The time for exceptional heavy flavor physics @ ATLAS & CMS

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HEAVY FLAVOR PRODUCTION @ HADRON COLLIDERS

Outline

- Intro': SUSY & the LHC so far ...
- Possible holes in searches & interplay \w flavor precision.
- Battle for naturalness & the window of charm:

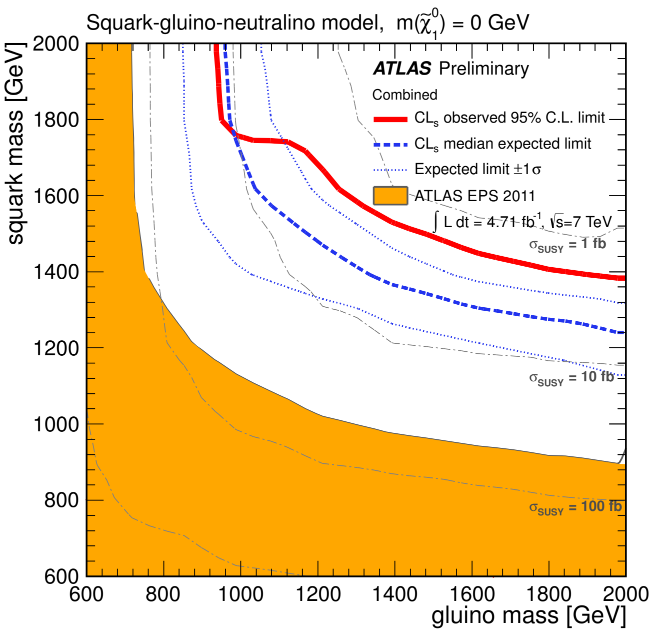
  (*i*) stop searches; (*ii*) implications of Higgs on composite light flavors.
- *t*op precision b-physics @ ATLAS & CMS. (& beyond)

  (if time permits)
- Summary.

Current status of Supersymmetry

Putting stops aside, what are the bounds on first 2-generation "light" squarks?

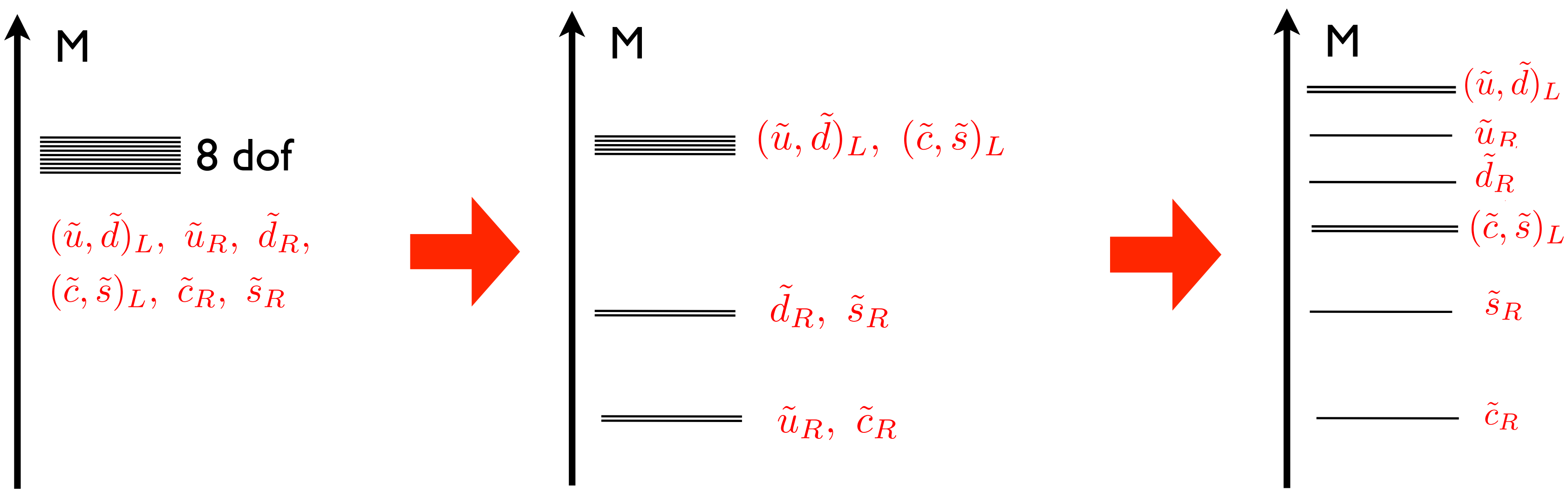
Bounds from ATLAS & CMS:



Light squarks > 1.4 TeV?

What if first 2 generation squark not degenerate?

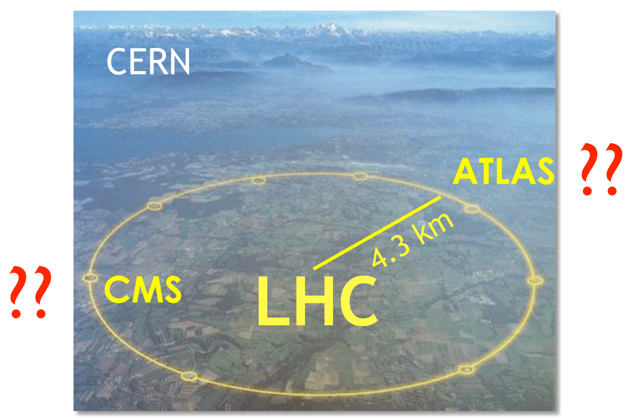
Mahbubani, Papucci, GP, Ruderman & Weiler (12).



Everything degenerate

Split, but MFV

Anarchy!



What drives the experimental limits?

- Squark multiplicity;
- Signal efficiencies;
- Production rate, PDFs.

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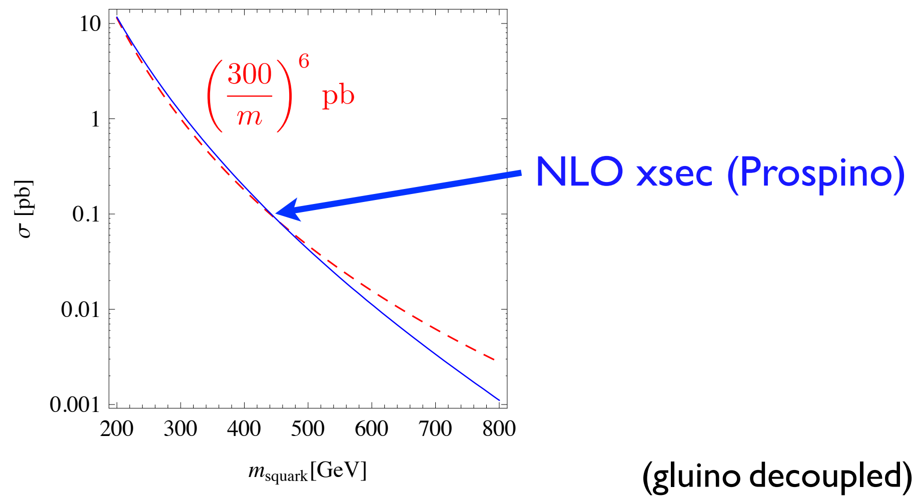
Multiplicity: how bound changes when one doublet is made lighter ?

Cross-sections vs. mass

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



(gluino decoupled)

$$8/m^6 = 6/m_H^6 + 2/m_L^6$$

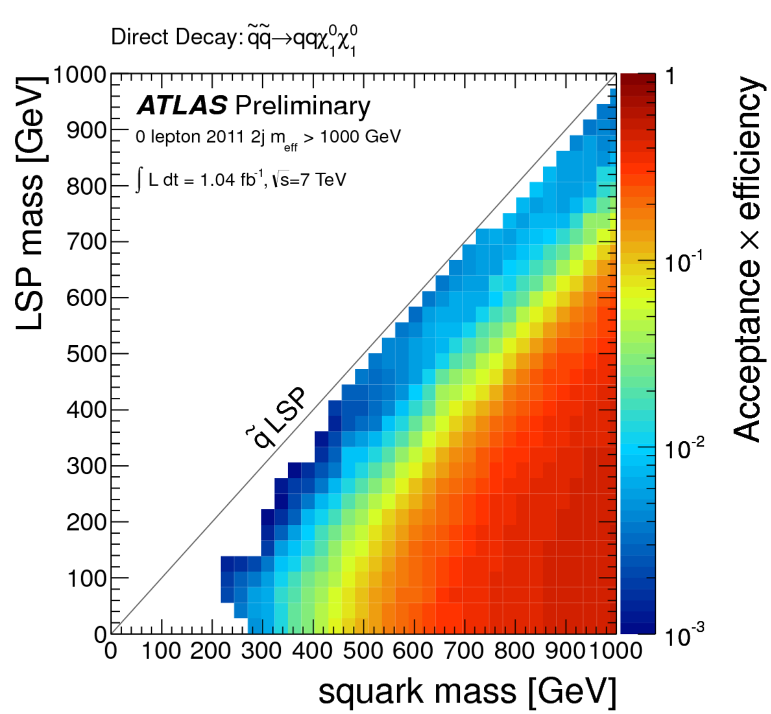
$$(m_L/m_H) = (1/4)^{1/6} \sim 0.8$$

gain is marginal

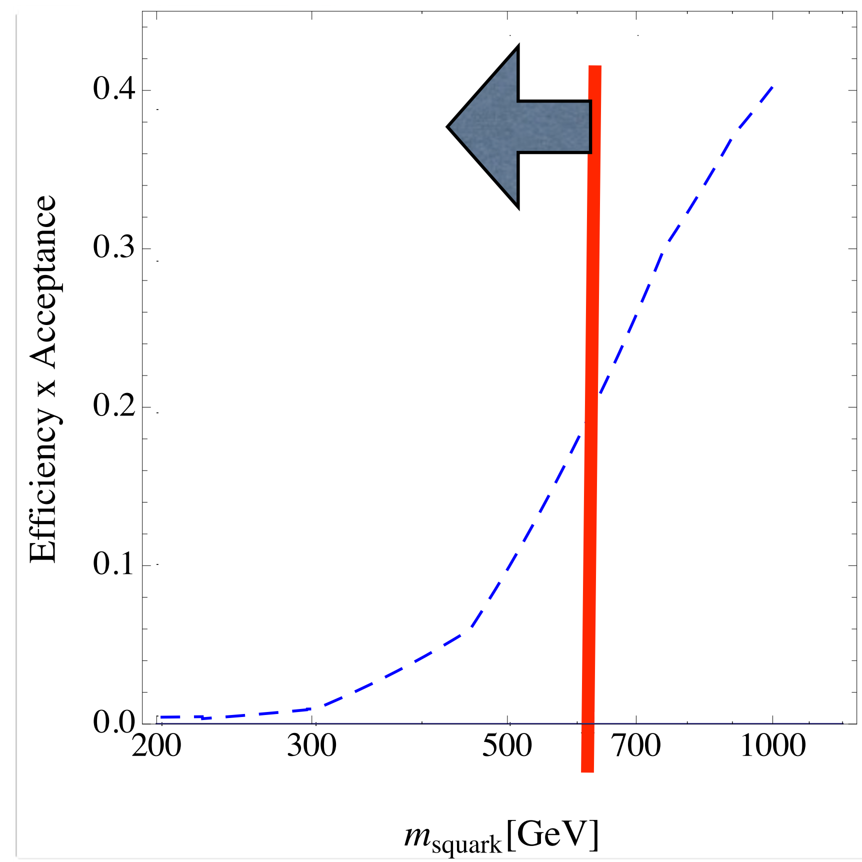
Efficiencies, strong mass dependence!

