Absolute Electron and Positron Fluxes from PAMELA/Fermi as Indirect Detection of Dark Matter ?

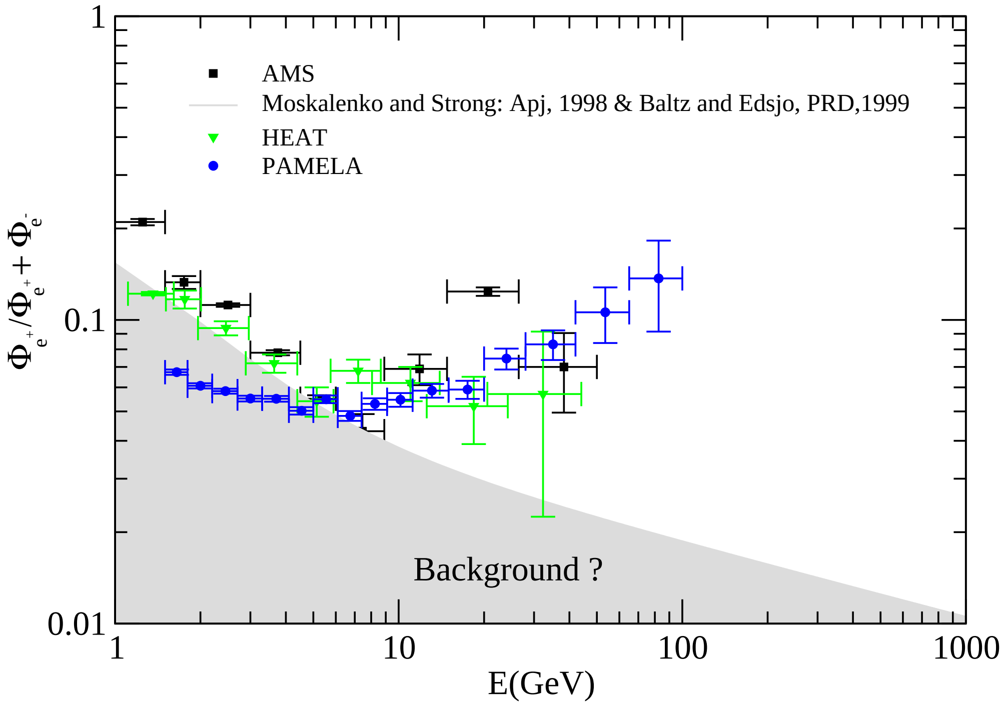
NARENDRA SAHU

e-mail: Narendra.Sahu@ulb.ac.be

Service de Physique Theorique, University Libre de Bruxelles, 1050 Brussels, Belgium

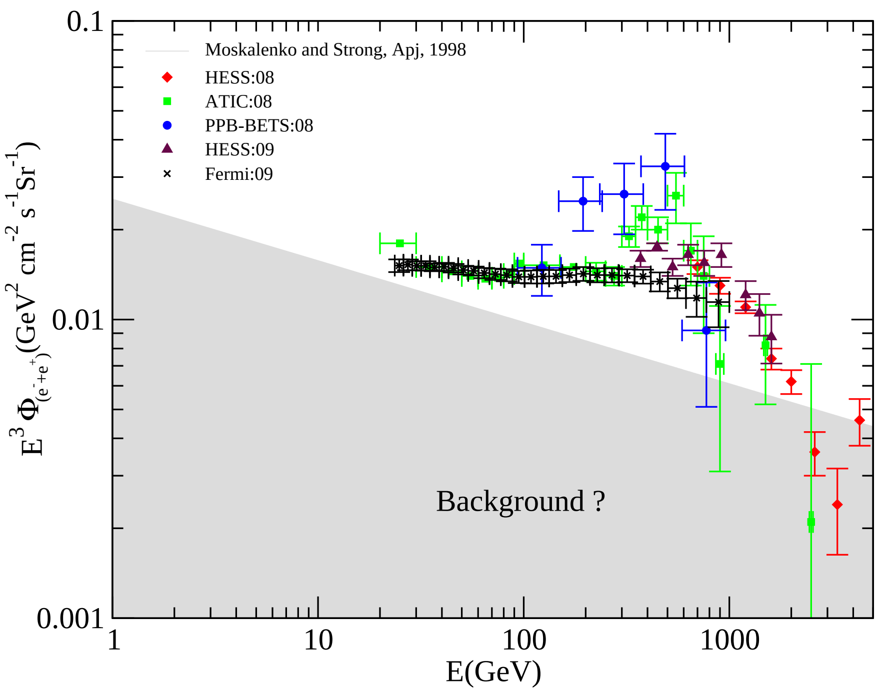
Interpretation
of
Electron and Positron Data

AMS, HEAT, PAMELA Positron Excess ?



HESS, ATIC, PPB-BETS and FermiLAT

$e^- + e^+$ excess ?



Absolute e^+ and e^- fluxes

$$\Phi_{e^+} = \left(\frac{\Phi_{e^+}}{\Phi_{e^-} + \Phi_{e^+}}\right)_{\text{PAMELA}} \times \left(\Phi_{e^-} + \Phi_{e^+}\right)_{\text{Fermi}}$$

$$\Phi_{e^-} = \left(\Phi_{e^-} + \Phi_{e^+}\right)_{\text{Fermi}} - \Phi_{e^+}$$

Ref. Balazs, Sahu, Mazumdar, [arXiv:0905.4302], JCAP 2009

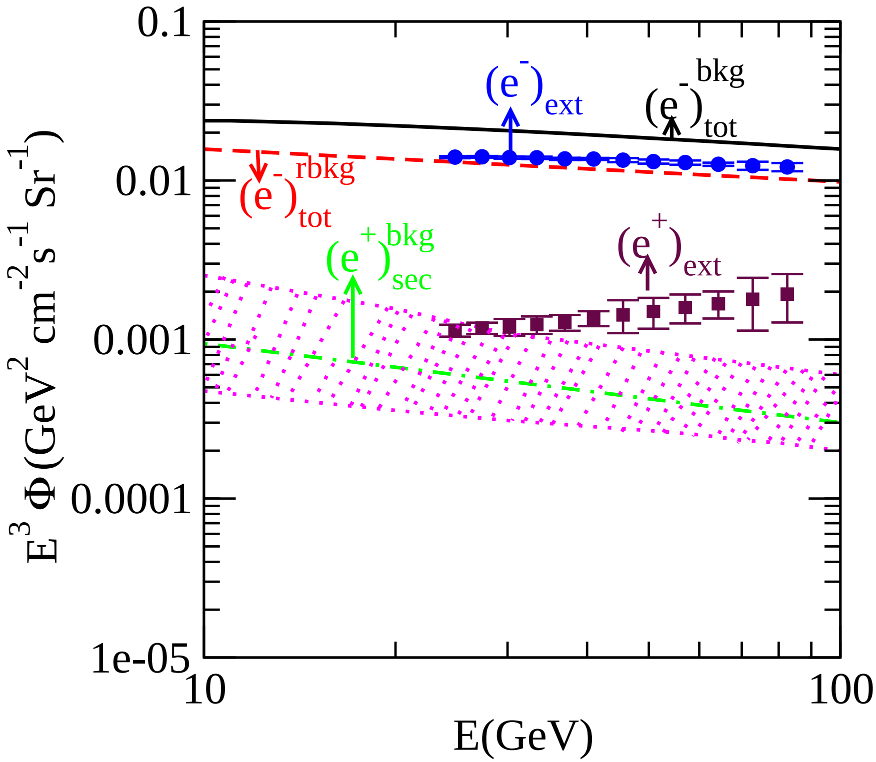
Uncertainty in absolute e^- and e^+ fluxes

