The IceCube Neutrino Anomaly

Carlo Mascaretti, Andrea Palladino, Francesco Vissani

LNGS & GSSI

PAHEN Workshop, Naples, September 2017

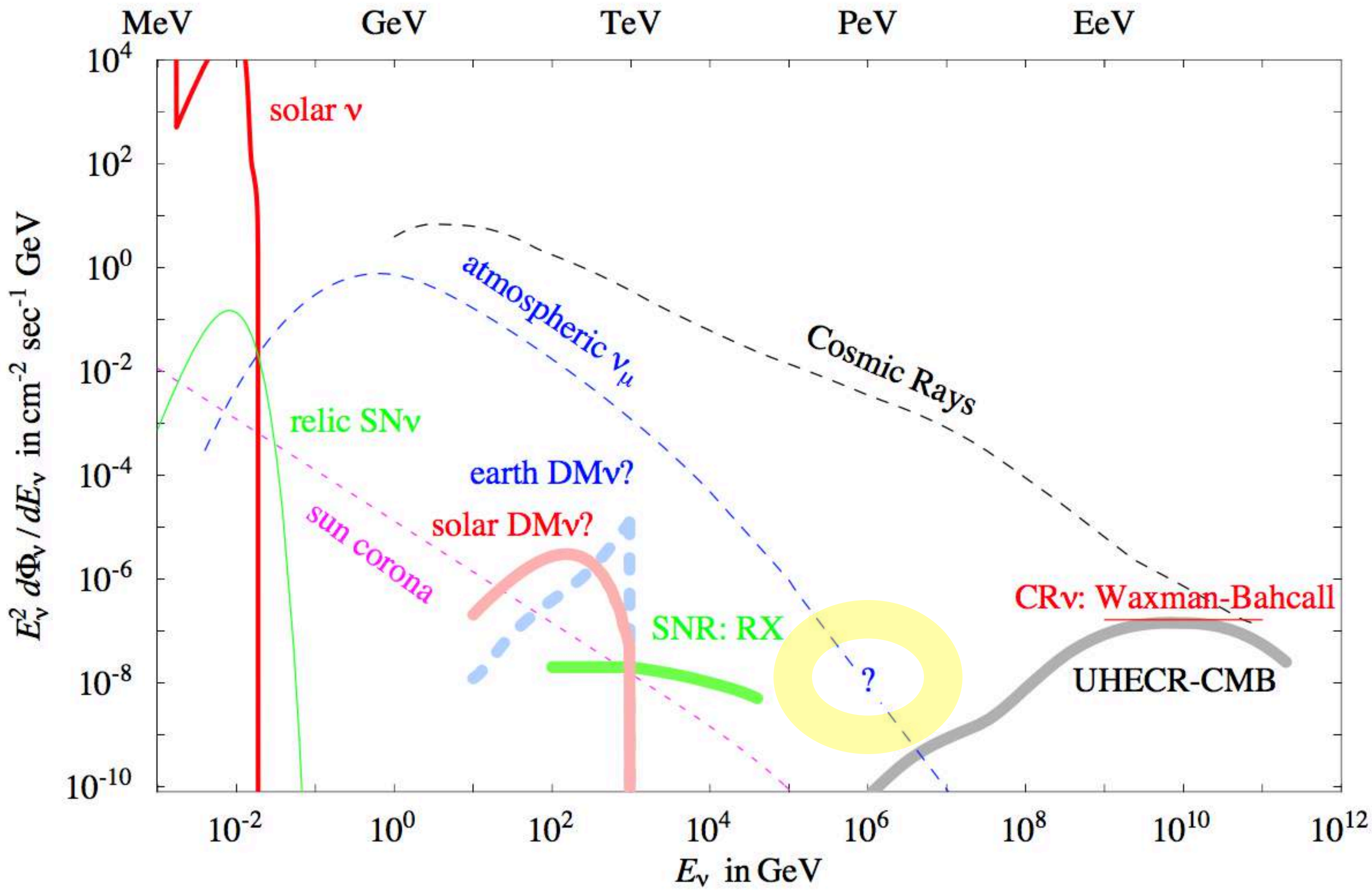

Figure 11.1: *Plausible optimistic sketch of neutrino fluxes from astrophysical sources. Present experimental constraints (not shown) are somewhat above unseen sources: from left to right one has neutrinos from relic SN, from DM annihilations in the sun or earth, from SN remnants, from CR.*

NEUTRINO ASTRONOMY 10 YEARS AGO [HEP-PH/0606054]

GSSI + LNGS + Aquila U.

Palladino, Celli, Mascaretti, Esmaili, Pagliaroli, Villante, Vissani + Spurio

On the compatibility of the IceCube results with an universal neutrino spectrum arXiv:1708.02094 [astro-ph.HE].

On the IceCube spectral anomaly JCAP 1612 (2016) no.12, 045.

Extragalactic plus Galactic model for IceCube neutrino events Astrophys.J. 826 (2016) no.2, 185.

Can BL Lac emission explain the neutrinos above 0.2 PeV? Astron.Astrophys. 604 (2017) A18.

Neutrinos and γ-rays from Galactic Center Region after H.E.S.S. multi-TeV measurements Eur.Phys.J. C77 (2017) 66.

A discussion of IceCube neutrino events, circa 2015 EPJ Web Conf. 116 (2016) 11002.

Double pulses and cascades above 2 PeV in IceCube Eur.Phys.J. C76 (2016) no.2, 52.

Testing nonradiative neutrino decay scenarios with IceCube data Phys.Rev. D92 (2015) no.11, 113008.

The natural parameterization of cosmic neutrino oscillations Eur.Phys.J. C75 (2015) 433.

What is the flavor of the cosmic neutrinos seen by IceCube? Phys.Rev.Lett. 114 (2015) no.17, 171101.

KEY QUESTION

- We had in advance *more or less precise* expectations on solar-, supernova-, geo-neutrinos as well

- We *did not know* the existence of a new HE neutrino flux component-and still we do not know a lot about it

<u>How should we summarize/describe/model the new component that IceCube has seen/is seeing?</u>

Conventional answer

Adopt the simplest functional form, that resembles the theoretical expectations and it is not incompatible with the data

Which theoretical expectations we should adopt?

