Why the GeV gamma-ray excess cannot originate from DM

(From a true multifrequency, multimessenger analysis: mm CO maps Planck, MeV ^{26}Al Integral, GeV Fermi)

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What is the GeV Excess?

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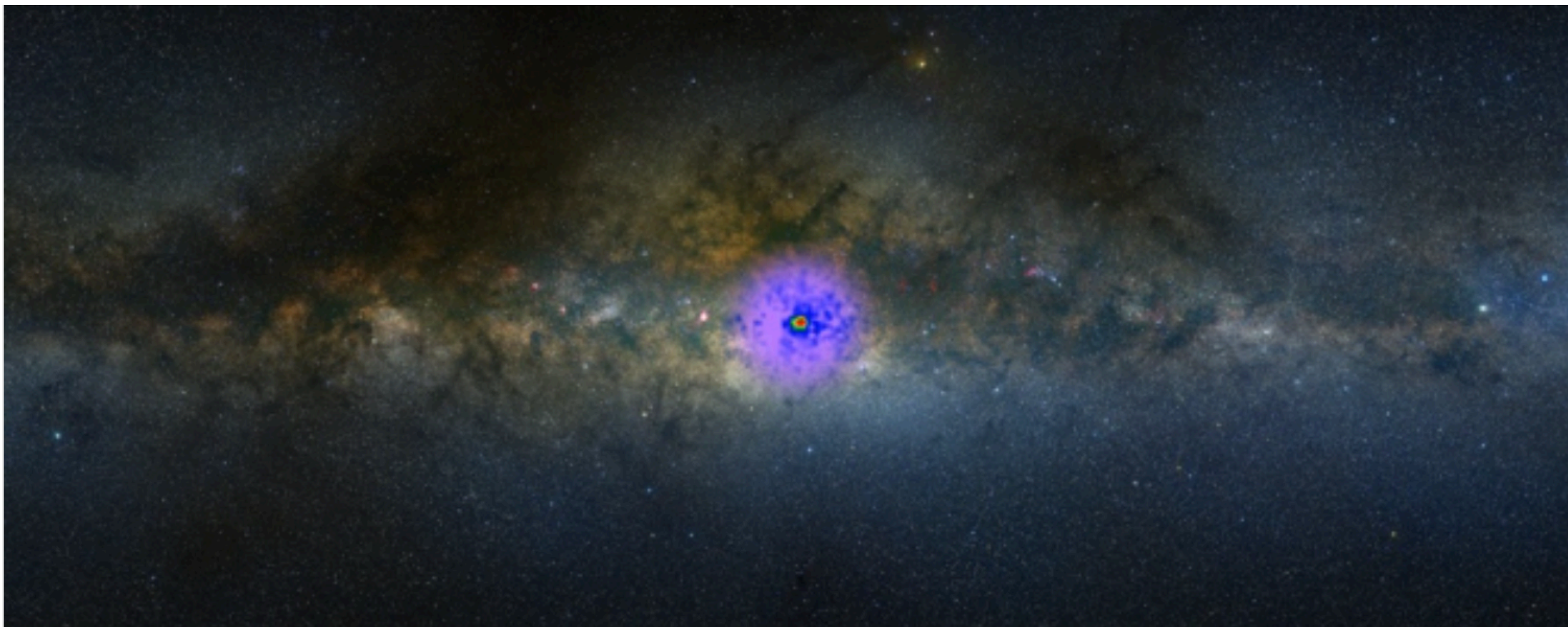
Nature 2015:

Mysterious galactic signal points LHC to dark matter

See: http://www.nature.com/news/mysterious-galactic-signal-points-lhc-to-darkmatter-1.17485



A. Mellinger, CMU; T. Linden, Univ. of Chicago/NASA Goddard

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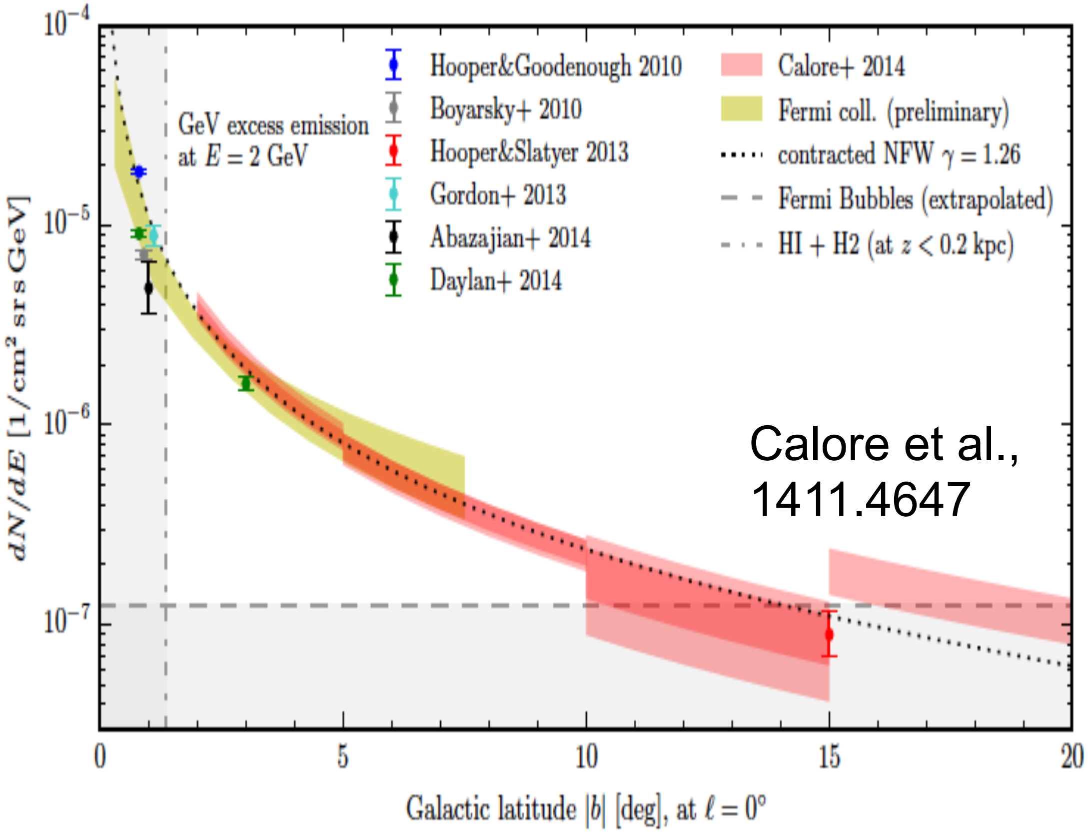
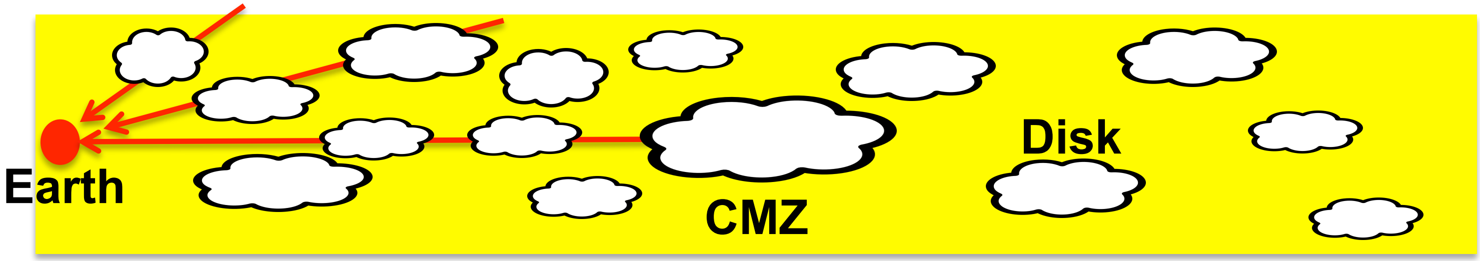
Previous measurements claiming GeV excess in GC



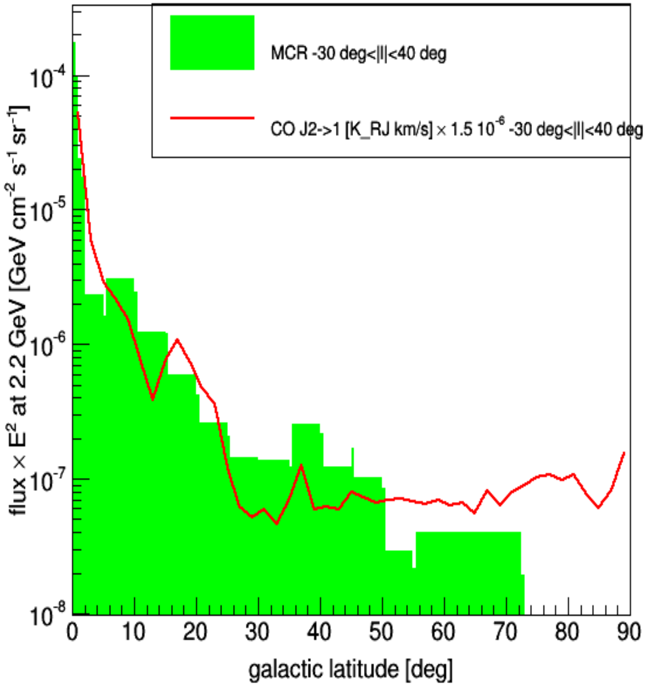
Calore et al.,1411.4647:
"The indications for a higher-latitude tail of the GeV excess provide a rather non-trivial test for the DM interpretation and provides a serious benchmark for any astrophysical explanation of the excess emission."

Unfortunately, every excess in the plane will show up in the halo with a steep latitude dependence

If Molecular Clouds are responsible for excess, how would latitude distribution look like?



Only MCs along line-of-sight contribute → **steep function of latitude! See latitude distribution of CO sky map**



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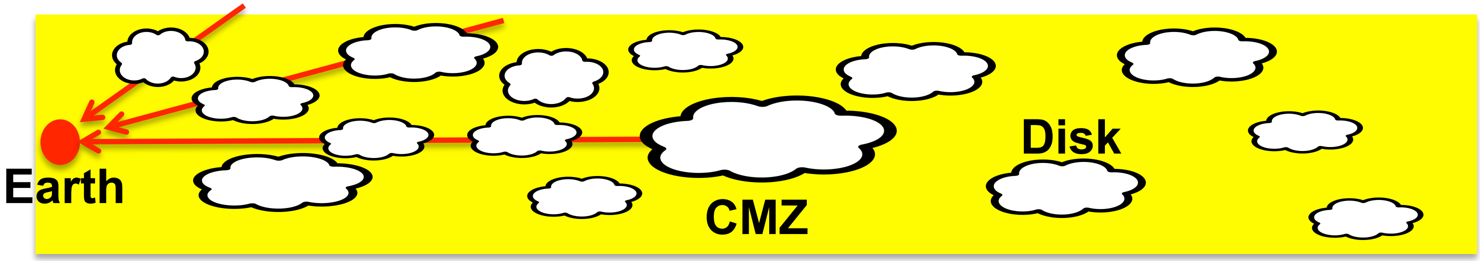
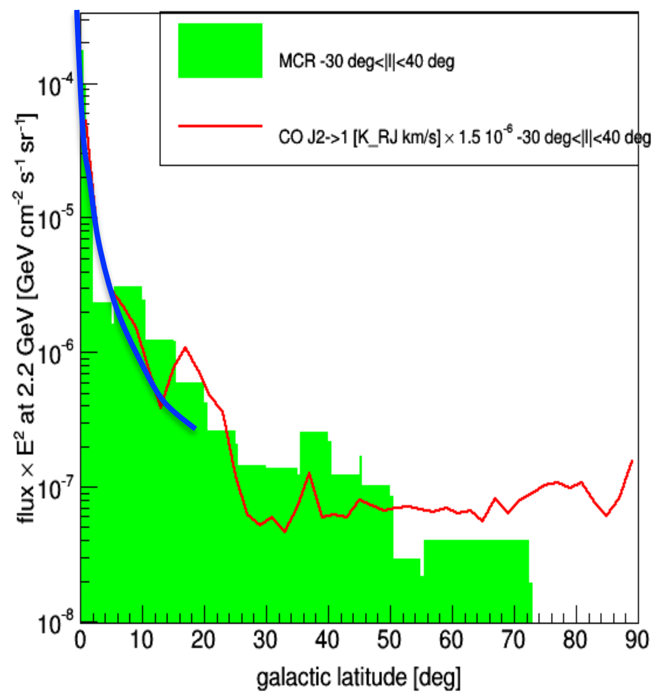
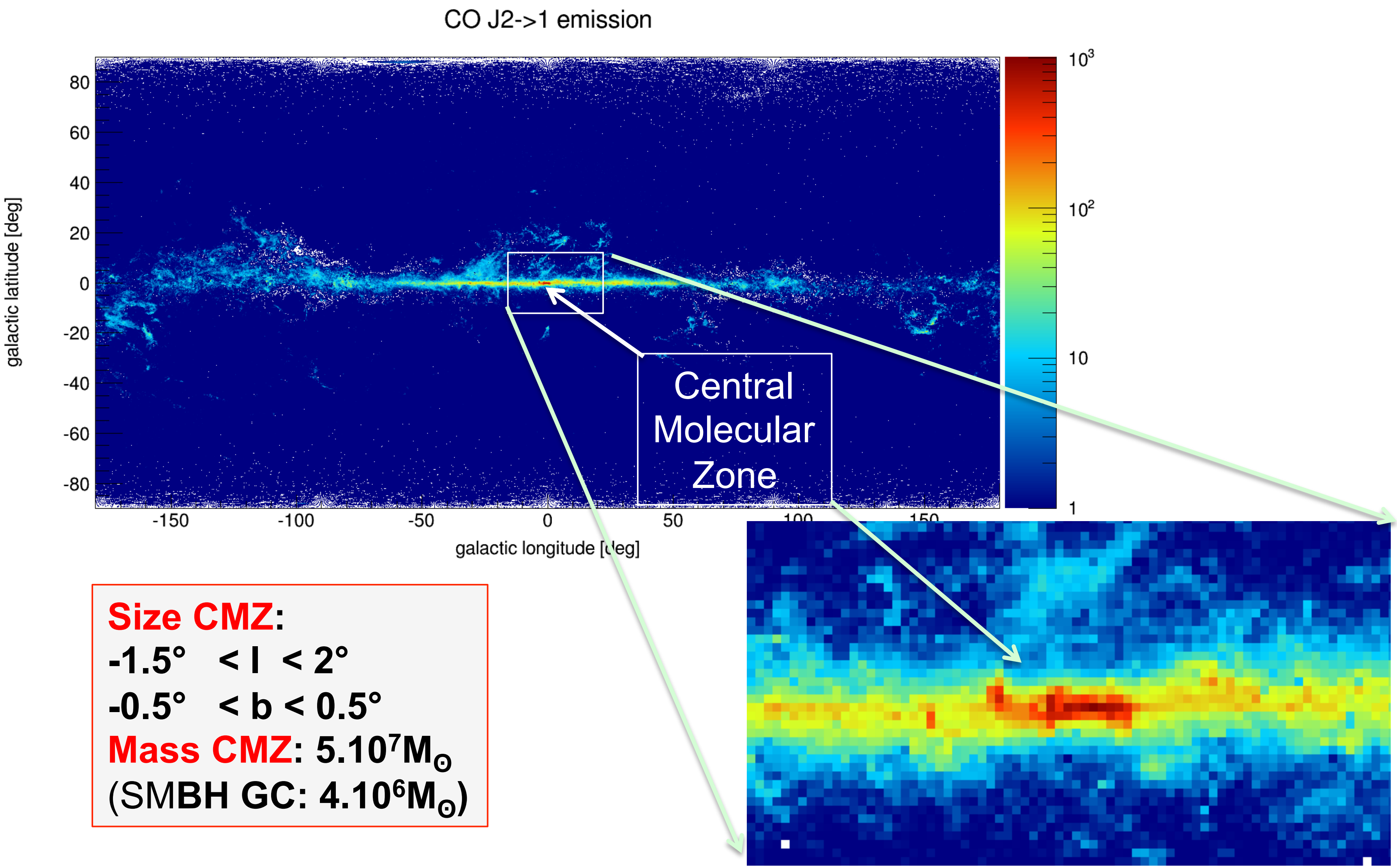


