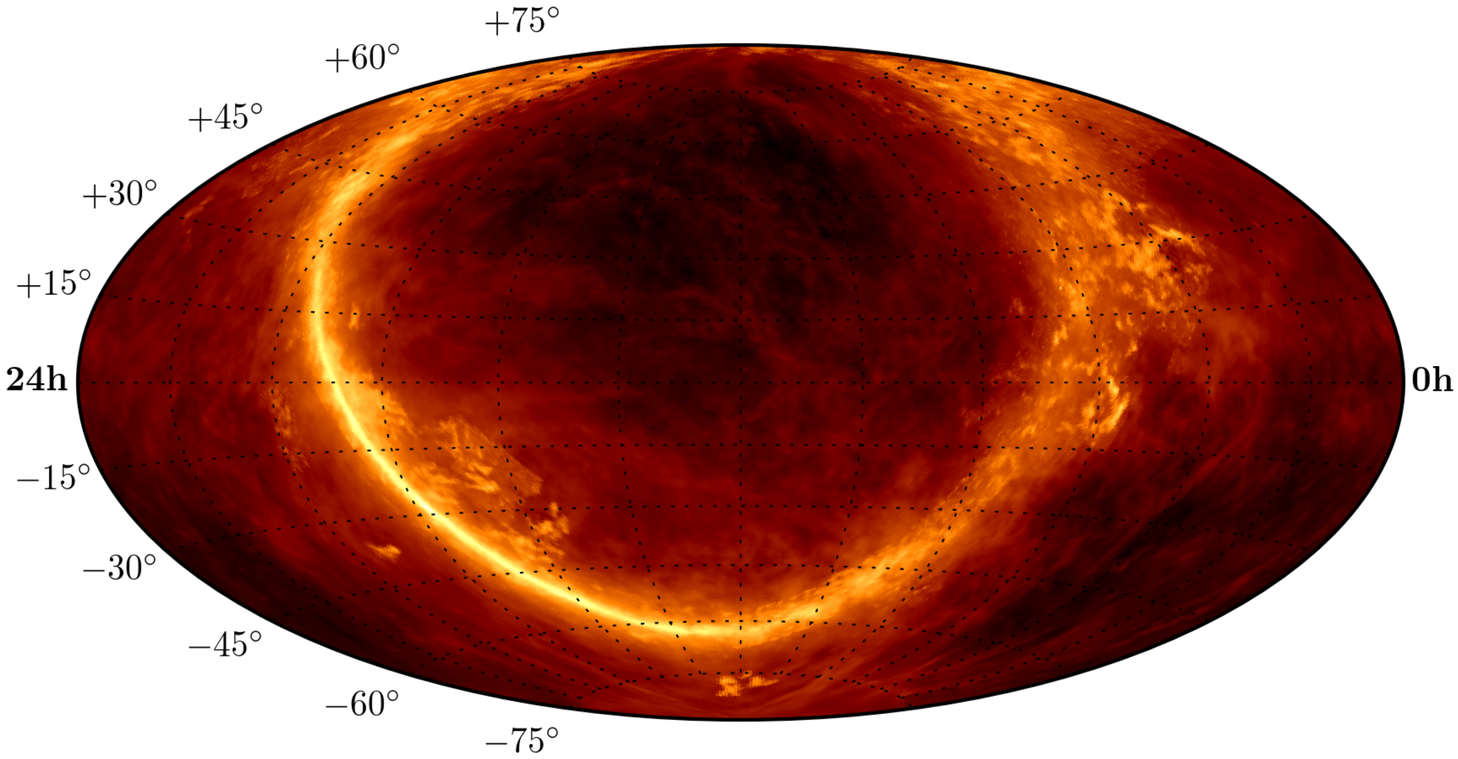
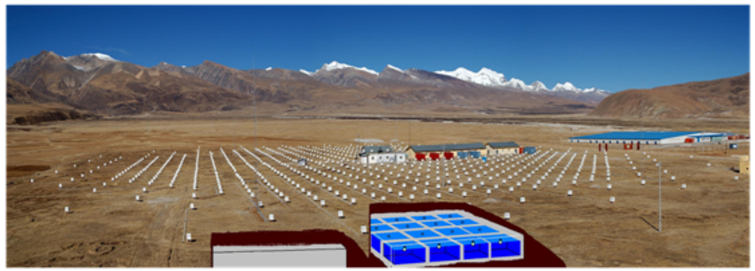



# GAMMA RAYS AND NEUTRINOS FROM THE GALACTIC PLANE AT THE PEV FRONTIER

D. Grasso (INFN, Pisa) with
P. De la Torre Luque, D. Gaggero and A. Marinelli

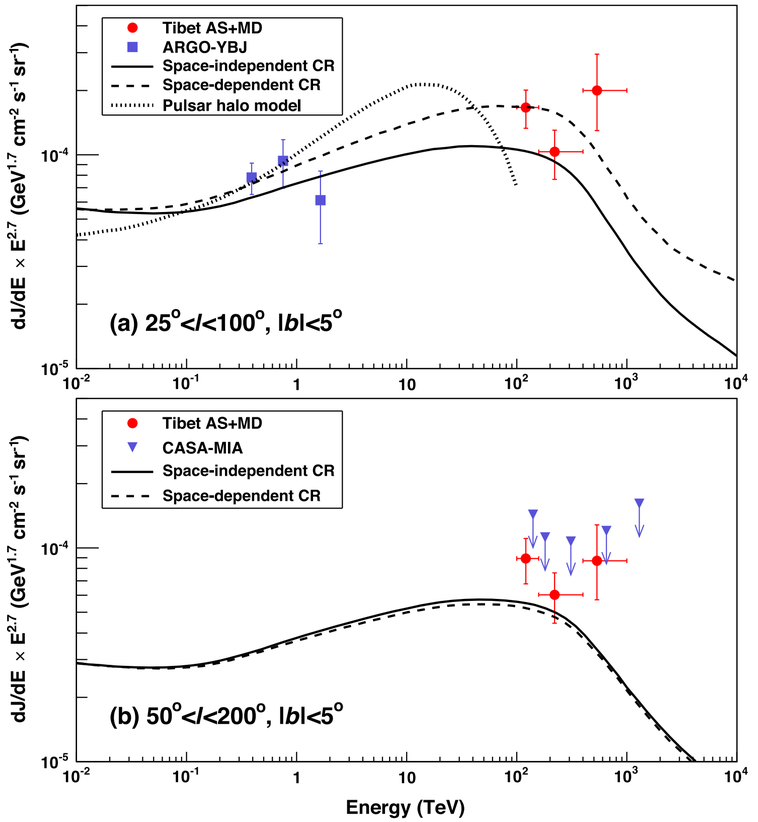
*CRIS 2022 - Napoli*

# TIBET AS$\gamma$ RESULTS



Air-Shower + muon detector at 4300 m a.s.l.

*Tibet AS$\gamma$ coll., PRL 2021*




- First detection of the $\gamma$-ray diffuse emission from the Galactic plane above few hundred TeV. **5.9$\sigma$ significance** (ON/OFF analysis. 23 events E > 398 TeV |b|< 10 ◦ , 10 ev. | b| > 20 ◦ )

- **No events from known TeV sources above 398 TeV while above 100 TeV TeVCAT sources contribute a 13%**

- 4 events - out of a total number of 10 above 398 TeV - from the Cygnus cocoon ( $l \simeq$ 80 ◦ )

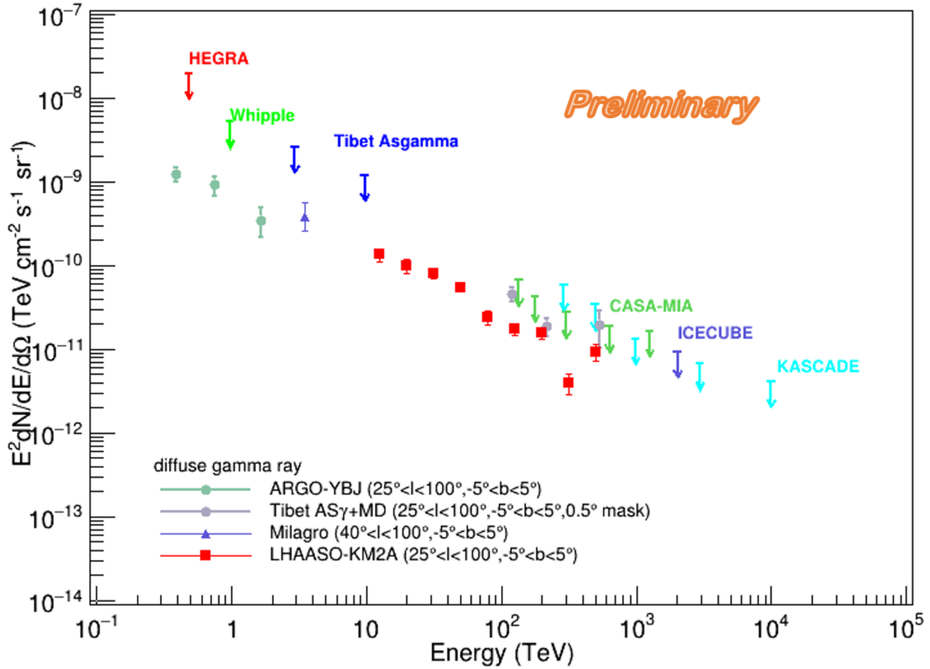
- Under the hypothesis the emission is originated by CR, a good agreement with the predictions of a space dependent CR transport scenario (wait few slides) it is claimed

Estimated systematic error - 30%
Angular resolution > 400 TeV : 0.16 ◦

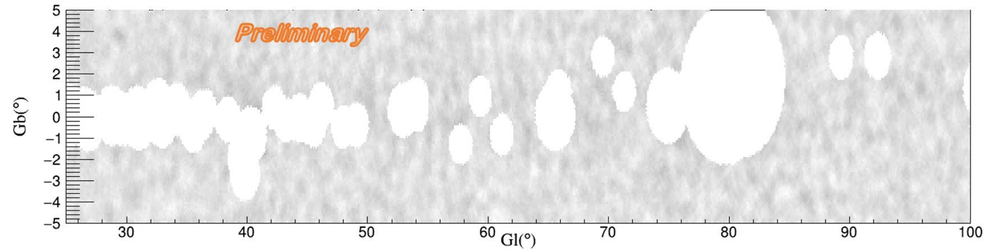
# LHAASO (PRELIMINARY) RESULTS


Air-Shower + muon detector at 4400 m a.s.l.

