Bilinear R-parity violating

Sneutrino decays

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Based on

arXiv:1212.3310 (submitted to JHEP)

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Motivation

SUSY searches

Searches based on specific signals e.g:

Signal I: Hadronic final states + missing E_T

Signal II: Hadronic + lepton final states + missing E_T

Signal III Lepton final states + missing E_T

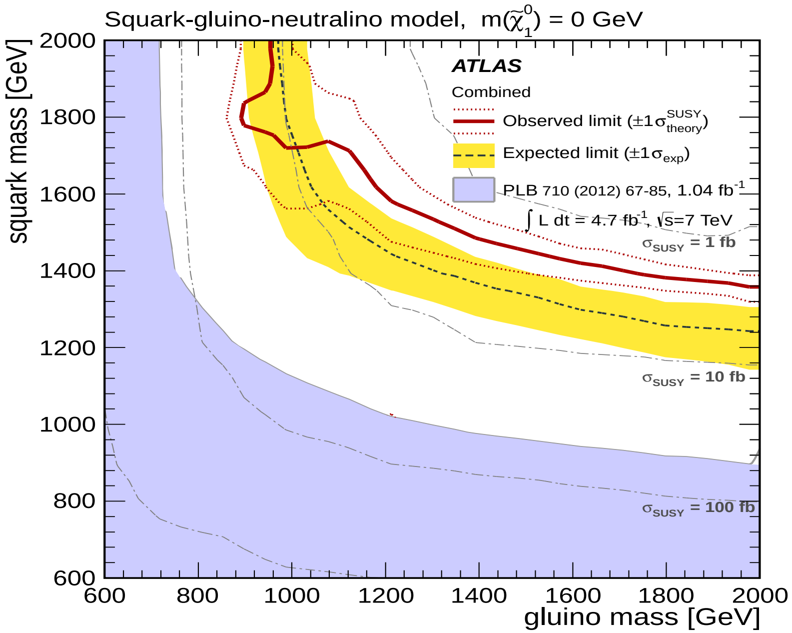
At present no evidence for SUSY at LHC

Upper limits on SUSY masses

$\sigma_{\tilde{q},\tilde{g}} \gg \sigma_{\tilde{\ell},\tilde{\nu},\tilde{\chi}^0} \Rightarrow$ More stringent for $\tilde{g}$ and $\tilde{q}$

Example: Non evidence for Signal I at ATLAS with $\mathcal{L} \sim 4.7$ fb^{-1} assuming a simplified SUSY model

ATLAS, arXiv:1208.0949



In general applied to models involving missing $E_T \Rightarrow m_{\tilde{g},\tilde{g}} > 1$ TeV

What does this implies for SUSY?

Cornered SUSY?

Up to now LHC data $\Rightarrow$ Heavy squark and gluinos masses $>$ 1 TeV

Solving the hierarchy problem (HP) through
SUSY requires $\mathcal{O}(M_{\tilde{X}}) \sim \Lambda_{EW}$

SOME PATHWAYS

- SUSY nothing to do with the HP — **PREMATURE**
- Decouple sparticles — Fine-tuned SUSY [Arkani-Hamed et. al. (arXiv:1212.6971)]

Searches mainly driven by
hard missing p_T

Bounds on $M_{\tilde{X}}$ very sensible to SUSY model
e.g. R-hadron models $m_{\tilde{g},\tilde{b}} > 560, 290$ GeV

arXiv:1103.1984, PLB,701

- Models with "non-standard" SUSY signals — **R-parity violating SUSY**

Receiving a great deal of attention:

D. Kaplan et. al., arXiv:1204.6038; T. Slater et. al., arXiv:1207.5787

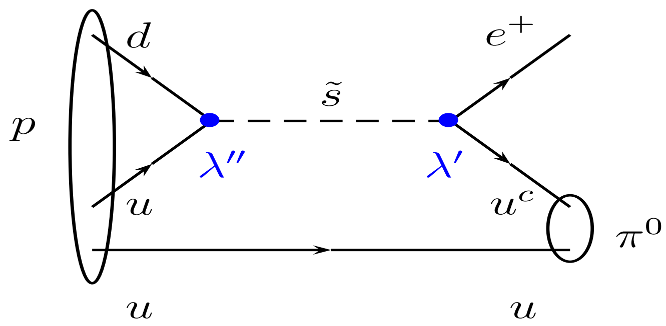
E. Ponton et. al., arXiv:1210.0541; T. Yanagida et. al., arXiv:1301.2336

