Flavor in (Non-SUSY & Warped) Extra Dimension Models

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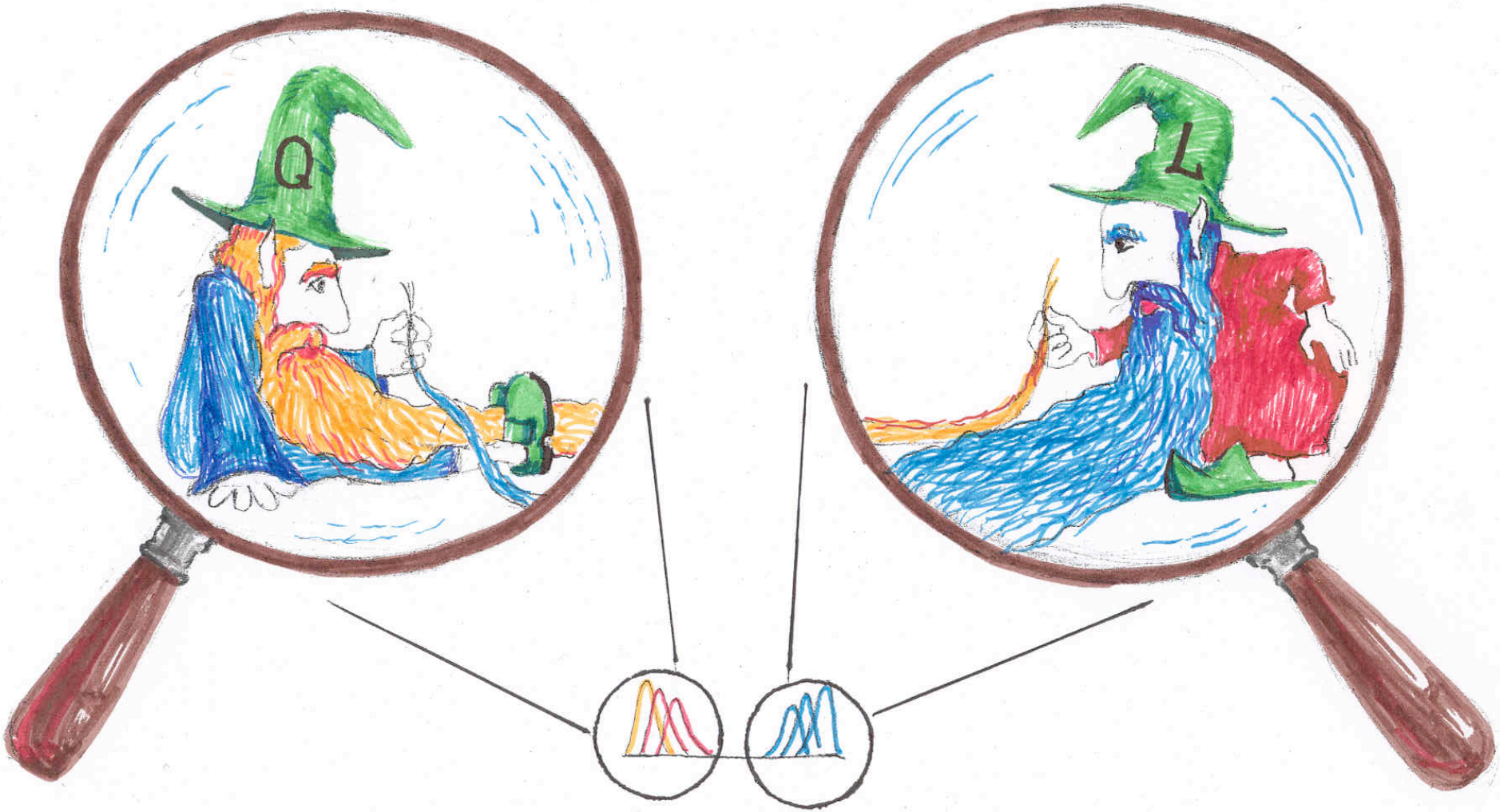
Main issues (50 mins' outline ☺)

- Flavor in extra-dim' the good & bad.
- Natural protection in warped version (RS-GIM).
- The ϵ_K and EDM's warped "little" CP problems.
- Solution- Alignment.
- Near future tests and predictions at the LHC/LHCb.

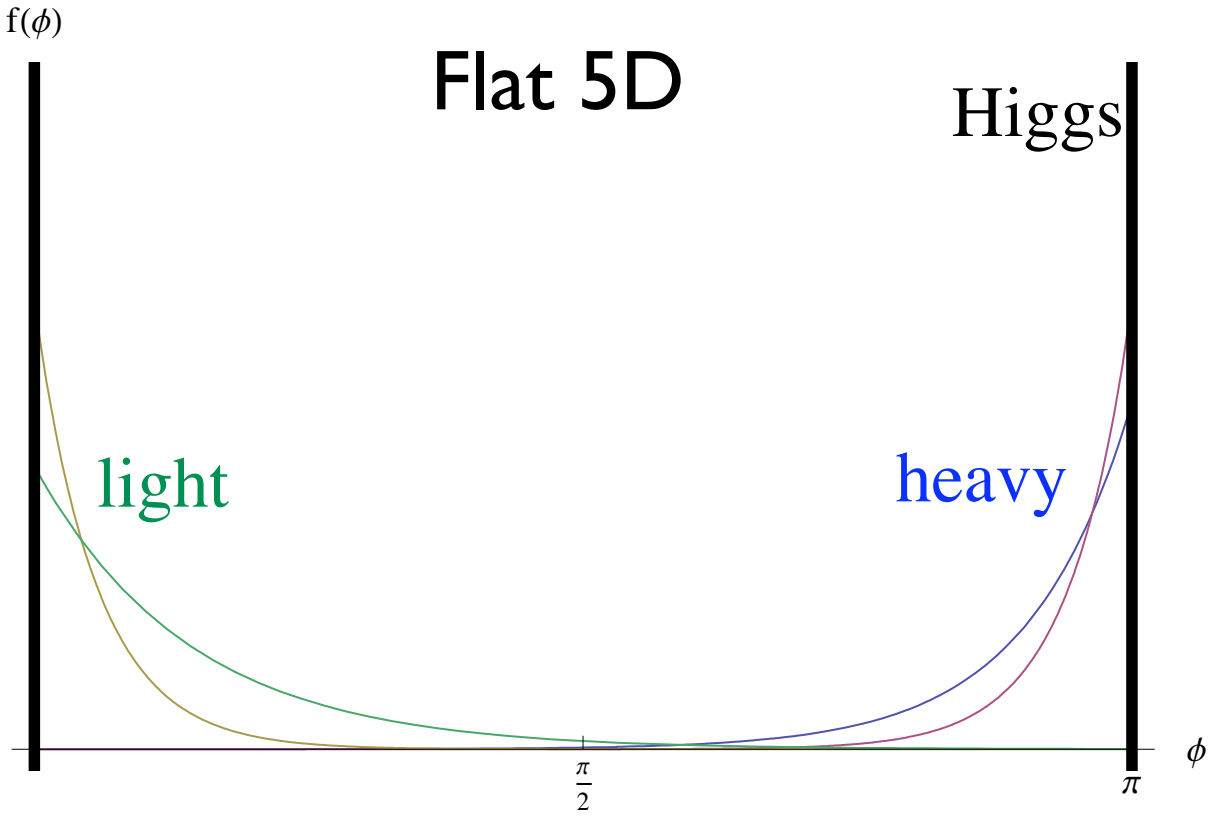
Flavor Physics & Extra Dim'



Central Feature: Geometrical Sequestering, Split Fermions

- The flavor puzzle is solved due to exponential sensitivity of WFs overlaps on the 5D bulk masses, C_i .

