

Implications of the positron/electron excesses on Dark Matter properties

- 1) The data
- 2) DM annihilations?
- 3) Testing with γ and ν
- 4) DM decays?

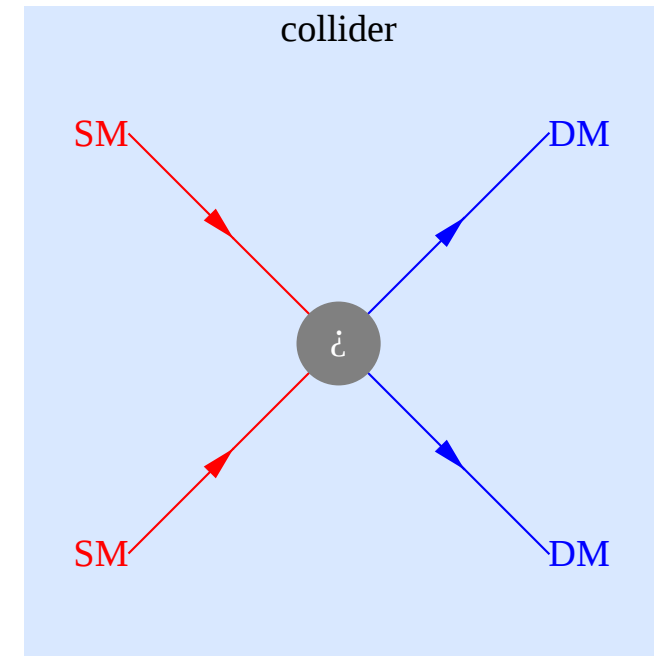
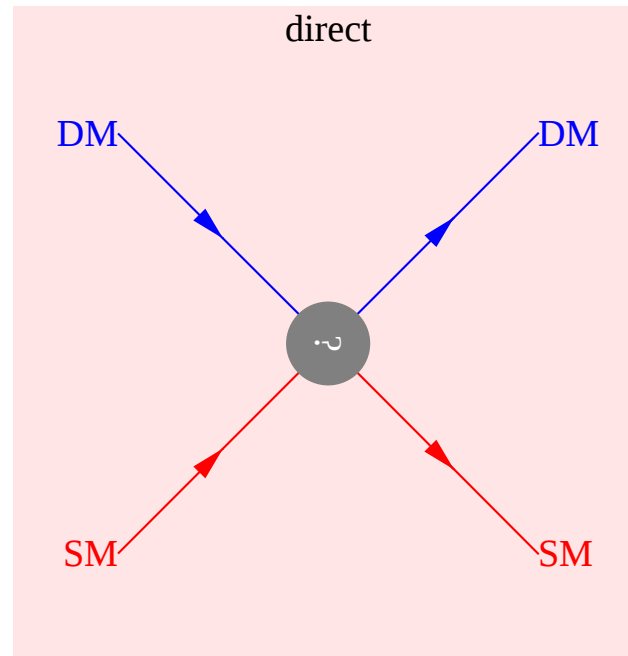
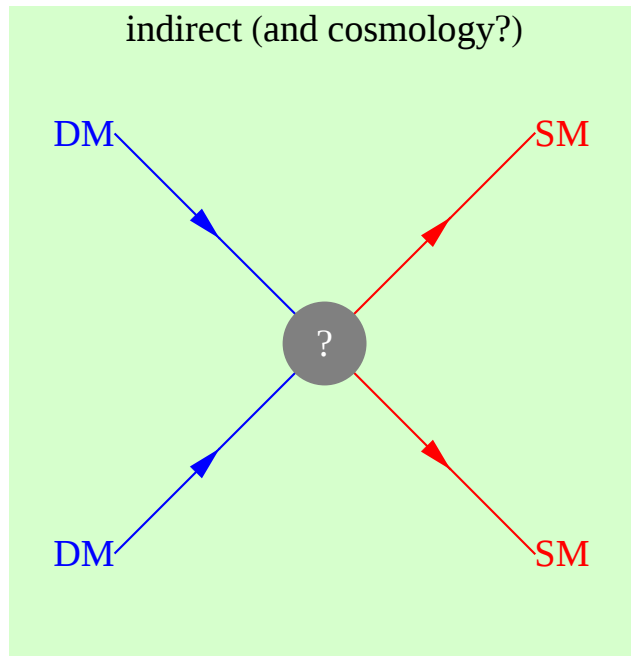
Alessandro Strumia, Quarks 2010, Kolomna, June 10, 2010

DM is. Everywhere. Waiting for a sign

from the sky

from the underworld

from CERN



PAMELA, ATIC, FERMI CDMS, CoGenT, Xenon $\int_{\text{start}}^{\text{now}} L \, dt = 2 \text{ sec} \times L_{\text{design}}$

Status of the field: messianic awaiting for DM. Many fakes

Indirect signals of Dark Matter



DM DM annihilations in our galaxy might give detectable γ , e^+ , $\bar{p}$, $\bar{d}$.

The galactic DM density profile

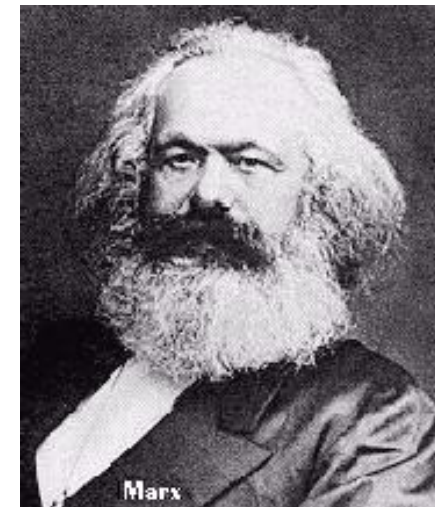
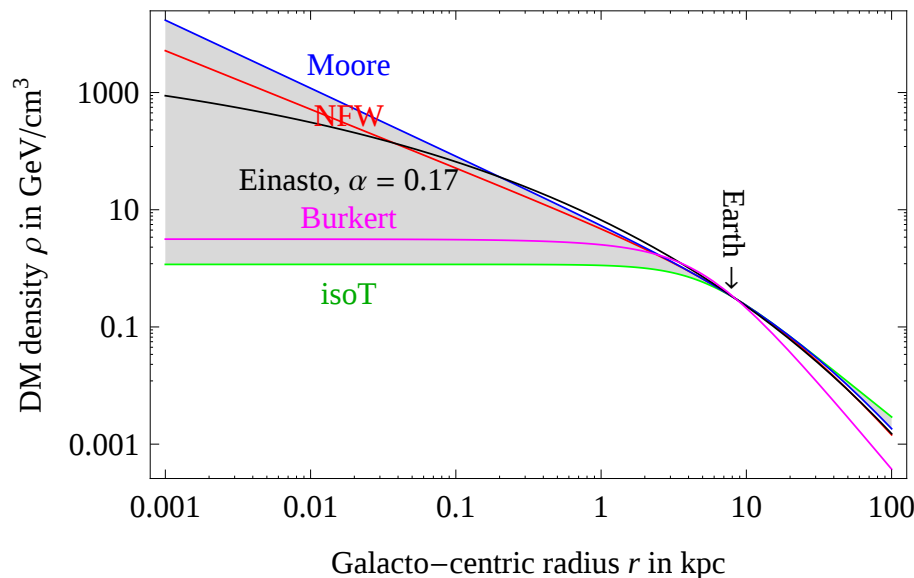
DM velocity: $\beta \approx 10^{-3}$. DM is **spherically** distributed with uncertain profile:

$$\rho(r) = \rho_{\odot} \left[\frac{r_{\odot}}{r} \right]^{\gamma} \left[\frac{1 + (r_{\odot}/r_s)^{\alpha}}{1 + (r/r_s)^{\alpha}} \right]^{(\beta-\gamma)/\alpha}$$

$r_{\odot} = 8.5 \text{ kpc}$ is our distance from the Galactic Center, $\rho_{\odot} \equiv \rho(r_{\odot}) \approx 0.38 \text{ GeV/cm}^3$,

DM halo model		α	β	γ	r_s in kpc
Isothermal	'isoT'	2	2	0	5
Navarro, Frenk, White	'NFW'	1	3	1	20

$\rho(r)$ is uncertain because DM is like capitalism according to Marx:
a gravitational system (slowly) collapses to the ground state $\rho(r) = \delta(r)$.
Simulations favor NFW or Einasto, rotation curves of galaxies favor Burkert



DM DM signal boosted by sub-halos?

N -body simulations suggest that DM might clump in subhalos:



Annihilation rate $\propto \int dV \rho^2$ increased by a boost factor $B = 1 \leftrightarrow 100 \sim$ a few

Simulations neglect normal matter, that locally is comparable to DM.

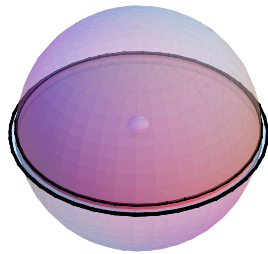
Propagation of $e^\pm$ in the galaxy

$\Phi_{e+} = v_{e+} f / 4\pi$ where $f = dN/dV dE$ obeys: $-K(E) \cdot \nabla^2 f - \frac{\partial}{\partial E}(\dot{E} f) = Q$.

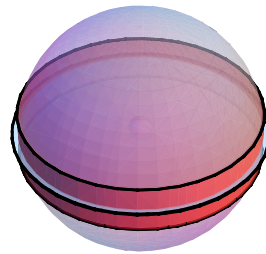
- **Injection:** $Q = \frac{1}{2} \left(\frac{\rho}{M} \right)^2 \langle \sigma v \rangle \frac{dN_{e+}}{dE}$ from DM annihilations.
- **Diffusion** coefficient: $K(E) = K_0 (E/\text{GeV})^\delta \sim R_{\text{Larmor}} = E/eB$.
- **Energy loss** from IC + syn: $\dot{E} = E^2 \cdot (4\sigma_T/3m_e^2)(u_\gamma + u_B)$.
- **Boundary:** f vanishes on a cylinder with radius $R = 20 \text{ kpc}$ and height $2L$.

Propagation model	δ	K_0 in kpc^2/Myr	L in kpc	V_{conv} in km/s
min	0.85	0.0016	1	13.5
med	0.70	0.0112	4	12
max	0.46	0.0765	15	5

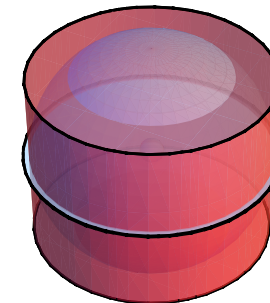
min



med



max



Small diffusion in a small volume, or large diffusion in a large volume?
Main result: $e^\pm$ reach us from the Galactic Center only in the max case

1

The data

ABC of charged cosmic rays

$e^\pm$, $p^\pm$, He, B, C... Their directions are randomized by galactic magnetic fields $B \sim \mu\text{G}$. The info is in their energy spectra.

We hope to see DM annihilation products as excesses in the rarer e^+ and $\bar{p}$.

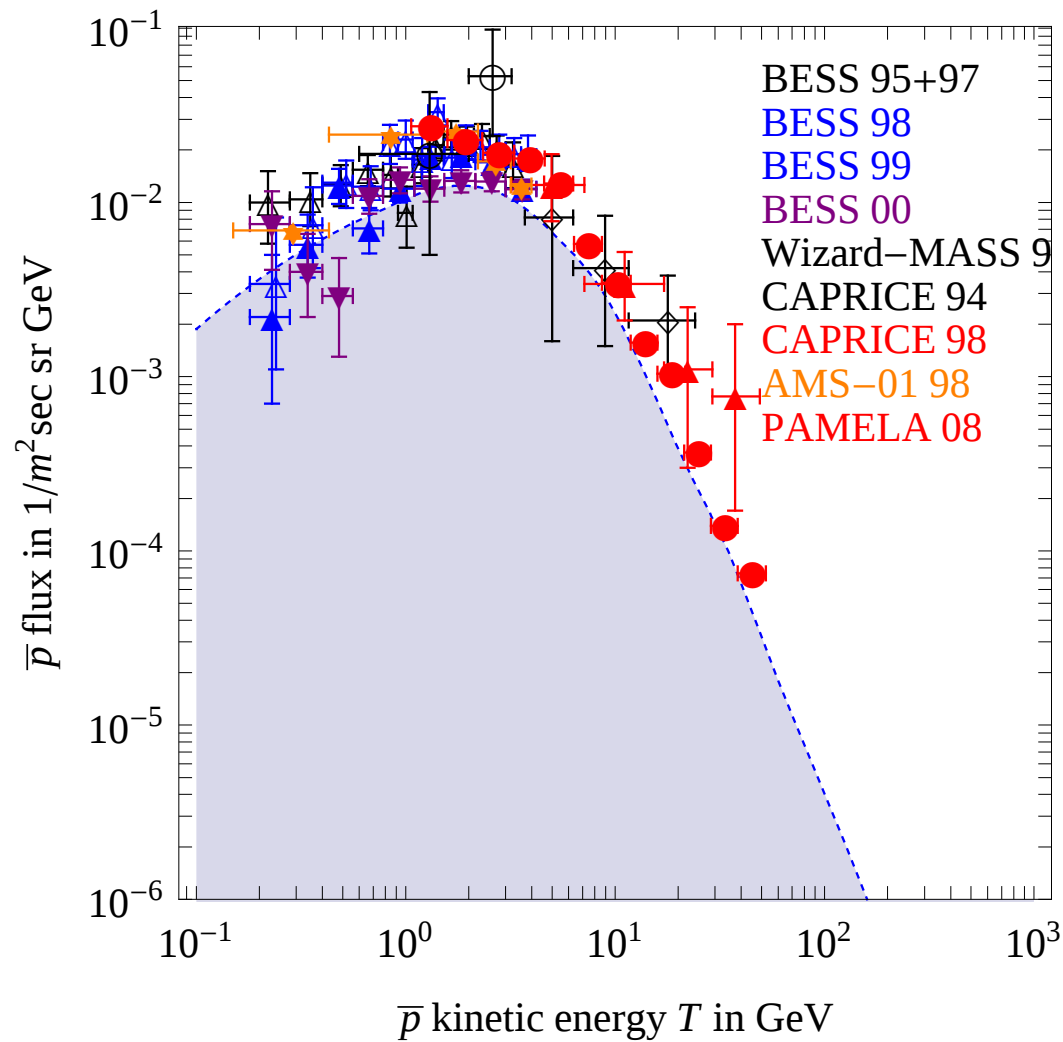
Experimentalists need to bring above the atmosphere (with balloons or satellites) a spectrometer and/or calorimeter, able of rejecting e^- and p .

This is difficult above 100 GeV, also because CR fluxes decrease as $\sim E^{-3}$.

Energy spectra below a few GeV are $\sim$ useless, because affected by solar activity.

$\bar{p}/p$: PAMELA

Consistent with background



Future: PAMELA, AMS

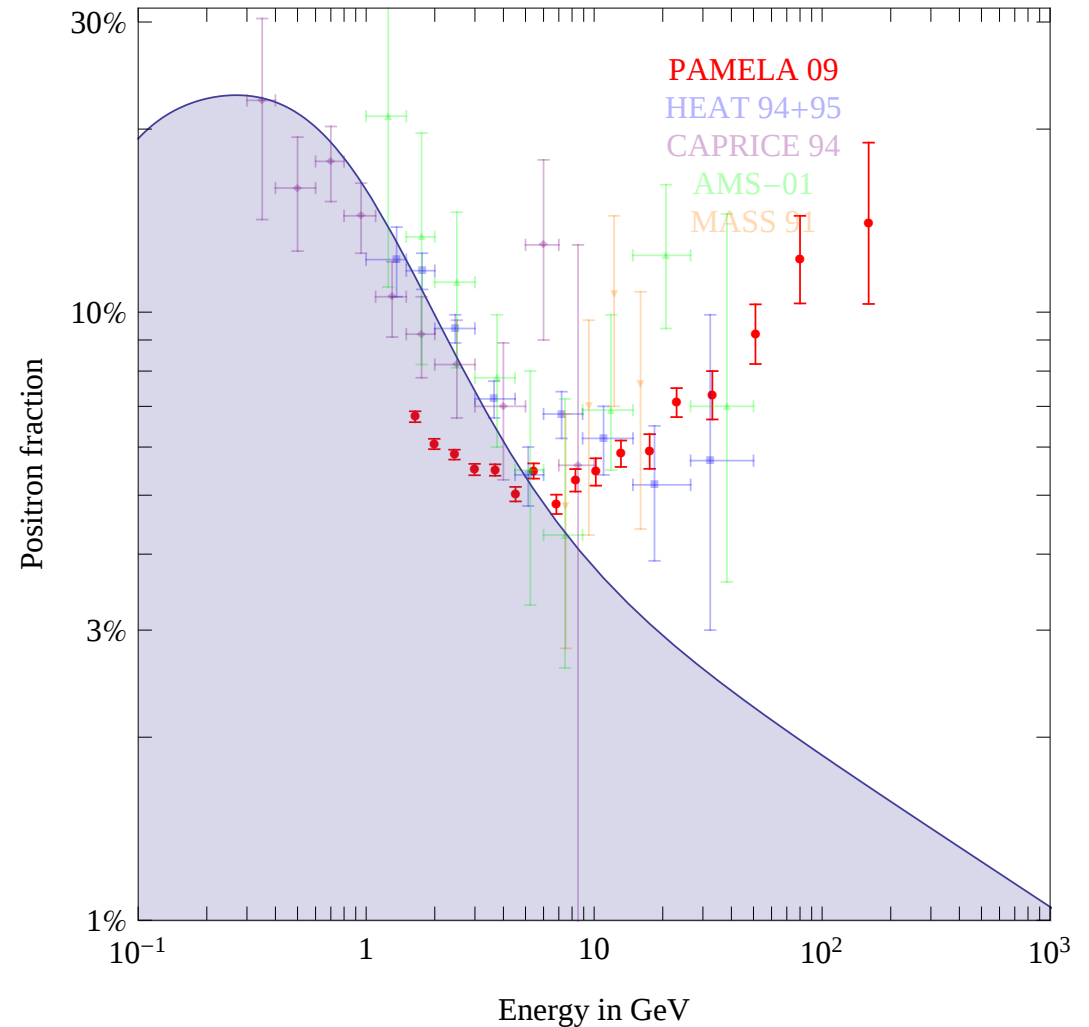
$e^+/(e^+ + e^-)$: PAMELA

PAMELA is a spectrometer + calorimeter sent to space. It can discriminate $e^+, e^-, p, \bar{p}, \dots$ and measure E up to ~ 200 GeV.

e^- are primaries and e^+ secondaries, so e^+/e^- decreases as the containment time $\tau \sim E^{-\delta}$.

