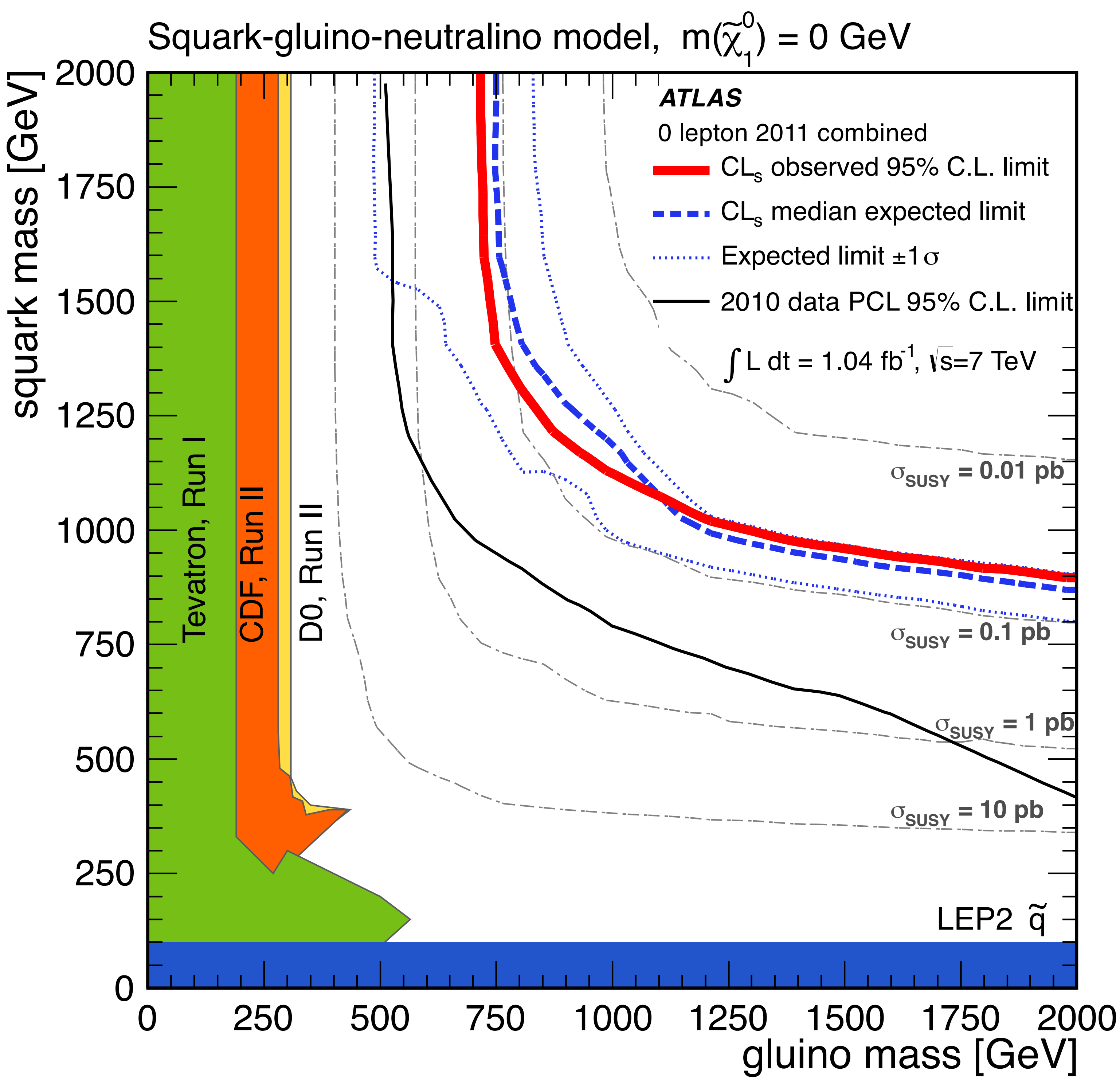
Natural SUSY Endures

Josh Ruderman

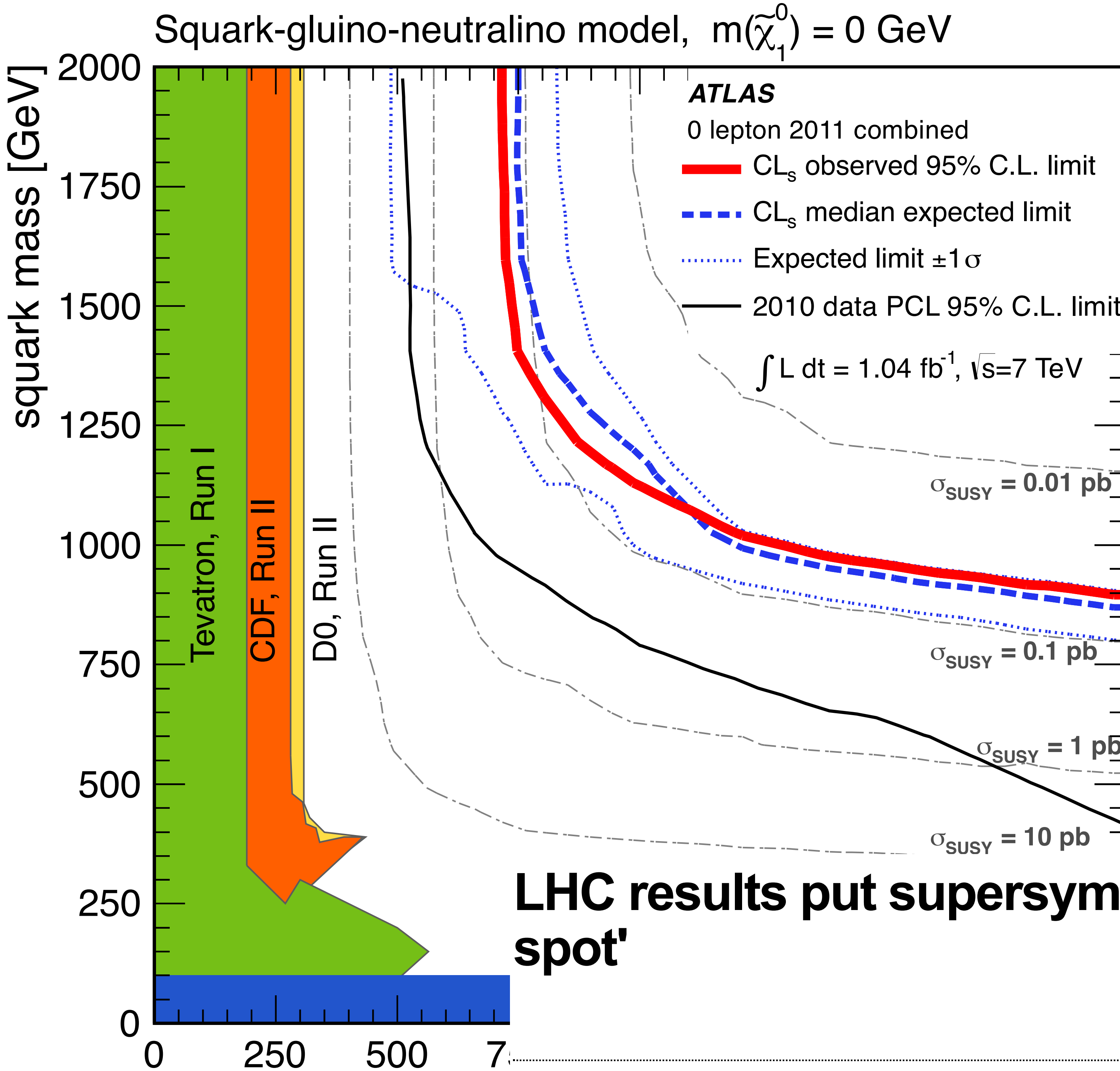
UC Davis: Hidden-SUSY

Nov. 8, 2011

Michele Papucci, JTR, Andreas Weiler, 1110.6926.



Squark-gluino-neutralino model, $m(\tilde{\chi}_1^0)$ = 0 GeV
ATLAS
0 lepton 2011 combined
CL_s observed 95% C.L. limit
CL_s median expected limit
Expected limit ±1σ
2010 data PCL 95% C.L. limit
$\int L\,dt$ = 1.04 fb^{-1}, $\sqrt{s}$=7 TeV
σ_{SUSY} = 0.01 pb
σ_{SUSY} = 0.1 pb
σ_{SUSY} = 1 pb
σ_{SUSY} = 10 pb
Tevatron, Run I
CDF, Run II
D0, Run II
LEP2 $\tilde{q}$
squark mass [GeV]
gluino mass [GeV]
0
250
500
750
1000
1250
1500
1750
2000



LHC results put supersymmetry theory 'on the spot'

By Pallab Ghosh
Science correspondent, BBC News

Results from the Large Hadron Collider (LHC) have all but killed the simplest version of an enticing theory of sub-atomic physics.

- do the LHC results disfavor weak-scale SUSY?

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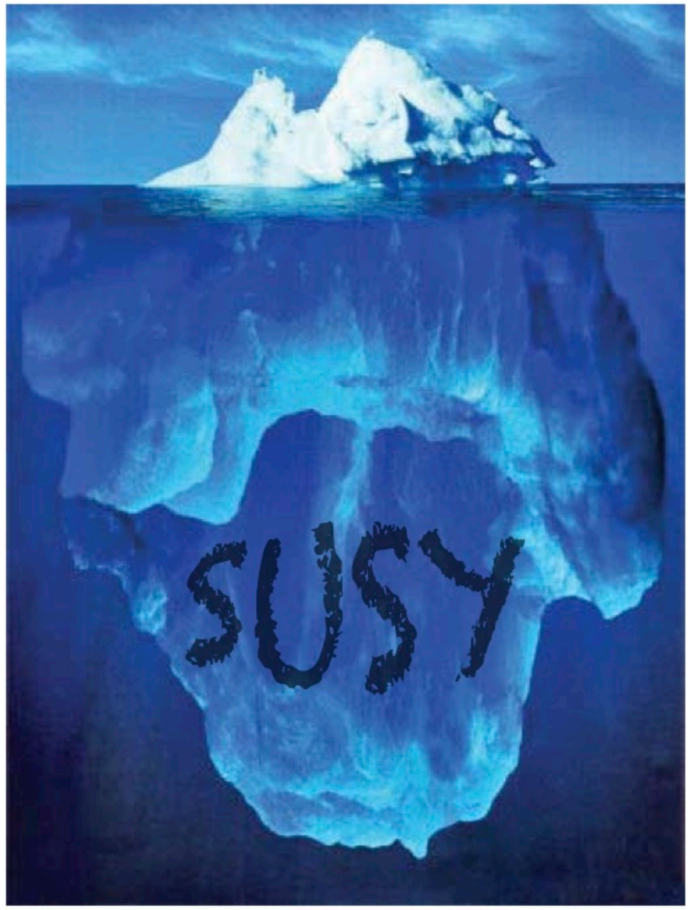
- should we be building models that hide SUSY?



- do the LHC results disfavor weak-scale SUSY?

