Testing the ***Dark Matter*** *Interpretation of the* ***PAMELA*** *Positron Excess with the* ***FERMI*** *Telescope*

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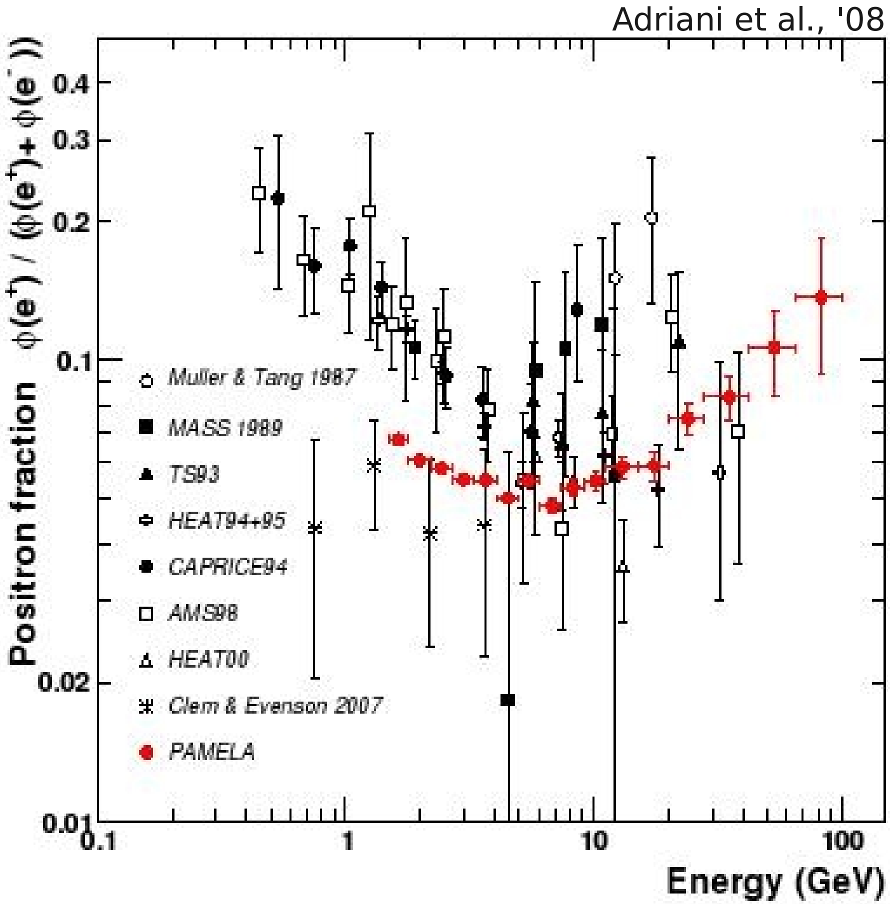
Positron fraction



Puzzle:
explanation of the sharp raise assuming the source is given by interactions of CRs with the interstellar medium

→ **nearby source of positrons**

In abstracts on astro-ph/hep-ph:
pamela positron: 198 papers
" " + dark matter: 172 papers
" " + pulsar: 21 papers

Test for the interpretations of the excess

Test of the interpretation of the PAMELA excess
with an observable such that:

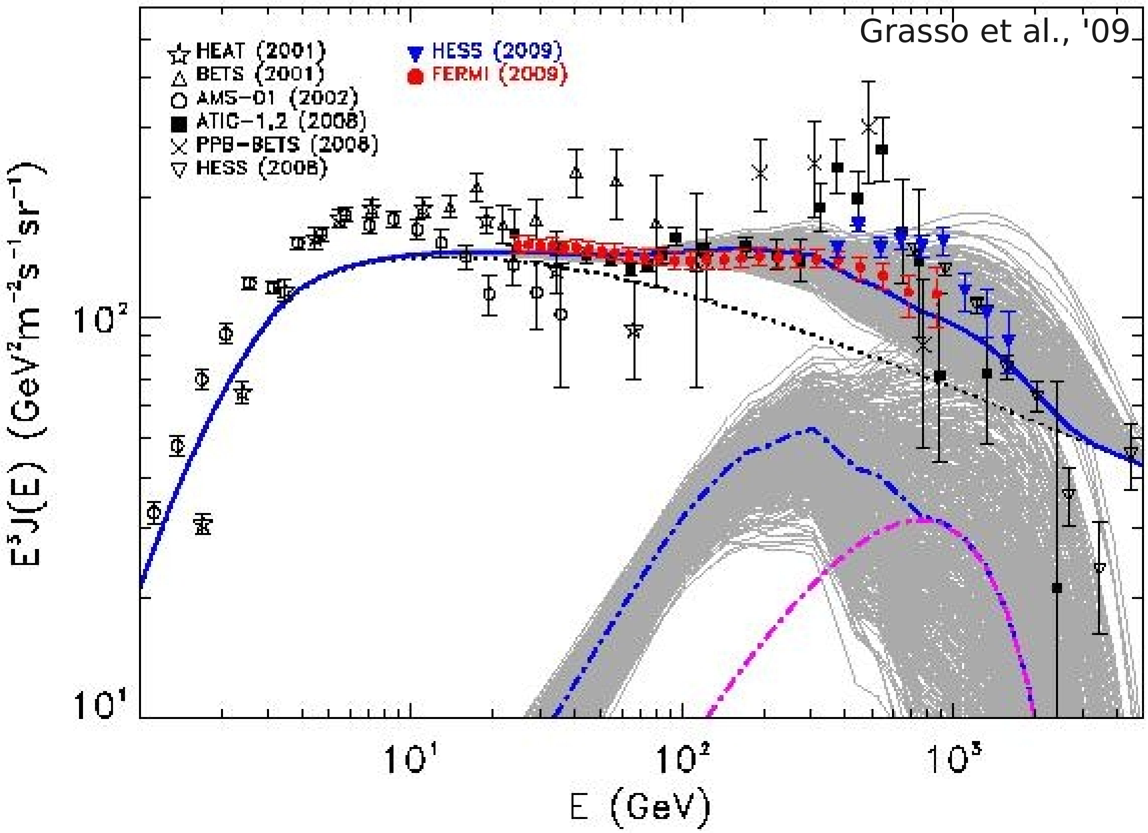
1) Predictions for the DM-induced signal and for the CR-induced signal (or other astrophysical sources) are very different:
disentanglement possible even in presence of some theoretical uncertainties

2) Predictions relying on the same assumptions as for the positron fraction:
self-consistent test

Spectrum

SPECTRAL ANALYSIS

PULSARS:



DM interpretation: The induced spectrum is even more uncertain (annihilation/decay modes, mass, source, ..)

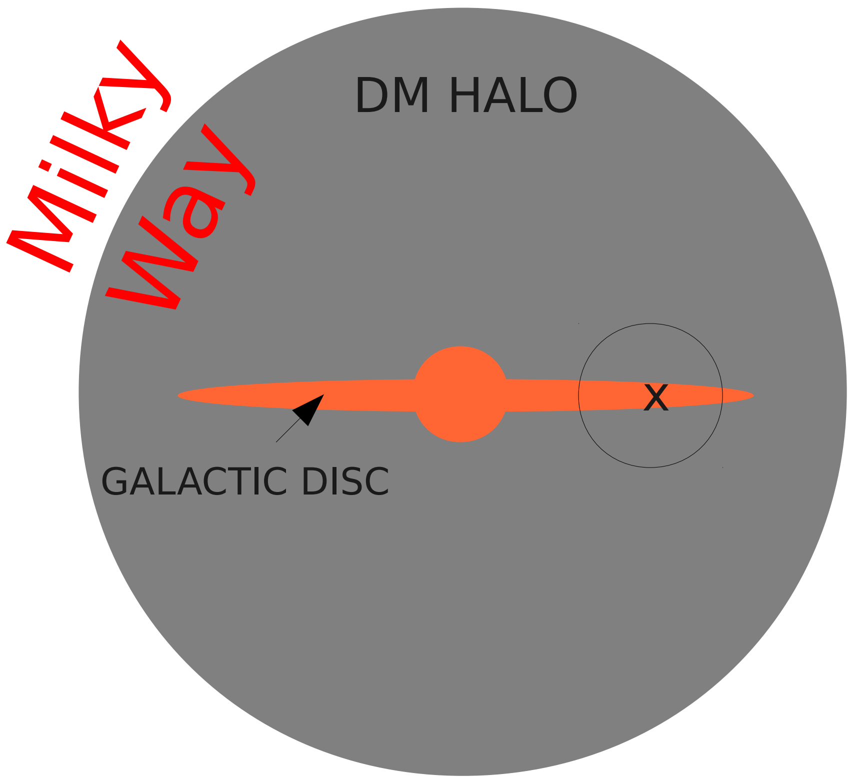
Distinguishing between DM and other astrophysical source is very hard from spectral analysis only.

