D physics (+t-phys.): SM & new physics potential

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Weizmann Institute

Flavor Physics & CP Violation 2010

Outline

- Brief Intro', the importance of uFCNC measurements.
- $D-\bar{D}$ mixing, tFCNC, theory+data.
- Covariant formalism => immune bounds; show also generic.
- Implications for general minimal flavor violation & SUSY+RS.
- Outlook, the LHC era.

Why Up ?

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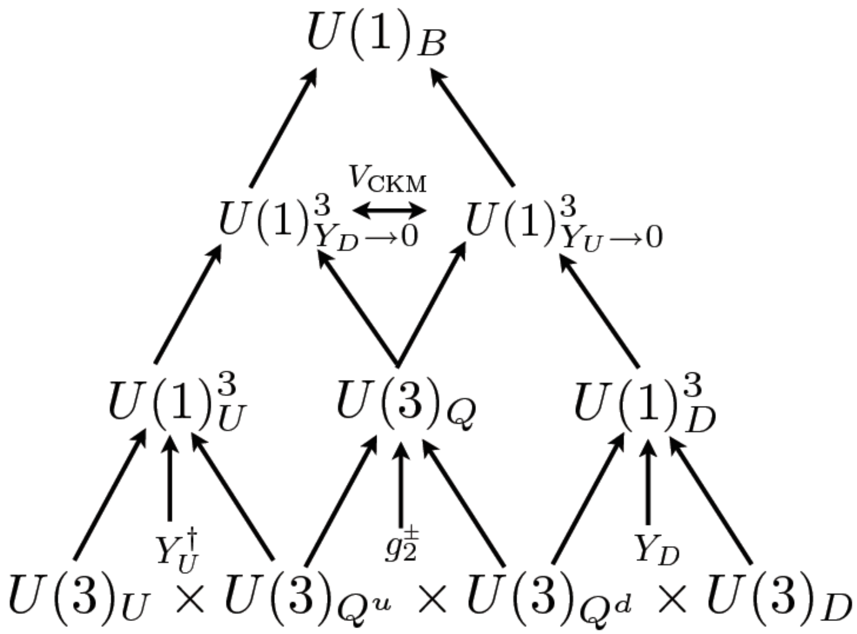

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- Absence (?) of deviation from SM predictions implies severe bound on new physics (NP).

- Most of precise information involves K, B mesons, linked to down type FCNC.

- Most severe hierarchy problem is induced by the top sector, which is indeed extended in most of natural NP models.

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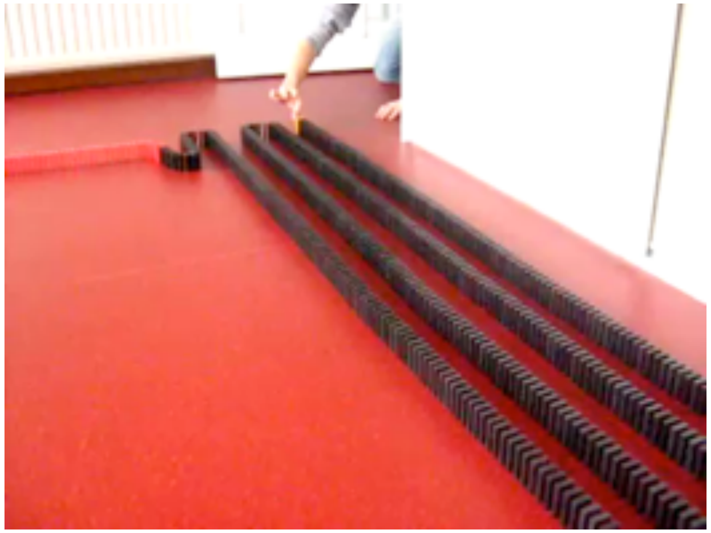

careful domino *alignment*

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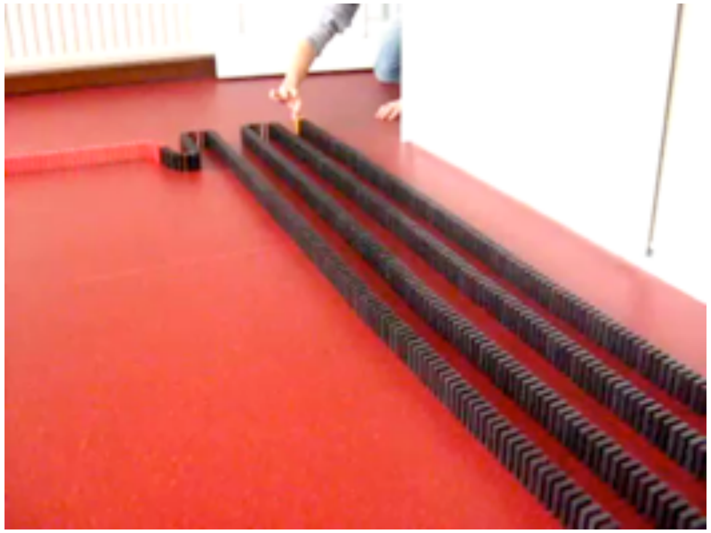

careful domino *alignment*

Up sector

Look Down

Look Up

$D^0 - \bar{D}^0$ *Mixing*

δ

Δ

Huge recent progress in measurement of mass splitting & CP violation (CPV) in the D system:

- System parameters roughly determined (HFAG):

$$\begin{aligned} x &= (1.00 \pm 0.25) \times 10^{-2}, \\ y &= (0.77 \pm 0.18) \times 10^{-2}, \\ 1 - |q/p| &= +0.06 \pm 0.14, \\ \phi &= -0.05 \pm 0.09, \end{aligned}$$

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Bottom contribution is down by:

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Absence of D CPV
a SM victory!

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The power of CPV in the D system

Assuming no direct CP: [Golowich, Pakvasa & Petrov (07); Kagan and M. D. Sokolof (09)]

$$y_{12} \equiv |\Gamma_{12}|/\Gamma, \qquad x_{12} \equiv 2|M_{12}|/\Gamma, \qquad \phi_{12} \equiv \arg(M_{12}/\Gamma_{12}).$$

$$x_{12}^{\rm NP} \lesssim x_{12}^{\rm exp} \sim 0.012, \qquad x_{12}^{\rm NP} \sin\phi_{12}^{\rm NP} \lesssim x_{12}^{\rm exp} \sin\phi_{12}^{\rm exp} \sim 0.0022,$$

Gedalia, et. al (09).

long distance dominated?

Falk, et. al (02).

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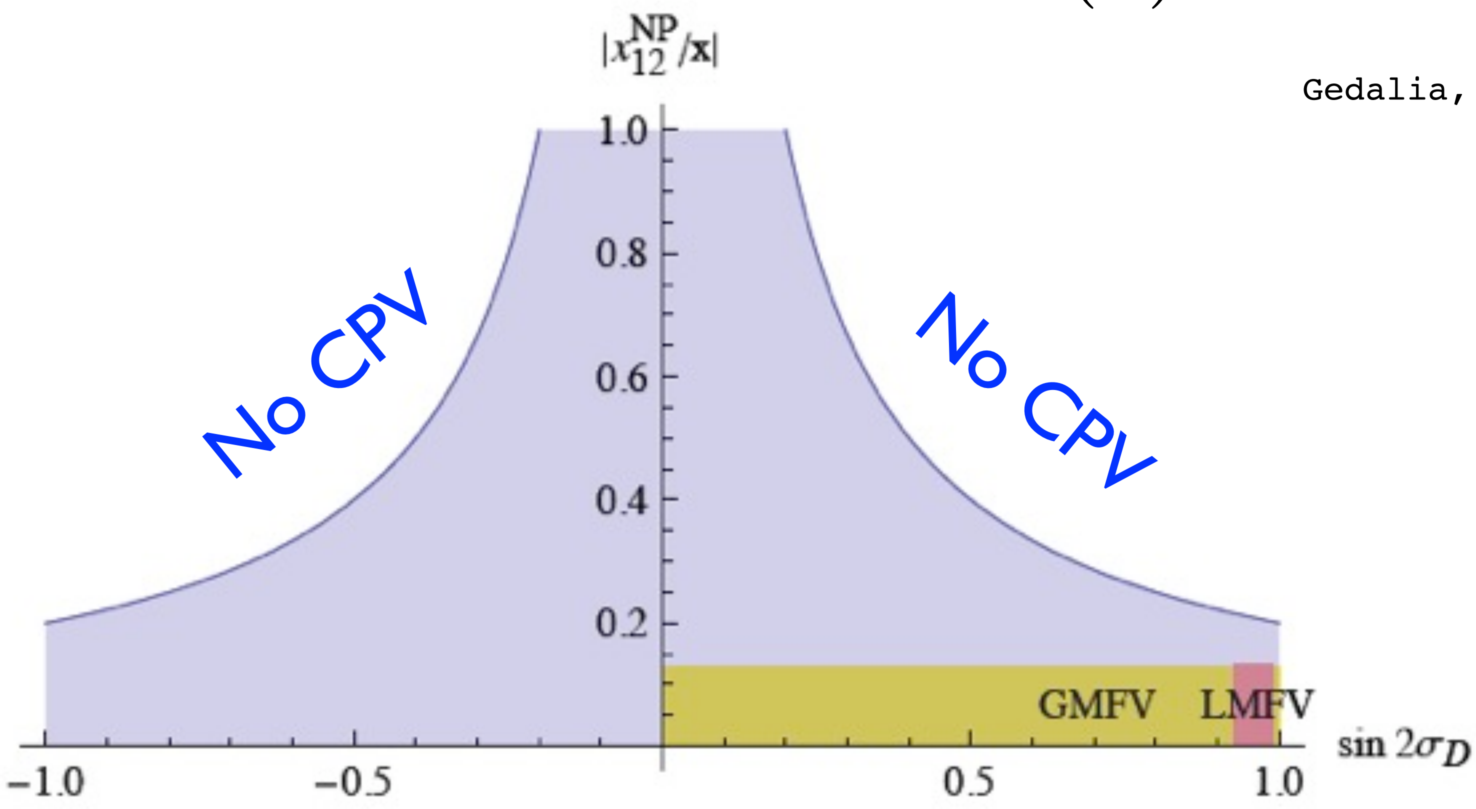

