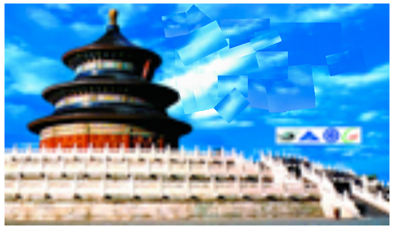
Theoretical review on the prospect for new physics in charm sector

Gilad Perez

Weizmann Institute



The 4th Int. Workshop on Charm Physics:

Charm 2010

Outline

- Brief introduction, importance of up flavor physics.
- Model independent information (effective field theory).
- Charm physics & alignment models.
- $D - \bar{D}$ mixing, the connection with tFCNC.
- Model dependent information: (MFV, SUSY, RS).
- The potential of $D^0 \to \mu^+ \mu^-$.
- Conclusions.

Why Up ?

- SM way to induce flavor conversion & CPV is unique.

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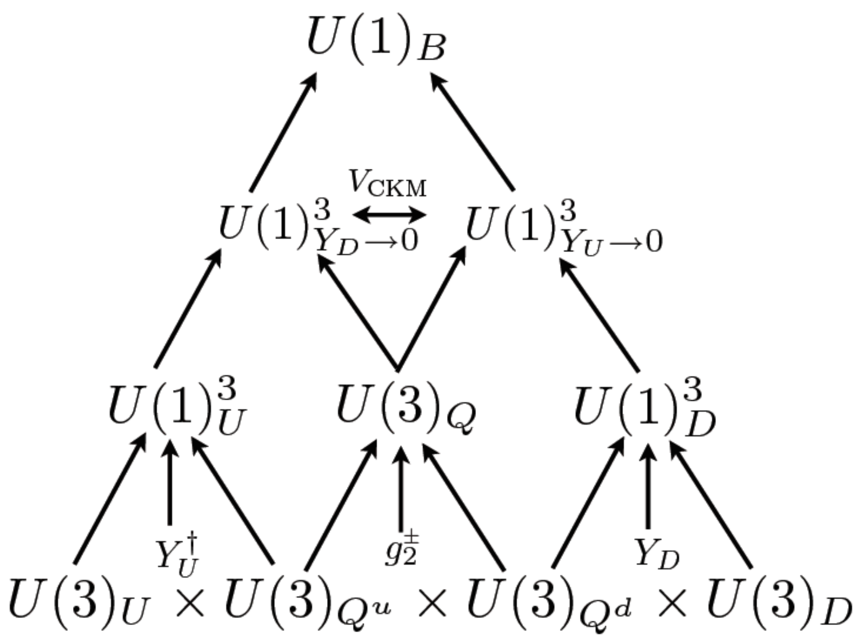

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- SM way to induce flavor conversion & CPV is unique.

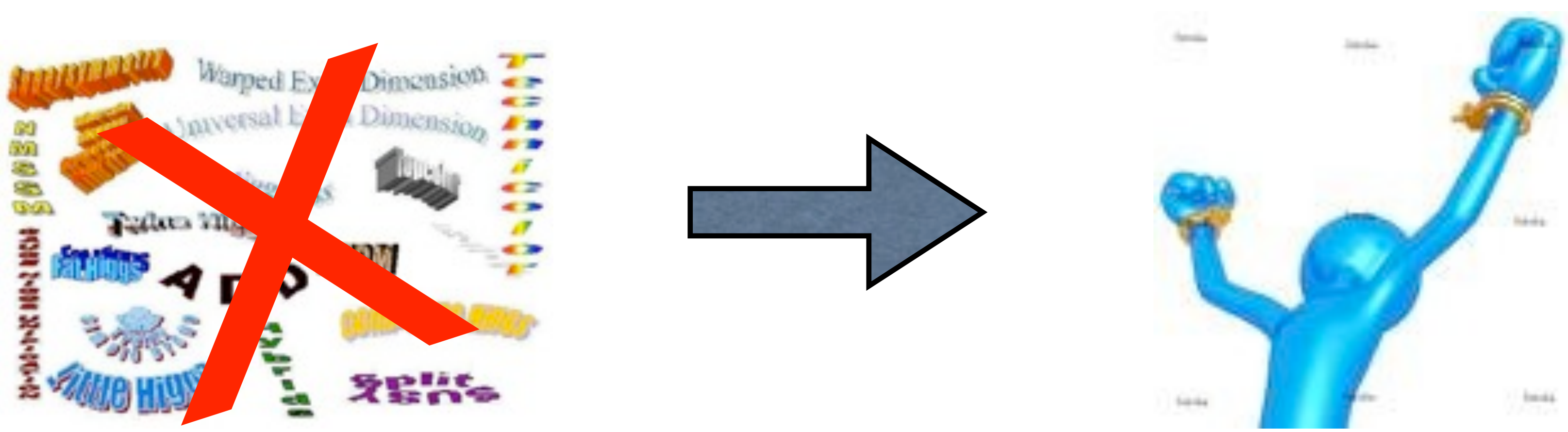
- Absence (?) of deviation from SM predictions implies severe bound on new physics (NP).

- 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.

Prelude

What do we know about New Phys. flavor sector, model independently?



Generic bounds via effective theory

$\Delta F = 2$ processes among the cleanest.

In the SM proceed at loop and highly suppressed.

To leading order beyond the SM:

$$\frac{(\bar{q}_i q_j)(\bar{q}_i q_j)}{\Lambda_{\rm NP}^2}$$

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What are the bounds on Λ_{NP}

for different flavor transitions?

$\Delta F = 2$ status

Isidori, Nir & GP, Ann. Rev. Nucl. Part. Sci. (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}	Δm_K; ϵ_K
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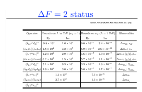

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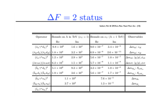

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D-system falls only behind the K-one

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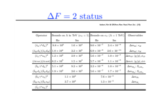

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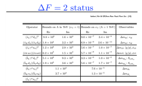
tFCNC linked
to $\Delta C = 2$
stay tuned!

D-system f[illegible] nd the K-one



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$(\bar{c}_L\gamma^\mu u_L)^2$	$1.2 \times$ …				$\lvert q/p\rvert, \phi_D$
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	$6.2 \times$ …				$\lvert q/p\rvert, \phi_D$
$(\bar{b}_L\gamma^\mu d_L)^2$	$5.1 \times$ …				… $_d$; $S_{\psi K_S}$
$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$	$1.9 \times$ …				… $_d$; $S_{\psi K_S}$
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$(\bar{t}_L\gamma^\mu u_L)^2$			?		?

$\Delta C = 1$ are weaker, will become very interesting in the future (see later), provide independent probe.

tFCNC linked to $\Delta C = 2$ stay tuned!

D-system f… …nd the K-one

Friday, October 22, 2010

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

δ

Δ

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

- System parameters roughly determined (HFAG):

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

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

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

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Absence of D CPV a SM victory!

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Absence of D CPV a SM victory!

SM: D system is controlled by 2 gen' physics $\Rightarrow$ CP conserving

Bottom contribution is down by:

$$\mathcal{O}\left(\frac{m_c^2}{m_b^2} \times \frac{V_{ub}V_{cb}^*}{V_{us}V_{cs}^*}\right) = 10^{-4}$$

(see talk by Lenz)

The power of CPV in the D system

Assuming no direct CP: [Golowich, Pakvasa & Petrov, PRL (07); Kagan and M. D. Sokolof, PRD (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, Grossman, Nir & GP, PRD (09).

long distance dominated?

Falk, et. al (02).

The power of CPV in the D system

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If x is due to NP then it missed a chance to revealed itself in $\mathcal{O}(1)$ CPV. ☹

