Indirect Dark Matter detection at the time of Fermi and PAMELA

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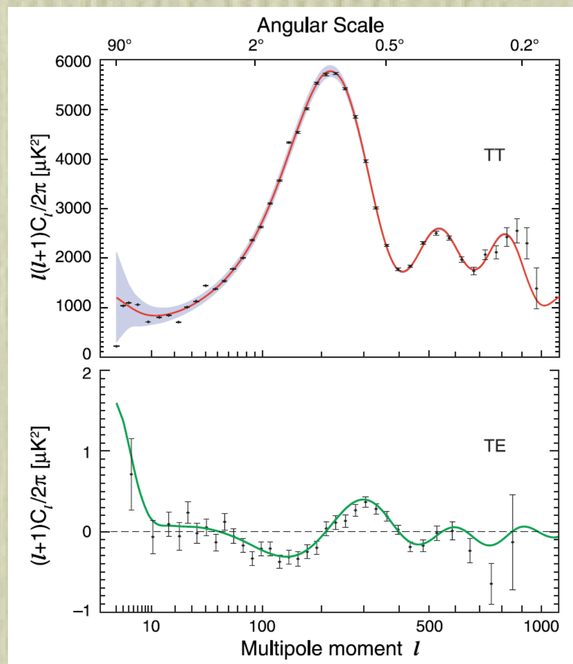
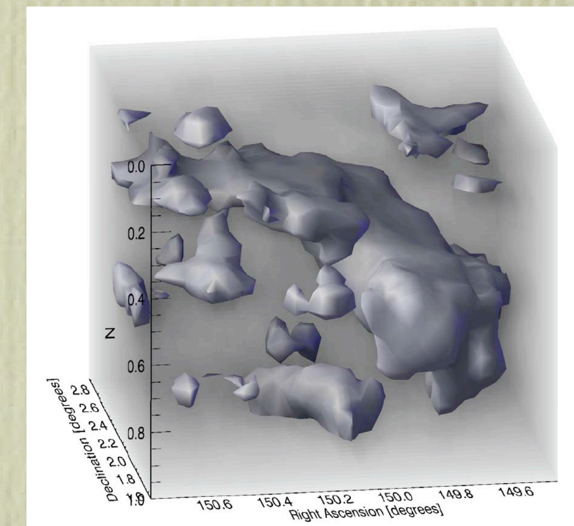
Outline

- The WIMP framework for dark matter candidates
- Indirect detection and the recent focus on positrons & electrons (why the standard astrophysical lore does not work)
- DM with peculiar properties (large annihilation cross-sections? large effects from substructures?)
- The cross-correlation with other DM detection signals
- Perspectives rather than conclusions

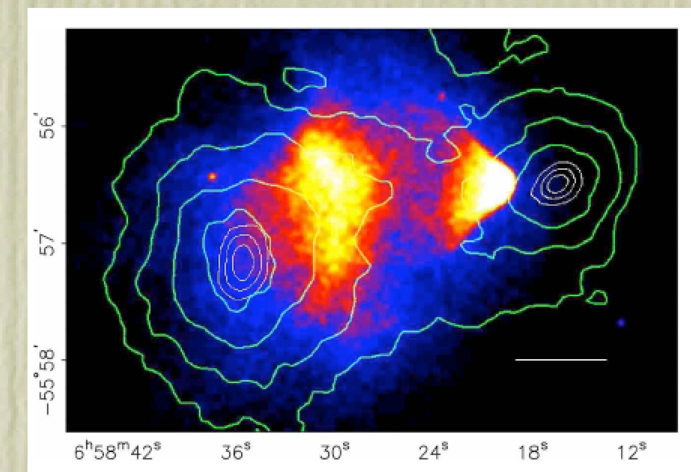
Overwhelming evidence for CDM as building block of all structures in the Universe, from the largest scales down to galactic dynamics:



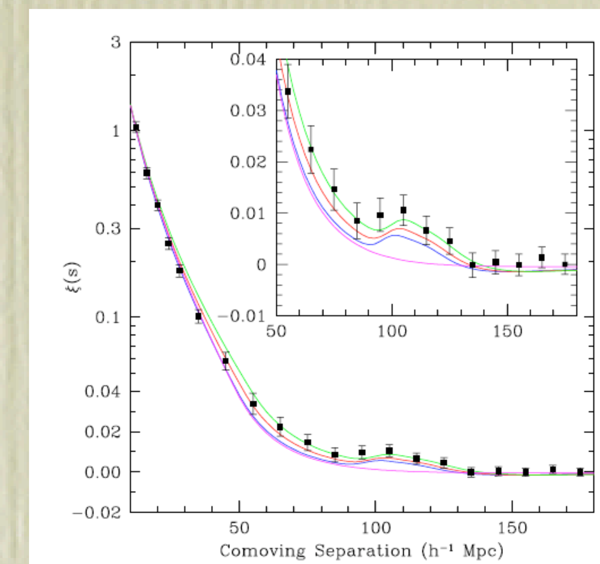
CMB



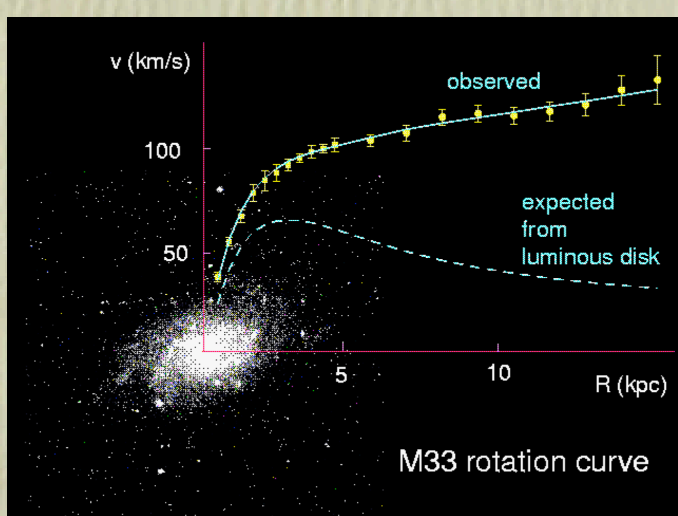
grav. scaffold



“Bullet” cluster



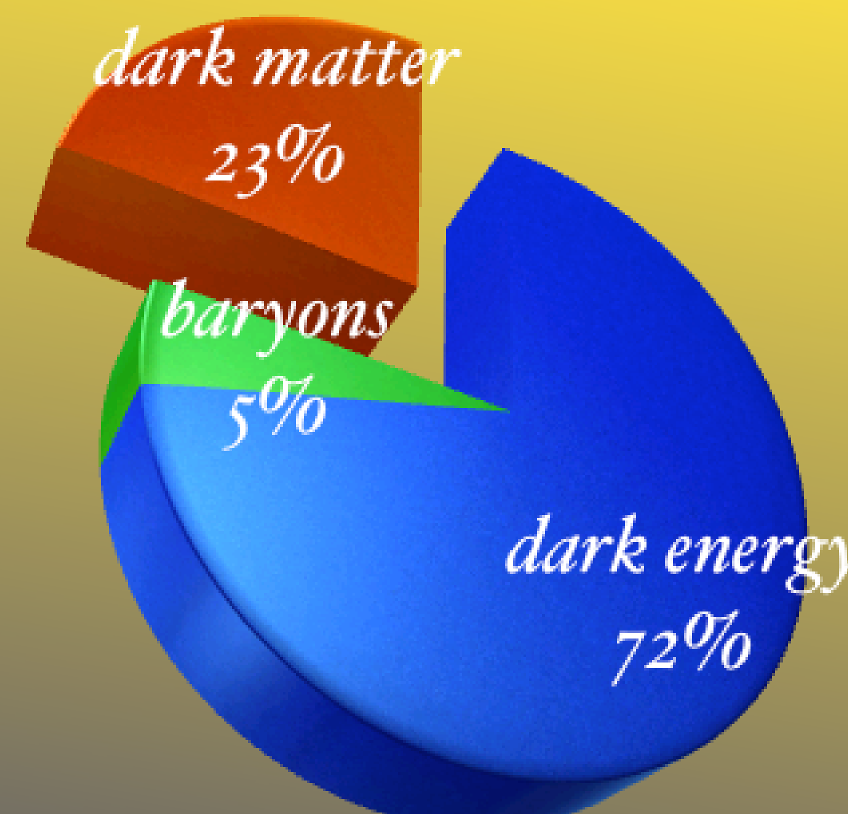
BAO



galaxies

+ many others:

All point to a single “concordance” model:



Cosmological and astrophysical observations suggest that dark matter is: an optically-dark (i.e. dissipation-less), collision-less, classical fluid with negligible free-streaming effects. This excludes some models, such as, e.g.:

~~**Baryonic DM**~~

~~**Hot DM (e.g. SM neutrinos)**~~

From the cosmologist perspective, Non-baryonic Cold DM is the preferred paradigm (i.e., for DM only gravity matters). Not helping much the particle physicist: there are only (weak) upper limits on the DM interaction strength, while other crucial properties (e.g., the mass scale) are missing.

"Particle Dark Matter", Cambridge U. Press, edited by G. Bertone

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The picture becomes slightly more focussed addressing the question: How was DM generated? The most beaten paths have been:

i) DM as a ***thermal relic product*** (or in connection to thermally produced species);

ii) DM as a ***condensate***, maybe at a phase transition; this usually leads to very light scalar fields;

iii) DM ***generated at large T***, most often at the end of (soon after, soon before) inflation; candidates in this scheme are usually supermassive.

CDM particles as thermal relics

Let χ be a stable particle, with mass M_χ, carrying a non-zero charge under the SM gauge group. Processes changing its number density are:

$$\boxed{\chi\bar{\chi} \leftrightarrow P\bar{P}}$$

with P some (lighter) SM state in thermal equilibrium. The evolution of the number density is described by the Boltzmann equation:

$$\frac{dn_\chi}{dt} + 3Hn_\chi = -\langle\sigma_A v\rangle_T \left[(n_\chi)^2 - \left(n_\chi^{eq}\right)^2\right]$$

dilution by Universe expansion

thermally averaged annihilation cross section

$P\bar{P} \to \chi\bar{\chi}$

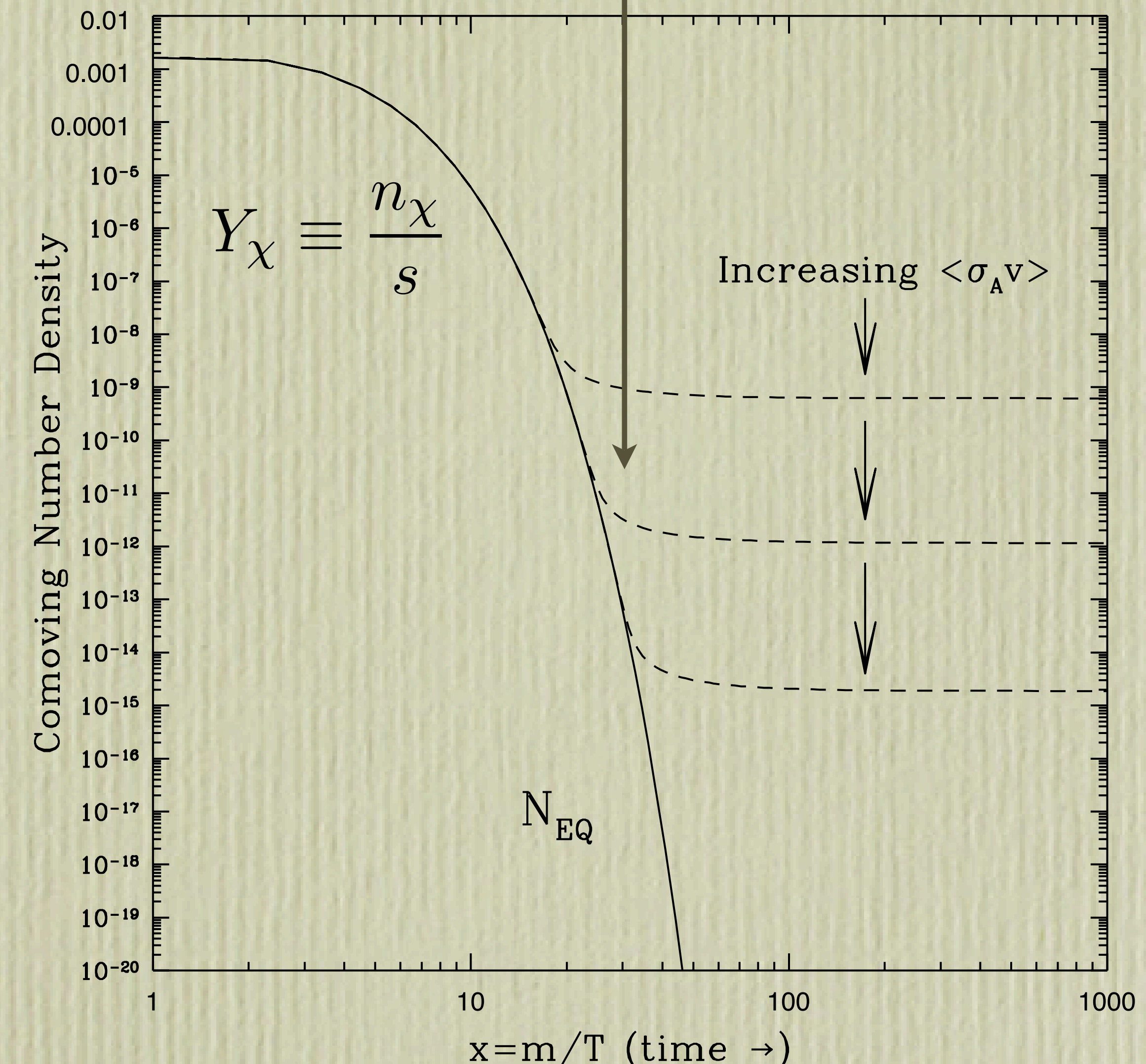
$\chi\bar{\chi} \to P\bar{P}$

χ in thermal equilibrium down to the freeze-out T_f , given, as a rule of thumb, by:

$$\Gamma(T_f) = n_\chi^{eq}(T_f)\langle\sigma_A v\rangle_{T=T_f} \simeq H(T_f)$$

After freeze-out, when $\Gamma \ll H$, the number density per comoving volume becomes constant. For a species which is non-relativistic at freeze-out:

$$\Gamma(T_f) \simeq H(T_f)$$



$$Y_\chi \equiv \frac{n_\chi}{s}$$

$$\Omega_\chi h^2 \simeq \frac{M_\chi \, s_0 \, Y_\chi^{eq}(T_f)}{\rho_c/h^2}$$

(freeze-out + entropy conservation)

$$\simeq \frac{M_\chi \, s_0}{\rho_c/h^2} \frac{H(T_f)}{s(T_f)\langle\sigma_A v\rangle_{T_f}}$$

(standard cosmology)

$$\simeq \frac{M_\chi}{T_f} \frac{g_\chi^\star}{g_{\rm eff}} \frac{1 \cdot 10^{-27}{\rm cm}^{-3}{\rm s}^{-1}}{\langle\sigma_A v\rangle_{T=T_f}}$$

with: $M_\chi/T_f \sim 20$

$$\Omega_\chi h^2 \simeq \frac{3 \cdot 10^{-27}{\rm cm}^{-3}{\rm s}^{-1}}{\langle\sigma_A v\rangle_{T=T_f}} \longrightarrow \text{WIMP}$$

The WIMP recipe to embed a dark matter candidate in a SM extension: foresee an extra particle χ that is stable (or with lifetime exceeding the age of the Universe), massive (non-relativistic at freeze-out) and weakly interacting.

WIMP dark matter candidates:

A simple recipe in which maybe the most delicate point is the requirement of stability. You can enforce it via a discrete symmetry:

- R-parity in SUSY models
- KK-parity in Universal Extra Dimension models (Servant & Tait, hep-ph/0206071)
- T-parity in Little Higgs models (Bickedal et al., hep-ph/0603077)
- Z_2 symmetry in a 2 Higgs doublet SM extension (the "Inert doublet model", Barbieri et al. hep-ph/0603188)
- Mirror symmetry in 5D models with gauge-Higgs unification (Serone et al., hep-ph/0612286)
- ...

or via an accidental symmetry, such as a quantum number preventing the decay: [Mirror DM], DM in technicolor theories (Gudnason et al., hep-ph/0608055), "minimal" DM (Cirelli et al., hep-ph/0512090) , ...

In most of these, DM appears as a by-product from a property considered to understand or protect other features of the theory.

Incomplete list of models and very incomplete list of references!

E.g.: neutralino LSP in the CMSSM

Minimal scheme,
but general enough to
illustrate the point.

Set of assumptions:

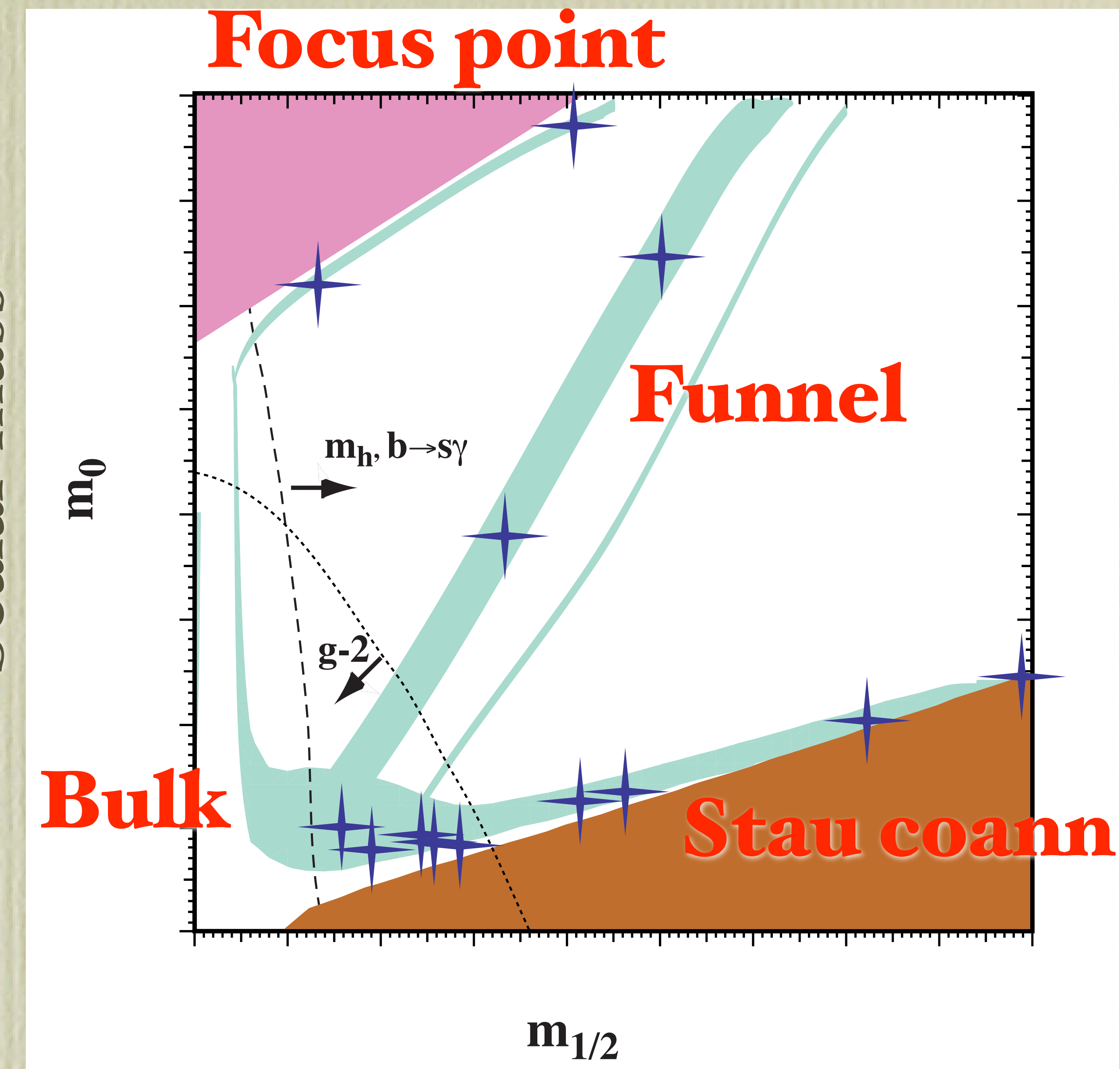
Unification of gaugino masses:
$M_i(M_{GUT}) \equiv m_{1/2}$

Unification of scalar masses:
$m_i(M_{GUT}) \equiv m_0$

Universality of trilinear couplings:
$A^u(M_{GUT}) = A^d(M_{GUT}) =$
$A^l(M_{GUT}) \equiv A_0 m_0$

Other parameters: $sign(\mu)$, $\tan\beta$

Scalar mass



Gaugino mass

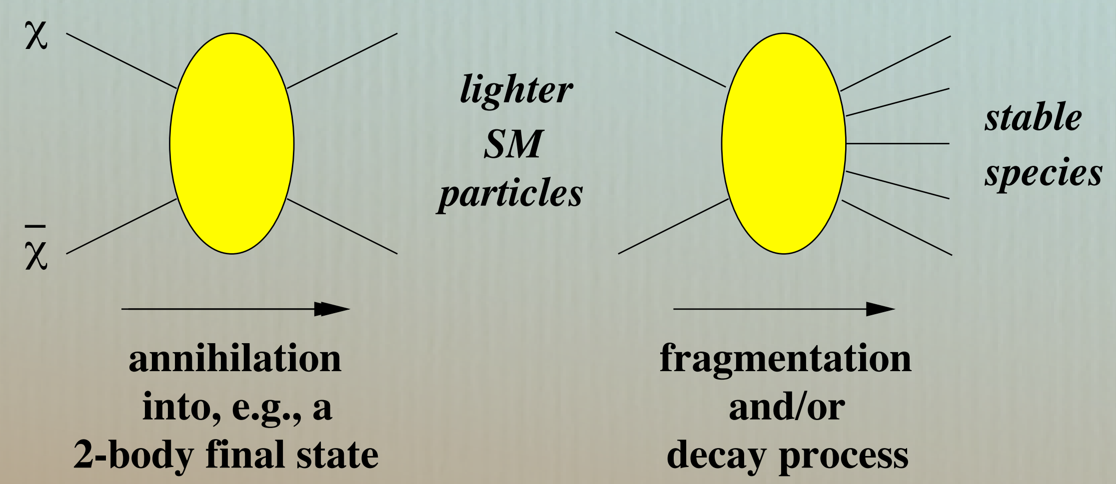
Battaglia et al. 2001

Indirect detection of WIMP dark matter

A chance of detection stems from the WIMP paradigm itself:

Pair annihilations of WIMPs in DM halos (i.e. at T≅0)

$$(\sigma v)_{T\simeq 0} \sim \langle \sigma v \rangle_{T=T_f}$$



Focus on: antiprotons, positrons, antideutrons, gamma-rays, (neutrinos)

Signatures:

I) in energy spectra: One single energy scale in the game, the WIMP mass, rather then sources with a given spectral index; edge-line effects?