R-parity violating SUSY

The supersymmetric version of the SM contains L and B breaking operators

Talks by G. Villadoro and Marco Nardecchia

$$W = \underbrace{\overbrace{\epsilon L H_u}^{\text{BRpV}} + \overbrace{\lambda L L E + \lambda' L Q D}^{\text{TRpV}}}_{\text{Lepton breaking}} + \underbrace{\lambda'' U U D}_{\text{Baryon breaking}}$$



$$R_p = (-1)^{3(B-L)+2S}$$

The MSSM is R_p conserving (by "construction") but R_p is not the only symmetry that guarantees proton stability:

$$L \text{ parity forbids } \Delta L \neq 0: \quad (L, E) \to -(L, E), (Q, U, D, H_u, H_d) \to (Q, U, D, H_u, H_d)$$

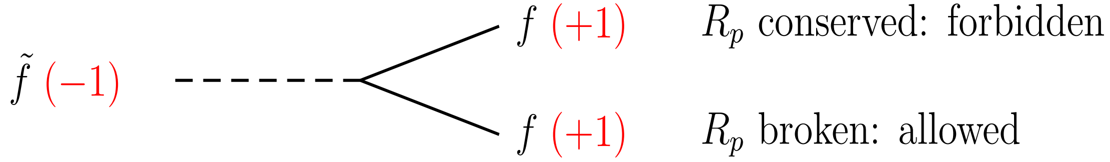
$$B \text{ parity forbids } \Delta B \neq 0: \quad (Q, U, D, H_u, H_d) \to -(Q, U, D, H_u, H_d), (L, E) \to (L, E)$$

In general B or L breaking operators should be considered

Can DRASTICALLY change the SUSY phenomenology

Phenomenological aspects

If R_p is broken the (LSP) is unstable. Any supersymmetric particle can be the LSP



R_p conserved e.g: $$\tilde{g} \to q\tilde{q} \to qq\chi_2^0 \to qq\ell\tilde{\ell} \to \underbrace{q + q + \ell + \ell + \chi_1^0}_{\text{jets + leptons}+\not{E}_T}$$

R_p broken e.g: $$\tilde{g} \to q\tilde{q} \to qq\chi_2^0 \to qq\ell\tilde{\ell} \to qq\ell\ell\chi_1^0 \to \underbrace{q + q + \ell + \ell + X_{\text{SM}}}_{\text{jets + leptons}}$$

Phenomenological differences

☞ Signals not necessarily involve large missing E_T.

☞ If missing E_T it won't be hard as it is when stemming from χ_1^0.

☞ Phenomenological constraints, in particular those from neutrino physics, imply LSP decays might involve displaced vertices.

Explicit BRpV SUSY

Generalities

In addition to the MSSM superpotential BRpV models involve a set of bilinear terms:

$$W_{\text{BRpV}} = \epsilon_i \, \hat{L}_i \, \hat{H}_u$$

Consistency then requires at the the soft scalar potential level:

$$V^{\text{soft}} = \underbrace{V^{\text{soft}}_{\text{MSSM}}}_{\text{D-terms + F-terms}} + V^{\text{soft}}_{\text{BRpV}} = V^{\text{soft}}_{\text{MSSM}} + B_i \epsilon_i \tilde{L}_i H_u$$

$V^{\text{soft}}_{\text{BRpV}}$ induces $\langle \tilde{\nu}_i \rangle \neq 0$ calculable in terms of v_d, v_u, μ and B, B_i, ϵ_i

Minimization of the scalar potential requires the tadpole equations (t_a) to vanish:

$$V_{\text{Linear}}(S_i) = \sum_{a=1,\cdots,5} t_a S_a^0 = 0 \quad \Rightarrow \quad t_a = 0$$

