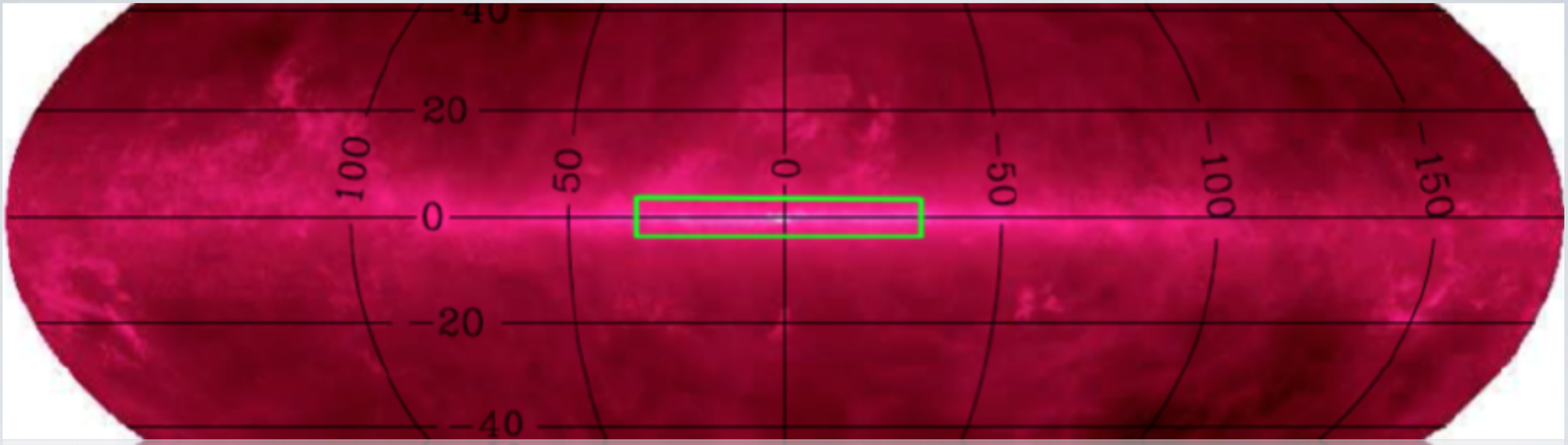


Gamma-ray and neutrino diffuse emissions of the Galaxy above the TeV

(with spatial dependent CR transport)

D. Grasso (INFN, Pisa)
with D. Gaggero, A. Marinelli, A. Urbano, M. Valli

IceCube recent results

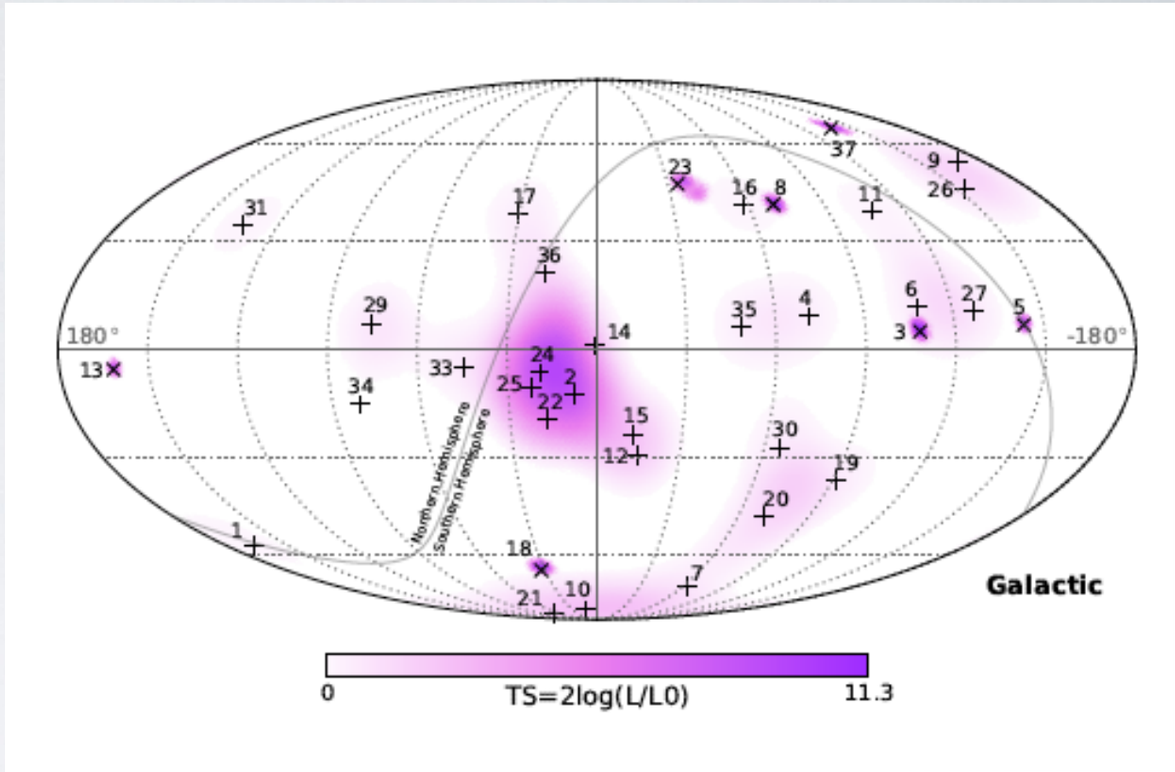
IceCube coll. evidence for 28 (2 years, PRL 2013) then 37 events (3 yrs PRL 2014) with reconstructed direction above 30 TeV corresponding to a
5.7σ excess respect to the atm. bkg.

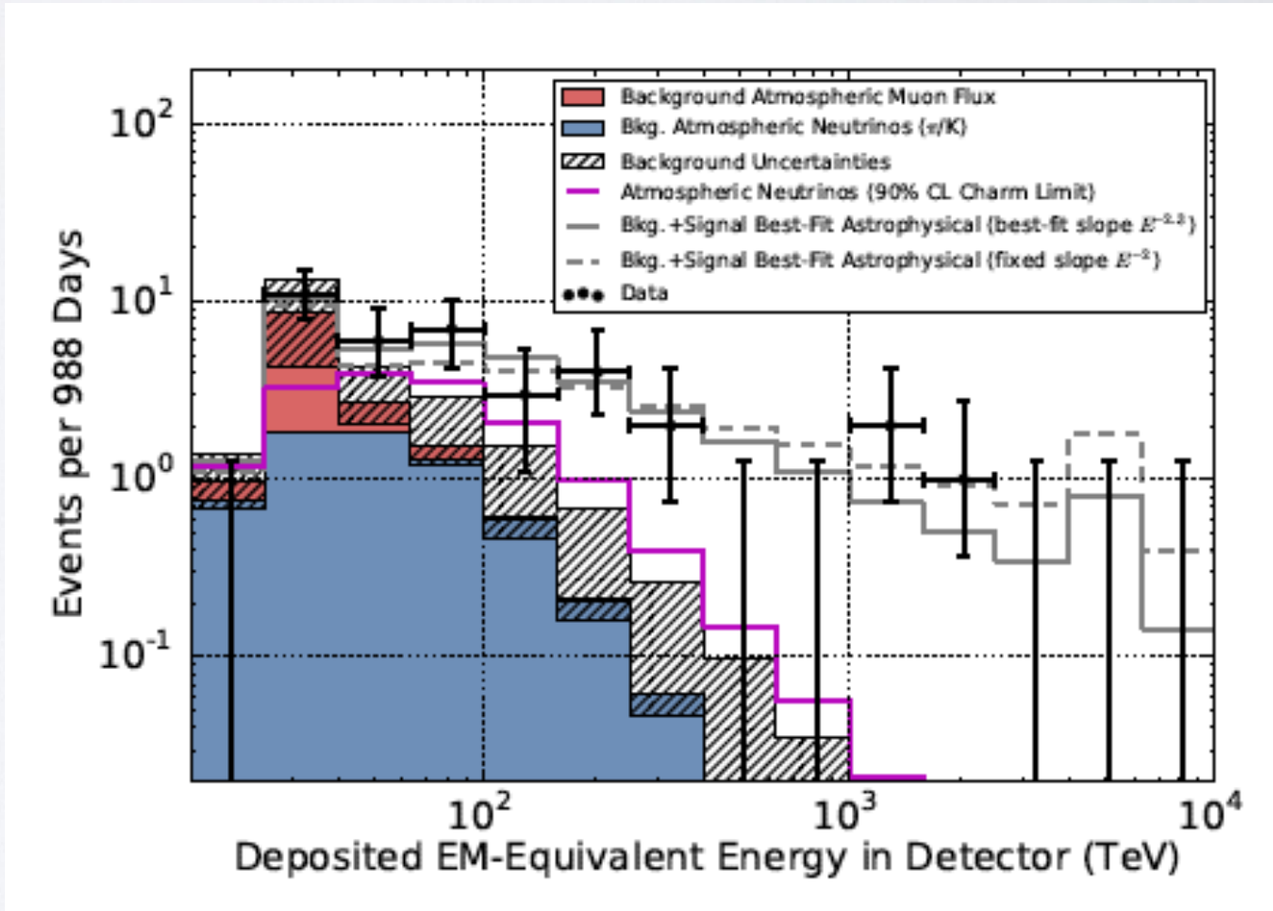
angular distribution compatible with isotropic (see however below)

composition compatible with a equal mixture of e, μ, τ as expected for astrophysical generated neutrino

Best fit spectral index - 2.3 ± 0.3

Slightly softer than expected for extragalactic astrophysical source





IceCube recent results

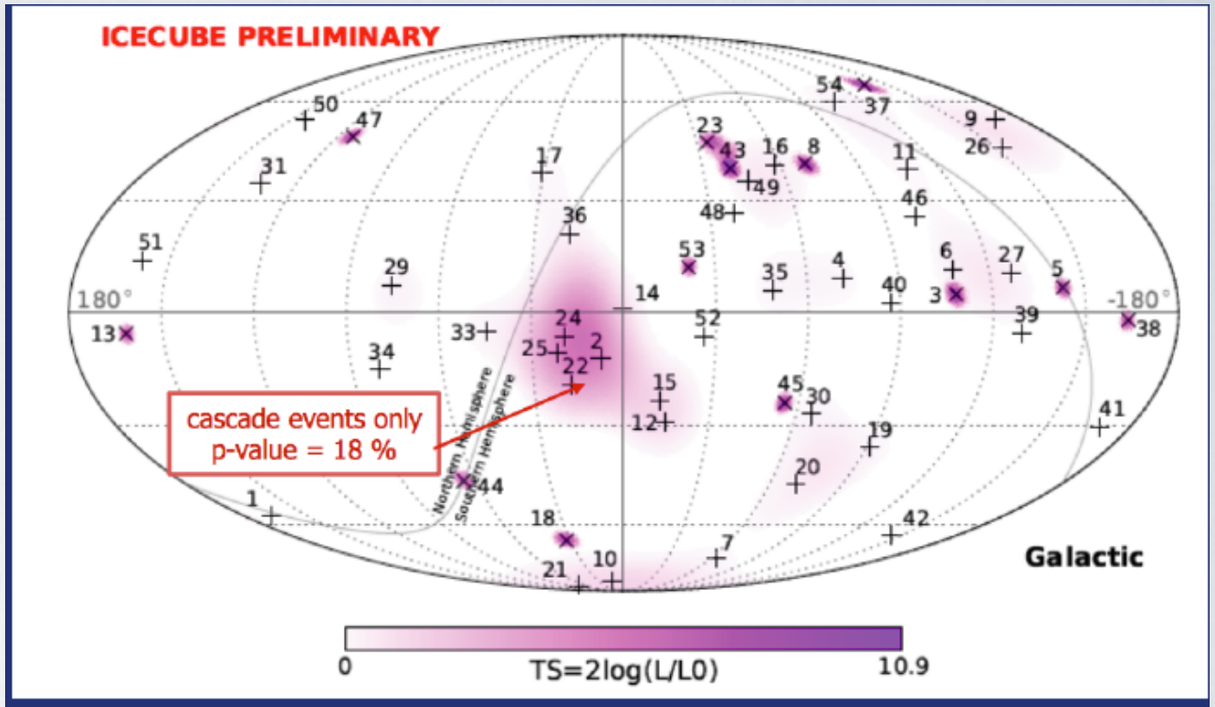
IceCube coll. evidence for 54 events (4 yrs preliminary) with reconstructed direction above 30 TeV corresponding to 7σ excess respect to the atm. bkg.

angular distribution compatible with isotropic (see however below)

