Atmospheric neutrinos and diffuse fluxes of cosmic neutrinos with the ANTARES telescope

A. Margiotta
Dipartimento di Fisica e Astronomia Università and INFN - Bologna

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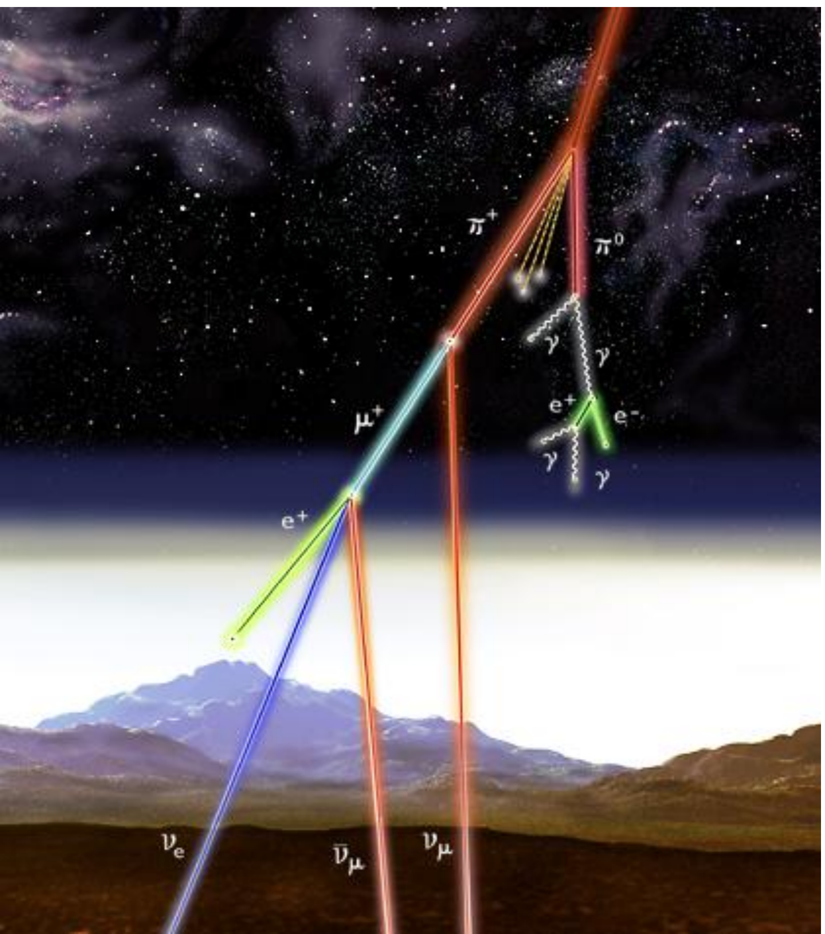
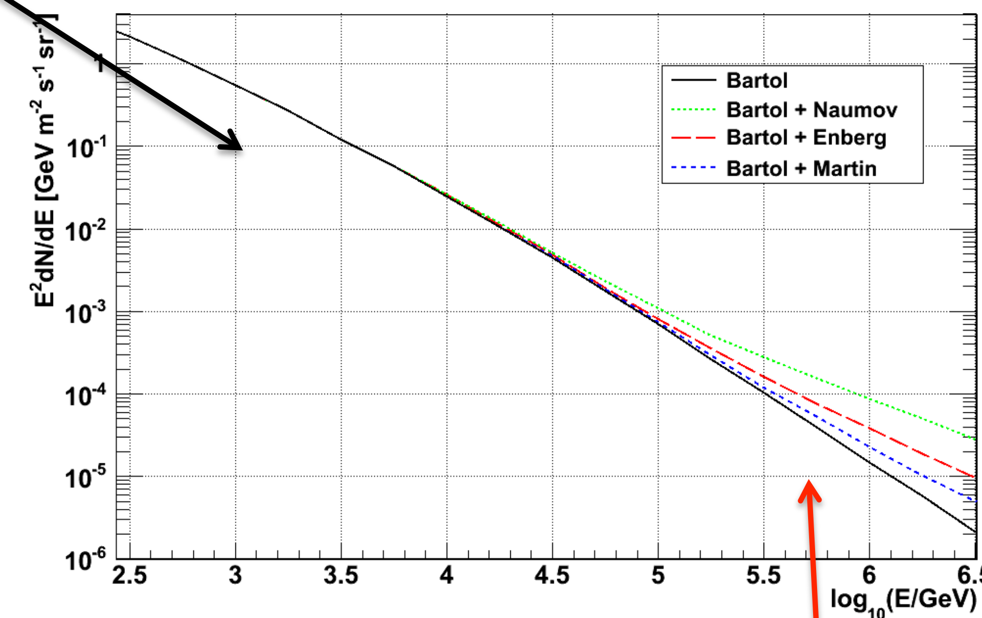
Overview

- The atmospheric ν_μ energy spectrum
- Diffuse flux search:
  - Full sky
    - Muon channel
    - Shower channel → Thomas Eberl
  - Special regions
    - Fermi Bubbles
    - Galactic plane

“Conventional” spectrum
(νs from π and K)

