IL NUOVO CIMENTO **47 C** (2024) 71
DOI 10.1393/ncc/i2024-24071-6

Colloquia: IFAE 2023

Neutrino astronomy in the Mediterranean and the KM3NeT/ARCA telescope(*)

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received 13 February 2024

Summary. — The KM3NeT collaboration is building two neutrino telescopes in the Mediterranean Sea. One is the ARCA detector, optimised for searches for high-energy neutrino sources in the Universe and it is under construction at the Capo Passero site, Italy, 80 km offshore at a depth of 3500 m; and the other is ORCA detector, near Toulon, France, 40 km offshore at a depth of 2500 m, aimed at the determination of the mass hierarchy of neutrinos. In the final configuration, ARCA will consist of 2 Building Blocks (BB), each one of 115 Detection Units (DU), with a total of more than 64000 optical sensor in a volume of about 1 km^3 of water. In this contribution, the results of the KM3NeT/ARCA telescope obtained with data collected from May 2021 to December 2022 with evolving detector geometries and the perspectives for the KM3NeT/ARCA full telescope to detect the high energy neutrino sources in the Universe are presented.

1. – The Neutrino astronomy and the KM3NeT/ARCA telescope

The observation of high-energy neutrinos of astrophysical origin [1, 2] has opened a new window for the study of our Universe. Although detecting very high-energy neutrinos of cosmic origin represents a breakthrough in Neutrino Astronomy and Multi Messenger Astronomy, the sources these neutrinos originate from remain unknown. The identification of cosmic objects emitting high energy neutrinos will provide a new insight of our Universe, leading to a deeper understanding of cosmic sources.

The KM3NeT detector for Astroparticle Research with Cosmics in the Abyss (ARCA), is currently under construction in the Mediterranean Sea, at the Capo Passero site, Italy, 80 km offshore at a depth of 3500 m. The KM3NeT/ARCA detector has been optimised for the searches of high-energy neutrino sources in the Universe. The detector will have an instrumented volume of a cubic kilometre and, thanks to its unprecedented angular resolution (smaller than 0.1 degrees for ν_μ with $E > 100$ TeV), will be able to identify and discover cosmic neutrino sources in the Universe.

(*) IFAE 2023 - "Cosmology and Astroparticles" session

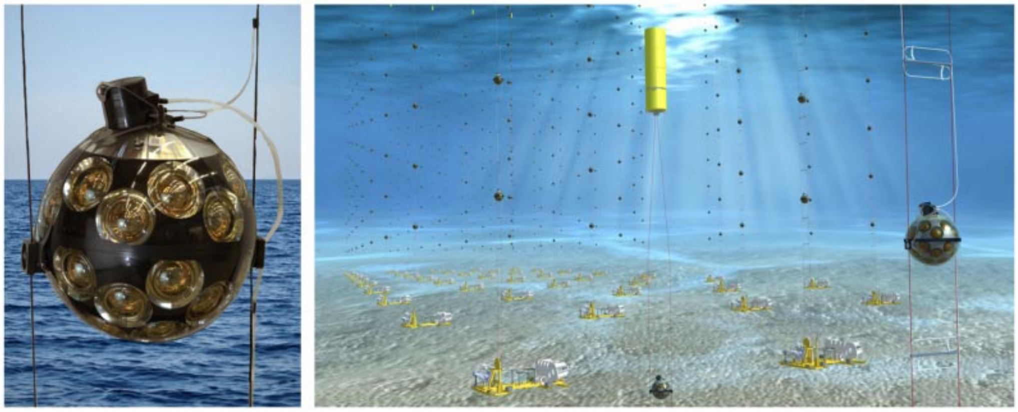


Fig. 1. – On the left the KM3NeT optical module is shown. On the right a view from inside a detector building block of detection units is presented.