$$(\delta\Phi_{e^+})^2 = (\Phi_{e^+})^2 \times$$

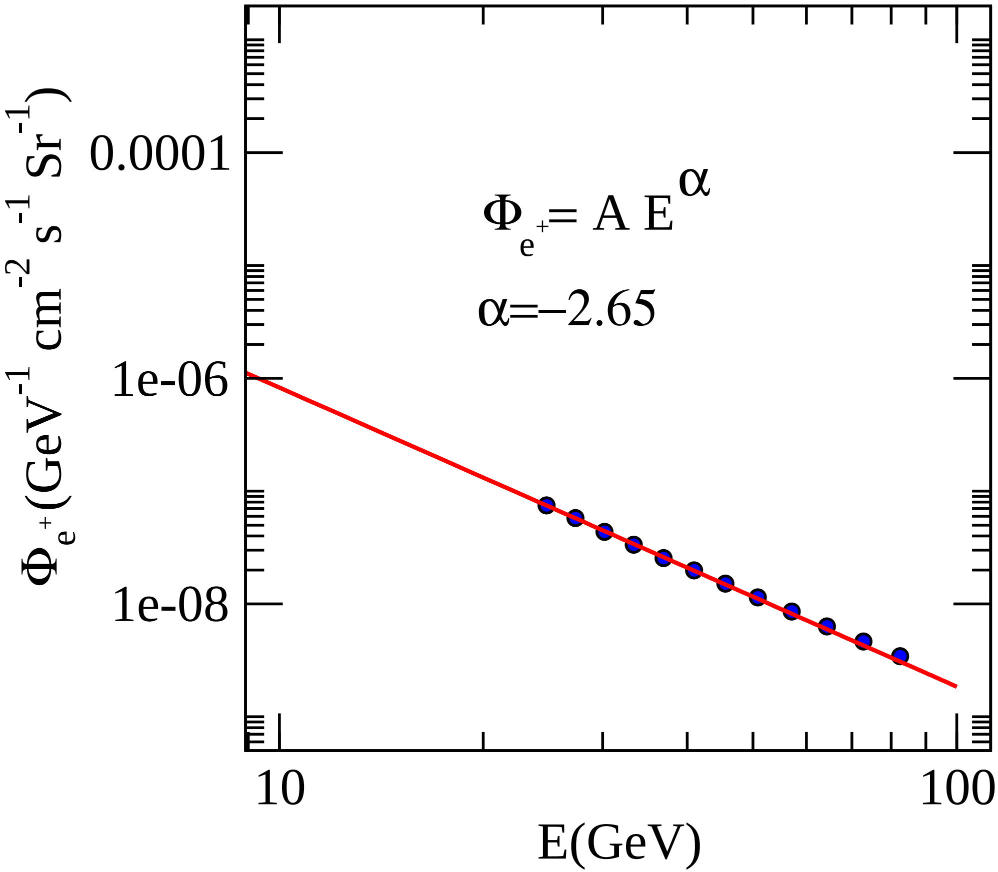
$$\left[\left(\frac{\delta(\Phi_{e^+}/(\Phi_{e^-}+\Phi_{e^+}))}{\Phi_{e^+}/(\Phi_{e^-}+\Phi_{e^+})}\right)^2 + \left(\frac{\delta(\Phi_{e^-}+\Phi_{e^+})}{\Phi_{e^-}+\Phi_{e^+}}\right)^2\right]$$

$$(\delta\Phi_{e^-})^2 = \left(\delta\Phi_{e^-+e^+}\right)^2 + \left(\delta\Phi_{e^+}\right)^2$$

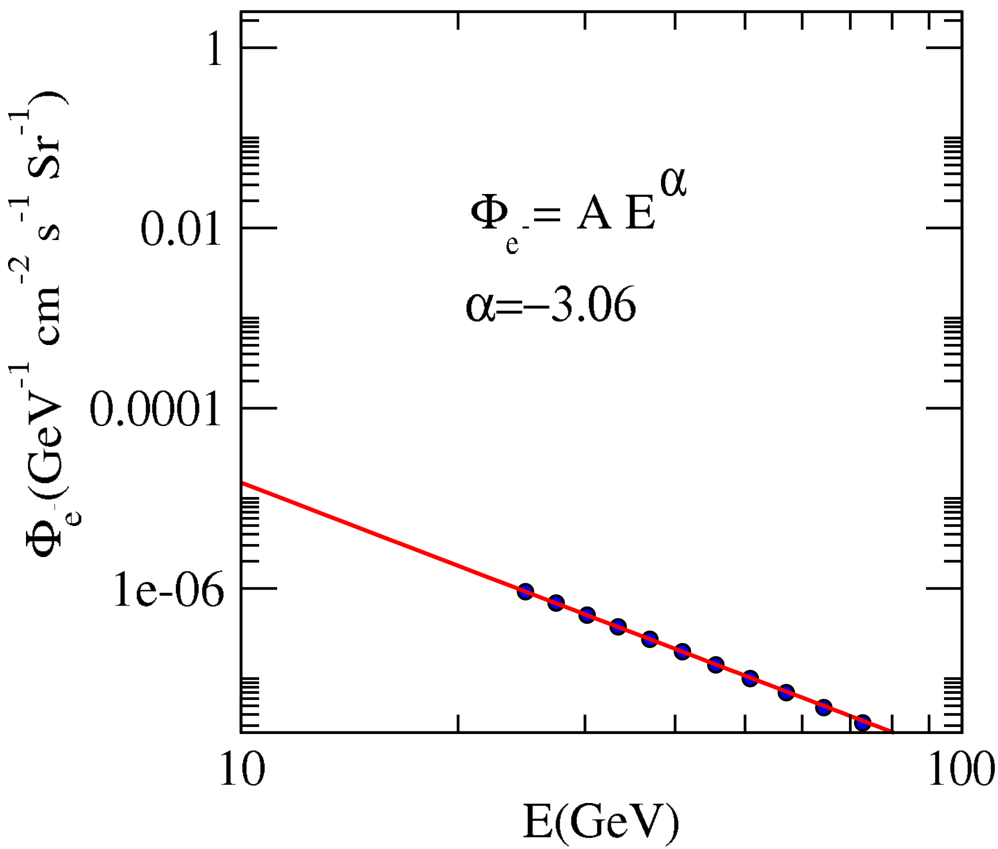
Ref. Balazs, Sahu, Mazumdar, [arXiv:0905.4302], JCAP 2009



