Current status of R-parity violating supersymmetry

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August 10, 2024

"Frontiers in Particle Physics 2024"

Centre for High Energy Physics, IISc

Plan of the Talk :

- Neutrino masses and mixing in RPV SUSY models.
- Other phenomenological implications.
- LHC constraints from Run-I and Run-II data
- Future HL-LHC projection
- Summary

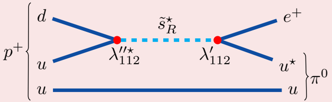
R-parity violating SUSY

R-Parity violating Superpotential

$$W_{\not R_p} = \epsilon_i \hat{L}_i \hat{H}_u + \lambda_{ijk} \hat{L}_i \hat{L}_j \hat{E}^c_k + \lambda'_{ijk} \hat{L}_i \hat{Q}_j \hat{D}^c_k + \lambda''_{ijk} \hat{U}^c_i \hat{U}^c_j \hat{D}^c_k$$

- In contrast with RPC SUSY models → LSP is unstable, not a good dark matter candidate anymore.
- First three terms → $\Delta L = 1$; Last term → $\Delta B = 1$

Presence of both λ' and λ'' couplings → Proton decay into $l^+\pi$



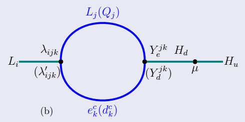
- Robust constraints → $\frac{|\lambda'^{11i}\lambda''^{11i}|}{m^2_{\tilde{d}_i}} (\mathrm{GeV})^2 < 2 \times 10^{-31}$

R-parity violating SUSY

- R-parity conserving MSSM $\rightarrow$ No neutrino mass or mixing
- Neutrino mass and mixings $\rightarrow$ can be generated without invoking dimension-5 Weinberg operator in RPV MSSM.

- Bilinear term can generate light neutrino masses at tree level.
- λ and λ' contribute to the neutrino masses at one-loop level.

- Bilinear term $\rightarrow$ can be completely rotated away $\rightarrow$ shows up at some other energy scale. Barger et al., hep-ph/9511473; S. Chakraborty and J. Chakraborty (1701.04566)
- Trilinear couplings can give rise to these bilinear terms. Carlos & White (1996), Nardi (1997)

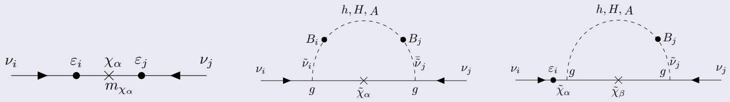


- On the other hand, trilinear interactions can be generated starting from non-zero bilinear couplings S. Roy and B. Mukhopadhyaya (1996)

Neutrino mass in bRPV SUSY Model

$$W_{\not{R}_p} = \varepsilon_i L_i H_u; \;\; \mathcal{L}_{\not{R}_p} = [\varepsilon_i(\tilde{H}_u^0 \nu_{iL} - \tilde{H}_u^+ l_{iL})]; \quad \mathcal{L}_{soft} = B_i \tilde{L}_i H_u$$

Tree and loop level diagrams



- Mixing of light neutrino and neutralino states $\rightarrow$ only one neutrino becomes massive at tree level (ν_3)
- Other neutrino masses are generated at one loop level $\rightarrow$ BB loop (mainly ν_2) and ϵB loop (mainly ν_1).
- BB loop(dominant)$\rightarrow$mixing between sneutrinos-neutral Higgs

Davidson and Losada (2000); Grossman and Rakshit(2004); Rakshit(2004); Allanach, Dedes and Dreiner (2004); R. Barbier et al. (2005)

Neutrino mass in bRPV SUSY Model

$$[m_\nu]_{ij} = [m_\nu]_{ij}^{\epsilon\epsilon} + [m_\nu]_{ij}^{BB} + [m_\nu]_{ij}^{\epsilon B}$$
$$[m_\nu]_{ij}^{\epsilon\epsilon} \sim \frac{\cos^2\beta}{\tilde{m}} \epsilon_i \epsilon_j \sin^2\zeta$$
$$[m_\nu]_{ij}^{BB} \sim \frac{g^2}{64\pi^2 \cos^2\beta} \frac{B_i B_j}{\tilde{m}^3} \epsilon_H$$
$$[m_\nu]_{ij}^{\epsilon B} \sim \frac{g^2}{64\pi^2 \cos\beta} \frac{\epsilon_i B_j + \epsilon_j B_i}{\tilde{m}^2} \epsilon'_H$$

