The time for exceptional heavy flavor physics @ ATLAS & CMS

Gilad Perez

CERN & Weizmann Inst.

Mahbubani, Papucci, GP, Ruderman & Weiler (12);
Kadosh, Paride & GP, to appear;
Blanke, Giudice, Paride, GP & Zupan, in preparation;
Delaunay, Grojean & GP, to appear;
[Gedalia, Isidori, Maltoni, GP, Selvaggi & Soreq (12) ?]

zpw 2013 the zurich phenomenology workshop Particle physics in the LHC era

Outline

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

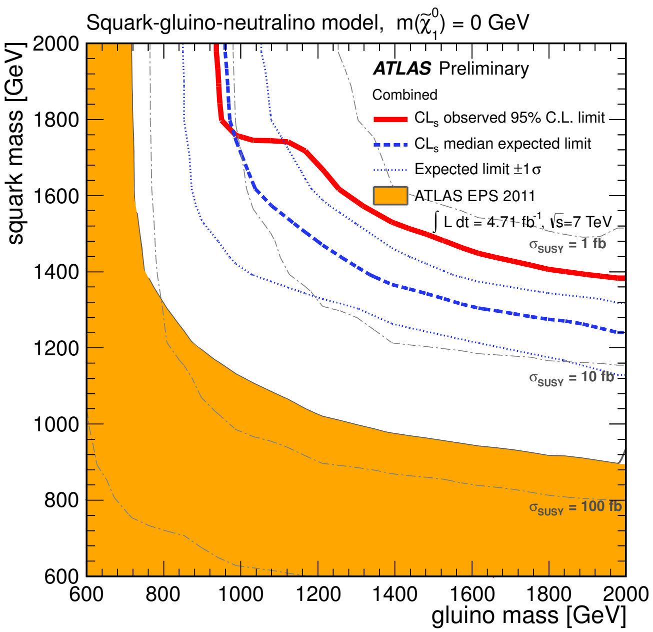
  (*i*) stop searches; (*ii*) implications of Higgs on composite light flavors.
- *t*op precision b-physics @ ATLAS & CMS. (& beyond)

  (if time permits)
- Summary.

Current status of Supersymmetry

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

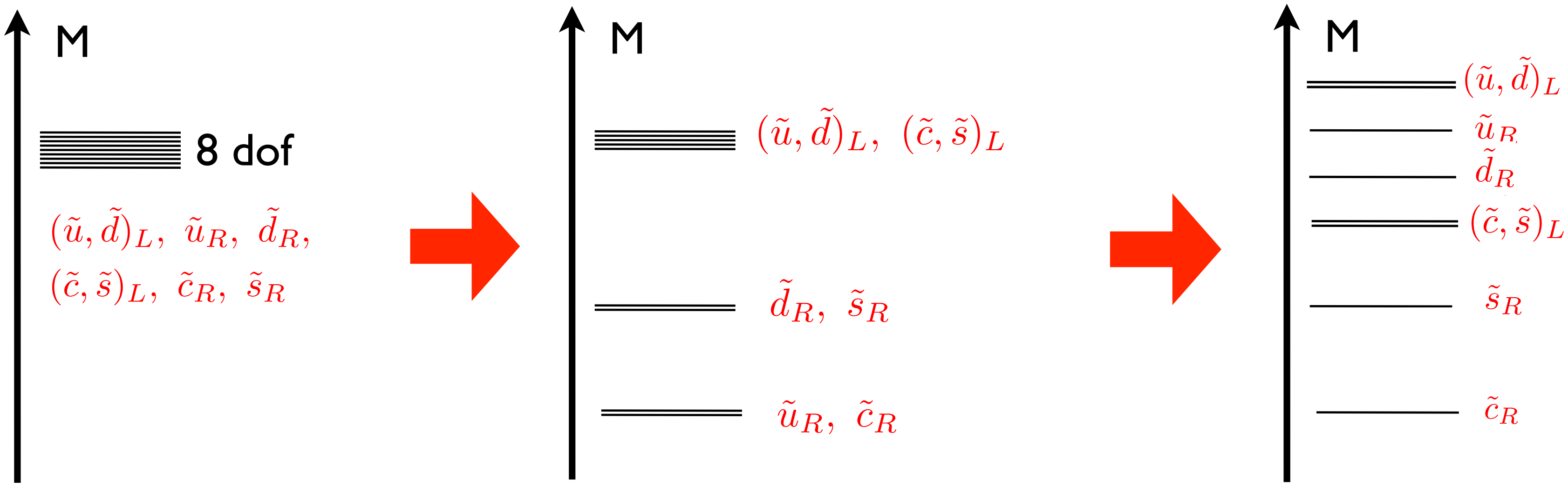
Bounds from ATLAS & CMS:



Light squarks > 1.4 TeV?

What if first 2 generation squark not degenerate?

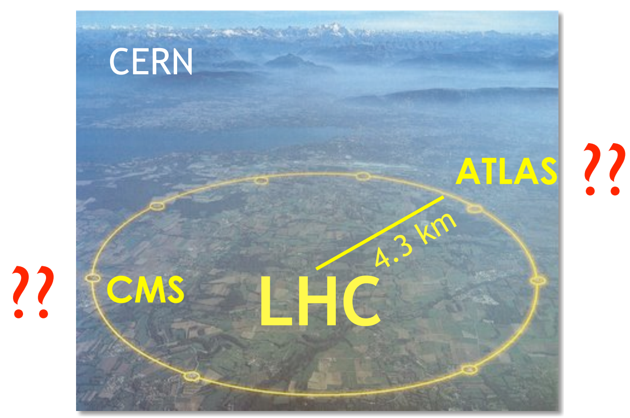
Mahbubani, Papucci, GP, Ruderman & Weiler (12).



Everything degenerate

Split, but MFV

Anarchy!



What drives the experimental limits?

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

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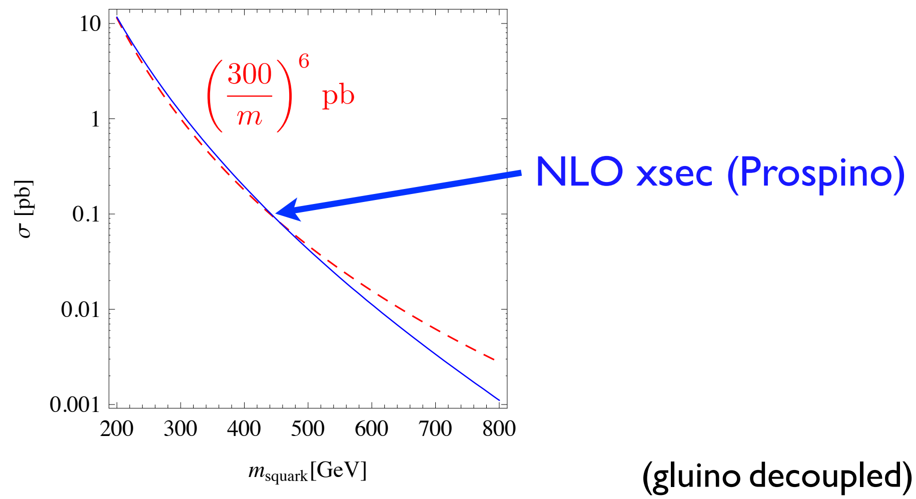
Multiplicity: how bound changes when one doublet is made lighter ?

