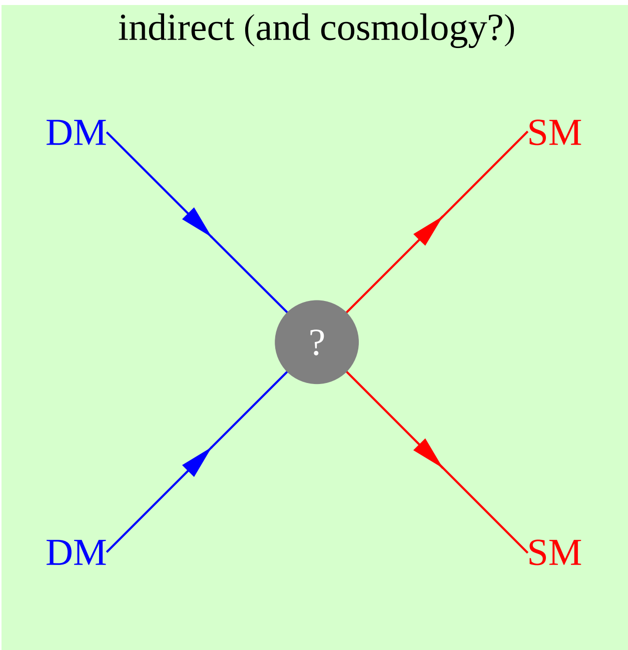
Dark Matter news 2010

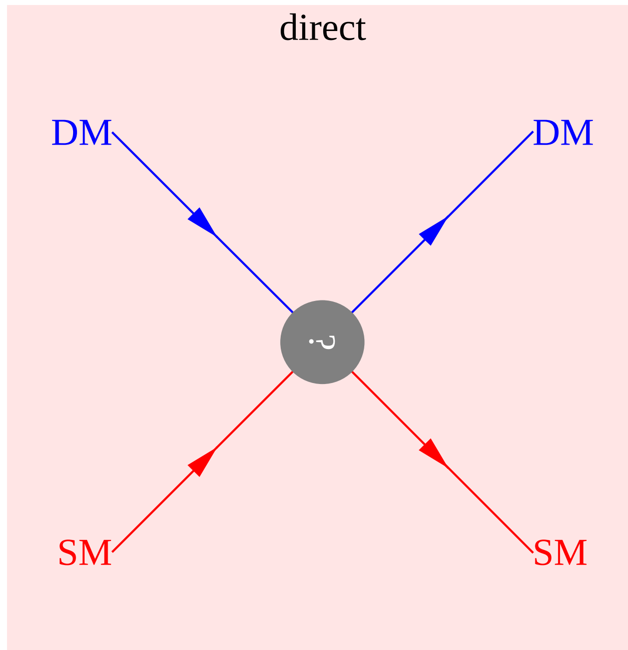
1) New data
2) New discoveries
3) New bounds
4) New theories

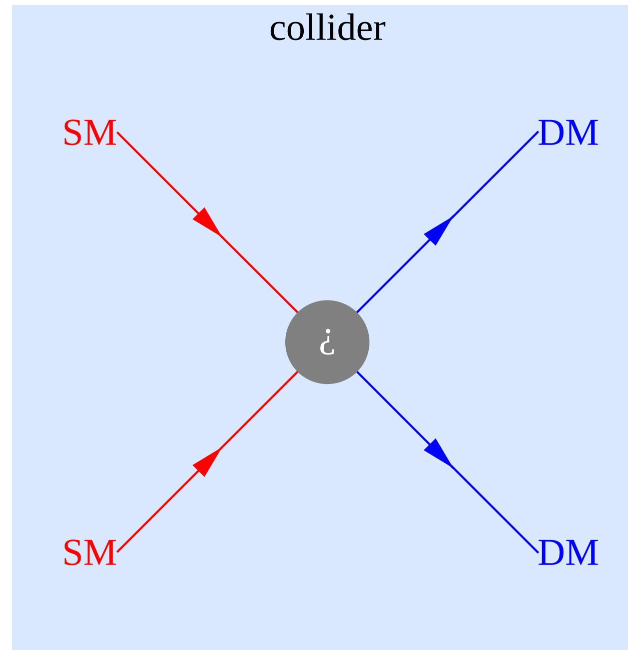
Alessandro Strumia, Planck 2010, June 1, 2010

DM is. Everywhere. Waiting for a sign

from the sky | from the underworld | from CERN







Prophets looked at the Universe and told $\sigma v = 3\ 10^{-26}\,\text{cm}^3/\text{sec}$.
Prophecy don't say which SM particles couple to DM: q? ℓ? W?

Data is coming

Status of the field: messianic awaiting for the coming. New data this year:

- Indirect: FERMI γ sky
- Direct: CDMS/CoGenT/Xenon
- Collider: work in progress

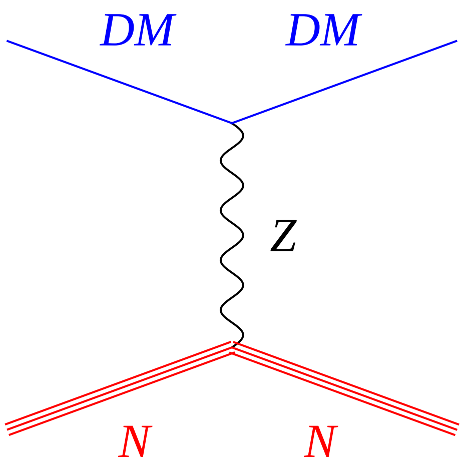
New claims of Dark Matter: a few per year

past years:
PAMELA
ATIC-FERMI
WMAP haze
DAMA
511 keV

last year:
FERMI Haze
FERMI γ twice
CDMS/Edelweiss
CoGeNT
Tunguska

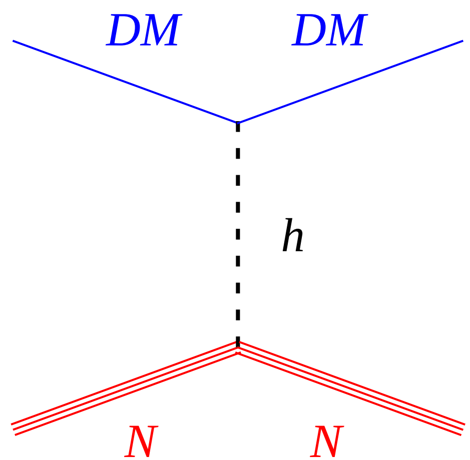
Year Zero? Beware to fake Messiahs? "*And they shall turn away their ears from the truth, and shall be turned unto fables*" Timothy 4: 3,4.

