Search for diffuse cosmic neutrino fluxes with the ANTARES detector

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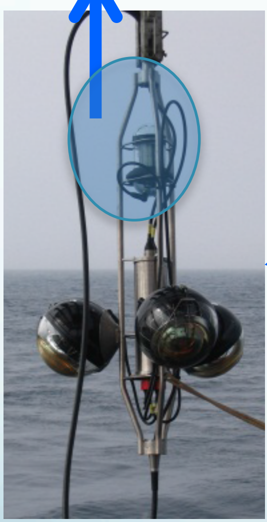
The ANTARES Collaboration

Overview

- ANTARES description
- Full sky searches
- Special region searches
  - Fermi bubbles
  - Milky Way
- Future plans

The ANTARES detector

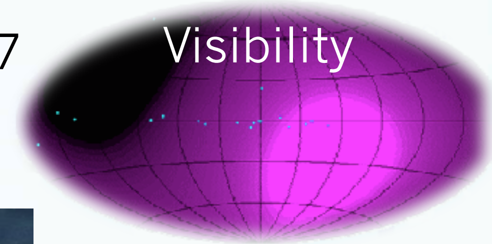
LED beacon

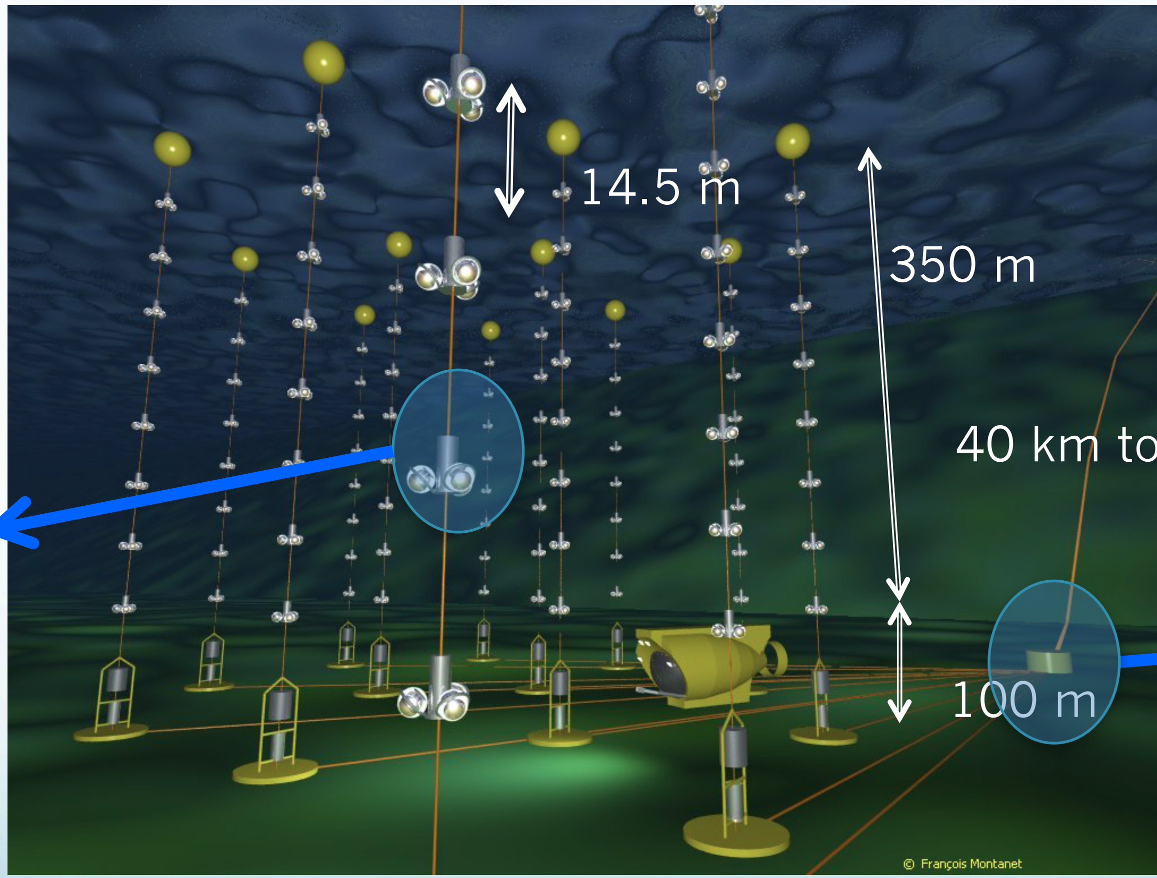


storey

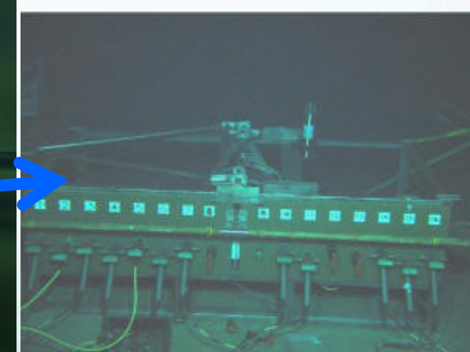
12 lines (885 10” PMTs)
25 storeys/line
3 PMTs / storey