Spectra below 10 GeV distorted by the present solar polarity.

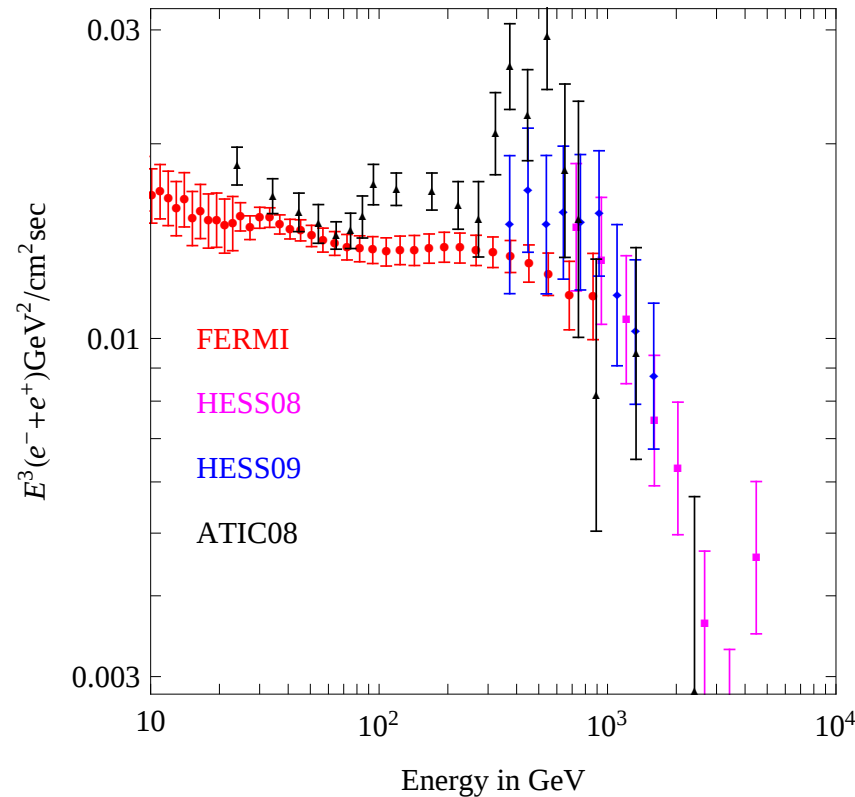
Growing excess above 10 GeV



The PAMELA excess suggest that it might manifest in other experiments: if e^+/e^- continues to grow, it reaches $e^+ \sim e^-$ around 1 TeV...

$e^+ + e^-$: FERMI, ATICs, HESS, BETS

These experiments cannot discriminate e^+/e^- , but probe higher energy.



Hardening at 100 GeV + softening at 1 TeV

Are these real features? Likely yes. Hardening also in ATICs.

Systematic errors, not yet defined, are here incoherently added bin-to-bin to the smaller statistical error, allowing for a power-law fit.

... Just astrophysics?

1) Maybe secondaries are produced in the acceleration region: then e^+/e^- can grow with E , but also $\bar{p}/p$, B/C, Ti/Fe...

2) A pulsar is a neutron star with a rotating intense magnetic field. The resulting electric field ionizes and accelerates $e^- \rightarrow \gamma \rightarrow e^+e^-$, that are presumably further accelerated by the pulsar wind nebula (Fermi mechanism).

- $E_{\text{pulsar}} = I\omega^2/2$, $\dot{E}_{\text{pulsar}} = -B_{\text{surface}}^2 R^2 \omega^4 / 6c^3 =$ magnetic dipole radiation.
- The guess is $\Phi_{e^-} \approx \Phi_{e^+} \propto \epsilon \cdot e^{-E/M} / E^p$ where $p \approx 2$ and M are constants.

Known nearby pulsars (B0656+14, Geminga, ?) would need an unplausibly (?) large fraction ϵ of energy that goes into $e^\pm$: $\epsilon \sim 0.3$.

Test: angular anisotropies (but can be faked by local $B(\vec{x})$, pulsar motion).

2

Model-independent theory of DM indirect detection

Model-independent DM annihilations

Indirect signals depend on the DM mass M , non-relativistic σv , primary BR:

$$\text{DM DM} \rightarrow \begin{cases} W^+W^-, & ZZ, & Zh, & hh & \text{Gauge/higgs sector} \\ e^+e^-, & \mu^+\mu^-, & \tau^+\tau^- & & \text{Leptons} \\ b\bar{b}, & t\bar{t}, & q\bar{q} & & \text{quarks, } q = \{u, d, s, c\} \end{cases}$$

No γ because DM is neutral. Direct detection bounds suggest no Z .

The energy spectra of the stable final-state particles

$$e^\pm, \quad p^\mp, \quad (\bar{\nu})_{e,\mu,\tau}, \quad \bar{d}, \quad \gamma$$

depend on the polarization of primaries: W_L or T and μ_L or R .

The γ spectrum is generated by various higher-order effects:

$$\gamma = (\text{Final State Radiation}) + (\text{one-loop}) + (\text{3-body})$$

We include FSR and ignore the other comparable but model dependent effects

The DM spin

Non-relativistic s -wave DM annihilations can be computed in a model-independent way because they are like decays of the two-body $\mathcal{D} = (\text{DM DM})_{L=0}$ state.

If DM is a fundamental weakly-interacting particle, its spin J can be 0, 1/2 or 1, so **the spin of $\mathcal{D}$ can only be 0, 1 or 2**:

$$1 \otimes 1 = 1, \quad 2 \otimes 2 = 1_{\text{asymm}} \oplus 3_{\text{symm}}, \quad 3 \otimes 3 = 1_{\text{symm}} \oplus 3_{\text{asymm}} \oplus 5_{\text{symm}}$$

So:

- **$\mathcal{D}$ can have spin 0 for any DM spin.** It couples to vectors $\mathcal{D}F_{\mu\nu}^2$ and to higgs $\mathcal{D}h^2$, not to light fermions: $\mathcal{D}\ell_L\ell_R$ is m_ℓ/M suppressed.
- **$\mathcal{D}$ can have spin 1 only if DM is a Dirac fermion or a vector.**
PAMELA motivates a large $\sigma(\text{DM DM} \rightarrow \ell^+\ell^-)$: only possible for $\mathcal{D}_\mu[\bar{\ell}\gamma_\mu\ell]$.

DM annihilations into fermions f

- Scalar $\mathcal{D}$ can only couple as

$$\mathcal{D}f_L f_R + \text{h.c.} = \mathcal{D}\bar{\Psi}_f \Psi_f$$

with $\Psi_f = (f_L, \bar{f}_R)$ in Dirac notation.
It means zero helicity on average, and is typically **suppressed by** m_f/M . *Huge* weak corrections if $M \gg M_W$.

- Vector $\mathcal{D}_\mu$ can couple as

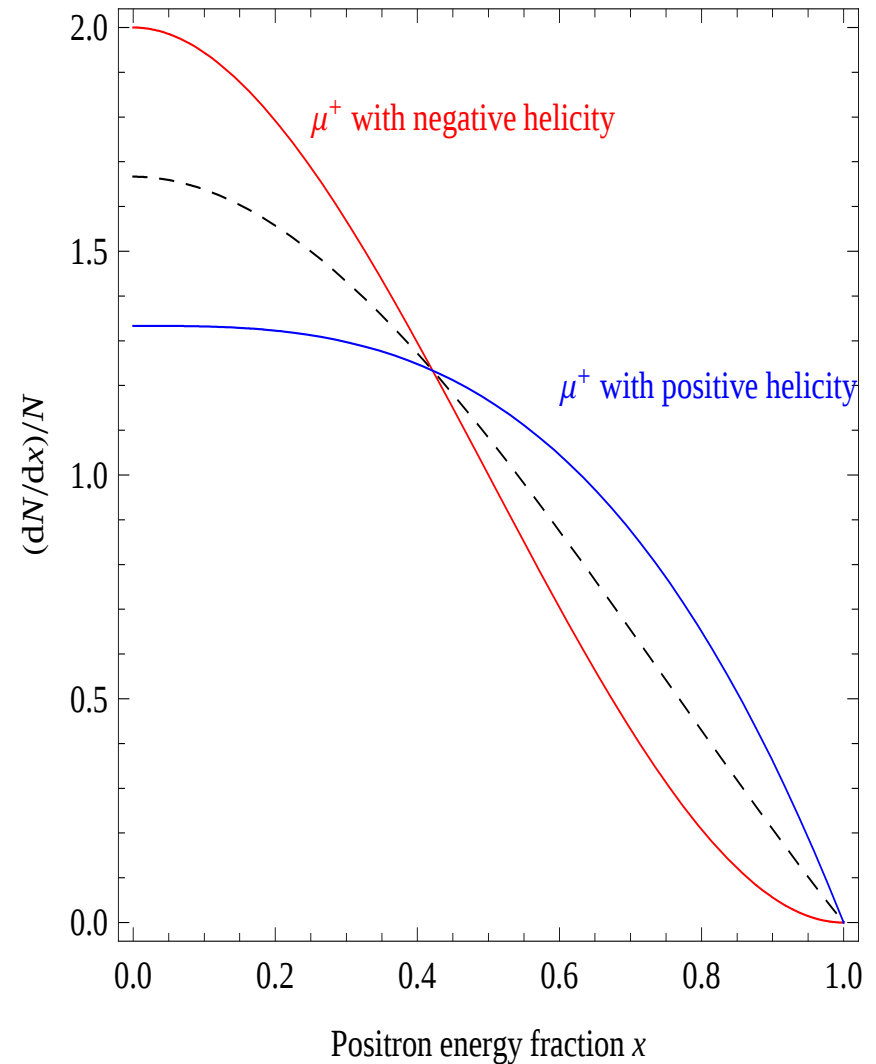
$$\mathcal{D}_\mu[\bar{f}_L \gamma_\mu f_L] \quad \text{or} \quad \mathcal{D}_\mu[\bar{f}_R \gamma_\mu f_R]$$

i.e. fermions with **Left** or **Right** helicity.

Decays like $\mu^+ \rightarrow \bar{\nu}_\mu e^+ \nu_e$ give e^+ with

$$dN/dx|_L = 2(1-x)^2(1+2x)$$

$$dN/dx|_R = 4(1-x^3)/3$$



DM annihilations into W, Z

- The effective interactions

$$\mathcal{D}F_{\mu\nu}\epsilon_{\mu\nu\rho\sigma}F_{\rho\sigma} \quad \text{and} \quad \mathcal{D}F_{\mu\nu}^2$$

give vectors with **Transverse** polarization (with different unobservable helicity correlations), that decay in $f\bar{f}$ with $E = xM$ as:

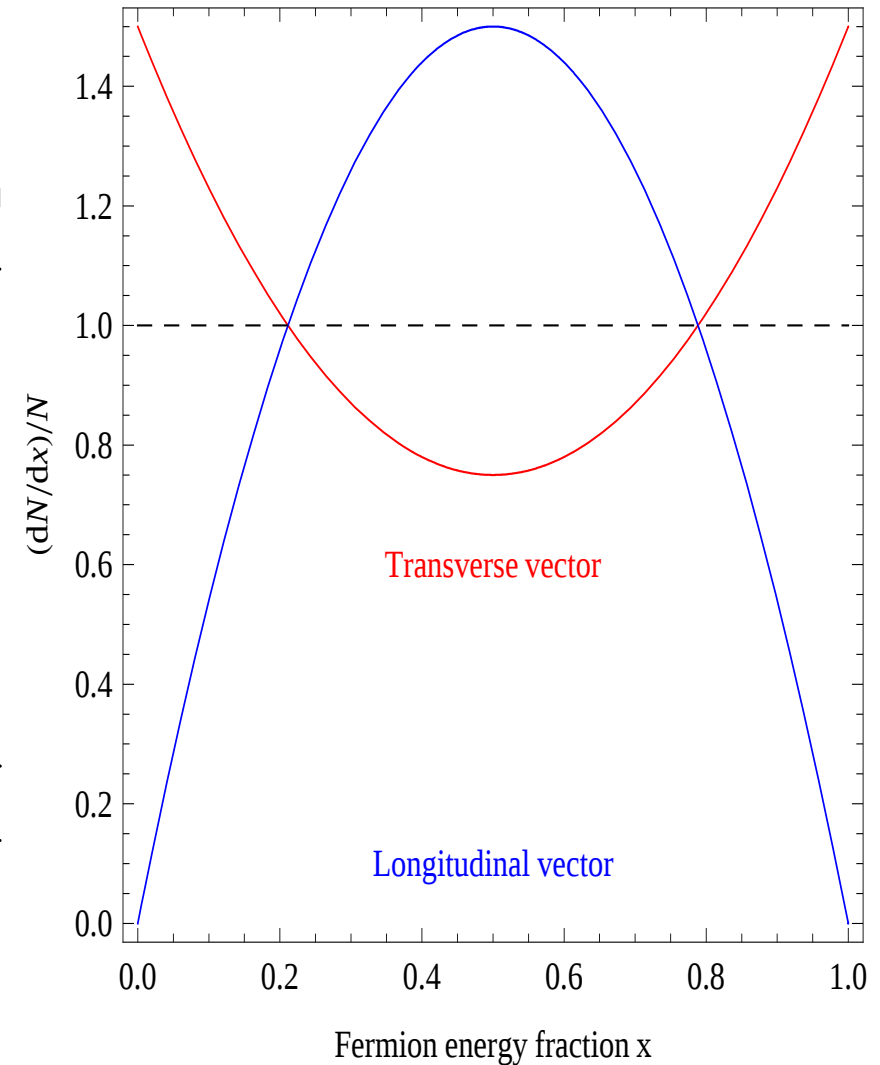
$$dN/d\cos\theta = 3(1 + \cos^2\theta)/8$$

$$dN/dx = 3(1 - 2x + 3x^2)/2,$$

- $\mathcal{D}A_\mu^2$ gives **Longitudinal** vectors (accounting for DM annihilations into Higgs Goldstones), that decay as

