Karlsruhe Institute of Technology

# Evidence for an hadronic origin of the Fermi Bubbles, formed by outflows from star-forming regions

(Details in arXiv:1407.4114)

Wim de Boer, Iris Gebauer, Simon Kunz, Alexander Neumann, Karlsruhe Institute of Technology

Institut für Experimentelle Kernphysik

# What is different from other analysis?

- **Most analysis:** take **spatial** templates from Galprop and parametrize CR distribution to fit data. Fit in each energy bin to see missing contributions

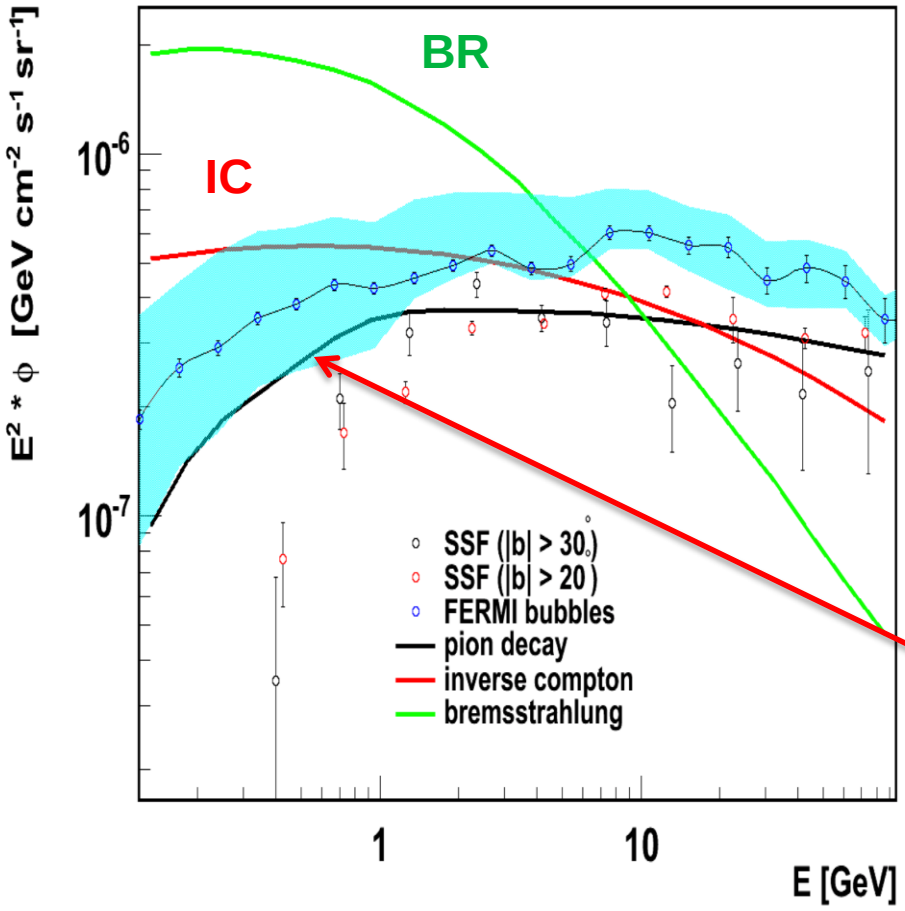
- **Here:** take **energy** templates and fit not each energy bin, but complete energy spectrum (21 data points with only few parameters):

$$|\text{total spectrum}\rangle = n_1|\pi^0\rangle + n_2|\text{BR}\rangle + n_3|\text{IC}\rangle + n_4|\text{Fermi Bubble}\rangle + n_5|\text{isotropic}\rangle$$

- Templates depend on CR spectrum of protons and electrons, which can be parametrized with power laws using local CR spectra as first estimate and optimize them for gamma-ray sky

- **Big ADVANTAGE**: **high spatial resolution**, because no spatially smoothed templates AND all components determined by fit, i.e. NO foreground subtraction. **DO NOT HAVE TO MASK THE GALACTIC PLANE.**

# Bubble template




SSF=Su, Slayter, Finkbeiner, arXiv:1005.5480

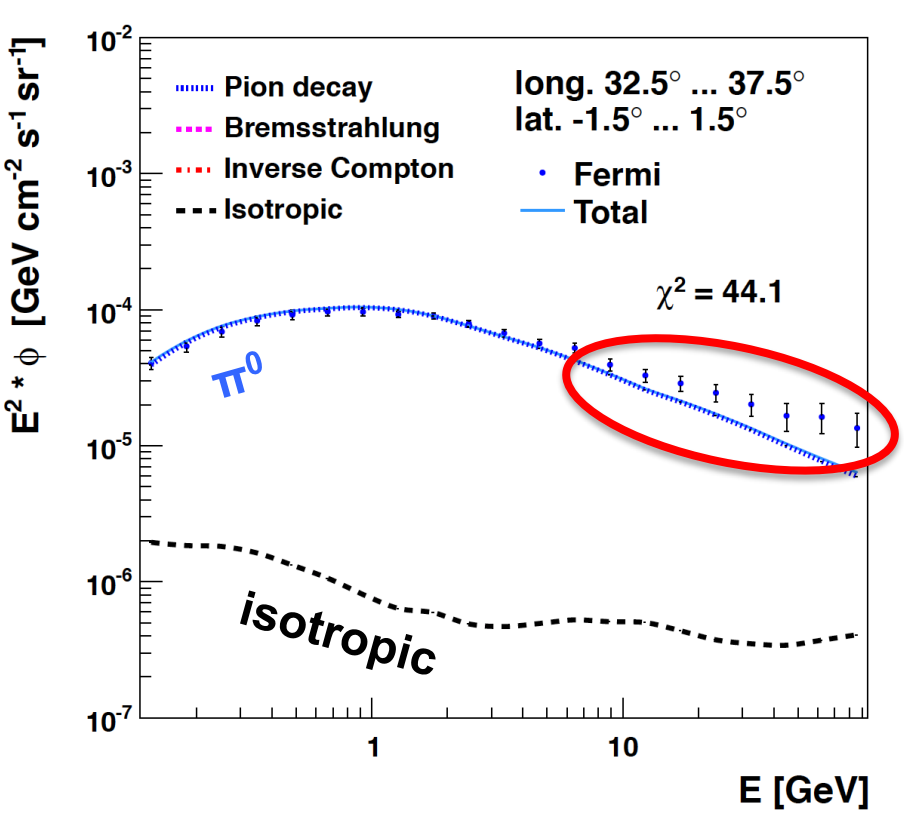
**Black line corresponds to "Source Cosmic Rays", i.e. CRs producing $\pi^0$s during acceleration, expected to correspond to a proton spectrum with slope 2.1 (Hillas, J. Phys. G31 (2005) 95).**

