FINALLY
A REALISTIC
HIGGSLESS MODEL

Guido Marandella
University of California, Davis

G. Cacciapaglia, C. Csáki, GM, J, Terning, hep-ph/0607146

Santa Fe - June 24 2006

OUTLINE

- Review about Higgsless models
- Main challenges
- The third generation: top mass and Zbb
- New realization of the custodial symmetry
- Summary

HIGGSLESS MODELS

Why do we need the Higgs ?

- Break the ElectroWeak symmetry
- Fermion masses
- Unitarize the WW scattering

All this can be achieved through extra dimensions

HIGGSLESS MODELS

Why do we need the Higgs ?

- Break the ElectroWeak symmetry -> BC
- Fermion masses -> BC
- Unitarize the WW scattering -> KK gauge bosons

All this can be achieved through extra dimensions

(C. Csaki, C. Grojean, J. Hubisz, H. Murayama, L. Pilo, Y. Shirman, J. Terning)

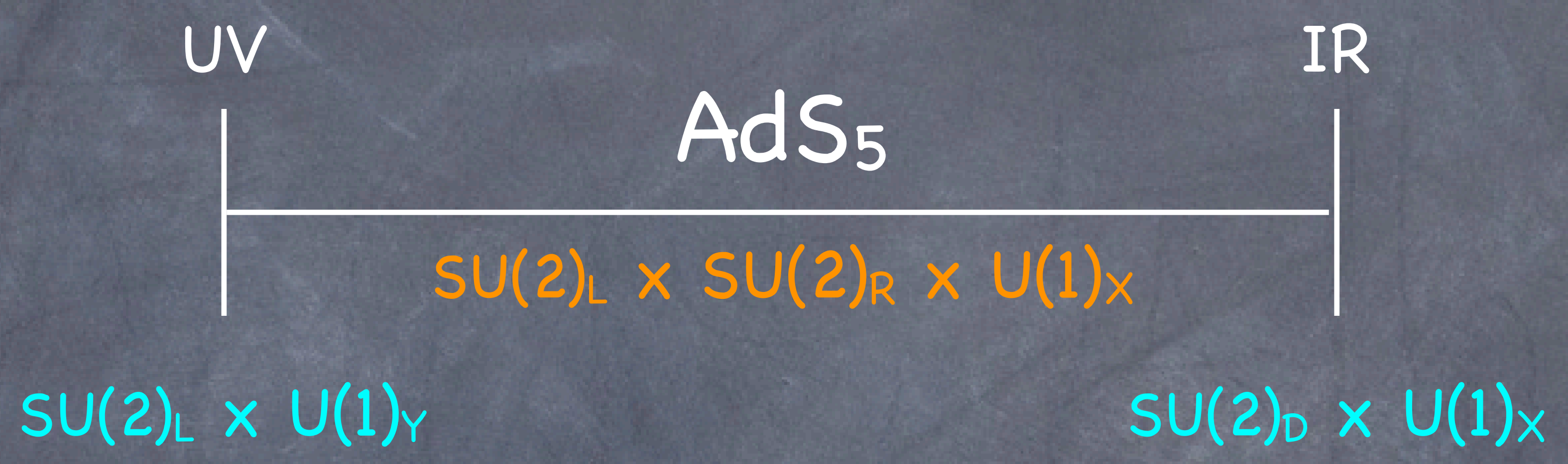
HIGGSLESS MODELS

Attempts to build realistic Higgsless models face two main challanges already at tree-level

- ElectroWeak Precision Data (S-parameter)
- Top mass without spoiling Zbb

HIGGSLESS MODELS

The setup



Embedding fermions

$$\Psi = \begin{pmatrix} \chi \\ \psi \end{pmatrix}$$

χ: Left-handed

ψ : Right-handed

Chiral spectrum with different BC

HIGGSLESS MODELS

For massless fermions
(under $SU(2)_L \times SU(2)_R \times U(1)_X$)

$$\Psi_L = (\mathbf{2},\mathbf{1})_Y\,, \qquad \Psi_R = (\mathbf{1},\mathbf{2})_Y$$

BC (UV,IR)

χ_R = (-,-) $\qquad$ χ_L = (+,+)

ψ_L = (-,-) $\qquad$ ψ_R = (+,+)

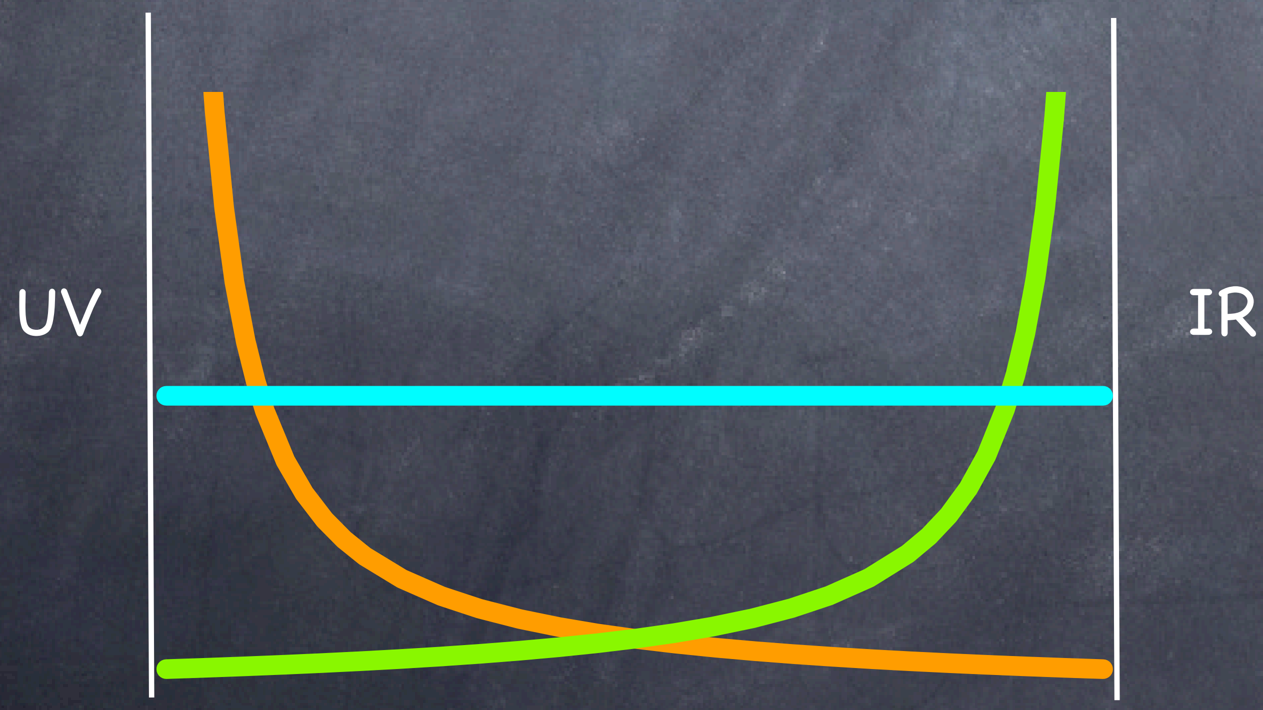
give a LH zero mode living in Ψ_L and a RH zero mode living in Ψ_R

