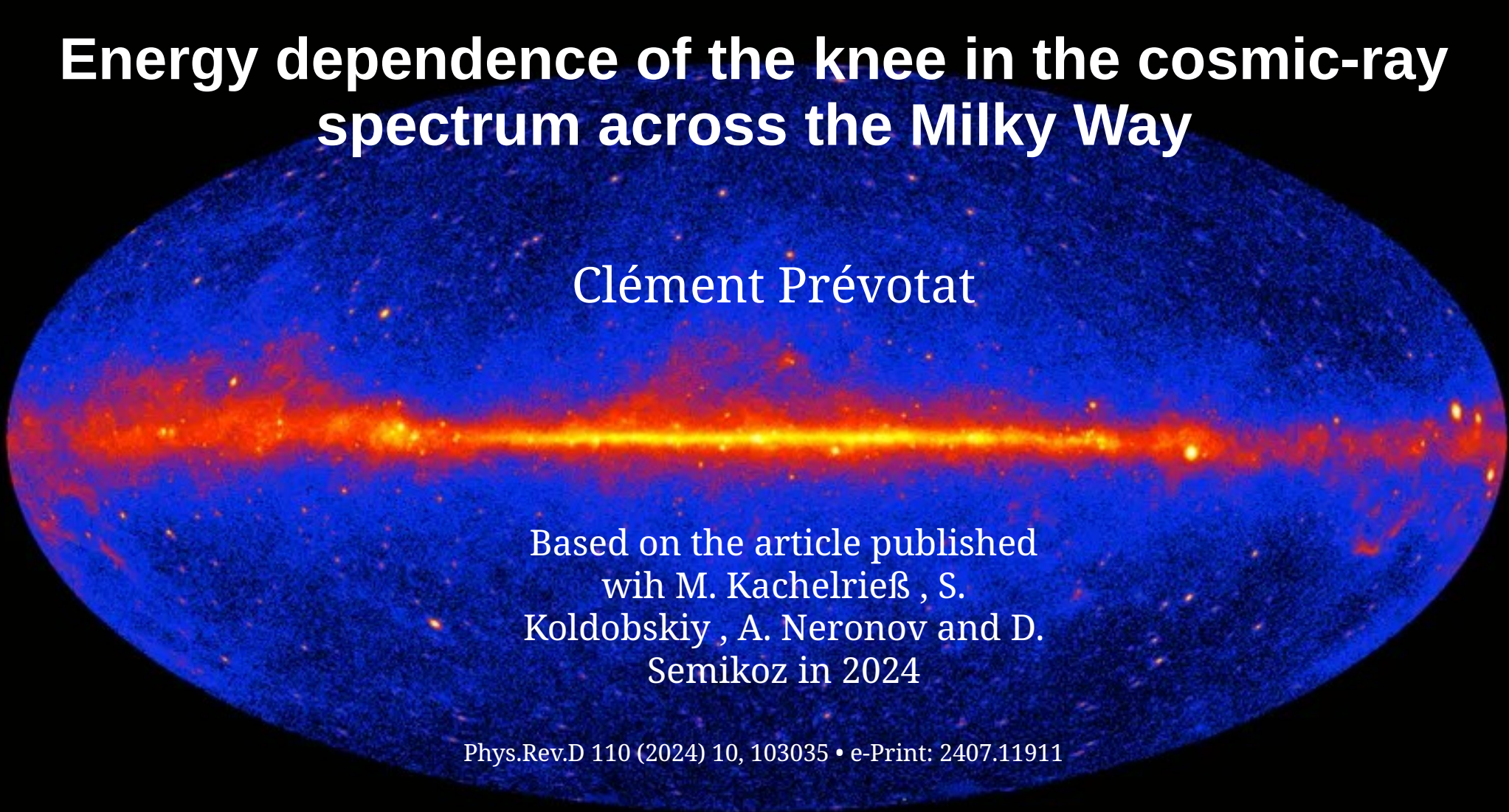
Energy dependence of the knee in the cosmic-ray spectrum across the Milky Way



Clément Prévotat

Based on the article published wih M. Kachelrieß , S. Koldobskiy , A. Neronov and D. Semikoz in 2024

