Decaying LSP in the SO(10) GUT and PAMELA's Cosmic Positron

arXiv:0909.3139 [ph] (PLB)
arXiv:0902.3578 [ph] (JHEP)
arXiv:0902.0071[ph] (JCAP)

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"WIMP miracle"

Weakly Interacting Massive Particle (WIMP)
can explain naturally Dark Matter.

Lightest Supersymmetric Particle (LSP) in MSSM
is one of the best examples of WIMP.

Recently PAMELA/Fermi reported very challenging observational results.

PRL102,051101(2009); Nature 458, 607 (2009)
arXiv:0905.0025(astro-ph HE)

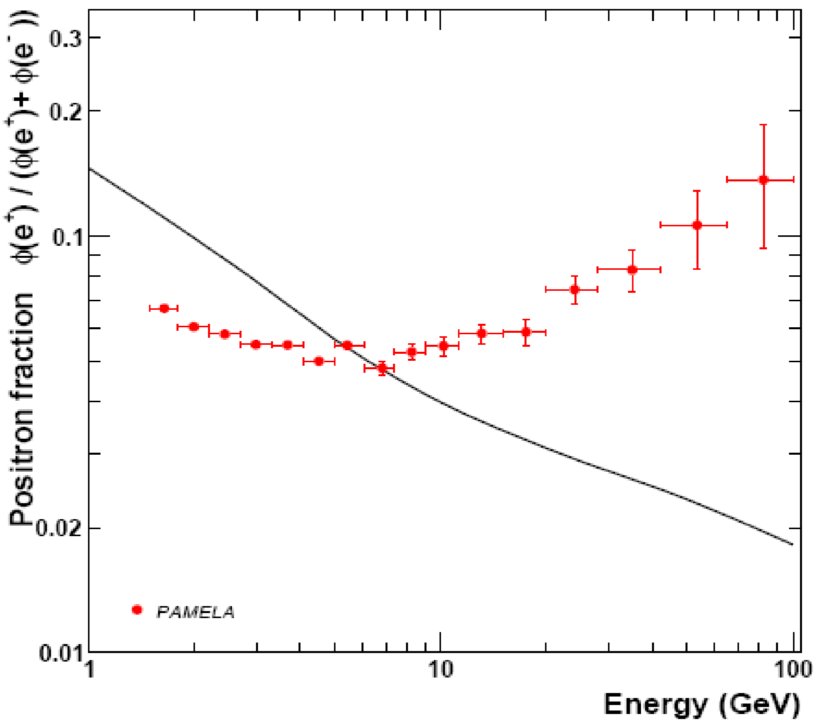
- **PAMELA** (**P**ayload for **A**nti **M**atter **E**xploration and **L**ight nuclei **A**strophysics)

  [exp. by a **SATELLITE]** measures **particles & nuclei fluxes** in cosmic ray.

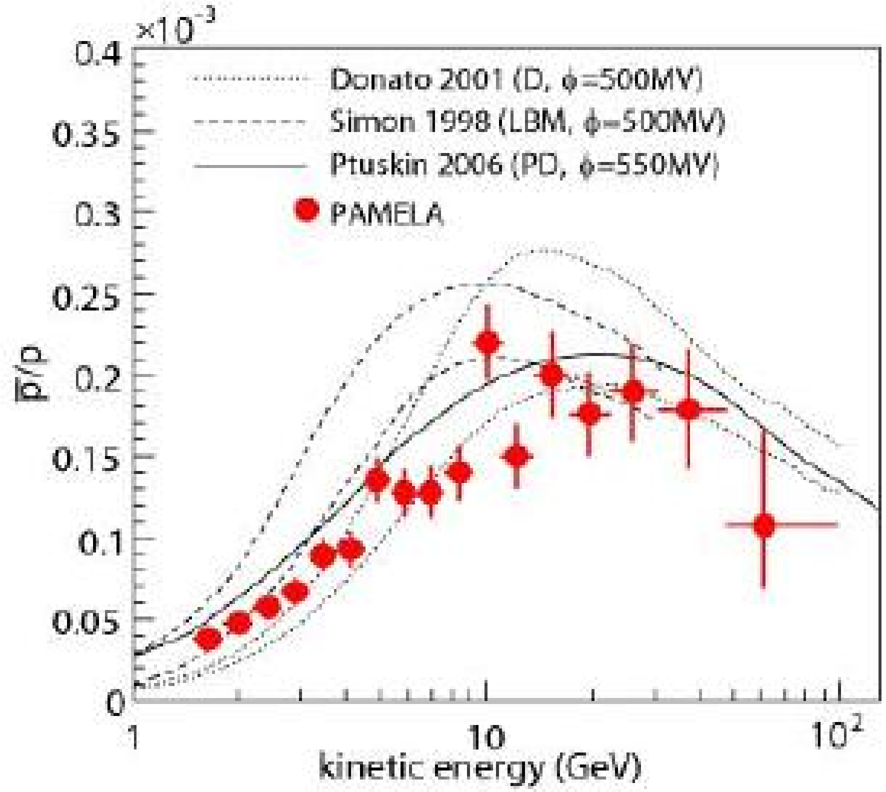
- **Fermi** **[**exp. by a **SATELLITE]** released data on **electrons & positrons fluxes** in cosmic ray.

What are surprising?

PAMELA [arXiv.0810.4994,4995]



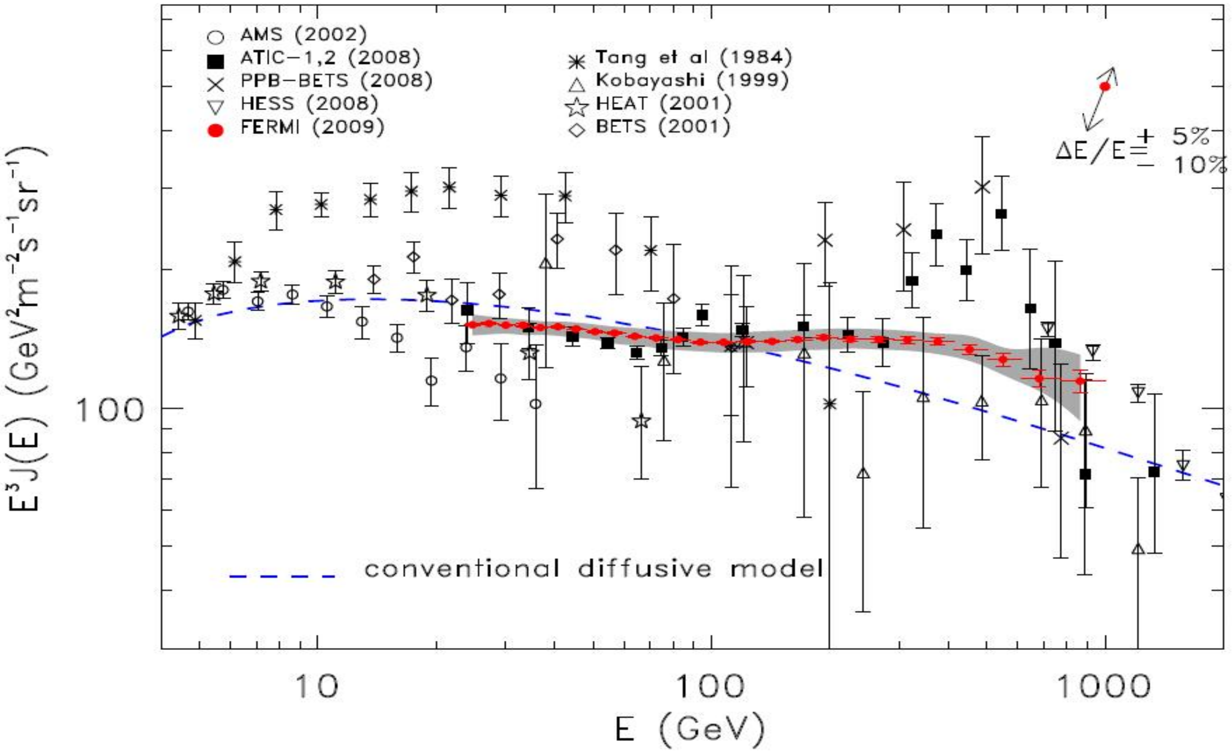
PAMELA positron fraction
v.s. theoretical models
(by Moskalenko & Strong '98)