Only MCs along line-of-sight contribute➔**steep function of latitude! See latitude distribution of CO sky map**

As it happens, the CO lat distribution resembles an NFW profile



CO Skymap Planck Satellite

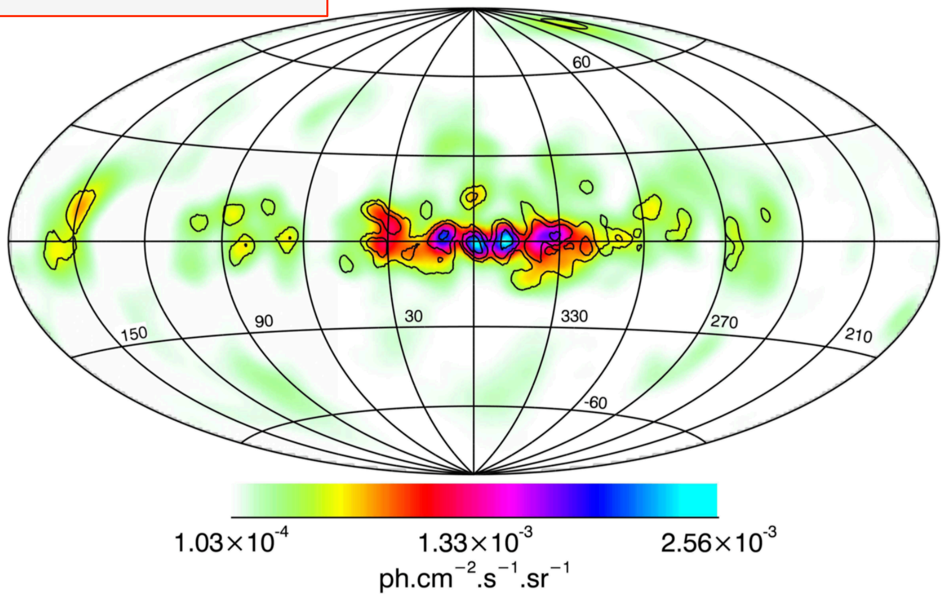


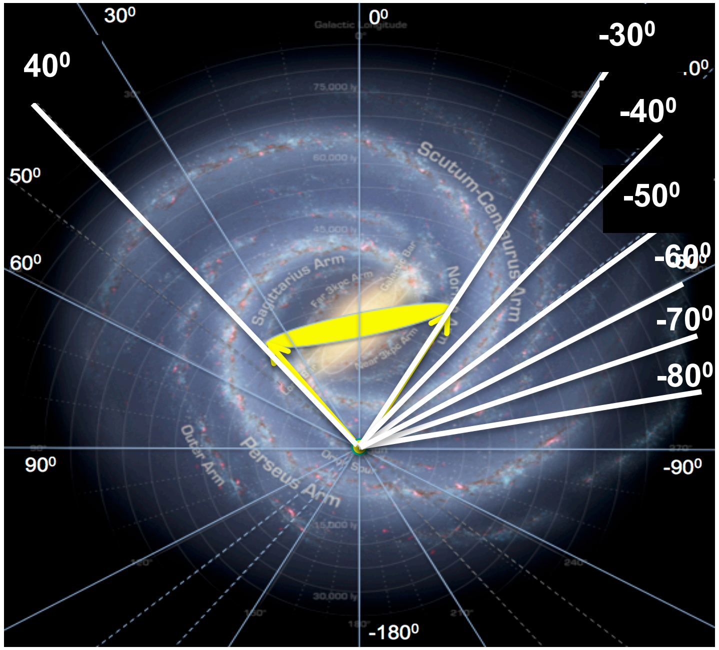
Size CMZ:
-1.5° < l < 2°
-0.5° < b < 0.5°
Mass CMZ: 5.10⁷M⊙
(SM**BH GC: 4.10⁶M⊙)**

1.8 MeV gamma line from the radioactive isotope ^{26}Al

- ^{26}Al synthesized in heavy stars by proton capture of ^{25}Mg (see Prantzos, Diehl, Physics Reports 267 (1996) l-69)
- ^{26}Al emits a 1.8 MeV line, which is a good tracer of sources embedded in molecular clouds
- ^{26}Al are low energy nuclei, so they decay near the source, but lifetime 10^6 yrs, so still propagation

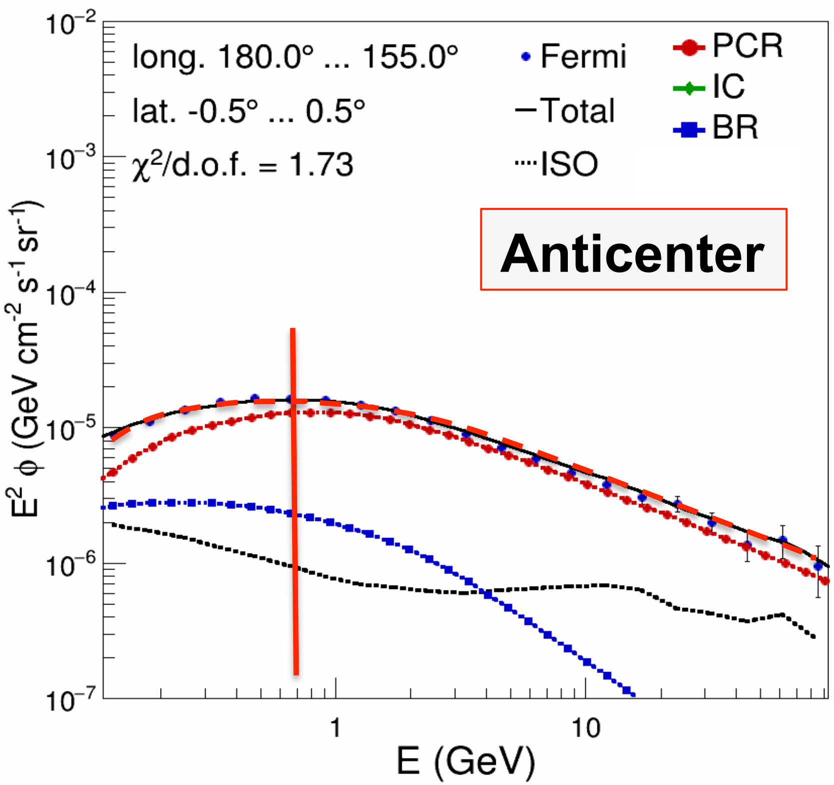
Integral 2015 map
1501.05247

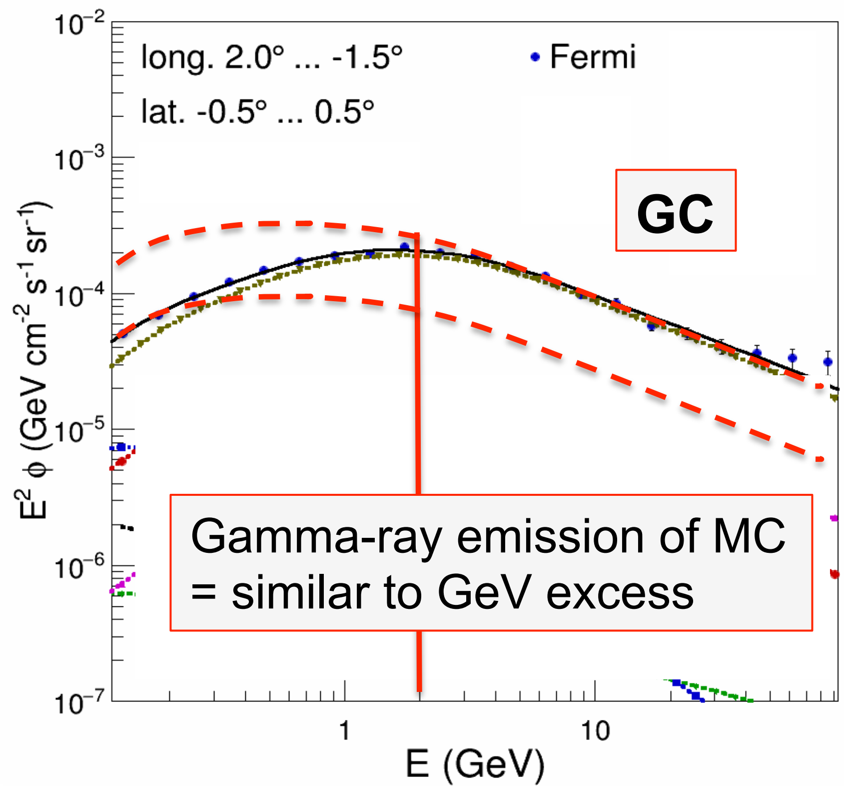




Gamma-ray spectra

Template Fit: $|\Phi\rangle = n_1|\pi^0\rangle + n_2|BR\rangle + n_3|IC\rangle + n_4|isotropic\rangle$



