Natural Susy Endures

Andreas Weiler
(DESY)

Implications of LHC results
for TeV-scale physics: WG2 meeting
11/1/11

In collaboration w/
Michele Papucci & Josh Ruderman (Berkeley)
arXiv:1110.6926

The next 16 minutes

$\rightarrow$ Nima's talk

- Reminder about bottom-up naturalness: Which super-partners need to be light?
- Current status of SUSY searches
- Our Limits
  - Method & Caveats
  - Stop limits
  - +Gluino limits

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- Reminder about bottom-up naturalness: Which super-partners need to be light?
- Current status of SUSY searches
- Our Limits
    - Method & Caveats
    - Stop limits
    - +Gluino limits

Which current searches work best?

Natural EWSB & SUSY *

* valid beyond MSSM

Do not want tuning in (Higgs mass)^2

$$\frac{m^2_{Higgs}}{2} = -|\mu|^2 + \ldots + \delta m^2_H$$

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Higgsinos

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Higgsinos

1loop $\quad \delta m^2_H|_{stop} = -\frac{3}{8\pi^2} y_t^2 \left(m^2_{U_3} + m^2_{Q_3} + |A_t|^2 \right) \log\left(\frac{\Lambda}{\mathrm{TeV}}\right)$

2loop $\quad \delta m^2_H|_{gluino} = -\frac{2}{\pi^2} y_t^2 \left(\frac{\alpha_s}{\pi}\right) |M_3|^2 \log^2\left(\frac{\Lambda}{\mathrm{TeV}}\right)$

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$$\frac{m^2_{Higgs}}{2} = -\boxed{|\mu|^2} + \ldots + \boxed{\delta m^2_H}$$

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1loop $\boxed{\delta m^2_H|_{stop}} = -\frac{3}{8\pi^2} y_t^2 \left(m^2_{U_3} + m^2_{Q_3} + |A_t|^2\right) \log\left(\frac{\Lambda}{\mathrm{TeV}}\right)$

stops, sbottom$_L$

2loop $\boxed{\delta m^2_H|_{gluino}} = -\frac{2}{\pi^2} y_t^2 \left(\frac{\alpha_s}{\pi}\right) |M_3|^2 \log^2\left(\frac{\Lambda}{\mathrm{TeV}}\right)$

gluino

Bottom-up natural spectrum

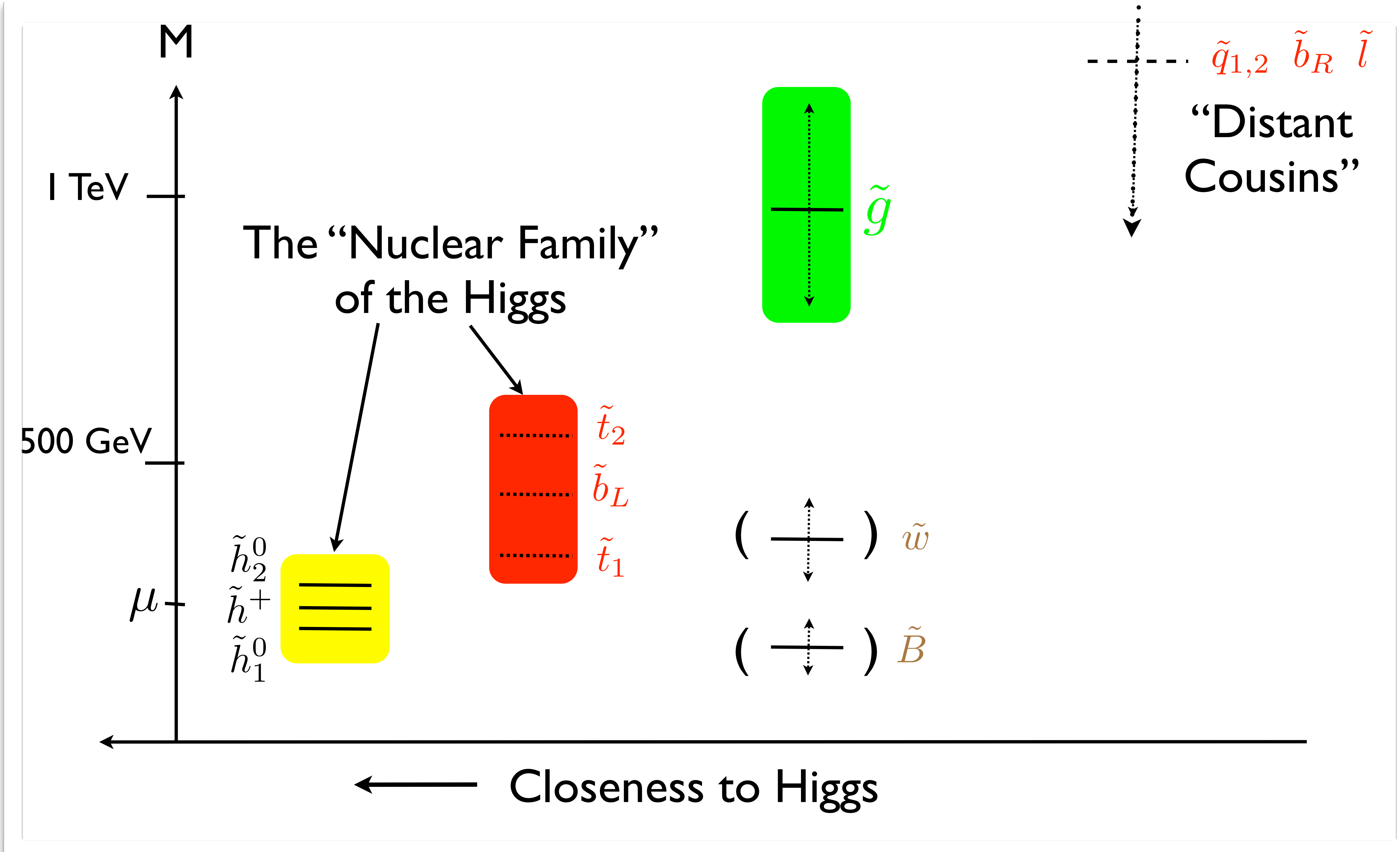


Fig. from L.Hall's recent talk @ LBL

Bottom-up natural spectrum

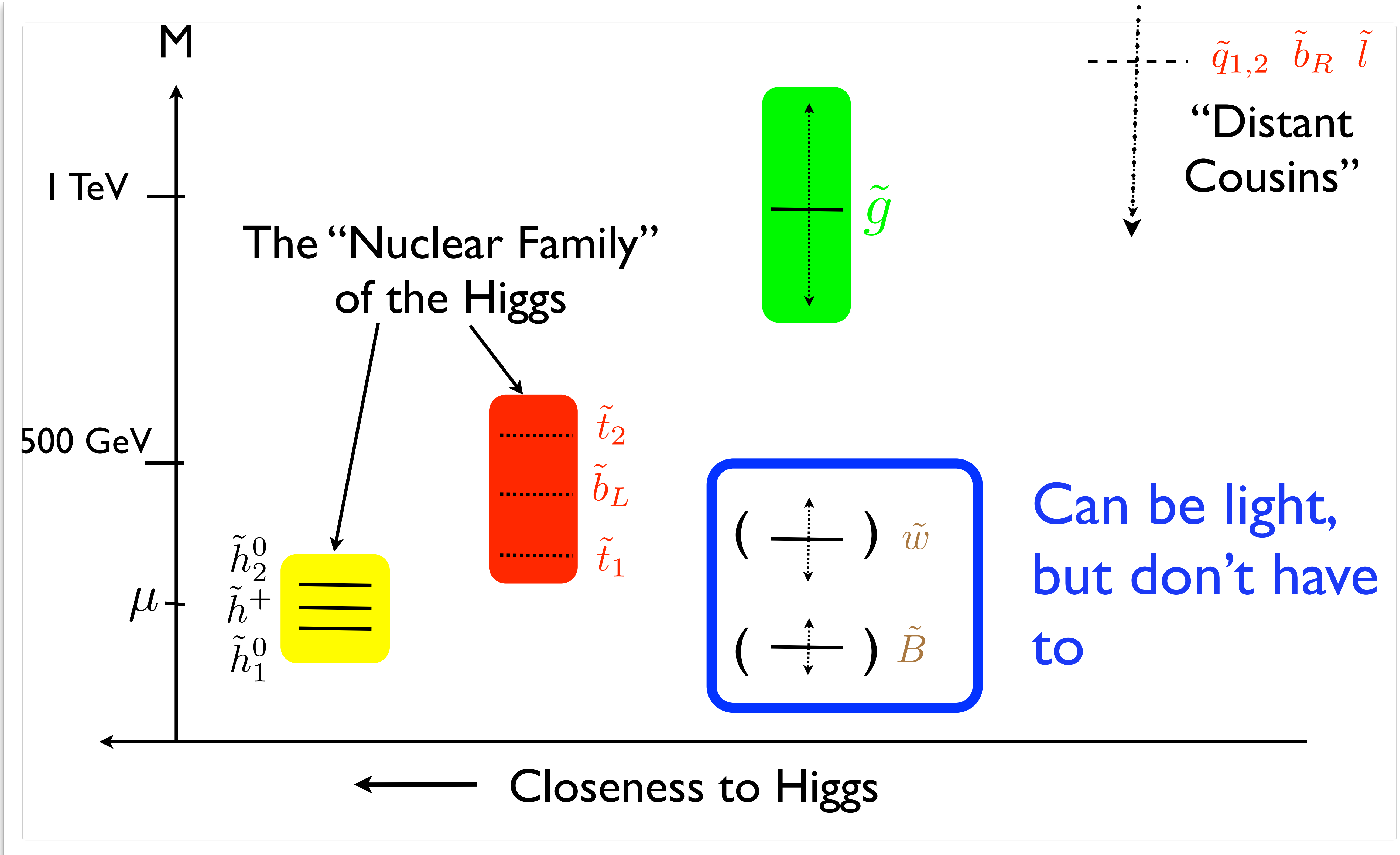
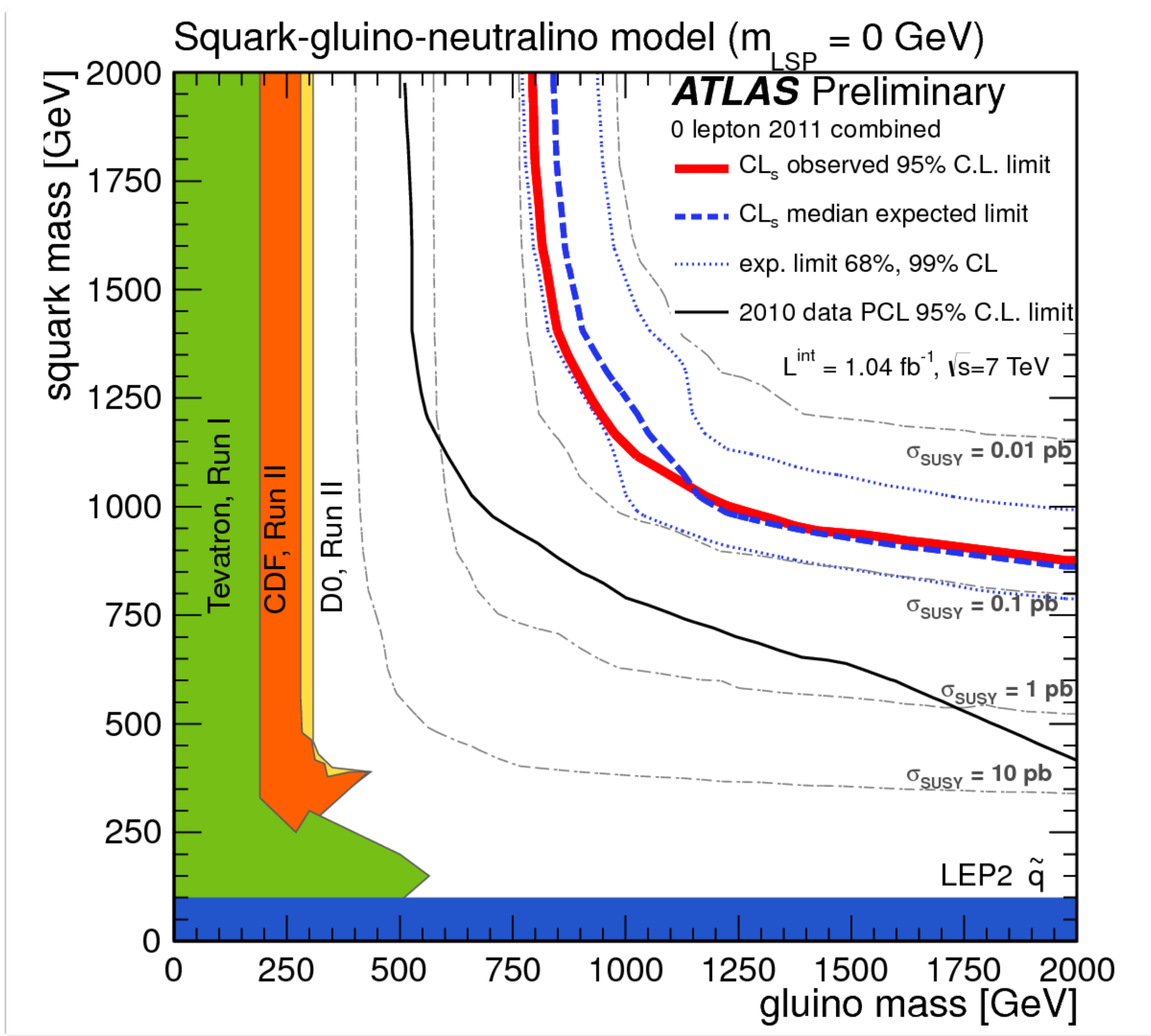