Yielding three constraints that can be written according to:

$$v_i = \frac{\epsilon_i v}{m_{\tilde{\nu}_i}} (\mu \cos\beta - B_i \sin\beta)$$

Constraints

BRpV being lepton number breaking violating gives non-zero contributions to neutrino masses

e.g. Hirsch & Valle, NJP,6,2006

Normal spectrum case

- **Neutralino-neutrino mixing:** Induces a seesaw-like 7×7 mass matrix

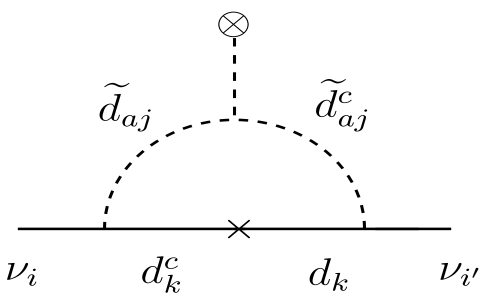
$$\boldsymbol{m_\nu^{\text{eff}}} = \begin{pmatrix} \Lambda_e^2 & \Lambda_e\Lambda_\mu & \Lambda_e\Lambda_\tau \\ \Lambda_e\Lambda_\mu & \Lambda_\mu^2 & \Lambda_\mu\Lambda_\tau \\ \Lambda_e\Lambda_\tau & \Lambda_\mu\Lambda_\tau & \Lambda_\tau^2 \end{pmatrix}$$

$$\Lambda_{ij} = \mu v_i - v_d \epsilon_i$$

$$\tan^2\theta_{\text{Atm}} = \frac{\Lambda_\mu^2}{\Lambda_\tau^2} \qquad \tan^2\theta_{\text{Reac}} = \frac{\Lambda_e^2}{\Lambda_\mu^2 + \Lambda_\tau^2}$$

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

- **Sbottom loops:** Contributions from τ suppressed



$$\tan\theta_\odot^2 = \frac{\bar\epsilon_1^2}{\bar\epsilon_2^2} \qquad \bar\epsilon_{1,2} = \bar\epsilon_{1,2}(\epsilon_{1,2,3})$$

$$\Delta m_{21}^{\text{BRpV}} = \frac{3\sin 2\theta_{\tilde b}}{8\pi^2}\frac{m_b^3}{v^2\cos^2\beta}\Delta B_0^{\tilde b_1\tilde b_2}\frac{\bar\epsilon_1^2+\bar\epsilon_2^2}{\mu}$$

Λ_i: $\{\theta_{23}, \theta_{13}, \Delta m_{32}\}$ $\Rightarrow$ Λ_i's are fully constrained by Atm. ν-data

ϵ_i: $\{\theta_{12}, \Delta m_{21}\}$ $\Rightarrow$ One ϵ is left as free parameter