HIGGSLESS MODELS

Where do fermions live ?

Bulk mass terms

$$S_m = \int d^5x \left(\frac{R}{z}\right)^5 \left[\frac{c_L}{R}\bar{\Psi}_L\Psi_L + \frac{c_R}{R}\bar{\Psi}_R\Psi_R\right]$$



$c_L < 1/2 \ \ (c_R > -1/2)$

$c_L > 1/2 \ \ (c_R < -1/2)$

$c_L = -c_R = 1/2$

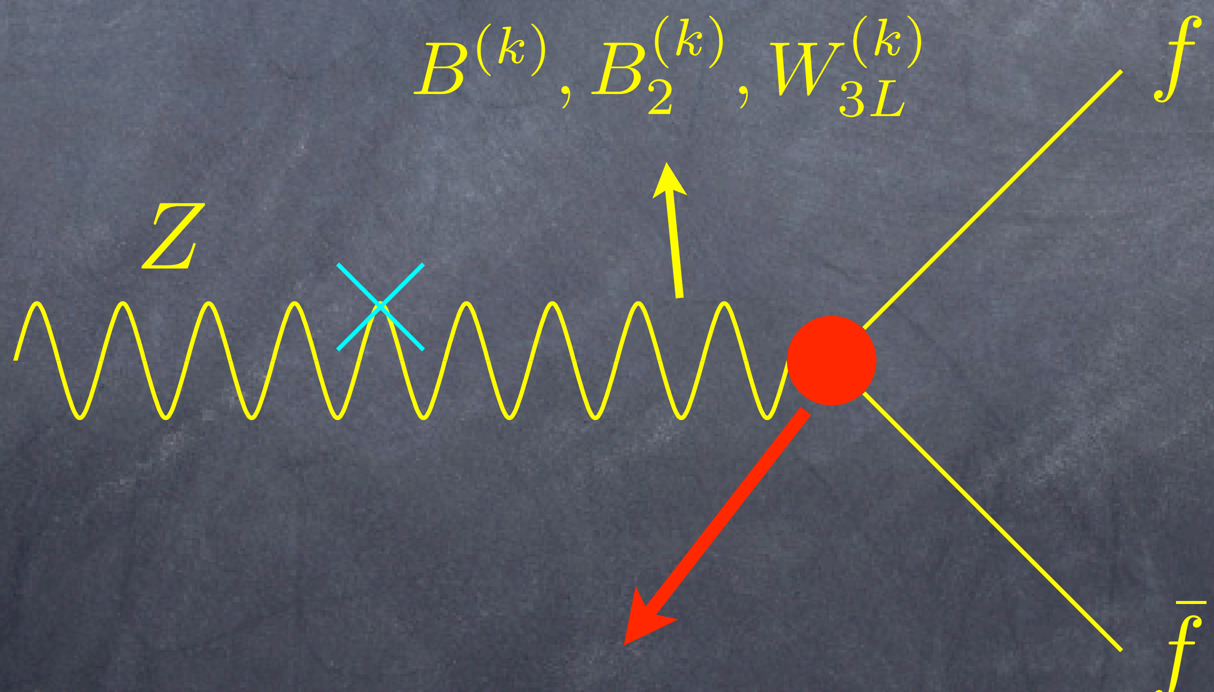
HIGGSLESS MODELS

Three KK towers of neutral gauge boson.

Before EWSB

W_{3L} (+,+), B_Y (+,+), B_2 (-,+)

