Stealth SUSY

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Basic Mechanism

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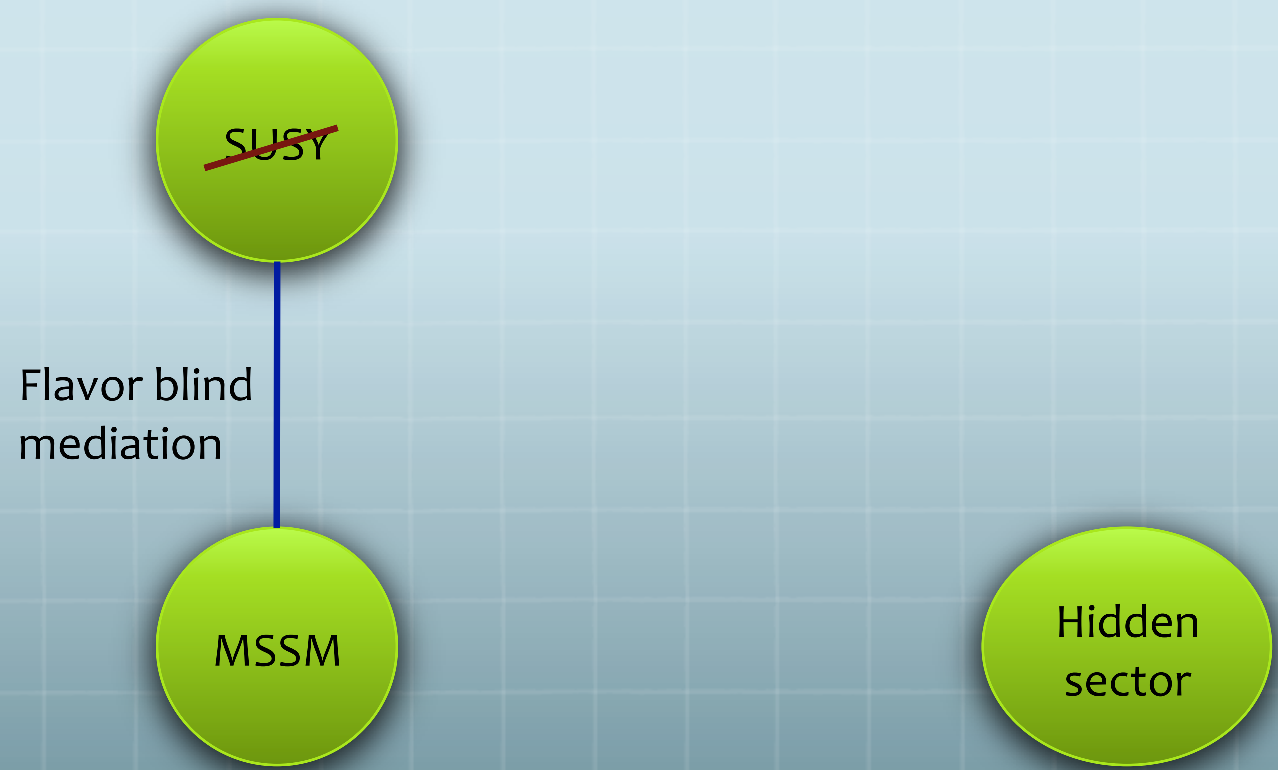
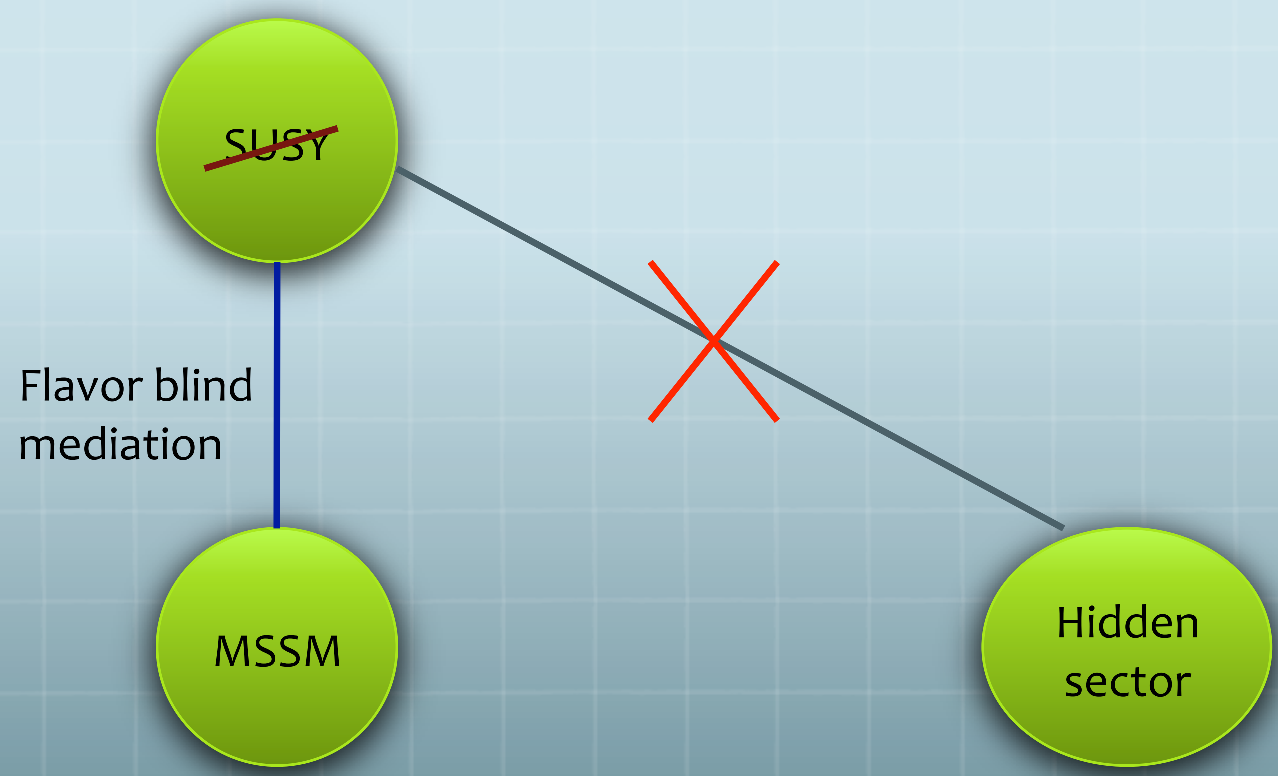
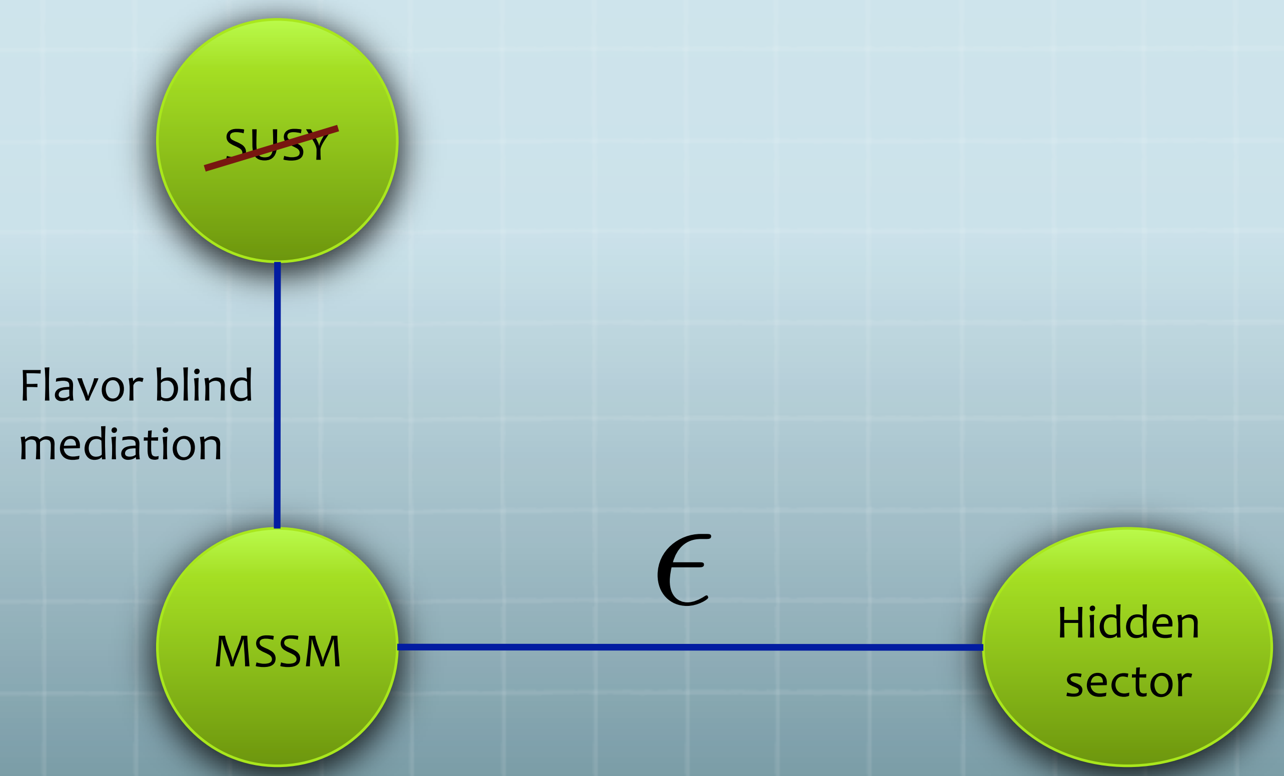


