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The galactic diffuse neutrino emission: a new comprehensive scenario

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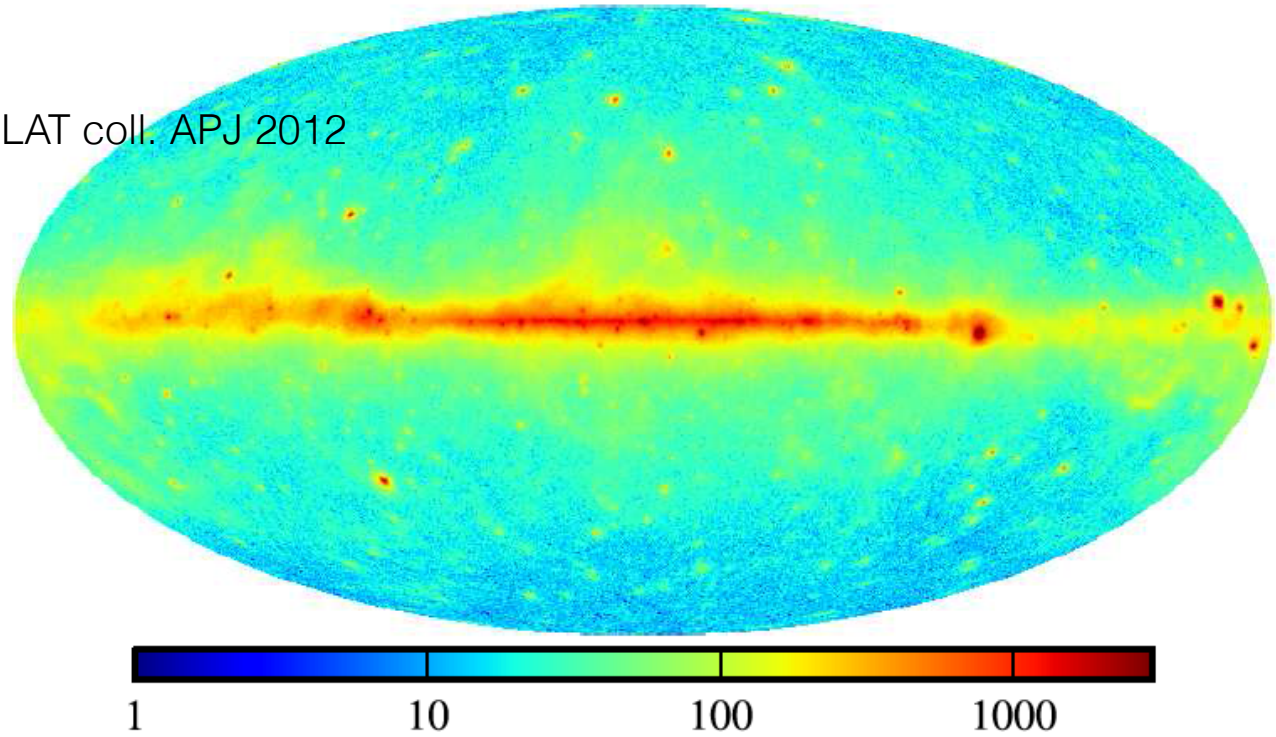
Credits of http://hdw.eweb4.com

Origin of diffuse Galactic Plane gamma-ray emission

Fermi-LAT coll. APJ 2012

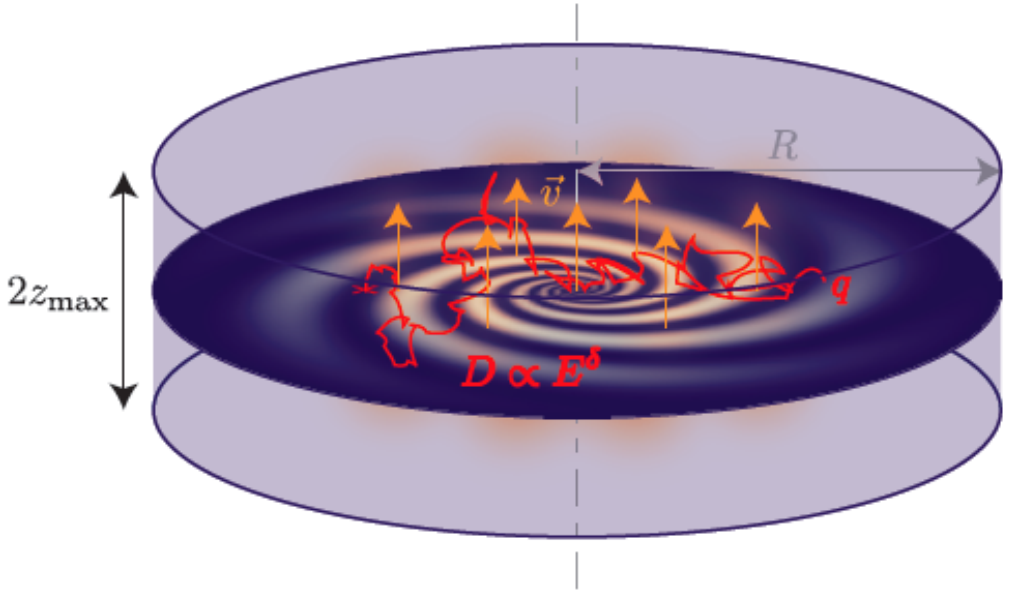


Observed Fermi-LAT counts in the energy range 200 MeV to 100 GeV after point-sources subtraction (log scale = counts/pixel)

