Searches for diffuse fluxes of cosmic neutrinos with the ANTARES telescope

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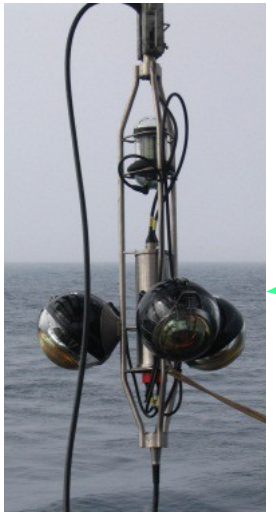
On behalf of the ANTARES Collaboration

Overview

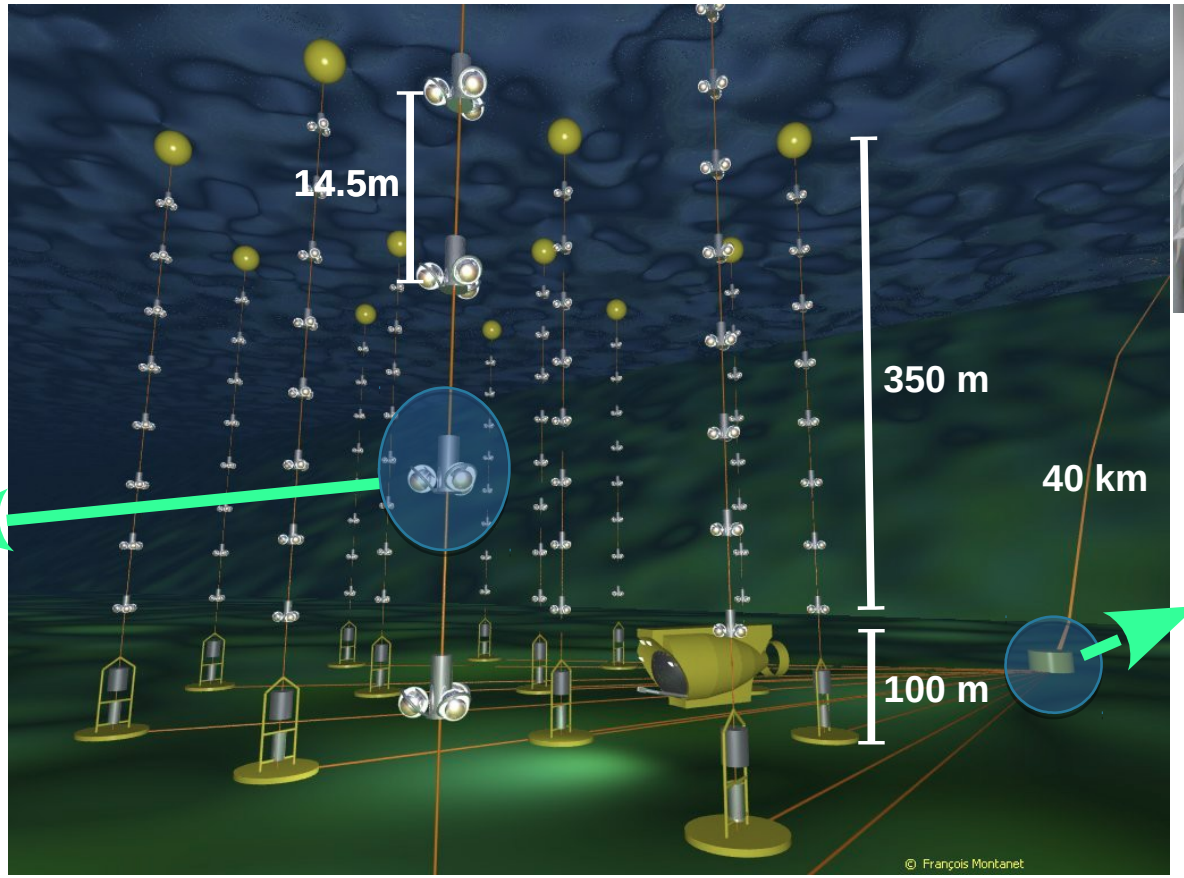
- The ANTARES neutrino telescope
- Full sky searches
  - Muon channel
  - Cascade channel
  - The atmospheric ν background
- Special regions
  - Fermi Bubbles
  - Galactic plane
- Future plans