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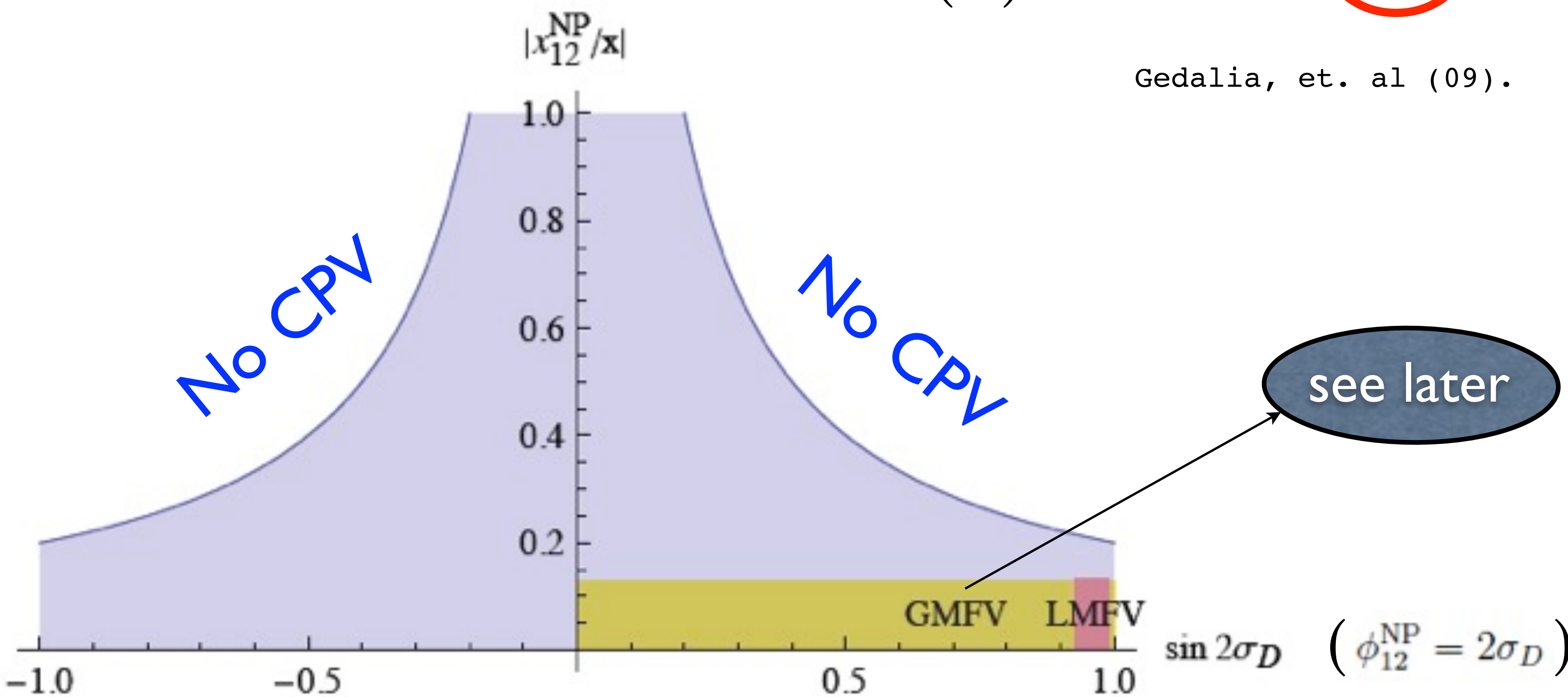

What do we know about the NP flavor sector, model independently?

$\Delta F = 2$ status

Isidori, Nir, GP (10)

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}	$\Delta m_K;\ \epsilon_K$
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D-system falls only behind the K-one

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t-FCNC
stay
tuned!

D-system fall ... ind the K-one

The importance of up-type FCNC

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u-FCNC data remove immunities!

2-gen' effective theory for $\Delta F = 2$

Robust model independent bounds:

(i) robust   *(ii) LLRR* - stronger, but model dependent.

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[More info' in Δc=1, Golowich, et. al (09), Kagan & Sokolof (09)]

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Two gen' flavor structure (no CPV)

When effects of $SU(2)_L$ breaking are small, the terms that lead to z_1^K and z_1^D have the form

$$\frac{1}{\Lambda_{\rm NP}^2}(\overline{Q_{Li}}(X_Q)_{ij}\gamma_\mu Q_{Lj})(\overline{Q_{Li}}(X_Q)_{ij}\gamma^\mu Q_{Lj}),$$

One cannot eliminate the constraint from K & D systems simultaneously! Nir (07); Blum et. al. (09).

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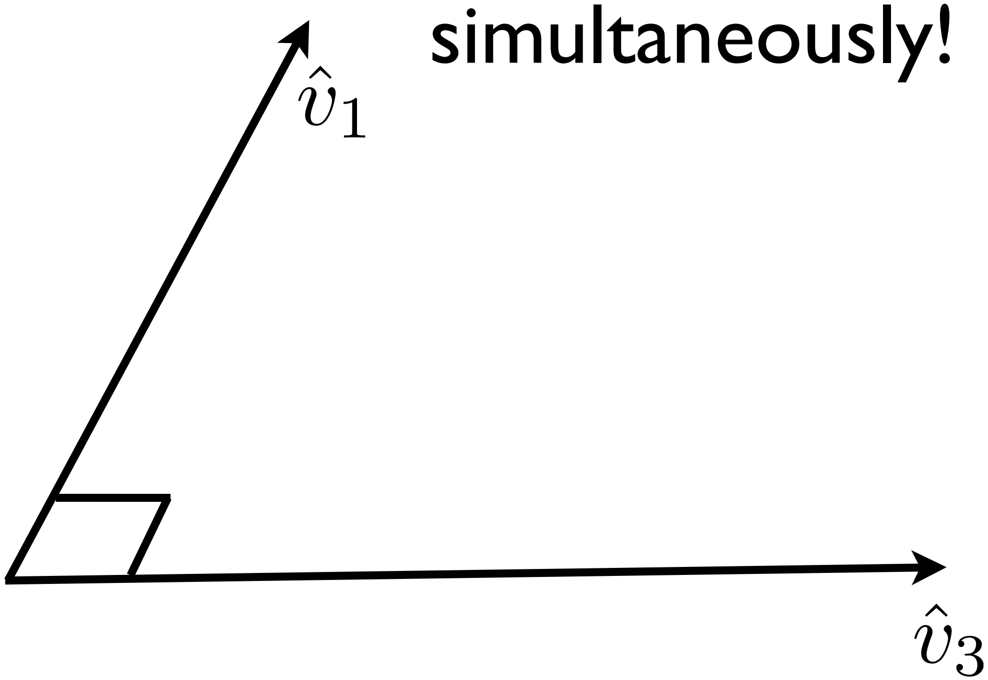

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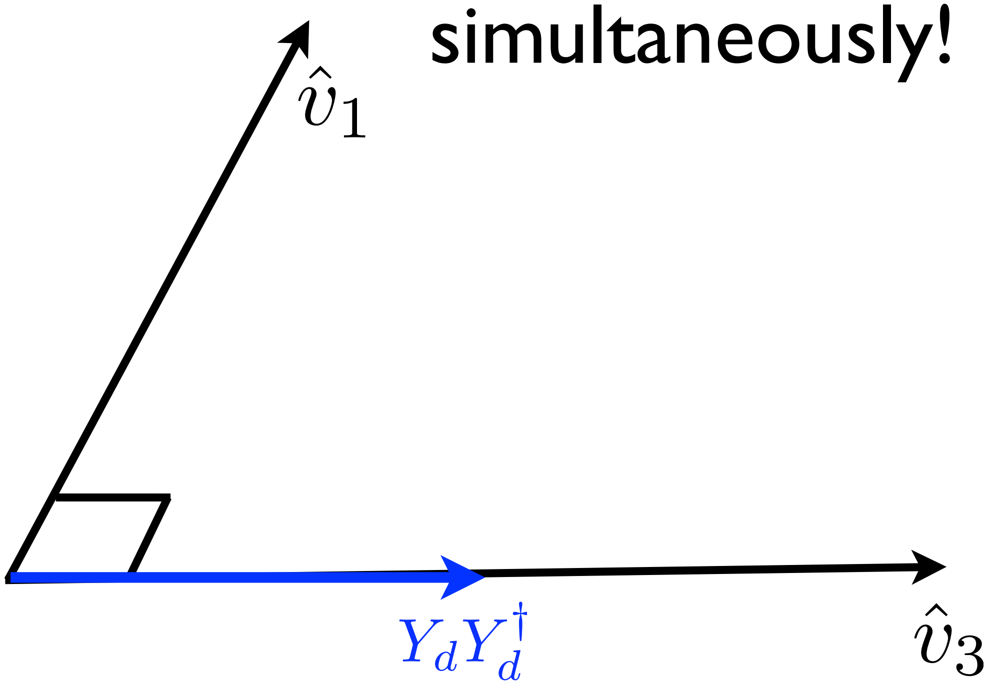

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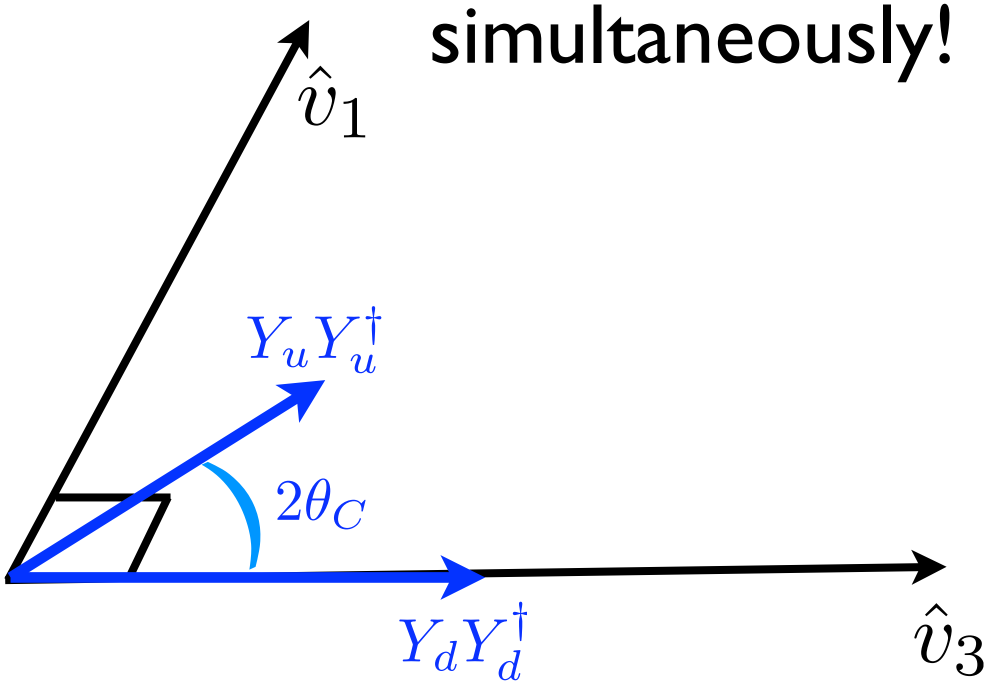

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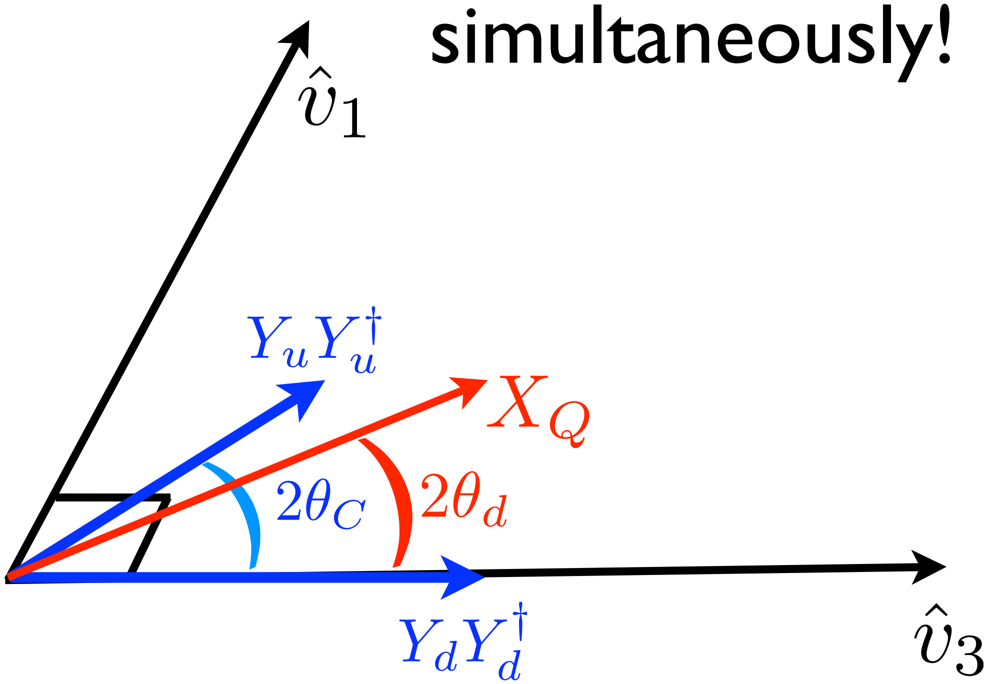

