Novel R-Parity breaking decays

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Based on

D.R, D. Aristizabal Sierra, S. Spinner, arXiv:1212.3310 (JHEP) and
C. FLórez, D.R, M. Velásquez, O. Zapata, arXiv:1303.0278 (PRD)

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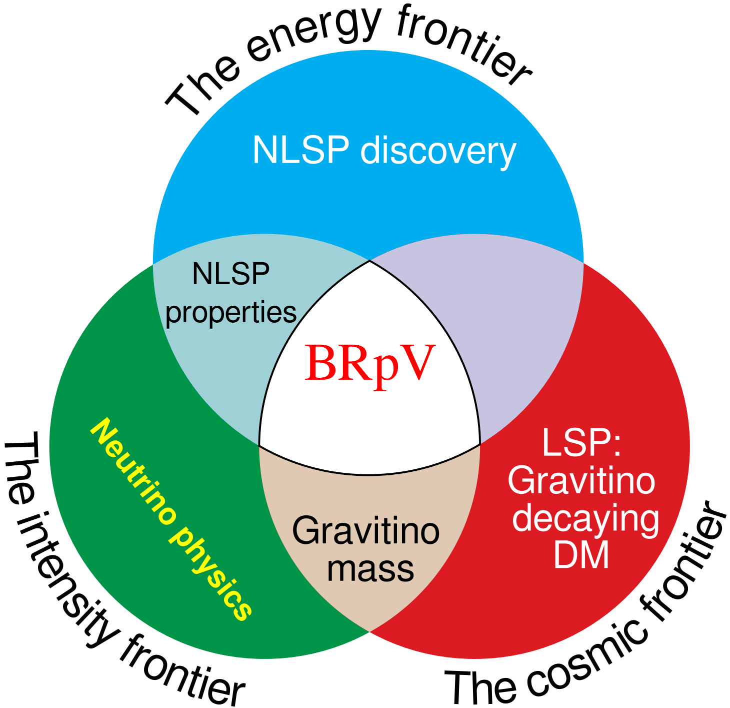
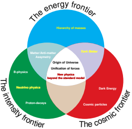

The energy frontier
NLSP discovery
NLSP properties
BRpV
Neutrino physics
LSP: Gravitino decaying DM
Gravitino mass
The intensity frontier
The cosmic frontier



Bilinear R-parity Violation (BRpV) Supersymmetric Model

$$W = W_{\mathrm{MSSM}} + \epsilon_i L_i H_u$$

$$i = 1, 2, 3$$

Bilinear R-parity Violation (BRpV) Supersymmetric Model

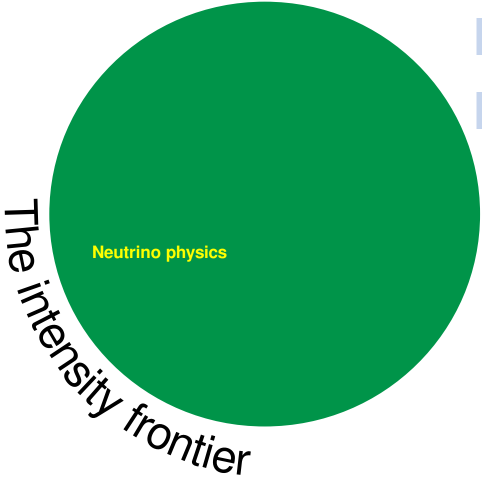
$$W = W_{\mathrm{MSSM}} + \epsilon_i L_i H_u$$

$$L_i \to v_i$$

$$i = 1, 2, 3$$

$$\frac{\Lambda_i}{\mu\, v_d} = \frac{\epsilon_i}{\mu} + \frac{v_i}{v_d}$$

6 new parameters



Parámetro	1σ
$\Delta m^2_{32}[10^{-3}\mathrm{eV}^2]$	$2.50^{+0.09}_{-0.16}$
$\Delta m^2_{21}[10^{-5}\mathrm{eV}^2]$	$7.59^{+0.20}_{-0.18}$
$\sin^2\theta_{23}$	$0.52^{+0.06}_{0.07}$
$\sin^2\theta_{12}$	$0.312^{+0.017}_{-0.015}$
$\sin^2\theta_{13}$	$0.013^{+0.007}_{-0.005}$

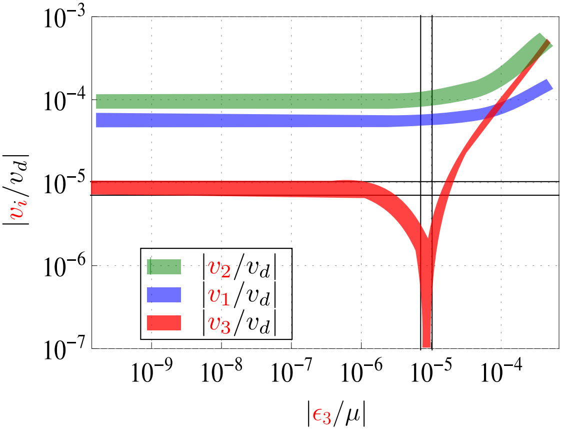
Valle et al, arXiv:1108.1376

$$\Delta m_{32} = \frac{M_{\tilde{\gamma}}}{4|\boldsymbol{M_{\chi}^{0}}|}\, |\boldsymbol{\Lambda}|^2$$

$$\tan^2\theta_{i3} = \frac{\Lambda_i^2}{\Lambda_3^2} \qquad i = 1, 2$$

$$\Delta m_{21} = \frac{3}{8\pi^2} \sin 2\theta_{\tilde{b}} \frac{m_b^3}{v^2\, c_\beta^2} \times \Delta B_0^{\tilde{b}_2 \tilde{b}_1} \frac{(\bar{\epsilon}_1^2 + \bar{\epsilon}_2^2)}{\mu^2}$$

$$\tan^2\theta_{12} = \frac{\bar{\epsilon}_1^2}{\bar{\epsilon}_2^2}\,.$$



$$\bar{\epsilon}_i = f_i(\Lambda_i, \epsilon_i)$$

Fully implemented in SPheno [by W. Porod]

$$\Delta m_{32} = \frac{M_{\tilde{\gamma}}}{4|M_{\chi}^{0}|}\,|\boldsymbol{\Lambda}|^2$$

