Higgsless confronts electroweak and flavor precision tests

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Higgs particle is a hypothetical particle introduced to explain the origin of mass in the particle physics.

Experimentalists have not yet found the Higgs, however. Moreover, Higgs sector of the standard model is known to be problematic.

Is it possible to construct models without a Higgs, then?

The role of the Higgs boson in the SM:

- Renormalizability :

  W and Z are gauge bosons (universality of weak interaction).

  Explicit breaking of electroweak gauge symmetry makes the theory *non-renormalizable*. We need, at least, one Higgs boson so as to feed W and Z masses in a renormalizable manner.

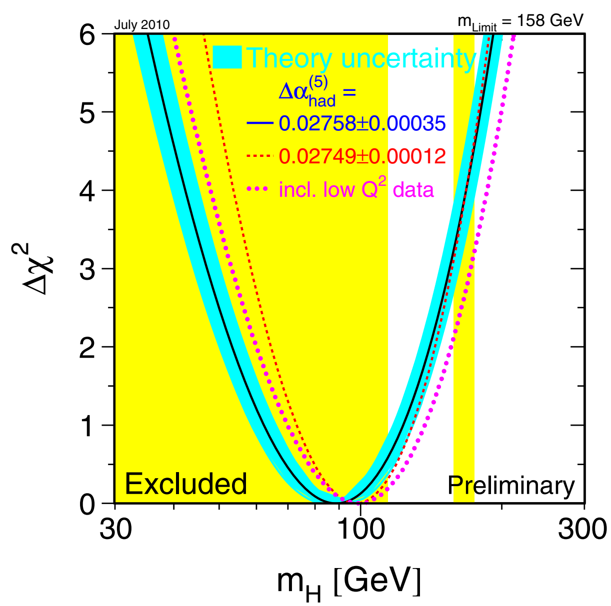
- Unitarity :

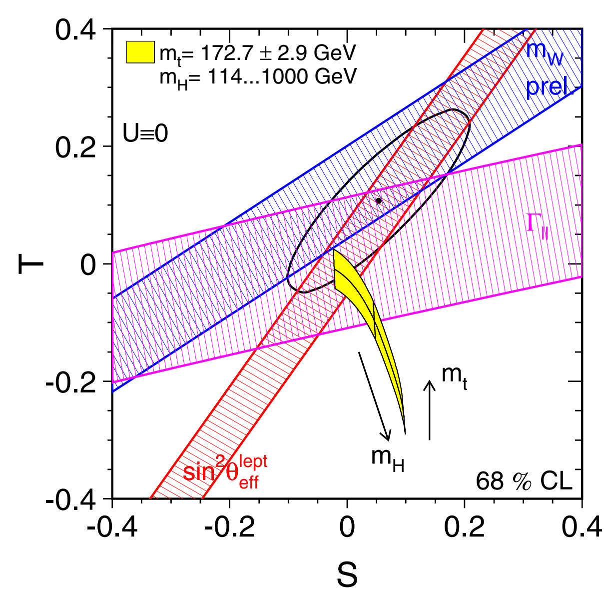
  The longitudinal W boson (W_L) scattering amplitude grows as the CM energy increases. If there is no Higgs boson, it eventually violates the unitarity.

Life without a Higgs

Renormalizability :

New physics (cutoff scale of SM) is believed to exist at TeV. In principle, renormalizability is not a primary issue in this sense. However, the lack of renormalizability usually implies a loss of robust predictability. How can we ensure the consistency with the existing precision electroweak measurements without introducing a Higgs boson then?





Unitarity

$W_L W_L$ scattering amplitude grows as the CM energy increases.

$$\mathcal{M} \propto \frac{s}{v^2}$$

The probability of the $W_L W_L$ scattering exceeds unity at the energy scale $s = 8\pi v^2$.

$$\Downarrow$$

unitarity violation

Unitarity bound : $\sqrt{8\pi}v \simeq 1.2$TeV

Two possibilities

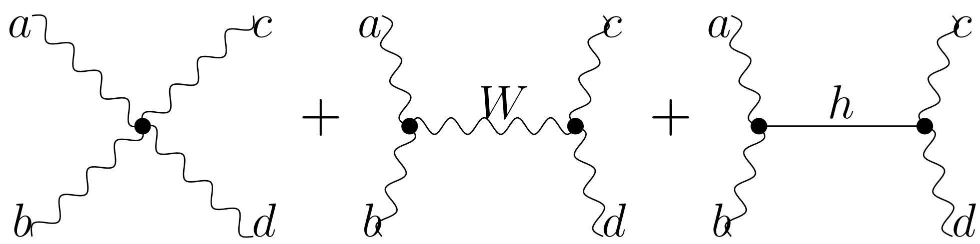
- non-perturbative casse

  The theory becomes non-perturbative above the unitarity bound. The unitarity should be recovered in a non-perturbative manner. (technicolor models, predictability may be lost.)

- perturbative case

  The $W_L W_L$ scattering behavior is modified thanks to the existence of particles lighter than the unitarity bound (predictable model.)

In the standard model, perturbative unitarity is guaranteed by the spin-0 Higgs exchange diagram.

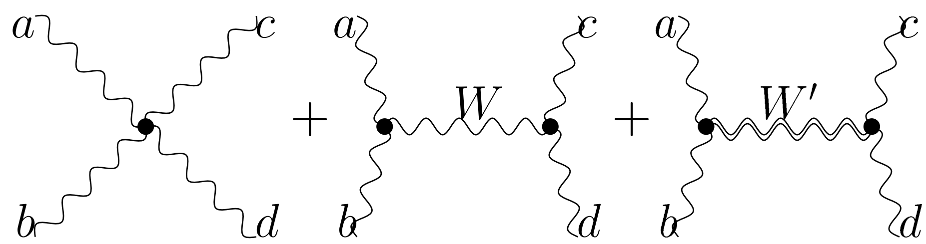
$i\mathcal{M}(ab \to cd) =$  + crossed.

we notice that the $s \sim E^2$ term cancels

$$\mathcal{M}(ab \to cd) = \mathcal{M}_{\rm gauge} + \mathcal{M}_{\rm Higgs} = \frac{s}{v^2} \frac{M_h^2}{M_h^2 - s} \delta^{ab}\delta^{cd} + \cdots .$$

- The amplitude agrees with the low energy theorem at $s \ll M_h^2 = \lambda v^2$.
- The amplitude approaches to a constant λ at the region $s \gg M_h^2 = \lambda v^2$. The theory is perturbative if the constant λ is sufficiently small.