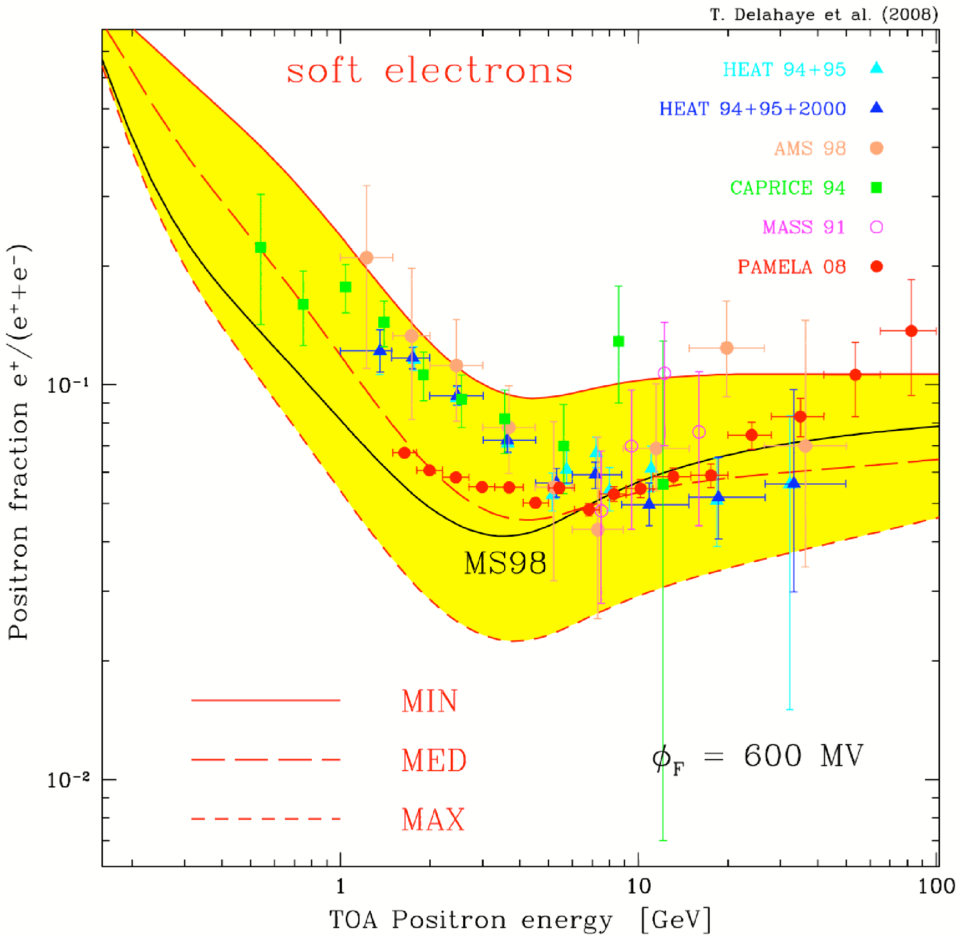
Ref. Balazs, Sahu and Mazumdar, JCAP 2009
Background Uncertainty : T.Delahaye et.al **arXiv:0809.5268**

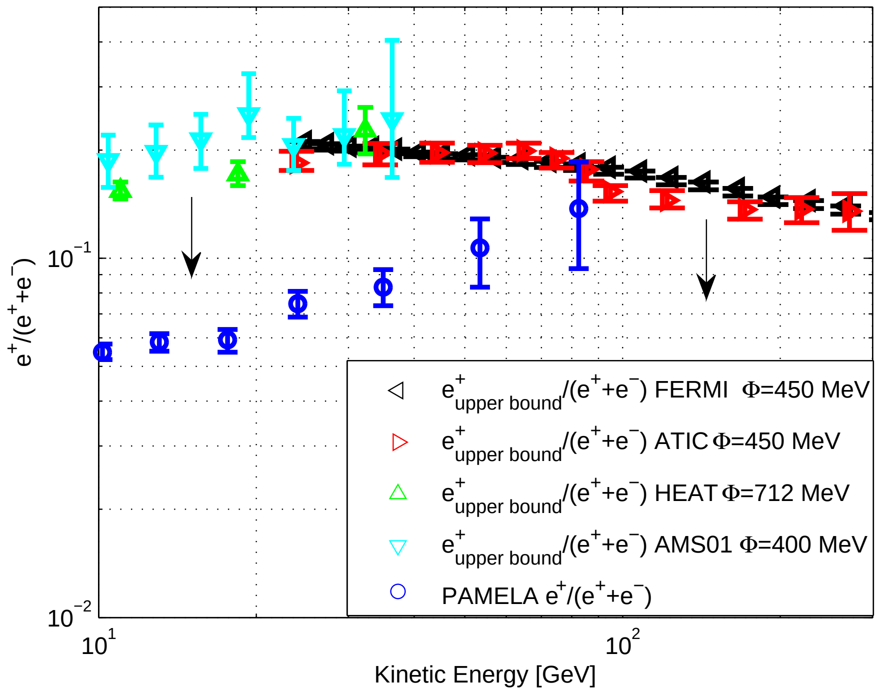


$\Phi_{e^+}(GeV^{-1}\ cm^{-2}\ s^{-1}\ Sr^{-1})$
0.0001
1e-06
1e-08
$\Phi_{e^+} = A\ E^{\alpha}$
$\alpha = -2.65$
10
100
E(GeV)

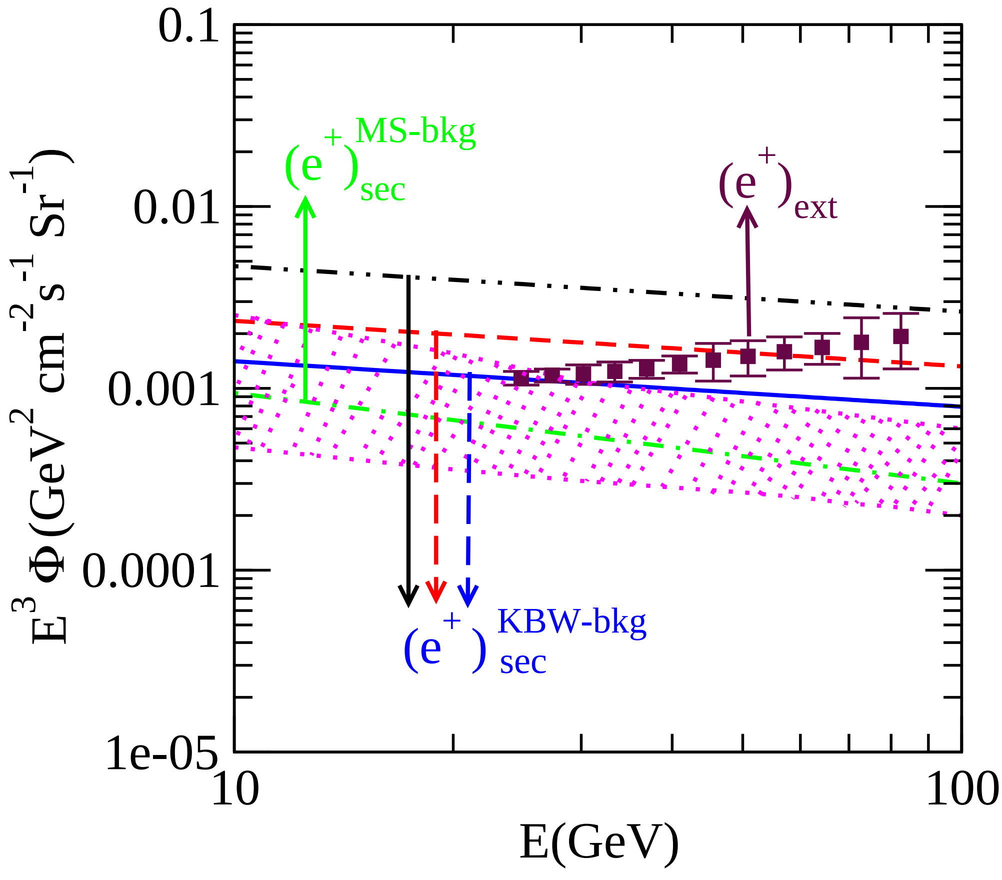

$\Phi_{e^-} = A\,E^{\alpha}$
$\alpha = -3.06$
1
0.01
0.0001
1e-06
10
100
E(GeV)
$\Phi_{e^-}(\mathrm{GeV^{-1}\,cm^{-2}\,s^{-1}\,Sr^{-1}})$

Does PAMELA Positron Fraction is an excess ?


