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The status of the KM3NeT project

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Abstract

The main aim of the KM3NeT project is the construction of a deep underwater high energy neutrino telescope in the Mediterranean Sea. In this paper we report on the status of the KM3NeT project that is presently starting the construction phase. The future research infrastructure will also be an important node for Earth and Sea Science research. In this work the main components of the telescope and some results from prototypes together with the first construction phase will be described. Finally a brief discussion on the detector performances on the main physics aims is reported.

Selection and peer review is the responsibility of the Conference lead organizers, Frank Avignone, University of South Carolina, and Wick Haxton, University of California, Berkeley, and Lawrence Berkeley Laboratory

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1. Introduction

Neutrinos are a powerful probe for high energy astrophysics. Thanks to its faint interaction probability, neutrinos can propagate between the astrophysical source and the Earth preserving the initial direction and energy and thus carrying important information on the high energy acceleration mechanisms. For the same reason they are extremely difficult to detect and cubic-kilometer detectors with a very low background level are necessary. After the success of the first underwater (BAIKAL and ANTARES) and under ice (AMANDA) detectors it was clear that the detection technique, based on the detection of the Cherenkov light emitted by secondary particles produced in the neutrino interaction occurring in the volume inside or around the detector volume, was mature for the construction of larger under ice (IceCube) and underwater (KM3NeT) detectors. The IceCube telescope, that is taking data in its full configuration of 86 strings since December 2010, is installed at a depth of 2500 m in the South Pole ice. In 2006 the Mediterranean neutrino telescope collaborations (ANTARES, NEMO, NESTOR) started the R&D for the construction of a multi cubic-kilometer detector: the KM3NeT detector [1]. The collaboration today has defined a project for a research infrastructure in the Mediterranean Sea, hosting a high energy neutrino telescope and nodes for Earth and Sea sciences. Due to its location in the Mediterranean Sea, the neutrino telescope will be located in an optimal position to investigate neutrino fluxes from the Southern sky, in particular from the Galactic Centre and from a large fraction of the Galactic plane complementing the field of view of the already existing IceCube detector. The identification of Galactic neutrino sources is one of the main physics goals of the KM3NeT detector.

The recent IceCube discovery of 28 extraterrestrial neutrino events (of which 10.4 are compatible with the background) [2] that correspond to a flux is of 3.6×10^{-8} GeV cm^{-2} s^{-1} sr^{-1} has set the starting point of the neutrino astronomy. Many of these events, 21 out of 28, are cascade events (shower of elementary

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particles) which are detected with a poor angular resolution (10°-15°) making the source pointing very hard. The question where the detected neutrinos came from is one of the most addressed question and many possibilities have been explored [3]. The future KM3NeT detector, with its higher angular resolution, larger field of view and effective area can put some constraints on the origin of these diffuse neutrino flux.

In this work the main components of the KM3NeT neutrino telescope will be presented. Prototype results and the next steps toward the construction of the detector will be discussed as well as the physics performance of the KM3NeT in terms of discovery potential for the detection of a diffuse flux from the Galactic Center region and from the SNR RXJ1713 Galactic source.

2. The KM3NeT detector

In this section a brief description of the main technical components of the detector (section 2.1 and 2.2) will be reported following closely the discussion in [4].

The detector of the KM3NeT telescope consists of an array of Digital Optical Modules (DOMs) attached to vertical structures, called detection units. The detection units are flexible structures anchored to the sea floor, kept vertical by buoys and connected to shore by an electro-optical cable. An array 115 detection units will constitute a detector building block. Several building blocks will be installed at one or more installation sites at depths ranging from about 2500 m to 4500 m. The choice for a distributed research infrastructure made of several detector blocks with common detector technology, management, data handling and operation control was based on both technical (related to redundancy and management of the deep sea cable network for data transmission and electrical power) and funding-related (to secure a significant amount of regional funding that can only be spent locally) arguments. Simulation results show that, at least for the ν_μ detection, the building block concept does not affect the expected sensitivity. Moreover, the distributed infrastructure is the preferred choice of the Sea and Earth Science community to profit from KM3NeT infrastructures to construct a network of sensors in the Mediterranean Sea.