Direct DM detection: theory



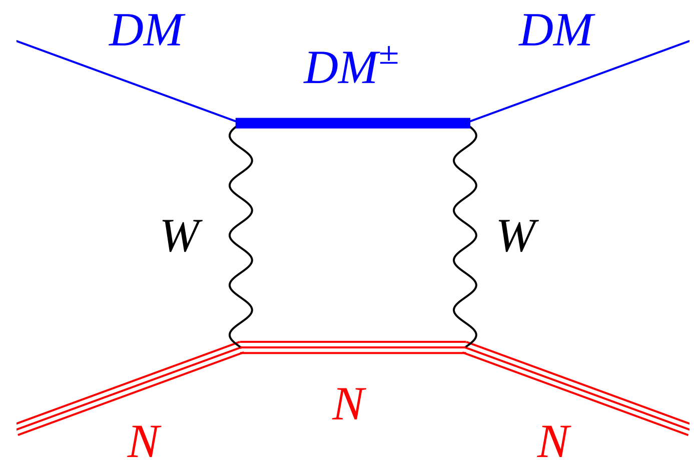
tree, vector

$$\sigma_{\rm SI} \approx \frac{\alpha^2\, m_N^2}{M_Z^4}$$



tree, scalar

$$\sigma_{\rm SI} \approx \frac{\alpha^2\, m_N^4}{M_h^6}$$

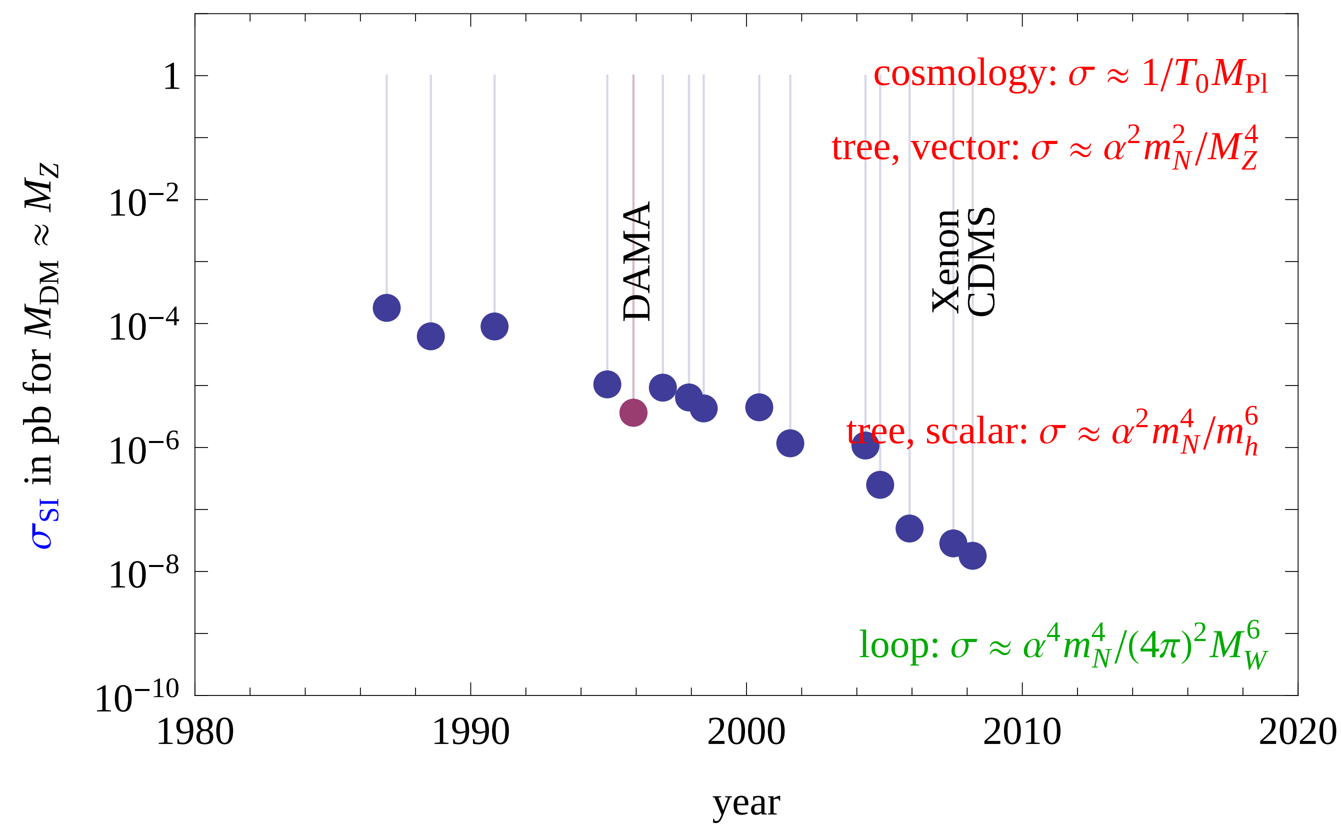


loop

$$\sigma_{\rm SI} \approx \frac{\alpha^4\, m_N^4}{M_W^6}$$

Direct DM detection: experiment

Bounds on the Spin-Independent $\sigma_{\rm SI}$(DM nucleon) parameter:



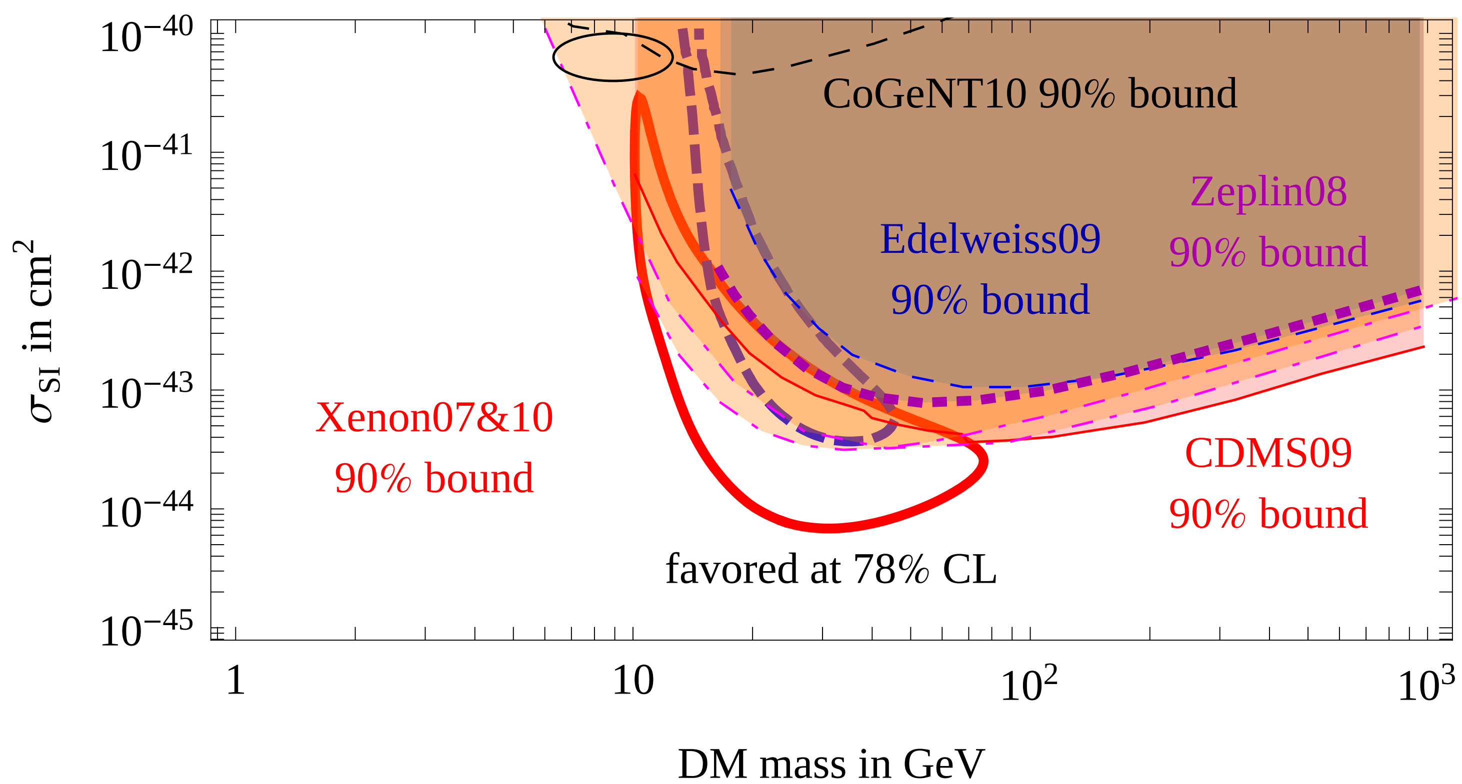
DM must be neutral under the γ, g and almost neutral under the Z

