Flavour in Warped Extra Dimensions

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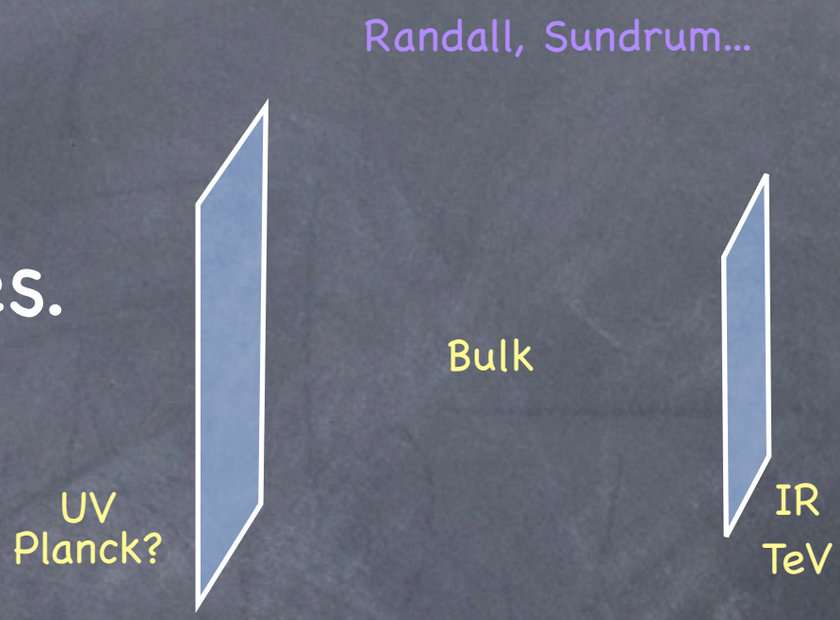
Why warping?

- Easy to generate hierarchies.



- Can explain hierarchies in the EWSB (many models: composite Higgs, Higgsless...)
- It has a 4D dual: dynamical symmetry breaking (Technicolour)