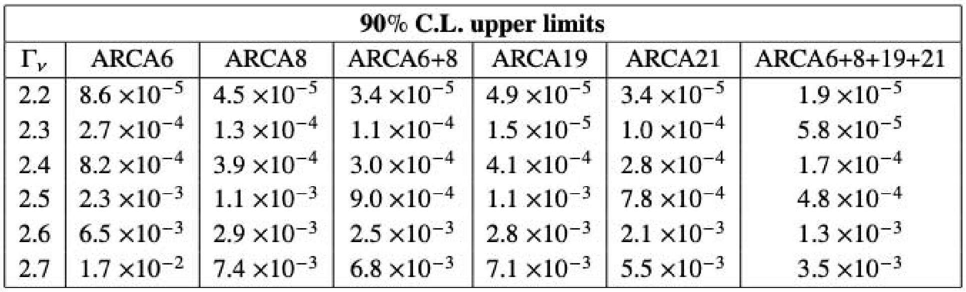
The basic detection element of the KM3NeT detector is the Digital Optical Module (DOM), see fig. 1. The module is a pressure resistant glass sphere, containing 31 photomultipliers tubes (PMTs). Eighteen modules are arranged in the Detection Unit (DU), a vertical string anchored on the sea floor. The DU are deployed on the seabed to form a three-dimensional array of optical modules to detect Cherenkov light produced by neutrino-induced particles. The detection of the time, position and amplitude of PMTs pulses (the so called hits) allow both direction and energy reconstructions of neutrino events. At the end of the construction, ARCA will consist of 2 Building Blocks (BB), each one of 115 DUs. A seafloor network, composed of electro-optical cables and Junction Boxes (JBs) for DU power and optical connections, allows to communicate with the telescope and collect data from offshore to onshore.

The KM3NeT/ARCA telescope is sensitive to cosmic neutrinos in a wide range of energies, extending from about 100 GeV up to PeV, with a field of view of the sky which is complementary to IceCube. Since the detector is under construction, the KM3NeT/ARCA telescope has an evolving detector geometry. This contribution will present the results of point source and extended source searches with KM3NeT/ARCA data collected from May 2021 to December 2022 with evolving detector geometries and the astronomy potential for the full ARCA detector.

2. – The KM3NeT/ARCA 6 sensitivity studies

The KM3NeT/ARCA detector is currently taking data with a detector geometry consisting of 28 DUs. In this contribution the sensitivities studies for theKM3NeT/ARCA 6 and for the data collected from May 2021 to Dicember 2022 with evolving detector geometries are presented.

2˙1. *Search for a diffuse astrophysical neutrino flux from the Galactic Ridge*. – The KM3NeT/ARCA data taken in a detector configuration with 6 DUs have been analysed searching for a diffuse neutrino flux originated from the Galactic Ridge region, as presented in [3]. The events considered in the analysis are track candidate events, generated



90% C.L. upper limits						
Γ_ν	ARCA6	ARCA8	ARCA6+8	ARCA19	ARCA21	ARCA6+8+19+21
2.2	8.6×10^{-5}	4.5×10^{-5}	3.4×10^{-5}	4.9×10^{-5}	3.4×10^{-5}	1.9×10^{-5}
2.3	2.7×10^{-4}	1.3×10^{-4}	1.1×10^{-4}	1.5×10^{-5}	1.0×10^{-4}	5.8×10^{-5}
2.4	8.2×10^{-4}	3.9×10^{-4}	3.0×10^{-4}	4.1×10^{-4}	2.8×10^{-4}	1.7×10^{-4}
2.5	2.3×10^{-3}	1.1×10^{-3}	9.0×10^{-4}	1.1×10^{-3}	7.8×10^{-4}	4.8×10^{-4}
2.6	6.5×10^{-3}	2.9×10^{-3}	2.5×10^{-3}	2.8×10^{-3}	2.1×10^{-3}	1.3×10^{-3}
2.7	1.7×10^{-2}	7.4×10^{-3}	6.8×10^{-3}	7.1×10^{-3}	5.5×10^{-3}	3.5×10^{-3}