*S.P. Zhao et al. - LHAASO coll., ICRC 2021*




- Statistics larger than Tibet
- Energy threshold lower than Tibet
- TeVCAT sources were masked
- As a consequence the measured spectrum has to be intended as a lower limit



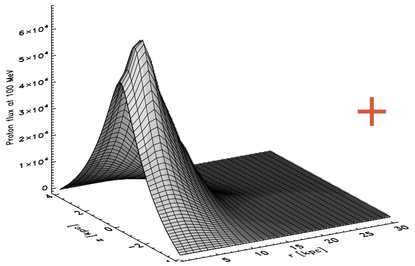
# MAIN QUESTIONS

- *Does this emission share the same nature of the Interstellar Diffuse Emission (originated by the CR sea) measured by Fermi-LAT or it is the blurred superposition of unresolved sources dominating at large energy ?*
- *Is the spectral shape and normalization of the inferred primary CR population different from the local one ?*
- *What is the CR spectrum and composition around the PeV ?*
- *What these results may imply for the search of Galactic neutrinos and what we may learn detecting the Galactic neutrino diffuse emission ?*

# MODELLING THE INTERSTELLAR DIFFUSE EMISSION

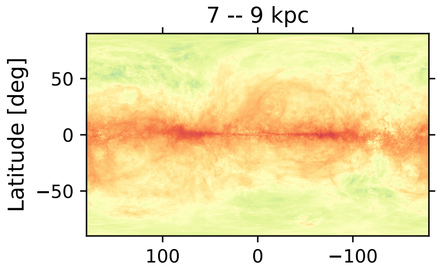
## The conventional scenario

**CR spatial/energy distribution** from numerical codes (GALPROP/ DRAGON)



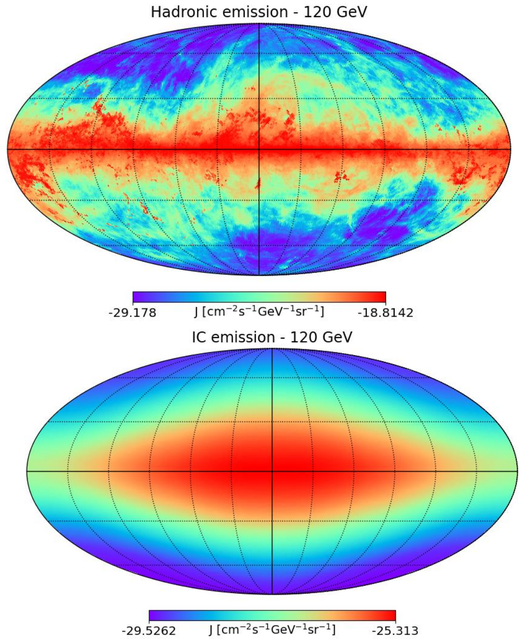
+

**Astrophysical inputs** : gas maps , interstellar radiation fields, magnetic fields




LOS integration

GALPROP/HERMES



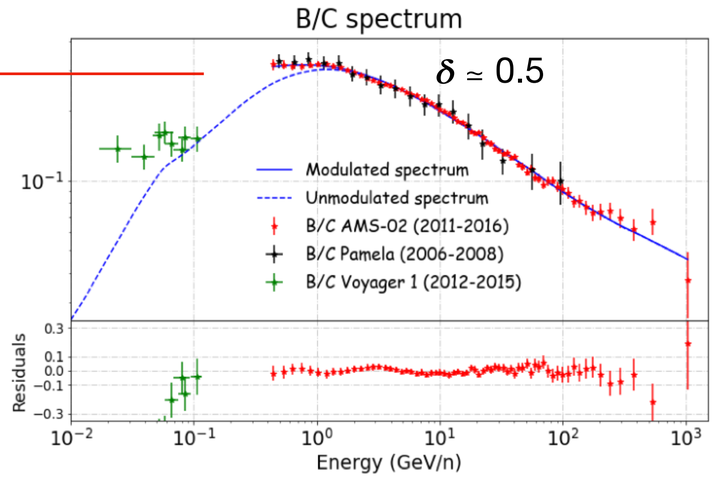

$\rho$ : particle rigidity

Schematically, for CR nuclei

given a (uniform) source spectrum $J_S(\rho, \mathbf{x}) \propto n_S(\mathbf{x})\, \rho^{-\alpha}$

for a uniform diffusion coefficient $D(\rho, \mathbf{x}) \propto D_0\, \rho^{-\delta}$

$$J_{CR}(\rho, \mathbf{x}) \propto J_0(\mathbf{x})\, \rho^{-(\alpha+\delta)} \quad \text{in the whole Galaxy}$$



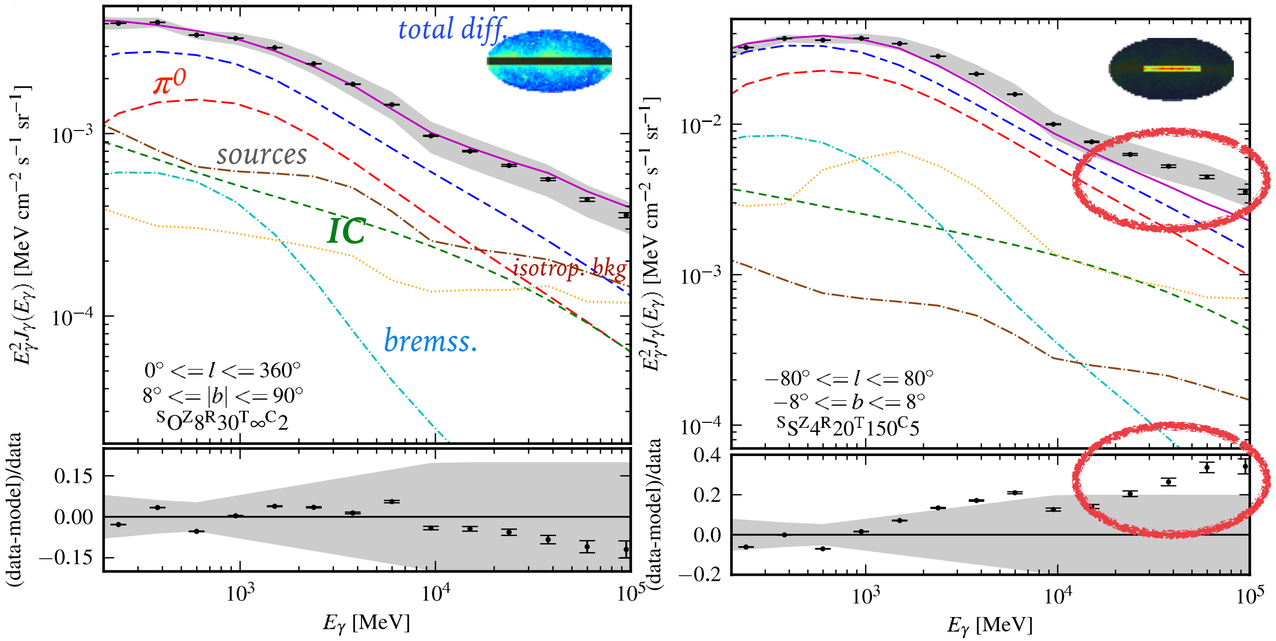

Factorized rigidity - position dependence

$\alpha$ and $\delta$ may however change with rigidity !