PAMELA anti-proton/proton flux ratio
v.s. theoretical calculation

What are surprising?

Fermi-LAT [arXiv:0905.0025(astro-ph HE)]



($e^+ + e^-$) excesses of cosmic ray **are observed.**

[100 GeV − 1000 GeV]

What are surprising?

(Fermi-LAT)

Positron excess keeps rising

mildly upto 1 TeV.

As a strong possibility, it can be interpreted as a result from TeV scale DM annihilation or decay.

To explain the e^+ excess with annihilation,

- **Should overcome "helicity suppression," to enhance DM annihl. to e^+e^- .**
  [Need a Large Boost Factor (> 10^4)]

- **Should suppress the hadronic modes.**

"Leptophilic annihilation !!"

Moreover,

Berstone etal. [arXiv:0811.3744]

DM annihl. seems to be disfavored by Gamma ray constraint,

if m_{DM} ∼ TeV (for explaining Fermi),
[$\Phi_{e+} \propto (\rho/m_{DM})^2$] and

if accept the **galactic profile** of

NFW or **Einstasto**, because of

Bremsstrahlung at the galactic center.

DM **DECAY** for e^+ flux

(DM → $e^+ e^-$, $\mu^+ \mu^-$, $\tau^+ \tau^-$ + neutral ptl.)

- We DON'T have to consider "helicity suppression."
- Gamma ray constraint is NOT serious.

  $[\Phi_{e+} \propto (\rho/m_{DM})^1]$
- Hadronic decay should not exceed 10 %.

  i.e. should be "Leptophilic Decay"
- $\Gamma_{DM} \sim 10^{-26}$ sec^{-1} for need e^+ flux
- $m_{DM} \sim 2$ TeV for explaining Fermi
- Various and/or many body leptonic decays are needed for mild positron excess. [Bergtrom etal '09]

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Important Notice [comment 1]

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$$\Gamma_{\rm DM} \sim \frac{m_{\rm DM}^5}{192\pi^3 M_{\rm GUT}^4} \sim 10^{-26} \ \text{sec.}^{-1}$$

by **Dim. 6 operator** suppr. by $\mathbf{M^2_{GUT}}$ (4 fermion int.)

for $m_{DM} \sim 2$ TeV , $M_{GUT} \sim 10^{16}$ GeV

($m_{DM} \sim 100$ GeV , $M_{GUT} \sim 10^{15}$ GeV)

PAMELA/Fermi's observ. might be **a signal of GUT.**

For a promising
DM Decay Model

- Introduce **Leptophilic** int. between superheavy fields and DM.

- Introduce **other** (global) **symmetries** to completely **kill** the **dim. 5** operators.

- Introduce **an extra DM** component with a **TeV scale mass** for light enough Higgs mass.

PAMELA/Fermi anomaly is **easily explained** in 2-DM decay model !!

$$\Phi_{e+}(E) = \left(\frac{\rho}{m_{\rm DM}}\right) \cdot \Gamma_{\rm DM} \times \frac{1}{4b(E)} \int_E^{m_{\rm DM}} dE' \, \frac{dN_{e+}}{dE'} \, I(\lambda_D),$$

In 2-DM model, $(\rho/m_{DM}) = n_N$ can be smaller, only if Γ_{DM} is larger, [but $\Gamma_{DM} < 10^{-17}$ sec^{-1}, (age of univ.)$^{-1}$],

because the needed **$\rho_{DM} \sim 10^{-6}$ GeV cm^{-3} can be supported by χ.**

2 component DM

χ : Thermally produced, Absolutely stable,
Main comp. Relic density explained.

N : Non-thermally produced, Meta-stable,
decay to e^+e^-, PAMELA/Fermi explained.

χ : Absolutely stable, Thermally produced.
N : Meta-stable, Non-thermally produced.

Even extremely small amount of N

$$[\ O(10^{-10}) < (n_N / n_\chi)\ ]$$

can produce the positron flux needed to account for PAMELA/Fermi data,

only if the decay rate is enhanced by relatively lighter M_* ,

$$[10^{12}\ \mathrm{GeV} < M_* < 10^{16}\ \mathrm{GeV}].$$

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In DM decay Models, (1st scenario)

[BK], [K.Bae, BK], [J.Huh, J.E.Kim], etc.

- Explain PAMELA/Fermi data with leptophilic YUKAWA couplings between GUT scale fields and an extra DM component N ($N \to \chi l^+ l^-$).
- Even extremely small amount of N can explain the PAMELA/Fermi data.
- The nobleness of the MSSM (SUSY at 10^2 GeV, gauge coupling unif., χCDM) can be maintained.
- The models can be easily embedded in Flipped SU(5).

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Disadvantages(?) in 1-DM decay Models

- **A natural explanation for 10^{-26} sec.$^{-1}$ decay rate is required.** **(→ Need a Model)**

- **Ad-hoc new TeV DM and new leptophilic interactions are introduced.**

- **Desired relic density is Not automatic.**

  (Need elaborate Non-thermal production of DM.)

I attempt to explain PAMELA (Fermi) only within the framework of a well-known Particle physics model, SO(10) without introducing any new DM and new special interactions. **(2nd scenario)**

[arXiv:0909.3139, **BK**]

From now on,
I will suppose that <u>DM is the bino-like LSP</u>.