Signal efficiency falls very rapidly with decreasing squark mass

Below $\sim$ 600 GeV $\epsilon\sigma = 1$

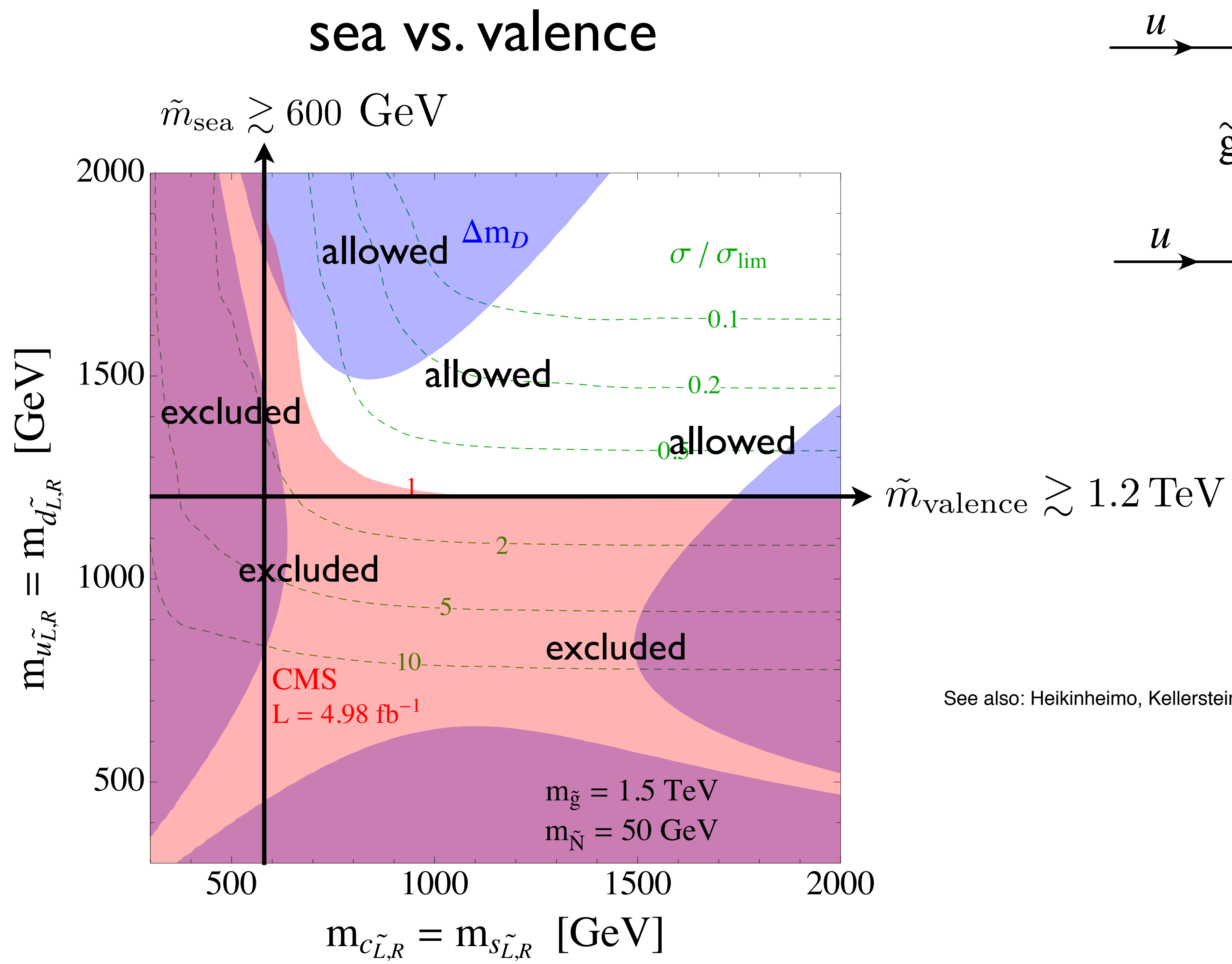


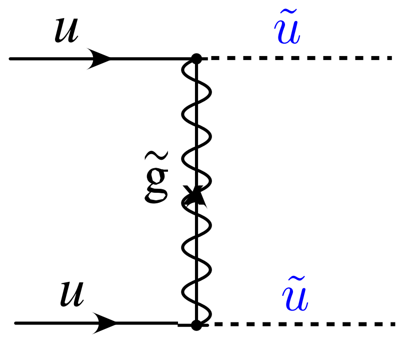
ATLAS 1/fb,
2jet M_{eff}>1TeV



meff is the scalar sum of transverse momenta of the leading N jets with E^{miss}.

PDFs: all 4 flavor "sea" squarks can be rather light!





See also: Heikinheimo, Kellerstein & Sanz (11); Kribs & Martin (12),

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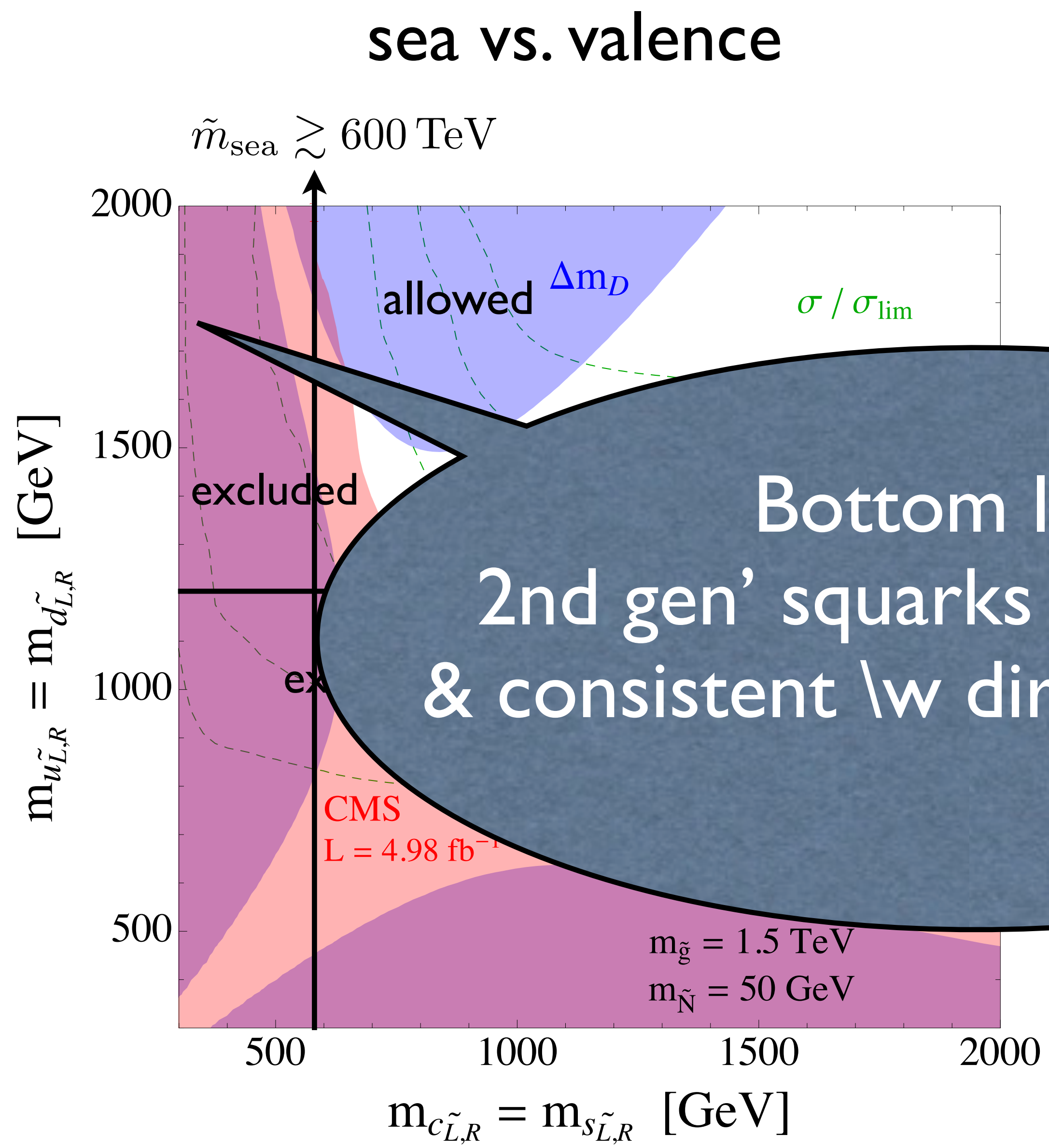
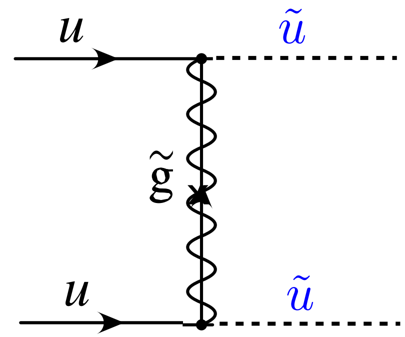




Bottom line:
2nd gen' squarks can be light
& consistent \w direct searches!

