Vectorlike quarks in gauge-mediated SUSY breaking

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Based on 1205.nnnn with James Wells, and 0910.2732.

Gauge-mediated SUSY breaking is in tension with $M_h \sim$ 125 GeV.

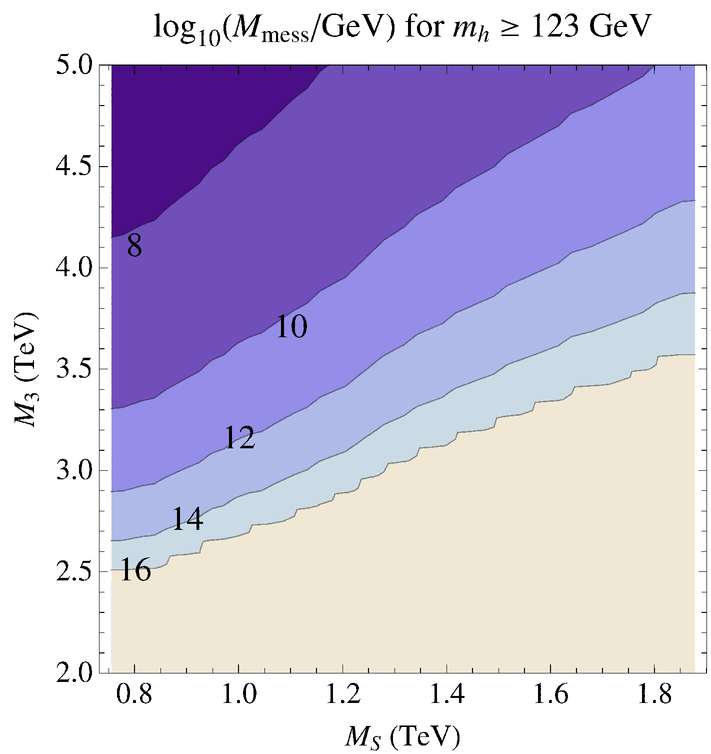
Need <u>very</u> heavy stops, or large stop mixing from $H_u \tilde{t}_L \tilde{t}_R$ coupling.

$$M^2_{\rm stops} \approx \begin{pmatrix} m^2_{\tilde{t}_L} & A_t m_t \\ A_t m_t & m^2_{\tilde{t}_R} \end{pmatrix}$$

But, in GMSB, $A_t = 0$ at the messenger scale, and renormalization effects are limited.

Draper, Meade, Reece, Shih

1112.3068 $\longrightarrow$



New vector-like quarks can raise the Higgs mass

Moroi, Okada 1992; Babu, Gogoladze, Kolda hep-ph/0418085; Babu, Gogoladze, Rehman, Shafi 0807.3055; SPM 0910.2732

New superfields: $Q, \overline{Q},\ U, \overline{U},\ E, \overline{E}\ = \mathbf{10} + \overline{\mathbf{10}}$ of $SU(5)$.

Exotic new quarks t_1', t_2', b', τ' and scalar partners.

$$t_1', t_2' \text{ mass matrix} = \begin{pmatrix} M_Q & k v_u \\ 0 & M_U \end{pmatrix}$$

$$\Delta M_h^2 \approx \frac{3}{4\pi^2} k^4 v^2 \left[\ln(x) - \frac{1}{6}\left(5 - \frac{1}{x}\right)\left(1 - \frac{1}{x}\right)\right], \qquad x = M_S^2/M_F^2$$

There is an IR fixed point at $k = 1.0$ to 1.05. Large positive ΔM_h^2.

Apply this idea to GMSB

See also: Endo, Hamaguchi, Iwamoto, Yokozaki 1108.3071, 1112.5653; Evans, Ibe, Yanagida 1108.3437

- $M_h = 125$ GeV is easy. (For constraint, we use $122 < M_h < 128$ to account for uncertainties.)
- Don't need large stop mixing
- Precision electroweak constraints are easily satisfied.
- Unlike chiral (sequential) quarks, no significant effect on h production, decay from vector-like quarks.
- t' discovery may precede SUSY at LHC

Unification assumptions for masses, mixings

Applied sometimes, but not always, in the following.

