ANTARES constraints to a Galactic component of the HESE ν's

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Details: see arXiv 1409.4552

Constraints to a Galactic Component of the Ice Cube cosmic neutrino flux from ANTARES

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Abstract

The IceCube evidence for cosmic neutrinos in the high-energy starting events (HESE) sample has inspired a large number of hypothesis on their origin, mainly due to the poor precision on the measurement of the direction of showering events. The fact that most of HESE are downward going suggests a possible Galactic component. This could be originated either by a single point-like source or to a directional excess from an extended Galactic region. These hypotheses are reviewed and constrained, using the present available upper limits from the ANTARES neutrino telescope.

ANTARES detects ν_μ from sources in the Southern sky with an effective area larger than that providing the IceCube HESE for $E_\nu < 60$ TeV and a factor of about two smaller at 1 PeV. The use of the ν_μ signal enables an accurate measurement of the incoming neutrino direction. The Galactic signal allowed by the IceCube HESE and the corresponding ANTARES limits are studied in terms of a power law flux $E^{-\Gamma}$, with spectral index Γ ranging from 2.0 to 2.5 to cover most astrophysical models.

A galactic component in HESE

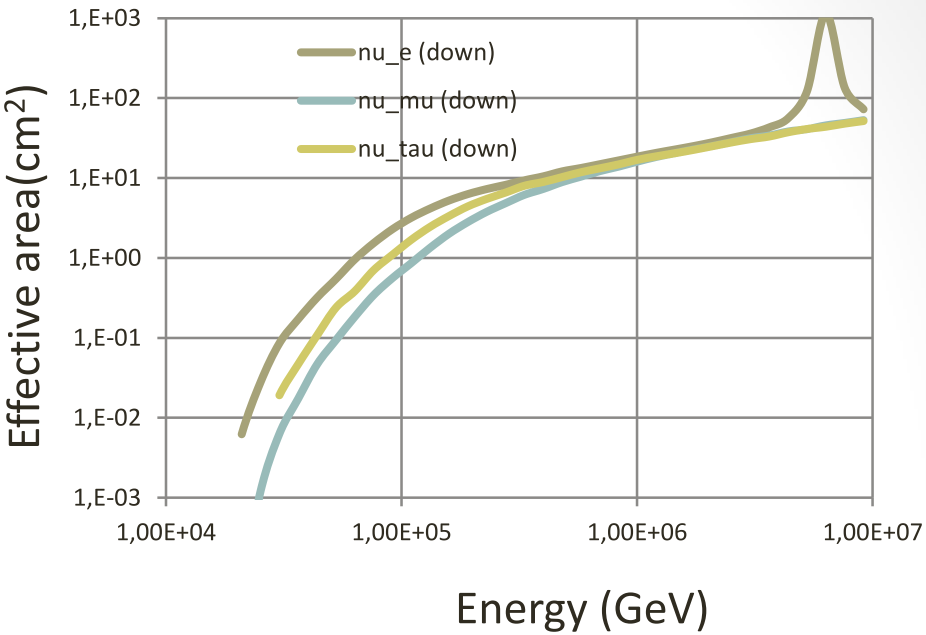
- A correlation with the galactic plane/center is quoted statistically non-significant in the PRL;
- The expected signal from the Northern hemisphere (~purely extragalactic) is a factor of 2 larger than measured;
- Assuming 3.6 Up and symmetric extragalactic contribution, the expected Down HESE of extragalactic origin are: =6.2 (5.8) events for the $E^{-2.0}$ ($E^{-2.5}$) spectrum.
- **Galactic contribution**= 13.7-6.2 ≅ **7.5 events**

	Data	Bck	n'_{IC}	N'_{IC} E^{-2} (best fit)
All	20	2.7	17.3	18.2
Up (North)	5	1.4	3.6	6.7
Down (South)	15	1.3	13.7	11.5