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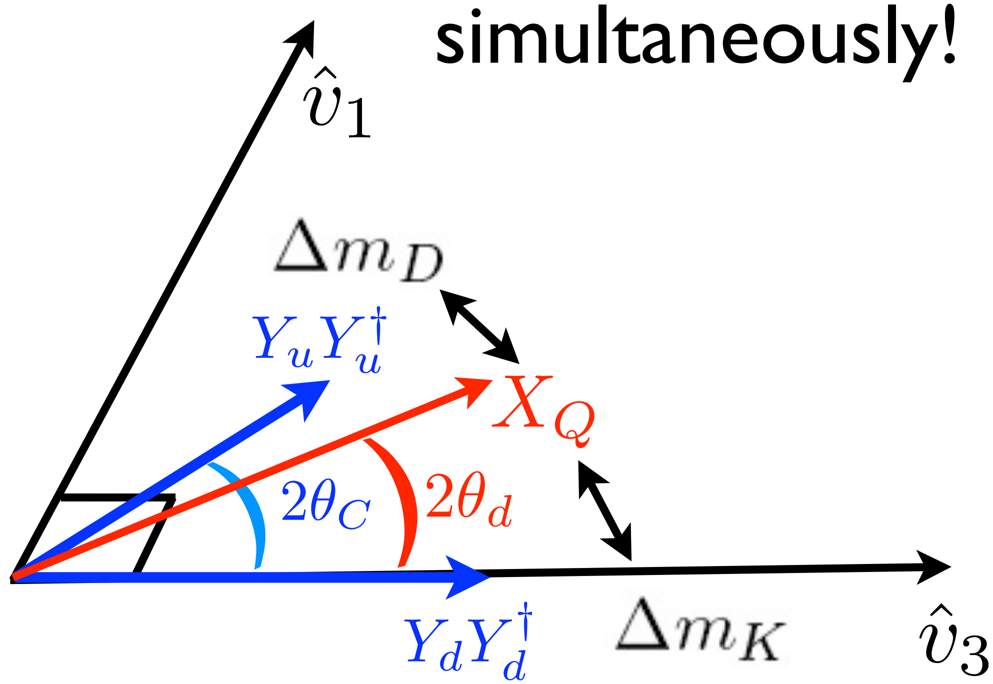

Covariant, basis independent, description of flavor violation

2 x [Gedalia, Mannelli, GP (10)]

Can be understood in a covariant, basis independent manner (needed for 3gen')

Two generation case:

- Any Hermitian 2x2 matrix => expressed as sum of Pauli matrices.
- A matrix corresponds to a vector in SU(2) space.
- Can define set of operations, like scalar product and cross product:

$$|\vec{A}| \equiv \sqrt{\frac{1}{2}\mathrm{tr}(A^2)}\,, \quad \vec{A}\cdot\vec{B} \equiv \frac{1}{2}\mathrm{tr}(A\,B)\,, \quad \vec{A}\times\vec{B} \equiv -\frac{i}{2}\,[A,B]\,,$$

$$\cos(\theta_{AB}) \equiv \frac{\vec{A}\cdot\vec{B}}{|\vec{A}||\vec{B}|} = \frac{\mathrm{tr}(A\,B)}{\sqrt{\mathrm{tr}(A^2)\mathrm{tr}(B^2)}}\,.$$

- The SM basic vectors: $\mathcal{A}_u \equiv (Y_u Y_u^\dagger)_{\not{tr}}\,, \qquad \mathcal{A}_d \equiv (Y_d Y_d^\dagger)_{\not{tr}}\,.$

Covariant basis, 2 gen'

- Define a covariant, physical, basis using the SM basis vectors:

$$\hat{\mathcal{A}}_{u,d} \equiv \frac{\mathcal{A}_{u,d}}{|\mathcal{A}_{u,d}|}\,, \quad \hat{J} \equiv \frac{\mathcal{A}_d \times \mathcal{A}_u}{|\mathcal{A}_d \times \mathcal{A}_u|}\,, \quad \hat{J}_{u,d} \equiv \hat{\mathcal{A}}_{u,d} \times \hat{J}\,.$$

- Up,down flavor violation is misalignment between SM mass basis

unit vector & new sources of flavor breaking:

$$\left|z_1^{D,K}\right| = \left|X_Q \times \hat{\mathcal{A}}_{u,d}\right|^2 .$$ (say in $\frac{z_1}{\Lambda_{\rm NP}^2} O_1 = \frac{1}{\Lambda_{\rm NP}^2}\left(\overline{Q}_i (X_Q)_{ij} \gamma_\mu Q_j\right)\left(\overline{Q}_i (X_Q)_{ij} \gamma^\mu Q_j\right)$)

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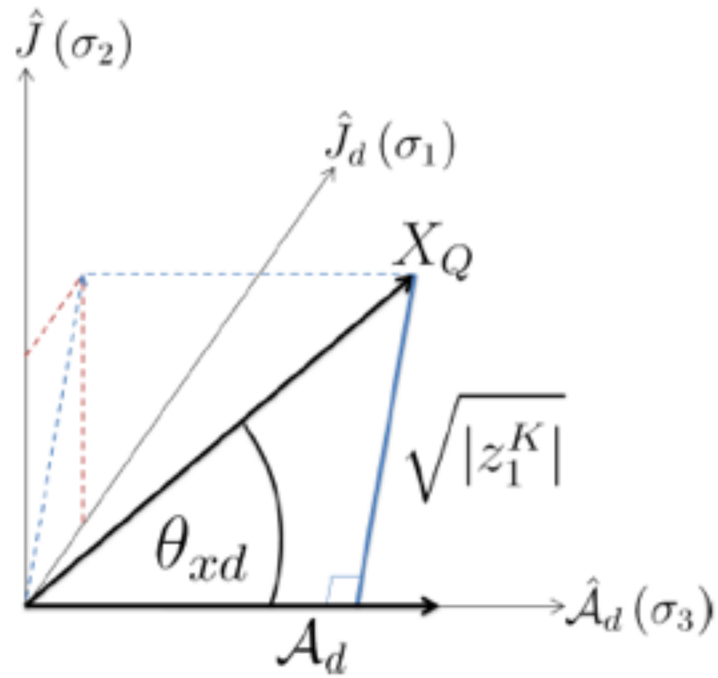
contribution of X_Q to $K^0 - \overline{K^0}$ mixing, Δm_K, given by the solid blue line.

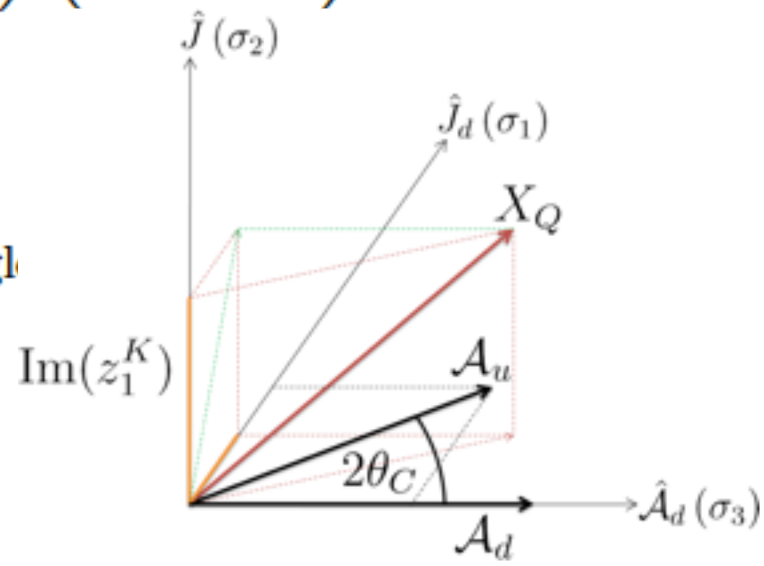


Covariant basis, CPV (strongest bounds)

- CPV in $\Delta F = 2:\quad \mathrm{Im}\left(z_1^{K,D}\right) = 2\left(X_Q \cdot \hat{J}\right)\left(X_Q \cdot \hat{J}_{u,d}\right)\,.$

$\mathrm{Im}(z_1^K)$ is twice the product of the two solid orange lines.

Note that the angle between $\mathcal{A}_d$ and $\mathcal{A}_u$ is twice the Cabibbo angl



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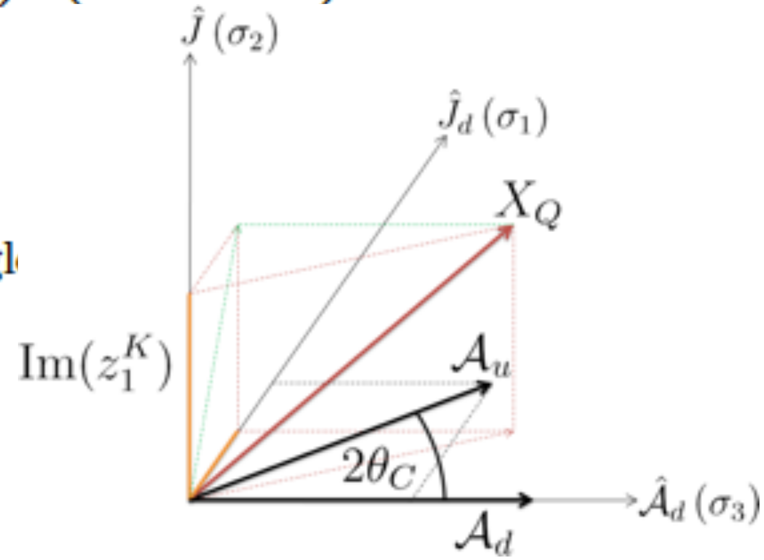

- Deriving a robust bound:

$$\text{In the covariant bases} - \quad X_Q = X^{u,d}\hat{\mathcal{A}}_{u,d} + X^J\hat{J} + X^{J_{u,d}}\hat{J}_{u,d}\,,$$

and the two bases are related through

$$X^u = \cos 2\theta_C X^d - \sin 2\theta_C X^{J_d}\,, \quad X^{J_u} = -\sin 2\theta_C X^d - \cos 2\theta_C X^{J_d}\,,$$

Covariant basis - physical interpretation

- The axis $\hat{J}$ is the 2-gen' "Jarlskog": $X^J \propto \mathrm{tr}\left(X_Q\left[\mathcal{A}_d, \mathcal{A}_u\right]\right) \neq 0\,,$

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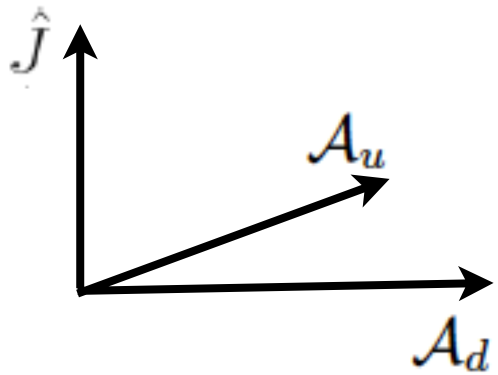

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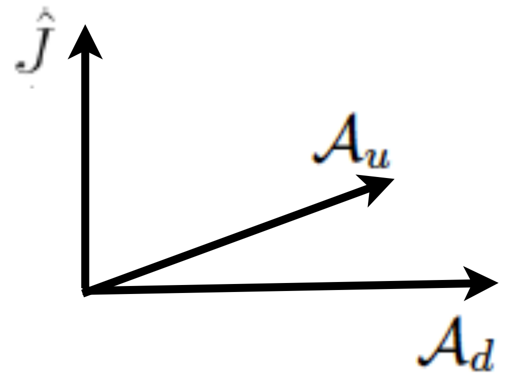

- The axes $\hat{J}_{u,d}$ dials CPV in $\Delta F = 2$ (new model indep' condition):

$$X^{J_{u,d}} \propto \mathrm{tr}\left(X_Q\left[\mathcal{A}_{u,d}, \left[\mathcal{A}_d, \mathcal{A}_u\right]\right]\right) \neq 0$$

Gedalia, Mannelli, GP (10)

Implications of CPV in $D^0 - \bar{D}^0$ mixing

(i) Model independent;
(ii) General minimal flavor violation (GMFV);
(iii) SUSY;
(iv) Randall-Sundrum (RS).

