Three body decay of Gravitino and the indirect detection

Ki Young Choi
(Pusan National University, Korea)

30 September 2010

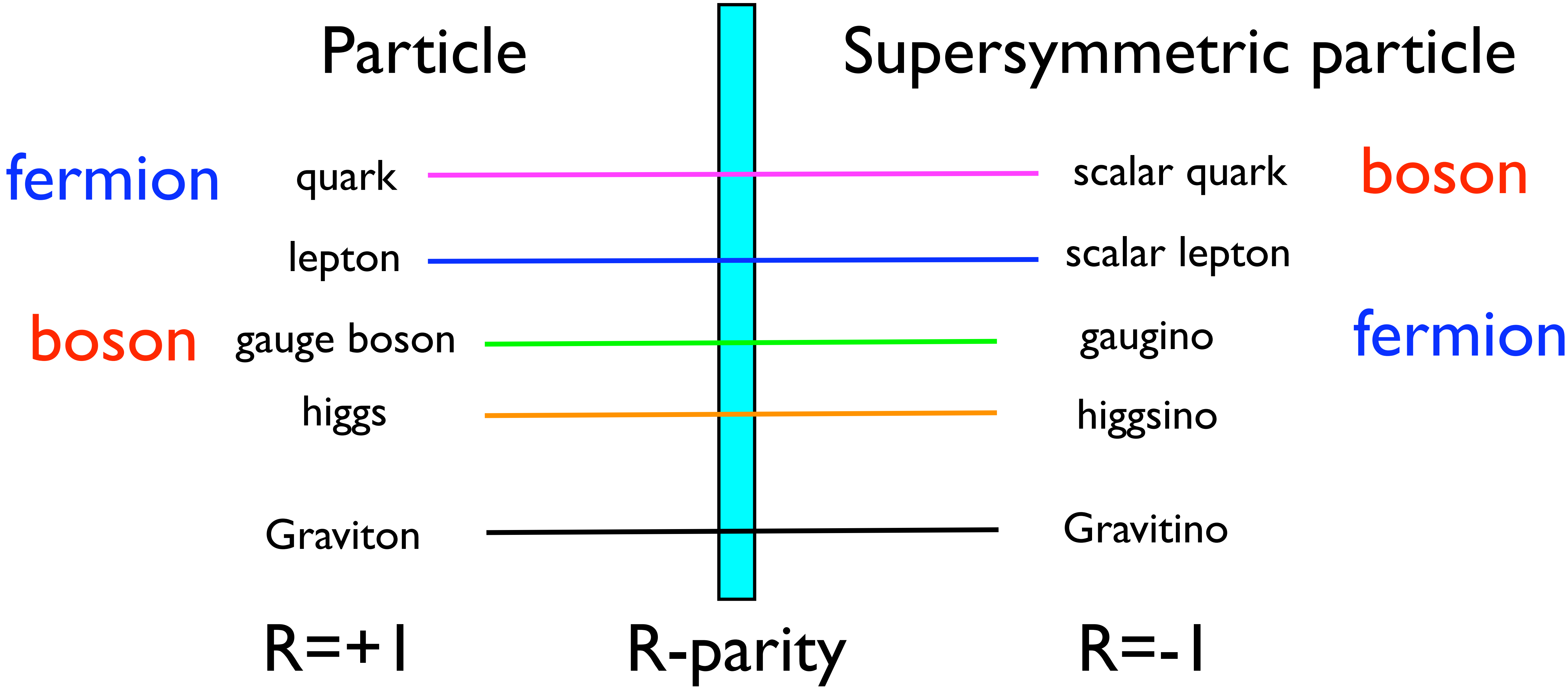
COSMO/CosPA 2010

HORIBA INTERNATIONAL CONFERENCE, The Uiversity of Tokyo

1. Gravitino LSP and Dark Matter
2. R-parity violation and Gravitino decay
3. Gravitino three-body decay and indirect detection
4. Discussion

• Supersymmetry and Gravitino

Supersymmetry introduces the symmetry between bosons and fermions



- Lightest Spersymmetric Particle (LSP) is stable with R-parity

a good candidate for Dark Matter : Neutralino, sneutrino, Gravitino, Axino, etc

[Talk by L.Roszkowski and L. Covi]

- Gravitino is massless in the supersymmetric limit

→ become massive with SUSY breaking

$$m_{\widetilde{G}} = \langle W e^{K/2} \rangle = \frac{F_X}{M_P}$$

from eV to TeV depending on the SUSY breaking mechanism

eg, GMSB, Gravity-MSB, gaugino-MSB, Anomaly-MSB, ...