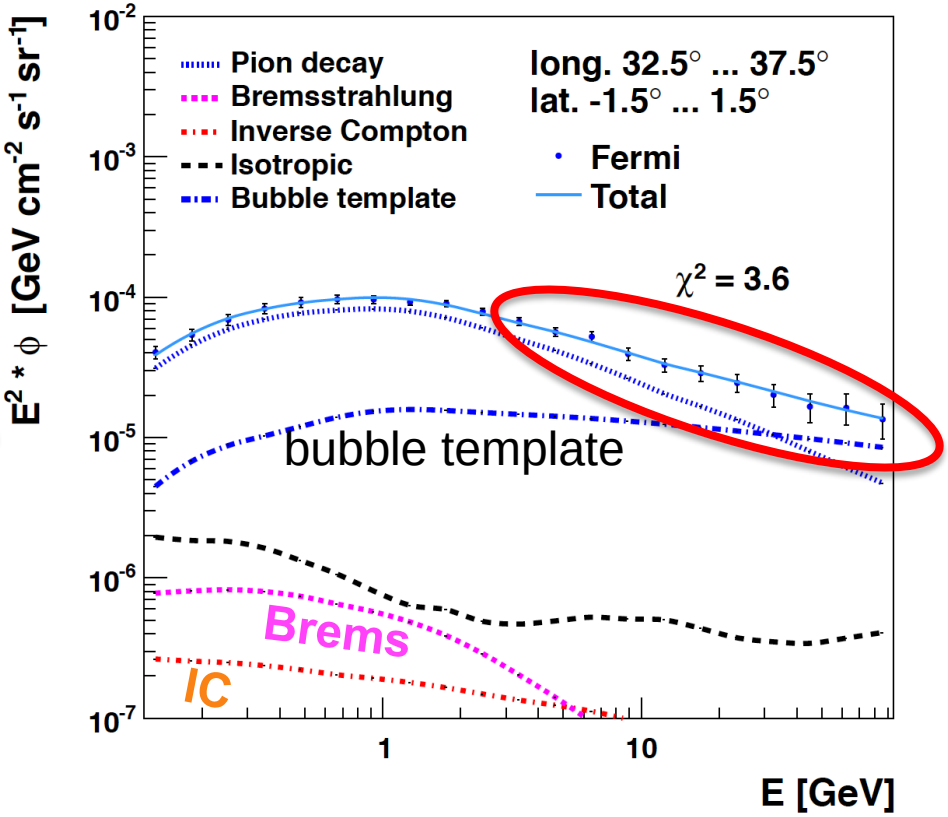
**This theoretically predicted contribution (Völk, Berezhko, 1309.3955) agrees with the Bubble spectrum from the Fermi Coll. (1407.7905) (blue band)**

**Fall-off at low energies from kinematics of pion mass BR and IC do not produce this characteristic fall-off**

# How does the template fit work?

## Template fits to Fermi data (6 yr, Pass 7)



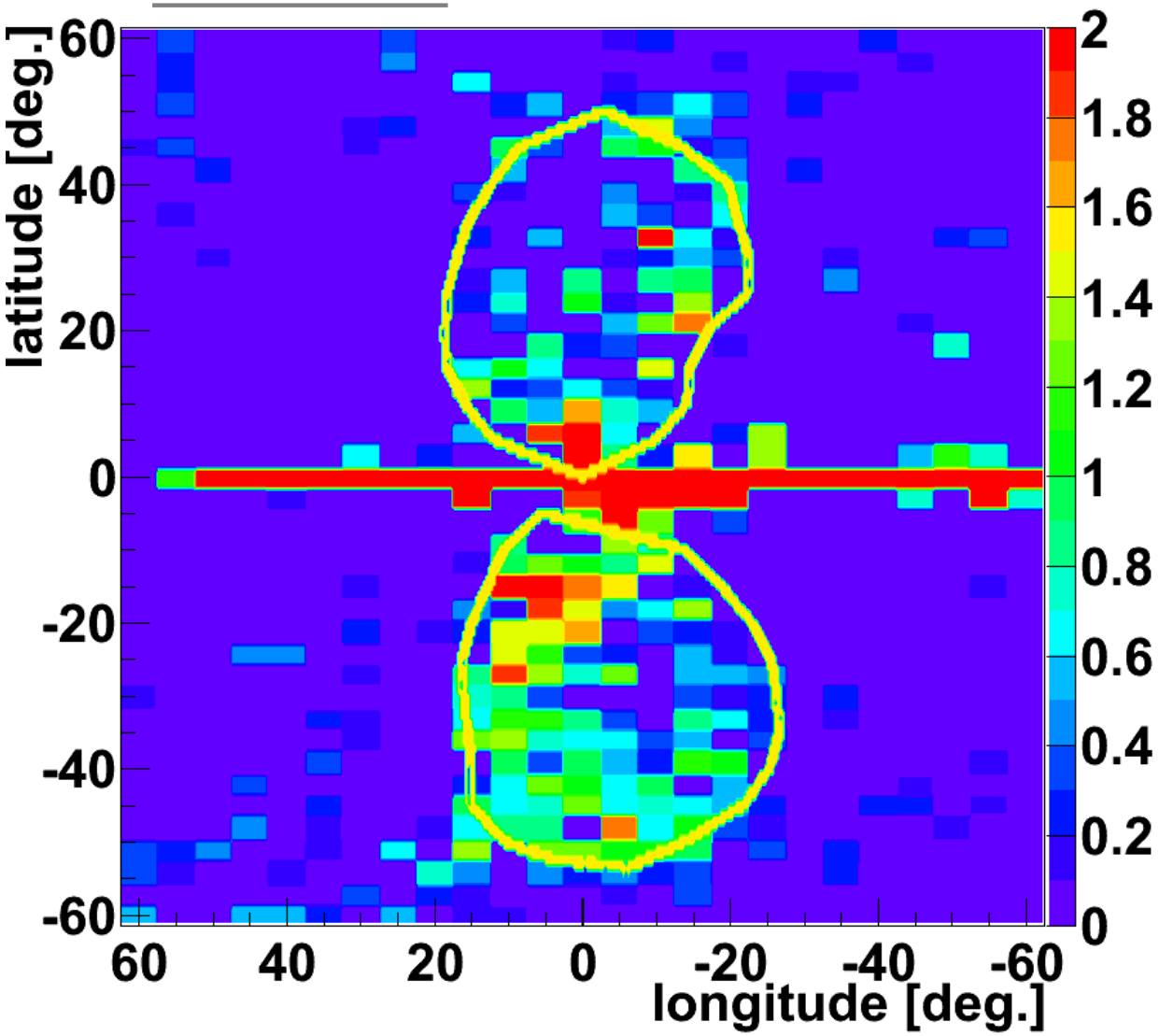




**Adding bubble template improves $\chi^2$ significantly!**
**$1/E^{2.1}$ contribution shows up as bending of spectrum at high energies!**