If there are free parameters, should we use the same parameters for different data analyses?

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Extragalactic neutrinos from pp-sources

Energy spectrum (assumption)

$$\frac{d\Phi^{\rm inj}_{\rm CR}}{dE_{\rm CR}} \propto E_{\rm CR}^{-\alpha_{\rm inj}} \text{ with } \alpha_{\rm inj} = 2 \div 2.4$$

$$\frac{d\Phi_\nu}{dE_\nu} \propto E_\nu^{-\alpha_\nu} \text{ with } \alpha_\nu \approx \alpha_{\rm inj} - 0.1$$

Angular distribution (assumption)

$$\frac{d\Phi_\nu}{d\Omega} = \frac{1}{4\pi}$$

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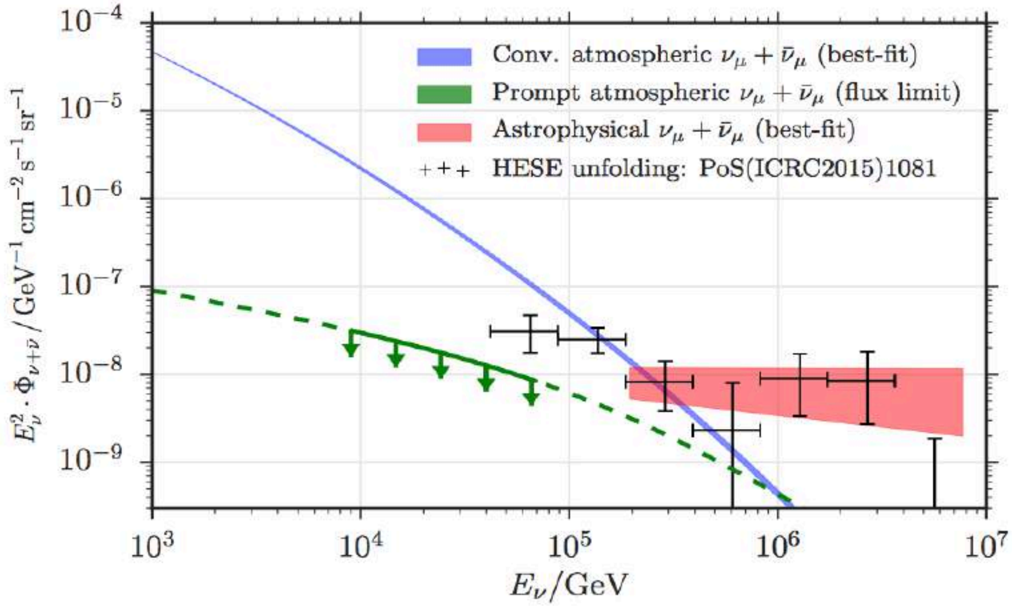
Reasonable, simple, few parameters



[ApJ833, 2016]

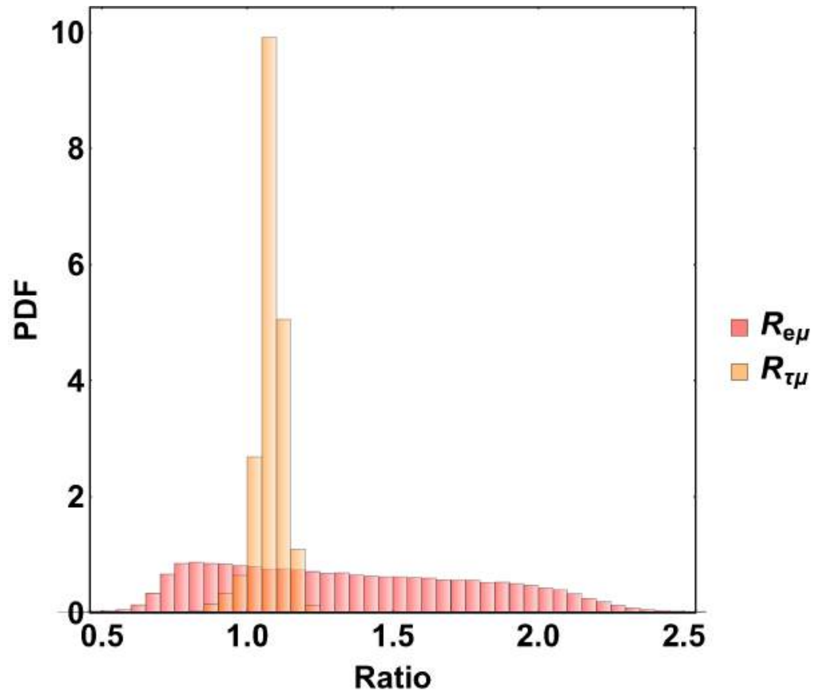
IceCube passing-μ signal fits with these expectations

The slope consistent with six year of data analysis is α=2.13±0.13. Note that,

① This description concerns data in the decade 0.2 PeV-2 (some) PeV;

② The break/cutoff, if present, is above some PeV;

③ The HESE above 0.2 PeV are *consistent* with the same description.



[Palladino et al, arXiv1708.02094]

This means, tau neutrino signal is within reach

Three-flavor oscillations imply that the ratio of muon and tau neutrino fluxes is very close to unity, *whatever the mechanism of production* (orange histogram). We expect ~2/3 double pulse events from tau neutrinos, with ~50% uncertainty, in current dataset.

[See the poster of C. Mascaretti & arXiv1708.02094 for details & quantitative statements.]

