Implications of charm and top asymmetries for the TeV scale

Cédric Delaunay
CERN-TH

[hep-ph/very.soon]^2 *with*
J.F. Kamenik, G. Perez, L. Randall
&
L. da Rold, C. Grojean, G. Perez

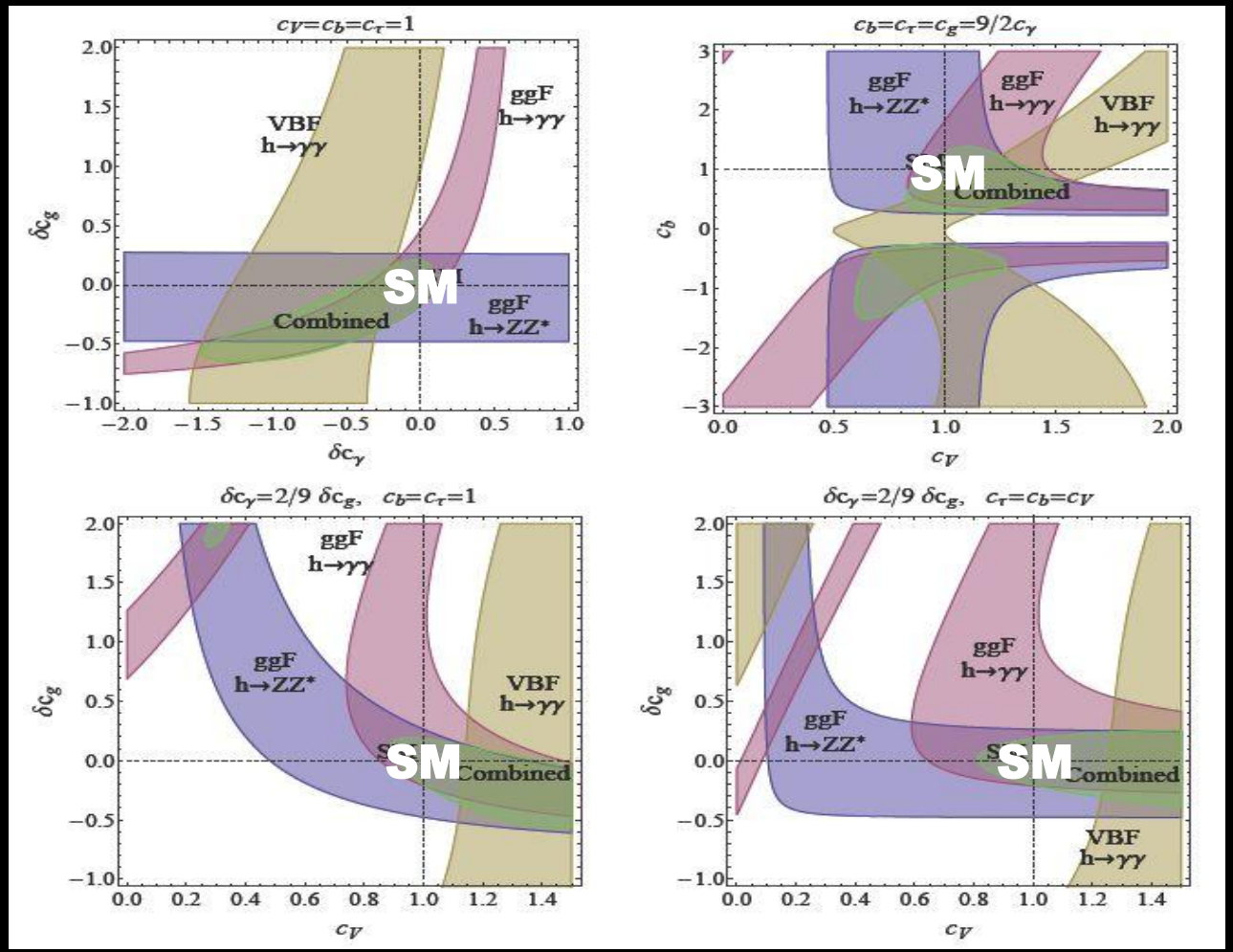
GDR 2012 meeting
Clermont-Ferrand| *24* Apr. *2012*

So far we learned from LHC7 that:

1) there is most likely a ~125 GeV Higgs and it is mostly SM-like…

$$\mathcal{L}_{eff} = c_V \frac{2m_W^2}{v} h W_\mu^+ W_\mu^- + c_V \frac{m_Z^2}{v} h Z_\mu Z_\mu - c_b \frac{m_b}{v} h \bar{b}b - c_\tau \frac{m_\tau}{v} h \bar{\tau}\tau$$
$$+ c_g \frac{\alpha_s}{12\pi v} h G^a_{\mu\nu} G^a_{\mu\nu} + c_\gamma \frac{\alpha}{\pi v} h A_{\mu\nu} A_{\mu\nu} \,.$$