Take $M_Q = M_U = M_E$ at GUT scale. [$SU(5)$ or $SO(10)$ motivated]
Then, at the TeV scale,

$$M_Q : M_U : M_E \; = \; 1.8 : 1 : 0.45$$

Decays to Standard Model quarks occur through mixing couplings:

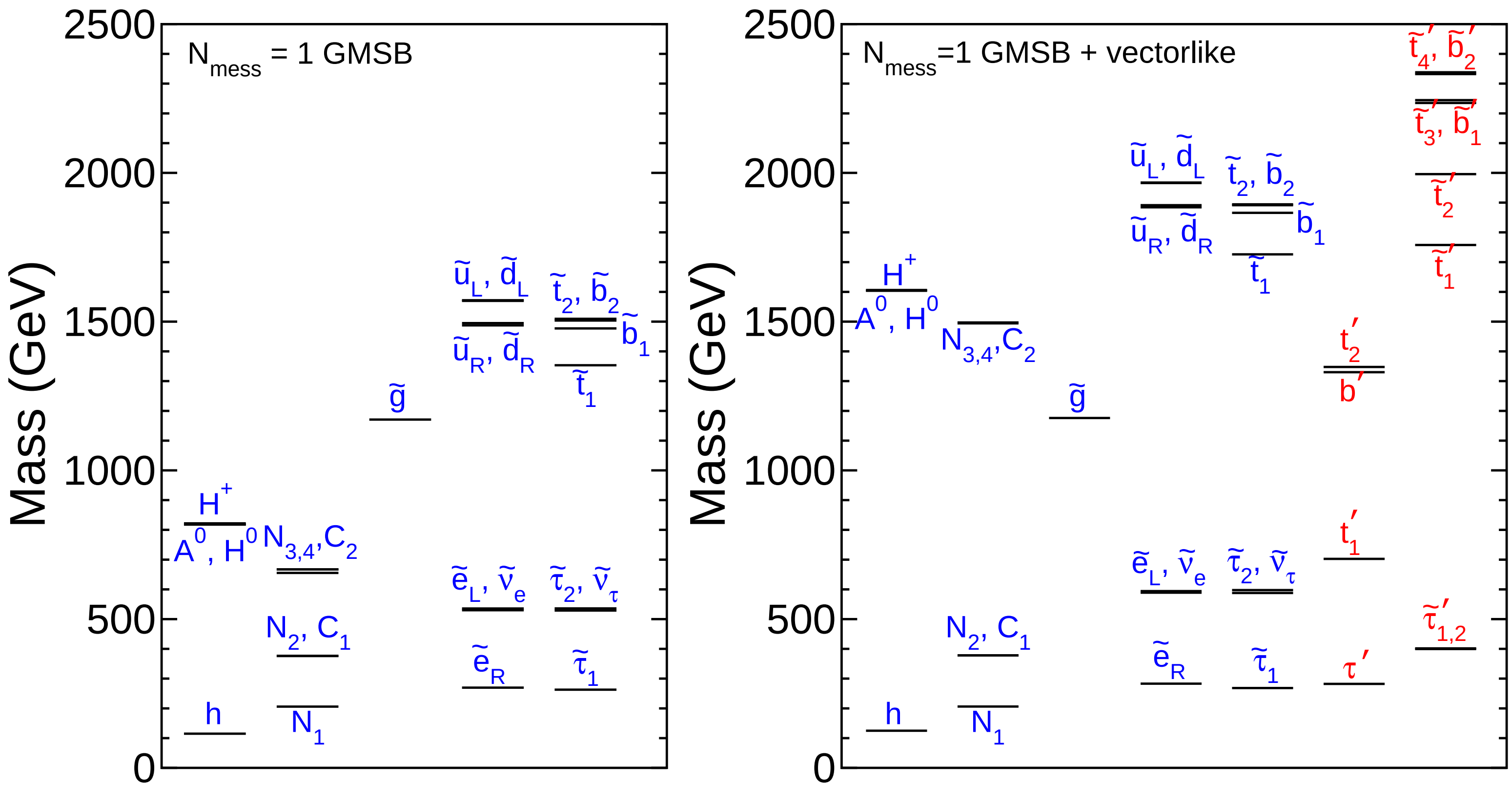
$$W = \epsilon_U H_u q_3 \overline{U} + \epsilon'_U H_u Q \overline{u}_3 - \epsilon_D H_d Q \overline{d}_3$$

