Precision constraints on warped scenarios with custodial protection

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Based on work with M. Carena, J. Santiago and C. Wagner
hep-ph/0607106, hep-ph/0701055 and work in progress

The RS scenario: generalities

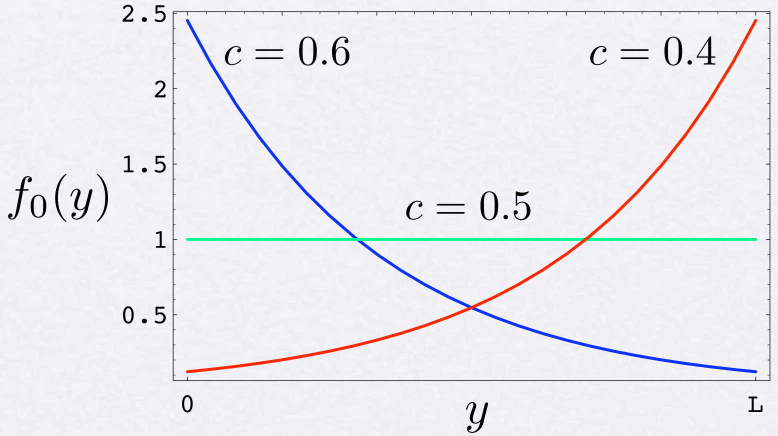
Sensitivity to UV physics in Higgs sector $\longrightarrow$ new physics at weak scale

Randall-Sundrum proposal (1999)

UV brane IR brane

Slice of AdS: $ds^2 = e^{-2ky}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2$ $\quad y \in [0, L]$

- If Higgs on IR brane: scales of order TeV
- Bulk fermions:
  - geom. mass hierarchies
  - Suppression of FCNC



- Breaking of symmetries by B.C.'s

  $\longrightarrow$ Light states are a common ocurrence

- 4-dimensional description through AdS/CFT

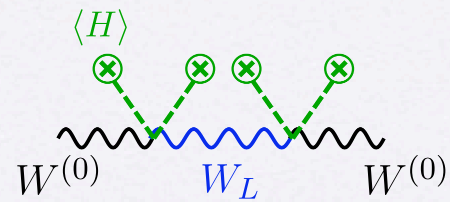
  (However, actual computation performed in 5D theory)

- Potentially exciting phenomenology at the TeV scale...

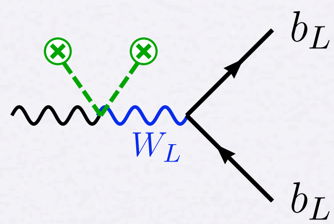
But how light the new physics?

Tree level corrections to SM observables $\longrightarrow$ stringent constraints

Large contributions to oblique parameters, e.g. T



Shifts in fermion-gauge boson couplings



... or other fermions

These constraints can put the new physics beyond the reach of the LHC

In this talk I will consider models that tame the large tree-level corrections by

- Imposing a custodial SU(2) symmetry **(Agashe,Delgado,May,Sundrum)**
- Quantum numbers such that bottom couplings are protected **(Agashe,Contino,DaRold,Pomarol)**

S parameter remains as source of most important constraints...

... however, protected parameters can still be important

Custodial Symmetry: $SU(2)_L \times SU(2)_R$

Unlike in SM with Higgs doublet, large custodial violation due to KK of hypercharge and top quark: $g'\sqrt{2kL}$ and $y_t\sqrt{2kL}$ with $\sqrt{2kL} \sim 8$.

