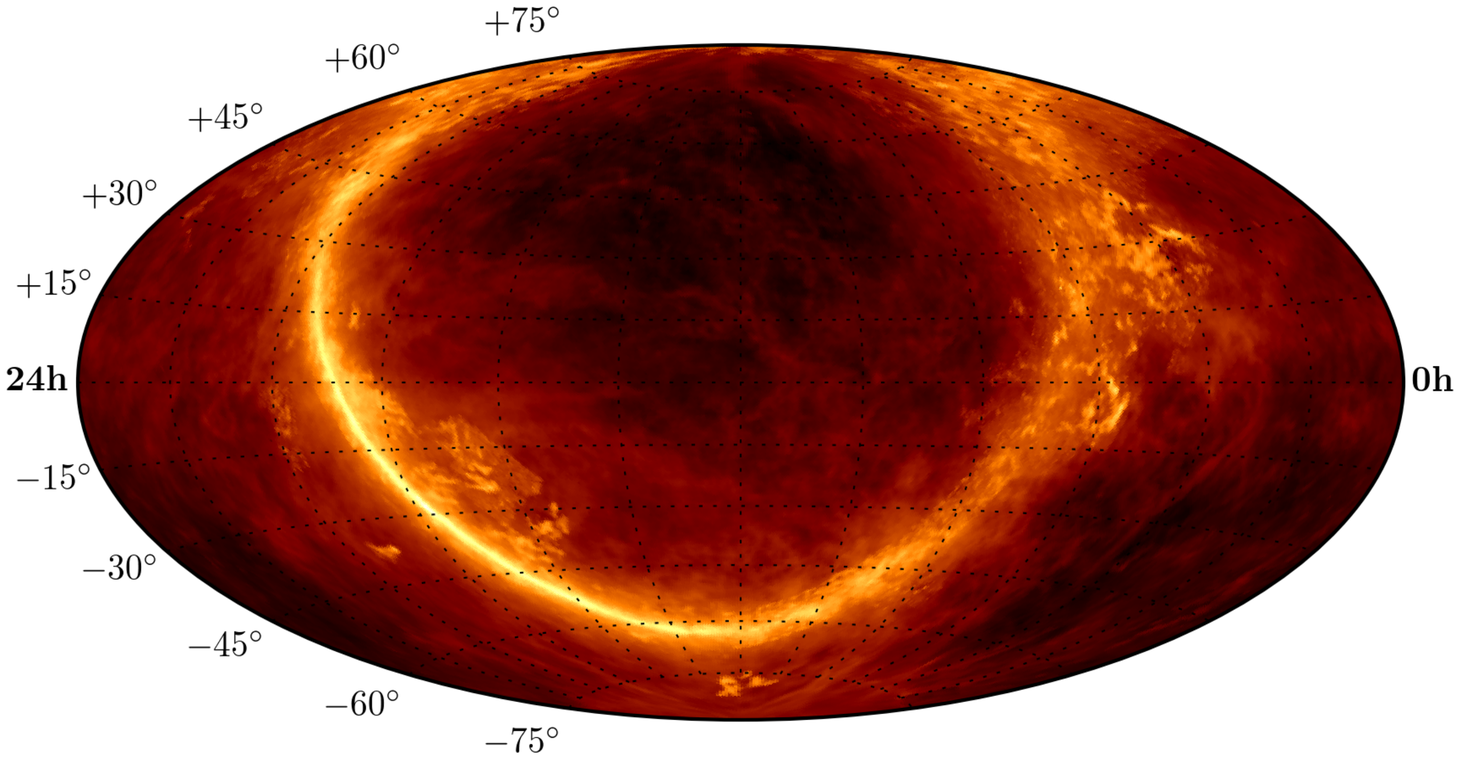
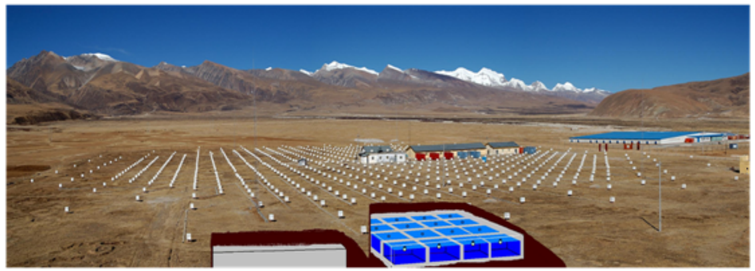


PEV COSMIC RAY PROPERTIES FROM TIBET AND LHAASO

D. Grasso (INFN, Pisa) with
P. De la Torre Luque, D. Gaggero, O. Fornieri, K. Egberts, C. Steppa and C. Evoli

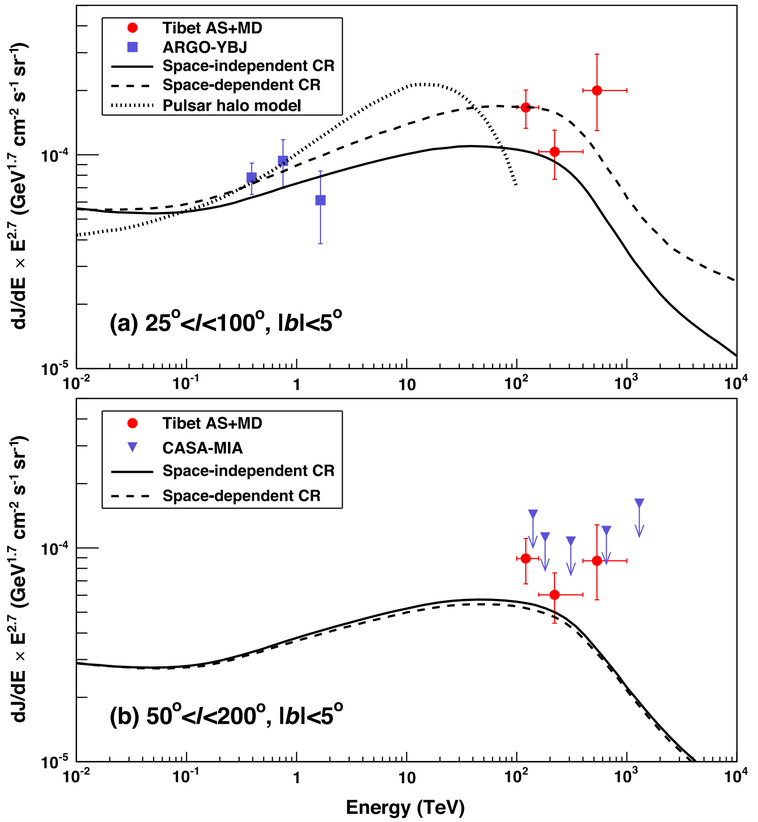
ECRS - Nijmegen 2022

TIBET ASγ RESULTS



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

Tibet ASγ coll., PRL 2021



- First detection of the γ-ray diffuse emission from the Galactic plane above few hundred TeV. **5.9σ 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 ◦)