Phys.Rev.D 110 (2024) 10, 103035 • e-Print: 2407.11911

The CR spectrum

- The « knee » : change of slope around 4 PeV

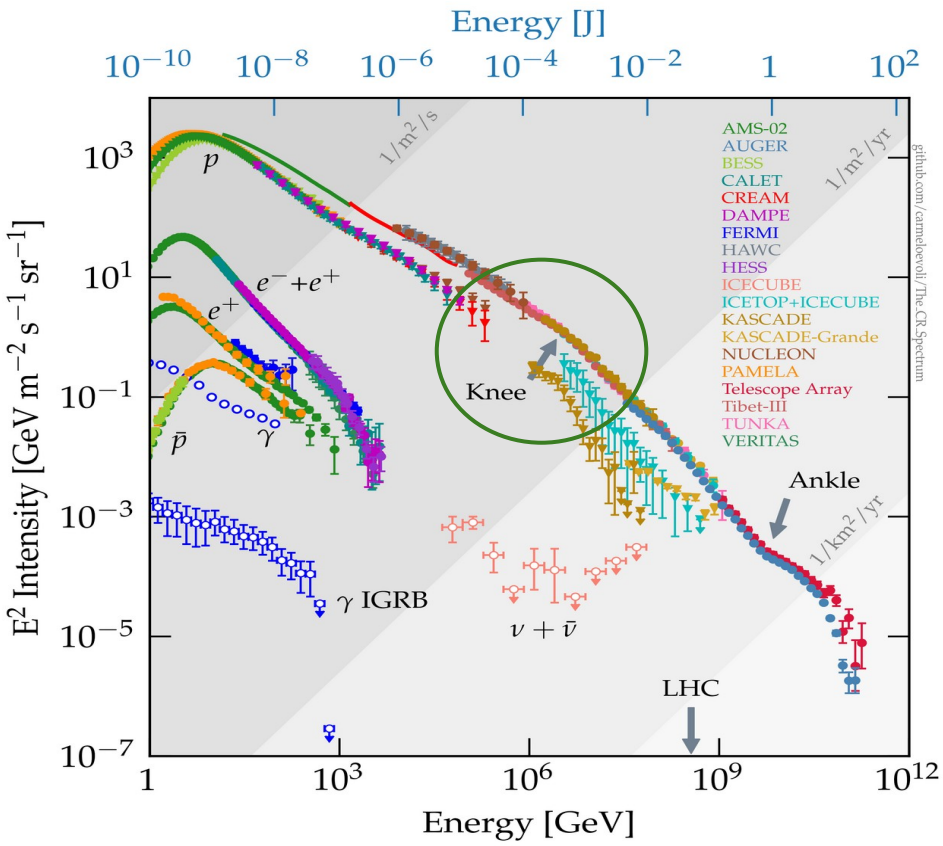
  - Change of diffusion regime ?

  - Acceleration limit ?

  - Dominated by local source(s) ?

