KM3NeT/ARCA Sensitivity to Starburst Galaxies

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Abstract. In this work, the expectations of the full detector KM3NeT/ARCA are presented for particular starburst galaxies signals. For the point-like search approach, we considered the most promising local starburst galaxies to be observed as point-like neutrino excesses: NGC 1068, the Small Magellanic Cloud and the Circinus Galaxy. In both cases, we provide the energy-integrated sensitivity for two ARCA building blocks in the energy range 100 GeV − 10 PeV. In the diffuse scenario, both track and shower events were considered. For the point like analysis, only ν_μ charge current events were taken into account. Interestingly, ARCA has the potential to constrain the selected phenomenological scenarios, providing evidence of the link between star-forming processes and hadronic emissions.

1 Introduction

The KM3NeT/ARCA telescope is an under water Cherenkov telescope under construction in the Mediterranean sea [1]. The telescope is composed of two different detectors: ORCA and ARCA. Being sensitivity to low energy neutrinos, ORCA is devoted to neutrino physics studies. ARCA is devoted to high-energy neutrino astronomy, being sensitive to neutrinos above $\sim 10^2$ GeV. In this contribution the integrated sensitivity of ARCA to constrain high-energy neutrinos from Starburst Galaxies is obtained, using a cut count approach. Both a diffuse and a point-like analysis is presented. From the point-like side, the most promising point-like sources were considered. In particular: NGC 1068, since IceCube has found strong evidence for its neutrino emissions [2], and also the Small Magellanic Cloud (SMC) and Circinus since [3] has found that ARCA could possibly see evidence of the star forming activity occuring in their cores. For the diffuse study, the spectra of [4] were considered. This model implemented a blending of spectral indices to exploit the variability of this parameter along the source class. This paper is organised as follows: in Sec. 2, the sensitivity calculation and the diffuse analysis are discussed; in Sec. 3 the sensitivities for the point-like search are presented. Finally, in Sec. 4 the discussion and the conclusions are reported.

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2 Sensitivity Calculation and Diffuse Analysis

The Feldman and Cousins method was used to evaluate of the 90% C.L. upper limits, for further details see [5]. The sensitivity is defined as $\Phi_{90} = (\bar{\mu}_{90}/n_s)\Phi_\nu$, where $\bar{\mu}_{90}$ is the average upper limit, n_s the signal events predicted by the signal neutrino flux Φ_ν. $\bar{\mu}_{90}/n_s$ is defined as the Model Rejection Factor (MRF). For the diffuse analysis, the energy range [100 GeV – 10 PeV] was considered. For the background, atmospheric muons were simulated with MUPAGE ([6]) and gSeaGen([7]) was used for the atmospheric neutrinos. The spectrum provided by [4] was used for the signal which represents the expected neutrino diffuse signal of SBGs. In order to reject background and minimize the sensitivity, dedicated track-like and cascade-like event selections were performed. For the **track-like** events, only upgoing events were selected: $\theta < 100°$, where θ is the Zenith angle of the reconstruction event. To reject poorly reconstructed tracks, additional criteria were applied: $\beta_0 < 1$ deg, where β_0 is the error on the reconstructed angle; Len > 300 m, where Len is the reconstructed track-length; $\mathrm{Len}/\mathrm{n_{hits}} > 0.7$, where n_{hits} is the number of hits. In order to select the good track up-going events and reject atmospheric muons, a boosted decision tree (BDT) was implemented. The BDT training was based in the main reconstructed variables (e.g. Len, β_0, n_{hits}), using the KM3NeT/ARCA115 Monte Carlo simulated events (atmospheric muons and neutrinos). For the final event selection, BDT score conditions were used: for $80° < \theta < 100°$, $BDT_{score} > 0.9$ - for $\theta < 80$ deg, $BDT_{score} > 0.4$. For the **cascade-like** event selection, several conditions were applied: the events containment required to be inside the effective volume of the detector ($R_{det} < 600, Z_{det<650}$) , short events length (Len<300 meters) and the selection on quality reconstruction variables ($n_{\mathrm{hits}} > 450, L < -500$). In addition, A BDT trained and optimized for cascade events (BDT_{casc}) was applied. Regarding the direction of the events, a selection of BDT scores was applied:
• $cos(\theta) > 0.6$: $BDT_{casc} > -1.1$
• $0.2 < cos(\theta) < 0.6$: $BDT_{casc} > -0.9$
• $-0.2 < cos(\theta) < 0.2$: $BDT_{casc} > -0.8$
• $-0.6 < cos(\theta) < -0.2$: $BDT_{casc} > 0.8$
• $cos(\theta) < -0.6$: $BDT_{casc} > 1.1$
Fig. 1 summarizes the results. The computed sensitivity is compared with two different SBG scenarios: on the left the expected signal was calculated considering HESE (IceCube) and Fermi-LAT EGB, and on the right using CASCADE (IceCube) and Fermi- LAT EGB (see [4] for furher details). The sensitivity is shown in the range where 90% of the signal is concentrated. The comparison with the theoretical expectations shows that ARCA is sensitive for such a spectrum and in few years of data taking it will put several constrain on such a scenario.