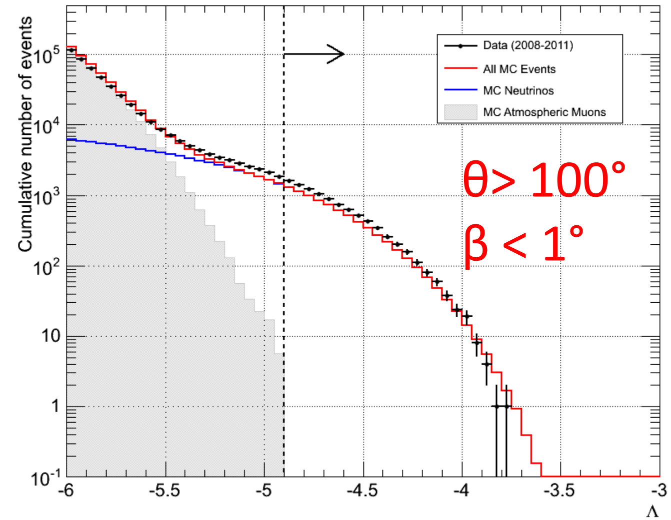




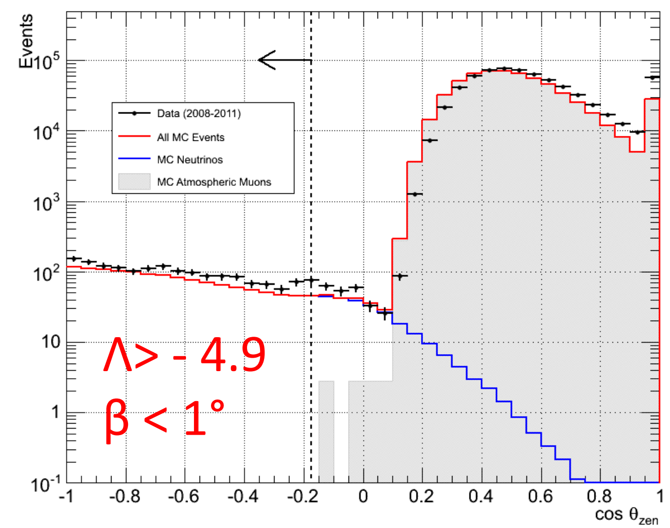
prompt contribution
(νs from charmed
particles)

The atmospheric ν_μ energy spectrum 0.1 - 200 TeV

- Data sample: Dec 2007 – Dec 2011; LT= 885 d
- Monte Carlo :
  - Detector configuration + optical BG from data "in situ" acq conditions
  - GENHEN - ν_μ simulation
  - MUPAGE – atm. muons



- High quality upgoing (θ> 100°) tracks
  atmospheric muon contamination < 0.4%
  - Reconstruction quality parameter (Λ> - 4.9)
    +
  - β < 1° - small angular uncertainty



- Good agreement data/MC

Main ingredients:

- Muon energy estimators
  - based on the amount of direct and scattered light reaching the OMs ($<n_{pe}>$)

  $<n_{pe}>$ depends on muon energy, water properties, detector configuration, distance and orientation of OMs…

- Unfolding procedures
  - to derive the parent neutrino energy distribution.

$$A\,\mathbf{e} = \mathbf{x}$$

  A = response matrix; **e** = “true” distribution; **x** = measured distribution

Two independent analyses

(S. Adrian-Martinez et al., Eur. Phys. J. C (2013) 73:2006)

Analysis 1

- Muon energy estimator : *energy likelihood method*

maximization of the agreement between the expected amount of light in the OMs and the observation

- Unfolding procedure : *singular value decomposition*

"regularization" (external constraints) process to avoid statistical inconsistencies

Analysis 2

- Muon energy estimator : *energy loss method*

Q_i = charge amplitude on ith OM

L_μ = track length

ε = overall ANTARES light collection efficiency

$$\frac{dE}{dX} \propto \rho = \frac{\sum_{i=1}^{N_{hit}} Q_i}{\varepsilon} \cdot \frac{1}{L_\mu}$$

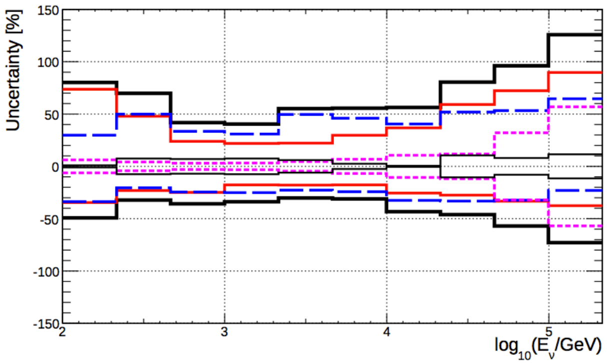
- Unfolding procedure : *Bayesian method*

iterative procedure → stable solution

Both procedures are available in the RooUnfold package (ROOT)

Analyses 1 & 2 combined results

Systematic uncertainties



OM efficiency (+/- 10%)

water absorption length (+/- 10%)

statistical uncertainties

total uncertainties

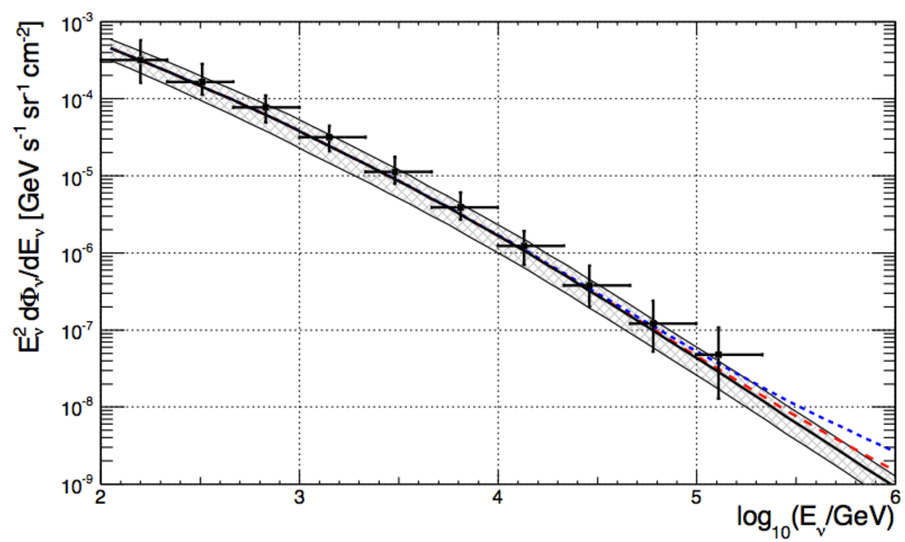
relative difference between unfolding methods