SO(10)

$$45_G \;=\; SM + \{E, E^c\} + N$$
$$+ \{Q', Q'^c\} + \{Q, Q^c;\, U, U^c\}$$

where $E = (1,1)_{-1}$, $N = (1,1)_0$,
$Q' = (3,2)_{-5/6}$, $Q = (3,2)_{1/6}$, $U = (3,1)_{2/3}$

$SM + \{E, E^c\} + N = LR$

$SM + \{Q', Q'^c\} = SU(5)$

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$SO(10) \rightarrow SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L} = LR$

by $\langle 45_H \rangle$, $\{Q', Q'^c\}$, $\{Q, Q^c; U, U^c\}$ massive

$SO(10) \rightarrow SU(5)$ by $\langle 16_H \rangle$, $\langle 16^*_H \rangle$

$\{E, E^c\}$, N, $\{Q, Q^c; U, U^c\}$ massive

$\langle 45_H \rangle$ is 10^{16} GeV from RG eff.of the MSSM gauge couplings, but

$\langle 16_H \rangle$ is not pinned down yet.

If **$\langle 45_H \rangle > \langle 16_H \rangle = \langle 16^*_H \rangle$,**

masses of **{Q',Q'^{c}}, {Q,Q^c; U,U^c} > {E,E^c}, N**

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So **{Q,Q^c; U,U^c} are always heavier.**

Superheavy fields in SO(10)

- **Gauge boson/Gauginos** of SO(10)/SM
- **Triplets** in $\mathbf{10_h}$ (=$\{D^c,h_d\}+\{D,h_u\}$)

  e.g. by $\mathbf{10_h \langle 45_H \rangle 10_h}$
- **GUT breaking Higgs**

due to its VEV, they couple to MSSM fields only via non-renormalizable terms. They weakly coupled to SM

LSP decay due to sRH ν

- If (1) R-parity is absolutely preserved, and (2) χ is the LSP, χ can not decay.
- BUT if sRH ν develops a VEV (R viol.), or sRH ν is lighter than χ (sRH ν LSP), χ could decay.
- RH ν and sRH ν are neutral singlets under SM. Were it not for $W=lh_u\nu^c$, it extremely weakly interacting with SM.

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LSP decay due to sRH ν

How can one obtain

e.g. extremely small

R-parity violating effects

NATURALLY?

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Interactions of the MSSM fields and heavy gauginos			
$\tilde{e}_i^{c*}\nu_i^c\tilde{E}^c$,	$\tilde{d}_i^{c*}u_i^c\tilde{E}^c$,	$h_u^{+*}\tilde{h}_d^0\tilde{E}^c$,	$h_u^{0*}\tilde{h}_d^-\tilde{E}^c$
$\tilde{\nu}_i^{c*}e_i^c\tilde{E}$,	$\tilde{u}_i^{c*}d_i^c\tilde{E}$,	$h_d^{0*}\tilde{h}_u^+\tilde{E}$,	$h_d^{-*}\tilde{h}_u^0\tilde{E}$
$\tilde{\nu}_i^{c*}\nu_i^c\tilde{N}$,	$\tilde{u}_i^{c*}u_i^c\tilde{N}$,	$h_u^{+*}\tilde{h}_u^+\tilde{N}$,	$h_u^{0*}\tilde{h}_u^0\tilde{N}$
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$\tilde{e}_i^{c*}q_i\tilde{Q}'^c$,	$\tilde{d}_i^{c*}l_i\tilde{Q}'^c$,	$\tilde{q}_i^*u_i^c\tilde{Q}'^c$	
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$\tilde{q}_i^*\nu_i^c\tilde{Q}$,	$\tilde{l}_i^*u_i^c\tilde{Q}$,	$\tilde{d}_i^{c*}q_i\tilde{Q}$	
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For leptophilic χ decay,

- $\langle 16_H \rangle \ll \langle 45_H \rangle$, effectively LR model
- If $s\nu^c$ is heavier than χ, a non-zero VEV $\langle s\nu^c \rangle$ must be assumed.
- Squarks, charged Higgs, and soft para. are much heavier (~TeV) than a slepton.
- For PAMELA, $m_\chi \sim 300$ GeV, Fermi is explained with astrophys. source.
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Even with 2 heavy RH ν, seesaw mech. is still O.K.

$$W_\nu = y_{ij}^{(\nu)}\ l_i h_u \nu_j^c (j \neq 1) + \frac{1}{2} M_{i,j}\ \nu_i^c \nu_j^c (i, j \neq 1),$$

$$m_\nu = m_\nu^T = - \begin{pmatrix} 0 & v_{12} & v_{13} \\ 0 & v_{22} & v_{23} \\ 0 & v_{32} & v_{33} \end{pmatrix} \begin{pmatrix} 0 & 0 & 0 \\ 0 & M_{22}^{-1} & M_{23}^{-1} \\ 0 & M_{23}^{-1} & M_{33}^{-1} \end{pmatrix} \begin{pmatrix} 0 & 0 & 0 \\ v_{12} & v_{22} & v_{32} \\ v_{13} & v_{23} & v_{33} \end{pmatrix}$$

Still 3 LH ν can be maximally mixed.

[Frampton, Glashow, Yanagida (2002)]

If sRHν is lighter than χ, a VEV of sRHν is not essential. → 4 bdy decay !!

