Three Site Higgsless Model

Masafumi Kurachi

C.N. Yang Institute for Theoretical Physics
SUNY at Stony Brook

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Collaborators :

Michigan State University

R. Sekhar Chivukula
Elizabeth H. Simmons
Baradhwaj Coleppa
Stefano Di Chiara

Tsinghua University

Hong-Jian He

Nagoya University

Masaharu Tanabashi

Outline

1. Introduction
2. The Three Site Model
3. Comparison to 5D Higgsless Models
4. Discussion
5. Summary

Introduction

- Higgsless model was proposed as a new scenario of the EWSB

  Csaki, Grojean, Murayama, Pilo, Terning Phys. Rev. D 69, 055006 (2004)

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- EW symmetry is broken by the boundary condition of the gauge fields

- The spectrum includes states identified with γ, W, Z and also an infinite tower of additional massive vector bosons

- Unitarization of the longitudinal W and Z boson scattering is ensured by the exchange of heavy gauge bosons

  Chivukula et. al. PLB 525, 175 (2002), PLB 532, 121(2002), PLB 562, 109 (2003)

Introduction

- Much has been written about models based on a five-dimensional $SU(2)_L \times SU(2)_R \times U(1)_{\mathrm{B-L}}$ gauge theory in a slice of AdS space

Agashe, Delgado, May, Sundrum, JHEP 0308, 050 (2003)

Csaki, Grojean, Pilo, Terning, Phys. Rev. Lett. 92, 101802 (2004)

Burdman, Nomura, Phys. Rev. D 69, 115013 (2004)

Cacciapaglia, Csaki, Grojean, Terning, Phys. Rev. D 70, 075014 (2004)

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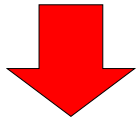
Introduction

Deconstruction (Arkani-Hamed-Cohen-Georgi, Hill-Pokorski-Wang) :

an alternative approach to study the Higgsless models



- Arbitrary 5D geometry
- Position dependent couplings
- Brane localized kinetic terms

Introduction

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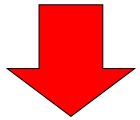


Higgsless model with localized fermions cannot simultaneously

- satisfy unitarity bound
- provide acceptably small EW corrections

Chivukula, Simmons, He, Kurachi, Tanabashi, Phys. Rev. D 71, 015016 (2005)

Introduction

Fermion delocalization reduce the EW corrections

Cacciapaglia, Csaki, Grojean, Terning, Phys. Rev. D 71, 035015 (2005)

Foadi, Gopalakrishna, Schmidt, Phys. Lett. B 606, 157 (2005)

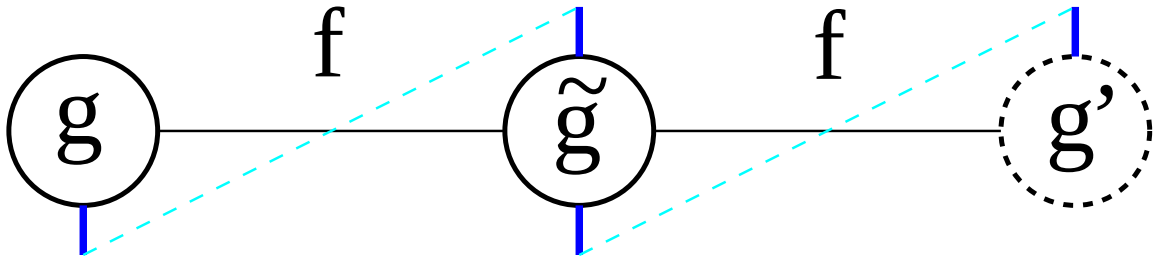
For an arbitrary Higgsless models, choosing the probability distribution of the delocalized fermions to be related to the wavefunction of the W boson makes the S and T parameters vanish at tree-level

Ideal delocalization

Chivukula, Simmons, He, Kurachi, Tanabashi, Phys. Rev. D 72, 015008 (2005)

Three Site Higgsless Model

Chivukula, Coleppa, Di Chiara, Simmons, He, Kurachi, Tanabashi, PRD 74, 075001 (2006)



