The flavor problem of RS and the holographic pGB Higgs

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2nd general meeting
Interplay of Collider and Flavour Physics

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From 14:16 until 14:36

Finetuning ?

RS is an interesting theory of flavor but has a flavor problem.

Possible ways out?

The SM flavor puzzle

$$Y_D \approx (10^{-5}, 0.0005, 0.026)$$

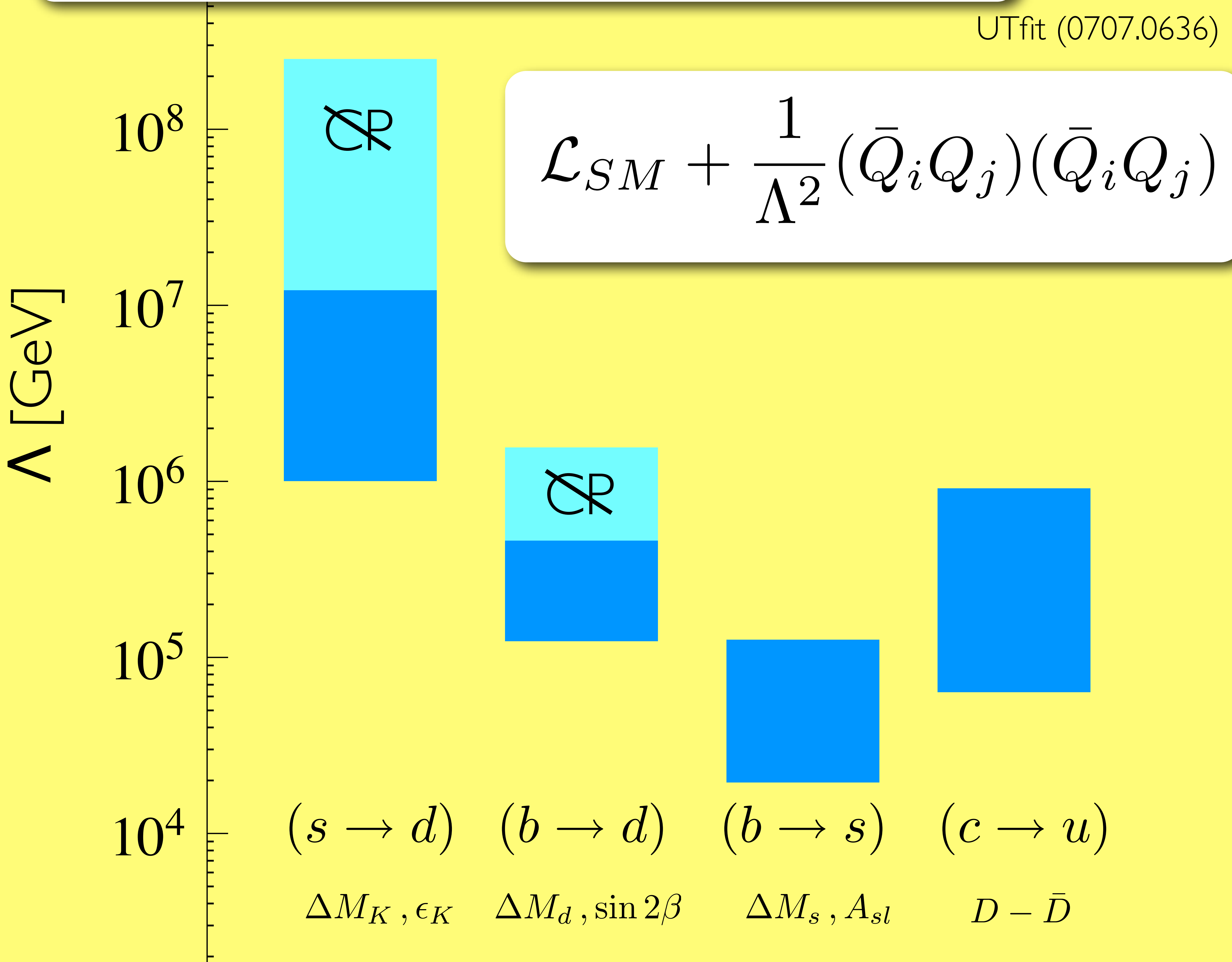
$$Y_U \approx \begin{pmatrix} 10^{-5} & -0.002 & 0.007 + 0.004i \\ 10^{-6} & 0.007 & -0.04 + 0.0008i \\ 10^{-8} + 10^{-7}i & 0.0003 & 0.96 \end{pmatrix}$$

The SM flavor parameters have structure:
small & hierarchical. Why?