The installation sites will be located close to Toulon, France (KM3NeT-Fr), near the East coast of Sicily, Italy (KM3NeT-It), and West of the Peloponnesus, Greece (KM3NeT-Gr) (see Fig. 1). The technical design of the detector including aspects such as data acquisition and data formats is identical at the three sites.

2.1. The Detection Units

In the single building block made of 115 detection units the average distance between neighbouring detection units is 90 m. The footprint and a schematic view of the detector are shown in Fig. 2.

Each detection unit carries 18 Digital Optical Modules (DOMs), starting 100m above the sea floor and with 36m of vertical distance between adjacent DOMs. The detection units are supported by two prestretched Dyneema© ropes and kept vertical by a submerged buoy at their top. A single vertical electro-optical cable is used to connect the DOMs to the base of the detection unit. It consists of a flexible, oil-filled hose that is in equi-pressure with the sea water and contains optical fibres for data transport and copper for the provision of electrical power to the DOMs. For each DOM, a break-out box provides connection to one fibre and two wires. Overall, this design minimises the number of pressure transitions and allows for a slim, light-weight construction with moderate drag in sea currents. A schematic view of the detection unit is shown in Fig. 3 (a). For deployment, a detection unit will be wrapped on a spherical frame with diameter if about 2.2m (Launcher of Optical Modules, LOM [5]) which is deposited on the seabed and then unfurls in a rotating upwards movement (see Fig. 3 (b) and (c)). The LOM rises to the sea surface, where it is collected for reuse.

2.2. The Digital Optical Module

Each DOM (see Fig. 4) is a pressure-resistant glass sphere of 17-inch diameter that carries 31 3-inch photomultiplier tubes (PMTs) with their high-voltage bases [6]. The lower hemisphere of each DOM contains 19 of the PMTs, which are thus downward-looking, whereas the other 12 PMTs look upwards. Photomultipliers from two companies (Hamamatsu, ETEL) have been demonstrated to fullfil the KM3NeT specifications and can be produced in the required quantities in due time. Each tube is surrounded by a

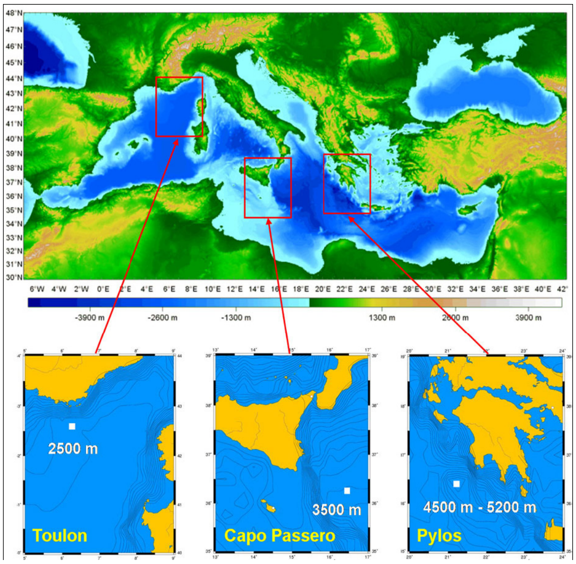


Fig. 1. The three selected installation sites of the KM3NeT research infrastructure.