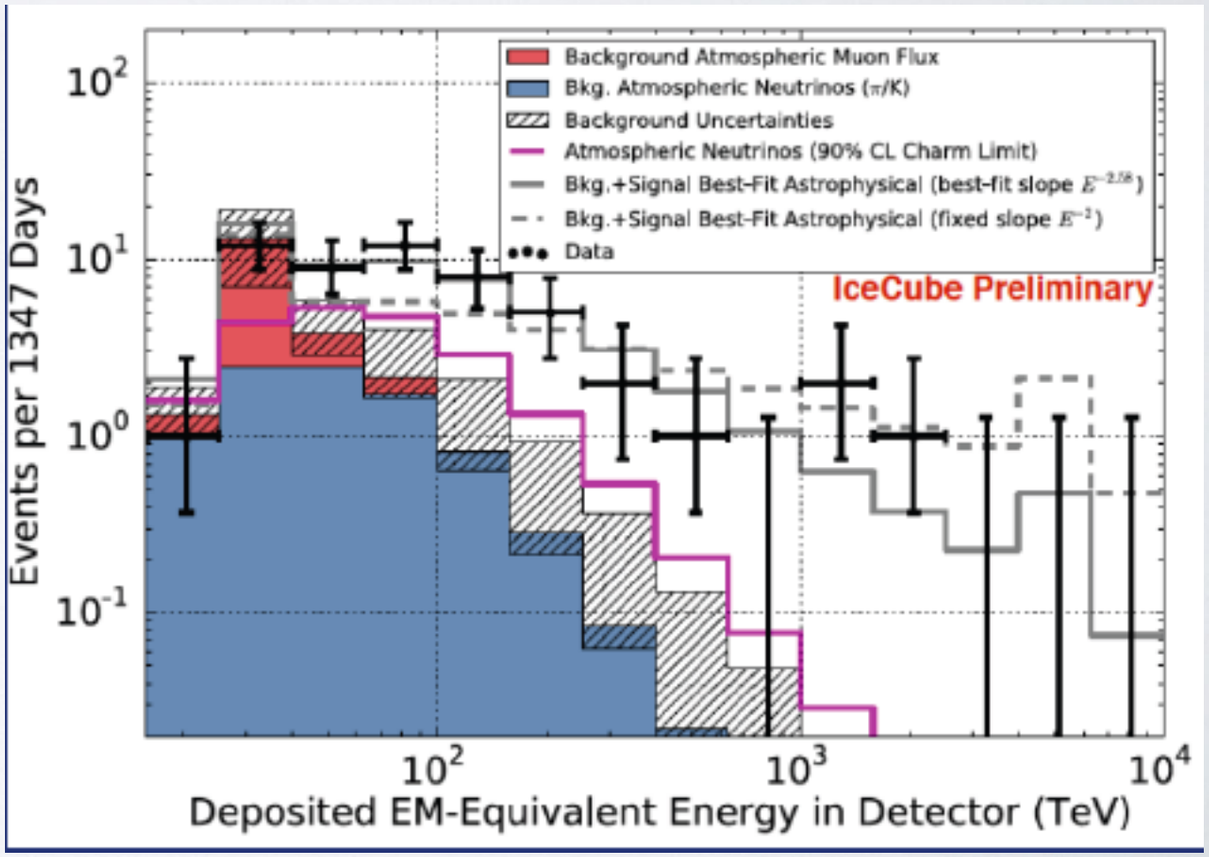
composition compatible with a equal mixture of e, μ, τ as expected for astrophysical generated neutrino

Best fit spectral index ~ - 2.5

Significantly softer than expected for extragalactic astrophysical source



O. Botner (IPA2015)



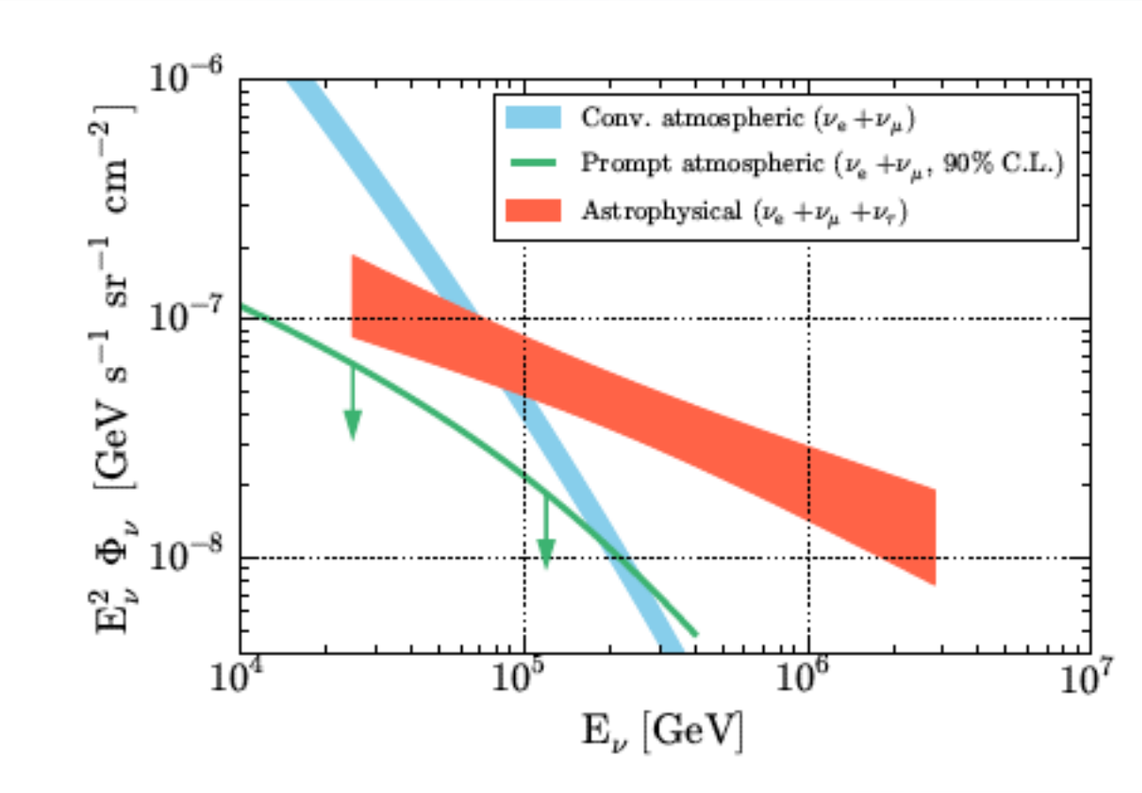
IceCube recent results

A recent template fitting analysis of a larger number of events, including those with unreconstructed direction and with E > 25 TeV)

found a steeper spectrum for the astrophysical neutrino component
Best fit single power-law spectral index
- 2.46 ± 0.12 PRD 2015
- 2.50 ± 0.09 ApJ 2015

a North-South analysis favors (though <u>still with low significance</u>) a larger and flatter spectrum from the South hemisphere

all this may be indicating the presence of a significant Galactic component !



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} GeV^{-1}s^{-1}sr^{-1}cm^{-2}.

Galactic ν and γ from conventional models

Evoli, DG, Maccione JCAP 2007

Stecker 1979
Berezinsky 1990

The expected event rate for ν produced by cosmic ray spallation onto the ISM is ~ 1 per year in km3 detectors

Interestingly those model underestimate the γ-ray flux measured by Milagro at 15 TeV !

(see below)

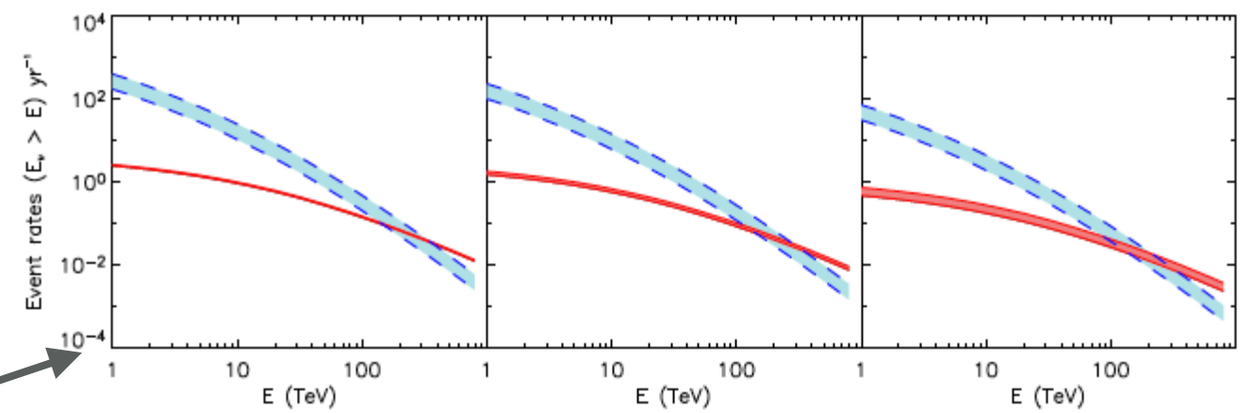
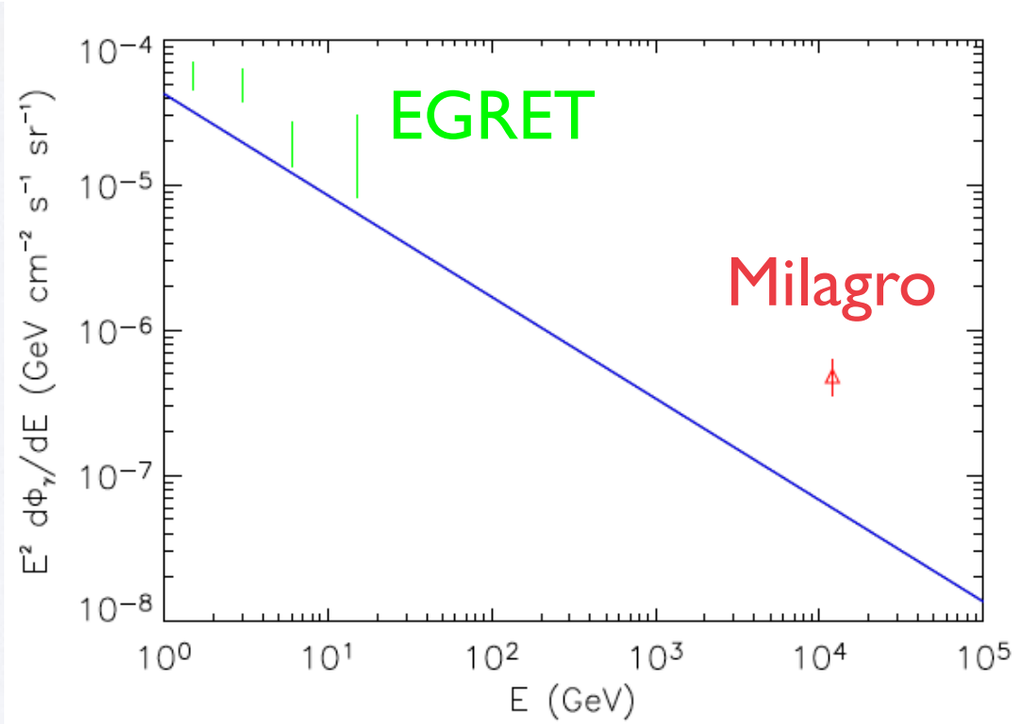


Figure 13. The expected $\nu_\mu + \bar{\nu}_\mu$ detection rate (red band, between continuos line) from the regions $|l| < 50°$, $|b| < 1.5°$ (left), $|l| < 30°$, $|b| < 1.5°$ (centre), $|l| < 10°$, $|b| < 1.5°$ (right), is compared with the background due to atmospheric neutrinos from the same region (ligth blue band, between dashed lines). An effective area 40 times larger than ANTARES has been adopted. E is the neutrino energy.



