Bounds on trilinear couplings in the baryon triality mSUGRA model from neutrino masses

Marja Hanussek

in collaboration with H. K. Dreiner and S. Grab

Physikalisches Institut, Universität Bonn

Workshop Neutrino Masses and LFV at the LHC, Würzburg, 2009

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Introduction

- neutrino oscillation data indicates that neutrinos are massive
- neutrinos contribute to hot dark matter
- "**Cosmological bound**": WMAP and LSS data combined[1] yield at 99.9% C.L.

$$\sum_i m_{\nu_i} < 0.40 \text{ eV}$$

- in the B_3 mSUGRA model, neutrino masses are generated via lepton number violating (LNV) parameters

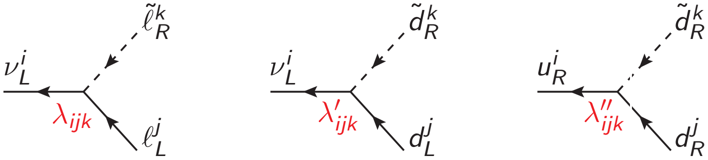
  $\Rightarrow$ cosmological bound can be used to restrict LNV parameters

[1] M. Cirellia and A. Strumia, Cosmology of neutrinos and extra light particles after WMAP3, astro-ph/0607086

Baryon triality mSUGRA model

Full gauge invariant and renormalizable superpotential:

$$W = W_{MSSM} + \frac{1}{2}\lambda_{ijk}\, L_i L_j \bar{E}_k + \lambda'_{ijk}\, L_i Q_j \bar{D}_k - \kappa_i L_i H_u + \frac{1}{2}\lambda''_{ijk}\, \bar{U}_i \bar{D}_j \bar{D}_k$$



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- MSSM: R-Parity forbids all additional terms to prevent rapid proton decay
- but: R-Parity still allows dimension-five operators leading to proton decay
- **Baryon Triality** (B_3)
  - forbids BNV terms: λ'' + dim.-5 operators
  - allows LNV terms: λ, λ', κ

  $\Rightarrow$ proton stability ensured
- further motivation: LNV in leptogenesis, majorana mass terms

mSUGRA model

- SUSY cannot be an exact symmetry
- after soft SUSY breaking, there are $\sim$ 200 free parameters in a generic B_3 SSM
- **Minimal Supergravity:** SUSY breaking takes place in a "hidden sector" which couples to the observable sector only via gravitational interactions.
- 5 free R_P conserving parameters

$$M_0,\ M_{1/2},\ A_0,\ \tan\beta,\ \mathrm{sgn}\mu$$

$\Rightarrow$ additionally, LNV parameters

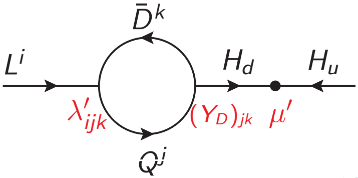
B_3 mSUGRA model

- λ, λ' and κ constitute 39 additional parameters.
- all κ_i can be rotated away at the GUT scale

$$W \supset \mu H_u H_d + \kappa_i H_u L_i$$

$$\begin{pmatrix} \mu \\ \kappa_i \end{pmatrix} \to \begin{pmatrix} \mu' \\ 0 \end{pmatrix} \quad \text{for} \quad \begin{pmatrix} H_d \\ L_i \end{pmatrix} \to \begin{pmatrix} \mathcal{L}_0 \\ \mathcal{L}_i \end{pmatrix} = \mathcal{O}_{4\times 4} \begin{pmatrix} H_d \\ L_i \end{pmatrix}$$

- running from $M_{\rm GUT}$ to M_Z, non-zero κ_i will be generated



B_3 mSUGRA model

- λ, λ' constitute 36 new parameters.
- makes sense assuming a strong hierarchy, analogously to the case of higgs yukawa couplings
- we select one (dominant) LNV coupling $\Lambda \in (\lambda_{ijk}, \lambda'_{ijk})$
  $\Rightarrow$ 6 free parameters in total

$$\Lambda,\ M_0,\ M_{1/2},\ A_0,\ \tan\beta,\ \mathrm{sgn}\mu$$

- fix these at the GUT scale, use RGEs to calculate mass spectrum and couplings at M_Z
  $\Rightarrow$ SOFTSUSY-3.0.12[2] + routines for ν masses & bounds

[2] B. C. Allanach, "SOFTSUSY: A C++ program for calculating supersymmetric spectra," hep-ph/0104145.