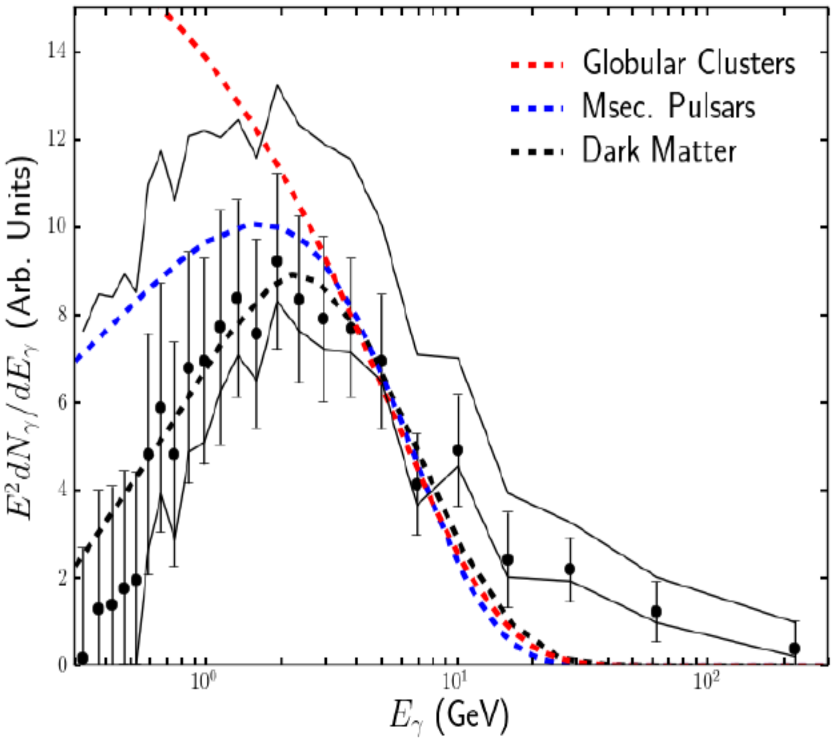


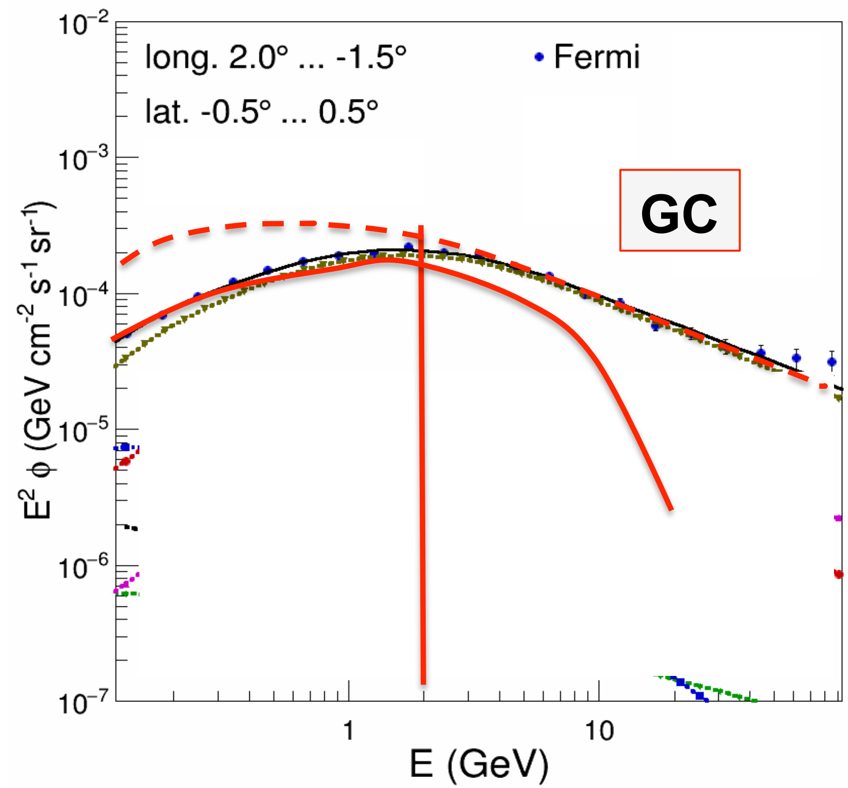
GC: Shift of max. to 2 GeV
Slope at high energy same
Feature of molecular clouds?

Depletion at low energies from CRs?
Or is it due to millisecond pulsars?
Is the shift correlated with CO?

Can the CMZ be dominated by MSPs?

Cholis, Hooper, Linden, 1407.5625

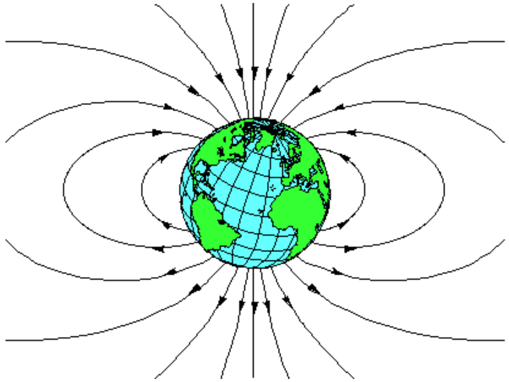




Millisecond pulsars have spectrum with cut-off at 30 GeV.
They cannot be dominant source of gamma-ray emission in CMZ

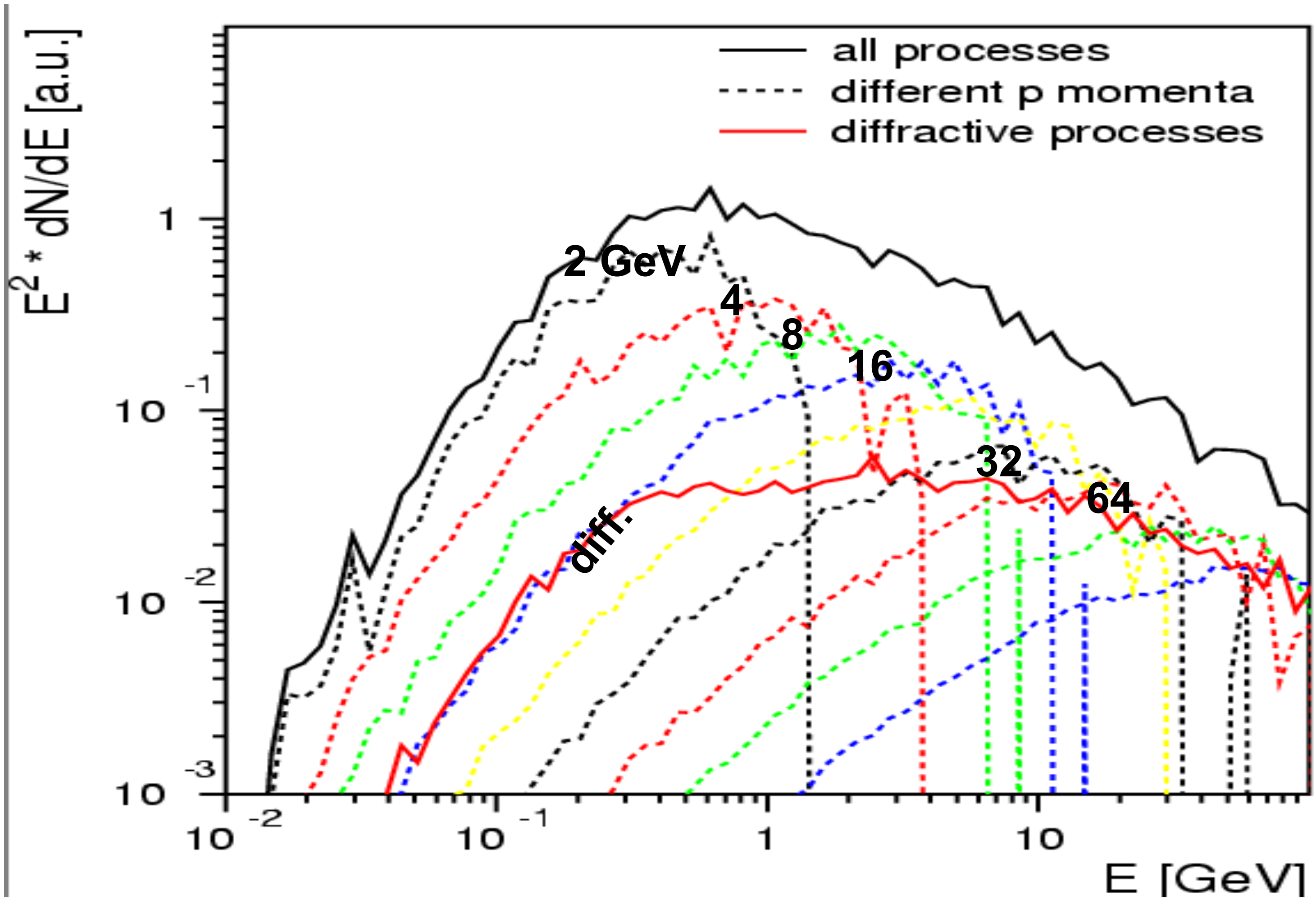
Shift in spectrum by geomagnetic cut-off in proton spectrum in MCs?

Think about what happens, if protons enter earth magnetic field: near magnetic equator protons below 20 GV do not reach the earth because of the geomagnetic cut-off.



The same may happen inside MCs:
the high magnetic fields inside MCs easily give similar magnetic moments:
the geomagnetic cut-off ensures that only protons above this cut enter, thus shifting the gamma-ray spectrum to higher energies.
Need cut-off of 14 GV to describe CMZ data

Gamma spectrum from slices of proton spectrum



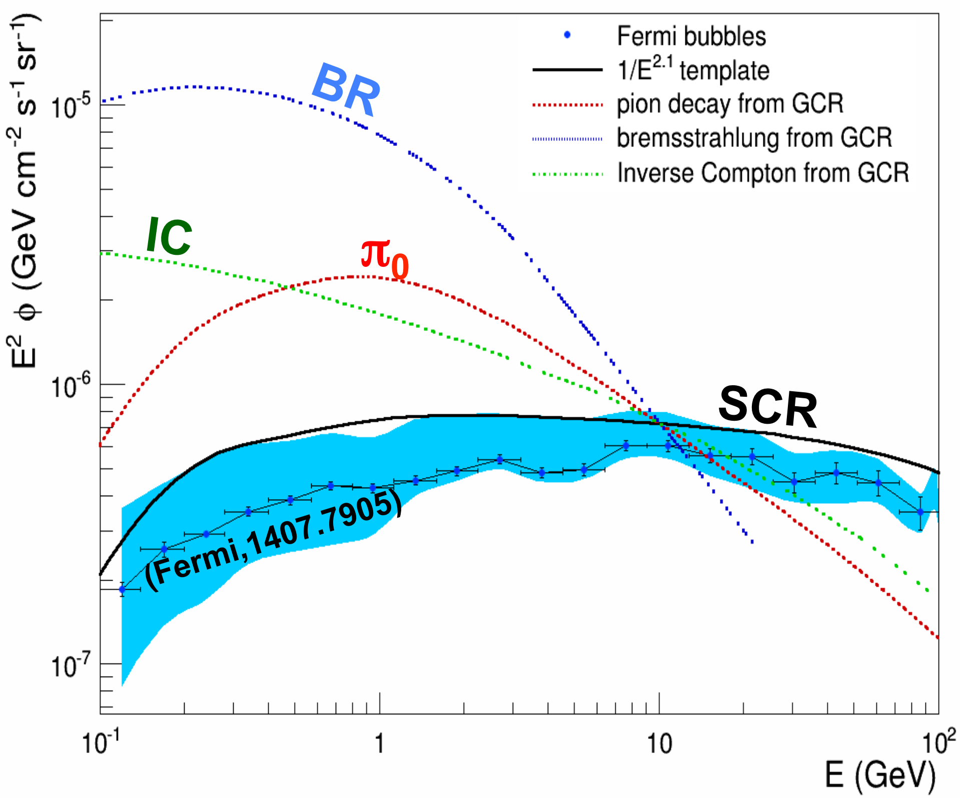
Max. in gamma spectrum at 2 GeV requires protons below 14 GV to contribute little to π^0 production

Template for Fermi bubbles

(Similar to template for Source Cosmic Rays, SCRs)

CRs accelerated in sources see high density gas in shockwave, so expect copious π^0 production with a spectrum from $1/R^2$ protons

(Völk, Berezhko, 1309.3955, de Boer et al., 1407.4114, 1509.05310, Biermann et al. 1009.5592, Hillas, J. Phys. G31 (2005) 95).