(Agashe,Delgado,May,Sundrum)

Solution: Make $SU(2)_R$ exact:

Gauge

$$SU(2)_L \times \underbrace{SU(2)_R \times U(1)_X}_{U(1)_Y}$$

... and brake it minimally (at UV brane only)

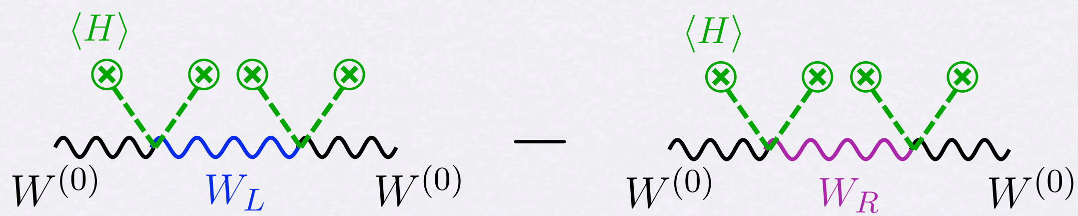
$$W^a_{L\,\mu} \sim (+,+)\,, \quad B_\mu \sim (+,+) \qquad a = 1,2,3$$

$$W^b_{R\,\mu} \sim (-,+)\,, \quad Z'_\mu \sim (-,+) \qquad b = 1,2$$

$$B_\mu = \frac{g_{5\,X} W^3_{R\,\mu} + g_{5\,R} X_\mu}{\sqrt{g^2_{5\,R} + g^2_{5\,X}}}$$

Custodial violation due to small KK-mode splittings: $M_{W^n_L} \neq M_{W^n_R}$, $g_{W^n_L} \neq g_{W^n_R}$

Schematically, the T parameter at tree-level:



Tower with 0-mode **Tower with no 0-mode**

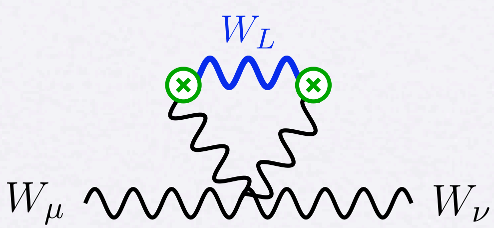
$$= \Delta_{++} - \Delta_{-+} \approx 0$$

The T-parameter at one-loop

Non-local breaking of custodial $SU(2)$ $\longrightarrow$ $T \neq 0$, calculable

Types of contributions discussed by Agashe, Delgado, May, Sundrum

Gauge:
(Schematic)



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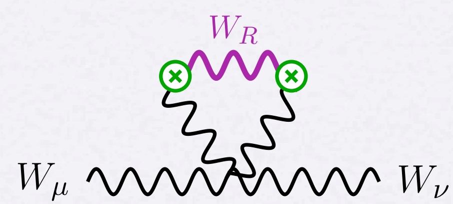
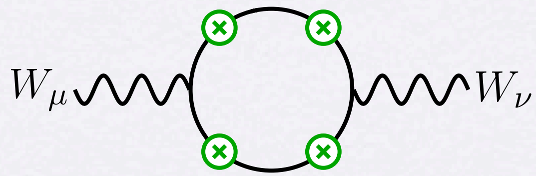


$\sim$ small

Fermions:



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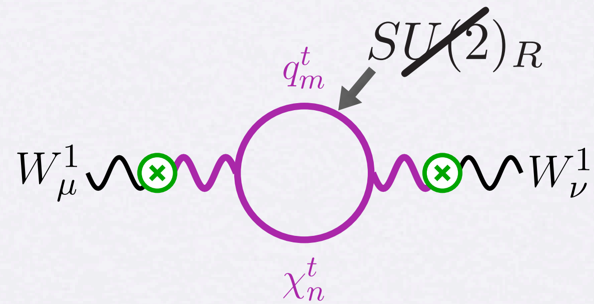


(subdominant)

These depend on various localization parameters!

Why one-loop interesting?