Basic Mechanism



Basic Mechanism



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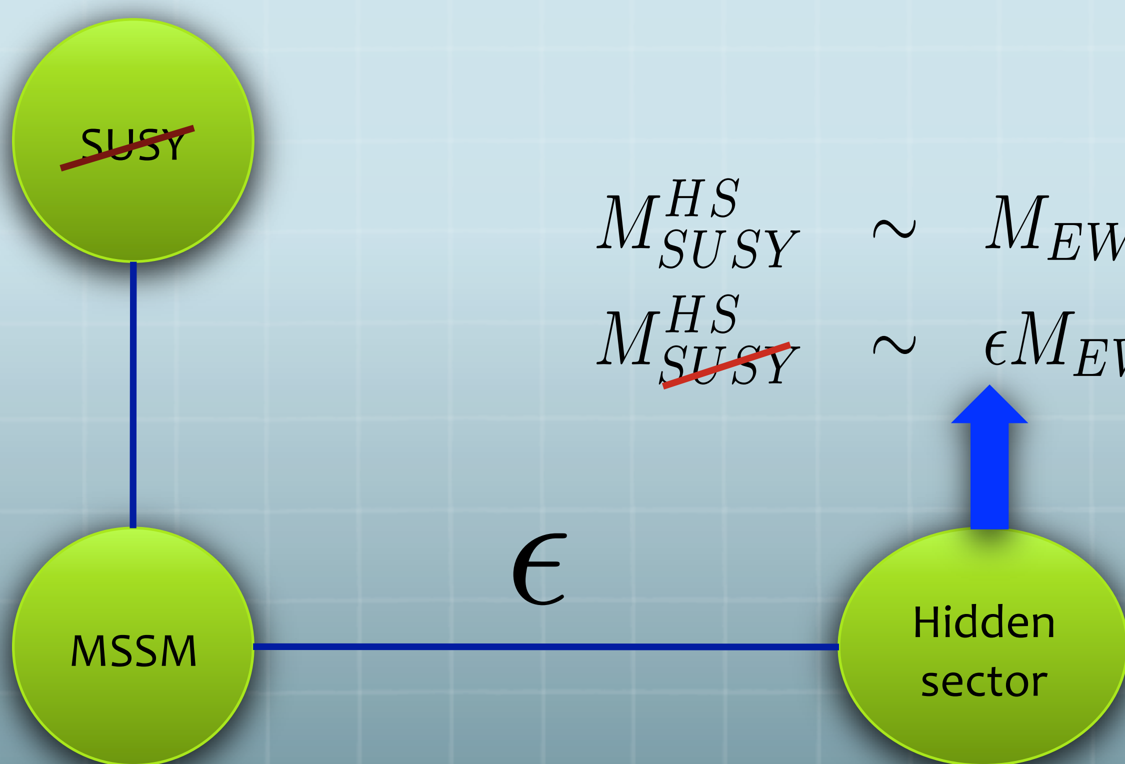
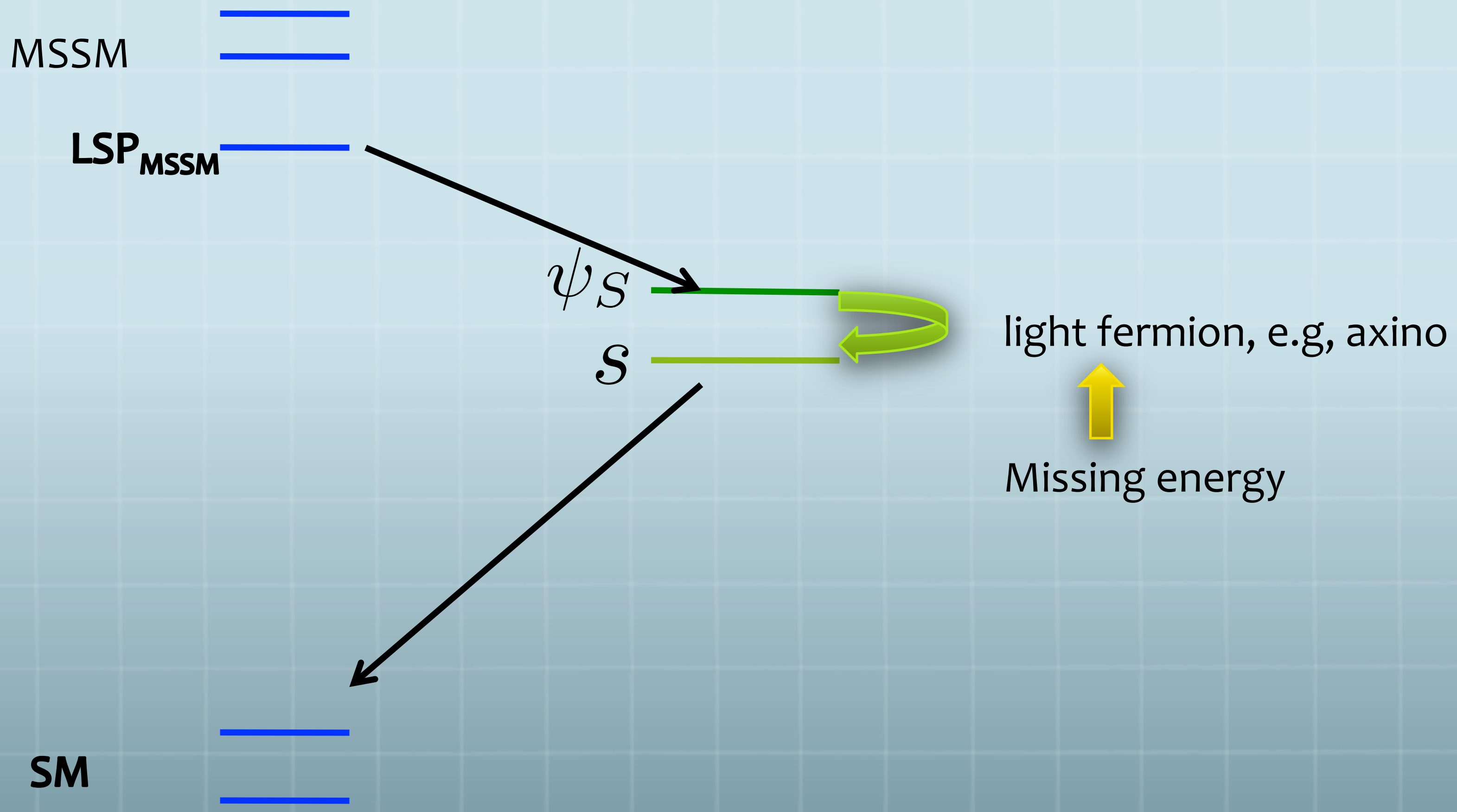
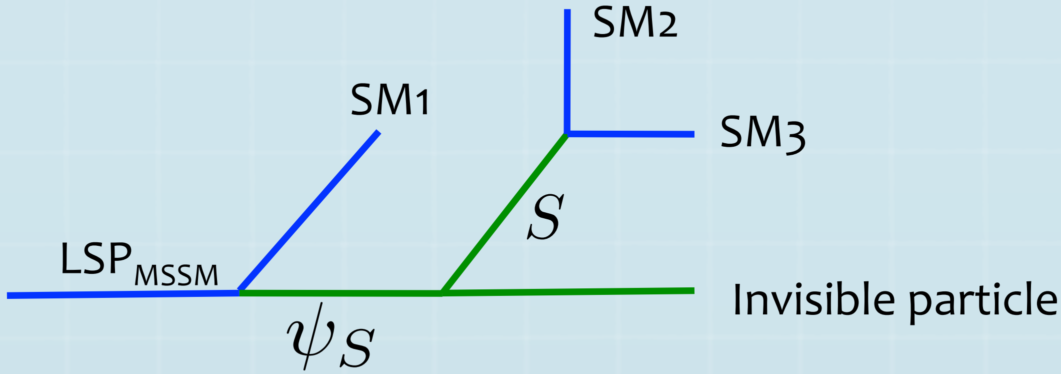


$$M^{HS}_{SUSY} \sim M_{EW}$$
$$M^{HS}_{\cancel{SUSY}} \sim \epsilon M_{EW} \ll M^{HS}_{SUSY}$$

E.g., hidden sector is a SM singlet S





Fermion mass Scalar mass

$$\delta m \equiv m_{\tilde{S}} - m_S$$

In the ψ_S rest frame,

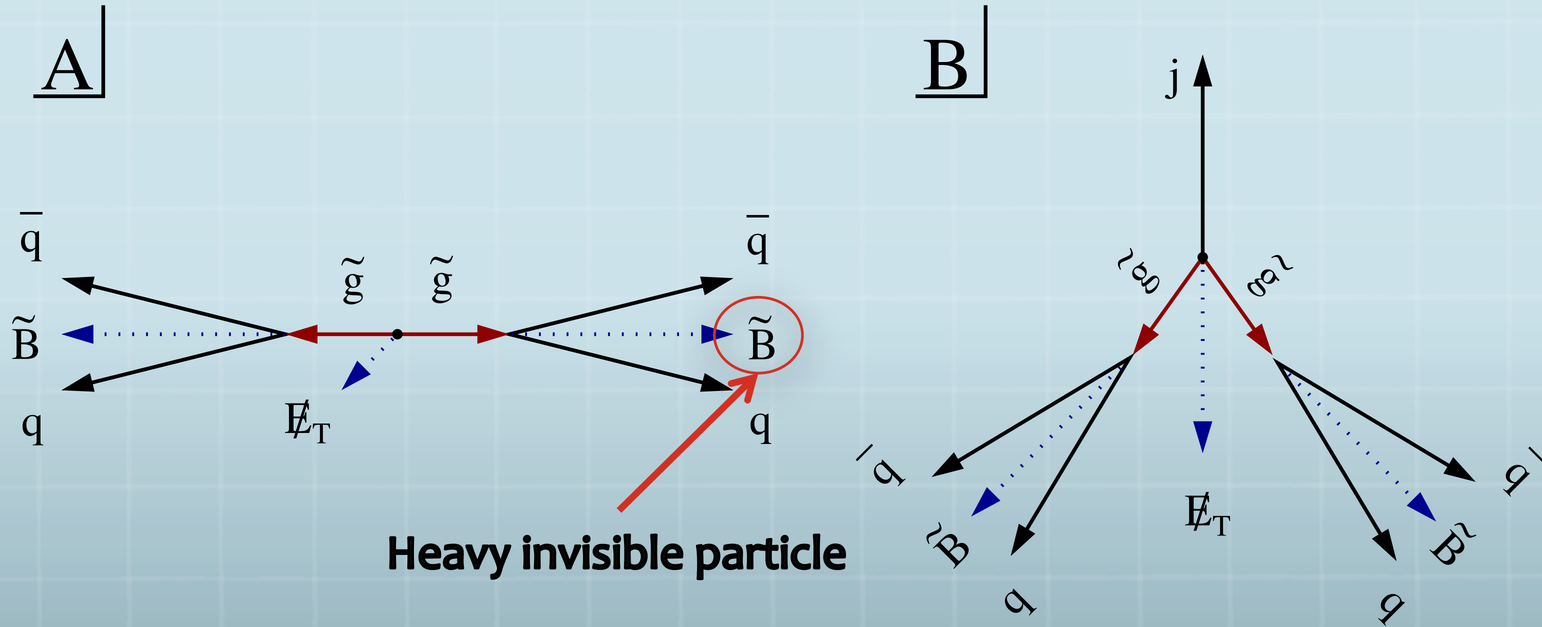
$$E_{missing} = \frac{m_{\tilde{S}}^2 - m_S^2}{2m_{\tilde{S}}} \approx \delta m$$

