What We Learn from Top Quark Physics ?

Gilad Perez

CERN & Weizmann Inst.

CKM 2012

7th Workshop on ~~CKM~~ aspects of flavor physics

Outline & Rationale*

◆ Why is the top quark interesting, why in flavor conference?

Just because:

(i) Perturbative, we can calculate;
(ii) Special, we can measure stuff.

mass & Xsection, forward backward asym' (AFB)

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* Hundreds of papers, just give brief subjective impression.

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Theoretical importance:

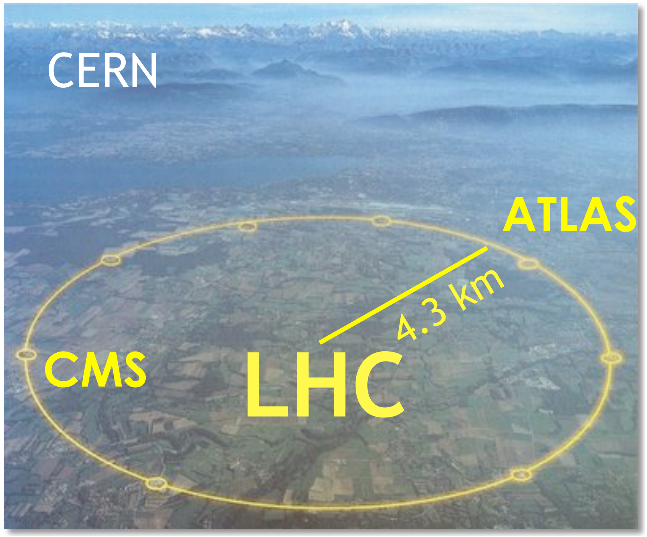
(i) Affect electroweak physics
& electroweak sym' breaking;
(ii) Yields the most severe fine tuning problem;
(iii) Dominates flavor & CP violation (CPV)+(ii)
expect *new* top contributions to flavor & CPV.

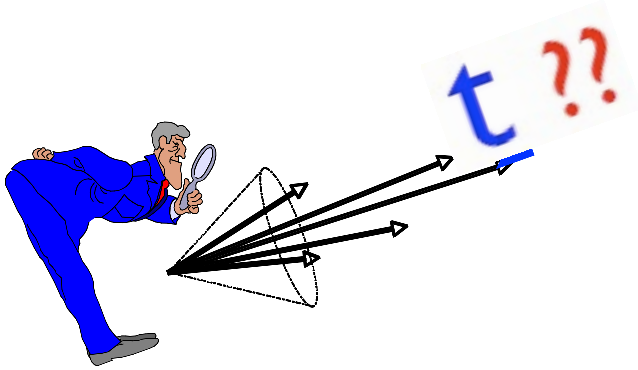
stability,
top partners &
resonances,
up flavor,
alignment &
burried squarks,
flavoverse

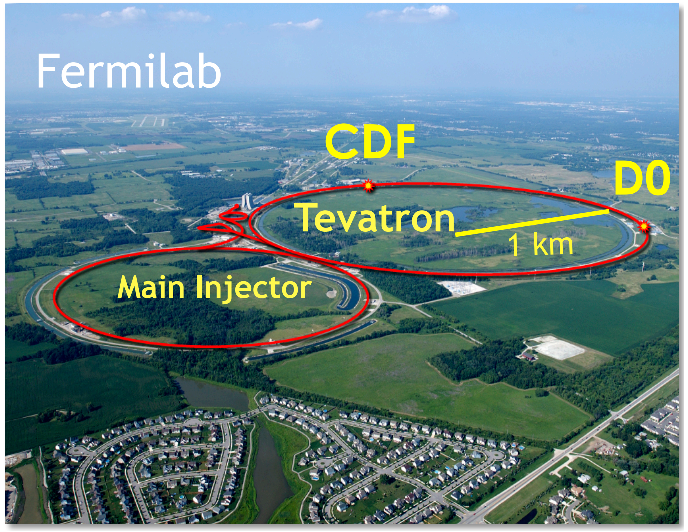
◆ Conclusions.

* Hundreds of papers, just give brief subjective impression.

Just because, interesting calculations & measurements







Top mass/Yukawa & production Xsection

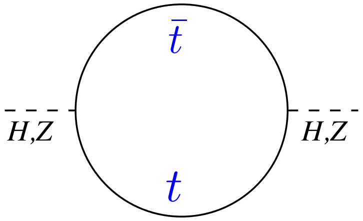
Will be discussed in detail, WG VI.

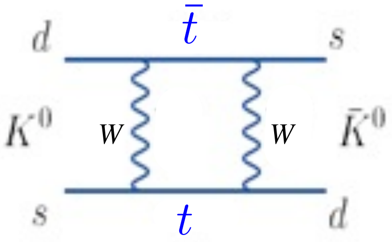
◆ Tevatron: top mass now known to 0.5%, m_t = 173.2 ± 0.9 GeV

Tevatron combination (11).

Standard Model (SM): top coupling to Higgs is perturbative but LARGE: $y_t \simeq 1$

Quantum effects (virtual tops) => dramatic impact on EW & flavor phys.: $\frac{2N_c\, {y_t}^2}{16\pi^2} \simeq 5\%$





◆ Theory: t-Xsection (Tevatron) now known to NNLO (+NNLL resum')

Bärnreuther, Czakon & Mitov (12).

$$\sigma_{\rm tot}^{\rm res} = 7.067 \; {}^{+0.143\,(2.0\%)}_{-0.232\,(3.3\%)} \;[\text{scales}]\; {}^{+0.186\,(2.6\%)}_{-0.122\,(1.7\%)} \;[\text{pdf}]$$

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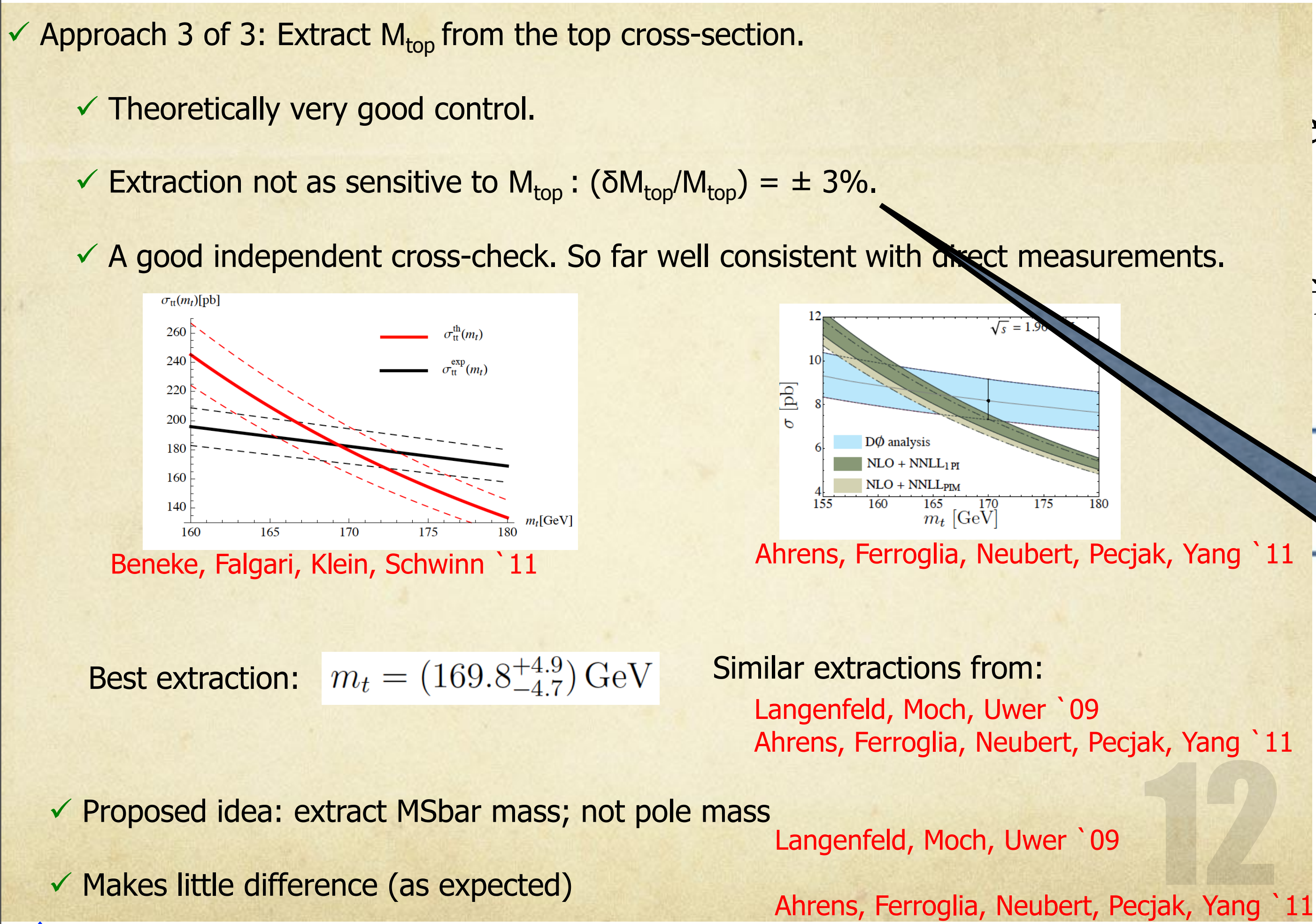

✓ Approach 3 of 3: Extract M_{top} from the top cross-section.

- ✓ Theoretically very good control.
- ✓ Extraction not as sensitive to M_{top} : $(\delta M_{top}/M_{top}) = \pm 3\%$.
- ✓ A good independent cross-check. So far well consistent with direct measurements.

Beneke, Falgari, Klein, Schwinn `11

Ahrens, Ferroglia, Neubert, Pecjak, Yang `11

Best extraction: $m_t = (169.8^{+4.9}_{-4.7})\,\mathrm{GeV}$

Similar extractions from:
Langenfeld, Moch, Uwer `09
Ahrens, Ferroglia, Neubert, Pecjak, Yang `11

✓ Proposed idea: extract MSbar mass; not pole mass

Langenfeld, Moch, Uwer `09

✓ Makes little difference (as expected)

Ahrens, Ferroglia, Neubert, Pecjak, Yang `11

: but LARGE: $y_t \simeq 1$

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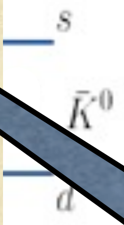

Xsec', consistent, less sensitve to m_t.
(Mitov, PLHC12)

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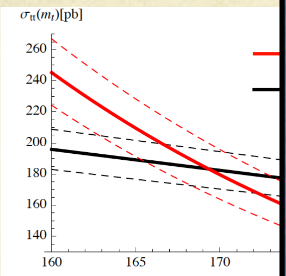

Beneke, Falgari, Klein, Sc

Best extraction: $m_t =$

✓ Proposed idea: extract M

✓ Makes little difference (as expected)

Ahrens, Ferroglia, Neubert, Pecjak, Yang `11

LARGE: $y_t \simeq 1$

phys.: $\frac{2N_c\, y_t{}^2}{16\pi^2} \simeq 5\%$

But possibly one step from shedding light on a Tevatron anomaly!

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(Mitov, PLHC12)

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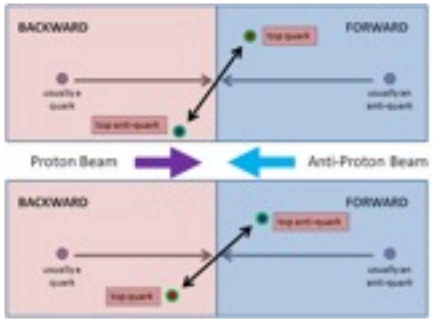
Tevatron's $t\bar{t}$ forward backward asymmetry.

2 kind of anomalous asymmetries (**6** measurements):

(i) Top forward backward asymmetry (*AFB*).

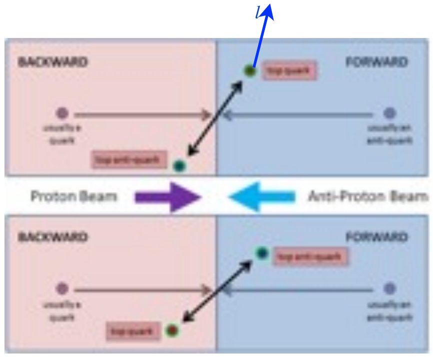


- Combined CDF+DO results: $A_{FB}^{\text{inclusive}} \approx (18\pm4)\%$ *in ttbar rest frame*

  post-Moriond 2012 $A_{FB}^{>450\text{GeV}} \approx (28\pm6)\%$

QCD+EW state of the art: $A_{FB}^{[\text{inclusive}|>450\text{GeV}]} \approx [6.6|10]\% \pm ??$ (NLOx30%?)

Delaunay, Top physics workshop, CERN 12; Amidei, Top12, Winchester.

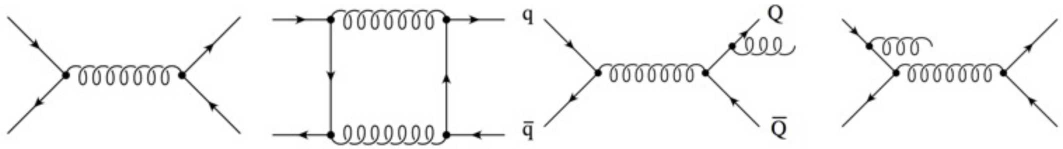


(ii) Lepton asymmetry (A_l).

CDF with 8.7 fb^{-1}	**D0** with 5.4 fb^{-1}	**SM**
$A_\ell = 6.6 \pm 2.5\%$	$A_\ell = (11.8 \pm 3.2)\%$	$A_\ell \simeq 4\%$

AFB & A_l within the SM

◆ Contribution to AFB start at NLO QCD, i.e. ~$(\alpha_S)^3$. Kuhn & Rodrigo (98)



Higher order soft effects probed. No essential new effects (beyond Kuhn & Rodrigo). Awaiting for real EW calculation & most importantly the NNLO answer!

Kuhn, Moch, Penin & Smirnov (01); Almeida, Sterman, Wogelsang (08);Melnikov, Schultze (09); Ahrens, Ferroglia, Neubert, Pecjak, Yang; Kuhn & Rodrigo; Hollik, Pagani (11); Manohar, Trott; Skands, Webber, Winter (12).

QCD+EW state of the art: $A_{FB}^{[\text{inclusive}|>450\text{GeV}]} \approx [6.6|10]\%$ ±?? (NLOx30%?)

◆ Contribution to A_l , now known to full NLO. Bernreuther & Si(10,12); Campbell & Ellis (12).

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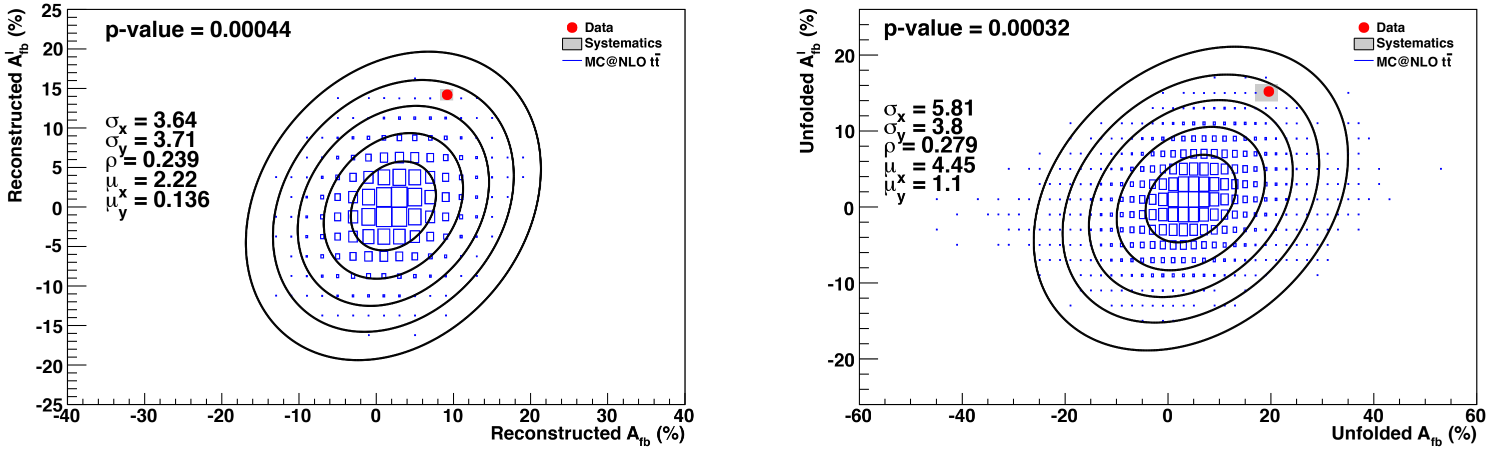
◆ Contribution to *AFB* start at NLO QCD, i.e. ~(α_S)^3. `Kuhn & Rodrigo (98)`

A_l vs. *AFB* “uncorrelation” plots (D0, CERN Top Phys. workshop, 12)



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odrigo).

`Schultze (09);`

`;`

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◆ Co

`Si(10,12);`

`is (12).`

- 100,000 pseudo experiments made from signal and background simulation
- Results from actual experiment shown in red
- Left: Detector level results; Right: Unfolded results

- $A_\ell = 6.6 \pm 2.5\%$
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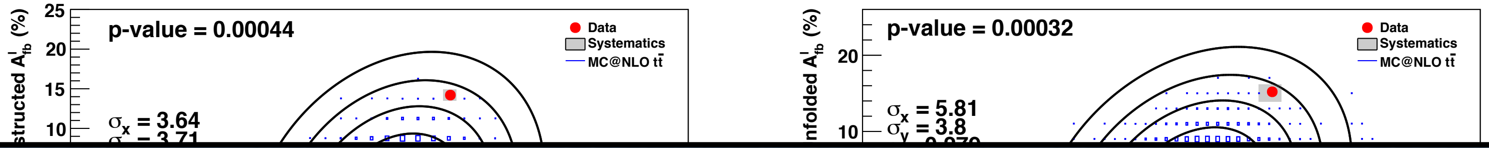

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odrigo).

Bottom line: among few serious anomalies, perturbative nature, should able to get sharp predictions within SM!

;

◆ Co

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- Results from actual experiment shown in red
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Si(10,12);
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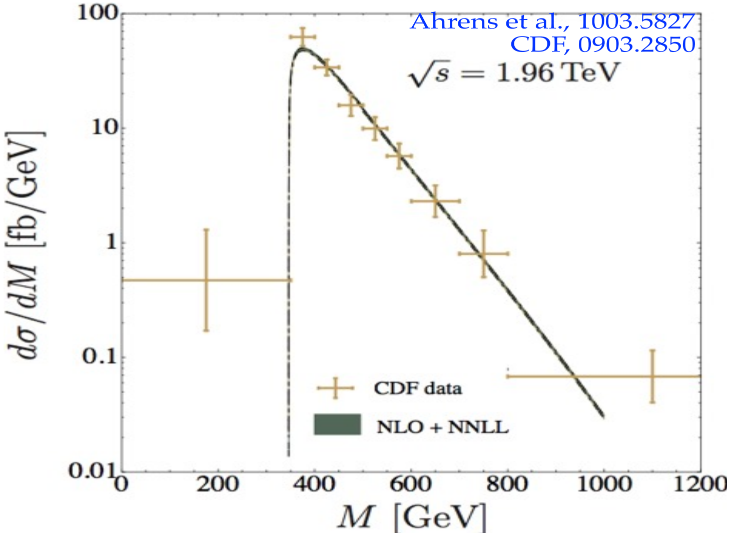
- $A_\ell = (11.8 \pm 3.2)\%$
- $A_\ell \simeq 4\%$

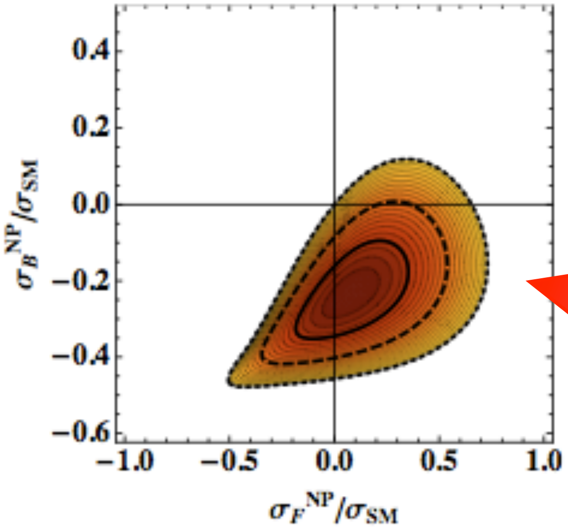
Some features of new physics (NP) interpretations*

- Top asymmetry is special, not only top sector is probed:

Large asymmetry (PDFs) => new dynamics couple to both $u\bar{u}$ & $t\bar{t}$.
(furthermore the lepton asymmetry need not be related to top physics) Falkowski, GP & Schmaltz (11)

- Challenged by agreement \w SM Xsec' => SM-NP interference.





Grinstein, Kagan, Trott, Zupan (11)

negative Xsec' favors,
new physics interference.

- Two broad classes of models: *(i)* hard physics; *(ii)* on shell physics.

* Hundreds of papers, just give brief subjective impression.