Neutrino masses at tree level

- In the B_3 mSUGRA model, neutrinos mix with neutralinos

$$\mathcal{L} = -\frac{1}{2}\left(-i\widetilde{\mathcal{B}} \quad -i\widetilde{\mathcal{W}}^3 \quad \tilde{h}_u^0 \quad \tilde{h}_d^0 \quad \nu_\iota\right)\mathcal{M}_N \begin{pmatrix} -i\widetilde{\mathcal{B}} \\ -i\widetilde{\mathcal{W}}^3 \\ \tilde{h}_u^0 \\ \tilde{h}_d^0 \\ \nu_\jmath \end{pmatrix},$$

$$\mathcal{M}_N = \begin{pmatrix} \mathcal{M}_{\chi^0} & m^T \\ m & 0 \end{pmatrix}$$

$\Rightarrow$ analogous to standard seesaw mechanism

- effective neutrino mass matrix

$$\mathcal{M}^\nu_{\text{eff}} = -m\mathcal{M}^{-1}_{\chi^0} m^T$$

- just one non-zero eigenvalue $m_\nu^{\text{tree}} \sim -\sum_{i=1}^3 (\frac{v_d}{\mu}\kappa_i - v_i)^2$.

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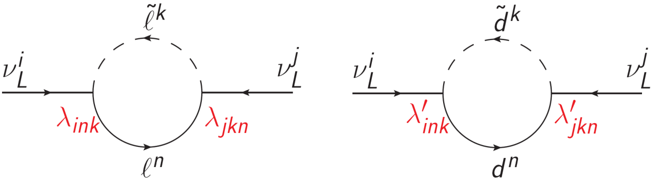
Loop contributions to neutrino masses

- usually,

$$\frac{m_\nu^{\rm loops}}{m_\nu^{\rm tree}} \sim \mathcal{O}(10^{-2})$$

- but there are regions of parameter space where $m_\nu^{\rm tree} \longrightarrow 0$
  $\Rightarrow$ loops become dominant!
- important contributions that are not aligned to tree level mass:

$\lambda\lambda$- and $\lambda'\lambda'$-loops



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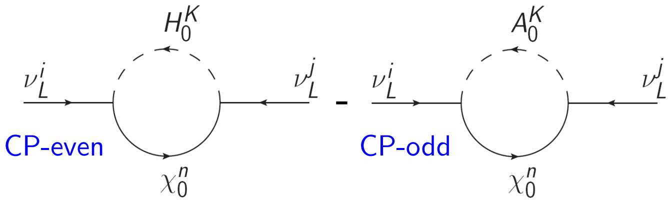
Neutral Scalar - Neutralino loops



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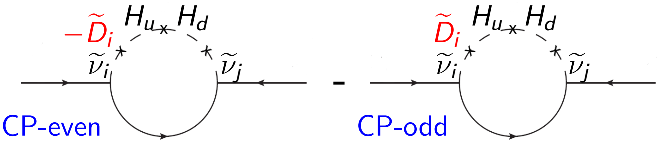
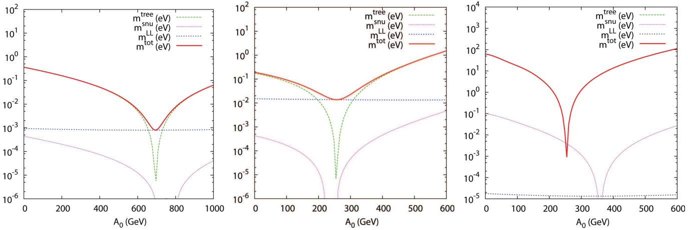
Neutral Scalar - Neutralino loops $\sim \Delta m^2_{\tilde{\nu}}$