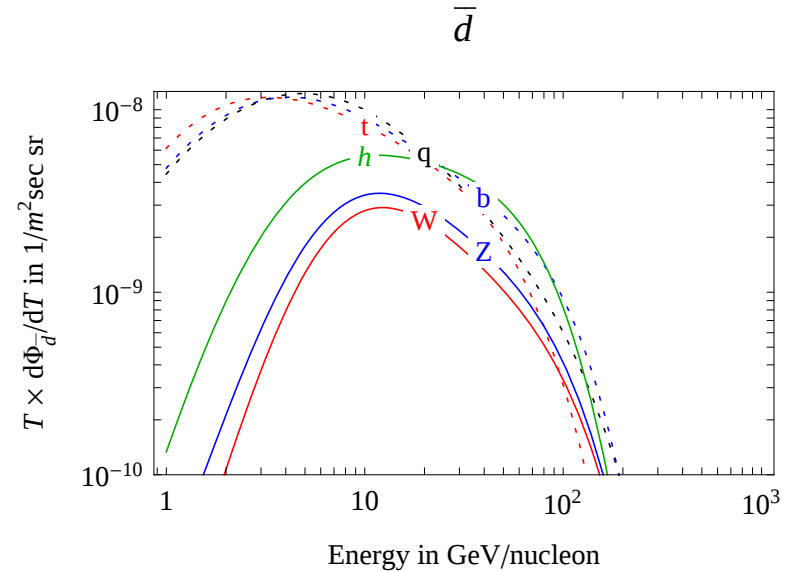
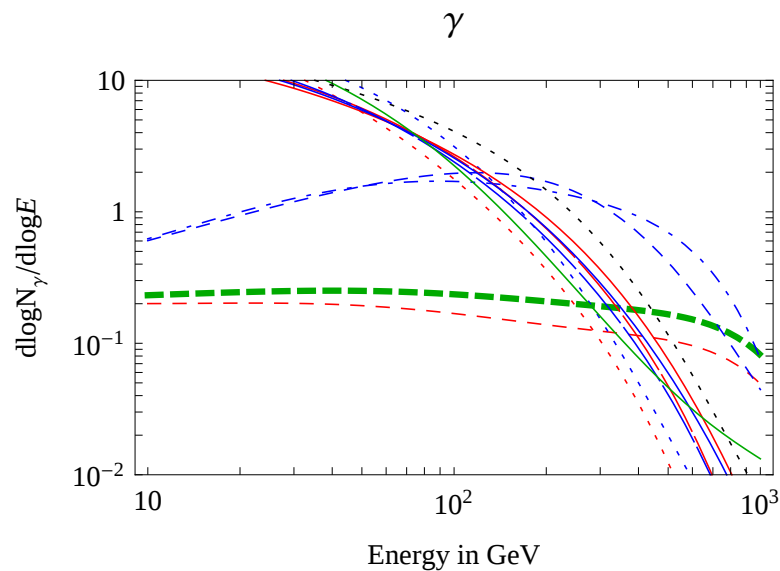
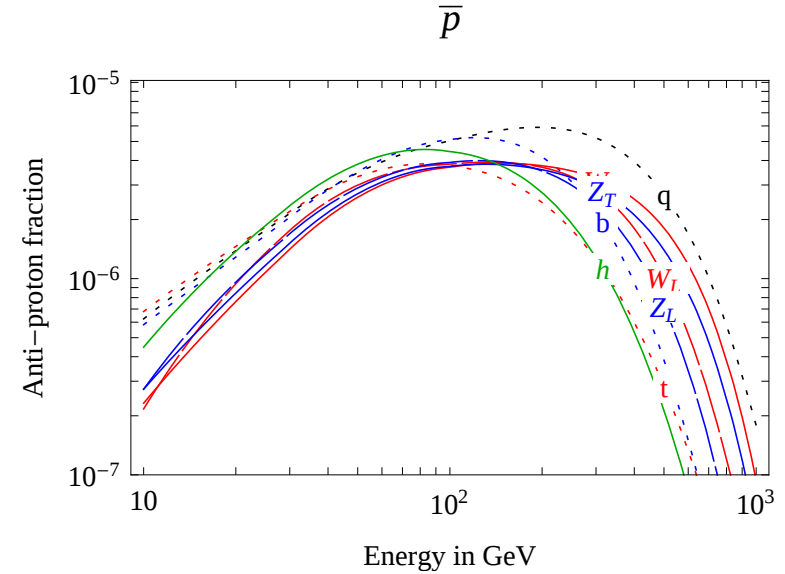
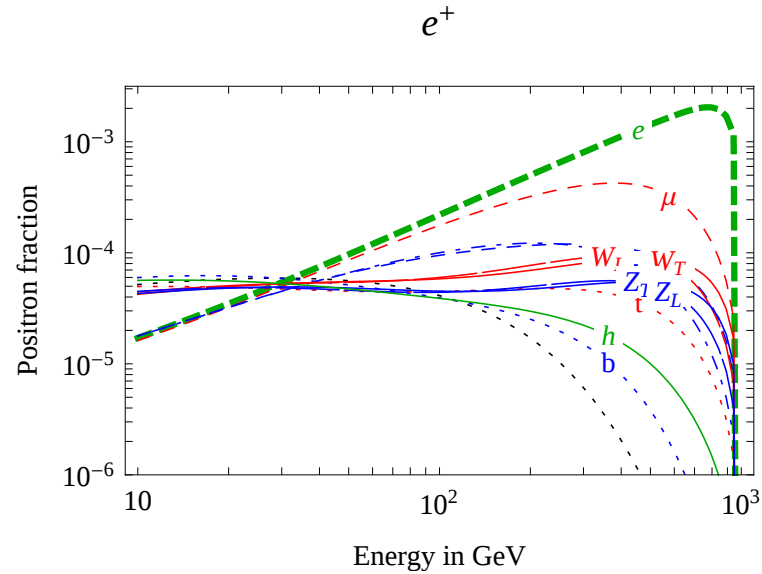
$$dN/d\cos\theta = 3(1 - \cos^2\theta)/4$$

$$dN/dx = 6x(1 - x).$$



Final state spectra for $M = 1$ TeV

Two-body primary channels: $e, \mu_L, \mu_R, \tau_L, \tau_R, W_L, W_T, Z_L, Z_T, h, q, b, t$.



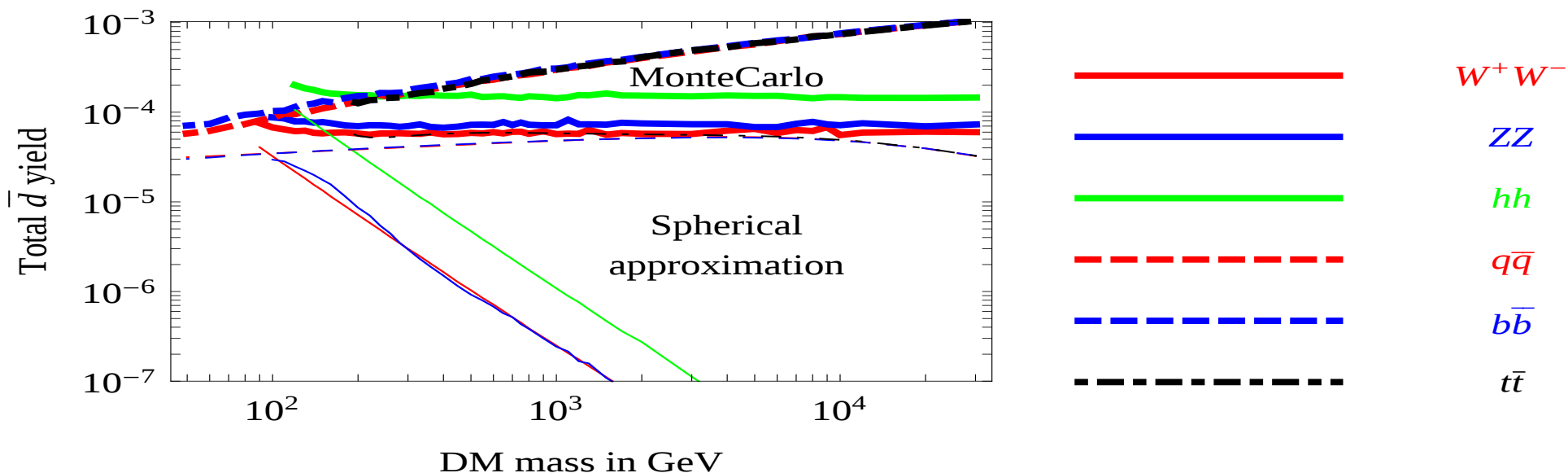
Annihilations into leptons give qualitatively different energy spectra.

Anti-deutერიუმი

$\bar{d}$ forms when DM produces a $\bar{p}$ and a $\bar{n}$ with momentum difference below $p_0 \approx 160 \text{ MeV}$. The analytical approximation assuming spherical-cow events

$$\frac{dN_{\bar{d}}}{dT_{\bar{d}}} = \frac{p_0^3}{3k_{\bar{d}}m_p} \left(\frac{dN_{\bar{n},\bar{p}}}{dT} \right)^2_{T=T_{\bar{d}}/2}$$

misses the jet structure of events, such that $N_{\bar{d}} \propto 1/M^2$ is very wrong. Relativity demands that higher M boosts $\bar{p}, \bar{n}, \bar{d}$, leaving $N_{\bar{d}} \sim \text{constant}$. Running PYTHIA on GRID we find orders of magnitude enhancement:



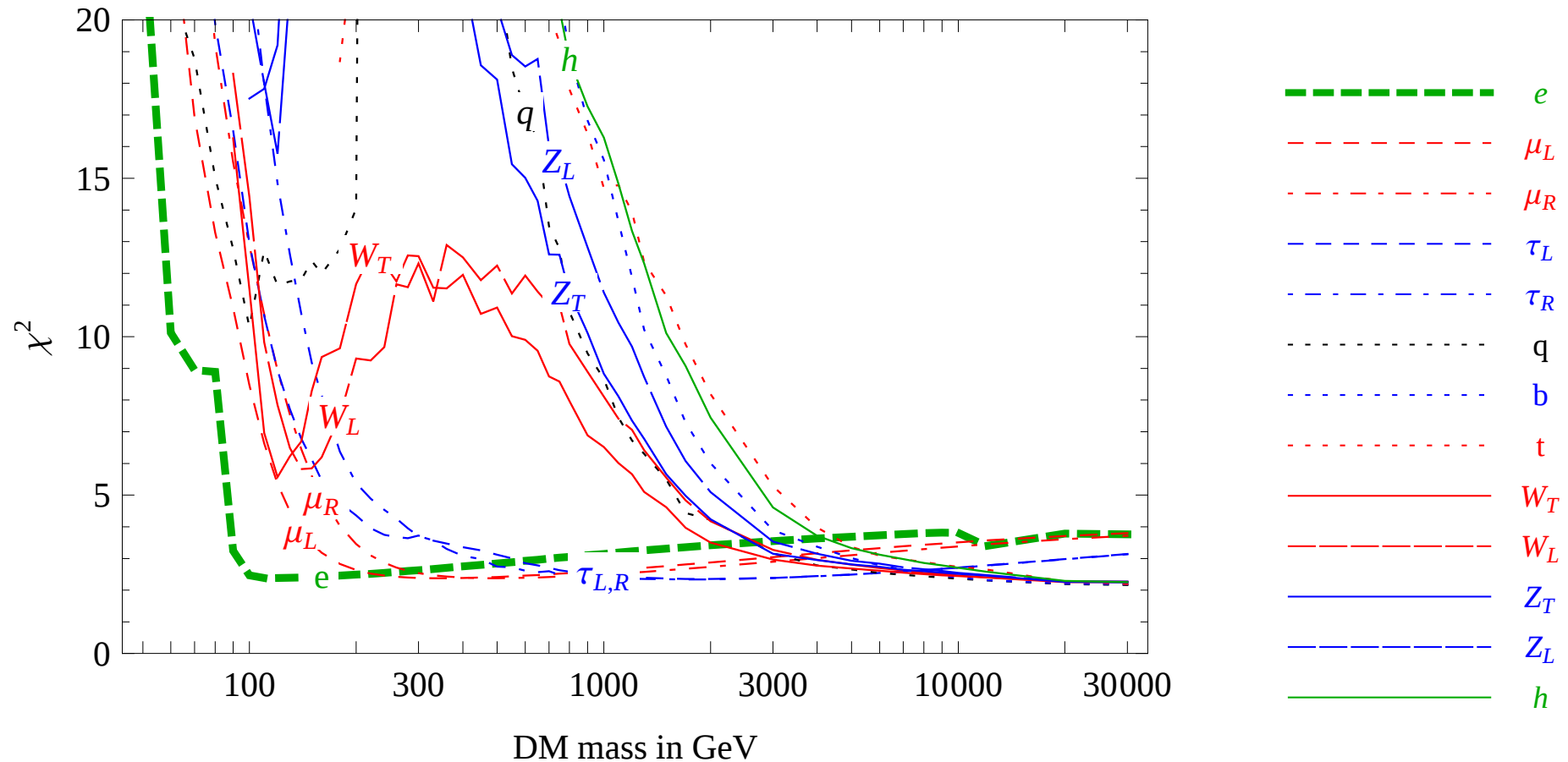
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Implications of the data

Fitting procedure

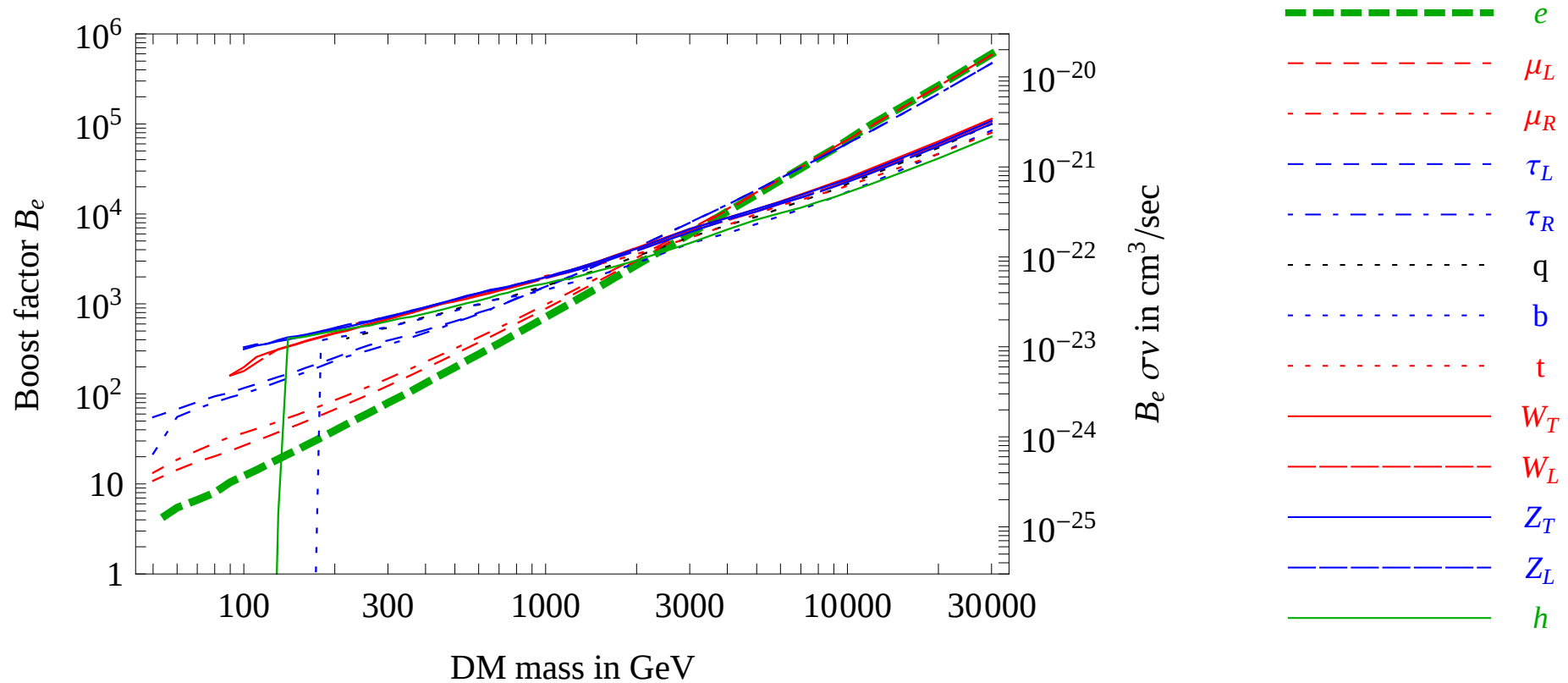
- **PAMELA** and **FERMI** systematic uncertainties?
- multiply each expected e^+ , e^- , p^+/p^- **backgrounds** times $A_i E^{p_i}$ with free A_i and $p_i = 0 \pm 0.05$, and marginalize over A_i, p_i .
- **solar modulation** as uncorrelated uncertainty below 20 GeV: $\pm 6\%$ at 10 GeV, $\pm 30\%$ at 1 GeV.
- **DM halo**: marginalize over isoT/NFW/Moore with flat prior.
- **Propagation**: marginalize over MIN/MED/MAX with flat prior. (MED is favored?).
- Statistical techniques: as reviewed in appendix B of hep-ph/0606054.

Fitting PAMELA positron data



If $M > \text{TeV}$ everything fits. At smaller M only annihilations into leptons or W .

