Minimal SUSY Dark Matter for Fermi-LAT/PAMELA Cosmic-ray data

Based on
JHH, J. E. Kim and B. Kyae, Phys. Rev. D79 (2009) 063529
K. J. Bae, JHH, J. E. Kim, B. Kyae, and R. D. Viollier, Nucl. Phys. B817 (2009) 58
JHH and Jihn E. Kim, Phys. Rev. D 80 (2009) 075012

Ji-Haeng Huh

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BEYOND 2010, Cape Town

Outline

DM

Nowadays, there is no doubt in existence of Dark Matter(DM).

- Rotation curves of galaxies
- Multi-disciplinary study on galaxy clusters (Bullet cluster)
- Cosmic Microwave Background (WMAP)

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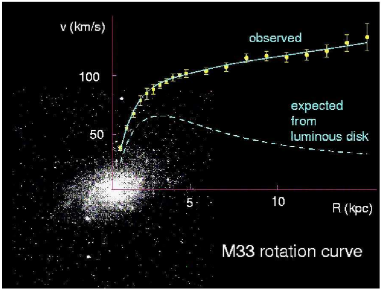

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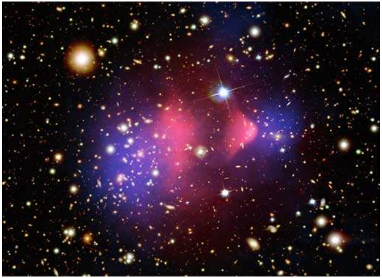

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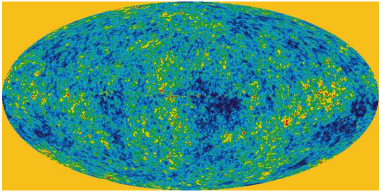

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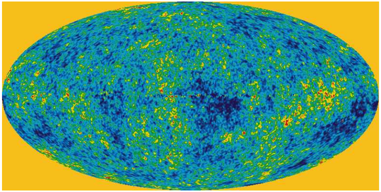

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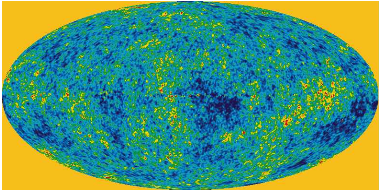
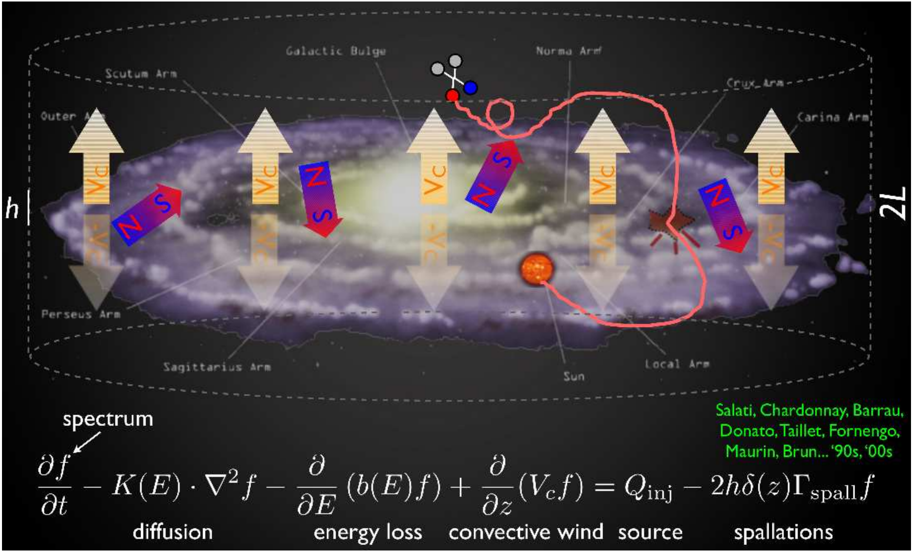


- But nobody knows non-gravitatinal nature of DM at all.
- Recently, however, charged Cosmic-Ray(CR) excesses are reported. It's a candidate of firstly-observed, non-gravitational DM signal.