Four-dimensional gauge invariant Lagrangian which includes

- $SU(2) \times SU(2) \times U(1)$ gauge fields (Circles) $\Longrightarrow$ γ, W, Z, W', Z'
- $(SU(2) \times SU(2))/SU(2)$ non-linear sigma fields (Links)

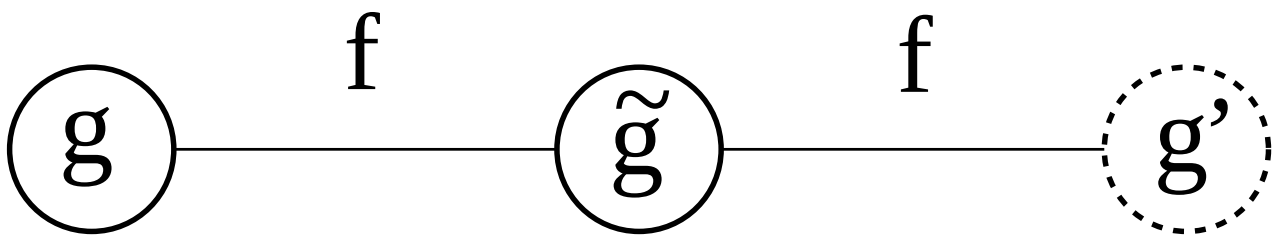
Eaten by massive gauge fields

- Two left and right handed fermions (Vertical lines)

$\Longrightarrow$ SM fermions and their heavy partners

Three Site Higgsless Model

Chivukula, Coleppa, Di Chiara, Simmons, He, Kurachi, Tanabashi, PRD 74, 075001 (2006)



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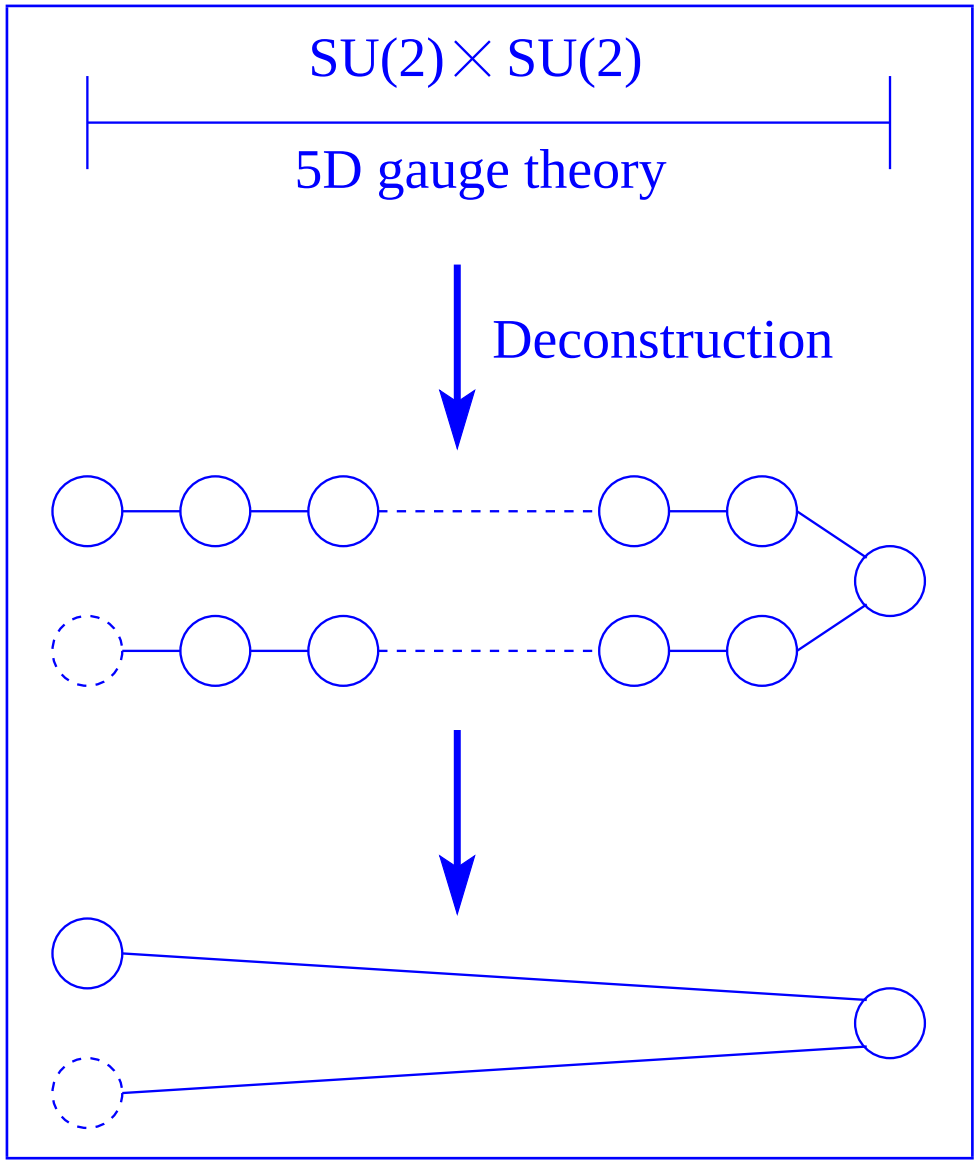
Eaten by massive gauge fields