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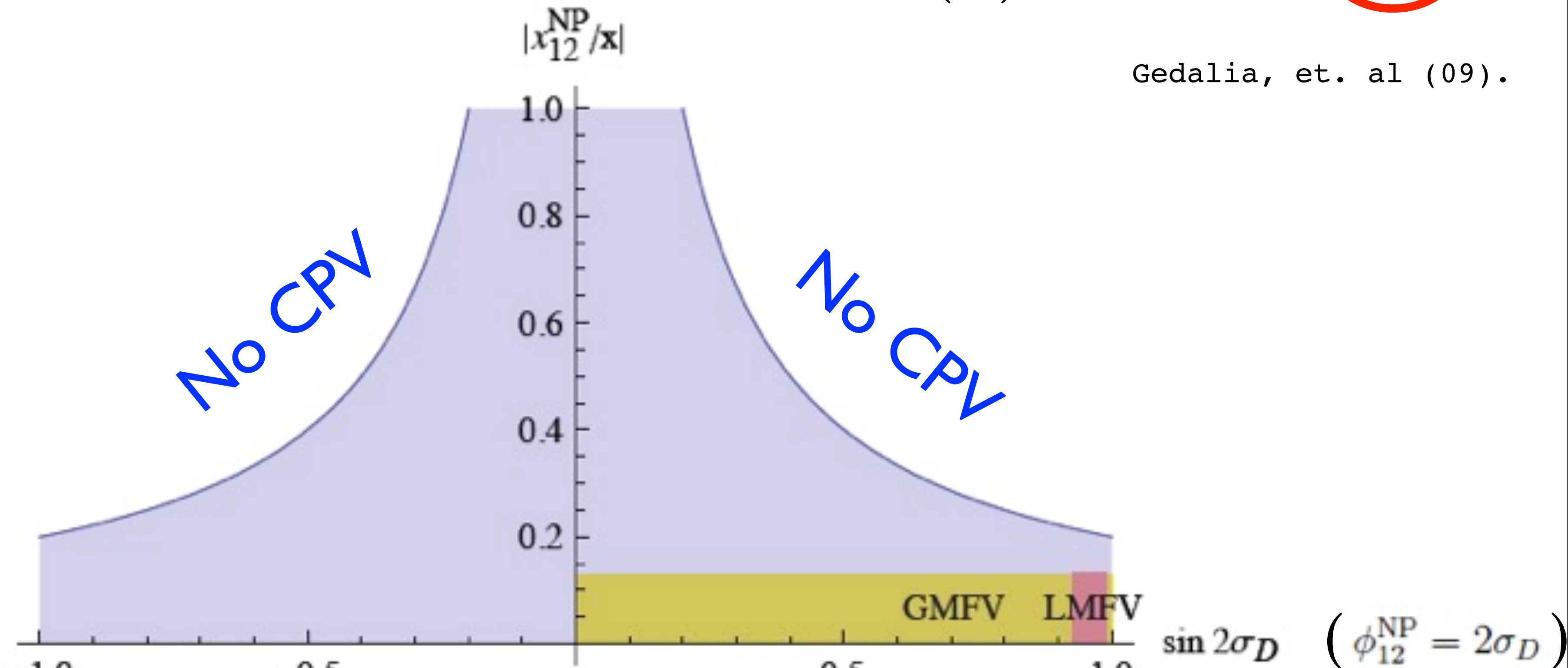

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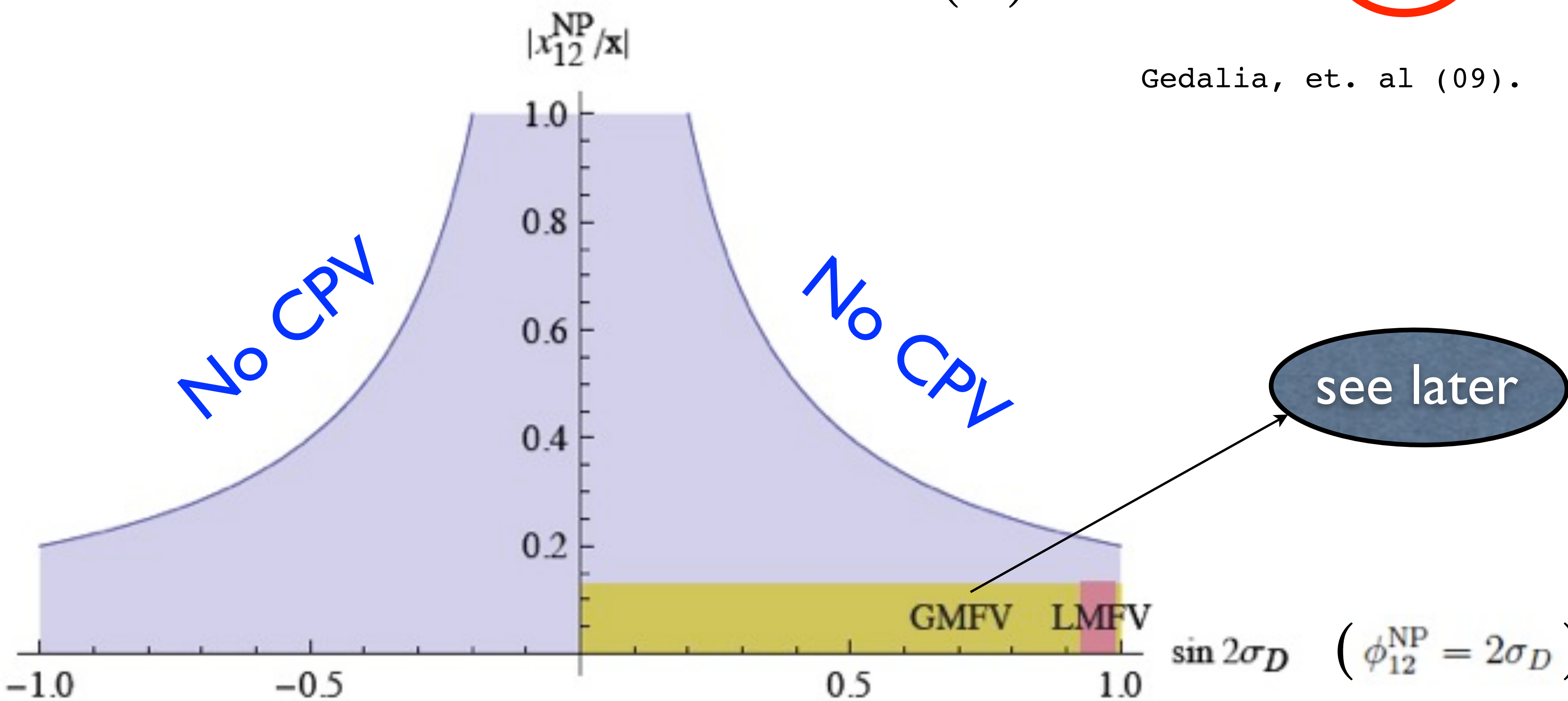

$(\phi_{12}^{\rm NP} = 2\sigma_D)$

What do we conclude ?

- SM mechanism to induce flavor & CPV

is successful.

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Toshihide Maskawa

$\Delta F = 2$ status

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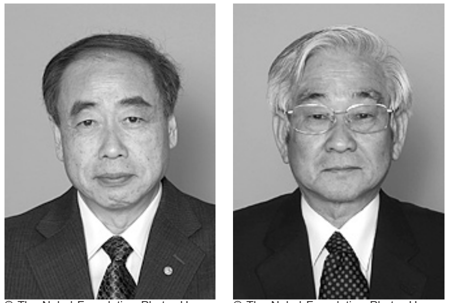

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- Resulting bounds are too strong to allow for generic TeV-scale NP - tension with solving the fine tuning problem.

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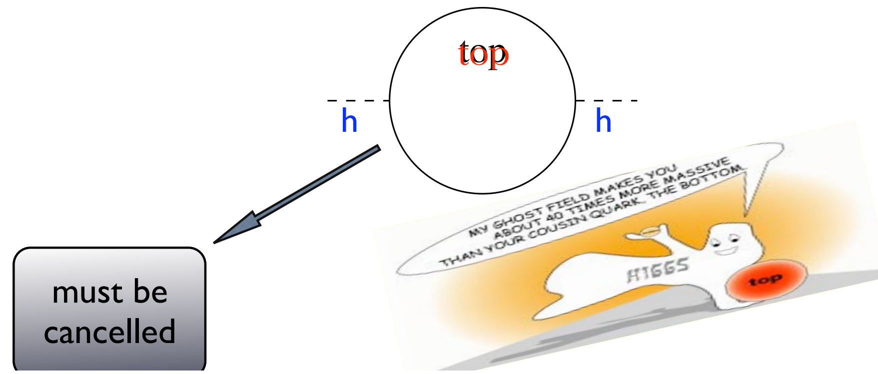
$(\bar{t}_L\gamma^\mu u_L)^2$					

- Resulting bounds are too strong to allow for generic TeV-scale NP - tension with solving the fine tuning problem.

- Hint for underlying structure of microscopic laws of nature.

What kind of NP survives?

- Flavor blind/universal NP, for sure, but then cancellation of top divergencies looks like a miracle.



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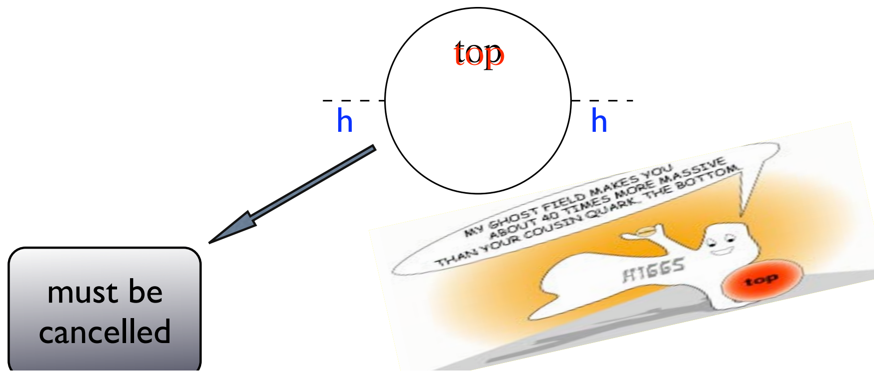

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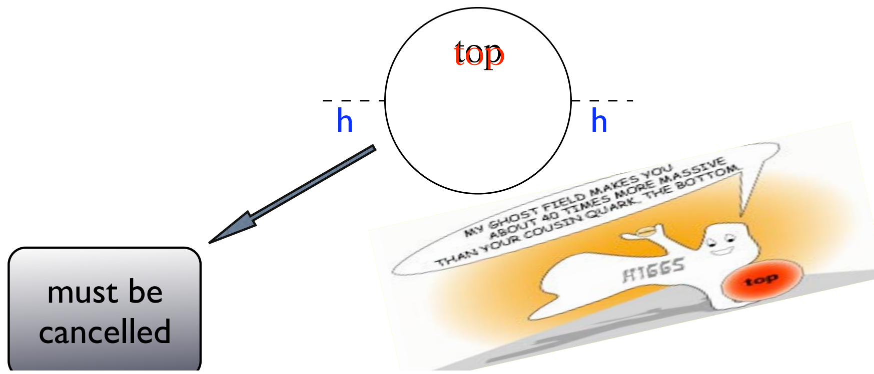

◆ Maybe NP flavor structure is controlled by SM one, minimal flavor violation (MFV) => more exciting then guessed, see later ...

