High energy neutrino astronomy with KM3NeT

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Abstract. The KM3NeT Collaboration aims at the observation of high neutrino sources in the Universe and at the determination of the neutrino mass hierarchy. This talk is focused on ARCA. The deployment of the first Detection Units at 3500 m depth offshore CapoPassero (Italy) started and two are in operation. ARCA will made of two buildings blocks made of 115 Detection Units corresponding to an instrumented volume of about 1 km3 and will provide a very large coverage of the neutrino sky - 87% for up going muon neutrinos). The superior angular resolution, 0.1^o at energy higher of 10 TeV, will be important for source search. In this talk the detector technology, status and perspectives for detection of high energy neutrinos signals from different candidate sources are discussed.

1. Introduction

In the landscape of multimessenger astroparticle, high energy neutrinos play an important role. Indeed, to the fact that they are neutral particles and affected only by the weak interaction, they can travel cosmological distances and carry information from the core of the most powerful cosmic accelerators. High energy neutrinos are expected to shed light on the violent Universe providing information on astrophysical distant objects in which hadronic interactions take place [1, 2]. Their detection in association with specific sources will clarify the still unknown origin of cosmic rays. The discovery of a cosmic neutrino flux reported by the IceCube collaboration [3, 4] initiated de facto the era of neutrino astronomy. However, most of the questions raised about the origin of the observed neutrino cosmic flux remain unsolved. Many hypotheses on the sources of these cosmic neutrinos have been proposed including galactic (and extragalactic sources, but also Dark Matter and other exotic explanations [5]. The need for a km^3-scale neutrino telescope in the Northern Hemisphere is enforced to complement the observations of high energy neutrinos IceCube at the South Pole. Indeed, a telescope installed in the depths of the Mediterranean Sea, due to its favorable latitude and the Earth rotation, has a field of view of about 87% of the Galactic Plane including the Galactic Centre (marginally accessible from IceCube) thus allowing a full coverage of the sky. Moreover, the much better angular resolution achievable in deep sea water with respect to ice, i.e. about an order of magnitude both for tracks and cascade events, can have a strong impact on the potential discovery of a neutrino telescope and eventually increase the chance of identification of point-like sources.

   KM3NeT is a distributed infrastructure with two deep sites in the Mediterranean Sea hosting two neutrino telescopes built with the same technology, but with different granularity and physics goals. The Capo Passero site (Italy), KM3NeT-It at 3500 m depth, will host the ARCA (Astroparticle Research with Cosmic in the Abyss) detector dedicated to high energy neutrino astronomy, while the Toulon site (France), KM3NeT-Fr at 2500 m depth, will host the ORCA

(Oscillation Research with Cosmic in the Abyss)[6] detector dedicated to the determination of the Neutrino Mass Hierarchy via the measurement of atmospheric neutrinos. The KM3NeT physics case and the detector technology are described in the KM3NeT 2.0 Letter on Intent [7] that includes the ARCA and ORCA proposal. The results concerning ARCA reported here focus on some improvements with respect to the Letter of Intent.

2. Detector technology and atmospheric muon data

The goal of the KM3NeT technology[8] is to instrument, at minimal cost and maximal reliability, the largest possible volume of sea water with a three dimensional grid of light sensors. Due to the complexity of the technological challenges related to the construction, installation and operation of a detector in the depths of the sea (2500m - 3500 m), the path towards a km^3 underwater neutrino telescope proceeds stage by stage. The basic element of the detector is the optical sensor, the so-called Digital Optical Module (DOM) made of 31 3-inch PMTs with their read-out electronics within a 17-inch pressure-resistant glass sphere.

This design offers several advantages compared to previous designs based on a single large area PMT: larger photo-cathode area per optical module, digital photon counting, directional information, wider field of view and reduced aging effects. The optical module also incorporates an acoustic sensor and a compass used for position and orientation calibration. Eighteen DOMs suspended by to thin Dynema Ropes and interconnected by an electrooptical backbone cable, form a Detection Unit (DU). One end of the DU is anchored to the sea floor and the other end is kept close to vertical by the pull of a buoy. A collection of 115 DUs forms a KM3NeT building block. A sea floor network ensures power distribution and data communication. The DUs are connected to junction boxes via interlink cables laying on the seabed. A main electro-optical cable provides the connection between the deep sea infrastructure and the shore station. The readout of the detector is based on a all-data-to-shore concept while a trigger system is implemented on shore.

On site, the shore station is equipped to provide power, computing and a high-bandwidth internet connection to the central data repository. Since the concept of strings is modular by design, the construction and operation of the research infrastructure allows for a phased implementation. After the *in situ* validation of the key technologies with prototypes installed at 2500 m and 3500 m depth [9, 10], the first phase of ARCA construction started with the installation of two DUs in the Capo Passero site.

The first data from the two DUs deployed at Capopassero have been analyzed and are in very good agreement with Montecarlo simulations of atmospheric muons. The depth dependence of the coincidence rates induced by atmospheric muons was measured using the first two KM3NeT Detection Units. The KM3NeT multi-PMT design allows each DOM, considered as a stand-alone unit, to be calibrated in-situ and allows to identify atmospheric muon events by requiring high-multiplicity local coincidences. These results are reported in Fig. 1.