The σv needed for PAMELA



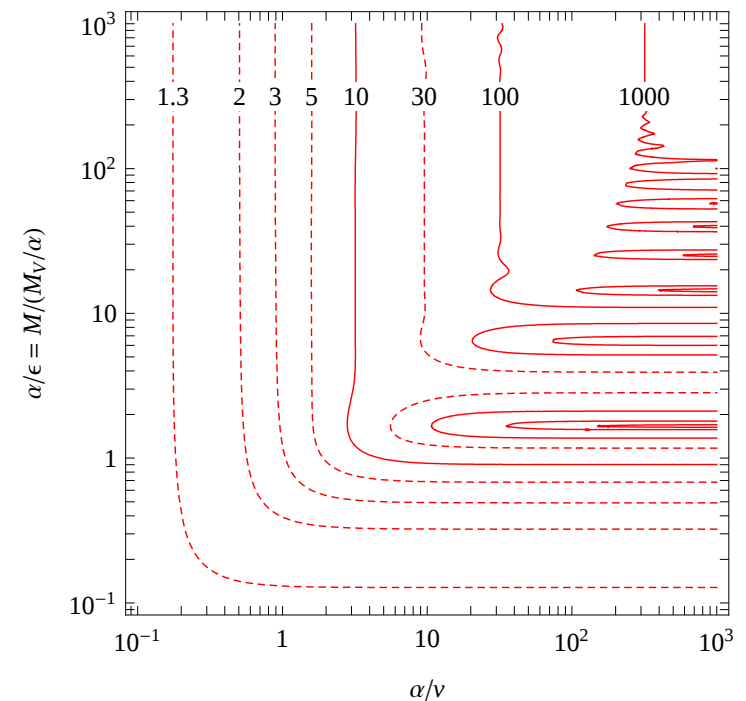
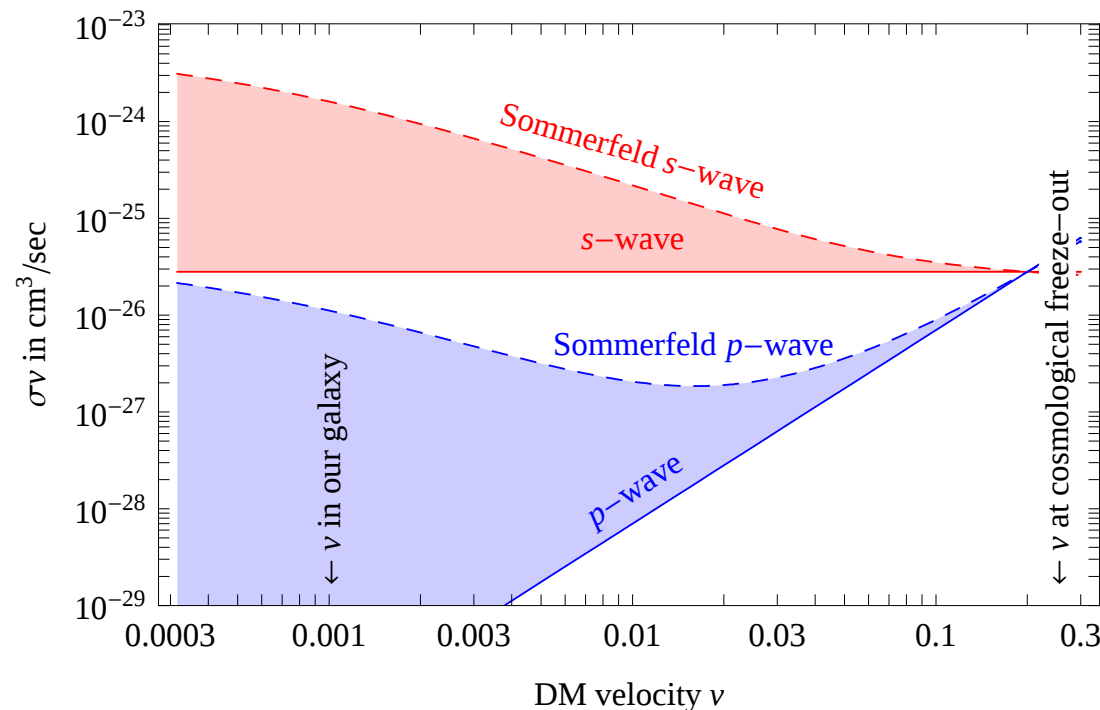
σv larger than what suggested by cosmology by a factor B_e

The cosmological σv

Thermal DM reproduces the cosmological DM abundance $\Omega_{\text{DM}} h^2 \approx 0.11$ for

$$\sigma v \approx 3 \times 10^{-26} \text{ cm}^3/\text{sec} \quad \text{around freeze-out, i.e. } v \sim 0.2.$$

up to co-annihilations and resonances. Possible extrapolations to $v \sim 10^{-3}$:



The Sommerfeld effect is the quantum analogous of this classical effect: the sun attracts slower bodies, enhancing its cross section: $\sigma = \pi R_{\odot}^2 (1 + v_{\text{escape}}^2/v^2)$

If DM is thermal PAMELA needs s -wave + **Sommerfeld** and/or a boost factor (DM in sub-halos has small velocity dispersion: Sommerfeld boosts the boost)

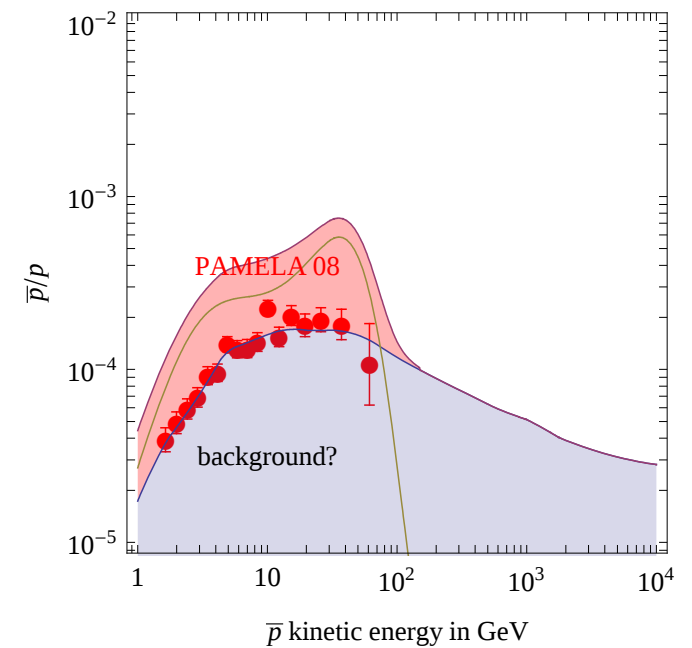
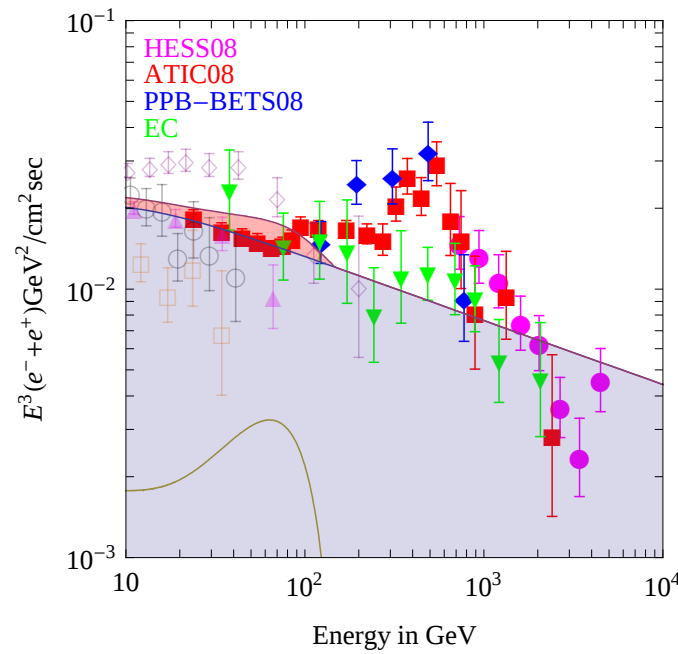
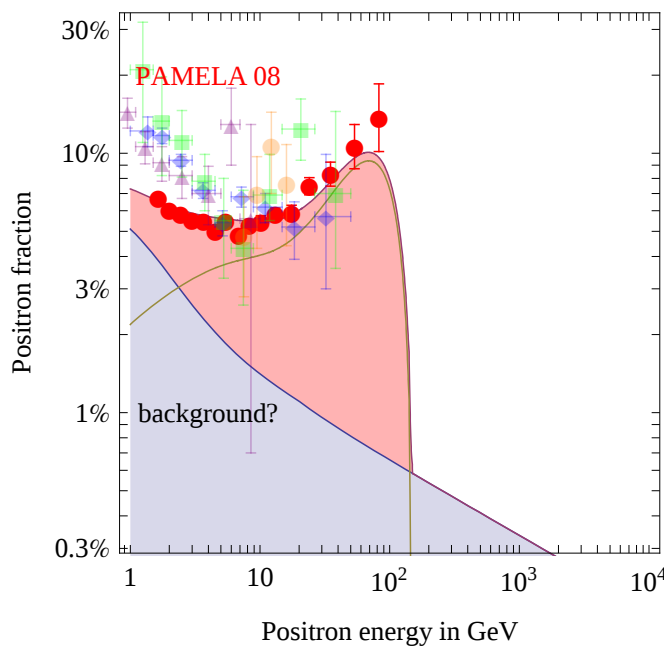
Non thermal DM

E.g. a wino that with $M \approx 100$ GeV annihilates into $W_T^+ W_T^-$ with the correct

$$\sigma v = \frac{g_2^4 (1 - M_W^2/M^2)^{3/2}}{2\pi M^2 (2 - M_W^2/M^2)^2}$$

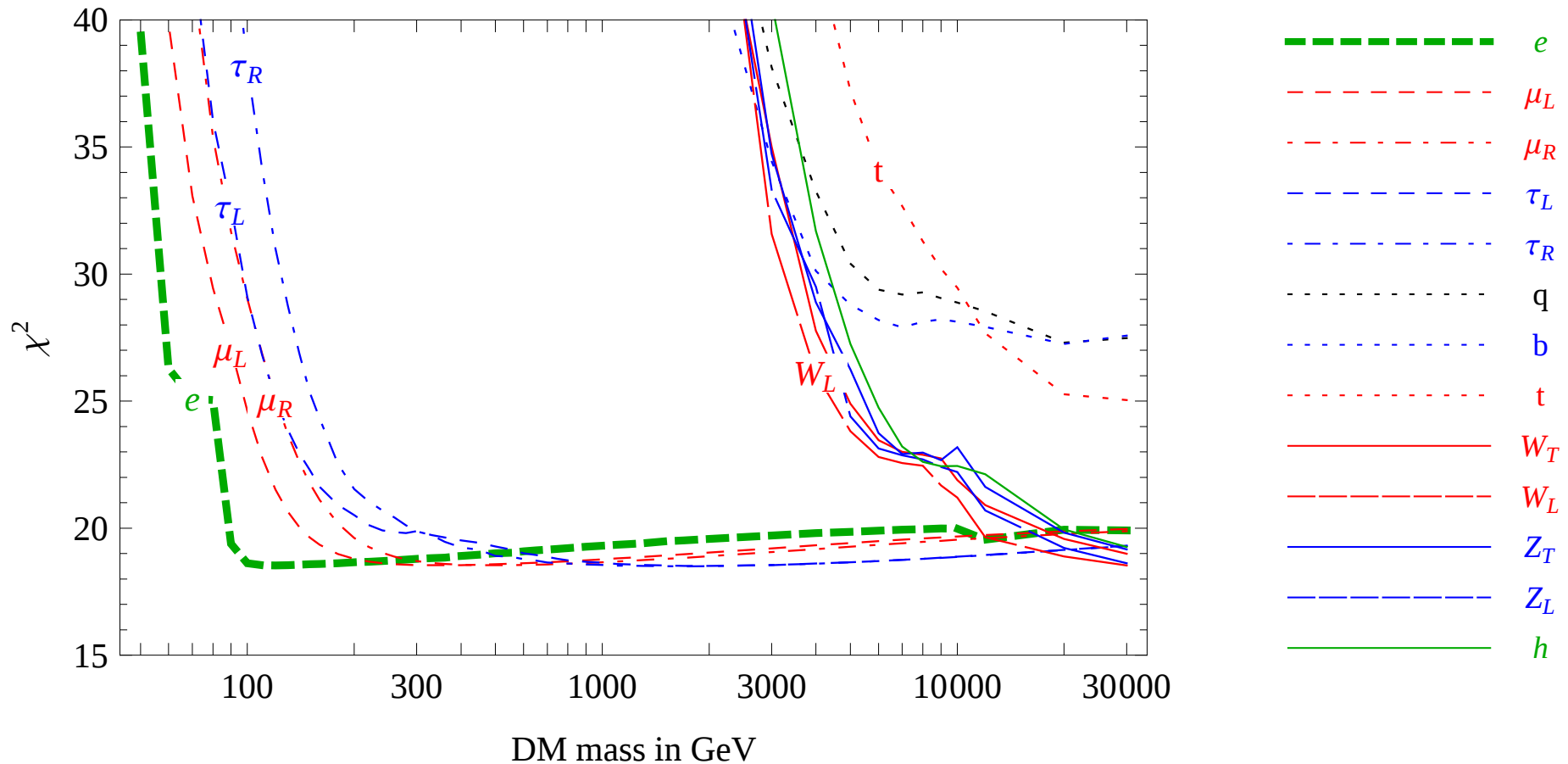
Problematic with PAMELA $\bar{p}$, reconsidered by Kane et al., excluded by FERMI.

DM with $M = 150$ GeV that annihilates into $W^+ W^-$



Fitting PAMELA e^+ anti $\bar{p}$ data

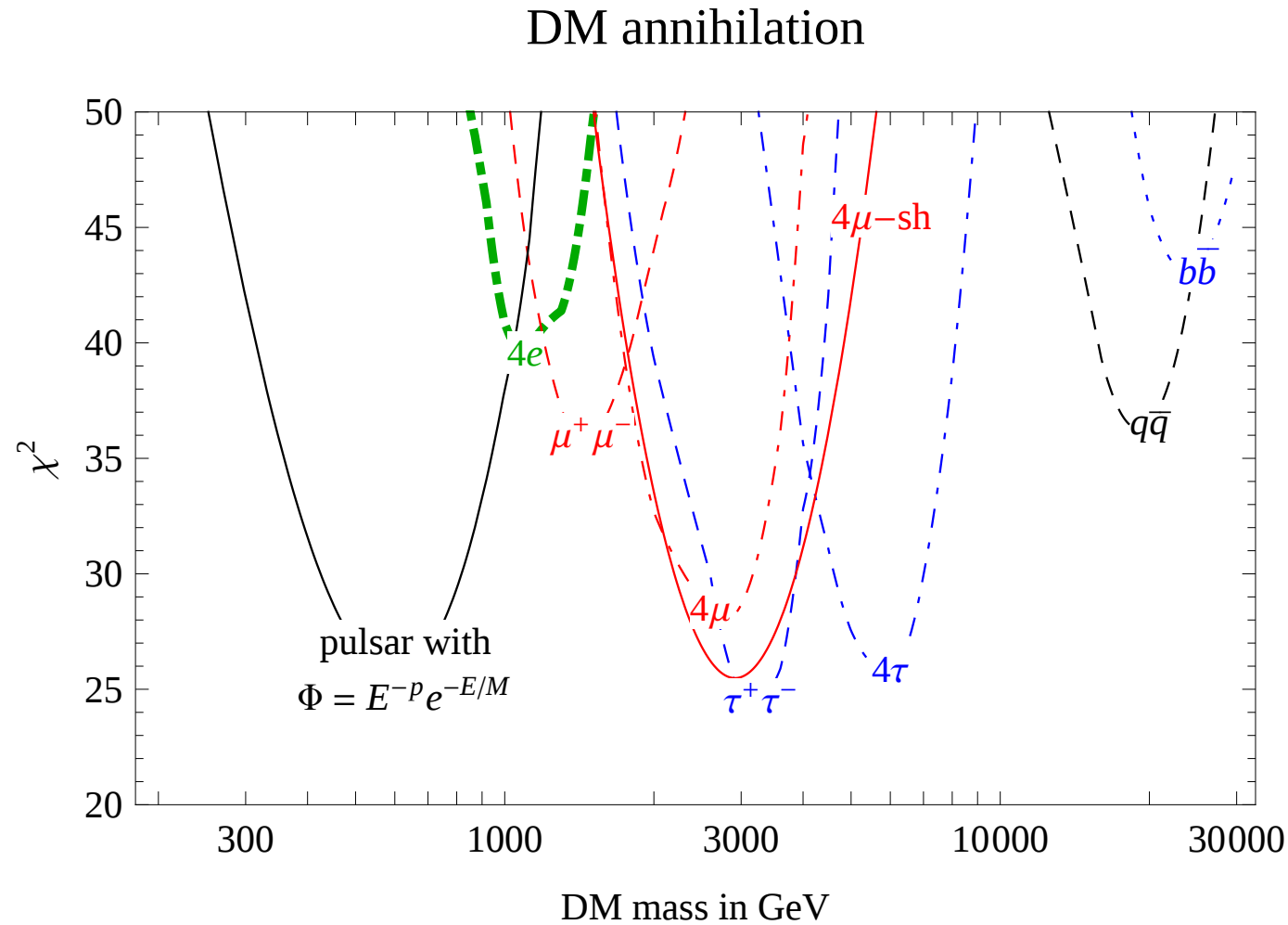
Assuming equal boost & propagation for e^+ and $\bar{p}$ (otherwise everything goes):



DM must annihilate into leptons or into W, Z with $M \gtrsim 10$ TeV

Indeed a W at rest gives $\bar{p}$ with $E_p > m_p$. So a W with energy $E = M$ gives $E_p > Mm_p/M_W$, above the PAMELA threshold for $M > 10$ TeV.