= most generic L_{eff} *below* m_{top}

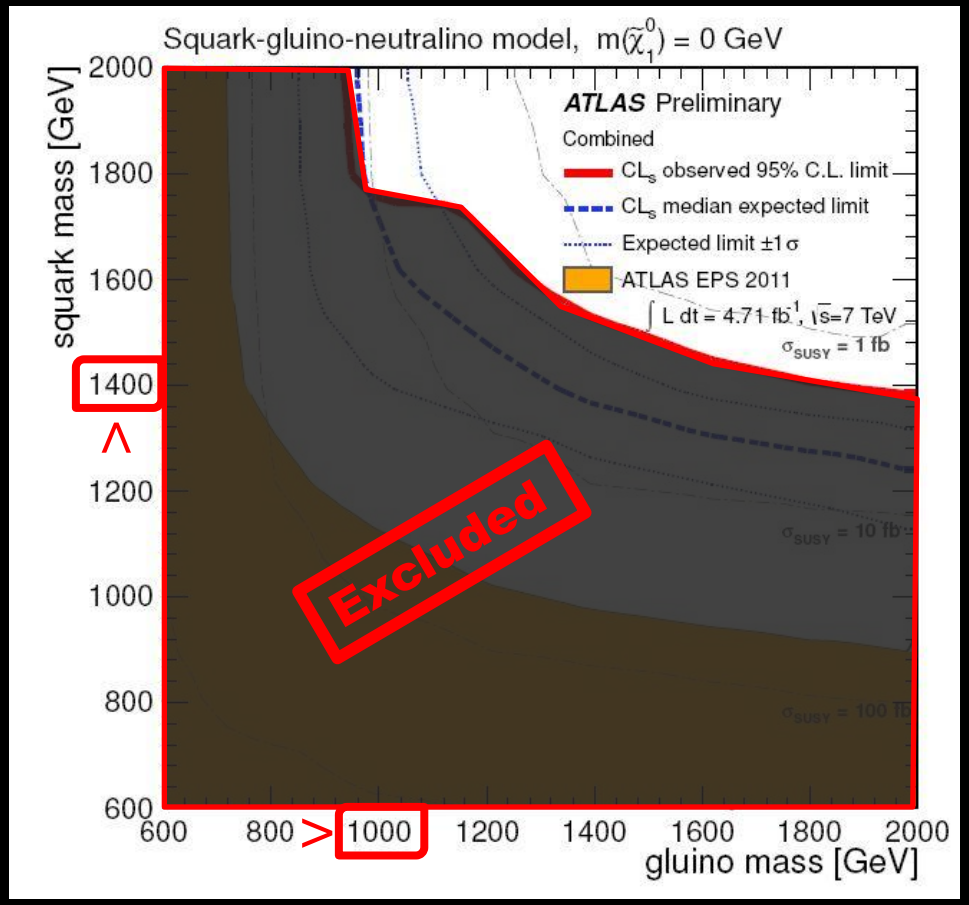


Carmi, Falkowski, Kuflic & Volansky '12

see also:

Contino et al.
Grojean et al.
Strumia et al.

2) while TeV scale SUSY remains elusive



ATLAS-CONF-2012-033

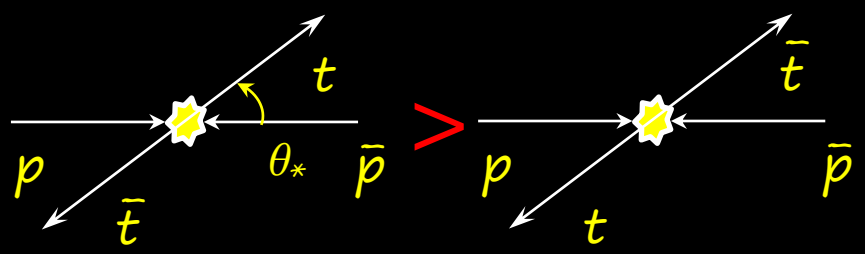
** assumes degeneracy of 1+2 generation squarks*

1)+2) seems a bit depressing for new physics enthousiasts…
…but there are other intriguing flavorful data!

Forward-backward asymmetry
in top pair production

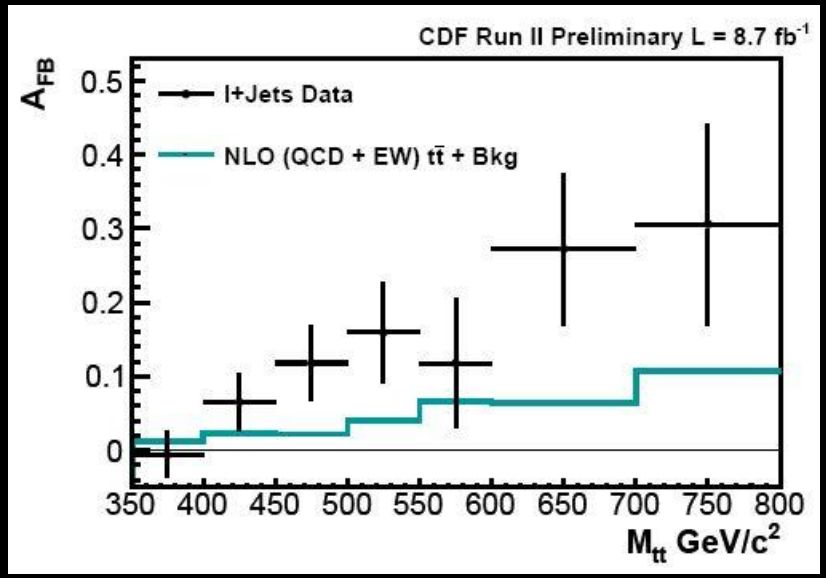
t-tbar forward-backward asymmetry: A_{FB}