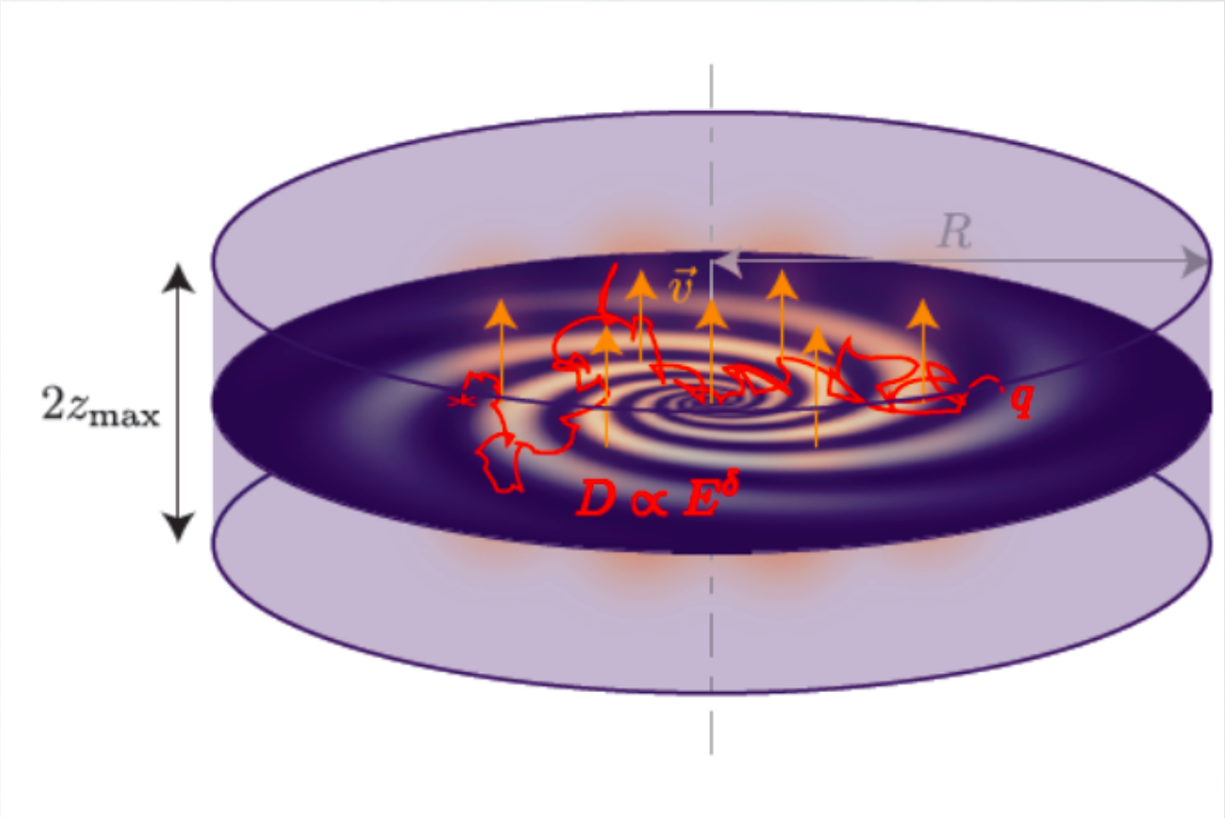
The conventional CR propagation scenario

- The diffusion coefficient $D \propto (\rho/\rho_0)^{\delta}$ and the convection velocity V_C are treated as independent on the Galactocentric distance R

ρ: particle rigidity

- The relevant 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 behaves quite differently in the GC region !

- Indeed while this scenario is very successful reproducing **local** quantities it faces some tensions with γ-ray data from the GC region



The Inner GP Milagro anomaly

a long standing (almost) forgotten problem

ABDO ET AL. *ApJ 2008*

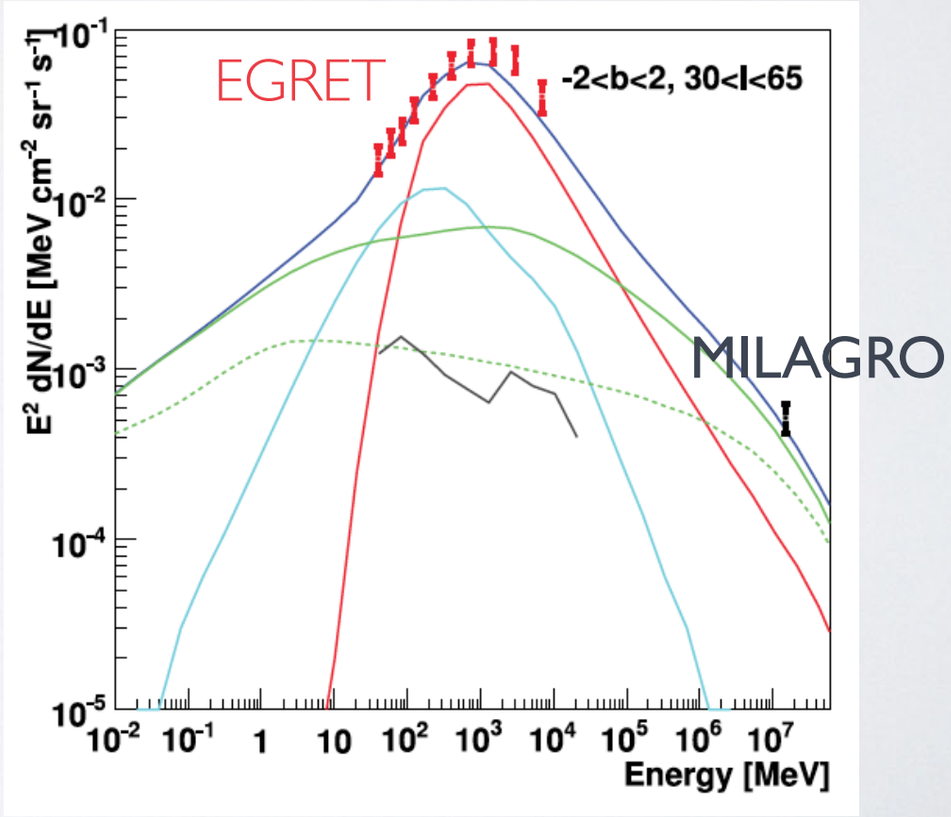
TABLE 1

GAMMA-RAY EMISSION FROM THE GALACTIC PLANE AROUND 15 TeV

Region for $\lvert b\rvert < 2^\circ$ (l, deg)	Statistical Significance σ	Diffuse Flux ($\times 10^{-13}$ TeV^{-1} cm^{-2} s^{-1} sr^{-1}) Milagro[a]	GALPROP Optimized	GALPROP Conventional
30–65	5.1	$23.1 \pm 4.5^{+7.0}_{-8.0}$	20.0	4.9

- the measured flux is 5 times (4 σ) larger than computed with the conventional model

- an optimized model (augmented IC contribution) - proposed to account for the EGRET GeV excess - was found to match Milagro



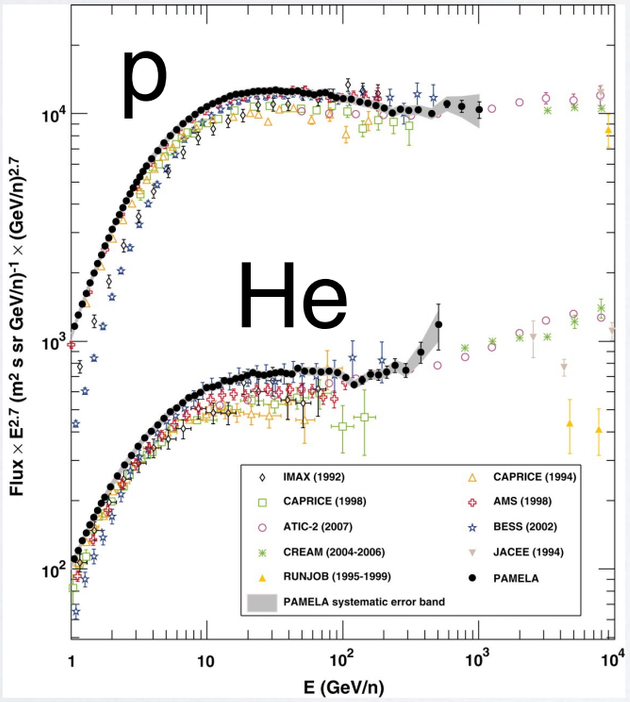
The Milagro anomaly holds on

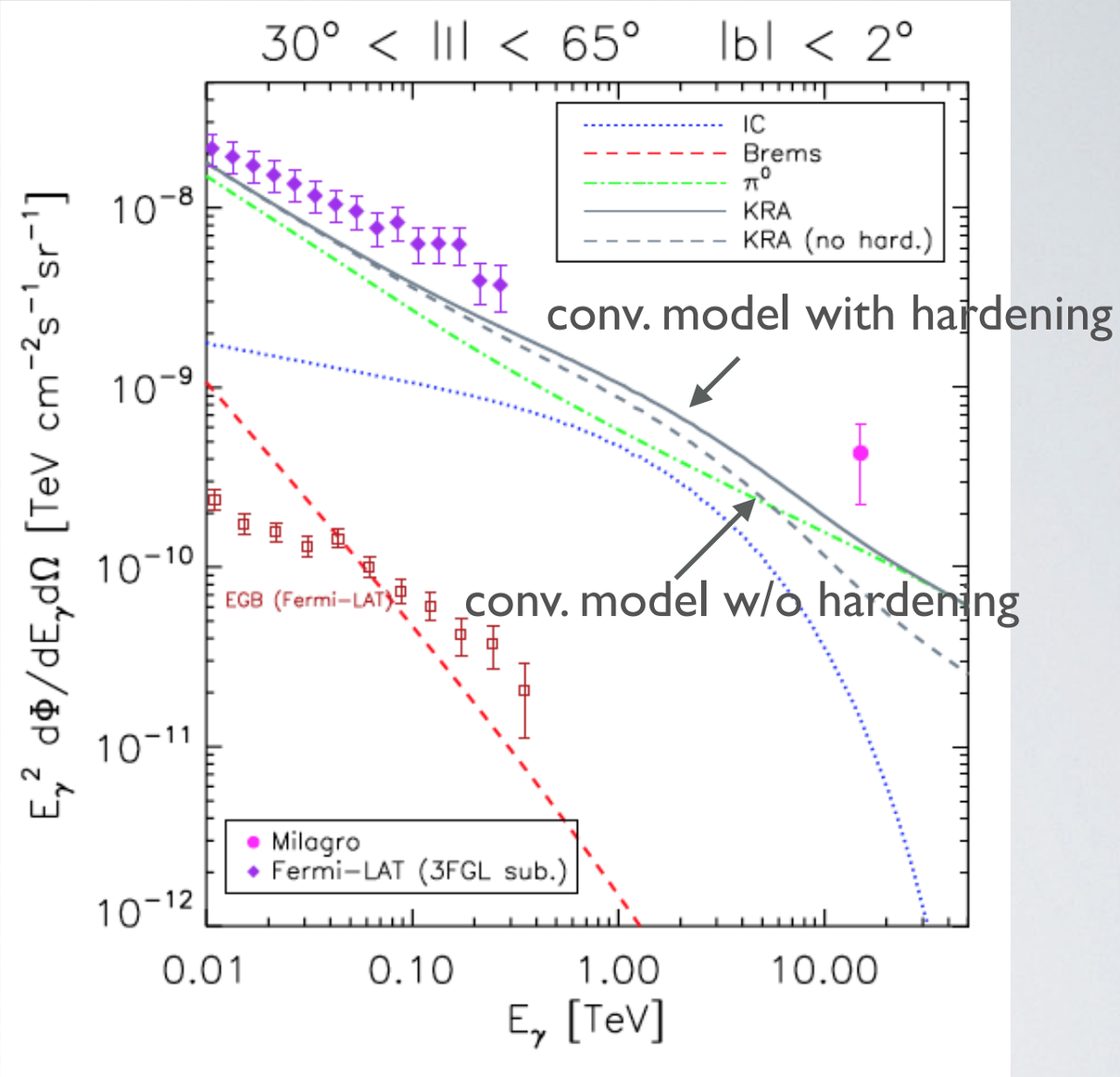
- Fermi-LAT excluded the GeV excess and the optimized model *Fermi-LAT coll. PRL 2009*

- conventional models tuned against local CR observables and matching the "full-sky" Fermi-LAT diffuse emission do not match Milagro !