◆ Maybe NP is anarchic but aligned.

uFCNC data, a crucial test of alignment

♦ Down type flavor violation can be shut off via alignment, where anarchic NP is diagonal in the down mass basis.

careful domino *alignment*

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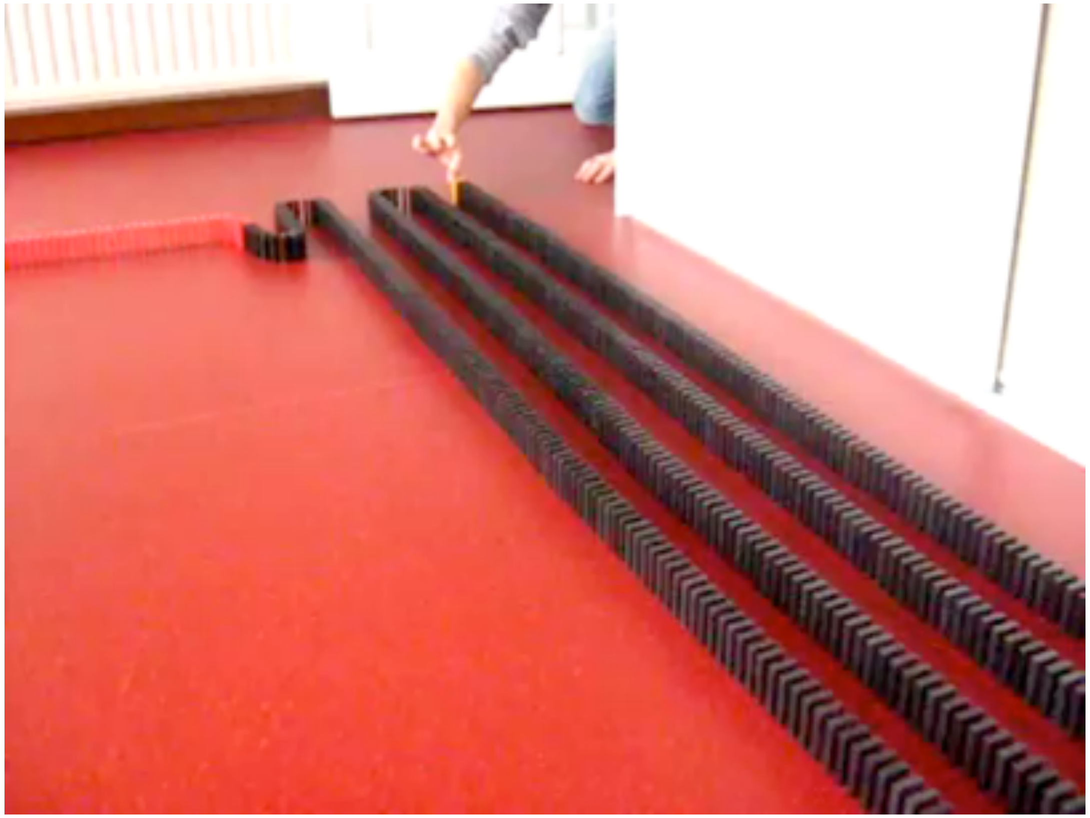

careful domino *alignment*

The importance of up-type FCNC

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
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u-FCNC data remove immunities!

Up sector

Look Down

Look Up

The power of CPV in D mixing & how it kills alignment models

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

δ

Δ

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

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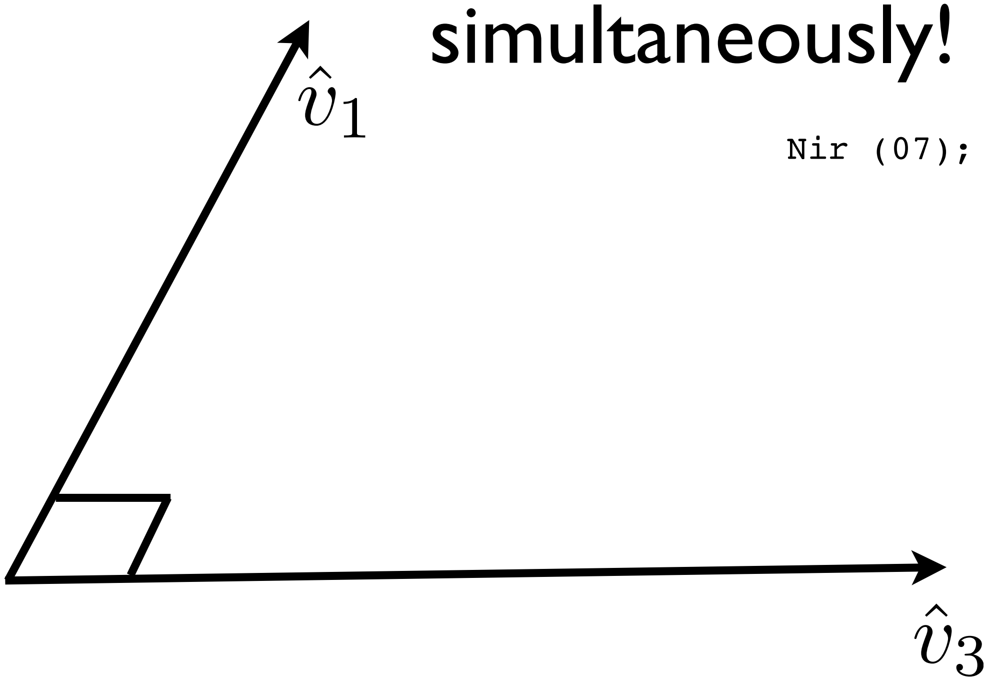

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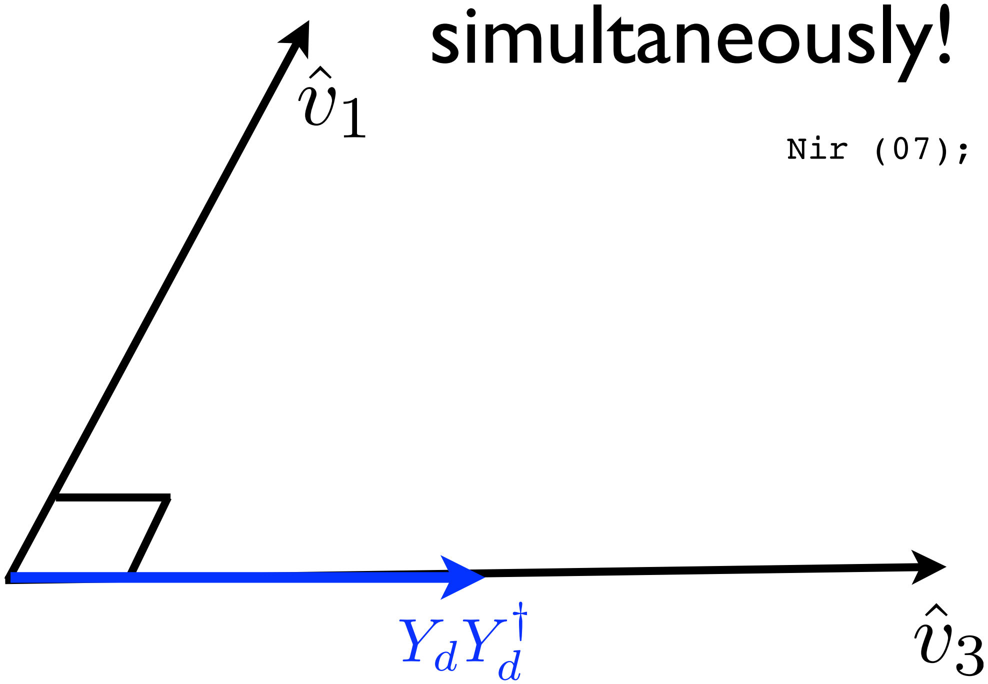