Just for simplicity, assume a VEV of sRHν.
(→ 3 bdy decay)   e.g. by

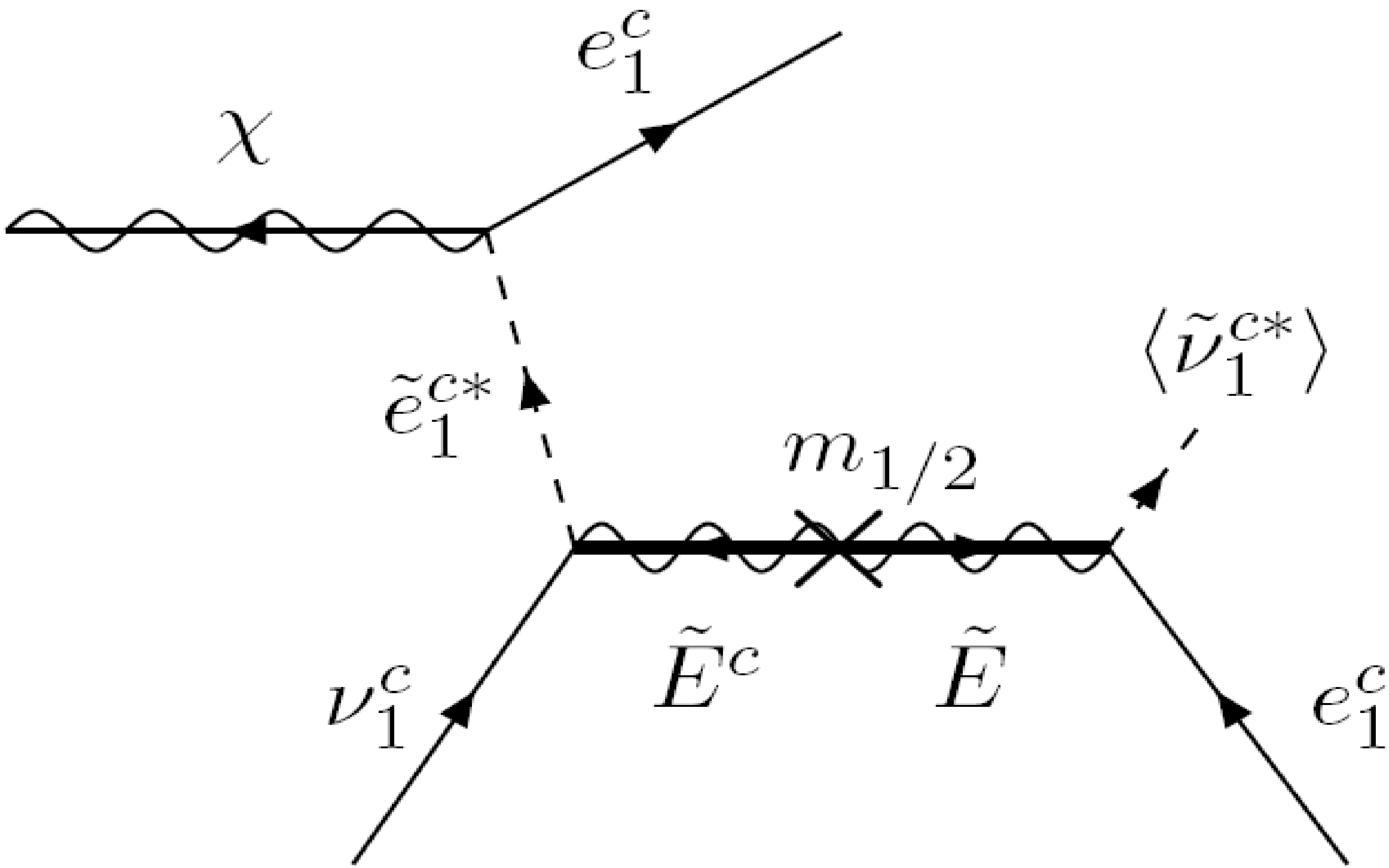
$$W \supset \frac{1}{M_P} \langle \overline{\mathbf{16}}_H \rangle \mathbf{16}_1 S^2 + S^3$$

$R(16_1) = R(S) = 2/3$
$R(16^*_H) = 0$

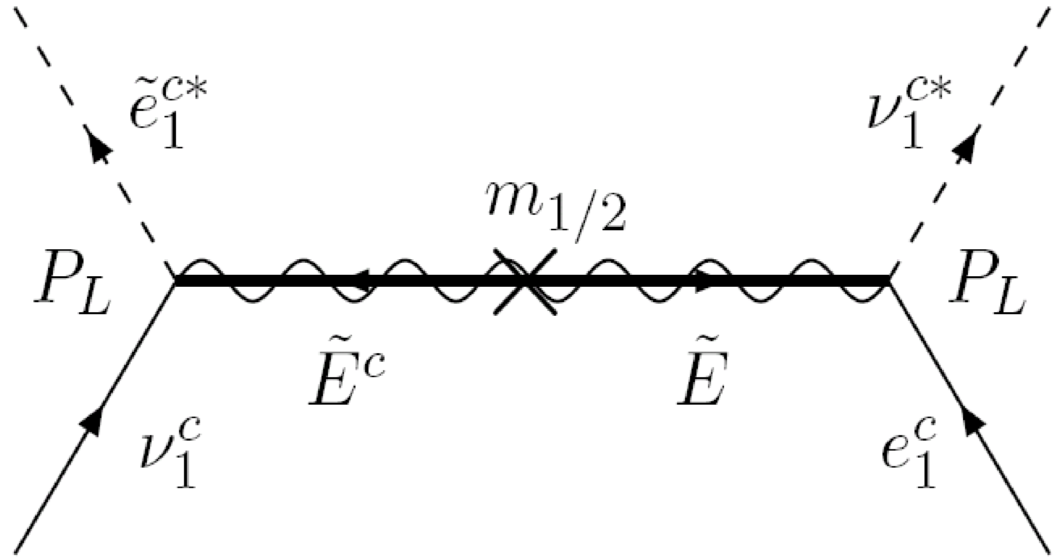
including soft terms in V,

$$\langle \tilde{\nu}_1^c \rangle \sim m_{3/2} \times \frac{M_E}{M_P}$$

LSP decay diagram



Charged gaugino mediation

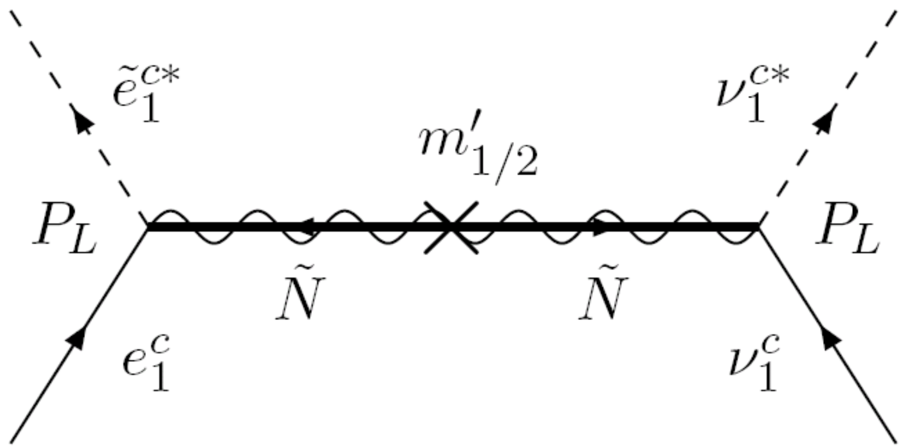


Dirac mass M_E by Gauge sym. breaking >> Majorana mass $m_{1/2}$ by SUSY breaking