The vector effect vanishes if DM is real (e.g. a 'neutralino' Majorana fermion)

CDMS, Edelweiss, CoGeNT and Xenon

experiment	expected background	events seen	significance	sensitivity
CDMS	0.8 events	2	1.5σ	best
Edelweiss	0.15 events	1	1.5σ	good
CoGeNT	?	100+	?	at low M

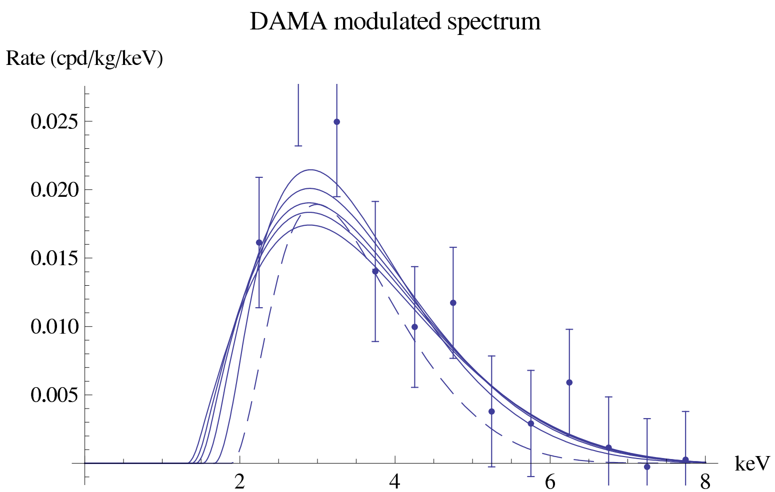
CoGeNT is small and has low bck: competitive at low energy, so for light DM

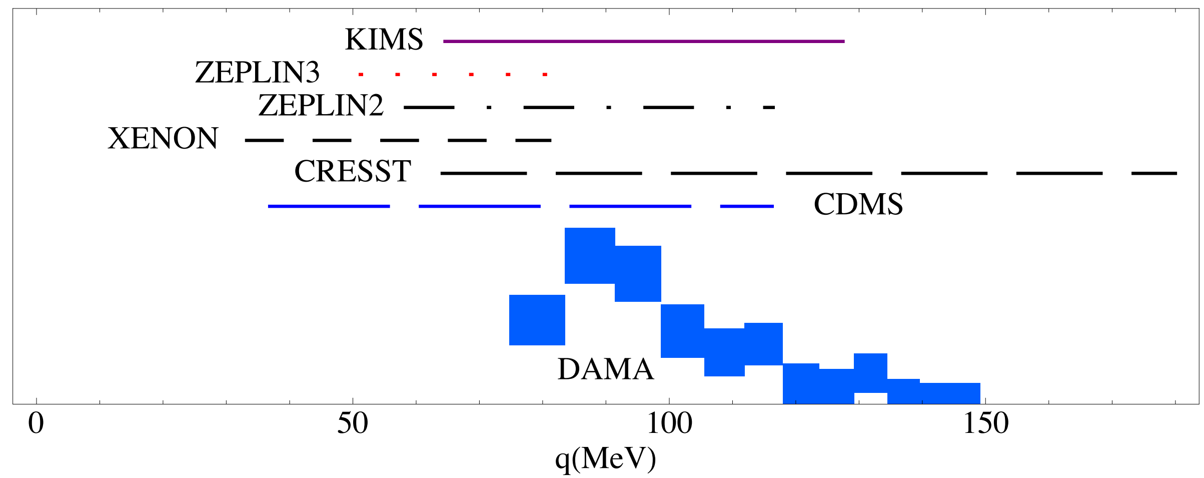


DAMA: new ideas / last hopes

Channeling. Mildly disfavored region at $M \sim 10\,\text{GeV}$ around CoGeNT.
Inelastic. DM $N \to$ DM$'$ N can explain DAMA for $M' - M \sim \mu v^2 \sim 100\,\text{keV}$.
Form factor: the DM/nucleon coupling could be $\propto q^2 = (P_{\text{DM}} - P_N)^2$ or q^4

Non standard DM models can also fit the DAMA non-exponential spectrum.





Staus: disfavored. Xenon will tell. Heterotic DM: combine the previous ideas.

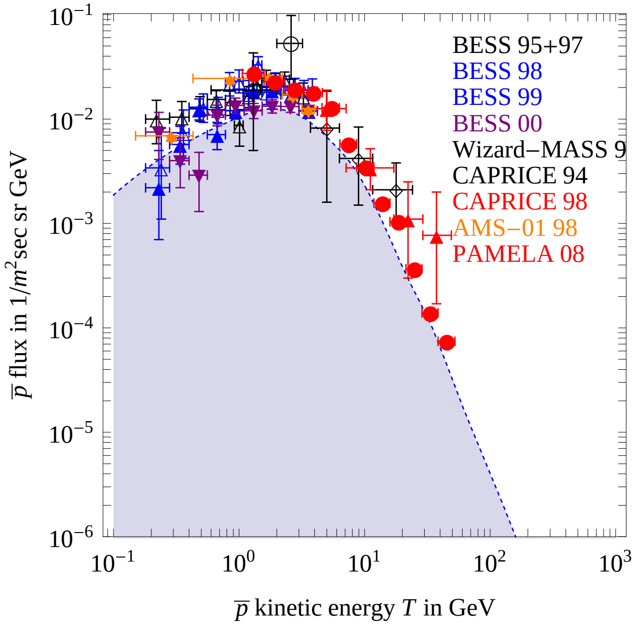
Indirect signals of Dark Matter

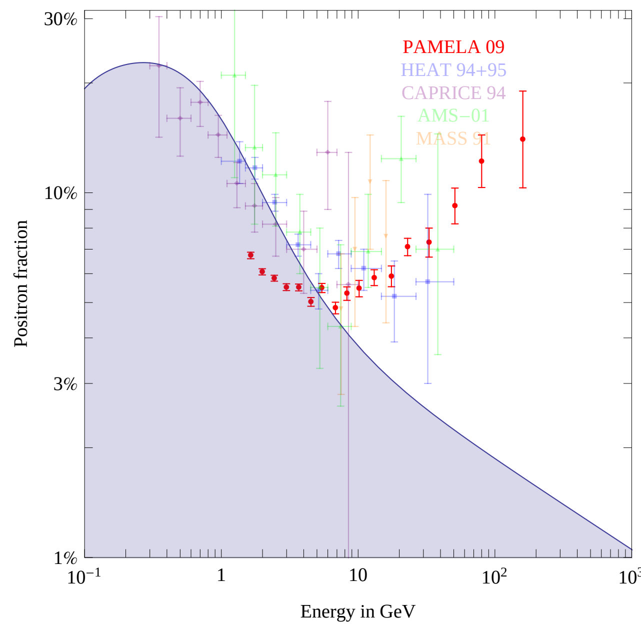
DM DM annihilations in our galaxy might give detectable γ, e^+, $\bar{p}$, $\bar{\mathrm{d}}$, ν.

