Constraints on the diffuse neutrino flux with ANTARES

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Outline

1. Diffuse neutrino fluxes
2. The ANTARES analysis
3. Constraints on the spectral properties

A.Albert et al. JCAP08(2024)038

Diffuse fluxes

- The ensemble of all sources which are too faint to be detected individually produces a diffuse neutrino signal
- We know it comes from high-energy CRs interacting somewhere in the Universe
- It should follow the same spectral behaviour of the parent cosmic rays

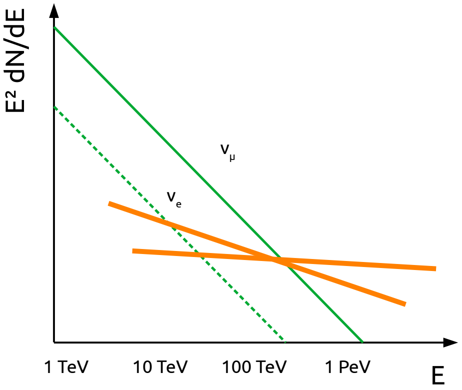
$$\frac{\Phi^{1f}_{\mathrm{astro}}(E_\nu)}{C_0} = \phi_{\mathrm{astro}} \times \left(\frac{E_\nu}{E_0}\right)^{-\gamma}$$

with $2 \lesssim \gamma \lesssim 3$

Diffuse flux searches

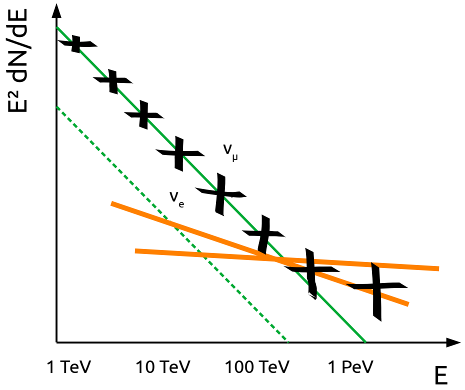
- Atmospheric neutrinos produced by CR interactions in the atmosphere
- Cosmic flux directly from CR sources
  - Soft spectrum for atmospheric neutrinos
  - Harder spectrum for cosmic neutrinos
    $\Rightarrow$ Search for high-energy excess

Conventional flux, neutrinos from pion and Kaon decays
+ **some cosmic flux**

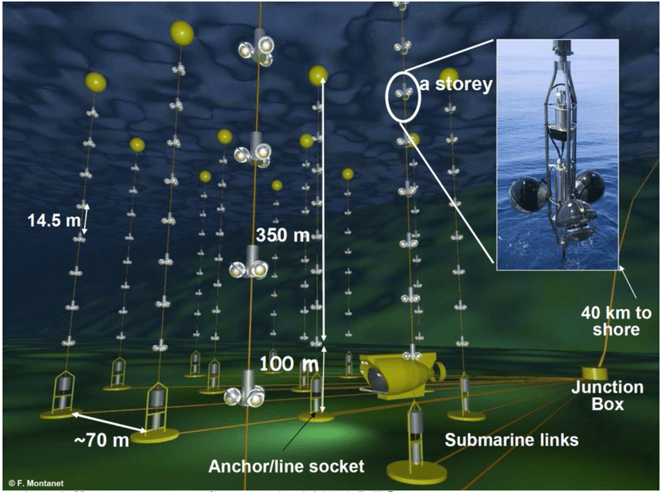


Diffuse flux searches

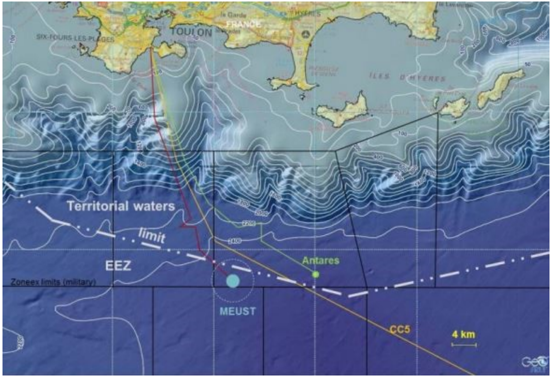
- Data will follow the atmospheric flux at low energies and the cosmic one at high energy
- From the energy distribution, extract the cosmic flux parameters



ANTARES (2007 – 2022)



ANTARES (2007 – 2022)