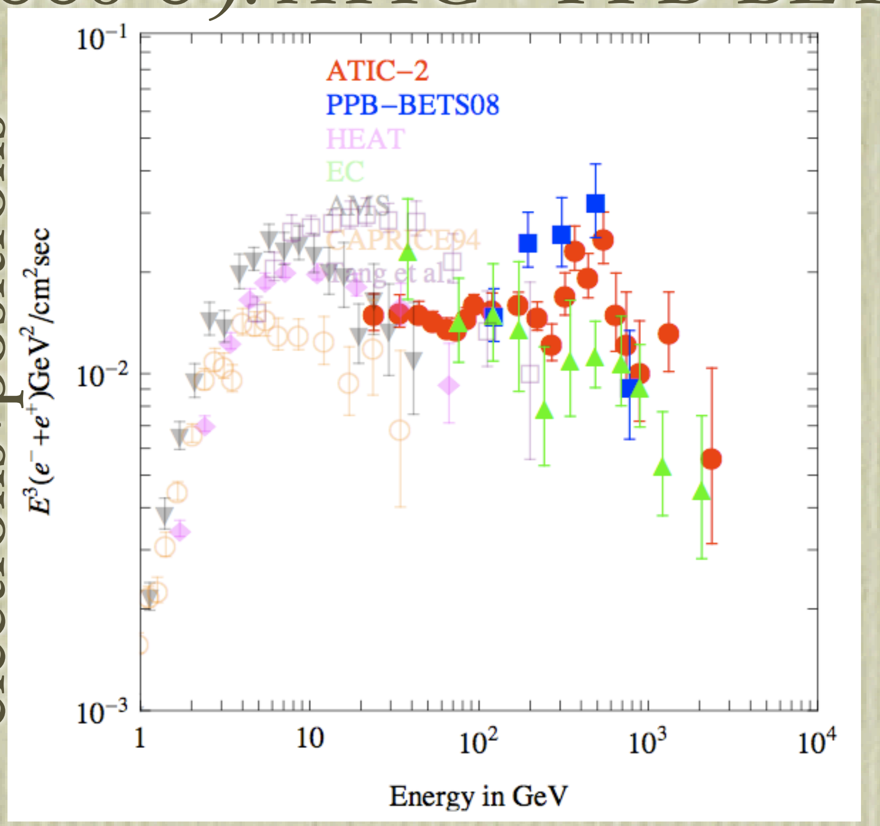
II) angular: flux correlated to DM halo shapes and with DM distributions within halos: central slopes, rich substructure pattern.

A fit of a featureless excess may set a guideline, but will be inconclusive.

The focus on electrons and positrons because of recent experimental results:

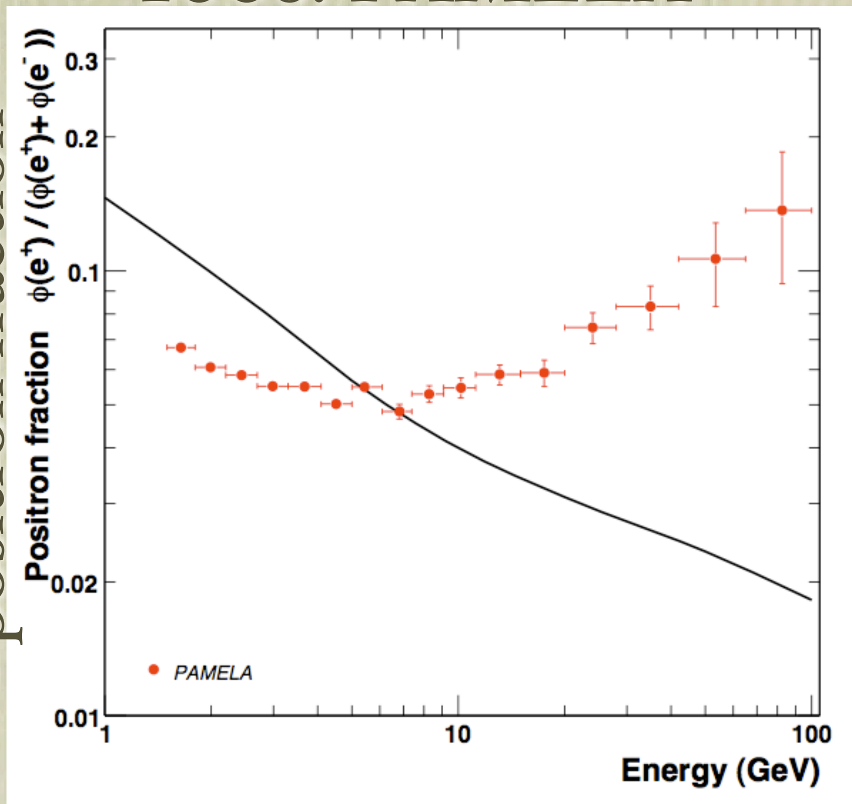
2008-09: ATIC + PPB-BETS

electrons+positrons



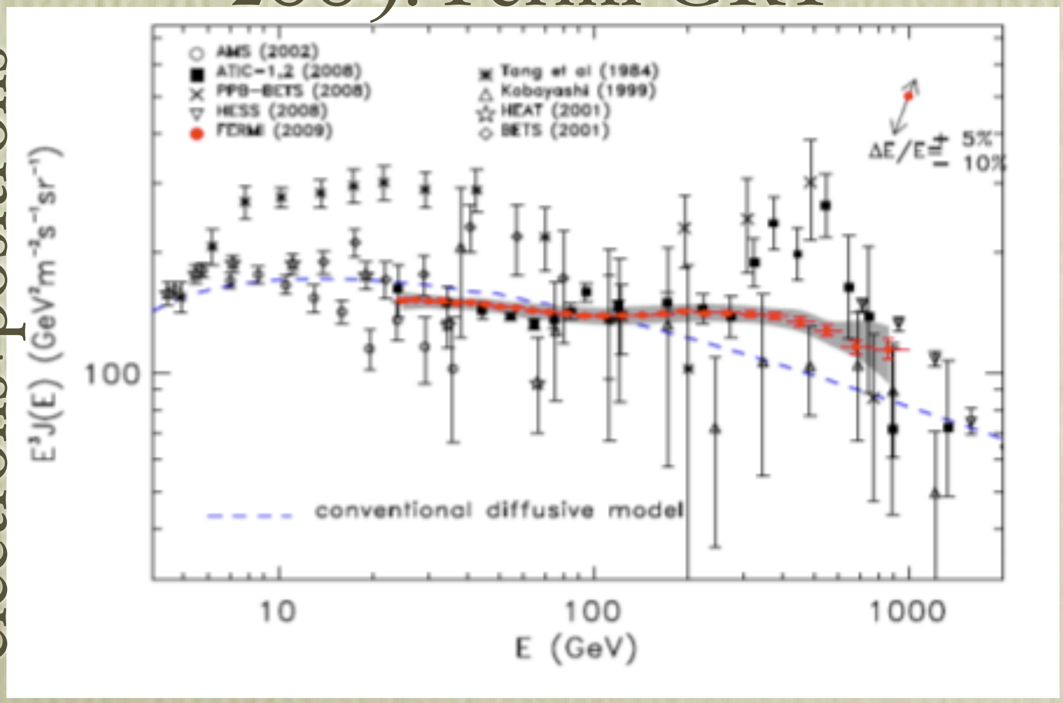
2008: PAMELA

positron fraction



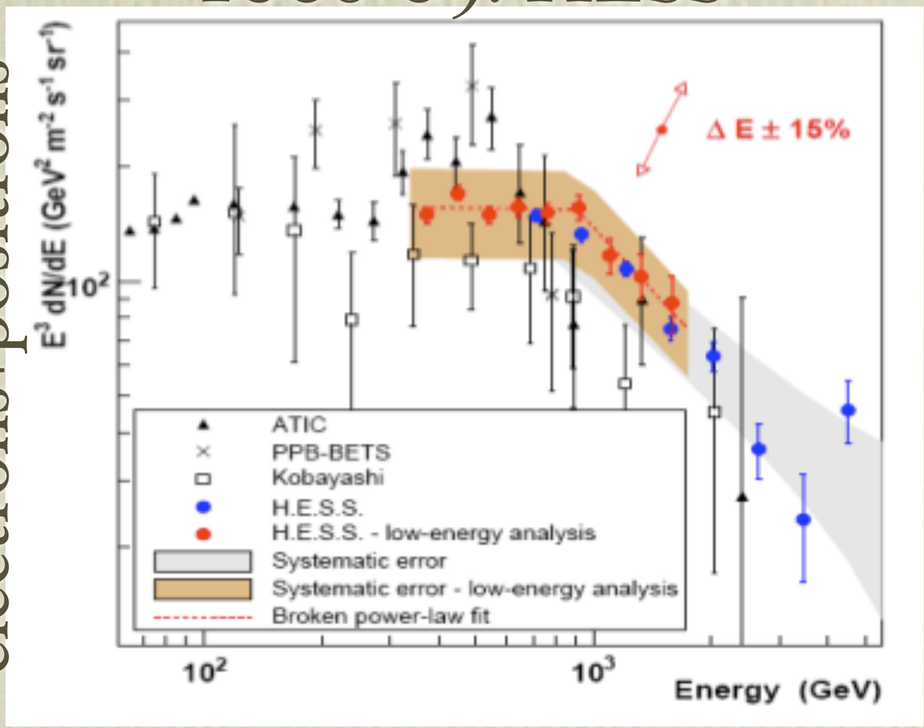
2009: Fermi GRT

electrons+positrons



2008-09: HESS

electrons+positrons



Charged particles in the Galaxy

A random walk (maybe with a preferred drift direction) in turbulent & regular magnetic fields, modeled through a diffusion equation:

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

spatial diffusion

reacceleration

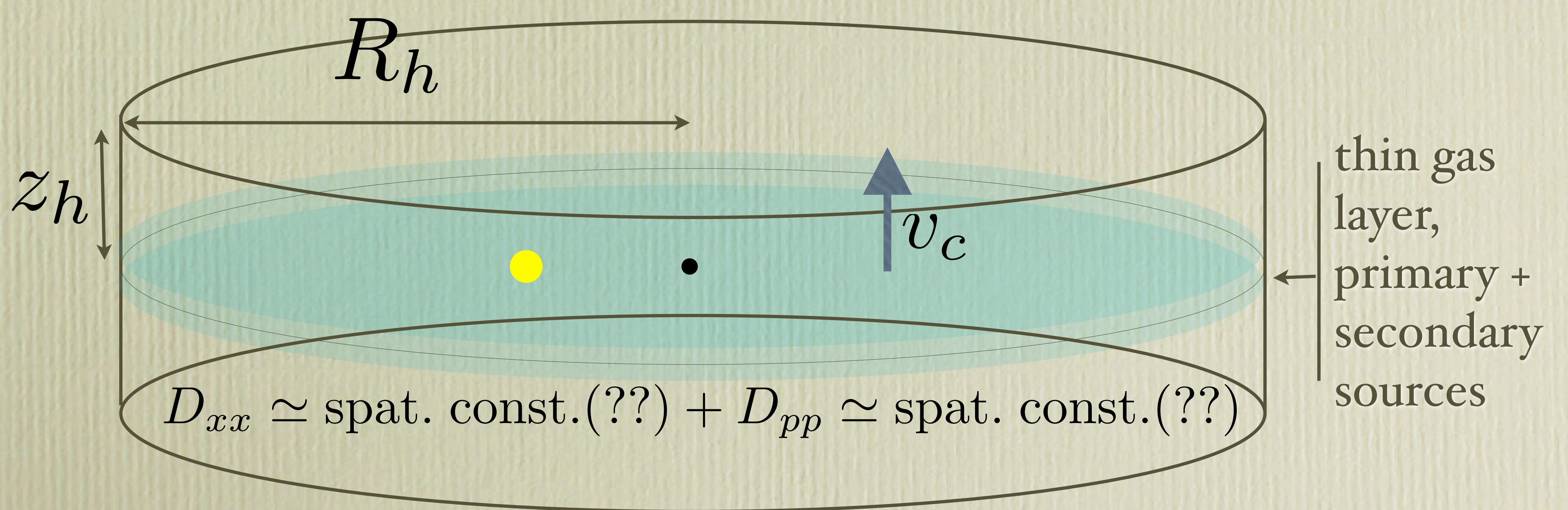
energy loss

source

decay, fragmentation

convection

usually solved in steady state (l.h.s. put to zero) and applied to some schematic picture of the Galaxy :



What are the main sources of galactic cosmic rays?

Some simplified argument (close to numerology):

The energy density in CRs is about: $$w_{CR} \simeq 0.5\,\mathrm{eV\,cm^{-3}}$$

The total energy stored in the confinement volume is then about: $$W_{CR} \simeq w_{CR} V_{conf} \simeq 2 \cdot 10^{55}\,\mathrm{erg}$$

Dividing by the CR confinement time, you find the required CR luminosity: $$L_{CR} \simeq \frac{W_{CR}}{\tau_{conf}} \simeq 5 \cdot 10^{40}\,\mathrm{erg s^{-1}}$$

Compare with the typical Supernova luminosity (rate times injected energy): $$L_{SN} = R_{SN} E_{SN} \simeq 3 \cdot 10^{41}\,\mathrm{erg s^{-1}}$$

SNe are the CR sources
if the efficiency is about 10-20%

Start with primary nucleon species:

At "high energy" (say, above 10-GeV), energy losses and reacceleration are small:

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

Neglect for the moment also convection; spatial diffusion is the term setting the confinement time:

$\tau_{conf} \propto 1/D_{xx}$ with $D_{xx}(p) \propto p^{\alpha}$ and (??)

$\alpha = 1/3$	Kolmogorov
$\alpha = 1/2$	Kraichnan

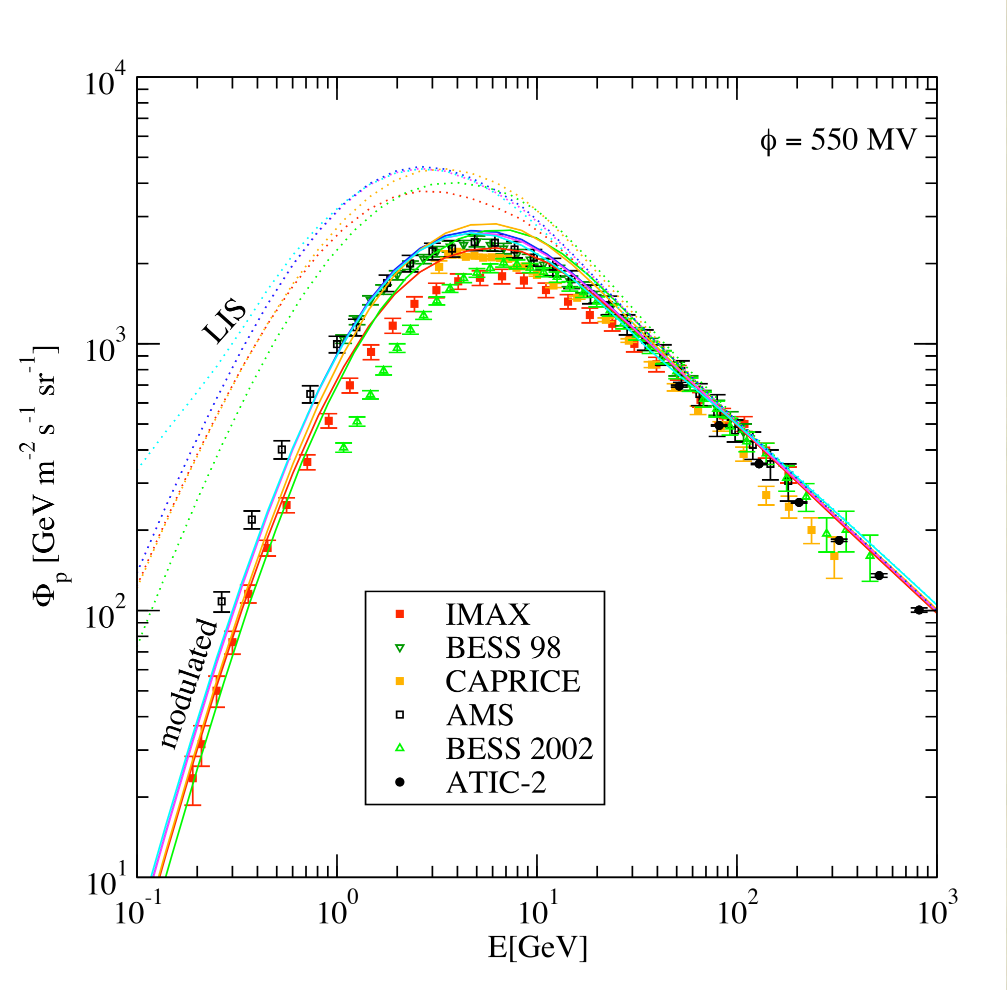
Consider, e.g., primary protons. The source function is in the form:

$q_p \propto p^{-\beta_{inj,p}}$ with $\beta_{inj,p} \simeq 2$ (strong shock limit)

Solving the propagation eq. and comparing the result to the local proton flux:

$\phi_p \propto q_p \cdot \tau_{conf} \propto p^{-\beta_{obs,p}}$ with $\beta_{obs,p} \simeq 2.7$

In fair agreement with the prediction: $\beta_{obs,p} = \beta_{inj,p} + \alpha$



Regis & P.U., arXiv: 0904.4645

Apply the same to secondary nucleon species:

“Secondaries” are particles generated in the interaction of primary species with the interstellar medium in “spallation” processes. Example: secondary Boron from the primary Carbon. The Boron source function proportional to the Carbon flux (after propagation):

$$q_B \propto \phi_C \propto p^{-\beta_{obs,C}}$$

The Boron flux (after propagation) is in the form:

$$\phi_B \propto p^{-\beta_{obs,B}}$$

predicting:

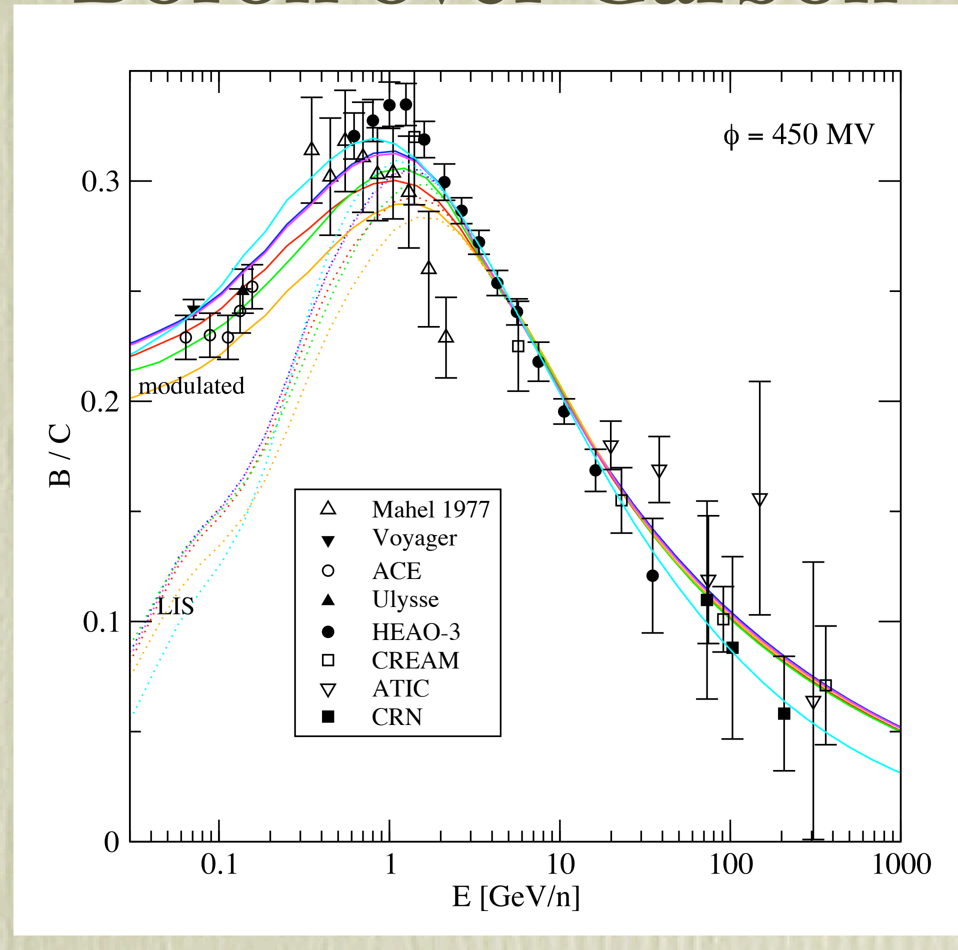
$$\beta_{obs,B} = \beta_{obs,C} + \alpha$$

i.e., the secondary to primary ratio:

$$\phi_B/\phi_C \propto p^{-\beta_{obs,B}+\beta_{obs,C}} = p^{-\alpha}$$

is predicted to be independent of the (unknown) Carbon injection index.

