Natural and flavorful SUSY at the LHC

Andreas Weiler

DESY

Blois
29/5/12

w/ M. Papucci[1,2], J. Ruderman[1,2] (LBL Berkely)
Gilad Perez[2], Rakhi Mahbubani[2] (CERN)

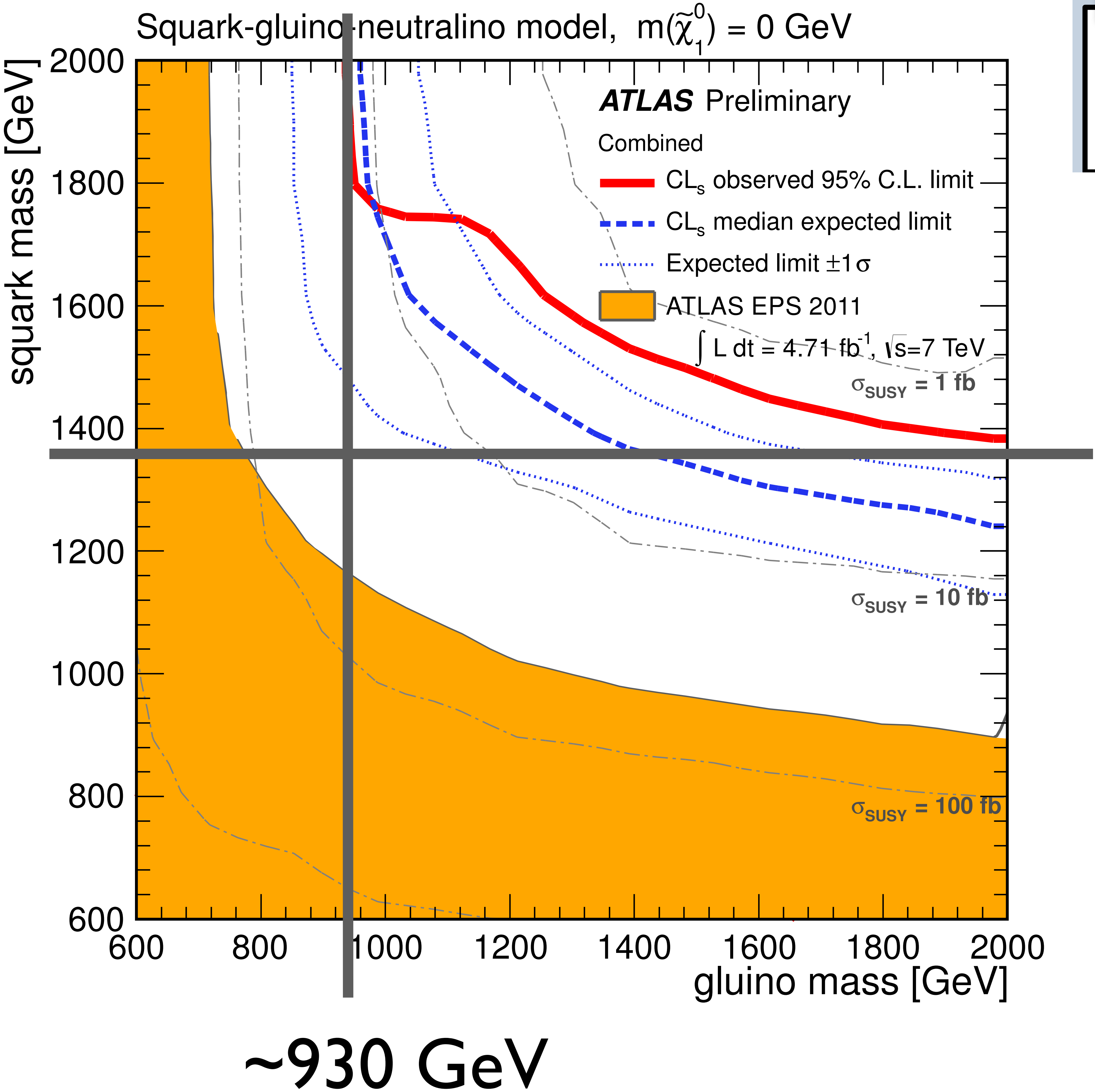
[1] 1110.6926 [2] 1206.xxxx

Direct searches

→ Sunil Somalwar's talk

- Implications of a 125 GeV Higgs for the MSSM →~~Nima's~~ & Csaba Csaki's talk

4.7 /fb Susy, post-Moriond



Susy searches

What have we learned about the susy spectrum after 5 1/fb ?

- 1st & 2nd generation squarks need to be heavy > 1.2-1.5 TeV from jets+MET searches with 5/fb
- gluino limits above ~900 GeV (also from various other channels)

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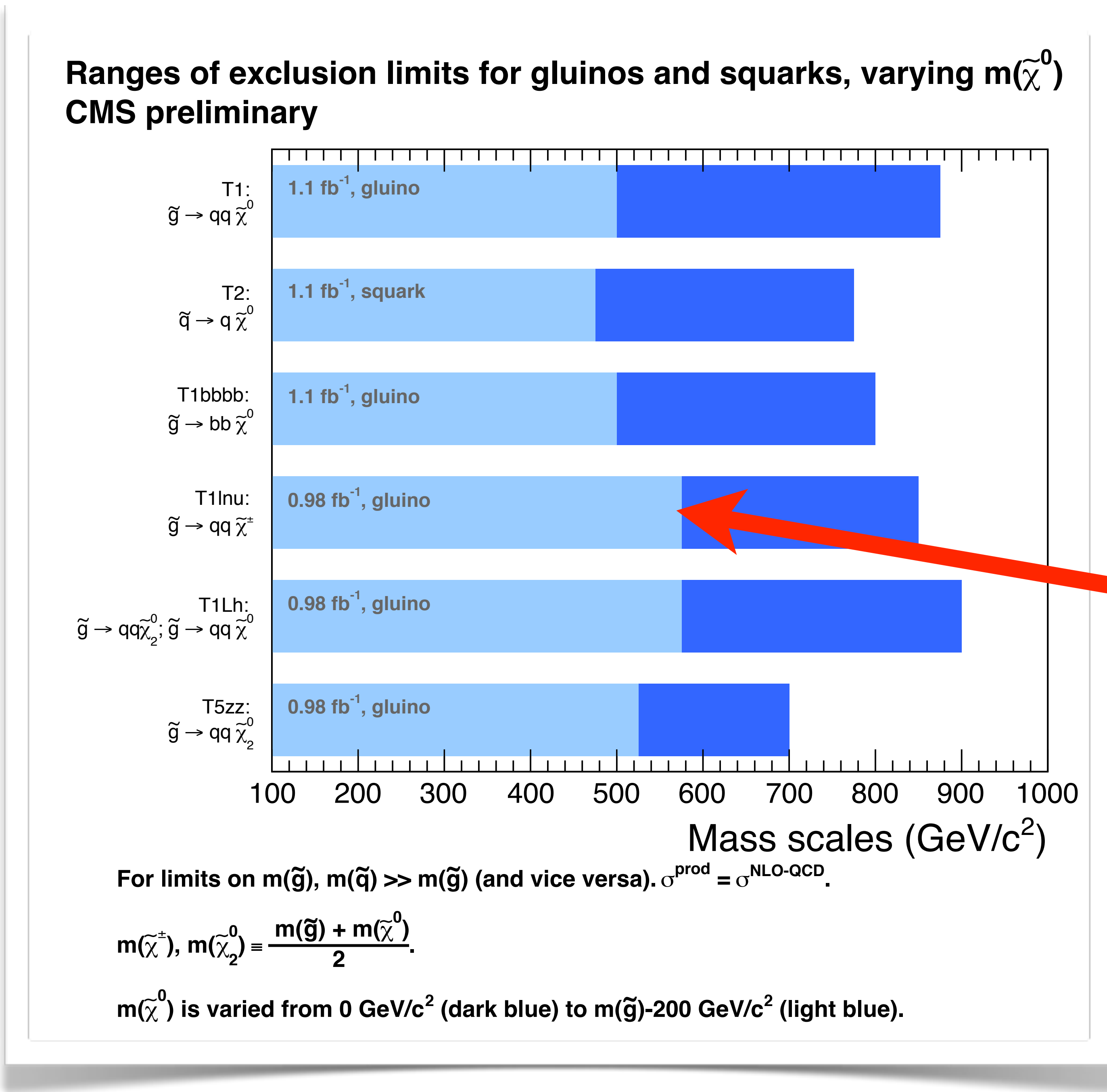
Caveats?

Impact of LSP mass

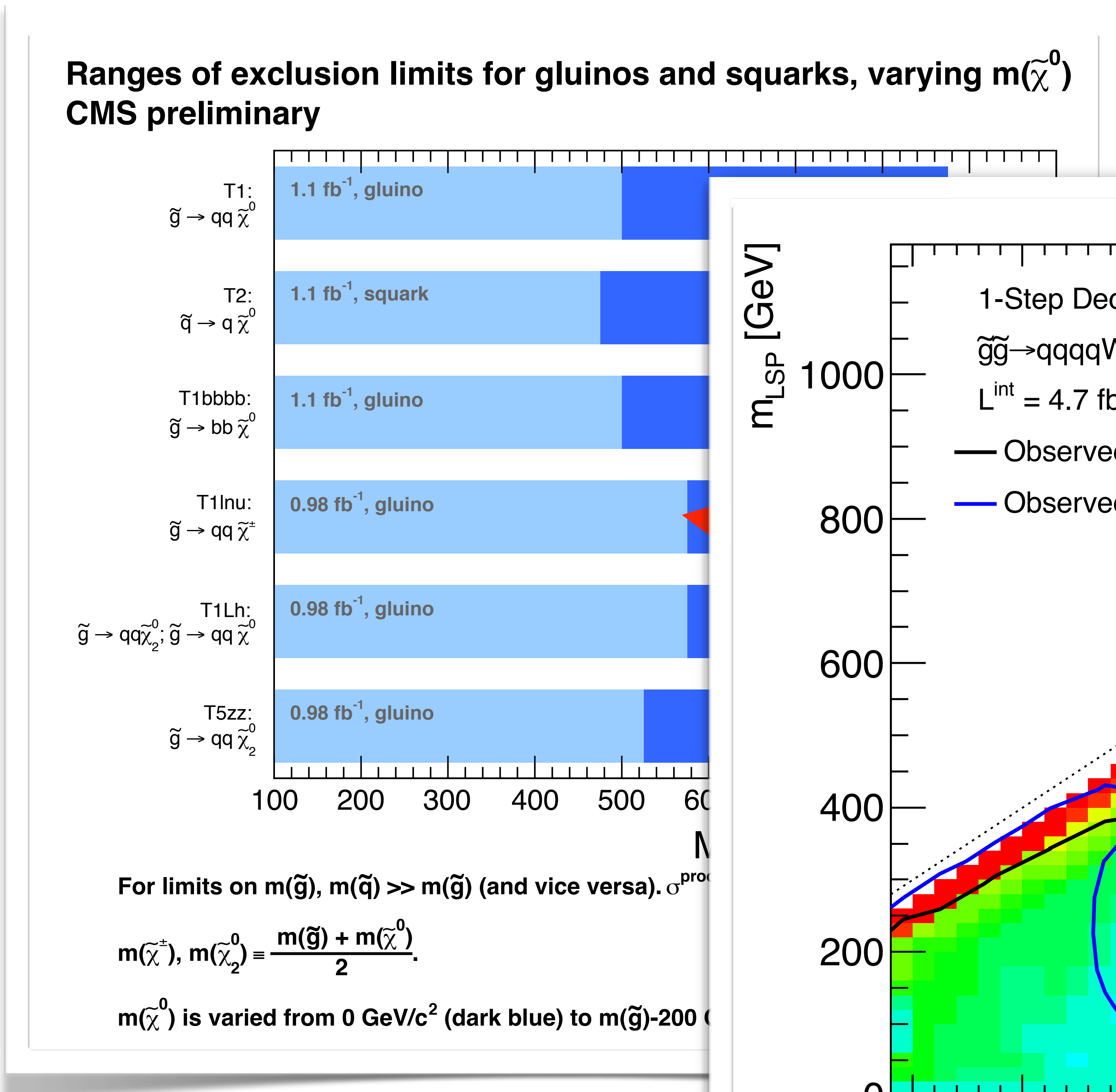


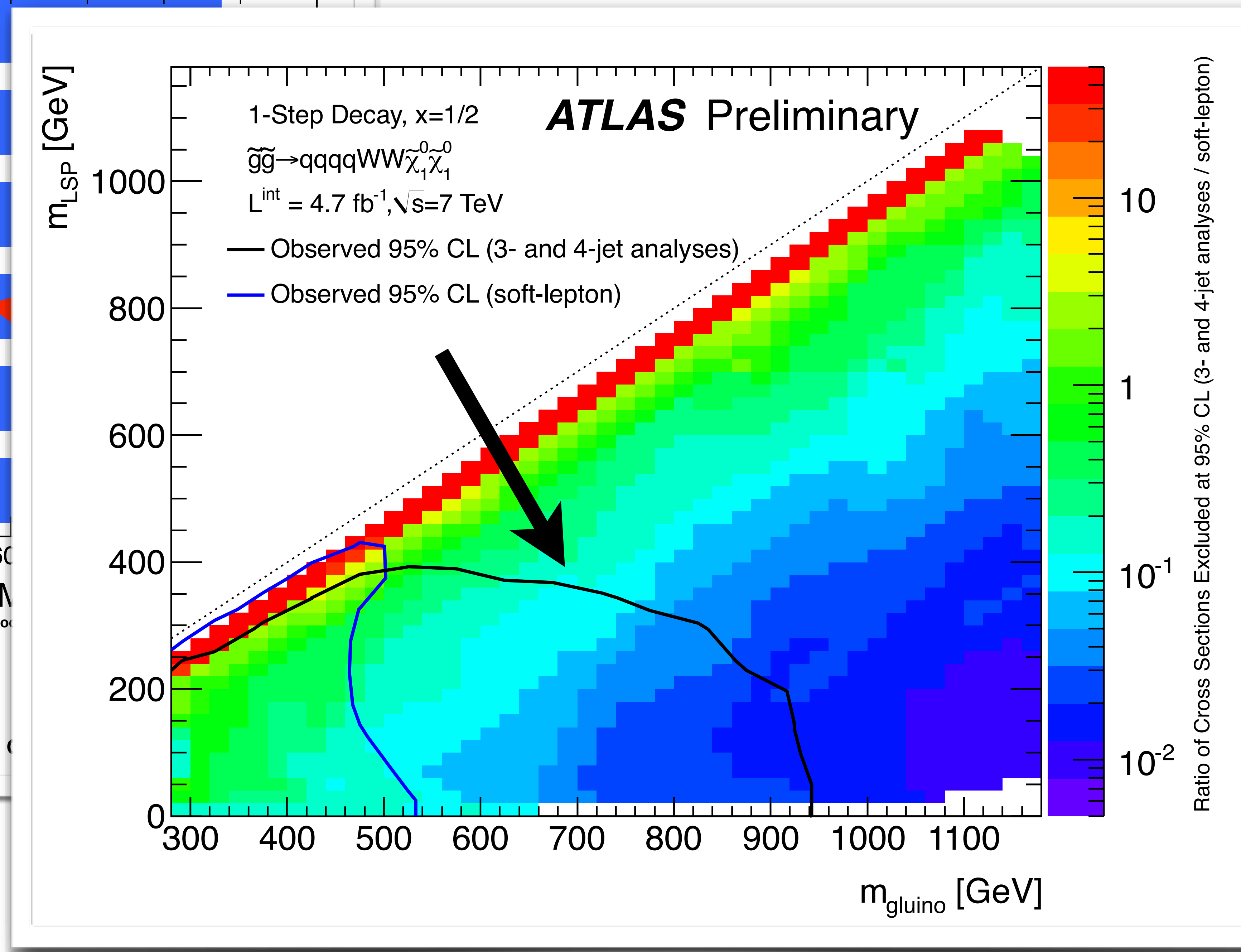
Compressed spectrum alleviates bounds

$m_{gluino} - m_{LSP} = 200$ GeV

Impact of LSP mass

Compressed spectrum alleviates bounds





While limits are pushed we need to make sure that no stone is left unturned:

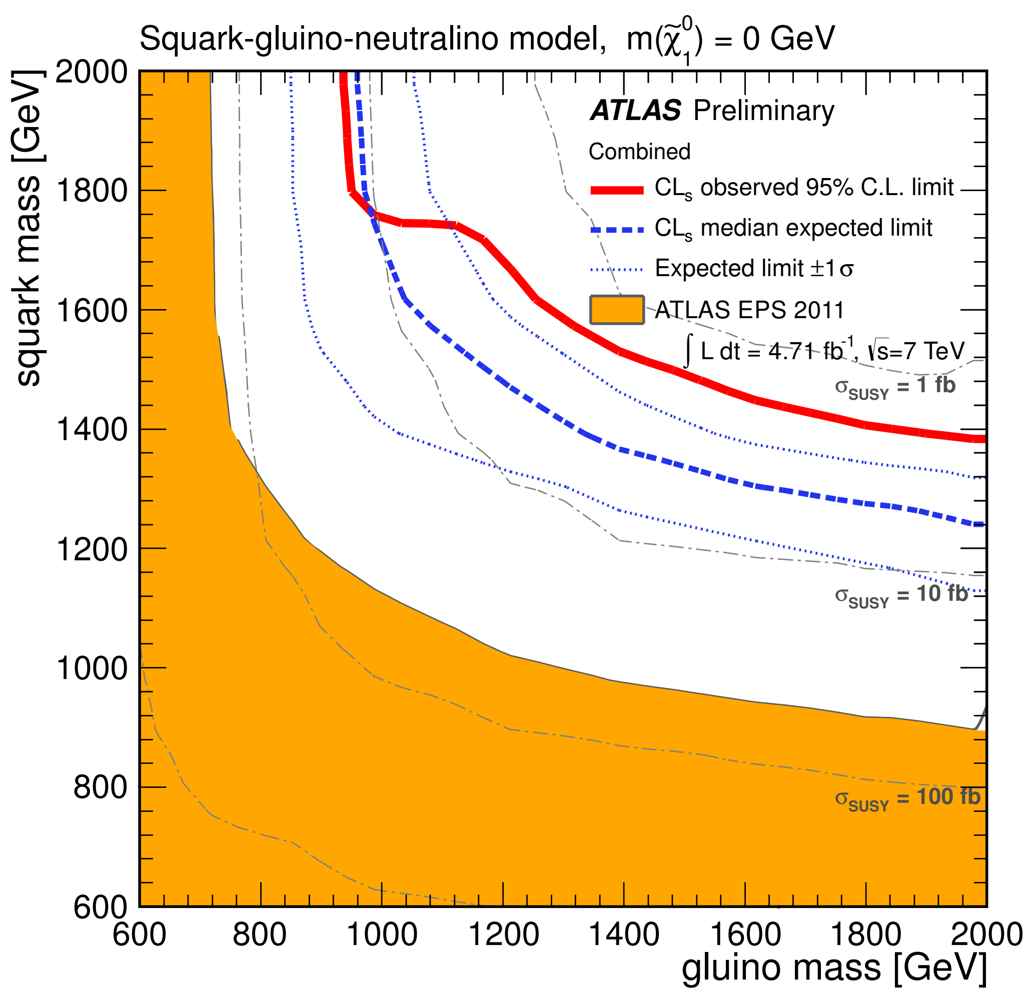
- Globally scan SUSY parameter space (e.g. pMSSM, e.g. Hewett et al., 1205.5903)
- Modify CMSSM/mSUGRA, … talk by H. Rzehak
- Focus the relevant kinematic features (this talk)
- Focus on theoretically-motivated models first (also this talk)

1st and 2nd generation squark limits

work in progress with

Michele Papucci, Josh Ruderman,
Gilad Perez, Rakhi Mahbubani

1st & 2nd genenenation squark limits



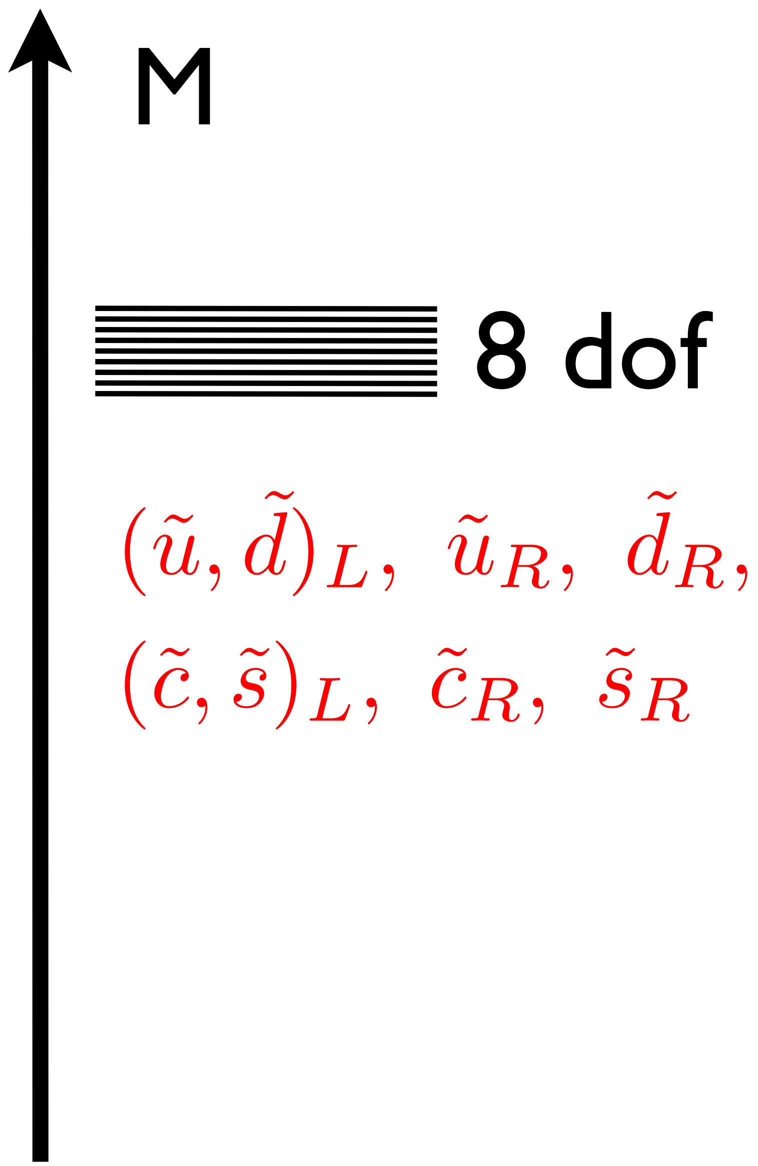
Light squarks > 1.4 TeV?

Assumptions? Necessary b/c of flavor?

What is driving the limit?

Holes in the net?

Do 1st & 2nd gen' squarks have to be degenerate?



