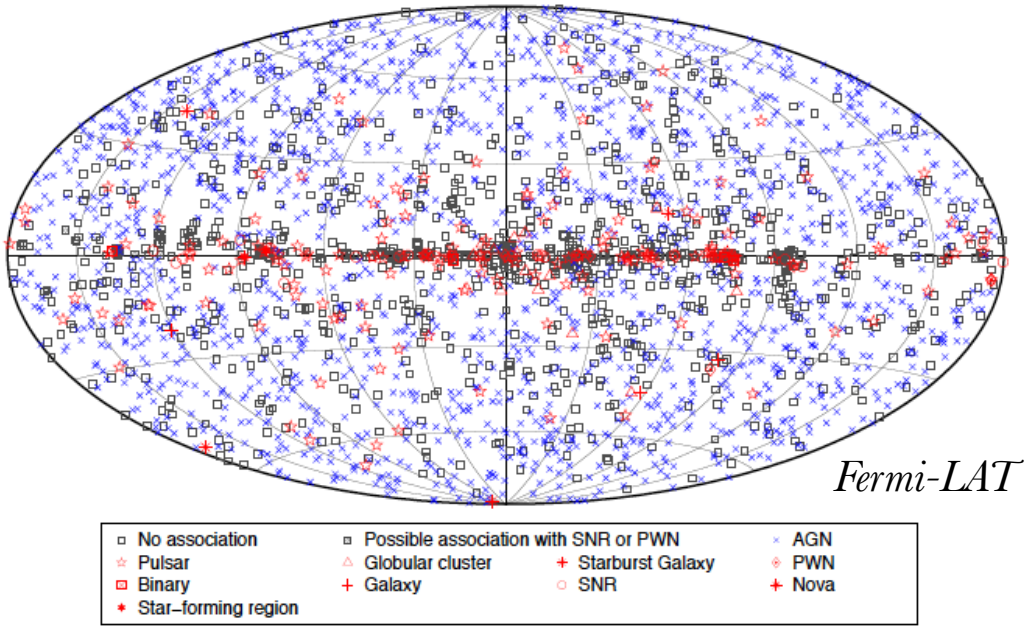
GDR Neutrino
Saclay 4-5/11/2015

A Hadronic scenario for the galactic ridge & constrains for Galactic vs Extragalatic neutrino origin.

Antonio Marinelli (University of Pisa & INFN)
in coll. with D. Gaggero, D. Grasso, A. Urbano, M. Valli

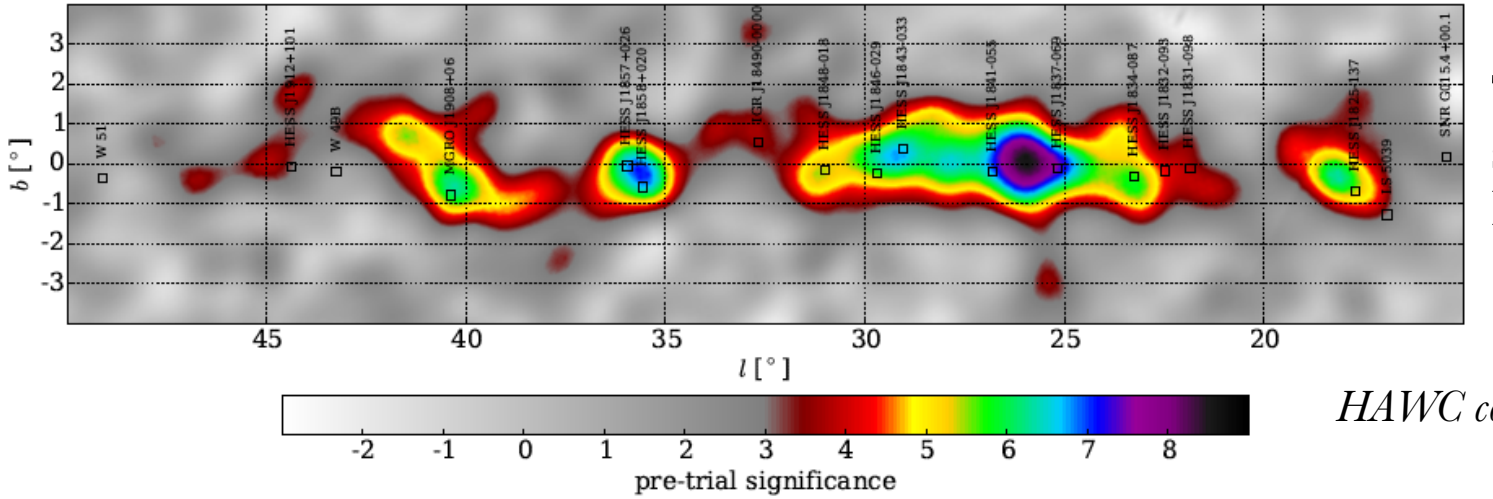
Credits of http://hdw.eweb4.com

Galactic point-like gamma-ray catalogue of sources



The 3FGL catalog of sources for 100 MeV–300 GeV gamma-ray emission released by Fermi-LAT collaboration this year.
Contribution of unresolved sources to diffuse galactic emissions ~ 3%

Fermi-LAT coll., ApJ, vol.810, 2015

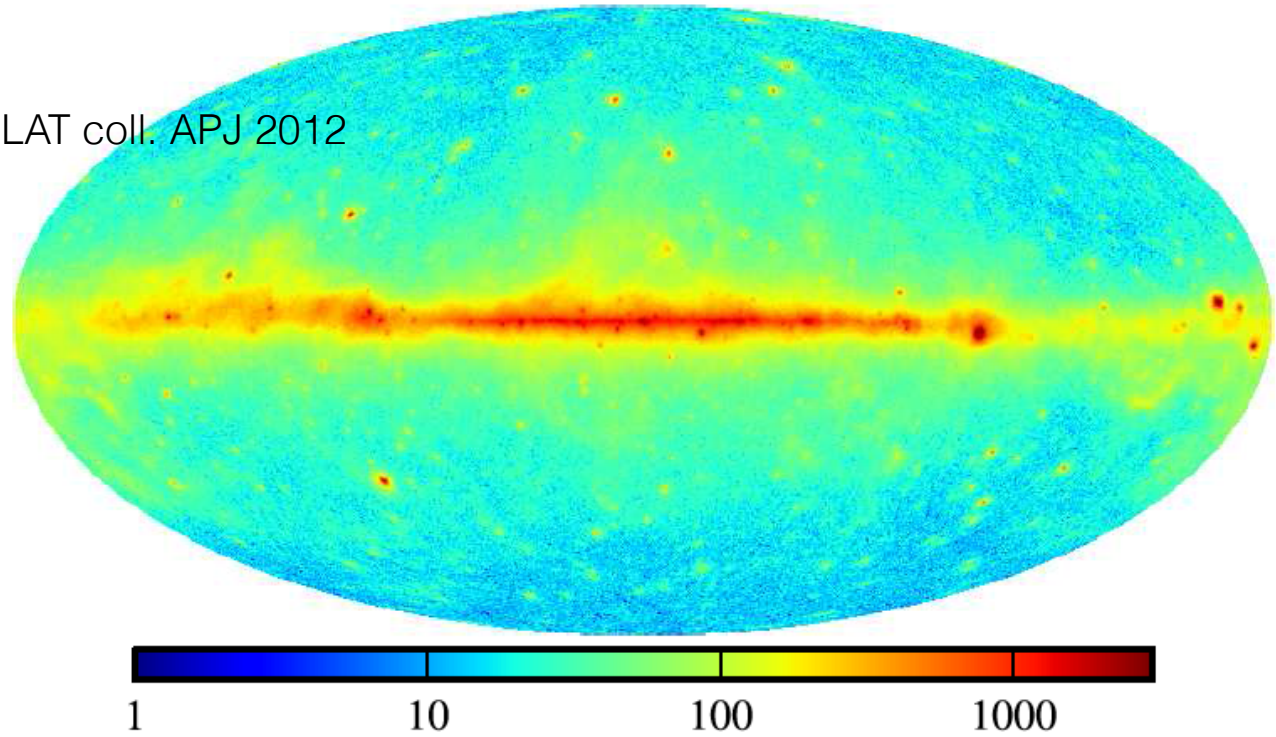


TeV catalogue of point-like sources by H.E.S.S. and HAWC observatories.

HAWC coll., ArXiv:1509.05401

Diffuse Galactic Plane gamma-ray emission

Fermi-LAT coll. APJ 2012

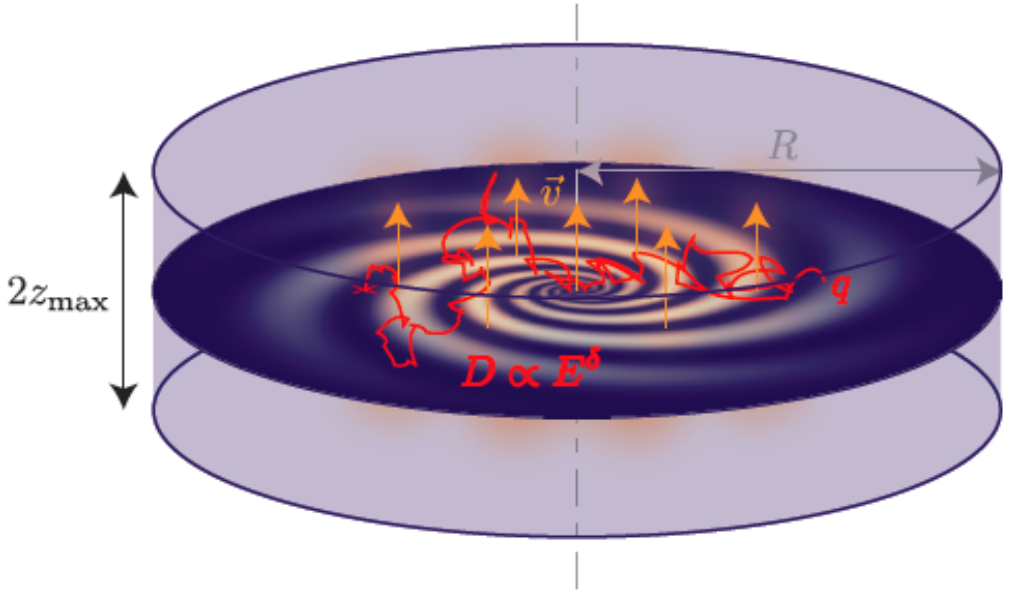


Observed Fermi-LAT counts in the energy range 200 MeV to 100 GeV after point-sources subtraction (log scale = counts/pixel)

The gamma-ray diffuse emission is mainly related:

- Photopion production due to the CR/gas collision - Dominant for the inner GP, produce also ν
- Bremsstrahlung of relativistic electrons in gas
- Inverse-Compton of relativistic electrons with ISRF

The conventional propagation scenario for cosmic rays



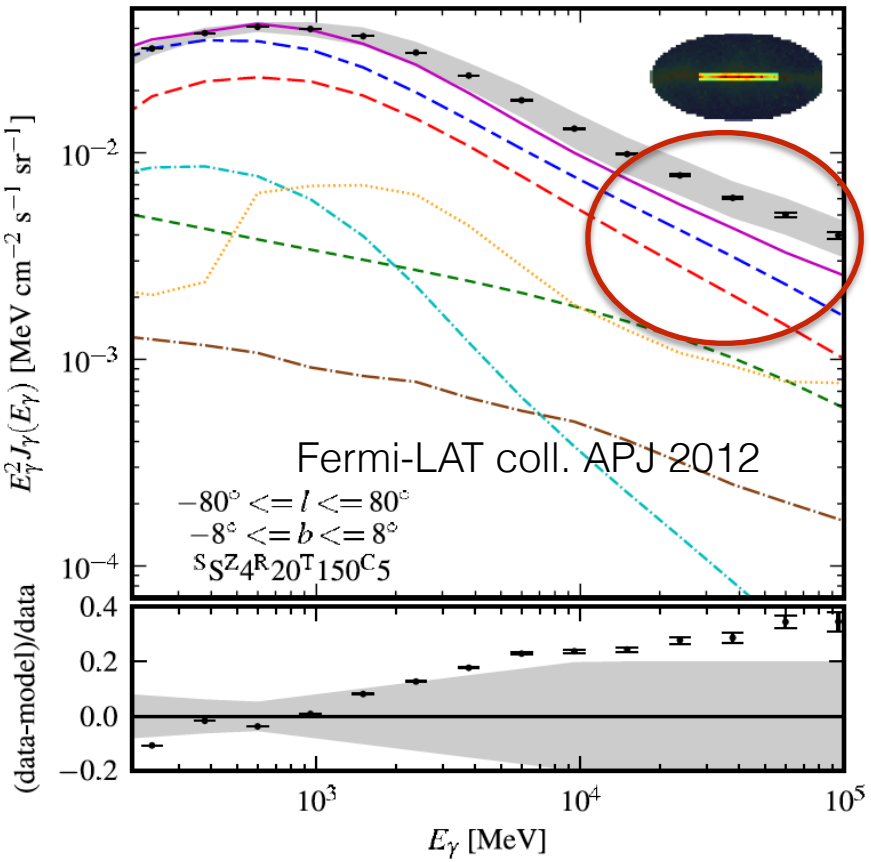
ρ : particle rigidity

D : diffusion coefficient

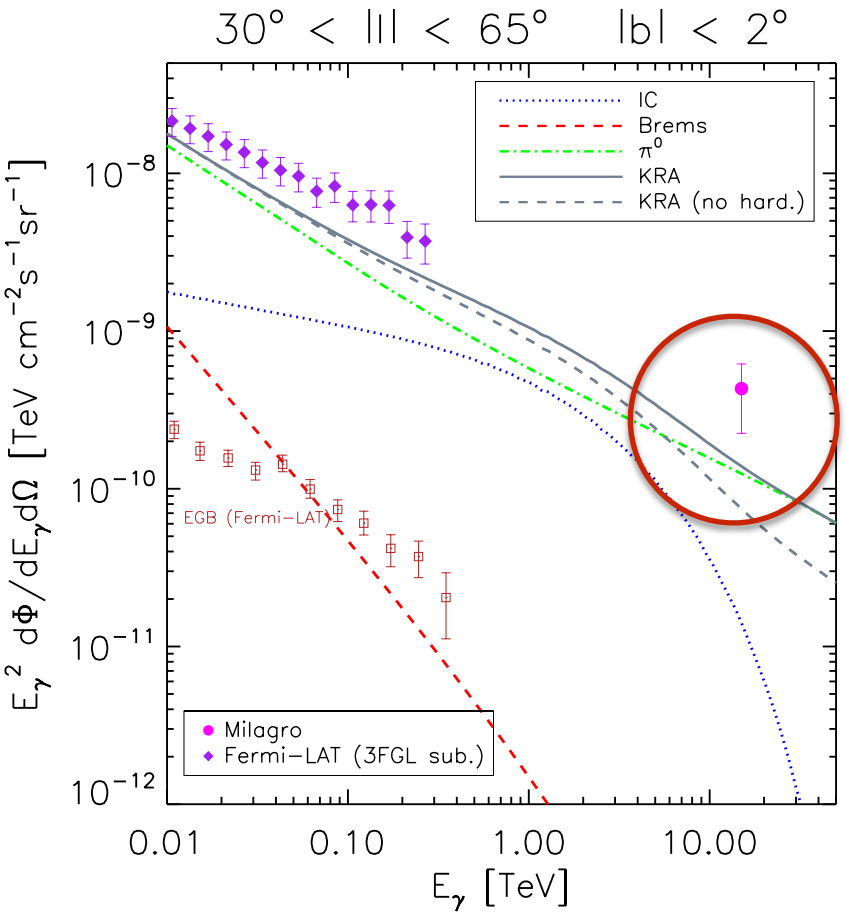
R : distance from galaxy center

- The diffusion coefficient $D \propto \rho^{\delta}$, <u>in a conventional scenario δ is constant</u>.
- Parameters are tuned against local CR spectra and the secondary/primary ratios.
- These quantities however probe only few kpc's about our position. <u>Propagation may behave quite differently in the inner few kpc of the Galaxy !</u>