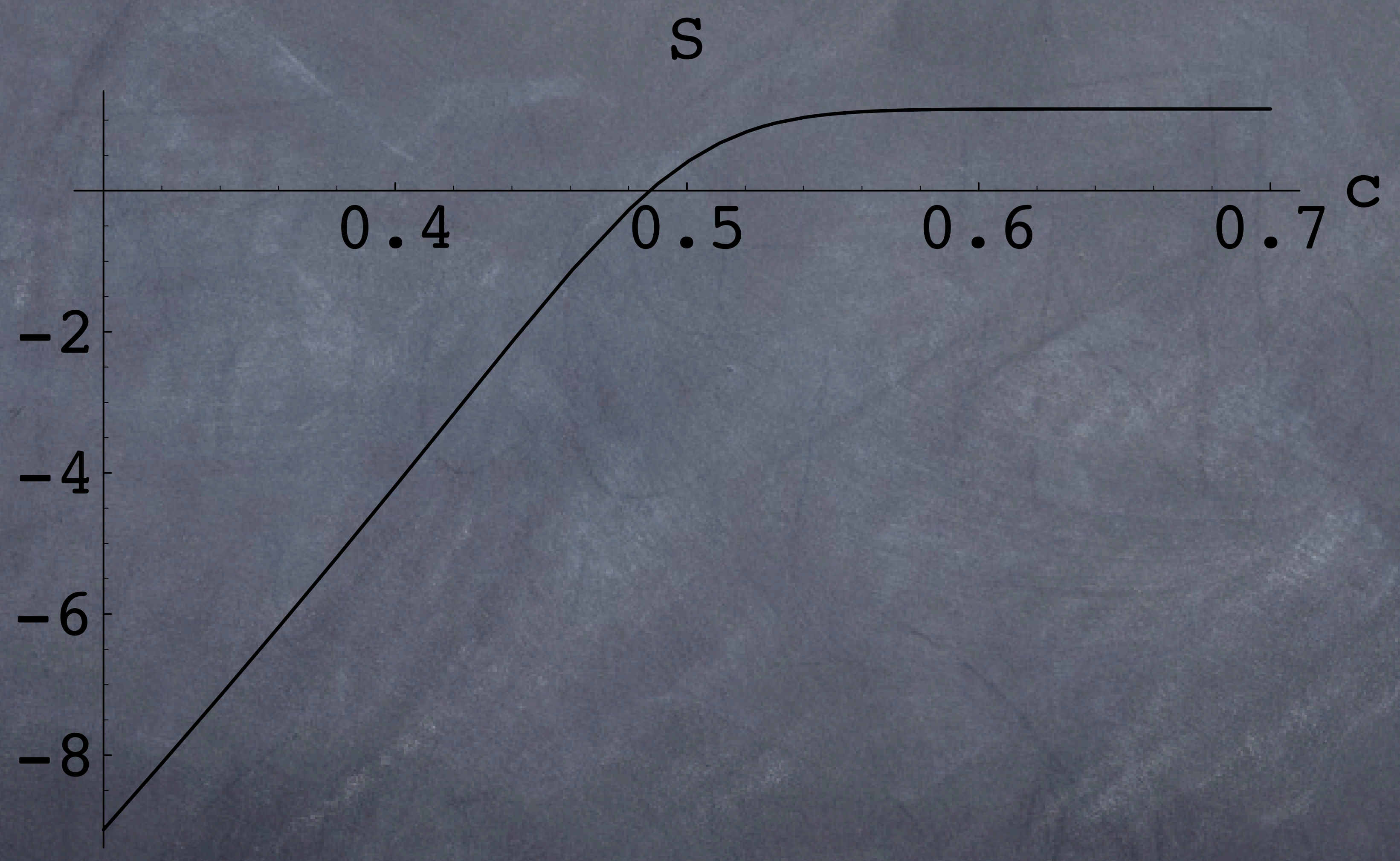
Corrections to precision observables



make it $\simeq 0$

HIGGSLESS MODELS

S-parameter



$1/R = 10^{-8}$ GeV, $1/R' = 280$ GeV

(G. Cacciapaglia, C. Csaki, C. Grojean and J. Terning, hep-ph/0409126)

TOP MASS AND Zbb

The third generation is special due to the heaviness of the top quark

$$\Psi_L^{(2,1)_{1/6}} = \begin{pmatrix} \chi_L \\ \psi_L \end{pmatrix} \qquad \Psi_R^{(1,2)_{1/6}} = \begin{pmatrix} \chi_R \\ \psi_R \end{pmatrix}$$

Big Dirac mass on the TeV brane

$$M\left(\chi_L \psi_R + \chi_R \psi_L\right)$$

$$\chi_L = \begin{pmatrix} \chi_{t_L} \\ \chi_{b_L} \end{pmatrix}, \qquad \psi_L = \begin{pmatrix} \psi_{t_L} \\ \psi_{b_L} \end{pmatrix} \quad \ldots..$$

TOP MASS AND Zbb

Boundary conditions on the TeV brane

$$\psi_L = MR' \, \psi_R \qquad \chi_R = -MR' \, \chi_L$$

It is not possible to get arbitrarily high mass. For $MR' \to \infty$ the BC become

$$\psi_R = \chi_L = 0$$

So the top is a KK excitation: its mass is set by $1/R' \simeq 300$ GeV

The bottom mass is suppressed with a big kinetic terms localized on the Planck brane

TOP MASS AND Zbb

To have Zbb ok we need $c_L \simeq 0.46$, i.e. the bottom wave function almost flat. But

$$\chi_R = -MR' \, \chi_L$$

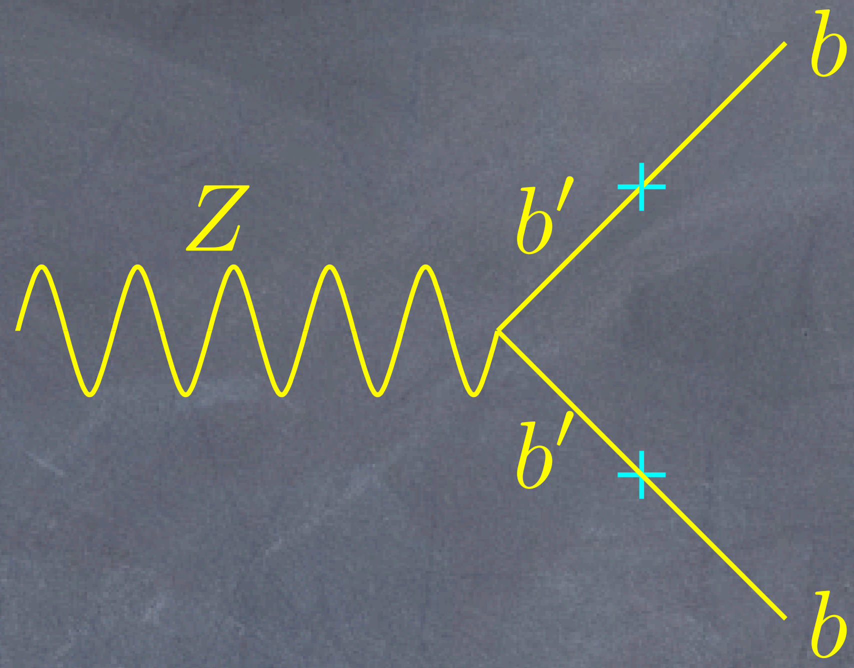
M has to be $\simeq 1/R'$ to get the top mass