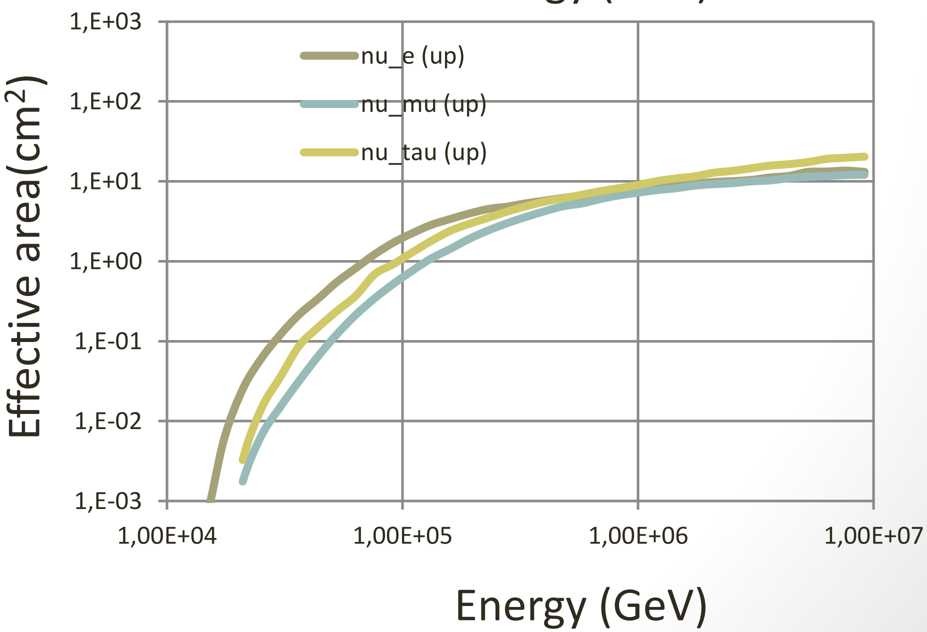
$60\ \mathrm{TeV} < E_{dep} < 3\ \mathrm{PeV}$

HESE effective area for:

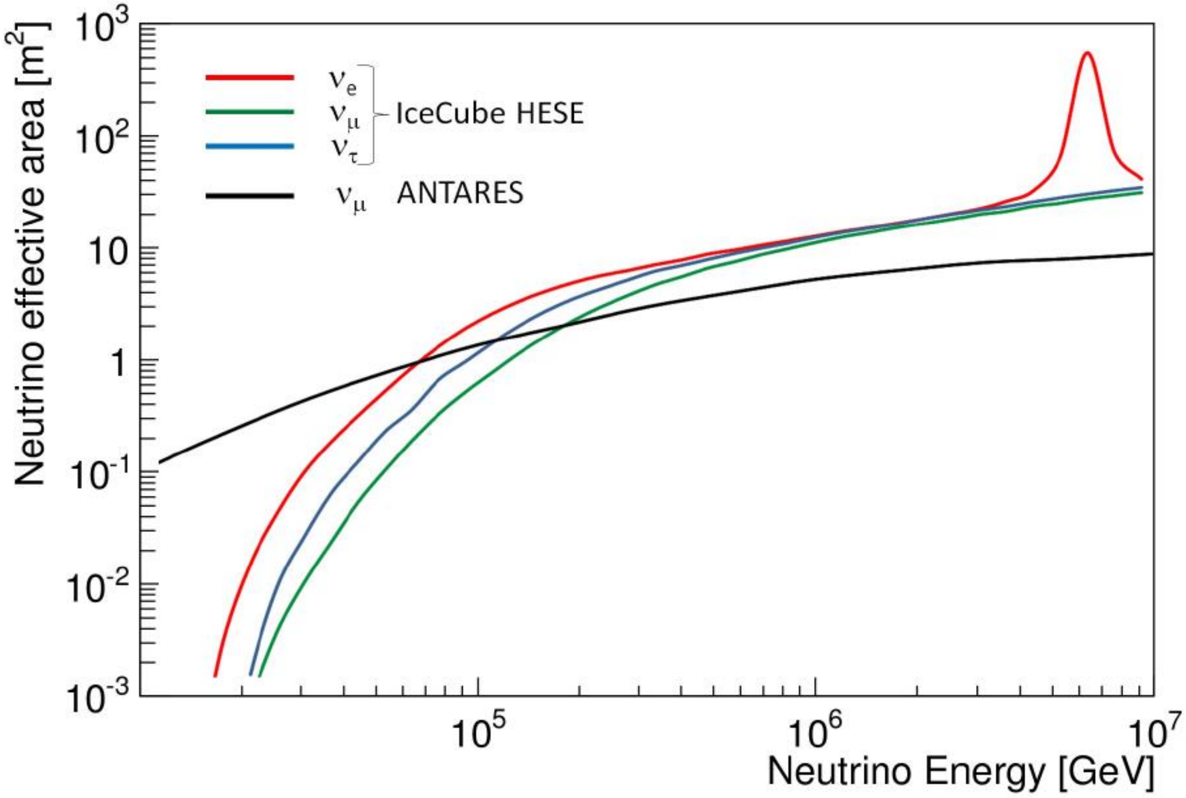
Downgoing



Upgoing



Comparison between HESE/ANTARES A_{eff}



- IceCube = 4π, high energy sample (E_ν>30 TeV), almost bck free
- ANTARES= ν_μ only, **southern sky only**

The HESE signal

$$E^2\Phi(E) \equiv \Phi_0^{D,2.0}$$
$$= (0.95 \pm 0.3) \times 10^{-8}\ \mathrm{GeV\ cm^{-2}s^{-1}sr^{-1}}$$

From IceCube PRL113(2014)101101

$$E^2\Phi(E) = 1.5 \times 10^{-8}\ (E/\Lambda)^{-0.3}\ \mathrm{GeV\ cm^{-2}s^{-1}sr^{-1}}$$

$$\Lambda \equiv 100\ \mathrm{TeV}$$

$$\frac{E^{2.3}}{\lambda^{0.3}}\Phi^{D,2.3}(E) \equiv \Phi_0^{D,2.3}$$

$$\lambda \equiv 1\ \mathrm{GeV} \qquad = 4.7 \times 10^{-7}\ \mathrm{GeV\ cm^{-2}s^{-1}sr^{-1}}.$$

- It is possible, using the effective area, to obtain the **normalization factor** $\Phi^{D,\Gamma}$ for any spectral index Γ;
- This extend the possible range of astrophysical models for the signal
- In particular, we are interested on a possible Galactic component

The HESE normalization factors for different Γ's (1) $\Phi_0^{D,\Gamma}$

- Valid for a generic $E^{-\Gamma}$ spectrum
- Derived from the IC effective areas

observed events

livetime

Diffuse flux

$$N_{IC} = T \cdot \int \Phi^{D,\Gamma}(E) \cdot [A^{\nu_e}_{eff} + A^{\nu_\mu}_{eff} + A^{\nu_\tau}_{eff}] \cdot dE \cdot d\Omega$$

$$= 4\pi T \cdot \Phi_0^{D,\Gamma} \cdot \int E^{-\Gamma} \cdot A_{eff}(E) \cdot dE$$

$$= 4\pi T \; \Phi_0^{D,\Gamma} \cdot \mathcal{D}_\Gamma \; . \qquad (5)$$

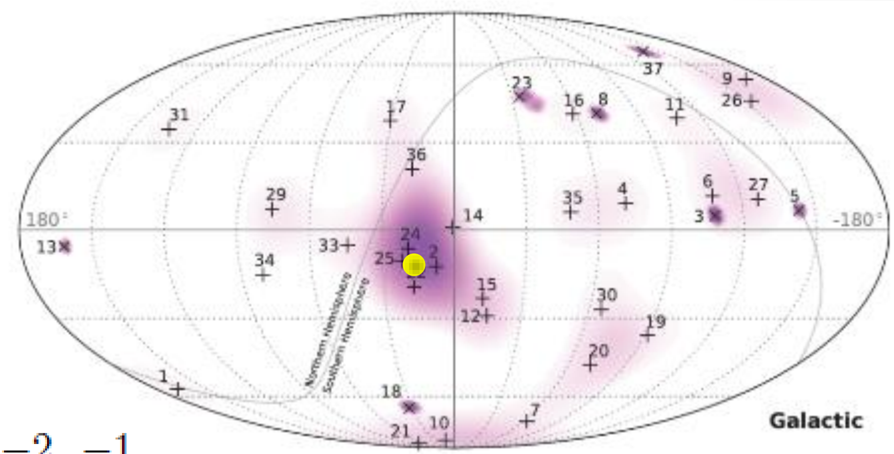
Detector response, computed numerically

The HESE normalization factors for different Γ's (2)

- By imposing the same N_{IC} from the previous formula:

$\Gamma =$	$\Phi_0^{D,\Gamma}$ (GeV cm^{-2} s^{-1} sr^{-1})	$\frac{\Phi_0^{D,\Gamma}}{\Phi_0^{D,2}}$	0.1-1 PeV	> 1 PeV
2.0	0.95×10^{-8}	1	60%	31%
2.1	3.5×10^{-8}	3.7	63%	26%
2.2	1.2×10^{-7}	13.5	66%	21%
2.3	4.6×10^{-7}	48	68%	17%
2.4	1.6×10^{-6}	170	68%	13%
2.5	5.4×10^{-6}	580	68%	10%

I) A point-like Galactic source



- Galactic contribution from a point-like source
- n_p events out N_{IC} are due to this source, with energy spectrum:

$$E^{\Gamma}\Phi^{p,\Gamma}(E) = \Phi_0^{p,\Gamma} \quad \text{units: GeV cm}^{-2} s^{-1}$$

The normalization factor can be derived with the use of the A_{eff} (E)

- The normalization factor depends on the diffuse normalization factor $\Phi_0^{D,\Gamma}$ (for Γ=2.0 , that reported in the IceCube paper)

$$\Phi_0^{p,\Gamma} = 4\pi \cdot \left(\frac{n_p}{N_{IC}}\right) \cdot \Phi_0^{D,\Gamma}$$

Same formula as in:

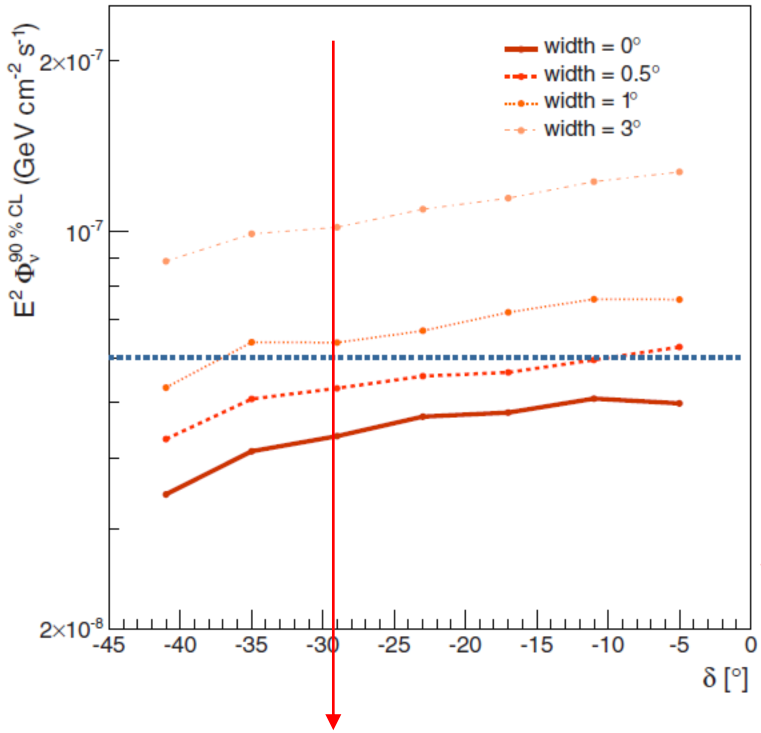
S. Razzaque. Phys. Rev. D 88 (2013) 081302;

Luis A. Anchordoqui et al. JHEAp (2013)

M.C. Gonzalez-Garcia, F. Halzen, V. Niro. Astropart.Phys. 57-58 (2014) 39-48; arXiv:1310.7194 [astro-

ANTARES has upper bounds

THE ASTROPHYSICAL JOURNAL LETTERS, 786:L5 (5pp), 2014 May 1



For different energy spectra $E^{-\Gamma}$:
(similar method using the A_{eff})

$\Gamma =$	$\Phi_0^{A,\Gamma}$ (GeV cm^{-2} s^{-1})	$\Phi_0^{A,\Gamma}/\Phi_0^{A,2}$
2.0	4.0×10^{-8}	1
2.1	1.2×10^{-7}	2.9
2.2	3.2×10^{-7}	8.1
2.3	8.4×10^{-7}	21
2.4	2.2×10^{-6}	56
2.5	5.5×10^{-6}	138

$$E^2\Phi^{A,2.0} \equiv \Phi_0^{A,2.0} \simeq 4.0 \times 10^{-8}\ \text{GeV cm}^{-2}\text{s}^{-1},\ \text{point-like}$$

$$\simeq 5.0 \times 10^{-8}\ \text{GeV cm}^{-2}\text{s}^{-1}\ ,\ \text{for } 0.5^\circ$$

$$\simeq 6.5 \times 10^{-8}\ \text{GeV cm}^{-2}\text{s}^{-1}\ ,\ \text{for } 1^\circ$$

$$\simeq 10 \times 10^{-8}\ \text{GeV cm}^{-2}\text{s}^{-1}\ ,\ \text{for } 3^\circ$$