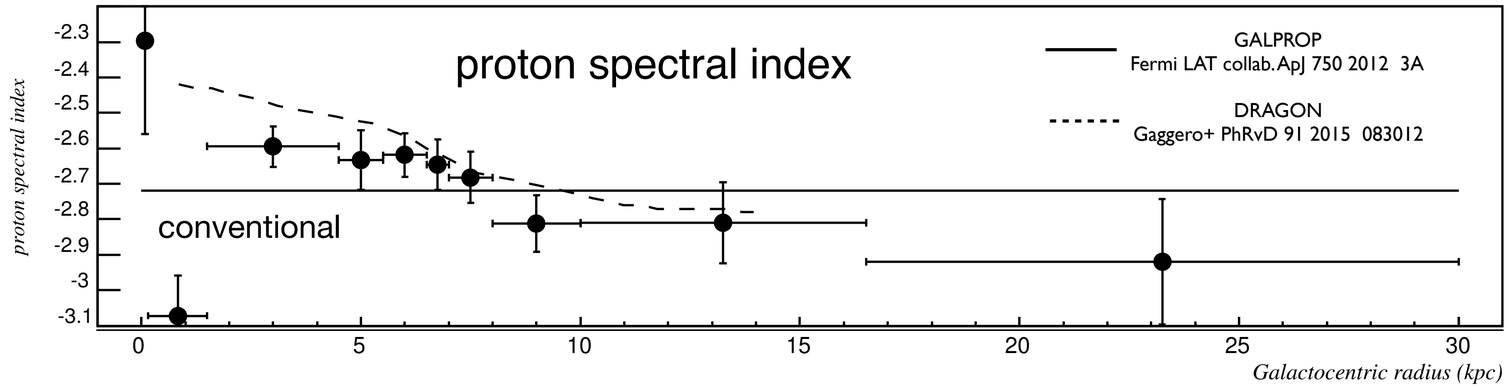
# MODELLING THE INTERSTELLAR DIFFUSE EMISSION

## The conventional approach - issues

*Fermi-LAT coll. 2012*




*Fermi-LAT coll. 2016*



# MODELLING THE INTERSTELLAR DIFFUSE EMISSION

## The "gamma optimized" scenario

Schematically, for CR nuclei

given a (uniform) source spectrum $J_S(\rho, \mathbf{x}) \propto n_S(\mathbf{x})\, \rho^{-\alpha}$

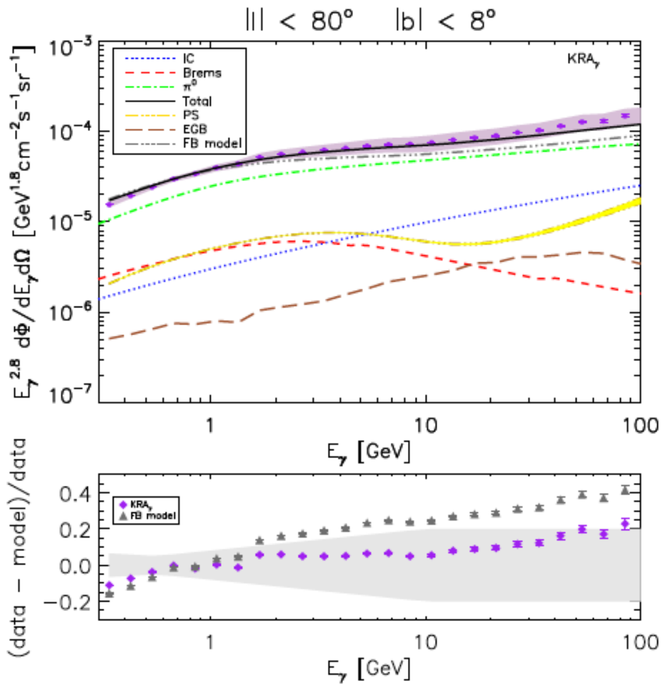
for **not** uniform diffusion coefficient $D(\rho, \mathbf{x}) \propto D_0\, \rho^{-\delta(\mathbf{x})}$

$$J_{CR}(\rho, \mathbf{x}) \propto J_0(\mathbf{x})\, \rho^{-(\alpha + \delta(\mathbf{x}))}$$

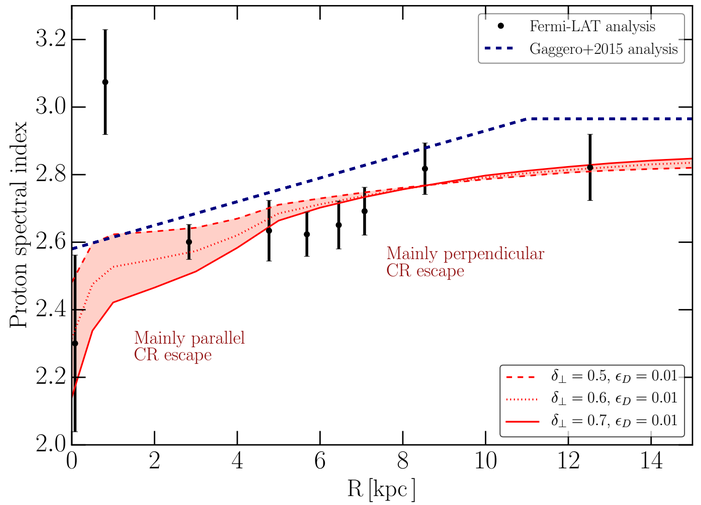
Unfactorized rigidity-position dependence

*Gaggero, Urbano, Valli & Ullio, PRD 2015*

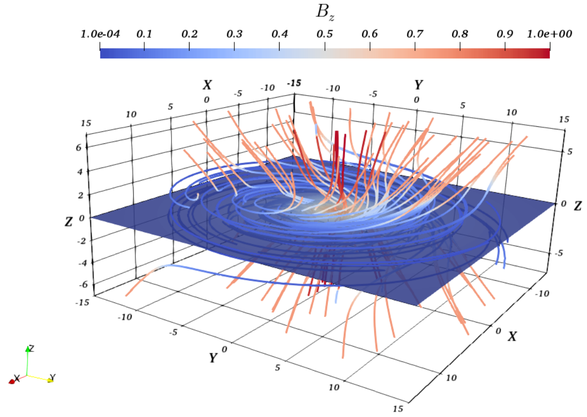
$\delta(R) = A\,R + B$ for $r < 11$ kpc




**Theoretically motivated !**




*Cerri, Gaggero, Vittino, Evoli & DG, JCAP 2017*




Magnetic field model
*Jansson & Farrar ApJ 2012*
*Terral & Ferriere 2016*

- Poloidal magnetic field become larger toward the GC
- Parallel diffusion (irrelevant at large radii) becomes dominant at small R
- Particle tracing numerical simulations
  *Casse+ 2001, De Marco+ 2007 , Snodin + 2015*

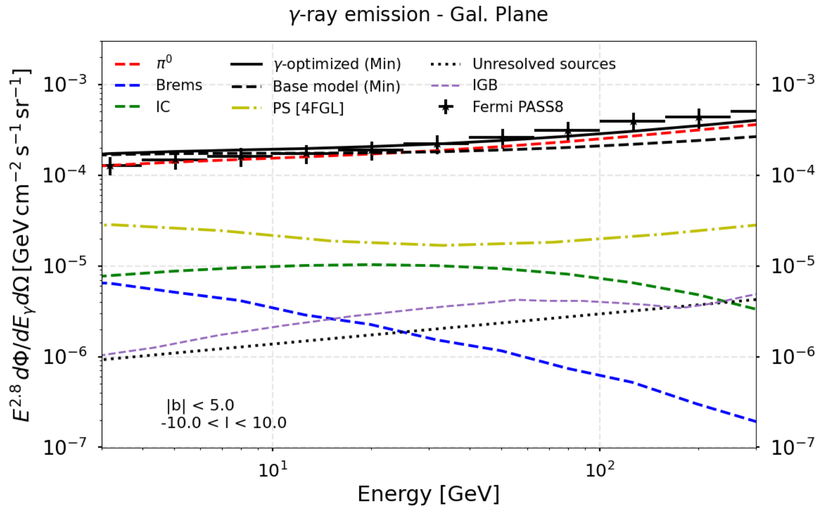
$$D_{\parallel} \propto \rho^{1/3} \qquad D_{\perp} \propto \rho^{1/2}$$

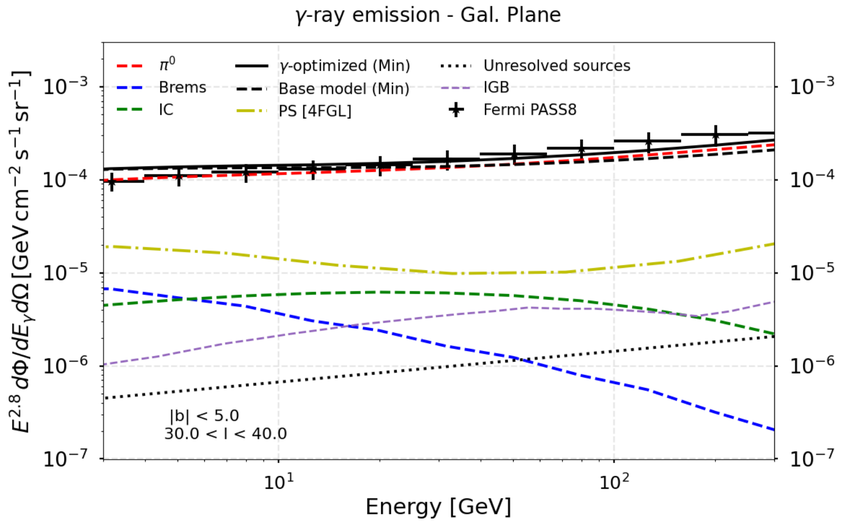
➜ CR spectrum becomes harder for R ➜ 0 . The effect holds at large energies

# MODELLING THE INTERSTELLAR DIFFUSE EMISSION

## Updated models against Fermi-LAT

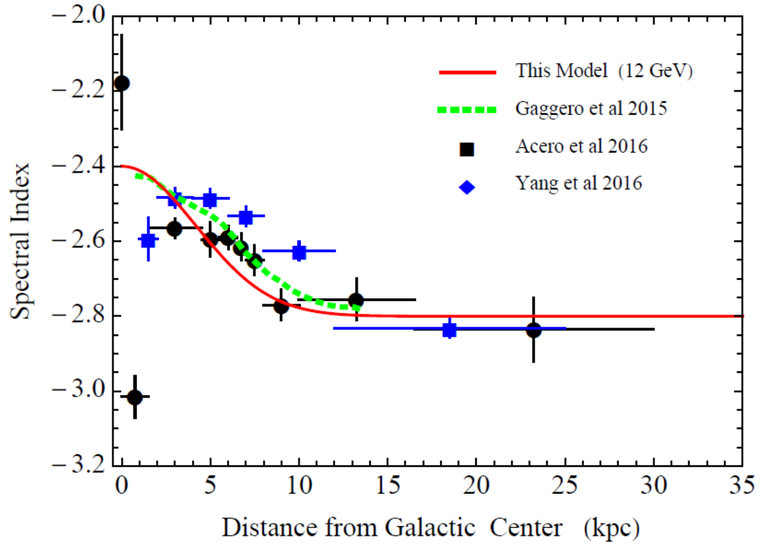
*P. De La Torre Luque, D. Gaggero, DG, O. Fornieri, K. Hegberts, C. Steppa, C. Evoli, 2203.15759*