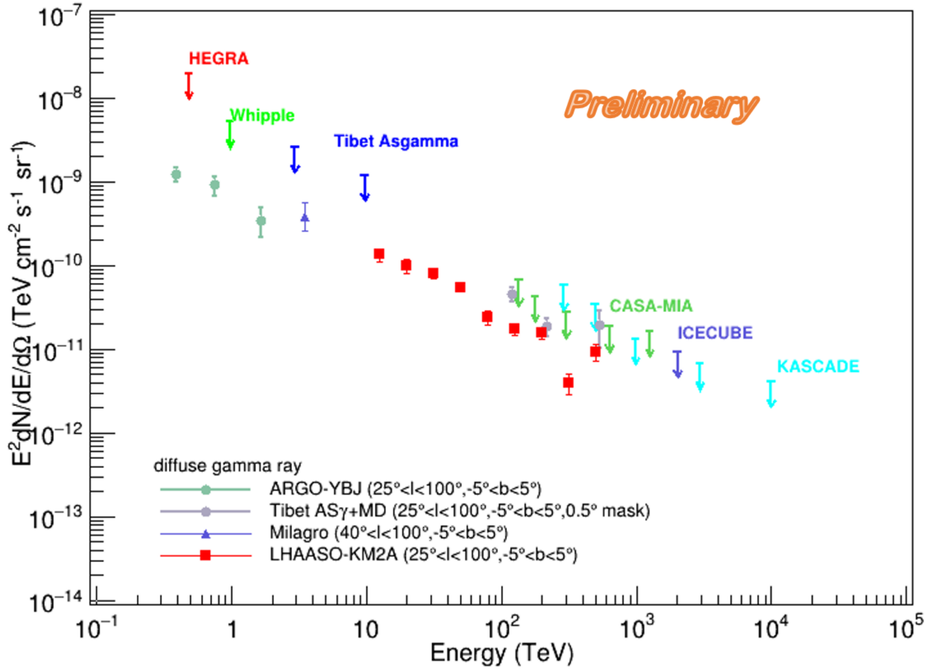
- It is claimed a good agreement with the predictions of a space dependent CR transport scenario (wait few slides)

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

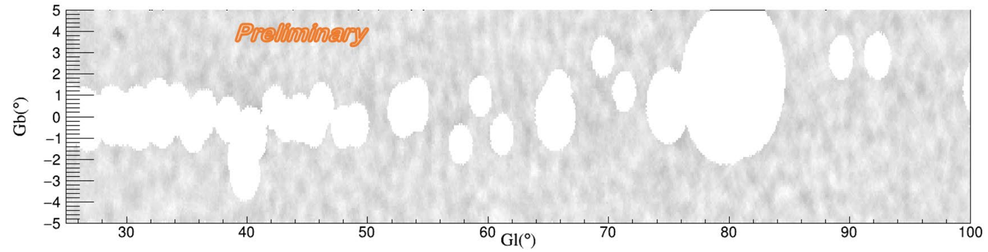
LHAASO (PRELIMINARY) RESULTS

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



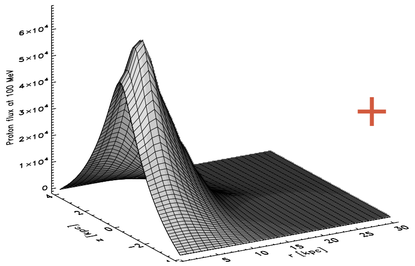
IS IT REALLY DIFFUSE ? IF POSITIVE WHAT WE MAY LEARN ?

- *Does this emission share the same nature of the Interstellar Diffuse Emission (IDE) measured by Fermi-LAT or it is originated by unresolved sources popping out at large energy?*
- *Is the spectral shape and normalization of the primary CR population compatible with the local one ? Under which conditions ?*
- *What is the CR spectrum and composition around the PeV ?*
- *The Galaxy is one of the few sources from which we may detect photon and neutrinos in the PeV range ! What we may learn from combined detection of gamma and neutrino galactic diffuse emissions ?*

MODELING THE INTERSTELLAR DIFFUSE EMISSION

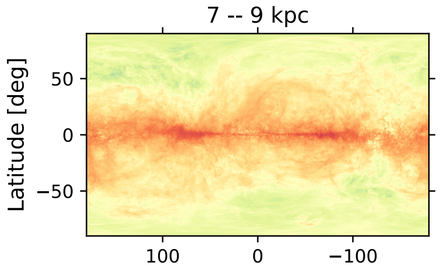
The conventional scenario

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



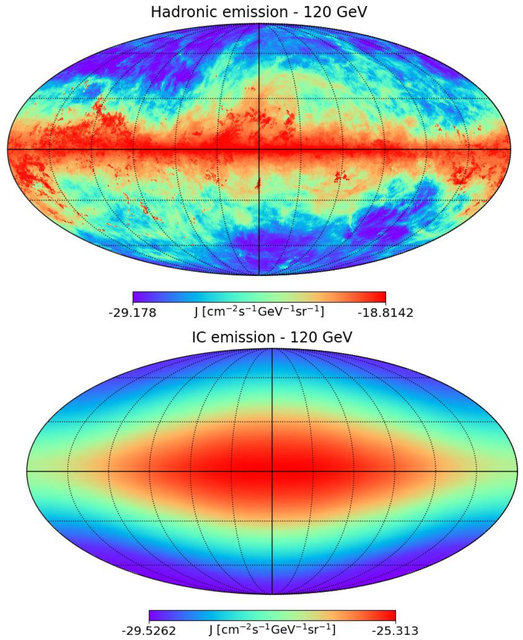
+

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



LOS integration

GALPROP/HERMES



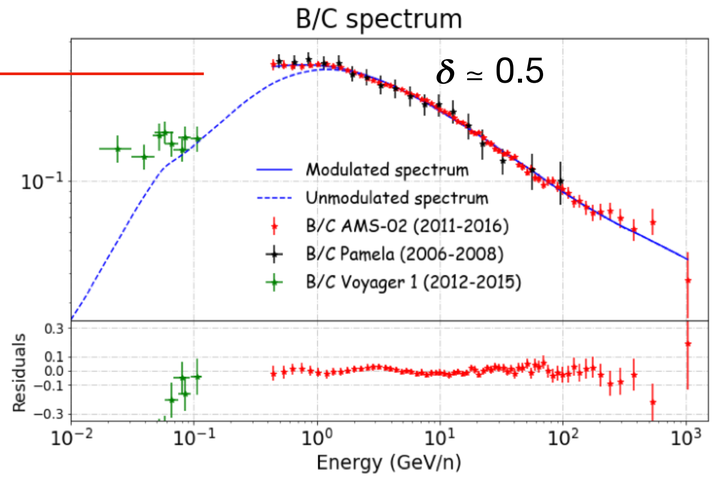
ρ : particle rigidity

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 $D(\rho, \mathbf{x}) \propto D_0\, \rho^{-\delta}$

