Searching for SUSY and decaying gravitino dark matter at the LHC and Fermi-LAT with the μνSSM

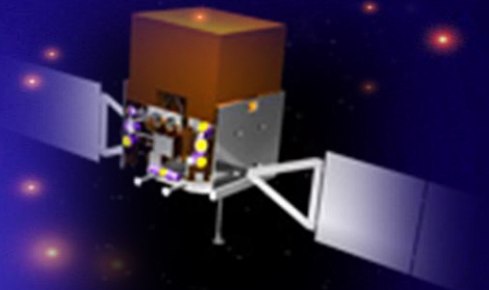
Carlos Muñoz

Instituto de Física Teórica UAM-CSIC

Universidad Autónoma de Madrid
Departamento de Física Teórica

Madrid, Spain

MultiDark
Multimessenger Approach for Dark Matter Detection



DSU 2015, Kyoto, December 14-18

OUTLINE

Several SUSY models have been proposed in the literature:

MSSM, NMSSM, TRPV, BRPV, $\mu\nu$**SSM**, …

If SUSY is discovered at the LHC, one of them will be proved

The $\mu\nu$**SSM**, including right-handed neutrinos solves the μ problem of the MSSM while simultaneously explaining the origin of neutrino masses

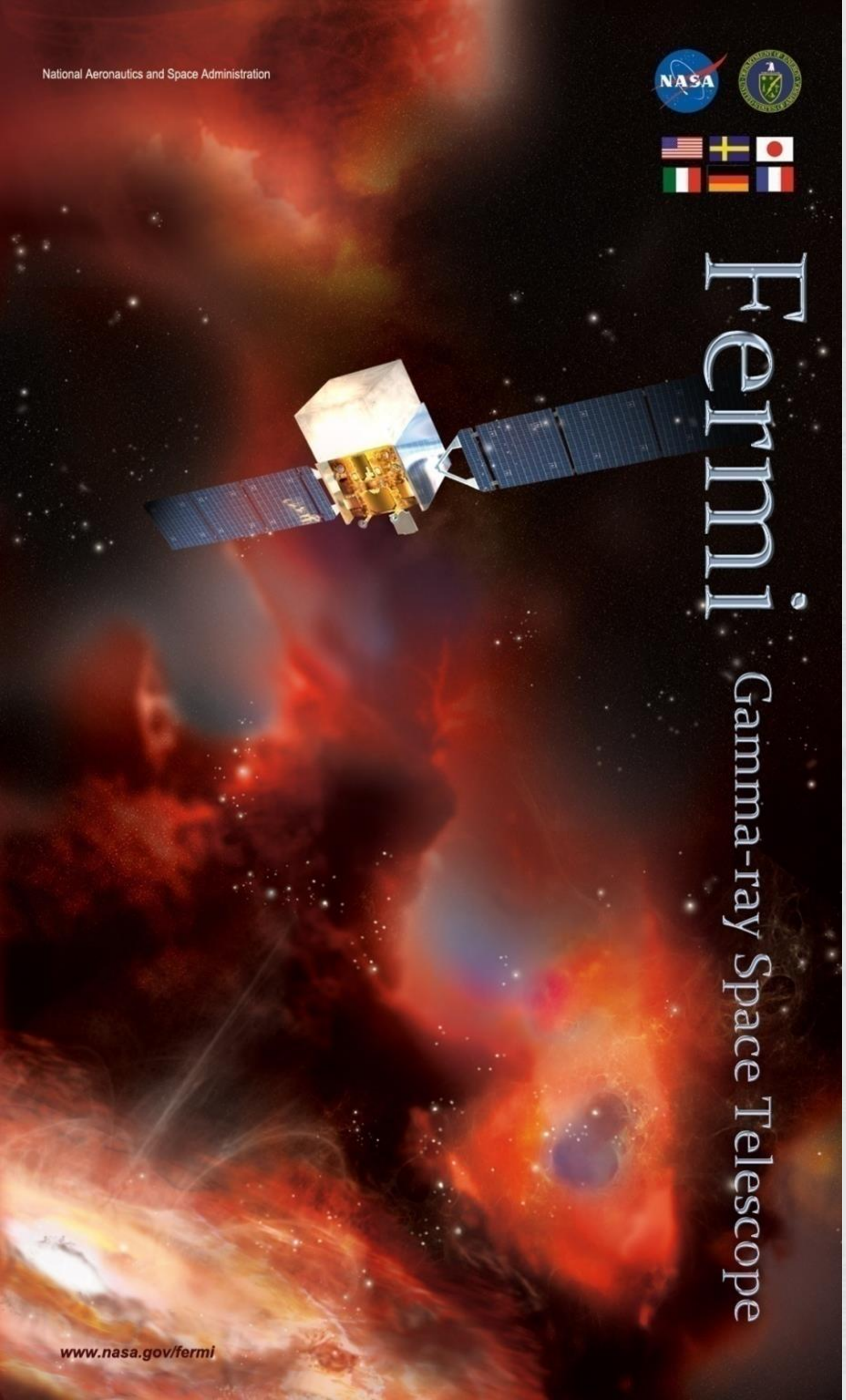
Lopez-Fogliani, C. M., PRL 97 (2006) 041801

This solution implies that R parity is explicitly broken

- In models with RPV the **LSP** is no longer stable

Thus the neutralino or the RH sneutrino cannot be used as candidates for DM

- Gravitino can be a (decaying) DM candidate in the $\mu\nu$SSM



Fermi Gamma-ray Space Telescope

MultiDark
Multimessenger Approach for Dark Matter Detection

Recently, together with Fermi-LAT collaborators we performed the following:

Search for 100 MeV to 10 GeV γ-ray lines in the *Fermi*-LAT data and implications for gravitino dark matter in the μνSSM

arXiv:1406.3430 [astro-ph.HE], ***JCAP* 10 (2014) 023**

Category II paper:
-*Fermi*-LAT Collaboration: Albert, Bloom, Charles, Gómez-Vargas, Mazziotta, Morselli
External authors: C. M., Grefe, Weniger

E.g. we constrained $m_{3/2}$ to be smaller than ~ **5** GeV

In this talk I will update the result, and we will see that once

- several theoretical assumptions on gaugino masses are relaxed
- and three-body decay channels are taken into account

The photon spectrum consists of a line from the two-body decay, plus a continuum distribution from the three-body decay,

and

values of $m_{3/2}$ larger than **5** GeV are not excluded in the μνSSM yet

Gómez-Vargas, López-Fogliani, C.M., Pérez, Ruiz de Austri, in preparation

On the way we will also see that the phenomenology of the μνSSM at the LHC can be very interesting

- SUSY has a crucial problem, the so-called **μ problem**

Kim, Nilles, PLB 138 (1984) 150

Currently we know that Higgsinos must be massive, $\mu \, \tilde{H}_1 \, \tilde{H}_2$,
since experimental bounds on chargino masses imply: $\mu \geq 100$ GeV

Masses are generated if we include a mass term in the MSSM superpotential:

$$W = Y_u^{ij} \, \hat{H}_2^b \, \hat{Q}_i^a \, \hat{u}_j^c + Y_d^{ij} \, \hat{H}_1^a \, \hat{Q}_i^b \, \hat{d}_j^c + Y_e^{ij} \, \hat{H}_1^a \, \hat{L}_i^b \, \hat{e}_j^c + \mu \, \hat{H}_1 \, \hat{H}_2$$

μ problem:
*** What is the origin of μ ?**
*** Why is μ so small ?,**
It contributes to the Higgs potential and therefore must be $\mu \sim M_W << M_{Planck}$

e.g in Supergravity mediated SUSY breaking

$$V(H_1, H_2) = \underbrace{\frac{1}{8}(g_2^2+g'^2)\left[|H_1|^2-|H_2|^2\right]^2}_{\text{D-terms}} + \underbrace{m_1^2|H_1|^2 + m_2^2|H_2|^2}_{\text{soft terms}} + (m_3)^2 \, H_1 \, H_2$$

$(m_3)^2 \equiv B\mu$

Thus, the Minimal Supersymmetric Standard Model (**MSSM**)

W = $Y_u^{ij}\,\hat{H}_2^b\,\hat{Q}_i^a\,\hat{u}_j^c + Y_d^{ij}\,\hat{H}_1^a\,\hat{Q}_i^b\,\hat{d}_j^c + Y_e^{ij}\,\hat{H}_1^a\,\hat{L}_i^b\,\hat{e}_j^c$ + **μ** $\hat{H}_1\,\hat{H}_2$

is an effective theory

One takes for granted that the **μ term is there, and that's it**

μνSSM In addition to the MSSM Yukawas for quarks and charged leptons, the $\mu\nu$SSM superpotential contains Yukawas for neutrinos, and two additional type of terms

$$W = \epsilon_{ab} \left(Y_u^{ij} \, \hat{H}_2^b \, \hat{Q}_i^a \, \hat{u}_j^c + Y_d^{ij} \, \hat{H}_1^a \, \hat{Q}_i^b \, \hat{d}_j^c + Y_e^{ij} \, \hat{H}_1^a \, \hat{L}_i^b \, \hat{e}_j^c + Y_\nu^{ij} \, \hat{H}_2^b \, \hat{L}_i^a \, \hat{\nu}_j^c \right) - \epsilon_{ab} \lambda^i \, \hat{\nu}_i^c \hat{H}_1^a \hat{H}_2^b + \frac{1}{3} \kappa^{ijk} \hat{\nu}_i^c \hat{\nu}_j^c \hat{\nu}_k^c \, ,$$

Dirac neutrino masses

effective μ term generated by the VEVs of the **3** righ-handed sneutrinos

with $\mu \equiv \lambda^i \langle \tilde{\nu}_i^c \rangle$.