T. Delahaye et al. (2008)
soft electrons
HEAT 94+95
HEAT 94+95+2000
AMS 98
CAPRICE 94
MASS 91
PAMELA 08
MS98
MIN
MED
MAX
ϕ_F = 600 MV
Positron fraction $e^+/(e^++e^-)$
10^{-1}
10^{-2}
1
10
100
TOA Positron energy [GeV]



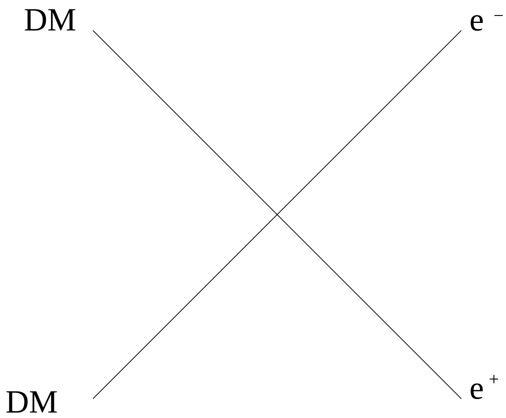
Katz, Blum and Waxman, arXiv: 0907.1686


0.1
0.01
0.001
0.0001
1e-05
10
100
E(GeV)
E^3 Φ(GeV^2 cm^-2 s^-1 Sr^-1)
(e+)sec MS-bkg
(e+)ext
(e+)sec KBW-bkg

Dark Matter
and
Indirect Detection

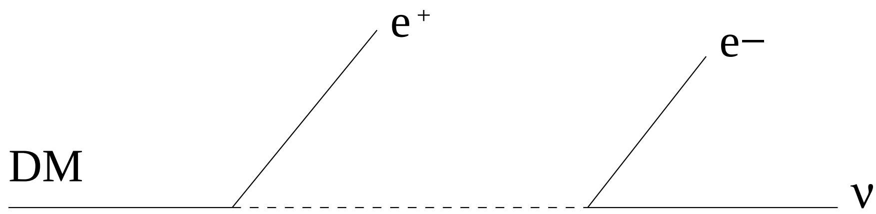
Absolute $e^{\pm}$ fluxes and Dark Matter

- **If DM couples to visible sector then it can explain the observed positron excess through annihilation or decay.**



$$\langle \sigma |v| \rangle_{\text{ann}} = B \times \langle \sigma |v| \rangle_{\text{canonical}}$$
$$\langle \sigma |v| \rangle_{\text{canonical}} \approx 3 \times 10^{-26} \text{cm}^3/\text{sec}$$

Absolute $e^{\pm}$ fluxes and Dark Matter



$\tau_{\mathrm{DM}} \approx 10^{8-9}\tau_0$ **where** $\tau_0 =$ **Age of the universe.**

Note: Annihilation/Decay of DM produces equal positrons and electrons. Since the background of electrons is significantly larger than positrons, it is worth looking for signature of DM, if any, in the cosmic ray positrons.

Propagation Equation for $e^{\pm}$ in the Galaxy

$$\frac{\partial}{\partial t} f_{e^+}(E,\vec{r},t) = K_{e^+}(E)\nabla^2 f_{e^+}(E,\vec{r},t)$$

$$+\frac{\partial}{\partial t}[b(E) f_{e^+}(E,\vec{r},t)] + Q(E,\vec{r})$$

Moskalenko and Strong, APJ, 1998

Baltz and Edsjo, PRD, 59, 1999

- f_{e^+} = **Number density of positrons per unit energy E**

- K_{e^+} = **diffusion constant, obtained by comparing the measurement of B/C in the cosmic rays and the cosmic rays simulation result in which the diffusion model is used.**

• $b(E)$ **= Energy Loss Rate, mostly due to the inverse compton scattering with CMBR and star light, and the synchroton radiation with the Galactic magnetic field.**

• The positron source term for DM:

(1) In case of annihilation:

$$Q(E,\vec{r}) = \frac{1}{2} n_{\mathrm{DM}}^2 \langle \sigma_{\mathrm{DM}} |v_{\mathrm{rel}}| \rangle \frac{dN_{e^+}}{dE}$$

(2) In case of Decay:

$$Q(E,\vec{r}) = n_{\mathrm{DM}} \Gamma_{\mathrm{DM}} \frac{dN_{e^+}}{dE}$$

Solution of Propagation Equation of $e^{\pm}$

- It is plausible that the positrons from DM annihilation/decay are in equilibrium in the present universe. Which implies:

$$\frac{\partial}{\partial t} f_{e^+}(E, \vec{r}, t) = 0$$

- Then by using cylindrical co-ordinates and using the fact that f_{e^+} vanishes at the boundary, one can solve the diffusion equation:

$$K_{e^+}(E)\nabla^2 f_{e^+}(E, \vec{r}) + \frac{\partial}{\partial t}[b(E) f_{e^+}(E, \vec{r})]$$

$$+Q(E, \vec{r}) = 0$$

In case of stable DM, one gets the total positron flux:

$$\Phi_{e^+}(E, \vec{r}_\odot) = \frac{v_{e^+}}{4\pi b(E)} (n_{\mathsf{DM}})^2_\odot \langle \sigma_{\mathsf{DM}} |v_{\mathsf{rel}}| \rangle \times$$

$$\int_E^{M_{\mathsf{DM}}} dE' \frac{dN_{e^+}}{dE'} I(\lambda_D(E, E'))$$

where

(1) $\lambda_D(E, E')$= **Diffusion length from energy** E' **to** E

(2) $I(\lambda_D(E, E')) =$ **Halo function, which is independent of particle physics.**

Delahaye *et. al.*, **PRD, 77, 2008**

Cirelli, Franceschini, Strumia, NPB, 800, 2008.

Hisano et.al. PRD, 76, 2006

In case of unstable DM, one gets the total positron flux:

$$\Phi_{e+}(E,\vec{r}_\odot) = \frac{v_{e+}}{4\pi M_{\mathrm{DM}}\tau_{\mathrm{DM}}}\times$$

$$\int_E^{M_{\mathrm{DM}}} dE' G_{e+}(E,E')\frac{dN_{e+}}{dE'}$$

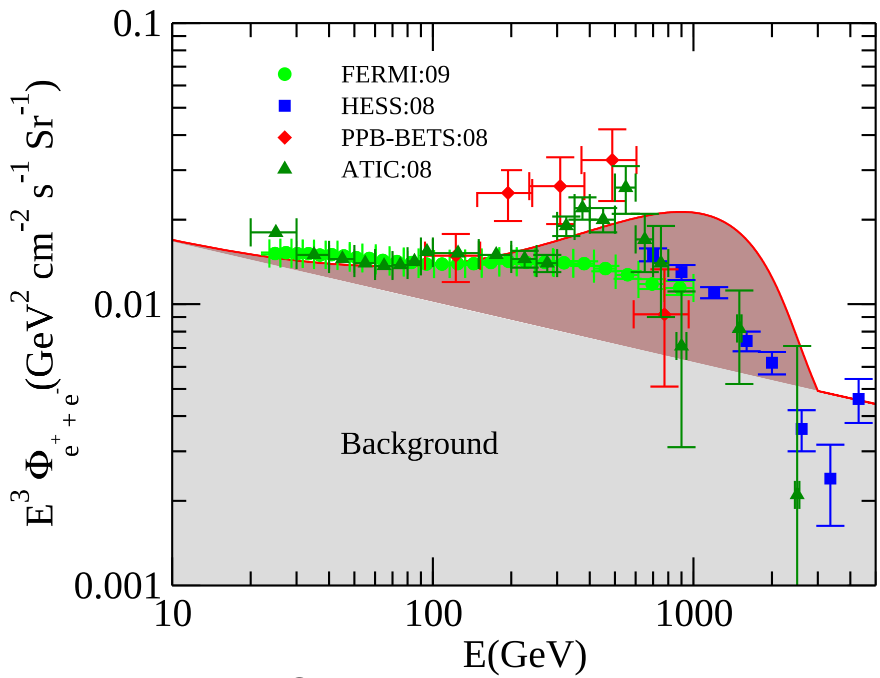
where $G_{e+}(E,E')$ = Diffusion function, which is independent of particle physics.

