PROCEEDINGS OF SCIENCE

Astronomy potential of KM3NeT/ARCA230

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The KM3NeT/ARCA neutrino detector is currently under construction at the bottom of the Mediterranean Sea. The main science objective is the detection of high-energy cosmic neutrinos and the discovery of their sources. This is achieved by instrumenting a cubic kilometre of seawater with photo-multiplier tubes that detect Cherenkov radiation from neutrino interaction products. In recent years, there have been advancements in the reconstruction algorithms for muon neutrinos, along with the development of techniques for identifying and accurately reconstructing electron and tau neutrinos. This contribution will present the updated prospects for cosmic sources using the track and cascade detection signatures for the full detector.

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1. Introduction

The detection of high-energy neutrinos from TXS 0506+056 and NGC 1068 are the first discoveries of cosmic neutrino sources in our Universe [1, 2]. The KM3NeT/ARCA detector is currently under construction and is optimised for the discovery of cosmic neutrino sources. The detector consists of optical modules that are attached to vertical detection strings. Each string is mounted to the seabed of the Mediterranean sea and houses 18 optical modules. The final detector configuration will consist of two blocks with 115 strings each (KM3NeT/ARCA230).

Statistical methods have been developed to study the sensitivity and discovery potential of KM3NeT/ARCA to point sources and the diffuse cosmic neutrino flux. The KM3NeT collaboration is sharing first analyses with recent data in [citations], but this contribution covers updated sensitivity projections for the full detector using the combination of tracks and showers.

2. Simulation and selection

Neutrino events are generated over the full-sky with energies in the range $10^2 < E_\nu < 10^8$ GeV using the gSeaGen framework [3]. Atmospheric muons are simulated using the MUPAGE software [5]. All events are passed through the KM3NeT light simulation and detector response software packages. The track and shower reconstruction is applied as described in [6].

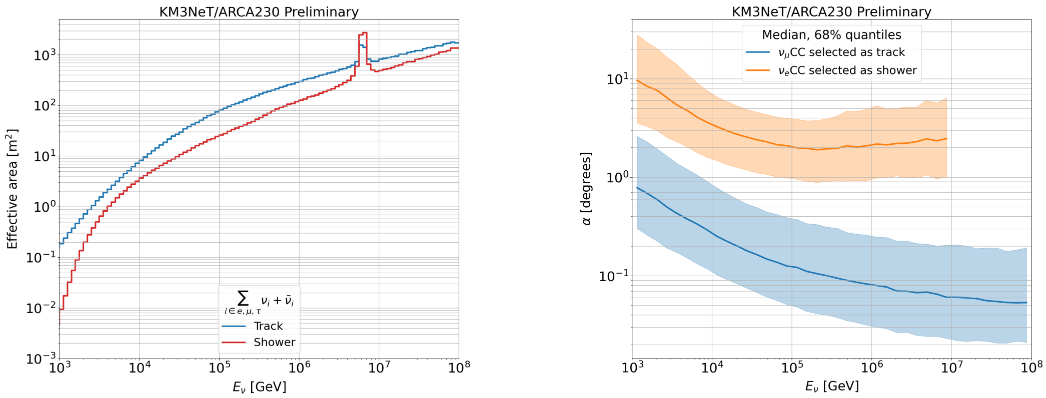
The track selection is optimised to select upgoing muons produced in neutrino interactions. The background from atmospheric muons and noise is rejected using a boosted decision tree model trained on reconstructed quantities like the reconstructed zenith angle and energy, the track length length and the fit quality. The shower selection covers the full-sky and also uses a boosted decision tree model to reject atmospheric muons. Events are selected based on the height of the reconstructed shower vertex using the top layer of optical modules as a veto. The effective area of both selections is given in Figure 1 (a). The angular resolution for ν_μCC which are selected as track and for ν_eCC selected as shower are shown in Figure 1 (b).

