R-Partity Breaking via Type II Seesaw, Gravitino Dark Matter and Positron Excess

Shao-Long Chen

University of Maryland

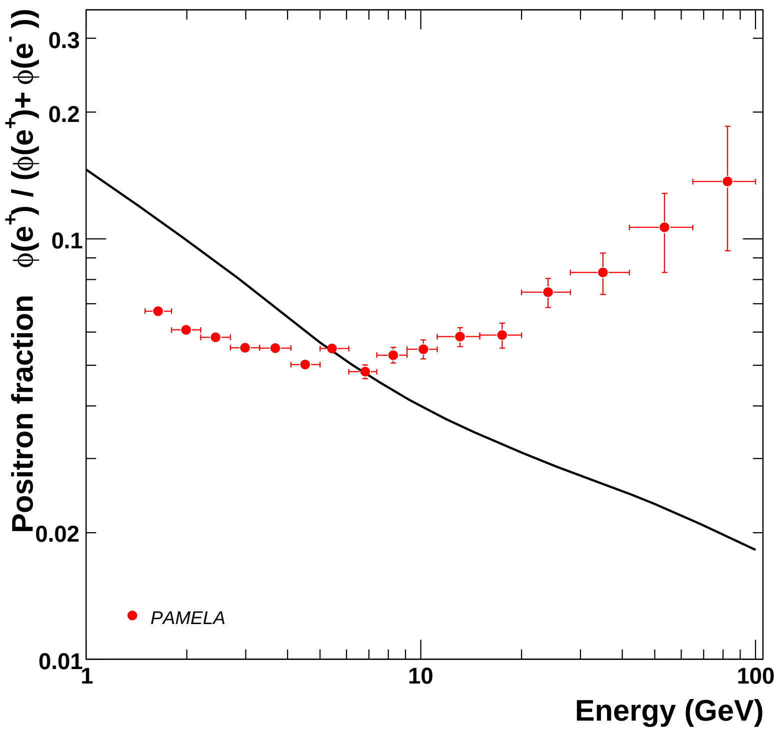
Pheno 2009
Based on arXiv:0903.2562

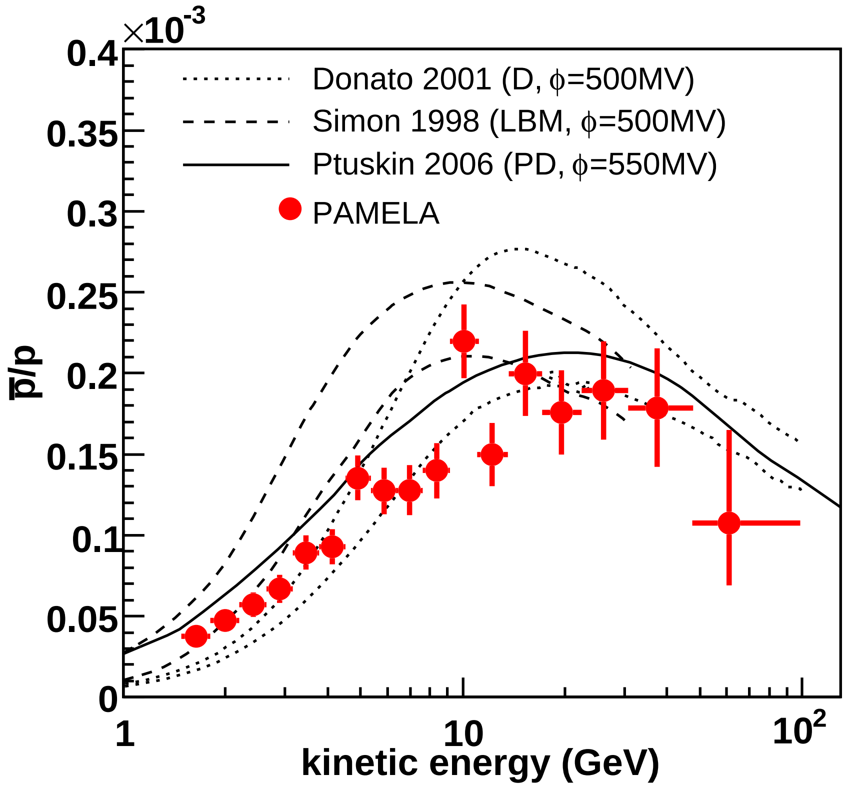
in collaboration with R. N. Mohapatra, S. Nussinov and Yue Zhang