The ANTARES detector

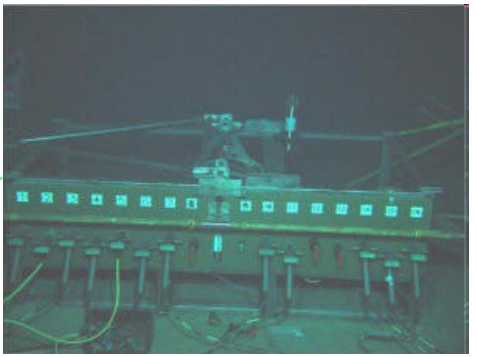
885 10” PMTs
on 12 lines
25 storeys/line
3 PMTs / storey



storey



shore station



junction box

In the Mediterranean Sea (Toulon): Southern sky visibility
Depth of ~2500 m: atmospheric muon background reduced

Diffuse flux searches

- Diffuse fluxes
  - Neutrinos from unresolved cosmic sources
- Hard energy spectra expected
  - Spectral index ~2
  - Signal shows up in high energy events
- Background from atmospheric events
  - Down-going muons
  - Up-going atmospheric neutrinos with a softer spectrum

Full sky searches – ν_μ diffuse flux

- Updated analysis* (2008-2011)

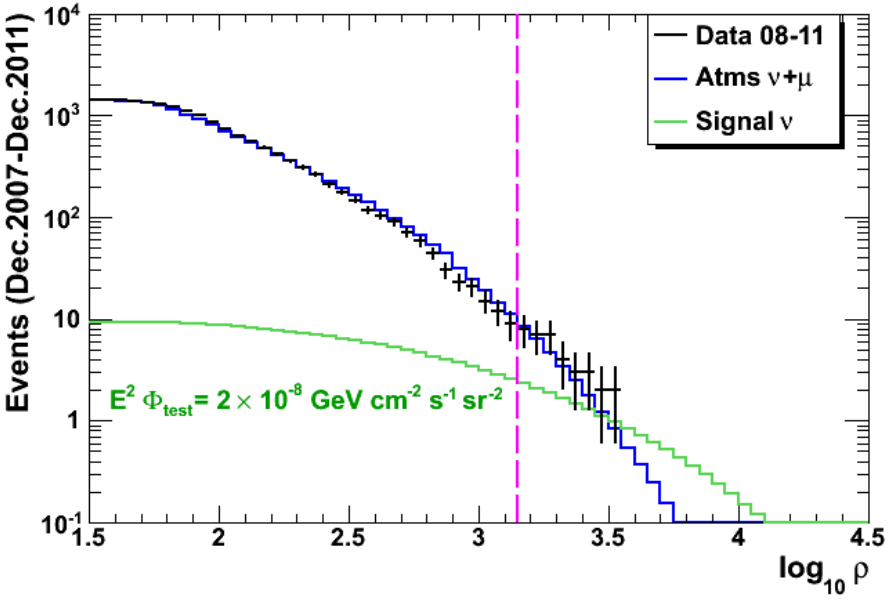
  855 days livetime

- Negligible μ contamination

  track quality, zenith and energy cut

- Improved energy estimation

  $\rho \approx dE/dX$



- Sensitivity: $E^2 \Phi_{90\%} = 4.7 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}
- After unblinding: **$n_{obs} = 8$, $n_{bkg} = 8.4$**
- Upper limit: $E^2 \Phi_{90\%} = 5.1 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1} (45 TeV – 10 PeV)

* Old published results:
Phys. Lett. B 696:16-22, 2011

Full sky searches – shower analysis

- 2007-2012 data (1247 days) – events with shower reconstruction algorithm (ν_e, NC ν_μ, ν_τ)
- Selection chain:

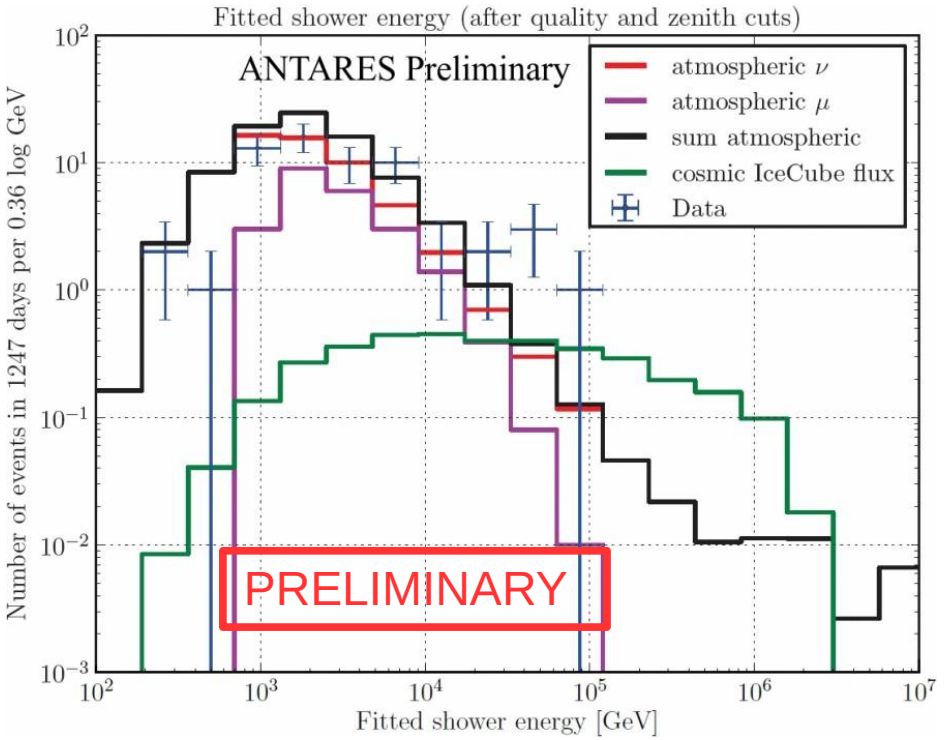
  N_{hit} and N_{lines} → muon filter → spark* cut → $\theta_{fit} > 94°$ and $E_{fit} > 10$ TeV
- Expectations after final cut from Monte Carlo simulations:

  - 2.79 cosmic events for $E^2\Phi_{cosm} = 1.2\ 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}

  - 4.92 atmospheric events (1.86 from atmospheric muons)
- Sensitivity per flavour $E^2\ \Phi_{90\%} = 2.21\ ^{+0.87}_{-0.73} \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}

* Spurious events from PMT behavior, mimicking showers

Full sky searches – shower analysis



- After unblinding

Cut	Obs.	Exp. (bkg)
Zenith > 94°	60	82 ± 40
Energy > 10 TeV	8	$4.92\ ^{+2.84}_{-2.95}$

- Corresponding Upper Limit (including systematics)