Remarks

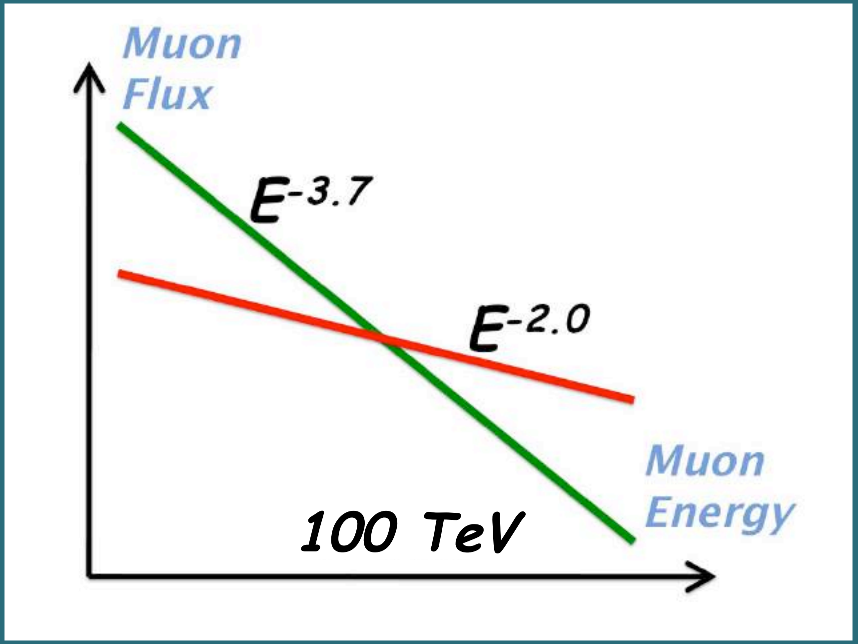
The passing-μ signal was first discussed end of 50s

Largely free from atmospheric μ-background

The signal in IceCube is from the northern sky

Most μs>0.2 PeV from a crown below horizon,

but still, the signal is compatible with isotropy



Even in absence of a firm theory as a guidance, IceCube has seen the long-sought passing muon signal, and this agrees with reasonable theoretical ideas.

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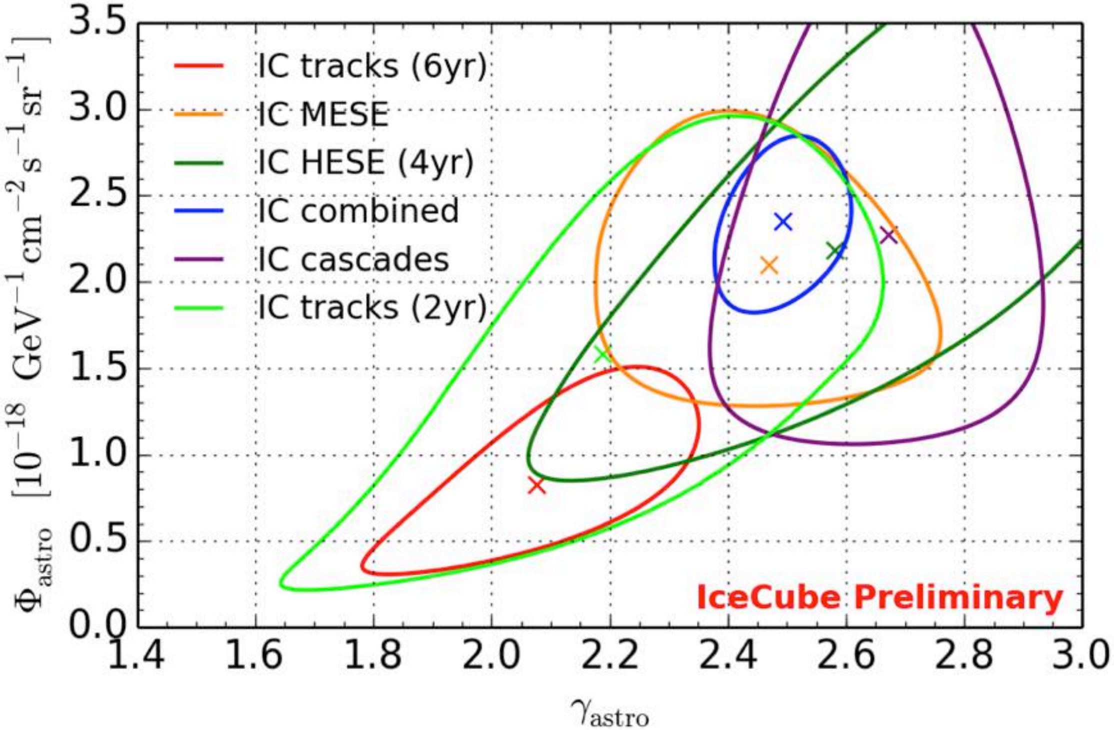
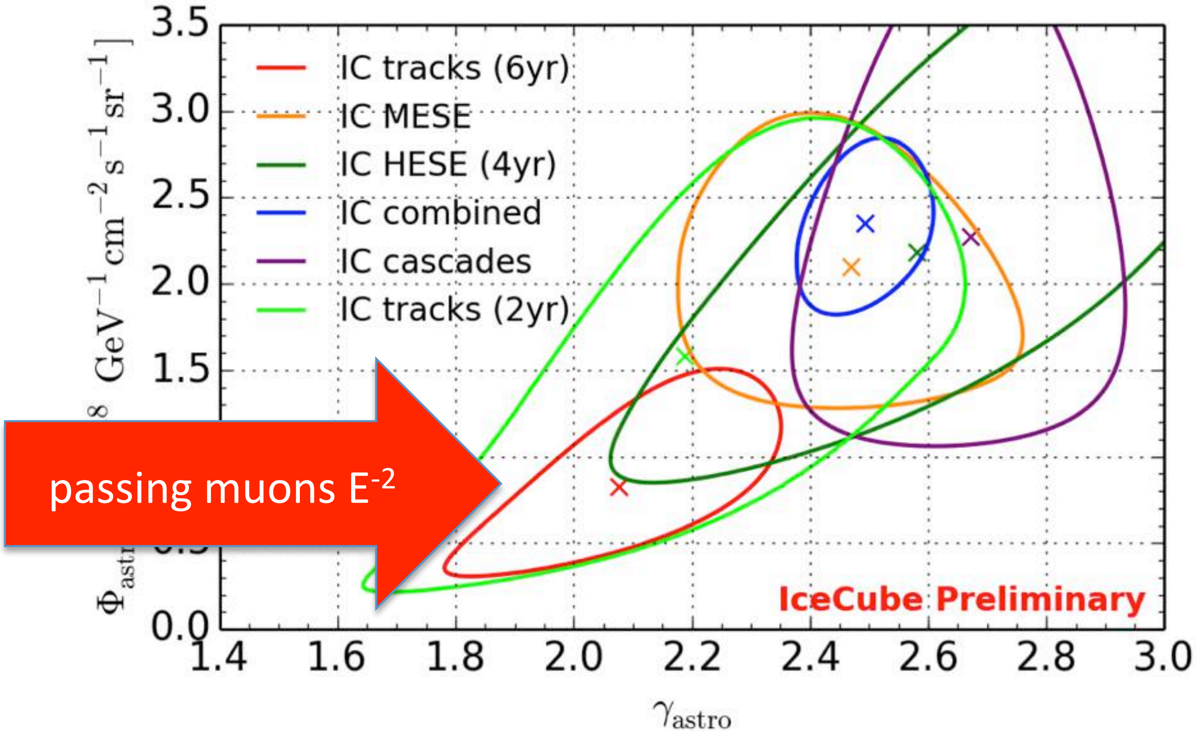
What is the problem then?