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



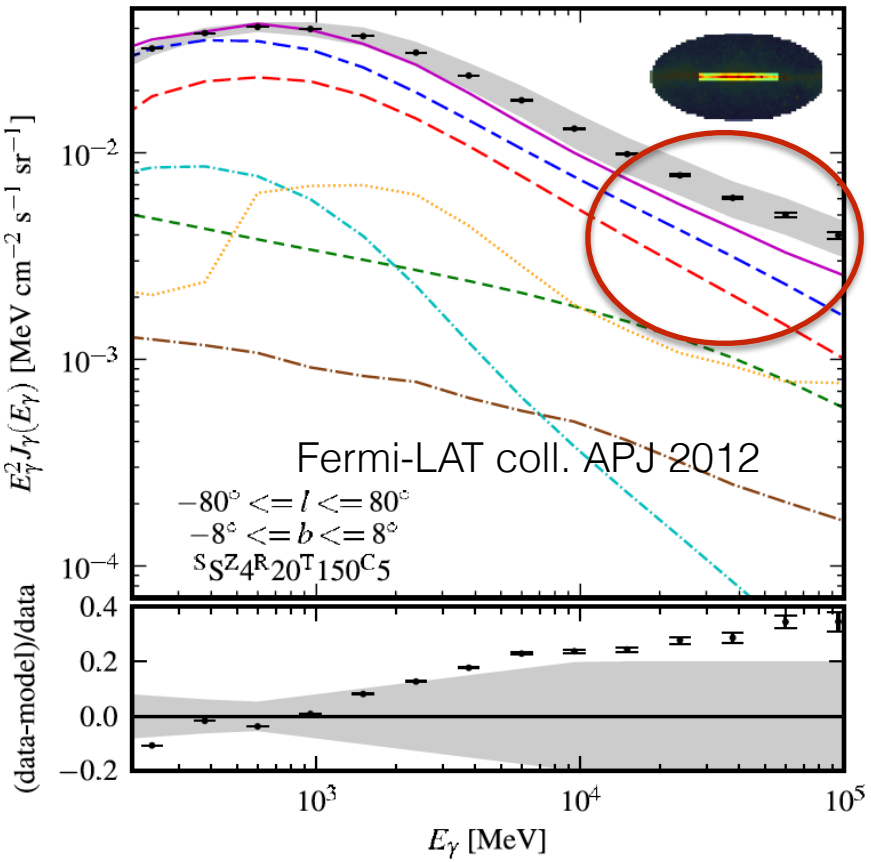
ρ : particle rigidity

D : diffusion coefficient

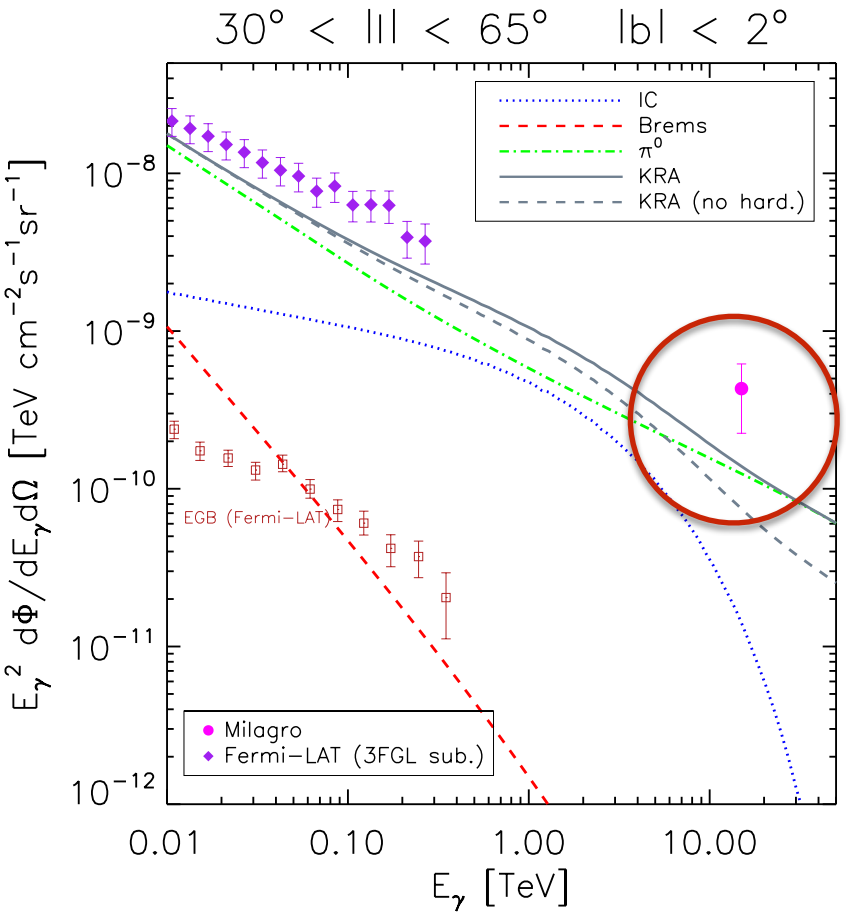
R : distance from galaxy center

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

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

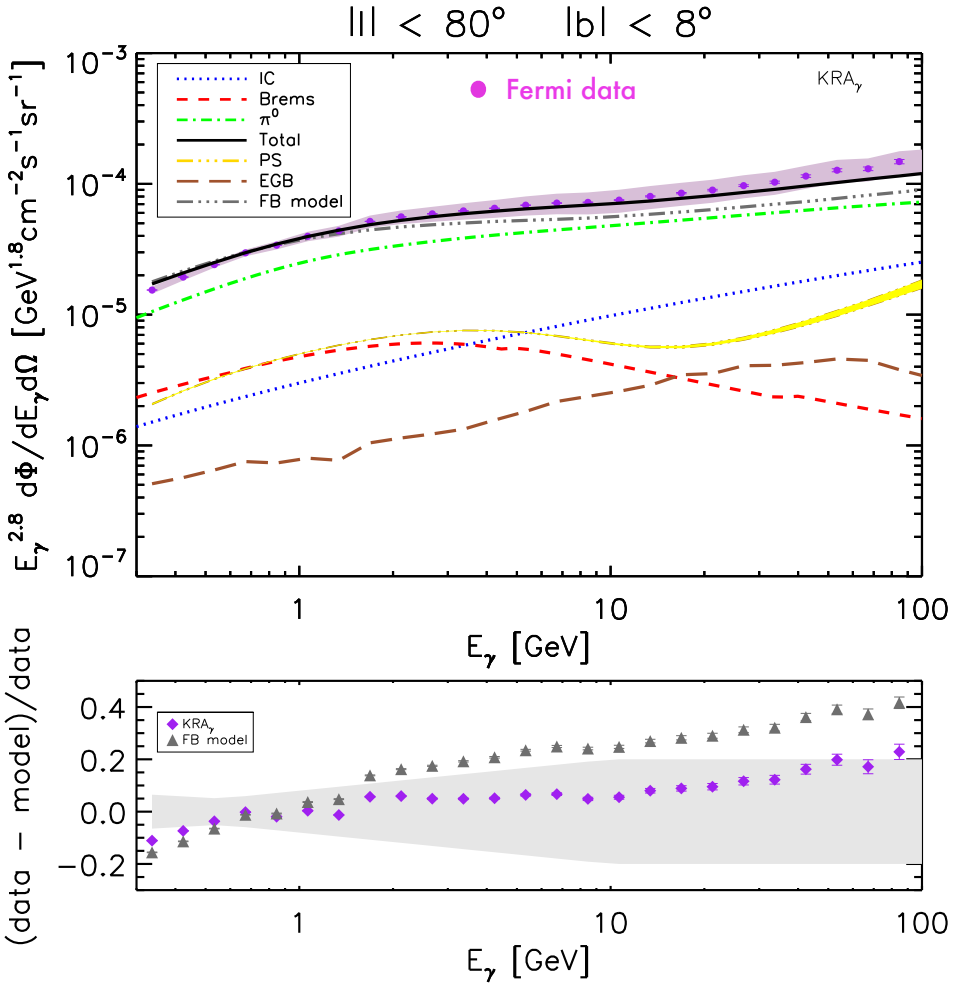
The KRA$_\gamma$ model: Radial dependency of CR transport

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.

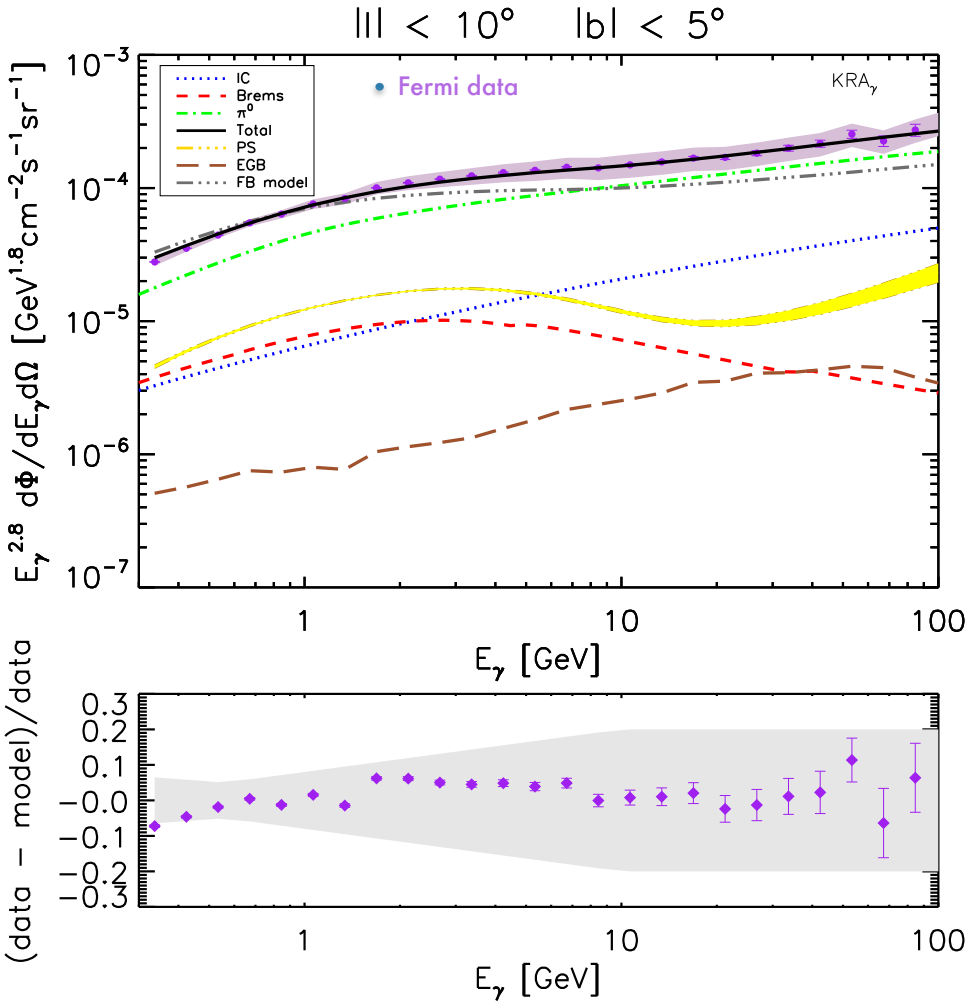
Differently from the Fermi benchmark model (FB) based on GALPROP under the hypothesis of uniform cosmic ray (CR) diffusion, the KRA$_\gamma$ model adopts a radial dependent diffusion coefficient ($\delta(R) = a*R + b$) which turns into a spectral hardening toward the GC region. This is implemented with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