- Interaction is suppressed by Planck scale

→ suffers from the Gravitino problem

$$\tau \sim 10^2 - 10^{12} \text{ sec}$$

: disturb the standard Big Bang Nucleosynthesis

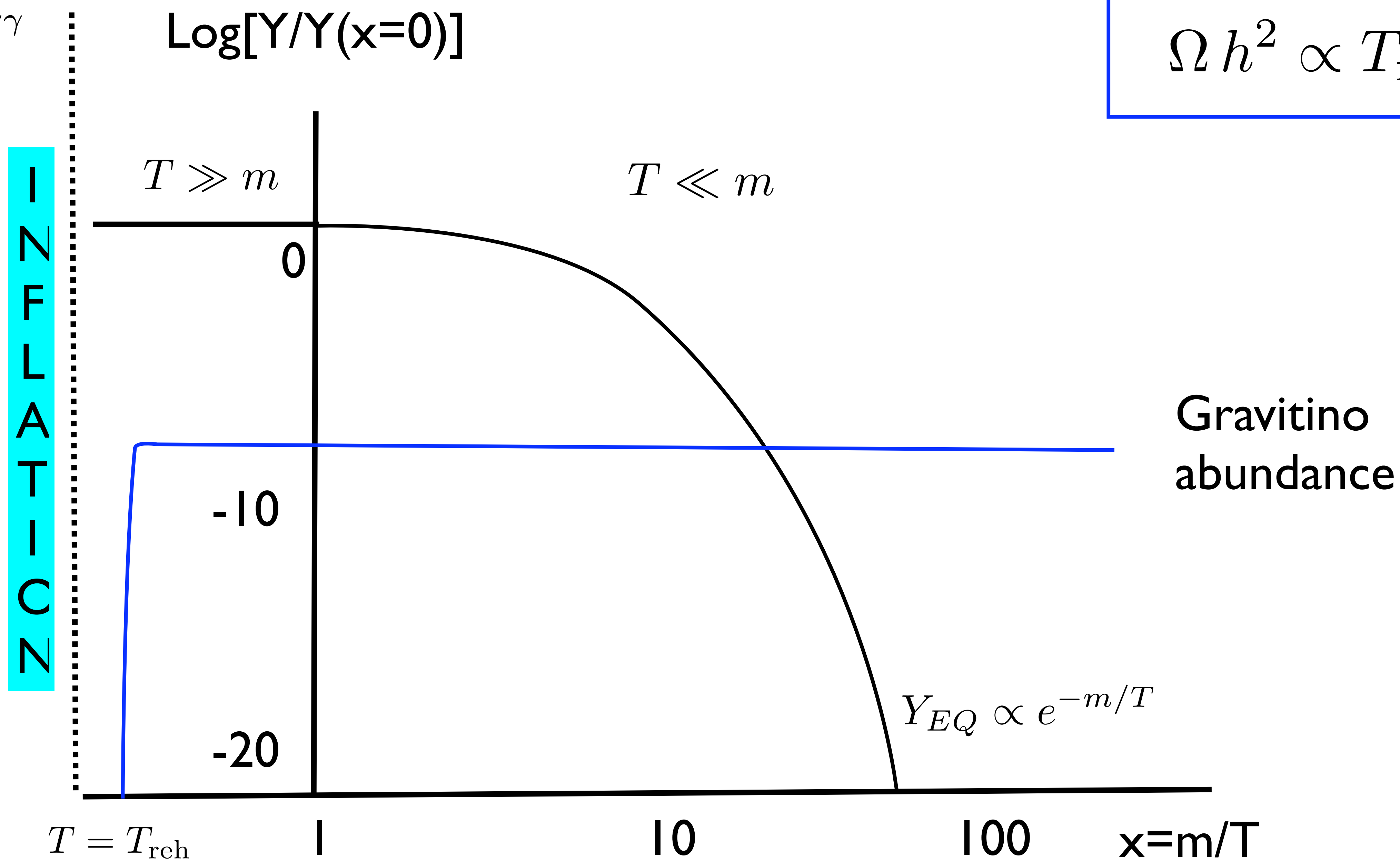
- Production of gravitinos

  - Thermal production: from the scaterings of the particles in the thermal equilibrium

[Ellis, Kim, Nanopoulos, 1984]

$$Y \equiv \frac{n}{n_\gamma}$$

$$\Omega\, h^2 \propto T_{\rm reh}$$



- Non-thermal production

: from the decay of next LSP such as neutralino, stau, etc

and/or from the decay of inflaton, during preheating

or from the decay of moduli field

- Total relic density of gravitino

$$\Omega_{\widetilde{G}} h^2 = \Omega_{\widetilde{G}}^{TP} h^2 + \Omega_{\widetilde{G}}^{NTP} h^2$$

→ Gravitinos can be produced to give correct amount required for Dark Matter

- Supersymmetry with R-parity violation and Gravitino LSP

No symmetry to protect the decay of LSP

Gravitino LSP can decay

: However Gravitino lifetime can be much longer than the age of Universe with small R-parity breaking and Planck suppressed interaction

and still can be a good candidate for dark matter

- Bilinear R-parity violation and Gravitino DM [Takayama, Yamaguchi, 2000]

$$W = \mu H_1 H_2 + \sum_{i=1}^{3} \mu_i L_i H_2$$

: No BBN probelm due to early decay of NLSP

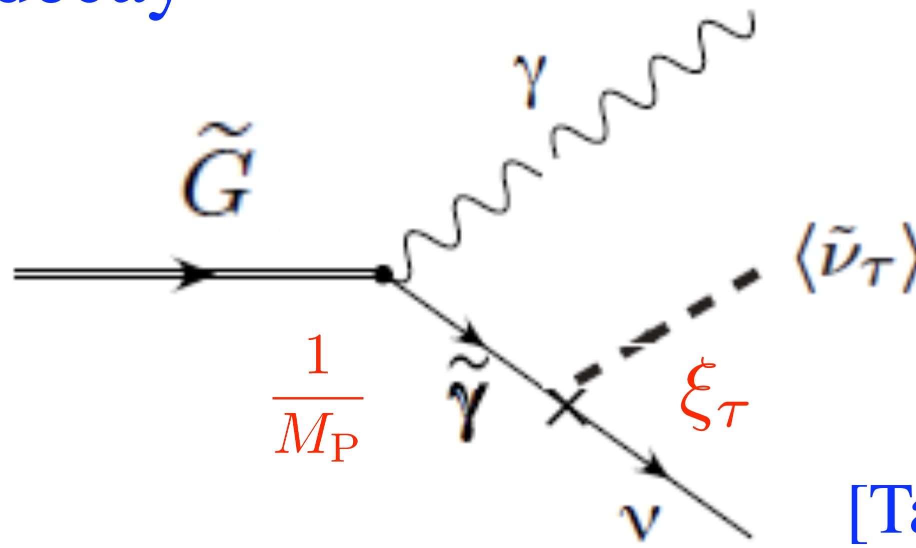
$$\mathcal{L}_{soft} = B_i \widetilde{L}_i H_u + m^2_{L_i H_2} \widetilde{L}_i H_1^* + h.c.$$