This diagram is suppressed by

$$m_{1/2}/ M_E^2$$

Neutral gaugino mediation



$g_{LR} = (2/3)^{1/2}\, g_{B-L} = g_{10}$

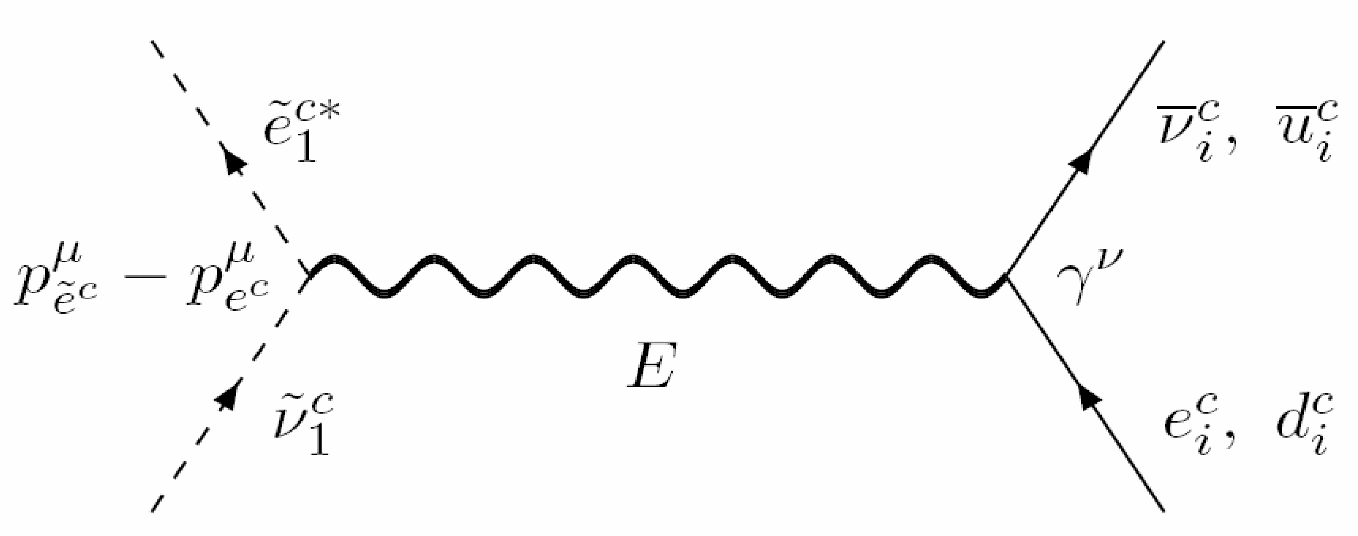
$M_N = M_E \times (5/2)^{1/2}$

Eff. coupling is ¼ of the C.C. case.

Suppressed by 2/5 x 1/4 = 1/10

Compared to the C.C. case

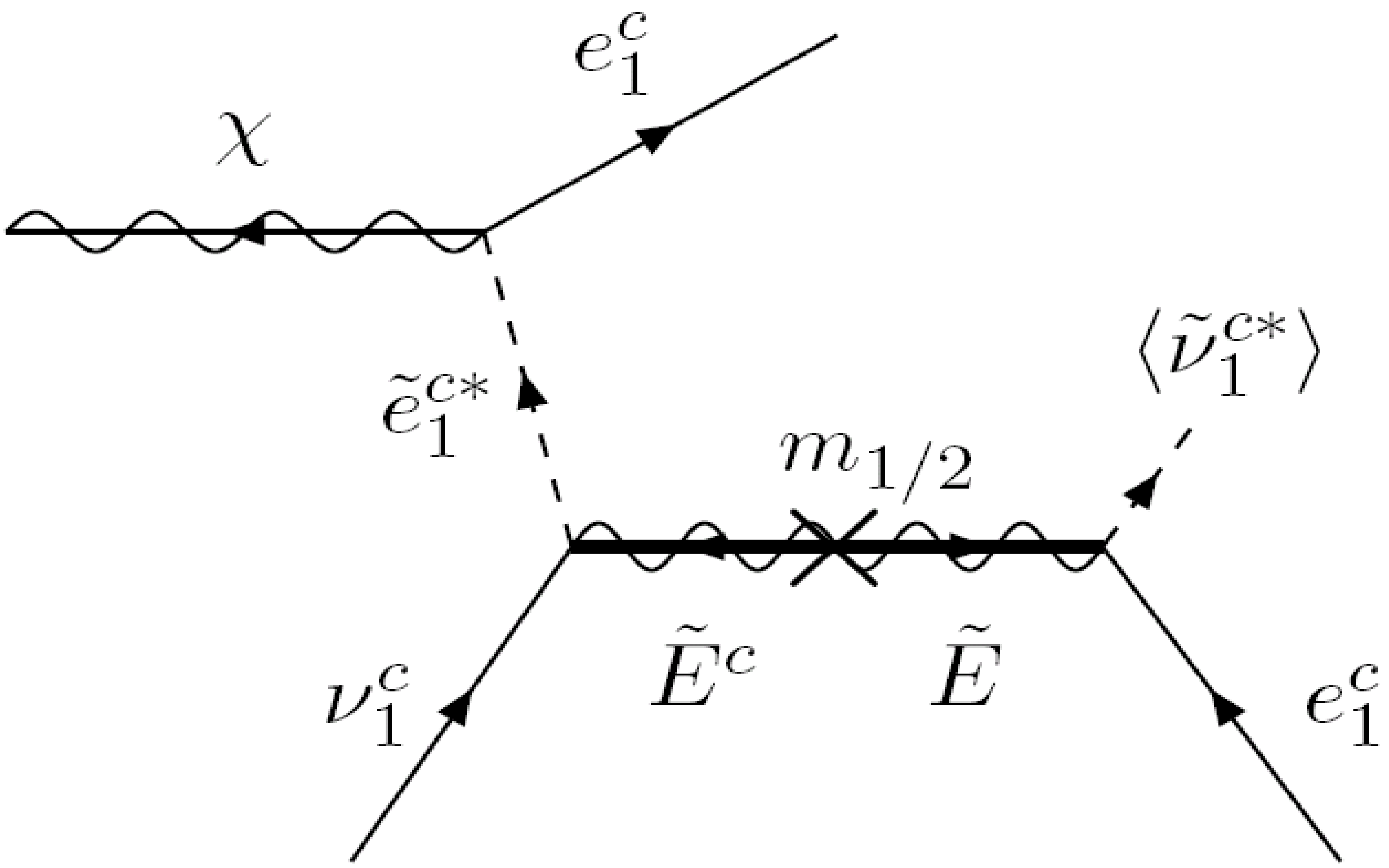
Charged gauge field mediation



A derivative coupling is involved.

Since $m_{1/2} >> m_{\chi}$ this diagram is suppressed.

LSP decay diagram



The 1st realization of $\Gamma_\chi \sim 1 / (M_{GUT})^4$ from the gauge interaction.