Compare to: **g_s ~1, g ~ 0.6, g ~ 0.3, λ_{Higgs} ~ 1**

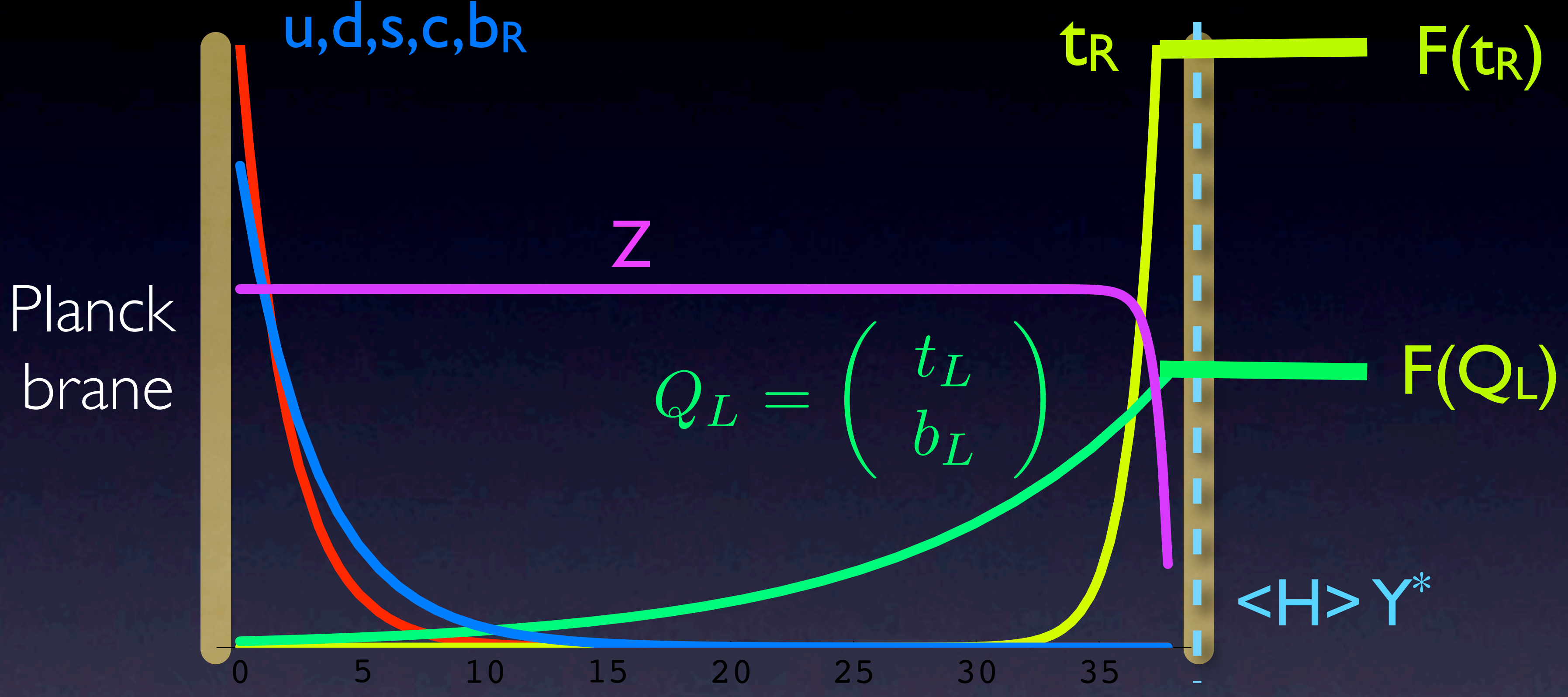
Bounds on generic flavor violation

$$\mathcal{L}_{SM} + \frac{1}{\Lambda^2}(\bar{Q}_i Q_j)(\bar{Q}_i Q_j)$$



Hierarchies without symmetries

Arkani-Hamed, Schmaltz; Grossman, Neubert; Gherghetta, Pomarol



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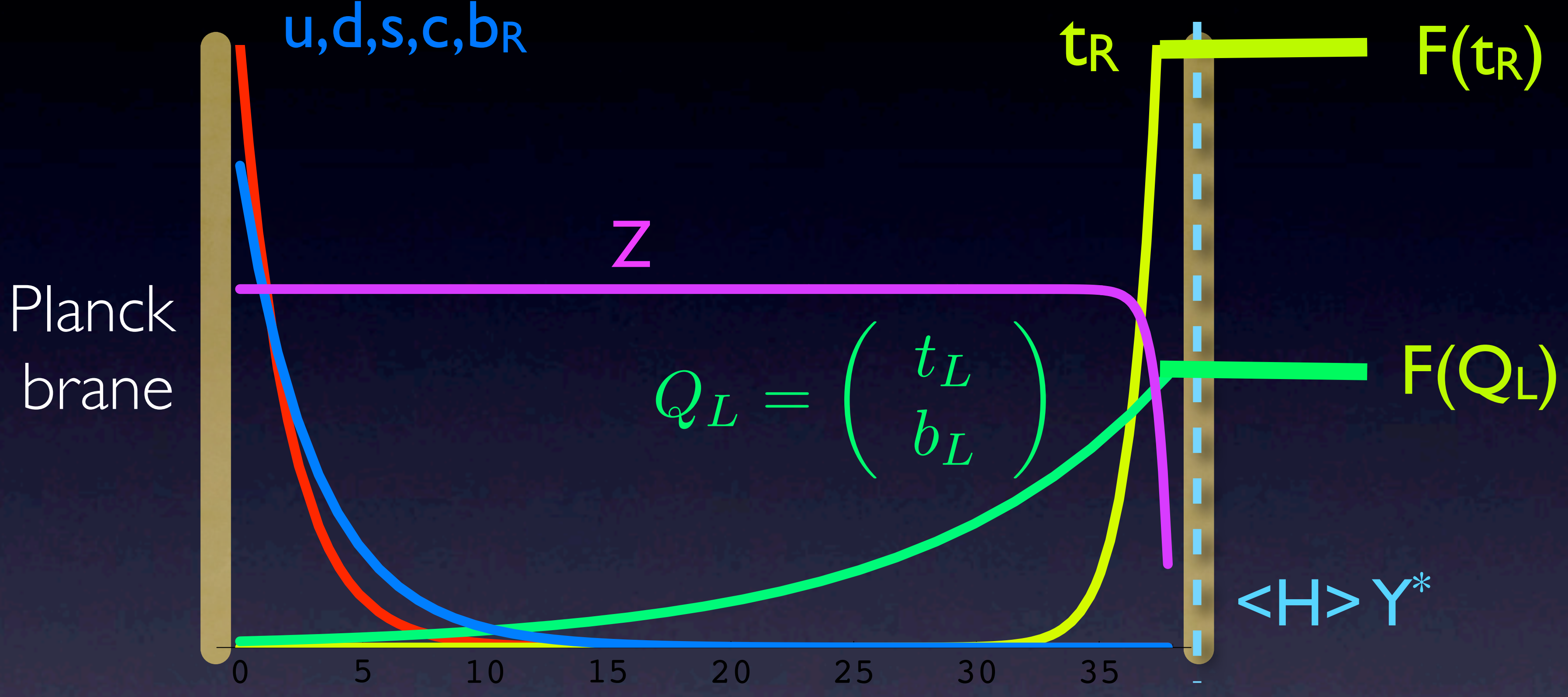
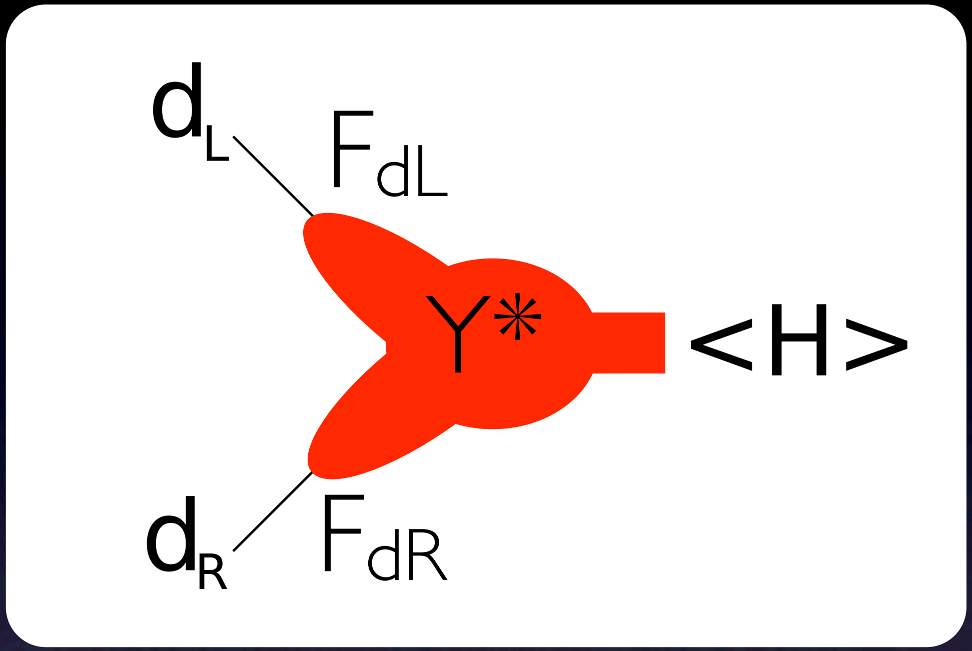


- Can explain SM flavor puzzle starting with anarchic Yukawas
- Exponential hierarchies natural, $F(c) \sim (\mathrm{TeV/Planck})^{2c-1}$
- Predicts $V_{12} V_{23} \sim V_{13}$

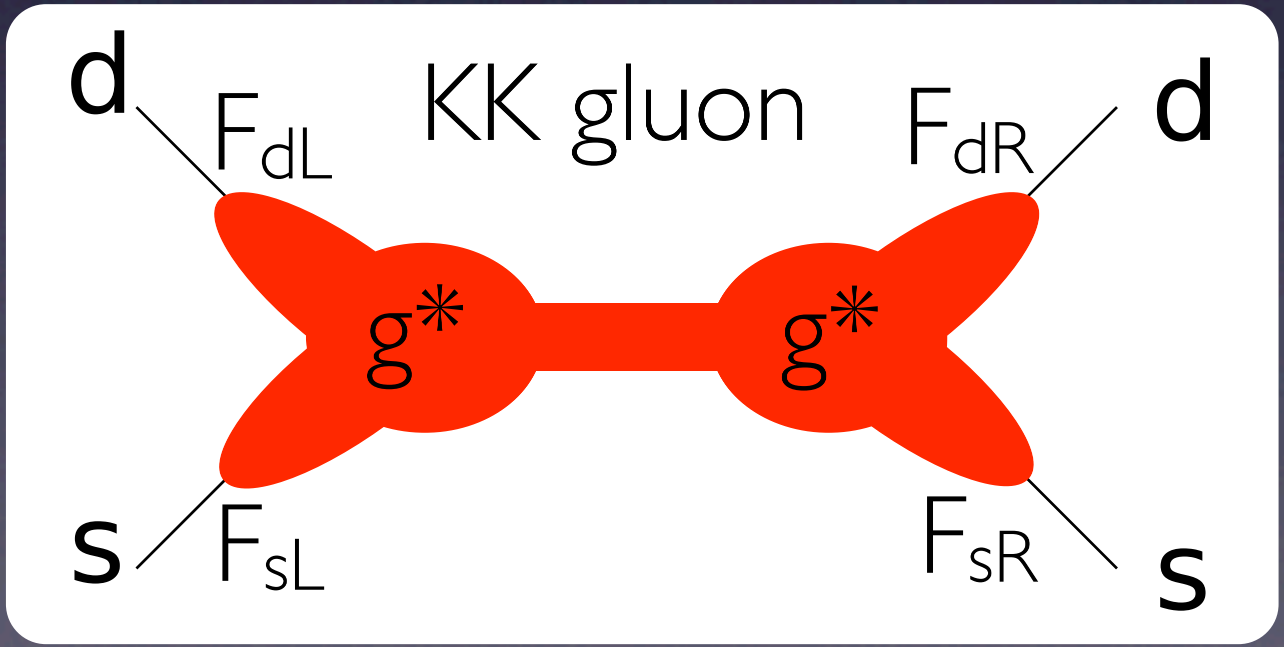
Masses, mixings and FCNCs

Gherghetta, Pomarol; Huber; Agashe, Perez, Soni



Masses and mixings from hierarchical overlaps

$$m_d \sim v\, F_{d_L} Y^* F_{d_R}$$



KK gluon FCNCs due to the same small overlaps F_i :

$$\sim \frac{(g^*)^2}{M_{KK}^2} F_{d_L} F_{d_R} F_{s_L} F_{s_R}$$

$$\sim \frac{(g^*)^2}{M_{KK}^2} \frac{m_d\, m_s}{(vY^*)^2}$$

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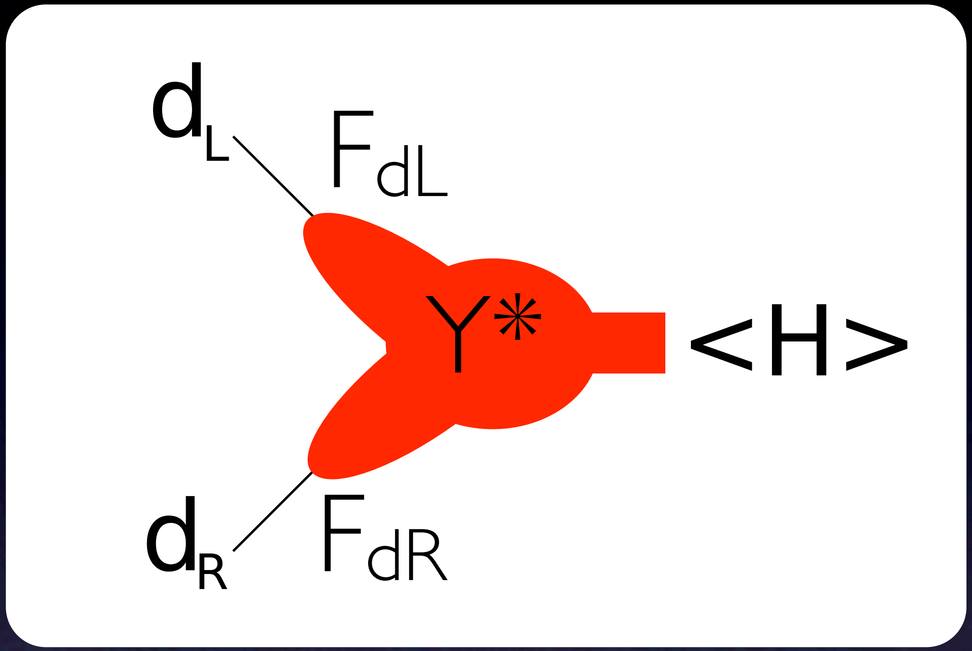

