized by a higher gamma flux and a harder energy spectrum. VHE gamma emission from an outer ring 0.8ą-1.2ą has been also investigated, however this last contribution is not considered in the neutrino emission. The neutrino emission spectrum has been derived from the gamma spectrum using the Vissani prescription[8] based on the hypothesis of transparent source and 100% hadronic emission. For the RXJ1713 this method provides results very similar to ones obtained with the Kelner spectrum. The source extension was simulated as a flat spatial distribution within a disk with 0.8^o radius. Our binned analysis indicates that a 5° discovery is reached after 2.8 (5.2) years for the updated (old) spectrum. The reconstruction based on scanning can be easily used also as a starting point for an unbinned analysis that is expected to provide better results as already seen on IceCube and Antares data. The main drawback of the unbinned analysis is the large increase of the needed CPU time. In this case, first results based on 1 year of observation time, have been estimated for the RXJ1713.

The preliminary values of discovery potential at 3σ and 5σ are reported in table 1.

	source	**years**
3σ binned	RXJ1713	2.1
5σ binned	RXJ1713	5.8
3σ unbinned	RXJ1713	1.8
5σ unbinned	RXJ1713	4.8
3σ binned	VelaX	1.1 (2.0)
5σ binned	VelaX	2.8 (5.2)

Table 1: Number of years to claim the discovery at 5σ 50%CL and the evidence (3σ 50%CL) of the RXJ1713.7-3946 and of the VelaX (preliminary results). For VelaX the values in parenthesis refer to the old high energy gamma data.

The inclusion in the simulations of a realistic source morphology for the RXJ1713 extrapolated from the high-energy gamma map measured by Hess is in progress. This will provide a more realistic description of the spatial extension of the source. Such an approach is needed also for the investigation of several other candidate galactic sources.

An analysis of the Fermi Large Area Telescope data provided evidence of the emission of high-energy gamma rays with a high intensity E^{-2} spectrum from two large areas, spanning 50^o above and below the Galactic Center (the "Fermi bubbles"). Several hypotheses have been proposed for the emission mechanism. In a hadronic scenario the Fermi bubbles are promising sources of high-energy neutrinos. Indeed, under the hypothesis that the gamma emission mechanism is totally due to a hadronic processes the results of Monte Carlo simulations[20] indicate that neutrinos from the bubbles could be discovered in about one year of KM3NeT operation, making this source very interesting for the staging detector construction.

The estimate of the sensitivity of KM3NeT to the neutrino flux observed by IceCube is in progress as well as the possibility of a re-optimisation of the detector for such a signal.

4. Conclusions and perspectives

The first phase of KM3NeT is underway. A prototype DOM was deployed at the Toulon site in the Antares Instrumentation Line and it has been validated showing performance in agreement with expectations. The results presented in this paper represent the state of art of the optimization aiming at the detection of galactic point-like sources and show that at least the Fermi Bubbles and the more intense SNRs are at reach for the full KM3NeT.

Further improvements of detector performance are expected, indeed more simulations devoted to detector optimization and to the tuning of strategy for better background rejection and track reconstruction are on-going.

In conclusion, KM3NeT has good chance to detect neutrino sources, in particular we reported expectations for RXJ1713.7-3946 and Vela X and for Fermi Bubbles. The estimate of discovery potential for other sources, as well as a stacking analysis of several candidate galactic sources, will be investigated in the near future.The estimate of the response of KM3NeT to the neutrino flux observed by IceCube is in progress.

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