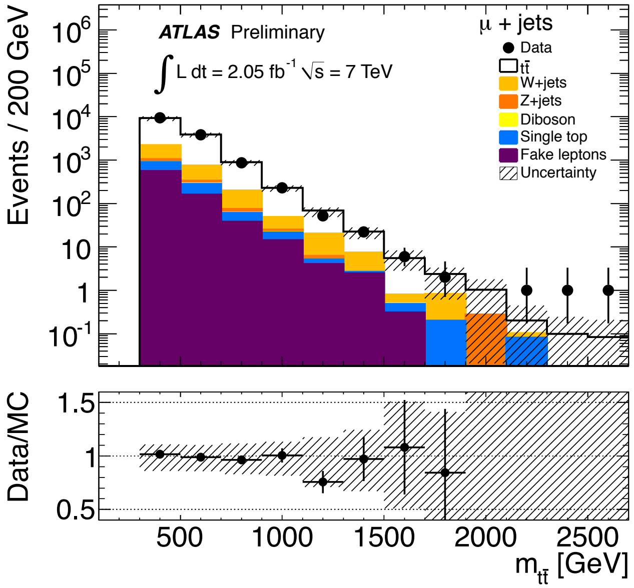
Relevant observables (constraints) @ the LHC

- Charged asymm' A_c, large errors, consistent \w SM, $A_C = \frac{N(\Delta|y|>0) - N(\Delta|y|<0)}{N(\Delta|y|>0) + N(\Delta|y|<0)}$

ATLAS	CMS
A_C(l+jets) = -0.018 ± 0.028 ± 0.023	A_C(l+jets) = 0.004 ± 0.010 ± 0.012
A_C(dilept.) = 0.057 ± 0.024 ± 0.015	
A_C(comb.) = 0.029 ± 0.018 ± 0.014	MC@NLO: 0.0115 ± 0.0006
MC@NLO: 0.006 ± 0.002	

- $t\bar{t}$ spectrum finally approaching the 2TeV barrier, both differential

& cumulative distributions consistent \w SM (more below):

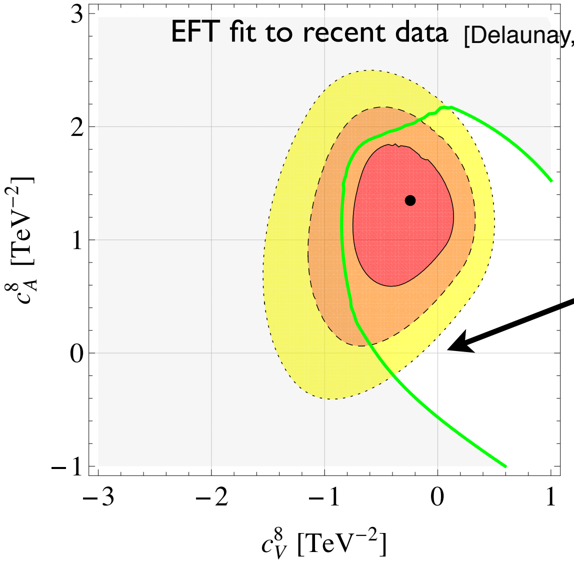


$$\mathcal{S} = \frac{\int_{m_{t\bar{t}}>1\,\mathrm{TeV}/c^2} \frac{d\sigma_{SM+NP}}{dm_{t\bar{t}}} dm_{t\bar{t}}}{\int_{m_{t\bar{t}}>1\,\mathrm{TeV}/c^2} \frac{d\sigma_{SM}}{dm_{t\bar{t}}} dm_{t\bar{t}}}$$ **< 2.6 at 95% CL**

CMS:1204.2488.

Hard physics explanation (*e.g.*: heavy axigluon-KKgluon variety)

- A rough idea is obtained from effective field theory (EFT) analysis:



EFT fit to recent data [Delaunay, Gedalia, Hochberg & Soreq (12)]

no interference.

shaded area left of green curve excluded by CMS cumulative bound for $M_{t\bar{t}} > 1$ TeV.

`Chivukula, et al.; Degrande, et al.; Cao, et al. (10);`
`Delaunay, et al.; Aguilar-Saavedra, et al.; Westhoff (11).`

$$\mathcal{L}_{\rm eff} = \sum_i \frac{C_i}{\Lambda^2}\mathcal{O}_i \equiv \sum_i c_i \mathcal{O}_i\,, \; \mathcal{O}_A^8 = (\bar{u}\gamma_\mu\gamma^5 T^a u)(\bar{t}\gamma^\mu\gamma^5 T^a t)\,, \quad \mathcal{O}_V^8 = (\bar{u}\gamma_\mu T^a u)(\bar{t}\gamma^\mu T^a t)\,.$$

Issues: spectrum; dijet; flavor $g_{u\bar{u}} = -g_{t\bar{t}}$.

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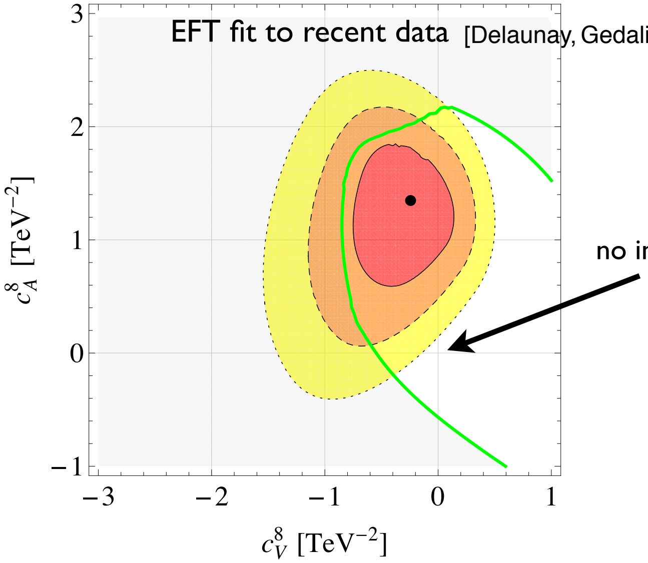

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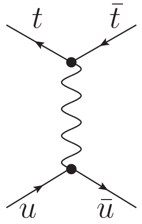
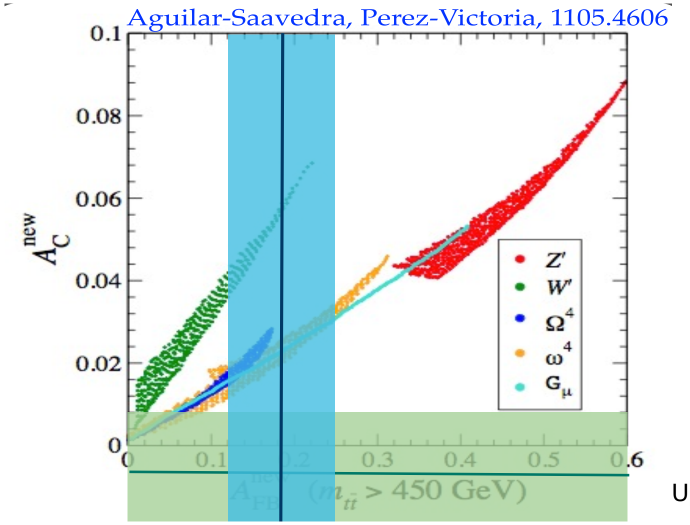
Westhoff, et al.; Bai, et al.; Delaunay, et al. (11)

On shell (*e.g.*: "s-channel", "t-channel" models)

◆

Impossible to cover all models, common exchange light particles.





Aguilar-Saavedra, Perez-Victoria, 1105.4606

Issues: spectrum; dijet; flavor; A_c; $t\bar{t}+j$;
& APV (atomic parity violation).

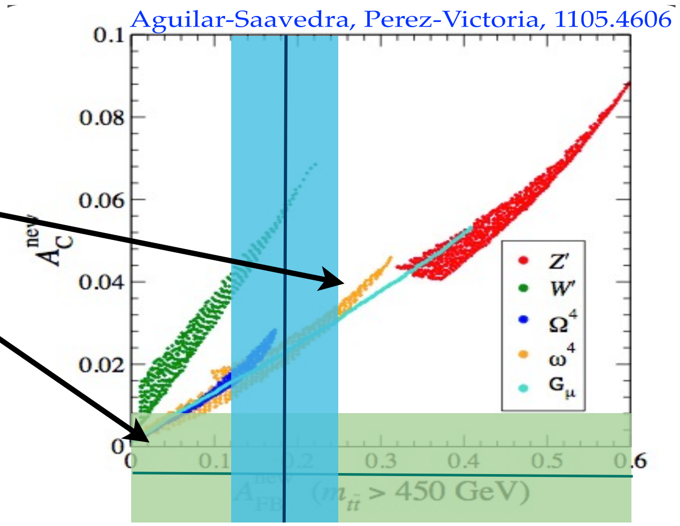
Isidori-Kamenik; Grinstein, et al.; Ligeti, et al.;
Gresham, et al. x 3; Blum, et al. x 2; Tavares-Schmaltz (11)

Update by J. Zupan, CERN, Th. colloquium, 6/12.

Forward Tevatron Tops & Backward LHC Tops

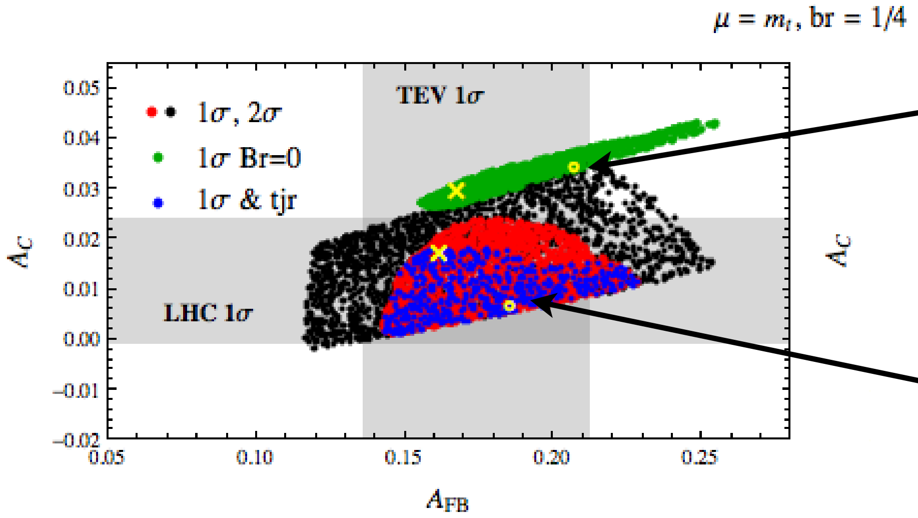
More on WG VI's talks ...

◆ Apparent serious tension with A_C.


Aguilar-Saavedra, Perez-Victoria, 1105.4606

◆ However, A_{FB} & A_C indep' observables, associate production => natural venue for negative A_C.

Aguilar-Saavedra & Juste; Drobnak, Kamenik & Zupan;
Alvarez & Leskow; Drobnak, Kagan, Kamenik, GP, Zupan (12).



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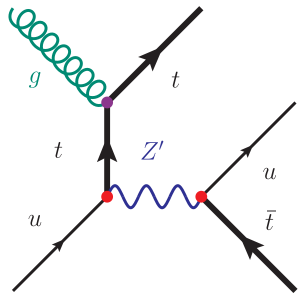
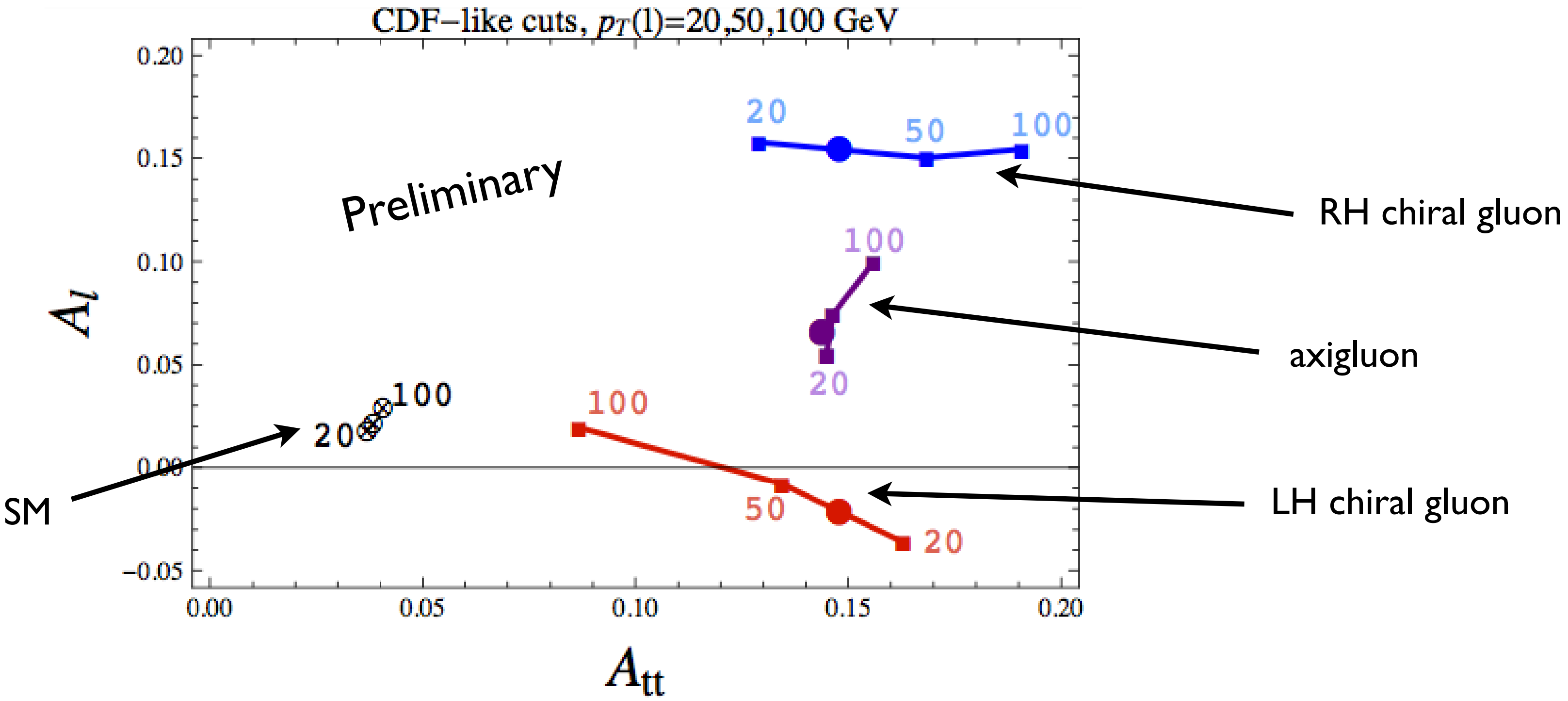


Near future improvement:

- LHC: Progress on A_c & spectrum (more channels, better sys' & stat').
- Tevatron: looking at A_{FB} vs. A_l as a function of the lepton p_T (since are correlated within the SM)

Progress \w: Falkowski, Mangano, Martin, GP & Winter.
See also: Godbole et al. (10) ; Krohn, et al.; Jung, et al.; Cao et al.; Berger, et al. x2 (11);
Fajfer, et al.; Berger, et al.; Aguilar-Saavedra & Herrero-Hahn (12).

"Trade" A_{FB} curve for A_l or look at slope => cleaner extraction:

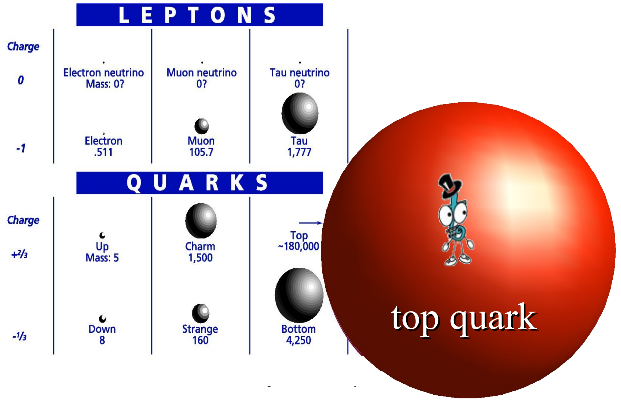


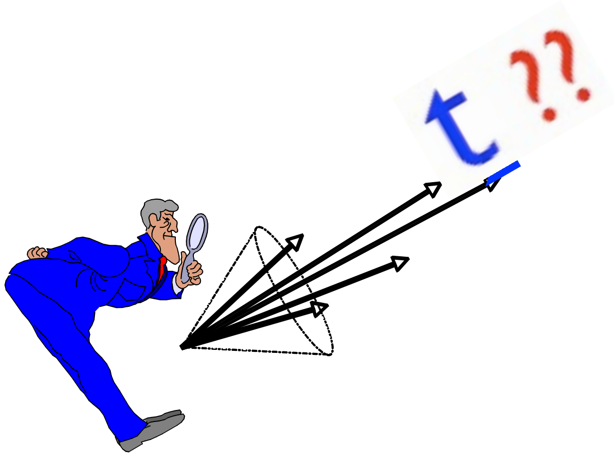
Why is the top quark interesting theoretically?

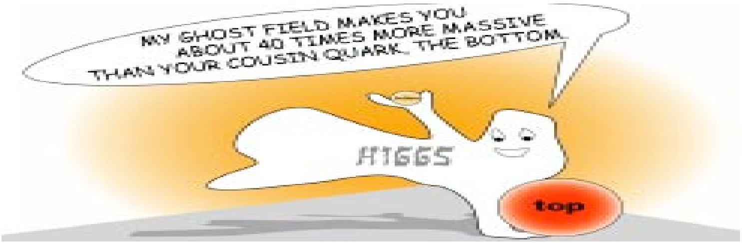
(*i*) Electroweak symmetry breaking.

(*ii*) The fine tuning problem.

(*iii*) The (NP) flavor puzzle & the top.

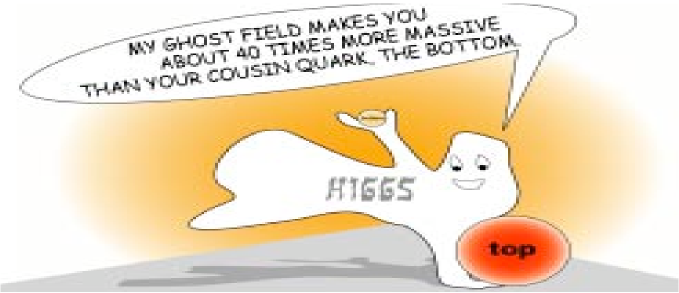




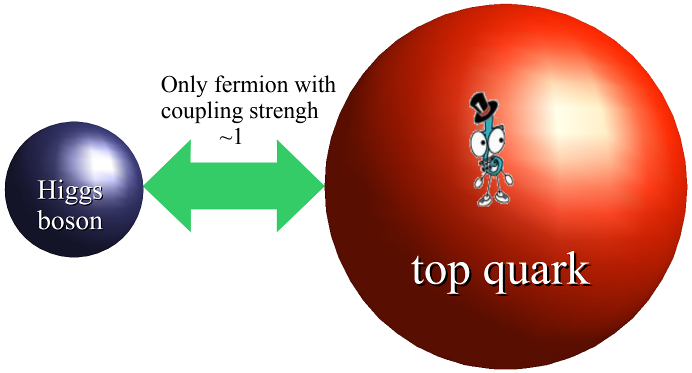


The top & electroweak (EW) breaking

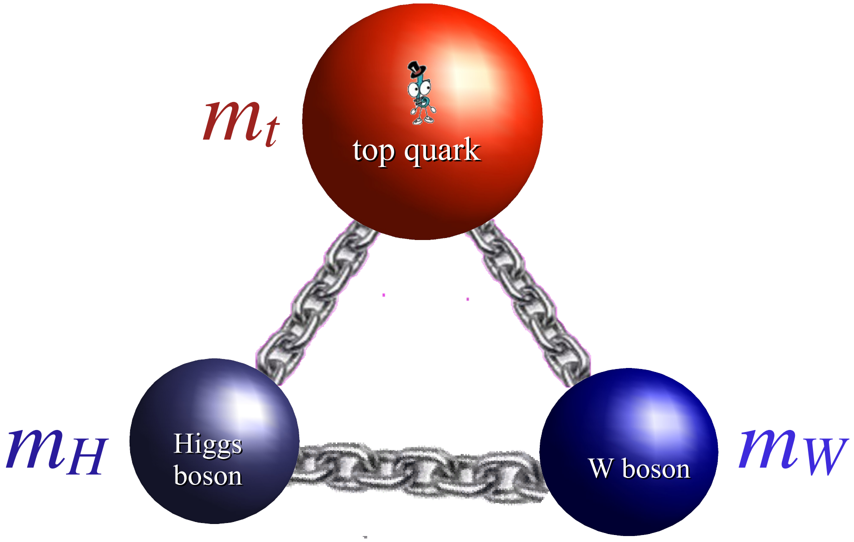
- Coupling to the Higgs => top mass; biggest coupling @ the TeV.



Top quark mass

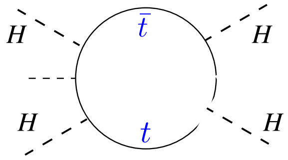


- In most natural models top is linked to EW symmetry breaking.

