Natural R-parity Violating Supersymmetry

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My Favorite Supersymmetry

- Not ruled out by LHC or flavor
- Natural
- No ad hoc assumptions
- LHC signatures
- Dark matter candidate & Unification

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Is this all too much to ask?

Outline: A New Hope

- The MSSM's demons: R-parity and flavor
- Model for R-parity violation: MFV SUSY
- Collider signatures

R-parity and Flavor

What is R-parity?

- R-parity charges SM and superpartners differently

$$R_P = (-1)^{L+3B+2S}$$

- General philosophy
  - Write down most general renormalizable Lagrangian compatible with gauge symmetries
  - Any non-gauge symmetries are happy accidents
- Imposing R-parity is arbitrary restriction

Why impose R-parity?

- Following philosophy: most general Lagrangian has B and L violation

$$W_{\text{RPV}} = \lambda'' \overline{UDD} + \lambda' LQ\overline{D} + \lambda LL\overline{E} + \mu' LH_u$$

- With large B and L violation, we get very rapid proton decay!
- R-parity, i.e. $(-1)^{L+3B+2S}$, prevents all these terms
- Note: SM has accidental B and L symmetry

R-parity is very predictive

- Superpartners are pair produced
- LSP stable + Cosmology $\rightarrow$ Must be neutral
- Pro: LSP makes a good dark matter candidate
- Con: Restricts scope of signatures
  - Most searches look for missing energy
  - Must cover all bases to ensure discovery!

Even more parameter space

- MSSM with R-parity: 105 new parameters
- RPV adds additional 190 parameters
- Strong constraints from flavor,

  stronger constraints from nuclear stability
- Should explore all possibilities but...

Is there a principle that naturally restricts

us to allowed parameters?

What is Minimal Flavor Violation?

- Without quark and lepton Yukawa couplings to Higgs, SM has large flavor symmetry
- Assume that BSM flavor violation only sourced by Yukawas
- Strongly suppresses flavor changing interactions induced by new physics