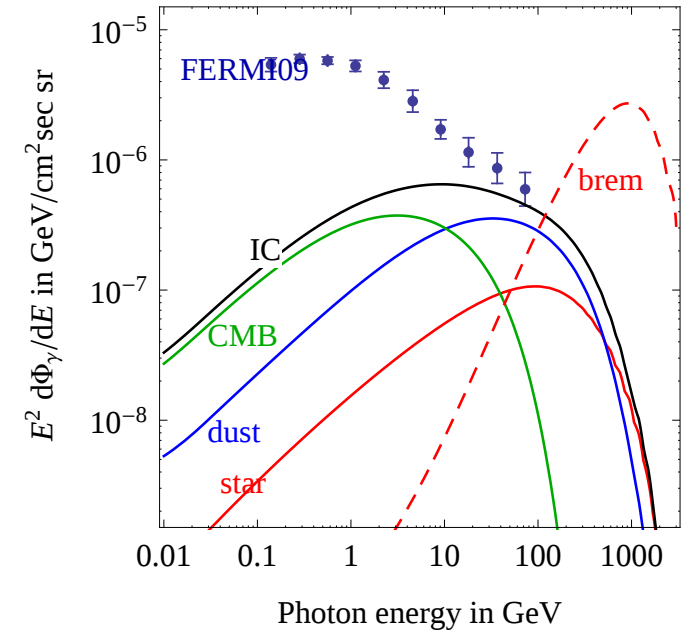
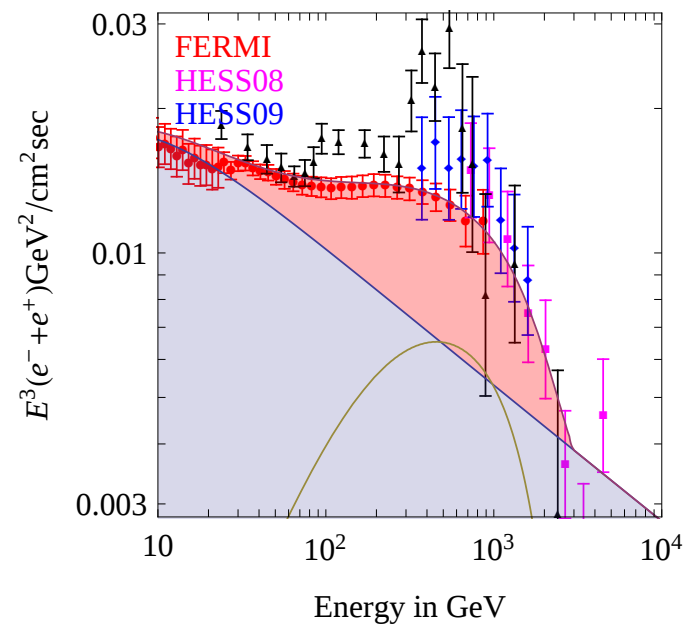
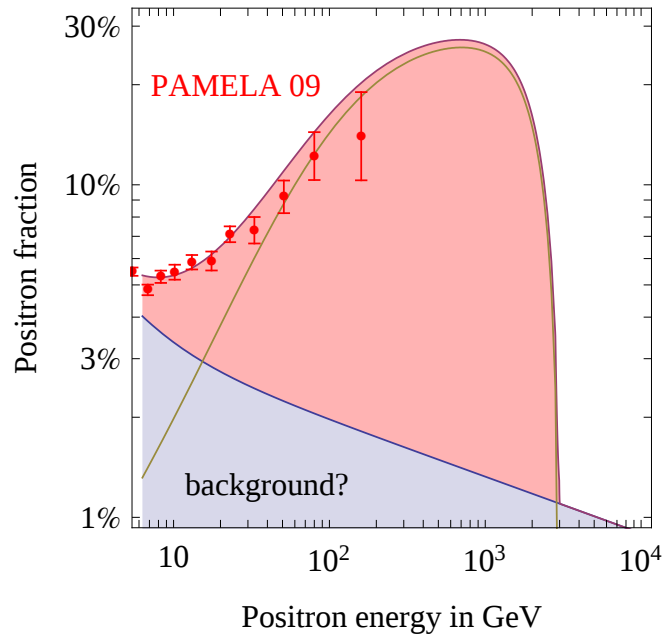
Fitting PAMELA e^+ and FERMI $e^+ + e^-$



Compatible if DM has few TeV mass and annihilates into some leptons

Dark Matter best fit

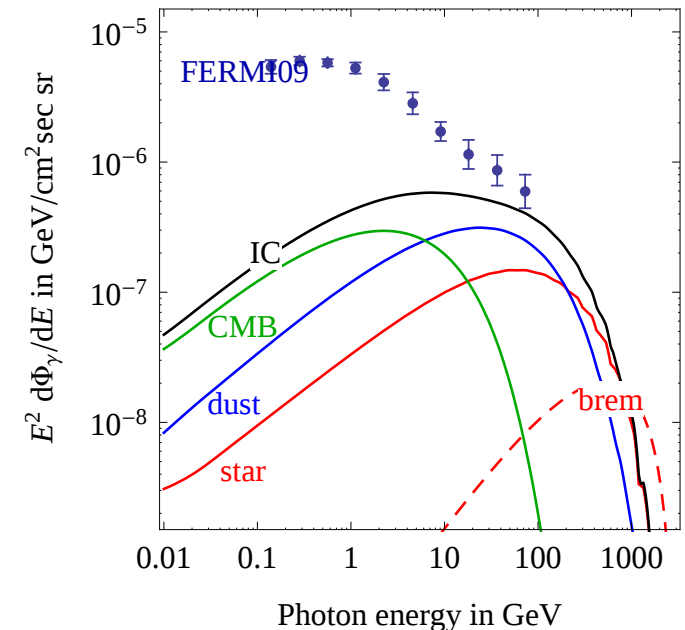
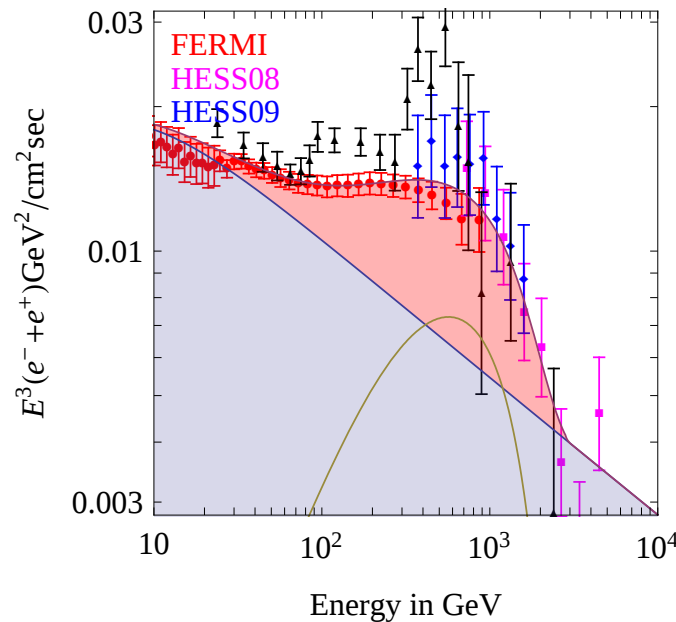
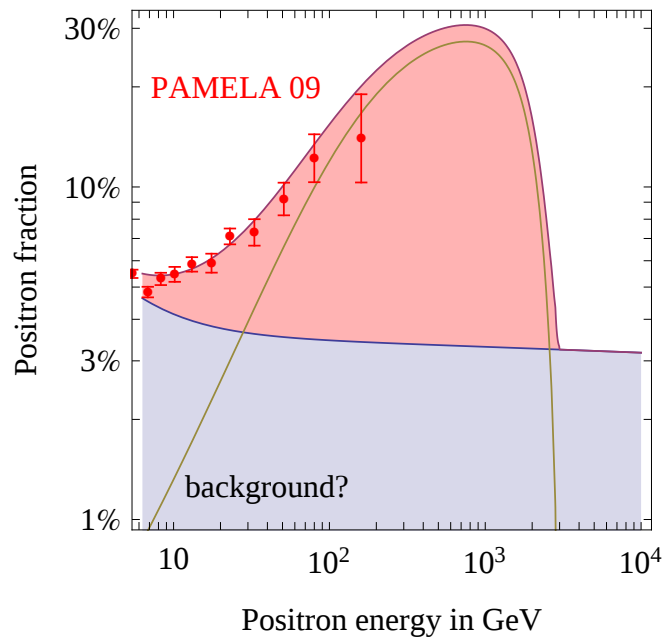
DM with $M = 3$. TeV that annihilates into $\tau^+\tau^-$ with $\sigma v = 1.8 \times 10^{-22} \text{ cm}^3/\text{s}$



New DM theories

(Neutralinos and standard DM models can hardly fit the $e^\pm$ excesses).
 DM is charged under a **dark gauge group**, to get the Sommerfeld enhancement.
 DM annihilates into the new vector. If light, $m \lesssim \text{GeV}$, it can only decay into the lighter leptons. Large $\sigma(\text{DM DM} \rightarrow \ell^+ \ell^+ \ell^- \ell^-)$ obtained.

DM with $M = 3. \text{ TeV}$ that annihilates into 4μ with $\sigma v = 7.7 \times 10^{-23} \text{ cm}^3/\text{s}$



Smoother $e^\pm$ spectrum good for FERMI

γ brehmstrahlung reduced from $\ln M/m_\ell$ to $\ln m/m_\ell$

3

Bounds from γ, ν indirect detection

Bounds on DM from γ and ν

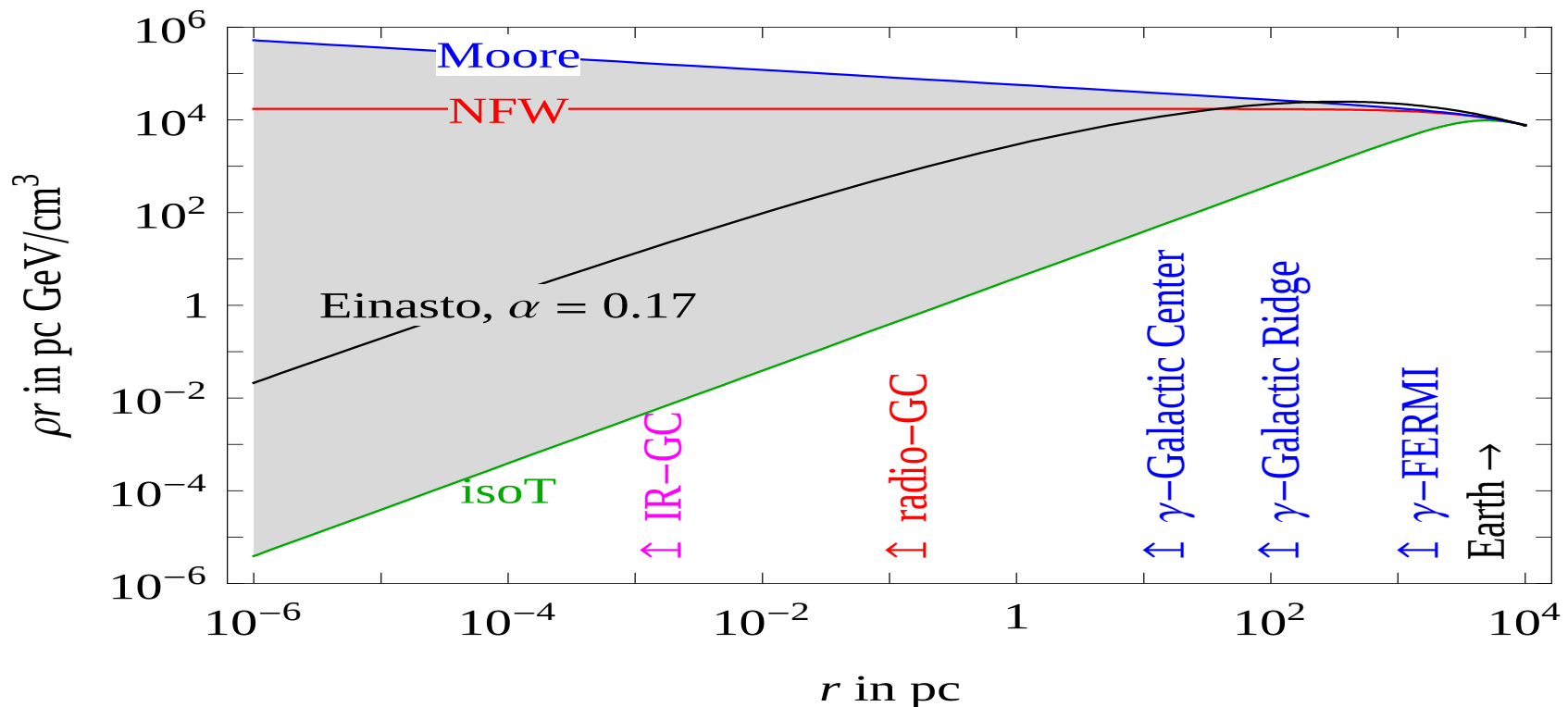
DM DM $\rightarrow \ell^+ \ell^-$ is unavoidably accompanied by photons:

- **Bremstrahlung** from $\ell^\pm$ (if $\ell = \tau$ also $\tau \rightarrow \pi^0 \rightarrow \gamma\gamma$).
Largest $E_\gamma \sim M$, probed by HESS.
- **Inverse Compton**: $e^\pm \gamma \rightarrow e^\pm \gamma'$ scatterings on CMB and star-light: $\dot{E} \propto u_\gamma$.
Intermediate $E_{\gamma'} \sim E_\gamma (E_e/m_e)^2 \sim 50 \text{ GeV}$ being probed by FERMI.
- **Synchrotron**: $e^\pm$ in the galactic magnetic fit: $\dot{E} \propto u_B = B^2/2$.
Small $E_\gamma \sim 10^{-6} \text{ eV}$, probed by radio-observations: Davies, VLT, WMAP.

γ from bremsstrahlung

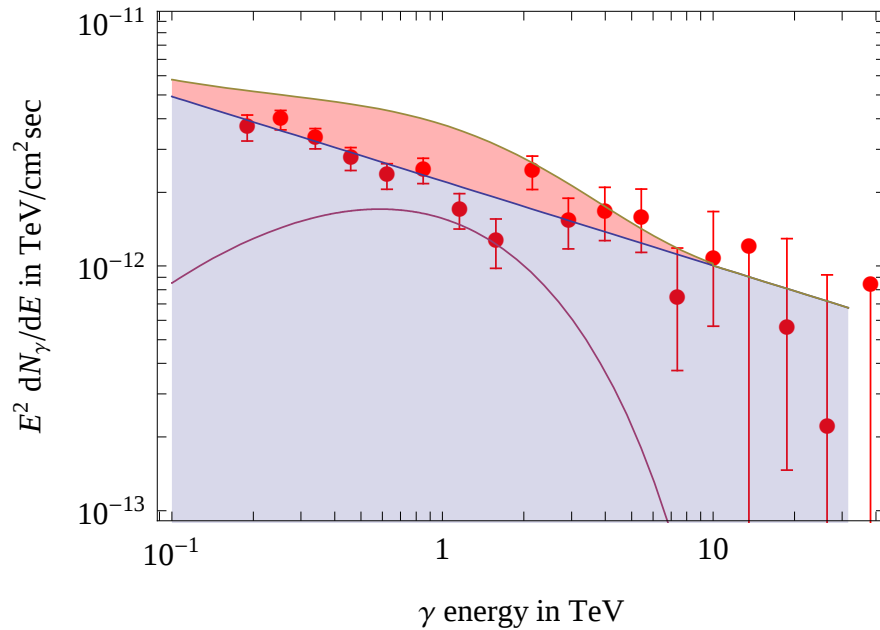
$$\frac{d\Phi_\gamma}{d\Omega dE} = \frac{1}{24\pi} \frac{r_\odot}{M_{\text{DM}}^2} \rho_\odot^2 J \langle \sigma v \rangle \frac{dN_\gamma}{dE}, \quad J = \int_{\text{line-of-sight}} \frac{ds}{r_\odot} \left(\frac{\rho(r)}{\rho_\odot} \right)^2$$

$$\langle J \rangle_{\Delta\Omega} = \begin{cases} \text{NFW} & \text{Einasto} & \text{isoT} \\ 14700 & 7600 & 14 \\ 2400 & 3000 & 14 \end{cases} \begin{array}{|c|c|} \hline \text{region} & \Delta\Omega \\ \hline \text{Galactic Center} & 1 \cdot 10^{-5} \\ \text{Galactic Ridge} & 3 \cdot 10^{-4} \\ \hline \end{array}$$

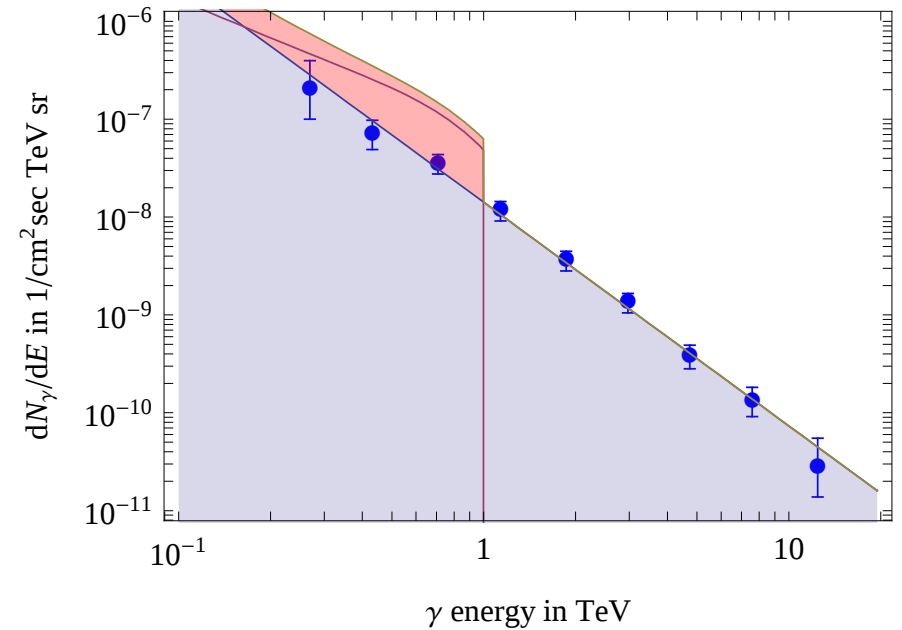


HESS observations

a) $M = 10$ TeV into W^+W^- , Galactic Center



b) $M = 1$ TeV into $\mu^-\mu^+$, Galactic Ridge



DM signals computed for NFW and $\sigma v = 10^{-23} \text{ cm}^3/\text{sec}$. We **conservatively** impose that no point is exceeded at 3σ : so the 1st example above is allowed.