IC tracks (6yr)
IC MESE
IC HESE (4yr)
IC combined
IC cascades
IC tracks (2yr)
IceCube Preliminary
Φ_{astro} $[10^{-18}\ \mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}]$
γ_{astro}
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0



IC tracks (6yr)
IC MESE
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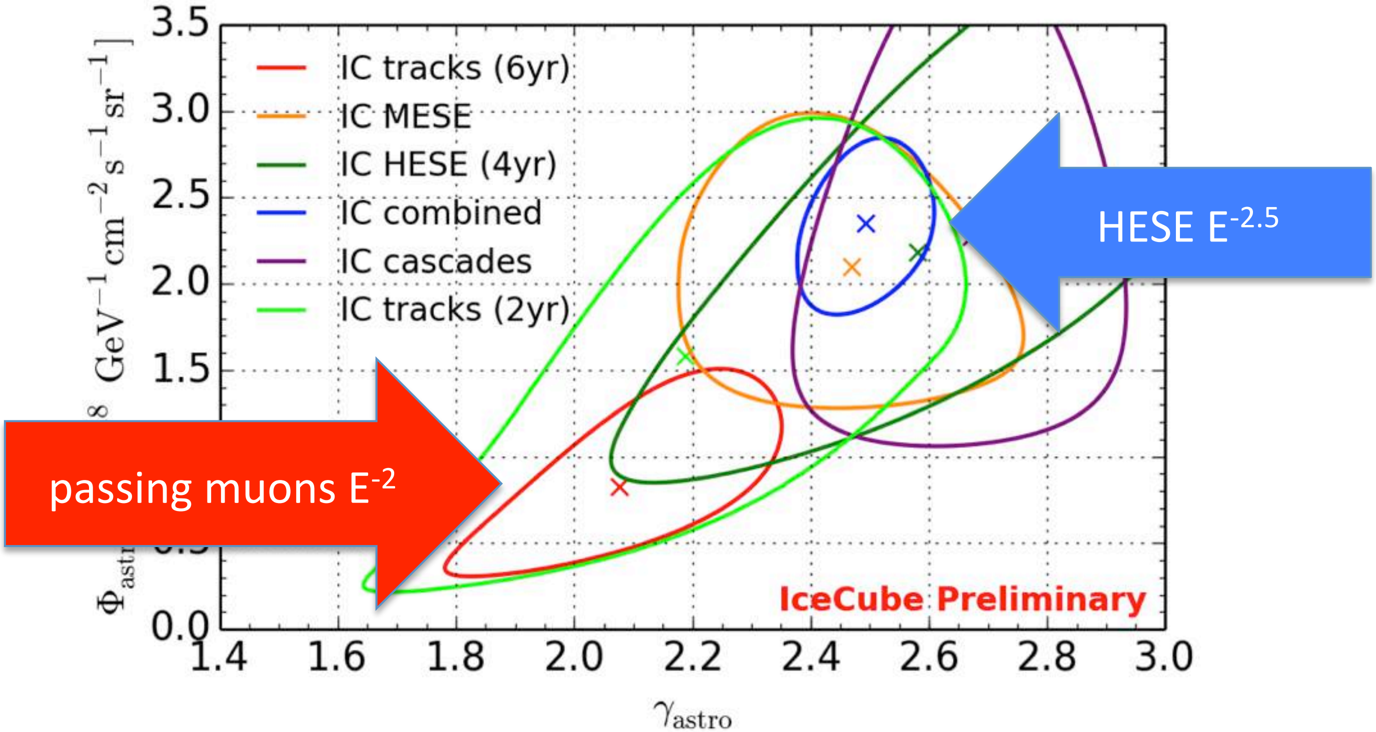
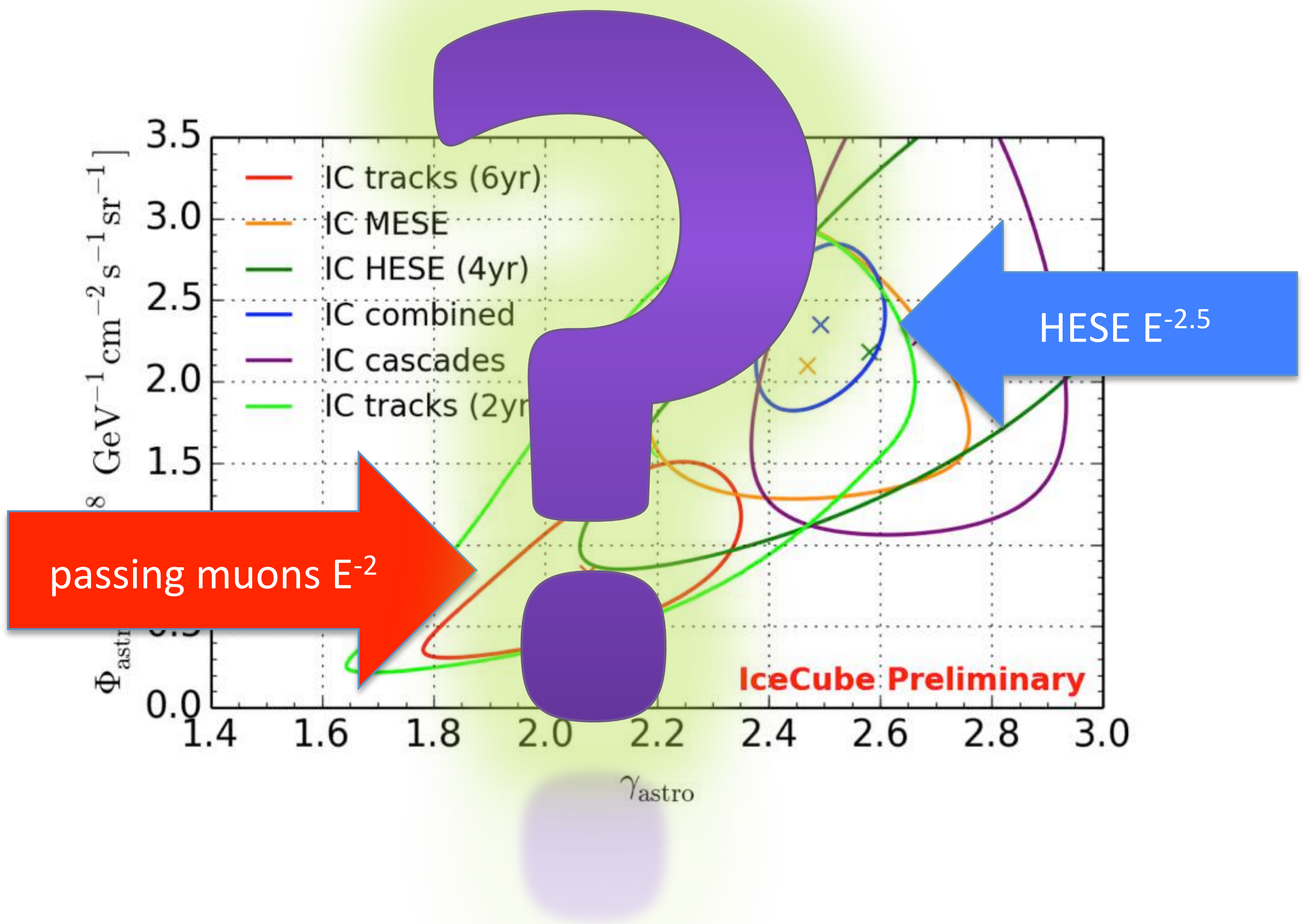
IceCube Preliminary
passing muons E-2