- the problem holds even assuming that the p and He spectral harden at $\sim$ 250 GeV

(required to match PAMELA and AMS-02 and CREAM data)





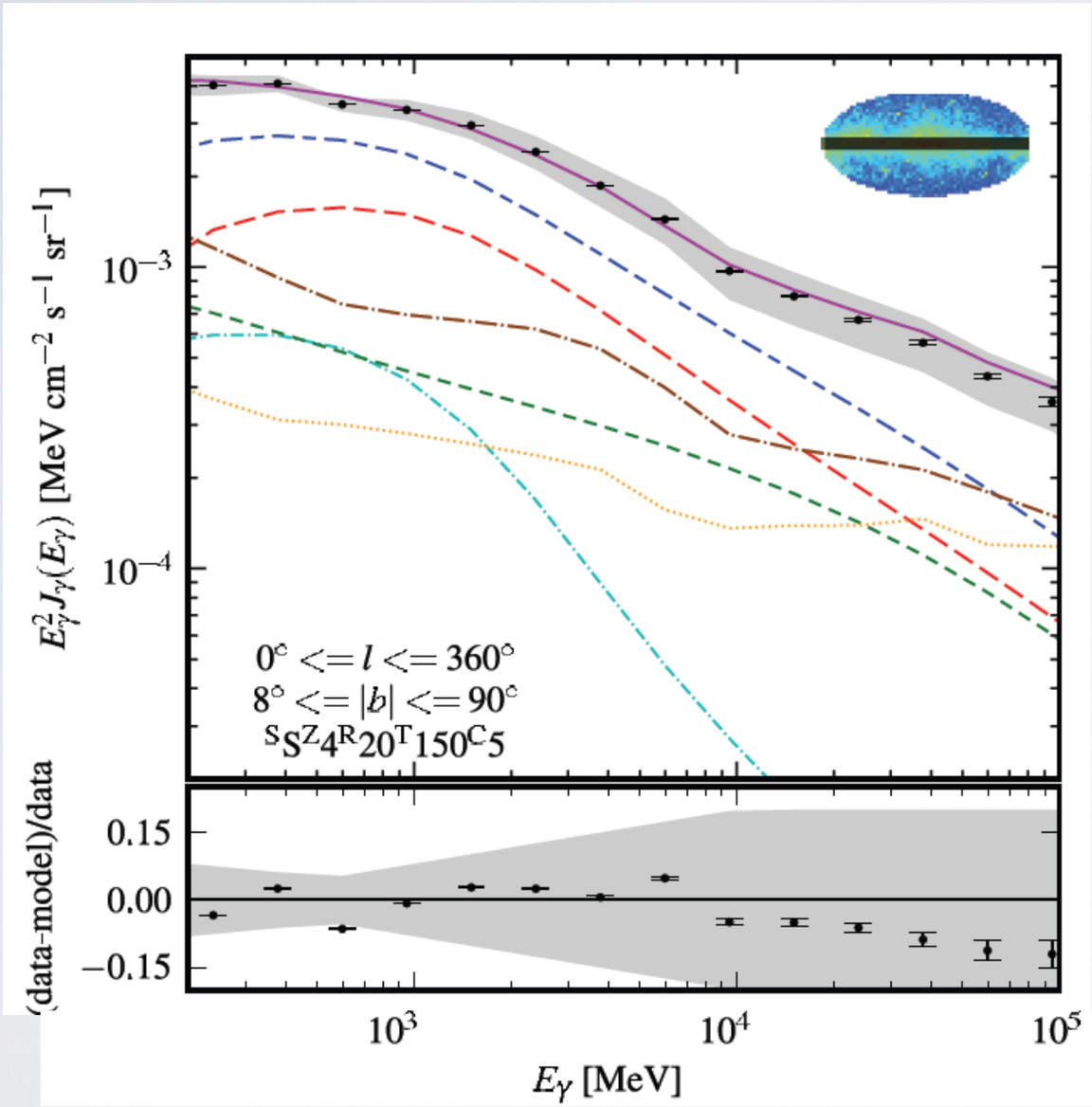
KRA: representative conv. model tuned against CR spectra (see below). Same result with GALPROP benchmark models (which do not account for hardening)

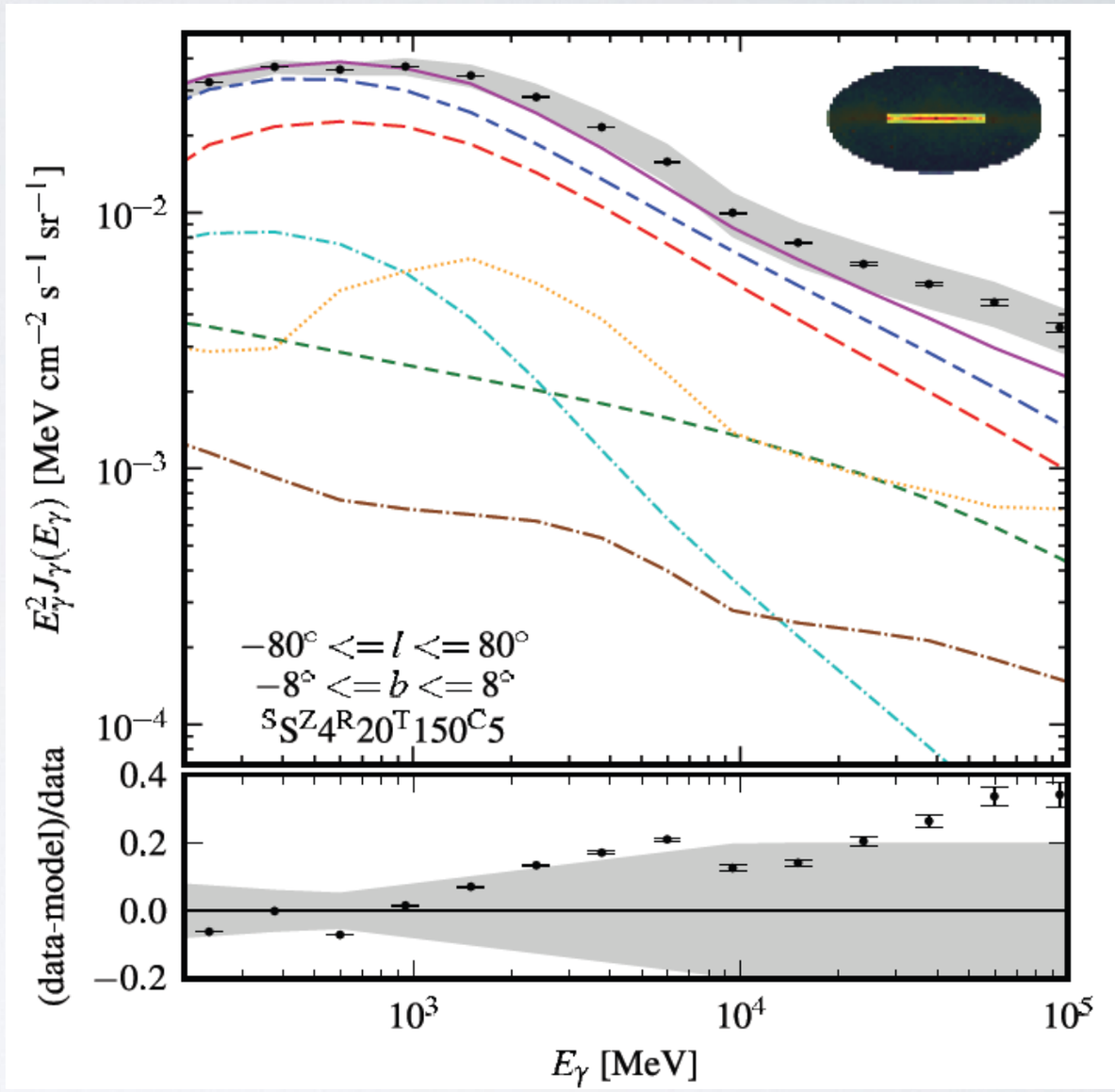
Conventional models against Fermi data

full-sky but the GP

inner GP

Fermi coll. ApJ 2012





Fermi Benchmark (FB) conventional model:

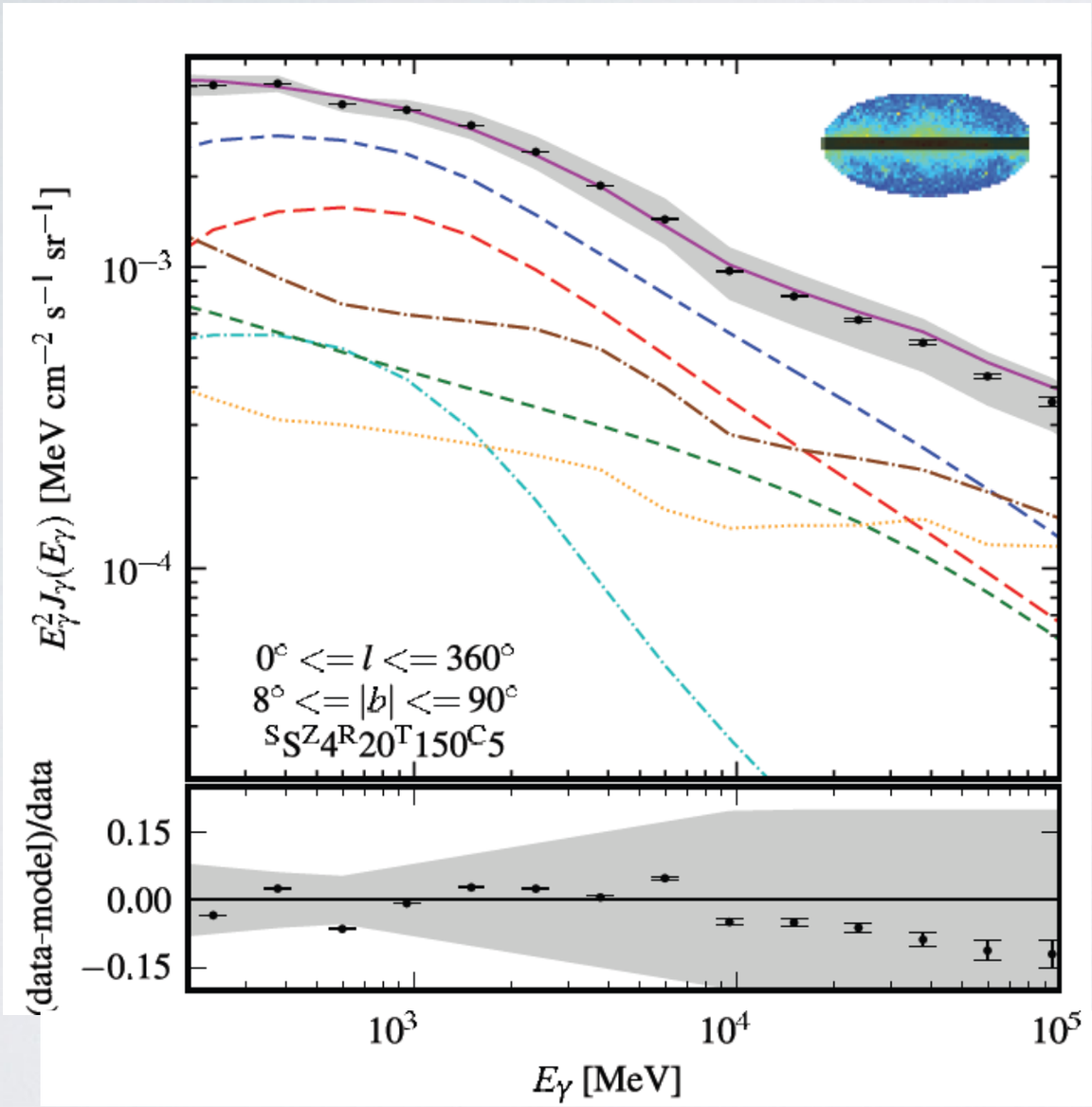
$\delta = 0.3$, $\gamma_P = 2.72$ (in the whole Galaxy), $z_h = 4$ kpc

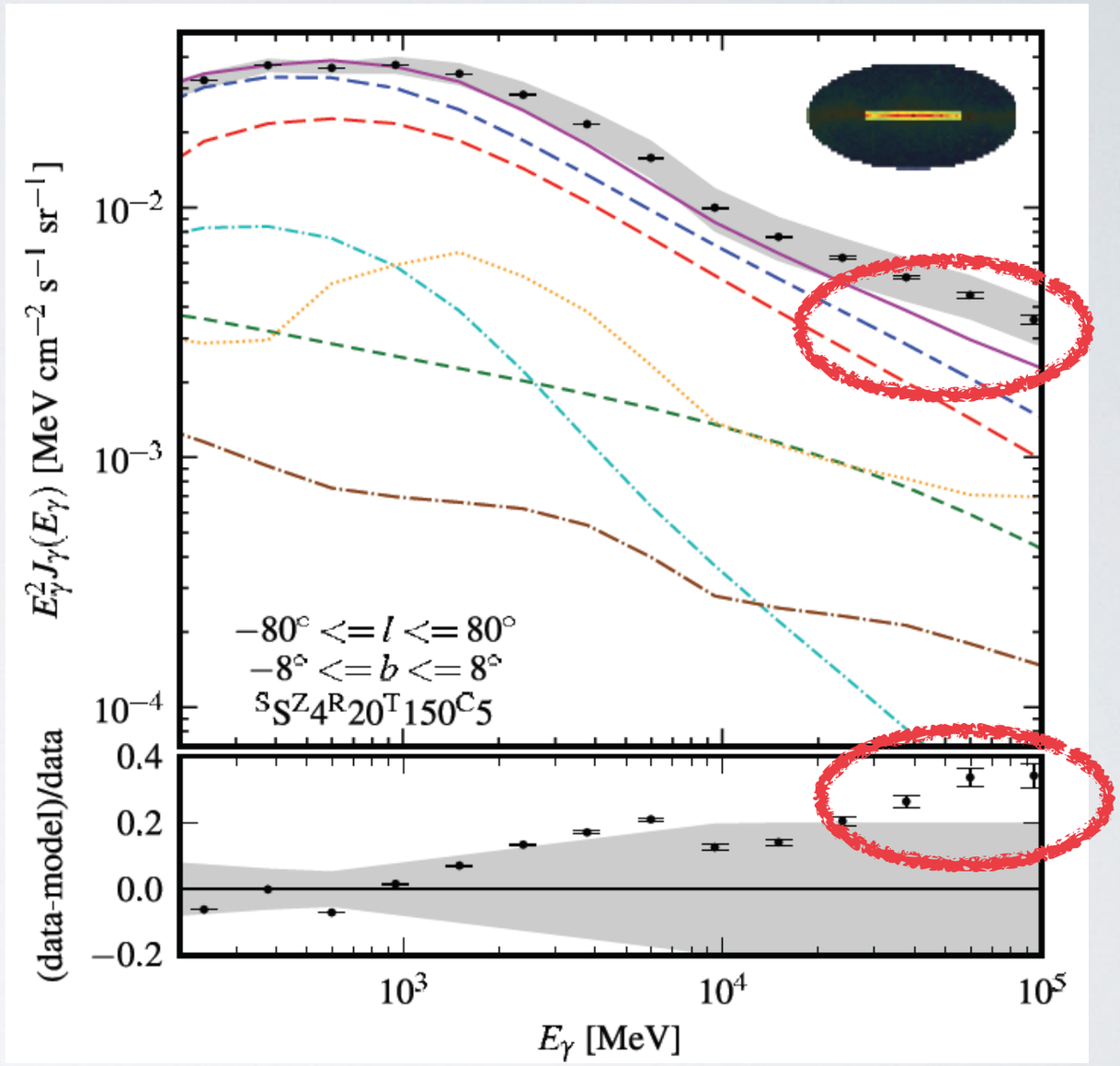
Conventional models against Fermi data

full-sky but the GP

inner GP

Fermi coll. ApJ 2012





Fermi Benchmark (FB) conventional model:

$\delta = 0.3$, $\gamma_P = 2.72$ (in the whole Galaxy), $z_h = 4$ kpc

An unconventional approach

Gaggero, Urbano, Valli & Ullio
arXiV: 1411.7623 PRD 2015

The KRAγ model - implemented with the DRAGON code - adopts a radial dependent diffusion coefficient

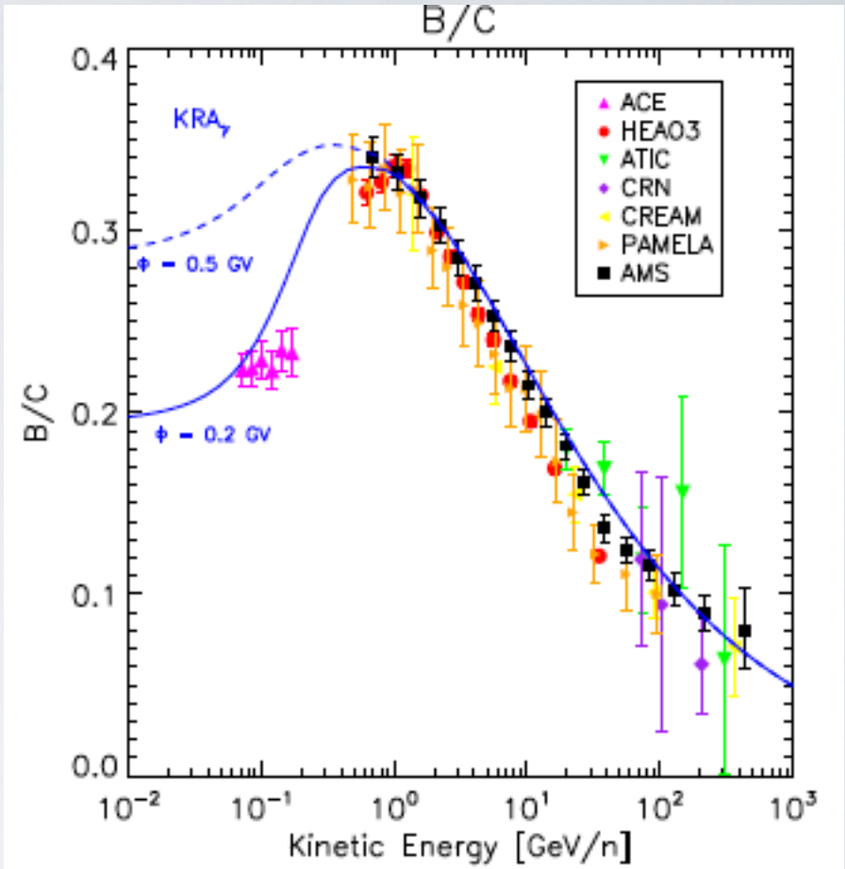
$\delta(R) = A\,R + B$ for R < 11 kpc

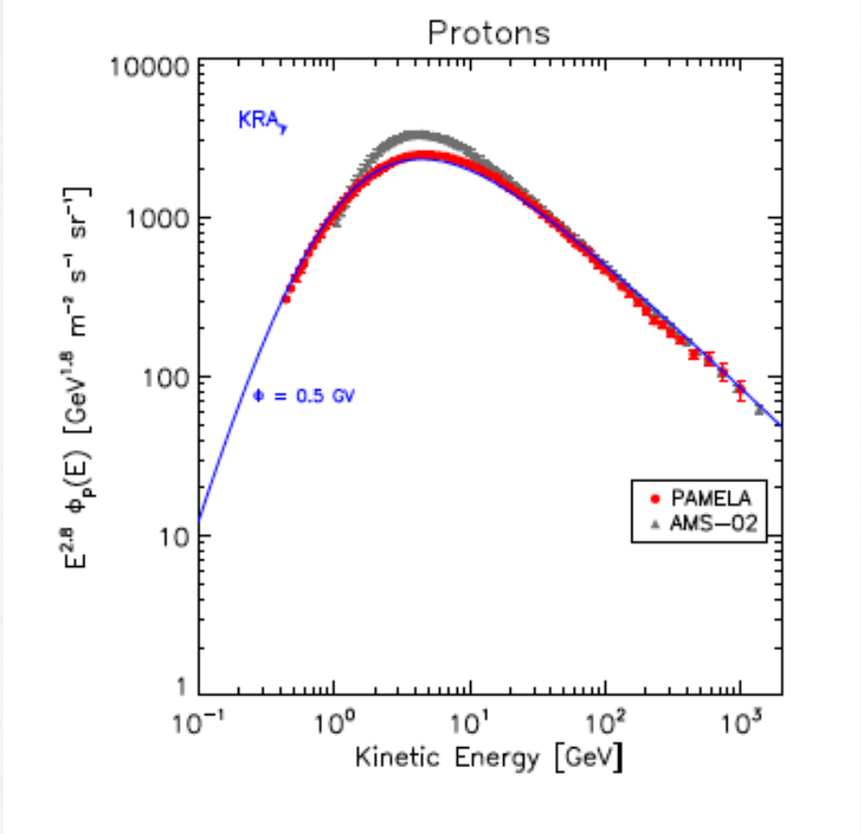
such that $\delta(R_{sun}) = 0.5$

and convective velocity

$$\frac{dV_C}{dz} = 100\ \mathrm{km\ s^{-1}\ kpc^{-1}}$$ for R < 6.5 kpc

The model is tuned to reproduce the proton spectrum measured by PAMELA and B/C (antiprotons also matched by secondary prod.) as well as updated diffuse γ-ray Fermi data