Arkani Hamed & Schmaltz (99)



Two major difficulties in flat models

- Profiles (C_i) non-universality => new sources of flavor breaking (3 5D adjoints).

Exchange of gauge KK states induce FCNC: Delgado, Pomarol & Quiros (99)

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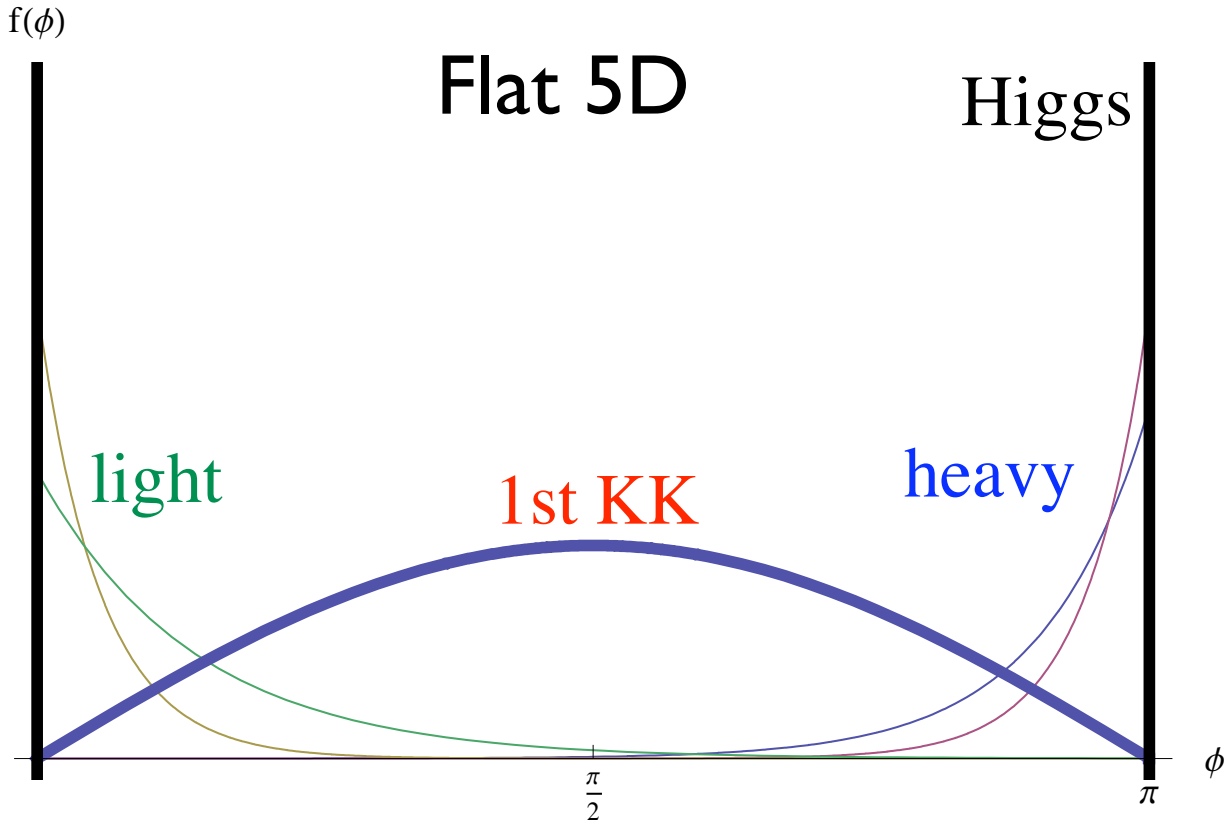

$$\epsilon_K \Rightarrow M_{\rm KK} \sim R^{-1} > 1000\,{\rm TeV}$$

Induce intermediate hierarchy problem, $(M_W R)^2 > 10^{-8}$!

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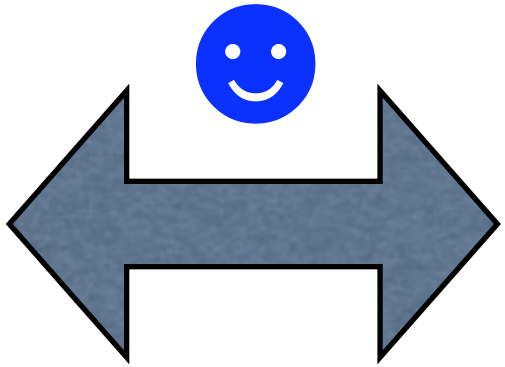
- SM Extra dim' models are effective theories:

$$\Lambda R \sim \frac{4}{\alpha^{1/n}} \sim \begin{cases} 30 \text{ for } D = 5 \\ 10 \text{ for } D = 6 \end{cases}$$

Even with flavor universality (UED), $\Lambda \ll 10^4\,{\rm TeV}$.

Thus suppression of higher dim' operator is unexplained.