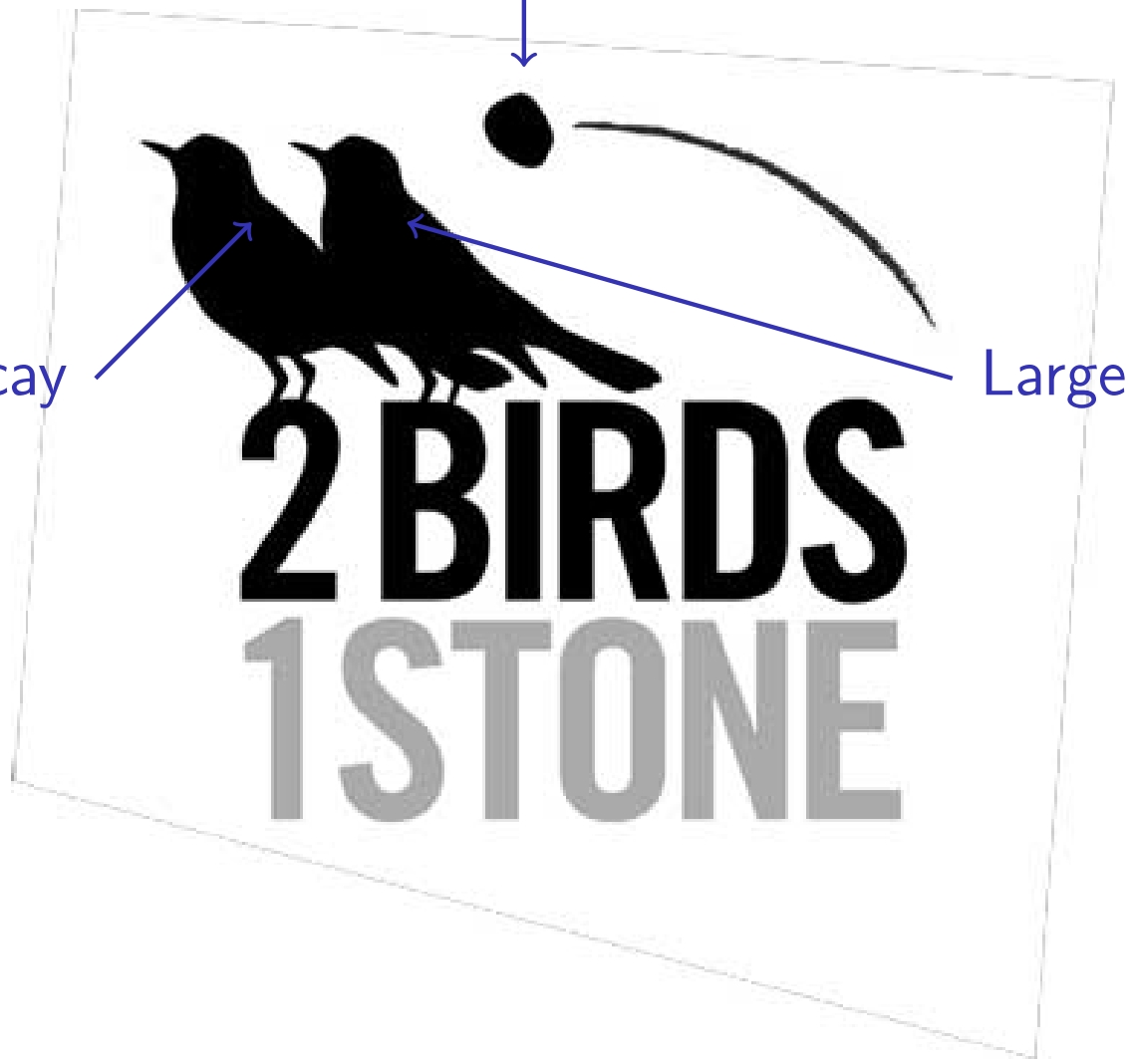
The new physics flavor puzzle

- Parametrize effects of new physics:

$$c\frac{(\overline{Q}_1 Q_2)(\overline{Q_3} Q_4)}{\Lambda^2}$$

- Flavor experiments put extremely strong bounds
- Two possibilities:
  - $\Lambda \gtrsim 10^4$ TeV, but want $m_{\text{SUSY}} \sim 1$ TeV
  - $c \ll 1 \rightarrow$ non-trivial structure
- MFV provides consistent framework that evades flavor bounds and determines c's

Minimal Flavor Violation



Nuclear decay

Large flavor violation

Model for R-parity Violation

RPV + MFV

Nikolidakis, Smith '07; Csáki, Grossman, Heidenreich '11

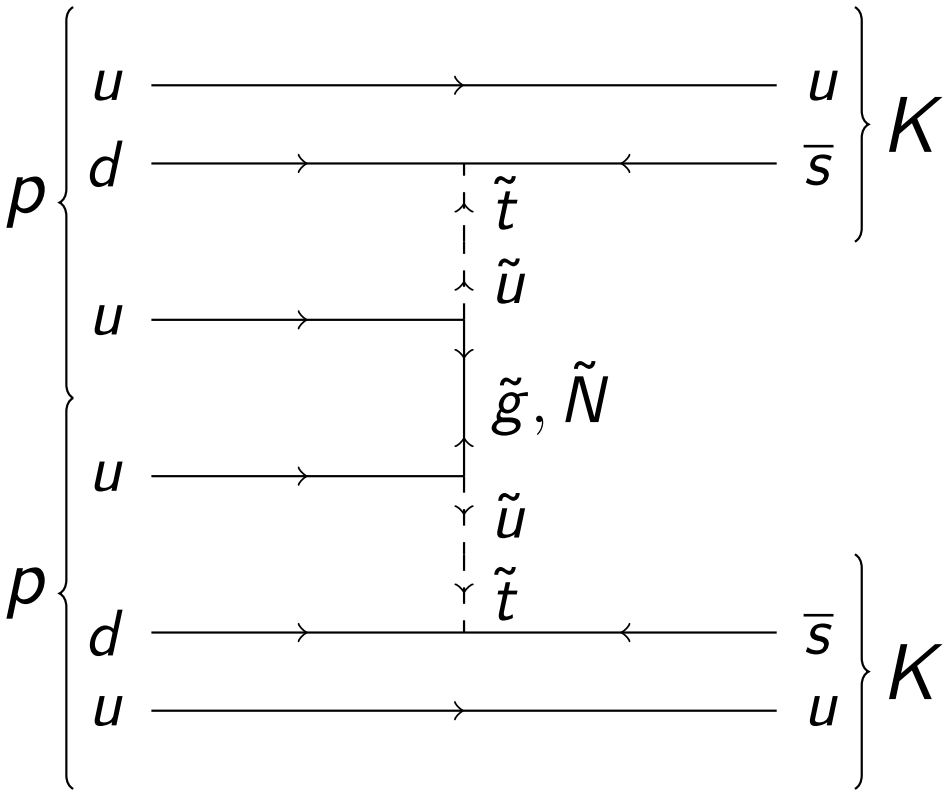
- Without neutrino masses, $W_{\not R}$ restricted:

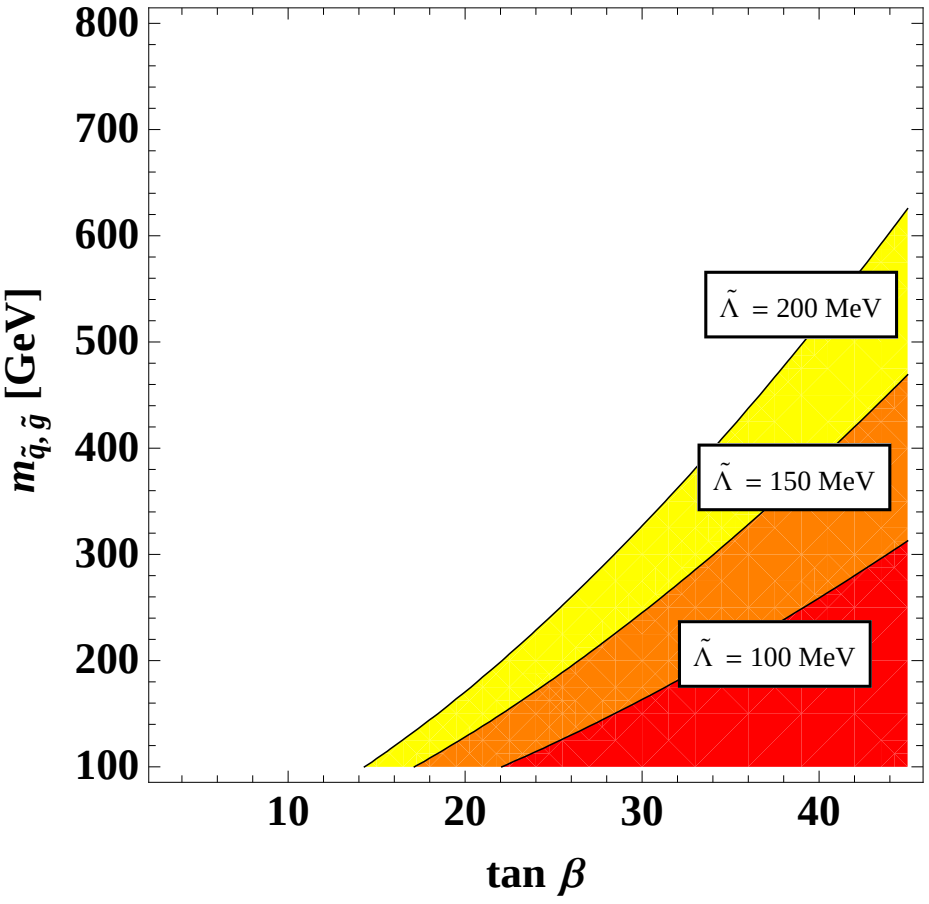
$$W_{\not R} = \lambda'' \overline{UDD} + \cancel{\lambda' LQ\overline{D}} + \cancel{\lambda LL\overline{E}} + \cancel{\mu' LH_u}$$

- Structure of $\lambda'' \sim Y_u Y_d Y_d$
- Largest one is $\lambda''_{tbs} \sim V_{td} y_t y_b y_s \sim 10^{-4}$