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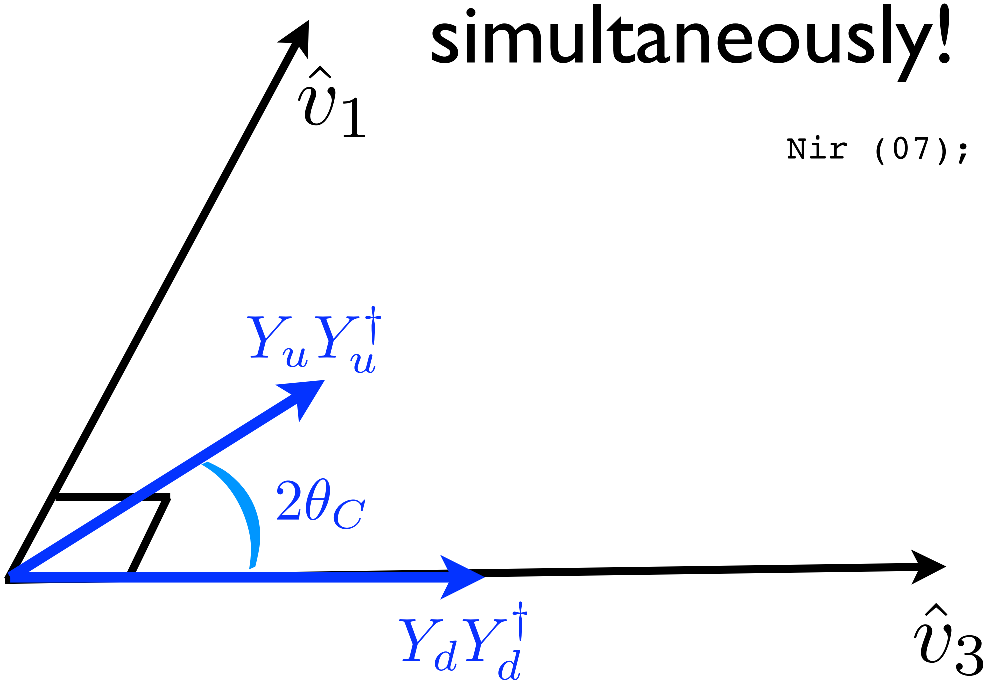

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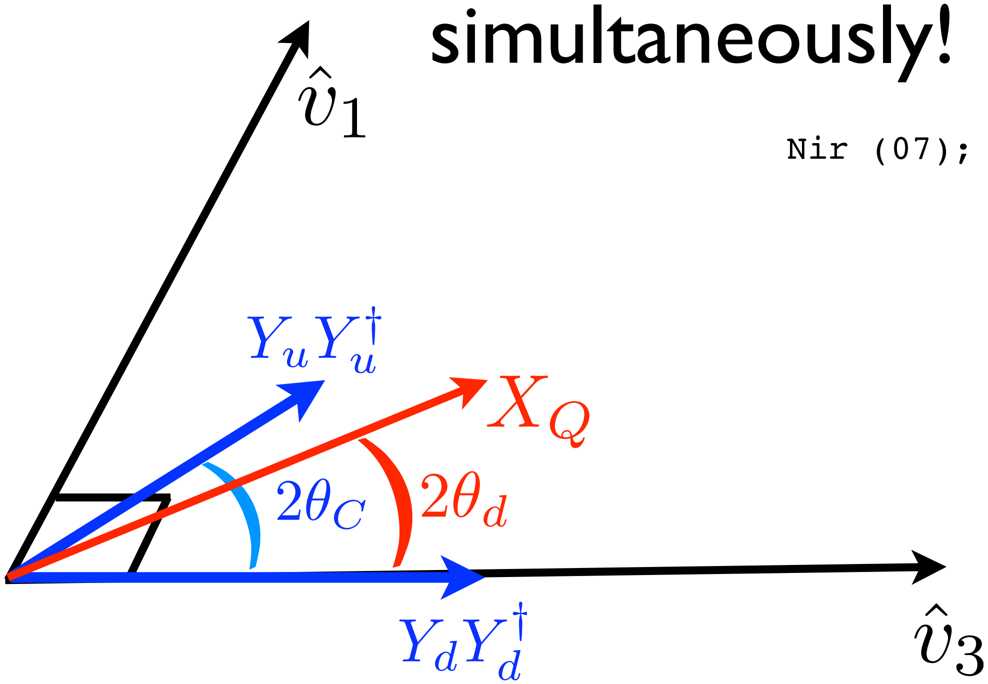

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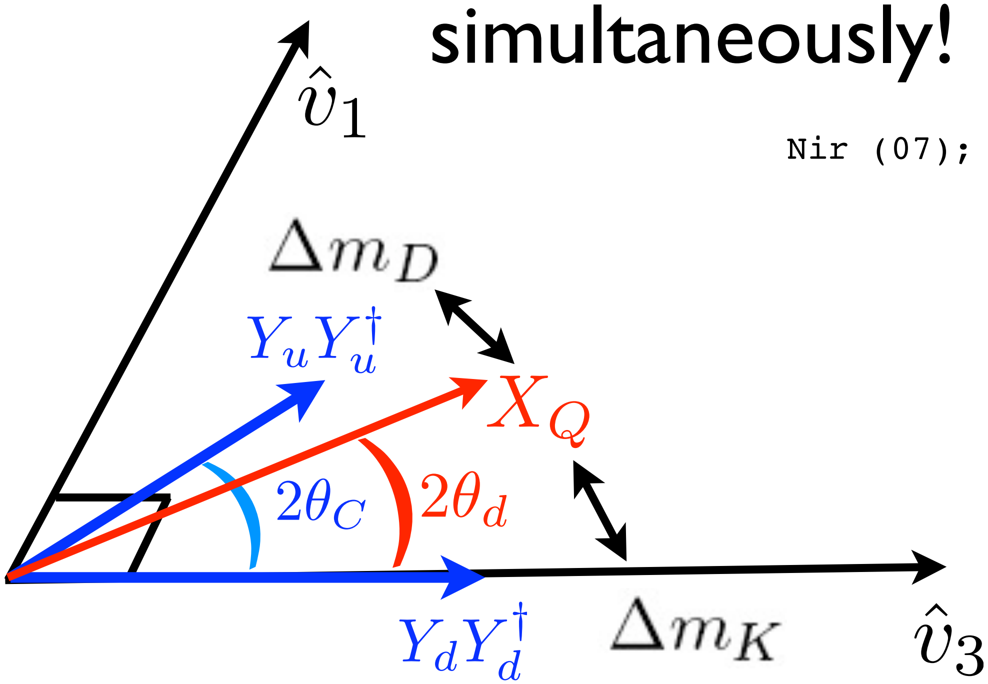
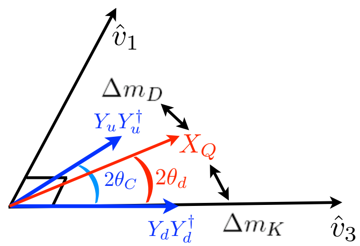


Implications of CPV in $D^0 - \bar{D}^0$ mixing

(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



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

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

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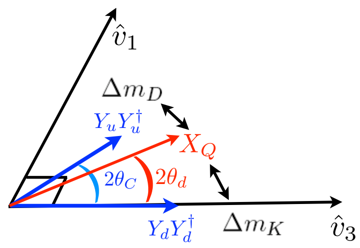

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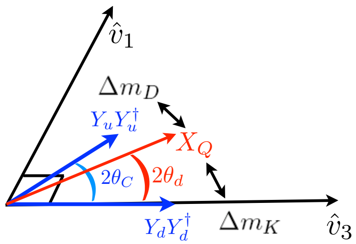

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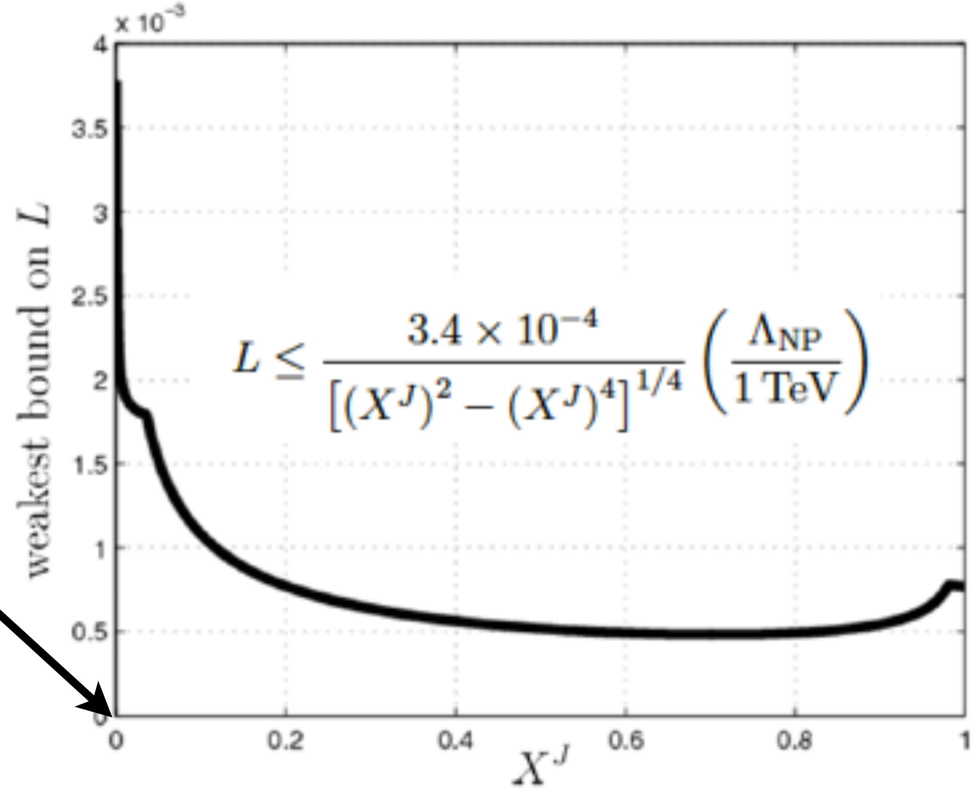