effective Majorana masses $M_M = \kappa_{ijk} \langle \tilde{\nu}_k^c \rangle$

a "μ from ν" Supersymmetric Standard Model ($\mu\nu$SSM)

No ad-hoc scales

$m_\nu \sim m_D^2/M_M = (\mathbf{Y}_\nu H_2)^2/(k\, \nu_R) \sim (10^{-6}\, 10^2)^2/10^3 = 10^{-11}$ GeV $= 10^{-2}$ eV

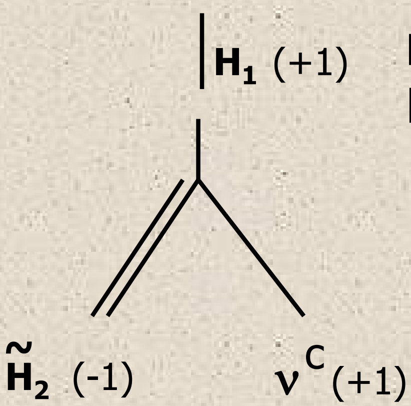
Like the electron Yukawa

Indeed we will also have the three heavy neutrinos with masses ~ EW (eletroweak-scale seesaw)

Lopez-Fogliani, C. M., PRL 97 (2006) 041801

$$W = \epsilon_{ab} \left(Y_u^{ij} \, \hat{H}_2^b \, \hat{Q}_i^a \, \hat{u}_j^c + Y_d^{ij} \, \hat{H}_1^a \, \hat{Q}_i^b \, \hat{d}_j^c + Y_e^{ij} \, \hat{H}_1^a \, \hat{L}_i^b \, \hat{e}_j^c + Y_\nu^{ij} \, \hat{H}_2^b \, \hat{L}_i^a \, \hat{\nu}_j^c \right)$$

$$- \epsilon_{ab} \lambda^i \, \hat{\nu}_i^c \, \hat{H}_1^a \hat{H}_2^b + \frac{1}{3} \kappa^{ijk} \hat{\nu}_i^c \hat{\nu}_j^c \hat{\nu}_k^c \, ,$$



Because of the simultaneous presence of these three terms in the μνSSM **R parity** (+1 for particles and -1 for superpartners) **is explicitly broken**

i.e. SUSY particles do not appear in pairs

Size of the breaking:

is small because the EW seesaw implies $\mathbf{Y_\nu} \sim 10^{-6}$

Since R-parity is broken, the phenomenology of the μνSSM is going to be very different from the one of the MSSM/NMSSM

(1) the LSP is no longer stable since it can decay to two SM particles

(2) Mass matrices are augmented in the μνSSM with respect to the MSSM

Once the electroweak symmetry is spontaneously broken, the neutral scalars develop in general the following VEVs:

$$\langle H_d^0\rangle = v_d\,, \quad \langle H_u^0\rangle = v_u\,, \quad \langle\tilde{\nu}_i\rangle = \nu_i\,, \quad \langle\tilde{\nu}_i^c\rangle = \nu_i^c\,. \qquad 2.7)$$

"Neutralinos"

$$\chi^{0T} = (\tilde{B}^0, \tilde{W}^0, \tilde{H}_d, \tilde{H}_u, \nu_{R_i}, \nu_{L_i}),$$

Lightest neutralino ← $\tilde{\chi}_4$, $\tilde{\chi}_{5,6,7,8,9,10}$, $\tilde{\chi}_{1,2,3}$ mass eigenstates

"Neutral Higgses"

$$\mathbf{S}'_\alpha = (h_d, h_u, (\tilde{\nu}_i^c)^R, (\tilde{\nu}_i)^R)$$

$h_{4,5} \equiv$ h, H , $h_{1,2,3}$, $h_{6,7,8}$

$$\mathbf{P}'_\alpha = (P_d, P_u, (\tilde{\nu}_i^c)^I, (\tilde{\nu}_i)^I)$$

$P_4 \equiv A$, $P_{1,2,3}$, $P_{5,6,7}$

(2) Mass matrices are augmented in the μνSSM with respect to the MSSM

Once the electroweak symmetry is spontaneously broken, the neutral scalars develop in general the following VEVs:

$$\langle H_d^0 \rangle = v_d\,, \quad \langle H_u^0 \rangle = v_u\,, \quad \langle \tilde{\nu}_i \rangle = \nu_i\,, \quad \langle \tilde{\nu}_i^c \rangle = \nu_i^c\,. \qquad 2.7)$$

"Neutral Higgses"

$$\mathbf{S}'_\alpha = (h_d, h_u, (\widetilde{\nu}_i^c)^R, (\widetilde{\nu}_i)^R)$$

$h_{4,5} \equiv h, H$, $h_{1,2,3}$, $h_{6,7,8}$

$$\mathbf{P}'_\alpha = (P_d, P_u, (\widetilde{\nu}_i^c)^I, (\widetilde{\nu}_i)^I)$$

$P_4 \equiv A$, $P_{1,2,3}$, $P_{5,6,7}$

"Neutralinos"

$$\chi^{0T} = (\tilde{B}^0, \tilde{W}^0, \tilde{H}_d, \tilde{H}_u, \nu_{R_i}, \nu_{L_i}),$$

Lightest neutralino ← $\tilde{\chi}^0_4$, $\tilde{\chi}^0_{5,6,7,8,9,10}$, $\tilde{\chi}^0_{1,2,3}$

mass eigenstates

• • •

Neutrino Physics in the $\mu\nu$SSM

Escudero, Lopez-Fogliani, C. M., Ruiz de Austri, JHEP 12 (2008) 099
Ghosh, Roy, JHEP 04 (2009) 069
Fidalgo, Lopez-Fogliani, C.M., Ruiz de Austri, JHEP 08 (2009) 105
Ghosh, Dey, Mukhopadhyaya, Roy, JHEP 05 (2010) 087

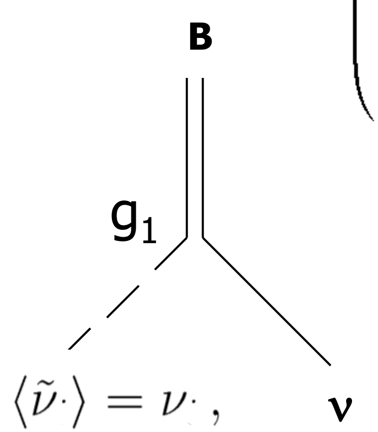
Including the 3 families of neutrinos: "Neutralinos" $\chi^{0T} = (\tilde{B}^0, \tilde{W}^0, \tilde{H}_d, \tilde{H}_u, \nu_{R_i}, \nu_{L_i}),$

$$\mathcal{M}_n = \begin{pmatrix} M & m \\ m^T & 0_{3\times 3} \end{pmatrix},$$

Because of the breaking of R-parity the model has a **generalized seesaw**, involving not only the right-handed neutrinos, but also the neutralinos

$$M = \begin{pmatrix} M_1 & 0 & -Av_d & Av_u & 0 & 0 & 0 \\ 0 & M_2 & Bv_d & -Bv_u & 0 & 0 & 0 \\ -Av_d & Bv_d & 0 & -\lambda_i \nu_i^c & -\lambda_1 v_u & -\lambda_2 v_u & -\lambda_3 v_u \\ Av_u & -Bv_u & -\lambda_i \nu_i^c & 0 & -\lambda_1 v_d + Y_{\nu_{i1}} \nu_i & -\lambda_2 v_d + Y_{\nu_{i2}} \nu_i & -\lambda_3 v_d + Y_{\nu_{i3}} \nu_i \\ 0 & 0 & -\lambda_1 v_u & -\lambda_1 v_d + Y_{\nu_{i1}} \nu_i & 2\kappa_{11j} \nu_j^c & 2\kappa_{12j} \nu_j^c & 2\kappa_{13j} \nu_j^c \\ 0 & 0 & -\lambda_2 v_u & -\lambda_2 v_d + Y_{\nu_{i2}} \nu_i & 2\kappa_{21j} \nu_j^c & 2\kappa_{22j} \nu_j^c & 2\kappa_{23j} \nu_j^c \\ 0 & 0 & -\lambda_3 v_u & -\lambda_3 v_d + Y_{\nu_{i3}} \nu_i & 2\kappa_{31j} \nu_j^c & 2\kappa_{32j} \nu_j^c & 2\kappa_{33j} \nu_j^c \end{pmatrix}$$

RR



LR

$$m^T = \begin{pmatrix} -\frac{g_1}{\sqrt{2}}\nu_1 & \frac{g_2}{\sqrt{2}}\nu_1 & 0 & Y_{\nu_{1i}}\nu_i^c & Y_{\nu_{11}} v_u & Y_{\nu_{12}} v_u & Y_{\nu_{13}} v_u \\ -\frac{g_1}{\sqrt{2}}\nu_2 & \frac{g_2}{\sqrt{2}}\nu_2 & 0 & Y_{\nu_{2i}}\nu_i^c & Y_{\nu_{21}} v_u & Y_{\nu_{22}} v_u & Y_{\nu_{23}} v_u \\ -\frac{g_1}{\sqrt{2}}\nu_3 & \frac{g_2}{\sqrt{2}}\nu_3 & 0 & Y_{\nu_{3i}}\nu_i^c & Y_{\nu_{31}} v_u & Y_{\nu_{32}} v_u & Y_{\nu_{33}} v_u \end{pmatrix}.$$