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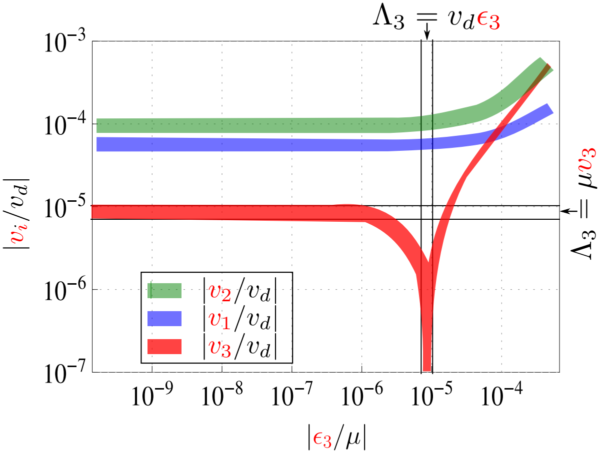
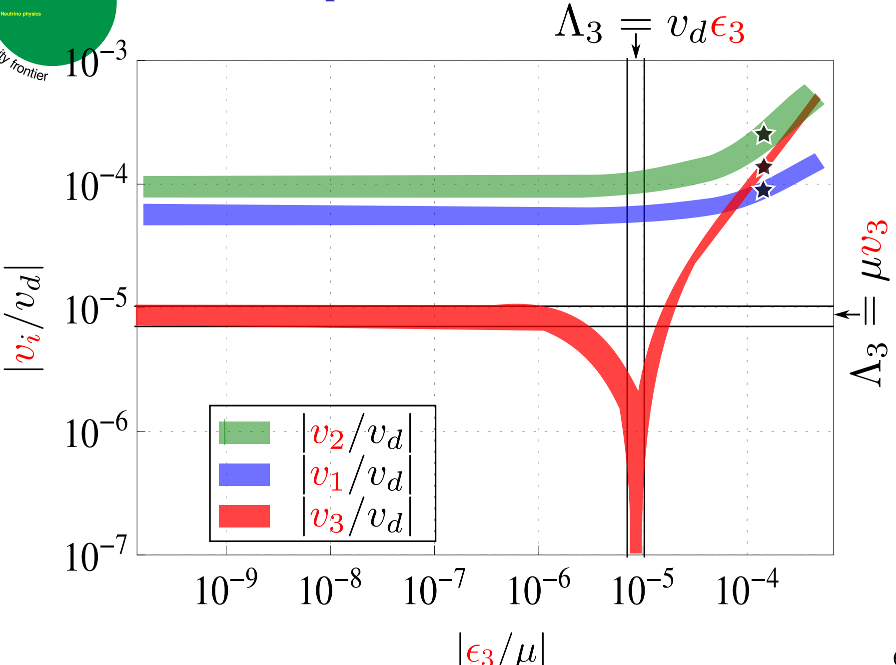
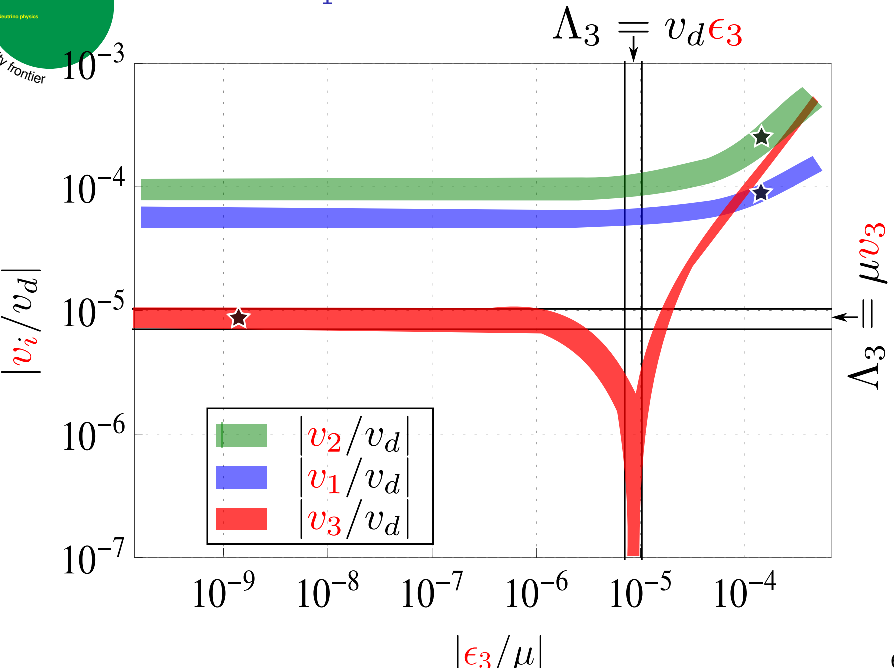


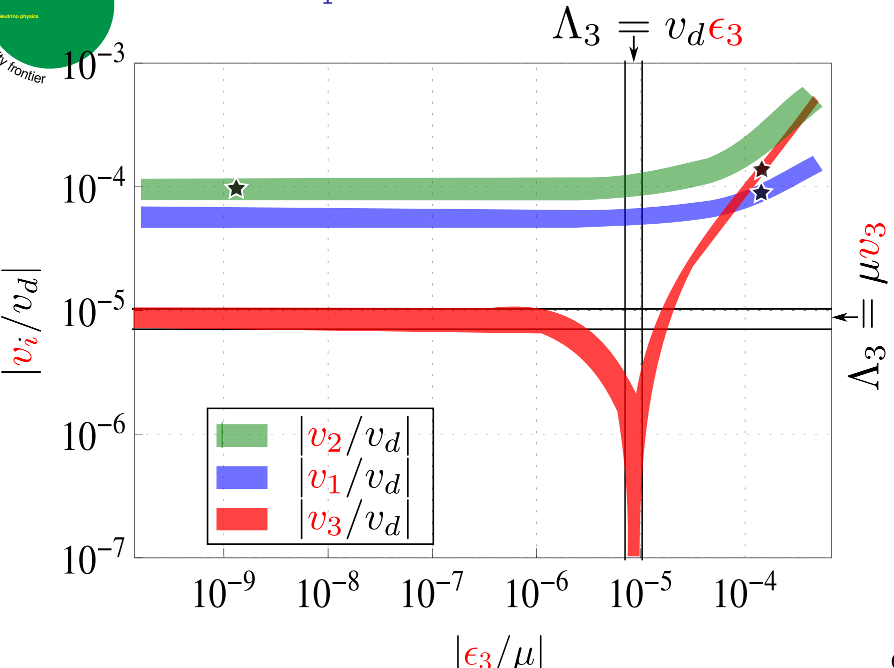
Non Zero ν_1 mass



Zero ν_1 mass



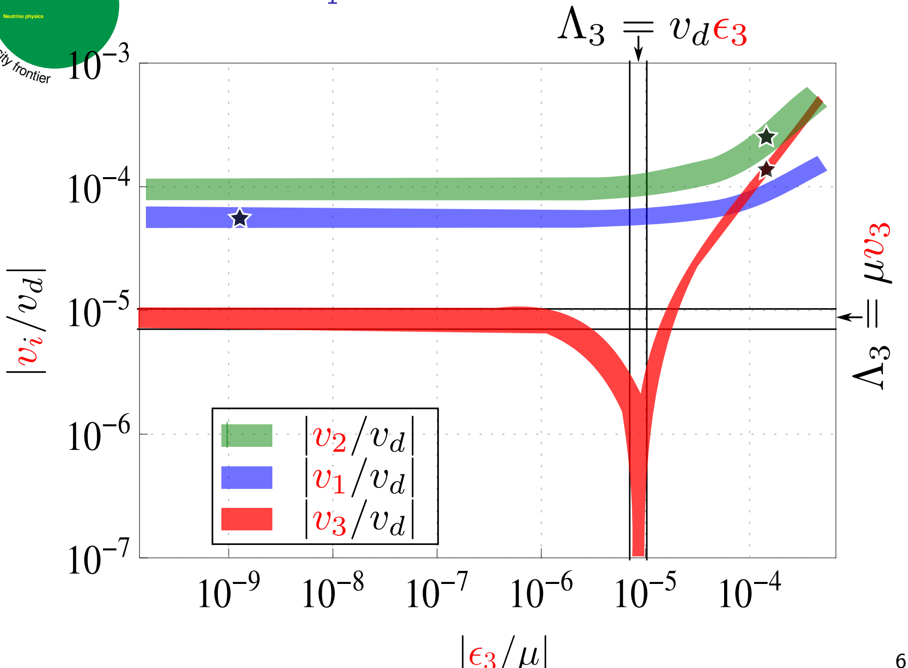
Zero ν_1 mass



The intensity frontier

Neutrino physics

Zero ν_1 mass

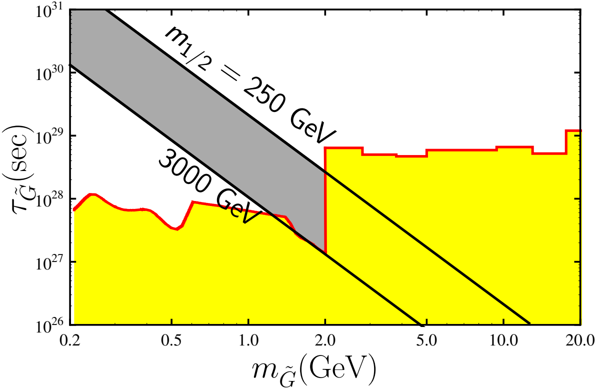


Inestable gravitino dark matter

D.R, M. Taoso, JWF. Valle, O. Zapata, PRD

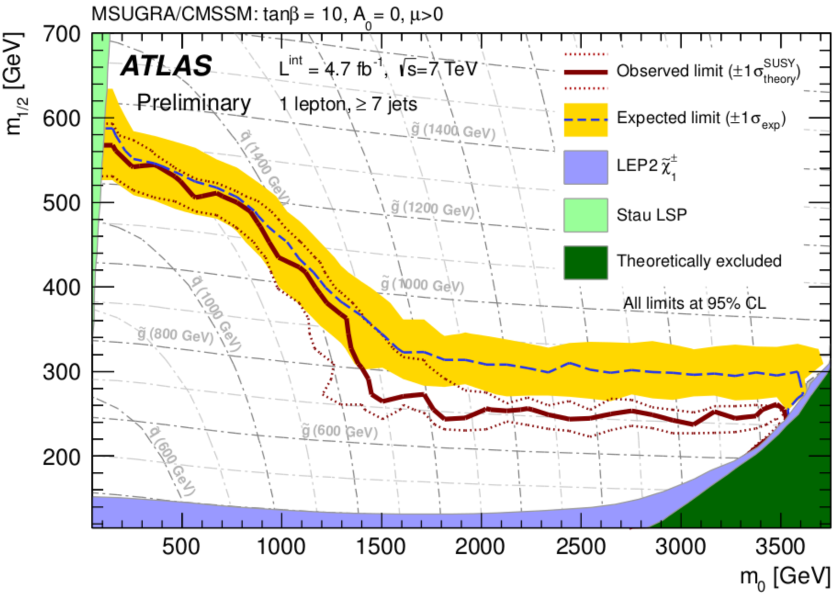
$$\Gamma = \Gamma(\tilde{G} \to \sum_i \nu_i \gamma) \simeq \frac{1}{32\pi} |U_{\tilde{\gamma}\nu}|^2 \frac{m_{\tilde{G}}^3}{M_P^2}$$

