Testing a DM explanation of the positron excess with the Inverse Compton scattering

Gabrijela Zaharijaš

Oskar Klein Center, Stockholm University

Work with A. Sellerholm, L. Bergstrom, J. Edsjo

on behalf of the Fermi/LAT collaboration

Cosmic ray e^+/e^- data

- PAMELA experiment measured a positron fraction between 1 and 100 GeV, which shows a steep rise with energy, contrary to the standard cosmic ray expectation (***Nature 458:607-609*, *(2009)***)

- Recently, Fermi collaboration has reported a high precision measurement of the electron (+ positron) spectrum from 20 GeV to 1 TeV performed with its Large Area Telescope (***Phys. Rev. Lett. 112 (2009)***).

- Fermi/LAT finding agrees with ATIC below 300 GeV, but does not confirm the prominent peak at higher energies.

- Fermi as well as PAMELA, HESS and ATIC show ***an excess*** *with respect to* ***the pre-LAT cosmic ray spectra predictions***.

- Standard astrophysical sources, nearby mature ***pulsars*** as well as an improved description of acceleration processes in ***Super Novae*** could offer an explanation of the local excess.

- ***Modification of the galactic cosmic ray model*** (*i.e*. hardening of the injection index of electrons) can also result in a relatively flat spectrum observed by Fermi (but it leaves excess in positron fraction unaccounted for).

- Several groups computed confidence regions of the parameters needed in the ***dark matter sector*** to fit the PAMELA positron fraction and FERMI/LAT and HESS electron measurements.

- DM annihilations dominantly to leptons are preferred *since **no excess in anti-proton measurement has been observed*** *(->see talk by G. Kane)*. Annihilations to τ's (Meade et al, '09), μ's (Bergstrom et al., '09) or leptophilic (Grasso et. Al, '09) channels (w equal branching to e, μ, τ) have been proposed.

- Solutions for the DM mass are generally in the *1-4 TeV* range, where Sommerfeld enhancements are expected to play an important role ().

Dark matter models

- For brevity we will focus on direct dark matter annihilation to $\mu^+\mu^-$ (electrons give a too pronounced peak at DM mass, while τs have softer spectra resulting in higher ‘best fit’ masses/cross sectons, and may produce too many gammas)

- Dominant annihilation to μs (leptons) is a challenge for particle physics builders

- However, if the ***annihilation is first into low-mass states which subsequently decay into leptons*** (I.e. Arkani-Hamed and Nomura Thaler type of models), both the absence of heavier annihilation channels (for kinematical reasons) and the enhanced cross sections can be explained.

In this talk:

- I will briefly go over details of the DM fits to the Fermi+PAMELA excess , for $\mu^+\mu^-$ and Nomura-Thaler (benchmark model ***NT3***, of Bergstrom et al., arXiv:0812.3895) *(--> see talk by J. Edsjo)*

- We will then test these models against newly presented Fermi Data on the ***extra Galactic*** and ***Galactic diffuse emission***.

- We do not try to fit DM component, but instead only ***preliminary*** check whether these models can survive the current set of data. More thorough analysis will follow.

Fitting Fermi+PAMELA data: e^+e^- propagation models

- At high energies (~1 TeV; Fermi and HESS) electrons sample ***local halo*** and are quite insensitive to the details of propagation model;
- then, in the first approximation, only *the energy loss parameter* τ_0 and *local halo density* play a significant role — we define an *enhancement factor:*

$$E_F = \left(\frac{\rho_0}{0.3\ \mathrm{GeV\,cm^{-3}}}\right)^2 \left(\frac{\tau_0}{10^{16}\ \mathrm{s\,GeV^{-2}}}\right) B_F$$

- Where $B_F = BF_{CS} BF_{SS}$ is an enhancement of the cross section (and/or local substructure, --> talk by C. Frenk).
- ***BF_{CS} is a quantity typically constrained by indirect searches.***