- 40 km off-shore Toulon, France
- 2.5 km of depth
- 0.01 km^3 of instrumented volume

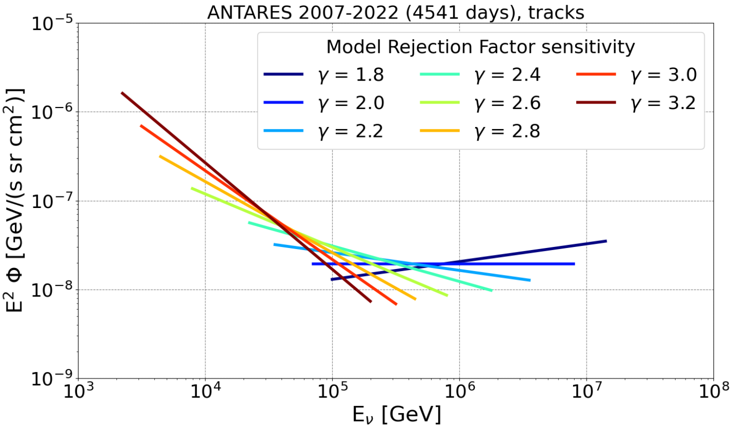
ANTARES data samples

- "Legacy" ANTARES data sample from 2007–2022
- 4541 days of equivalent livetime
- All-flavour neutrinos
  - Track events: mainly ν_μ CC interactions
  - Shower events: all flavour ν_x NC and ν_e CC
  - Low-energy shower events: additional TeV showers to boost sensitivity to soft signals

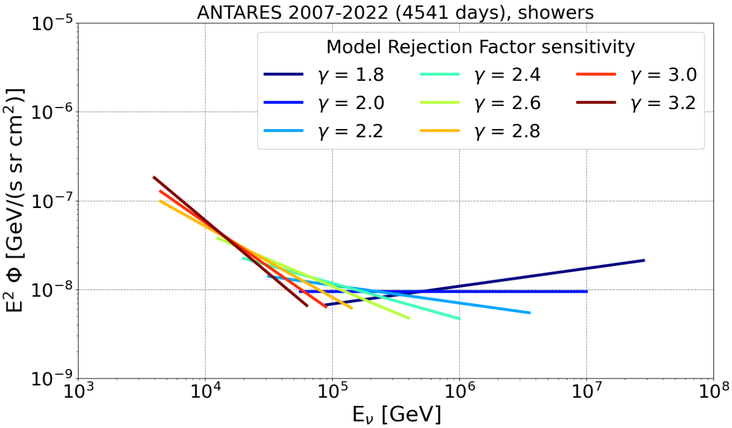
Sample sensitivities

- Sensitivities have been computed for a cut-and-count analysis in each sample
- Tested varying the signal spectral index from 1.8 to 3.2
- Sensitivity energy range defined as where 90% of signal events are expected
- Blind analysis optimised on Monte Carlo simulations

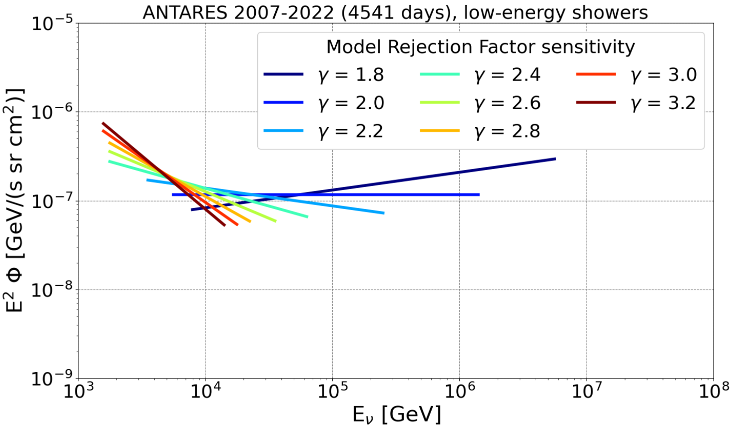
Sample sensitivities



Sample sensitivities



Sample sensitivities



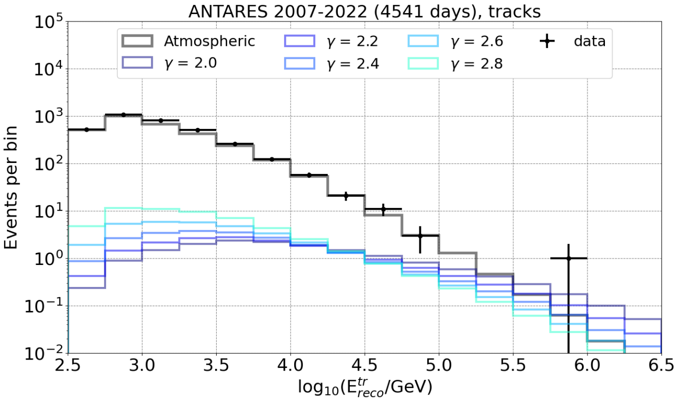
Unblinding results

Looking at data:

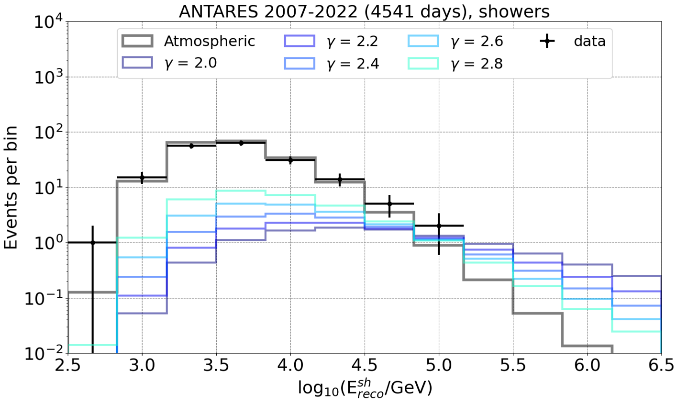
- No significant excess of high-energy events is found
- Constraints on the neutrino flux properties are extracted

Note: in the previous analysis, a mild excess (2σ) was observed. New event selection leads to a more pure neutrino sample which is more robust against systematics

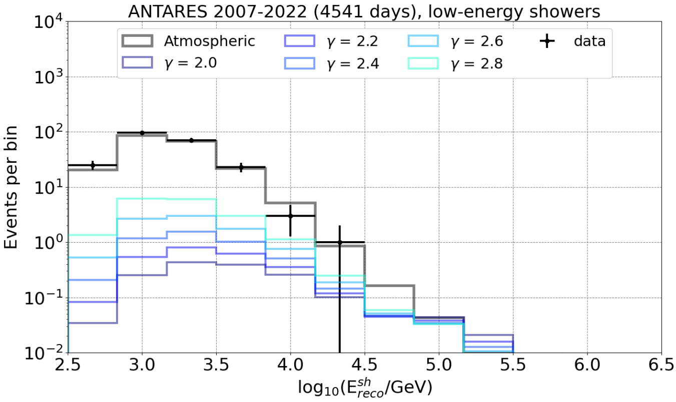
Reconstructed energy distributions



Reconstructed energy distributions



Reconstructed energy distributions

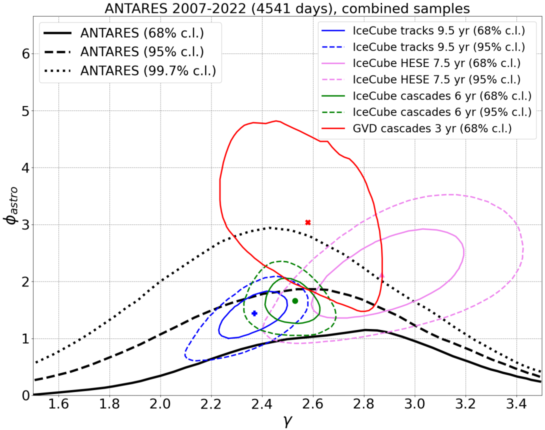


Constraining the cosmic spectrum

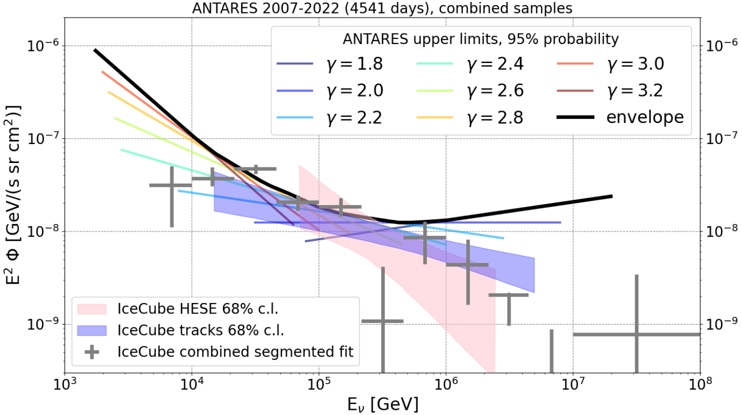
- Binned reconstructed energy distributions used to estimate normalisation-spectral index of the signal+background
- Bayesian analysis
- Systematic uncertainties on the flux and on the detector efficiencies included