Spatial distribution

More promising by studying the spatial distribution of the signal

1) anisotropy in the local electron/positron spectrum

2) radiative diffuse emission in the nearby region
(synchrotron radiation and Inverse Compton scattering)

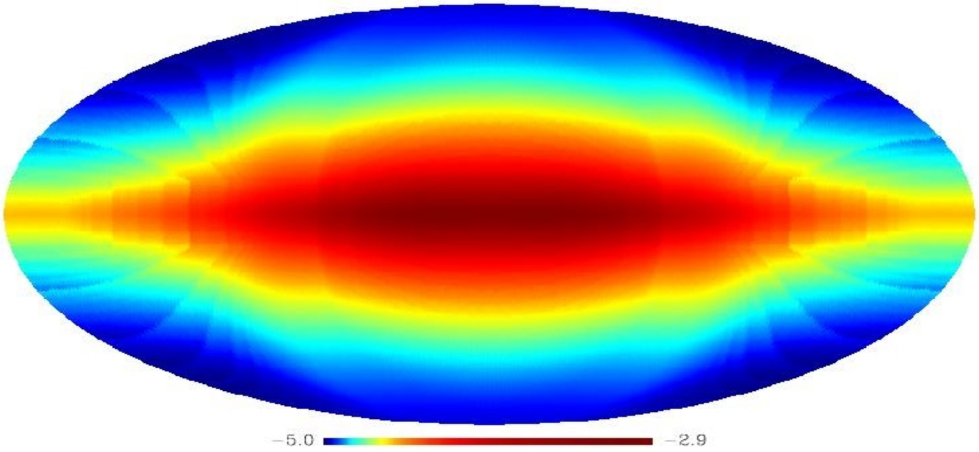


Self-consistent test

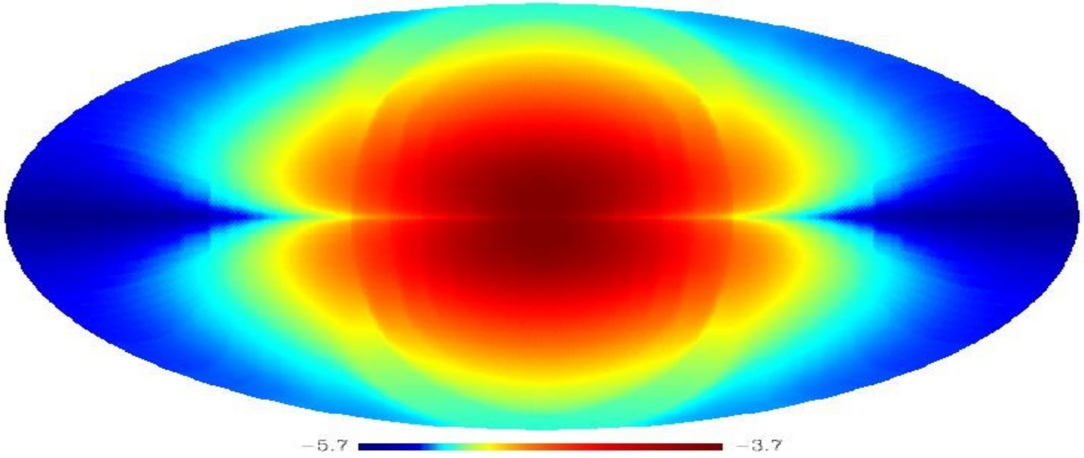
Diffuse emission

IC sky-map at 150 GeV

from CR e^-+e^+



from DM induced e^-+e^+



DM (and astrophysical) sources fitting the PAMELA positron excess **do not show a clear bump** in the diffuse emission at **low latitudes**.

DM models induce an **excess** at **mid-high latitudes** in the γ-ray band (E>100 GeV).

Disentanglement is possible

Transport equation

SPATIAL DIFFUSION — REACCELERATION — ENERGY LOSS — SOURCE

$$\frac{\partial n_i(\vec{r},p,t)}{\partial t} = \vec{\nabla}\cdot(D_{xx}\vec{\nabla} n_i - \vec{v}_c n_i) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p}\frac{1}{p^2} n_i - \frac{\partial}{\partial p}\left[\dot{p} n_i - \frac{p}{3}(\vec{\nabla}\cdot\vec{v}_c) n_i\right] + q(\vec{r},p,t) + \frac{n_i}{\tau_f} + \frac{n_i}{\tau_r}$$

CONVECTION — DECAY FRAGMENTATION

Data give indications of averages of **propagation parameters over the nearby region of the Galaxy**

Solved numerically on a grid using the Crank-Nicolson scheme (**GALPROP code**: Strong&Moskalenko, '98) and assuming **steady-state** and **cylindrical symmetry**.

Positron Source / WIMP induced $e^+ - e^-$

annihilating DM

$$Q_i^a(r,E) = (\sigma_a v)\,\frac{\rho(r)^2}{2\,M_\chi^2} \times \frac{dN_i^a}{dE}(E)$$

decaying DM

$$Q_i^d(r,E) = \Gamma_d\,\frac{\rho(r)}{M_\chi} \times \frac{dN_i^d}{dE}(E)$$

$$\Gamma_d^{-1} = \tau \simeq (\sigma_a v)^{-1} \cdot M_\chi/\rho_0$$

PAMELA data:

- mass above 100 GeV
- leptophilic
- “large” annihilation rate

	M_χ [GeV]	$\sigma_a v$ [$cm^3 s^{-1}$]	annihilation modes	spatial profile	line coding
DMe	300	$3.8 \cdot 10^{-24}$	e^+e^-	Burkert	dotted
DMτ	400	$6.6 \cdot 10^{-24}$	$\tau^+\tau^-$	Burkert	dashed
DMμ	1500	$2.5 \cdot 10^{-23}$	$\mu^+\mu^-$	Burkert	dashed-dotted

DM spatial profile:

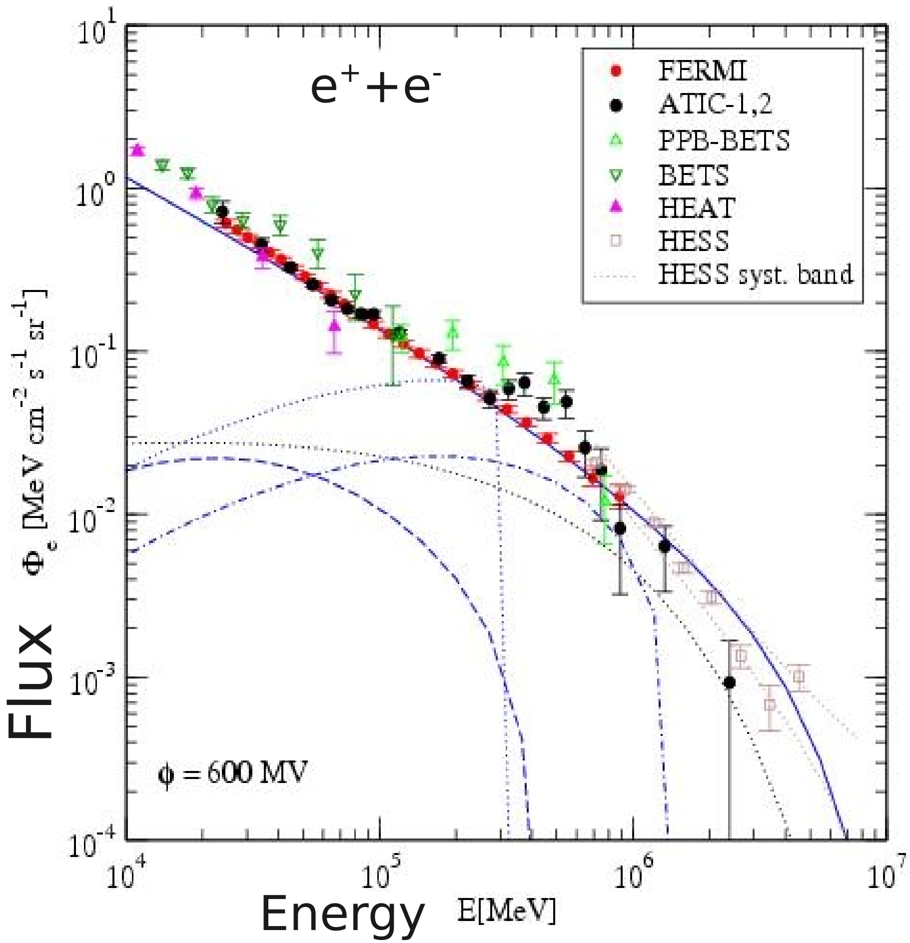
(To avoid constraints from GC)

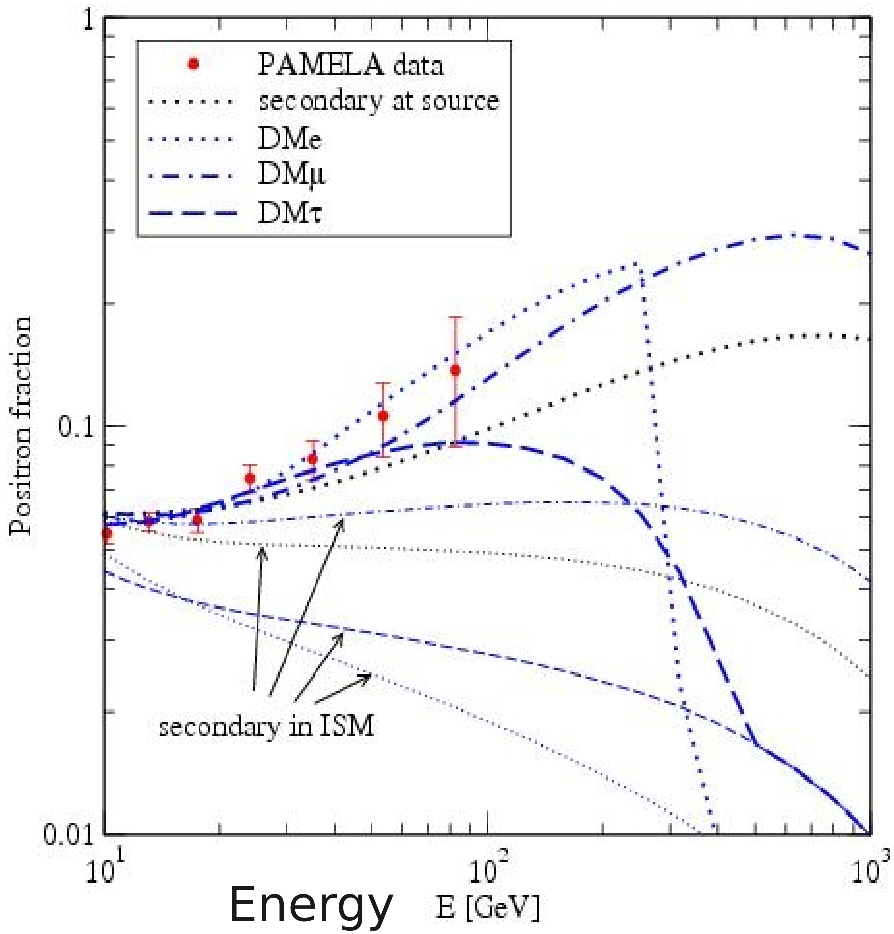
Burkert form: (r_c=11.7 kpc)

$$\rho(r) = \frac{\rho_0}{(1 + r/r_c)\,(1 + (r/r_c)^2)}$$

Electrons/positrons spectrum

"Conventional" propagation model B0:



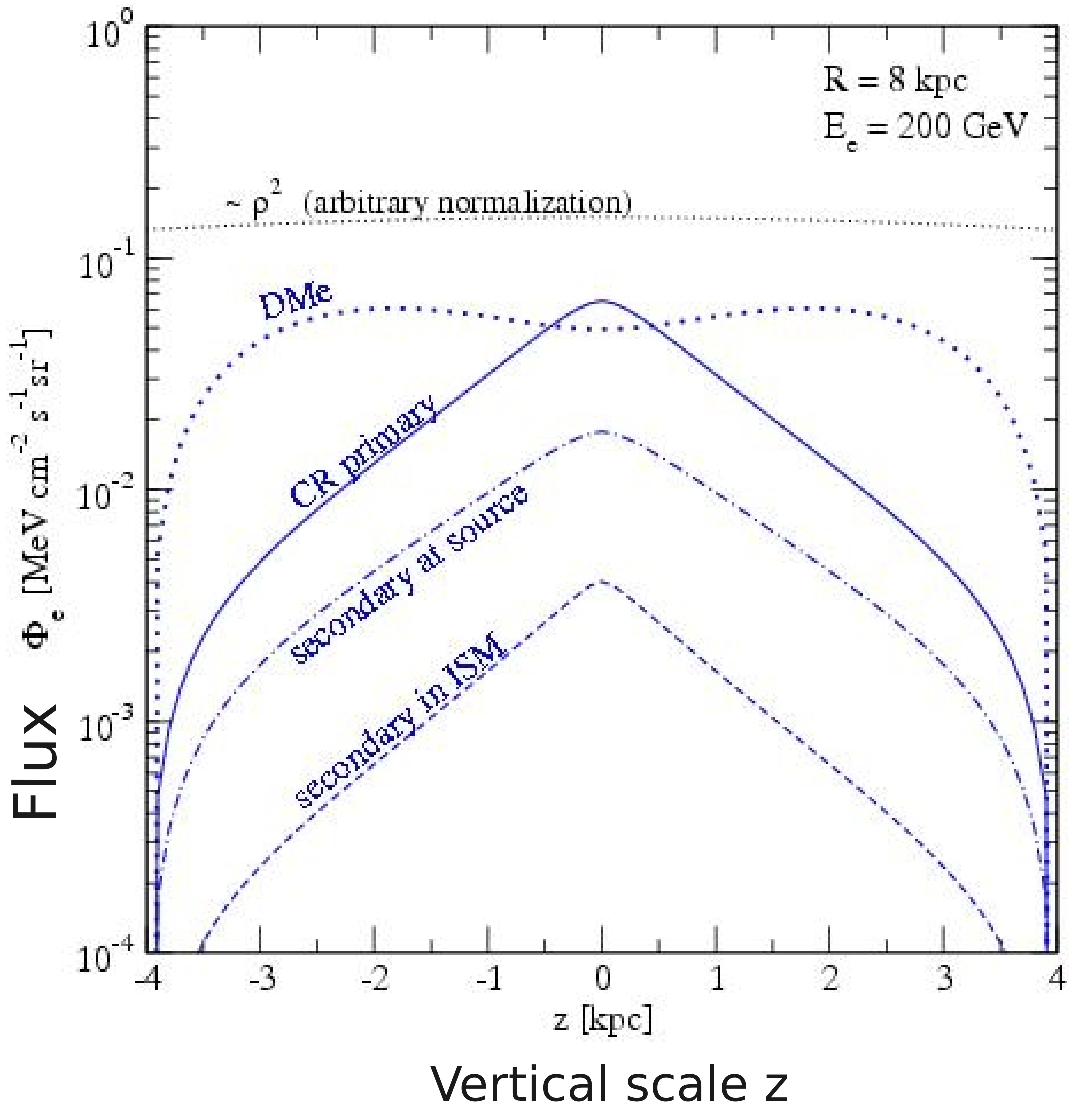


Satisfactory fits to the PAMELA+FERMI data for all the models, but **DMe**.

CR background for diffuse emission: fit to data with CR alone.

e^+-e^- vertical profile /1

Vertical density profile at R=8 kpc for the "**conventional" propagation model B0** at E=200 GeV



CR primary/secondary sources confined to the Galactic disc, while DM induced source extending much further.

Diffuse emission

GALACTIC DIFFUSE EMISSION

Cosmic rays:

protons : γ–rays from π^0 decay

e^-/e^+ : IC e bremsstrahlung emission in the γ- and X-ray bands
synchrotron emission at radio frequencies

confined to the disc (analogous for astrophysical explanations of PAMELA)

Dark matter:

e^-/e^+ : IC and synchrotron emission

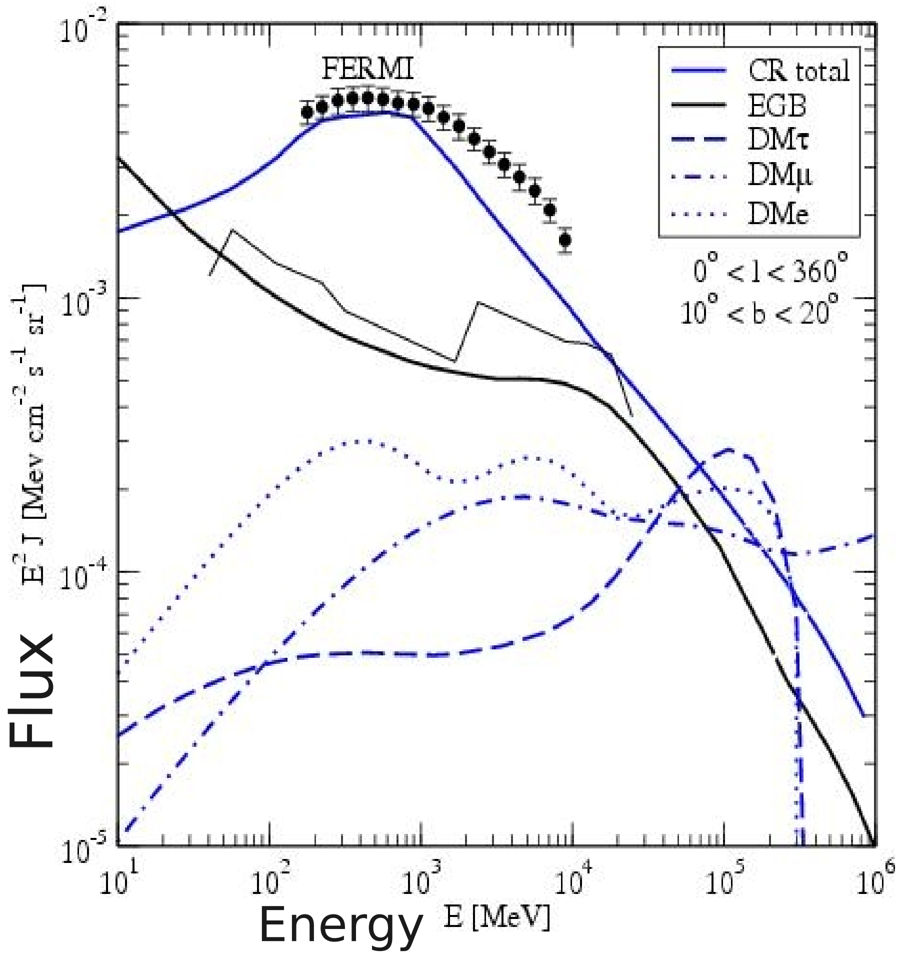
γ–ray prompt emission : π^0 decay (DMτ) and final state radiation (DMe and DMμ)