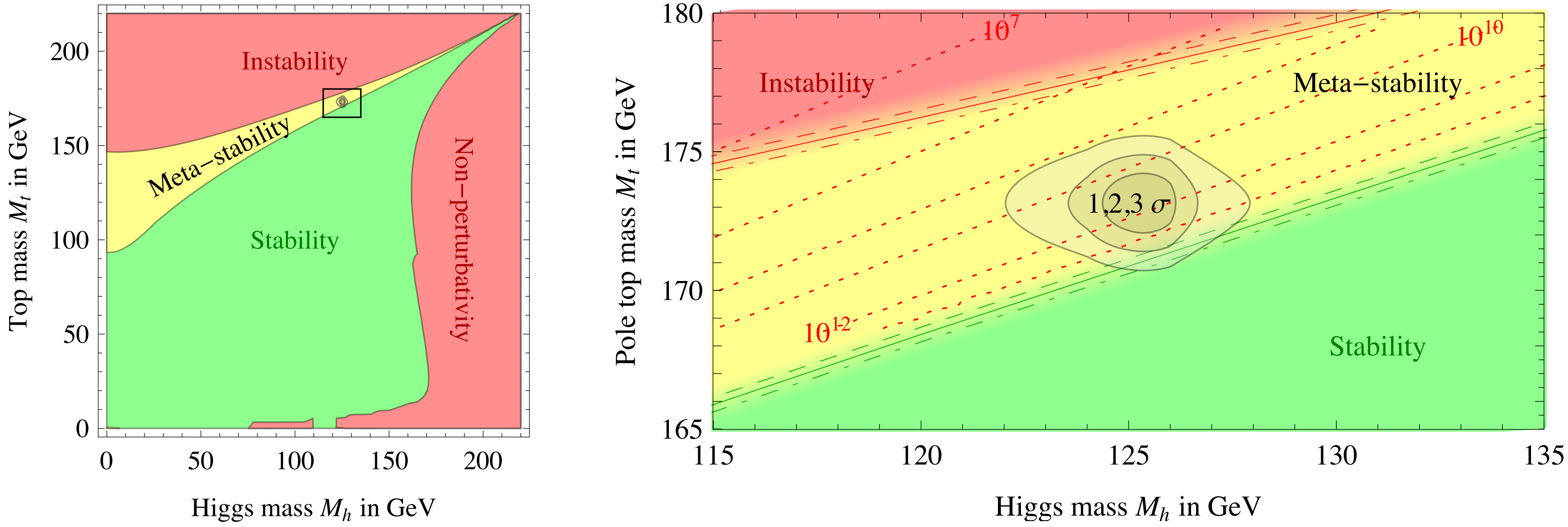


125 GeV Higgs -> top is ~ saturating metastability

$$m_h > 111\,\mathrm{GeV} + 2.8\,\mathrm{GeV}\left(\frac{m_t - 173.2\,\mathrm{GeV}}{0.9\,\mathrm{GeV}}\right) - 0.9\,\mathrm{GeV}\left(\frac{\alpha_s(M_Z) - 0.1184}{0.0007}\right) \pm 3\,\mathrm{GeV}\,.$$



See e.g.: Cabibbo, et al.; Hung (79); Elias-Miro, et al. (11); Degrassi et al.; Alekhin et al.; Bezrukov et al. (12)



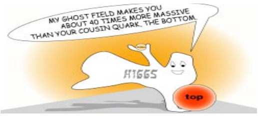
Degrassi, Vita, Elias-Miro, Espinosa, Giudice, Isidori & Strumia (12)

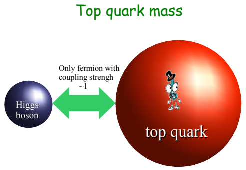
A raise of < 3% in top Yukawa => weakless universe!

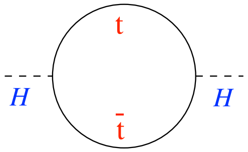
The top & the fine tuning problem

- Higgs mass & EW scale are sensitive to quantum corrections.

- The most severe problem is due to top coupling:



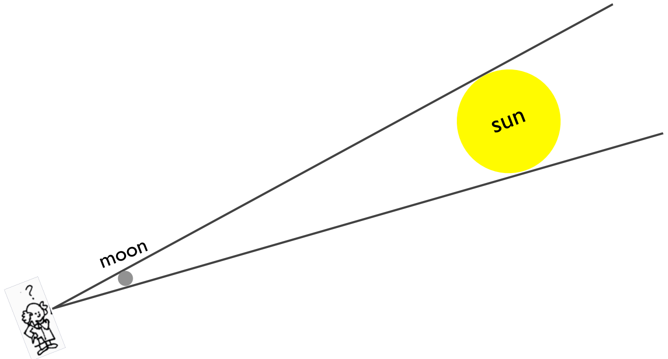




$$\text{Assume cutoff } \Lambda = 6\,\text{TeV};\ \delta_t m_h^2 = \frac{3}{8\pi^2} y_t^2 \Lambda^2 \sim (1.2\text{TeV})^2$$

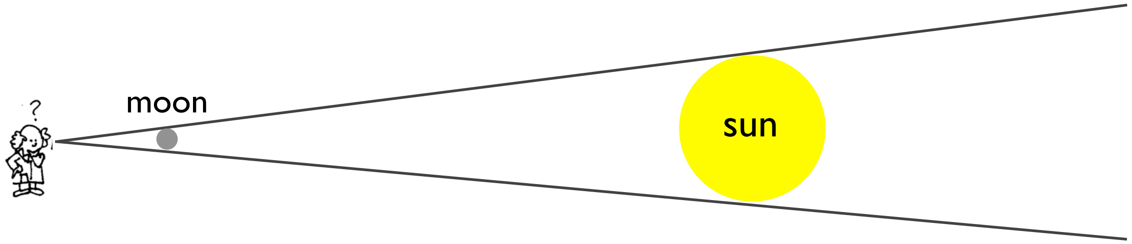
$$m_{h,\text{phys}}^2 = m_{\text{tree}}^2 + \delta_t m_h^2 = m_{\text{tree}}^2 + (1.2\text{TeV})^2 \approx (0.125\text{TeV})^2$$

fine tuning of ~ 1:100 !



Dominant paradigm to solve fine tuning problem

- Extending top sector adding top partners states that due to sym' contribute to Higgs mass in opposite way => reduce sensitivity.



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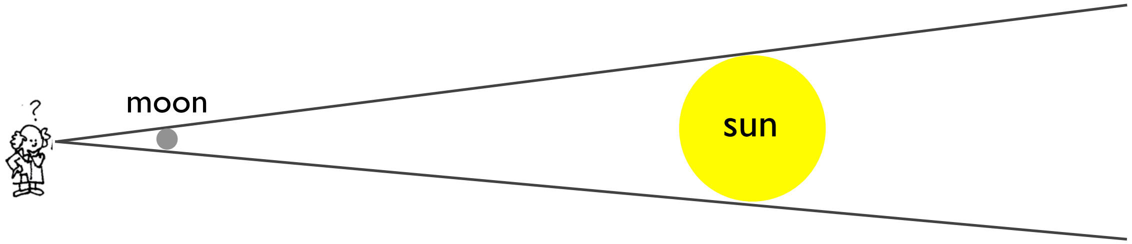

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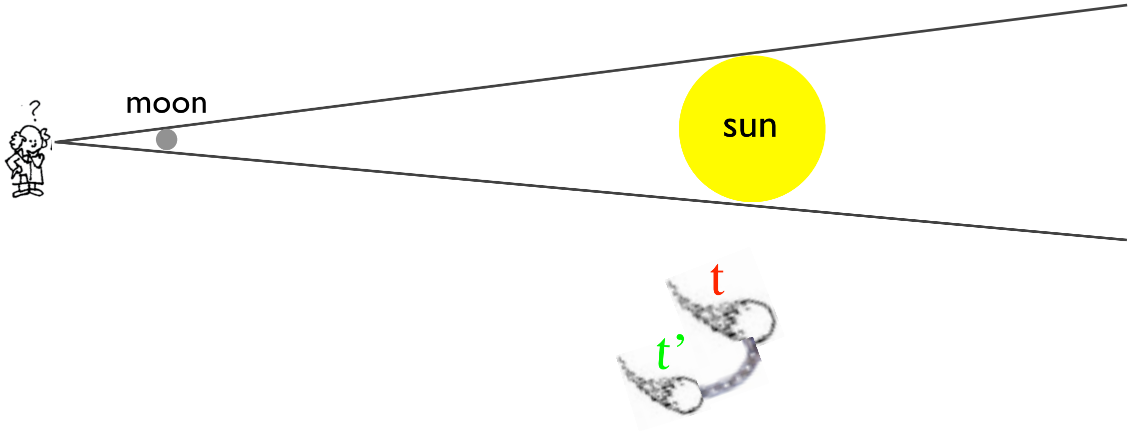

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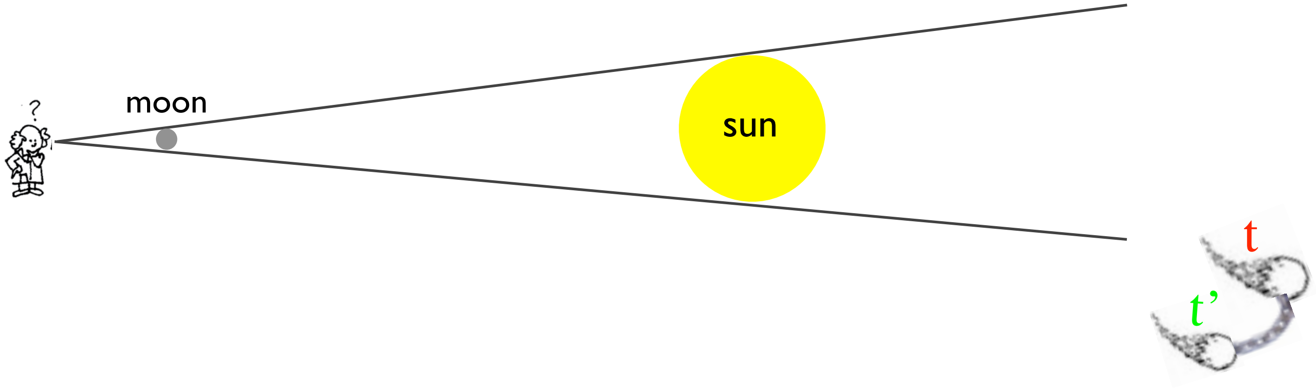

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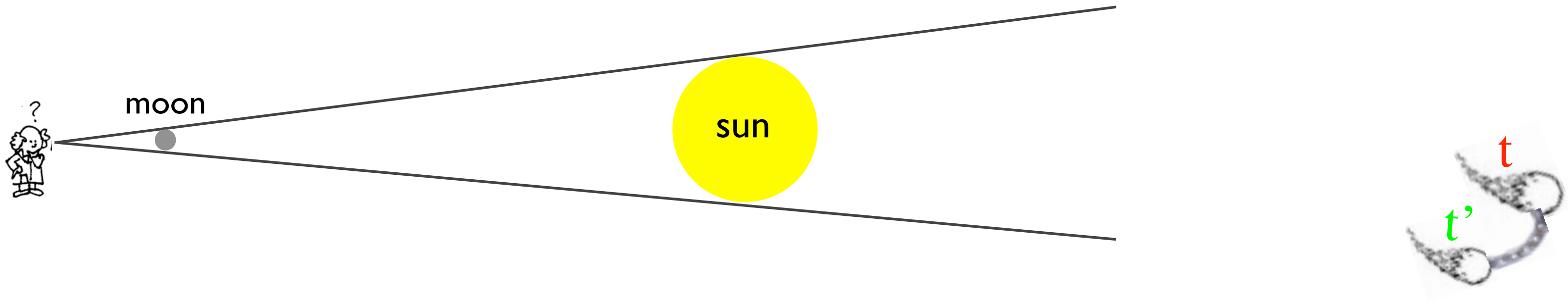

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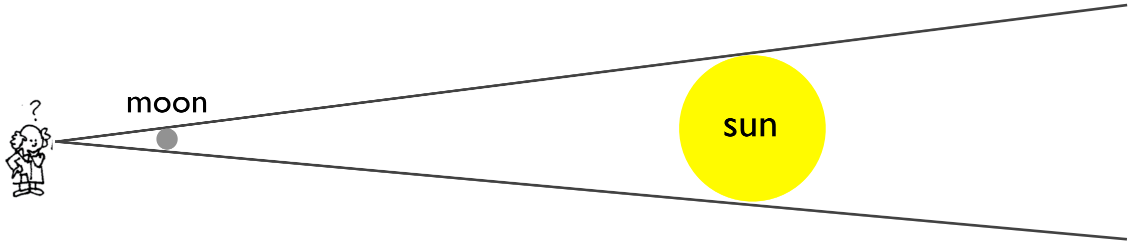
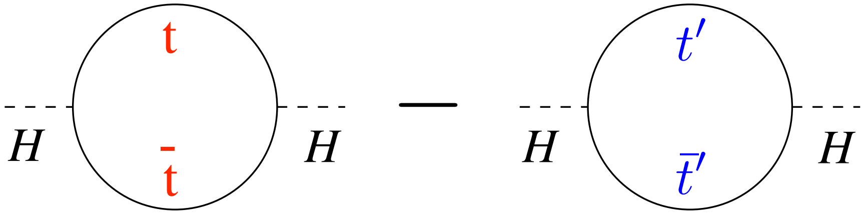


$$\left(m_W^2/m_{\rm Pl}^2\right)_{\rm obs} \sim \left(m_H^2+\delta m_H^2\right)/m_{\rm Pl}^2 \sim m_W^2 +$$



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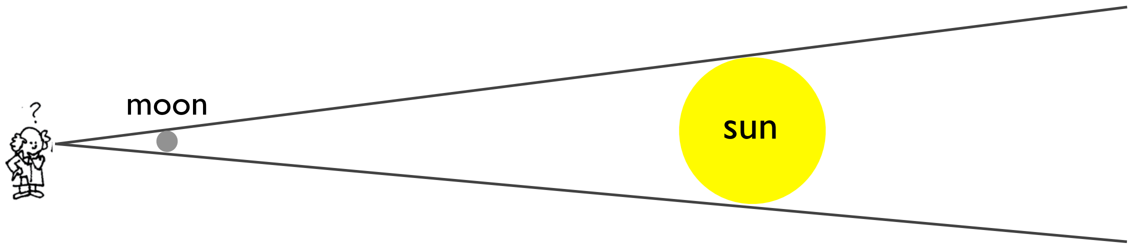

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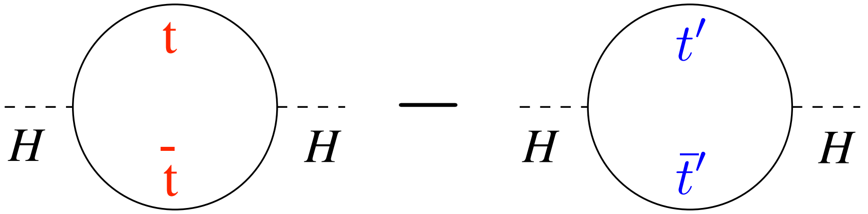
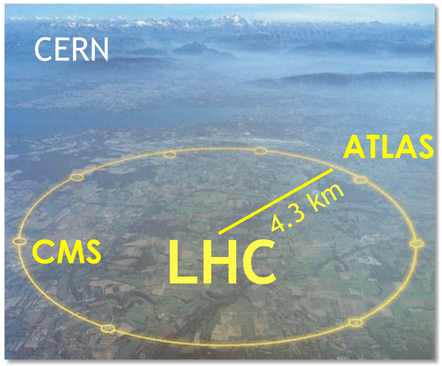
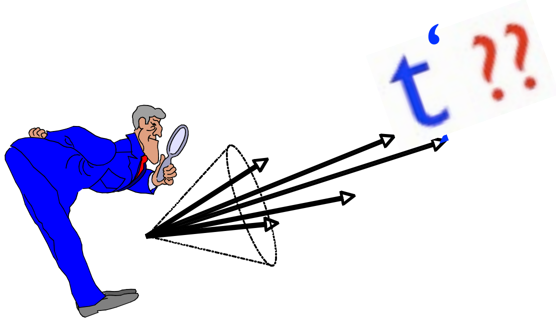


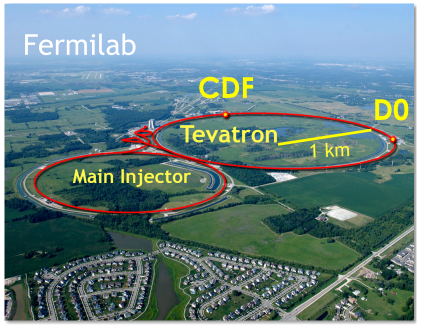
Top physics expected to yield insight on how the fine tuning problem is solved.

So where are those top partners?

The LHC battle for naturalness







More in Papucci & Weiler's talks ...

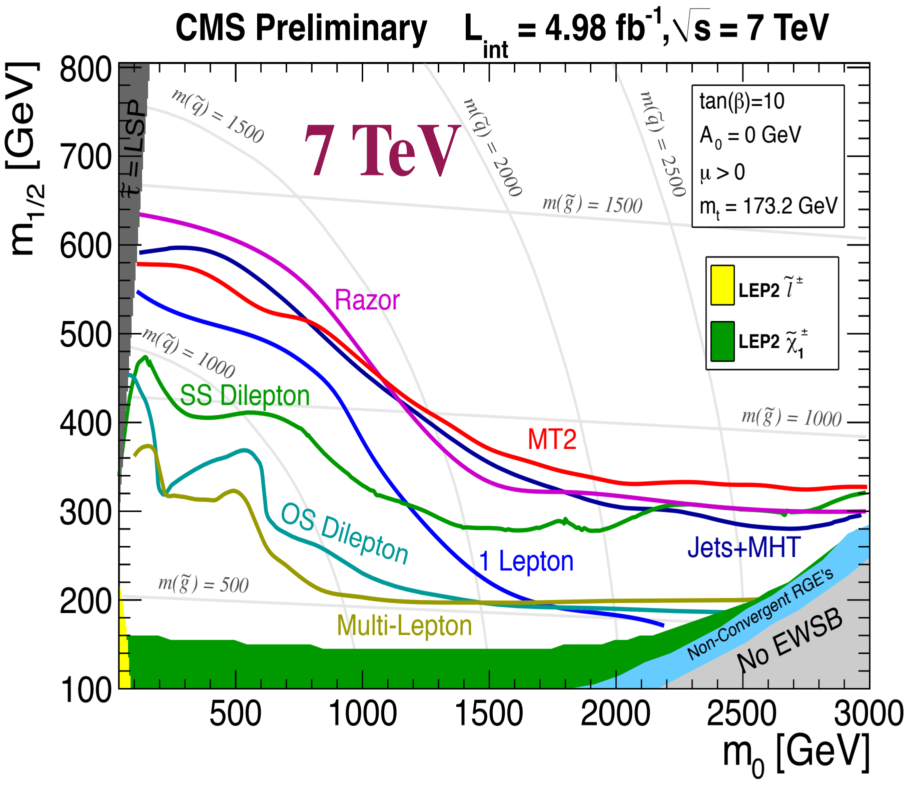
(i) SUSY: stop searches & fine tuning;

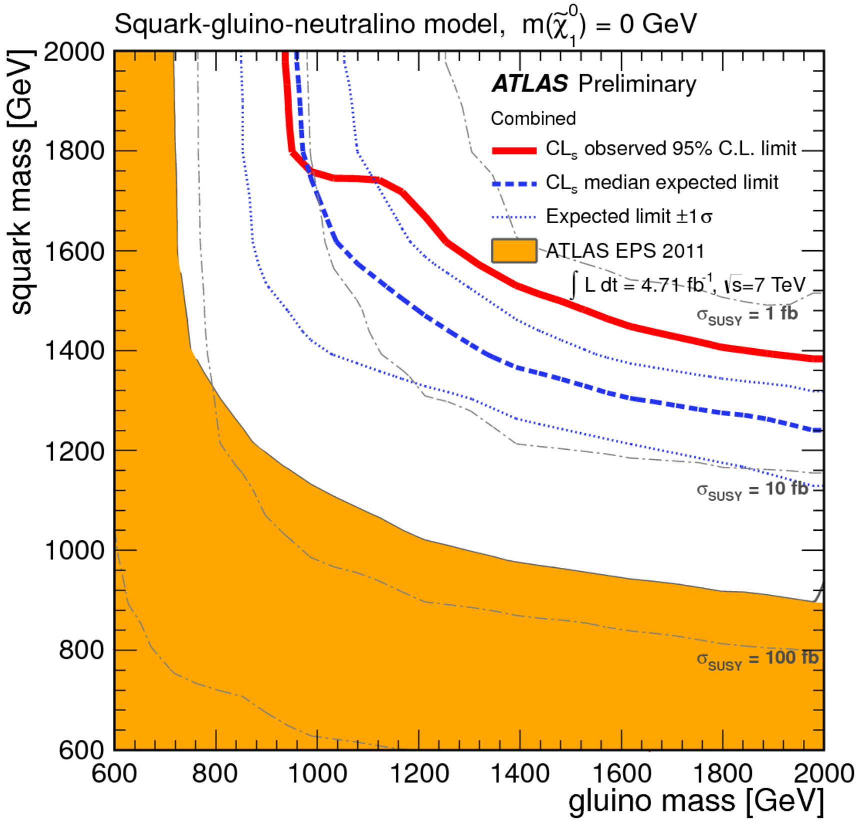
(ii) Composite Higgs: t' searches & fine tuning,
+ top resonance searches;

[*(iii)* Indirect: impact on Higgs couplings.]