Take $\epsilon_U = \epsilon'_U = \epsilon_D$ at GUT scale, then

$$\epsilon_U : \epsilon'_U : \epsilon_D \; = \; 1 : 1.1 : 3.5$$

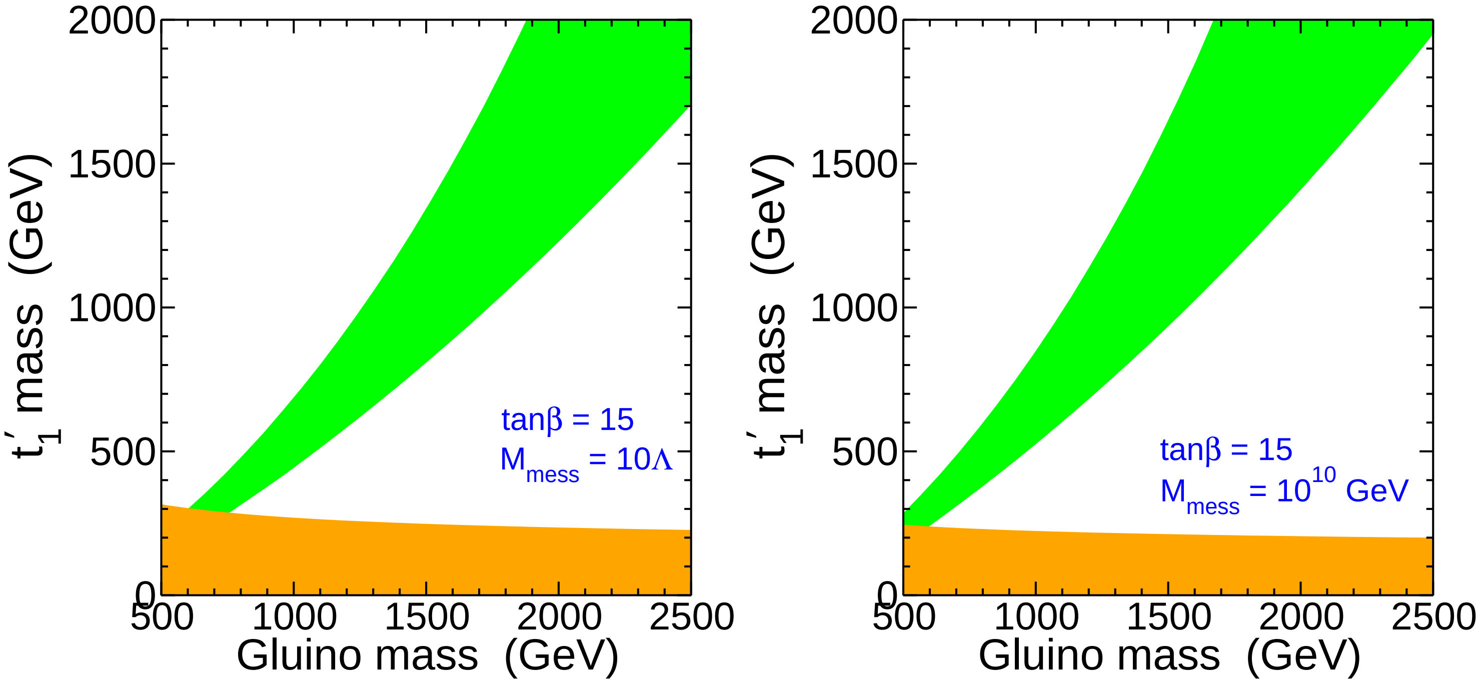
at the TeV scale.

Comparison of minimal GMSB, extra $\mathbf{10} + \overline{\mathbf{10}}$ model:



Note: squark masses, $|\mu|$ become larger. “Bad” for fine-tuning, but allows $M_h = 125$ GeV.

Allowed regions with 122 GeV $< M_h <$ 128 GeV:

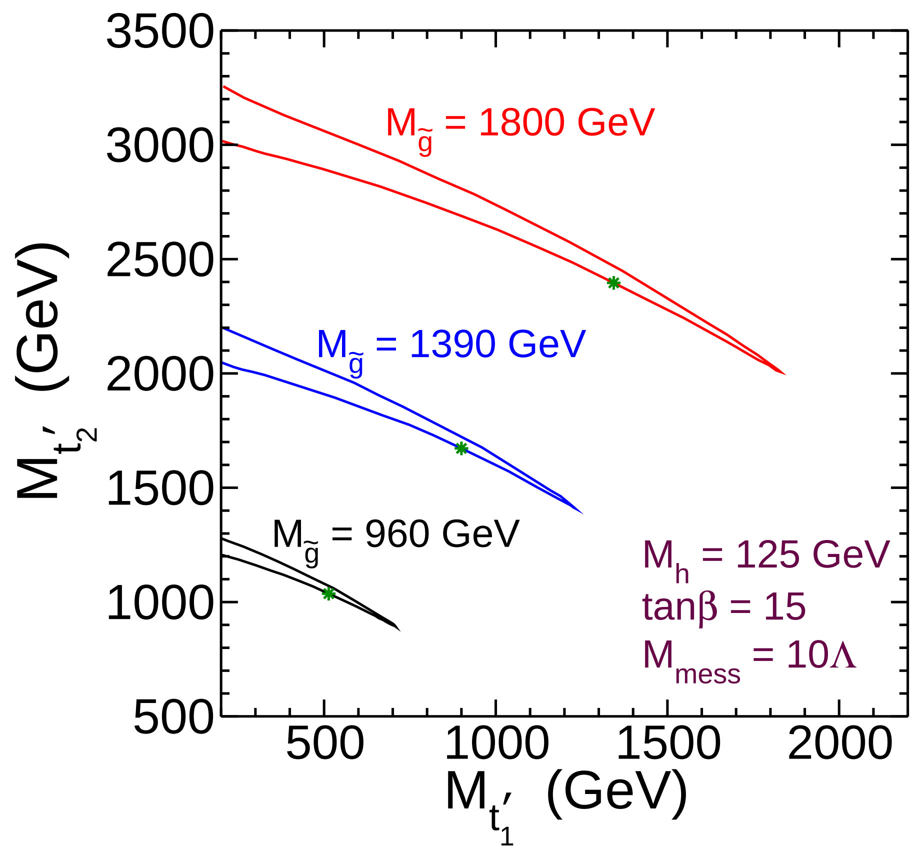


Orange: $M_{\tau'} < 100$ GeV

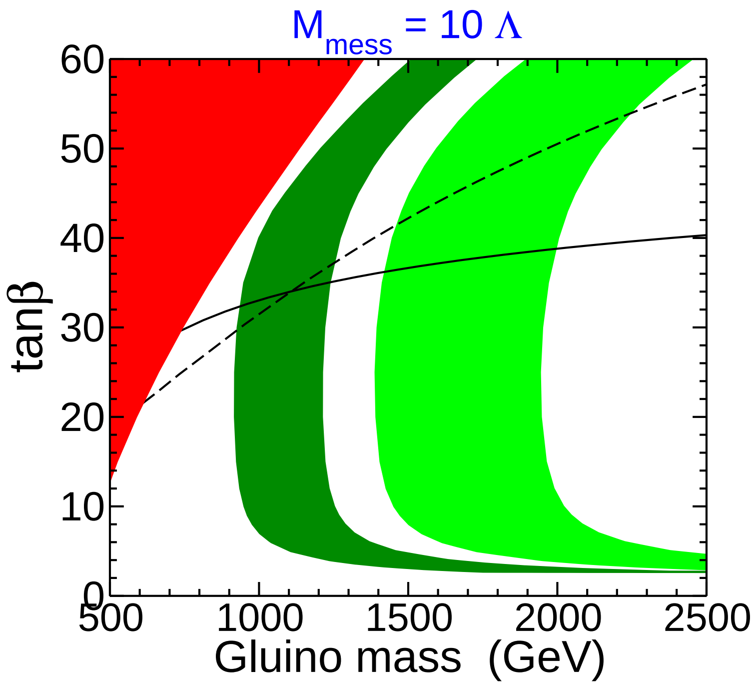
$M_h = 125$ GeV is perfectly happy with superpartners as light as you can make them, stops nearly unmixed.

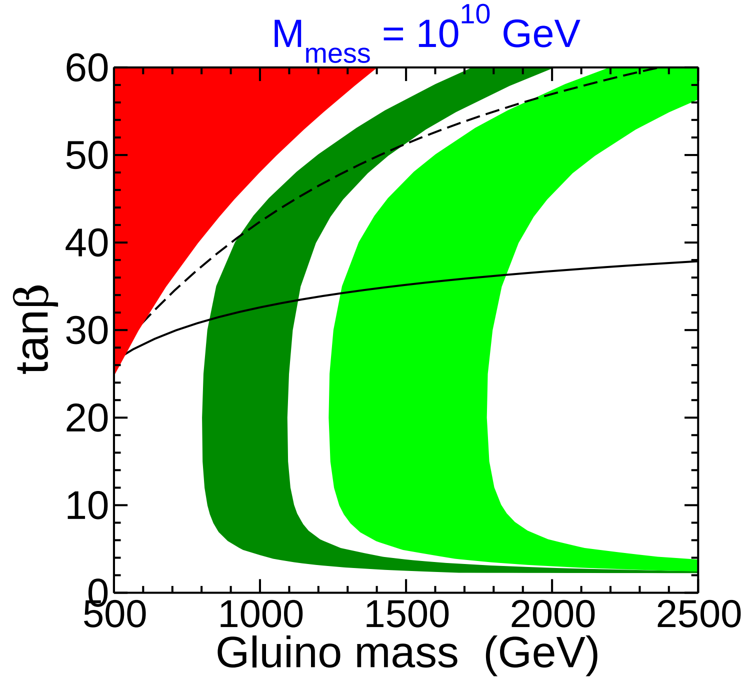
Allowed regions in the t'_1 vs. t'_2 mass plane, for various gluino masses.