Cross-sections vs. mass

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



(gluino decoupled)

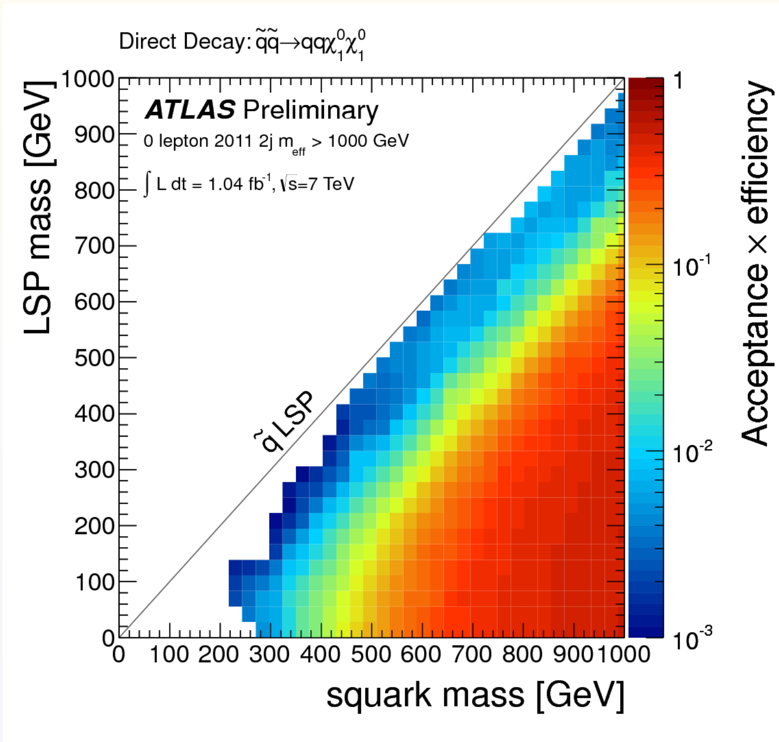
$$8/m^6 = 6/m_H^6 + 2/m_L^6$$

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

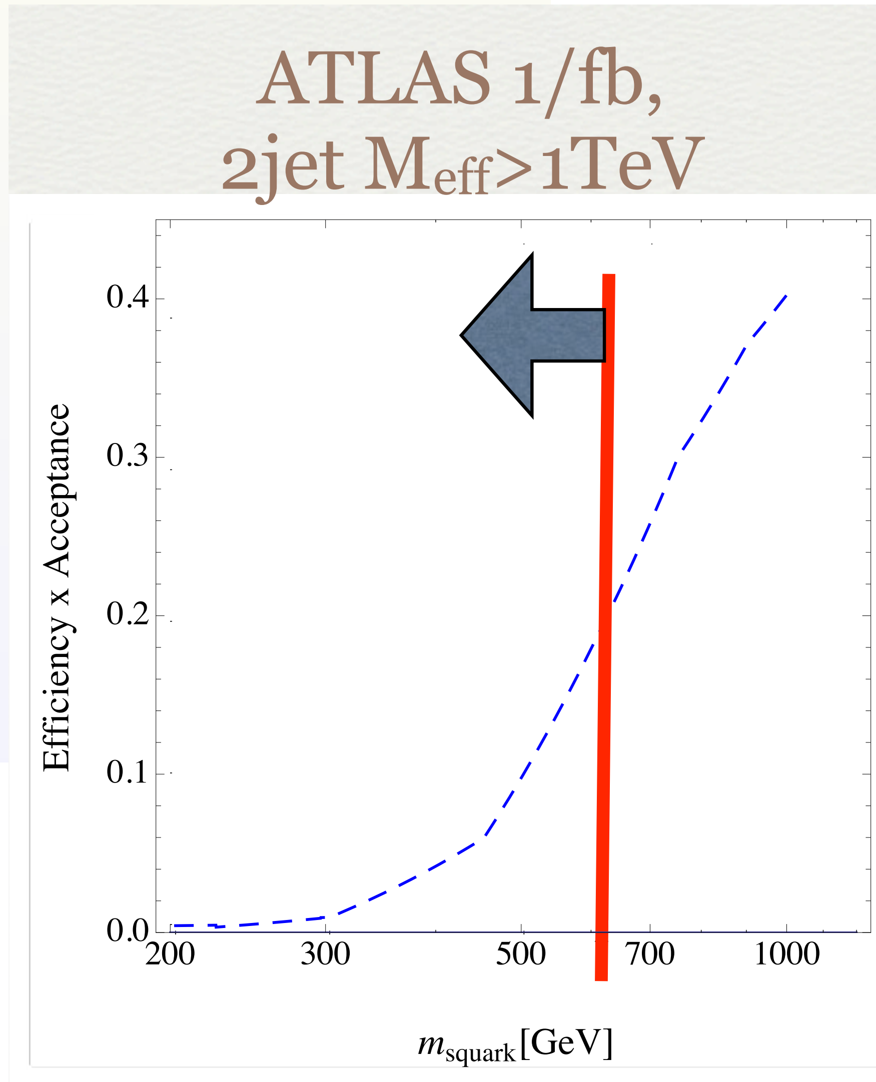
gain is marginal

Efficiencies, strong mass dependence!