♢ Outline

1. Motivation;
2. R-parity violating via Type-II seesaw;
3. Cosmic electrons excess from Gravitino decay;
4. Summary.

PAMELA positrons excess

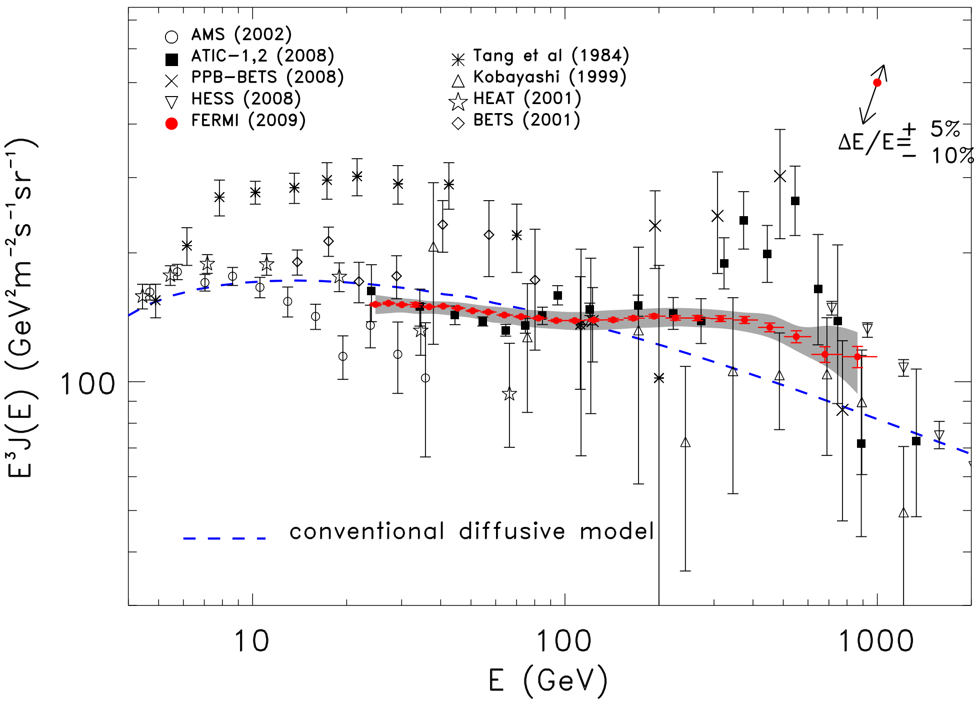


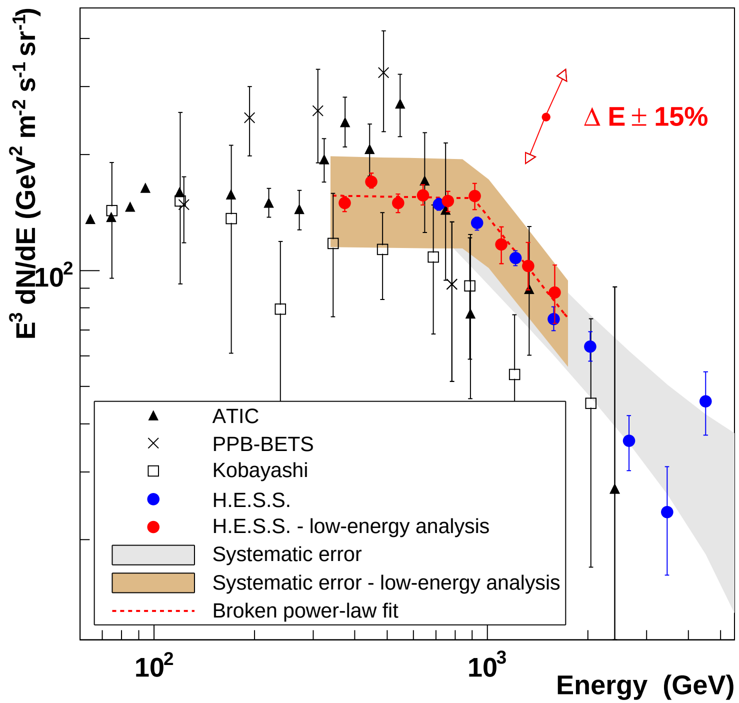


PAMELA: positron excess but no anti-proton in the energy range of $10 \sim 100$ GeV.

PAMELA collaboration ArXiv:0810.4994, 0810.4995

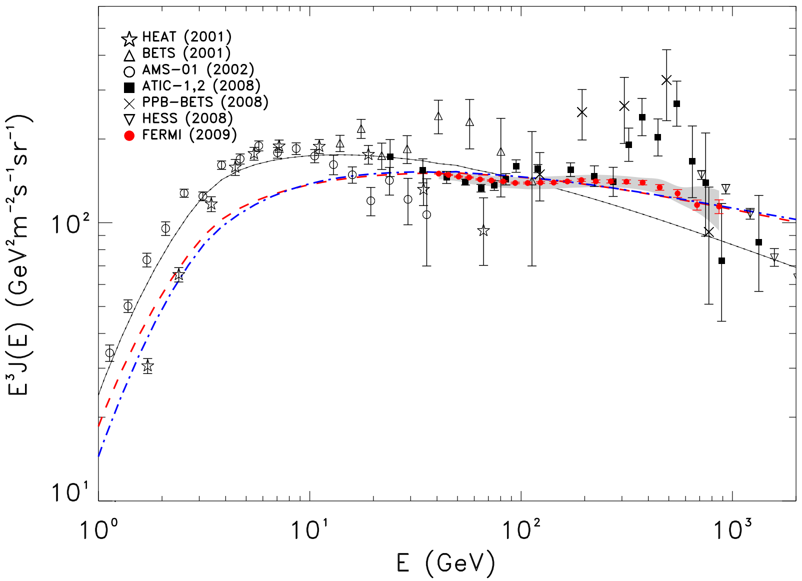