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



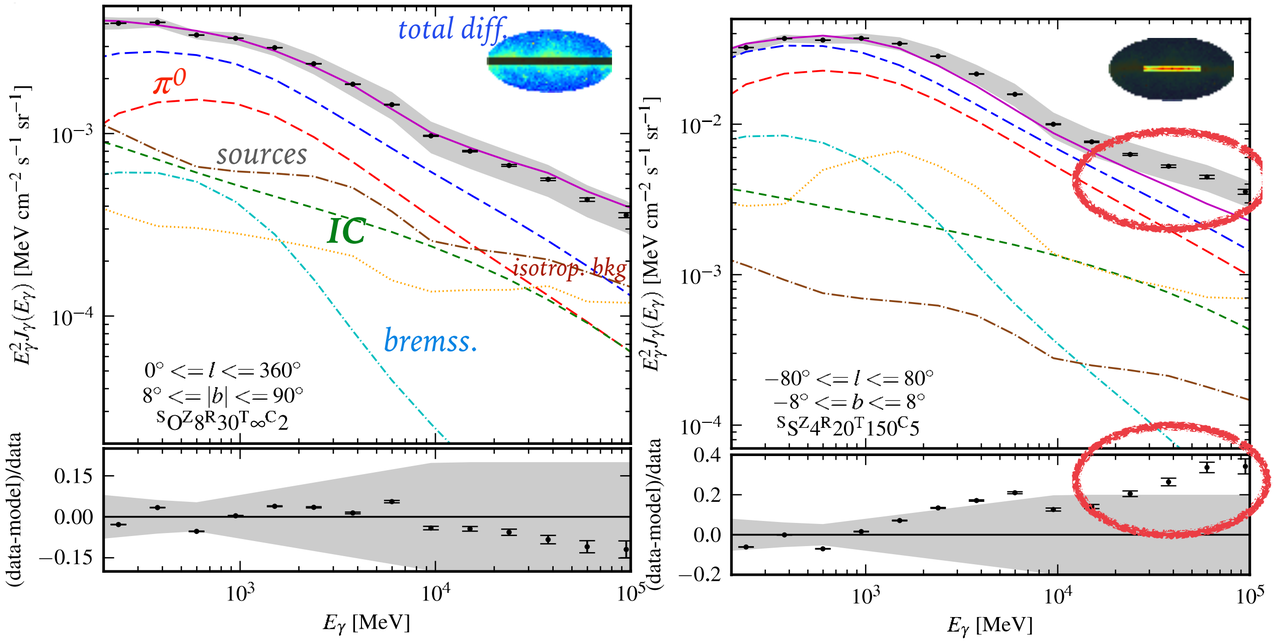
Factorized rigidity - position dependence

α and δ may however change with rigidity !

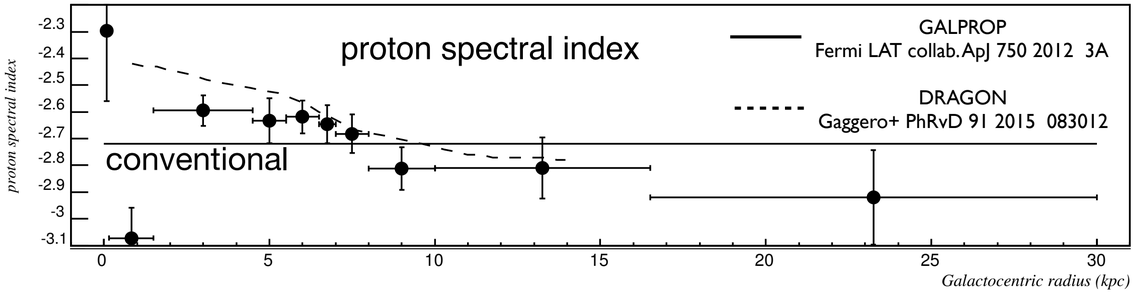
MODELING THE INTERSTELLAR DIFFUSE EMISSION

The conventional approach - issues

Fermi-LAT coll. 2012



Fermi-LAT coll. 2016



Moreover

THERE ARE NO THEORETICAL REASONS TO EXPECT SPACE INDEPENDENT CR TRANSPORT !

MODELING THE INTERSTELLAR DIFFUSE EMISSION

The "gamma optimized" scenario

Schematically, for CR nuclei

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

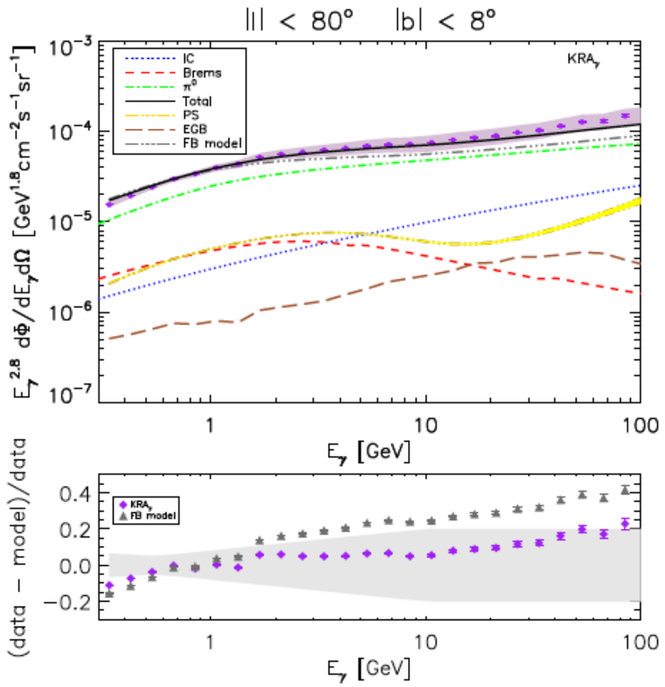
for **not** uniform diffusion coefficient $D(\rho, \mathbf{x}) \propto D_0\, \rho^{-\delta(\mathbf{x})}$

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

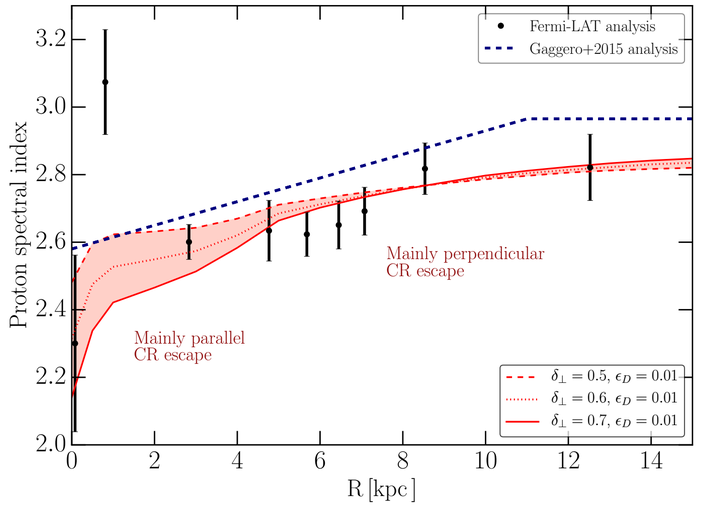
Unfactorized rigidity-position dependence