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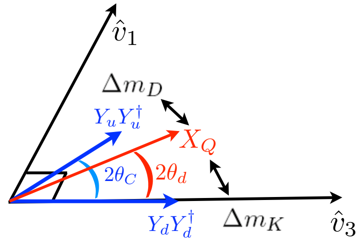

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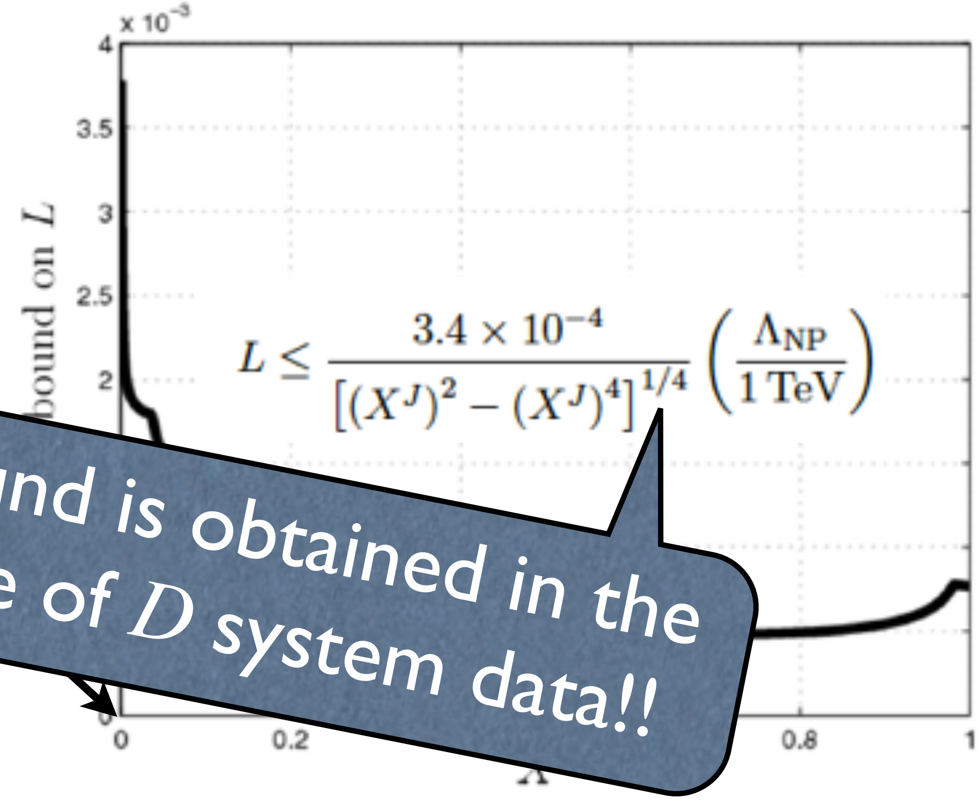

No CPV

No bound is obtained in the absence of D system data!!

CPV in D: Model Dependent Implications

(i) MFV (exciting #1); (ii) SUSY; (iii) Randall-Sundrum (RS).

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

Kagan, GP, Volanksy & Zupan, PRD (09); Gedalia, Grossman, Nir & GP, PRD (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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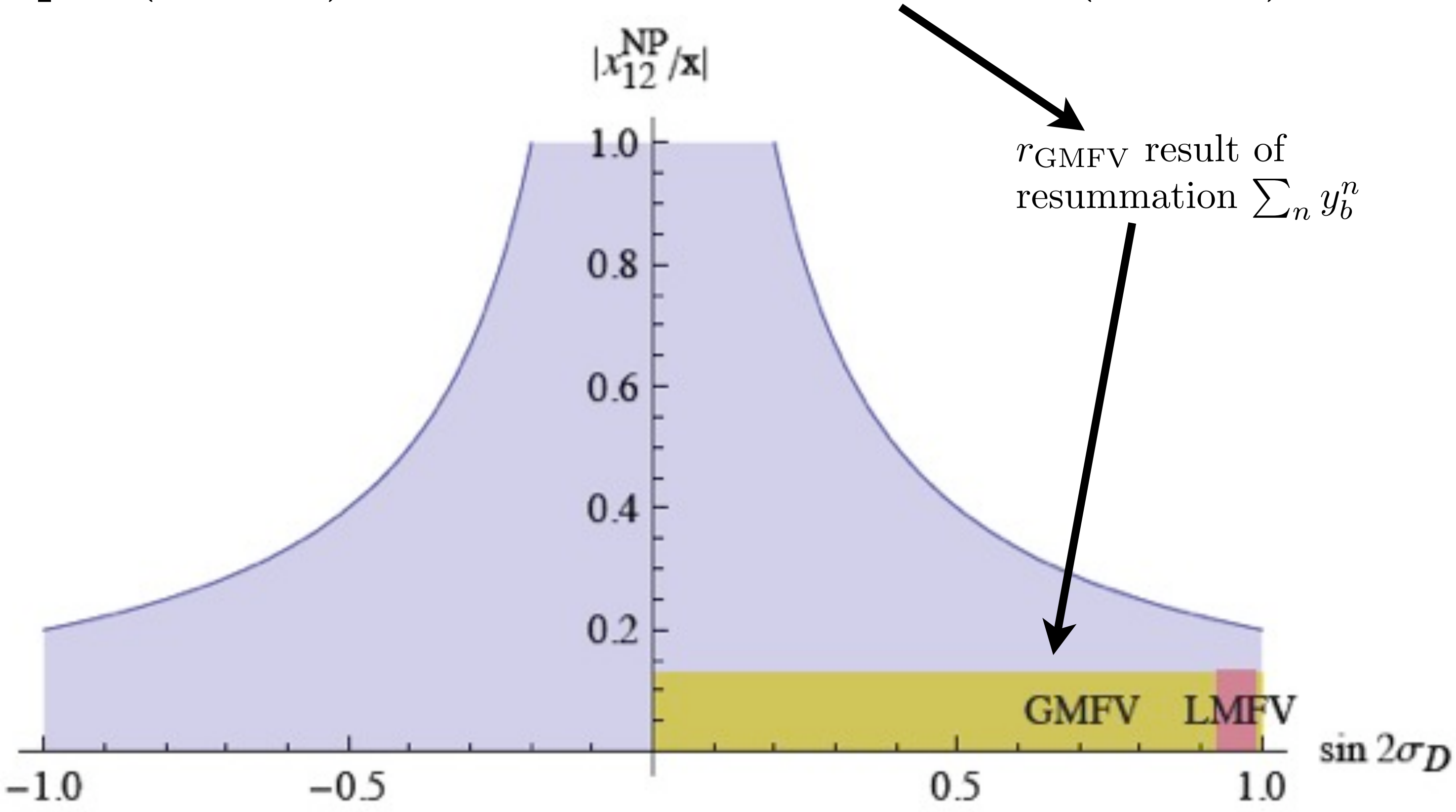