: gives sneutrino VEV and mixing between neutrino and neutralino

$$\langle \tilde{\nu}_i \rangle = \frac{B_i \sin\beta + m^2_{L_i H_d} \cos\beta}{m^2_{\tilde{\nu}_i}} v$$

- Gravitino two-body decay

$\widetilde{G} \to \gamma + \nu$



[Takayama, Yamaguchi, 2000]

$$\Gamma(\widetilde{G} \to \gamma\nu) = (10^{23}\,\mathrm{sec})^{-1} \left(\frac{m_{\widetilde{G}}}{100\,\mathrm{GeV}} \right)^3 \left(\frac{\xi_\tau}{10^{-7}} \right)^2 |U_{\tilde{\gamma}\widetilde{Z}}|^2$$

$$\xi_\tau \equiv \frac{\langle \tilde{\nu}_\tau \rangle}{v} \qquad \langle \tilde{\nu}_i \rangle = \frac{B_i \sin\beta + m^2_{L_i H_d} \cos\beta}{m^2_{\tilde{\nu}_i}} v$$

$$|U_{\tilde{\gamma}\widetilde{Z}}| \simeq \frac{M_Z (M_2 - M_1) s_W c_W}{(M_1 c_W^2 + M_2 s_W^2)(M_1 s_W^2 + M_2 c_W^2)}$$

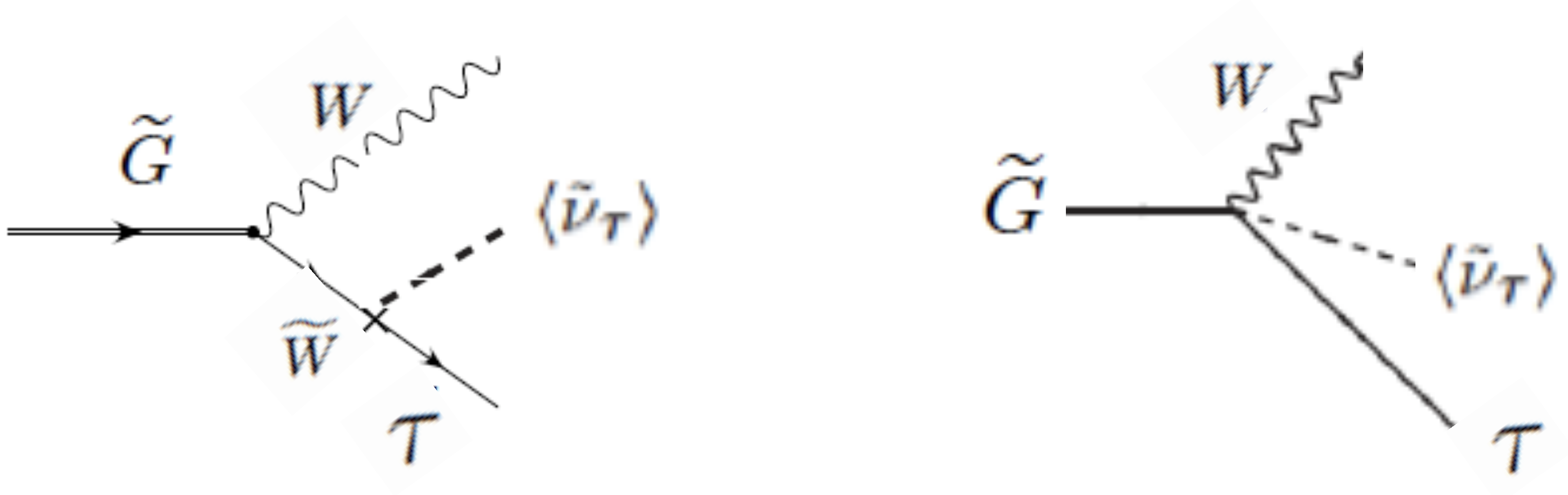
[Ibarra, Tran, 2008]