Gaggero, Urbano, Valli & Ullio, PRD 2015

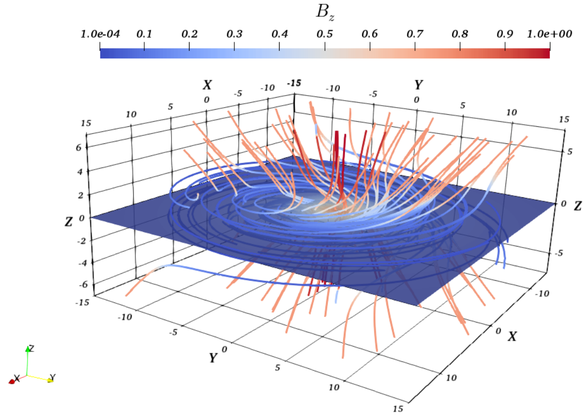
$\delta(R) = A\,R + B$ for $r < 11$ kpc



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

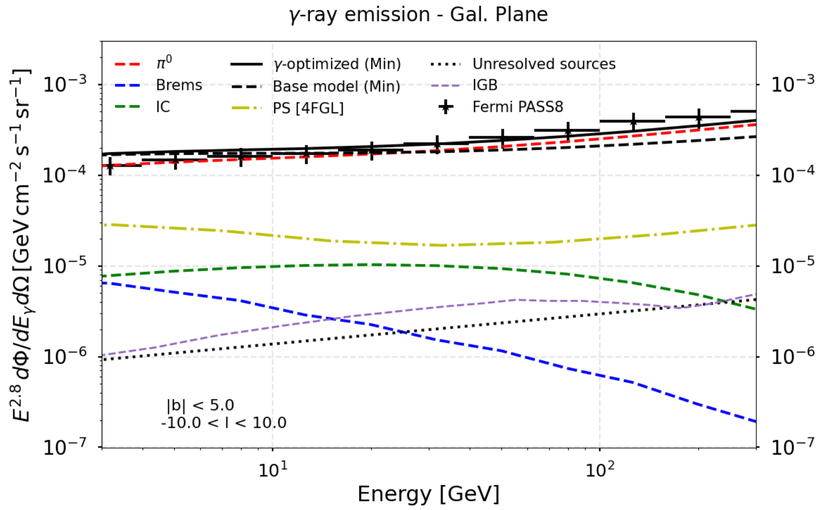
$$D_{\parallel} \propto \rho^{1/3} \quad D_{\perp} \propto \rho^{1/2}$$

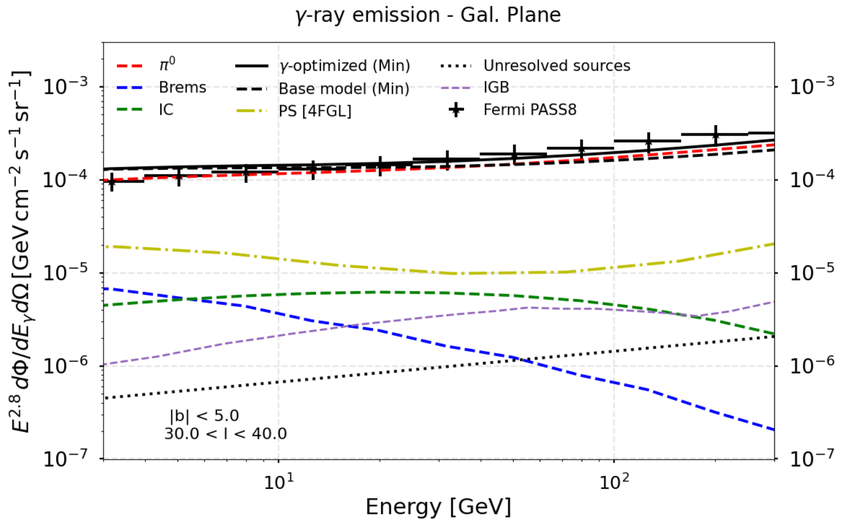
➜ CR spectrum becomes harder for R ➜ 0 . The effect holds at large energies

MODELING THE INTERSTELLAR DIFFUSE EMISSION

Updated models against Fermi-LAT

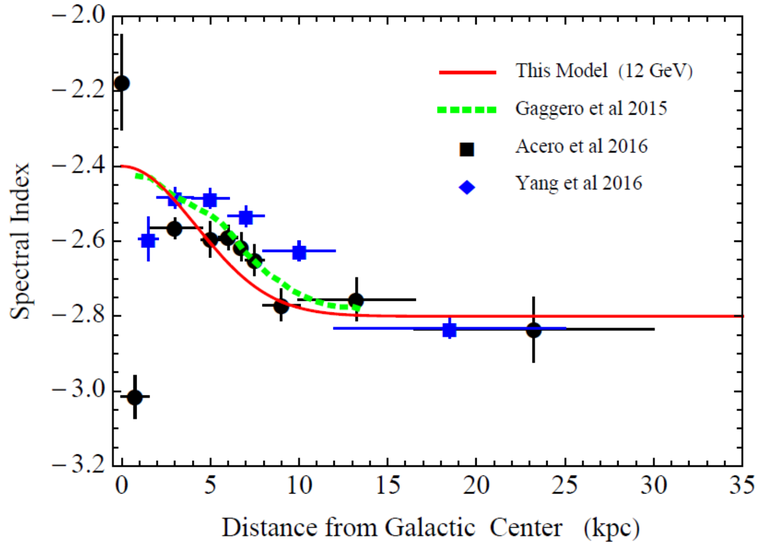
P. De La Torre Luque, D. Gaggero, DG, O. Fornieri, K. Hegberts, C. Steppa, C. Evoli, 2203.15759