Are non-degenerate first 2-generation squarks consistent with flavor bounds?

Surprisingly: answer is yes both from low energy & UV perspectives!

Let us focus on the low energy, model indep', effective story.

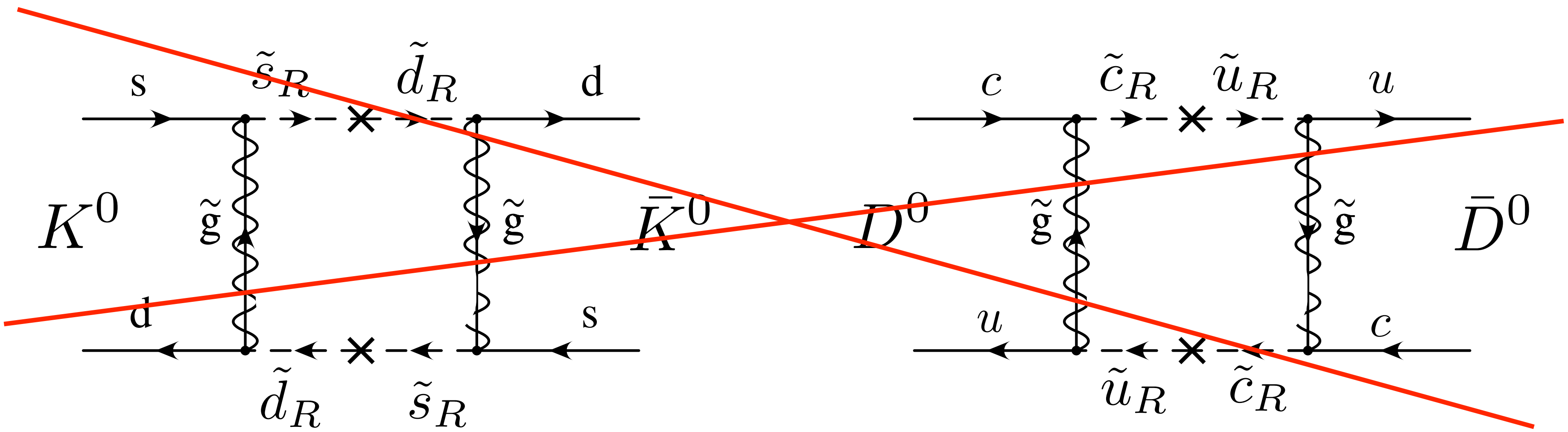
(ask if you want to hear the recents on UV story)

Are non-degenerate first 2-generation squarks consistent with flavor bounds?

♦SUSY flavor & CP violation => misalignment between squark soft masses & standard model (SM) Yukawa matrices.

♦SM: right handed (RH) flavor violated by single source, $Y_d^\dagger Y_d$ or $Y_u^\dagger Y_u$, => RH SUSY masses are alignable removing RH flavor & CP violation:

$$[\tilde{m}_d^2\,, Y_d^\dagger Y_d] = 0 \ \& \ [\tilde{m}_u^2\,, Y_u^\dagger Y_u] = 0$$



The SUSY left handed flavor challange

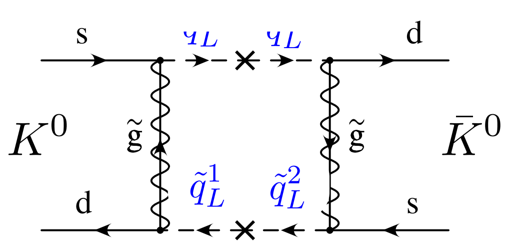
- SM LH sector consist of 2 flavor breaking sources: $Y_d Y_d^\dagger$ & $Y_u Y_u^\dagger$

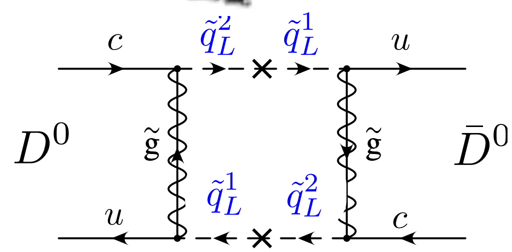
- SUSY: cannot align LH masses simultaneously with both sources! Dangerous direction wins to reduce bounds ...

$\mathrm{NP} = \tilde{m}_Q^2$

$\Delta M_K, \epsilon_K$

$\Delta M_D, A_\Gamma^D$





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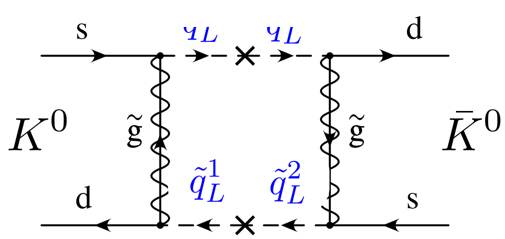

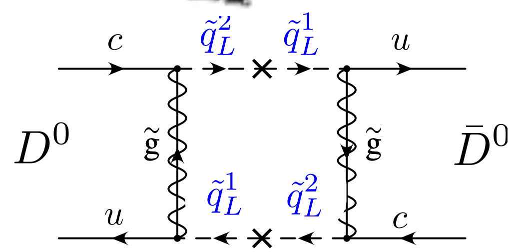

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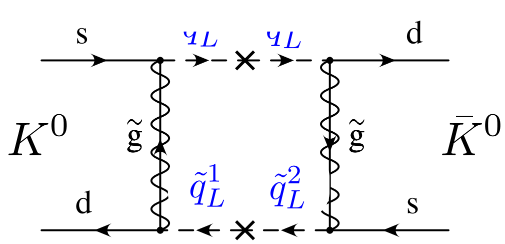

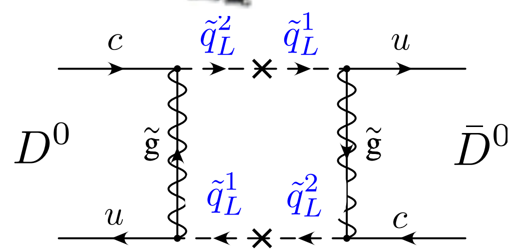

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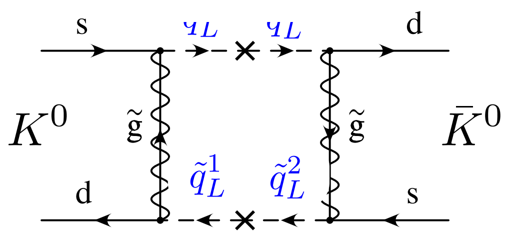

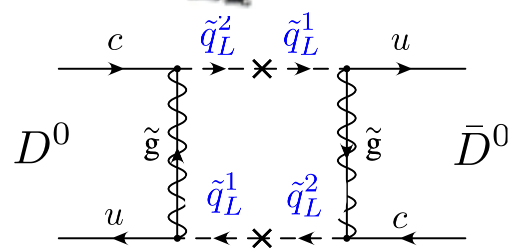

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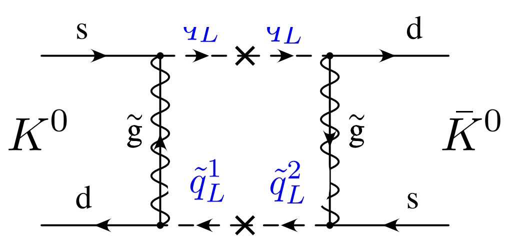

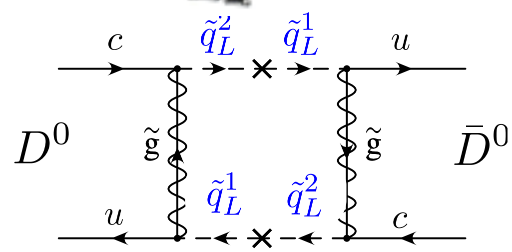

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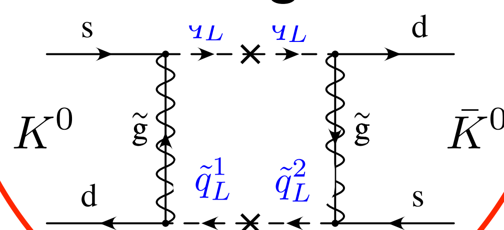
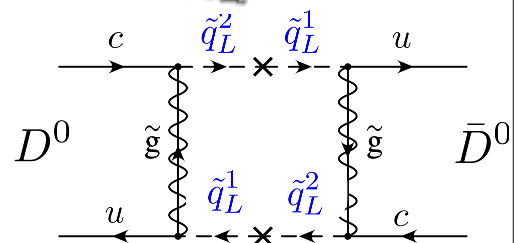
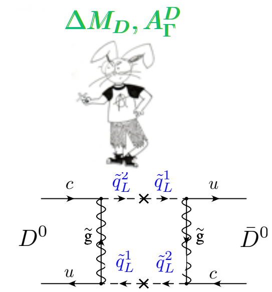
Nir & Seiberg (93)

down alignment





Last 4 yrs: dramatic progress in studying charm CPV



SUSY implications: no hope for non-degeneracy ...

$$\frac{m_{\tilde{Q}_2} - m_{\tilde{Q}_1}}{m_{\tilde{Q}_2} + m_{\tilde{Q}_1}} \leq \begin{cases} 0.034 & \text{maximal phases} \\ 0.27 & \text{vanishing phases} \end{cases}$$

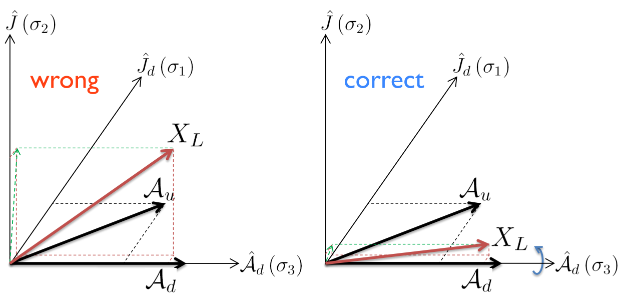
(squark doublets, gluino, 1TeV)

Blum, Grossman, Nir & GP (09)

With phases, first 2 gen' squark need to have almost equal masses.
Looks like squark anarchy/alignment is dead!

However ...