Anomaly in the Galactic Plane gamma-ray emission



Fermi Benchmark model: δ=0.3
γ_p=2.72 (in the whole galaxy)
z_h=4 kpc do not match
Fermi data of GP at high energies



Also Milagro excess cannot be explained with a standard conventional model

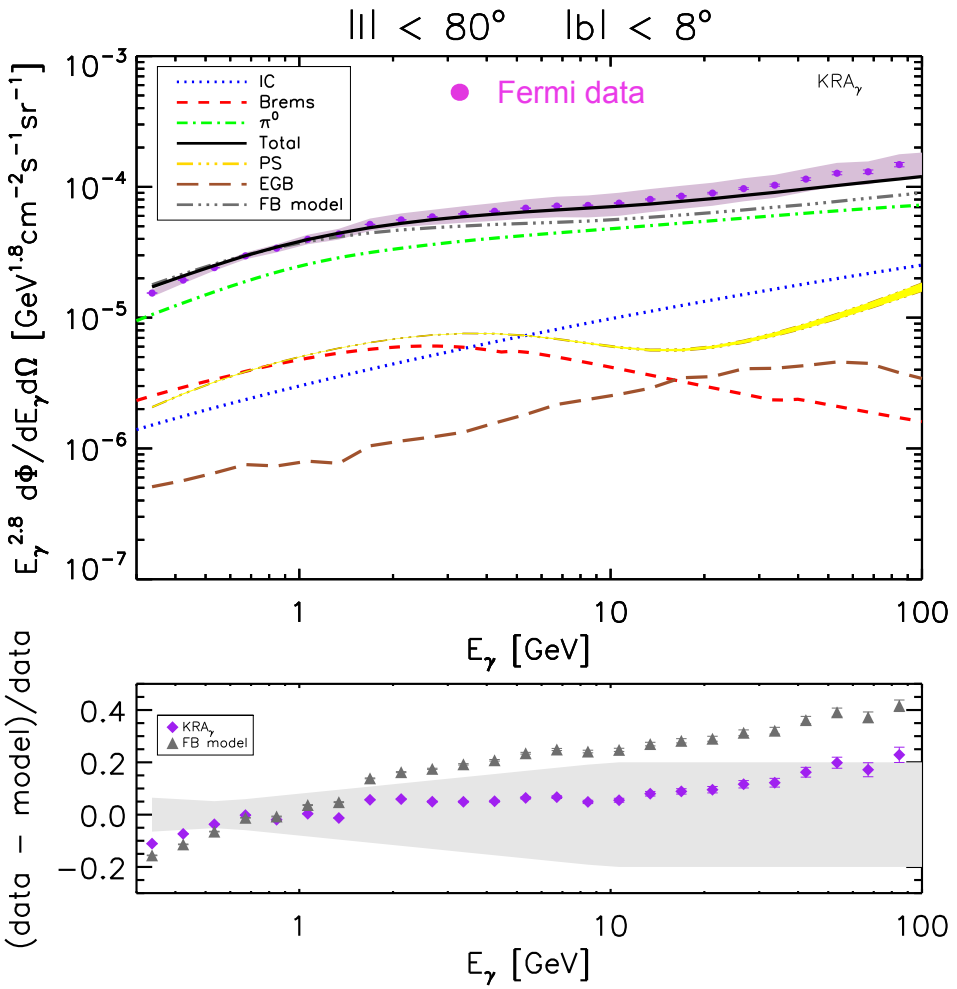
The KRA$_\gamma$ model: Radial dependency of CR transport

This is a phenomenological model built to reproduce over the entire sky the diffuse γ-ray emission spectrum of the Galaxy as measured by Fermi-LAT.

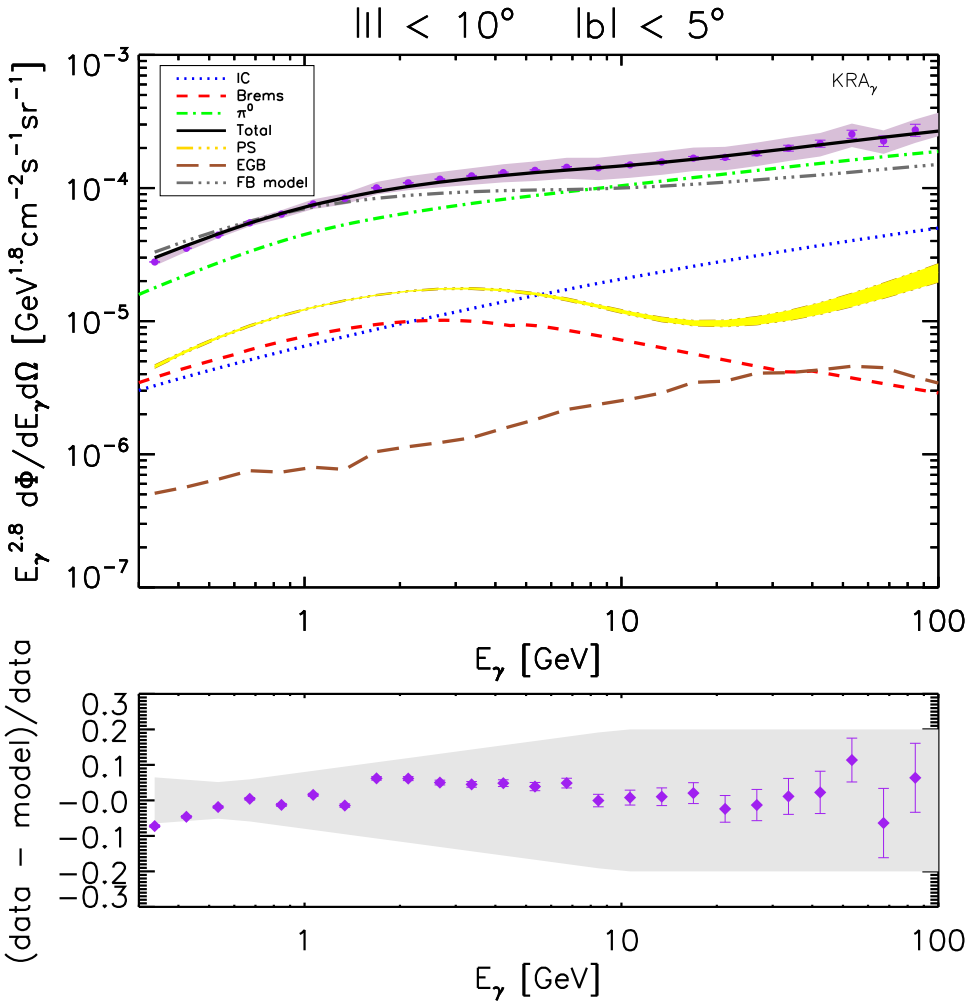
Differently from the Fermi benchmark model (FB) based on GALPROP under the hypothesis of uniform cosmic ray (CR) diffusion, the KRA$_\gamma$ model adopts a radial dependent diffusion coefficient ($\delta(R) = A * R + B$) which turns into a spectral hardening toward the GC region. This is implemented with the DRAGON code.

This allows to correct the discrepancy between high energy Fermi data and the FB model in the inner Galactic plane region without spoiling the local cosmic-ray quantities (spectra, B/C, antiprotons…)

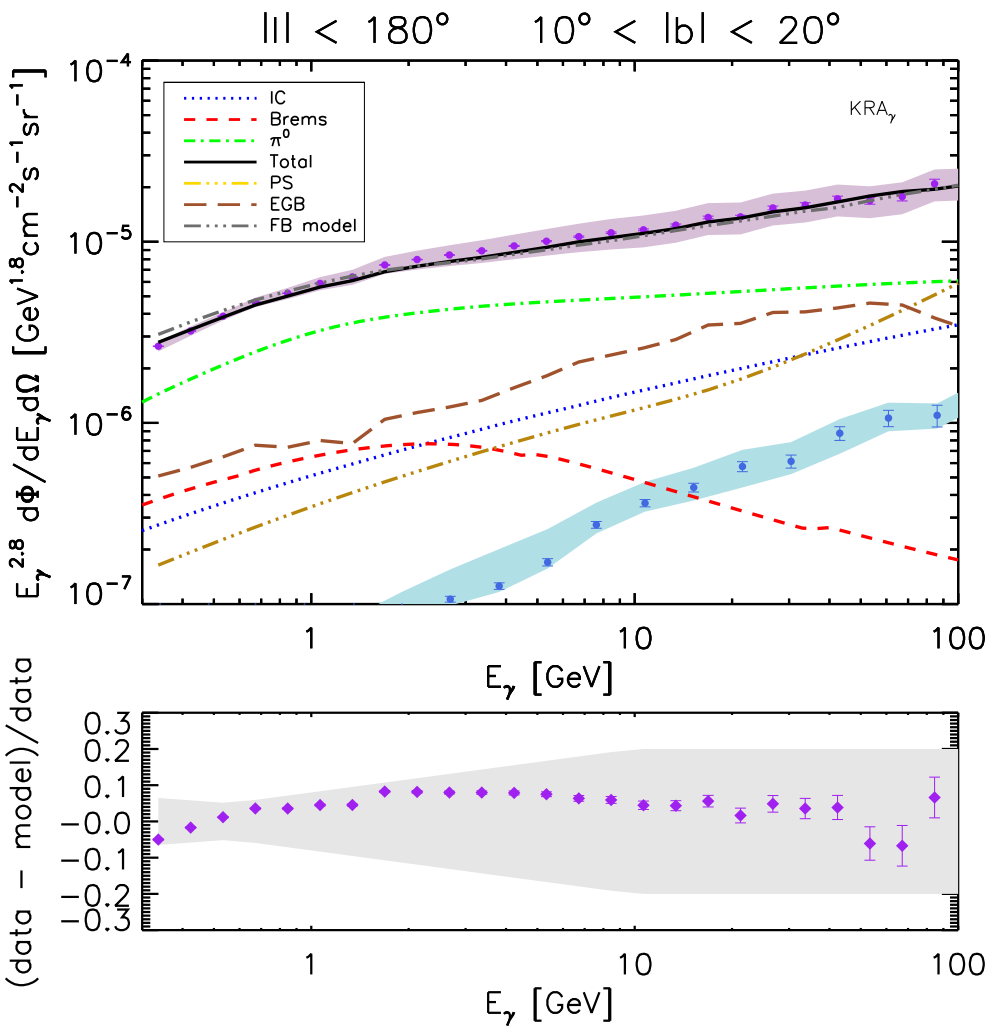
Gaggero, Urbano, Valli, Ullio, Phys.Rev. D91 (2015) 8, 083012



Model tested on different regions of the sky



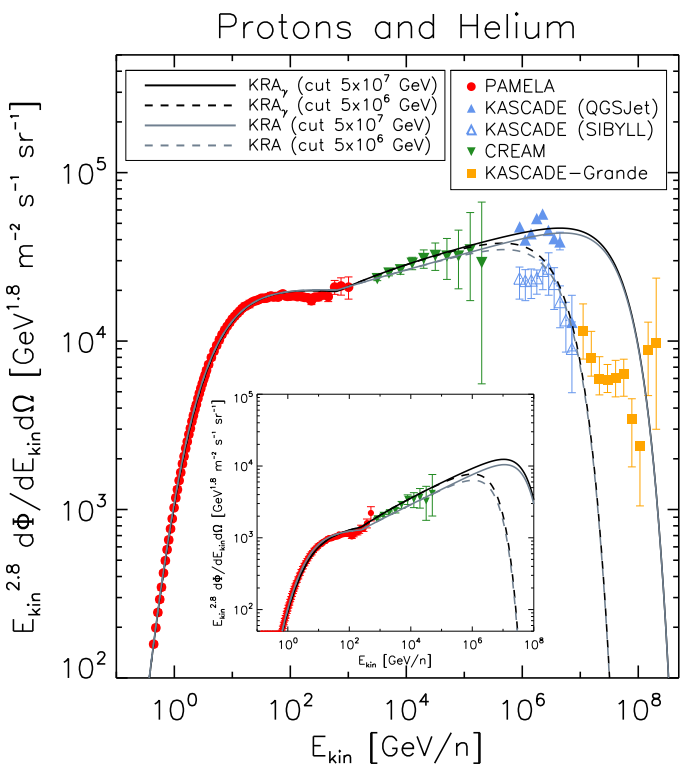
Inside the inner galactic plane

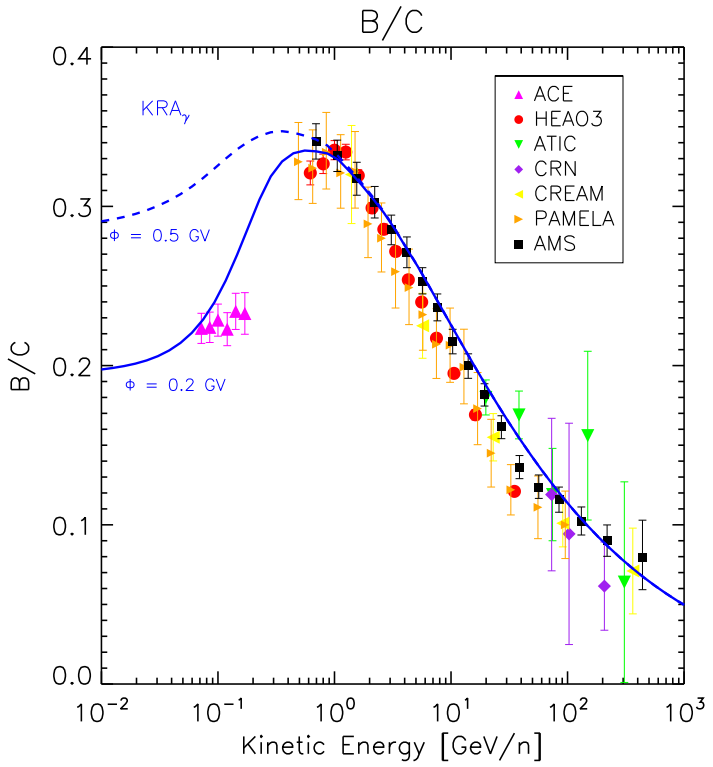


Outside the inner galactic plane

Model well tuned through CR observations

- Model is tuned to reproduce also (local) CR data, CR proton and Helium spectra and the B/C ratio most importantly.
- The spectral hardening at ~ 250 GeV/n, required to reproduce PAMELA (now confirmed by AMS-02) and CREAM p, He spectra is imposed in the source spectrum. This will be crucial to reproduce the γ-ray data above the TeV and for ν prediction !!
- Above the PeV (relevant for neutrinos) we consider two cutoff energies (5×10^6 and 5×10^7 GeV/n) which roughly reproduce two different analysis of KASCADE data.