Can a spin-1 resonance unitarize the $W_L W_L$ scattering amplitude?

$i\mathcal{M}(W_L^a W_L^b \to W_L^c W_L^d) =$  +crossed.

Answer: *Yes!* *if we suitably adjust WWW' coupling.*

$$\mathcal{M}(W_L^a W_L^b \to W_L^c W_L^d) = \frac{1}{3v^2}\left((s-u)\frac{M_{W'}^2}{M_{W'}^2 - t} + (s-t)\frac{M_{W'}^2}{M_{W'}^2 - u}\right)\delta^{ab}\delta^{cd} + \cdots$$

Cancellation of bad high-energy behavior is achieved through *exchange of massive spin-1 particle W'*.

Note, however,

we need to introduce yet another massive vector particle W'' so as to unitarize the $W'_L W'_L \to W'_L W'_L$ amplitude ....

$$\Downarrow$$

A tower of massive vector particles:

$$W, \quad W', \quad W'', \quad W''', \cdots$$

This situation is naturally realized in gauge theory with an *extra dimension*

A tower of massive Kaluza-Klein modes

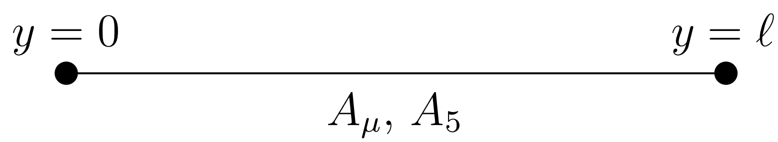
Chivukula, Dicus and He ; Csaki, Grojean, Murayama, Pilo and Terning

Gauge symmetry breaking through boundary conditions

Higgsless models in 5D

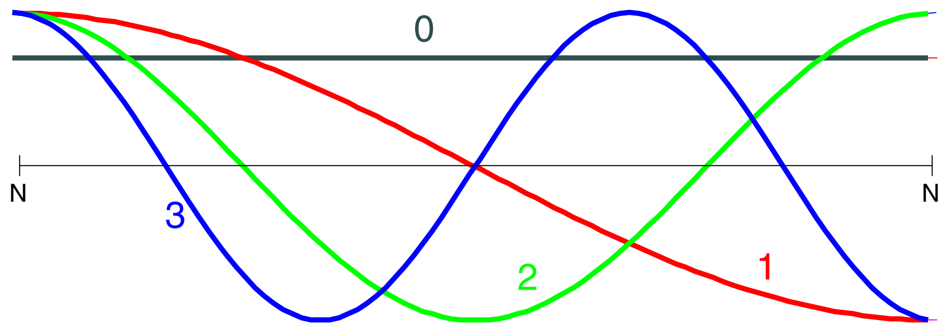
Gauge symmetry breaking through boundary conditions

5D gauge theory with an interval extra dimension



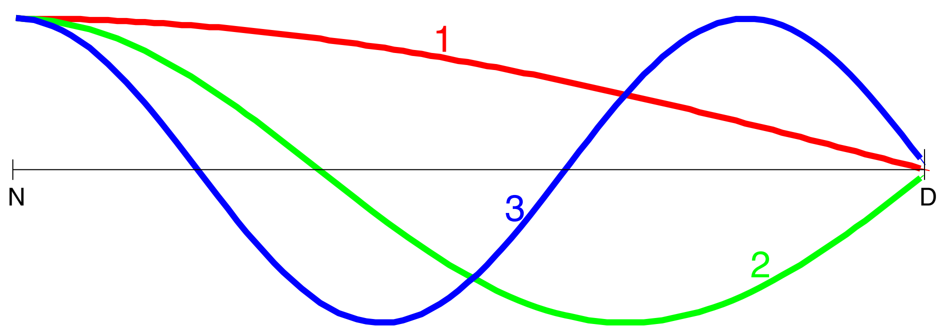
BC: Neumann(N)? Dirichlet(D)?

1. $\partial_y A_\mu(x,y)|_{y=0} = 0$ (N), $\quad \partial_y A_\mu(x,y)|_{y=\ell} = 0$ (N) [NN]



massless spin-1 field: unbroken 4D gauge symmetry

2. $\partial_y A_\mu(x,y)|_{y=0} = 0$ (N), $\quad A_\mu(x,y)|_{y=\ell} = 0$ (D) [ND]



absence of massless spin-1 field: 4D gauge sym is broken

4D gauge sym and spectrum

In addition to the massive spin-1 KK particles, we have

1. [NN]: massless spin-1 (unbroken 4D gauge sym)
   photon
2. [ND]: absence of massless particle (4D gauge syms are all broken)
3. [DN]: absence of massless particle (4D gauge syms are all broken)
   $W^{\pm}$, Z
4. [DD]: massless spin-0 (gauge and global syms are broken)

Applying this mechanism to EWSB, we can push up the unitarity vilation scale around 10TeV.

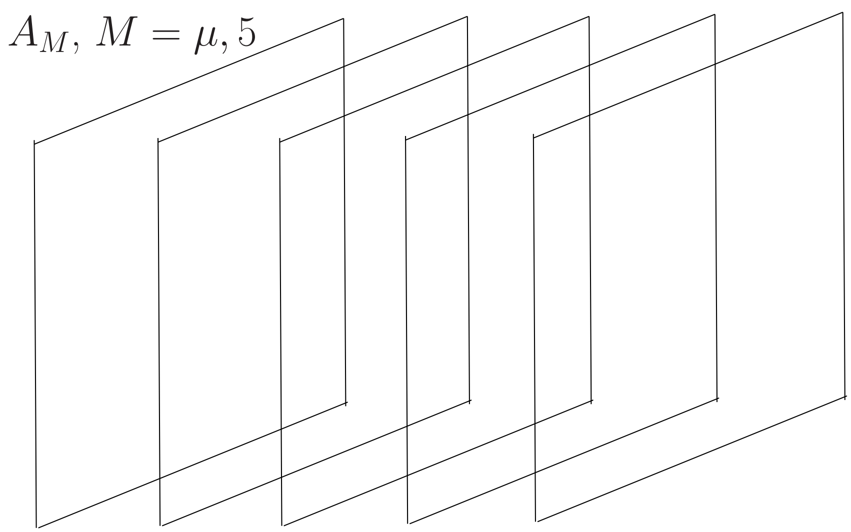
- R. Sekhar Chivukula, D. A. Dicus and H. J. He, "Unitarity of compactified five dimensional Yang-Mills theory," Phys. Lett. B **525**, 175 (2002) [arXiv:hep-ph/0111016].
- C. Csaki, C. Grojean, H. Murayama, L. Pilo and J. Terning, "Gauge theories on an interval: Unitarity without a Higgs," Phys. Rev. D **69**, 055006 (2004) [arXiv:hep-ph/0305237].