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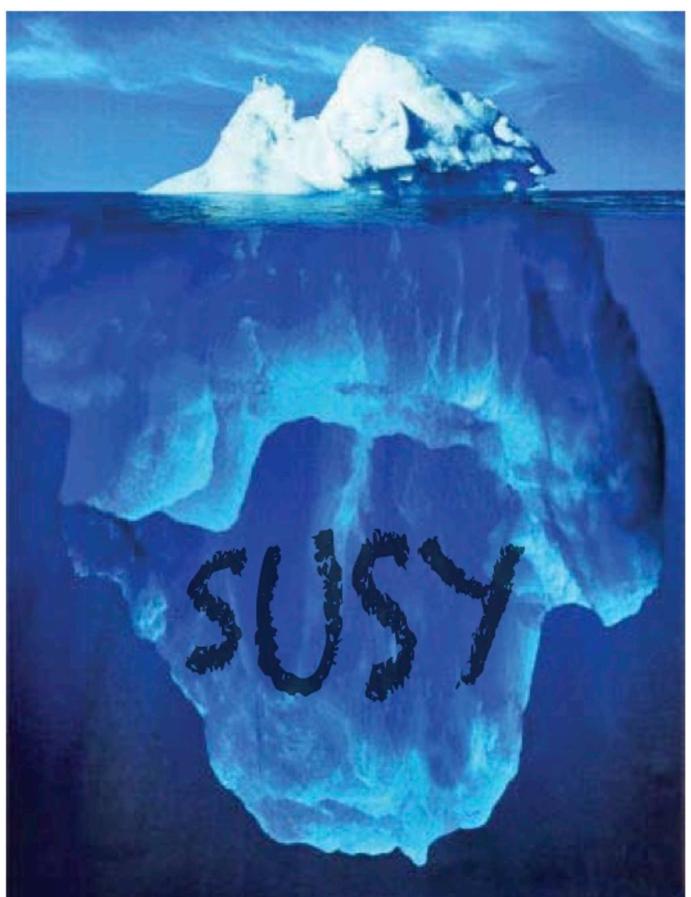

I advocate that fine-tuning provides a framework for thinking about these questions.

the plan

1. bottom-up naturalness in SUSY

2. limits on natural SUSY

fine tuning in SUSY

tree-level:

$$-\frac{m_Z^2}{2} = |\mu^2| + m_{H_u}^2 + \mathcal{O}\left(\frac{1}{\tan^2\beta}\right)$$

fine tuning in SUSY

tree-level:

$$-\frac{m_Z^2}{2} = \boxed{|\mu^2|} + m_{H_u}^2 + \mathcal{O}\left(\frac{1}{\tan^2\beta}\right)$$

light Higgsinos

fine tuning in SUSY

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light Higgsinos

one-loop:

$$\delta m_{H_u}^2 \approx -\frac{3y_t^2}{8\pi^2}\left(m_{Q_3}^2 + m_{u_3}^2 + |A_t|^2\right)\log\left(\frac{\Lambda}{m_{\tilde{t}}}\right)$$

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light stops

(and left-handed sbottom)

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two-loop:

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light stops

(and left-handed sbottom)

two-loop:

$$\delta m_{\tilde{t}}^2 = \frac{8\alpha_3}{3\pi}\boxed{M_3^2}\log\left(\frac{\Lambda}{m_{\tilde{t}}}\right)$$

light gluino

how light should they be?

a general, bottom-up criterion:

there should not be large cancellations in the quadratic term of the higgs potential

consider the potential in the direction that gets a VEV:

$$V = m_H^2 |h|^2 + \frac{\lambda}{4}|h|^4 \qquad m_h^2 = \lambda v^2 = -2m_H^2$$

$$\Delta = \frac{2|\delta m_H^2|}{m_h^2}$$

how light should they be?

stops:

$$m_{\tilde{t}}^2 \lesssim (400\ \mathrm{GeV})^2 \frac{1}{1 + A_t^2/2m_{\tilde{t}}^2} \left(\frac{20\%}{\Delta^{-1}}\right) \left(\frac{3}{\log \Lambda/m_{\tilde{t}}}\right) \left(\frac{m_h}{120\ \mathrm{GeV}}\right)^2$$

Kitano and Nomura 2006.

higgsinos:

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

gluino:

$$M_3^2 \lesssim (900\ \mathrm{GeV})^2 \left(\frac{20\%}{\Delta^{-1}}\right) \left(\frac{3}{\log \Lambda/m_{\tilde{t}}}\right)^2 \left(\frac{m_h}{120\ \mathrm{GeV}}\right)$$

There are now two logically different fine-tuning problems:

1. Little Hierarchy Problem

The LEP2 limit on the higgs mass, 114 GeV, leads to heavy stops in the MSSM, which leads to fine tuning of EWSB.

$$m_h^2 \approx m_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\left[\log\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{X_t^2}{12 m_{\tilde{t}}^2}\right)\right]$$

Model Dependent!!! physics beyond the MSSM can raise higgs mass or change higgs decays

2. Direct LHC Limits

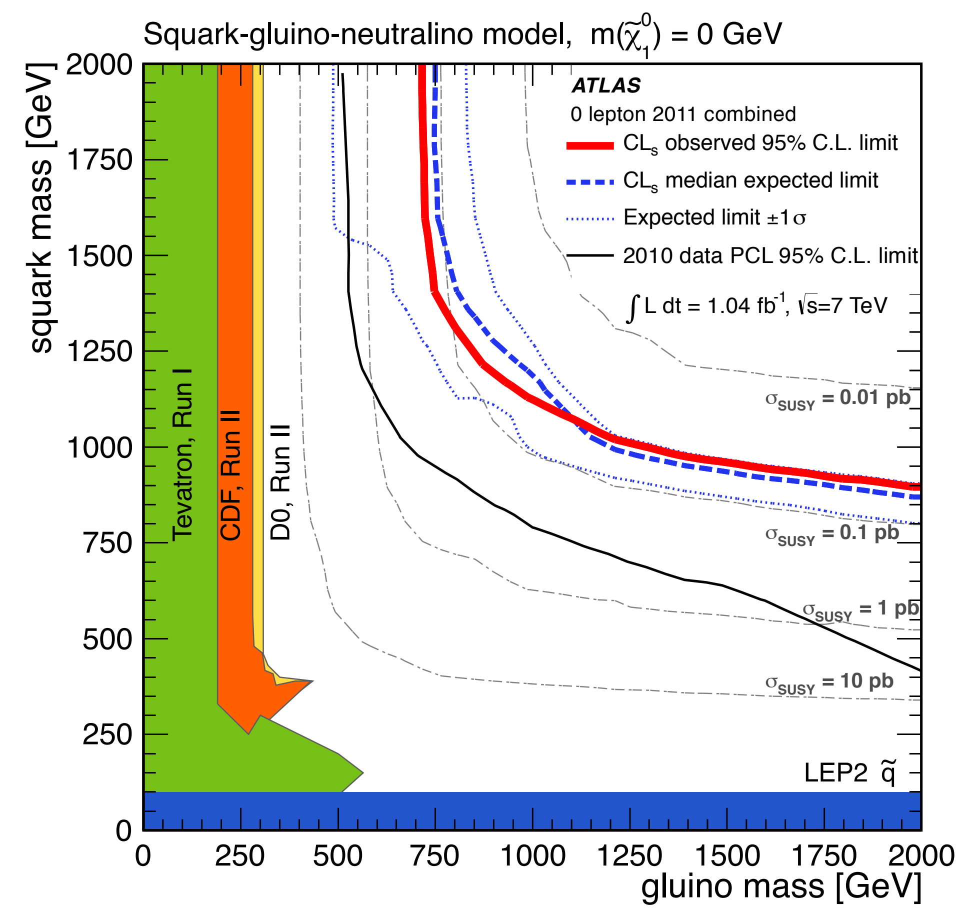
Direct collider limits lead to heavier stops/gluinos, which lead to fine tuning of EWSB, independently of the details of the higgs sector

flavor violating squark mass

- flavor degenerate squarks mean:
  TeV stop limits $\longrightarrow$ few % fine tuning

- this motivates splitting the stops from the other squarks

- Splitting the stops with the RG (starting from a flavor symmetric boundary condition) is not sufficient!

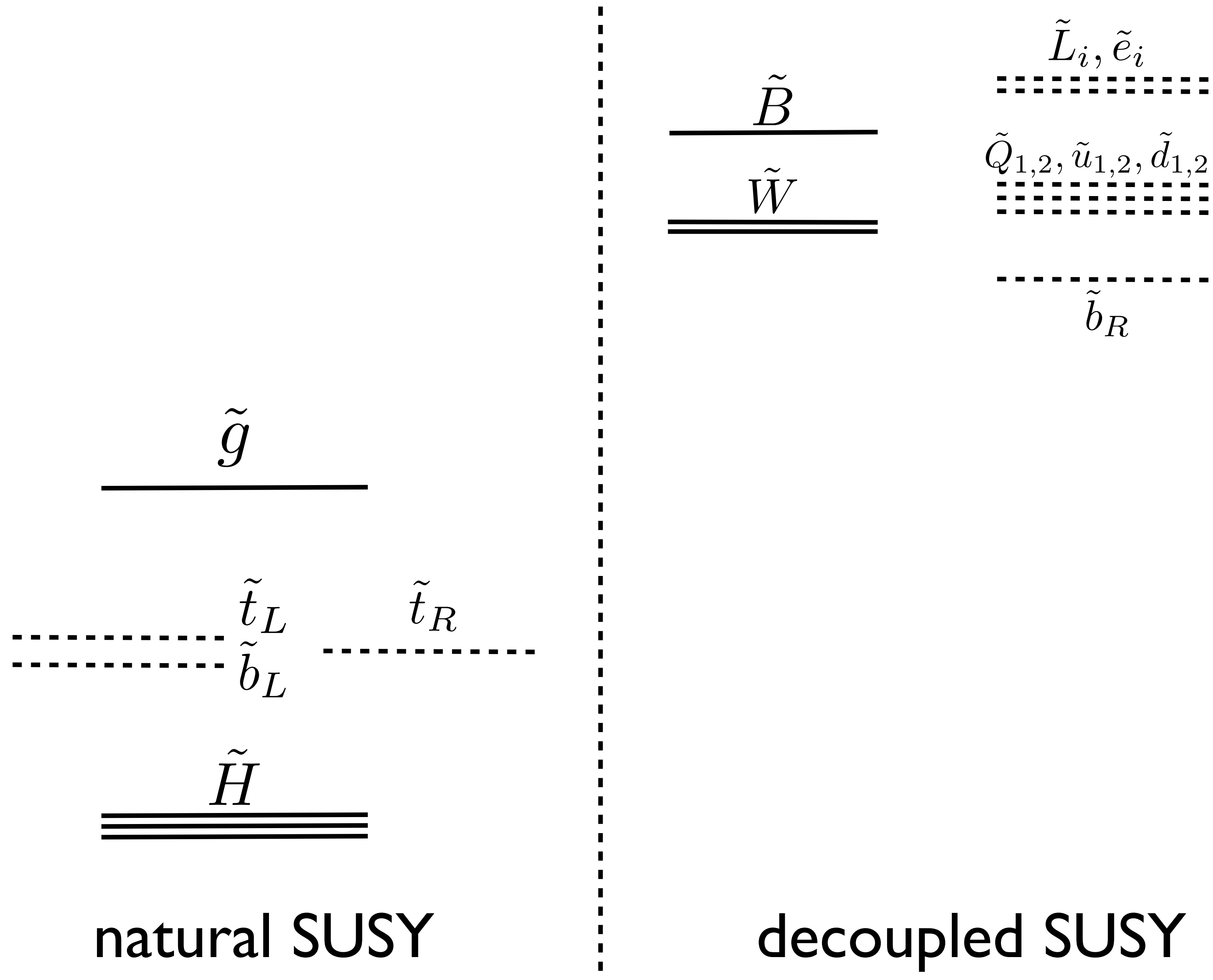


$$\delta m_{H_u}^2 \simeq 3\left(m_{Q_3}^2 - m_{Q_{1,2}}^2\right) \simeq \frac{3}{2}\left(m_{u_3}^2 - m_{u_{1,2}}^2\right)$$

- Really need a flavor-violating boundary condition, which can be MFV,

$$m_{u_3}^2 = c_1 \mathbb{I} + c_2\, Y_u Y_u^\dagger + \ldots$$

a natural spectrum



not a new idea:

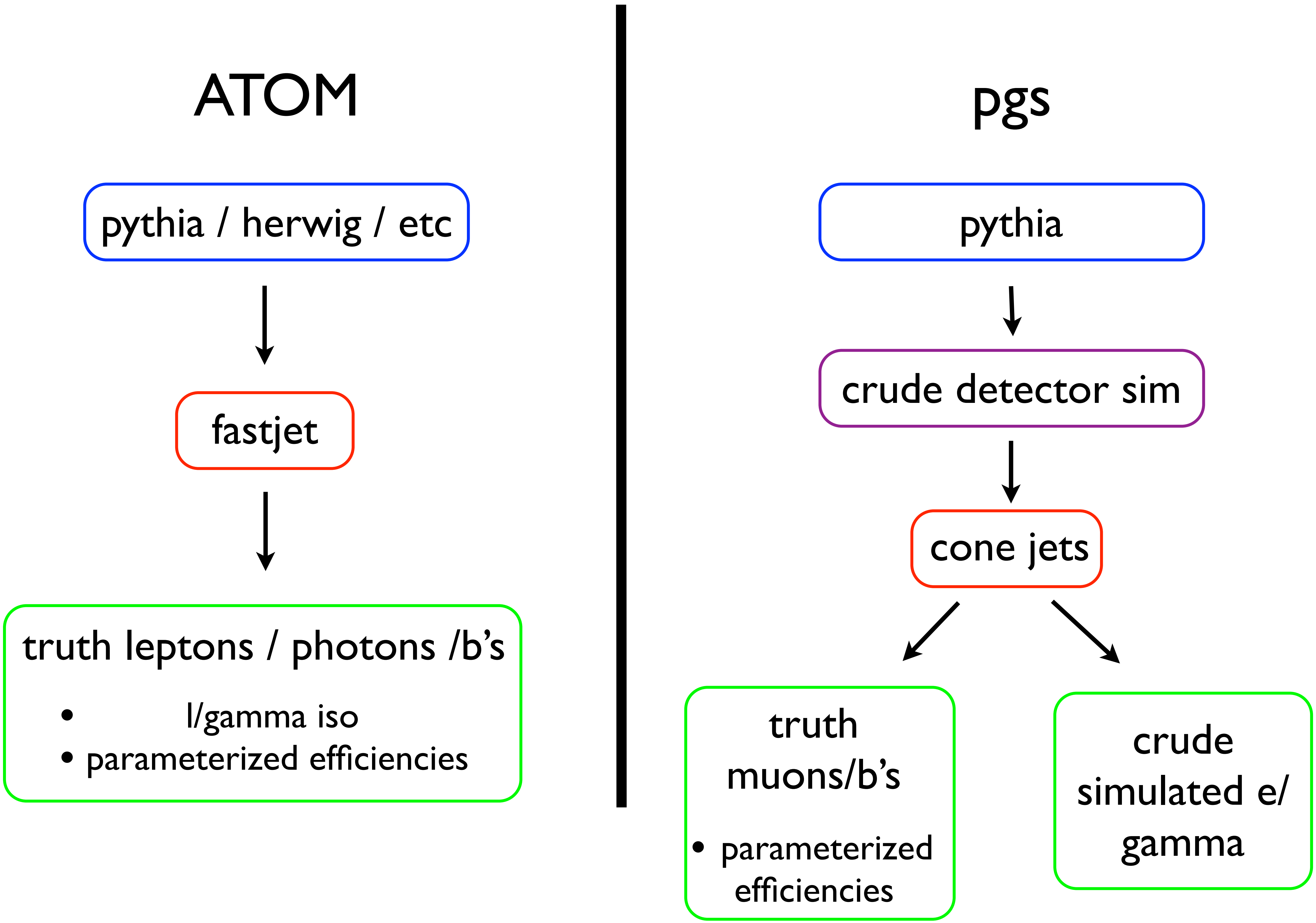
Barbieri, Dvali, Hall 1995.
Dimopoulos, Giudice 1995.
Cohen, Kaplan, Nelson 1996.
etc

1/fb searches that are relevant for natural susy:

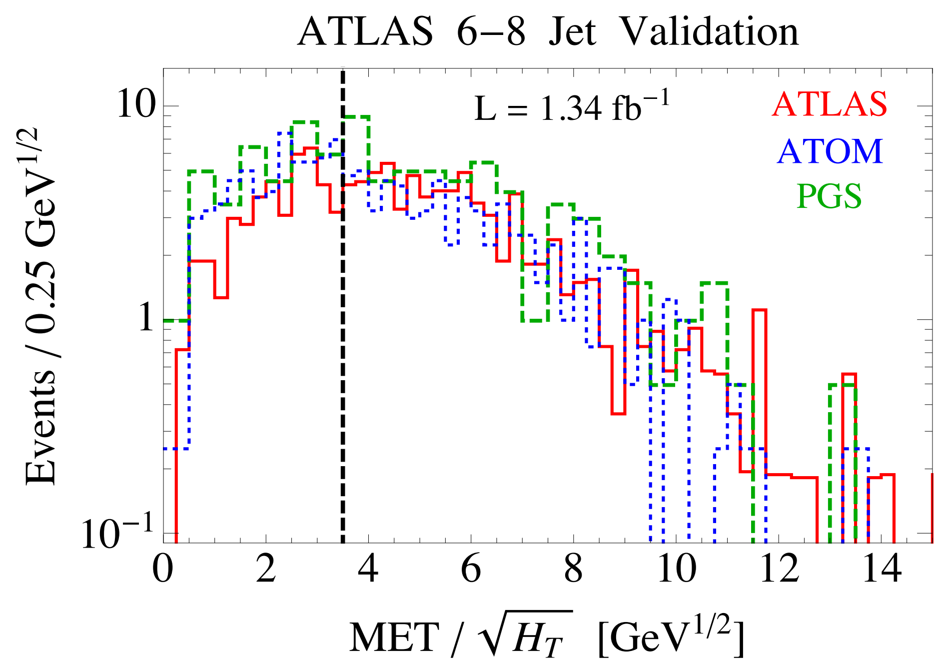
	ATLAS			CMS		
	channel	$\mathcal{L}$ [fb^{-1}]	ref.	channel	$\mathcal{L}$ [fb^{-1}]	ref.
jets + $\not\!\!E_T$	2-4 jets	1.04	[1]	α_T	1.14	[11]
	6-8 jets	1.34	[2]	H_T, $\not\!\!H_T$	1.1	[12]
b-jets (+ l's + $\not\!\!E_T$)	$1b, 2b$	0.83	[3]	m_{T2} $(+b)$	1.1	[13]
	$b + 1l$	1.03	[4]	$1b, 2b$	1.1	[14]
				$b'b' \to b + l^\pm l^\pm, 3l$	1.14	[15]
				$t't' \to 2b + l^+l^-$	1.14	[16]
multilepton (+ $\not\!\!E_T$)	$1l$	1.04	[5]	$1l$	1.1	[17]
	$\mu^\pm\mu^\pm$	1.6	[6]	SS dilepton	0.98	[18]
	$t\bar{t} \to 2l$	1.04	[7]	OS dilepton	0.98	[19]
	$t\bar{t} \to 1l$	1.04	[8]	$Z \to l^+l^-$	0.98	[20]
	$4l$	1.02	[9]	$3l, 4l + \not\!\!E_T$	2.1	[21]
	$2l$	1.04	[10]	$3l, 4l$	2.1	[22]

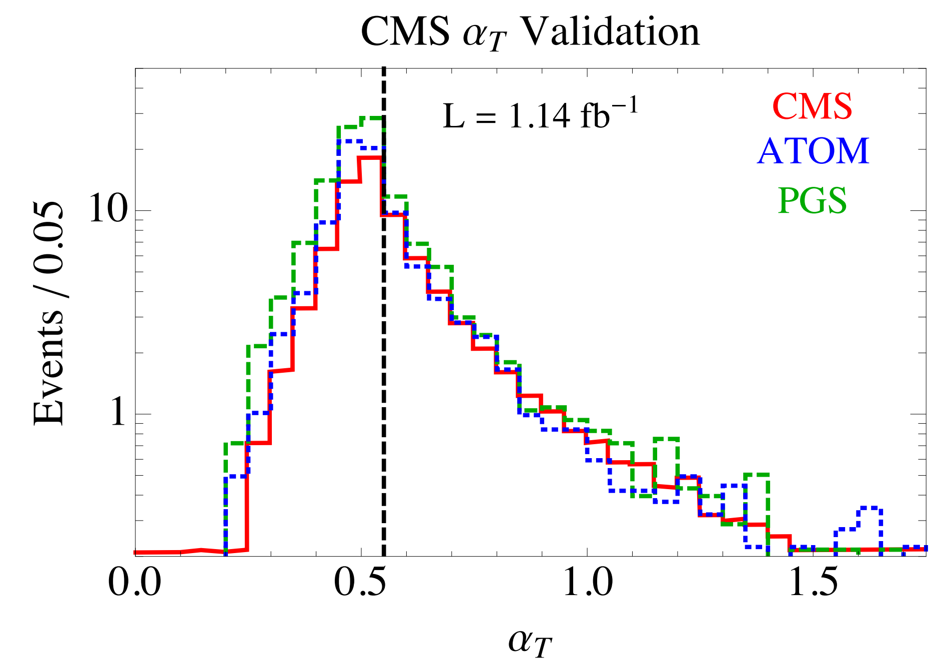
we simulated all of these searches (minus the red ones), and checked how they constrain natural SUSY

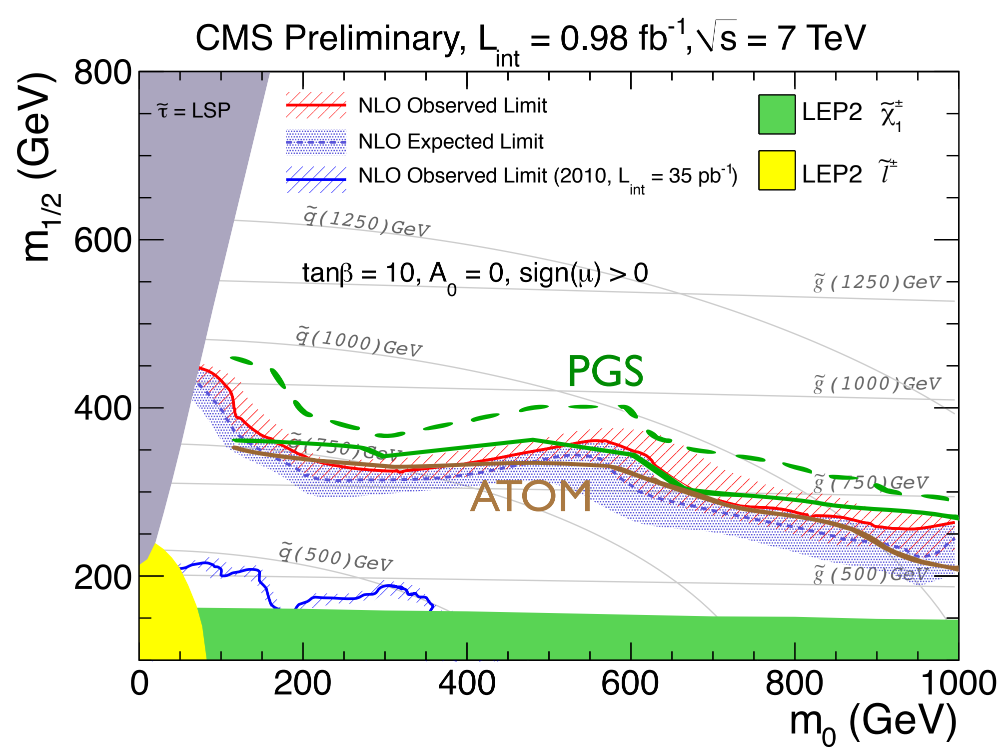
our pipelines

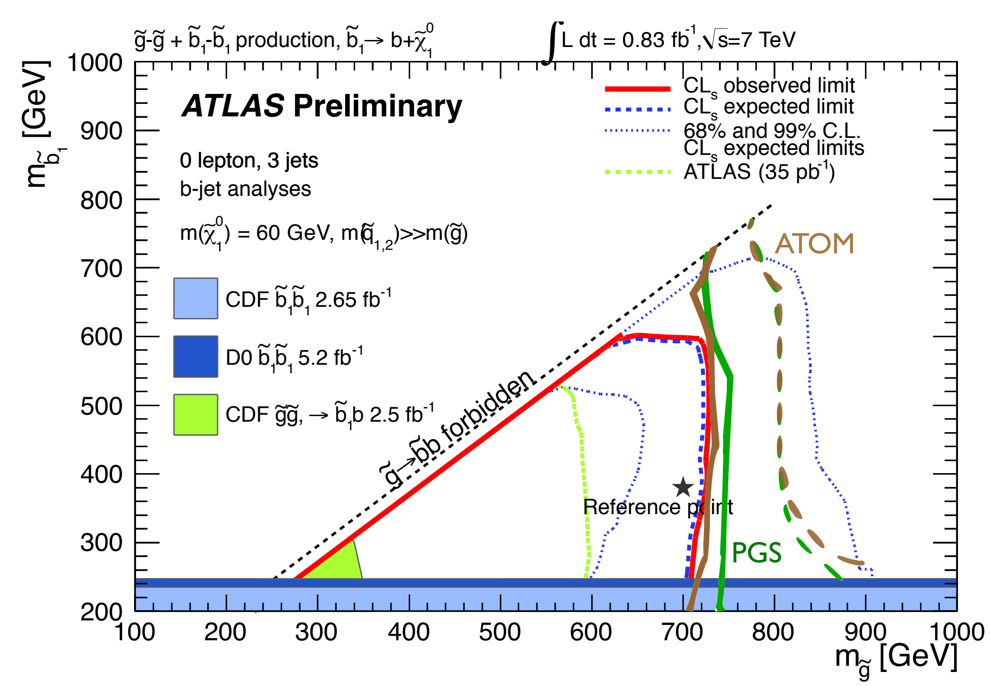


we calibrated all of the searches by comparing with the signal efficiencies published by the experimentalists