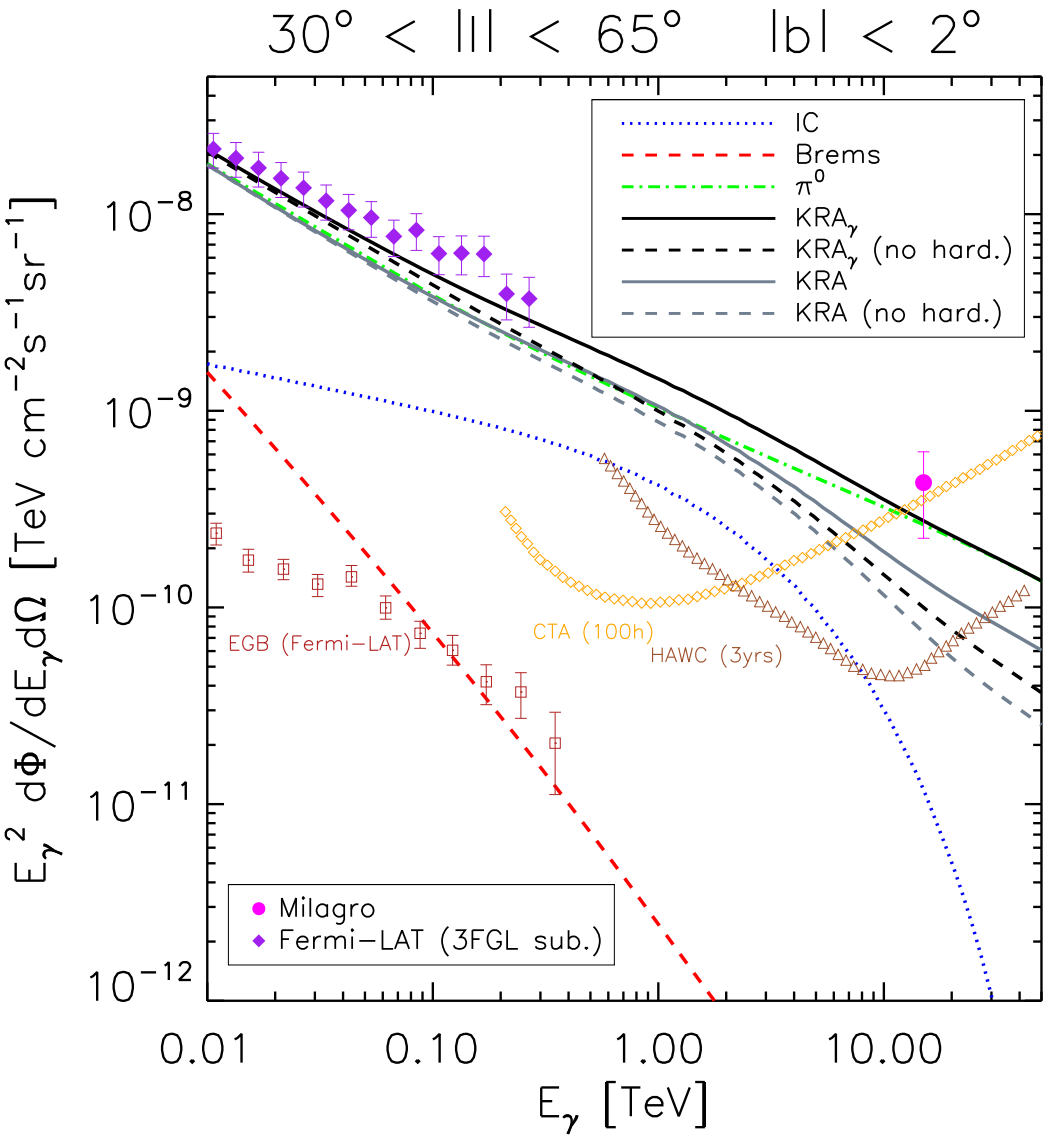




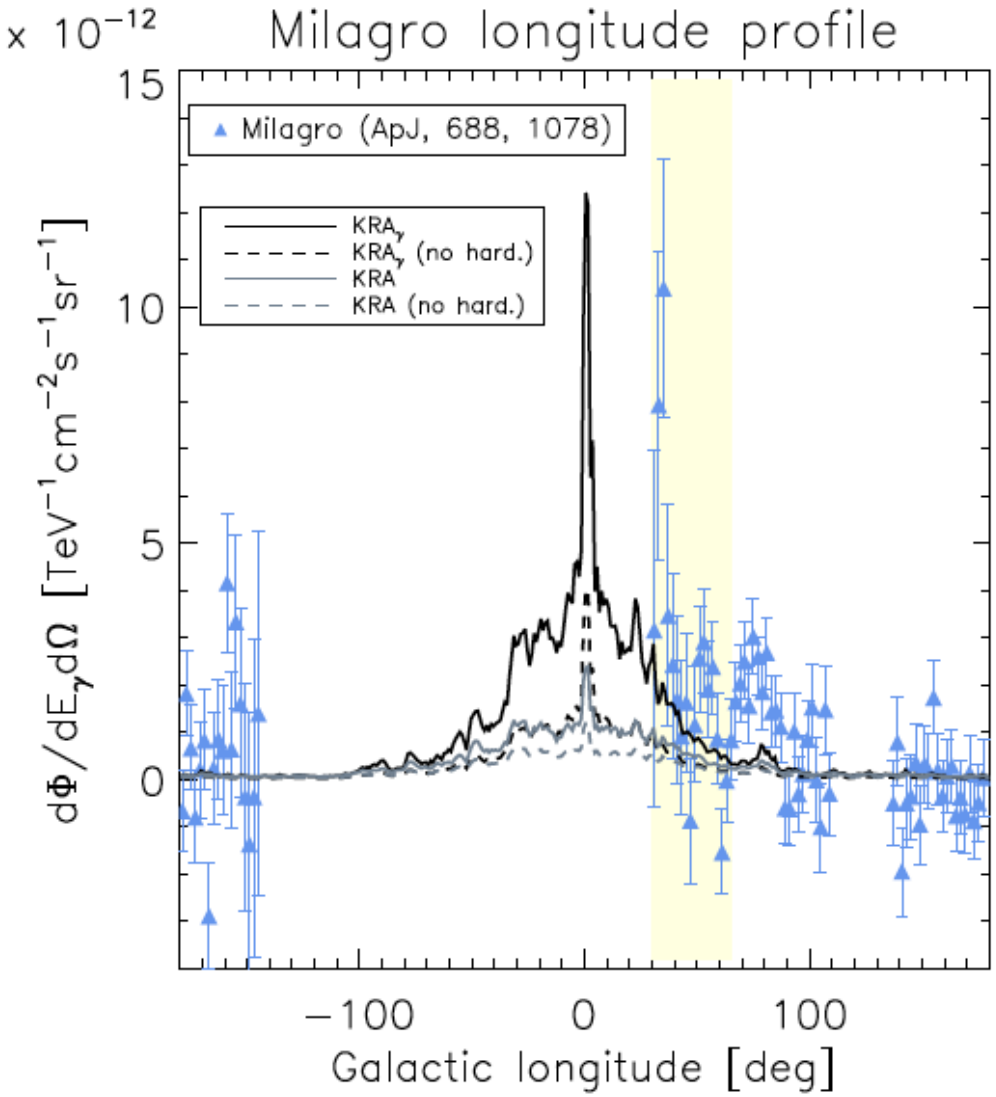
The KRA$_\gamma$ model solves the Milagro anomaly at 15 TeV

- Milagro measured the diffuse γ-ray flux from the inner Galactic plane @ 15 TeV
- Milagro flux exceeds the predictions of conventional models based on GALPROP. This a longstanding problem in CR physics
- The KRA$_\gamma$ model consistently reproduces Fermi-LAT data (point sources properly subtracted) and Milagro. No extra-tuning required !
- CR hardening @ 250 GeV/n is crucial though not sufficient.

Gaggero, Grasso, Marinelli, Urbano, Valli, arXiv:1504.00227



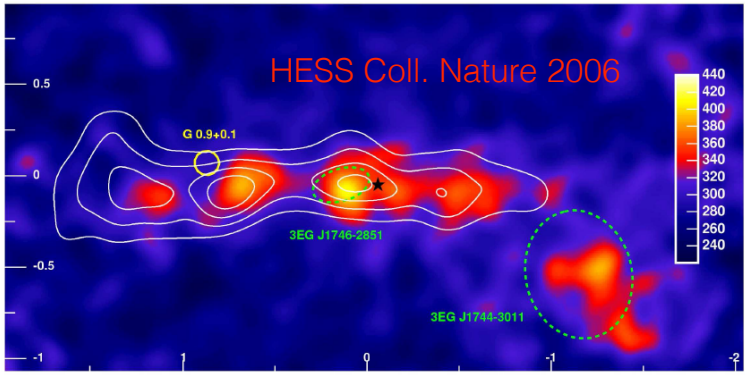
The galactic gamma-ray flux profile obtained with KRA$_\gamma$ model

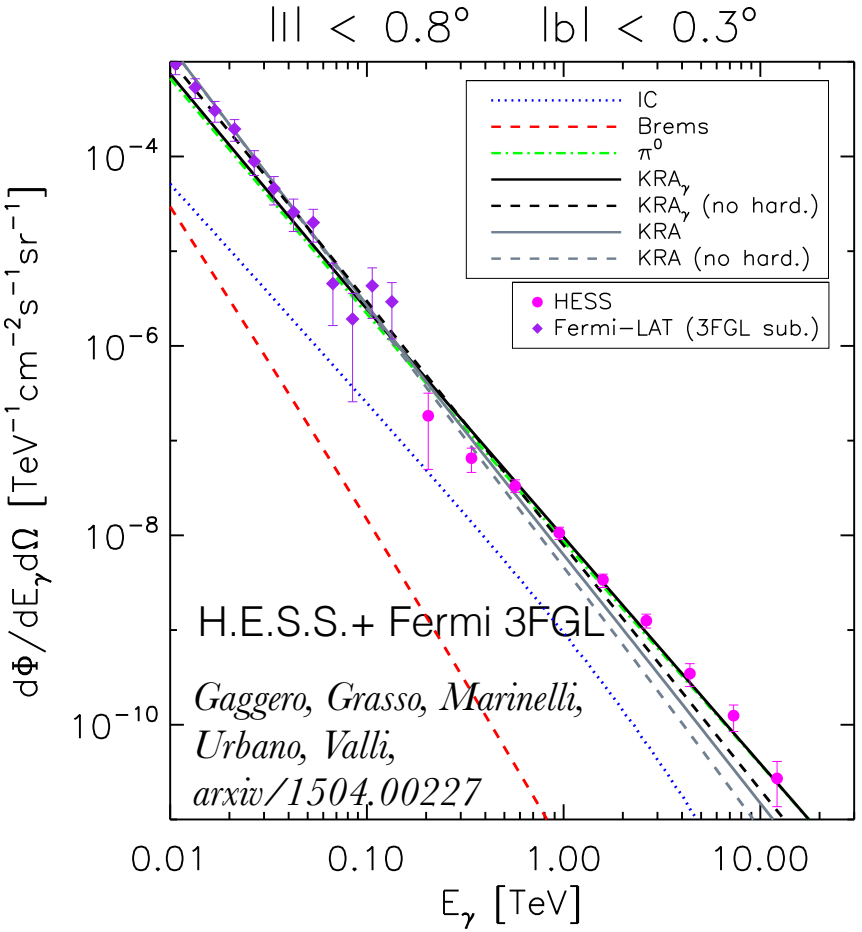


Gaggero, Grasso, Marinelli, Urbano, Valli, arXiv:1507.07796

We can see from this plot how the diffuse gamma-ray profile from the galactic plane obtained with KRAγ (scenario with a variable diffusion coefficient) better reproduce the measured Milagro profile respect to the KRA (standard scenario).

The KRA$_\gamma$ model through the Galactic Ridge





- KRA$_\gamma$ scenario is consistent with the hard spectrum Γ=2.3 of Galactic Ridge published by HESS coll. in 2006
- The KRA$_\gamma$ model well fits the gamma-ray emission (HESS+Fermi-LAT) from the central 200 pc of our galaxy
- A detailed gas model was used for the central molecular zone (Ferriere et al. 2007)
- FERMI + HESS
  KRAγ: χ2 = 1.79 /2.27 with/w.o. hard.
  KRA: χ2 = 2.92 /3.99 with/w.o. hard.

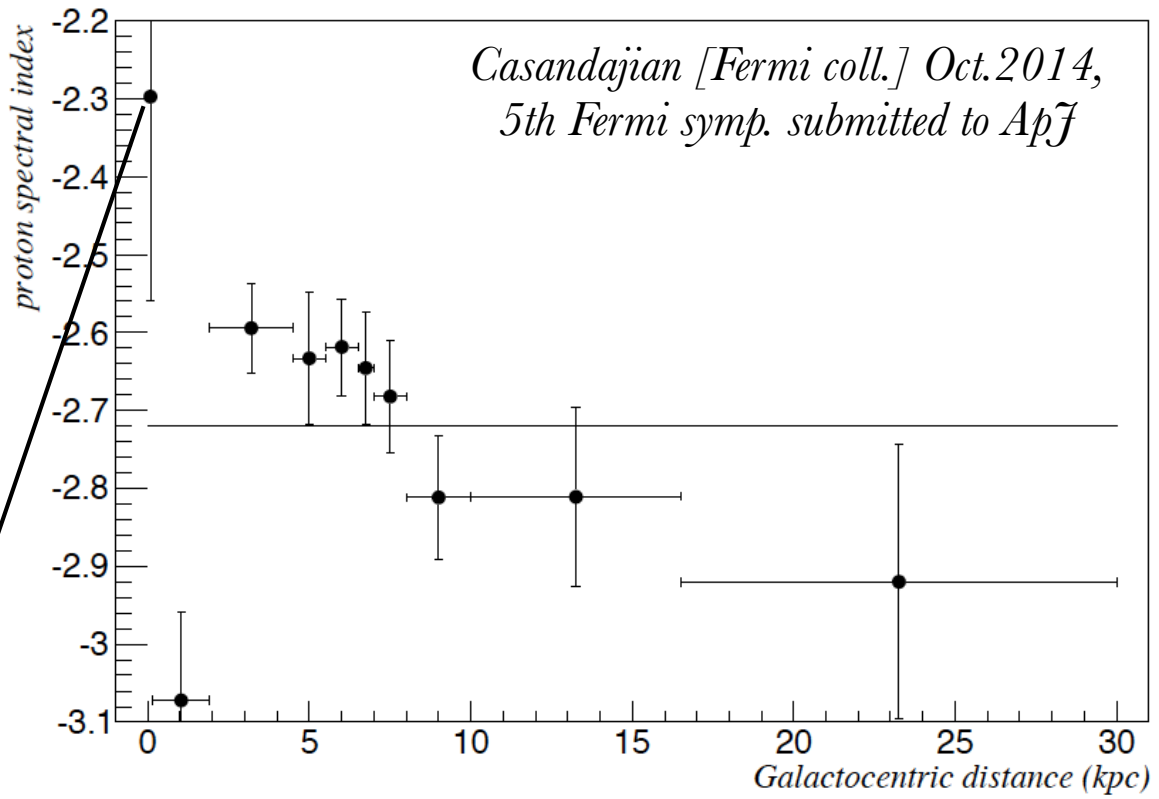
Evidences of CR spectral index radially variable

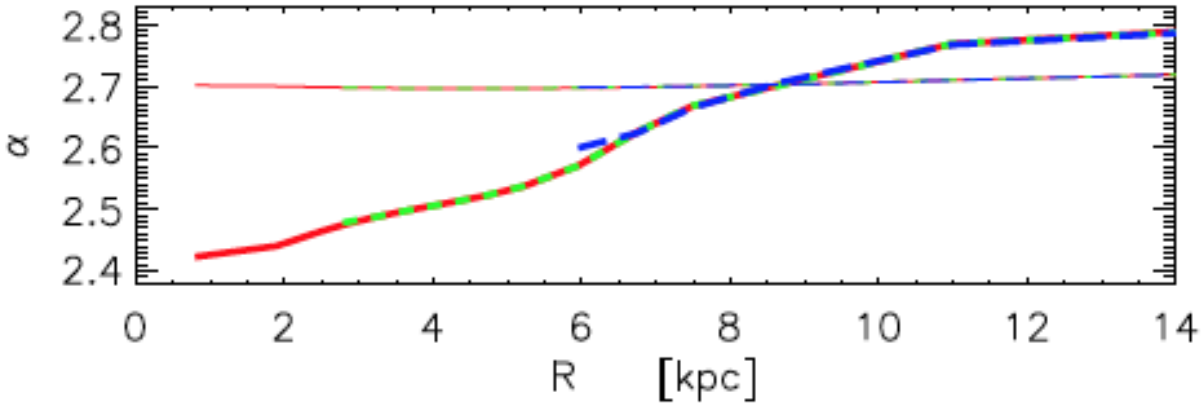
- A template fitting analysis of the diffuse gamma-ray emission measured by Fermi-LAT found such evidence.