5-line setup in 2007
completed in 2008





40 km to shore station

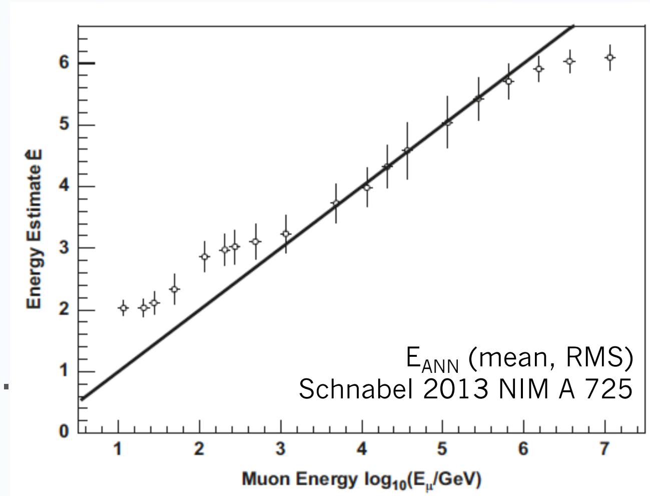


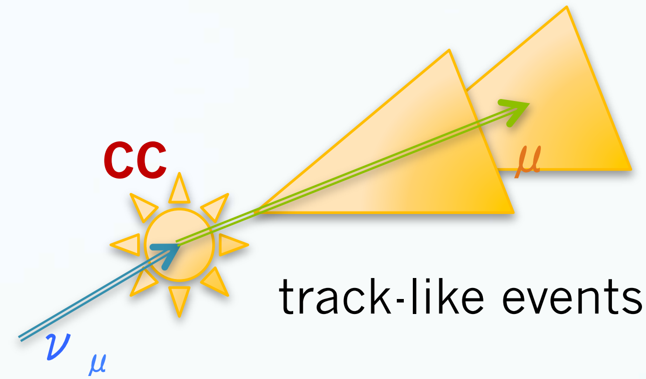
Junction box

In the Mediterranean Sea (near Toulon) at 2500 m depth

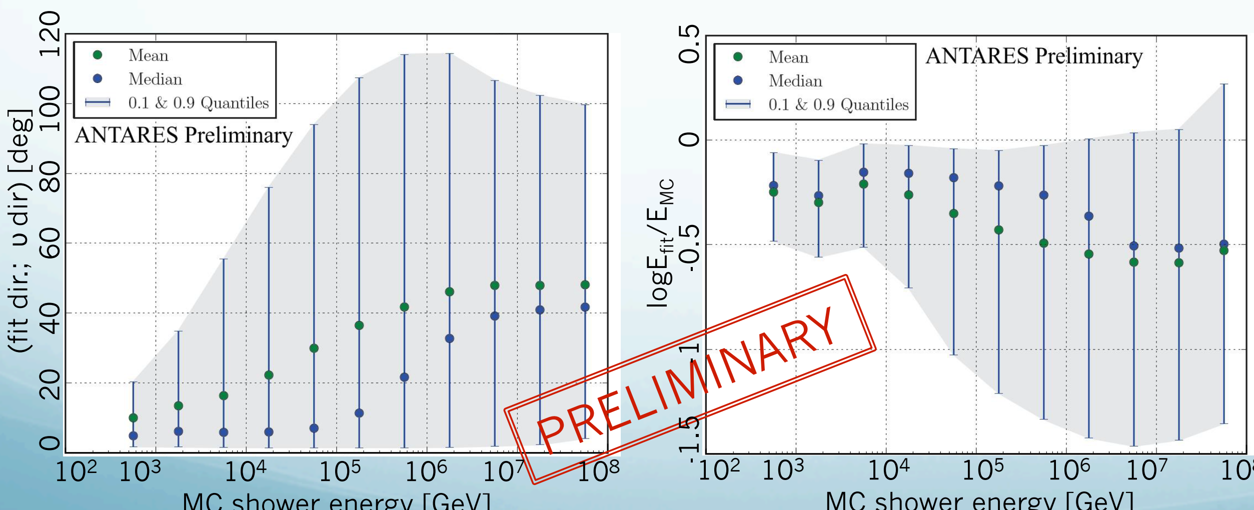
Detector performance

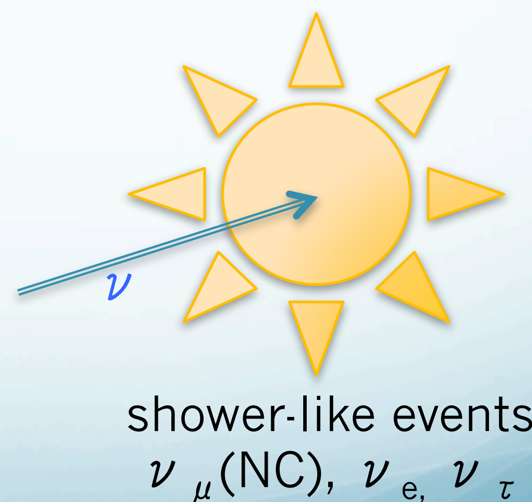
83% of cosmic track events (E^{-2} spectrum) are reconstructed better than 1^{o} (selected with $\Lambda > -5.2$ and $\beta < 1^{o}$).