- Because of flavor constraints? Not really.

spectrum in ATLAS/CMS plots

→ Gino Isidori's talk

UTfit 08, Isidori, Perez, Nir '10

Operator	Bounds on Λ in TeV ($c_{ij}=1$) Re	Bounds on Λ in TeV ($c_{ij}=1$) Im	Bounds on c_{ij} ($\Lambda = 1$ TeV) Re	Bounds on c_{ij} ($\Lambda = 1$ TeV) Im	Observables
$(\bar{s}_L \gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ϵ_K
$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	Δm_K; ϵ_K
$(\bar{c}_L \gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p \rvert, \phi_D$
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	Δm_D; $\lvert q/p \rvert, \phi_D$
$(\bar{b}_L \gamma^\mu d_L)^2$	5.1×10^2	9.3×10^2	3.3×10^{-6}	1.0×10^{-6}	Δm_{B_d}; $S_{\psi K_S}$
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Very strong suppression! New flavor violation must either approximately (exactly?) follow SM structure…

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… or exist only at very high scales (10^2 - 10^5 TeV)

SUSY & Flavor

Flavor Bounds (K, D, B, Bs mixing, …) controlled by

$$(\delta^q_{ij})_{MM} = \frac{1}{\tilde{m}_q^2} \sum_\alpha (K^q_M)_{i\alpha} (K^q_M)^*_{j\alpha} \Delta \tilde{m}^2_{q_\alpha}$$

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mixing matrices

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mixing matrices   mass splitting

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mixing matrices mass splitting

(m=1TeV)

q	ij	$(\delta^q_{ij})_{MM}$	$\langle\delta^q_{ij}\rangle$
d	12	0.03	0.002
d	13	0.2	0.07
d	23	0.6	0.2
u	12	0.1	0.008

Isidori et. al '10

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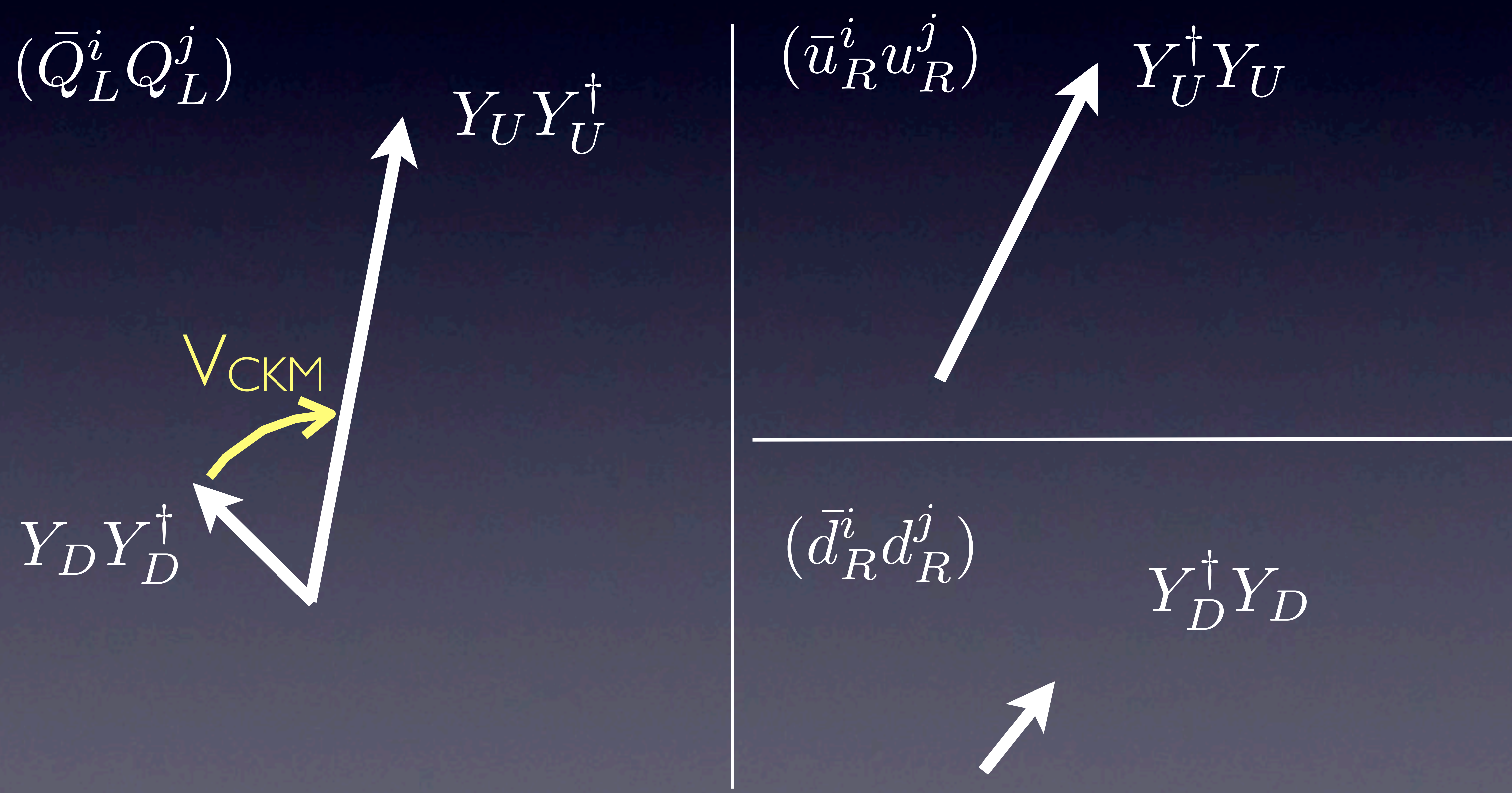
u	12	0.1	0.008

large mixing means splitting must be << 1

Isidori et. al '10

A picture of flavor

Yukawa matrices Y_U & Y_D encode flavor violation



+ LR, RL

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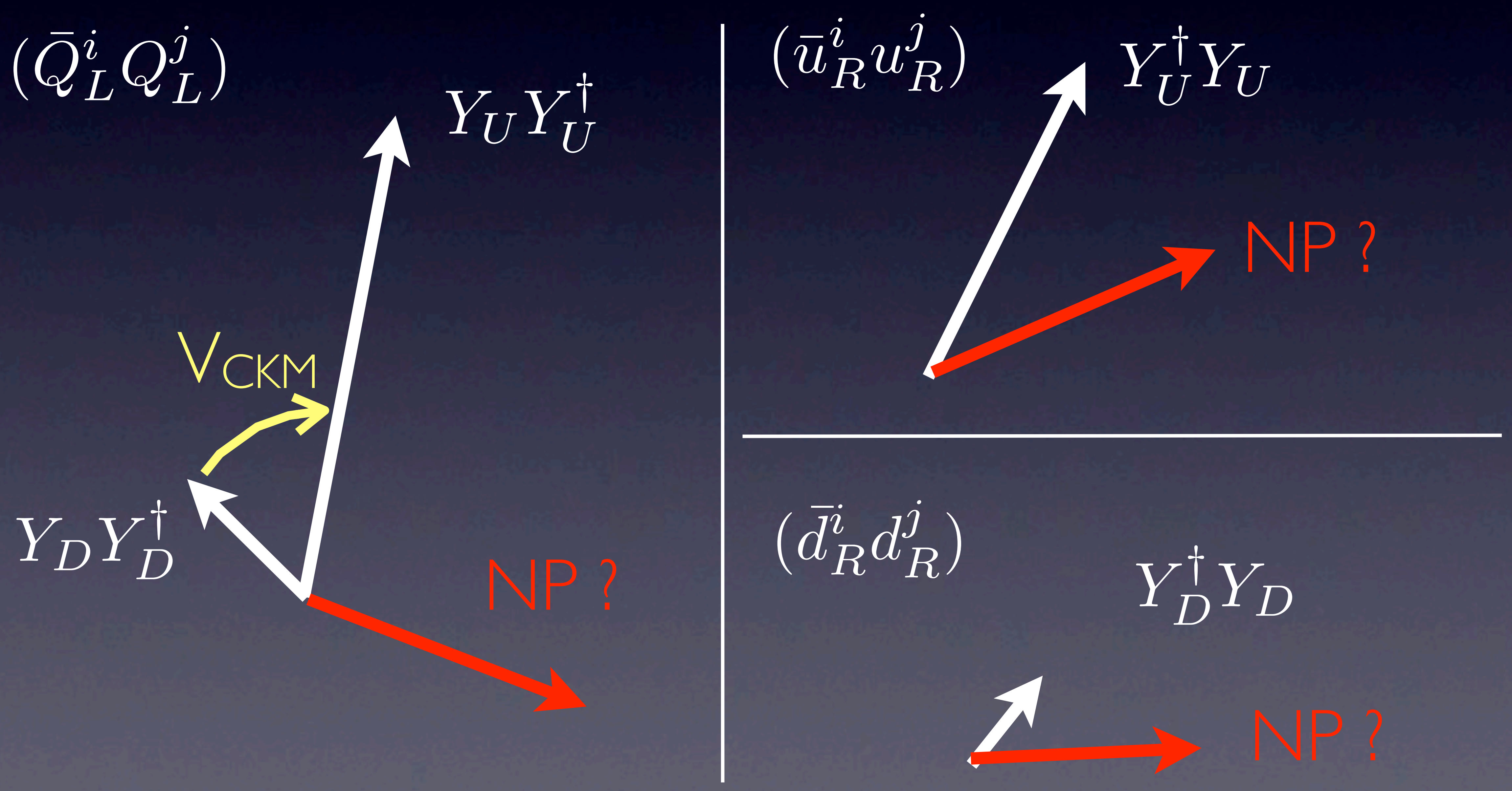

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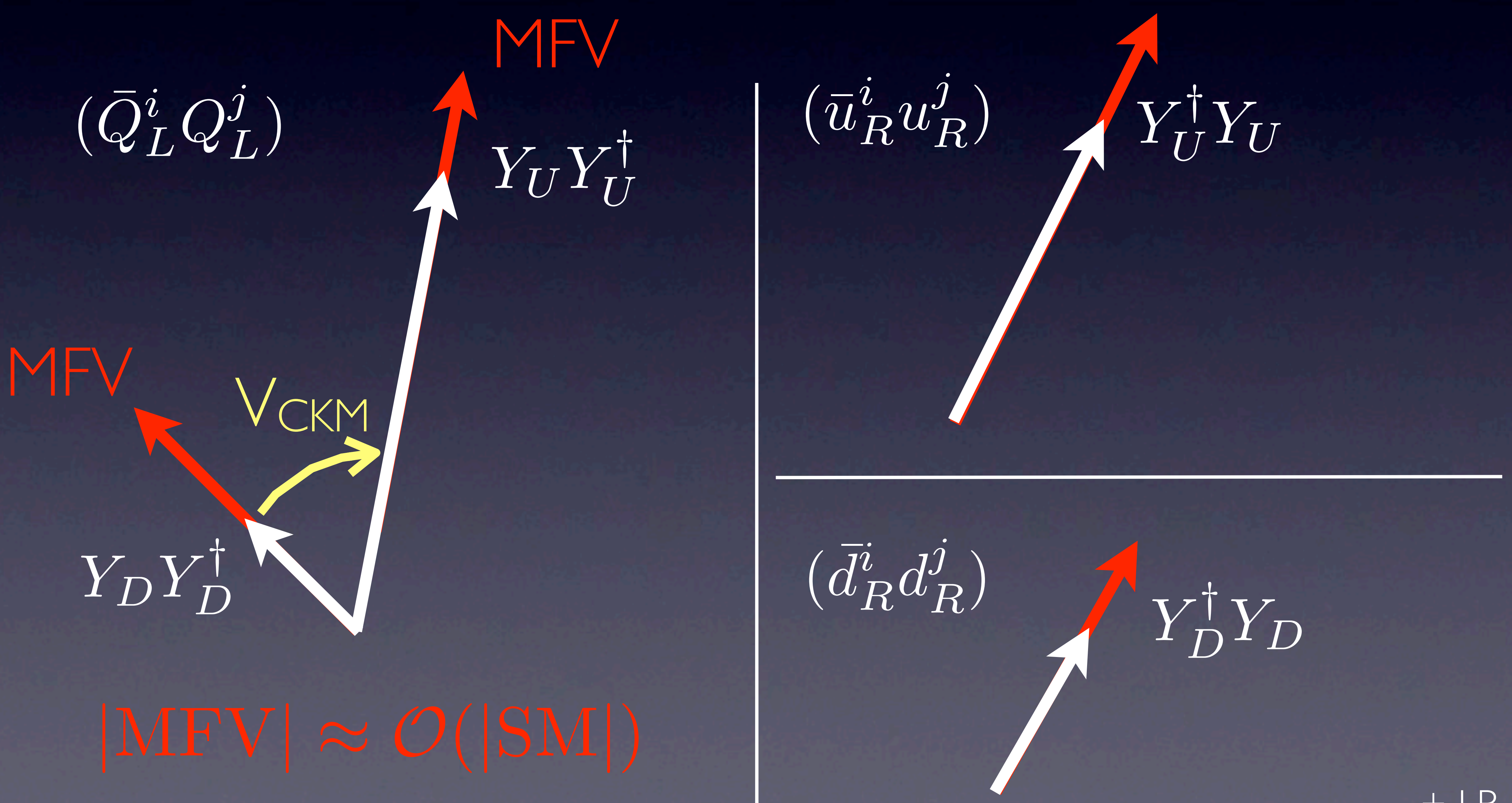
Minimal flavor violation

Chivukula Georgi; Buras et. al; D'Ambrosio et. al

New particles/interactions, but flavor structure ~ V_{CKM}



$|\mathrm{MFV}| \approx \mathcal{O}(|\mathrm{SM}|)$

+ LR, RL

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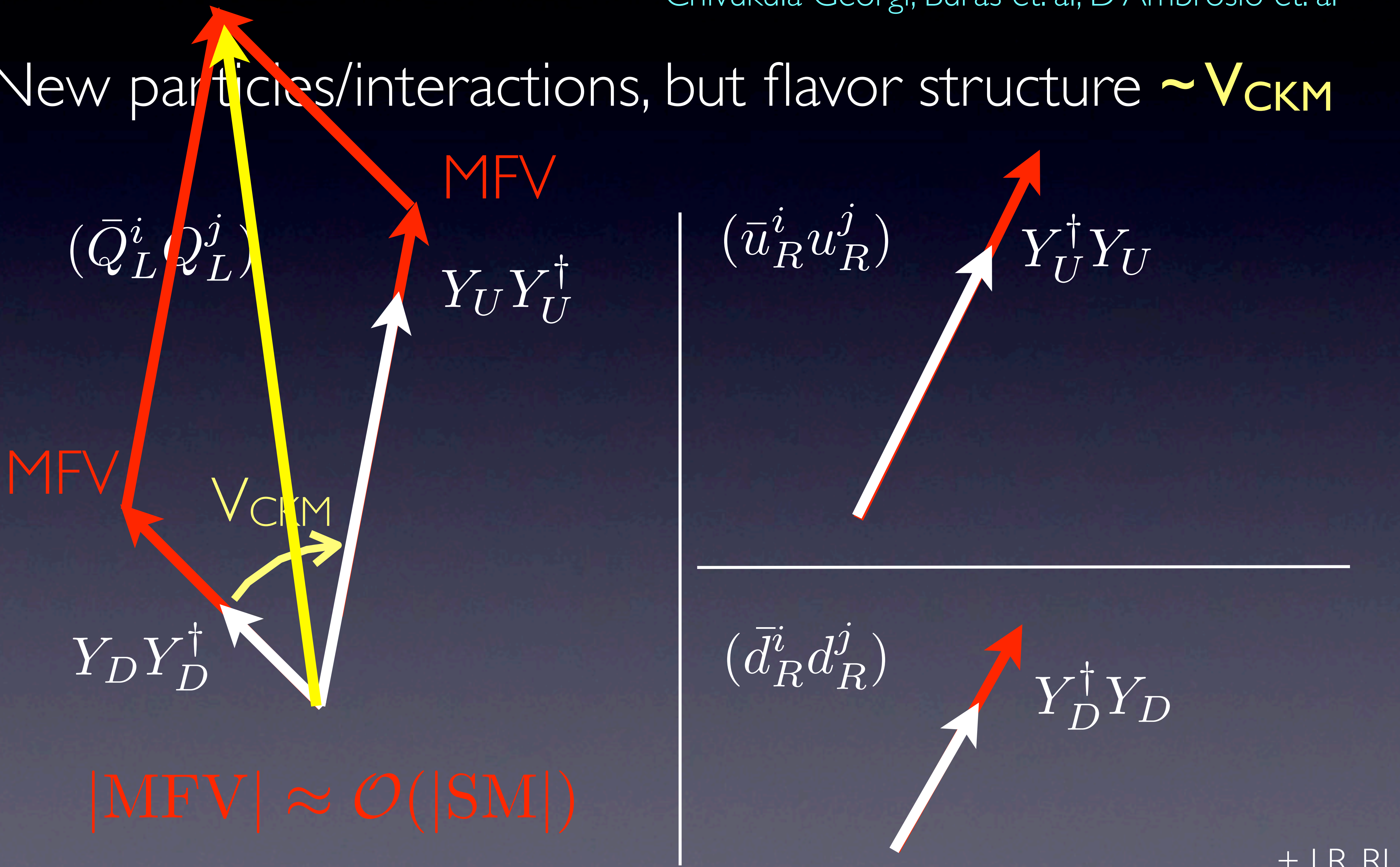
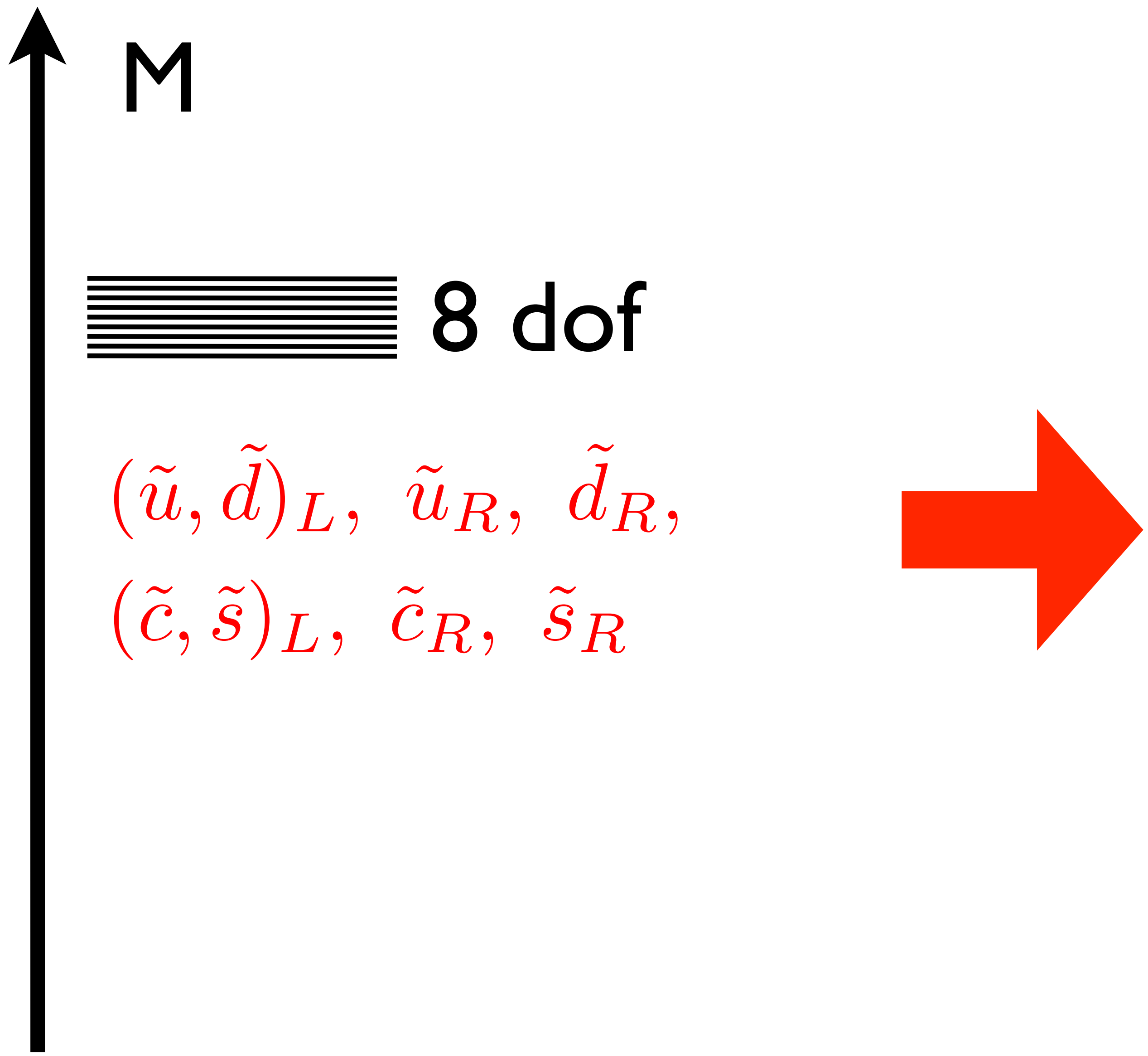
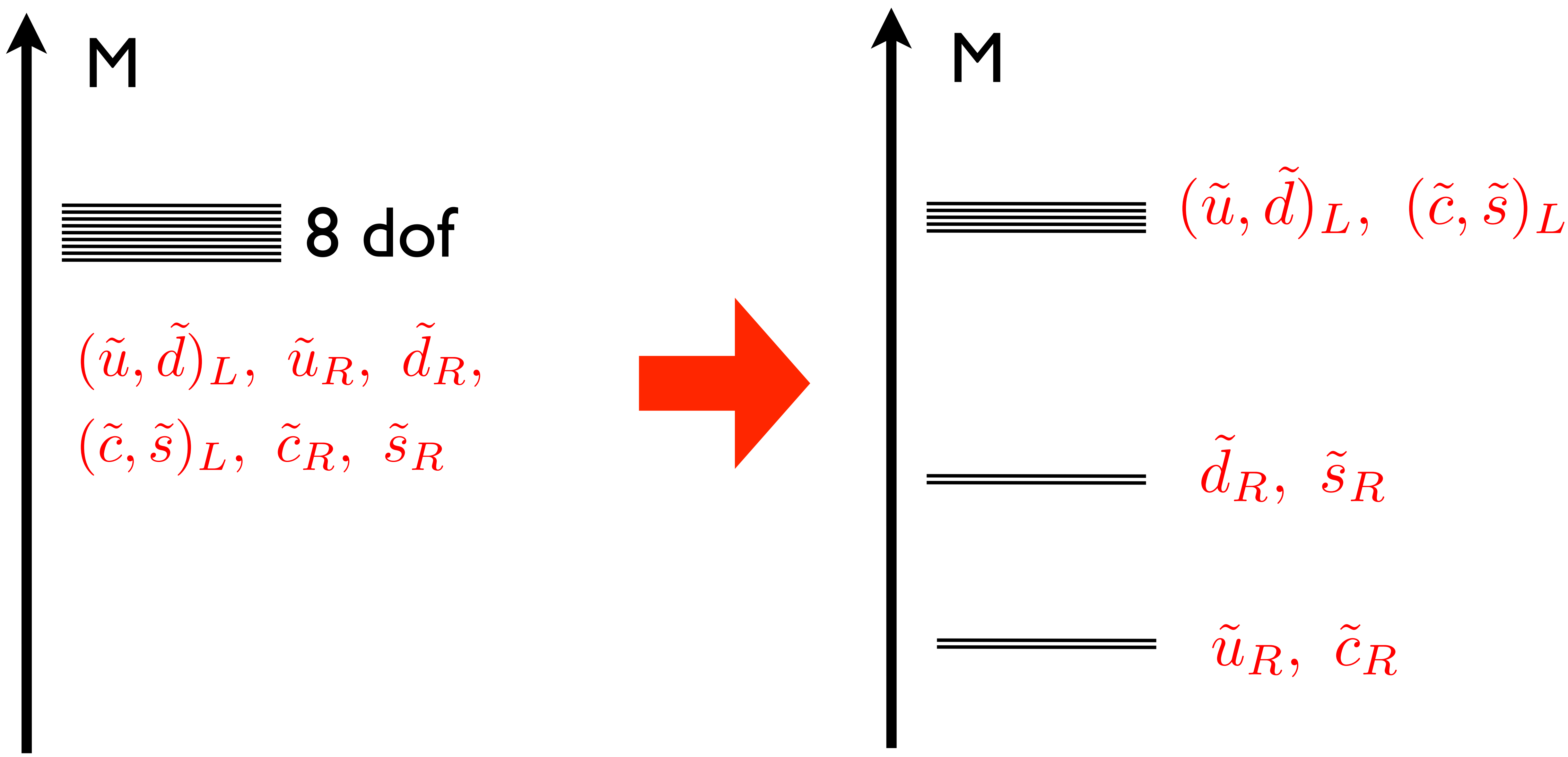


Minimal Flavor Violation

- Trivial: Squark masses same for all three generations but split between $\tilde{Q}_L, \ \tilde{u}_R, \ \tilde{d}_R$
- Split among generations but split like in SM: mass-differences $\propto Y_{U,D} \sim (0,0,1)$



Fully degenerate

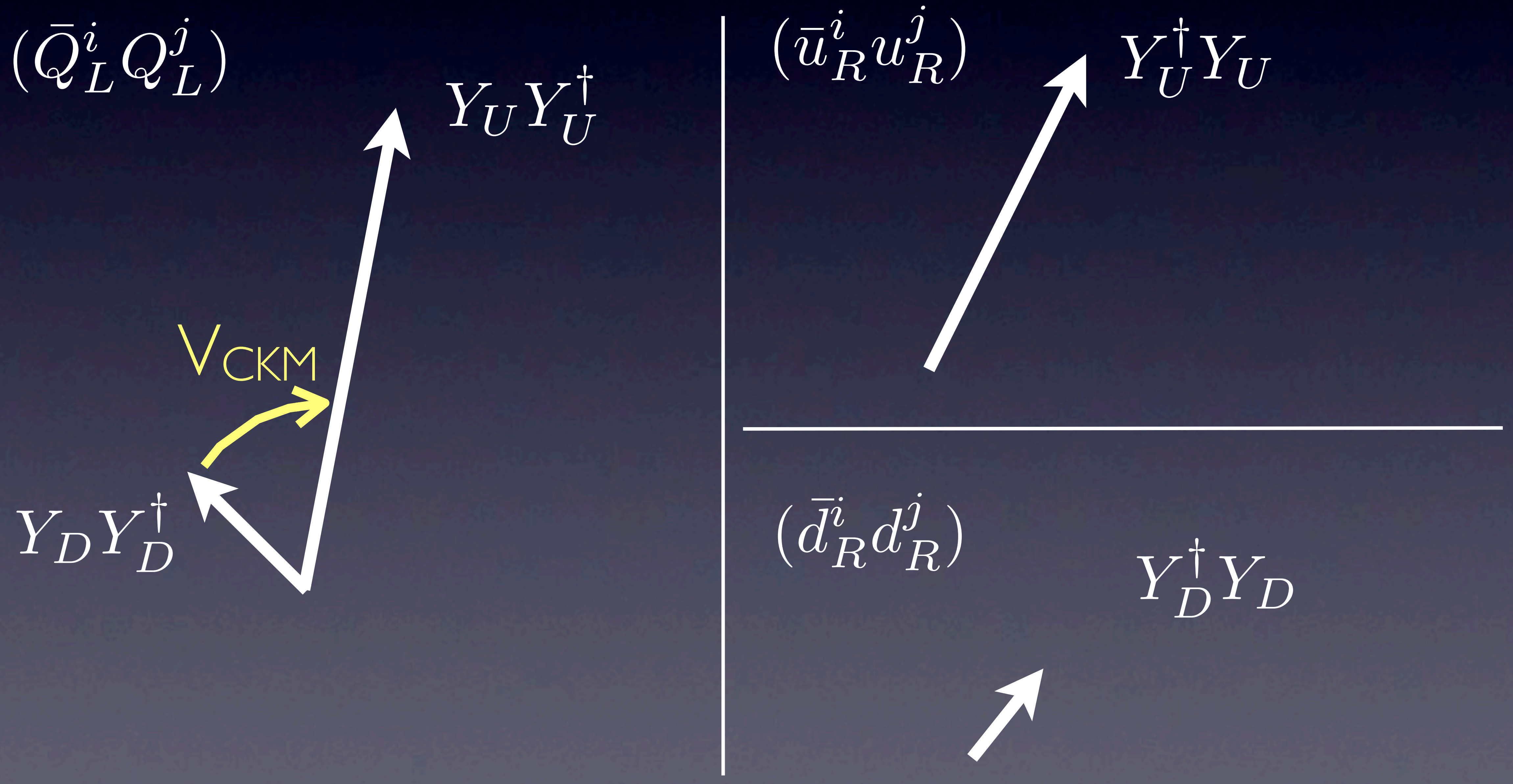


Fully degenerate

Vertical splitting,
still MFV & no problem!