- This result is hardly compatible with the standard scenario adopting a uniform diffusion coefficient.

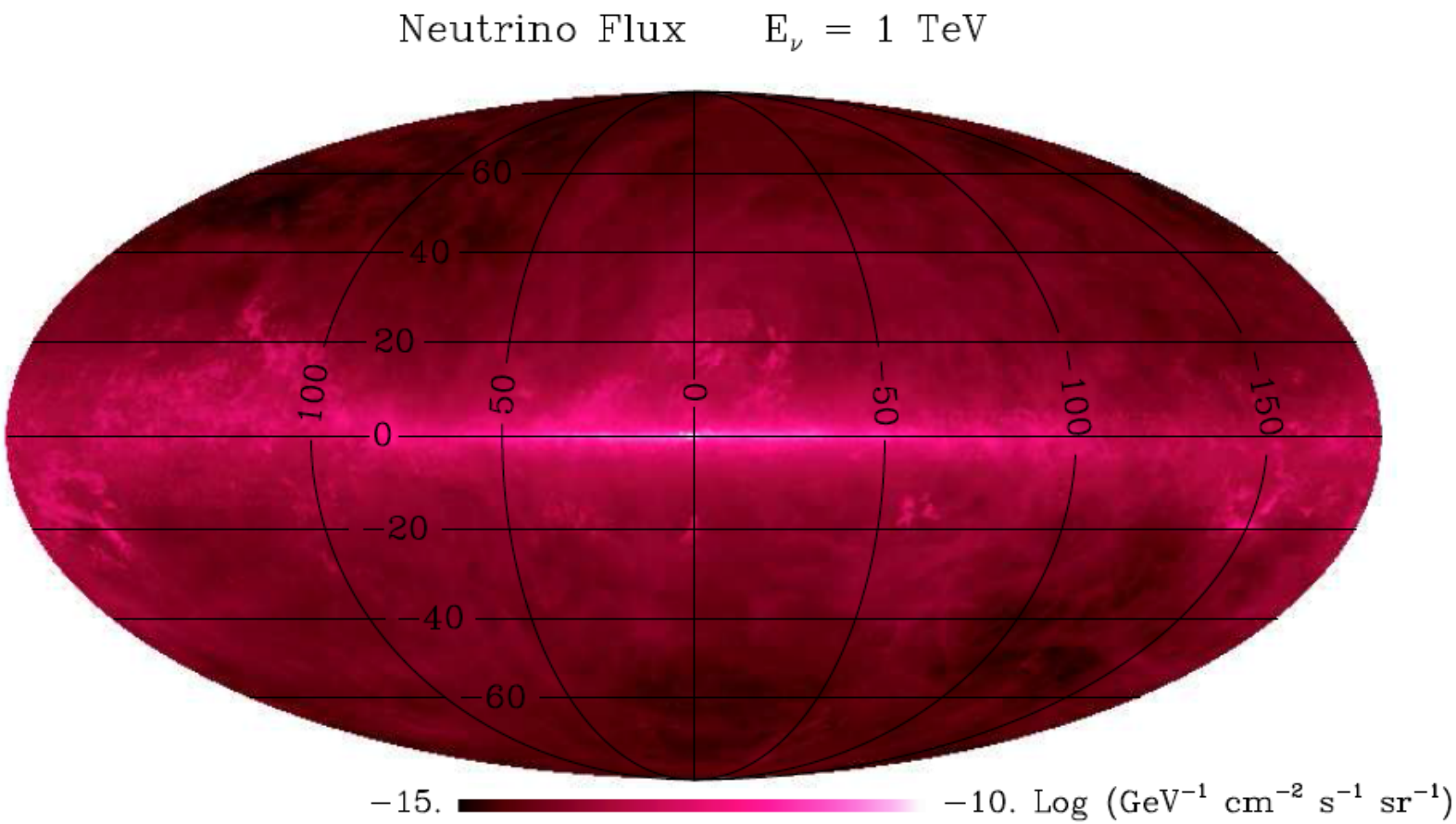
- Whereas it is in agreement with the KRA$_\gamma$ model presented here.

This is an important experimental evidence of spectral hardening toward the GC region.





Galactic neutrino flux Skymap from the KRA$_\gamma$ model.

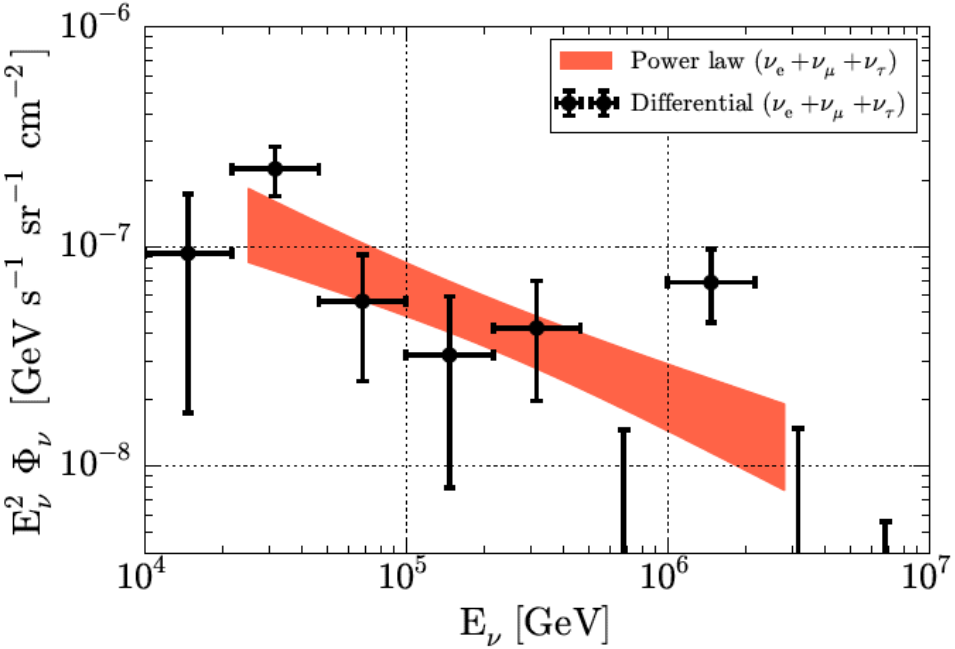


Skymap of neutrino flux produced with KRA$_\gamma$ model.

- The p-nucleon interaction is computed following *Kamae et al. 2006*
- The target gas distribution is the same used for gamma-ray production (as also used by the Fermi collaboration)

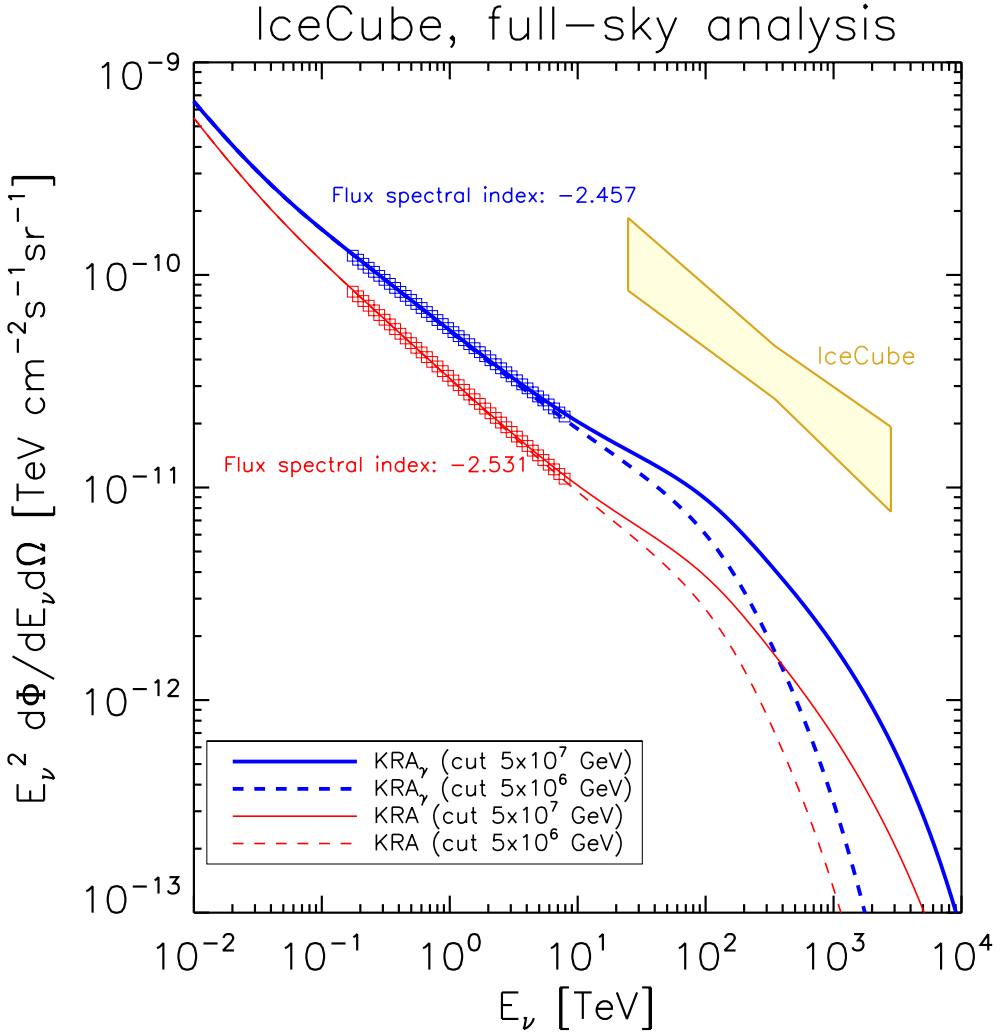
All Sky neutrino from KRA (δ uniform) & KRAγ (δ variable)

IceCube arXiv:1507.03991



The Shape of astrophysical neutrinos spectrum measured by IceCube for the whole sky is in accordance with the spectrum obtained by KRAγ.

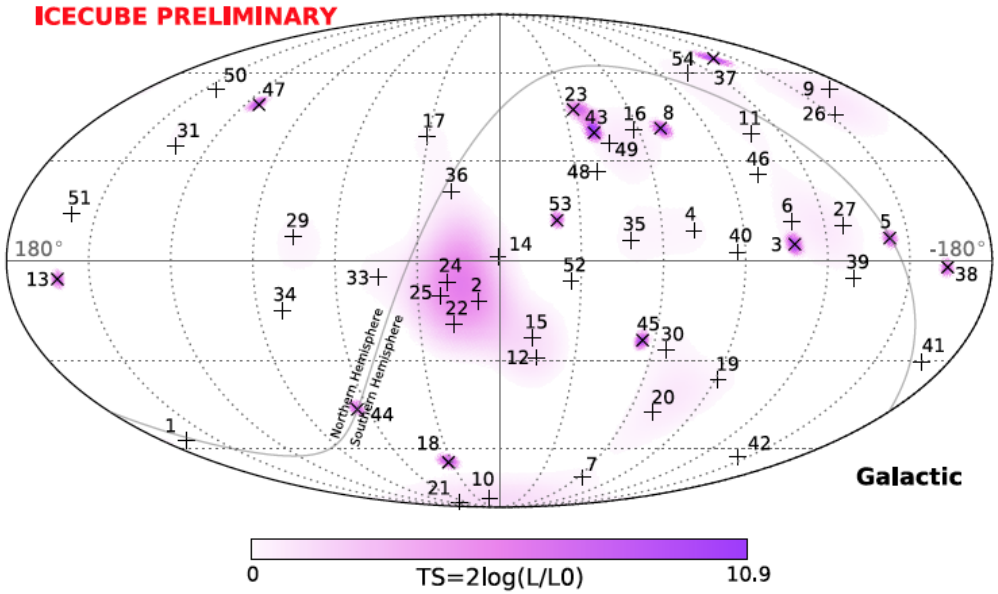
Gaggero, Grasso, Marinelli, Urbano, Valli, arXiv:1507.07796



IceCube measured ν events compared with KRA$_\gamma$ ν events

On the other hand considering the catalog of 54 ν events KRA$_\gamma$ may account between 10% and 25% (depending on CR cut-off) above 60 TeV. More than double of standard scenario. Compatible with events distribution.

Another hint of a galactic component in the measured ν flux may come from the softer contribution of southern SED possibly related with more galactic plane neutrino.