Boron over Carbon



compare against observations and find α (plus a combination of other parameters in the full propagation model)

Regis & P.U., arXiv: 0904.4645, using Galprop

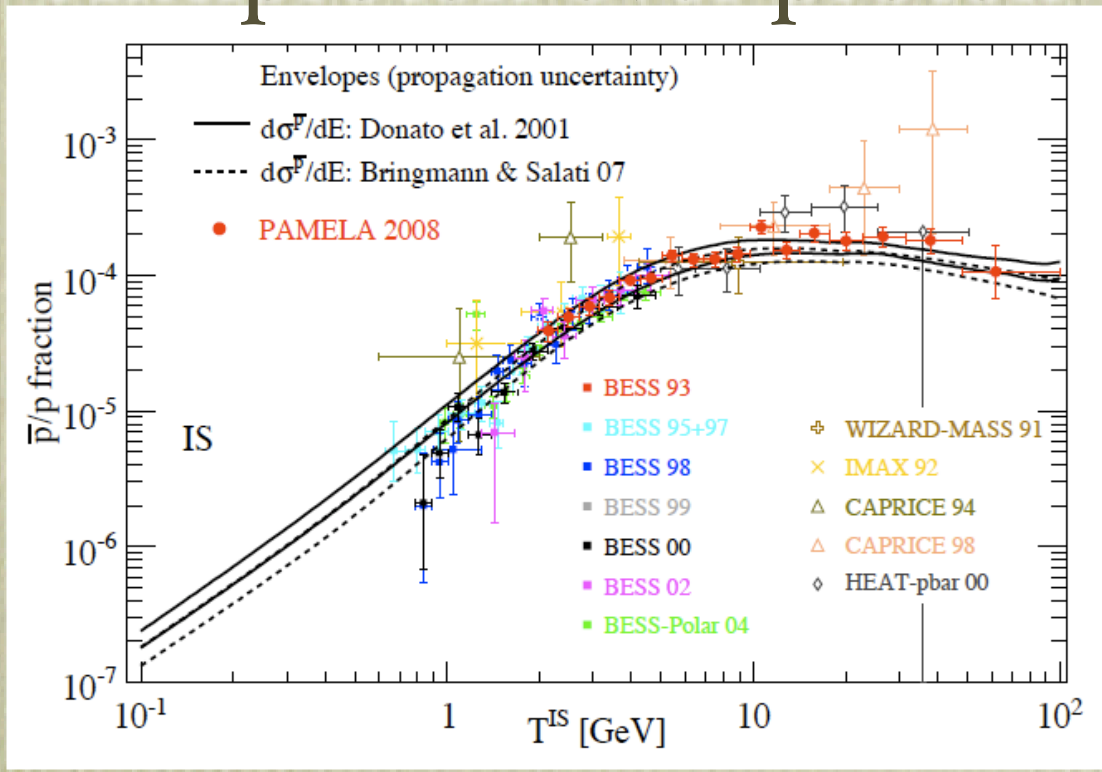
The picture for antiprotons is totally consistent:

Antiprotons are generated in the interaction of primary proton and helium cosmic rays with the interstellar gas (hydrogen and helium), e.g., in the process:

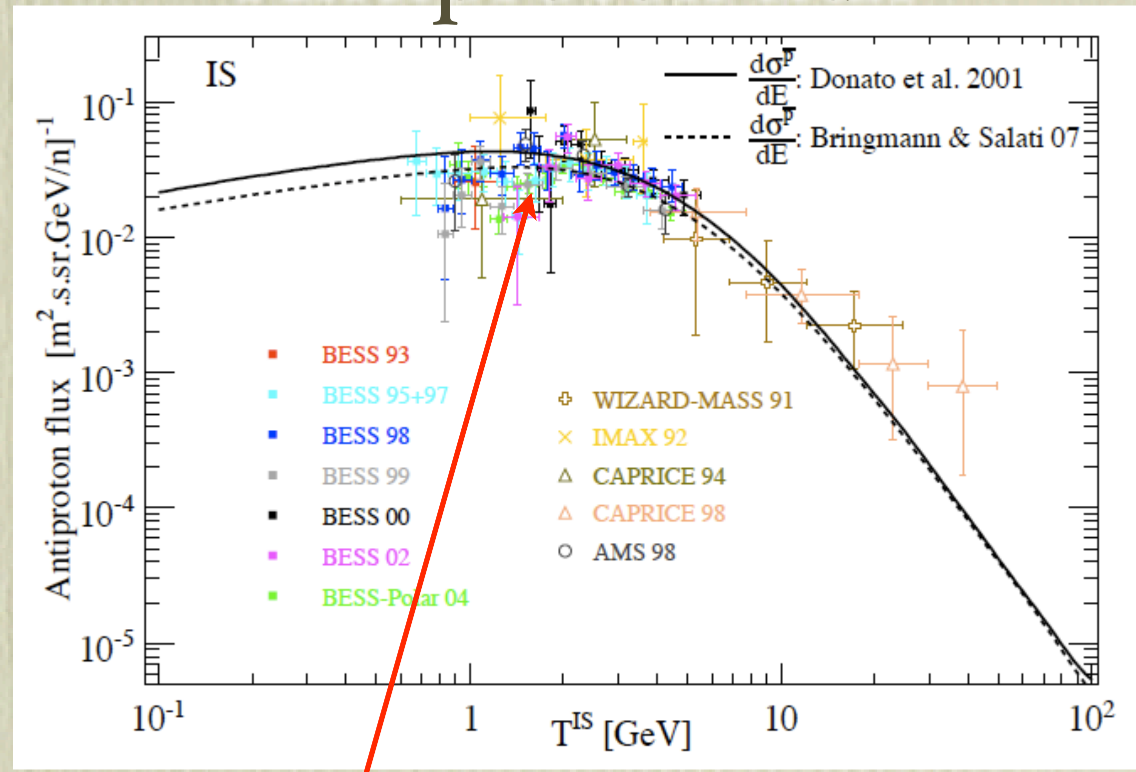
$$p + H \rightarrow 3\,p + \bar{p}$$

Use the parameter determination from the B/C ratio, to extrapolate the prediction for the $\bar{p}/p$ ratio: excellent agreement for secondaries only!

Antiproton over proton



Antiproton flux



Donato et al., arXiv:0810.5292

Latest Pamela data: Adriani et al., arXiv:0810.4994

kinematic peak expected for secondaries, not for a primary component

Coming to electrons and positrons:

Energy losses cannot be neglected (at any energy) for electrons/positrons:

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

The main effects are due to synchrotron emission on the galactic magnetic fields and inverse Compton emission on the CMB and starlight:

$$\dot{p} \propto p^2$$ setting a new timescale: $$\tau_{loss} \simeq \frac{p}{\dot{p}} \propto p^{-1}$$

The solution to the diffusion equation becomes (approximately):

$$\phi_{e^-} \propto q_{e^-}\cdot \min\left[\tau_{loss}, \tau_{conf}\right] \propto p^{-\beta_{inj,e}-\delta}$$

with $\delta=1$ for energy losses or $\delta=\alpha$ for diffusion.

Secondary electron/positrons are produced, e.g., through:

$$\begin{aligned} p + H \rightarrow \ldots \rightarrow \pi^{\pm} &+ \ldots \\ \hookrightarrow\ \mu^{\pm} &+ \nu_\mu \\ \hookrightarrow\ e^{\pm} &+ \nu_e + \nu_\mu \end{aligned}$$

The secondary electron/positron source function is proportional to the proton flux (after propagation), i.e. it scales like:

$$q_{e^\pm} \propto \phi_p \propto p^{-\beta_{inj,p}-\alpha}$$

with the induced flux, predicted to be about:

$$\phi_{e^\pm} \propto q_{e^\pm} \cdot \min\left[\tau_{loss}, \tau_{conf}\right] \propto p^{-\beta_{inj,p}-\alpha-\delta}$$

Looking at the ratio between the (secondary only) positron flux to the (mostly primary) electron flux, you expects it to scale like:

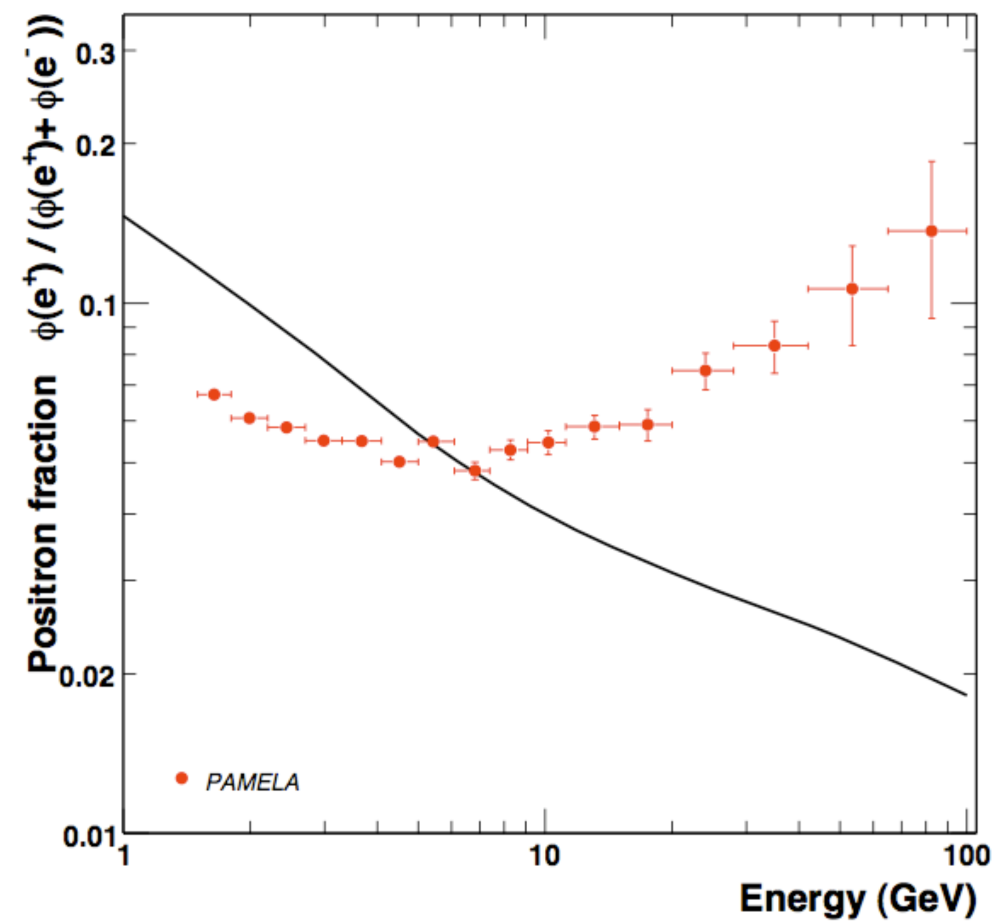
$$\frac{\phi_{e^+}}{\phi_{e^-}} \propto p^{-(\beta_{inj,p}-\beta_{inj,e}+\alpha)}$$

i.e. decreasing with energy since it would be hard to find a scheme in which:

$$\beta_{inj,p} - \beta_{inj,e} + \alpha$$

is negative.

PAMELA measured a rising positron fraction



Adriani et al., arXiv:0810.4995

How to explain a rising positron fraction?

- The propagation model is wrong: there are extra energy-dependent effects which affect secondary positrons (or primary electrons) but not the secondary to primary ratios for nuclei (at least at the measured energies), e.g.: Piran et al., arXiv:0905.0904; Katz et al., arXiv: 0907.1686

- There is production of secondary species within the CR sources with a mechanism giving a sufficiently hard spectrum (reacceleration at SN remnants?), e.g.: Blasi, arXiv:0903.2794; Mertsch & Sarkar, arXiv: 0905.3152

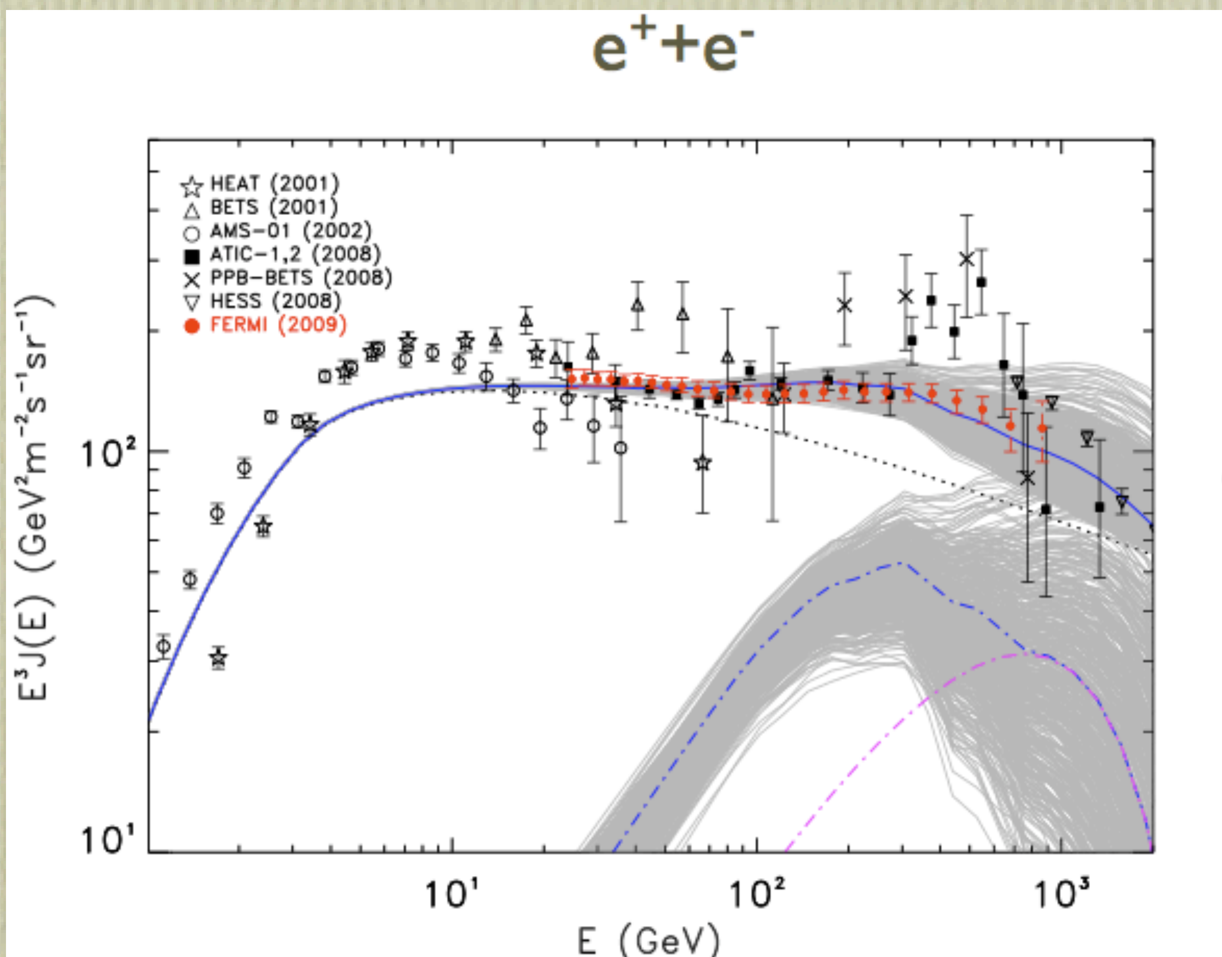
- There are additional astrophysical sources producing primary positrons and electrons: pulsars are the prime candidate in this list.

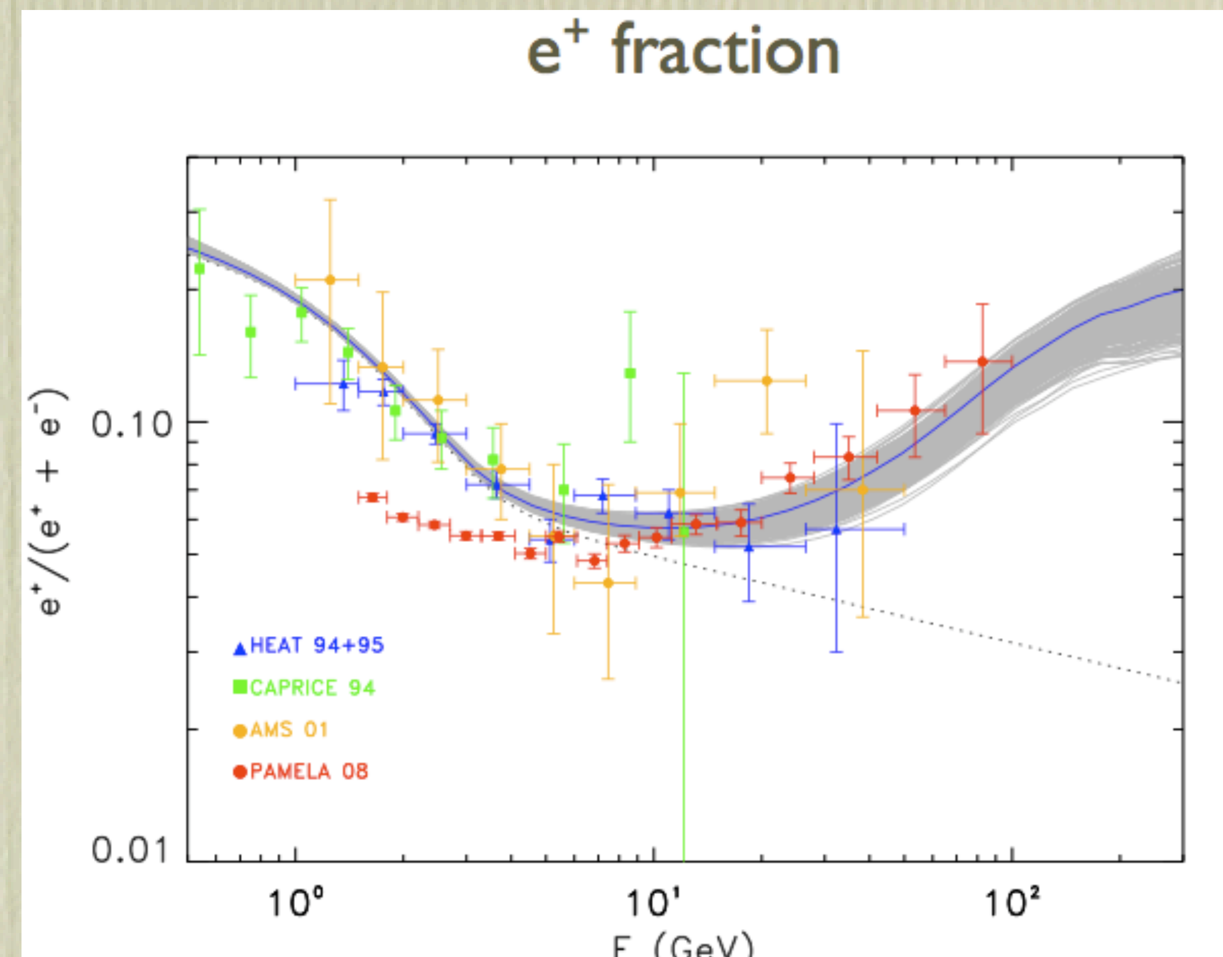
- There is an exotic extra source of primary positrons and electrons: a dark matter source is the most popular option in this class.

- ...

Few words on the pulsar interpretation:

There are a few nearby pulsars (Geminga is at only 100 pc) within which electron/positron pair production could be efficient enough. Take a phenomenological approach and fit the data, e.g.:





Grasso et al., arXiv:0905.0636

Successful fits but with a few caveats, e.g.: you need extremely hard source spectra, $\beta \approx 1.5$-1.7; you need to get e^-/e^+ out of the source keeping such hard spectra; the deduced properties of nearby pulsars should be consistent with what you deduce from CRs and photons elsewhere in the Galaxy.

Primary electrons/positrons from DM WIMPs:

The relevant process is the pair annihilations of non-relativistic WIMPs in the DM halo, proceeding mostly through two-body final states:

$$\chi\bar{\chi} \to f\bar{f}$$

(the energy of f is equal to the WIMP mass) corresponding to the source function:

$$Q_i(r,E) = \langle\sigma v\rangle_0 \sum_f \frac{dN_i^f}{dE}(E) B_f \mathcal{N}_{\text{pairs}}(r)$$

total rate

branching ratio into f

density of WIMP pairs

e^+/e^- energy spectra of two kinds:

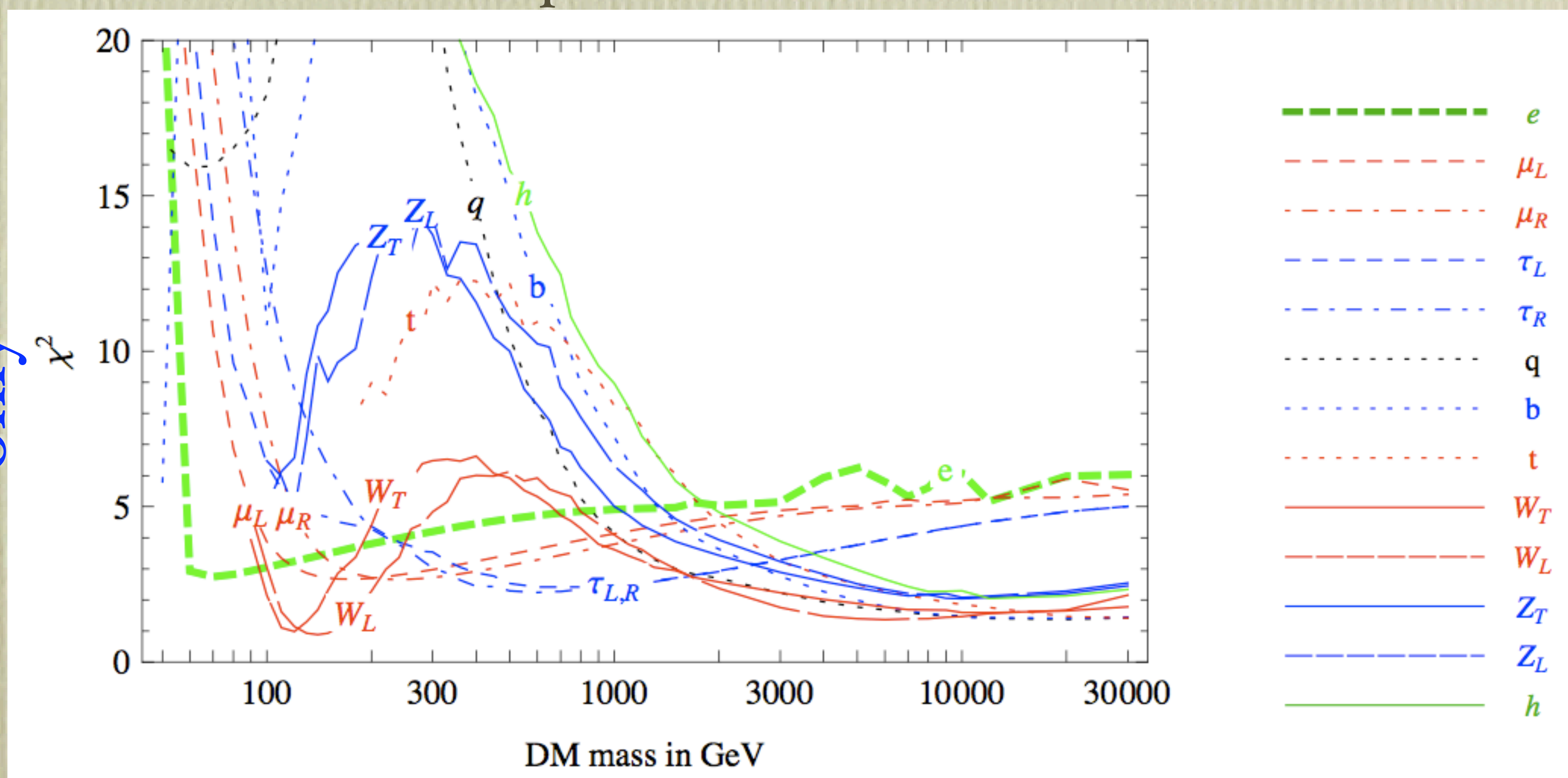
Soft spectra from, e.g., quark final states which produce charged pions decaying into leptons;

Hard spectra from, e.g., lepton or gauge boson final states, in which electrons and positrons are produced promptly or in a short decay chain.