The energy resolution is defined as half the difference between the 16th and 84th percentiles of the energy bias distributions where

$$\text{Energy bias} = 100\% \cdot \left(\frac{E_{rec}}{E_{visible}} - 1 \right). \tag{1}$$

The energy resolution is shown in Figure 2.

The detector simulations are stored in detector response functions containing the effective area, angular resolution and energy response for different flavours, interactions and observation channels. These functions are input to the analysis described in the next section. This contribution extends the track analysis [4] with the shower channel and uses updated Monte Carlo simulations.



(a) **(b)**

Figure 1: Effective area (a) for the track and shower channel. The effective area contains the sum of interactions from ν_e, ν_μ, ν_τ and averaged over $\nu, \bar{\nu}$. The angular resolution (b) for ν_μCC selected as track and for ν_eCC selected as shower.

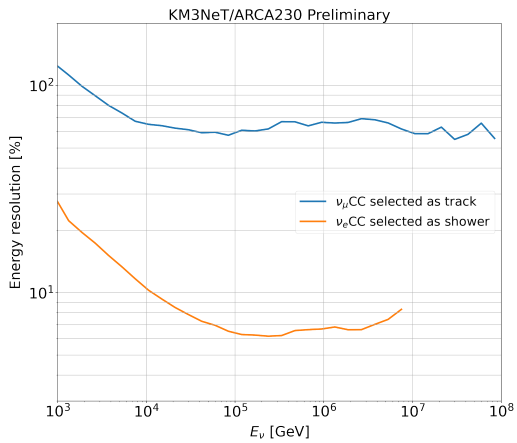
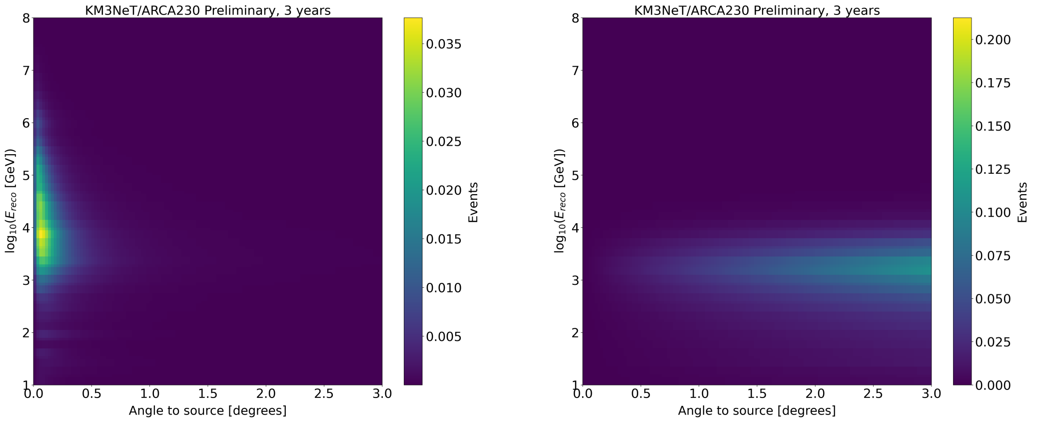


Figure 2: Energy resolution of ν_μCC for the track selection (a) and ν_eCC for the shower selection (b).

3. Method

The detector response functions are used to create expected distributions for signal and background for different flux models and observation times. The flux models are characterised by different spectral indices for point sources while the IceCube spectral index of [7] is adopted for the diffuse analysis. The flux models are convoluted with the effective area and detector response to obtain two-dimensional distributions for expected signal (S_i) and background (B_i). An arbitrary flux normalisation is scaled with a varying signal strength (μ) to study the sensitivity and discovery potential of KM3NeT/ARCA230.

