Displaced Supersymmetry

Prashant Saraswat

with Peter Graham, David E. Kaplan and Surjeet Rajendran

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Motivations for Low-Energy SUSY

1) Stabilize the weak scale

2) LSP Dark Matter

3) Gauge coupling unification

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Strongly constrained!

Alternative: Challenge some standard assumptions about SUSY signatures:

- Large missing transverse energy
- All decays are prompt

Can we relax these assumptions using *R*-parity violation, and what happens to collider constraints if we do?

Bilinear *R*-Parity Violation

$$W \supset \mu_{L,i} L_i H_u$$

- Lowest dimension RPV operator– most relevant at low energies
- Can be embedded in *SU*(5) models:

$$\bar{\mathbf{5}}_L \mathbf{5}_{H_u} \rightarrow \mu_{L,i}(L_i H_u + D_j H_u^c)$$

- Doublet-triplet splitting problem requires that H^c decouple, so baryon number violation is suppressed.

Bilinear *R*-Parity Violation

$$W \supset \mu_{L,i} L_i H_u + \mu H_u H_d$$

L and H_d mix with angle μ_L/μ, diagonalization gives trilinears

$$W \supset \epsilon_i y^e_{jk} L_i L_j E_k + \epsilon_i y^d_{jk} L_i Q_j D_k \quad \epsilon_i \equiv \frac{\mu_{L,i}}{\mu}$$

Predictive: largest *R*-parity violating effects involve heavier generation particles, particularly bottoms

In an *SU*(5) GUT, *UDD* will obtain contributions

$$\frac{\mu_{L,i}}{M_{H^c}} y^u_{jk} D_i D_j U_k$$

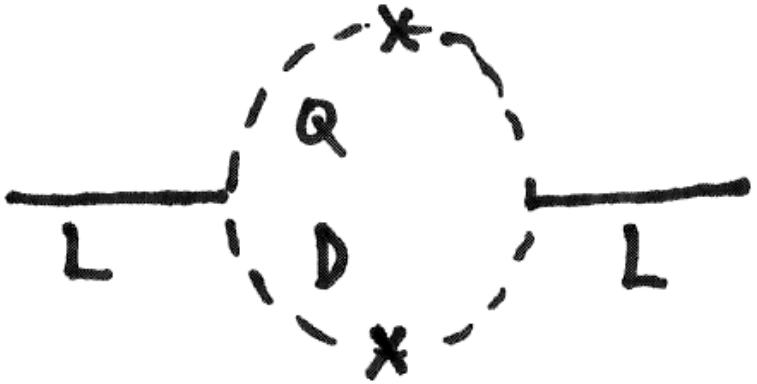
GUT-scale B violation

$$\frac{\mu_{L,i}}{\Lambda} D_i D_j U_k$$

Planck Slop

Constraints on Bilinear R-Parity Violation

L violation → Contributions to neutrino masses



$$\Delta m_\nu \sim \frac{\epsilon^2 y_b^4}{16\pi^2} v$$

Requires $\varepsilon < 10^{-3}$ to not exceed largest neutrino mass splitting. This also avoids proton decay bounds for GUT completions.

Signatures of Bilinear RPV

Dominant operators are $\epsilon_i y_b L_i Q_3 D_3, \epsilon_i y_\tau L_i L_3 E_3$

LSP	$\tilde{\chi}$	$\tilde{\nu}$	$\tilde{\tau}$	$\tilde{u}_L$	$\tilde{b}$
Dominant Decays	$\nu b\bar{b}$, $\nu\tau l$	$b\bar{b}$	$l^{\pm}\nu$	$l^{\pm}q$	$b\nu$