The model adopts a hardening of the source spectrum at 300 GeV to reproduce AMS-02 (global feature)

CR (proton) spectral index as inferred from several analysis of *Fermi*-LAT γ-ray data →

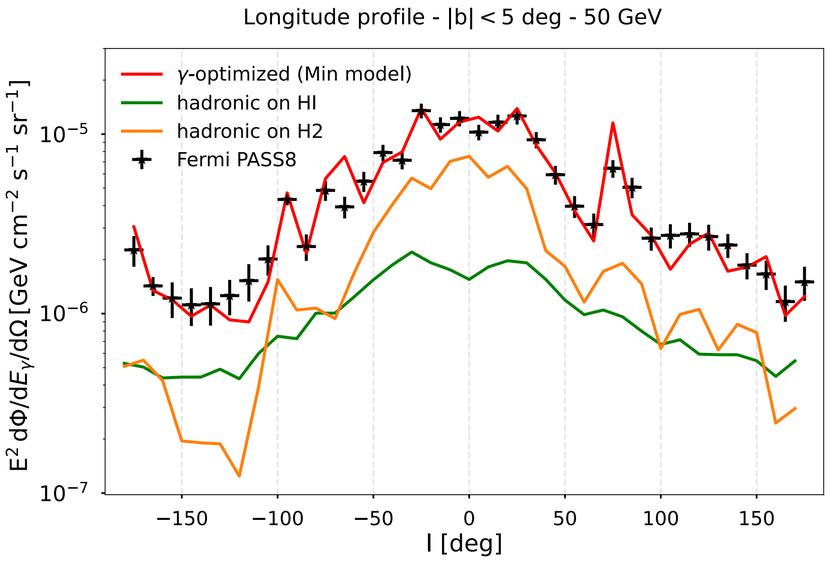


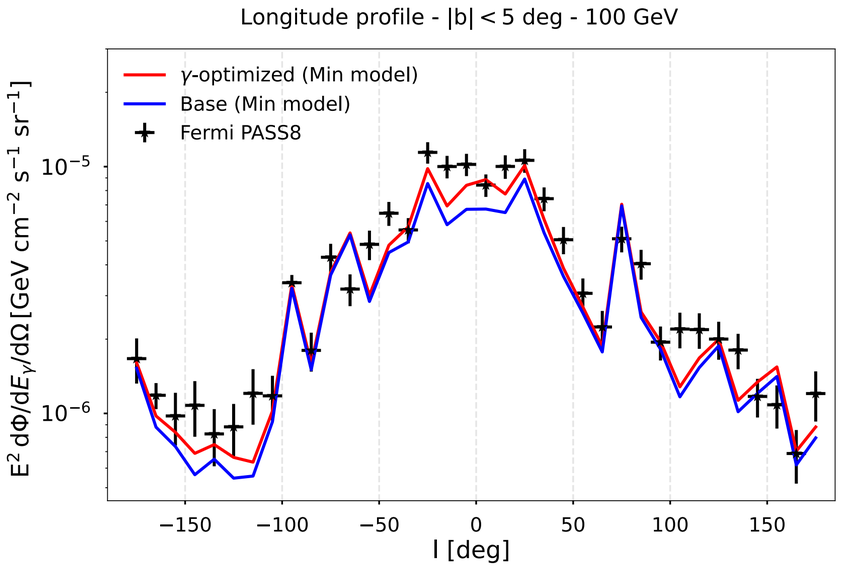

The unresolved source model is based on the H.E.S.S. galactic plane survey
*Steppa & Egberts A&A 2022*
less than 1% in the Fermi range

# MODELING THE INTERSTELLAR DIFFUSE EMISSION

## Updated models against Fermi-LAT

*De La Torre Luque, DG, Gaggero, Marinelli, accepted by Frontiers*



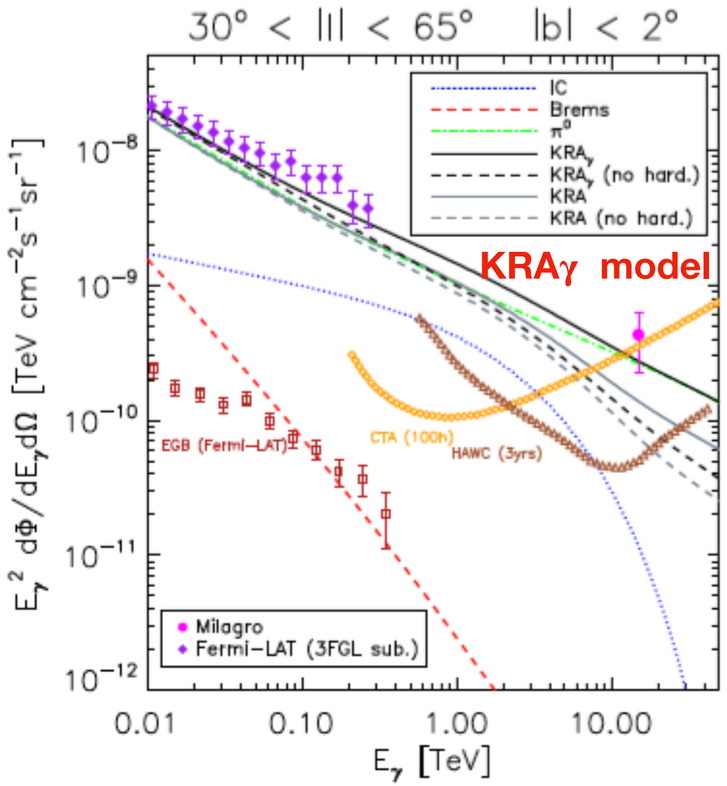

**Performed with HERMES**

https://github.com/cosmicrays/hermes

# MODELLING THE INTERSTELLAR DIFFUSE EMISSION

## Towards the PeV

*Gaggero, D.G., A. Marinelli, Urbano, Valli ApJ L 2015*



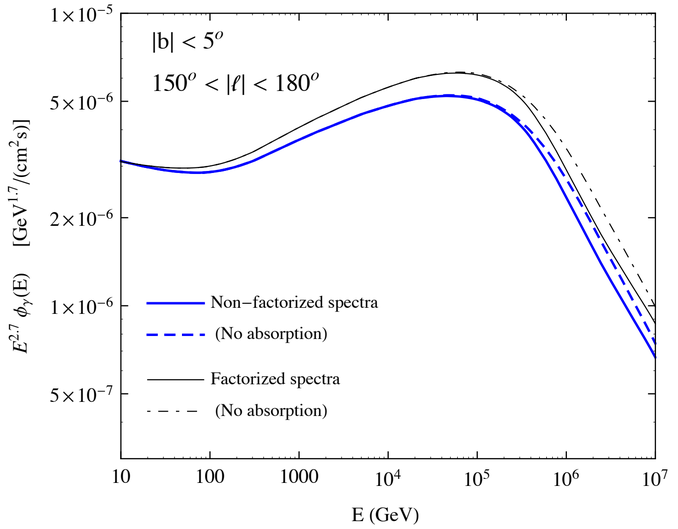

As pointed out in both papers

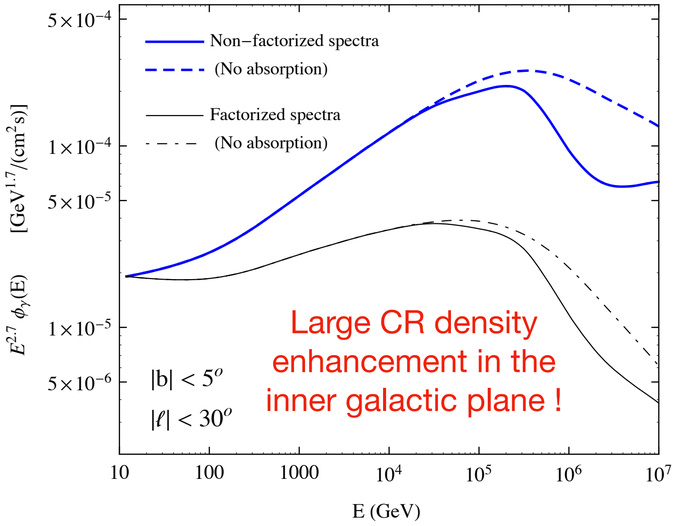
**Relevant implications for neutrino astronomy too !**