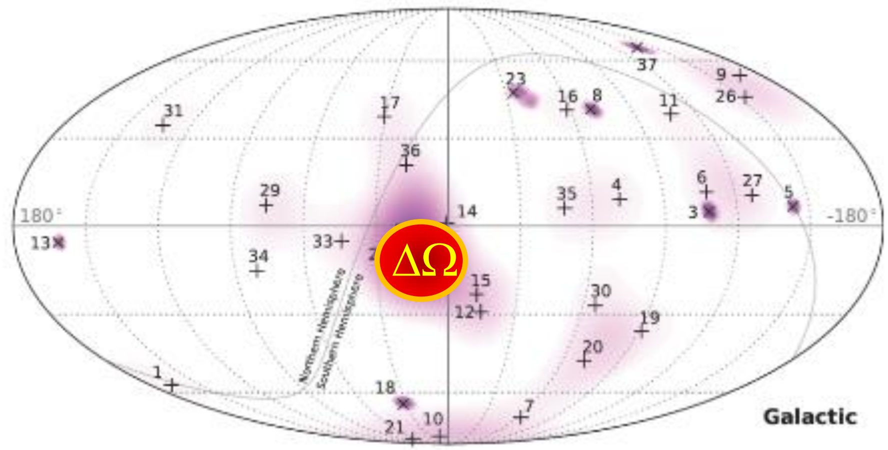
Results

$$\Phi_0^{p,\Gamma} = 4\pi \cdot \left(\frac{n_p}{N_{IC}}\right) \cdot \Phi_0^{D,\Gamma}$$

$\Gamma =$	IceCube $\Phi_0^{p,\Gamma}$ (GeV cm^{-2} s^{-1}) $n_p = 1$	$n_p = 2$	$n_p = 3$	$n_p = 4$	$n_p = 5$	ANTARES 90% C.L. upper limit
2.0	$6.9\ 10^{-9}$	$1.4\ 10^{-8}$	$2.1\ 10^{-8}$	$2.8\ 10^{-8}$	$3.5\ 10^{-8}$	$4.0\ 10^{-8}$
2.1	$2.6\ 10^{-8}$	$5.1\ 10^{-8}$	$7.7\ 10^{-8}$	$1.0\ 10^{-7}$	$\underline{1.3\ 10^{-7}}$	$1.2\ 10^{-7}$
2.2	$9.0\ 10^{-8}$	$1.8\ 10^{-7}$	$2.7\ 10^{-7}$	$\underline{3.6\ 10^{-7}}$	-	$3.2\ 10^{-7}$
2.3	$3.3\ 10^{-7}$	$6.6\ 10^{-7}$	$\underline{9.9\ 10^{-7}}$	-	-	$8.4\ 10^{-7}$
2.4	$1.2\ 10^{-6}$	$\underline{2.3\ 10^{-6}}$	-	-	-	$2.2\ 10^{-6}$
2.5	$3.9\ 10^{-6}$	$\underline{7.9\ 10^{-6}}$	-	-	-	$5.5\ 10^{-6}$

- The ANTARES 90% C.L. upper limit excludes that a single point-like source produces more than 5 HESE, assuming Γ=2.0.
- A single point-like source yielding a cluster of more than 2 events is excluded for Γ=2.3
- A clusters made of two or more events is excluded for Γ> 2.3.