- @Tevatron tops are produced preferentially along the direction of the proton
  → $A_{FB} > 0$ *and sizable!*



$$A_{FB}^{t\bar{t}} \equiv \frac{N(cos\theta_\star > 0) - N(cos\theta_\star < 0)}{+}$$

- o(5) CDF+DO concording measurements reported o(1) effects in asym. tt production, more pronounced @higher E



- amateur combination yields:

in ttbar rest frame:

$A_{FB}^{\text{inclusive}} \approx (18\pm4)\%$

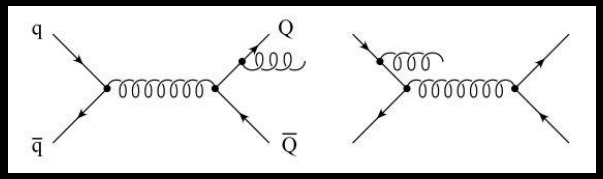
$A_{FB}^{>450\text{GeV}} \approx (28\pm6)\%$

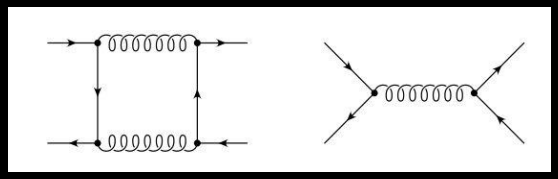
Forward-backward asymmetry in the SM

- CP invariance → $A_{FB} = A_C$ (charge asymmetry)
- QCD is C invariant → asymmetry only @higher α_s orders

$$A_{FB}^{QCD} = \frac{\alpha_s^3 \sigma_A^{(0)} + \alpha_s^4 \sigma_A^{(1)} + \dots}{\alpha_s^2 \sigma_S^{(0)} + \alpha_s^3 \sigma_S^{(1)} + \dots} \simeq \alpha_s \frac{\sigma_A^{(0)}}{\sigma_S^{(0)}}$$

- NLO: *Kuhn & Rodrigo '98*



$-\infty$ +  $+\infty$ = *finite* > 0 (few %)

- NNLO? unknown yet, but large log from soft glu' have been resummed!

[NLO+NLL] *Almeida, Sterman & Vogelsang '08*
[NLO+NNLL] *Ahrens et al. '10-11 | Kidonakis '11*
→ small effects ~NLO x 10%

- QCD+EW state of the art: $A_{FB}^{[\text{inclusive}|>450\text{GeV}]} \approx [6.6|10]\%$ → ~3σ tension

CP violation asymmetries
in charmed meson decay

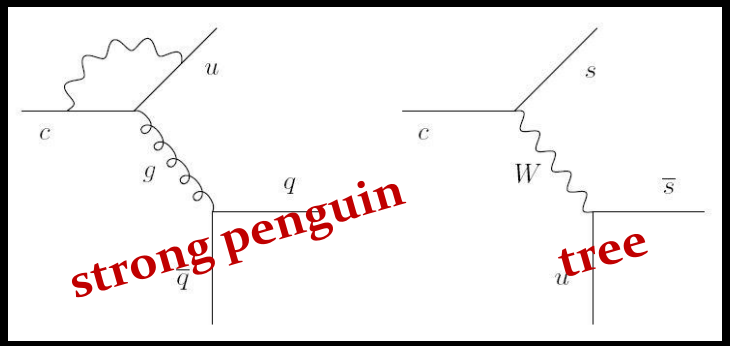
CP violation in SCS charm decay: Δa_{CP}

- $a_{CP}(ff) = \frac{\Gamma(D^0 \to f^+ f^-) - CP}{+}$, $\Delta a_{CP} = a_{CP}(KK) - a_{CP}(\pi\pi)$

- LHCb+CDF: $\Delta a_{CP} = (-0.656 \pm 0.154)\% = 0 - 4.26\sigma$ = SM??
- CPV in 2 generation systems is pertubatively suppressed:

$$\Delta a_{CP}^{SM} \sim arg[(V_{cd}^* V_{ud})/(V_{cs}^* V_{us})] \approx O(10^{-3})$$

- rates are \propto Penguin/Tree ~ $\alpha_s(m_c)/\pi \approx 0.1$



- but $m_c \sim \Lambda_{QCD}$ → overwhelming *uncalculable* long distance corrections

data requires $P/T \sim 3$, it seems hard to get, but answer is unknown...*could be NP!*

Implications for the TeV scale

- Why new physics @TeV? → Naturalness of $G_F \ll G_N$
  → *top quark comes with a top sector*

- We built hadron colliders → top related anomalies only observable if NP also knows of up quark (...or gluons)

- Top A_{FB} supports sizable NP coupling to **top + up** quarks
- Charm CPV suggests NP knows also of charm quark