Other bounds from DM-dominated dwarf spheroidals around the Milky Way.

Inverse Compton

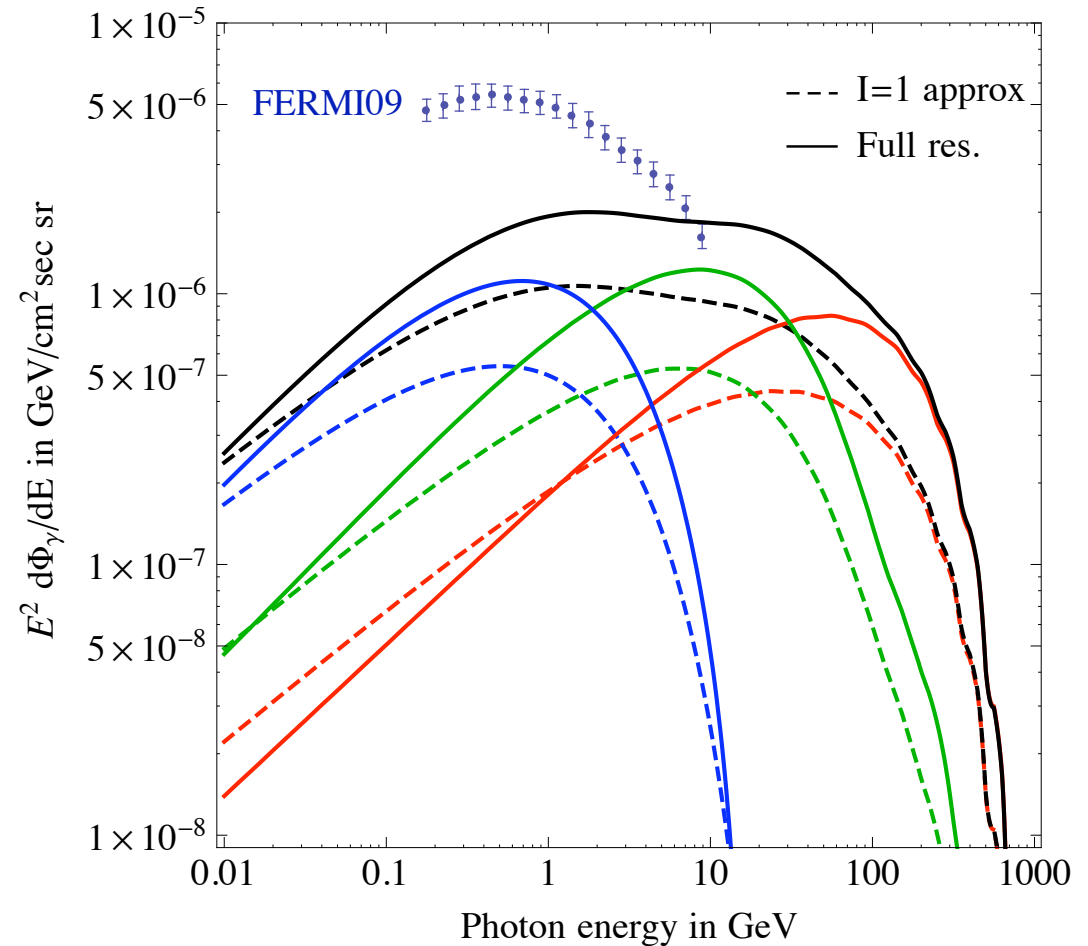
Galactic $e^\pm$ diffuse ($I \neq 1$) while loosing most of their energy as

$$e\gamma \rightarrow e'\gamma' \quad E_{\gamma'} \sim E_\gamma \frac{E_e^2}{m_e^2} \sim 30 \text{ GeV}$$

Initial γ :

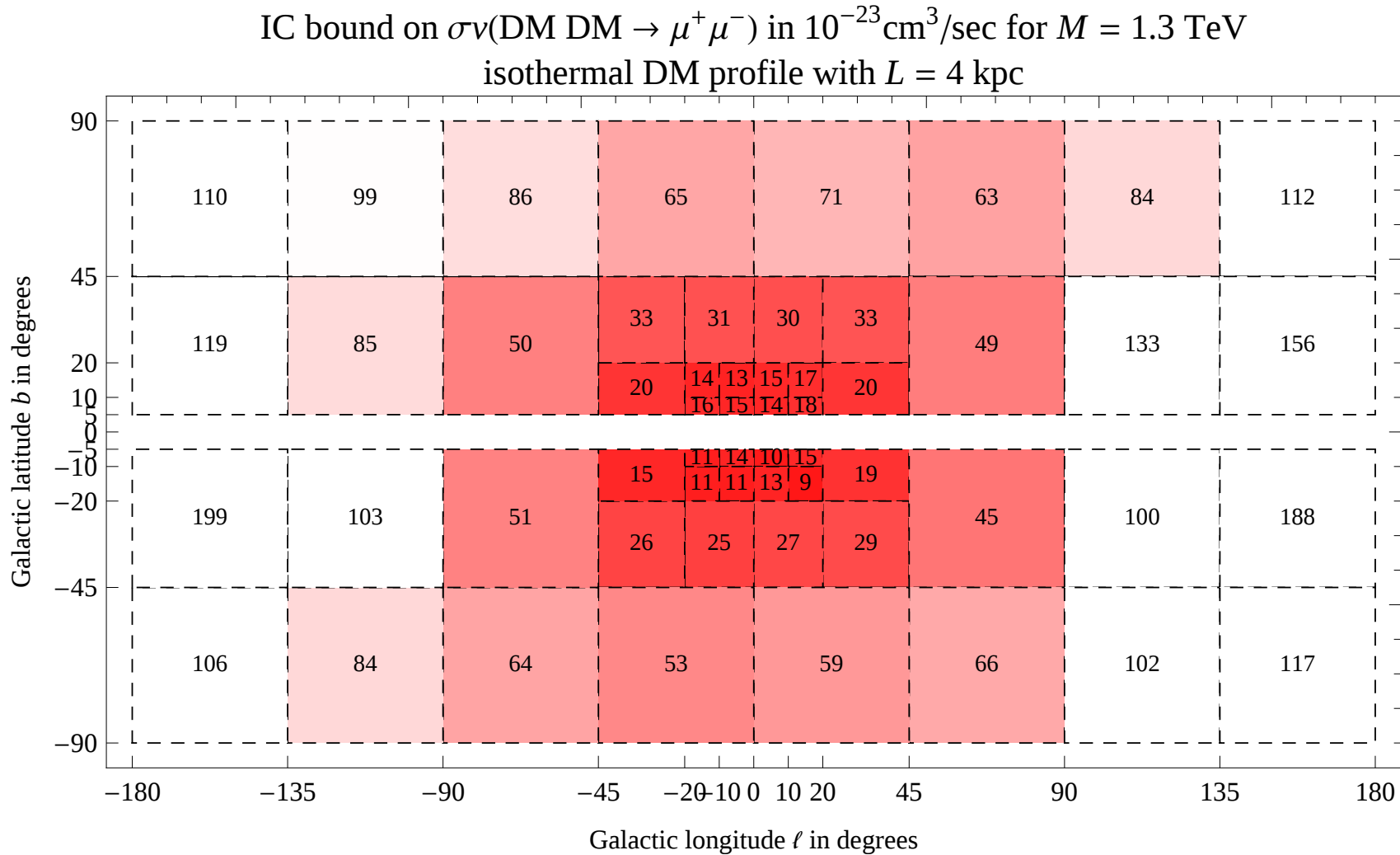
- i) $E_\gamma \sim \text{eV}$ from star-light;
- ii) $E_\gamma \sim 0.1 \text{ eV}$ from dust rescattering;
- iii) $E_\gamma \sim \text{meV}$ from CMB.

IC $_\gamma$ dominate over FSR $_\gamma$ at FERMI E



FERMI full-sky observations

Point sources and hadron contamination (around 100 GeV) still present. **No clear excess.** Robust bounds imposing $\text{DM} < \text{exp}$ in all sky and energy regions:



$$\text{global fit: } \chi^2 = \sum_i^{\text{all bins}} \frac{(\Phi_i^{\text{DM}} - \Phi_i^{\text{exp}})^2}{\delta\Phi^2} \Theta(\Phi_i^{\text{DM}} - \Phi_i^{\text{exp}}) < 9$$

ν observations

$(\bar{\nu})_{\mu}$ scattering in the rock below the detector produce through-going $\mu^{\pm}$

$$\Phi_{\mu} \approx \frac{r_{\odot} \langle \sigma v \rangle}{8\pi} \frac{\rho_{\odot}^2}{M^2} \frac{3G_F^2 M^2 p}{\pi \alpha_{\mu}} \cdot J \cdot \Delta\Omega \cdot \int_0^1 dx \, x^2 \frac{dN_{\nu}}{dx}$$

where $p \sim 0.125$ is the momentum fraction carried by each quark in the nucleon and $\alpha_{\mu} = 0.24 \text{ TeV/kmwe} = -dE/d\ell$ is the $\mu^{\pm}$ energy loss.

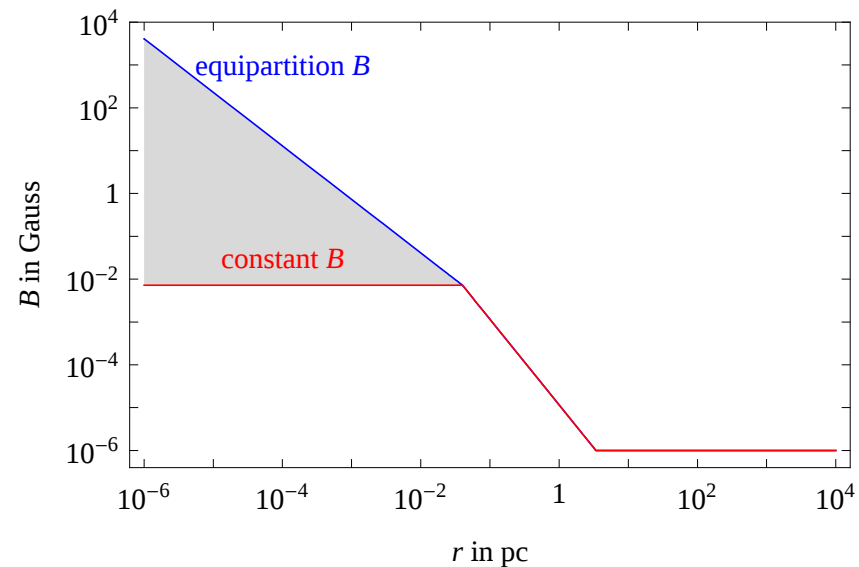
The total $\mu^{\pm}$ rate negligibly depends on the DM mass M .

SuperKamiokande got the dominant bounds in cones up to 30° around the GC

$$\Phi_{\mu} < 0.02/\text{cm}^2\text{s}$$

Radio observations

Around the GC magnetic fields B contain more energy than light, diffusion and advection seem negligible, so **all the $e^\pm$ energy E goes into synchrotron radiation**. The unknown B only determines the maximal ν_{syn} :



$$\frac{dW_{\text{syn}}}{d\nu} \approx \frac{2e^3 B}{3m_e} \delta\left(\frac{\nu}{\nu_{\text{syn}}} - 1\right) \quad \text{where} \quad \nu_{\text{syn}} = \frac{eBE^2}{4\pi m_e^3} = 1.4 \text{ MHz} \frac{B}{\text{G}} \left(\frac{p}{m_e}\right)^2.$$

Davies 1976 observations at the lower $\nu = 0.408 \text{ GHz}$ give the **robust and dominant** bound as the observed GC radio-spectrum is harder than synchrotron:

$$\nu \frac{dW_{\text{syn}}}{d\nu} = \frac{\sigma v}{2M^2} \int_{4'' \text{ cone}} dV \rho^2 E(\nu) N_e(E(\nu)) < 4\pi r_\odot^2 \times 2 \cdot 10^{-16} \frac{\text{erg}}{\text{cm}^2 \text{ s}}$$

BIG uncertainty in the DM density ρ at 1pc from the GC: NFW or ...?

Bounds from cosmology

DM annihilation rate $\propto \rho^2$ is enhanced in the early universe: its products can

1. affect BBN at $T \sim \text{MeV}$ fragmenting ^4He , D, ^3He ...

Primordial abundances are not safely known.

2. affect CMB reionizing H after matter/radiation decoupling, $z \lesssim 1000$.

$13.6 \text{ eV} \times n_e \ll u_\gamma$ ionizes all H changing CMB anisotropies

3. heat gas after structure formation $z \sim 10$.

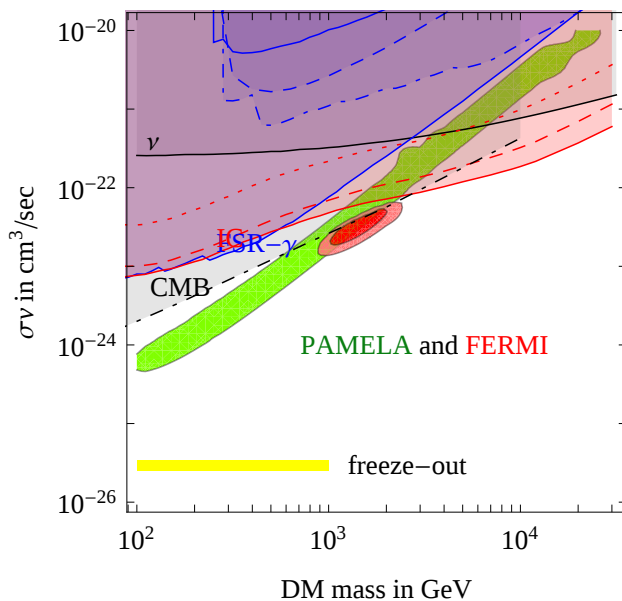
Depends on unknown non-linear small-scale DM clustering.

1, 2 and 3 give comparable constraints at the PAMELA-level, $\sigma v \sim 10^{-23} \text{ cm}^3/\text{sec}$.
2 is stronger and robust and can be improved by PLANCK.