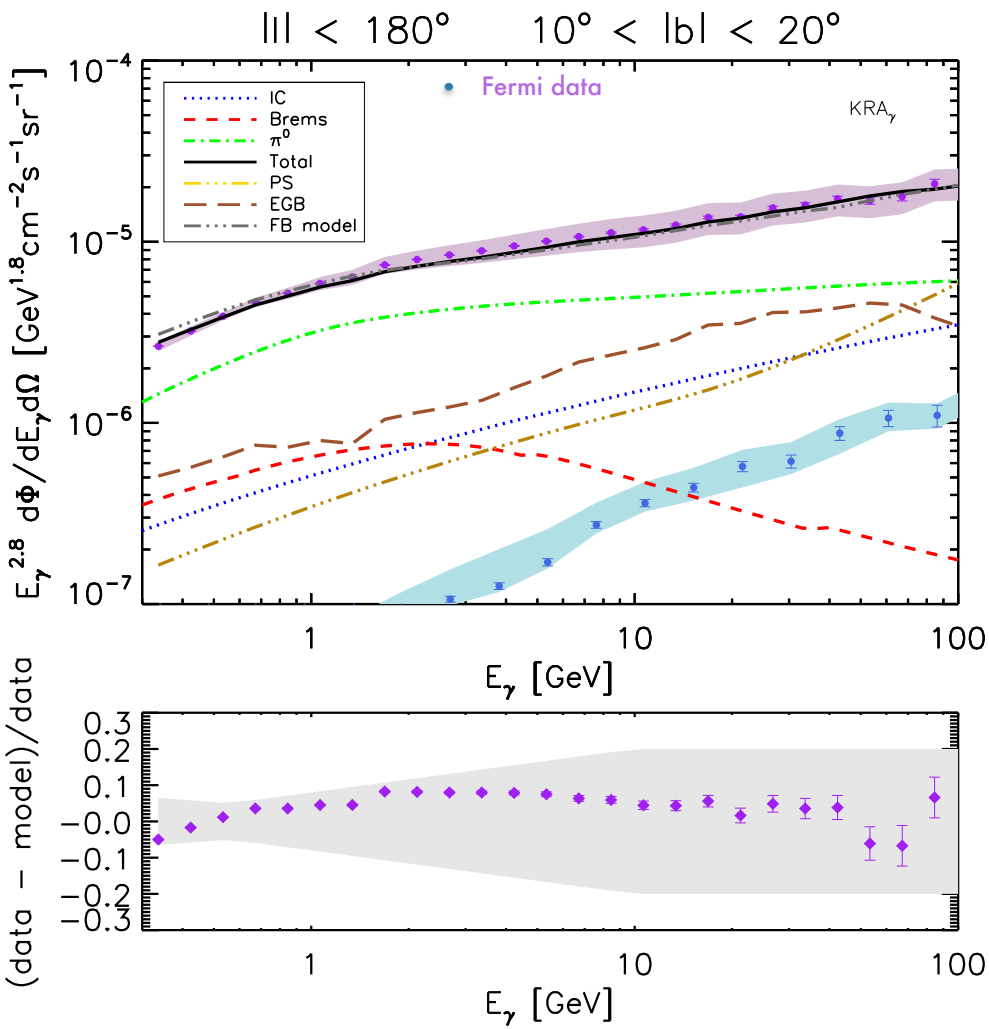
Gaggero, Urbano, Valli, Ullio, Phys.Rev. D91 (2015) 8, 083012



Model tested on different regions of the sky



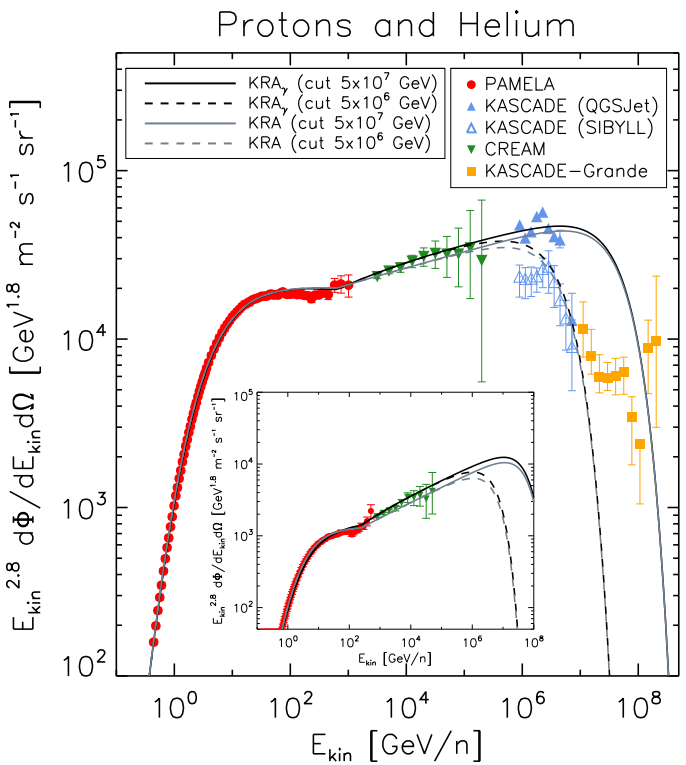
Inside the inner galactic plane

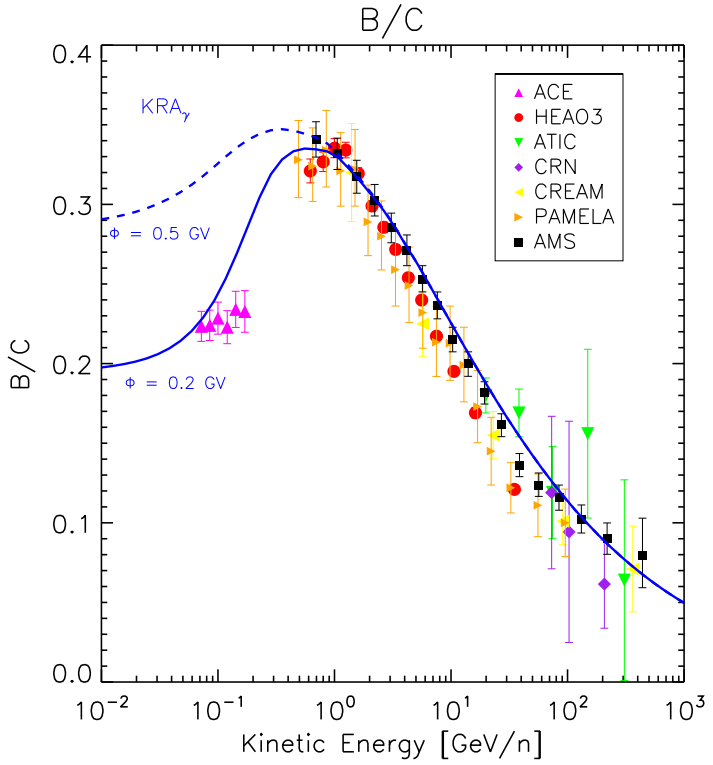


Outside the inner galactic plane

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.





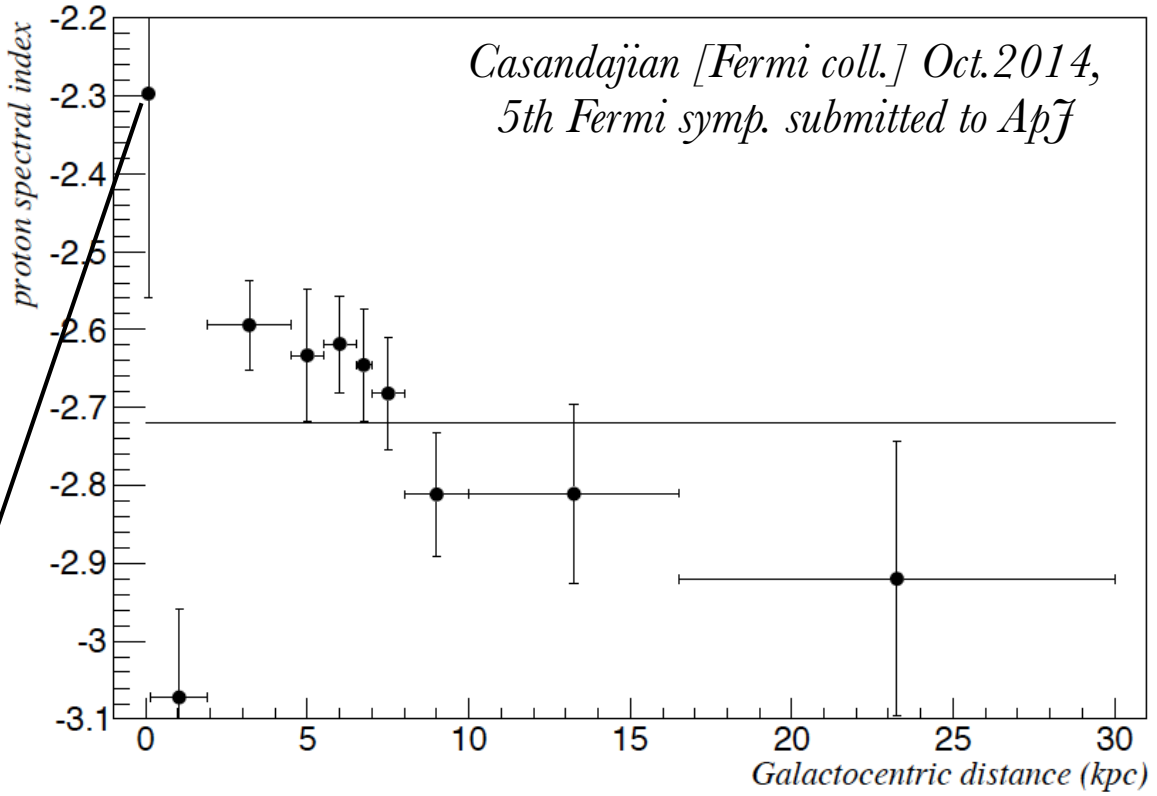
Evidences of CR spectral index radially variable

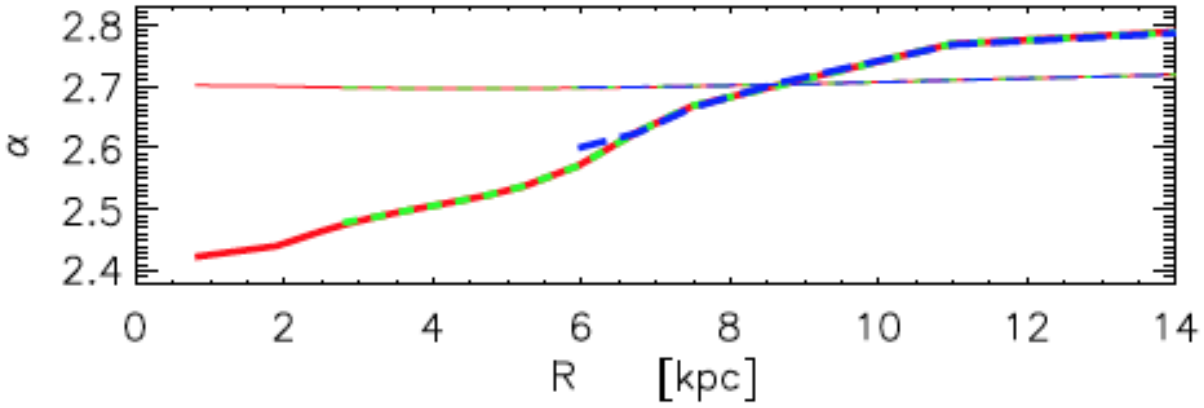
- A template fitting analysis of the diffuse gamma-ray emission measured by Fermi-LAT found such evidence.