$$|U_{\tilde{\gamma}\nu}|^2 \approx \frac{\mu^2 g^2 \sin^2\theta_W}{4|M_\chi^0|} (M_2 - M_1)^2 |\vec{\Lambda}|^2$$



$T_R < 10^{-8}$ GeV

ATLAS-CONF-2012-140 (Oct)



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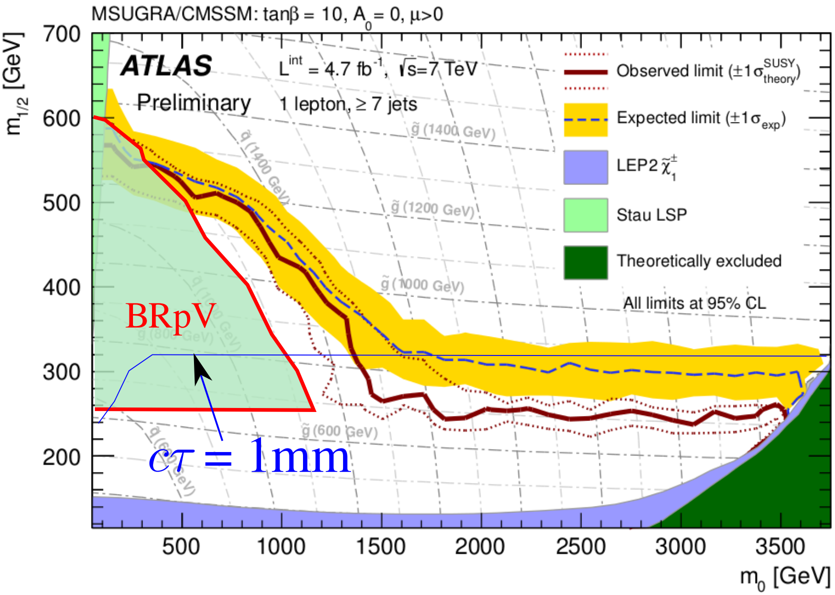

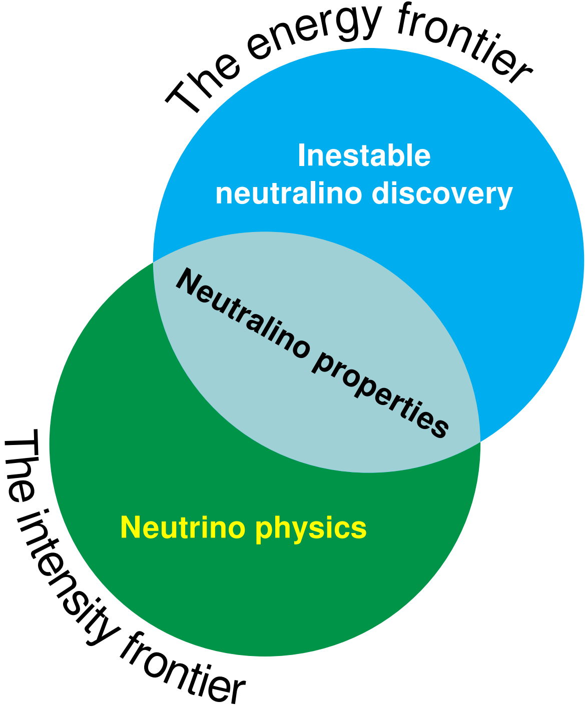
The energy frontier
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neutralino discovery
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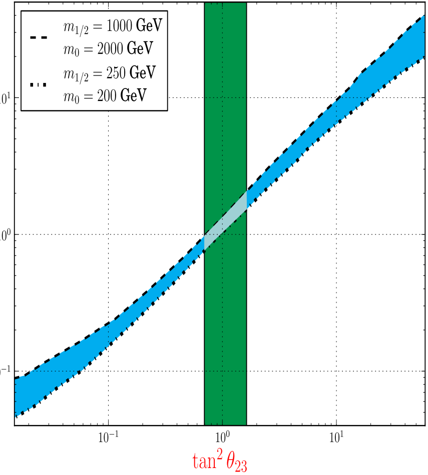
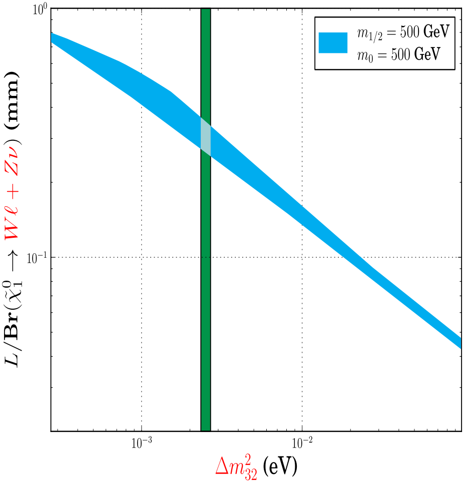
Neutralino properties

D.R. *et al*: arXiv:1006.5075 [PRD]

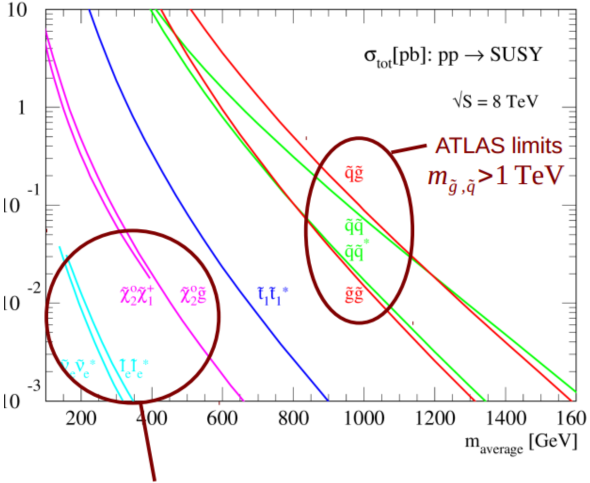


arXiv:1206.3605 [PRD]



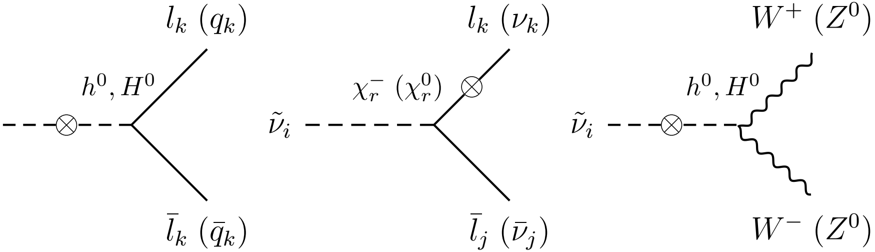
Only depend in Λ_i

Electroweak production

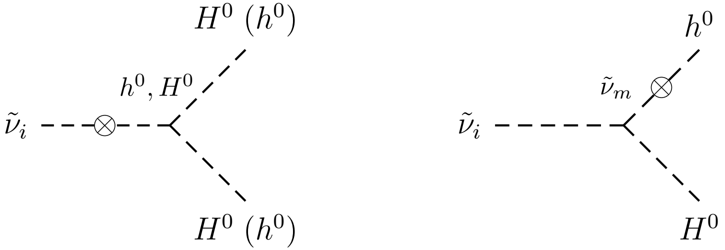


Direct gaugino/higgsino/slepton production may be the dominant SUSY cross-section at the LHC

