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Status of the KM3NeT project

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ABSTRACT: KM3NeT is a deep-sea research infrastructure being constructed in the Mediterranean Sea. It will be installed at three sites: KM3NeT-Fr, off-shore Toulon, France, KM3NeT-It, off-shore Portopalo di Capo Passero, Sicily (Italy) and KM3NeT-Gr, off-shore Pylos, Peloponnese, Greece. It will host the next generation Cherenkov neutrino telescope and nodes for a deep sea multidisciplinary observatory, providing oceanographers, marine biologists, and geophysicists with real time measurements. The neutrino telescope will search for Galactic and extra-Galactic sources of neutrinos, complementing IceCube in its field of view. The detector will have a modular structure and consist of six building blocks, each including about one hundred Detection Units (DUs). Each DU will be equipped with 18 multi-PMT digital optical modules. The first phase of construction has started and shore and deep-sea infrastructures hosting the future KM3NeT detector are being prepared in France near Toulon and in Italy, near Capo Passero on Sicily. The technological solutions for KM3NeT and the expected performance of the detector are presented and discussed.

KEYWORDS: High-energy neutrinos; Neutrino telescopes; Photomultipliers; KM3NeT.

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Contents

1. Introduction

The characteristics of the neutrino make it the perfect astronomical probe, able to cross extremely large distances and to transport information directly from the core of its production sites. Until recently this idea was shown to be successful in two major occasions: when detectors on Earth intercepted neutrinos coming from the Sun and neutrinos produced during a SuperNova explosion in the Large Magellanic Cloud. In the first case the evidence of a tiny neutrino mass and of flavor oscillations was settled. The second measurement confirmed the basic nuclear processes of stellar collapses. Recently, the first evidence of a high energy neutrino flux was announced by the IceCube Collaboration [1]. A bunch of neutrinos, whose energy ranges from 60 TeV to more than 1 PeV, from unresolved sources has been detected. This claim can be considered the opening of a new era for the exploration of the Universe, the age of neutrinos. The same features making neutrinos so useful in the exploration of the far Universe and of dense astrophysical objects put severe constraints for the construction of an appropriate neutrino detector, requiring the instrumentation of huge amount of matter.

2. The physics case

More than one century after their discovery [2], the origin and the acceleration mechanism of cosmic rays impinging on the Earth atmosphere have not been completely clarified yet. Primary cosmic rays are fully ionized atomic nuclei, mainly free protons. Their energy spectrum spans over several decades from some MeV up to 10^{20} eV and falls steeply, showing some typical features connected to the specific production sites of the particles. The slope of the energy spectrum shown in Fig. 1 changes at 10^6 GeV, the *knee*, and around 10^{10} GeV, the *ankle*. Galactic Supernova remnants are generally considered as potential sites of production and acceleration of galactic