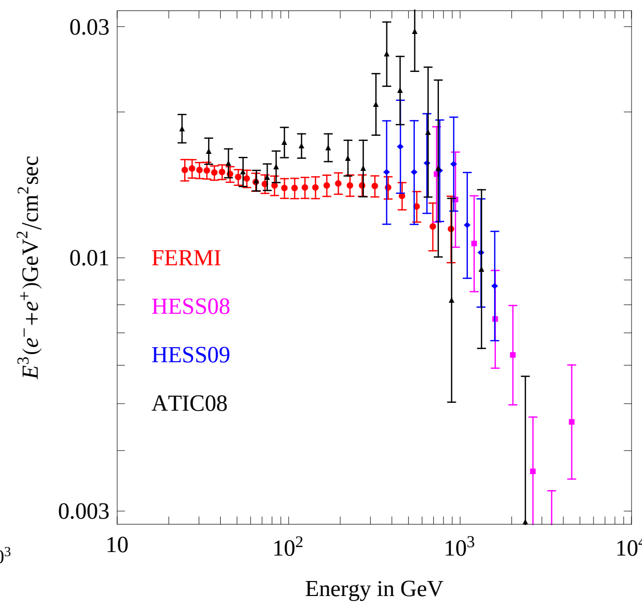
Indirect signals

Charged particles

PAMELA, FERMI/ATIC, HESS







$\bar{p}$: consistent with bck

e^+/e^-: excess

$e^- + e^+$: feature?

Bad news for the future:

The $e^{\pm}$ excesses can be unexpected DM

PAMELA e^{+} needs either leptonic DM channels or any channel if $M \gtrsim$ TeV.

PAMELA $\bar{p}$ disfavor non-leptonic channels, unless $M \gtrsim 10$ TeV.

ATIC or FERMI want leptonic channels and $M \sim 3$ TeV.

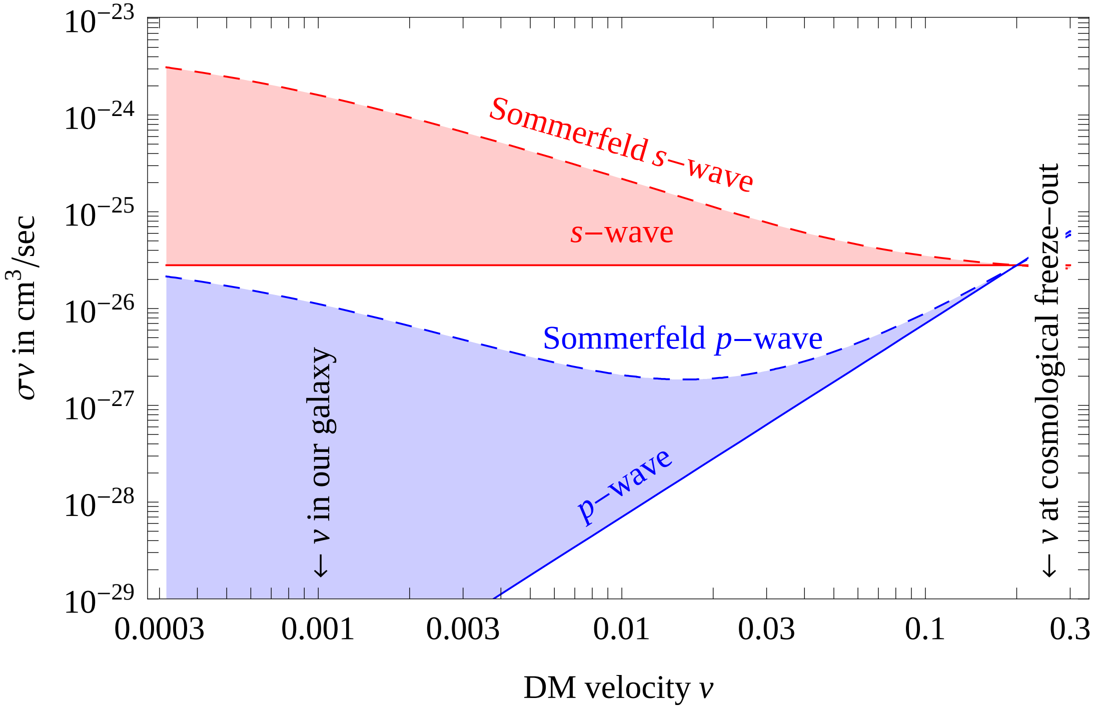
σv a few orders above the value suggested by cosmology or $\tau \sim 10^{26}$ sec.

(caveats)

σ(PAMELA + FERMI) $\gg \sigma$(cosmo)

up to co-annihilations, resonances, sub-clumps, ..., Sommerfeld enhancement: how to extrapolate the cosmological σv at $v \sim 0.2$ down to $v \sim 10^{-3}$?

Usually bad $\sigma v \propto v^0$ (s-wave) or worse $\sigma v \propto v^2$ (p-wave). Classic analogy: the sun attracts slower bodies, enhancing its cross section: $\sigma = \pi R_\odot^2 (1 + v_{\rm escape}^2/v^2)$. Quantum Sommerfeld effect: $\sigma v \propto 1/v$ if DM is charged under a lighter particle.



Present in the SM if $M \gtrsim M_W/\alpha$, but DM would annihilate into W^+W^-.

New DM theories

DM is charged under a dark gauge group, to get the Sommerfeld enhancement.