Squarks & Gluino searches at the LHC

$$\text{Naively: } \tilde{m}_q \gtrsim 1.5\,\text{TeV} \quad \tilde{m}_g \gtrsim 1\,\text{TeV}$$





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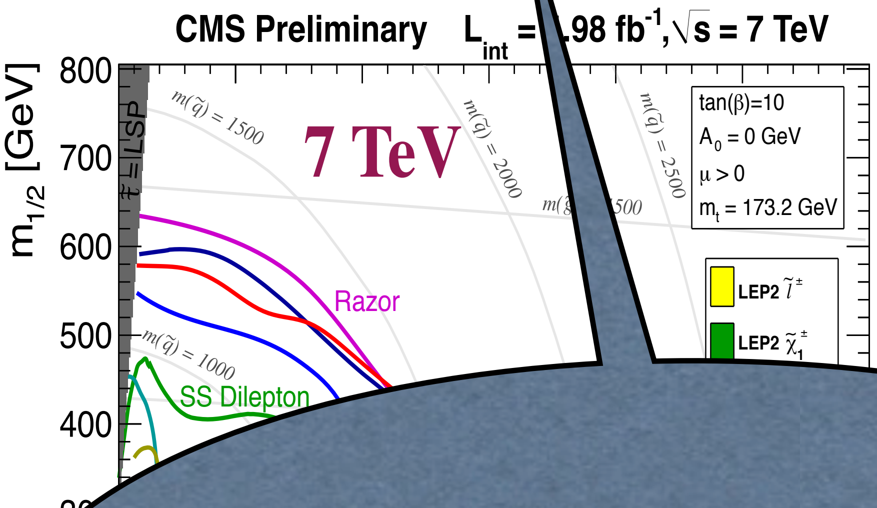
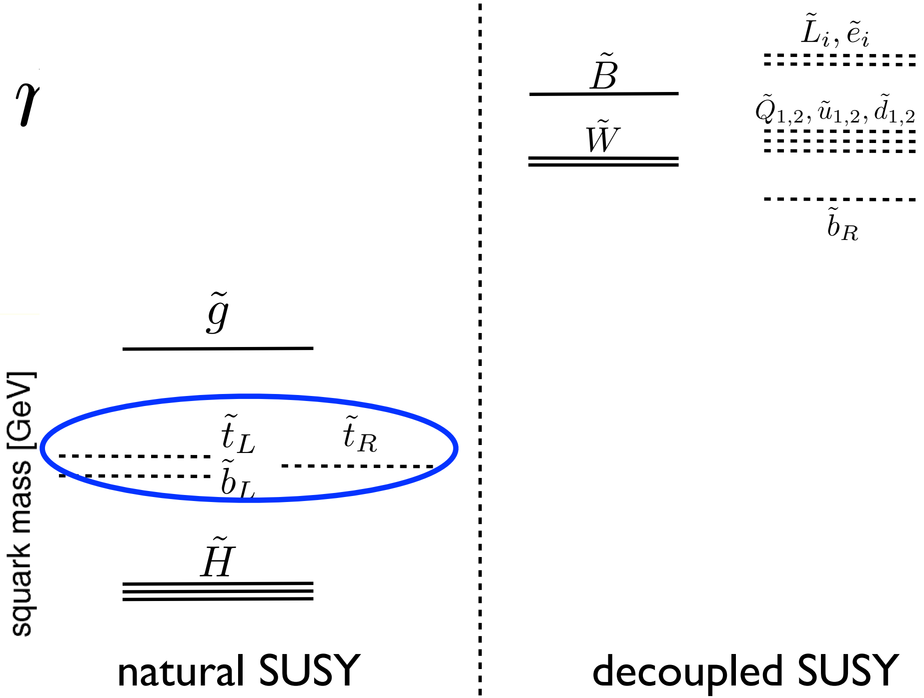
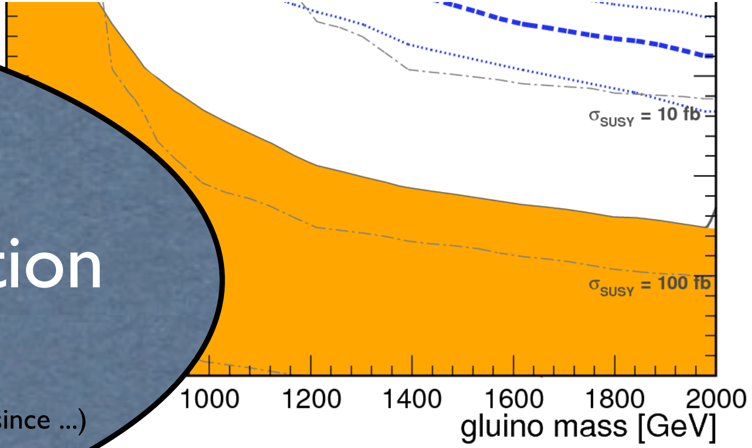






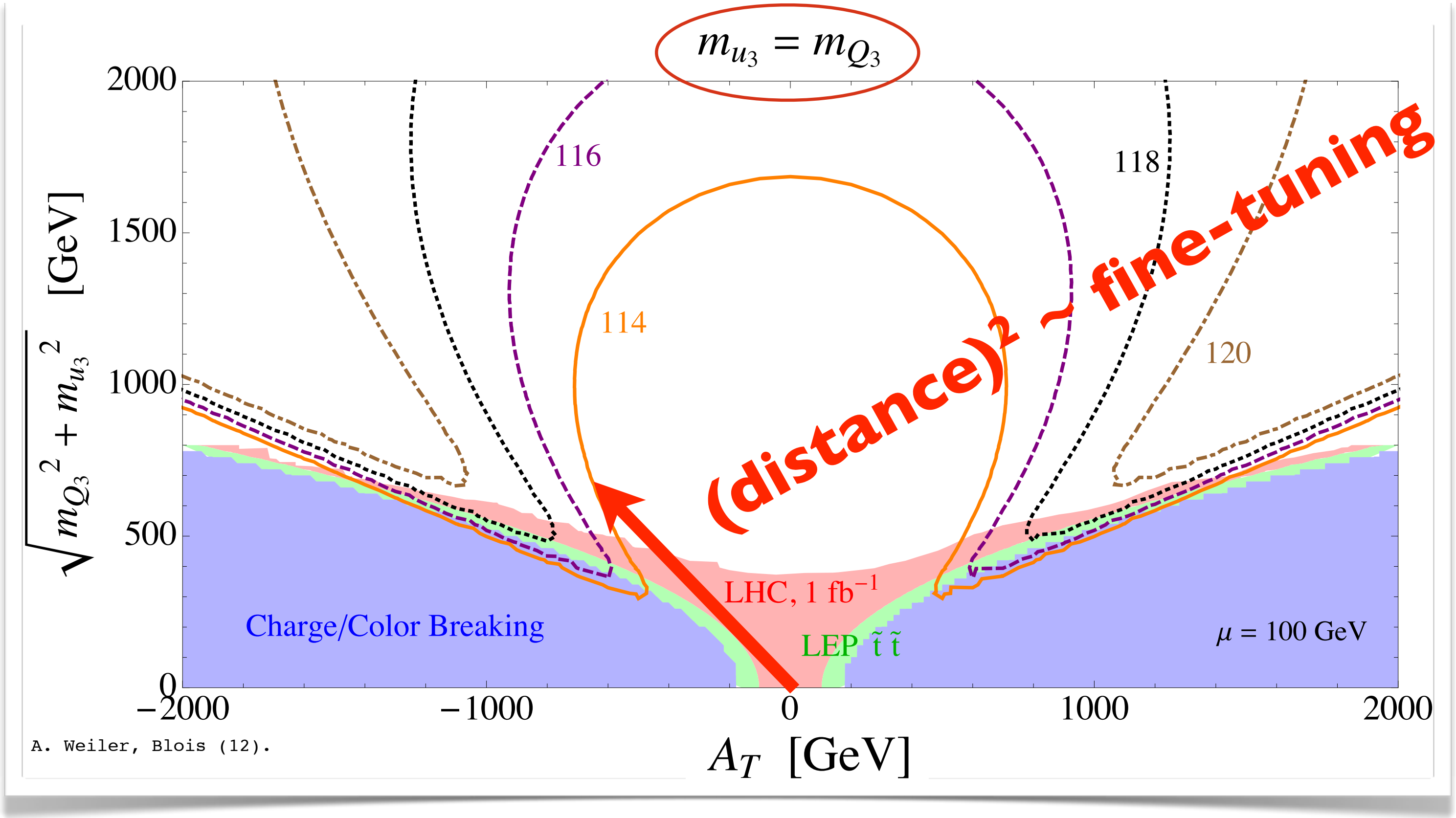
However, nothing to do with naturalness, only 3rd generation partners' mass matters.

(see e.g.: Barbieri-Giudice (88) & many more since ...)

Natural SUSY endures, only now gaining sensitivity to robustly test models

LHC: excluding $\tilde{m}_t \lesssim 500\,\mathrm{GeV}$

MSSM higgs: LEP2 tuning vs. direct stop searches.



A. Weiler, Blois (12).

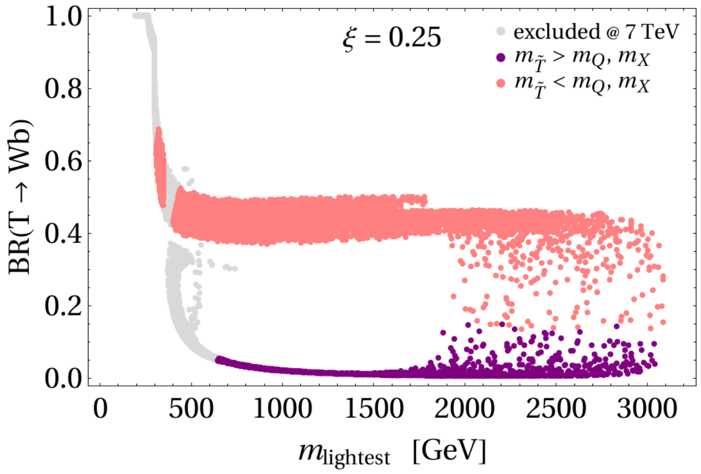
$$\delta m_H^2|_{stop} = -\frac{3}{8\pi^2} y_t^2 \left(m_{U_3}^2 + m_{Q_3}^2 + |A_t|^2\right) \log\left(\frac{\Lambda}{\mathrm{TeV}}\right)$$

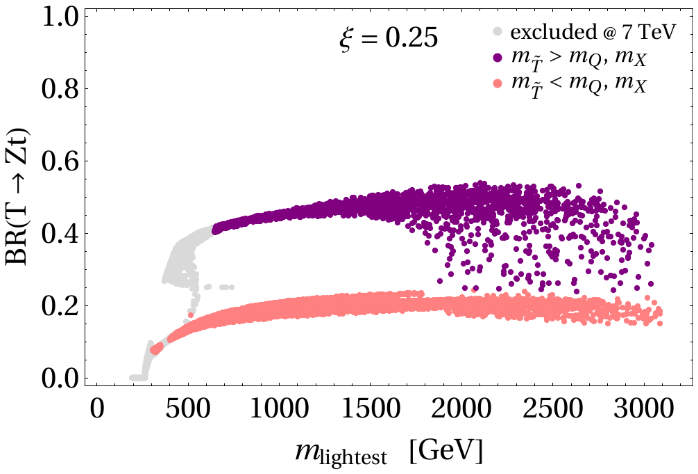
Recent: Essig, et al.; Izaguirre, et al.; Kats, et al.; Brust, et al.; Papucci, et al.. (11) many many more before and after ...)-:

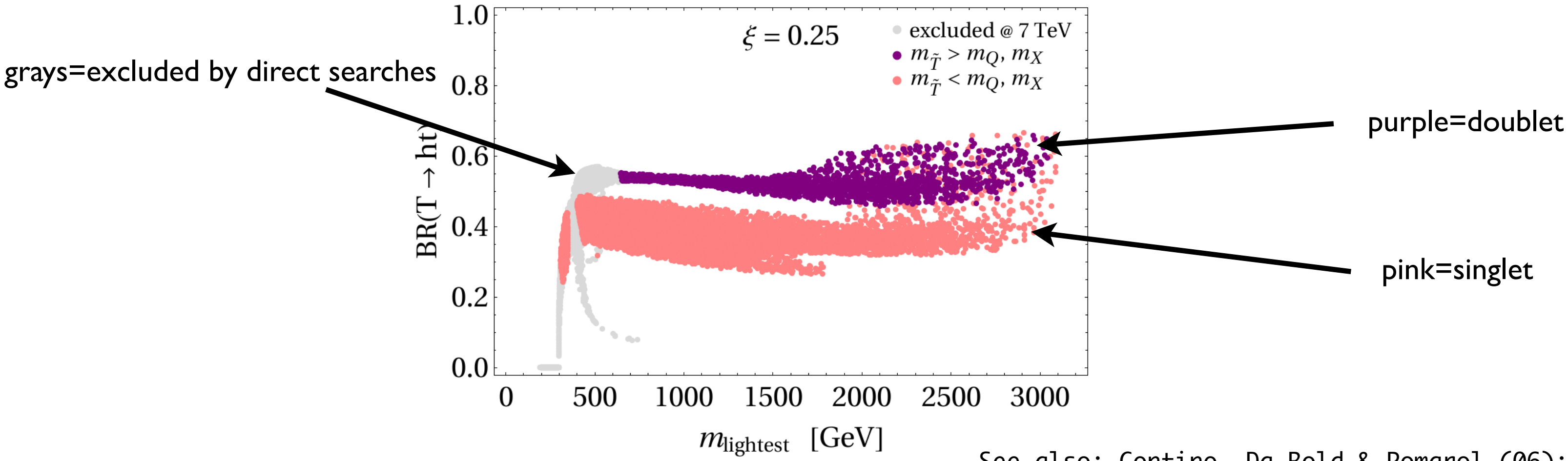
Composite Higgs

LHC: excluding $m_{t'} \lesssim 500\,\mathrm{GeV}$

Plots from update by: Gillioz, Grober, Grojean, Muhlleitnerb & Salvioni (12).







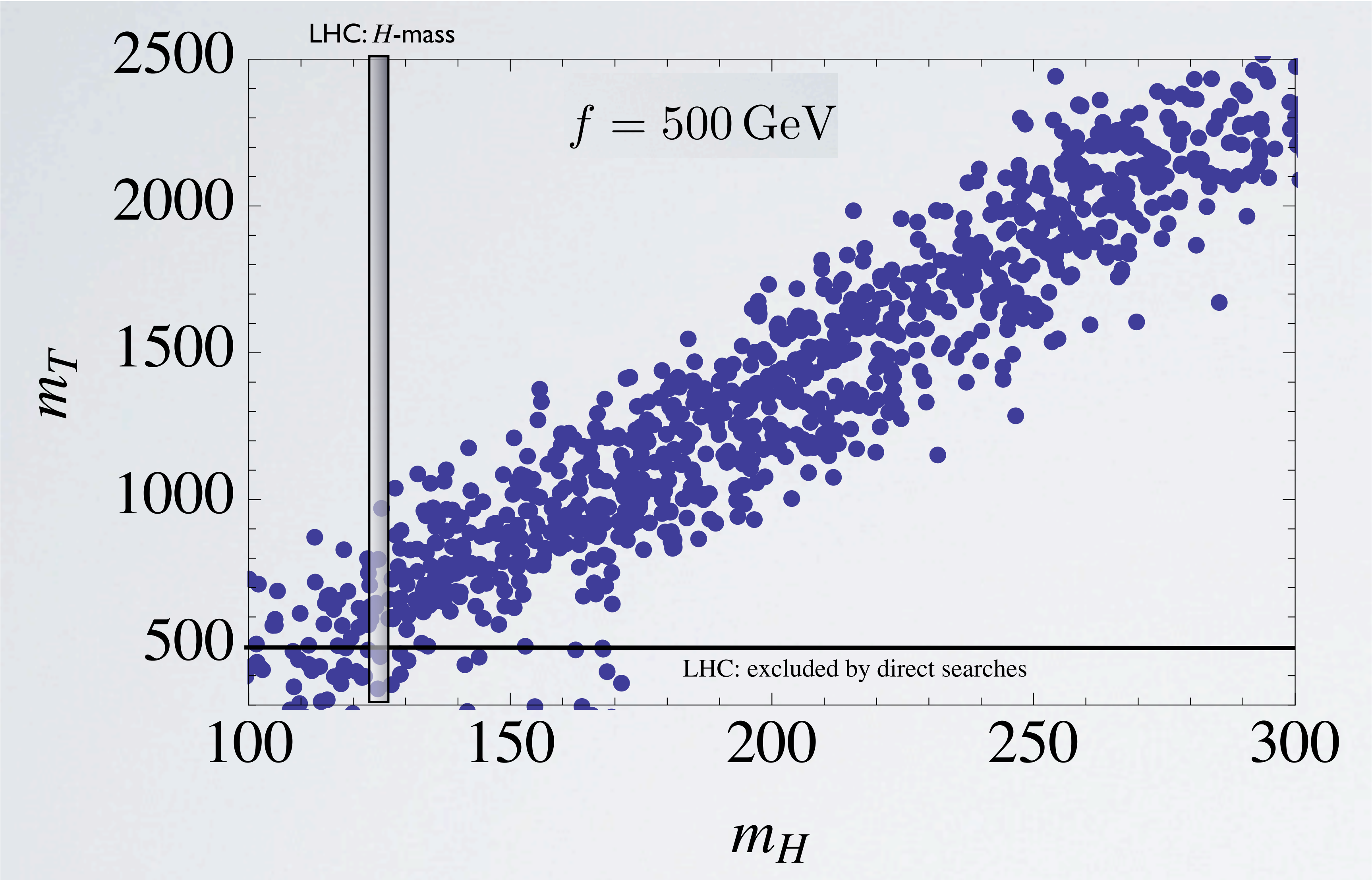
grays=excluded by direct searches

purple=doublet

pink=singlet

`See also: Contino, Da Rold & Pomarol (06);`
`Berger, Hubisz & Perelstein; Redi & Tesi; Matsedonskyi, Panico &`
`Wulzer; Marzocca, Serone & Shu, Pomarol & Riva (12).`

Partner's mass & fine tuning?



Taken from: Redi& Tesi (12) [analyzing the MCH5 of Contino, da Rold, Pomarol, (06)]

Resonances searches & emergence of top jets

(i) Strong dynamics inspired models (composite Higgs, Randall-Sundrum ...) => heavy Kaluza-Klein (KK) resonances, $m_{\mathrm{KK}} \gtrsim 1\,\mathrm{TeV}$.

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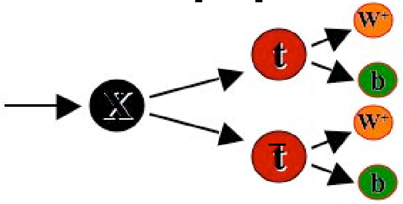

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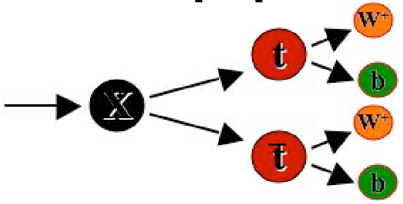

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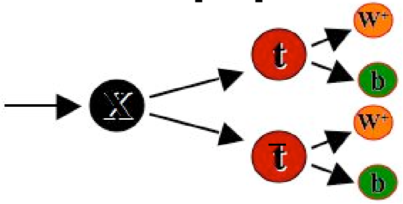

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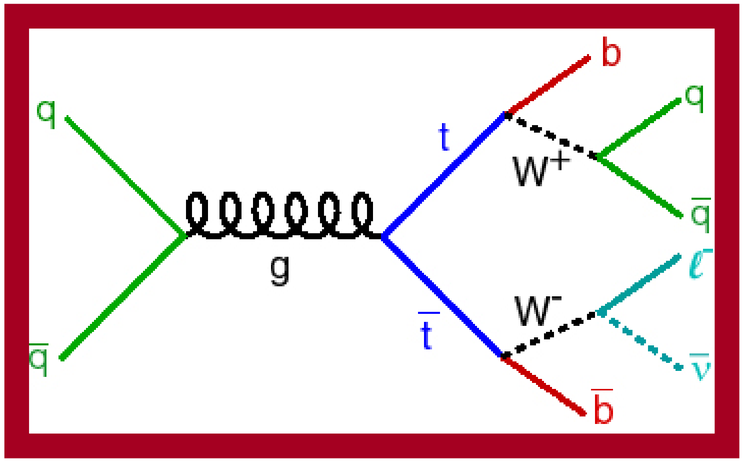

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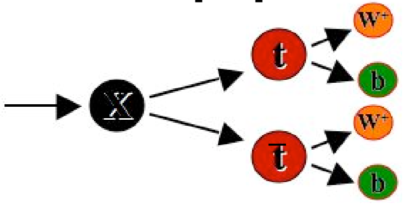

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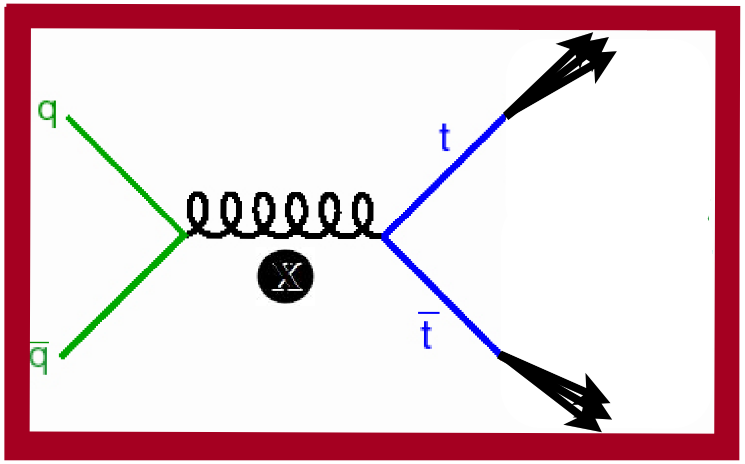