Localization towards IR brane $\longrightarrow$ better custodial protection

But in SM, top gives (1-loop)

$$T_{\text{top}} = \frac{N_c m_{\text{top}}^2}{16\pi s^2 c^2 m_Z^2} \sim 1$$

$\longrightarrow$ **Expect some degree of cancellation in this limit**

New physics may contribute $\Delta T < 0$ (top sector)

Example: Simplest implementation of $SU(2)_R$ in fermion sector

$SU(2)_L$ doublet

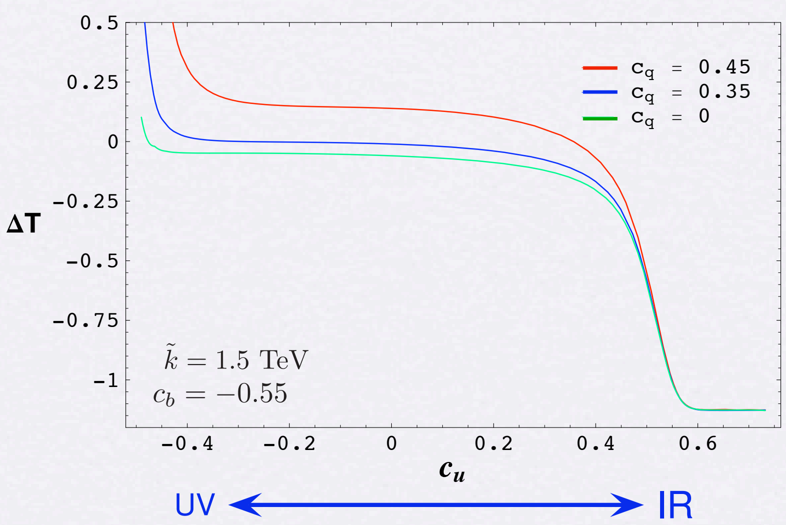
$$q_L = \begin{pmatrix} t_L(+,+) \\ b_L(+,+) \end{pmatrix},$$

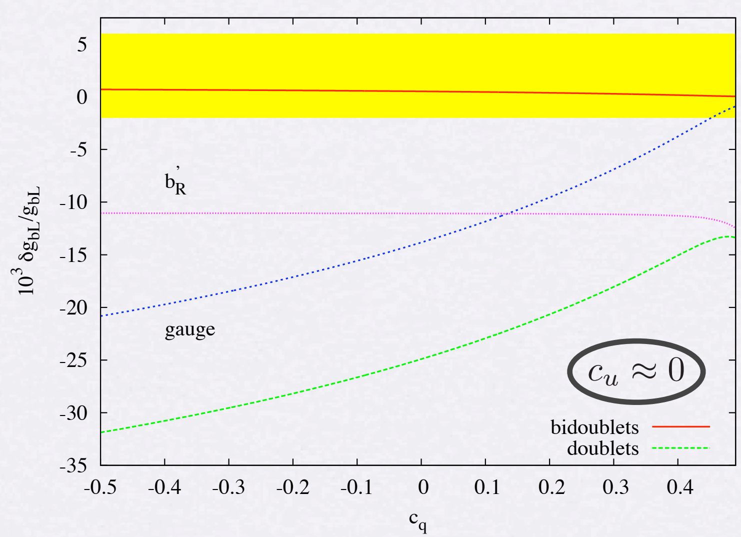
$SU(2)_R$ doublet

$$Q_R = \begin{pmatrix} t_R(+,+) \\ b'_R(-,+) \end{pmatrix}$$

$c_Q > 1/2$

$\rightarrow b'_R$ ultralight



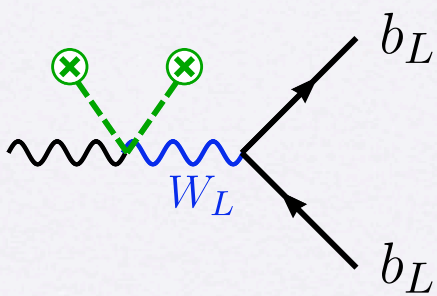


Large corrections to $Zb\bar{b}$ anyway!
(mixing of b_L and b'_R)

Coupling of Z to bottom and custodial protection

(Agashe,Contino, DaRold,Pomarol)

