Constraints on the diffuse cosmic neutrino flux from the ANTARES neutrino telescope

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Introduction

The neutrino sample collected with the ANTARES neutrino telescope in the 15 years from 2007 to 2022 has been analysed to study the diffuse flux of cosmic neutrinos, searching for an excess of high-energy events. Upward-going all-flavour neutrino interactions collected over 4541 days of effective livetime are selected and classified according to three topologies:

Tracks. Muons from ν_μ-CC interactions are selected on the basis of the track reconstruction quality.
3392 neutrino events are selected, 99% of which are expected to be originating from cosmic rays interactions in the atmosphere, and $\sim 1\%$ of which should be of cosmic origin. The contamination from atmospheric muons is below 0.3%.

Showers. High-energy (TeV and above) showers from all-flavour neutrino interactions contained in a fiducial volume around the apparatus are selected.
187 events are observed, more than 95% of which are neutrino-induced, $\sim 8\%$ of cosmic origin.

Low-energy showers. Low-energy (below a few TeV) showers are selected using a boosted decision tree.
219 events pass this selection, and at least 99% of these events are neutrino-induced. About 2.5% of them should be of cosmic origin.

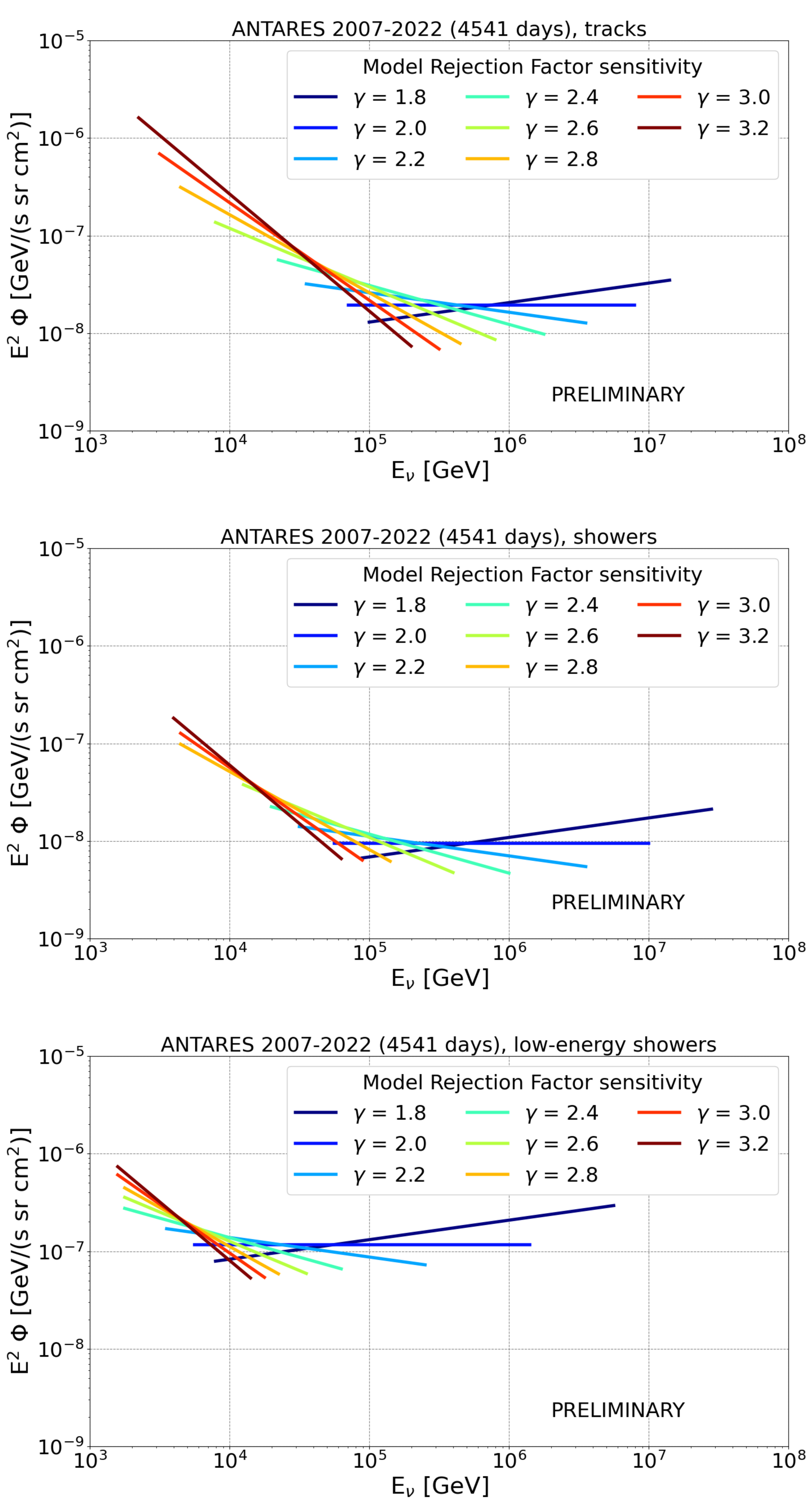

Figure 1: Sensitivity of the three analysed event samples to a diffuse flux of cosmic neutrinos following a power-law spectrum $\frac{\Phi^{1f}_{astro}(E_\nu)}{C_0} = \phi_{astro} \times \left(\frac{E_\nu}{E_0}\right)^{-\gamma}$, computed with the Model Rejection Factor procedure [1].

Results

No excess of high-energy events is observed in neither of the three samples.

The distributions of the energy estimator are shown in figure 2 for the three event samples, comparing data and Monte Carlo simulations.