Effective theory viewpoint
— Deconstruction —

Deconstruction of boundary conditions

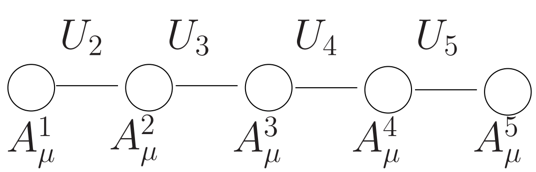
Deconstruction (latticization) of extra dimension

Arkani-Hamed, Cohen and Georgi ; Hill, Pokorski and Wang



a : lattice spacing

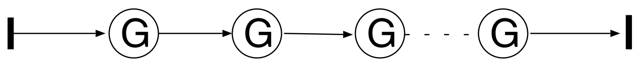
- $A^j_\mu = A_\mu(x, y = ja)$: gauge field at site j
- $U_j = \exp(i \int_{(j-1)a}^{ja} dy A_5(x,y))$: link field. non-linear σ model field.

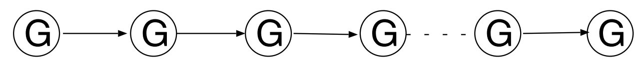


moose diagram

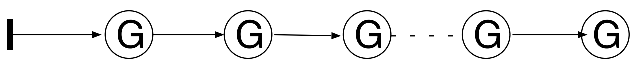
Note: Moose model can be viewed as a generalization of Bando-Kugo-Yamawaki's Hidden Local Symmetry (HLS) model (Phys.Rep.164,217(1988)) + Georgi's vector symmetry model (NPB331,311(1990)).

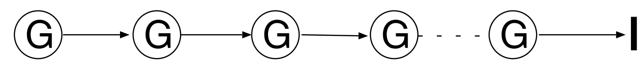
Deconstructions of an interval in “moose” notation:

[DD] 

[NN] 

$$\#(U_j) = \#(A^j_\mu) + 1. \qquad \#(U_j) = \#(A^j_\mu) - 1.$$

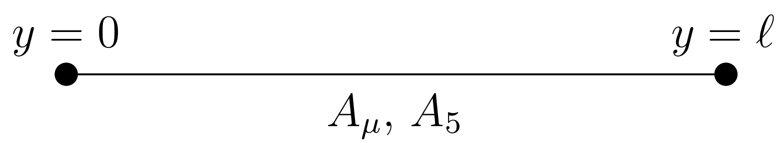
[DN] 

[ND] 

$$\#(U_j) = \#(A^j_\mu). \qquad \#(U_j) = \#(A^j_\mu).$$

which correspond to 5D gauge theories with an interval compactification:

H.-J. He, hep-ph/0412113



[DD] $A_\mu(x,y)|_{y=0} = 0$ (D), $\quad \partial_5 A_5(x,y)|_{y=0} = 0$ (N),
$A_\mu(x,y)|_{y=\ell} = 0$ (D), $\quad \partial_5 A_5(x,y)|_{y=\ell} = 0$ (N).

[NN] $\partial_5 A_\mu(x,y)|_{y=0} = 0$ (N), $\quad A_5(x,y)|_{y=0} = 0$ (D),
$\partial_5 A_\mu(x,y)|_{y=\ell} = 0$ (N), $\quad A_5(x,y)|_{y=\ell} = 0$ (D).

[DN] $A_\mu(x,y)|_{y=0} = 0$ (D), $\quad \partial_5 A_5(x,y)|_{y=0} = 0$ (N),
$\partial_5 A_\mu(x,y)|_{y=\ell} = 0$ (N), $\quad A_5(x,y)|_{y=\ell} = 0$ (D).

Advantages for deconstruction in 5D Higgsless models

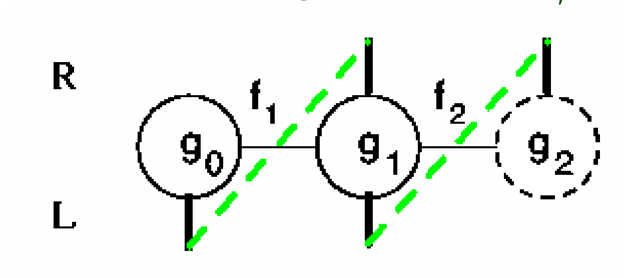
- Familiar language of spontaneous gauge symmetry breaking (gauged nonlinear σ model).
- Easier to understand the physics behind the delay of unitarity violation.
- Easier to calculate corrections to electroweak interactions.
- Allowing for arbitrary background 5D geometry, spatially dependent gauge couplings, and brane kinetic terms.
- Easier to perform loop analysis using well-known chiral perturbation method.

Very Low Energy Effective Theory

How can we contruct a model consistent with the existing precision electroweak and flavor measurements?

Three-site Higgsless model

Chivukula, Coleppa, Di Chiara, Simmons, He, Kurachi and M.T., PRD72 075012 (2006);
See also Bando, Kugo, Yamawaki's HLS model Phys.Rep.164,217(1988).