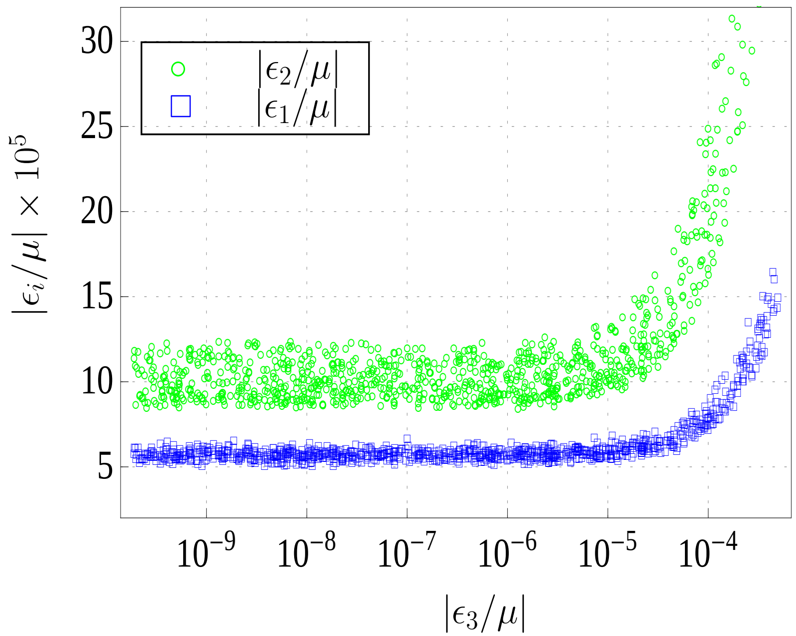
Parameter behavior

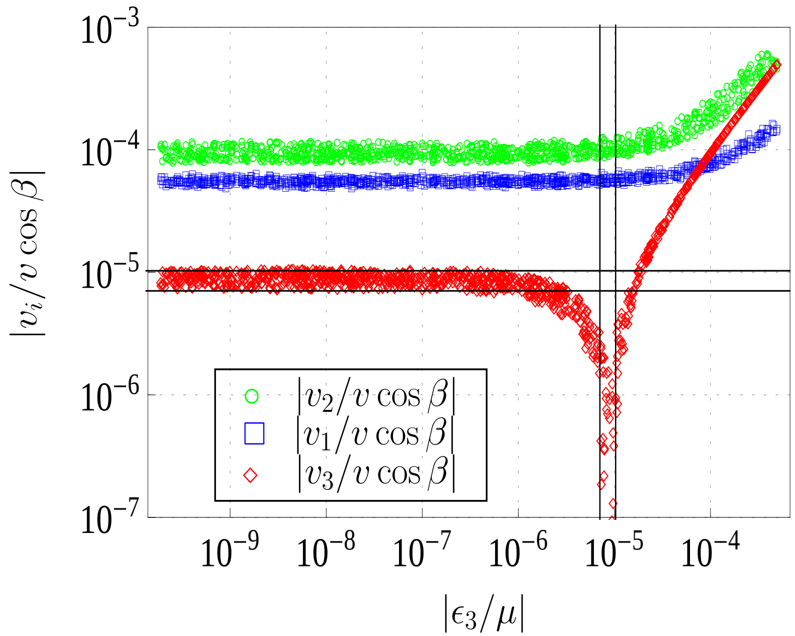
Assuming BRpV accounts for neutrino data:

$$D_\odot = \{\Delta m_{21}, \tan\theta_{21}\} \quad \Rightarrow \quad \epsilon_{1,2} = \epsilon_{1,2}(\epsilon_3)$$

$$D_{\text{Atm}} = \{\Delta m_{32}, \tan\theta_{23}, \tan\theta_{13}\} \quad \Rightarrow \quad \Lambda_{1,2,3}$$

$$v_i = \frac{\Lambda_i - v_d \epsilon_i}{\mu}$$
$$v_i = v_i(\epsilon_3)$$





$\mu = 650$ GeV $\Rightarrow \epsilon_{1,2} \sim 10^{-1}$ GeV

$\tan\beta = 10 \Rightarrow v_d \simeq 25 \Rightarrow v_{1,2} \sim 10^{-3}$ GeV

$v_{1,2} \ll \epsilon_{1,2}$

Region 1: $\epsilon_3 \sim \epsilon_{1,2} \Rightarrow v_3 \ll \epsilon_3$

Region 2: $\epsilon_3 \ll v_3 \Rightarrow \epsilon_3 \ll \epsilon_{1,2}$

In the literature $\tilde{\nu}_3$ studied in **R1**!

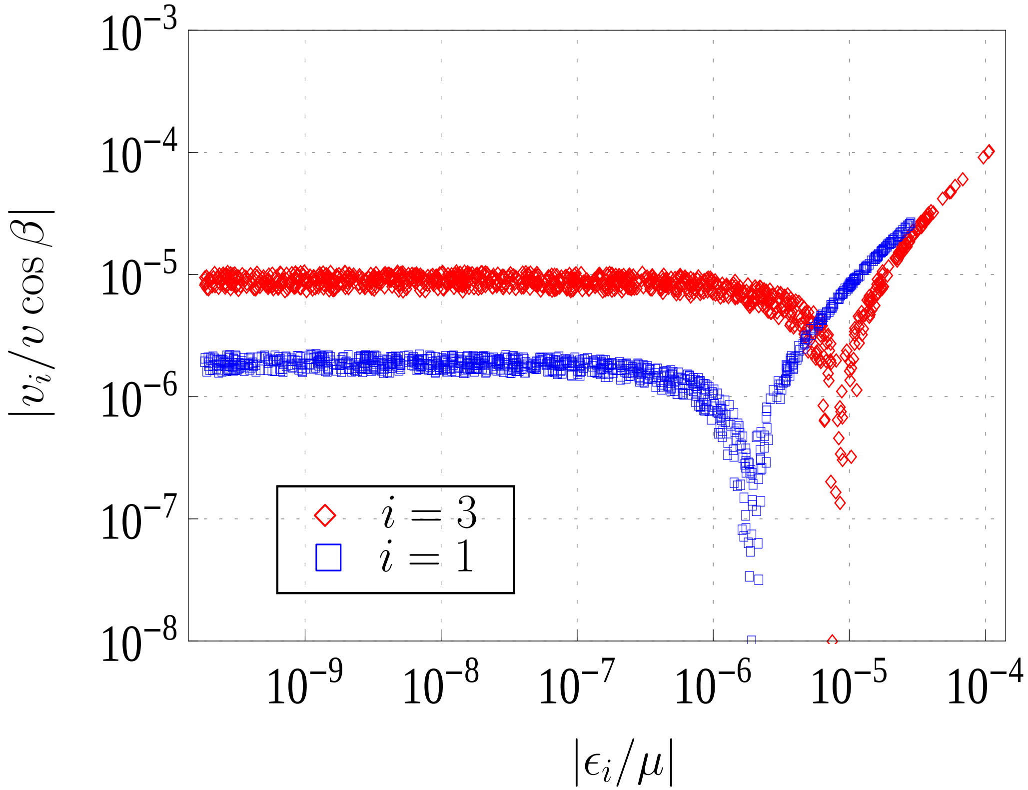
How does $\tilde{\nu}_3$ decays behave in **R2**?