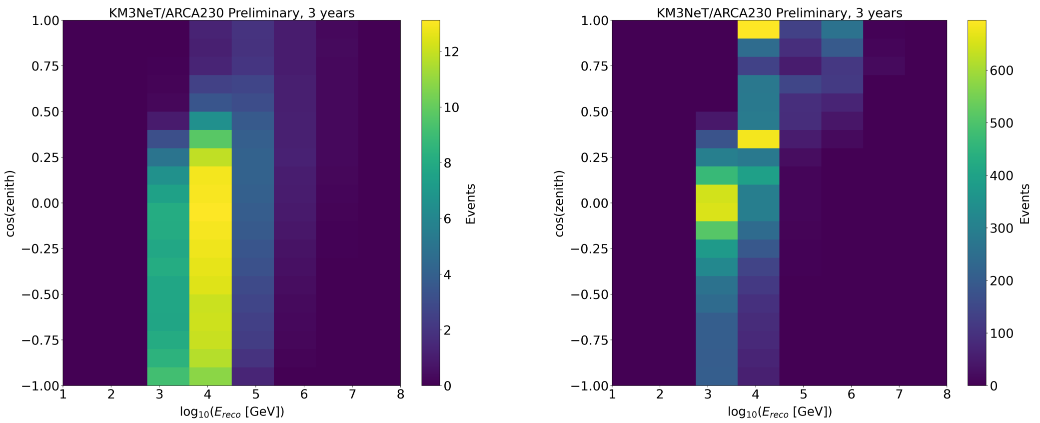
The expected event rate distributions for the point source analysis have bins in reconstructed energy and distance to source in degrees. An example distribution of signal and background events is shown in Figure 3. Both distributions are shown for events selected as tracks with a source at sin(declination) = 0.1, a spectral index γ = 2 and 3 years of KM3NeT/ARCA230 operation.



(a) **(b)**

Figure 3: Expected signal (a) and background (b) distributions for events selected as track for the point source analysis. The distributions were obtained for a source at sin(declination) = 0.1, spectral index γ = 2 and 3 years of KM3NeT/ARCA230 operation.

The diffuse analysis uses two-dimensional distributions with bins in reconstructed energy and zenith. The corresponding signal and background distributions for events selected as showers are shown in Figure 4. Both distributions are obtained for 3 years of KM3NeT/ARCA230 operation.



(a) **(b)**

Figure 4: Expected signal (a) and background (b) distributions for events selected as shower for the diffuse flux analysis. The distributions were obtained for 3 years of KM3NeT/ARCA230 operation.

Based on these expected signal and background distributions, pseudo experiments using Poissonian statistics are made where the expectation value is defined as

$$E(N_i) = B_i + \mu S_i. \tag{2}$$

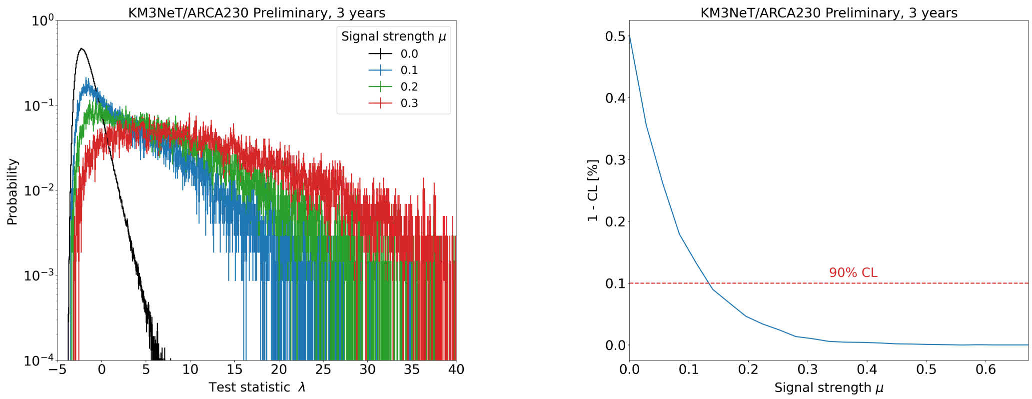
The signal strength (μ) is varied to obtain test statistic distributions for the statistical analysis. The definition of the likelihood for a pseudo dataset is