Fig. 2. – 90% C.L. upper limits under a single power-law assumption (see [3]) for KM3NeT/ARCA6, KM3NeT/ARCA8, KM3NeT/ARCA19, KM3NeT/ARCA21 and the combined data sets. All the results are expressed in units of $GeV^{-1}cm^{-2}s^{-1}sr^{-1}$.

by ν_μ charged current interactions, that have passed quality selection criteria. The surviving background, represented by atmospheric muons, has been reduced using Boost Decision Trees (BDTs) algorithm. The strategy adopted for the analysis is an on-off technique similarly to what has been done in [4,5]. The on-region is defined as the region of the Galactic Plane with $|l| < 30°$ and $|b| < 2°$, while the background expectation is directly estimated from data in off-regions having the same sky coverage of the on-region but shifted in right ascension, avoiding the region of the Fermi Bubbles. The expected neutrino signal has been simulated by using the standard Monte Carlo chain developed within the KM3NeT collaboration [6], assuming the signal to be originated inside the Galactic Ridge with a single power-law energy spectrum. The analysis strategy is the same described in [4]. No excess of events has been found with respect to the background expectation and the 90% C.L. upper limits have been calculated and reported in fig. 2. Limits for different detector configuration and for the combination KM3NeT/ARCA6+8 and KM3NeT/ARCA6+8+19+21 are reported in order to highlight the impact of including data sets.

2˙2. *Search for cosmic neutrino from point sources and extended sources.* – The results of point source and extended source searches with KM3NeT/ARCA6 data and with data from 2021 and 2022 taken with an evolving detector geometry are presented [7]. A list of 101 astrophysical objects has been tested verifying whether the selected sources are high energy neutrino emitters. In order to reduce the atmospheric muon contamination and remove badly reconstructed events, event selection criteria have been used, based on the likelihood of the reconstruction, on the number of hits used in the reconstruction and on the reconstructed direction. To identify a cosmic neutrino signal, the selected events have been analysed through statistical methods based on Monte Carlo pseudo experiments and the expected sensitivity of KM3NeT/ARCA6 has been calculated in a binned likelihood analyses. For every (pseudo) dataset the compatibility of the dataset with the expected signal + background model (H_1), and with the background-only model (H_0) has been determined. All candidate sources are consistent with a background-only hypothesis. A list of the most signal-like sources is reported in [7]. Since no significant detection is made upper limits have been set on the flux. The results are shown in fig. 3 together with the sensitivity for the KM3NeT/ARCA8, 19 and 21 DUs and for the full detector.