Bartol normalization + prompt contributions

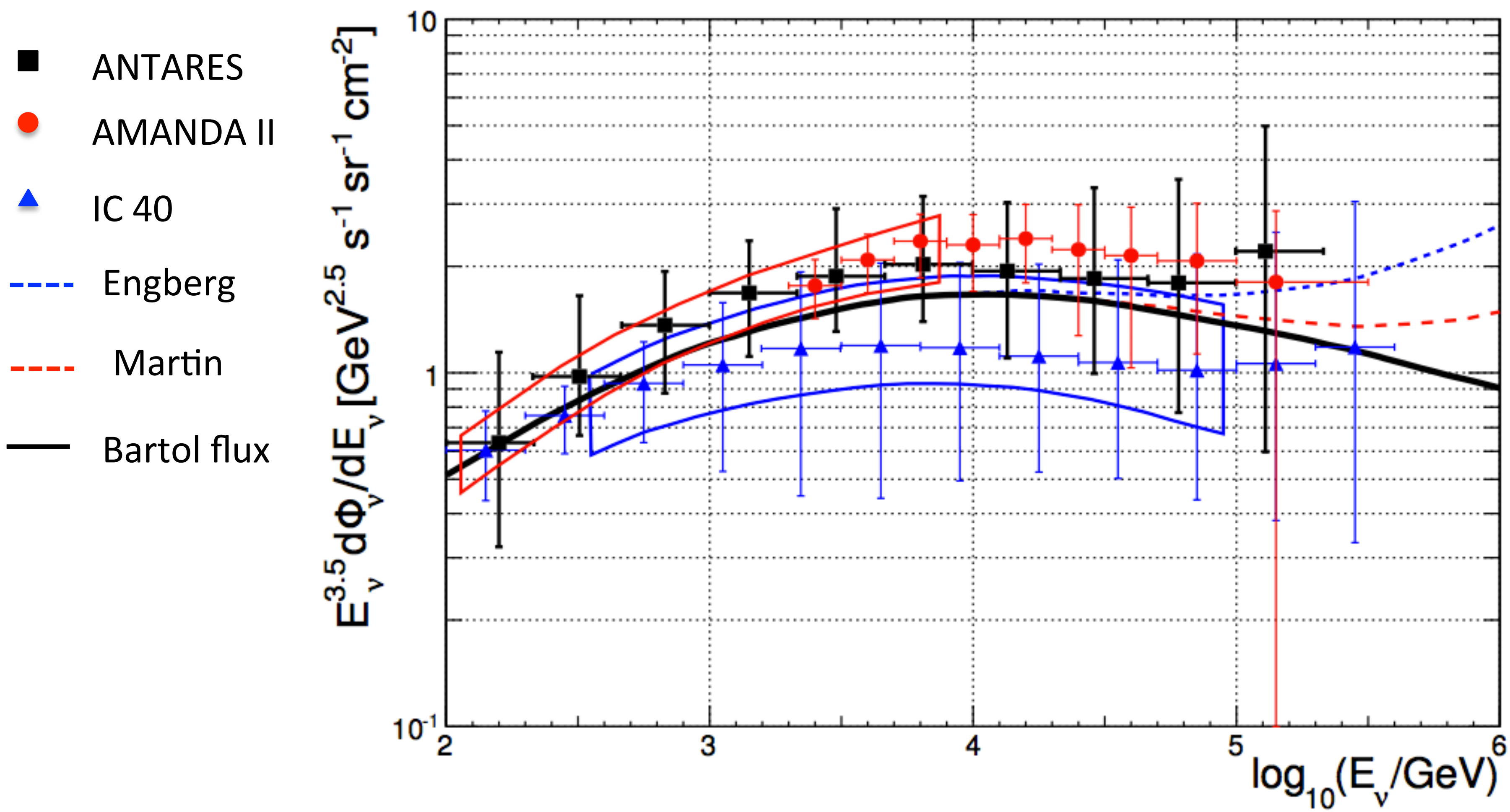
A. Martin et al. - 2003

R. Engberg et al. - 2008

Barr et al. – 2004



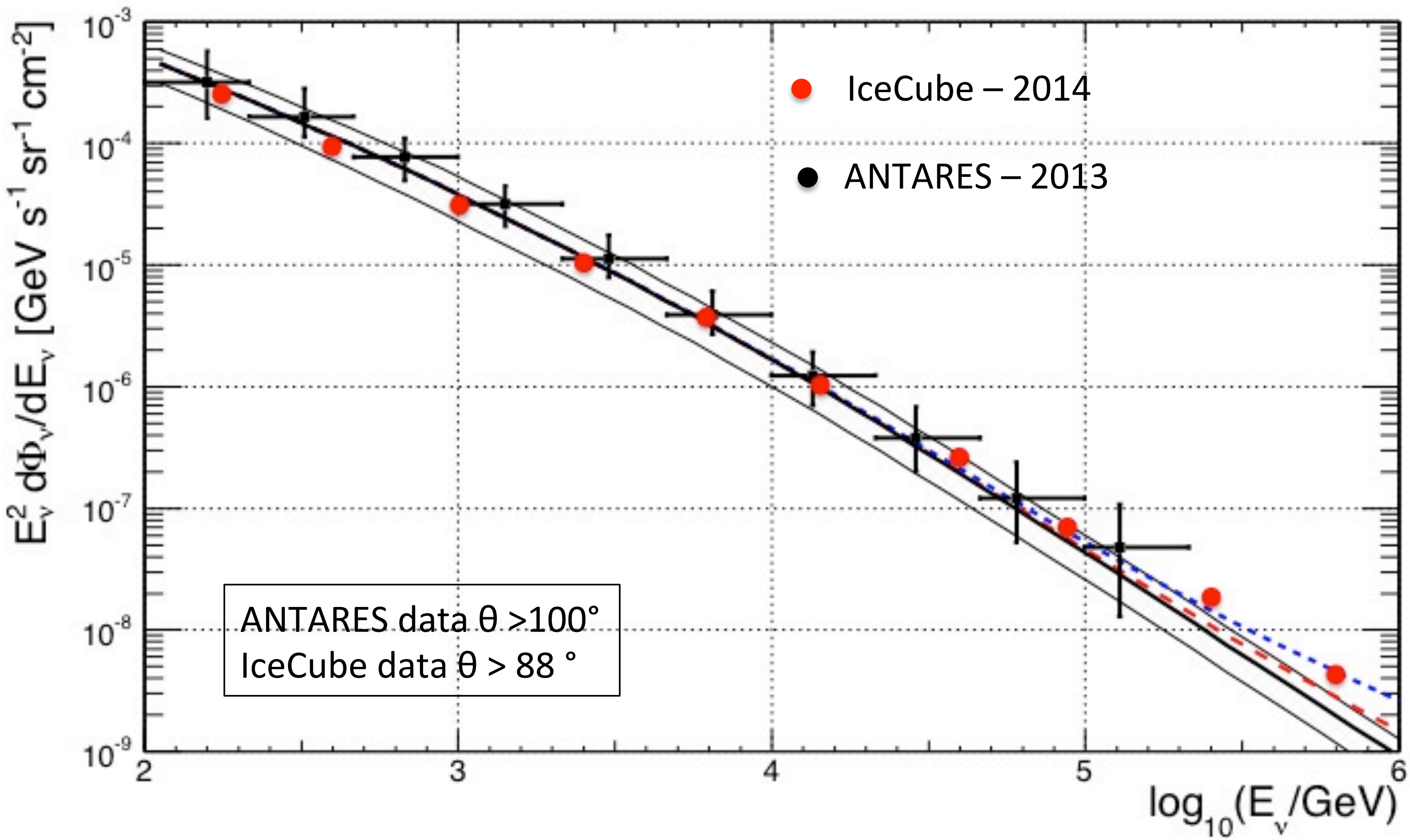
Analyses 1 & 2 combined results



Results compatible with expectations from a conventional neutrino flux.

Power low with $\gamma_{meas} = 3.58 \pm 0.12$; 25% higher normalization

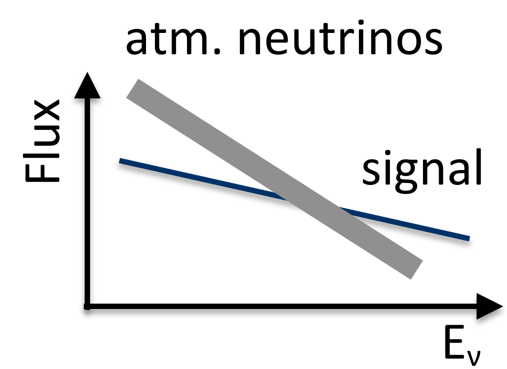
Limited statistics → no constraints on prompt contribution



Done yesterday afternoon on the train to Geneva… Very rough comparison