Ibarra and Tran, JCAP, 2008

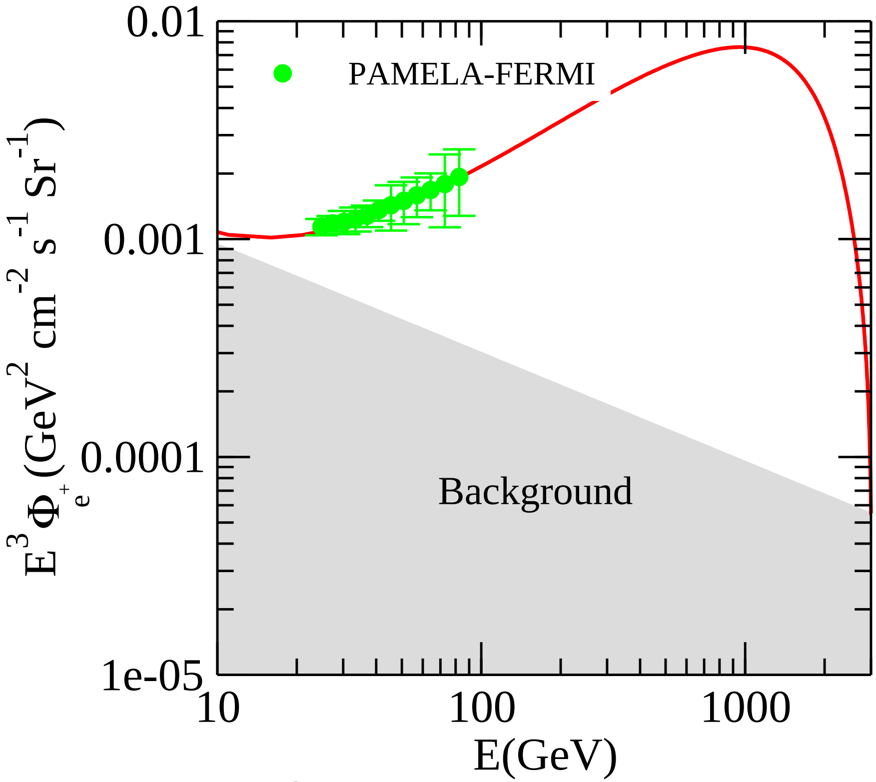
Note: Depending on the height of Galactic plane [≤ 1 kpc (MIN), ≤ 4 kpc (MED), ≤ 15 kpc (MAX)] and the nature of halo function [NFW, Einasto, Isothermal] the final flux may vary.