If $g_L = g_R$ and $T^3_L(b_L) = T^3_R(b_L)$:



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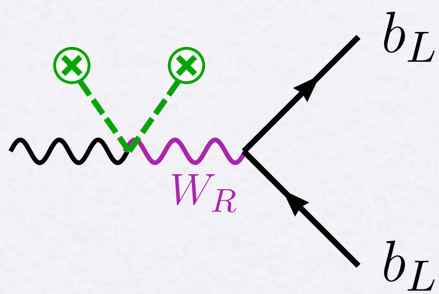
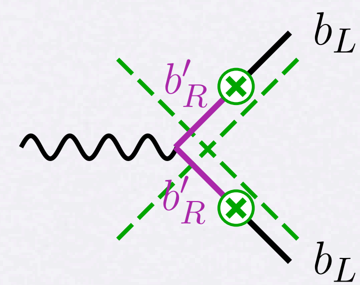


$$= G^{b_L}_{++} - G^{b_L}_{-+} \approx 0$$

$SU(2)_R$

$$SU(2)_L \quad \begin{pmatrix} \chi^u_L(-,+) & q^t_L(+,+) \\ \chi^d_L(-,+) & q^b_L(+,+) \end{pmatrix} \sim (2,2)_{2/3} \sim \begin{pmatrix} 5/3 & 2/3 \\ 2/3 & -1/3 \end{pmatrix}$$



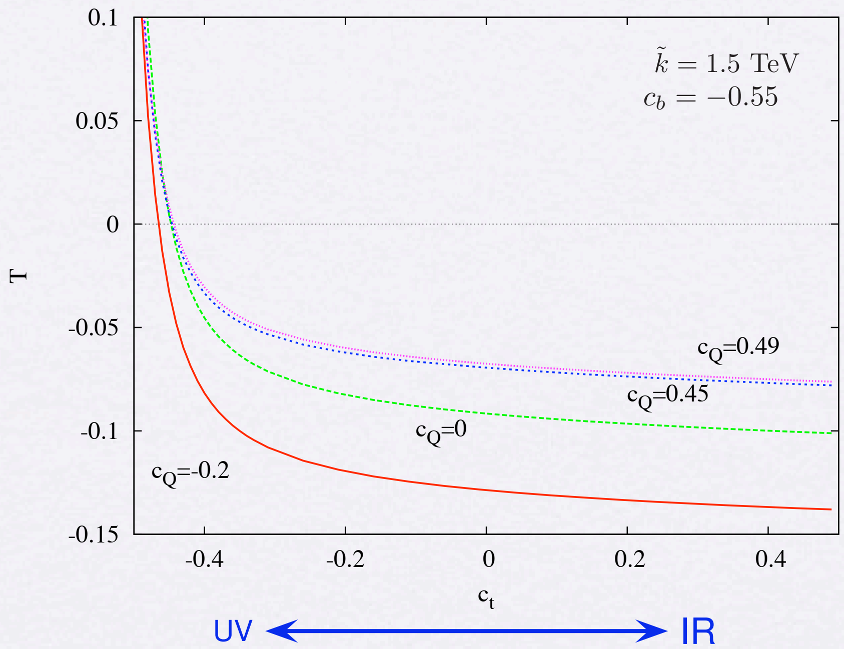
Impose discrete P_{LR} and choose quantum numbers of b_L

(No counterterms that correct $Zb_L\bar{b}_L$ vertex allowed!)