Neutralino mass eigenstates $\tilde{\chi}^0_{1,\ldots,10}$:
- 7 eigenvalues from the mixing of neutralinos and ν_{Ri}
- 3 very small eigenvalues corresponding to the light neutrino masses

neutralinos RH neutrinos

LH neutrinos

$$\mathcal{M}_n = \begin{pmatrix} M & m \\ m^T & 0_{3\times3} \end{pmatrix} ;$$

This generalized seesaw
implies that although neutrino masses and mixing angles are not predicted, they can easily be fitted to experimental data (even with flavour diagonal neutrino Yukawa couplings)

In a sense, this gives an answer to the question
why the mixing angles are so different in the quark and lepton sectors
(because no generalized seesaw exists for the quarks)

Discovery of new physics at the LHC with the μνSSM

Bartl, Hirsch, Vicente, Liebler, Porod, JHEP 05 (2009) 120

Bandyopadhyay, Ghosh, Roy, PRD 84 (2011) 115022

Fidalgo, Lopez-Fogliani, C.M., Ruiz de Austri, JHEP 10 (2011) 020

Lieber, Porod, NPB 855 (2012) 774

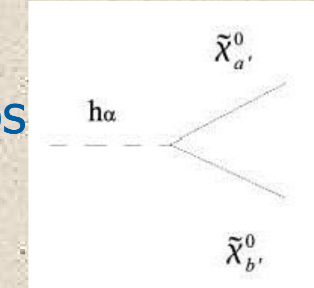
Ghosh, Lopez-Fogliani, Mitsou, C.M., Ruiz de Austri, PRD 88 (2013) 015009

Ghosh, Lopez-Fogliani, Mitsou, C.M., Ruiz de Austri, arXiv:1403.3675

Ghosh, Lopez-Fogliani, Mitsou, C.M., Ruiz de Austri, arXiv:1410.2070

Higgs decays in the μνSSM

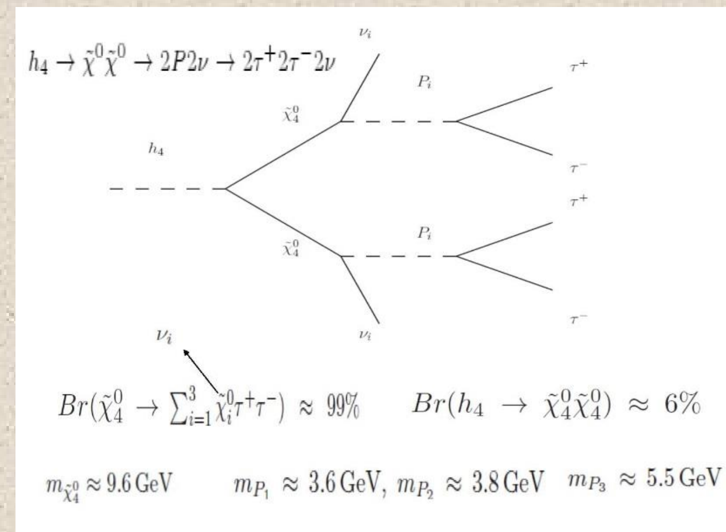
h_{MSSM} may have a sizeable branching ratio into two light neutralinos



Since R parity is broken,
each neutralino can decay into a scalar/pseudoscalar and a neutrino
inside the detector

due to the mixing of the MSSM neutralinos and neutrinos

Bartl, Hirsch, Vicente, Liebler, Porod, JHEP 05 (2009) 120



with a length large enough to show

because RPV is small given the value of $Y_\nu \sim 10^{-6}$

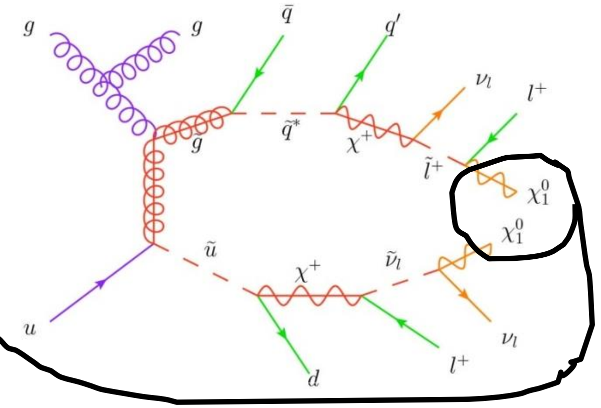
DISPLACED VERTICES

Ghosh, Lopez-Fogliani, Mittsou, C.M., Ruiz de Austri, PRD 88 (2013) 015009

$\tau_{\tilde{\chi}^0_4} \approx 10^{-9}$ s. $\quad c\tau_{\tilde{\chi}^0_4} \approx 30$ cm,

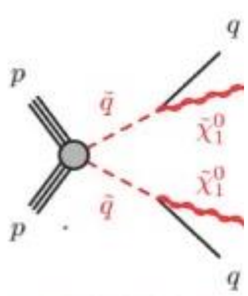
If the decay of the pseudoscalars into two b's is kinematically forbidden ($2m_\tau < m_P < 2m_b$): **multileptons**!

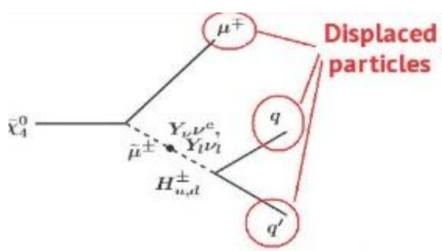
After 3 years of LHC running, direct searches of SUSY based mainly on the existence of missing energy in the final state
have failed to find a signal that exceeds the SM background



Time for experimentalists to look for RPV SUSY in more detail ?

Many other processes giving rise to new physics, e.g.:
Squark pair production in the **μνSSM**





$\tilde{q}\tilde{q} \longrightarrow$ 2 jet (prompt) + 2l + 2q2q'

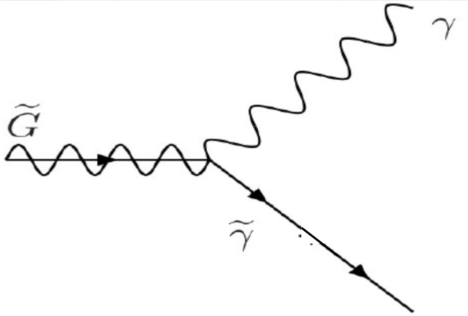
Ghosh, Kpatcha, Lara, Lopez-Fogliani, Mitsou, C.M., Ruiz de Austri, in preparation

Gravitino as a DM candidate in models with RPV

The addition of the gravitino to the SUSY spectrum leads to the so-called cosmological gravitino problems

In supergravity, the gravitino can decay.
E.g. through the interaction gravitino-photon-photino

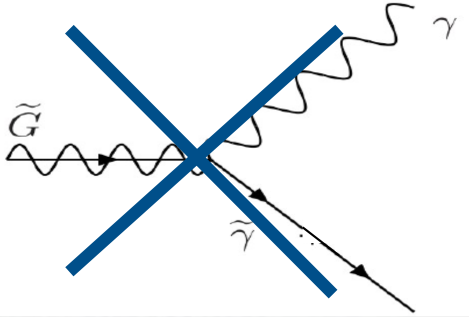
$$L_{int} = -\frac{i}{8M_{pl}}\bar{\psi}_\mu[\gamma^\nu, \gamma^\rho]\gamma^\mu \lambda F_{\nu\rho},$$



Although it is supressed by the Planck mass, the gravitino cannot be a candidate for DM:

$$\tau_{3/2} \sim \frac{M_{\rm Pl}^2}{m_{3/2}^3} \approx 3\,\text{years}\left(\frac{100\,\text{GeV}}{m_{3/2}}\right)^3.$$

Nevertheless, if it is the LSP, then it is stable in RPC models, and therefore a candidate for DM

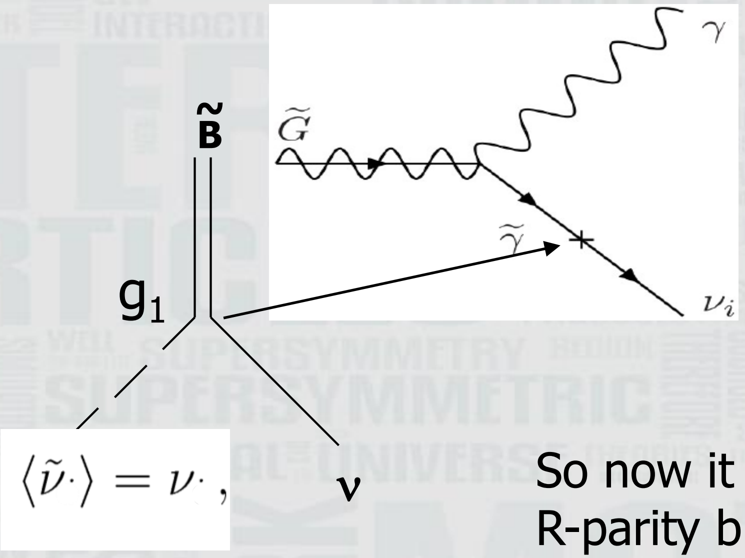


However, the late NLSP decays may spoil the predictions of BBN

$$\tau_{\rm NLSP} \simeq \frac{48\,\pi\, M_{\rm Pl}^2\, m_{3/2}^2}{m_{\rm NLSP}^5} \approx 9\,\text{days}\left(\frac{m_{3/2}}{10\,\text{GeV}}\right)^2\left(\frac{150\,\text{GeV}}{m_{\rm NLSP}}\right)^5.$$

This problem is not present in RPV models, since the NLSP decays into ordinary particles, and its lifetime becomes much shorter than 1 second.