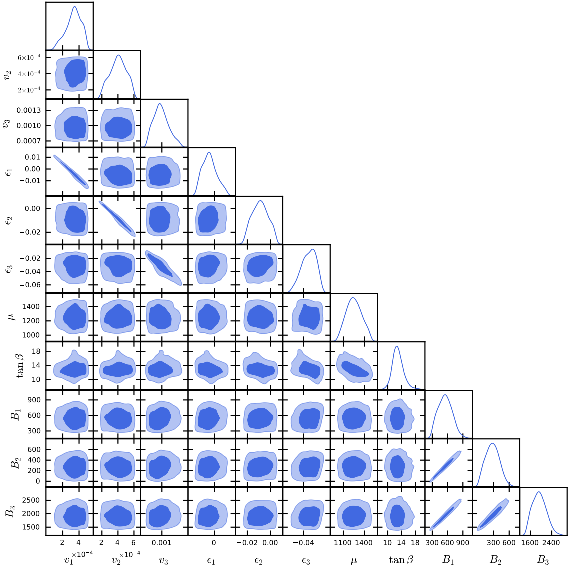
Sampling the bRPV parameter space using MCMC

- Latest global fit of different neutrino oscillation data.
- Updated measurement of Higgs mass and coupling strengths.
- Low energy data from rare b-decays.
- Relevant constraints from LHC Run-I and Run-II data

- 68% and 95% C.L. allowed regions of the 9 RPV parameters alongside μ and tanβ.

AC, S. Mitra, A. Mondal and S. Mondal (JHEP02(2024)004, arxiv:2305.15211)

Marginalized posterior distributions or corner plots

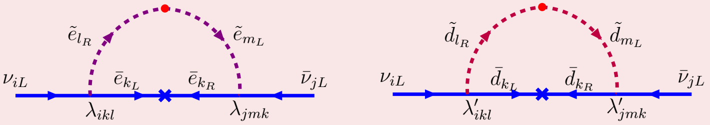


AC, S. Mitra, A. Mondal and S. Mondal (2024)

Neutrino mass in trilinear Model

$$W_{\not{L}} = \frac{1}{2}\lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k$$

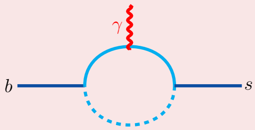
Loop diagrams



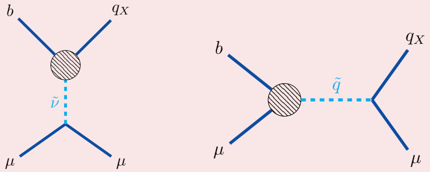
- Large number of parameters $\rightarrow$ Very difficult to sampling the parameter space using likelihood analysis.
- Dominant contribution comes from only third generation couplings λ_{i33} and λ'_{i33}

AC, S. Mitra, A. Mondal and S. Mondal (ongoing)

Low energy observables (few examples)



combination $\lambda'_{ij2}\lambda'_{ij3} \neq 0$ or $\lambda''_{i12}\lambda''_{i13} \neq 0$ can contribute to the decay width of $b \to s\gamma$. Dreiner, Nickel and Staub, [arxiv:1309.1735]

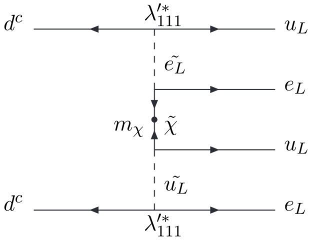


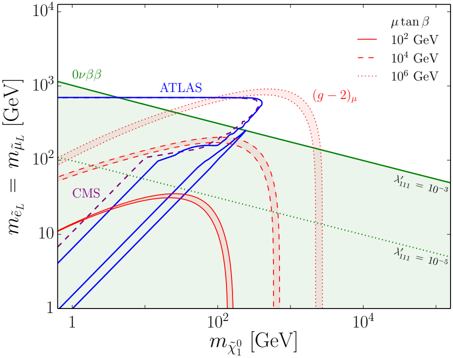
Bounds on $|\lambda_{i22}\lambda'_{i12}|$, $|\lambda'_{2i2}\lambda'_{2i2}|$ subjected to the sparticle masses from $B_{s,d} \to \mu^+\mu^-$. Dreiner, Nickel and Staub, [arxiv:1309.1735]

Lepton flavor violating (LFV) decays, Meson oscillation $\to$ put constraints on RPV couplings.

Low energy observables (cont.)