The model adopt 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 →

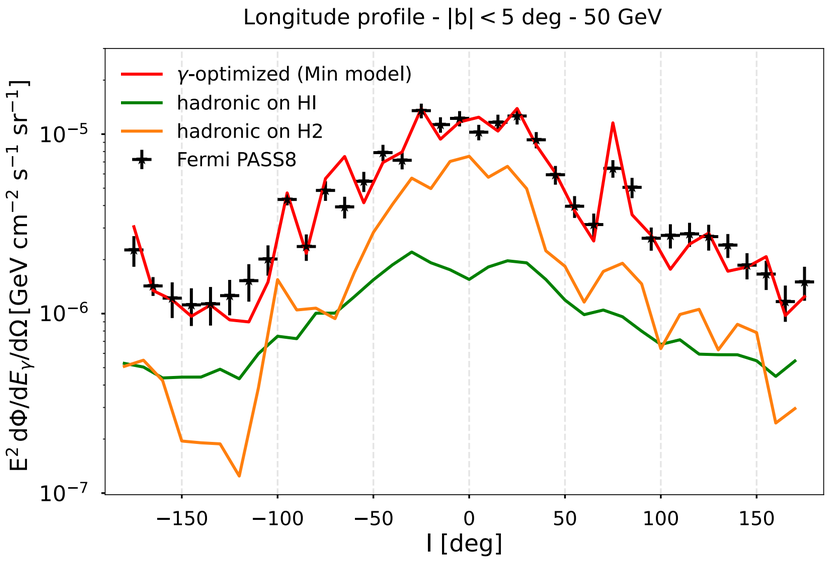


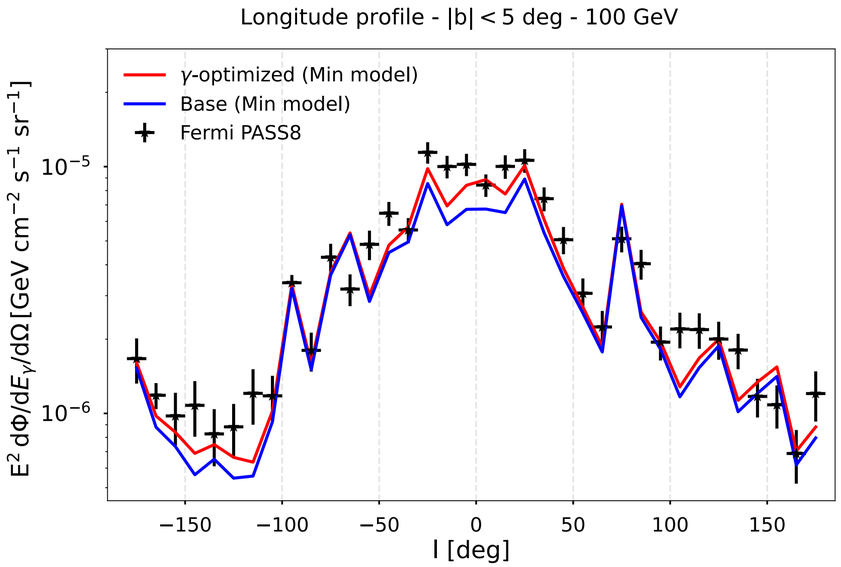
The unresolved source model is based on the H.E.S.S. galactic plane survey
Steppa & Egberts A&A 2022
less than 1% in the Fermi range

MODELING THE INTERSTELLAR DIFFUSE EMISSION

Updated models against Fermi-LAT

P. De La Torre Luque at al., in progress



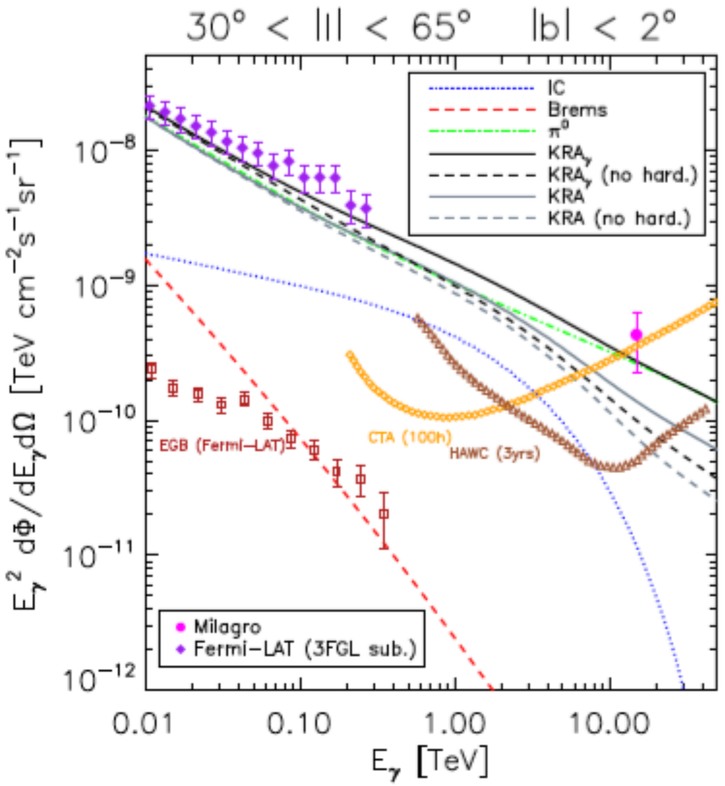


https://github.com/cosmicrays/hermes

MODELING THE INTERSTELLAR DIFFUSE EMISSION

Towards the PeV

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



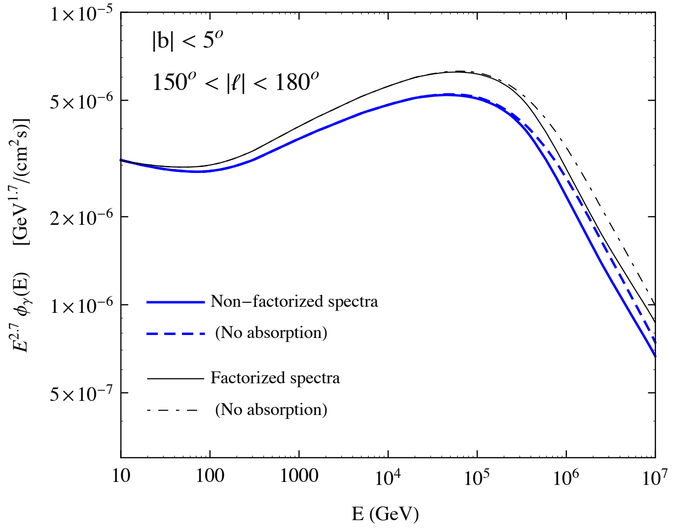
As pointed out in both papers

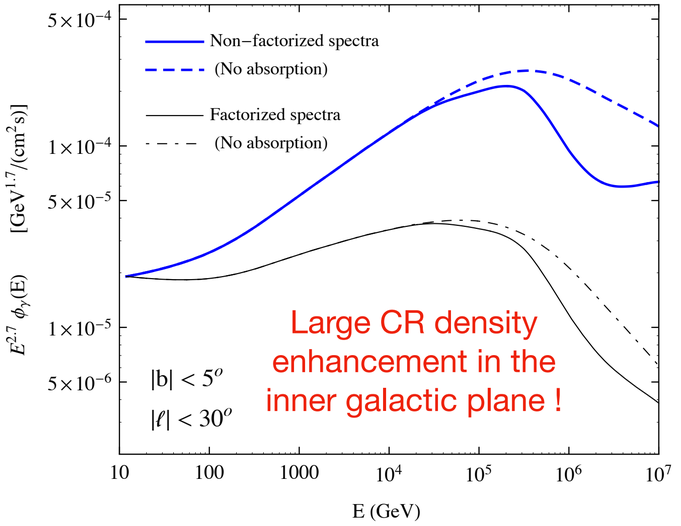
Relevant implications for neutrino astronomy too !