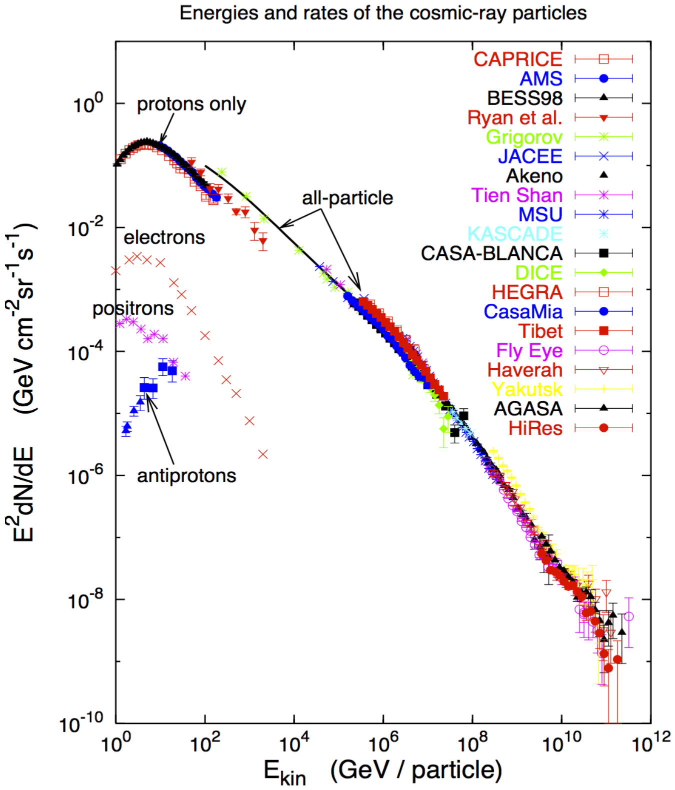

Figure 1. Cosmic ray spectrum as measured on Earth. The contributions of protons, electrons, positrons and antiprotons at low energy, when measurements are available, are also reported. References to the experiments can be found in [3]. The figure is due to Tom Gaisser.

CRs, below the *knee* energy. More energetic CR cannot be explained with a Galactic origin and most likely have an extragalactic origin. The same astrophysical accelerators, Galactic and extra-Galactic, could be the responsible for production of TeV gamma rays detected by several ground based instruments [4] and for other extremely energetic phenomena like gamma ray bursts.
In the framework of a beam dump scenario, neutrinos can be produced in association with high energy gamma rays as the result of pion decay (hadronic model) when the accelerated hadrons, present in the core of massive objects, interact with ambient matter or photon fields:

$$\begin{array}{lll} p/A + A/\gamma \longrightarrow \pi^0 & + \pi^{\pm} & + N + \ldots \\ \qquad\qquad\quad \downarrow & \quad \downarrow & \\ \qquad\qquad\quad \gamma + \gamma & \quad \mu^{\pm} + \nu_\mu \ (\overline{\nu}_\mu) & \\ & \quad \downarrow & \\ & \quad e^{\pm} + \nu_e \ (\overline{\nu}_e) + \overline{\nu}_\mu \ (\nu_\mu) & \end{array}$$

Differently from what happens to other astrophysical messengers, they can deliver direct information from their production sites, because they are not deflected by magnetic fields, are stable and have a small interaction cross section.
Starting from the hypothesis of a common origin of neutrinos and gamma rays, benchmark fluxes have been evaluated and published in literature, which set the size of an astrophysical neutrino detector to the kilometre cube scale [5], [6].

3. Neutrino telescopes

In the 60's Markov suggested the use of ocean or lake water as target and active medium for neutrino detectors [7]. This idea is at the basis of the neutrino telescope concept. The neutrino telescope detection principle relies on the measurement of the Cherenkov light emitted in a natural transparent medium, like water or ice, by the particles produced in neutrino interactions in the vicinity of a three dimensional array of photon detectors.
Due to the long muon path length, the effective size of the detector is much larger for charged current muon neutrino interactions than for other channels. Starting from time, position and amplitude of the photon signals, dedicated algorithms can reconstruct the trajectory of the muons, inferring the neutrino direction. The neutrino and the muon directions are almost collinear at high energy, and this allows the identification of a possible source with a high resolution. Measuring the total amount of light released in the detector, also the energy of the event can be evaluated within a factor 2-3.
Neutrino telescopes are located under large layers of matter, buried in the Antarctic ice or submersed under kilometers of oceanic water, to stop the bulk of cosmic radiations. Indeed, the flux of high energy atmospheric muons, produced in the interactions of primary cosmic rays with atmospheric nuclei, exceeds that of atmospheric neutrinos by several orders of magnitude, even at very large depth, see Fig. 2.
An efficient method to select neutrino-induced muons relies on a geometrical selection of reconstructed tracks, which rejects downward going muons due to atmospheric showers.
A source of background that cannot be eliminated with simple geometrical selections is represented by atmospheric neutrinos. A cosmic neutrino flux can be identified either by looking for an excess of event over the atmospheric neutrino background, or searching for a deformation of the atmospheric neutrino energy spectrum, typically due to an excess of events above a certain energy.
A search for coincident events with other astrophysical messengers provides a further possibility to reduce the background, looking for neutrino candidates at a specific time and from known directions. This approach can be applied to transient sources like gamma ray bursts or micro quasars.