The MSSM with MFV has approximate R-parity

Dinucleon decay bounds



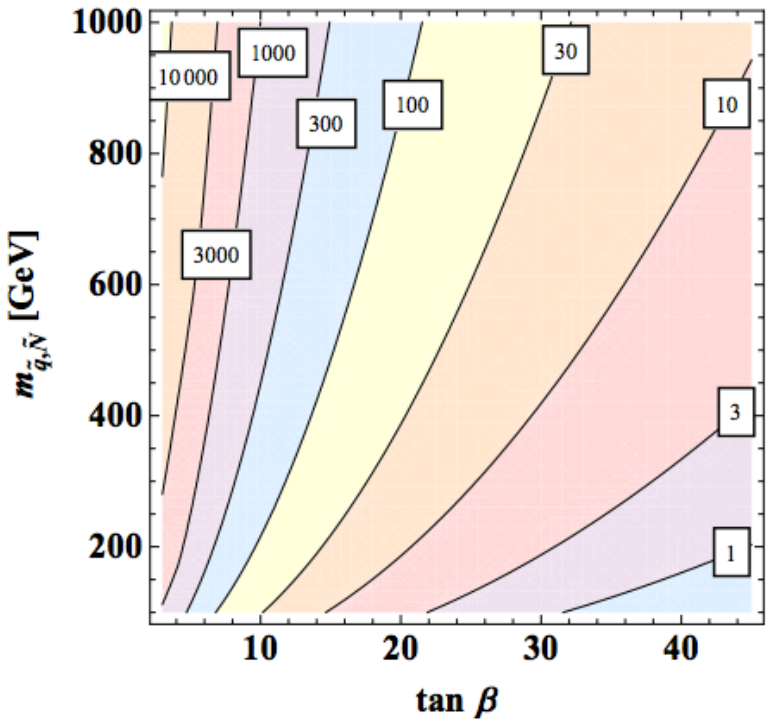


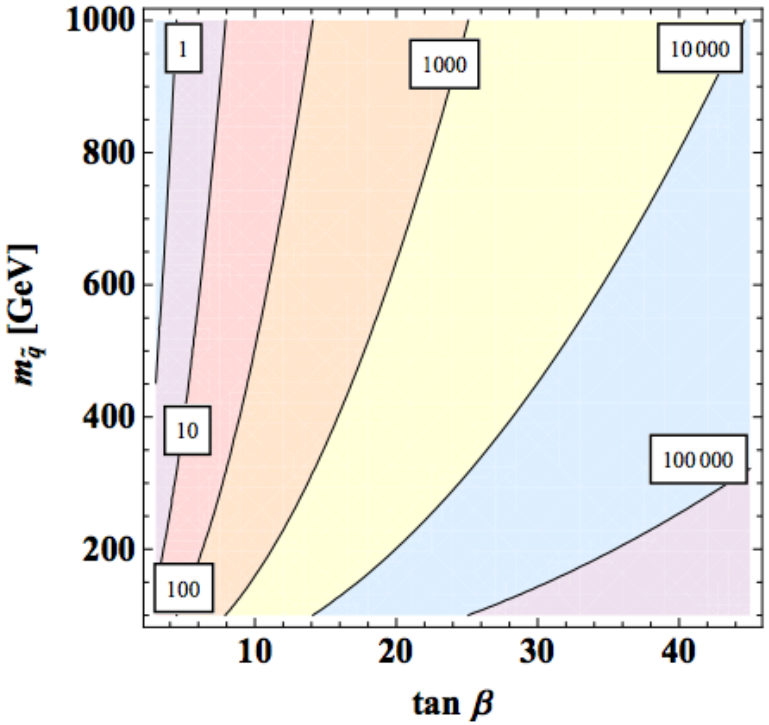
- Strongest bound, but still mild

Other nuclear bounds

- $n - \overline{n}$ oscillation: at least an order of magnitude above bound on t_{osc}
- Proton decay can potentially proceed two ways
  - Upper bound on RH neutrino scale
  - Lower bound on gravitino mass