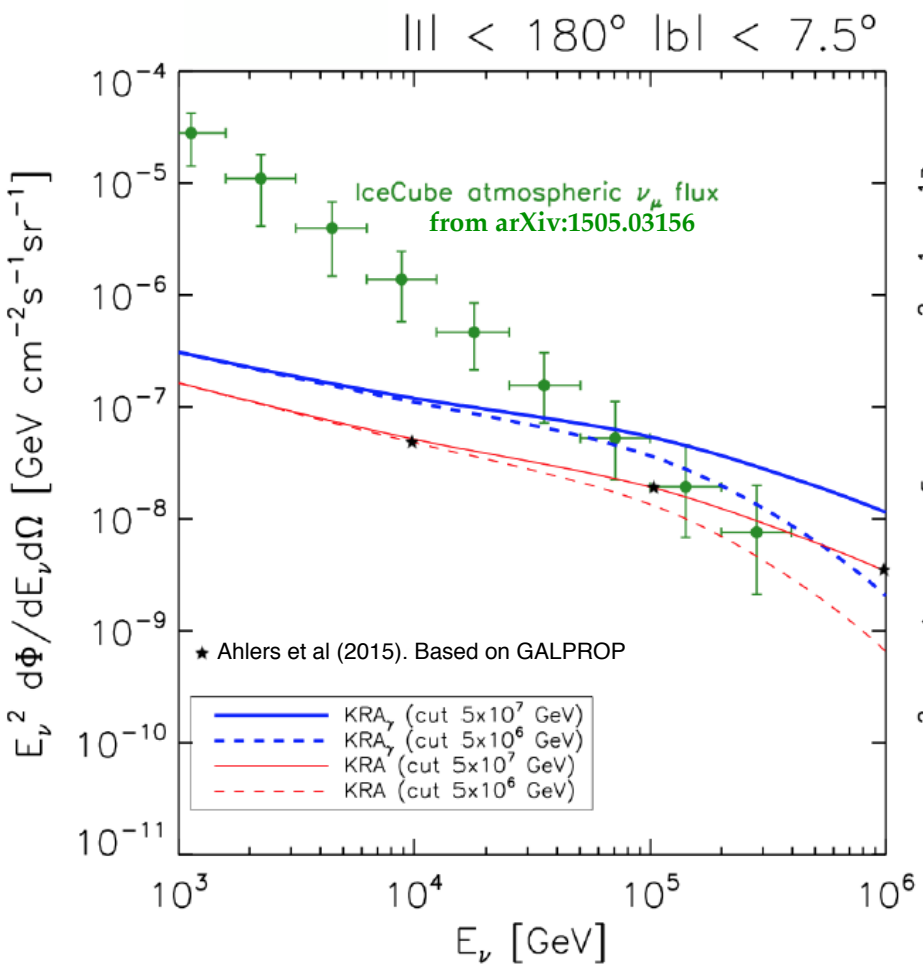


IceCube coll., ICRC proceeding, 2015, ID1081

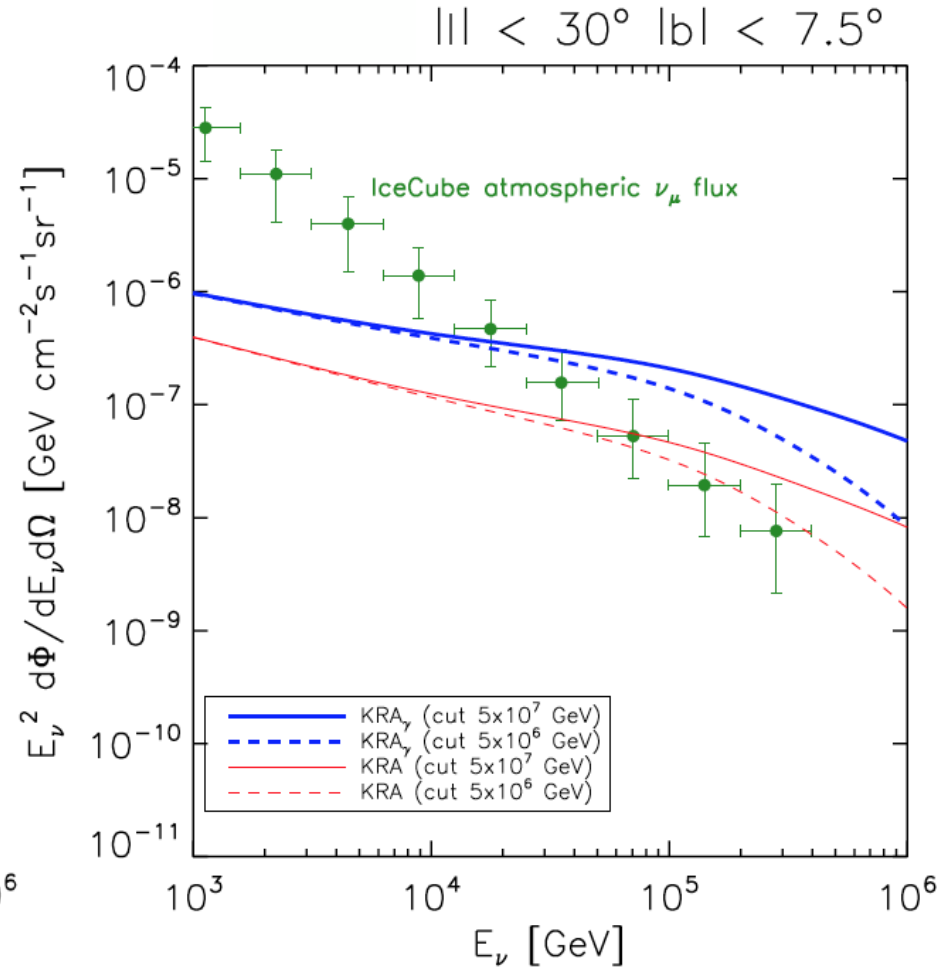
Parameter	Best fit	68% C.L.	90% C.L.
ϕ_N	2.1	$0.5 - 5.0$	$0.1 - 7.3$
γ_N	2.0	$1.6 - 2.3$	$1.2 - 2.5$
ϕ_S	6.8	$5.3 - 8.4$	$4.4 - 9.5$
γ_S	2.56	$2.44 - 2.67$	$2.36 - 2.75$

Note. — ϕ_N and ϕ_S are the all-flavor neutrino fluxes at 100 TeV in the northern and southern sky, respectively; γ_N and γ_S are the corresponding spectral indices. The fluxes are given in units of $10^{-18}\,\mathrm{GeV}^{-1}\mathrm{s}^{-1}\mathrm{sr}^{-1}\mathrm{cm}^{-2}$.

Galactic Plane neutrino with KRA (δ uniform) & KRA$_\gamma$ (δ variable)

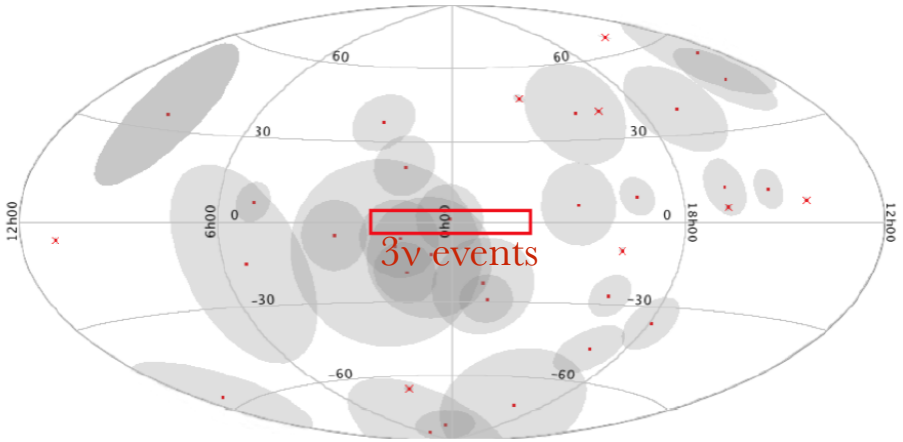


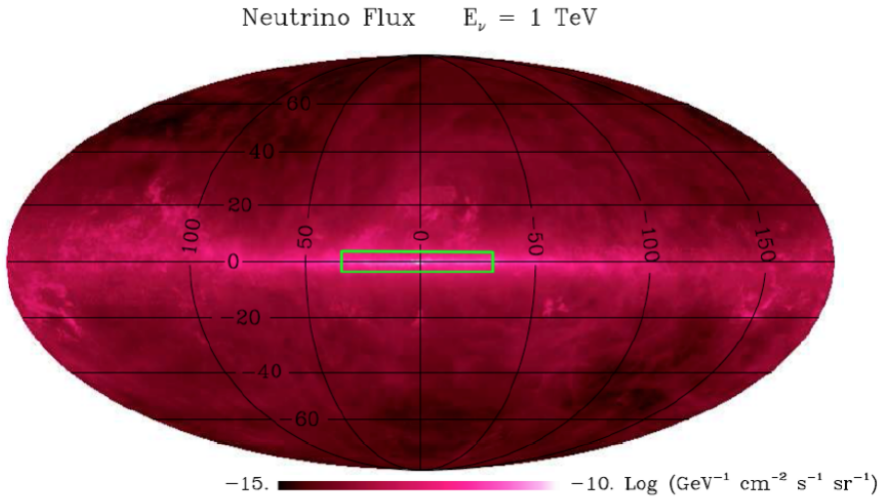
Comparison between neutrino spectrum produced with standard KRA model and the new KRAγ model from the entire galactic plane. The black stars show the equivalence between standard KRA (based on DRAGON code) and standard GALPROP obtained spectra.



The diffuse neutrino spectrum obtained considering the KRAγ model for the inner galactic plane can exceed the atmospheric neutrino flux measured by IceCube above 20 TeV

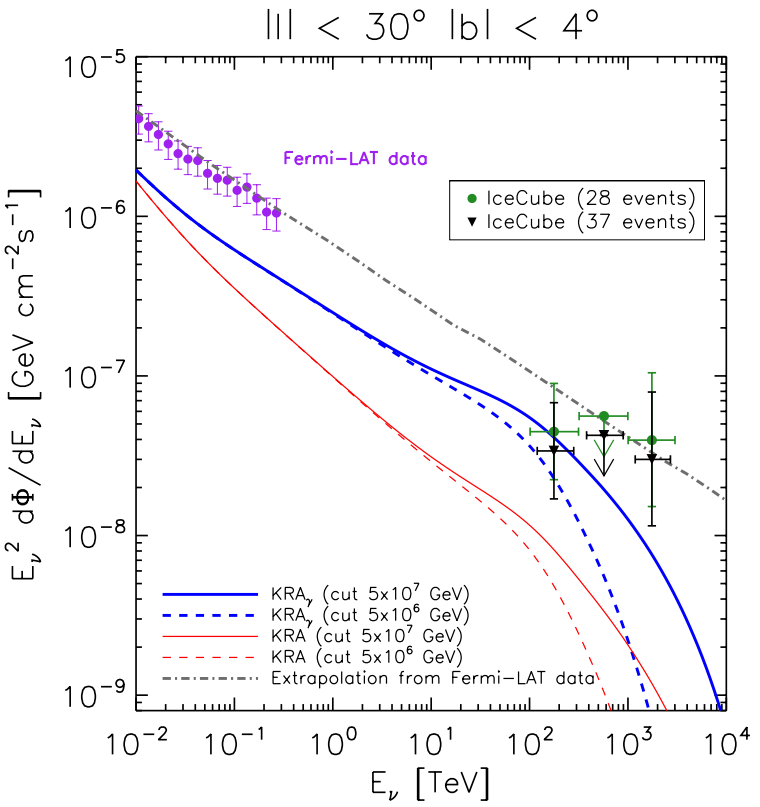
KRA and KRA$_\gamma$ neutrino spectra expected for |b|<4°, |l|<30°



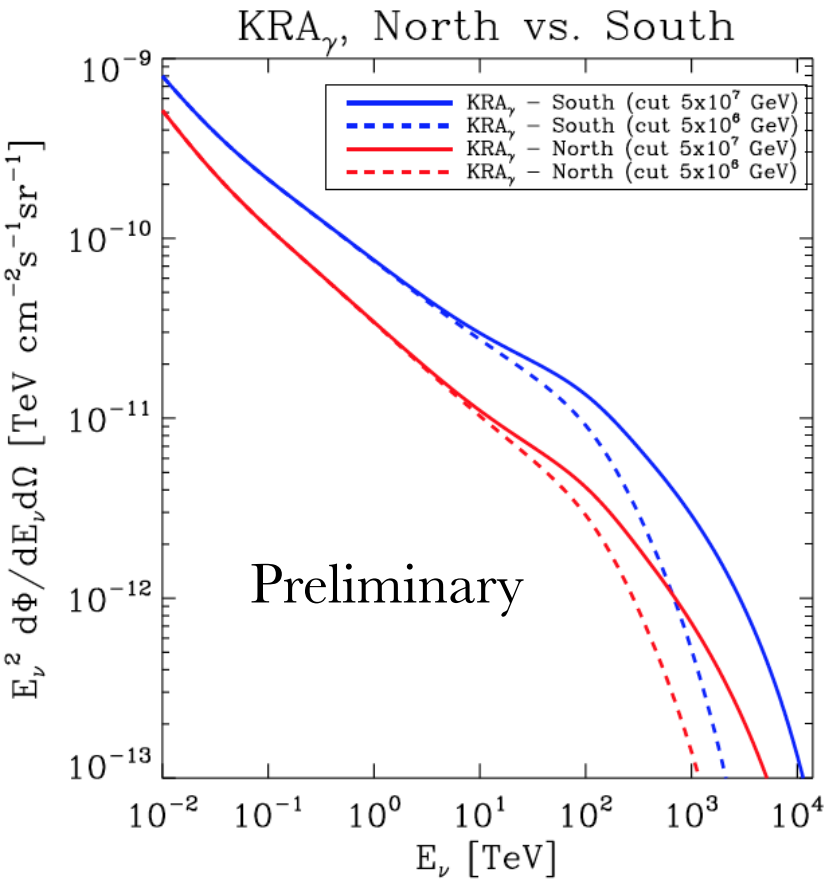


- Skymap with the last catalog of IceCube extraterrestrial neutrino of 37 events: 29 shower-like and 8 track-like. Only 3 shower-like events are reconstructed in a position of the sky compatible with the |b| <4° and |l|<30°

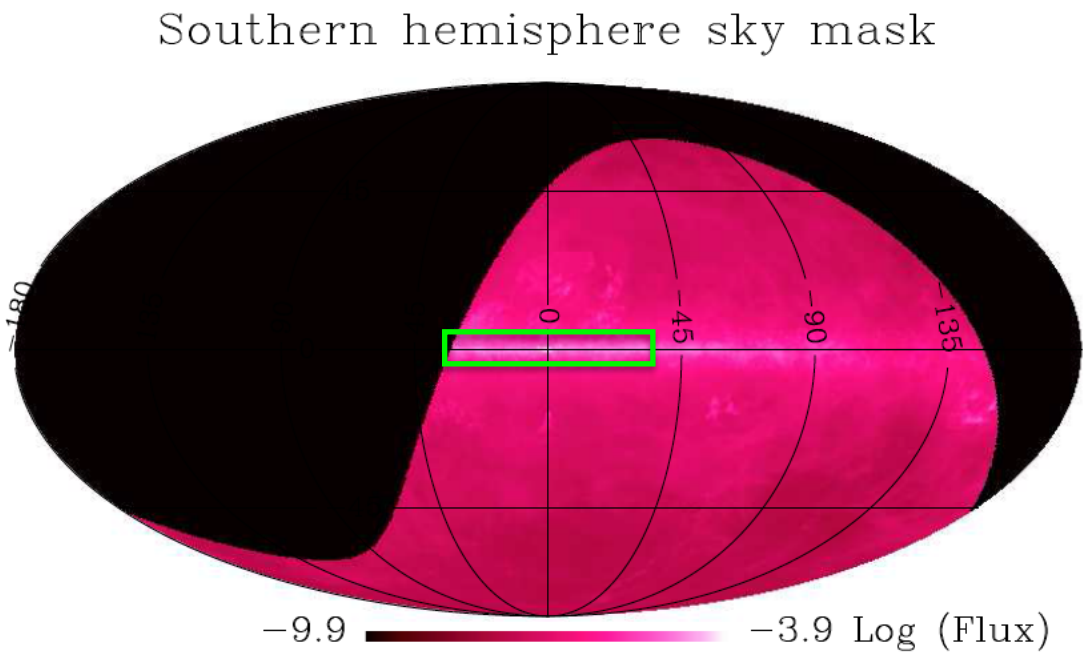
- From the neutrino spectra obtained with KRA and KRA$_\gamma$ models we can estimate the galactic component of the IceCube observation in this region of the sky.