In this short talk, we focus on the EW gauge sector of the model

Comparison to 5D Higgsless Models



The three site model can be viewed as a highly deconstructed version of $SU(2)_L \times SU(2)_R$ 5D Higgsless models

In this talk, we discuss how well the three site model approximates 5D Higgsless models

We compare the model to 5D Higgsless model with a flat and a warped extra dimension

$SU(2)_L \times SU(2)_R$ Higgsless Model with a flat extra dimension

$$0 \leq z \leq \pi R$$

$$S_{5D} = \int_0^{\pi R} dz \int d^4x \left[\frac{1}{g_5^2} \left(-\frac{1}{4} W_{\mu\nu}^{La} W_{\alpha\beta}^{La} \eta^{\mu\alpha} \eta^{\nu\beta} + \frac{1}{2} W_{\mu z}^{La} W_{\nu z}^{La} \eta^{\mu\nu} \right) + \frac{1}{g_5^2} \left(-\frac{1}{4} W_{\mu\nu}^{Ra} W_{\alpha\beta}^{Ra} \eta^{\mu\alpha} \eta^{\nu\beta} + \frac{1}{2} W_{\mu z}^{Ra} W_{\nu z}^{Ra} \eta^{\mu\nu} \right) \right]$$

We introduce brane localized kinetic terms for $SU(2)_L$ and $U(1)_Y$ at $z = 0$ to achieve $M_W / M_{W'} \ll 1$

$$S_{z=0} = \int_0^{\pi R} dz \int d^4x \delta(z - \epsilon) \left[-\frac{1}{4g_0^2} W_{\mu\nu}^{L\,a} W_{\alpha\beta}^{L\,a} \eta^{\mu\alpha} \eta^{\nu\beta} - \frac{1}{4g_Y^2} W_{\mu\nu}^{R\,3} W_{\alpha\beta}^{R\,3} \eta^{\mu\alpha} \eta^{\nu\beta} \right]$$