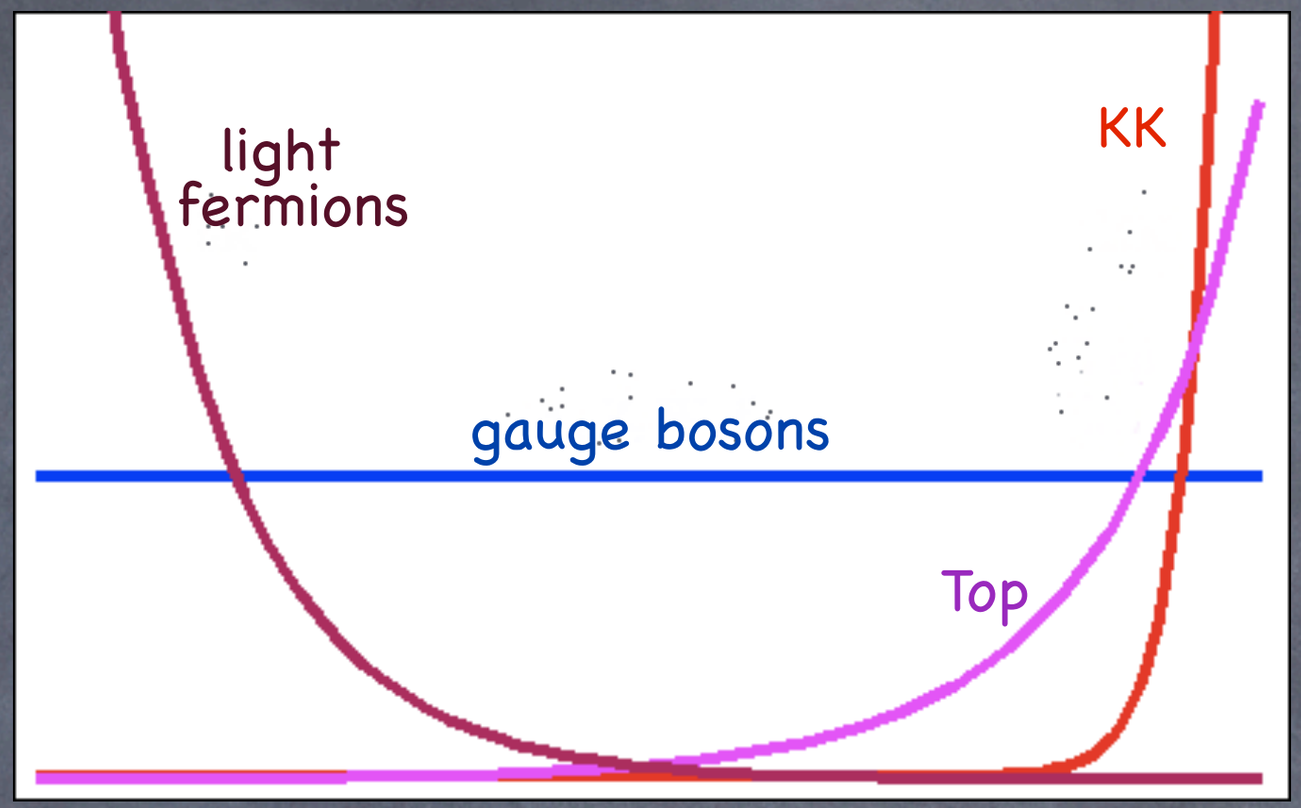
Flavour in WED

$$\mathcal{L} \sim c_{Q,u,d}\, \bar{\psi}_{Q,u,d} \psi_{Q,u,d} + Y_{u,d}\, \bar{\psi}_Q H \psi_{u,d} + \ldots$$

- Fermionic wave functions exponentially sensitive to bulk mass c
- Small range in c (0.4 to 0.7) can explain the fermion hierarchies
- We need to worry about:

CP violating phases
Couplings to KK bosons (FCNC)
Higher dimensional operators

Generic EWSB model



- EWSB on the IR brane (Yukawa) + bulk custodial symmetry
- Light fermions on the UV brane: higher order operators are suppressed
- Flavour depends on the value of the wave functions on the IR brane

Generic EWSB model

Agashe, Perez, Soni: hep-ph/0406101 & hep-ph/0408134

- Assuming anarchic Yukawas: the values of the WFs on the IR brane determine masses and mixing angles
- Couplings of KK states different from the SM gauge bosons, however:

Small entries for light quarks.
Universal up to $\mathcal{O}(m_f^2 R'^2)$ corrections
-> RS-GIM mechanism
Heavy top: FV induced by the 3rd generation
i.e. FCNC ~ Vts and/or Vtd

However, the bounds are severe:

- $\Delta F = 2$ processes (Kaon mixing): KK masses above 8 TeV.
- CP problem: too large 1-loop contributions to neutron EDM.
- Flavour constraints push the models un-natural!

Flavour Symmetries in the bulk

GC, Csaki, Galloway, Marandella, Terning, Weiler
hep-ph/0709.1714

- $SU(3)_Q$ x $SU(3)_R$ in the bulk.
- $SU(3)^2$ -> $SU(3)_D$ on the IR brane (Yukawas).

c's and Yukawa couplings are universal:
give up solution to flavour hierarchy...

- $SU(3)_R$ broken on UV.
- $SU(3)_Q$ unbroken.

Hierarchies and mixings generated by UV kinetic terms for d and u.
2 flavour violating matrices -> No CP problem

- No FCNCs at tree level: $SU(3)_{up}$ and $SU(3)_{down}$ can be used to diagonalize the UV kinetic terms
- FV in charged currents (W, W'...) are all (approx.) proportional to V_{CKM}.
- No CP problem
- Higher order operators are flavour diagonal (except on the UV brane...)

The wave functions are universal, except the normalization A and the mass dependence:

$$\chi_L^\alpha = A^\alpha f_L(m,z) \quad \chi_R^\alpha = A^\alpha f_R(m,z)$$
$$\psi_L^\alpha = A^\alpha g_L(m,z) \quad \psi_R^\alpha = A^\alpha g_R(m,z)$$

The norm A's are the eigenvectors of the kinetic mixing matrices K:

$$U^\dagger \mathcal{K} U = \begin{pmatrix} k_1 & 0 & 0 \\ 0 & k_2 & 0 \\ 0 & 0 & k_3 \end{pmatrix}$$

$$f_R(m, z_{UV}) A = m\, g_R(m, z_{UV})\, \mathcal{K} \cdot A$$
$$\Downarrow$$
$$\mathcal{K} \cdot A = \frac{f_R(m, z_{UV})}{m\, g_R(m, z_{UV})} A$$