Flavor dynamics: alignment

Dynamics (e.g. U(1)$_{\text{horiz.}}$) generates hierarchies in masses & mixings. Consequence: partial alignment with SM



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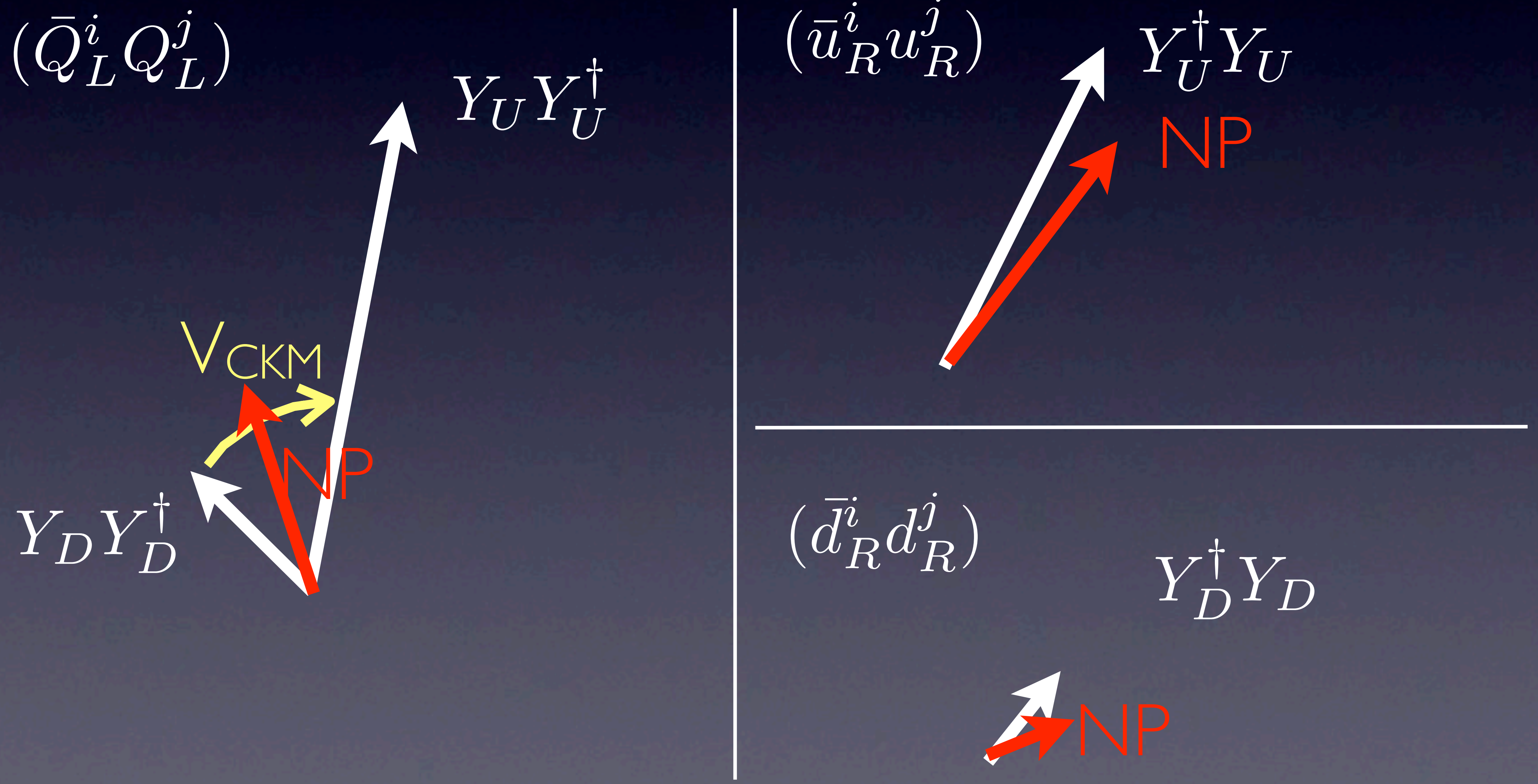
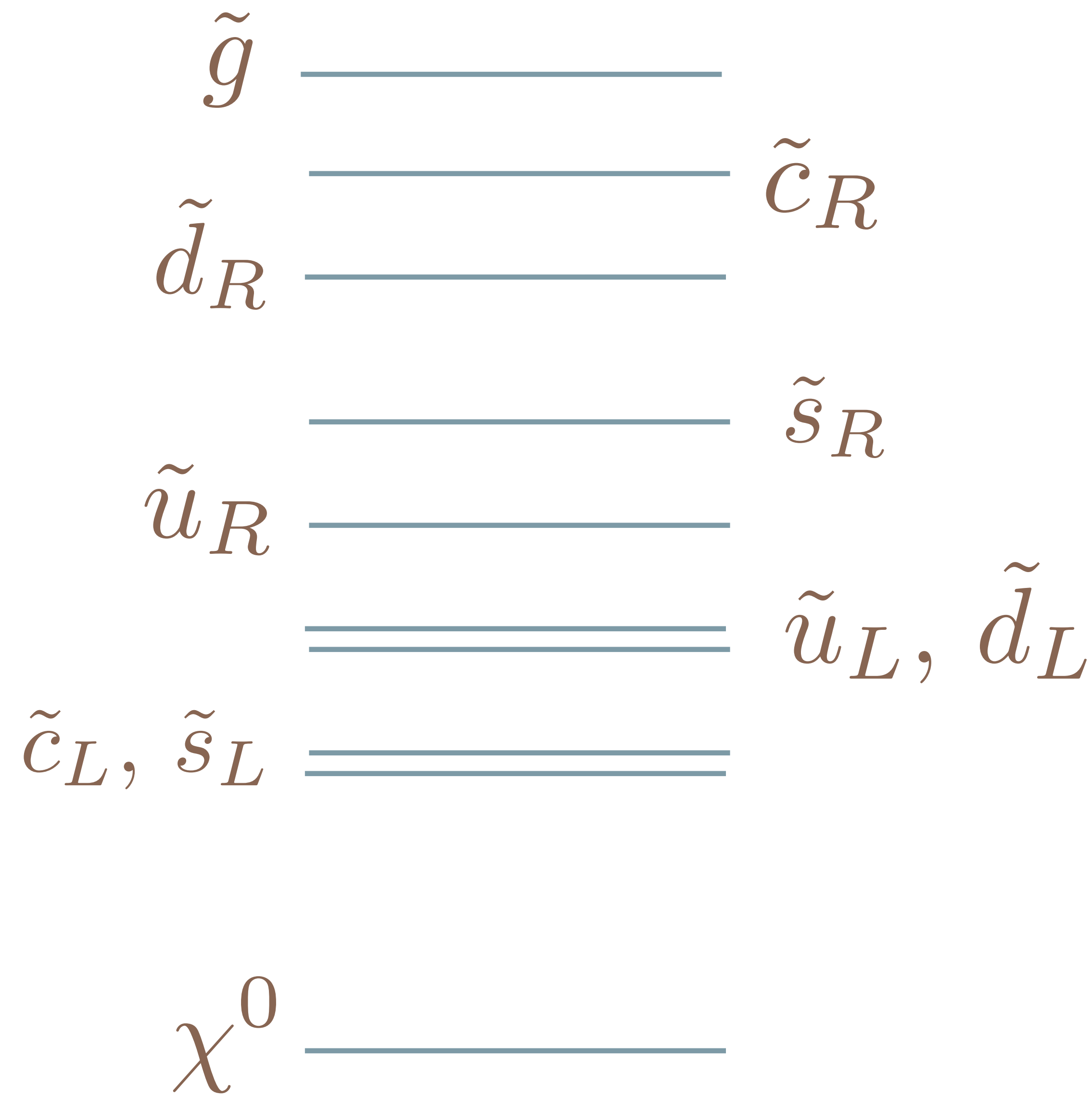


+ LR, RL

Leurer, Nir, Seiberg '92

- Right handed squarks can be strongly aligned → O(1) splitting possible
- Left handed squarks can be aligned either to up or down quarks
- Existence of V_{CKM} → Left handed squarks contribute to K or D mixing
- Left handed squark splitting mildly constrained (CP phases generically small)



Alignment

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mixing / misalignment between
SM Yukawas and squark mass matrices

Alignment

Seiberg & Nir

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If by symmetry: K_{ij} ~ diagonal => O(1) mass splitting allowed!

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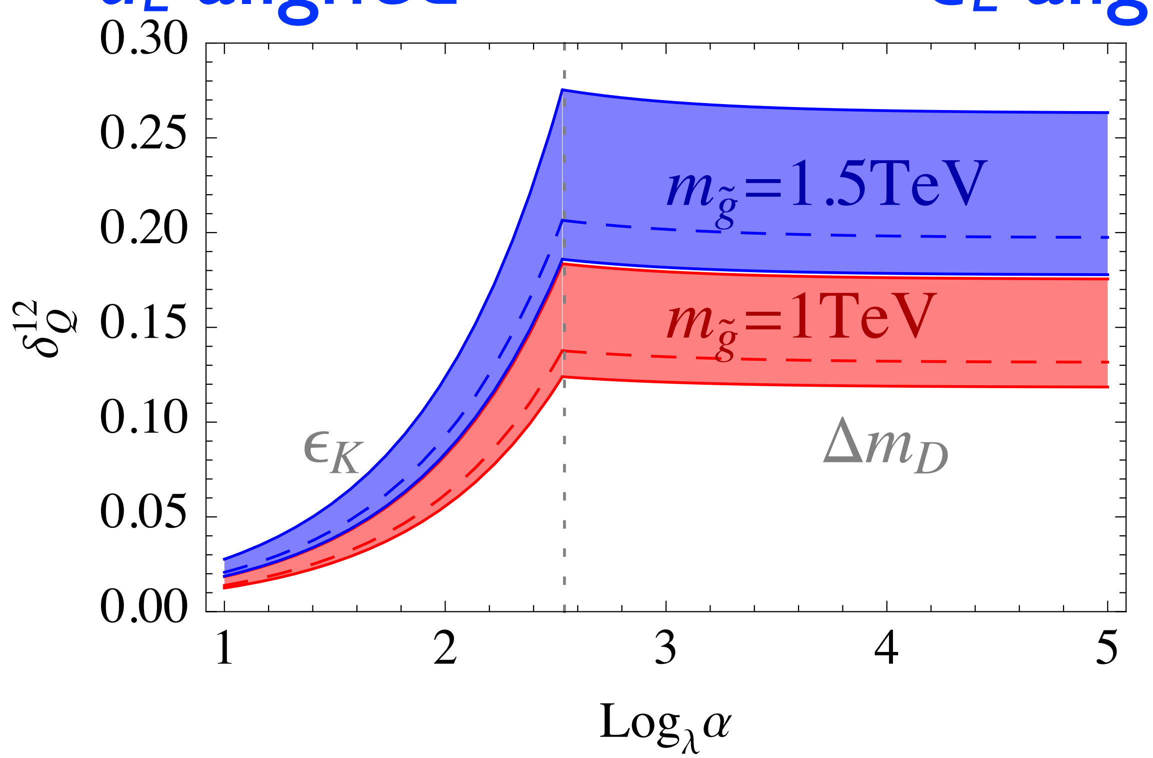
Gedalia et. al

u_L aligned ⟷ d_L aligned

squark splitting



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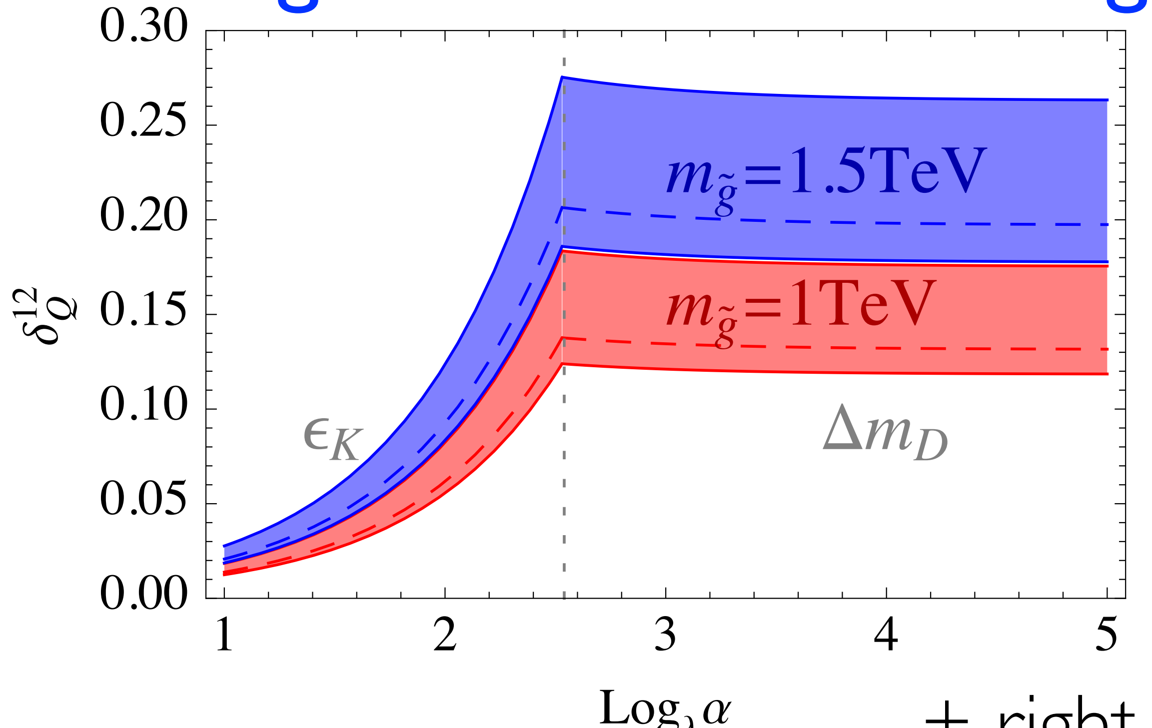


Example:

m_{gluino} = 1.3 TeV

m_{Q1} = 550 GeV

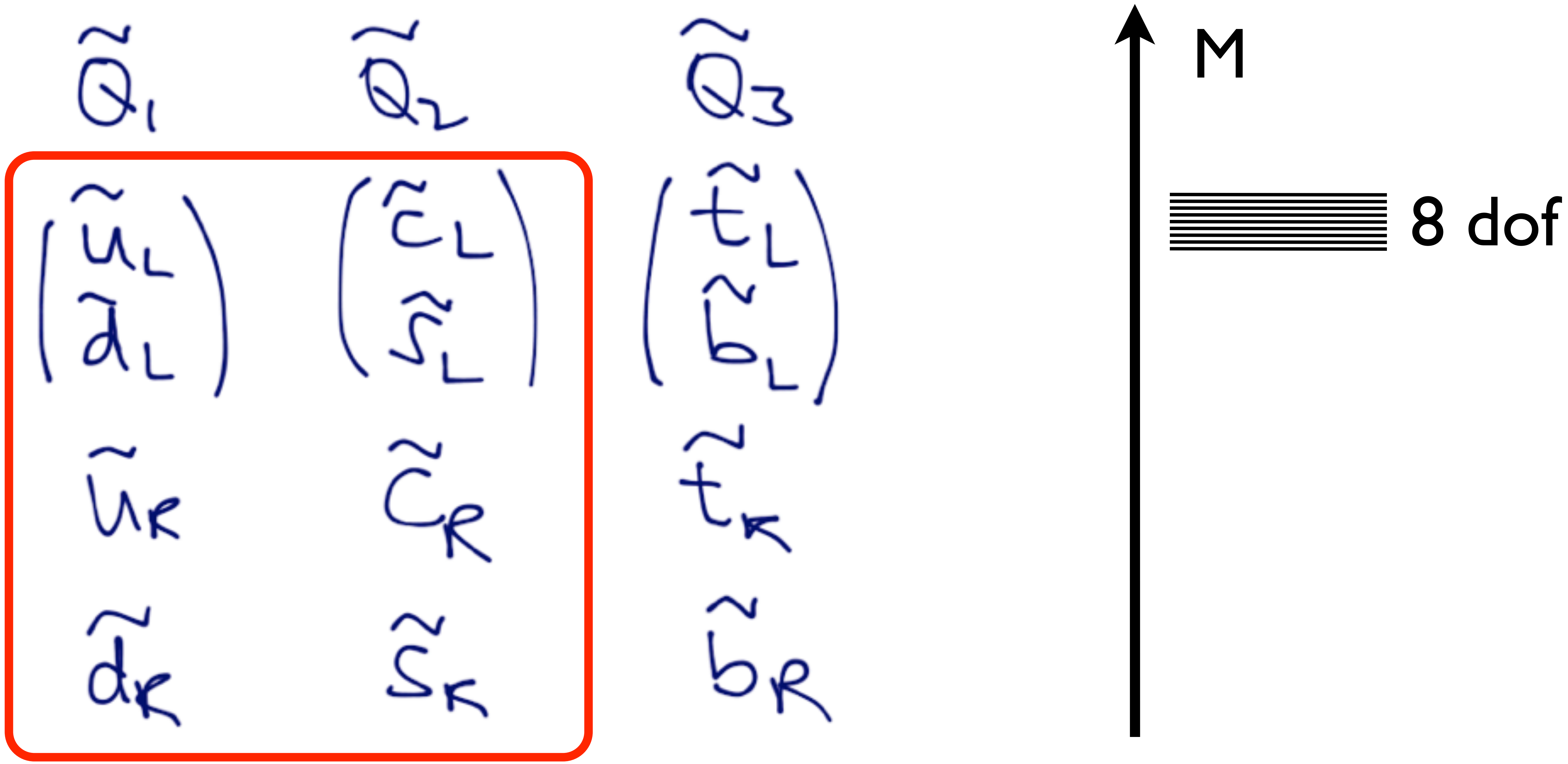
m_{Q2} = 950 GeV

+ right handed squarks split by arbitrary amount

Flavor vs. squark masses: summary

- Generic 1-2 splitting has to be small, BUT:
- Can split vertically: split irrep's, MFV
- Can split horizontally, if squark flavor aligned

1st & 2nd gen' squarks degenerate



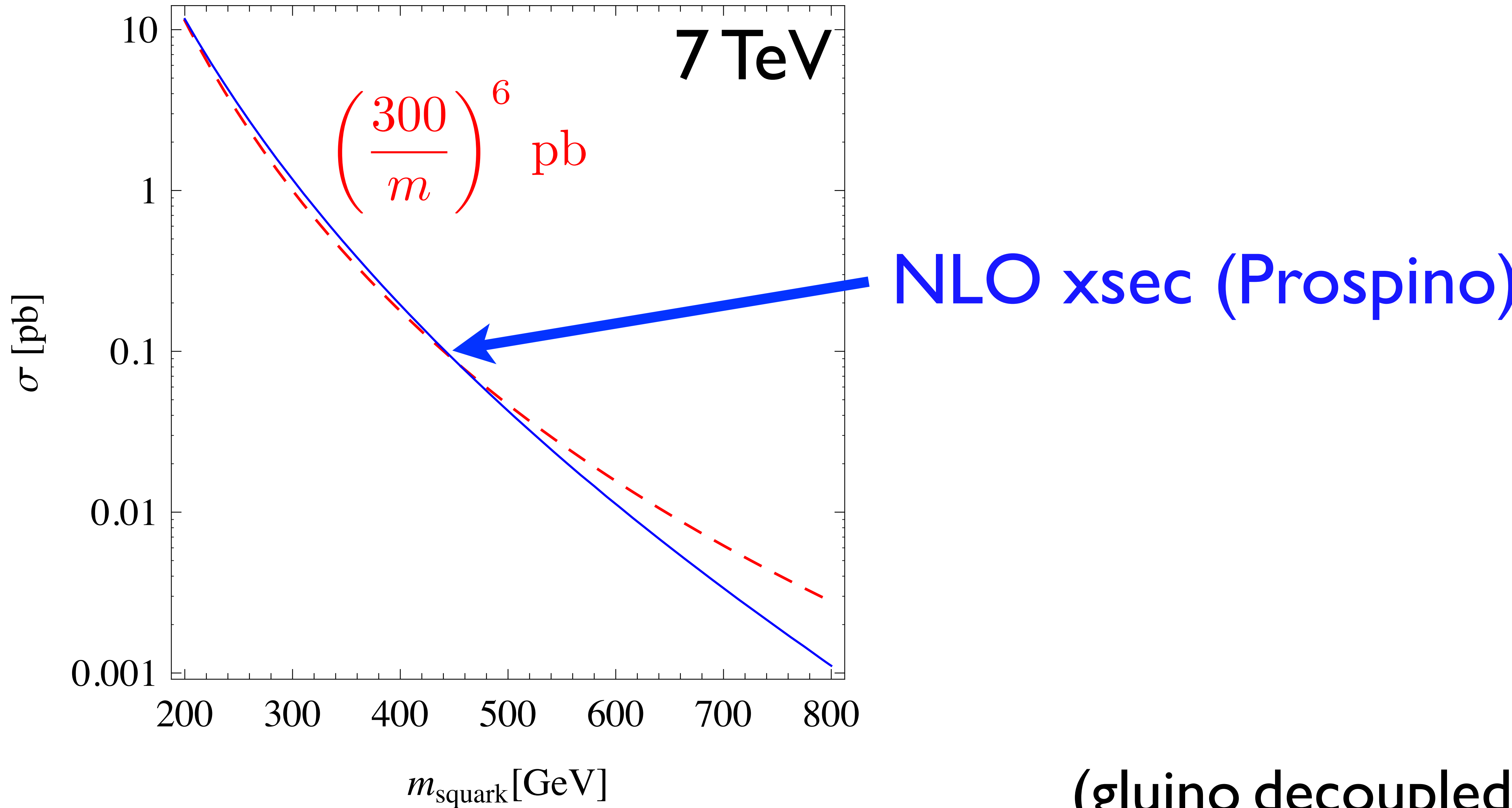
assumption in ATLAS/CMS plots

Does it matter if we relax the degeneracy assumption?

Naive answer: not so much.

Cross-sections vs. mass

$$\sigma(pp \to \tilde{u}_R \tilde{u}_R^*) \propto \frac{1}{m^6}$$ (roughly)



(gluino decoupled)

Back of the envelope estimate

Cross-sections roughly scale like ~1/m^6.

Example: 8 light squarks → 2 light squarks

Shift limit only by $\sim 4^{1/6} - 1 \approx 25\%$

→ too naive!

Dedicated study needed

- Production cross-section can be flavor dependent if gluino is not fully decoupled through p.d.f's (*u* vs. *d*, sea vs. valence)
- Experimental efficiencies for light squarks are not very good : efficiencies have hard thresholds and current limits are on the thresholds

How can we extract limits on non-degenerate 1st and 2nd gen' squarks from experimental searches?

"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.

Let’s check!

* not his real attitude.

DYI limits

CERN-PH-EP-2011-145

Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in $\sqrt{s} = 7$ TeV proton-proton collisions

The ATLAS Collaboration

Example:
jets+ MET 1.041/fb

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Example:
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Signal Region	≥ 2-jet	≥ 3-jet	≥ 4-jet	High mass
E_T^{miss}	> 130	> 130	> 130	> 130
Leading jet p_T	> 130	> 130	> 130	> 130
Second jet p_T	> 40	> 40	> 40	> 80
Third jet p_T	–	> 40	> 40	> 80
Fourth jet p_T	–	–	> 40	> 80
$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff}	> 1000	> 1000	> 500/1000	> 1100

signal bins

Bgd's are left to the experimentalists… stay out of control regions!