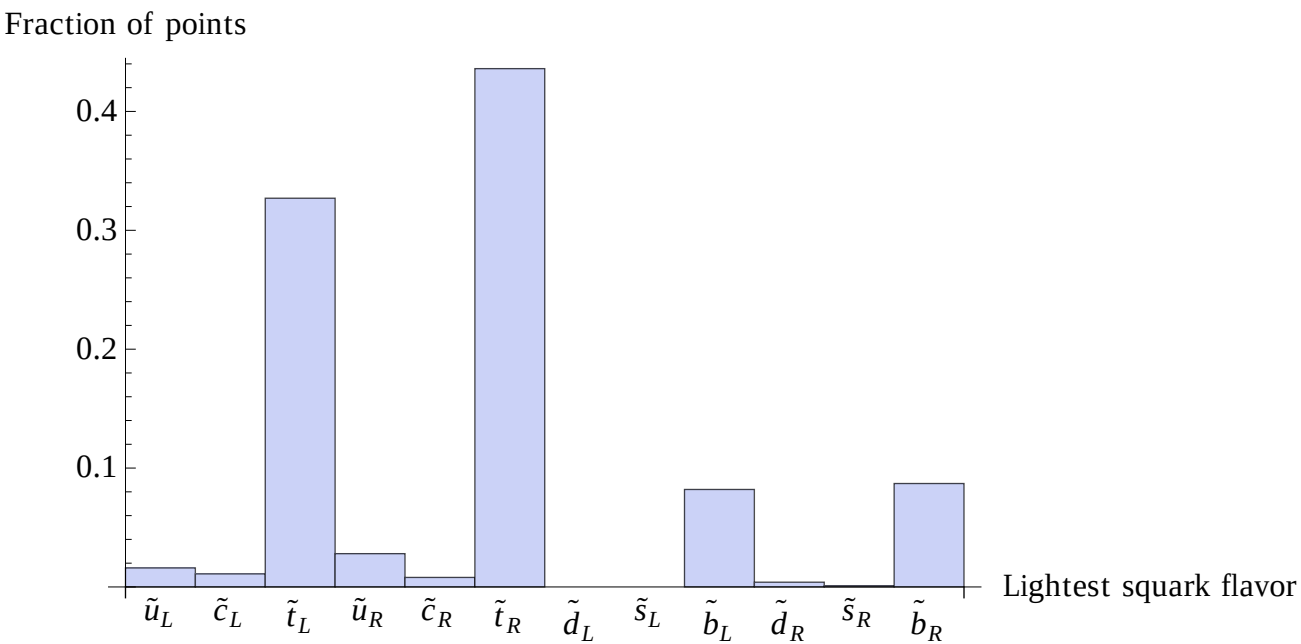
Other nuclear bounds





MFV affects spectrum, too

$$M^2_{\tilde{u}} = \begin{pmatrix} m^2_{\tilde{q}}(1 + aY_u Y_u^\dagger + bY_d Y_d^\dagger) + D_L & cY_u \\ c^* Y_u^\dagger & m^2_{\tilde{u}}(1 + dY_u^\dagger Y_u) + D_R \end{pmatrix}$$