$E^2\ \Phi_{90\%} < 4.9 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}

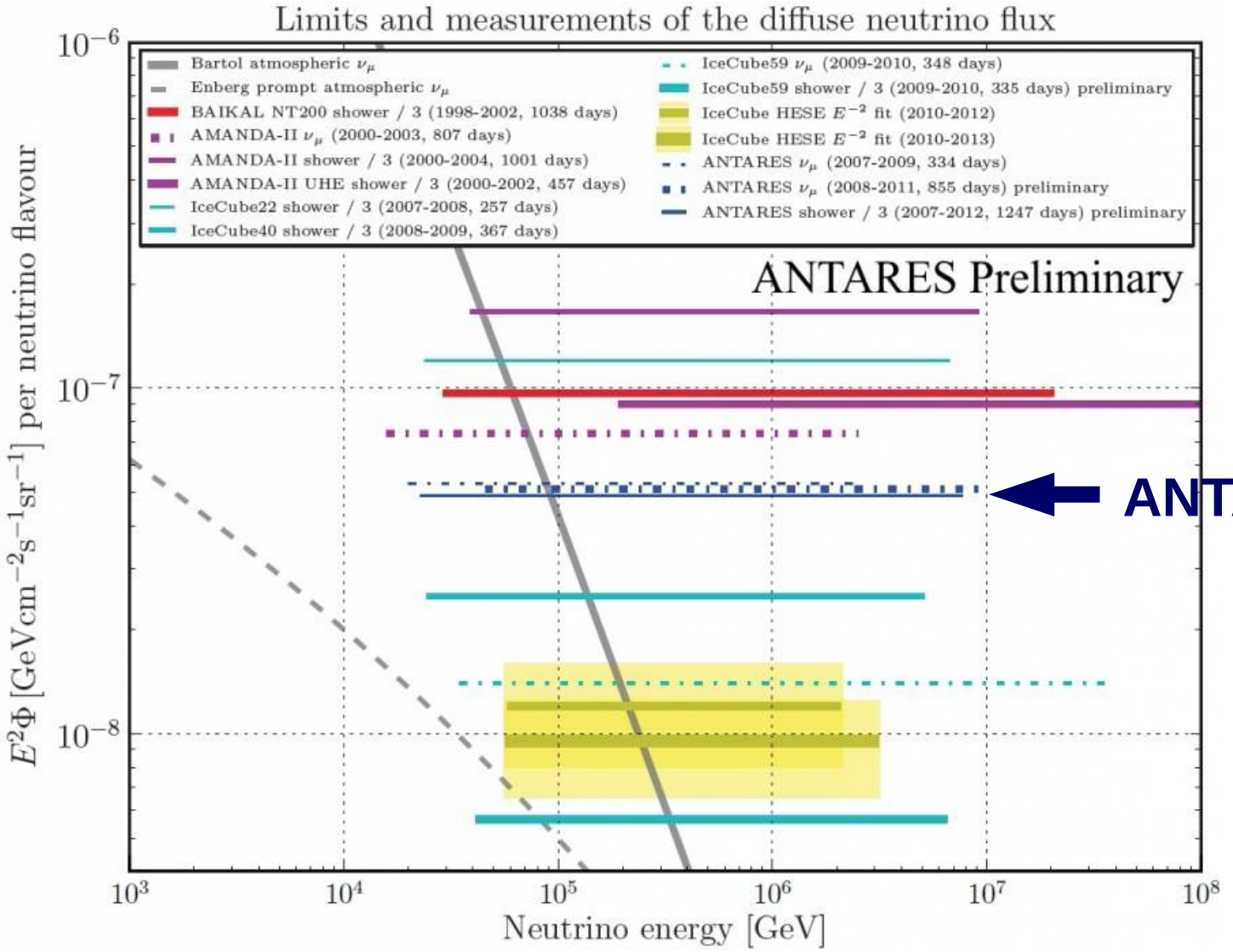
for 23 TeV < E_ν < 7.8 PeV

Diffuse fluxes summary

Analysis	**Showers**	**Tracks**
Flavours	All flavours	Muon neutrinos
Period	2007-2012	2008-2011
Exp. background	4.9 events	8.4 events
Observed	**8 events**	**8 events**
Upper Limit $E^2 \Phi_{90\%}$ GeV cm^{-2} s^{-1} sr^{-1} (systematics included)	**4.9×10^{-8}** PRELIMINARY	**5.1×10^{-8}**
Energy range	23 TeV – 7.8 PeV	45 TeV – 10 PeV

Schnabel 2014, Phys. Proc. 00 (TAUP2014)

Diffuse fluxes summary



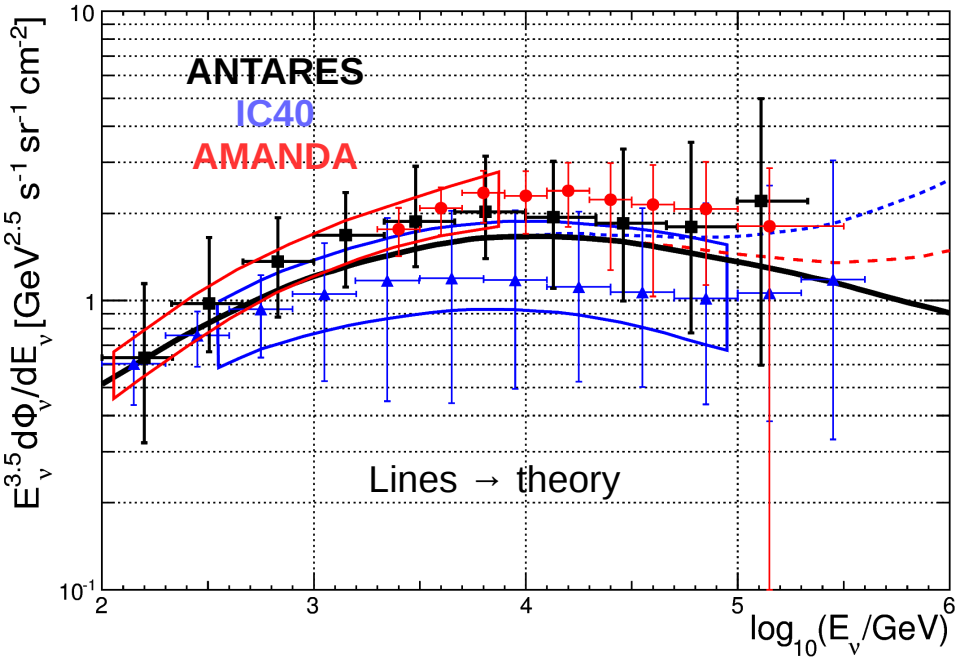
Full sky searches – atmospheric neutrinos