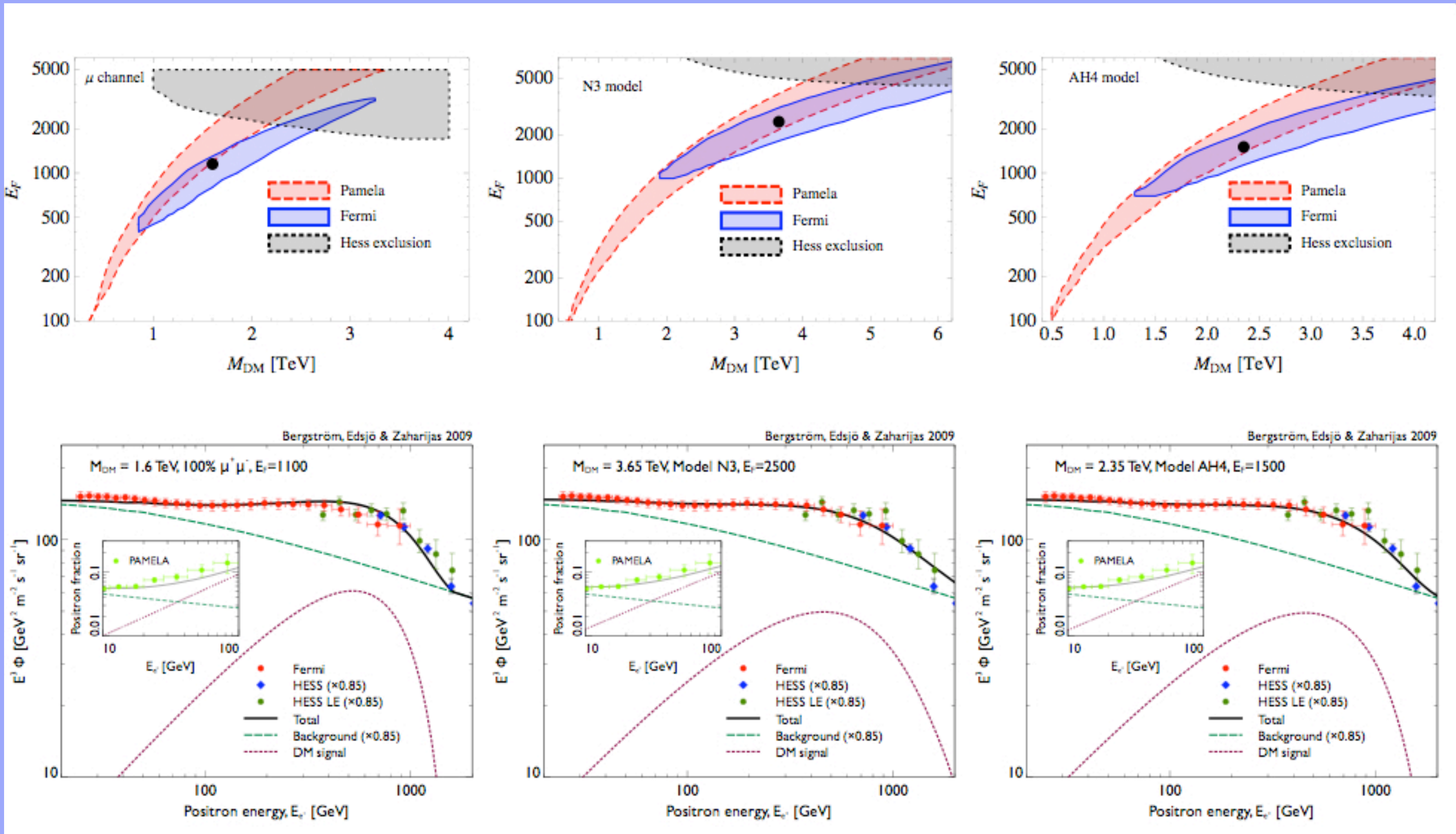
Fitting Fermi+PAMELA data: e^+e^- propagation models

- However, at energies <~ 100 GeV (PAMELA) the details of diffusion are more important.