In the lab frame,

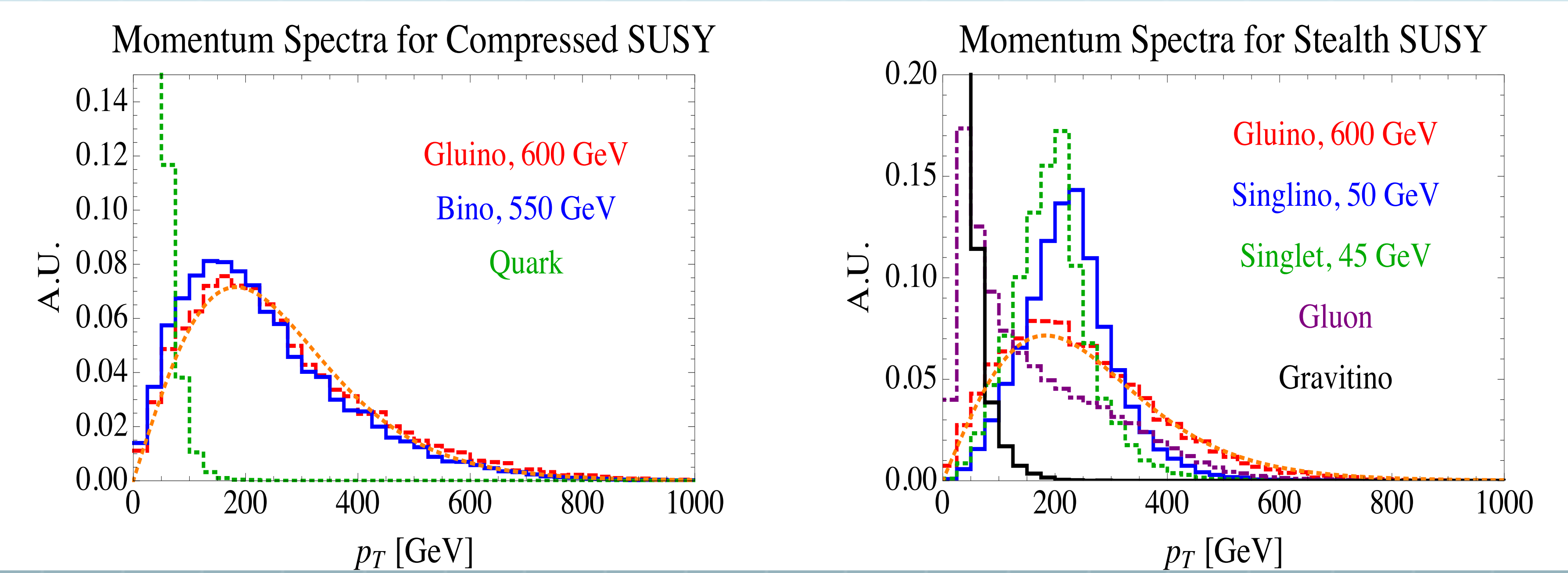
$$E_{missing} = \gamma \delta m \approx \frac{m_{LSP_{SM}}}{m_{\tilde{S}}} \delta m$$

$$\delta m \rightarrow 0, E_{missing} \rightarrow 0$$

Aside: Stealth SUSY is not compressed SUSY



Aside: Stealth SUSY is not compressed SUSY



An example model

- **Portal:** $Y, \bar{Y}$ $\quad 5 + \bar{5}$ **under SM SU(5)**
- **Model:**

$$W = \lambda S Y \bar{Y} + m_S S^2 + m_Y Y \bar{Y}$$

m_S is taken to be 100 GeV

- **Soft mass of S is generated at one-loop (in gauge mediation)**

$$m_s^2 \sim -\frac{|\lambda|^2}{(4\pi)^2} \left(6\tilde{m}_D^2 + 4\tilde{m}_L^2\right) \log \frac{M_{\rm mess}^2}{m_Y^2}$$

$$W = \lambda S Y \bar{Y} + m_S S^2 + m_Y Y \bar{Y}$$

$SY\bar{Y}$	
$m = 100$ GeV	$m_{\tilde{s}} = 100$ GeV
$\lambda = 0.2$	$m_{s,a} = 91$ GeV
$m_Y = 1000$ GeV	$\Gamma_{s,a} = 2 \times 10^{-7}$ GeV
$\tilde{m}_D = 300$ GeV $\quad \tilde{m}_L = 200$ GeV	$\mathrm{Br}_{s,a\to\gamma\gamma} = 4 \times 10^{-3}$
$M_{\mathrm{mess}} = 100$ TeV	

$$\lambda \lesssim 0.1 - 0.2 \quad \delta m \lesssim 10 GeV$$

- Integrating out ``messengers” Y’s,
- Portal in $$\lambda^a \sigma_{\mu\nu} G^{a\mu\nu} \psi_S$$

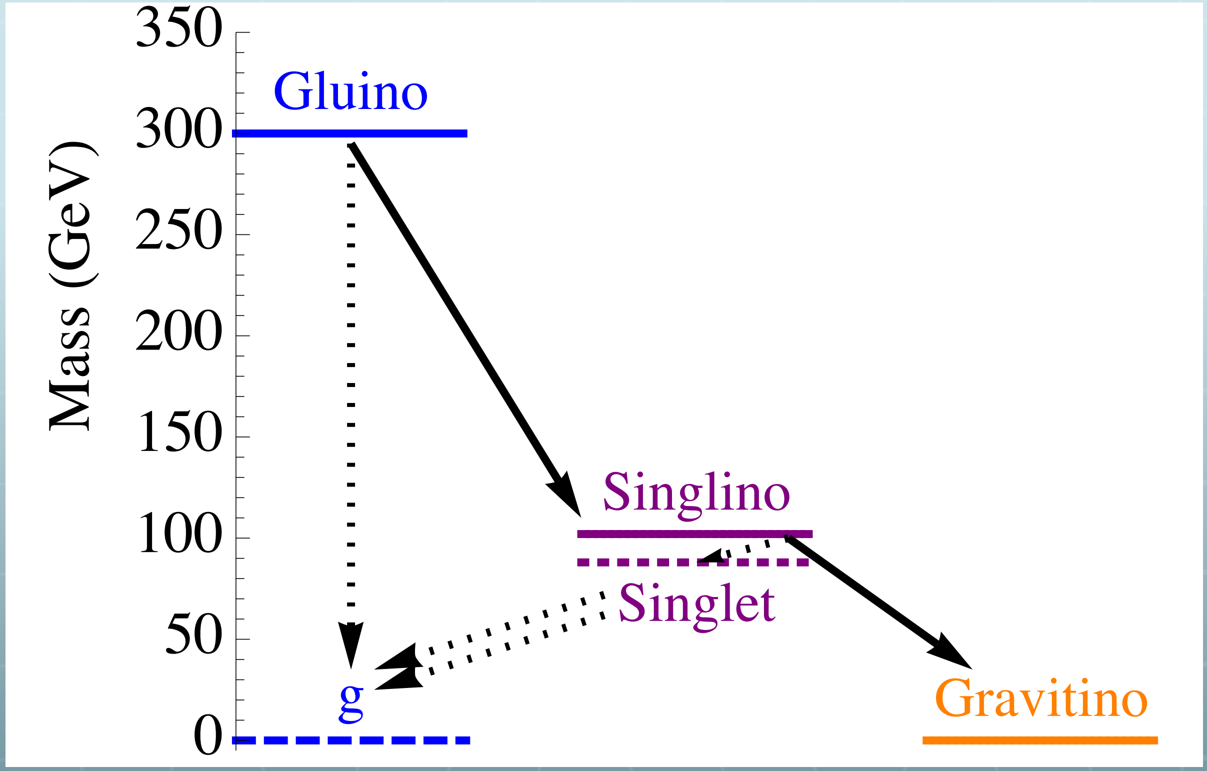
$$\tilde{g} \rightarrow g + \psi_S$$

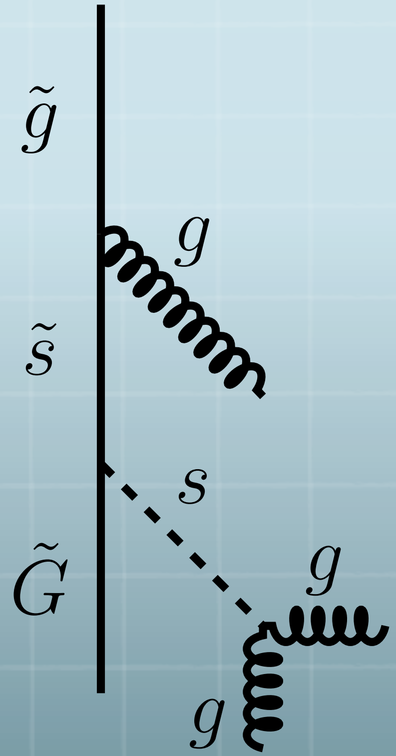
$$\tilde{B} \rightarrow \gamma + \psi_S$$

- Portal out $$s G^a_{\mu\nu} G^{a\mu\nu}$$

$$s \longrightarrow gg$$

Spectrum and decay chain





Zoo of stealth SUSY models

S Hu Hd:

$$W = \frac{m}{2}S^2 + \frac{\kappa}{3}S^3 + \lambda S H_u H_d + \mu H_u H_d.$$

Mix singlino and higgsino; singlet and higgs

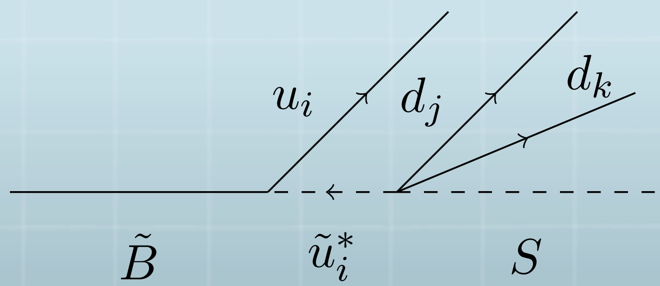
$SY\bar{Y}$	
$m = 100$ GeV	$m_{\tilde{s}} = 100$ GeV
$\lambda = 0.2$	$m_{s,a} = 91$ GeV
$m_Y = 1000$ GeV	$\Gamma_{s,a} = 2 \times 10^{-7}$ GeV
$\tilde{m}_D = 300$ GeV $\quad \tilde{m}_L = 200$ GeV	$\text{Br}_{s,a\to\gamma\gamma} = 4 \times 10^{-3}$
$M_{\text{mess}} = 100$ TeV	