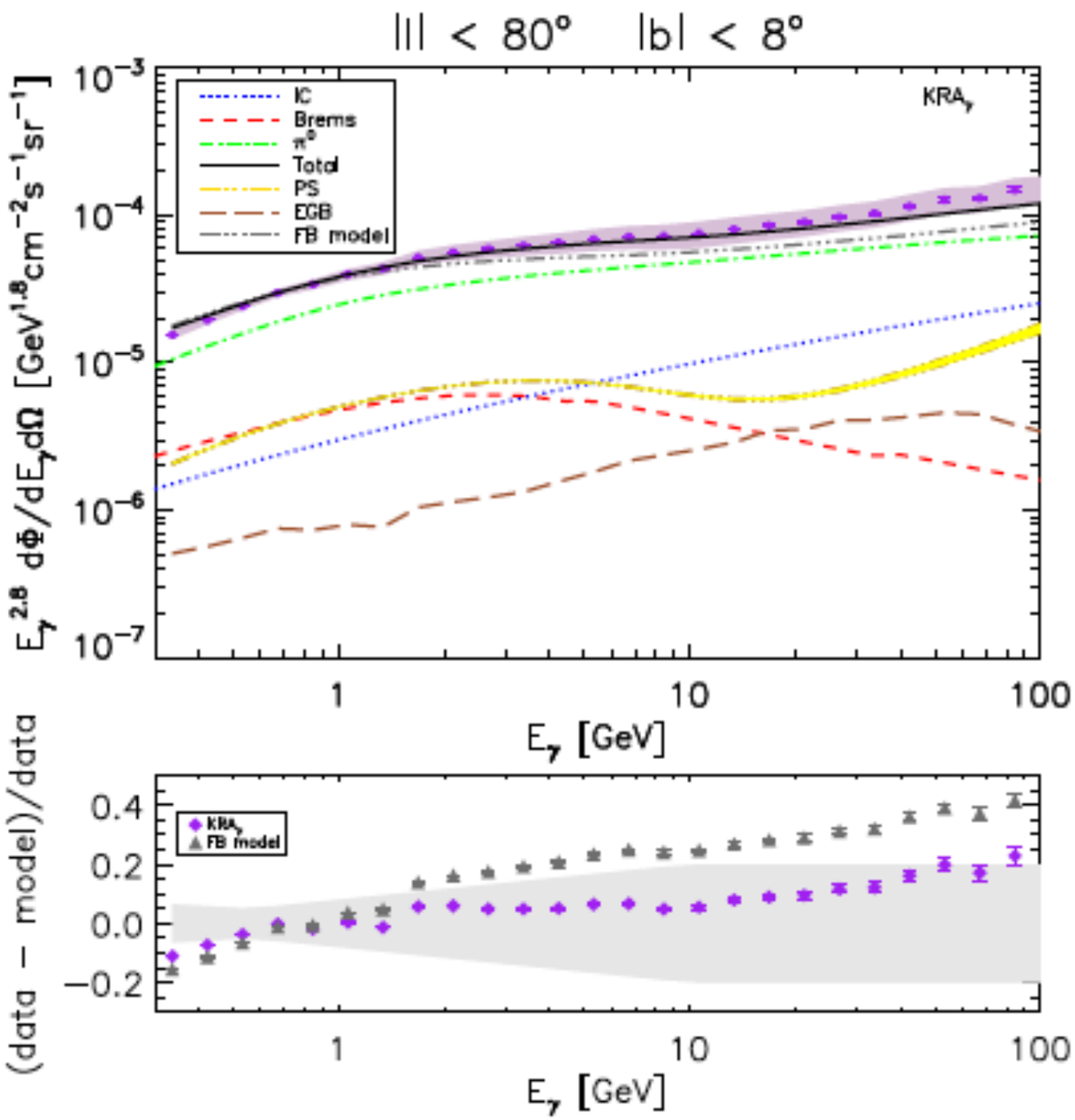


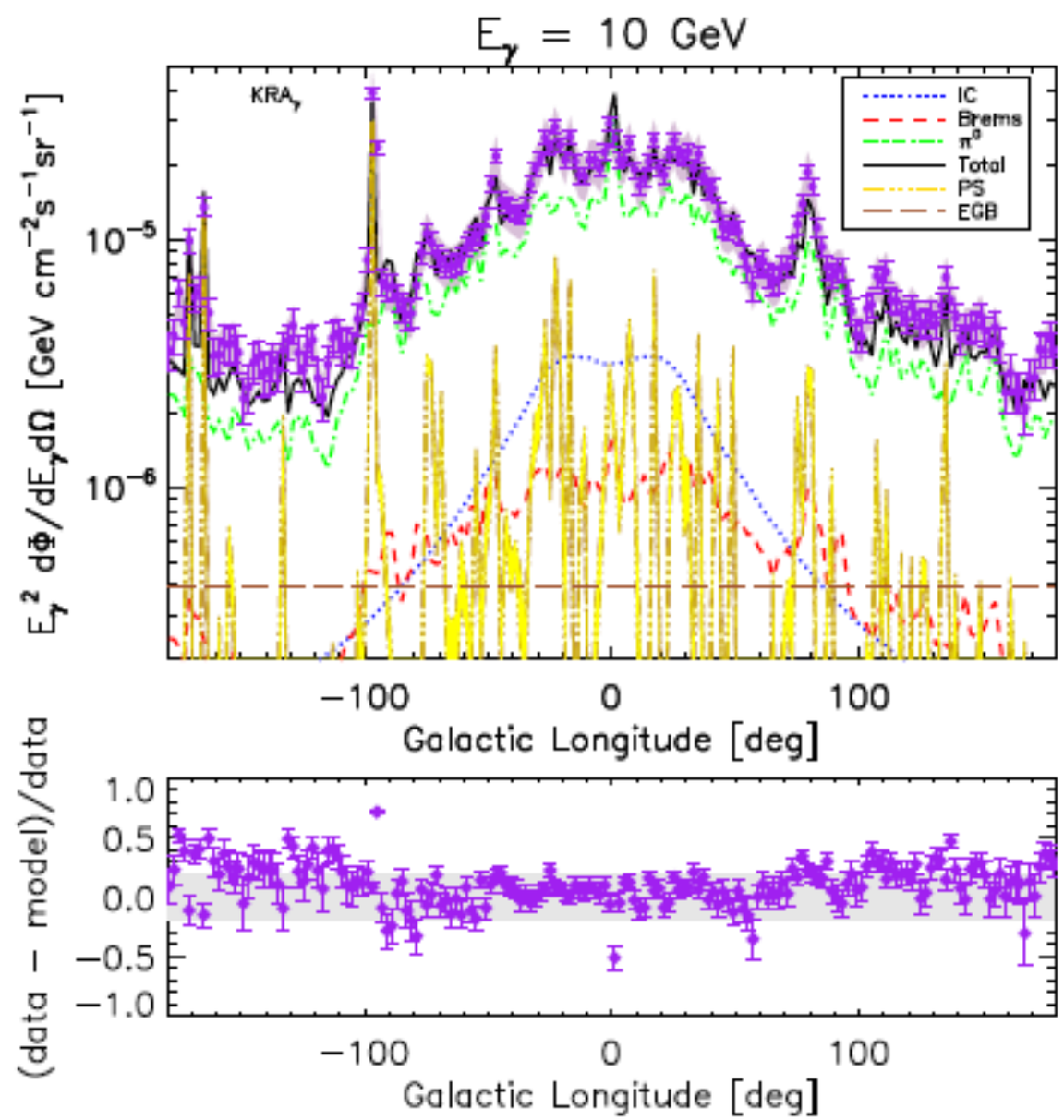


An unconventional approach

The KRAγ model reproduces the full-sky Fermi spectrum and angular distribution. It also provides a better fit in the inner GP region

Gaggero, Urbano, Valli & Ullio
arXiV: 1411.7623 PRD 2015





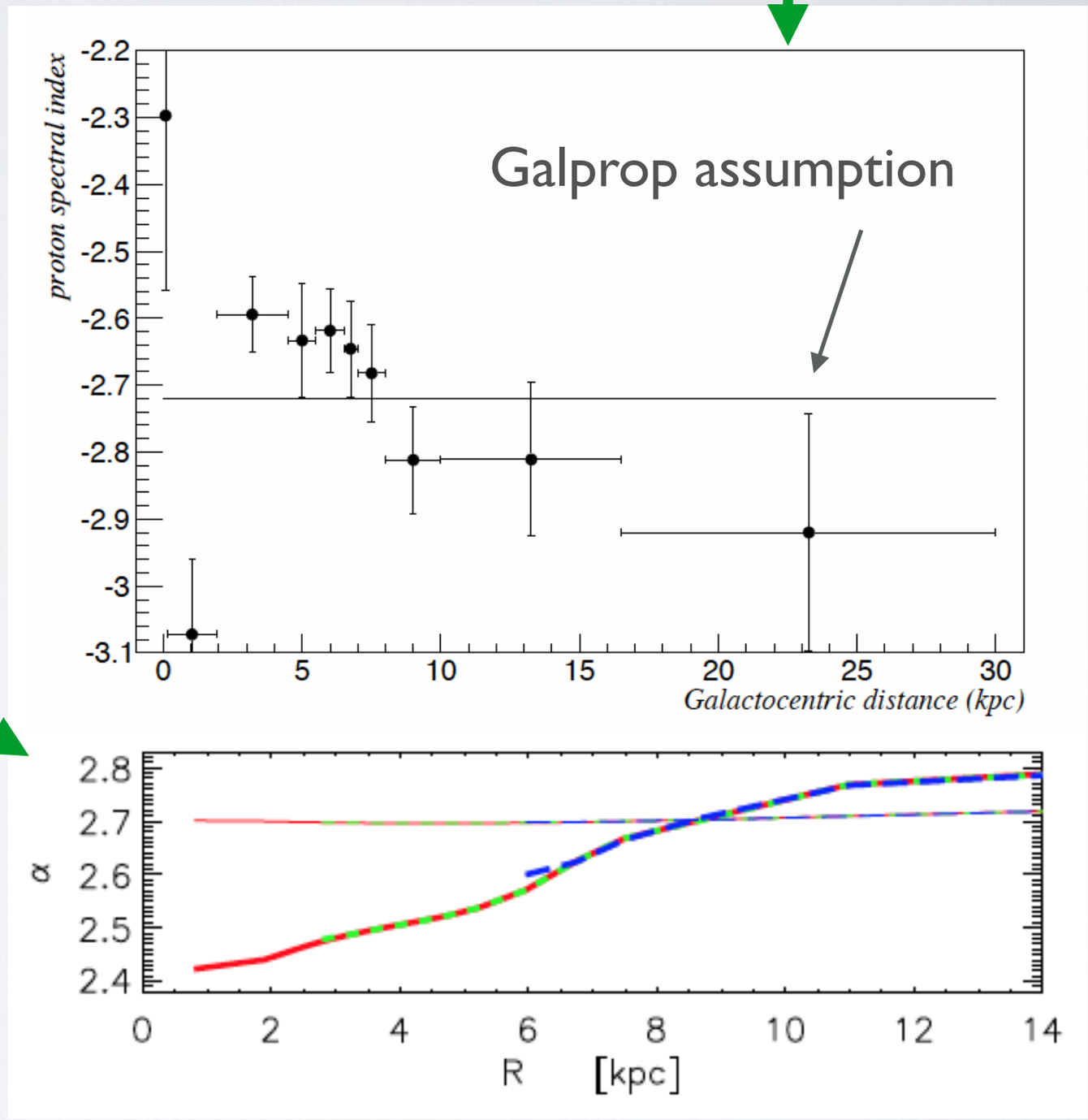
Evidence of radial dependent CR spectral index in the Fermi data

Casandajian [Fermi coll.], 5th Fermi symp. 2014
submitted to ApJ

a template-fitting analysis of the diffuse γ-ray emission measured by Fermi found such evidence

this is at odds with conventional models implemented with GALPROP

Gaggero et al. 2015 KRAγ model predictions are consistent with such finding !



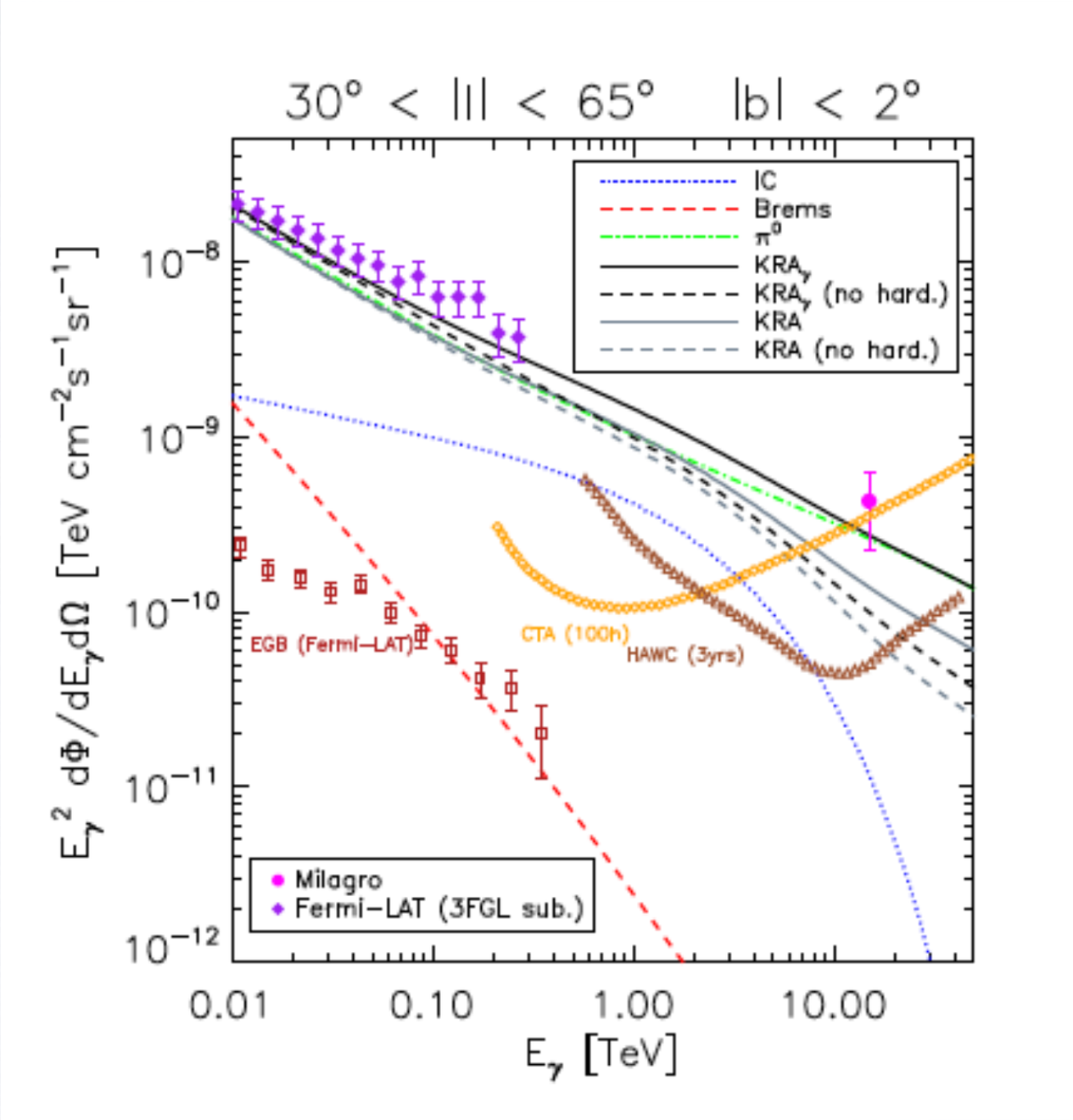
Solution of the Milagro anomaly

Gaggero, D.G., Marinelli Urbano &Valli
arXiV: 1504.00227

The KRAγ model nicely matches MILAGRO consistently with Fermi data (point sources cleaned) without further tuning !

Since the model assumes a CR spectral hardening at 250 GeV/n to match PAMELA and AMS-02 the hardening cannot be a local effect instead it must be present at least in a large fraction of the inner GP volume !

HAWC may soon test this prediction



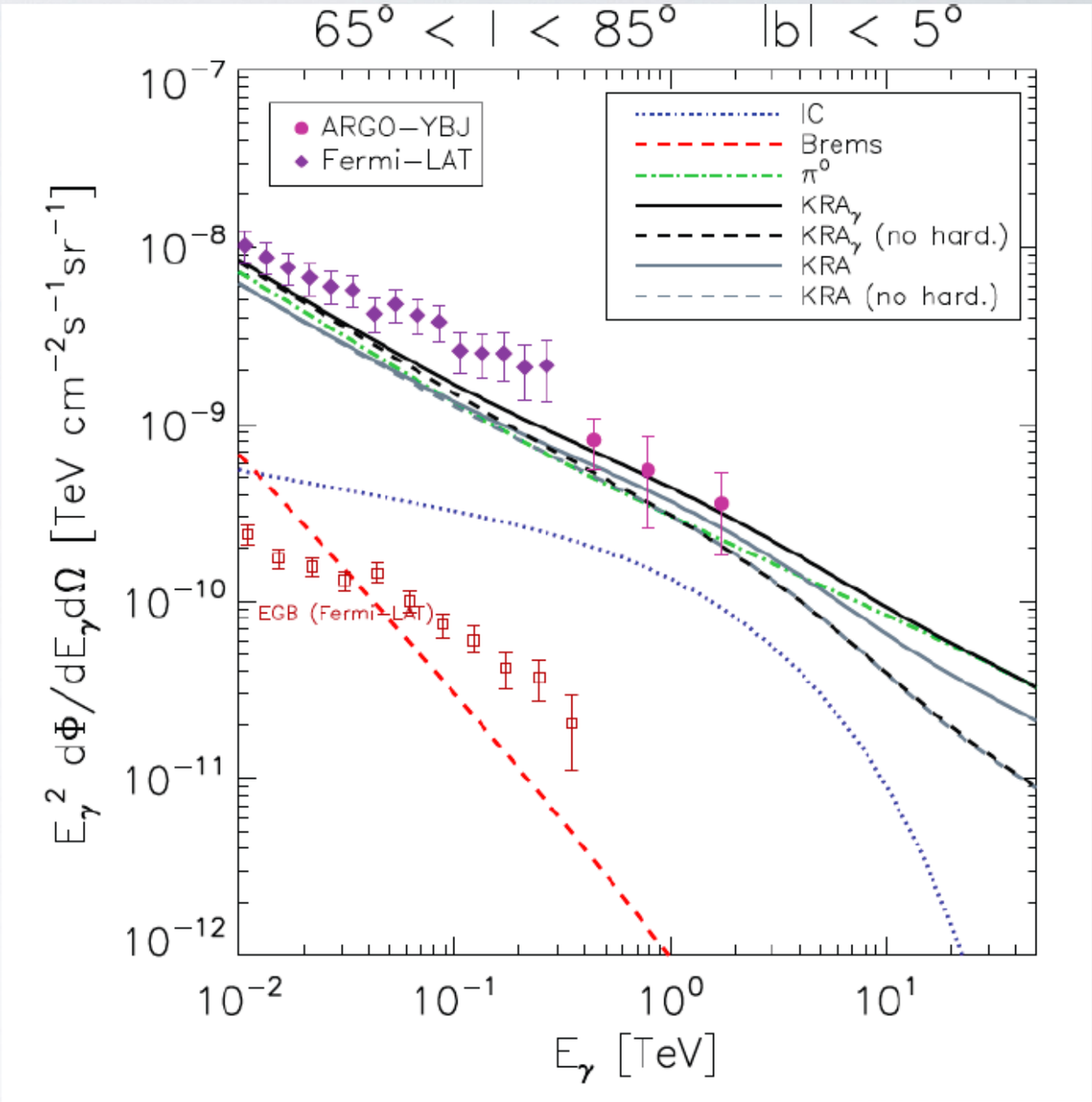
Our model against ARGO-YBJ results

ARGO-YBJ coll., ApJ 2015

the innermost region for which they released data is 65 < l < 85 deg. including Cygnus region

ARGO does not allow to discriminate among conventional and spatial dependent diffusion scenarios

The KRAγ model agrees with those data (if not preferred).