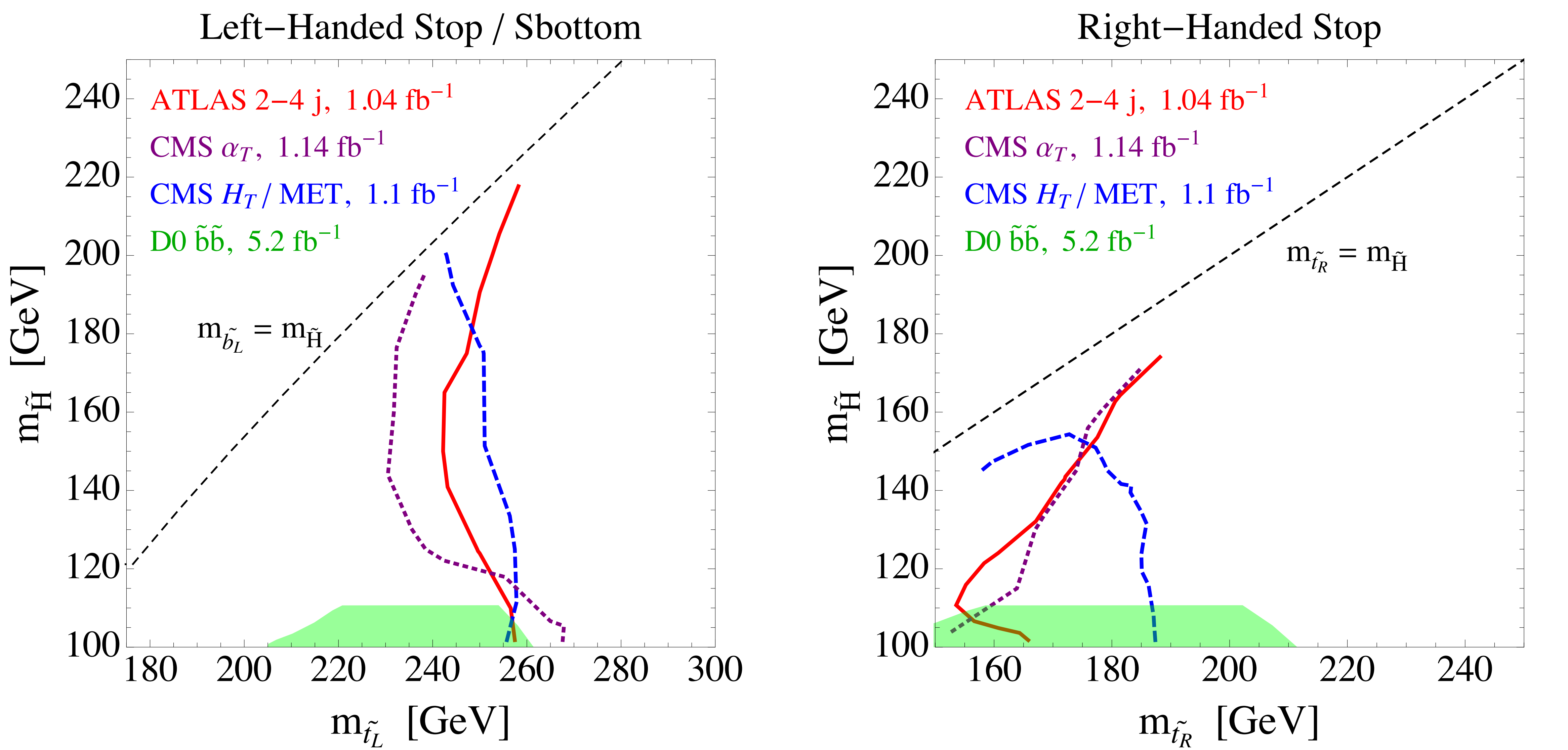




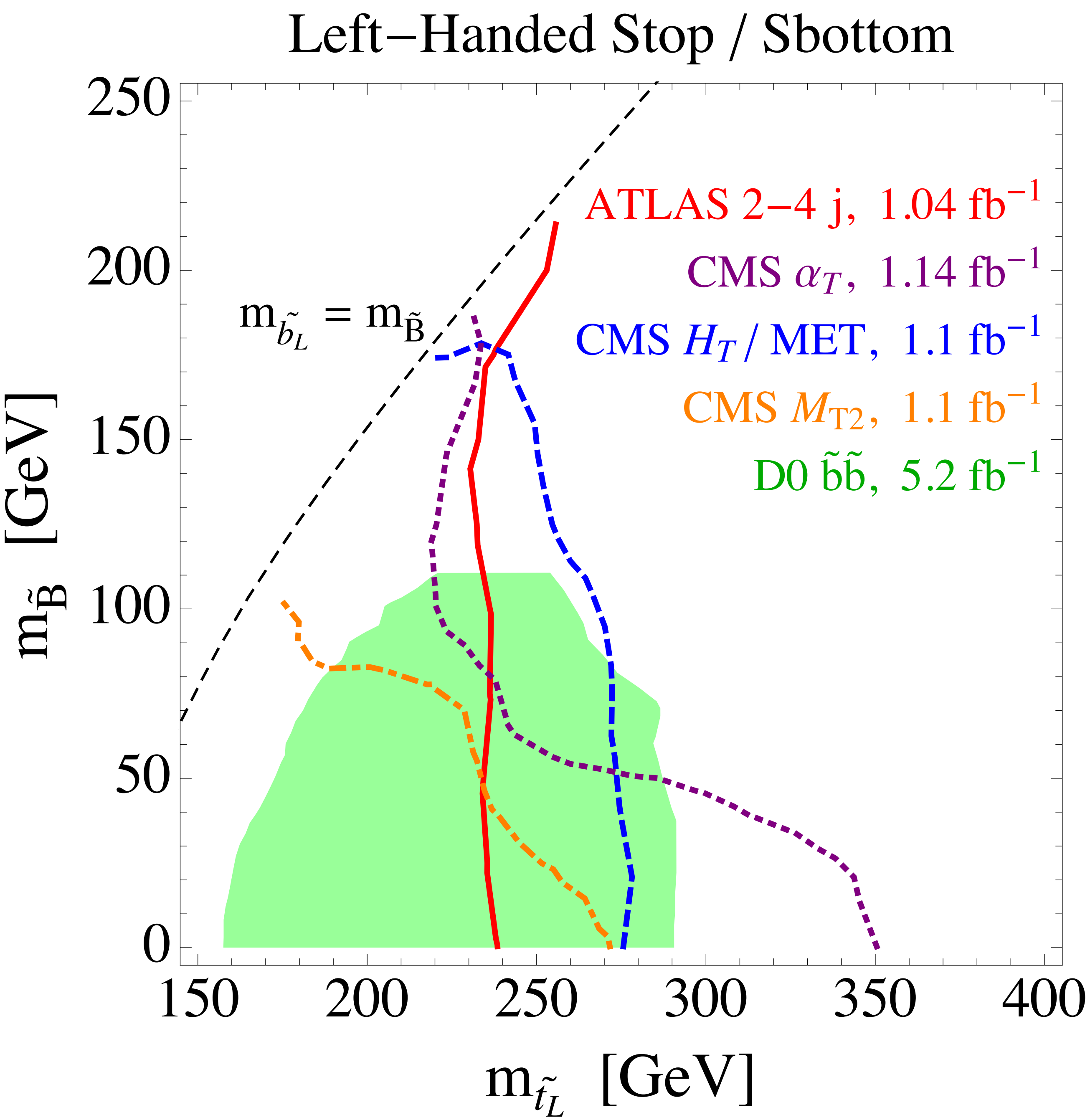


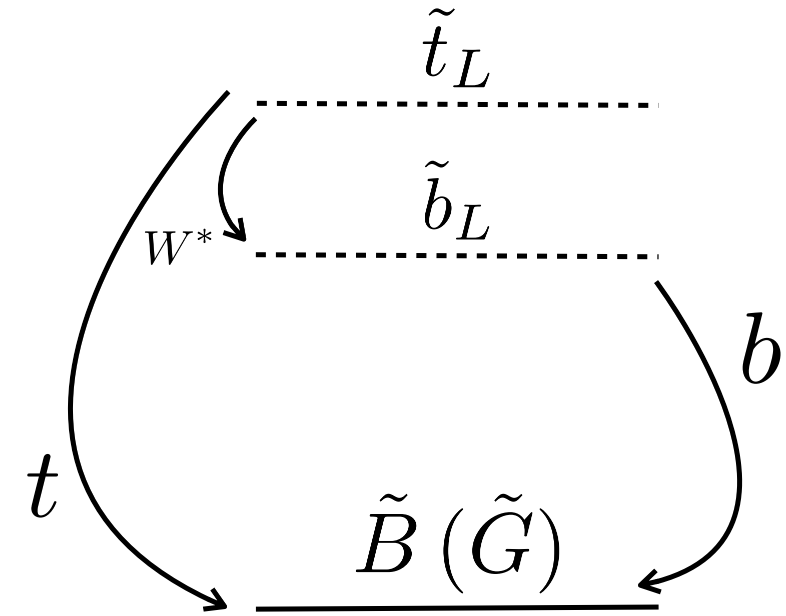
and now for the results...