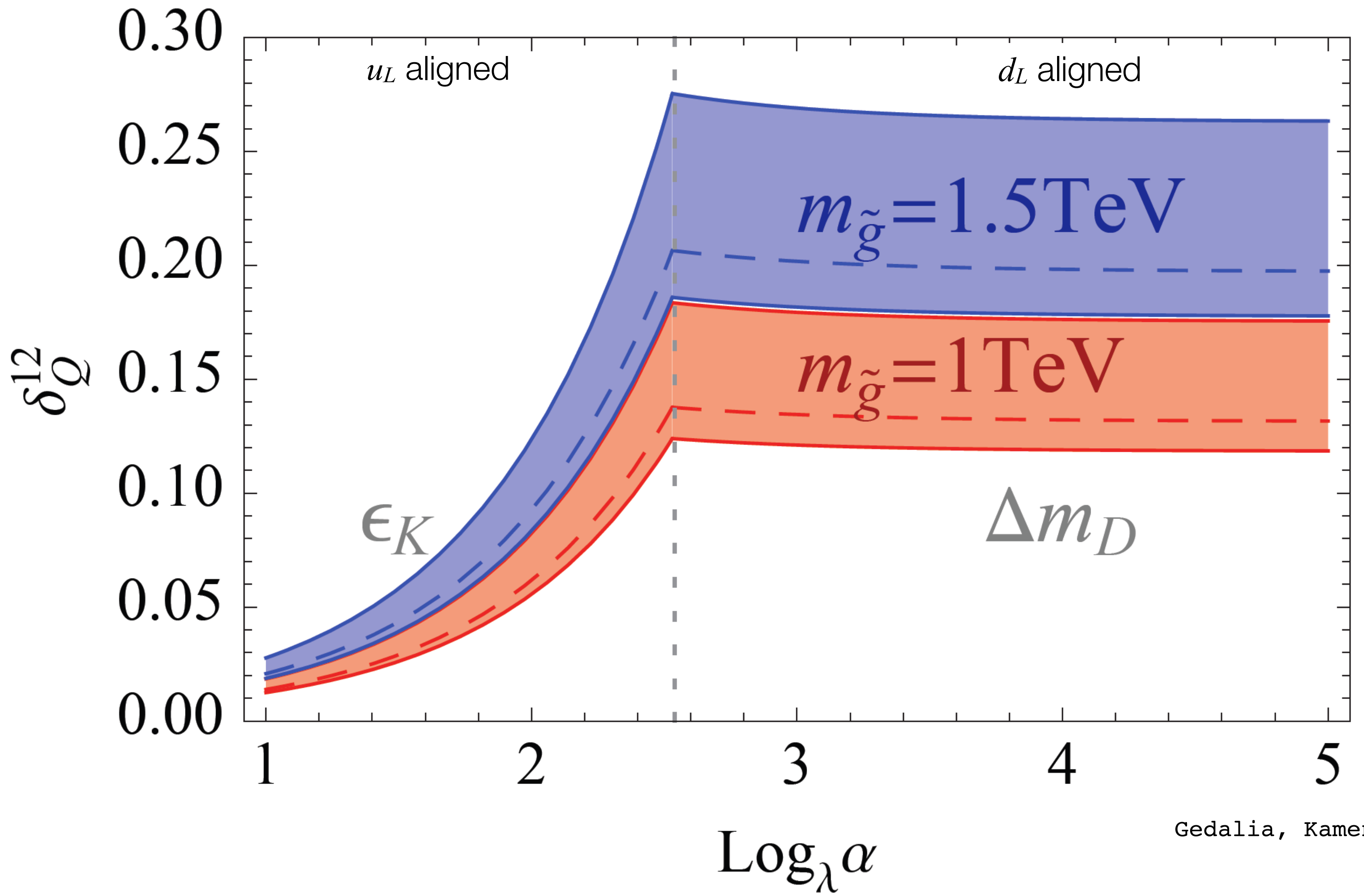
Successful alignment models guarantee small physical CP phase!



Gedalia, Kamenik, Ligeti & GP (12);

Formalism: Gedalia, Mannelli & GP (10) x2

Degeneracy of Squarks



$$\delta_Q^{12} \equiv \frac{m_{\tilde{Q}_2} - m_{\tilde{Q}_1}}{m_{\tilde{Q}_2} + m_{\tilde{Q}_1}}$$

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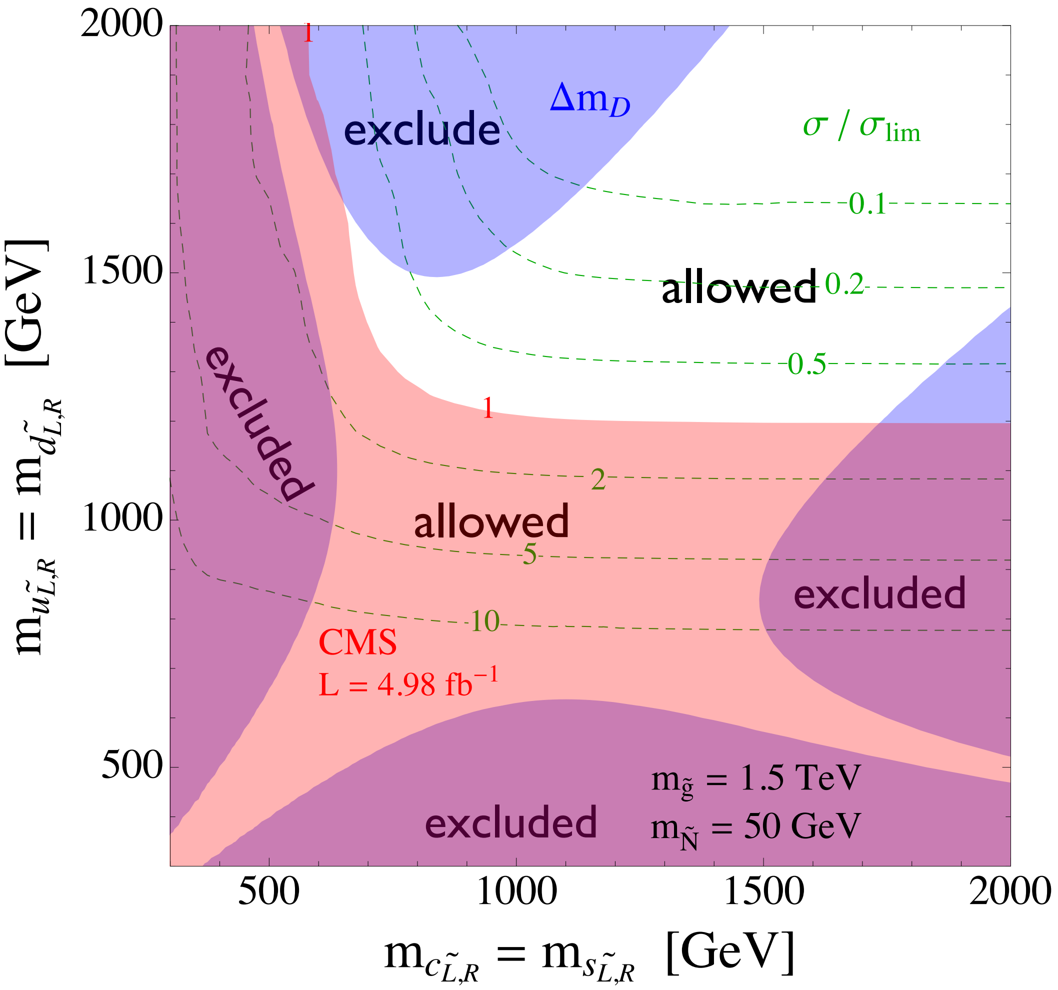
Sea LH squarks vs. valence RH squarks

Adding flavor constraints (Δm_D) for LH squarks:

Kadosh, Paride & GP, to appear;



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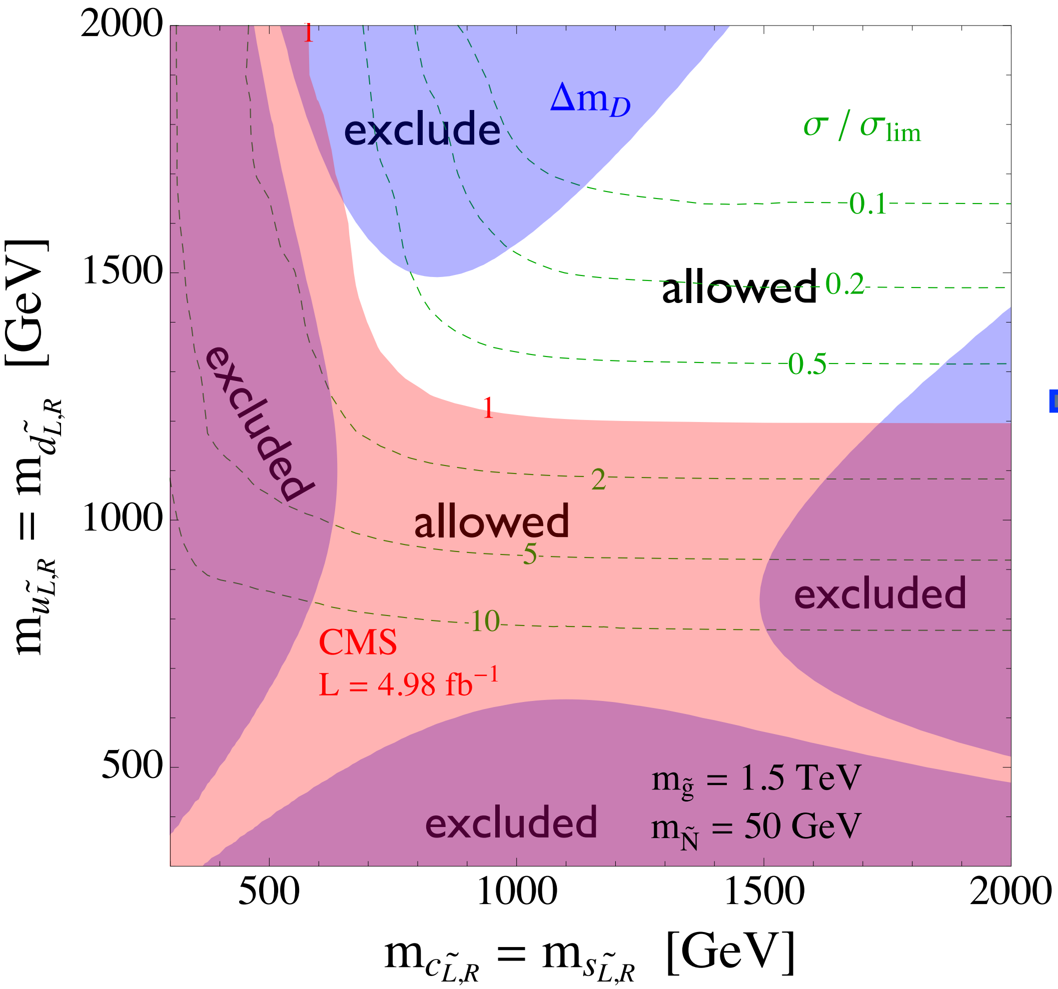

alignment: new upper bound on CP violation (CPV) in *D-phys.*:

$$\text{CPV in } D-\bar D:\ \delta_{\epsilon_K}/2\lambda_C\,\delta_Q^{12} \lesssim 10\% \times (0.3/\delta_Q^{12})$$

$$(\delta_{\epsilon_K} \sim 1\%)$$

LHCb soon start testing alignment paradigm!