Signal efficiency falls very rapidly with decreasing squark mass

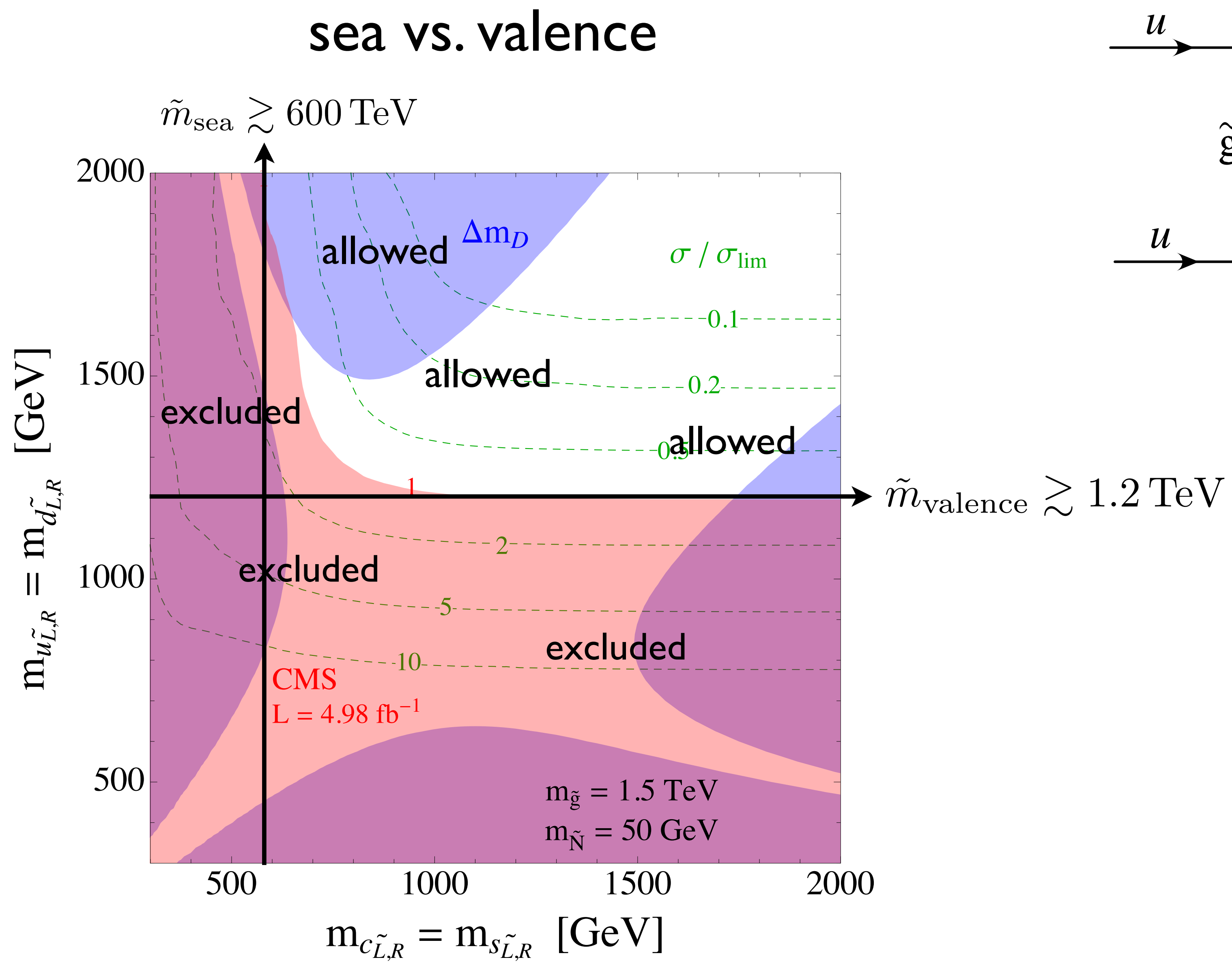


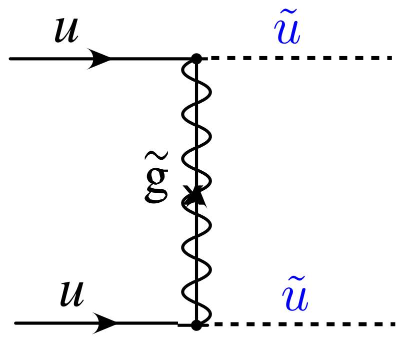
Below $\sim$ 600 GeV $\epsilon\sigma = 1$



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!





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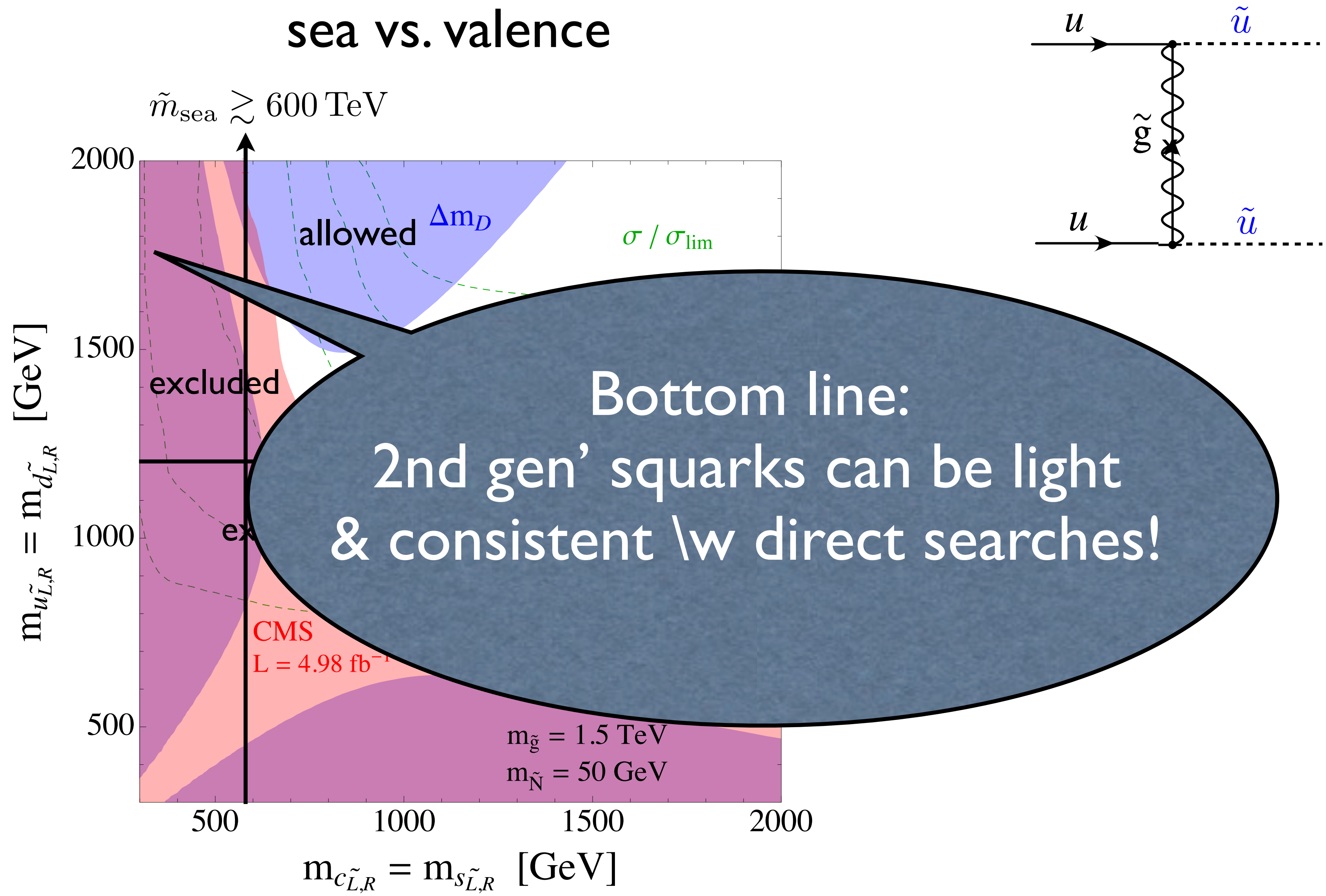


Are non-degenerate first 2-generation squarks consistent with flavor bounds?

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

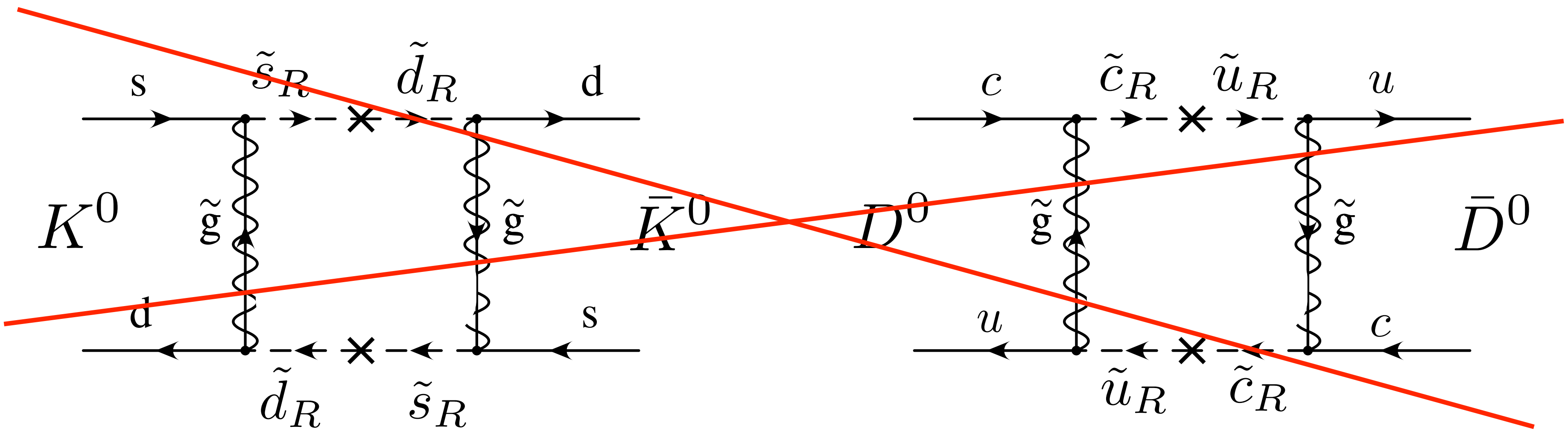
Let us focus on the low energy, model indep', effective story.

