Playing with fermion couplings in Higgsless models

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- **Introduction**
- **A $SU(2)_L \times SU(2)^K \times U(1)$ linear moose**
- **Electroweak precision tests**
- **Unitarity bounds**
- **Delocalizing fermion interactions**
- **Conclusions**

Based on:

Casalbuoni, De Curtis, D., PRD hep-ph/0405188

Casalbuoni, De Curtis, Dolce, D., PRD hep-ph/05022209

(Modern) Higgsless Models

- **Symmetry breaking mechanism of a gauge theory in $4+1$ dims by boundary conditions on the branes.** (Csáki, Grojean, Murayama, Pilo, Terning; Nomura).
- **The scale where partial wave unitarity is lost is delayed with respect to the SM without the Higgs, due the exchange of KK excitations of gauge bosons.** (Chivukula, Dicus, He).
- **Problem: $\epsilon_3(S)$ electroweak parameter too big, if unitarity is fine** (Barbieri, Pomarol, Rattazzi).
- **Solutions:**
  brane kinetic terms (Cacciapaglia, Csaki, Grojean, Terning; Carena, Tait, Wagner; Carena, Ponton Tait, Wagner; Davoudiasl, Hewett, Lillie, Rizzo).
  fermion delocalization (Cacciapaglia, Csaki, Grojean, Terning; Foadi, Gopalakrishna, Schmidt; Bhattacharya, Csaki, Martin, Shirman, Terning).

Alternative approach: dimensional deconstruction and moose models

(Arkani-Hamed, Cohen, Georgi)

Theory with gauge symmetry $[G]^{K+1}$ in $3+1$ dims:

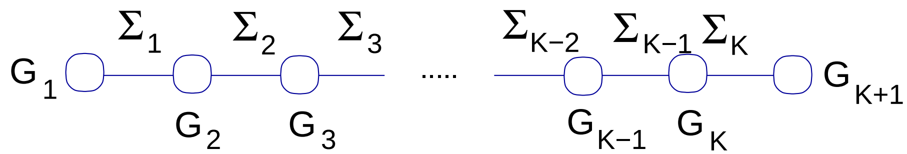
$$A^j = A^{ja}T^a, \quad g_c; \quad j = 1, \cdots, K+1.$$

Non linear σ-model fields:

$$\Sigma_i = e^{i/(2f_c)\pi^a T^a}, \quad \Sigma_i \rightarrow U_i \Sigma_i U_{i+1}^\dagger, \quad U_i \in G_i, \quad i = 1, 2, \cdots, K.$$

Covariant derivatives: $D_\mu \Sigma_i = \partial_\mu \Sigma_i - i g_c A_\mu^i \Sigma_i + i g_c \Sigma_i A_\mu^{i+1}$.

$$\mathcal{L}_{moose} = \sum_{i=1}^{K} f_c^2 \mathrm{Tr}[D_\mu \Sigma_i^\dagger D^\mu \Sigma_i] - \frac{1}{2} \sum_{i=1}^{K+1} \mathrm{Tr}[(F_{\mu\nu}^i)^2].$$



Mass spectrum

Mass matrix $\{A_\mu^1, A_\mu^2, \dots, A_\mu^{K+1}\}$:

$$M^2 = g_c^2 f_c^2 \begin{pmatrix} 1 & -1 & 0 & \dots & 0 & 0 \\ -1 & 2 & -1 & \dots & 0 & 0 \\ 0 & -1 & 2 & \ddots & 0 & 0 \\ \vdots & \vdots & \ddots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \dots & 2 & -1 \\ 0 & 0 & 0 & \dots & -1 & 1 \end{pmatrix}.$$

Mass eigenvalues:

$$M_k^2 = 4 g_c^2 f_c^2 \sin^2\left(\frac{\pi k}{2(K+1)}\right) \longrightarrow \left(\frac{k}{R}\right)^2 : \quad |k| \ll K.$$

For $|k| \ll K$ they reproduce the masses of KK excitations for a five dimensional theory with gauge symmetry G, compactification radius R, gauge coupling g_5, lattice spacing a,

$$\pi R = (K+1)a, \qquad \frac{a}{g_5^2} = \frac{1}{g_c^2} : \qquad a = \frac{1}{g_c f_c}.$$

Extra dimension on a lattice

(Hill, Pokorski, Wang; Randall, Shadmi, Weiner; Abe, Kobayashi, Maru, Yoshioka)

