PROCEEDINGS OF SCIENCE

Diffuse astrophysical neutrino flux searches with KM3NeT/ARCA

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An all-flavour search for diffuse astrophysical neutrino fluxes, using data obtained with the first KM3NeT/ARCA configurations, is presented. The KM3NeT research infrastructure includes two neutrino telescopes under construction with one of them, KM3NeT/ARCA, focusing on the detection of high energy neutrinos (>TeV) originated in astrophysical sources. The KM3NeT/ARCA detection units are deployed offshore Capo Passero, Italy at a depth of 3500 m, delivering data as the construction of the detector is ongoing. The two search cases considered here are an all-sky diffuse flux and a flux coming from the Galactic Ridge, namely $|b| < 2^o$ and $|l| < 30^o$, in Galactic coordinates. The event selection is based on machine learning techniques and a bayesian method for the statistical analysis is employed.

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1. Introduction

Astrophysical sources generate high-energy cosmic rays which produce neutrinos through pp and $p\gamma$ interactions. Neutrinos can travel cosmic distances without interacting with interstellar medium, thus carrying information about the physical processes taking place in the source itself. The data-analyses, which aim to identify astrophysical neutrinos, through data collected with neutrino telescopes can be classified in two categories: those originating from known point sources, and those that come from extended regions of the sky, responsible for a diffuse flux. In this contribution, two scenarios are followed. One search is to track the flux coming from the Galactic Ridge, namely $|b| < 2^o$ and $|l| < 30^o$, in Galactic coordinates. The other is an all-sky search which measures the flux coming from a collection of emitters that can not be identified individually.

Signal events come from neutrinos and anti-neutrinos of all 3 flavours (ν_e, ν_μ, ν_τ) and both interaction channels (CC and NC) reconstructed as tracks. The flux in each scenario is assumed to follow an unbroken power-law. Monte Carlo simulations are used to compute the sensitivity of the detector to such neutrino fluxes.

2. KM3NeT Detector & Data taking periods

KM3NeT [1] is a research infrastructure hosting two Cherenkov detectors in the Mediterranean Sea: KM3NeT/ARCA, offshore Capo Passero, Italy at a depth of 3500 meteres, optimized for the detection of high-energy (TeV-PeV) astrophysical neutrinos, and KM3NeT/ORCA, offshore Toulon, France at a depth of 2500 meters, optimized for atmospheric neutrino oscilation studies. Both detectors share the same technology with the main detector element being the Digital Optical Module (DOM) [2]. A DOM is a pressure resistant glass sphere housing 31 3"-PMTs. 18 DOMs anchored at the seafloor with buoyancy at the top form a Detection Unit (DU). KM3NeT follows a staged approach, where data are collected even before the full completion of the detector is reached, using the number of commissioned DUs at the time. When complete, KM3NeT/ARCA wll consist of 2 Bulding Blocks (BB) with 115 DUs each and KM3NeT/ORCA of 1 BB. The two detectors differ in the spacing of their elements (due to their different physics goal). For ARCA the distance between DUs is on average 90 meters with DOMs vertically spaced by 36 meters, while for ORCA the distance between DUs is on average 20 meters with DOMs vertically spaced by 9 meters. Currently, ARCA is operating with 33 DUs.

Since data are collected during the detector construction, data-taking periods are named according to the number of active DUs and are analysed independently. Here, data are presented from the early stages of KM3NeT/ARCA, namely the ARCA6-8-19-21 configurations. ARCA6 ran from May 2021 to September 2021 [102 analyzed days], ARCA8 from September 2021 to June 2022 [212 analyzed days] and ARCA19 from July 2022 to September 2022 [51 analyzed days]. For ARCA21 a portion of the total livetime is used which corresponds to a period from September 2022 to December 2022 [67 analyzed days]. The ARCA21 Monte Carlo simulations are scaled up to the total uptime of the configuration [288 days] to extract an estimate of the expected sensitivity of the detector.

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3. Event selection & BDT

Events reconstructed as up-going tracks are selected (based on the type of the search) using trigger level information and variables indicating the quality of the track reconstruction. A set of cuts regarding the likelihood and length of the reconstructed track as well as on the error of the track parameters is imposed and is common in both searches (referred to as *Common level cuts*) serving as a starting point. Later on additional cuts are applied according to the scenario followed.