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

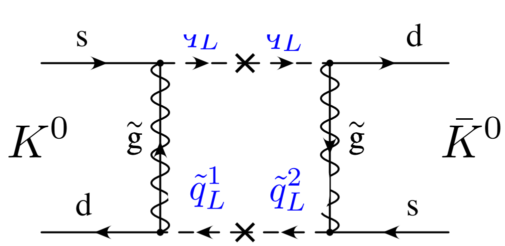
- SM LH sector consist of 2 flavor breaking sources: $Y_d Y_d^\dagger$ & $Y_u Y_u^\dagger$

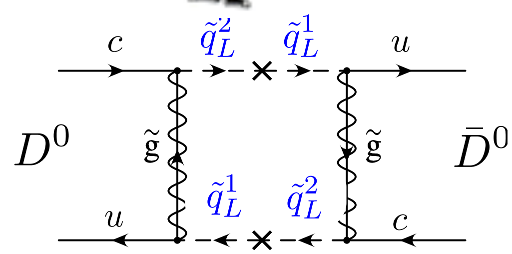
$\text{NP} = \tilde{m}_Q^2$

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

$\Delta M_K, \epsilon_K$

$\Delta M_D, A_\Gamma^D$





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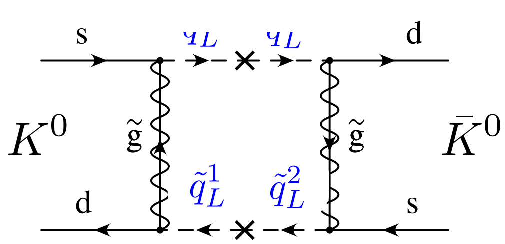

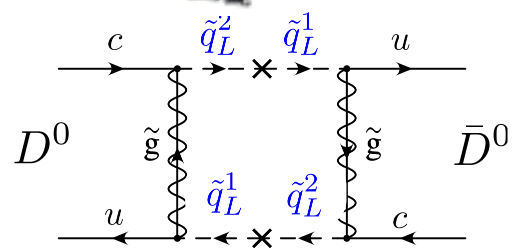

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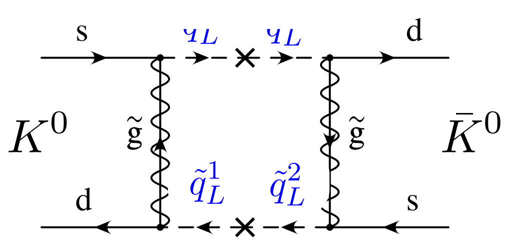

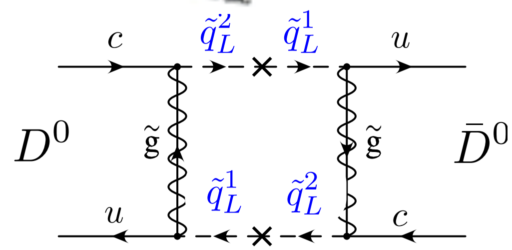

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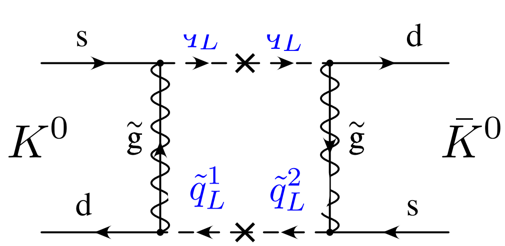

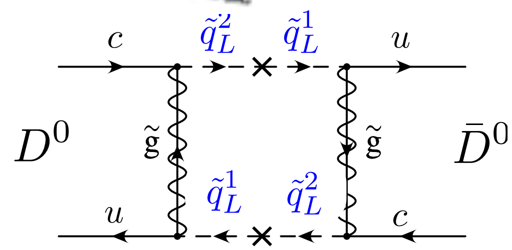

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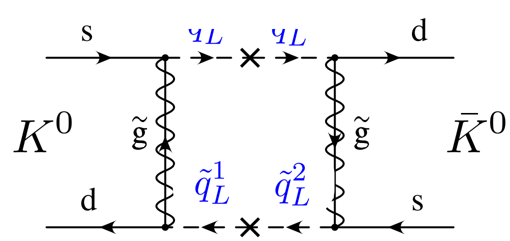

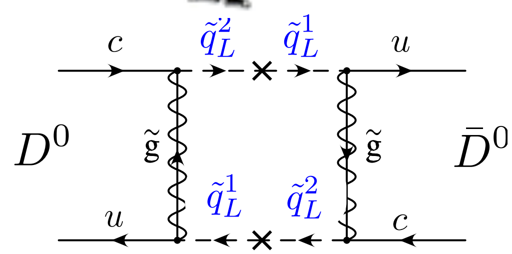

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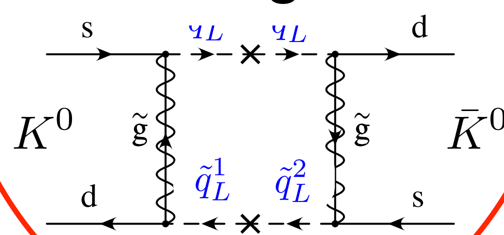
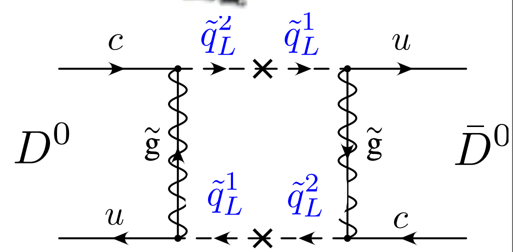
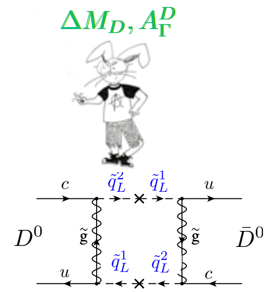
Nir & Seiberg (93)

down alignment





Last 4 yrs: dramatic progress in studying charm CPV



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

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

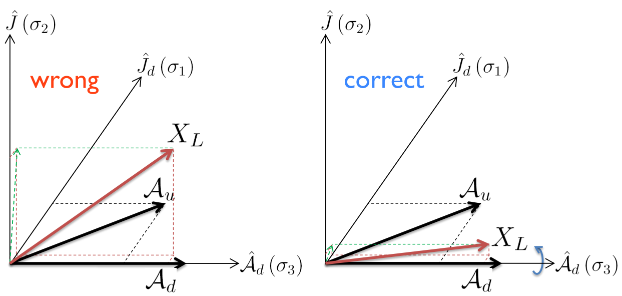
(squark doublets, gluino, 1TeV)

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 ...