At present, an under-ice neutrino telescope, with an instrumented volume of about 1 km^3 large, is operated at South Pole, IceCube, [10]. Underwater detectors have been built in the lake Baikal, in Russia, and in the Mediterranean Sea. Currently, the Baikal neutrino telescope is not taking data, due to an upgrade that will extend its volume to 1 Gton, [11]. In the Mediterranean Sea, three collaborations, ANTARES [12], NEMO [13] and NESTOR [14], have been active since a couple of decades. The Mediterranean Sea is considered a privileged area for a very large neutrino telescope because of logistic and scientific motivations: it has several deep sea sites (up to 5 km deep), with excellent transparency properties of water, a good availability of on-shore infrastructures and the possibility of observing the Galactic centre, which is considered a very interesting region of the Universe, hosting many potential neutrino sources.
The ANTARES collaboration built a 0.1 km^3 neutrino telescope close to the Provencal coast, in France. It is taking data in its full configuration since 2008. The ANTARES, NEMO and NESTOR groups joined their efforts in long term R&D activities creating the KM3NeT consortium, funded

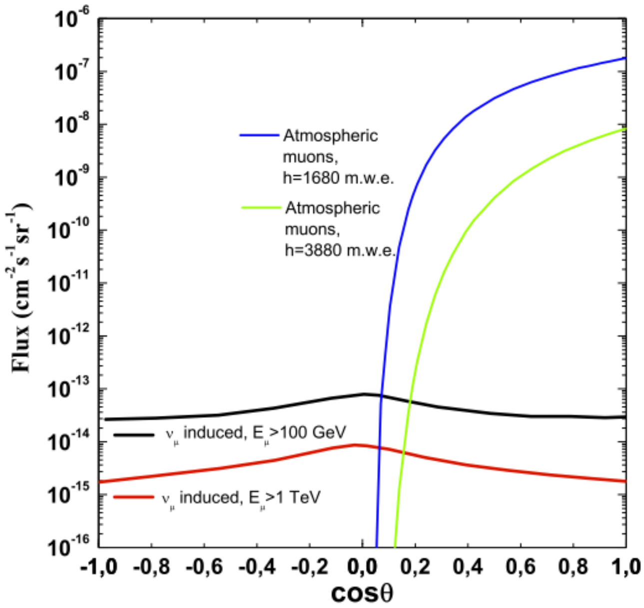

Figure 2. Flux of *i*) atmospheric muons (computed according to [8]) at two different depths and of *ii*) atmospheric neutrino induced muons (from [9]), for two different muon energy thresholds.

by the EU in the framework of FP6 and FP7 in the period 2006-2012, [1]. In this context, new technological solutions have been developed and deep sea sites were accurately characterized.
At the beginning of 2013, the consortium has been transformed into a Collaboration and started the construction of a KM3NeT Mediterranean neutrino telescope. The KM3NeT Collaboration gathers more than two hundreds scientists and engineers from ten European countries. Its main objective is the construction of a multidisciplinary observatory in the Mediterranean Sea, which will host a km^3-size neutrino telescope, complementary to the IceCube detector in its field of view. In particular it will look directly to the Galactic centre. The KM3NeT infrastructure will include also a number of sea and Earth science devices that will provide biologists, geophysicists, marine scientists with data collected at very high depth and will monitor the environmental conditions around the telescope.

