Multi-messengers and dark matter interpretation

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Cosmic ray backgrounds in dark matter searches,
Stockholm, January 27, 2010

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:

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

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

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

dilution by Universe expansion

thermally averaged annihilation cross section

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

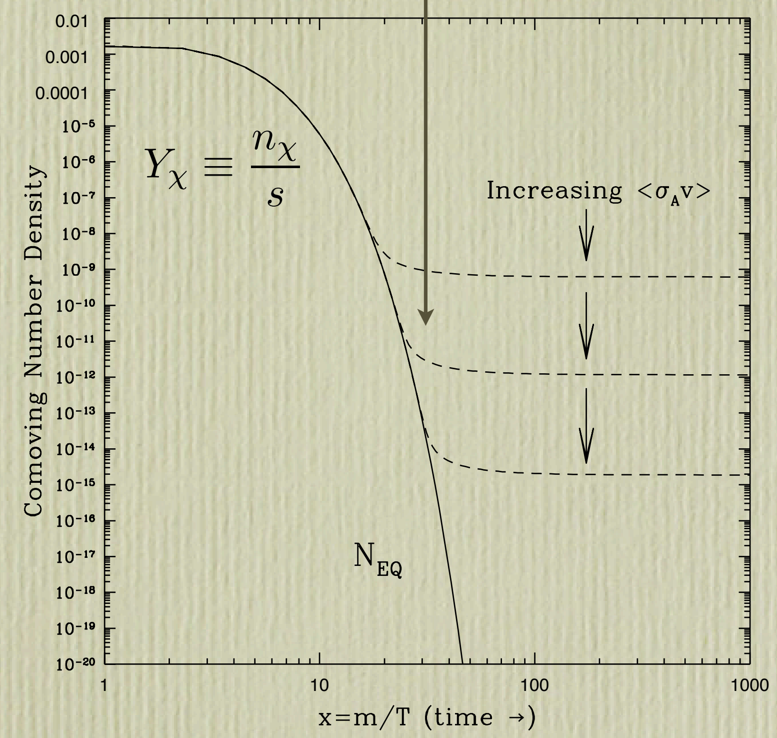
$\chi\bar{\chi} \to P\bar{P}$

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:

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



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

(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) , ...

Incomplete list of models and very incomplete list of references!

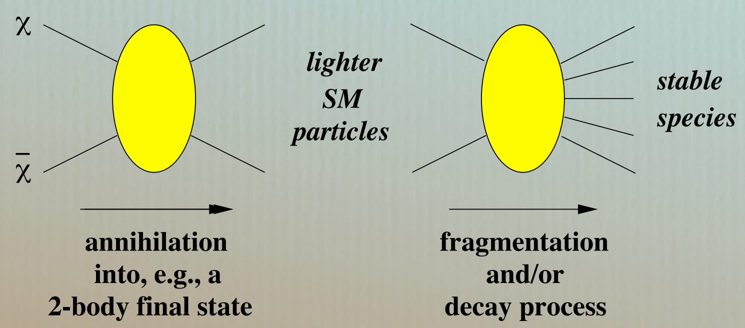
In most of these, DM appears as a by-product from a property considered to understand or protect other features of the theory.

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)

The cases of non-thermal or decaying DM may lead to a very similar phenomenology (but in some cases are less convincingly motivated)

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?

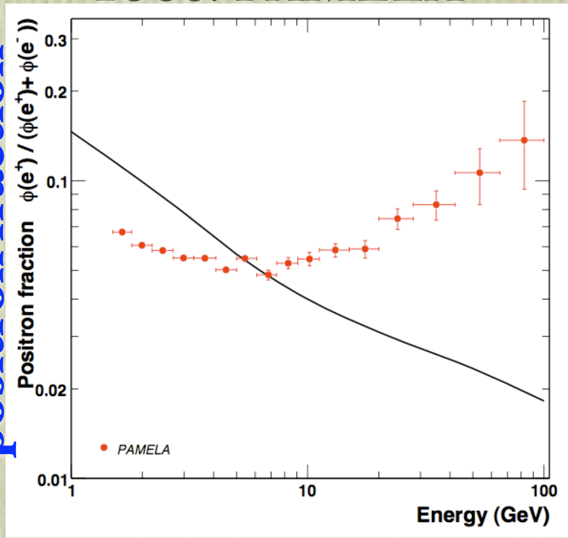
II) angular: flux correlated to DM halo shapes and with DM distributions within halos: central slopes, rich substructure pattern.

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 (taking antiprotons into account)

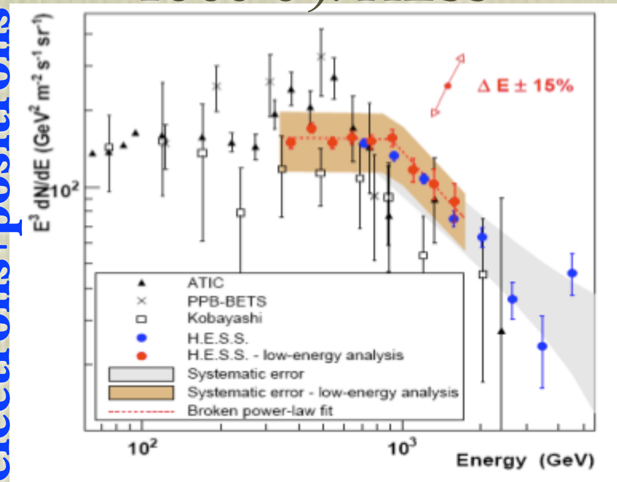
2008: PAMELA

positron fraction



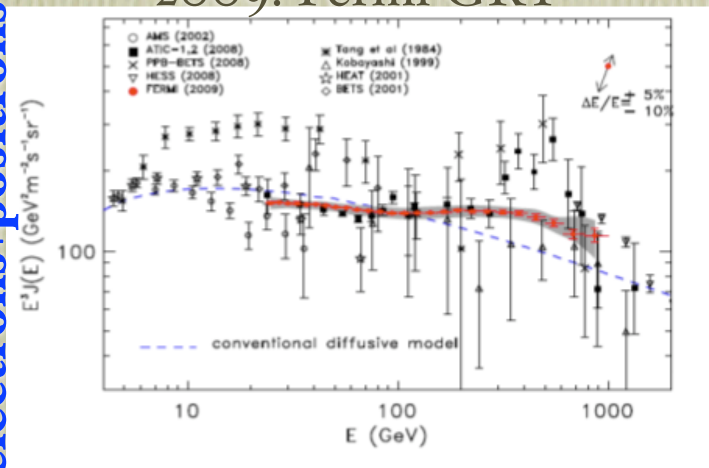
2008-09: HESS

electrons+positrons



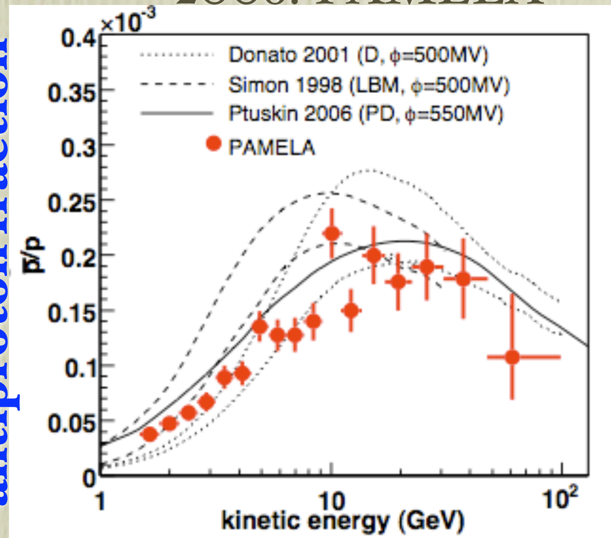
2009: Fermi GRT

electrons+positrons



2008: PAMELA

antiproton fraction



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:

$$\chi\bar{\chi} \rightarrow f\bar{f}$$

(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

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

branching ratio into f

density of WIMP pairs

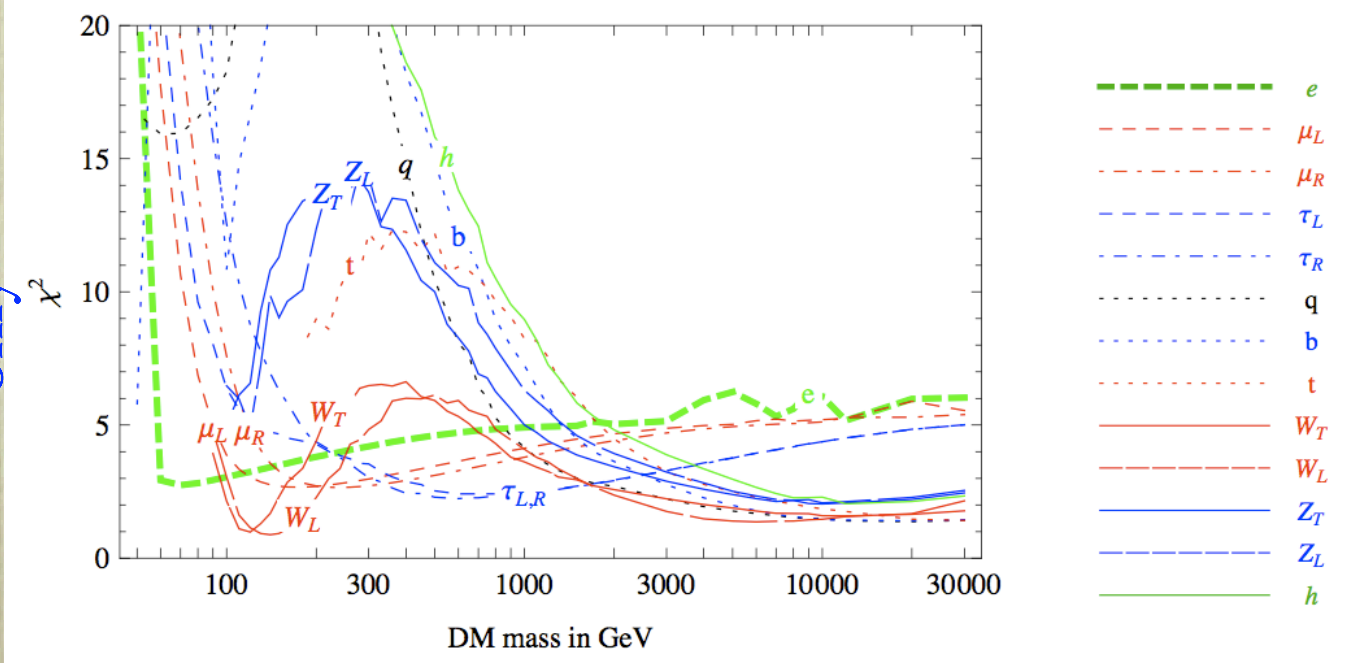
Soft spectra from, e.g., quark final states which produce charged pions decaying into leptons;

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 a phenomenological approach and adjust a generic WIMP model (defined by WIMP mass and dominant annihilation channel) to the data (i.e., 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