- We use DarkSusy to propagate DM e^+e^-; we check that the results are the same for all propagation models implemented in DS, at energies >~ 100 GeV. For definiteness, we use *propagation model from Delahaye et al., 08 (the choice would affect only PAMELA regions).*

- *We conservatively assume DM Isothermal sphere halo profile, with local normalization of 0.3 GeV/cm³.*

Fit Regions



Further in the talk I will focus on models with M_{DM} and E_F from the Fermi+PAMELA fit region.

Notice

- The value of the E_F is determined through the subtle play between several parameters

$$E_F = \left(\frac{\rho_0}{0.3\ \mathrm{GeV\,cm^{-3}}}\right)^2 \left(\frac{\tau_0}{10^{16}\ \mathrm{s\,GeV^{-2}}}\right) B_F$$

- ***ρ_0:*** The value for local DM density is likely higher than the one assumed: ***Catena et al, '09*** find 0.385 ± 0.027 GeV/cm^3. (for Einasto profile, but assert that the value holds also for cored profiles) (--> talk by L. Strigari)
- Rescaling the E_F for ***higher local DM density*** would lower the value of actual B_F by a factor of $(0.3/0.4)^2$~**1/2**.

Notice

$$E_F = \left(\frac{\rho_0}{0.3\ \mathrm{GeV\,cm^{-3}}}\right)^2 \left(\frac{\tau_0}{10^{16}\ \mathrm{s\,GeV^{-2}}}\right) B_F$$

- *τ_0:* The commonly assumed effective value of $\tau=10^{16}$ s is calculated by taking into account ***synchrotron*** (assuming 3μG random magnetic fields in the diffusion zone -> 0.2 eV/cm^3) and ***IC losses*** on CMB and starlight (with energy densities of 0.3 and 0.6 eV/cm^3, respectively.
- Recent measurements indicate that the local value of the magnetic field is a factor of 6μG, and that the local value of ISRF is ~1 eV/cm^3. Then, $\tau=0.5\ 10^{16}$ s is more realistic.
- ***In the remainder of the talk we will use E_F~ B_F and E_F~2 B_F (boost factors of 1/2 lower than shown on the best fit regions), in an attempt to capture these uncertainties.***

Constraints on 'leptonic' DM models

- Enhanced 'leptonic' annihilation channels inevitably produce a substantial population of very energetic (~TeV) electrons
- Those electrons scatter off of photons and produce **IC radiation**:
  - scatter off of CMB in all halos all redshifts shows up in the EG diffuse background,
  - interstellar radiation field (Galactic Diffuse),
  - or produce IC signals in clusters of galaxies and dwarfs (->*see talk of T. Jeltema*)
- They also produce synchrotron radiation in magnetic field (i.e. in the GC),
- alter recombination (through ionization and heating of the plasma) and reionization of the Universe (-> *talk of T. Slayter and F. Iocco*),
- Further constraints come from: BBN and
- Neutrinos from the Galactic center…

Constraints from the Galactic Center

- For Einasto or NFW profiles, the “muon channel” best fit models are excluded due to **prompt (FSR)** ***gamma rays from the galactic centre***, (Bertone *et al.*, ‘08),
- Similarly, in the case of AH and NT models ***synchrotron radiation*** excludes Einasto and NFW profiles, (Bergstrom *et al.*, ‘08).
- *These constraints imply that* ***the DM halo profile is less steep (i.e. isothermal sphere) at least on the scales of a Milky Way halo*** *(and possibly smaller).*
- *This might agree with an observational evidence that the rotational curves of dwarfs and low surface brightness galaxies are better described by cored DM profile (*van Eymeren, J., ‘09)