4. Sites and technology

4.1 Sites

Three sites have been identified as good locations for the KM3NeT, see Fig. 3:

- KM3NeT-Fr: this site is close to the ANTARES detector site, at about 20 km from the French coast, in front of Toulon;

[1] FP6 Design Study; Project Acronym: KM3NET; Project Reference: 011937. FP7 Preparatory Phase; Project Acronym: KM3NET-PP; Project Reference: 212525

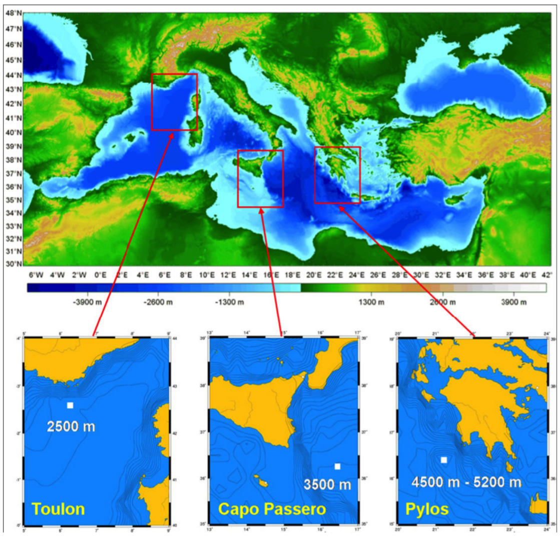

Figure 3. Location of the three proposed sites for the construction of the KM3NeT neutrino telescope in the Mediterranean Sea.

- KM3NeT-It: this is the site chosen by the NEMO Collaboration for the deployment of a prototype tower that has been in acquisition since March 2013 (see T. Chiarusi's contribution at this workshop, [15]). It is at 3500 m under sea level at about 100 km from Capo Passero, in Sicily.
- KM3NeT-Gr: this is the deepest site of the three proposed locations, at 4500/5000 m under sea level. There are four possible installation sites at about 20-50 km far from Pylos, in Greece.

As a consequence of the regional nature of funding, a multisite approach has been decided. Several studies done by the KM3NeT consortium concluded that the sensitivity of the telescope to point like sources of neutrinos is not significantly degraded in the case of a detector spread over the three sites. The use of more than one site also offers some practical advantages such as a flexible deployment strategy for the use of a ROV or a boat, redundancy in the case of rare events such as Earthquakes, subsea landslides, whale collision with infrastructure, fishing net entanglement, exceptional bioluminescence activity, etc., [16].

4.2 Technology

The design of the detector is based on the concept of the Building Block. Each building block is made of Detection Units (DU). The final design, optimized for the search of point like sources of neutrinos, sees a total of 6 building blocks with 115 DUs each, at a distance of ~ 90 m, corresponding to an instrumented volume of about 3 km^3.
Each DU consists of a flexible string, 700 m long, anchored at the sea bottom and kept taut by a system of buoys, carrying 18 storeys that will host one Digital Optical Module (DOM) each, with a vertical spacing of 36 m. The first storey will be at 100 m from the sea bottom. The mechanical

Figure 4. Photo of the prototype multiPMT DOM, presently in data taking on the ANTARES detector.