$SU(2) \times SU(2) \times U(1)$ gauge theory

- The gauge sector is precisely that of the BESS model. Casalbuoni et al., PLB 155 95 (1985))
- Fermion mass terms:

$$\mathcal{L}_f = -m_1 \bar{\psi}_{L0} U_1 \psi_{R1} - M \bar{\psi}_{R1} \psi_{L1} - \bar{\psi}_{L1} U_2 \begin{pmatrix} m_{2u} & \\ & m_{2d} \end{pmatrix} \begin{pmatrix} u_{R2} \\ d_{R2} \end{pmatrix} + \text{h.c.}.$$

- For simplicity, we examine the case $f_1 = f_2 = \sqrt{2} v$ and work in the limit

$$\frac{g_0}{g_1} \ll 1, \quad \frac{g_2}{g_1} \ll 1, \qquad \text{and thus,} \quad g_W \simeq g_0, \quad g_Y \simeq g_2.$$

Fermion mass matrix: (seesaw like)

$$\begin{pmatrix} m_1 & 0 \\ M & m_{2f} \end{pmatrix} \equiv M \begin{pmatrix} \varepsilon_L & 0 \\ 1 & \varepsilon_{fR} \end{pmatrix}, \qquad \varepsilon_L \equiv \frac{m_1}{M}, \quad \varepsilon_{fR} \equiv \frac{m_{2f}}{M}$$

Light fermion mass:

$$m_f \simeq \frac{m_1 m_{2f}}{\sqrt{M^2 + m_{2f}^2}} = \frac{\varepsilon_L}{\sqrt{1 + \varepsilon_{fR}^2}} m_{2f}$$

and its eigenstate

$$\psi_L^{f,\mathrm{light}} \simeq -\left(1 - \frac{\varepsilon_L^2}{2}\right) \psi_{L0}^f + \varepsilon_L \psi_{L1}^f$$

where we assumed $\varepsilon_{fR} \ll 1$.

Heavy (KK) fermion mass:

$$M_{f,KK} \simeq \sqrt{M^2 + m_{2f}^2} \simeq M$$

For $M \gg v$, we can integrate out the heavy KK-fermion. The fermion delocalization effect can then be replaced by an operator

$$\mathcal{L}'_f = -x_1 \bar{\psi}_L (i \not{D} U_1 \cdot U_1^\dagger) \psi_L, \qquad x_1 \equiv \varepsilon_L^2, \quad \varepsilon_L = \frac{m_1}{M}$$

ψ_L is a left-hand fermion at site-0,

$$D_\mu \psi_L = \partial_\mu \psi_L - i g_0 W_{0\mu} \psi_L.$$

S-parameter at tree level

$$S = \frac{4\pi}{g_1^2} \left(1 - \frac{2 g_1^2}{g_0^2} x_1 \right)$$

vanishes in the ideal delocalization limit:

$$x_1 = \frac{g_0^2}{2 g_1^2}, \qquad g_{W' f f} = 0.$$

c.f. Anichini, Casalbuoni, and De Curtis, PLB348 521 (1995).

Higgsless confronts electroweak precision tests at one-loop

Matsuzaki, Chivukula, Simmons, and M.T., PRD75, 073002 (2007)
Chivukula, Simmons, Matsuzaki, and M.T., PRD75, 075012 (2007)
Abe, Matsuzaki, and M.T., PRD78, 055020 (2008)
See also, Abe, Chivukula, Christensen, Hsieh, Matsuzaki, Simmons, and M.T., PRD79, 075016 (2009)

- $S = 0$ can be achieved by assuming the ideal delocalization limit $g_{W'ff} = 0$ in the tree level.

- We have no symmetry reason which guarantees the smallness of S and T parameters at the loop level.

- There do exist loop induced higher derivative operators contributing to S and T parameters in the electroweak chiral perturbation theory (Appelquist and Bernard, Prof. Wang's talk).

$$\alpha_{(1)1}\mathrm{tr}\left[W_{(0)\mu\nu}U_1 W_{(1)}^{\mu\nu}U_1^\dagger\right] + \alpha_{(2)1}\mathrm{tr}\left[W_{(1)\mu\nu}U_2\frac{\tau^3}{2}B^{\mu\nu}U_2^\dagger\right]$$

$$\beta_{(2)}\frac{f_2^2}{4}\mathrm{tr}\left[U_2^\dagger D_\mu U_2\tau^3\right]\mathrm{tr}\left[U_2^\dagger D^\mu U_2\tau^3\right]$$

- Even if we assume coefficients of these higher derivative operators vanish at the cutoff scale Λ ($\Lambda \gg M_W'$), these coefficients can be generated through the electroweak chiral perturbation renormalization group:

$$\mu \frac{d}{d\mu} \alpha_{(i)1} = \frac{1}{6(4\pi)^2}, \quad \mu \frac{d}{d\mu} (\beta_{(2)} f_2^2) = \frac{3}{4(4\pi)^2} g_Y^2 f_2^2.$$

We evaluate the size of these low energy induced coefficents as

$$\alpha_{(i)1}(\mu) \simeq -\frac{1}{6(4\pi)^2} \ln \frac{\Lambda}{\mu}, \quad \beta_{(2)}(\mu) \simeq -\frac{3}{4(4\pi)^2} g_Y^2 \ln \frac{\Lambda}{\mu}$$

- Matching with the usual electroweak chiral perturbation theory (aka 2-site model), which includes

$$\alpha_1 \mathrm{tr}\left[W_{\mu\nu} U B^{\mu\nu} U^\dagger\right]$$

$$\beta \frac{f_2^2}{4} \mathrm{tr}\left[U^\dagger D_\mu U \tau^3\right] \mathrm{tr}\left[U^\dagger D^\mu U \tau^3\right]$$

At $\mu = M_{W'}$,

$$\alpha_1 = -\frac{v^2}{4M_{W'}^2}\left(1 - \frac{x_1}{2}\frac{M_{W'}^2}{M_W^2}\right) + \frac{1}{2}\alpha_{(1)1} + \frac{1}{2}\alpha_{(2)1}$$

$$\beta = \frac{1}{2}\beta_{(2)}$$

- We evaluate α_1 and β at $\mu = M_Z$ by solving RGE from $\mu = M_{W'}$ down to $\mu = M_Z$

$$\alpha_1|_{\mu=M_Z} = \alpha_1|_{\mu=M_{W'}} - \frac{1}{6(4\pi)^2}\ln\frac{M_{W'}}{M_Z}$$

$$\beta|_{\mu=M_Z} = \beta|_{\mu=M_{W'}} - \frac{3}{4(4\pi)^2}g_Y^2\ln\frac{M_{W'}}{M_Z}$$