The expected KRA$_\gamma$ neutrinos from north/south hemisphere

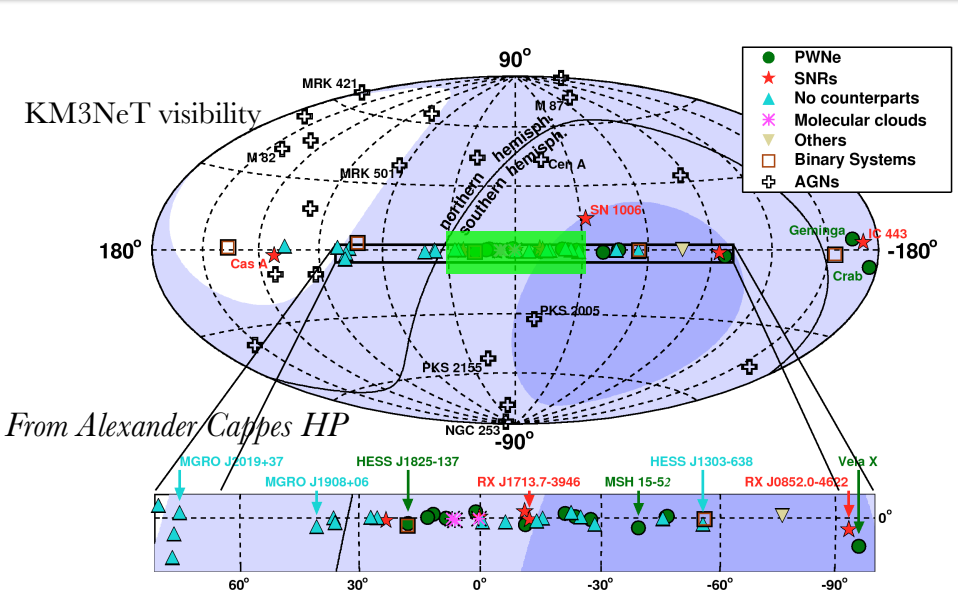


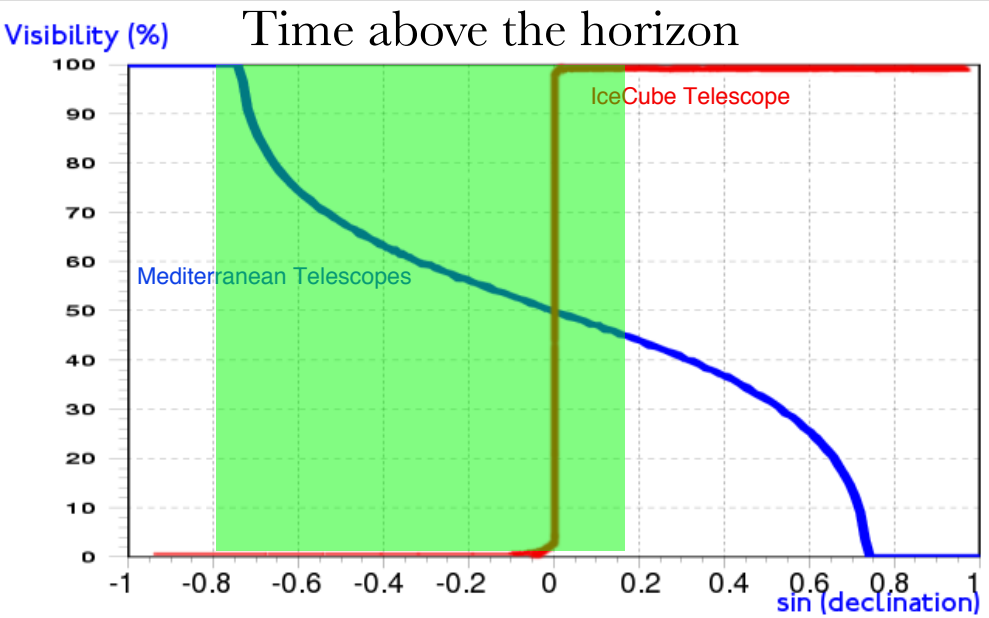
The Southern hemisphere expected neutrinos, obtained with KRAγ scenario, are more than double the expected from the Northern one.



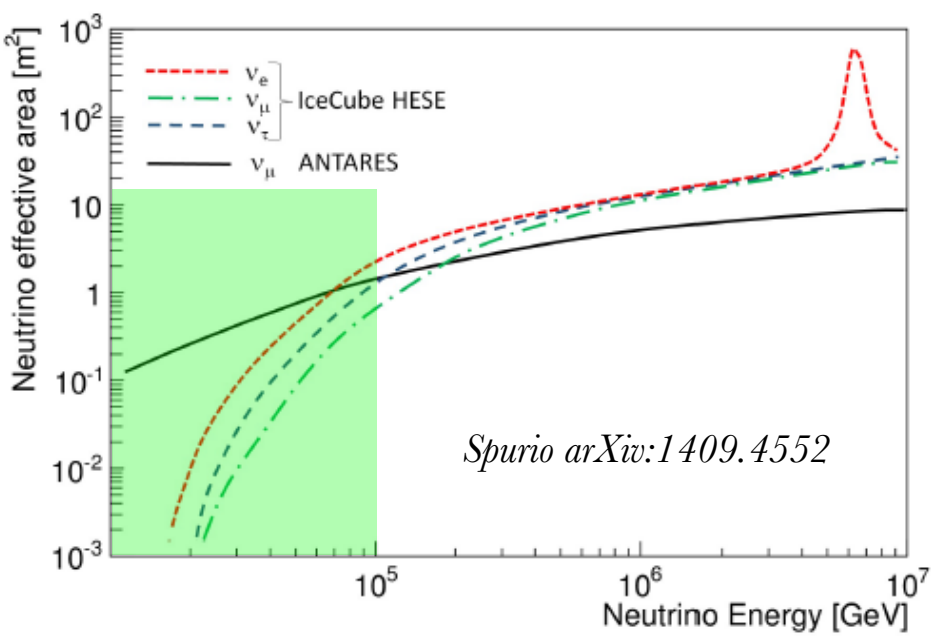
The inner galactic plane neutrino diffuse emission mostly comes from the Southern hemisphere.

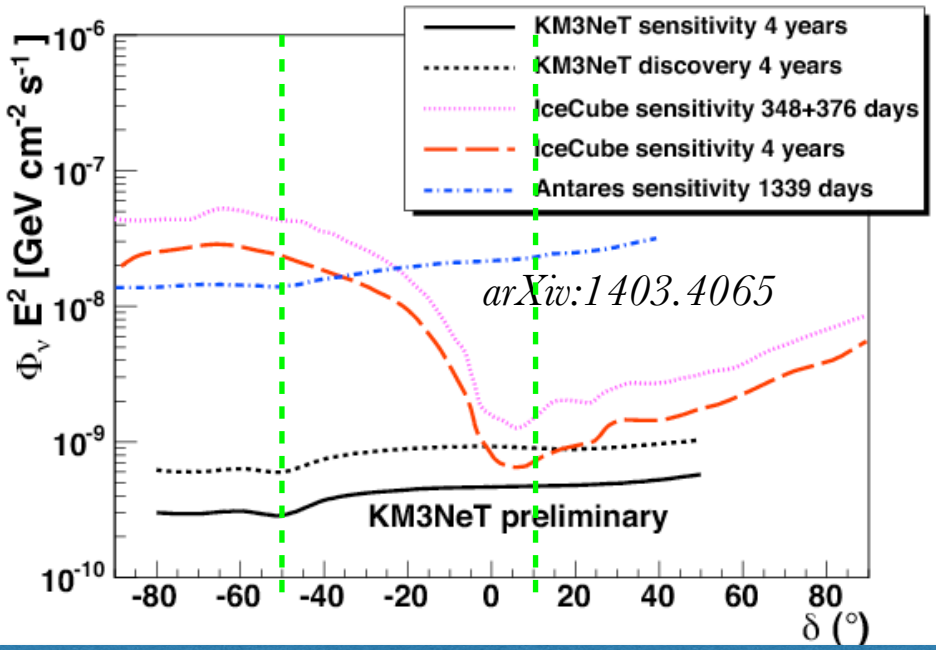
Inner Galactic plane visibility for the Global Neutrino Network



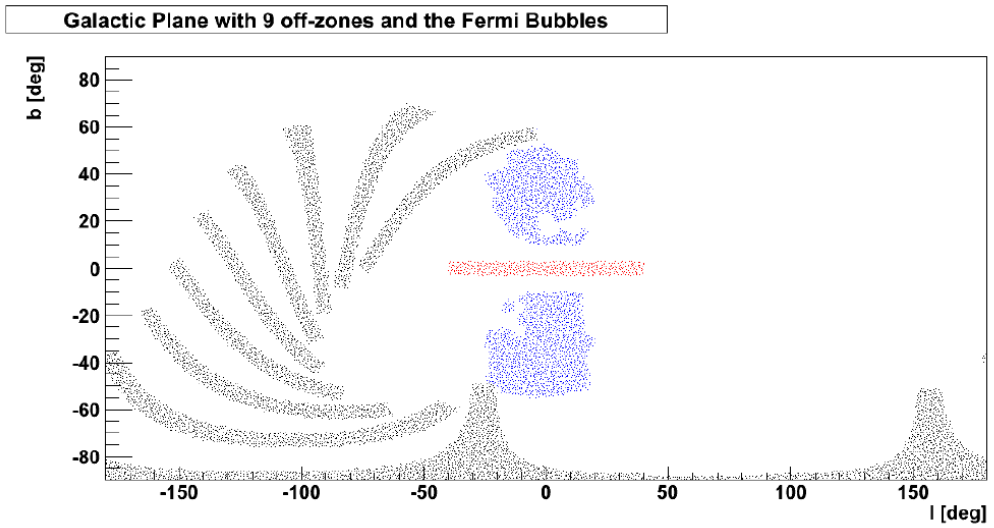


Mediterranean ν telescopes can be more sensitive to this region of the sky

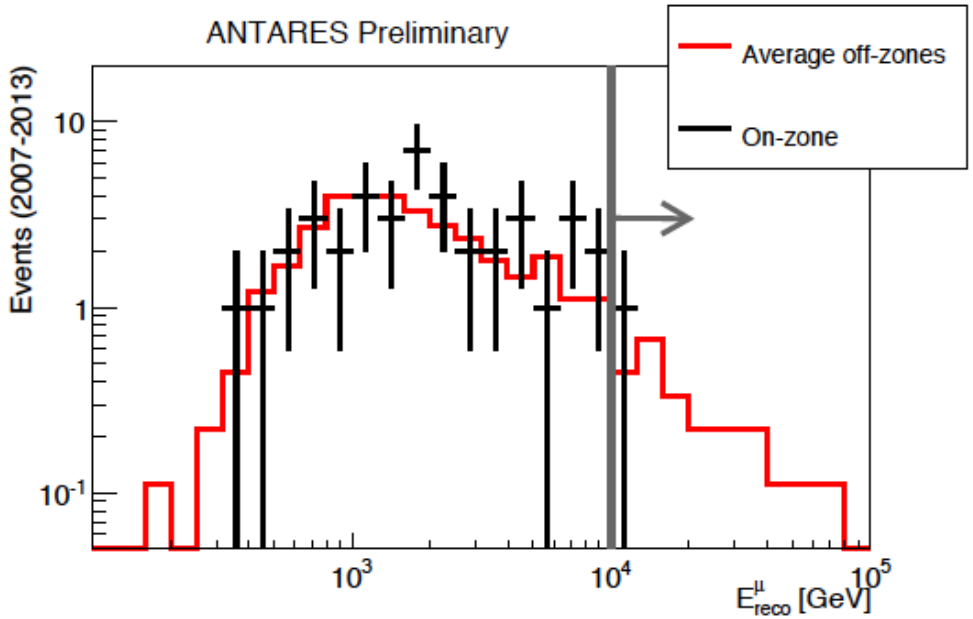




Antares unblinding analysis for the Galactic Ridge



L.Fusco for Antares coll., ICRC2015, arXiv:1510.04508



(b) Galactic Plane

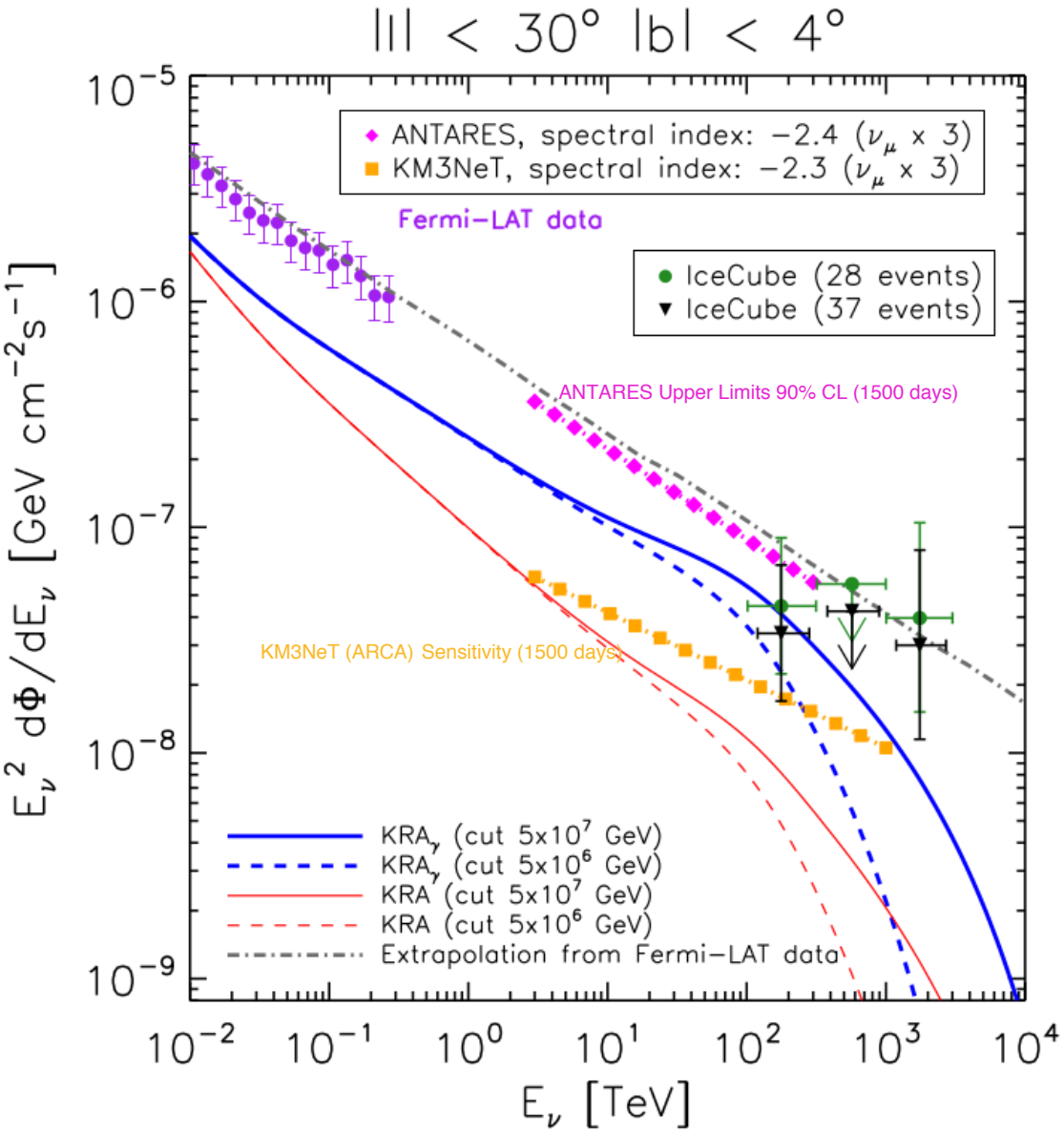
- A unblinded analysis was performed with Antares data collected between 2007 and 2013. No neutrino excess was found in the Galactic ridge region respect to the background expectation obtained considering the nine off-zone regions.