Warping may overcome both difficulties



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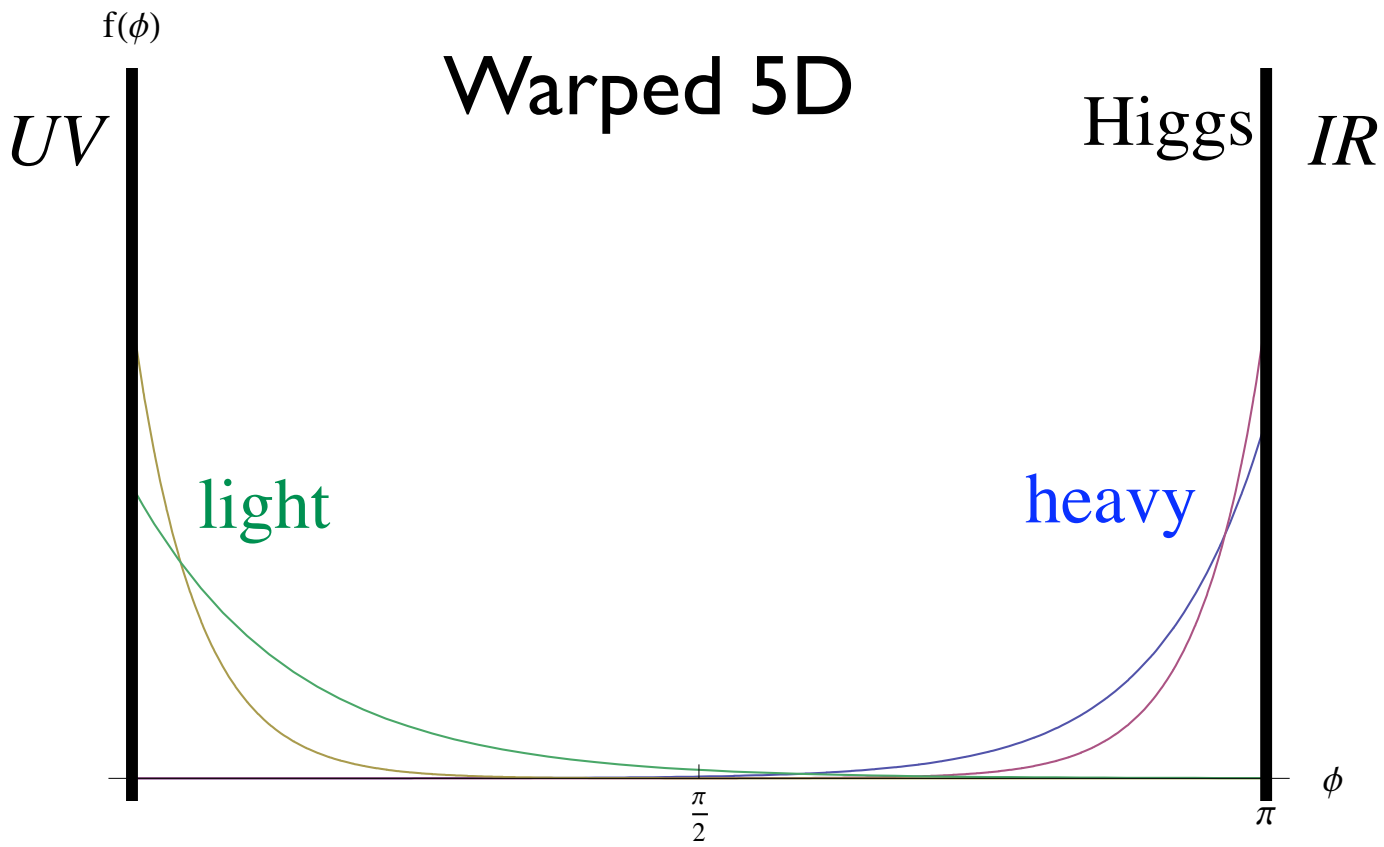
- 0-modes configuration looks similar to flat case.

Gherghetta & Pomarol;
Huber & Shafi (00)



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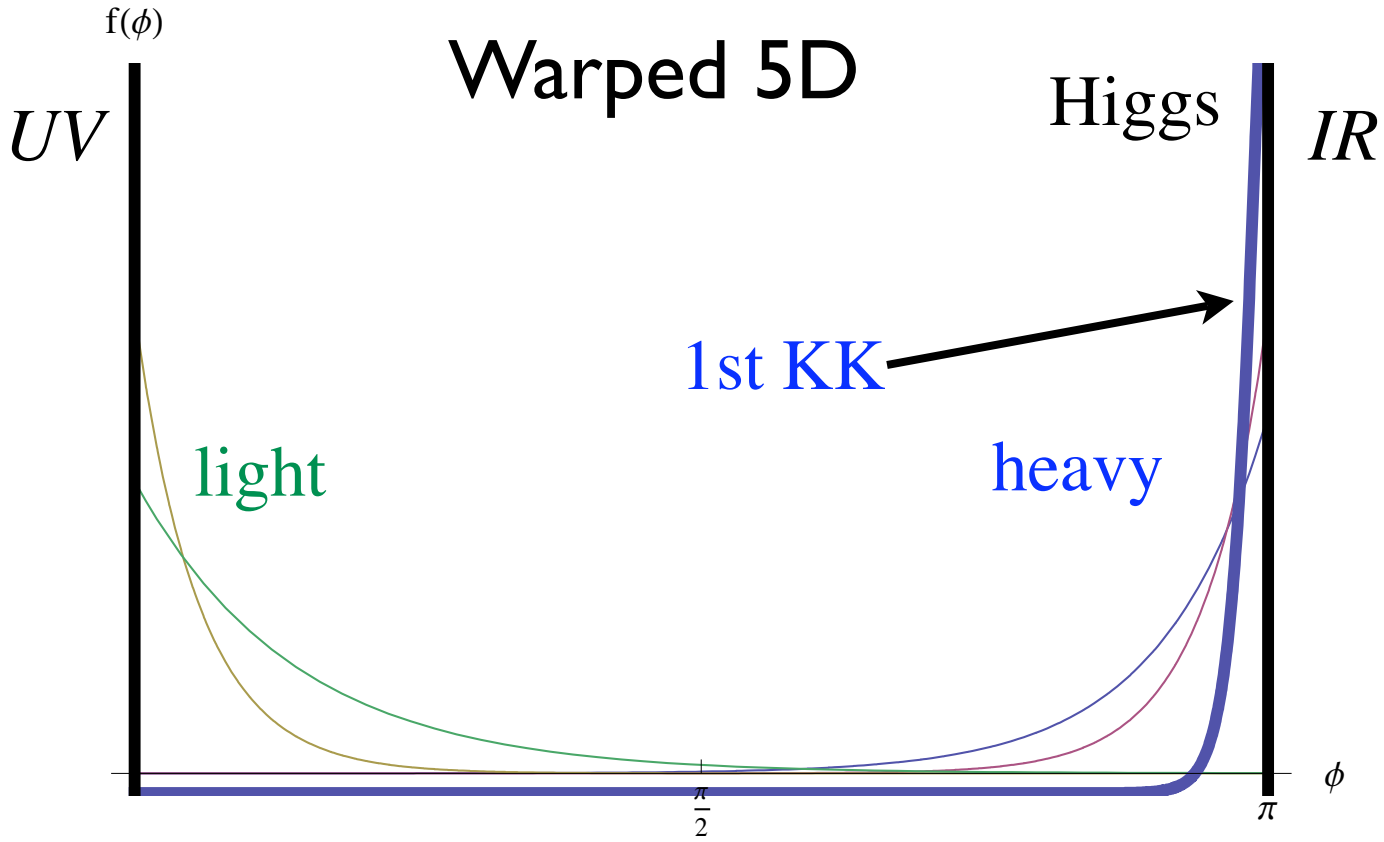

Higgs and KK states are localized on the IR.

Light fields have highly suppressed coupling to KK modes!

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Flavor protection induced by the mechanism which solves the flavor puzzle = RS-GIM Agashe, GP & Soni (04)