Black line is theoretically predicted spectrum from π^0 production in sources

Agrees with the bubble spectrum from the Fermi Coll. (1407.7905) (blue band)➔

1) strong support that Bubbles have a hadronic origin (1407.4114)

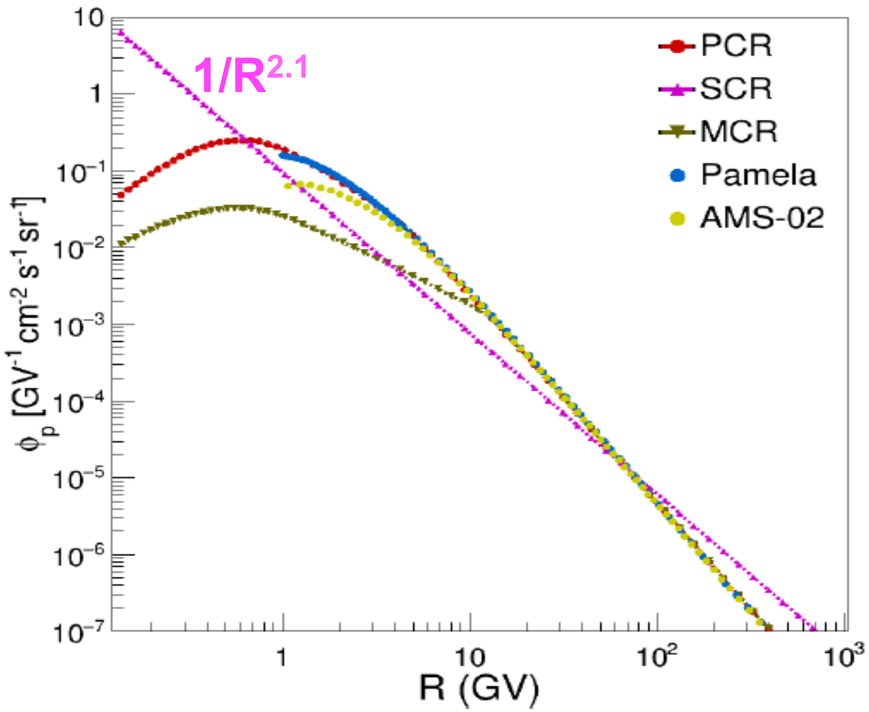
2) and evidence that bubbles are outflows of SNRs

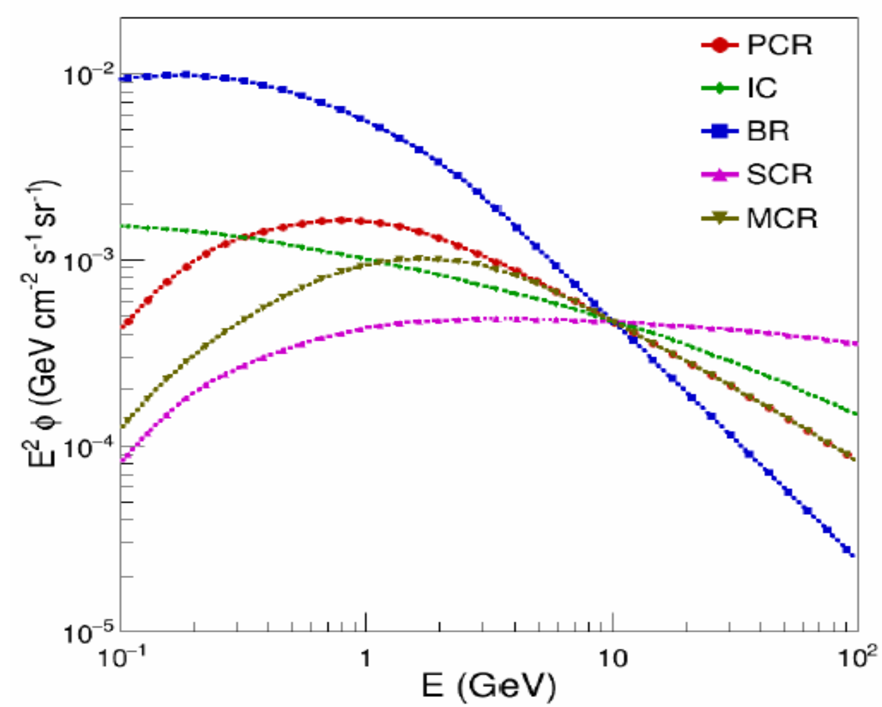
By adding this template in fit ➔ should find bubble spectrum in disk with strength closely correlated with ^{26}Al

Allows to get bubble contribution in GC!

Template fit

$|\Phi\rangle = n_1|\pi^0\rangle + n_2|BR\rangle + n_3|IC\rangle + n_4|isotropic\rangle + n_5|SCR\rangle + n_6|MCR\rangle$

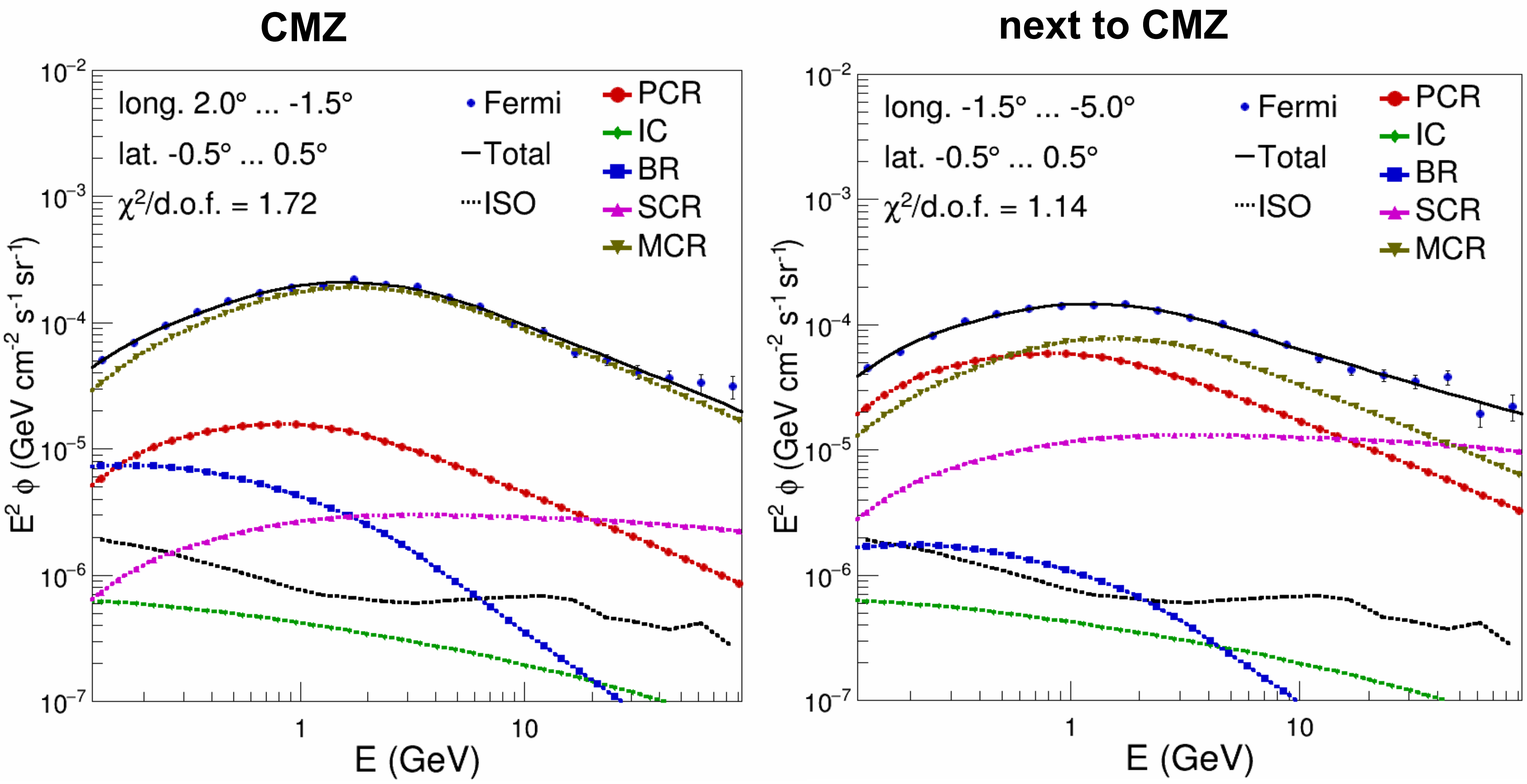




2 **advantages** of using **spectral** templates instead of **spatial** emissivity templates:

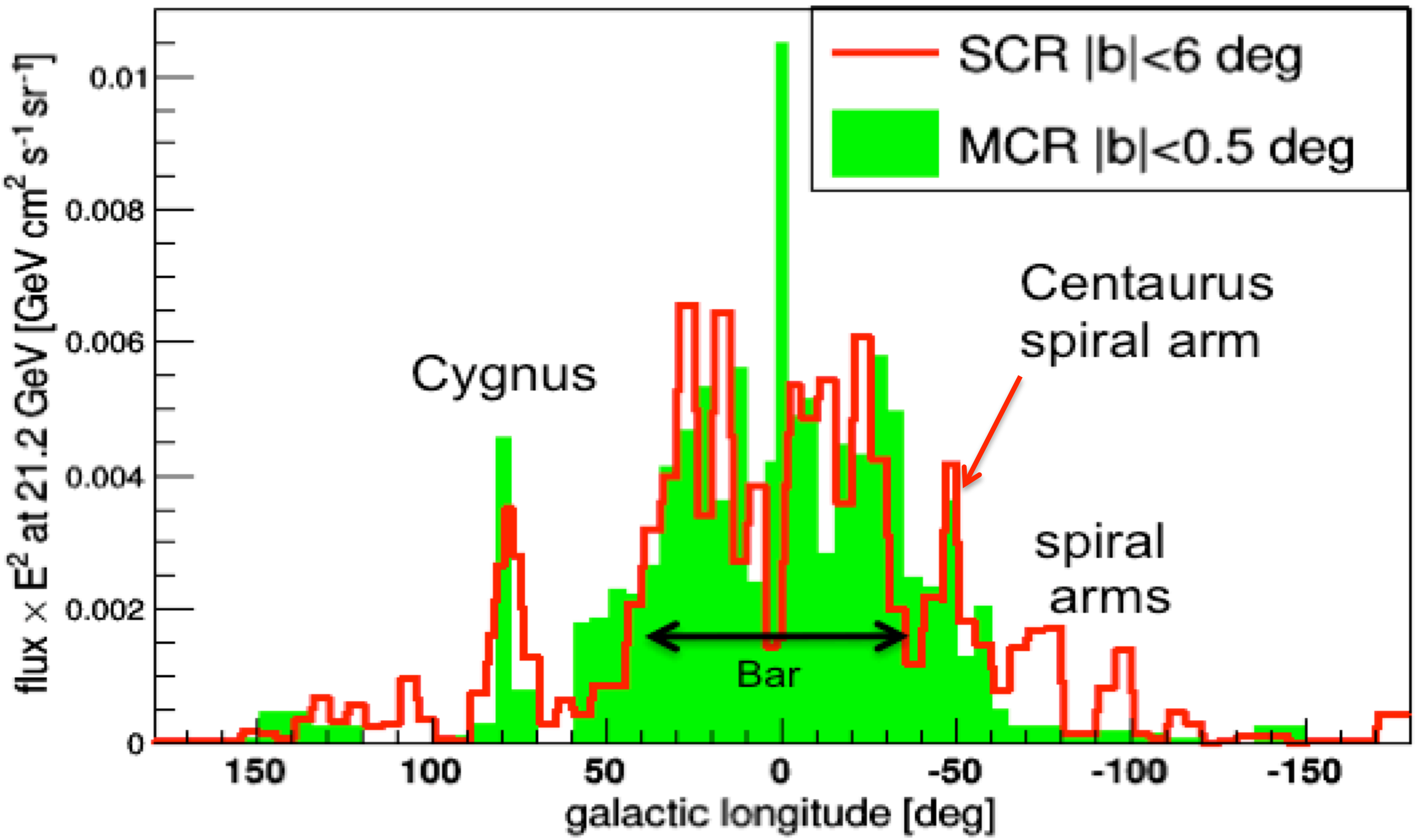
1) **high spatial resolution**, since can choose many narrow, independent cones
2) **overconstrained fit** of 6 parameters n_i to 21 energy bins in each of about 800 cones
3) Can determine LIS spectrum from data in halo and anticenter. LIS close to data!
   Very little solar modulation (150 MeV instead of 650 usually assumed, this is most important propagation parameter, usually not varied, if people use GALPROP)

Examples (CMZ)



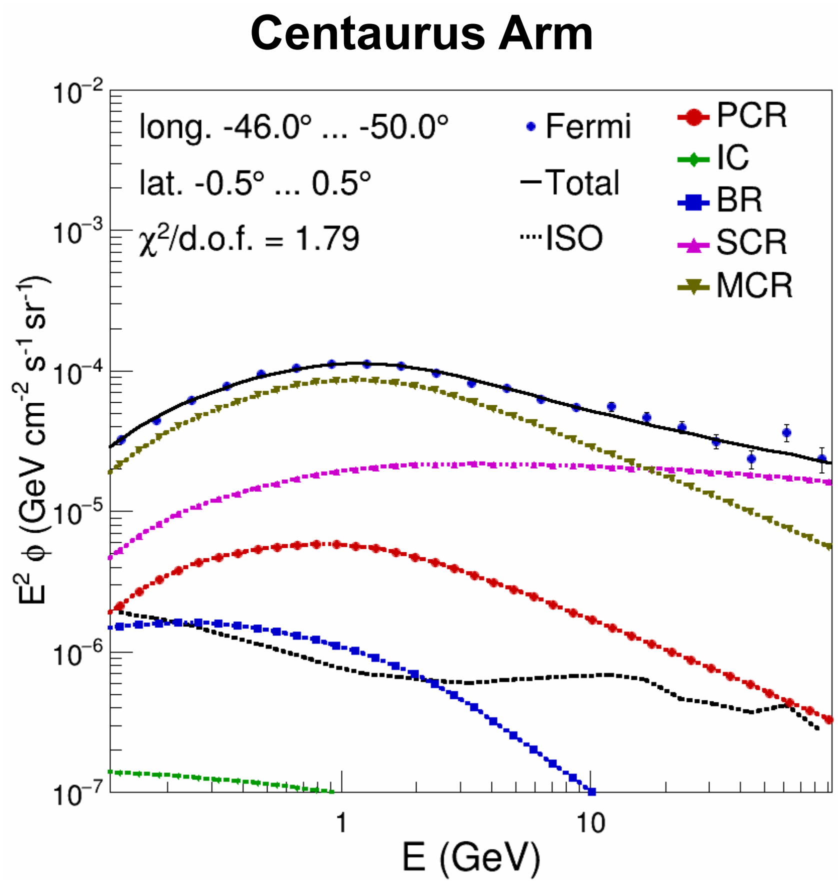
Systematic errors on Fermi data scaled by 0.25 to get chi2/d.o.f around 1