- Why measuring atmospheric neutrinos?
  - Irreducible background for diffuse flux searches
  - Energy calibration of the detector
  - Cosmic Rays physics (knee, prompt secondary emissions...)
  - Complete detector systematic uncertainties study
- Only under-ice measurements above TeV energies
- 2008-2011 data unfolding analysis – 2 different methods and merged results:

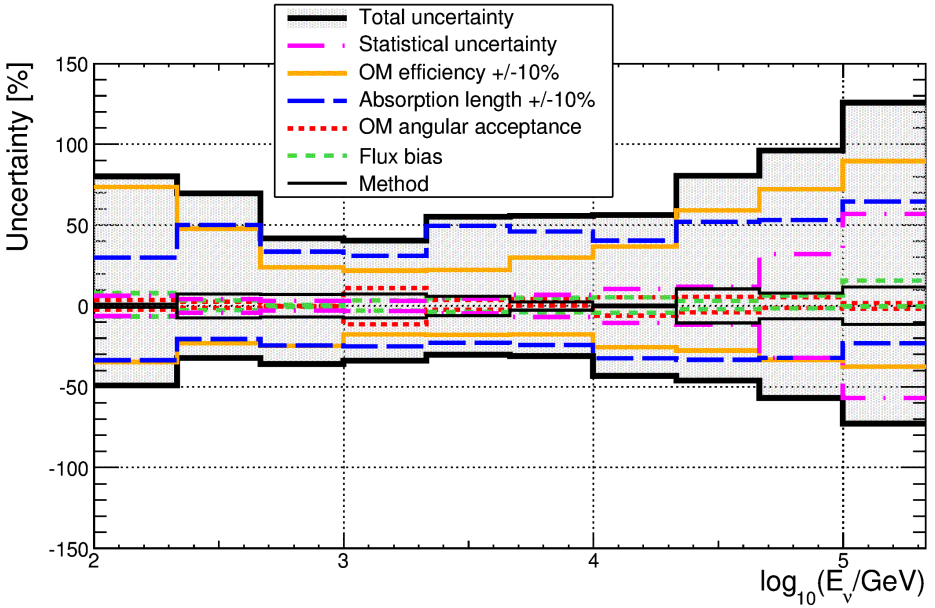
  ANTARES atmospheric spectrum from 100 GeV to 200 TeV

Full sky searches – atmospheric neutrinos

Unfolded energy distribution:
- dE/dX estimator + Bayesian unfolding
- max. likelihood estimation + SVD



Complete systematics studies



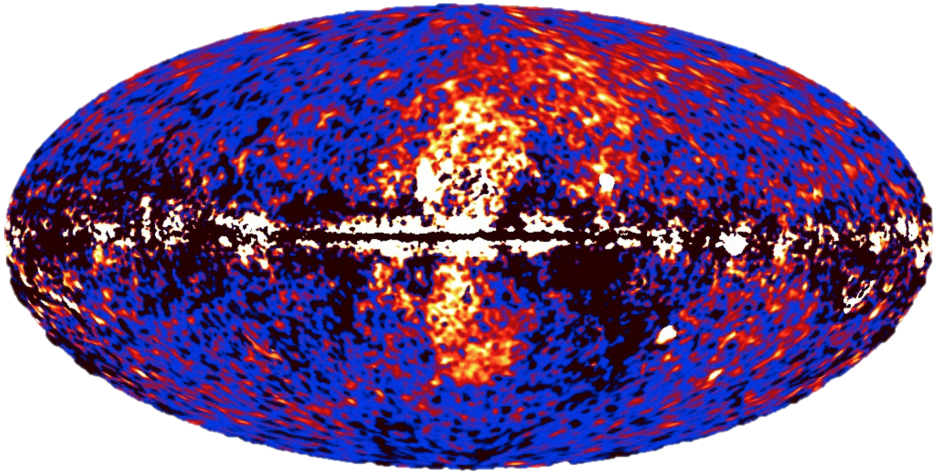
Results compatible with conventional expectations.
Limited statistics → cannot put limits on prompt contributions to the flux

Eur. Phys. J. C (2013) 73:2606

Special regions – Fermi Bubbles

- Excess of gamma-rays:
  - Homogeneous intensity and hard spectrum

$$E^2 \frac{\mathrm{d}\Phi_\gamma}{\mathrm{d}E} \approx 3 - 6 \times 10^{-7}\,\mathrm{GeV\,cm^{-2}\,s^{-1}sr^{-1}}$$



Credit: NASA/DOE/FERMI LAT/D. Finkbeiner et al.