The eigenvalues fix the spectrum:

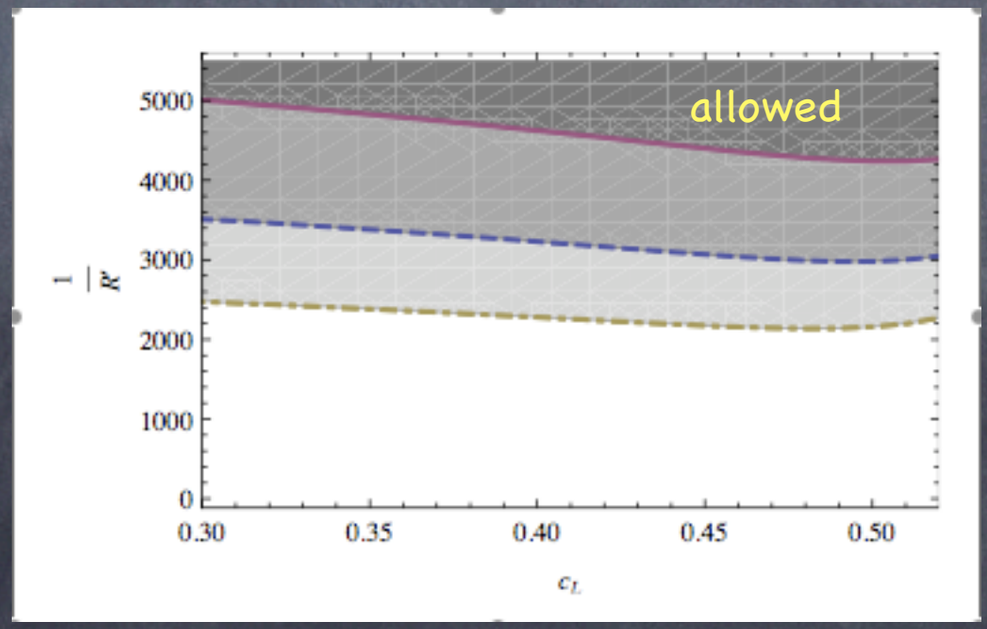
$$\frac{f_R(m_i, z_{UV})}{m_i\, g_R(m_i, z_{UV})} = k_i\,, \quad i = 1 \ldots 3$$

$$V_{CKM} \sim U_u^\dagger U_d + \mathcal{O}(m_i^2)$$

However, life is not so easy: the top is too heavy!

- In this scenario, all the quarks share the (top) yukawa/mass on the IR brane
- The heaviness of the top induces large universal corrections to the couplings

KK mass = 2.4 x 1/R'



A realistic model.