Cosmic-ray (CR)

- Victor Hess(Aug.7, 1912) first discovered CR.
- In 1948, it was found that CR contains various nuclei.
- Their relative abundances give us hints about their origin and propagation mechanism.
  -B/C ratio ; ratio between prmary and secondary component
  -K-capture decaying isotope ; propagation length and time
- There two kinds of CR.
  - Primary CR
    (from Supernova Remnants)
  - Secondary CR
    (from spallation process between primary CR and Inter Stellar Medium)
- In conventional CR model, primary CR doesn't contain anti-particle. (e.g., positron or antiproton)

CR propagation model



Cirelli's talk in SUSY '09

diffusion and propagation

- Diffusion-loss equation

$$\frac{\partial f}{\partial t} - K(E) \cdot \nabla^2 f - \frac{\partial}{\partial E}(b(E)f) + \frac{\partial}{\partial z}(V_c f) = q$$

- diffusion coefficient $K(E) = K_0(E/\mathrm{GeV})^\delta$ (turbulent magnetic fields)
- energy loss coefficient $b(E) = E^2/(\mathrm{GeV}\tau_E)$ with $\tau_E = 10^{16}$s (synchrotron radation and inverse Compton scattering)
- convecting wind $V_c = V_c(z)$ (To explain observed galatic wind of ext-galaxies and isotope ratio spectrum.)
- source term $q = q_{\mathrm{primary}} + q_{\mathrm{secondary}}$ and $q_{\mathrm{primary}} \propto (E/E_0)^{-\gamma}$ (primary source is supernovae remnants. The Acceleration mechanism is not understood enough to fix the injection spectrum γ. Fitting with EGRET data gives $\gamma \sim 2.54$.)

CR experiments

- These days, there are lot of CR experiments.
- AMS, ACE, HESS, Fermi-LAT(a.k.a GLAST), ATIC, BESS, PPB-BETS, CAPRICE, CREAM, HEAT, PAMELA

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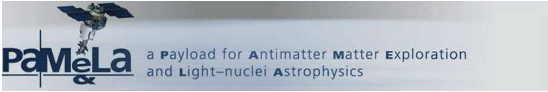
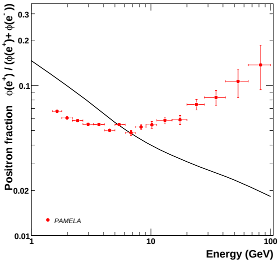
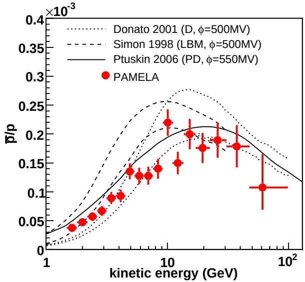
- AMS, ACE, HESS, Fermi-LAT(a.k.a GLAST), ATIC, BESS, PPB-BETS, CAPRICE, CREAM, HEAT, PAMELA
- Some of them reported excess of CR. Moreover, recently, two experiments confirms these excesses with better statistics.

PAMELA



- positron fraction $e^+/(e^+ + e^-)$
- anti-proton/proton ratio $\bar{p}/p$





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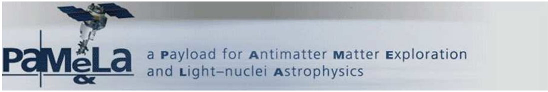
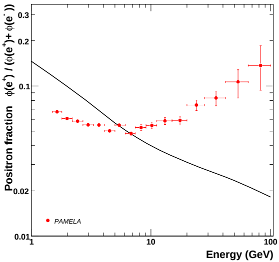
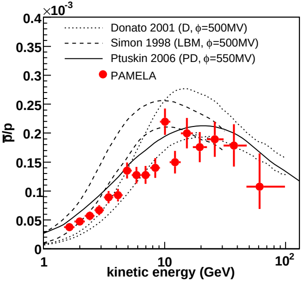
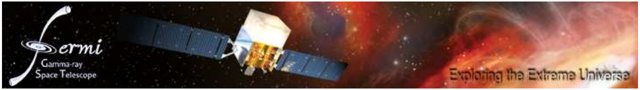