M_1, M_2 : gaugino mass $\quad s_W, c_W$: weak mixing angle

• Gravitino two-body decay: If Gravitino is massive than W and Z bosons

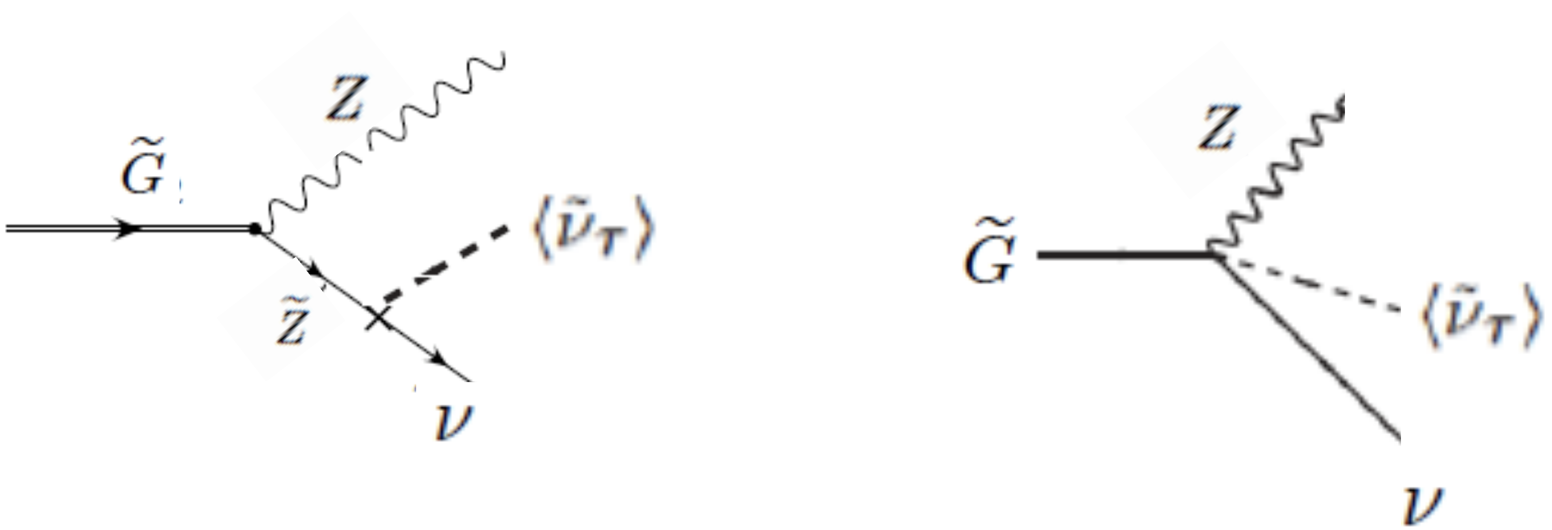
[Ibarra, Tran, 0709.4593]

$\widetilde{G} \to W + \tau$



$$\Gamma \propto \frac{\xi_\tau^2}{M_{\rm P}^2}\left(A|U_{\widetilde{W}\widetilde{W}}|^2 + BU_{\widetilde{W}\widetilde{W}} + C\right)$$

$\widetilde{G} \to Z + \nu$: similar diagrams to W-boson production



• Gravitino two-body decay and the indirect detection

Leptogenesis and gamma ray signature [Buchmuller, Covi, Hamaguchi, Ibarra, Yanagida, 2007]

Gamma rays from decaying dark matter [Bertone, Buchmuller, Covi, Ibarra, 2007]
[Ibarra, Tran, 0709.4593]

Antimatter signatures of Gravitino dark matter decay [Ibarra, Tran, 0804.4596]

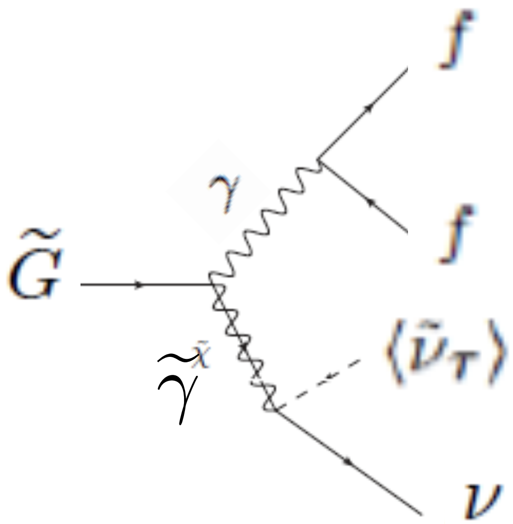
High energy cosmic rays from the decay of Gravitino DM decay
[Ishiwata, Matsumoto, Moroi, 0805.1133]

Unstable Gravitino dark matter and neutrino flux [Covi, Grefe, Ibarra, Tran, 0809.5030]

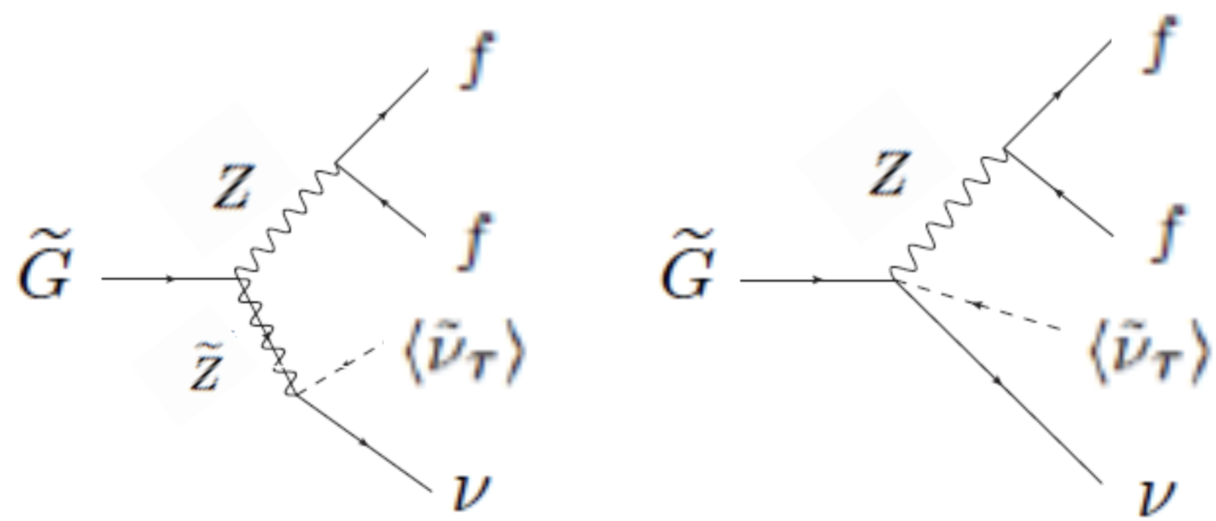
Probing Graviitno dark matter with PAMELA and Fermi
[Buchmuller, Ibarra, Shindou, Takayama, Tran, 2009]