Solution of the HESS Galactic ridge anomaly

HESS (*Nature 2006*) measured a spectrum harder ($\Gamma \sim 2.3$) than expected on the basis of conventional CR models, associated with the molecular complex in the inner 200 pc of Galaxy

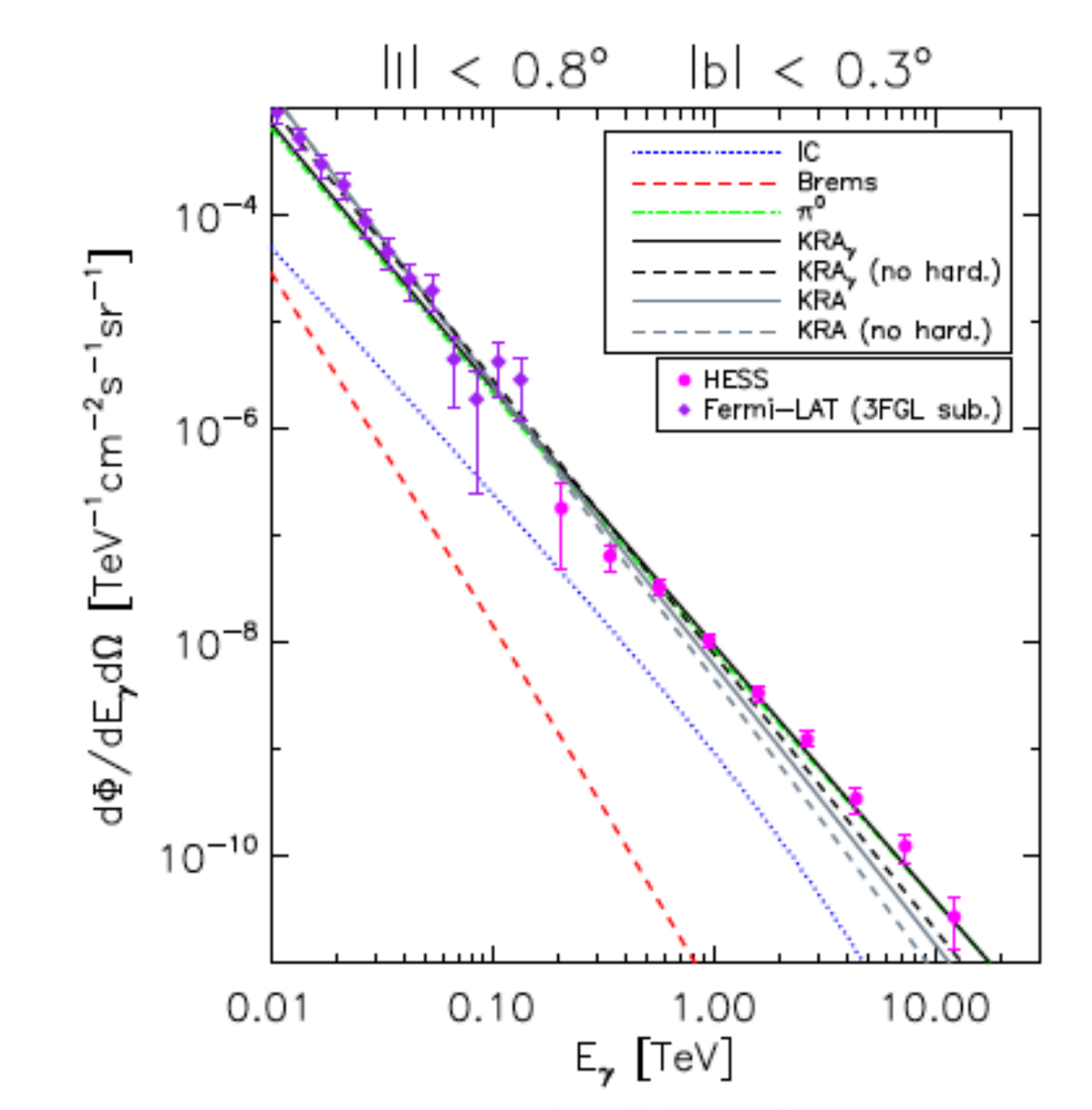
this is also the case for the updated Fermi benchmark conv. model

FERMI + HESS

KRAγ: $\chi 2$ = 1.79 /2.27 with/w.o. hard.

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

the spectrum normalization is correctly reproduced using an improved gas model in the G.C. region (*Ferriere et al. 2007*)

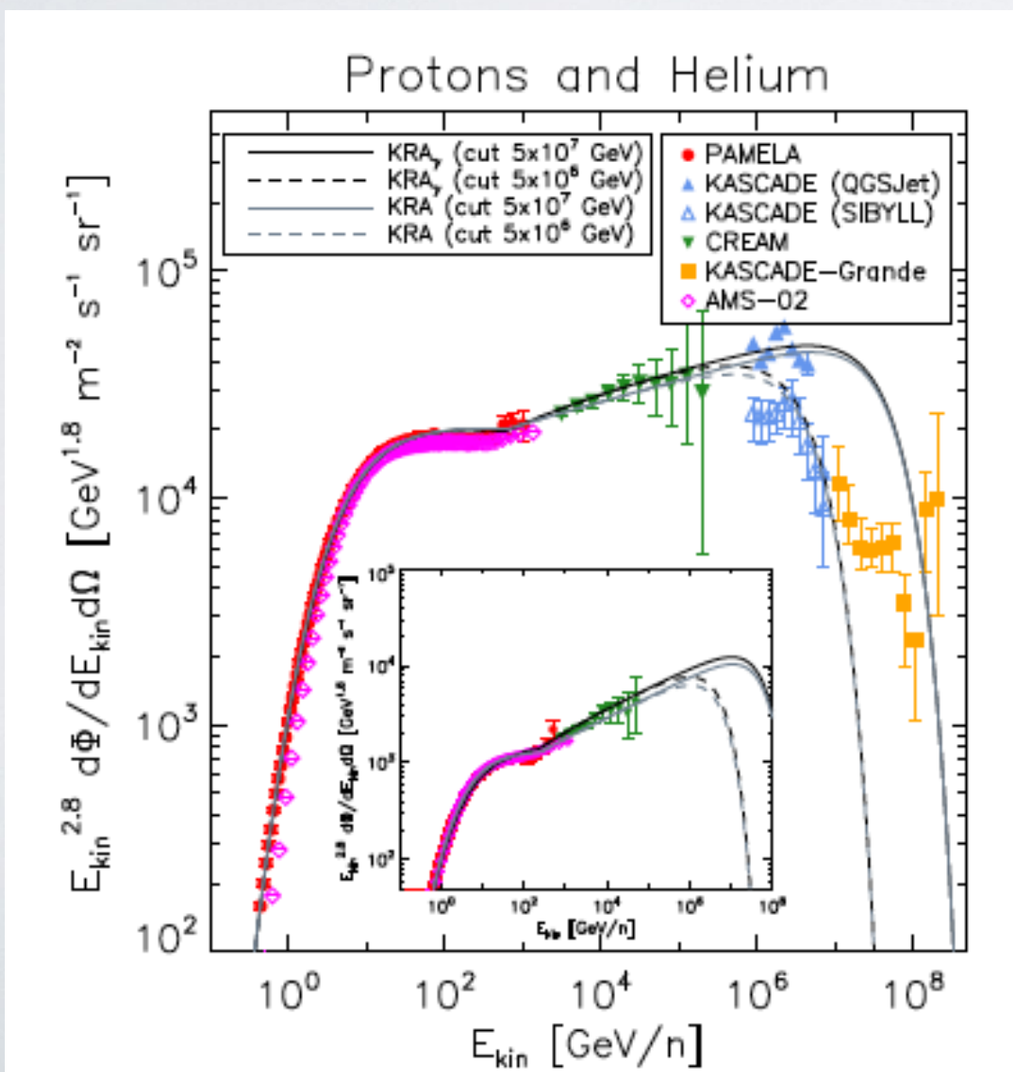


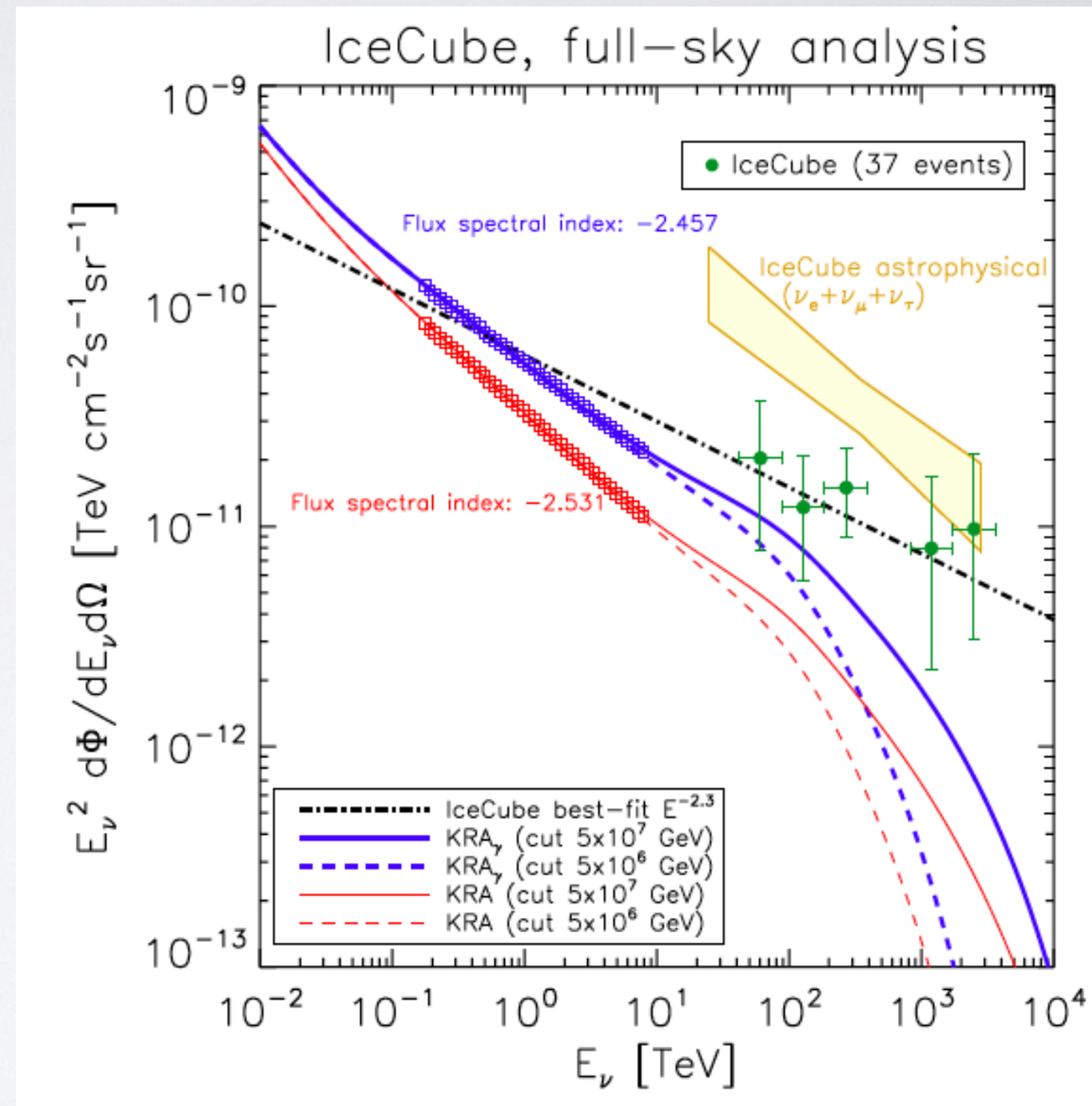
Enhanced ν emission of the Galaxy from the KRAγ model

Conventional CR models predict a low and steep ν spectrum

the KRAγ setup naturally predicts a higher and slightly harder spectrum.