- positron fraction $e^+/(e^+ + e^-)$
  rising from 20 GeV –> primary positron source
- anti-proton/proton ratio $\bar{p}/p$
  no observed anti-proton excess –> leptophilic source

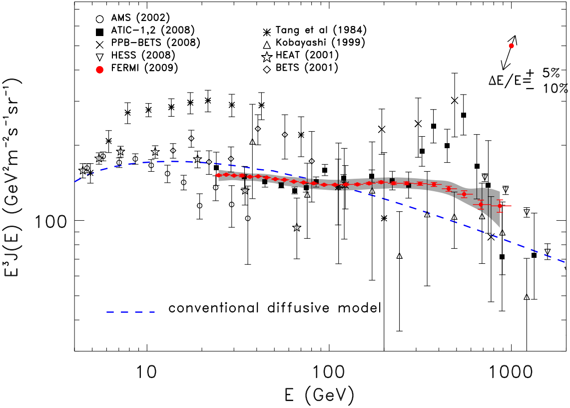




Fermi-LAT

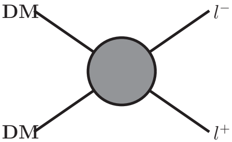


- electron(+positron) flux $e^+ + e^-$

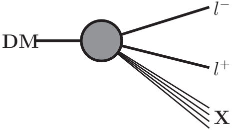


DM vs Pulsar

- Primary positrons from nearby pulsar
  -Curvature Radiation produced in the magnetosphre decays into e^+e^- by the strong magnetic field.
- Primary positrons from DM
  - annhilating DM
    $q \propto \sigma_{\mathrm{ann.}}(\rho/M_{\mathrm{DM}})^2$



  - decaying DM
    $q \propto \Gamma_{\mathrm{decay}}(\rho/M_{\mathrm{DM}})$



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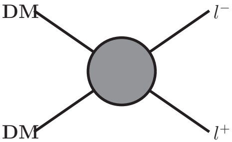

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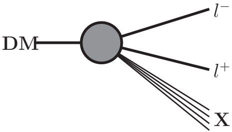

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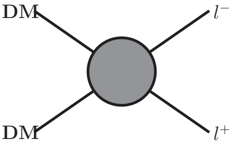

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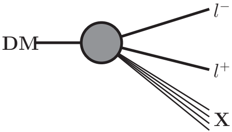

γ-ray constraint (Annhilation vs Decay)

- In DM origin CR scenario, γ-ray excess is comming from synchrotron radiation and inverse compton scattering with CMB or starlight.
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- Charged particles scatter many times in the propagation, while γ-ray goes straight. As a result, the injection position of observed CR is near our solar system.(100pc for the relavant energy.)
- Roughly speaking, $\Phi_\gamma \propto (\rho_{\mathrm{G.C.}}/\rho_{sun})^n$ where $n = 1$ or 2 for decaying DM or annhilating DM, respectively

Decaying dark matter

- CR can be from decaying of DM with few TeV mass.
- To make sufficient postiron flux, decay rate should be $\Gamma \sim 10^{-26} s^{-1} \sim \text{(phase factor)} \times m_{\text{DM}}^5 / M_{\text{GUT}}^4$
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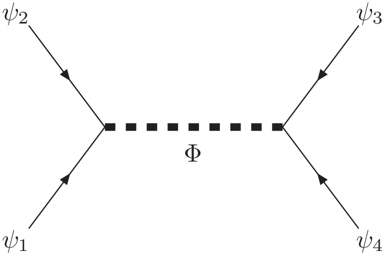
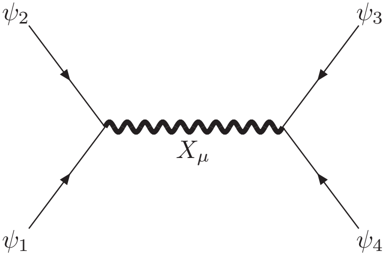
Question?
Grand Unified Theory is something to do with decaying DM?
If so, what is the origin of that interaction?

dim-6 in SUSY GUT (1)

- If we assume SUSY, however, it's not the simple task to achive it by integrating super heavy particle with GUT scale mass.