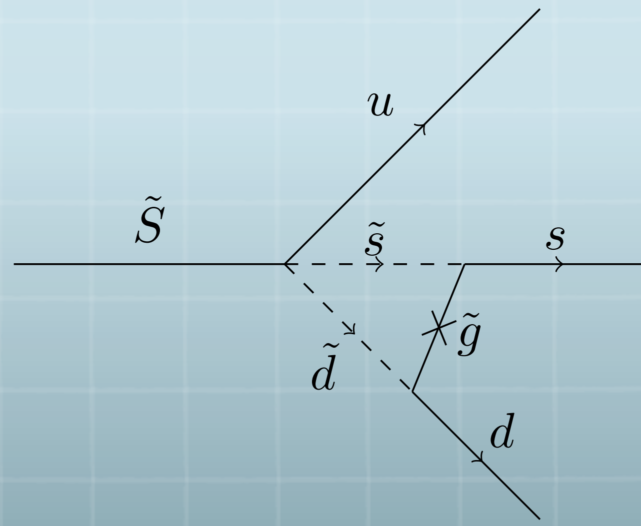
$$\tilde{g} \longrightarrow \tilde{b} \longrightarrow \tilde{B} \longrightarrow \tilde{s} \longrightarrow s + \tilde{G}$$

$$\tilde{B} \searrow h \qquad s \searrow b + \bar{b}$$

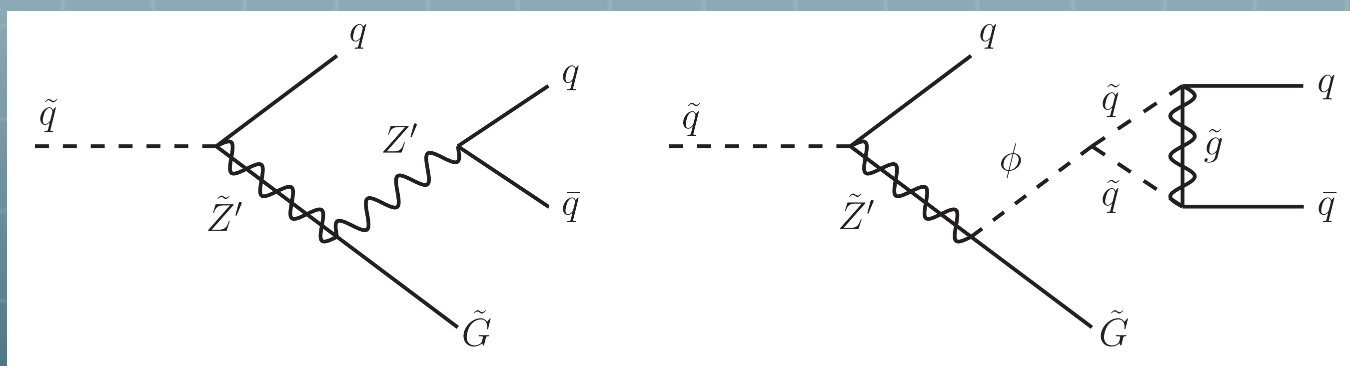
Zoo of stealth SUSY models

Baryon portal: $$W \supset \frac{\lambda_{ijk}}{M} u_i d_j d_k S$$





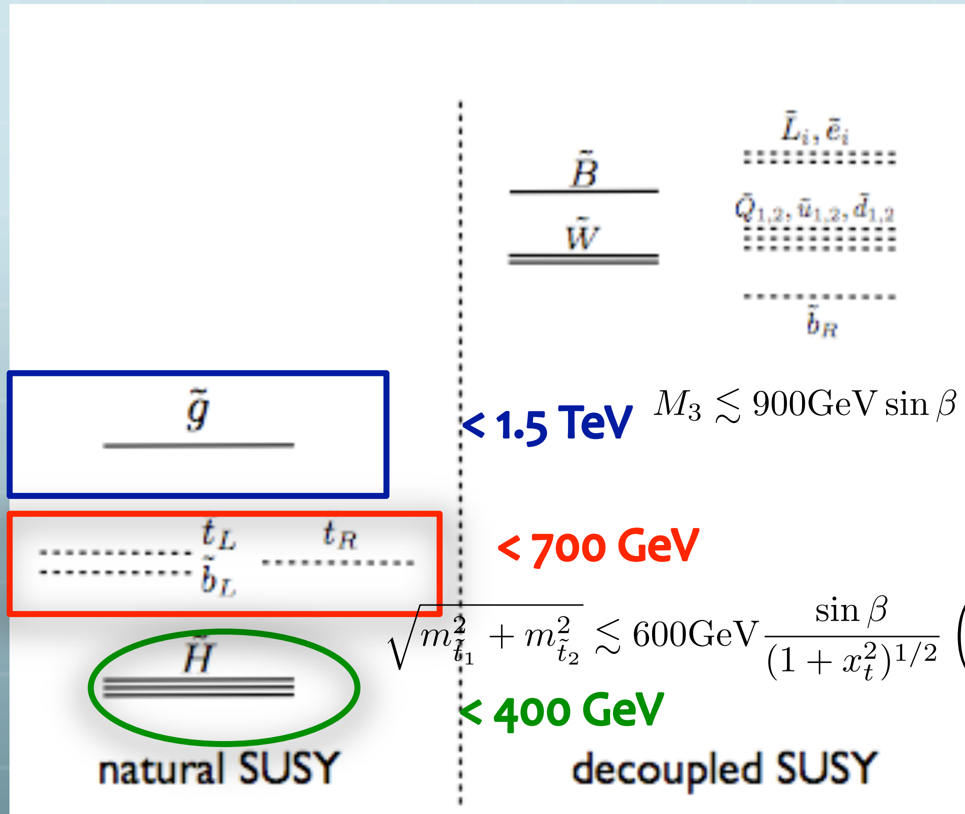
Z' model:



Natural SUSY

- **Basic ingredients of natural SUSY:**

Papucci, Ruderman, Weiler 2011



$$M_3 \lesssim 900\text{GeV} \sin\beta \left(\frac{\log(\Lambda/\text{TeV})}{3}\right)^{-1} \left(\frac{m_h}{120\text{GeV}}\right) \left(\frac{\Delta^{-1}}{20\%}\right)^{-1/2}.$$

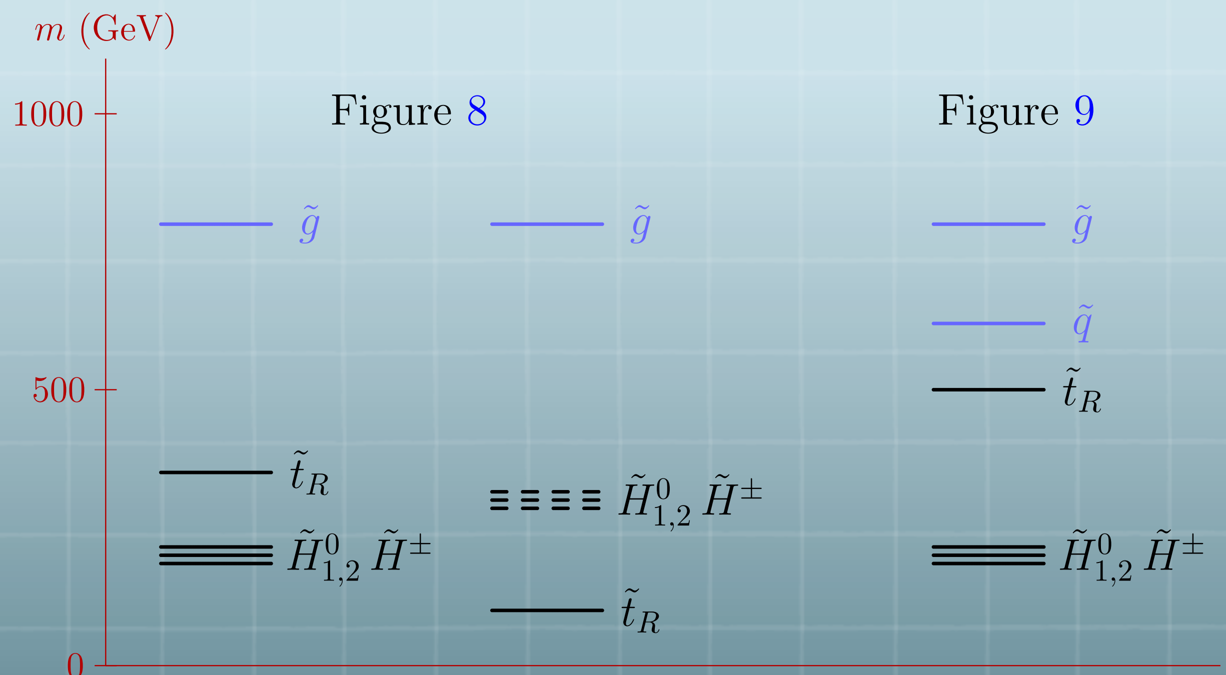
$$\sqrt{m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2} \lesssim 600\text{GeV} \frac{\sin\beta}{(1+x_t^2)^{1/2}} \left(\frac{\log(\Lambda/\text{TeV})}{3}\right)^{-1/2} \left(\frac{m_h}{120\text{GeV}}\right) \left(\frac{\Delta^{-1}}{20\%}\right)^{-1/2}$$

$$\mu \lesssim 200\text{GeV} \left(\frac{m_h}{120\text{GeV}}\right) \left(\frac{\Delta^{-1}}{20\%}\right)^{-1/2}$$