- These operators contribute S and T parameters at $\mu = M_Z$ scale

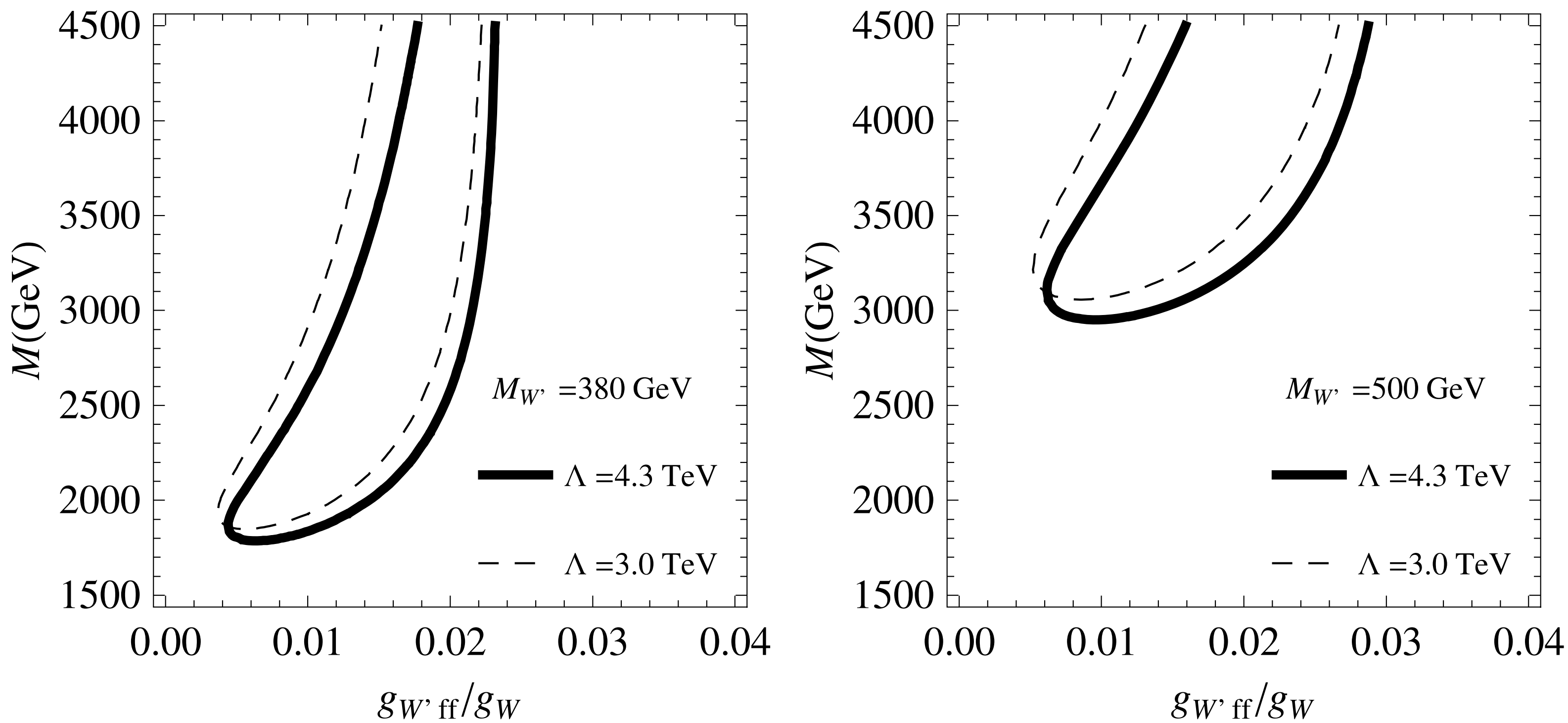
$$S \simeq \frac{4\pi v^2}{M_{W'}^2}\left(1 - \frac{x_1}{2}\frac{M_{W'}^2}{M_W^2}\right) + \frac{1}{6\pi}\ln\frac{\Lambda}{M_Z}$$

$$\alpha T \simeq -\frac{3g_Y^2}{4(4\pi)^2}\ln\frac{\Lambda}{M_{W'}} - \frac{3g_Y^2}{2(4\pi)^2}\ln\frac{M_{W'}}{M_Z} + \frac{1}{16\pi^2}\frac{{m_t}^4}{M^2 v^2 x_1^2},$$

  where we have also added top and KK-top contribution to T parameter.

- Re-tuning of the delocalization parameter x_1 is required to make the theory consistent with the precision electroweak measurements. Corrections to the ideal delocalization: $g_{W'ff} \neq 0$.

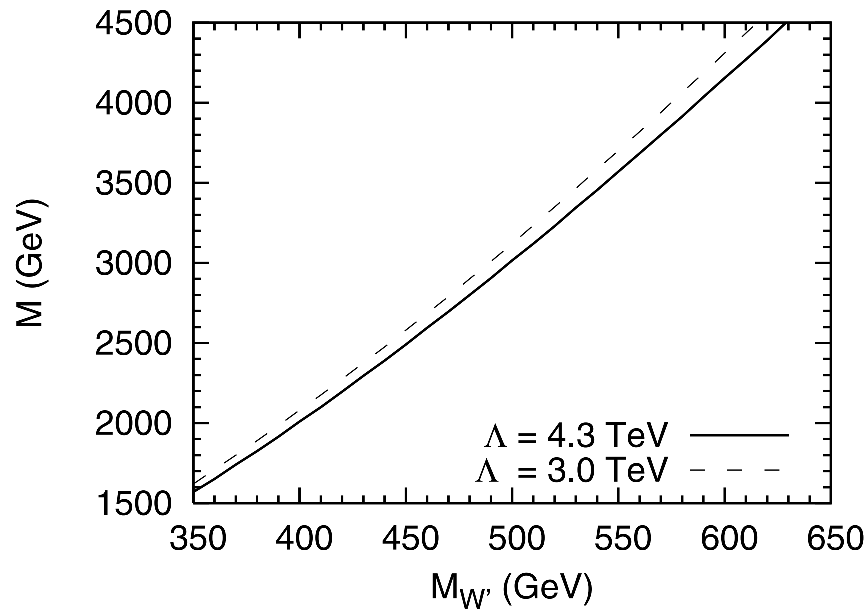
One loop constraint from precision electroweak measurements (95%CL):



T. Abe, S. Matsuzaki, and M.T., PRD78, 055020 (2008)

The cutoff dependence is small.