3. ARCA sensitivity to astrophysical neutrino fluxes

The signal observed by IceCube contains cascade and track events with neutrino energies from a few tens of TeV to several PeVs. Although the signal is statistically very significant, the properties of the underlying neutrino flux (energy spectrum, directionality, flavor composition) are not fully established.

An analysis [11] extended the search for cosmic neutrinos to lower energy, i.e. above 1 TeV, but at price of a dramatic reduction of the fiducial volume. The bulk of data indicates a possible excess of signal from the Southern Hemisphere with a softer spectral index that could suggest the presence of a galactic component.

In the energy region of interest for high energy neutrino astronomy (E $\geq$ TeV) a rather sparse detector is required. The ARCA telescope, with an instrumented volume of 1 km^3, will consist
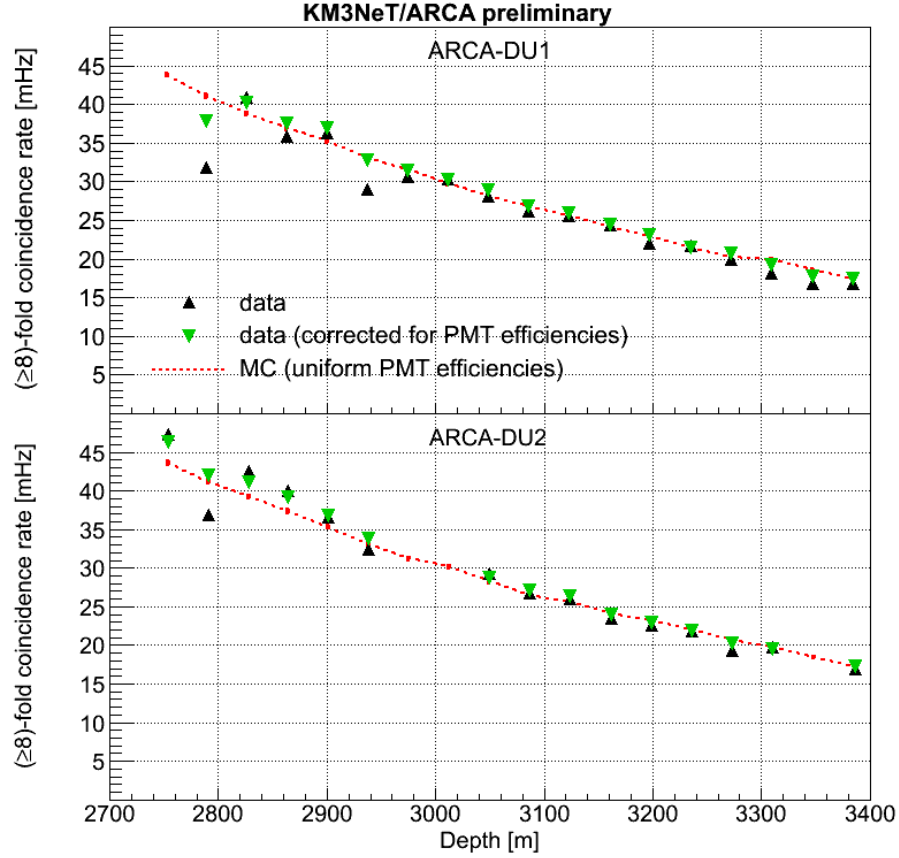
Figure 1. $\geq$ 8-fold coincidence rate as a function of the depth below the sea surface. The red dashed line shows the base expectation from an ideal MC with uniform PMT efficiencies which neglects the differences between individual PMTs as determined from in-situ calibration. The black points show the uncorrected data. The green points show the data corrected for the effect of the PMT efficiencies. Statistical errors bars are included but are too small to be visible over the markers.

of two building blocks of 115 strings each with 36 m inter DOM vertical spacing and 90 m inter DU spacing. ARCA will allow a measurement of cosmic neutrinos at the latitude of the Mediterranean Sea with different methodology, improved resolution and complementary field of view with respect to the IceCube at the South Pole location.