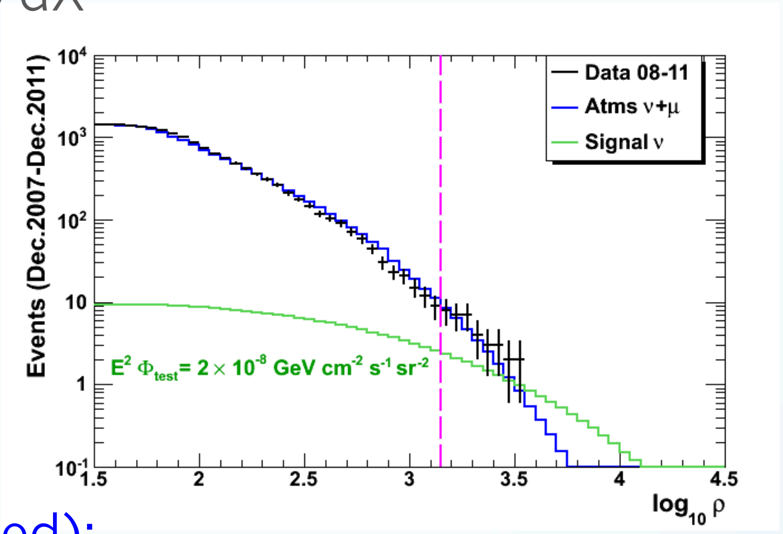
Shower events: after the muon filter (the cut on the reduced vertex log-likelihood at 7.9)





Diffuse cosmic ν_μ flux

- Updated analysis: 2008-2011 (855 days livetime)
- Improved energy estimate based on dE/dX
- Unblinded result: n_{obs}=8 n_{bkg}=8.4
- Muon contamination negligible (<0.4%)



- Analysis sensitivity:
- $E^2\Phi = 4.7 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}
- Upper limit (no systematic errors included):
- $E^2\Phi_{90\%} = 4.8 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1} (45 TeV< E < 10 PeV)
- 1.4 expected signal event for $E^2\Phi_{90\%} = 1.2 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1} (IceCube HESE measurement)

Shower analysis

- 29 Jan 2007 – 31 December 2012 (total livetime: 1247 days, burn sample: 135 days)
- Shower reconstruction algorithm. *Compares well with simulation ("run-by-run Monte Carlo" with environmental conditions simulated).*
- Selection chain:
  Muon filter -> Hits -> 2 lines -> No spark events -> Fitted zenith > 94° & E_{shower} > 10 TeV
- Sensitivity per neutrino flavour: $E^2 \cdot \Phi_{90\%} = 2.21^{+0.87}_{-0.73} \cdot 10^{-8}\ \mathrm{GeV/(cm^2\ sr\ s)}$

Contribution to the event counting	**Event numbers after the final cuts**	
	Cosmic signal events	Atmospheric background events
Cosmic signal (test flux 1.2*10-8 per flavour)	1.75	
Conventional atmospheric neutrinos		2.32
Prompt atmospheric neutrinos		0.56
Tau neutrino estimation	0.78	0.02 (prompt)
Atmospheric muon extrapolation		1.85
Correction for missing vertex showers in CC muon simulations	0.26	0.16
High multiplicity muon bundles	-	0.01
TOTAL	**2.79**	**4.92**

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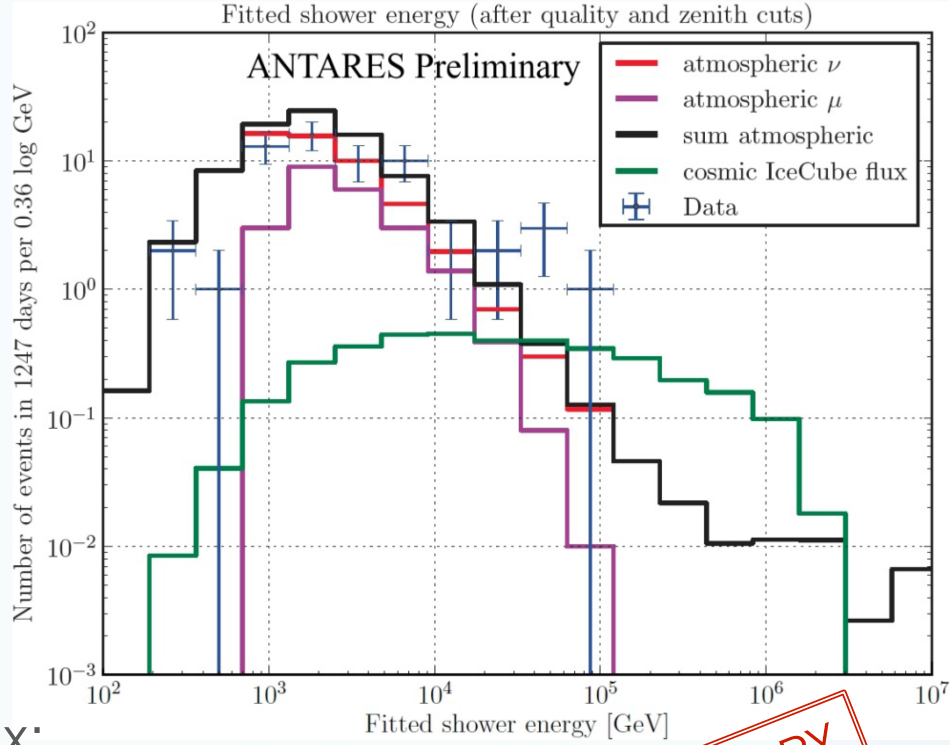
Shower analysis -unblinding