Sneutrino RPV decays

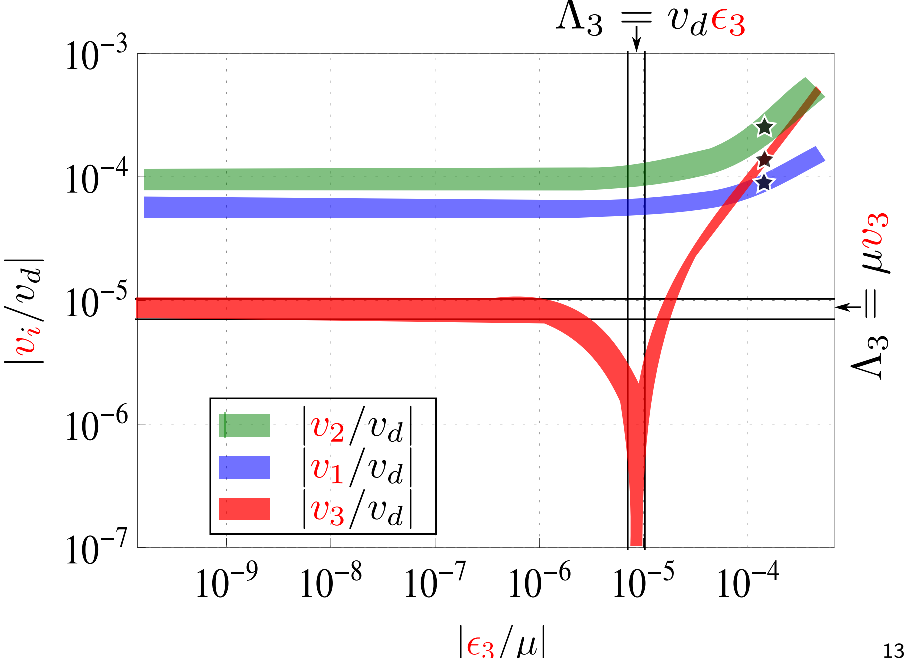


(a) (b) (c)

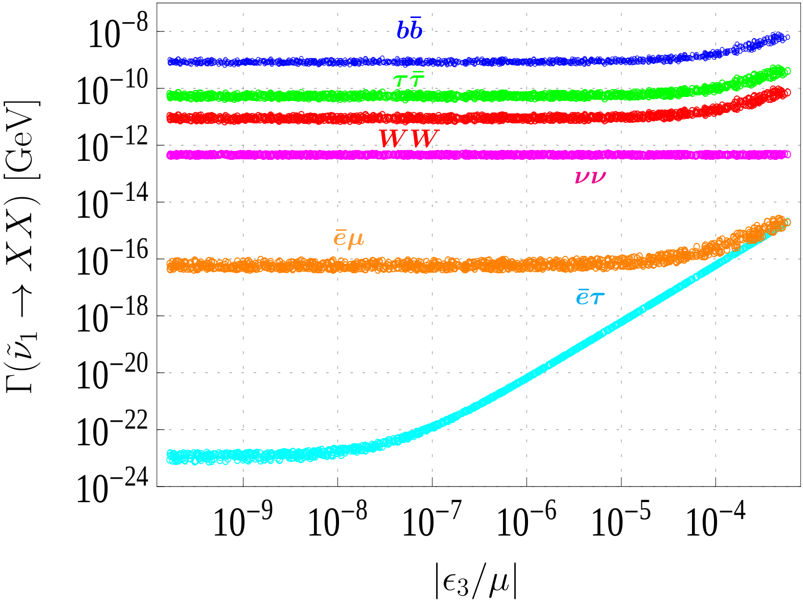


(a) (b)

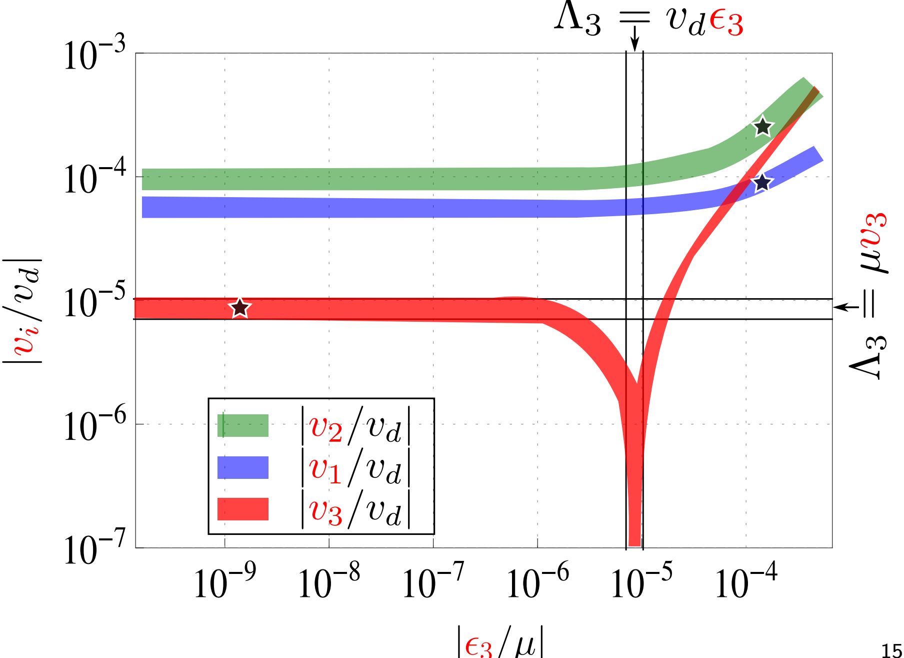
Sneutrino LSP with ϵ_3 as a free parameter



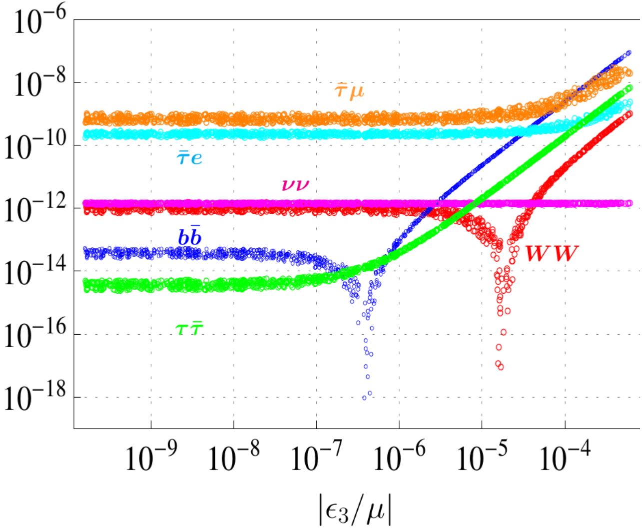
$\tilde{\nu}_1$ RPV decays with large ϵ_1. $m_{\tilde{\nu}_i} \approx 300$ GeV.



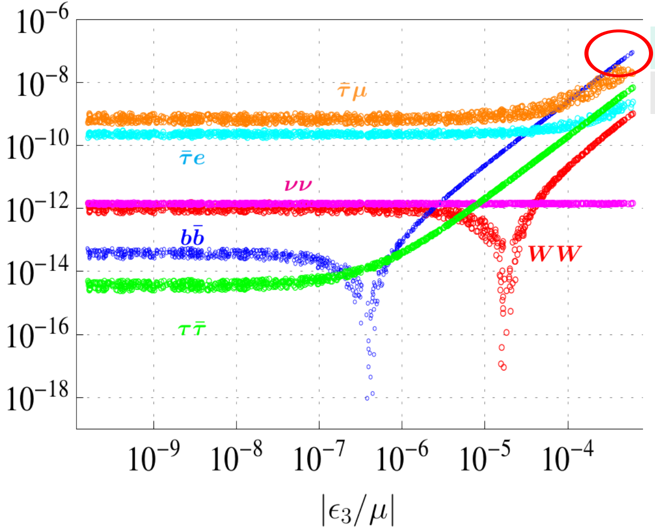
Sneutrino LSP with ϵ_3 as a free parameter