Process	Signal Region				
	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet, $m_{\text{eff}} > 500$ GeV	$\geq$ 4-jet, $m_{\text{eff}} > 1000$ GeV	High mass
Z/γ+jets	$32.3 \pm 2.6 \pm 6.9$	$25.5 \pm 2.6 \pm 4.9$	$209 \pm 9 \pm 38$	$16.2 \pm 2.2 \pm 3.7$	$3.3 \pm 1.0 \pm 1.3$
W+jets	$26.4 \pm 4.0 \pm 6.7$	$22.6 \pm 3.5 \pm 5.6$	$349 \pm 30 \pm 122$	$13.0 \pm 2.2 \pm 4.7$	$2.1 \pm 0.8 \pm 1.1$
$t\bar{t}$+ single top	$3.4 \pm 1.6 \pm 1.6$	$5.9 \pm 2.0 \pm 2.2$	$425 \pm 39 \pm 84$	$4.0 \pm 1.3 \pm 2.0$	$5.7 \pm 1.8 \pm 1.9$
QCD multi-jet	$0.22 \pm 0.06 \pm 0.24$	$0.92 \pm 0.12 \pm 0.46$	$34 \pm 2 \pm 29$	$0.73 \pm 0.14 \pm 0.50$	$2.10 \pm 0.37 \pm 0.82$
Total	$62.4 \pm 4.4 \pm 9.3$	$54.9 \pm 3.9 \pm 7.1$	$1015 \pm 41 \pm 144$	$33.9 \pm 2.9 \pm 6.2$	$13.1 \pm 1.9 \pm 2.5$
Data	58	59	1118	40	18

Table 2: Fitted background components in each SR, compared with the number of events observed in data. The Z/γ+jets background is constrained with co regions CR1a and CR1b, the QCD multi-jet, W and top quark backgrounds by control regions CR2, CR3 and CR4, respectively. In each case the first (sec quoted uncertainty is statistical (systematic). Background components are partially correlated and hence the uncertainties (statistical and systematic) on the background estimates do not equal the quadrature sums of the uncertainties on the components.

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[5] has improved the ATLAS reach at large m_0. The five signal regions are used to set limits on $\sigma_{new} = \sigma A \epsilon$, for non-SM cross-sections (σ) for which ATLAS has an acceptance A and a detection efficiency of ϵ [44]. The excluded values of σ_{new} are 22 fb, 25 fb, 429 fb, 27 fb and 17 fb, respectively, at the 95% confidence level.

upper bound on signal xsec

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stay out of control regions!

Process	Signal Region				
	≥ 2-jet	≥ 3-jet	≥ 4-jet, $m_{\rm eff}$ > 500 GeV	≥ 4-jet, $m_{\rm eff}$ > 1000 GeV	High mass
Z/γ+jets	32.3 ± 2.6 ± 6.9	25.5 ± 2.6 ± 4.9	209 ± 9 ± 38	16.2 ± 2.2 ± 3.7	3.3 ± 1.0 ± 1.3
W+jets	26.4 ± 4.0 ± 6.7	22.6 ± 3.5 ± 5.6	349 ± 30 ± 122	13.0 ± 2.2 ± 4.7	2.1 ± 0.8 ± 1.1
$t\bar{t}$+ single top	3.4 ± 1.6 ± 1.6	5.9 ± 2.0 ± 2.2	425 ± 39 ± 84	4.0 ± 1.3 ± 2.0	5.7 ± 1.8 ± 1.9
QCD multi-jet	0.22 ± 0.06 ± 0.24	0.92 ± 0.12 ± 0.46	34 ± 2 ± 29	0.73 ± 0.14 ± 0.50	2.10 ± 0.37 ± 0.82
Total	62.4 ± 4.4 ± 9.3	54.9 ± 3.9 ± 7.1	1015 ± 41 ± 144	33.9 ± 2.9 ± 6.2	13.1 ± 1.9 ± 2.5
Data	58	59	1118	40	18

Table 2: Fitted background components in each SR, compared with the number of events observed in data. The Z/γ+jets background is constrained with co regions CR1a and CR1b, the QCD multi-jet, W and top quark backgrounds by control regions CR2, CR3 and CR4, respectively. In each case the first (sec quoted uncertainty is statistical (systematic). Background components are partially correlated and hence the uncertainties (statistical and systematic) on the background estimates do not equal the quadrature sums of the uncertainties on the components.

[5] has improved the ATLAS reach at large m_0. The five signal regions are used to set limits on $\sigma_{new} = \sigma A\epsilon$, for non-SM cross-sections (σ) for which ATLAS has an acceptance A and a detection efficiency of ϵ [44]. The excluded values of σ_{new} are 22 fb, 25 fb, 429 fb, 27 fb and 17 fb, respectively, at the 95% confidence level.

upper bound on signal xsec

"Only" need efficiency x Acceptance of the signal bins for your model…

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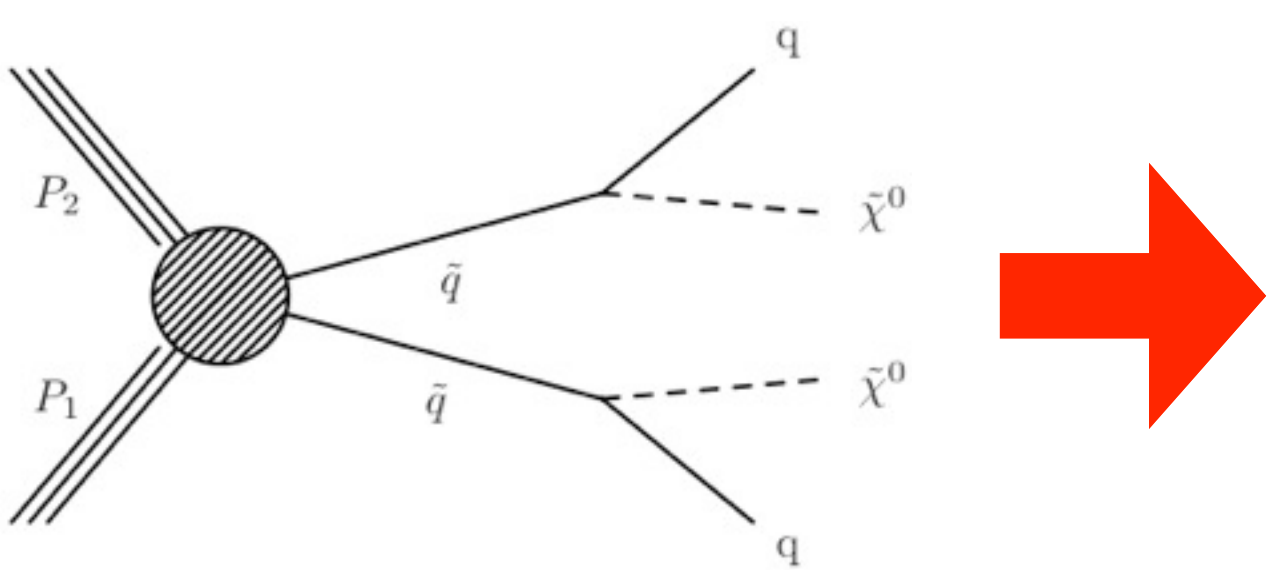
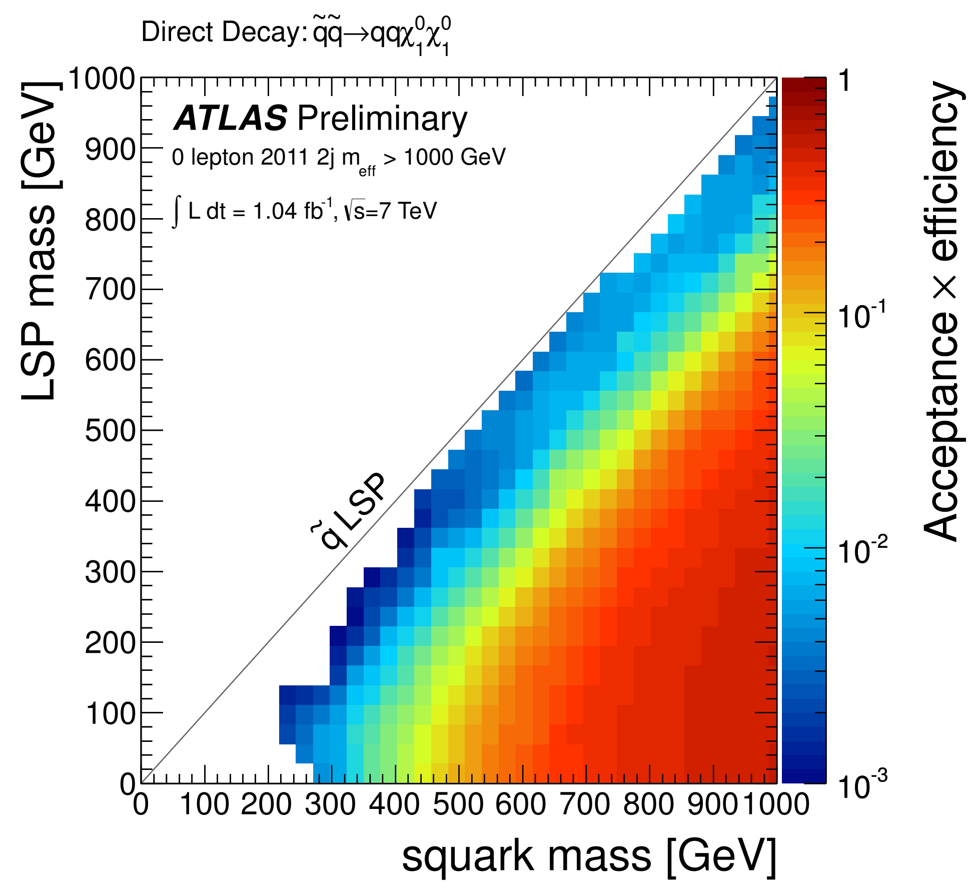
LIMIT!

Simplified Models to the rescue!

- Luckily ATLAS and CMS provide efficiencies for simplified models (so far only for 1/fb)

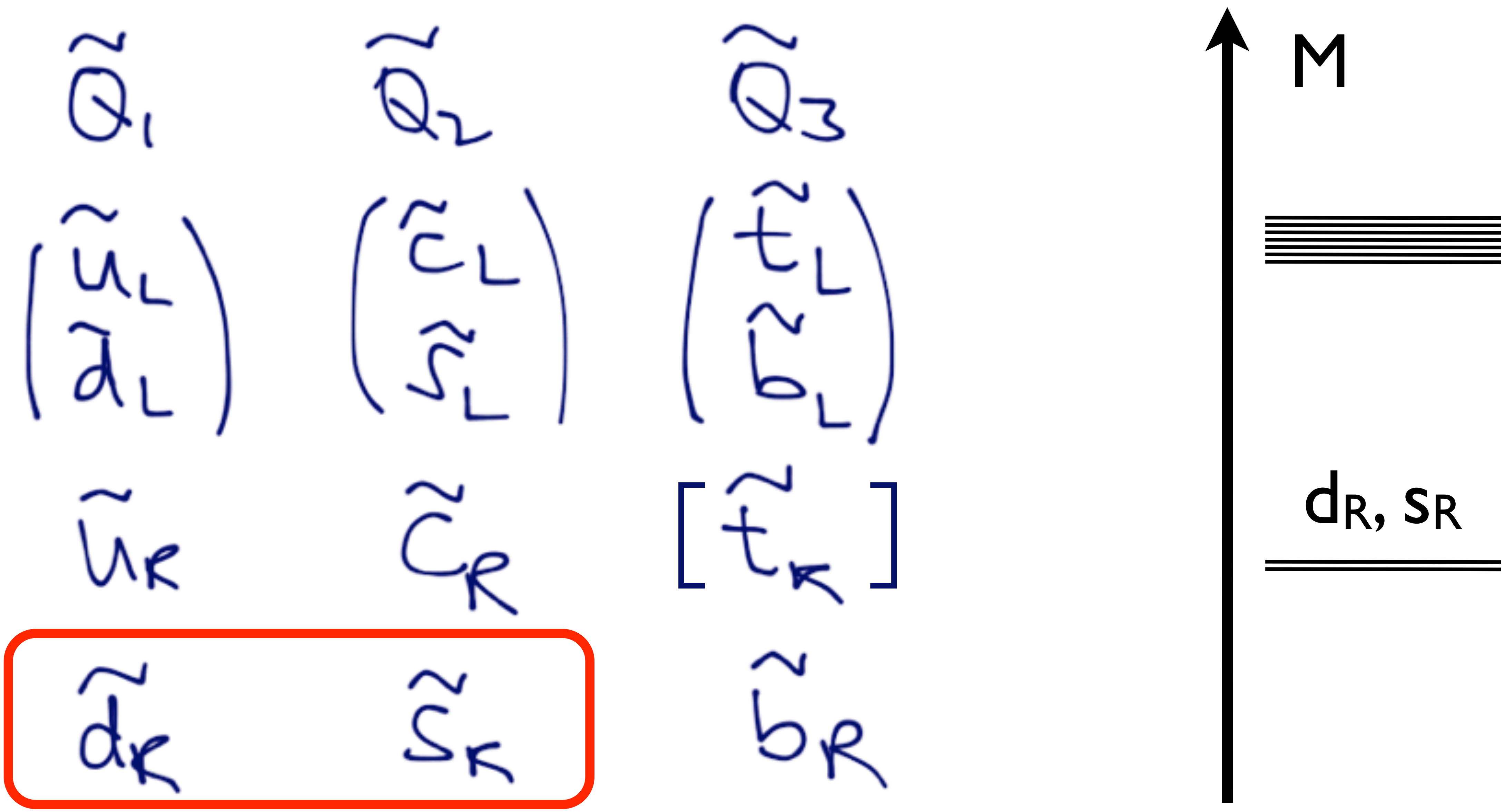




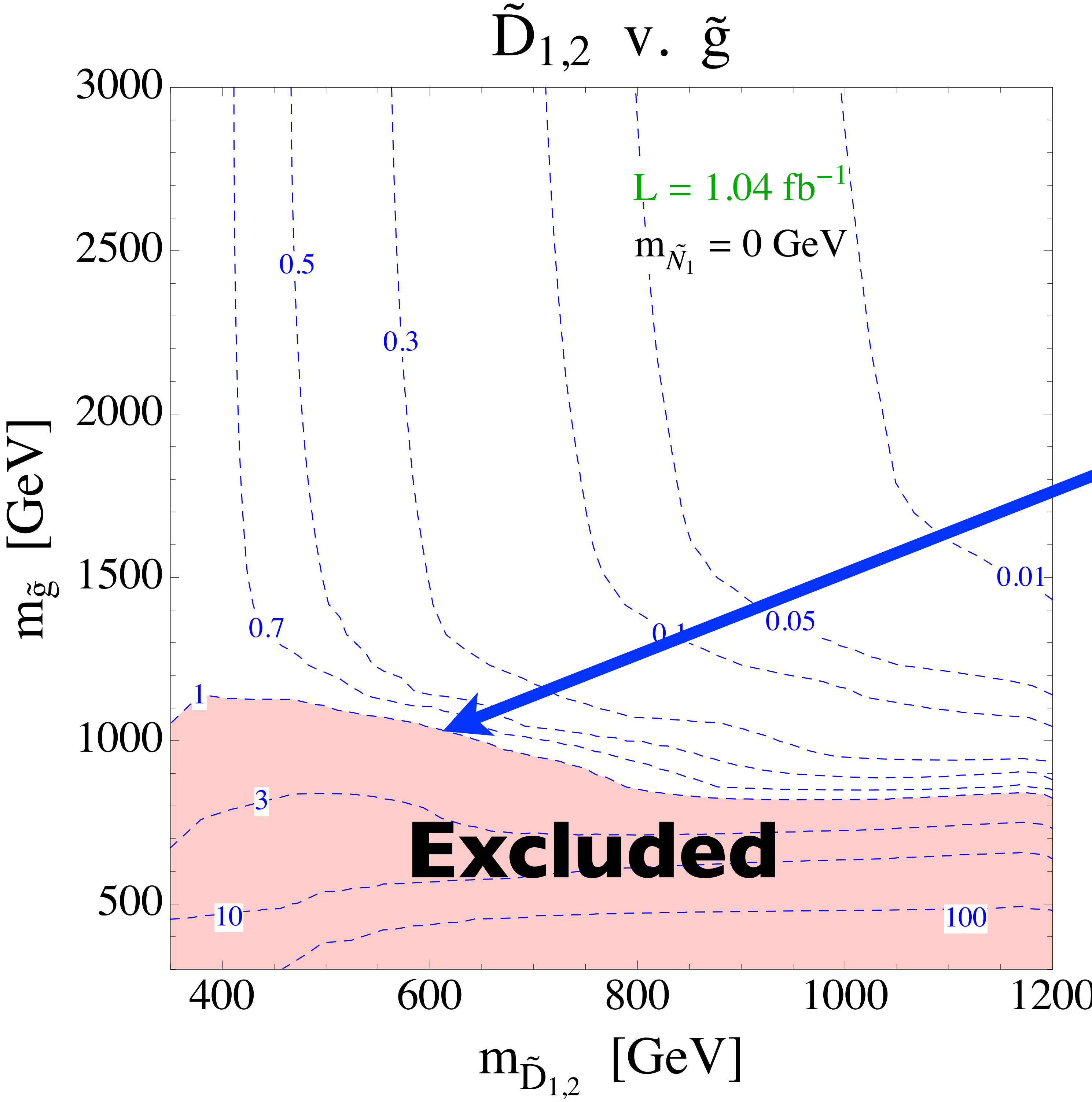
simplified topologies

e.g. CMSPublic/PhysicsResultsSUS11004 or ATLAS-CONF-2011-155/
Thanks for providing root files, HEPDATA,...

Split squarks w/ different quantum numbers (vertical)



Vertical non-degeneracy



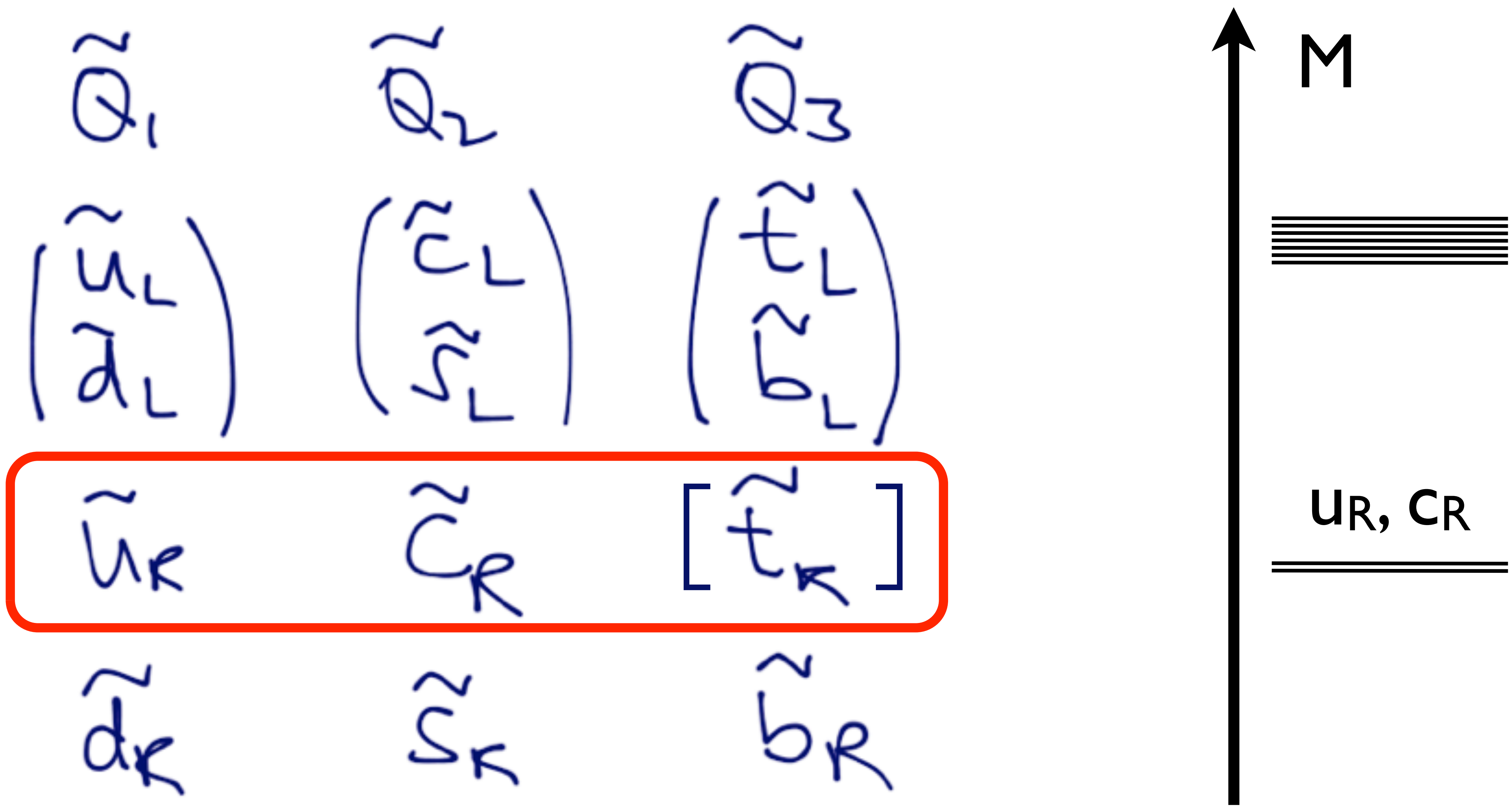
Contours of

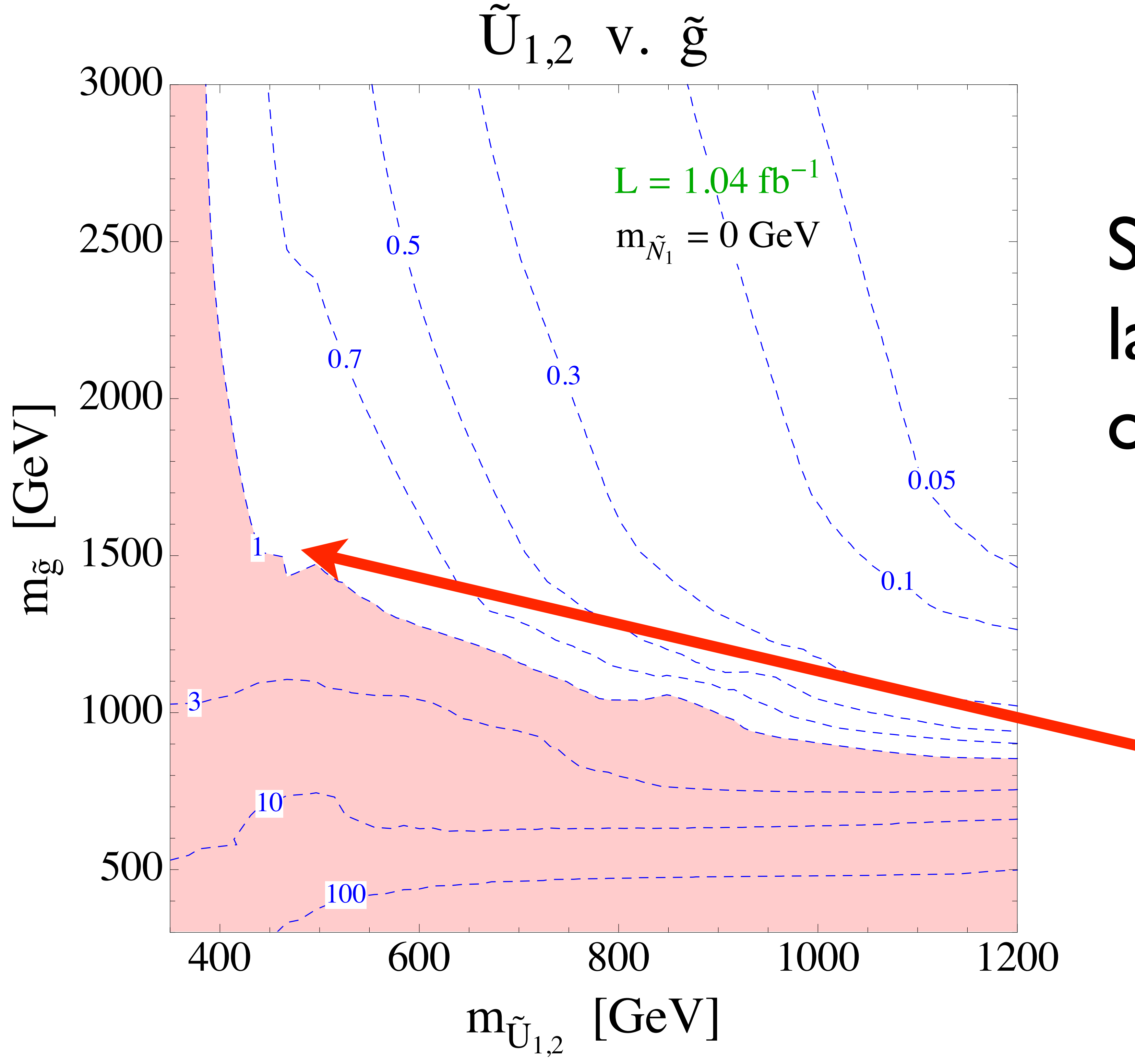
$\sigma/\sigma_{\mathrm{limit}}$

Exclusion (at 95CL) if this is = 1

For m_{gluino} > 1.2 TeV, limit can even disapear (m_{LSP} =0 GeV)

Split squarks w/ different quantum number (vertical)



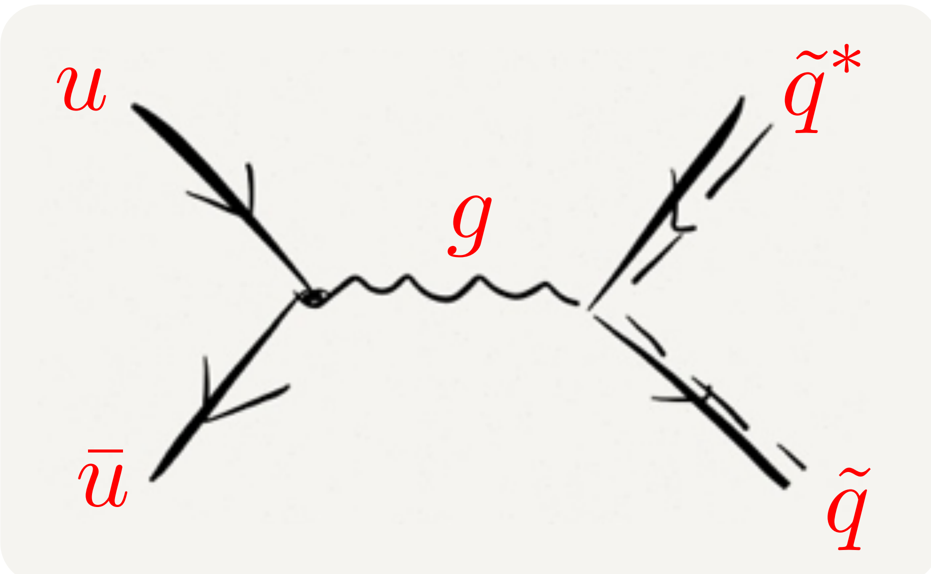


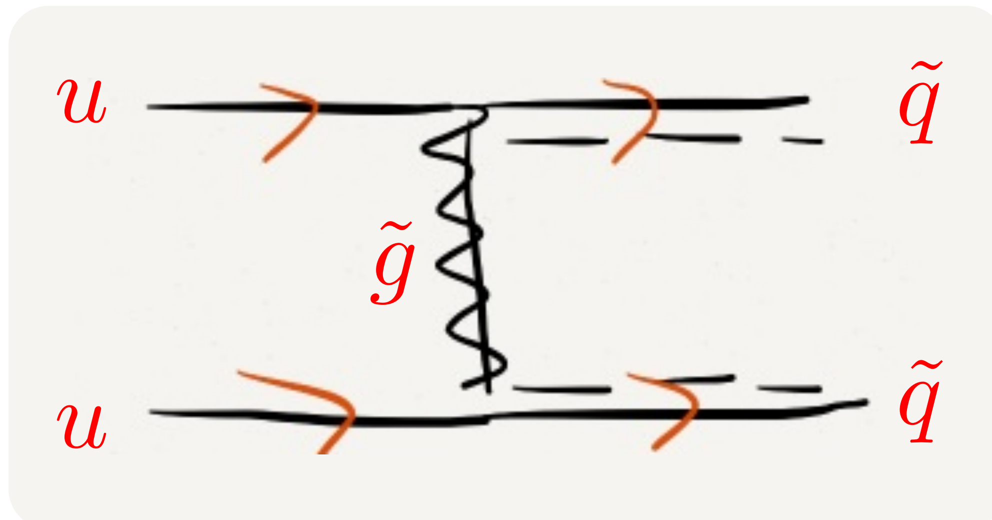
Stronger limits, later decoupling of gluino

Why much more sensitive to gluino mass? →

What is driving the strong ATLAS/CMS limit?