(No unification assumption here; green dot = unified models.)



Allowed regions in $\tan\beta$ vs. $M_{\rm gluino}$ plane.





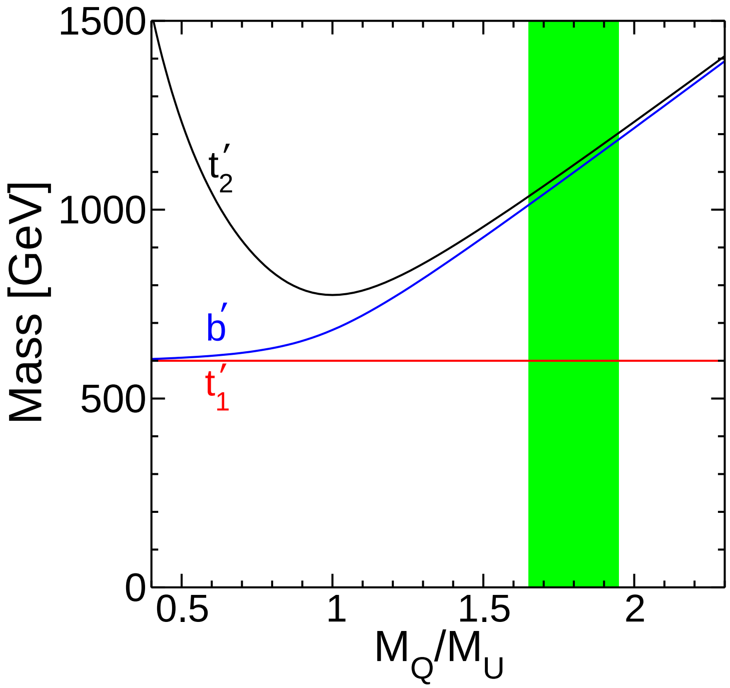
Darker region: $M_{t'_1} = 600$ GeV.   Lighter region: $M_{t'_1} = 1200$ GeV.

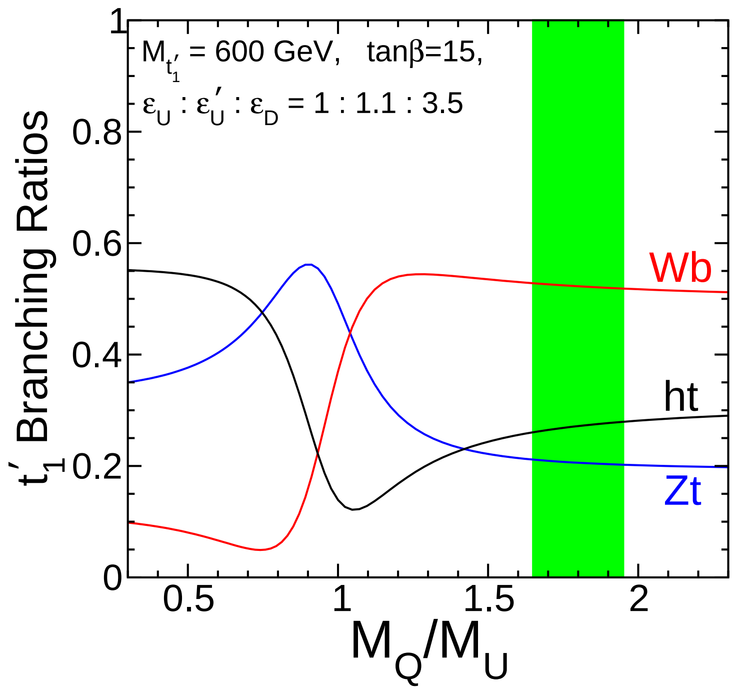
Above dashed line: stau is NLSP.   Below dashed line, neutralino is NLSP.

Above solid line: ruled out by vacuum stability (stau VEVs).