Fermi, HESS, ATIC electrons/positrons excess

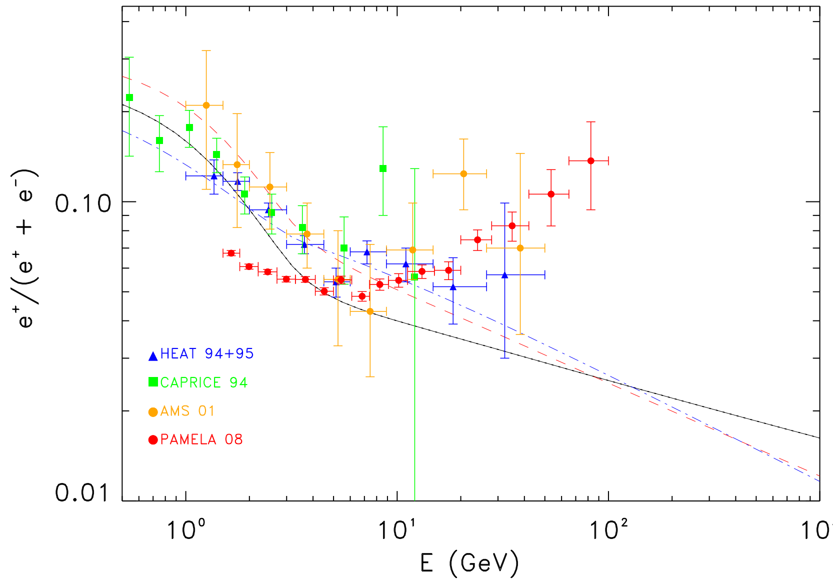




ArXiv:0905.0025, 0905.0105

Modified background ArXiv:0905.0636[astro-ph.HE]





The black continuos line corresponds to the conventional model used in (Strong et al. 2004) and the red dashed and blue dot-dashed lines are obtained with modified injection indexes in order to fit Fermi-LAT CRE data.