Detailed studies have been and are being conducted to estimate the sensitivity of KM3NeT to diffuse neutrino fluxes with properties deduced from the IceCube observations. In particular, we assume that the IceCube signal originates from an isotropic, flavor-symmetric neutrino flux following a E^{-2} power-law spectrum with a cut-off at a few PeV. The value of the cut-off energy, E_{cut}= 3 PeV, represents a rather conservative value; larger values would improve the sensitivity of the measurement. The background of atmospheric neutrinos assumed in this analysis corresponds to the so-called Honda flux [12] with a prompt component as calculated by Enberg [13]. A correction taking into account the knee in the cosmic ray spectrum has
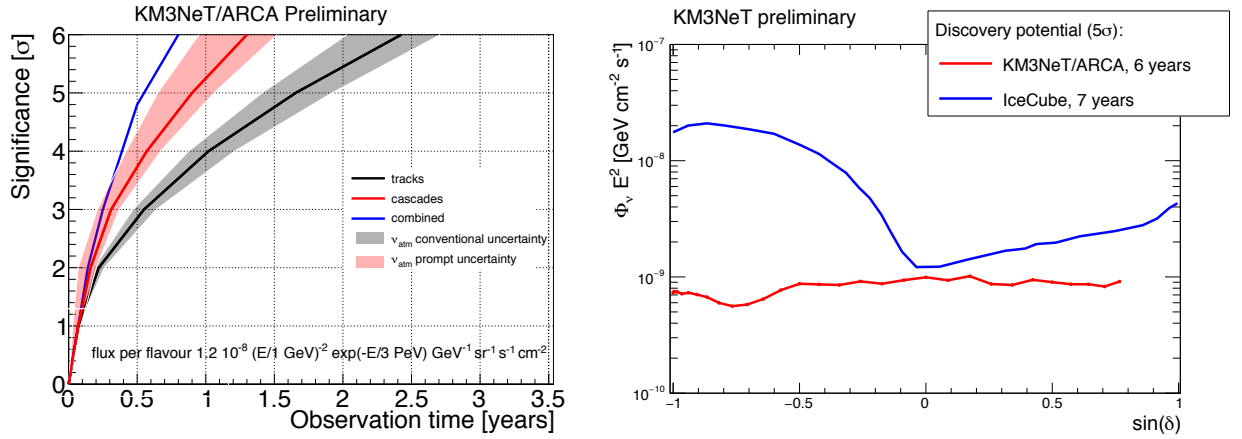
Figure 2. KM3NeT sensitivity to high energy neutrino fluxes. Left: Preliminary significance for the discovery of cascade and up-going muon fluxes to the cosmic neutrino flux observed by IceCube. Right: Preliminary discovery flux for point-like sources with a E^{-2} spectrum as a function of the declination for the detector of KM3NeT/ARCA. IceCube performance for an equivalent exposure is also shown for comparison

been applied to both conventional and prompt atmospheric neutrino fluxes according to the prescription in reference [14] and references therein. The background from atmospheric muons has also been considered. Cascade events from a neutrino and anti-neutrino diffuse flux and muon track events with the interaction vertex inside the detector volume were considered. This analysis includes all neutrino flavors. Another analysis concerns an up-going, diffuse flux of muon neutrinos and anti-neutrinos, which does not include the upper hemisphere, with the exception of a small zenith region above the horizon. The results of these analyses are summarized in Fig. 2 where the sensitivity to an IceCube-like flux is reported as a function of the number of years of observation. A significance of 5σ is obtained after one year in the all-flavor cascade channel and after about 2.2 years in the up-going muon channel.

The ultimate goal of a high energy neutrino telescope is the discovery and identification of point-like sources. In order to quantify the sensitivity of the ARCA detector extragalactic point sources of neutrinos, a dedicated analysis has been performed for a detector setup with two detector building blocks. The background from atmospheric muons and neutrinos has been included in the analysis in the same way as for the diffuse flux analysis. In the search for point-like sources one of the most important features of a neutrino telescope is the angular resolution that is of crucial importance for the rejection of the atmospheric neutrino background. In the muon track channel beyond a few tens of TeV a resolution of about 0.1 degrees is achieved. This value has to be compared to the corresponding value of about one degree quoted by the IceCube collaboration for track events [4]. A generic E^{-2} spectrum that represents a standard approximation for extra-galactic sources has been considered. The KM3NeT/ARCA discovery potential for point-like sources as a function of the declination and the comparison with IceCube for about the same exposure is reported in Fig. 2. The red and black lines represent the ARCA two block detector. KM3NeT has a veryfield of view thus not only complementing, but also overlapping to large extent to the IceCube field of view with performances that exceed that of IceCube by more than one order of magnitude in the Southern hemisphere and comparable or better elsewhere.

Due to its location that allows the survey of most of the galactic plane, the search for high energy neutrino emission from galactic sources is of prime interest for KM3NeT. In particular, the Super Nova Remnants RXJ1713.6-3946 and Vela Jr and the Pulsar Wind Nebula VelaX,

that are at present among the most intense and best measured objects in gamma TeV region of this type, have been studied. ARCA discovery potential studies indicates that a significance of 3σ can be reached in few years for these sources.

4. Conclusions

The IceCube discovery of a cosmic neutrino flux strongly enforced the physics case of KM3NeT. In particular the almost complete survey of the galactic plane including the Galactic Centre from its location in the Mediterranean Sea and its excellent performances in terms of angular resolution can provide important contributions to the new born field of neutrino astronomy. The ARCA detector for high energy neutrino astronomy will be located at the KM3NeT-It site off-shore Capo Passero, Italy at 3500 m depth. The key technologies, i.e. the DOM and a prototype of string with three DOMs, have been fully validated *in situ* , at the ANTARES and KM3NeT-It sites respectively. The expected performances in terms of sensitivity for diffuse and point-like sources have been estimated. In particular the neutrino cosmic flux observed by IcCube is expected to be observed at 5σ level by ARCA in less of one year. At present, ARCA is partially funded and the construction started. The analysis of muon atmospheric data are in good agreement with MonteCarlo simulations.

5. References

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