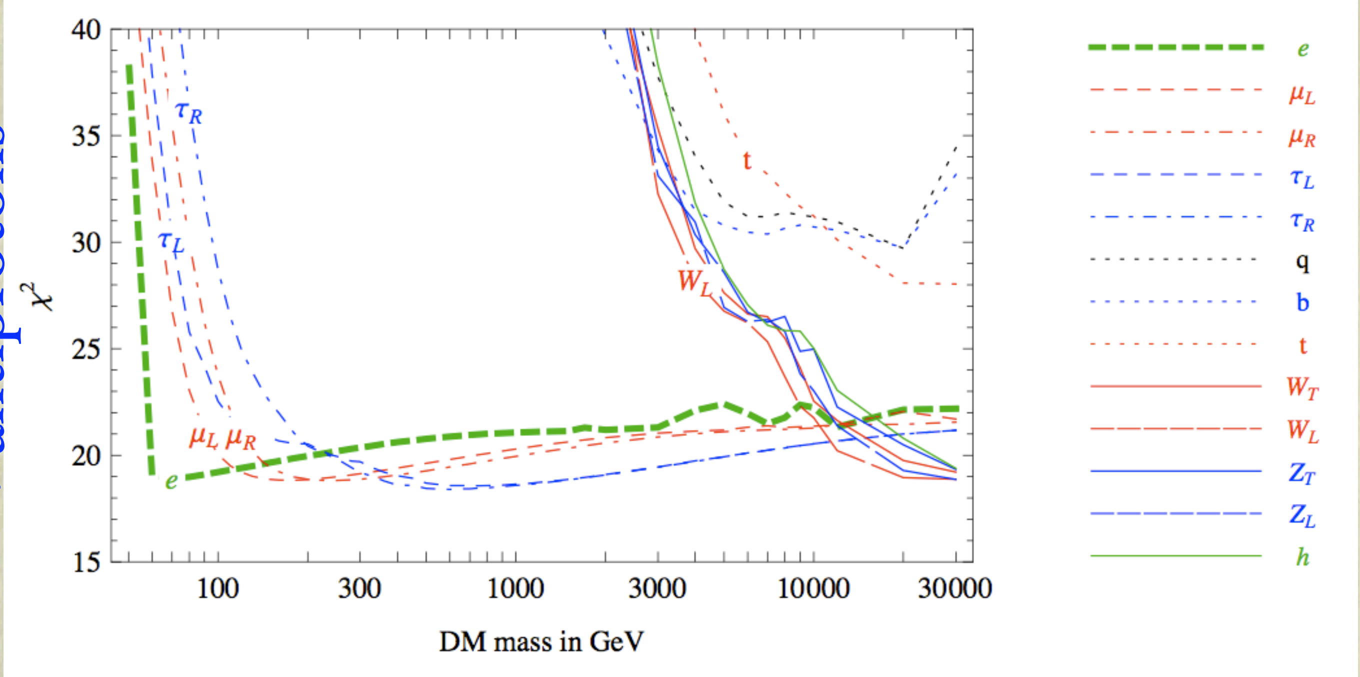


either very massive WIMPS, or lighter WIMPs but hard annihilation spectra (leptons or W-bosons)

Cirelli et al., arXiv:0809.2409

... 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

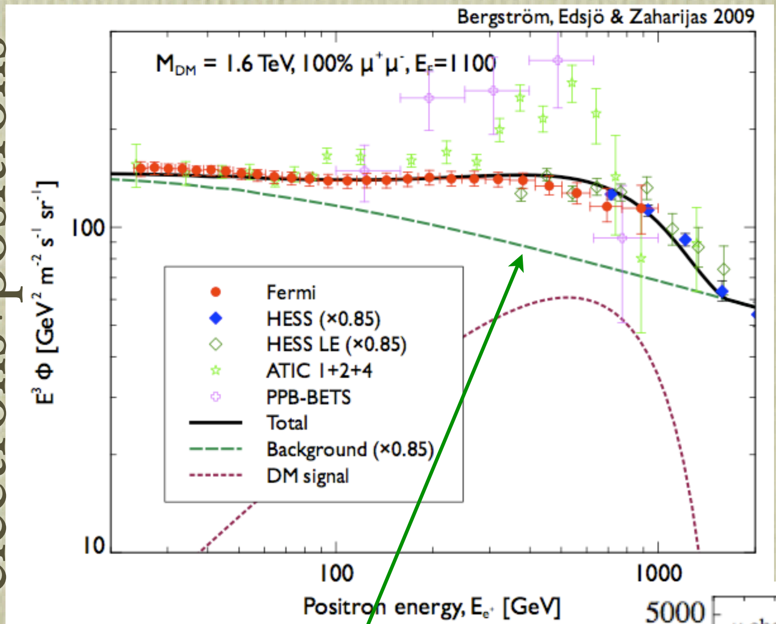


Cirelli et al., arXiv:0809.2409

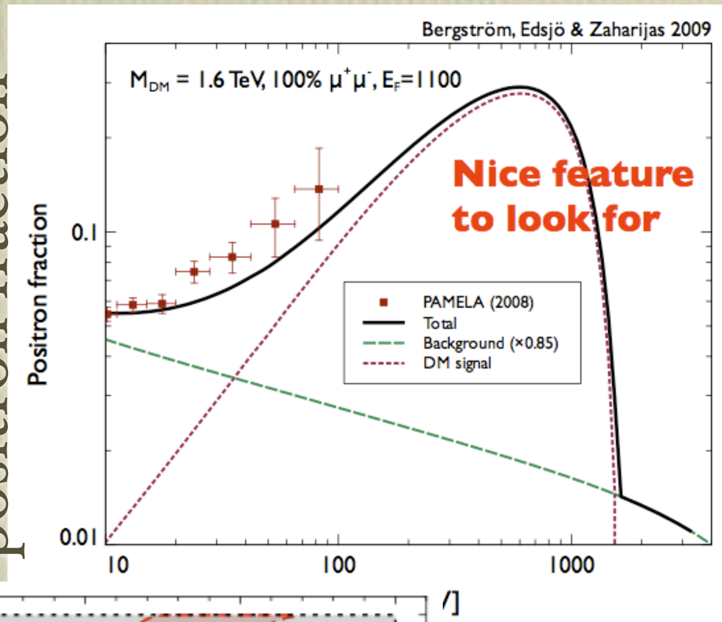
The W-boson annihilation channel has an antiproton yield which is large and inconsistent with antiproton data for WIMPs lighter than 10 TeV or so; leptonic channels are unaffected (they do not give rise to a positron yield).

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

electrons+positrons

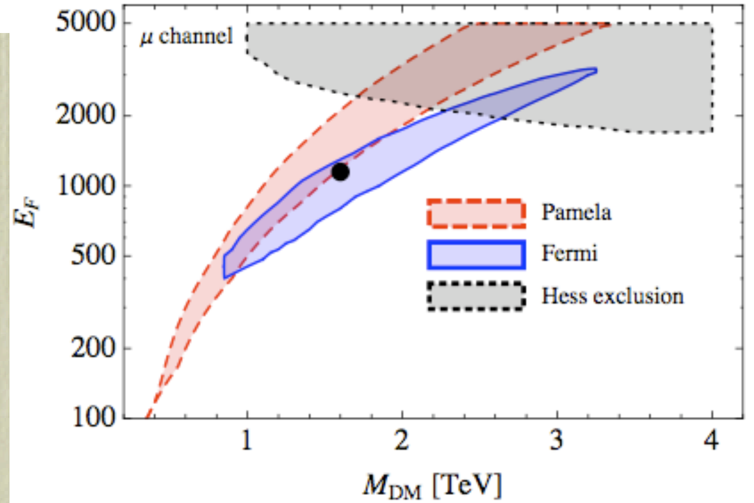


positron fraction



Bergström et al., arXiv:0905.0333

background ?!?



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:

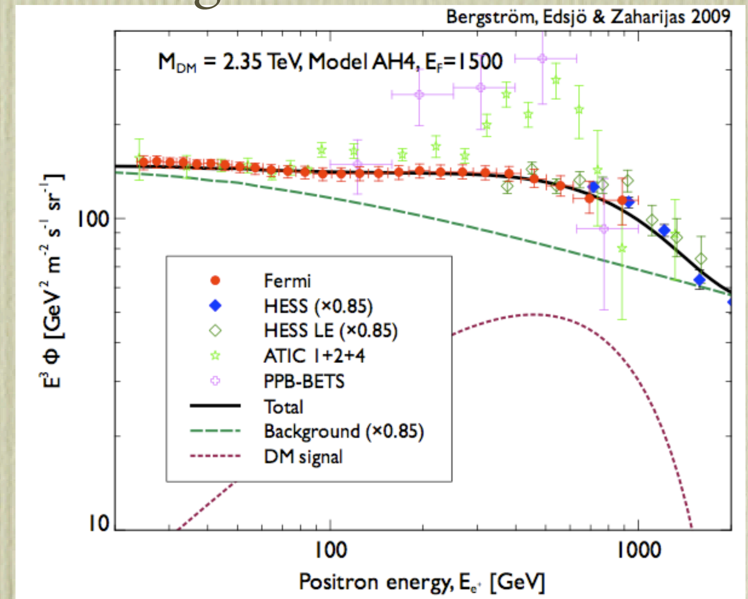
- **leptophilic**, i.e. with pair annihilation into leptons only, or into light (pseudo)scalars which for kinematical reasons can decay into leptons only (for this second class, see, e.g.: Arkani-Hamed et al., arXiv:0810.0713; Nomura & Thaler, arXiv:0810.5397);

- **heavy**, with WIMP masses above the 1 TeV scale;

- with a **large** (order 1000 or more) **"enhancement factor"** in the source function, either: i) in the annihilation rate because $\langle \sigma v \rangle_{T_0} \gg \langle \sigma v \rangle_{T_{f.o.}}$ (Sommerfeld effect? or there is a resonance effect, or DM is simply non-thermal), or: ii) in the WIMP pair density because $\langle \rho_\chi^2 \rangle \gg \langle \rho_\chi \rangle^2$.

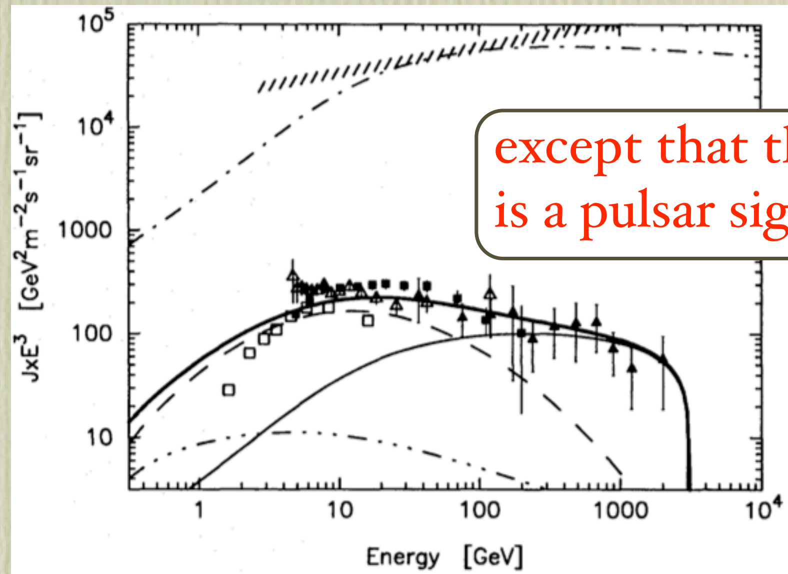
Caveat: we may have seen a DM signal, but have not seen a DM signature.

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:

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

total rate

branching ratio into f

density of WIMP pairs

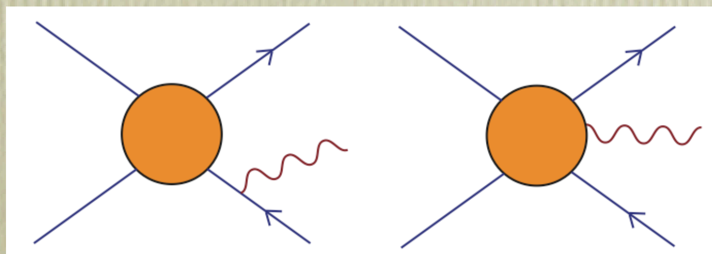
Prompt emission of γ-rays associated to three components:

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:

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

in case of Majorana fermions

The induced gamma-ray flux can be factorized:

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

Particle Physics — 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
- ...

All of these are targets for FERMI.