- 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.

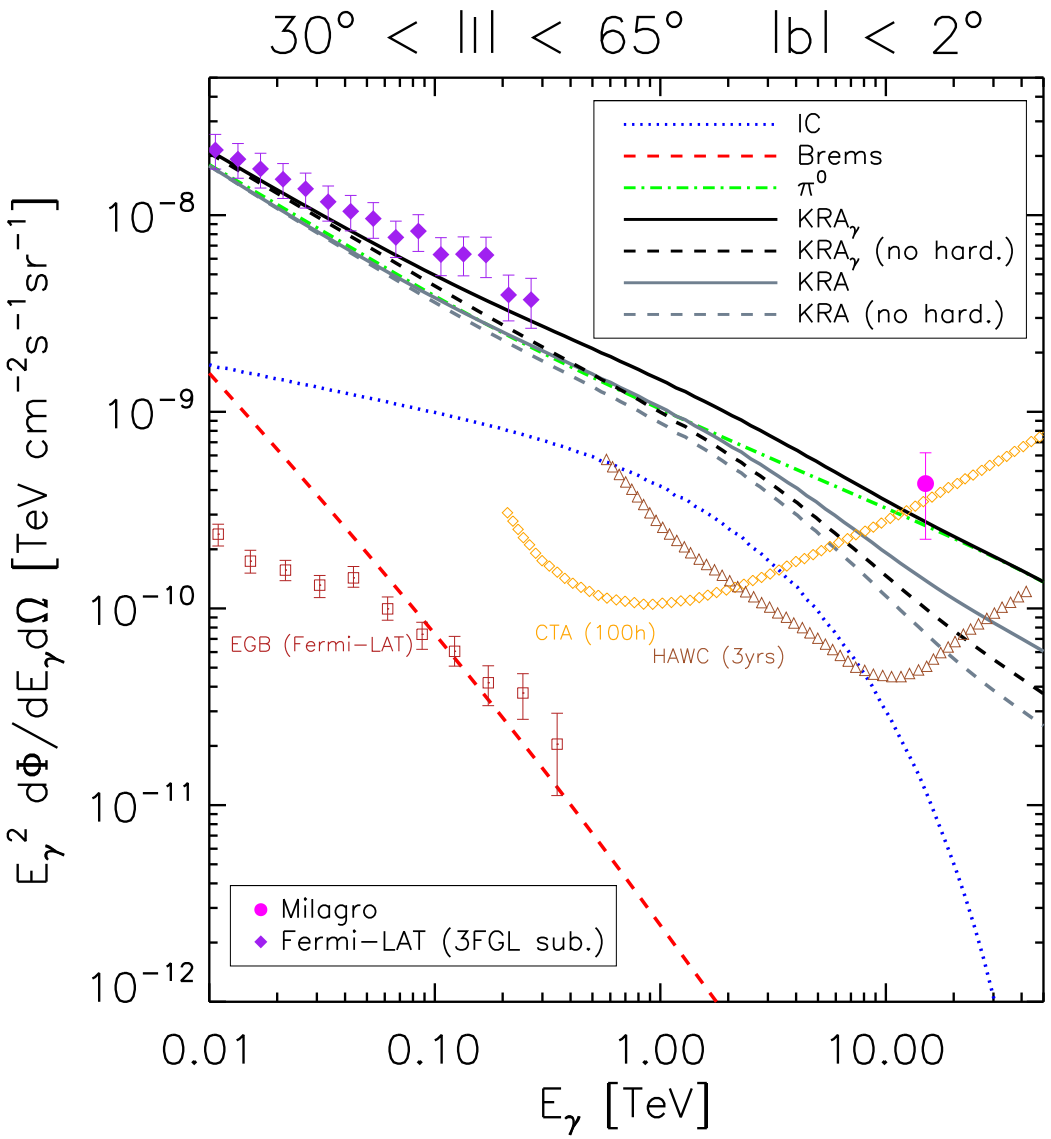




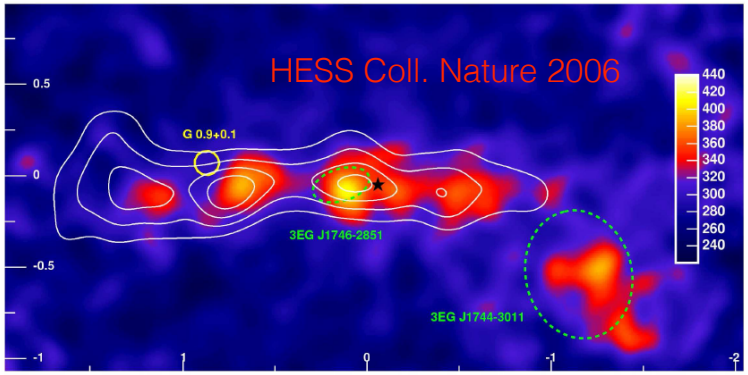
The KRA$_\gamma$ model solves the Milagro anomaly at 15 TeV

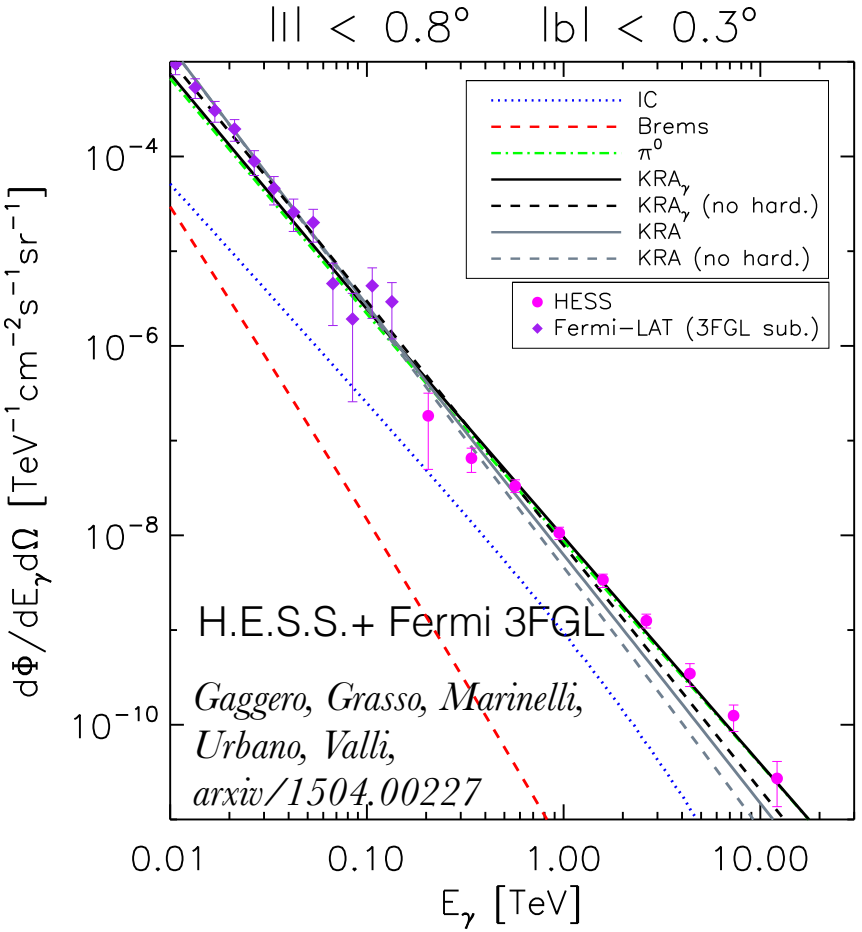
- Milagro measured the diffuse γ-ray flux from the inner Galactic plane @ 15 TeV
- Milagro flux exceeds the predictions of conventional models based on GALPROP. This a longstanding problem in CR physics
- The KRA$_\gamma$ model consistently reproduces Fermi-LAT data (point sources properly subtracted)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