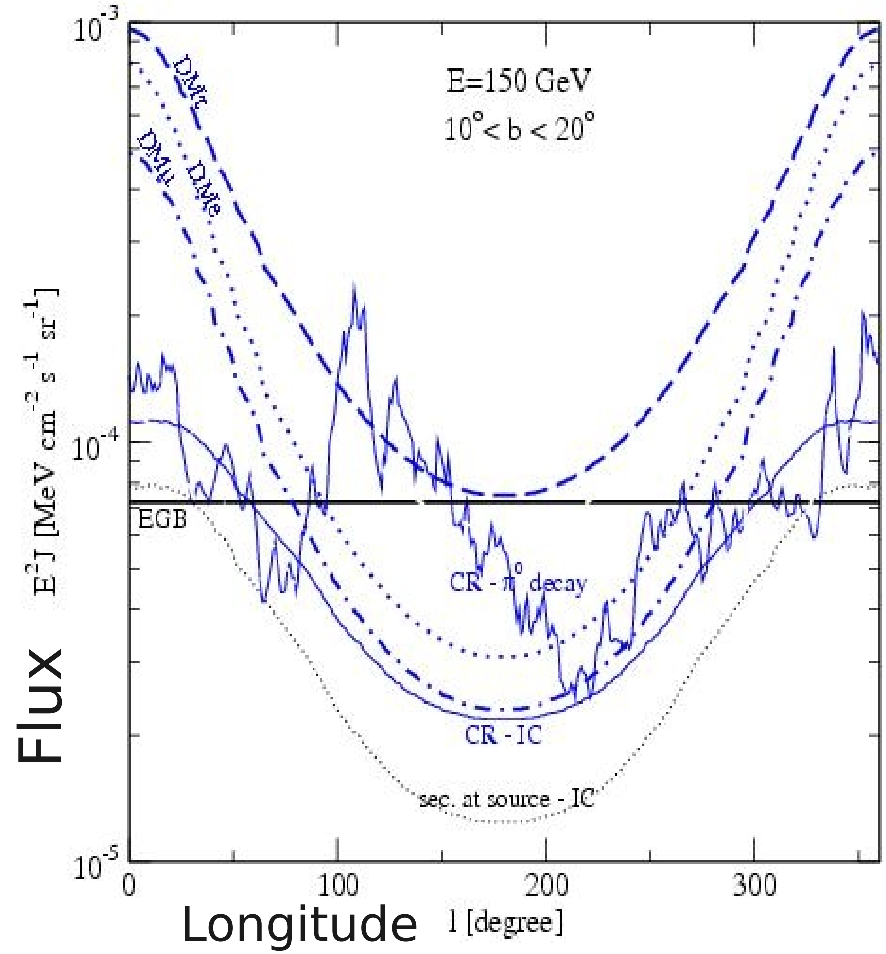
from an extended halo

EXTRAGALACTIC DIFFUSE EMISSION

- Unresolved active galactic nuclei (**blazars**)
- Model for **absorption** at high energy
- Dominant component at **high latitudes**
- FERMI can significantly improve the analysis of the EGB

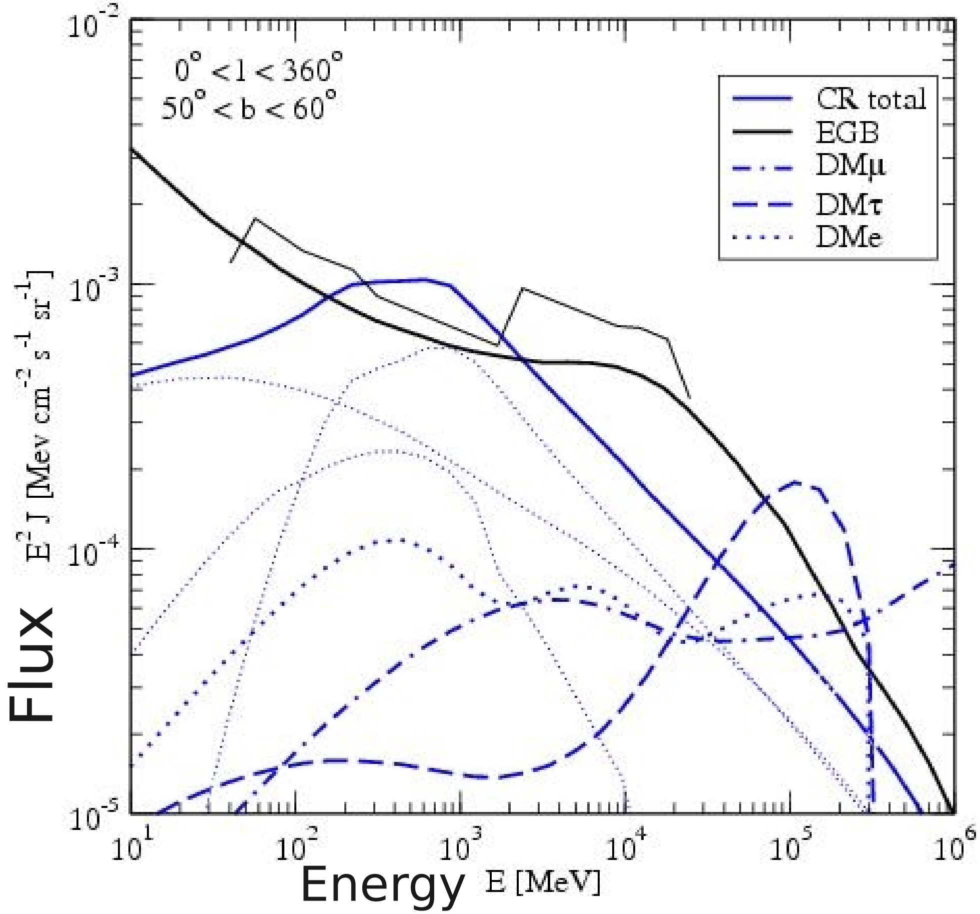
gamma rays at intermediate latitudes

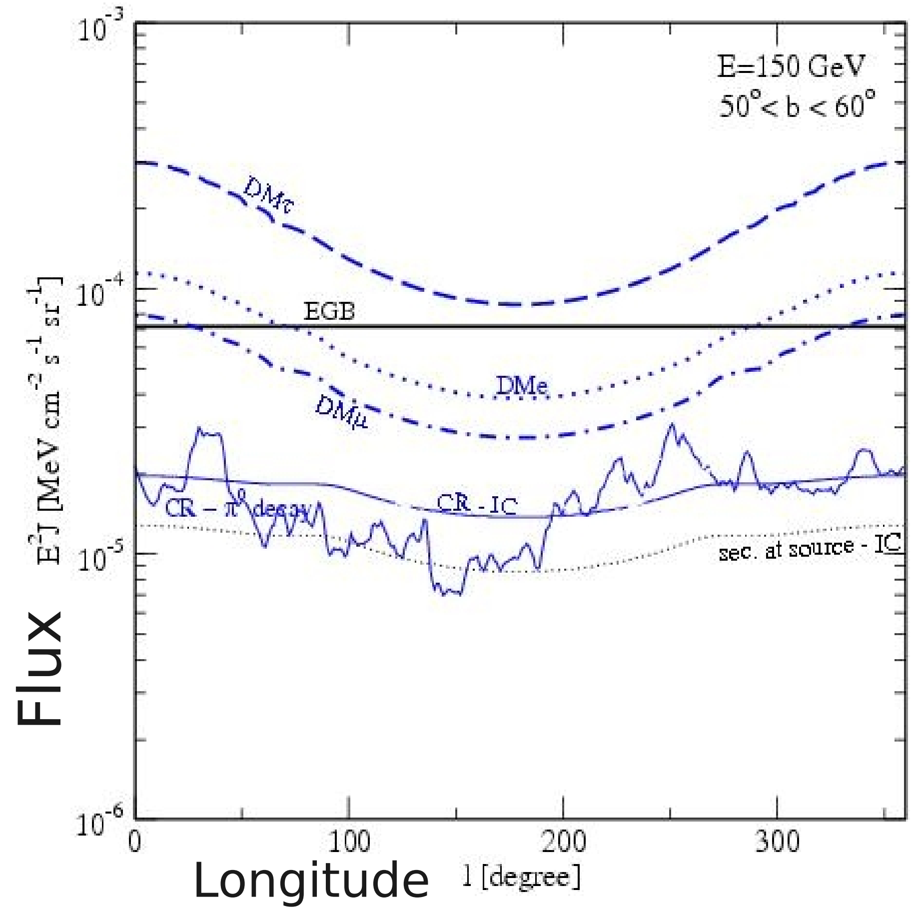




- **Good fit at E<10 GeV given by the CR component**
- **Excess at E>100 GeV for any of the DM benchmark models**
- DM induced component dominates over a large range of longitudes
- Subdominant emission in the case of secondaries at the source

gamma rays at high latitudes





Ratio DM vs Galactic CR signal is enhanced

Extra Galactic background emission starts to become very important

Benchmark models of propagation

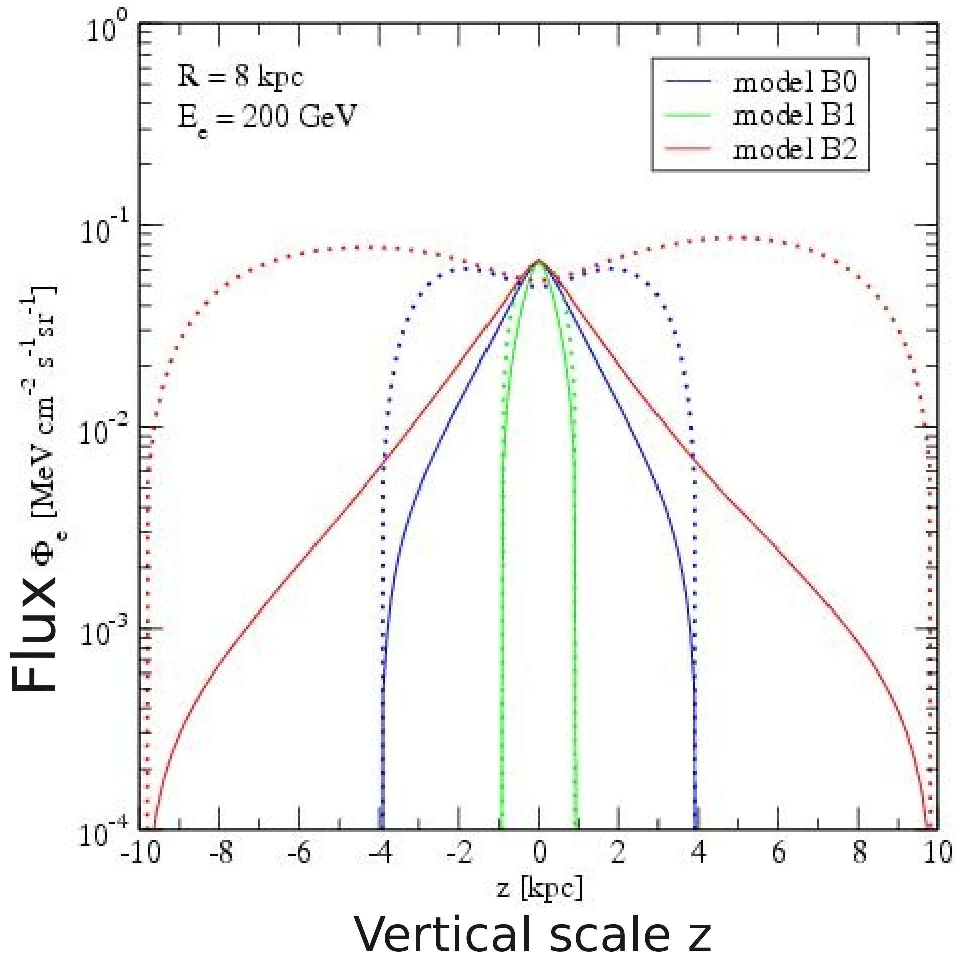
We want to investigate how **different scalings along the z-direction** due to different propagation models can affect the predictions for the **DM signal to CR background ratio**.

