How SuperB can probe R-parity violation through τ and B meson decays

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Outline

Introduction to R-parity violation

SuperB's reach in RPV

Models with RPV predictions

Summary

Reminder: what is R-parity and what would violate it?

R-parity is a $\mathbb{Z}_2$ multiplicative symmetry.

$$\begin{aligned} R_p &= (-1)^R \\ R &= 3B + L + 2s \end{aligned}$$

Only terms with $R_p = +1$ are normally allowed in the MSSM.

Without R-parity, H_d has same gauge quantum numbers as L!

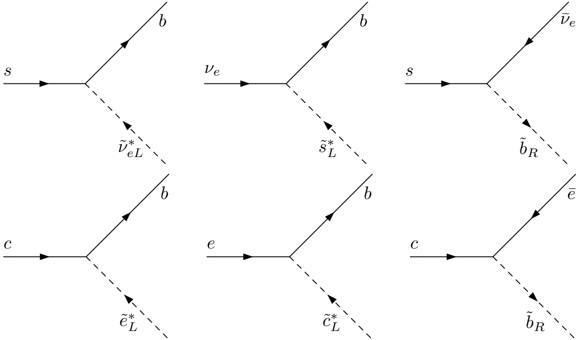
R-parity conserving "Yukawa" superpotental

$\mu H_u H_d$
$+Y^e_{jk} H_d L_{jL} e^c_{kR}$
$+Y^d_{jk} H_d Q_{jL} d^c_{kR}$
$+Y^u_{jk} H_u Q_{jL} u^c_{kR}$

R-parity violating "Yukawa" superpotental

$\mu'_j H_u L_{jL}$
$+\frac{1}{2}\lambda_{ijk} L_{iL} L_{jL} e^c_{kR}$
$+\lambda'_{ijk} L_{iL} Q_{jL} d^c_{kR}$
$+\frac{1}{2}\lambda''_{ijk} u^c_{iR} d^c_{jR} d^c_{kR}$

e.g. λ'_{123}:

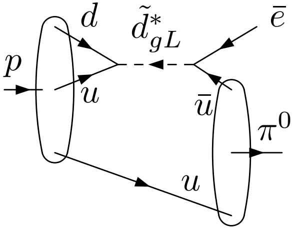


Reminder: why is R-parity conservation usually assumed?

Proton decay:

$\lambda'_{ijk}, \lambda''_{ijk} \sim \mathcal{O}(1)$, $m_{\tilde{q}} \sim \mathcal{O}(1)$ TeV $\Rightarrow \quad \tau_p^{\mathrm{RPV}} \quad \sim \quad 10^{-50} \tau_p^{\mathrm{exp.min.}}$

(R. Barbier *et al.*, Phys. Rept. **420** (2005) 1 [arXiv:hep-ph/0406039])



However, either lepton number conservation*:

- $\lambda_{ijk} = \lambda'_{ijk} = 0$,

or baryon number conservation

- $\lambda''_{ijk} = 0$.

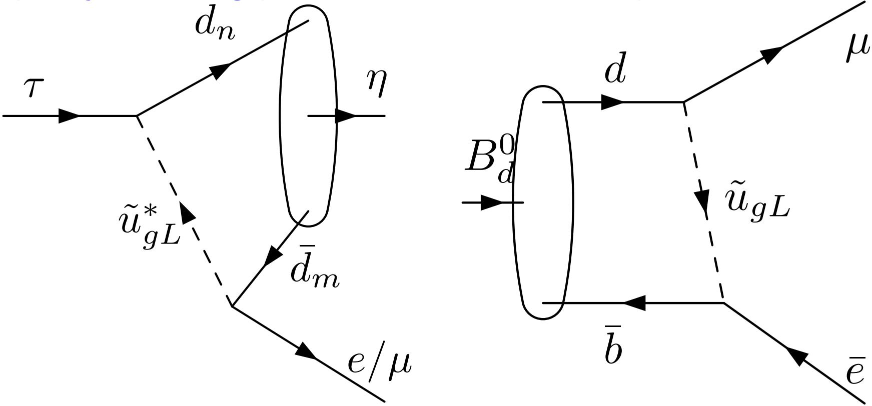
is sufficient.

Also, almost any $\mathbb{Z}_2$ gives a dark matter candidate!