Fig. from L.Hall's recent talk @ LBL

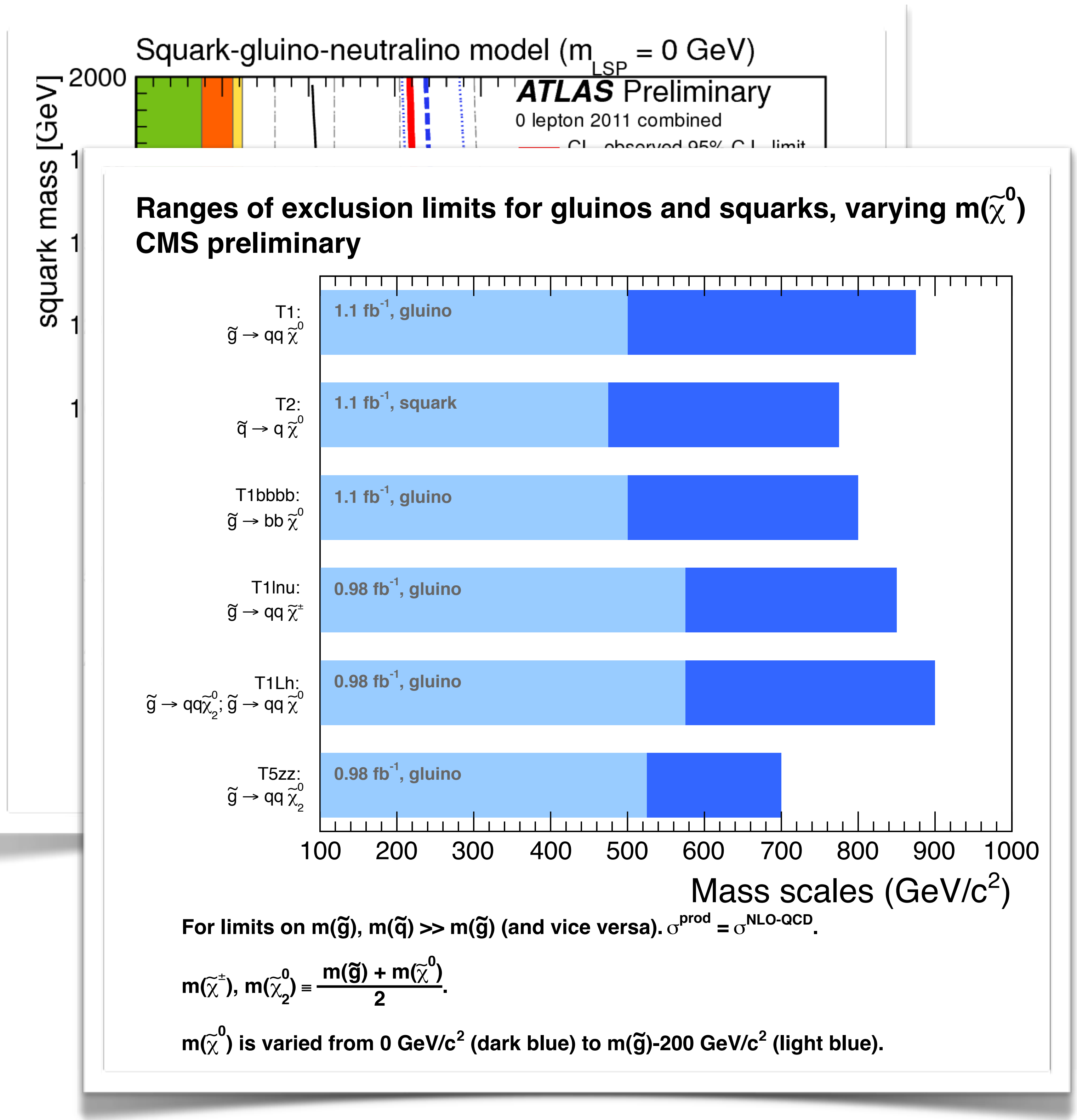
Current status



Gluino $\gtrsim$ 0.7-0.9 TeV

Squarks$_{1,2}$ $\gtrsim$ 0.8 -1 TeV

Current status



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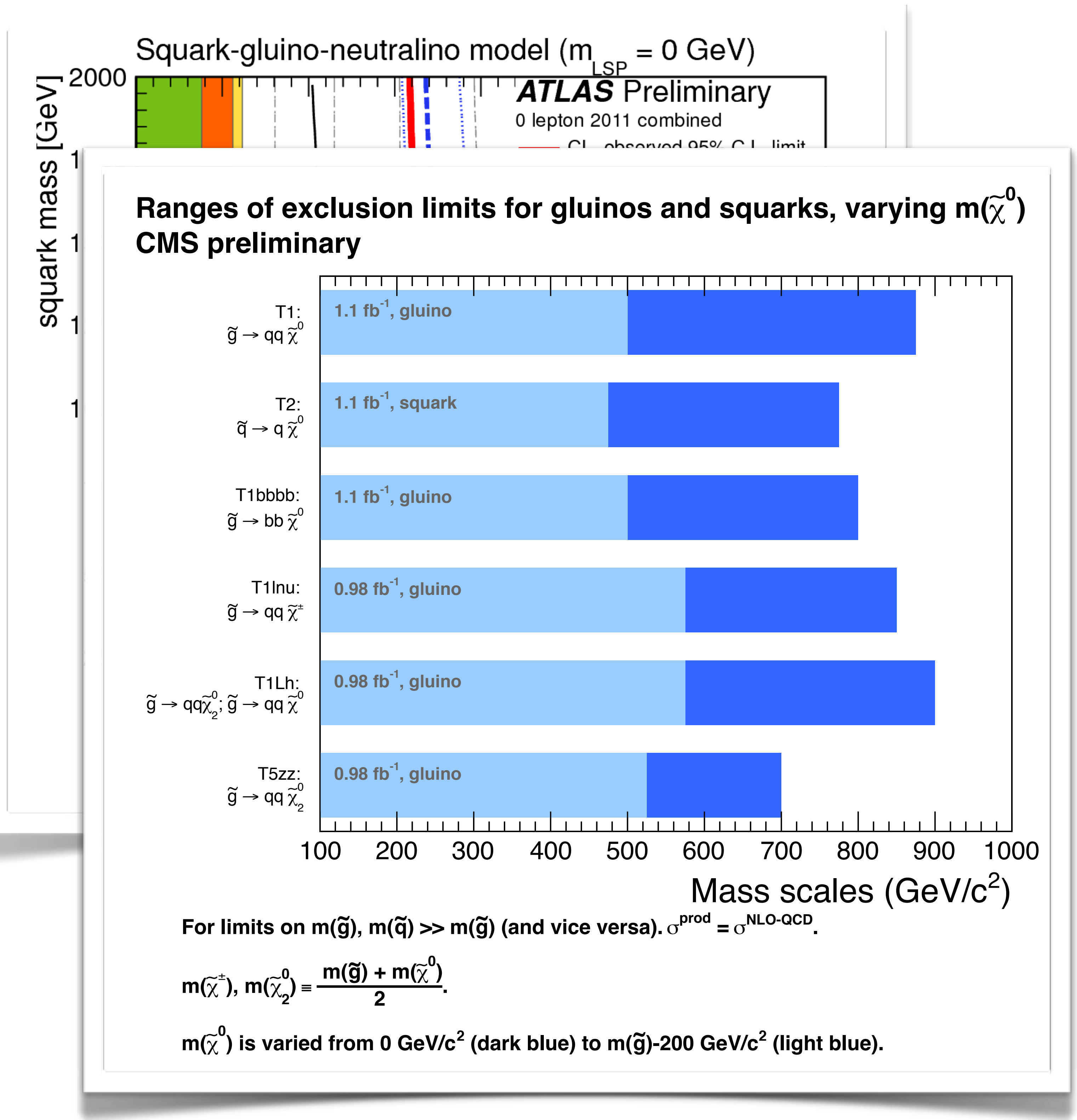


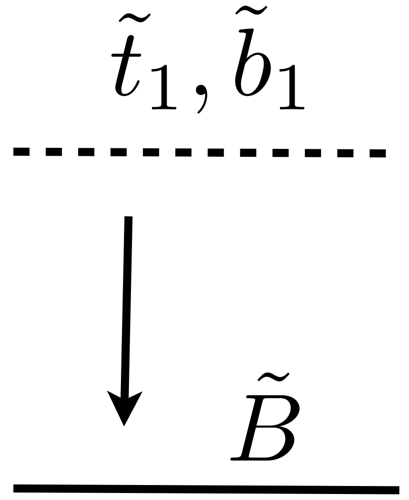
Gluino $\gtrsim$ 0.7-0.9 TeV

Squarks$_{1,2}$ $\gtrsim$ 0.8 -1 TeV

For natural spectrum need to split 1,2 vs. 3rd generation squarks

Existing limits on Stops and sbottoms

- Tevatron:
  - Stops can still be light (even 120-180 GeV)
  - Sbottoms should be > 250 GeV



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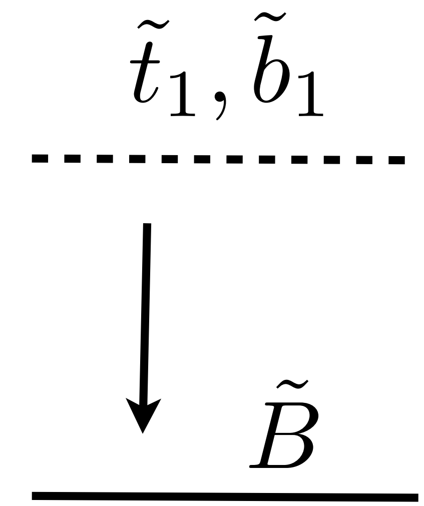
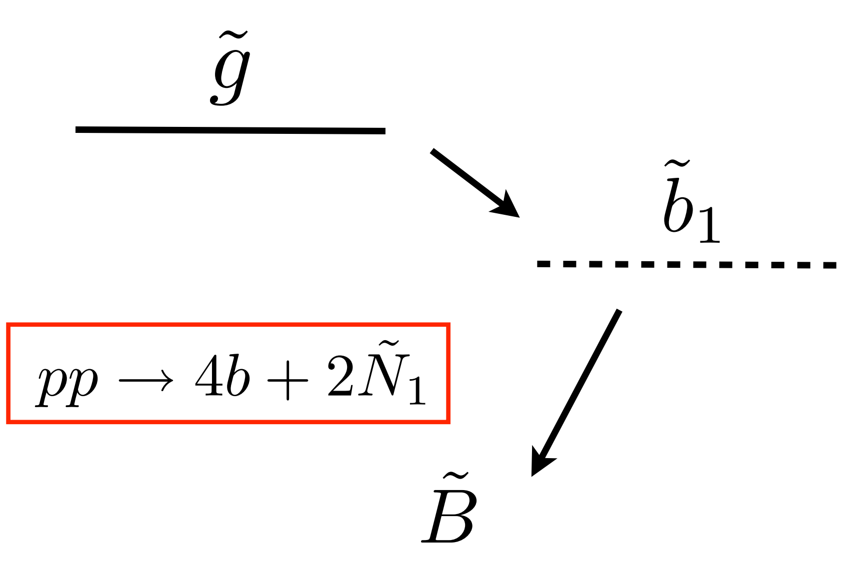
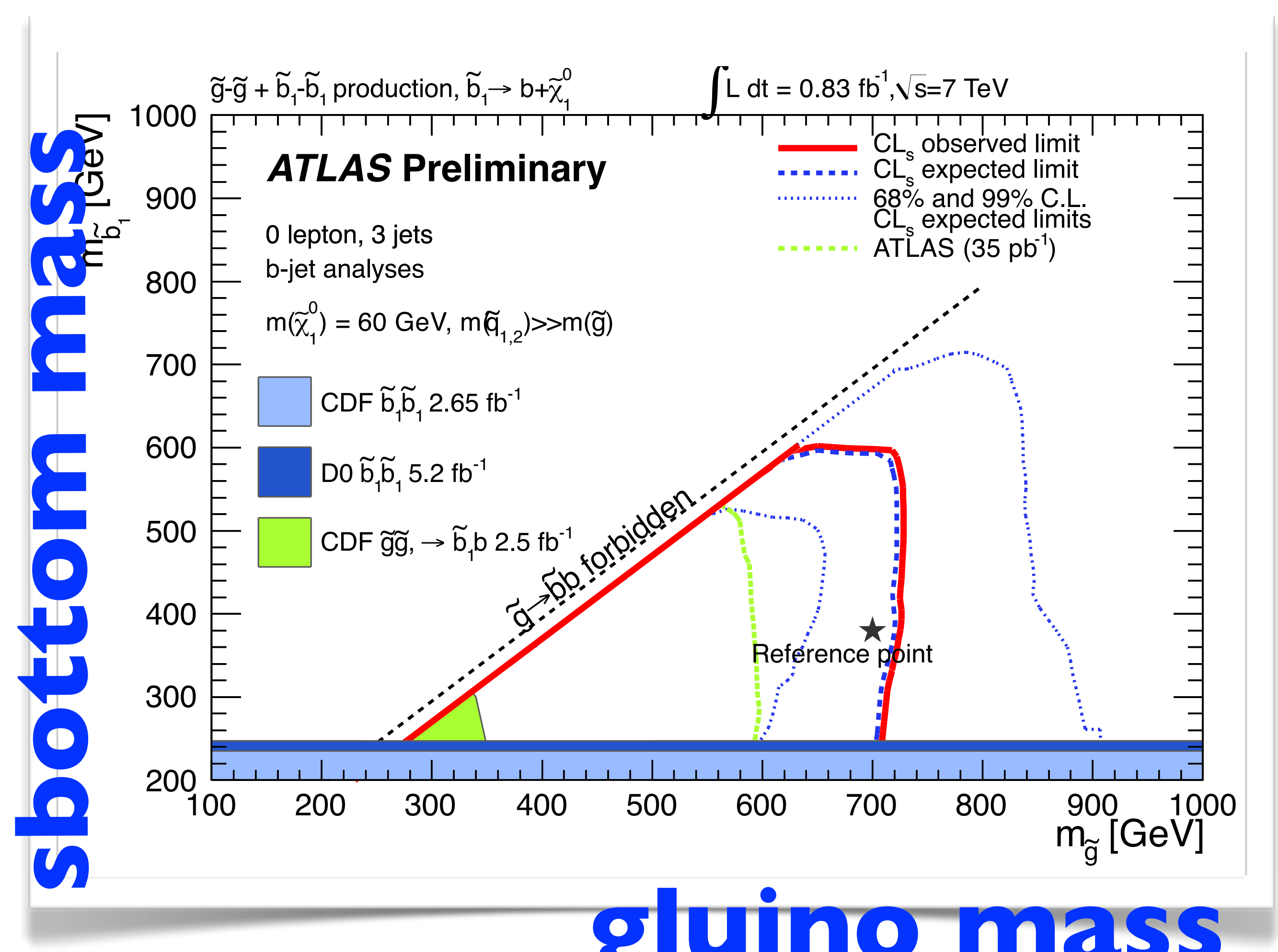
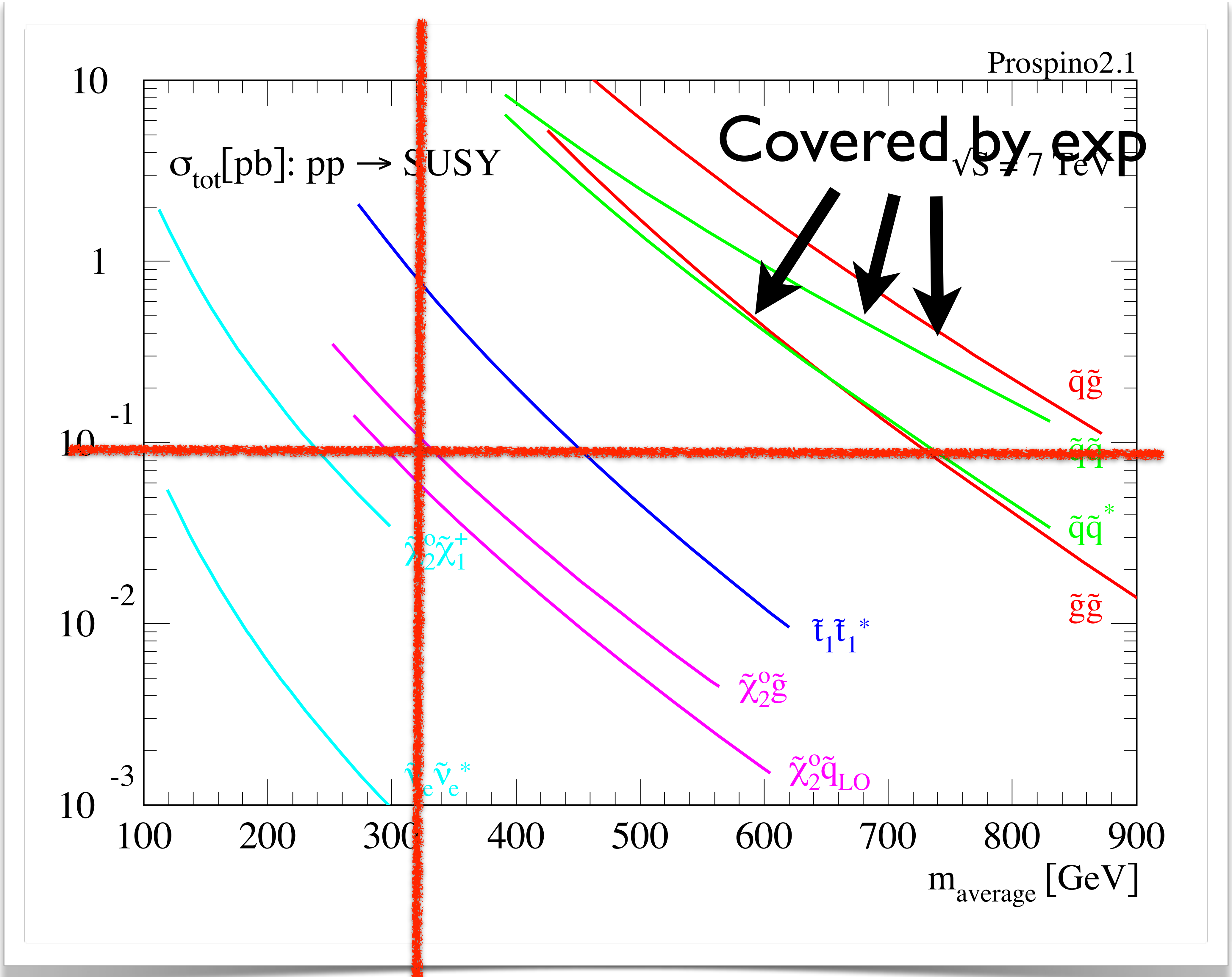


- LHC on 3rd generation:
    - exclusion driven by gluinos





Direct stop prod. with 1/fb ?