stop v higgsino

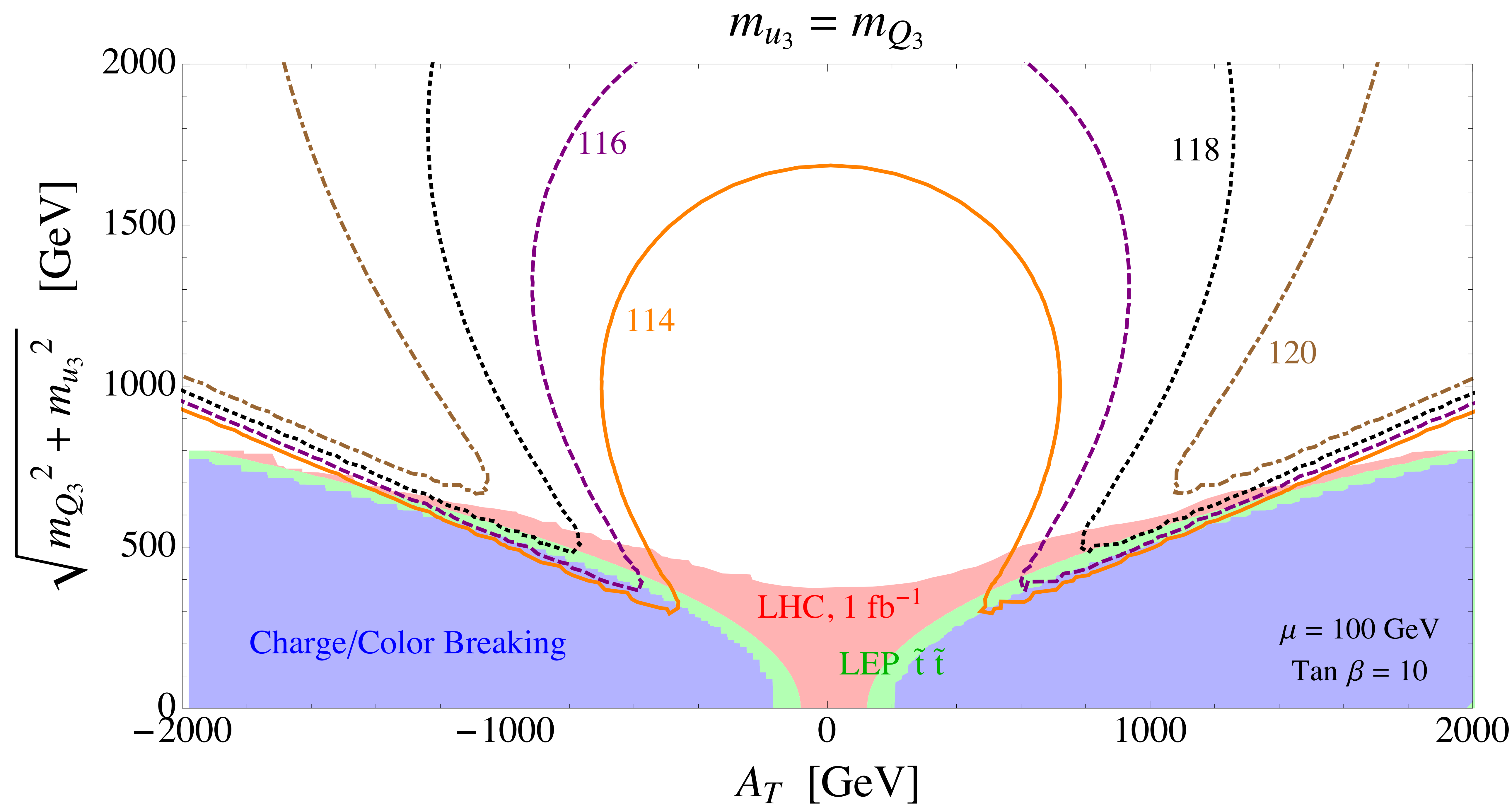


(lefty) stop v bino





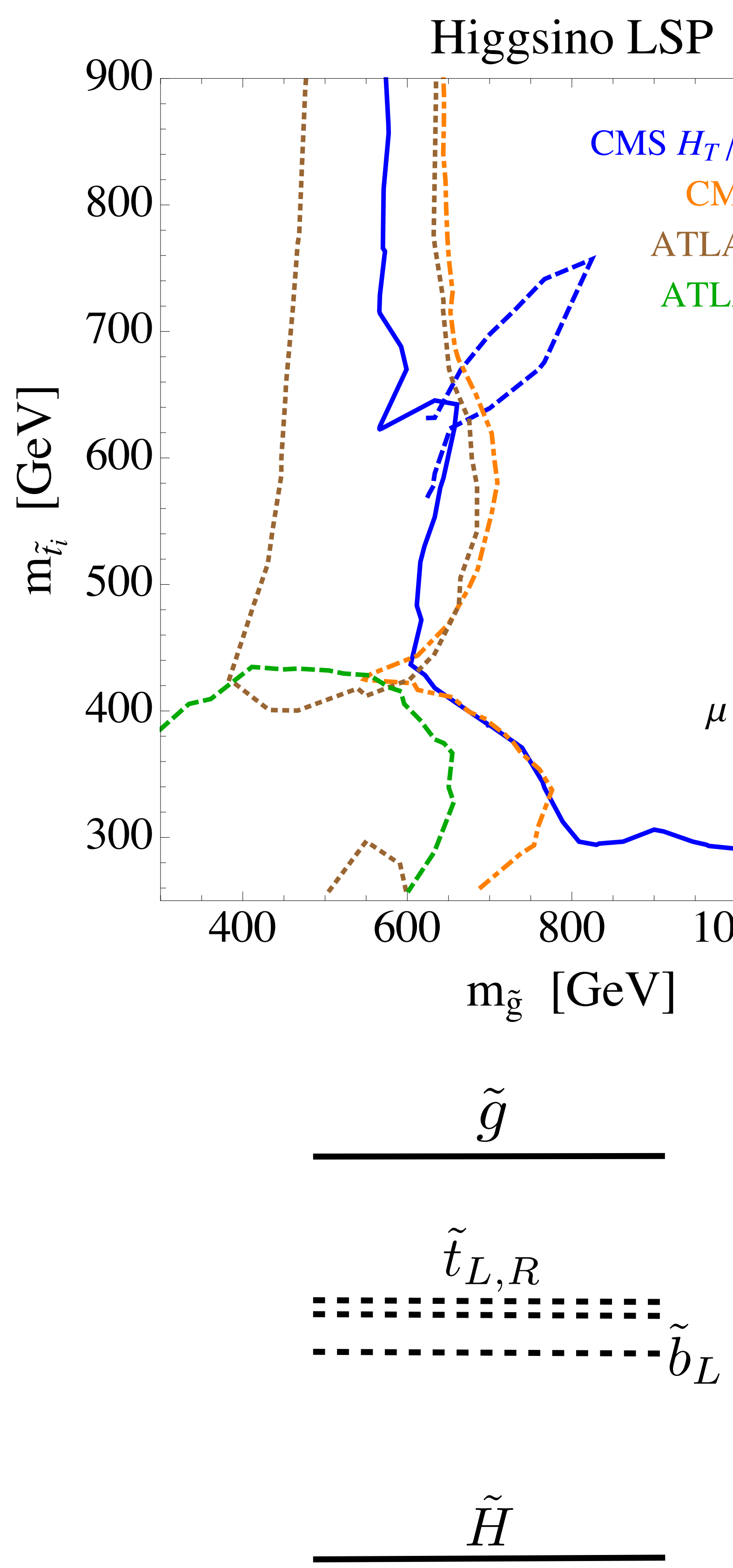
what about the MSSM?

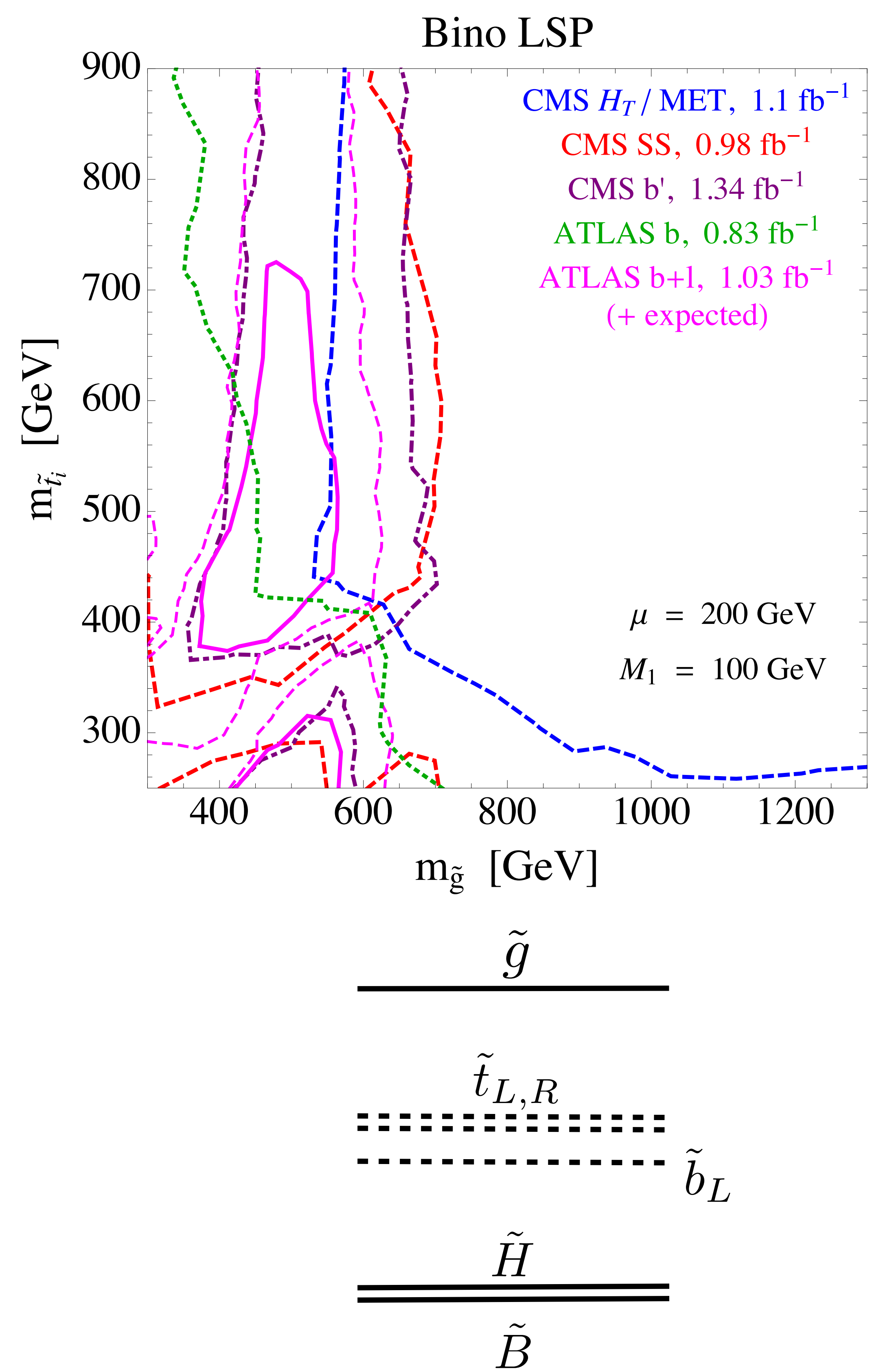


note that the fine-tuning is
proportional to the (squared)
distance from the origin

$$\delta m_{H_u}^2 \propto m_{Q_3}^2 + m_{u_3}^2 + |A_t|^2$$

gluinos decaying to stops and sbottom





take away points

- higgsinos, stops, and the gluino should be light and the rest of the spectrum doesn't matter

- fine tuning points towards light stops split from the other squarks

- We find limits that are still consistent with ~1/3 fine tuning.

$$m_{\tilde{H}} \gtrsim 100 \text{ GeV}$$
$$m_{\tilde{t}} \gtrsim 300 \text{ GeV}$$
$$m_{\tilde{g}} \gtrsim 700 \text{ GeV}$$

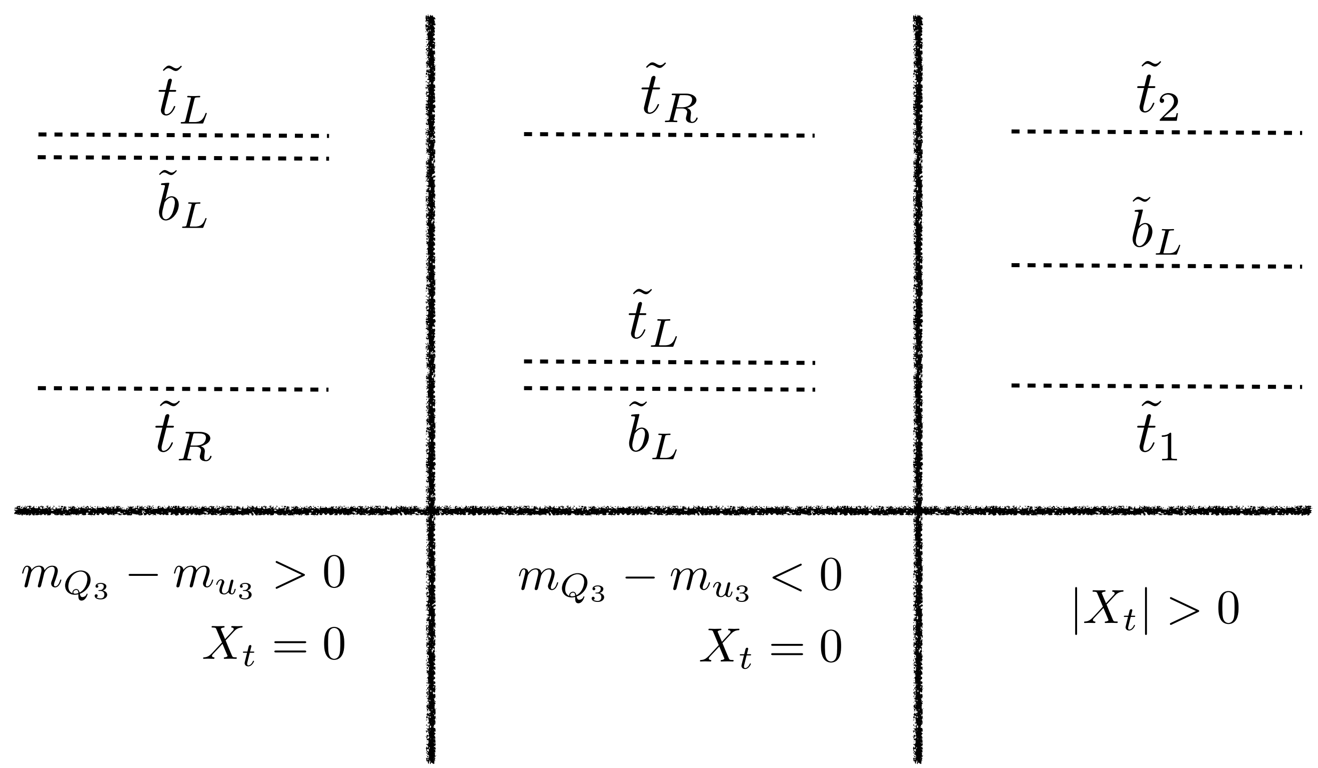
- don't worry, be happy.