# 1. Fermi Bubble

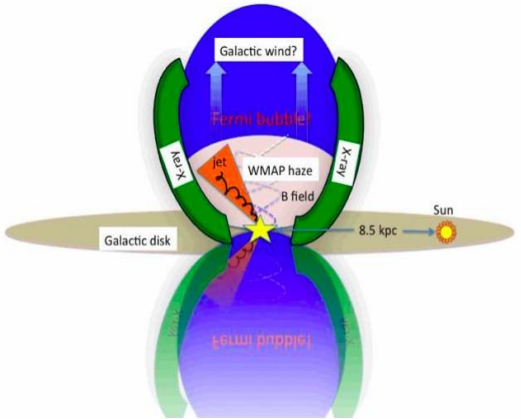
# Strength of $1/E^{2.1}$ template

arXiv:1407.4114

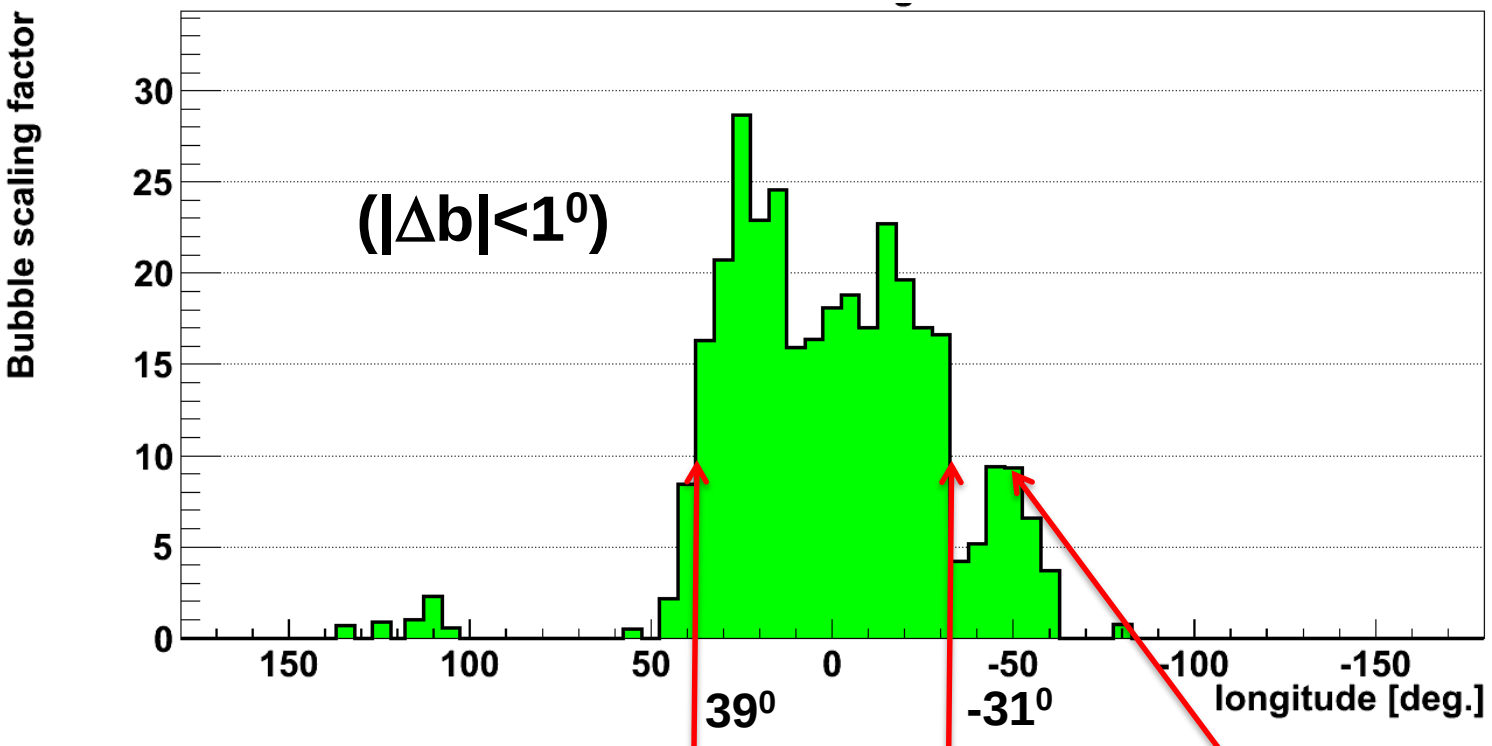



**Hard spectrum from neutral pion decay, so expect also electrons from muons produced in charged pion decay->**

**WMAP Haze from electron induced radiation**



# Strength of $1/E^{2.1}$ contribution as function of longitude




Why sharp edges?

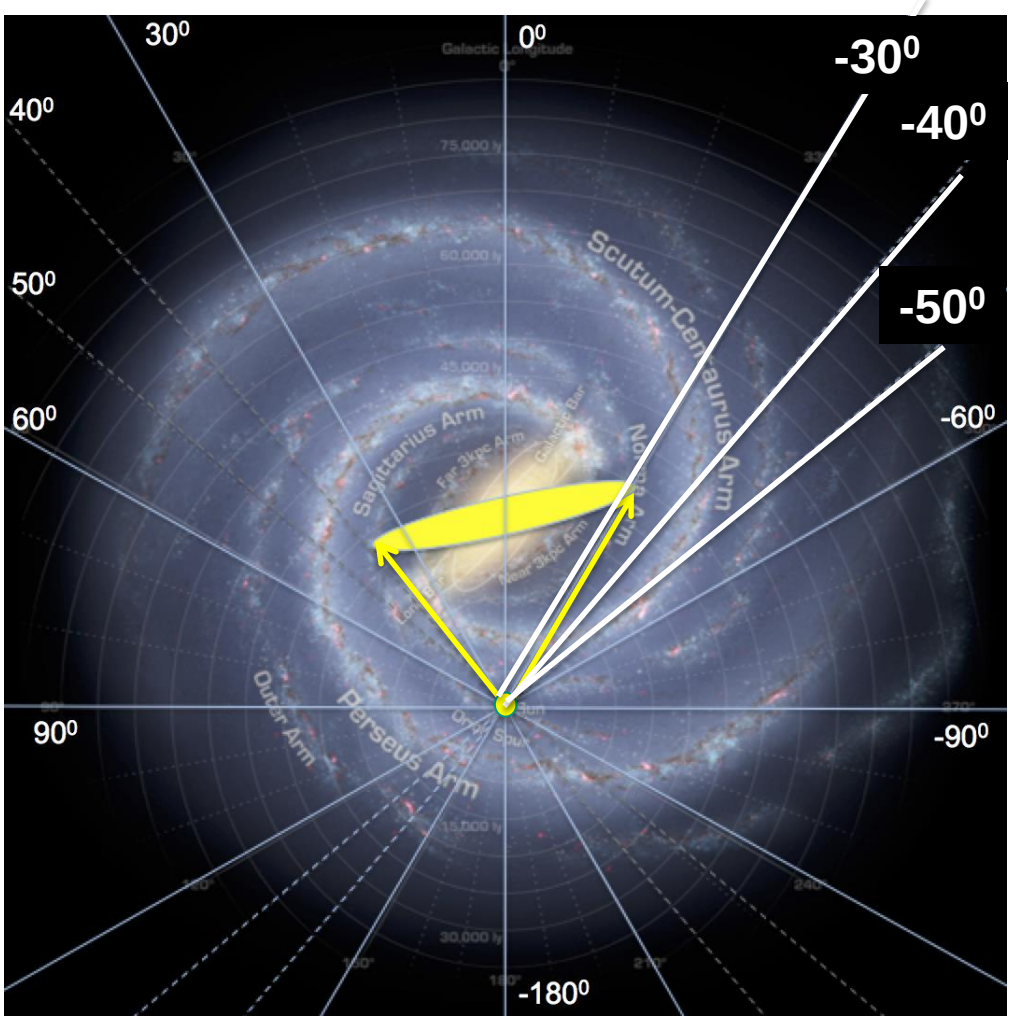
Why second peak?