➡ Gamma-rays : probe the CR spectrum in different regions of the Galaxy

➡ Probe the knee in other regions



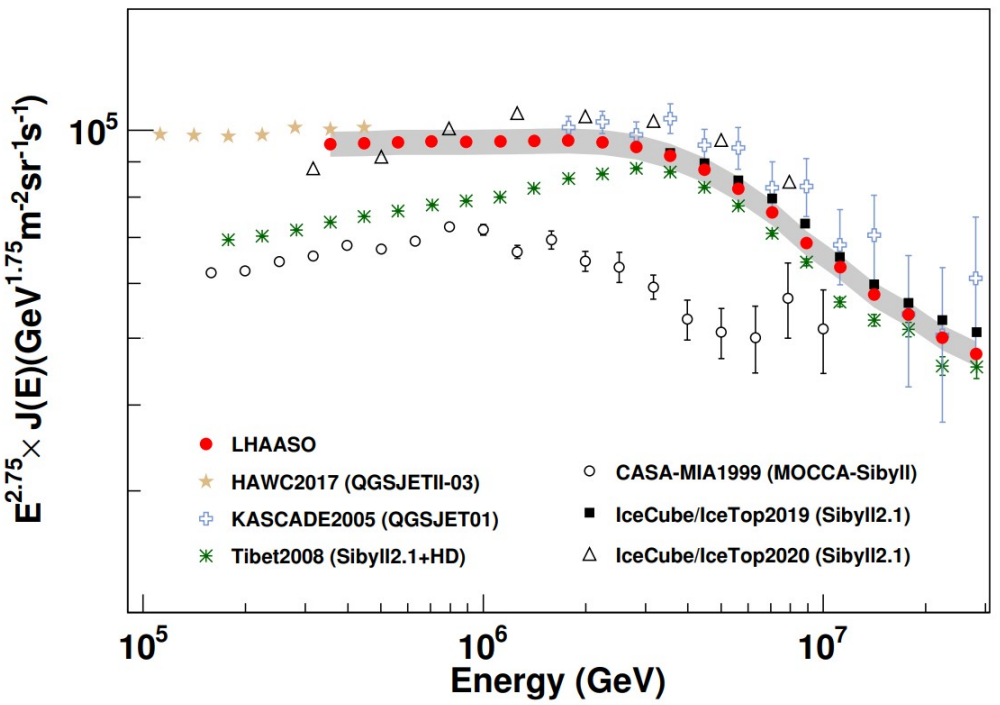
C. Evoli, 2023

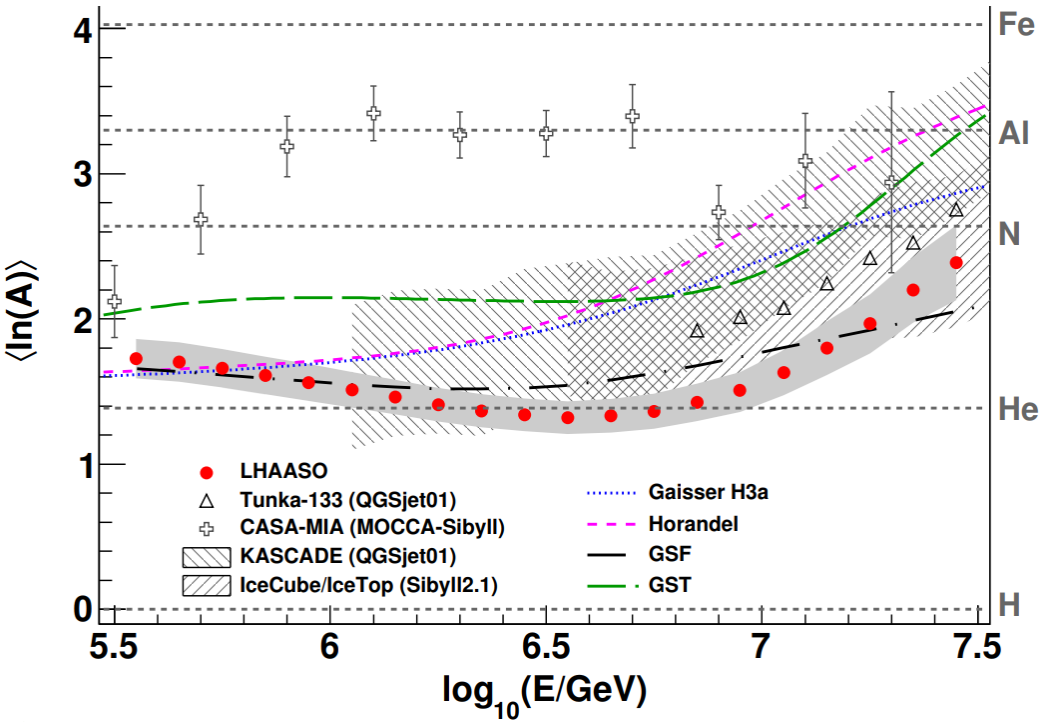
LHAASO data

All particles spectrum

A : mass of the CR

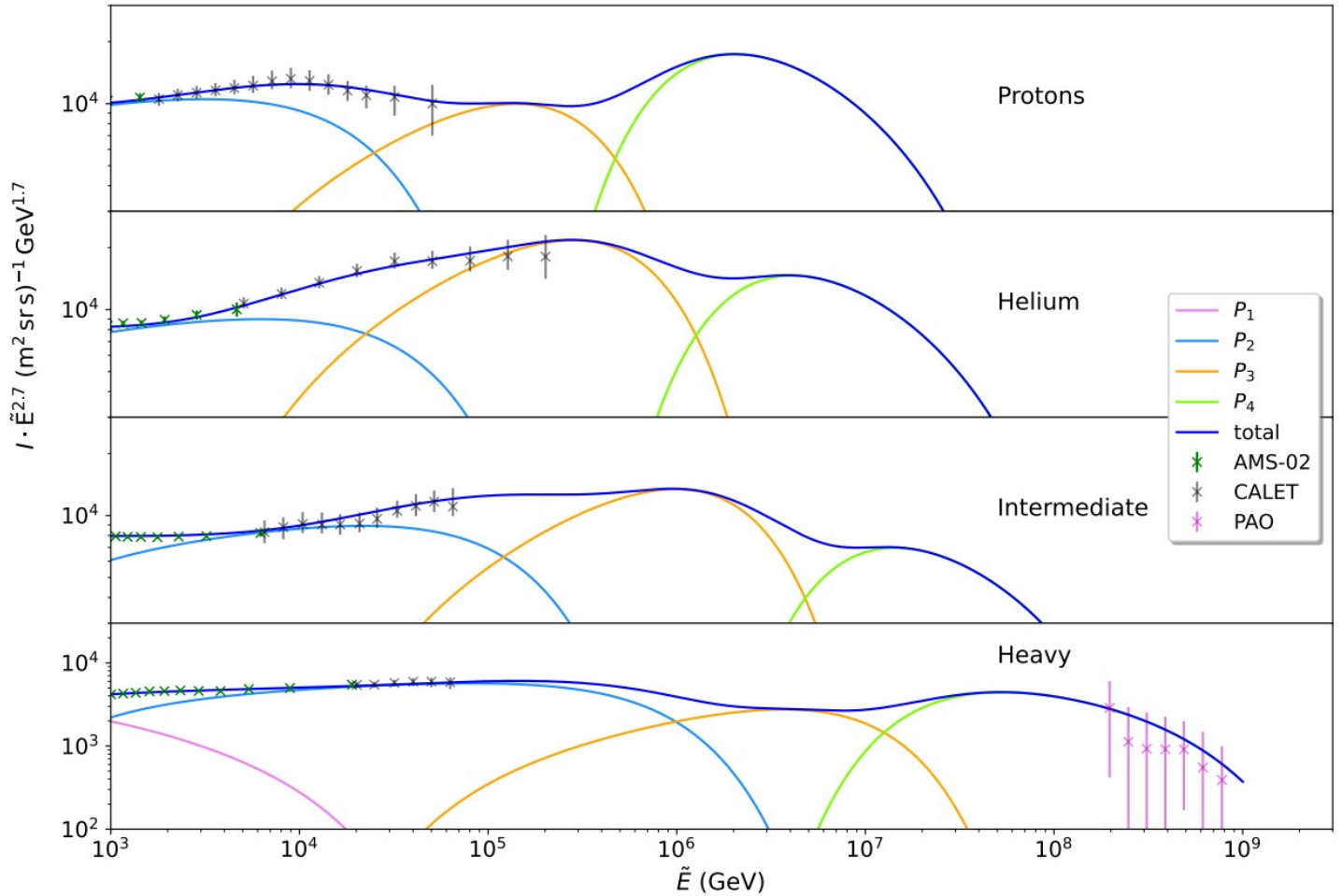
LHAASO collaboration, 2024





Lighter than previous measurements

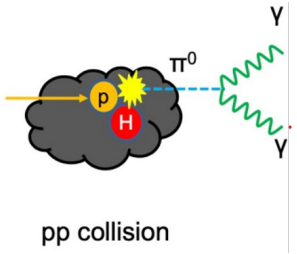
Fitted CR spectra



- Power laws with exponential cut-offs