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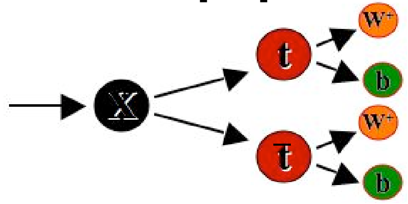

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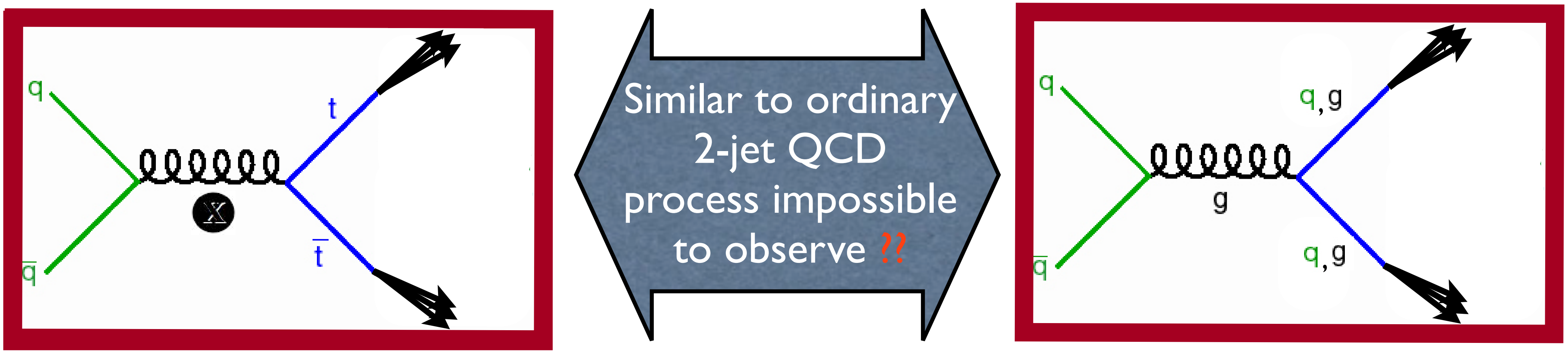
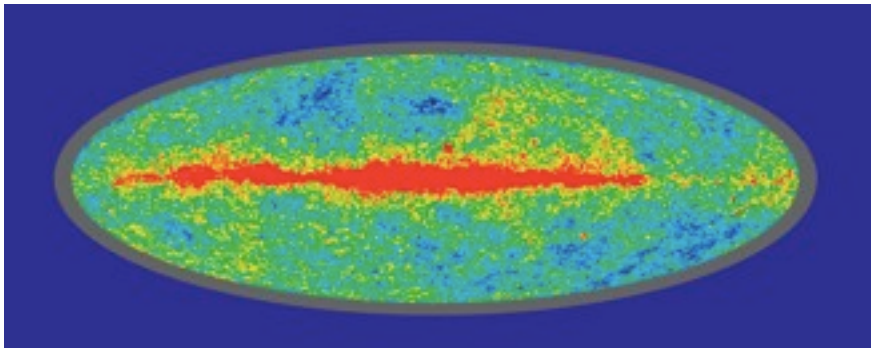
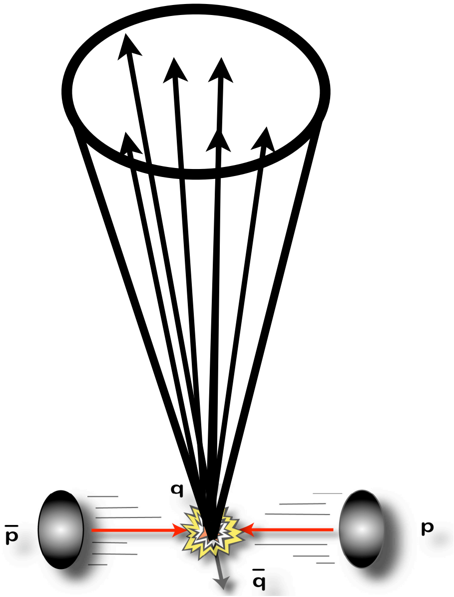


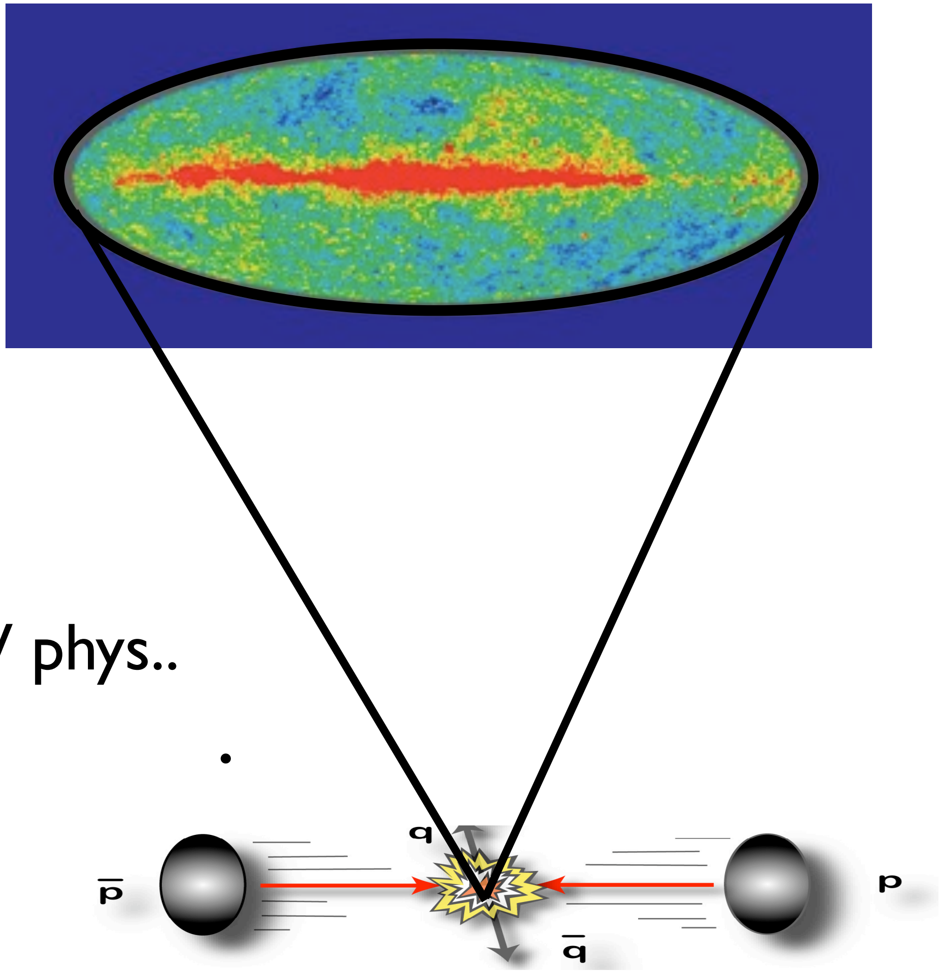
Similar to ordinary 2-jet QCD process impossible to observe ??

Need to distinguish between top & ordinary QCD jet





Need to understand the energy flow inside jet jet shapes or jet substructure



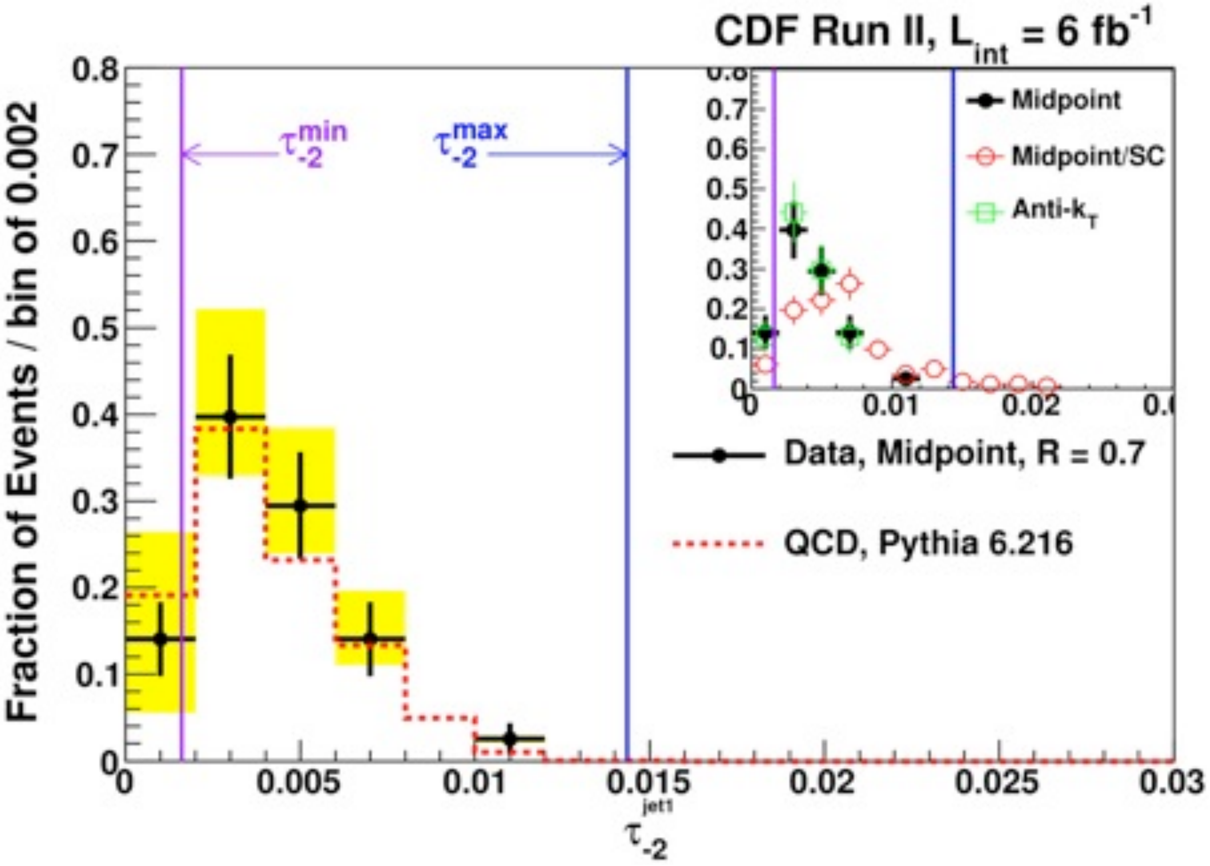
Still learning ...
Important in other direction, e.g. EW phys..

`[Butterworth, Davison, Rubin & Salam (08)]`

Boosted jets' angular distribution, angularity τ_{-2}

$$\frac{d\sigma}{d\theta} \to \frac{d\sigma}{d\tau_{-2}} \approx 1/\tau_{-2}\,,\ \ \tau_{-2}^{\min} = \left(\frac{m_J}{2E_J}\right)^3 \quad \left(\tau_{-2} \sim \sum_{i\in J} E_i\theta_i^4\right)$$

`Almeida, et al. (10)`



jets with mass ∈ (90, 120) GeV/c², p_T > 400 GeV/c

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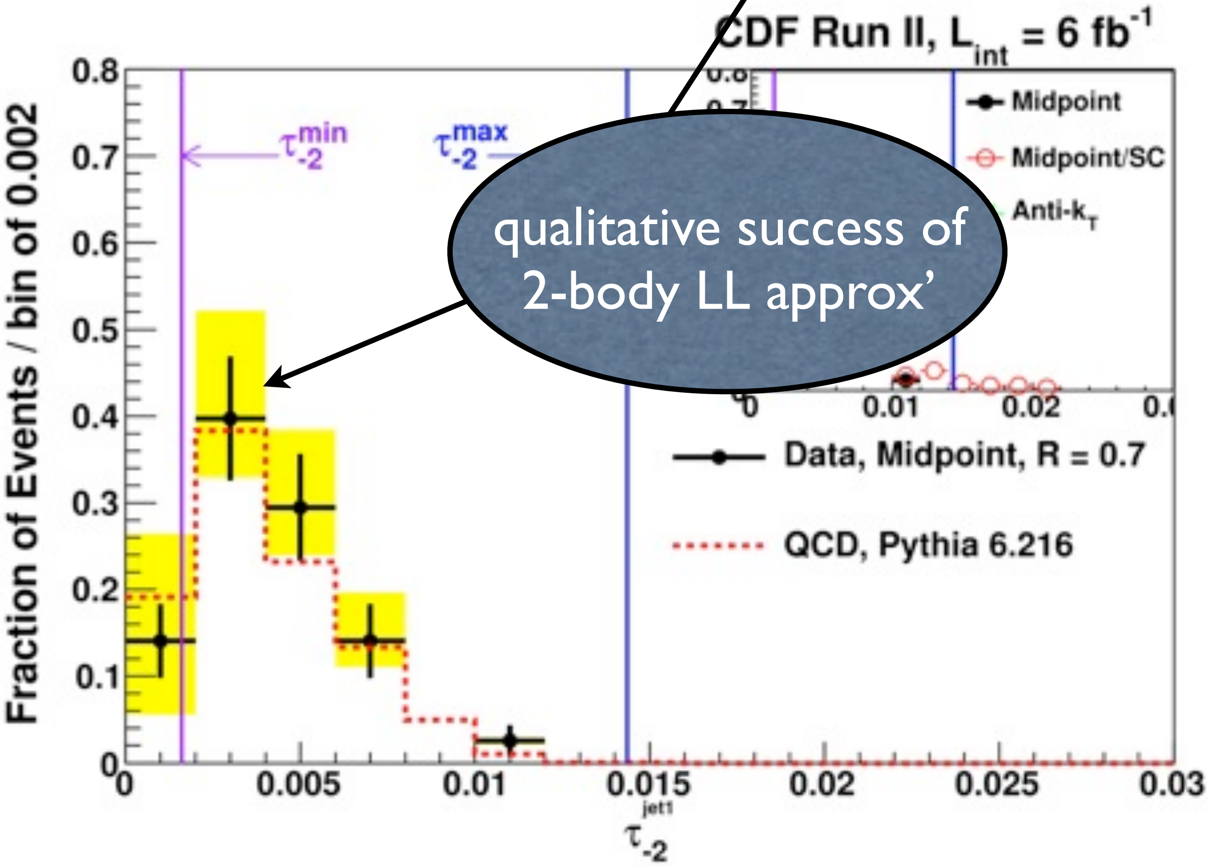
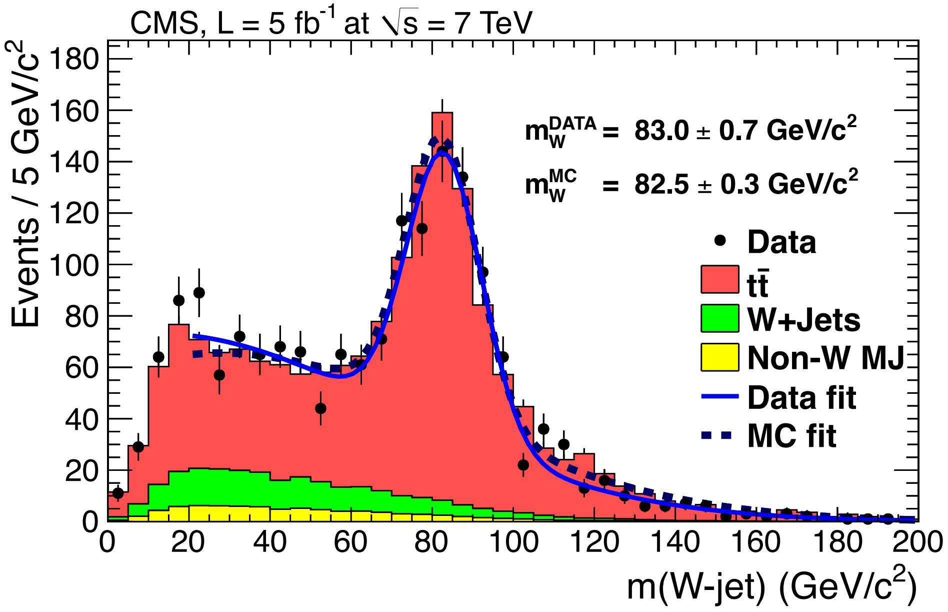


qualitative success of 2-body LL approx'

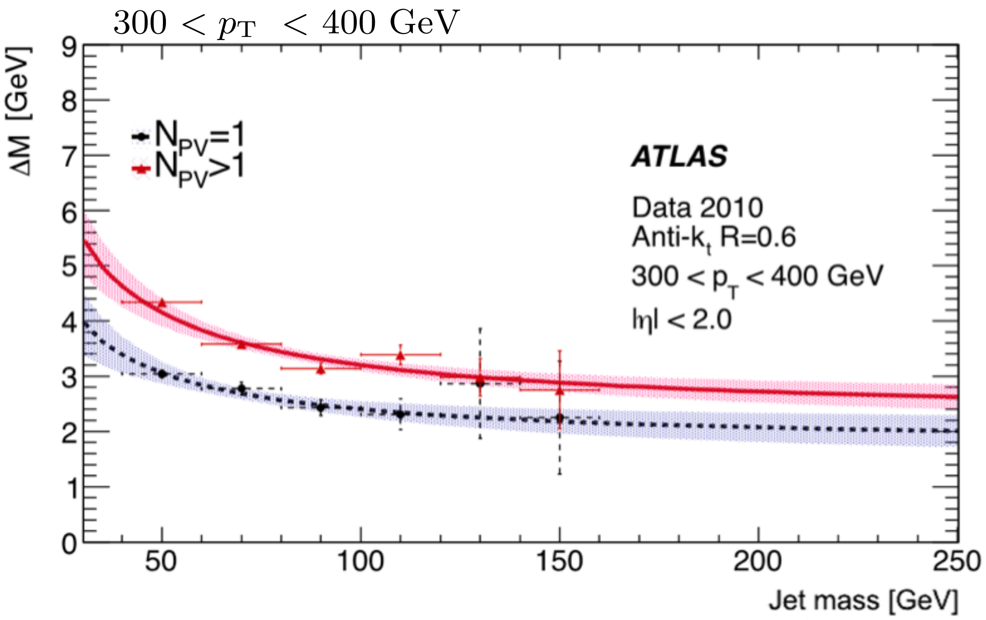
jets with mass ∈ (90, 120) GeV/c², p_T > 400 GeV/c

ATLAS & CMS

CMS, 1204.2488

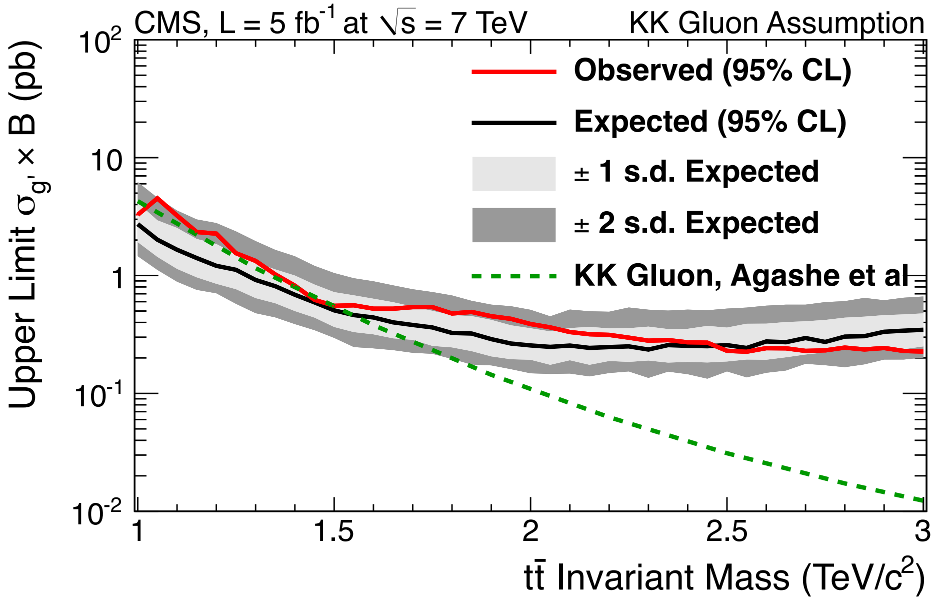


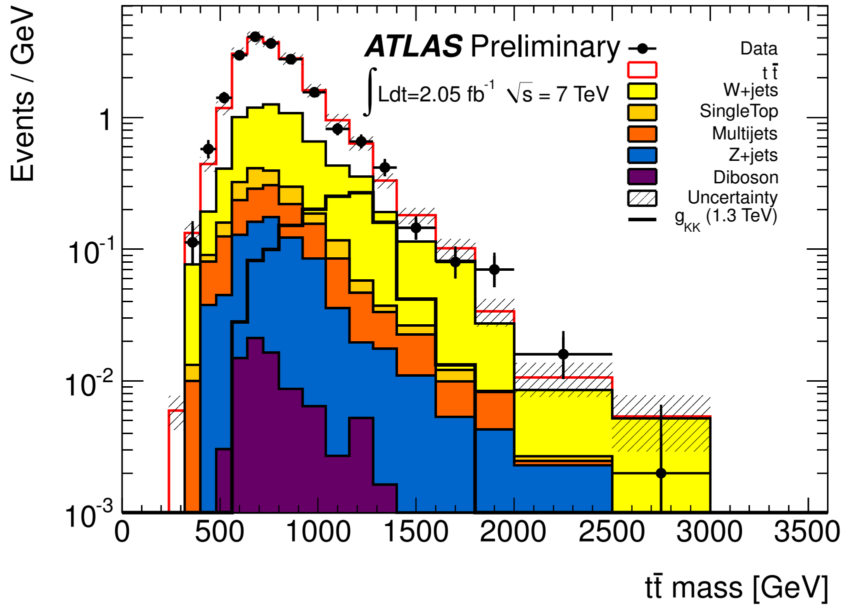
ATLAS,1206.5369



Left: The W tagging algorithm uses a jet “pruning” technique. Right: the size of the mass shift in anti-kt R = 0.6 jets \w & \wo pileup. For rev. see: Boost 2011 writeup,1201.0008.