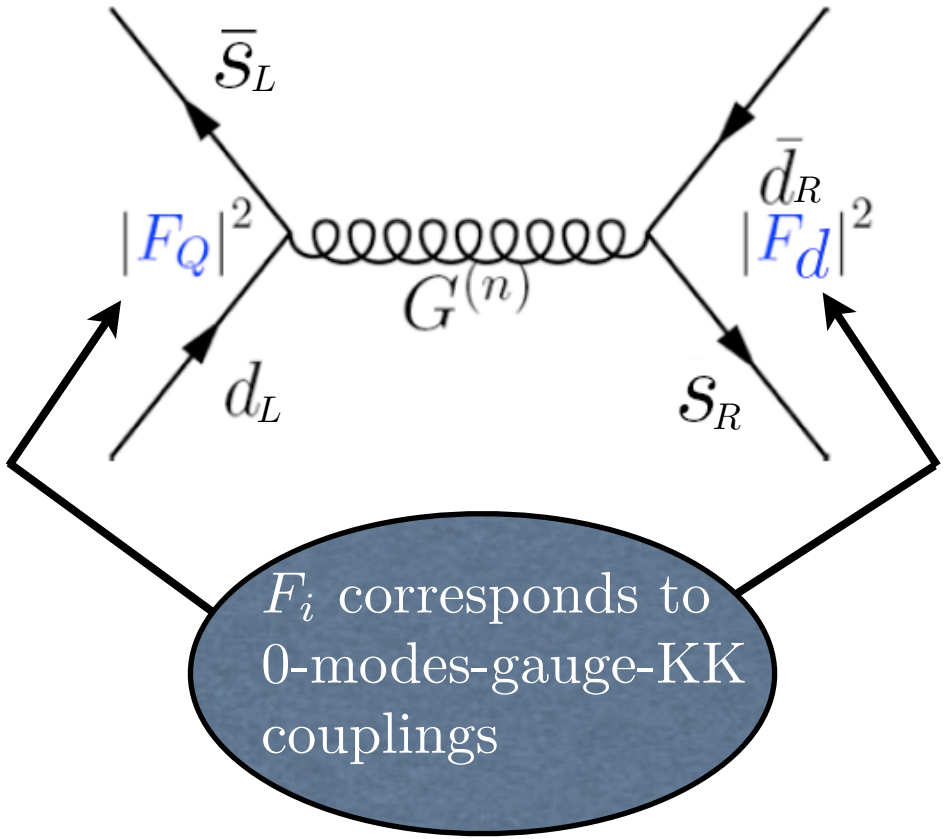
- The 2nd problem solved due to warping, light modes

are localized at a region where $\Lambda \gg 10^4\ \mathrm{TeV}$.

2 Residual "little" CP problems

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

a severe bound on IR Higgs, $M_{\rm KK} \gtrsim 10 - 20\,{\rm TeV}$.



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

=> ϵ_K

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

Agashe, GP & Soni (04)

Solutions (within the above framework)

- The problem may be ameliorated with bulk Higgs.

Agashe, Azatov & Zhu (08)

- Gauge the SM approx' sym' => alignment with Y_d.

Fitzpatrick, GP & Randall (07); GP & Randall;
Csaki, Falkowski & Weiler; Santiago (08);
Csaki, Grossman, GP, Surujon & Weiler, to appear.

- Generically, alignment models tends to induce "anarchy"

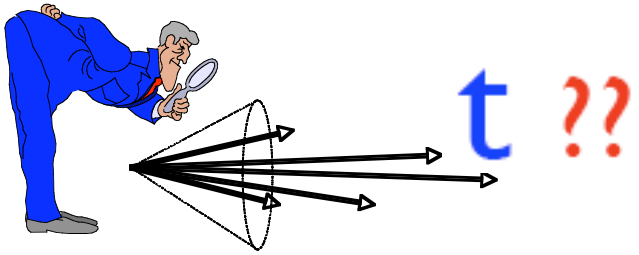
in the up sector.

Predictions & Tests

Look Up

Look Down

Fascinating Top Warped Physics @ LHC



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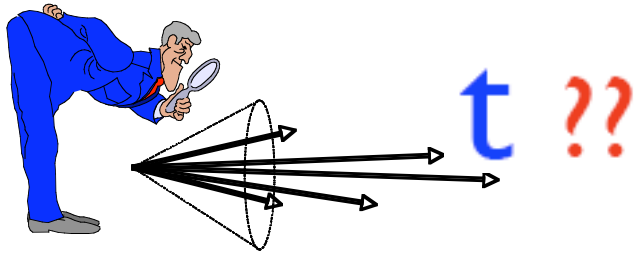


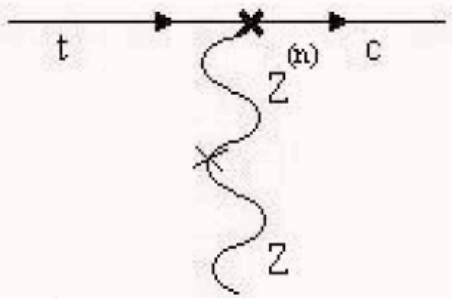
top FCNC

SM: $BR(t \to qZ, \gamma, G) \sim 10^{-12}$.

Díaz-Cruz (89); Eilam, Hewett & Soni (90)

LHC ($100 fb^{-1}$): $BR(t \to qZ, \gamma) \gtrsim 10^{-5}$.

RS: $BR(t \to c_R Z) \propto |U_R|_{23} \times \delta g_Z \sim 10^{-5}$.



Agashe, GP & Soni (06)

MFV: $BR(t_{L,R} \to c_L \gamma, Z) \sim |y_b|^4 \, |V_{cb}|^2 \lesssim 10^{-5} \left(\frac{\tan\beta}{50}\right)^4$.

Kagan, GP, Volansky & Zupan (09)

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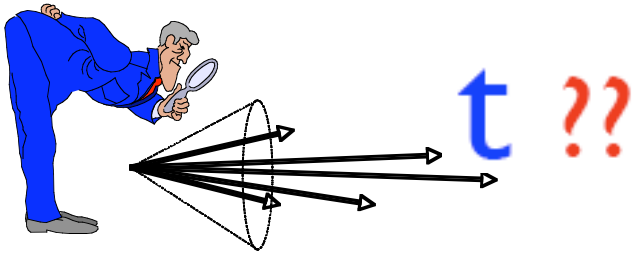

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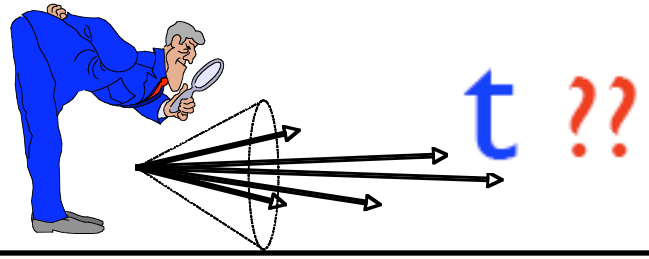

top jets, road to KK's discovery

Agashe, Belyaev, Krupovnickas, GP & Virzi (07);
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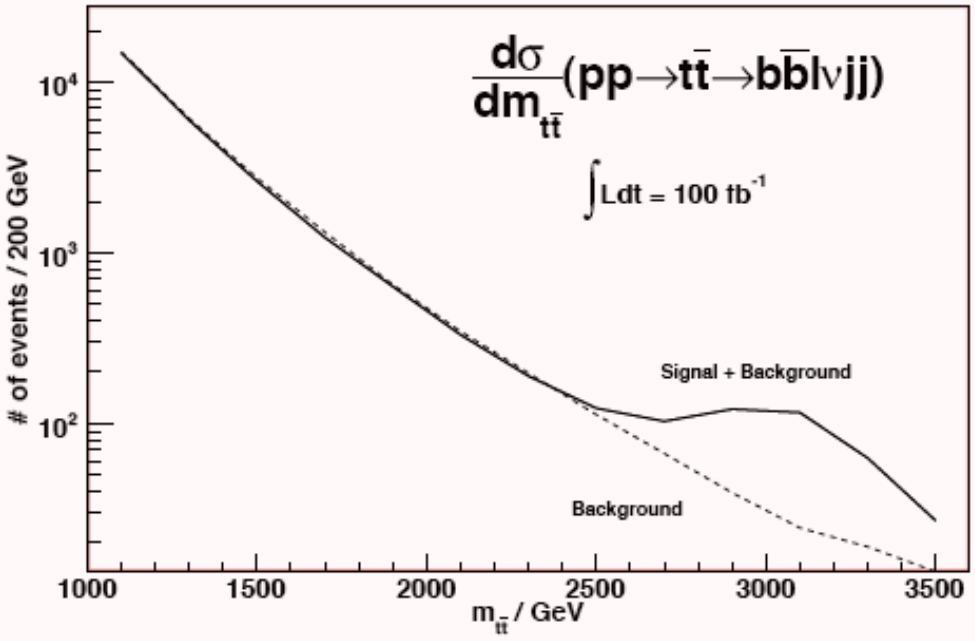
KK's decay to boosted tops:



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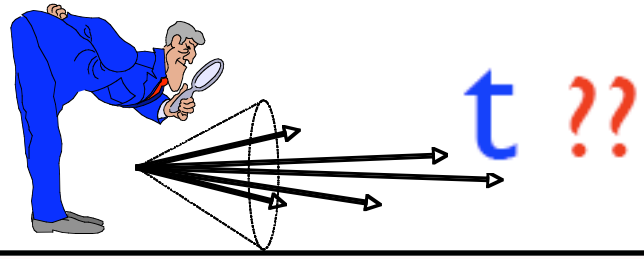

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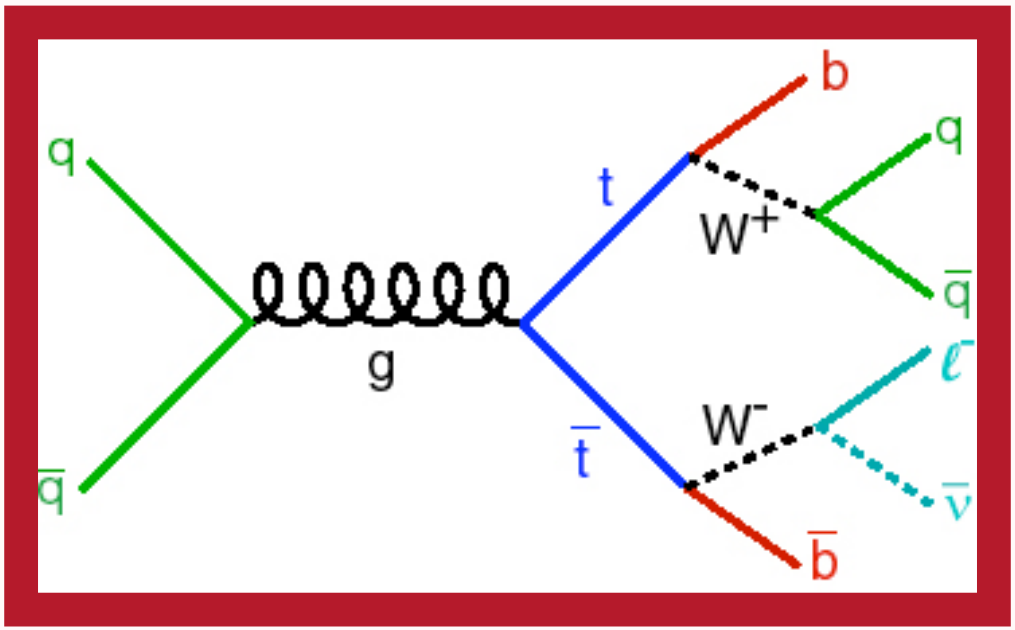

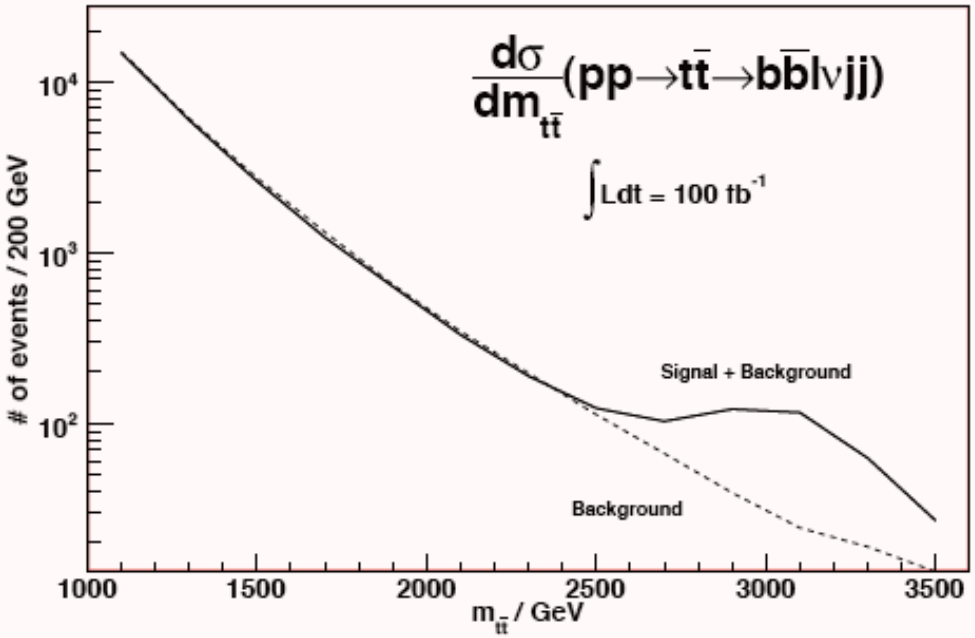

Collimation is a challange

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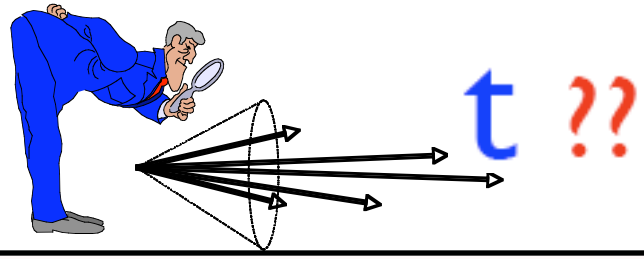