A Boosted Decision Tree (BDT) classifier using ROOT TMVA [3] is trained, based on previous iterations of the analysis [4] considering as signal well reconstructed upgoing muon-neutrino CC events and as background badly reconstructed atmospheric muons still constituing the main background source. Similar models are used, one for the ARCA6/ARCA8 configurations and one for the ARCA19/ARCA21. The BDT score distribution for ARCA21 can be seen in Figure 1.

For each configuration an optimal BDT score cut is selected based on the minimization of the Model Rejection Factor (MRF) [5].

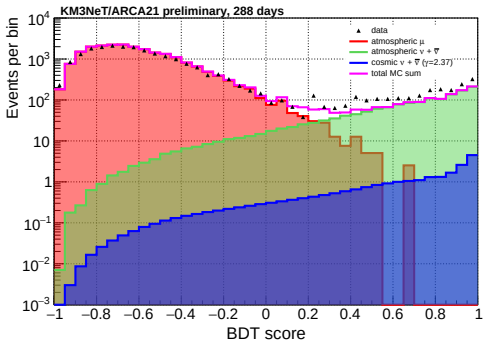

Figure 1: BDT score distribution for ARCA21 period. Data and MC have been upscaled from 67 days to 288 days to give an estimate of the period's full uptime.

The usage of a BDT classifier greatly suppresses the contamination of mis-reconstructed atmospheric muons. When an upgoing selection is made, only (anti)neutrinos can survive passing through the Earth, so any atmospheric muons remaining represent wrongly reconstructed events.

	before BDT	after BDT
atm. $\nu + \bar{\nu}$	~ 1200	~ 960
atm. μ	~ 27000	~ 29
cosmic $\nu + \bar{\nu}$	~ 21	~ 16

Table 1: Number of expected events for each category for the ARCA21 period for an exposure time of approximately 288 days. Numbers and BDT cut refer to the all-sky search selection.

4. Analysis method

4.1 Galactic Ridge Search

The measurement of a possible excess of events coming from the Galactic Ridge (ON zone) is attempted. An ON-OFF zone technique, adopted also in previous ANTARES analyses [6] is

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employed. The search takes place around an extended region with Galactic coordinates $|b| < 2^o$ and $|l| < 30^o$. Background is derived directly from data, using regions where no contribution from the signal is expected. Each event is moved in time in order to avoid Fermi Bubbles and the Galactic Ridge region. This methodology has the advantage of re-using the same events multiple times, reducing the overall final statistical error.

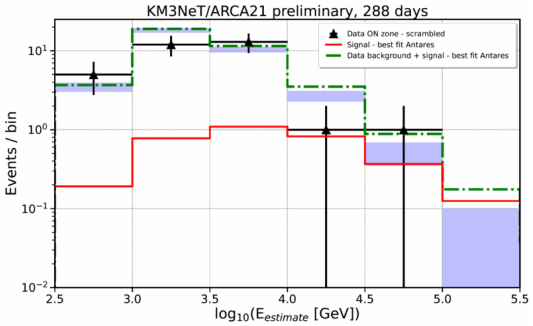

Figure 2: Logarithm of the ARCA21 energy estimate after the Galactic Ridge final event selection.

4.2 All-sky Search

The measurement of a diffuse flux of cosmic neutrinos can provide an insight in resolving the particle acceleration mechanisms at place at distant astrophysical sources. Signal events come from upgoing neutrinos of astrophysical origin of all 3 flavours and both interaction channels (CC and NC) reconstructed as tracks. Atmospheric upgoing neutrinos (Honda [7] & Enberg [8] along with a correction for the presence of the cosmic ray knee) and atmospheric muons represent the physics background. The flux is parameterized with an unbroken power-law and as a baseline, IceCube's reported values [9] ϕ_0 = 1.44 x 10 $^{-18}$GeV^{-1}cm^{-2}s^{-1}sr^{-1} and γ = 2.37. Results will be compared with the values reported by ANTARES' all-flavour search for a diffuse flux with 9 years of data [10].