$t\bar{t}$ resonance searches





Bottom line: $m_X \gtrsim 2\,\mathrm{TeV}$ (still long way to go ...)

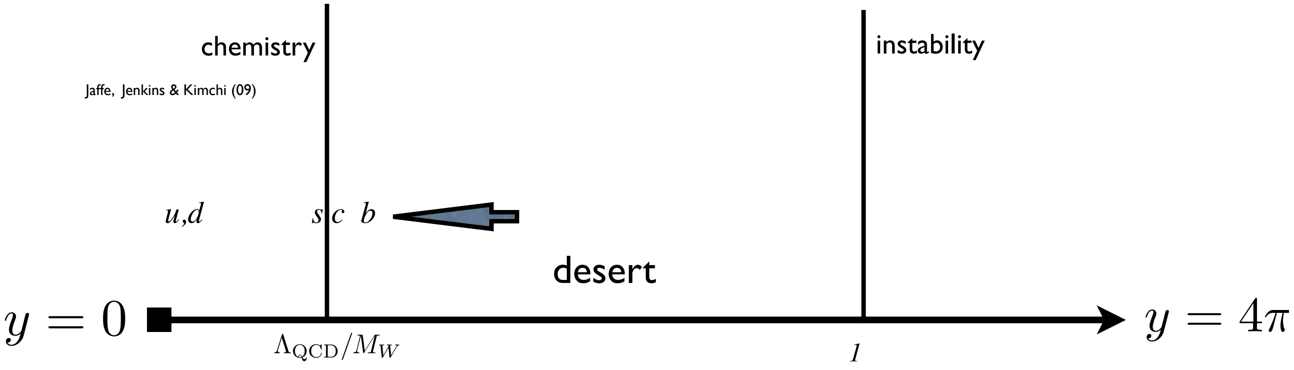
The up flavor connection

Look Down

Look Up

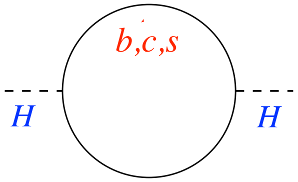
The up flavor connection

- Without the top, SM flavor sector looses a lot from its glamour:



- Without top, linkage between flavor & hierarchy problem weakens:

non-univ. cutoff to sustain < 1:100 fine tuning?



$$s: \ \Rightarrow \Lambda_s \lesssim 2\times 10^4\,{\rm TeV}$$

$$c: \ \Rightarrow \Lambda_c \lesssim 2\times 10^3\,{\rm TeV}$$

$$b: \ \Rightarrow \Lambda_b \lesssim 4\times 10^2\,{\rm TeV}$$

Robust linkage \w direct collider probes is lost!

The up flavor connection

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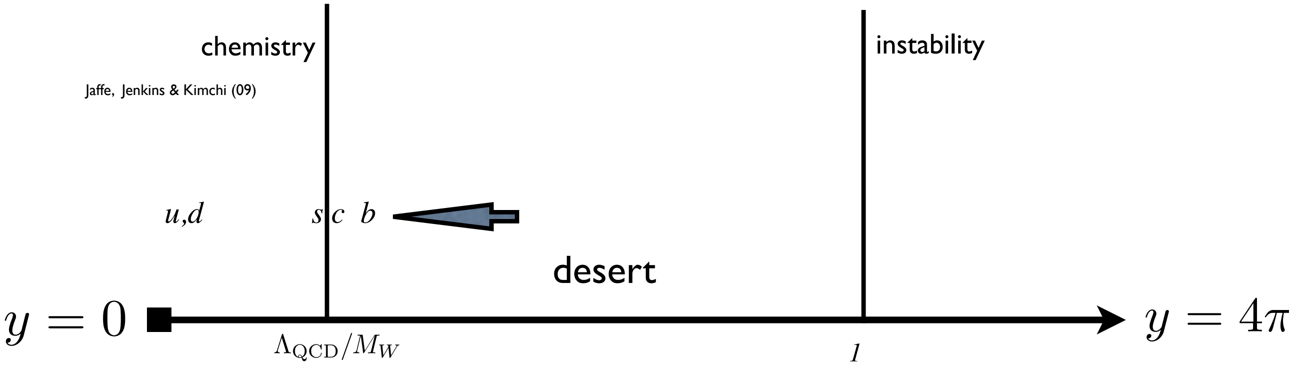

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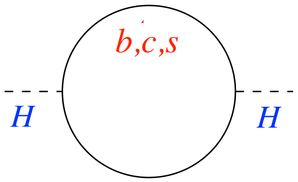

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However:

Operator	Bounds on Λ in TeV ($c_{ij}=1$)	
	Re	Im
$(\bar s_L\gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4
$(\bar s_R\, d_L)(\bar s_L d_R)$	1.8×10^4	3.2×10^5
$(\bar c_L\gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3
$(\bar c_R\, u_L)(\bar c_L u_R)$	6.2×10^3	1.5×10^4
$(\bar b_L\gamma^\mu d_L)^2$	5.1×10^2	9.3×10^2
$(\bar b_R\, d_L)(\bar b_L d_R)$	1.9×10^3	3.6×10^3
$(\bar b_L\gamma^\mu s_L)^2$	1.1×10^2	
$(\bar b_R\, s_L)(\bar b_L s_R)$	3.7×10^2	

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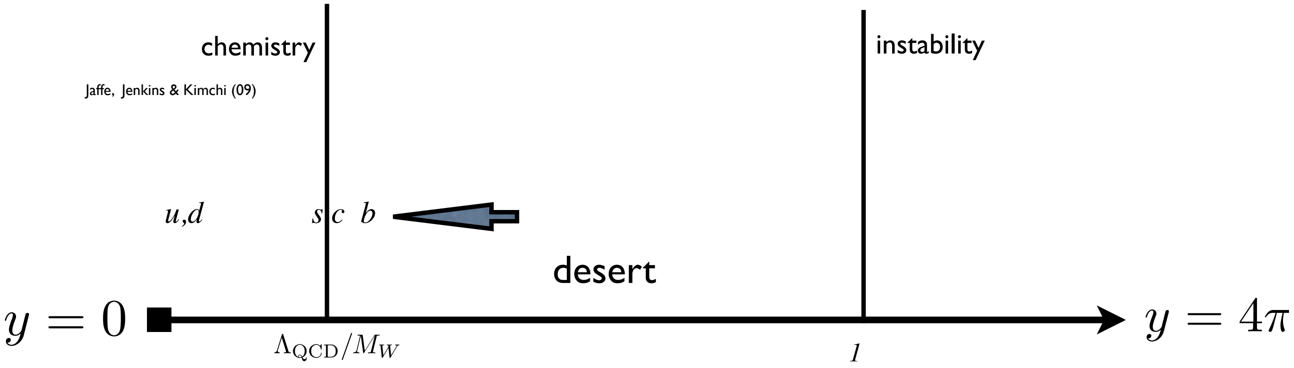
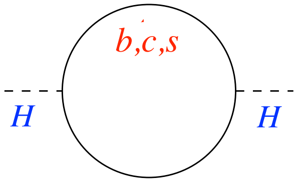


◆Without top, linkage between flavor & hierarchy problem weakens:

non-univ. cutoff to sustain < 1:100 fine tuning?



$$s: \ \Rightarrow \Lambda_s \lesssim 2\times 10^4\ \text{TeV}$$

$$c: \ \Rightarrow \Lambda_c \lesssim 2\times 10^3\ \text{TeV}$$

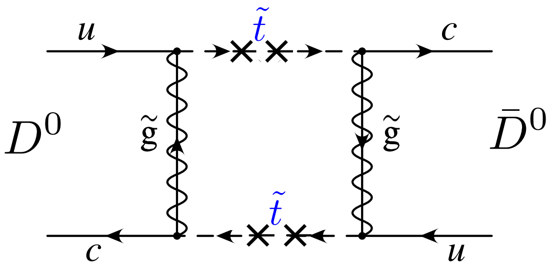
$$b: \ \Rightarrow \Lambda_b \lesssim \boxed{4\times 10^2\ \text{TeV}}$$

B system: only case with tension \w LLLL operators; Dramatic improvement expected in D system!

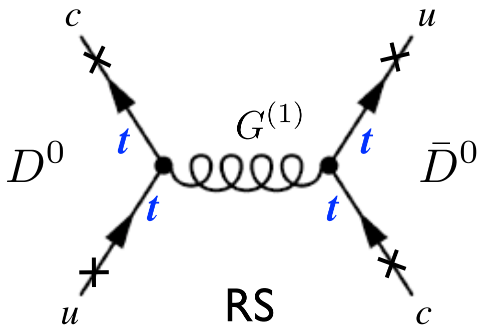
		TeV $(c_{ij}=1)$
		Im
		$\times 10^4$
$(\bar{s}_R$		3.2×10^5
$(\bar{c}_L\gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4
$(\bar{b}_L\gamma^\mu d_L)^2$	5.1×10^2	9.3×10^2
$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$	1.9×10^3	3.6×10^3
$(\bar{b}_L\gamma^\mu s_L)^2$	1.1×10^2	
$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	3.7×10^2	

uFCNC data, a crucial test of NP structure

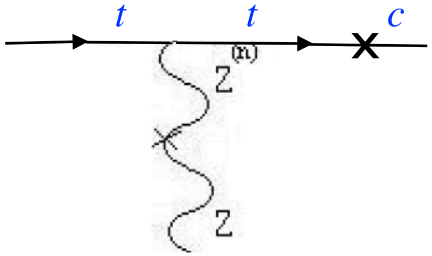
- General: dominant NP constraints coming from extended strong sector, need not “talk” to down & charged lepton sector:



SUSY



RS



- Down & lepton flavor violation maybe removed via alignment, anarchic NP is diagonal in down/charged-lepton mass basis.

[Nir & Seiberg (93);
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NP

$\Delta M_K, \epsilon_K$

$\Delta M_D, A_\Gamma^D$

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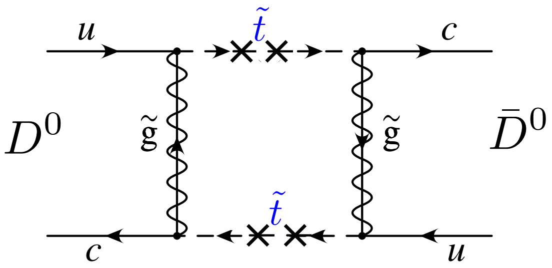

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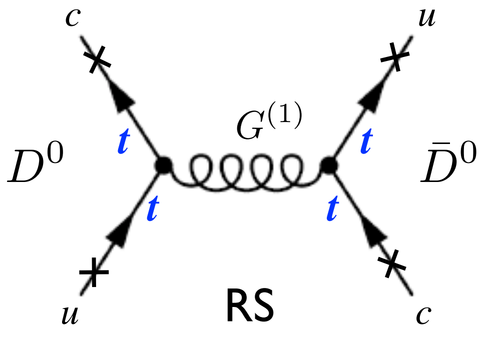

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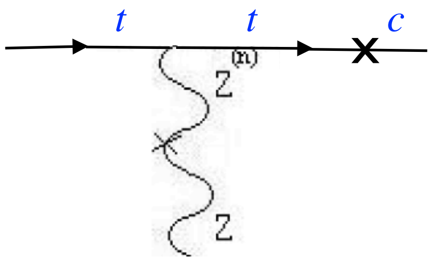

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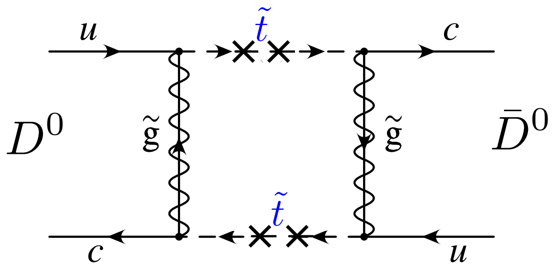

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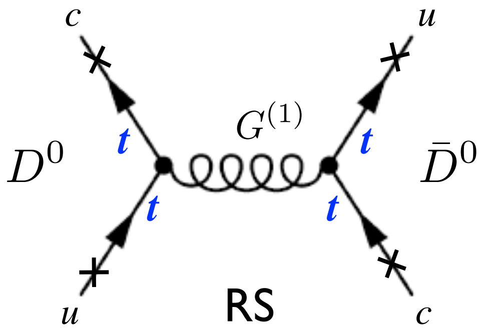

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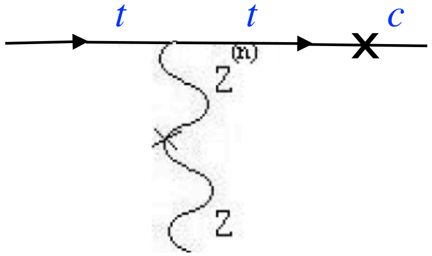

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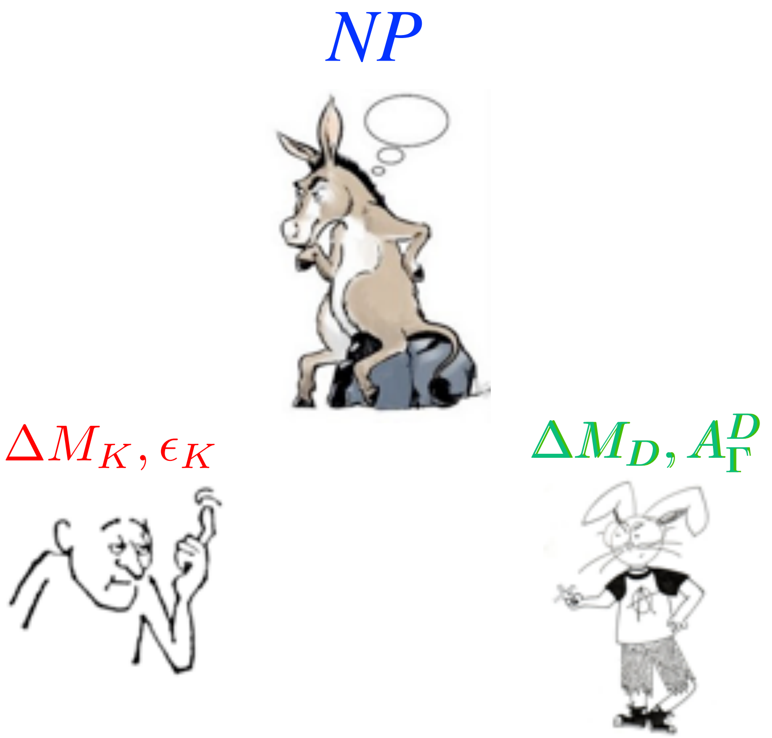

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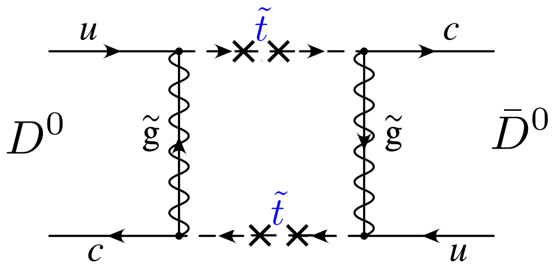

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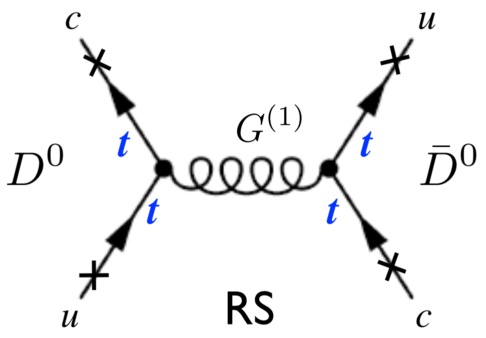

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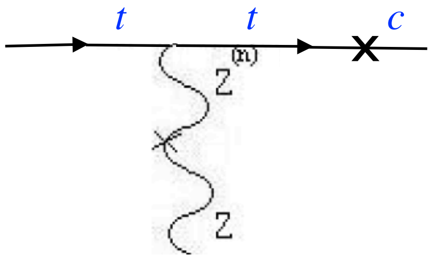

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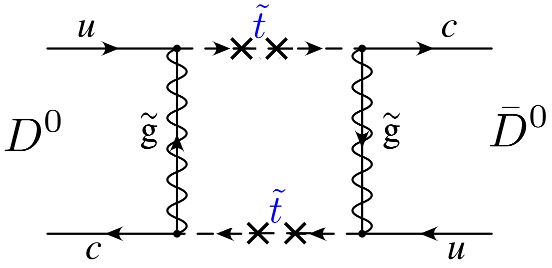

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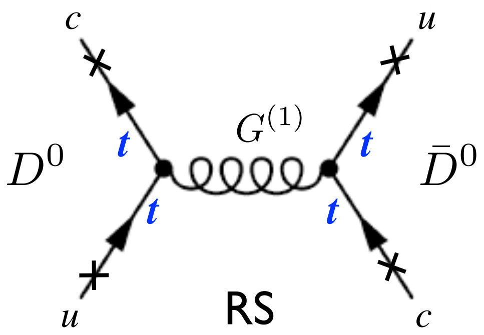

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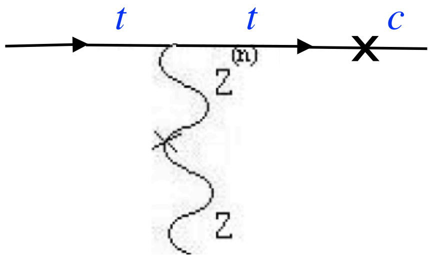

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Last 4 yrs: dramatic progress in studying charm CPV

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)

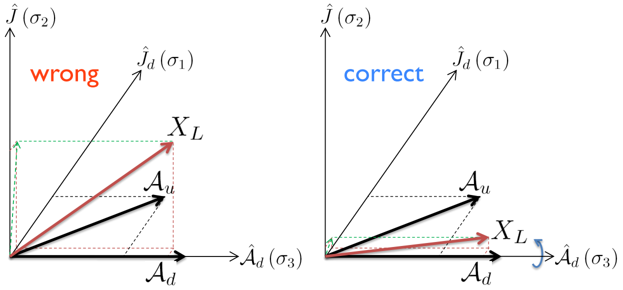
With phases, first 2 gen’ squark need to have almost equal masses.
Looks like squark anarchy/alignment is dead!

However ...

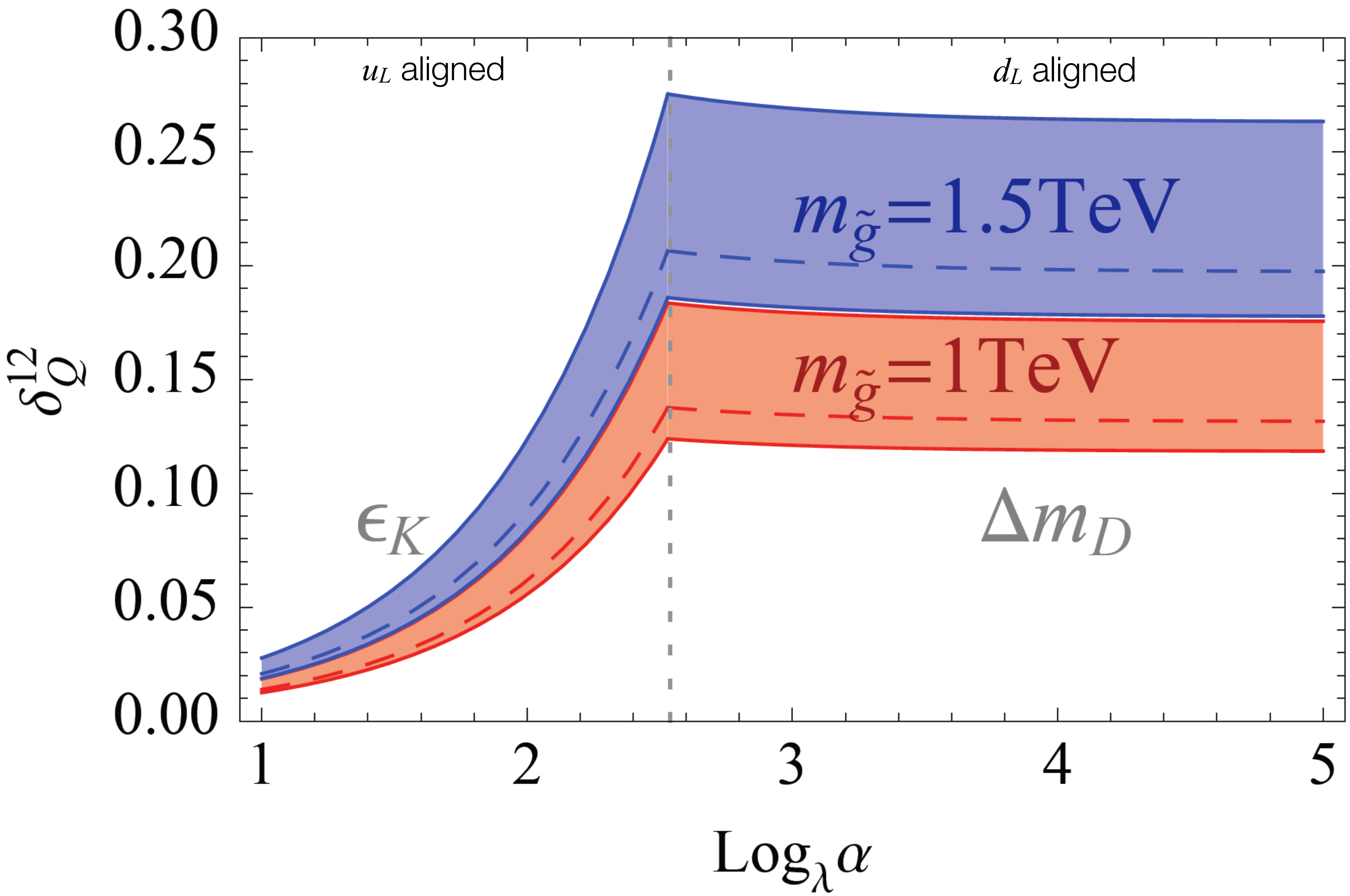
See Kamenik’s talk.