(the most interesting parameter space lies just ahead, but is challenging)

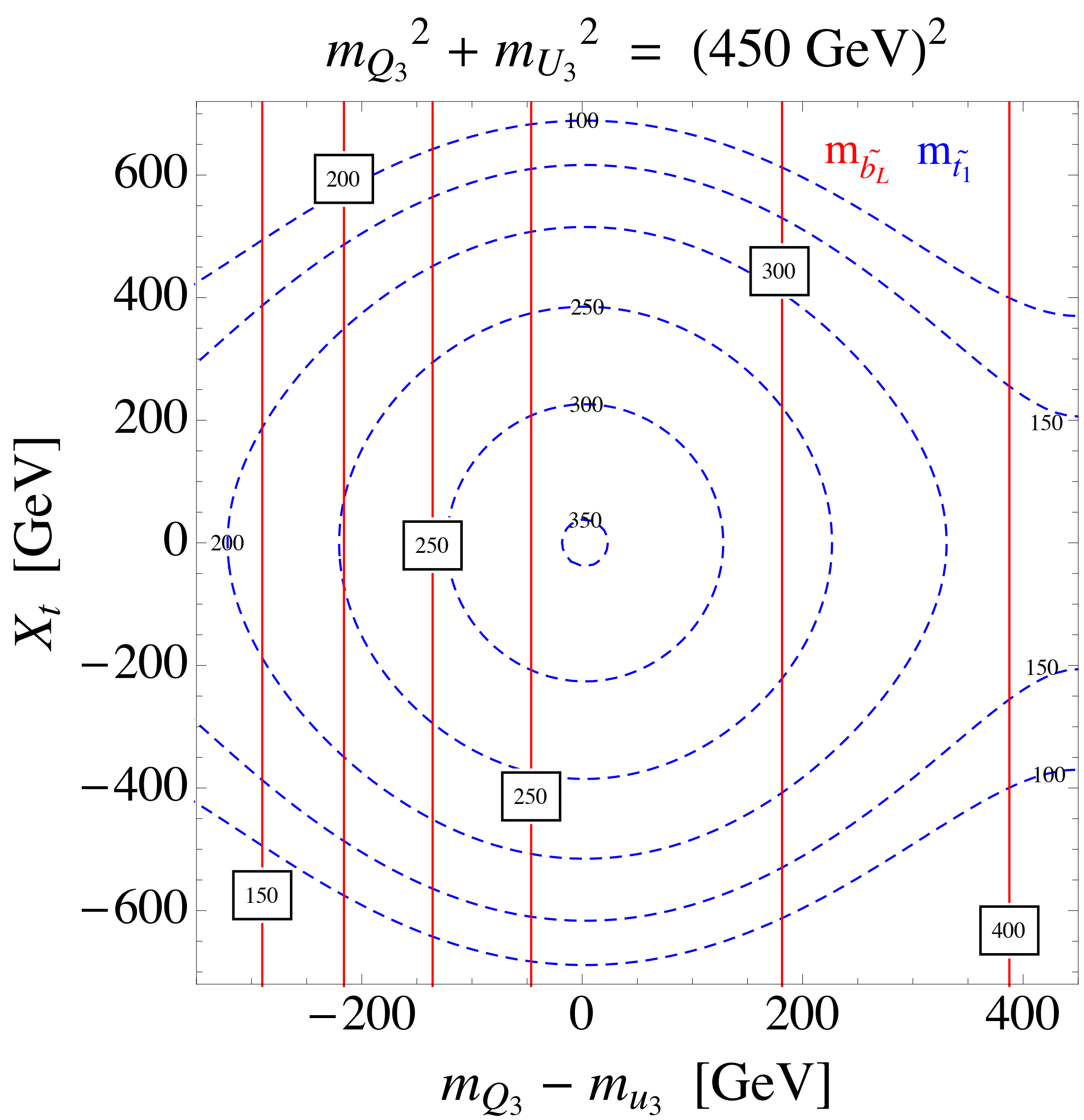
backup slides

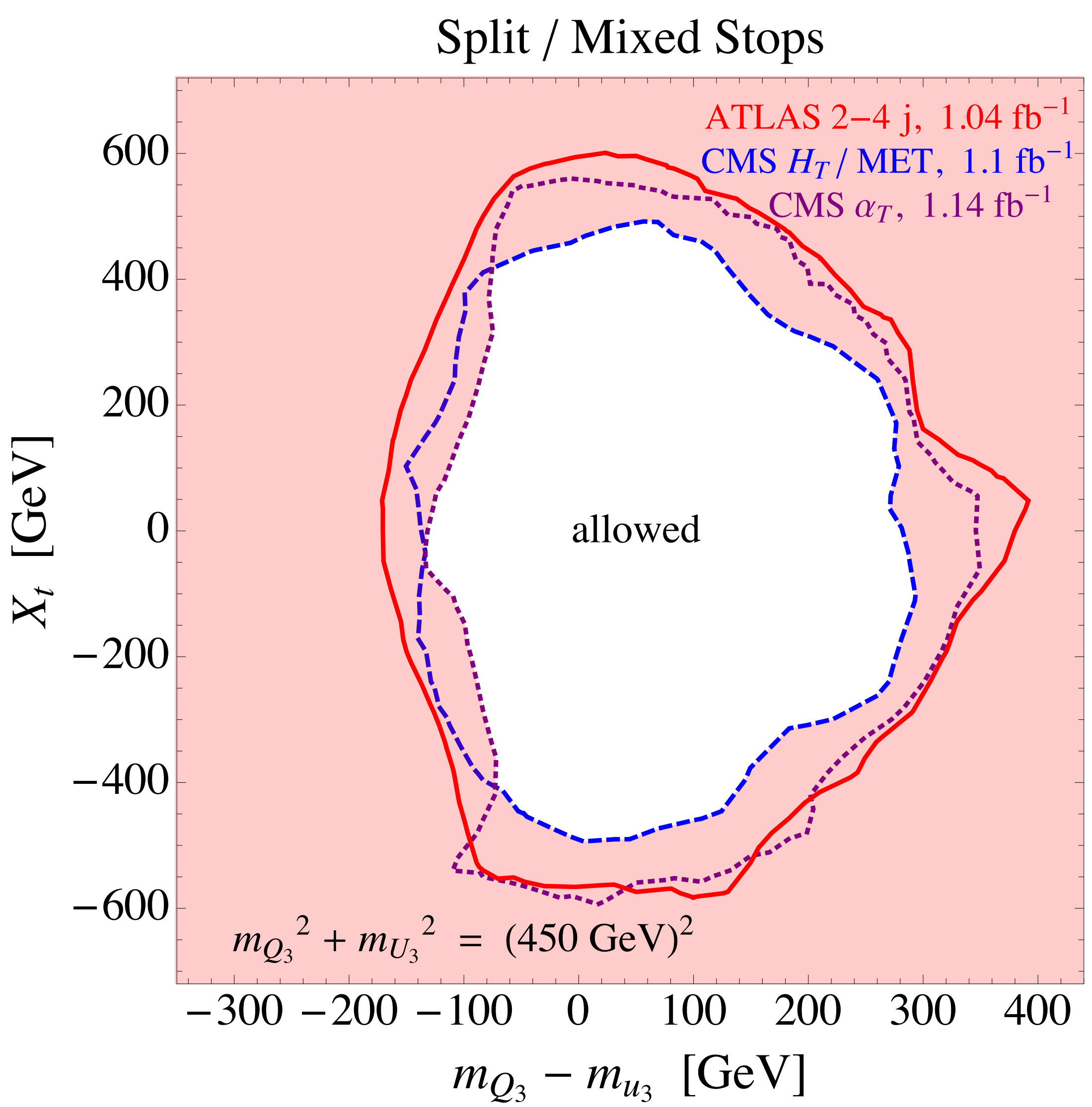
split/mixed stops

$$\begin{pmatrix} m_{Q_3}^2 + m_t^2 + t_L m_Z & m_t X_t \\ m_t X_t & m_{U_3}^2 + m_t^2 + t_R m_Z^2 \end{pmatrix}$$