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



Limits on normalization for an E^{-2} flux:

- Feldman-Cousins 90% CL upper limit

$$E^2 \cdot \Phi_{90\%} < 3.9 \cdot 10^{-8}\ \mathrm{GeV/(cm^2\ sr\ s)}$$

- Including systematic uncertainties using Pole

$$E^2 \cdot \Phi_{90\%} < 4.9 \cdot 10^{-8}\ \mathrm{GeV/(cm^2\ sr\ s)}$$

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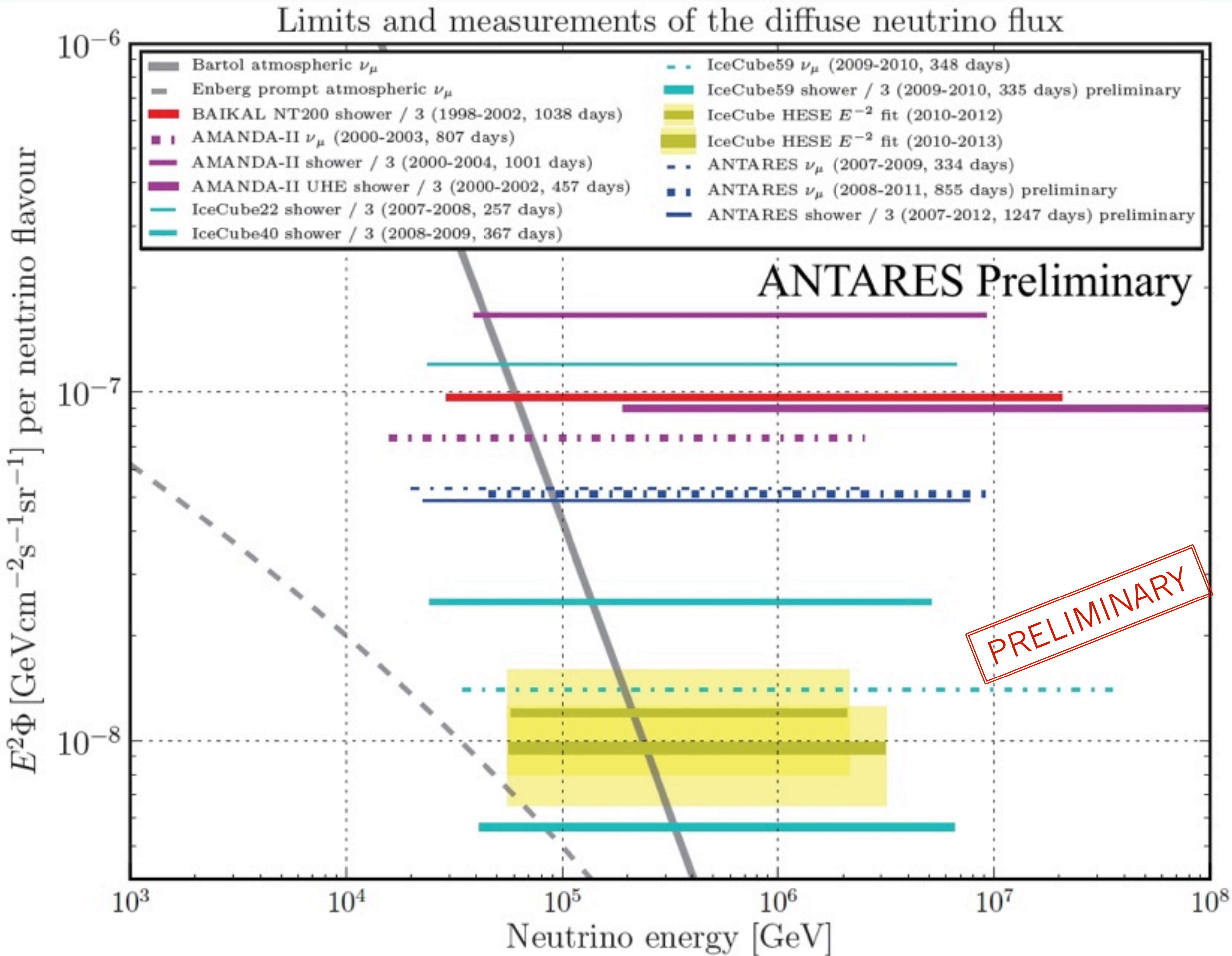
Diffuse flux summary