Tau-sneutrino novel decays. $m_{\tilde{\nu}_\tau} = 300$ GeV

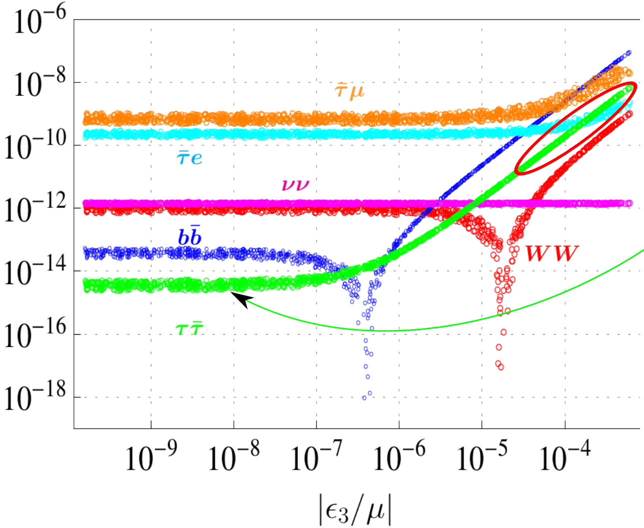


Tau-sneutrino novel decays. $m_{\tilde{\nu}_\tau} = 300$ GeV



ϵ_i	mode
large	$b\bar{b}$

Tau-sneutrino novel decays. $m_{\tilde{\nu}_\tau} = 300$ GeV



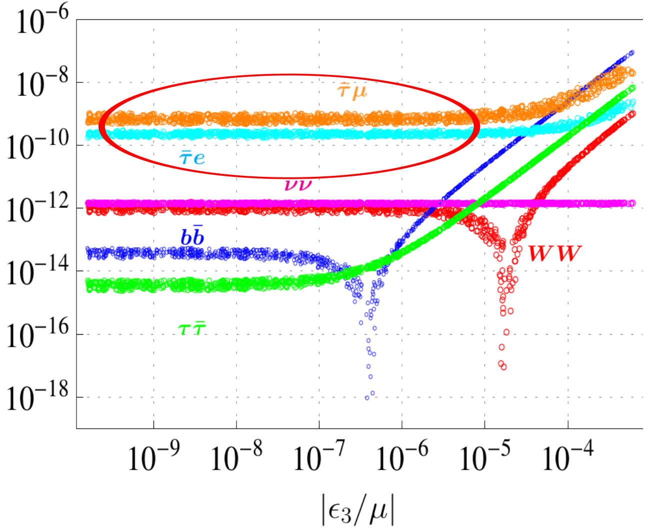
ϵ_3	mode
large	$\tau^+\tau^-$

$\lambda_{33k} = h_\tau \epsilon_k$

$k \neq 3$

Pure bilinear mode!

Tau-sneutrino novel decays. $m_{\tilde{\nu}_\tau} = 300$ GeV



ϵ_3	mode
small	$\tau^+ l_k^-$

$\lambda_{33k} = h_\tau \epsilon_k$

$k \neq 3$

ϵ_2	mode
small	$\mu^+ l_k^-$

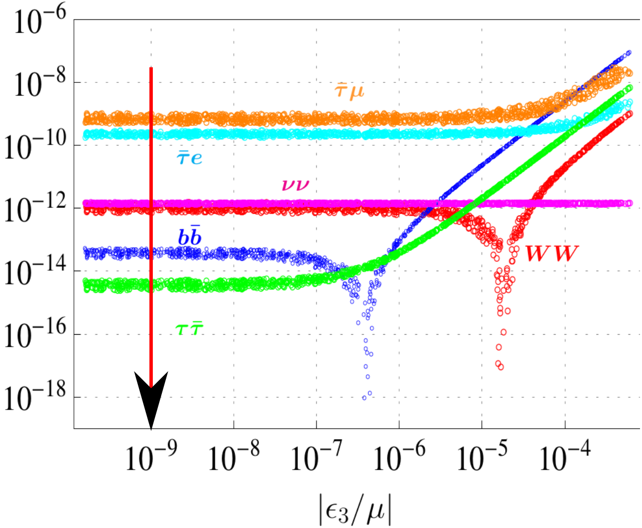
$\lambda_{22k} = h_\mu \epsilon_k$

$k \neq 2$

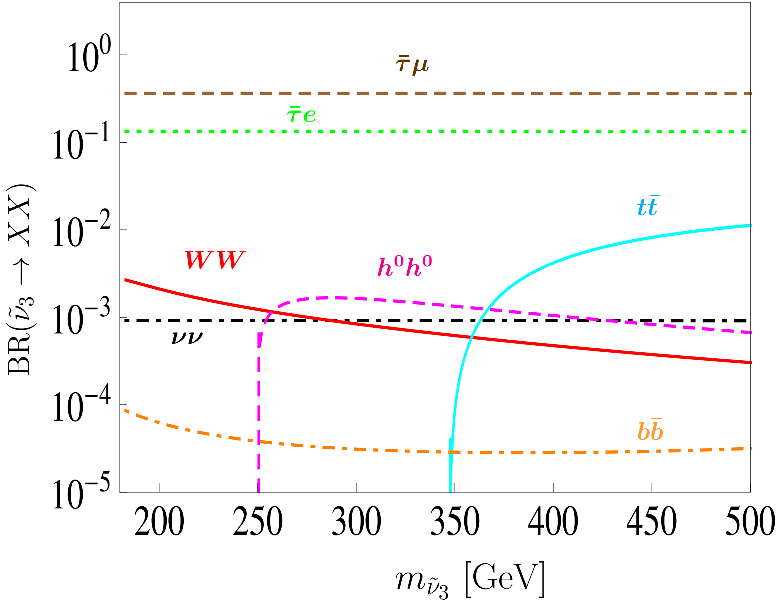
ϵ_1	mode
small	WW

$\lambda_{11k} \approx 0$

Tau-sneutrino novel decays. $m_{\tilde{\nu}_\tau} = 300$ GeV



$\tilde{\nu}_3$ RPV decays with $\epsilon_3 = 10^{-9}$ GeV



BRpV

- Gravitino does provide a viable radiatively decaying dark matter particle, provided its mass and reheating temperature are bounded as $m_{\widetilde{G}} < 1 - 10$ GeV and $T_R < 10^{-8}$ GeV,
- The properties of the LSP at LHC are fixed by neutrino physics.
- In the tau or muon sneutrino cases, decay to different-flavor leptons is possible if one of the neutrinos is massless.

Fermion mass hierarchy in SUSY

Abelian horizontal symmetry with a single flavon for everything

- General framework
- MSSM ($m_\nu = 0$, LSP stable)
- Bilinear R-parity violation ($m_\nu \neq 0$, LSP inestable)
- Trilinear R-parity breaking (LSP inestable)
  - Lepton number violation ($m_\nu \neq 0$)
  - Baryon number violation$_{new}$ ($m_\nu = 0$)

Fermion mass hierarchy problem

In units of $\theta \approx 0.22$:

$$\frac{m_e}{m_t} \sim \theta^9 \qquad\qquad \frac{\sqrt{\Delta m^2_{32}}}{m_t} \sim \theta^{19}\,.$$

In supersymmetry get worst: 45 new "Yukawas"+ 3 μ_i

$$W = \underbrace{\mu_\alpha}_{\mu_i}\widehat{L}_\alpha\widehat{H}_u + h^u_{ij}\widehat{H}_u\widehat{Q}_i\widehat{u}_j + \underbrace{\lambda_{\alpha\beta k}}_{\lambda_{ijk}}\widehat{L}_\alpha\widehat{L}_\beta\widehat{l}_k + \underbrace{\lambda'_{\alpha jk}}_{\lambda'_{ijk}}\widehat{L}_\alpha\widehat{Q}_j\widehat{d}_k + \lambda''_{ijk}\widehat{u}_i\widehat{d}_j\widehat{d}_k\,,$$

$$\widehat{L}_0 = \widehat{H}_d \qquad \alpha,\beta,\ldots = 0,1,2,3, \qquad i,j,\ldots = 1,2,3$$

- μ problem

$$\frac{\mu_0}{M_{\text{Planck}}} \sim \theta^{25} \qquad\qquad \frac{\mu_i}{M_{\text{Planck}}} \sim \theta^{30}$$