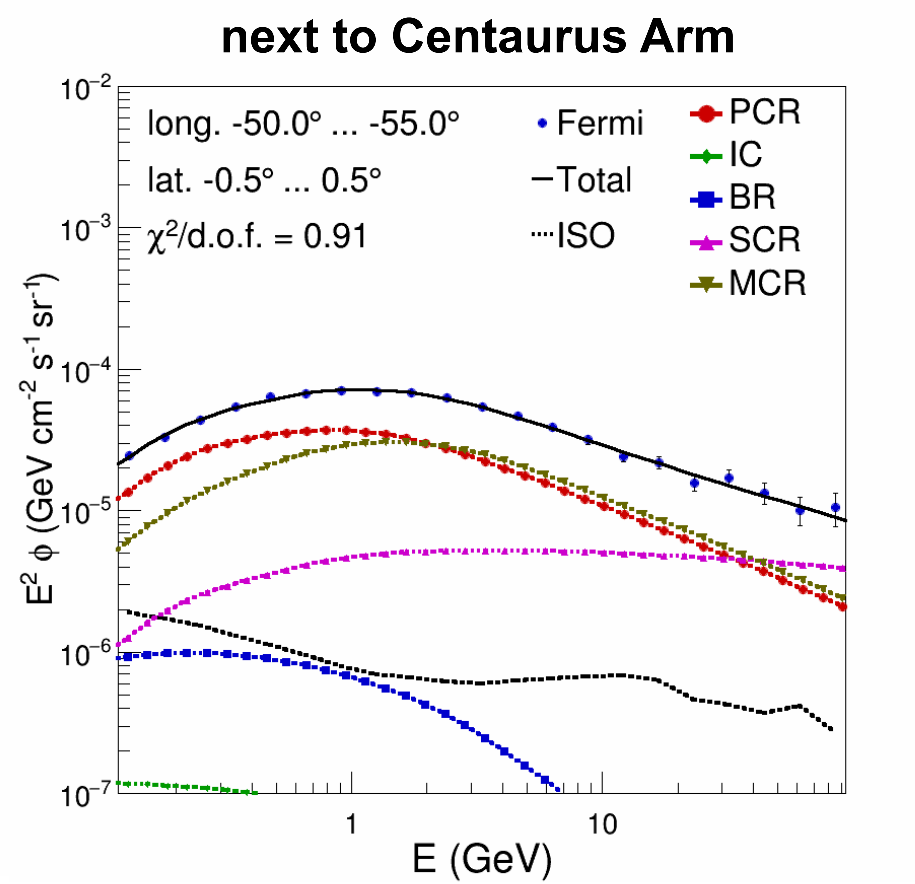
Correlation between SCR and MCR



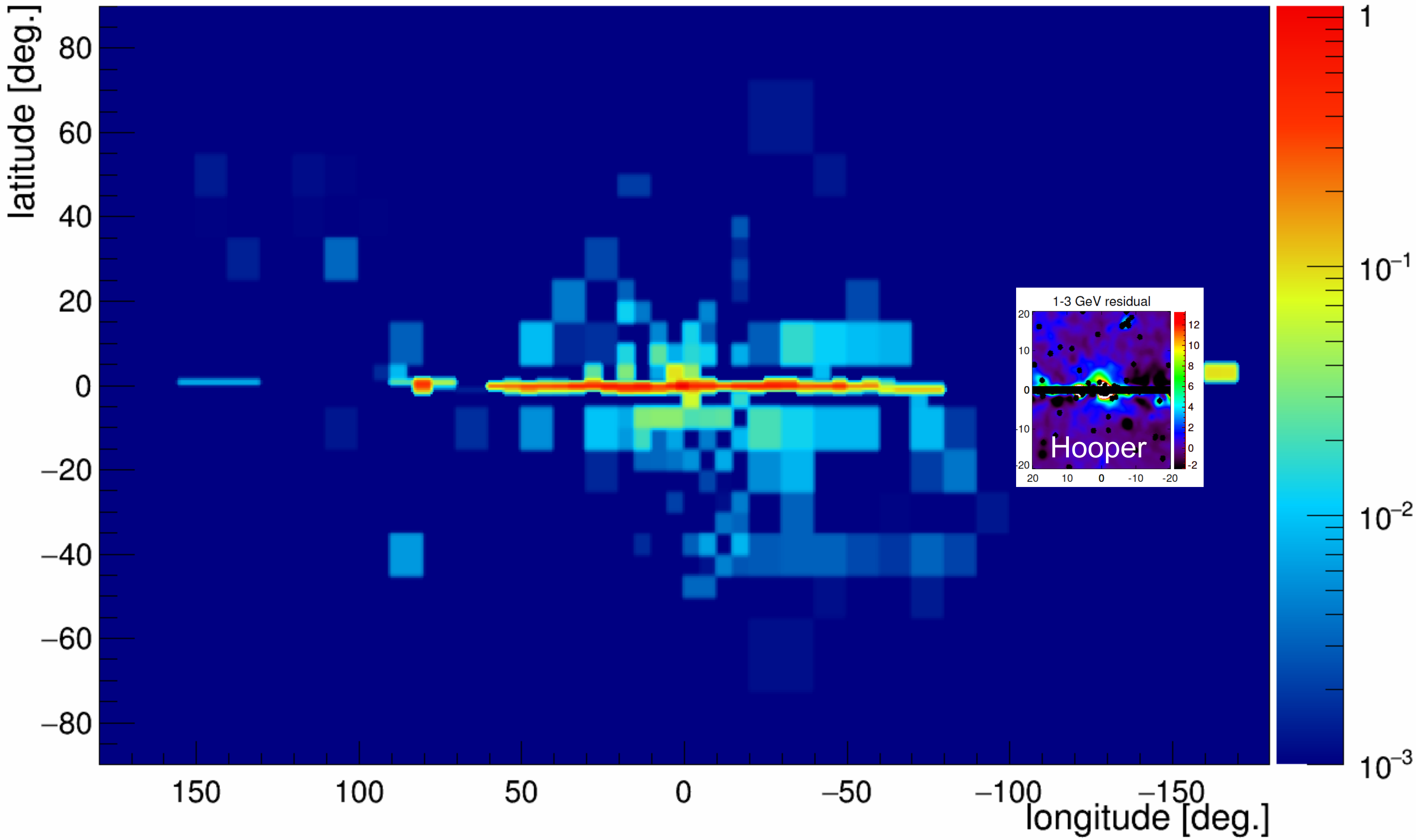
Remember: **SCR is tracer of sources** from tail in data above 30 GeV ($1/R^2$)
MCR is tracer of shift in spectrum, observed in CMZ
SCR and MCR happen both in MCs, so should have same morphology. MCs found in bar region and spiral arms

Tangent point of nearest spiral arm

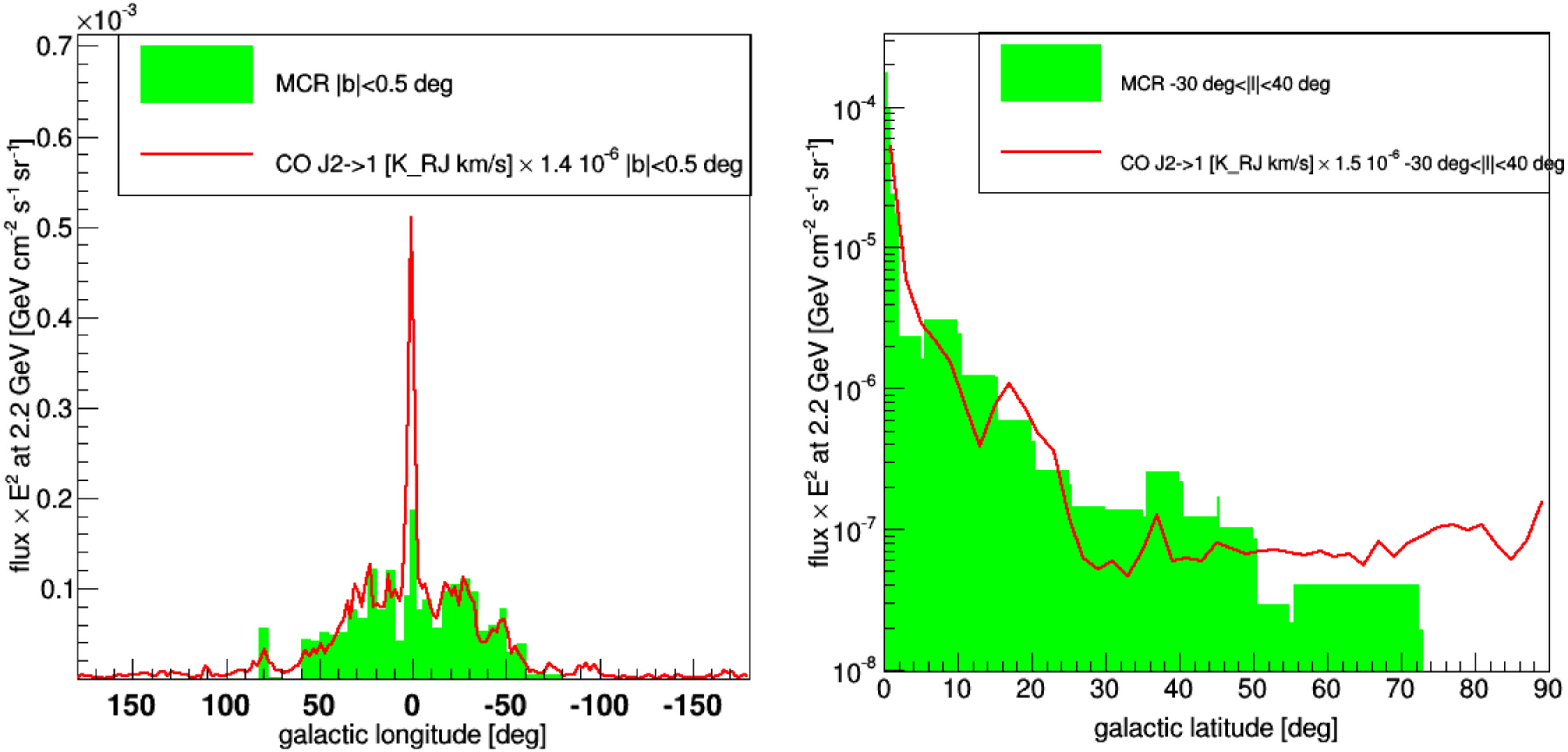




MCR Skymap (=shifted spectrum in data)