Gamma-ray detection from Graviitno DM decay in the MuNuSSM
[K.Y.Choi, Lopez-Fogliani, Munz, Ruiz de Austri, 2010]

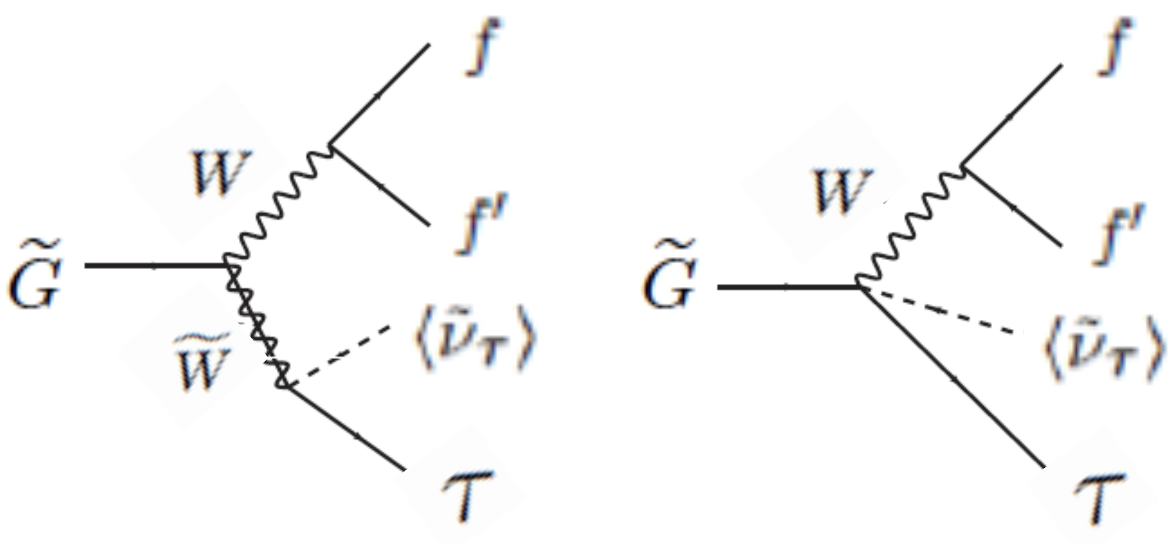
• Three-body decays of Gravitino [KYChoi, Yaguna, 2010]



$\widetilde{G} \to \gamma * + \nu \to f + f + \nu$



$\widetilde{G} \to Z^* + \nu \to f + \bar{f} + \nu$



$\widetilde{G} \to W^* + \tau \to f + \bar{f}' + \tau$

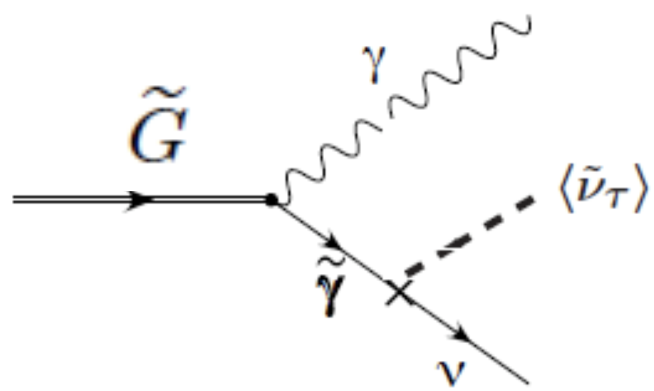
- Three-body decays:

  usually suppressed compared to two-body decays

- However unusual situation happens

  : just below the threshold of new decay modes $m_{\tilde{G}} < m_W$

- Two-body decay: Gravitino to photon and neutrino

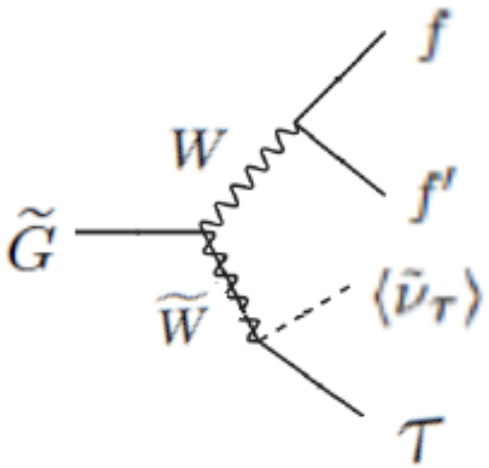


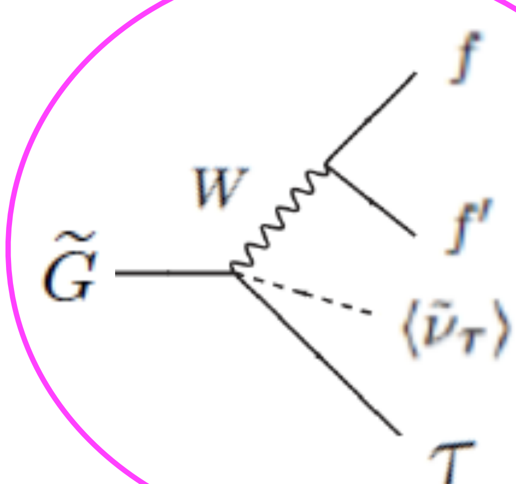
$$\Gamma \propto \frac{\xi_\tau^2}{M_\mathrm{P}^2}|U_{\tilde{\gamma}\tilde{Z}}|^2 \quad \propto \left(\frac{M_Z}{M_1}\right)^2$$