The **decay rate of χ** is

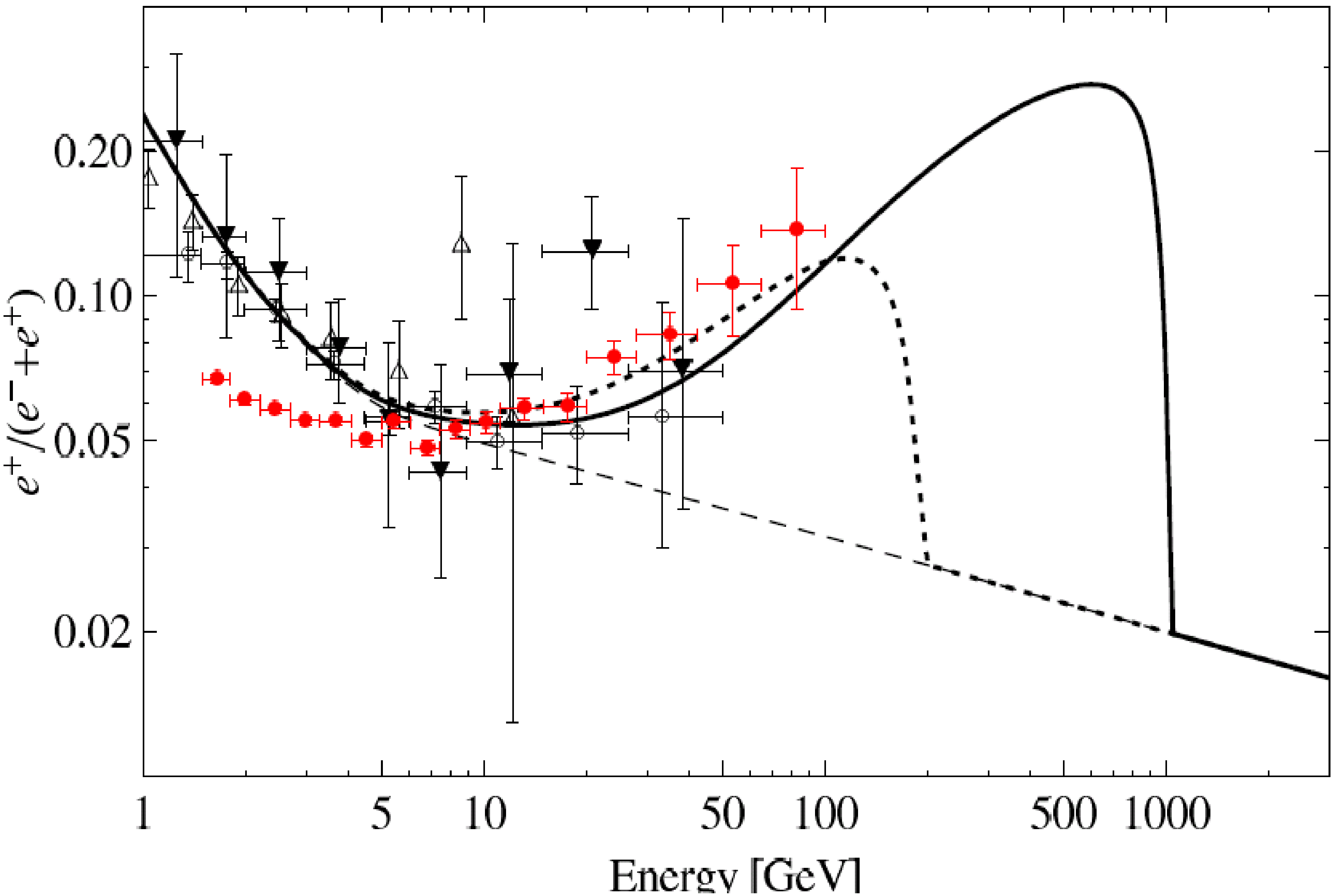
$$\Gamma_\chi = \frac{\alpha_{10}^2 \alpha_Y m_\chi^5}{96 M_E^4} \left(\frac{m_{3/2} \langle \tilde{\nu}_1^c \rangle}{m_{\tilde{e}_1^c}^2} \right)^2 \sim \frac{\alpha_{10}^2 \alpha_Y m_\chi^5}{96 M_E^2 M_P^2} \left(\frac{m_{3/2}}{\kappa m_{\tilde{e}_1^c}} \right)^4 \sim 10^{-26}\ \mathrm{sec.}^{-1},$$

To be consistent with the **PAMELA**'s data,

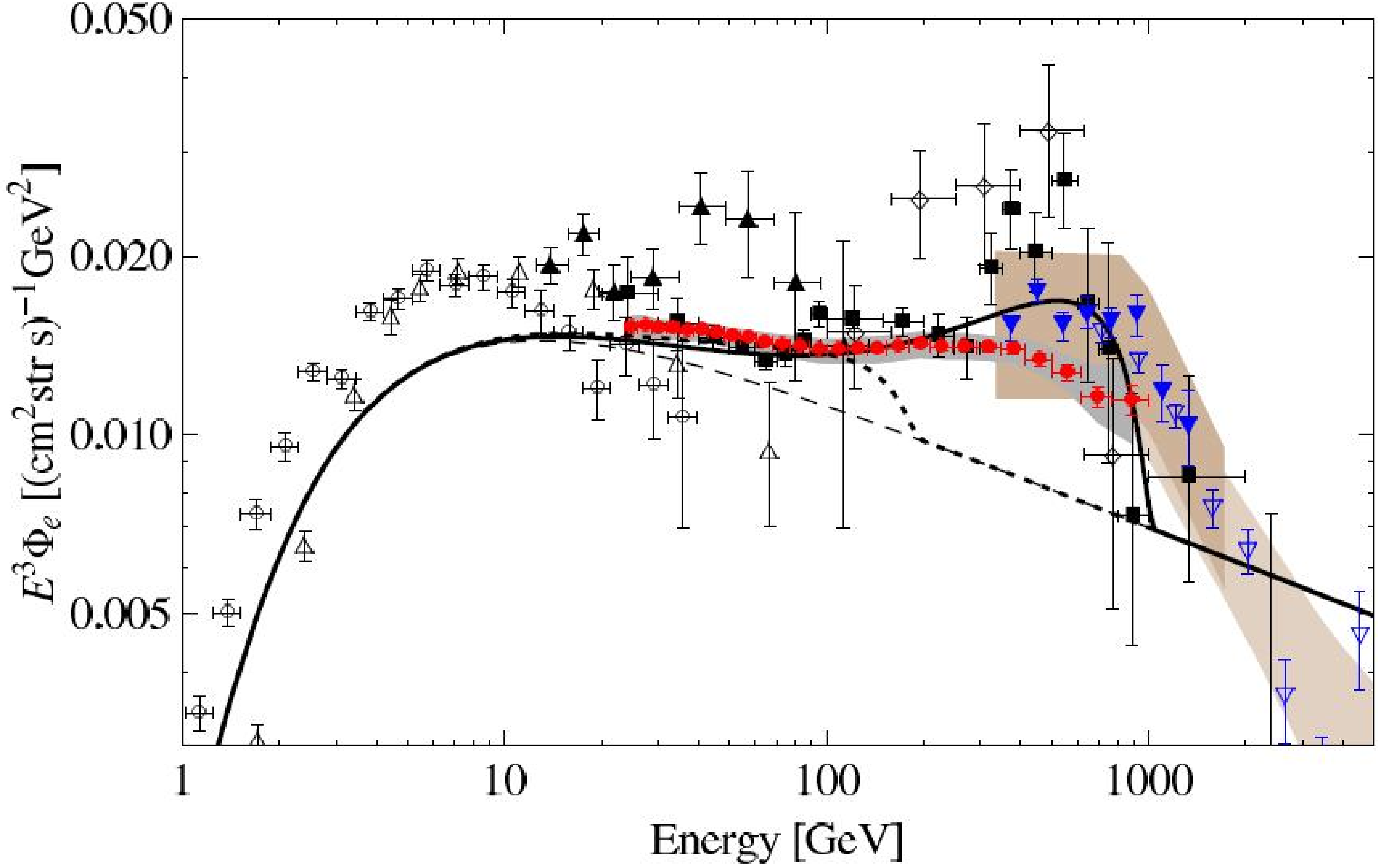
$M_E \sim \langle 16_H \rangle \sim 10^{14}$ GeV