$$(\epsilon \to 0+)$$

Four free parameters : $R,\ g_5,\ g_0,\ g_Y$

$SU(2)_L \times SU(2)_R$ Higgsless Model with a warped extra dimension

$$R\left(\equiv R' e^{-b/2}\right) \leq z \leq \pi R'$$

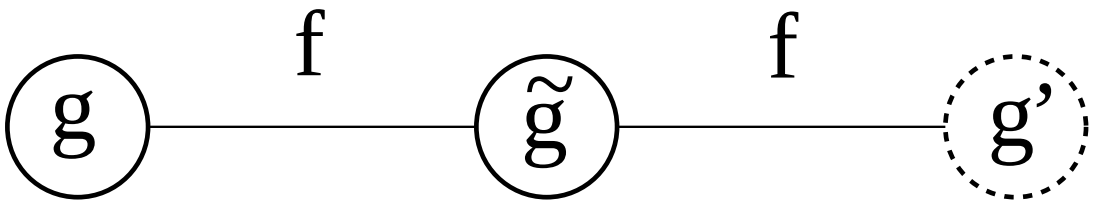
$$\begin{aligned} S_{5D} &= \int_R^{R'} dz \left(\frac{R}{z}\right) \int d^4x \left[\frac{1}{g_5^2} \left(-\frac{1}{4} W_{\mu\nu}^{La} W_{\alpha\beta}^{La} \eta^{\mu\alpha} \eta^{\nu\beta} + \frac{1}{2} W_{\mu z}^{La} W_{\nu z}^{La} \eta^{\mu\nu} \right) \right. \\ &\quad \left. + \frac{1}{g_5^2} \left(-\frac{1}{4} W_{\mu\nu}^{Ra} W_{\alpha\beta}^{Ra} \eta^{\mu\alpha} \eta^{\nu\beta} + \frac{1}{2} W_{\mu z}^{Ra} W_{\nu z}^{Ra} \eta^{\mu\nu} \right) \right] \end{aligned}$$

We introduce brane localized kinetic terms for $U(1)_Y$ at $z = R$ in order to arrange non-trivial weak mixing angle ($M_W / M_{W'} \ll 1$ is achieved by taking $b \gg 1$)

$$S_{z=0} = \int_R^{R'} dz \int d^4x \delta(z - R - \epsilon) \left[-\frac{1}{4 g_Y^2} W_{\mu\nu}^{R3} W_{\alpha\beta}^{R3} \eta^{\mu\alpha} \eta^{\nu\beta} \right]$$

$$(\epsilon \to 0+)$$

Four free parameters : R', b, g_5, g_Y



EW gauge sector of the three site model also has four free parameters

We choose four free parameters in each model to fix the values of four physical quantities (three EW quantities + $M_{W'}$)

We calculate other quantities and compare the results in each model to see how much reasonable the three site Higgsless model is as a low energy effective theory of each 5D Higgsless model

We focus on triple-gauge-boson couplings

Triple-gauge-boson couplings of SM gauge bosons

Hagiwara-Peccei-Zeppenfeld-Hikasa notation (Nucl. Phys. B 282, 253 (1987))

$$\begin{aligned}\mathcal{L}_{TGV} &= -ie\frac{c_Z}{s_Z}\left[1+\Delta\kappa_Z\right]W^+_\mu W^-_\nu Z^{\mu\nu} - ie\left[1+\Delta\kappa_\gamma\right]W^+_\mu W^-_\nu A^{\mu\nu} \\ &- ie\frac{c_Z}{s_Z}\left[1+\Delta g_1^Z\right](W^{+\mu\nu}W^-_\mu - W^{-\mu\nu}W^+_\mu)Z_\nu \\ &- ie(W^{+\mu\nu}W^-_\mu - W^{-\mu\nu}W^+_\mu)A_\nu \ ,\end{aligned}$$

$$\Delta\kappa_\gamma = 0, \quad \Delta\kappa_Z = \Delta g_1^Z$$

	Three Site	5D Flat	5D Warped
Δg_1^Z	$\frac{1}{2}\frac{1}{c^2}\left(\frac{M_W^2}{M_{W'}^2}\right)$	$\frac{\pi^2}{12}\frac{1}{c^2}\left(\frac{M_W^2}{M_{W'}^2}\right)$	$\frac{3x_1^2}{16}\frac{1}{c^2}\left(\frac{M_W^2}{M_{W'}^2}\right)$

$(x_1 \simeq 2.4048)$

$$\frac{\Delta g_1^Z|_{\rm three-site}}{\Delta g_1^Z|_{\rm flat-5D}} \simeq 0.61, \qquad \frac{\Delta g_1^Z|_{\rm three-site}}{\Delta g_1^Z|_{\rm warped-5D}} \simeq 0.46$$