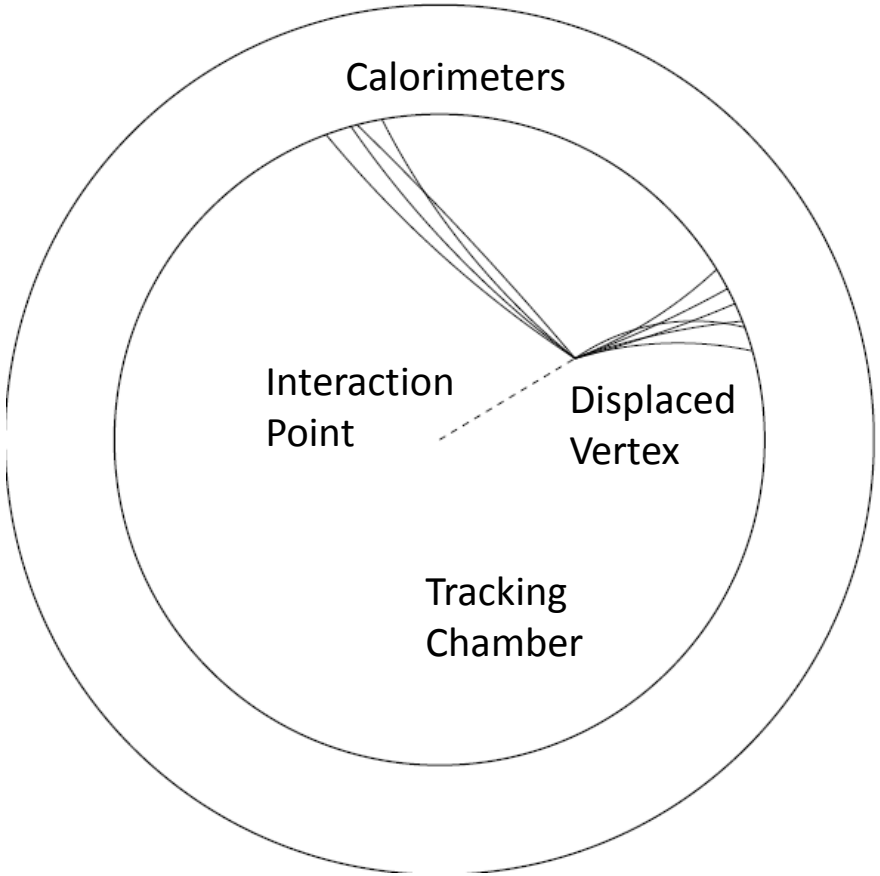
Final states in SUSY events can have

- suppressed, but nonzero, missing energy
- many jets, including *b*-jets
- possibly leptons

Displaced Vertices

For weak R-parity violation (small ε), the LSP decay length can be macroscopic (> 1 mm)

Unlike any Standard Model signal!



Typical inner detector size ∼ meter

Existing Collider Constraints on BRPV

Bilinear RPV with displaced decays can avoid constraints from many SUSY searches:

Collider Search	Issues Limiting Sensitivity to Displaced BRPV Decays
Searches in leptons and *b*-jets	Displaced tracks prevent reconstruction
Searches in jets + MET	Highly suppressed missing energy, CMS jets require good tracks
Searches for displaced vertices	Specific decay topologies not yet searched for