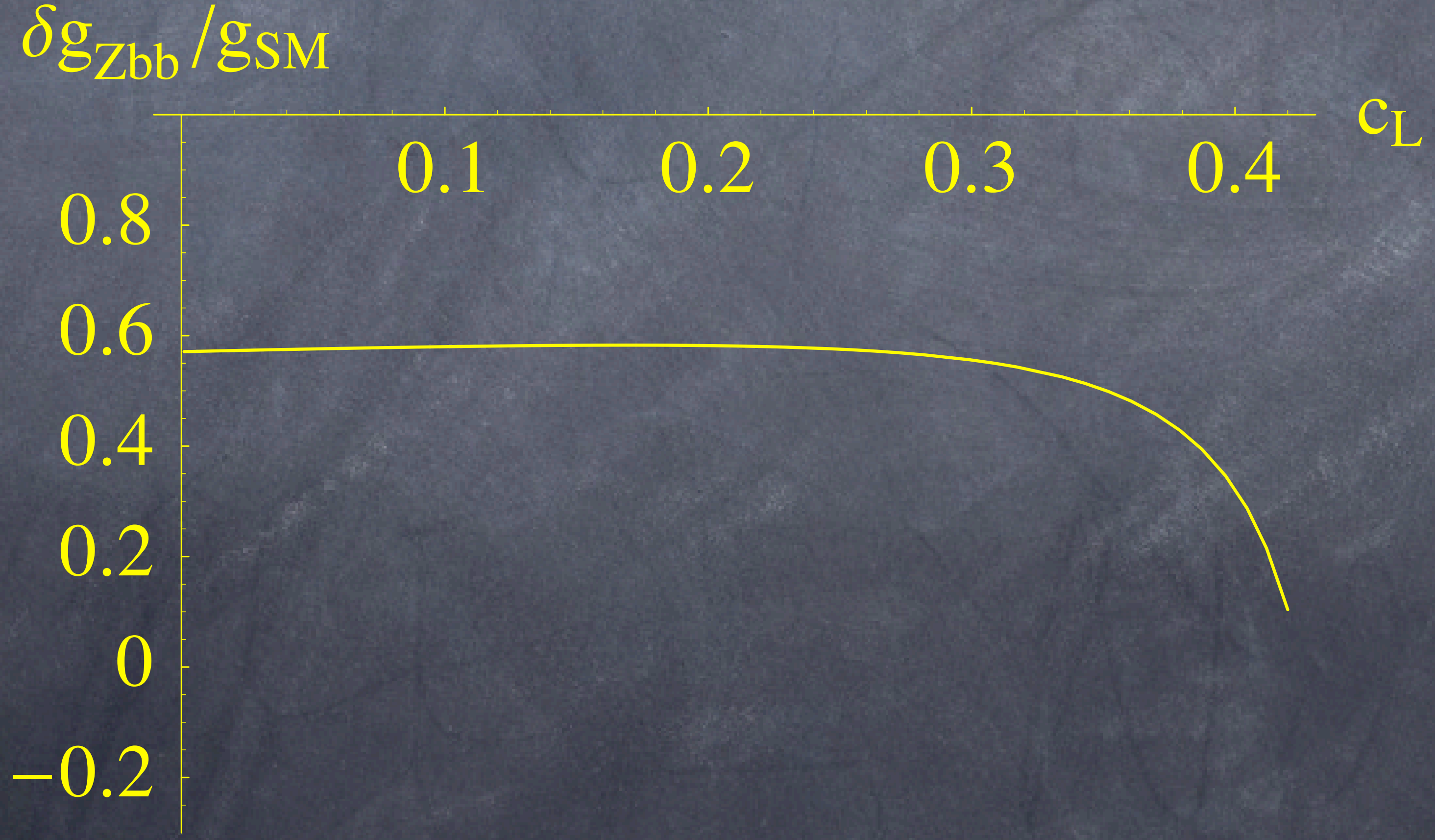
$$\chi_R = \begin{pmatrix} \chi_{t_R} \\ \chi_{b_R} \end{pmatrix}$$

χ_{b_R} is a LH bottom quark with Y = -1/3 !

The coupling of the LH bottom to the Z modified

TOP MASS AND Zbb





A NEW REALIZATION

An alternative realization of the custodial symmetry

(K. Agashe, R. Contino, L. Da Rold, A. Pomarol, hep-ph/0605341

M. Carena, E. Ponton, J. Santiago and C. Wagner, hep-ph/0607106)

Consider a BSM sector symmetric under

$$O(4) \sim SU(2)_L \otimes SU(2)_R \otimes P_{LR}$$

broken to

$$O(3) \sim SU(2)_V \otimes P_{LR}$$

A NEW REALIZATION

Z coupling to a fermion

$$\frac{g}{\cos\theta_W}\left[Q_L^3 - Q\sin^2\theta_W\right] Z^\mu \bar{\psi}\gamma_\mu\psi$$