Analysis type	Showers	Track
Nu flavours	All flavours	Muonic
Period	2007-2012 (1247 days)	2007-2011 (885 days)
Exp. background events	4.9	8.4
Observed events	8	8
Upper limit $E^2 \cdot \Phi_{90\%}$, $\mathrm{GeV}/(\mathrm{cm}^2\ \mathrm{sr\ s})$ (per flavour, 90% CL, systematic included)	4.9×10^{-8}	5.1×10^{-8}
Energy range	23 TeV < E < 7.8 PeV	45 TeV < E < 10 PeV

PRELIMINARY

Schnabel 2014, Phys. Proc. 00 (TAUP2014)



Limits and measurements of the diffuse neutrino flux
Bartol atmospheric ν_μ
Enberg prompt atmospheric ν_μ
BAIKAL NT200 shower / 3 (1998-2002, 1038 days)
AMANDA-II ν_μ (2000-2003, 807 days)
AMANDA-II shower / 3 (2000-2004, 1001 days)
AMANDA-II UHE shower / 3 (2000-2002, 457 days)
IceCube22 shower / 3 (2007-2008, 257 days)
IceCube40 shower / 3 (2008-2009, 367 days)
IceCube59 ν_μ (2009-2010, 348 days)
IceCube59 shower / 3 (2009-2010, 335 days) preliminary
IceCube HESE E^{-2} fit (2010-2012)
IceCube HESE E^{-2} fit (2010-2013)
ANTARES ν_μ (2007-2009, 334 days)
ANTARES ν_μ (2008-2011, 855 days) preliminary
ANTARES shower / 3 (2007-2012, 1247 days) preliminary
ANTARES Preliminary
PRELIMINARY
$E^2\Phi$ [GeVcm^{-2}s^{-1}sr^{-1}] per neutrino flavour
10^{-6}
10^{-7}
10^{-8}
10^3
10^4
10^5
10^6
10^7
10^8
Neutrino energy [GeV]

Special regions

Su et al. 2010 ApJ 724 2

Crocker & Aharonian, 2011 Phys. Lett. B 106 10

Fermi Bubbles

- Excess of gamma-rays (together with X-rays and radio) in extended "bubbles" above and below the Galactic Centre. Homogenous intensity, hard spectrum (E^{-2}) probably with cutoff

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

- Galactic Wind scenario and other hadronic models predict neutrino flux. Its muonic component can be estimated as:

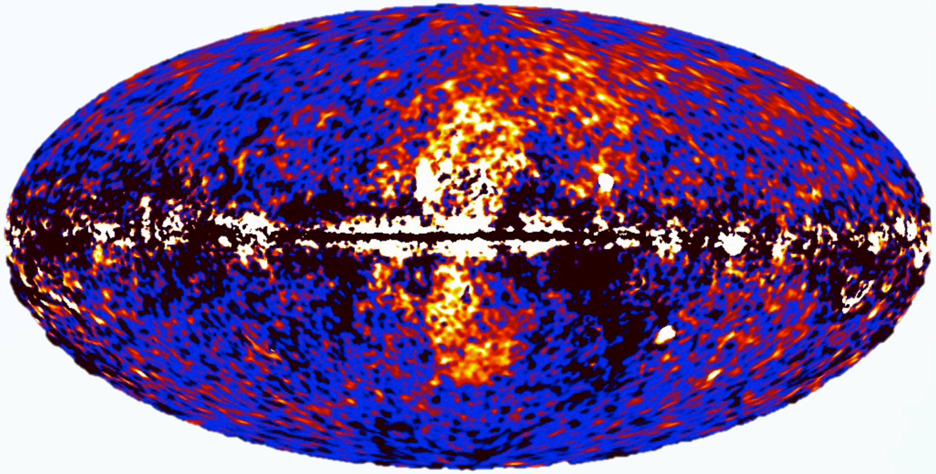
$$E^2 \frac{\mathrm{d}\Phi_{\nu_\mu+\overline{\nu}_\mu}}{\mathrm{d}E} \approx 1.2-2.4\times 10^{-7}\,\mathrm{GeV\,cm^{-2}\,s^{-1}sr^{-1}}$$

Milky Way

- The Galactic plane is the most populated region CRs can interact and produce neutrinos.
- $E^{-2.6}$ spectrum expected (leptons can decay due to the low density). Magnetic field can enhance the neutrino signal.