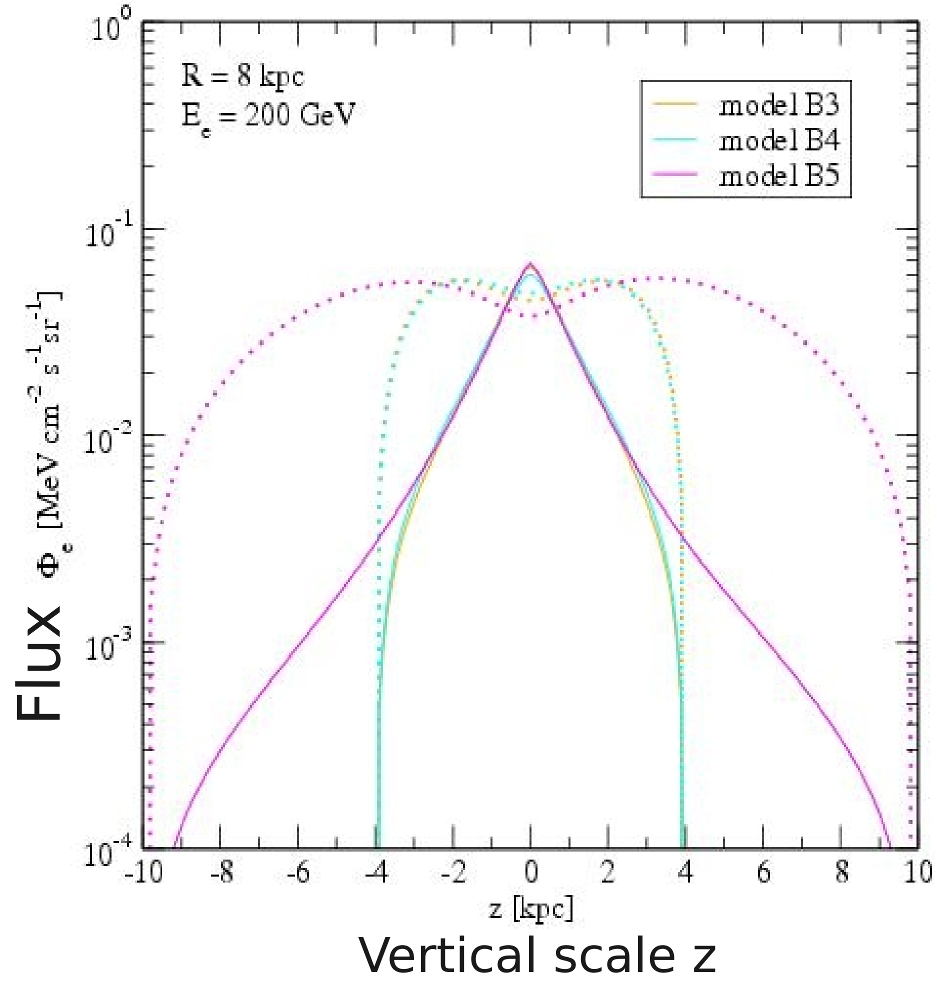
Benchmark models of propagation

		z_h kpc	D_0 10^{28} cm^{2}s^{-1}	α	v_a km/s	$\beta_{inj,nuc}$	$\beta_{inj,e}$	dv_c/dz km/s kpc^{-1}	χ^2_{red} (d.f.=19)	color coding
Conventional	B0	4	3.3	1/3	35	1.85/2.36	1.50/2.35	0	0.67	blue
Thin halo	B1	1	0.81	1/3	35	1.65/2.36	1.50/2.35	0	0.77	green
Thick halo	B2	10	6.1	1/3	35	1.85/2.36	1.50/2.35	0	0.74	red
Wind	B3	4	3.25	1/3	45	1.85/2.36	1.50/2.35	10	0.84	orange
Kraichnan spectrum	B4	4	1.68	1/2	22	2.4/2.2	2.1/2.35	0	0.86	cyan
Spatially varying D_{xx}	B5	10	$2.8 \cdot e^{\lvert z \rvert / z_s}$	1/3	35	1.85/2.36	1.50/2.35	0	0.66	magenta