The case of hybrid BRpV

In the generation of neutrino masses several mechanisms might intervene i.e. hybrid neutrino mass models

e.g. DAS et. al., PRD, hep-ph/0304141

$$D^{\text{BRpV}}_{\text{Atm}} = D^{\text{BRpV}}_{\text{Exp}}$$
$$D^{\text{BRpV}}_{\odot} \neq D^{\text{Exp}}_{\odot}$$



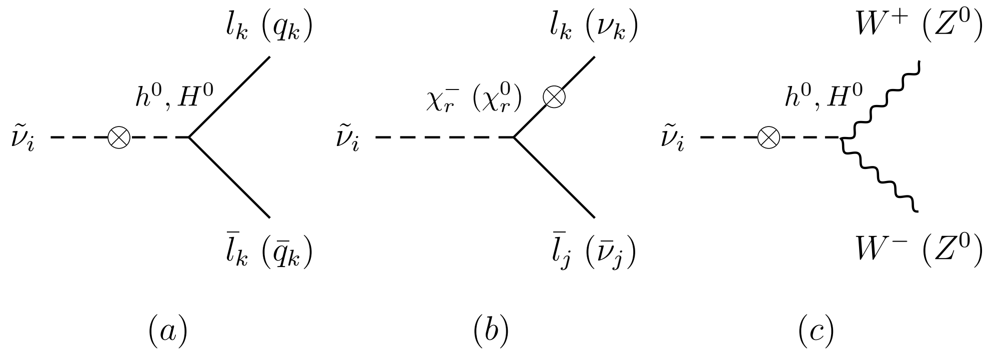
$D^{\text{BRpV}}_{\odot,\text{Atm}} = D^{\text{Exp}}_{\odot,\text{Atm}} \Rightarrow v_i > \epsilon_i$ only possible in a single $\tilde{\nu}$ generation

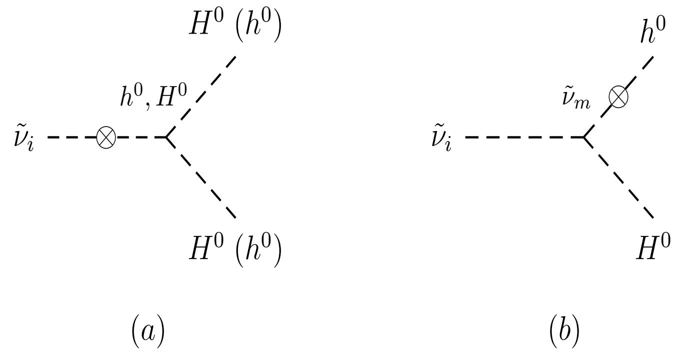
$D^{\text{BRpV}}_{\odot,\text{Atm}} \neq D^{\text{Exp}}_{\odot,\text{Atm}} \Rightarrow v_i > \epsilon_i$ possible for all three $\tilde{\nu}$ generations