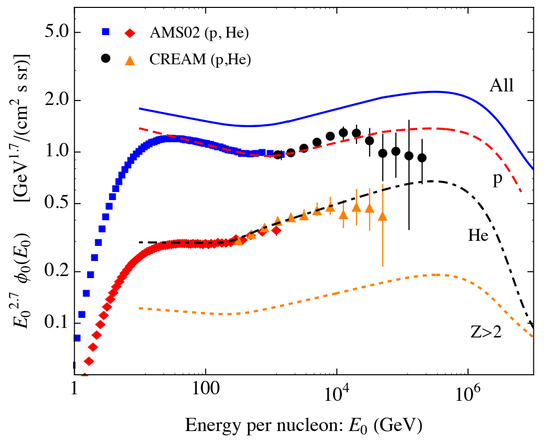
wait few slides

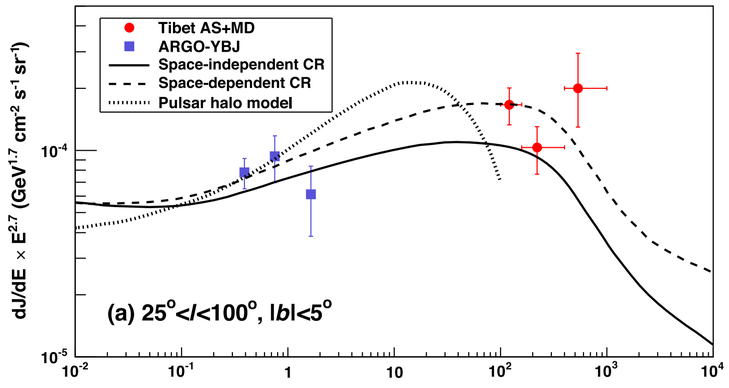
## An analytical implementation

*Lipari & Vernetto, 2018*



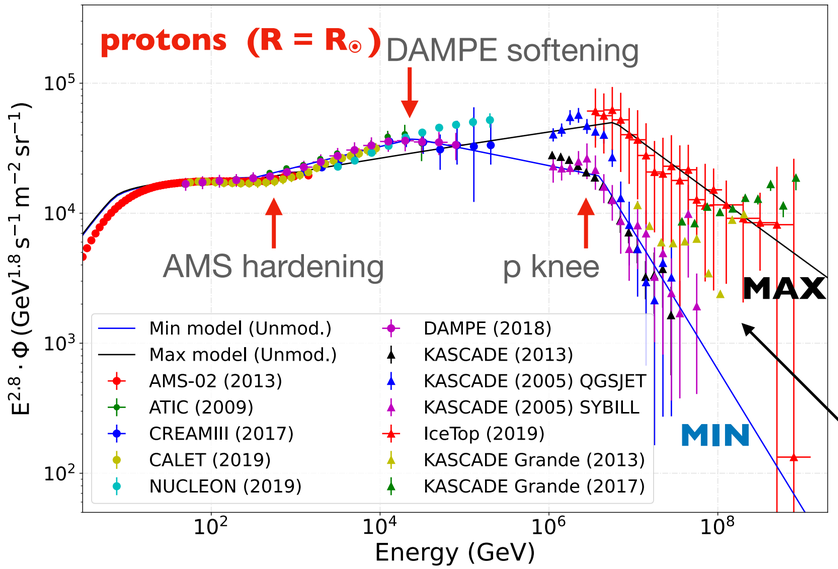



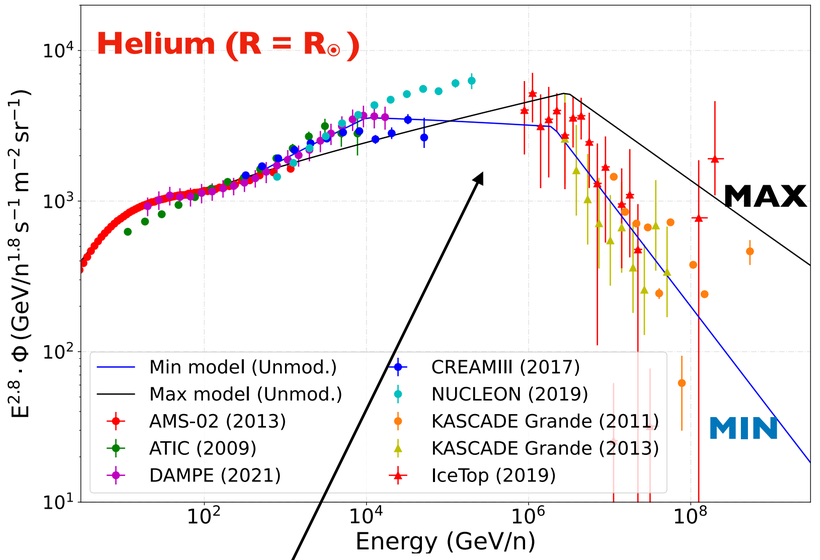



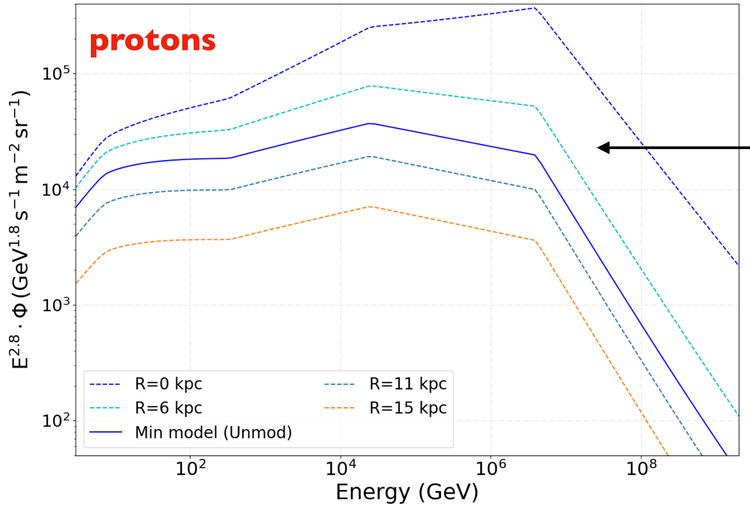



# WHICH PRIMARY CR SPECTRUM/COMPOSITION ABOVE 100 TEV ?

*P. De La Torre Luque at al., 2203.15759*




Lines represent local propagated spectra for both scenarios.

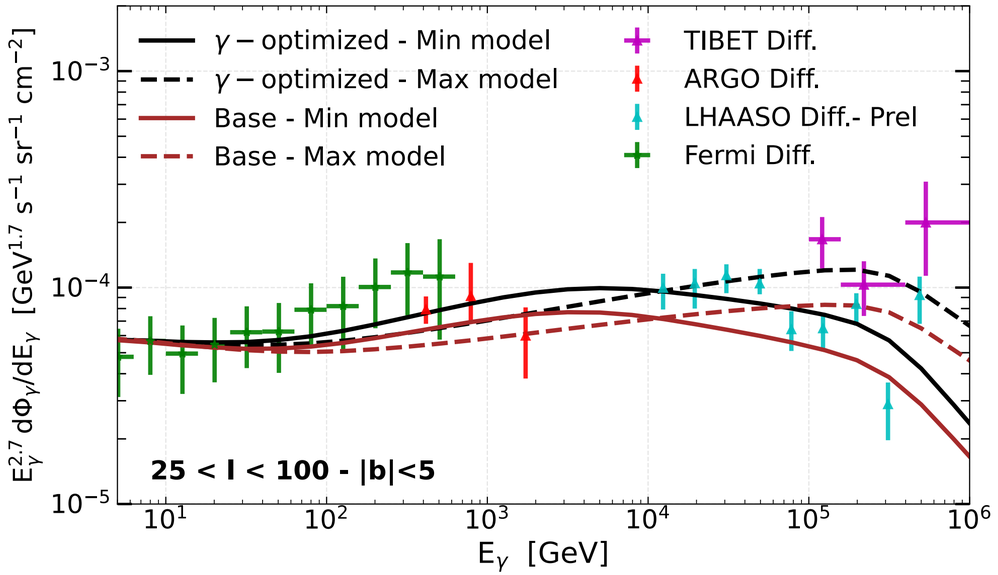
Propagated spectra at several galactocentric radii for the γ-optimized scenario

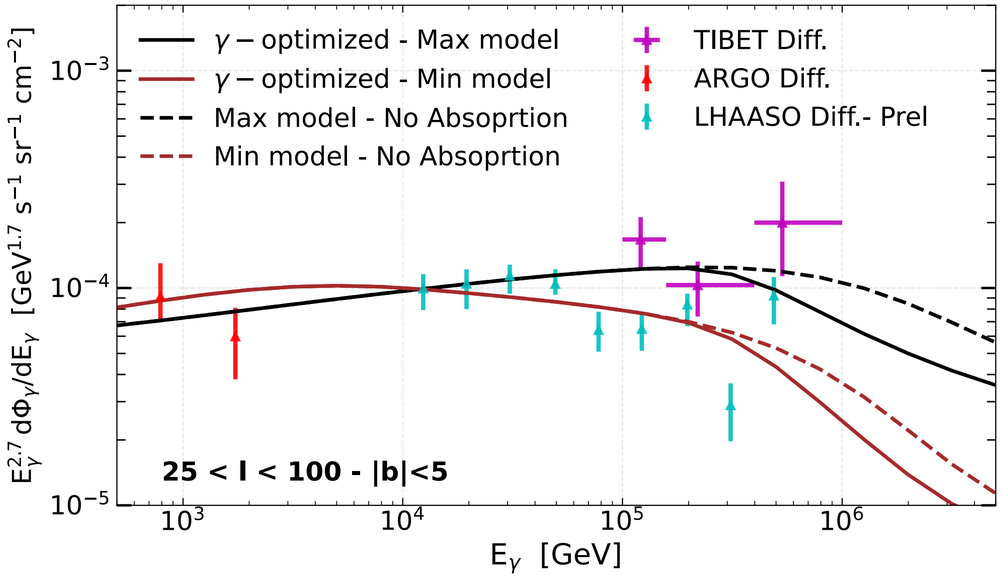
The source spectra is assumed to be the same in the whole Galaxy