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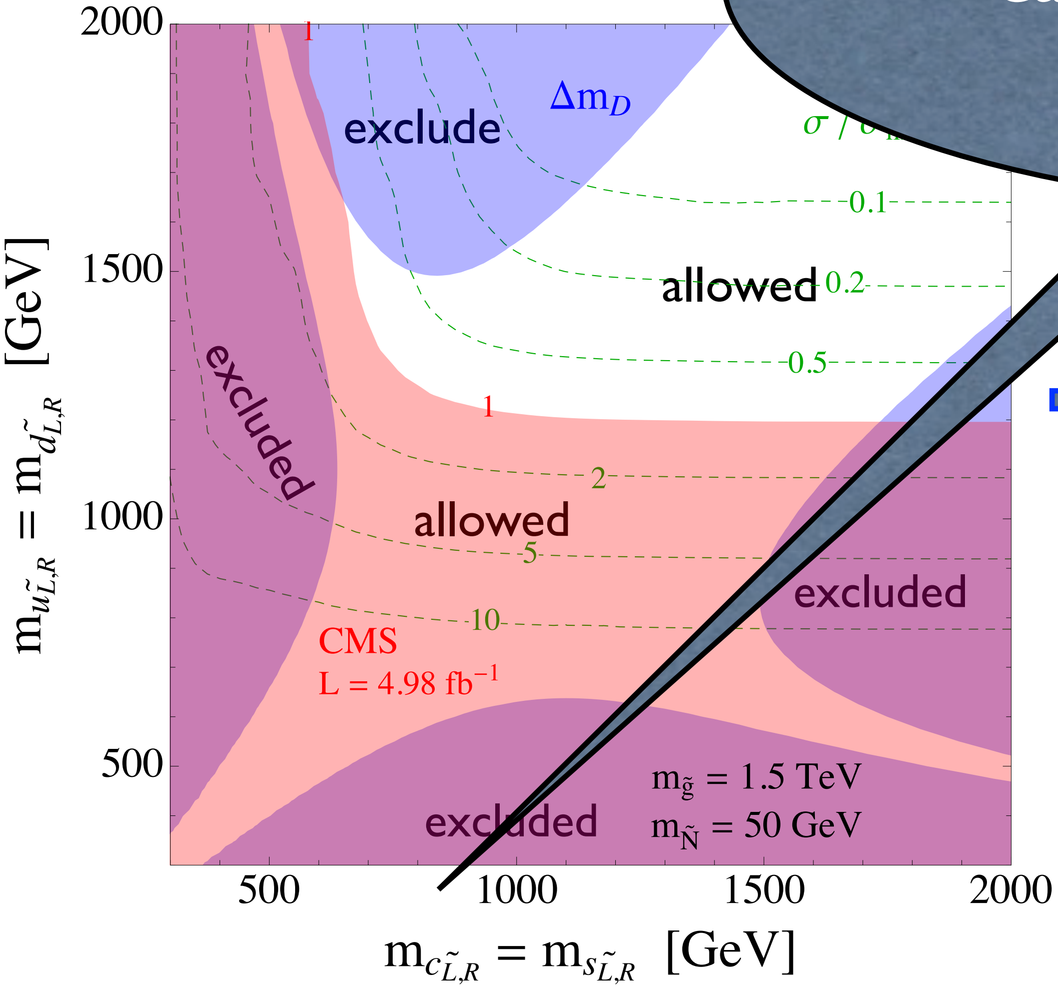

ATLAS & CMS
can improve sensitivity
via charm tagging !

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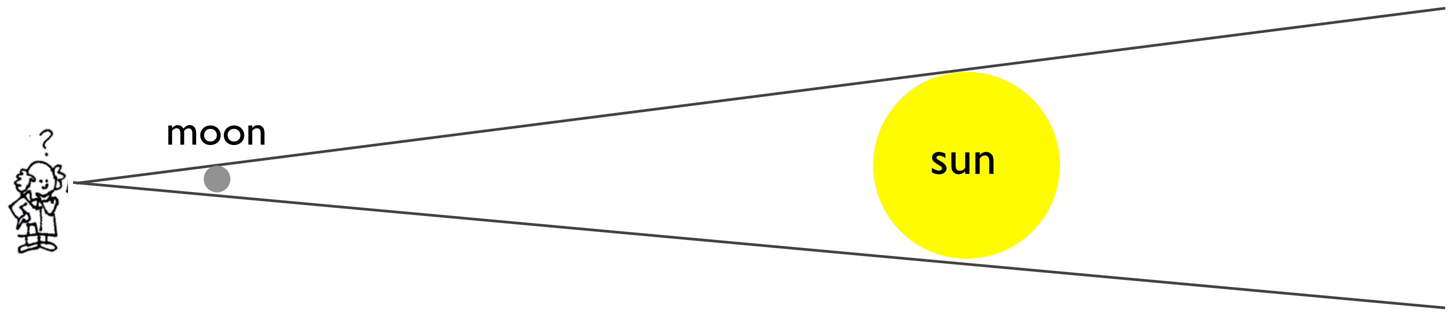
The Battle for Naturalness



So far: case #1 (scharm->charm searches) for interesting, high p_T, heavy flavor phys., not directly linked to naturalness.

Next: 8 slides x two other cases, potentially linked to naturalness:
(i) impact of squark flavor violation on stop searches;
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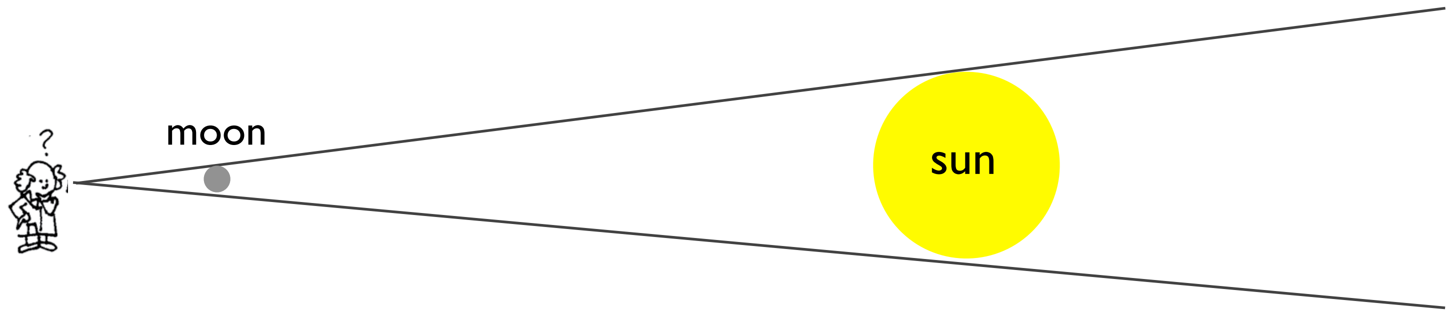

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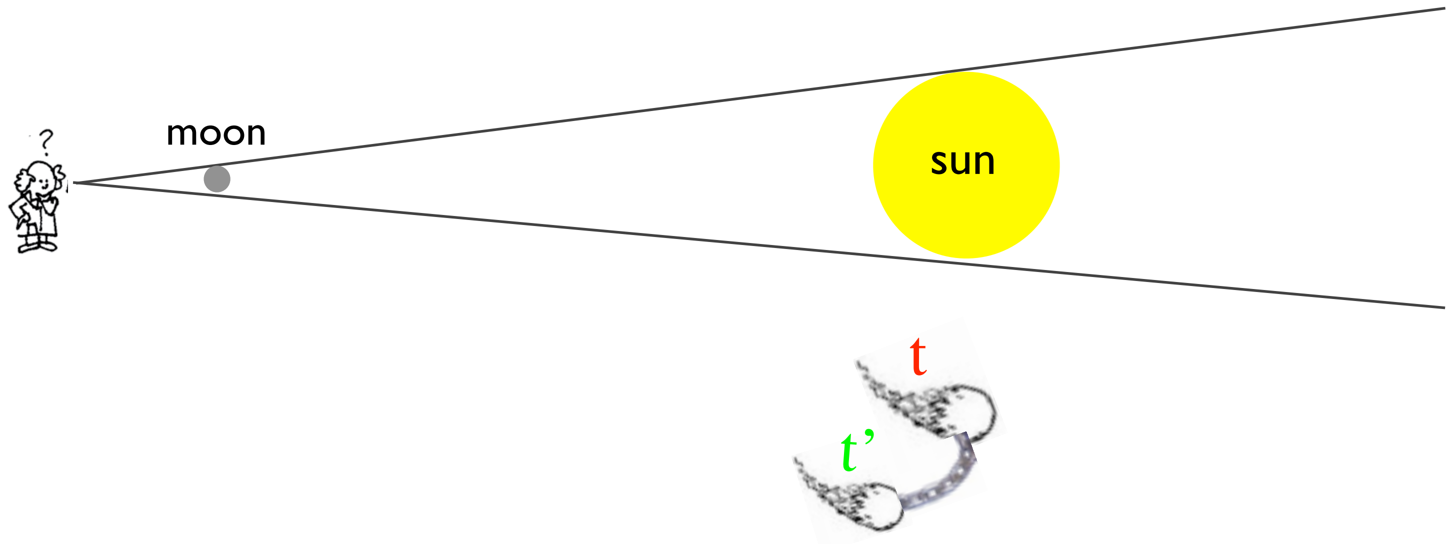