$\sim (1/M^2)\psi_1\psi_2\psi_3\psi_4$



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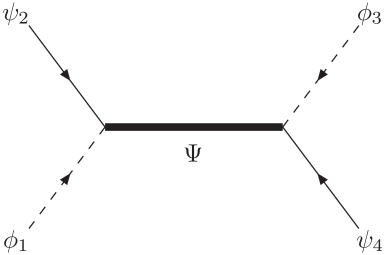

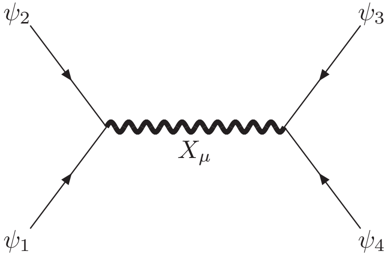

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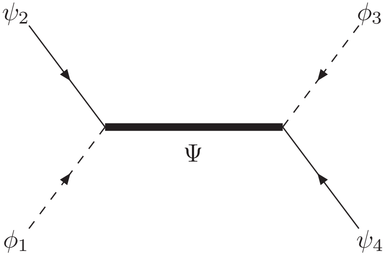

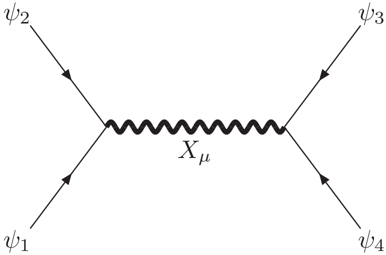

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GUT group must be enlarged significantly!!

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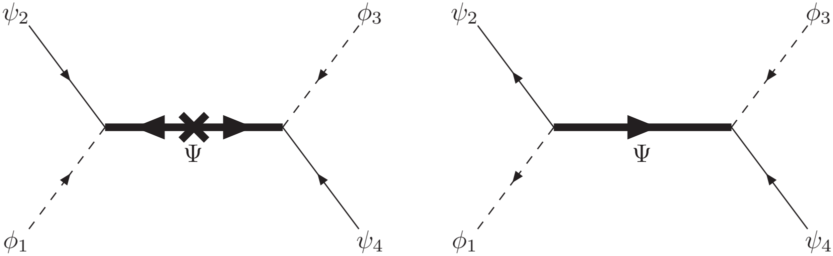

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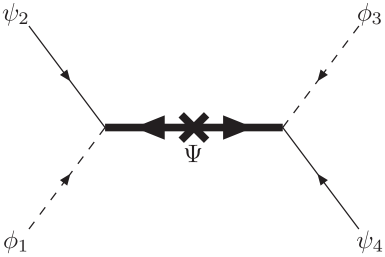

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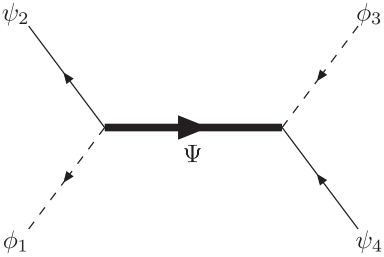
- The first one which has Majorana mass insertion gives dim-5.
  $M/(p^2 - M^2)$



$\sim (\partial/M^2)\phi_1\psi_2\phi_3\psi_4$

- The second one gives dim-6 with derivative coupling.
  $p \cdot \sigma/(p^2 - M^2)$

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Barr(1982), Derendinger,J.E.Kim&Nanopoulos(1984)

SU(5) vs. flipped-SU(5)

- $G_{\rm GG}$=SU(5)
  Y=Y_5 $\equiv$(-1/3,-1/3,-1/3,1/2,1/2)
  (MSSM) = 10+$\bar{5}$+(1)

- $G_{\rm flip}$=$U(1)_X \times$SU(5)
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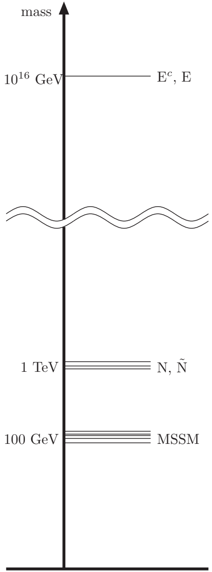
- In flipped-SU(5), We are free to add charged lepton singlet pair E, E^c in GUT scale, because they're appeared as GUT singlet.