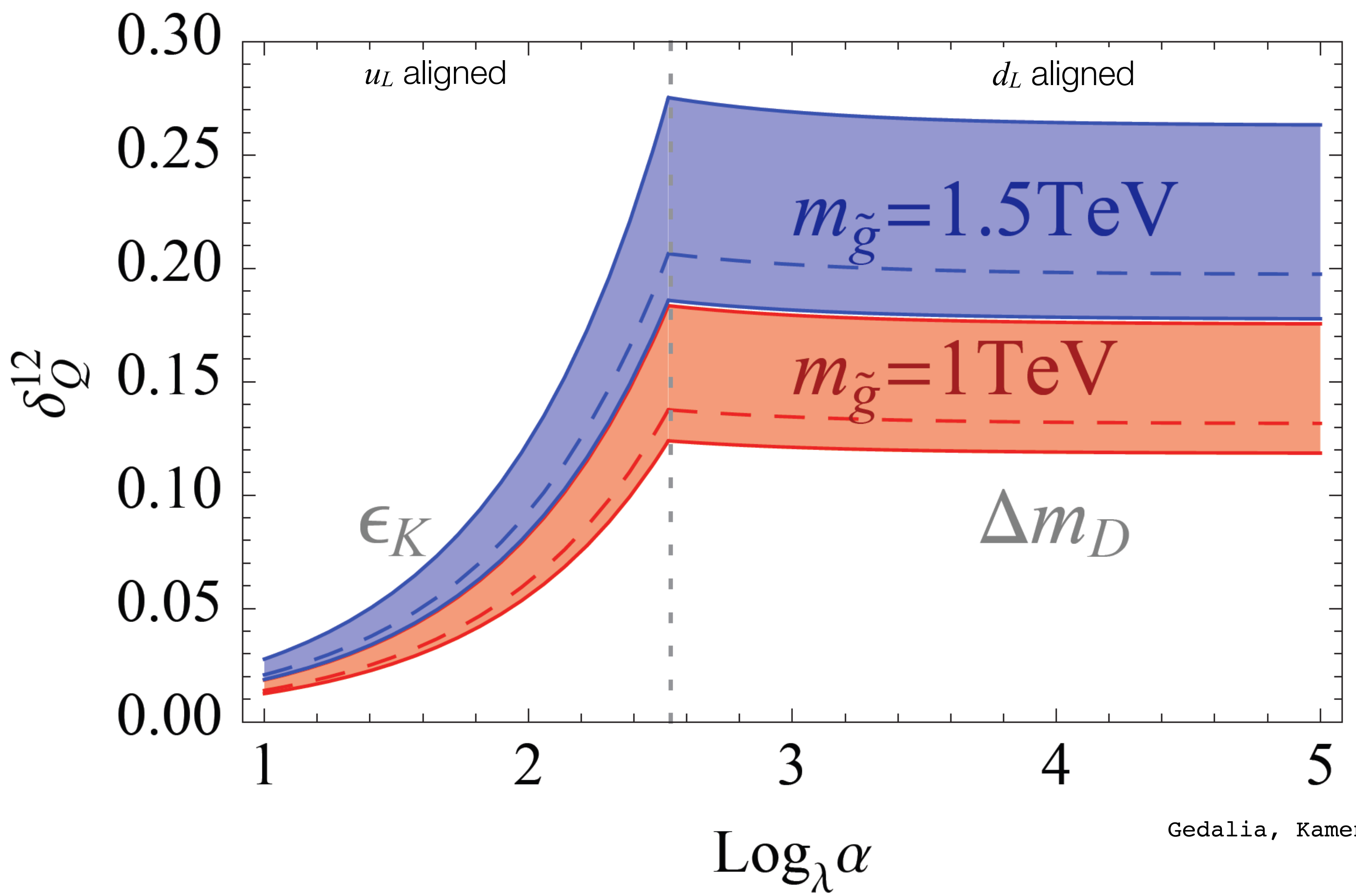
Successful alignment models guarantee small physical CP phase!



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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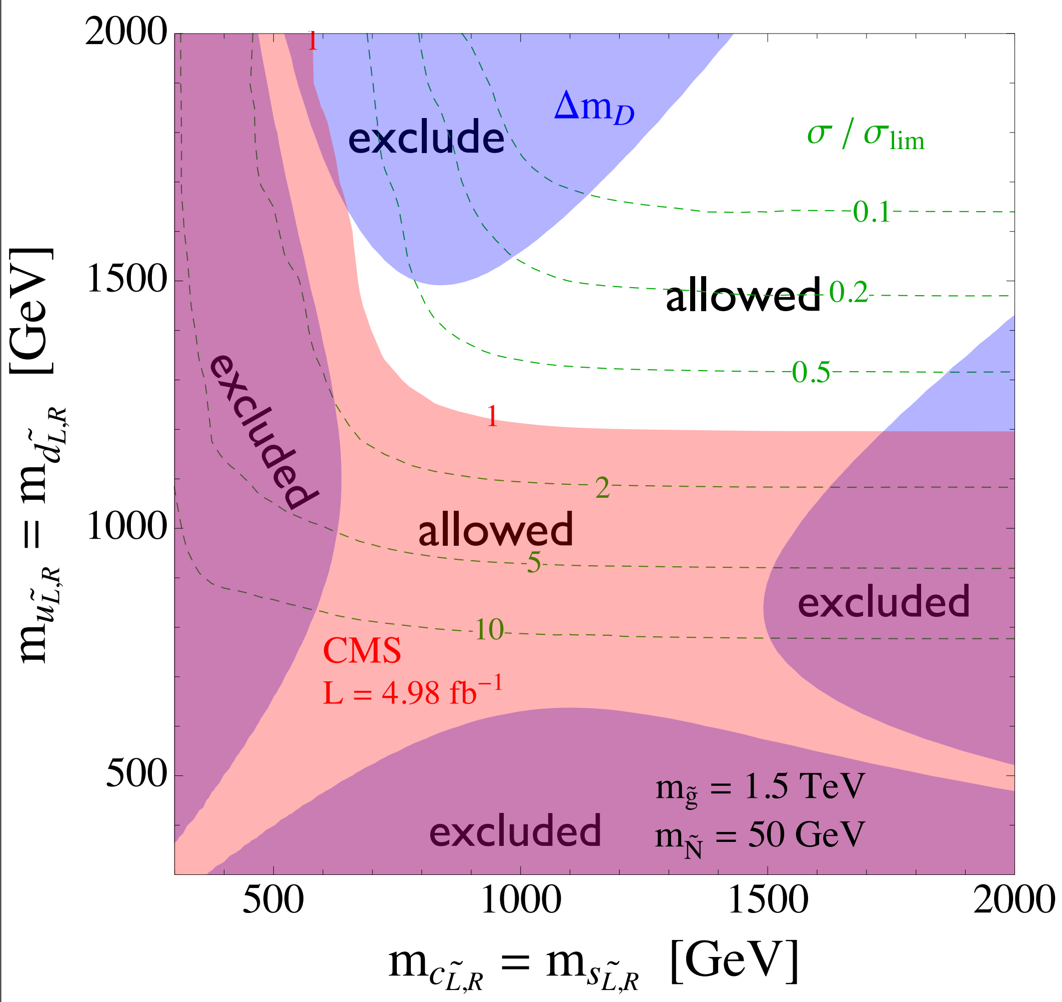
Sea LH squarks vs. valence RH squarks

Adding flavor constraints (Δm_D) for LH squarks:

Kadosh, Paride & GP, to appear;