Propagate this extra source in analogy to standard primary and secondary astrophysical components (only caveat: this source is not located in the gas disc, as the astrophysical sources, but spreads out in the full diffusive halo).

Different strategies. One possibility is to take again a phenomenological approach and adjust a generic WIMP model (defined by WIMP mass and dominant annihilation channel) to the data (i.e. find, for a given WIMP density, find the annihilation cross section). E.g.: start only with the fit of the PAMELA excess in the positron ratio:

Positron ratio only

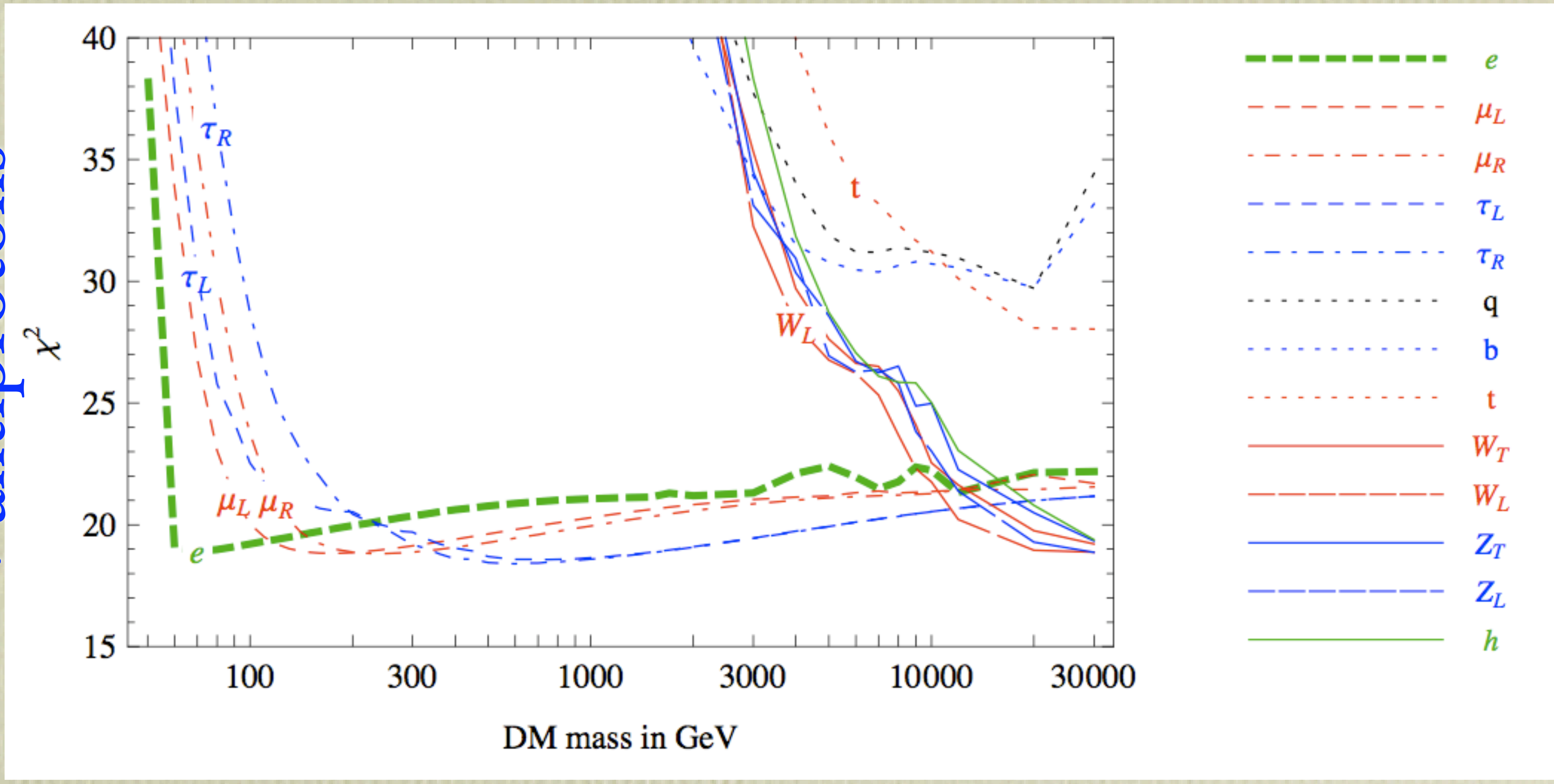


Cirelli et al., arXiv:0809.2409

either very massive WIMPS, or lighter WIMPs but hard annihilation spectra (leptons or W-bosons)

... then cross correlate, for the same WIMP model, other signals. The comparison with antiprotons is very powerful, since there is very little room for an exotic component in that channel:

Positron ratio
+ antiprotons

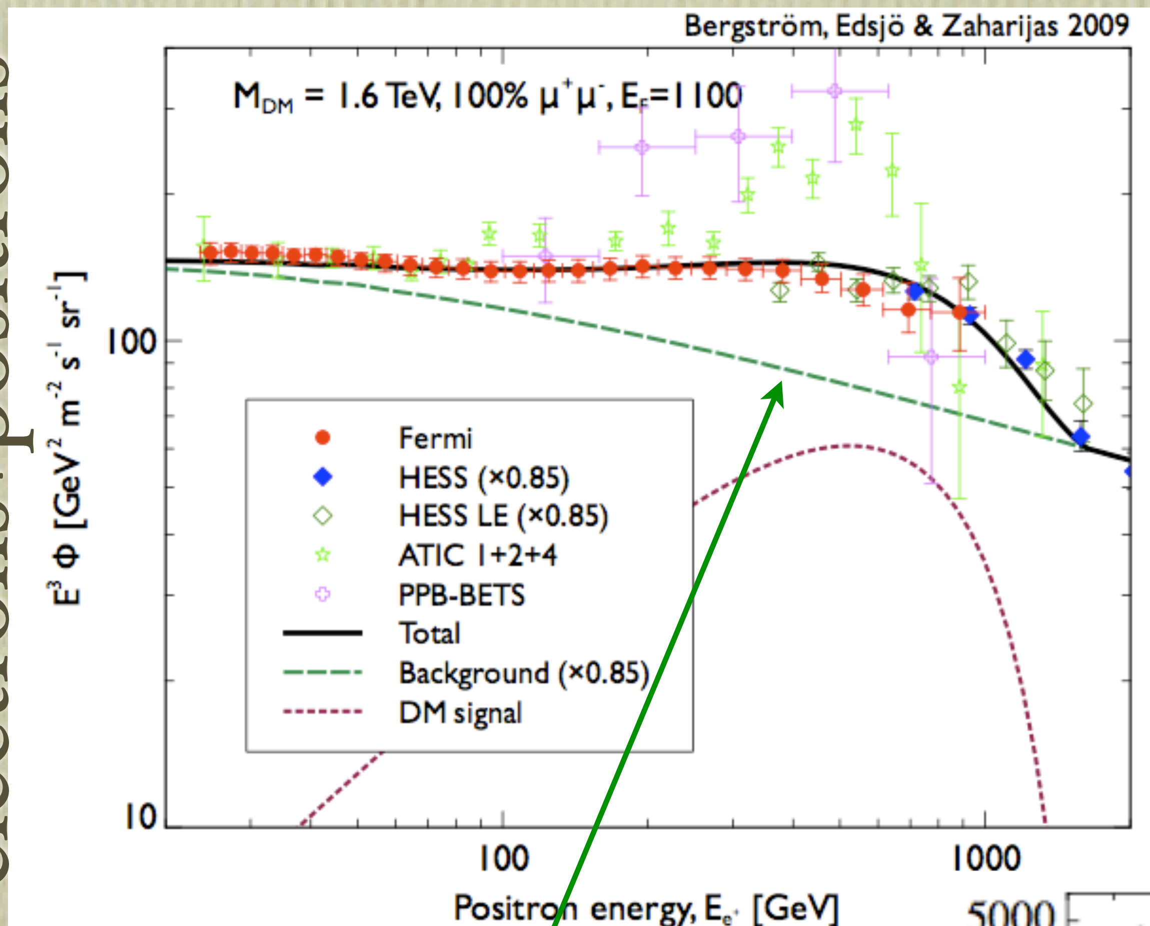


Cirelli et al., arXiv:0809.2409

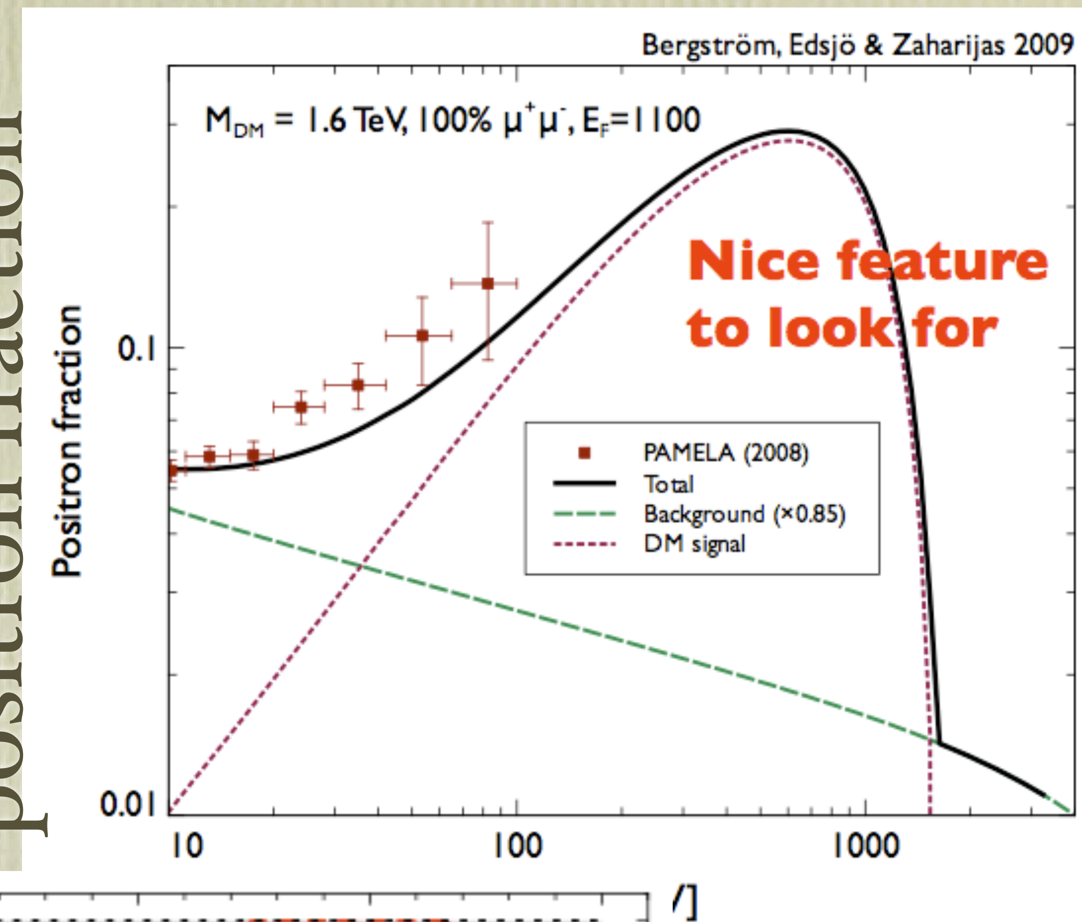
The W-boson annihilation channel has an antiproton yield which is large and inconsistent with antiproton data for WIMPs lighter than 10 TeV or so; leptonic channels are unaffected (they do not give rise to a positron yield).

... add in the recent measurement of the electron+positron flux by FERMI (and disregard previous claims by ATIC and PPB-BETS):

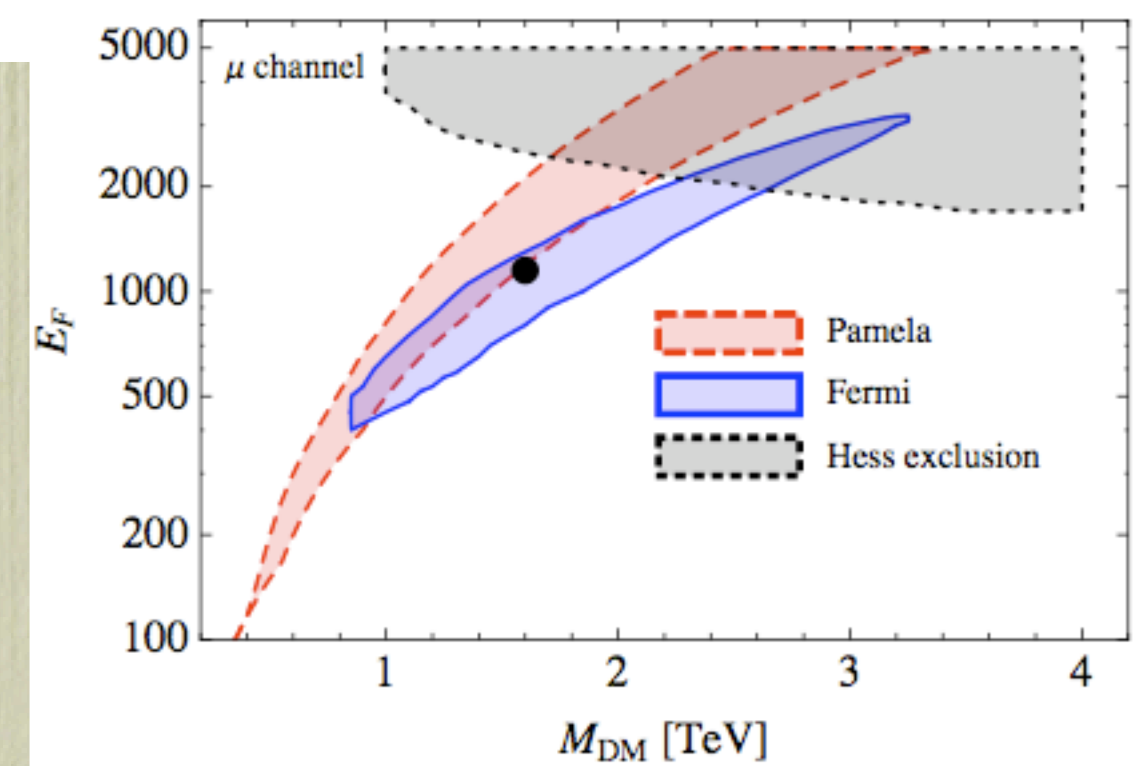
electrons+positrons



positron fraction



background ?!?



Bergström et al., arXiv:0905.0333

This "solution":

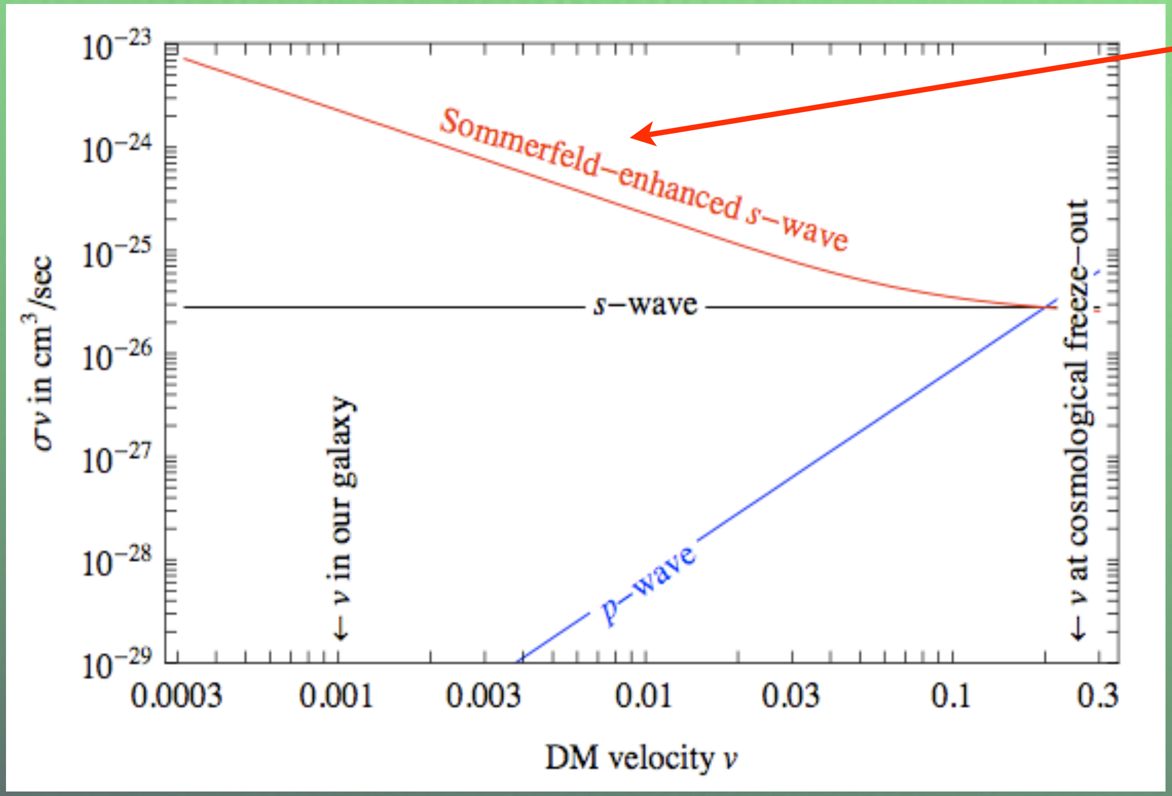
annihilation into muons, heavy WIMPs, large "enhancement factors"

Slightly different results among the numerous fits to the recent data, but convergence on models which are very different from "conventional" WIMP models (e.g. neutralinos in the MSSM). DM seems to be:

- leptophilic, i.e. with pair annihilation into leptons only, or into light (pseudo)scalars which for kinematical reasons can decay into leptons only (for this second class, see, e.g.: Arkani-Hamed et al., arXiv:0810.0713; Nomura & Thaler, arXiv:0810.5397);
- heavy, with WIMP masses above the 1 TeV scale;
- with a large (order 1000 or more) "enhancement factor" in the source function, either in the annihilation rate because $\langle \sigma v \rangle_{T_0} \gg \langle \sigma v \rangle_{T_{f.o.}}$ (or there is a resonance effect, or DM is simply non-thermal) or in the WIMP pair density because $\langle \rho_\chi^2 \rangle \gg \langle \rho_\chi \rangle^2$.

First possibility: Sommerfeld effect

Different possibilities for extrapolating the cross section from the early Universe:



a non-perturbative enhancement in the cross section at low velocities

Hisano, Matsumoto & Nojiri,(2003); e.g.: Cirelli et al., arXiv:0809.2409

DM is charged under a (new) gauge force, mediated by a “light” boson: this sets a non-perturbative long-range interaction, analogously to Coulomb interaction for positronium:

$$V(r) = -\frac{\alpha}{r}$$

gives the enhancement in the cross section:

$$S = \left|\frac{\psi(\infty)}{\psi(0)}\right|^2 = \frac{\pi\,\alpha/v}{1 - e^{-\pi\,\alpha/v}} \xrightarrow{v \ll \alpha} \frac{\pi\,\alpha}{v}$$

The same 1/v enhancement is obtained for a Yukawa potential. In a DM context, first studied in the MSSM for pure very massive Winos or Higgsinos and weak interaction as gauge force (light W boson limit).