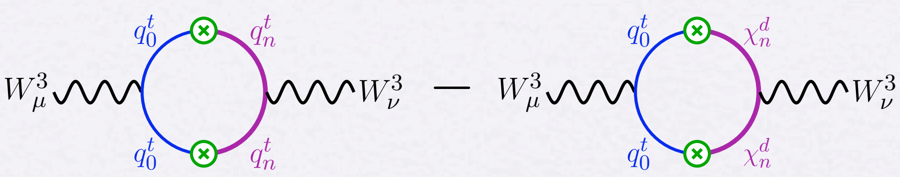
T and custodial protection of $Zb_L\bar{b}_L$

When $Q_L = \begin{pmatrix} \chi_L^u(-,+) & q_L^t(+,+) \\ \chi_L^d(-,+) & q_L^b(+,+) \end{pmatrix} \oplus t_R(+,+)$, b_R from $SU(2)$ triplets

(Carena,E.P,Santiago,Wagner)

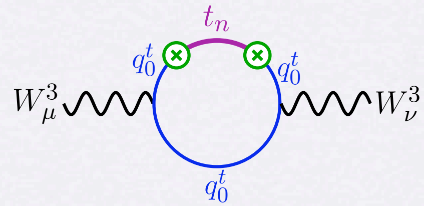


Negative contribution: EWSB mixing of bidoublet KK modes with t_R



χ's lighter and more strongly coupled to Higgs than q's

Positive T from mixing with singlet!



Together with S > 0 $\rightarrow t_R$ far from IR brane seems preferred

Light singlet states that mix strongly with the top quark

Global fit to EW observables

(Carena,E.P.,Santiago,Wagner)

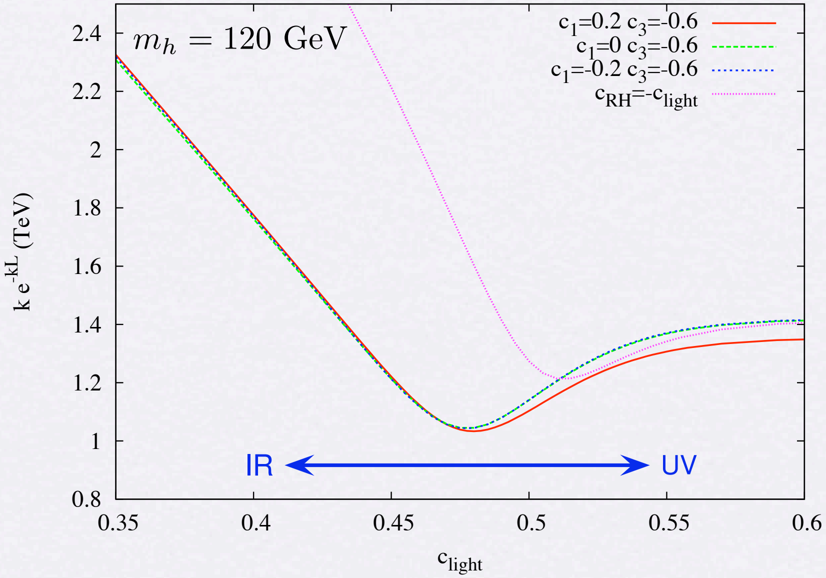
We would like to address the following, in the context of the previous models:

- Localizing the light fermions near the "conformal" point can decouple the tower of KK modes of the SM gauge bosons

  $\longrightarrow$ Can one get rid of the bounds from the "S parameter"?

- How important are the 1-loop contributions to T and the $Zb_L\bar{b}_L$ vertex ?

"S,T,U" analysis insufficient, global fit is required



Non-trivial constraints remain due to

- Couplings to W_R non-universal
- Shifts in up- and down-type couplings different
- Positive T preferred: constraints on localization parameters of 3rd generation quark sector

$$\tilde{k} \equiv ke^{-kL} \gtrsim 1 \text{ TeV } (95\% \text{ C.L.})$$

$$\Longrightarrow \quad M_{\rm KK}^{\rm gauge} \gtrsim 2.5 \text{ TeV}$$

Application: holographic Higgs

Bulk gauge symm: $SU(3)_c \times SO(5) \times U(1)_X \longrightarrow SO(5) \supset SU(2)_L \times SU(2)_R$

UV: $SU(2)_L \times U(1)_Y$ IR: $SO(4) \times U(1)_X \simeq SU(2)_L \times SU(2)_R \times U(1)_X$