Positron Excess through annihilation/decay of DM

$e^{\pm}$ fluxes from $DM \to \mu^+\mu^-$

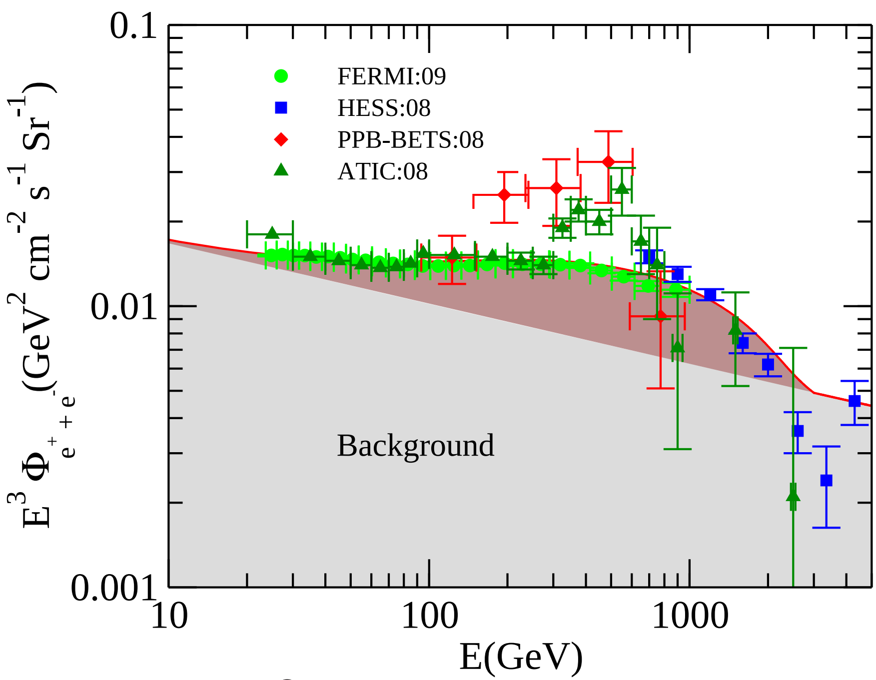


B= 5.3×10^3 **[MED-model, NFW profile]**

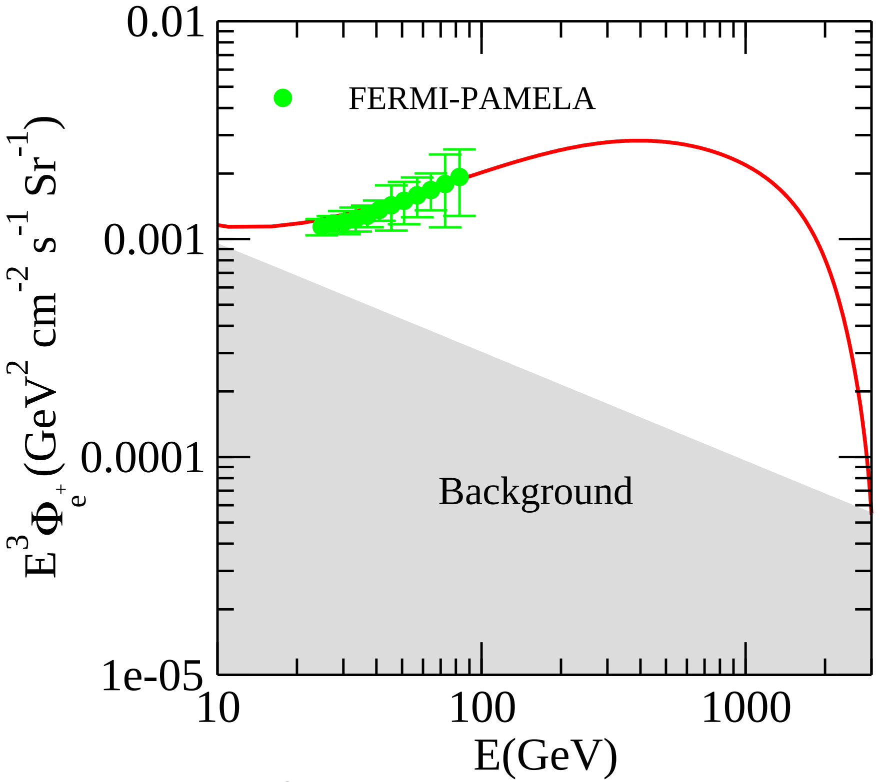


B= 5.3×10^3 **[MED model, NFW profile]**

$e^{\pm}$ fluxes from $DM \to \tau^+\tau^-$

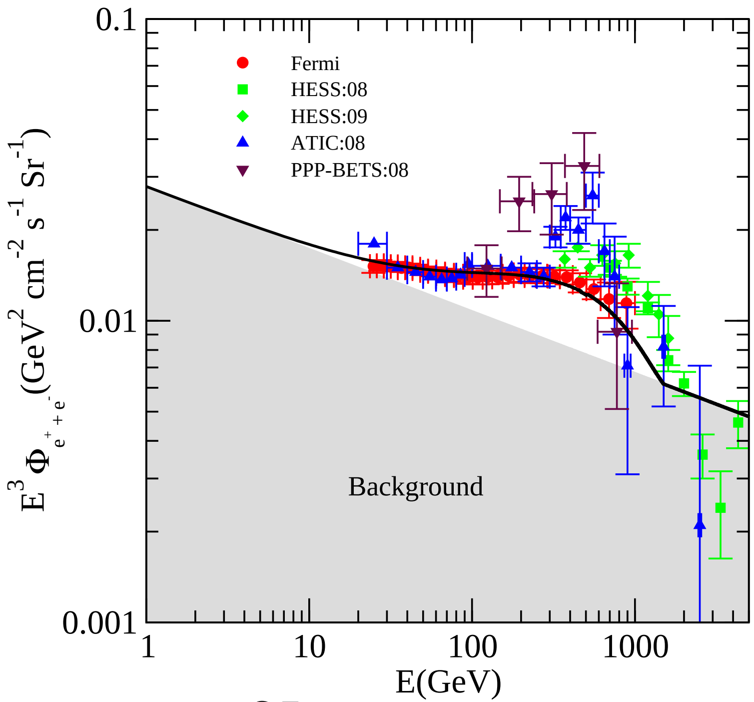


B=6.7×10^3 **[MED model, NFW profile]**



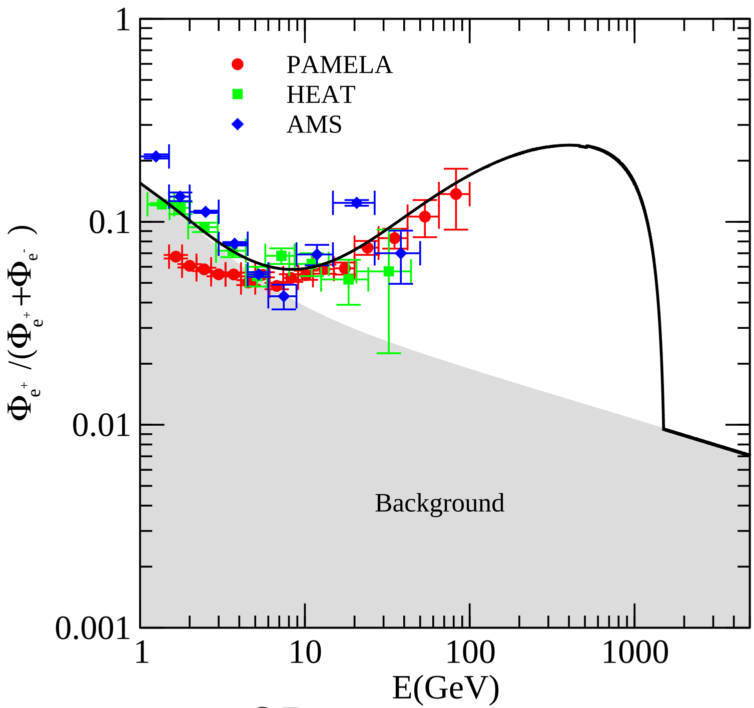
B=5.3×10^3 [MED model, NFW profile]

$e^{\pm}$ fluxes from $DM \rightarrow \tau^+\tau^-\nu$



$\tau_{\rm DM} = 4.0 \times 10^{25}$**s [MED model, NFW profile]**

$e^{\pm}$ fluxes from $DM \to \tau^+\tau^-\nu$



$\tau_{\rm DM} = 4.0 \times 10^{25}$s **[MED model, NFW profile]**

Fermi/PAMELA excesses and Lesson from DM annihilation/decay

- **In case of stable DM, to explain PAMELA and Fermi excesses one needs**

$$\langle\sigma_{\rm DM}|v_{\rm rel}|\rangle = \mathcal{O}(10^3)\langle\sigma_{\rm DM}|v_{\rm rel}|\rangle_{\rm canonical}$$

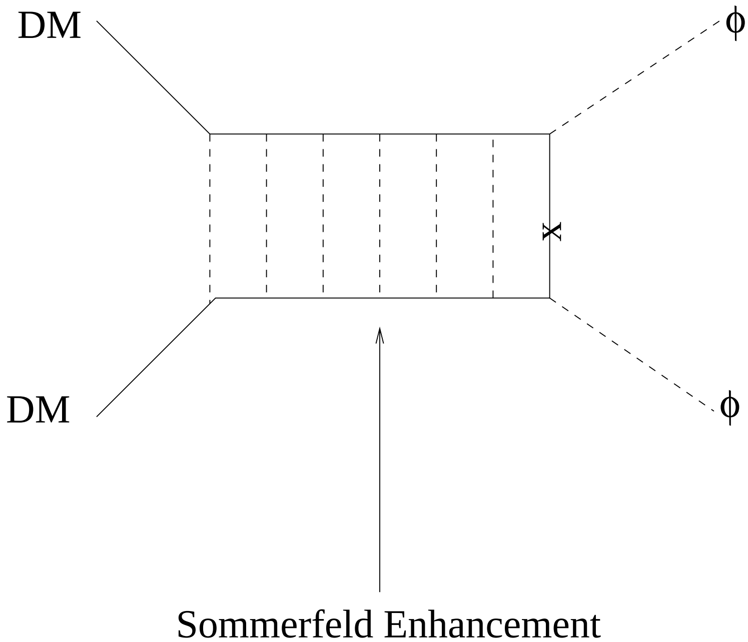
- **In case of unstable DM, to explain PAMELA and Fermi excesses one needs**

$$\tau_{\rm DM} = \mathcal{O}(10^9) \times \tau_0$$

where τ_0 = Age of the Universe.

- **DM should annihilate/decay to leptons and not to hadrons upto 100 GeV (current limit).**

Sommerfeld Enhancement



Ref. Arkani-Hamed *et.al*, **[0810.0713]**
Ref. Hisano *et.al.*, **PRL, 2005**

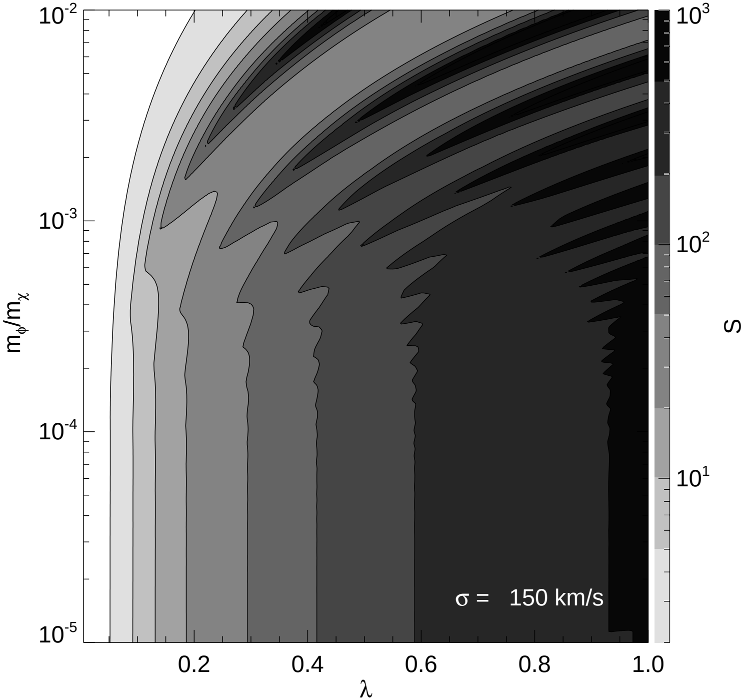
Sommerfeld Enhancement

The attractive potential can be given as:

$$V = -\frac{\lambda^2}{4\pi r} e^{-m_\phi r}$$

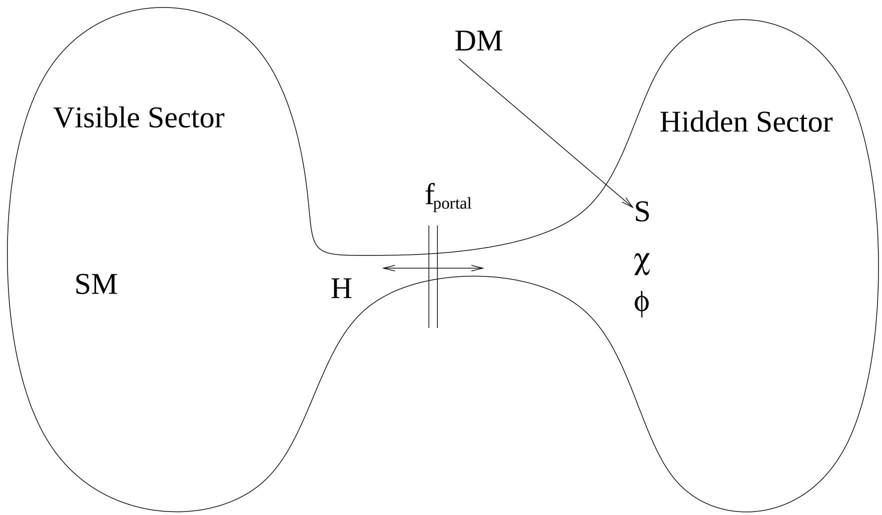
At least one bound state requires:

$$\text{Comptonwavelength} > \left(\frac{\lambda^2}{4\pi} M_{\text{DM}}\right)^{-1}$$



Ref. Arkani-Hamed *et.al*, **[0810.0713]**

Boosted DM Annihilation with Higgs Portal Coupling to Hidden Sector



Ref. Kohri, McDonald and Sahu, [0905.1312]

Higgs Portal Model

• **Upgrade SM to** $SU(2)_L \times U(1)_Y \times U(1)_{\text{hidden}}$ **under which** $S(1,0,3/2)$, $\chi(1,0,1)$ **and** $\phi(1,0,1)$ **nontrivially transforms.**

$$\mathcal{L} \supseteq f_{\text{portal}} H^\dagger H \left(S^\dagger S + \phi^\dagger \phi + \chi^\dagger \chi + \phi^\dagger \chi \right)$$

$$+ f_{S\phi} S^\dagger S \phi^\dagger \phi + f_{S\chi} S^\dagger S \chi^\dagger \chi + f_{S\chi\phi} S^\dagger S \chi^\dagger \phi + h.c.$$

• **Below 100 GeV** χ **acquires a vev and breaks** $U(1)_{\text{hidden}}$ **down to a surviving** Z_2 **symmetry under which** S **is odd, while rest of the fields are even.**

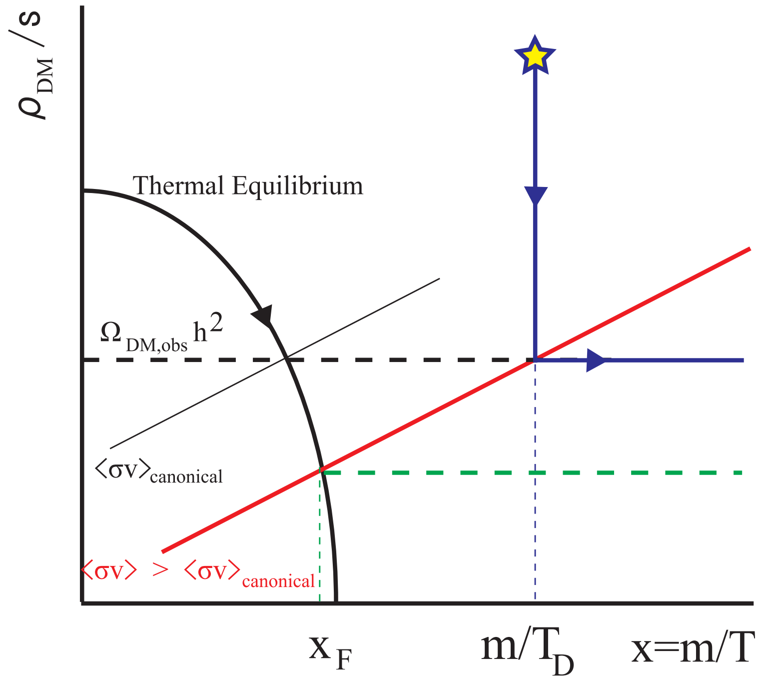
Higgs Portal Model

- **MeV scale mass of ϕ requires $f_{\rm portal} \approx 10^{-6}$.**
- **At least one bound state of S and ϕ requires**

$$f_{S\chi\phi} \gtrsim 0.5 \left(\frac{M_\phi}{200\text{MeV}}\right)^{1/2} \left(\frac{M_S}{1\text{TeV}}\right)^{1/2} \left(\frac{100GeV}{\langle\chi\rangle}\right)$$

- **The coupling $f_{\rm portal} \ll f_{S\chi\phi}$ ensures that antiproton fluxes from $S^\dagger S$ annihilation is suppressed.**

Non-thermal DM and Boost Factor



Ref. Kohri, Mazumdar, Sahu and Stephens, PRD (Rapid), 2009

Non-thermal DM and Boost Factor

Boost factor can be given as:

$$B \approx \frac{\langle \sigma |v| \rangle}{\langle \sigma |v| \rangle_{\text{canonical}}}$$

Relic abundance can be obtained as:

$$Y_{\text{DM}} = Y_{th} + Y_{nth} \approx Y_{nth}$$

BBN Constraints on DM cross-section

In case of $DMDM \to \mu^+\mu^-$

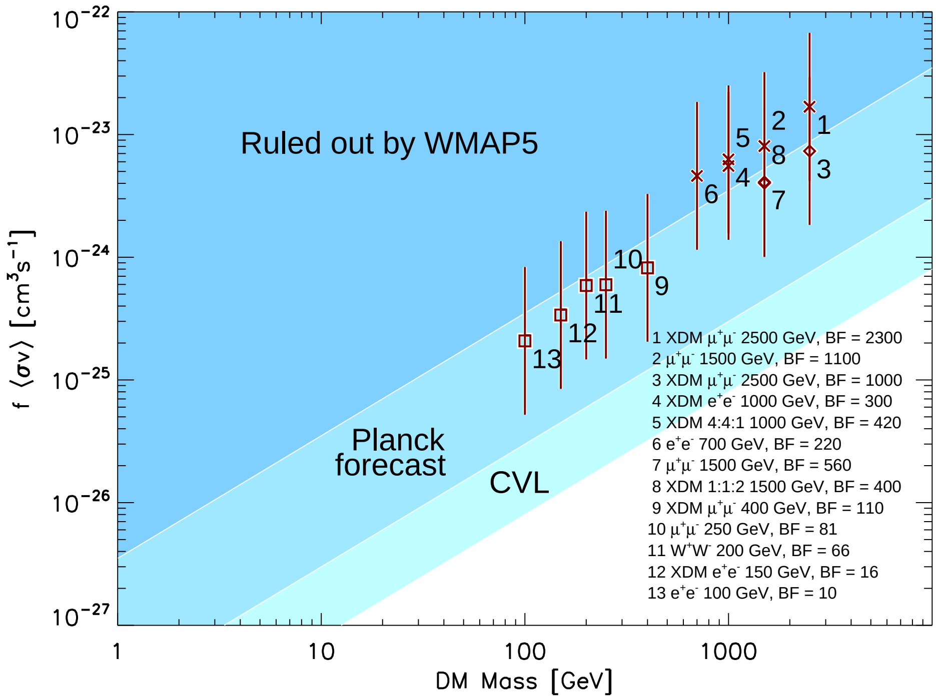
$$\langle \sigma |v| \rangle \leq 1.0 \times 10^{-21} \mathrm{cm}^3/\mathrm{s} \times \left(\frac{M_{\mathrm{DM}}}{1\mathrm{TeV}} \right)^{-1}$$