Example: a new (sub-)Gev scale dark sector:

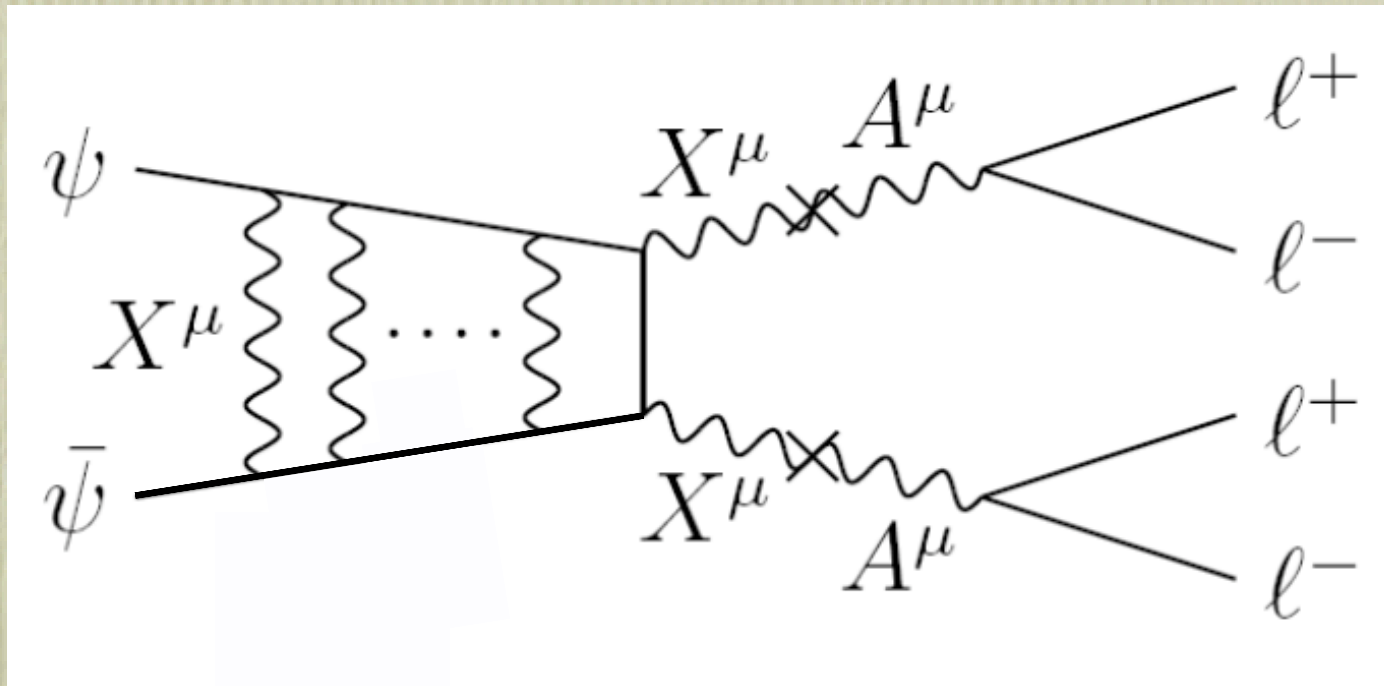
Arkani-Hamed et al., arXiv:0810.0713

The DM particle ψ is charged under a new gauge force mediated by X^μ :

$M_\psi \sim 100$ GeV $-$ 1 TeV

$m_X \sim 100$ MeV $-$ 1 GeV

The dark gauge field X^μ mixes with the photon A^μ :



leptonic final states:

$m_X \lesssim 2\,m_\mu :\ e^+\,e^-$

$2\,m_\mu \lesssim m_X \lesssim 2\,m_\pi :\ 50\%\ e^+\,e^-,\ 50\%\ \mu^+\,\mu^-$

$2\,m_\pi \lesssim m_X \lesssim GeV :\ 40\%\ e^+\,e^-,\ 40\%\ \mu^+\,\mu^-,\ 20\%\ \pi^+\,\pi^-$

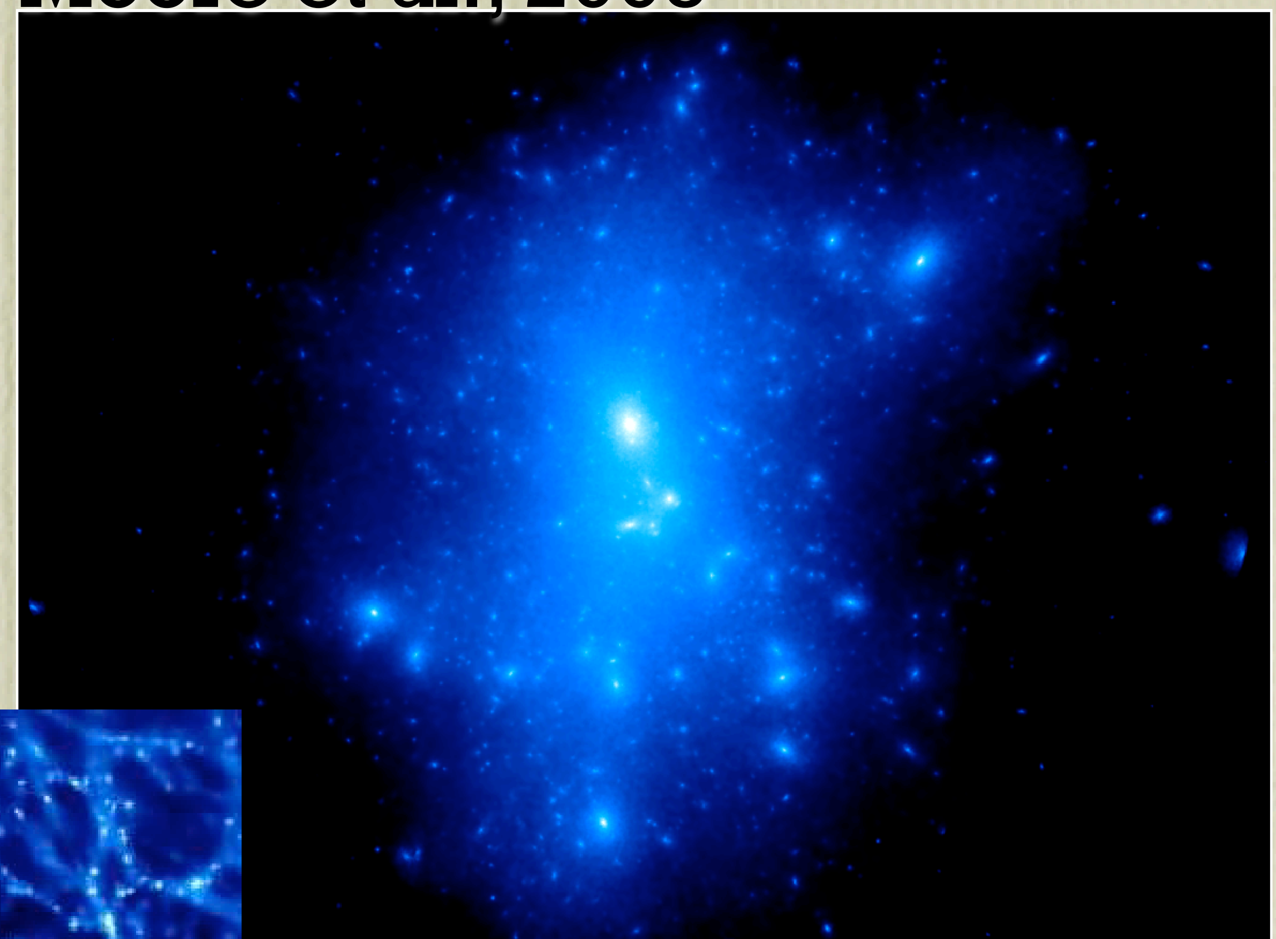
non-perturbative Sommerfeld enhancement

$$\frac{m_X}{M_\psi} \lesssim v \lesssim \alpha$$

Second possibility: Enhancements in the indirect detection DM signals are often invoked in connection to substructures within the Galaxy, assuming: $\langle \rho^2 \rangle \gg \langle \rho \rangle^2$.

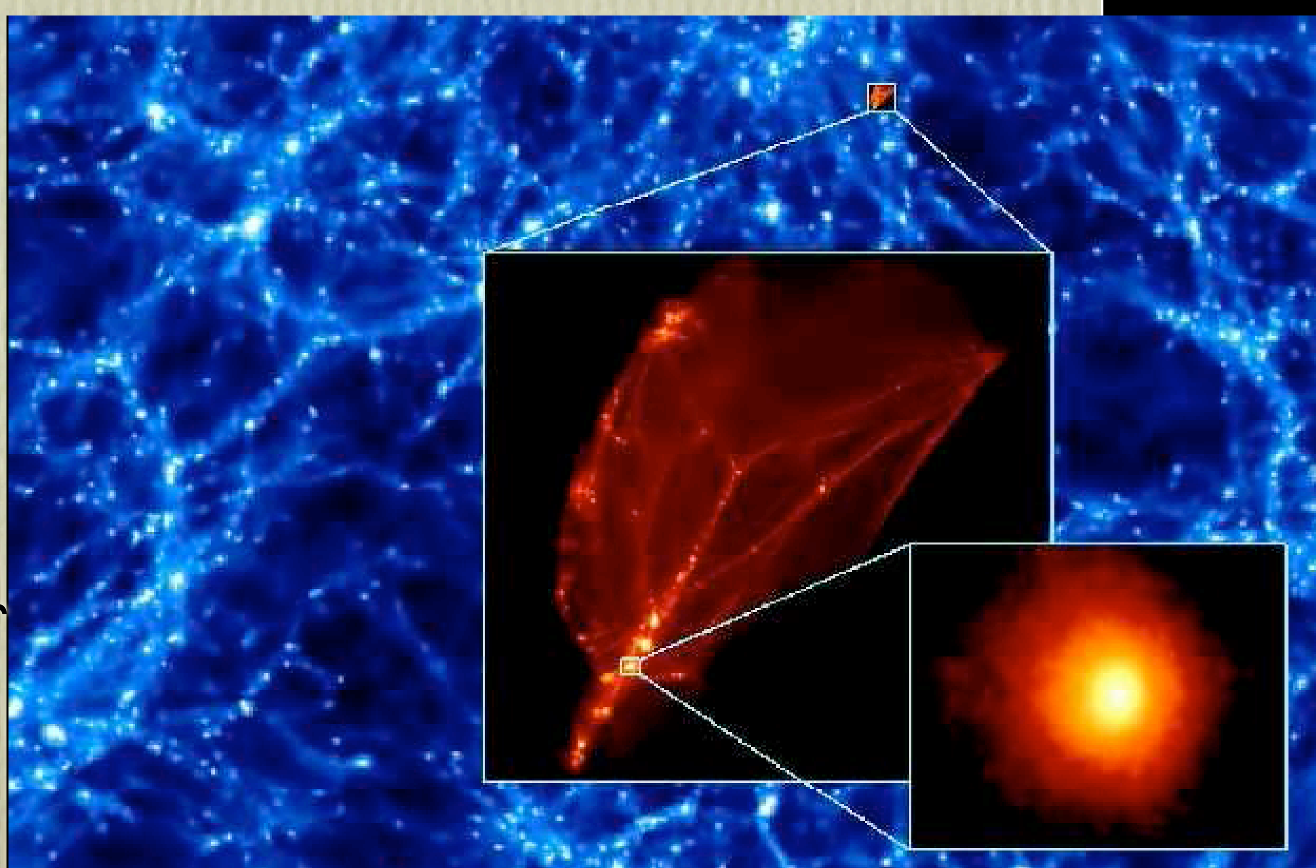
In hierarchical CDM structure formation, small dense structures collapse first, merging then into larger and less dense objects, with a substructure population partially surviving tidal disruption in the merging:

Moore et al., 2005



~ 300 kpc

Diemand, Moore & Stadel, 2005



0.024 pc

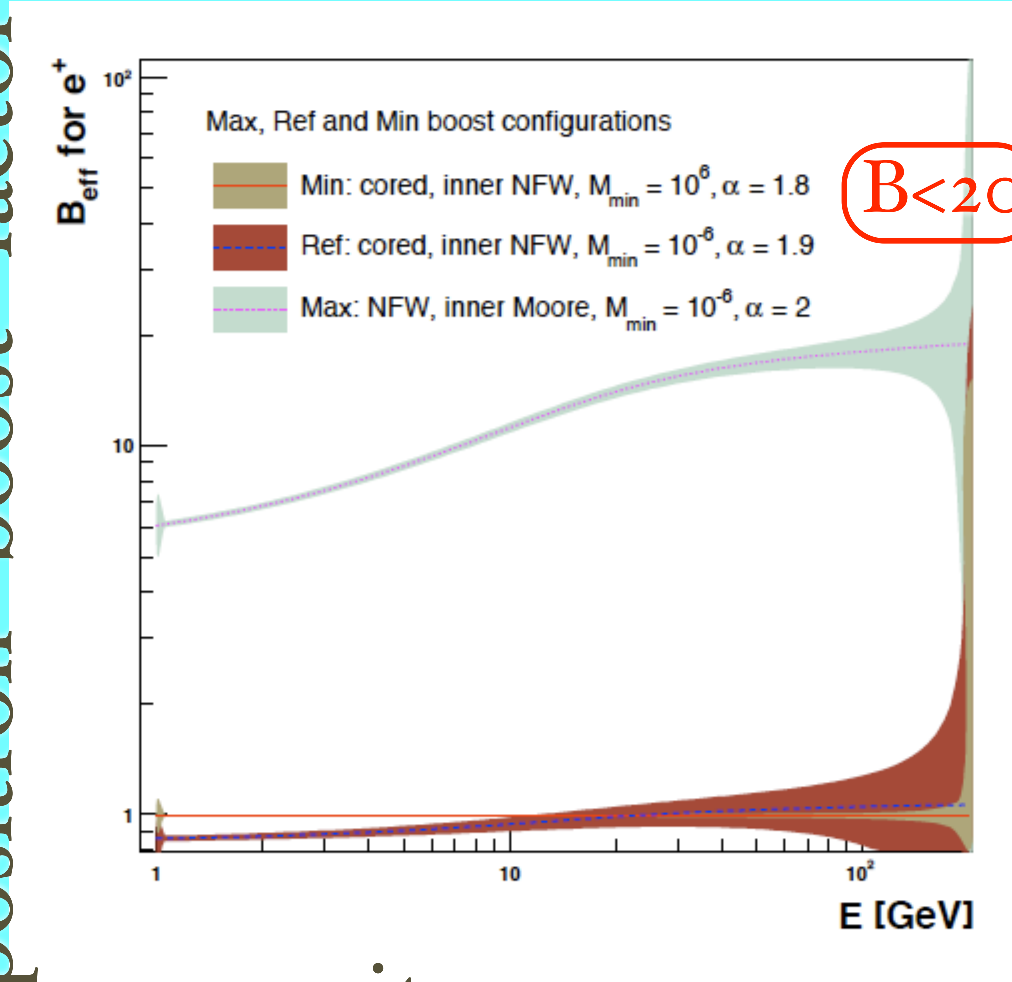
The smallest substructures on the scale corresponding to the WIMP free-streaming scale, ~ $10^{-6} M_{\odot}$

Green, Hofmann & Schwartz, 2004

Several analysis and slightly different results:

the enhancement in a **typical realization** in a CDM halo (summing the contributions over all substructures and averaging over a statistical ensemble of realizations) is unlikely to be larger than a factor or few (maybe 100), e.g.:

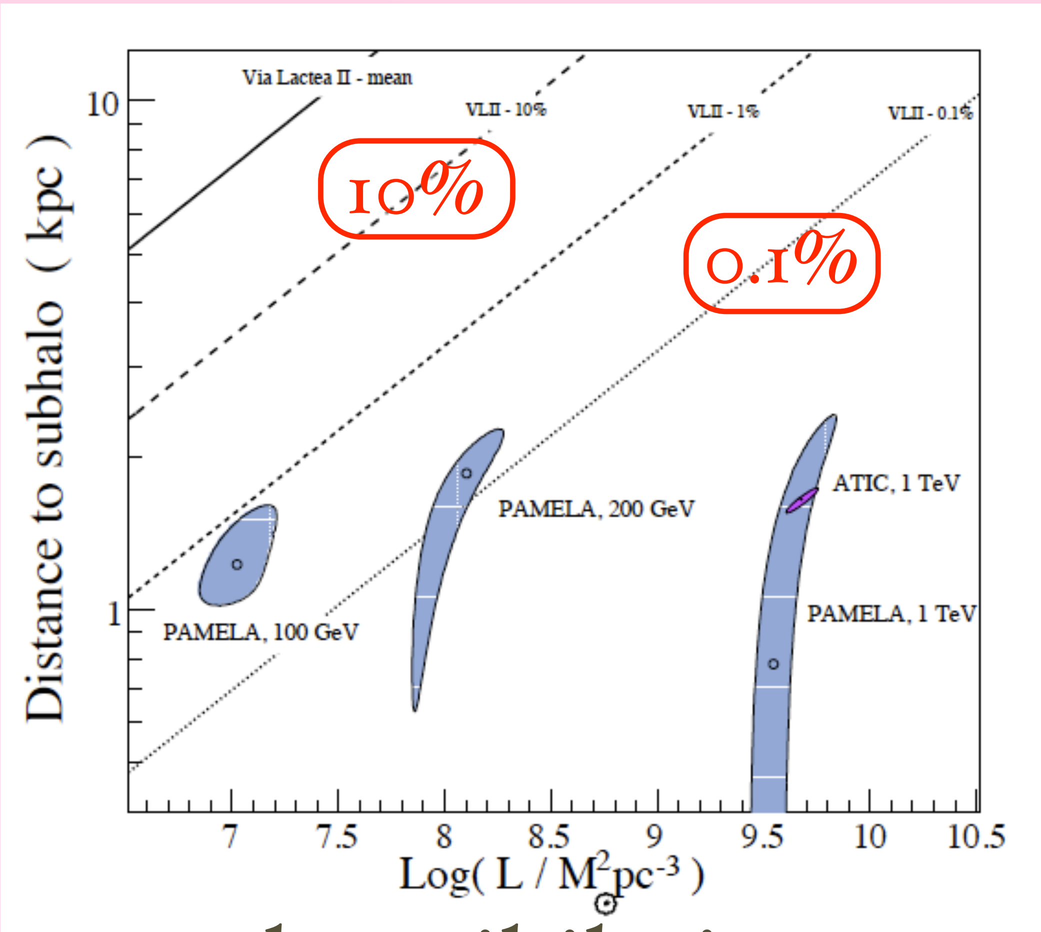
Lavalle et al., arXiv:0709.3634



positron “boost” factor

positron energy

Brun et al., arXiv: 0904.0812



~ total annihilation rate

The signal might be dominated by the **closest/densest substructure** in the distribution - a configuration with a very small probability within CDM simulations (have we “won the lottery”?)

Single DM substructures and proper motion effects

DM clumps have been mostly treated as static point sources (propagation eq. solved in the steady limit). However clumps are expected to have, on average, a velocity of the order of the velocity dispersion for non-rotationally-supported galactic populations, i.e. about: $\sqrt{\langle v^2 \rangle} \simeq 300\ \mathrm{km\ s^{-1}}$.

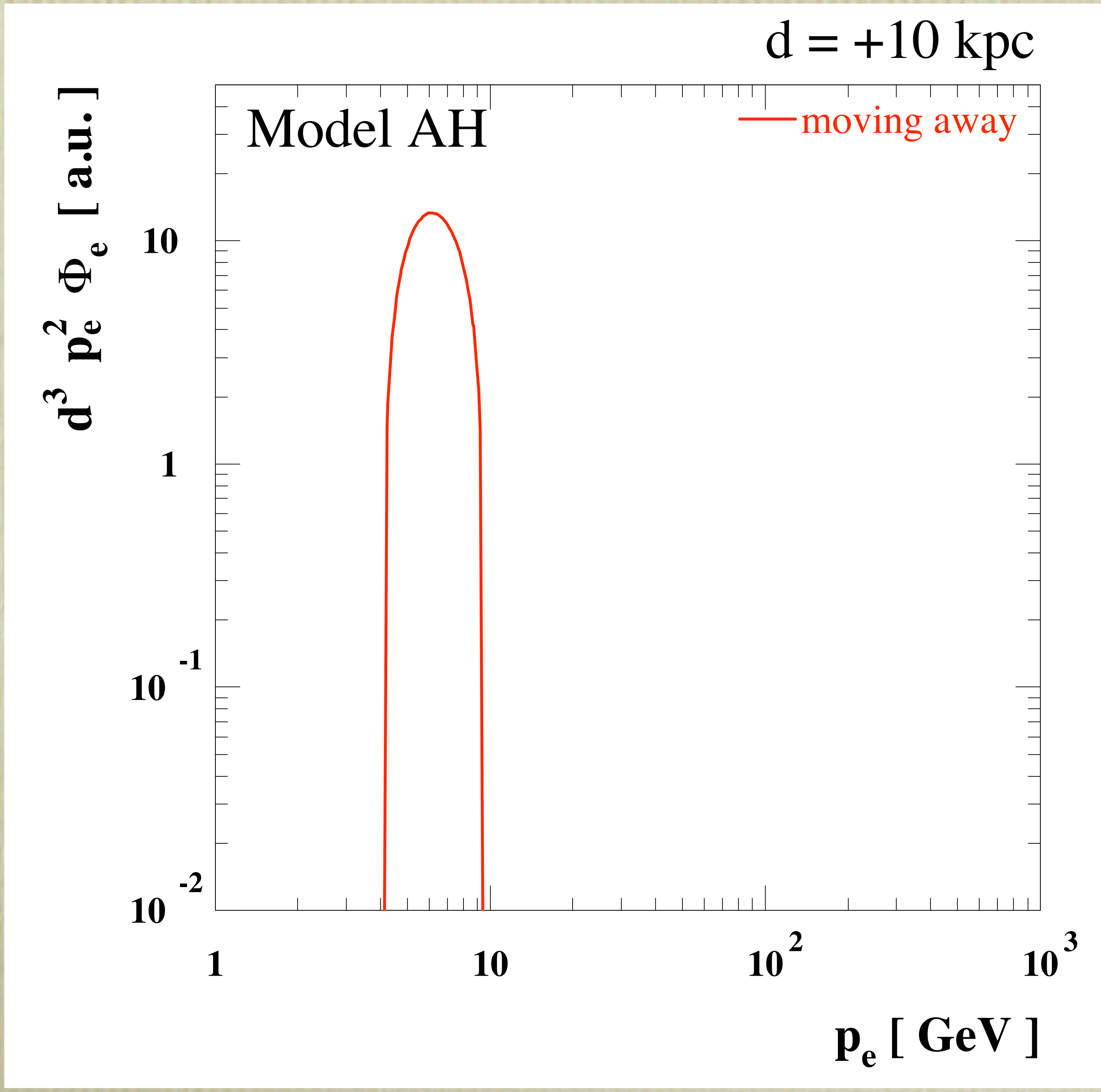
This effect defines a "proper-motion" timescale which turns to be comparable or even smaller than the energy loss or spatial diffusion timescales: it is necessary to solve the propagation equation for charged particles in the Galaxy without assuming the steady state limit, as recently done for electrons/positrons and antiprotons, see:

Regis & P.U., arXiv: 0907.5093

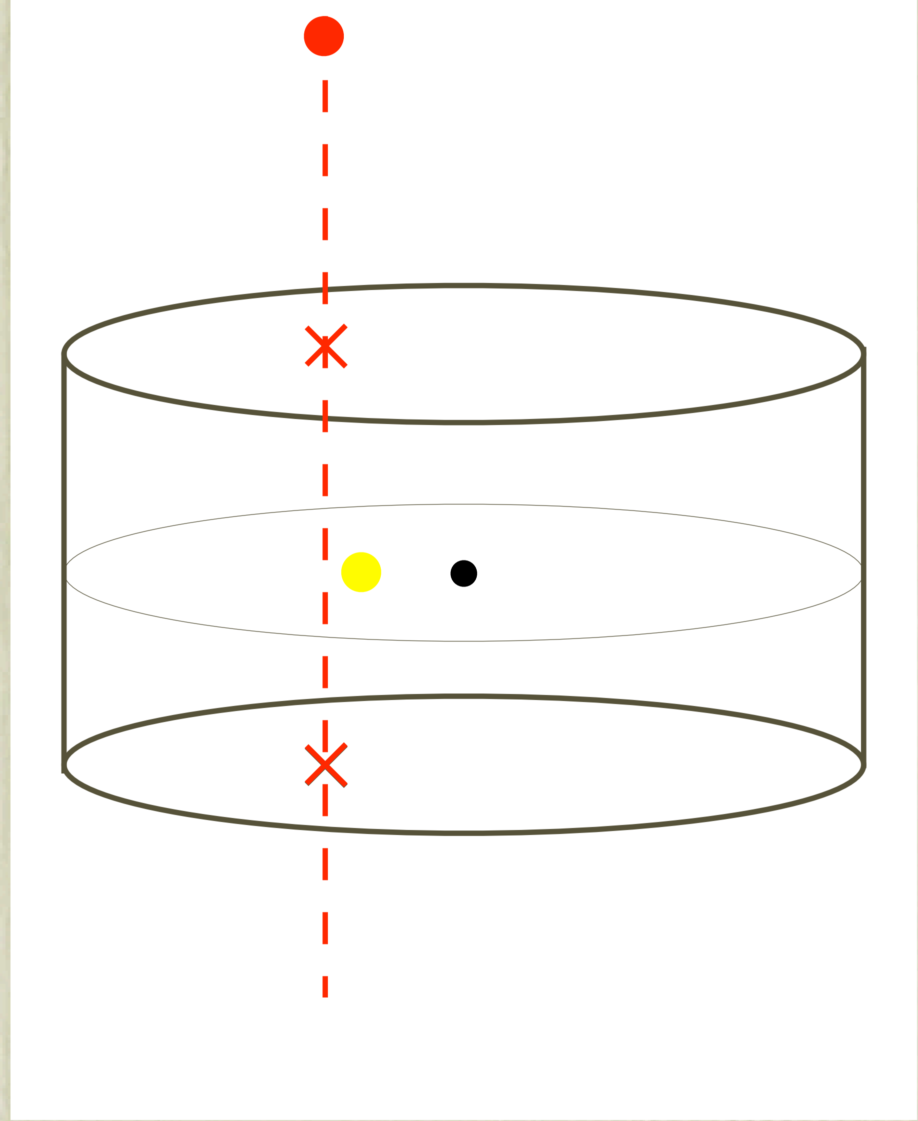
The result is that proper motion matters, possibly being the dominant effect, in all cases except for very close substructures or at very high energies.