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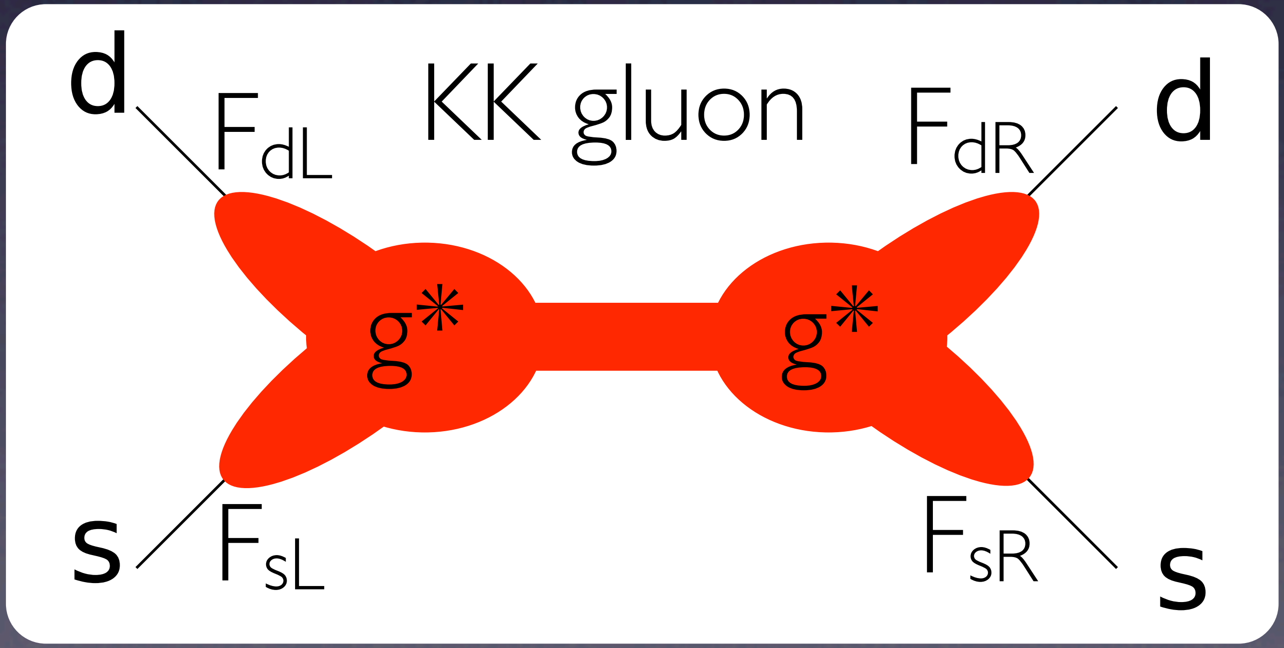
RS GIM



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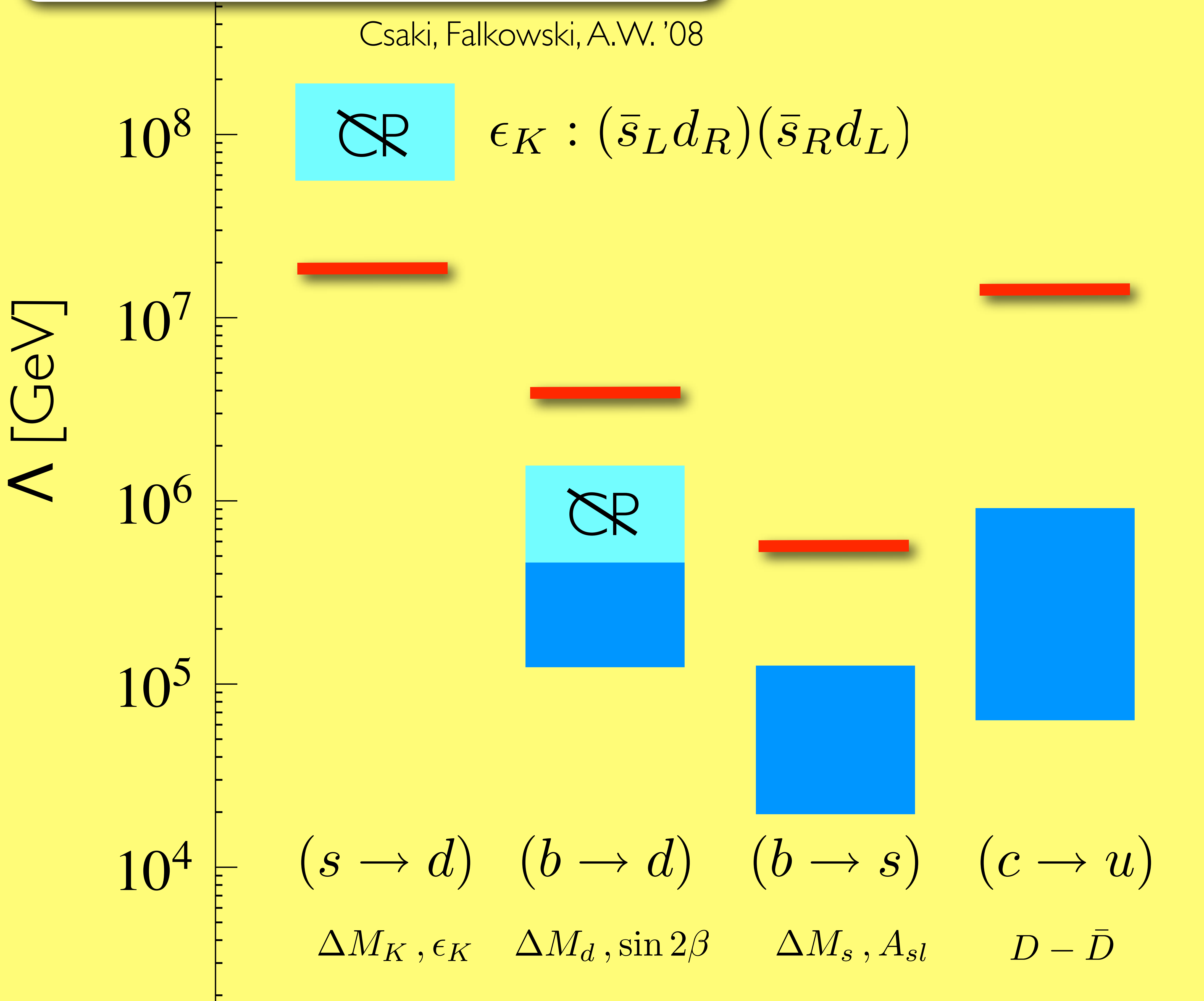
RS flavor almost works