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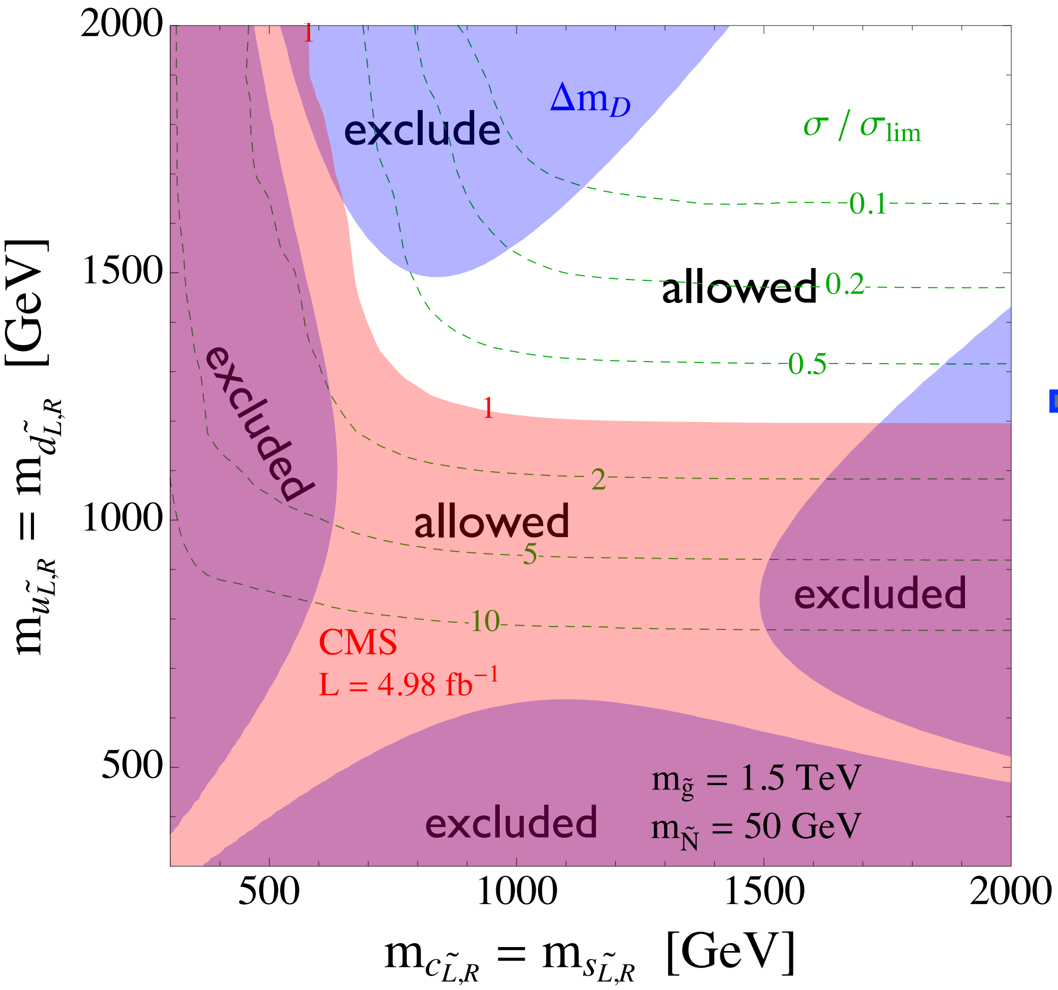

alignment: new upper bound on CP violation (CPV) in *D-phys*.:

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

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

LHCb soon start testing alignment paradigm!

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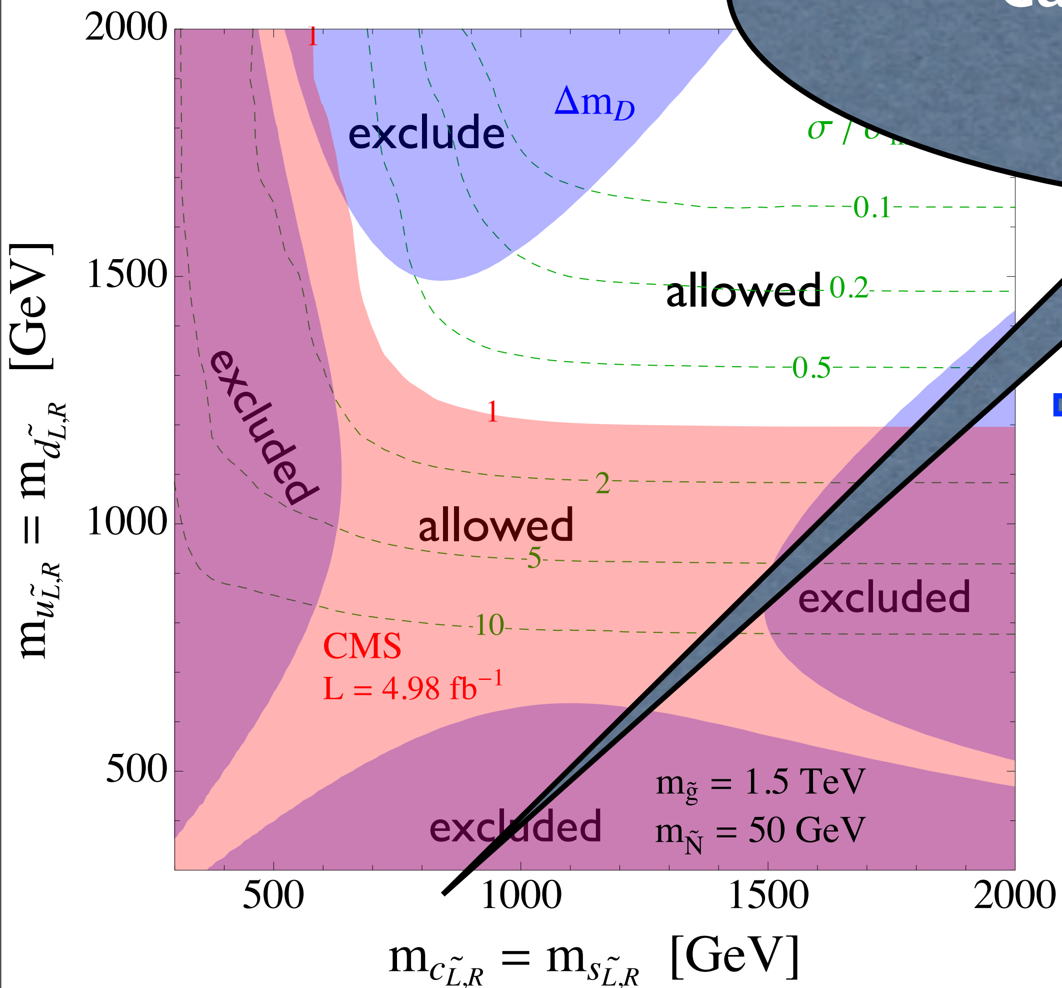

ATLAS & CMS
can improve sensitivity
via charm tagging !

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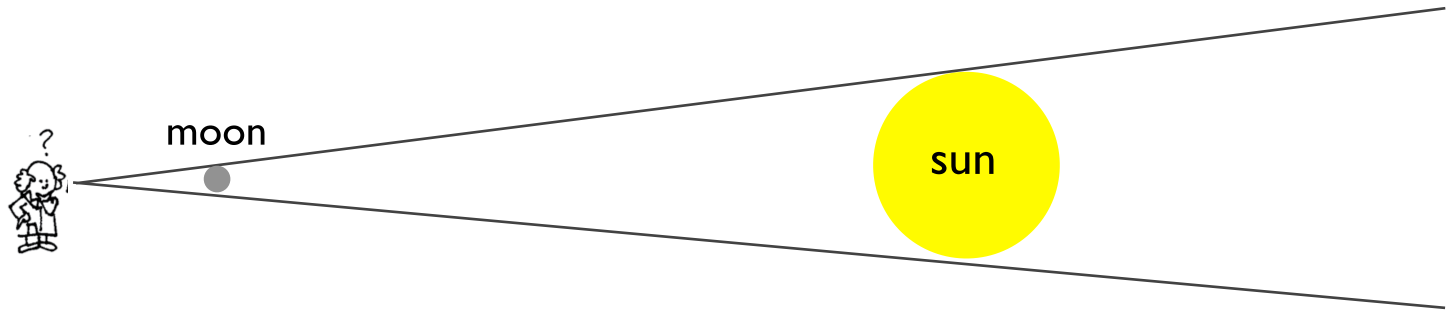

So far: case #1 (scharm->charm searches) for interesting, high p_T, heavy flavor phys., not directly linked to naturalness.

Next: a slide per two other cases, potentially linked to naturalness:

(i) impact of squark flavor violation on stop searches; Delaunay, Grojean & GP, to appear.