Answers:

Endpoints of bar region

Tangent point of spiral arm

# Central Bar in disc



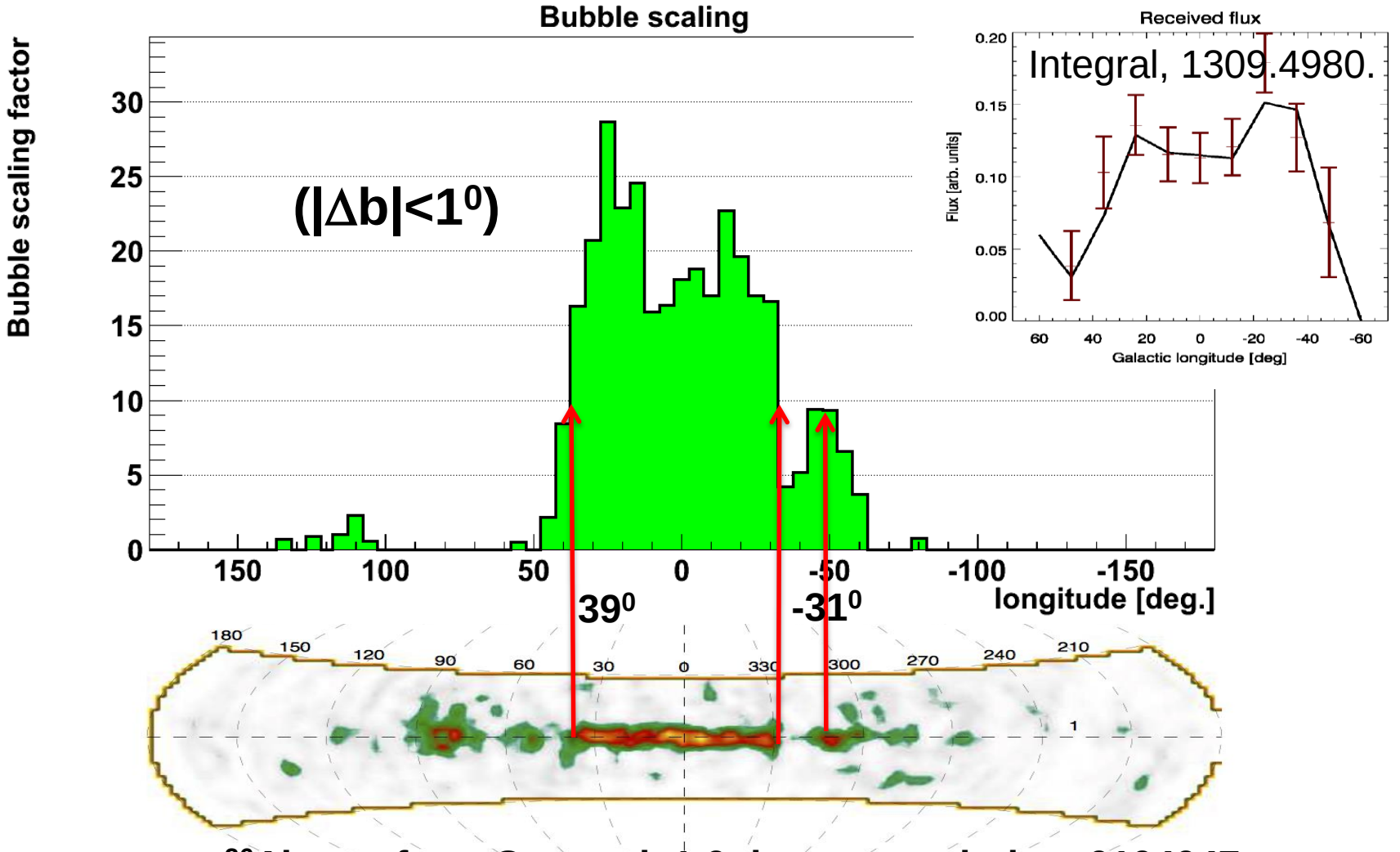

Infrared sky maps of Spitzer Space Telescope showed lots of stars along the bar- Churchwell et al., "A New View of the Milky Way", Publ.Astron.Soc.Pac. 121,213 (2009): **Bar angle 44±10⁰**