II) Enhanced diffuse Galactic source



- Signal due to a extended source, comparable with the IC angular resolution
- Size ΔΩ much larger than the ANTARES angular resolution
- $n_{\Delta\Omega}$ events out N_{IC} are due to this source, with energy spectrum:

$$E^{\Gamma}\Phi^{D',\Gamma}(E) = \Phi_0^{D',\Gamma}$$

$$\Phi_0^{D',\Gamma} = \left(\frac{n_{\Delta\Omega}}{N_{IC}}\right)\cdot\left(\frac{4\pi}{\Delta\Omega}\right)\cdot\Phi_0^{D,\Gamma}$$

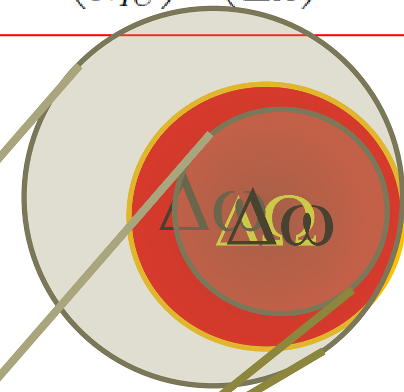
$(\mathrm{GeV\ cm^{-2}\ s^{-1}\ sr^{-1}})$

Predictions ($n_{\Delta\Omega}$, $\Delta\Omega$) vs. Γ

$$\Phi_0^{D',\Gamma} = \left(\frac{n_{\Delta\Omega}}{N_{IC}}\right) \cdot \left(\frac{4\pi}{\Delta\Omega}\right) \cdot \Phi_0^{D,\Gamma}$$

units: (GeV cm^{-2} s^{-1} sr^{-1})

$\Delta\Omega$		$\Phi_0^{D',\Gamma}$ (from HESE)			
(sr)	$\Gamma =$	$n_{\Delta\Omega} = 3$	$n_{\Delta\Omega} = 4$	$n_{\Delta\Omega} = 5$	$n_{\Delta\Omega} = 6$
0.06	2.0	3.5 10^{-7}	4.6 10^{-7}	5.8 10^{-7}	7.0 10^{-7}
	2.2	4.5 10^{-6}	6.0 10^{-6}	7.5 10^{-6}	9.0 10^{-6}
	2.3	1.7 10^{-5}	2.2 10^{-5}	2.8 10^{-5}	3.3 10^{-5}
	2.4	5.9 10^{-5}	7.8 10^{-5}	9.8 10^{-5}	1.2 10^{-4}
0.38	2.0	5.4 10^{-8}	7.3 10^{-8}	9.1 10^{-8}	1.1 10^{-7}
	2.2	7.1 10^{-7}	9.4 10^{-7}	1.2 10^{-6}	1.4 10^{-6}
	2.3	2.6 10^{-6}	3.6 10^{-6}	4.4 10^{-6}	5.2 10^{-6}
	2.4	9.3 10^{-6}	1.2 10^{-5}	1.5 10^{-5}	1.9 10^{-5}



- This is observed as a directional cosmic neutrino flux

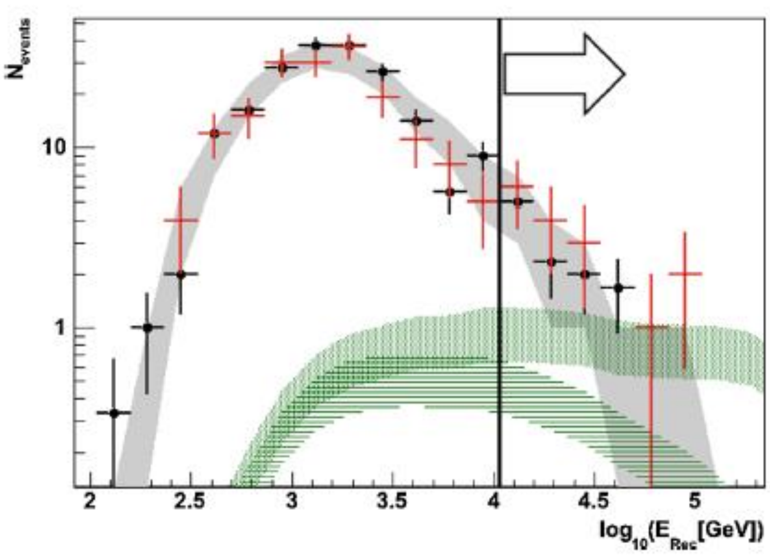
$$\Phi^{\Delta\omega,\Gamma} = \Phi^{D',\Gamma} \cdot \Delta\omega \quad \text{units: GeV cm}^{-2}\ \text{s}^{-1}$$