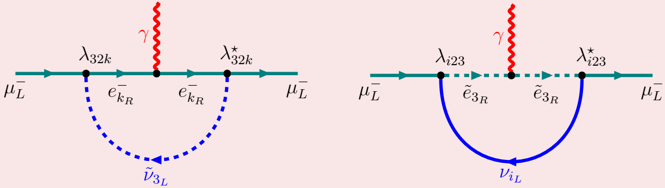
- Contributes to lepton number violating signal: Neutrinoless double beta decay





P. D. Bolton, F. F. Deppisch, P. S. Bhupal Dev, arXiv: 2112.12658

Anomalous muon magnetic moment

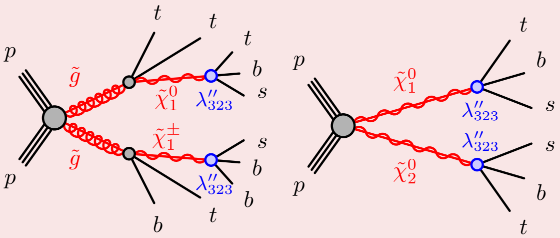


- $[\Delta a_\mu]^{\lambda\lambda} = \frac{m_\mu^2}{96\pi^2}[|\lambda_{23k}|^2\frac{2}{m^2_{\tilde{\nu}_\tau}} + |\lambda_{3k2}|^2\{\frac{2}{m^2_{\tilde{\nu}_\tau}} - \frac{1}{m^2_{\tilde{\tau}_L}}\} - |\lambda_{k23}|^2\frac{1}{m^2_{\tilde{\tau}_R}}]$
- Similarly, the non-zero λ' couplings can contribute to muon (g-2).

J. E. Kim, B. Kyae and H. M. Lee, hep-ph/0103054;
A. Chakraborty and S. Chakraborty, arxiv:1511.08874

R-parity violating SUSY at the collider

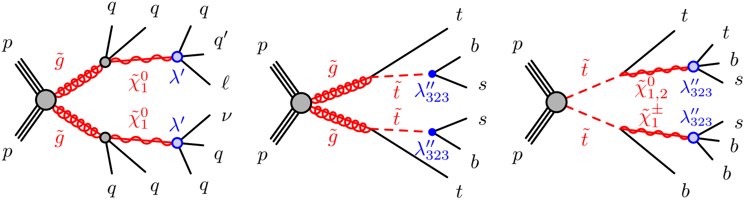
- LSP can decay to standard model particles.
- Missing Energy is smaller compare to RPC MSSM.
- But jet/lepton multiplicities become higher in RPV scenarios.
- Strength of couplings lead to various signals: Prompt Decay, Displaced Vertex

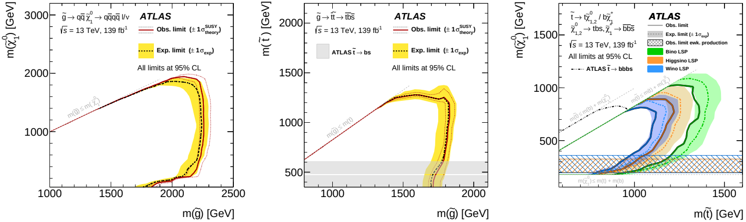


- Prompt decay $\rightarrow$ Explore the LSP or NLSP pair production.

Searches for strong sector sparticles:

- Final states $\rightarrow$ high jet multiplicity + $\geq 1l$ and (0-3) b-jets
- Analysis results independent of value of the coupling.

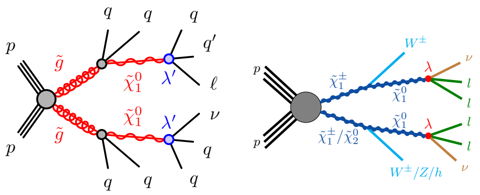


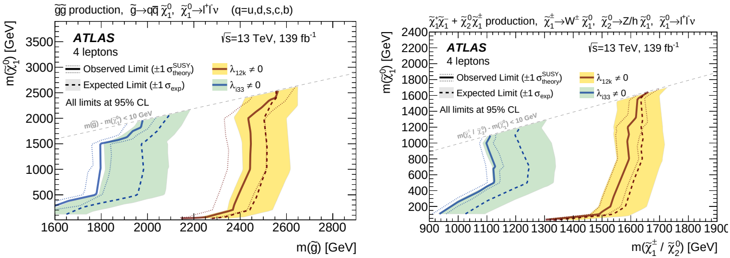


arxiv:2106.09609

Searches for strong/electroweak sector sparticles:

- Final states $\rightarrow$ Four or more leptons
- Both the LSP ($\tilde{\chi}_1^0$) decay via λ_{ijk} type coupling.