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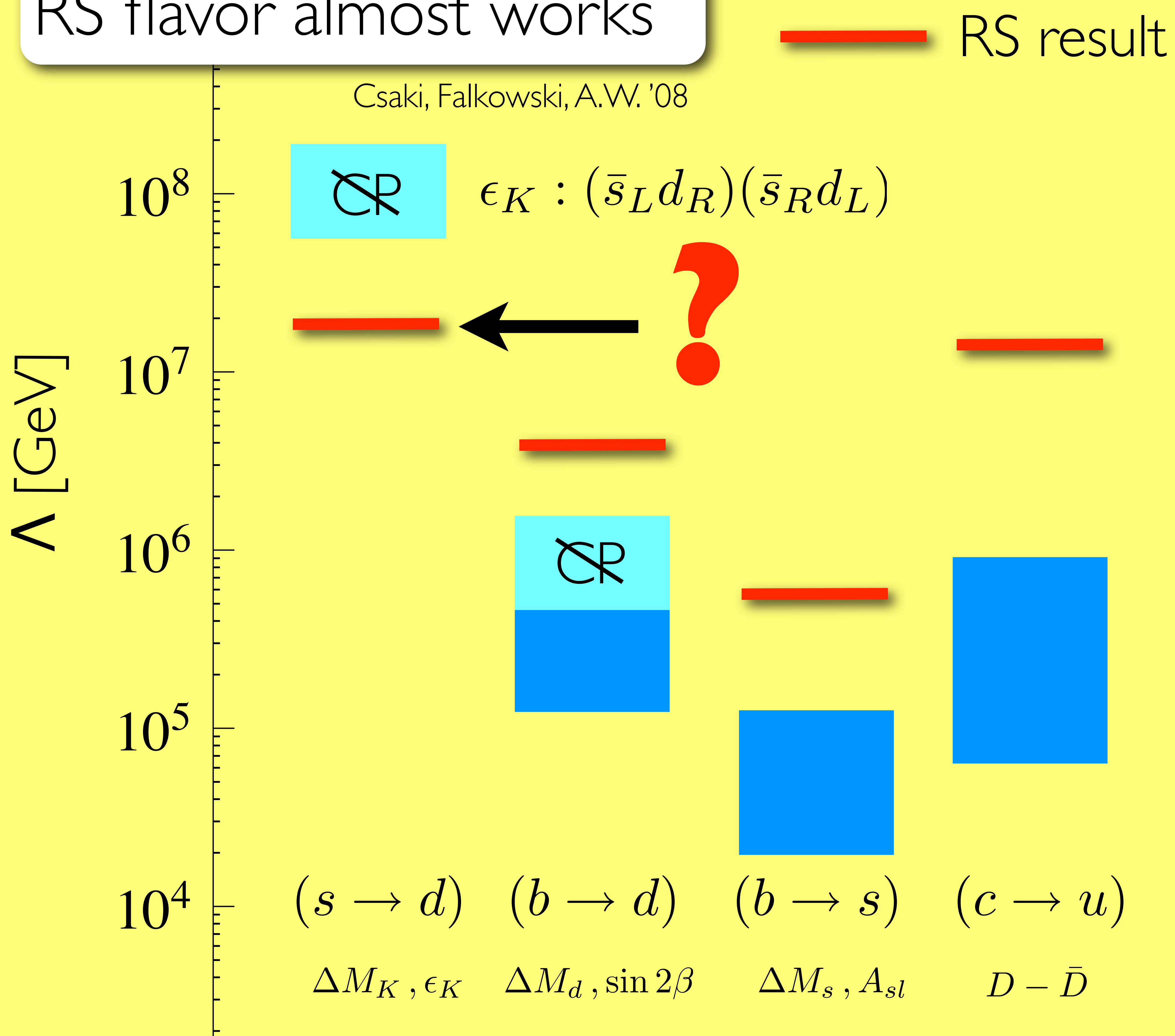
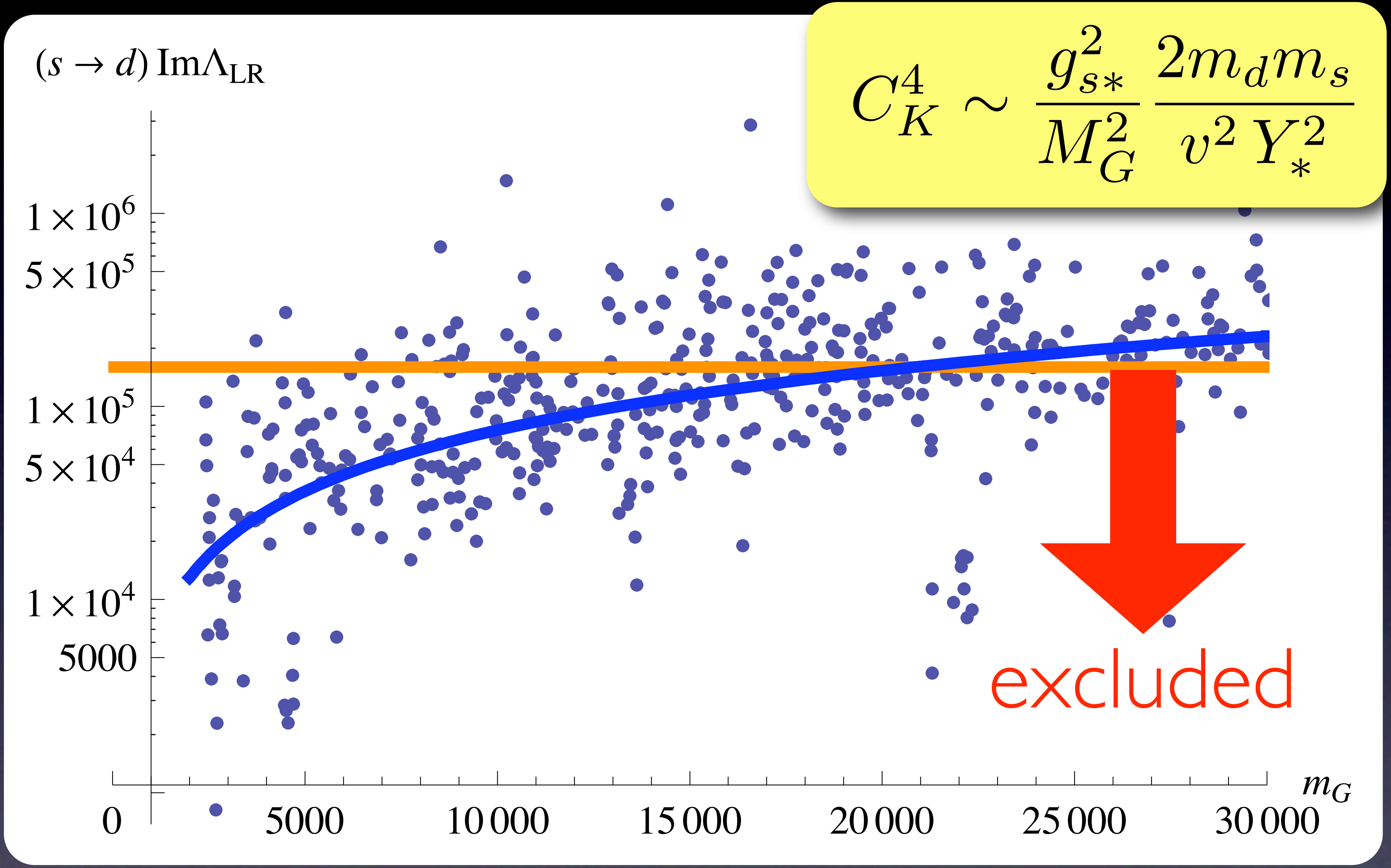


Csaki, Falkowski, A.W. '08

KK gluon mass bound in RS

Csaki, Falkowski, A.W.; Buras et. al.



$$C_K^4 \sim \frac{g_{s*}^2}{M_G^2}\frac{2m_d m_s}{v^2\,Y_*^2}$$

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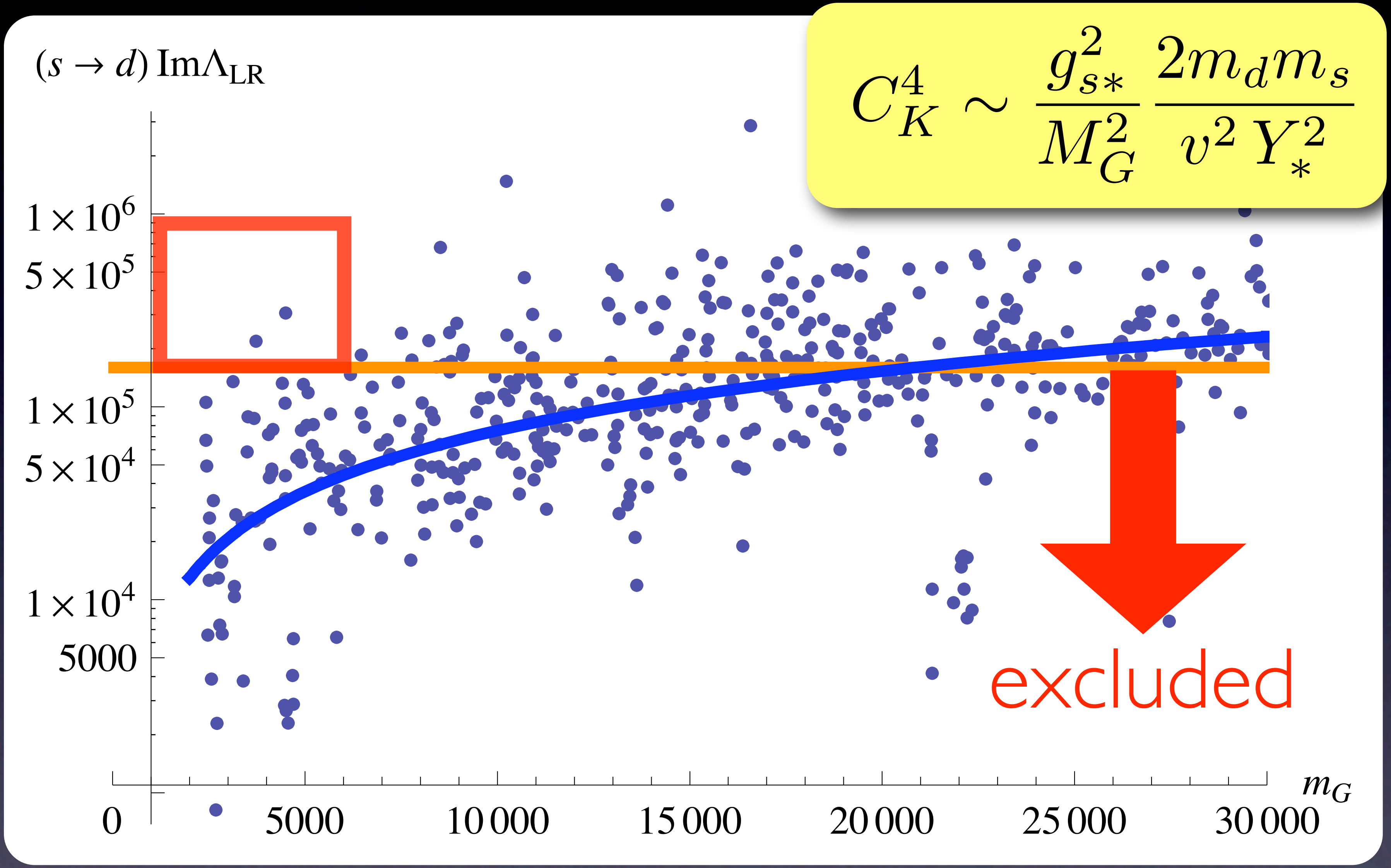

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Some points are ok: any rationale to live here?

Radiative stability?