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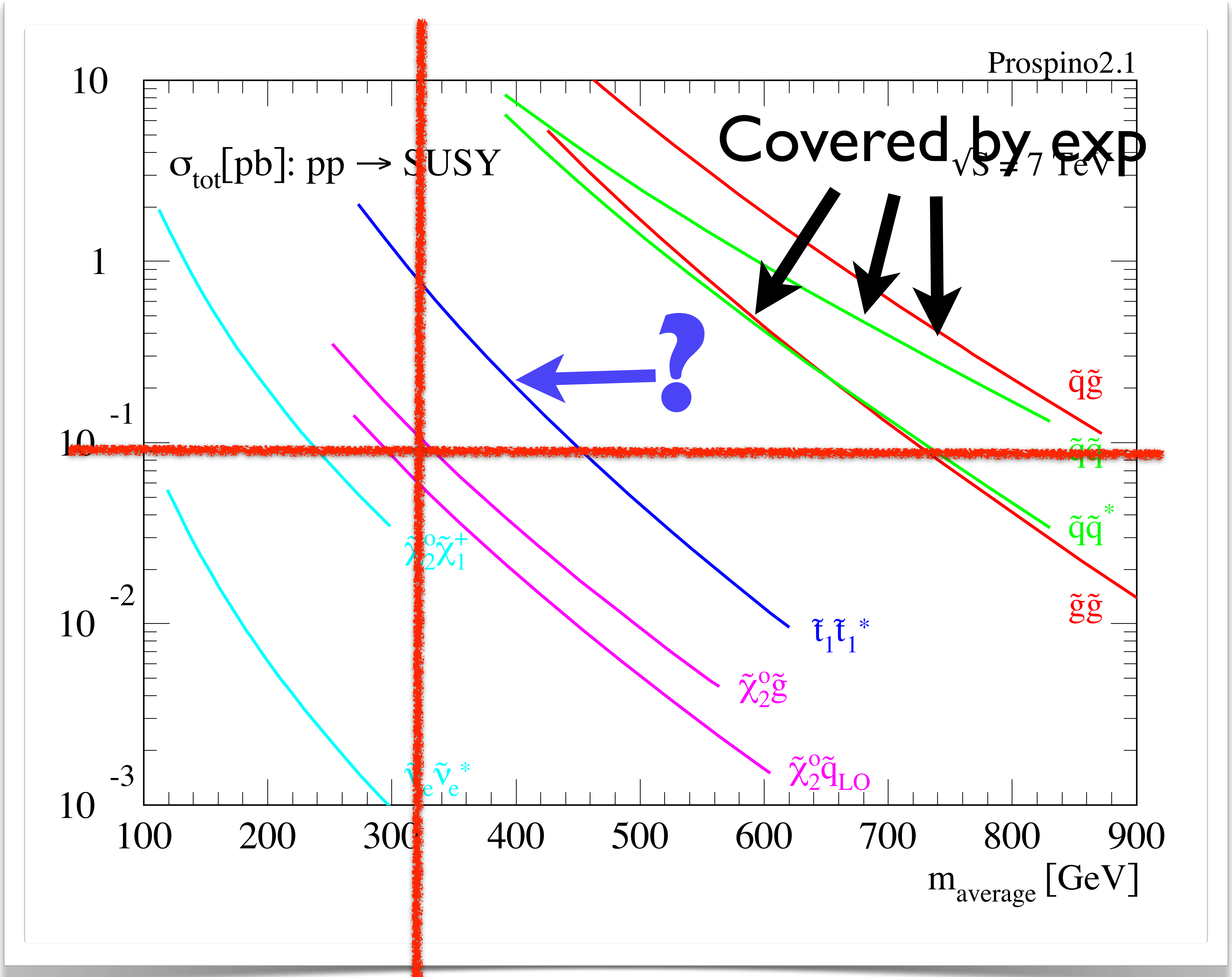


"The experiments haven't covered my favorite model"

Relax & Wait?

vs.

* not his real attitude.

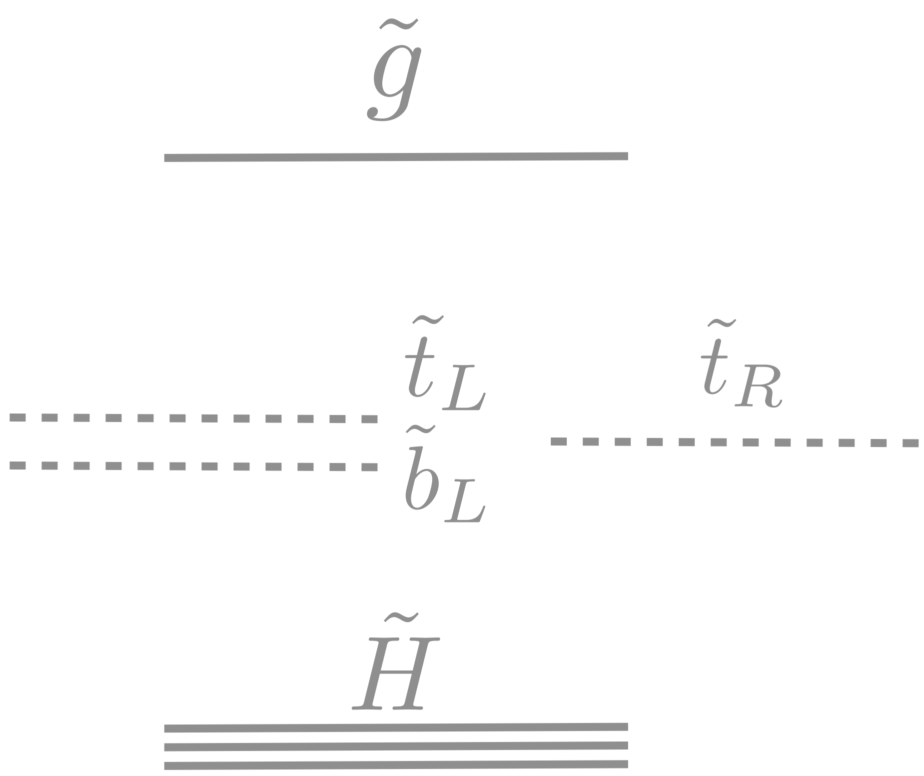
“The experiments haven’t covered my favorite model”

Relax & Wait?

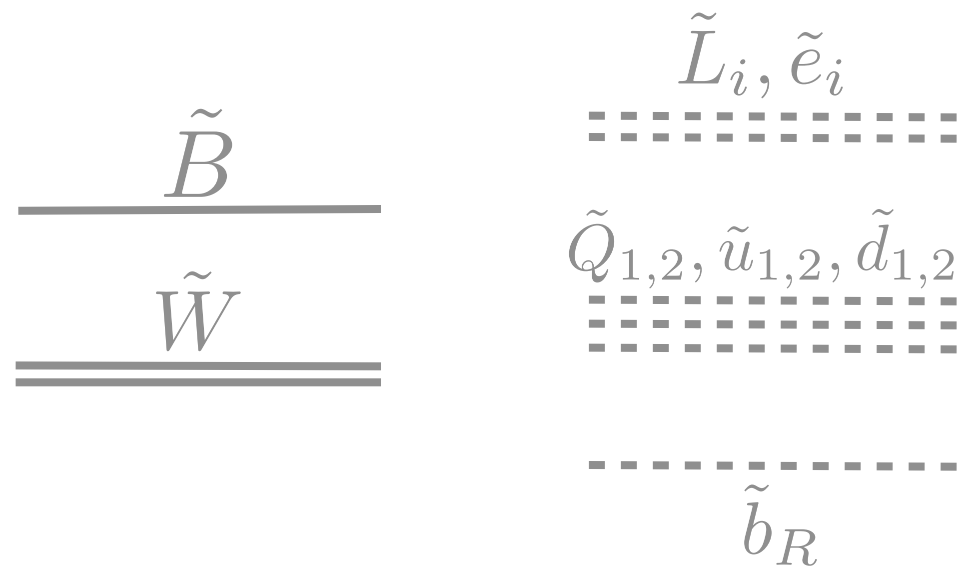
vs.

Check yourself!

* not his real attitude.



natural SUSY



decoupled SUSY

Our Limits

today: *arXiv:1110.6926*

M. Papucci, J. Ruderman, AW

our pipelines

ATOM

public code soon

pythia / herwig / etc

↓

fastjet

↓

truth leptons / photons /b's

- l/gamma iso
- parameterized efficiencies

checks sensitivity of cut & leakage in control region

pgs

pythia

↓

crude detector sim

↓

cone jets

↙ ↘

truth muons/b's

- parameterized efficiencies

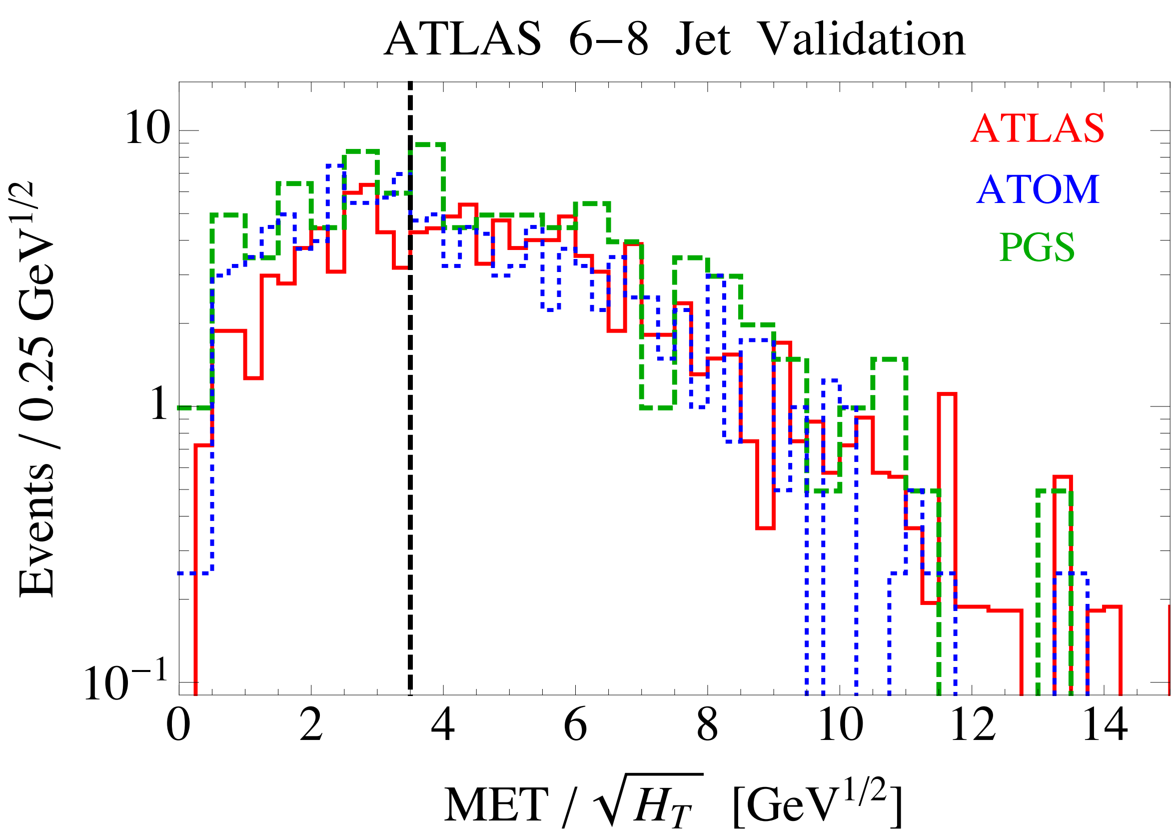
crude simulated e/ gamma

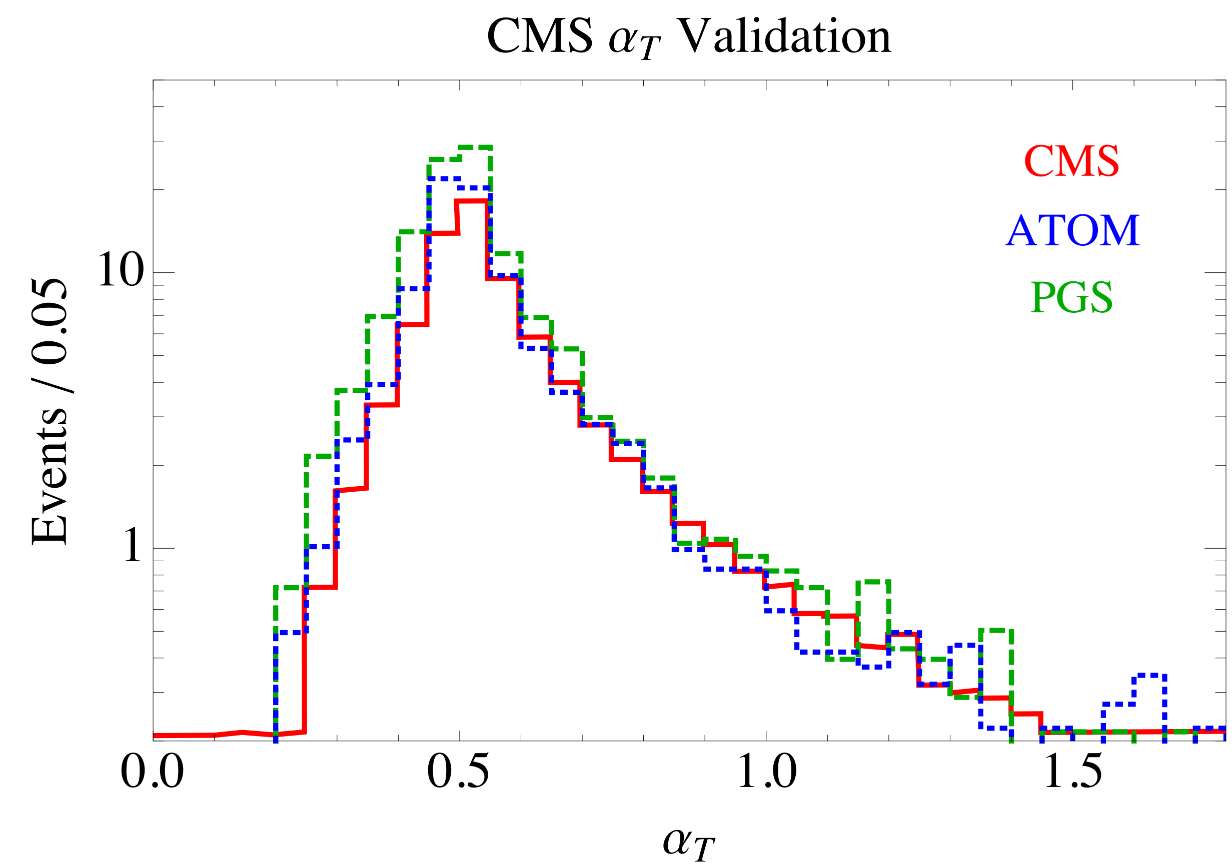
Calibration

"theorist limits"

To calibrate compare:

1) key kinematical distributions
2) limits





Check:

- kinematic distortions (shape)
- signal $\epsilon \times \mathcal{A}$ (normalization)

+ compare to all available limit plots…

~ 50 GeV accuracy (usually better)