Tiny non-zero $W'ff$ coupling (correction to the ideal delocalization).



- The limit $M_{W'} \gtrsim 380$GeV is from the ZWW measurement at LEP2.

- The cutoff Λ should satisfy

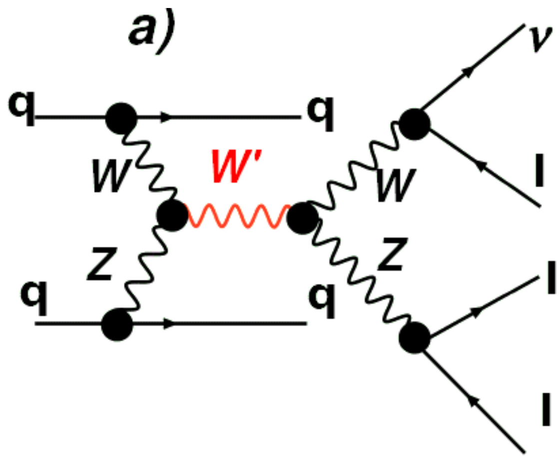
$$M < \Lambda \lesssim 4\pi f_1 = 4\pi f_2 = 4.3\text{TeV},$$

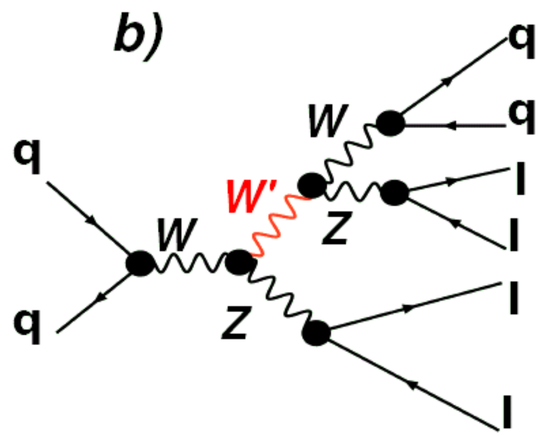
which implies

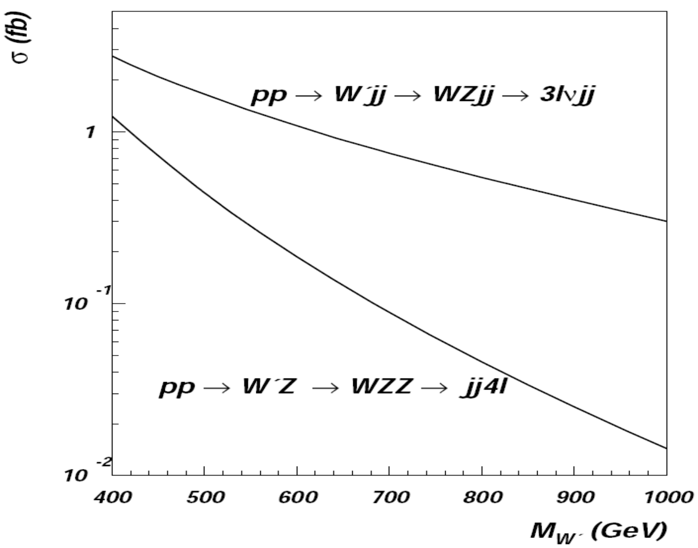
$$M_{W'} \lesssim 600\text{GeV}$$

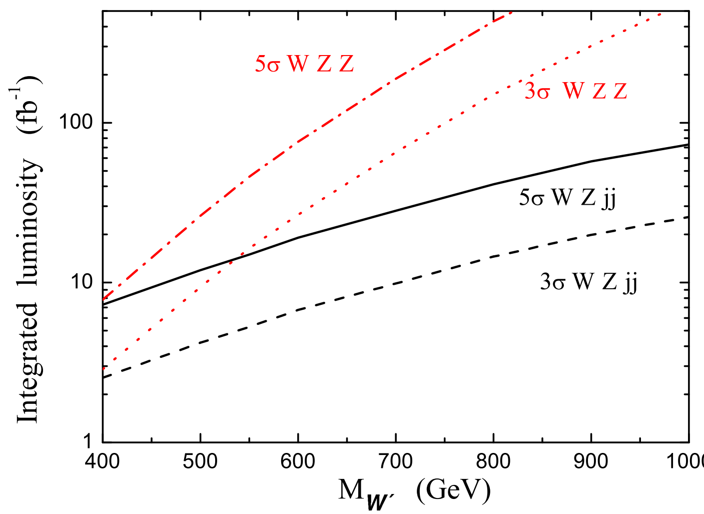
W' production cross sections through $W'WZ$ vertex:

H.-J. He et al., arXiv:0708.2588



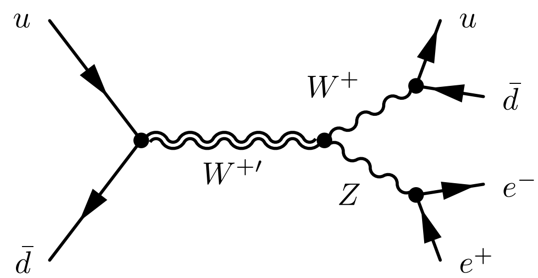


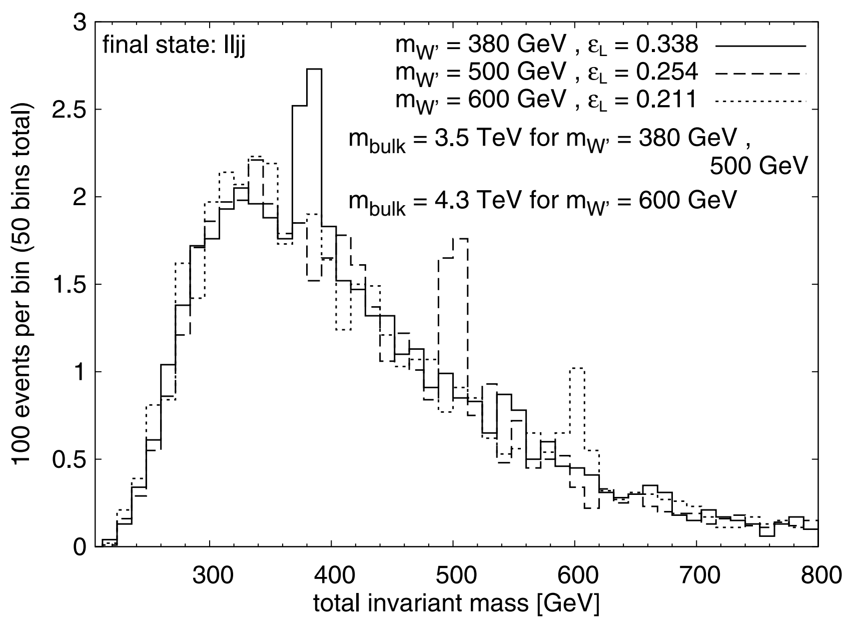




W' production cross sections at LHC through $W'ff$ vertex:

T. Ohl and C. Speckner, arXiv:0809.0023





100fb^{-1}

Higgsless confronts flavor precision tests at one loop

Abe, Chivukula, Simmons, and M.T., in preparation.
See also, Kurachi and Onogi, arXiv:1006.3414

- Flavor physics observables such as ϵ_K and $B(b \to s\gamma)$ are known to provide severe constraints on models with a warped extra dimension. See, e.g., Agashe, Azatov and Zhu, arXiv:0810.1016.

- Actually, in RS model with fully "anarchic" Yukawa couplings, an extremely severe KK gluon mass limit

$$M_{\rm KK} \gtrsim 33\text{TeV}$$

  is obtained from the K-$\bar{K}$ mixing constraints.
  (Cśaki-Falkowski-Weiler, arXiv:0804.1954)

- If this severe bound on $M_{\rm KK}$ equally applies to Higgsless models, it is almost impossible to solve the unitarity problem in the RS framework using the KK boson exchange.

- Here, we try to address flavor issues in the three site model by studying its flavor structures.

Flavor structure in the three site model

- Consider quark "Yukawa" sector of the three site model,

$$-\bar{q}_L^0 U_1 \mathbf{m}_1 q_R^1 - \bar{q}_L^1 \mathbf{M} q_R^1 - \bar{q}_L^1 U_2 \mathbf{m}_{2u} \begin{pmatrix} u_R^2 \\ 0 \end{pmatrix} - \bar{q}_L^1 U_2 \mathbf{m}_{2d} \begin{pmatrix} 0 \\ d_R^2 \end{pmatrix},$$

  where summation over flavor indices is implicit.

- We consider $SU(3)$ flavor rotations

$$q_L^0 \to L q_L^0, \quad q_L^1 \to L_D q_L^1, \quad q_R^1 \to R_D q_R^1,$$

$$u_R^2 \to R_u u_R^2, \quad d_R^2 \to R_d d_R^2$$

- If the mass-parameters were simultaneously changed as

$$\mathbf{m}_1 \to L \mathbf{m}_1 R_D^\dagger, \quad \mathbf{M} \to L_D \mathbf{M} R_D^\dagger, \quad \cdots$$

  the theory would be symmetric under these flavor rotations.

- Without any futher assumptions on these masses, one could go to a basis where $\mathbf{m}_1$ and $\mathbf{m}_{2d}$ are diagonal — but one would not have freedom to diagonalize the other $\mathbf{m}_{2u}$ and $\mathbf{M}$. Flavor is violated not only by $\mathbf{m}_{2u}$ but also by $\mathbf{M}$. (Non-minimal flavor violation). We expect the theory would be constrained severely from its precision flavor tests.

- In the three site model, we often assume both $\mathbf{m}_1$ and $\mathbf{M}$ are proportional to the identity matrix. (Minimal Flavor Violation, MFV). With MFV assumption, we can go to a basis where $\mathbf{m}_1$, $\mathbf{M}$ and $\mathbf{m}_{2d}$ are diagonal. The flavor vilation is governed solely by $\mathbf{m}_{2u}$ in this case.

- However, even in this case, flavor-violating contributions to $\mathbf{M}$ are induced at one-loop.

- We consider

$$\mathbf{M} = \begin{pmatrix} M & & \\ & M & \\ & & M \end{pmatrix} + \mathbf{\Delta M}, \qquad \delta \equiv \frac{\mathbf{\Delta M}}{M}$$

in the basis where $\mathbf{m}_1$ and $\mathbf{M}$ are diagonal. In this talk, we focus on the constraints of δ_{sd} derived from the K-$\bar{K}$ mixing. For more extensive study using varieties of quark and lepton flavor measurements, see Abe-Chivukula-Simmons-M.T.

We consider K-$\bar{K}$ mixing operator

$$C_1^K(\bar{s}_L\gamma^\mu d_L)(\bar{s}_L\gamma_\mu d_L)$$

In the three site model, the coefficient C_1^K is calculated as

$$C_1^K = \frac{1}{v^2}\frac{m_1^4}{M^4}(\delta_{sd})^2$$

We assume the ideal delocalization

$$\frac{m_1^2}{M^2} = 2\frac{M_W^2}{M_{W'}^2},$$

which leads to

$$C_1^K \simeq 1.1\cdot 10^{-7}(\delta_{sd})^2\left(\frac{400\ \text{GeV}}{M_{W'}}\right)^4\ \text{GeV}^{-2}.$$

95%CL allowed range obtained by UTfit group

$$-9.6 \cdot 10^{-13}\mathsf{GeV} < \mathsf{Re}(C_1^K) < 9.6 \cdot 10^{-13}\mathsf{GeV},$$

and

$$-4.4 \cdot 10^{-15}\mathsf{GeV} < \mathsf{Im}(C_1^K) < 2.8 \cdot 10^{-15}\mathsf{GeV}.$$