Endo, Hamaguchi, Iwamoto and Yokozaki 1202.2751;   Hisano, Sugiyama 1011.0260

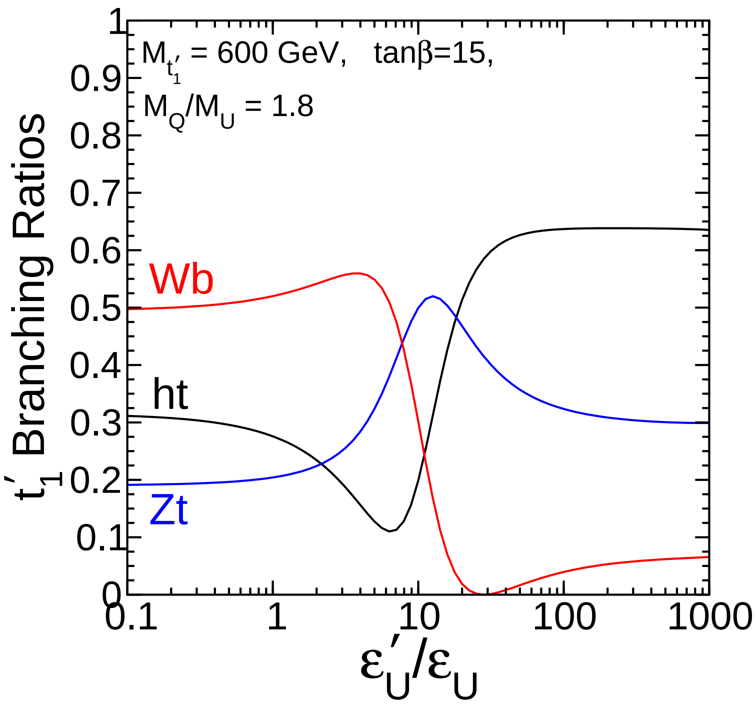
Plot t_2' and b' masses, and t_1' branching ratios, for various M_Q/M_U, with fixed $M_{t_1'} = 600$ GeV.

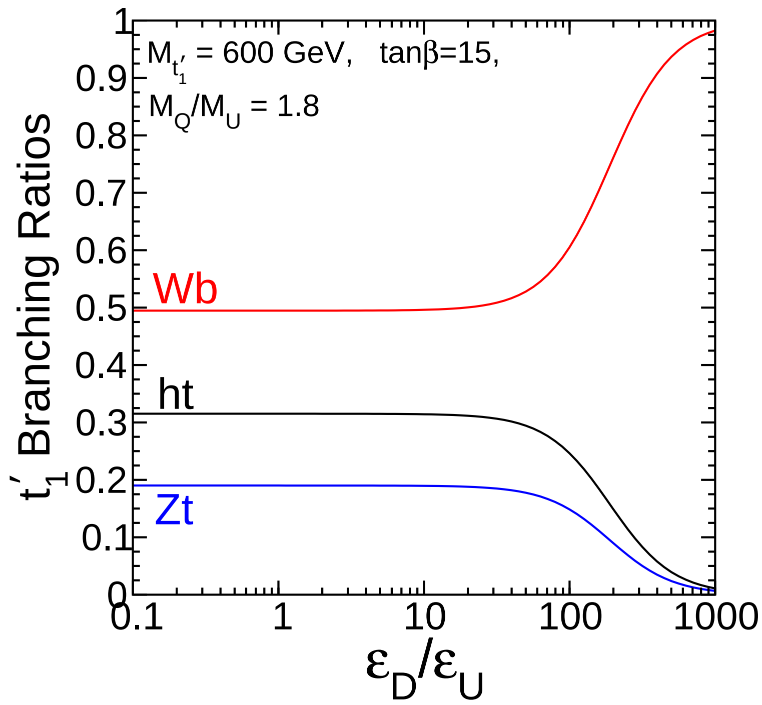




Green band = GUT unification assumption $\longrightarrow$ t_1' is mostly isosinglet.

Other possibilities for t_1' Branching Ratios:



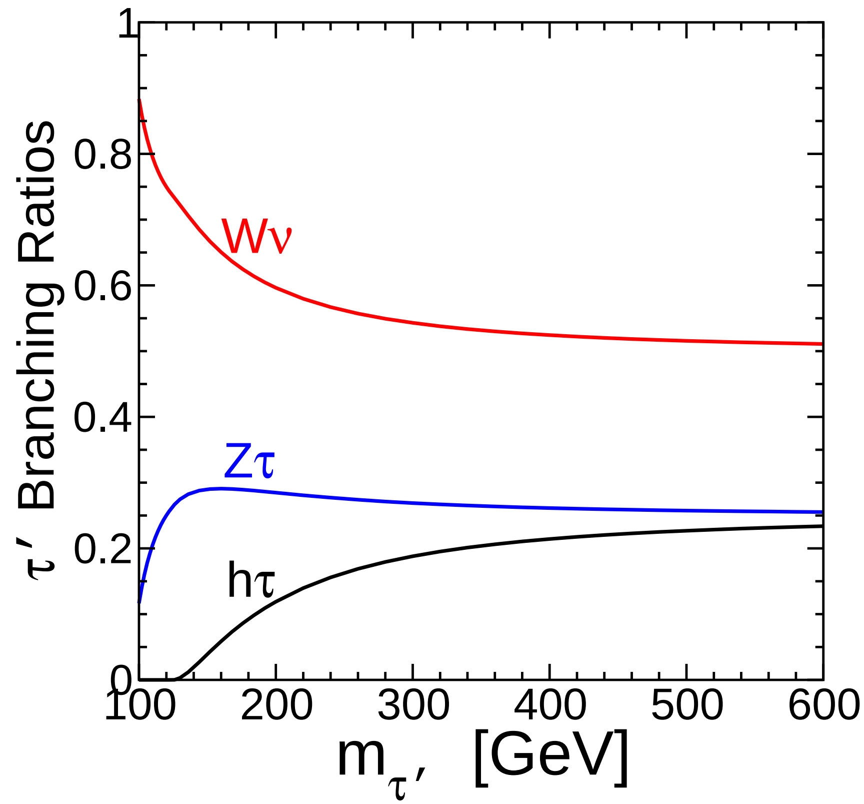


LHC searches should exploit all Wb, Zt, ht branching ratio combinations without prejudice!

Present LHC bounds:

- $M_{t'_1} > 557$ GeV if $BR(Wb) = 1.$ (CMS 4.7 fb^{-1})
- $M_{t'_1} > 475$ GeV if $BR(Zt) = 1.$ (CMS 1.14 fb^{-1})
- $M_{b'} > 480$ GeV if $BR(Wt) = 1.$ (ATLAS 1.04 fb^{-1})
- $M_{b'} > 611$ GeV if $BR(Wt) = 1.$ (CMS 4.9 fb^{-1})
- $M_{b'} > 400$ GeV if $BR(Zb) = 1.$ (ATLAS 2.0 fb^{-1})
- $M_{t'_1} > 415$ GeV for any Wb, Zt, ht. (Rao, Whiteson reinterpretation.)
- $M_{t'_1} \geq 950$ GeV if stable. (Extrapolation from CMS-11-022.)

This model also comes with an exotic singlet charge ± 1 lepton, τ':