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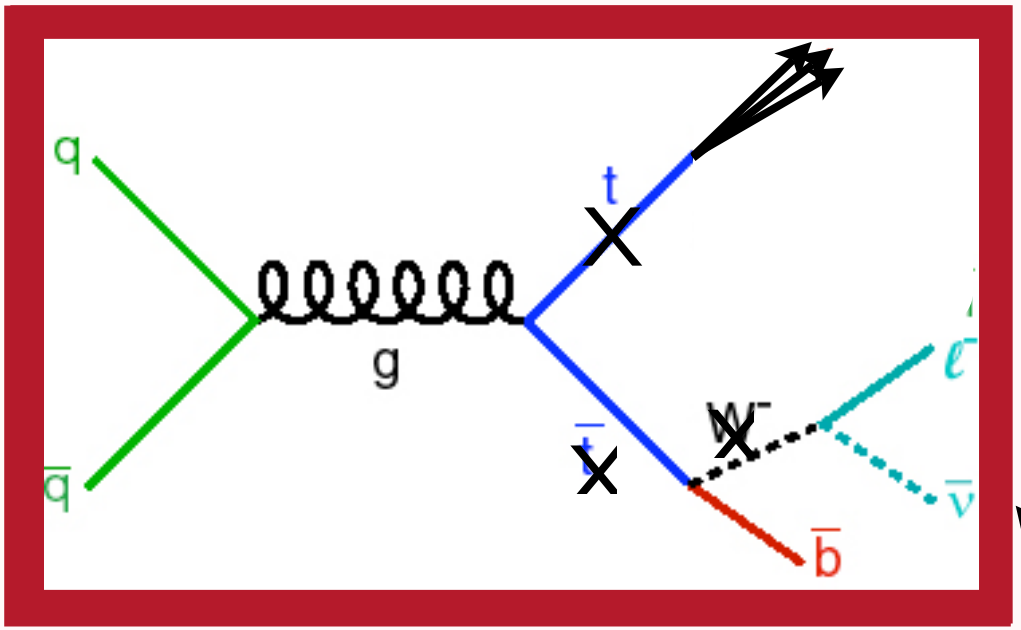

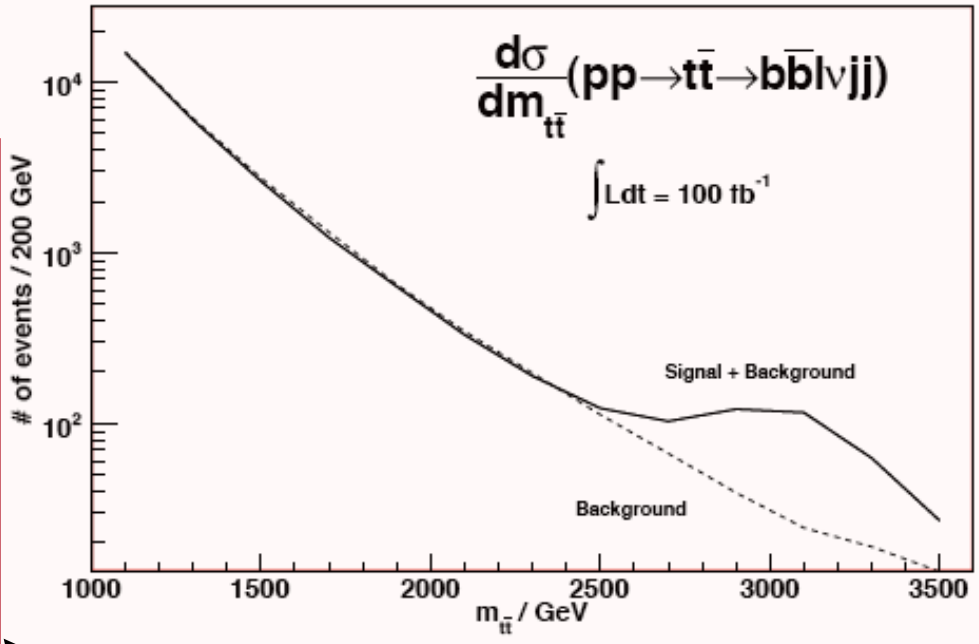

Collimation is a challange

$D^0 - \bar{D}^0$ vs. $K^0 - \bar{K}^0$

Blum, Grossman, Nir & GP (09)

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

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

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

- Powerful model indep' constraint on NP :

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

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no CPV

$$|z_1^K| \leq z_{\rm exp}^K = 8.8 \times 10^{-7}\left(\frac{\Lambda_{\rm NP}}{1\ {\rm TeV}}\right)^2$$
$$|z_1^D| \leq z_{\rm exp}^D = 5.9 \times 10^{-7}\left(\frac{\Lambda_{\rm NP}}{1\ {\rm TeV}}\right)^2$$

with CPV

$$\mathcal{I}m(z_1^K) \leq z_{\rm exp}^{IK} = 3.3 \times 10^{-9}\left(\frac{\Lambda_{\rm NP}}{1\ {\rm TeV}}\right)^2$$
$$\mathcal{I}m(z_1^D) \leq z_{\rm exp}^{ID} = 1.0 \times 10^{-7}\left(\frac{\Lambda_{\rm NP}}{1\ {\rm TeV}}\right)^2$$

Two generations flavor structure

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

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

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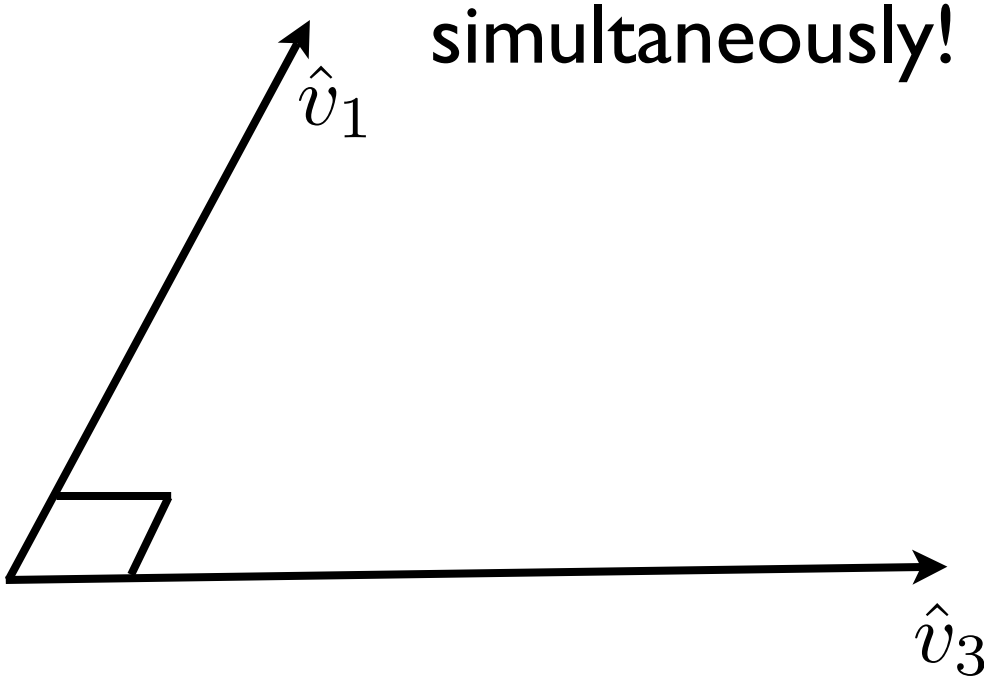