- Proton stability ($m_{\text{sfermion}} \approx 1\,\text{TeV}$)

$$\lambda'_{ijk}\lambda''_{11k} < \theta^{34}$$

- Neutralino dark matter stability ($m_{\text{sfermion}} \approx 1\,\text{TeV}$)

$$\lambda^{(\prime,\prime\prime)}_{ijk} < \theta^{34}$$

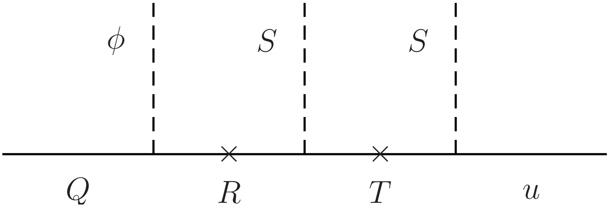
Flavor puzzle

Anomalous Horizontal Abelian symmetry with a single flavon

Froggat-Nielsen mechanism

Single flavon of H–charge -1: S

At high energy M_P: $\mathcal{L} = \bar{Q}\phi_{(0)}R + \bar{R}S_{(-1)}T + \bar{T}S_{(-1)}u$



At low energies: $\mathcal{L}_{eff} \sim \left(\frac{\langle S\rangle}{M_P}\right)^n \bar{Q}\phi u = \theta^n \bar{Q}\phi u,$

$$n = n_Q + n_\phi + n_u = 2,$$

where

$$\theta = \frac{\langle S\rangle}{M_P} \approx 0.22\,.$$

Phenomenological conditions

mass ratios

$$M_u \sim v_u \begin{pmatrix} \theta^8 & & \\ & \theta^4 & \\ & & 1 \end{pmatrix}$$

$$m_u : m_c : m_t \sim \theta^8 : \theta^4 : 1$$

$$m_d : m_s : m_b \sim \theta^4 : \theta^2 : 1$$

$$m_e : m_\mu : m_\tau \sim \theta^5 : \theta^2 : 1$$

TOTAL$= 6$

Phenomenological conditions

$V_{12} \sim \frac{\theta^5}{\theta^4} \sim \theta$

$$M_u \sim v_u \begin{pmatrix} \theta^8 & \theta^5 & \\ & \theta^4 & \\ & & 1 \end{pmatrix}$$

TOTAL$=7$

Phenomenological conditions

$$V_{23} \sim \frac{\theta^4}{\theta^2} \sim \frac{\theta^6}{\theta^8} \sim \theta^2$$

$$M_u \sim v_u \begin{pmatrix} \theta^8 & \theta^5 & \\ & \theta^4 & \\ & \theta^2 & 1 \end{pmatrix}$$

TOTAL$=8$

Phenomenological conditions

Prediction:
$V_{13} \sim \frac{\theta^5}{\theta^2} \sim \theta^3$

$$M_u \sim v_u \begin{pmatrix} \theta^8 & \theta^5 & \\ & \theta^4 & \\ & \theta^2 & 1 \end{pmatrix}$$

TOTAL$=8$

Phenomenological conditions

Third generation masses

$$M_u \sim v_u \begin{pmatrix} \theta^8 & \theta^5 & \\ & \theta^4 & \\ & \theta^2 & 1 \end{pmatrix}$$

$$h_u \sim 1$$

$$h_b \sim h_\tau \sim \theta^x, \qquad x = 0, 1, 2, 3$$

$$\text{where: } \tan\beta \sim \theta^{x-3} \sim (\underbrace{1}_{x=3}, \underbrace{100}_{x=0}).$$

TOTAL$=$ 10

Theoretical conditions

Anomaly conditions
(Green-Schwartz)

$$
\begin{aligned}
c_1 &: U(1)_Y^2 \times U(1)_H \\
c_1 &: SU(2)_L^2 \times U(1)_H \\
c_3 &: SU(3)_C^2 \times U(1)_H \\
c^{(2)} &: U(1)_H^2 \times U(1)_H
\end{aligned}
$$

$$c_3 = c_2 = \frac{c_1}{k_1} \qquad \text{with } k_1 = \frac{5}{3}$$

$$c^{(2)} = 0$$

TOTAL$=$ 13

If $c_1 = c_2 = c_3 = 0 \Longrightarrow m_u = 0$ Mira,Nardi,D.R hep-ph/9911212 (PLB)

Horizontal charges: 17

$$H(f_i) \equiv f_i \qquad f_{ij} = f_j - f_j \qquad \mathcal{N} = \sum_{\alpha=0}^{4} n_\alpha$$

$$n_\alpha = L_\alpha + H_u \qquad \mathcal{L}_{23} = e_{23} + L_{23} \qquad x = Q_3 + d_3 + L_0$$

Horizontal charges: 17

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Horizontal charge	Number
Q_i	3
$\bar{u}_{Ri} \to u_i$	3
$\bar{d}_{Ri} \to d_i$	3
L_i	3
$\bar{e}_{Ri} \to e_i$	3
H_u	1
$H_d \to L_0$	1
Total	17

Horizontal charges: 17−13 = 4 free charges:

$$H(f_i) \equiv f_i \qquad f_{ij} = f_j - f_j \qquad \mathcal{N} = \sum_{\alpha=0}^{4} n_\alpha$$

$$n_\alpha = L_\alpha + H_u \qquad \mathcal{L}_{23} = e_{23} + L_{23} \qquad x = Q_3 + d_3 + L_0$$

Horizontal charge	Number
Q_i	3
$\bar{u}_{Ri} \to u_i$	3
$\bar{d}_{Ri} \to d_i$	3
L_i	3
$\bar{e}_{Ri} \to e_i$	3
H_u	1
$H_d \to L_0$	1
Total	17

Horizontal charge	Number
$Q_{13},\ Q_{23},\ Q_3$	3
$u_{13},\ u_{23},\ u_3$	3
$d_{13},\ d_{23},\ d_3$	3
$\mathcal{L}_{13},\ \mathcal{L}_{23},\ L_3 + e_3$	3
$\mathcal{N}$	1
n_i	3
x	1
Total	17

4 free charges: $n_1,\ n_2\ , n_3\ , x$

Solution with positive H–charge differences

Q_{13}	Q_{23}	u_{13}	u_{23}	d_{13}	d_{23}	$\mathcal{L}_{13}$	$\mathcal{L}_{23}$
3	2	5	2	1	0	5	2

$$M_u = v_u \begin{pmatrix} \theta^8 & \theta^5 & \theta^3 \\ \theta^7 & \theta^4 & \theta^2 \\ \theta^5 & \theta^2 & 1 \end{pmatrix} \qquad M_d = v_d \theta^{x} \begin{pmatrix} \theta^4 & \theta^3 & \theta^3 \\ \theta^3 & \theta^2 & \theta^2 \\ \theta & 1 & 1 \end{pmatrix}$$

$$M_E = v_d \theta^{x} \begin{pmatrix} \theta^5 & & \\ & \theta^2 & \\ & & 1 \end{pmatrix}$$

$$\eta_d = \sum_i (Q_{i3} + d_{i3} + x) = 6 + x \qquad \eta_e = \sum_i (\mathcal{L}_{i3} + x) = 7 + x \,.$$

μ–problem

Self consistent condition:

$$n_0 + \eta_e - \eta_d \propto \left(k_1 - \frac{5}{3} \right)$$

$$n_0 = -1 \qquad \text{if } k_1 = \frac{5}{3}$$

$$\mu_\alpha \sim \begin{cases} M_P \theta^{n_\alpha} & \text{if } n_\alpha \geq 0 \ \mu\text{–problem!} \\ m_{3/2} \theta^{|n_\alpha|} & \text{if } n_\alpha < 0 \\ 0 & \text{if } n_\alpha \text{ is fractional} \end{cases}$$

μ–problem solution(Giudice–Masiero mechanism):

$$n_0 = -1 \Longrightarrow \mu_0 \sim m_{3/2} \theta^{-1}$$

Final solution

$$
\begin{aligned}
Q_3 &= -\frac{-3x(x+10)+(x+4)n_1+(x+7)n_2+(x+9)n_3-67}{15(x+7)} \\
L_3 &= \frac{2(x+1)(3x+22)-(2x+23)n_1-2(x+7)n_2+(13x+97)n_3}{15(x+7)} \\
L_2 &= L_3 + n_2 - n_3 \\
L_1 &= L_3 + n_1 - n_3 \\
H_u &= n_3 - L_3 \\
H_d &= -1 - H_u \\
u_3 &= -Q_3 - H_u \\
d_3 &= -Q_3 - H_d + x \\
e_3 &= -L_3 - H_d + x \\
Q_1 &= 3 + Q_3 \\
Q_2 &= 2 + Q_3 \\
u_1 &= 5 + u_3 \\
u_2 &= 2 + u_3 \\
d_1 &= 1 + d_3 \\
d_2 &= d_3 \\
e_1 &= 5 - n_1 + n_3 + e_3 \\
e_2 &= 2 - n_2 + n_3 + e_3
\end{aligned}
$$

Can n_i, x be fixed to explain proton stability in SSM?