Squark - Squark production:

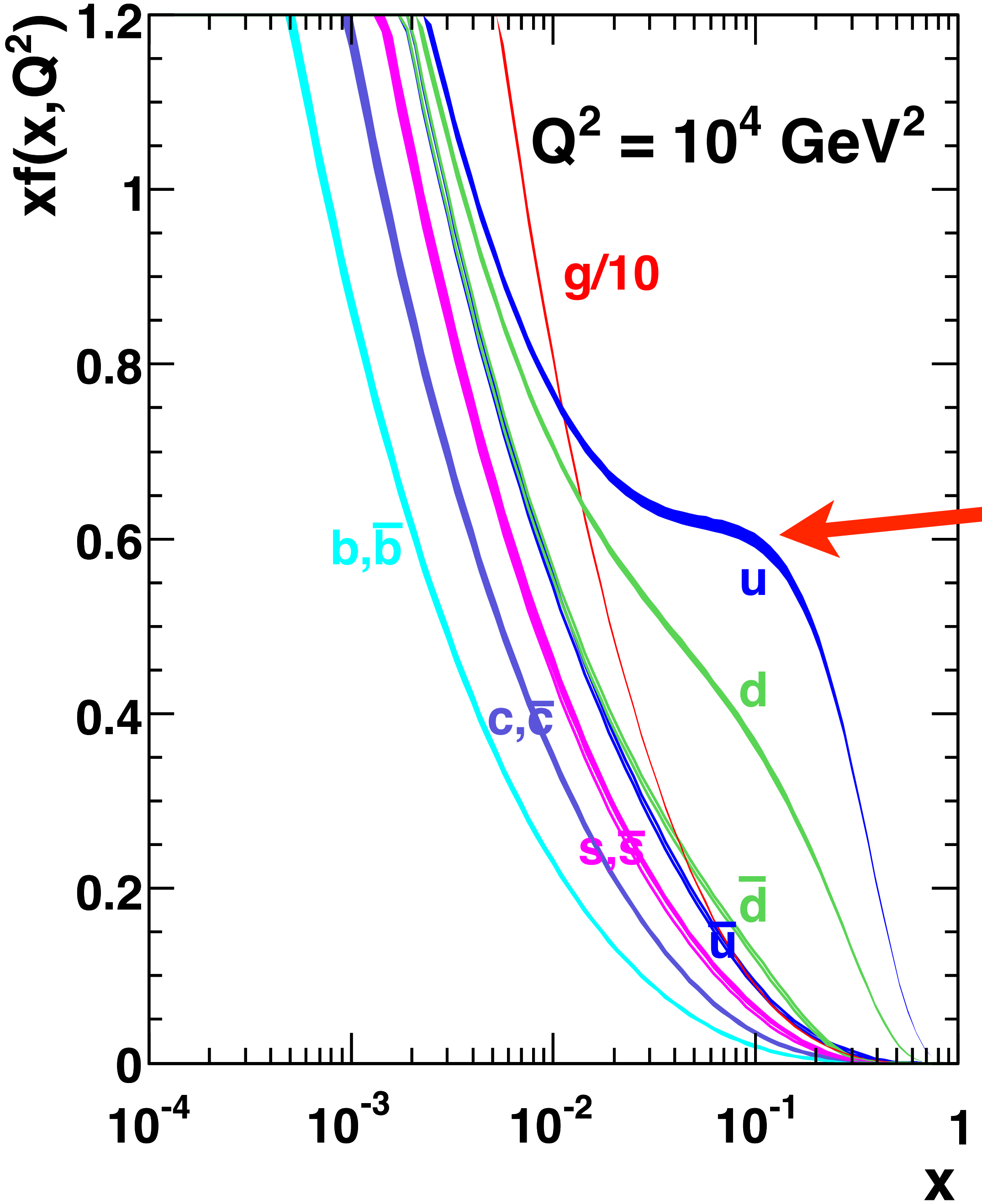


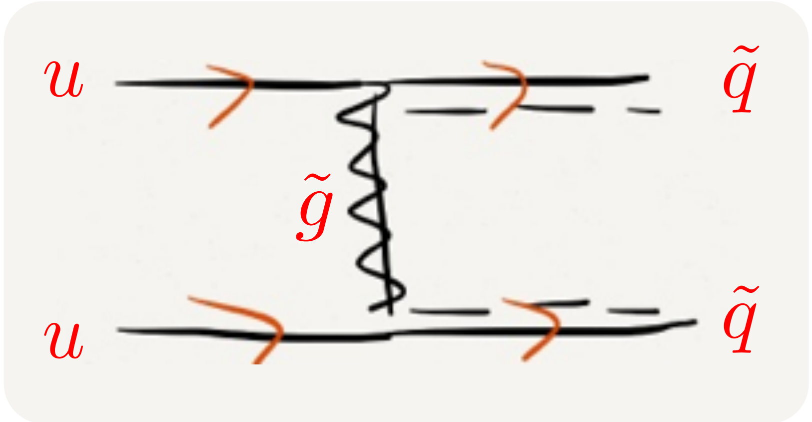


Independent of squark flavor (and gluino mass)

Majorana nature of gluino allows **u u** initial state!

Simple d.o.f rescaling





access to large up quark pdf

$E \approx x \cdot 7\,\mathrm{TeV}$

$\frac{1}{m_{\tilde{g}}} \tilde{q}\tilde{q}\, u_R u_R$ dim5 op.

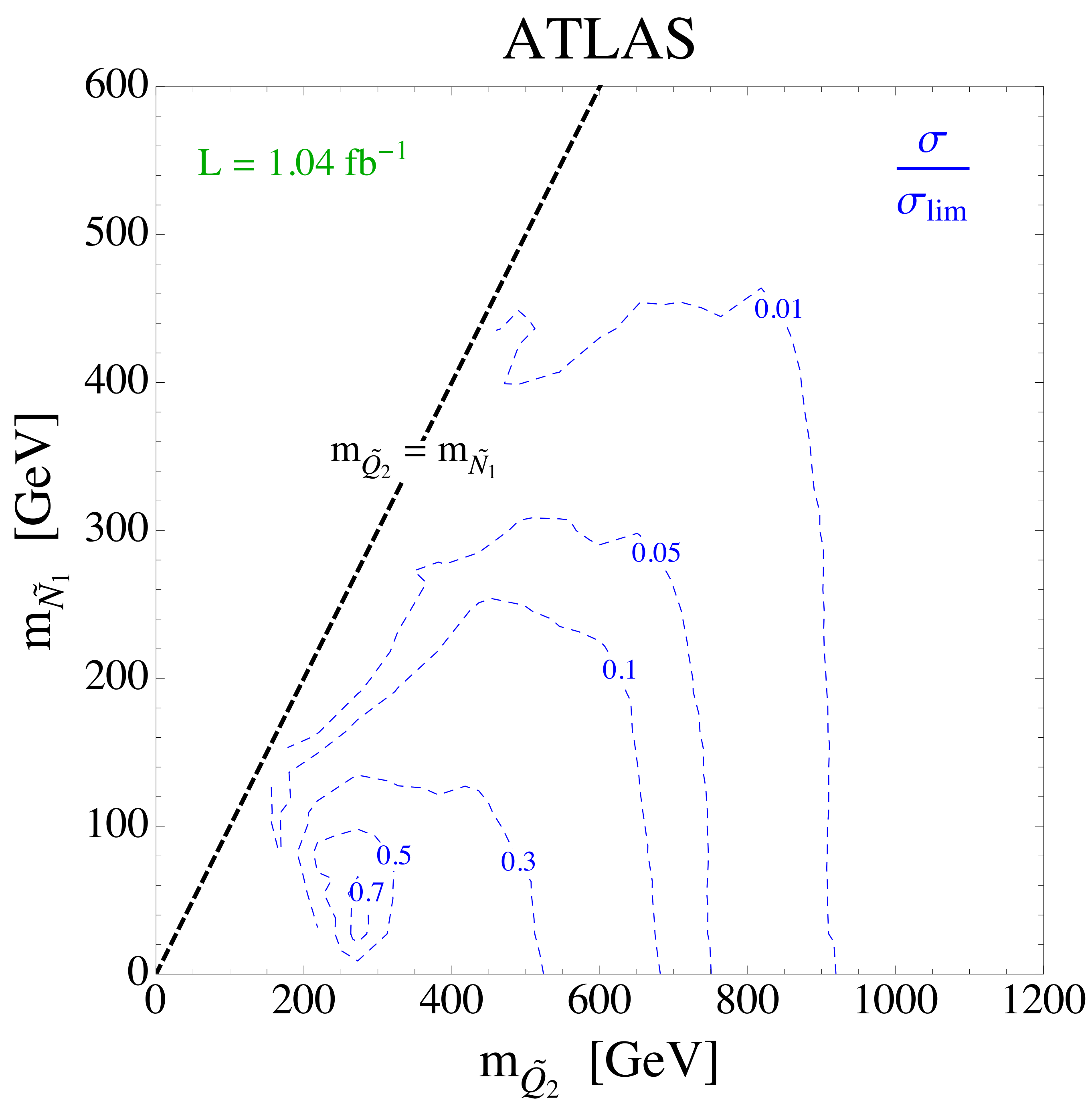
$\rightarrow \quad \sigma \sim 1/m_{\tilde{g}}^2$

slow decoupling

Aligned LH squarks

	$\tilde{Q}_1$	$\tilde{Q}_2$	$\tilde{Q}_3$
Squarks	$\begin{pmatrix} \tilde{u}_L \\ \tilde{d}_L \end{pmatrix}$	$\begin{pmatrix} \tilde{c}_L \\ \tilde{s}_L \end{pmatrix}$	$\begin{pmatrix} \tilde{t}_L \\ \tilde{b}_L \end{pmatrix}$
	$\tilde{u}_R$	$\tilde{c}_R$	$\tilde{t}_R$
2 d.o.f	$\tilde{d}_R$	$\tilde{s}_R$	$\tilde{b}_R$

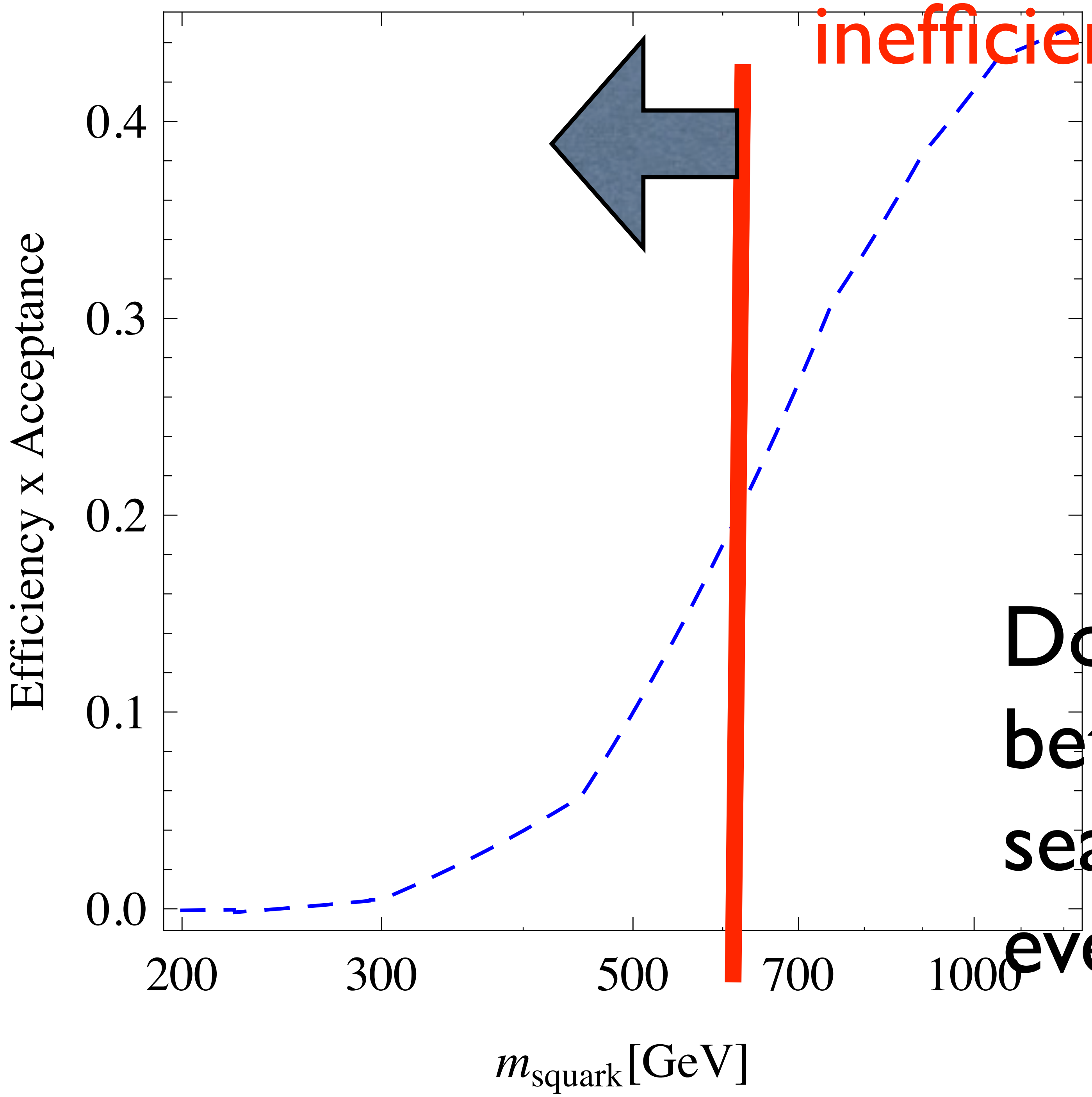
No limit on LH 2nd gen' squark



No bounds for Q_2 in 1/fb of data
(decoupled gluinos at 3TeV)

Efficiencies

Searches have hard thresholds, inefficient for light squarks

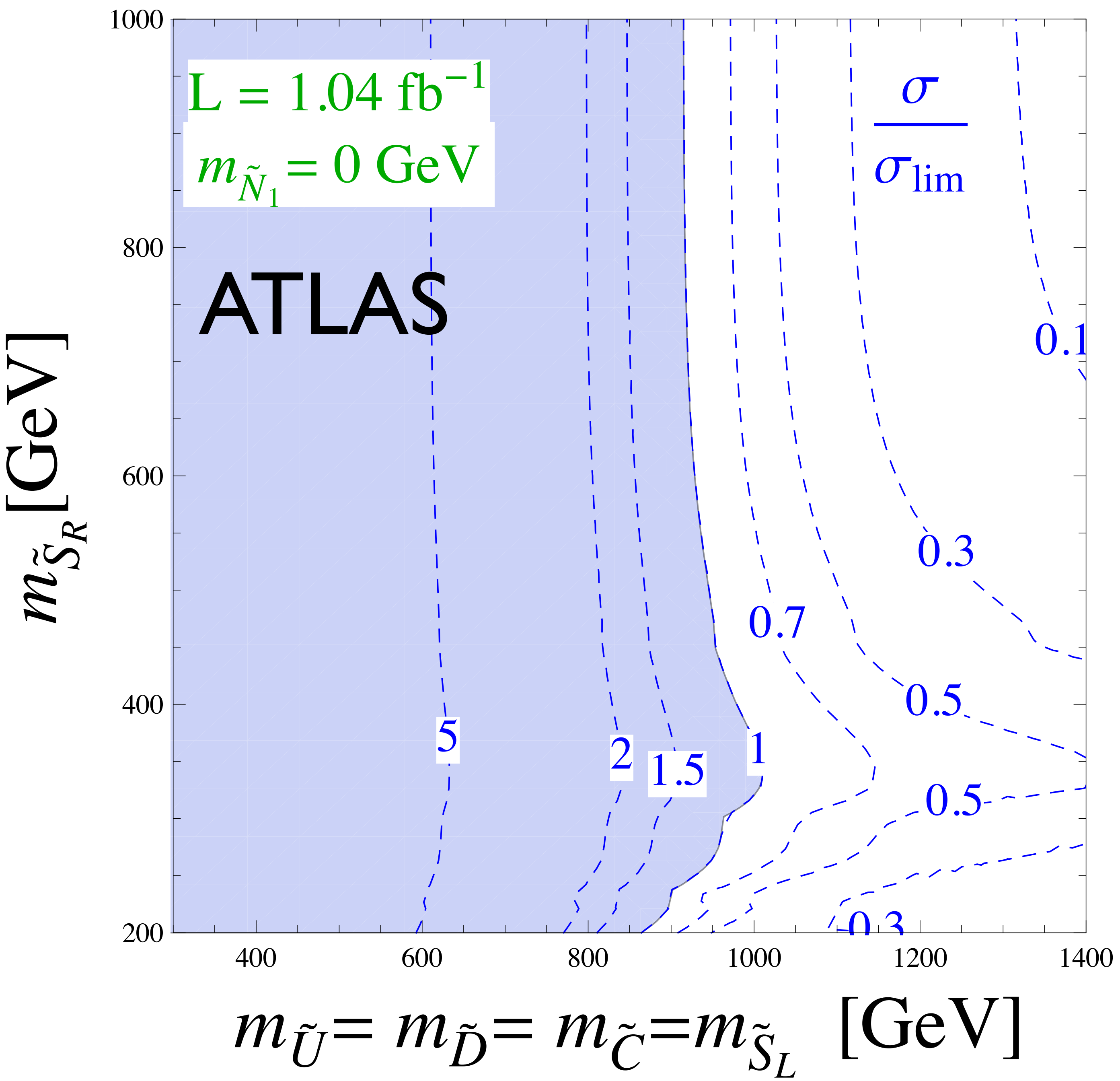


Example: ATLAS 1/fb 2jet, Meff > 1TeV, m_{LSP} = 0GeV

Do no expect it to be much better for higher luminosity searches (> 5 /fb) b/c even harder cuts used

Decoupling of the remaining squarks?

S_R mass
sea squark



$U_{L,R}, D_{L,R}, C_{L,R}, S_L$ - squark mass

Todo

- No efficiency maps available yet for 5 /fb searches. We simulate and validate using Monte-Carlo mockups (see part 2 on how to do that) to check limits
- Associated prod' of squarks of different mass important in various cases (b/c of efficiency behavior) → need to simulate also for 1/fb, cannot use Prospino NLO out-of-the-box for xsecs
- BUT: similar conclusions expected due to hard cuts on M_{eff} / H_T in 5 1/fb searches

work in progress with
Michele Papucci, Josh Ruderman (LBL Berkely)
Gilad Perez, Rakhi Mahbubani (CERN)

Summary part 1

- Squarks spectra can be vertically and horizontally split.
- Limits for 1st gen' squarks very dependent on gluino mass, for heavy gluino almost no limit
- Are there light squarks hiding in the data?
- Need dedicated light squark searches!

low mass →

Natural SUSY

- Bottom-up naturalness reminder → Csaba's talk
- Current limits?

→ Weber's talk on 3rd gen squarks

h = linear combination of fields whose vev breaks EW symmetry

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

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

measures fine-tuning

Natural EWSB & SUSY

MSSM, NMSSM, DMSSM, ...

Fine-tuning of (Higgs mass)^2

→ Bertuzzo's talk

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

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Higgsinos

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Higgsinos

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

stops, sbottom$_L$

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

gluino

- Amount of cancelation has not been directly probed yet! (experimental question)
- Interesting to look first for those cases where this cancelation is not strong (naturalness)

- **Minimal requirements for a "natural" weak-scale SUSY?**

☑ 2 light stops
☑ 1 light "left-handed" sbottom (near the stops by weak isospin)
☑ light higgsinos, i.e. 2 neutralinos and 1 chargino
☑ a not-too-heavy gluino

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Model dependence:

if low scale mediation, a light gravitino
if WIMP DM, another neutralino (bino?)

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if WIMP DM, another neutralino (bino?)

Rest could be decoupled... What about numbers?