structure is based on two dyneema ropes.
A Vertical Electro-Optical Cable (VEOC), an oil-filled pressure-balanced hose equipped with 18 optical fibers and two copper conductors, connects all DOMs to the DU base for power, readout and data transmission.
The DOM used in the KM3NeT has a new design if compared to the optical modules of previous neutrino telescopes. A pressure resistant 17-inch sphere will host 31 3-inch photomultipliers (PMTs), for a total cathode area equivalent to the area of 3 10-inch PMTs, together with the front-end electronics to extract the time-over-threshold (TOT) from the analogue signals and custom-made bases for the PMTs. A light collection ring will increase the effective photocathode area by 20-40%. The segmented photocathode area of the multiPMT- DOM will improve the sensitivity to photon coincidences and provide some information on photon direction. A detailed description of the DOM is in the contribution of O. Kalekin at this workshop, [17]. Also several calibration and monitoring devices such as tilt meters, compasses and piezo-sensors for acoustic positioning, nano beacon (single LED pulsers) for time calibration are positioned inside each DOM.
A fully equipped multiPMT-DOM, Fig. 4, has been mounted on the Instrumentation Line of the ANTARES detector, a line completely dedicated to sea and Earth science devices, and has been deployed and connected in April 2013. Since then it has been taking data regularly and according to expectations. Fig. 5 shows a preliminary comparison between collected data and MC expectations. Simply requiring a coincidence among 6-7 PMTs the bulk of hits due to the decay of ^{40}K dissolved in the sea water can be rejected. Measurements are still on going.
The string deployment will be done using a recoverable launcher vehicle specifically designed (LOM), [18]. A Remotely Operated Vehicle (ROV) will connect each DU cable to a junction box connected to a sea floor infrastructure, receiving and delivering signal and power from/to the shore. Several qualification campaigns have been performed to validate the deployment concept.

5. Present status of the project

The first phase of the project (Phase-1) is funded mainly by Italian, Netherlands and French con-

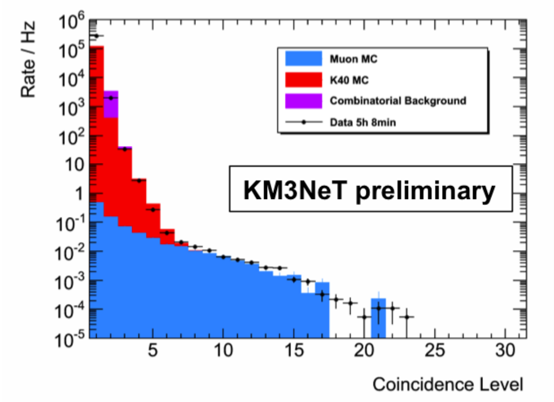

Figure 5. Comparison between the measured and expected rate on the PPM-DOM hosted by the ANTARES detector as a function of the number of coincident hits. The red histogram represents the contribution due to the decay of ^{40}K dissolved in the sea water. Measurements are still ongoing and the plot must be considered as preliminary.

tributions and foresees the construction and the deployment of 31 DUs, 24 DUs at the KM3NeT-It site and the remaining at the KM3NeT-Fr site. First strings will be deployed by early 2015.
The KM3NeT-It site will host also a set of 8 detection units constructed according to a previous design (NEMO tower, see [15]), which will be operated independently.
The geometry of the detector of KM3NeT Phase-1 has been optimized to search for point like or extended sources of neutrinos, exploiting mainly the charged current interaction channel of muon neutrinos.
In Phase-2 of the project the also the KM3NeT-Gr sit will be included, provided funding will be allocated. In this phase, the detector will be completed to its full size of several cubic kilometres.
Since the publication of the recent results of IceCube, suggesting the existence of a diffuse flux of high energy neutrinos from unresolved sources, an intense effort has started to evaluate the sensitivity of a Mediterranean Sea telescope to collect this category of events and to define an optimized configuration for a possible intermediate detector.

6. Conclusions

The KM3NeT collaboration has just started to build a cubic kilometer size neutrino telescope in the Mediterranean sea. It will complement the IceCube neutrino telescope, located at the South Pole, in its field of view. In particular, it will observe directly the Galactic Centre. The first phase of the project has started with the aim to deploy the first detection units by early 2015 at the Italian and French sites. In the second phase of the project also the Greek site should be included. During this phase, a 3 km^3 size neutrino undersea neutrino telescope will be constructed with unprecedented angular resolution for the search of high energy neutrino sources.
An intense program of simulations has been started to define the optimal geometry and size for an early measurement of a diffuse flux of neutrinos and evaluate the KM3NeT sensitivity to the high-energy events recently published by IceCube.

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