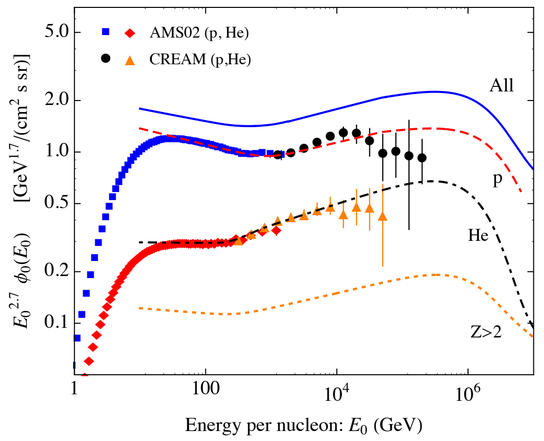
wait few slides

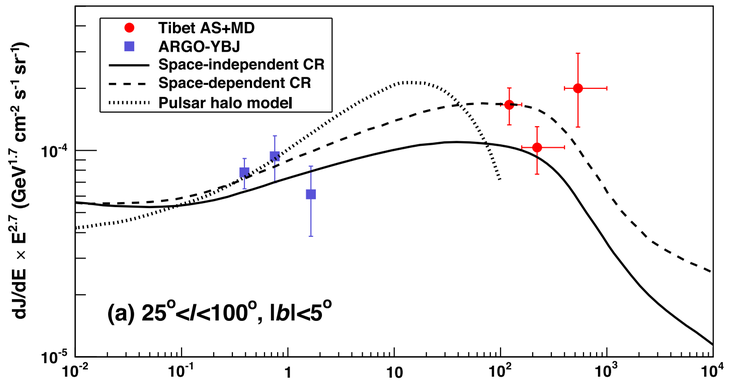
An analytical implementation

Lipari & Vernetto, 2018



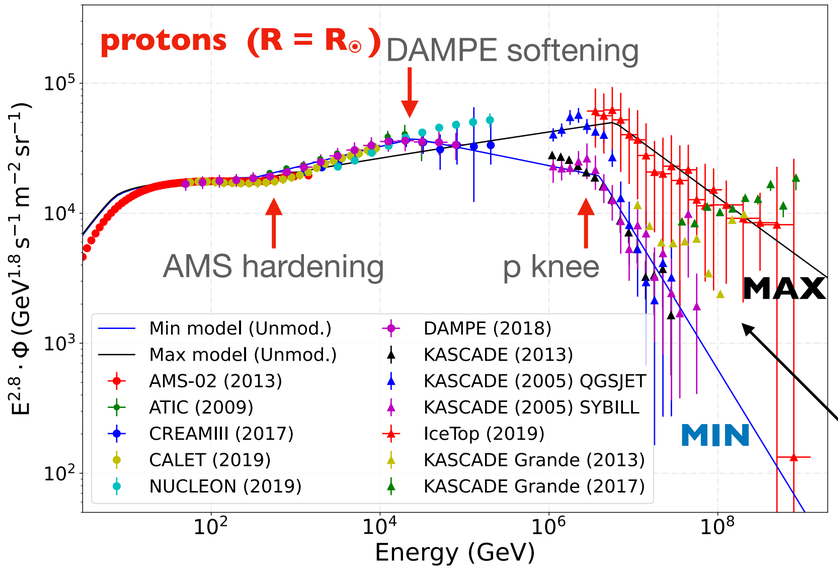


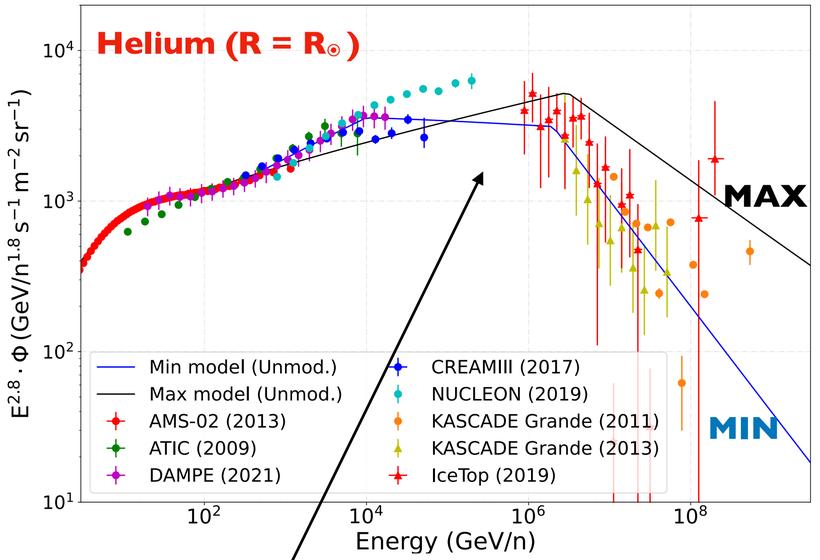


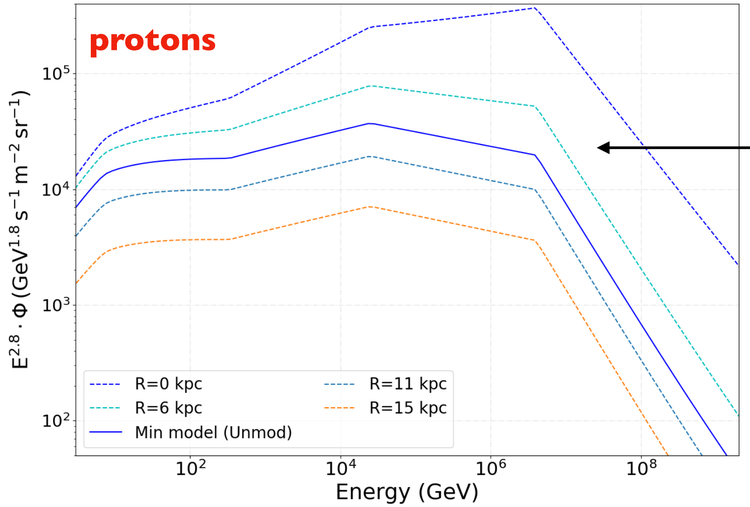


WHICH PRIMARY CR SPECTRUM/COMPOSITION ABOVE 100 TEV ?

P. De La Torre Luque at al., 2203.15759







Lines represent local propagated spectra for both scenarios.

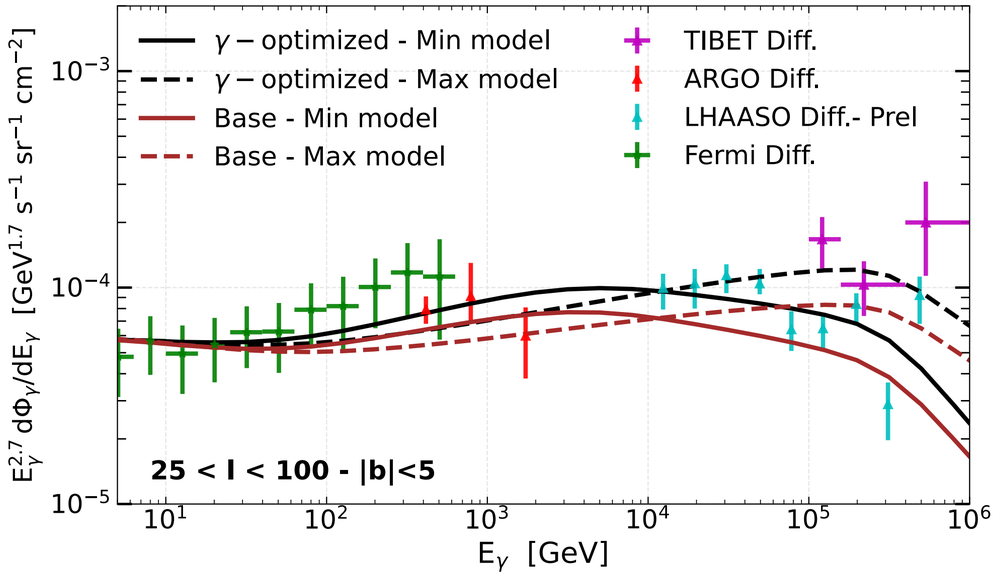
Propagated spectra at several galactocentric radii for the γ-optimized scenario