Extra gauge bosons have the quantum numbers of the Higgs

$$SO(5)/SO(4) \longrightarrow A_\mu^{\hat{a}}(-,-) \quad A_5^{\hat{a}}(+,+) \longleftarrow \boxed{\textbf{Identify with H}}$$

No tree-level Higgs potential $\longrightarrow$ induced at one-loop (calculable)

Coleman-Weinberg potential has been computed for the model considered here by *Medina, Shah and Wagner* (to appear)

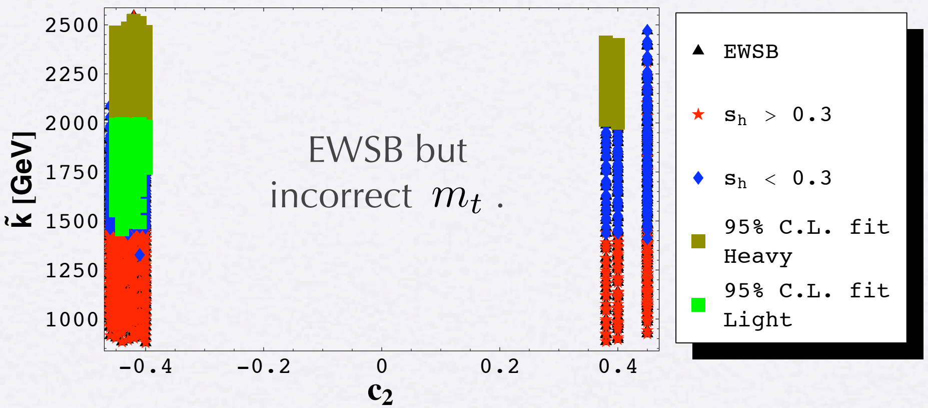
- EWSB minima in large regions of parameter space
- Can be consistent with Z, W, top masses and Higgs LEP bound

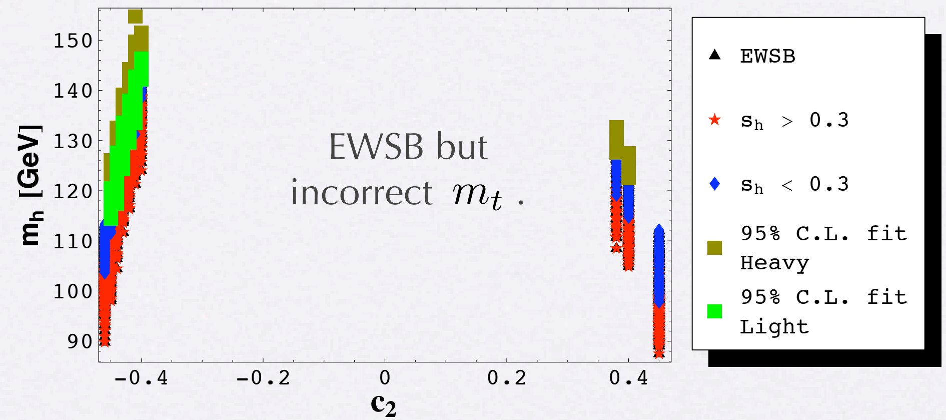
- EW fit easier to perform in regions where Higgs couplings are "linear", i.e. very similar to those of a standard model Higgs
- We restrict to "oblique region" with light fermions far from IR brane (fit unlikely to improve significantly in other regions)

Preliminary results!!