IC tracks (6yr)
IC MESE
IC HESE (4yr)
IC combined
IC cascades
IC tracks (2yr)
HESE E-2.5
passing muons E-2
IceCube Preliminary
3.5
3.0
2.5
2.0
1.5
0.0
1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0
γ_{astro}



IC tracks (6yr)
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The "spectral anomaly"

Journal of Cosmology and Astroparticle Physics

On the IceCube spectral anomaly

Andrea Palladino[a], Maurizio Spurio[b] and Francesco Vissani[a,c]

Published 28 December 2016 •

Journal of Cosmology and Astroparticle Physics, Volume 2016, December 2016

Article PDF

+ Article information

Abstract

Recently it was noted that different IceCube datasets are not consistent with the same power law spectrum of the cosmic neutrinos: this is the *IceCube spectral anomaly*, that suggests that they observe a multicomponent spectrum. In this work, the main possibilities to enhance the description in terms of a single extragalactic neutrino component are examined. The hypothesis

One dataset is from south sky, one from north; one is shower, one is track; systematics is different, *etc etc.* But still, one wonders…

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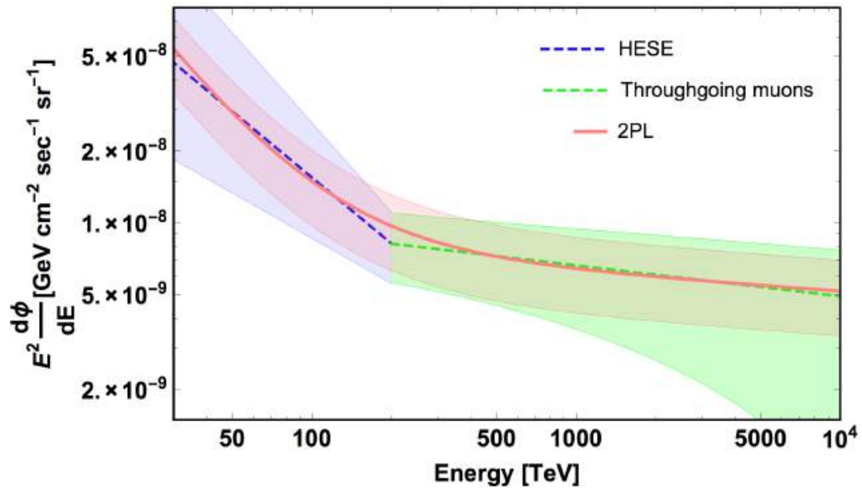
How to to reconcile

Passing-μs **and** ***HESE*** **findings?**

Let's work out the spectra step by step

We may try to maintain the assumption of isotropy, and then,

- ❑ The high energy part is given by passing-μ data
- ❑ Let's model the low energy shape on HESE
- ❑ Glue it, assuming regularity (continuity)
- ❑ Get a two-power law model