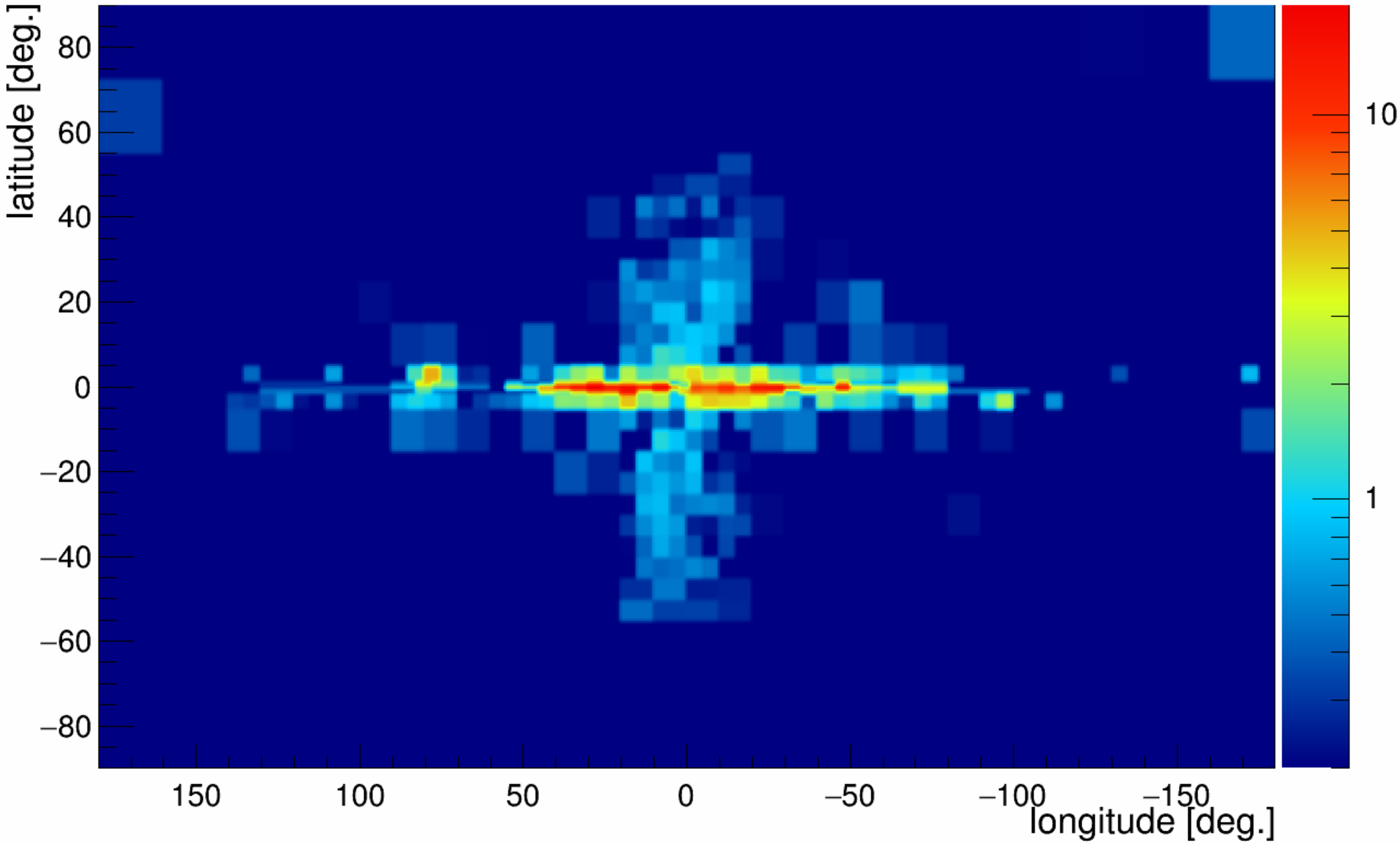


MCR template compared with CO

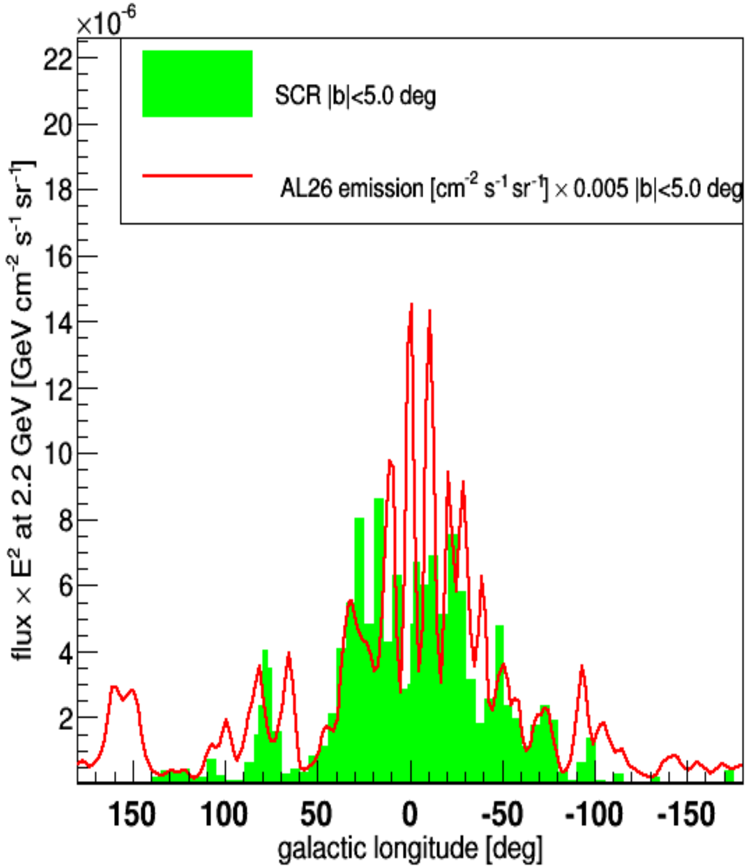


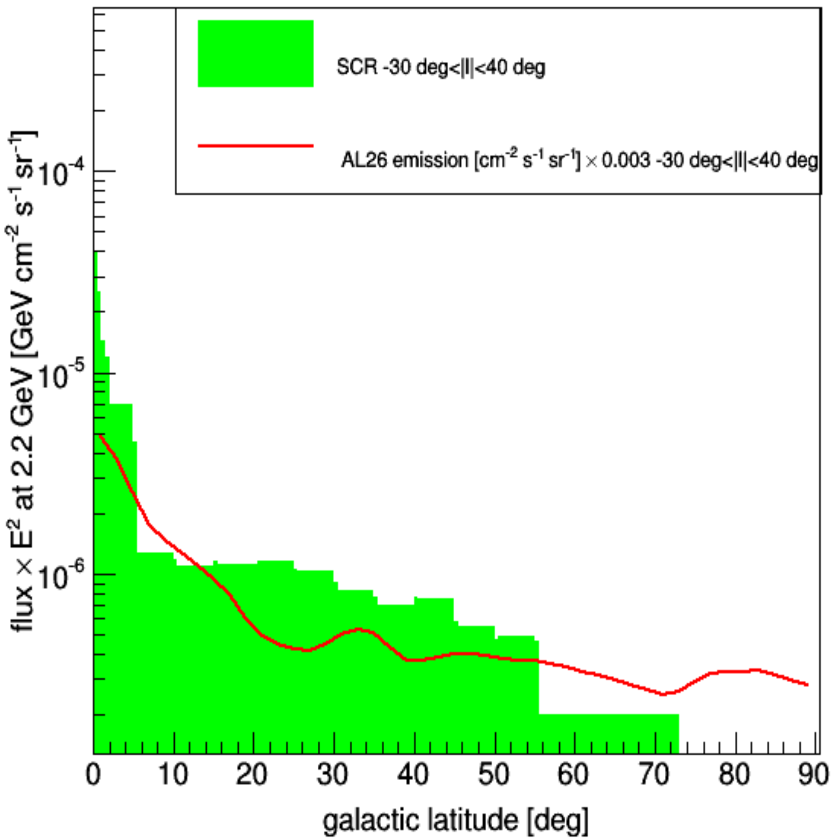
MCR= Integral (MC density x CR density)
CO=MC density

SCR Skymap (=high energy tail in data)



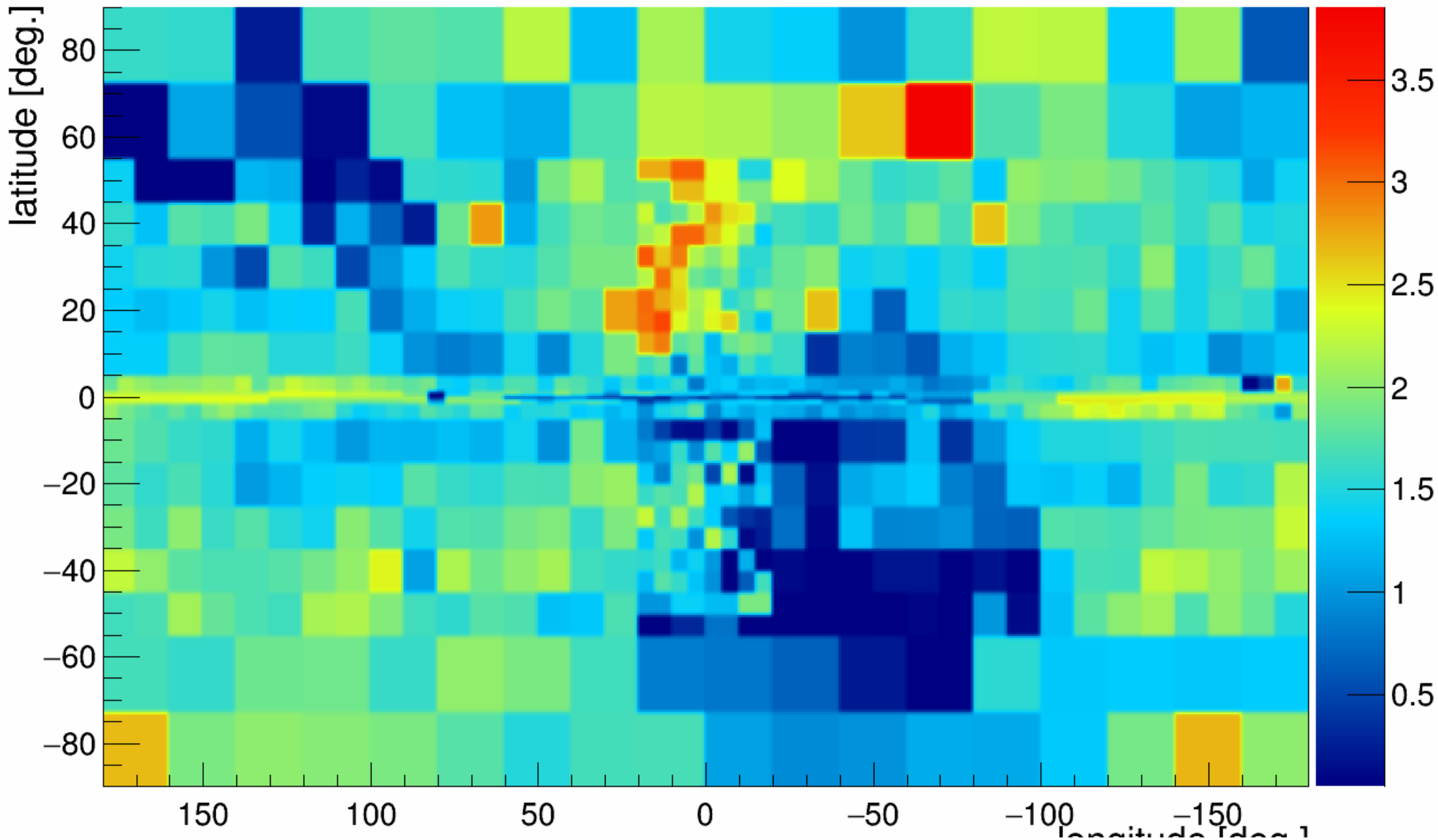
SCR Distribution





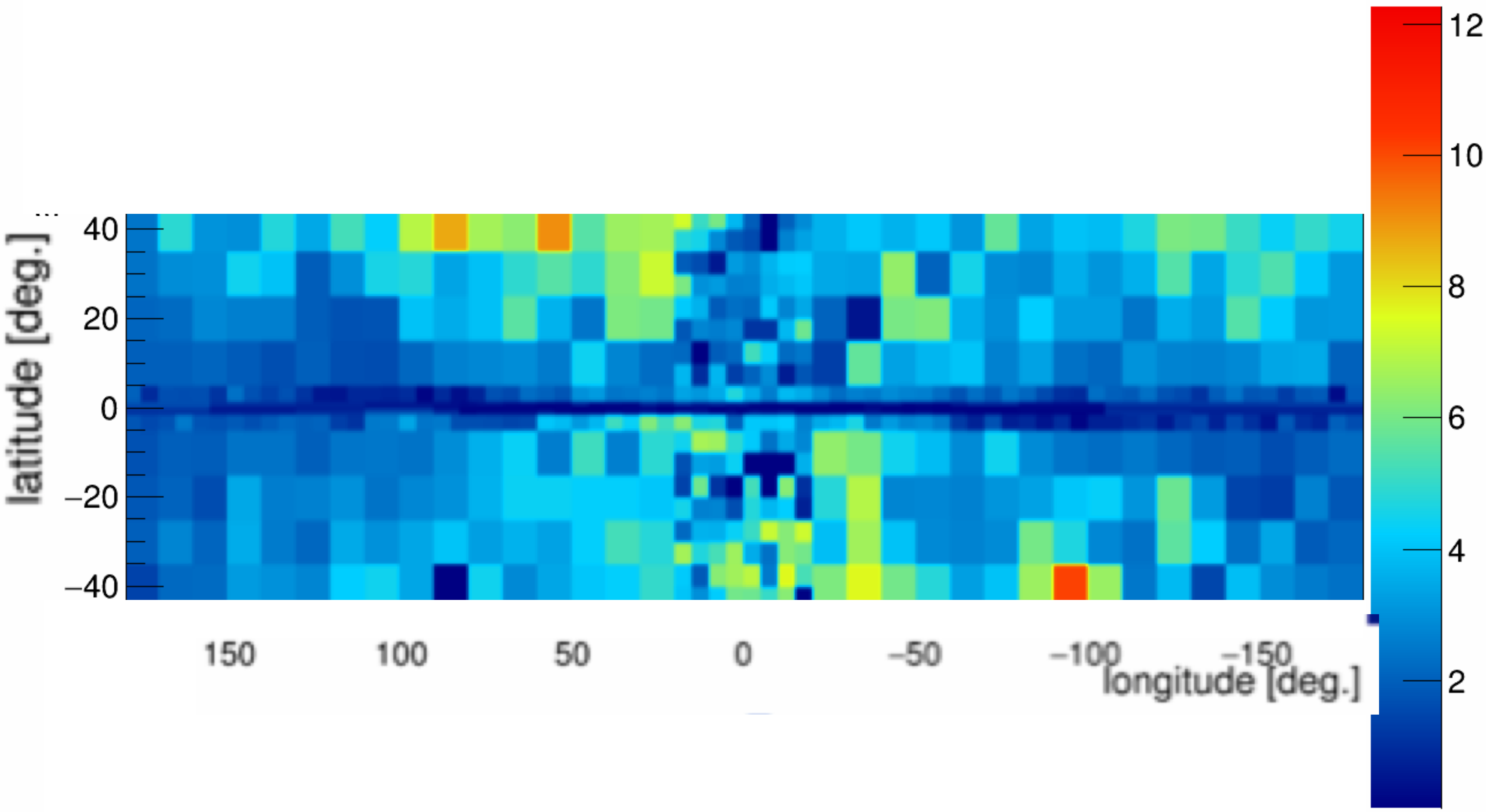
SCR= Integral (source density x CR density)
^{26}Al=source density for (massive) sources with ^{25}Mg