No signals but several preliminary upper limits reported, e.g., at the 2009 Fermi Symposium; see, e.g.:
Vitale & Morselli, arXiv:0912.3828

DM annihilations and radiative emission:

The annihilation yields give rise to a multicomponent spectrum:

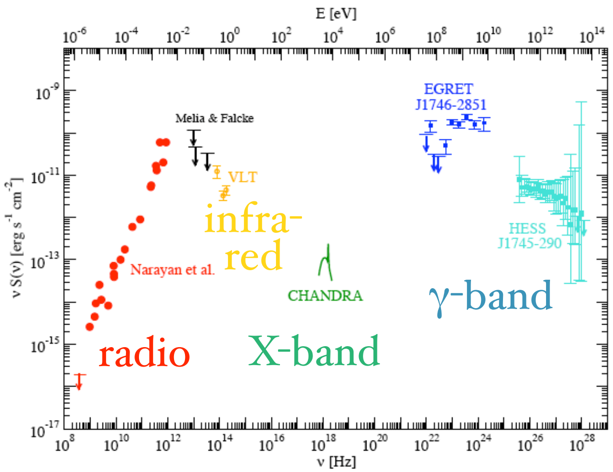
$$\chi\,\bar{\chi} \rightarrow \begin{cases} e^+\,e^- \\ l^+\,l^- \text{ or } \phi\,\phi \rightarrow \ldots + e^+\,e^- \\ P\,\bar{P} \rightarrow \ldots + \pi^\pm \rightarrow \ldots + e^\pm \end{cases}$$

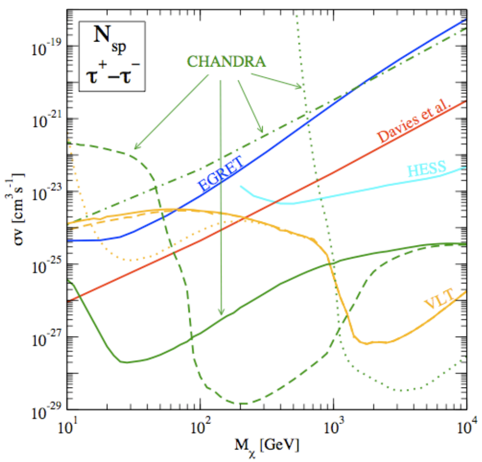
ambient backgrounds and fields

- Synchrotron
- Inv. Compton
- Bremstrahlung
- Coulomb
- Ionization

- radio
- IR
- X-rays
- γs

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)

Regis & P.U., arXiv:0802.0234

Back to the standard DM interpretation from the positron/electron data:

DM is leptophilic, heavy, and has a large "enhancement factor" in the annihilation rate

Two points will be addressed in the remaining part of the talk:

Does the cross-correlation with other observables allow a discrimination against alternative hypotheses? Try to answer this question without paying the price of additional extrapolations on top of the minimal set of assumptions actually needed to give the electron/positron flux.

Regis & P.U., arXiv: 0904.4645

Even giving for granted the fact that DM provides the correct solution to the electron/positron puzzle, should the "standard" interpretation really be taken as the guideline for other searches, e.g., in direct detection or LHC ?

Regis & P.U., arXiv: 0907.5093

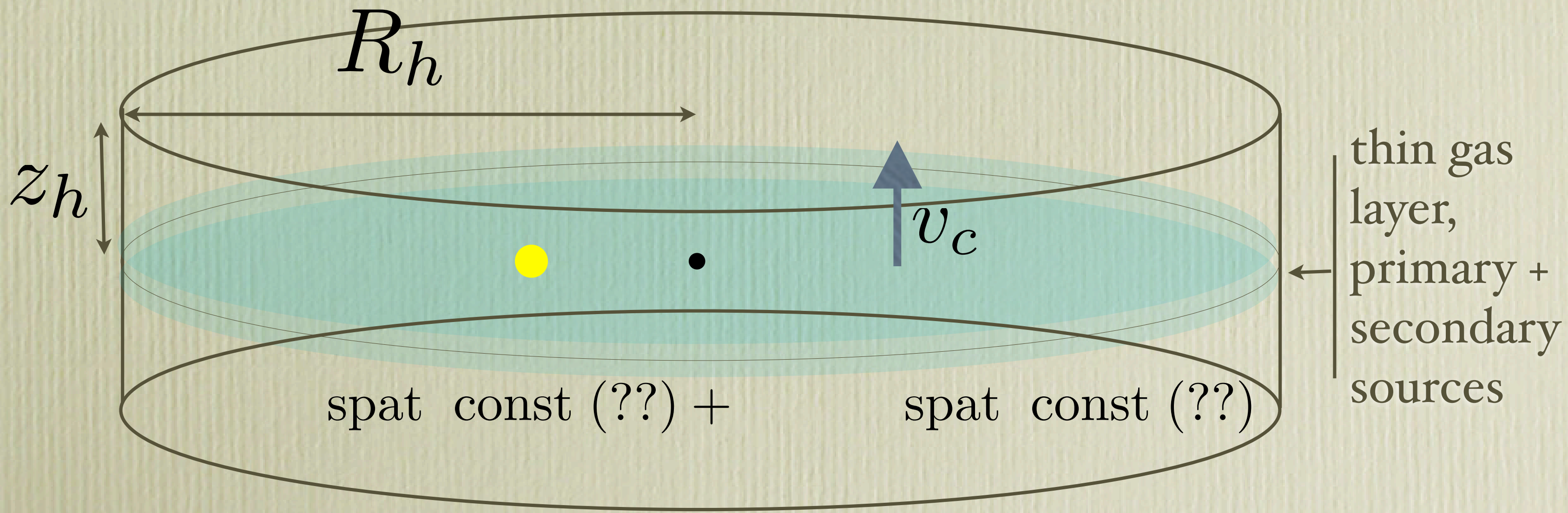
Charged particles in the Galaxy

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

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

spatial diffusion — reacceleration — energy loss — convection — source — decay, fragmentation

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



An effective approach (no parameter derived from first principles) successful (flexible enough) in reproducing secondary to primary cosmic-ray nuclei and antiproton to proton ratios.

Secondary to primary measurements are probes of sources localized in a thin disk by an observer located within the disc, i.e. they mostly give an indications of averages of propagation parameters over a nearby region of the Galaxy. There are well-known correlation patterns in the parameter space and hence the model cannot be selected univocally. E.g.:

"Reference" model

"thin halo" model

	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
B0	4	3.3	1/3	35	1.85/2.36	1.50/2.54	0	0.67	blue
B1	1	0.81	1/3	35	1.65/2.36	1.50/2.54	0	0.77	green
B2	10	6.1	1/3	35	1.85/2.36	1.50/2.54	0	0.74	red
B3	4	3.25	1/3	45	1.85/2.36	1.50/2.54	10	0.84	orange
B4	4	1.68	1/2	22	2.4/2.2	2.1/2.54	0	0.86	cyan
B5	10	$2.8 \cdot e^{\lvert z\rvert/z_s}$	1/3	35	1.85/2.36	1.50/2.54	0	0.66	magenta

"thick halo" model

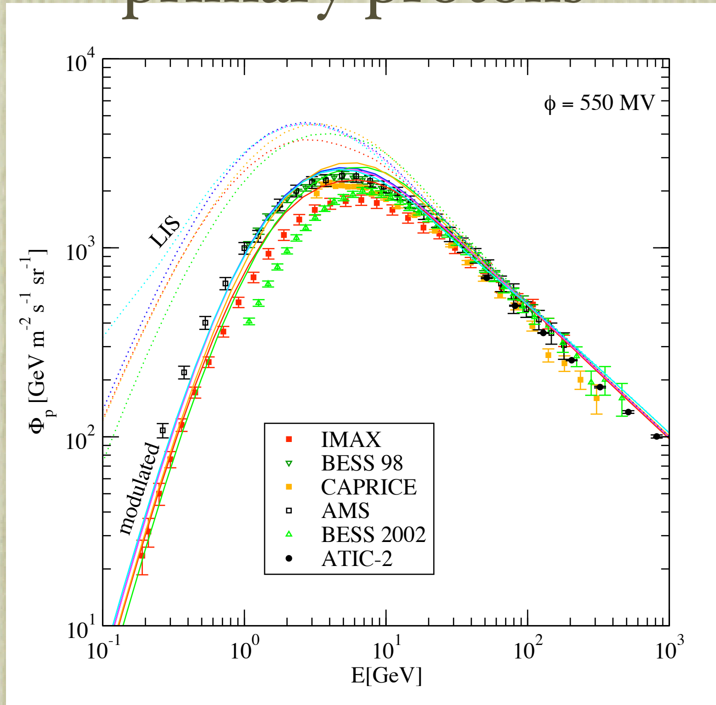
"wind" model

vertically varying diffusion

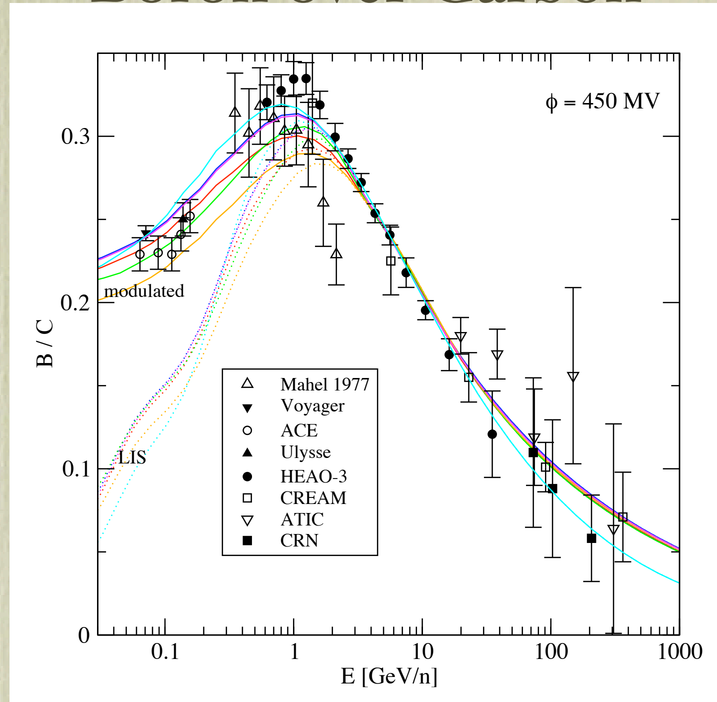
Kraichnan spectrum

At the level of primary/secondaries nuclei all these sample cases are (have been to constructed to be) essentially equivalent:

primary protons



Boron over Carbon



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

Is this sufficient for a reliable estimate of the background (i.e. essentially equivalent) for, e.g., antimatter and gamma-ray DM searches in the Galaxy? Or we are actually relying on extrapolations on parameters of an effective model which are not actually fitted to the data?

The central region of the Galaxy (or low up to, maybe, intermediate latitudes) may be problematic. Predictions for the background rely on severe extrapolations, such as on :

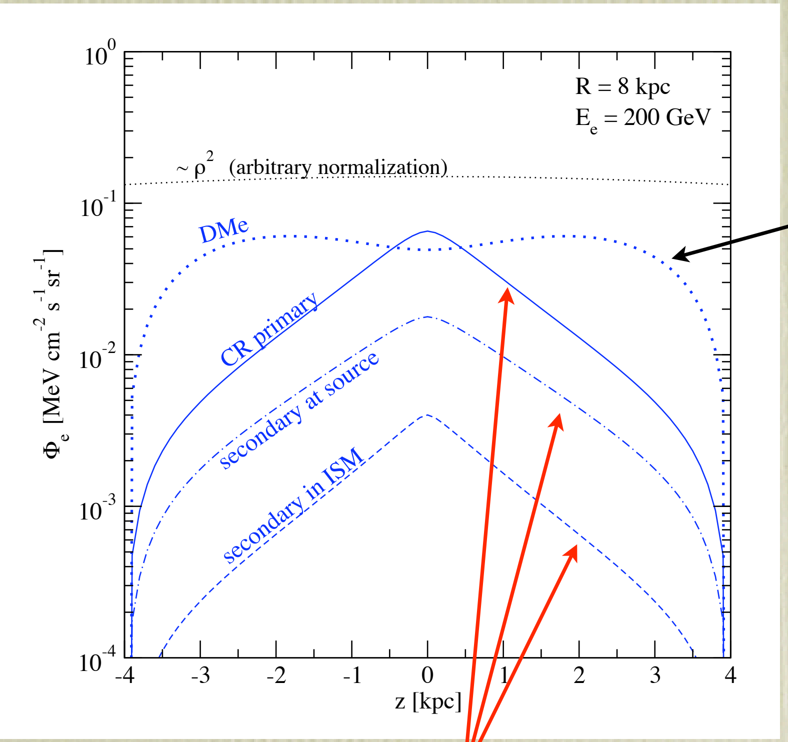
- the radial (vertical ?) distribution of sources which is very poorly known towards the GC;
- the diffusion and reacceleration terms (in most cases assumed spatially constant, ignoring the observed pattern of magnetic fields on large scales, and probably some structure in the turbolent component as well);
- the interstellar medium, again poorly determined in the central region of the Galaxy;
- ...