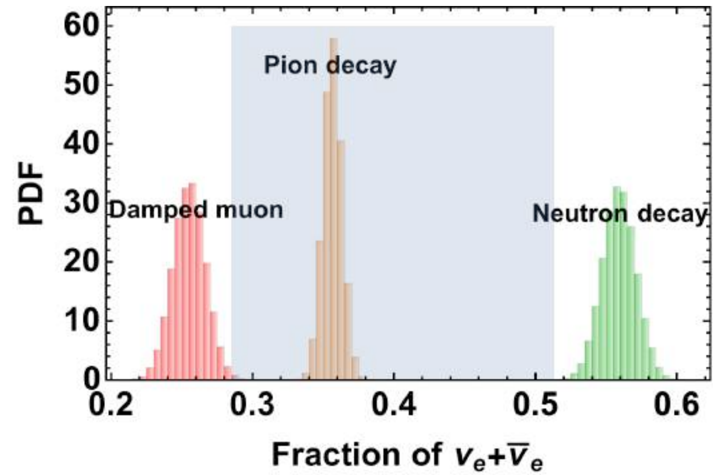
Palladino et al, arXiv1708.02094

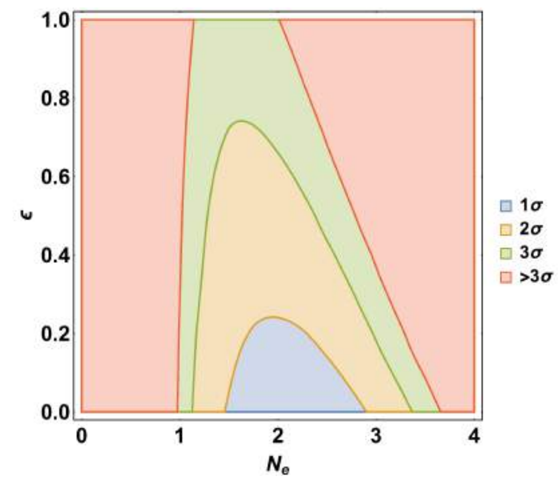
Next thing to do

- ◆ Assume three-flavor oscillations
- ◆ Test ν_e and $\bar{\nu}_e$
- ◆ Test $\nu_\tau+\bar{\nu}_\tau$

SPECTRA OF OTHER FLAVORS FIT NICELY …

- The τ-signal is as for the single power law model− it depends only upon the HE part
- The normalization of ν_e-flux is consistent with pion decay hypothesis
- There is a small excess of Glashow resonance events w/o spectral breaks
- so that the p-γ mechanism'd fares a bit better, especially if the new 6 PeV event is track-type

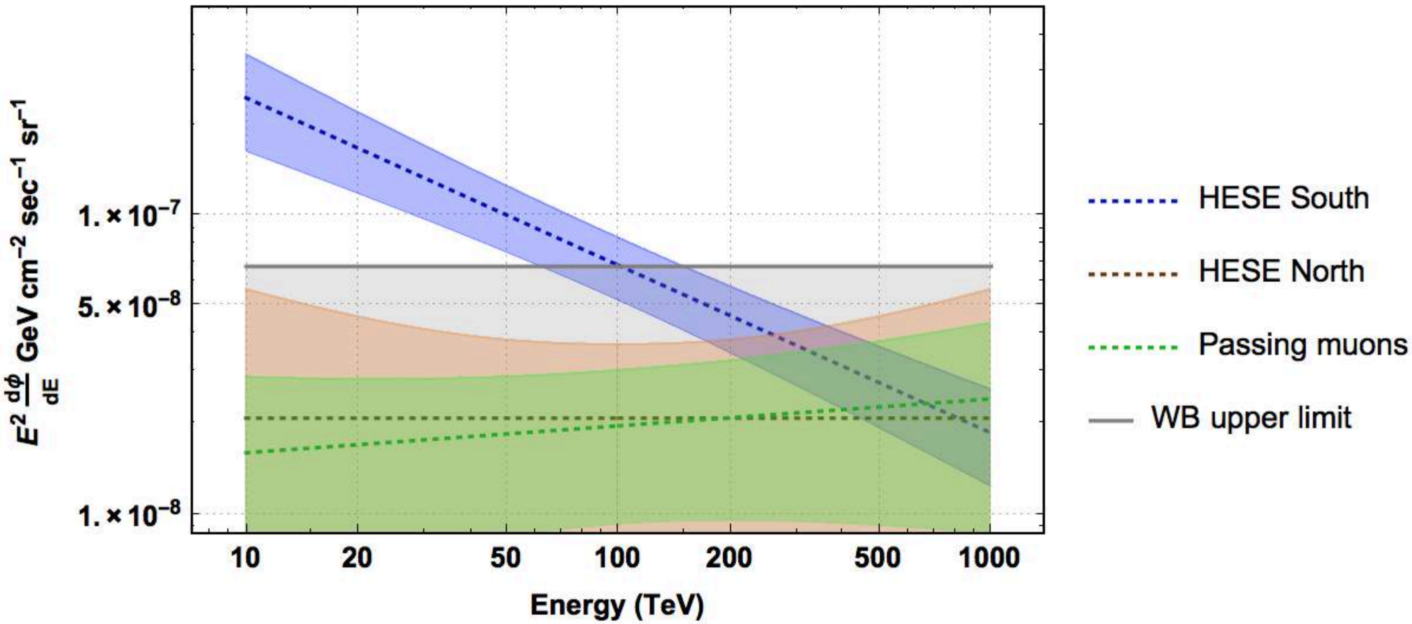




Palladino et al, arXiv1708.02094

…but some issues are still unresolved [1/3]

Especially, if the soft component (the low-energy one) has cosmic origin, and therefore the corresponding flux is assumed to be isotropic.



Palladino et al, ApJ 2016

(1)- Waxman-Bahcall bound exceeded at low energy (similarly, EGRB)