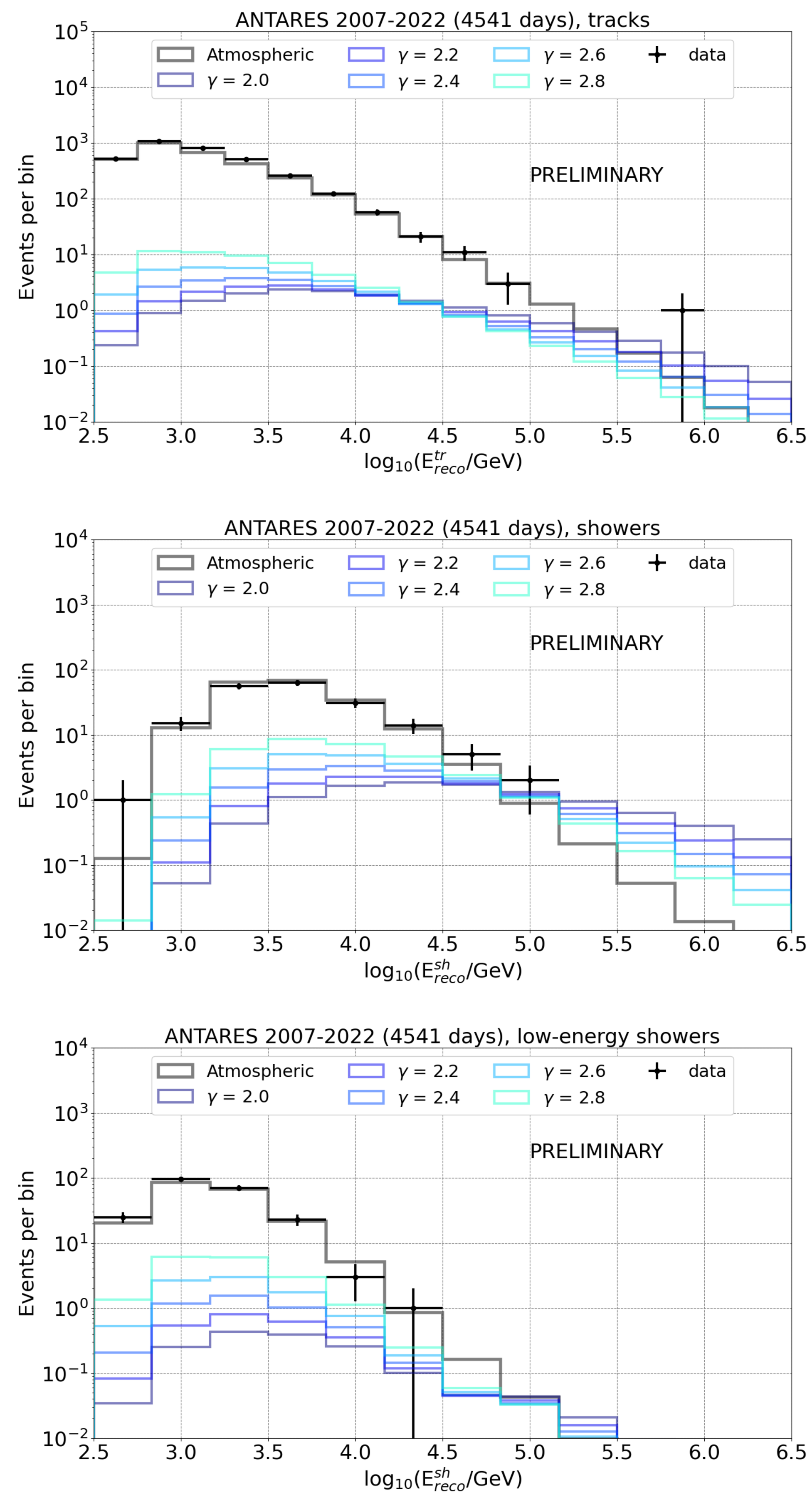

Figure 2: Energy estimator distribution for the selected events in data (black crosses) compared to simulations for atmospheric neutrinos (grey) and cosmic neutrinos (blue lines, for different spectral indexes γ).

The binned distributions of the energy estimators, from each event sample, are compared to a template of the atmospheric neutrino flux and to power-law templates describing the diffuse cosmic flux. The same statistical method used in the search for neutrinos from the Galactic Ridge is used [2]. Bayesian posterior probabilities are computed in the (ϕ_0, γ) space, including systematic uncertainties on the signal and background estimations. Limits on the single power-law hypothesis are extracted profiling the posterior probability for fixed values of γ. The 95% probability limits are shown in figure 3.

Given the good sensitivity of ANTARES in the 10-50 TeV energy range, the hypothesis of a sharp cut-off in the energy spectrum at low energies is studied, mofifying the cosmic signal templates with a step function at an energy E^{cut}. The resulting contours in the (ϕ_0, γ) space for 95% posterior probability are shown in figure 4.