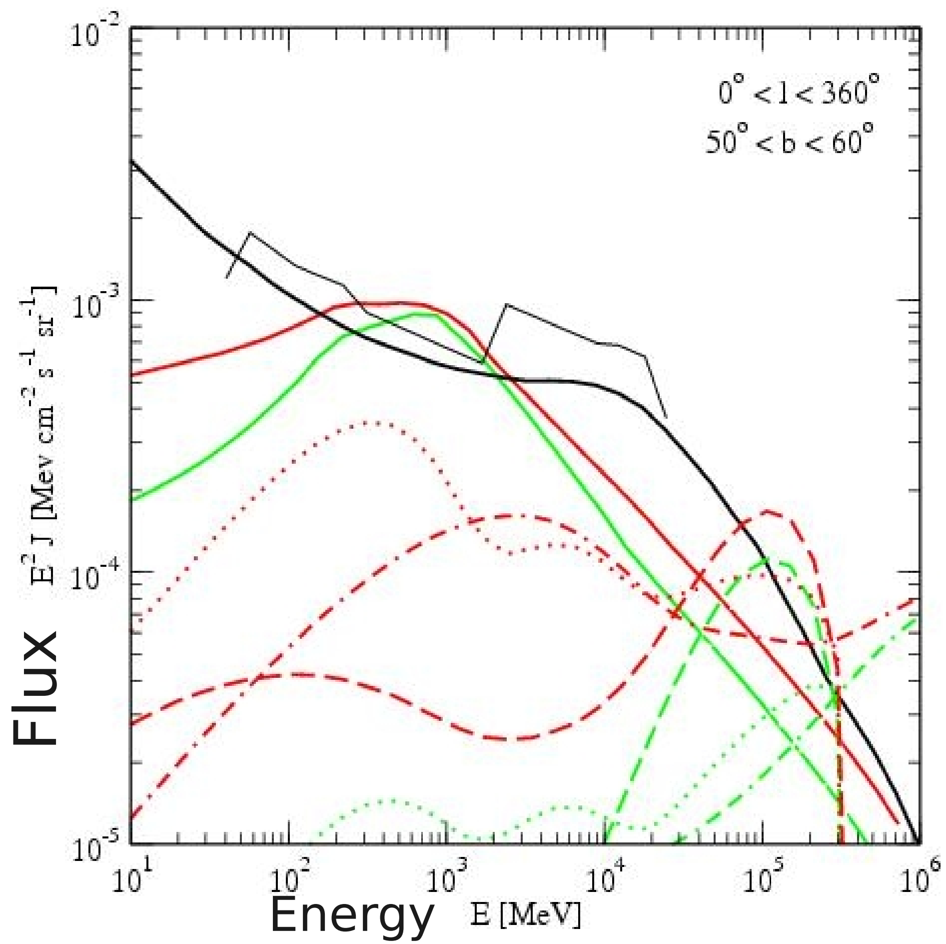
$e^+ - e^-$ vertical profile /2

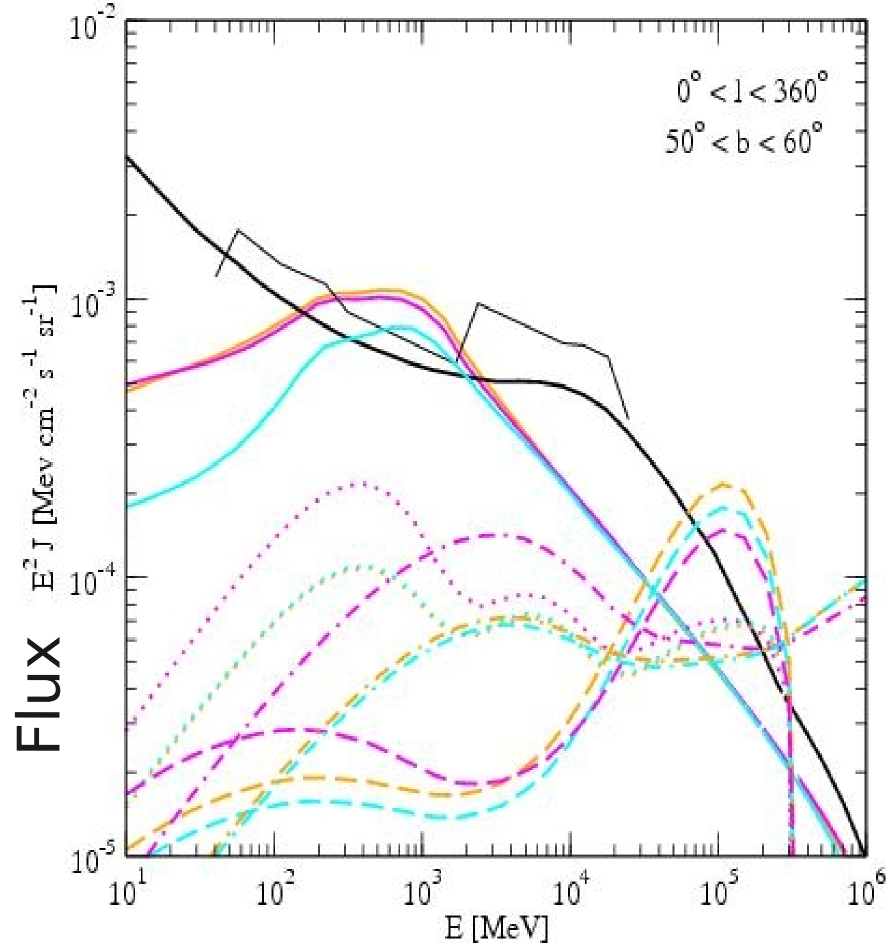
Similar picture for all the benchmark propagation models, but the model B1 which assumes a thin (z_h=1 kpc) disc of propagation





gamma rays at high latitudes /2





For any benchmark model of propagation, the excess at E>100 GeV is present.

The case of the model with thin halo is less favorable than B0 if the bulk of the emission is due to IC (DMe and DMμ), while with thick halo is more favorable.

Discussion on assumptions for DM /1

Spatial distribution

• DM PROFILE
Prediction quite **insensitive** to the halo model since it is well away from the GC

• DARK DISC
Analysis affected only if density dark disc > density dark halo (**unlikely**)

• EXTRAGALCTIC DM CONTRIBUTION
Uncertain and (being conservative) **subdominant** w.r.t. AGN contribution

• DM SUBSTRUCTURES
Large **uncertainties**. Prediction strengthened if distribution anti-biased w.r.t. halo.

Discussion on assumptions for DM /2

Spectrum

- prediction **insensitive** to whether it is related to decaying or annihilating DM

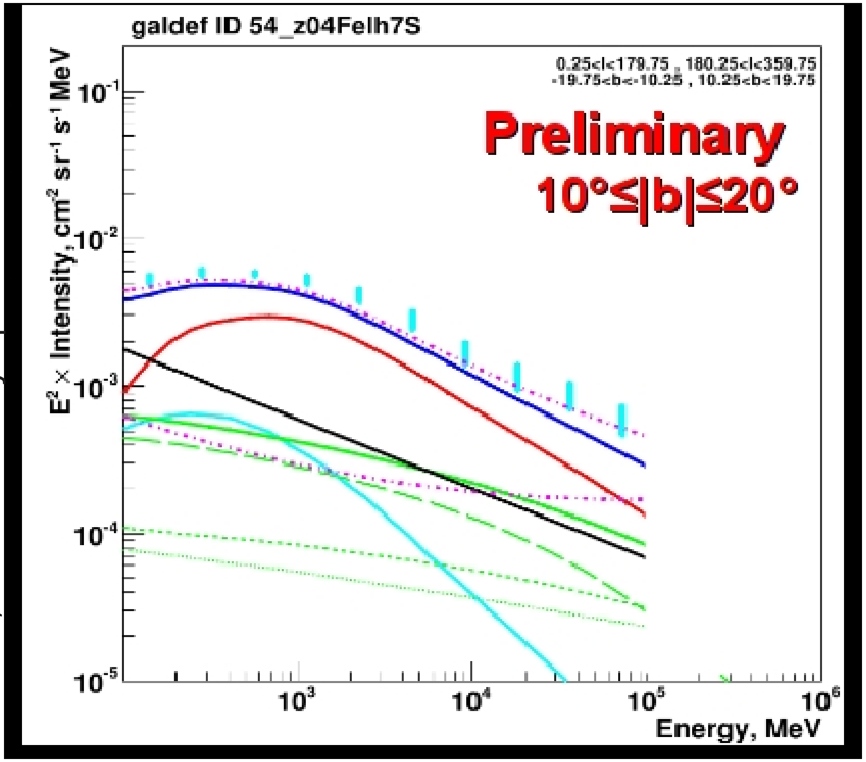
- Mχ~ TeV : **detectable IC** emission
- Mχ ~ few hundreds of GeV and hard spectrum : **detectable IC** emission
- Mχ ~ few hundreds of GeV and $\tau^+\tau^-$ final state : **detectable π^0-decay** emission
- Mχ ~ few hundreds of GeV and “soft” spectrum and no τ's : **hardly detectable**

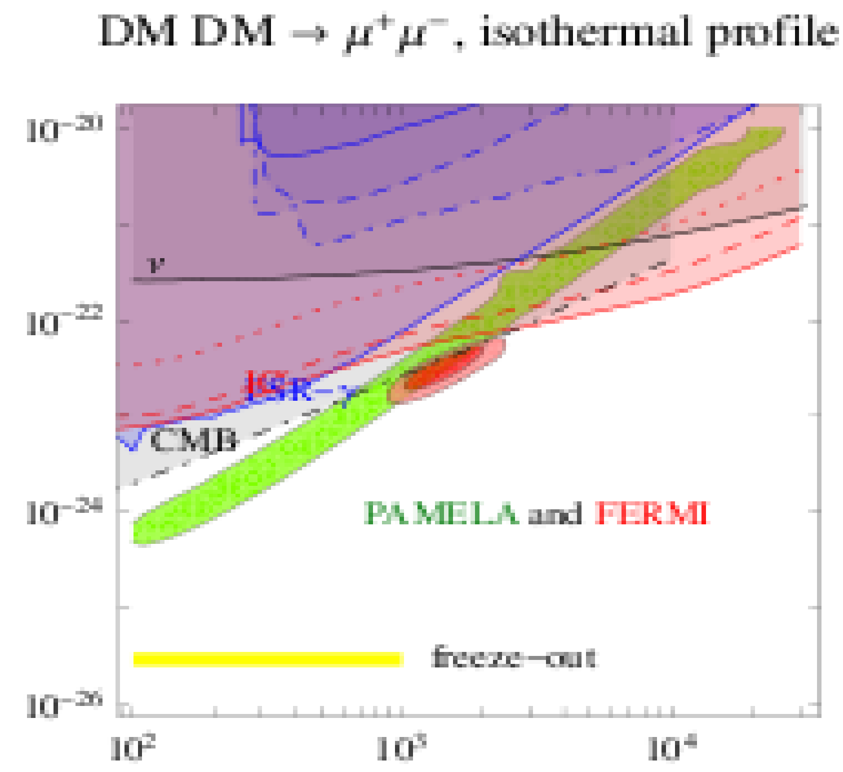
→ if FERMI data on the diffuse emission shows **no excess**, the **DM** interpretation of the PAMELA excess is **strongly constrained**

Current data

FERMI DATA
for DIFFUSE gamma-ray background

T. Porter, 2009 Fermi Symposium





Papucci&Strumia, 2009

To completely test DM interpretation of PAMELA positron fraction with FERMI, we need **cleaning from systematics** and **more statistics** at high energies (**E_γ ~100 GeV**)

Conclusions

• **CR** sources (and astrophysical sources of positrons) are confined to the **Galactic disc**, while the **DM** component has a **spherical distribution**.

• The ratio of **DM signal vs CR background** in the diffuse emission is **enhanced at mid-high latitudes**

• Extrapolation of **propagation** parameters and **DM profile** is rather robust in the **nearby region**

• **DM models**, tuned to explain the positron excess, typically lead to a **detectable diffuse emission at E>100 GeV and mid-high latitudes**.

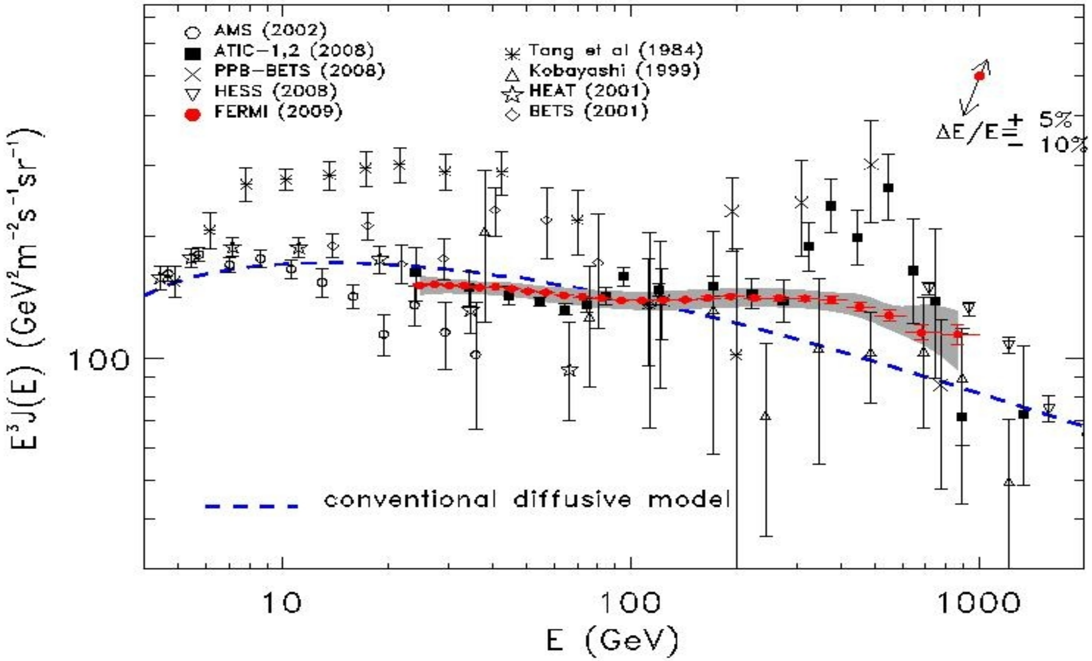
FERMI data on diffuse emission at such energies and latitudes to be released in the next few months