mSUGRA dependence of the neutrino mass contributions



(a) $\lambda'_{233} = 10^{-5}$, $M_{1/2} = 300$ GeV, $M_0 = 500$ GeV, $\tan\beta = 20$, sgn$\mu = +1$
(b) $\lambda_{211} = 0.2$, $M_{1/2} = 600$ GeV, $M_0 = 0$ GeV, $\tan\beta = 15$, sgn$\mu = +1$
(c) $\lambda_{211} = 0.001$, $M_{1/2} = 100$ GeV, $M_0 = 0$ GeV, $\tan\beta = 10$, sgn$\mu = +1$

- RGEs tell us that ν mass always displays this minimum, for

$$A_0 \approx 2M_{1/2} \text{ (case } \Lambda \in \lambda'\text{)}$$
$$A_0 \approx 1/2 M_{1/2} \text{ (case } \Lambda \in \lambda\text{)}$$

- shifted to higher values of A_0 for $\tan\beta \lesssim 10$
- for all contributions, $m_\nu \propto \Lambda^2$

Upper bounds on the LNV coupling

- neutrino mass minimum yields bounds that are 1-2 orders of magnitude weaker than in previous studies
- Upper bounds on λ'_{ijk} at M_{GUT} for SPS1a-like parameters[3]:

	Up mixing			Down mixing		
A_0 (GeV)	-100	500	550	-100	500	550
λ'_{i11}	2×10^{-3}	3×10^{-2}	1×10^{-1}	1×10^{-3}	1×10^{-2}	7×10^{-2}
λ'_{i22}	1×10^{-4}	1×10^{-3}	7×10^{-3}	1×10^{-4}	1×10^{-3}	6×10^{-3}
λ'_{i33}	3×10^{-6}	3×10^{-5}	2×10^{-4}	3×10^{-6}	3×10^{-5}	2×10^{-4}
$\lambda'_{i21}, \lambda'_{i12}$	-	-	-	5×10^{-4}	7×10^{-3}	4×10^{-2}
$\lambda'_{i32}, \lambda'_{i23}$	2×10^{-2}	4×10^{-1}	-	8×10^{-5}	9×10^{-4}	4×10^{-3}
$\lambda'_{i31}, \lambda'_{i13}$	-, 2×10^{-2}	-, 6×10^{-2}	-, 2×10^{-1}	9×10^{-4}	9×10^{-3}	4×10^{-2}

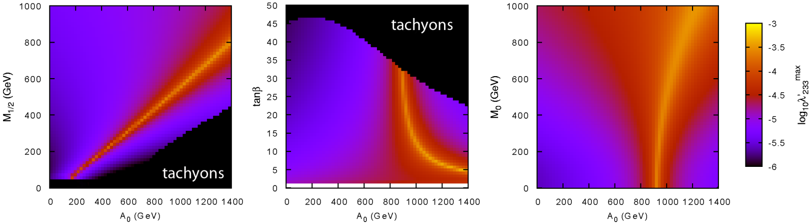
- usually strongest bounds on LNV couplings are from ν masses
- in vicinity of minimum, other bounds become comparable, e.g.

$$\lambda'_{211} < 0.06 \text{ from } \Gamma(\pi^- \to \ell^- \bar{\nu}_\ell)^4$$

[3] $A_0 = -100$ GeV column from B. C. Allanach et al., "The RPV mSUGRA model," hep-ph/0309196.

[4] Y. Kao and T. Takeuchi, "Single-Coupling Bounds on R-parity violating SUSY, an update," arXiv:0910.4980.