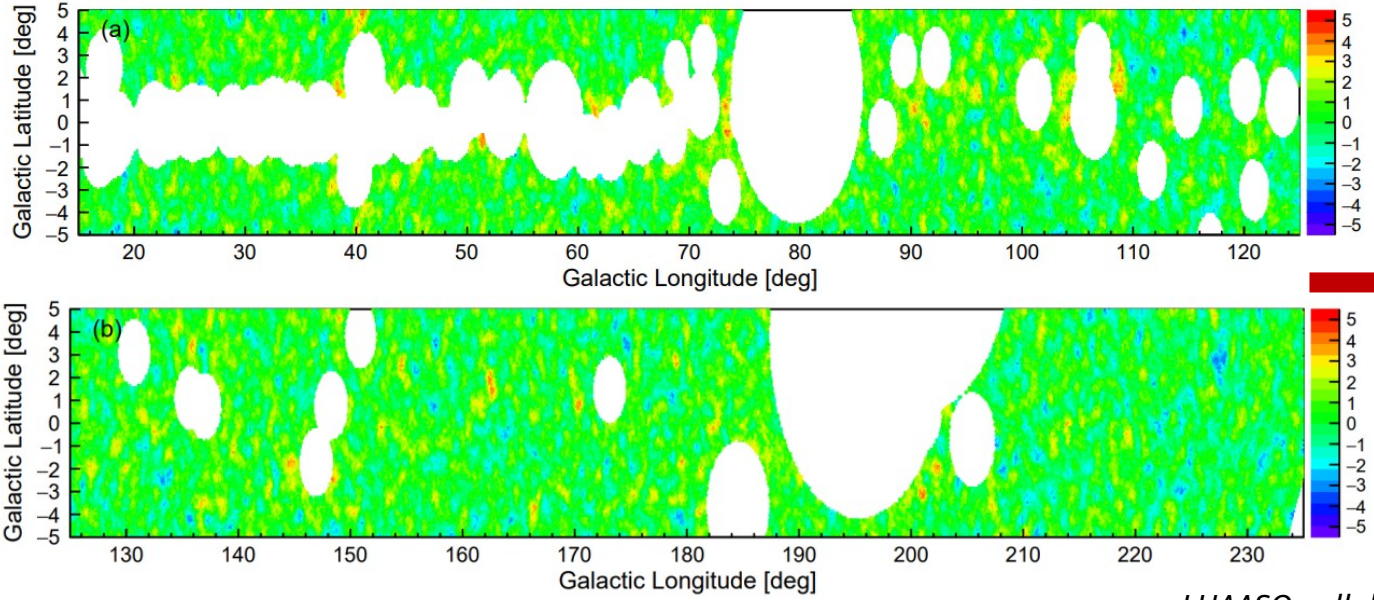
- Peter's cycles : spectra are similar in rigidity

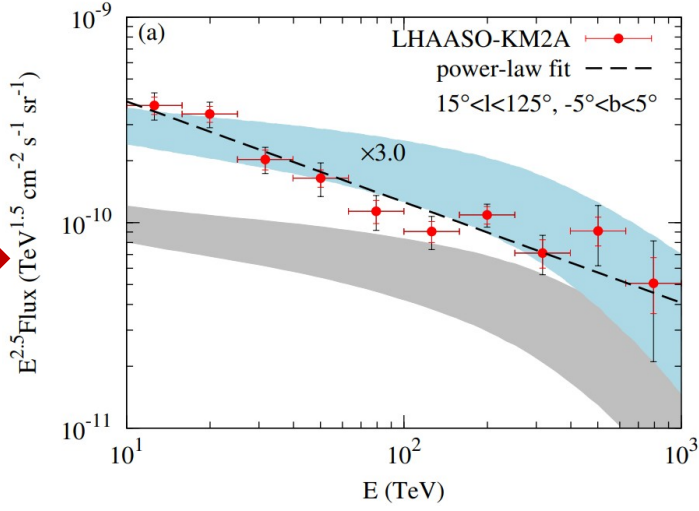
Diffuse gamma-ray background



$$A + A_{\text{target}} \rightarrow N(\pi^0 + \pi^+ + \pi^-) + X$$

$$\pi^0 \rightarrow 2\gamma$$





LHAASO collaboration, 2023

Diffuse gamma-ray background

Fit to data

$$I_\gamma(E,l,b) = \sum_{A,A'} \int_0^\infty ds\, n^A_{\rm gas}(x)\, e^{-\tau(s)} \int_E^\infty dE' \frac{d\sigma^{A'A}(E',E)}{dE} I_{\rm CR}(E',l,b)$$

