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Search for a diffuse flux of cosmic neutrinos with the ANTARES neutrino telescope

L.A. Fusco[a,*] on behalf of the ANTARES Collaboration
(a complete list of authors can be found at the end of the proceedings)

[a] *Aix Marseille Univ, CNRS/IN2P3, CPPM, Marseille, France*
E-mail: fusco@cppm.in2p3.fr

The previous analysis of the ANTARES all-flavour 12-year neutrino data sample provided the observation of an excess of events, at the highest energies, above the expected atmospheric foregrounds. This excess, even though mild (1.8σ), has been found to be consistent in spectral slope and normalisation with the high-energy diffuse cosmic neutrino signal detected by the IceCube Neutrino Observatory. Even though the smaller detector size does not provide sufficient statistics to claim an independent discovery, the analysis of ANTARES data can provide valuable information in the study of the high-energy neutrino signal, in particular for what concerns the details of its energy distribution in the case of soft-spectra solutions. To improve the previous ANTARES results, a new event selection has been developed for cascade-like events, relying on a Boosted Decision Tree multivariate-analysis technique. This increased the event statistics in this channel by a factor of 5, while also dramatically reducing the surviving foregrounds and the related systematic uncertainties. This contribution will report on the status of the analysis and the prospects emerging from the use of this new event sample in the search for a diffuse flux of cosmic neutrinos.

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[*] Presenter

1. Executive summary

The ANTARES under-sea neutrino telescope aims at detecting cosmic neutrinos beyond the TeV energy scale. High-energy cosmic neutrinos produced in the decay chains of short-lived particles induced by the primary cosmic ray interactions within or around their sources, or as they travel through the Universe, can reach the detector and produce a detectable Cherenkov signal. Unresolved individual sources, too faint to be detected, cosmic ray propagation effects, or both, can generate a diffuse flux of cosmic neutrinos. Such a flux as been detected by the IceCube Collaboration and can be described with a single unbroken power-law $d\Phi/dE \propto E^{-Gamma}$.

A non-significant observation of this flux has been obtained in the past with ANTARES data. In order to improve the previous results a new event selection chain developed for the measurement of the atmospheric neutrino energy spectrum, which largely boosts the event statistics and allows for a reduction of systematic uncertainties related to the atmospheric foregrounds estimation, can be exploited. This new approach takes advantage of multivariate analysis techniques to reject more efficiently atmospheric muon events, while still producing a larger sample of neutrinos passing the event selection.

Previous ANTARES results were based on one-dimensional binned methods, where the estimated energy distributions of the events that survived the pre-selection had been fitted by means of a binned maximum likelihood method. An unbinned maximum likelihood approach has been investigated, which also now uses two-dimensional information in the estimated energy and zenithal direction of events.

Applying the unbinned method on pseudo-data sets a significant boost in sensitivity is obtained for the cascade sample. Since this updated sample is more sensitive at lower energies with respect to any previous search, this new ANTARES analysis expands the sensitivity energy range down to the TeV range for the first time in searches for diffuse fluxes of cosmic neutrinos. Thus, this new analysis would allow testing for the first time if also a break in the spectrum is present below 10 TeV. The study of the low-energy regime of the diffuse cosmic flux is crucial because it would allow understanding whether energy spectra that are too soft would overshoot the γ-neutrino correlation when considering the diffuse extra-galactic photons. Also, softer spectra might be tracing local features of the overall flux.

This search has made use, so far, of detailed Monte Carlo simulations only. The next step is foreseen to happen soon and will involve analysing the real data-set collected by ANTARES between 2007 and 2020. The results presented in this contribution show that, even though an ANTARES study of the cosmic neutrino component in the diffuse neutrino flux would be marginally significant, it would still provide interesting insights in the study of this cosmic flux that is still largely unknown, also in the case of a non-observation.