Large signature space

arXiv:1110.6926

	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]

non susy analyses

Large signature space

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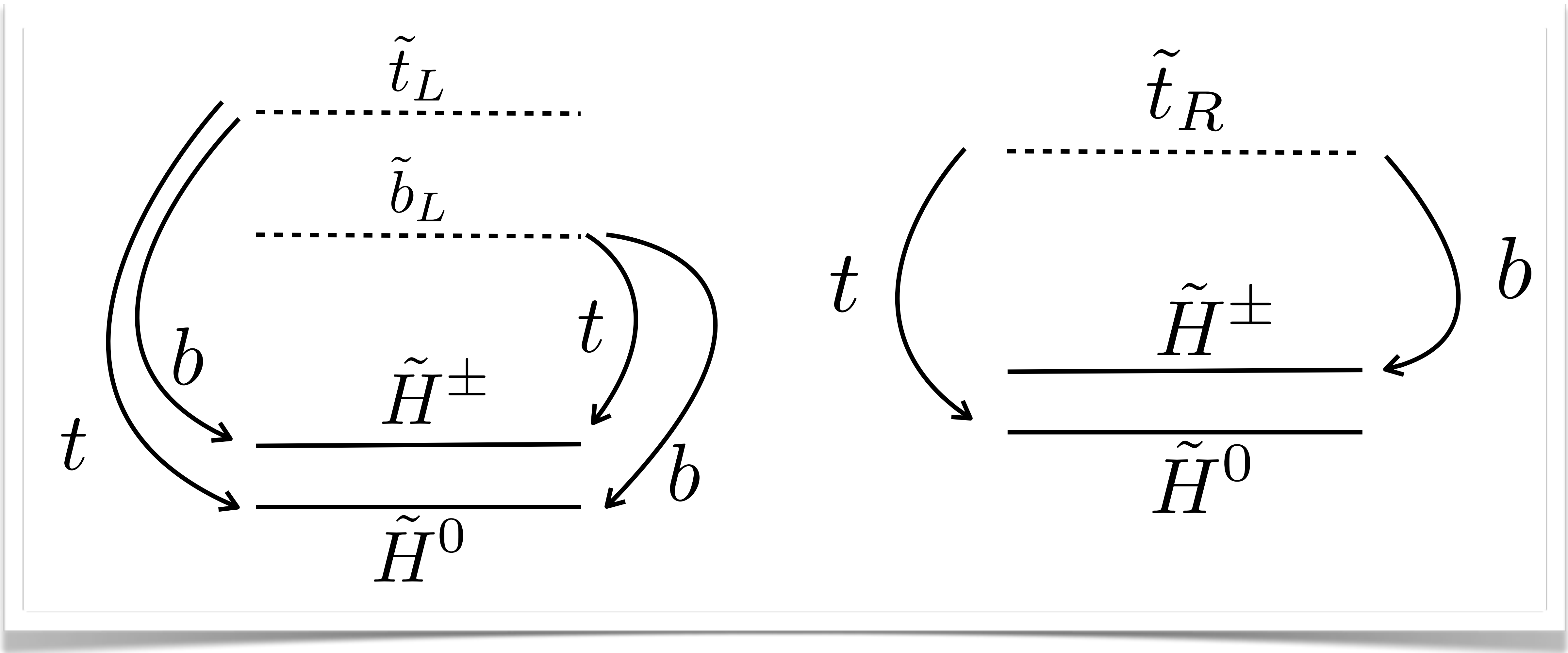
non susy analyses

too recent

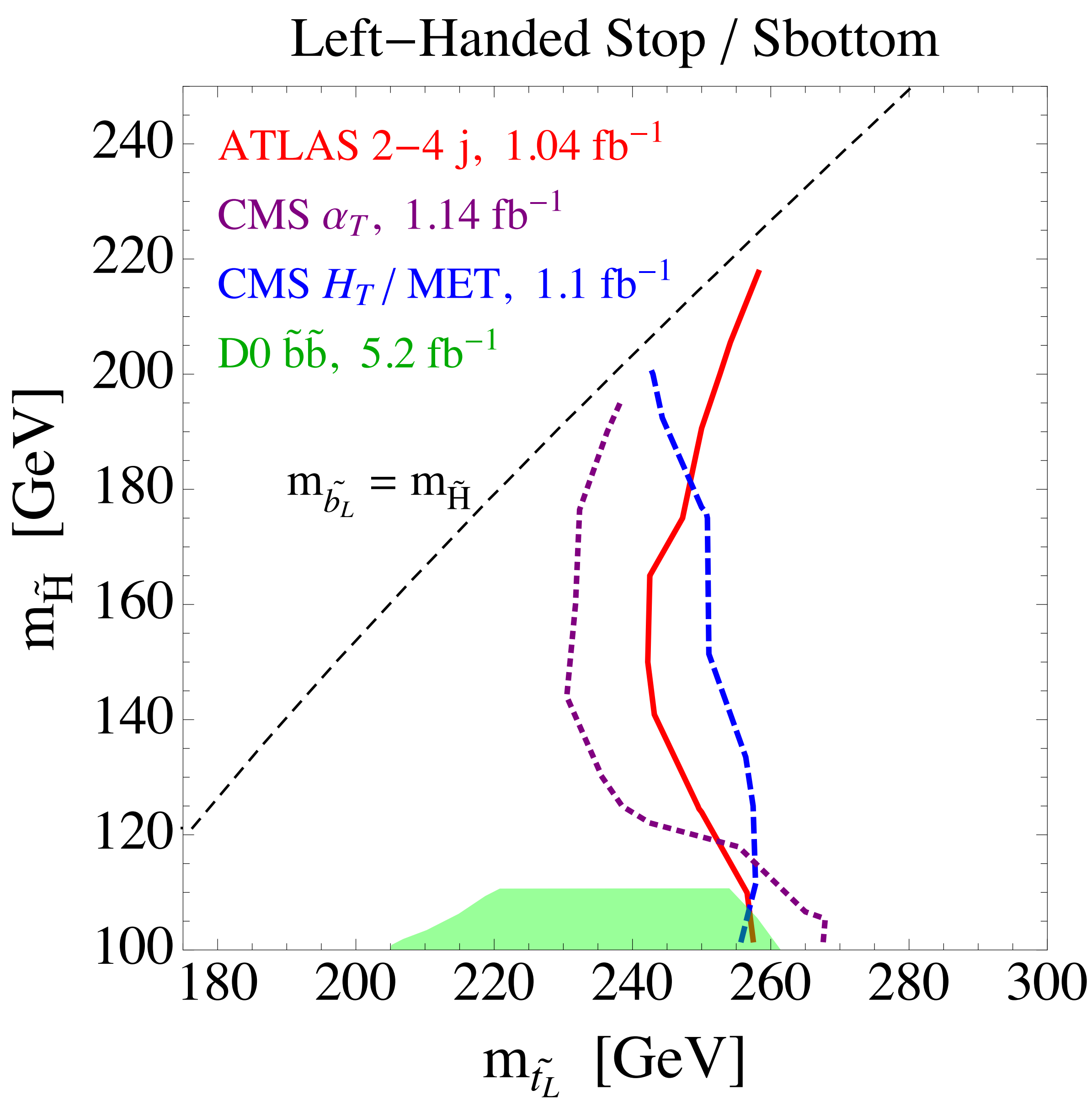
Stops (sbottom) + Higgsinos

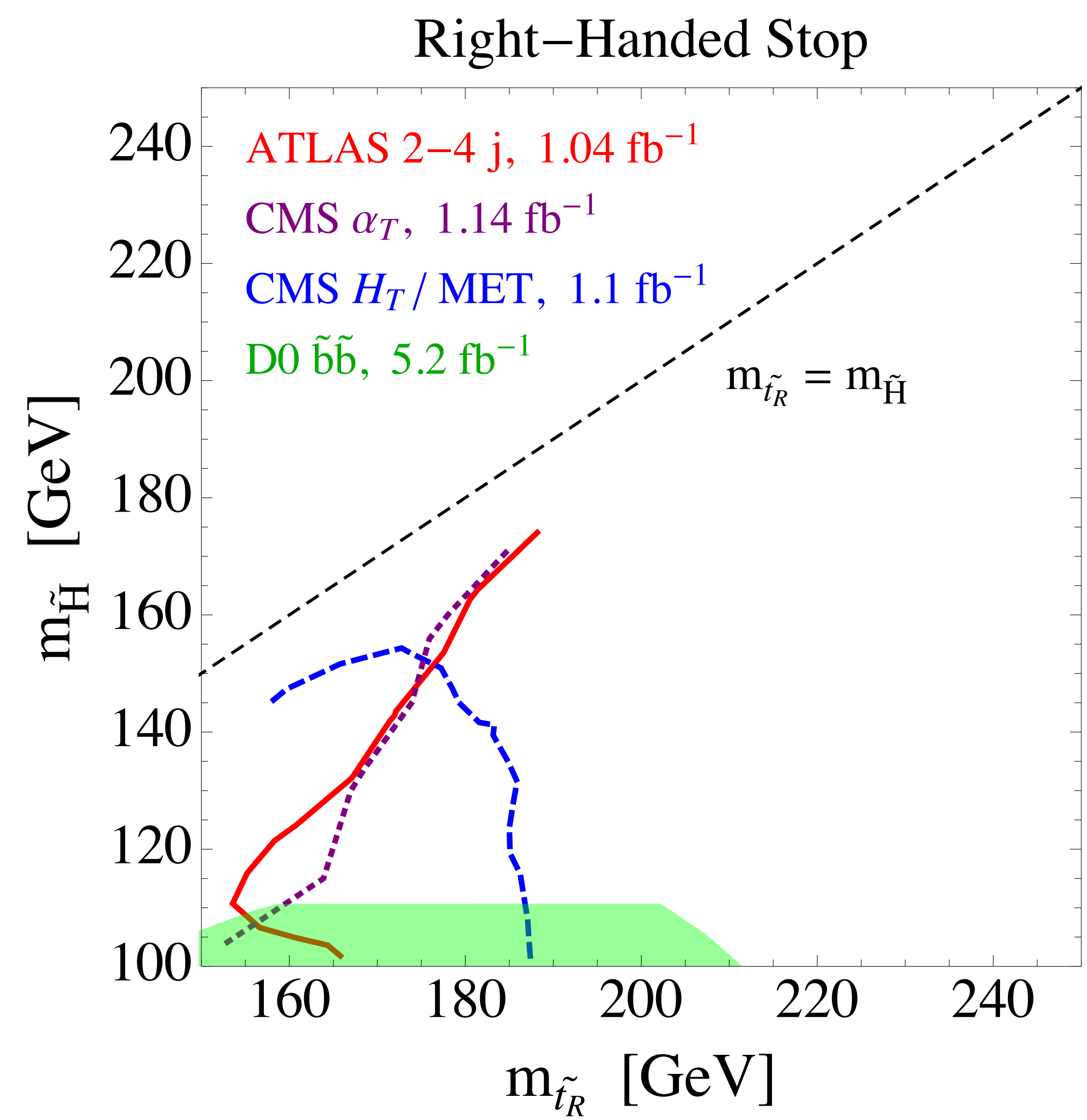


Stops can act as "sbottom" (bjet+χ) !

Chargino-neutralino splitting irrelevant for present searches

Stops (sbottom) + Higgsinos

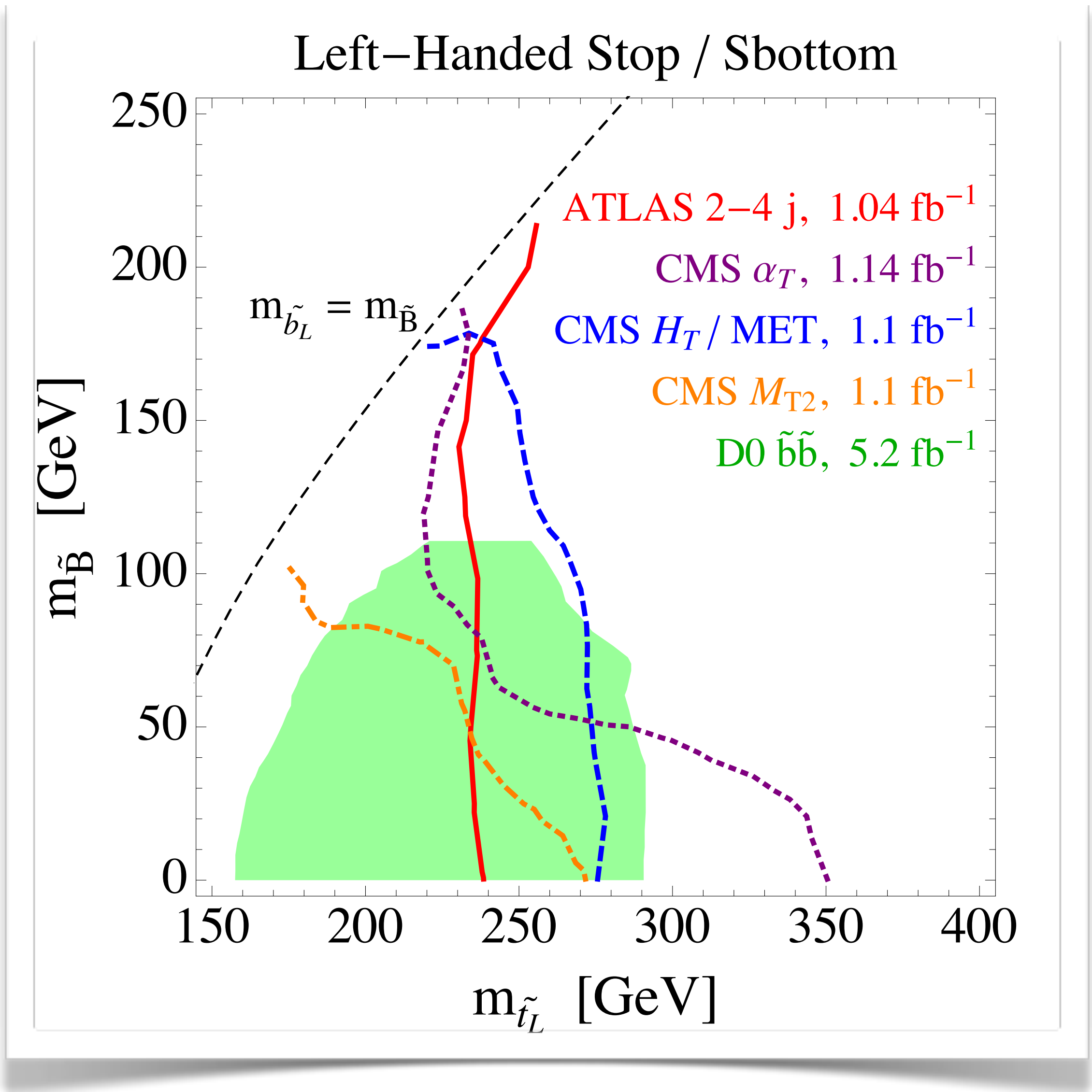


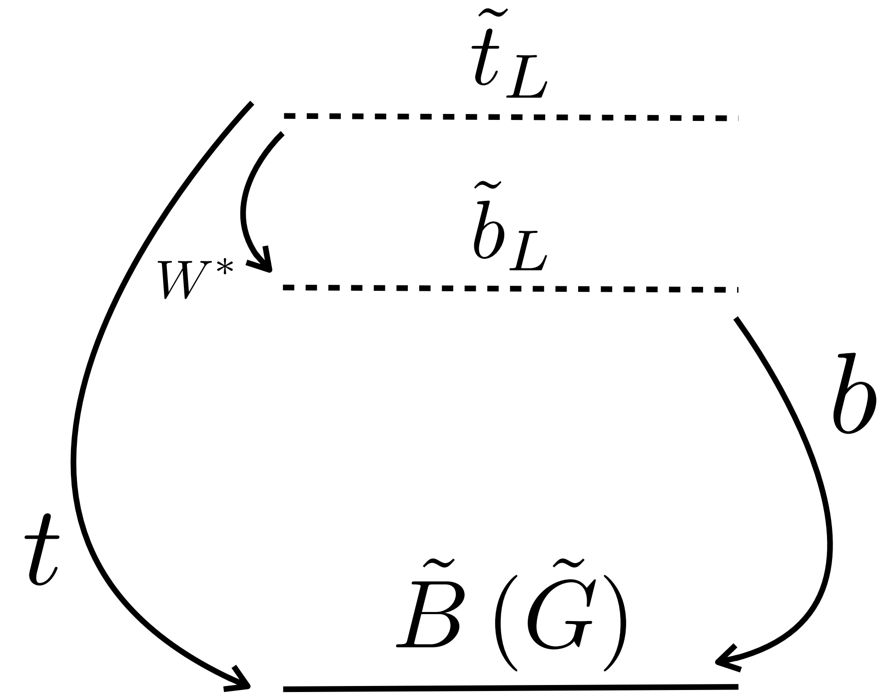


LHC surpasses Tevatron:

Strongest bounds from jets + MET

Stops (sbottom) + Bino (gravitino)

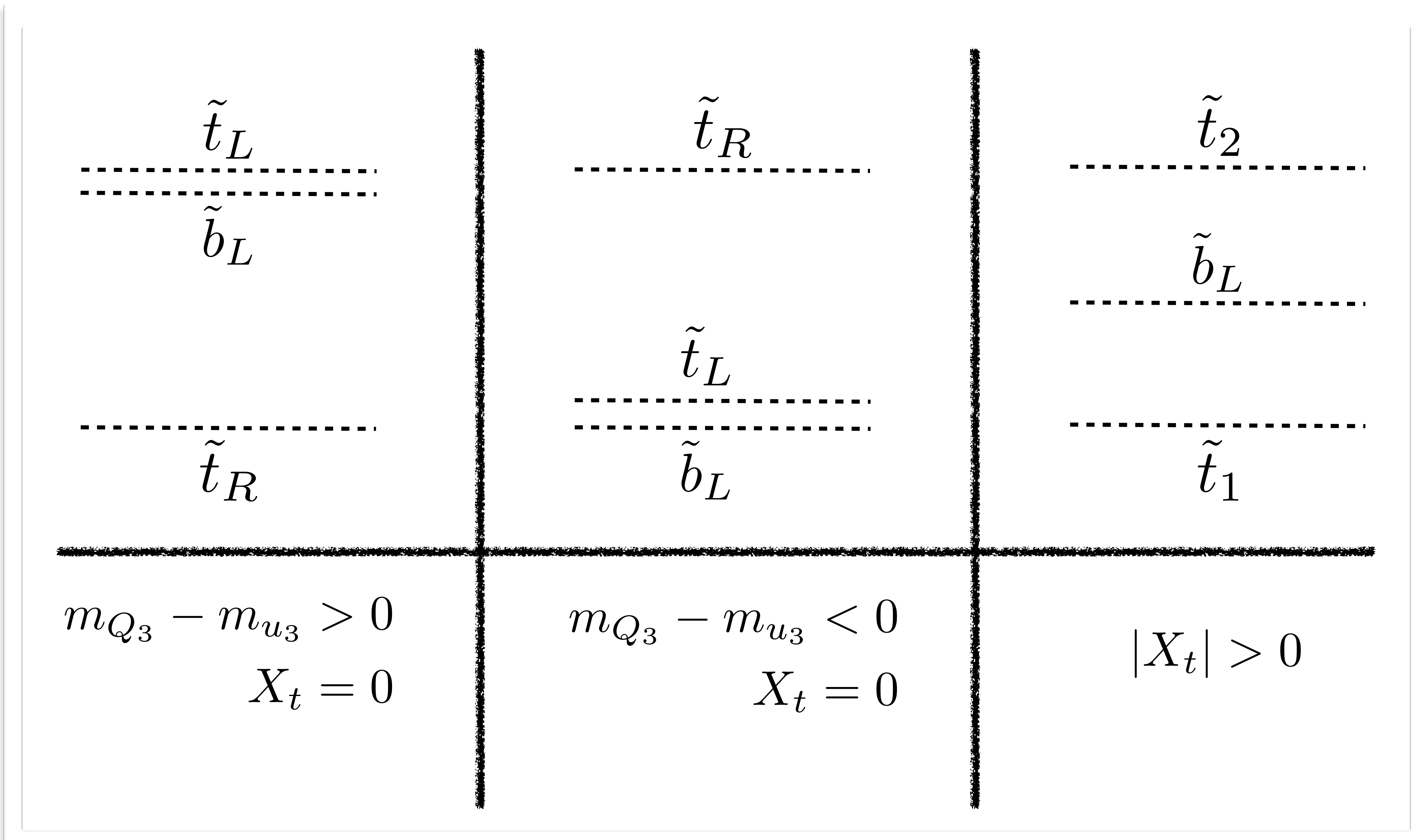




jets+MET searches powerful here too

- RH stop→Bino: top-like final state. Weak bound around 200GeV, but we don't trust it too much. Further (exp') study needed...