Q is conserved, $Q_L{}^3$ not necessarily

If ψ is a +1 eigenstate of P_{LR} then

$$T_L = T_R, \qquad T_L^3 = T_R^3$$

which implies

$$\delta Q_L + \delta Q_R = 0, \qquad \delta Q_L = \delta Q_R$$

i.e. $Q_L{}^3$ is protected

A NEW REALIZATION

$T_{3L} = T_{3R} = -1/2$

Promote

$$\Psi_L = (\mathbf{2},\mathbf{1})_{1/6} \longrightarrow (\mathbf{2},\mathbf{2})_{2/3} = \begin{pmatrix} t_L & X_L \\ b_L & T_L \end{pmatrix}$$

for the RH fields

$$t_R = (\mathbf{1},\mathbf{1})_{2/3} \qquad \Psi_R = (\mathbf{1},\mathbf{3})_{2/3} = \begin{pmatrix} X_R \\ T_R \\ b_R \end{pmatrix}$$

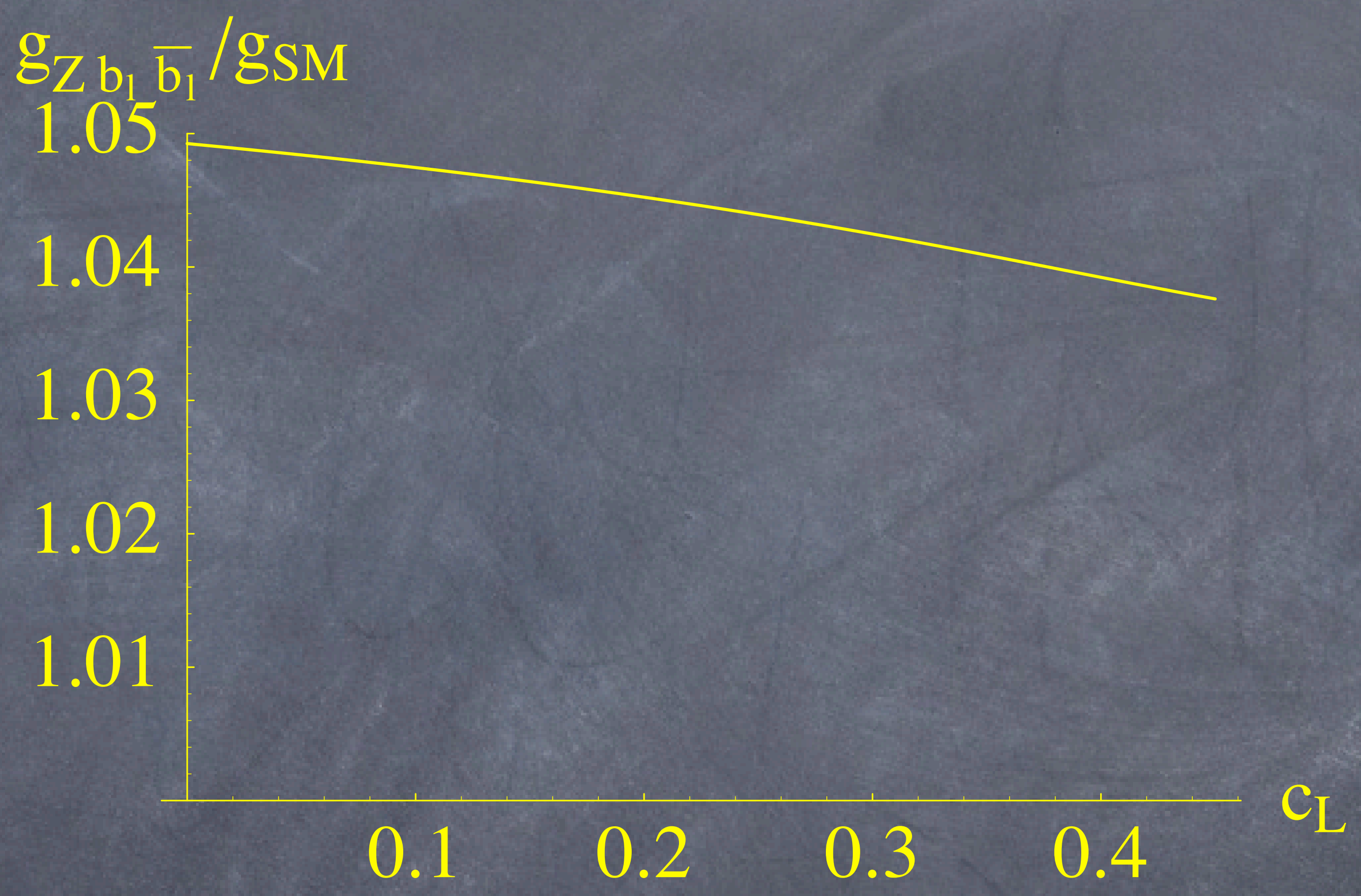
Mass for top and bottom

$$\frac{M_1}{\sqrt{2}}\, t_R\, (t_L - T_L) +$$

$$M_3 \left[\frac{1}{\sqrt{2}} T_R\, (t_L + T_L) + b_R b_L \right]$$

A NEW REALIZATION

Not enough though



(Almost) constant +4/5 % deviation.

Where does it come from ?