- No high energy neutrino events were observed from the Galactic ridge by considering the Antares data.

- Thanks to this unblinding analysis of the region, upper limits at 90% C.L. where set.

Better constrains to the KRA$_\gamma$ neutrino spectrum of Galactic Ridge introducing Mediterranean telescopes.

Gaggero, Grasso, Marinelli, Urbano, Valli, arXiv:1508.03681

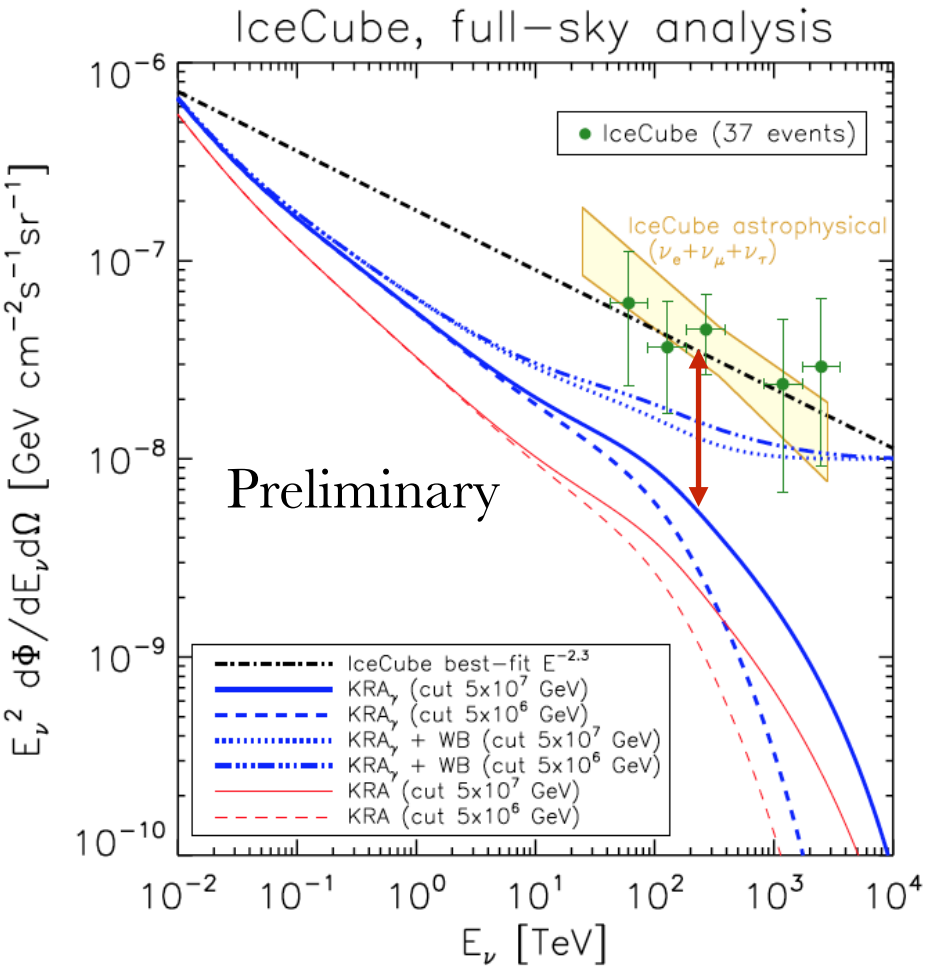


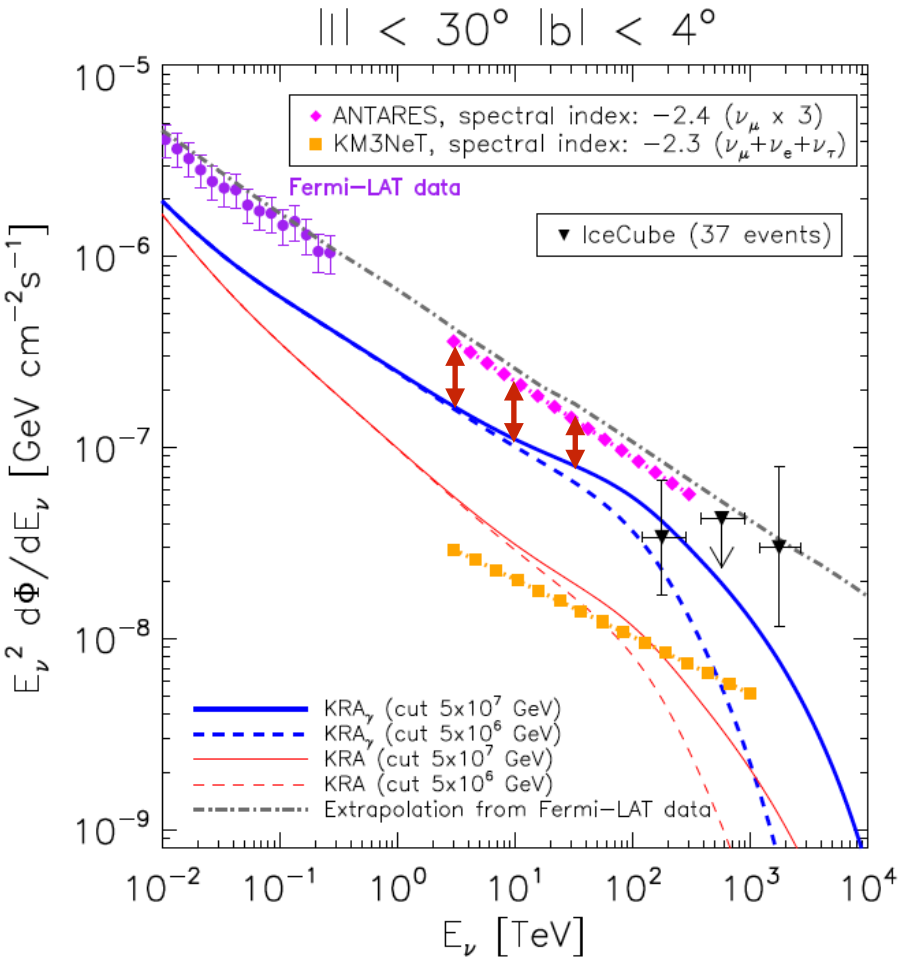
The KRA (δ uniform) and KRA$_\gamma$ (δ variable) produced ν spectra of the inner galactic plane with the CR cut-off at 5 PeV and 50 PeV compared to:

- ANTARES upper limits obtained with ν track events reconstructed in 1500 days of experiment live time.
- IceCube constraints of the flux with observation of 3 ν shower like events in 662 and 998 days of experiment live time.
- Deduced KM3NeT sensitivity for this region of the sky with 1500 days of experiment live time.

From the Galactic Ridge to the Extragalactic emission

Gaggero, Grasso, Marinelli, Urbano, Valli, arXiv:1504.00227

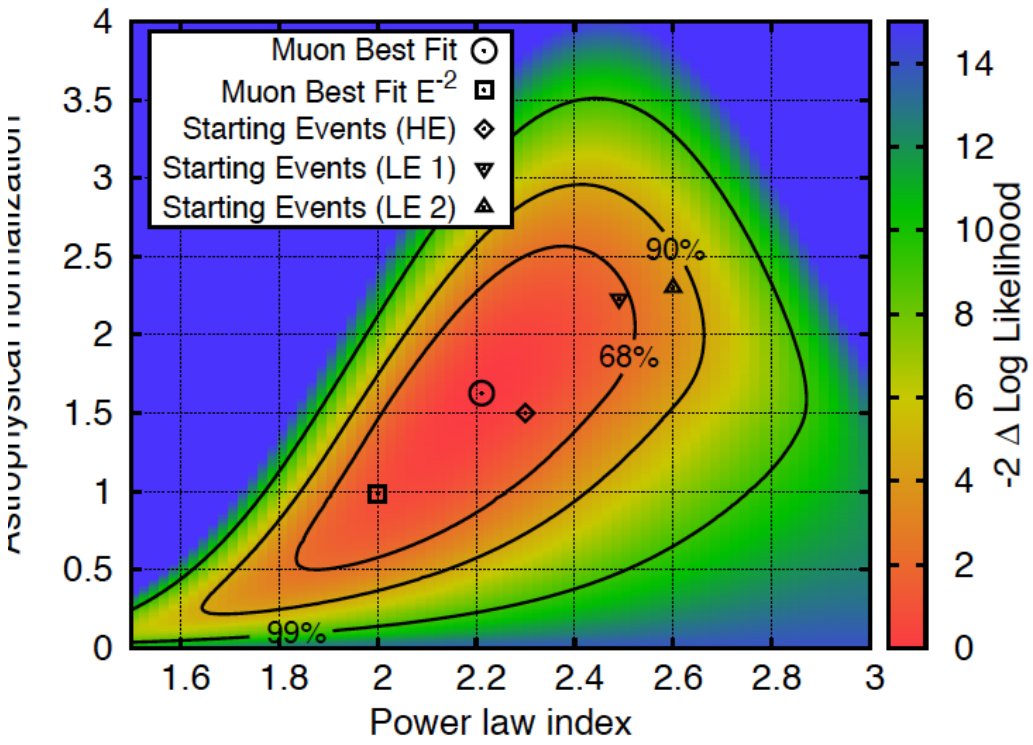


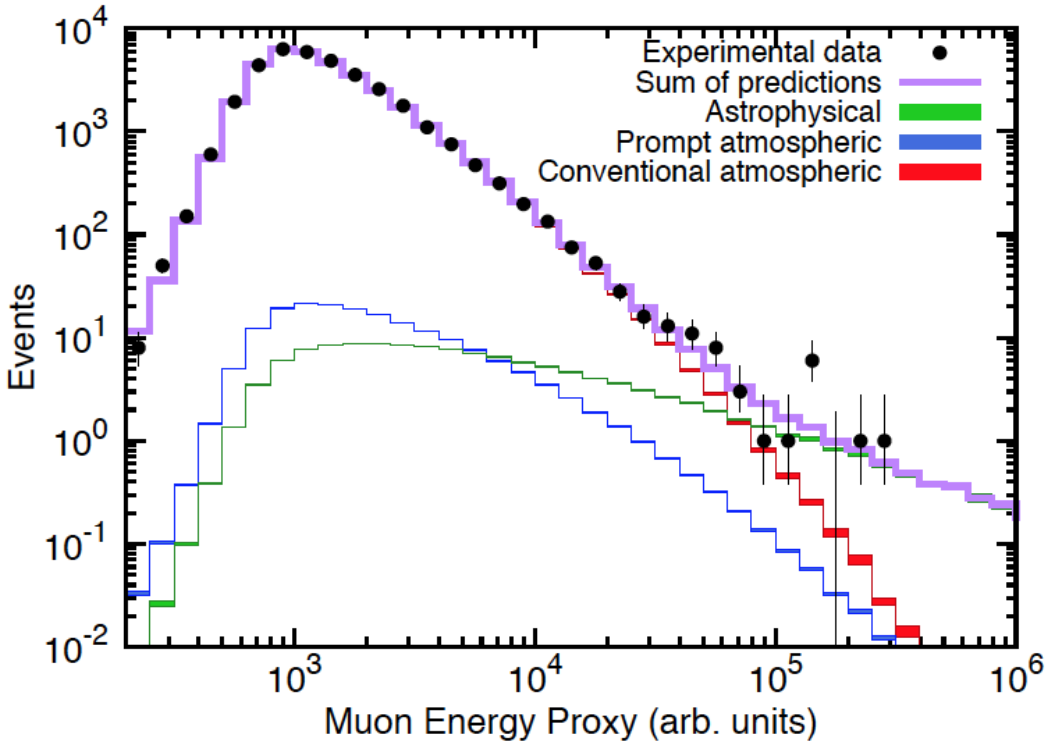


In the full sky analysis we have a large room for a extragalactic component to be added at the diffuse galactic KRAγ neutrinos. Thanks to the Antares upper limits a constrain for these two components can be obtained from the Galactic ridge region.