Diffuse fluxes

- Search for neutrinos from unresolved cosmic sources
- Hard energy spectra expected
  - Spectral index around 2
  - Signal in the high energy region → distortion of the atmospheric (conventional+prompt) component
- Background due to: atmospheric
  - muons ↓
  - neutrinos ↑



Diffuse fluxes from the full sky

only track-like events – for shower-like event analysis - T. Eberl's talk

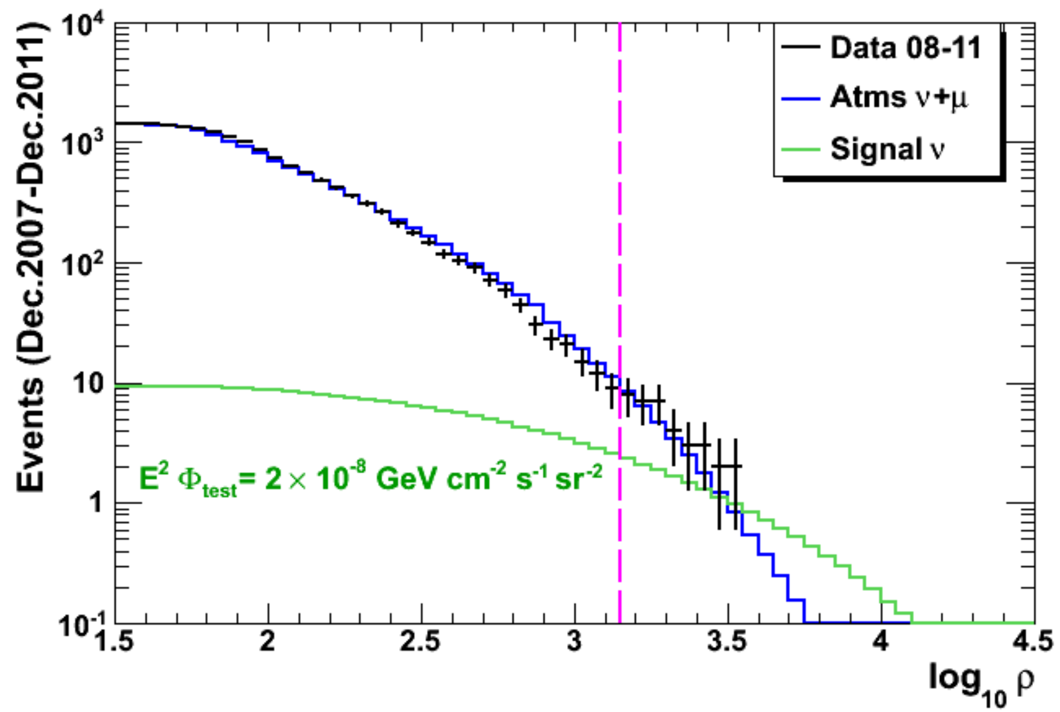
(the old analysis: J.A.Aguilar et al., Phys. Lett. B 696 (2011)16; LT= 334 d, Dec 2007- Dec 2009)