Difficult to make sharp quantitative statements (just a guidance): What is "natural"? 10-9=1? 100-99=1? 1000-999=1? 1 part in 10^4? …

Stops:

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

(e.g. Kitano & Nomura 2006)

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$$\mu \lesssim 190\,\mathrm{GeV}\left(\frac{m_h}{120\,\mathrm{GeV}}\right)\left(\frac{\Delta^{-1}}{20\%}\right)^{-1/2}$$

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Gluinos:

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1st-2nd gen' squarks not very constrained

3rd gen spectrum:

Two Stops: $$\begin{pmatrix} m_{Q_3}^2 + (165GeV)^2 & m_t(A_t - \mu\cot\beta) \\ m_t(A_t - \mu\cot\beta) & m_{U_3}^2 + (170GeV)^2 \end{pmatrix}$$

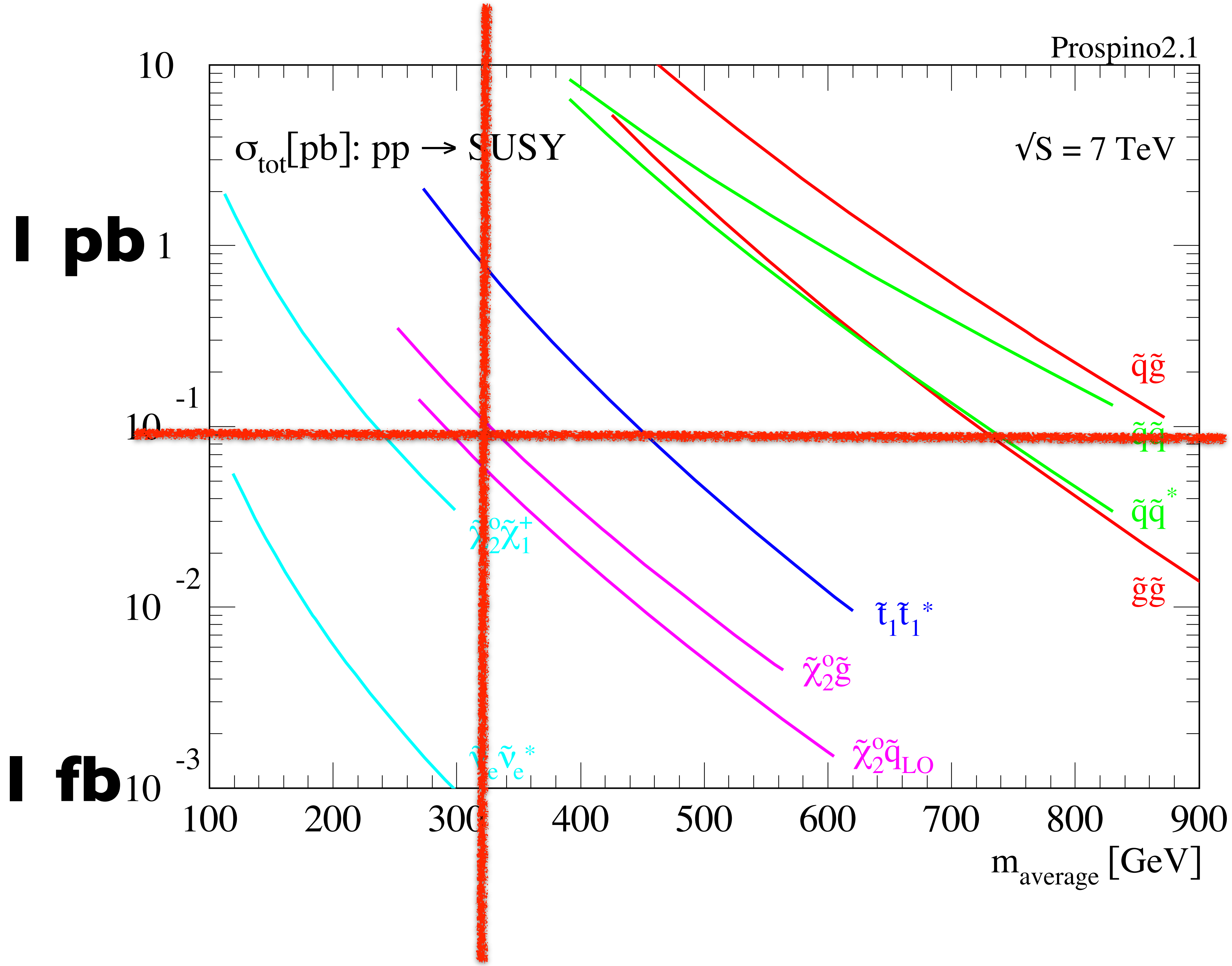
$$X_t = A_t - \mu\cot\beta$$

One Sbottom: $m_{Q_3}^2 + (70GeV)^2$

Fixed by Isospin

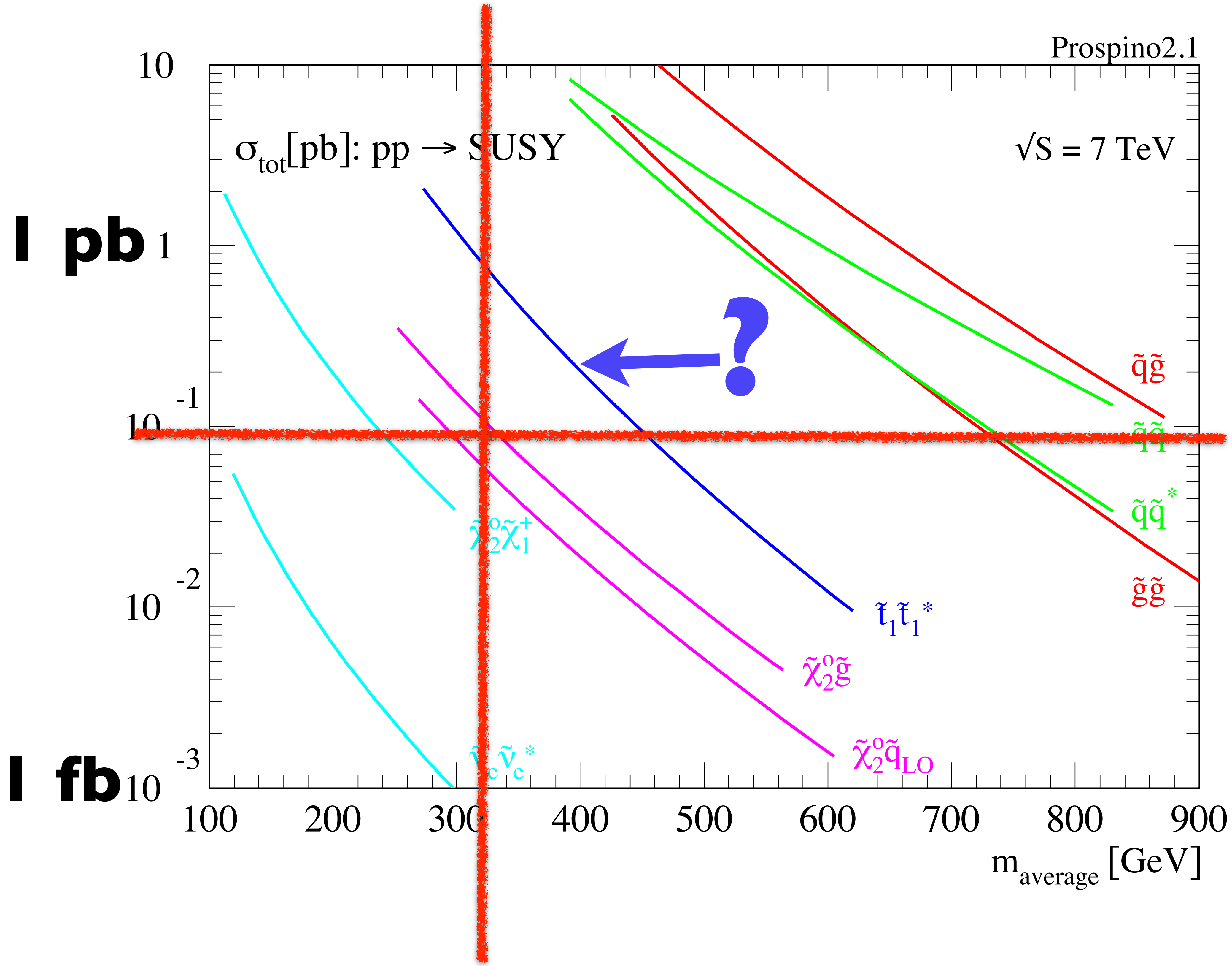
The other sbottom mass is basically free

Reach?

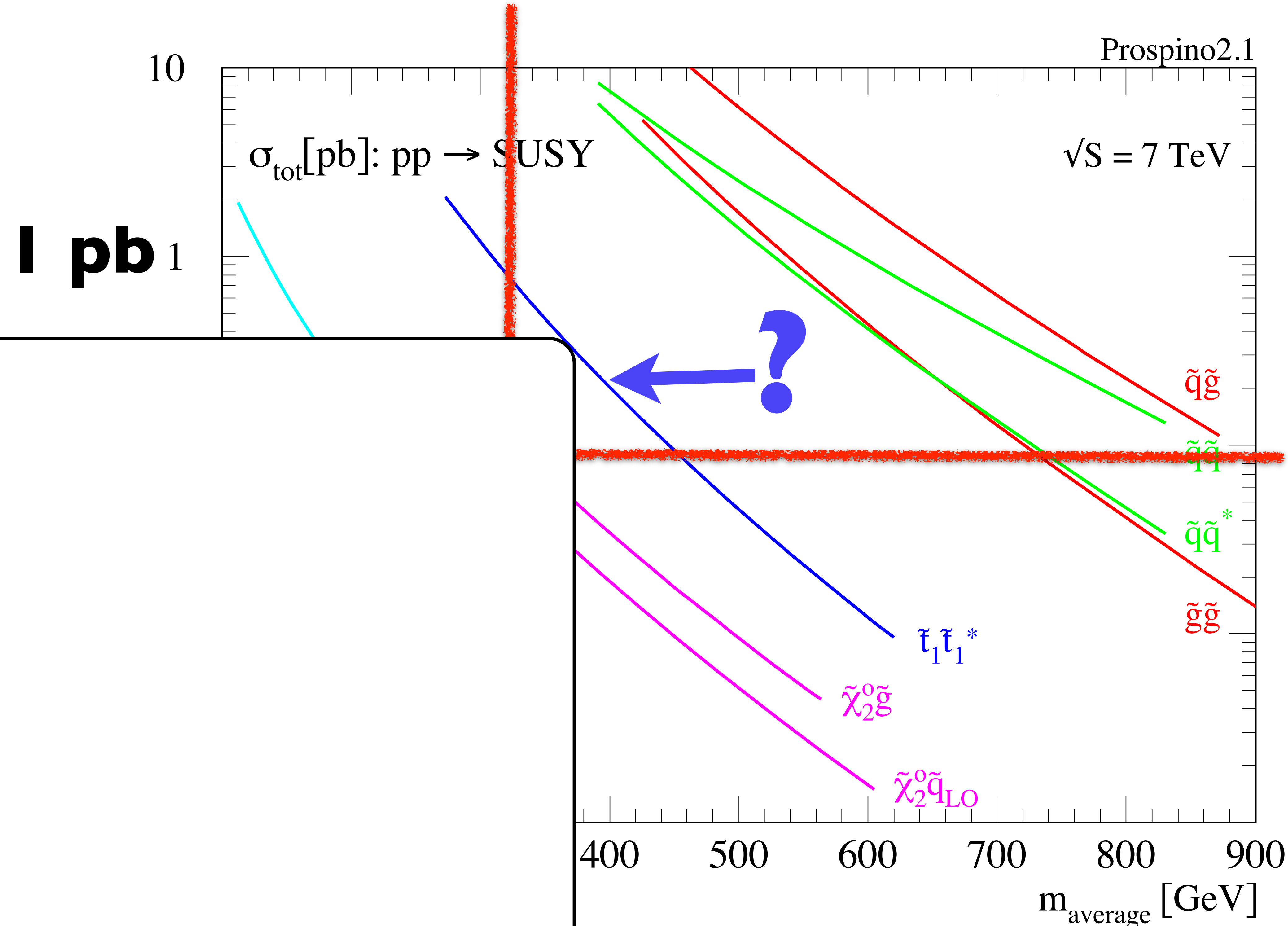


Prospino2.1
σ_{tot}[pb]: pp → SUSY
√S = 7 TeV
1 pb
1 fb
10
1
10^{-1}
10^{-2}
10^{-3}
100
200
300
400
500
600
700
800
900
$m_{average}$ [GeV]
$\tilde{q}\tilde{g}$
$\tilde{q}\tilde{q}$
$\tilde{q}\tilde{q}^*$
$\tilde{g}\tilde{g}$
$\tilde{t}_1\tilde{t}_1^*$
$\tilde{\chi}_2^o\tilde{g}$
$\tilde{\chi}_2^o\tilde{q}_{LO}$
$\tilde{\chi}_2^o\tilde{\chi}_1^+$
$\tilde{\nu}_e\tilde{\nu}_e^*$

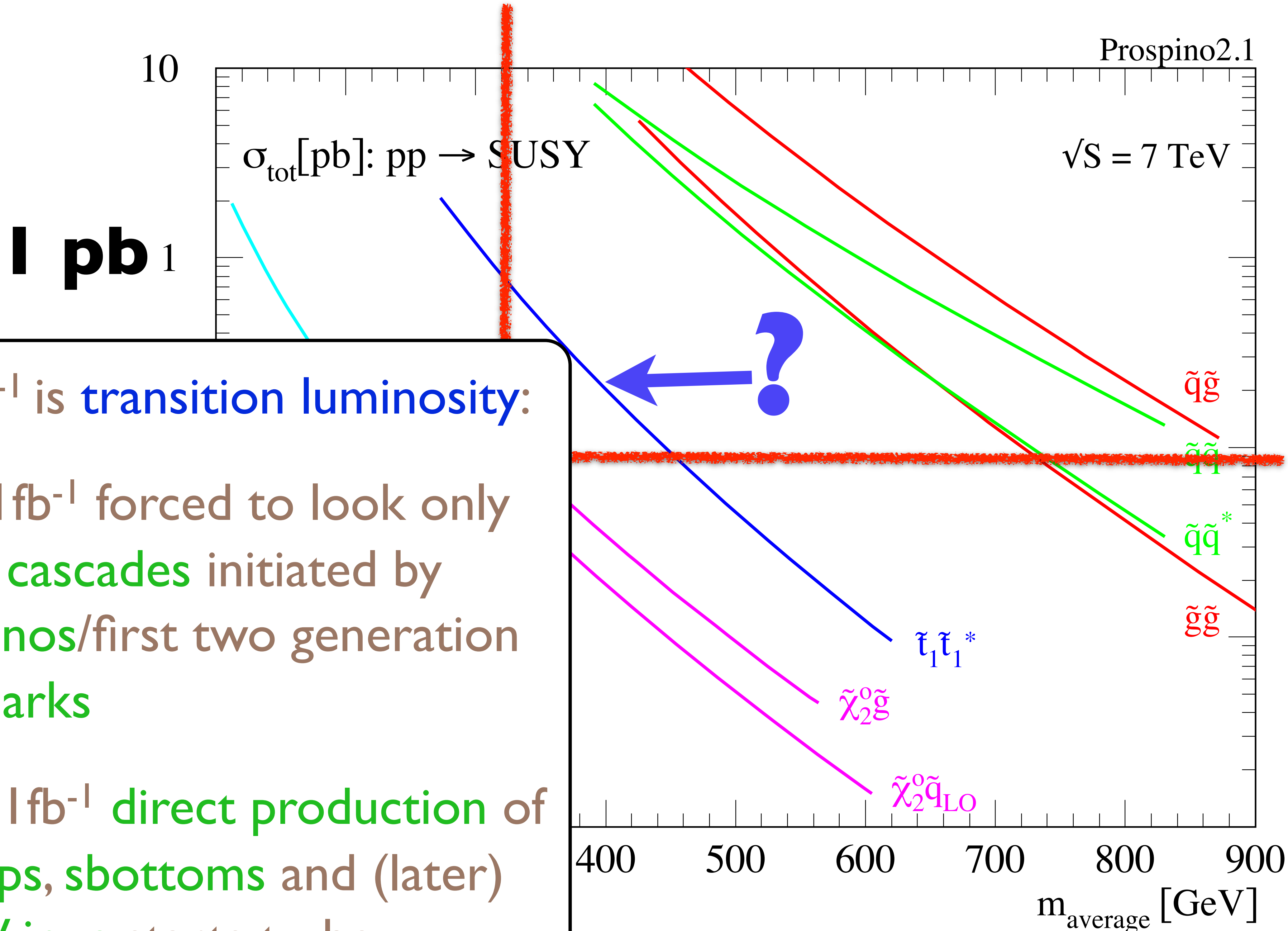
Reach?


Prospino2.1
σ_tot[pb]: pp → SUSY
√S = 7 TeV
1 pb
1 fb
10
1
10^-1
10^-2
10^-3
100
200
300
400
500
600
700
800
900
m_average [GeV]
q̃g̃
q̃q̃
q̃q̃*
g̃g̃
t̃1t̃1*
χ̃2ºg̃
χ̃2ºq̃LO
χ̃2ºχ̃1+
ν̃eν̃e*
?

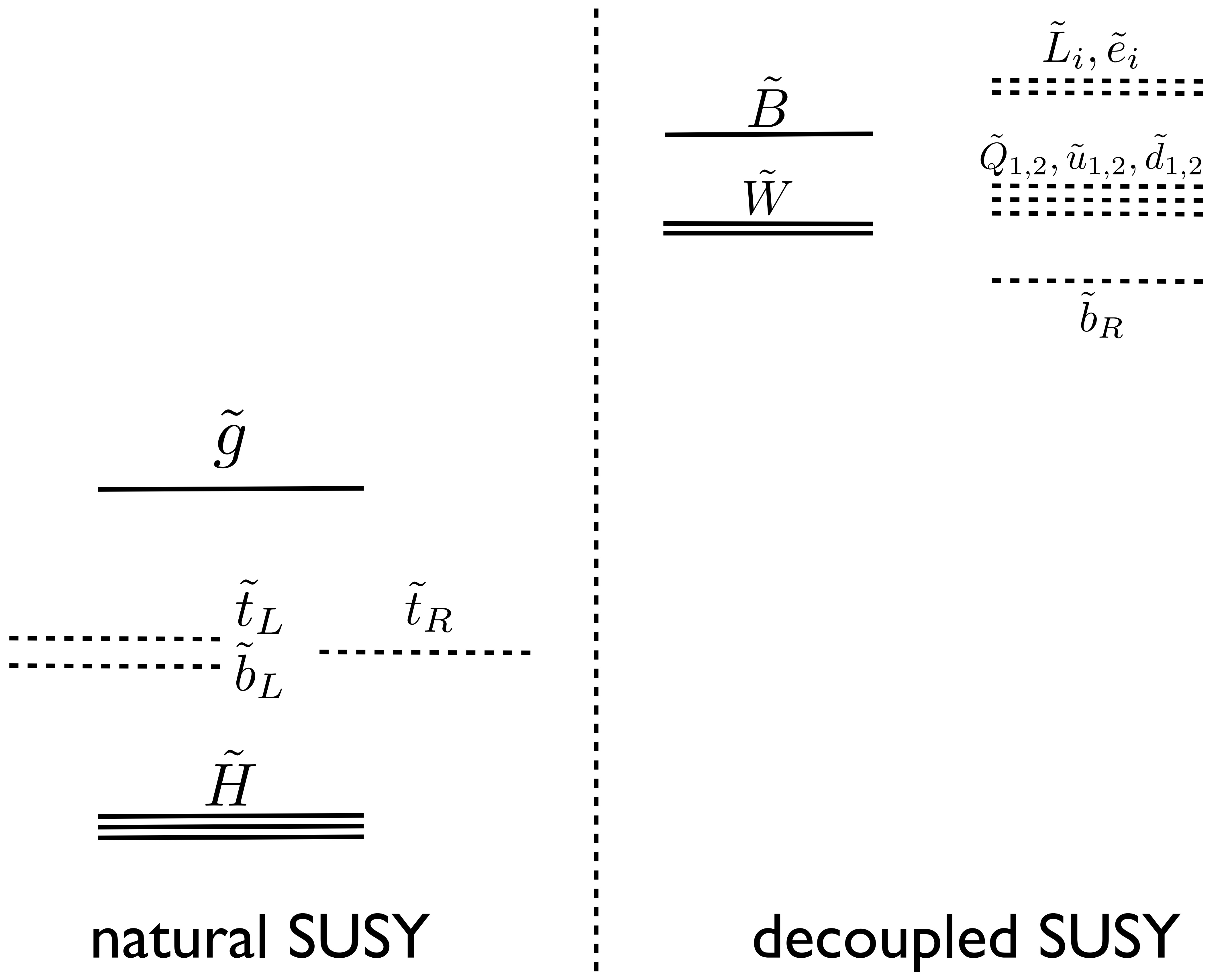
Reach?


Prospino2.1
10
1 pb
1
σ_tot[pb]: pp → SUSY
√S = 7 TeV
?
q̃g̃
q̃q̃
q̃q̃*
g̃g̃
t̃1t̃1*
χ̃2og̃
χ̃2oq̃LO
400
500
600
700
800
900
m_average [GeV]

Reach?



- 1fb^{-1} is transition luminosity:
- L<1fb^{-1} forced to look only for cascades initiated by gluinos/first two generation squarks
- L>1fb^{-1} direct production of stops, sbottoms and (later) EW-inos starts to be accessible

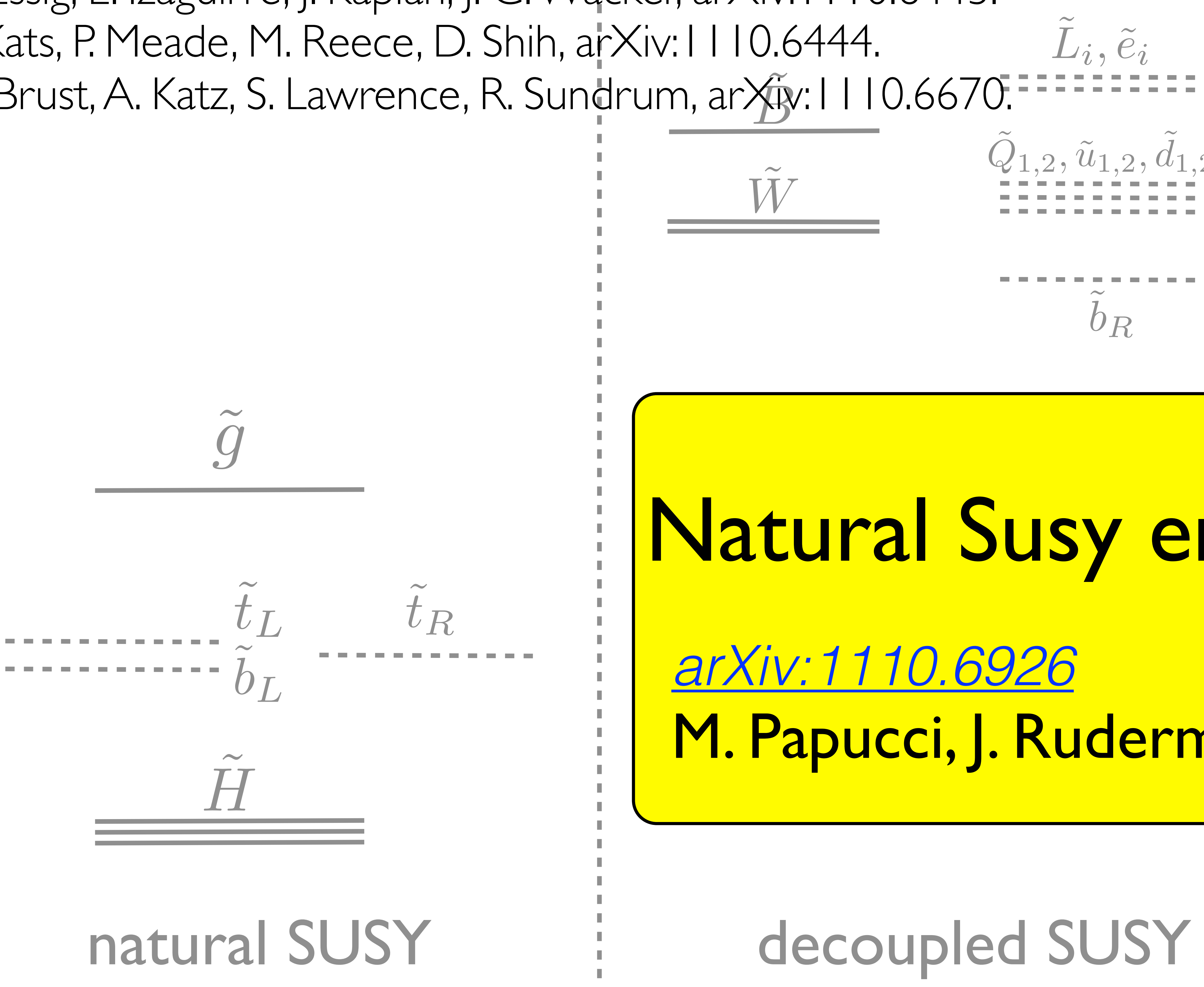

$\tilde{L}_i, \tilde{e}_i$
$\tilde{B}$
$\tilde{Q}_{1,2}, \tilde{u}_{1,2}, \tilde{d}_{1,2}$
$\tilde{W}$
$\tilde{b}_R$
$\tilde{g}$
$\tilde{t}_L$
$\tilde{t}_R$
$\tilde{b}_L$
$\tilde{H}$
natural SUSY
decoupled SUSY

Related:

R. Essig, E. Izaguirre, J. Kaplan, J. G. Wacker, arXiv:1110.6443.

Y. Kats, P. Meade, M. Reece, D. Shih, arXiv:1110.6444.

C. Brust, A. Katz, S. Lawrence, R. Sundrum, arXiv:1110.6670.



Natural Susy endures

arXiv:1110.6926

M. Papucci, J. Ruderman, AW

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

arXiv:1110.6926

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non susy analyses

too recent

Bgd's are left to the experimentalists…
stay out of control regions!

Process	Signal Region				
	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet, $m_{\rm eff} > 500$ GeV	$\geq$ 4-jet, $m_{\rm eff} > 1000$ GeV	High mass
Z/γ+jets	32.3 ± 2.6 ± 6.9	25.5 ± 2.6 ± 4.9	209 ± 9 ± 38	16.2 ± 2.2 ± 3.7	3.3 ± 1.0 ± 1.3
W+jets	26.4 ± 4.0 ± 6.7	22.6 ± 3.5 ± 5.6	349 ± 30 ± 122	13.0 ± 2.2 ± 4.7	2.1 ± 0.8 ± 1.1
$t\bar{t}$+ single top	3.4 ± 1.6 ± 1.6	5.9 ± 2.0 ± 2.2	425 ± 39 ± 84	4.0 ± 1.3 ± 2.0	5.7 ± 1.8 ± 1.9
QCD multi-jet	0.22 ± 0.06 ± 0.24	0.92 ± 0.12 ± 0.46	34 ± 2 ± 29	0.73 ± 0.14 ± 0.50	2.10 ± 0.37 ± 0.82
Total	62.4 ± 4.4 ± 9.3	54.9 ± 3.9 ± 7.1	1015 ± 41 ± 144	33.9 ± 2.9 ± 6.2	13.1 ± 1.9 ± 2.5
Data	58	59	1118	40	18

Table 2: Fitted background components in each SR, compared with the number of events observed in data. The Z/γ+jets background is constrained with co regions CR1a and CR1b, the QCD multi-jet, W and top quark backgrounds by control regions CR2, CR3 and CR4, respectively. In each case the first (sec quoted uncertainty is statistical (systematic). Background components are partially correlated and hence the uncertainties (statistical and systematic) on the background estimates do not equal the quadrature sums of the uncertainties on the components.