Sum over targets and projectiles

AAfrag

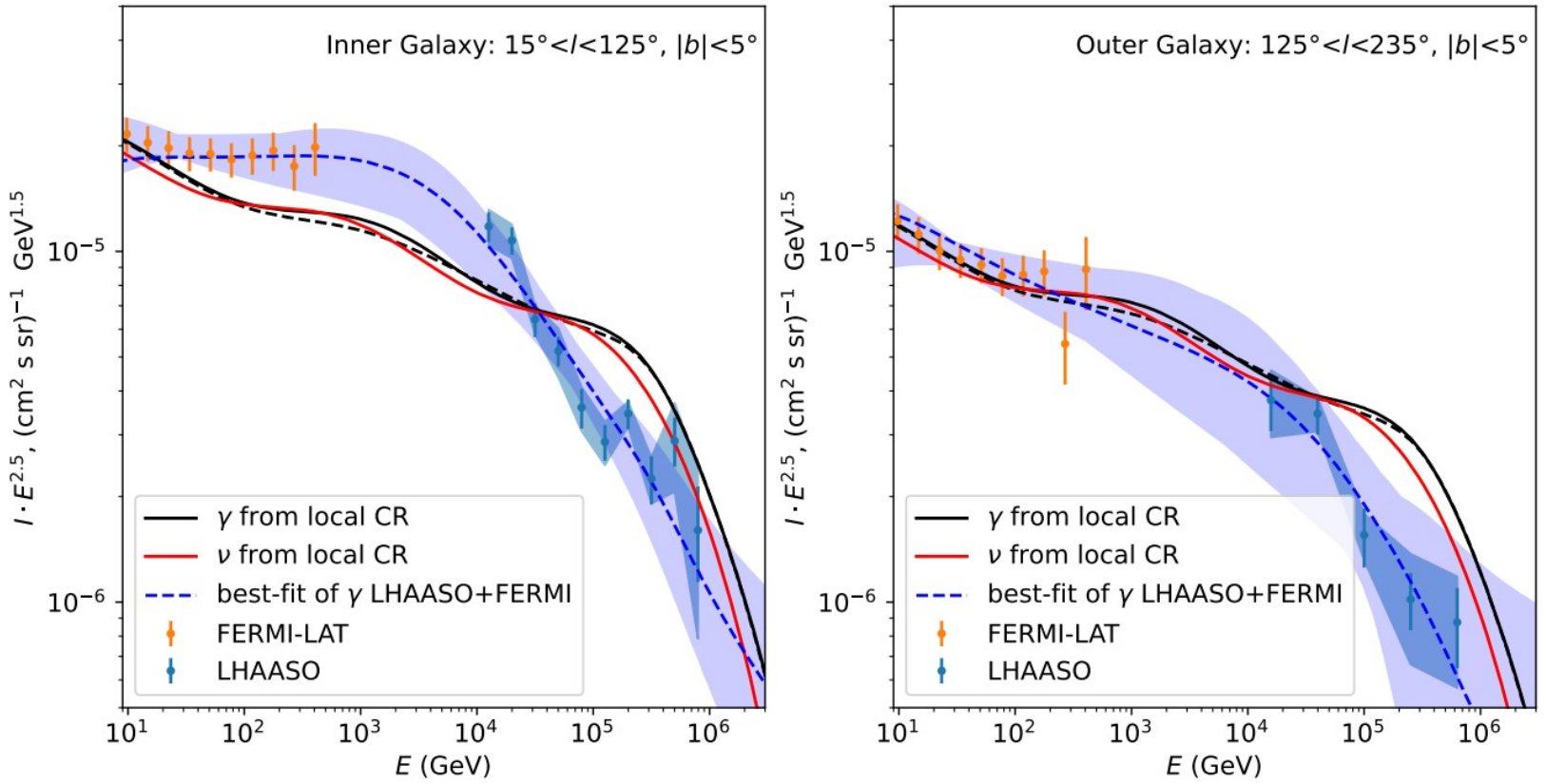
M.Kachelriess, I.V.Moskalenko, S.Ostapchenko, 2019

$$n^A_{\rm gas}(r,z) = n^A_0(r) \exp\left[-\frac{z^2}{2\sigma_z(r)}\right]$$

P. Lipari and S. Vernetto, 2018

Only considered pair creation with the CMB for absorption

Comparison with data



The knees do not correspond to the same energies : not universal !