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



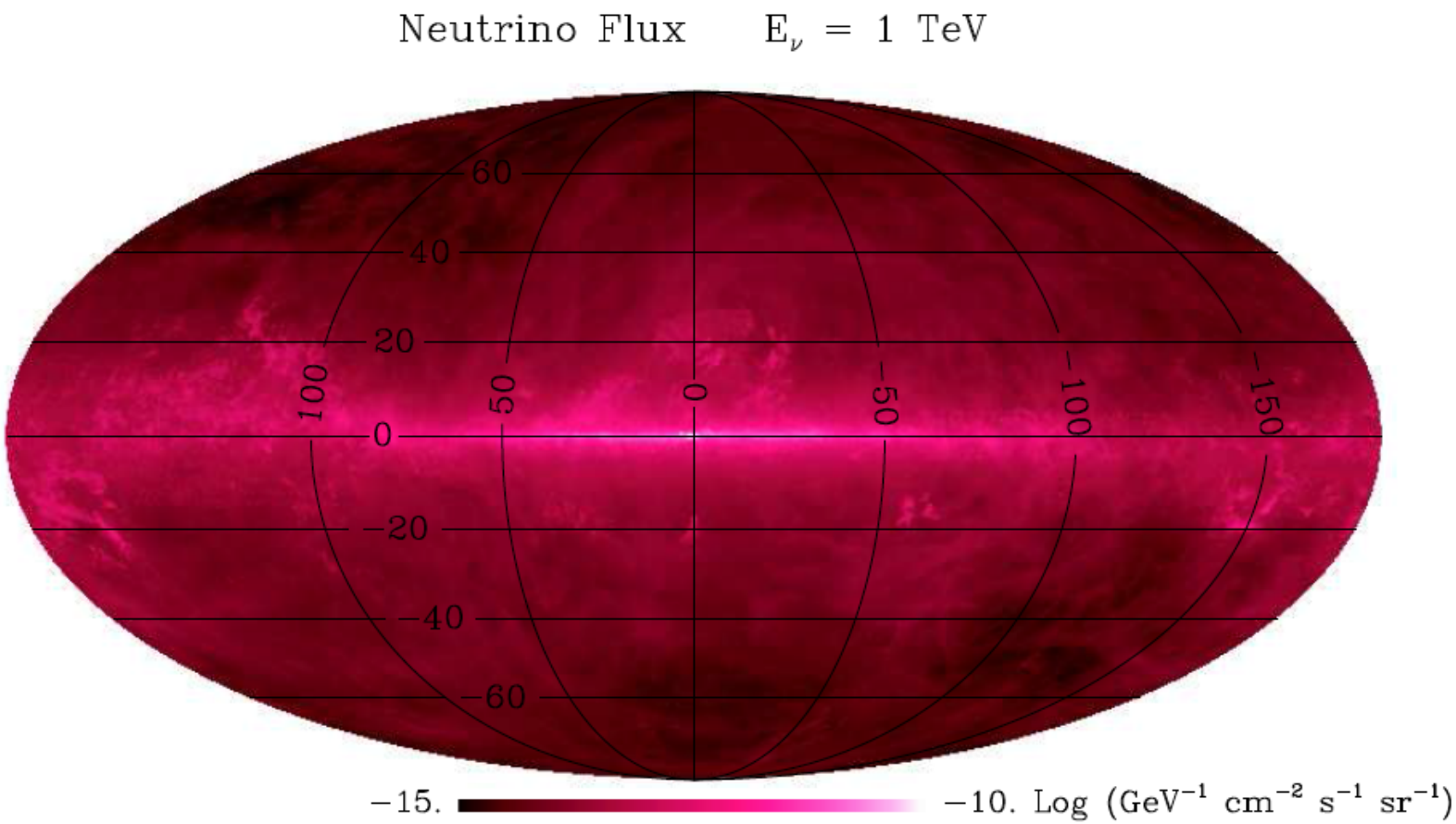
The KRA$_\gamma$ model through the Galactic Ridge





- 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: $\chi 2$ = 1.79 /2.27 with/w.o. hard.
  KRA: $\chi 2$ = 2.92 /3.99 with/w.o. hard.

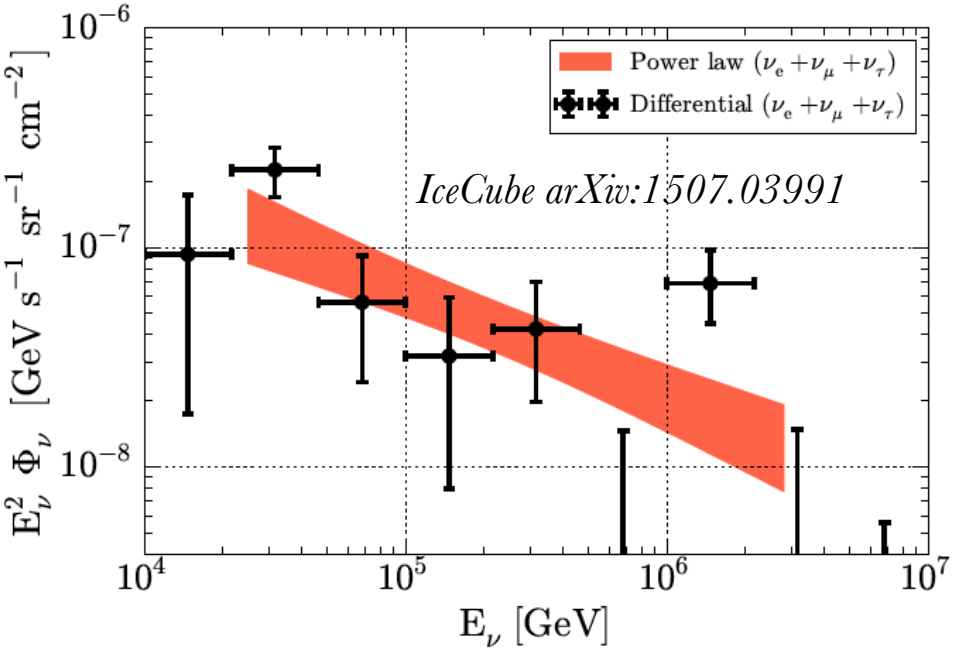
Galactic neutrino flux Skymap from the KRA$_\gamma$ model.



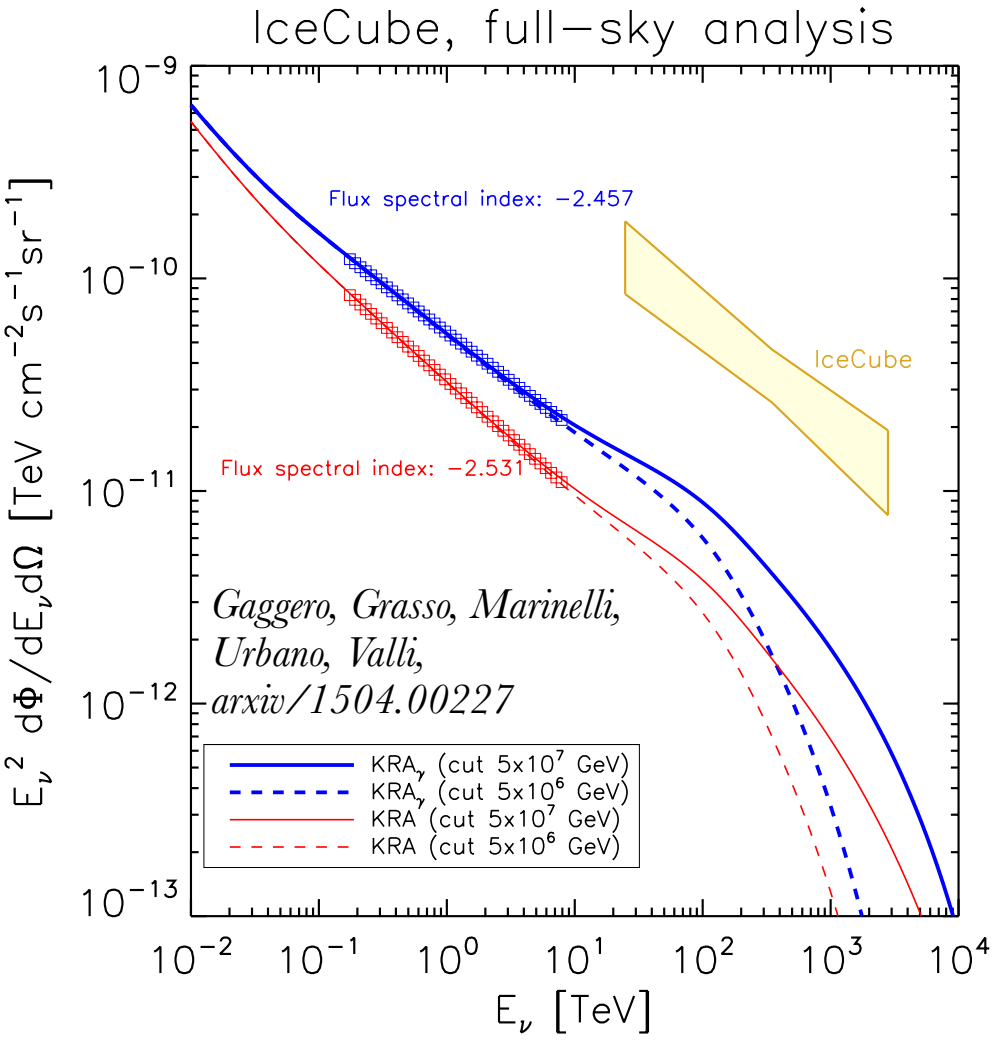
Skymap of neutrino flux produced with KRA$_\gamma$ model.

- 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)



The Shape of astrophysical neutrinos spectrum measured by IceCube for the whole sky is in accordance with the spectrum obtained by KRAγ. A the same time this all sky comparison leave a large room for extragalactic components of measured neutrino flux.