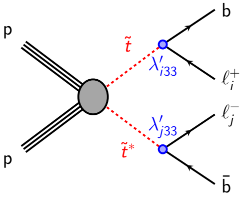


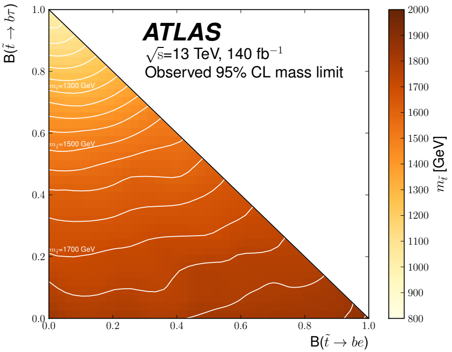


arxiv:2103.11684

Searches for top squarks:

- Final states $\rightarrow \geq 2l + 2j(1b)$
- Target $\widetilde{t}_1 \rightarrow bl$ decay via λ'_{i33} coupling; Limits on stop masses 800 (1900) GeV for 100% $b\tau$ (be) decay.

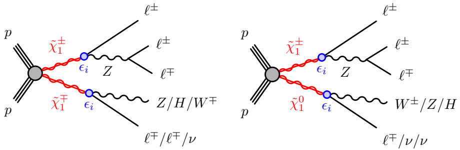


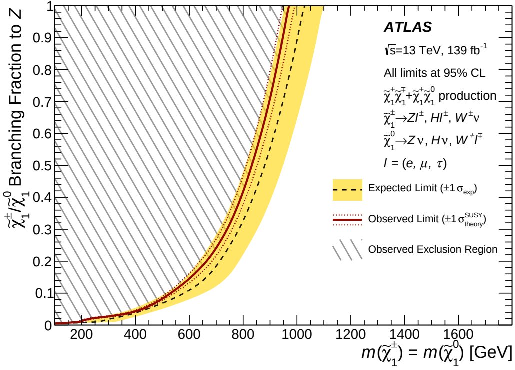


arxiv:2406.18367

Trilepton resonances in bRPV model

- Atleast one $\tilde{\chi}_1^{\pm}$ is reconstructed from $N_l \geq 3$ final states.

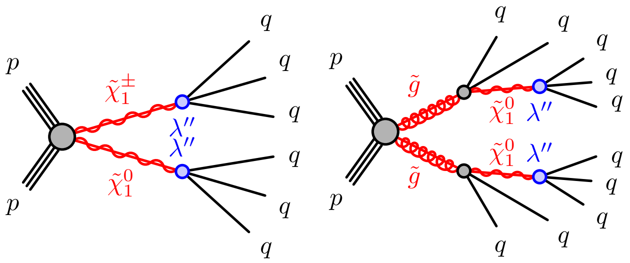




arXiv: 2011.10543

Search for long-lived particle

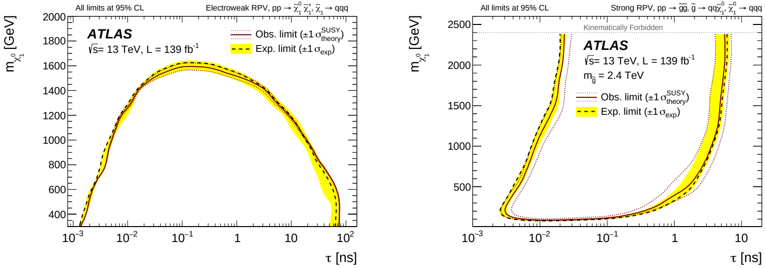
- LLPs are very common in RPV → either the RPV couplings or the NLSP-LSP mass gap is very small.
- Signatures: displaced vertices, disappearing tracks, non-pointing photons etc.
- See yesterday's talks by Swagata, Shankha and Shilpi
- Direct pair production of Higgsinos(LLP) and gluinos (NLSP).



arXiv:2301.13866

Search for long-lived particle for UDD type RPV couplings

- Electroweakinos with masses below 1.5 TeV are excluded for mean proper lifetime between 0.03 ns ($c\tau = 0.9$ cm) to 1 ns ($c\tau = 30$ cm)