Un-Splitting the spectrum



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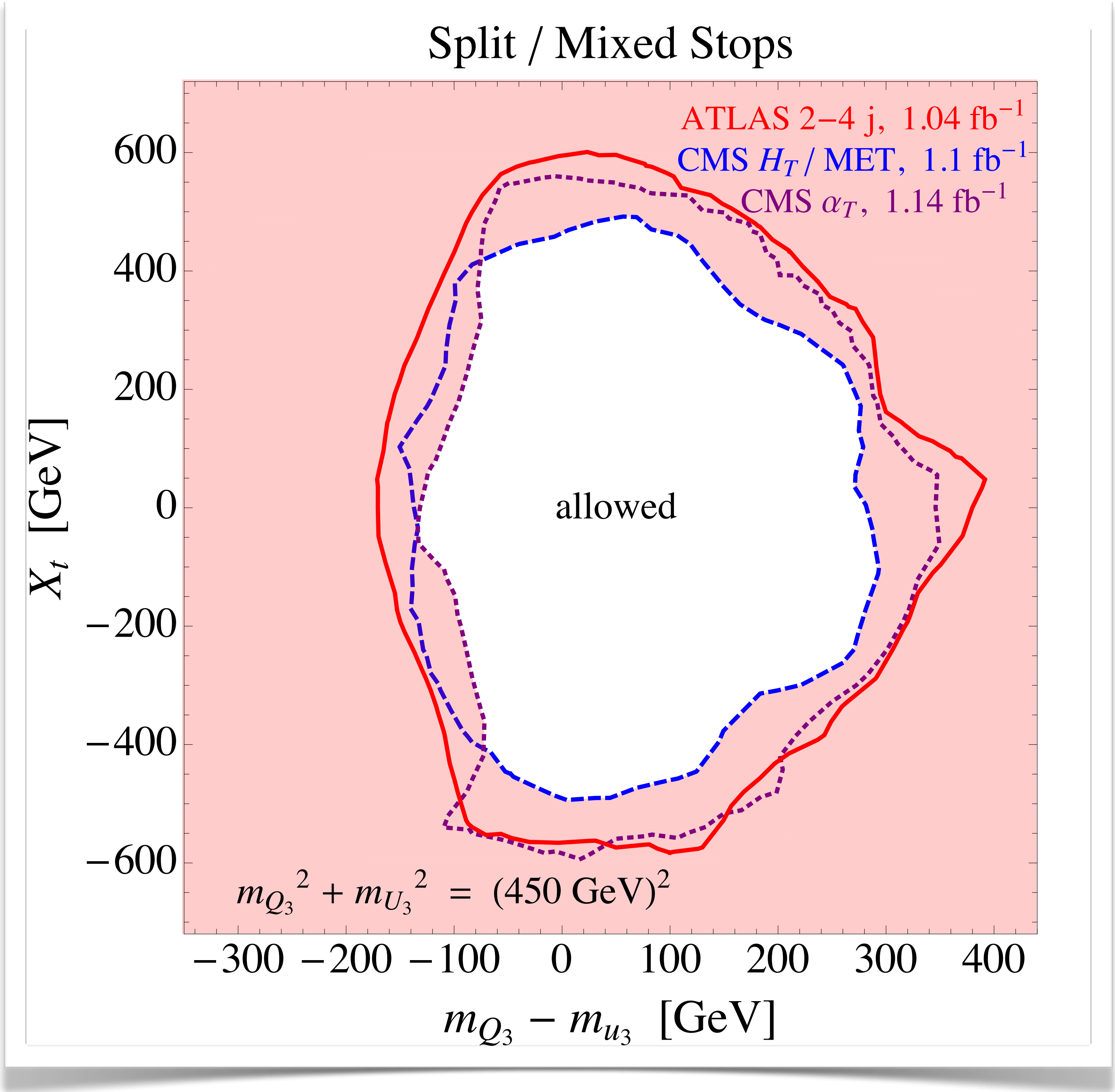
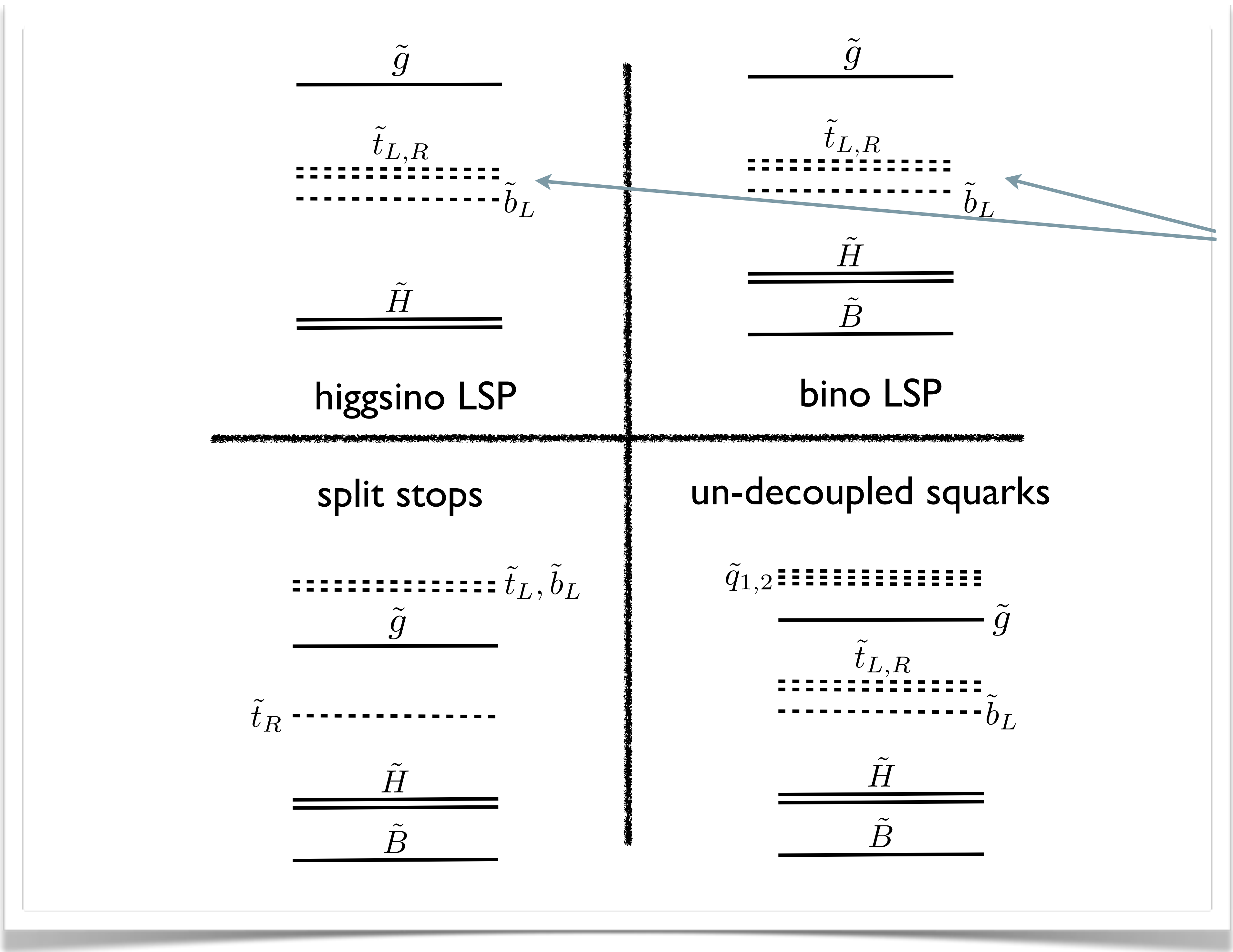


stronger bound on the left due to light sbottom

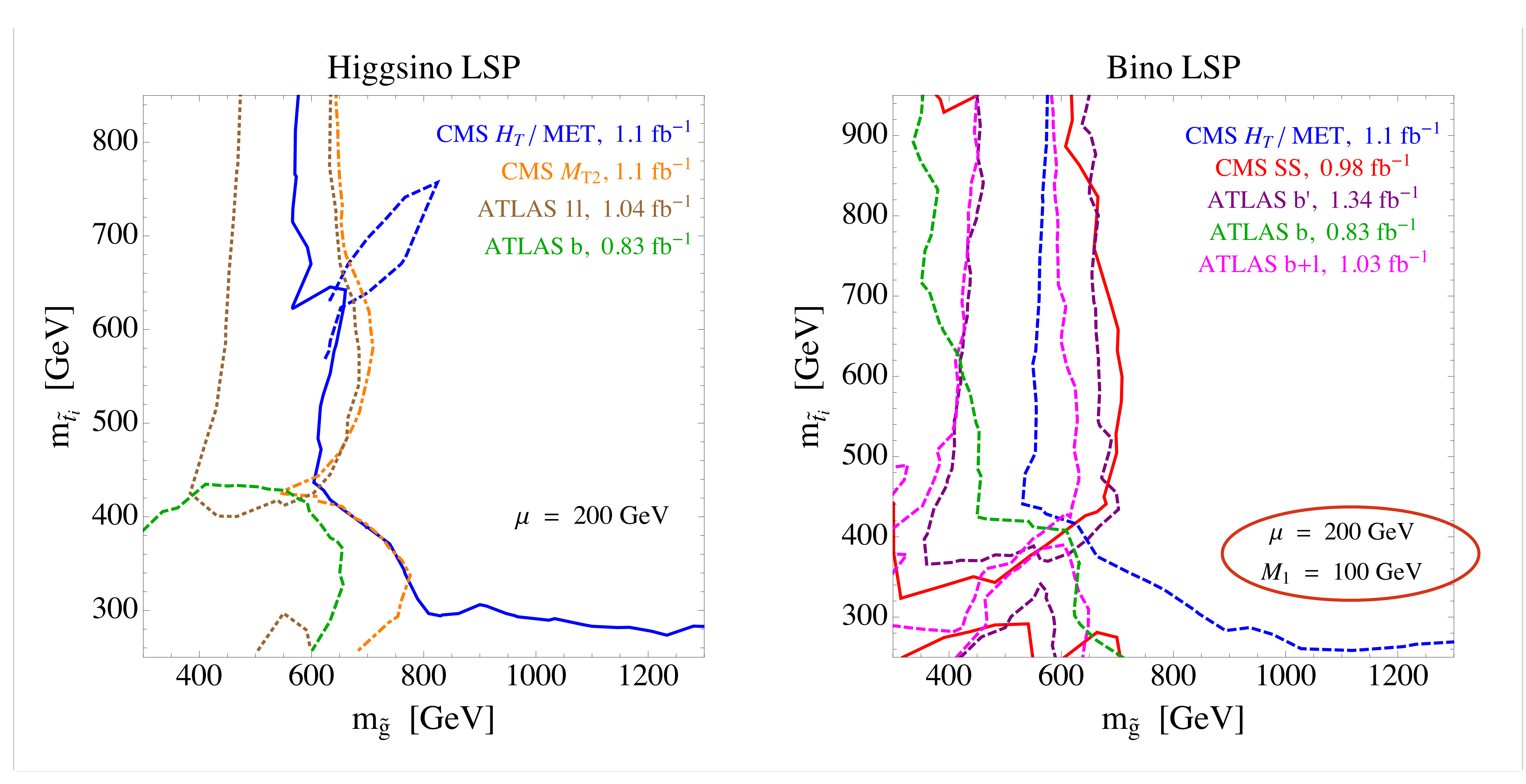
TeVatron bounds not shown b/c they have no sensitivity for m_{LSP} >110GeV

Adding gluinos



quasi-degenerate 3-rd gen'