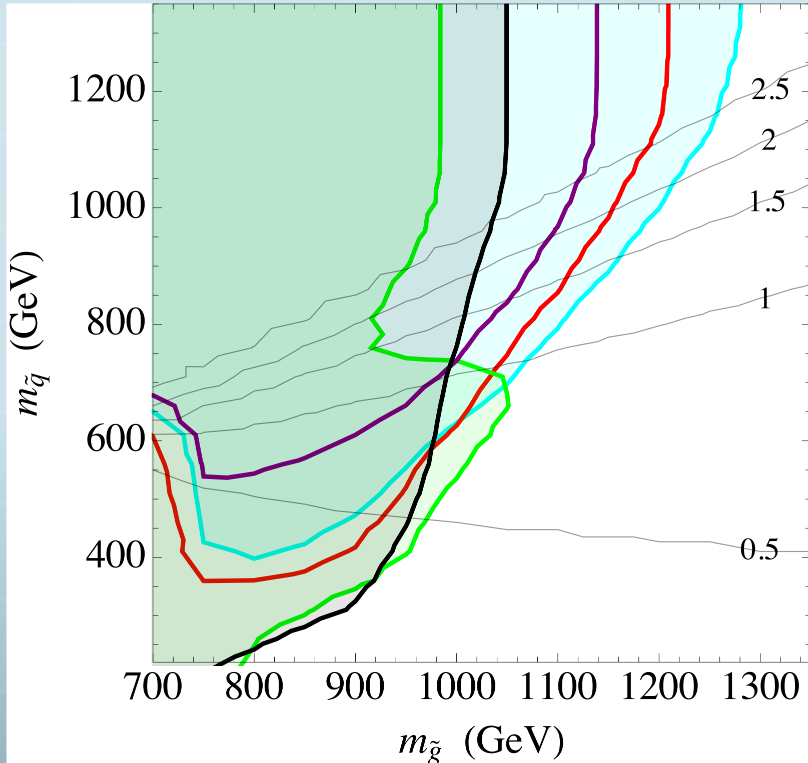
Constraints on gluino

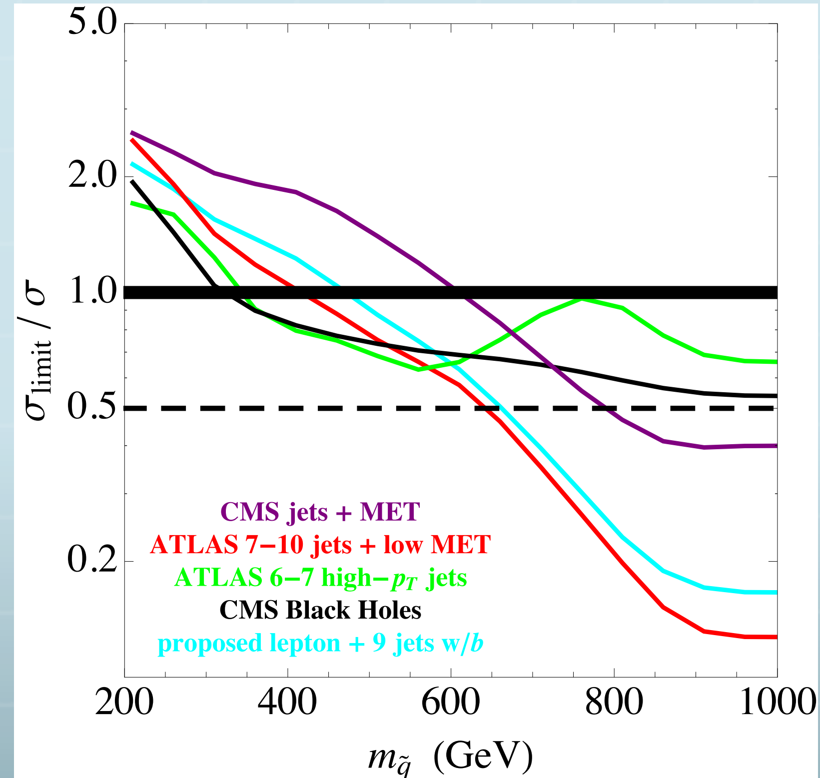
Almost any natural SUSY models where gluino decays frequently produce top quarks, or significantly missing energy, or a high mulitplicity of high-pT objects is excluded for gluino mass at least up to ~ 1 TeV.

Evans, Kats, Shih and Strassler 2013



$$\tilde{H} \to S + \tilde{S} \to gg\tilde{S} \qquad \tilde{H} \to jjj$$





$\tilde{g} \to t\tilde{t}$ and $\tilde{g} \to q\tilde{q}$

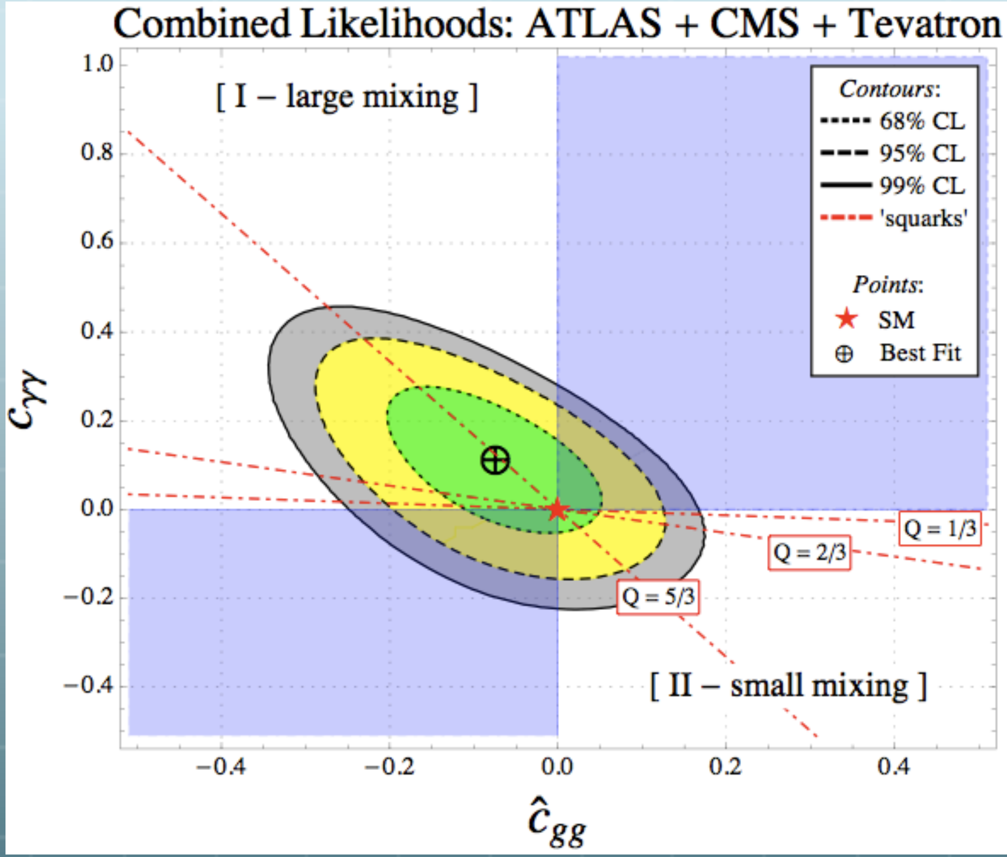
Add light second generation squark to dilute the top production could help

Constraints on stops

Constraints from Higgs couplings:

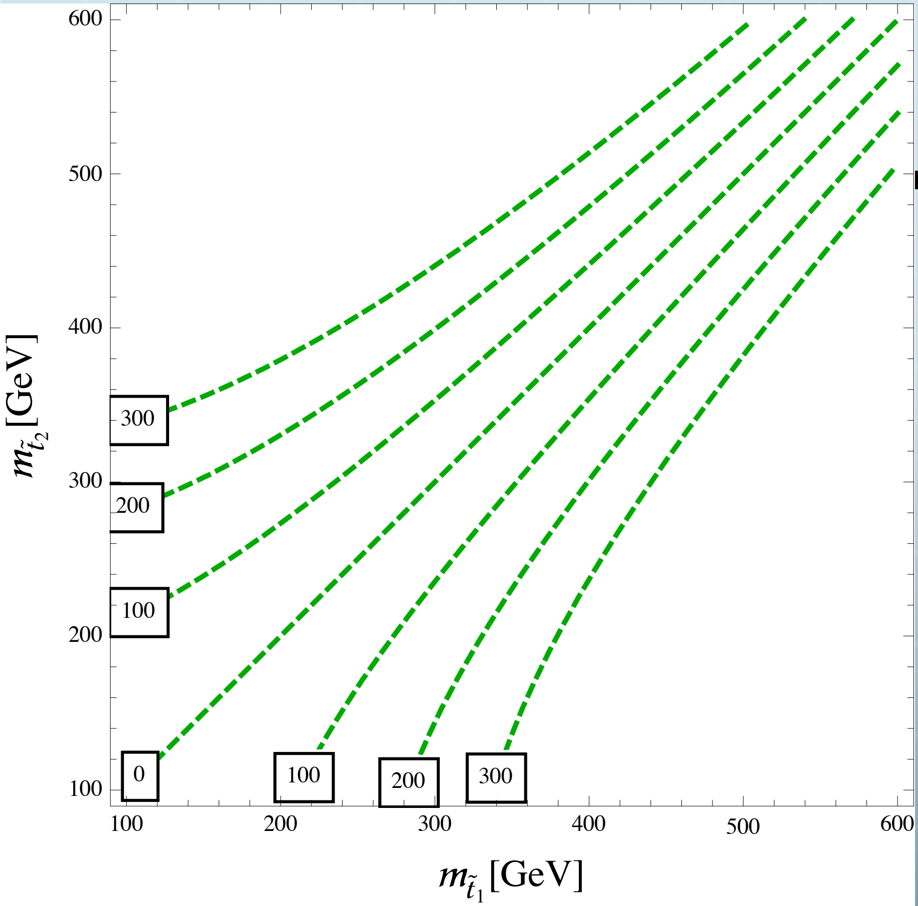
Higgs digluon coupling $$r_G^{\tilde{t}} \approx \frac{1}{4}\left(\frac{m_t^2}{m_{\tilde{t}_1}^2} + \frac{m_t^2}{m_{\tilde{t}_2}^2} - \frac{m_t^2 X_t^2}{m_{\tilde{t}_1}^2 m_{\tilde{t}_2}^2}\right), \quad \text{stop contribution,}$$