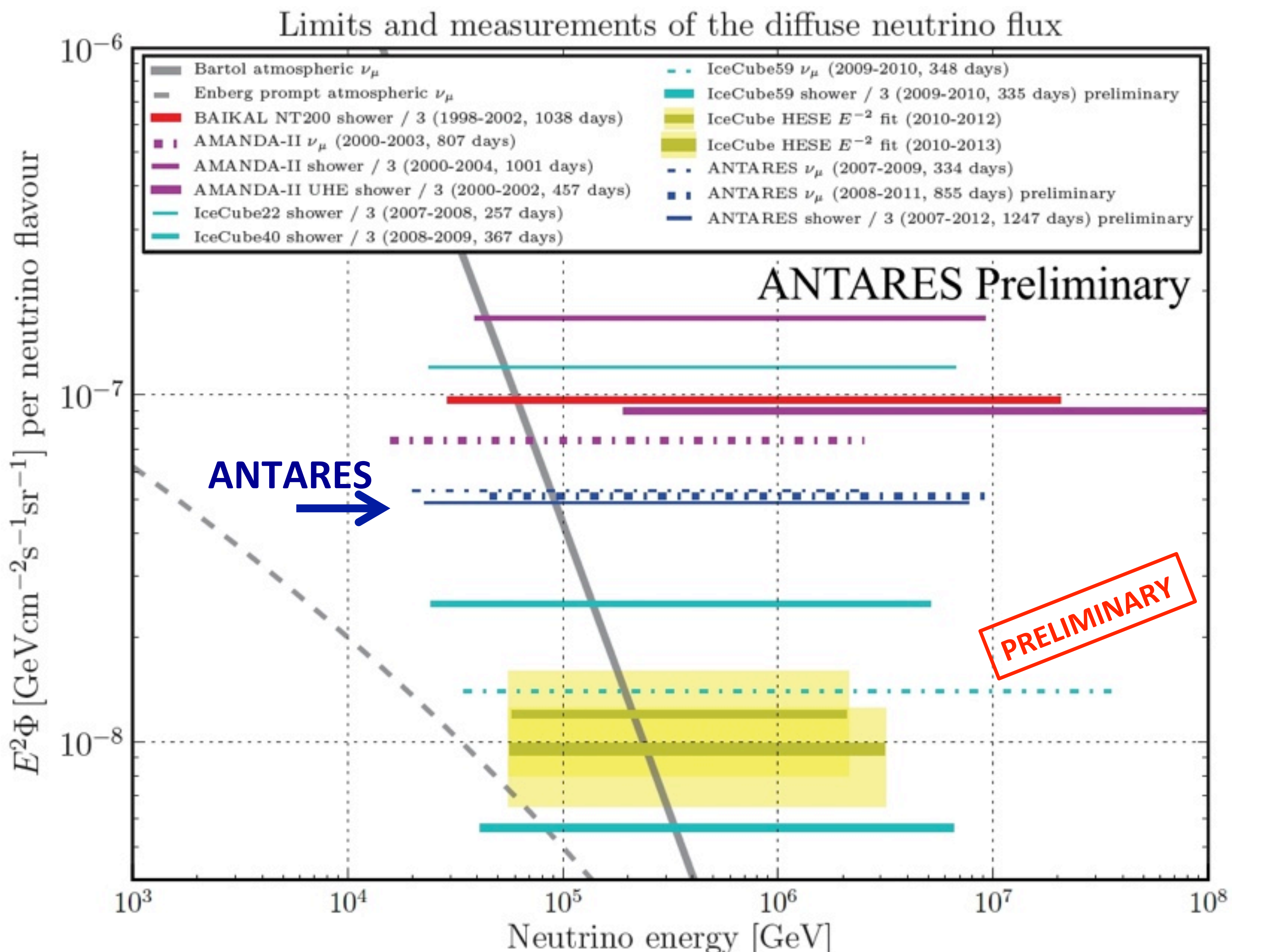
- Update analysis (2008-2011; LT = 885 d)
- High quality reconstruction ➔ atm μ contamination < 0.4 %
- Improved energy estimator: ρ = dE/dX
- Sensitivity :

$E^2\,\Phi_{90\%} = 4.7 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}

- $N_{bkg} = 8.4$; $N_{obs} = 8$
- Upper limit (45 GeV - 10 PeV) systematic included :

$E^2\,\Phi_{90\%} = 5.1 \times 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}