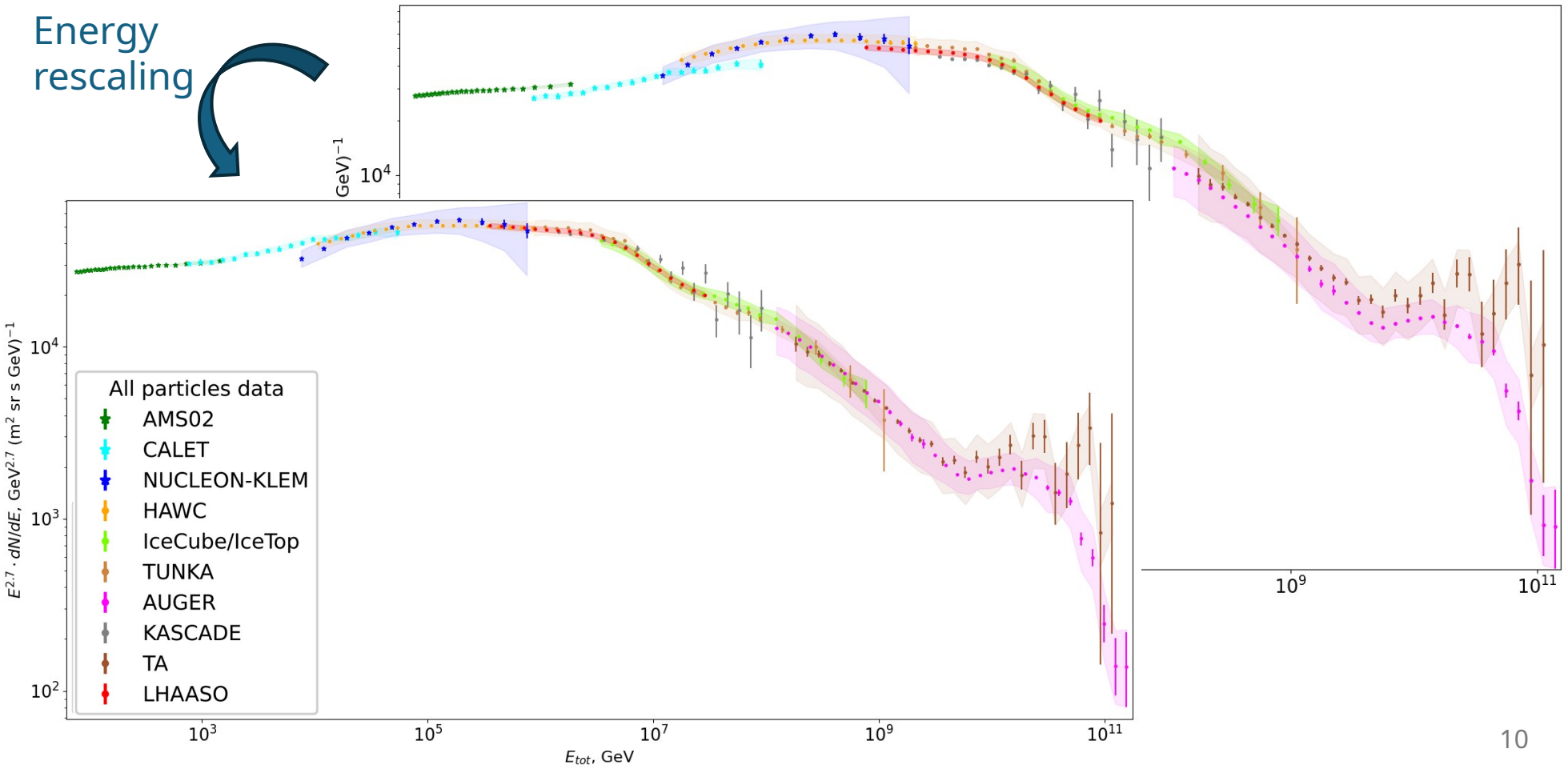
Thanks for your attention 

Acknowledgements

This work is supported by the Agence Nationale de la Recherche (ANR), project ANR-23-CPJ1-0103-01.