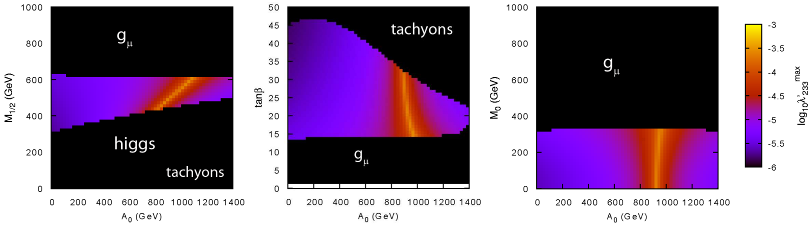
Two dimensional scans



Upper bounds on $\Lambda \in \lambda'_{233}$ around $M_{1/2} = 500$ GeV, $M_0 = 100$ GeV, $\tan\beta = 20$, sgn$\mu = +1$

- approx 2 orders of magnitude variation in bounds
- excluded regions due to tachyons

Other bounds on B_3 mSUGRA parameter space



Upper bounds on $\Lambda \in \lambda'_{233}$ around $M_{1/2} = 500$ GeV, $M_0 = 100$ GeV, $\tan\beta = 20$, sgn$\mu = +1$

- including bounds from
  - LEP2 (higgs)
  - tachyons
  - anomalous magnetic moment of the muon ("g_μ")[5]
  - BR($b \to s\gamma$)[5]
  - BR($B_s \to \mu^+\mu^-$)[5]
- still seizable regions with weaker bounds

[5] using micrOMEGAs2.2 by G. Belanger et al.

Summary

- there are extended regions of parameter space where bounds on LNV coupling become one to two orders of magnitude weaker than previously considered, up to $\Lambda \sim \mathcal{O}(0.1)$
- in these regions, loop contributions to neutrino mass from $\lambda\lambda$-($\lambda'\lambda'$-) and sneutrino-antisneutrino mixing loops are important
- large LNV couplings give new LSP candidates (e.g. sneutrino, $\tilde{e}_R$) and can lead to resonant single slepton production at the LHC
- to explain neutrino oscillation data ($\rightarrow$ neutrino mass hierarchy), we need additionally to dominant LNV coupling at least one more small coupling

Appendix (LHC phenomenology)

- for large LNV couplings, resonant single slepton production possible at the LHC e.g.

$$u_j \bar{d}_k \to \tilde{\ell}_i^+ \to \ell_i^+ \tilde{\chi}_m^0$$

- promising like-sign dilepton signature for $\lambda' = \mathcal{O}(10^{-2})$, e.g. neutralino LSP scenario with $\lambda'_{211} = 0.01$[6]

$$\tilde{\mu}^+ \to \mu^+ \tilde{\chi}_1^0 \stackrel{\lambda'}{\hookrightarrow} \mu^+ \bar{u}\, d$$

- current bound from hadron collider resonant production:

$$\lambda'_{211}|_{M_{GUT}} < 0.059$$

[6] S. Grab et al., "Supersymmetric NLO QCD corrections to resonant slepton production and signals at the Tevatron and the LHC," hep-ph/0611195

Appendix (LHC phenomenology)

- new LSP candidates beyond χ_1^0, $\tilde{\tau}_1$ if $\Lambda = \mathcal{O}(0.1)$
- e.g. sneutrino LSP for $\lambda'_{ijk} > 0.05$ possible[7]
- will domiantly decay into two jets via λ'_{ijk} ($\tilde{\nu}_i \to \bar{d}_j d_k$)
- other possible LSPs: $\tilde{e}_R$ (for λ_{121}, λ_{131}, λ_{231}), $\tilde{\mu}_R$ (for λ_{132})[8]
- for these values of Λ, direct and dominating B_3 decays of heavy sparticles

[7] M. A. Bernhardt et al., "Sneutrino as Lightest Supersymmetric Particle in B_3 mSUGRA Models and Signals at the LHC,"arXiv:0810.3423

[8] H. K. Dreiner et al., "All Possible LSPs in R-Parity Violating mSUGRA Models," arXiv:0909.5407