Final solution

$$
\begin{aligned}
Q_3 &= -\frac{-3x(x+10)+(x+4)n_1+(x+7)n_2+(x+9)n_3-67}{15(x+7)} \\
L_3 &= \frac{2(x+1)(3x+22)-(2x+23)n_1-2(x+7)n_2+(13x+97)n_3}{15(x+7)} \\
L_2 &= L_3 + n_2 - n_3 \\
L_1 &= L_3 + n_1 - n_3 \\
H_u &= n_3 - L_3 \\
H_d &= -1 - H_u \\
u_3 &= -Q_3 - H_u \\
d_3 &= -Q_3 - H_d + x \\
e_3 &= -L_3 - H_d + x \\
Q_1 &= 3 + Q_3 \\
Q_2 &= 2 + Q_3 \\
u_1 &= 5 + u_3 \\
u_2 &= 2 + u_3 \\
d_1 &= 1 + d_3 \\
d_2 &= d_3 \\
e_1 &= 5 - n_1 + n_3 + e_3 \\
e_2 &= 2 - n_2 + n_3 + e_3
\end{aligned}
$$

Can n_i, x be fixed to explain proton stability in SSM?

Yes!

One flavon anomalous horizontal Abelian symmetry

The superpotential

$$
\begin{aligned}
W =& \mu_\alpha \widehat{L}_\alpha \widehat{H}_u + h^u_{ij} \widehat{H}_u \widehat{Q}_i \widehat{u}_j + \lambda_{\alpha\beta k} \widehat{L}_\alpha \widehat{L}_\beta \widehat{e}_k + \lambda'_{\alpha jk} \widehat{L}_\alpha \widehat{Q}_j \widehat{d}_k + \lambda''_{ijk} \widehat{u}_i \widehat{d}_j \widehat{d}_k, \\
=& h^u_{ij} \widehat{H}_u \widehat{Q}_i \widehat{u}_j + h^l_{ij} \widehat{H}_d \widehat{L}_j \widehat{e}_k + h^d_{ij} \widehat{H}_d \widehat{Q}_j \widehat{d}_k \\
& + \mu_0 \widehat{H}_d \widehat{H}_u \\
& + \mu_i \widehat{L}_i \widehat{H}_u \\
& + \lambda_{ijk} \widehat{L}_i \widehat{L}_j \widehat{l}_k + \lambda'_{ijk} \widehat{L}_i \widehat{Q}_j \widehat{d}_k \\
& + \lambda''_{ijk} \widehat{u}_i \widehat{d}_j \widehat{d}_k
\end{aligned}
$$

- Further constraints to avoid fast proton decay on μ_i, $\lambda_T = \{\lambda_{ijk}, \lambda'_{ijk}, \lambda''_{ijk}\}$

FN in SSM

FN mechanism can also explain all parameters in W.
The effective bilinear and trilinear $\cancel{R_P}$ terms are given by

$$\mu_\alpha \sim \begin{cases} M_P \theta^{n_\alpha} & n_\alpha \geq 0 \\ m_{3/2} \theta^{|n_\alpha|} & n_\alpha < 0 \\ 0 & n_\alpha \text{ fractional} \end{cases}$$

$$\lambda_T \sim \begin{cases} \theta^{n_{\lambda_T}} & n_{\lambda_T} \geq 0 \\ (m_{3/2}/M_P) \theta^{|n_{\lambda_T}|} & n_{\lambda_T} < 0 \\ 0 & n_{\lambda_T} \text{ fractional} \end{cases}$$

R_p violating operators

$$
\begin{aligned}
H(\lambda''_{ijk}) =& n_{\lambda''} + \mathcal{I}''(i,j,k) && (j<k)\\
H(\lambda'_{ijk}) =& n_i + \left[x + \mathcal{I}'(i,j,k)\right] && \\
H(\lambda_{ijk}) =& n_i + n_j - n_k + [x - 1 + \mathcal{I}(i,j,k)] && (i<j)\\
=& \begin{cases} n_{i(\text{or } j)} + [x - 1 + \mathcal{I}(i,j,k)] & \text{if } i = k \ (\text{or } j = k)\\ 3n_{\lambda''} - 2n_k + [\mathcal{I}(i,j,k) - 2x] & \text{if } i \neq k \text{ and } j \neq k \end{cases},
\end{aligned}
$$

$$n_{\lambda''} = x + \mathcal{N}/3$$

Model	n_i	$n_{\lambda''}$	Ref
MSSM	fractional	fractional	Dreiner...
μ_i-SSM	fractional	high negative integer	D.R...
λ-SSM	$3n_{\lambda''} - 2n_k$ integer	fractional	D.R...
λ''-SSM	not half-integer fractional	integer	

λ''-SSM

$$\begin{pmatrix} \lambda''_{112} & \lambda''_{212} & \lambda''_{312} \\ \lambda''_{113} & \lambda''_{213} & \lambda''_{313} \\ \lambda''_{123} & \lambda''_{223} & \lambda''_{323} \end{pmatrix} \approx \begin{cases} \theta^{n_{\lambda''}} \begin{pmatrix} \theta^6 & \theta^3 & \theta \\ \theta^6 & \theta^3 & \theta \\ \theta^5 & \theta^2 & 1 \end{pmatrix} & n_{\lambda''} \geq 0\,. \\ \text{any} & -6 < n_{\lambda''} \geq -1\,. \\ \text{MSSM-like} & n_{\lambda''} < -6. \end{cases}$$

Indirect constraints

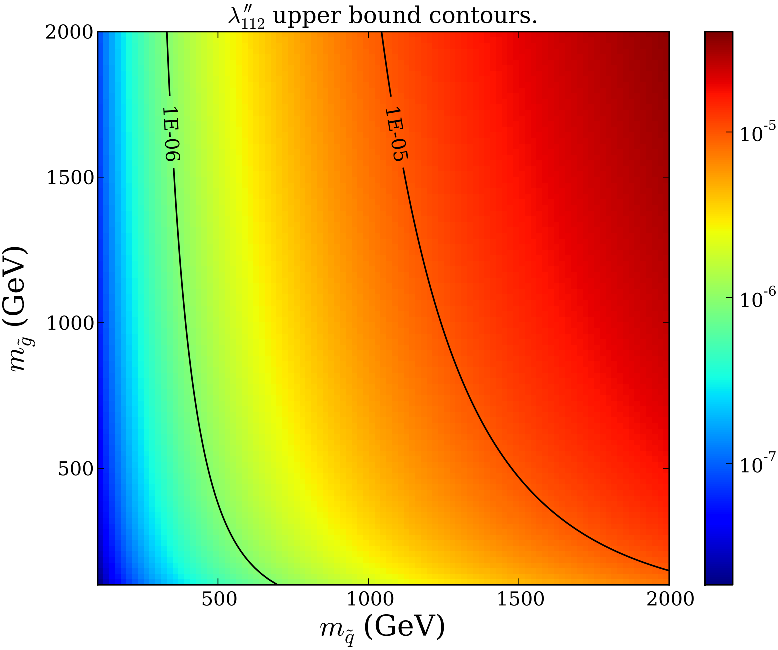
the most restrictive constraint comes from the dinucleon $NN \to KK$ width

$$\Gamma \sim \rho_N \frac{128\pi\alpha_s^2|\lambda_{112}|^4(\tilde{\Lambda})^{10}}{m_N^2 m_{\tilde{g}}^2 m_{\tilde{q}}^8}\,,$$

$$\rho_N \approx 0.25\ \mathrm{fm}^{-3} \qquad m_N \approx m_p \qquad \tilde{\Lambda} \sim 100$$