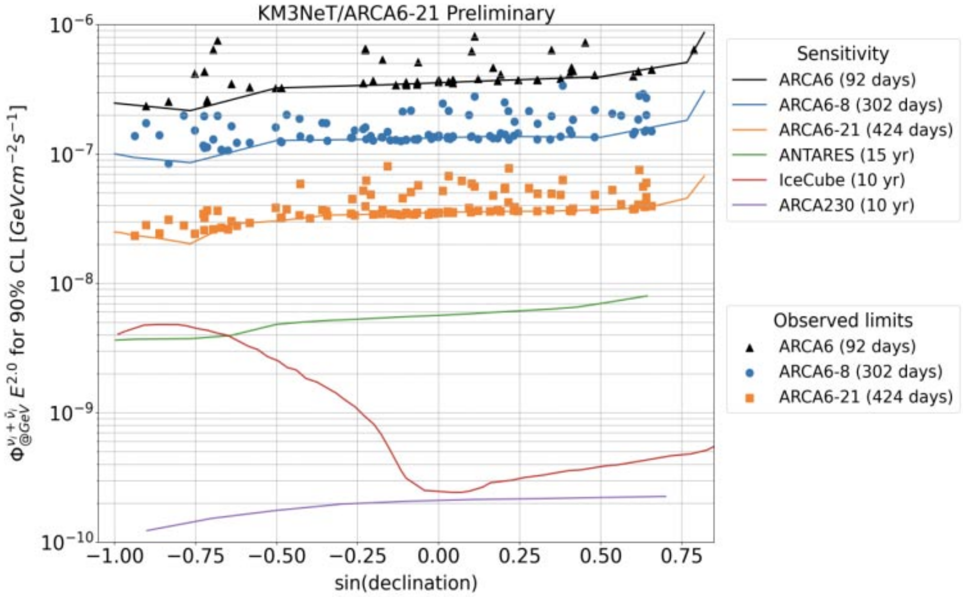


Fig. 3. – Comparison of the observed limits on the flux for the ARCA6-21 point source analysis assuming an E^{-2} source spectrum as a function of $sin(\delta)$, with earlier presented results of ANTARES 15 years [8] and IceCube [9, 10], as well as the ARCA230 10 years sensitivity [11].

3. – Astronomy potential for the full ARCA detector

The sensitivity estimates and the astronomy potential of the full ARCA detector for diffuse, point-like and extended neutrino sources have been also estimated [12]. After applying the quality cuts to increase the signal to background ratio, the detector response functions, like the so called effective area, the energy resolution and angular resolution are converted to probability density functions and are used as an input for the unbinned likelihood analysis to calculate the expected sensitivity of KM3NeT/ARCA to diffuse, point source and extended sources in our universe. The sensitivity of KM3NeT to point sources with an E^{-2} flux have been estimated for different sky positions and for 3 and 7 years of data taking. These results are shown in fig. 4 (left) in comparison to similar studies for 13 years of data taking with ANTARES and 7 years for IceCube [9]. For the extended source analysis the results are summarised in fig. 4 (right). This study demonstrates the capability of the KM3NeT/ARCA detector to achieve a 90% CL sensitivity for 3 of the 4 considered sources in less than 4 years, while for the most promising source (HAWC J1825-134) the sensitivity is achieved approximately in 1 year.

4. – Conclusions

In these proceedings, the first results of the analysis of the KM3NeT/ARCA data taken with a detector geometry of 6 DUs and the astronomy potential of the full KM3NeT ARCA detector have been presented. These studies, together with the combined analyses

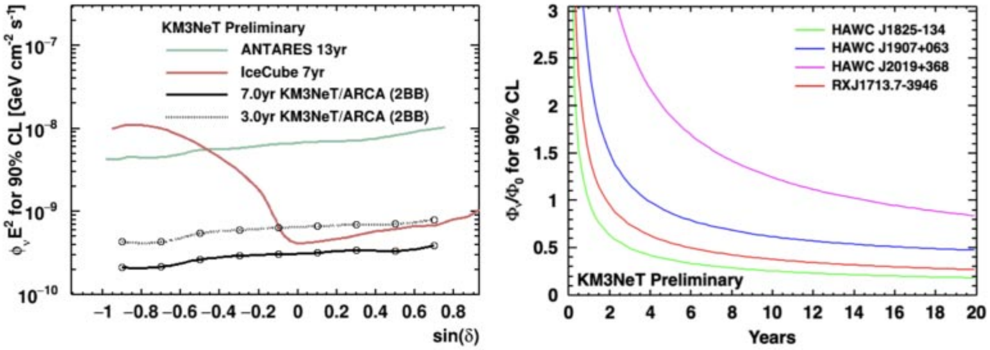


Fig. 4. – On the left the flux normalisation for 90% CL limits to detect a E^{-2} point source with KM3NeT/ARCA in comparison with ANTARES 13 years and and IceCube 7 years [9]. On the right the expected sensitivity at 90% CL for the E^{-2} energy spectrum for promising extended sources.

of data taken with the evolving detector geometry, have already shown the great potential of the KM3NeT/ARCA telescope. Even though the limits presented are not competitive with the results reported by ANTARES and IceCube, the planned deployment of further DUs will improve these limits and constrain neutrino emission further.

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The author gratefully acknowledge the financial support of MUR-PNRR project KM3NeT4RR (IR0000002) funded by European Union - NextGenerationEU, Dipartimento di Fisica e Astronomia "Ettore Majorana" - Università degli Studi di Catania and Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud.

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