A NEW REALIZATION

On the Planck brane

$$SU(2)_R \times U(1)_Y \rightarrow U(1)_Y$$

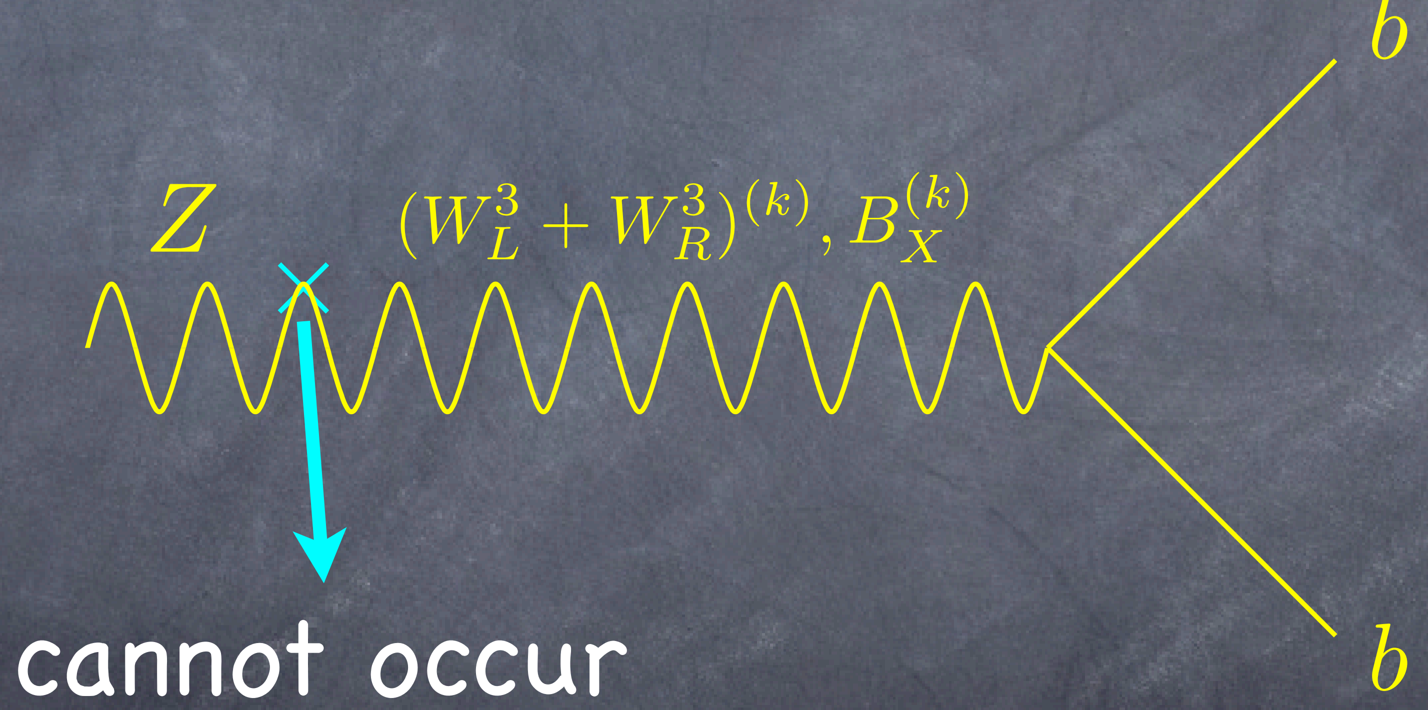
breaks the discrete parity P_{LR}

Suppose that there is no such breaking on the UV brane. Before EWSB all gauge bosons have a flat zero mode and the same KK tower

A NEW REALIZATION

$W_L^3 - W_R^3$ is broken on the TeV brane

$W_L^3 + W_R^3$
B_X are not



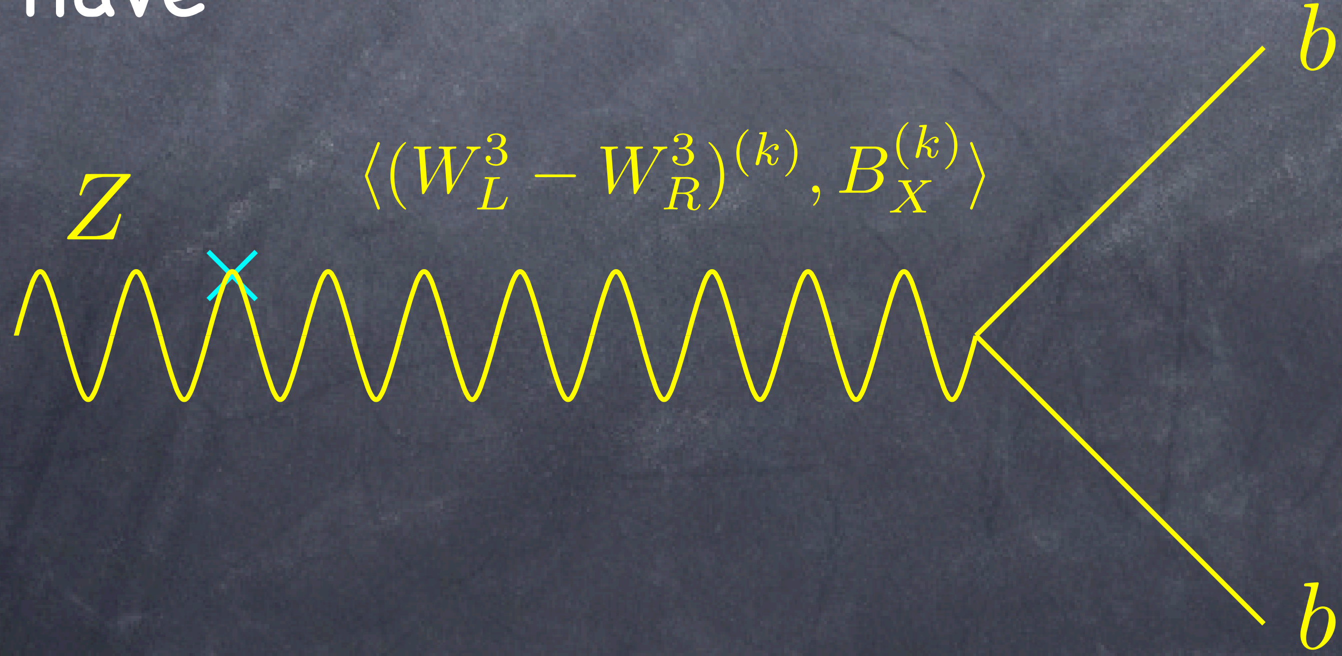
A NEW REALIZATION

However, $W_R^3 - B_X$ is broken on the UV brane, so its KK tower is different from $W_R^3 + B_X$, W_L^3