- Various hadronic models predicting neutrino fluxes* – a cutoff in energy is expected

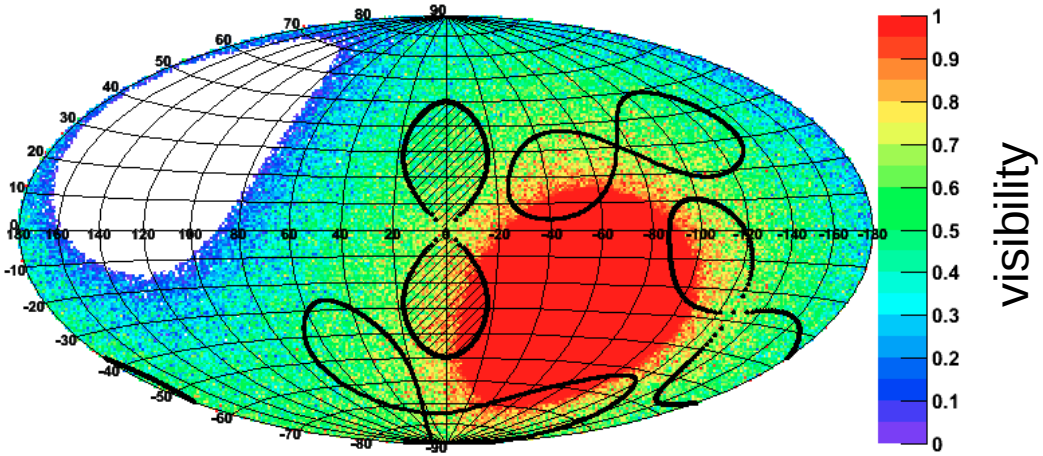
*e.g Phys. Rev. Lett. 106 (2011) 101102
or arXiv:1304.6137 (2013)
or arXiv:1304.6972 (2013)

$$E^2 \frac{\mathrm{d}\Phi_{\nu_\mu+\overline{\nu}_\mu}}{\mathrm{d}E} \approx 1.2 - 2.4 \times 10^{-7}\,\mathrm{GeV\,cm^{-2}\,s^{-1}sr^{-1}}$$

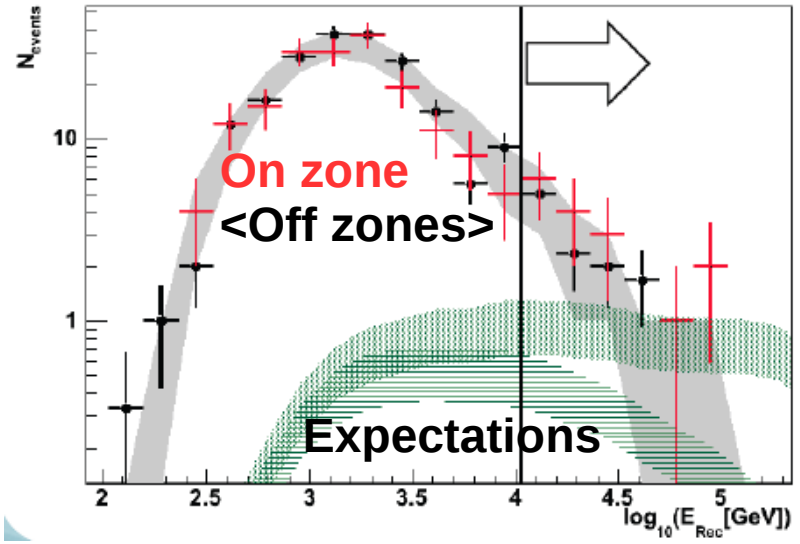
~0.8 sr region → diffuse flux for ANTARES
Mainly in the southern sky → good visibility in neutrinos

Special regions – Fermi Bubbles

- On/Off zone search:
  - Bkg from 3 off-zones, where no signal is expected, same shape/efficiency/coverage
- Energy estimator cut:
  - Reject atmospheric events



