FLAVOR SIGNATURES IN SUPERSYMMETRY

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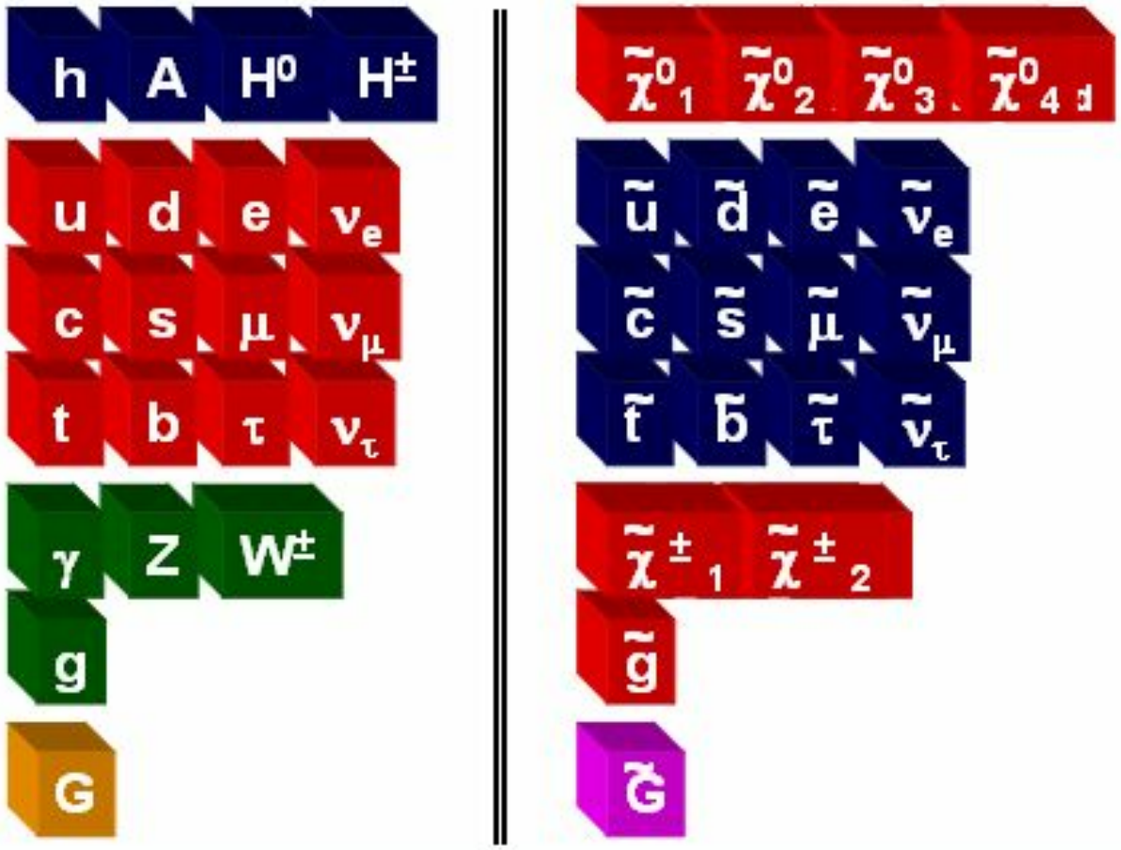
SNOWMASS ENERGY FRONTIER WORKSHOP

SUPERSYMMETRY IS GREAT!

- Elegant extension of spacetime symmetries
- Grand unification works better than SM
- Well motivated *R*-parity automatically gives dark matter candidate
- Solves hierarchy problem?