Estimating the extragalactic contribution from the North hemisphere

IceCube coll., PRL, vol.115, n.8, 2015



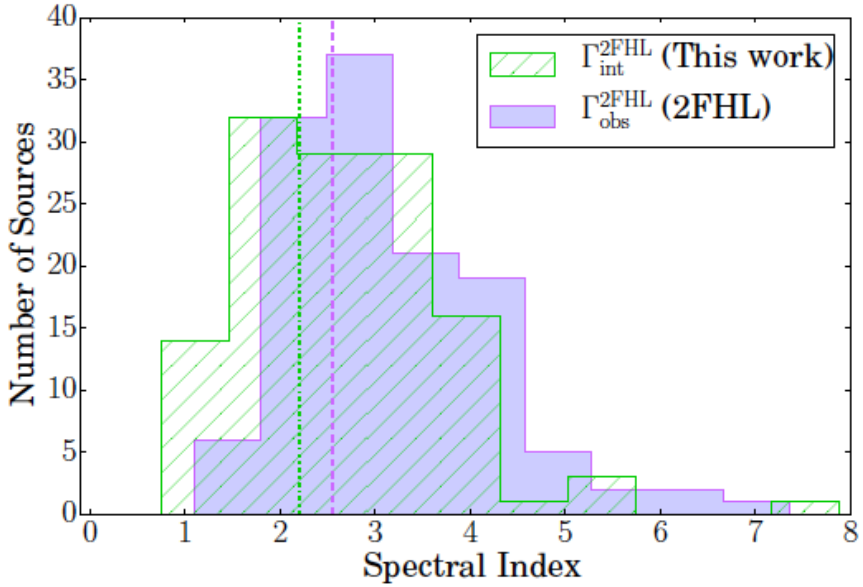


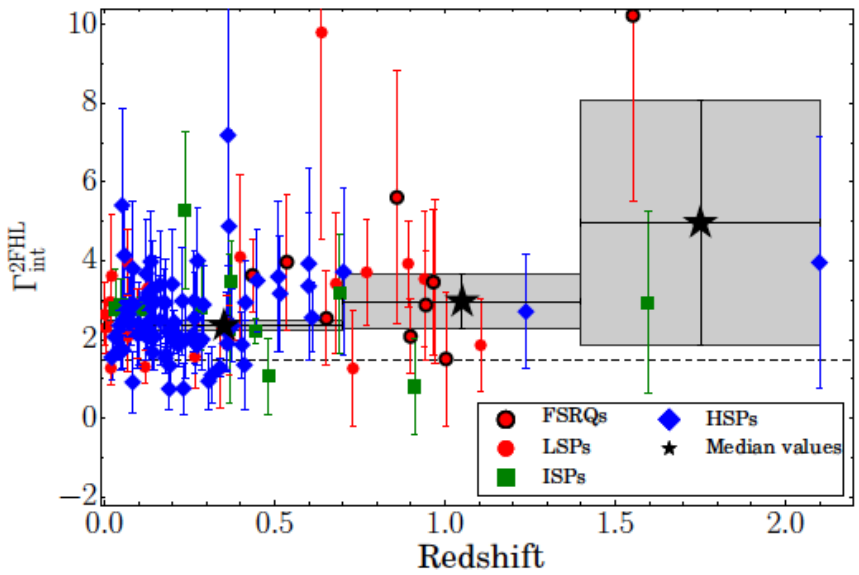
- IceCube collaboration recently published a evidence of astrophysical muon neutrinos from the Northern hemisphere. The neutrinos collected during 659.5 days of live time between May 2010 and May 2012 are inconsistent with the background at the level of 3.7 σ.

- Assuming a modest diffuse galactic contribution from this hemisphere we can consider the observed muon neutrinos as a good bound for the extragalactic neutrino signal. In this case the best-fit analysis gives a $\Gamma \sim 2.2$.

A class of extragalactic sources compatible with Γ ~ 2.2

Domingüéz & Ajello, ArXiv:1510.07913

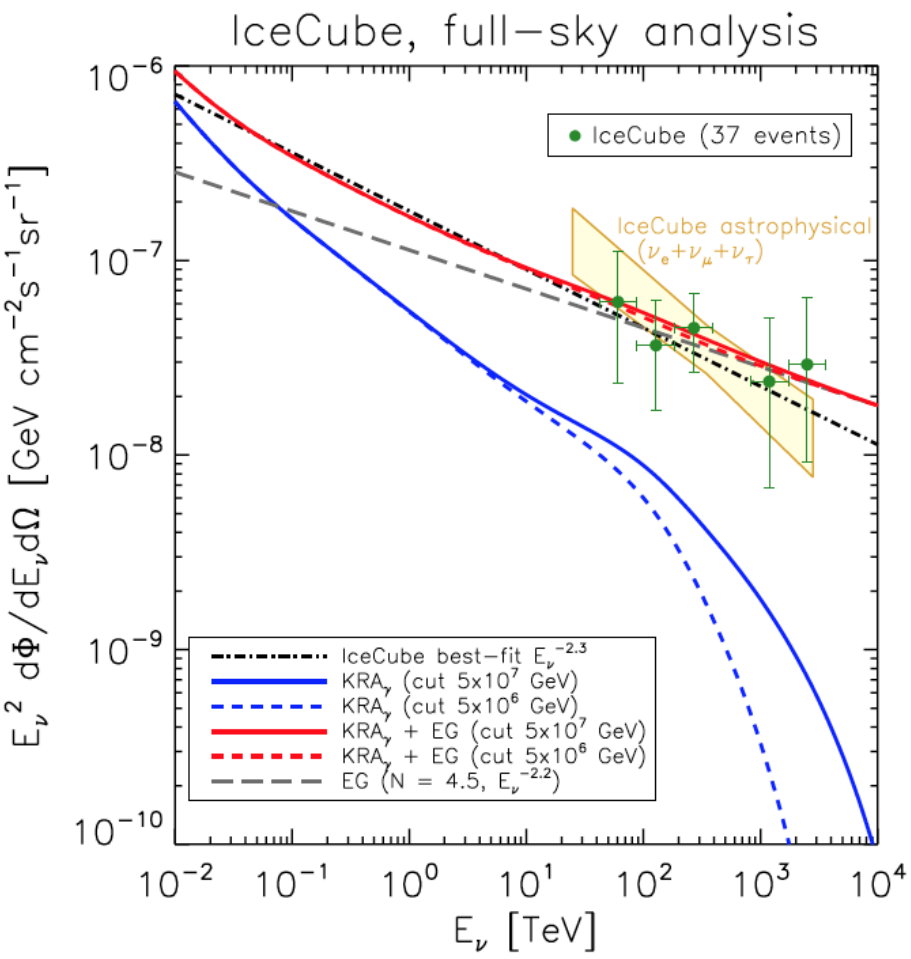


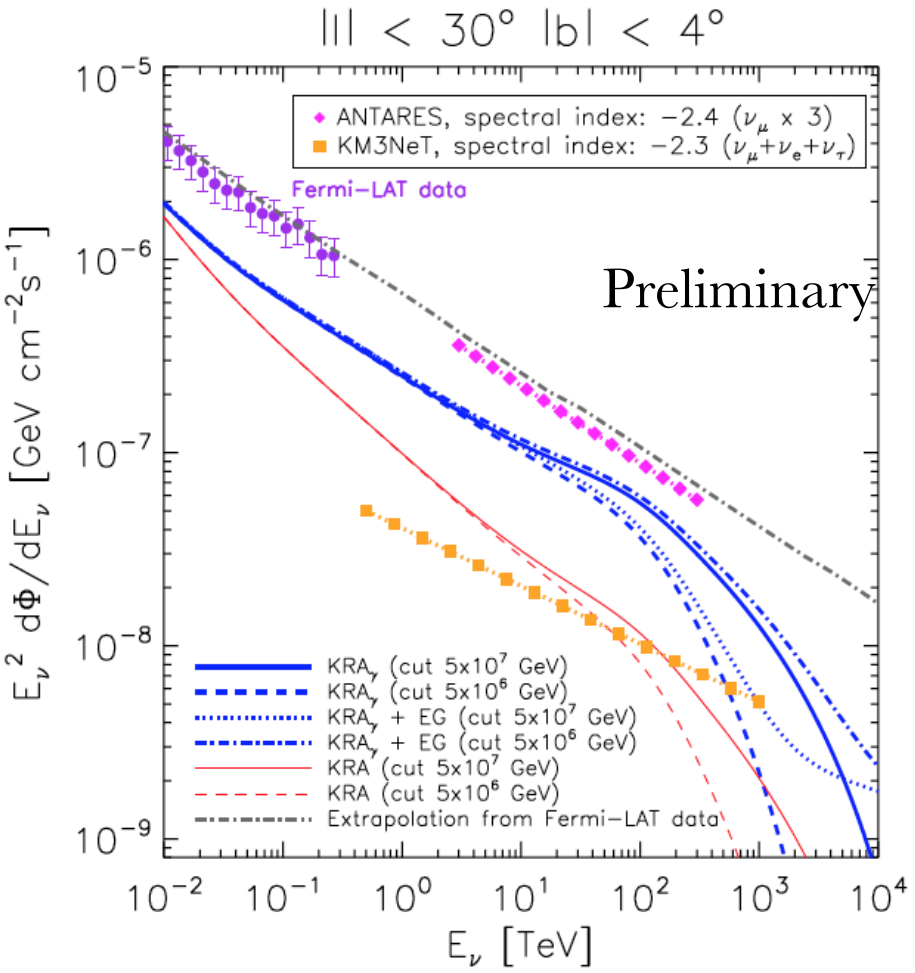


- A analysis of 128 extragalactic sources (mostly Blazars) from the 2FHL (E>50 GeV) catalog set the average intrinsic (unattenuated from the EBL) spectral index at Γ ~ 2.2 versus the measured average Γ ~ 2.5
- If the gamma-ray are produced through pion decay we can expect a corresponding neutrino spectrum described by the obtained intrinsic Γ ~ 2.2 .
- A physical motivation for this spectral assumption of the extragalactic component.

Galactic+Extragalactic expectations vs Antares upper bounds

Gaggero, Grasso, Marinelli, Urbano, Valli, arXiv:1504.00227

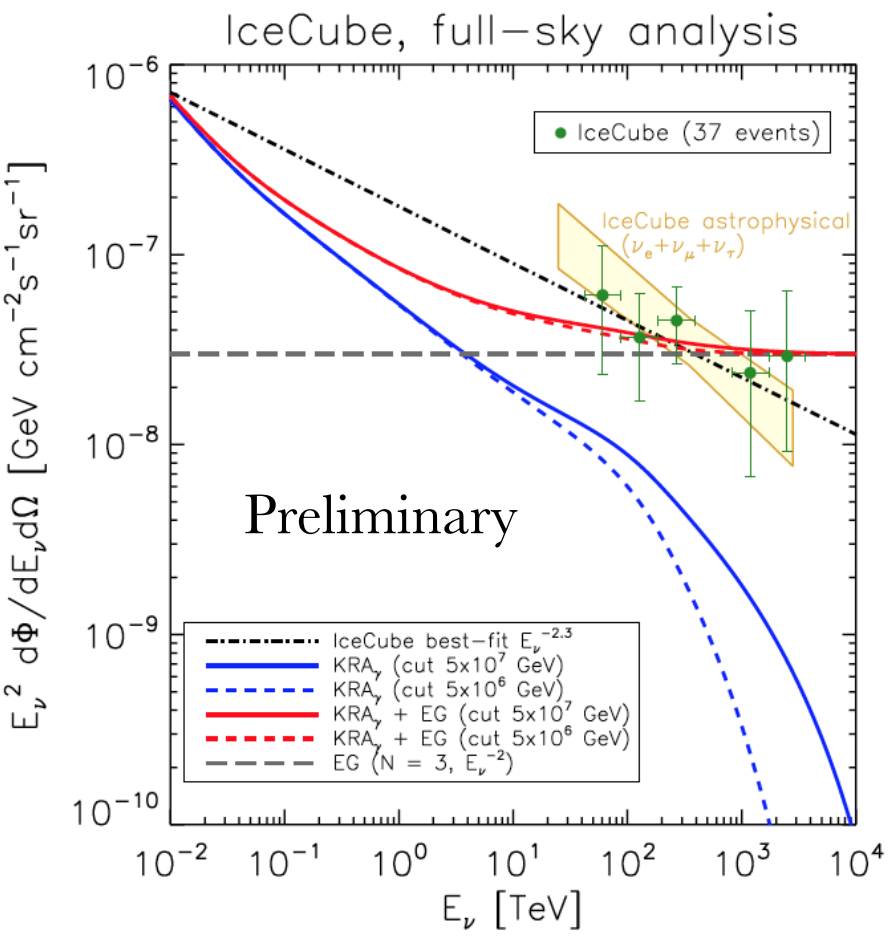




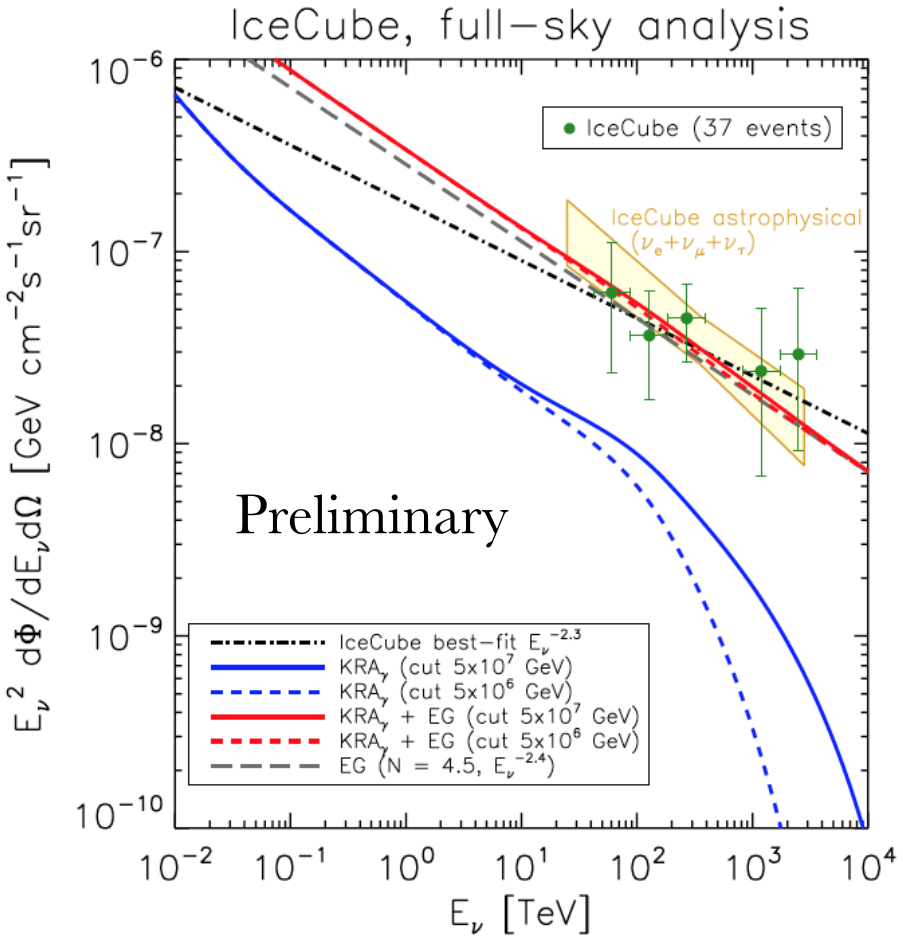
The KRAγ spectrum + extragalactic spectrum (obtained from the muon neutrino analysis of the Northern hemisphere) give a physical meaning to the IceCube full sky measured spectrum and is still consistent, in the ridge region, with the Antares measured upper limits.

Looking at Galactic + extreme Extragalactic scenarios

Extragalactic $\Gamma = 2$



Extragalactic $\Gamma = 2.4$



These extragalactic scenarios are still compatible with Antares upper limits when adding the KRAγ neutrinos, however are less coupled with the full sky IceCube spectrum.

SUMMARY

- The introduction of a radially variable diffusion coefficient for the galactic CRs allows to solve some longstanding problems (es. Milagro excess) in gamma-ray astronomy and it seems to be required by recent Fermi-LAT results
- This model, called KRA$_\gamma$, reproduces CR spectra measured by PAMELA, AMS-02, CREAM as well as the γ-ray diffuse emission measured by Fermi
- This model predicts a Galactic neutrino flux larger than expected for conventional models (δ uniform). This may help explaining possible evidences of a Galactic neutrino component in IceCube results.
- In the GR (Galactic Ridge) region the computed neutrino emission is constrained by the Antares and the IceCube observations.
- Combining the Antares upper limits for the GR with IceCube all-sky observations we are able to infer a comprensive galactic+extragalactic neutrino scenario.
- Soon a combined IceCube & Antares analysis of the galactic plane and the arrival of KM3NeT observatory will shed light on the presented model for the diffuse galactic neutrino emission.