On/Off zones - Gal. coordinates



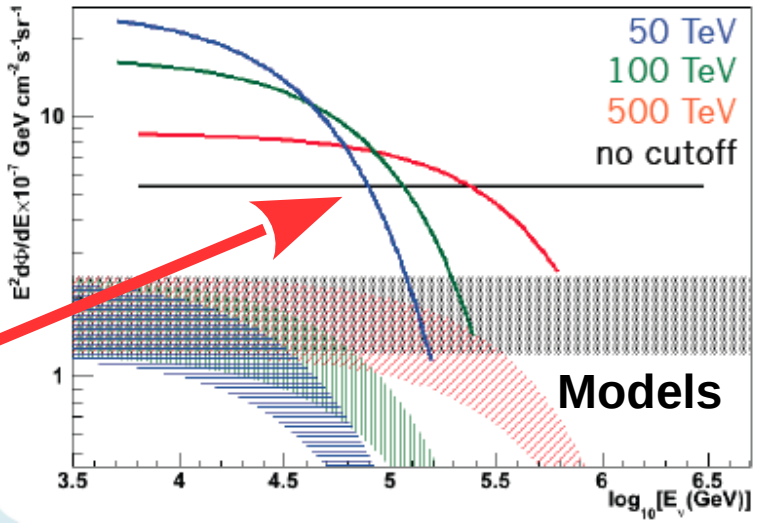
2008-2011 data

$N_{obs} = 16$

$\langle N_{bkg} \rangle = 11$

1.2σ excess

Upper Limits

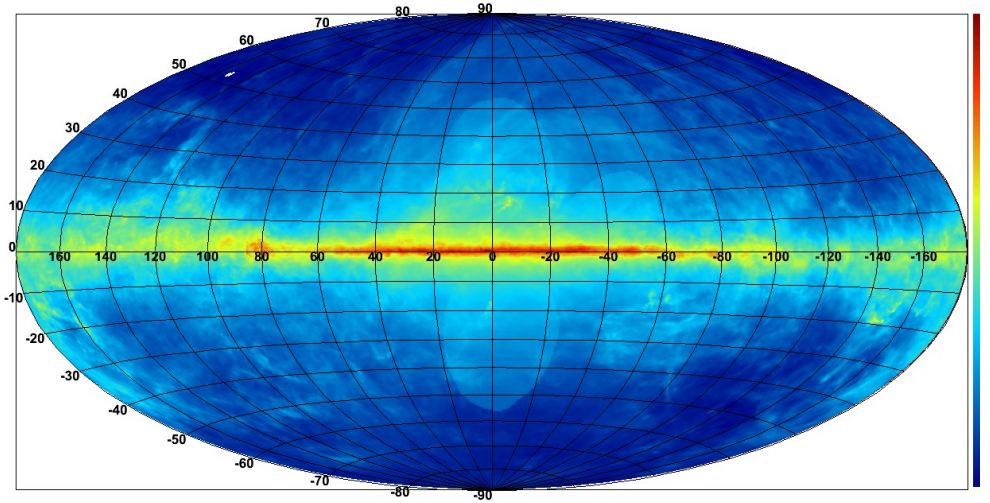


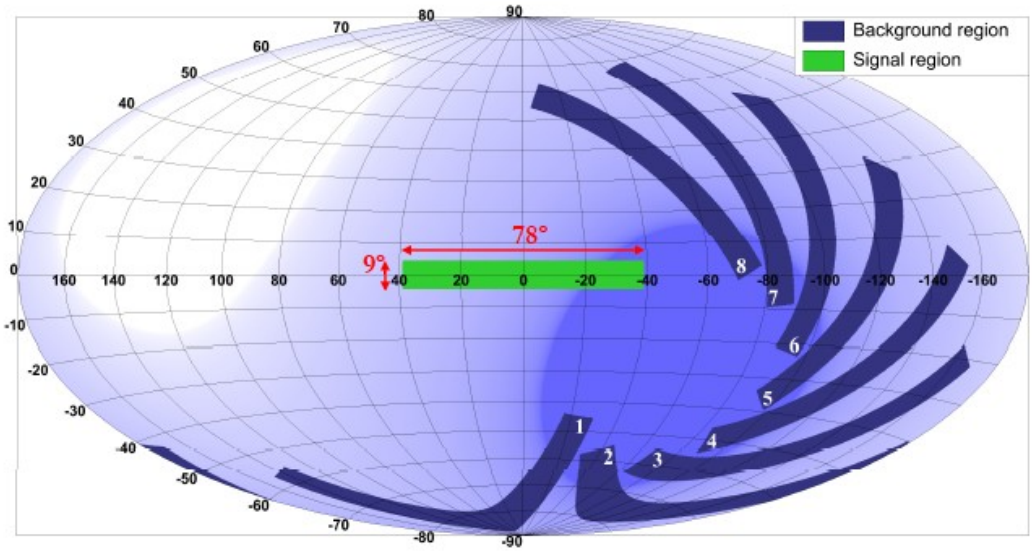
Eur. Phys. J. C (2014) 74:2701

Special regions – Galactic Plane

- CR interaction in the ISM
  - Pions giving ν and gamma
  - $E^{-2.6}$ spectrum expected; magnetic field can enhance the neutrino signal
- On/Off zones approach
  - On-zone optimized for different models and MRF
  - N_{off} (= 8) is determined on the on-zone dimensions