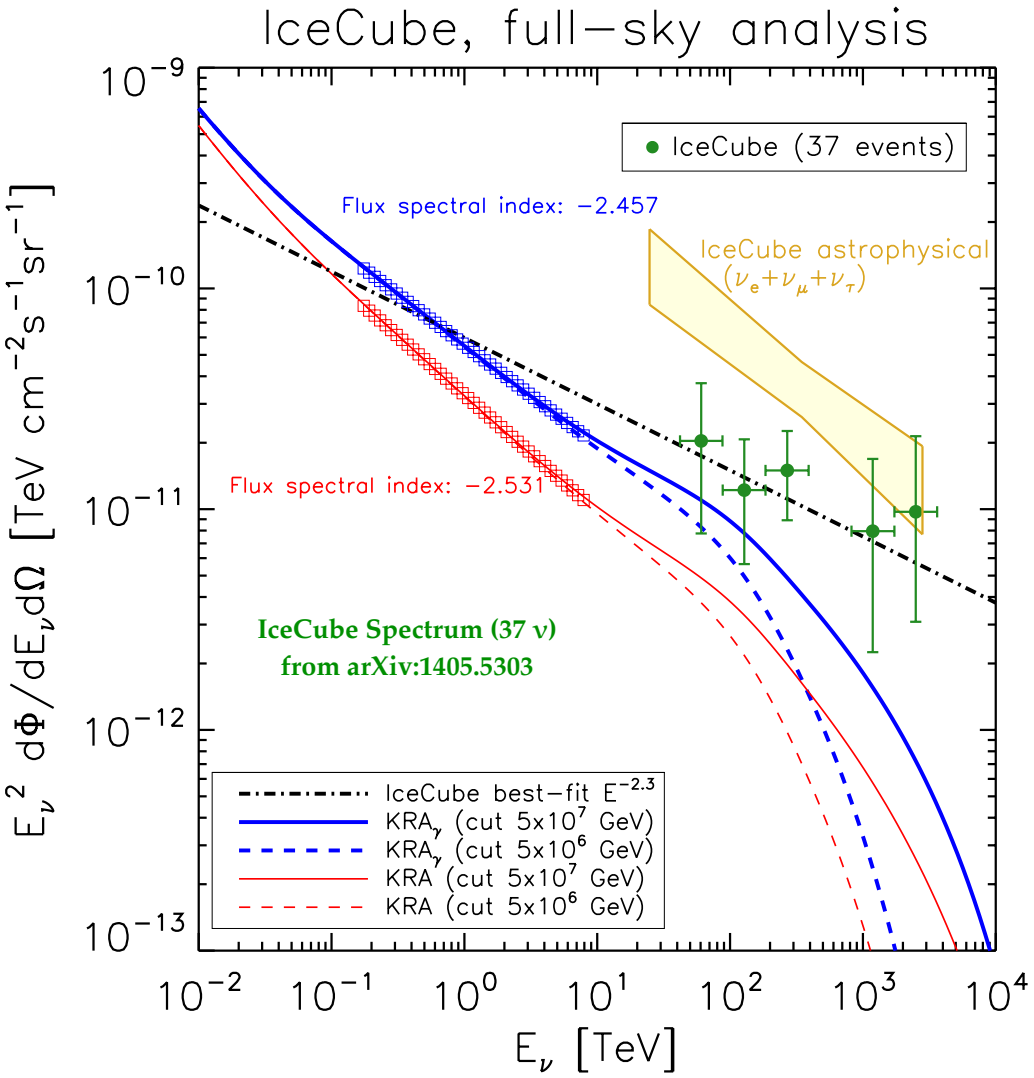
IceCube measured ν spectra compared with KRA & KRA$_\gamma$

On the other hand considering the catalog of 37 ν events KRA$_\gamma$ may account between 10% and 40% (depending on CR cut-off) between 30 TeV and 3 PeV.

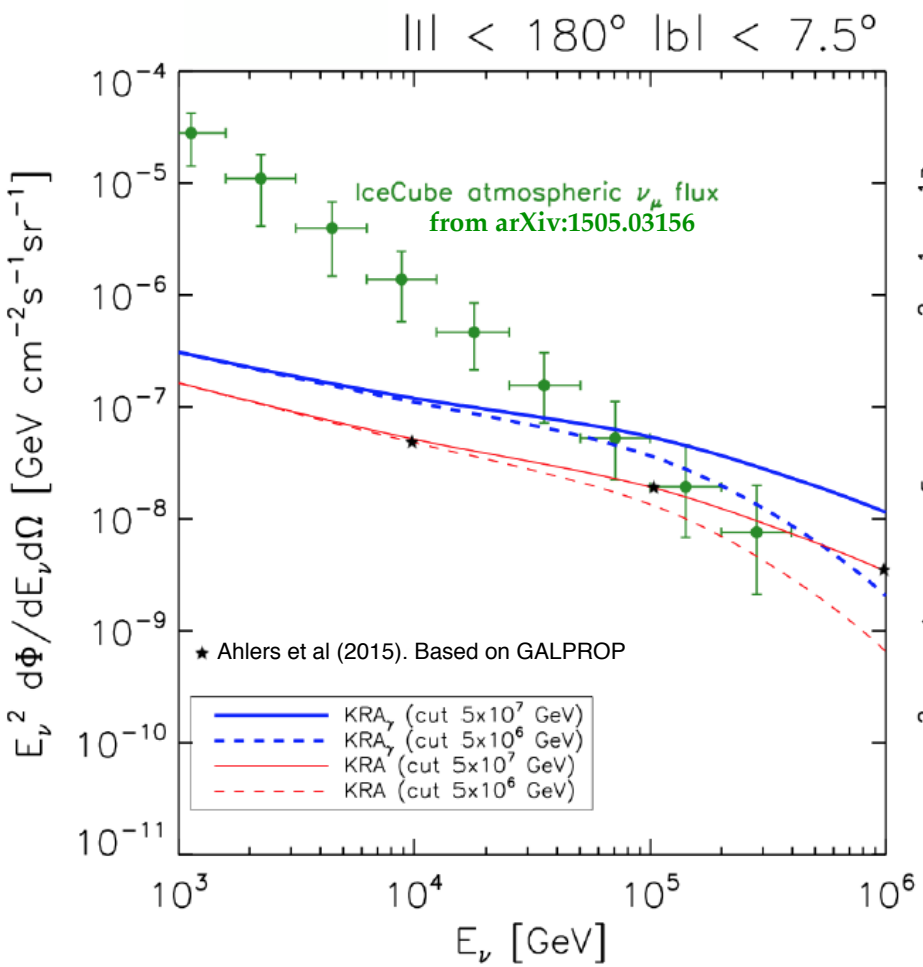
Another hint of a galactic component in the measured ν flux may come from the softer contribution of southern SED (arXiv:1507.0399) possibly related with more galactic plane neutrinos.

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	$2.44 - 2.67$	$2.36 - 2.75$

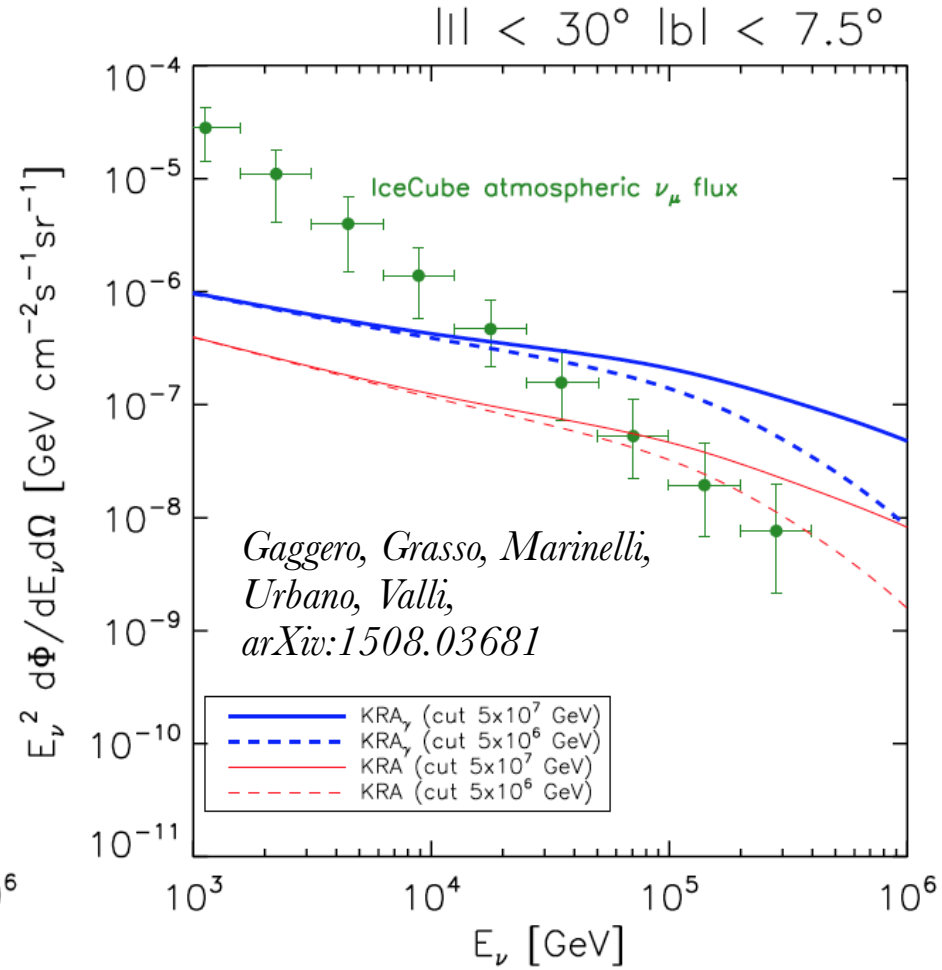
Note. — ϕ_N and ϕ_S are the all-flavor neutrino fluxes at 100 TeV in the northern and southern sky, respectively; γ_N and γ_S are the corresponding spectral indices. The fluxes are given in units of $10^{-18}\,\mathrm{GeV}^{-1}\mathrm{s}^{-1}\mathrm{sr}^{-1}\mathrm{cm}^{-2}$.