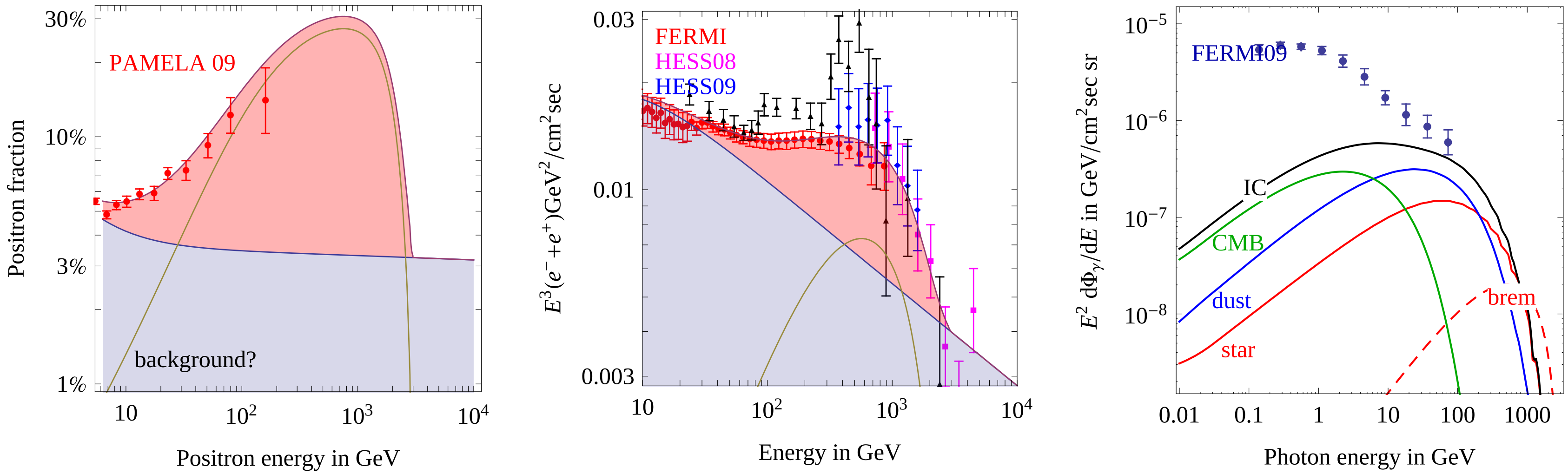
DM annihilates into the new vector. If light, $m \lesssim$ GeV, it can only decay into the lighter leptons. Large $\sigma(\text{DM DM} \to \ell^+\ell^+\ell^-\ell^-)$ obtained.

γ has a mixing θ with the new light vector, giving a $\sigma_{\text{SI}}(\text{DM } N)$ which is too large if elastic or possibly consistent with DAMA if inelastic thanks to a 100 keV splitting among Re DM and Im DM induced by the hidden higgs.

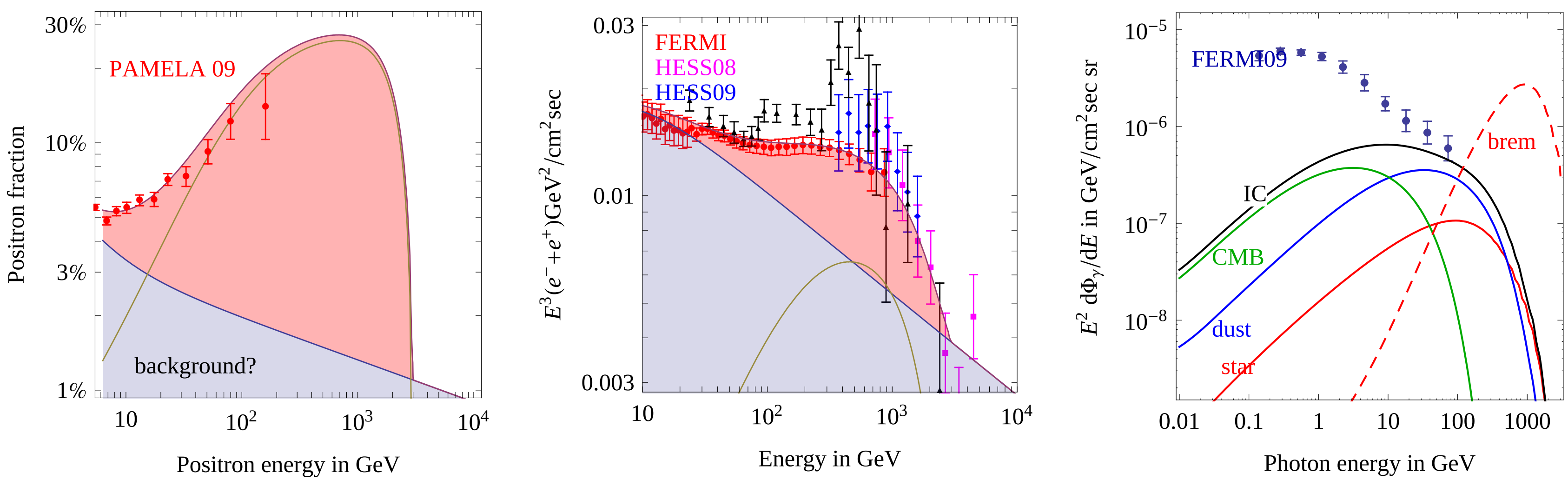
Sensitivity to θ, m can be best improved by e beam-dump experiments.

Dark Matter fit

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



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



(Inverse Compton depends only on the $e^\pm$ spectrum)

γ from DM

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

- **Brehmstralung** from charged particles and $\pi^0 \to \gamma\gamma$ decays.
  Largest $E_\gamma \sim M_{\text{DM}}$, probed by HESS.

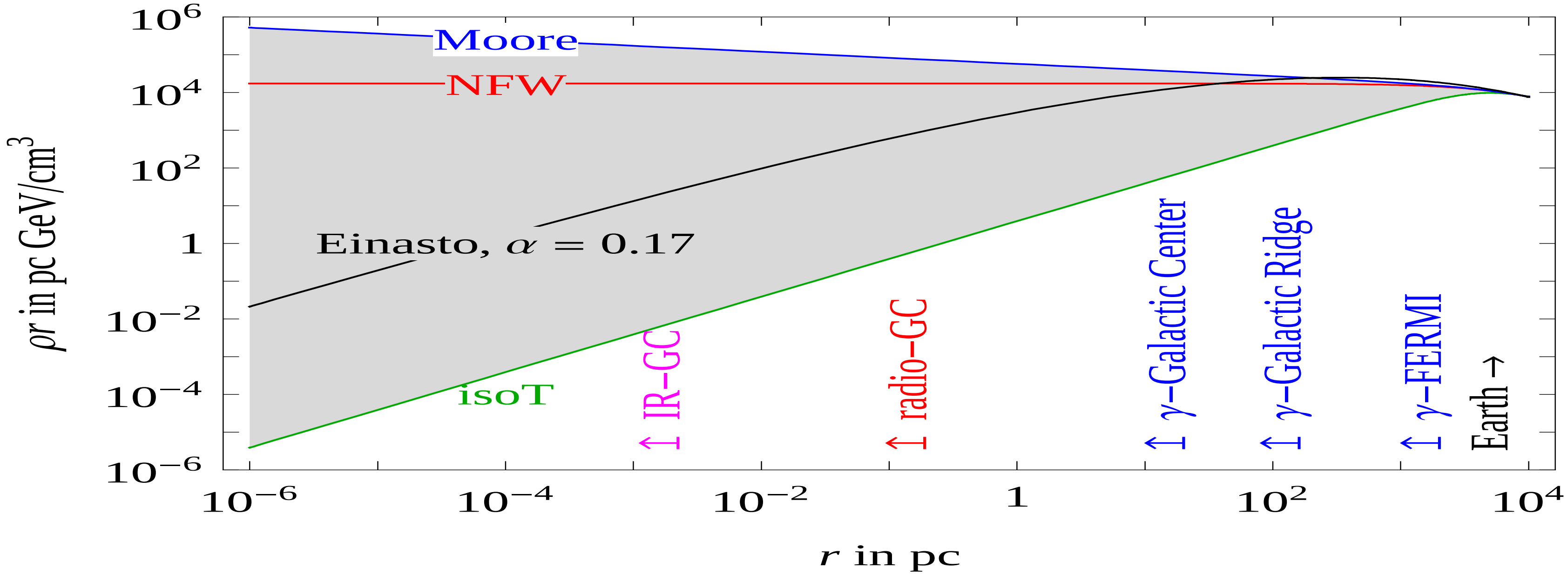
- **Inverse Compton**: $e^\pm\gamma \to e^\pm\gamma'$ scatterings on CMB and star-light: $\dot{E} \propto u_\gamma$.
  Intermediate $E_{\gamma'} \sim E_\gamma(E_e/m_e)^2 \sim 10\,\text{GeV}$ probed by FERMI

- **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.