Collider Phenomenology

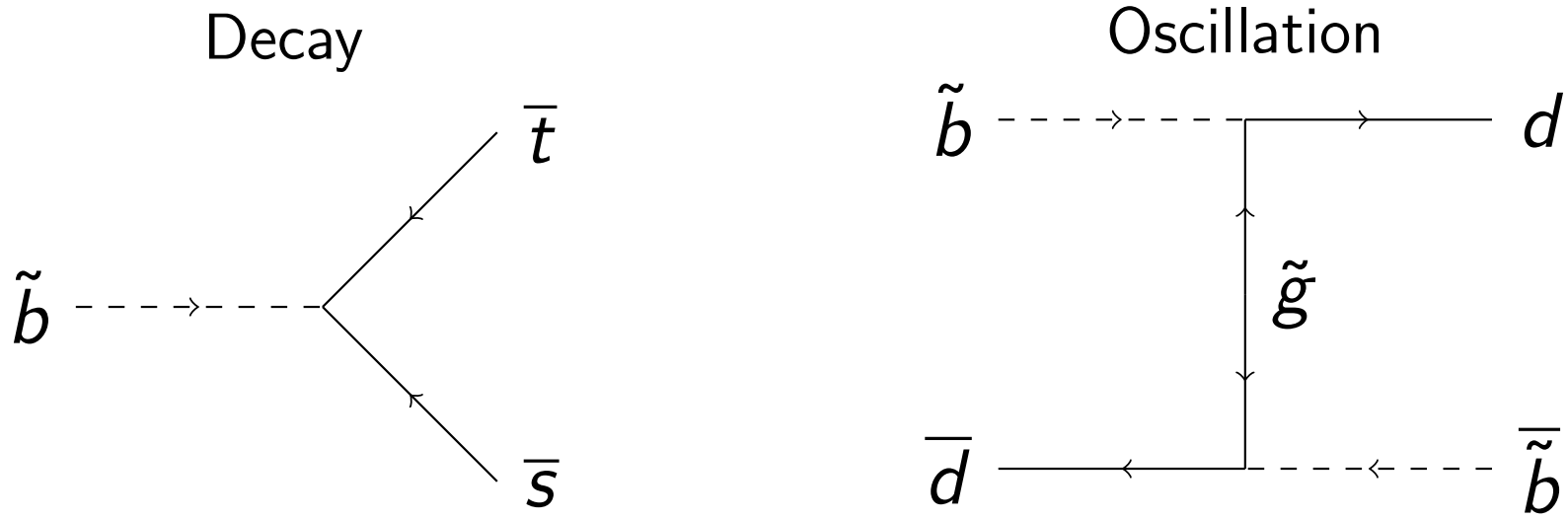
Several possibilities

- Production just as in R-parity conserving MSSM
  - RPV couplings too small for single production of sparticles
- Decay chain to LSP, then LSP decays via possibly off-shell squarks
- LSP decay depends strongly on which particle it is

Pick an LSP, any LSP

Sbotom LSP & Oscillation

Berger, Csáki, Grossman, Heidenreich forthcoming



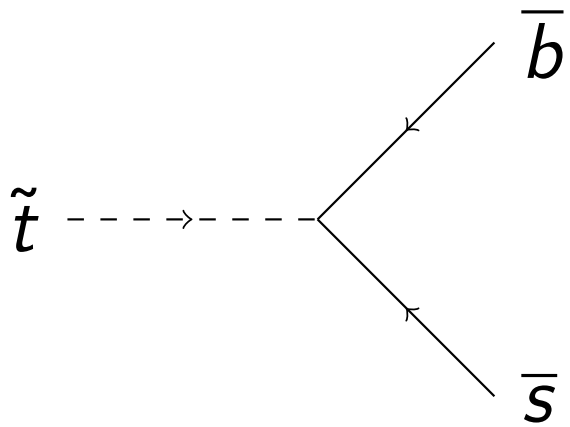
- Colored LSPs live long enough to hadronize
- Can get mesino oscillation $\rightarrow$ Same-sign dilepton