E.g.: assume you have a 500 GeV DM candidate annihilating into monochromatic e^+/e^-, on a orbit perpendicular to the galactic plane and passing close to the Sun:

Regis & P.U., arXiv: 0907.5093



labeling time with the distance along the orbit, for $v_s = 300 \text{ km s}^{-1}$



The matching between the measured excesses and the particle physics properties, which used to be:

i) the DM mass to the energy threshold of the excess;

ii) the annihilation channel to its spectral shape;

iii) the annihilation rate to the normalization of the signal;

is now totally spoiled!

In fact:

i) the energy threshold can be drastically shifted if you allow the substructure to be far away from the observer;

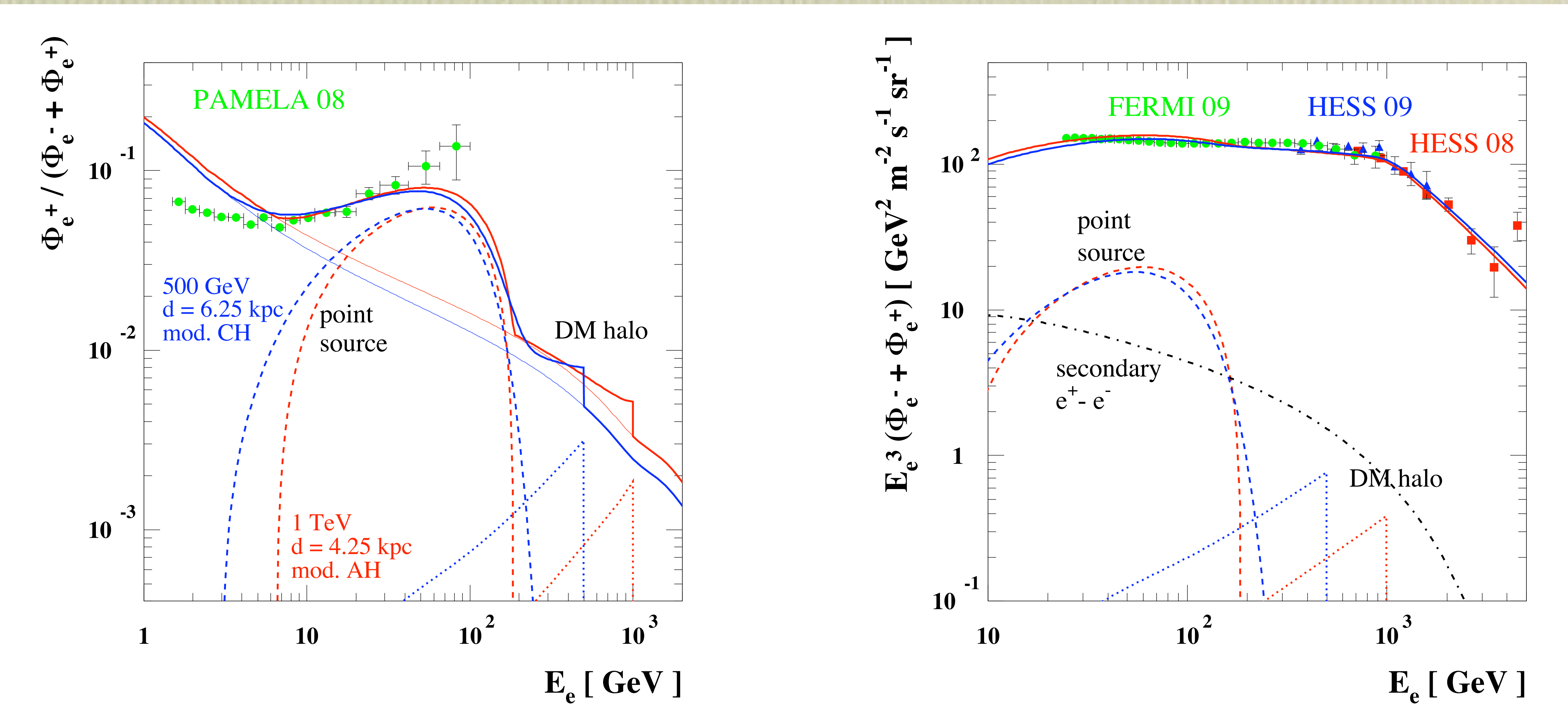
ii) the spectral shape is mostly determined by the transient, and is very sensitive to the specific transient one considers;

iii) the normalization depends mainly on the dark matter density within the substructure.

This is clearly an extreme case, however it illustrates nicely the point that one should never give for granted quantities that are deduced in modeling of a given data set, rather than directly measured in the data.

Sample fit to the Pamela and Fermi electron/positron data

Assumes a given: i) DM annihilation channel: monochromatic e^+/e^-, ii) DM mass, & iii) clump orbit/velocity. Fit optimized with respect to: 1) the distance along the orbit, & 2) the source normalization. The electron background is assumed to follow from Fermi data:

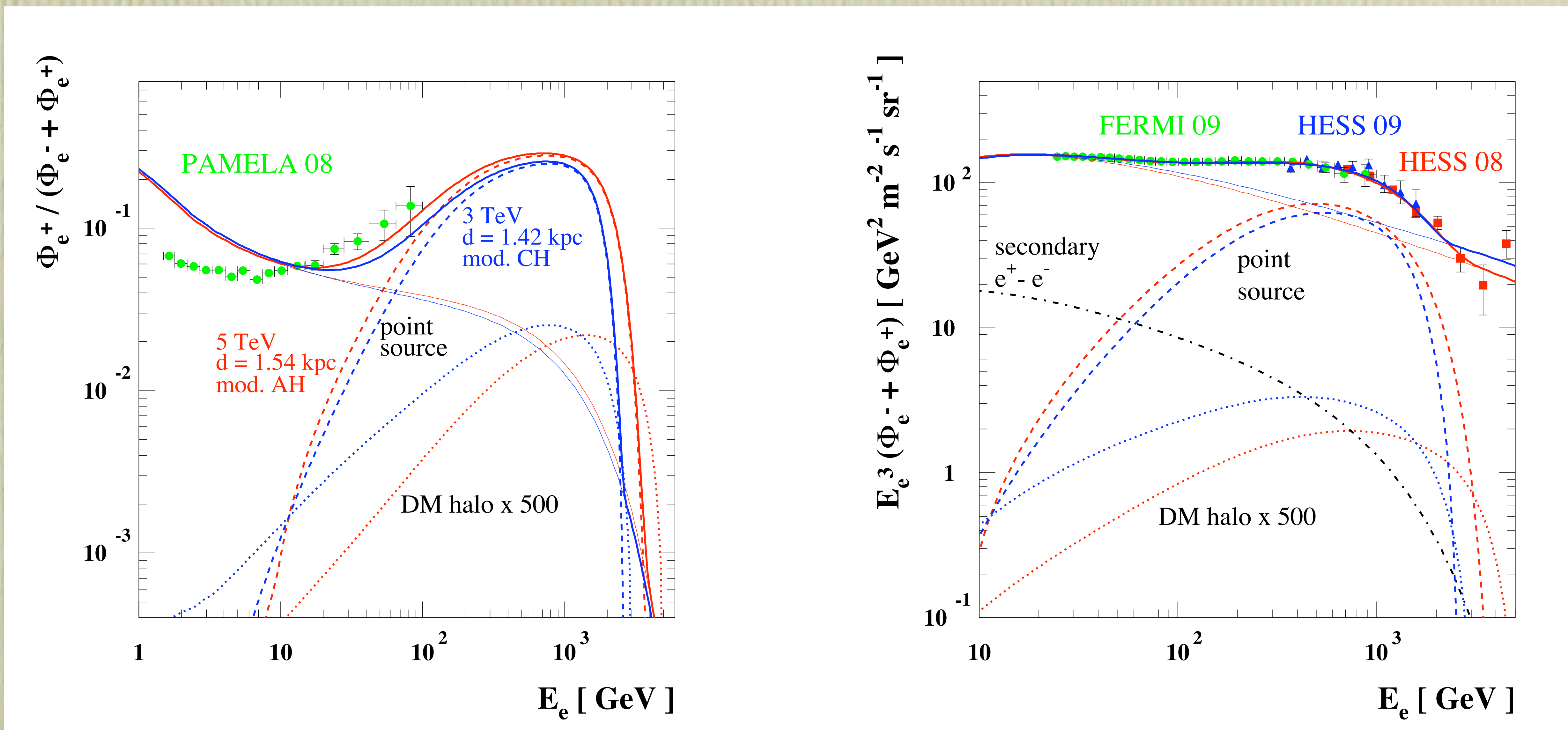


Regis & P.U., arXiv: 0907.5093

Hardly any correlation between the point source contribution and the contribution from the smooth DM halo component (which in all studies displayed so far was scaled by by the "enhancement factor")

Sample fit to the Pamela and Fermi electron/positron data

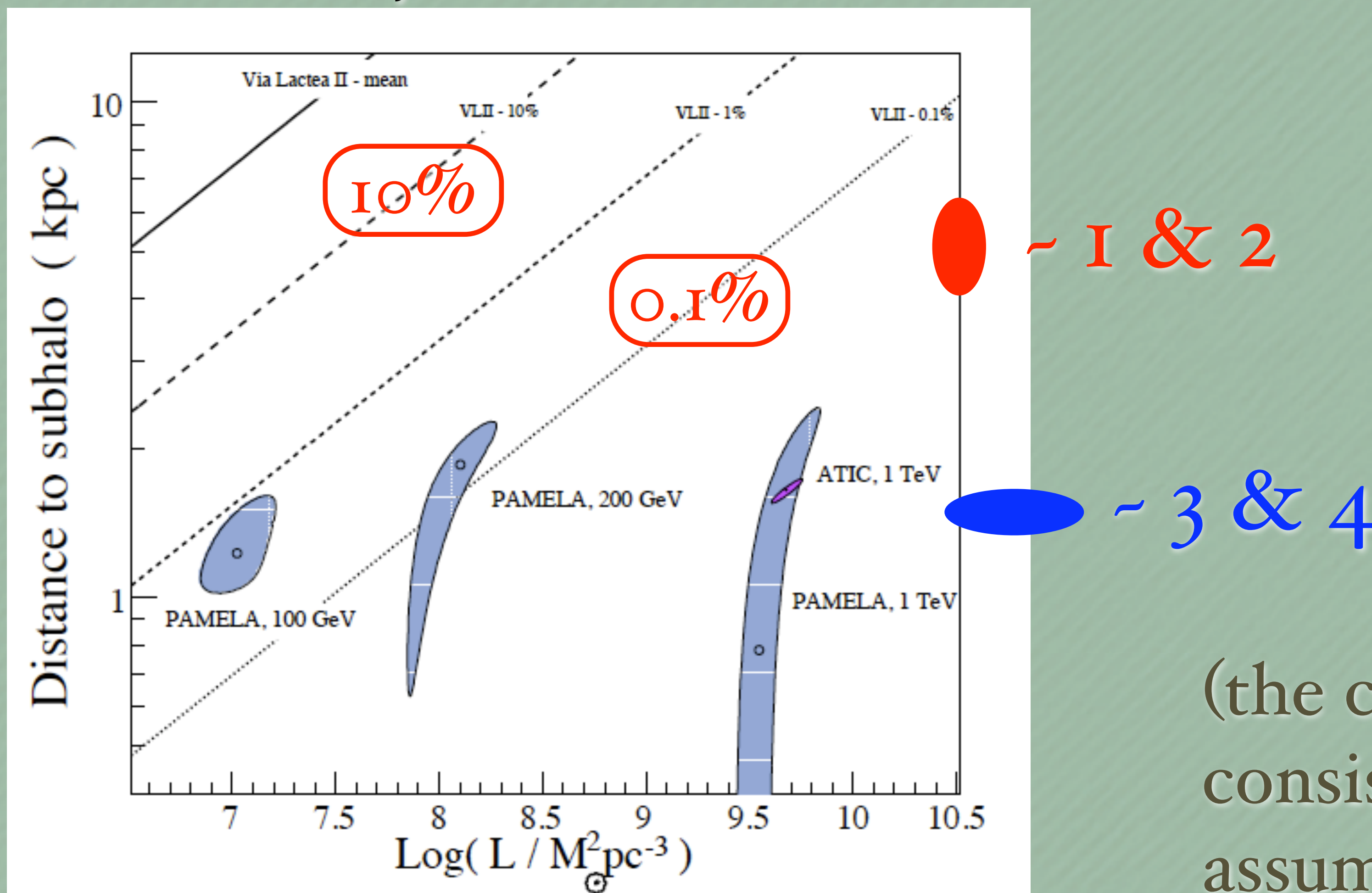
Assumes a given: i) DM annihilation channel: τ^+/τ^-, ii) DM mass, & iii) clump orbit/velocity. Fit optimized with respect to: 1) the distance along the orbit, & 2) the source normalization. The electron background is assumed to be significantly below the Fermi data:



Regis & P.U., arXiv: 0907.5093

Are these fits meaningful?

Brun et al., arXiv: 0904.0812



~ total annihilation rate

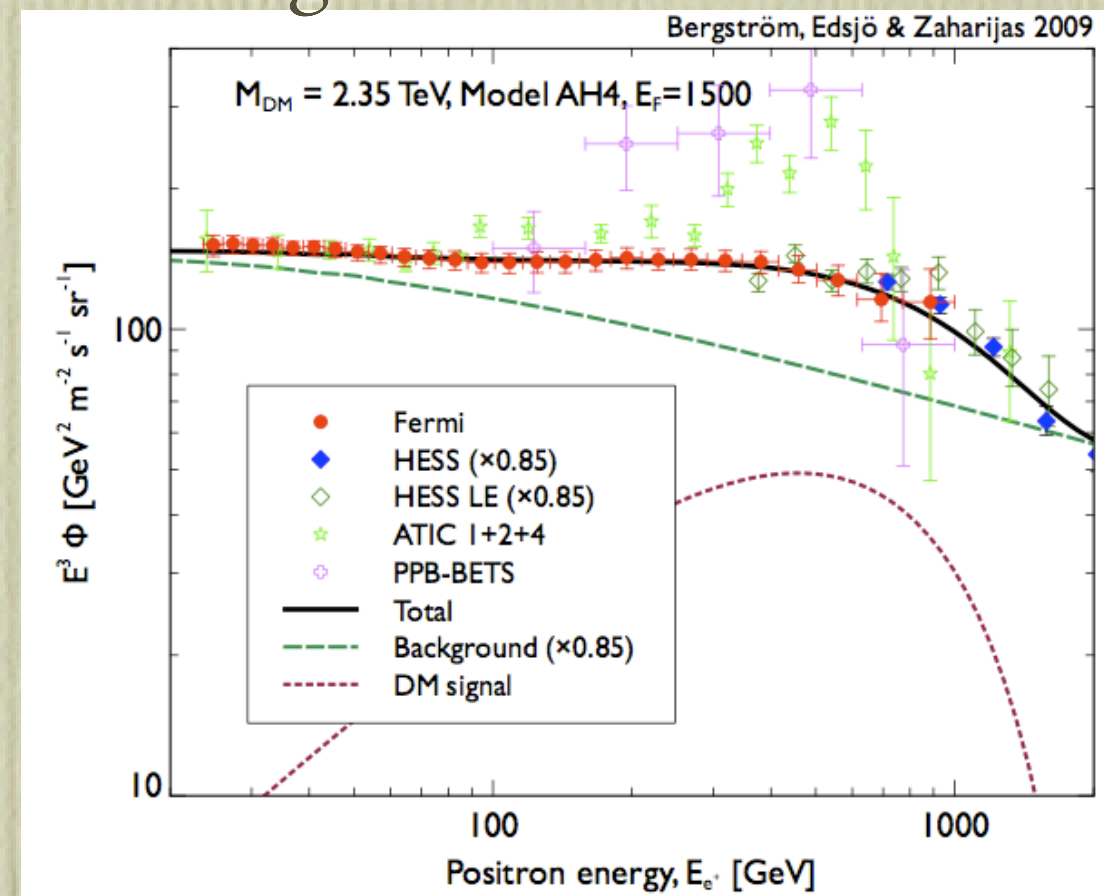
Indeed the required total (i.e. volume integrated) annihilation rates are very large, much larger than the expected values in substructures according to CDM N-body simulations.

(the comparison is not totally consistent since the plot assumes static substructures)

Much larger annihilation rates are predicted in other scenarios. One possibility: in the first DM halos, intermediate-mass black holes may form and, during this process, DM is adiabatically compressed in the center of these systems, inducing very dense DM “spikes”; such objects are expected to be present in the Milky Way, possibly corresponding to extremely bright DM sources. Bertone, Zenter & Silk (2005), Brun et al. (2007).

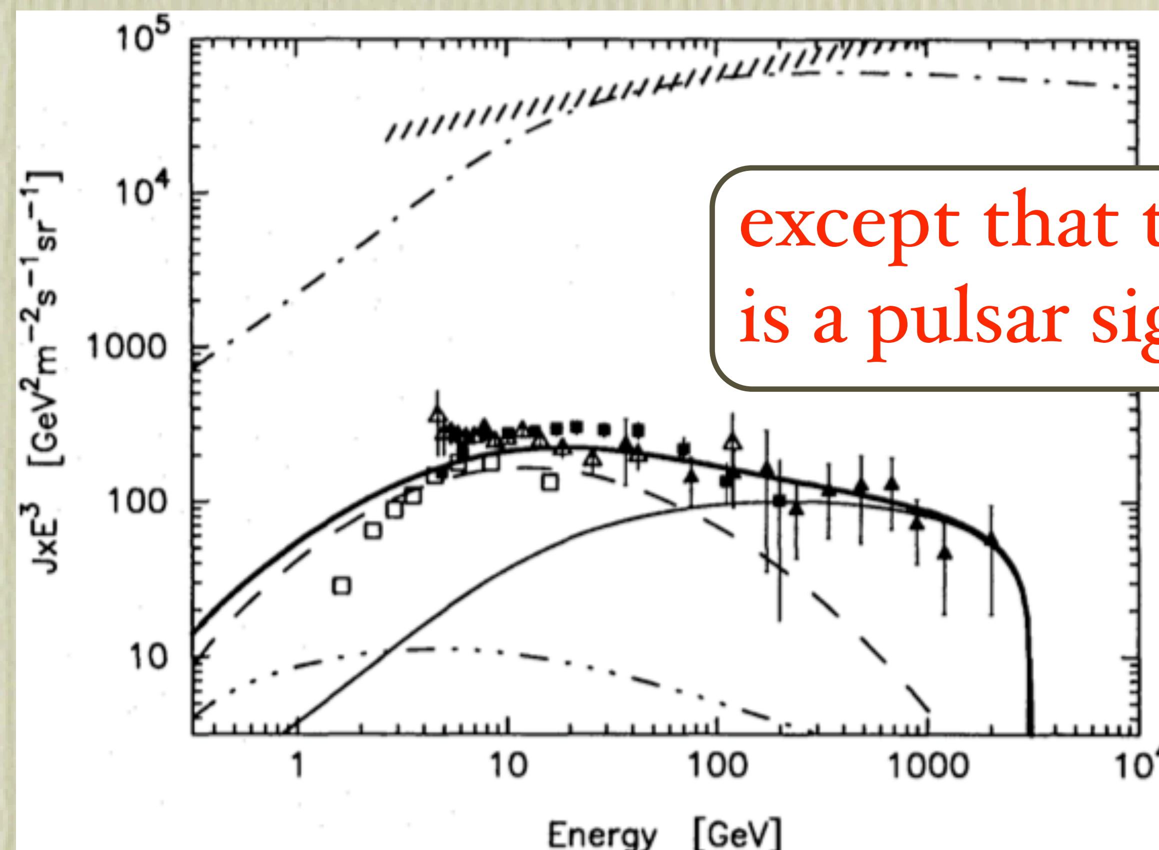
Caveat: we may have seen a DM signal, but have not seen a DM signature.

The sample fit of the data with a DM signal:



Bergström et al. on model by **Arkani-Hamed et al.**

is analogous to the signal foreseen in models of more than a decade ago:



except that this is a pulsar signal

Aharonian et al., 1995

Cleaner spectral features in upcoming higher statistics measurements (???).
Pay attention to cross correlations with other DM detection channels.