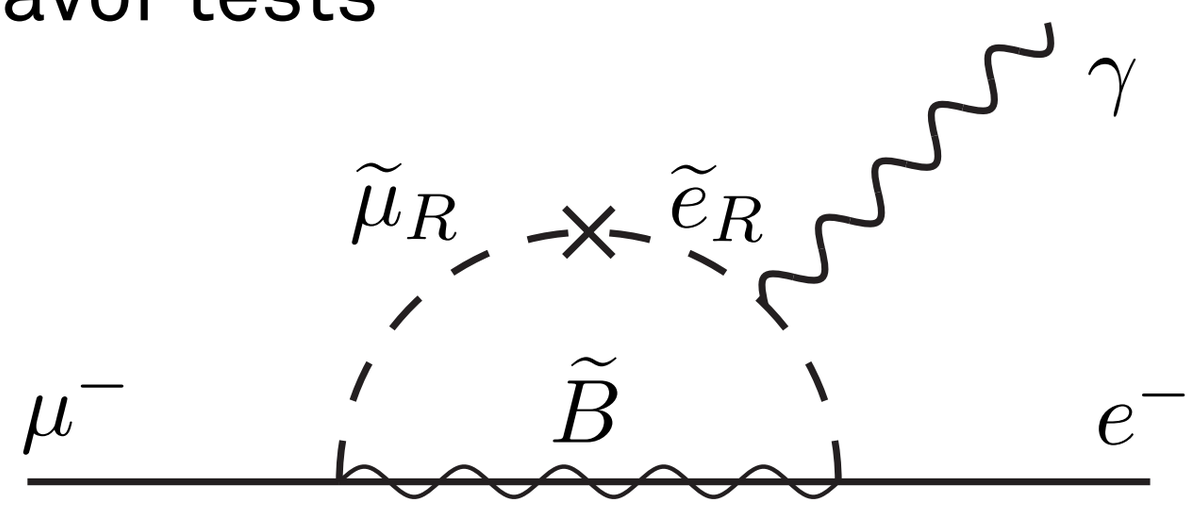


SUSY FLAVOR PROBLEM

SUSY must be broken, many new flavor violating parameters

$$\begin{pmatrix} \tilde{q}_1 & \tilde{q}_2 & \tilde{q}_3 \end{pmatrix}^\dagger \times \begin{pmatrix} \# & \# & \# \\ \# & \# & \# \\ \# & \# & \# \end{pmatrix} \times \begin{pmatrix} \tilde{q}_1 \\ \tilde{q}_2 \\ \tilde{q}_3 \end{pmatrix}$$

Generic TeV scale values of mass matrix are badly ruled out by low energy flavor tests



MFV SUSY

Soft SUSY parameters fixed up to flavor universal dimensionful coefficients

Chivukula and Georgi, 1987. Hall and Randall, 1990. Ciuchini et. al. 1998. Buras et. al. 2001. D'Ambrosio et. al. 2002. Cirigliano et. al. 2005.

$$m^2_{\rm soft}\tilde{u}_i^\dagger\left(\mathbb{1}+Y_u^\dagger Y_u+\ldots\right)_{ij}\tilde{u}_j$$

$$A_{\rm soft}(Y_u+\ldots)_{ij}\tilde{q}_i\tilde{u}_j h_u$$

Flavor universality up to corrections that are largest for 3rd generation

Flavor bounds are easily satisfied

FLAVORFUL SUSY

Soft SUSY parameters parametrically the same size as Yukawa's, matrices not aligned

Nomura, Papucci, DS, 2007. Nomura, DS 2008.

$$\mathbf{a}_{ij} \sim A_{\rm soft}\, Y_{ij} \qquad\qquad \mathbf{a} \not\propto Y$$

Low energy constraints can still be easily satisfied, phenomenology often quite be different

Other frameworks with similar philosophy:

Feng, Lester, Nir, Shadmi, 2007. Kribs, Poppitz, and Weiner, 2007.