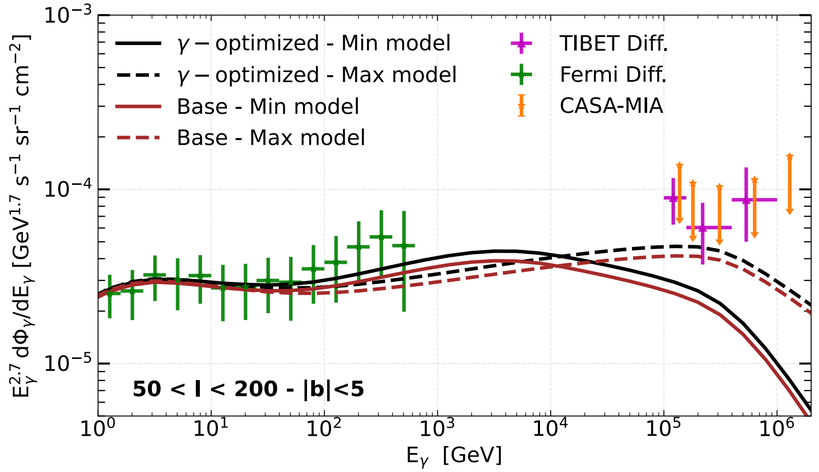
# NEW RESULTS

## Against Tibet and LHAASO

*P. De La Torre Luque at al., 2203.15759*



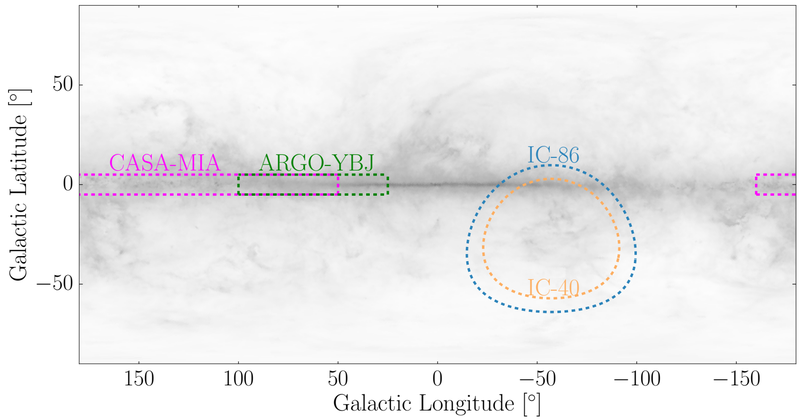




- Strong degeneracy between the CR transport scenario and the source spectral shape though LHAASO + ARGO + Fermi seems to favor the $\gamma$-optimized scenario
- LHAASO + Tibet favor the Max source spectrum setup
- $\gamma$-ray opacity due to $\gamma$-$\gamma_{CMB}$ significant only for E > 100 TeV . ISRF almost irrelevant
- At large longitudes the observed spectrum is expected to be almost independent on the transport scenario. Measurements at low galactic longitudes would be resolutive !

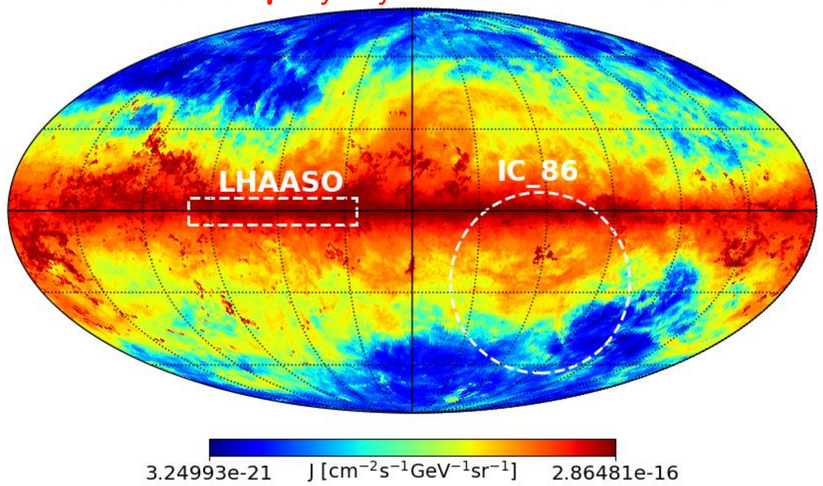
# NEW RESULTS

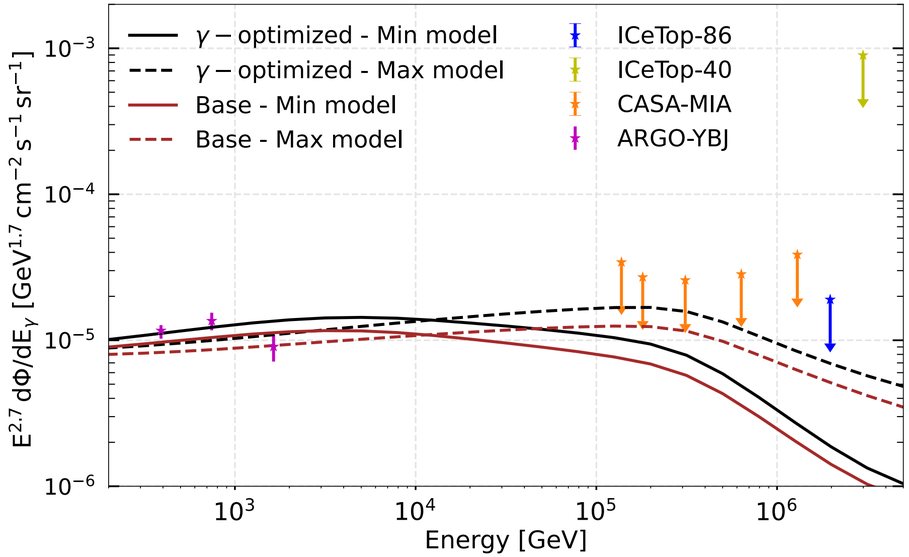
## Against IceTop

*IceCube coll., Astrophys.J.* 891 (2019) 9




100 TeV γ-ray sky simulated with HERMES




**Performed with HERMES**

https://github.com/cosmicrays/hermes

This is a template likelihood analysis
model: Fermi angular distribution
Gamma ray slope - 3

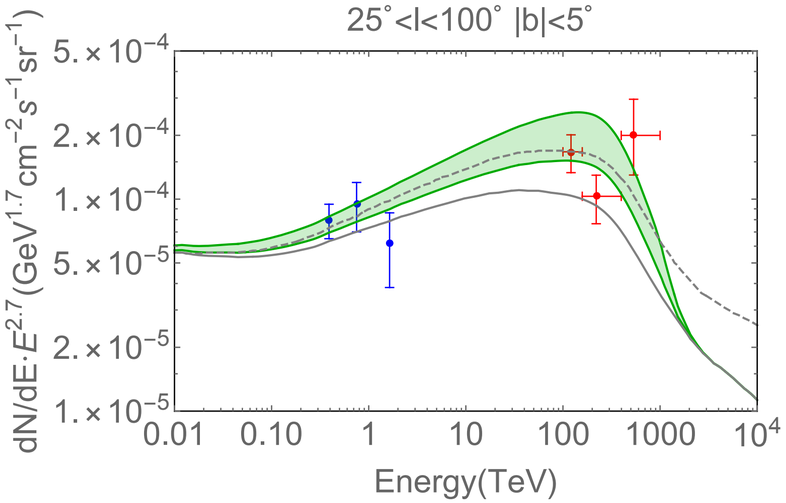
# A LARGER CONTRIBUTION FROM UNRESOLVED SOURCES ?

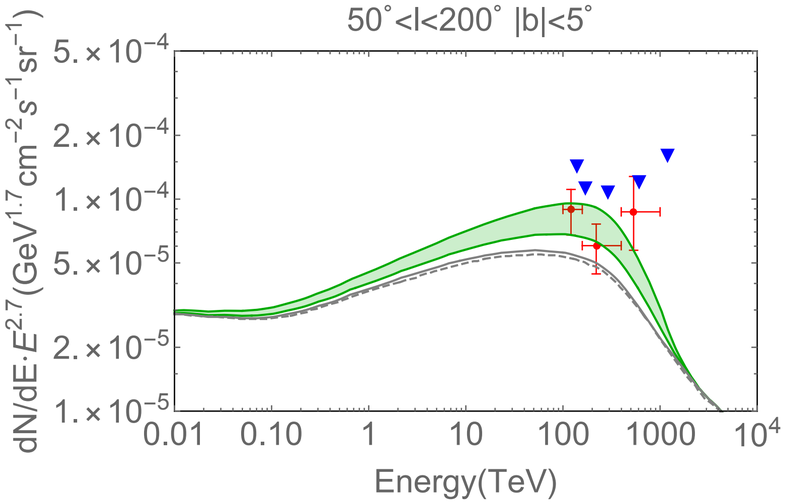
*Vecchiotti et al., 2107.14584*

Although unlikely (no emission from TeVCAT above 400 TeV was found) an interpretation of Tibet and LHAASO results is these terms cannot be excluded

It assumes leptonic accelerators (PWNe, TeV halos) as the main unresolved sources