Indirect signals: γ

New FERMI data

FERMI full-sky γ maps



Main results:

- lots of stupid pulsars
- $\Phi_\gamma(E, b, \ell)$ can be fitted by conventional astrophysics: π_0 + IC + brem.
- Attempts to see DM contributions (Hooper, Raidal, Finkbeiner...)

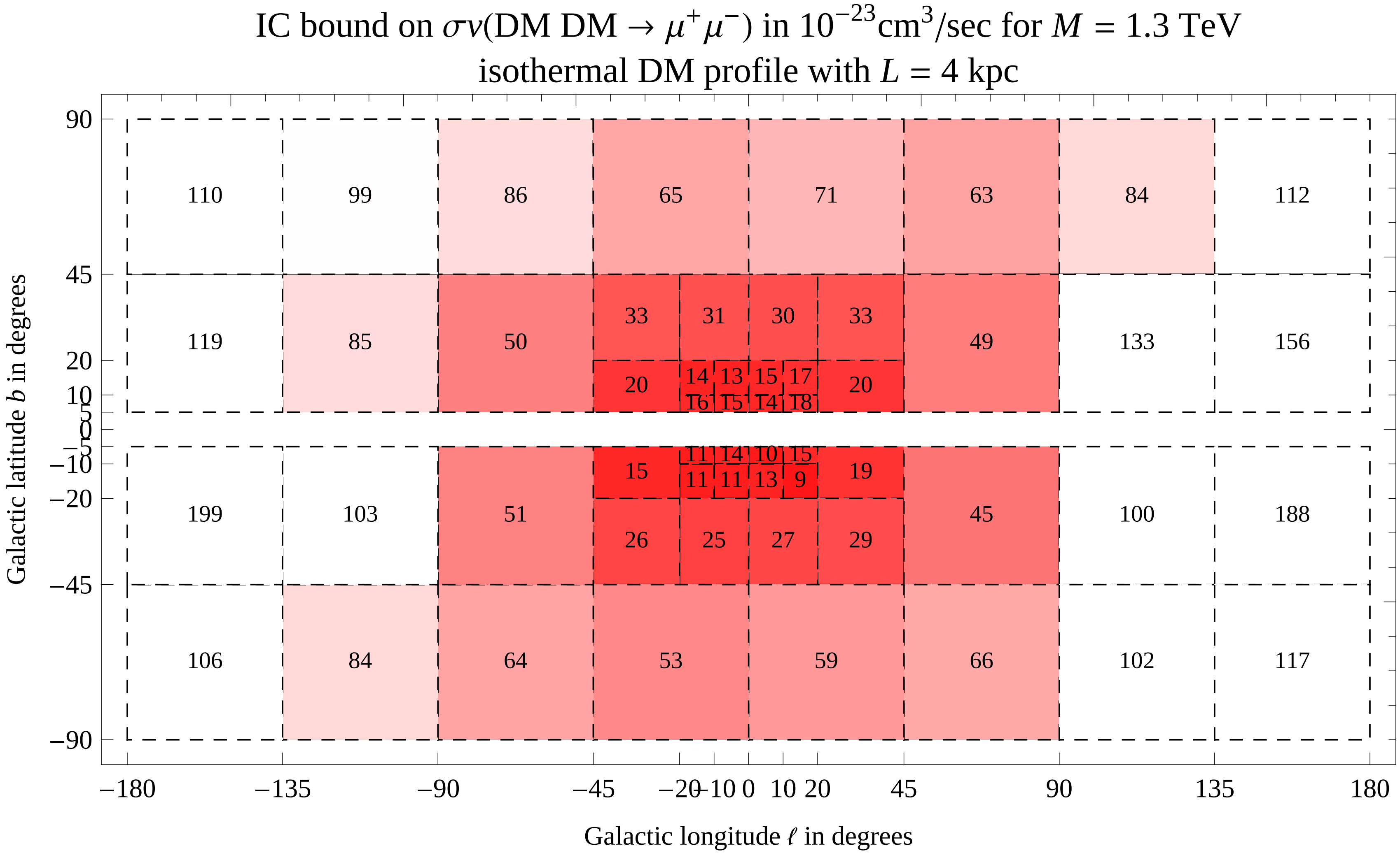
Contract with NASA respected: all γ raw data freely available.

But work in progress: public data still contain backgrounds to DM searches:

- misidentified hadrons above ~ 100 GeV.
- point and transient astrophysical sources.

Robust bound from FERMI maps

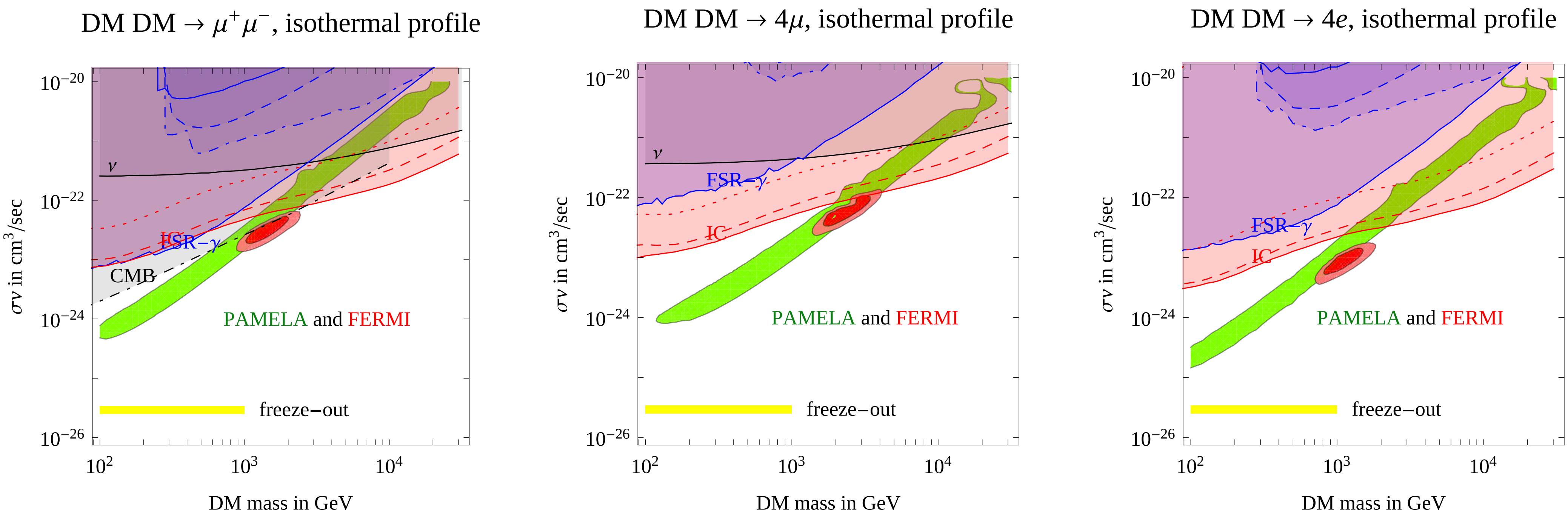
Just impose DM < exp in all sky and energy regions:



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

PAMELA/FERMI as DM annihilations?