: suppressed by the mass of gaugino

* Gravitino two-body decay to W or Z boson is kinematically disallowed

- Three-body decays mediated by W- and Z-boson





$$\Gamma \propto \frac{\xi_\tau^2}{M_\mathrm{P}^2}\left(A|U_{\tilde{W}\tilde{W}}|^2 + BU_{\tilde{W}\tilde{W}} + C\right)$$

$\propto \left(\frac{M_Z}{M_1}\right)^2$ $\quad \propto \left(\frac{M_Z}{M_1}\right)$

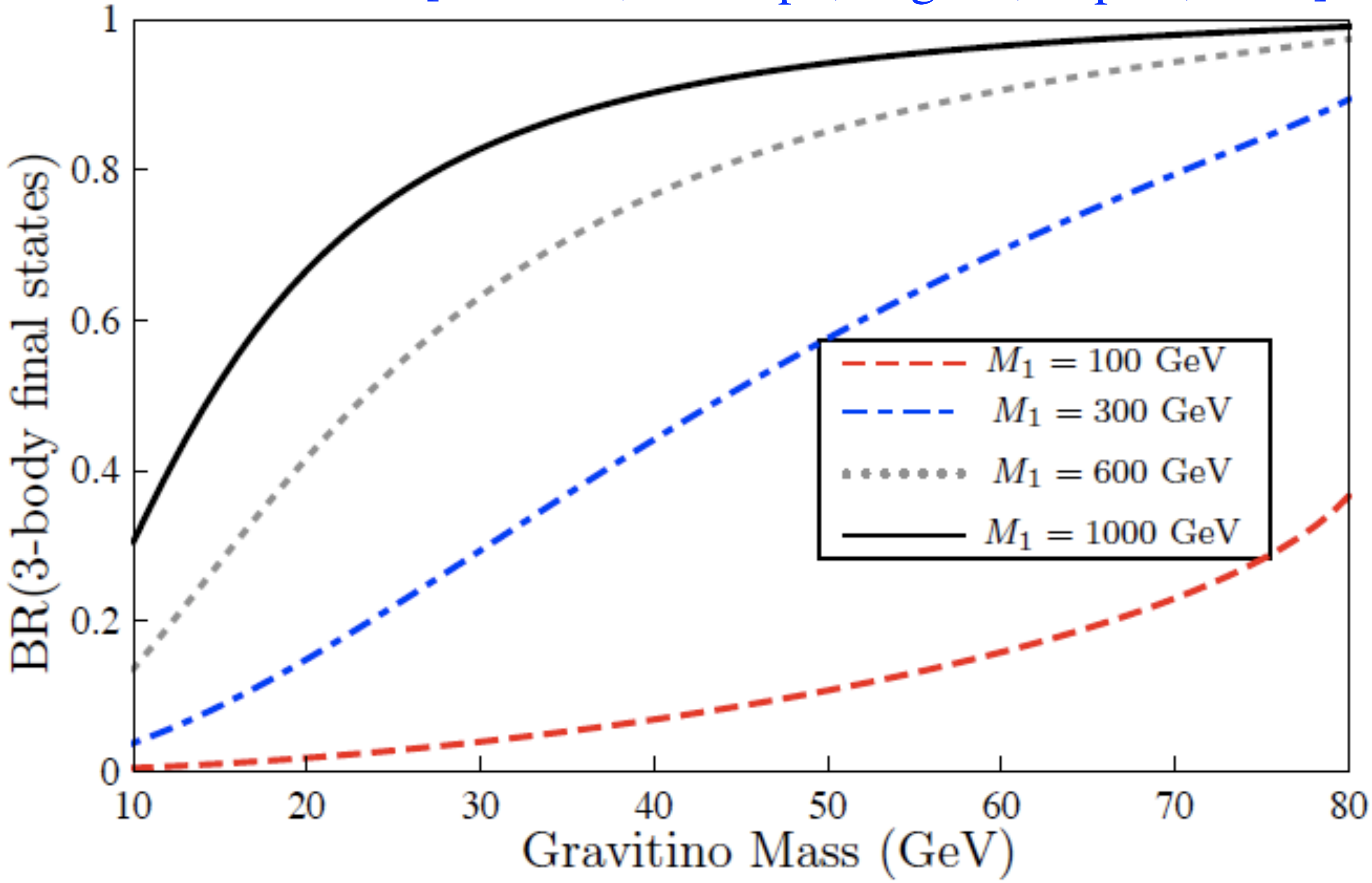
* Similar to Z-boson mediated ones

- 4-vertex interaction

  : No suppression due to the gaugino mass

- Branching ratio of three-body decays of Gravitino
  - With large gaugino mass, 3-body decay dominates 2-body decay

[KYChoi, Restrepo, Yaguna, Zapata, 2010]