(E.P. and Santiago)

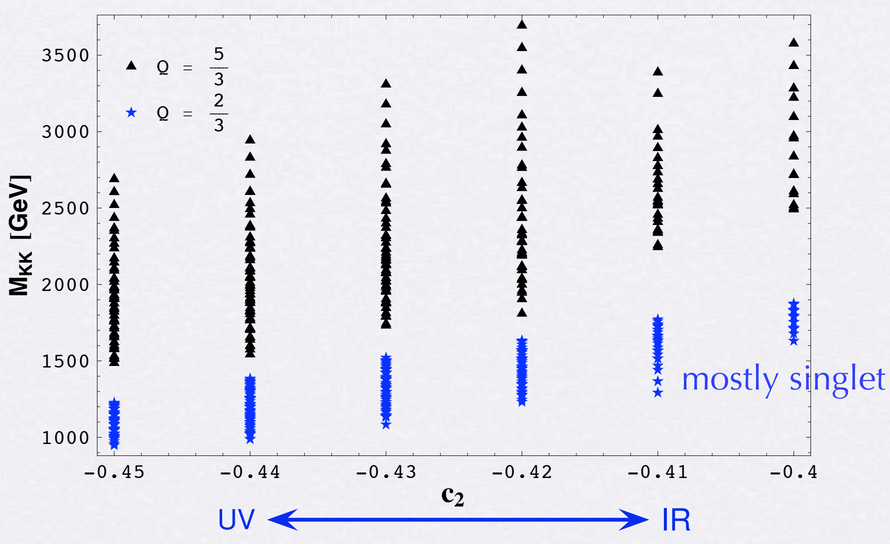
Green region: EWSB, linear approx holds, correct m_t, m_b, m_h above LEP bound, and $\tilde{k} < 2$ TeV $(M_{KK}^{\rm gauge} < 5$ TeV$)$



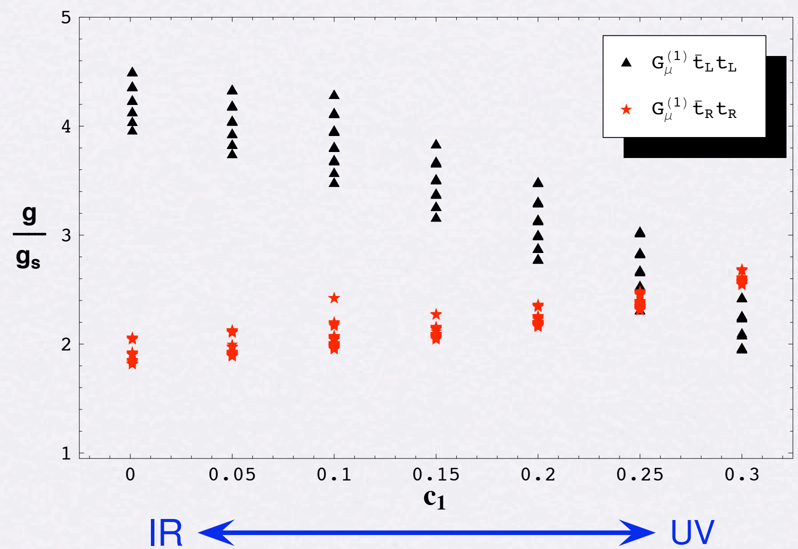


All points obey conditions of green region in above two figures

Lightest KK fermion states



Couplings of G'_μ to 3^{rd} gen. in units of g_s



Conclusions

- Gauge boson KK resonances likely accessible at the LHC
- KK fermions of 3rd quark generation lighter than KK gauge modes
- Such states affect SM observables at loop level $\longrightarrow$ possible constraints on localization parameters of this sector
  - Couplings of (t_L, b_L) to new physics need not be suppressed compared to those of t_R .
  - Lightest states likely to have a large singlet component
  - Exotic states (charge 5/3) also lighter than KK gauge bosons
  - Possible interesting decay chains of KK gluons
- Might expect interesting flavor physics if b_L indeed close to IR brane (but recall that IR localized kinetic terms can be relevant for couplings)
- Under study: how robust is the resulting picture, e.g. consider BKT terms in "minimal" models, or non-minimal extensions

Details of fermion sector

The fermion sector is more model dependent. Built out of

$$5 \sim (2,2) \oplus 1 \quad \text{and} \quad 10 \sim (2,2) \oplus (3,1) \oplus (1,3)$$

In gauge-Higgs unification scenarios Yukawa's arise from gauge coupl.