Intensities

Energy rescaling



Fit of the CR spectrum to the gamma data

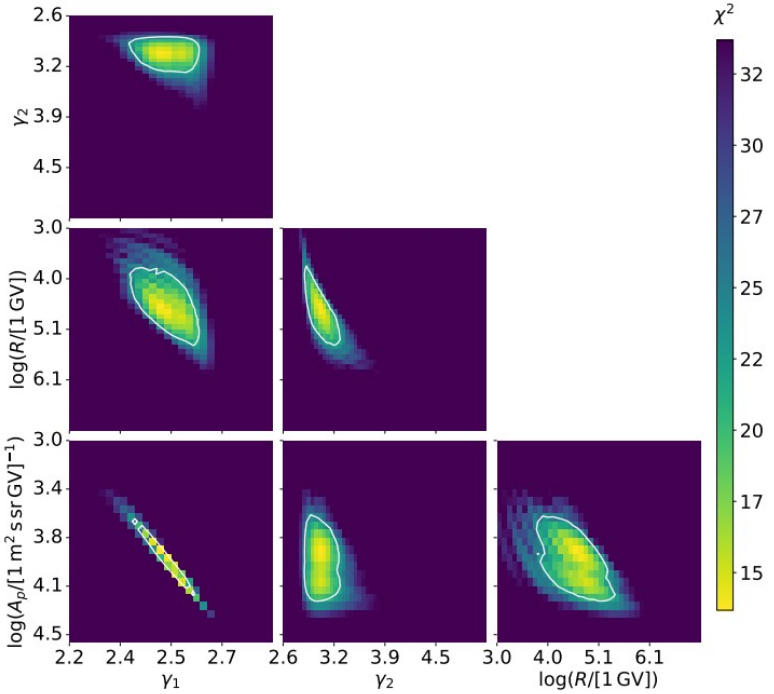
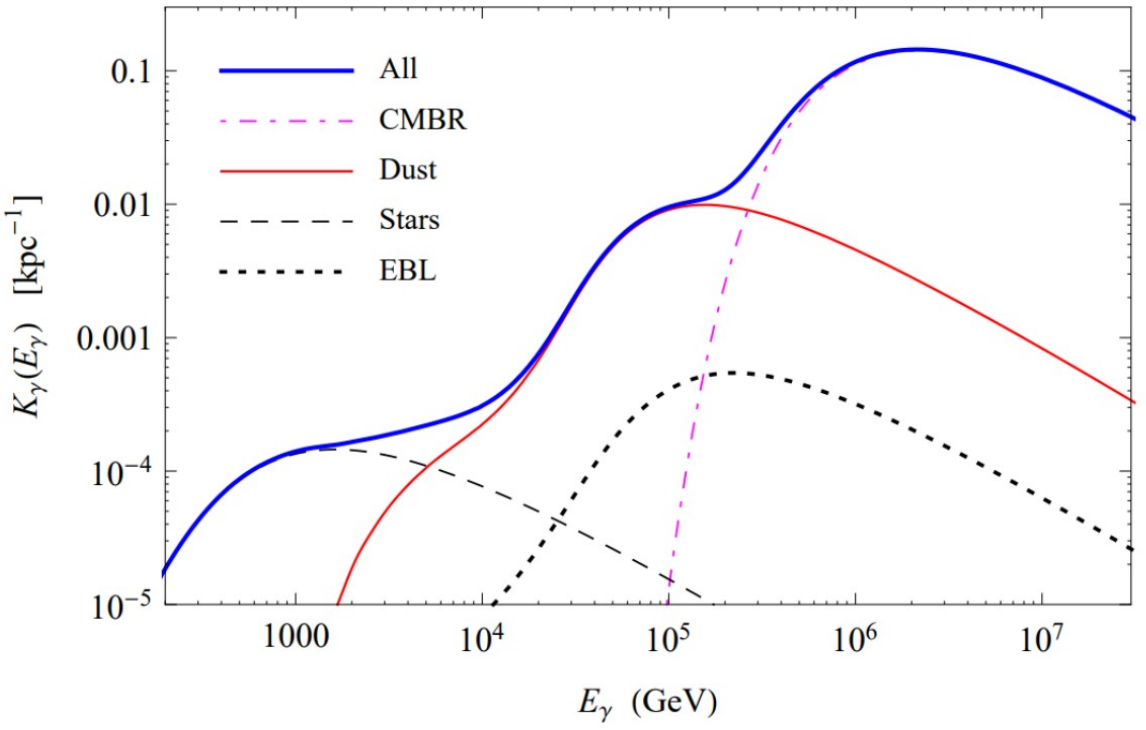


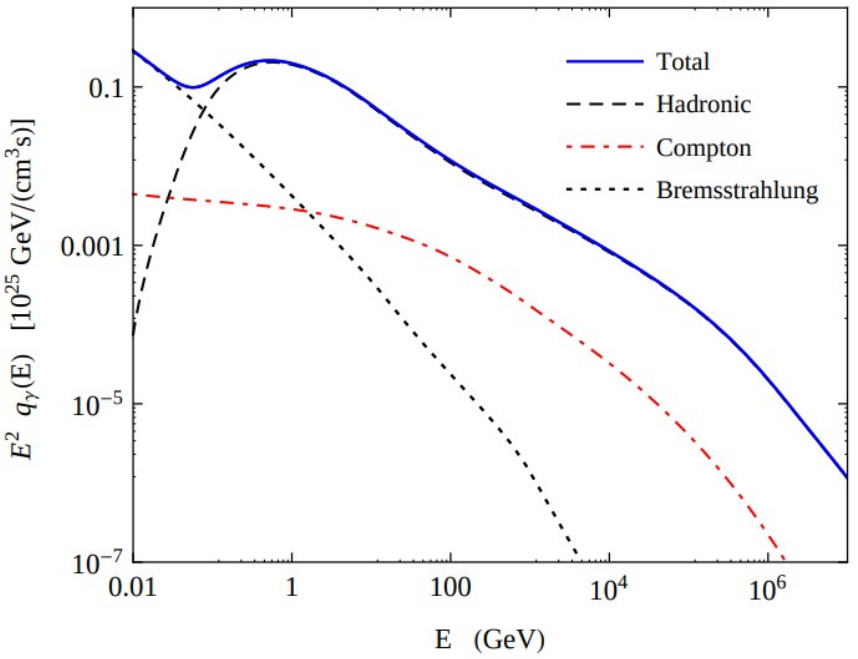
FIG. 4: Parameter space for the broken-power law fit of the combined LHAASO+Fermi-LAT data for the inner Galaxy region; white contours denote the 95% C.L.