$$r_G^{\tilde{t}} \approx -3.65 r_\gamma^{\tilde{t}}$$



Azatov, Galloway 2013

Contours of maximal Xt allowed by two physical masses

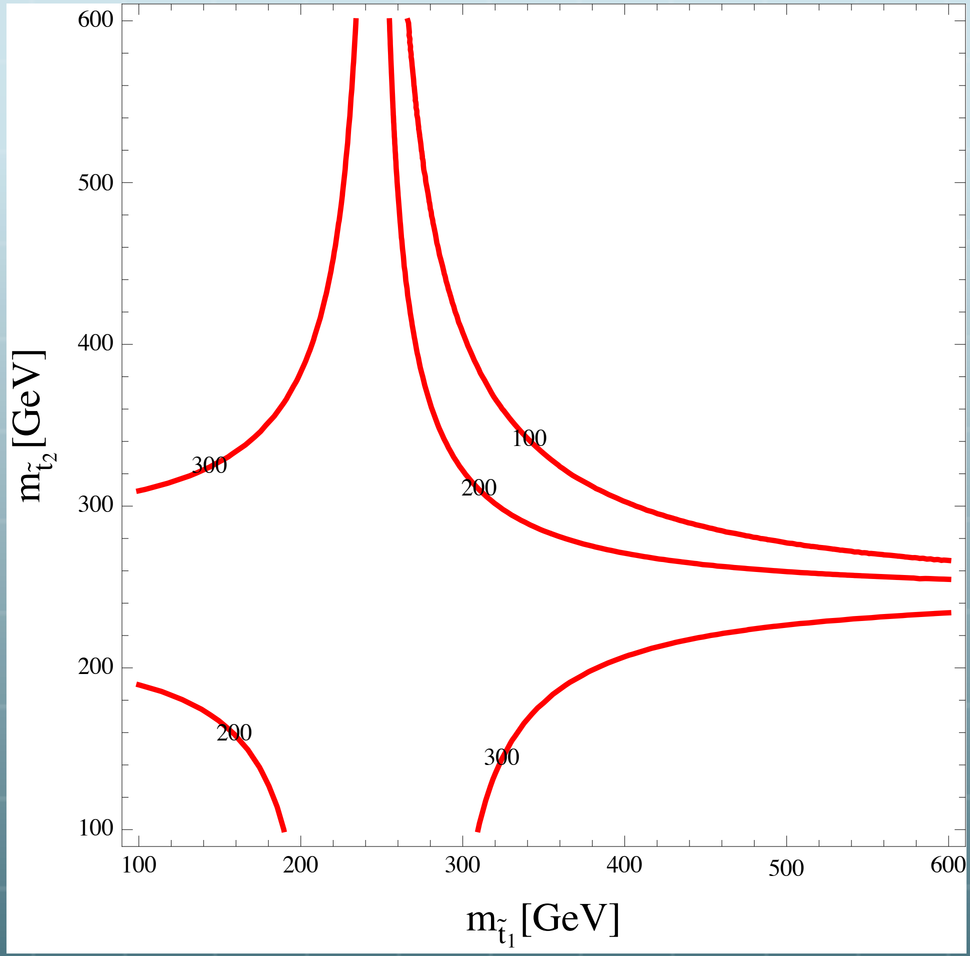


X_t

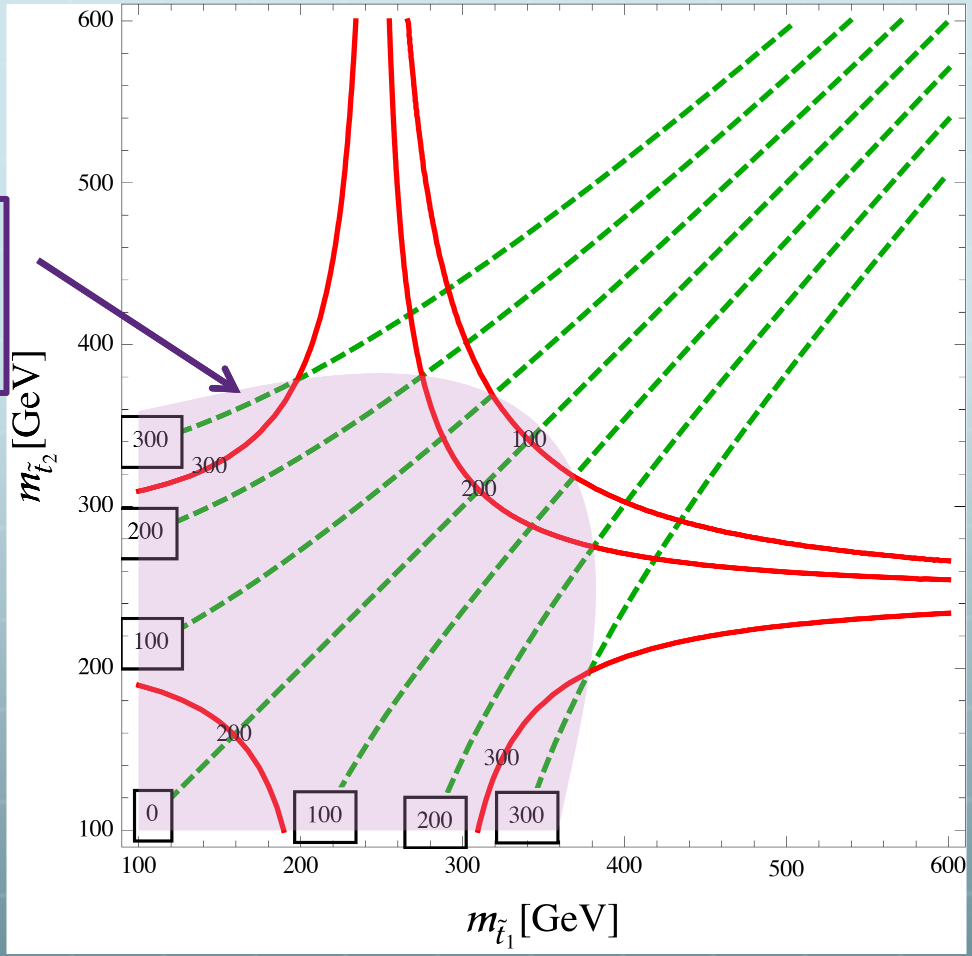
$$\mathbf{m}^2_{\tilde{\mathbf{t}}} = \begin{pmatrix} m^2_{Q_3} + m_t^2 + \Delta_{\tilde{u}_L} & v(a_t^* \sin\beta - \mu y_t \cos\beta) \\ v(a_t \sin\beta - \mu^* y_t \cos\beta) & m^2_{\bar{u}_3} + m_t^2 + \Delta_{\tilde{u}_R} \end{pmatrix}.$$

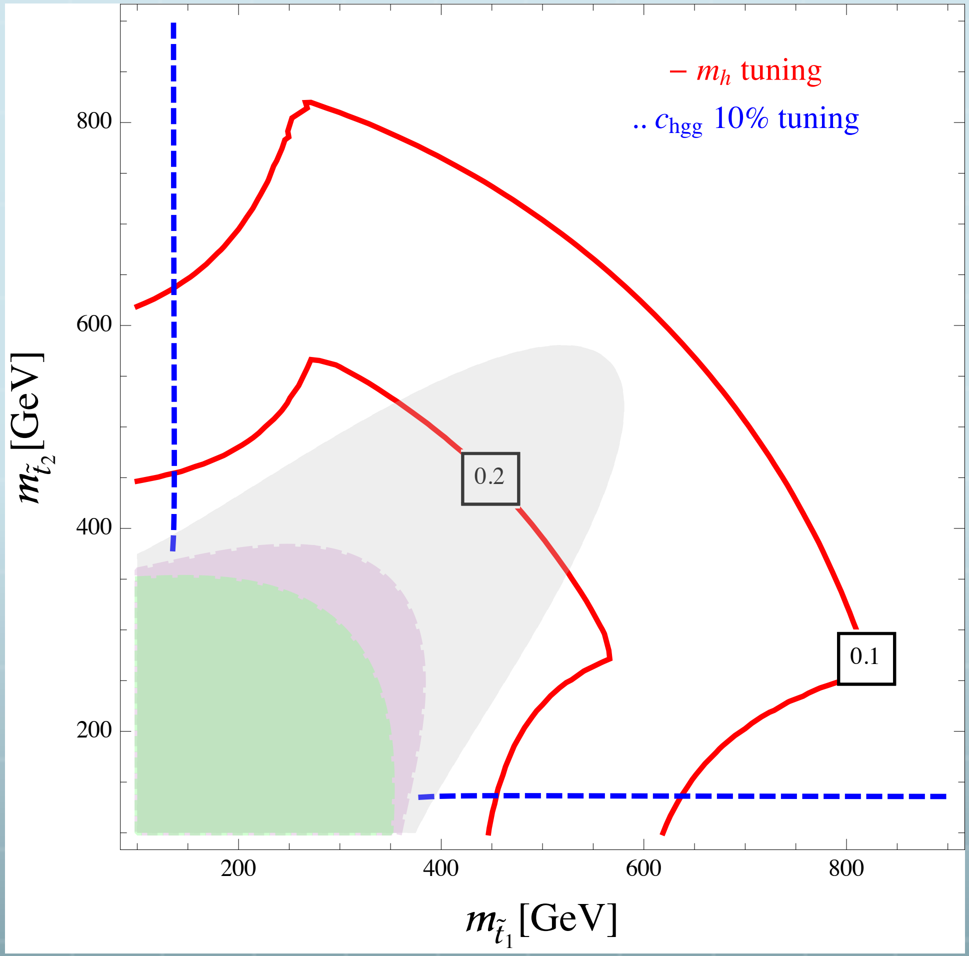
Contours of minimal Xt allowed by Higgs couplings (at 95 %)

$$r_G^{\tilde{t}} \approx \frac{1}{4}\left(\frac{m_t^2}{m_{\tilde{t}_1}^2} + \frac{m_t^2}{m_{\tilde{t}_2}^2} - \frac{m_t^2 X_t^2}{m_{\tilde{t}_1}^2 m_{\tilde{t}_2}^2}\right), \quad \text{stop contribution,}$$



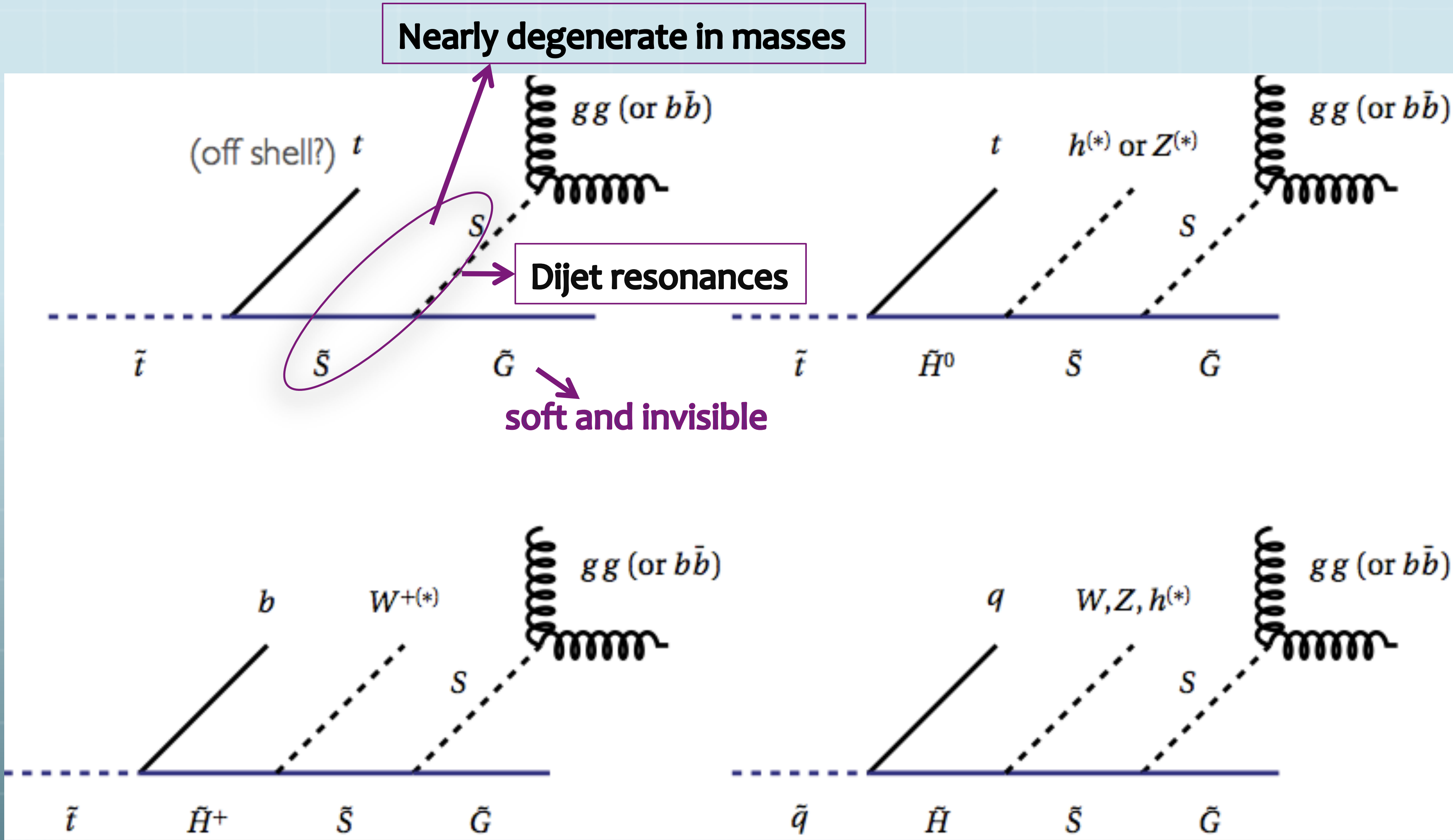
X_t^{max} allowed by stop masses < X_t^{min} consistent with Higgs coupling data