Models with $B - L$ as gauge quantum number (*e.g.* left-right symmetric models) automatically conserve R-parity.

* lepton number conservation is not anomaly-free.

R-parity-violating processes relevant to SuperB



H. K. Dreiner, M. Krämer and B. O'L., Phys. Rev. D **75** (2007) 114016 [arXiv:hep-ph/0612278]:

- Bounds with old data (PDG 2007).
- BUT correct formulae for *B* meson related bounds.
- Bounds shown in this talk are updated (but not given in depth).

How these processes bound R-parity-violating couplings

- Integrate out sfermion to get effective four-fermion term
  - *e.g.* $[\lambda'^{*}_{321}\bar{\tau}P_R d\tilde{c}^{*}_L][\lambda'_{221}\bar{d}P_L\mu\tilde{c}_L] \Rightarrow (-\lambda'^{*}_{321}\lambda'_{221}/m^2_{\tilde{c}_L})[\bar{\tau}P_R d][\bar{d}P_L\mu]$
- Rearrange with Fierz identities
  - $\Rightarrow (\lambda'^{*}_{321}\lambda'_{221}/2m^2_{\tilde{c}_L})[\bar{\tau}\gamma_\nu P_L\mu][\bar{d}\gamma^\nu P_R d]$
- Apply PCAC assuming isospin invariance
  - $\langle 0|\bar{d}\gamma^\nu\gamma^5 d|\pi^0\rangle \Rightarrow if_\pi p^\nu_{\pi^0}/\sqrt{2}$
- Integrate over phase space
- Compare to experimental bound

The reach of SuperB in R-parity-violating parameter space

How SuperB's estimated reach with 75 ab^{-1} improves bounds (all bounds scale as $(100\text{ GeV}/m_{\tilde{f}})^2$):

- $B_d \to \ell_i \bar{\ell}_j$ ($B_d \to \mu\bar{\mu}$):
  - $\lambda_{gij}\lambda'_{g13} < 3.8\text{E}{-6} \Rightarrow < 3.2\text{E}{-7}$
  - $\lambda'_{jg3}\lambda'_{ig1} < 3.3\text{E}{-4} \Rightarrow < 2.1\text{E}{-5}$
- $B_s \to \ell_i \bar{\ell}_j$ ($B_s \to \mu\bar{\mu}$):
  - $\lambda_{gij}\lambda'_{g23} < 6.7\text{E}{-6} \Rightarrow < 3.1\text{E}{-7}$
  - $\lambda'_{jg3}\lambda'_{ig2} < 5.6\text{E}{-4} \Rightarrow < 2.6\text{E}{-5}$
- $\tau \to \ell_i P^0/V^0$ ($\tau \to \mu\eta$):
  - $\lambda_{gi3}\lambda'_{gmn} < 4.4\text{E}{-5} \Rightarrow < 3.4\text{E}{-6}$
  - $\lambda'_{3gm}\lambda'_{ign} < 6.1\text{E}{-4} \Rightarrow < 4.8\text{E}{-5}$
- $\tau \to \ell_i \bar{\ell}_j \ell_k$ ($\tau \to \mu\mu\bar{\mu}$):
  - $\lambda_{gij}\lambda_{gk3} < 2.8\text{E}{-4} \Rightarrow < 2.2\text{E}{-5}$

($B \to K\ell_i\bar{\ell}_j$ is much more involved)

R-parity-violating Model 1: long-lived-yet-unstable gravitino dark matter model

W. Buchmüller, L. Covi, K. Hamaguchi, A. Ibarra and T. Yanagida, JHEP **0703** (2007) 037 [arXiv:hep-ph/0702184]:

- "primordial nucleosynthesis, thermal leptogenesis and gravitino dark matter are naturally consistent for $10^{-14} < \lambda, \lambda' < 10^{-7}$ and $m_{3/2} \gtrsim 5$ GeV."