In case of $DMDM \to \tau^+\tau^-$

$$\langle \sigma |v| \rangle \leq 1.2 \times 10^{-21} \mathrm{cm}^3/\mathrm{s} \times \left(\frac{M_{\mathrm{DM}}}{1\mathrm{TeV}} \right)^{-1}$$

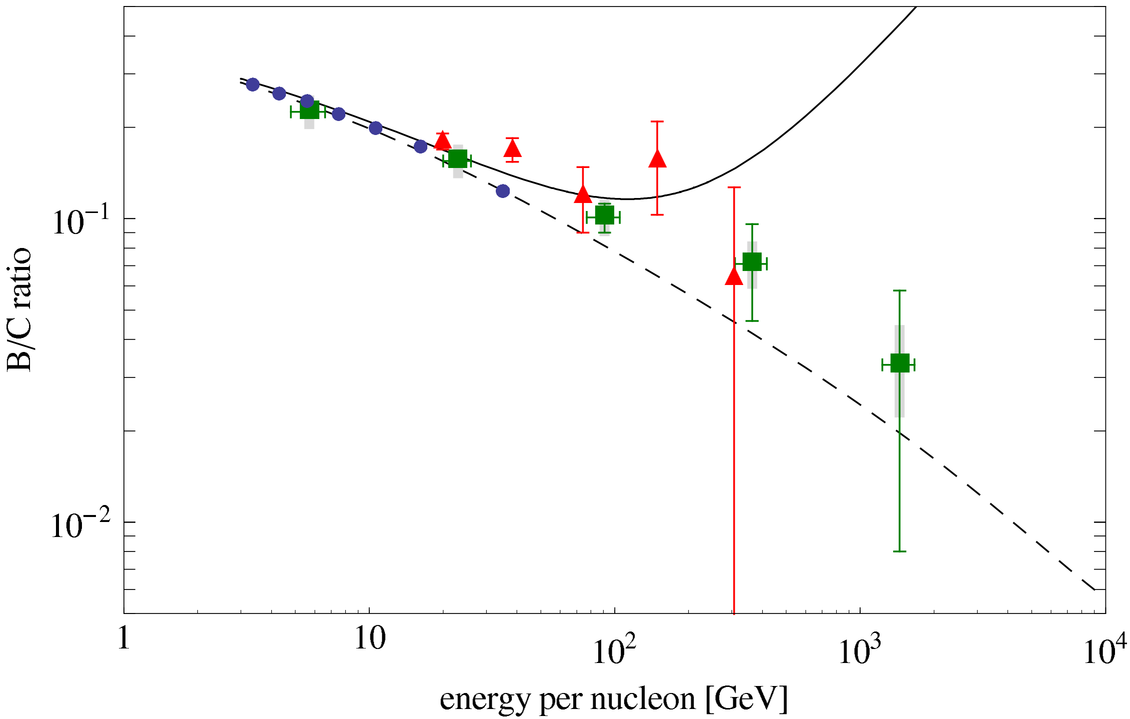
Ref. Hisano *et.al* **0901.3582[hep-ph]**

CMB Constraints on DM cross-section

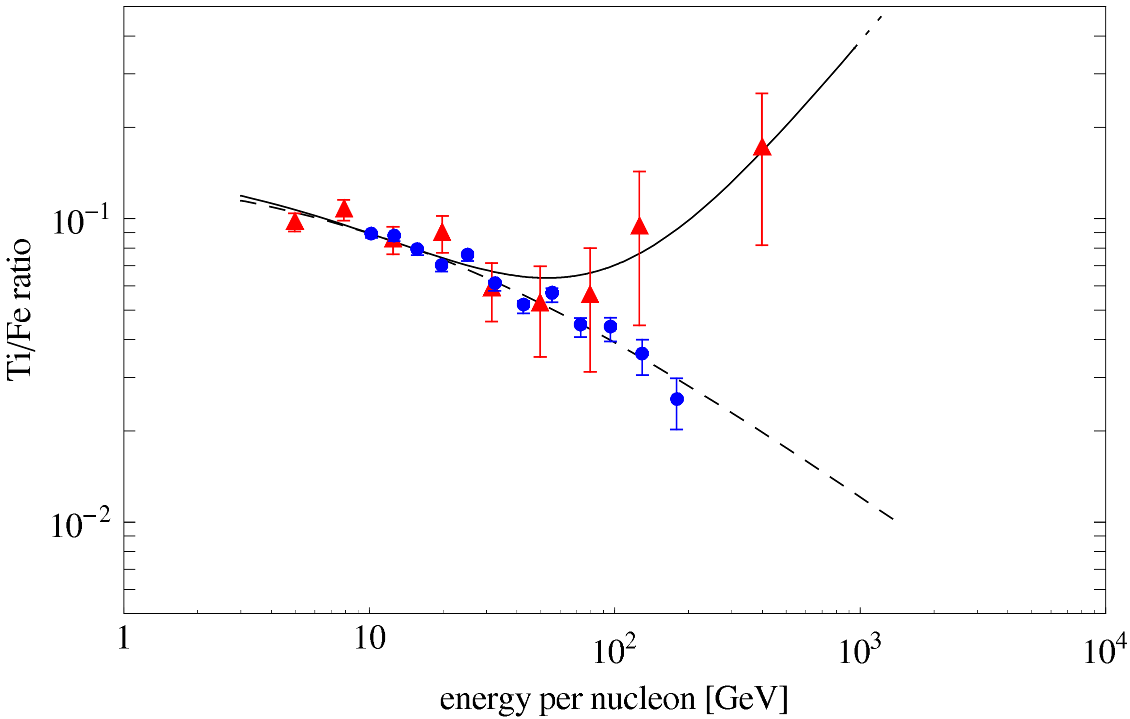


Slatyer, Padmanabhan and Finkbeiner, arXiv: 0906.1197
Galli, Iocco,Bertone,Melchiorri, arXiv: 0905.0003

Dark Matter versus Astrophysical Sources



Ref. P. Mertsch and S. Sarkar, PRL, 2009



Ref. P. Mertsch and S. Sarkar, PRL, 2009

Conclusions and Outlook

• Excess of absolute positron flux is still in question. Future data from PAMELA can confirm it.

• Annihilation and/or Decay of DM may be an interesting possibility to explain the excess of absolute positron flux. Future data of secondary nuclei (B/C ratio) may provide a clue about it.

• A boost factor of $\mathcal{O}(1000)$ for stable DM and/or Decaying DM with life time $10^9 \times \tau_0$ are required to explain the observed positron excess.

• Higgs portal may be an interesting possibility and an alternative to leptophilic model to explain positron flux without producing excess of antiprotons.