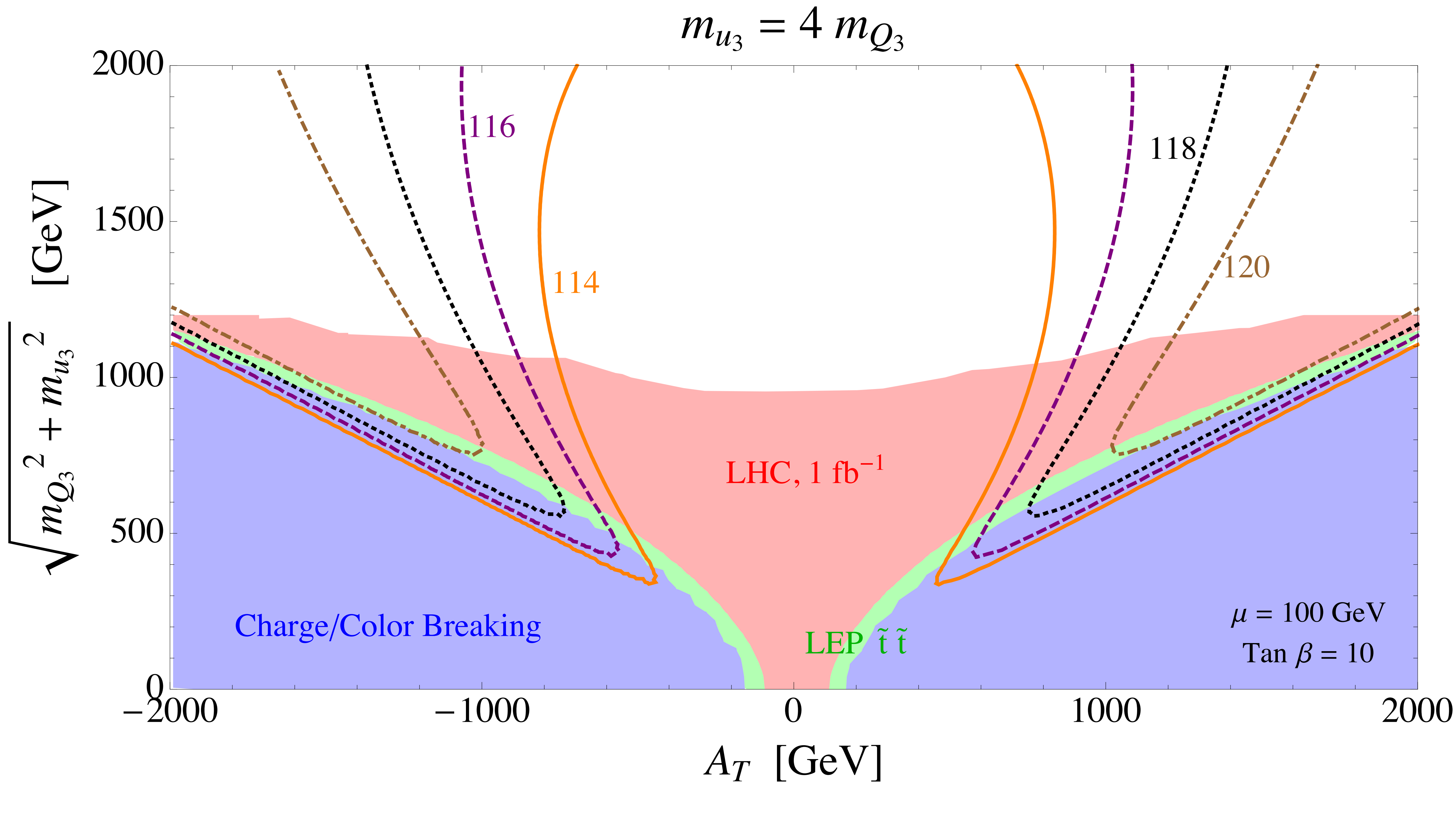


split/mixed stops

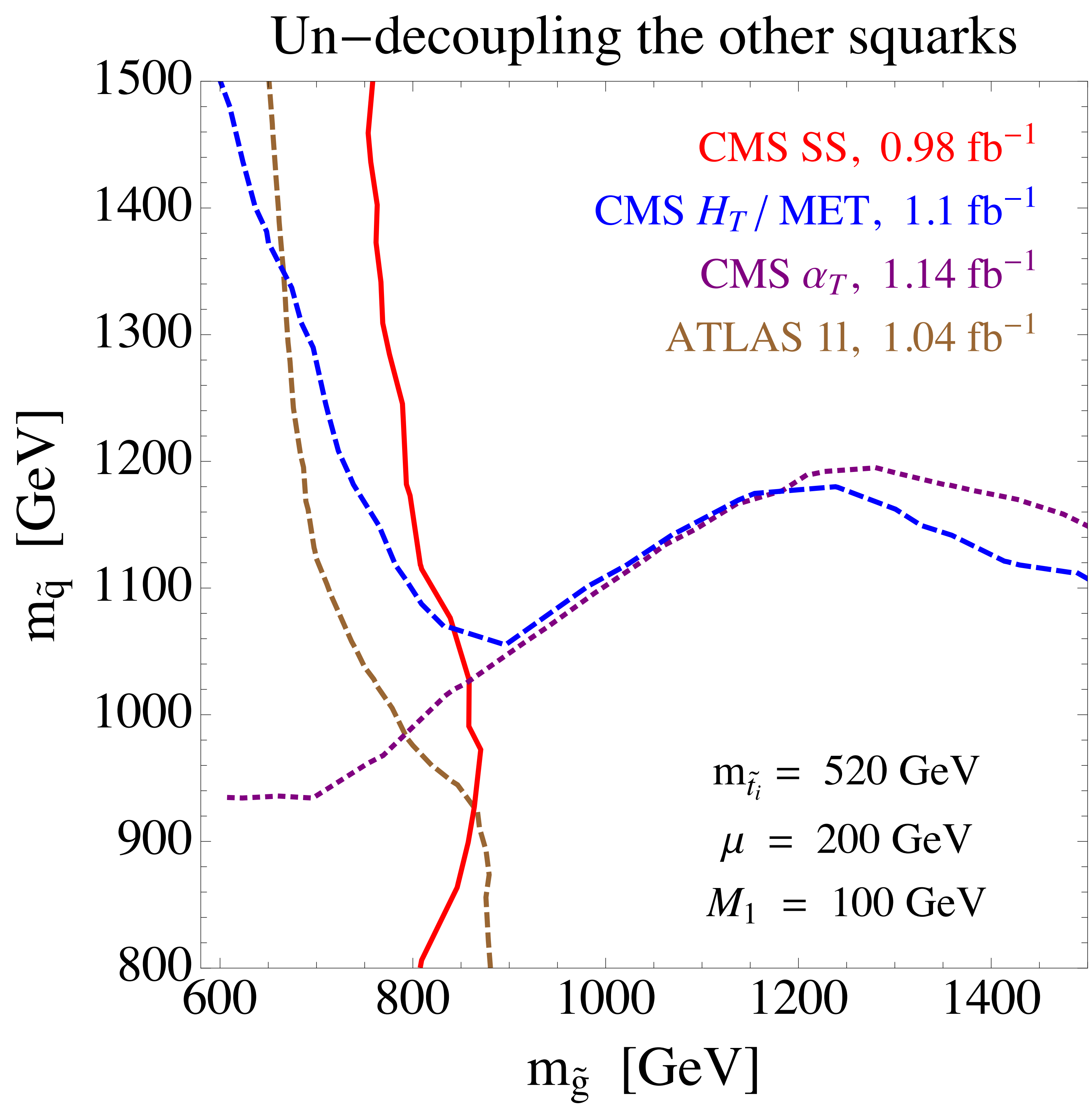


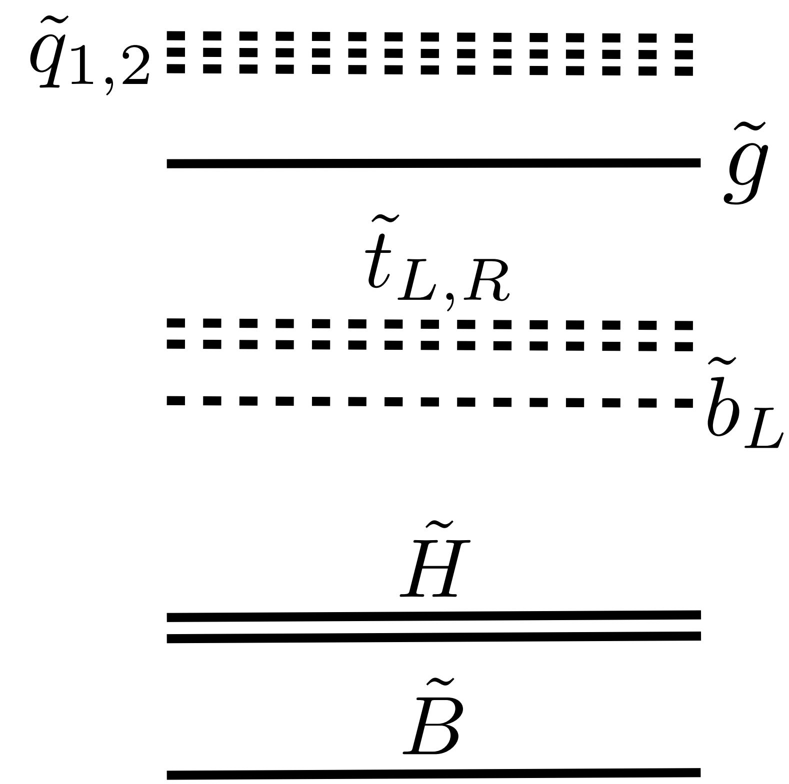


split/mixed stops



the other squarks?





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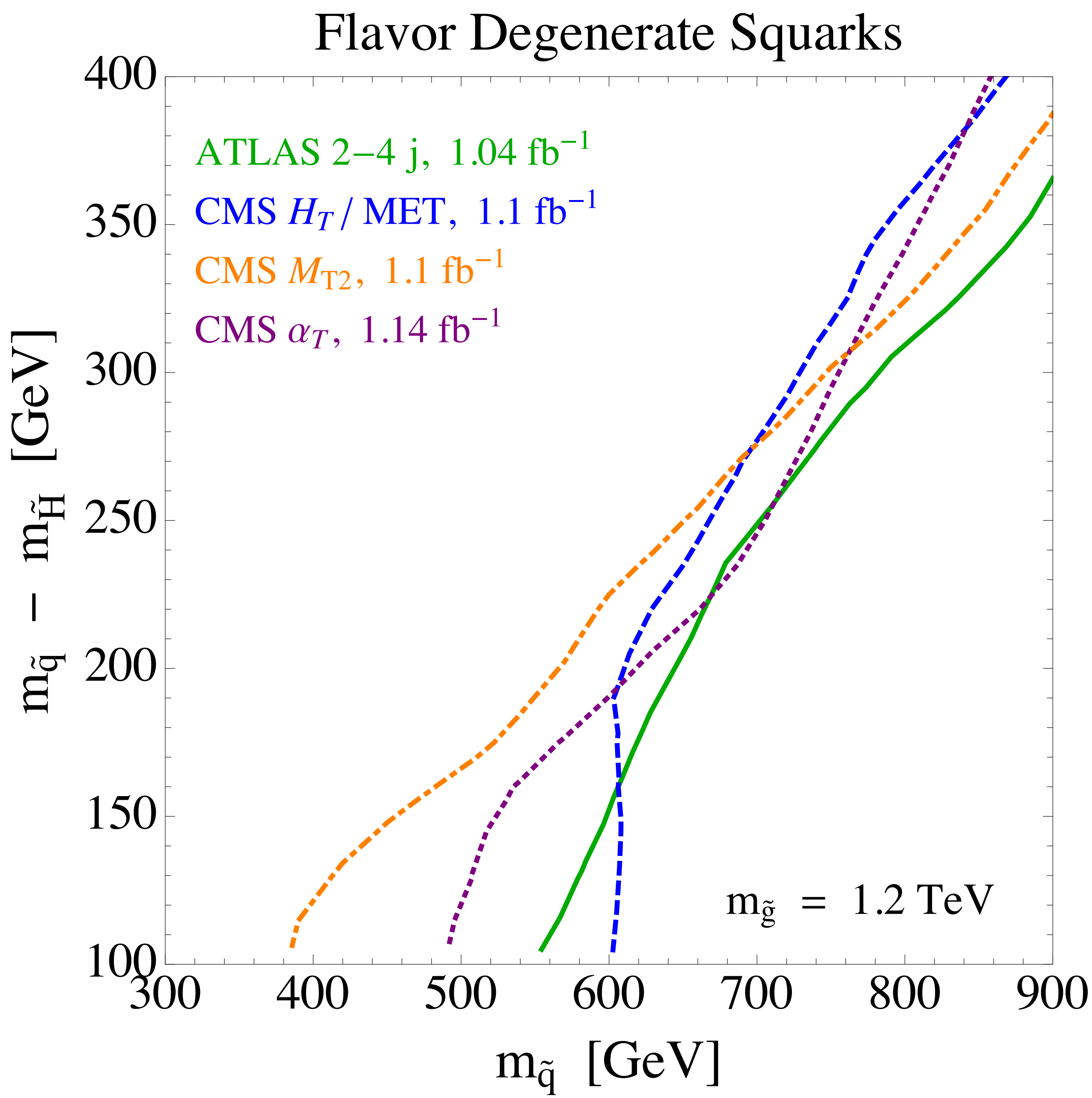
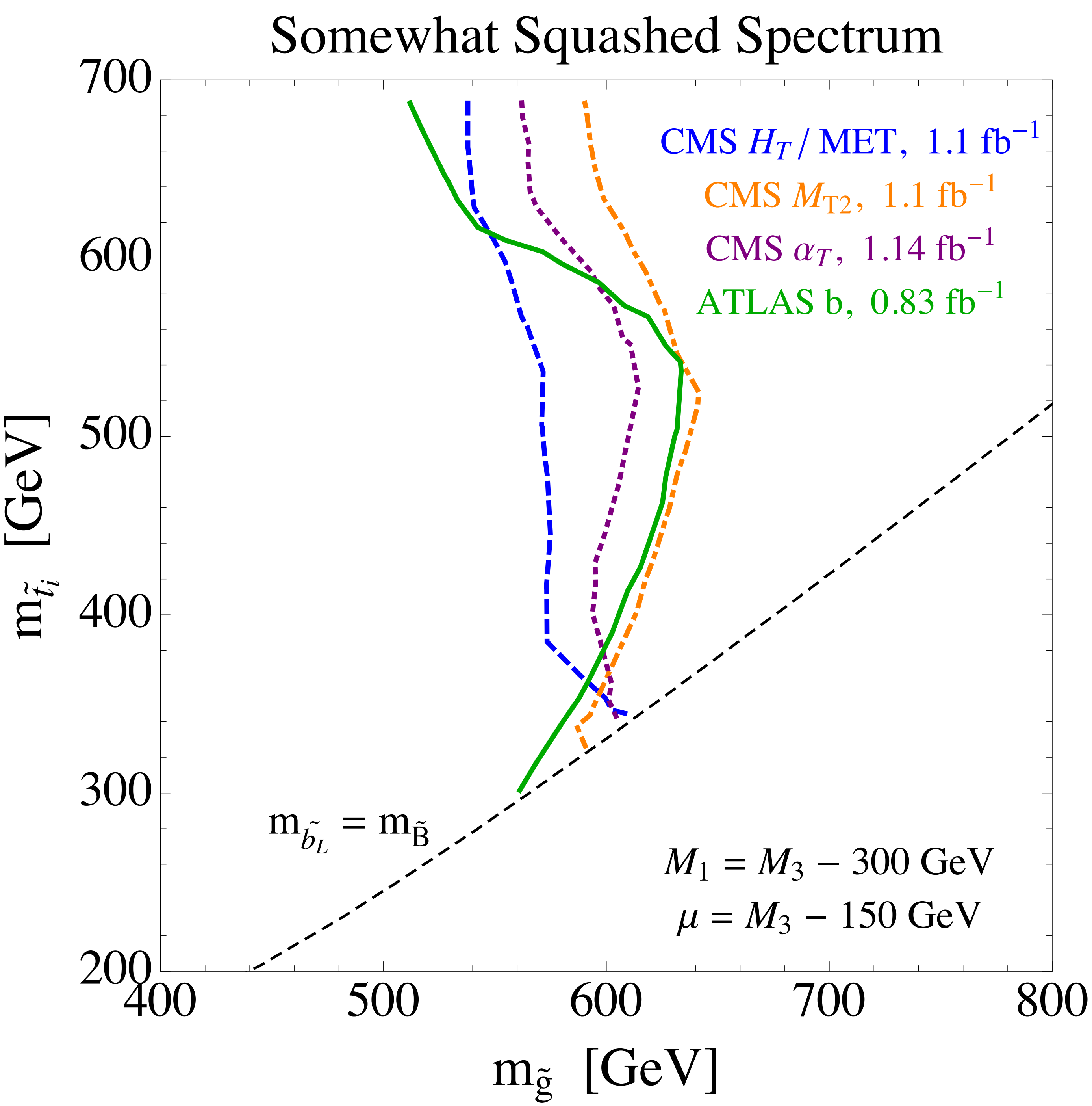
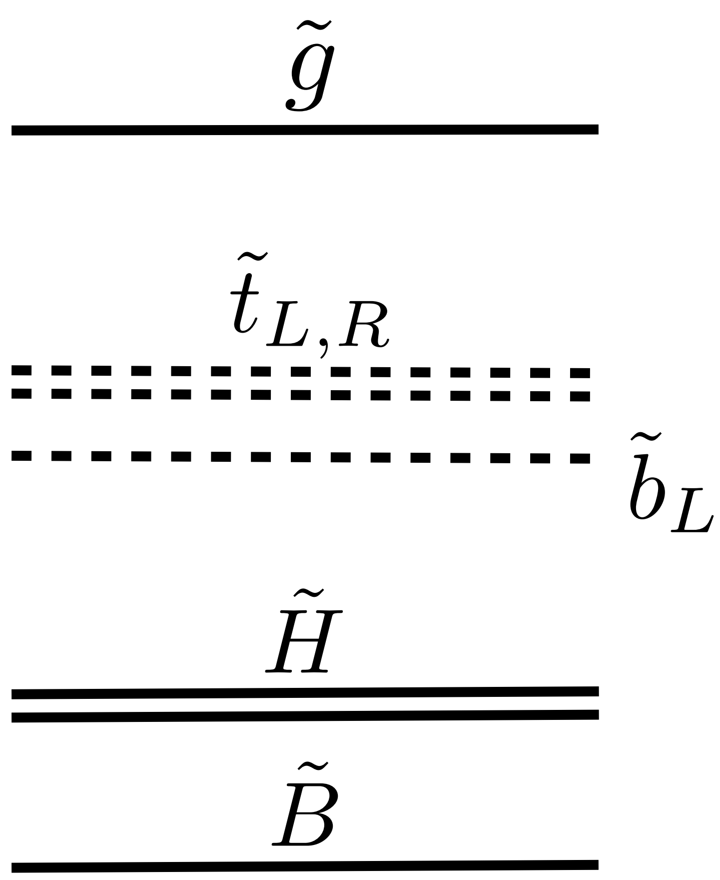