(ii) impact of composite (light) fermions on Higgs; Blanke, Giudice, Paride, GP & Zupan, to appear.

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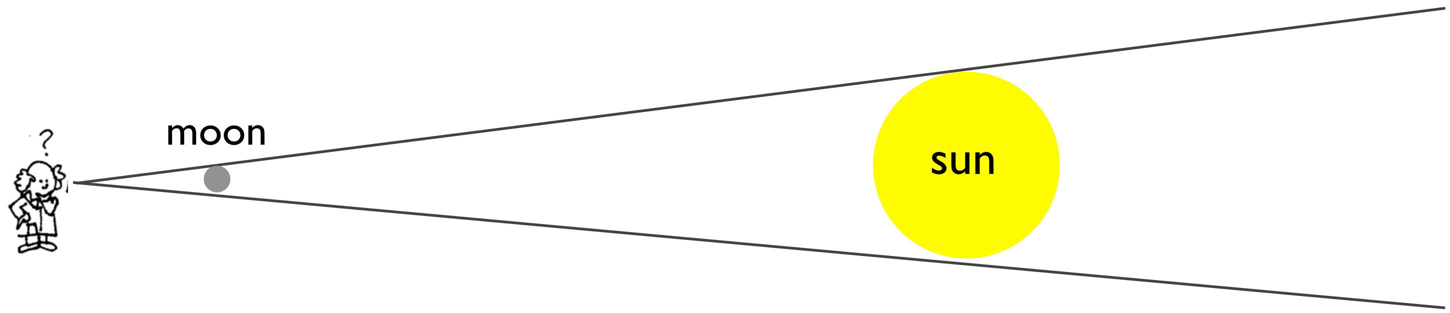

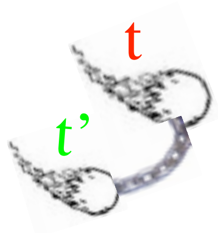

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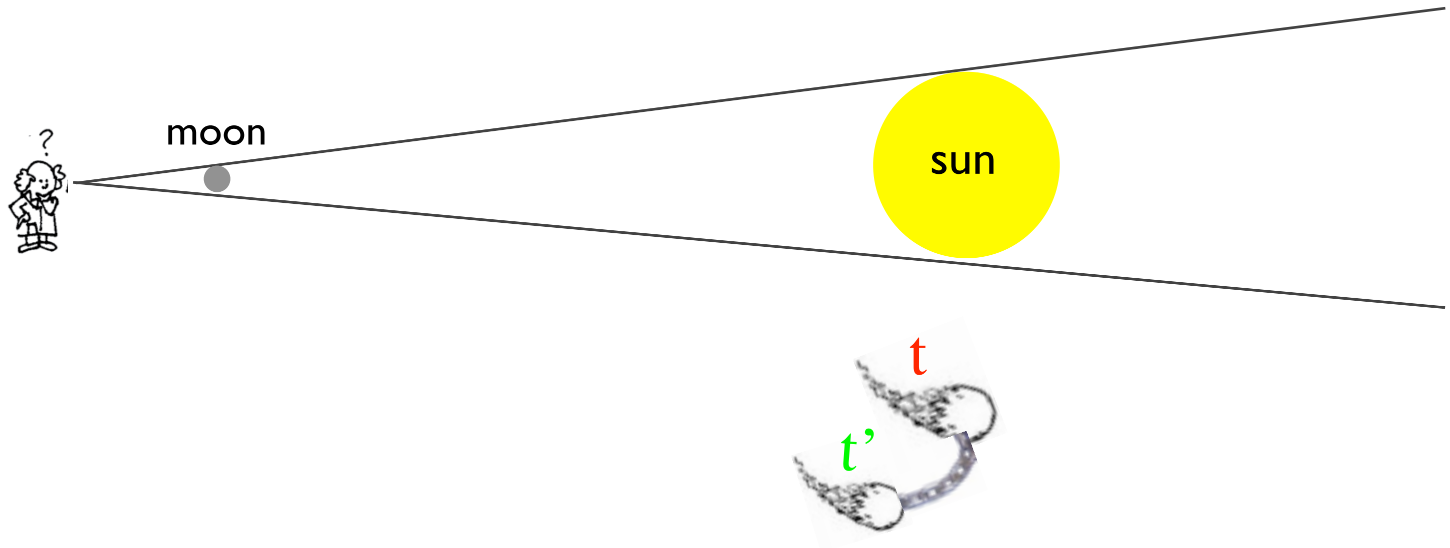

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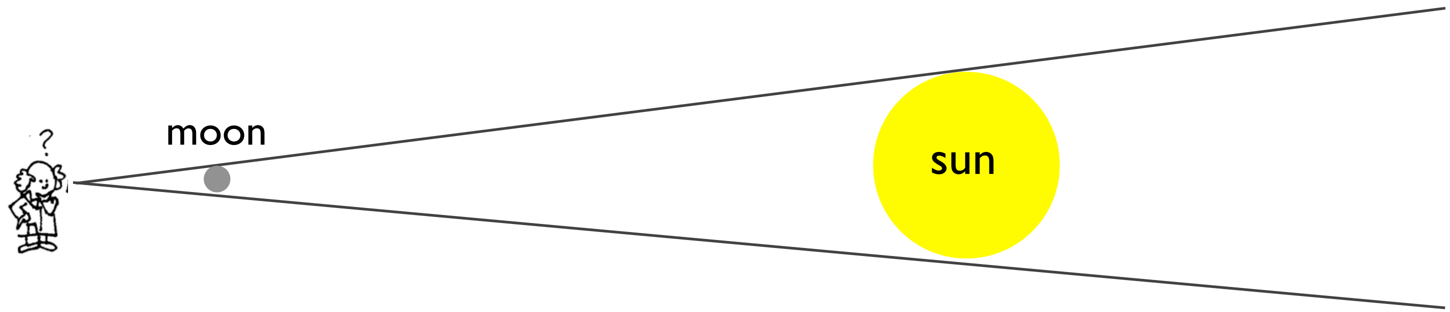

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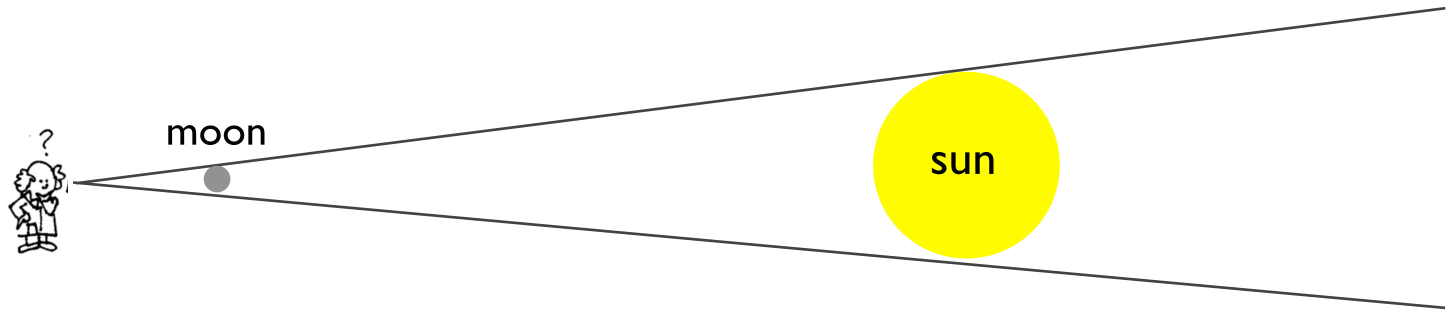

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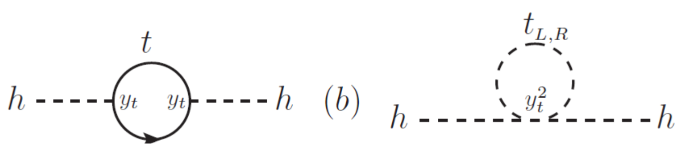
What is the impact of adding flavor violation on stop searches ? (flavored naturalness)

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 ...