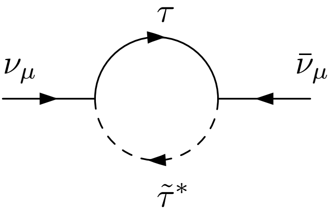
... *waaaaaay* too small to be relevant to SuperB... (remember, SuperB probes $\lambda\lambda' \sim 10^{-7} \Rightarrow \lambda' \sim 10^{-3}$)

R-parity-violating Model 2: R-parity-violating MSSM benchmark scenarios

B. C. Allanach, M. A. Bernhardt, H. K. Dreiner, C. H. Kom and P. Richardson, Phys. Rev. D **75** (2007) 035002 [arXiv:hep-ph/0609263]:

- R-parity-violating mSUGRA benchmark points
- Only one R-parity-violating coupling non-zero at GUT scale
- RGE $\Rightarrow$ other non-zero R-parity-violating couplings at EW scale
- *but* only one remains $> 10^{-4}$

R-parity-violating Model 3: neutrino mass through trilinear couplings



τ-$\tilde{\tau}$ loop contribution to muon neutrino mass:

- $|\lambda_{233}|^2/m^2_{\tilde{\tau}_L} \approx (4\pi)^2 m_{\nu_\mu}/(\mu \tan(\beta) m^2_\tau)$

Assuming $\mu \approx m_{\tilde{\tau}_L} \approx 100$ GeV, $\tan\beta \approx 30$, $m_{\nu_\mu} \approx 0.3$ eV,

- $|\lambda_{233}|^2 \approx 10^{-5}(m_{\tilde{\tau}_L}/100 \text{ GeV})^2$

H. K. Dreiner, J. Soo Kim and M. Thormeier, arXiv:0711.4315 [hep-ph]:

- $\lambda_{g33} \approx 3.6\text{E}{-5}, \lambda'_{223} \approx 4.0\text{E}{-6}, \lambda'_{233} \approx 9.6\text{E}{-5}$, rest $< 10^{-6}$

... a bit beyond SuperB, also not good combinations for visible signals ($B_s \to \nu\bar{\nu}, \Upsilon \to \tau\bar{\tau}$)

R-parity-violating Model 4: 2 non-zero couplings to explain D meson decays

G. Bhattacharyya, K. B. Chatterjee and S. Nandi, arXiv:0911.3811 [hep-ph]:

- $\lambda'_{223} \approx \lambda'_{323} \approx 0.3$.
- Explains excess for $D_s \to \nu\bar{e}/\nu\bar{\mu}$ for $m_{\tilde{q}} \approx 300$ GeV (compared to SM prediction with lattice decay constant).

P. Dey, A. Kundu, B. Mukhopadhyaya and S. Nandi, JHEP **0812** (2008) 100 [arXiv:0808.1523 [hep-ph]]:

- addition of $\lambda'_{223} \sim 0.1$ and soft squark mixing parameters within current bounds allows ν mass at 2-loop level.

Couplings seem large enough to be probed, but would need good data on $\Upsilon \to \tau\bar{\mu}$

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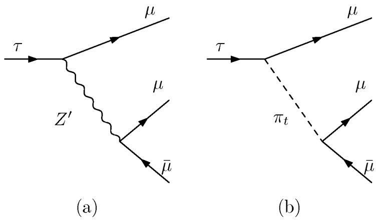
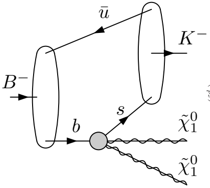
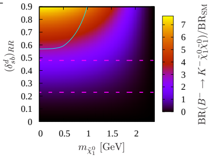


(plus diagrams with the muons crossed.)

M. Giffels, J. Kallarackal, M. Krämer, B. O'L. and A. Stahl, Phys. Rev. D **77** (2008) 073010 [arXiv:0802.0049 [hep-ph]]: asymmetry in $\tau \to \mu\mu\bar{\mu}$ at LHC to distinguish between RPV, MSSM, LHT, TC2, ...





H. K. Dreiner, S. Grab, D. Koschade, M. Krämer, B. O'L. and U. Langenfeld, Phys. Rev. D **80** (2009) 035018 [arXiv:0905.2051 [hep-ph]]: bounds on MSSM models with very light neutralinos (through relaxation of gaugino mass relations)

Summary and Outlook

- SuperB can significantly improve bounds on interesting R-parity-violating couplings in combinations.
- R-parity violation is motivated by cosmology, but only for small amounts way below the reach of SuperB.
- R-parity violation is motivated by neutrino mass:
  - 1-loop mechanisms *might* be within reach of SuperB;
  - 2-loop mechanisms *should* be within reach of SuperB.
- SuperB can also probe some other interesting models.