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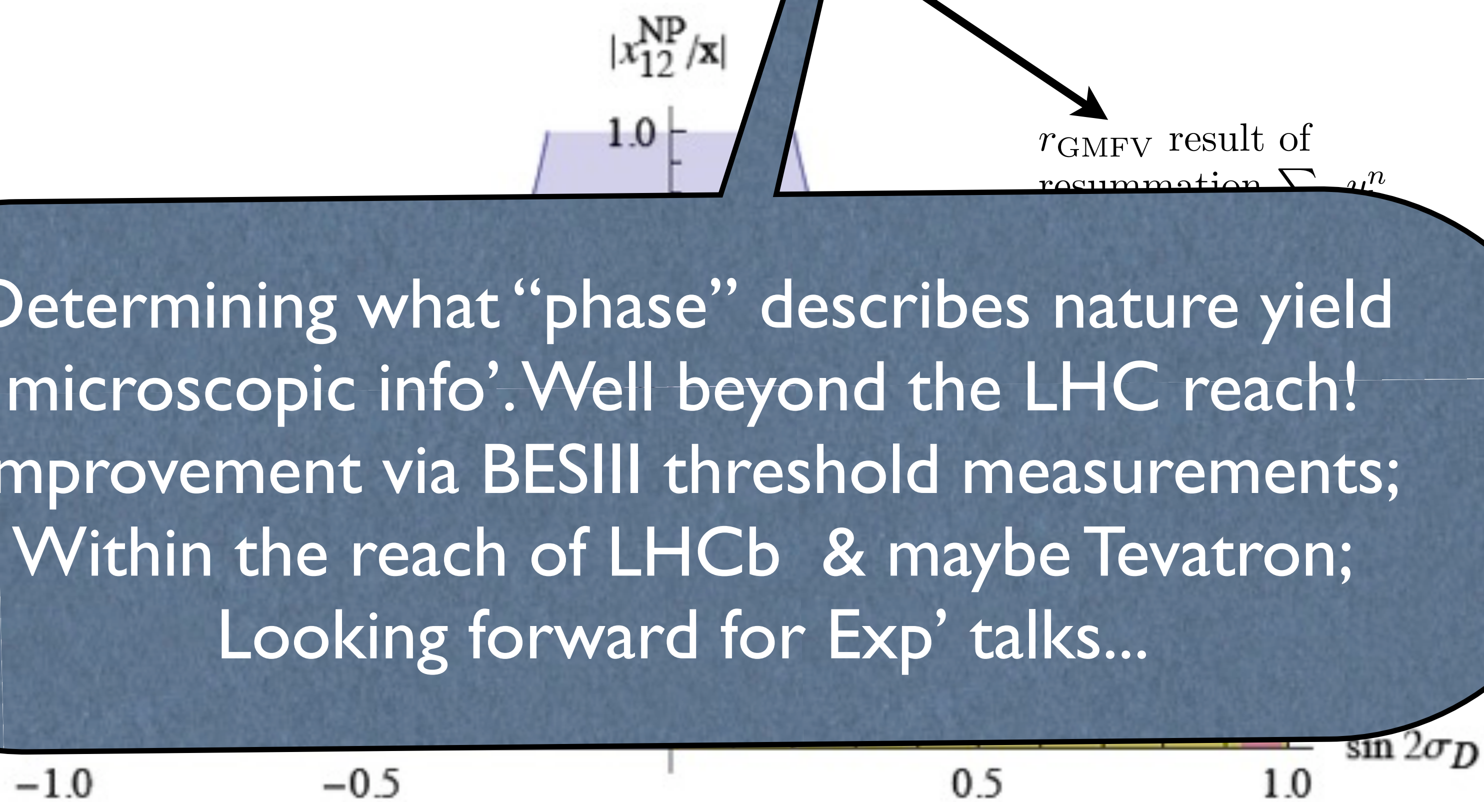


Determining what "phase" describes nature yield microscopic info'. Well beyond the LHC reach! Improvement via BESIII threshold measurements; Within the reach of LHCb & maybe Tevatron; Looking forward for Exp' talks...

SUSY+RS

SUSY (doom of alignment)

Gedalia, et. al (09).

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

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

average of the doublet & singlet mass splitting.

RS (constraining alignment)

Csaki, Falkowski & Weiler, PRD (09); Gedalia, et. al (09).

Robust

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

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

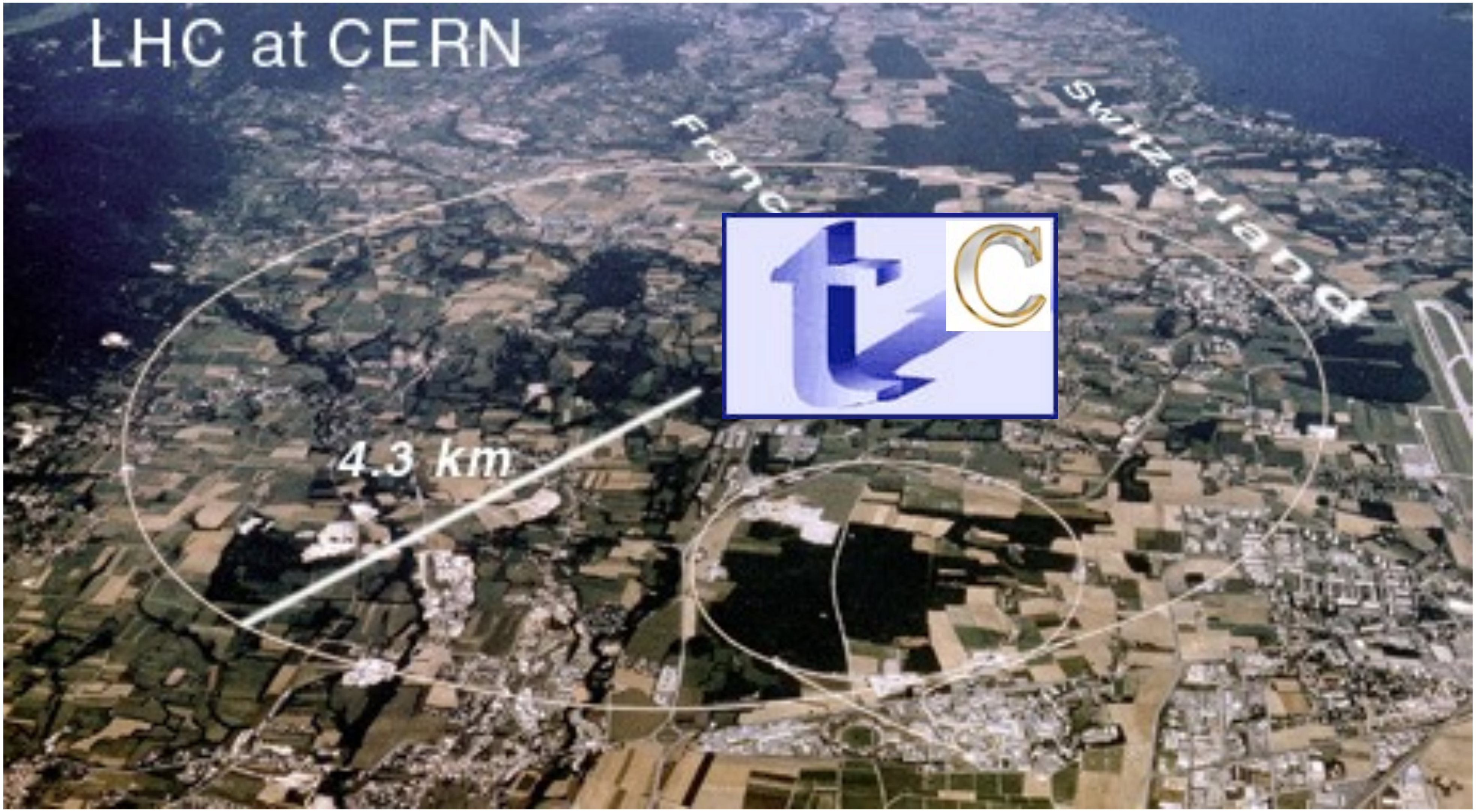
Generic

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

IR (bulk) Higgs

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

charming top Phys. @ the LHC



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

Gedalia, Mannelli & GP, PLB; JHEP (10).

- Signal is in same sign tops: $uu \to tt$

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}	$\Delta m_{B_d};\ S_{\psi K_S}$
$(\bar{b}_R\,d_L)(\bar{b}_L d_R)$	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}
$(\bar{t}_L\gamma^\mu u_L)^2$	?		?		?

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

- Projected LHC bound, same sign tops.

Operator	Bounds on Λ in TeV ($c_{ij}=1$)		Bounds on c_{ij} ($\Lambda = 1$ TeV)		Observables
	Re	Im	Re	Im	
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$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	3.7×10^2		1.3×10^{-5}		Δm_{B_s}
$(\bar{t}_L\gamma^\mu u_L)^2$	12		7.1×10^{-3}		$uu\to tt$

What gives strongest bound on $\left[(\bar{t},\bar{b})_L X_Q (u,d)_L\right]^2$?

Define: $L \equiv \left|X_Q^{\Delta F=2}\right|$

$uu \to tt$ (LHC projected): $L < 12\left(\frac{\Lambda_{\rm NP}}{1\,{\rm TeV}}\right)\;;\quad \Lambda_{\rm NP} > 0.08\,(1)\,{\rm TeV}\,,$

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$D^0 - \bar{D}^0$ (present): $L < 1.8 \left(\frac{\Lambda_{\rm NP}}{1\,{\rm TeV}} \right)$; $\Lambda_{\rm NP} > 0.57\,(7.2)\,{\rm TeV}$,

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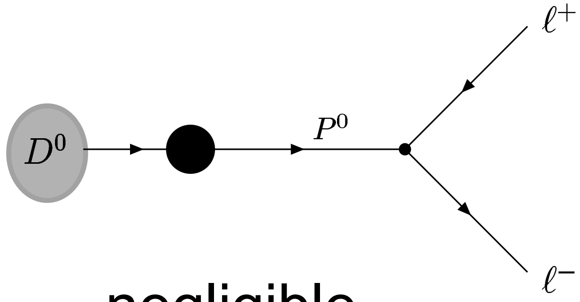
$D^0 - \bar{D}^0$ (present): $L < 1.8 \left(\frac{\Lambda_{\rm NP}}{1\,{\rm TeV}}\right)$; $\Lambda_{\rm NP} > 0.57\,(7.2)\,{\rm TeV}$,

Despite $\mathcal{O}(\lambda_C^5)$ suppression, CPV in D mixing is more powerful in constraining 3rd gen' FCNC!