The LSP sneutrino case

Sneutrino BRpV induced decays

Sneutrino decays in BRpV are controlled by BRpV induced mixings: $\chi^0 - \nu$, $\chi^\pm - \ell^\pm$ and $H^0_{u,d} - \tilde{\nu}_i$

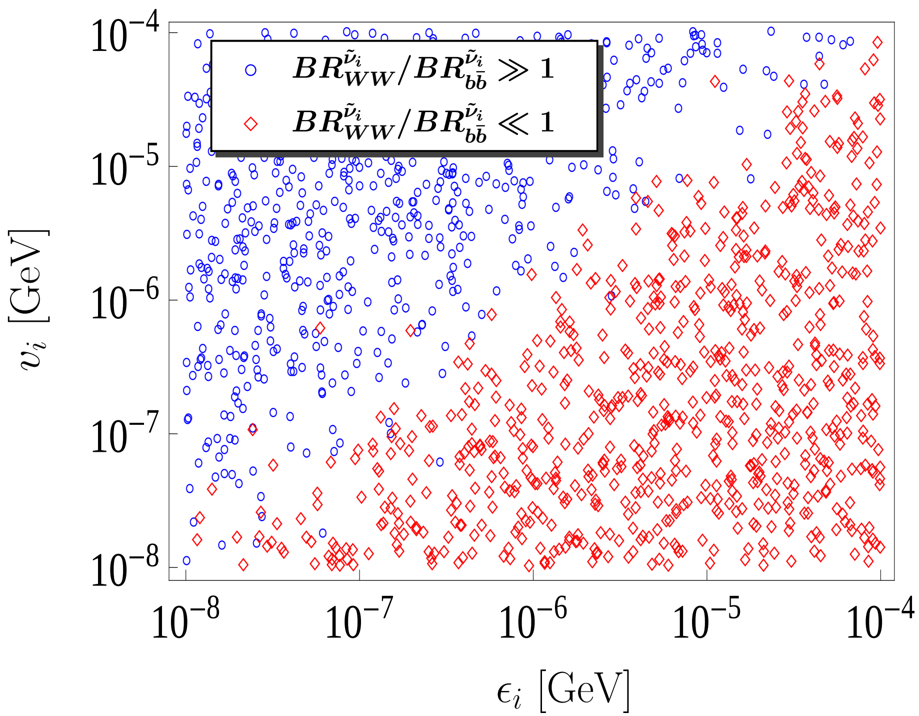




Sparticle-particle BRpV induced mixings are controlled by the ϵ_i and v_i parameters

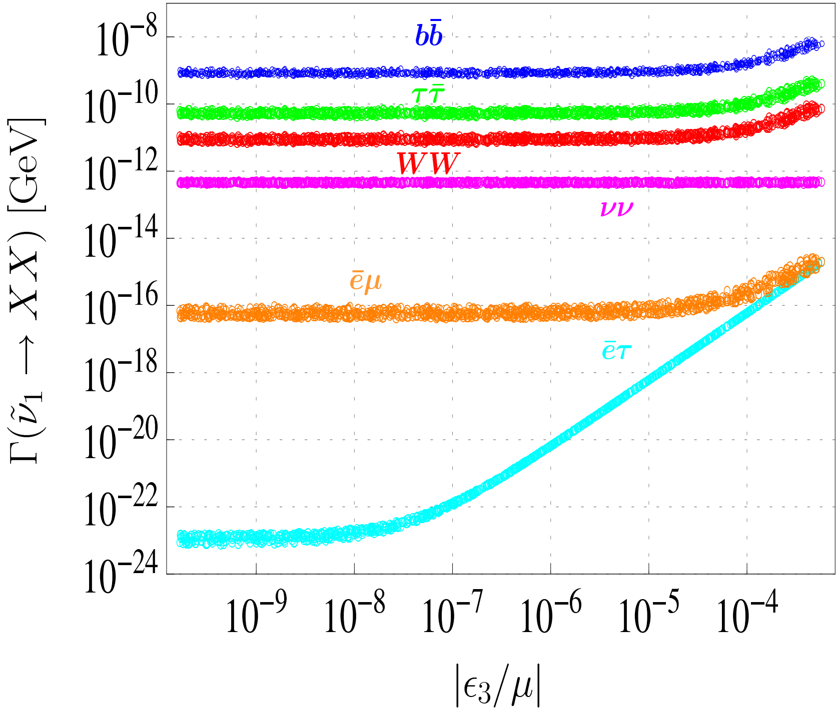
In the literature $b\bar{b}$ considered to be dominant