$$\log L = \sum_{i \in \text{bins}} N_i \log(B_i + \mu S_i) - B_i - \mu S_i \tag{3}$$

and the test statistic (λ) is a likelihood ratio defined as

$$\lambda = \log L(\mu = \hat{\mu}) - \log L(\mu = 0). \tag{4}$$

The test statistic distributions are used to calculate the confidence level and p-values. An example of the test statistic and confidence level for the point source analysis is shown in Figure 5.



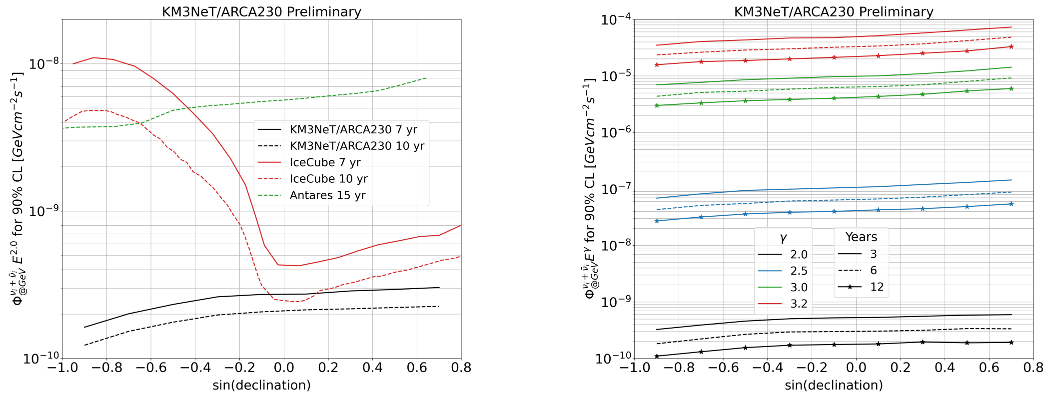
(a) **(b)**

Figure 5: Test statistic distribution (a) of the point source analysis for various signal strengths for a source at sin(declination) = 0.1 and 3 years of KM3NeT/ARCA230 operation. The corresponding confidence levels and the 90% confidence level (b).

4. Results

4.1 Point sources

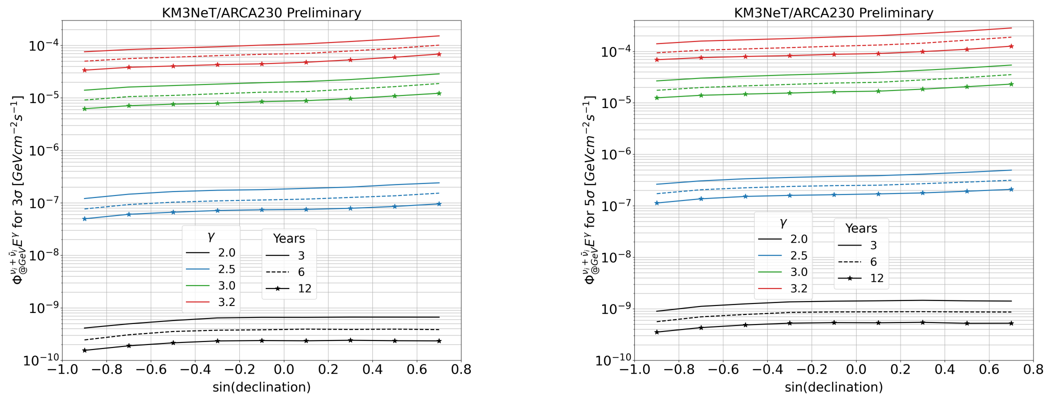
The point source sensitivity for different spectral indices is given in Figure 6. For a spectral index of $\gamma = 2$ the KM3NeT/ARCA230 sensitivity is compared with the corresponding sensitivity of 15 years of Antares [8] and 7 years of IceCube [9].