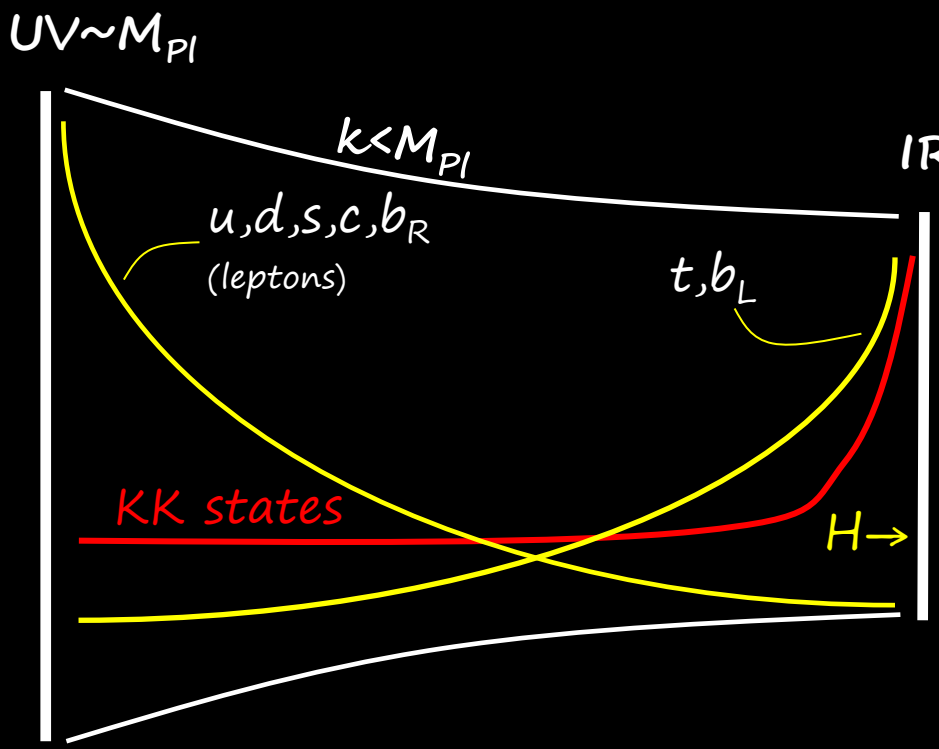
- naturalness+A_{FB}+Δa_{CP}, an interesting paradigm emerges:
  → new physics couples sizably to the (RH) up sector
  Damokles' sword = dijets
- is there a (technically) natural setup realizing this picture?
  → *a* N_{susy}=0 dedicated framework:
  warped extra-dimesion (or 4D composite Higgs)

Predictions of RS model with flavor anarchy

Warped essentials

RS'99: « Hierarchy problem is solved in AdS$_5$ bckg: $ds^2 = e^{-2ky} dx^2 - dy^2$ »

Flavor anarchy = $Y_{u,d}$ & $C_{Q,u,d}$ are generic, structureless flavor matrices



- EWPTs → m_{KK}>3-4TeV
  custodial symmetry @work
- SM flavor puzzle addressed
- NP flavor problem almost solved
  RSGIM @work, yet:

$Im[\epsilon_K]+Im[\epsilon'/\epsilon] \rightarrow m_{KK}$>5TeV

- a way out *(supported by Daya bay)*:

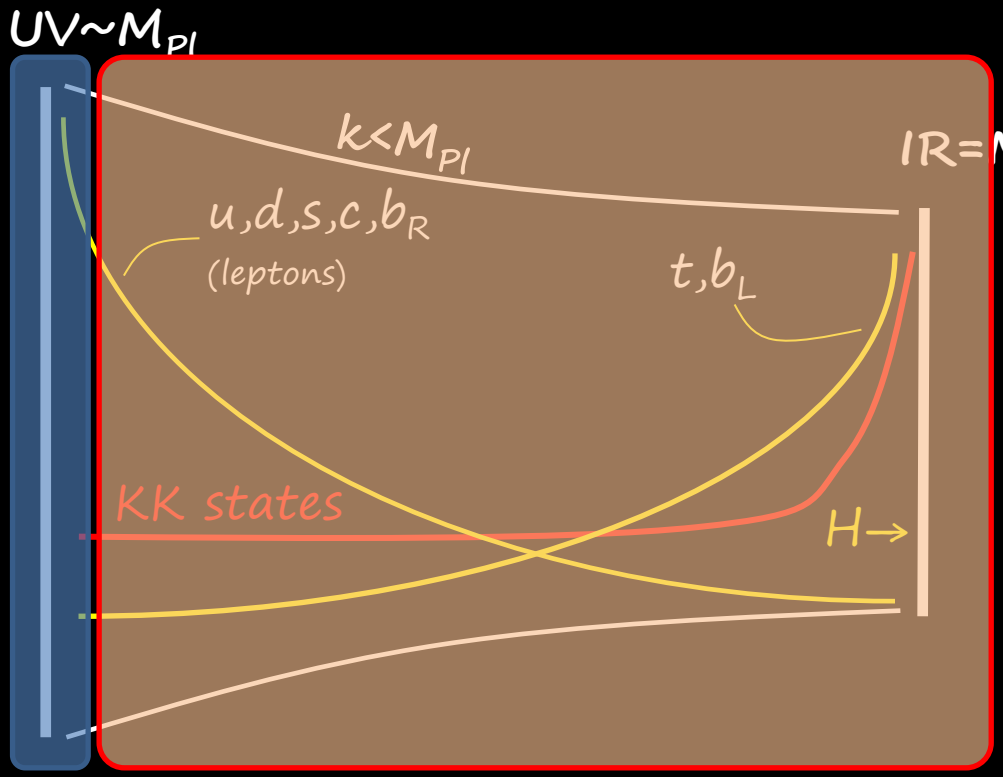
down alignment, but up anarchy

thanks to color strength couplings
KK-gluon is the main player @ hadron collider

Warped essentials

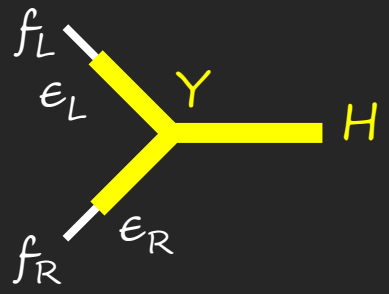
RS'99: « Hierarchy problem is solved in AdS$_5$ bckg: $ds^2 = e^{-2ky}\, dx^2 - dy^2$ »

Flavor anarchy = $Y_{u,d}$ & $C_{Q,u,d}$ are generic, structureless flavor matrices



elementary sector ← linear mixing → strong sector

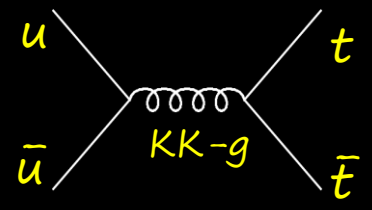
partial compositeness in 4D:



$$Y_{SM} = \epsilon_L Y\, \epsilon_R$$

RS + flavor anarchy

✓ top AFB? we need $(\bar{u}u)_A(\bar{t}t)_A$ w/ $\Lambda \approx TeV$ *e.g.* Weizmann group '11



elementary up has suppressed vector-like coupling to KK-g → no AFB!

✓ charm CPV? two possible NP routes:

→ $(\bar{u}c)_{V+A}(\bar{q}q)_{V+A}$ w/ $\Lambda_{4f} \approx 15 TeV$ *(potential DDbar issue* Isidori et al '11*)*

q=u,d or s → elementary light quarks → $\Lambda_{4f} >> 15 TeV$ *...hopeless*

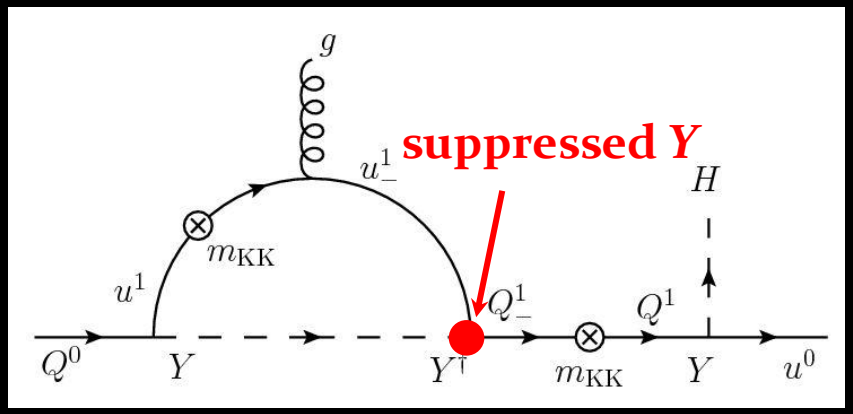
→ $g_s m_c \bar{u}_L \sigma_{\mu\nu} G^{\mu\nu} c_R$ w/ $\Lambda_8 \approx 20 TeV$ *(chirality flipping → no Ddbar tension* Grossman, Kagan, Nir '06*)*

light quark compositeness is swallowed in m_c → *hope!*

Charm CPV from a chromo-dipole operator

CD, Kamenik, Perez & Randall '12

- flavor changing dipole induced at 1-loop by Yukawa int.
- bulk Higgs: «wrong» chirality KK fermions dominate



$$C_8 = \frac{\lambda_c Y_5^2}{16\pi^2 m_{KK}^2} O_\beta$$

H overlap corr. ≈0.1 for $\beta=0$

$\rightarrow \Delta a_{CP} = 0.6\%$ for $m_{KK}=3\text{TeV}$, $Y_5=6$

- First implications:
  - overlap suppression requires a larger *Y* than in generic 4D duals
    → DDbar mixing in 5D is typically more suppressed
  - gluon coupling is flavor blind → $a_{CP}(KK) \sim a_{CP}(\pi\pi)$

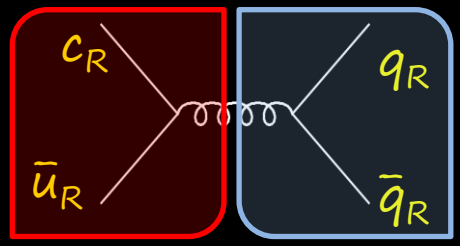
Predictions of RS model with RH quark compositeness