Minimal extension

- Keep SUSY 100 GeV to be a solution of *gauge hierarchy problem*, i.e. LSP mass $\sim$ 100 GeV
- Introduce neutral singlet N with mass TeV order to explain Fermi-LAT
- Introduce E and E^c pair with GUT scale mass and interaction $W \sim Ne^cE$ to make N decay into lepton and slepton by dim-6 operator.
- $W \sim Ne^cE + m_{\rm TeV}N^2 + M_{\rm GUT}E^cE$



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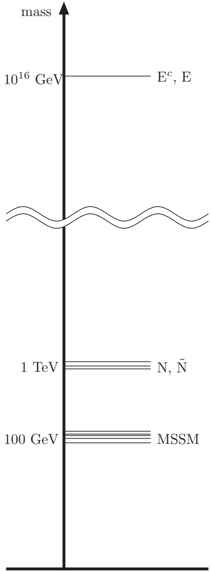


PQ symmetry and singlets

	N	Σ	E	E^c	ℓ_l	e_l^c	ϕ_u	ϕ_d
R	$+$	$+$	$-$	$-$	$-$	$-$	$+$	$+$
Y	0	0	-1	$+1$	$-\frac{1}{2}$	$+1$	$+\frac{1}{2}$	$-\frac{1}{2}$
Γ	$+1$	$+2$	0	0	-1	1	$+2$	0

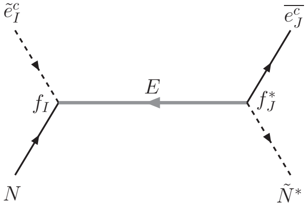
Table: Color singlet chiral fields and their quantum numbers.

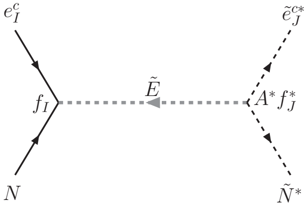
- Using Giudice-Masiero mechanism, N gets supersymmetric mass at TeV
  $\int d^4\theta \, \frac{\Sigma^\dagger}{M_{pl}} N^2 \sim \int d^2\theta \, \frac{F_\Sigma^\dagger}{M_{pl}} N^2 \sim \int d^2\theta \, m_{\rm TeV} N^2$
- PQ-symmetry forbids un-wanted terms and makes accidental parity symmetry which assigns odd only to N, E and E^c.
  N becomes stable.

3 scenario

There are 3 possible scenario which depends on spectrum of N multiplet and whether $\tilde{N}$ developes VEV or not

- case (a)
  $m_N > m_{\tilde{N}}$ and $\langle \tilde{N} \rangle = 0$
  $N \to \tilde{N} + e + \tilde{e}$
- case (b)
  $m_N < m_{\tilde{N}}$ and $\langle \tilde{N} \rangle = 0$
  $\tilde{N} \to N + e + \tilde{e}$
- case (c)
  $m_N < m_{\tilde{N}}$ and $\langle \tilde{N} \rangle \neq 0$
  $\tilde{N} \to e + \tilde{e}$





3 scenario

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- case (a)
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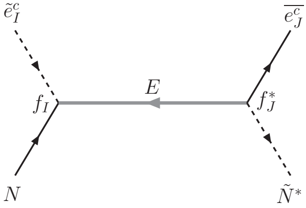
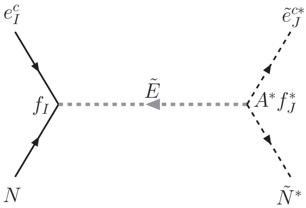
  $\tilde{N} \to N + e + \tilde{e}$
- case (c)
  $m_N < m_{\tilde{N}}$ and $\langle\tilde{N}\rangle \neq 0$
  $\tilde{N} \to e + \tilde{e}$
  Relatively harder spectrum than case (a) and (b)