Constraints on spectral properties

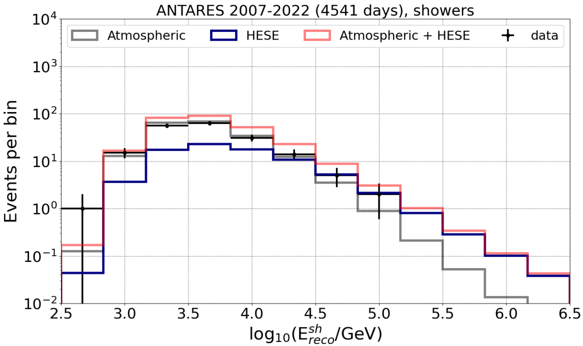
$$\frac{\Phi^{1f}_{\mathrm{astro}}(E_\nu)}{C_0} = \phi_{\mathrm{astro}} \times \left(\frac{E_\nu}{E_0}\right)^{-\gamma}$$



Upper limits



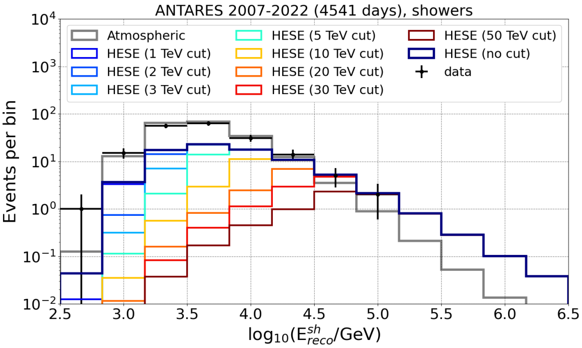
Where is the sensitivity coming from?



ANTARES showers compared to:

- Atmospheric neutrinos
- IceCube HESE best fit expectations
- Sum of the two

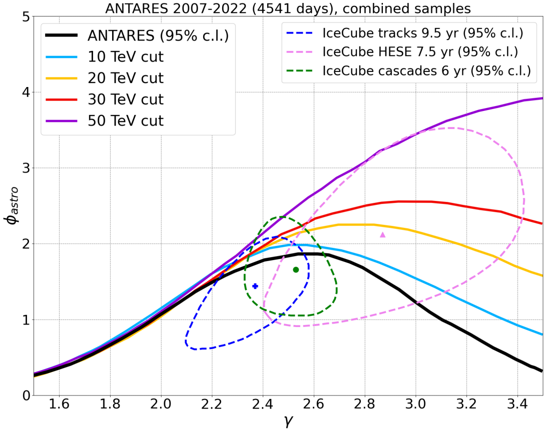
Where is the sensitivity coming from?



ANTARES showers compared to:

- Atmospheric neutrinos
- IceCube HESE best fit expectations assuming a sharp cut below different neutrino energies

Constraints on low-energy spectral cut-offs



The highest-energy ANTARES events

Three remarkable events are found, with "signalness" of about 2/3

Event name	Type	E_ν [TeV]	E_ν 68% range [TeV]	T [MJD]	$(\delta,\ RA)$ [deg]	β [deg]	s
Eärendil	track	700	[240, 2300]	58813.9136016	(-21.9, 156.4)	0.3	0.66
Beren	shower	110	[80, 210]	55562.2854789	(-82.3, 246.7)	0.5	0.69
Luthien	shower	95	[70, 180]	56473.3361997	(-12.8, 191.0)	2.0	0.66

- Angular uncertainty β from the event reconstruction
- Most-probable neutrino energies estimated from Monte Carlo simulations of analogous events
- No obvious source candidate found in astronomical catalogues

Conclusions

- ANTARES has concluded its long and successfull operation
- The “legacy” data is currently being analysed
  - **Constraints on the properties of the diffuse neutrino flux**
  - Many other analyses are being finalised
- Looking at the future: combination of ANTARES data with KM3NeT is already in progress