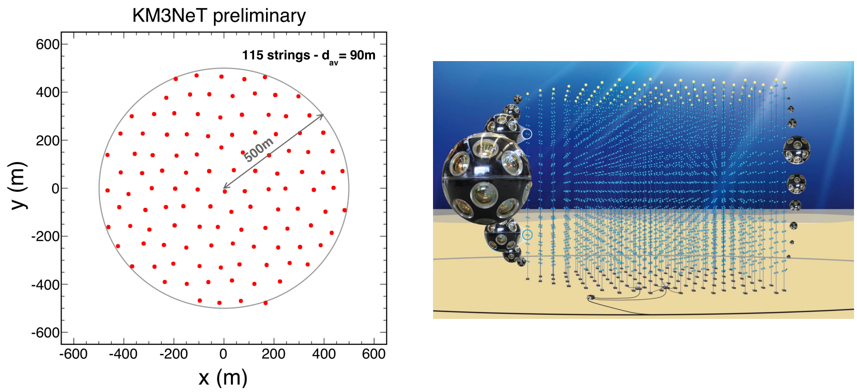
reflector that effectively increases the collection efficiency per PMT by about 27% [7]. All PMTs are controlled and read out individually. The DOM contains front-end electronics to amplify the PMT signals and to transform them into digital time-over-threshold information that is fed into the readout via optical fibres. For further details on DOM electronics and data acquisition see [8]. All PMT signals above an adjustable noise threshold (typically the equivalent of 0.3 photo-electrons) are sent to shore, where event candidates are selected by online filters running on a computer farm. The main advantages of the multi-PMT design are: segmented photocathode, allowing for unambiguous recognition of coincident hits and providing some directional sensitivity; almost 4π solid angle coverage by each DOM; reduced cost and risk of failure thanks to a large photocathode area and a single pressure transition per DOM and a simple mechanical structure of the detection unit.

The time synchronisation of the DOMs at nanosecond precision is achieved by a combination of the White Rabbit ethernet protocol [9] for the shore-to-DOM communication and laser and LED flashers in the neutrino telescope. The position calibration of each DOM is achieved at about 10 cm precision using acoustic triangulation. The acoustic system includes transponders at the seafloor and a receiver in each DOM. These sensors use piezo elements that are integrated with the digitisation electronis and can thus be operated in electromagnetically noisy environments. The DOM orientations are monitored at a few degrees using compass and tilt sensors in the DOMs

2.3. Results from the first DOM prototype

The first DOM prototype of the future KM3NeT neutrino telescope has been integrated in the instrumented line of the ANTARES detector for in-situ testing and validation. This DOM is taking data since April 2013 and the first 8 months of data has shown the background rejection and the signal recognition capabilities. The main preliminary results will be briefly shown in this section.

For the prototype DOM module ETEL R782D photomultiplier tubes (PMTs) were used. The data are transported to shore over a 45km fiber-optic Ethernet link at 1 Gb/s. In Fig. 5 (a) the number of PMTs with hits in coincidence in a time window of 20ns (coincidence level) are reported together with the Monte Carlo (MC) expectation for the ^{40}K, the combinatorial background of the single rate and the hits from atmospheric muon background. The agreement between data and MC is demonstrates that from single DOM it is possible



(a) (b)

Fig. 2. The footprint of a building block of the detector (a) and an artist's impression of the layout of such a building block (b).

to identify unambiguously atmospheric muons. The directional capability of the DOM is demonstrated in Fig. 5 (b) where the distribution of the hits as a function of the PMT position in the DOM is reported. The drop in hit count in some of the PMTs rings is due to a shadowing effect of the electronics cylinder of the ANTARES line that is not included in the present MC simulation. Such a cylinder will not be present in the KM3NeT mechanics of the detection unit as shown in section 2.1 and Fig. 3 (a).

2.4. Current status and the next steps

Currently, the KM3NeT Collaboration is finalizing the qualification tests with the deployment of a reduced-size detection unit at the KM3NeT-It site expected in the early summer 2014 and the deployment of an engineering version of the detection unit at the KM3NeT-Fr site expected early 2015.

In parallel the Collaboration is preparing the first phase of construction which complies a total of 31 detection units at the KM3NeT-Fr (7 units) and KM3NeT-It (24 units) installation sites which is foreseen to be completed by the end of 2016.