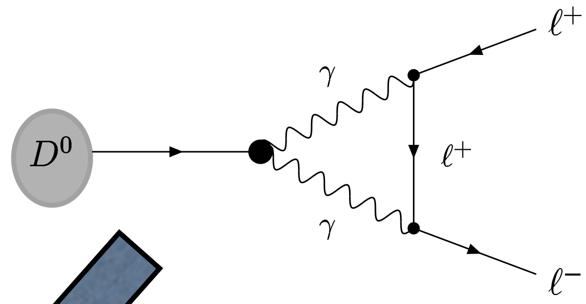
On the potential power of $D^0 \to \ell^+\ell^-$

Practically no SM short distance:

Burdman, Golowich, Hewett & Pakvasa PRD (02).



negligible



$$\mathcal{B}r^{(\gamma\gamma)}_{D^0\to\mu^+\mu^-} \simeq 2.7\times 10^{-5}\mathcal{B}r_{D^0\to\gamma\gamma} \sim 10^{-13}$$

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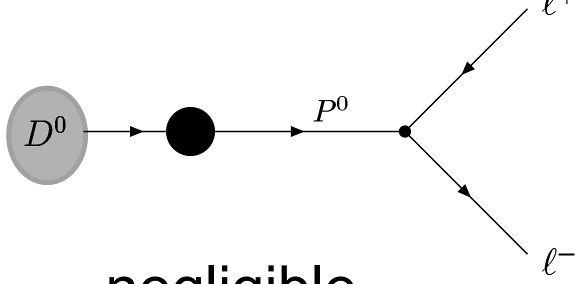
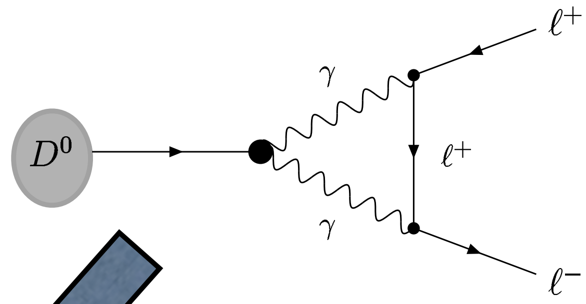


negligible



$$\mathcal{B}r^{(\gamma\gamma)}_{D^0\to\mu^+\mu^-} \simeq 2.7\times 10^{-5}\mathcal{B}r_{D^0\to\gamma\gamma} \sim 10^{-13}$$

$$\mathcal{H}_{\mathcal{V}} = \bar{u}_L\gamma^\mu c_L V_\mu + \bar{\ell}\gamma^\mu \ell V_\mu + \ldots$$

Golowich, Hewett, Pakvasa & Petrov, PRD (09)

On the potential power of $D^0 \to \ell^+\ell^-$

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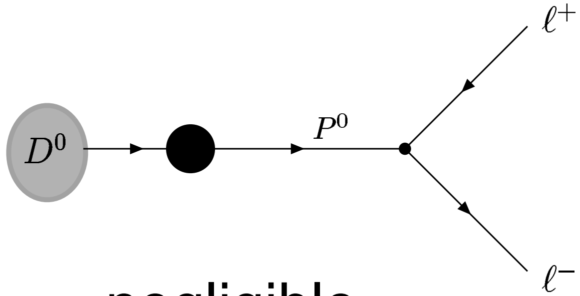
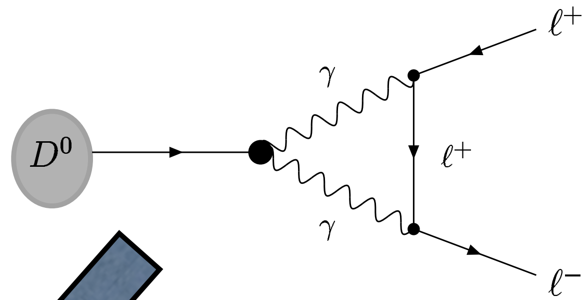


negligible



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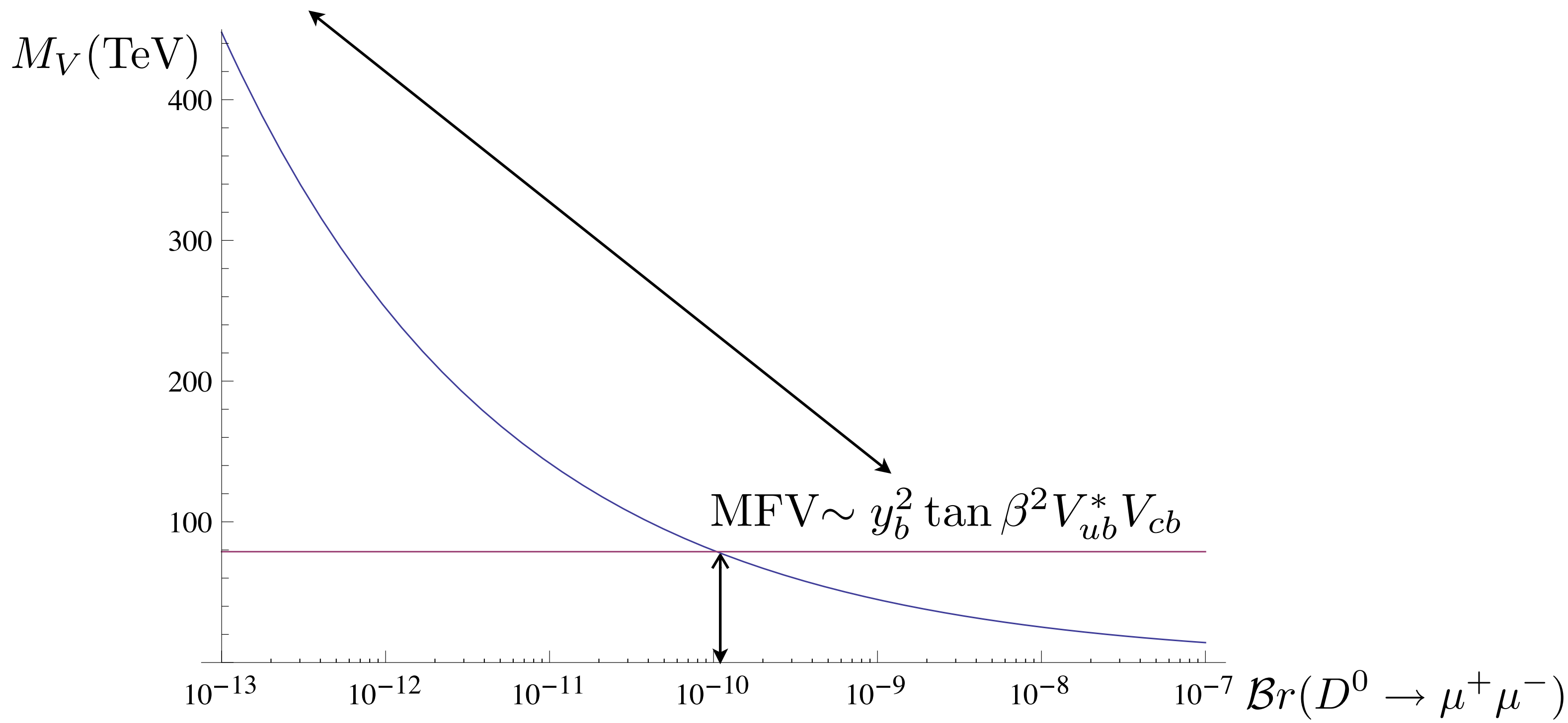


Conclusions

- uFCNC is playing important role in learning about the microscopic world.
- Charm phys. remove "immunities" => constrains alignments.
- CPV in $D-\bar{D}$ mixing extremely powerful:

  (i) disfavors SUSY alignment; (ii) constraining RS alignment;
  (iii) approaching 1TeV MFV models (factor of a few away).
- Constraining 3rd generation physics.
- $D^0 \to \mu^+\mu^-$ particularly interesting, promising future.

Backups

Robust bounds for $\Delta t = 1$

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

Gedalia, Mannelli & GP, PLB; JHEP (10).

$\mathrm{Br}(B \to X_s \ell^+ \ell^-)$

$\mathrm{Br}(t \to (c,u) Z)$

- 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.