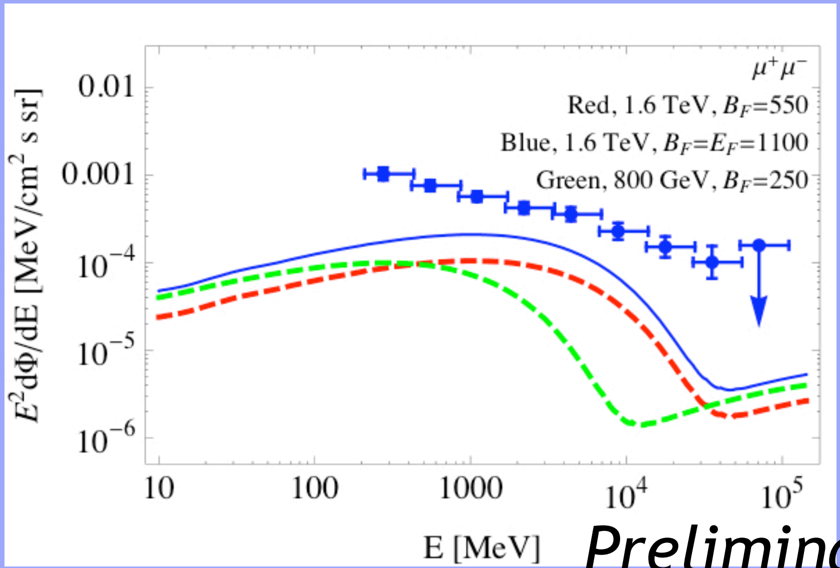
Constraints from the ***extragalactic diffuse*** *signal*

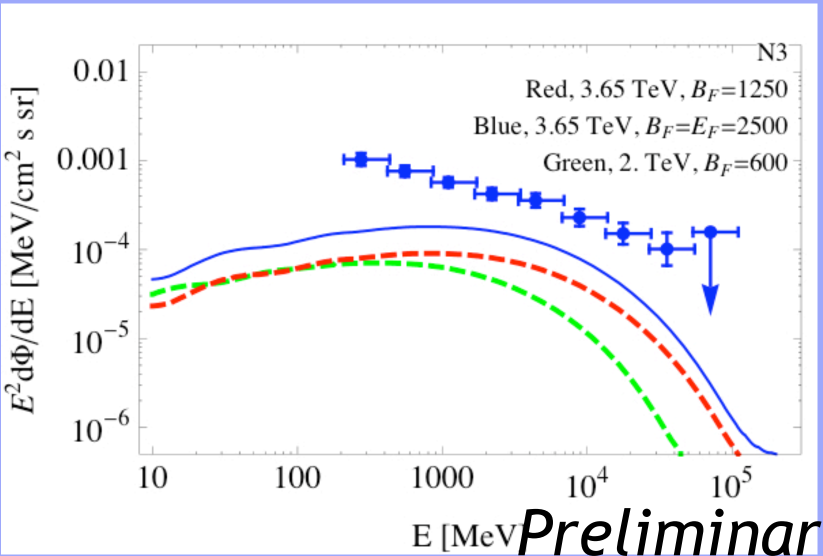
- Fermi recently presented its measurement of the EG signal (-->talk by *M. Ackermann at ICRC, and TeVPa*).
- Preliminary data for Isotropic Diffuse emission is compatible with a ***power law of index γ=2.45 between 200 MeV and 50 GeV***. New data significantly improves sensitivity at energies >1 GeV
- The spectrum as well as the characterization of the uncertainties from foreground modeling are preliminary. *Systematic effects due to the foreground modeling* are still under investigation and we do not show them here (other systematic erors, i.e. charge particle identification.. are added in quadratures).
- Here, I compare the signal expected from DM all halo, all redshift annihilation to the Fermi data.