Besides, the gravitino LSP also decays due to the photino-neutrino mixing, after sneutrinos develop VEVs , opening the channel



$$\Gamma(\psi_{3/2} \to \gamma\nu) = \frac{1}{32\pi}|U_{\tilde{\gamma}\nu}|^2 \frac{m_{3/2}^3}{M_P{}^2} .$$

$$|U_{\tilde{\gamma}\nu}|^2 = \sum_{i=1}^{3} |N_{i1}\cos\theta_W + N_{i2}\sin\theta_W|^2 .$$

Here N_{i1} (N_{i2}) is the Bino (Wino) component of the i-neutrino.

So now it is supressed both by the Planck mass and the R-parity breaking, which is expected to be smaller than 10^{-12}

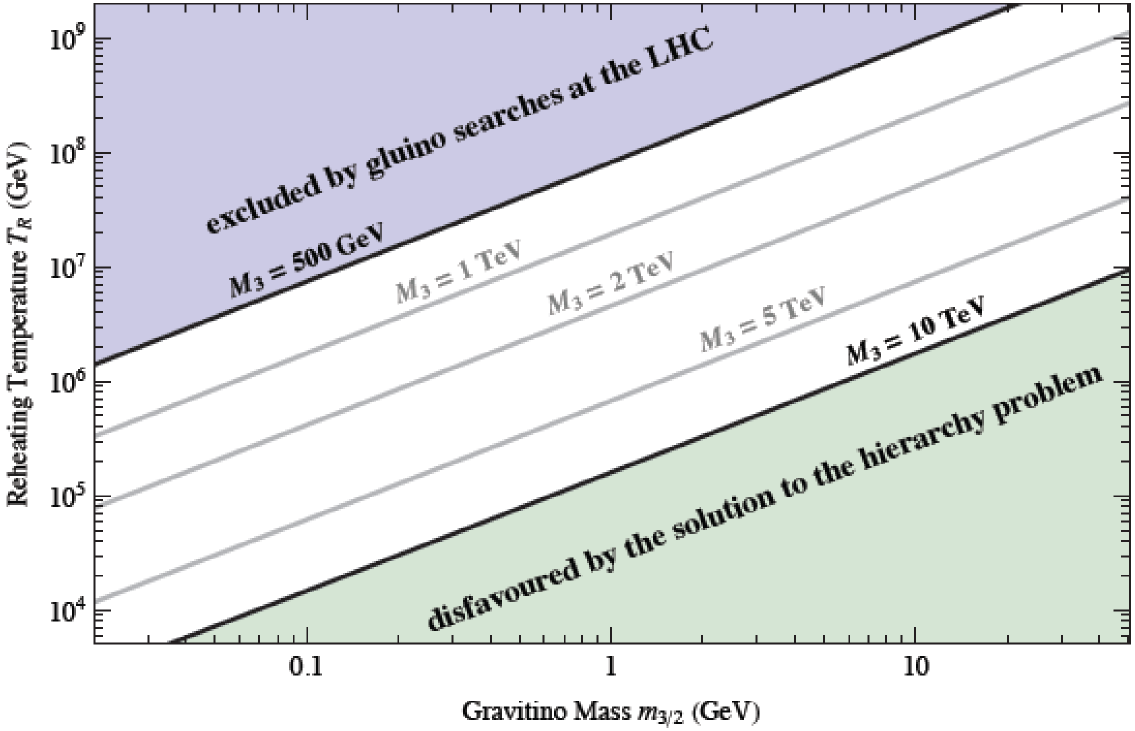
Thus the lifetime can be longer than the age of the Universe (~10^{17} s), and the gravitino can be a good DM candidate

$$\tau_{3/2} = \Gamma^{-1}(\tilde{G} \to \gamma\nu) \simeq 8.3 \times 10^{26}\,\text{sec} \times \left(\frac{m_{3/2}}{1\text{GeV}}\right)^{-3} \left(\frac{|U_{\gamma\nu}|^2}{7 \times 10^{-13}}\right)^{-1}$$

gravitino relic density

If the gravitino is thermally produced, its relic density can match the observed dark matter density ~ 0.1 (diagonal lines) tuning the reheating temperature after inflation

$$\Omega_{3/2}h^2 \simeq 0.27 \left(\frac{T_R}{10^{10}\,\mathrm{GeV}}\right)\left(\frac{100\,\mathrm{GeV}}{m_{3/2}}\right)\left(\frac{m_{\tilde{g}}}{1\,\mathrm{TeV}}\right)^2,$$



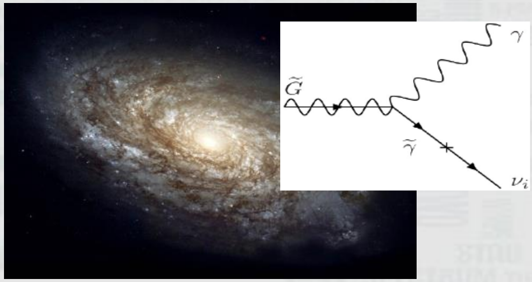
e.g., $m_{3/2} \sim$ 1-1000 GeV

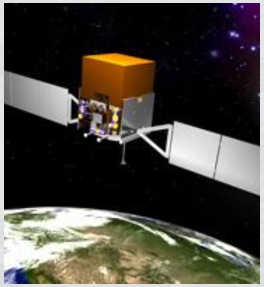
↓

$T_R \sim 10^8 - 10^{11}$ GeV

Detection of gravitino DM

- Decays of **gravitinos** in the galactic halo, at a sufficiently high rate, would produce gamma rays that could be detectable in experiments





***Fermi* Large Area Telescope (LAT)**, might in principle detect this flux of gamma rays predicted in RPV models with gravitino DM

Buchmuller, Covi, Hamaguchi, Ibarra, Yanagida, 07
Bertone, Buchmuller, Covi, Ibarra, 07
Ibarra, Tran, 08
Ishiwata, Matsumoto, Moroi, 08

$$\left[E^2 \frac{dJ}{dE}\right]_{\rm halo} = \frac{2E^2}{m_{3/2}} \frac{dN_\gamma}{dE} \frac{1}{8\pi\tau_{3/2}} \int_{\rm los} \rho_{\rm halo}(\vec{l}) d\vec{l} \, ,$$

Since a gravitino decays into a photon (and a neutrino), this produces a line at energies equal to $\mathbf{m_{3/2}/2}$

μνSSM gravitino DM

K.Y. Choi, López-Fogliani, C.M., R. Ruiz de Austri,
JCAP 03 (2010) 028

photino content of the neutrino depends on the model →

$$\tau_{3/2} \simeq 3.8 \times 10^{27}\,\mathrm{s}\left(\frac{|U_{\tilde{\gamma}\nu}|^2}{10^{-16}}\right)^{-1}\left(\frac{m_{3/2}}{10\,\mathrm{GeV}}\right)^{-3}.$$

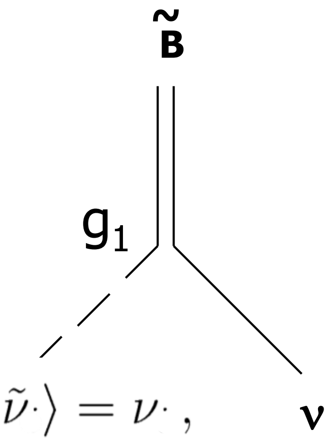
neutralino-neutrino mass matrix in the μνSSM

$$\chi^{0T} = (\tilde{B}^0, \tilde{W}^0, \tilde{H}_d, \tilde{H}_u, \nu_R, \nu_L),$$

$$\mathcal{M}_n = \begin{pmatrix} M & m \\ m^T & 0 \end{pmatrix}, \quad (7)$$

where

$$M = \begin{pmatrix} M_1 & 0 & -M_Z\sin\theta_W\cos\beta & M_Z\sin\theta_W\sin\beta & 0 \\ 0 & M_2 & M_Z\cos\theta_W\cos\beta & -M_Z\cos\theta_W\sin\beta & 0 \\ -M_Z\sin\theta_W\cos\beta & M_Z\cos\theta_W\cos\beta & 0 & -\lambda\nu^c & -\lambda v_2 \\ M_Z\sin\theta_W\sin\beta & -M_Z\cos\theta_W\sin\beta & -\lambda\nu^c & 0 & -\lambda v_1 + Y_\nu\nu \\ 0 & 0 & -\lambda v_2 & -\lambda v_1 + Y_\nu\nu & 2\kappa\nu^c \end{pmatrix}, \quad (8)$$



$$\langle\tilde{\nu}\rangle = \nu,$$

$$m^T = \begin{pmatrix} -g_1\nu & g_2\nu & 0 & Y_\nu\nu^c & Y_\nu v_2 \end{pmatrix}. \quad (9)$$

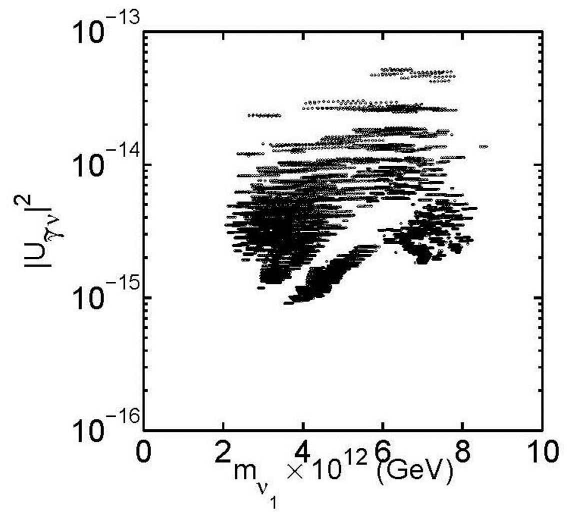
e.g. this diagram determines the bino-neutrino mixing