When going to the basis

$$W_L^3 - W_R^3$$
$$W_L^3 + W_R^3$$
$$B_X$$

one can have



A NEW REALIZATION

The solution

$T_{3L} = T_{3R} = -1/2$

$$\Psi_L = (\mathbf{2},\mathbf{1})_{1/6} \longrightarrow (\mathbf{2},\mathbf{2})_{2/3} = \begin{pmatrix} t_L & X_L \\ b_L & T_L \end{pmatrix}$$

$$t_R = (\mathbf{1},\mathbf{1})_{2/3} \qquad \Psi_R = (\mathbf{1},\mathbf{3})_{2/3} = \begin{pmatrix} X_R \\ T_R \\ b_R \end{pmatrix}$$

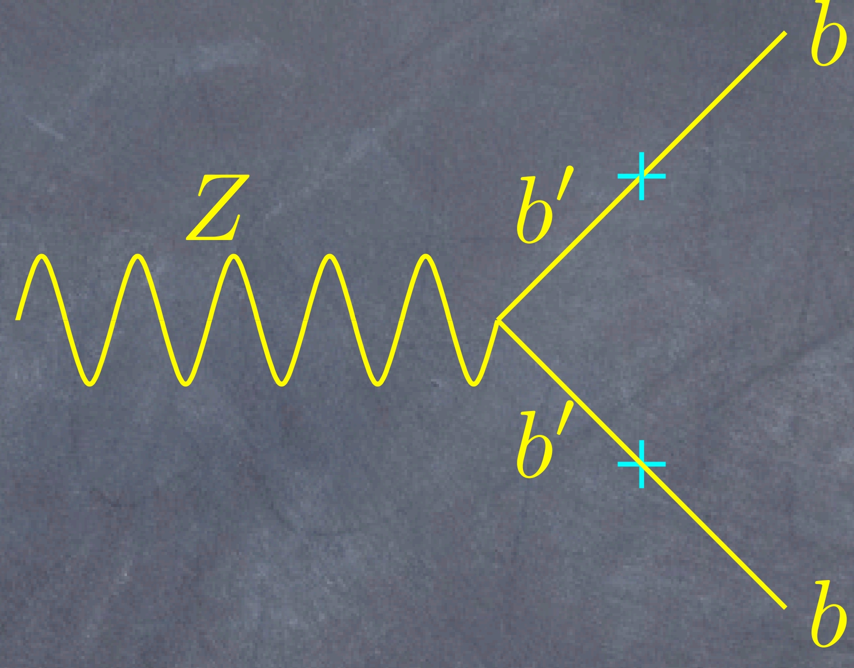
$$\mathcal{L}_m = M_3 \left[\frac{1}{\sqrt{2}} T_R \left(t_L + T_L \right) + b_R b_L \right]$$

$T_{3L} = 0, \quad T_{3R} = -1$

If b_L and b_R are localized far apart, M_3 has to be $\simeq 1/R'$ and a sizable component of the LH bottom lives in b_R -> modifications in Zb_lb_l

A NEW REALIZATION

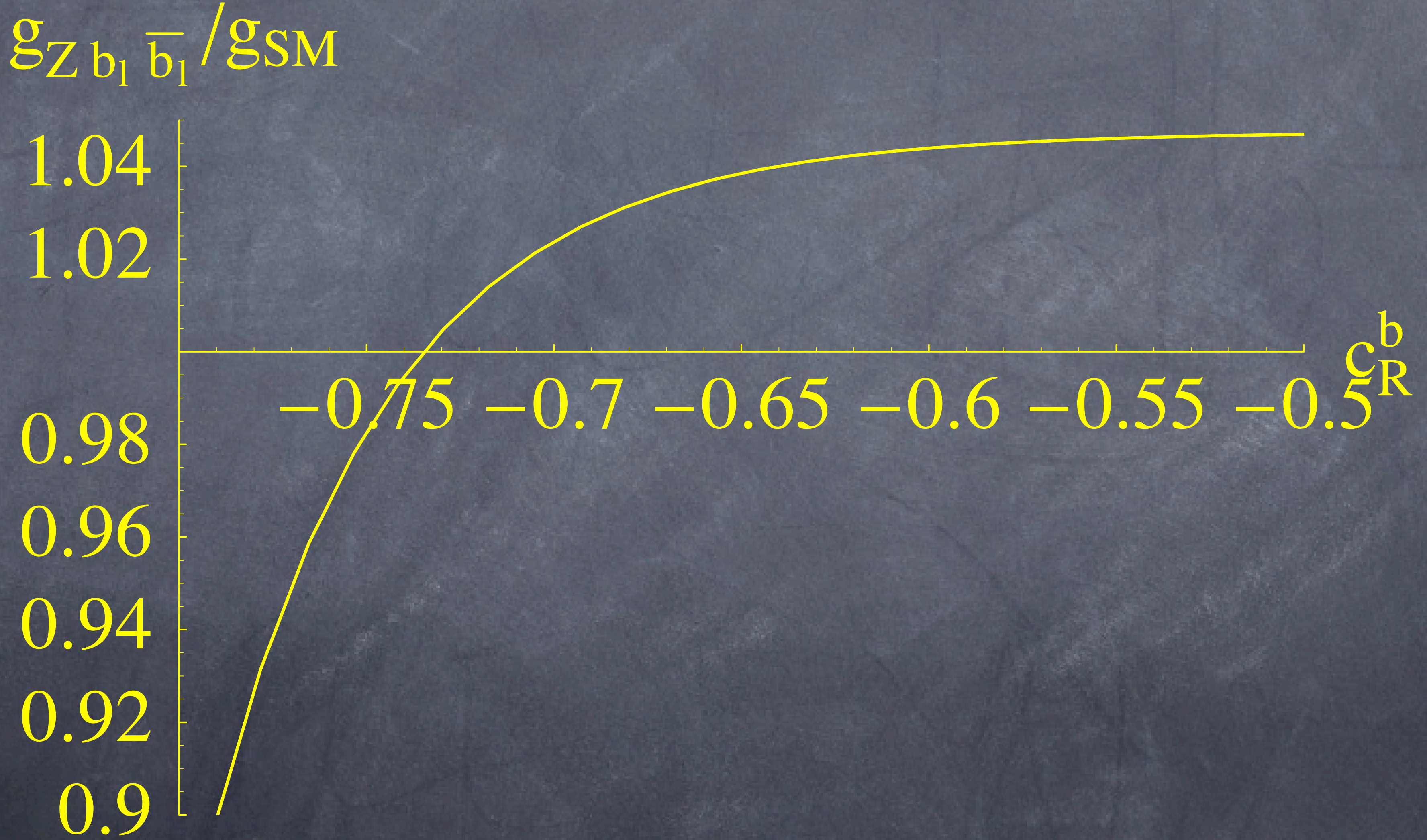
Diagramatically, before we were neglecting