**Peak at -50⁰ corresponds to tangent point of spiral arm**

# 2. Correlation with $^{26}$Al

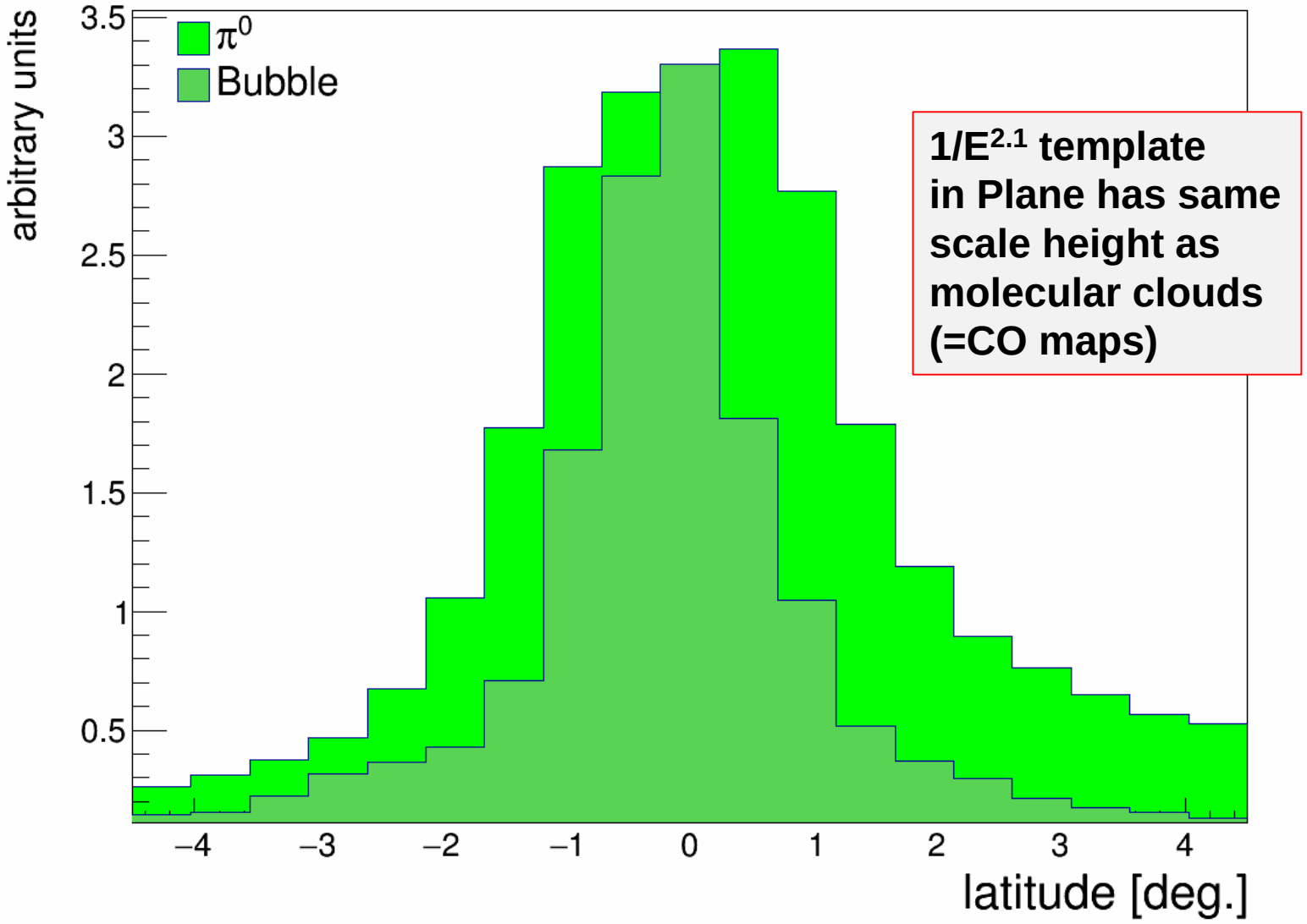
**(proves that we are looking at SNRs)**

# Comparison with $^{26}$Al (tracer of SNRs)




$^{26}$Al map from Comptel, 1.6 degree resolution, 0104047.

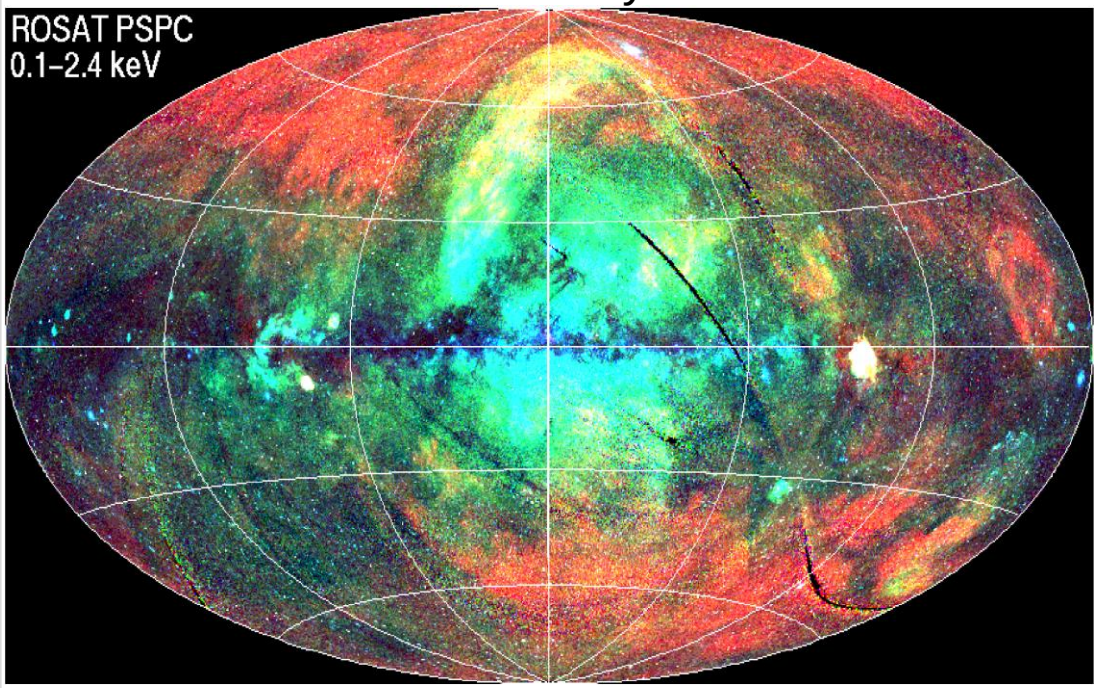
# $1/E^{2.1}$ intensity as function of latitude (near Galactic Plane)




**$1/E^{2.1}$ template in Plane has same scale height as molecular clouds (=CO maps)**

# Possible origin of Bubbles in the halo

ROSAT X-rays




**Easiest explanation for Bubble: they are outflows from star-forming regions.**

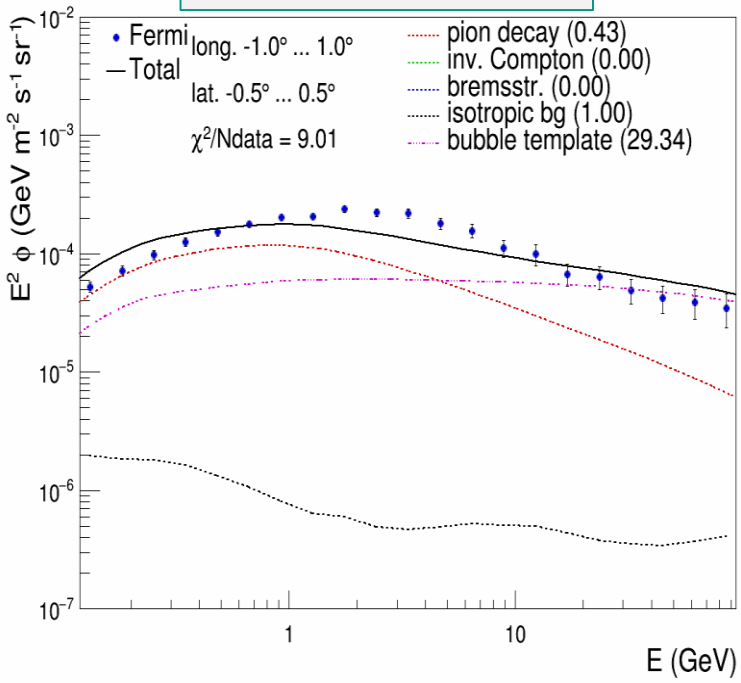
**SCR spectrum is preserved if CR are trapped in plasma, so this explains why excess in Plane and Bubbles are identical.**