Thus the photino content of the neutrino: $|U_{\tilde{\gamma}\nu}|^2 \sim |g_1\,\nu/M_1|^2 \sim 10^{-14} - 10^{-15}$

Since in the minimization equation for ν,
$Y_\nu \sim 10^{-6}$ in order to reproduce neutrino data, implying ν ~ **10^{-4}** GeV

The numerical scan of the low-energy parameter space of the model confirms this estimation:

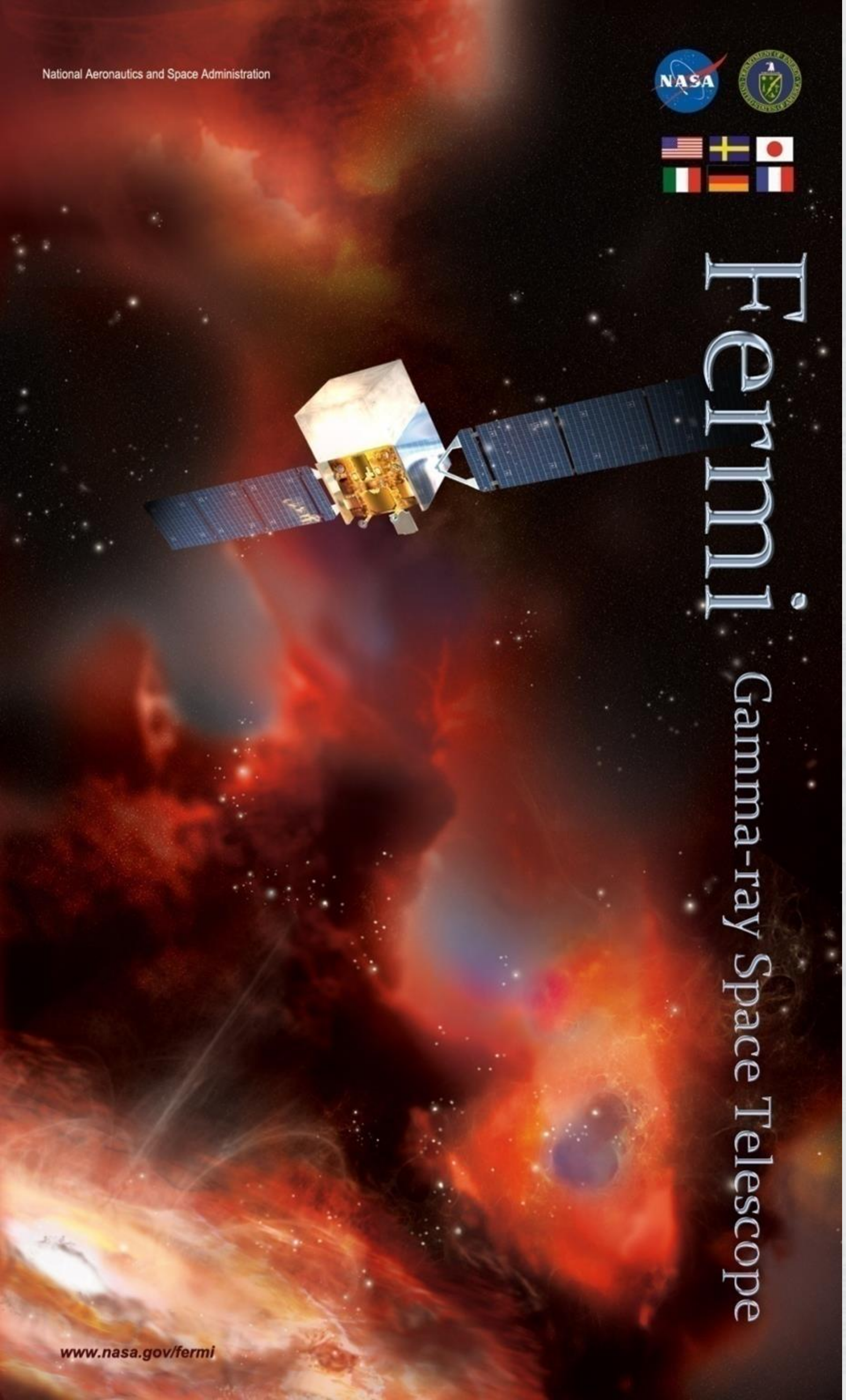
$$
\begin{aligned}
0 \leq & \quad \lambda & \leq 0.4, \\
0 \leq & \quad \kappa & \leq 0.4, \\
100\,\text{GeV} \leq & \quad \nu^c & \leq 3\,\text{TeV}, \\
-3\,\text{TeV} \leq & \quad M_2 & \leq 0\,\text{GeV}, \\
2 \leq & \quad \tan\beta & \leq 40, \\
10^{-7}\,\text{GeV} \leq & \quad \nu_1 & \leq 10^{-5}\,\text{GeV}, \\
10^{-6}\,\text{GeV} \leq & \quad \nu_2 = \nu_3 & \leq 10^{-4}\,\text{GeV}, \\
10^{-7} \leq & \quad Y_{\nu_1} & \leq 10^{-6}, \\
10^{-7} \leq & \quad Y_{\nu_2} = Y_{\nu_3} & \leq 10^{-6}.
\end{aligned}
$$



$$10^{-15} \lesssim |U_{\tilde{\gamma}\nu}|^2 \lesssim 5\times10^{-14}$$

where the GUT relation $M_2 \sim 2\, M_1$ is assumed

- Typically, the mass of the lightest neutralino is above 20 GeV, thus the gravitino can be used as the LSP because of bound that we will obtain from *Fermi* data, < 20 GeV



Fermi Gamma-ray Space Telescope

MultiDark
Multimessenger Approach for Dark Matter Detection

Together with Fermi-LAT collaborators we performed a:

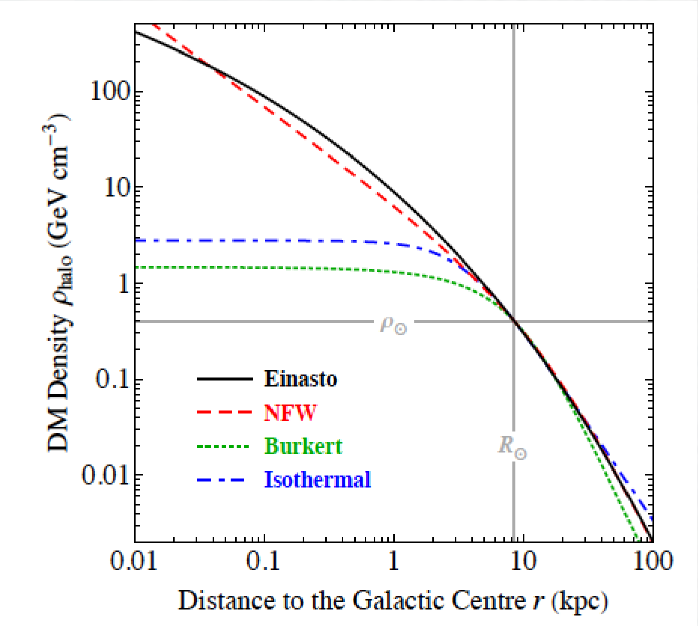
Search for 100 MeV to 10 GeV γ-ray lines in the *Fermi*-LAT data and implications for gravitino dark matter in the μνSSM

arXiv:1406.3430 [astro-ph.HE], ***JCAP* 10 (2014) 023**

Region of Interest (RoI) optimization

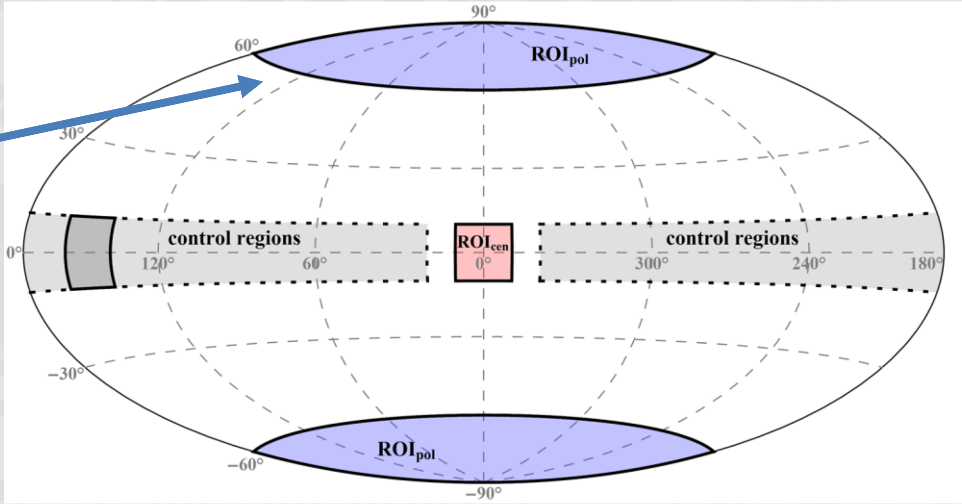
- Use Einasto profile as baseline, but present J factors for other profiles and the upper limit flux.