Flavour structure from mixing via IR localized mass terms

$$\xi^i_{1L} \sim Q^i_{1L} = \begin{pmatrix} \chi^{u_i}_{1L}(-,+) & q^{u_i}_L(+,+) \\ \chi^{d_i}_{1L}(-,+) & q^{d_i}_L(+,+) \end{pmatrix} \oplus u'^i_L(-,+)\,,$$

$$\xi^i_{2R} \sim Q^i_{2R} = \begin{pmatrix} \chi^{u_i}_{2R}(-,+) & q'^{u_i}_R(-,+) \\ \chi^{d_i}_{2R}(-,+) & q'^{d_i}_R(-,+) \end{pmatrix} \oplus u^i_R(+,+)\,,$$

$$\xi^i_{3R} \sim T^i_{1R} = \begin{pmatrix} \psi'^i_R(-,+) \\ U'^i_R(-,+) \\ D'^i_R(-,+) \end{pmatrix} \oplus T^i_{2R} = \begin{pmatrix} \psi''^i_R(-,+) \\ U''^i_R(-,+) \\ D^i_R(+,+) \end{pmatrix} \oplus Q^i_{3R} = \begin{pmatrix} \chi^{u_i}_{3R}(-,+) & q''^{u_i}_R(-,+) \\ \chi^{d_i}_{3R}(-,+) & q''^{d_i}_R(-,+) \end{pmatrix}$$

$$\mathcal{L}_m = \delta(y-L)\Big[\bar{u}'_L \tilde{M}_u u_R + \bar{Q}_{1L} M_u Q_{2R} + \bar{Q}_{1L} M_d Q_{3R} + \text{h.c.}\Big]$$

Other parameters relevant the for EW fit: $\longrightarrow$

c_L, c_R localization of $1^{st}, 2^{nd}$ gen.

c_1, c_2, c_3 localization of 3^{rd} gen.

Observables used in global fit

(bottom treated independently)

(Han,Skiba)

	Standard Notation	Measurement	Reference
Atomic parity violation	$Q_W(Cs)$	Weak charge in Cs	[21]
	$Q_W(Tl)$	Weak charge in Tl	[22]
DIS	g_L^2, g_R^2	ν_μ-nucleon scattering from NuTeV	[23]
	R^ν	ν_μ-nucleon scattering from CDHS and CHARM	[24, 25]
	κ	ν_μ-nucleon scattering from CCFR	[26]
	$g_V^{\nu e}, g_A^{\nu e}$	ν-e scattering from CHARM II	[27]
Z-pole	Γ_Z	Total Z width	[20]
	σ_h^0	e^+e^- hadronic cross section at Z pole	[20]
	$R_f^0(f = e, \mu, \tau, b, c)$	Ratios of decay rates	[20]
	$A_{FB}^{0,f}(f = e, \mu, \tau, b, c)$	Forward-backward asymmetries	[20]
	$\sin^2\theta_{eff}^{lept}(Q_{FB})$	Hadronic charge asymmetry	[20]
	$A_f(f = e, \mu, \tau, b, c)$	Polarized asymmetries	[20]
Fermion pair production at LEP2	$\sigma_f(f = q, \mu, \tau)$	Total cross sections for $e^+e^- \to f\overline{f}$	[20]
	$A_{FB}^f(f = \mu, \tau)$	Forward-backward asymmetries for $e^+e^- \to f\overline{f}$	[20]
	$d\sigma_e/d\cos\theta$	Differential cross section for $e^+e^- \to e^+e^-$	[28]
W pair	$d\sigma_W/d\cos\theta$	Differential cross section for $e^+e^- \to W^+W^-$	[29]
	M_W	W mass	[20, 30]

TABLE I: Relevant measurements