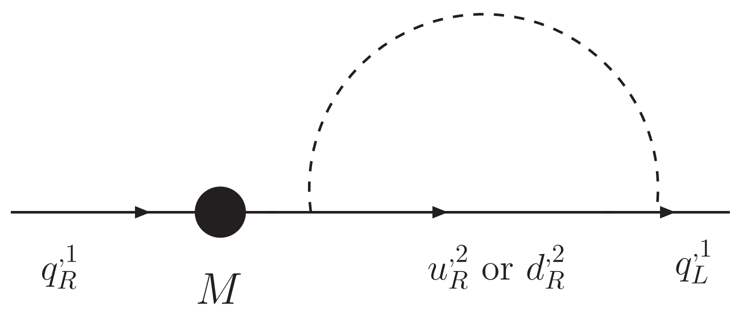
The bounds on δ_{sd} are therefore

$$-9.0 \cdot 10^{-6} < \mathsf{Re}(\delta_{sd})^2 \left(\frac{400\ \mathsf{GeV}}{M_{W'}}\right)^4 < 9.0 \cdot 10^{-6},$$

and

$$-4.1 \cdot 10^{-8} < \mathsf{Im}(\delta_{sd})^2 \left(\frac{400\ \mathsf{GeV}}{M_{W'}}\right)^4 < 2.6 \cdot 10^{-8}.$$

We next compare these limits with one-loop expected values



$$\delta_{sd}^{\rm one-loop} \sim \frac{1}{(4\pi)^2}\frac{m_t^2}{2v^2}\frac{M^2}{m_1^2}V_{ts}^* V_{td}$$

Assuming the ideal delocalization, we obtain

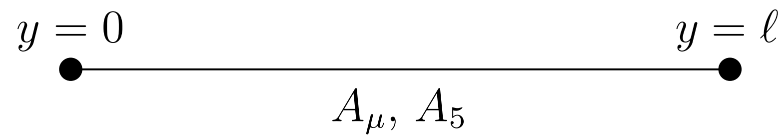
$$(\delta_{sd}^{\rm one-loop})^2 \sim (0.38 - 0.38i)\cdot 10^{-10}\left(\frac{M_{W'}}{400\text{GeV}}\right)^4$$

which is consistent with the phenomenological bounds we obtained.

Summary

- Higgsless theory is an interesting alternative to the standard model Higgs, achieving tree level unitarity at 1TeV.
- We analyzed an effective theory (three site Higgsless model) at one-loop level and found the model is consistent with the available precicion electroweak measurements. The allowed ranges of the KK gauge boson coupling $g_{W'ff}$, the KK gauge boson mass $M_{W'}$, and the KK quark/lepton masses M are severely constrained, however.
- Assuming MFV at tree level, FCNC constraints can be satisfied easily even if we include one-loop effects. (with T. Abe, R.S.Chivukula, and E.H. Simmons)
- The KK gauge boson W' will be discovered at LHC in near future.

Brane localized Higgs field (aka RS model)



BC: Neumann BC at both brane

$\partial_y A_\mu(x,y)|_{y=0} = 0$ (N), $\quad \partial_y A_\mu(x,y)|_{y=\ell} = 0$ (N) $\qquad$ [NN]

Brane localized Higgs ϕ:

$$S_{\text{Higgs}} = \int dy \delta(y - \ell + \epsilon) \left[(D_\mu \phi)^\dagger (D^\mu \phi) - V(\phi^\dagger \phi) \right]$$

$\Downarrow$ (VEV v_b)

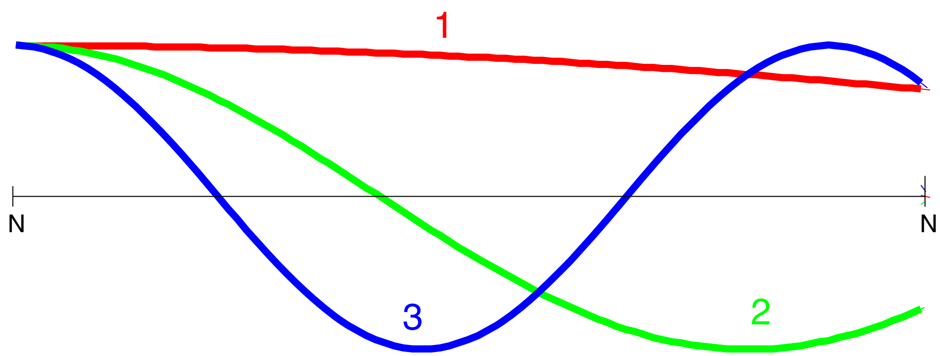
$$\int dy \delta(y - \ell + \epsilon) v_b^2 A_\mu A^\mu$$

KK mode equation for the gauge field

$$\left[-\partial_y^2 + \delta(y - \ell + \epsilon) g^2 v_b^2 \right] \chi^{(n)}(y) = M_n^2 \chi^{(n)}(y)$$

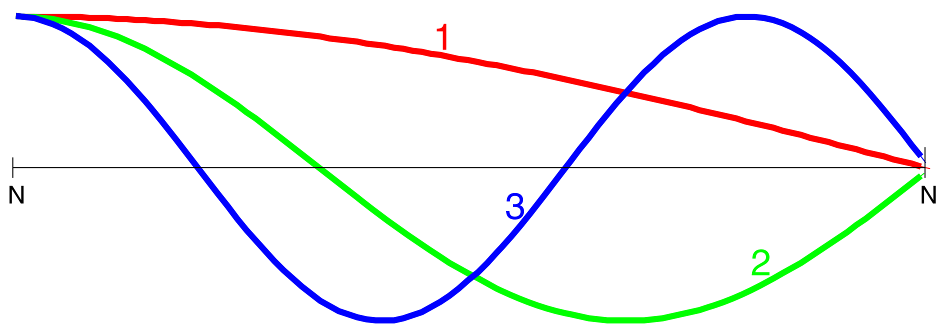
$\Leftrightarrow$ 1-dim Schroedinger eq. with δ-function repulsive force

1. finite v_b case



δ-function repulsive force at $y = \ell$ brane affects the wave-function form.

2. $v_b \to \infty$ case



δ-function repulsive force at $y = \ell$ brane affects the effective boundary condition at the brane.

Remarks

- Brane localized Higgs with an infinite VEV.

$$\Updownarrow \text{ (equivalent)}$$

Dirichlet BC (Higgsless)

- The KK gauge boson spectrum remains finite around the compactification scale even in the infinite Higgs VEV limit.
- Higgsless models can be regarded as a variant of usual RS model.