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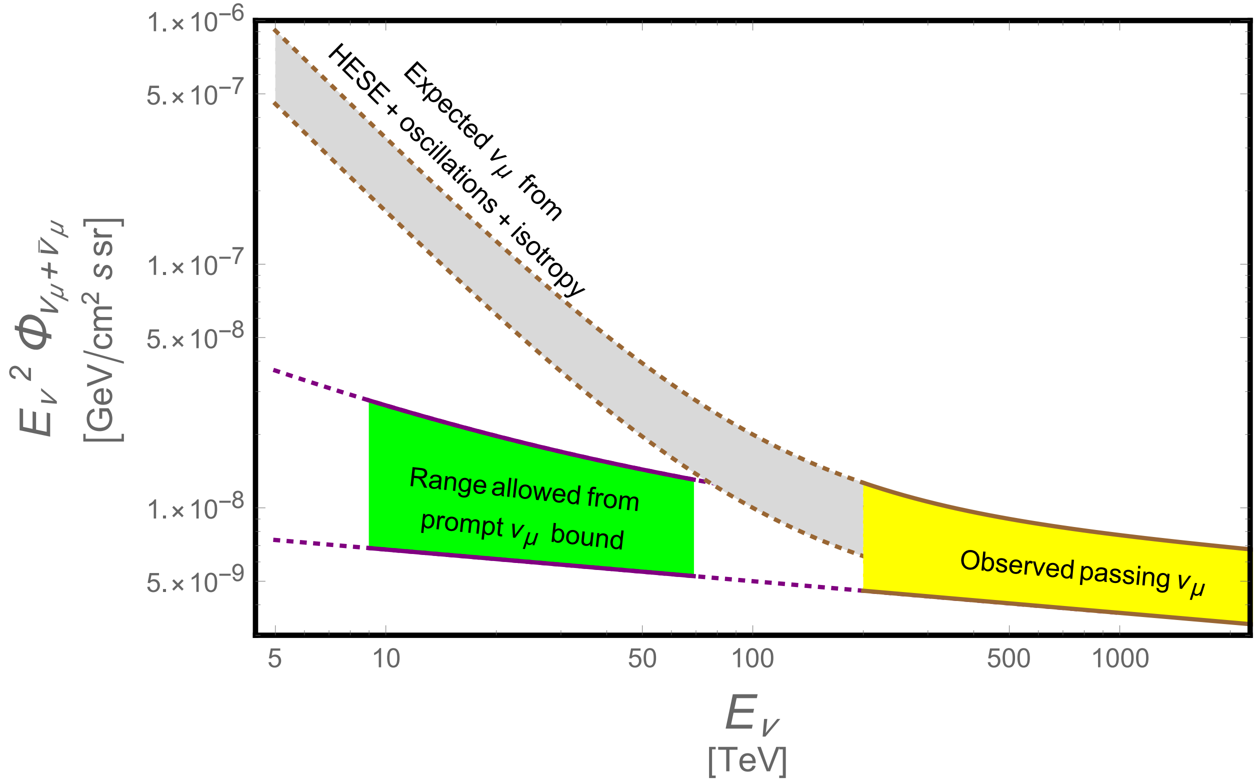

Palladino et al, JCAP 2016
and 1708:02094

(2)- In northern sky, we have also a tight bound on prompt-ν_μ

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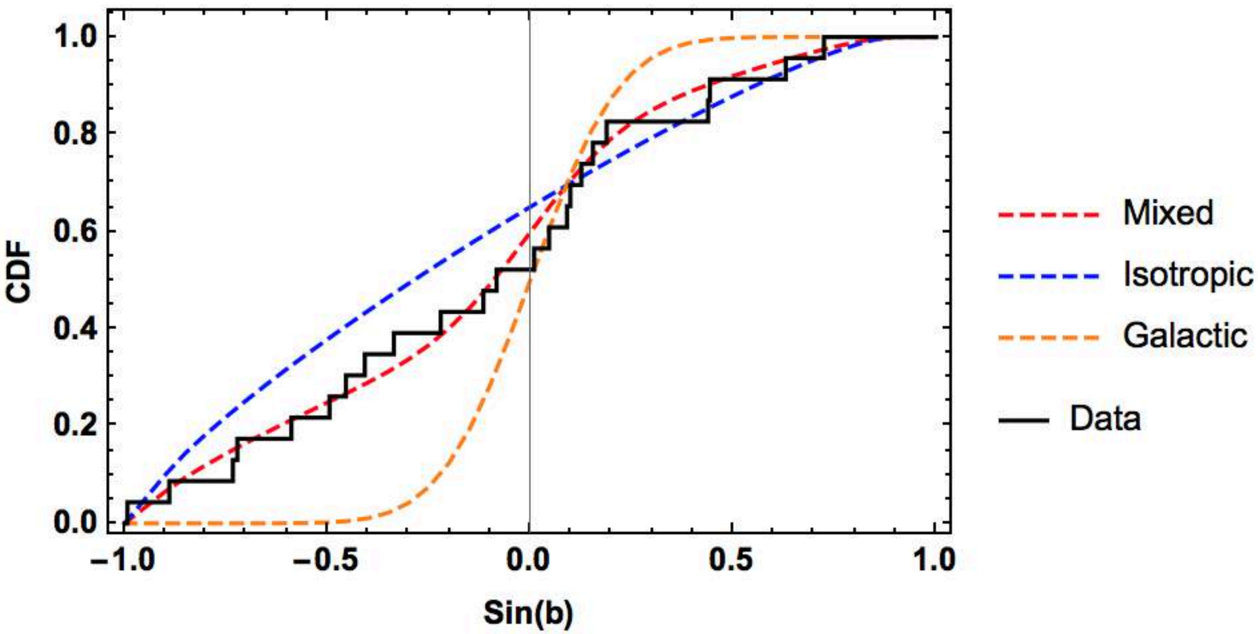

Palladino et al, ApJ 2016

(3)- Isotropy is not excluded, but a small galactic fraction is welcome

Southern Sky & Galactic Neutrinos

THE ASTROPHYSICAL JOURNAL

EXTRAGALACTIC PLUS GALACTIC MODEL FOR ICECUBE NEUTRINO EVENTS

Andrea Palladino[1] and Francesco Vissani[2]

Published 2016 July 29 •

The Astrophysical Journal, Volume 826, Number 2

Article PDF

Figures ▾ Tables ▾ References ▾ Citations ▾

+ Article information

Abstract

The hypothesis that high-energy cosmic neutrinos are power law distributed is critically analyzed. We propose a model with two components that better explains the observations. The extragalactic component of the high-energy neutrino flux has a canonical E_ν^{-2} spectrum while the galactic component has a $E_\nu^{-2.7}$ spectrum; both of them are significant. This model has several