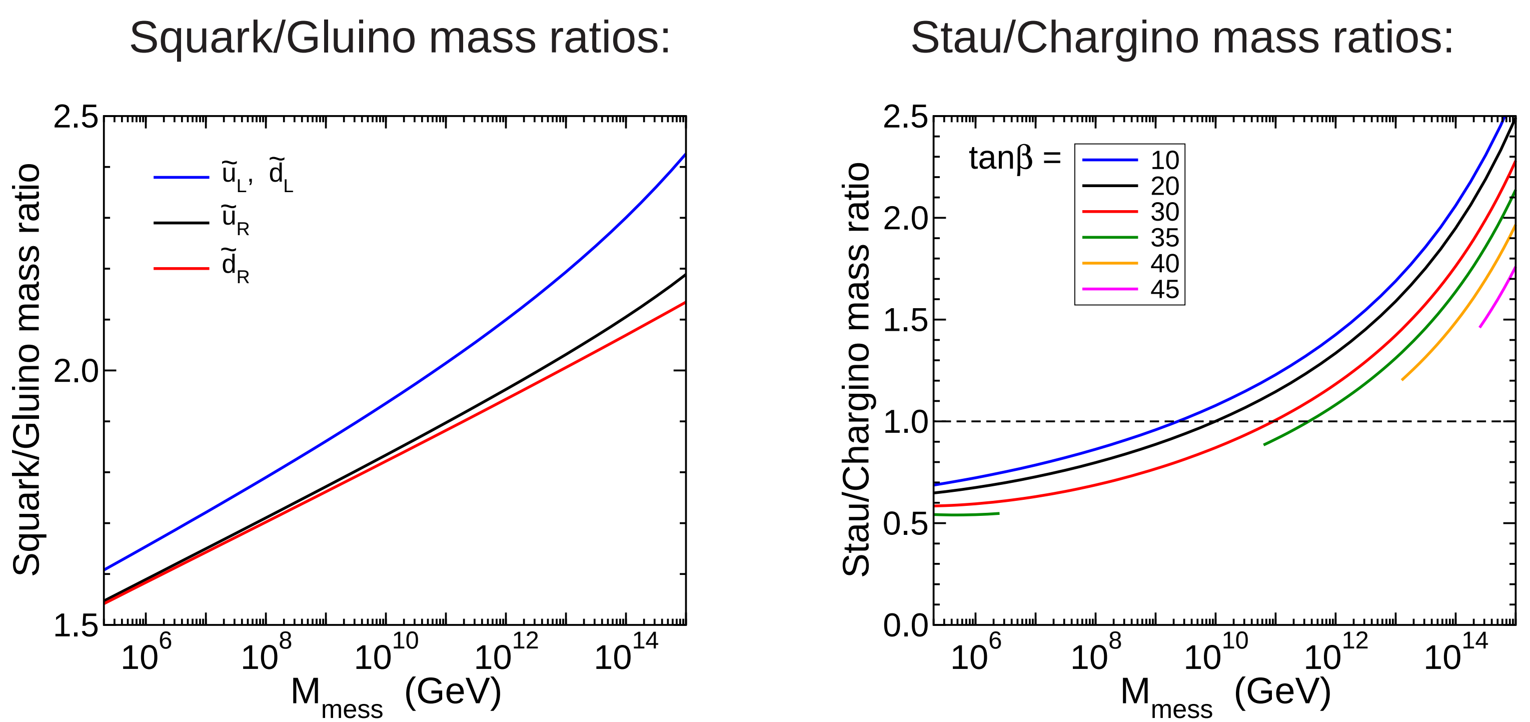


Interesting signals:

$pp \to \tau'^{+}\tau'^{-} \to \ell^{\pm}\tau^{\mp}h + E_T^{\rm miss}$

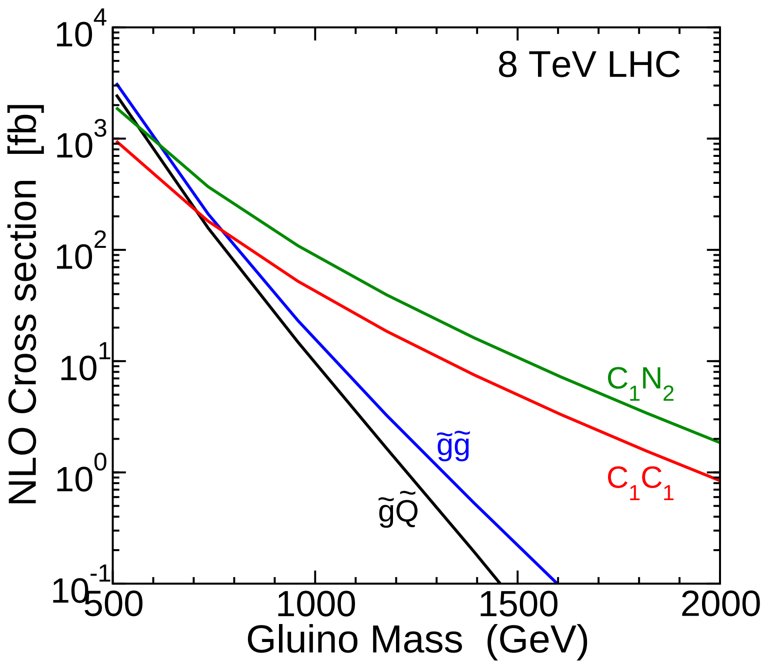
$pp \to \tau'^{+}\tau'^{-} \to \tau Z W + E_T^{\rm miss}$

SUSY signals follow from spectrum features, depend on messenger scale



- Squark always much heavier than gluinos (even more so than Minimal GMSB.)
- Signals divide into two cases, according to whether $M_{\tilde{\tau}_1} < M_{\tilde{C}_1}$.
  Corresponds to low vs. high messenger scale.

NLO production rates:



For low $M_{\rm mess}$:

$$\tilde{C}_1 \to \tilde{\tau}_1 \nu \to \tau + E_T^{\rm miss}$$

$$\tilde{N}_2 \to \tilde{\tau}_1 \tau \to \tau^+ \tau^- + E_T^{\rm miss}$$

For high $M_{\rm mess}$:

$$\tilde{C}_1 \to \tilde{N}_1 W \to W + E_T^{\rm miss}$$

$$\tilde{N}_2 \to \tilde{N}_1 h \to h + E_T^{\rm miss}$$

Gluino has 3-body decays, but with enhanced b multiplicity.

For low $M_{\rm mess}$, may also get $\tilde{N}_1 \to \gamma \tilde{G}$ as usual in GMSB, with easy isolated diphoton signals, possibly photons not pointing back to event vertex.

Conclusion

- Extra vector-like quarks can easily give $M_h \sim 125$ GeV in GMSB.
- $t'_1 \to Wb, Zt, ht$ with negotiable branching ratios.
- SUSY signals similar to Minimal GMSB, but with even heavier scalars.