Ciuchini, et al. (07); Csaki, et al. (08); Kagan, et al. (09); Gedalia, et al. (09,10,10); Blum, et al. (09); Buras et. al.; Csaki, et al. (09); Bauer, et al. (09); Bigi, et al. (09); Altmannshofer, et al. (09,10); Blanke, et al. (09); Crivellin & Davidkov (10).

Robust (immune) bounds

$$L = |X_Q| = \left(X_Q^2 - X_Q^1\right)/2$$

$$\left(X^d\right)^2 + \left(X^J\right)^2 + \left(X^{J_d}\right)^2 = \left(X^u\right)^2 + \left(X^J\right)^2 + \left(X^{J_u}\right)^2 = 1$$

Constraining the eigenvalue difference of flavor violation source, indep' of it's direction!

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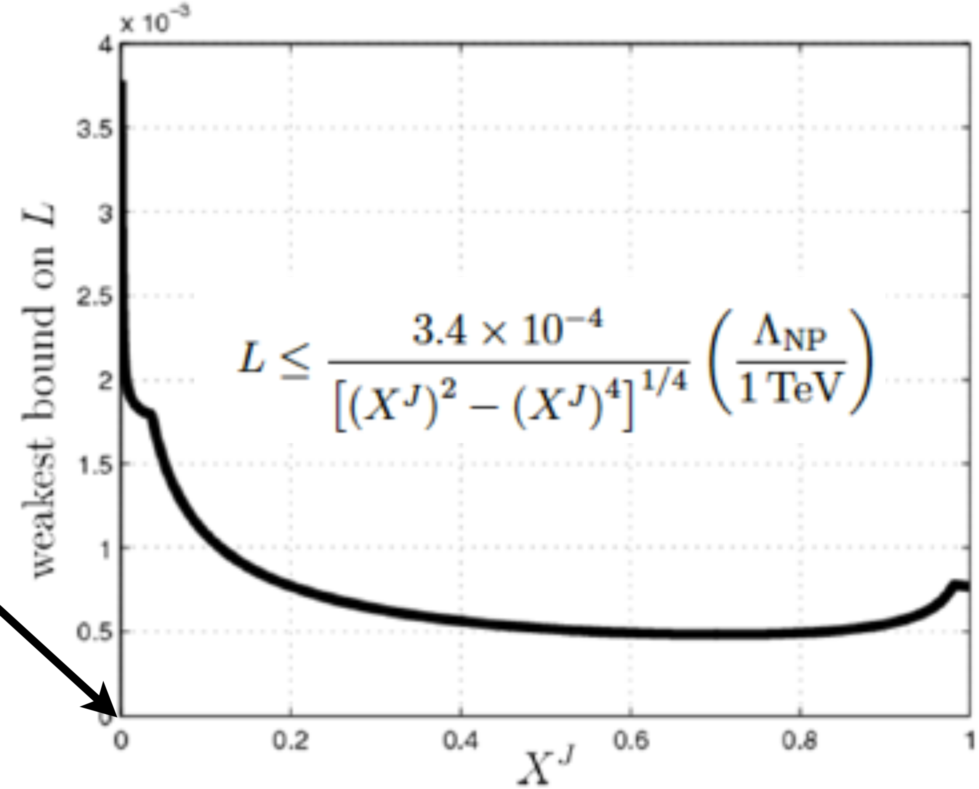

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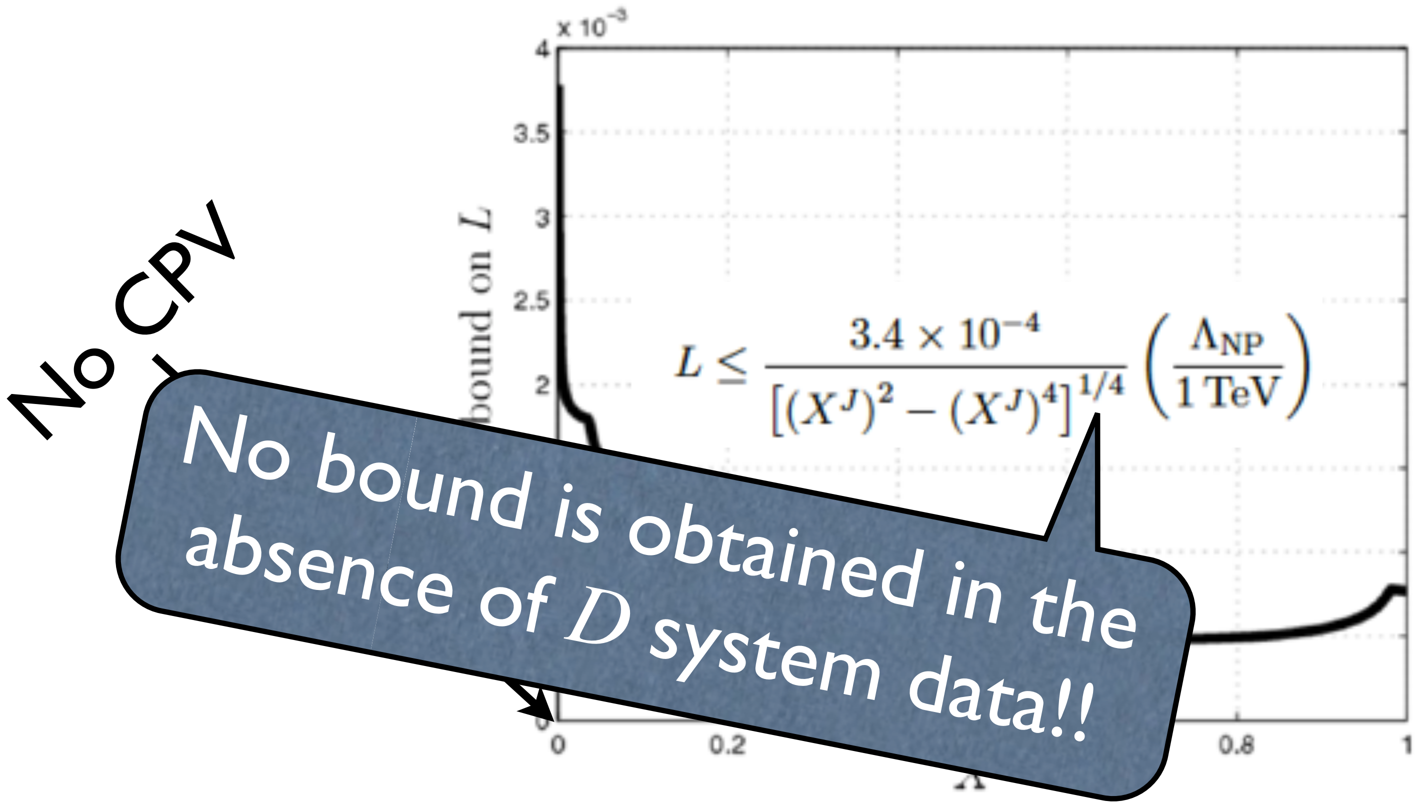

CPV in D: Model Dependent Implications

General MFV (GMFV) vs. Linear MFV (LMFV)

Kagan, et. al (09); Gedalia, et. al (09).

- Comparable NP contributions from strange & bottom (unlike SM)

$$r_{sb} \equiv \frac{y_s^2}{y_b^2}\left|\frac{V_{us}^{\rm CKM}V_{cs}^{\rm CKM}}{V_{ub}^{\rm CKM}V_{cb}^{\rm CKM}}\right| \sim 0.5\,,$$

$$C_1^{cu} \propto \left[y_s^2\left(V_{cs}^{\rm CKM}\right)^* V_{us}^{\rm CKM} + (1+r_{\rm GMFV})y_b^2\left(V_{cb}^{\rm CKM}\right)^* V_{ub}^{\rm CKM}\right]^2$$

$r_{\rm GMFV}$ result of resummation $\sum_n y_b^n$

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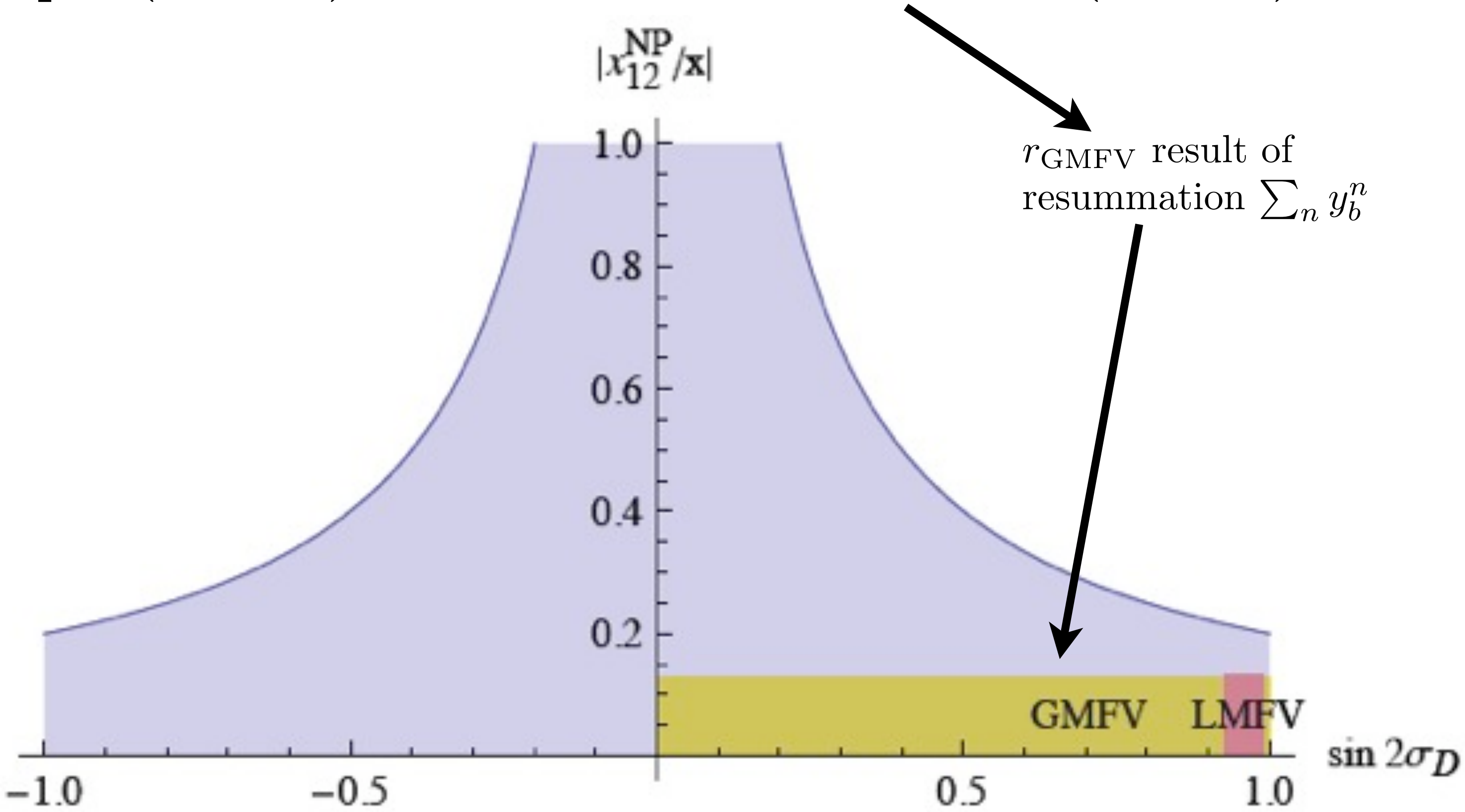