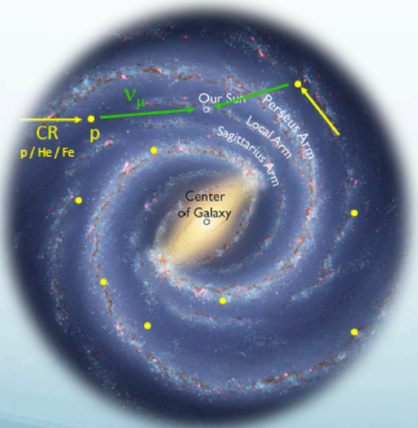
Special regions

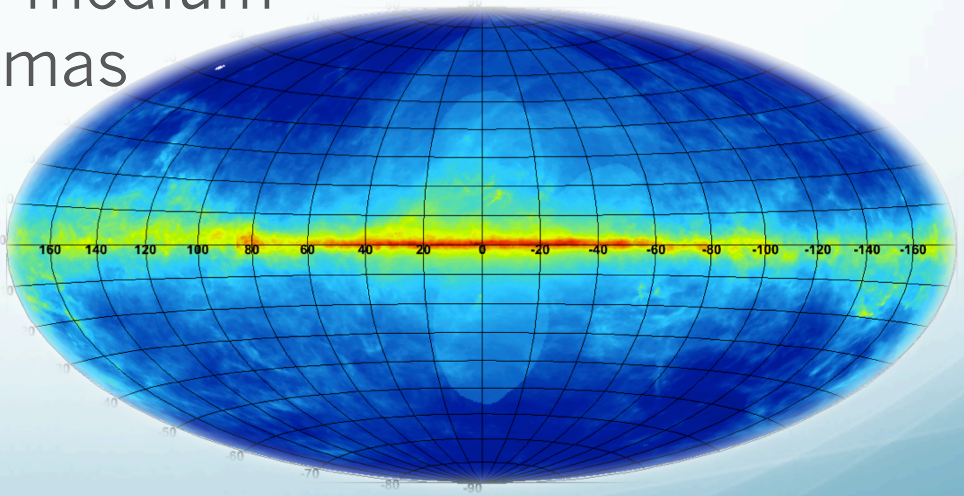
- Fermi Bubbles
  Gamma-rays observation
  with hard E^{-2} spectrum
  (Fermi-LAT)



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

- Milky Way
  CR interact with interstellar medium
  Pion decay: neutrinos, gammas





FERMI-LAT diffuse flux (E=3.4 GeV)

Search zones, offzones

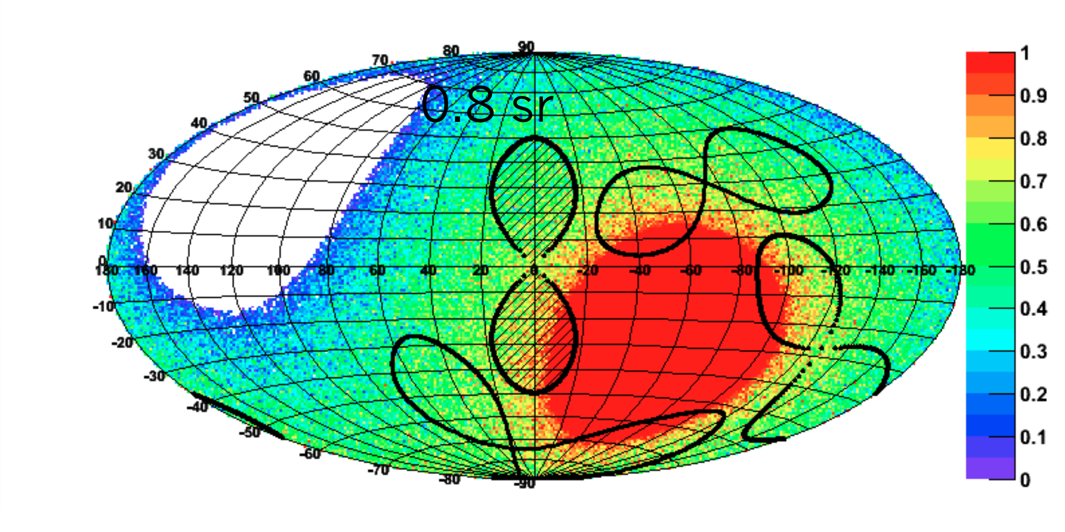
Fermi bubbles zone is approximated with Lemniscate of Bernoulli (0.8 sr)