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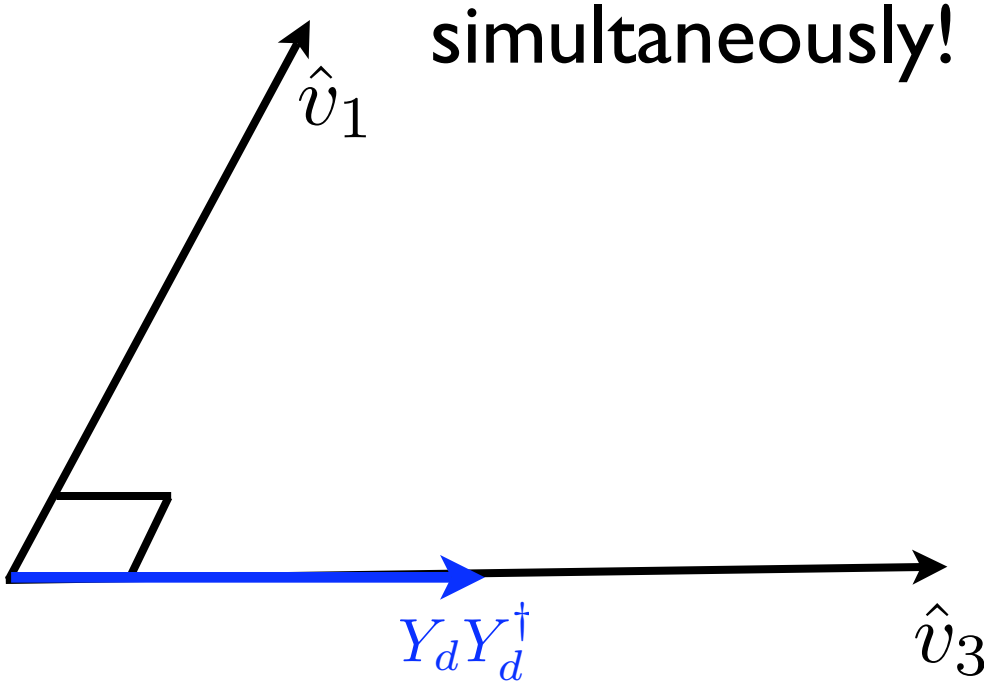

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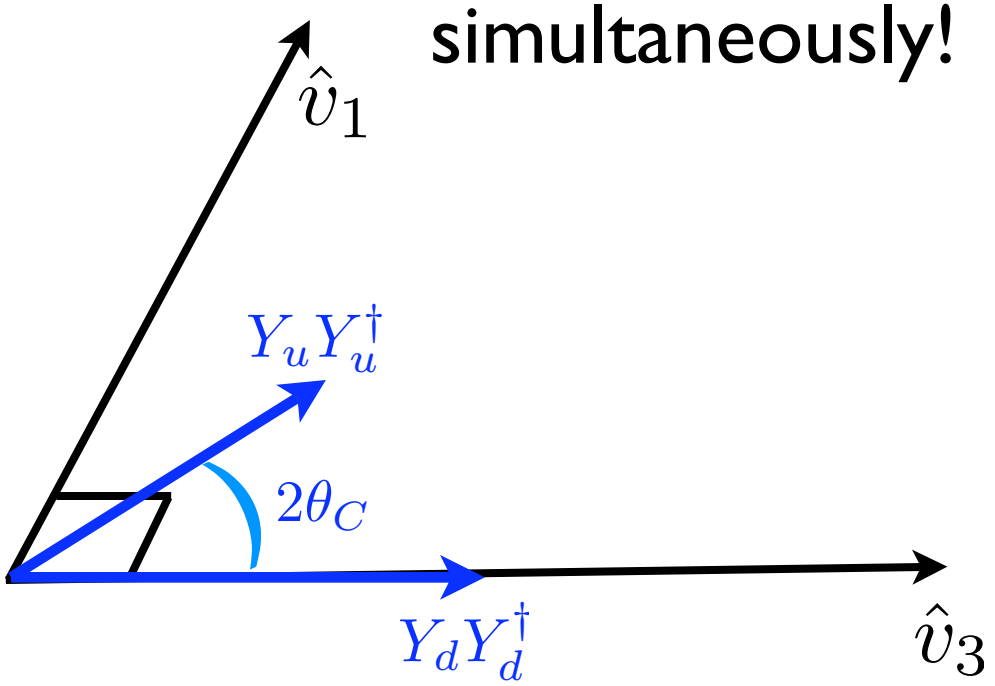

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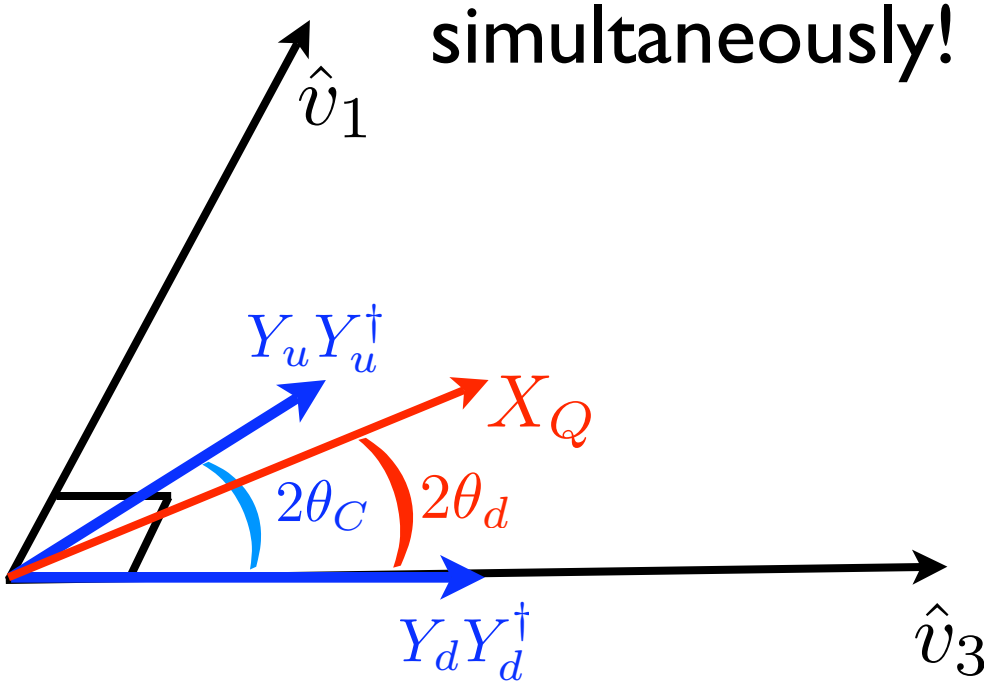

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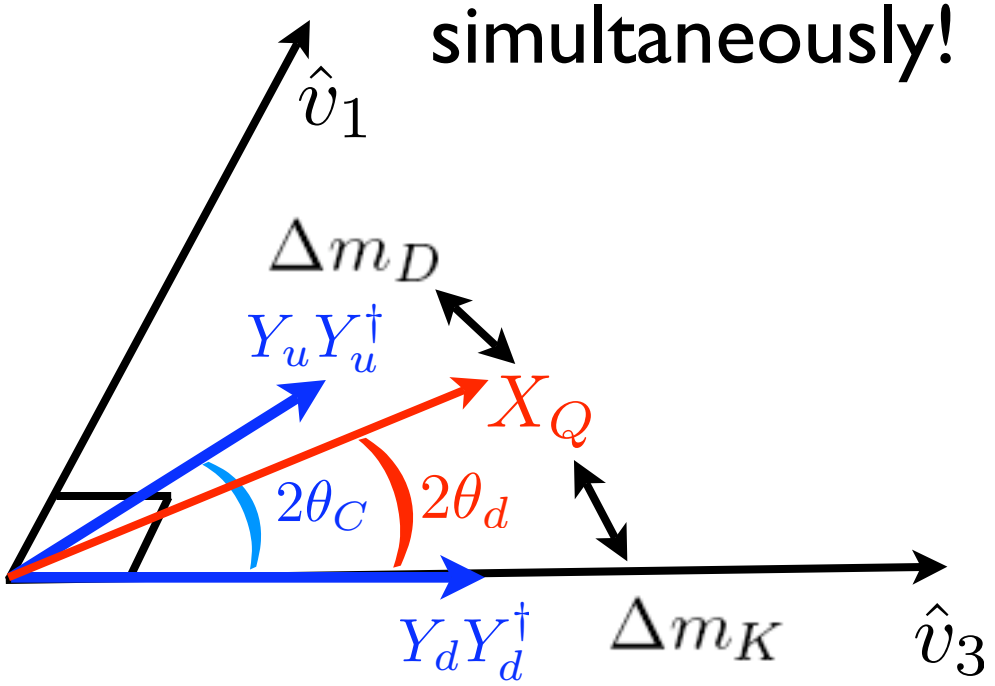