see *e.g.* CD, Gedalia, Lee, Perez, Ponton '10
& Redi, Weiler '11

Charm CPV from composite RH light quarks

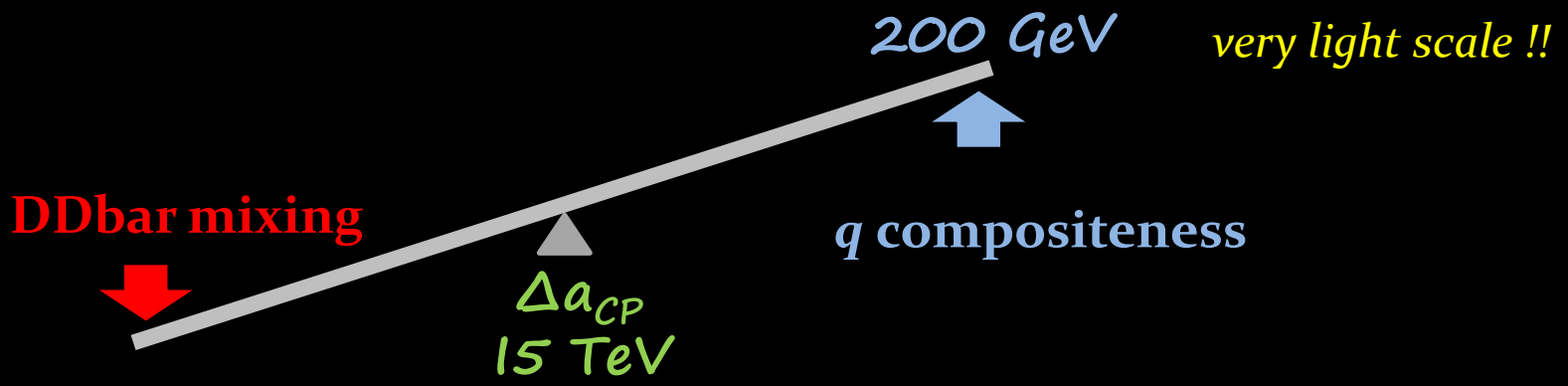
Da rold, CD, Grojean & Perez '12

- for *S*-channel mediated *ubar c* → *qbar q* transitions:



$$\rightarrow \frac{1}{\Lambda_{uc}} \times \frac{1}{\Lambda_{qq}} \approx \frac{1}{(15\ \text{TeV})^2}$$

- The D meson see-saw: $\Lambda_{\Delta c=2} \approx 1200\,\text{TeV} \gg \Lambda_{\Delta c=1} \approx 15\,\text{TeV}$

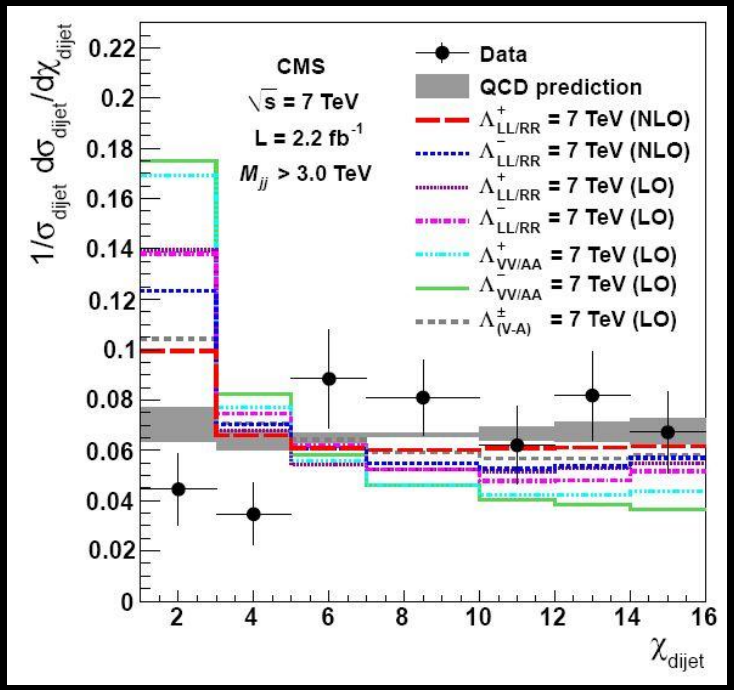


- $q=u,d$ excluded $\Lambda_{uu} \geq 3\,\text{TeV}$
  → what if $q=s$?
- 200GeV implies strong coupling:
  $\Lambda_{NDA} \sim 200\,\text{GeV} \times 4\pi \approx 2.5\,\text{TeV}$

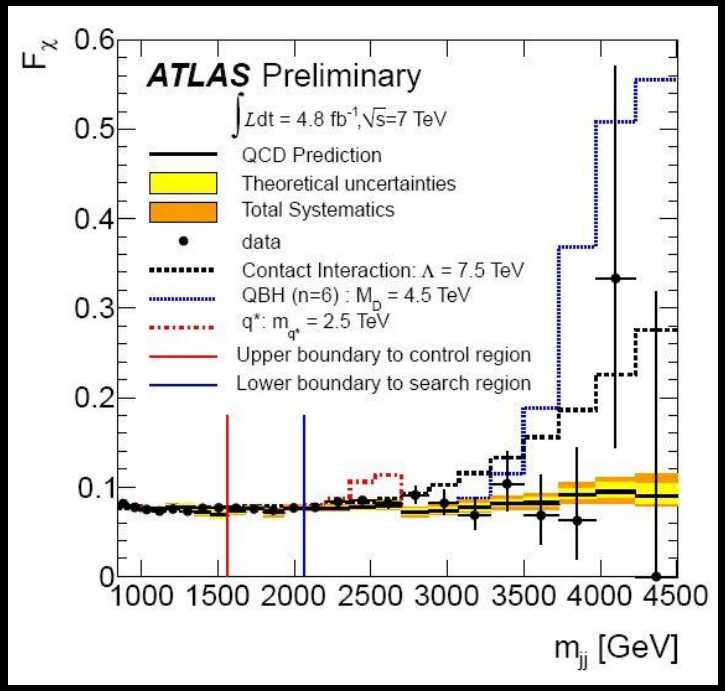
Dijet searches & compositeness scale

- Dijet searches sensitive to 4F operators involving light quarks
- strategy:
  - **QCD** mostly produces forward jets (exchange of massless particles in t-channel)
  - Contact interactions produce more isotropic jets → dominates @low y
  - construct angular variable $\chi = exp(2y)$ to exploit the different kin.