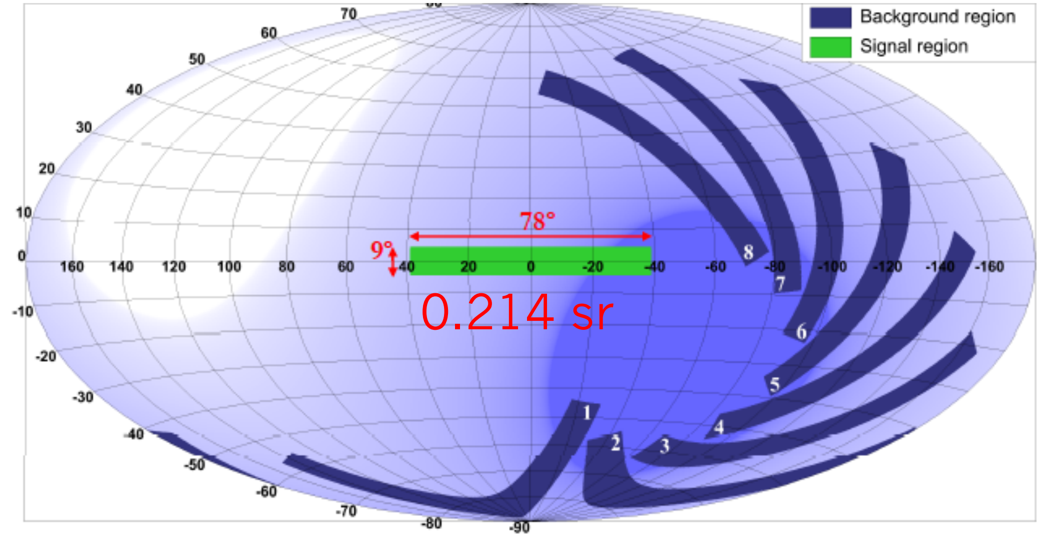
Size of the Galactic plane region is optimized according to different models and MRF

Background is estimated from the off-zones (same size, shape and average detector efficiency)

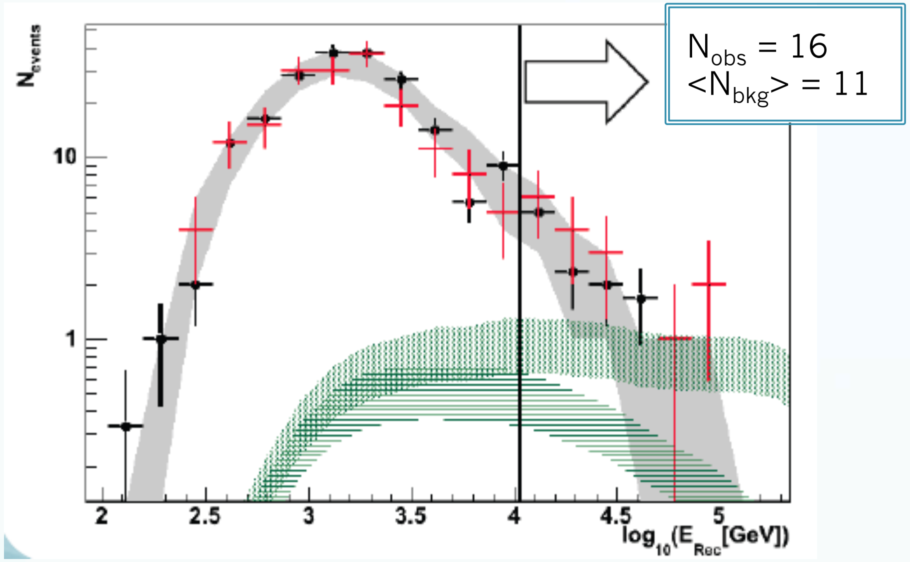
Number of off-zones is fixed for Fermi bubbles analysis – three

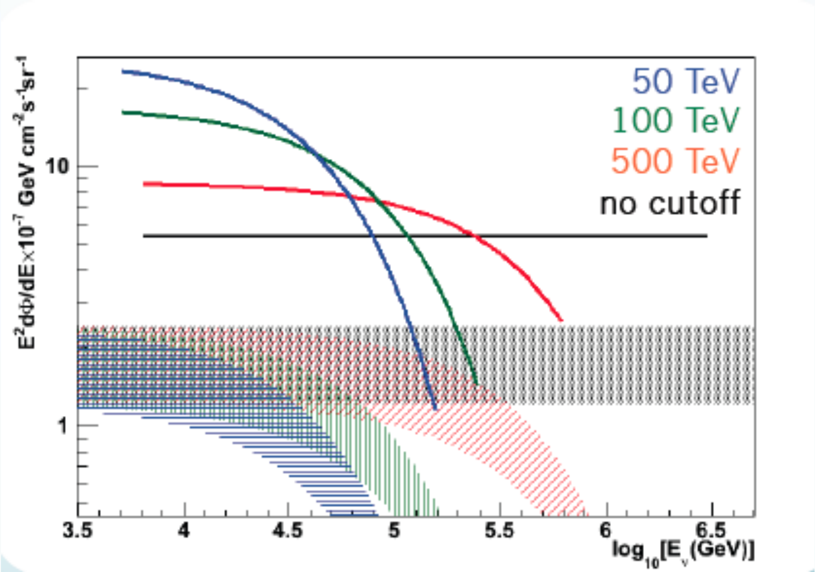
Depends on the on-zone size for Galactic plane (eight after the optimization)