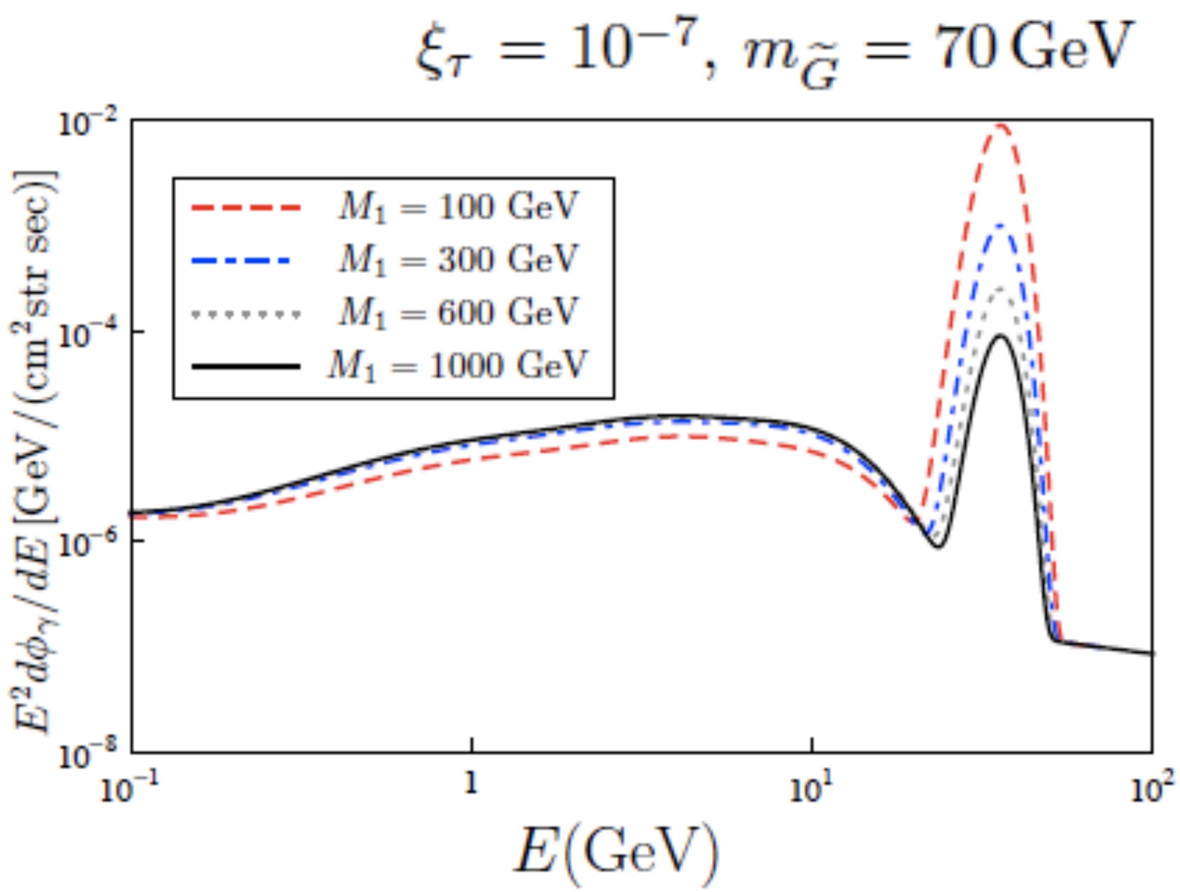
M1 : Bino mass

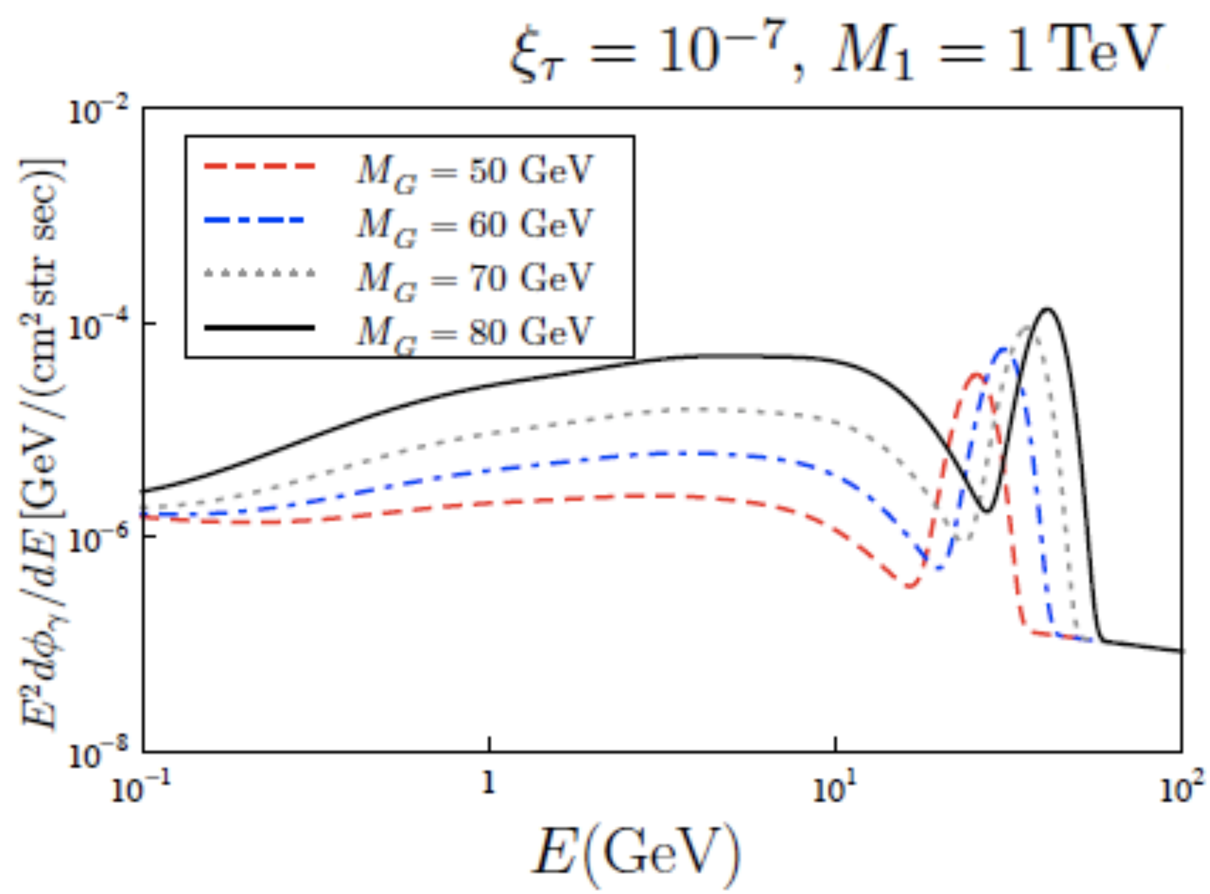
We assumed GUT unification of gaugino masses