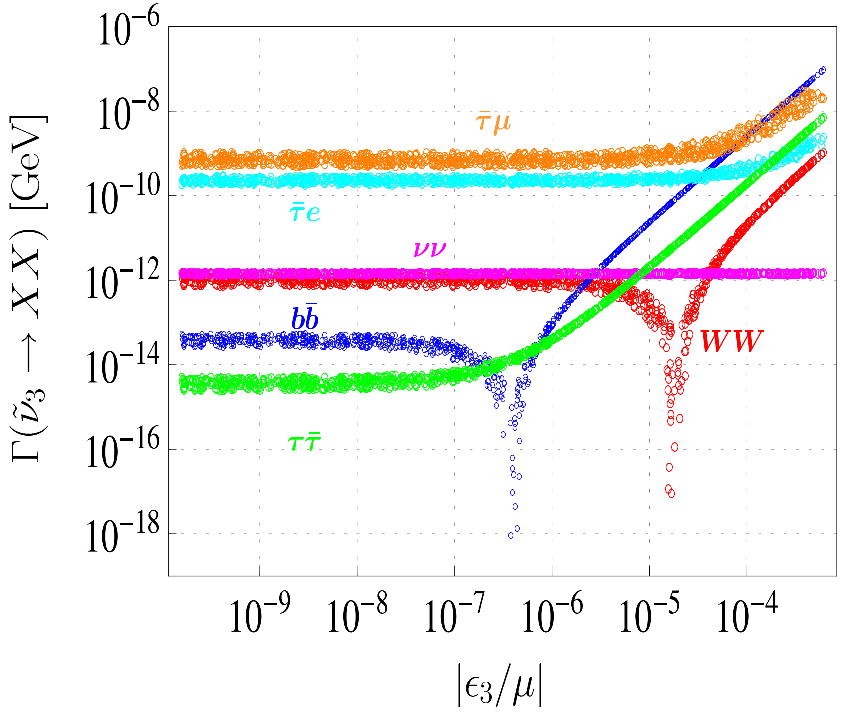
Compare decays with this mode



Sneutrino decays constrained by ν data

If BRpV entirely accounts for neutrino data i.e. $D^{\text{BRpV}}_{\odot,\text{Atm}} = D^{\text{Exp}}_{\odot,\text{Atm}}$, only a single sneutrino vev can be larger than ϵ:





Observing two sneutrino generations decaying in a "non-conventional" way (dominant $b\bar{b}$) will exclude BRpV as responsible for neutrino masses

Understanding leptonic modes

- Different-flavor charged leptons:

$$\Gamma(\tilde{\nu}_i \to \bar{l}_i l_k) \sim h_{l_i}^2 \frac{\epsilon_k^2}{\mu^2}$$

- Hadronic mode: $b\bar{b}$:

$$\Gamma(\tilde{\nu}_i \to b\bar{b}) \sim h_b^2 \left(\boldsymbol{R^{S^0}_{(i+2)1}}\right)^2 \quad \begin{cases} \text{Region 1}: \epsilon_i^2/\mu^2 \\ \text{Region 2}: v_i^2/\mu^2 \end{cases}$$

Region 1

$$\epsilon_i \sim \epsilon_k \Rightarrow \; R \equiv \text{BR}^{\tilde{\nu}_i}_{l_i l_k}/\text{BR}^{\tilde{\nu}_i}_{bb} \sim h_{l_i}^2/h_b^2 \quad \begin{cases} i = e,\mu \;\Rightarrow R \ll 1 \\ i = \tau \Rightarrow R < 1 \end{cases}$$