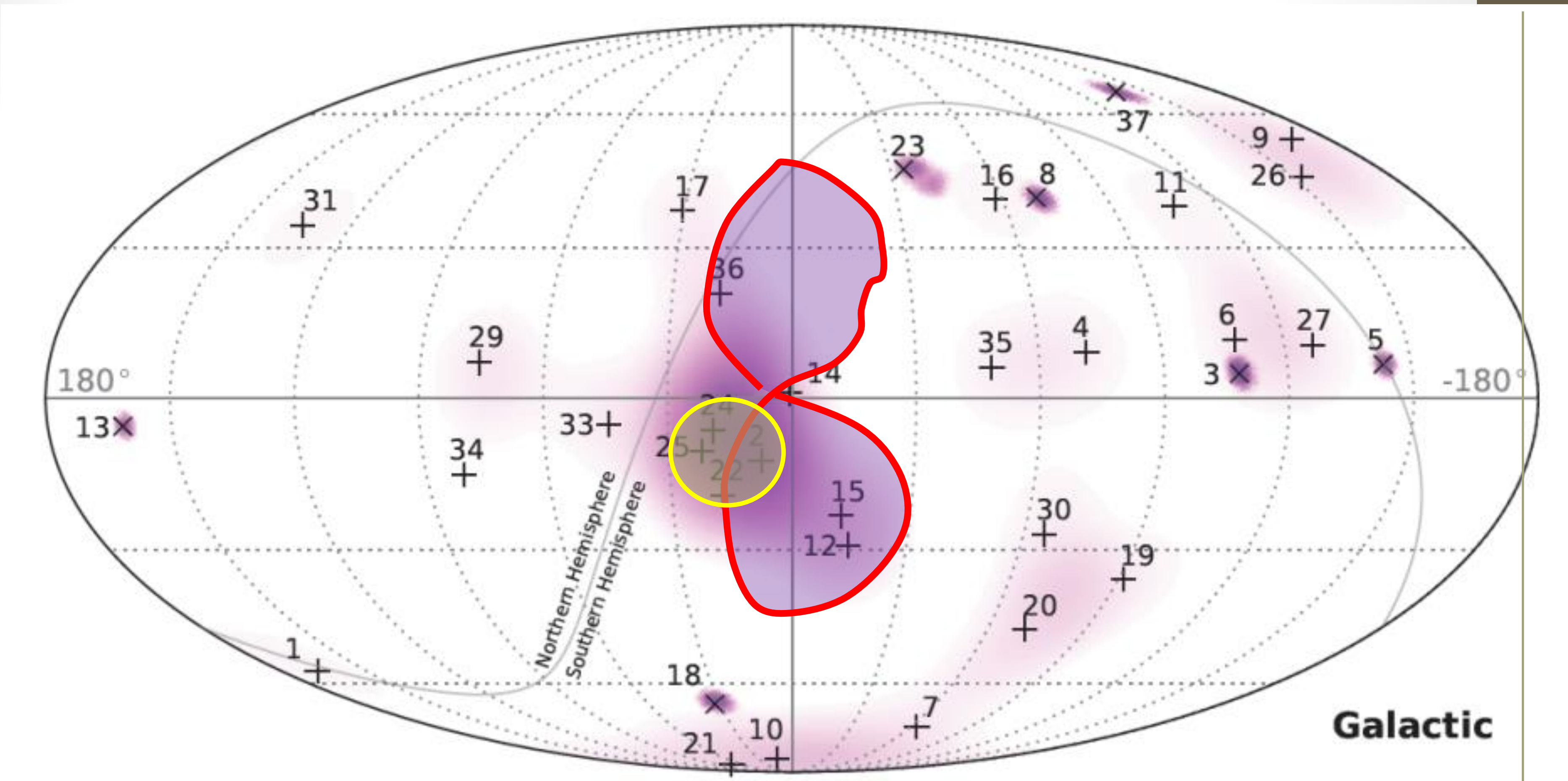
ANTARES bounds?