• Gamma rays from Gravitino decay

- **Monochromatic** from 2-body decay **+ continuum** from 3-body decay

[KYChoi, Restrepo, Yaguna, Zapata, 1007.1728]



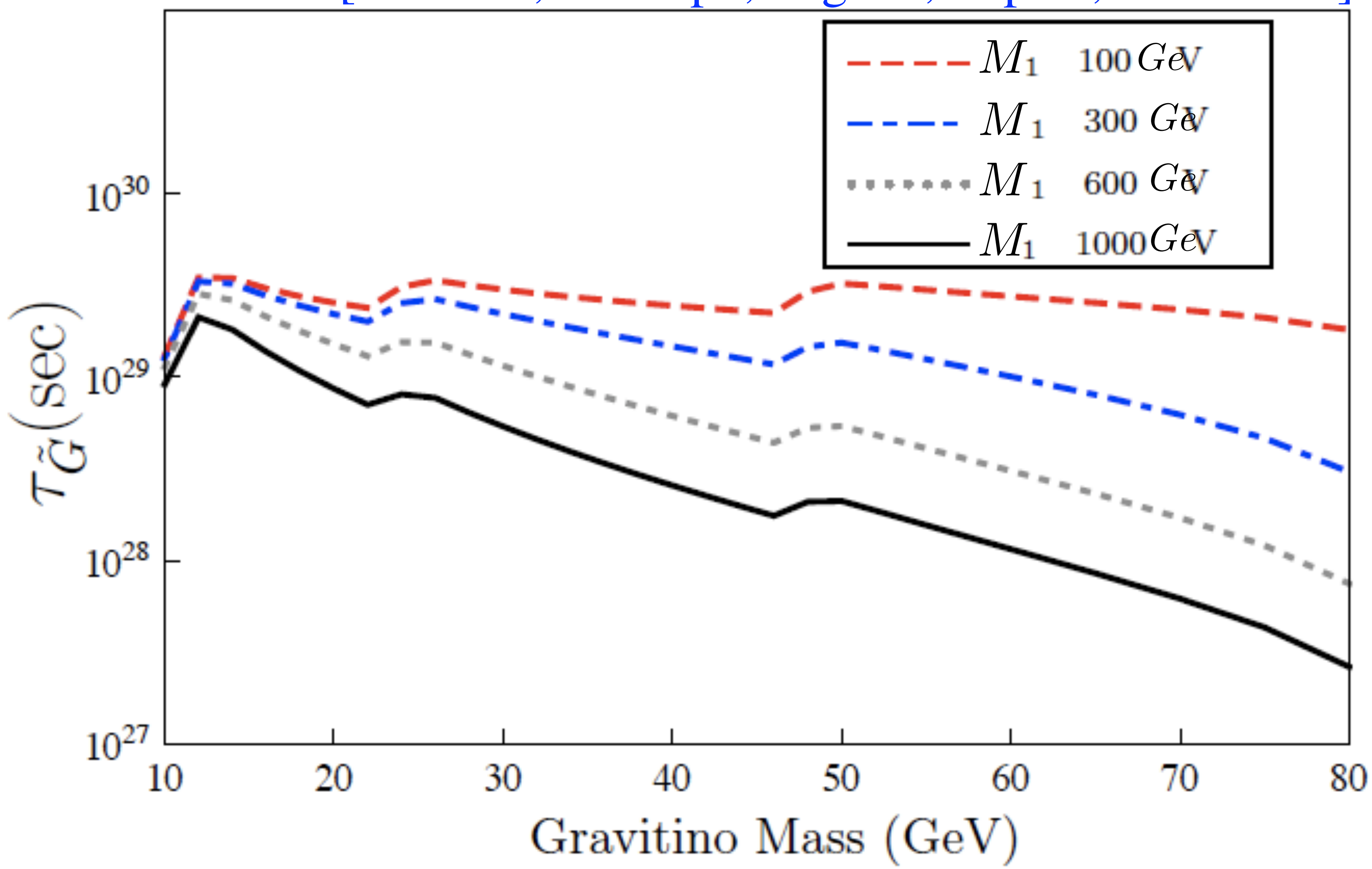


- Line signal is sensitive to the gaugino mass
- For larger gaugino mass, the line signal becomes smaller and continuum becomes larger

- Larger signal for larger gravitino mass
- The position of line signal depends on the mass of gravitino

• Constraint on the lifetime from diffuse gamma ray of Fermi

[KYChoi, Restrepo, Yaguna, Zapata, 1007.1728]



‣ The constraint on lifetime changes by one order of magnitude depending on the mass of gaugino

- Antimatter searches from Gravitino decay
  - Three-body decay give rise to non-zero positron and antiproton flux

    With compatible range of parameters from gamma ray observation
    it does not yield a visible signature for positron flux from gravitino decay

    However for antiproton flux, it is marginally consistent with observation
    and may show some signature

    [KYChoi, Restrepo, Yaguna, Zapata, 1007.1728]

Summary

• Gravitino can be the Lightest Supersymmetric Particle and become a good candidate for dark matter

• With slight R-parity violation, Graviitno can be Dark Matter and show Indirect Detection signatures

• Three-body decay of Gravitino can dominate the two-body decay and its lifetime and the signatures from the indirect detection are severely modified