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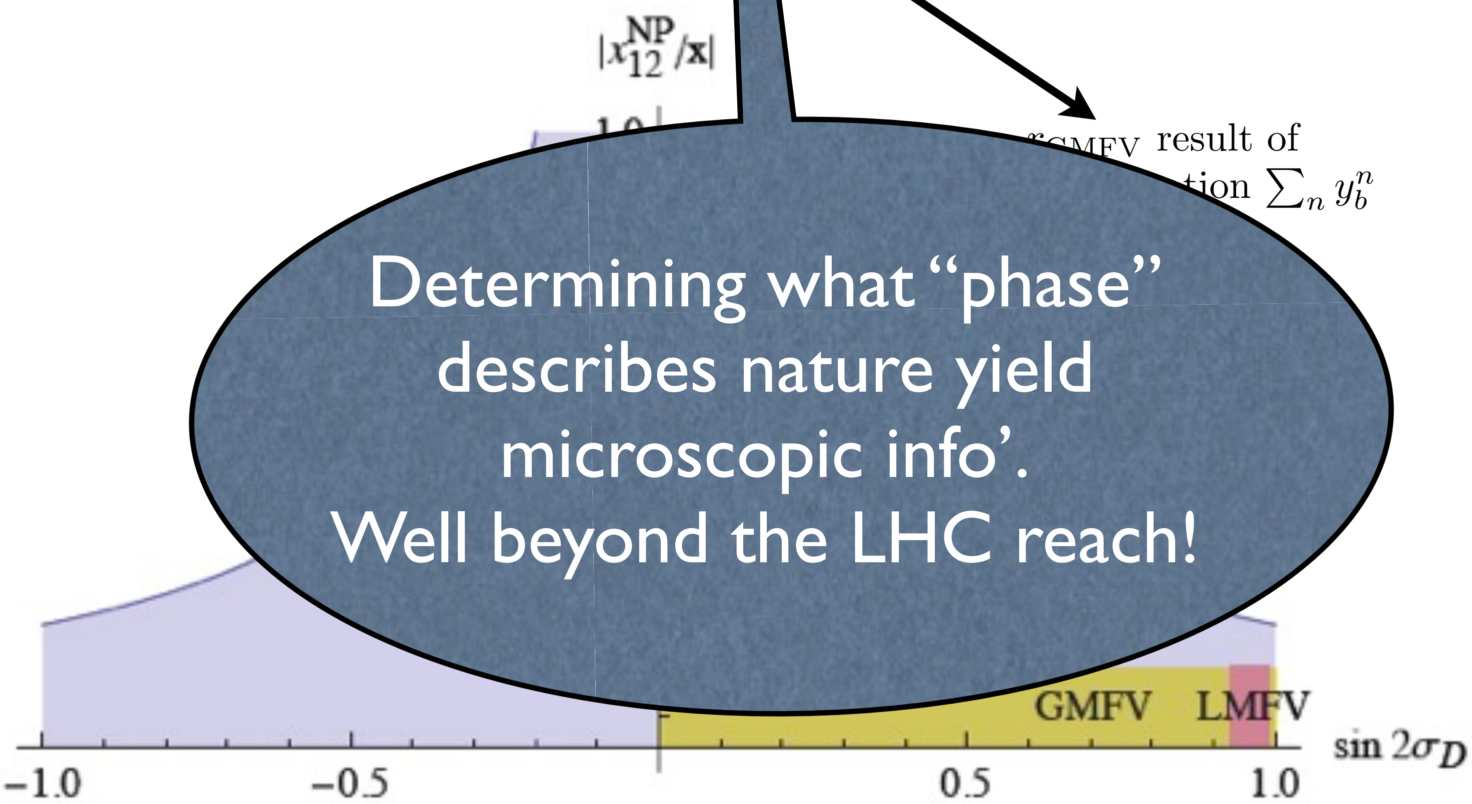


Determining what "phase" describes nature yield microscopic info'.
Well beyond the LHC reach!

SUSY+RS

SUSY (doom of alignment)

Robust

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

squark doublets, 1TeV;

Generic

Gedalia, et. al (09).

$$\frac{m_{\tilde{u}_2} - m_{\tilde{u}_1}}{m_{\tilde{u}_2} + m_{\tilde{u}_1}} \lesssim 0.02 - 0.04.$$

average of the doublet & singlet mass splitting.

Possible correlation with EDM's: $d_n \gtrsim 10^{-(28-29)} e\ \text{cm}$ Altmannshofer, et. al (09).

RS (constraining alignment)

Robust

$$m_{\text{KK}} > 2.1 f_{Q_3}^2\ \text{TeV}\,,$$

f_{Q_3} is typically in the range of 0.4-$\sqrt{2}$.

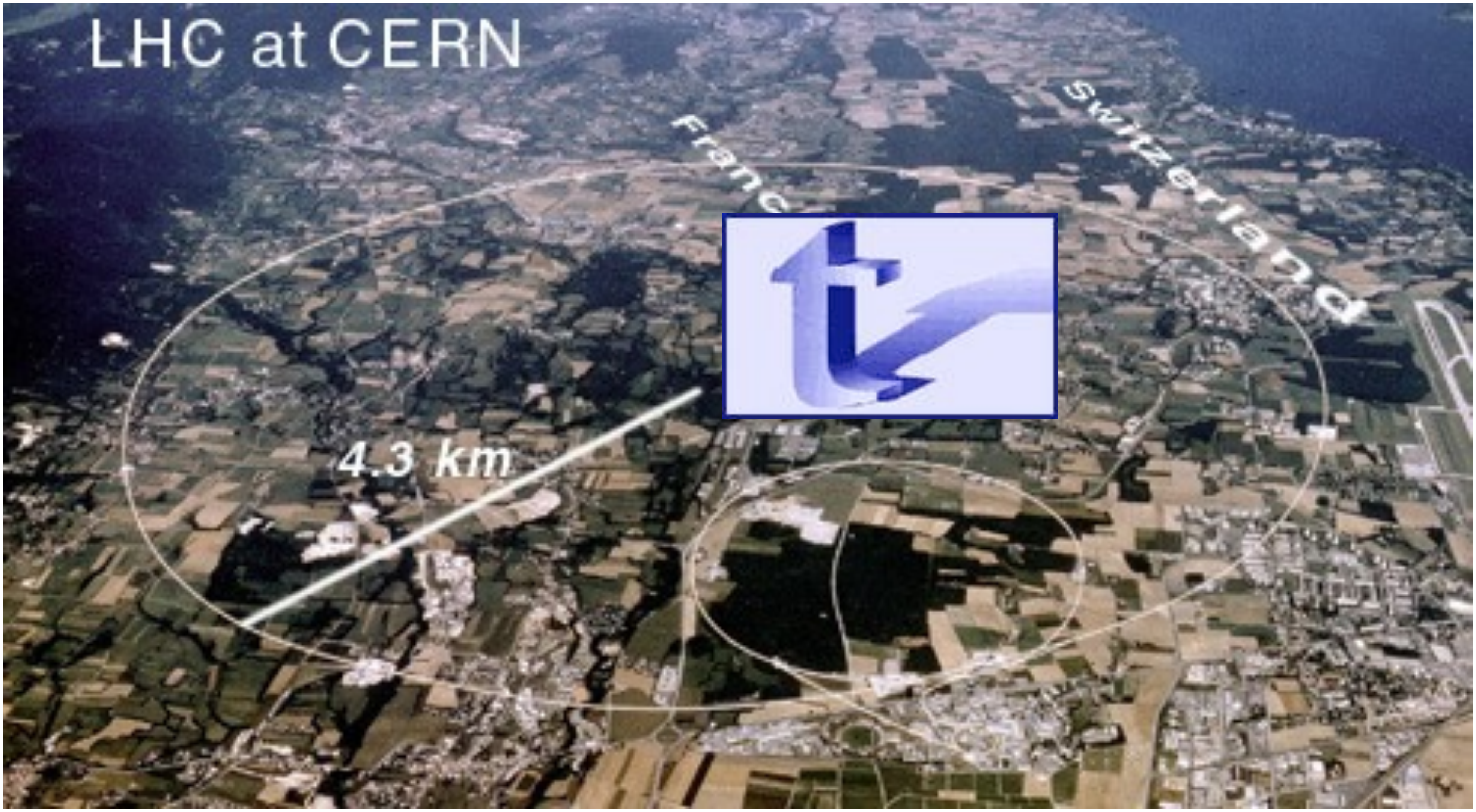
Generic

$$m_{\text{KK}} > \frac{4.9\,(2.4)}{y_{5D}}\ \text{TeV}$$

IR (bulk) Higgs

$\frac{1}{2} \lesssim y_{5\text{D}} \lesssim \frac{2\pi}{N_{\text{KK}}}$ for brane Higgs; $\frac{1}{2} \lesssim y_{5\text{D}} \lesssim \frac{4\pi}{\sqrt{N_{\text{KK}}}}$ for bulk Higgs,

3rd gen' Phys. @ the LHC



Top FCNC (tFCNC), $\Delta t = 1$

- LHC: study int' $\sim 10^{6-7}\ t\bar{t}/yr$
- Top FCNC: $t \to q, Z, \gamma, G$. $(q = u + c)$
  (also $t \to qh$ & single top production)
- SM: $BR(t \to qZ, \gamma, G) \sim 10^{-12}$.
  (Díaz-Cruz (89); Eilam, Hewett & Soni (90))
- LHC (100fb^{-1}): $BR(t \to qZ, \gamma) \gtrsim 10^{-5}$.
  (Carvalho, *et. al* (05))

tFCNC vs. bFCNC, generic bounds

Fox, et. al (07).