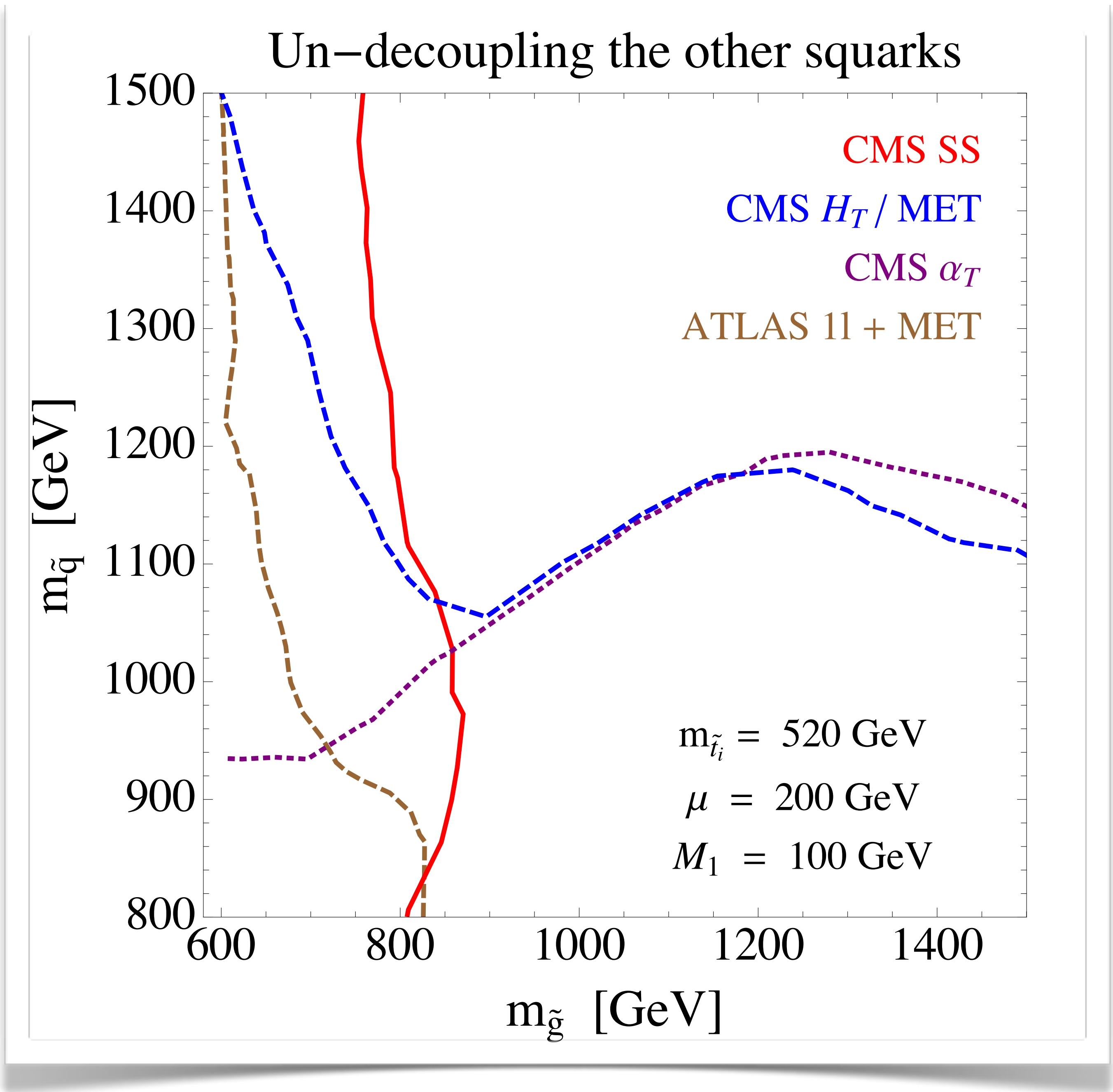
Adding the gluinos



Gluino bounded (again) by jets+MET, and 1lep searches

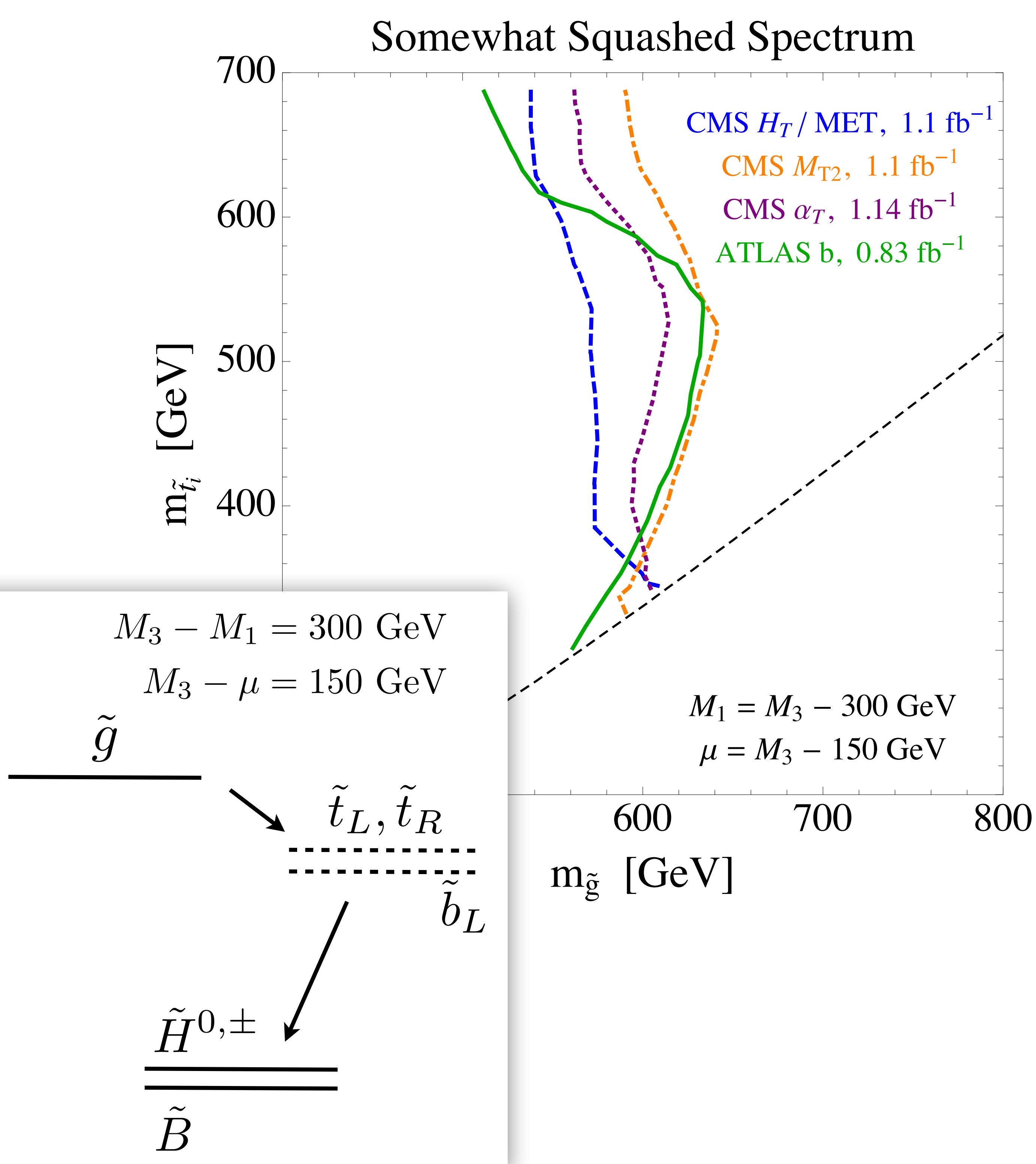
Gluino mostly bounded by Same Sign searches

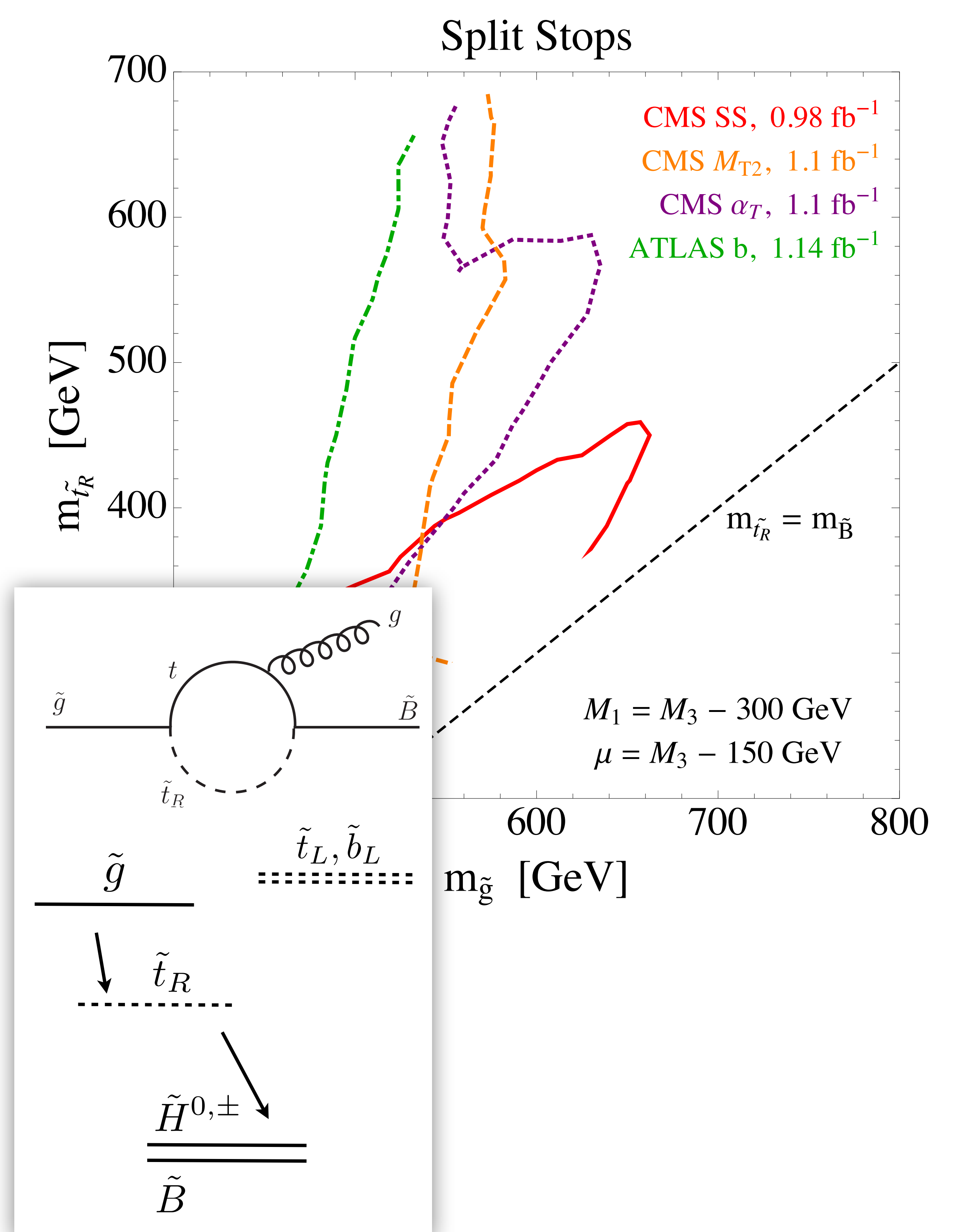
Adding the squarks, too



- Bounds similar to the ATLAS/CMS plots (800GeV-1TeV)
- Decoupling not effective until 1.2-1.4 TeV

Squashed spectrum

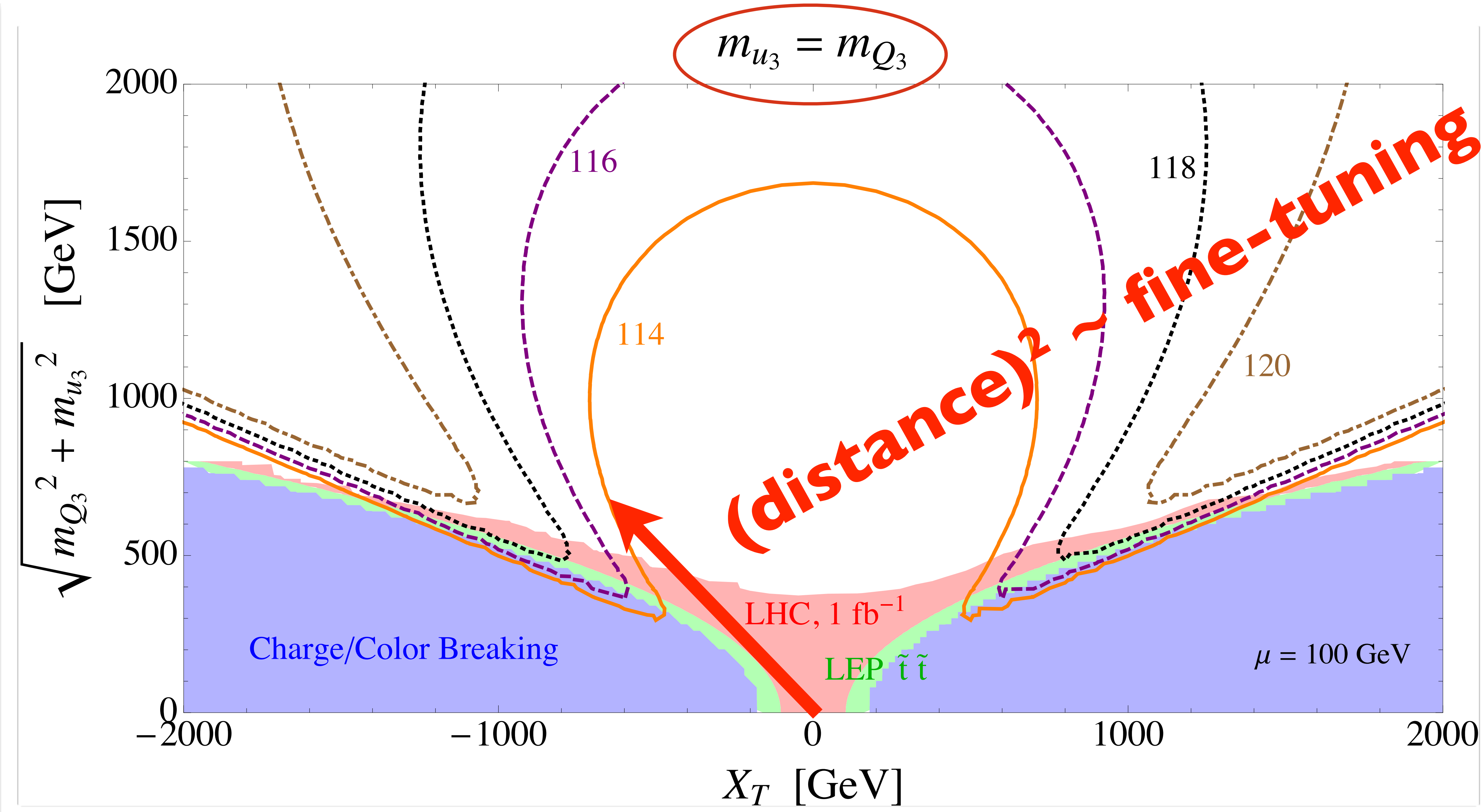




MSSM little hierarchy problem

- Higgs mass lifted by large A-terms → split stop spectrum, I stop may be light and constrained by searches
- Compare to constraints from the Higgs mass bound?
- CAVEAT: only for higgsinos (higgsinos+binos) lighter than stops...

MSSM higgs: LEP2 tuning vs. direct stop



$$\boxed{\delta m_H^2|_{stop}} = -\frac{3}{8\pi^2} y_t^2 \left(m_{U_3}^2 + m_{Q_3}^2 + |A_t|^2\right) \log\left(\frac{\Lambda}{\text{TeV}}\right)$$

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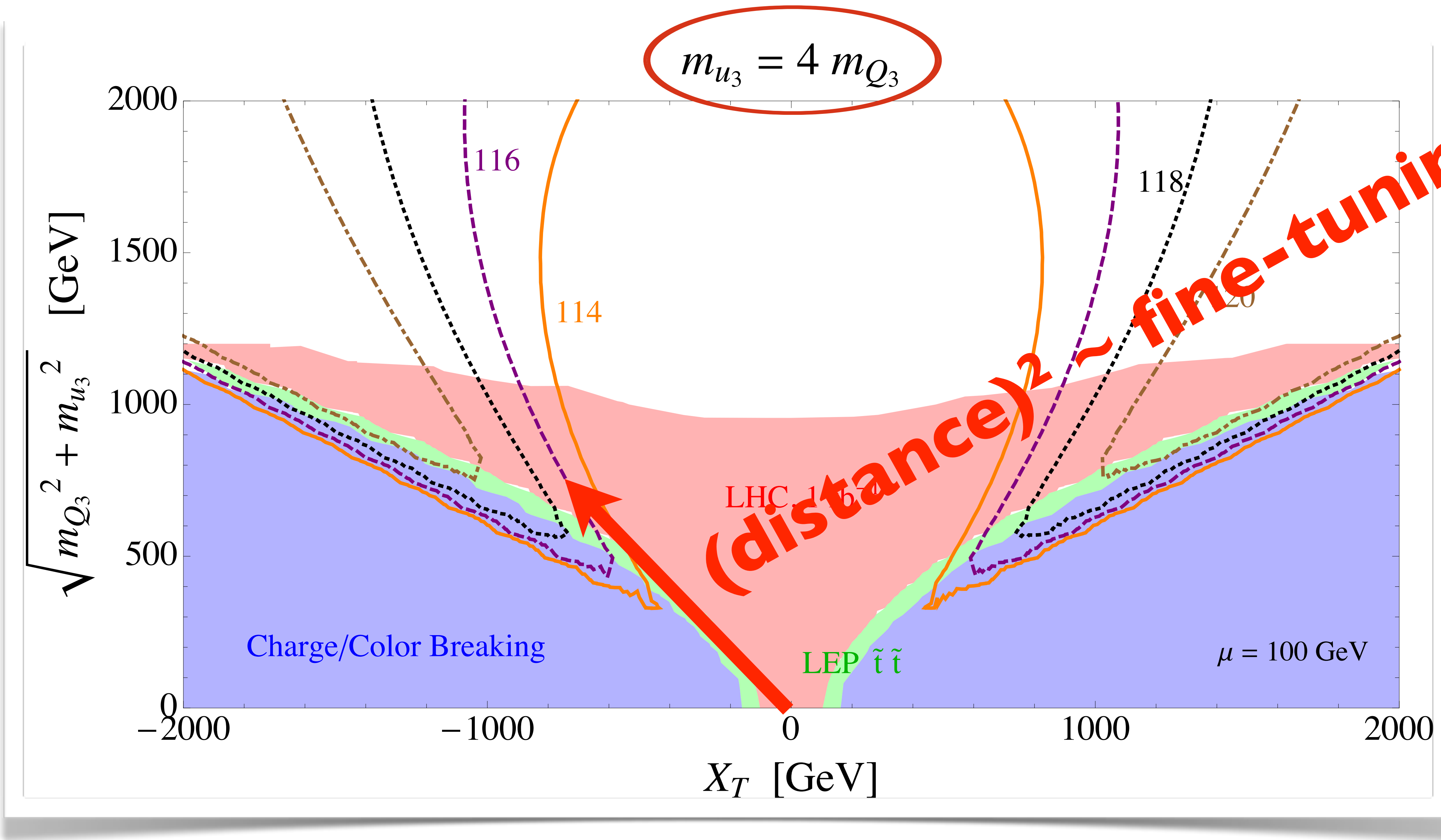


Maximal mixing (for light Higgsino case) probed by the LHC… interesting interplay with Higgs searches.