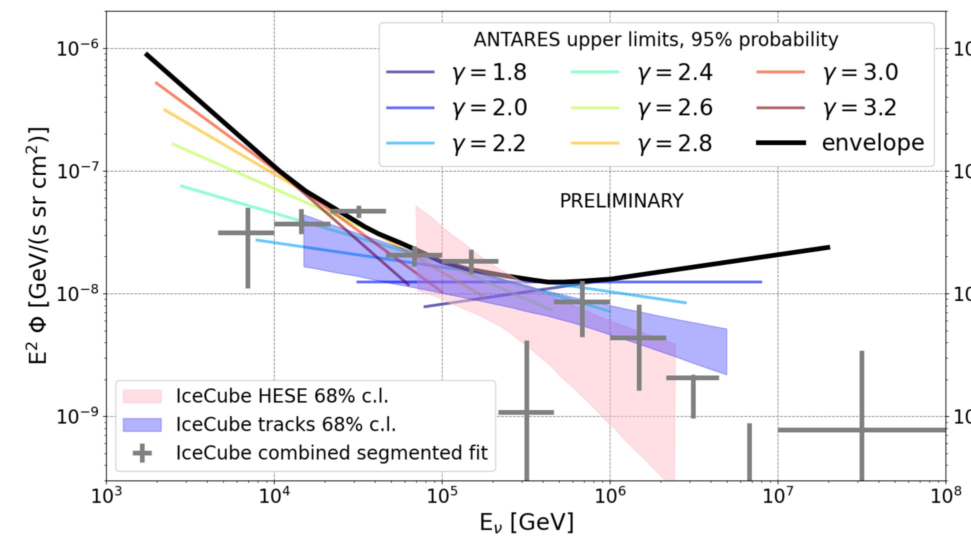

Figure 3: Limits on the single power-law spectrum for different spectral indexes γ, compared to different measurements from the IceCube Collaboration (HESE [3], tracks [4], segmented fit of the combined samples [5]).

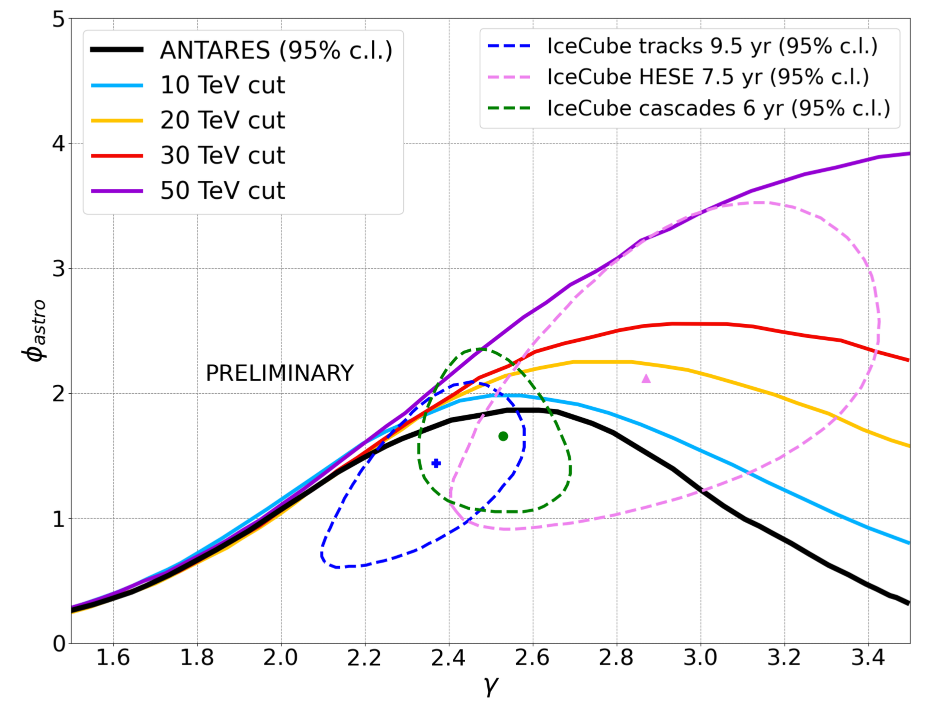

Figure 4: Contours at 95% posterior probability in the (ϕ_0, γ) space for a simple power law (black line) or with a low-energy cut-off (different E^{cut} as in the legend), compared with the 95% confidence level contours from IceCube measurements [3, 4, 6].

Summary and conclusions

No excess of events has been observed at high energy in the 15-year ANTARES data. The observations are compatible with the assumed atmospheric neutrino fluxes. Taking advantage of the large neutrino detection efficiency of ANTARES below 50 TeV, the hypothesis of a low-energy spectral break in the simple power-law energy spectrum assumption has been investigated. A power-law extension of the IceCube HESE best-fit below 10 TeV is excluded with a 99.7% Bayesian posterior probability. Such soft-spectra solutions become admissible within the 95% posterior probability only if a hard cut-off is present at least somewhere in the 10–20 TeV region.

References

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