- To model the effects of structure formation to DM annihilation signal (Δ), we use ***NFW DM profile and Bullock formalism*** in describing evolution of halo concentration parameter with redshift.

$$\frac{\mathrm{d}\phi_\gamma}{\mathrm{d}E_0} = \frac{\langle\sigma v\rangle}{8\pi}\frac{c}{H_0}\frac{\bar{\rho}_m^2}{m^2}\int \mathrm{d}z\frac{(1+z)^3\Delta^2(z)}{h(z)}\frac{\mathrm{d}N_{\mathrm{GR}}}{\mathrm{d}E}\left(E=E_0(1+z)\right),$$

- These plots solely illustrate that the DM models from the 'best-fit' regions produce IC signal over all-haloes and all-redshifts, which ****alone* is below current Fermi data***.



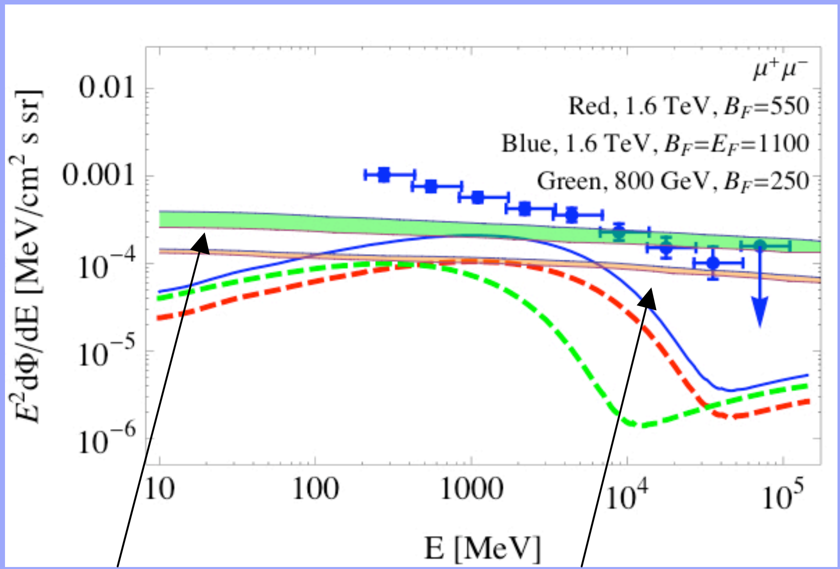


Preliminary *Preliminary*

Exclusion plots

- Caveat: We did not include DM signal enhancement due to the substructures, no rescaling of the Sommerfeld enhancement with velocity… ***Most importantly, we did not add the known astrophysical backgrounds to the DM signal.***

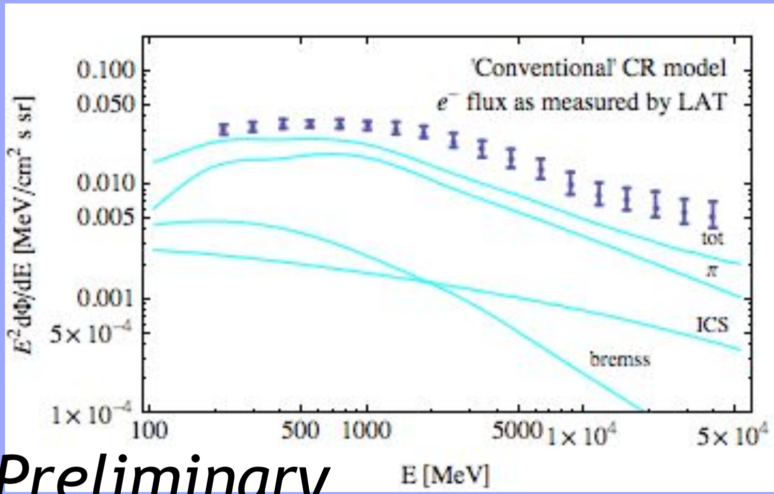
- Understanding of EB background is a very hard study in itself. The new LAT data ***(116 new blazars, discovery of a spectral break in blazar spectra, ->talk by J. Chiang)*** will soon result in an improved understanding of EGB background, and likely probe the existence of a DM signal in these type of models.