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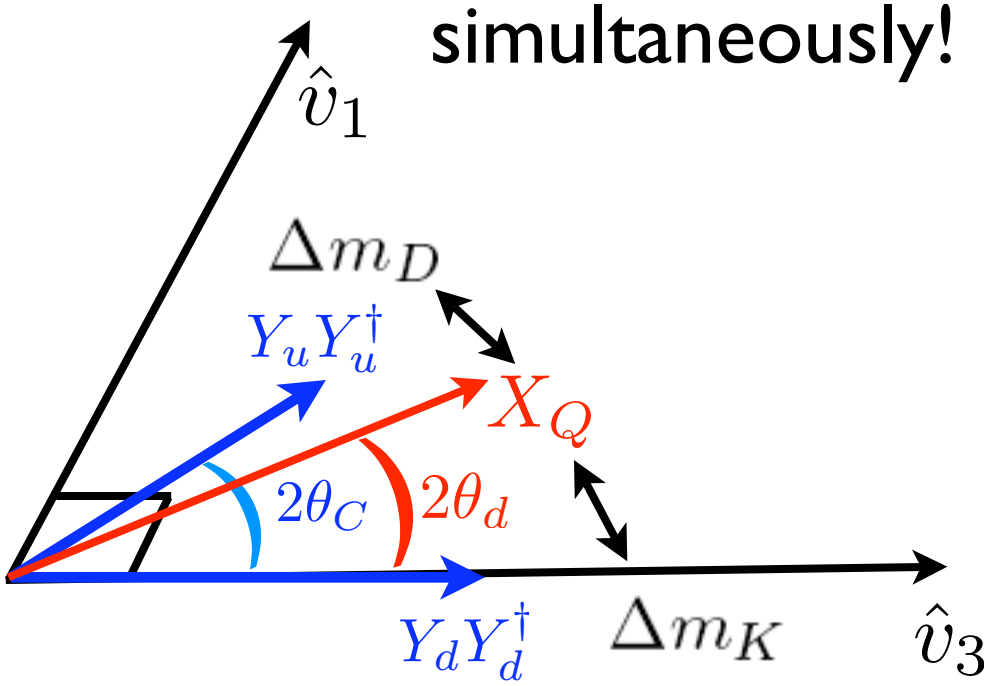
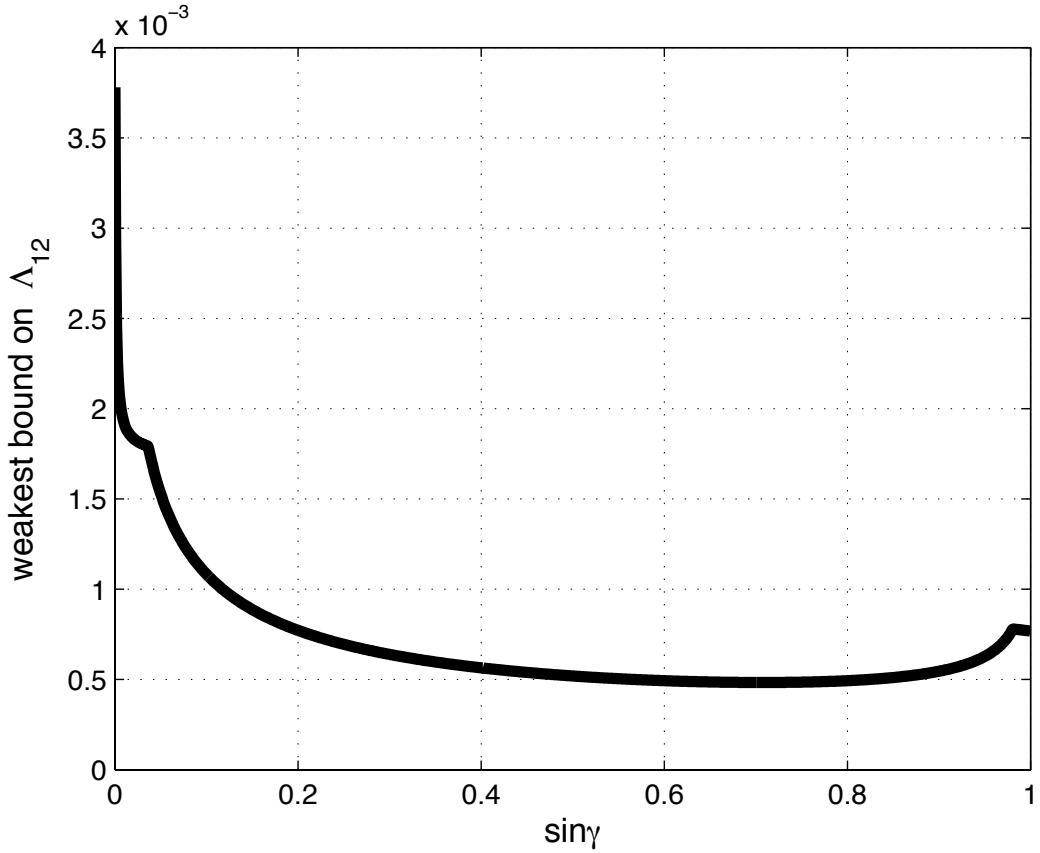


$$\lambda_Q = \mathrm{diag}(\lambda_1, \lambda_2),\ \lambda_{12} = \frac{1}{2}(\lambda_1 + \lambda_2),\ \delta_{12} = \frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2},\ \Lambda_{12} = \delta_{12}\lambda_{12}.$$

Constraining the flavor structure

Adding CPV, γ, yield strong constraint on

$$\Lambda_{12} = \delta_{12}\lambda_{12}.$$



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

RS: $$f_{Q^2} \leq \sqrt{\frac{m_{\rm KK}}{\rm TeV}} \times \begin{cases} 0.020 & \text{maximal phases} \\ 0.056 & \text{vanishing phases} \end{cases}$$

Conclusions

- Warped models integrate solution to the hierarchy problem with addressing the flavor problem.

- Consistent with flavor precision test, some alignment is required.

- Generically, flavor violation is expected in the up sector.

- Being tested via D physics & soon via top FCNC.