**Speeds of hot gas: up to 2000 km/s, (Breitschwerdt:„Blown away by CRs“, Nature 452(2008)826) (see also 0905.3071, 0905.0431)**

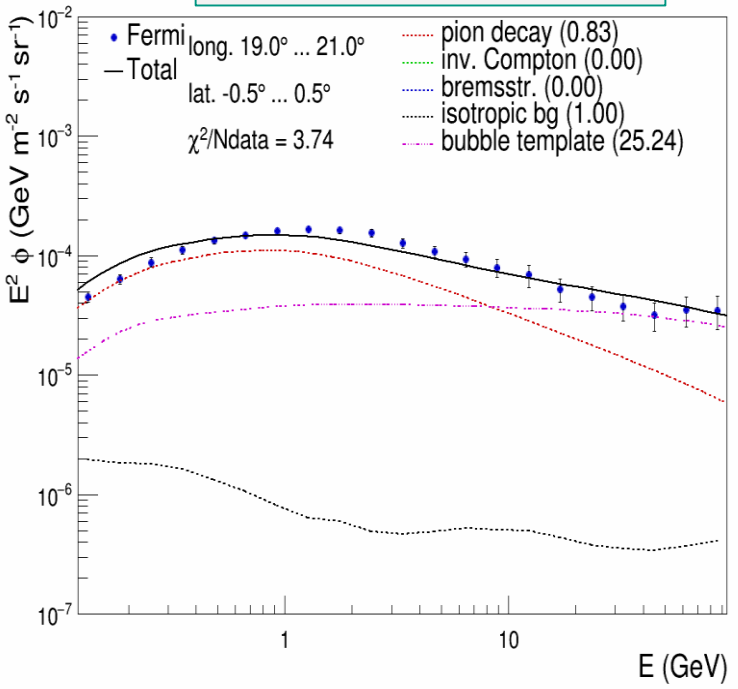
# 3. The Fermi few GeV Excess

# The GeV excess

**GeV excess clearly seen in GC**




**But everywhere where $1/E^{2.1}$ is strong**

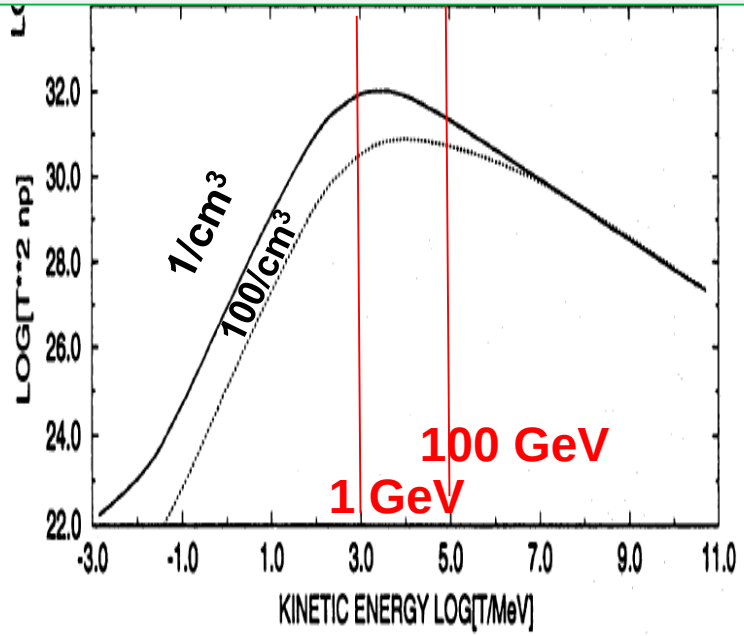


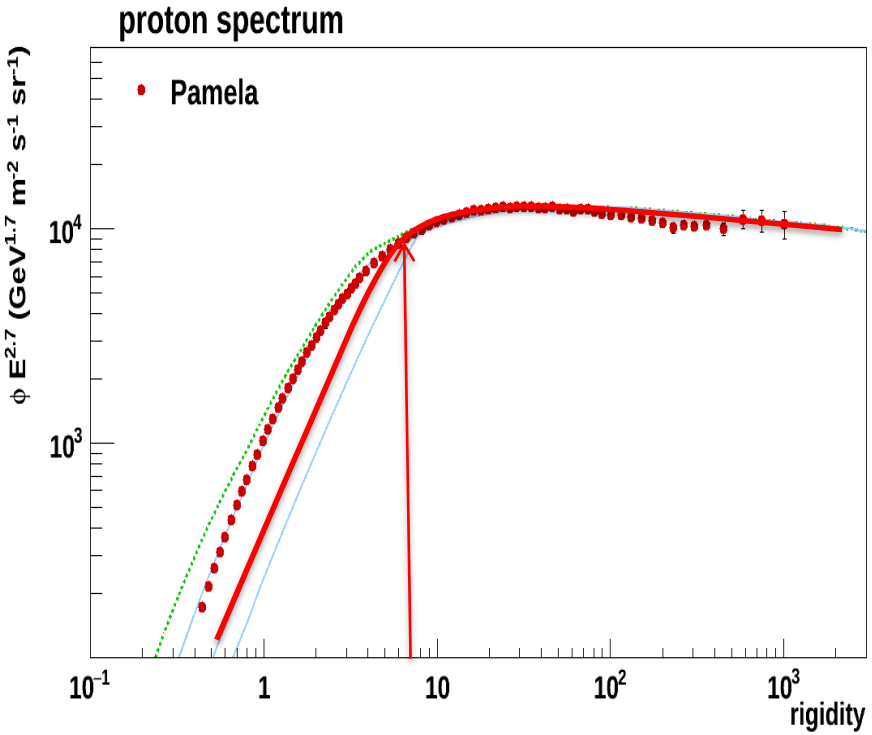

**$1/E^{2.1}$ contribution and GeV excess have Molecular Clouds in common! MCs have factor 100x energy losses than expected, see talk by Gabici yesterday.**

# Energy losses and proton spectrum

.