Bound depends on $\mathbf{g_{s*}}$ and $\mathbf{Y_*}$

Holographic pGB Higgs model

Agashe, Contino, Pomarol

Simple model with

- A_5 zero mode $\in SO(5)/SO(4)$ = **Higgs**
- UV insensitive, dynamical EWSB
- small corrections to S,T,U, $Z\underline{b}b$

Holographic pGB Higgs model

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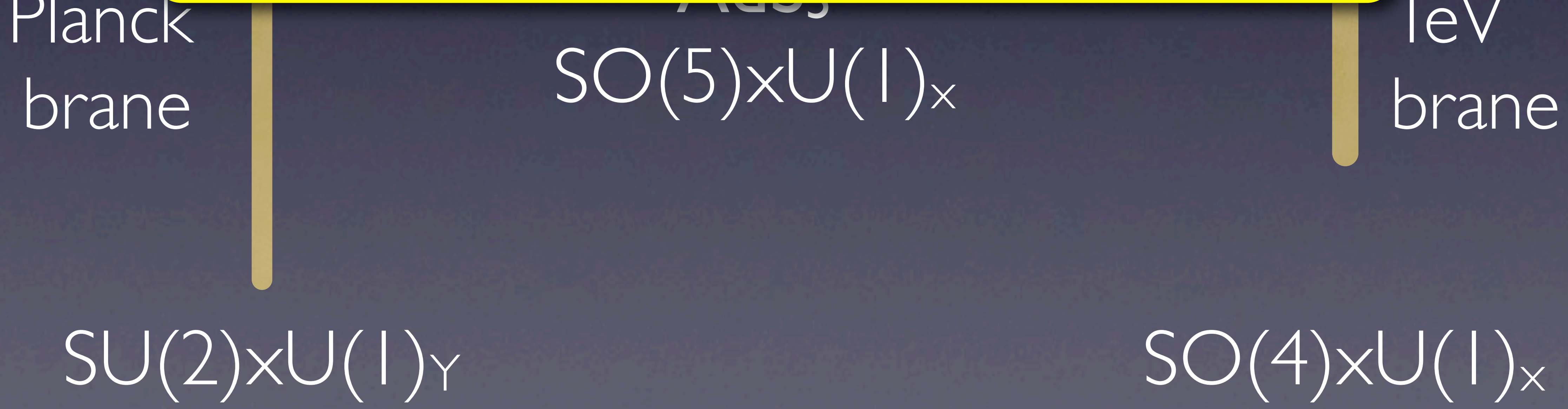
Simple model with

- A_5 zero mode ∈ SO(5)/SO(4) = **Higgs**
- UV insensitive, dynamical EWSB
- s

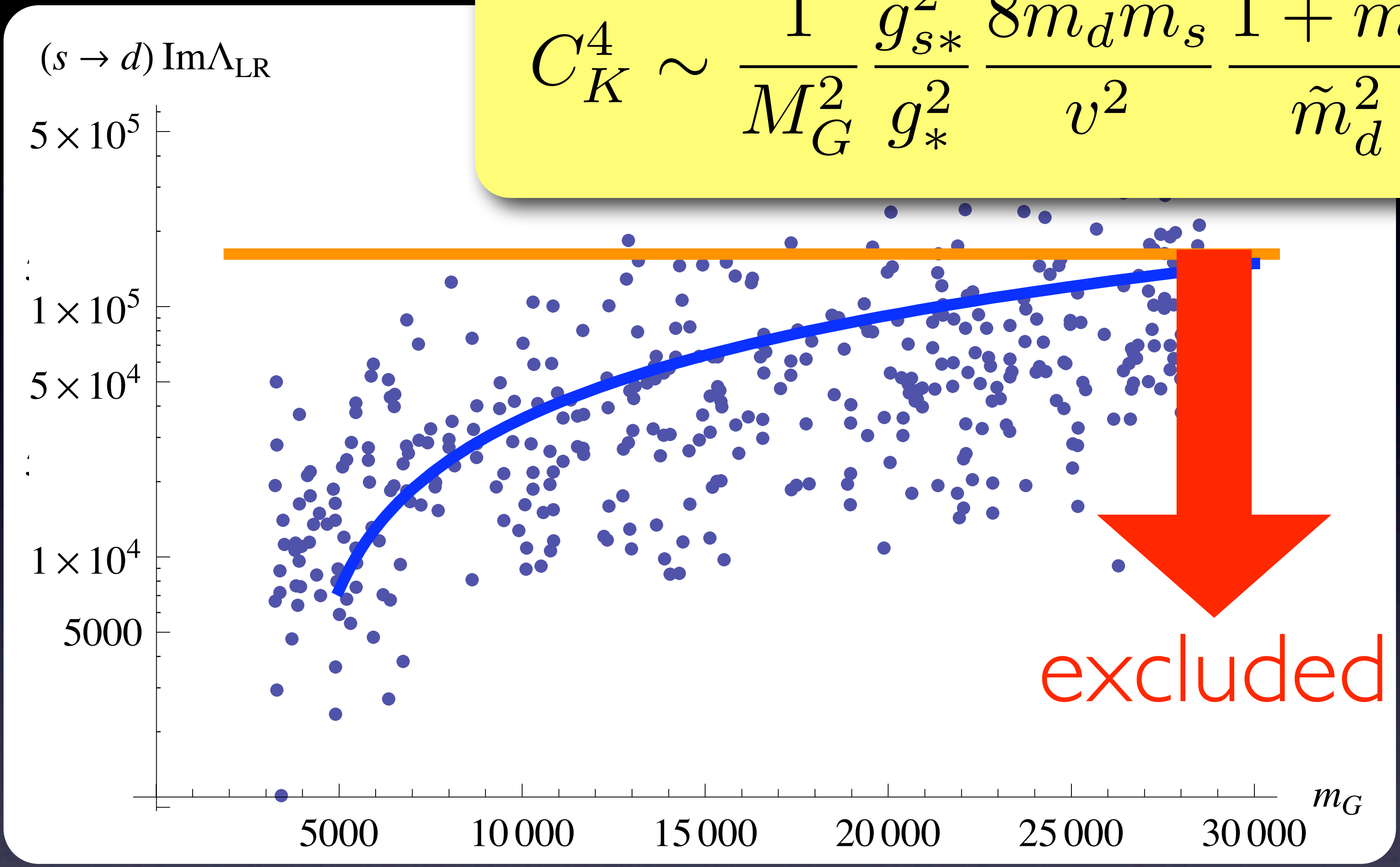
Dual to pGB composite Higgs (Georgi, Kaplan ’83)



Bound for pGB Higgs

Csaki, Falkowski, A.W.;

$$C_K^4 \sim \frac{1}{M_G^2} \frac{g_{s*}^2}{g_*^2} \frac{8 m_d m_s}{v^2} \frac{1+m^2}{\tilde{m}_d^2}$$



$M_{KK} > 30$ TeV

FCNC constraint more severe in composite pGB!

Why? $Y^* \rightarrow g_* / 2$ & fermionic kinetic mixings

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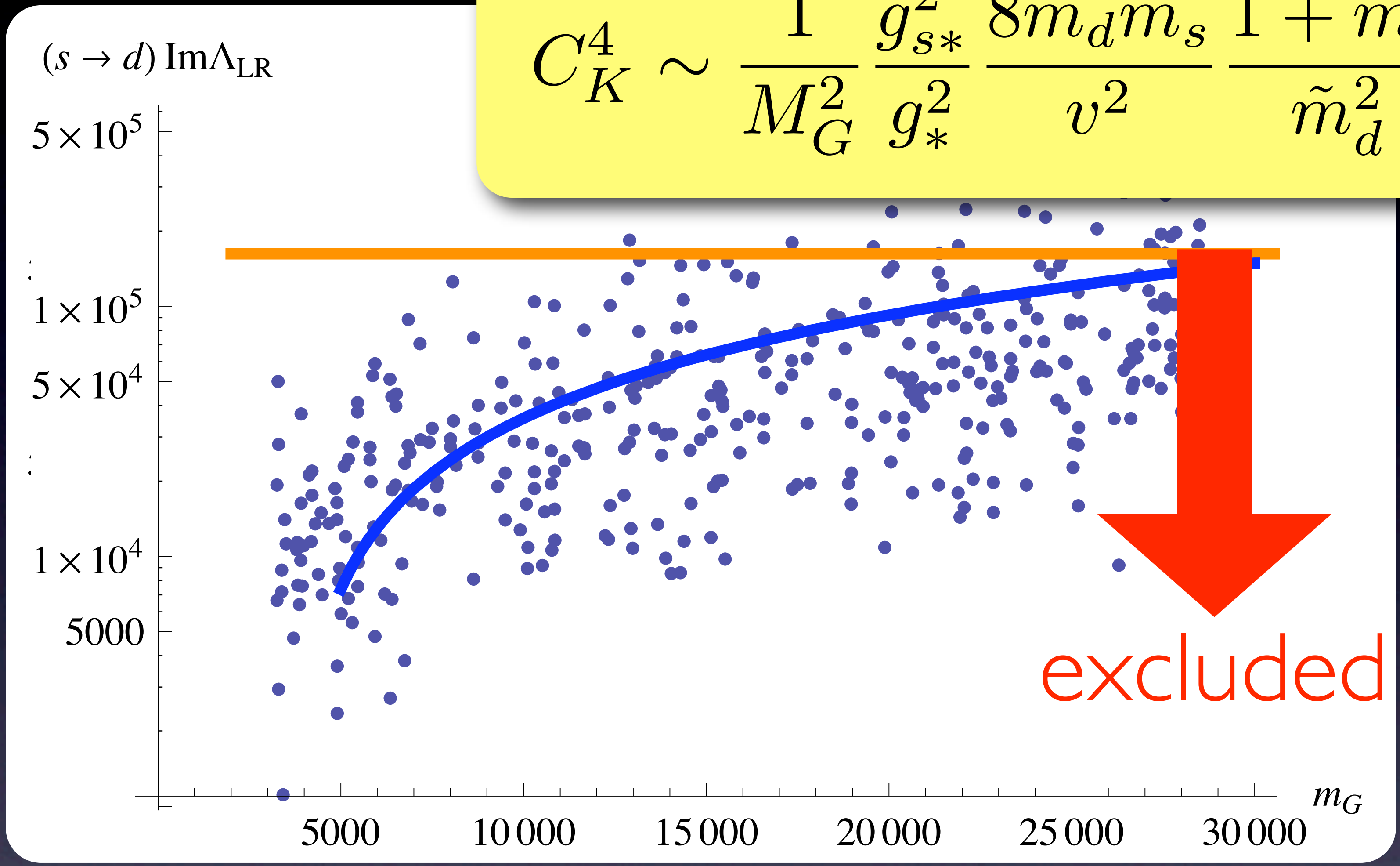


excluded

$M_{KK} > 30$ TeV

FCNC constraint more severe in composite pGB!