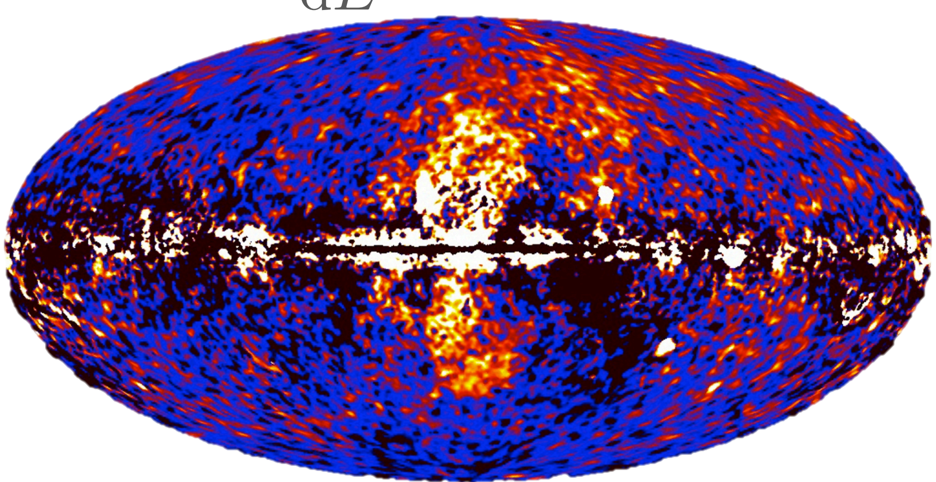
Limits and measurements of the diffuse neutrino flux
Bartol atmospheric ν_μ
Enberg prompt atmospheric ν_μ
BAIKAL NT200 shower / 3 (1998-2002, 1038 days)
AMANDA-II ν_μ (2000-2003, 807 days)
AMANDA-II shower / 3 (2000-2004, 1001 days)
AMANDA-II UHE shower / 3 (2000-2002, 457 days)
IceCube22 shower / 3 (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
ANTARES
PRELIMINARY
10^{-6}
10^{-7}
10^{-8}
$E^2\Phi$ [GeVcm^{-2}s^{-1}sr^{-1}] per neutrino flavour
10^3
10^4
10^5
10^6
10^7
10^8
Neutrino energy [GeV]

Neutrino fluxes from "special" regions – 1
Fermi bubbles

- Excess of gamma-rays (and X plus radio emission) in extended "bubbles" above and below the Galactic Centre.
- Hard spectrum (E^{-2}), possible cutoff.
- Estimated photon flux : $$E^2 \frac{\mathrm{d}\Phi_\gamma}{\mathrm{d}E} \approx 3 - 6 \times 10^{-7}\,\mathrm{GeV\,cm^{-2}\,s^{-1}sr^{-1}}$$
- Some models predicting neutrino fluxes.
- Estimated muon neutrino flux:

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

For example:
Phys. Rev. Lett. 106 (2011) 101102
arXiv:1304.6137 (2013)
arXiv:1304.6972 (2013)