Some of these issues are being addressed based on Fermi data; notice however that even the prediction for the DM gamma-ray signal from the inner Galaxy is based on extrapolations, the main one being on the DM density profile: although one usually refers to "standard" models, either from N-body simulations or hydrodynamics, dynamical observations do not require a DM term in the central region of the Galaxy!

Whether a DM component will be singled out will depend on the presence or not of a clean spectral feature.

A more conservative (and probably much more reliable) approach is to rely on observations of mostly local signals, with predictions for the signal and the background as estimated from local observables: e.g., extrapolate the locally measured electron/positron density to the nearby portion of the Galaxy:

Vertical density profile at the local Galacto-centric distance for the "reference" propagation model

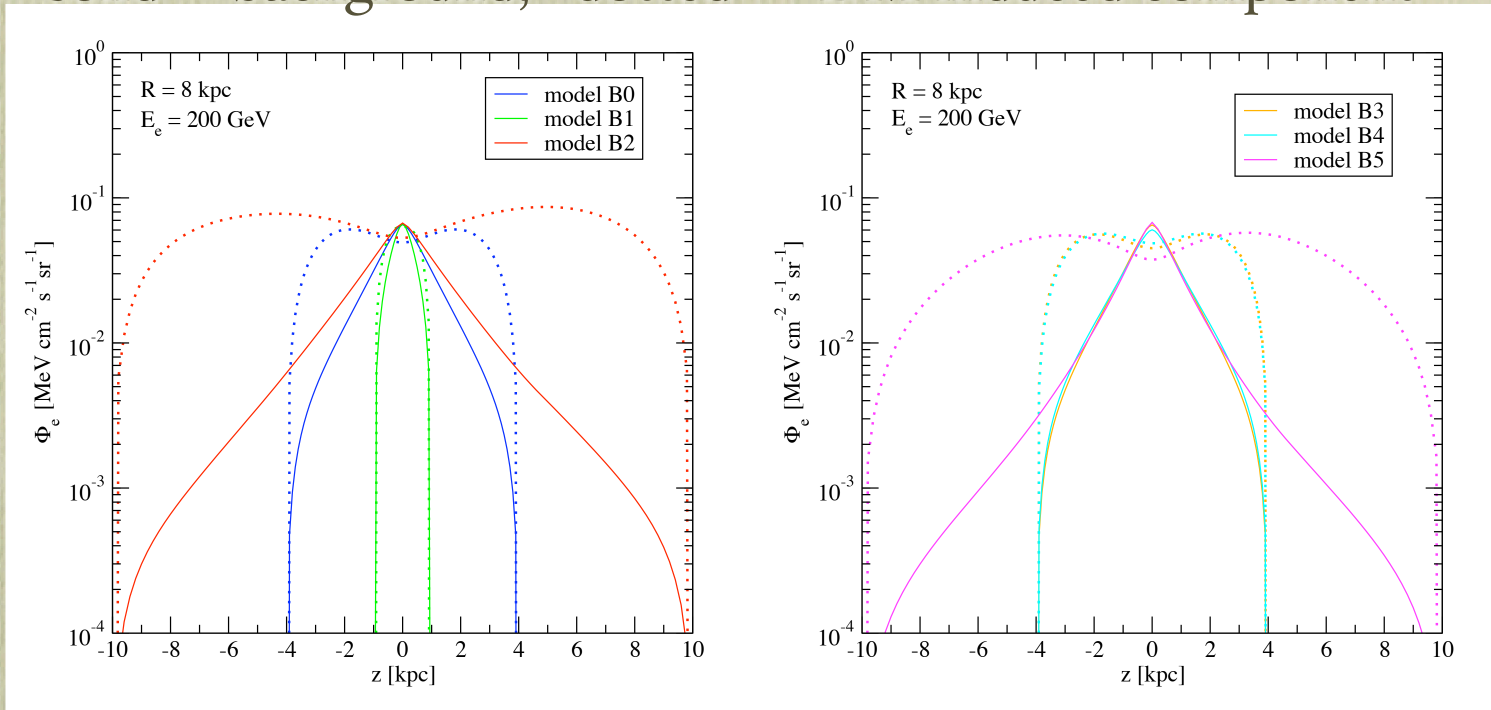


versus a DM term extending to much larger z

Primary/secondary astrophysical components mostly localized at z≅0

Similar picture for all the sample prop. models, except if you force the halo to be thin (and with sharp truncation):

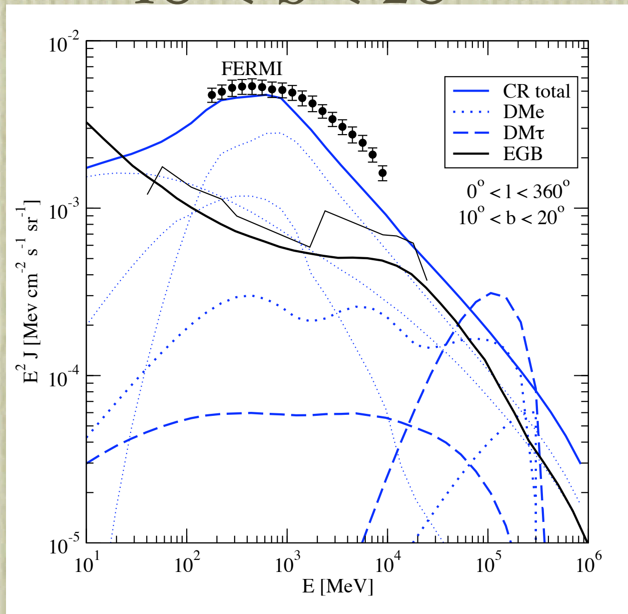
solid→ background; dotted → DM induced component



IC on a 1 μm starlight photon from 100 GeV (1 TeV) electrons gives a gamma-ray of 50 GeV (5 TeV); synchrotron emission on a 1 μG magnetic field 50 GHz (5000 GHz) radiation. Possibly a handle on this from Fermi and Planck.

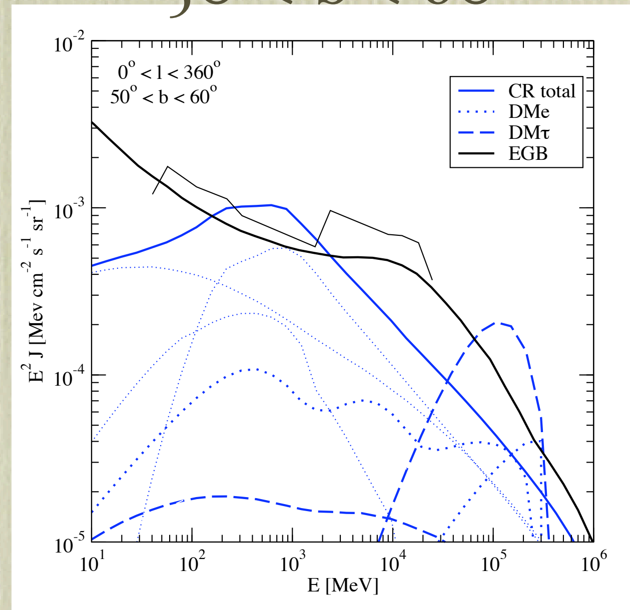
A prediction for the IC term (plus final state radiation or pion decay terms) for two sample (leptophilic, with a large “enhancement factor”) models fitting the Pamela excess in the positron ratio:

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



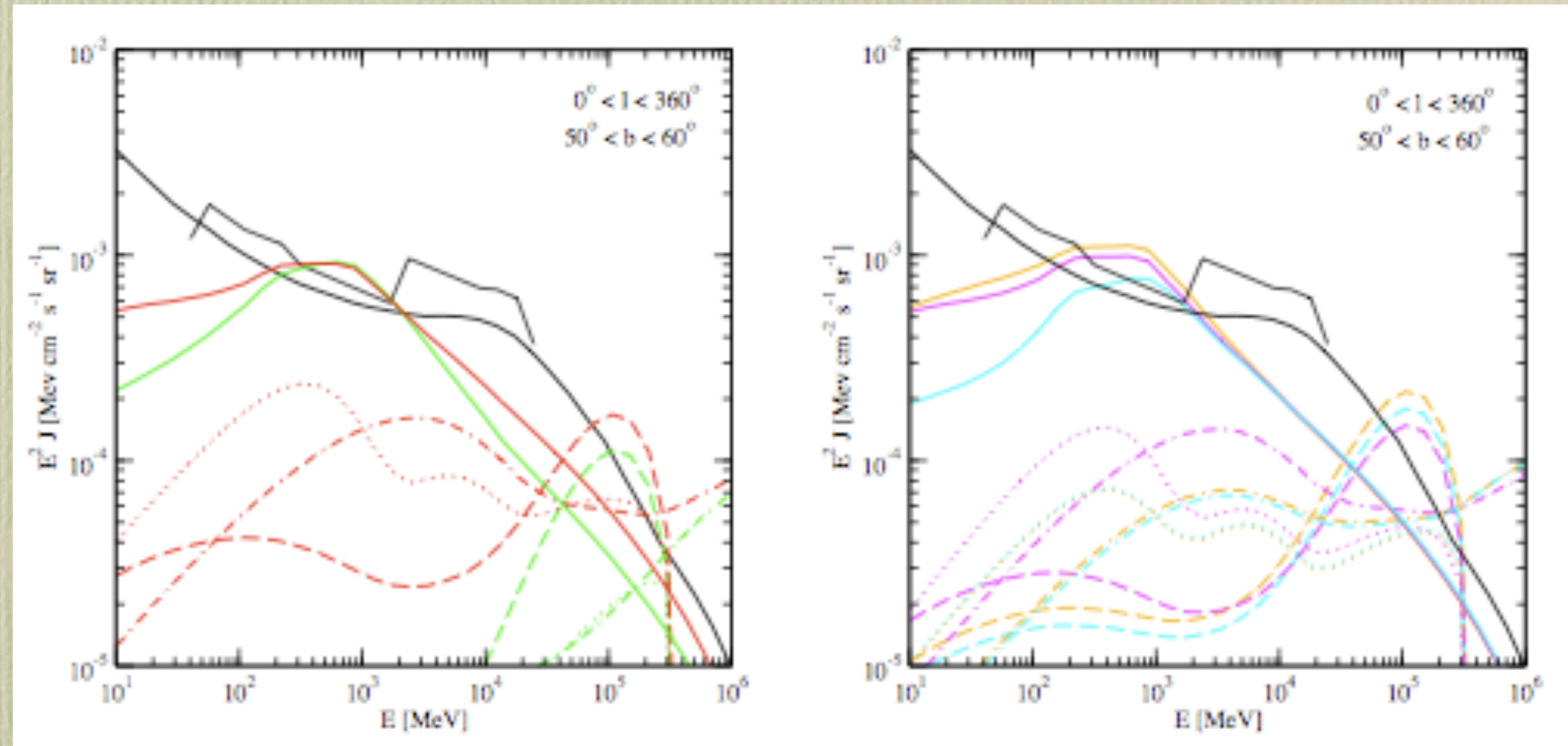
cross checked against Fermi preliminary data at intermediate latitudes