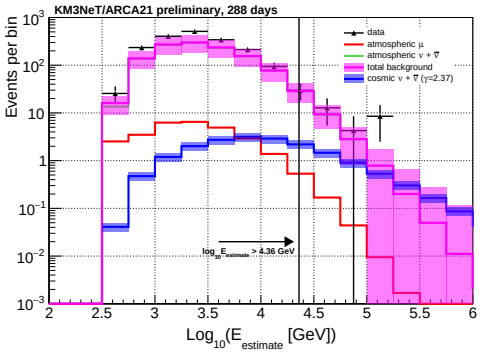

Figure 3: Logarithm of the ARCA21 energy estimate after the All-sky final event selection. The vertical line indicates the optimal energy cut returned by the MRF optimization.

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5. Statistical Analysis

A bayesian statistical analysis, as the one in ref. [6], has been used to derive upper limits, sensitivites and best-fit parameters. The posterior probabilities of the four configurations —ARCA6, ARCA8, ARCA19 and ARCA21— are combined to produce the detector sensitivity to an astrophysical neutrino flux at 90% C.I. as a function of the energy. The computation is performed over energy bins after the final event selection. Statistical and systematic uncertainties are incorporated in the framework through gaussian priors. Systematics include the difference in data and expected atmospheric muon events from MC, the PMTs' efficiency, lights's absorption length in water and the atmospheric (anti)neutrino flux normalization.

The sensitivity is compared with previous results, [11] & [12], and shows the potential of the detector when more livetime will be added. The convolution of sensitivities for a selection of spectral indices is plotted. This has the advantages of taking many flux scenarios into account at the same time. The KM3NeT/ARCA detector is rapidly growing and more data will be collected in the upcoming years, reaching a sensitivity comparable to the ANTARES and IceCube fitted fluxes.

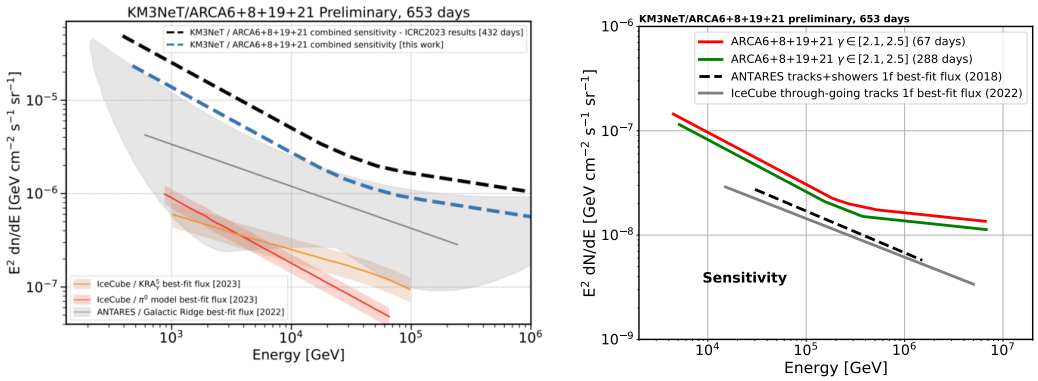

Figure 4: Convolution of sensitivities at 90% C.I. as a function of the energy for selected spectral indices for the Galactic Ridge search **(left)** and the All-sky search **(right)**. Results for the upscaled 288 days of ARCA21 are shown compared to the sensitivities reported at ICRC2023 for an ARCA21 livetime of 67 days -or a total ARCA6-8-19-21 livetime of 432 days. Best fitted fluxes from ANTARES and IceCube are also plotted for reference.

6. Conclusions and outlook

In this contribution the sensitivity for a diffuse astrophysical neutrino flux using the first KM3NeT/ARCA configurations, namely ARCA6-8-19-21, was computed. The sensitivity was computed for different spectral indices, under a single power-law assumption, for both the two regions addressed in this contribution: a flux coming from the Galactic Ridge and an all-sky flux. The analysis is based on previous iterations, where the full livetime of ARCA6-8-19 was used and a part of the ARCA21 period. Here, the Monte Carlo production for the ARCA21 period was scaled up to the final uptime of the ARCA21 configuration providing an estimate of the expected sensitivity. The addition of around 4.5 times more days improves noticeably the detector's performance. The results are compared with ANTARES best fitted flux demonstrating KM3NeT/ARCA's potential.

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