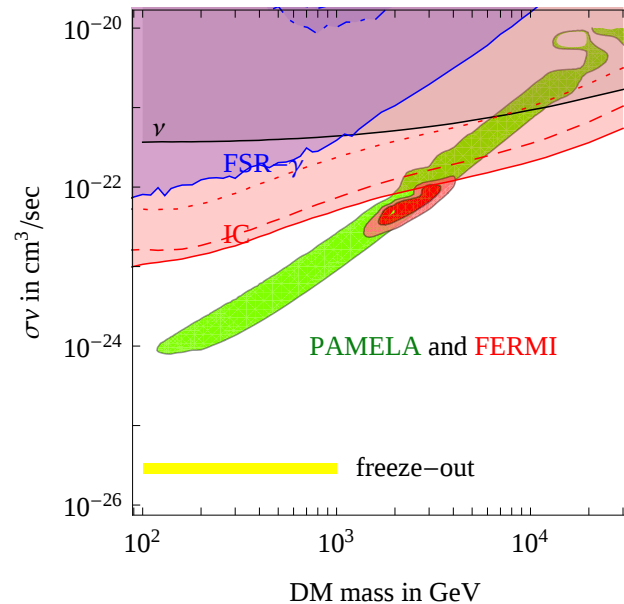
$e^\pm$ signals vs bounds

- All at 3σ : **region allowed by PAMELA e^+ and FERMI $e^+ + e^-$** vs bounds on: • **FSR- γ** from FERMI full sky, HESS Galactic Center, Ridge, Dwarf Spheroidals; • **IC- γ** for $L = 4, 2, 1$ kpc; • CMB; • ν ; • **radio observations of the GC**

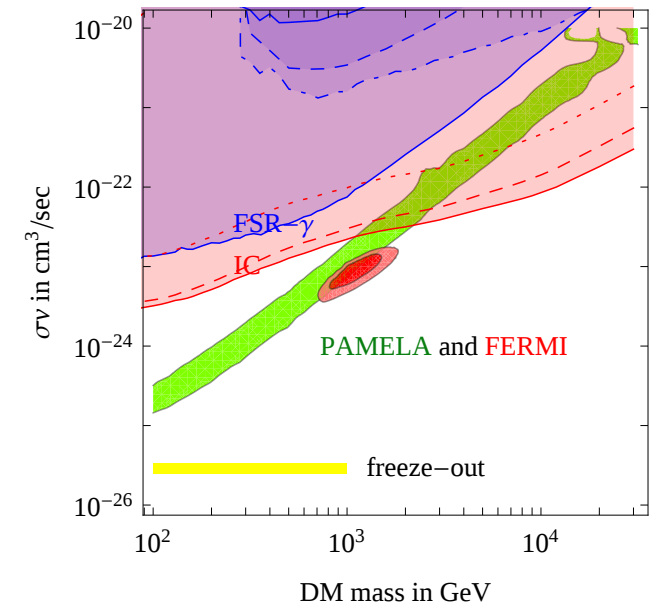
DM DM $\rightarrow \mu^+ \mu^-$, isothermal profile



DM DM $\rightarrow 4\mu$, isothermal profile



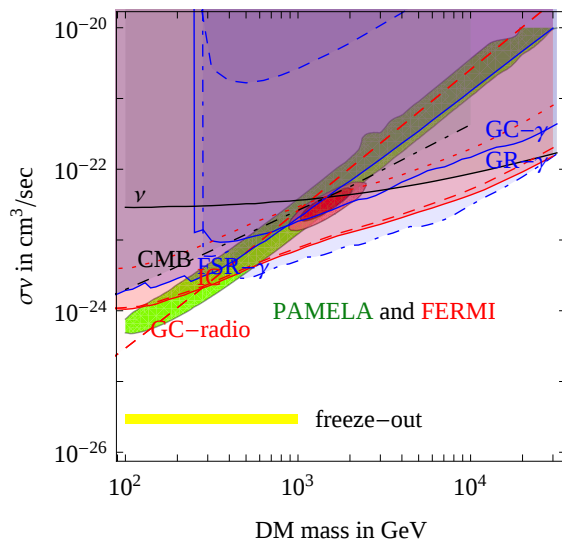
DM DM $\rightarrow 4e$, isothermal profile



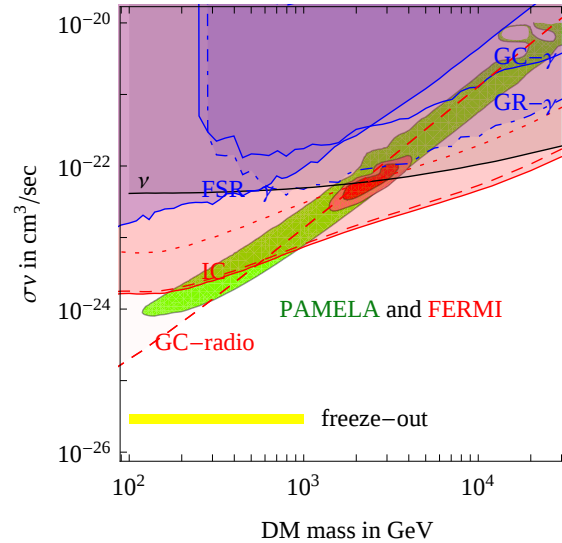
$e^\pm$ excesses can be DM DM $\rightarrow 2\mu, 4\mu, 4e$ if ρ is isothermal

not if Einasto or NFW

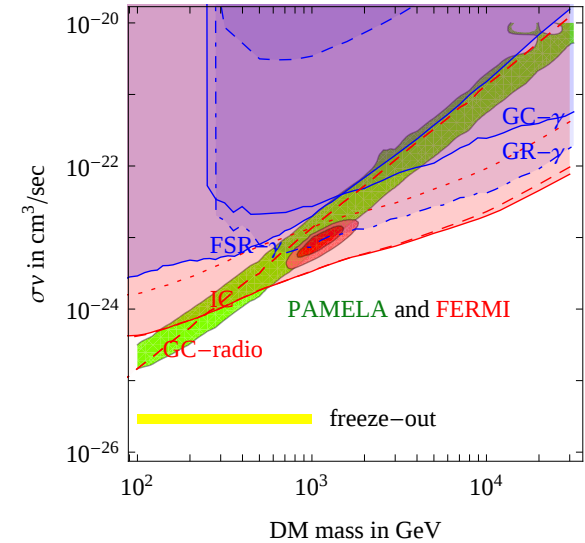
DM DM $\rightarrow \mu^+ \mu^-$, Einasto profile



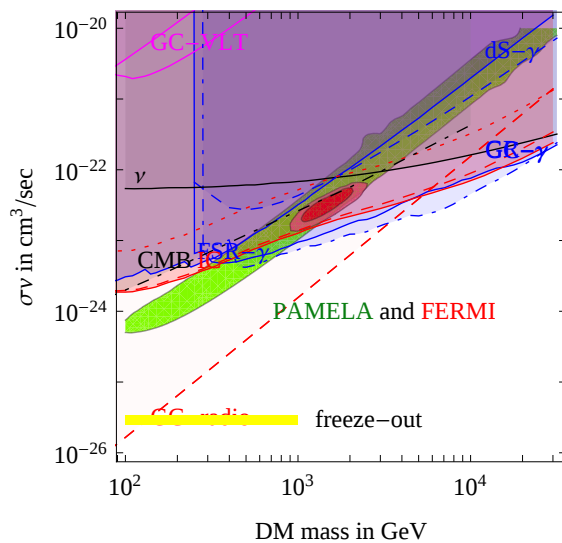
DM DM $\rightarrow 4\mu$, Einasto profile



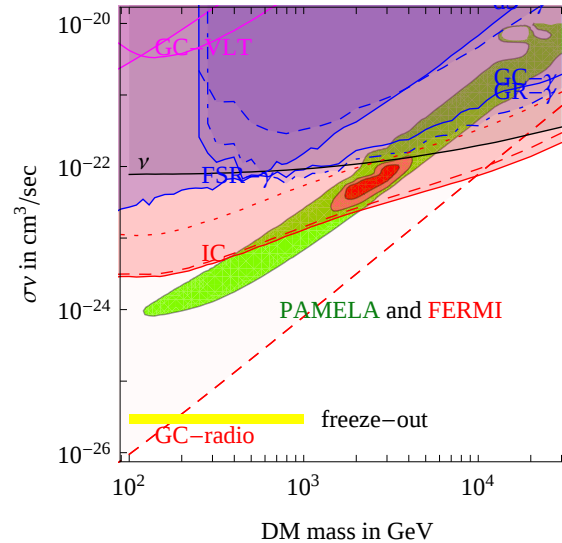
DM DM $\rightarrow 4e$, Einasto profile



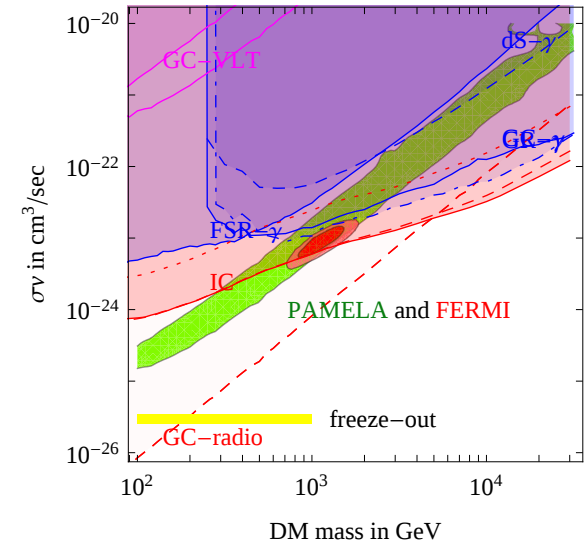
DM DM $\rightarrow \mu^+ \mu^-$, NFW profile



DM DM $\rightarrow 4\mu$, NFW profile



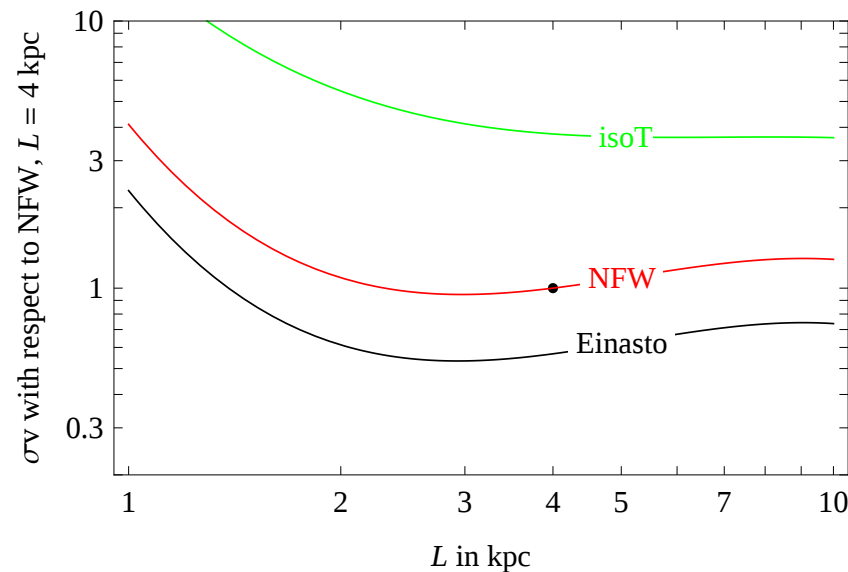
DM DM $\rightarrow 4e$, NFW profile



The problem is no longer only at small scales not tested by N -body simulations

Caveats

$L = 1$ kpc at the GC (ok?) would relax NFW or Einasto down to isoT: DM annihilations outside the diffusion volume contribute to FSR, but not to IC:

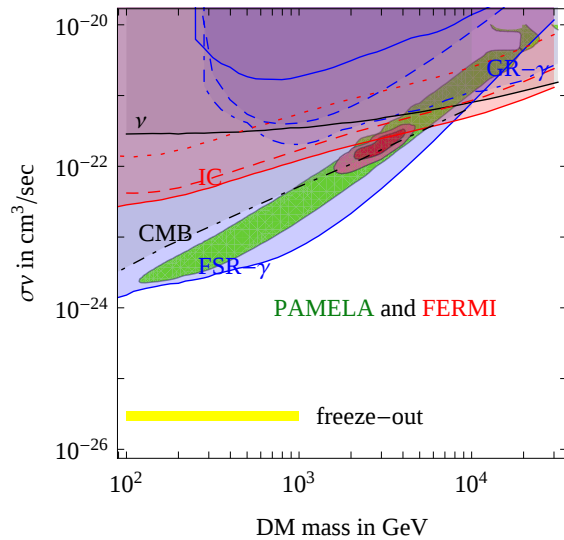


Disavored by a) global fits of charged CR; b) abundances of CR with $\tau \sim \tau_{\text{diff}}$; c) FERMI sees γ away from the GC. d) realistic smooth growth of $K(z)$.

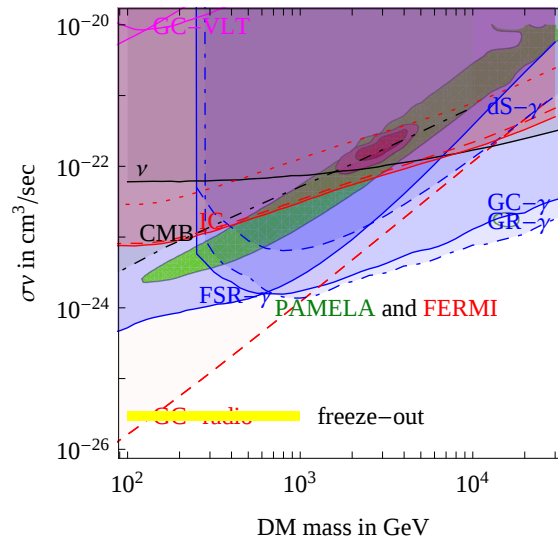
Can synchrotron dominate over IC? Only around the GC.

not if τ channels

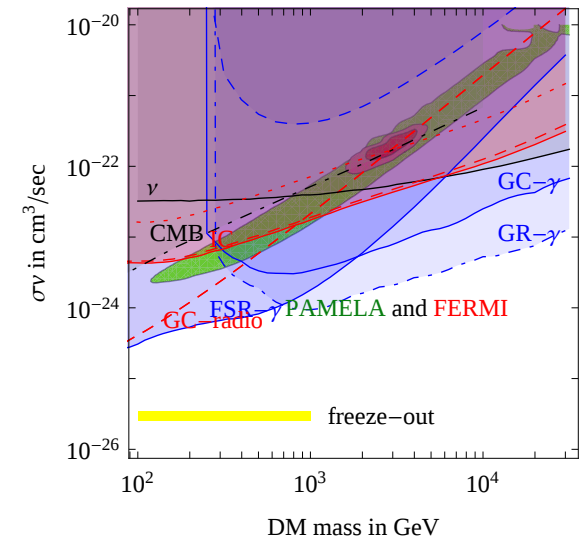
DM DM $\rightarrow \tau^+\tau^-$, isothermal profile



DM DM $\rightarrow \tau^+\tau^-$, NFW profile



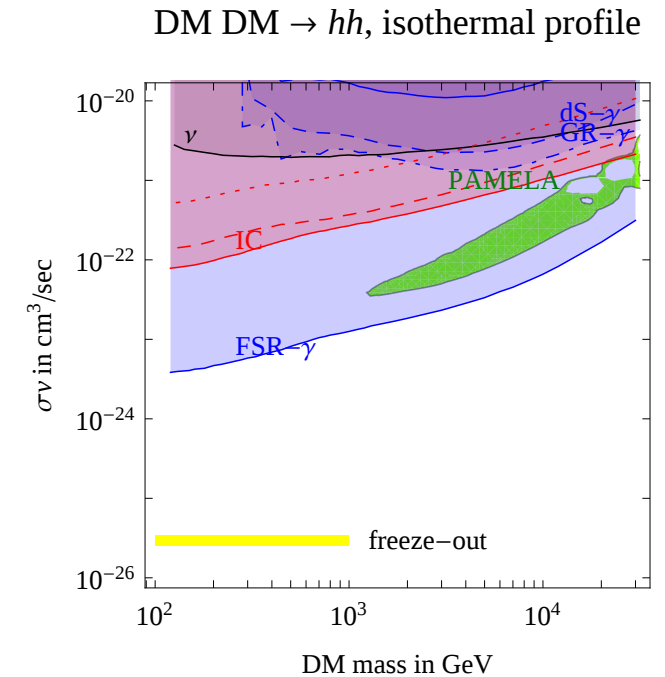
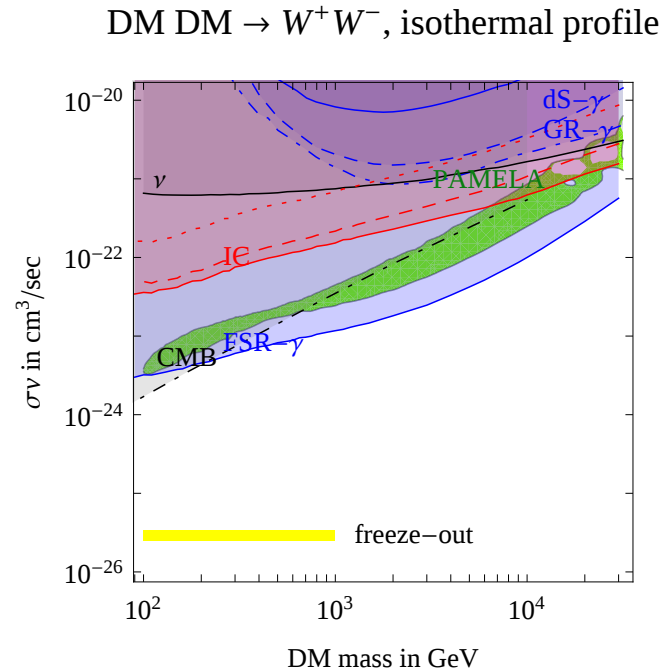
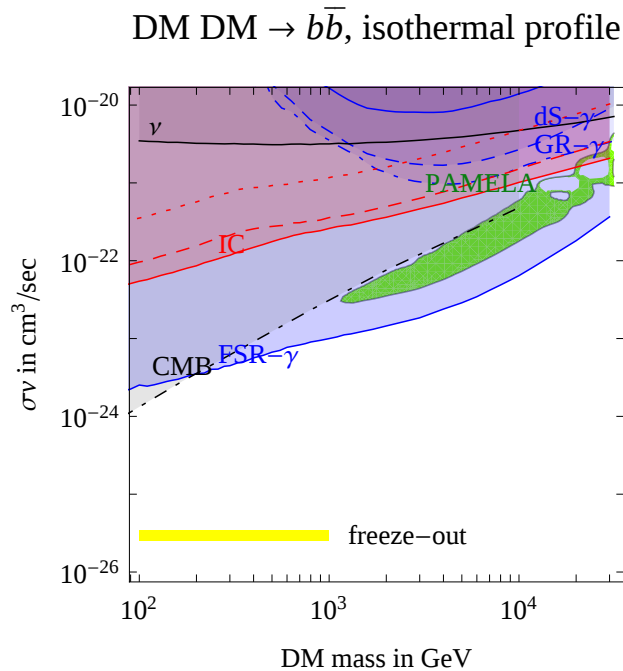
DM DM $\rightarrow \tau^+\tau^-$, Einasto profile



Too many $\tau \rightarrow \pi^0 \rightarrow \gamma$: FSR direct exclusion for any reasonable profile.

not if non-leptonic channels

Non-leptonic channels give many FSR- γ and can at most be subdominant:



The SUSY wino or Minimal Dark Matter no longer can fit PAMELA

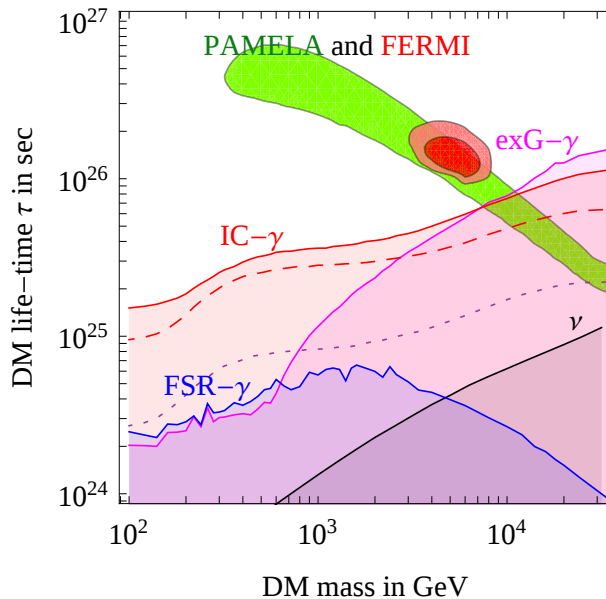
4

DM decays

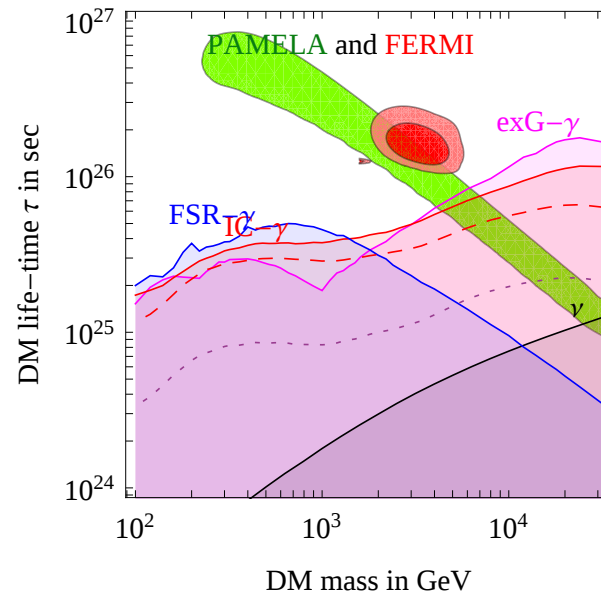
DM decays are compatible with NFW

If instead DM **decays** with life-time τ , replace $\rho^2 \sigma v / 2M^2 \rightarrow \rho^1 / M\tau$:

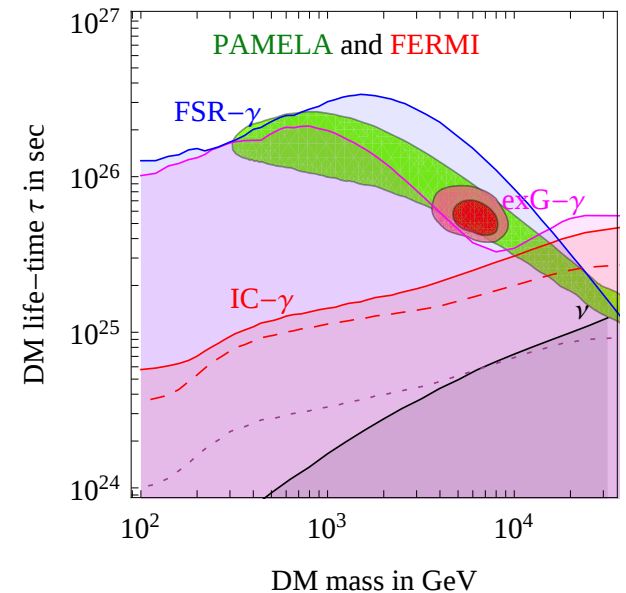
DM $\rightarrow 4\mu$, NFW profile



DM $\rightarrow \mu^+ \mu^-$, NFW profile



DM $\rightarrow \tau^+ \tau^-$, NFW profile



With DM decay **PAMELA**/**FERMI** are allowed for all DM density profiles

DM decays are compatible with cosmology

Weak bounds from BBN and CMB, again due to $\rho^{\text{red}}(t) \rightarrow \rho^{\text{green}}(t)$.

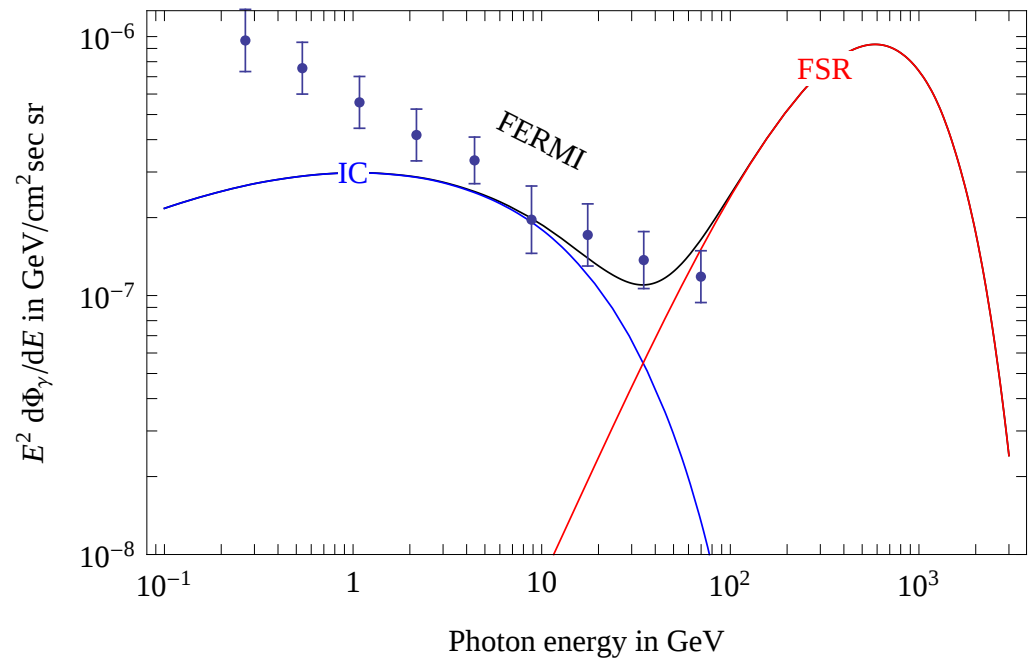
The extra-galactic γ flux is significant:

$$\frac{\Phi_{\text{cosmo}}}{\Phi_{\text{galactic}}} \sim \frac{\rho_{\text{cosmo}} R_{\text{cosmo}}}{\rho_{\odot} R_{\odot}} \sim 1$$

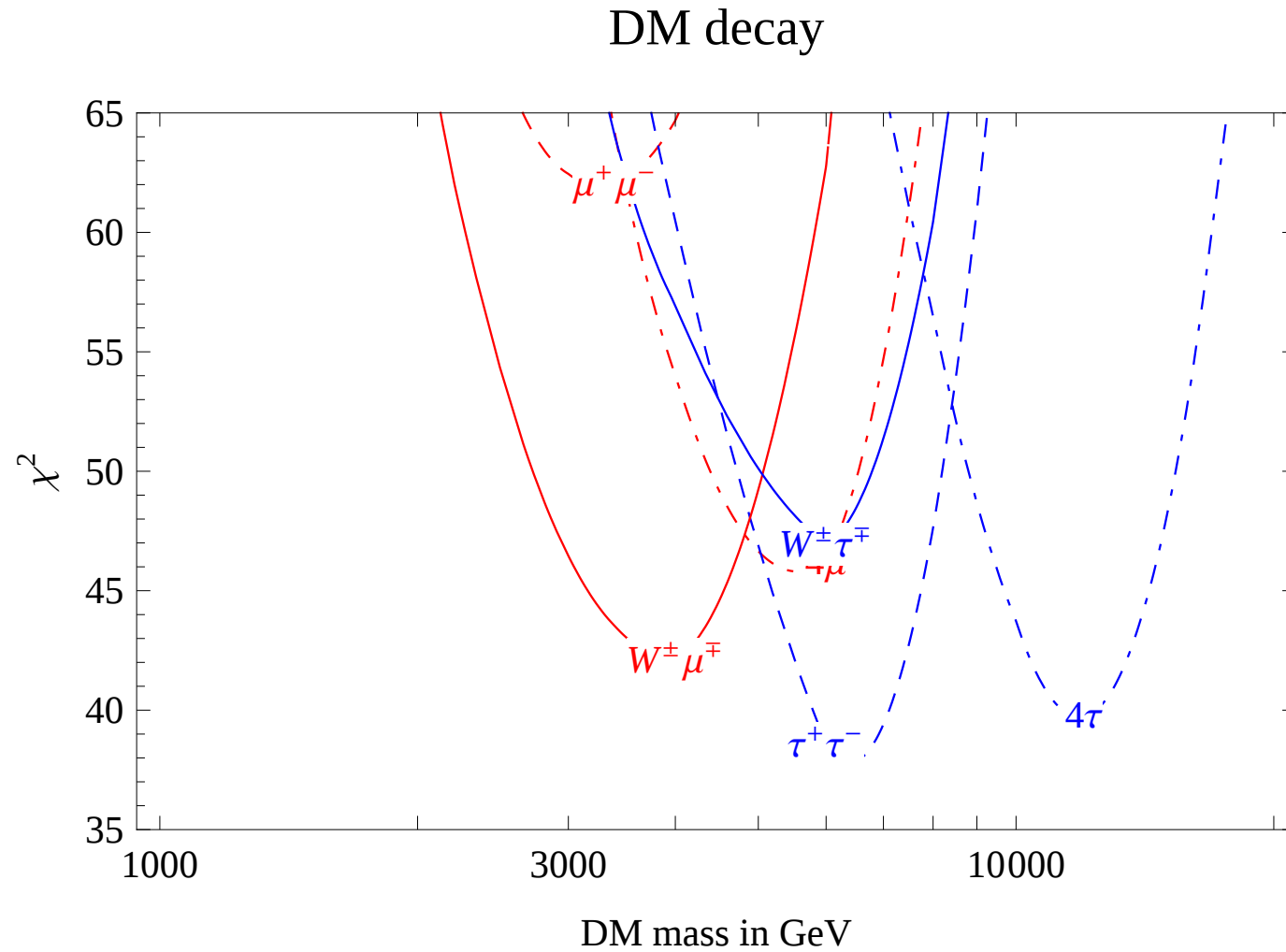
and can be computed reliably: no dependence on small-scale DM clustering.

The ‘exG- γ ’ bound on FSR+IC is competitive, helped by FERMI who already extracted (?) the diffuse γ flux, a few times below the less bright sky.

DM $\rightarrow \tau^+ \tau^-$ with $M = 6$ TeV and $\tau = 5.4 \times 10^{25}$ sec



PAMELA and FERMI as DM decay



$e^\pm$ excesses suggest SU(2) technicolor!?

DM decays suggests $M \sim \text{few TeV}$, which naturally implies the observed

$$5 \sim \frac{\rho_{\text{DM}}}{\rho_b} \sim \frac{M}{m_p} \left(\frac{M}{T_{\text{dec}}} \right)^{3/2} e^{-M/T_{\text{dec}}}$$

if the DM density is due to a baryon-like **asymmetry** kept in thermal equilibrium by weak **sphalerons** down to $T_{\text{dec}} \sim 200 \text{ GeV}$.

Possible if DM is a chiral fermion or is made of chiral fermions.

The DM mass is $M \sim \lambda v \sim 2 \text{ TeV}$ for $\lambda \sim 4\pi$: strong dynamics a-la **technicolor**.
GUT-suppressed dimension 6 4-fermion operators give $\tau \sim M_{\text{GUT}}^4/M^5 \sim 10^{26} \text{ s}$.

If the technicolor group is SU(2) with techni-q $Q = (2, 0)$ under $\text{SU}(2)_L \otimes \text{U}(1)_Y$

- DM is a QQ **bound state**, scalar and SU(2)-singlet as suggested by data.
- A 4-fermion $QQ\bar{L}L$ operator allows a slow $\text{DM} \rightarrow \ell^+\ell^-$: no $\Pi \simeq W_L$ involved.
- Usual problems of technicolor: minimal correction to the S parameter...

Conclusions

The PAMELA, FERMI-ATIC, HESS $e^\pm$ excesses attracted most attention. They could be due to astrophysics or to unexpected DM as follows:

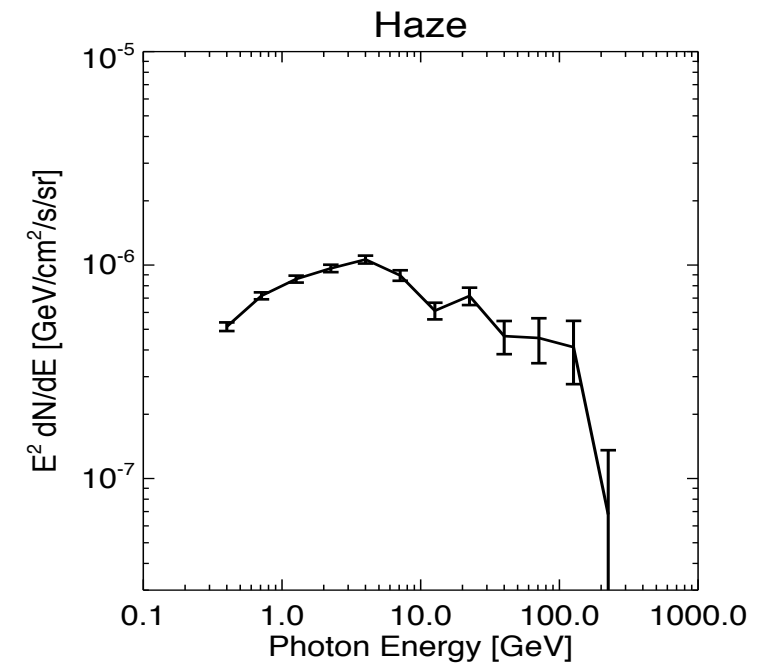
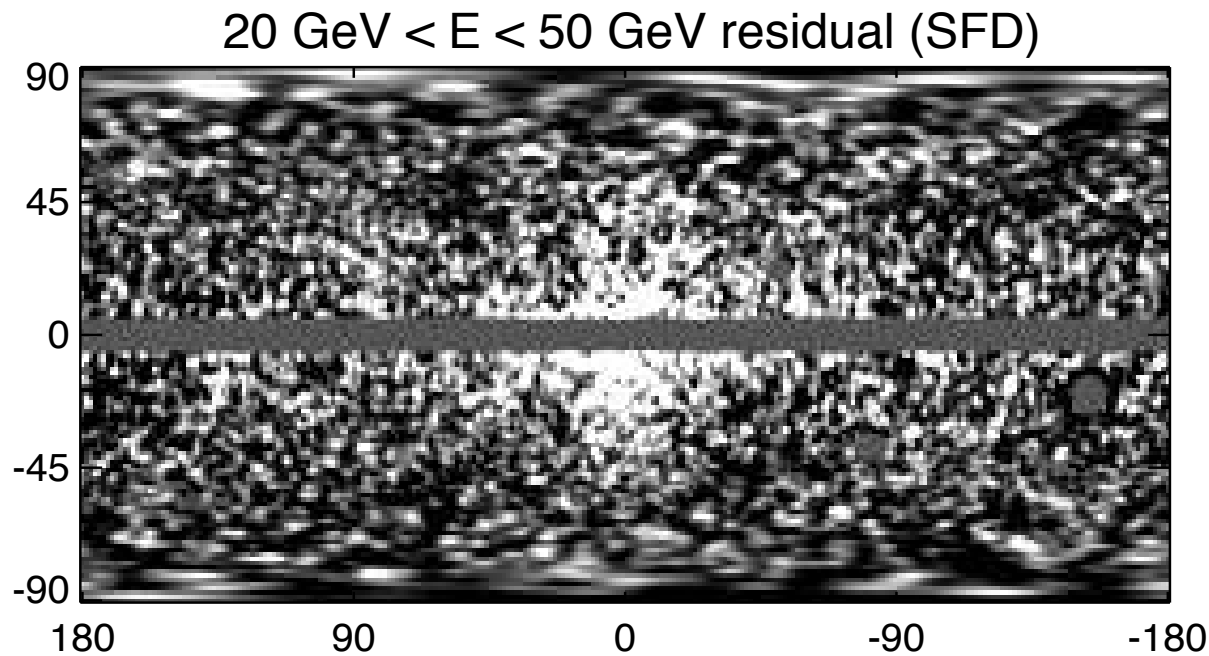
- × $2e$ channel gave the ATIC peak, not the FERMI $e^+ + e^-$ excess.
- × τ channels give too much γ .
- × W, Z, q, b, h, t channels can only fit PAMELA e^+ and give too much γ .
- 3 TeV DM that annihilates in $2\mu, 4\mu, 4e$. But only if the injection term is quasi constant: i) Isothermal profile; ii) DM decays.

DM predicts that the e^+ fraction must grow. DM IC- γ must be in FERMI sky.

Next: FERMI, PAMELA, AMS, PLANCK

The FERMI haze?

Some theorists claim they see a quasi-spherical 'FERMI haze' excess:



FERMIons disagree [arXiv:1003.0002]