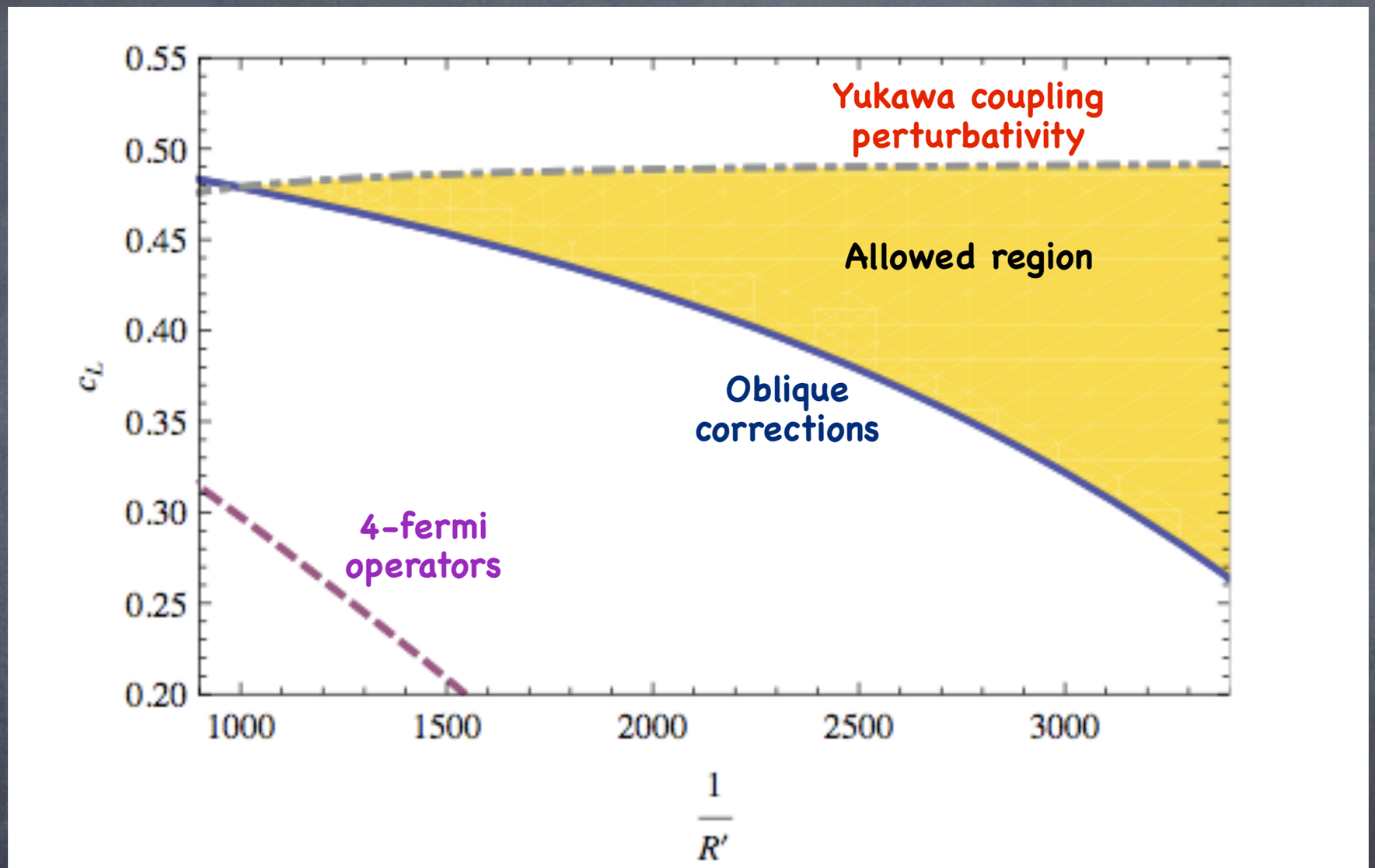
- Use new representations: u is a singlet of the custodial symmetry. Agashe, Contino, Da Rold, Pomarol hep-ph/0605341
- Break $SU(3)_{up}$ -> $U(1)_u \times U(1)_c \times U(1)_t$

$$Q_L \begin{pmatrix} m_u & & \\ & m_c & \\ & & m_t \end{pmatrix} t_R + m_b\, Q_L \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix} b_R$$

- All the mixing coming from the down sector on the UV brane (as before)

No FCNCs!

No large universal corrections or δZbb.


Yukawa coupling
perturbativity
Allowed region
Oblique
corrections
4-fermi
operators
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
c_L
1000
1500
2000
2500
3000
$\frac{1}{R'}$

5D MFV

Fitzpatrick, Perez, Randall
hep-ph/0710.1869

Assuming:

$$c_{u,d} \sim Y^\dagger_{u,d} Y_{u,d} + \dots \quad c_Q \sim r\, Y_u^\dagger Y_u + Y_d^\dagger Y_d + \dots$$

Anarchic Yukawa matrices

- Hierarchies generated by eigenvalues of the c-matrices (from anarchic Yukawas).
- CKM matrix generated by the same eigenvalues (WF on the IR brane).
- If r -> 0, the down sector can be diagonalized : most dangerous FCNCs suppressed by r.
- No CP problem: n EDM at 2 loops.
- Bounds relaxed to ~ 2 TeV.

Summary

- Flavour is a crucial issue for models in WED: constraints can be stronger than EWPTs and push the models un-natural or out of LHC's reach.
- The flavour puzzle can be formulated in a nice way: O(1) bulk masses give spectrum and mixing angles.
- Generically, many signals of NPh expected at B-factories and LHC (top physics).