  The uncertainty in the DM distribution within the ROI_{pol} is less tan 10%

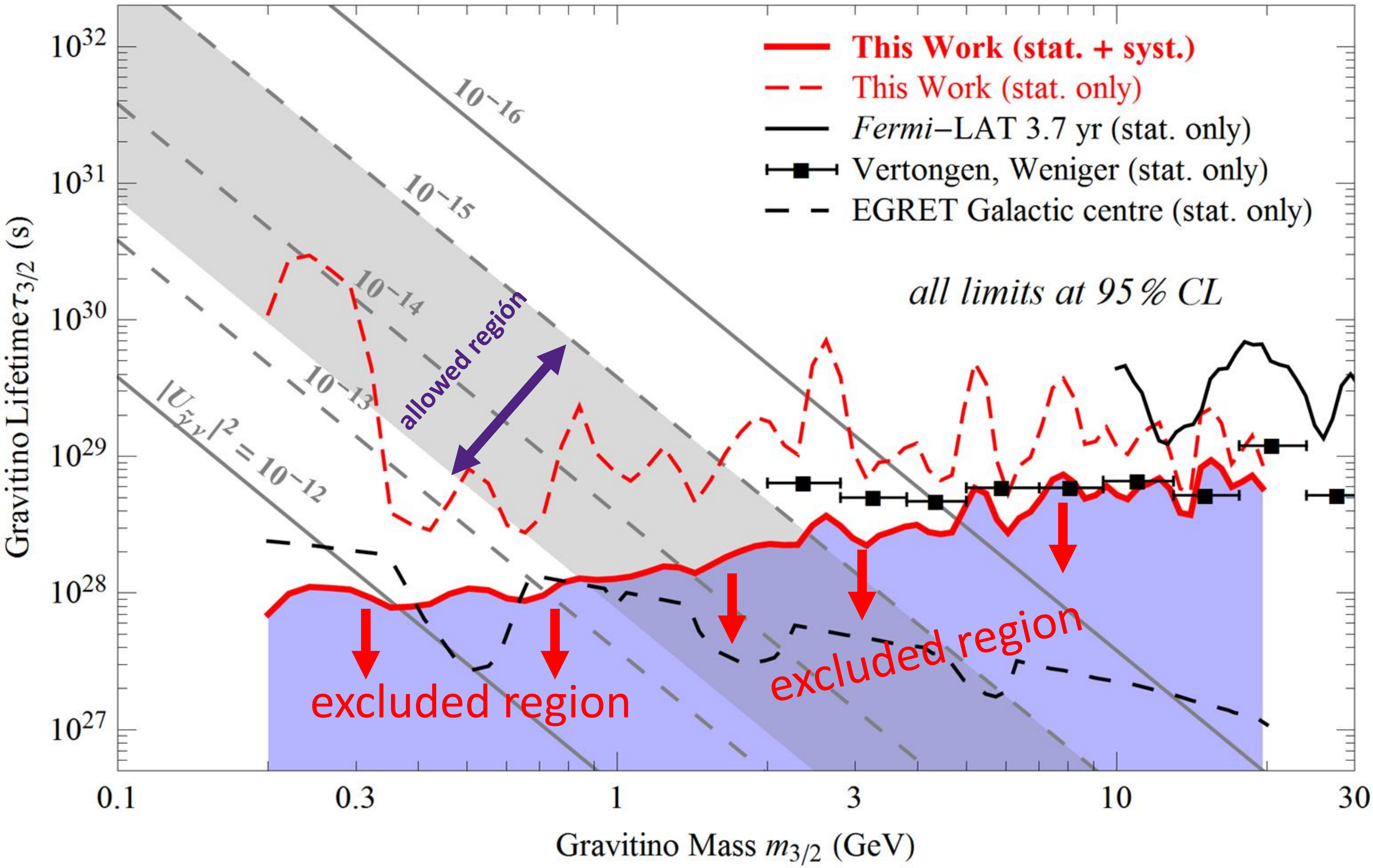


- Optimize **signal-to-background ratio** for decay ($\Psi_{3/2} \rightarrow \nu\gamma$)

  ROI_{pol} |b|>60º



Applying these bounds $10^{-15} \lesssim |U_{\tilde{\gamma}\nu}|^2 \lesssim 5\times 10^{-14}$ to our model: $\tau_{3/2} \simeq 3.8 \times 10^{27}\ \text{s} \left(\frac{|U_{\tilde{\gamma}\nu}|^2}{10^{-16}}\right)^{-1} \left(\frac{m_{3/2}}{10\,\text{GeV}}\right)^{-3}.$

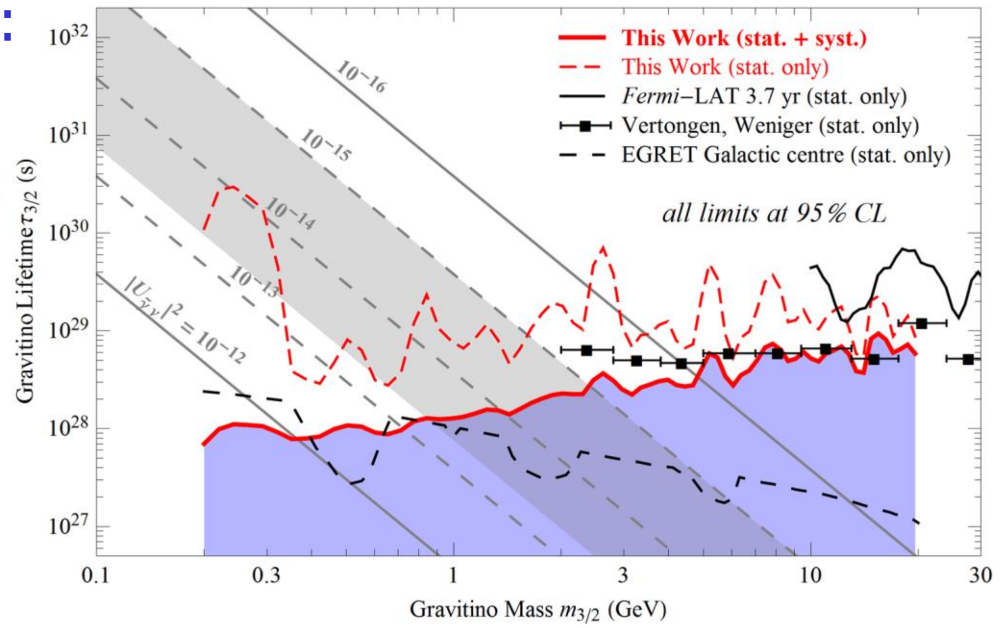


µνSSM gravitinos with masses larger than **2.4** GeV
or lifetimes smaller than **1.3 x 10^{28}** s are excluded as DM candidates

But, given the approximate formula:

$$|U_{\widetilde{\gamma}\nu}| \approx \frac{M_Z(M_2 - M_1)s_W c_W}{(M_1 c_w^2 + M_2 s_w^2)(M_1 s_W^2 + M_2 c_W^2)},$$

we might think in relaxing these bounds



- we can try to work with larger low-energy gaugino masses, $|M_{1,2}| > 1.5$ TeV

implying e.g. ~~$m_{3/2} < 2.4$ GeV~~ → $m_{3/2} < 3.5$ GeV for $M_1 = 10$ TeV

- or tune them, e.g. $M_2 = 1.1\, M_1$

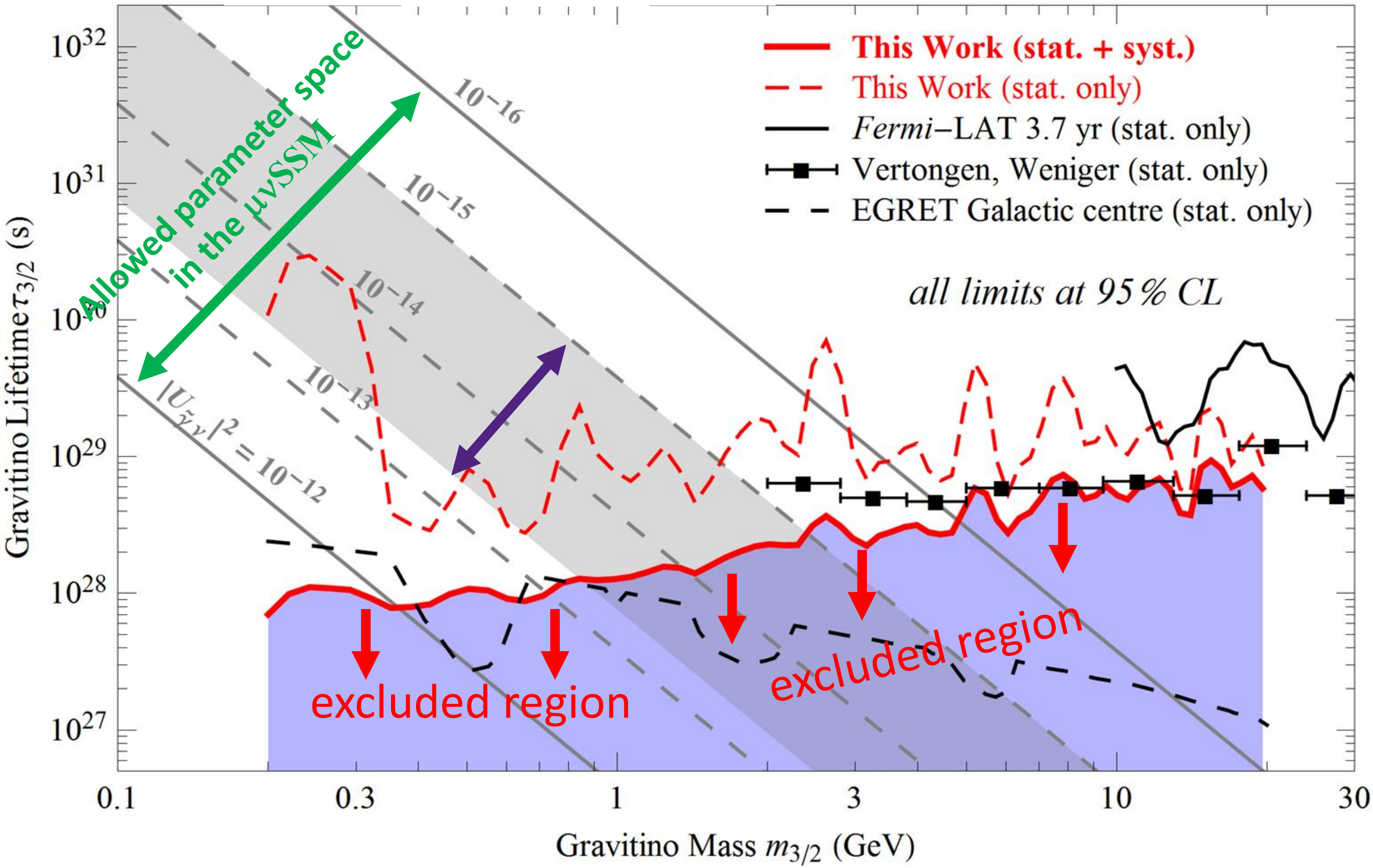
$$10^{-15} \lesssim |U_{\widetilde{\gamma}\nu}|^2 \lesssim 5\times 10^{-14} \longrightarrow 10^{-16} \lesssim |U_{\widetilde{\gamma}\nu}|^2 \lesssim 10^{-12}$$