Summary

production	LSP	$\tilde{t}$ limit [GeV]	figure
$\tilde{t}_L + \tilde{b}_L$	$\tilde{H}$	~ 250	3
$\tilde{t}_R$	$\tilde{H}$	~ 180	3
$\tilde{t}_L + \tilde{b}_L$	$\tilde{B}$	$\sim 250 - 350$	5

scenario	$\tilde{g}$ limit [GeV]	$\tilde{t}$ limit [GeV]	figure
$\tilde{H}$ - LSP	$\sim 650 - 700$	~ 280	10
$\tilde{B}$ - LSP	~ 700	~ 270	10
somewhat squashed	$\sim 600 - 700$	–	11
split $\tilde{t}$	$\sim 550 - 650$	–	11
flavor degen.	1200 (fixed)	$600 - 900$	16
gaugino unify	$\sim 750 - 800$	~ 260	16

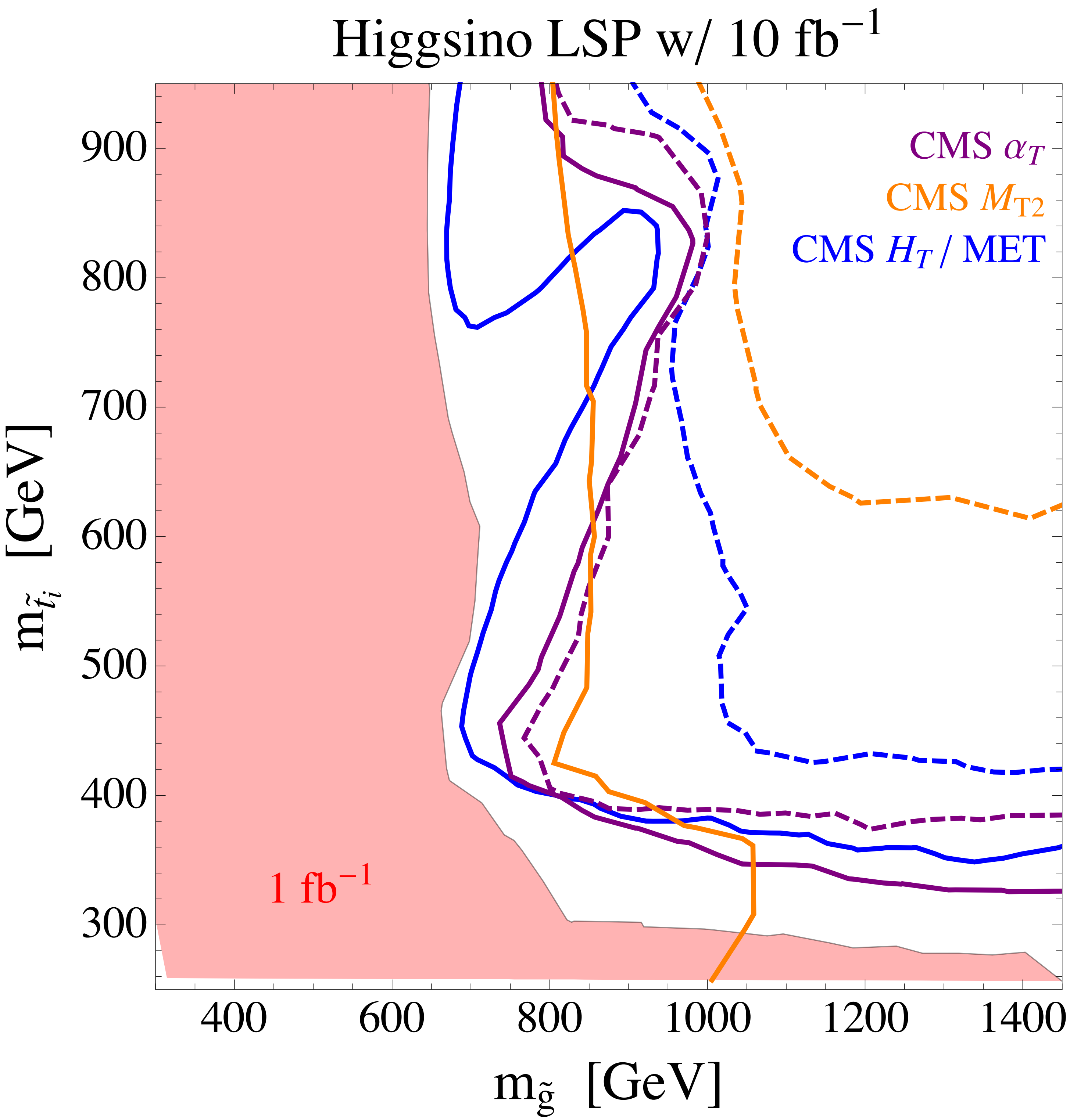
arXiv:1110.6926

Outlook

- Next frontier: Heavy flavor themed naturalness (Eder's & Andrey's talks), EW-inos (Shufang's talk)
- Natural SUSY not in trouble yet (and won't be before shutdown). Trouble only for high-scale, flavor universal models
- LHC will cover very exciting ground in the coming years

Backup

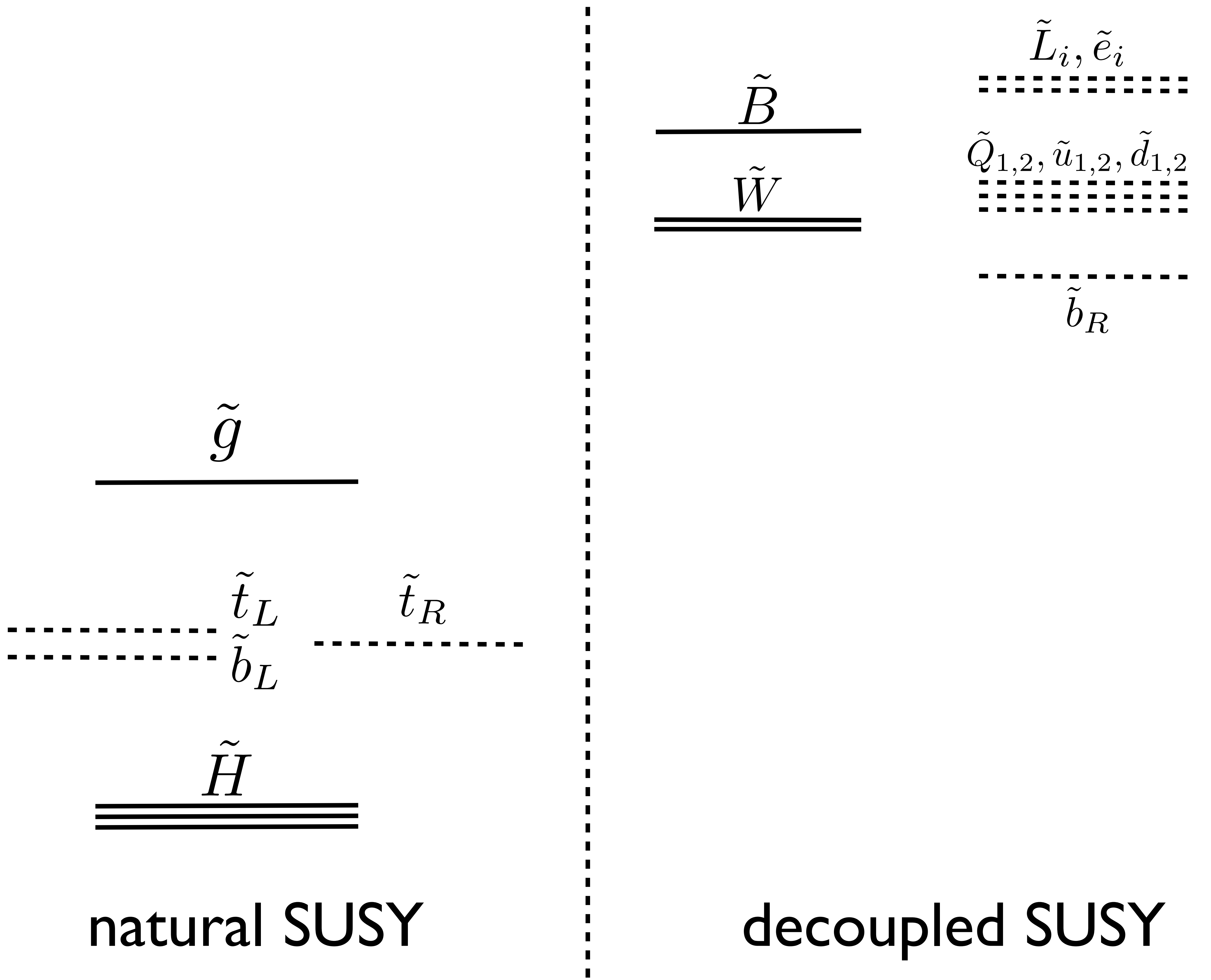
Projections?

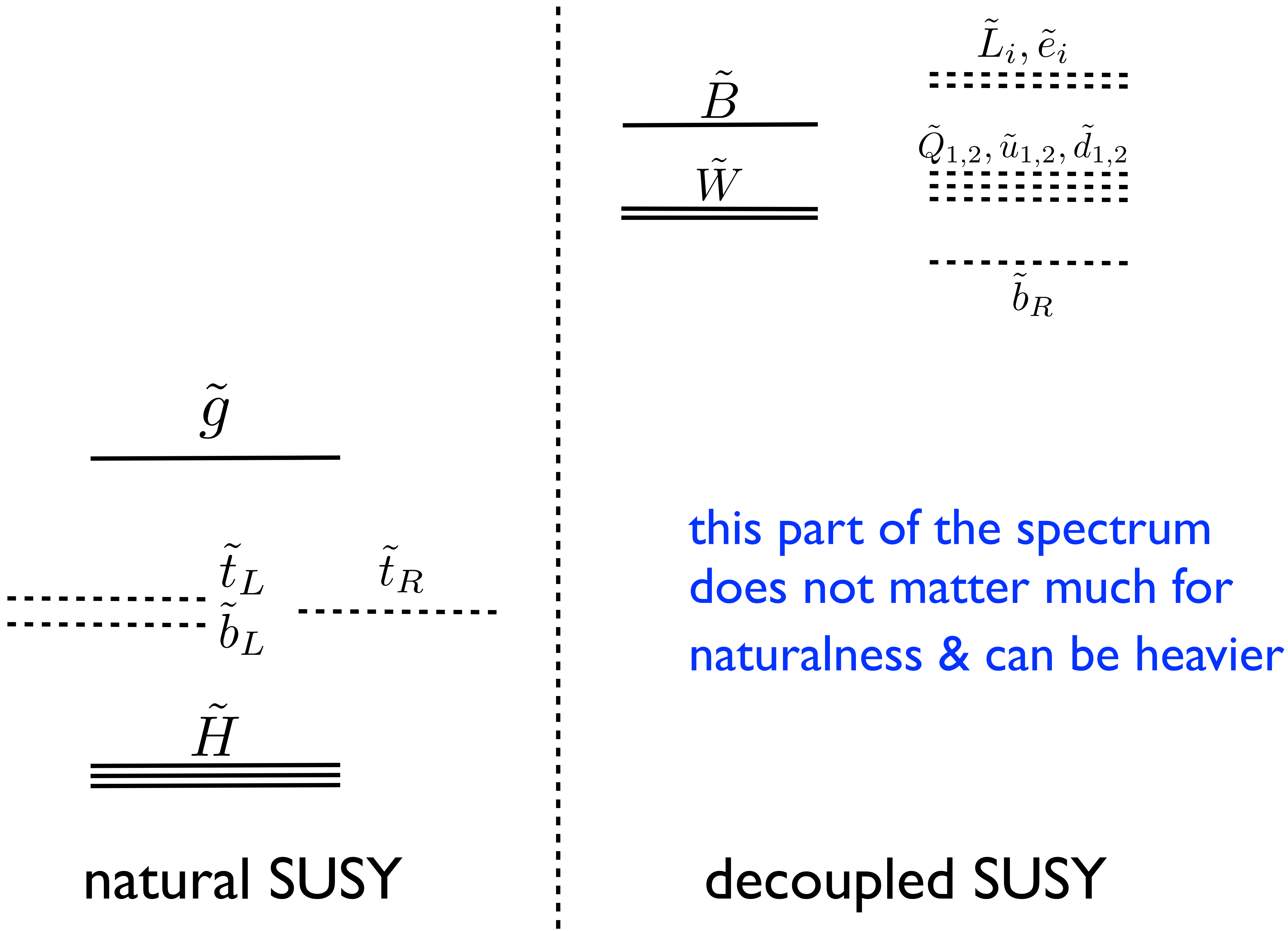


dashed - perfect bgd's

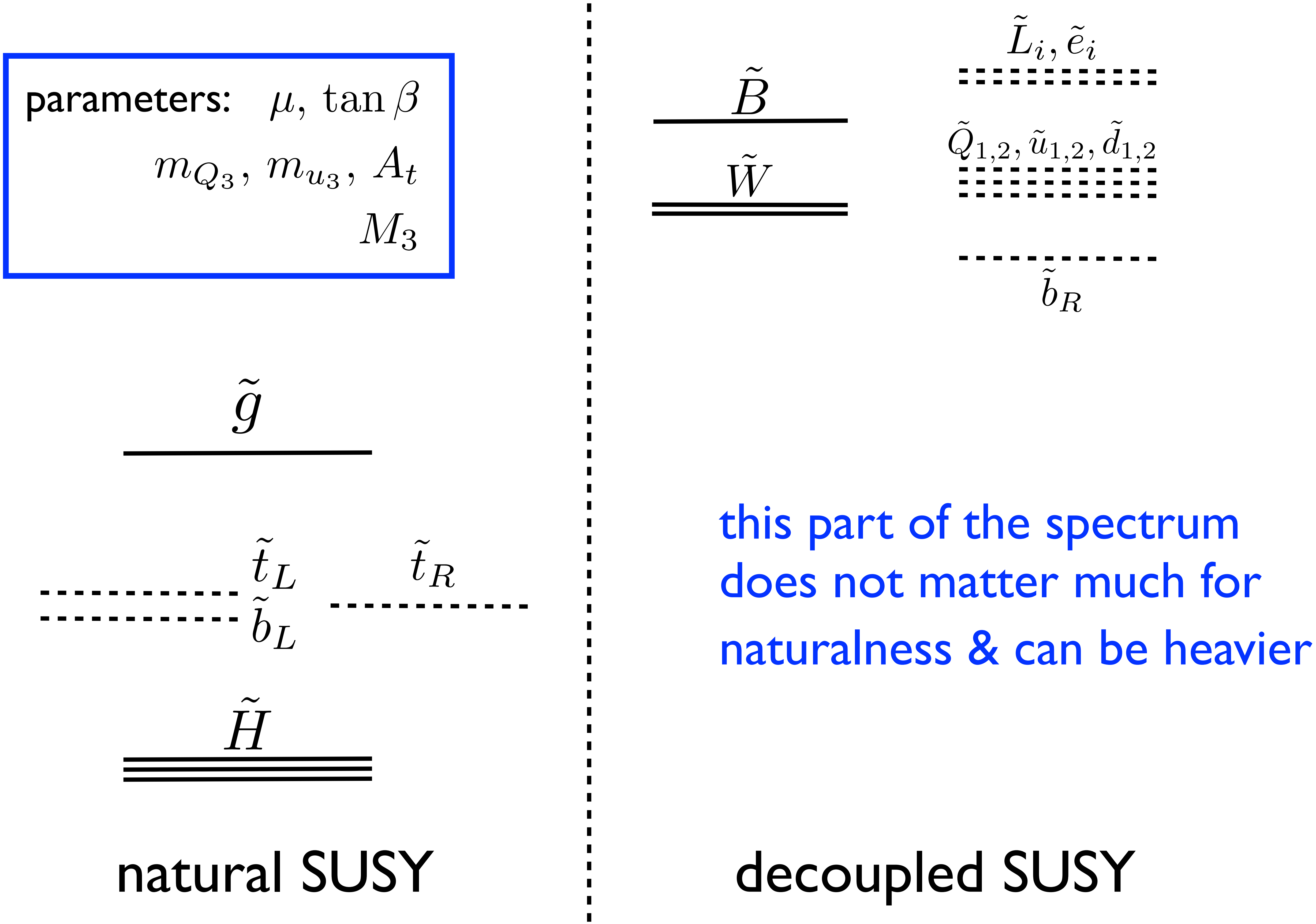
solid - statistics improves, systematics same fraction

* Large uncertainty
* Targeted searches do likely better.