PCR Skymap



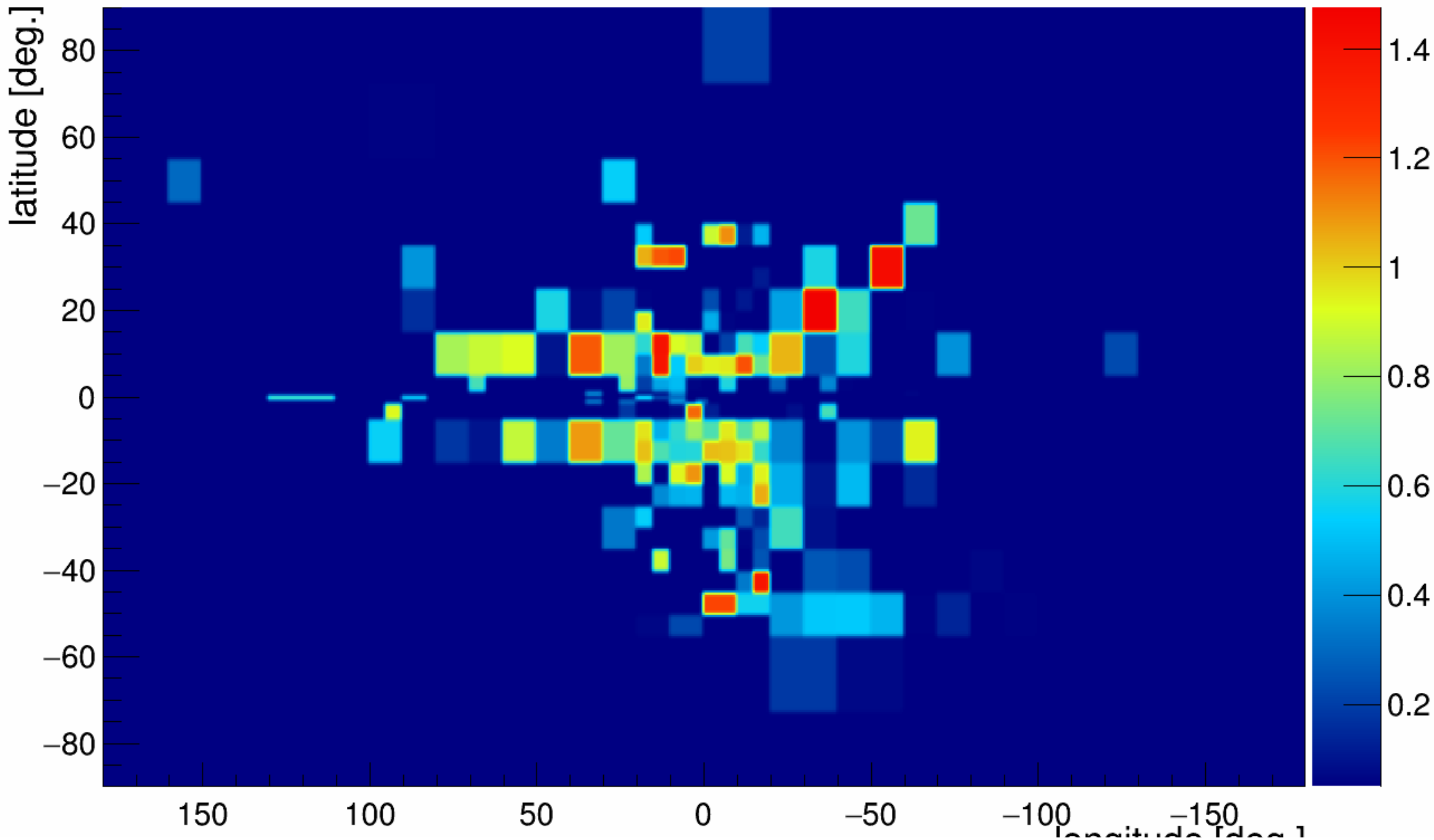
latitude [deg.]
80
60
40
20
0
−20
−40
−60
−80
150
100
50
0
−50
−100
−150
longitude [deg.]
3.5
3
2.5
2
1.5
1
0.5

BR Skymap



latitude [deg.]
40
20
0
−20
−40
150
100
50
0
−50
−100
−150
longitude [deg.]
12
10
8
6
4
2

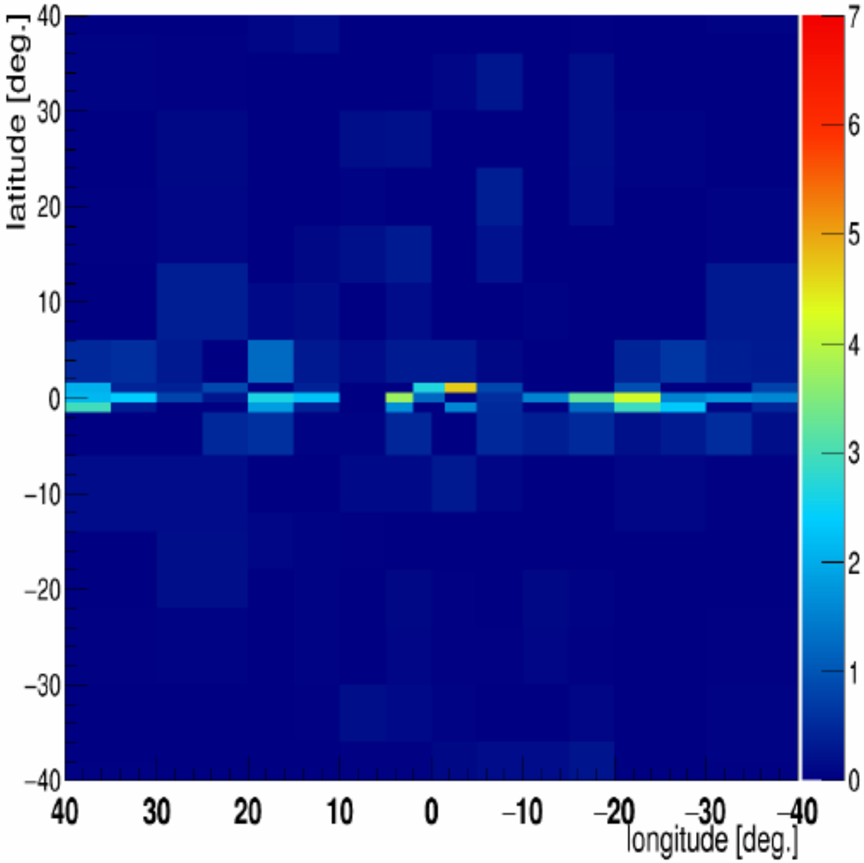
IC skymap



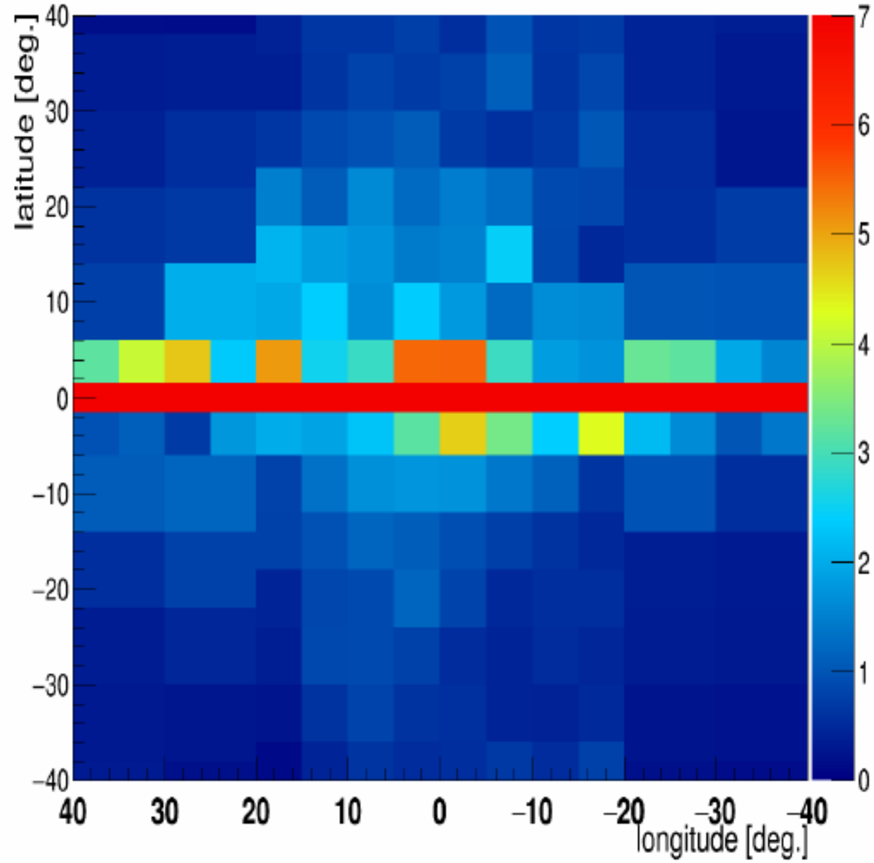
latitude [deg.]
80
60
40
20
0
−20
−40
−60
−80
150
100
50
0
−50
−100
−150
1.4
1.2
1
0.8
0.6
0.4
0.2

Residuals

including all templates



excluding SCR and MCR templates



$|\Phi\rangle = n_1|\pi^0\rangle + n_2|BR\rangle + n_3|IC\rangle + n_4|isotropic\rangle + n_5|SCR\rangle + n_6|MCR\rangle$

describes it all

(absolute difference between data and fit in 10^{-6} GeV cm^{-2} s^{-1} sr^{-1})

Summary

- Energy template fit: flux along a given l.o.s is described by

$$|\Phi> = n_1|\pi^0> + n_2|BR> + n_3|IC> + n_4|isotropic> + n_5|SCR> + n_6|MC>$$

(latter 2 absent in GALPROP, which is the main reason for disagreement between GALPROP and FERMI data in Galactic disk!)

- **All templates from DATA:** $|\pi^0>$, $|BR>$, $|IC>$ from fitting regions of sky excl. bubbles, and disk; $|SCR>$ from bubble/theory; $|MC>$ from CMZ

- all components determined by the fit, i.e. NO foreground subtraction. **DO NOT HAVE TO MASK THE GALACTIC PLANE**

- **High spatial resolution:** can perform template fit in narrow cones with 6 free parameters (n_i, i=1,6) with 21 energy bins. Overconstrained fit.

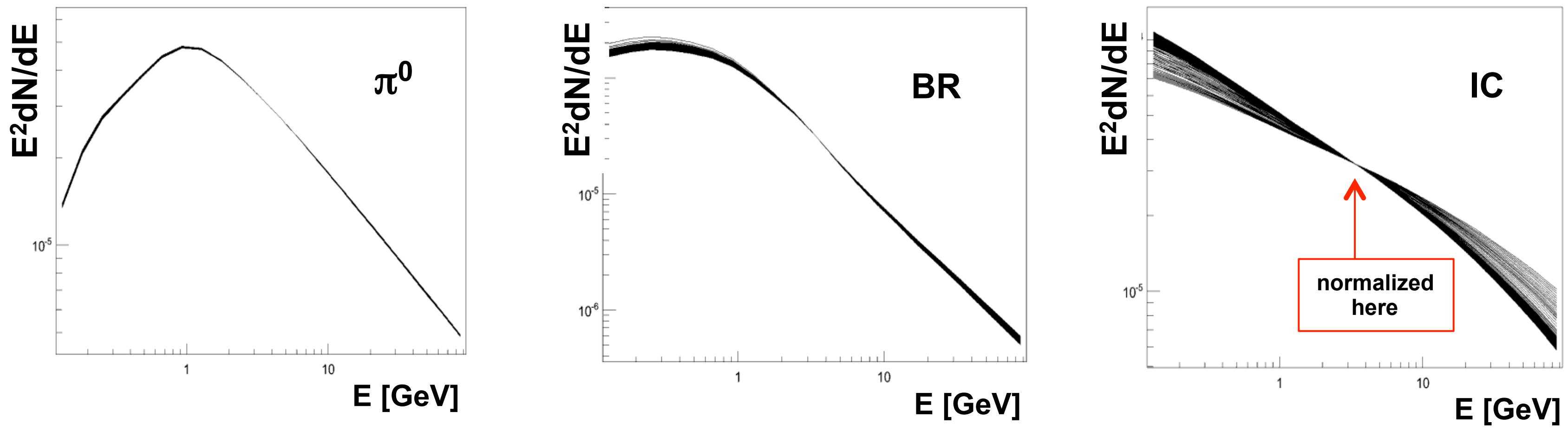
- Alternative explanation of GeV excess: **not an excess, but a depletion of the low energy gammas** in Molecular Clouds (magnetic cut-off?) **➔SHIFT in SPECTRUM**

- Latitude distribution of SHIFT in MCs follows CO distribution (close to NFW)

BACKUP

Variation of Background Templates

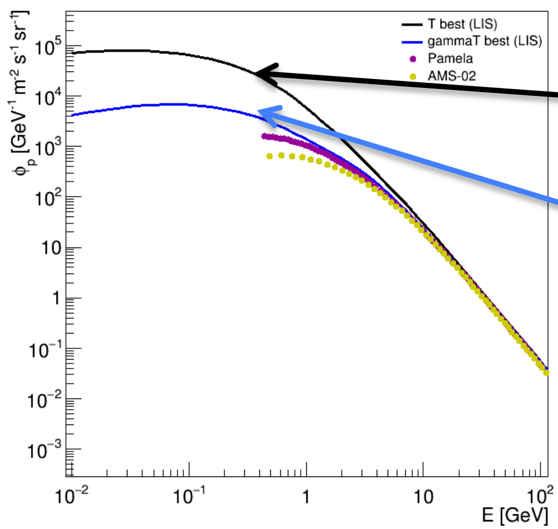
(superimposed in l,b cones in halo and disc)



Note: template shapes only depend on CR spectral shape, if spatial differences for IC targets (star light, dust, CMB) are taken into account.