This kind of matter instability requires only B violation. From Super-Kamiokande data (M. Litos PhD Thesis)

$$\tau_{NN\to KK} = \frac{1}{\Gamma} > 1.7 \times 10^{32}\ \mathrm{yr}\,.$$

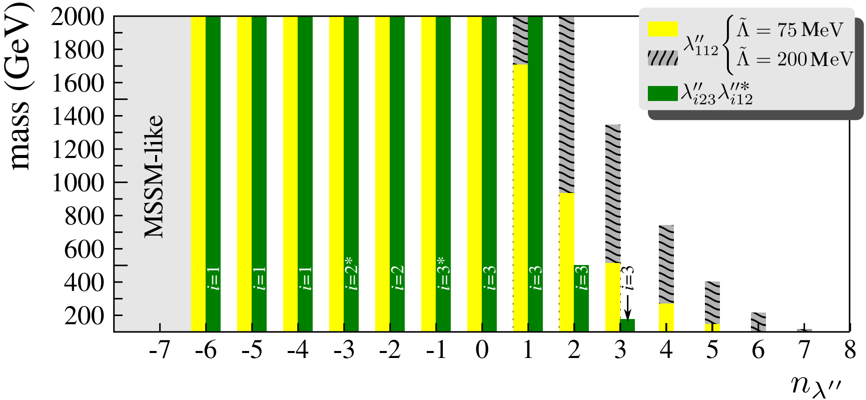

λ''_{112} upper bound contours.
2000
1500
1000
500
1E-06
1E-05
$m_{\tilde{g}}$ (GeV)
500
1000
1500
2000
$m_{\tilde{q}}$ (GeV)
10^{-5}
10^{-6}
10^{-7}

Most important constraint from quadratic coupling product bounds is obtained from the penguin decays $B \to \phi\pi$ (BaBar: hep-ex/0605037)

$$\mathrm{BR}(B^+ -> \phi\pi^+) < 2.4\times 10^{-7} \qquad \mathrm{BR}(B^0 -> \phi\pi^0) < 2.8\times 10^{-7}$$

which translates into

$$|\lambda''_{i23}\lambda''^{*}_{i12}| < 2\times 10^{-5}\left(\frac{m_{\tilde{u}_{iR}}}{100\ \mathrm{GeV}}\right)^2 . \tag{1}$$



Dirac neutrino mases

$$\theta^{n_\nu} = \theta^{H(L_i H_u N_j)} = \theta^{n_i + N_j} = \theta^{16} \qquad H(N_i N_j) \text{ fractional}$$

Example:

$$n_i = \frac{19}{3} \qquad N_i = \frac{29}{3}$$

Typical size

$$\begin{pmatrix} \lambda''_{112} & \lambda''_{212} & \lambda''_{312} \\ \lambda''_{113} & \lambda''_{213} & \lambda''_{313} \\ \lambda''_{123} & \lambda''_{223} & \lambda''_{323} \end{pmatrix} \lesssim \begin{pmatrix} \theta^{12} & \theta^{9} & \theta^{7} \\ \theta^{12} & \theta^{9} & \theta^{7} \\ \theta^{11} & \theta^{8} & \theta^{6} \end{pmatrix} \qquad n_{\lambda''} \geq 6\,.$$

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$$\theta^{n_\nu} = \theta^{H(L_i H_u N_j)} = \theta^{n_i + N_j} = \theta^{16} \qquad H(N_i N_j) \text{ fractional}$$

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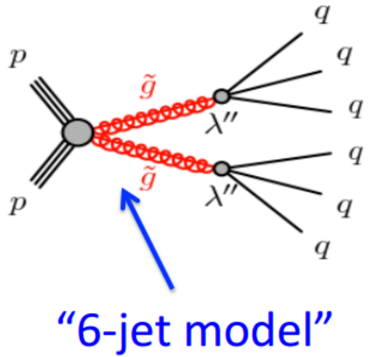
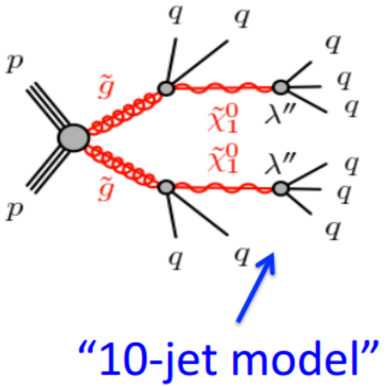
Typical size

$$\begin{pmatrix} \lambda''_{112} & \lambda''_{212} & \lambda''_{312} \\ \lambda''_{113} & \lambda''_{213} & \lambda''_{313} \\ \lambda''_{123} & \lambda''_{223} & \lambda''_{323} \end{pmatrix} \lesssim \begin{pmatrix} 10^{-8} & 10^{-6} & 10^{-5} \\ 10^{-8} & 10^{-6} & 10^{-5} \\ 5\times 10^{-8} & 5\times 10^{-6} & 10^{-4} \end{pmatrix} \qquad n_{\lambda''} \geq 6\,.$$

LHC phenomenology

Eperimental limits at LHC if the LSP is neutral particle decaying to multijets (ejemplos: gluino, neutralino). Better sensitivity if decay includes top or bottom quarks.

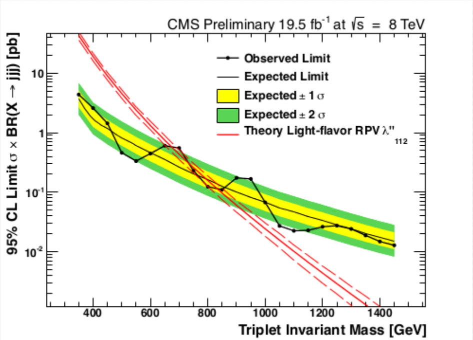


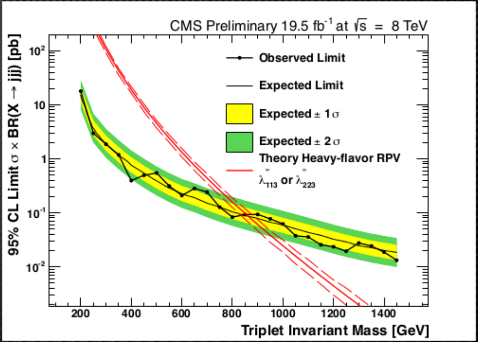


For squark LSP the limits are still around $m_{\tilde{q}} < 100 GeV$.
Pure hadronic displaced vertices no yet implemented in ATLAS.

Multijet Interpretations

- Interpret the multijet resonance search in a model where the gluino decays via an UDD coupling to 3 jets
- Limits correspond to a light-flavor coupling $\lambda''_{112} \neq 0$ or a heavy-flavor coupling λ''_{113} or $\lambda''_{223} \neq 0$
- First limits for the heavy flavor coupling





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Same-sign Interpretations

- Similar model to the multijet analysis gluinos decaying to 3-jets via λ''_{323}
- Exclude gluinos with mass below 850 GeV

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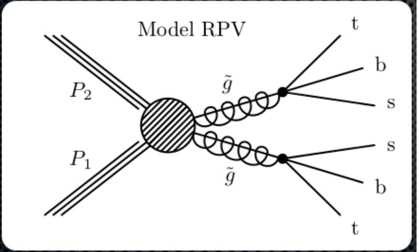

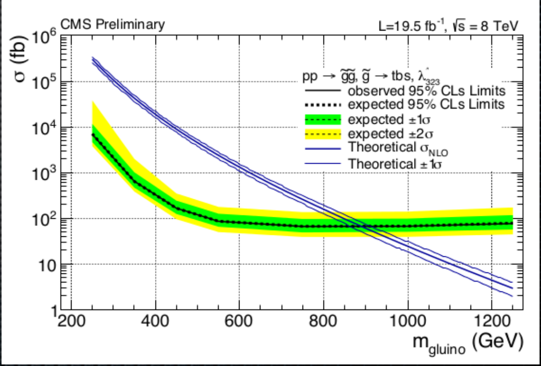

Conclusions

Model with Baryonic violation of R-parity

- After imposing existing constraints in both single and quadratic R-parity violating (RPV) couplings, only one precise hierarchy remains depending on a global suppression factor $\theta^{n_{\lambda''}}$ ($n''_\lambda > 1$) with λ''_{323} as the dominant coupling and very suppressed couplings for the first two generations.
- Additional suppression is required in order to obtain Dirac neutrino masses in the model, and only solutions with $n''_\lambda \geq 6$ remain allowed.
- The phenomenology at colliders depends strongly on the nature and decay length of the LSP. Specific searches at the LHC for the RPV with B violation have reported restrictions only in the case of prompt decays of the gravitino when it is the LSP.