- At present, missing constraints;
- Problem: for an extended source, large background of atmospheric neutrinos (~50 events in a 8° radius);
- Strategy: suppress the atmospheric neutrinos using the muon estimated energy
- Compare background in ON/OFF regions
- Method already used in the FB analysis
- Sensitivity:

$$3.1 \times 10^{-7} \text{ GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$$

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





180°
-180°
Galactic
Northern Hemisphere
Southern Hemisphere
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ANTARES sensitivities on an enhanced cosmic ν flux

- I assume an ANTARES analysis similar to that on FB;
- Sensitivity extrapolated to a region with **different size** and assuming a **generic spectral index** Γ;
- Effective area, before the cut on the energy estimator E_{obs}, equal to A_{eff} used for the point-like source;

$\Gamma =$	$\Phi_0^{A,\Gamma}$ (GeV cm^{-2} s^{-1})	$\Phi_0^{A,\Gamma}/\Phi_0^{A,2}$
2.0	4.0×10^{-8}	1
2.1	1.2×10^{-7}	3.5
2.2	3.2×10^{-7}	11.6
2.3	8.4×10^{-7}	36.3
2.4	2.2×10^{-6}	116
2.5	5.5×10^{-6}	343

- Optimization on the cut on E_{obs} has an effect on the number of accepted background events (reduces the effective area);
- This effect increases the ratios for softer Γ w.r.t. E^{-2} by a multiplicative factor $(1.2)^k$ for $\Gamma = 2 + 0.1 \times k$.
- No (first-order) effects for changing the size $\Delta\omega$;
  - Signal: events/$\Delta\omega$; events/$\Delta\omega$

Perspectives for an enhanced diffuse flux search in the hot spot region

$\Delta\Omega$ (sr)	$\Gamma =$	$\Phi_0^{D',\Gamma}$ (from HESE), units: (GeV cm^{-2} s^{-1} sr^{-1}) $n_{\Delta\Omega} = 3$	$n_{\Delta\Omega} = 4$	$n_{\Delta\Omega} = 5$	$n_{\Delta\Omega} = 6$	ANTARES sensitivity
0.06	2.0	$3.5\ 10^{-7}$	$4.6\ 10^{-7}$	$5.8\ 10^{-7}$	$7.0\ 10^{-7}$	$3.1\ 10^{-7}$
8°	2.2	$4.5\ 10^{-6}$	$6.0\ 10^{-6}$	$7.5\ 10^{-6}$	$9.0\ 10^{-6}$	$3.6\ 10^{-6}$
	2.3	$1.7\ 10^{-5}$	$2.2\ 10^{-5}$	$2.8\ 10^{-5}$	$3.3\ 10^{-5}$	$1.1\ 10^{-5}$
	2.4	$5.9\ 10^{-5}$	$7.8\ 10^{-5}$	$9.8\ 10^{-5}$	$1.2\ 10^{-4}$	$3.4\ 10^{-5}$
0.38	2.0	$5.4\ 10^{-8}$	$7.3\ 10^{-8}$	$9.1\ 10^{-8}$	$1.1\ 10^{-7}$	$3.1\ 10^{-7}$
20°	2.2	$7.1\ 10^{-7}$	$9.4\ 10^{-7}$	$1.2\ 10^{-6}$	$1.4\ 10^{-6}$	$3.6\ 10^{-6}$
	2.3	$2.6\ 10^{-6}$	$3.6\ 10^{-6}$	$4.4\ 10^{-6}$	$5.2\ 10^{-6}$	$1.1\ 10^{-5}$
	2.4	$9.3\ 10^{-6}$	$1.2\ 10^{-5}$	$1.5\ 10^{-5}$	$1.9\ 10^{-5}$	$3.4\ 10^{-5}$
FB						90% C.L. limit
0.66	2.0	$3.1\ 10^{-8}$	$4.2\ 10^{-8}$	$5.2\ 10^{-8}$	$6.3\ 10^{-8}$	$5.4\ 10^{-7}$

ΔΩ

ΔΩ

Conclusions

- The galactic component in the HESE sample quantitatively estimated (it could be over-fluctuation…)
- Due to the similarity on the IC HESE/ANTARES effective areas, a point-like signal or an enhanced diffuse signal in the Galaxy can be seen/excluded by ANTARES
- 1) **Presence of a point-like source**. Upper limits already published by ANTARES constrain severely some hypothesis, in particular for energy spectra $E^{-\Gamma}$ with $\Gamma > 2.2$
- 2) **Extended source**, seen as an enhanced diffuse flux. Model yielding more than 2 events within $\Delta\Omega$ = 0.06 sr and $\Gamma \geq 2.0$ can be confirmed or excluded by ANTARES by means of an analysis similar to that already done on FB
- The role of KM3NeT- Phase 1 (A_{eff} about 3-4 of ANTARES)