Why? Y^* → $g_* / 2$ & fermionic kinetic mixings

Bounds with caveats

Main problem is CPV LR contribution to $\epsilon_K : (\bar{s}_L d_R)(\bar{s}_R d_L)$

$$C_{4K}^{RS} \sim \frac{g_{s*}^2}{M_G^2}\frac{1}{Y_*^2}\frac{2m_d m_s}{v^2} \qquad C_{4K}^{pGB} \sim \frac{g_{s*}^2}{M_G^2}\frac{1}{g_*^2}\frac{8m_d m_s}{v^2}\frac{1+m^2}{\tilde{m}_d^2}$$

Csaki, Falkowski, A.W.

- o Reduce bulk QCD coupling g_{s*} by loop level matching × ½ and assume vanishing UV boundary kinetic terms

Agashe, Azatov, Zhu

- o Larger Y_* allowed if Higgs in the bulk, more perturbative × ½ control (also does *not* work for the pGBHiggs).

$m_G \sim$ 5-7 TeV ?

Uncomfortable corner of parameter space: Little hierarchy? Fine tuning? Perturbativity? Still no signal at LHC?

How can we evade the RS flavor problem?

Main message

Total anarchy does not seem to work

o Finetuned scales? Raise the scale to M_G ~ 20-30 TeV

o Finetuned Yukawas? Yukawas could miraculously give accidental cancellations

see A. Buras' talk

o No tuning, we need to add more structure: Alignment and flavor symmetries

Fitzpatrick, Randall, Perez; Santiago; Csaki Falkowski, A.W; Csaki, Grossman, Perez, Surujon,A.W. ; Agashe;

Spurion analysis

Without the Yukawas SM has

$$SU(3)_{Q_L} \times SU(3)_{u_R} \times SU(3)_{d_R}$$

global flavor symmetry.

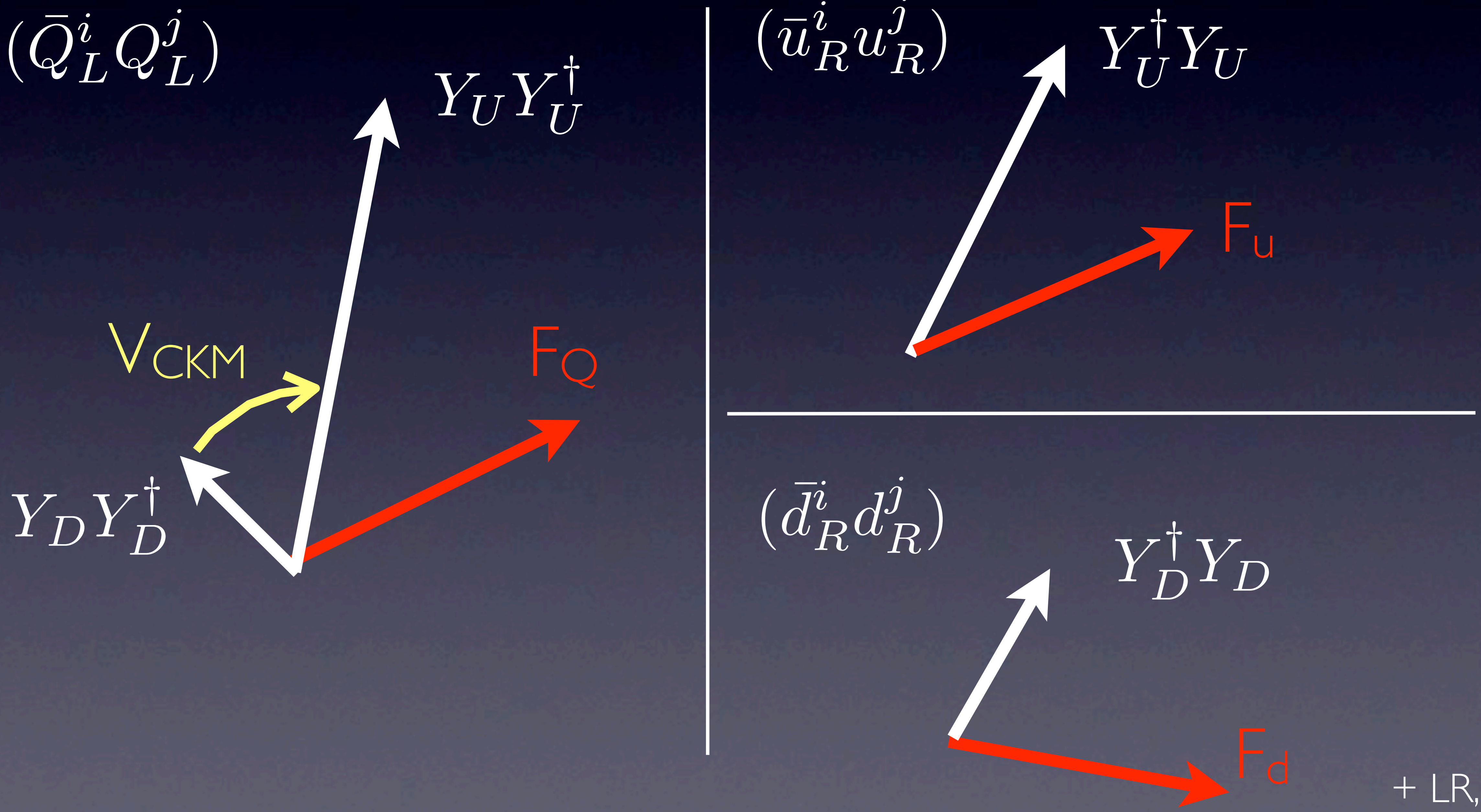
alternative picture: Davidson, Isidori, Uhlig

In RS broken by $Y_u^*, Y_d^* + F_Q, F_d, F_u$

No dangerous FCNCs in the down sector if

$Y_d^* + F_Q, F_d$ aligned (diagonal in the same basis)