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



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

… since as expected the result is specular for all propagation models (up to the “thin halo” counterexample):

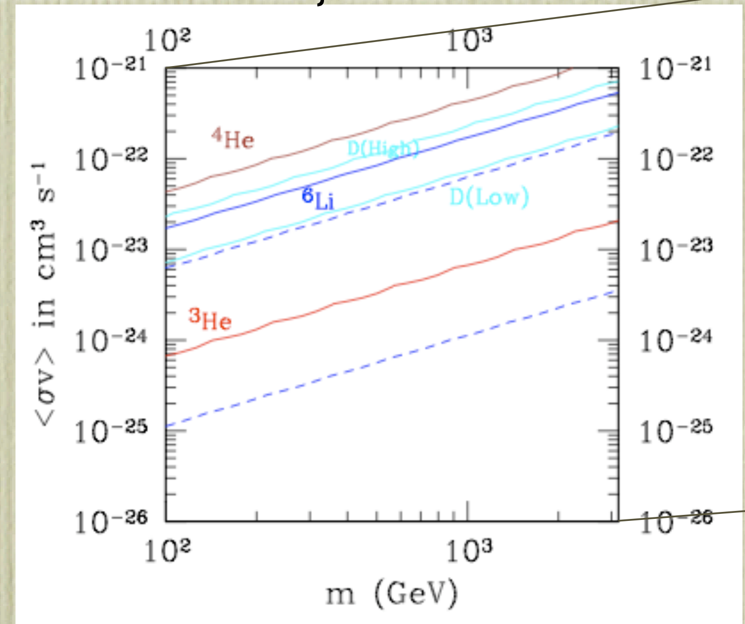


Note also: the prediction is insensitive to the halo model (since we are considering a DM signal well away from the GC), and to whether it is related to decaying or annihilating DM (since we have just normalized the signal to the locally measured electron/positron flux)

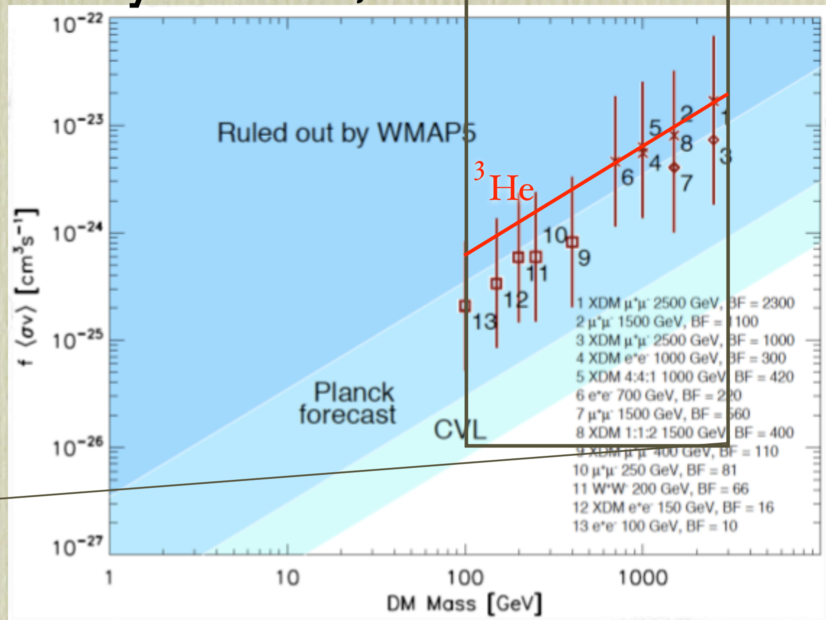
DM annihilations at early stages of the Universe:

Keep also track of the (largely model independent) limits following from the "pollution" of the early Universe environment with DM yields. E.g.:

Hisano et al., arXiv: 0901.3582



Slatyer et al., arXiv: 0906.1197



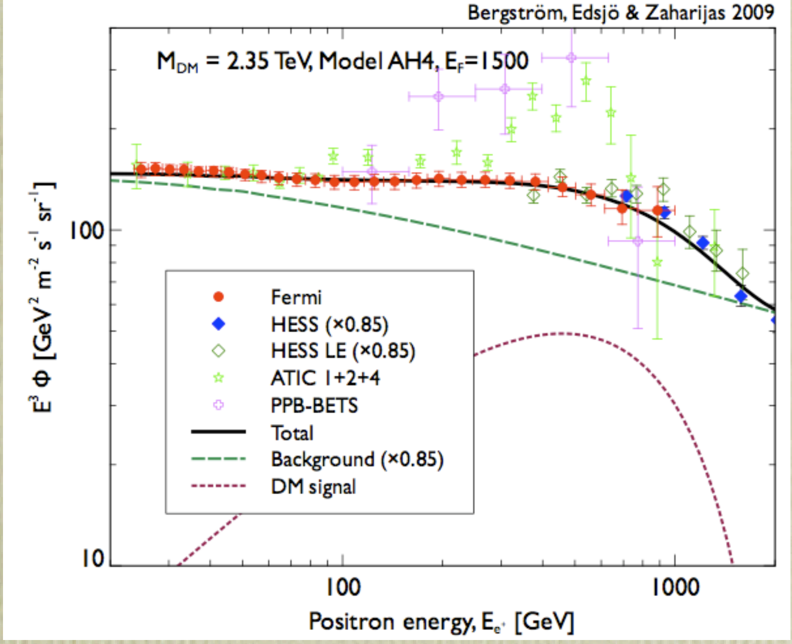
BBN limits: mainly from photo- and hadro-dissociation of light elements, and changes in the neutron to proton ratio

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)

Back to the statement:

DM is leptophilic, heavy, and has a large "enhancement factor" in the annihilation rate



Simple recipe for this result: just a blind fit matching the measured excesses with the particle physics properties, by adjusting:

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

ii) the annihilation channel to its spectral shape;

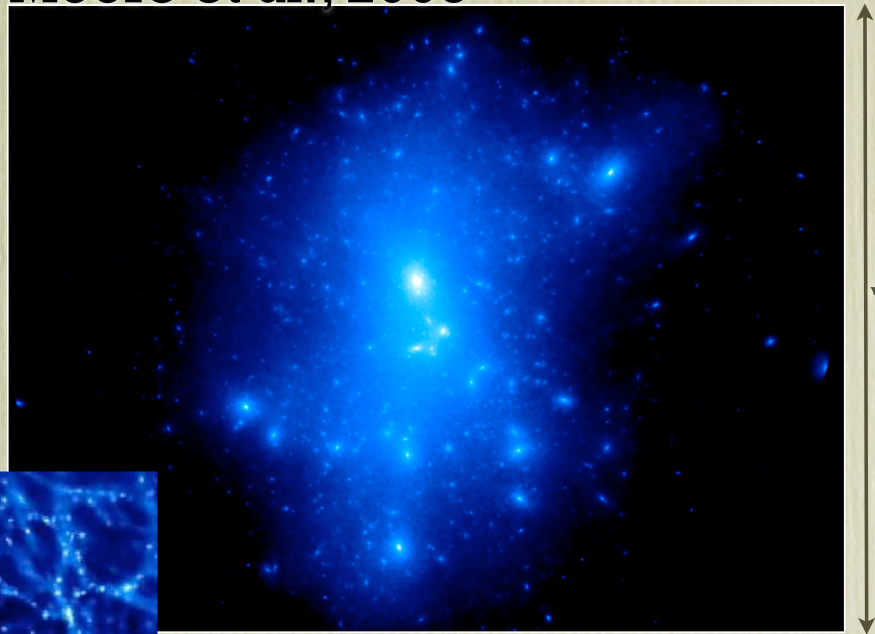
iii) the annihilation rate to the normalization of the signal.

Can we really trust this (simple) approach? let me sketch a (extreme and probably not too realistic) counterexample:

One possibility to enhancement indirect detection DM signals is in connection to substructures within the Galaxy, assuming: $\langle \rho^2 \rangle \gg \langle \rho \rangle^2$.

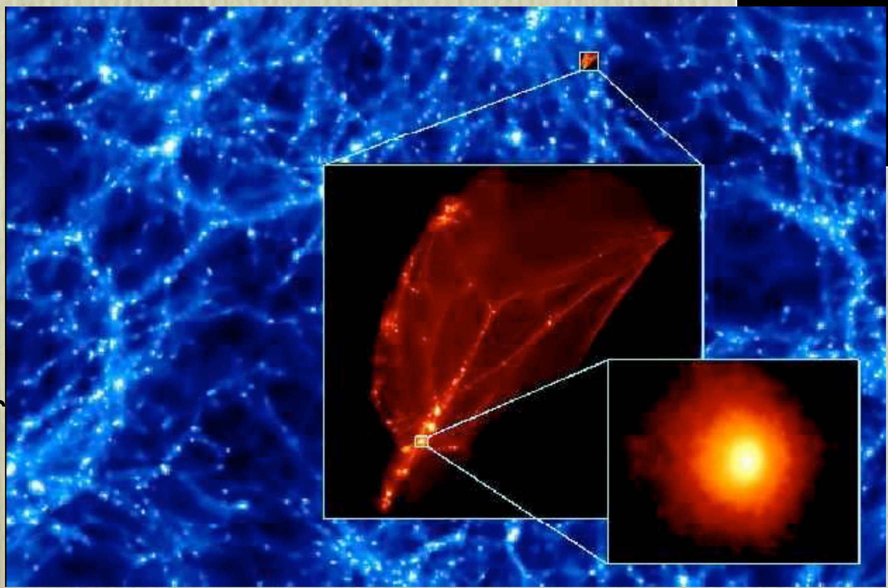
In hierarchical CDM structure formation, small dense structures collapse first, merging then into larger and less dense objects, with a substructure population partially surviving tidal disruption in the merging:

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, ~ $10^{-6} M_\odot$

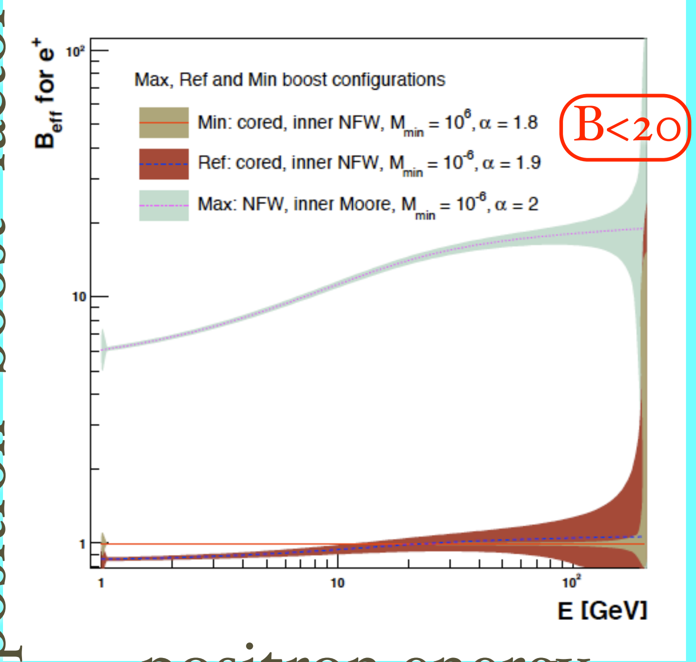
Green, Hofmann & Schwartz, 2004

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.:

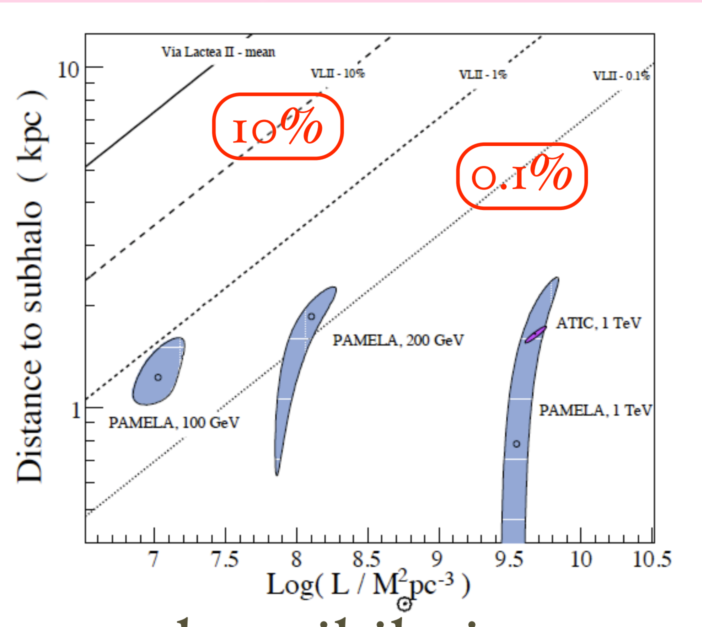
Lavalle et al., arXiv:0709.3634

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: $\sqrt{\langle v^2 \rangle} \simeq 300 \text{ km s}^{-1}$.