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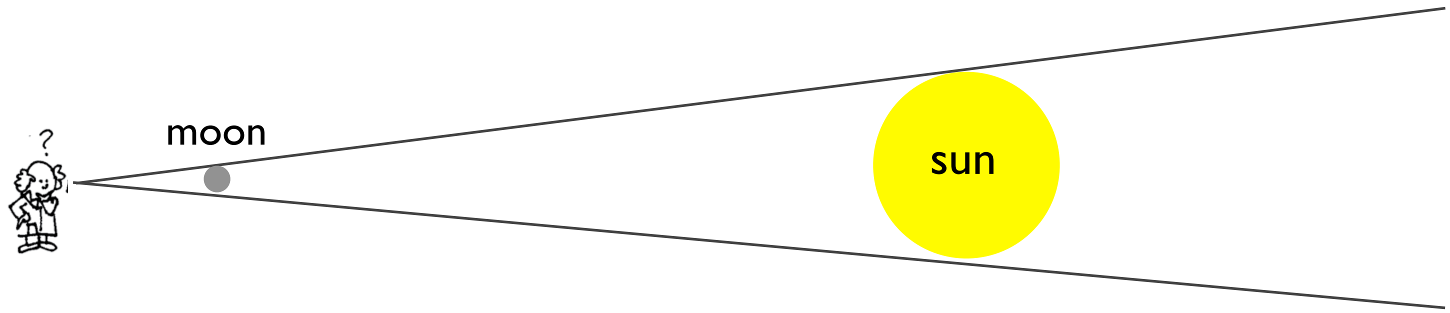

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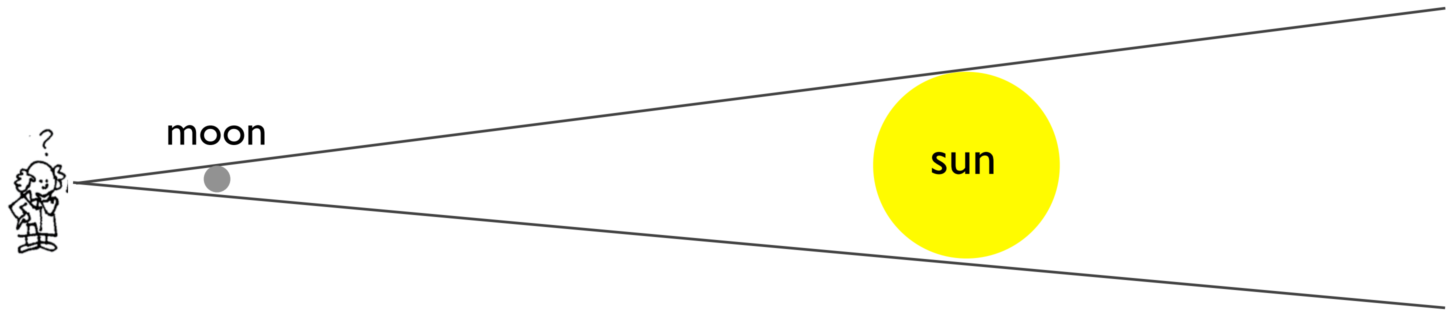

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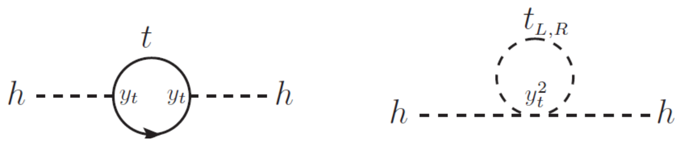
What is the impact of adding flavor violation on stop searches ? (flavored naturalness)

Blanke, Giudice, Paride, GP & Zupan, in preparation.

- Flavor: only $\tilde{t}_R - \tilde{u}_R$ or $\tilde{t}_R - \tilde{c}_R$ sizable mixing is allowed.

- Naively sounds crazy ...

Dine, Leigh & Kagan (93); Dimopoulos & Giudice (95).



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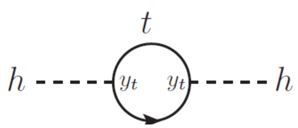
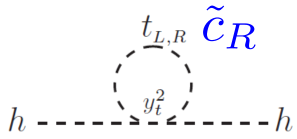




$$\delta m^2_{Hu} = -\frac{3y_t^2}{8\pi^2}\left(m^2_{\tilde{t}_L} + \cos^2\theta^{RR}_{23} m_1^2 + \sin^2\theta^{RR}_{23} m_2^2\right)$$

- However, just established the scharm can be light.

- The "$\tilde{t}_R\,\tilde{t}^*_R$" $\to t_R\,t^*_R$ production is suppressed by $\left(\cos\theta^R_{23}\right)^4$.

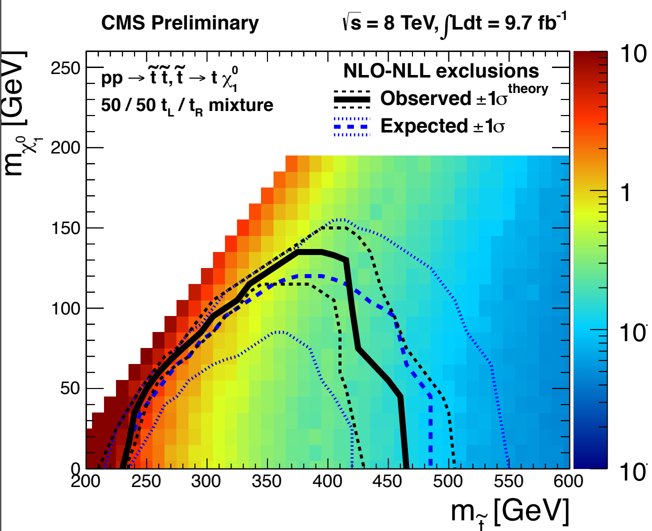
⇓

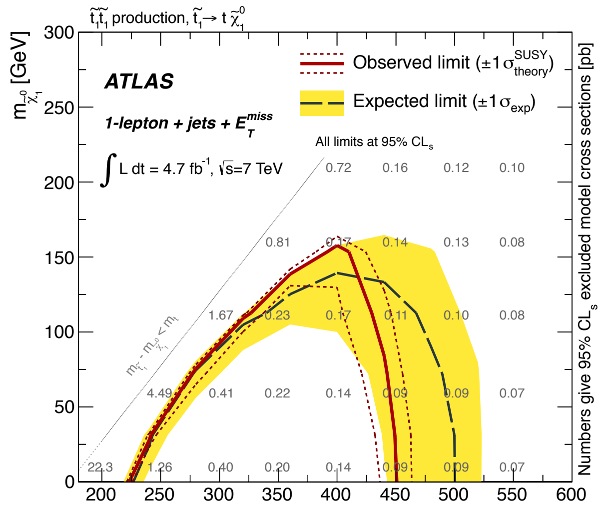
Potentially: improve naturalness or new hole in searches...

Flavored naturalness

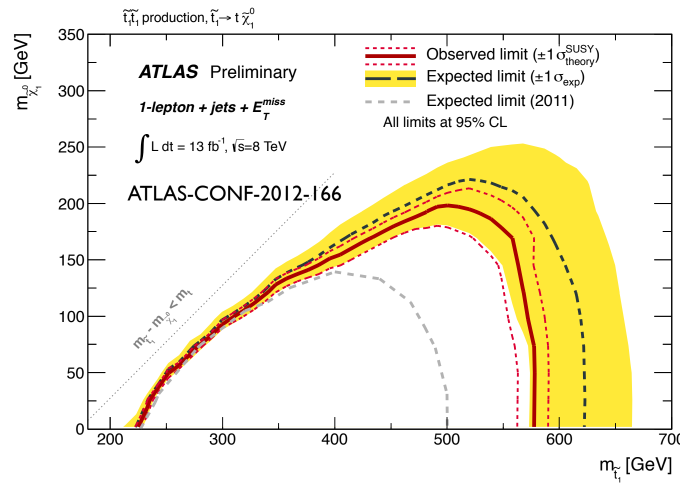
- Bounds on LH stops are weaker due to acceptance.

$\tilde{t} \to t\chi^0$ $\tilde{t} \to t\chi^0$





arXiv:1208.2590 [hep-ex]



CMS talk at HCP (12); see also Perelstein & Weiler (08).

Constraining flavored naturalness

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ATLAS (12).

- To constrain, look for: tt, cc & tc + MET.

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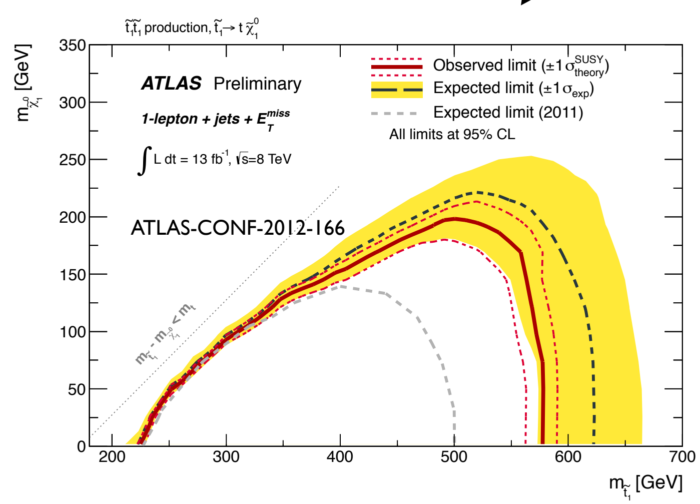