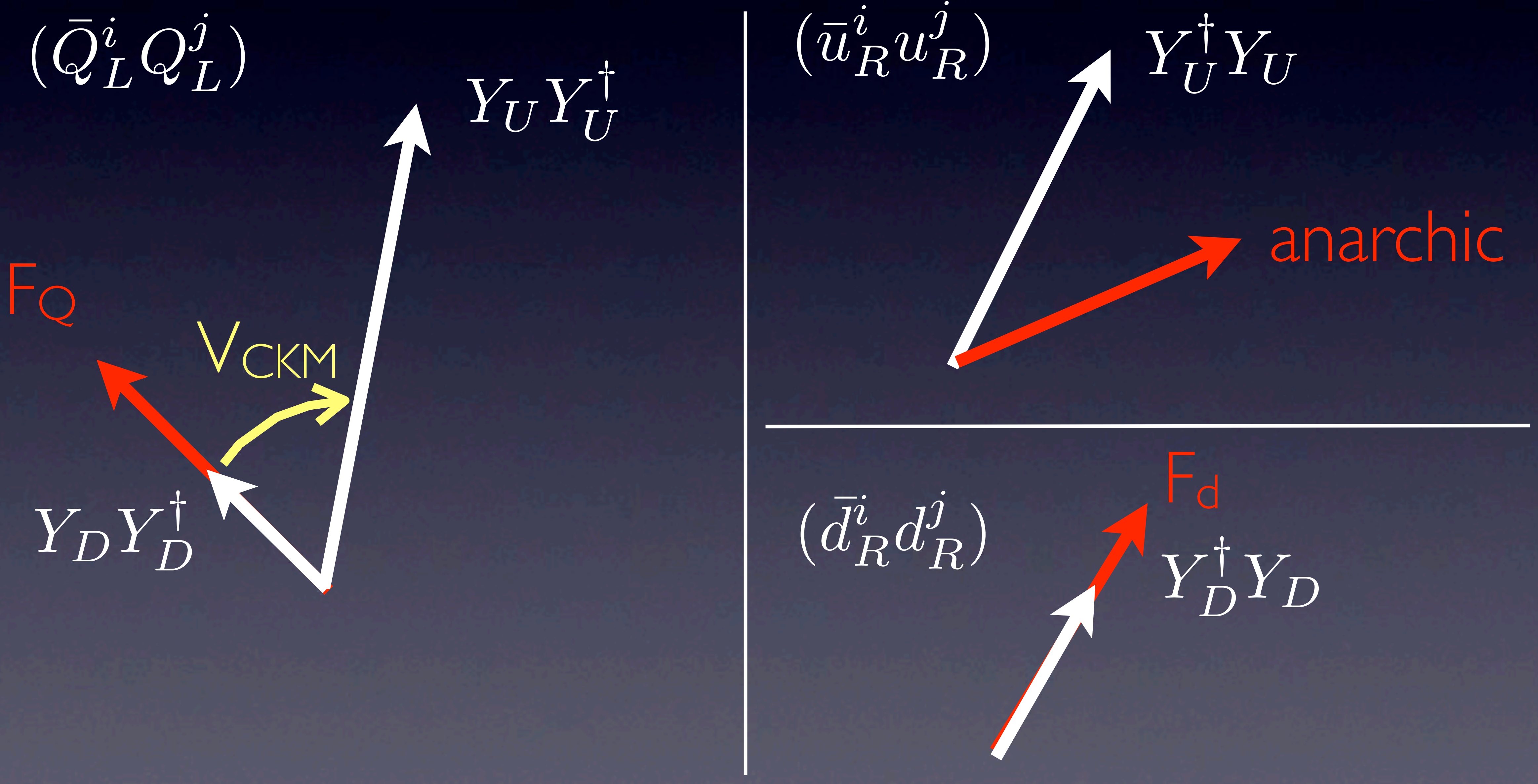
Anarchy



+ LR, RL

Align down sector

similar to Nir, Seiberg '93 for MSSM



$(\bar{Q}^i_L Q^j_L)$

$Y_U Y_U^\dagger$

F_Q

V_{CKM}

$Y_D Y_D^\dagger$

$(\bar{u}^i_R u^j_R)$

$Y_U^\dagger Y_U$

anarchic

$(\bar{d}^i_R d^j_R)$

F_d

$Y_D^\dagger Y_D$

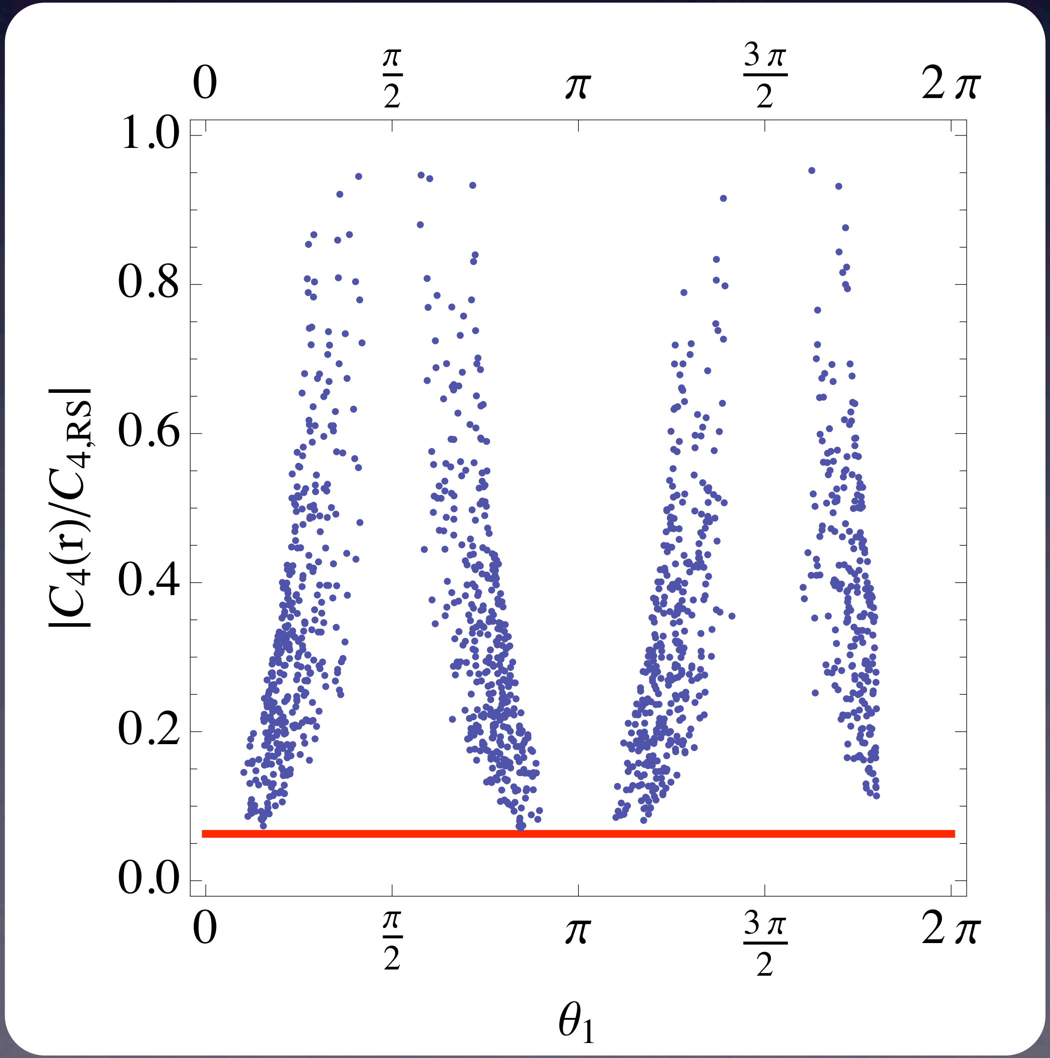
+ LR, RL

Aligning 5D MFV

Fitzpatrick, Randall, Perez; Csaki, Grossman, Perez, Surujon,A.W., in progress

$$c_Q \sim Y_d Y_d^\dagger + \epsilon Y_u Y_u^\dagger \qquad c_d \sim Y_d^\dagger Y_d \qquad c_u \sim Y_u^\dagger Y_u$$

for $\epsilon \to 0$ no FCNCs in the down sector.



Effective suppression, scan over 5D CKM keeping **ε** = 0.2 fixed.

Need $\epsilon \to 0$:
 points to symmetry

Alignment due to shining

Csaki, Grossman, Perez, Surujon,A.W., in progress

In the bulk: gauged $SU(3)_Q \times SU(3)_d$ flavor symmetry.

$$F(c_Q) = F(Y_{*d} {Y_{*d}}^\dagger), \qquad F(c_d) = F({Y_{*d}}^\dagger Y_{*d})$$

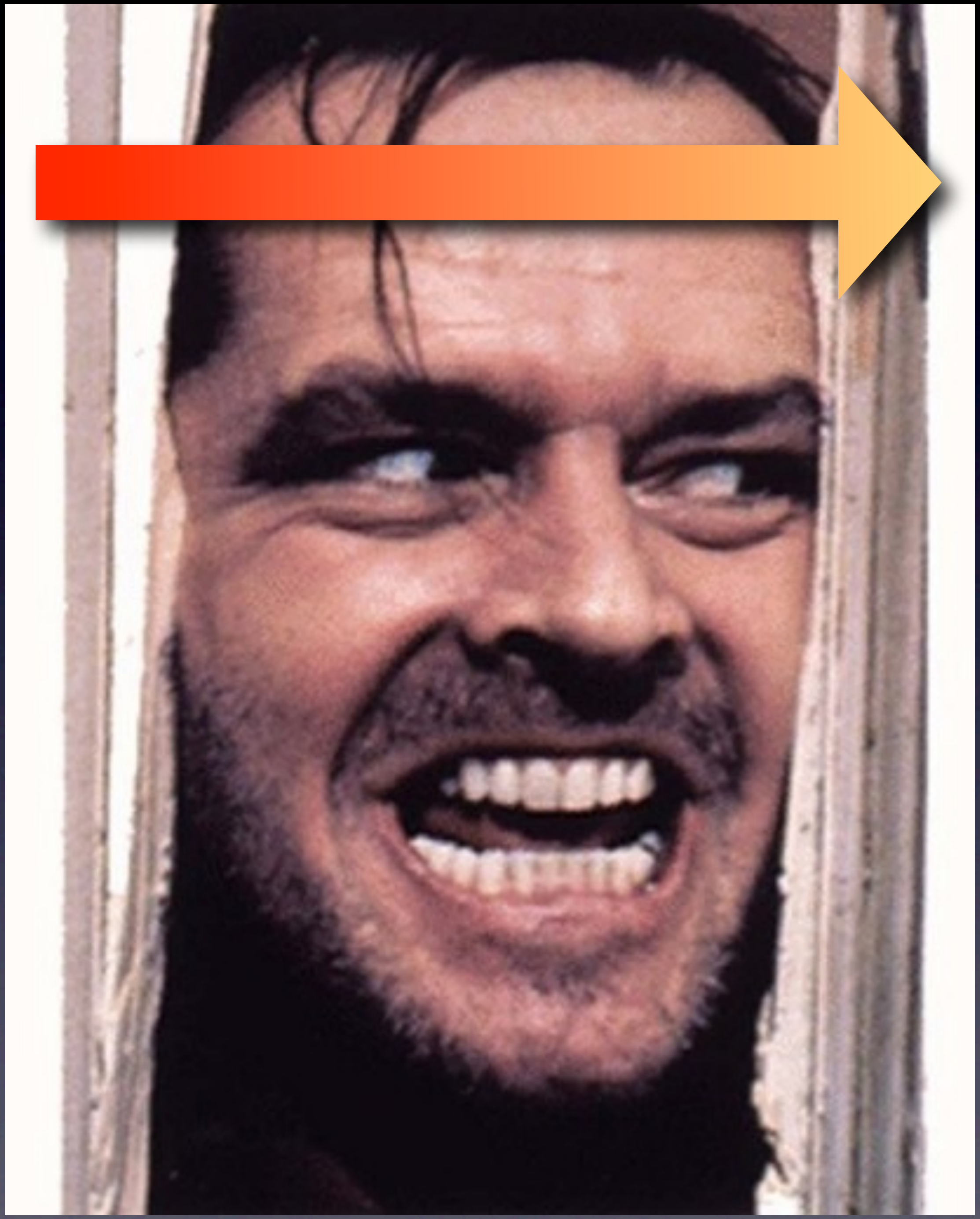
Rattazzi, Zafaroni

Breaking shines into the bulk by vev of dynamical Yukawa field Y_{*d} only (marginal operator)

Φ_d : (**3**,**1**,**$\underline{3}$**), $<\Phi_d> = Y_{*d}\ (z/R)^{-\varepsilon}$

The shining

Kubrick '80



UV brane

IR brane

Alternative: horizontal U(1)'s

Csaki, Falkowski, A.W.