Effective theory, dim' 6 operators:

$$
\begin{aligned}
O^u_{LL} &= i\left[\overline{Q}_3\tilde{H}\right]\left[(\not{D}\tilde{H})^\dagger Q_2\right] - i\left[\overline{Q}_3(\not{D}\tilde{H})\right]\left[\tilde{H}^\dagger Q_2\right] + \text{h.c.} \\
O^h_{LL} &= i\left[\overline{Q}_3\gamma^\mu Q_2\right]\left[H^\dagger \overleftrightarrow{D}_\mu H\right] + \text{h.c.}\,, \\
O^w_{RL} &= g_2\left[\overline{Q}_2\sigma^{\mu\nu}\sigma^a\tilde{H}\right] t_R W^a_{\mu\nu} + \text{h.c.}\,, \\
O^b_{RL} &= g_1\left[\overline{Q}_2\sigma^{\mu\nu}\tilde{H}\right] t_R B_{\mu\nu} + \text{h.c.}\,, \\
O^w_{LR} &= g_2\left[\overline{Q}_3\sigma^{\mu\nu}\sigma^a\tilde{H}\right] c_R W^a_{\mu\nu} + \text{h.c.}\,, \\
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O^u_{RR} &= i\,\bar{t}_R\gamma^\mu c_R\left[H^\dagger \overleftrightarrow{D}_\mu H\right] + \text{h.c.}\,.
\end{aligned}
$$

tFCNC vs. bFCNC, generic bounds

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tFCNC vs. bFCNC, generic bounds

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	C^u_{LL}	C^h_{LL}	C^w_{RL}	C^b_{RL}	C^w_{LR}	C^b_{LR}	C^u_{RR}
direct bound	9.0	9.0	6.3	6.3	6.3	6.3	9.0
LHC sensitivity	0.20	0.20	0.15	0.15	0.15	0.15	0.20
$B \to X_s\gamma,\ X_s\ell^+\ell^-$	$[-0.07,\ 0.036]$	$[-0.017,\ -0.01]$ $[-0.005,\ 0.003]$	$[-0.09, 0.18]$	$[-0.12, 0.24]$	$[-14, 7]$	$[-10, 19]$	—
$\Delta F = 2$	0.07	0.014	0.14	—	—	—	—
semileptonic	—	—	—	—	$[0.3, 1.7]$	—	—
best bound	0.07	0.014	0.15	0.24	1.7	6.3	9.0
Λ for $C_i = 1$ (min)	3.9 TeV	8.3 TeV	2.6 TeV	2.0 TeV	0.8 TeV	0.4 TeV	0.3 TeV
$\mathcal{B}(t \to cZ)$ (max)	7.1×10^{-6}	3.5×10^{-7}	3.4×10^{-5}	8.4×10^{-6}	4.5×10^{-3}	5.6×10^{-3}	0.14
$\mathcal{B}(t \to c\gamma)$ (max)	—	—	1.8×10^{-5}	4.8×10^{-5}	2.3×10^{-3}	3.2×10^{-2}	—
LHC Window	Closed*	Closed*	Ajar	Ajar	Open	Open	Open

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Looks as if B-phys. strongly constraint LH operators!

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LHC Window	Closed*	Closed*	Ajar	Ajar	Open	Open	Open

~~Looks as if B-phys strongly constraint LH operators!~~

Not valid if down alignment is at work 

2x Gedalia, et al. (10).

Robust bounds for $\Delta t = 1$

$$O^h_{LL} = i\,\left[\overline{Q}_i \gamma^\mu (X_Q^{\Delta F=1})_{ij} Q_j\right]\left[H^\dagger \overleftrightarrow{D}_\mu H\right]$$

$$\mathrm{Br}(B \to X_s \ell^+ \ell^-) \qquad\qquad \mathrm{Br}(t \to (c,u)Z)$$

- 3-gen' case the structure is much richer (8 Gell-Mann matrices), a covariant treatment is necessary. Simplification: @ LHC light quark jets look the same.

Approximate $U(2)$ Limit of Massless Light Quarks

The approximate U(2)

0th order question for a 3x3 adjoint:
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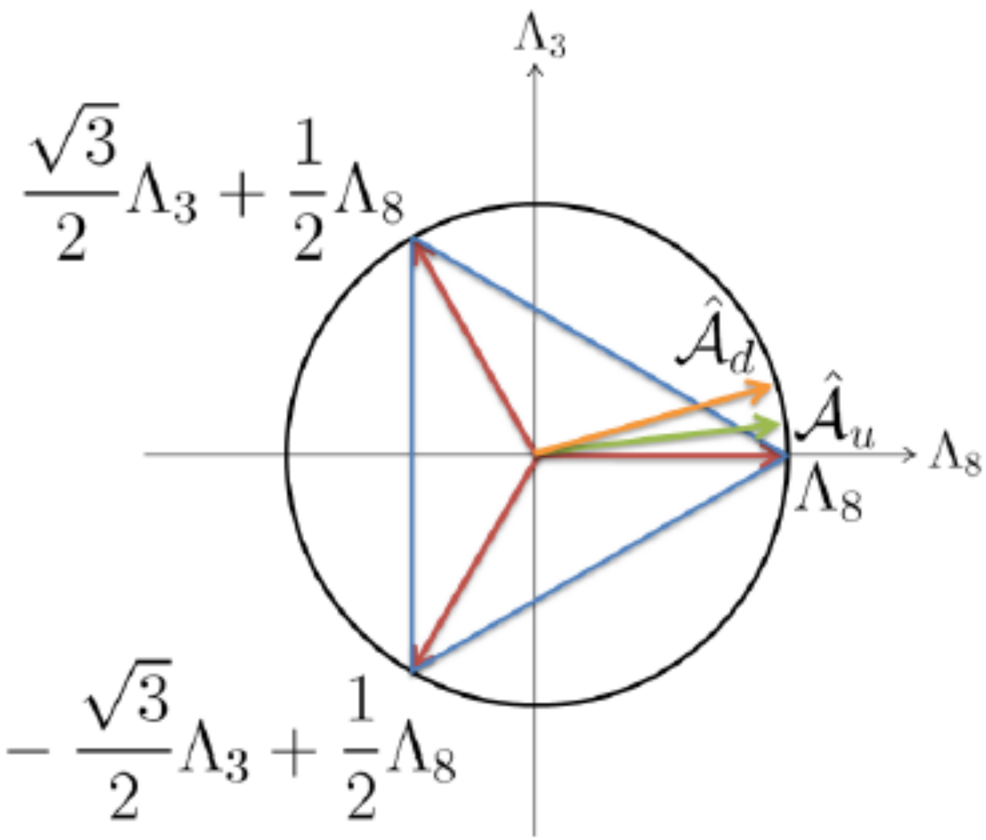

Covariant description of approx' U(2)

- Without loss of generality:

$$\mathcal{A}_d = \frac{y_b^2}{3}\begin{pmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 2 \end{pmatrix}, \qquad \mathcal{A}_u = y_t^2 \begin{pmatrix} \spadesuit & 0 & 0 \\ 0 & \spadesuit & \spadesuit \\ 0 & \spadesuit & \spadesuit \end{pmatrix},$$

- CKM has a single phase:

$$\theta \cong \sqrt{\theta_{13}^2 + \theta_{23}^2}\,,$$

- SM massless quarks are broken to active & sterile states:

$$\begin{array}{c} U(1)_Q \times U(1)_B \\ \uparrow V_{\mathrm{CKM}} \\ U(2)_Q \times U(1)_{Q_3} \\ \uparrow \mathcal{A}_{u,d}\ \ (V_{\mathrm{CKM}} \to \mathbb{1}_3) \\ U(3)_Q \end{array}$$

Covariant basis

- Start as in 2 gen': $\hat{\mathcal{A}}_{u,d} \equiv \frac{\mathcal{A}_{u,d}}{|\mathcal{A}_{u,d}|}\,, \quad \hat{J} \equiv \frac{\mathcal{A}_d \times \mathcal{A}_u}{|\mathcal{A}_d \times \mathcal{A}_u|}\,, \quad \hat{J}_{u,d} \equiv \hat{\mathcal{A}}_{u,d} \times \hat{J}\,.$

- Add a Cartan: $\hat{\mathcal{A}}_{u,d} \quad \text{and} \quad \hat{C}_{u,d} \equiv 2\hat{J} \times \hat{J}_{u,d} - \sqrt{3}\hat{\mathcal{A}}_{u,d}\,,$

or

$$\hat{\mathcal{A}}'_{u,d} \equiv \hat{J} \times \hat{J}_{u,d} \quad \text{and} \quad \hat{J}_Q \equiv \sqrt{3}\hat{J} \times \hat{J}_{u,d} - 2\hat{\mathcal{A}}_{u,d}\,.$$

$\hat{J}_Q$ corresponds to the conserved $U(1)_Q$ generator, $\left[\hat{J}_Q, \hat{\mathcal{A}}_{u,d}\right] = 0$

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$\hat{J}_Q$ corresponds to the conserved $U(1)_Q$ generator, $\left[\hat{J}_Q, \hat{\mathcal{A}}_{u,d}\right] = 0$

- Any adjoint can decompose according to:

$$X_Q^{\Delta F=1} = X'^{u,d}\hat{\mathcal{A}}'_{u,d} + X^J \hat{J} + X^{J_{u,d}}\hat{J}_{u,d} + X^{J_Q}\hat{J}_Q + X^{\vec{D}}\hat{\vec{\mathcal{D}}}\,.$$

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"big" directions

Covariant basis

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Robust projected bound (assuming no signal) & *t/b* flavor violation

- Overall 3rd gen' flavor violation: $\frac{2}{\sqrt{3}}\left|X_Q \times \hat{\mathcal{A}}_{u,d}\right|$,

which extracts $\sqrt{|(X_Q)_{13}|^2 + |(X_Q)_{23}|^2}$ in each basis.

- The bounds:

$$\mathrm{Br}(B \to X_s \ell^+ \ell^-) \longrightarrow \left|C^h_{LL}\right|_b < 0.018 \left(\frac{\Lambda_{\rm NP}}{1\,\mathrm{TeV}}\right)^2 ,$$

$$\mathrm{Br}(t \to (c,u)Z) \longrightarrow \left|C^h_{LL}\right|_t < 0.18 \left(\frac{\Lambda_{\rm NP}}{1\,\mathrm{TeV}}\right)^2 ,$$

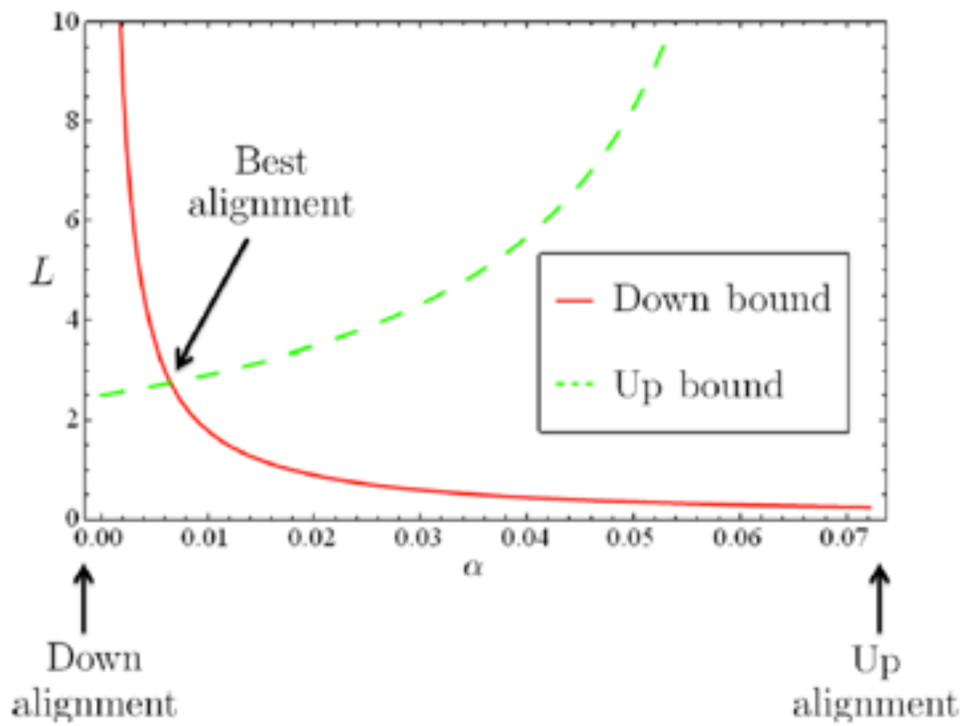
$$\frac{4}{3}\left|X_Q^{\Delta F=1} \times \hat{\mathcal{A}}_{u,d}\right|^2 = \left(X^J\right)^2 + \left(X^{J_{u,d}}\right)^2 , \quad X^{J_u} = \cos 2\theta\, X^{J_d} + \sin 2\theta\, X^{\prime d} ,$$