$\sigma^{-1} d\sigma/d\chi$ from CMS



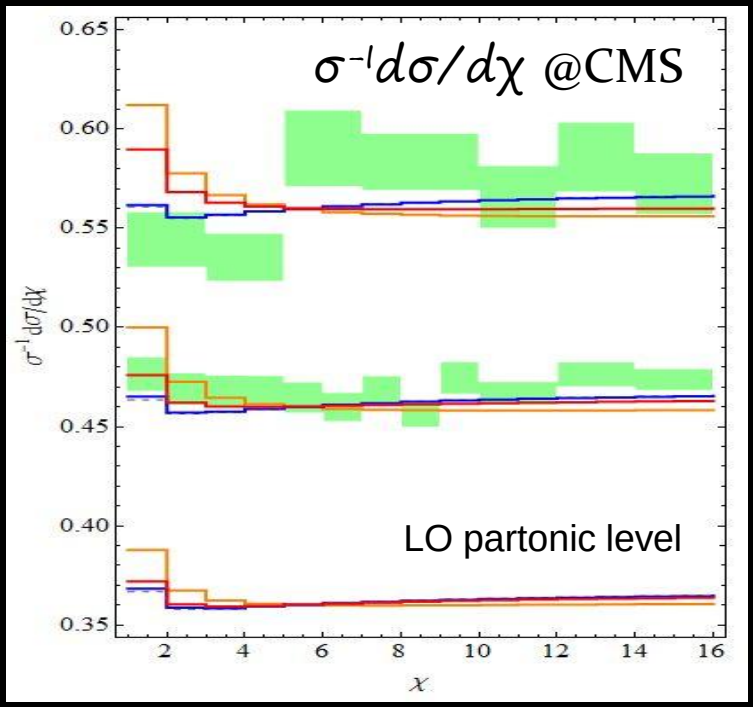
$F_\chi = \sigma(y<0.6)/\sigma(y<1.7)$ from ATLAS

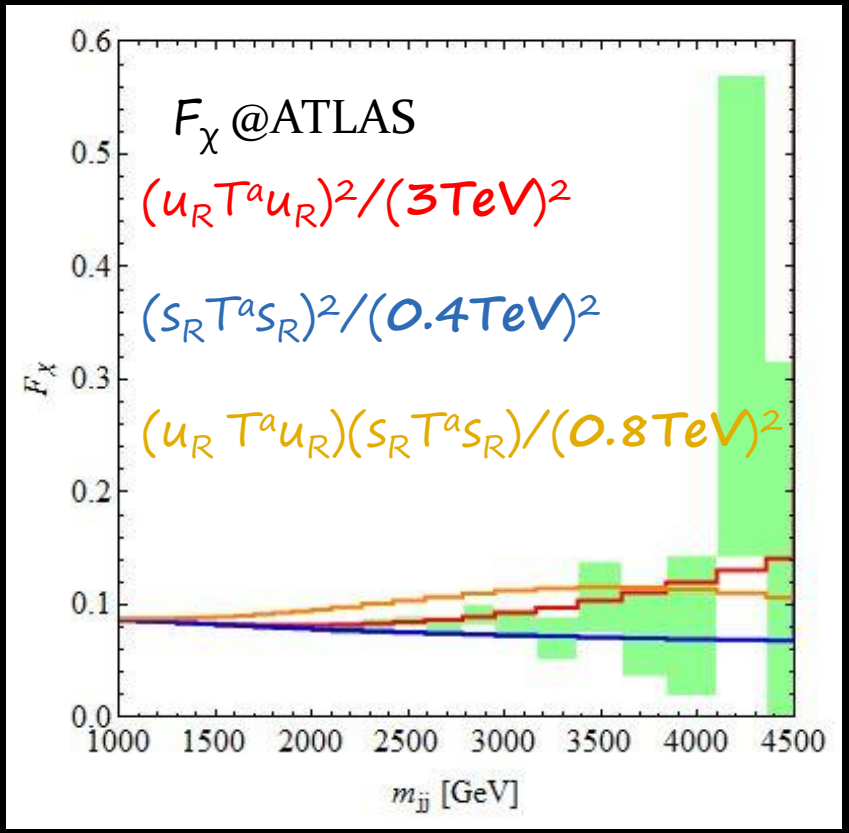


Light quark compositeness vs. dijet searches

Da rold, CD, Grojean & Perez '12

Δa_{CP} from s-channel FCNC → $(s_R\, s_R)^2/(200\text{GeV})^2$





- color octet favored bounds for singlet is ~√3 stronger
- typically negative Wilson coefficient induced

mild tension but:
- NP matrix elem. for charm direct CPV are unknown
- NLO QCD corr. applied to NP weakens bounds by $o(20\%)$