Interpretation of the observations

♣ Astrophysical sources: Nearby pulsars, ...
♣ Dark matter: stable dark matter pair annihilation and decaying dark matter

- how to explain the lack of any excess in the hadrons?
- how does one get an adequate enough electron/positron production rate to explain the excess?

◇ dark matter pair annihilation: an additional enhancement ($\sim 10^{2-3}$) is required for the annihilation cross section required by relic density. (Sommerfeld enhancement, Breit-Wigner resonance, non-thermal relic density, or nearby clump dark matter, ...)

◇ dark matter decay: $\sim 10^{26}$ sec lifetime.

with Leptophilic channels, either by dynamics or kinematically.

Gravitino as the decaying dark matter with RPV.

Due to the factor $1/M_{Planck}$ suppression, gravitino has very long lifetime to be dark matter.

Considering MSSM with RPV terms LLe^c, QLd^c, $u^cd^cd^c$ and LH_u. $\tilde{G}$ mainly decays to $Z\nu, \gamma\nu, W^{\pm}\ell^{\mp}$. $\Rightarrow$ both leptons as well as hadrons in the final states of gravitino decay.

If one kept only the LLe^c term, then the predominant decay mode of the gravitino will only be to leptons.

While the strength of the coupling λ required for keeping baryon asymmetry is too small ($\lambda < 10^{-7}$) [B. A. Campbell *et al.* (1991); H. Dreiner *et al.* (1993).] to explain neutrino masses via loop corrections.

We propose a new class of R-parity violating interactions that can arise in extensions of MSSM:

- ♢ explains small neutrino masses and mixings via the type II seesaw mechanism;
- ♢ keeps the baryon asymmetry of the universe untouched;
- ♢ able to explain the leptophilic nature of the PAMELA observations.

A well hidden in low energy processes RPV term

extend MSSM by adding $SU(2)_L$ triplets Δ, $\bar{\Delta}$ with $Y = \pm 2$.

with the superpotential as:

$$\begin{aligned} W &= \lambda_u Q^T i\tau_2 H_u u^c + \lambda_d Q^T i\tau_2 H_d d^c + \lambda_l L^T i\tau_2 H_d e^c + \mu H_u H_d \\ &+ f L^T i\tau_2 \Delta L + \epsilon_d H_d^T i\tau_2 \Delta H_d + \epsilon_u H_u^T i\tau_2 \bar{\Delta} H_u + \mu_\Delta \mathrm{Tr}\left(\Delta\bar{\Delta}\right) \\ &+ f_A \widetilde{L}^T i\tau_2 \Delta \widetilde{L} + \epsilon_{dA} H_d^T i\tau_2 \Delta H_d + \epsilon_{uA} H_u^T i\tau_2 \bar{\Delta} H_u + b_\Delta \mathrm{Tr}\left(\Delta\bar{\Delta}\right) + h.c. \,. \end{aligned}$$

♣ add R-parity violating term:

$$\delta W_{\not R} = a \Delta H_d L.$$

The associated soft breaking terms is:

$$\mathcal{L}_{\not R} = \rho \widetilde{L} \Delta H_d + \mathrm{h.c.}$$

Neutrino masse:
through by type II seesaw after the triplet Higgs gets vev $v_T \sim \epsilon_{u,d} v_{wk}^2 / M_S$.

$$m_\nu = 2 f v_T \lesssim 0.1 \text{eV} \,,$$

then implies that if $v_T \leq$ MeV ($\epsilon_{u,d} \leq 10^{-5}$), $f \geq 10^{-7}$.