FERMI-LAT diffuse flux (E=3.4 GeV)





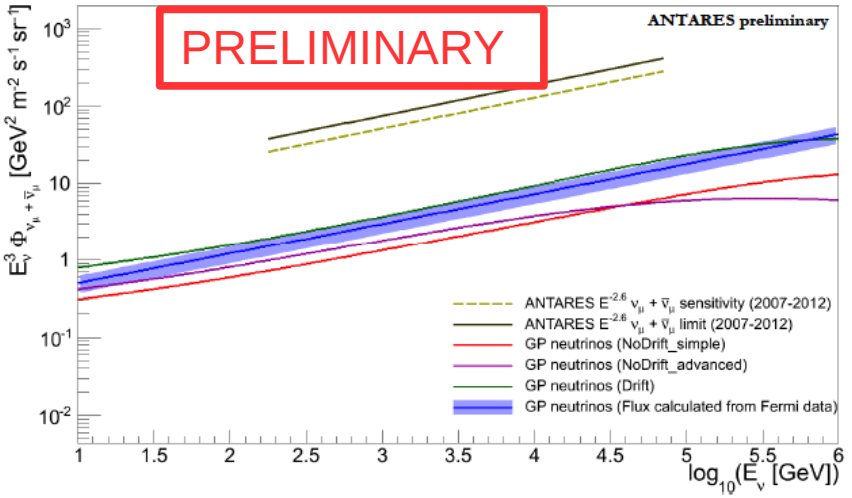
Special regions – Galactic Plane

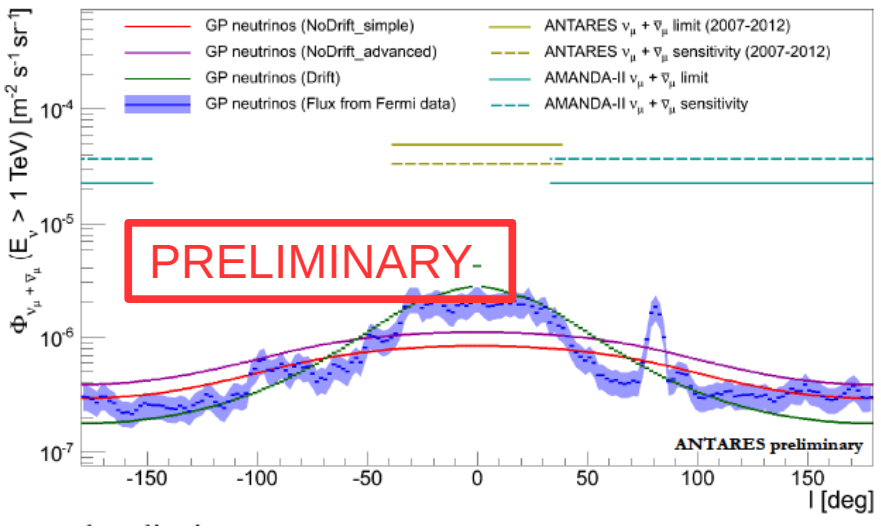
- 2007-2011 data:

  $n_{obs} = 177$, $n_{exp} = 166$

- 0.8σ excess and 90% upper limits set for different models

Model name	Reference	Matter density	Cosmic ray flux
NoDrift_simple	Ingelman and Thunman arXiv:hep-ph/9604286	constant: 1 nucleon / cm^3	constant
NoDrift_advanced	Candia and Roulet JCAP09(2003)005	constant: 1 nucleon / cm^3	constant
Drift	Candia JCAP11(2005)002	Radially dependent	Higher in GC due to drift of CRs





Conclusions and outlook

- Antares is the largest underwater neutrino telescope, in its 7th year of operation.
- Moderate size but good performance:
  - Diffuse flux limits in the most interesting energy range
  - Best performances in Southern sky – Galactic Plane and Fermi Bubbles
- Improvements:
  - Longer livetime being accumulated and analysed
  - Joint tracks and showers analysis in development
- Towards the next generation Mediterranean telescope: KM3NeT