Large A_{FB} from RH compositeness

Da rold, CD, Grojean & Perez '12

- composite u_R → large A_{FB}, but from a «chiral» KK-gluon

  $(uu)_{V+A}(tt)_{V-A}$ → @interference level: $\delta A_{FB}^{>450} \approx -0.2 \times \delta\sigma_{700-800} < 10\%$

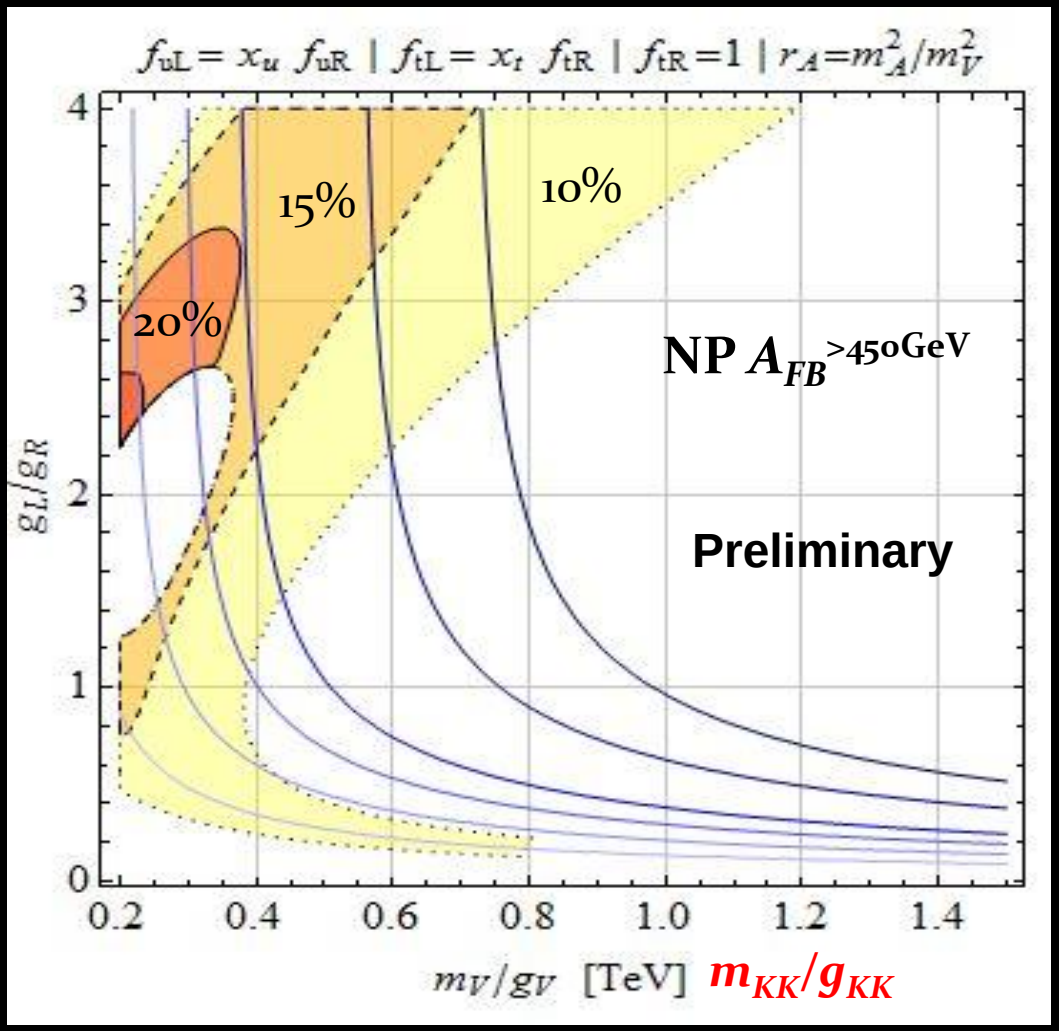
  could be good enough but recall Damocles' sword!

CMS: «u_R composite scale > 3TeV» → max $\delta A_{FB}^{>450} \approx 6\%$ (m_{KK}=3TeV | g_5=7)

- larger AFB? need an axigluon-like state
  one way is to extend color to $SU3_L \times SU3_R$
  which breaks down to QCD in the IR by $\langle\phi\rangle \sim (3^*,3)$

RS + color SU3xSU3

Da rold, CD, Grojean & Perez '12



+ charm CPV? also available from composite strange

→ this setup can accomodate large NP A_{FB} + a_{CP} …
… and it's technically natural

Conclusions/outlook

- Naturalness+a_{CP}+Daya bay supports RS (or composite Higgs) with flavor anarchy in the up-sector and alignment in the down-sector.

  flavor implications → no DDbar mixing
  + AFB is QCD-like
  + $a_{CP}(KK) \sim a_{CP}(\pi\pi)$

- Naturalness+A_{FB}+a_{CP} leads to an interesting alternative flavor paradigm @TeV: « RH quarks are composite objects »

  implications → DDbar mixing + dijets right around the corner + $a_{CP}(KK) \gg a_{CP}(\pi\pi)$