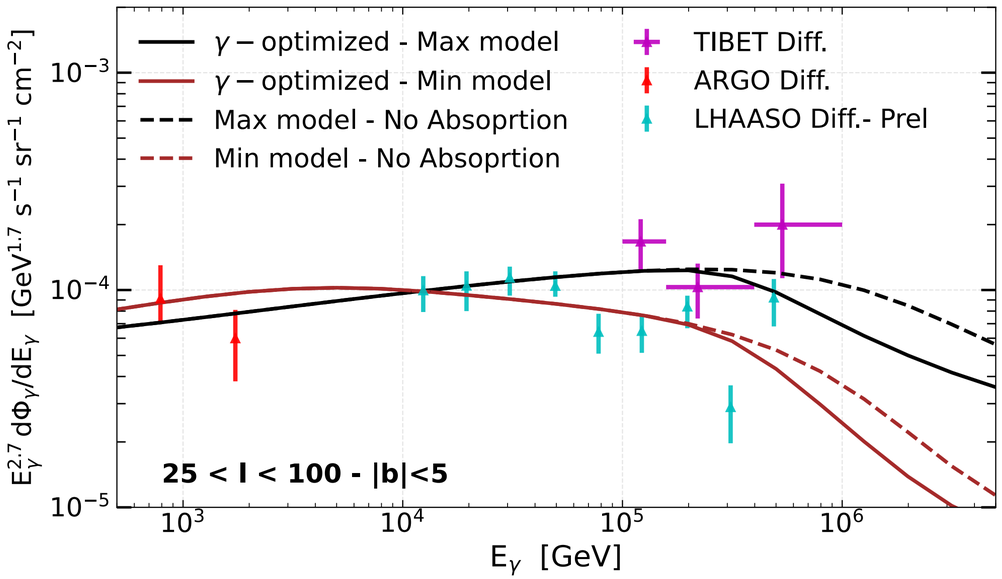
The source spectra is assumed to be the same in the whole Galaxy

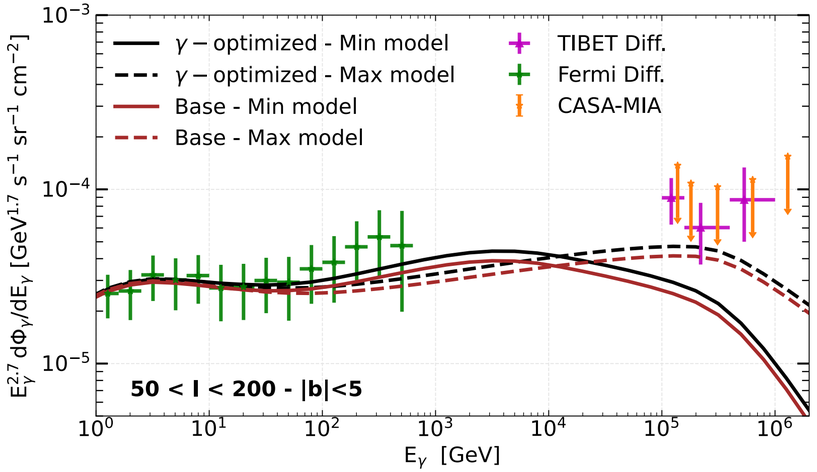
NEW RESULTS

Against Tibet and LHAASO

P. De La Torre Luque at al., 2203.15759





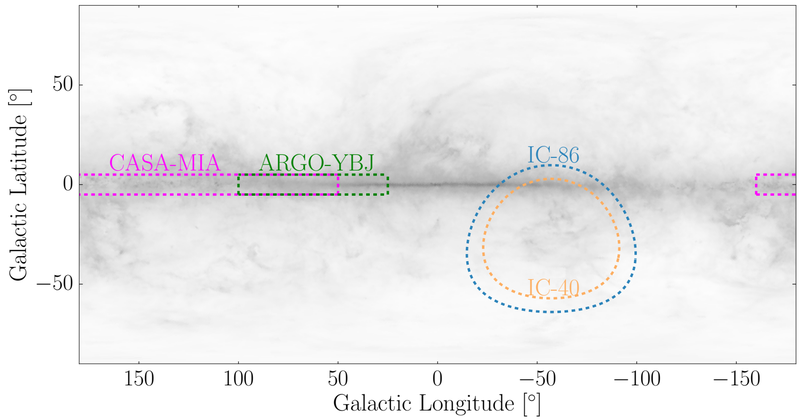


- Strong degeneracy between the CR transport scenario and the source spectral shape though LHASSO + ARGO + Fermi seems to favor the γ-optimized scenario
- γ-ray opacity due to γ-γ_{CMB} significant only for E > 100 TeV . ISRF almost irrelevant
- At large longitudes the observed spectrum is expected to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

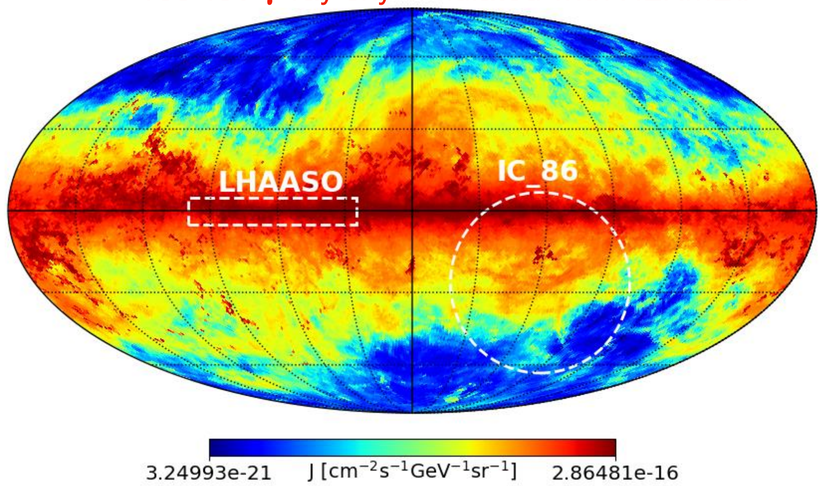
NEW RESULTS

Against IceTop

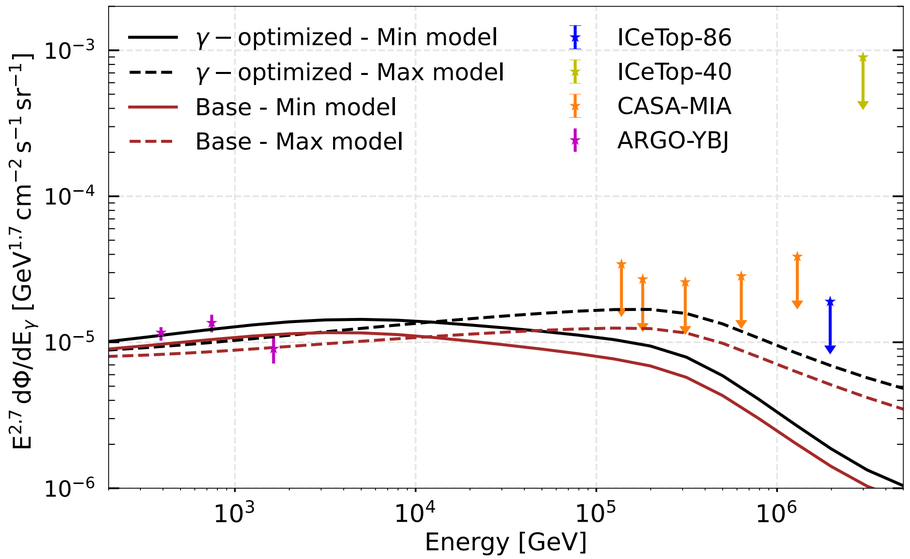
IceCube coll., Astrophys.J. 891 (2019) 9