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

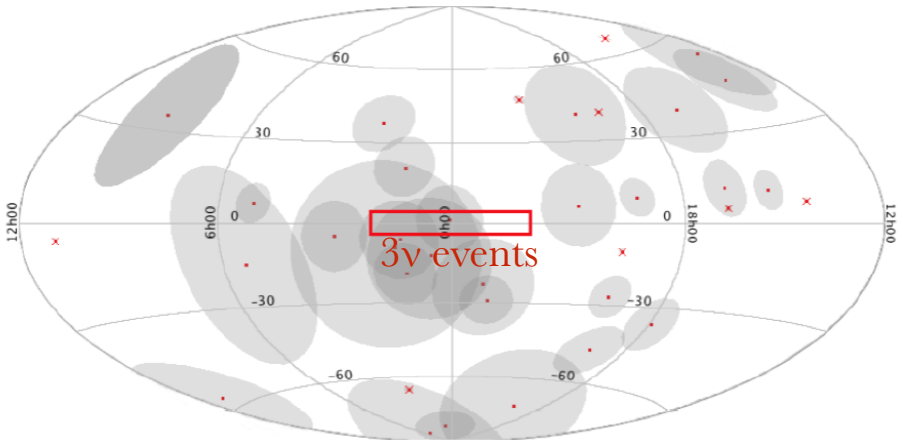


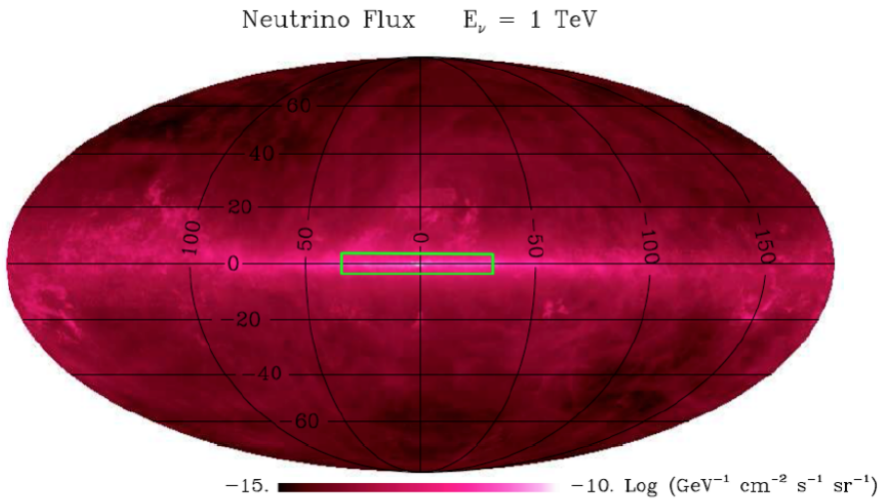
Comparison between neutrino spectrum produced with standard KRA model and the new KRAγ model from the entire galactic plane. The black stars show the equivalence between standard KRA (based on DRAGON code) and standard GALPROP obtained spectra.



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

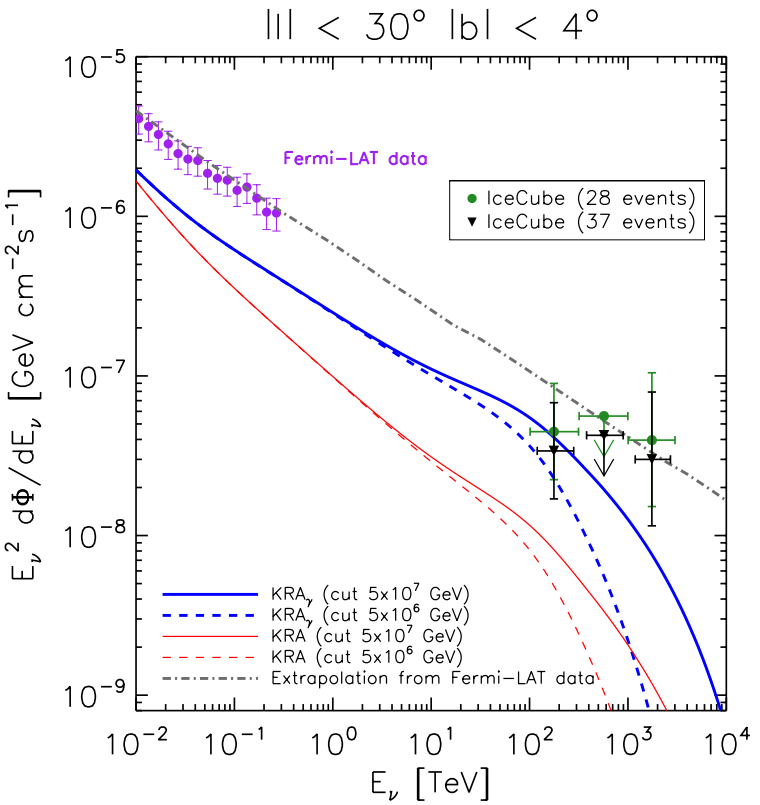
KRA and KRA$_\gamma$ neutrino spectra expected for |b|<4°, |l|<30°



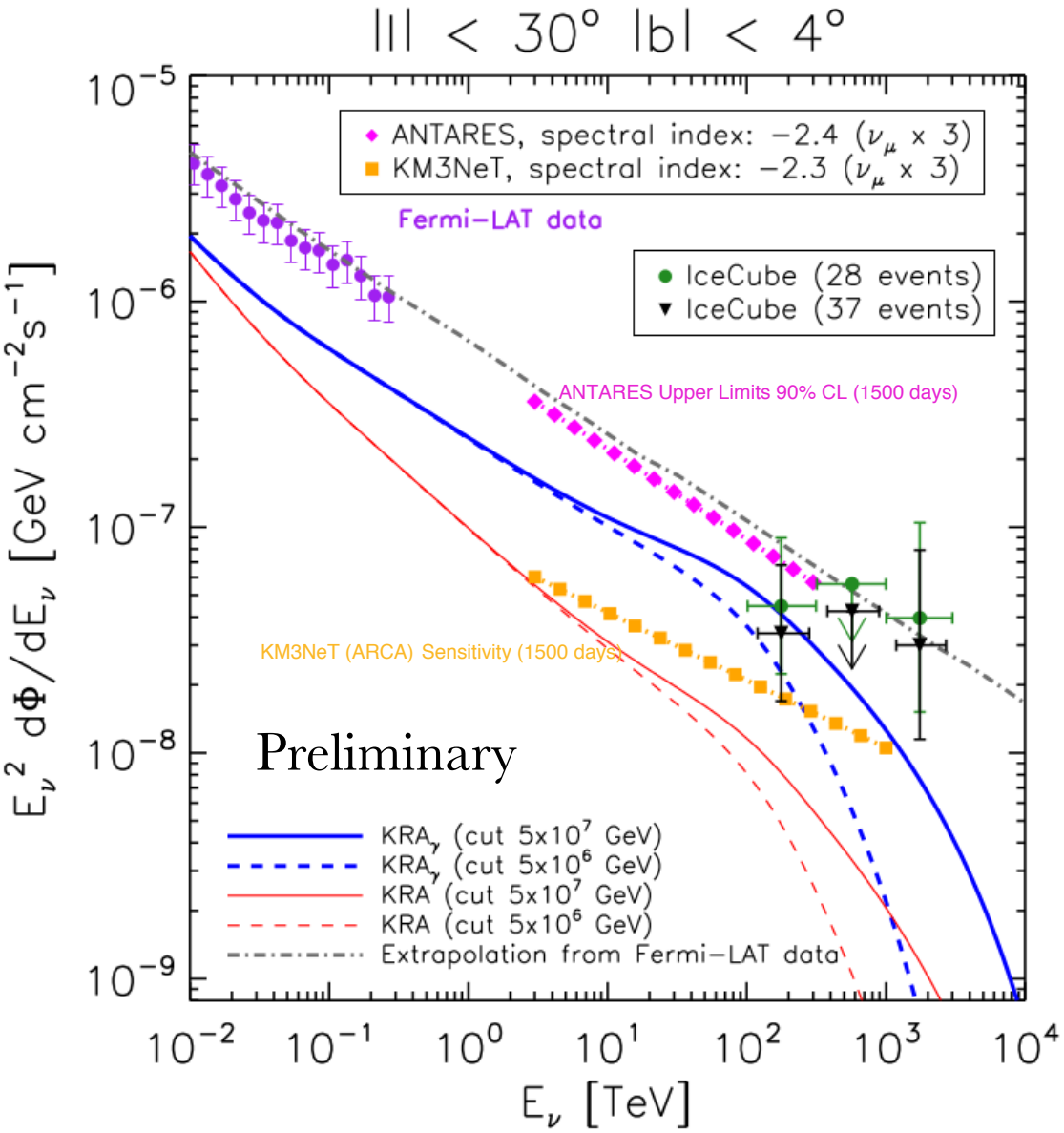


- Skymap with the last catalog of IceCube extraterrestrial neutrino of 37 events: 29 shower-like and 8 track-like. Only 3 shower-like events are reconstructed in a position of the sky compatible with the |b| <4° and |l|<30°

- 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.