Successful alignment models guarantee small physical CP phase!

Gedalia, Kamenik, Ligeti & GP (12)



Degeneracy of Squarks



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

- No strong degeneracy required!
- Ex.: $m_{\tilde{g}}$=1.3 TeV, $m_{\tilde{Q}_2}$ =550 GeV, $m_{\tilde{Q}_1}$ =950 GeV

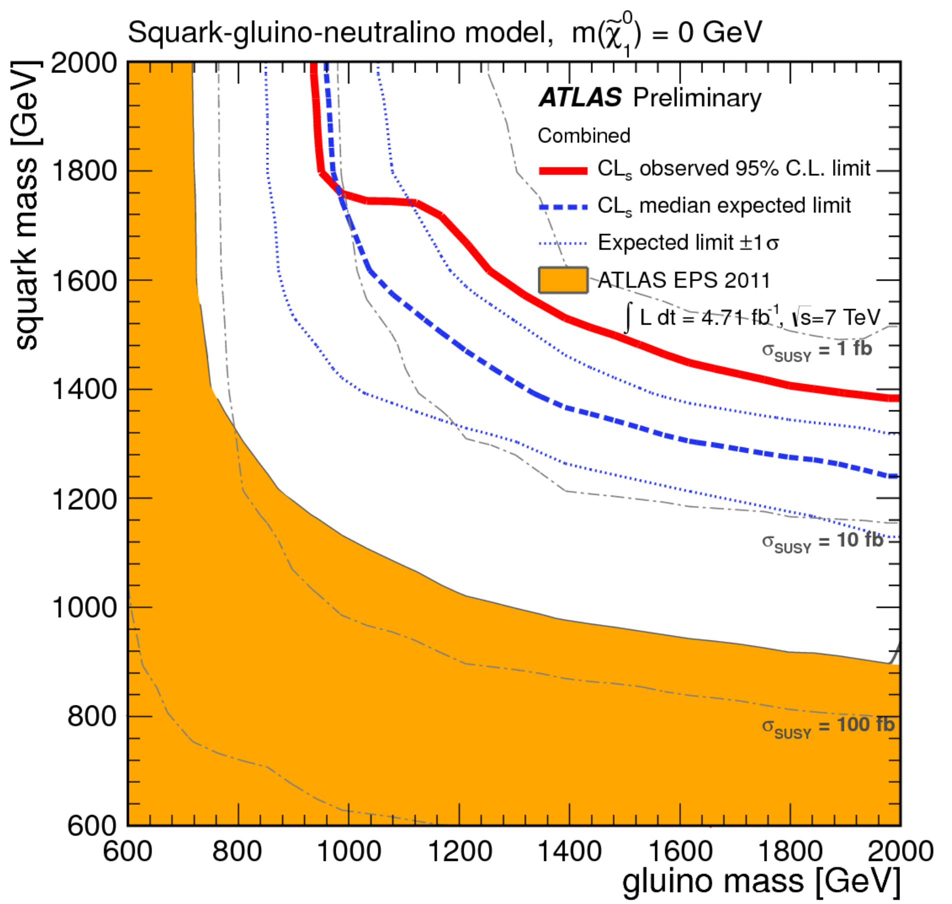
$$\text{(and CPV in } D - \bar{D} \lesssim 20\%)$$

Can this be consistent with LHC data??

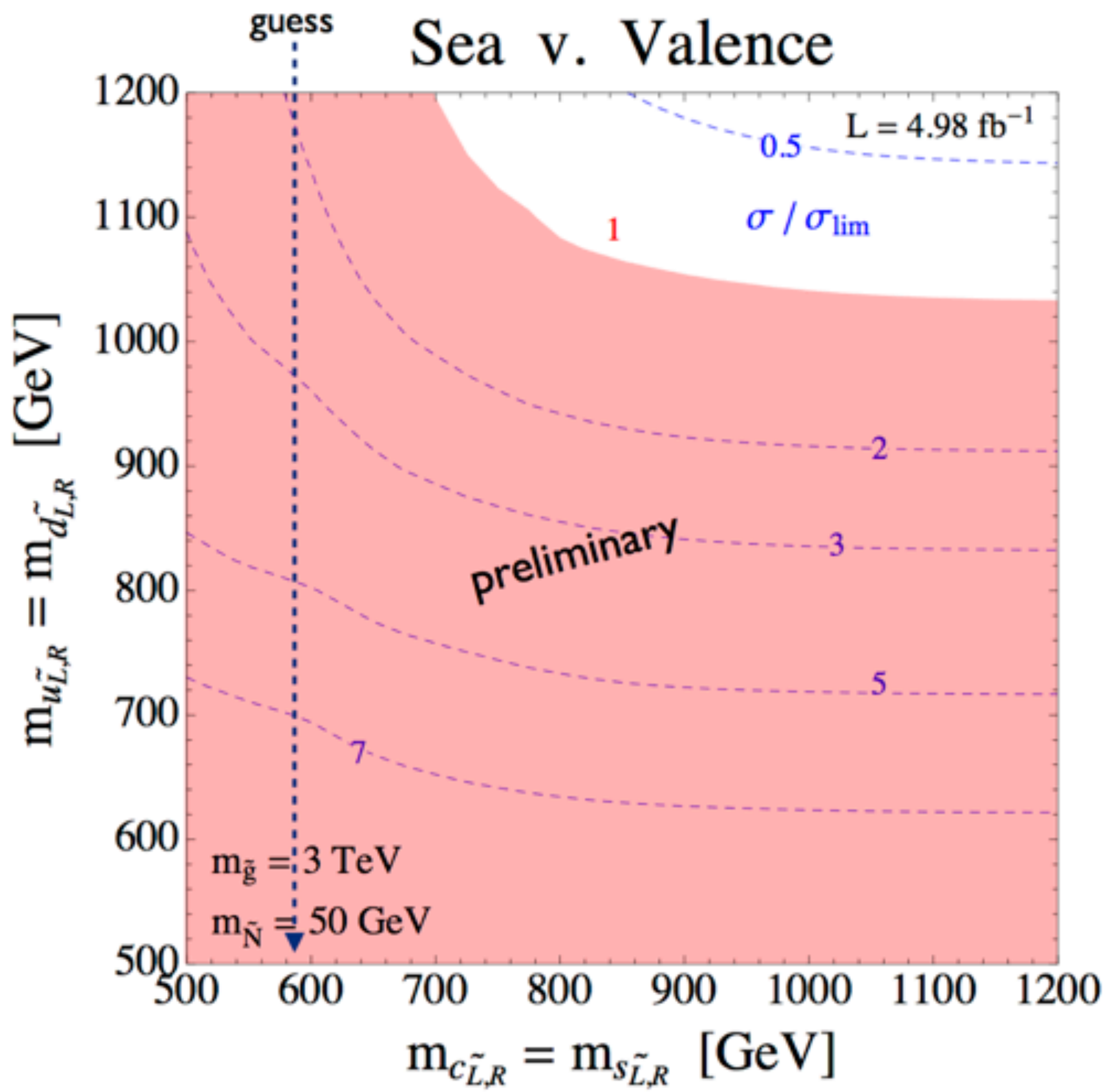
Mahbubani, Papucci, GP, Ruderman & Weiler, to appear.

See Papucci’s talk.

$m_{\tilde{Q}_2}$=550 GeV, $m_{\tilde{Q}_1}$=950 GeV



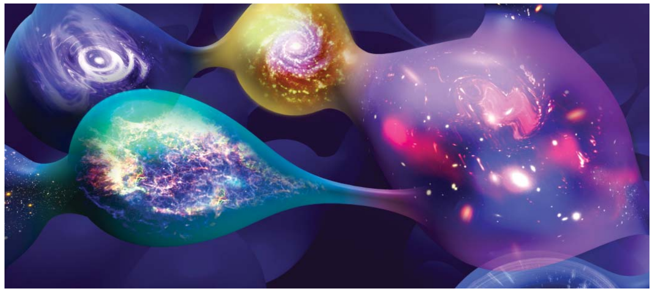
In fact, all 4 flavor “sea” squarks can be light!

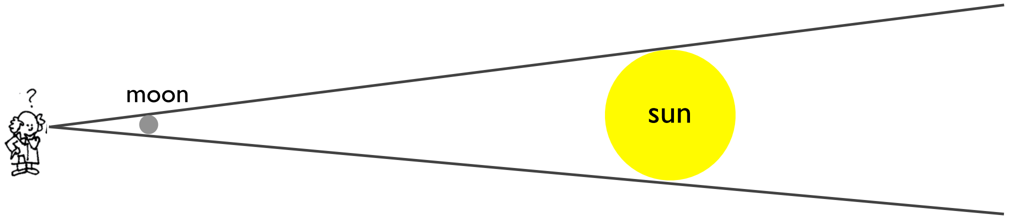


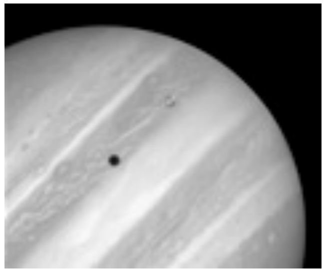
So far crazily reasonable, is there alternative paradigm?

Potential implications for a 125GeV Higgs on flavor physics

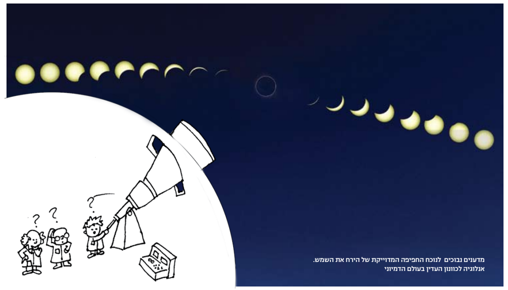
`Giudice, GP & Soreq (12).`







Jupiter's volcanic moon

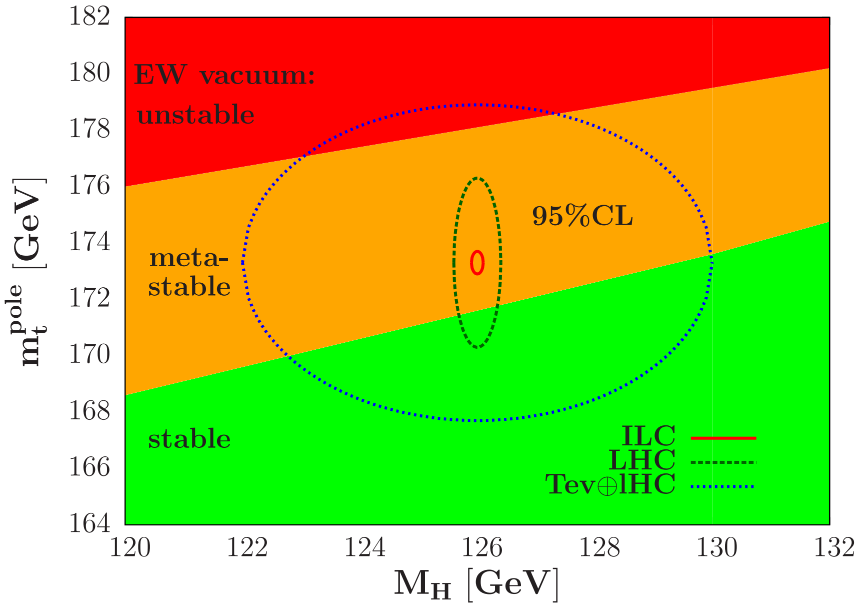


מדענים נבוכים לנוכח החפיפה המדוייקת של הירח את השמש.
אנלוגיה לכוונון העדין בעולם הדמיוני

Earth & our moon

125 GeV Higgs -> top is ~saturating metastability

$$y_t \lesssim 1.03 + 1.8 \cdot 10^{-3}\ (m_H - 125.5\,\mathrm{GeV})$$



Alekhin, Djouadi & Moch (12)

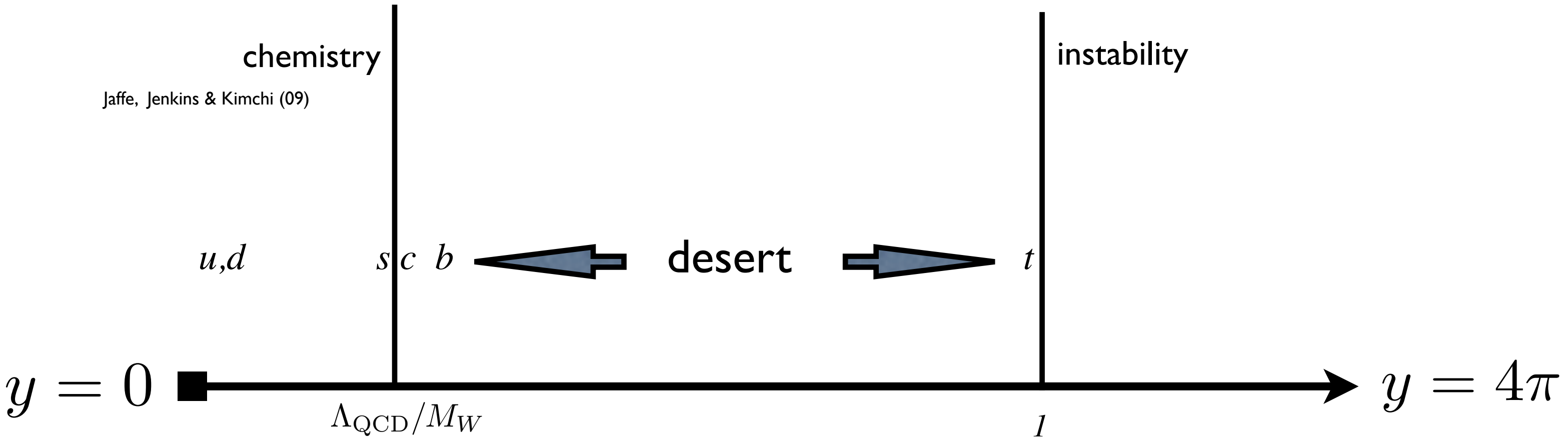
A raise of < 3% in top Yukawa => weakless universe!

A new coincidence, top *(H)* flavor puzzle?

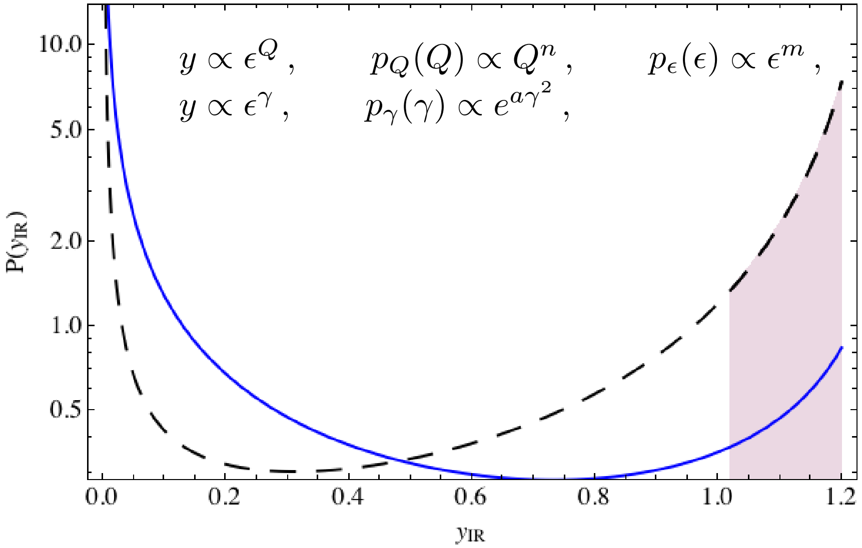
Getting a two-peaks distributions, ultra speculative solution to flavor puzzle (question more important than answer ...)

Giudice, GP & Soreq (12).

- Interpretation for quark spectrum, in view of new Higgs mass:



- RGE + “strong dynamics” inspired models can generate binary dist’.



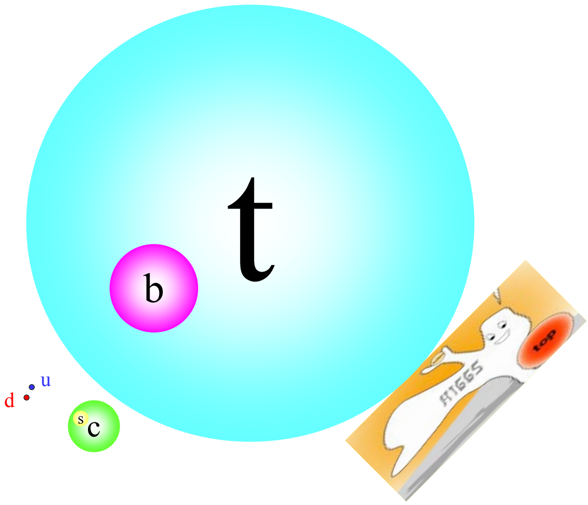
Summary

- Entered precision top phys. phase,

  LHC data => fantastic & consistent with SM.

- Combine effort resolving forward backward anomaly.
- Battle for naturalness: t-partner & resonance searches.
- Minimalism: up flavor & CPV might hold the key.
- Light (non-”sups”) squarks maybe buried (regardless of alignment).
- Is criticality of top Yukawa-Higgs mass coincidence?

Top Physics Pheno’ Perspective



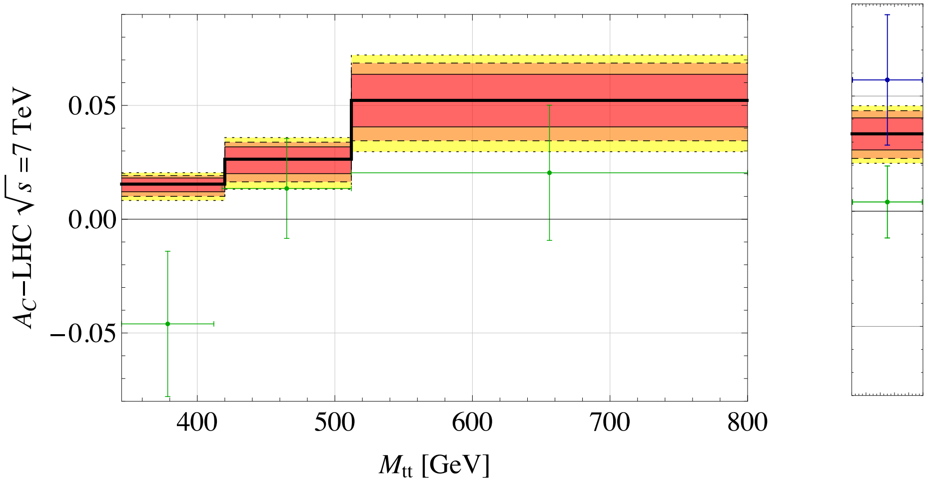
Thank you

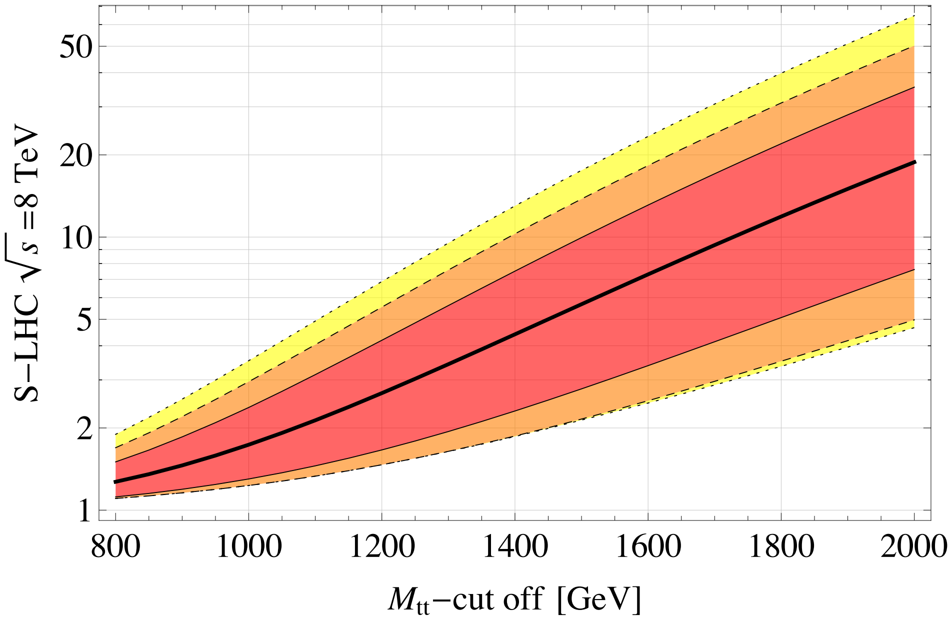
Gilad Perez

CERN & Weizmann Inst.