(a) **(b)**

Figure 6: Point source sensitivity for $\gamma = 2$ (a) and other spectral indices (b). The $\gamma = 2$ results are compared with 15 years of Antares and 7 years of IceCube [8, 9].

The discovery flux for point sources is given in Figure 7 with different spectral indices.



(a) **(b)**

Figure 7: Point source discovery flux for different spectral indices. The 3σ discovery flux is given in (a) and the 5σ is given in (b).

4.2 NGC 1068

The discovery potential for NGC 1068 was studied and is shown in Figure 8. A 5σ discovery can be claimed after 3 years of full KM3NeT/ARCA operation. The power law flux with $\gamma = 3.2$ was extended over the full energy range.

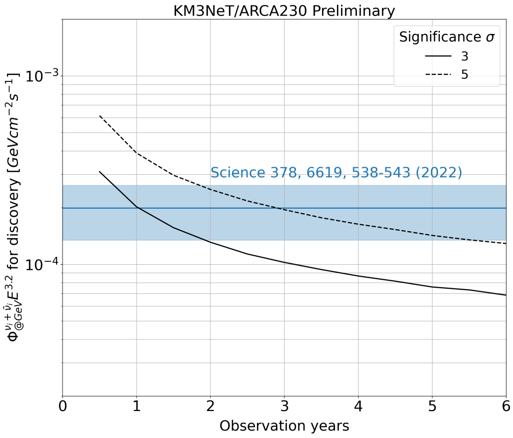


Figure 8: Discovery flux of KM3NeT/ARCA230 for NGC 1068 assuming a spectral index $\gamma = 3.2$ as reported by IceCube [2]. The blue lines represent the fitted flux normalisation of IceCube including statistical and systematic uncertainties.

4.3 Diffuse flux

The 3 and 5 σ discovery flux for KM3NeT/ARCA230 is shown in Figure 9 for a diffuse neutrino flux with $\gamma = 2.37$ as reported by IceCube [7]. The fitted flux normalisation of IceCube can be discovered with 5 σ within a half year of full KM3NeT/ARCA operation.

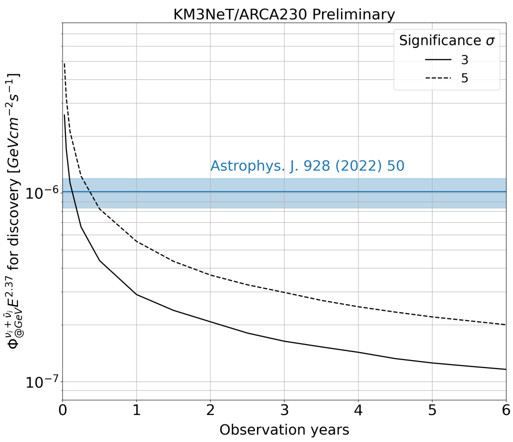


Figure 9: Discovery flux of KM3NeT/ARCA230 for the diffuse neutrino flux with spectral index $\gamma = 2.37$ as reported by IceCube [7]. The blue lines represent the fitted flux normalisation of IceCube including statistical and systematic uncertainties.

5. Conclusions

The KM3NeT/ARCA detector is currently under construction and is already contributing to neutrino and multi messenger astronomy. The full detector will be competitive in discovering point sources and will be able to detect the diffuse and NGC 1068 neutrino fluxes within respectively 3 and 0.5 years. Improvements in the shower reconstruction described in [6] will bring up to 10% improvement in the discovery potential of point sources and for the diffuse neutrino flux. Systematic uncertainties in the absorption and scattering length of water (±10%) and the effective area of an optical module (±10%) influence the results with < 10%.

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