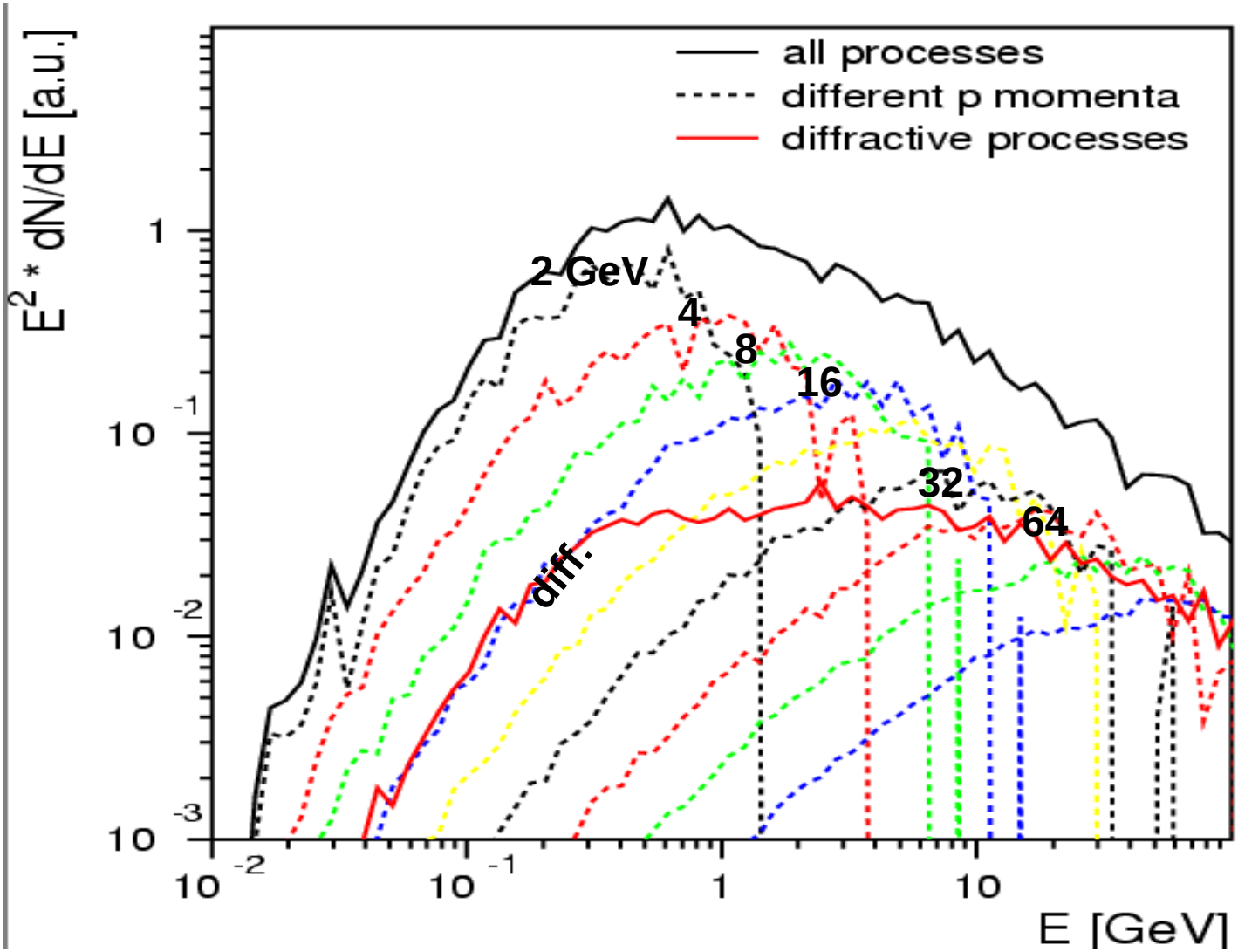
**Ionization losses deplete proton spectra below 7 GV for 100 atoms/cm$^3$**
**(Mannheim, Schlickeiser, A&A 286 (1994) 983)**



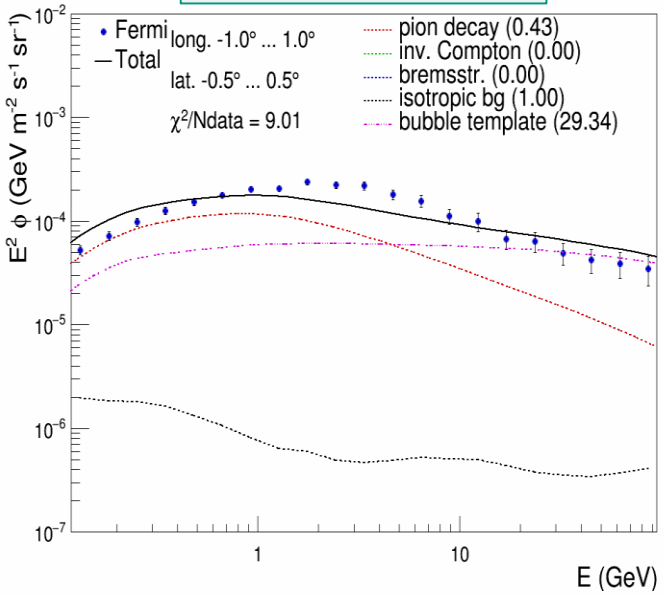




**Depletion of protons below 7 GeV for a factor 100 more energy loss**

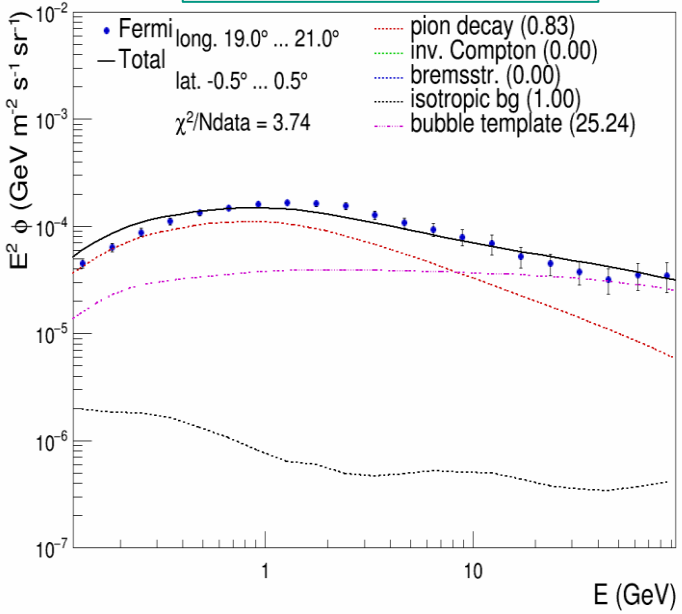
# Gamma spectrum from slices of proton spectrum