The bound

$$\text{(i)} \quad \alpha = 0\,, \quad L < 2.5\left(\frac{\Lambda_{\rm NP}}{1\,\rm TeV}\right)^2; \quad \Lambda_{NP} > 0.63\,(7.9)\ \rm TeV\,,$$

$$\text{(ii)} \quad \alpha = \frac{\sqrt{3}\,\theta}{1 + r_{tb}}\,, \quad L < 2.8\left(\frac{\Lambda_{\rm NP}}{1\,\rm TeV}\right)^2; \quad \Lambda_{NP} > 0.6\,(7.6)\ \rm TeV\,,$$

$$\tan\alpha \equiv \frac{X^{J_d}}{X^d} \qquad L \equiv \left|X_Q^{\Delta F=1}\right| \qquad r_{tb} \equiv \left|C_{LL}^h\right|_t / \left|C_{LL}^h\right|_b$$



$\Delta F = 2\,,\ \left[(\bar{t},\bar{b})_L X_Q (u,d)_L\right]^2$

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}	$\Delta m_K;\ \epsilon_K$
$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$	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}	$\Delta m_D;\ \lvert q/p\rvert, \phi_D$
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	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}	$\Delta m_{B_d};\ S_{\psi K_S}$
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$(\bar{b}_L\gamma^\mu s_L)^2$	1.1×10^2		7.6×10^{-5}		Δm_{B_s}
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$(\bar{t}_L\gamma^\mu u_L)^2$	?		?		?

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$(\bar{t}_L \gamma^\mu u_L)^2$	12		$7.1\ 10^{-3}$		$uu \to tt$

However, CPV in D system is stronger

Despite $\mathcal{O}(\lambda_C^5)$ suppression:

$$\mathrm{Im}(z_1^D) < 1.1 \times 10^{-7} \left(\frac{\Lambda_{\mathrm{NP}}}{1\,\mathrm{TeV}}\right)^2 ,$$

$$L < 12 \left(\frac{\Lambda_{\mathrm{NP}}}{1\,\mathrm{TeV}}\right) ; \quad \Lambda_{\mathrm{NP}} > 0.08\,(1)\,\mathrm{TeV} ,$$

for $uu \to tt$ and

$$L < 1.8 \left(\frac{\Lambda_{\mathrm{NP}}}{1\,\mathrm{TeV}}\right) ; \quad \Lambda_{\mathrm{NP}} > 0.57\,(7.2)\,\mathrm{TeV} ,$$

for D mixing.

Also applied to SUSY & RS => weak but robust bounds.

Outlook, Flavor at the LHC Era

LHC era ~ up FCNC, however, regarding tFCNC, despite orders mag' improvement => constraints rather weak.

Flavor diagonal NP (spectrum or couplings, say KK gluon BRs) could be exciting, especially deviation from U(2).

LMFV vs. GMFV could be next decade question:

LMFV lies on $\mathcal{A}_u$-$\mathcal{A}_d$ plane;
GMFV lies on large-axes sub-manifold .

$\{$Since CPV in GMFV $\propto [\mathcal{A}_u, \mathcal{A}_d]\}$

Backups

Precision Measurements in D mixing

- Huge recent progress in measurement of mass splitting & CP violation (CPV) in the D system:

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BABAR BELLE

$$\Delta m_D/m_D = (8.6 \pm 2.1) \times 10^{-15}$$
$$A_\Gamma = (1.2 \pm 2.5) \times 10^{-3}$$

$$A_\Gamma = \frac{\tau(\overline{D}^0 \to K^- K^+) - \tau(D^0 \to K^+ K^-)}{\tau(\overline{D}^0 \to K^- K^+) + \tau(D^0 \to K^+ K^-)};$$

$$A_\Gamma = \frac{1}{2}(|q/p| - |p/q|) y \cos\phi - \frac{1}{2}(|q/p| + |p/q|) x \sin\phi$$

$$\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}. \qquad \lambda_{K^+K^-} = -|q/p| e^{i\phi},$$

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- System parameters roughly determined (HFAG):

$$x = (1.00 \pm 0.25) \times 10^{-2},$$
$$y = (0.77 \pm 0.18) \times 10^{-2},$$
$$1 - |q/p| = +0.06 \pm 0.14,$$
$$\phi = -0.05 \pm 0.09,$$

$$m \equiv \frac{m_1 + m_2}{2}, \qquad \Gamma \equiv \frac{\Gamma_1 + \Gamma_2}{2},$$
$$x \equiv \frac{m_2 - m_1}{\Gamma}, \qquad y \equiv \frac{\Gamma_2 - \Gamma_1}{2\Gamma}.$$

Combining $K^0 - \overline{K^0}$ & $D^0 - \overline{D^0}$ mixings

- Powerful model indep' bound.

$$\frac{1}{\Lambda_{\rm NP}^2}\left[z_1^K(\overline{d_L}\gamma_\mu s_L)(\overline{d_L}\gamma^\mu s_L) + z_1^D(\overline{u_L}\gamma_\mu c_L)(\overline{u_L}\gamma^\mu c_L) + z_4^D(\overline{u_L}c_R)(\overline{u_R}c_L)\right].$$

no CPV $\longleftrightarrow$

$$|z_1^K| \le z_{\rm exp}^K = \boxed{8.8\times10^{-7}}\left(\frac{\Lambda_{\rm NP}}{1\ {\rm TeV}}\right)^2$$

$$|z_1^D| \le z_{\rm exp}^D = \boxed{5.9\times10^{-7}}\left(\frac{\Lambda_{\rm NP}}{1\ {\rm TeV}}\right)^2$$

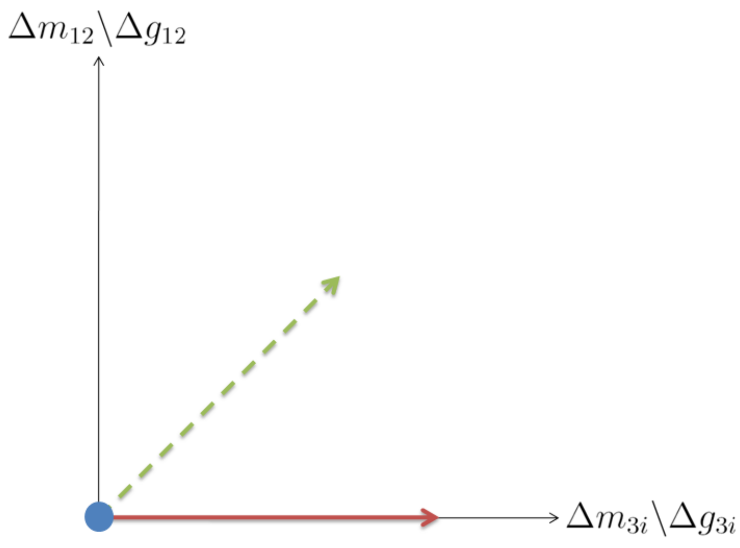
with CPV $\longleftrightarrow$

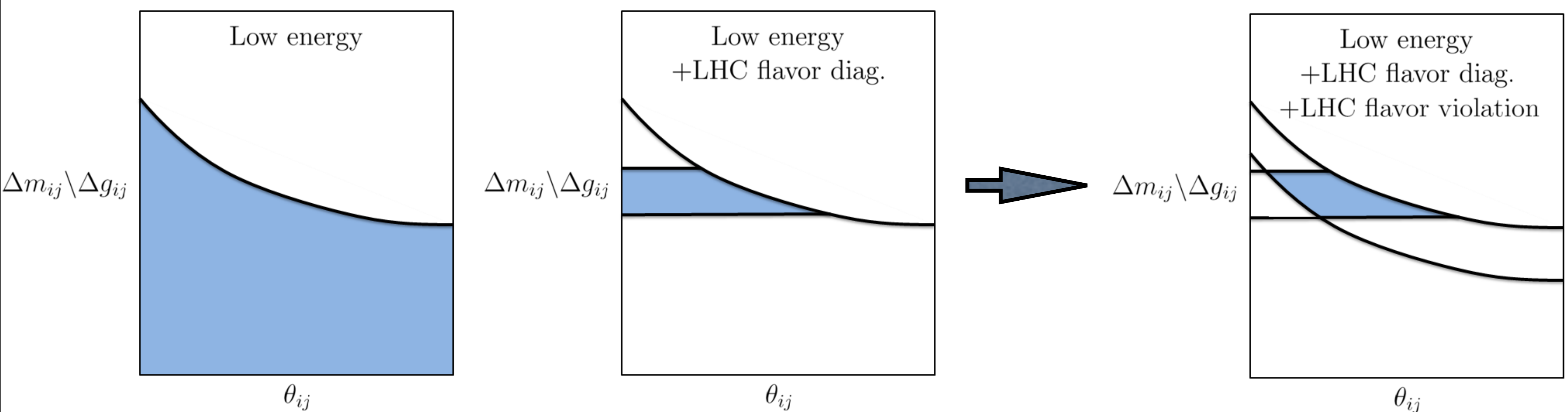
$$\mathcal{I}m(z_1^K) \le z_{\rm exp}^{IK} = \boxed{3.3\times10^{-9}}\left(\frac{\Lambda_{\rm NP}}{1\ {\rm TeV}}\right)^2$$

$$\mathcal{I}m(z_1^D) \le z_{\rm exp}^{ID} = \boxed{1.0\times10^{-7}}\left(\frac{\Lambda_{\rm NP}}{1\ {\rm TeV}}\right)^2$$

Flavor @ the LHC, spectrum/couplings very important

The importance of flavor diag' info



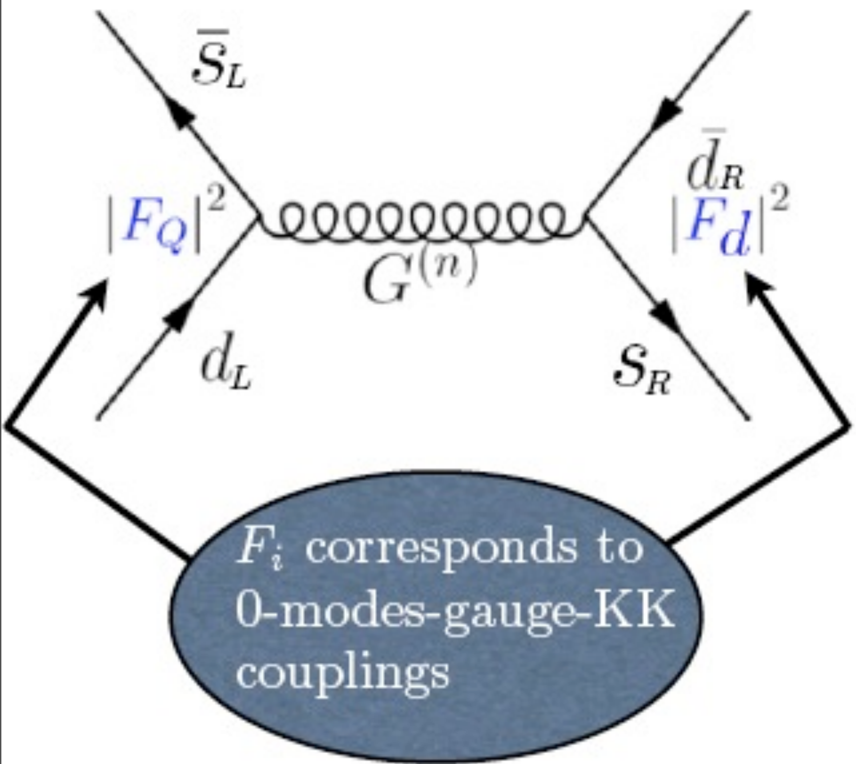


Grossman et al. (09); Gedalia & Perez (10)