It might provide a better agreement with Tibet results for $50 < l < 200$ °

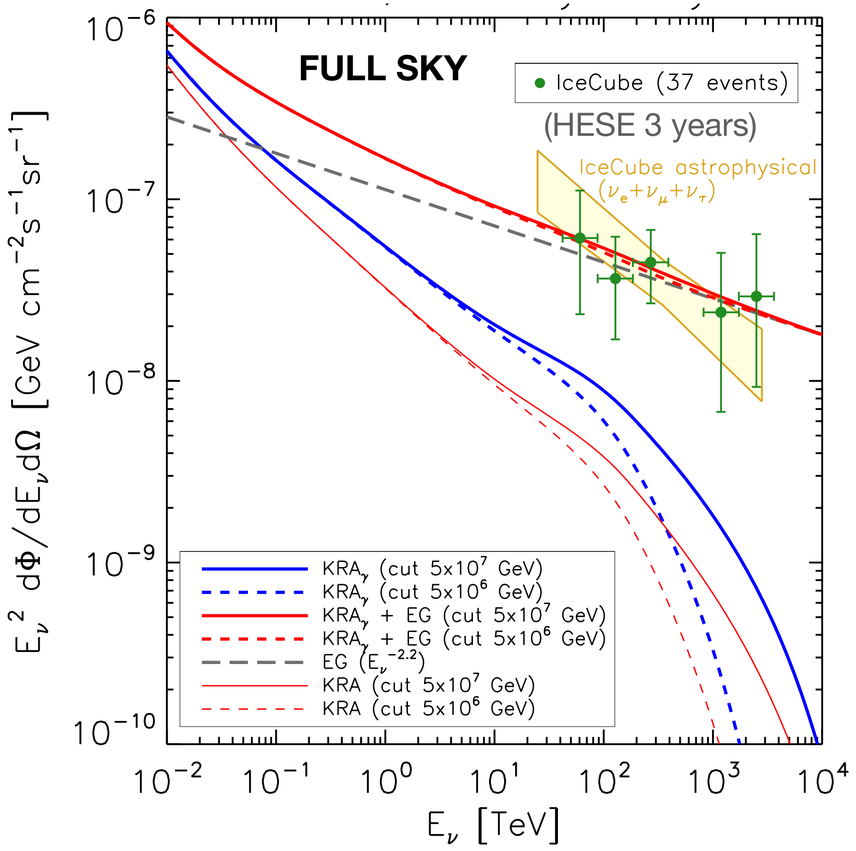


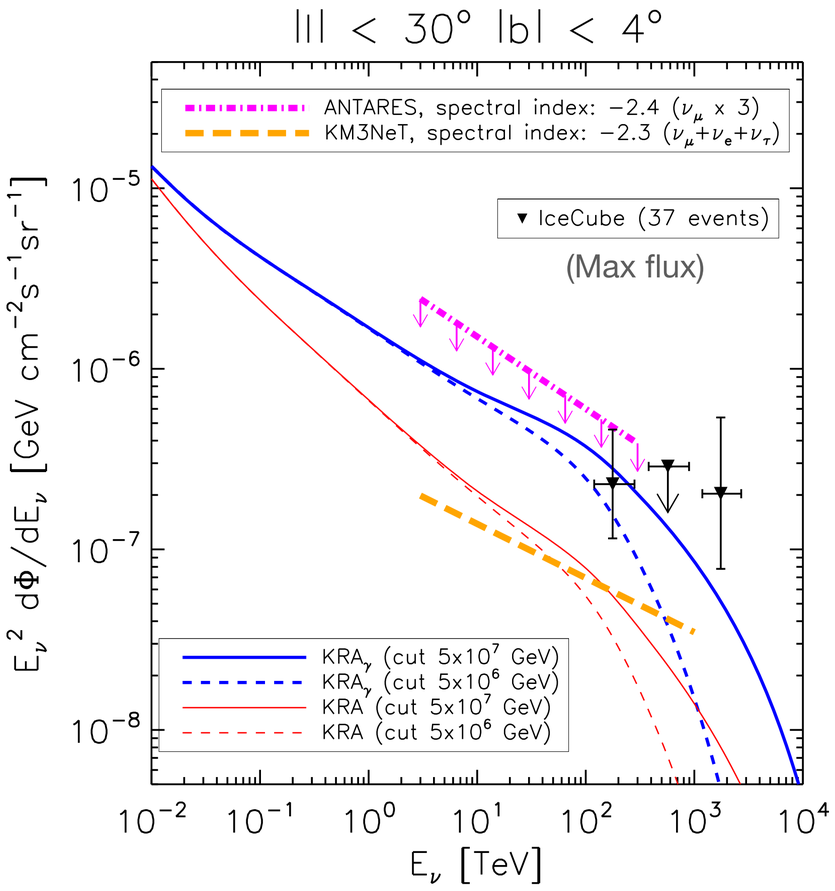



# NEUTRINO DIFFUSE EMISSION OF THE GALAXY

*Gaggero, D.G., A. Marinelli, Urbano, Valli ApJ L 2015*

The enhancement of the hadronic γ-ray emission predicted by the γ-optimized models must have a corresponding effect for neutrinos.
Here we show the prediction obtained with the KRAγ models.



# NEUTRINOS FROM THE GP

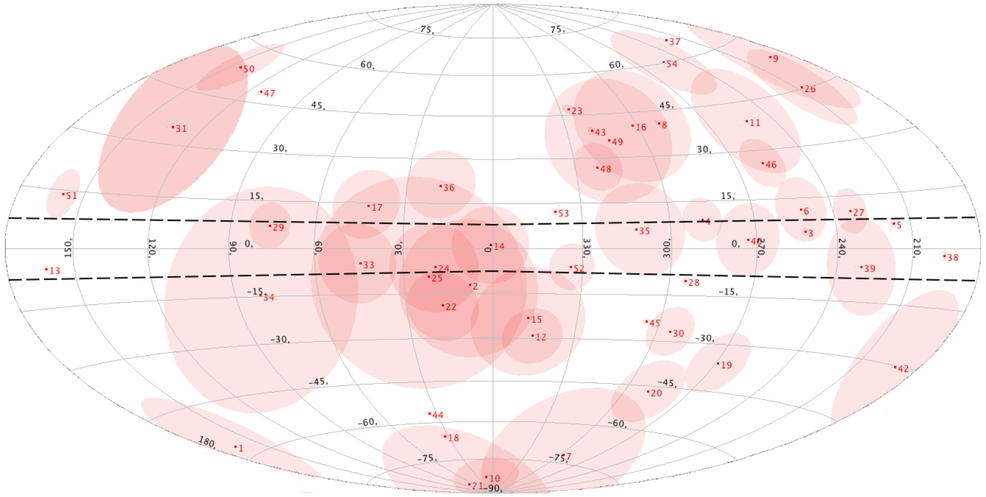
*IceCube + ANTARES constraints*

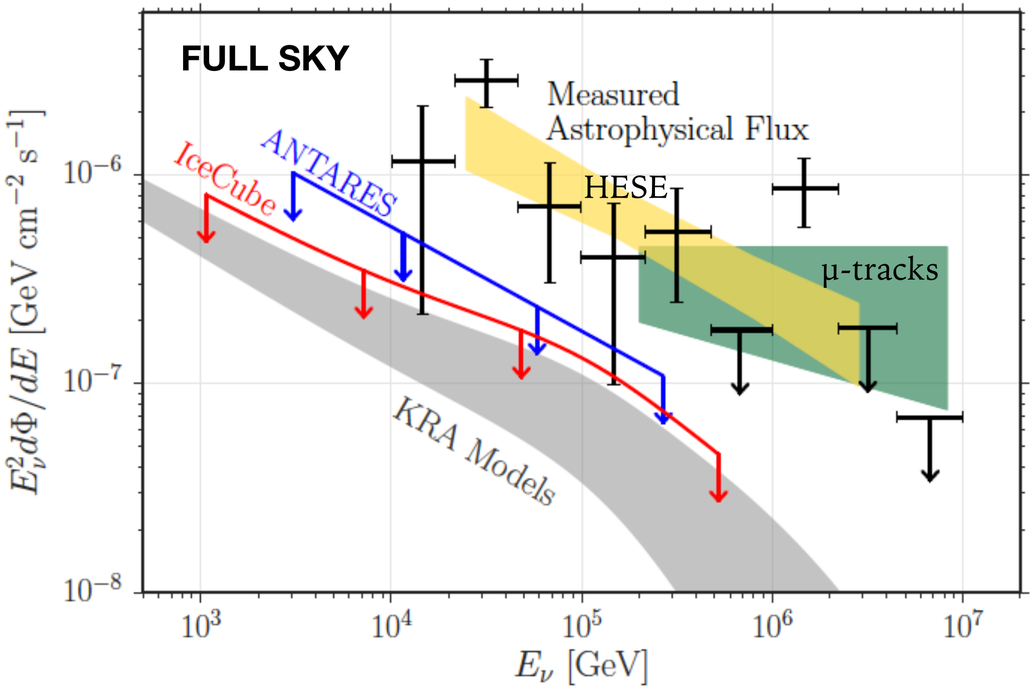
*ANTARES coll., Phys. Lett. B, 2016*

*ANTARES coll. + D. Gaggero & D.G. PRD 2017*

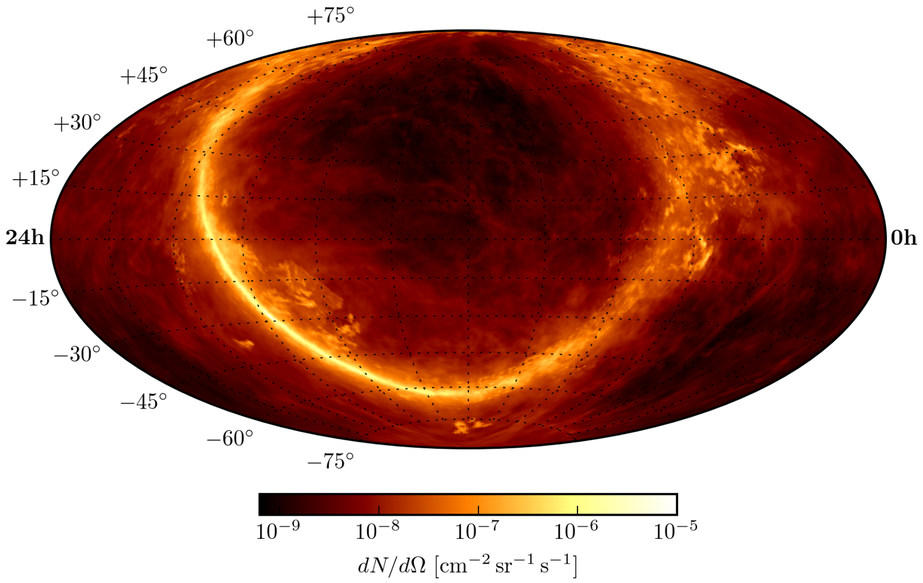
*ANTARES + IceCube + D. Gaggero & D.G., APJ 2018*