100 TeV γ-ray sky simulated with HERMES



https://github.com/cosmicrays/hermes



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

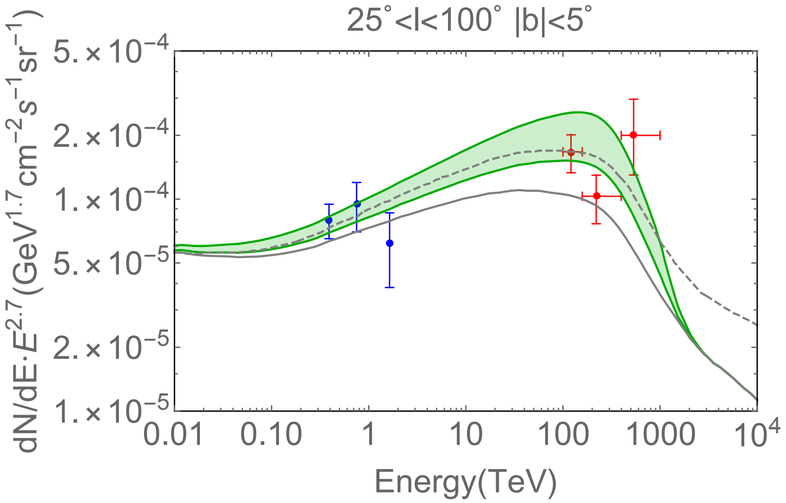
A LARGER CONTRIBUTION OF UNRESOLVED SOURCES ?

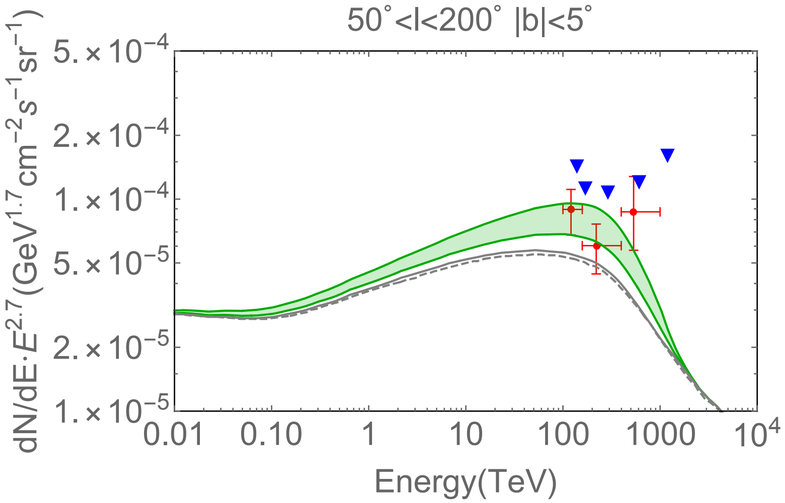
Vecchiotti et al., 2107.14584

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

Those models assume leptonic sources (PWNe, TeV halos)

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

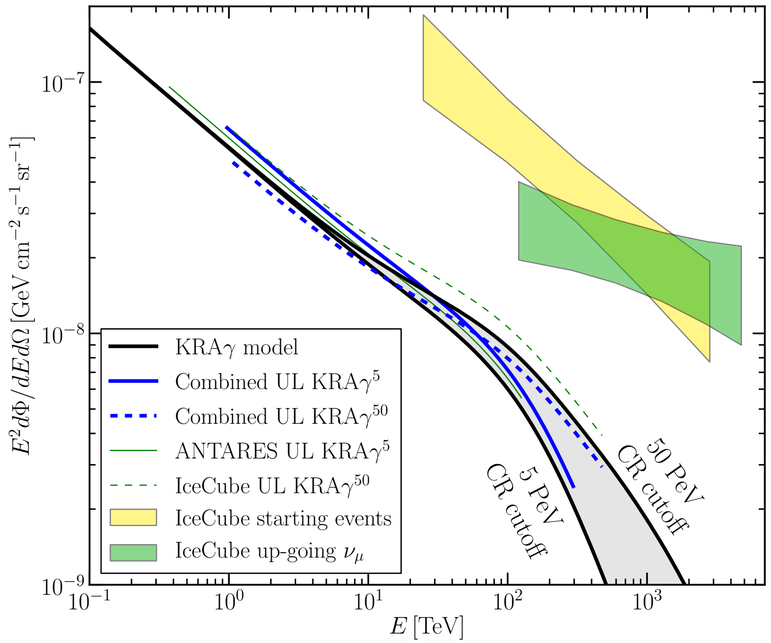




THE MILKY-WAY SHINING NEUTRINOS

IceCube coll. ApJ 849 (2017) 67

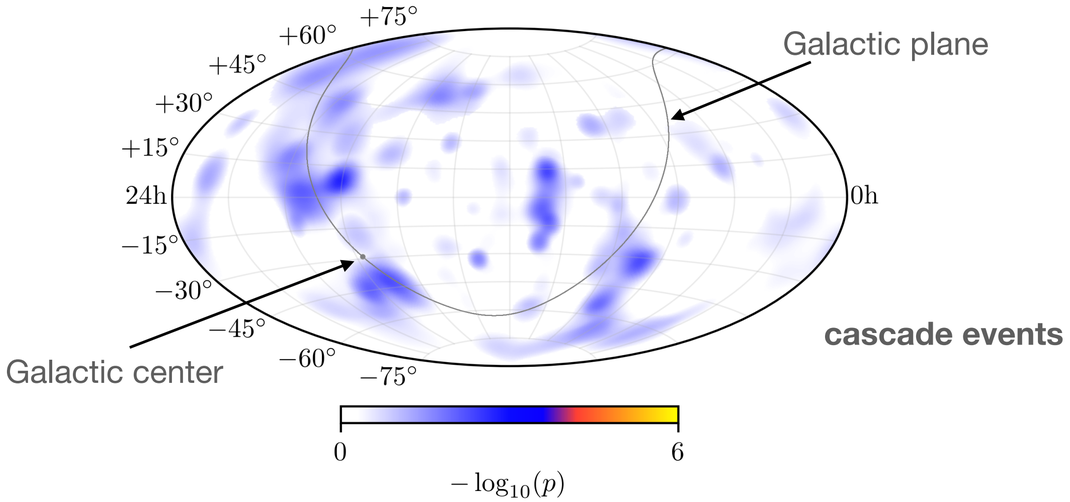
IceCube & ANTARES coll. ApJ L 868 (2018) 67



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

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

IceCube coll. ApJ 886 (2019) 12



In this paper a 2.0σ excess compatible with the 0.85 x KRA$_\gamma^5$ model (similar to the γ-optimized - MIN) 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

CONCLUSIONS

- Tibet ASγ and LHAASO (if confirmed) provide the first evidence of γ-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