implying $m_{3/2} < 4.8$ GeV

Applying these bounds to our model:

$$\tau_{3/2} \simeq 3.8 \times 10^{27}\ \mathrm{s} \left(\frac{|U_{\tilde{\gamma}\nu}|^2}{10^{-16}}\right)^{-1} \left(\frac{m_{3/2}}{10\,\mathrm{GeV}}\right)^{-3}.$$

$$10^{-16} \lesssim |U_{\tilde{\gamma}\nu}|^2 \lesssim 10^{-12}$$



μνSSM gravitinos with masses larger than **4.8** **(2.4)** GeV or lifetimes smaller than **7.9 x 10^{27}** **(1.3 x 10^{28})** s are excluded as DM candidates

- with $M_2 \sim M_1$ we could obtain $m_{3/2} < 7$ GeV

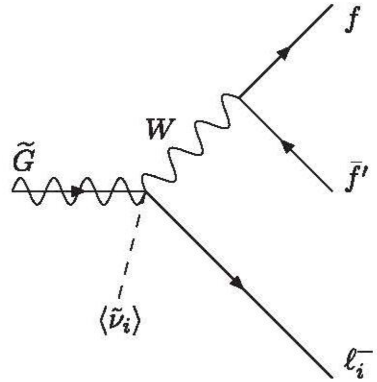
Can relax still more these bounds?

Although they seem to imply a small $m_{3/2}$, three-body decay channels could be relevant, specially for large M_i or tuned values e.g. $M_2 = 1.1\, M_1$

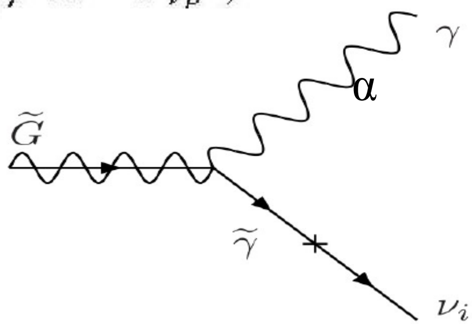
Gómez-Vargas, López-Fogliani, C.M., Pérez, Ruiz de Austri, in preparation

K.Y. Choi, Yaguna, 1003.3401
K. Y. Choi, Restrepo, Yaguna, Zapata, 1007
Diaz, García Saenz, Koch, 1106.0308

$$\mathcal{L} \ni -\frac{i}{\sqrt{2}M_P}\left[(D^*_\mu \phi^{i*})\bar{\psi}_\nu \gamma^\mu \gamma^\nu P_L \chi^i - (D_\mu \phi^i)\bar{\chi}^i P_R \gamma^\nu \gamma^\mu \psi_\nu\right] - \frac{i}{8M_P}\bar{\psi}_\mu[\gamma^\nu, \gamma^\rho]\gamma^\mu \lambda^{(\alpha)a} F^{(\alpha)a}_{\nu\rho},$$



$+ \cdots$ $\not\propto |U_{\tilde{\gamma}\nu}|^2$

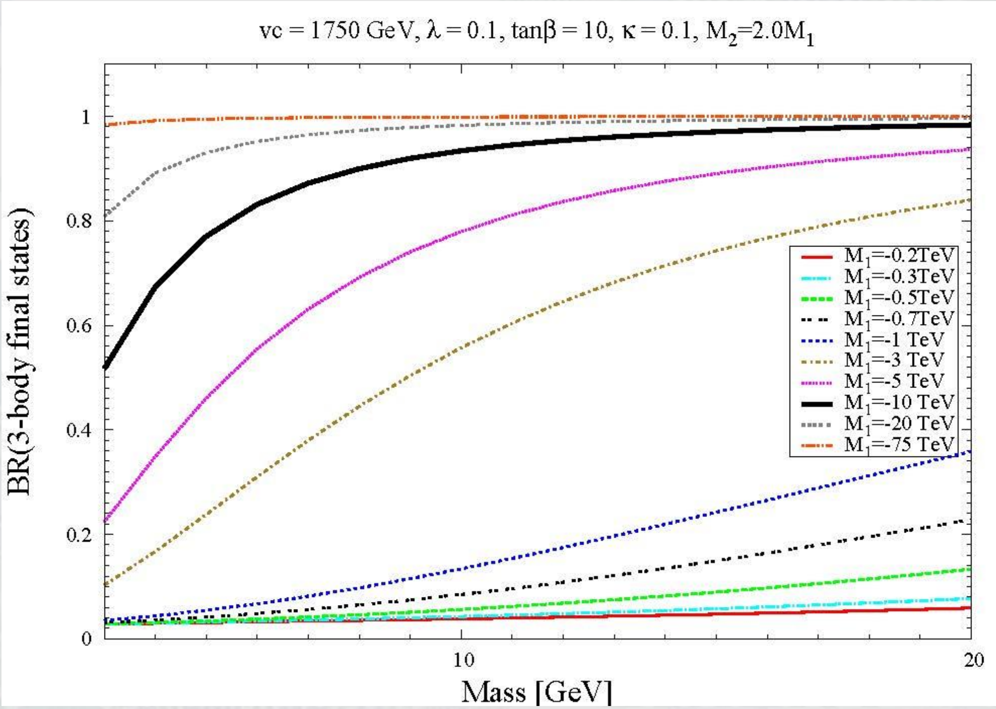


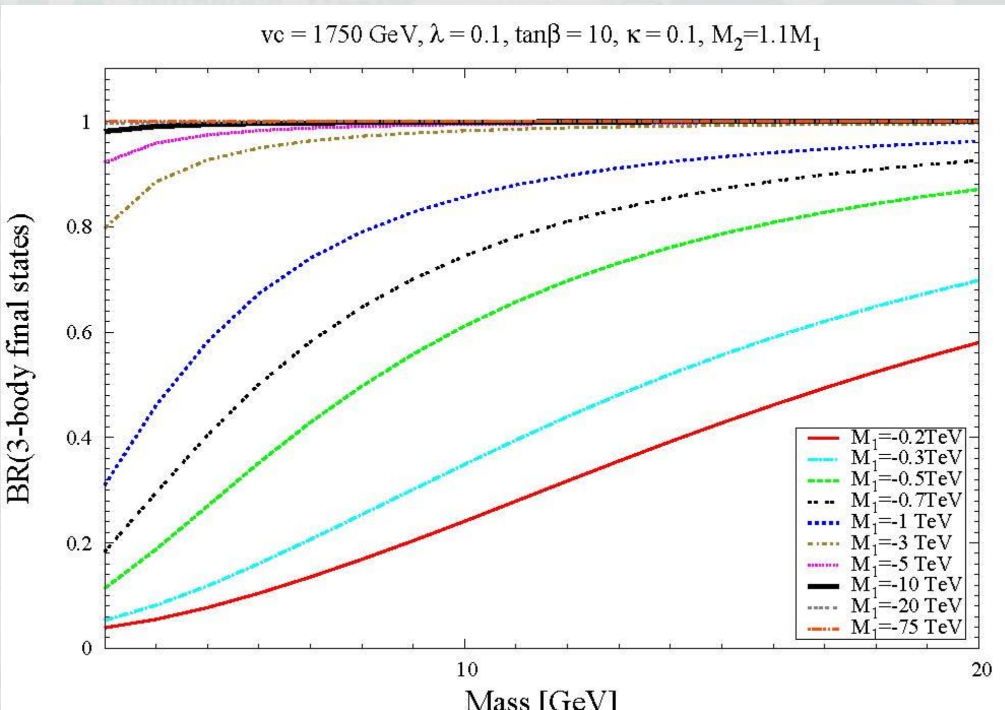
$\propto |U_{\tilde{\gamma}\nu}|^2$

Implying a significant correction to the gravitino decay width for regions of the parameter space where the mixing is made small