EXPERIMENTAL SIGNATURES

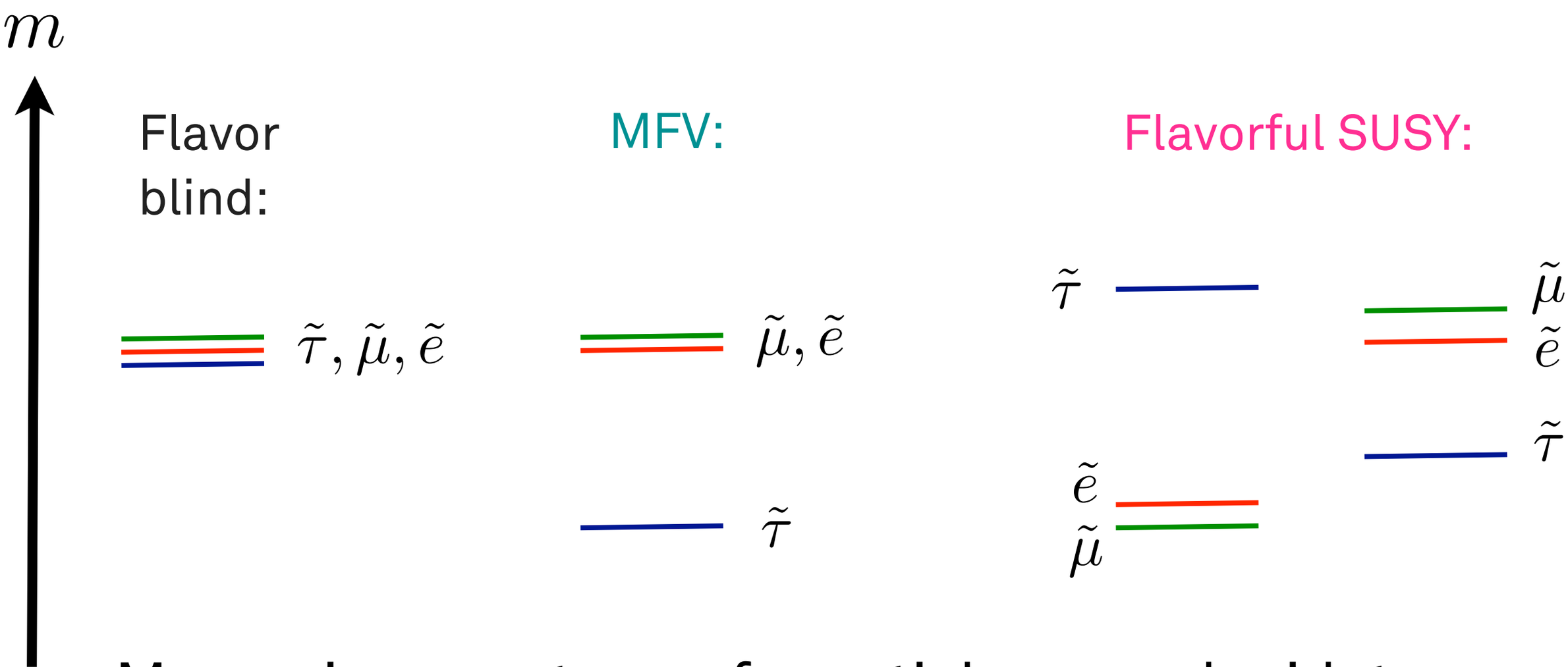
I will discuss some possible experimental signatures of non-trivial flavor structure

The parameter space of (flavor violating) MSSM is vast, even when taking into account low energy constraints

No way to give complete discussion in 20 minutes. I'll give interesting examples that can be easily generalized

MODIFY SPECTRA

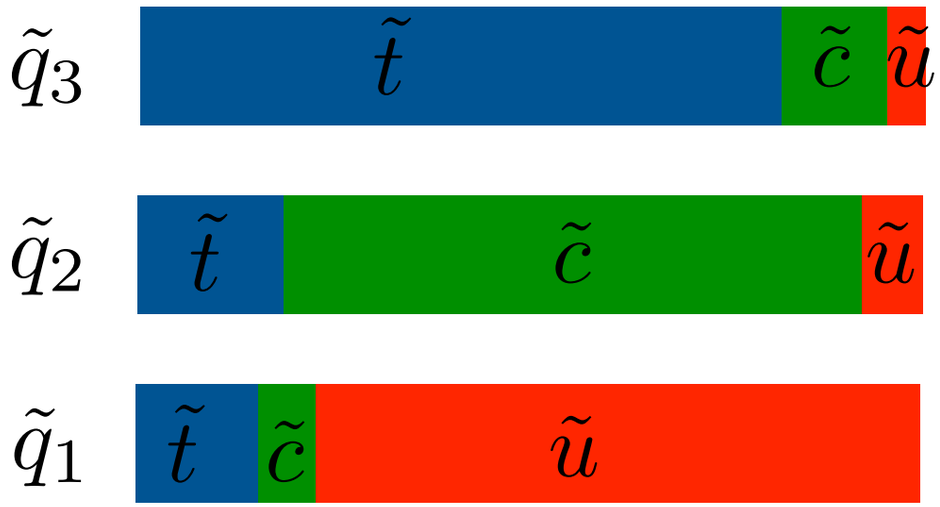
Take sleptons as example:



Measuring spectrum of sparticles can elucidate flavor structure of SUSY breaking

FLAVOR VIOLATING DECAY

Mass basis is not flavor basis



Example: Rare decay of stop like resonance.

Discovery:

$\tilde{t} \to t\chi^0$

Precision study:

$\tilde{t} \to c\chi^0$

More opportunities if “stop” nearly degenerate with top

Hiller, Nir, 2008.

SLEPTON DECAYS

If gravitino is LSP, and slepton NLSP, all SUSY production (squark, gluino) cascade down to sleptons.