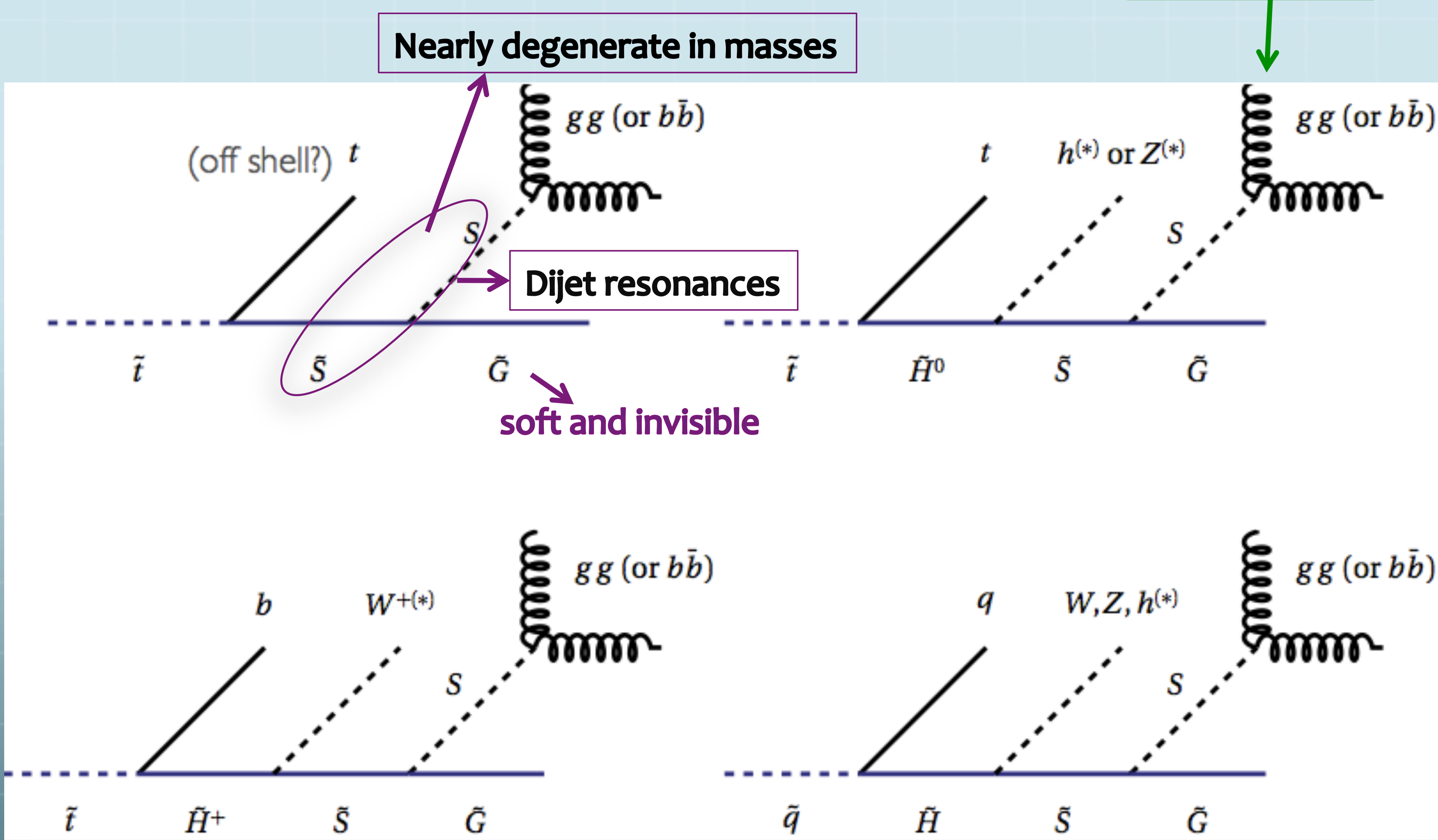
Conclusion: one can not have two light stops simultaneously;
Caveat: Additional light colored particles that cancel the stop's contribution or a combination of loop effects and mixing effects

Simplified models of stops in Stealth SUSY : Many jets in the final state

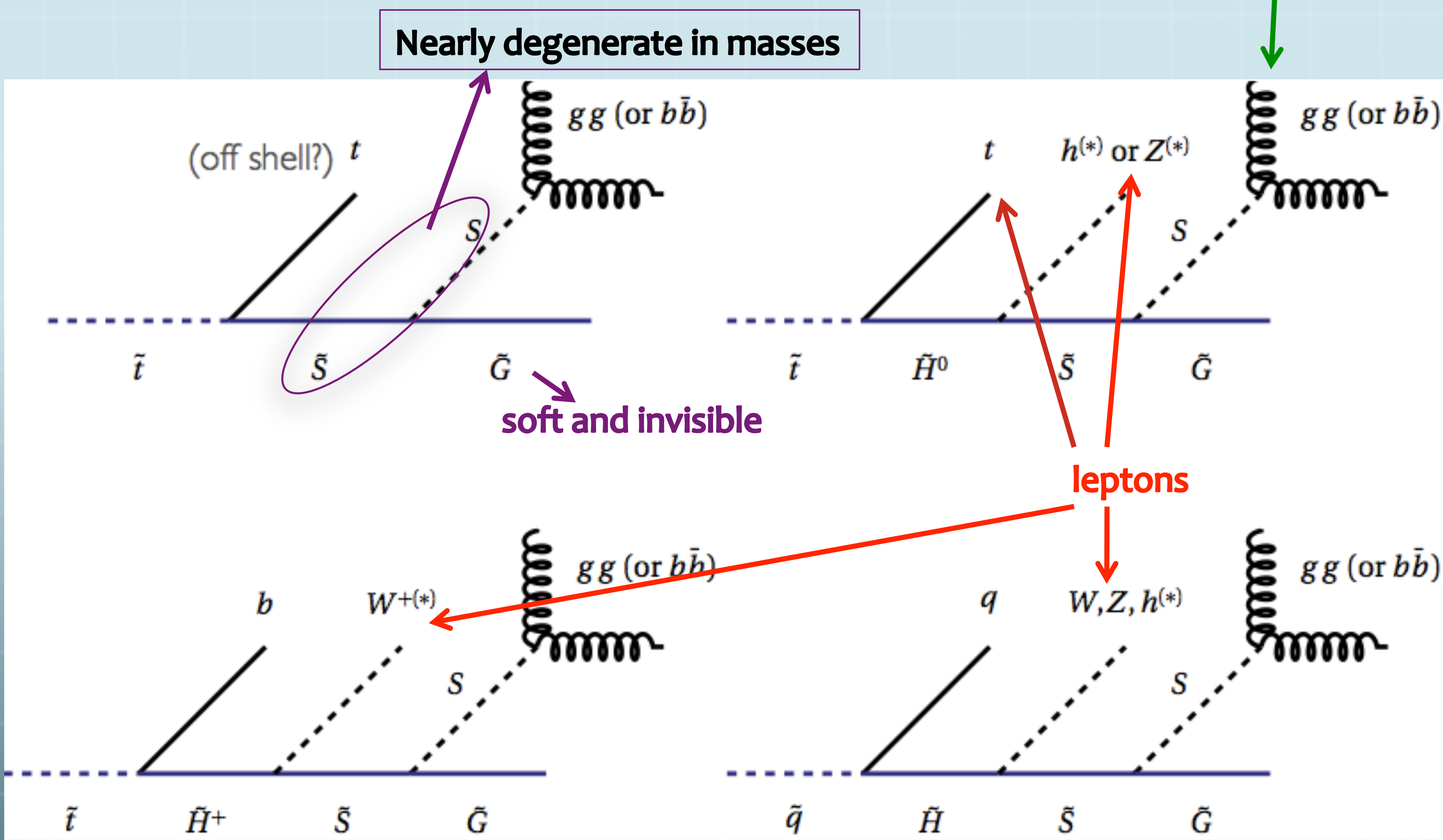


Simplified models of Stealth SUSY (stops) : Many jets in the final state

jets are softer

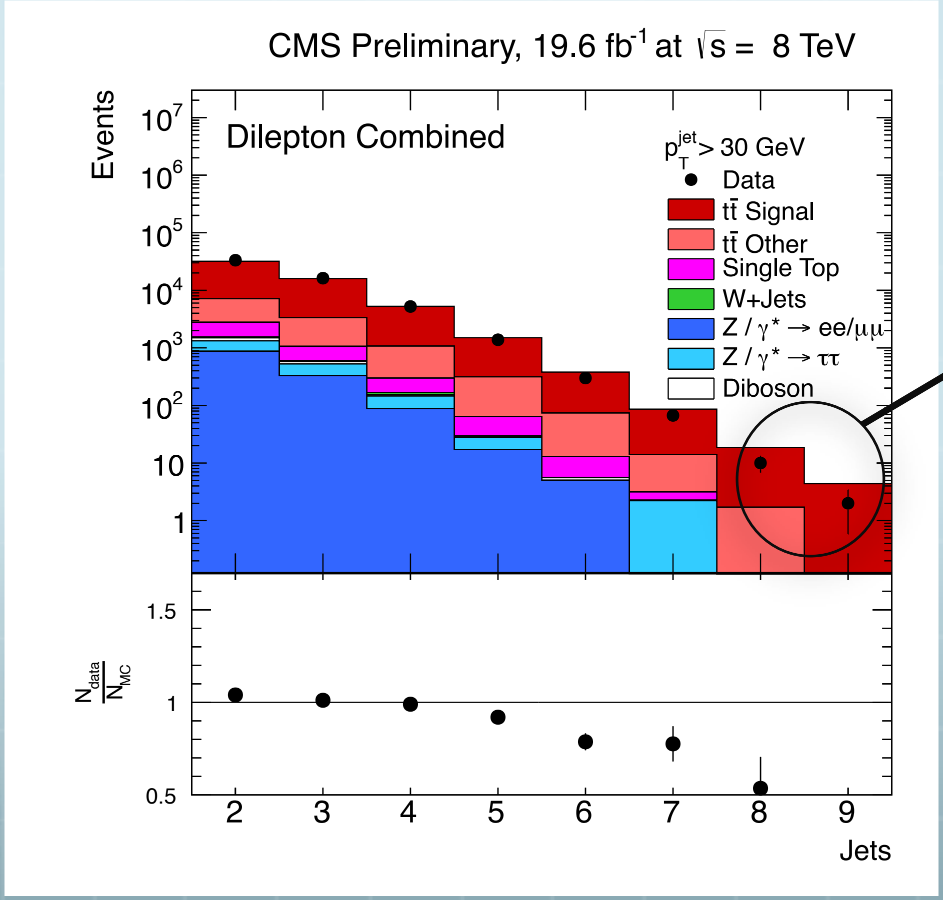


Simplified models of Stealth SUSY (stops) : Many jets in the final state **jets are softer**



JF, Rebecca Krall, Matt Reece, David Pinner, Josh Ruderman

CMS Top-12-041: Measurement of jet multiplicity in dileptonic top pair production



Stops in stealth scenario with mass below 500 GeV could contribute to the final two bins at the order of the observed events

Reconstructed jet multiplicity distribution after event selection for all jets with transverse momenta of at least 30 GeV

A preliminary reanalysis shows that it rules out stop in the stealth SUSY up to around 400 GeV

Summary

- Hidden sectors could modify the SUSY decay chains and topologies of final state dramatically
- It is important to set limits on simplified models with hidden sector such as stealth SUSY

Thank you!