3 Point-Like Analysis

For the point-like analysis, only ν_μ and $\bar{\nu}_\mu$ in charged current interactions (track-like events) were considered. The Monte Carlo simulations events were the same as for the diffuse analysis for the background events. The dedicated simulation events for the signal were generated using the gSeaGen code [7]. Circinus and NGC 1068 were simulated as point-like sources, while SMC was considered as a 0.5° extended source, compatible with the emissions coming from its nucleus [3]. In order to evaluate the sensitivity, a binned search was employed to evaluate the number of events through the region of interest (RoI). Therefore, α (the angular distance between the position of the source and the coordinates of the reconstructed track) is used to minimize the MRF. For the signal, only events in the RoI were taken into account. For the background, the whole corresponding declination band is considered and then rescaled

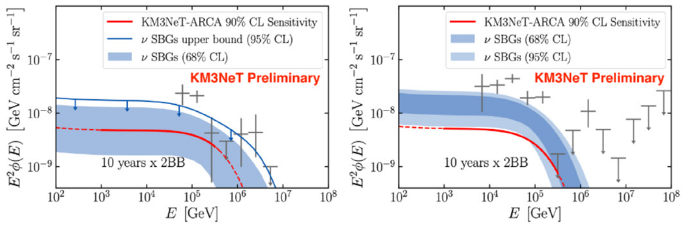

Figure 1. Left The 90% C.L. sensitivity (red curve) is compared with the corresponding theoretical 1σ uncertainty band of the SBG spectral energy distribution according to the analysis of [4]. This band has been obtained by fitting the Fermi-LAT EGB and the IceCube HESE data. the IceCube HESE measurements [8] are also shown for reference. **Right** The sensitivity is compared with the corresponding theoretical $1-2\sigma$ uncertainty band of the SBG spectral energy distribution according to the analysis of [4], considering EGB Fermi-lat and (6-year) of IceCube CASCADE samples. The IceCube cascades measurements ([9]) are shown for reference.

to be consistent with the width of the RoI. The rescaling factor is $\alpha/4 = \Omega_{\text{RoI}}/\Omega_{db}$, where $\Omega_{\text{RoI}} \simeq \pi\alpha^2$ and $\Omega_{\text{db}} \simeq 2\pi 2\alpha$. Finally, the MRF is minimized as a function of several parameters in order to obtain the optimized value for the sensitivity. Figs. 2-4 report the results for the three sources analyzed.

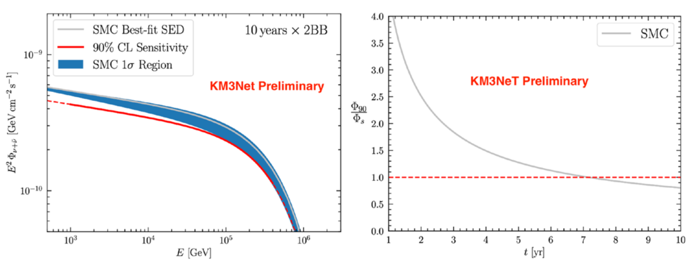

Figure 2. Left sensitivity compared with the theoretical 1 σ uncertainty band of the source (according to the analysis of [3]). **Right** Sensitivity as a function of time. The detector will be able to put strict constraints after 7 years of data taking.

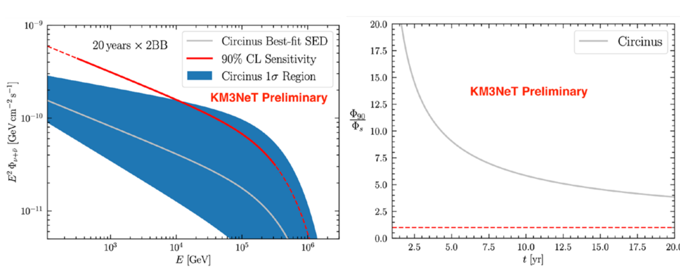

Figure 3. Left The integrated sensitivity compared with the theoretical 1 σ uncertainty band of the source (according to the analysis of [3]). The plot refers to 20 years of data taking for 2 Building Blocks. **Right** The ARCA sensitivity as a function of time. The detector is not able to discriminate the SBG scenario in the best-fit scenario. It can trace the upper limit of the expected emission.

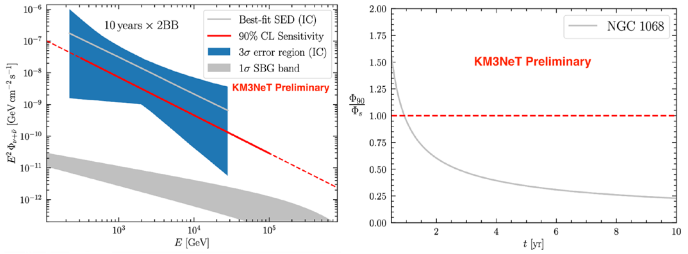

Figure 4. Left The sensitivity compared with the theoretical 1σ uncertainty band of the source (according to the analysis of [3]) as well as IceCube error region [2]. **Right** The ARCA sensitivity as a function of time. The detector will be able in 1 year to constrain the scenario inferred by IceCube.

In particular, the left panels of figures 2-4 show the sensitivity compared with the spectrum after 10 years (20) of data taking of 2 ARCA building blocks for SMC and NGC 1068 (Circinus). The right panel shows the obtained MRF scaling with time in the best-fit scenario. In each case, the results show that in few-years ARCA will be able to test these hadronic scenario posing strict constraints on the hadronic budget of Starburst Galaxies.

4 Conclusions

All the results point to the conclusion that KM3NeT/ARCA will be fundamental not only to unveil the origin of the astrophysical neutrino spectra, but also, it is going to test if the star forming activity can be traced by neutrino production. This will be an invaluable step forward for neutrino astronomy.

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