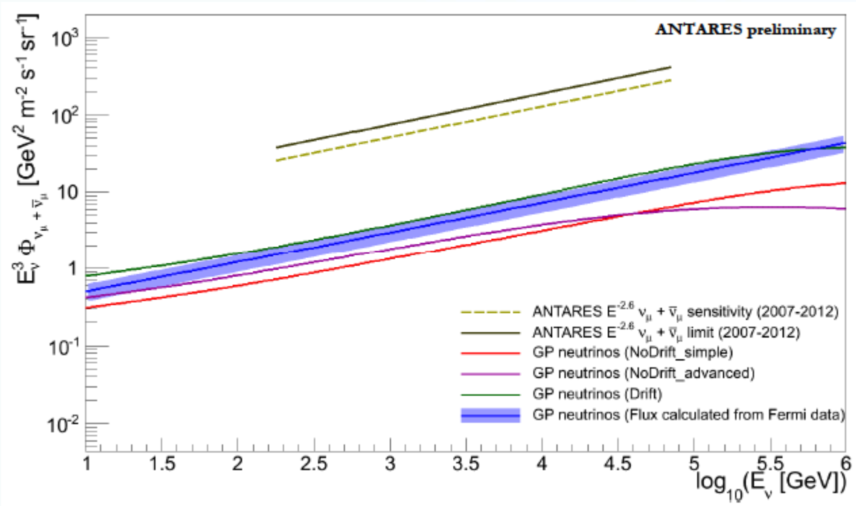
Fermi bubbles: results

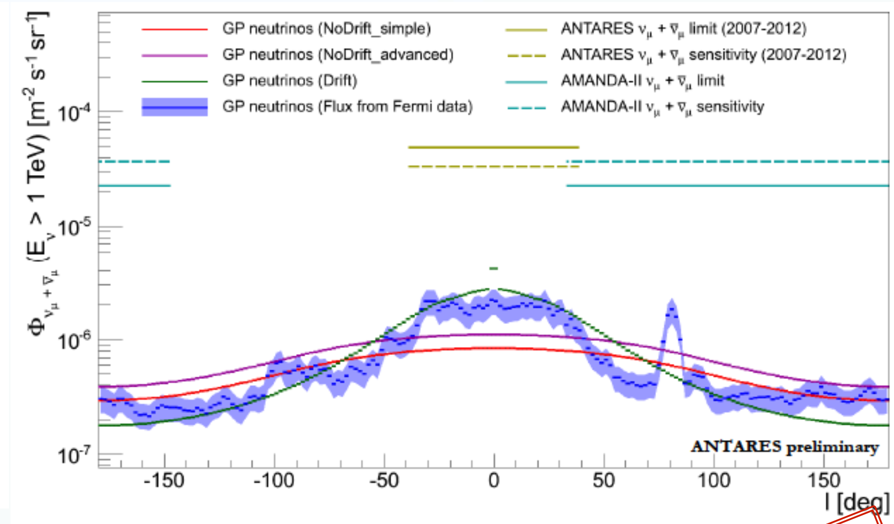




- 2008-2011 data analyzed (806 days of livetime)
- 16 events observed (11 background expected)
- 1.2 sigma significance
- 90% C.L. upper limits are set

Galactic Plane - results





- 2007-2012 data analyzed
- Observed 177 events (166 background expected)
- 0.8 sigma excess – 90% C.L. are set

PRELIMINARY

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

Special regions - summary

- Upper limits for the neutrino flux from the Fermi bubble regions: $$E^2 \frac{\mathrm{d}\Phi_{\nu_\mu+\bar{\nu}_\mu}}{\mathrm{d}E} < A \times 10^{-7}\,\mathrm{GeV\,cm^{-2}\,s^{-1}sr^{-1}}$$
  - no energy cutoff: A=5.3 (6 TeV < E_υ < 2 PeV)
  - 500 TeV cutoff : A=8.4 (6 TeV < E_υ < 600 TeV)
  - 100 TeV cutoff : A=16.0 (5 TeV < E_υ < 200 TeV)
  - 50 TeV cutoff : A=24.3 (5 TeV < E_υ < 160 TeV)

Adriàn-Martìnez et al. 2014 EPJ C 74 2

- Upper limits for the neutrino flux from the Galactic Plane central region (90% of the signal):

$$\frac{\mathrm{d}\Phi_{\nu_\mu+\bar{\nu}_\mu}}{\mathrm{d}E} < 4.61 \times 10^{-4}(E[\mathrm{GeV}])^{-2.6}\,\mathrm{GeV^{-1}\,cm^{-2}\,s^{-1}sr^{-1}}$$

(178 GeV < E_υ < 70.8 TeV)

PRELIMINARY

Conclusions and plans

- ANTARES – the first undersea Neutrino Telescope. It is in its 7th year of operation.
- Despite its moderate size, but thanks to its location and excellent angular resolution it is yielding:
  - Diffuse flux sensitivity in the relevant range
  - Best limits for the Galactic Centre and the Fermi bubble regions
- The measurements can be improved:
  - It is planned to run during 2015 and, probably, longer
  - More data are already collected and not analyzed yet
  - Joint track and shower analyses are in development
- Prepare for the next generation Mediterranean neutrino telescope – KM3NeT

- two of the 8 observed events (diffuse flux analysis with showers