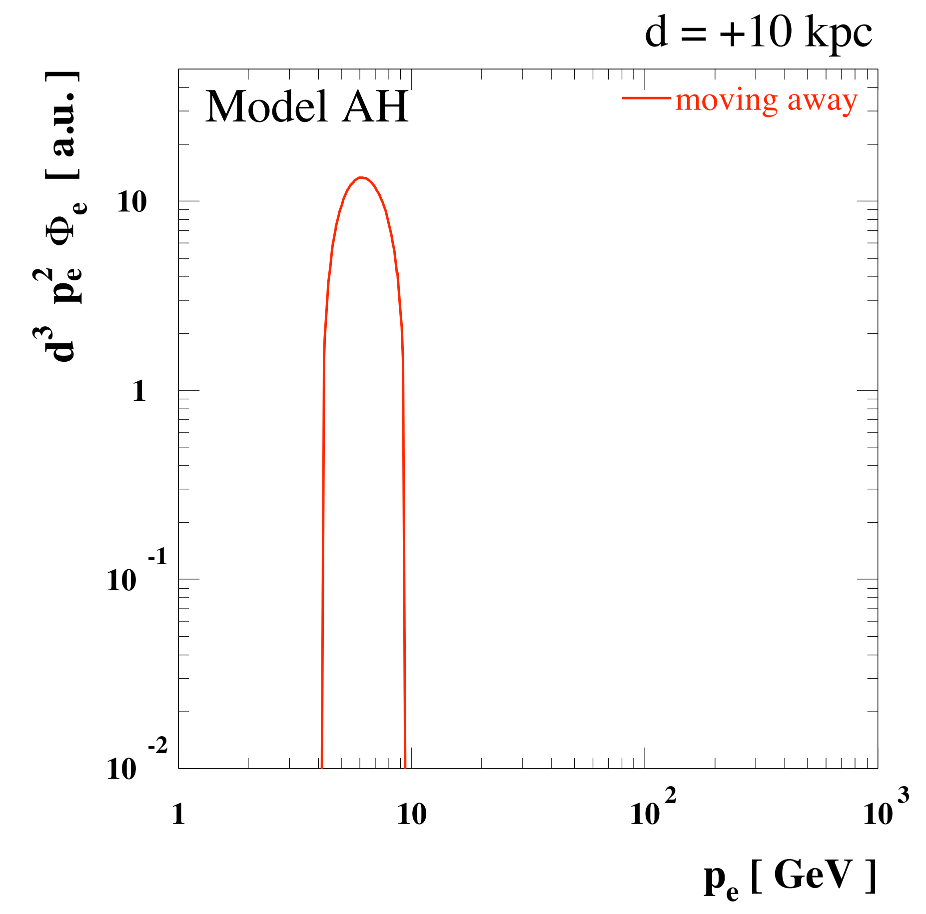
Consider the diffusion equation, including spatial diffusion, energy losses but without assuming the static limit. For electrons and positrons, you find two relevant length scales (slight generalization of **Baltz & Wai (2004)**):

diffusion length: $$\lambda = \left[4 \int_p^{p_0} d\tilde{p}\, D(\tilde{p}) / |\dot{p}(\tilde{p})| \right]^{1/2}$$

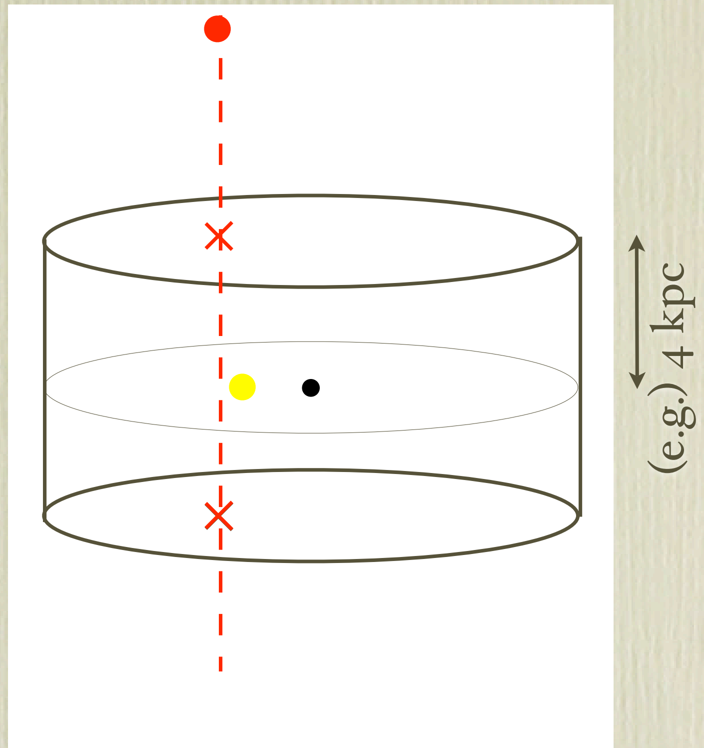
proper motion length: $$\Delta d \sim v_s \cdot \Delta\tau = v_s \cdot \int_p^{p_0} d\tilde{p} / |\dot{p}(\tilde{p})|$$

with $\Delta d \ll \lambda$ only in the limit of large momenta p (as measured locally) or for the ratio measured to injection momenta $p/p_0 \to 1$ (i.e. for nearby sources). In all other regimes proper motion matters, possibly being the dominant effect

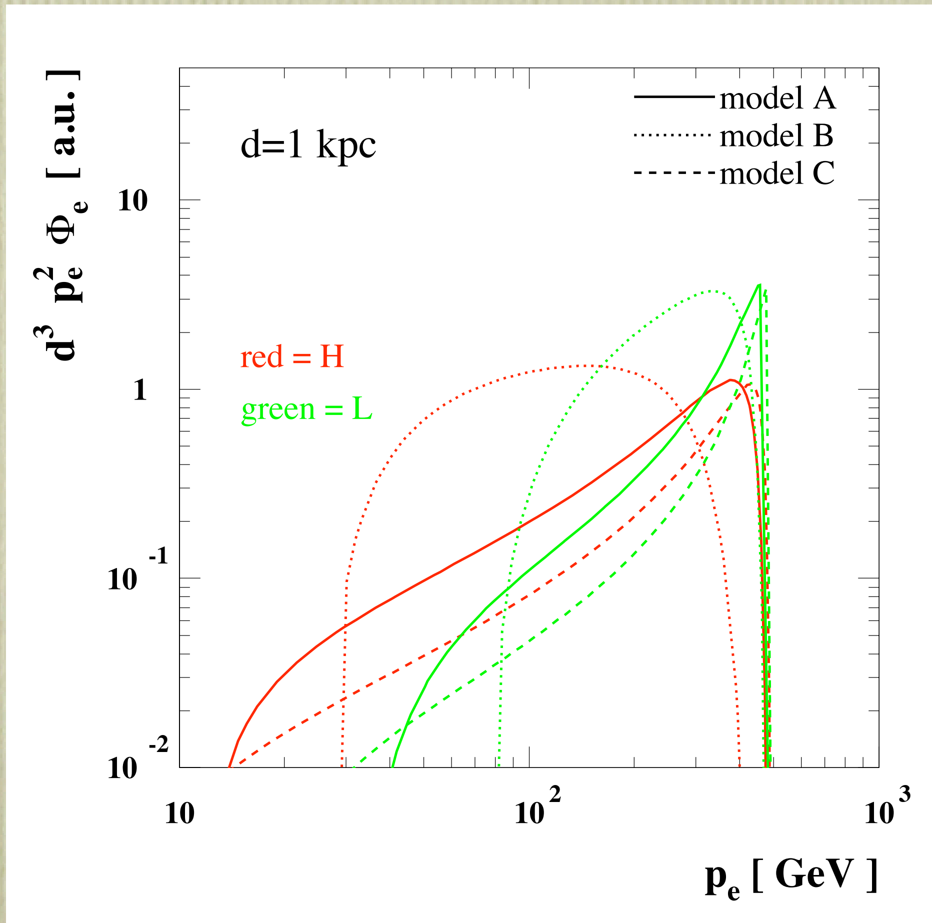
E.g.: assume you have a 500 GeV DM candidate annihilating into monochromatic e^+/e^-, on a orbit perpendicular to the galactic plane and passing close to the Sun:



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



Moreover there is a critical dependence on propagation models:



A → "reference" propagation model

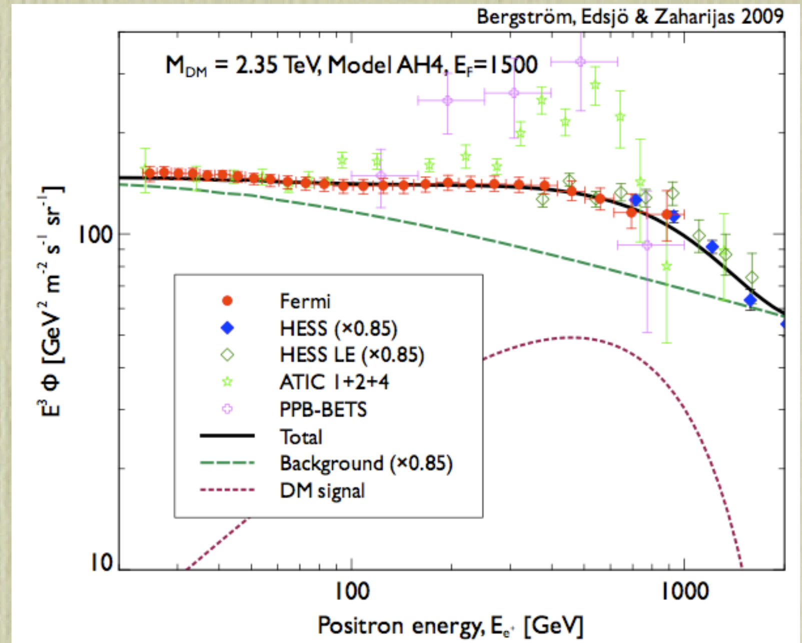
B → thin halo model

C → thick halo model

H → standard energy loss configuration

L → low energy loss configuration

... and now



~~Simple recipe for this result: just a blind fit matching the measured excesses with the particle physics properties, by adjusting:~~
~~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 **totally spoiled!** In facts:

i) the energy threshold can be drastically shifted for a substructure which is far away from the observer;