squished

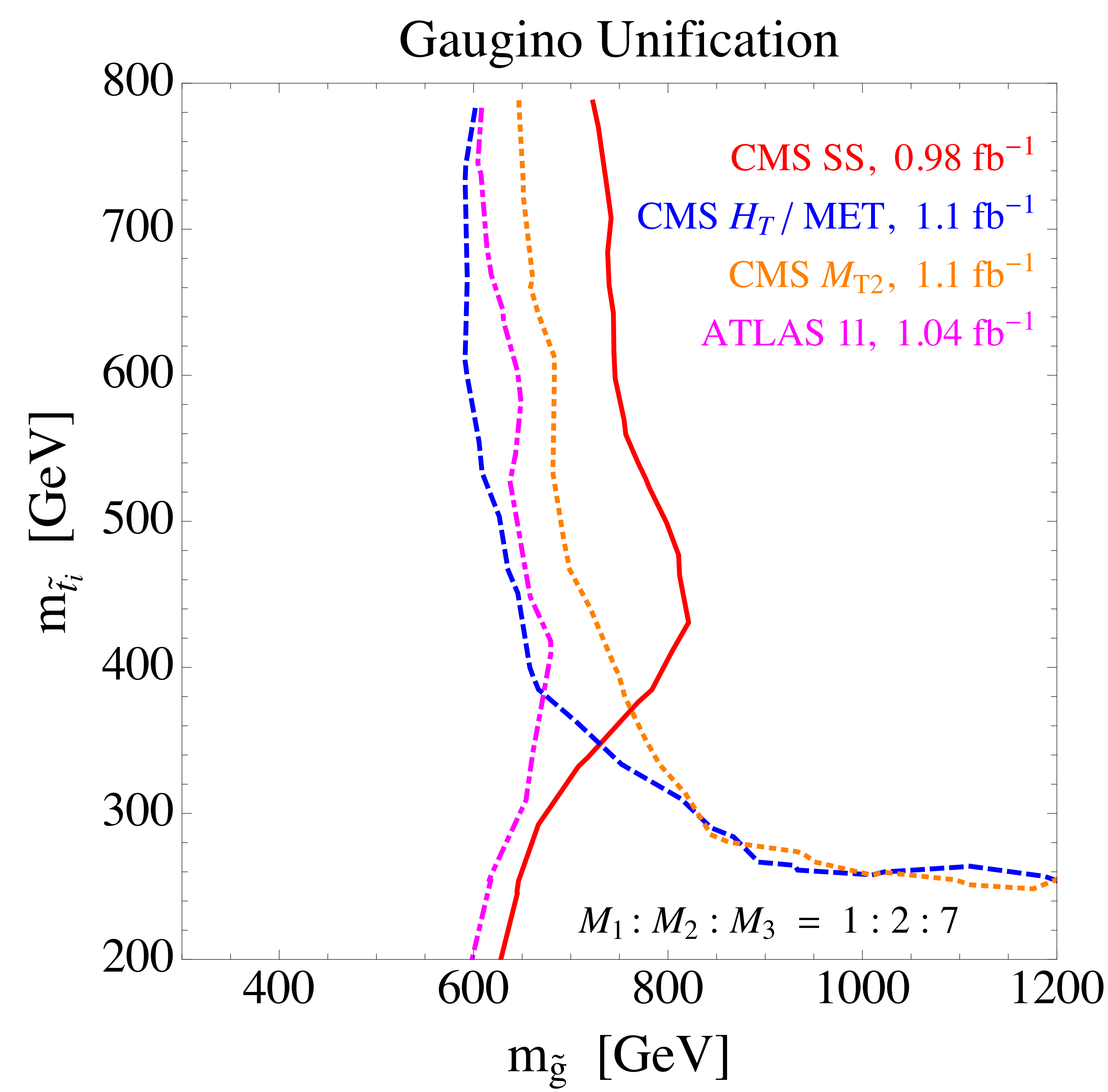


Somewhat Squashed Spectrum
CMS H_T / MET, 1.1 fb^{-1}
CMS M_{T2}, 1.1 fb^{-1}
CMS α_T, 1.14 fb^{-1}
ATLAS b, 0.83 fb^{-1}
$m_{\tilde{b}_L} = m_{\tilde{B}}$
$M_1 = M_3 - 300$ GeV
$\mu = M_3 - 150$ GeV
$m_{\tilde{t}_i}$ [GeV]
$m_{\tilde{g}}$ [GeV]
200
300
400
500
600
700
400
500
600
700
800



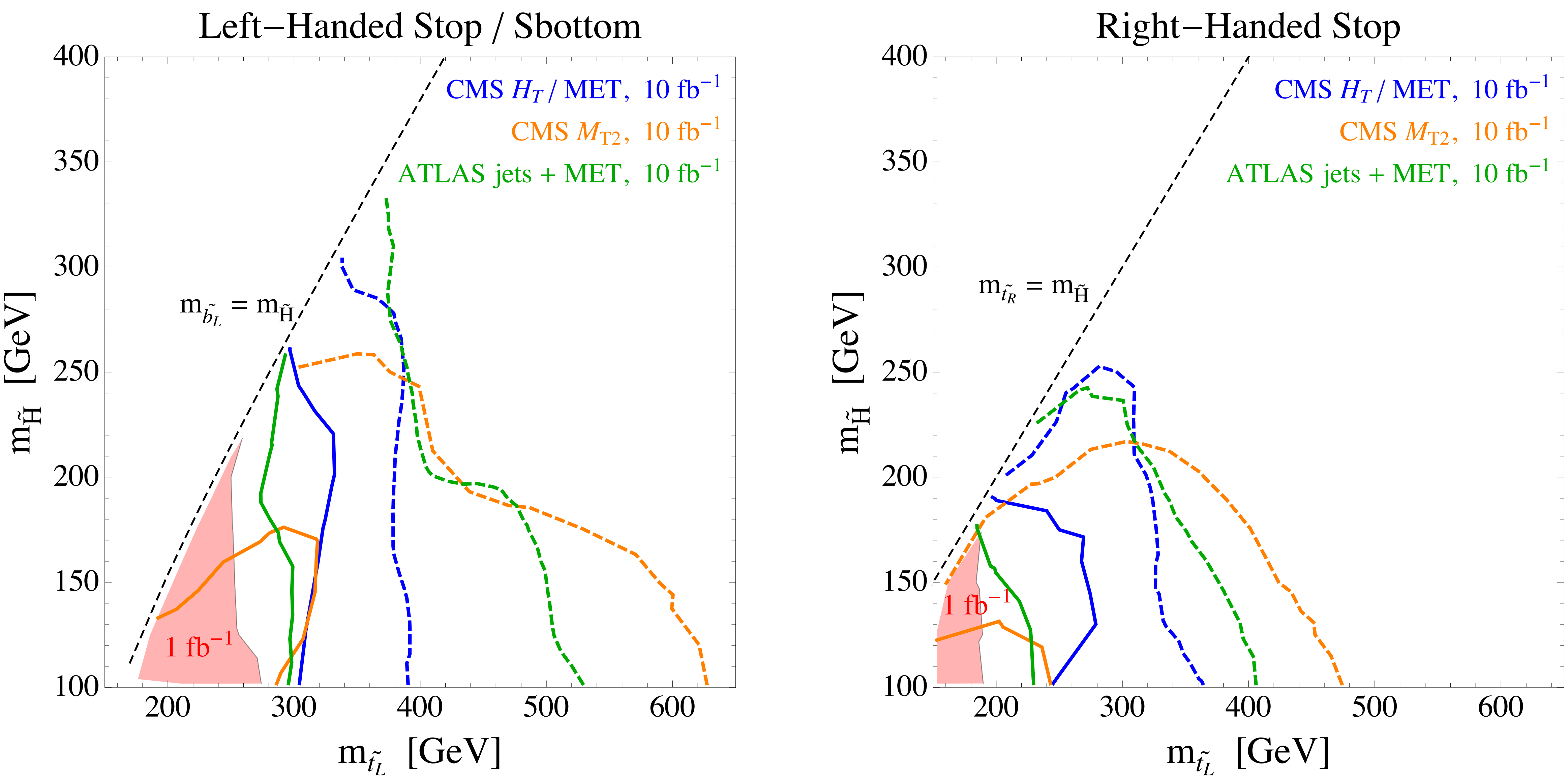
$\tilde{g}$
$\tilde{t}_{L,R}$
$\tilde{b}_L$
$\tilde{H}$
$\tilde{B}$

unify



Gaugino Unification
CMS SS, 0.98 fb^{-1}
CMS H_T / MET, 1.1 fb^{-1}
CMS M_{T2}, 1.1 fb^{-1}
ATLAS 1l, 1.04 fb^{-1}
$M_1 : M_2 : M_3 = 1 : 2 : 7$
$m_{\tilde{t}_i}$ [GeV]
$m_{\tilde{g}}$ [GeV]
200
300
400
500
600
700
800
400
600
800
1000
1200

stop reach



Left−Handed Stop / Sbottom
CMS H_T / MET, 10 fb^{-1}
CMS M_{T2}, 10 fb^{-1}
ATLAS jets + MET, 10 fb^{-1}
$m_{\tilde{b}_L} = m_{\tilde{H}}$
1 fb^{-1}
$m_{\tilde{H}}$ [GeV]
$m_{\tilde{t}_L}$ [GeV]
Right−Handed Stop
CMS H_T / MET, 10 fb^{-1}
CMS M_{T2}, 10 fb^{-1}
ATLAS jets + MET, 10 fb^{-1}
$m_{\tilde{t}_R} = m_{\tilde{H}}$
1 fb^{-1}
$m_{\tilde{H}}$ [GeV]
$m_{\tilde{t}_L}$ [GeV]

gluino/stop reach