Difference appears only in the next to leading order term

Triple-gauge-boson couplings which involve a heavy gauge boson

	Three Site	5D Flat	5D Warped
$g_{Z'WW}$	$-\frac{1}{2}\frac{e}{s}\left(\frac{M_W}{M_{W'}}\right)$	$-\frac{4\sqrt{2}}{\pi^2}\frac{e}{s}\left(\frac{M_W}{M_{W'}}\right)$	$-0.36\left(\frac{M_W}{M_{W'}}\right)$
$g_{ZW'W}$	$-\frac{1}{2}\frac{e}{sc}\left(\frac{M_W}{M_{W'}}\right)$	$-\frac{4\sqrt{2}}{\pi^2}\frac{e}{sc}\left(\frac{M_W}{M_{W'}}\right)$	$-0.36\frac{1}{c}\left(\frac{M_W}{M_{W'}}\right)$

- Values of $g_{Z'WW}$, $g_{ZW'W}$ are suppressed by a factor of $M_W/M_{W'}$
- Values of $g_{Z'WW}$, $g_{ZW'W}$ in flat and warped 5D Higgsless models are almost the same

$$\frac{g_{Z'WW}|_{\rm warped-5D}}{g_{Z'WW}|_{\rm flat-5D}} \simeq \frac{g_{ZW'W}|_{\rm warped-5D}}{g_{ZW'W}|_{\rm flat-5D}} \simeq 1$$

- Values of $g_{Z'WW}$, $g_{ZW'W}$ in the three site model are only about 13% smaller than those in 5D Higgsless models

$$\frac{g_{Z'WW}|_{\rm three-site}}{g_{Z'WW}|_{\rm warped-5D}} \simeq \frac{g_{ZW'W}|_{\rm three-site}}{g_{ZW'W}|_{\rm warped-5D}} \simeq 0.87$$

Discussion

Why $g_{Z'WW}$ and $g_{ZW'W}$ take similar values in different models?

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Why $g_{Z'WW}$ and $g_{ZW'W}$ take similar values in different models?

- Sum rules
- Lowest KK mode dominance

Sum rule for the cancellation of E^4 terms in $W_L^+W_L^- \to W_L^+W_L^-$

$$\sum_i g^2_{Z^{(i)}WW} = g_{WWWW} - g^2_{ZWW} - g^2_{\gamma WW}$$

Sum rule for the cancellation of E^2 terms in $W_L^+W_L^- \to W_L^+W_L^-$

$$3\sum_i g^2_{Z^{(i)}WW} M^2_{Z^{(i)}} = 4g_{WWWW} M^2_W - 3g^2_{ZWW} M^2_Z$$

Sum rule for the cancellation of E^4 terms in $W_L^+W_L^- \to W_L^+W_L^-$

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Sum rule for the cancellation of E^2 terms in $W_L^+W_L^- \to W_L^+W_L^-$

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	Three Site	5D Flat	5D Warped
$\frac{g^2_{Z'WW}}{g_{WWWW} - g^2_{ZWW} - g^2_{\gamma WW}}$	1	$\frac{960}{\pi^6} \simeq 0.996$	0.992
$\frac{3 g^2_{Z'WW} M^2_{Z'}}{4 g_{WWWW} M_W^2 - 3 g^2_{ZWW} M_Z^2}$	$\frac{3}{4}$	$\frac{96}{\pi^4} \simeq 0.986$	0.986

Summary

- We calculated $g_{Z'WW}$ and $g_{ZW'W}$ in the three site Higgsless model and 5D Higgsless models with a flat and a warped extra dimension
- At leading order in the expansion in terms of $(M_W/M_{W'})^2$, the flat and the warped 5D Higgsless models have almost the same values of couplings when we fix the value of $M_W/M_{W'}$
- The couplings in the three site Higgsless model are only about 13% smaller than those in the continuum 5D Higgsless models
- We conclude that the three site Higgsless model closely approximate 5D Higgsless models, and can be considered as a suitable effective theory for the studies of collider phenomenologies of 5D Higgsless models