[5] has improved the ATLAS reach at large m_0. The five signal regions are used to set limits on $\sigma_{new} = \sigma A \epsilon$ for non-SM cross-sections (σ) for which ATLAS has an acceptance A and a detection efficiency of ϵ [44]. The excluded values of σ_{new} are 22 fb, 25 fb, 429 fb, 27 fb and 17 fb, respectively, at the 95% confidence level.

upper bound on signal xsec

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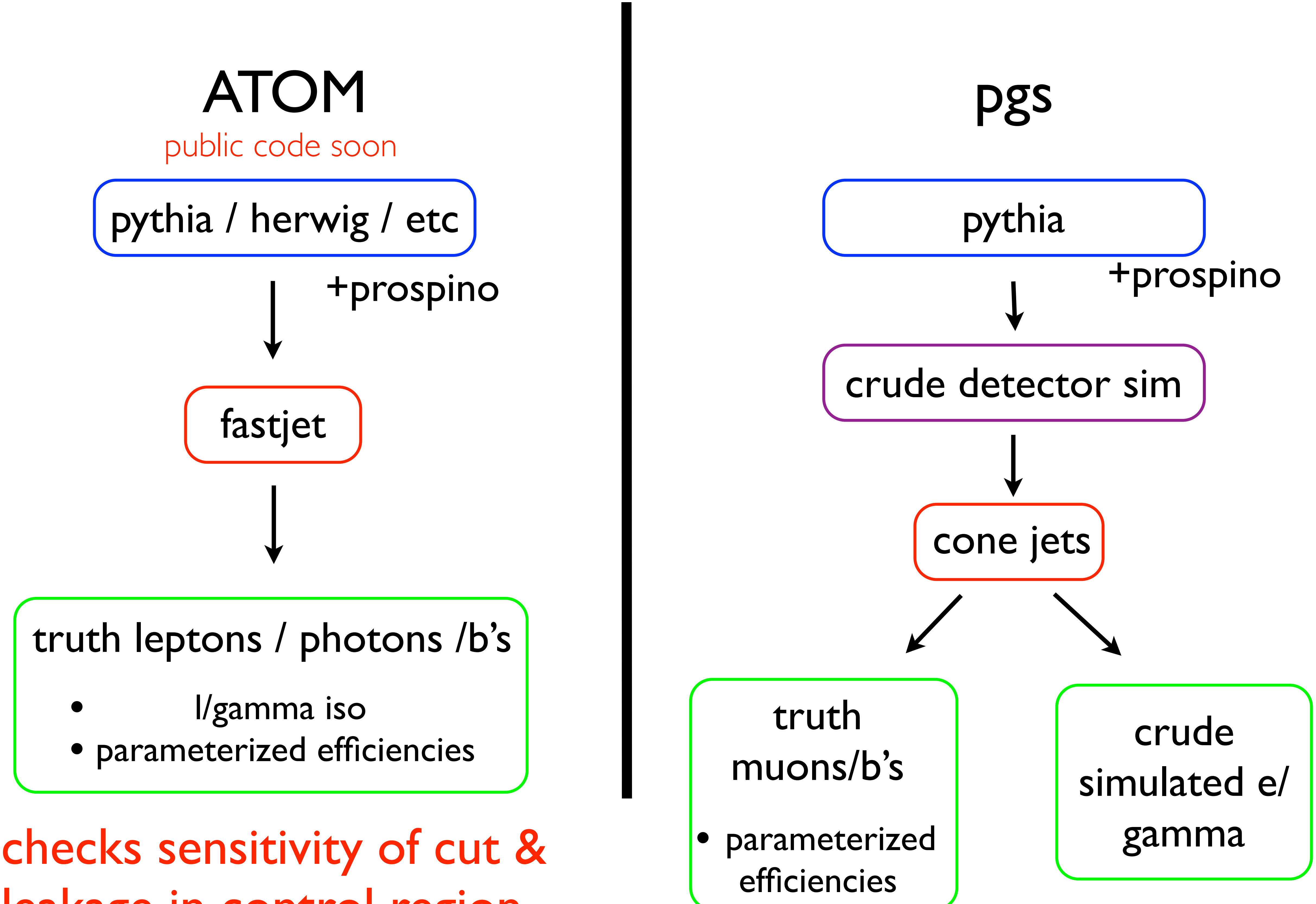
LIMIT!

our pipelines



checks sensitivity of cut & leakage in control region

ATOM

an **A**utomated **T**ester **O**f **M**odels

(soon to be) Public Tool developed by

QCD/Jets: C. Bauer (Berkeley), C. Vermillion (Berkeley)

BSM: M. Papucci (Berkeley),
T. Volansky (Tel Aviv), A. W. (DESY)

Calibration

“theorist limits”

To calibrate compare:

1) key kinematical distributions
2) limits

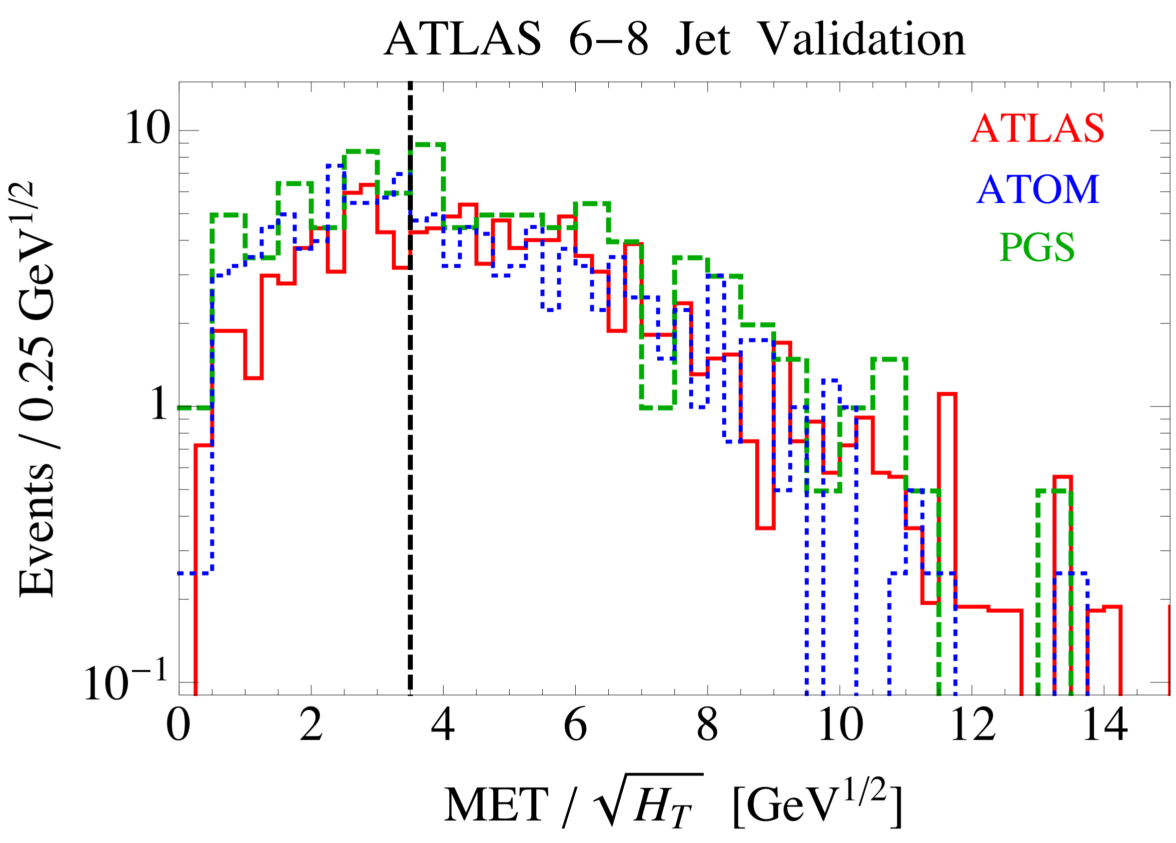
Calibration

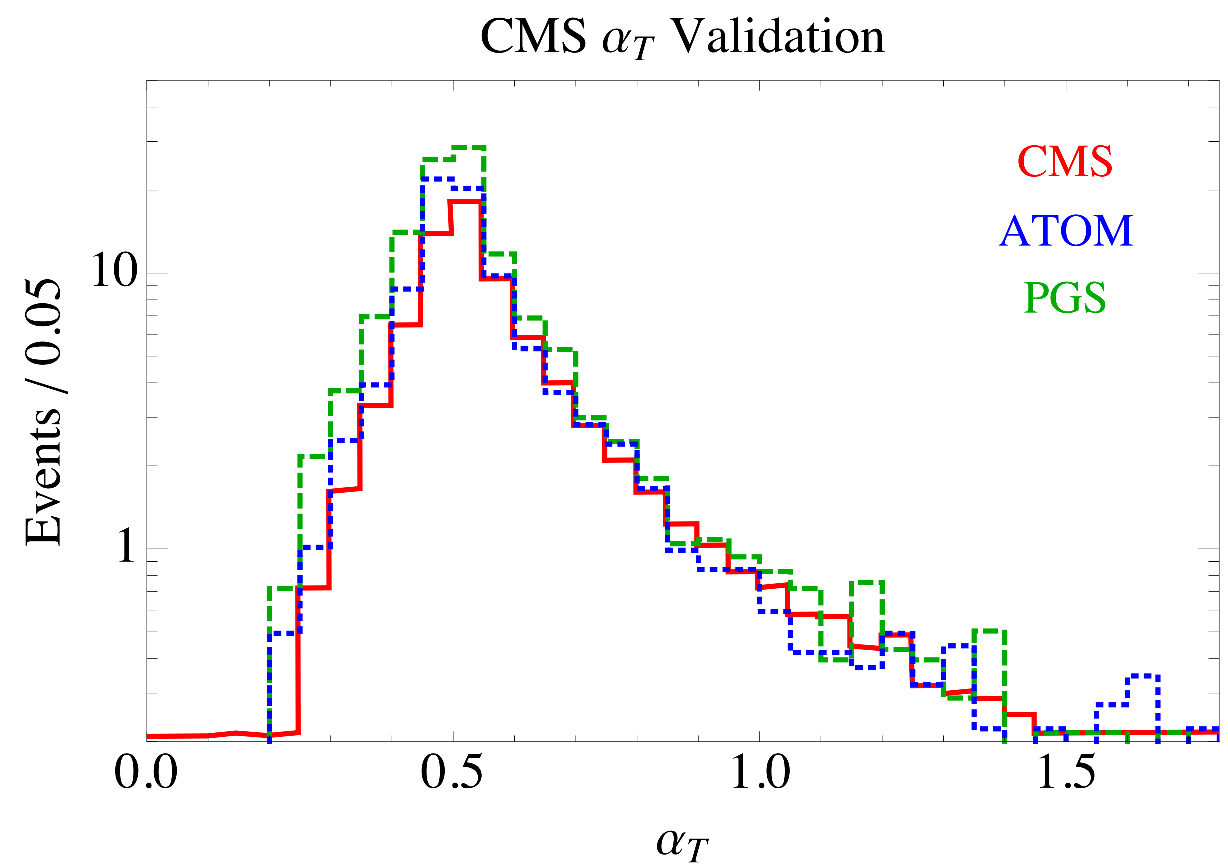
"theorist limits"

To calibrate compare:

1) key kinematical distributions
2) limits

simplified models work best!





Check:

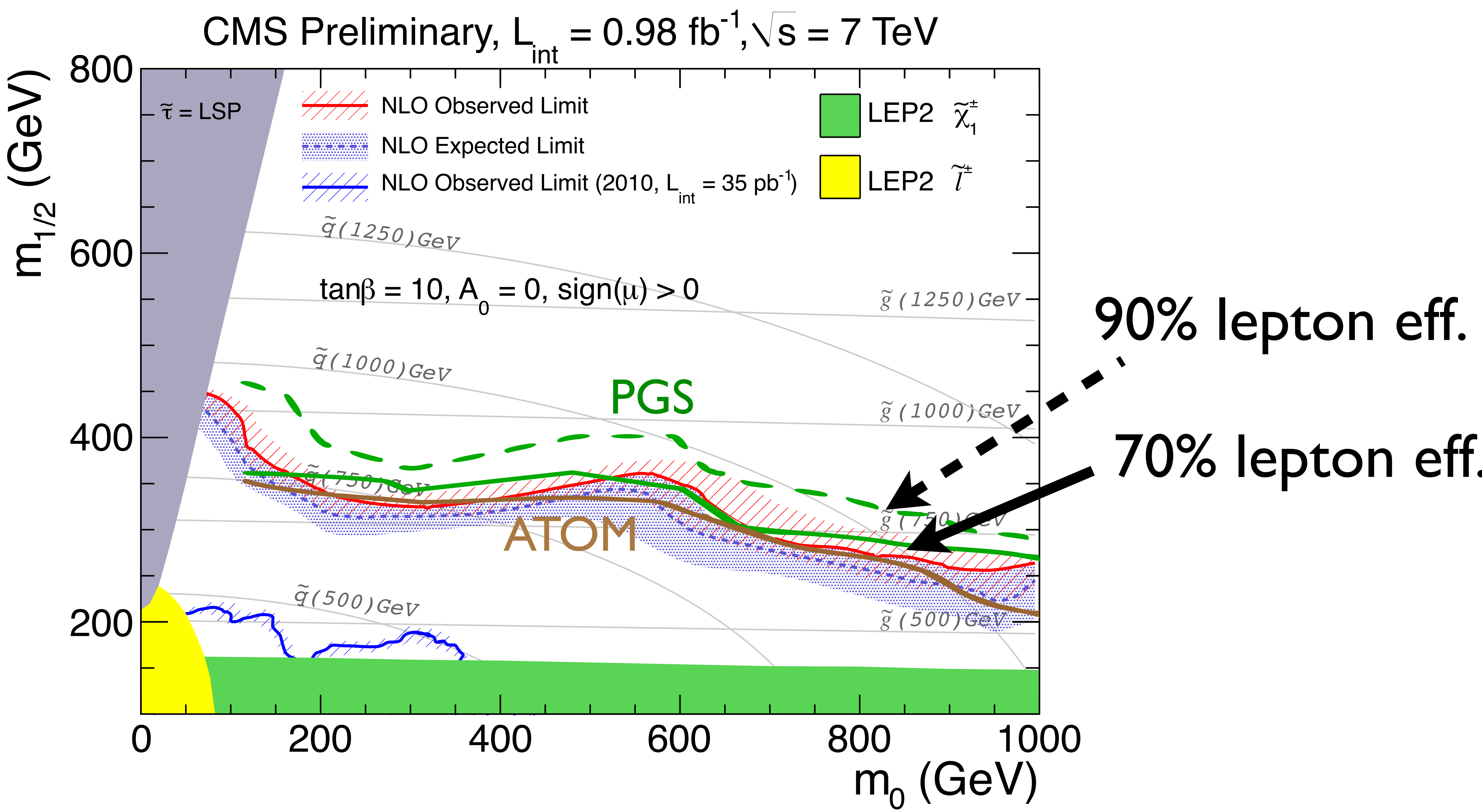
- kinematic distortions (shape)
- signal $\epsilon \times \mathcal{A}$ (normalization)

+ compare to all available limit plots…

~ 50 GeV accuracy (usually better)

Compare limits

Example: Same-Sign dilepton by CMS

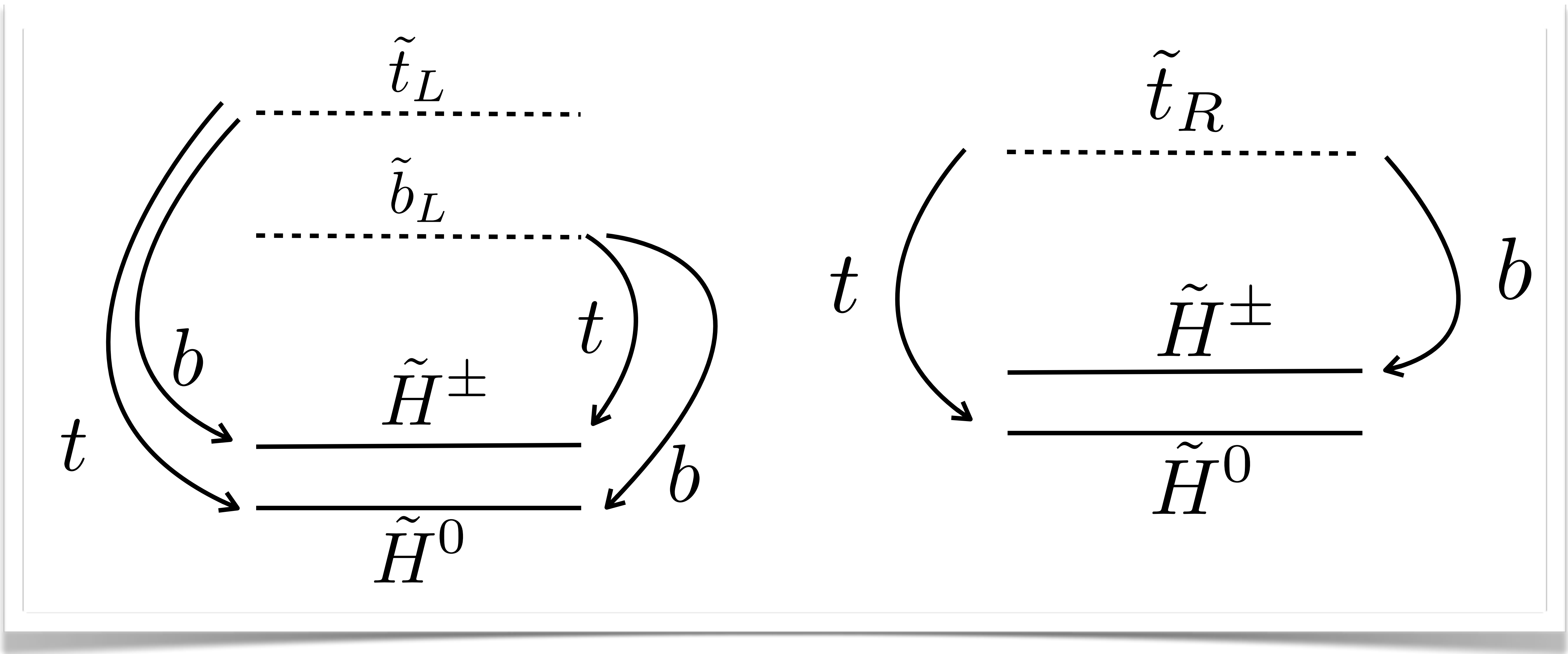


What we actually do

- Simplified topologies to slice the natural SUSY parameter space
- Highlight relevant kinematic features
- Which analyses give the most powerful constraints? Not necessarily those that are “designed” for the “signal”.

→ More recent results (>1/fb) not included (update in progress)

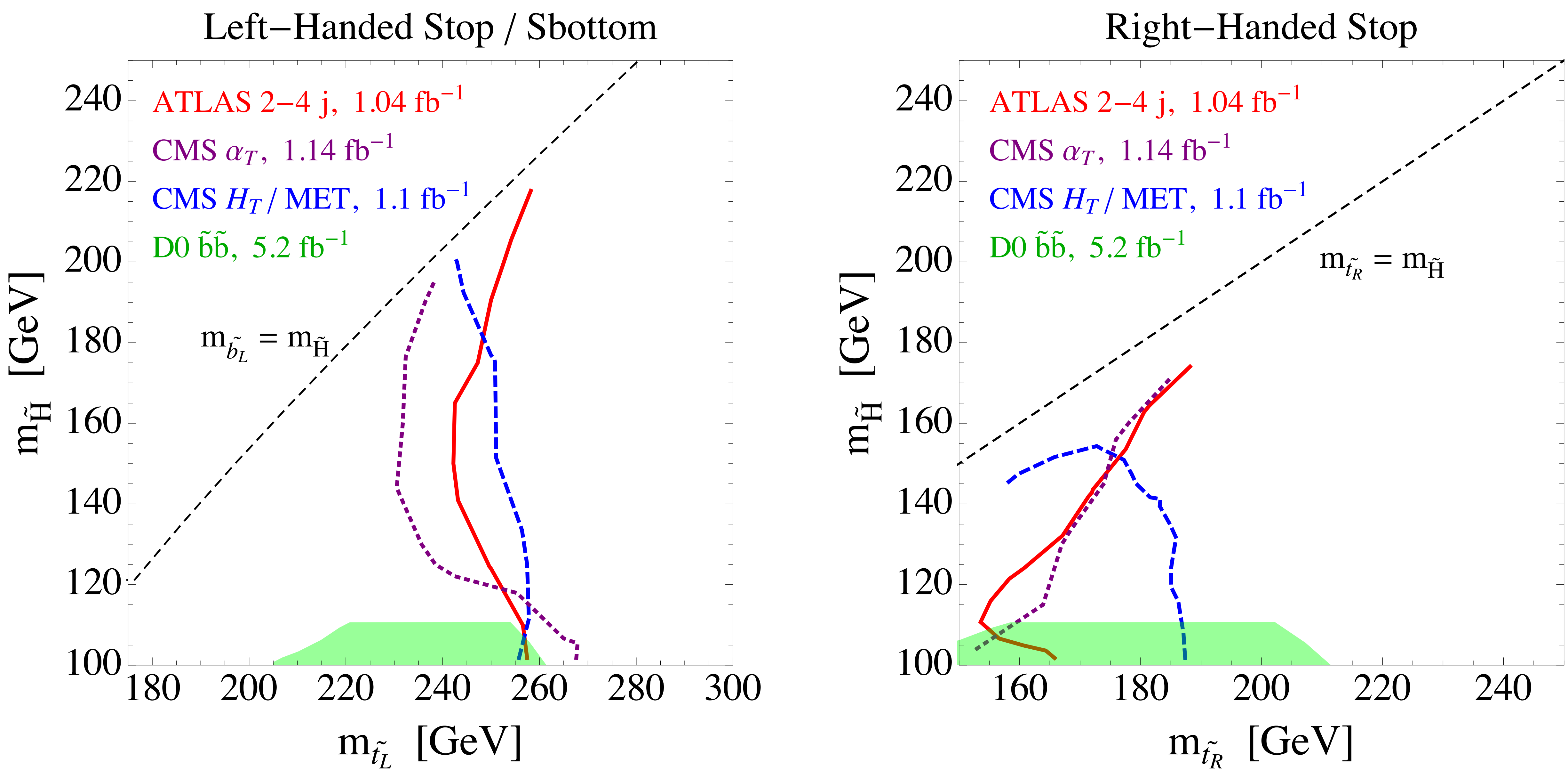
Stops (sbottom) + Higgsinos



Stops can act as "sbottom" (bjet+χ) !