Absorption of gamma-rays



P. Lipari and S. Vernetto, 2018

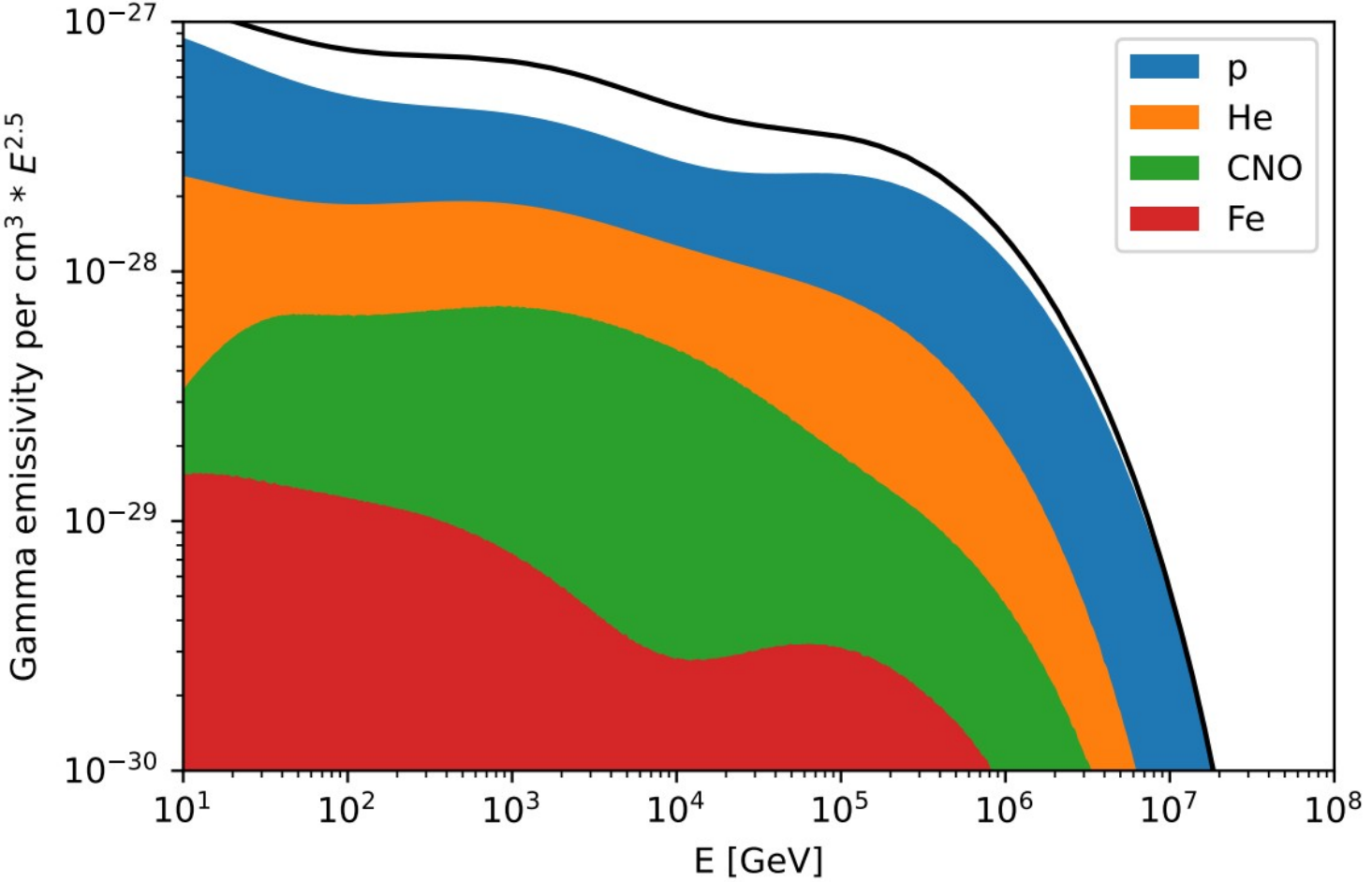
Hadronic VS Leptonic emission



P. Lipari and S. Vernetto, 2018

FIG. 4: Gamma ray emission rate in the solar neighborhood. The total emission and the single contributions of the three main mechanisms (hadronic, bremsstrahlung and Compton scattering) are shown. The assumed hydrogen density in the interstellar medium is $n = 1\ \mathrm{cm}^{-3}$.

Contribution of the different elemental groups



Diffuse gamma-ray background

$$I_\gamma(E,l,b) = \sum_{A,A'} \int_0^\infty ds\, n^A_{\rm gas}(x) e^{-\tau(s)} \int_E^\infty dE' \frac{d\sigma^{A'A}(E',E)}{dE} I_{\rm CR}(E',l,b)$$

Assuming a spectral shape independant of space for CRs :

$$I_{\rm CR}(\overrightarrow{x},E) = I_{\rm CR}(E) f(\overrightarrow{x})$$

$$f(r,z) = \frac{\cosh\left(\frac{r_\odot}{R_{CR}}\right)}{\cosh\left(\frac{r}{R_{CR}}\right)\cosh\left(\frac{z}{z_{CR}}\right)}$$