Easier to flavor tag than with squarks:

$$\tilde{\ell}_i \to \ell_j \tilde{G}$$

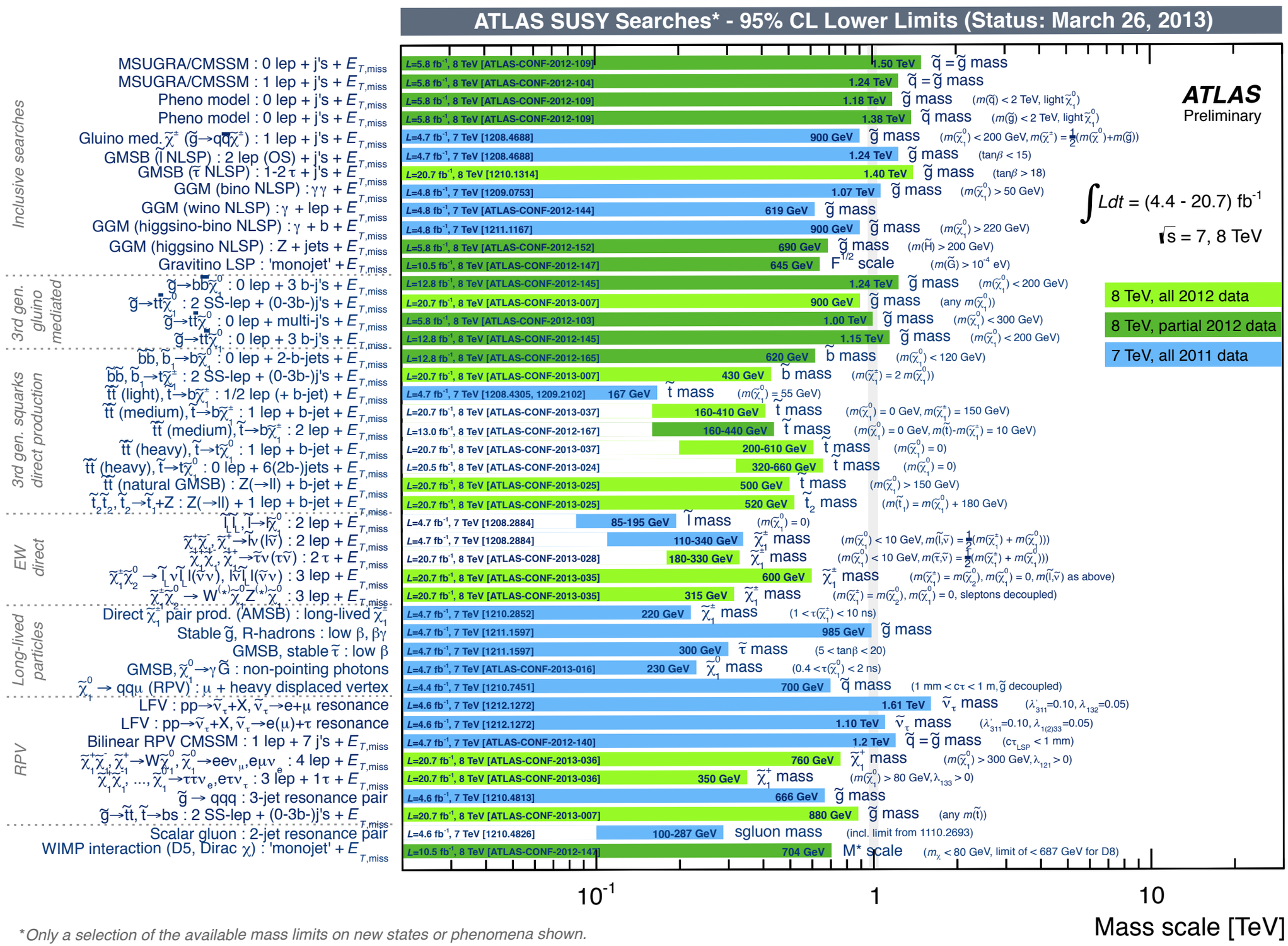
3 body slepton decays give more flavor handles

Feng, Galon, Sanford, Shadmi, Yu, 2009

$$\tilde{\ell}_i \to \tilde{\ell}_j \ell_k \ell_n$$

Even more opportunities if NLSP slepton is relatively long lived

NO SPARTICLES (YET?)