$$t_{\text{osc}} \sim \tau_{\tilde{b}} \sim 10 - 100\ \mu\text{m}$$

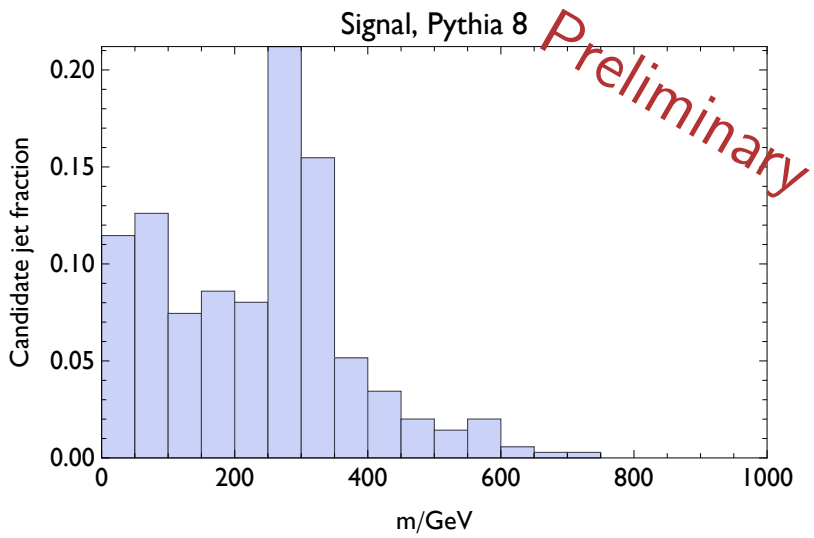
Stop LSP & Jet Resonances

Berger, Csáki, Grossman, Lee, Roy forthcoming

Decay



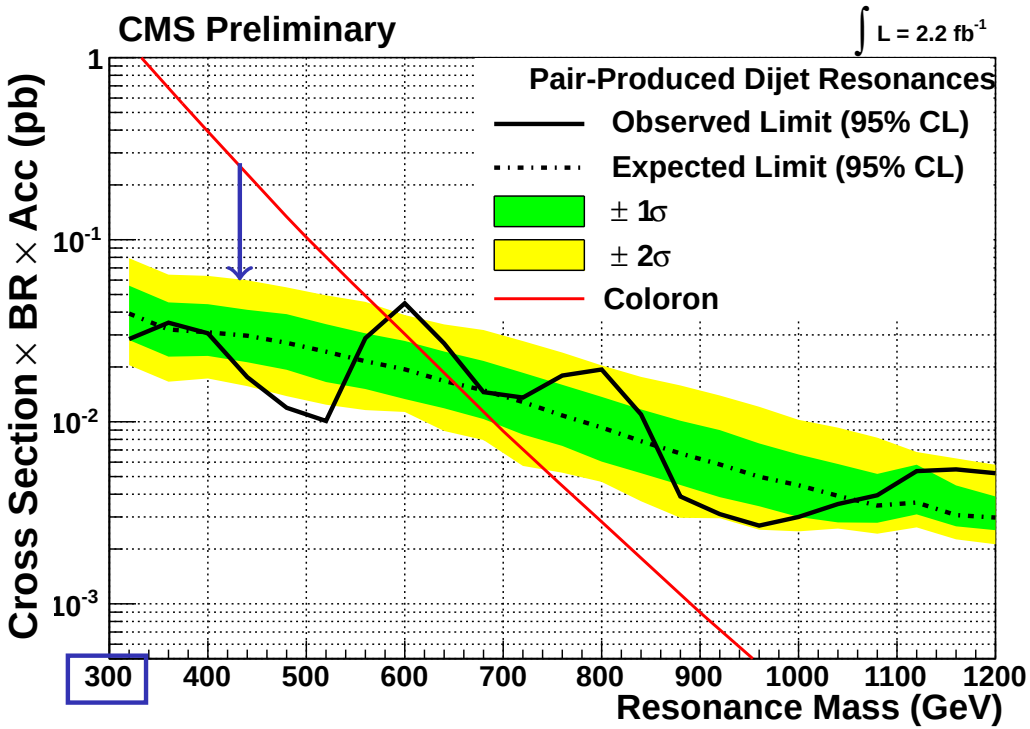
Stop Jet Mass



- Pair of dijet resonances + b tags
- May need more to beat down backgrounds
  - Jet substructure
  - Production via $\tilde{g} \to t\tilde{t}$

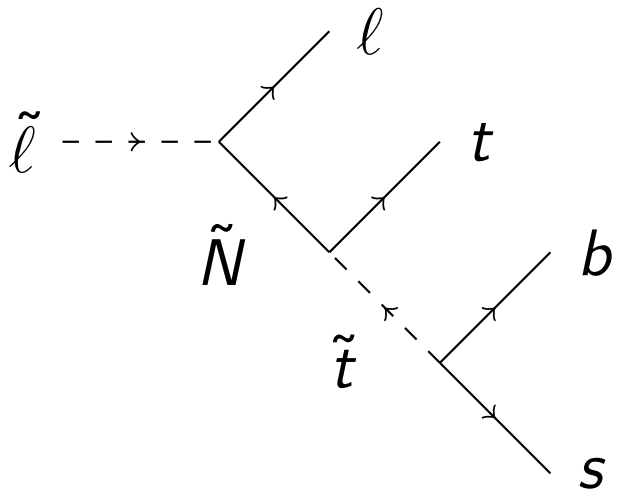
A CMS Search

PAS EXO-11-016



- Bounds are limited... so far!

Common Features



- All RPV decays proceed through squarks
- Many hard b jets and leptons
- Little or no missing energy
- Possible displaced vertices (particularly for $\tilde{\tau}$ LSP)

Conclusions

- MFV SUSY gives consistent and appealing framework for building natural SUSY models
- Bounds from low and high energy are mild (for now)
- Challenging signals may require new analysis techniques