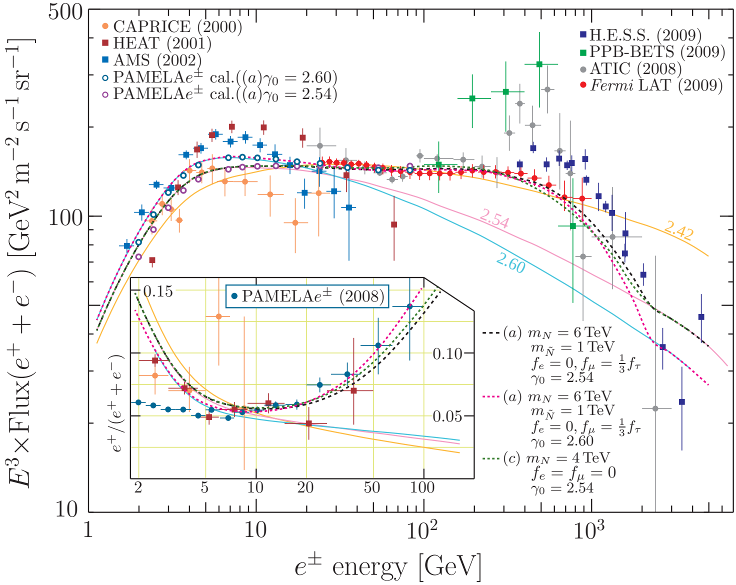




PYTHIA and Galprop

- PYTHIA
  - We used PYTHIA to calculate $e^{\pm}$ energy spectrum of slepton subsequent decay.
  - We also tested $\bar{p}$ spectrum. In certain MSSM parameters region, $\bar{p}$ production is small enough or even almost anti-proton free. But it may depend on detailed spectrum of right-handed sleptons and neutralinos.
- Galprop
  - Current public release version(v50) of Galprop has the routine for DM primary source.
  - But it's only for annihilating DM models and only specific form of CR injection spectrum (gaussian type) can be used.
  - Therefore, we partially re-write and add the module for Galprop to be used with decaying dark matter with arbitrary CR injection spectrum.

Results



CAPRICE (2000)
HEAT (2001)
AMS (2002)
PAMELA$e^{\pm}$ cal.((a)$\gamma_0 = 2.60$)
PAMELA$e^{\pm}$ cal.((a)$\gamma_0 = 2.54$)
H.E.S.S. (2009)
PPB-BETS (2009)
ATIC (2008)
Fermi LAT (2009)
PAMELA$e^{\pm}$ (2008)
2.54
2.60
2.42
(a) $m_N = 6$ TeV, $m_{\tilde N} = 1$ TeV, $f_e = 0, f_\mu = \frac{1}{3} f_\tau$, $\gamma_0 = 2.54$
(a) $m_N = 6$ TeV, $m_{\tilde N} = 1$ TeV, $f_e = 0, f_\mu = \frac{1}{3} f_\tau$, $\gamma_0 = 2.60$
(c) $m_N = 4$ TeV, $f_e = f_\mu = 0$, $\gamma_0 = 2.54$
$E^3 \times \mathrm{Flux}(e^+ + e^-)$ [GeV^2 m^{-2} s^{-1} sr^{-1}]
$e^{\pm}$ energy [GeV]
$e^+/(e^+ + e^-)$

Conclusion

- We interpret Fermi-LAT/PAMELA CR data in the context of decaying DM scenario.
- We find the model with only one additional chiral field N in the low energy.
- It can be easily embedded in flipped-SU(5) model.
- It fits Fermi-LAT/PAMELA well, because subsequent decays make primary $e^{\pm}$ spectrum soft enough.
- Doing so, PQ symmetry is crucially used.
  - Forbids un-wanted term while giving TeV mass to N and allowing Ne^cE coupling
  - Make accidental parity
  - Make model can be embedded in heavy axino decay scenario, so becomes more predictable. (I didn't mention here.)

THANK YOU

Thank you !