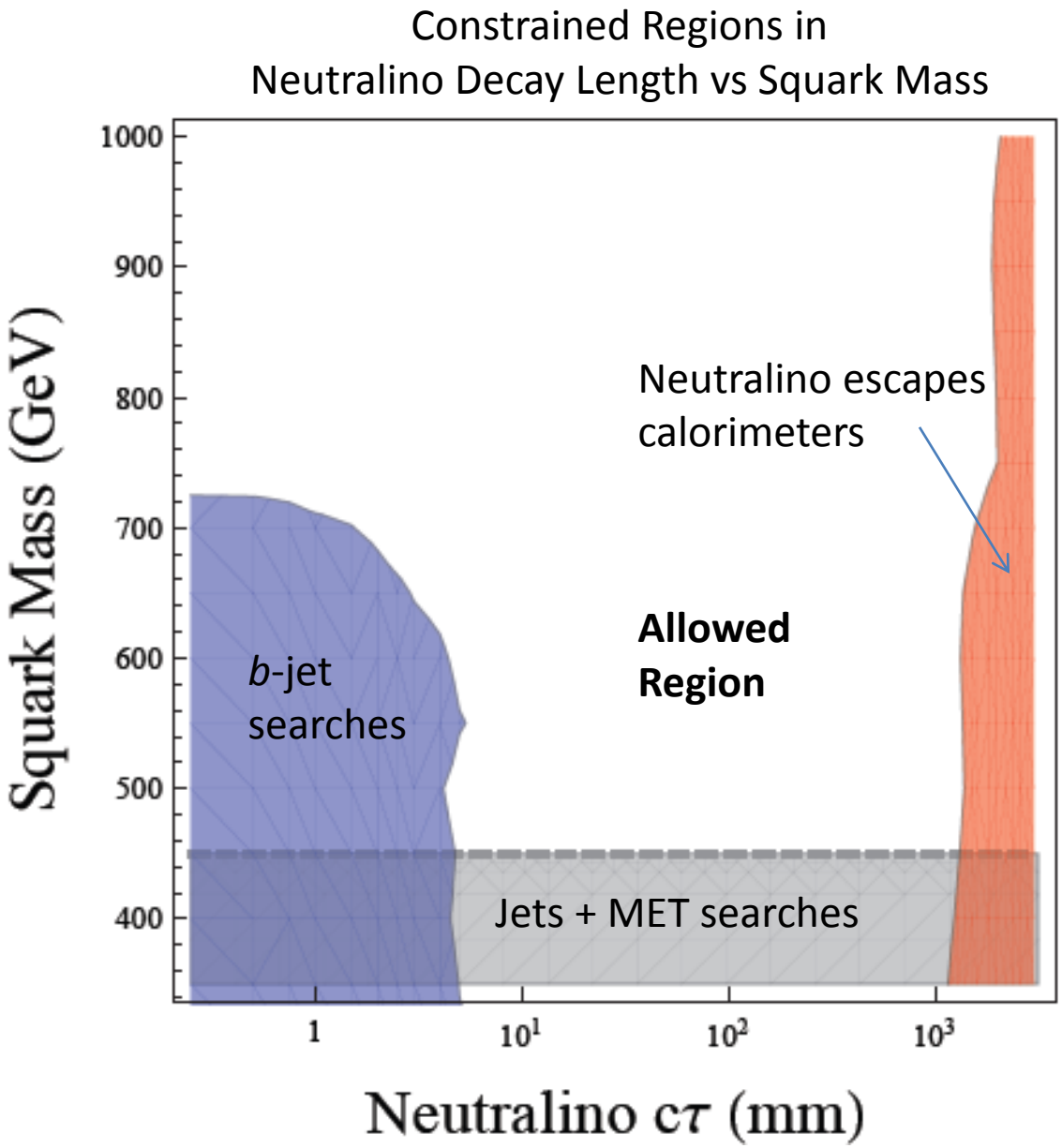
Neutralino LSP

For decay lengths

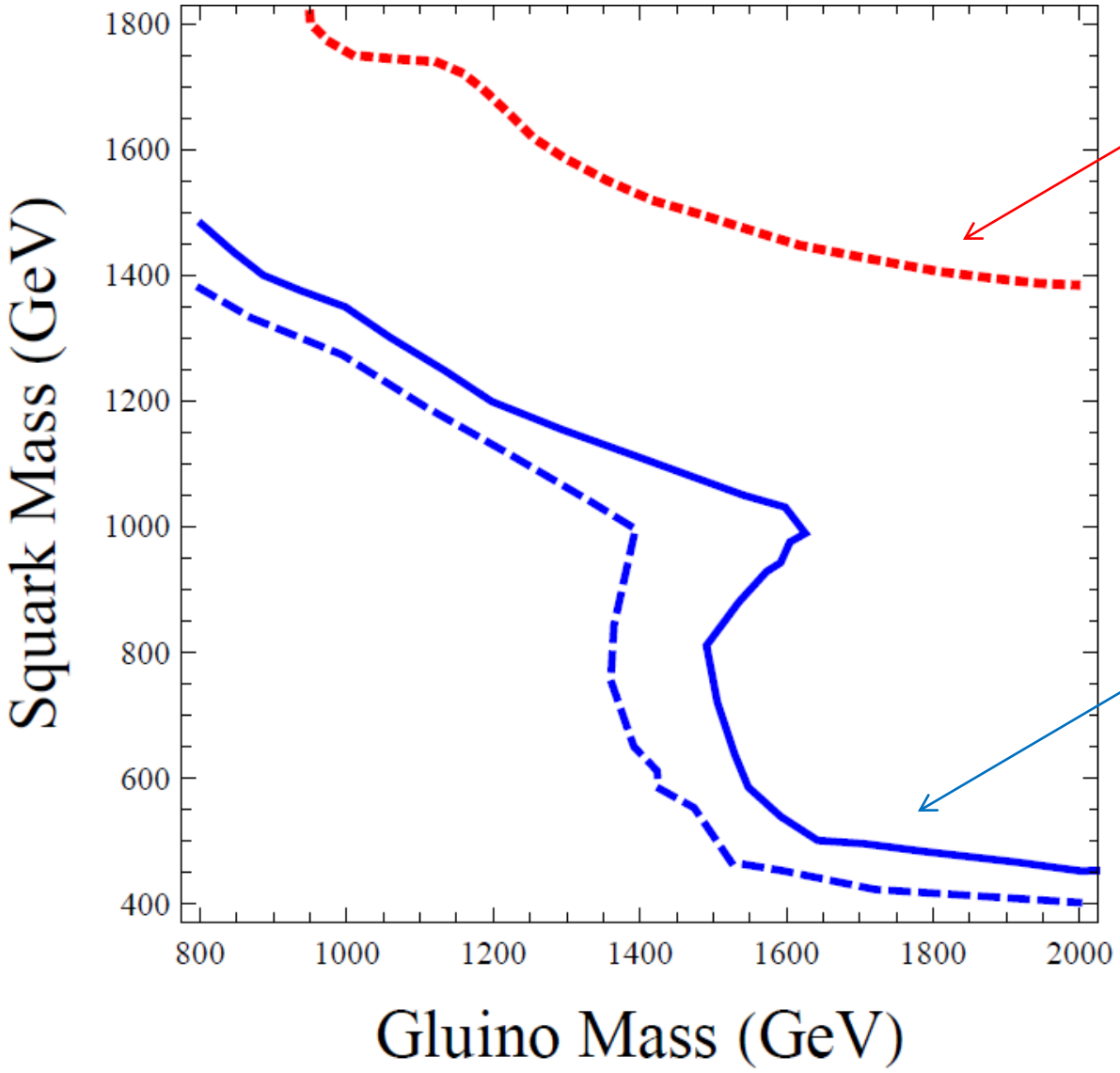
< few mm, *b*-jets and leptons from neutralino decays can be tagged

For decay lengths

> 1 meter, neutralinos often escape calorimeters



Constraints on Squark & Gluino Masses



Stable massless neutralino

50 GeV neutralino decaying to $\nu b\bar{b}$
Universal squark masses

LHC Displaced Vertex Searches

CMS: Search for displaced dilepton vertices in 1.1 fb^{-1}

ATLAS: Search for displaced vertices with many tracks in 35 pb^{-1}, using a high-p_T muon trigger

Only branching ratio to $\nu\tau\mu$ is significantly constrained by current searches

Discovery Prospects

SUSY production cross-sections ≈ pb still allowed:

Displaced decay searches have great discovery potential!

Two avenues for searches:

- Trigger on signatures of displaced decays

→Difficult for decays in the tracker

- Trigger on other aspects in the event and identify displaced decays offline

→Missing energy and multijet triggers are candidates

Conclusions

- Bilinear R-parity violation is well-motivated and consistent with low energy constraints
- RPV couplings can naturally be small, giving the LSP a macroscopic decay length
- Such decays greatly relax the constraints from existing searches on supersymmetry and squark mass in particular
- An appropriately designed search can have great discovery potential for these models.