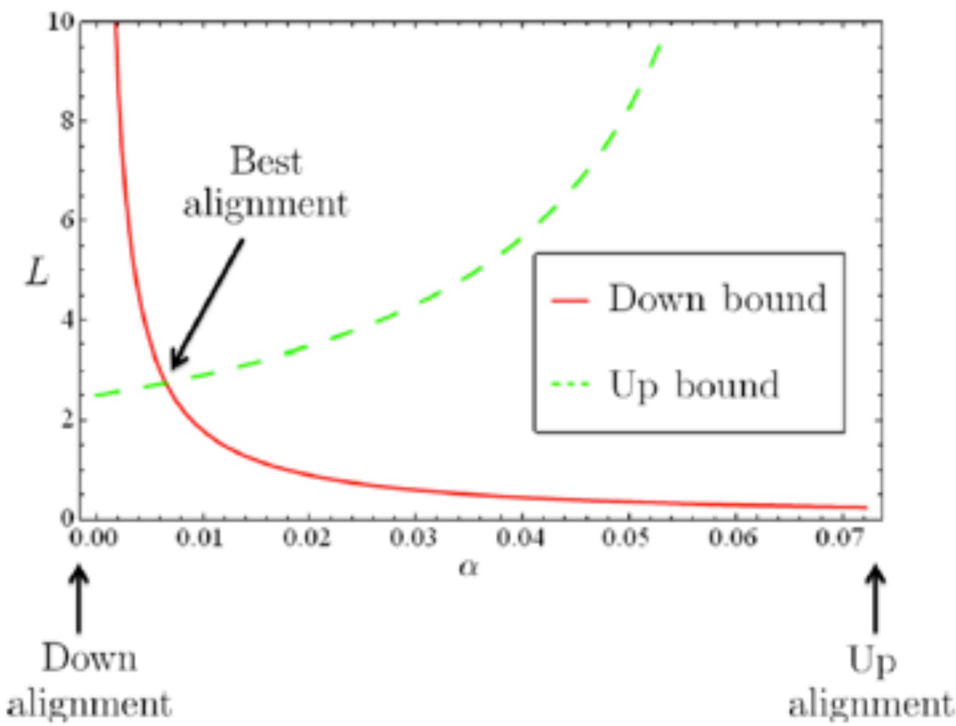
Approximate $U(2)$ Limit of Massless Light Quarks

LHC projected bound

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

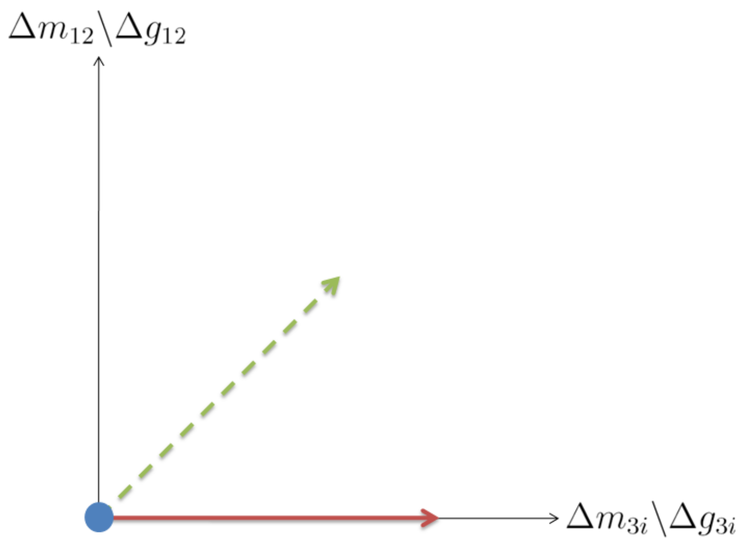
$$\text{(ii)} \quad \alpha = \frac{\sqrt{3}\,\theta}{1+r_{tb}}\,, \quad L < 2.8\left(\frac{\Lambda_{\rm NP}}{1\,\rm TeV}\right)^2; \quad \Lambda_{NP} > 0.6\,(7.6)\ \rm TeV\,,$$

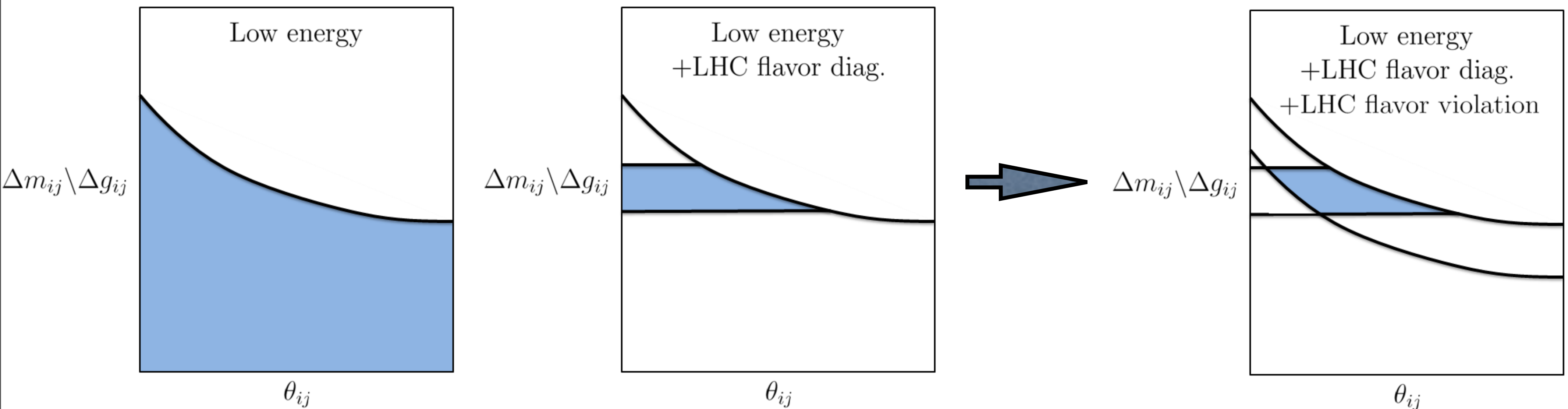
$$\tan\alpha \equiv \frac{X^{J_d}}{X^d} \qquad L \equiv \left|X_Q^{\Delta F=1}\right| \qquad r_{tb} \equiv \left|C_{LL}^h\right|_t / \left|C_{LL}^h\right|_b$$



Flavor @ the LHC, spectrum/couplings very important

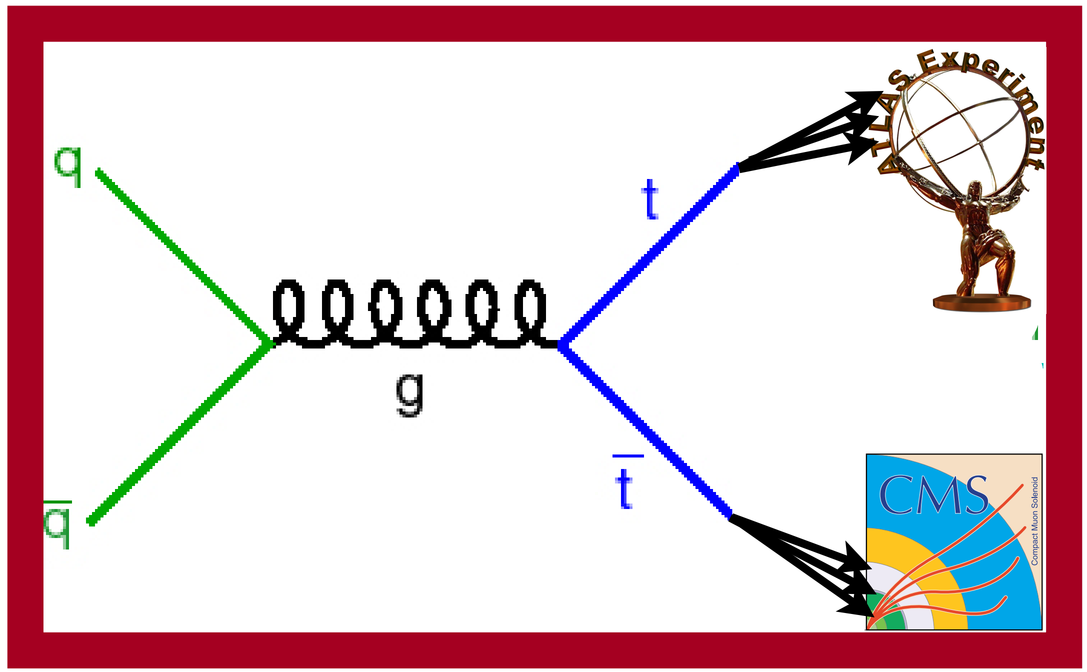
The importance of flavor diag' info





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

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



U-anarchy - constrained by *D* phys.

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

Observable	$M_G^{\min}$[TeV]		$y_{5D}^{\min}$ 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}	$4.2/y_{5D}$	$2.4/y_{5D}$	$y_{5D}^{\min}=1.4$	$y_{5D}^{\min}=0.82$
CPV-D^{LLLL}	$0.73 f_{Q_3}^2$	$0.73 f_{Q_3}^2$	no bound	no bound
CPV-D^{LLRR}	$4.9/y_{5D}$	$2.4/y_{5D}$	$y_{5D}^{\min}=1.6$	$y_{5D}^{\min}=0.8$
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}	$49/y_{5D}$	$24/y_{5D}$	above (6.7)	$y_{5D}^{\min}=8$

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).

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

⇒ Factor of few improvement exclude models.