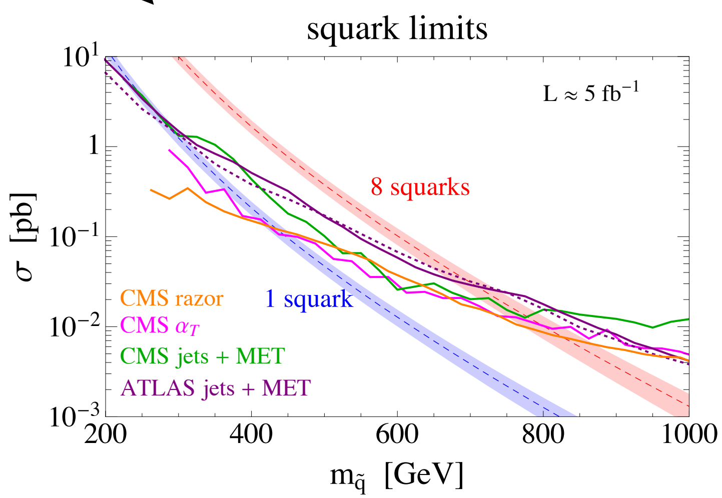

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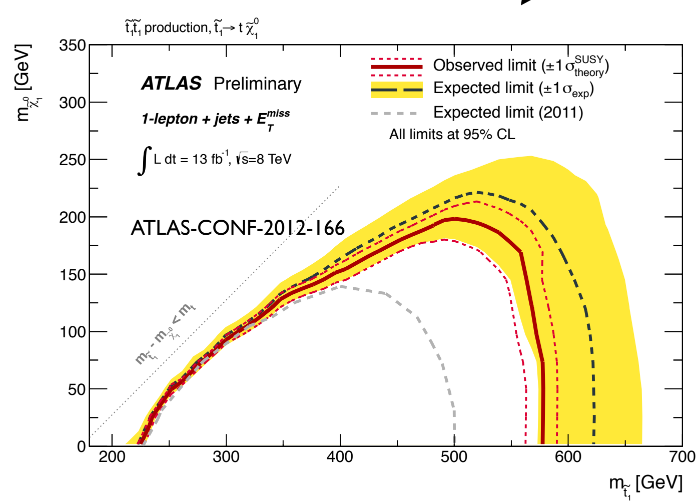

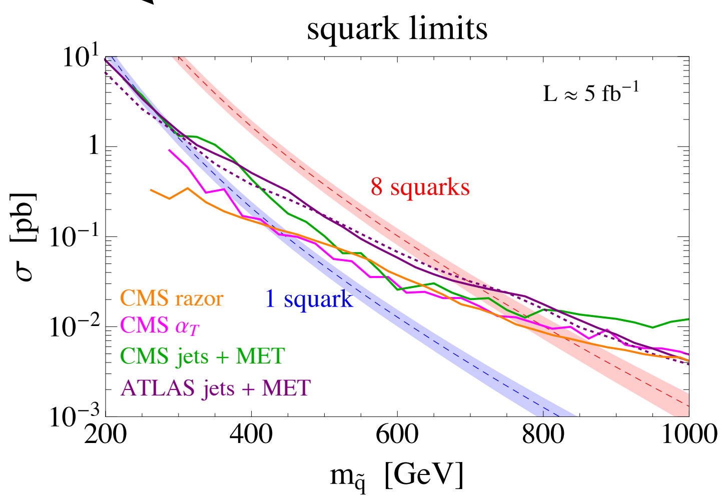

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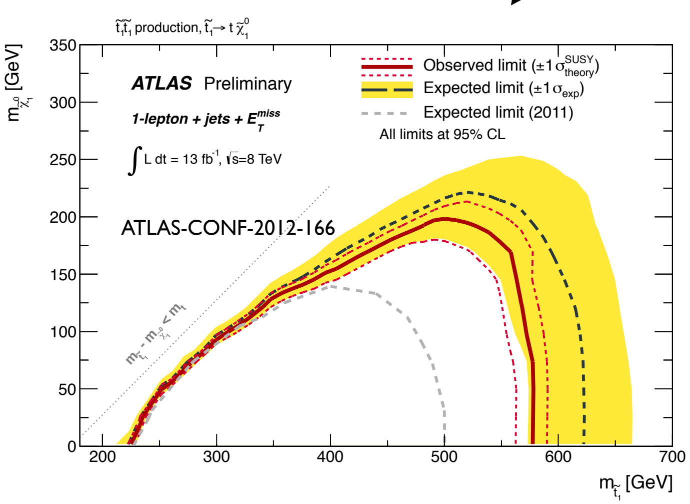
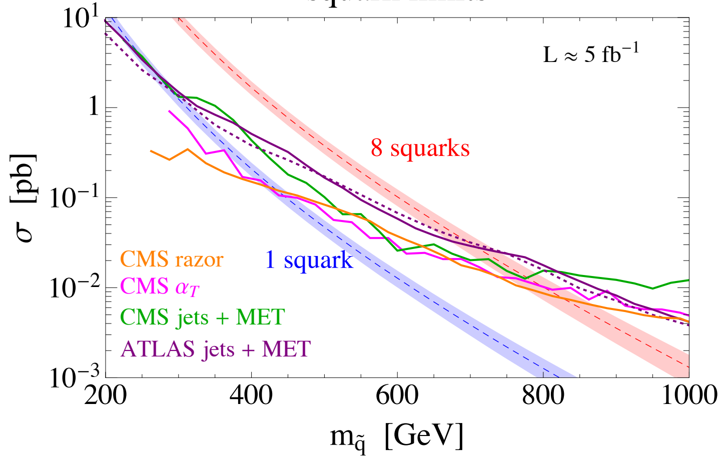
compromise



squark limits



Mahbubani, Papucci, GP, Ruderman & Weiler (12).

Flavored naturalness, *preliminary* results

Blanke, Giudice, Paride, GP & Zupan, in preparation.

- The relevant parameters to constrain are:

Define relative tuning measure: $\xi = \frac{\tilde{m}_1^2 c^2 + \tilde{m}_2^2 s^2}{m_0^2}$, $\quad (m_0 = 570\,\mathrm{GeV})$

stop,scharm like squark mass, $m_{1,2}$ & $C \equiv \cos\theta_{23}^{RR}$

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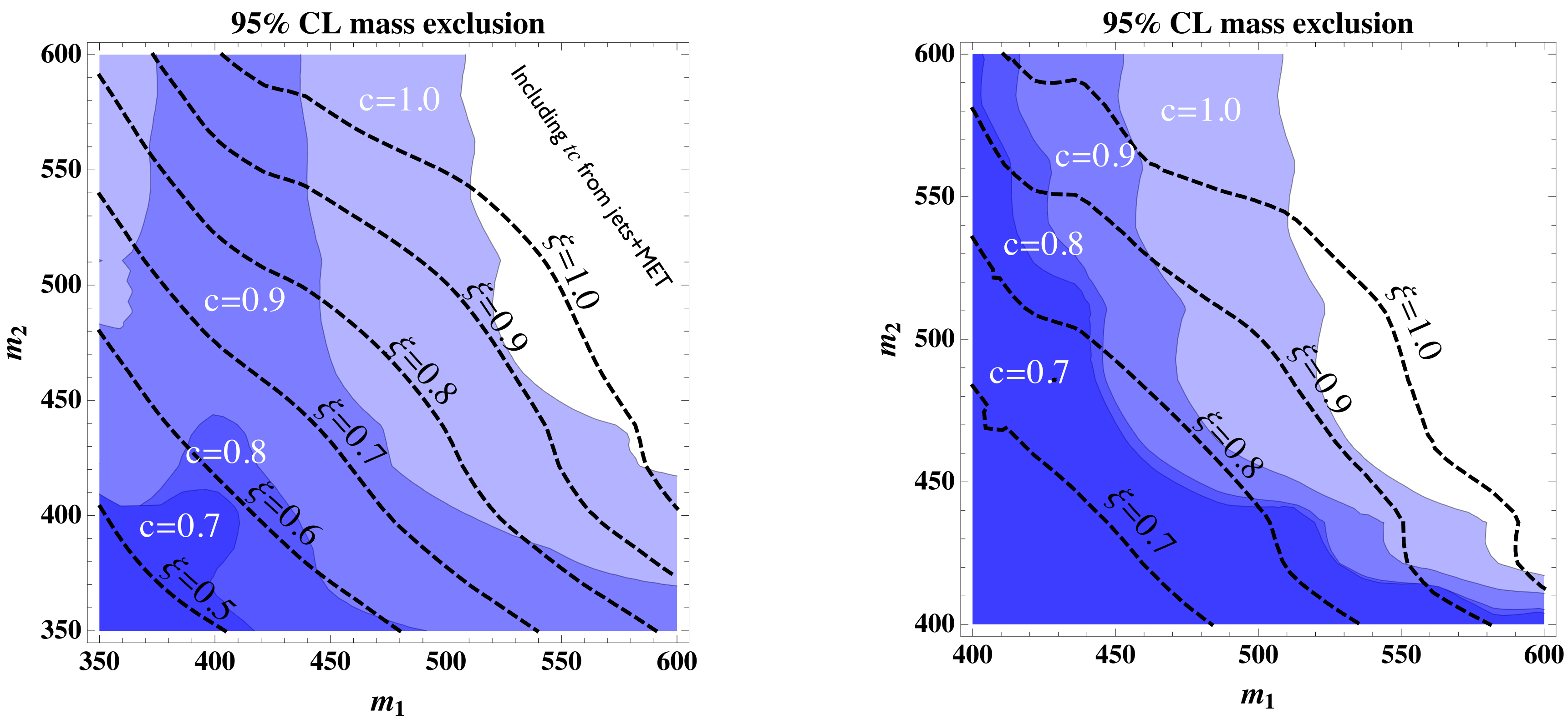

Can get $\xi \sim 0.5 - 0.8$ for $\theta_{23}^{RR} \sim 45^o$!