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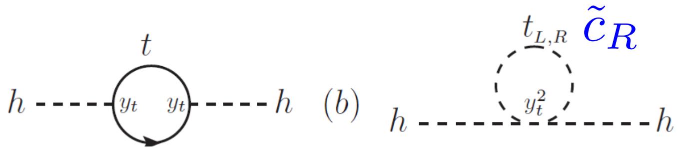

$$\delta m^2_{Hu} = -\frac{3y_t^2}{8\pi^2}\left(m^2_{Q3} + (\mathcal{M}_u^2)_{33}\cos^2\theta^R_{23} + (\mathcal{M}_u^2)_{22}\sin^2\theta^R_{23}\right)\log\frac{\Lambda}{m_{\tilde{t}}}\,.$$

- However, just established the scharm can be light.
- The "$\tilde{t}_R\,\tilde{t}_R^*$" $\rightarrow t_R\,t_R^*$ production is suppressed by $\left(\cos\theta^R_{23}\right)^4$.

Potentially leading to improve naturalness.

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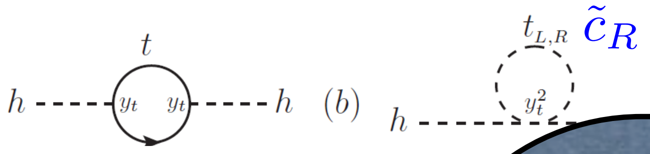


$$\ldots \sin^2\theta_{23}^R) \log \frac{\Lambda}{m_{\tilde{t}}} .$$

- However, ju…

- The "$\tilde{t}_R \tilde{t}^*_R$" … $\cos\theta_{23}^R)^4$.

Case # 2:
motivates search for RH light scharms
& mixed stop-scharm production
to constrain flavor naturalness

Potentially leading to improve naturalness.

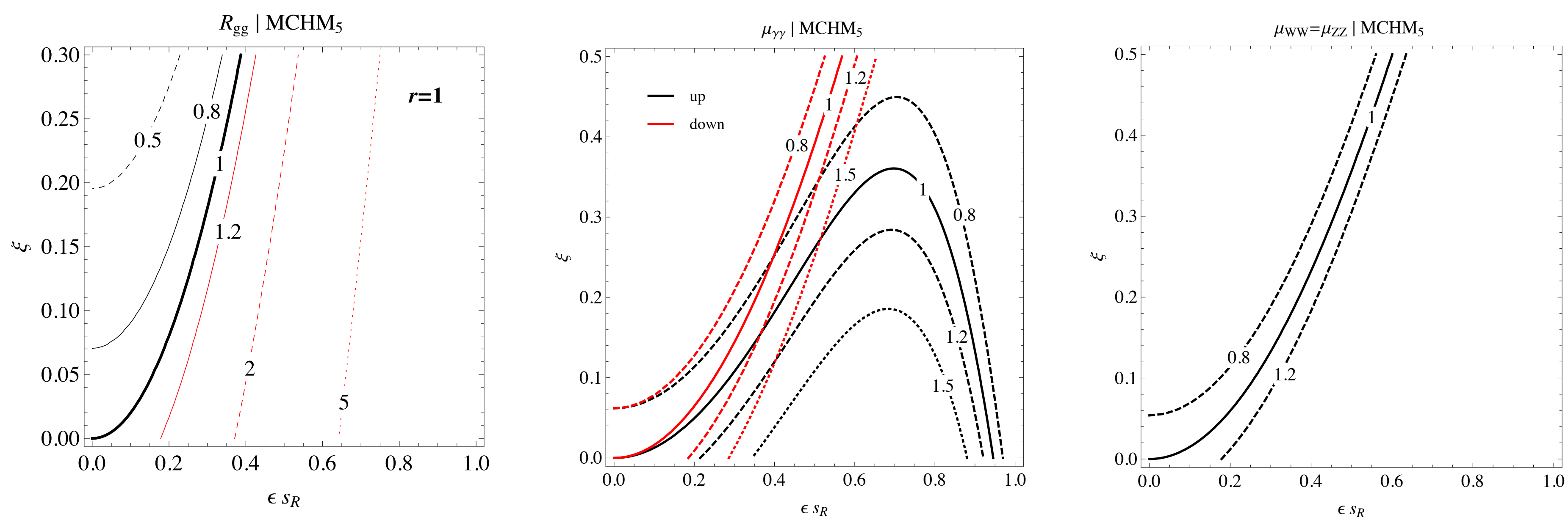
Composite light quarks & pseudo Goldstone boson Higgs

♦ 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:

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



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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…

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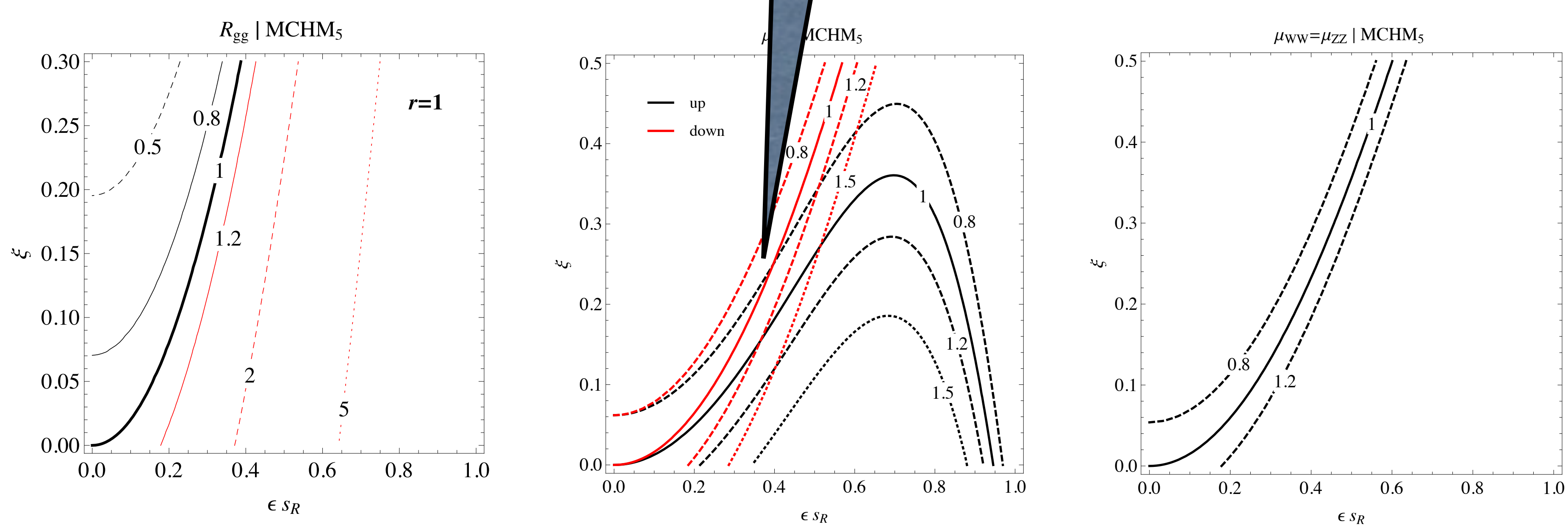
Case # 3:
right handed composite quarks
=>
excess of heavy flavor jets



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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.

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

- 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..