Gaggero, D.G., Marinelli Urbano &Valli arXiV: 1504.00227





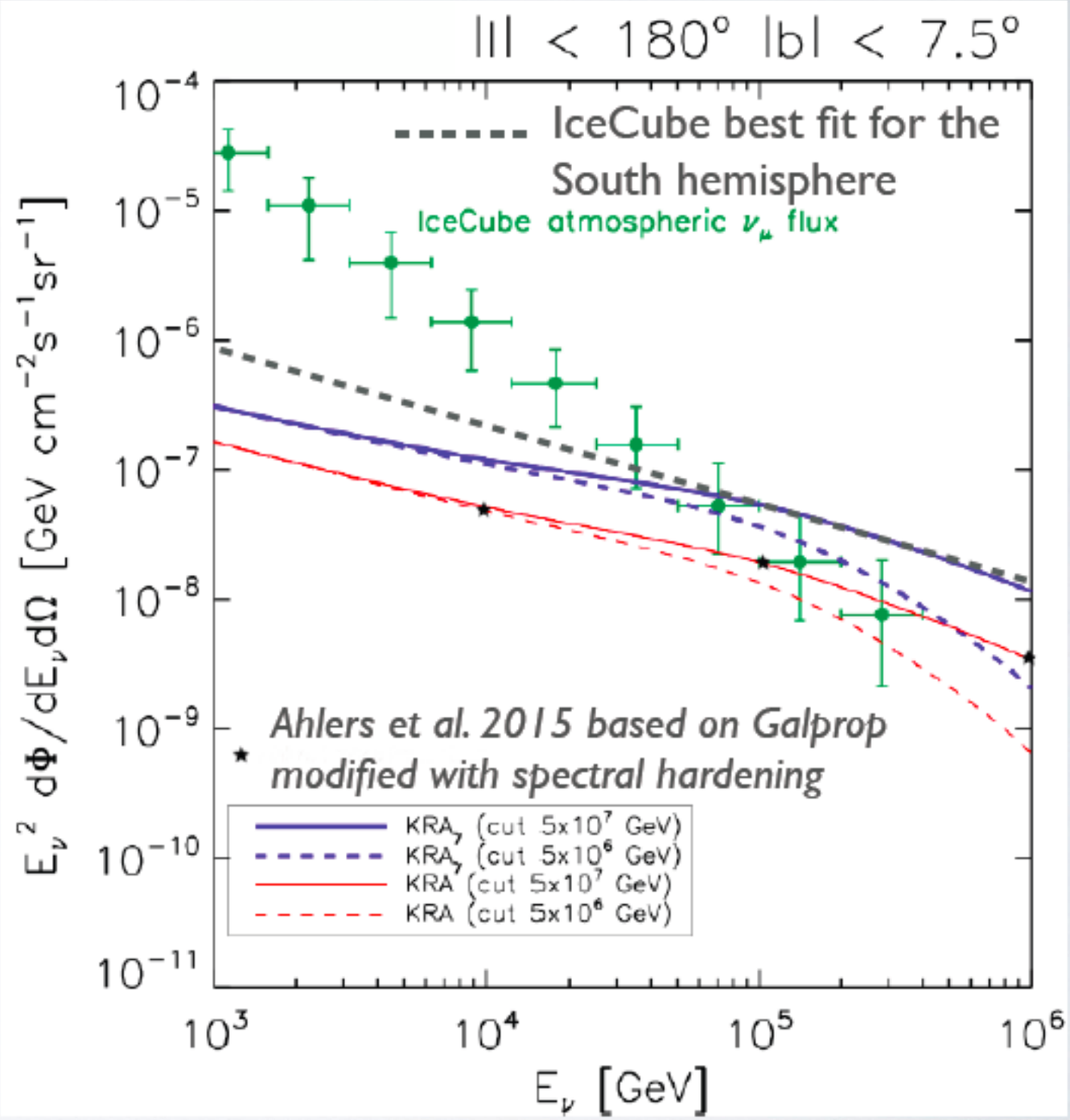
ν emissivities from Kamae et al. 2006

Enhanced ν emission of the Galaxy from the KRAγ model

The model can account up to 40 % of the IceCube HESE event excess above 60 TeV (full-sky) compared to 5 -10 % computed with GALPROP (Ahlers et al. 2015)

according to Ahlers et al. 2015 this is still compatible with the IC events angular distribution

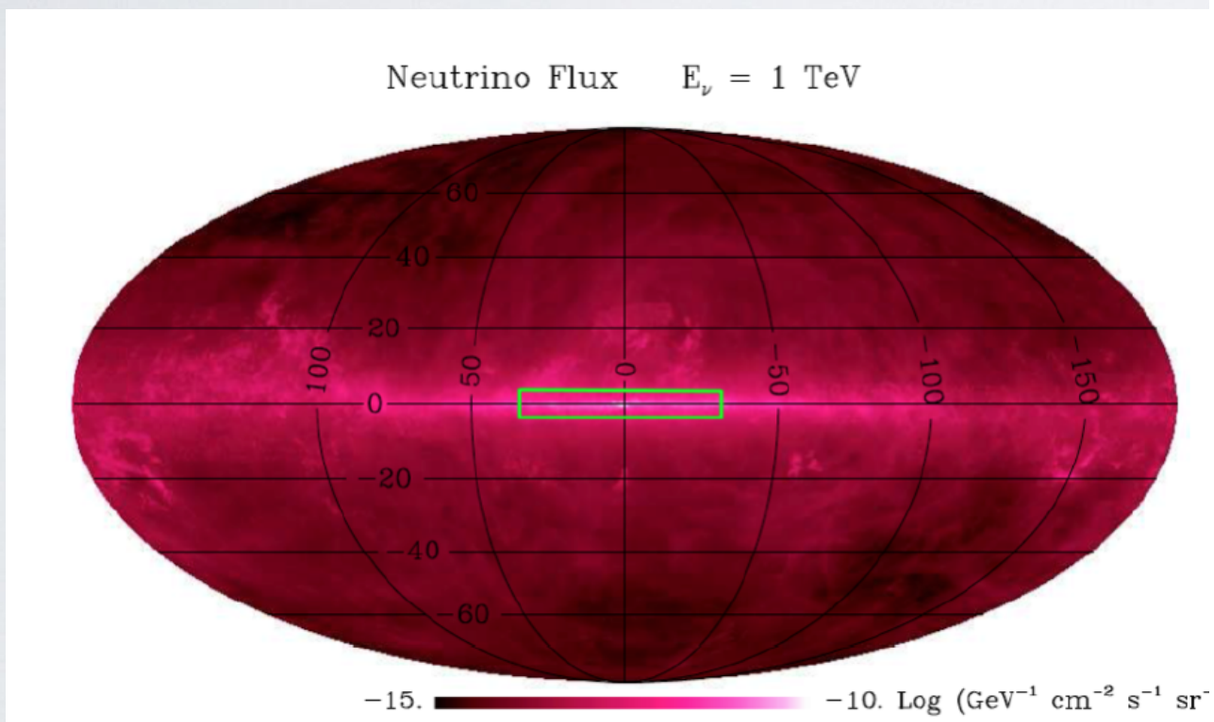
The excess may be better detected in the GP region where the flux should be dominated by the Galactic emission ➡

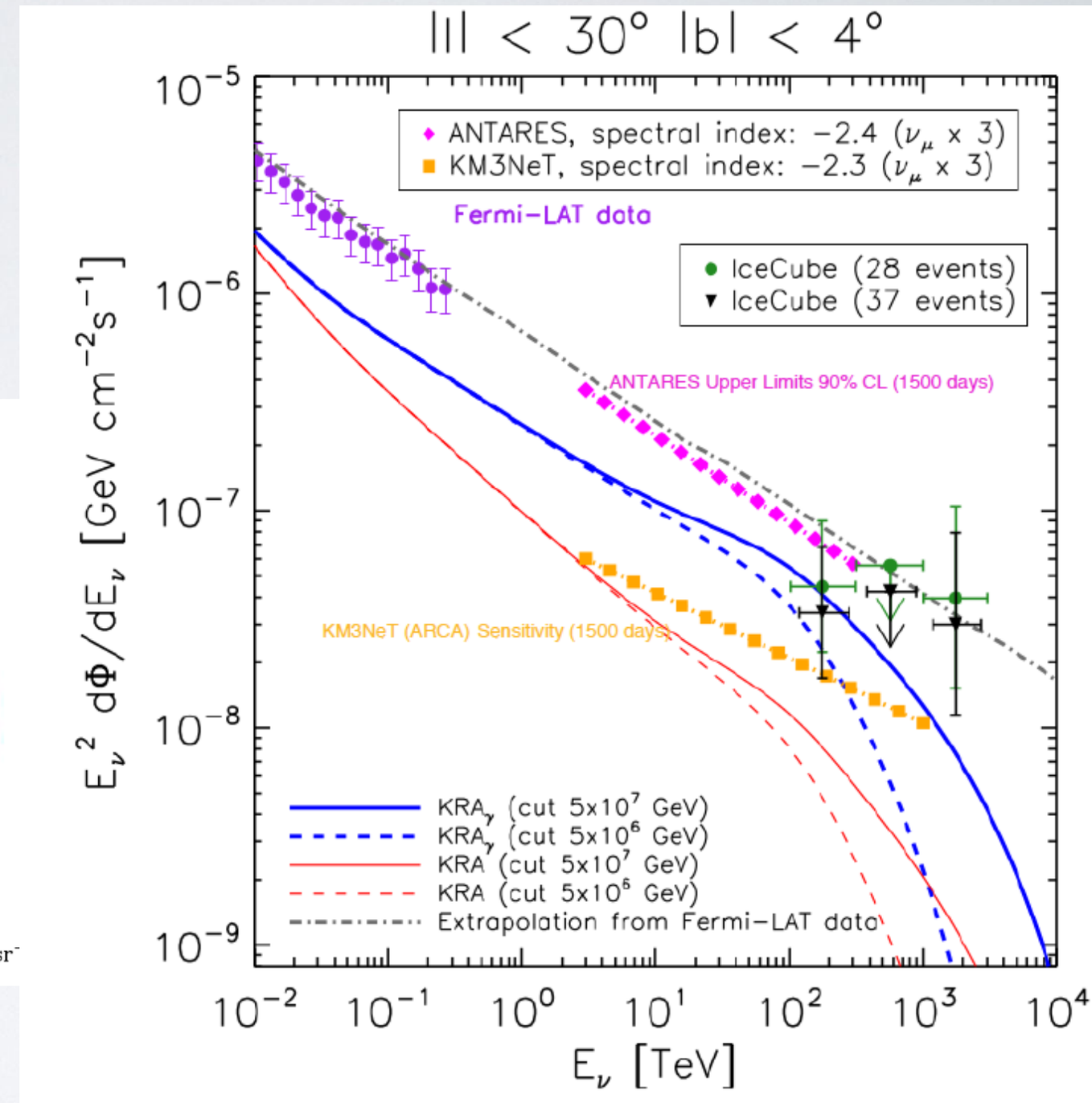


Enhanced ν emission of the Galaxy from the KRAγ model

Gaggero, D.G., Marinelli Urbano &Valli
arXiV: 1508.03681

The excess is expected to be higher in the GC region. This may be probed by ANTARES and Km3Net





CONCLUSIONS

- The same model, when accounting for the CR hardening at 250 GeV/n, allows to reproduce Milagro excess at 15 TeV (HESS Galactic ridge spectrum is also reproduce consistently with Fermi data). This provides the first consistent description of sub-TeV and TeV diffuse γ-ray diffuse emission data. HAWC may soon confirm this scenario
- Our model also predicts a significantly larger Galactic neutrino flux which may help interpreting the increasing evidence of a Galactic component in the IceCube signal.
- Fermi-LAT data favor a Galactic CR propagation model with δ decreasing with R (harder CR spectrum in the GC region)
- The Galactic neutrino emission should be dominant in the inner Galactic plane region. This may testable by ANTARES and, most likely, by Km3Net