2 RH ν masses $\sim 10^{10}$ GeV

from $$W \supset \frac{1}{M_P} \langle \overline{16}_H \rangle \langle \overline{16}_H \rangle 16_i 16_j (i,j \neq 1) \supset (10^{10}\ \mathrm{GeV}) \times \nu_i^c \nu_j^c (i,j \neq 1)$$



Dotted Line: $\chi \rightarrow e^+e^-\nu$, $M\chi$=400 GeV, [Ibarra,etal '09]



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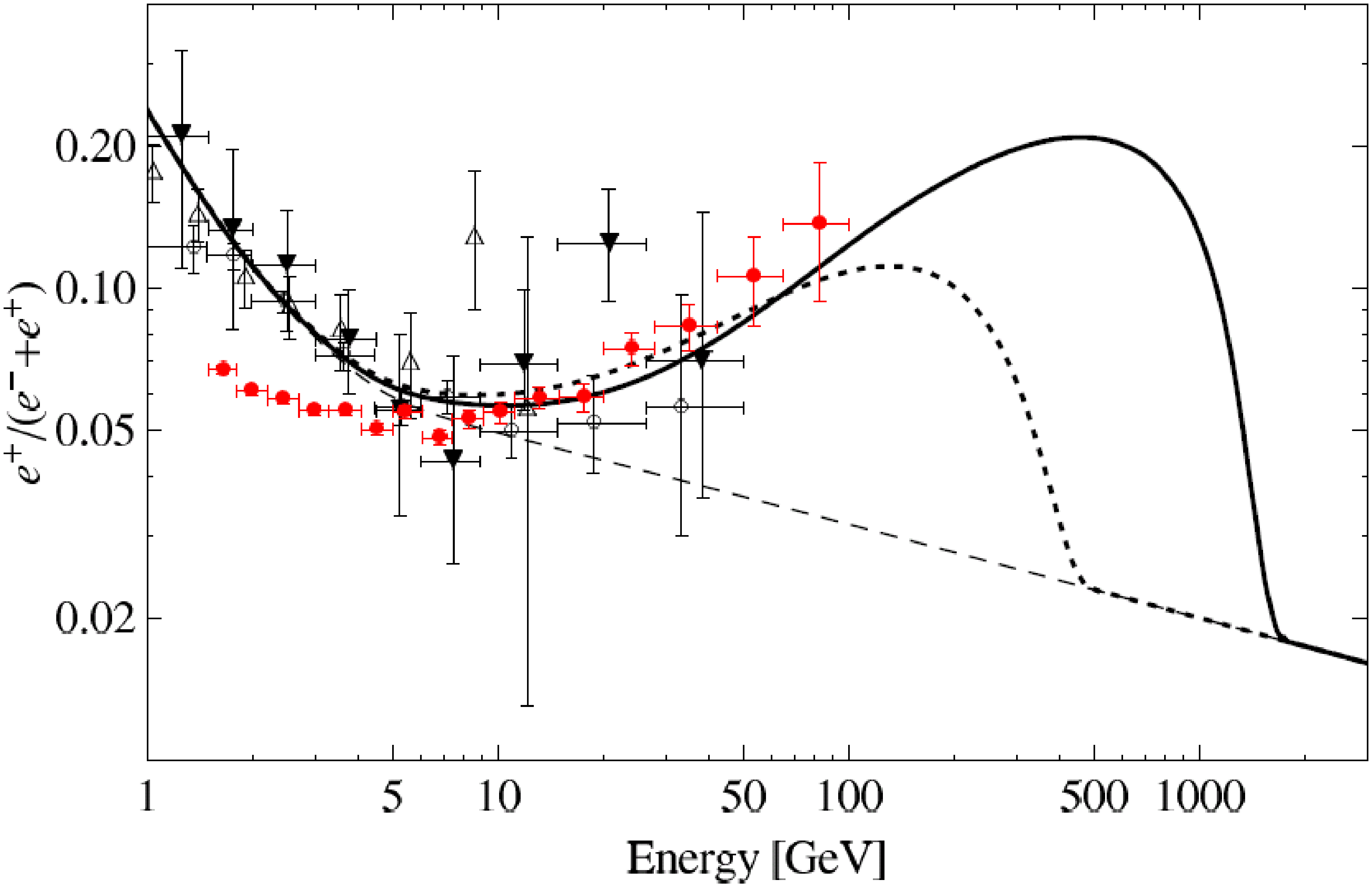
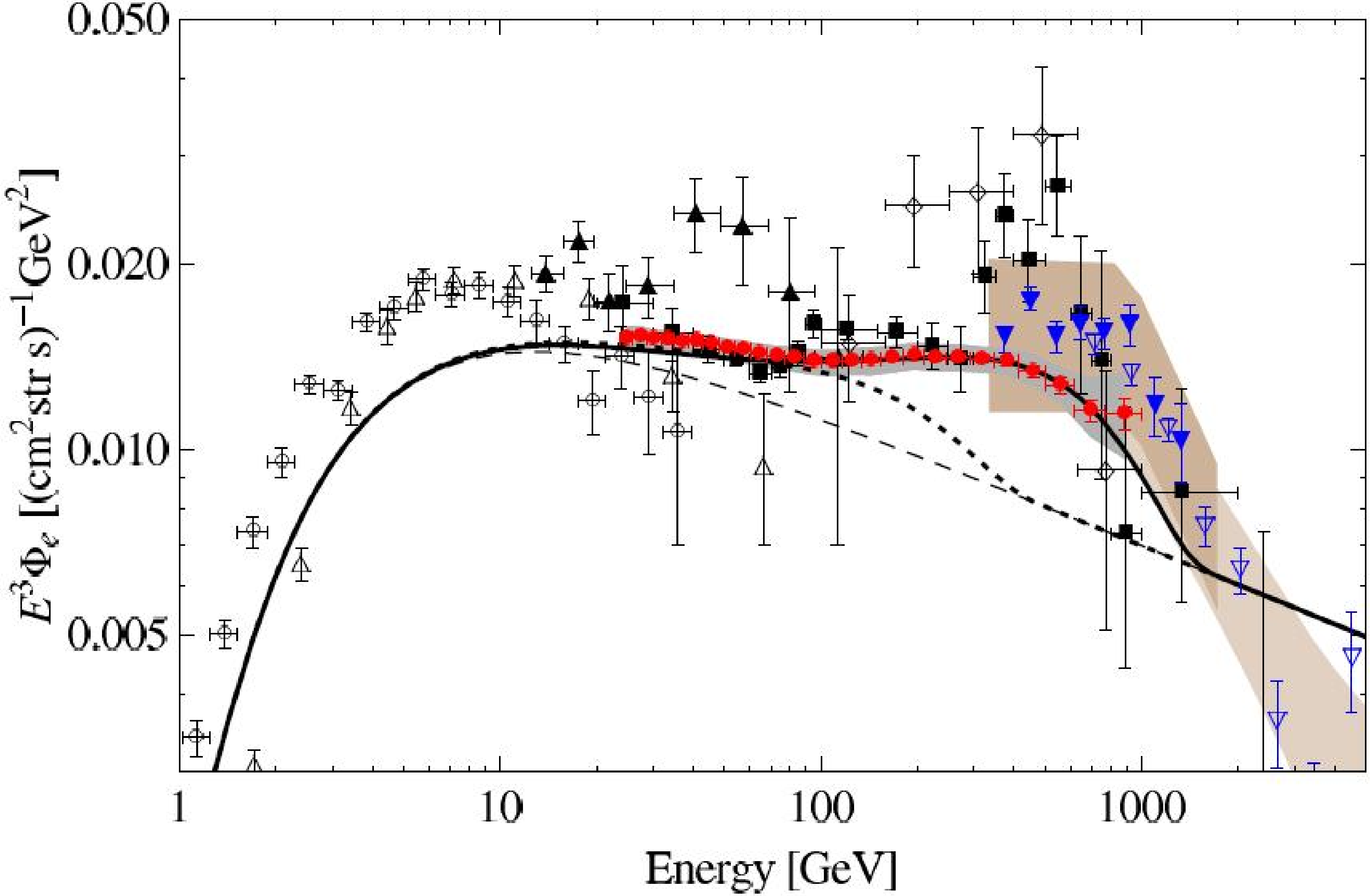
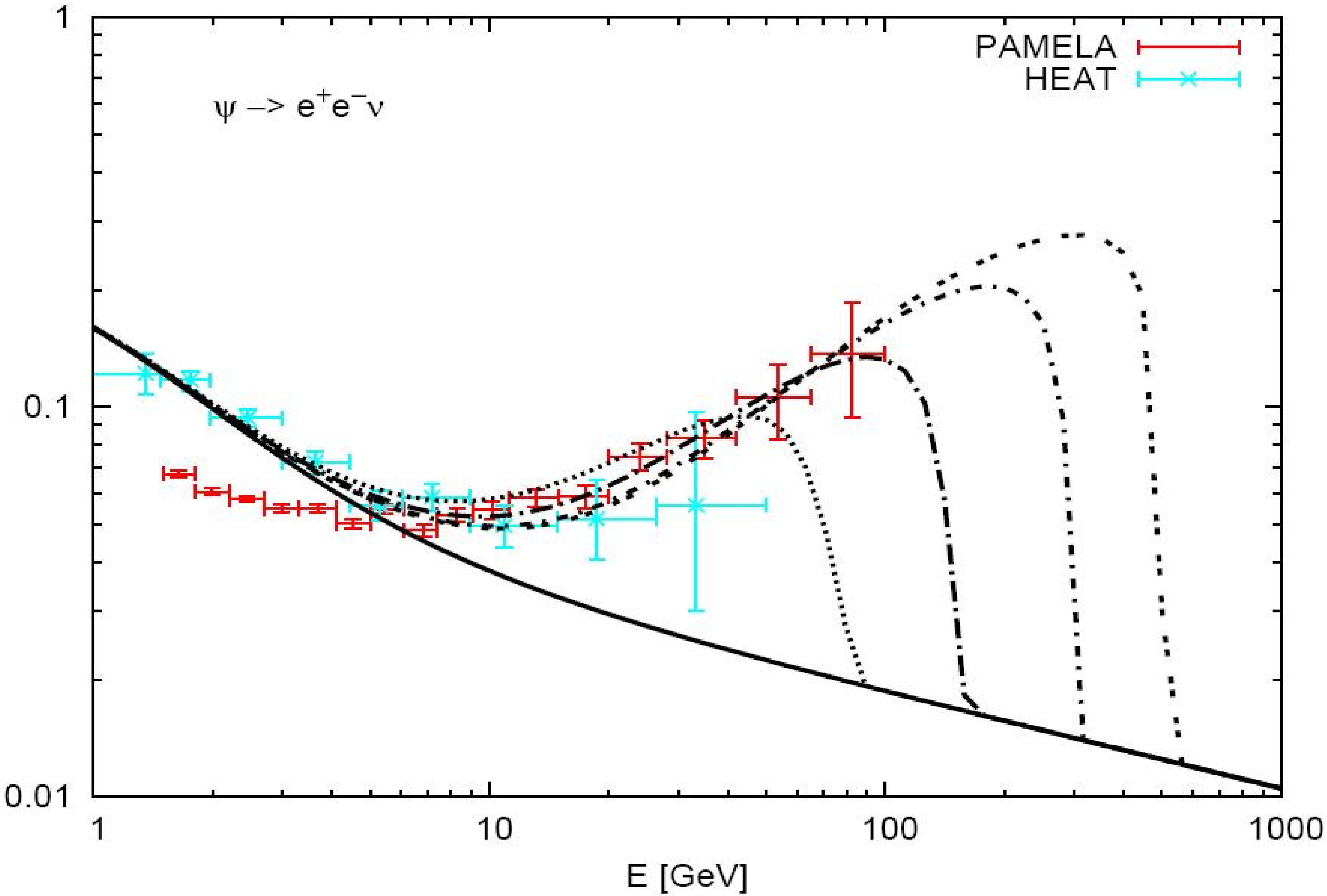


Solid Line: $\chi \to \mu^+\mu^-\nu$, M_χ=3.5 TeV, [Ibarra,etal '09]



Solid Line: $\chi \to \mu^+\mu^-\nu$, $M\chi$=3.5 TeV, [Ibarra,etal '09]



Thick Line: $\chi \rightarrow e^+e^-\nu$, M$\chi$=300 GeV, [Ibarra,etal '08]

Conclusions

- **Still the bino-like LSP DM scenario is consistent with PAMELA,**

  if sRH ν develops a VEV or is lighter than bino, and a RH ν is light enough.

- **SO(10) provides a relatively predictable explanation.**

- **In the specific case, LR breaking scale is 10^{14} GeV, and the seesaw scale is 10^{10} GeV.**