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Limits on R-parity-violating couplings from Drell-Yan and dijet processes at future colliders

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Energy Frontier Topical Groups:

- EF-08: BSM: Model-specific explorations
- Connected to: EF-09: BSM: More general explorations (BSM interplay with EFT)

The search for R-parity violation (RPV) in the Minimal Supersymmetric Standard Model (MSSM) will be a key target for any future collider at the energy frontier searching for physics beyond the Standard Model (SM). RPV models fall into two broad classes, depending on whether they violate baryon (B) or lepton (L) number. Meanwhile, searches and constraints on RPV tend to fall into one of three main categories:

1. Most RPV searches assume the sparticles are *pair-produced*, usually through their gauge interactions. The pair of sparticles are then allowed to decay, often through a cascading chain of R-parity-conserving (RPC) decays, until the lightest SUSY particle (LSP) is produced. The LSP then decays either promptly or with displaced track through its RPV couplings. With appropriate search strategies, that depend on the types of RPV under consideration (L-violating or B-violating), bounds on sparticle masses in RPV scenarios are usually similar to those in purely RPC models.

2. Another class of searches assumes *single production* of sparticles, via a sparticle's RPV coupling(s). In principle, such searches can be highly advantageous over the typical pair production modes, since resonant production of a single sparticle can be probed up to much higher masses than is possible with pair production (*i.e.*, roughly twice the mass reach). Observation of a new resonance would be a clear signal of new physics. However, non-observation would be difficult to interpret, since any given signature depends on a sparticle's RPV coupling, its mass, and its other decay modes; in particular, there is no reason to expect that the decay of the sparticle back into its initial state is the dominant decay mode. This introduces a strong model dependence into any bounds based on single sparticle production.

3. Finally, precision studies of SM processes are sensitive to the *exchange of single sparticles* which generate deviations from SM expectations. Contributions of RPV couplings to a variety of rare or forbidden low-energy SM processes have long been studied as a tool for constraining RPV couplings and sparticle masses. With only a few exceptions (namely couplings that contribute to neutrino masses), the strongest constraints are on *pairs* of couplings. Constraints on individual RPV couplings, on the other hand, are much less stringently constrained, with typical couplings constrained at no better than $O(1)$ for sparticle masses of 1 TeV.

However, recent studies have shown that precision studies of SM processes, particularly the differential cross section for Drell-Yan scattering at the LHC, can be used to provide the strongest current constraints on roughly half of the 27 RPV couplings of the LQd type [1, 2]; with additional data, the LHC will provide the constraints on the large majority of the LQd couplings. To provide some context, for couplings of $O(1)$, sparticle masses as heavy as 15 - 20 TeV can be probed at the High-Luminosity LHC. One can also attempt to repeat such an analysis using dijet data, in order to constrain the uud-type couplings [3]. Though yet unstudied, similar work could be performed at lepton colliders where both the LQd- and LLe-type couplings can be probed.

This Letter of Interest proposes to expand the current studies, which have been performed only for the LHC running at $\sqrt{s} = 13\,\text{TeV}$, to the range of future hadron and lepton colliders in order to provide benchmarks for studying the ability of each collider to discover, or constrain, RPV couplings and masses. Two issues will require special study:

1. Appropriate backgrounds, efficiencies and systematics will need to be estimated for the Drell-Yan and dijet measurements at future colliders. Fortunately these systematics should be no different than those used for future effective field theory (EFT) studies of the $QQLL$ and $QQQQ$ operators at those same colliders. Although EFT-type analyses cannot be *directly* translated into bounds on RPV masses and couplings due to the fact that each RPV coupling generates multiple effective operators which are then highly correlated, there is sufficient overlap in their systematics to allow both analyses to be done in parallel.

2. NLO corrections to Drell-Yan and dijet scattering could be significant (see, *e.g.*, [4]) and should be included to the extent feasible. At least in the Drell-Yan case, one would naively expect a sizable increase in the reach of a hadron collider in the sparticle mass-coupling plane.

In summary, studies of RPV couplings and masses in which the sparticles contribute to SM scattering processes at high energies by virtual exchange can be used to place some of the strongest possible constraints on the R-parity-violating MSSM, for RPV couplings of $O(10^{-2} - 1)$ and masses well above those typically probed by pair or even single production. Such studies should be a standard stratagem in the search for RPV physics.

References

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