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$-\gamma$ for $L = 4, 2, 1$ kpc; • CMB; • ν; • radio observations of the GC

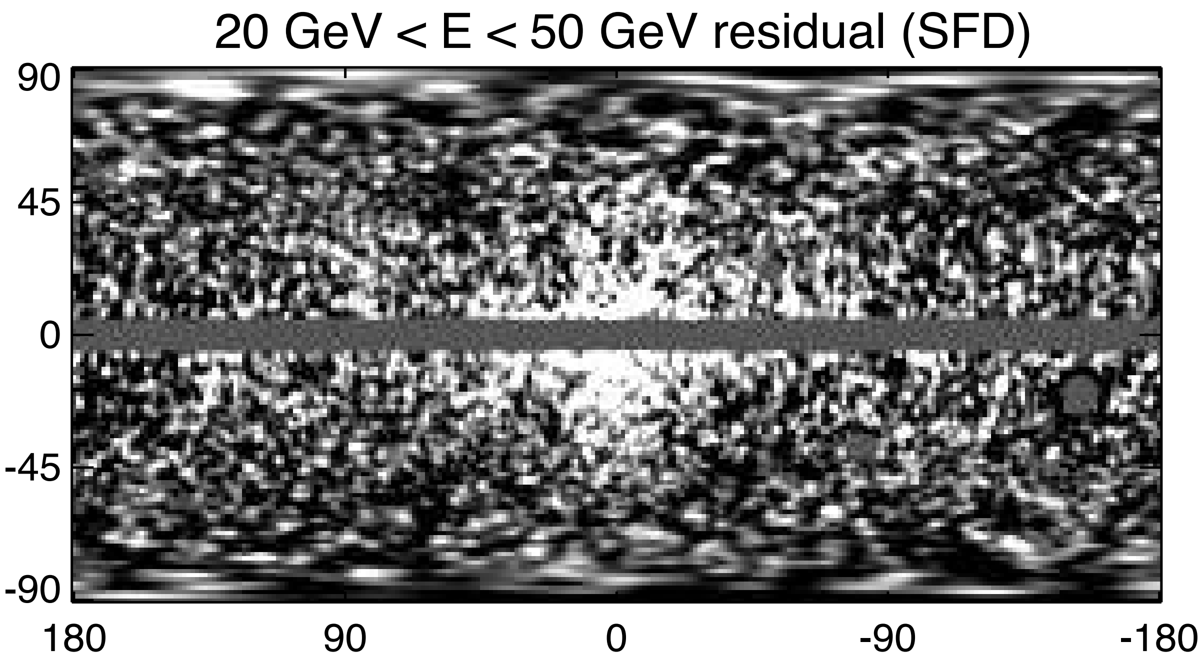


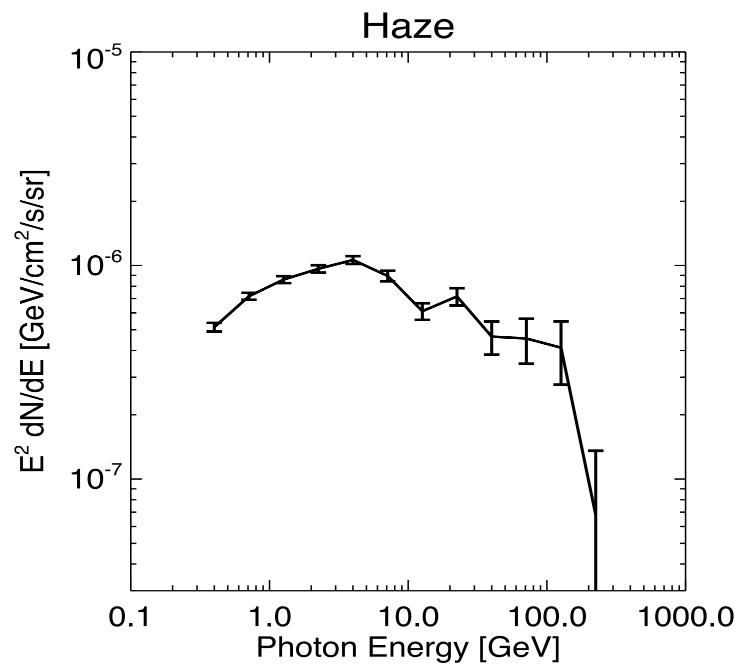
$e^\pm$ excesses can be DM DM $\to 2\mu, 4\mu, 4e$ if ρ is isothermal

Other profiles (NFW, Einasto...) and other channels (τ, W...) cannot fit

The FERMI haze?

Some theorists claim a quasi-spherical 'FERMI haze' excess

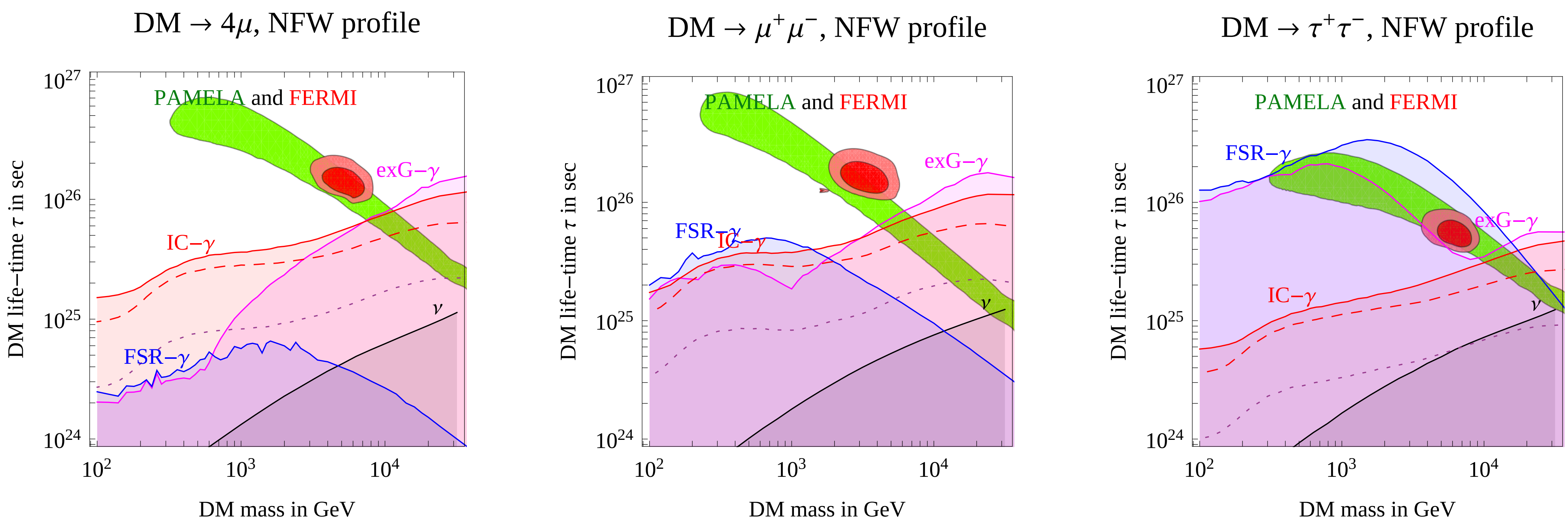




FERMIons disagree [arXiv:1003.0002]

PAMELA/FERMI as DM decays?