In parallel, the deployment of 8 DUs following the Italian flexible tower concept [1] will proceed at KM3NeT-It site. This activity is required to secure the Italian funding, but is not under the responsibility of the KM3NeT collaboration. A first prototype tower has been already deployed at a depth of 3400 m and is taking data since March 2013. The long term measurements of the environmental parameters confirm the low bioluminescence level at the KM3NeT-It site [10]. The foreseen detector of 24 detection units together with the 8 towers at the KM3NeT-It site, when completed, will constitute the most sensitive neutrino telescope in the Northern hemisphere. For the next step in the construction of KM3NeT, funding will be requested for a detector of two building blocks of 155 detector units each and a total instrumented volume of about 1 km^3.

The full KM3NeT detector will consist of a 6 building blocks of 115 detection units each with a total instrumented volume of 3-4 km^3.

3. Physics performances

The location in the Mediterranean Sea makes the KM3NeT detector a powerful tool to explore and identify Galactic sources. The detector lay-out described in Section 2 and used for MC simulations in

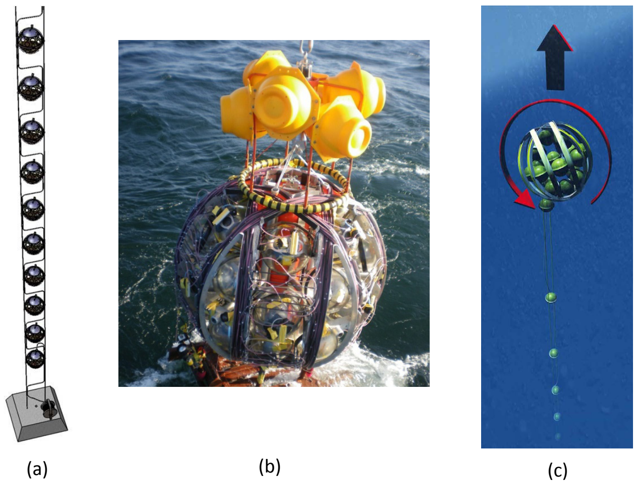


Fig. 3. A schematic view of the detection unit (a), the LOM during the deployment (b) and a scheme of the unfurling of the LOM (c) (picture by courtesy of Marijn van de Meer, Quest).

this work has been optimized for the detection of galactic sources using as a test case the very intense SNR gamma source RXJ1713.7-3946. The well measured high-energy gamma-ray emission [11] shows an energy spectrum with a cut off in the TeV region and from an extended region with radius of about 0.6°. The neutrino energy spectrum, calculated from the gamma-ray spectrum assuming an hadronic mechanism and a source transparent to gamma-ray emission was estimated in [12] and adopted in our simulation. Within these assumptions our MC simulations show that after 5 years of observation we should be able to detect the neutrino emission from RXJ1713.7-39.46 with a confidence level of 5σ at 50% probability. These simulation results were performed with the old detector configuration (2 blocks of 310 detection units) [13]. The same calculations with the equivalent 6 blocks 115 detection units detector are ongoing and from first results the differences appear to be small.

The recent IceCube detection of high-energy neutrino candidates has evidenced a hint of an overabundance from the direction of the Galactic Center region with no significant excess with respect to the background. Seven of these events, that are shower-like events, have the direction reconstructed within a 10° - 15° uncertainty, in the Fermi bubble region [14]. Among these 7 events 5 shower-like events, detected in the 0.1-1 PeV range, are also found to be consistent with the hypothesis that they are originated from cosmic-rays accelerated by supernovae in the Galactic Center region [15] or from the interaction between the CR with the ambient gas in the Galactic Halo [16].

Seven events detected by IceCube are originated from a large region around the Galactic Center that corresponds to a muon neutrino flux of about

$$\frac{d\phi_\nu}{dE} \approx 6 \times 10^{-8} \cdot E^{-2} \cdot e^{-E/3\mathrm{PeV}}\ \mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1} \quad (1)$$

This value was estimated in Ref. [17] from the detected IceCube flux of 3.6 $10^{-8}\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$. A cutoff of 3 PeV that is consistent with the maximum deposited energy measured by IceCube has been also considered.