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



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:

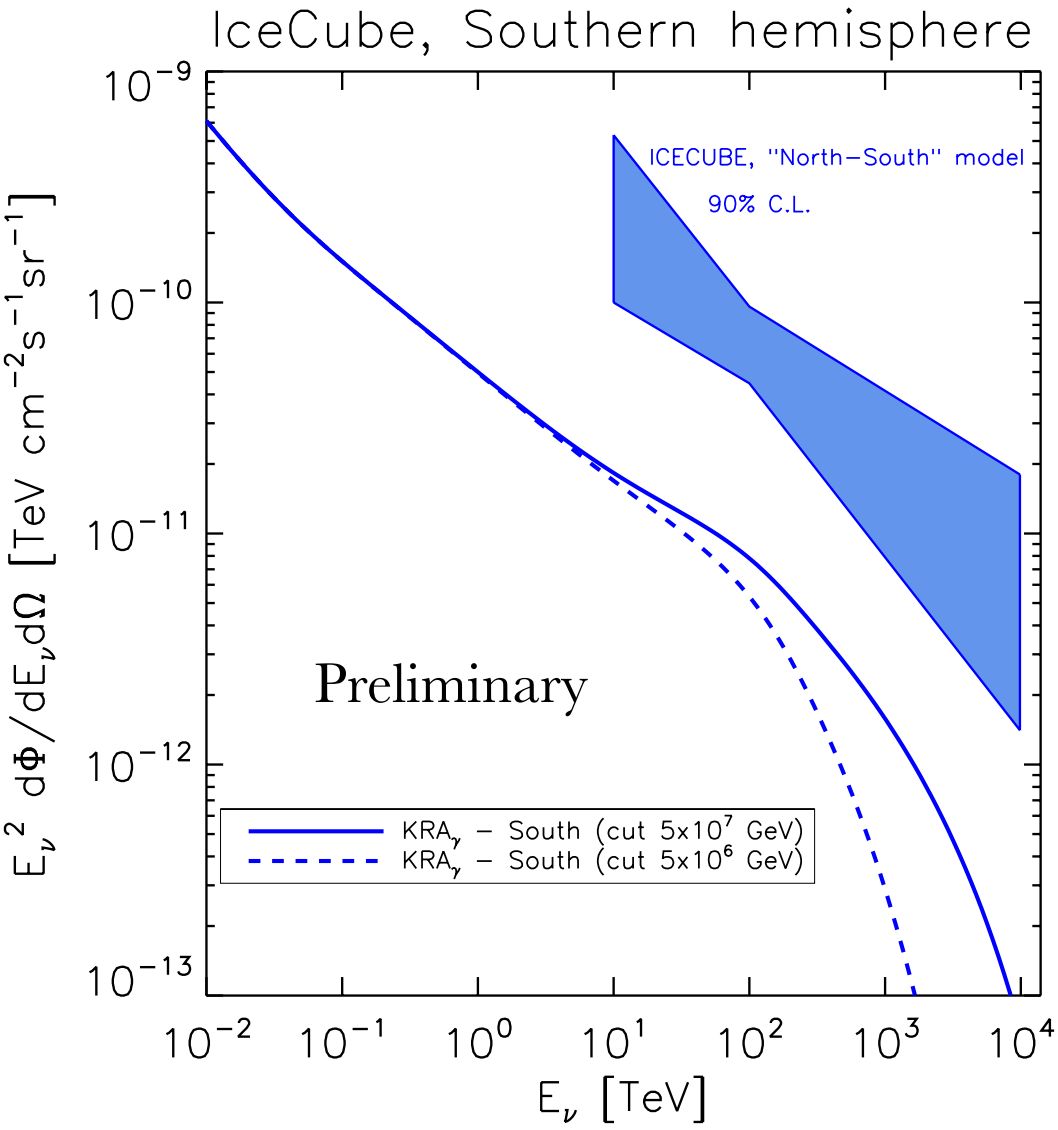
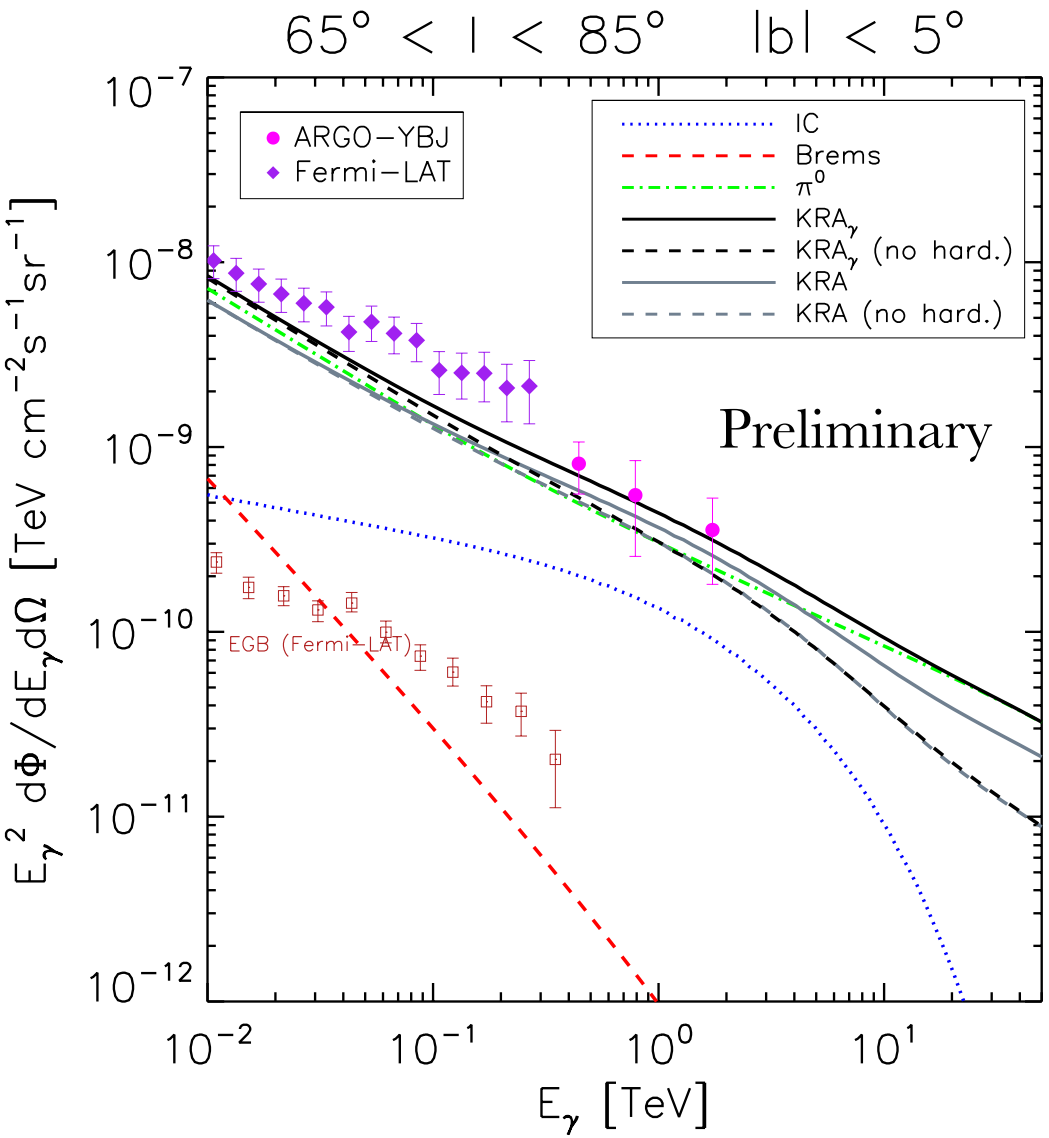
- ANTARES upper limits obtained with ν track events reconstructed in 1500 days of experiment live time. (see L.Fusco & M. Spurio talks)
- IceCube constraints of the flux with observation of 3 ν shower like events in 662 and 998 days of experiment live time.
- Deduced KM3NeT sensitivity for this region of the sky with 1500 days of experiment live time. (see R.Coniglione talk)

SUMMARY

- The introduction of a radially variable diffusion coefficient for the galactic CRs allows to solve some longstanding problems in gamma-ray astronomy and it seems to be required by recent Fermi-LAT results
- This was implemented in the KRA$_\gamma$ model reproducing 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 Galactic ridge region the computed neutrino emission start to be larger than the atmospheric background for $E \gtrsim 20$ TeV.
- The neutrino prediction of KRA$_\gamma$ for the Galactic ridge is consistent with Antares and IceCube observations and well confirmable with few years of KM3NeT observations.
- Giving light on diffuse galactic neutrino emission, the Global Neutrino Network will constrain also the Galactic cosmic-ray transport scenario.

Back up slides

The KRA$_\gamma$ and IceCube neutrino spectra of South hemisphere



The KRA$_\gamma$ can fit well also the gamma-ray spectrum of galactic plane measured by ARGO