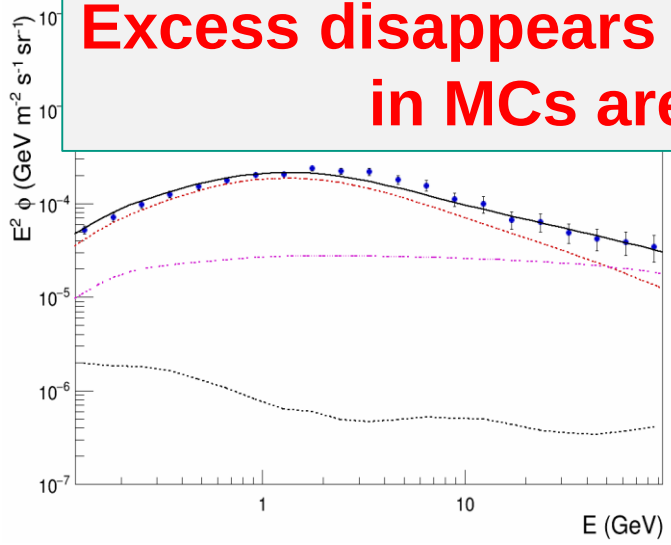
**2 GeV excess clearly seen in GC**

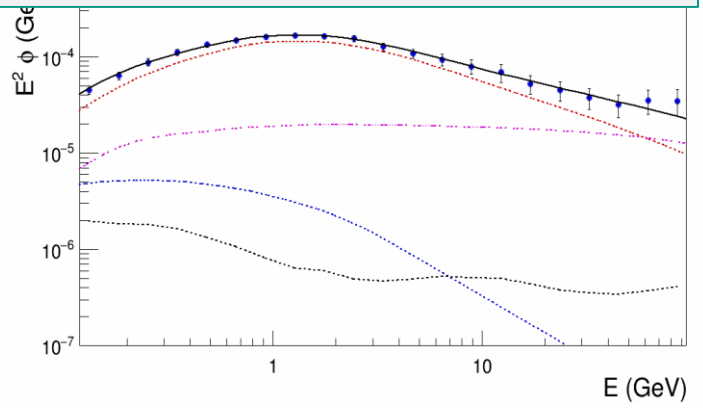



**But everywhere where $1/E^{2.1}$ is strong**




**Excess disappears everywhere, if energy losses in MCs are taken into account**



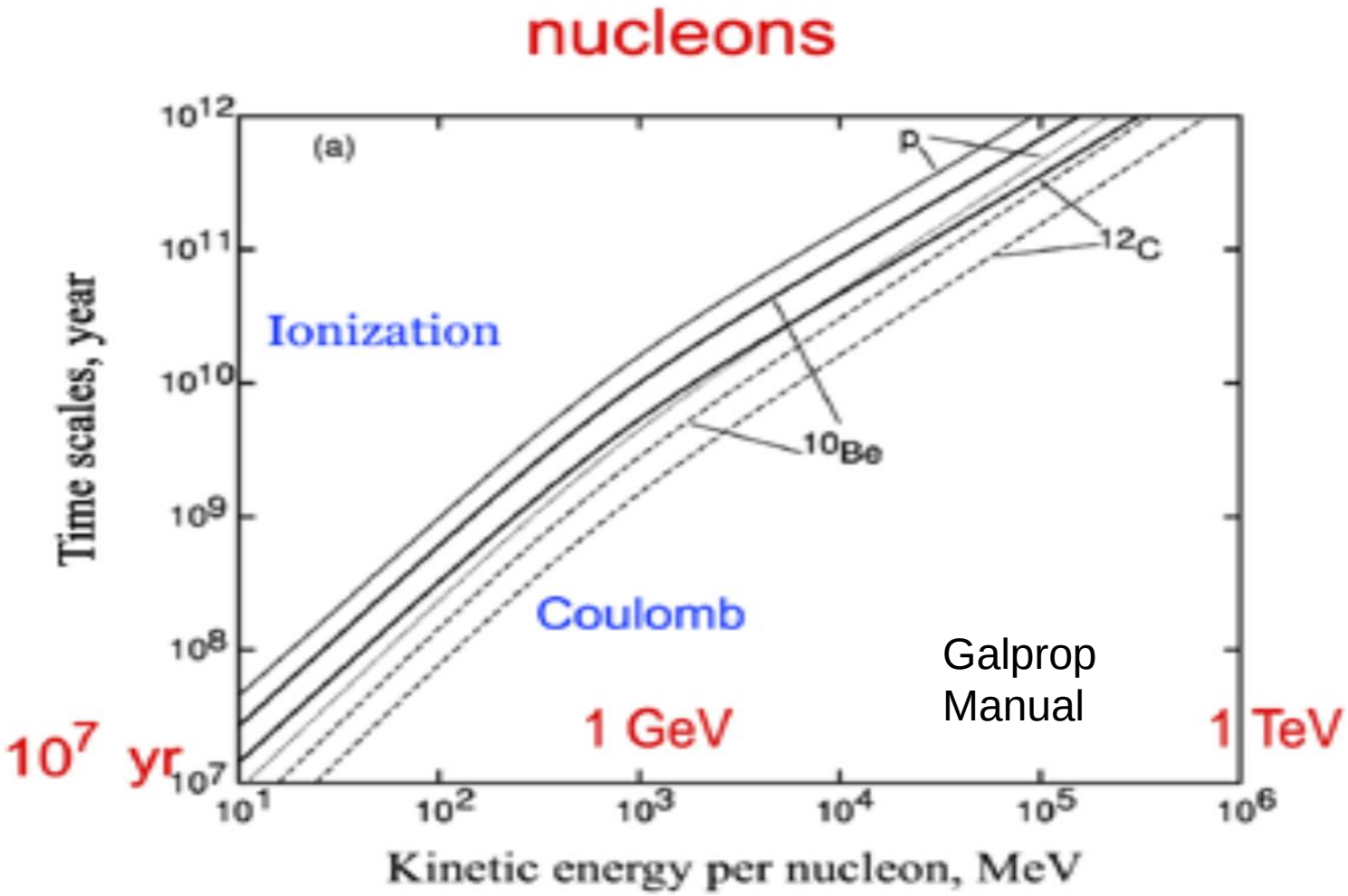



# Questions

- **Q: Why we do not see the excess in the well studied gamma ray spectra of the Orion MCs?**
- **Answer: they are too young: 3 million years only, energy loss times for protons are more like 100 million yrs.**

- **Q: Why we do not see extensive emissivity of MCs, if protons stick there to loose energy?**
- **Answer: this depends on the filling factor of the cloudlets inside MCs**

# Energy loss times for 1 atom /cm$^3$



# Summary

- Observe $1/E^{2.1}$ contribution not only in Bubbles, but also in star-forming regions of the Galactic Plane: GC, bar region, spiral arms
- Latitude of $1/E^{2.1}$ contribution restricted to scale height of Molecular Clouds AND highly correlated with $^{26}Al$ maps, which is a tracer of SNRs
- $1/E^{2.1}$ contribution EXPECTED from Source Cosmic Rays, producing $\pi^0$s during acceleration (Hillas,2005 for index, Berezhko, Völk for pred. 0404307)
- Since Bubbles and star-forming regions have an identical $1/E^{2.1}$ spectrum ➔ easiest explanation: bubbles are outflows from star-forming regions.

- MC regions better described by depletion of proton spectrum below 7 GeV, as expected because of higher energy losses in Molecular Clouds (MCs)
- With this depletion below 7 GeV: 2 GeV excess disappears
- Summary of summary: Allowing for SCRs and additional energy losses in MCs provides an excellent fit for every region of the gamma ray sky, unfortunately w.o. DM