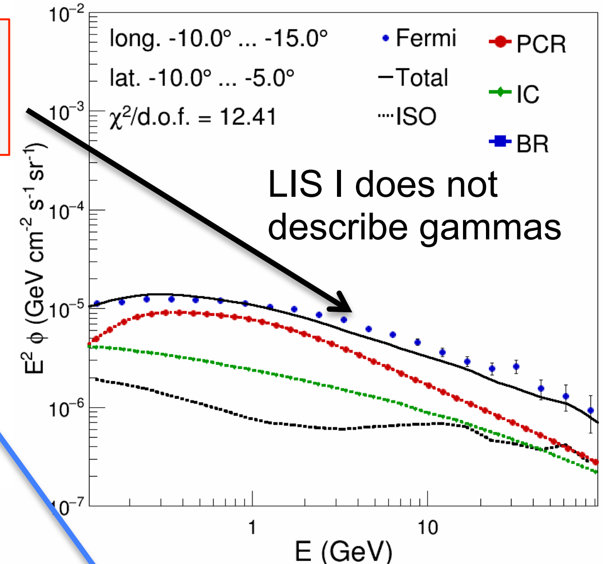
- If the sum of these templates does not describe the data (bad χ^2), this indicates a missing component.

Solar modulation tuned to gamma-rays

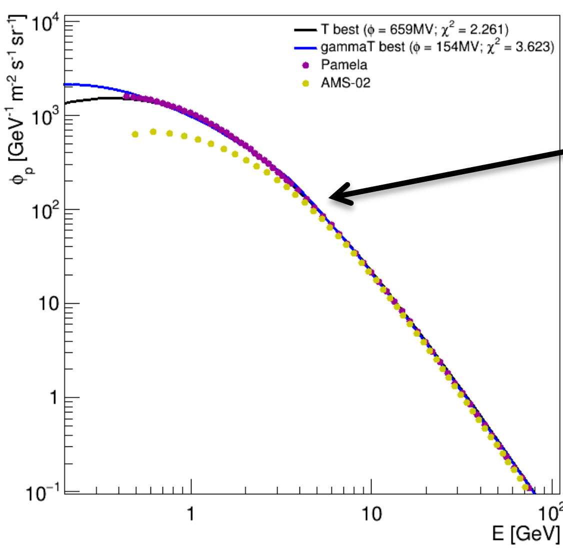


LIS I (needs 659 MeV SM)

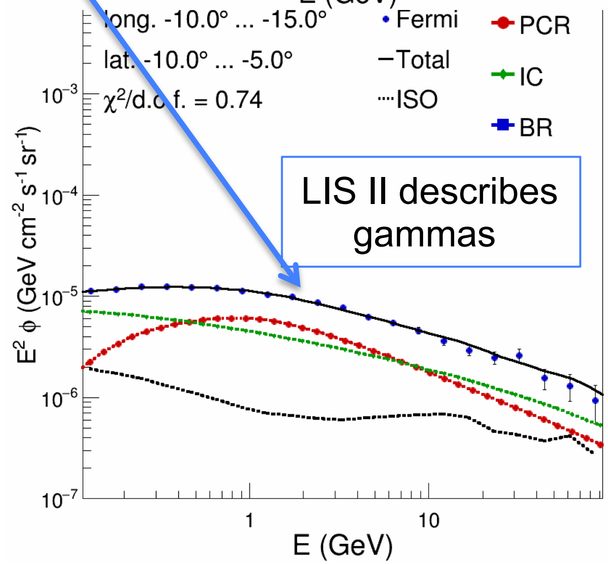
LIS II (needs 154 MeV SM)



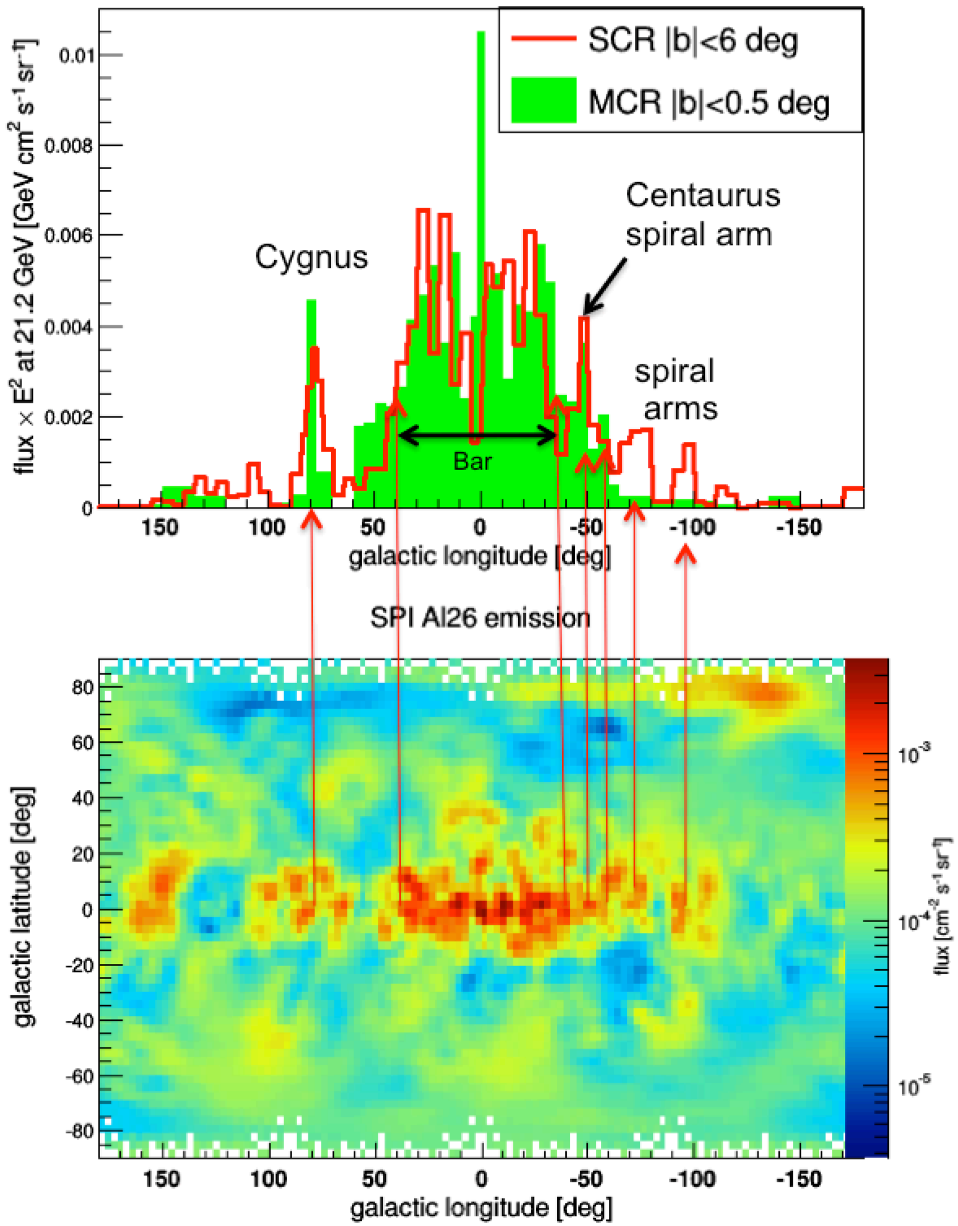
LIS I does not describe gammas



Both LIS spectra describe proton data for different solar modulation parameters



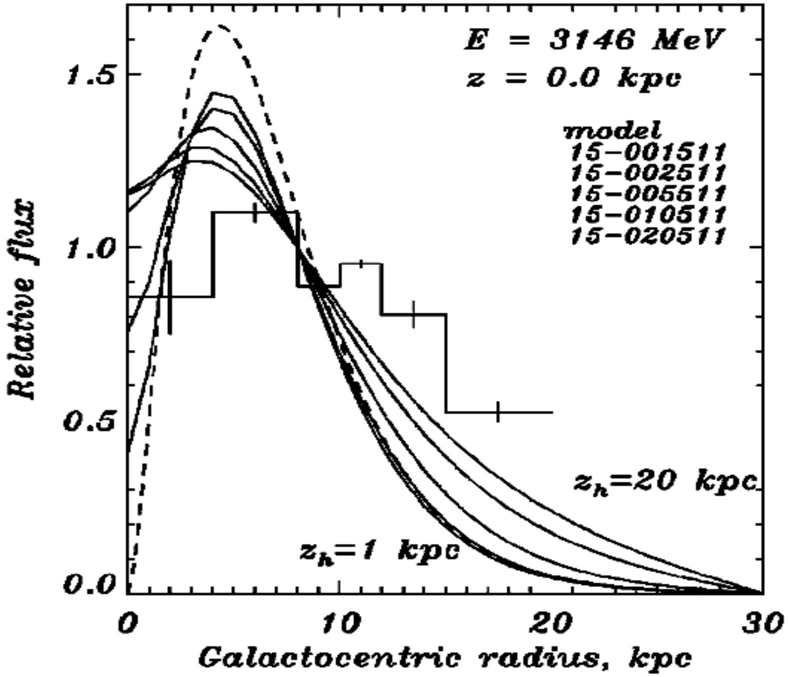
LIS II describes gammas


SCR |b|<6 deg
MCR |b|<0.5 deg
Centaurus spiral arm
Cygnus
spiral arms
Bar
flux × E^2 at 21.2 GeV [GeV cm^2 s^{-1} sr^{-1}]
galactic longitude [deg]
SPI Al26 emission
galactic latitude [deg]
flux [cm^{-2} s^{-1} sr^{-1}]
galactic longitude [deg]

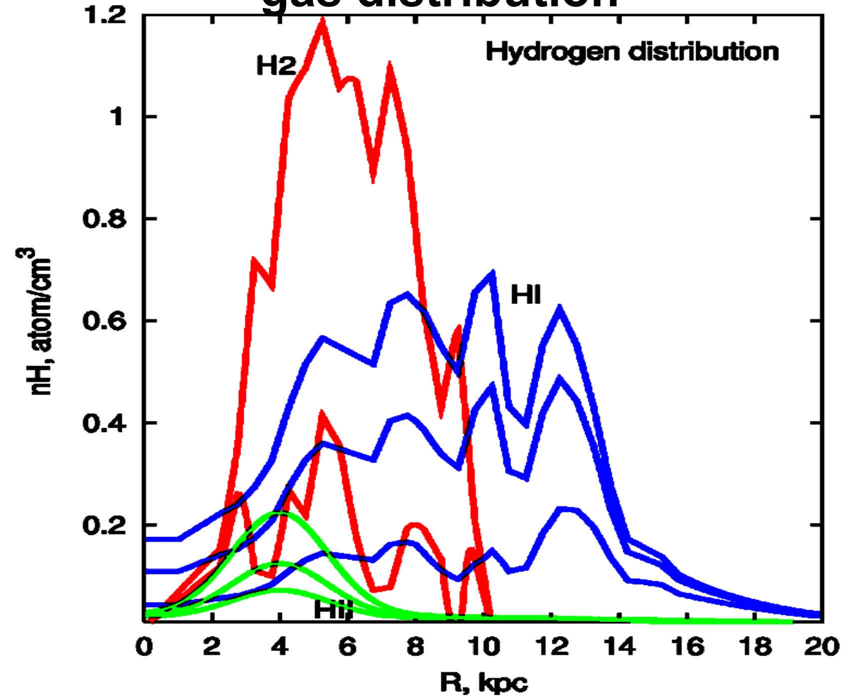
Side remark on use of Galprop for background estimate

Plots from http://galprop.stanford.edu/

source distribution



gas distribution



Source distribution disagrees with 26Al distribution (tracer of sources, which peaks at R=0

Gas distribution disagrees with CO distribution (tracer of H2 gas, which peaks at R=0

Galprop emissivity at GC likely to be underestimated, since spatial distribution of templates disagrees with ^{26}Al and CO peaks in GC. Reliable fits near GC??