Alignment due to horizontal flavor symmetries

	Ψ_u	Ψ_{q_u}	Ψ_{q_d}	Ψ_d
$U(1)_q\,(+,-)$	$\cdot$	q_i	q_i	$\cdot$
$U(1)_d\,(-,+)$	0	0	d_i	d_i

split doublet natural candidate for pGB (Zb$\underline{b}$)

U(1)$_q$ protects UV mixing $\theta q_{u,L}(0) - q_{d,L}(0) = 0$

U(1)$_d$ alignes Y_{d*}, c_{qd}, c_d

Predictions

Gauged flavor symmetries : flavor bosons at the LHC?

Large (but controlled) flavor violation in the up-sector D-$\underline{D}$ mixing

general discussion: Blum, Grossman, Nir, Perez

Parameter	Suppression	$f_{q_u^3} = 0.3$	$f_{q_u^3} = 1$	Bound (TeV)
$\lvert C_D^1 \rvert$	$\frac{\sqrt{6}}{g_{s*}\lambda^5 f_{q_u^3}^2} M_G$	$7.8 \cdot 10^3 M_G$	$0.7 \cdot 10^3 M_G$	$1.2 \cdot 10^3$
$\lvert C_D^1 \rvert$	$\frac{\sqrt{3} Y_*^2 v^2 \lambda^5 f_{q_u^3}^2}{\sqrt{2} g_{s*} m_u m_c} M_G$	$1.2 \cdot 10^3 M_G$	$1.3 \cdot 10^5 M_G$	$1.2 \cdot 10^3$
$\lvert C_D^4 \rvert$	$\frac{v Y_*}{g_{s*}\sqrt{2\, m_u m_c}} M_G$	$1.2 \cdot 10^3 M_G$	$1.2 \cdot 10^3 M_G$	$3.5 \cdot 10^3$
$\lvert C_K^1 \rvert$	$\frac{\sqrt{6}}{g_{s*}\lambda^5 f_{q_u^3}^2 \delta} M_G$	$3.0 \cdot 10^6 M_G$	$2.7 \cdot 10^5 M_G$	$1.5 \cdot 10^4$
$\lvert C_K^1 \rvert$	$\frac{\sqrt{3} Y_*^2 v^2}{\sqrt{2} g_{s*} m_d m_s \lambda \delta} M_G$	$1.5 \cdot 10^{10} M_G$	$1.5 \cdot 10^{10} M_G$	$1.5 \cdot 10^4$
$\lvert C_K^4 \rvert$	$\frac{Y_* v}{g_{s*}\sqrt{2 m_d m_s} \lambda^3 f_{q_u^3} \delta} M_G$	$2.8 \cdot 10^7 M_G$	$8.5 \cdot 10^6 M_G$	$1.6 \cdot 10^5$

Conclusions

RS provides a pretty good theory of flavor dual to partial compositeness

RS-GIM suppresses dangerous FCNCs, problem with CPV in Kaon sector

Anarchy alone needs finetuning to survive, additional structure in the flavor sector required => interesting predictions!

Mass terms from gauge interactions

Possible fermion embedding: **4** of SO(5)

$$\Psi_q = \begin{pmatrix} \boxed{q_q[+,+]} \\ u^c_q[-,+] \\ d^c_q[-,+] \end{pmatrix} \qquad \Psi_u = \begin{pmatrix} q_u[+,-] \\ \boxed{u^c_u[-,-]} \\ d^c_u[+,-] \end{pmatrix} \qquad \Psi_d = \begin{pmatrix} q_d[+,-] \\ u^c_d[+,-] \\ \boxed{d^c_d[-,-]} \end{pmatrix}$$

1) $\boxed{}$ = chiral zero modes

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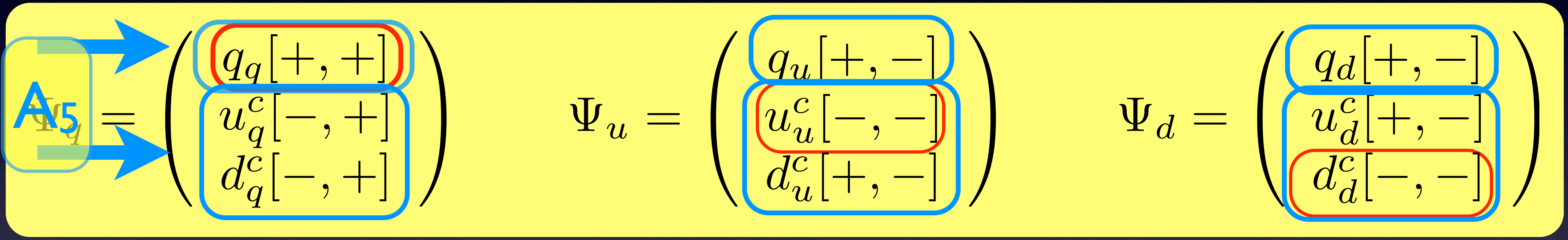

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2) <A_5> marries fields in same multiplet

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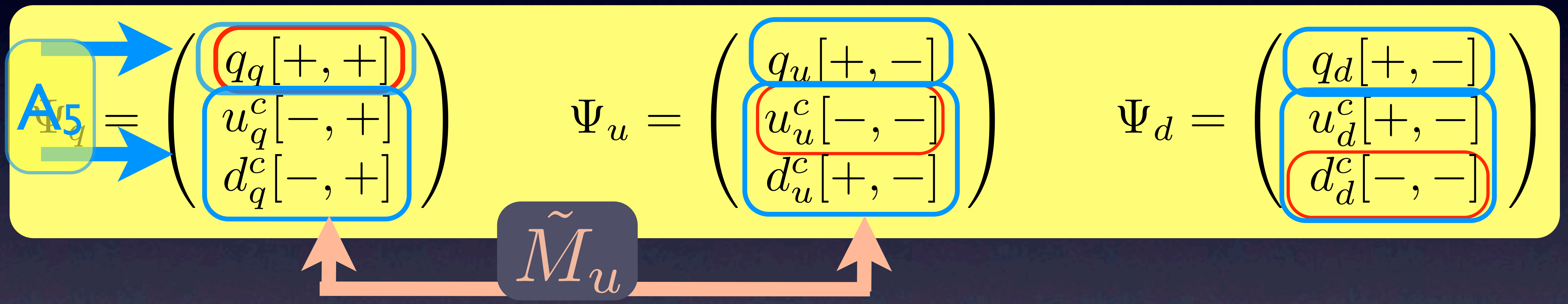

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3) SO(4) invariant brane masses mix multiplets

$$\mathcal{L}_{IR} = -\left(\frac{R}{R'}\right)^4 \left[\tilde{m}_u \chi_{q_q}\psi_{q_u} + \tilde{m}_d \chi_{q_q}\psi_{q_d} + \tilde{M}_u(\chi_{u^c_q}\psi_{u^c_u} + \chi_{d^c_q}\psi_{d^c_u}) + \tilde{M}_d(\chi_{u^c_q}\psi_{u^c_d} + \chi_{d^c_q}\psi_{d^c_d})\right]$$

Mass terms from gauge interactions

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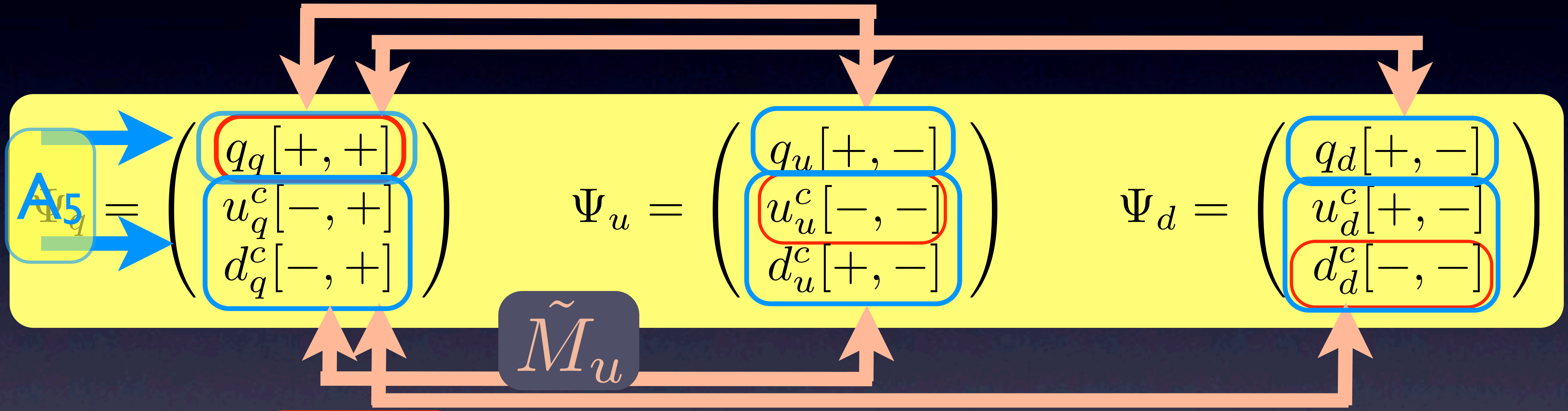

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