Total AGN (unresolved sources), Structure formation (isotropic), Dermer '07

Constraints from the ***galactic diffuse*** *signal*

- Fermi recently presented measurement of the galactic diffuse measurement in the inner galaxy region, |b|<10°, |l|<60° (*talk by A. Strong, at ICRC, T. Porter, TeVPa*).
- While the agreement between the data and the *'conventional' GALPROP model*, ***normalized to Fermi electron measurement***, is quite good at intermediate latitudes, in the region of inner Galaxy the model undershoots the data.

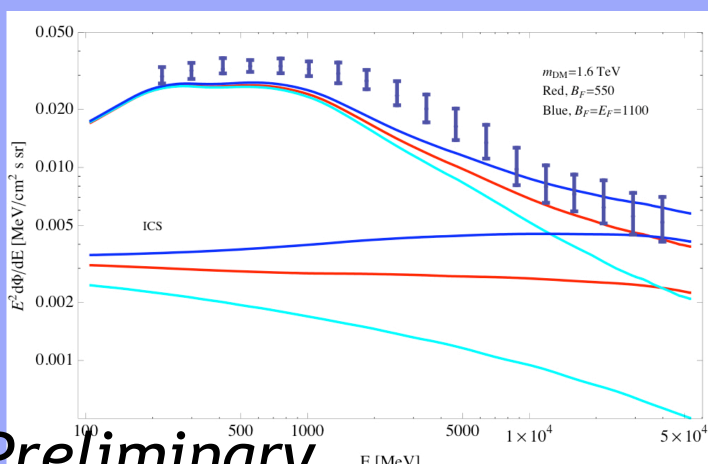


Preliminary

We use the old, publicly available version of **GALPROP 50.1p.**, with the primary electron component with a spectrum that is normalized to the LAT data

*Constraints from the **galactic diffuse** signal*

-> The understanding of cosmic ray model needs improvement over the pre-Fermi "conventional" model.



Preliminary

Here we naively use the *'conventional' GALPROP model*, ***normalized to Fermi electron measurement***, to check if the DM signal in the "best fit" regions are ruled out by this data.

We use Isothermal profile with local DM normalization of 0.4 GeV/cm^2.

The red and blue line correspond to the $\mu^+\mu^-$ mode from the fit region, and in this first round of the analysis, DM signal seems not to over produce gammas with respect to the data from the inner galaxy region.

Summary

- *Electron/positron data* can be fit with 1-4 TeV DM.
- We need to invoke boost factors (substructure and/or Sommerfeld enhancements) of the order of 10^3.
- These models inevitably produce high energy electrons and, among other ways, might be tested through Inverse Compton radiation on CMB and galactic interstellar medium.
- However, there are many uncertainties in the indirect probes of these models, i.e. DM profile in halos we consider, ***local DM density***, ***local values of the magnetic and ISR fields***, DM substructure, velocity dependence of the enhancement…
- ***If the account is taken of this uncertainties, current Fermi measurements of the Galactic and Extragalactic diffuse background do not rule out models within the 'best fit' regions***.
- With improved statistics of Fermi and ***understanding of backgrounds***, these models are close to be tested in the near future. ***Work in progress***.

- Extra slides…

Data and the standard cosmic ray signal

- As both data and background estimates have systematic uncertainties, we have some freedom of adjusting their relative normalizations.

- *We rescale down both HESS data and the pre-Fermi conventional model by 15%,* in order to get a good match to the Fermi data, which is within the expected systematic uncertainties of Fermi, HESS and the background estimates.

Notice

- The value of BF is a product of the enhancement to the cross section (Sommerfeld effect) or the local substructure, and is itself very model dependent (see talks by C. Frenk, L. Pieri).
- Sommerfeld effect: cross section dependence of 1/v is expected ($1/v^2$ in the case of bound states), with a cut off typically at $S_{max} \sim \alpha m/_{\chi} m_{\phi}$, for $v/c <\sim 0.5 m\phi/m\chi$