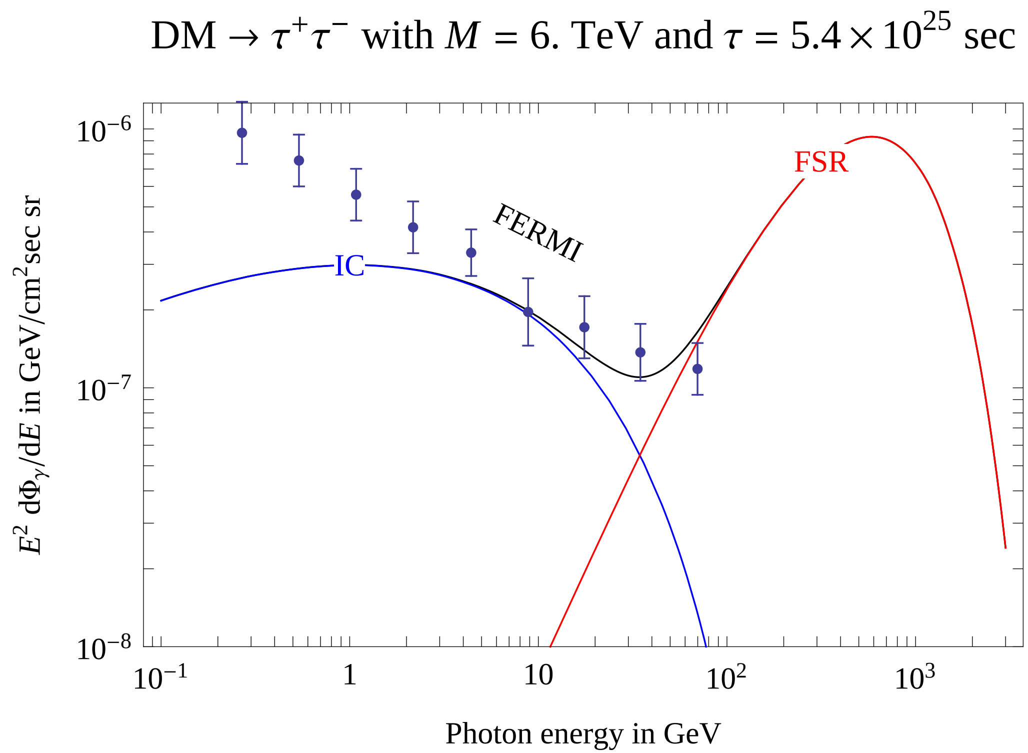
Compatible with all profiles $\rho(r)$ because $\rho^{2}\frac{\sigma v}{2M^2} \to \frac{\rho^{1}}{M\tau}$:



- GUT-suppressed dimension 6 operators give the needed $\tau \sim \frac{M_{\rm GUT}^4}{M^5} \sim 10^{26}\,{\rm s}$
- $M \sim 3\,{\rm TeV}$ gives the cosmological $\Omega_{\rm DM}$ if DM is a baryon-like asymmetry kept in thermal equilibrium by weak sphalerons down to $T_{\rm dec} \sim 200\,{\rm GeV}$.

FERMI diffuse

The spherical contribution was extracted from γ sky:



Reliable bounds on DM decays.

Bounds on DM annihilations depends on DM clustering history.

FERMI bound on γ lines

DM DM $\to \gamma\gamma$ with cosmological $\sigma v \approx 3\ 10^{-26}\mathrm{s/\,cm^3}$ excluded for $M < 200\,\mathrm{GeV}$!

E_γ (GeV)	95%CL (10^{-9} cm^{-2}s^{-1})	$\langle\sigma v\rangle_{\gamma\gamma}$ [γZ] (10^{-27} cm^{3}s^{-1})			$\tau_{\gamma\gamma}$ [γZ] (10^{28} s)		
		NFW	Einasto	Isothermal	NFW	Einasto	Isotherm
30	3.5	0.3 [2.6]	0.2 [1.9]	0.5 [4.5]	17.6 [4.2]	17.8 [4.2]	17.5 [4.
40	4.5	0.7 [4.2]	0.5 [3.0]	1.2 [7.2]	10.1 [2.9]	10.3 [2.9]	10.0 [2.
50	2.4	0.6 [2.7]	0.4 [1.9]	1.0 [4.6]	15.5 [5.0]	15.7 [5.1]	15.4 [5.
60	3.1	1.1 [4.2]	0.8 [3.0]	1.8 [7.3]	9.8 [3.5]	10.0 [3.5]	9.7 [3.5
70	1.2	0.6 [2.0]	0.4 [1.4]	1.0 [3.4]	21.6 [8.2]	21.9 [8.3]	21.5 [8.
80	0.9	0.5 [1.7]	0.4 [1.2]	0.9 [2.9]	26.0 [10.4]	26.4 [10.5]	25.8 [10
90	2.6	2.0 [6.0]	1.5 [4.3]	3.5 [10.3]	7.7 [3.2]	7.8 [3.2]	7.6 [3.1
100	1.4	1.4 [3.8]	1.0 [2.8]	2.4 [6.6]	12.6 [5.4]	12.8 [5.4]	12.5 [5.
110	0.9	1.0 [2.7]	0.7 [1.9]	1.7 [4.6]	18.9 [8.2]	19.2 [8.3]	18.8 [8.
120	1.1	1.6 [4.0]	1.1 [2.9]	2.7 [6.9]	13.3 [5.9]	13.5 [6.0]	13.2 [5.
130	1.8	3.0 [7.3]	2.1 [5.3]	5.1 [12.6]	7.6 [3.4]	7.8 [3.5]	7.6 [3.4
140	1.9	3.5 [8.4]	2.5 [6.0]	6.0 [14.3]	7.0 [3.2]	7.1 [3.3]	7.0 [3.2
150	1.6	3.5 [8.2]	2.5 [5.9]	6.0 [14.1]	7.5 [3.5]	7.6 [3.5]	7.4 [3.4
160	1.1	2.7 [6.3]	2.0 [4.5]	4.7 [10.9]	10.2 [4.8]	10.4 [4.8]	10.1 [4.
170	0.6	1.7 [4.0]	1.3 [2.9]	3.0 [6.8]	17.0 [8.0]	17.2 [8.1]	16.9 [7.
180	0.9	2.7 [6.1]	1.9 [4.4]	4.6 [10.4]	11.6 [5.5]	11.8 [5.6]	11.6 [5.
190	0.9	3.2 [7.1]	2.3 [5.1]	5.5 [12.2]	10.4 [4.9]	10.5 [5.0]	10.3 [4.
200	0.9	3.3 [7.3]	2.4 [5.2]	5.7 [12.5]	10.6 [5.1]	10.8 [5.1]	10.5 [5.

Bounds from cosmology

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

1. affect BBN at $T \sim$ MeV fragmenting ^{4}He, D, ^{3}He...
   Their primordial abundances are not safely known.

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

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.

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.

Summer 2010: XENON results
November 2010: AMS launch with Obama non-superconducting magnet
Planck 2011: results from Planck