Positron Source / WIMP induced e^+-e^-

FERMI+PAMELA data:

M_χ <1 TeV : needs softer e^+-e^-

M_χ >1 TeV : somehow favored



	M_χ [GeV]	$\sigma_a v$ [cm^{3}s^{-1}]	annihilation modes	spatial profile	line coding
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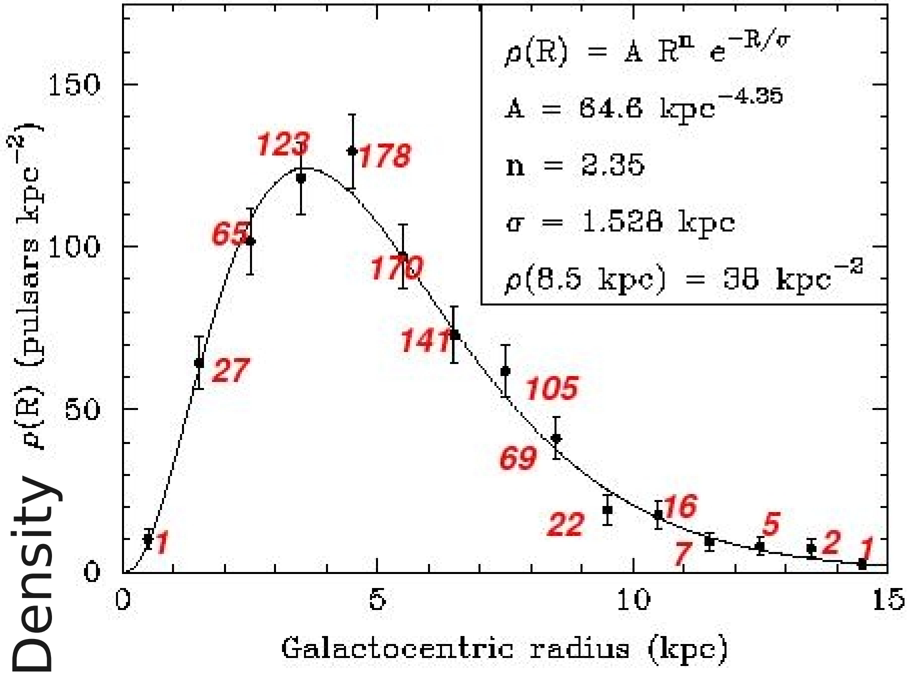
DMμ	1500	$2.5 \cdot 10^{-23}$	$\mu^+\mu^-$	Burkert	dashed-dotted

Source / Cosmic ray

PRIMARY SPECIES:
Strong indications that shock acceleration in SNRs is the source for energetic CR (with spectrum ~ $E^{-\beta}$, and β~2)

SPATIAL DISTRIBUTION traced by pulsars (Lorimer, 2004)



INJECTION SPECTRUM
We assume a broken power-law.

Spectral index suggested by
Local spectra at high energy
Diffuse emission at low energy

Normalized a posteriori to the measured flux at Sun position

SECONDARY SPECIES:
Produced by collisions of primary CRs with the gas (Strong&Moskalenko, '98).

Positron Source / astrophysical

PULSAR:
Rotating neutron stars with a strong surface magnetic field

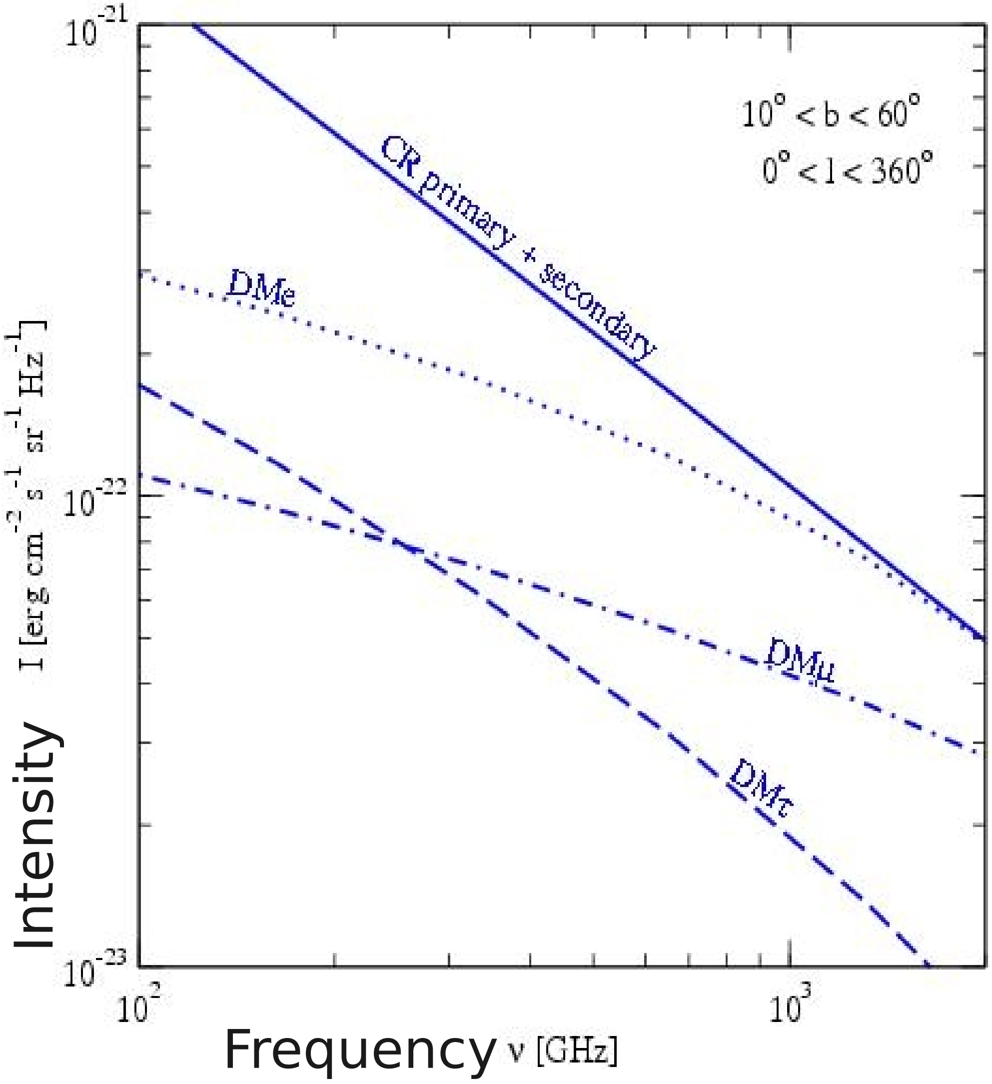
$Q = Q_0\, E^{-\beta} \exp(-E/E_c)\, \delta(\mathbf{x})\, \delta(t-\tau)$, $\beta \sim 1\text{-}2$, $E_c \sim 1\text{-}100$ TeV

POSITRONS IN THE SOURCE: (Blasi, '09)
Secondary positrons produced in the shock region of SN remnants
Spatial distribution analogous to primary CR

$Q = Q_0\, E^{-\beta} \exp(-E/E_c)$, $\beta \sim \beta_{pr} - \alpha$, $E_c \sim 1\text{-}10$ TeV

(In the following, β=1.36, E_c=1 TeV)

Synchrotron emission



Less promising than γ-ray emission, but, in some cases, the picture can be tested by the **Planck mission** (ν_{max} =850 Ghz)

Caveat: foreground disentanglement

X-ray frequencies are even less promising since they rely on "low-energy" electrons and positrons

Transport equation / 2

Spatial diffusion: $D_{xx} = \beta D_0 (R/1\ GV)^{\alpha}$

(for the Galaxy, α=0.3 – 0.6, $D_0 \sim 10^{28}\ cm^2/s$)

Diffusive reacceleration: $D_{pp} = v_a^2 p^2 / (9 D_{xx})$, v_a=Alfven velocity

Convection: $v_c = (dv_c/dz)\, z$, $dv_c/dz < 10$ km/s kpc^{-1}

Energy losses:

Magnetic field: $B(R,z) = B_0\, e^{-(R-Rsun)/50kpc}\ e^{-|z|/3kpc}$, $B_0 = 6\ \mu G$