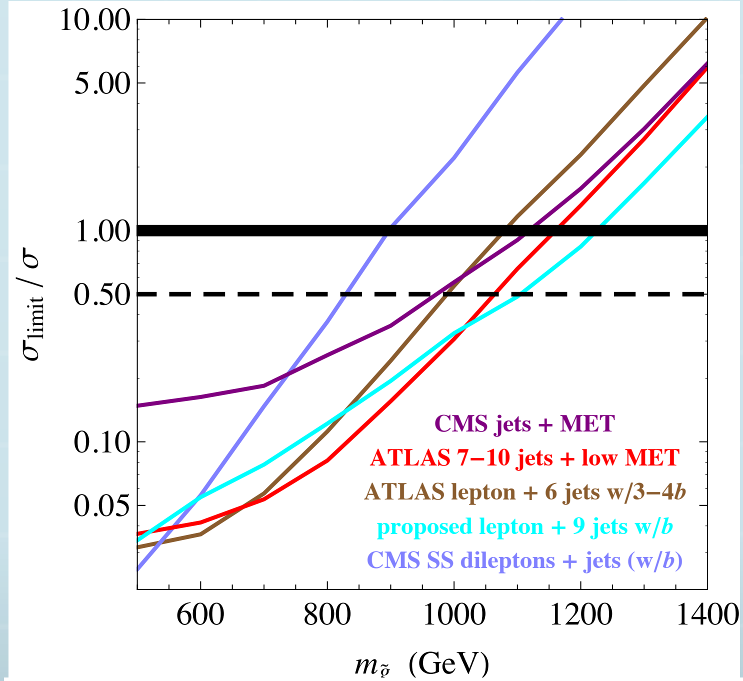
Backup

Search	Data (fb^{-1})	Reference
ATLAS 2-6 jets + large $\not{E}_T$	20.3	[16]
ATLAS 7-10 jets + low $\not{E}_T$	20.3	[18]
CMS jets + $\not{E}_T$	19.5	[17]
ATLAS 6-7 high-p_T jets	20.3	[20]
CMS black holes (BH)	12.1	our re-analysis of [21] (see section 3.2)
LSST lepton + many jets w/b	20 (expected)	our implementation of [19] (see section 3.3)

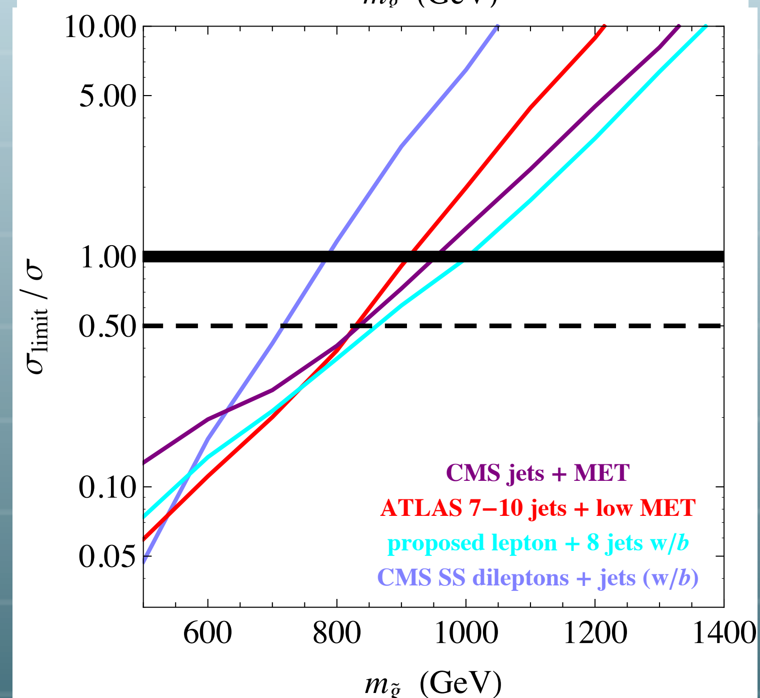
	Multi-jet + flavour stream					Multi-jet + M_J^Σ stream		
Identifier	**8j50**	**9j50**	$\geq$ **10j50**	**7j80**	$\geq$ **8j80**	$\geq$ **8j50**	$\geq$ **9j50**	$\geq$ **10j50**
Jet $\lvert\eta\rvert$	< 2.0			< 2.0		< 2.8		
Jet p_T	$> 50\,\mathrm{GeV}$			$> 80\,\mathrm{GeV}$		$> 50\,\mathrm{GeV}$		
Jet count	$= 8$	$= 9$	≥ 10	$= 7$	≥ 8	≥ 8	≥ 9	≥ 10
b-jets ($p_\mathrm{T} > 40$ GeV, $\lvert\eta\rvert < 2.5$)	0 / 1 / ≥ 2	0 / 1 / ≥ 2	—	0 / 1 / ≥ 2	0 / 1 / ≥ 2	—		
M_J^Σ [GeV]	—			—		> 340 and > 420 for each case		
$E_\mathrm{T}^\mathrm{miss}/\sqrt{H_\mathrm{T}}$	> 4 GeV$^{1/2}$			> 4 GeV$^{1/2}$		> 4 GeV$^{1/2}$		

Table 1: Definition of the nineteen signal regions. The jet $|\eta|$, p_T and multiplicity all refer to the $R = 0.4$ jets. Composite jets with the larger radius parameter $R = 1.0$ are used in the multi-jet + M_J^Σ stream when constructing M_J^Σ. A long dash '—' indicates that no requirement is made.

$$\tilde{g} \to \tilde{t}t,\ \tilde{t} \to b\tilde{H},\ \tilde{H} \to jjj,$$



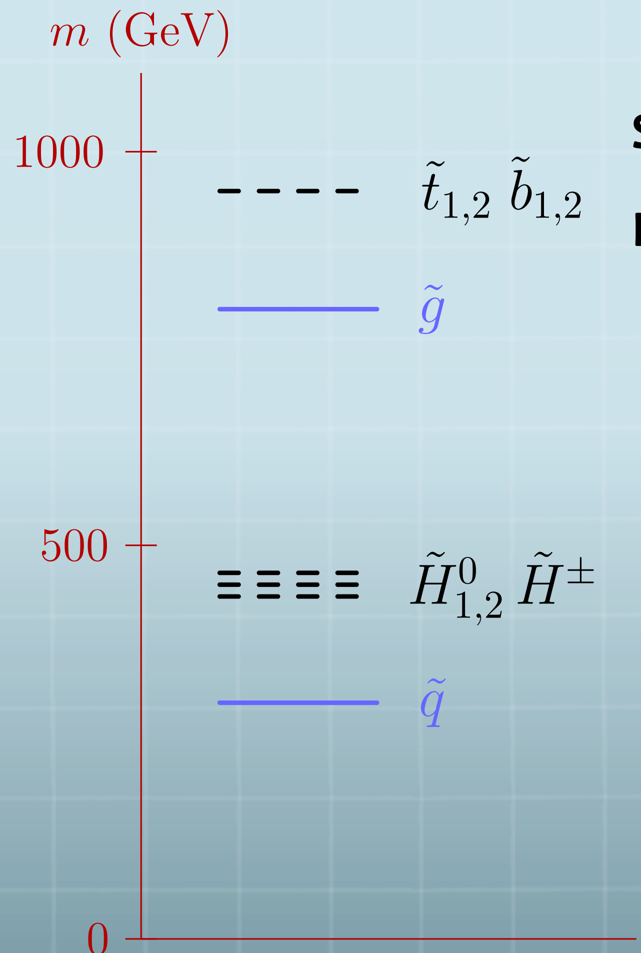
$$\tilde{g} \to \tilde{t}t,\ \tilde{t} \to jj,$$



Softened jets help!

Eg: ATLAS 6-7 high pT jet searches

ATLAS-CONF-2013-091



Sample	Jet p_T cut [GeV]	# jets	# b-tags	Signal	Background	Data
$m_{\tilde{g}}$ = 500 GeV	120	7	0	600±230	370±60	444
$m_{\tilde{g}}$ = 600 GeV	120	7	0	410±100	370±60	444
$m_{\tilde{g}}$ = 800 GeV	180	7	0	13±4	6.1±2.2	4
$m_{\tilde{g}}$ = 1000 GeV	180	7	0	6.8±2.3	6.1±2.2	4
$m_{\tilde{g}}$ = 1200 GeV	180	7	0	2.7±0.5	6.1±2.2	4

Table 2: Optimization results for the 6-quark model under a variety of gluino mass hypotheses when the RPV vertex has the branching ratio combination (BR(t), BR(b), BR(c))=(0%, 0%, 0%) corresponding to only RPV terms given by λ''_{112} being nonzero. The optimized signal region selection requirements are shown along with the resulting background and signal expectations and the number of observed data events. Quoted errors represent both statistical and systematic uncertainty.

$$\tilde{H} \to S\tilde{S}, \qquad \tilde{S} \to S\psi, \qquad S \to gg$$

- **More possibilities**

  Z' model: One additional U(1) both our sector and stealth sector is charged under and the U(1) is spontaneously broken in the stealth sector;

  Vector-like confinement sector: strongly coupled SQCD sector with SM gauge group as the flavor symmetry of the matter fields.

Decay to gravitino:

$$\Gamma_{\tilde{X}} = \frac{m_{\tilde{X}}^5}{16\pi F^2}\left(1 - \frac{m_X^2}{m_{\tilde{X}}^2}\right)^4 \approx \frac{m_{\tilde{X}}\,(\delta m)^4}{\pi F^2}\,.$$

$\sqrt{F} = 100\,\text{TeV},\ m_{\tilde{X}} = 100\ \text{GeV and } m_X = 90\ \text{GeV}$ $\quad 8\ \text{cm}$

Decay to axino:

$$K \supset \frac{1}{2} f^2 \left(A + A^\dagger\right)^2 + S^\dagger S + c\left(A + A^\dagger\right) S^\dagger S + \ldots,$$

$$\Gamma\left(\tilde{S} \to S\tilde{A}\right) = \frac{|c|^2}{4\pi} m_S \left(\frac{\delta m}{f}\right)^2 = |c|^2 \frac{m_S}{100\ \text{GeV}} \left(\frac{\delta m}{10\ \text{GeV}}\right)^2 \left(\frac{10^9\ \text{GeV}}{f}\right)^2 \frac{1}{25\ \text{cm}}$$