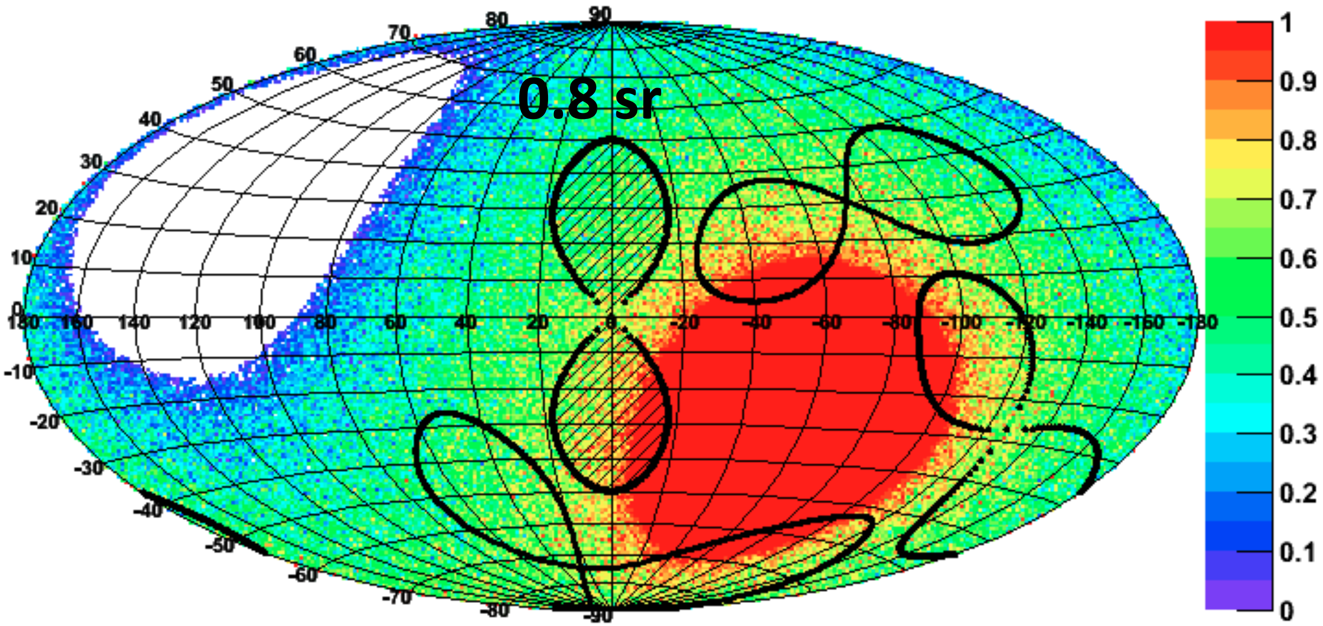


- 0.8 sr region
- mainly in the Southern sky → good visibility for ANTARES

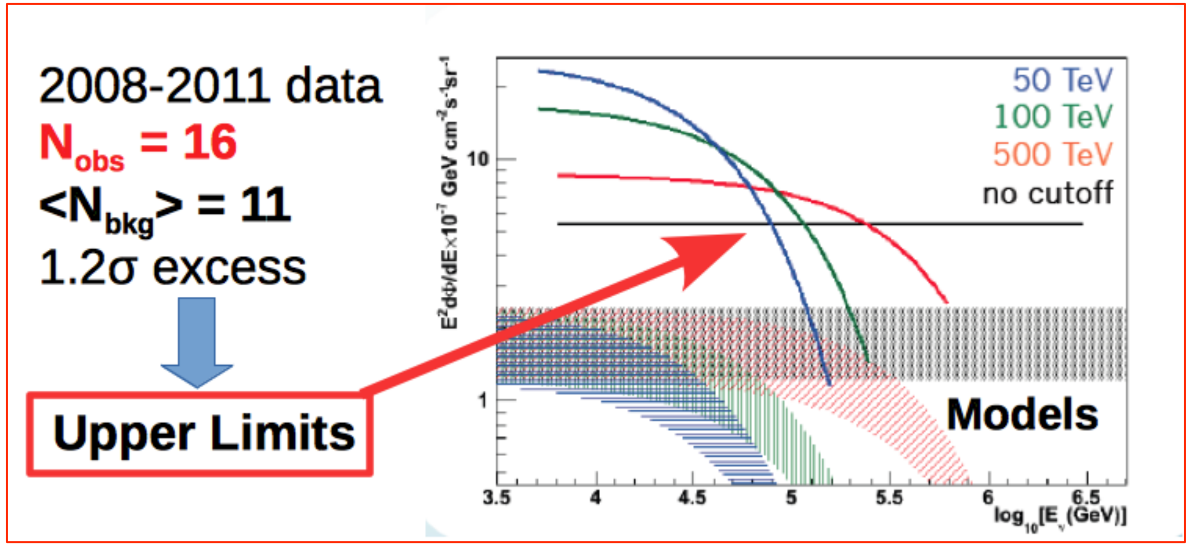
Neutrino fluxes from “special” regions – 1
Fermi bubbles

On/Off zone search:

- BKG from 3 off-zones
- no signal expected
- same shape/efficiency/coverage

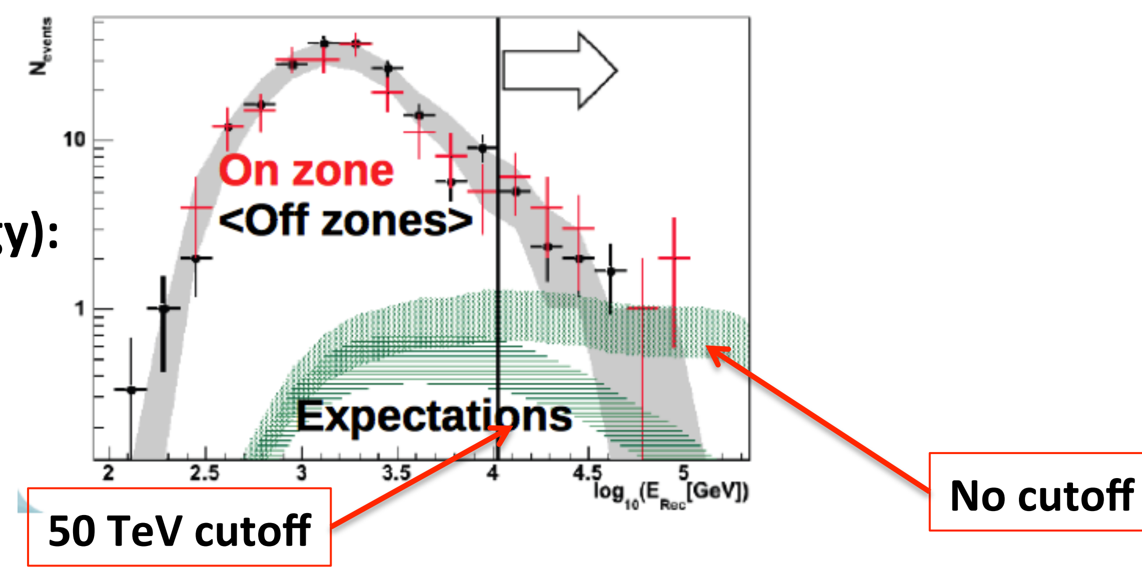


Neutrino fluxes from “special” regions – 1
Fermi bubbles



compatible with the no-signal hypothesis

S. Adriàn-Martìnez et al., EPJ C 74(2014) 2



Energy estimator cut (high energy):
atmospheric event rejection

Neutrino fluxes from “special” regions – 1
Fermi bubbles

Upper limits for the neutrino flux from the Fermi bubble regions:

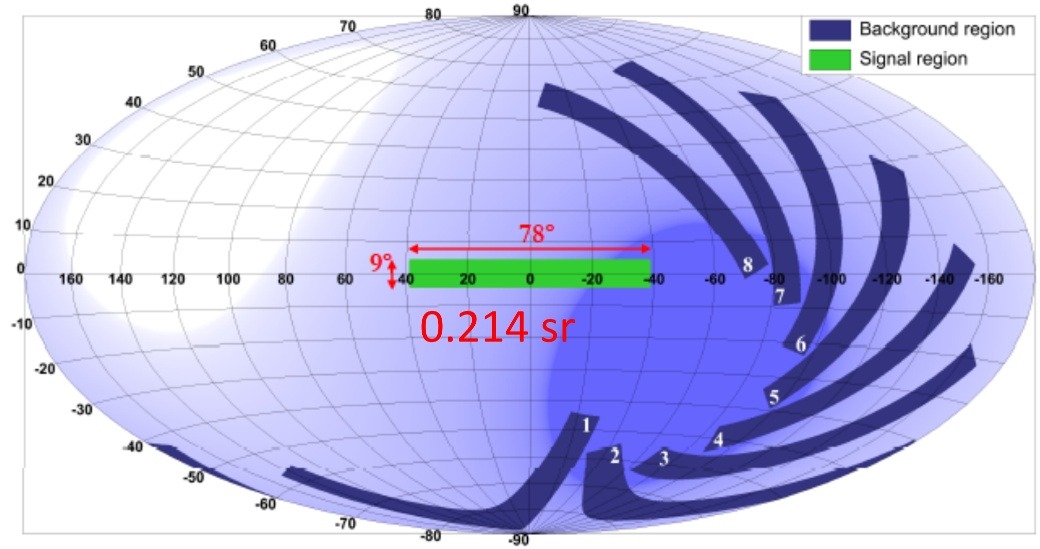
$$E^2 \frac{\mathrm{d}\Phi_{\nu_\mu + \bar{\nu}_\mu}}{\mathrm{d}E} < A \times 10^{-7}\,\mathrm{GeV\,cm^{-2}\,s^{-1} sr^{-1}}$$

where A value depends on the energy cutoff:

- no energy cutoff: A=5.3 (6 TeV < E_ν < 2 PeV)
- 500 TeV cutoff : A=8.4 (6 TeV < E_ν < 600 TeV)
- 100 TeV cutoff : A=16.0 (5 TeV < E_ν < 200 TeV)
- 50 TeV cutoff : A=24.3 (5 TeV < E_ν < 160 TeV)

Neutrino fluxes from “special” regions – 2
Galactic plane

- CR interaction in the ISM
- π → ν and gammas
- $E^{-2.6}$ spectrum expected;
- magnetic field can enhance the neutrino signal
- On/Off zones approach



- Different models and MRF considered to optimize the size of the on-zone
- Number (=8) and size of the off-zones optimized according to MC simulations

Neutrino fluxes from "special" regions – 2
Galactic plane

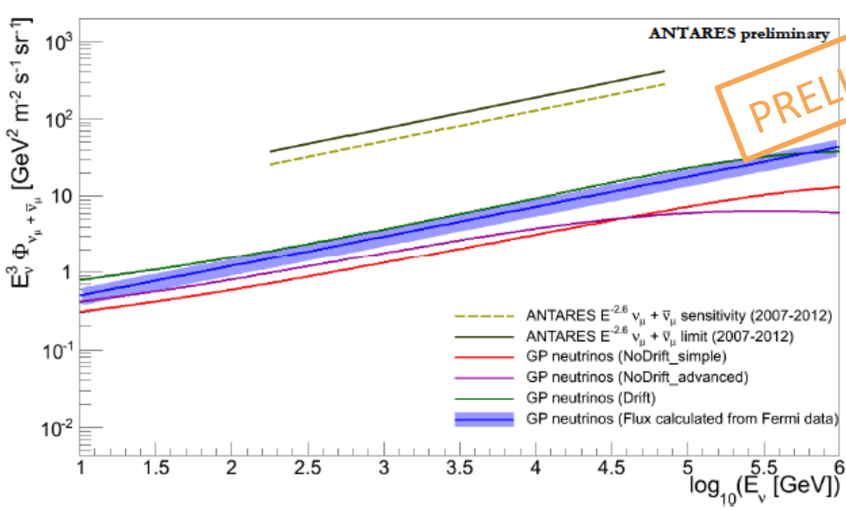
2007-2011 data:

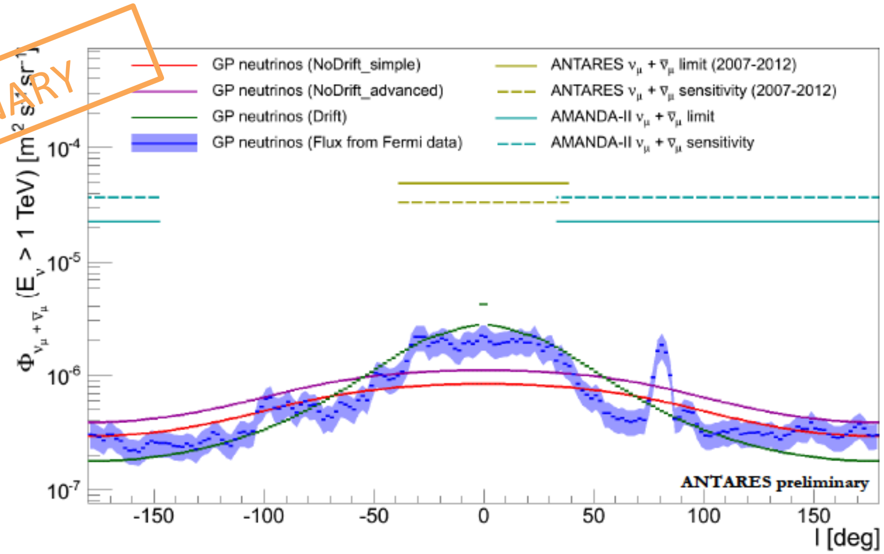
n_{obs}= 177, n_{exp}= 166

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

Upper limits for the neutrino flux from the Galactic Plane central (178 GeV < E_υ < 70.8 TeV)





Conclusions

- ANTARES: moderate size but good performances.
- Mediterranean Sea location → good visibility of the Southern sky (Galactic Plane and Fermi bubbles).
- Expected improvements:
  - Longer livetime being accumulated and analysed
  - Joint tracks and showers analysis(T. Eberl's talk) in progress
- Charm studies starting soon (hopefully!)