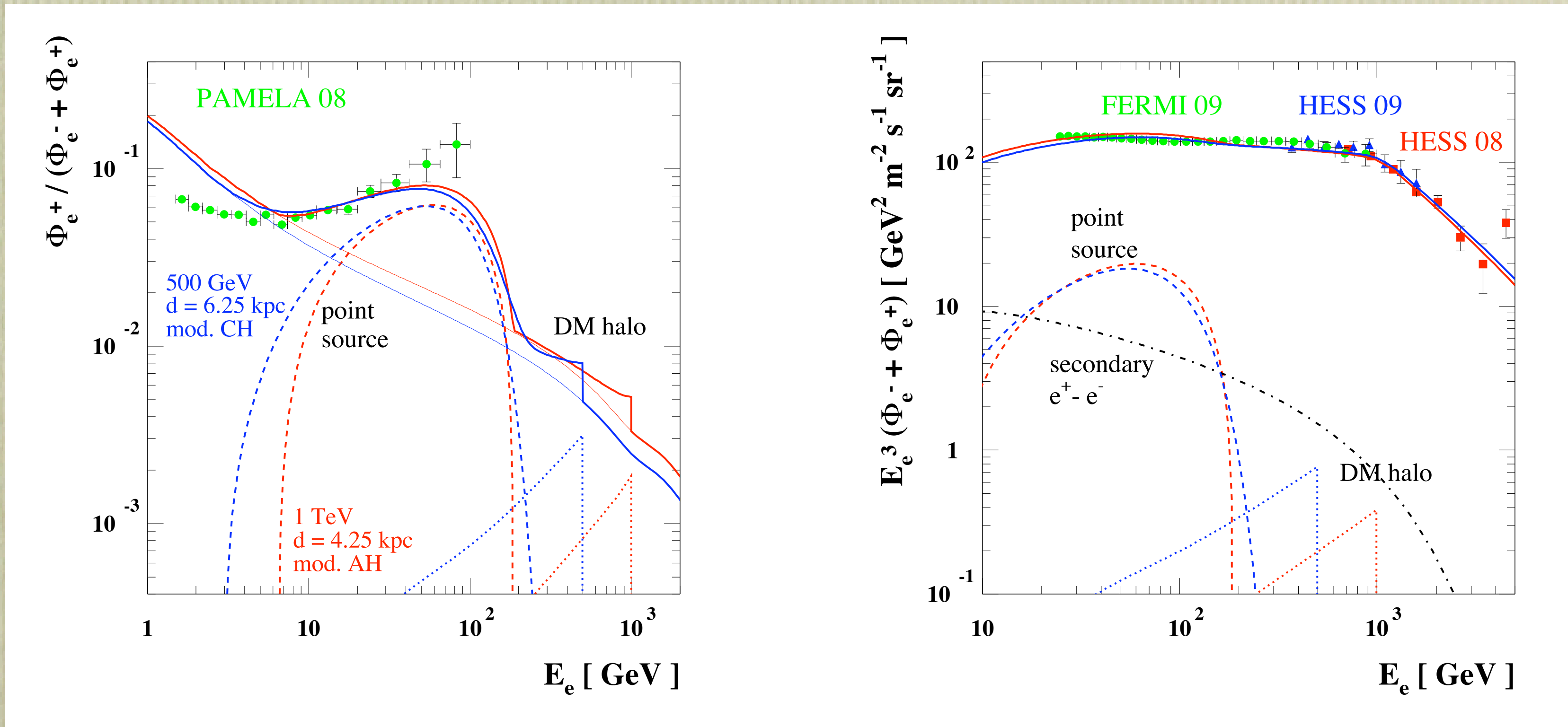
ii) the spectral shape is mostly determined by the transient, and is very sensitive to the specific transient one considers;

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

Clearly an extreme case, however it illustrates nicely that fact that derived quantities should be considered with care.

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:

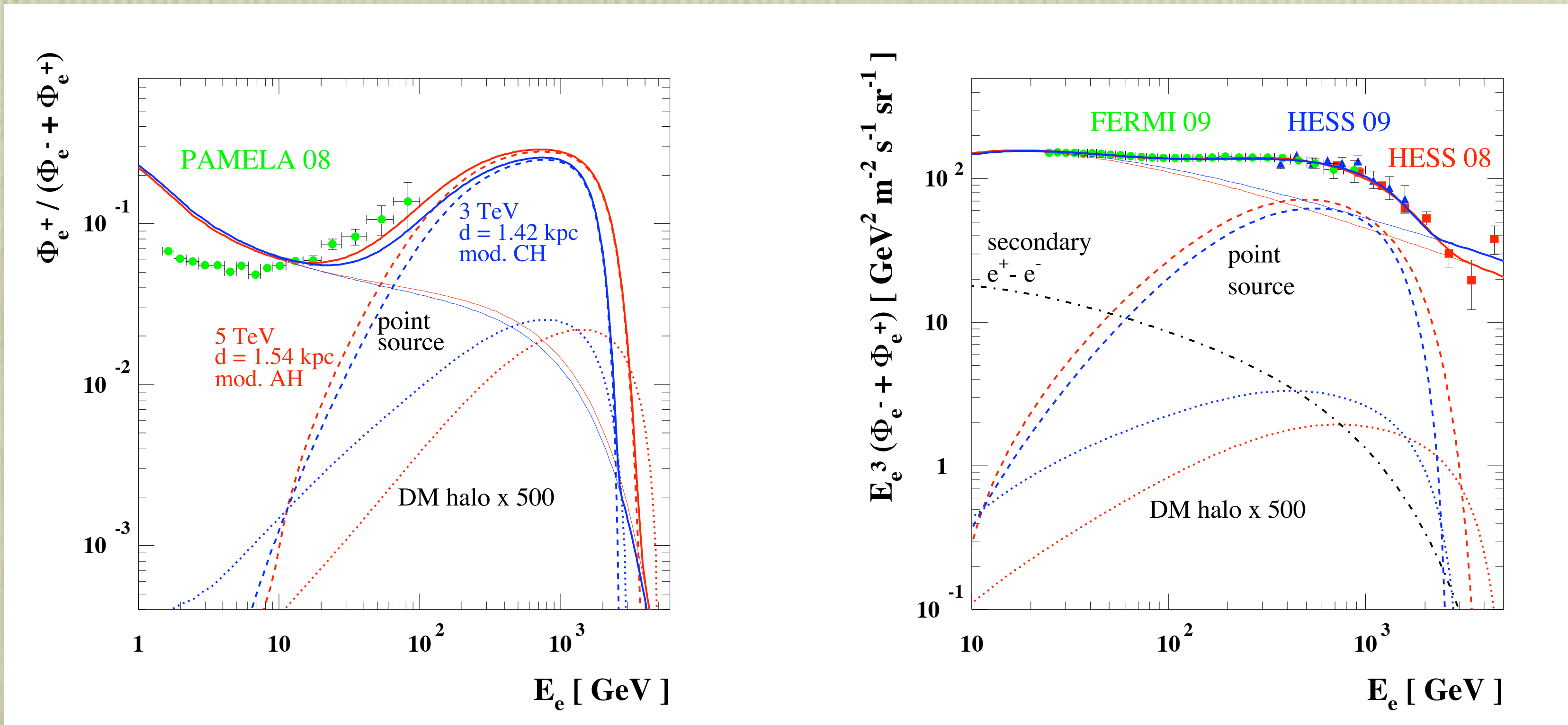


Model 1 (1 TeV) & 2 (500 GeV)

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

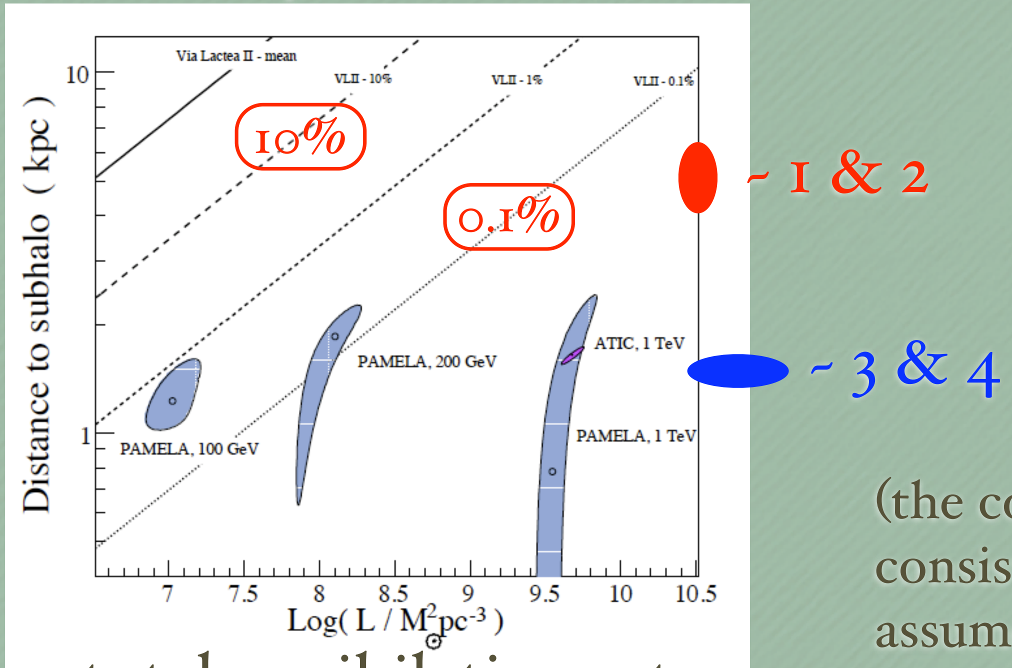
Assumes a given: i) DM annihilation channel: τ^+/τ^-, ii) DM mass, & iii) clump orbit/velocity. Fit optimized with respect to: 1) the distance along the orbit, & 2) the source normalization. The electron background is assumed to be significantly below the Fermi data:



Model 3 (5 TeV) & 4 (3 TeV)

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).

What about the associated gamma-ray fluxes?

final state radiation | mainly pion decays

	M_χ GeV	annihilation channel	Γ $10^{36}\,s^{-1}$	$\mathcal{V}_s$ kpc^3	prop. model	d kpc	$\Phi_\gamma(E > 0.1\,\mathrm{GeV})$ cm^{-2} s^{-1}	χ^2 (d.f.=50)
1	1000	e^+/e^-	20.9	$5.3 \cdot 10^5$	AH	4.25	$1.2 \cdot 10^{-8}$	46.7
2	500	e^+/e^-	73.4	$4.6 \cdot 10^5$	CH	6.25	$1.6 \cdot 10^{-8}$	42.3
3	5000	τ^+/τ^-	1.9	$12.6 \cdot 10^5$	AH	1.54	$1.1 \cdot 10^{-8}$	44.4
4	3000	τ^+/τ^-	2.4	$5.5 \cdot 10^5$	CH	1.43	$1.4 \cdot 10^{-8}$	60.9

Largest unidentified EGRET source: $\Phi_\gamma(> 0.1\,\mathrm{GeV}) \sim 7 \cdot 10^{-7}\,\mathrm{cm}^2\,\mathrm{s}^{-1}$