$\nu - \widetilde{\Delta}$ mixing gives contribution $\sim (a v_{wk})^2 / M_{SUSY}$ via a seesaw-like formula, but negligible compared to that from type II.

LFV constraints on the couplings f, eg. $\mu \to 3e$ gives $f_{11} f_{12} \leq 10^{-6}$.

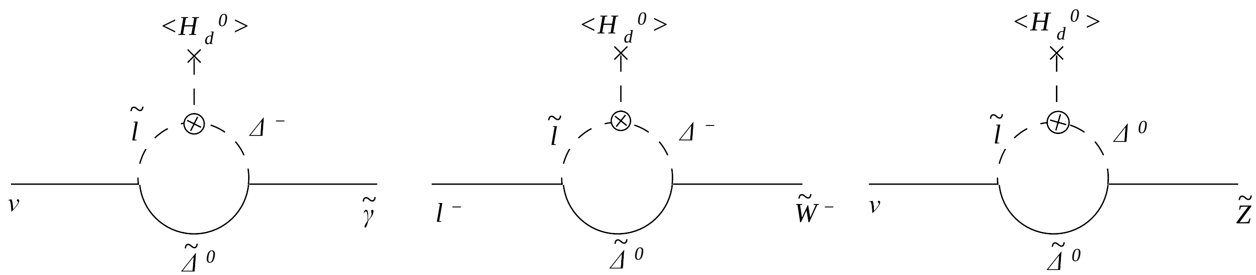
♣ RPV induced mixing and Gravitino decay:

The $\Delta - \widetilde{\ell}$ mixing:

$$U_{\widetilde{e}\Delta} \simeq \frac{(\rho + a\mu)v_{wk}}{m_{\widetilde{e}}^2 - m_\Delta^2} \; .$$

Then the gravitino will decay through $\widetilde{G} \to \ell\delta \to \ell\ell\nu$.

These mixings between $\widetilde{\gamma}\nu$, $\widetilde{W}\ell$, $\widetilde{Z}\nu$ etc. are severely suppressed.



♣ monochromatic neutrino signatures: $\tilde{G} \to \nu\delta^0(3\nu)$ when $m_{\tilde{G}} > m_\delta$.

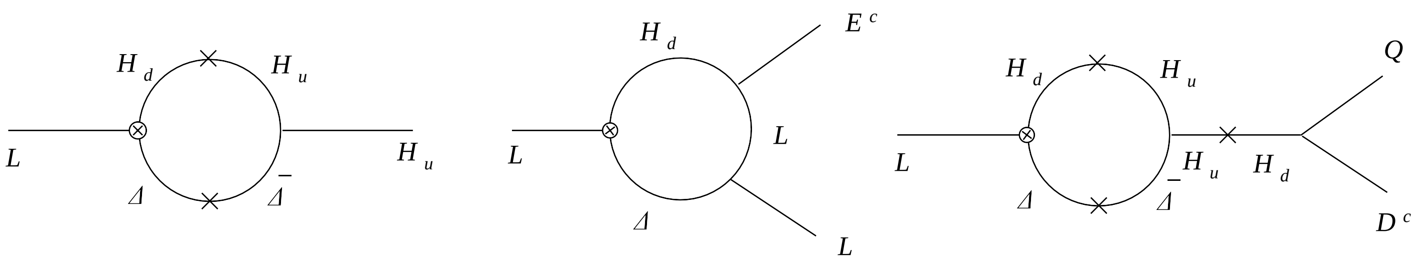
Radiative stability

- the radiative correction to ϵ is safe due to the non-renormalization theorem of SUSY.
- for ϵ_A, due to symmetry argument (lepton number and restored PQ symmetry by assigning charges to fields and spurion's parameters see Arxiv:0903.2562 appendix).

$$\delta\left(\frac{\epsilon_A}{v_{wk}}\right) \propto \frac{1}{16\pi^2} a^2 \, .f$$

So the smallness of ϵ_A is stable under radiative corrections.