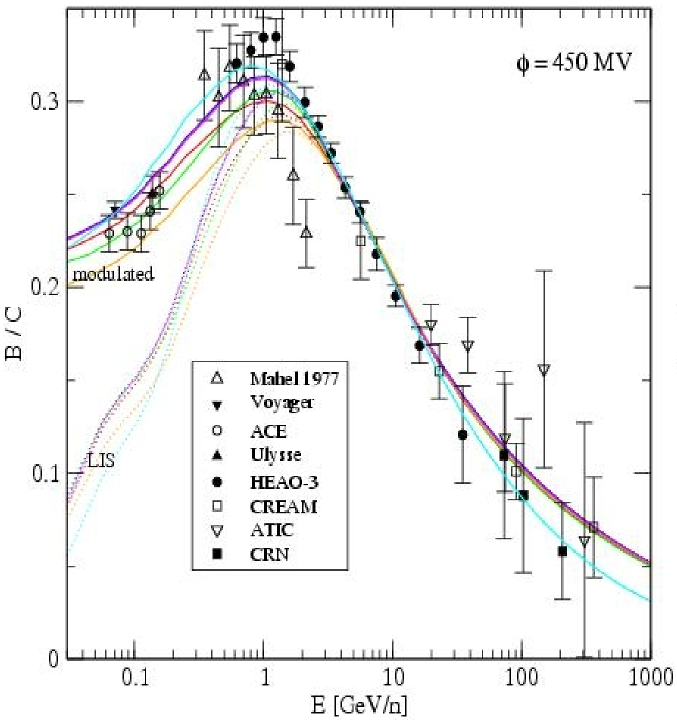
(Polarimetry, Zeeman splitting, Faraday rotation, Synchrotron emission studies)

GAS: HI and CO surveys

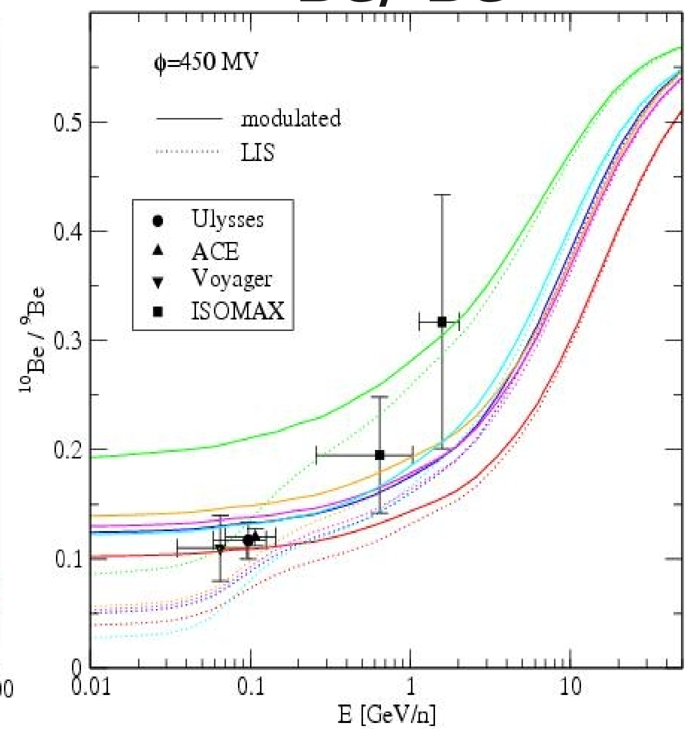
ISRF: COBE/DIRBE/FIRAS surveys

Benchmark models of propagation/ nuclei

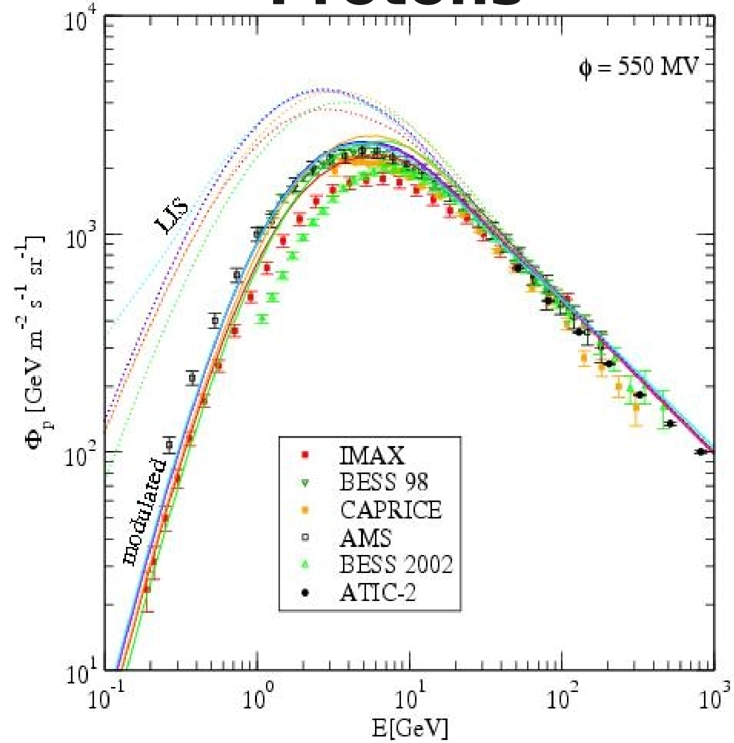
B/C



$^{10}Be/^{9}Be$



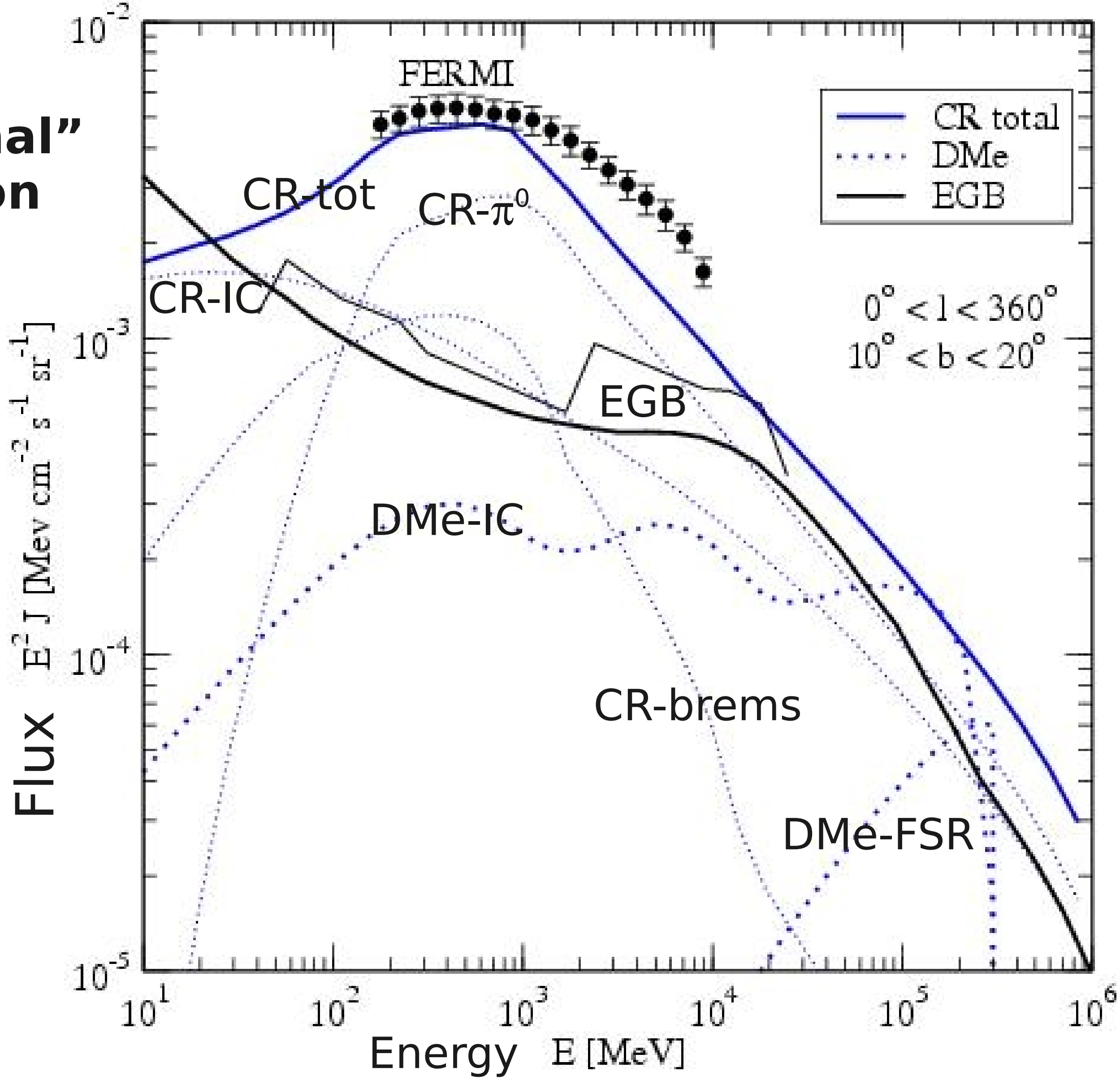
Protons



All the models are satisfactory in fitting the CR nuclei data.

gamma rays at intermediate latitudes

“Conventional” propagation model B0



WIMP induced signal

$$j_\gamma(E,r) = Q_\gamma(E,r)\,E$$ γ-rays emissivity

$$j_i(\nu,r) = 2\int_{m_e}^{M_\chi} dE\, P_i(r,E,\nu)\, n_e(r,E)$$ emissivity for a radiative process i

Intensity measured by a detector

$$S_i(\nu,\theta,\theta_d) = \int d\Omega' \exp\left(-\frac{\tan^2\theta'}{2\tan^2\theta_d}\right)\int_{l.o.s.} dI_i(\nu,s,\tilde{\theta})$$

$$\frac{dI_i(\nu,s,\tilde{\theta})}{ds} = -\alpha(\nu,s,\tilde{\theta})\, I_i(\nu,s,\tilde{\theta}) + \frac{j_i(\nu,s,\tilde{\theta})}{4\pi}$$