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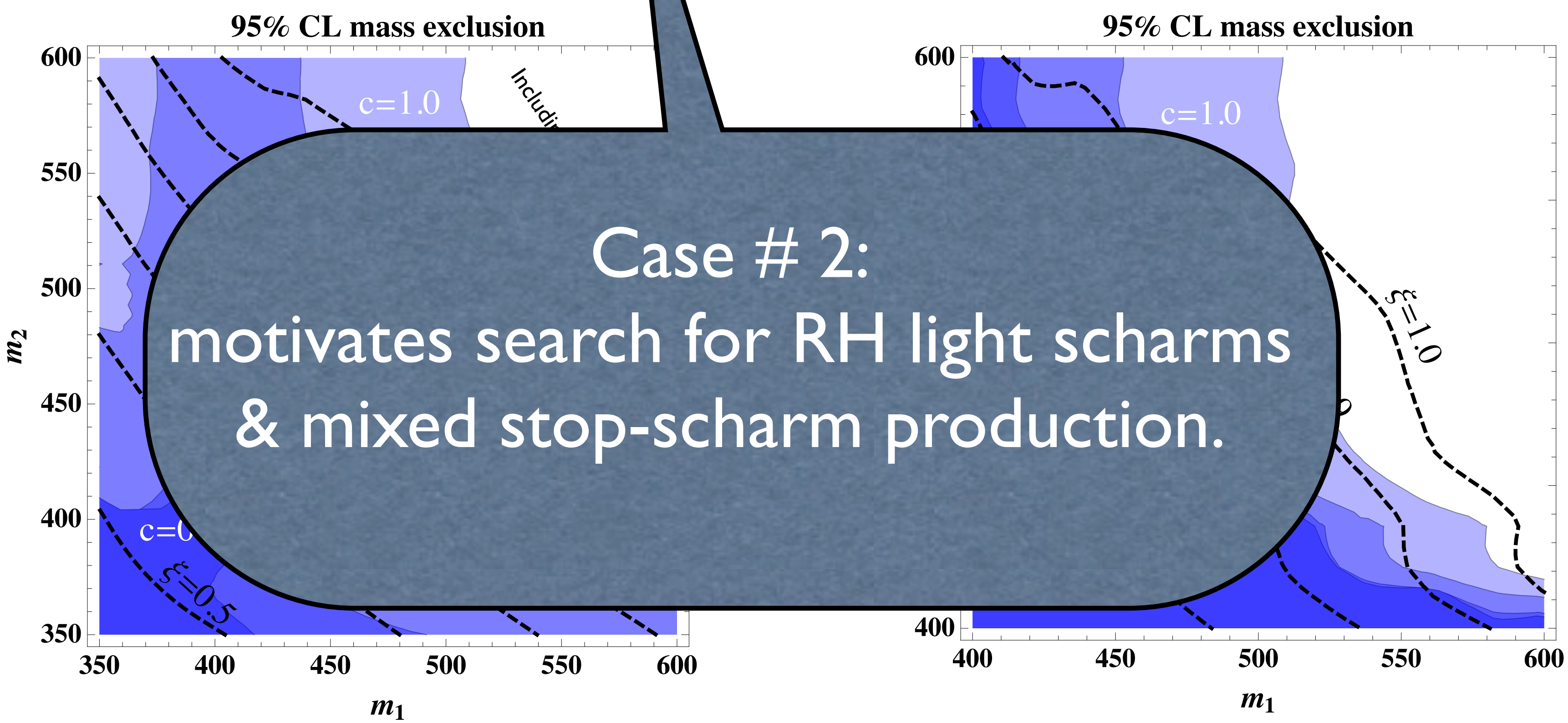

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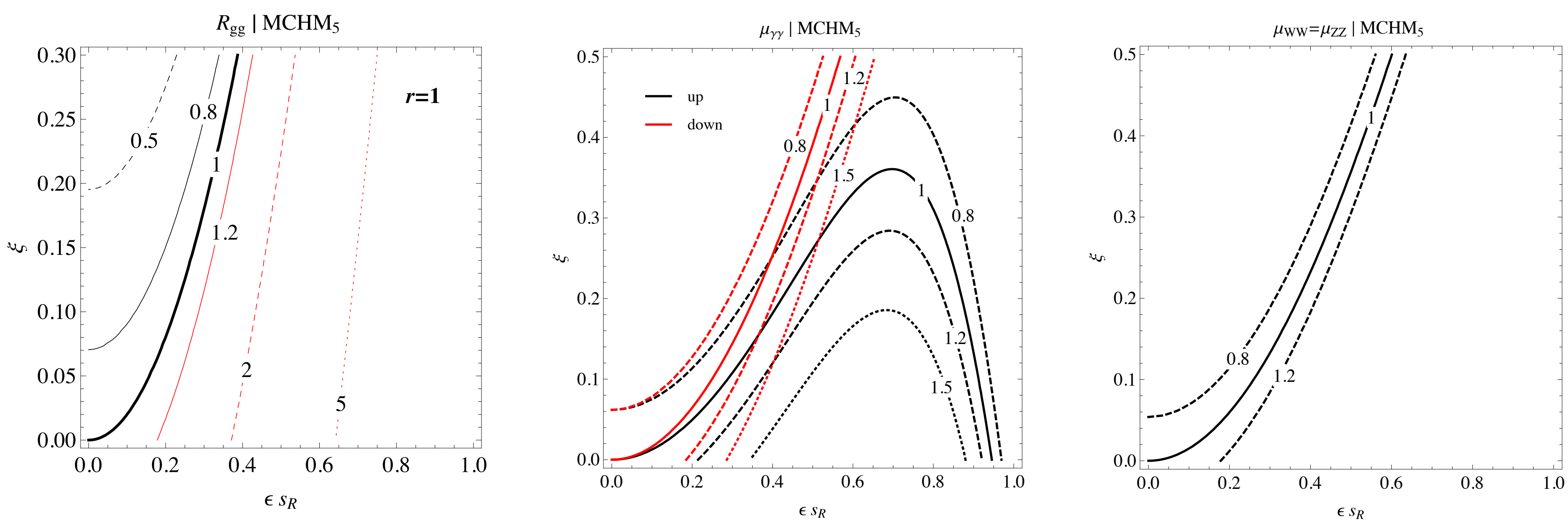
Composite light quarks & pseudo Goldstone boson Higgs

- General: strong sensitivity of Higgs coupling to its nonlinearity, but interestingly not to top compositeness.

Falkowski (07); Azatov & Galloway (11).

- On the other hand strong sensitivity to RH light quark compositeness:

$$\mu_i = \frac{\sum_j \sigma_{j\to h} \times \mathrm{Br}_{h\to i}}{\sum_j \sigma^{\mathrm{SM}}_{j\to h} \times \mathrm{Br}^{\mathrm{SM}}_{h\to i}}, \qquad R_{gg} \equiv \sigma_{gg\to h}/\sigma^{\mathrm{SM}}_{gg\to h}$$



Delaunay, Grojean & GP, to appear.

s_R: level of compositeness $\quad \xi = v^2/f^2, \quad \epsilon = Yv/\bar{M} \quad r = g_\Psi/Y \quad g_\Psi \equiv M/f$

Composite light quarks & pseudo Goldstone boson Higgs

♦ General: stro ... its

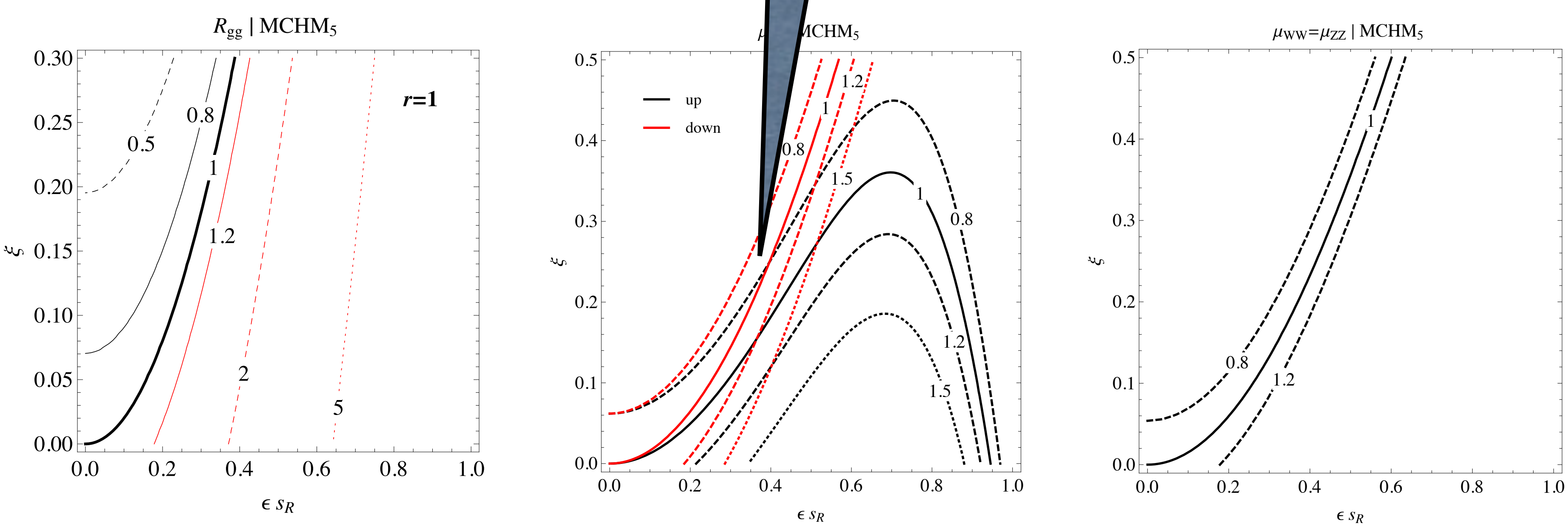
nonlinearity, ... ess.

... Galloway (11).

♦ On the ot ... uark

compositenes ...

Case # 3:
right handed composite quarks
=>
excess of heavy flavor jets



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Top B physics @ ATLAS & CMS

Gedalia, Isidori, Maltoni, GP, Selvaggi & Soreq (12)

- Already recorded more than 5 million top pairs were collected, many more to come.

- Window for new way to do precision heavy flavor physics.

- The top mass & small width => new type of b factory.

$$t \to \ell^+ \nu \; \left(b \to \bar{b}\right) \to \ell^+ \, \ell^+ \, X \, ,$$
$$t \to \ell^+ \nu \; \left(b \to c\right) \to \ell^+ \, \ell^+ \, X \, ,$$
$$t \to \ell^+ \nu \; \left(b \to \bar{b} \to c \, \bar{c}\right) \to \ell^+ \, \ell^+ \, X \, ,$$

- Can define for instance two type of CP asymmetry:

$$A_{\rm sl}^{ss} \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}} \qquad A_{\rm sl}^{os} \equiv \frac{N^{+-} - N^{-+}}{N^{+-} + N^{-+}}$$

Conclusions

- Light (non-"sups") squarks maybe buried (regardless of alignment).
- Stop-scharm mixing might lead to improve naturalness.
- Ask for new type of SUSY searches, charm tagging important, linked to CPV in D mixing, soon to be tested at LHCb.
- Interplay between composite PGB physics & presence of light composite fermions => motivates improve charm-jet searches.
- Top phys. @ ATLAS & CMS => precision heavy flavor phys..

Many thanks to:

Beate, Christian, Fabio, Michele

& Eric (you & other organizers)