HEAVIER SCALARS

Flavor bounds get weaker with heavier scalars, for example:

$$\mathrm{Im}(\delta^d_{12})_{LR} \lesssim 10^{-4} \left(\frac{m_{\tilde{q}}}{500\,\mathrm{GeV}}\right)$$

$$|(\delta^e_{12})_{LL}| \lesssim 10^{-4} \left(\frac{m_{\tilde{\ell}}}{200\,\mathrm{GeV}}\right)$$

Nomura, Papucci, DS, 2007

Allowed rates for flavor violating processes scale quadratically with scalar mass:

$m_{\tilde{t}}$	$\tilde{t} \to c\chi^0$
500 GeV	O(1%)
2 TeV	O(10%)
5 TeV	O(1)

MINI-SPLIT SUSY

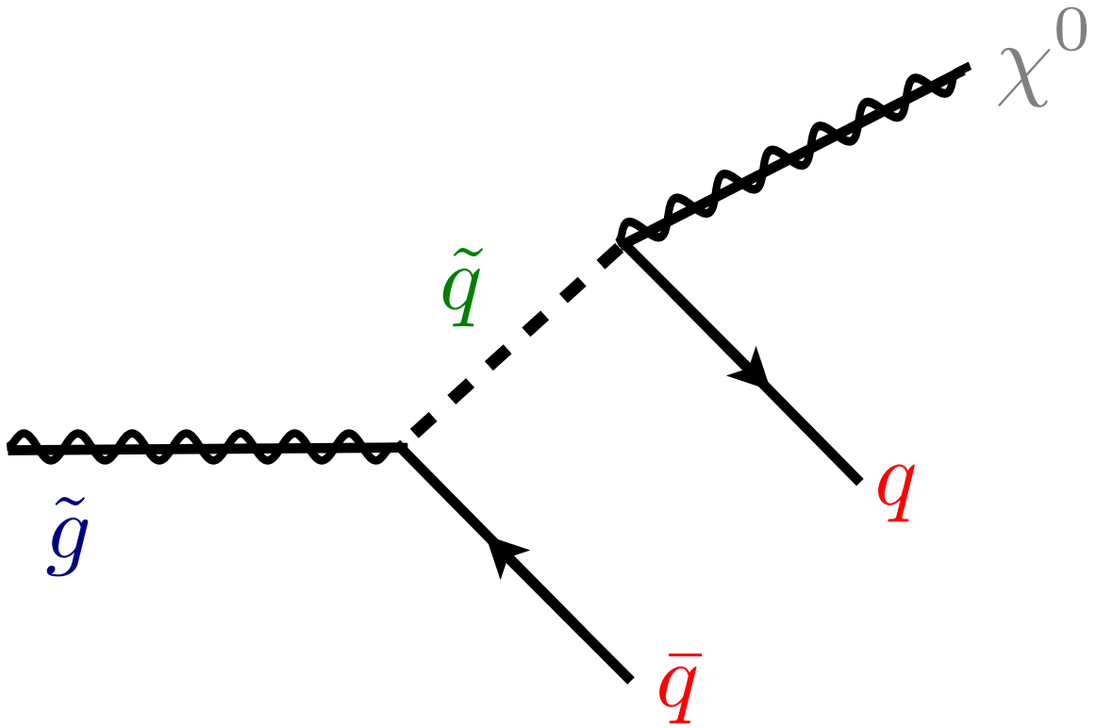
Scalars are very heavy, O(1000 TeV), gauginos can be O(1 TeV)

Arkani-Hamed, Gupta, Kaplan, Weiner, Zorawski, 2012. Arvanitaki, Craig, Dimopolous, Villadoro, 2012. Bhattacherjee, Feldstein, Ibe, Matsumoto, Yanagida, 2012

Gluino decays encode flavor information of (heavy) squarks

Two neutralino and one chargino accessible

Many flavor observables if you can flavor tag quarks



R-PARITY VIOLATION

Additional allowed operators usually forbidden by *R*-parity

$$W_{\mathrm{RPV}} = \frac{1}{2}\lambda^{ijk} L_i L_j e_k + \lambda'^{ijk} L_i Q_j d_k + \mu'^i L_i H_u \Big\} \Delta L = 1$$
$$+ \frac{1}{2}\lambda''^{ijk} u_i d_j d_k \Big\} \Delta B = 1$$

Rich flavor structure

Only some operators can be turned on to not decay the proton

Lose usual (WIMP) dark matter candidate

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<u>BIG RPV</u>

Third generation couplings will dominate

<u>SMALL RPV</u>

Operators can point in arbitrary direction in flavor space

See talks by Evans, Katz, and Kaadze tomorrow.

CONCLUSIONS

- Supersymmetry models with non-trivial flavor structure can satisfy all low energy constraints
- These models have very rich phenomenology
- If there are superpartners accessible at a collider, there will be many possible flavor measurements to be made
- These measurements could reveal explanations to both the SUSY flavor problem and the SM flavor puzzle

THANK YOU