The RS "little" CP problem

- O(100) chiral enhancement for *LLRR* current yield

a severe bound on IR Higgs, $M_{\rm KK} = \mathcal{O}(10\,\text{TeV})$

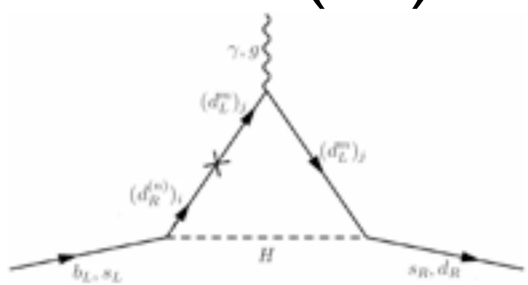


UTFit; Davidson, Isidori & Uhlig (07); Blanke et al.; Casagrande et al.; Csaki, Falkowski & Weiler; Agashe, Azatov & Zhu (08) Gedalia, GP & Isidori (09).

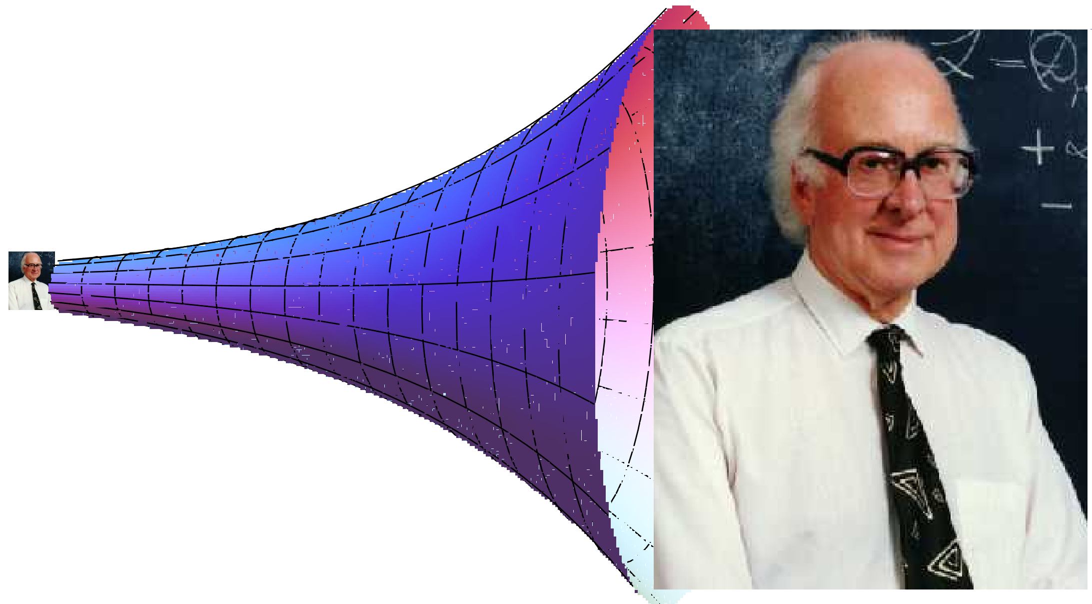
$$\Rightarrow \epsilon_K \propto F_Q^\dagger F_Q F_d^\dagger F_d \sim \frac{m_d m_s}{\left(Y_5^d\right)^2}$$

- Contributions to EDM's are O(20) larger than bounds.

Agashe, GP & Soni (04)



Warped Exra dimension



Randall Sundrum (RS)

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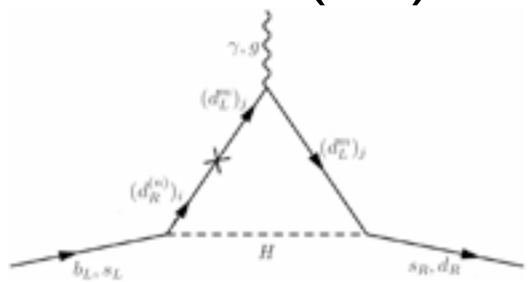

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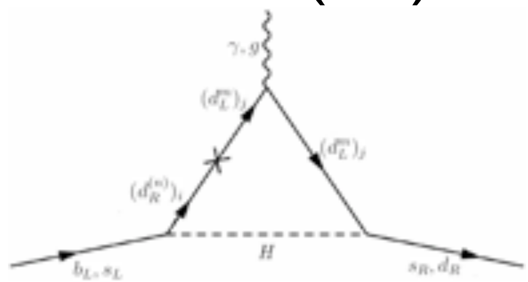
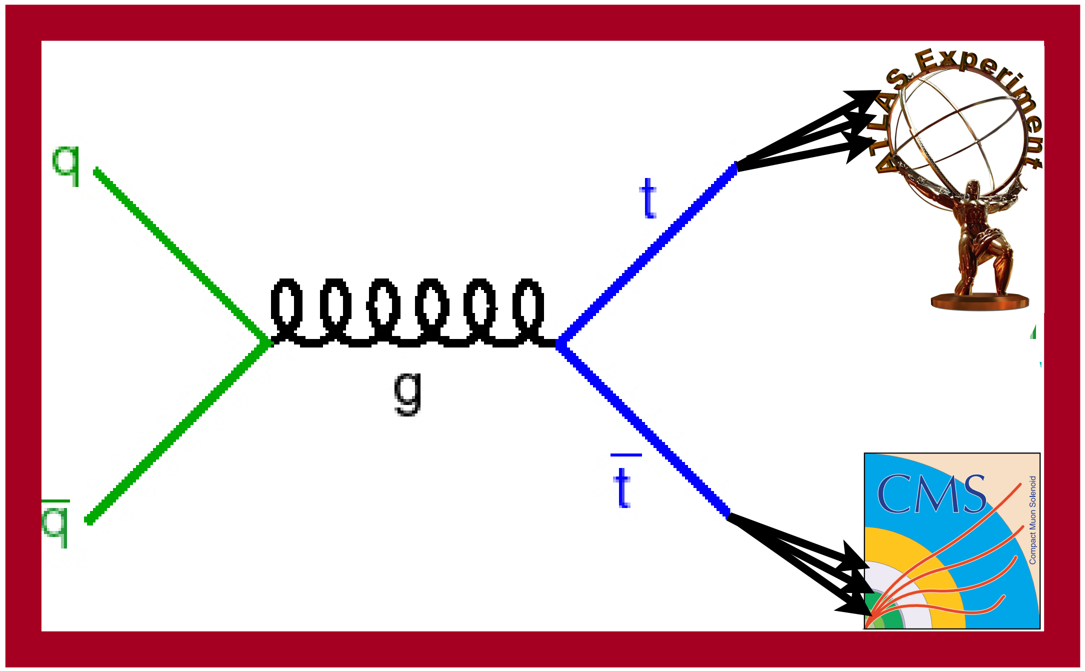


Severe tuning problem or fine tuning problem & null LHC pheno'.

Parametric solutions to the RS little CP problem & some LHC implications.



5D MFV & Shining

(either give up on solving the flavor puzzle, Rattazzi & Zaffaroni (00), Cacciapaglia, Csaki, Galloway, Marandella, Terning & Weiler (07) or)

- $Y_{u,d}$ => anarchic & the only source of flavor breaking.

Fitzpatrick, GP & Randall (07)

- Also, bulk masses are functions of same spurions:

$$C_{u,d} = Y_{u,d}^\dagger Y_{u,d} + \ldots\,, \quad C_Q = r Y_u Y_u^\dagger + Y_d Y_d^\dagger + \ldots\,,$$

$$\text{Shining} \Rightarrow \text{down alignment in the } r \to 0 \text{ limit.}$$

Csaki. et al. (09)

U-anarchy - constrained by D phys.

- Generic warped models (up-type anarchy): Agashe, et. al (04,06).

Observable	$M_G^{\min}$[TeV]		$y_{5\mathrm{D}}^{\min}$ or $f_{Q_3}^{\max}$	
	IR Higgs	$\beta=0$	IR Higgs	$\beta=0$
CPV-B_d^{LLLL}	$12 f_{Q_3}^2$	$12 f_{Q_3}^2$	$f_{Q_3}^{\max}=0.5$	$f_{Q_3}^{\max}=0.5$
CPV-B_d^{LLRR}	$4.2/y_{5\mathrm{D}}$	$2.4/y_{5\mathrm{D}}$	$y_{5\mathrm{D}}^{\min}=1.4$	$y_{5\mathrm{D}}^{\min}=0.82$
CPV-D^{LLLL}	$0.73 f_{Q_3}^2$	$0.73 f_{Q_3}^2$	no bound	no bound
CPV-D^{LLRR}	$4.9/y_{5\mathrm{D}}$	$2.4/y_{5\mathrm{D}}$	$y_{5\mathrm{D}}^{\min}=1.6$	$y_{5\mathrm{D}}^{\min}=0.8$
ϵ_K^{LLLL}	$7.9 f_{Q_3}^2$	$7.9 f_{Q_3}^2$	$f_{Q_3}^{\max}=0.62$	$f_{Q_3}^{\max}=0.62$
ϵ_K^{LLRR}	$49/y_{5\mathrm{D}}$	$24/y_{5\mathrm{D}}$	above (6.7)	$y_{5\mathrm{D}}^{\min}=8$

Gedalia, et. al (09);
Isidori, et. al (10).

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Gedalia, et. al (09);
Isidori, et. al (10).

- RS alignment (via shining): $y_{5\mathrm{D}}^{d} \gtrsim 3 y_{5\mathrm{D}}^{u}$ Csaki, et. al (09).

$$\frac{1}{2} \lesssim y_{5\mathrm{D}} \lesssim \frac{2\pi}{N_{\mathrm{KK}}} \quad \text{for brane Higgs}\,; \qquad \frac{1}{2} \lesssim y_{5\mathrm{D}} \lesssim \frac{4\pi}{\sqrt{N_{\mathrm{KK}}}} \quad \text{for bulk Higgs}\,,$$

$\Rightarrow$ Factor of few improvement exclude models.

Radical solutions

- Rattazzi-Zaffaroni's model: excellent protection but no solution for the little hierarchy problem.

- Is there a bulk version? Can one lower the KK scale?

(Delaunay,Lee & GP, preliminary)

Custodial sym': Non-universal oblique corrections & FCNC's are under control;

Agashe, et al. (06)

Universal oblique corrections are problematic.

- New type of LHC pheno', flavor gauge bosons.

Csaki, Lee, Weiler, in progress.