In Fig. 6 the discovery flux from two regions close to the Galactic Center corresponding to the north plus south ($\sim$ 0.8 sr) and south ($\sim$ 0.4 sr) Fermi bubble region are shown for a two building blocks detector

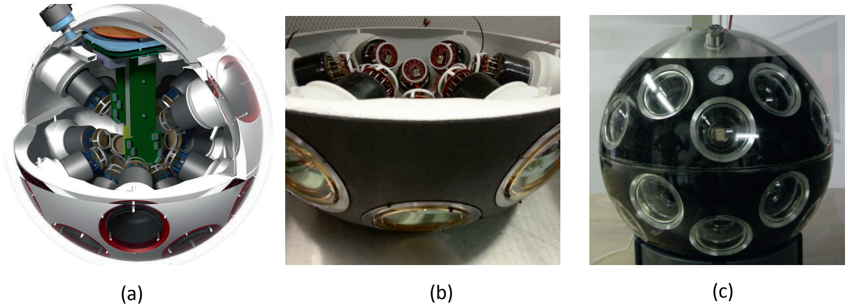


Fig. 4. The technical drawn of the DOM (a) the assembled topper hemisphere (b) and a picture of the already assembled DOM prototype (c).

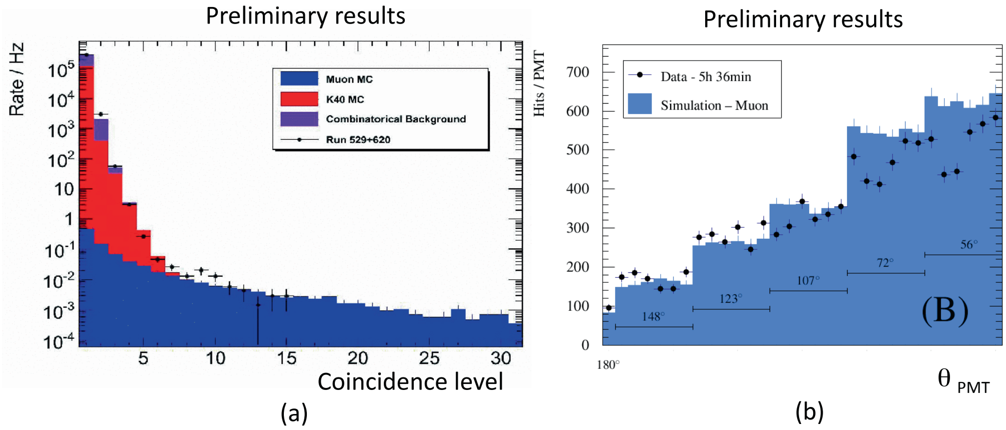


Fig. 5. Preliminary results: (a) event rate on the DOM as a function of the coincidence level. (b) distribution of hits in the single PMT as a function of the zenith angle in the DOM for events with a coincidence level higher than six.

(KM3NeT phase1.5). Details on the MC simulation can be found in Refs. [18] and [19]. From these simulations the 5σ at 50% probability can be reached after few years of observation time.

4. Summary

In this work the KM3NeT project has been briefly shown (Section 2) and the main technical components of the detector described (Sections 2.1 and 2.2). The collaboration is finalizing qualification tests and preparing the first phase of construction of the detector which will comprise a total of 31 detection units with 558 optical modules (Section 2.3). A prototype of the innovative design of the KM3NeT optical module is being operational in the ANTARES detector. The first preliminary results from this prototype (Section 2.3) show its capability of atmospheric muon track recognition. Finally the detector potential for the detection of Galactic sources and the IceCube diffuse flux from a region close to the Galactic Center has been reported (Section 2.4). A task force has been recently setup by the collaboration to investigate the potential of the KM3NeT detector for the identification of cascade events.