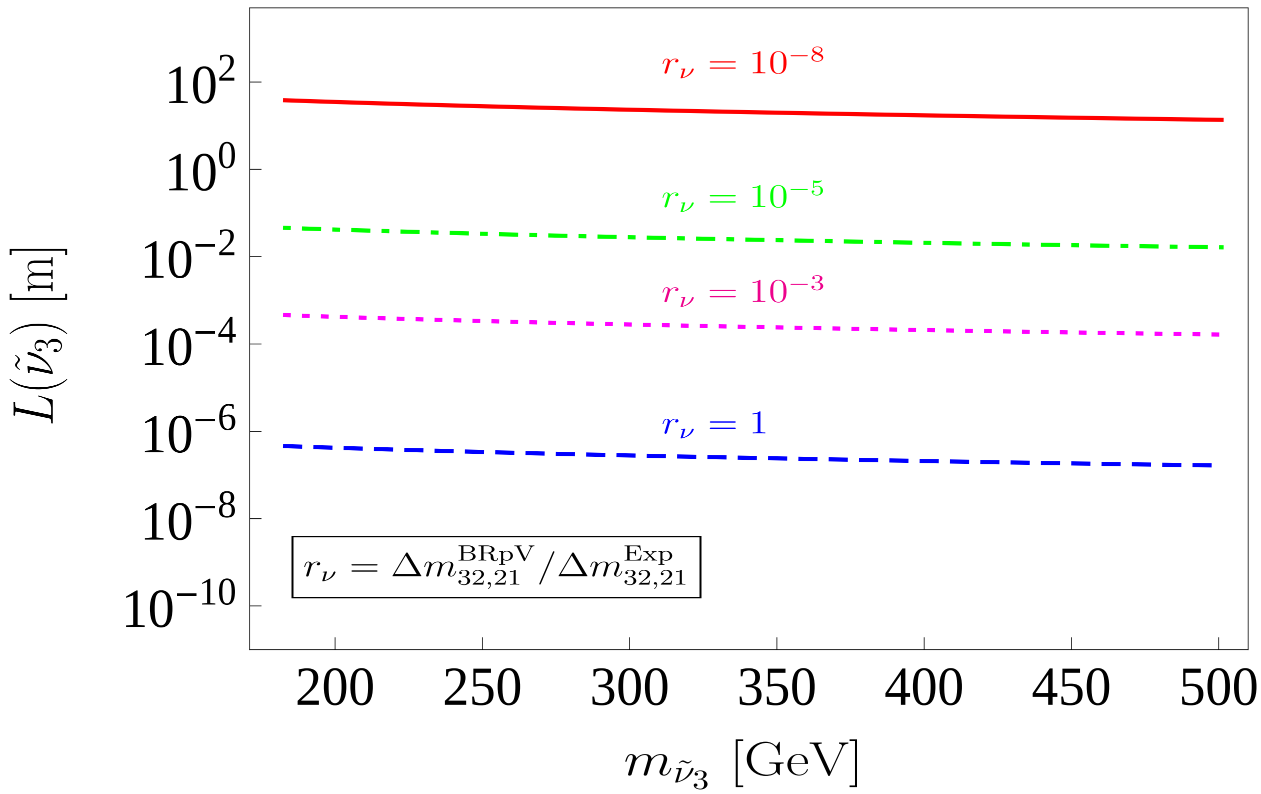
Region 2

$$\epsilon_i \ll v_i \ll \epsilon_k \Rightarrow \; R \equiv \text{BR}^{\tilde{\nu}_i}_{l_i l_k}/\text{BR}^{\tilde{\nu}_i}_{bb} \sim (h_{l_i}/h_b)^2 \underbrace{(\epsilon_k^2/v_i^2)}_{\sim 10^6} \quad \begin{cases} \tau,\mu : R \gg 1 \\ e : R \ll 1 \end{cases}$$

Different-flavor charged lepton decay modes are dominant for third and second sneutrino generation

Displaced vertices

Sneutrino decays might or not involve displaced vertices, depending on whether neutrino data is accounted by BRpV parameters



Conclusions

Final remarks

- Searches for SUSY at LHC have placed strong bounds on squark and gluinos masses...
  - Abandon the idea of natural SUSY...
  - Bounds are model dependent...
- **RpV** SUSY is a viable option for natural SUSY not so well experimentally explored.
- An example: sneutrino LSP decays in BRpV SUSY:
  - "Non-standard" SUSY signals e.g: $\tau\mu$, τe, μe or $h^0 h^0$: 4 b-jets; $\nu\nu$.
  - Constraints from neutrino data: displaced vertices which might be $\mathcal{O}$(m) easily escaping detection.

R-parity violation a possibility
that should be further explored

Thanks for your attention!!