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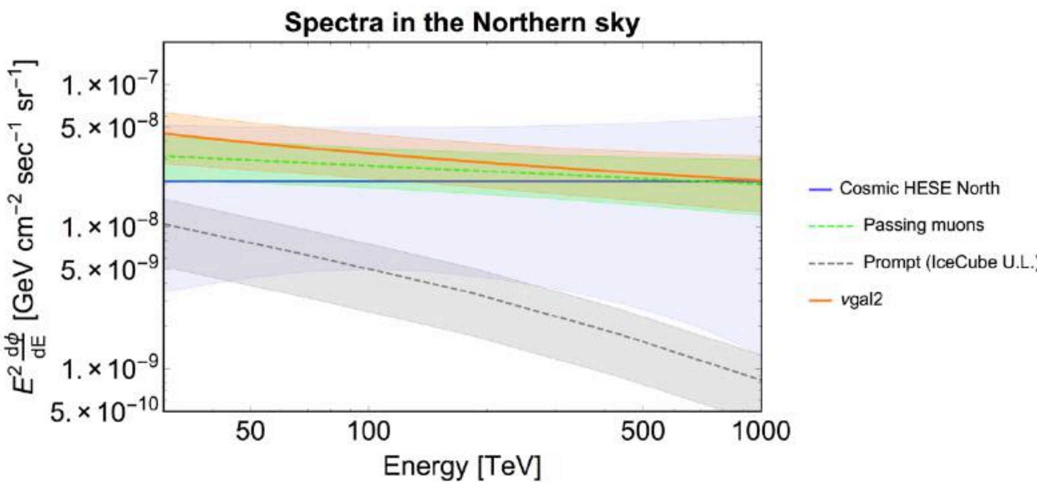
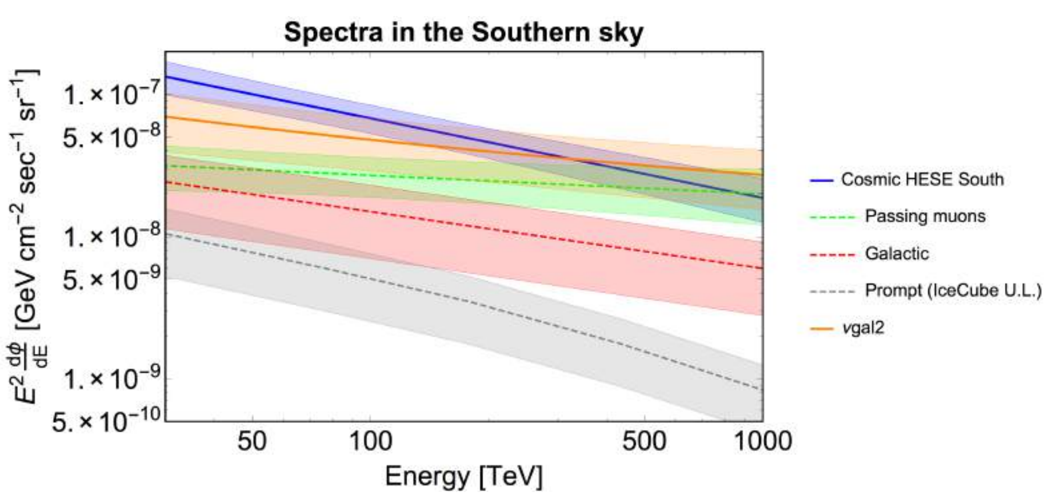


Component	North	South	Sum
Extragalactic [5]	8.8 ± 1.7	$16.1^{+1.5}_{-1.9}$	$24.9^{+3.2}_{-3.6}$
Galactic [11]	≈ 0	6.0 ± 3.5	6.0 ± 3.5
Prompt [5, 37]	1.5 ± 0.8	2 ± 1	3.5 ± 1.8
Atmospheric μ [3]	0	12.4 ± 6.2	12.4 ± 6.2
Conventional π/K [3]	6.2 ± 1.9	3.6 ± 1.2	9.8 ± 3.1
Total	16.5 ± 2.7	40.1 ± 7.5	56.6 ± 8.7
Observed [41]	16.5	37.5	54

Palladino et al, JCAP 2016



Discussion & Summary

IceCube has discovered a new component of the high energy neutrinos that reach the Earth, possibly of cosmic origin.

We should be cautious in accepting one model or another to describe these neutrinos, as the discovery was made in the absence of a clear theoretical guidance.

The angular distribution should be investigated further, not simply postulated—especially at low energies.

- The passing-μ data (from northern sky) agree with isotropy and E^{-2} distribution till very high energies. They allow us to predict observable τ-events.
- The HESE (mostly from southern sky & shower-like) suggest a softer distribution at low energies. This is the IceCube spectral anomaly.
- We discussed hints of anisotropy. Maybe galactic neutrino emission, that is small, plays a role for HESE.

Thanks!

Discussion [1/3]

Elisa Resconi: *We should not assume the validity of E^{-2} paradigm over a large region of energies, but rather discuss it, possibly backing it up with models.*

Answer: This is the reason why I insisted on the facts that a) we do not know the true distribution and b) we tested this assumption only on one decade of energy with neutrino data.

Note that this paradigm was used by IceCube in all early sensitivity analyses and it is part of the Waxman-Bahcall bound.

Concerning models, many of us (you and me included) are trying hard but I do not feel fair to claim that some of our models is any definitive yet.

Discussion [2/3]

Walter Winter: *1) The E^{-2} prejudice depends upon models, in particular, it agrees with PP collisions but not with other cases. 2) Maybe galactic neutrinos are there but it is not clear whether they are sufficient to explain the low energy part of HESE dataset.*

Answer: 1) I agree, as reflected by my discussion, however I would prefer to call it "hypothesis" rather than "prejudice", as I think this is the closest thing to a theoretical prior we had and we still have.

Moreover: E^{-2} does not disagree yet with the current high energy measurements and it is free from the problems that other distributions, such as $E^{-2.5}$, have at low energies--see above. (continues on next page)

Discussion [3/3]

(continued from previous page) 2) On this point I can be add something—see also the papers cited above: Consider the neutrinos, invoked to explain HESE below 100 TeV. If they resemble the published $E^{-2.5}$ distribution, galactic neutrinos can play a role; if they resemble the $E^{-2.9}$ distribution announced at the ICRC, instead, galactic neutrinos are not enough. Even worse, if they are closer to the atmospheric neutrino distribution (as claimed by Sergio in agreement with our findings).

For similar reasons, since a couple of years, we prefer to begin from passing muons the discussion of the cosmic neutrinos seen by IceCube, rather than from HESE.