*Based on 2780 days of ANTARES data (showers + tracks) + 2431 IceCube (tracks)*






*IceCube analysis is maximum liklihood analysis based on the KRA$\gamma$ templates (hadronic component)*



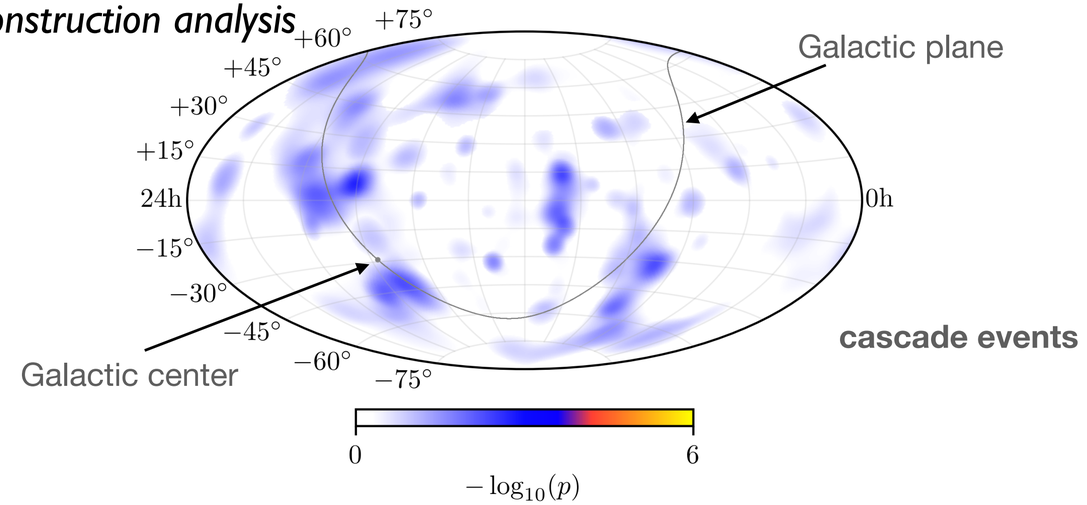
# ICECUBE SHOWER EVENT ANALYSIS

*IceCube coll. ApJ 849 (2017) 67*

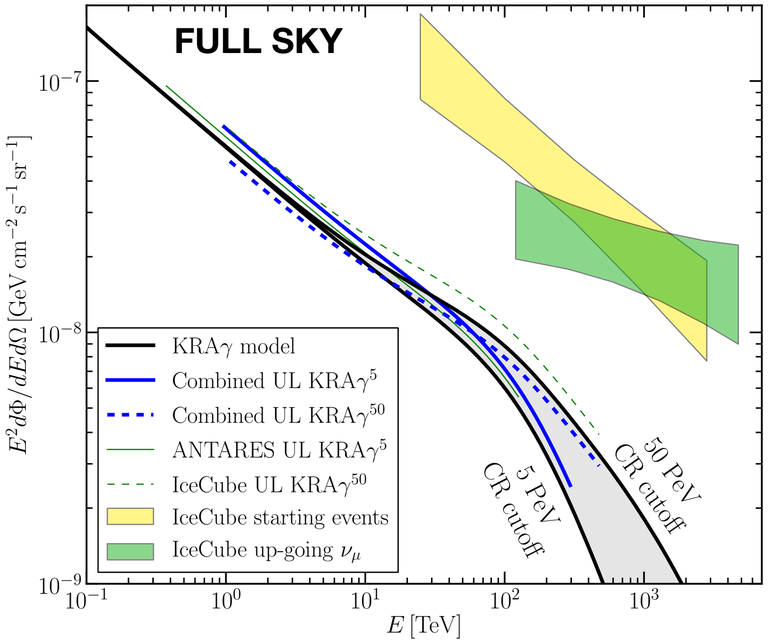
*7 years of data*

*New neural network reconstruction analysis*

*IceCube coll. ApJ 886 (2019) 12*




*IceCube & ANTARES coll. ApJ L 868 (2018) 67*




Angular and spectral likelihood analysis using the $\gamma$-optimized ( KRA$_\gamma^{5/50}$ ) templates we provided

*Gaggero, D.G., A. Marinelli, Urbano, Valli ApJ L 2015*

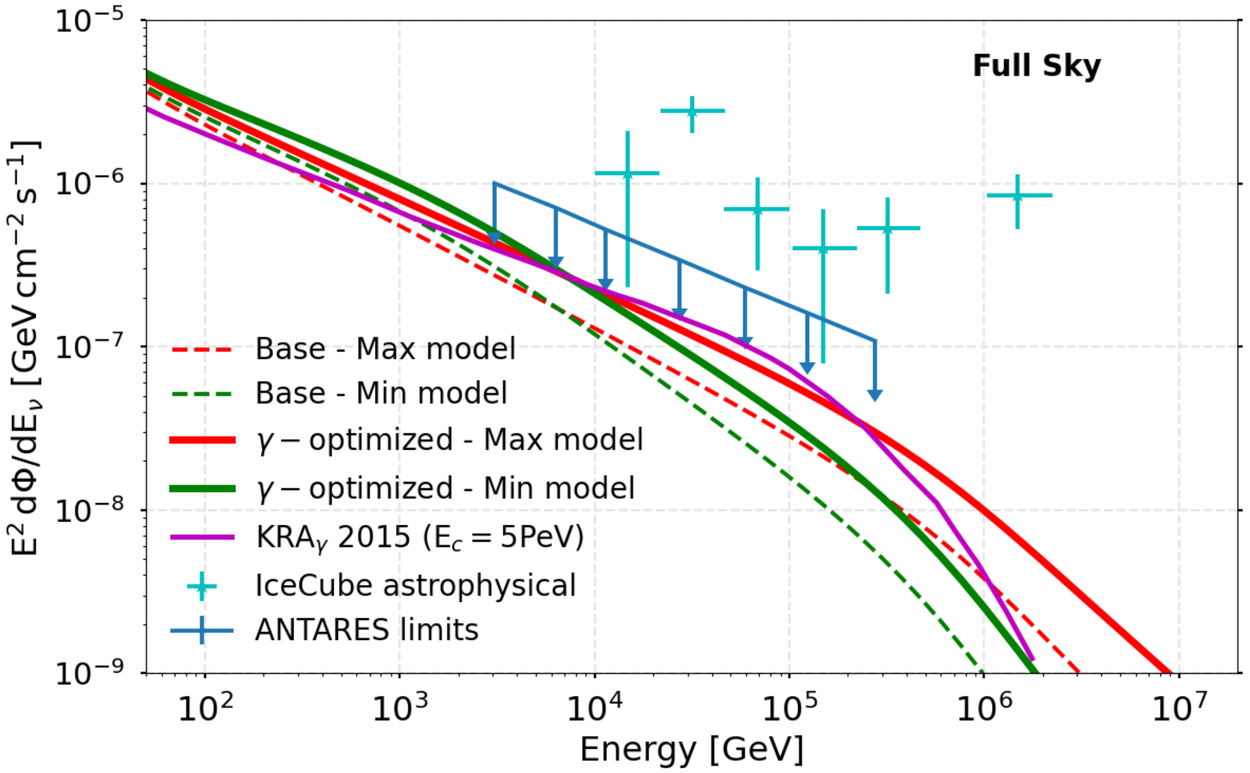
In this paper a **2.0$\sigma$ excess compatible with the 0.85 x KRA$_\gamma^5$ model was reported !** While a conventional *scenario* was disfavoured.

A new analysis with a larger statistics may be released soon

If IceCube will strengthen this result the interpretation of Tibet and LHAASO results in terms of unresolved sources (likely leptonic) would be further disfavoured with relevant implications for CR physics

# PREDICTIONS WITH THE UPDATED MODELS

*De La Torre Luque, DG, Gaggero, Marinelli, accepted by Frontiers*




- The predictions of the old KRA$\gamma^5$ are very close to those of the $\gamma$-optimized Max. Would IceCube confirm those models the spatial dependent propagation as well as a the IceTop CR spectral shapes were favoured !!
- The $\gamma$-optimized Min is closer to the Base scenario though with a lower normalization at low energies. $\gamma$-ray data at lower energy (e.g. LHAASO) may lift that degeneracy.

# CONCLUSIONS

- Tibet AS$\gamma$ and LHAASO (if confirmed) provide the first evidence of $\gamma$-ray diffuse emission from the Galactic plane up to the PeV.
- We showed that their results are naturally consistent with Fermi-LAT and ARGO-YBJ if the emission is originated by the galactic CR population
- Our results seems to favour a space-dependent CR transport scenario though, due to the uncertainties in the source spectrum above the 100 TeV, a solid confirmation requires more data especially at low Galactic longitudes ( SWGO is strongly wished ! ).
- IceCube and KM3Net may soon provide stronger and complementary evidences of that scenario with strong implications for CR physics

# NEW RESULTS

## Against Tibet and LHAASO

*P. De La Torre Luque at al., 2203.15759*