Chargino-neutralino splitting irrelevant for present searches

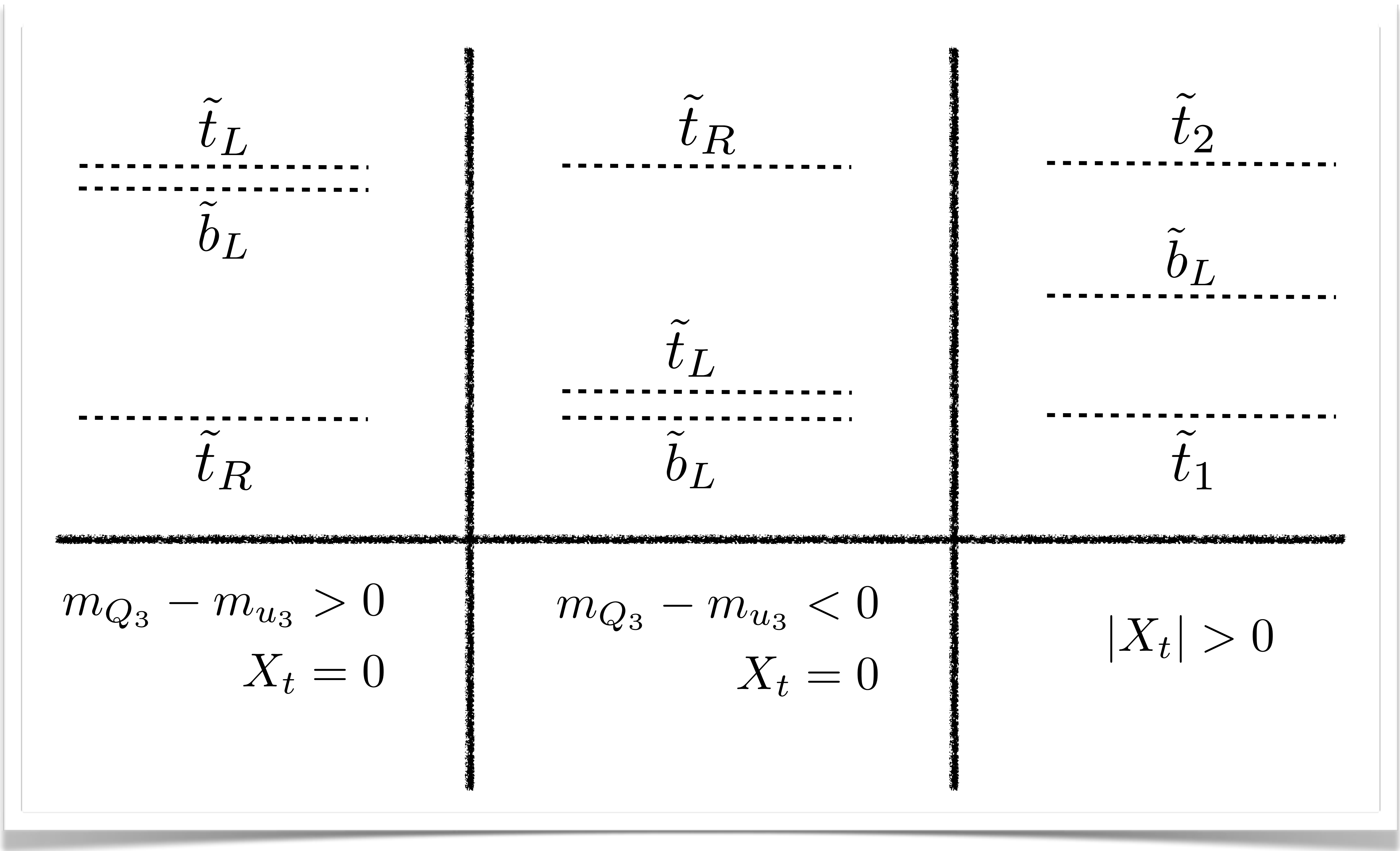
Stops (sbottom) + Higgsinos



LHC surpasses Tevatron:

Strongest bounds from jets + MET

Un-Splitting the spectrum



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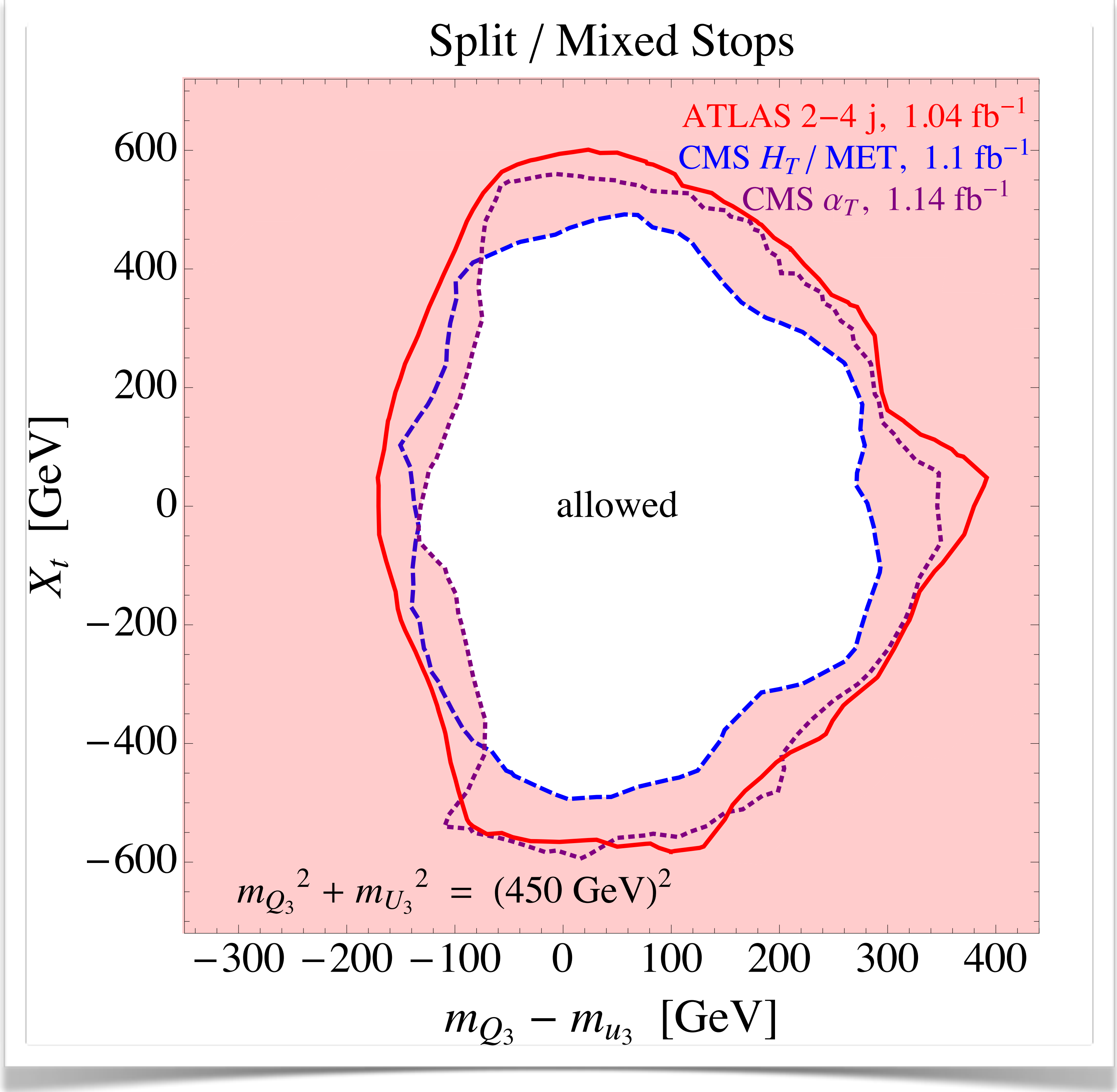
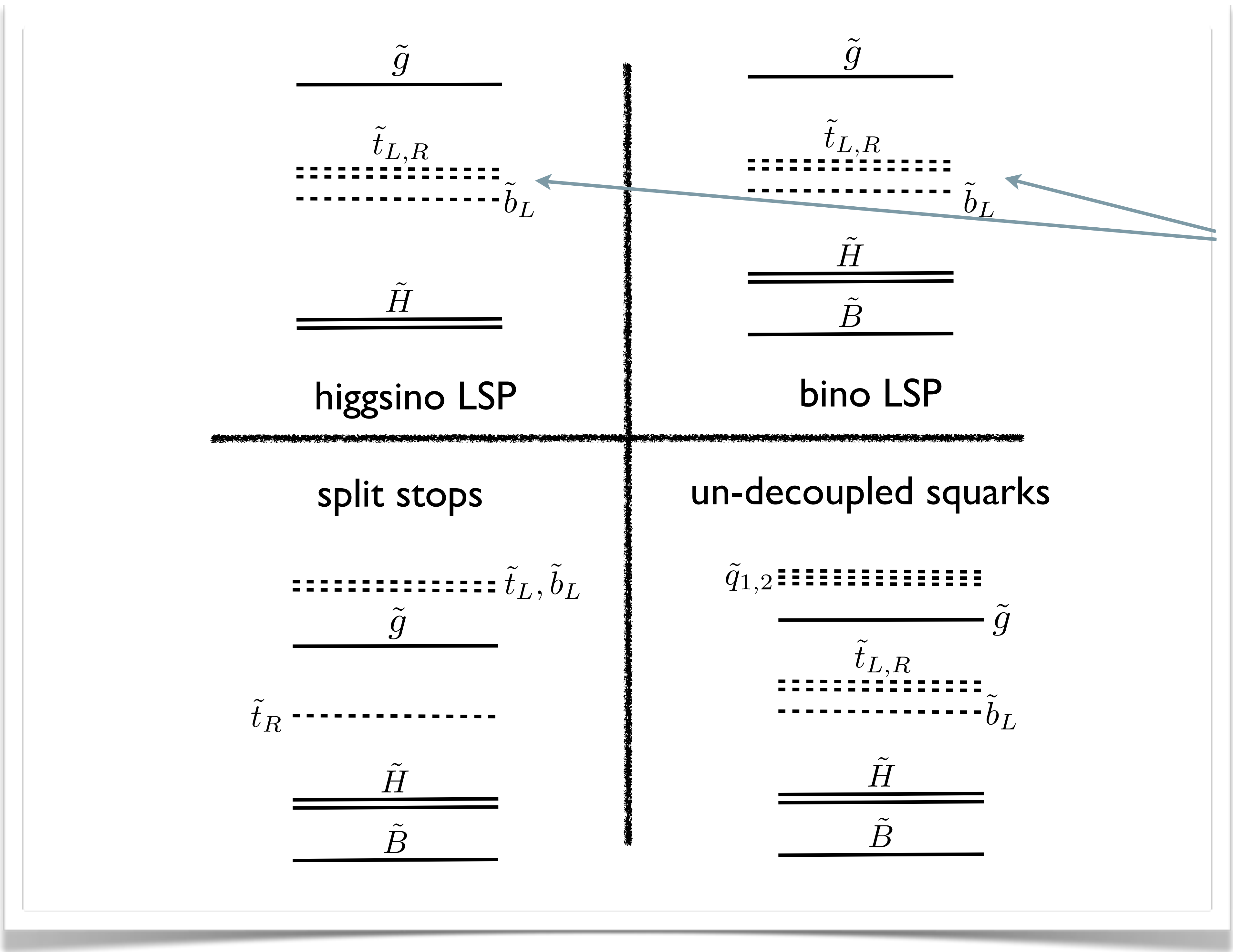


stronger bound on the left due to light sbottom

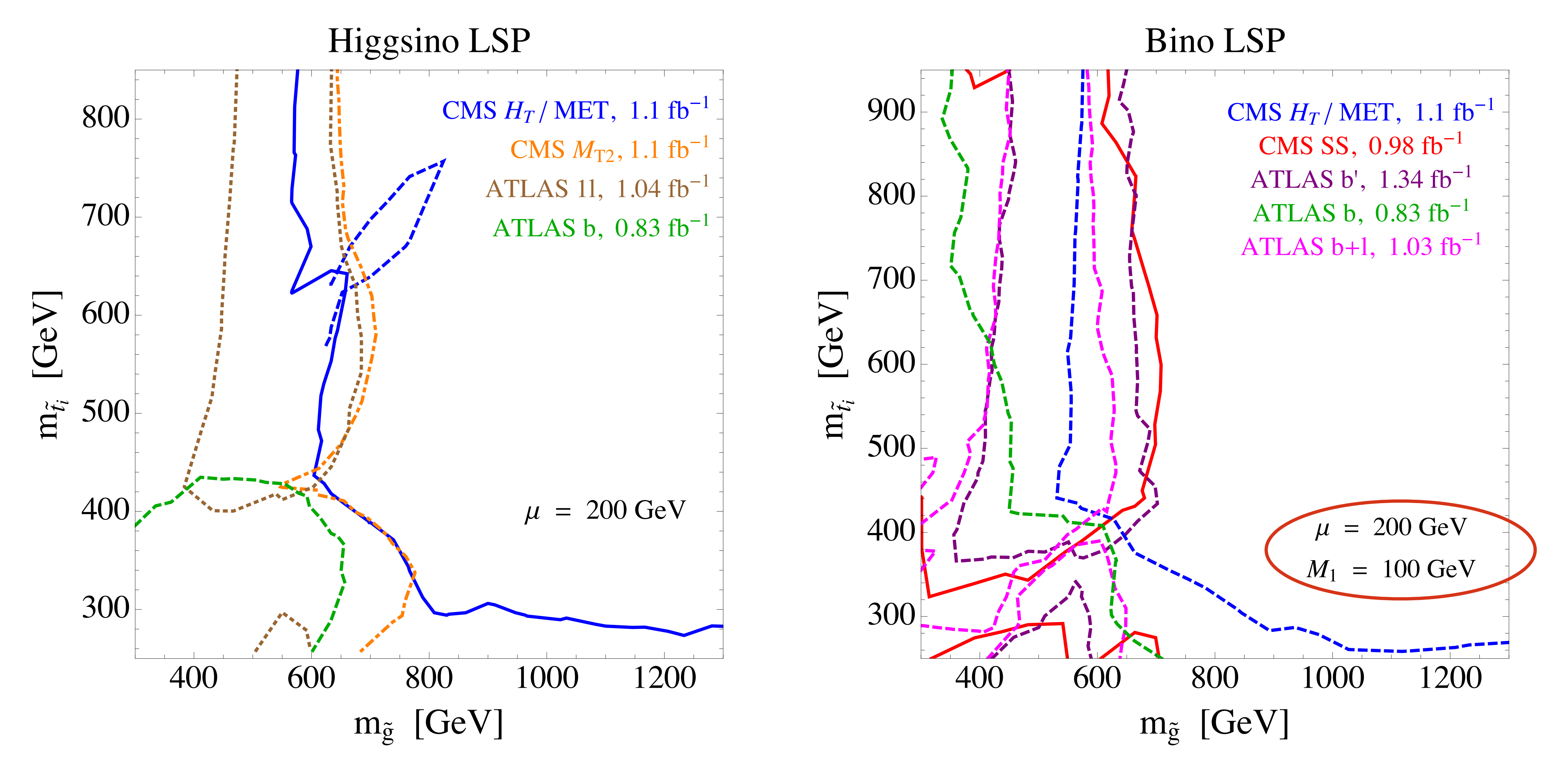
TeVatron bounds not shown b/c they have no sensitivity for m_{LSP} >110GeV

Adding gluinos



quasi-degenerate
3-rd gen’

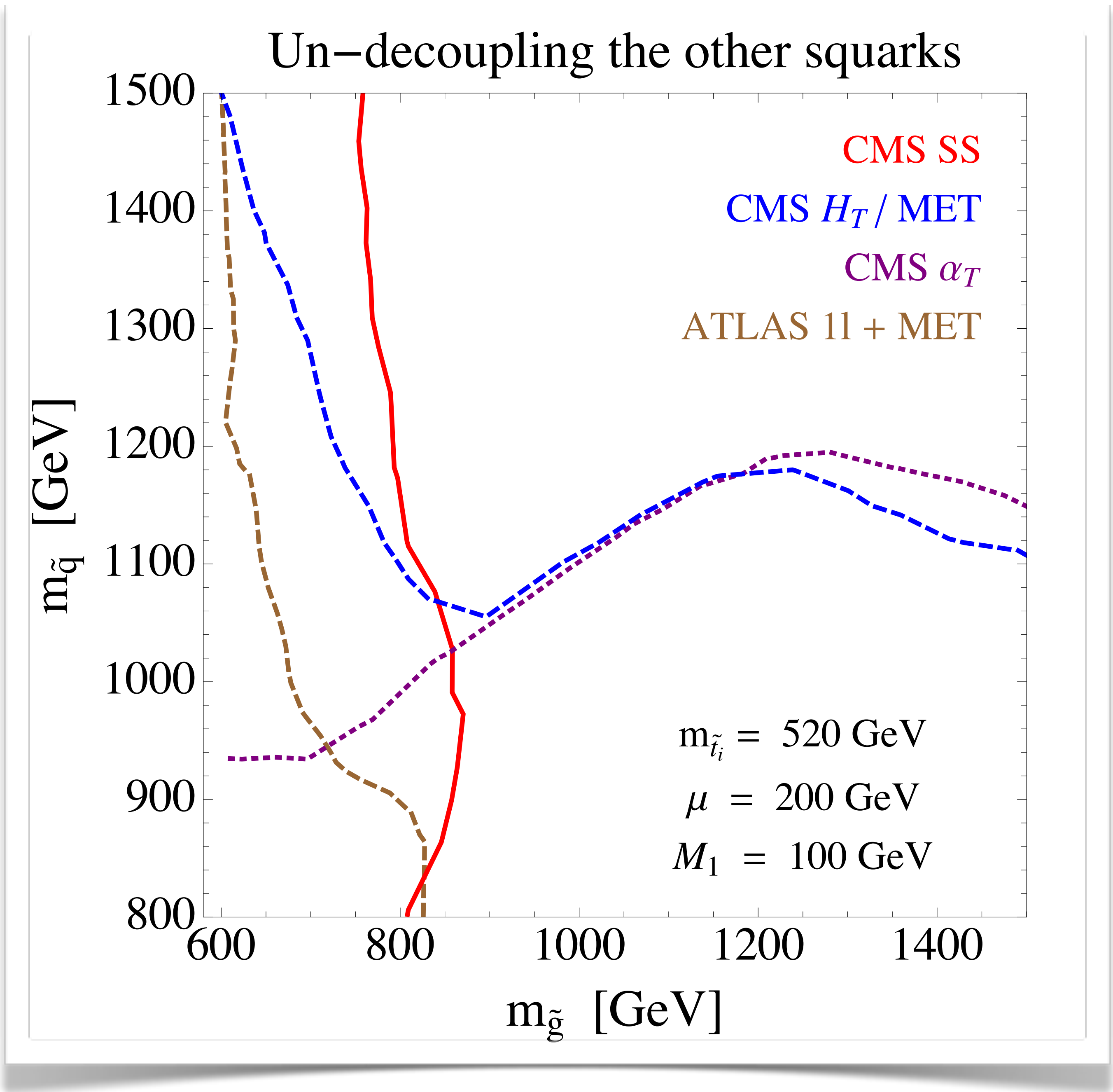
Adding the gluinos



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

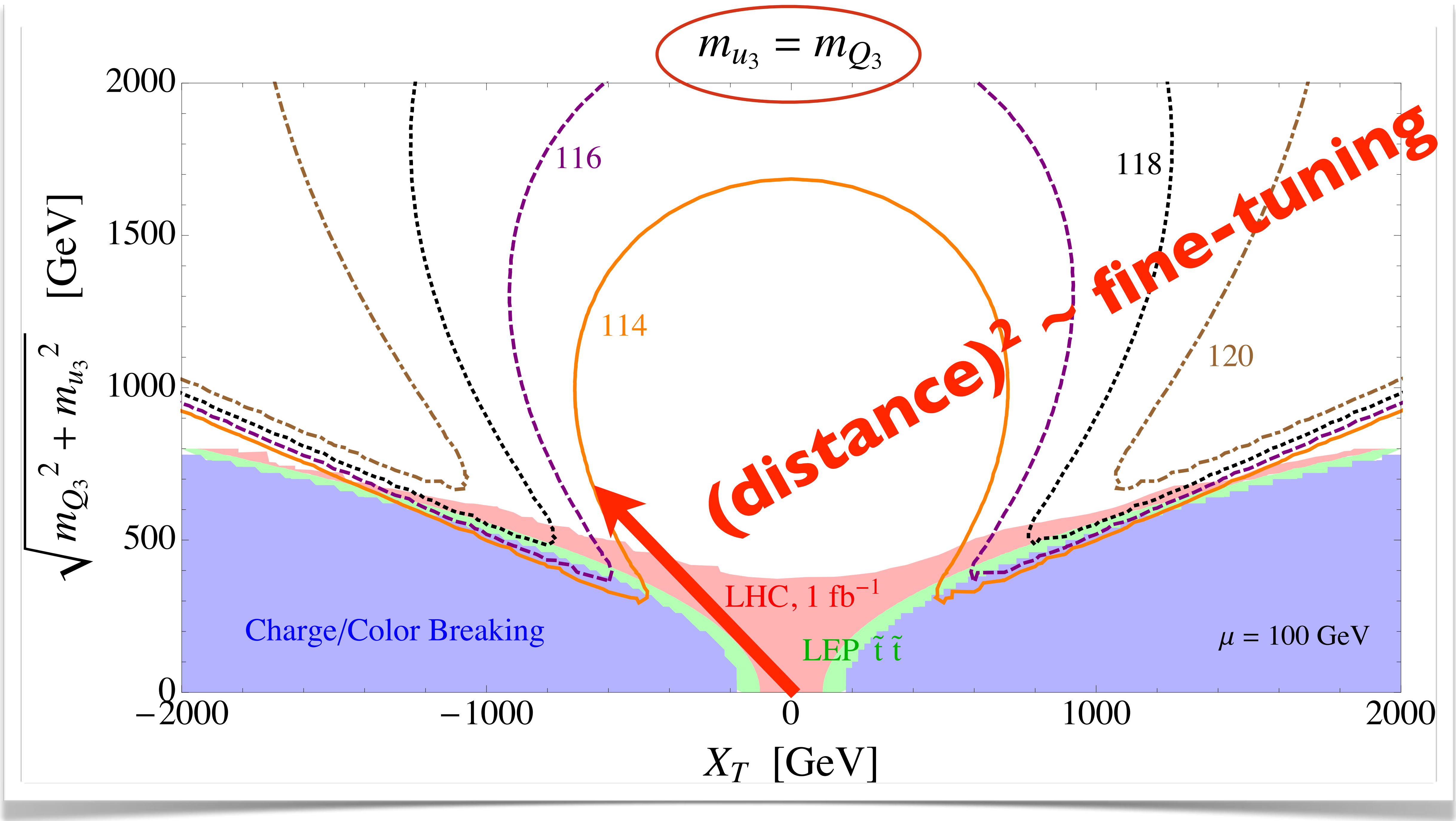
Gluino mostly bounded by Same Sign searches

Adding the squarks, too



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

MSSM higgs: LEP2 tuning vs. direct stop



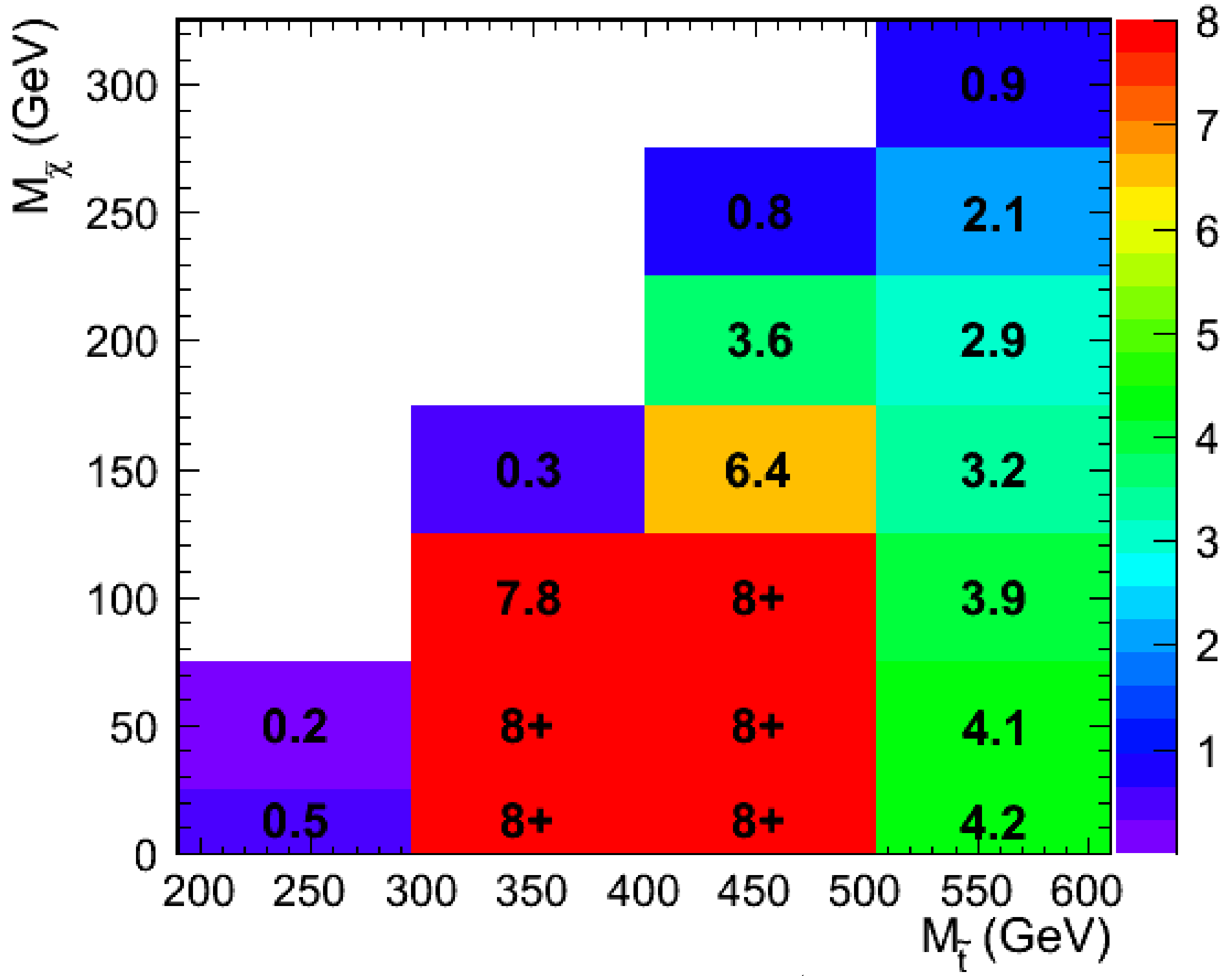
$$\delta m_H^2|_{stop} = -\frac{3}{8\pi^2} y_t^2 \left(m_{U_3}^2 + m_{Q_3}^2 + |A_t|^2 \right) \log\left(\frac{\Lambda}{\mathrm{TeV}} \right)$$

Sensitivity at 8 TeV & 20/fb

Kaplan, Rehermann, Stolarski

$$pp \to \tilde{t}\tilde{t}^* \to (t\chi^0)\ (\bar{t}\chi^0) \to (bjj\chi^0)\ (\bar{b}jj\chi^0)$$

LSP mass



significance

stop mass

related papers:
1205.2696 and
today(!): 1205.5805,
1205.5808

Conclusions

- Non-degenerate 1st & 2nd generation squarks poorly constrained, surprises in data? Dedicated experimental study needed.
- Next frontier: Heavy flavor themed naturalness, EW-inos
- Natural SUSY not in trouble yet and won't be for years to come
- Gluinos > 900 GeV, Stops > 200-300GeV, Higgsinos above 100GeV (LEP) is a completely viable spectrum