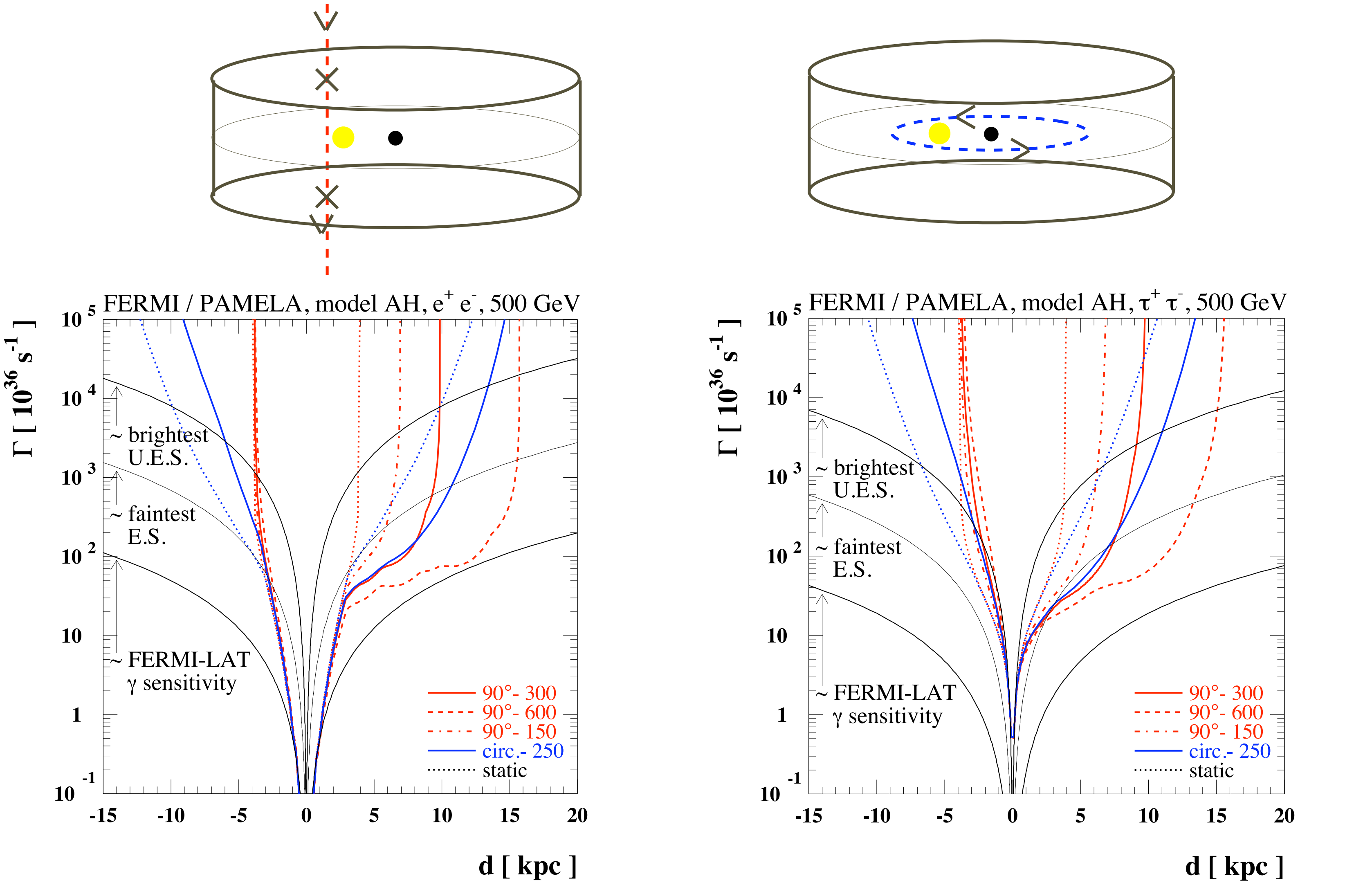
Faintest EGRET source: $\Phi_\gamma(> 0.1\,\mathrm{GeV}) \sim 6 \cdot 10^{-8}\,\mathrm{cm}^2\,\mathrm{s}^{-1}$

FERMI sensitivity (2 years): $\Phi_\gamma(> 0.1\,\mathrm{GeV}) \sim 4 \cdot 10^{-9}\,\mathrm{cm}^2\,\mathrm{s}^{-1}$

Pavlidou et al. (2007); Baltz et al. (2008).

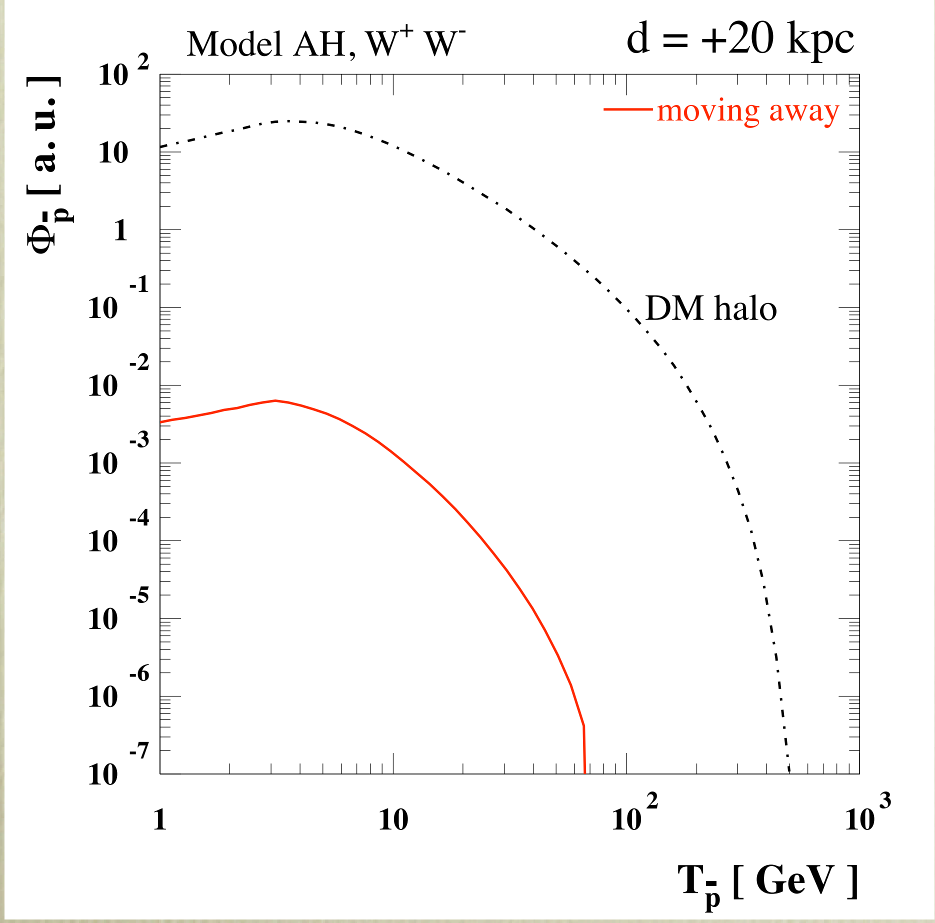
Models not yet excluded, but within the sensitivity of FERMI, possibly even within the currently available dataset.

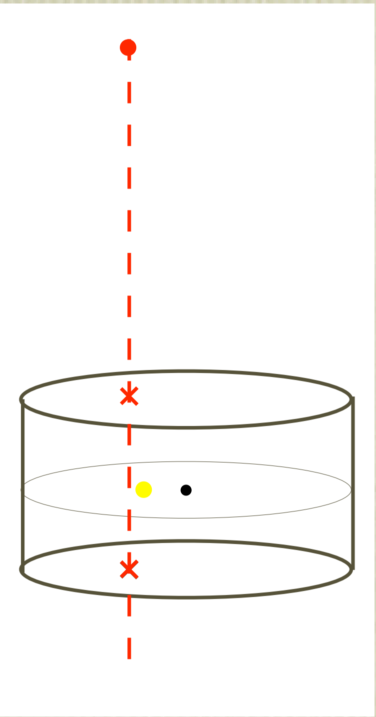
At present, e^+/e^- data set in general tighter bounds than γ-ray data but this hierarchy is going to get reversed soon; details in this is a statement depend on the WIMP model, as well as on the source orbit:



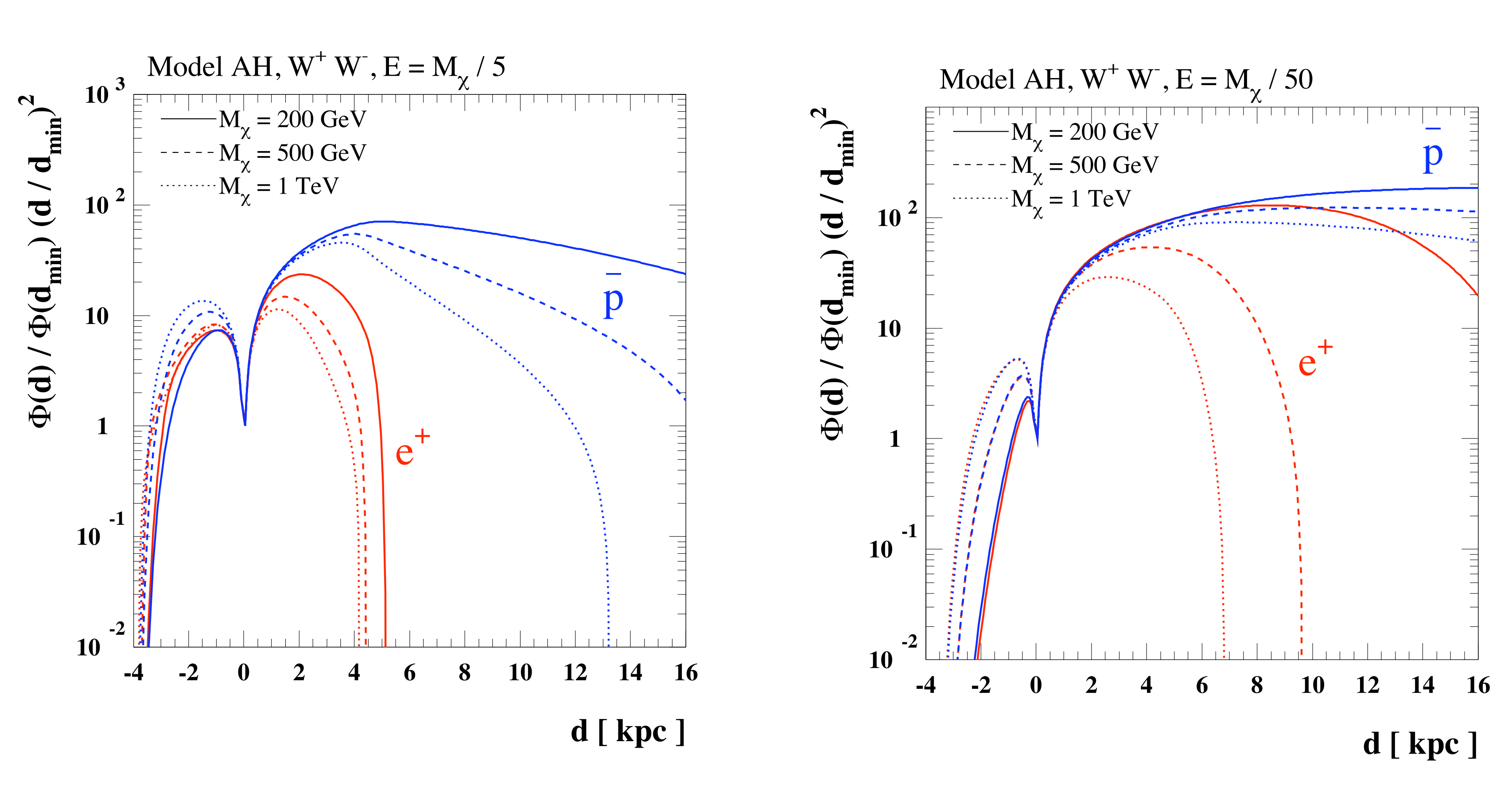
What about if the DM substructure injects antiprotons?

Consider the propagation equation, including spatial diffusion, annihilation in the gas disc, and again without assuming the static limit. E.g.: assume you have a 500 GeV DM candidate annihilating into W^+/W^-, again on a sample vertical orbit close to the Sun, with $v_s = 300 \text{ km s}^{-1}$:





Antiproton transients have weaker variations on the energy spectra than positron fluxes and are also much more persistent:



In general constraints from antiproton fluxes are tighter than positron constraints: still not feasible to define a model in which the positron flux is large, while the antiproton flux is suppressed.

Conclusions

The multi-wavelength and multi-messenger approach is a very powerful tool for dark matter searches.

Cross correlations among different observables are the key to discriminate between the DM interpretation and astrophysical interpretations of the current positron/electron puzzle. The issues of backgrounds is however delicate.

We have used the extreme case of the local positron flux being dominated by a single DM substructure to sketch often overlooked difficulties in extracting relevant informations on the DM model from current data.