which instead can be sizable if b_L and b_R are localized near opposite branes

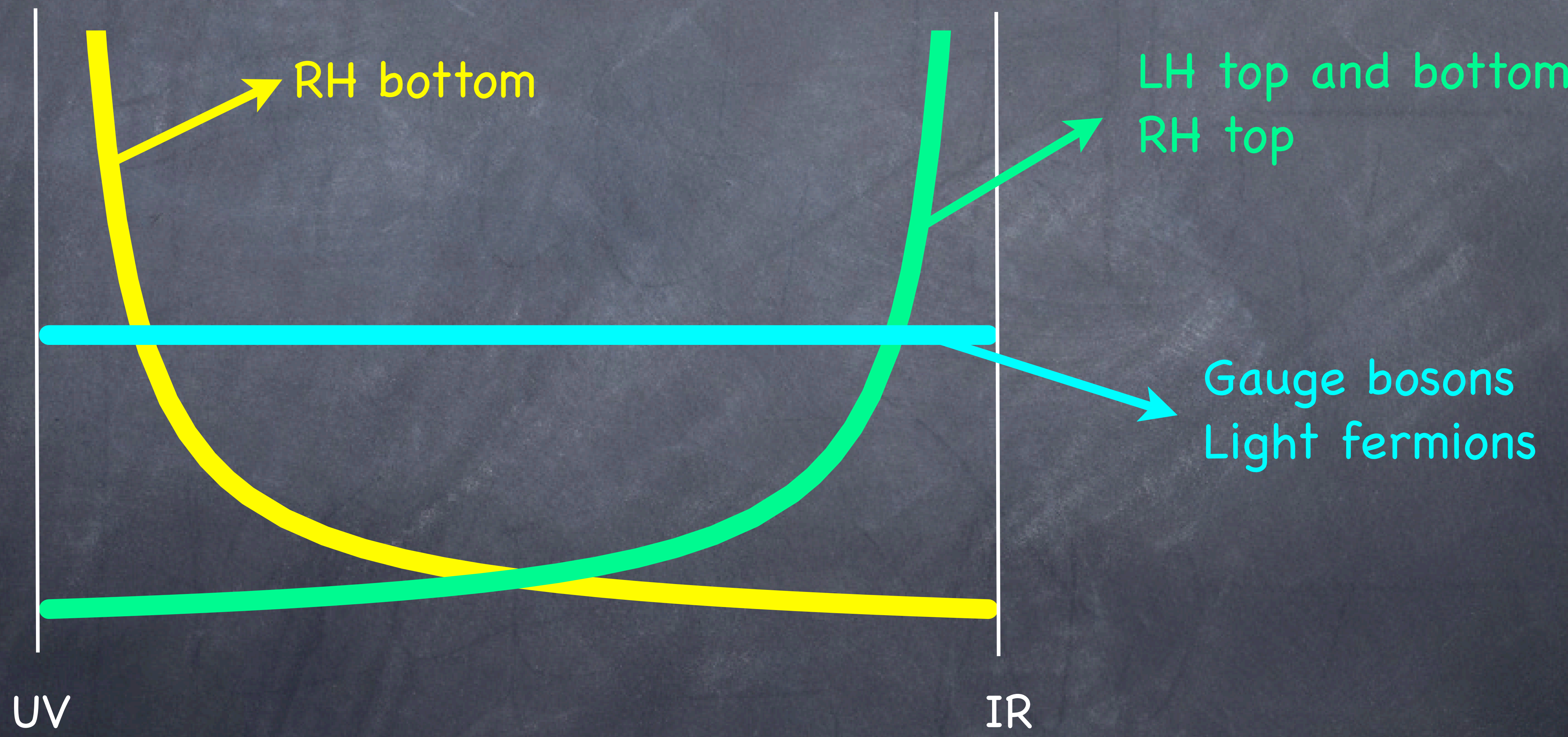
A NEW REALIZATION

$1/R = 10^{-8}$ GeV, $1/R' = 280$ GeV, $c_L = 0.1$



A NEW REALIZATION

Summarizing the configuration for zero modes



SUMMARY OF THE MODEL

The couplings of the third generation

	frac. of SM
$Zb_\ell\bar{b}_\ell$	1.004
$Zb_r\bar{b}_r$	0.993
$Zt_\ell\bar{t}_\ell$	0.461
$Zt_r\bar{t}_r$	1.908
$Wt_\ell\bar{b}_\ell$	0.862
$Wt_r\bar{b}_r$	$3\cdot 10^{-4}\ g_{Wt_\ell\bar{b}_\ell}$

$1/R = 10^{-8}$ GeV, $1/R' = 280$ GeV, $c_L = 0.1$, $c_R^t = 0$, $c_R^b = -0.73$

CONCLUSIONS

An alternative realization of the custodial symmetry allows with a discrete L-R parity

- obtain the top mass
- make Zbb deviations arbitrarily small

(Almost) flat light fermions allow an arbitrarily small S parameter.

The Higgsless model has finally a fully realistic formulation at tree level.

Loop effects to be analyzed (T-parameter ?)