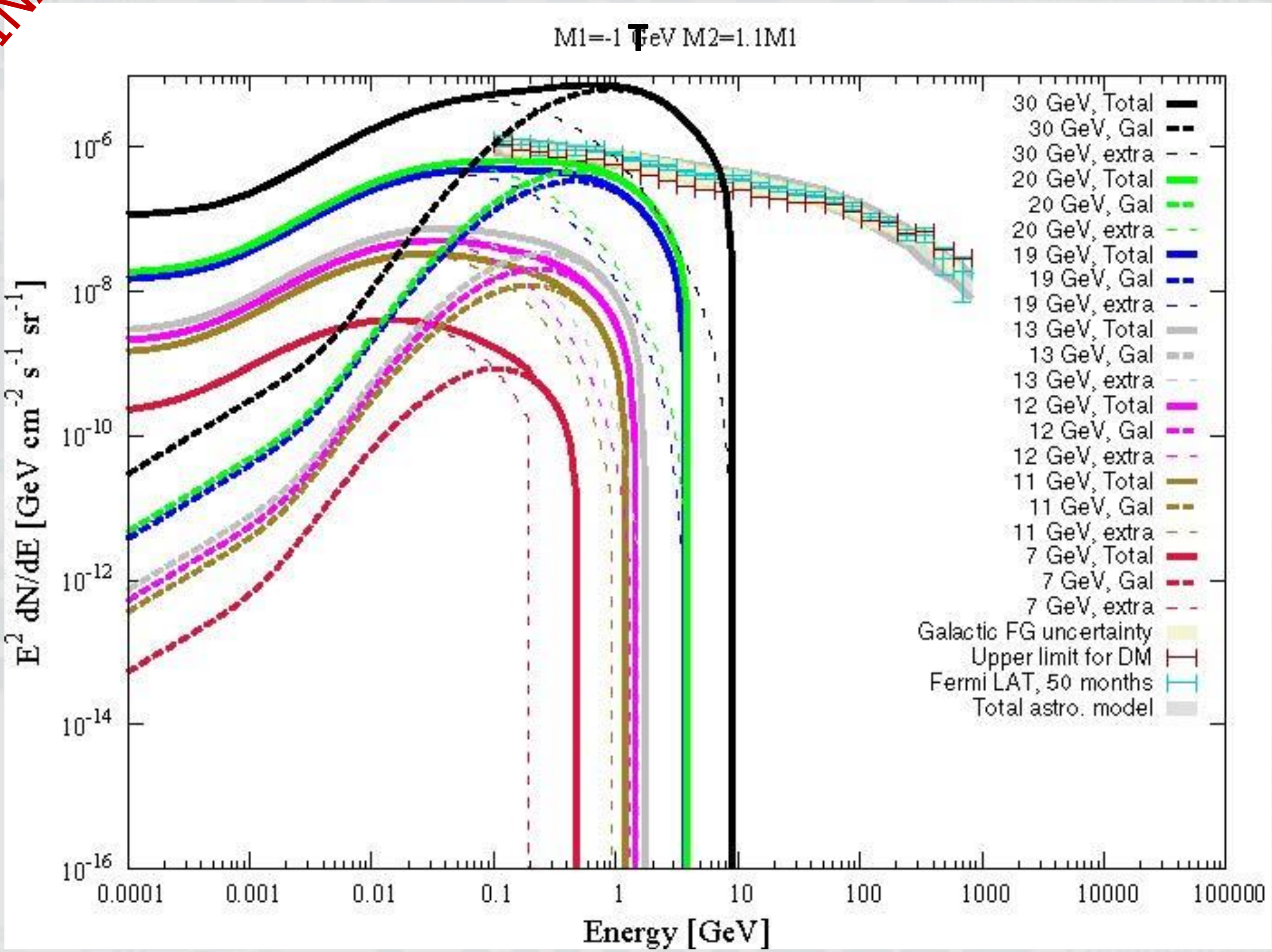
The photon spectrum consists then of a line from the two-body decay, plus a continuum distribution from the three-body decay

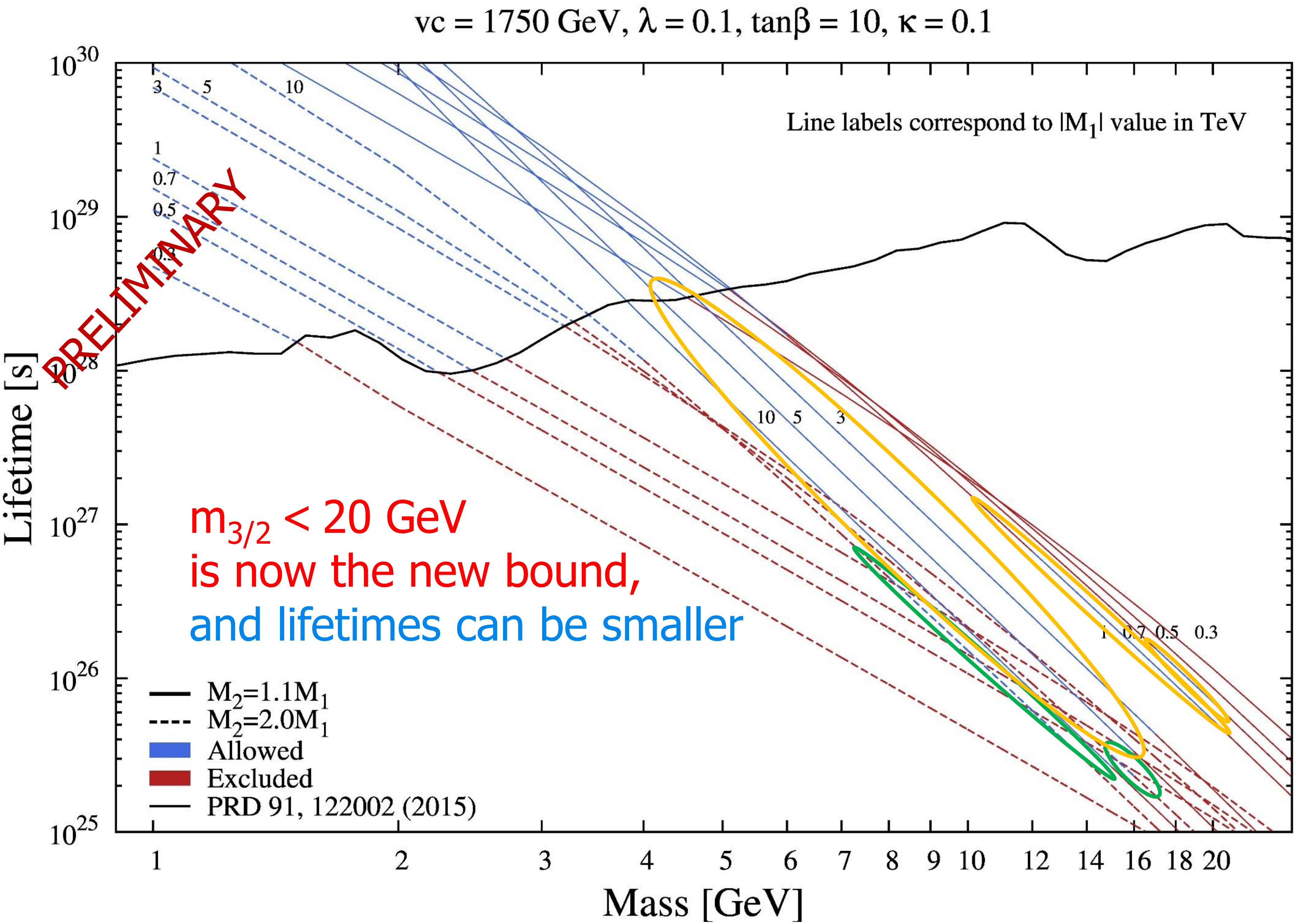
PRELIMINARY





PRELIMINARY




vc = 1750 GeV, λ = 0.1, tanβ = 10, κ = 0.1
Line labels correspond to |M1| value in TeV
PRELIMINARY
Lifetime [s]
Mass [GeV]
M2=1.1M1
M2=2.0M1
Allowed
Excluded
PRD 91, 122002 (2015)
m3/2 < 20 GeV
is now the new bound,
and lifetimes can be smaller

Conclusions

Solving the μ problem with **neutrinos** gives rise to a new SUSY model:

a "μ from ν" Supersymmetric Standard Model ($\mu\nu$SSM)

$$\hat{\nu}^c_i \, \hat{H}_1 \, \hat{H}_2$$

Only one scale in the model: the soft SUSY-breaking scale ~ TeV

$$\hat{\nu}^c_i \hat{\nu}^c_j \hat{\nu}^c_k$$

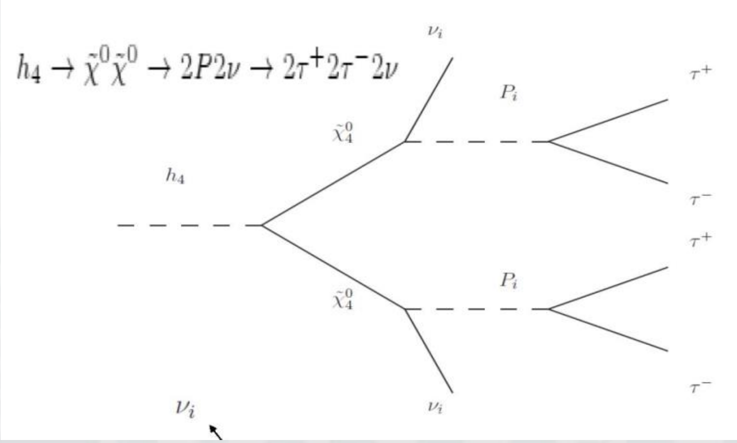
A electroweak seesaw is generated dynamically
(no Majorana masses have to be introduced by hand)

The phenomenology of this model is very rich, e.g.:

* The neutralino-LSP may decay within the detectors but with a length large enough to show a displaced vertex

- Multi-lepton/jet events can be produced in the SUSY cascade decay chains

e.g.:



Gravitino is an interesting DM candidate in the μνSSM that can be observed in indirect detection experiments

Fermi LAT data allow to constrain the parameter space of the model:

e.g. μνSSM gravitino DM must have a mass no larger than 20 GeV

THE END