- the usual R-parity violating MSSM terms generated through radiative corrections Their strengths are, however, very weak and do not lead to any observable effects.



Diffusion

The transport equation

$$\nabla \cdot (K(E,\vec{x})\nabla f_{e^+}) + \frac{\partial}{\partial E}(b(E,\vec{x}) f_{e^+}) + Q(E,\vec{x}) = 0 \ ,$$

f_{e^+} is the number density of positron per unit energy,
$K(E,\vec{x})$ is the diffusion coefficient,
$b(E,\vec{x})$ is the rate of energy loss $\quad b(E) \approx 10^{-16}(E/1\mathrm{GeV})^2 \mathrm{sec}^{-1}$.
The source term $\quad Q(E,\vec{x}) = \frac{\rho(\vec{x})}{m_{\widetilde{G}}\tau_{\widetilde{G}}}\frac{dN_{e^+}}{dE}$.
The solution of the transport equation at the Solar system can be expressed by the convention [Ibarra *et al.* 2008]

$$f_{e^+}(E) = \frac{1}{m_{\widetilde{G}}\tau_{\widetilde{G}}}\int_0^{E_{max}} dE' G(E,E')\frac{dN_{e^+}}{dE'} \ ,$$

The positron flux from gravitino decay can then be obtained from

$$\Phi_{e^+}^{prim}(E) = \frac{c}{4\pi} f_{e^+}(E) = \frac{c}{4\pi m_{\widetilde{G}}\tau_{\widetilde{G}}}\int_0^{E_{max}} dE' G(E,E')\frac{dN_{e^+}}{dE'} \ .$$

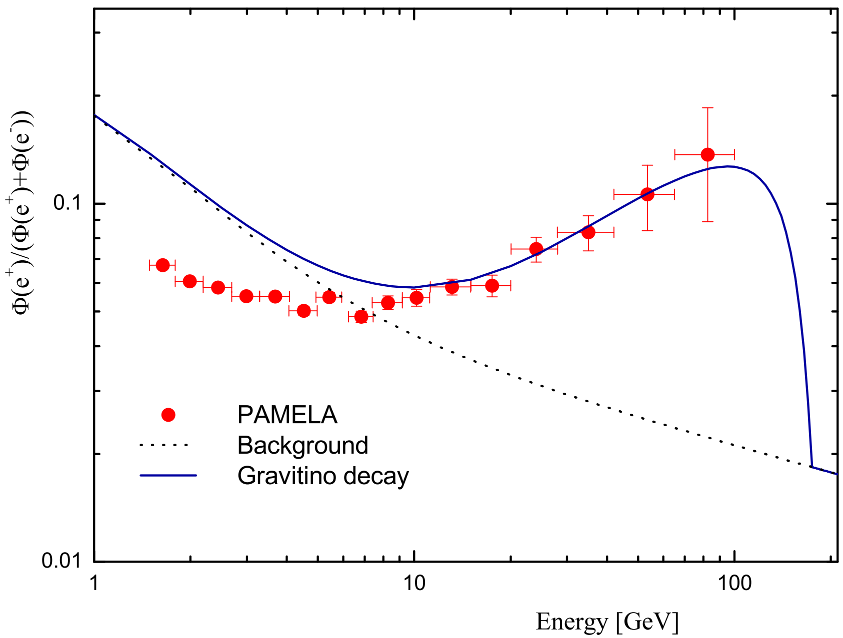
Astrophysical background:

We use the parametrizations obtained in [Baltz *et al* 1998, Moskalenko 1997] with the fluxes in units of (GeV^{-1} cm^{-2} sec^{-1} sr^{-1}):