Backups

EFT constraints from charge asym’ & enhancement of differential mass distribution





Delaunay, Gedalia, Hochberg & Soreq (12).

What is the fine tuning problem (personal view)?

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Coincidence of $1:10^2$ - moon subtends an angle of ~ **0.52°** while sun of ~ **0.53°**.

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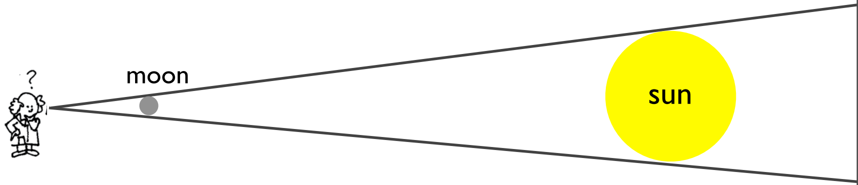
Imagine that they were equal to $1{:}10^{32}$!



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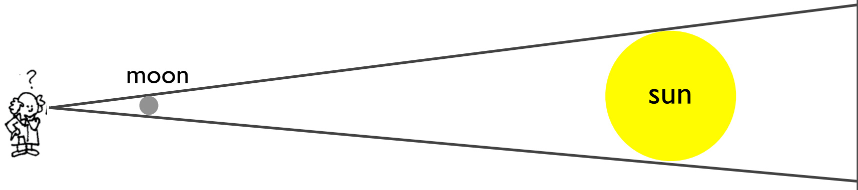


It would raise two questions:

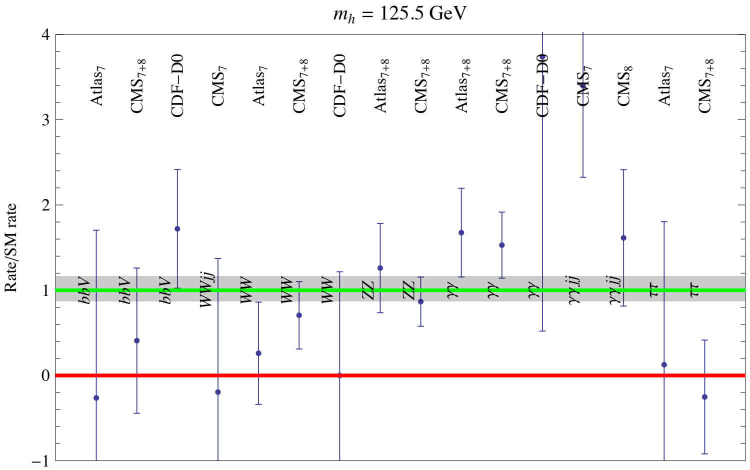
(i) What set their precise distance? <=> Tuning problem.

$$\text{why is } \delta\theta/\theta_{\rm max} \sim 10^{-32} \ll 1\,? \quad \longleftrightarrow \quad \text{why is } \left(m^2_{H,W}/m^2_{\rm Pl}\right)_{\rm obs} \sim 10^{-32} \ll 1\,?$$

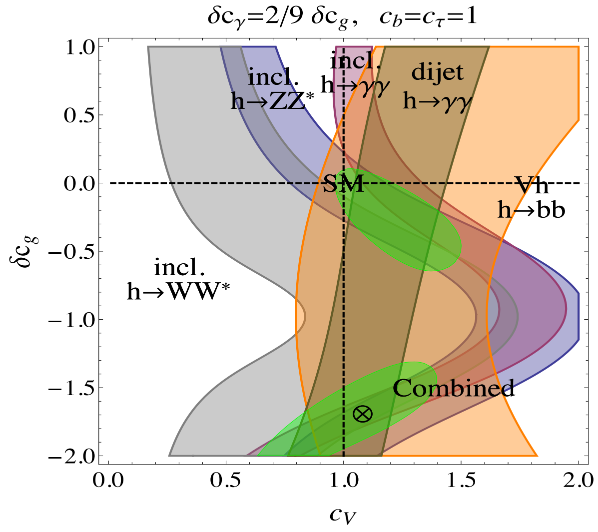
Indirect searches via Higgs precision tests (HPTs)

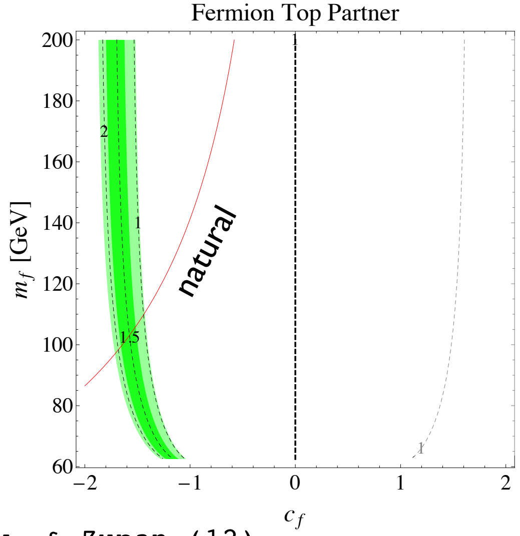
Beginning of HPTs era, sensitive to partners mass & couplings:

$$\frac{\text{Measured Higgs rate}}{\text{SM prediction}} = 1.02 \pm 0.15$$ `Giardino, et al. (5/7)`



`Giardino, Kannike, Raidal & Strumia (12)`





`Carmi, Falkowski, Kuflik, Volansky & Zupan (12).`

However, it's pretty hard to raise di-photon rate via t-partners in "real" natural theories ...

`Falkowski (07); Low & Vichi (10); Azatov & Galloway (11); Gillioz, et al.;`
`Blum, et al.; Carena, et al.; Corbett, et al.; Benbrik, et al.; Arbey, et al. (12);`

The importance of up-type FCNC

What if down/lepton alignment is at work ?

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Operator	Bounds on Λ in TeV ($c_{ij}=1$)		Bounds on c_{ij} ($\Lambda = 1$ TeV)		Observables
	Re	Im	Re	Im	
$(\bar{s}_L \gamma^\mu d_L)^2$	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}; $S_{\psi K_S}$
$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$	1.9×10^3	3.6×10^3	5.6×10^{-7}	1.7×10^{-7}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_L \gamma^\mu s_L)^2$	1.1×10^2		7.6×10^{-5}		Δm_{B_s}
$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	3.7×10^2		1.3×10^{-5}		Δm_{B_s}
$(\bar{t}_L \gamma^\mu u_L)^2$					same sign *t*'s
$\bar{L}_i \sigma^{\mu\nu} e_{Rj} H F_{\mu\nu}$	1.7×10^4 3.3×10^2 2.6×10^2				$Br\,(\mu \to e\gamma)$ $Br\,(\tau \to \mu\gamma)$ $Br\,(\tau \to e\gamma)$
$(\bar{\mu}\gamma^\mu P_L e)\,(\bar{u}\gamma_\mu P_L u)$	1.9×10^2				$\frac{\sigma(\mu^- Ti \to e^- Ti)}{\sigma(\mu^- Ti \to capture)}$

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~~$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$~~	~~1.8×10^4~~	~~3.2×10^5~~	~~6.9×10^{-9}~~	~~2.6×10^{-11}~~	~~$\Delta m_K;\ \epsilon_K$~~
$(\bar{c}_L\gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	$\Delta m_D;\ \lvert q/p\rvert, \phi_D$
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	$\Delta m_D;\ \lvert q/p\rvert, \phi_D$
~~$(\bar{b}_L\gamma^\mu d_L)^2$~~	~~5.1×10^2~~	~~9.3×10^2~~	~~3.3×10^{-6}~~	~~1.0×10^{-6}~~	~~$\Delta m_{B_d};\ S_{\psi K_S}$~~
~~$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$~~	~~1.9×10^3~~	~~3.6×10^3~~	~~5.6×10^{-7}~~	~~1.7×10^{-7}~~	~~$\Delta m_{B_d};\ S_{\psi K_S}$~~
~~$(\bar{b}_L\gamma^\mu s_L)^2$~~	~~1.1×10^2~~		~~7.6×10^{-5}~~		~~Δm_{B_s}~~
~~$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$~~	~~3.7×10^2~~		~~1.3×10^{-5}~~		~~Δm_{B_s}~~
$(\bar{t}_L\gamma^\mu u_L)^2$					same sign t's
~~$\bar{L}_i\sigma^{\mu\nu} e_{Rj} F_{\mu\nu}$~~	1.7×10^4 ~~3.3×10^2~~ [illegible]				$Br\,(\mu\to e\gamma)$ ~~$Br\,(\tau\to\mu\gamma)$~~ ~~$Br\,(\tau\to e\gamma)$~~
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~~$(\bar{s}_L\gamma^\mu d_L)^2$~~	~~9.8×10^2~~	~~1.6×10^4~~	~~9.0×10^{-7}~~	~~3.4×10^{-9}~~	~~$\Delta m_K;\ \epsilon_K$~~
~~$(\bar{s}_R\,d_L)(\bar{s}_L d_R)$~~	~~1.8×10^4~~	~~3.2×10^5~~	~~6.9×10^{-9}~~	~~2.6×10^{-11}~~	~~$\Delta m_K;\ \epsilon_K$~~
$(\bar{c}_L\gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	$\Delta m_D;\ \lvert q/p\rvert, \phi_D$
$(\bar{c}_R\,u_L)(\bar{c}_L u_R)$	6.2 [illegible]	[illegible]	[illegible]	[illegible] $\times10^{-8}$	$\Delta m_D;\ \lvert q/p\rvert, \phi_D$
~~$(\bar{b}_L\gamma^\mu d_L)^2$~~	[illegible]	[illegible]	[illegible]	[illegible]	~~$\Delta m_{B_d};\ S_{\psi K_S}$~~
~~$(\bar{b}_R\,d_L)(\bar{b}_L d_R)$~~	[illegible]	[illegible]	[illegible]	[illegible]	~~$\Delta m_{B_d};\ S_{\psi K_S}$~~
~~$(\bar{b}_L\gamma^\mu s_L)^2$~~	[illegible]		[illegible]		~~Δm_{B_s}~~
~~$(\bar{b}_R\,s_L)(\bar{b}_L s_R)$~~	~~3.7×10^2~~		~~1.3×10^{-5}~~		~~Δm_{B_s}~~
$(\bar{t}_L\gamma^\mu u_L)^2$					same sign t's

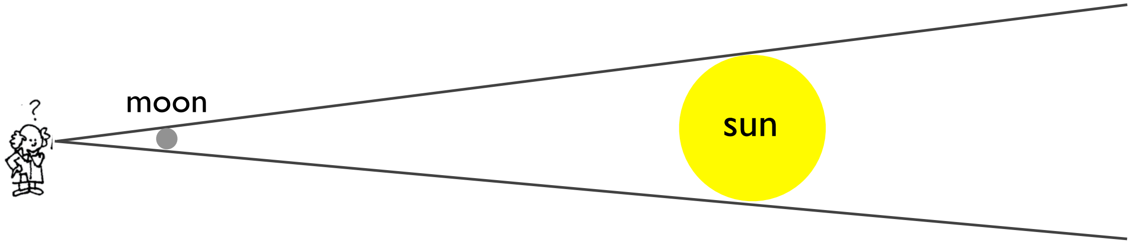
~~$\bar{L}_i\sigma^{\mu\nu}e_{Rj}F_{\mu\nu}$~~	1.7×10^4 ~~3.3×10^2~~ [illegible]			$Br\,(\mu\to e\gamma)$ ~~$Br\,(\tau\to\mu\gamma)$~~ ~~$Br\,(\tau\to e\gamma)$~~
$(\bar{\mu}\gamma^\mu P_L e)\,(\bar{u}\gamma_\mu P_L u)$	1.9×10^2			$\frac{\sigma(\mu^- Ti\to e^- Ti)}{\sigma(\mu^- Ti\to capture)}$

uFCNC remove immunities

The fine tuning problem

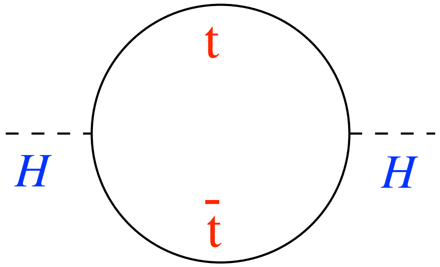
(ii) Why perturbations not destabilize system? <=> Fine tuning issue.

(displacing the sun by $\sim 10^{-19}\,\mathrm{m} \;\Rightarrow\; \delta\theta \sim 10^{-32}$)



“Additive” sensitivity / fine tuning due to top-Higgs coupling:

$$\left(m_W^2/m_{\mathrm{Pl}}^2\right)_{\mathrm{obs}} \sim \left(m_H^2+\delta m_H^2\right)/m_{\mathrm{Pl}}^2 \sim \; m_H^2 +$$



$$\sim 0.0100000000000000000000000000000001 - 0.01 \sim 10^{-32}$$

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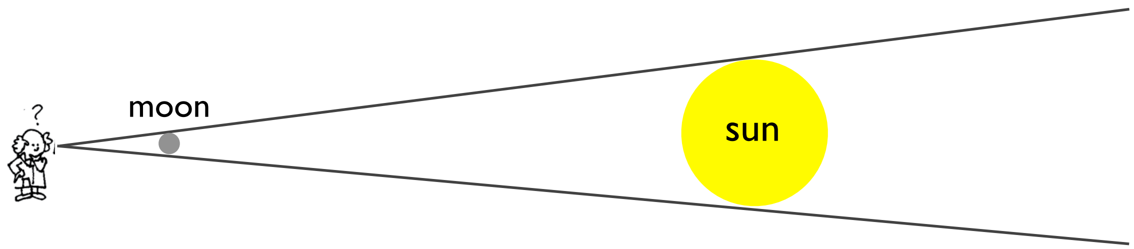

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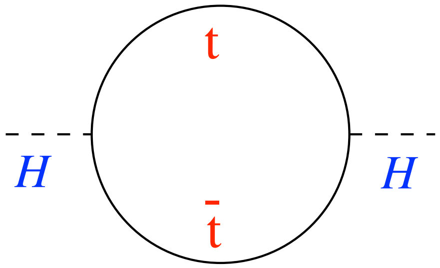

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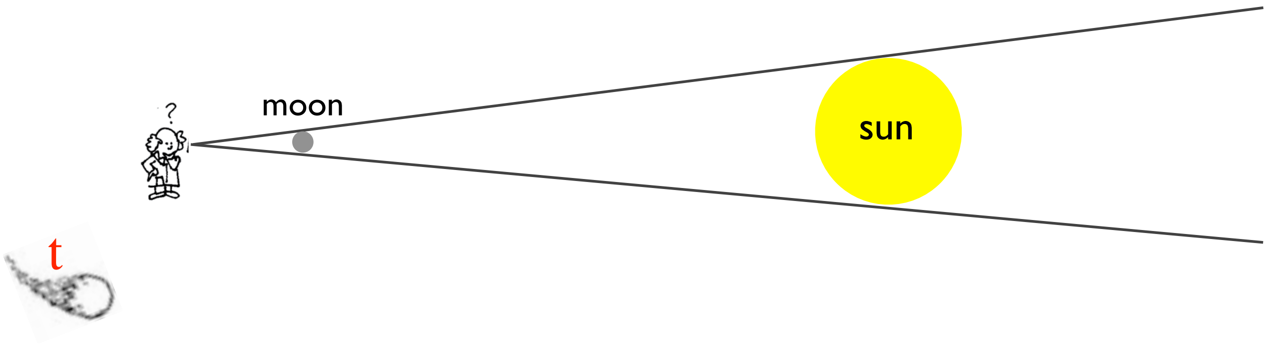

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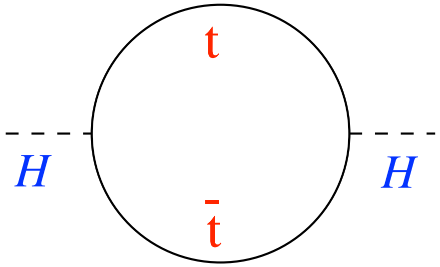

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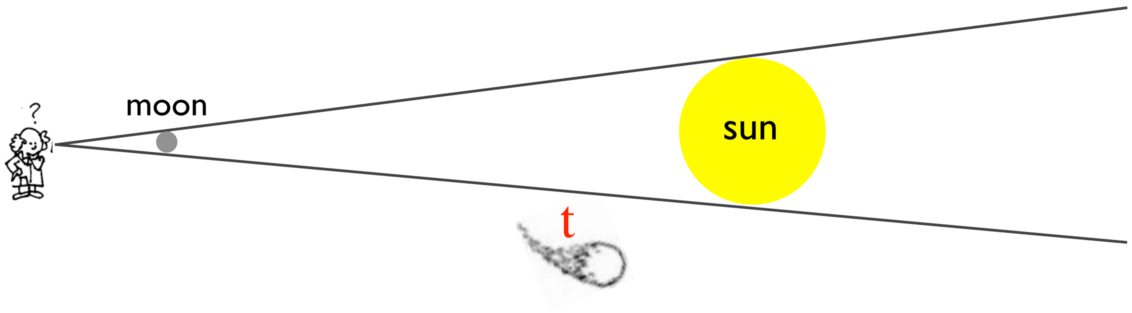

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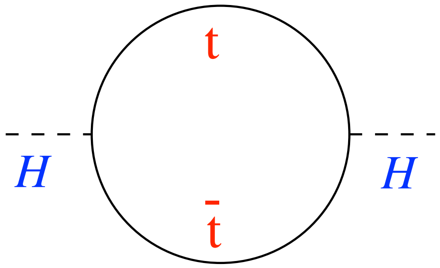

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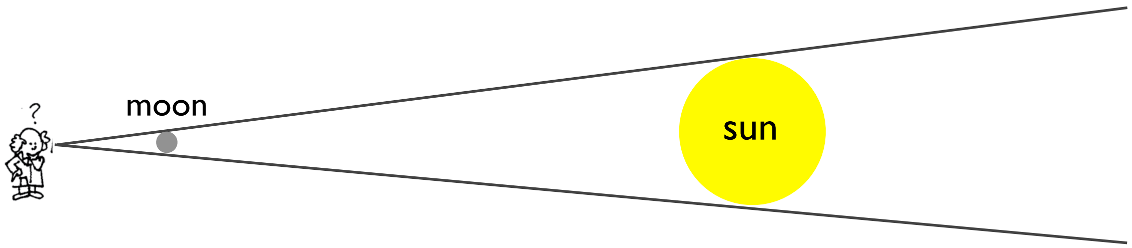

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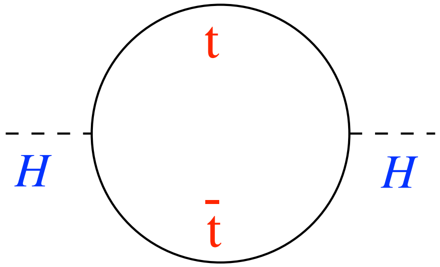

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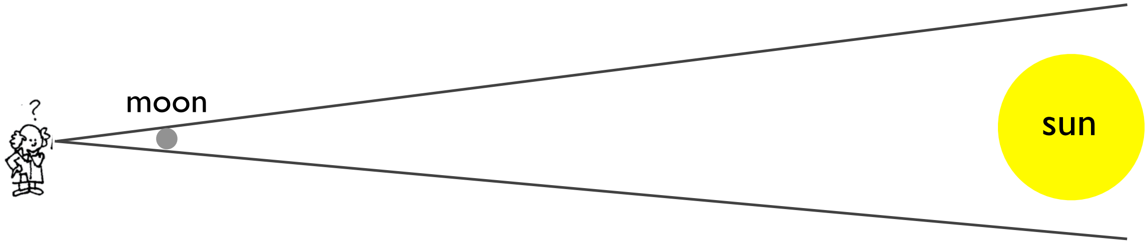

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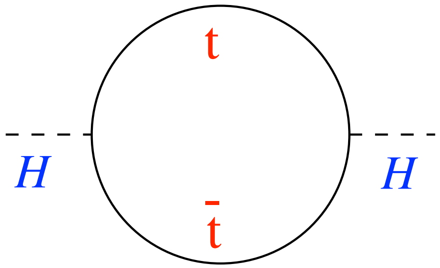

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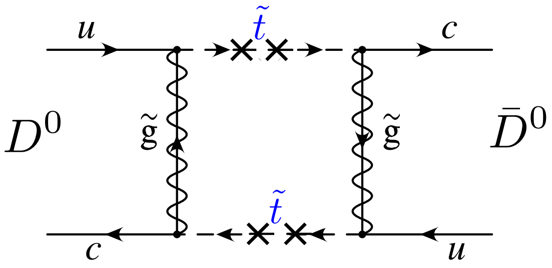
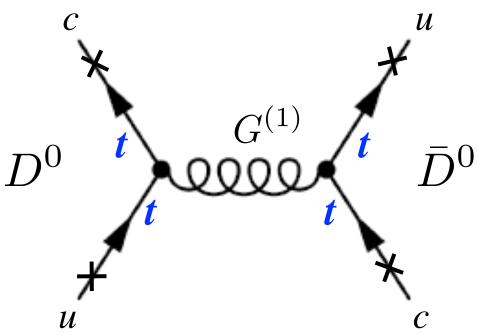
Fascinating Top Warped Physics @ LHC





SUSY

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