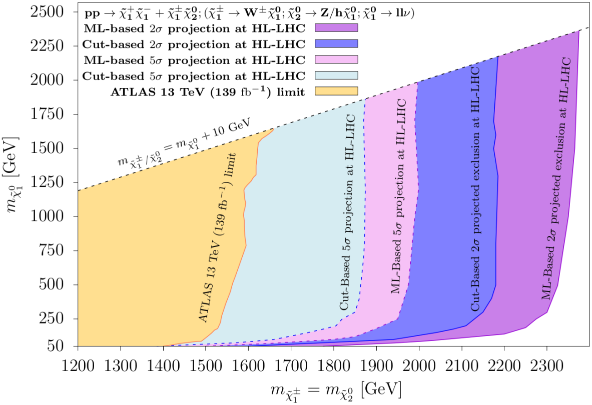
arXiv:2301.13866

- For HL-LHC prospect of long-lived LSP via wino/higgsino like pair production see $\rightarrow$ B. Bhattacherjee and P. Solanki, arxiv:2308.05804.

- For more detailed phenomenological implications and summary of updated LHC results see AC, A. Mondal and S. Mondal, arxiv:2402.04040

Prospect of electroweakino searches at the HL-LHC

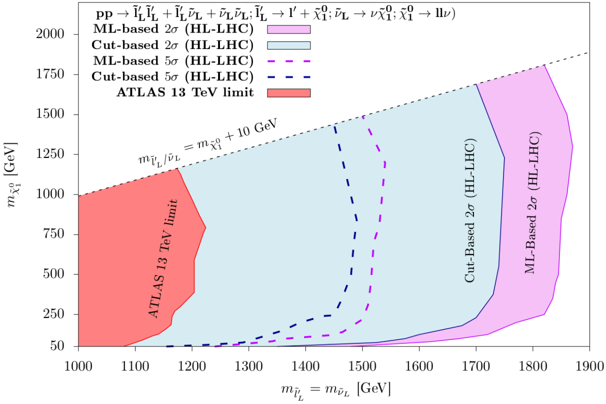
- 9 non zero λ_{ijk} couplings can give rise to four different scenarios
- nonzero λ_{121} and/or λ_{122}, the LSP pair always gives $4l$ final state



AC, A. Mondal, S. Mondal, S. Sarkar, arxiv:2308.02697

Prospect of slepton searches at the HL-LHC

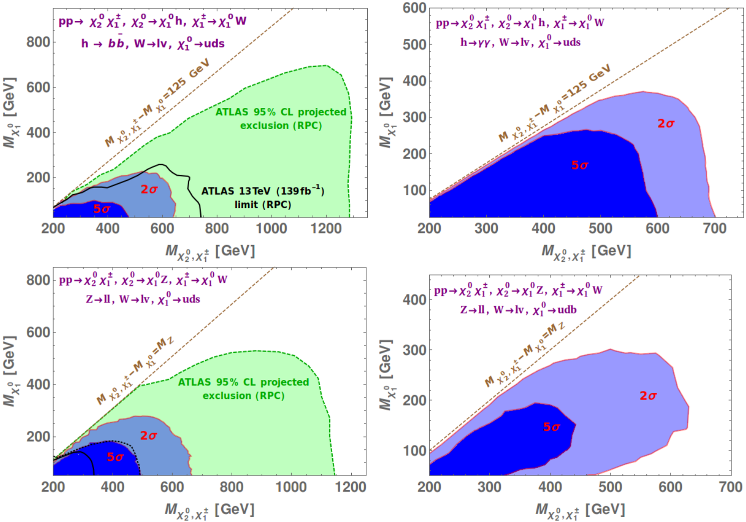
- For LLE couplings



AC, A. Mondal, S. Mondal, S. Sarkar, arXiv:2310.07532

Prospect of electroweakino searches at the HL-LHC

- For UDD couplings, the LSP decays to three quarks, $\rightarrow$ jet-enriched final states $\rightarrow$ provide a weaker limit.



R. K. Barman, B. Bhattacherjee, I. Chakraborty, AC, N. Khan, arXiv:2003.10920

Summary:

- RPV SUSY is a highly motivated BSM scenario.
- Several novel phenomenological implications.
- vast regions of electroweak sector still unconstrained.
- Can address neutrino oscillation, flavor anomalies, $(g-2)_\mu$ excess.
- RPV searches at LHC are quite exhaustive, still rooms for improvement.
- Regions with light LSP (typically) < 100 GeV need special attention.

THANK YOU