$\tilde{L}_i, \tilde{e}_i$
$\tilde{B}$
$\tilde{Q}_{1,2}, \tilde{u}_{1,2}, \tilde{d}_{1,2}$
$\tilde{W}$
$\tilde{b}_R$
$\tilde{g}$
$\tilde{t}_L$
$\tilde{t}_R$
$\tilde{b}_L$
$\tilde{H}$
natural SUSY
decoupled SUSY



$\tilde{L}_i, \tilde{e}_i$
$\tilde{B}$
$\tilde{Q}_{1,2}, \tilde{u}_{1,2}, \tilde{d}_{1,2}$
$\tilde{W}$
$\tilde{b}_R$
$\tilde{g}$
$\tilde{t}_L$
$\tilde{t}_R$
$\tilde{b}_L$
$\tilde{H}$
this part of the spectrum
does not matter much for
naturalness & can be heavier
natural SUSY
decoupled SUSY


parameters: μ, $\tan\beta$
m_{Q_3}, m_{u_3}, A_t
M_3
$\tilde{g}$
$\tilde{t}_L$
$\tilde{b}_L$
$\tilde{t}_R$
$\tilde{H}$
natural SUSY
$\tilde{L}_i, \tilde{e}_i$
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this part of the spectrum
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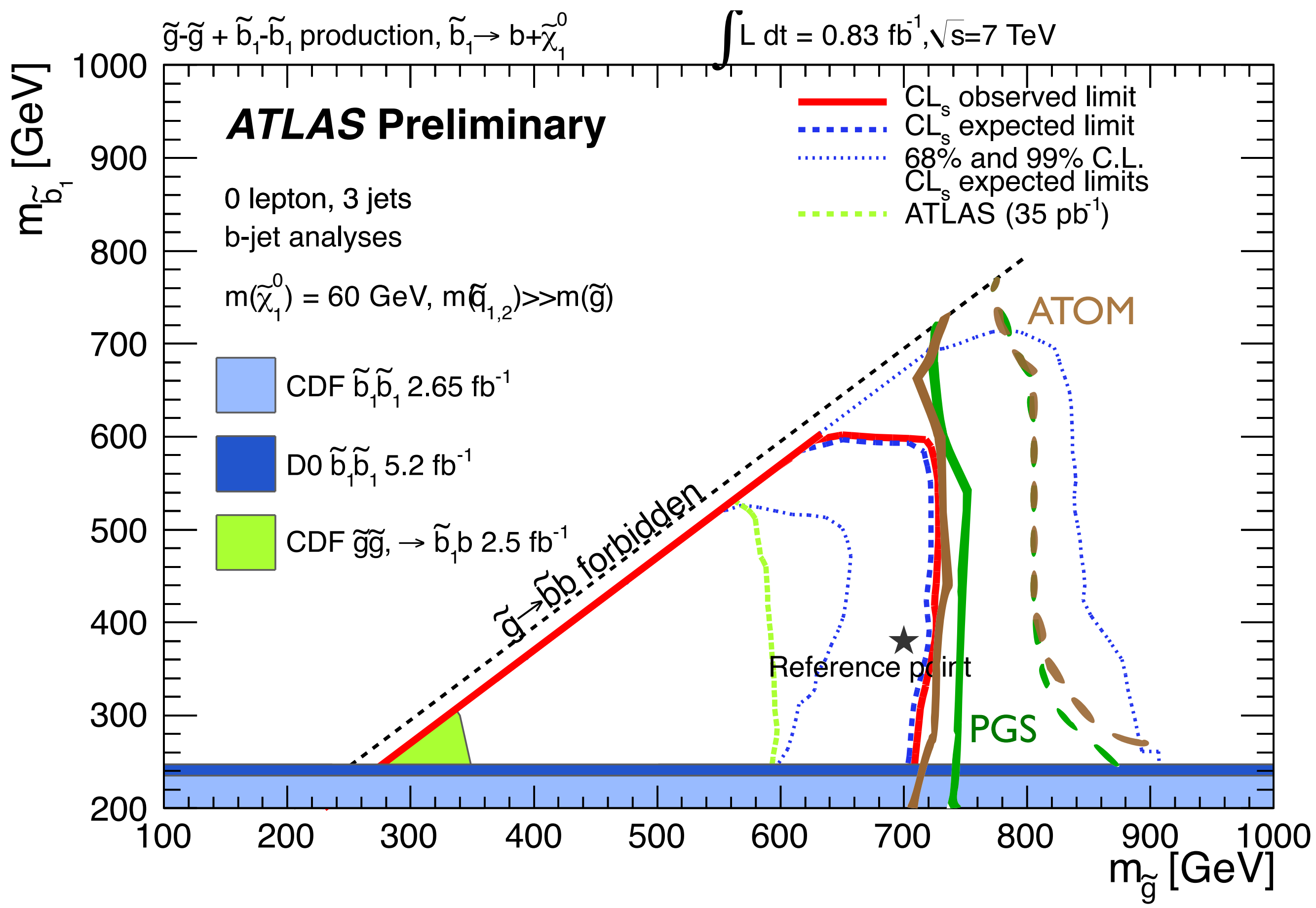
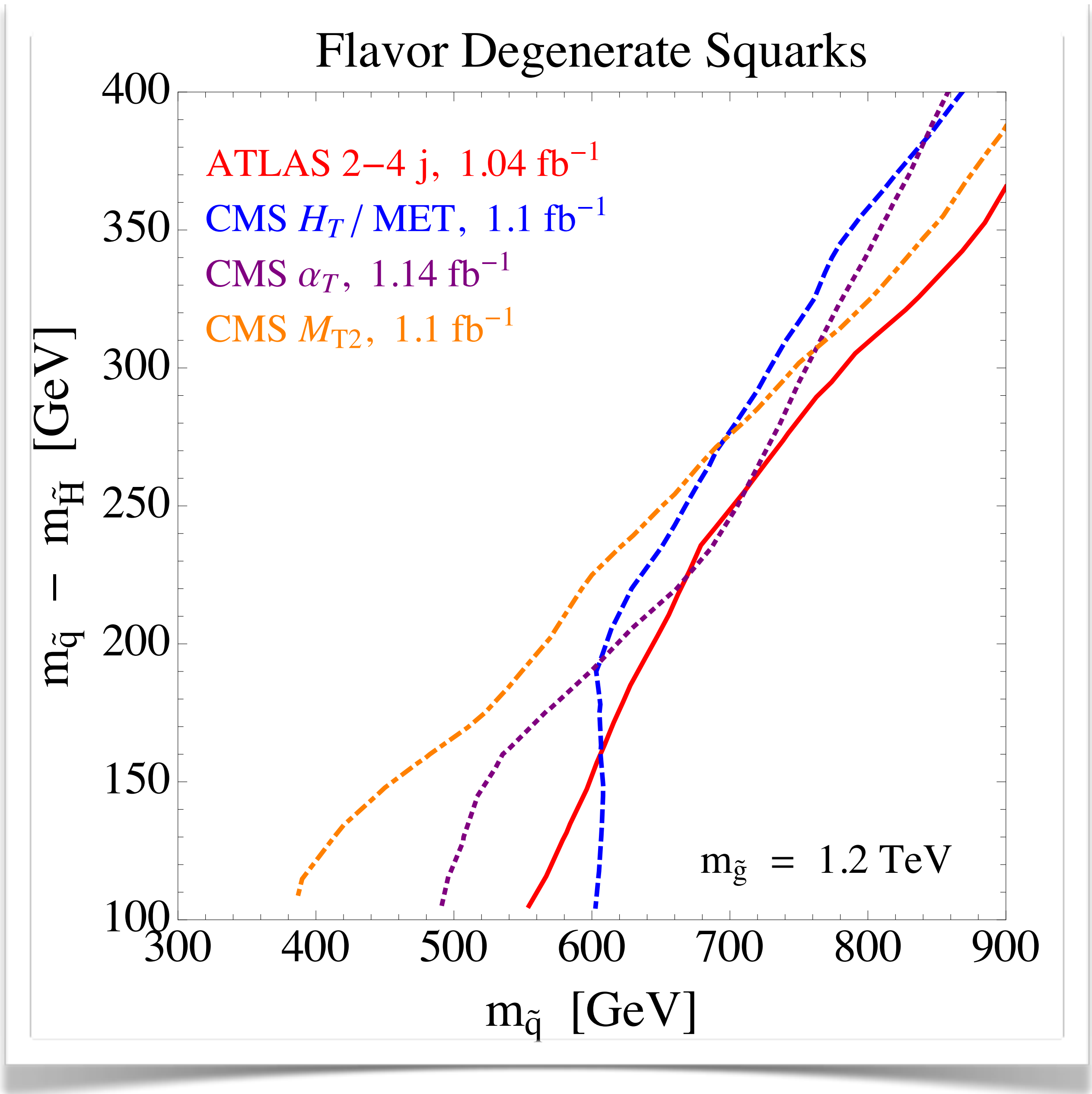
Calibrate w/ limit plots



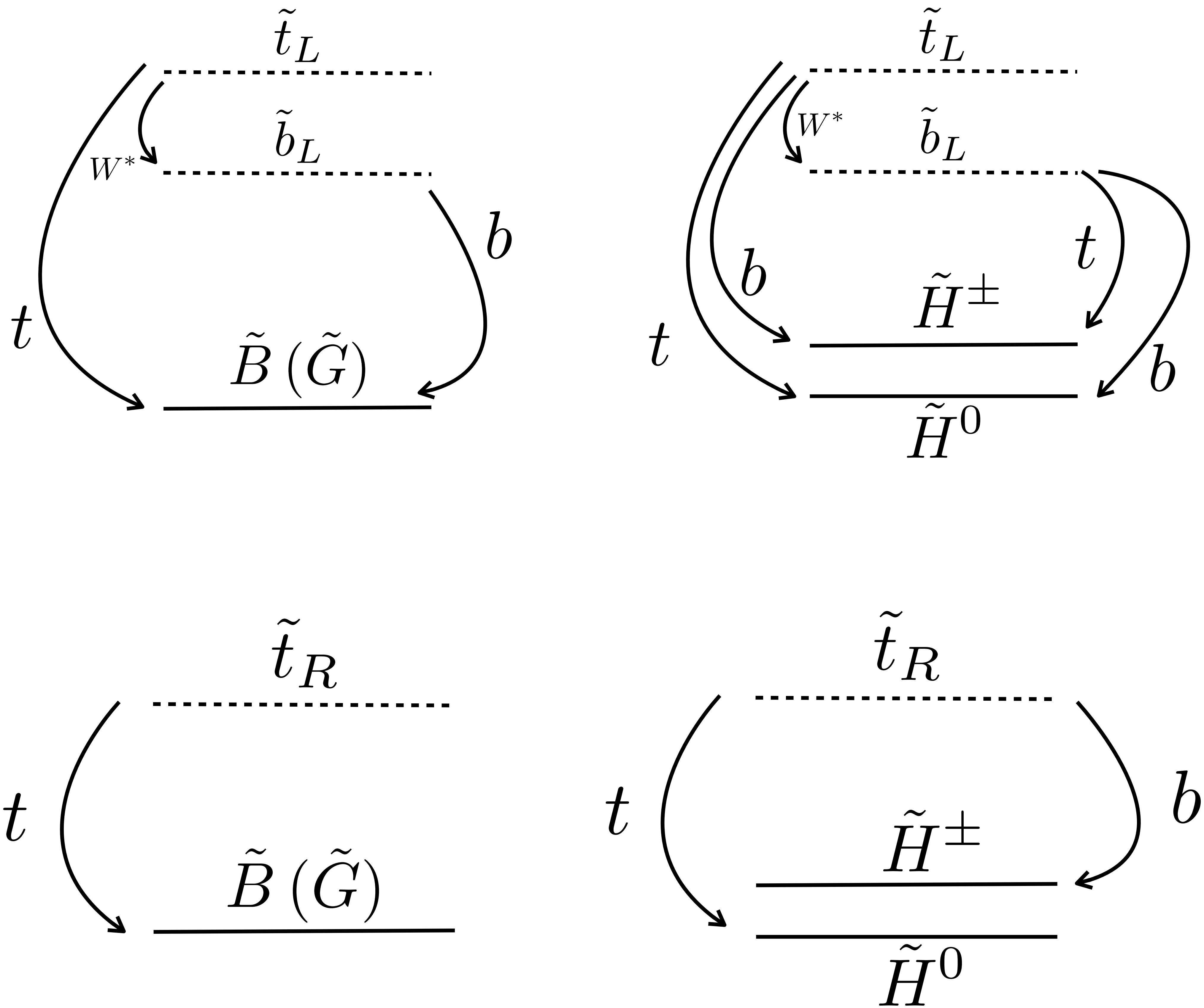
- broad range of kinematical configurations
- even with 50% accuracy of $\epsilon \times \mathcal{A}$ (mostly better) limits are very similar (thanks to pdf's!)

Caveat: if efficiency very sensitive to cut : wouldn't trust it (ATOM flags that).

Back to the flavor degenerate case



Hard to investigate more squashed spectra
(+ additional tuning due to squashing…)


$\tilde{t}_L$
$\tilde{b}_L$
W^*
t
b
$\tilde{B}\,(\tilde{G})$
$\tilde{t}_L$
$\tilde{b}_L$
W^*
t
b
t
b
$\tilde{H}^{\pm}$
$\tilde{H}^{0}$
$\tilde{t}_R$
t
$\tilde{B}\,(\tilde{G})$
$\tilde{t}_R$
t
b
$\tilde{H}^{\pm}$
$\tilde{H}^{0}$

Tuning in the MSSM

$$m_{h^0}^2 \approx m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2} \ln \frac{m_{\text{stop}}^2}{m_t^2}$$

Tuning in the MSSM

$$m_{h^0}^2 \approx m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2} \ln \frac{m_{\text{stop}}^2}{m_t^2}$$

Negative search at LEP: m_H > 114 GeV

Therefore need m_{stop} ~ O(1 TeV).

But at minimum,

Tuning in the MSSM

$$m_{h^0}^2 \approx m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2} \ln \frac{m_{\mathrm{stop}}^2}{m_t^2}$$

Negative search at LEP: $m_H > 114$ GeV

Therefore need $m_{\mathrm{stop}} \sim O(1\ \mathrm{TeV})$.

But at minimum,

$$\frac{m_Z^2}{2} = -|\mu|^2 - \frac{m_{H_u}^2 \tan^2\beta - m_{H_d}^2}{\tan^2\beta - 1} \approx -m_{H_u}^2$$

Tuning in the MSSM

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Therefore need $m_{stop} \sim O(1\ \text{TeV})$.

But at minimum,

$$\frac{m_Z^2}{2} = -|\mu|^2 - \frac{m_{H_u}^2 \tan^2\beta - m_{H_d}^2}{\tan^2\beta - 1} \approx -m_{H_u}^2$$

$$\delta m_{Hu}^2(\text{loop}) = -\frac{3y_t^2}{8\pi^2} m_{\text{stop}}^2 \ln \frac{\Lambda^2}{m_{\text{stop}}^2} \approx 600 \cdot \frac{m_Z^2}{2}$$

Tuning in the MSSM

$$m_{h^0}^2 \approx m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2} \ln \frac{m_{\text{stop}}^2}{m_t^2}$$

Negative search at LEP: m_H > 114 GeV

Therefore need m_{stop} ~ O(1 TeV).

But at minimum,

$$\frac{m_Z^2}{2} = -|\mu|^2 - \frac{m_{H_u}^2 \tan^2\beta - m_{H_d}^2}{\tan^2\beta - 1} \approx -m_{H_u}^2$$

Little Hierarchy problem

$$\delta m_{Hu}^2(\text{loop}) = -\frac{3y_t^2}{8\pi^2} m_{\text{stop}}^2 \ln \frac{\Lambda^2}{m_{\text{stop}}^2} \approx 600 \cdot \frac{m_Z^2}{2}$$

$$\delta m_{Hu}^2(\text{loop}) = -\frac{3y_t^2}{8\pi^2} m_{\text{stop}}^2 \ln \frac{\Lambda^2}{m_{\text{stop}}^2}$$

o Raise tree-level Higgs mass ? m_{stop} reduced !

a) F-Term (NMSSM)

b) D-term (extended gauge structure)

$$\delta m_{Hu}^2(\text{loop}) = -\frac{3y_t^2}{8\pi^2} m_{\text{stop}}^2 \ln \frac{\Lambda^2}{m_{\text{stop}}^2}$$

o Raise tree-level Higgs mass ? m_{stop} reduced !

a) F-Term (NMSSM)

b) D-term (extended gauge structure)

o Lower the cut-off ?

c) NMSSM (large SH_uH_d coupling $\Rightarrow \Lambda_{\text{Landau}} \ll M_{\text{Gut}}$)

d) Find rationale why Λ=(protection scale **f**)~ O(TeV)

(i.e. little Higgs like protection)