E.g.: a DM point source accounting for the PAMELA excess would be detected by the Fermi GST looking at the associated γ-ray flux

DM annihilations and gamma-ray fluxes:

The source function has exactly the same form as for positrons:

$$Q_i(r,E) = \langle \sigma v \rangle_0 \sum_f \boxed{\frac{dN_i^f}{dE}(E)} B_f \, \mathcal{N}_{\rm pairs}(r)$$

total rate

branching ratio into f

density of WIMP pairs

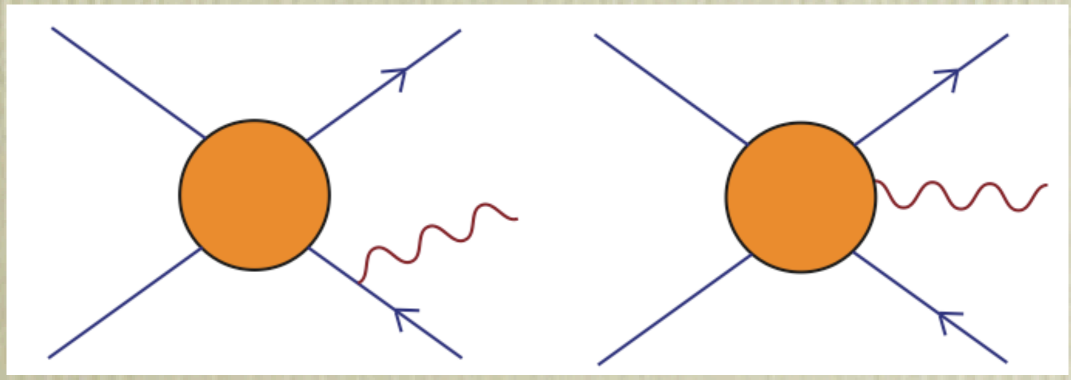
Prompt emission of γ-rays associated to three components:

I) Continuum: i.e. mainly from $f \to \ldots \to \pi^0 \to 2\gamma$

II) Monochromatic: i.e. the 1-loop induced $\chi\chi \to 2\gamma$ and

$\chi\chi \to Z^0\gamma$ (in the MSSM, plus eventually others on other models)

III) Final state radiation (internal Bremsstralungh)

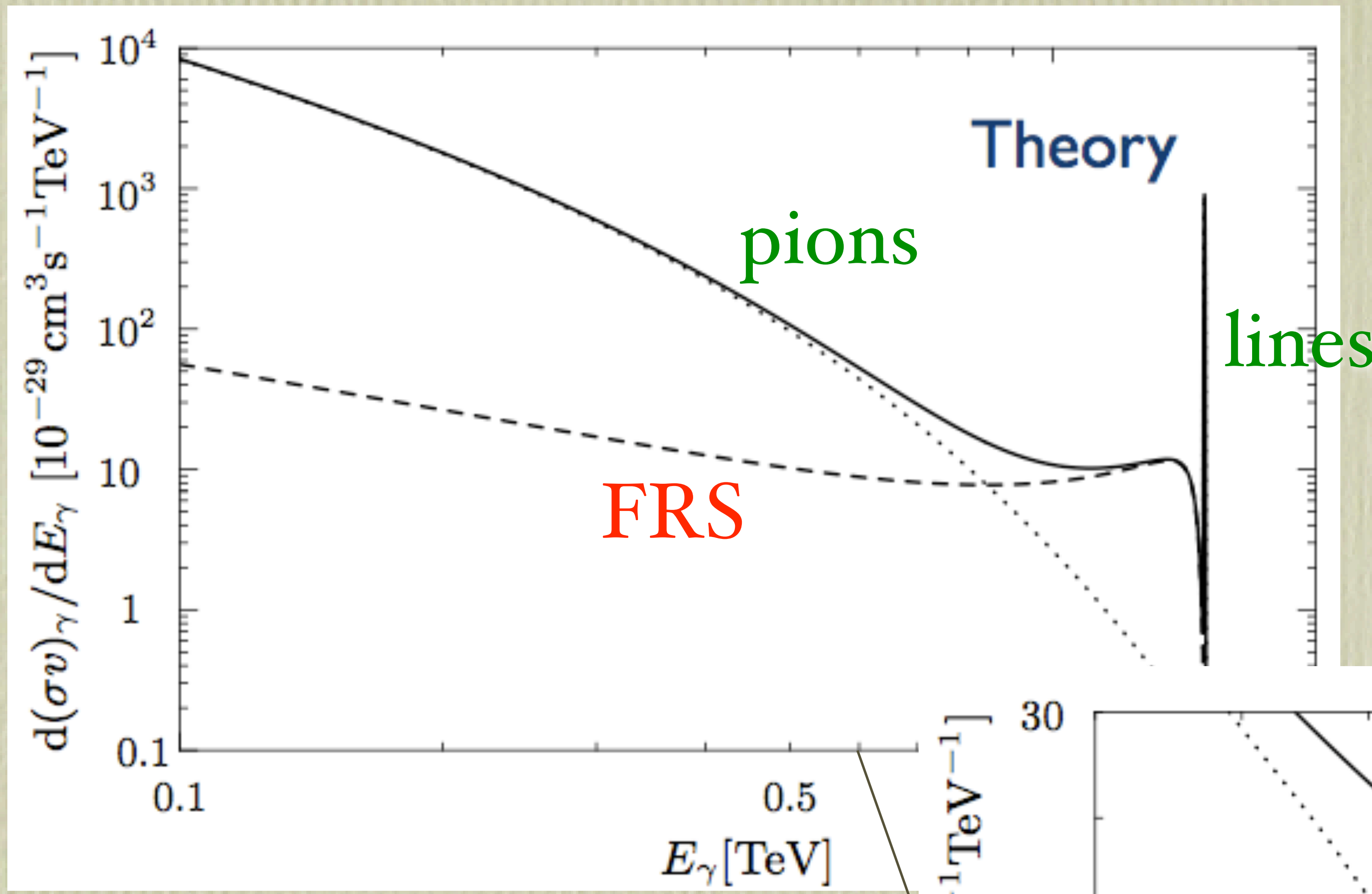


especially relevant for:

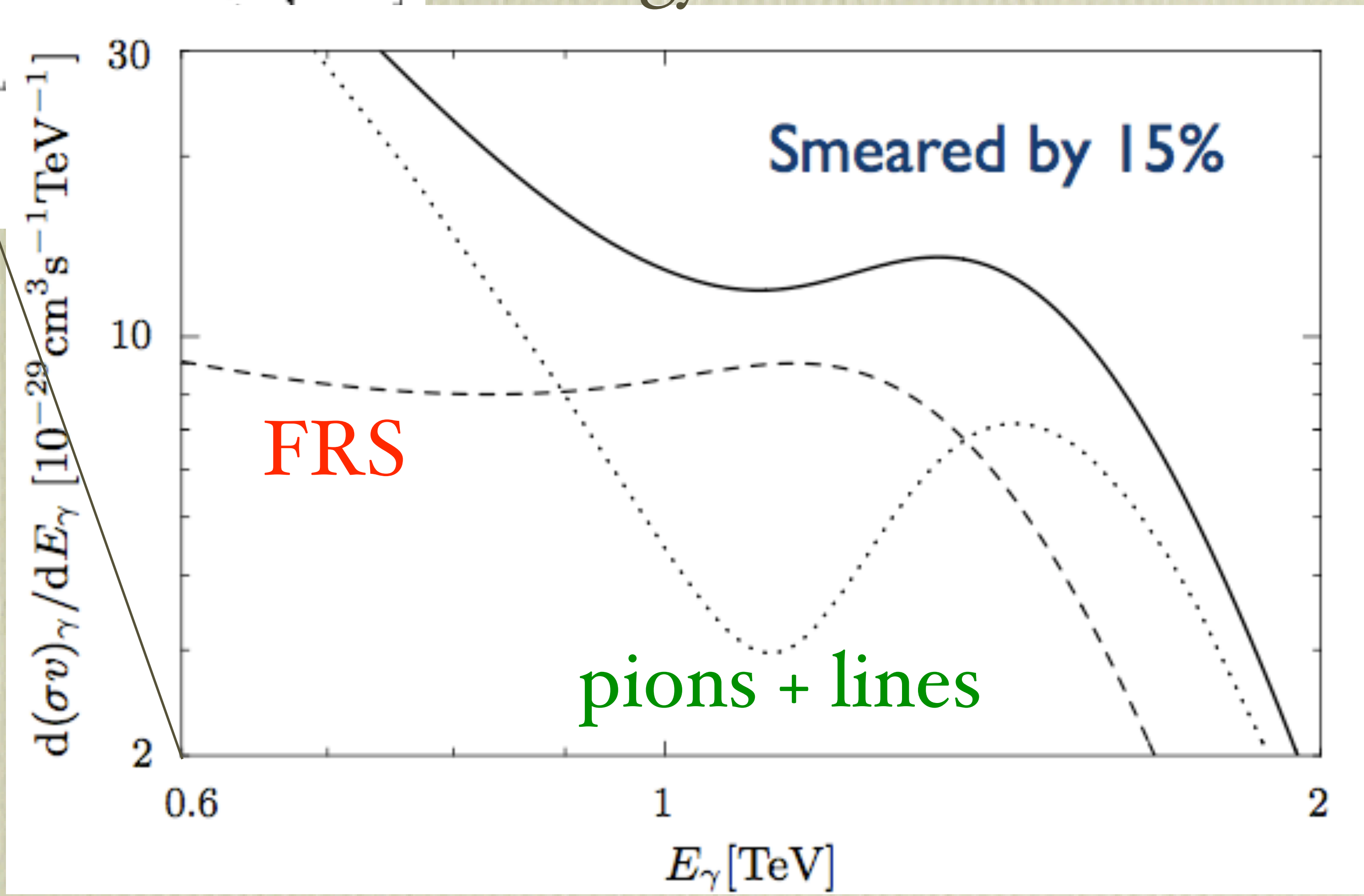
$\chi\chi \to l^+ l^- \gamma$

in case of Majorana fermions

Then for a model for which all three are relevant (e.g. pure Higgsino)The source function has exactly the same form as for positrons:



including a typical detector energy resolution



Bergström et al., astro-ph/0609510

The induced gamma-ray flux can be factorized:

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\theta,\phi) = \frac{1}{4\pi}\underbrace{\boxed{\frac{\langle\sigma v\rangle_{T_0}}{2\,M_\chi^2}\sum_f \frac{dN_\gamma^f}{dE_\gamma}B_f}}_{\text{Particle Physics}}\cdot\underbrace{\boxed{\int_{\Delta\Omega(\theta,\phi)} d\Omega' \int_{l.o.s.} dl\ \rho_\chi^2(l)}}_{\text{DM distribution}}$$

Targets which have been proposed:

- The Galactic center (largest DM density in the Galaxy)
- The diffuse emission from the full DM Galactic halo
- Dwarf spheroidal satellites of the Milky Way
- Single (nearby?) DM substructures without luminous counterpart
- Galaxy clusters
- The diffuse extragalactic radiation
- ...

A number of "excesses" claimed in recent years; the Fermi GRT has collected over one year of data by now and will allow for much firmer statements. Preliminary results on DM searches have been presented in summer conferences, unfortunately reporting upper limits only.

E.g.: S. Murgia, TeV Particle Astrophysics 09

- No evidence for a WIMP contribution within 1° of the GC;
- The diffuse Galactic emission at intermediate and E > 1 GeV is lower then from EGRET data, consistent with the background;
- A set of upper limits have been inferred for dwarfs and clusters;
- Upper limits on monochromatic emission from the Galaxy
- No evidence for extended sources without luminous counterpart;
- The diffuse extragalactic can be simply fitted by a single power law.

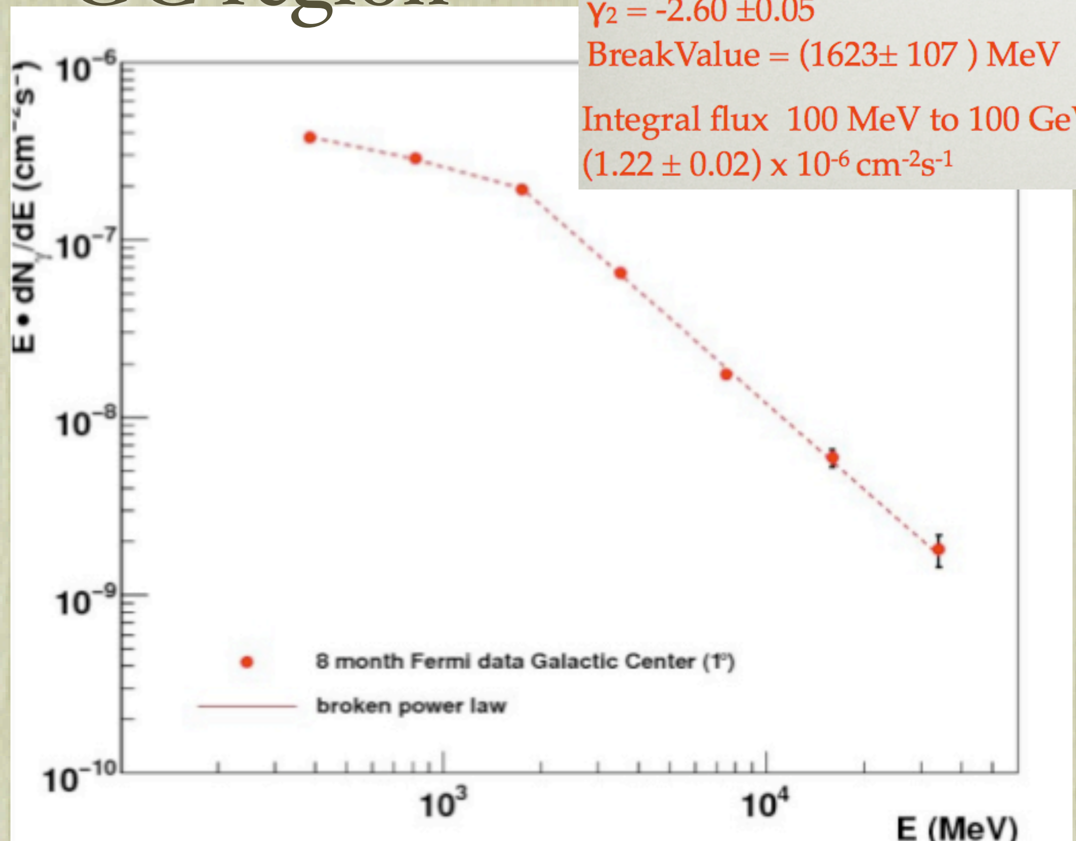
PRELIMINARY

S. Murgia, TeVPA09 -PRELIMINARY

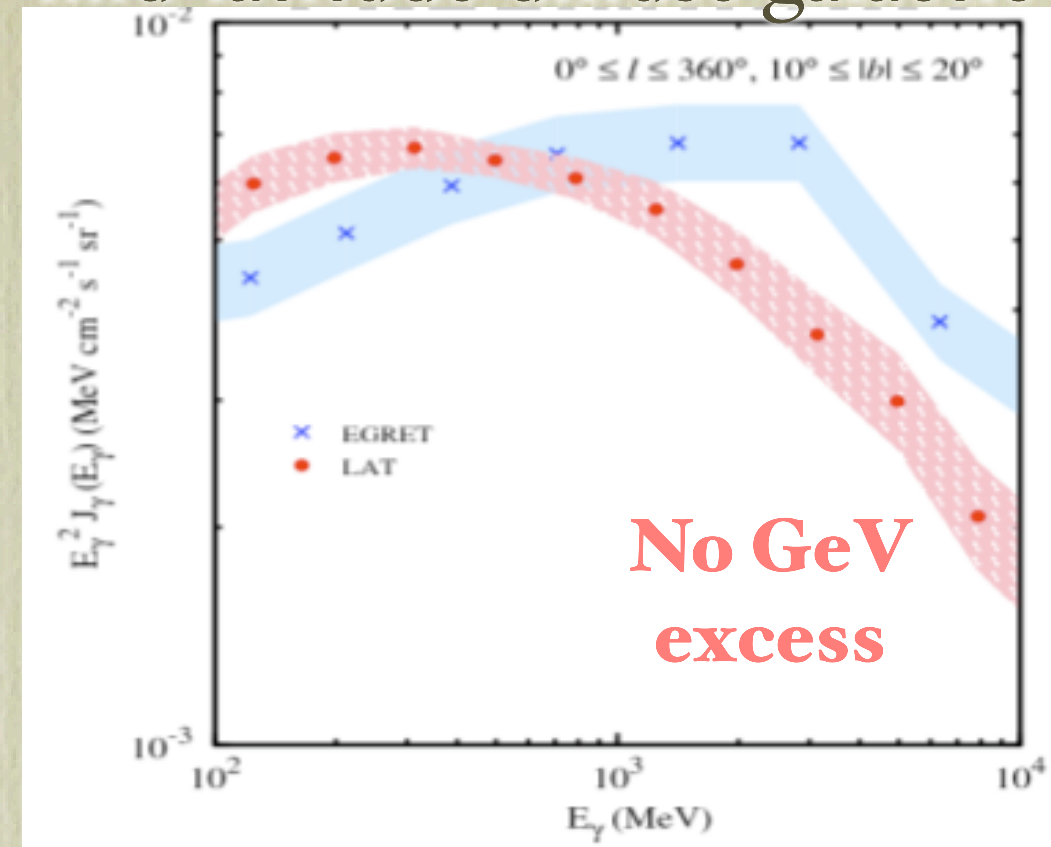
GC region

$\gamma_1 = -1.38 \pm 0.04$
$\gamma_2 = -2.60 \pm 0.05$
BreakValue = (1623± 107) MeV

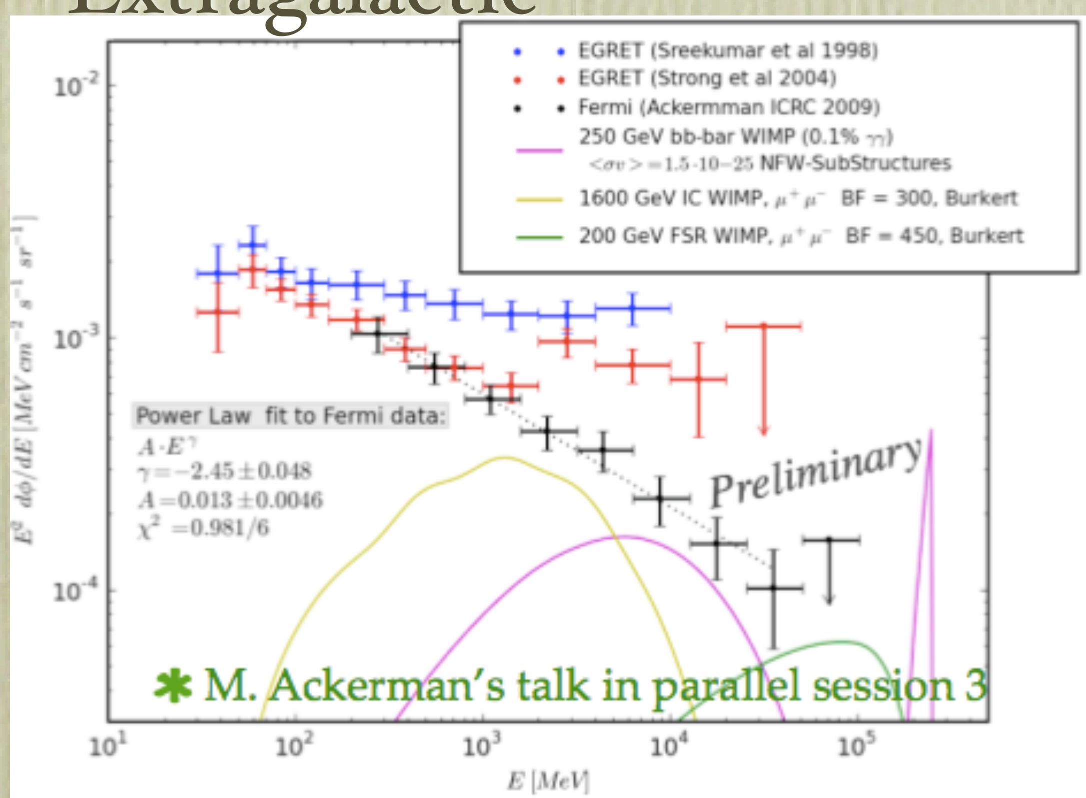
Integral flux 100 MeV to 100 GeV:
$(1.22 \pm 0.02) \times 10^{-6}\ cm^{-2}s^{-1}$



mid-latitude diffuse galactic

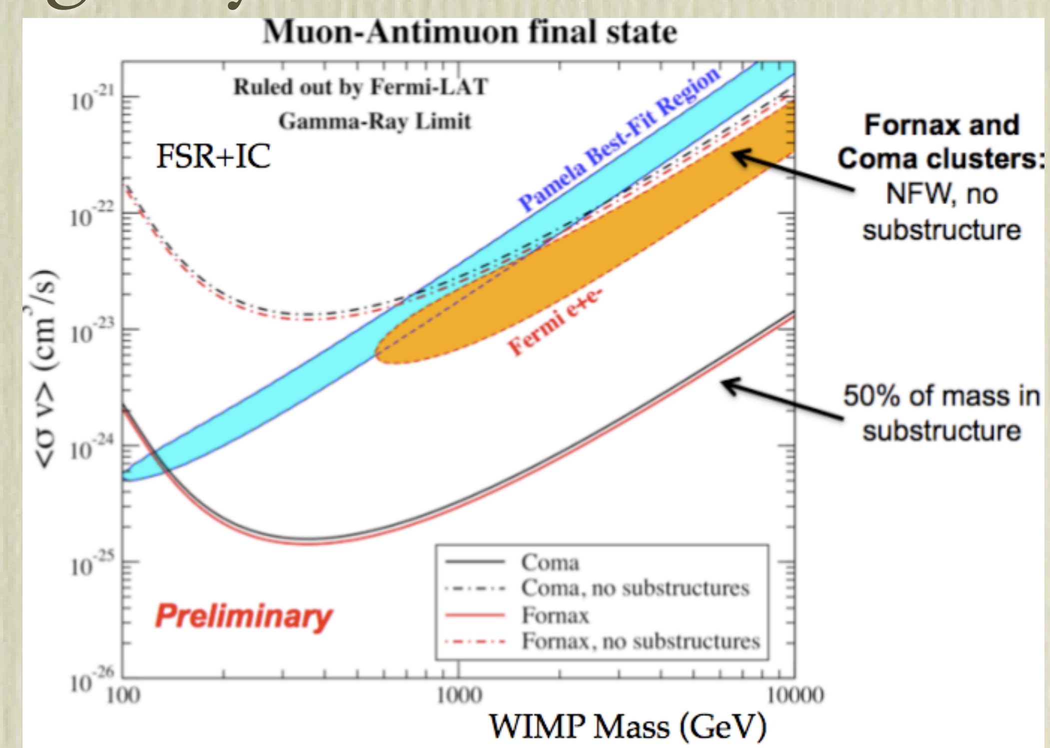


Extragalactic



✱ M. Ackerman's talk in parallel session 3

galaxy clusters



DM annihilations and radiative emission:

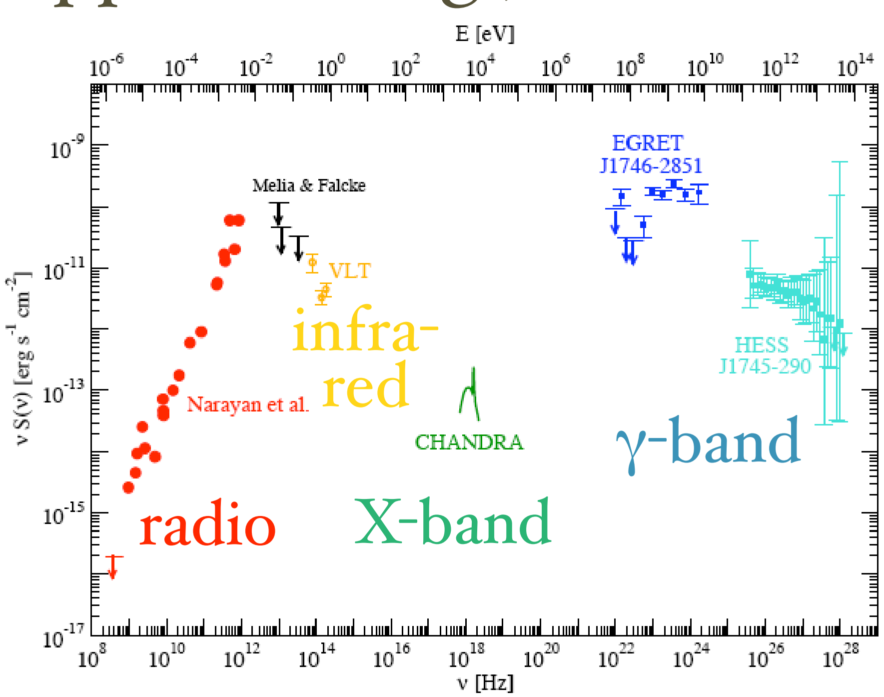
The annihilation yields give rise to a multicomponent spectrum:

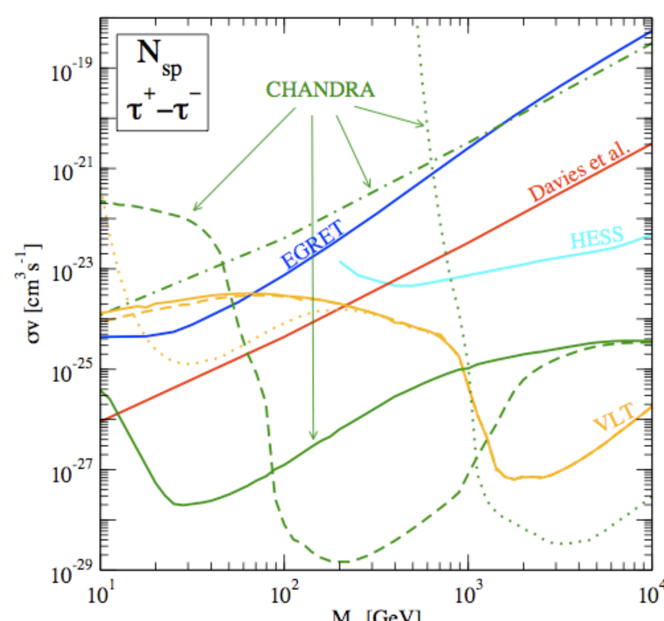
$$\chi\,\bar{\chi} \to \begin{cases} \boxed{e^+ e^-} \\ l^+ l^- \text{ or } \phi\,\phi \to \ldots + \boxed{e^+ e^-} \\ P\,\bar{P} \to \ldots + \pi^\pm \to \ldots + \boxed{e^\pm} \end{cases}$$

ambient backgrounds and fields

$$\begin{cases} \text{Synchrotron} \\ \text{Inv. Compton} \\ \text{Bremstrahlung} \\ \text{Coulomb} \\ \text{Ionization} \end{cases} \begin{cases} \text{radio} \\ \text{IR} \\ \text{X-rays} \\ \gamma\text{s} \end{cases}$$

For certain DM sources is a very powerful (although model dependent) approach. E.g., the Galactic center (Sgr A*) has a well-measured seed:



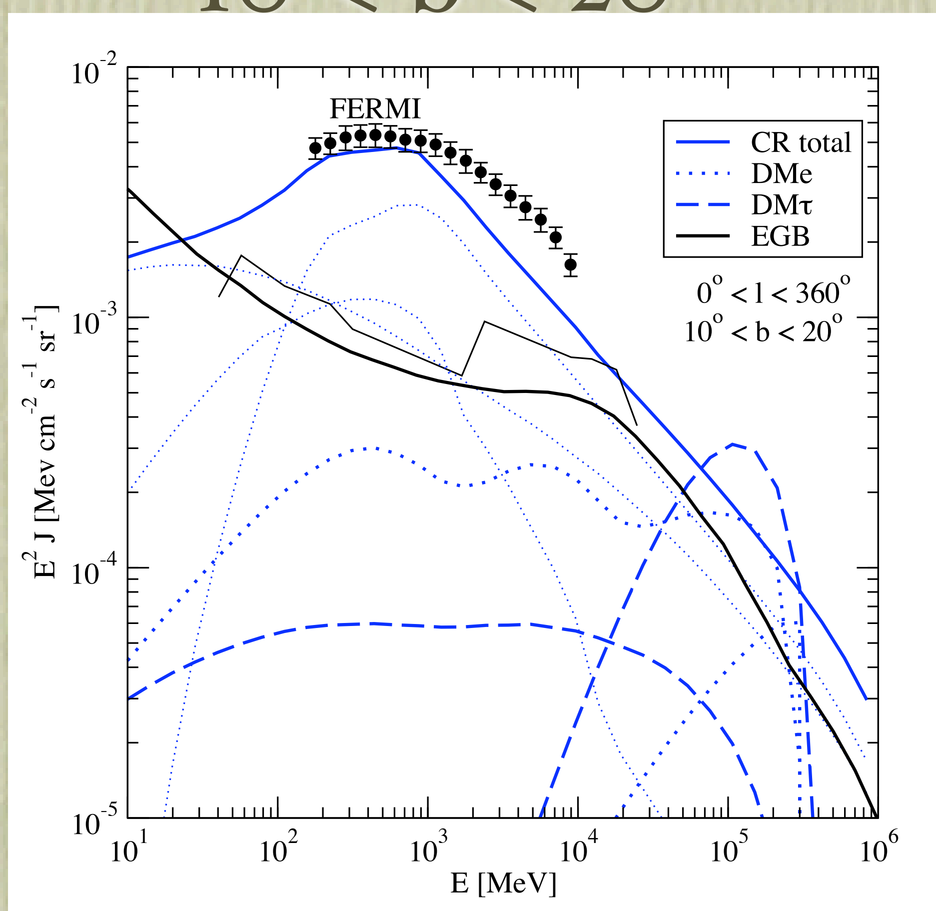


significant limits on WIMP models at any wavelength, unlikely the most stringent from the γ-band (even with Fermi)

Multifrequency approach to test local e^+/e^- excesses:

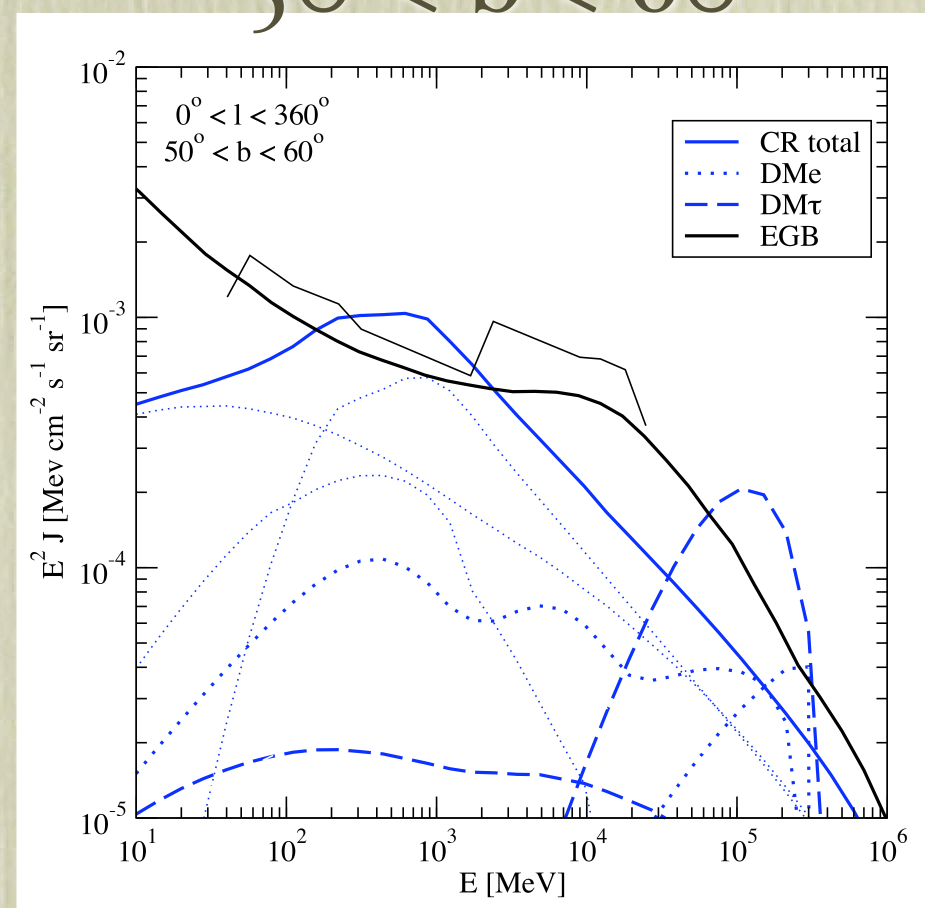
An excess from standard astrophysical sources would be confined to the galactic disc, one from DM annihilation would be spread out to a much larger scale, leading to different predictions for the IC radiation.
IC terms (plus FSR or pion terms) for two sample (leptophilic) models fitting the Pamela excess in the positron ratio:

$10^\circ < b < 20^\circ$



cross checked against Fermi preliminary data at intermediate latitudes

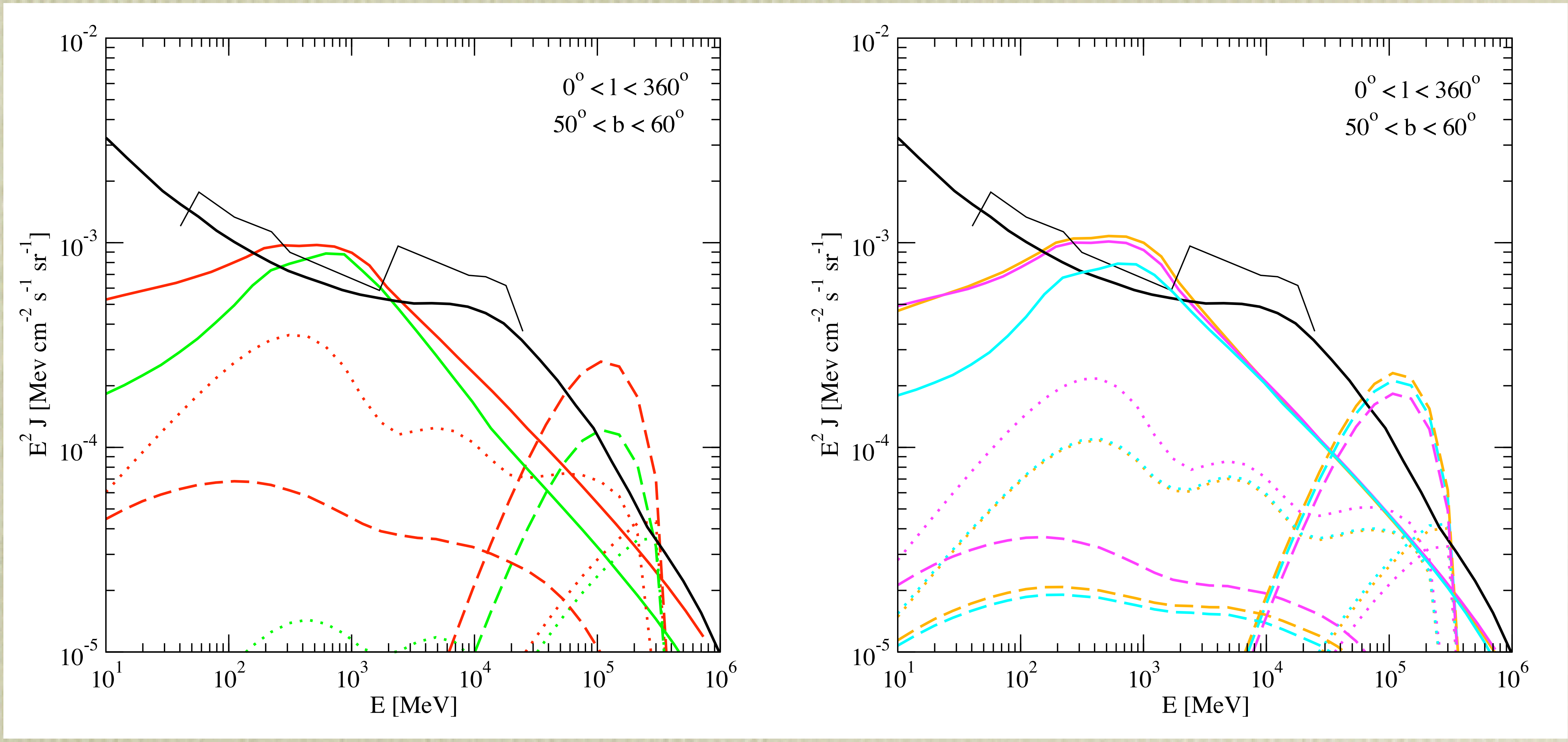
$50^\circ < b < 60^\circ$



a more solid prediction when looking at high latitudes ...

Regis & P.U., arXiv: 0904.4645

A result which is solid against uncertainties in the propagation model: the previous model extrapolated to a few sample setups consistent with B/C

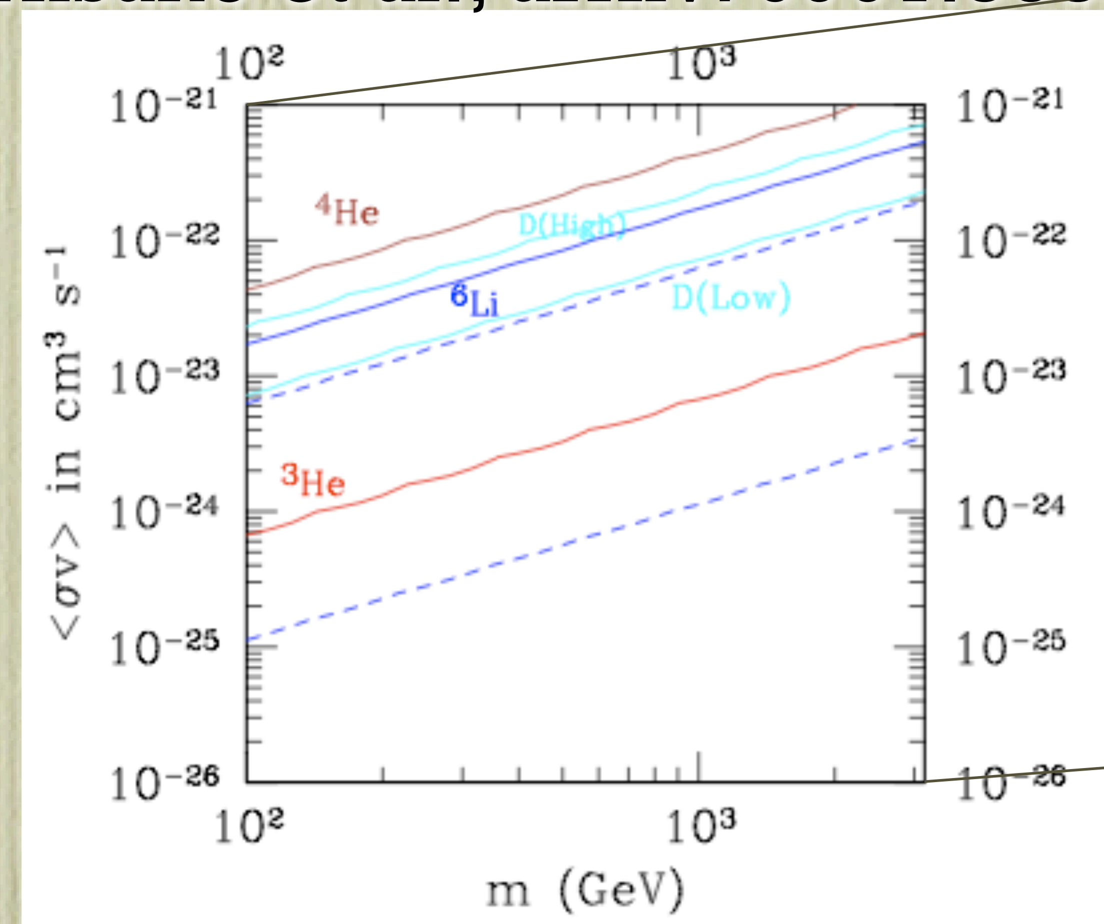


Note also: the prediction is insensitive to the halo model (since it is well away from the GC), and to whether it is related to annihilating or decaying DM (since it is normalized to the locally measured electron/positron flux)

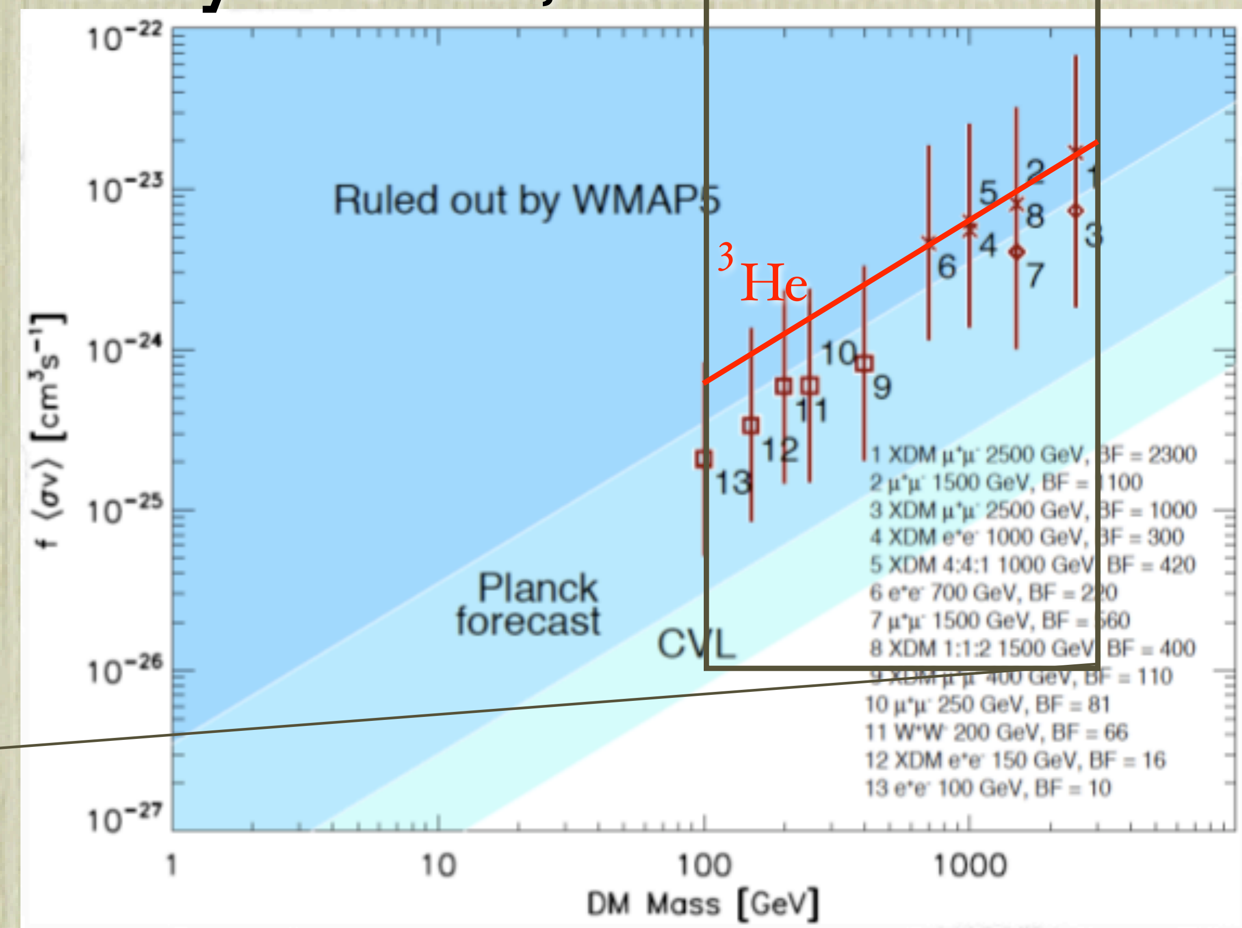
DM annihilations at early stages of the Universe:

The very large annihilation cross sections has lead to several reanalyses of the limits from "polluting" the early Universe with DM yields. E.g.:

Hisano et al., arXiv: 0901.3582



Slatyer et al., arXiv: 0906.1197



BBN limits: mainly from photo- and hadro-dissociation of light elements, and changes in the neutron to proton ratio

CMB limits: mainly from ionization of the thermal bath, Ly-α excitation of Hydrogen and heating of the plasma

These limits do not depend on the poorly-known fine graining of the local DM halo; note also that the velocity is different ($v \approx 10^{-8}$ at the LSS)

Too early for conclusions ...

See you at
GGI, Florence, Italy,
April 26 - June 19, 2010

http://ggi-www.fi.infn.it/