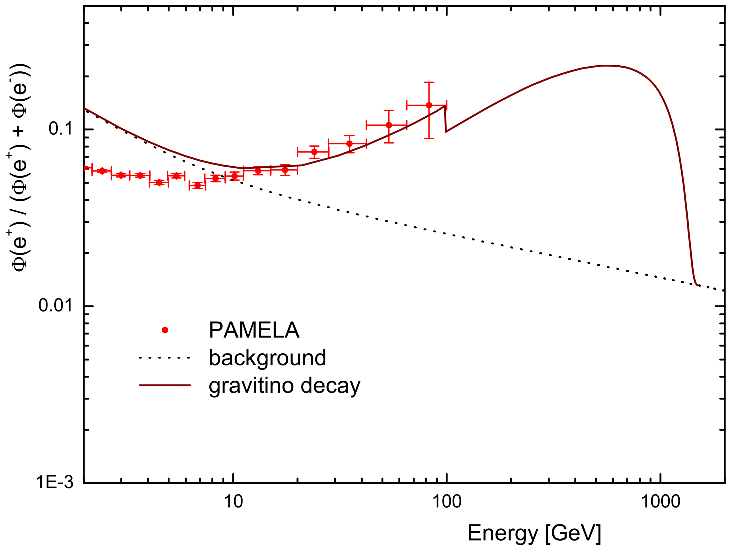
$$\begin{aligned}
\Phi_{e^-}^{prim}(E) &= \frac{0.16E^{-1.1}}{1 + 11E^{0.9} + 3.2E^{2.15}} \,, \\
\Phi_{e^-}^{sec}(E) &= \frac{0.7E^{0.7}}{1 + 110E^{1.5} + 600E^{2.9} + 580E^{4.2}} \,, \\
\Phi_{e^+}^{sec}(E) &= \frac{4.5E^{0.7}}{1 + 650E^{2.3} + 1500E^{4.2}} \,,
\end{aligned}$$

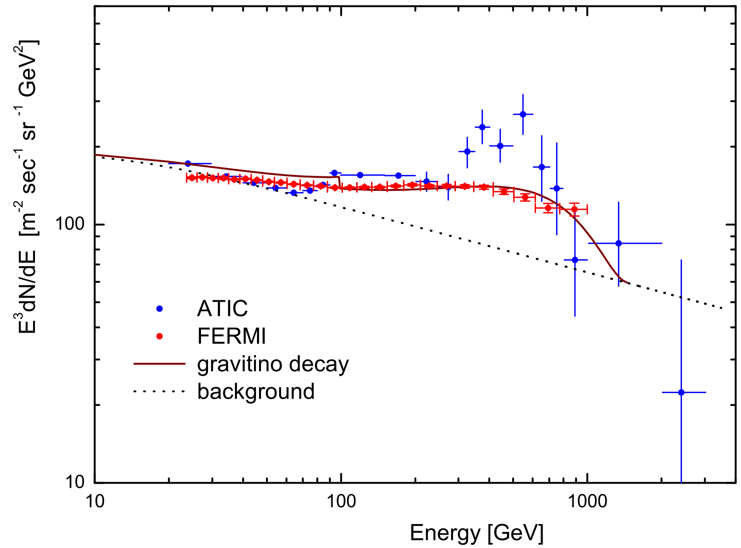
where E is expressed in units of GeV.

To fit the PAMELA's data, as an example, we take $m_{\widetilde{G}} = 350$ GeV, $m_\Delta = 700$ GeV, $|fU_{\widetilde{\ell}\Delta}| = 2.5 \times 10^{-8}$, therefore the lifetime of gravitino is about 2.1×10^{26} sec (for simplicity, degenerate neutrino mass hierarchy used).



The fit after Fermi LAT data





Here we use $m_{\tilde{G}} = 3$ TeV, m_δ=2.9 TeV, $\tau_{\tilde{G}} = 0.42 \times 10^{26}$ sec by taking the neutrino mass normal hierarchy. (Triplet Higgs Δ mainly decay to μ and τ's.)

Summary

- A new R parity violating scenario is proposed which related to the neutrino mass via type II seesaw.
- This provides a natural explain of small neutrino mass and the positron/electrons excess, but no excess in hadron.
- This class of R-parity breaking models remains very well hidden from low energy experimental probes.

backup slides