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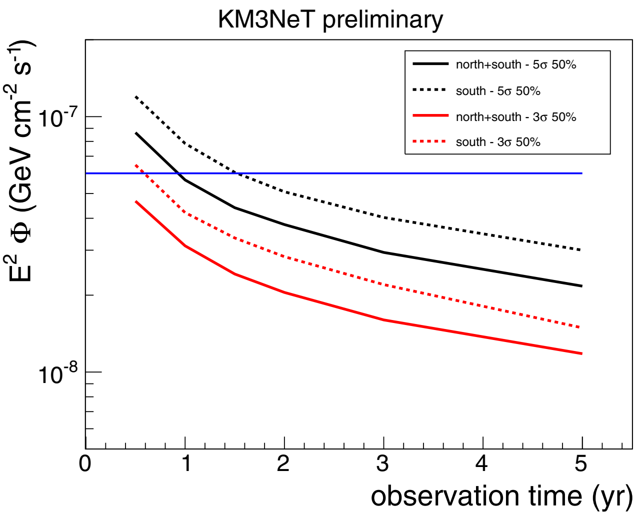

Fig. 6. Minimum flux detectable by KM3NeT with 50% probability at 5σ (black lines) and 3σ (red lines) significance, as a function of the observation time. Assumed is a neutrino spectrum with a 3 PeV cutoff (see text) and a detector comprising two building blocks. The blue line corresponds to the flux normalization of Eq. 1.

References

[1] P. Bagley et al., KM3NeT Coll., Technical Design Report, 2010. Available on http://www.km3net.org. ISBN 978-90-6488-033-9.
[2] M. G. Aartsen et al., IceCube Coll. Science 342, 1242856 (2013), [arXiv:1311.5238 [astro-ph.HE].
[3] L. A. Anchordoqui et al., Journal of High Energy Astrophysics 1-2 (2014) 1-30.
[4] U. F. Katz for the KM3NeT Coll., proceedings of the VLVnT13 workshop (5-7 August 2013 - Stockholm - Sweden).
[5] E. de Wolf et al., for the KM3NeT Coll., Nucl. Inst. Meth. A725, 241 (2013).
[6] S. Aiello et al., for the KM3NeT Coll., proceedings of the VLVnT13 workshop (5-7 August 2013 - Stockholm - Sweden).
[7] S. S. Adrián-Martínez et al., KM3NeT Coll. JINST 8, T03006 (2013).
[8] D. Real for the KM3NeT Coll., proceedings of the VLVnT13 workshop (5-7 August 2013 - Stockholm - Sweden)
[9] P. P. M. Jansweijer, H. Z. Peek and E. de Wolf, Nucl. Inst. Meth. A725, 488 (2013).
[10] M. G. Pellegriti et al. (NEMO collaboration) proceedings of the VLVnT13 workshop (5-7 August 2013 - Stockholm - Sweden).
[11] F. Aharonian et al., Astron. Astroph. 464, 235 (2007).
[12] S. R. Kelner, F. A. Aharonian and V. V. Bugayov, Phys. Rev. D 74, 063007 (2006).
[13] A. Trovato for the KM3NeT Coll., proceedings of the VLVnT13 workshop (5-7 August 2013 - Stockholm - Sweden).
[14] C. Lunardini, S. Razzaque, K. T. Theodoseauand, L. Yang, arXiv:1311.7188-28 Nov12.
[15] S.Razzaque, arXiv:1309.2756 - 4 October 2013.
[16] A. M. Taylor et al., arXiv:1403.3206 13 March 2014.
[17] M. C. Gonzalez-Garcia, F. Halzen and V. Niro arXiv:1310.7194 - 27 Oct 2013.
[18] R. Coniglione for the KM3NeT Coll., proceedings of the VLVnT13 workshop (5-7 August 2013 - Stockholm - Sweden)
[19] S. Adrián-Martínez et al., Astrop. Phys., 42, (2013) 7-14.