Theory with gauge symmetry G in $4+1$ dims and flat metric:

$$S = -\frac{1}{2}\int d^4x \int_0^{\pi R} dy \frac{1}{g_5^2}\left[\mathrm{Tr}[F_{MN}F^{MN}]\right], \quad M,N = 0,1\ldots,4$$

$$= -\frac{1}{2}\int d^4x \int_0^{\pi R} dy \frac{1}{g_5^2}\left[\mathrm{Tr}[F_{\mu\nu}F^{\mu\nu}] + 2\mathrm{Tr}[F_{\mu 5}F^{\mu 5}]\right]$$

$\downarrow$ **discretization of extra dim on a lattice**

$$S_{moose} \sim -\frac{1}{2}\int d^4x \frac{a}{g_5^2}\sum_j \left[\mathrm{Tr}[F^j_{\mu\nu}F^{\mu\nu j}] + \frac{2}{a^2}\mathrm{Tr}[(D_\mu\Sigma^j)^\dagger(D^\mu\Sigma^j)]\right],$$

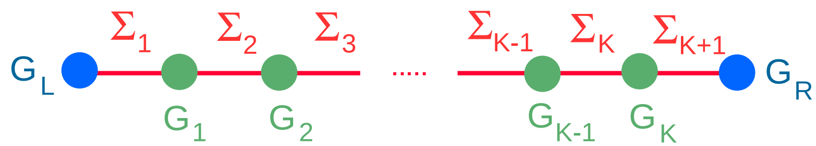
where

$$\Sigma^j \sim e^{i\int_{y_j}^{y_j+a} dt A_5(x,t)} \Rightarrow D_\mu\Sigma^j \sim aF^j_{\mu 5} = ia\partial_\mu A^j_5 - i(A^{j+1}_\mu - A^j_\mu).$$

Gauge theories with replicas of G $\Leftrightarrow$ compactified dimensions.

A $SU(2)_L \times SU(2)^K \times U(1)$ linear moose

(Casalbuoni, De Curtis, D., see also Foadi, Gopalakrishna, Schmidt; Hirn, Stern; Chivukula et al; Georgi)



The transformation properties of the fields are

$$\Sigma_1 \to L\Sigma_1 U_1^\dagger,$$
$$\Sigma_i \to U_{i-1}\Sigma_i U_i^\dagger \;, \qquad i = 2, \cdots, K,$$
$$\Sigma_{K+1} \to U_K \Sigma_{K+1} R^\dagger,$$

$$U_i \in G_i \equiv SU(2)_i, \quad i = 1, 2, \cdots, K \qquad A_\mu^i = A_\mu^{ia}\tau^a/2, \quad g_i,$$
$$L \in G_L \equiv SU(2)_L \qquad \tilde{W}_\mu = \tilde{W}_\mu^a \tau^a/2, \quad \tilde{g},$$
$$R \in G_R \equiv SU(2)_R \supset U(1)_Y \qquad \tilde{Y}_\mu = \tilde{\mathcal{Y}}_\mu \tau^3/2, \quad \tilde{g}'.$$

$$\mathcal{L} = \sum_{i=1}^{K+1} f_i^2 \mathrm{Tr}[D_\mu \Sigma_i^\dagger D^\mu \Sigma_i] - \frac{1}{2}\sum_{i=1}^{K} \mathrm{Tr}[(F^i_{\mu\nu})^2] - \frac{1}{2}\mathrm{Tr}[(F_{\mu\nu}(\tilde{W}))^2] - \frac{1}{2}\mathrm{Tr}[(F_{\mu\nu}(\tilde{Y}))^2].$$

Covariant derivatives

$$D_\mu\Sigma_1 = \partial_\mu\Sigma_1 - i\tilde{g}\tilde{W}_\mu\Sigma_1 + i\Sigma_1 g_1 A^1_\mu,$$
$$D_\mu\Sigma_i = \partial_\mu\Sigma_i - ig_{i-1}A^{i-1}_\mu\Sigma_i + i\Sigma_i g_i A^i_\mu, \qquad i = 2,\cdots,K,$$
$$D_\mu\Sigma_{K+1} = \partial_\mu\Sigma_{K+1} - ig_K A^K_\mu\Sigma_{K+1} + i\tilde{g}'\Sigma_{K+1}\tilde{Y}_\mu.$$

Global symmetry: $SU(2)_L \times SU(2)^K \times SU(2)_R$.
We assume standard fermionic couplings w.r.t. $SU(2)_L \otimes U(1)_Y$.
Therefore fermions are located at the end of the moose (ψ_L (ψ_R) to the left (right) end).
$f_i = f_c\ \forall i \Rightarrow$ **flat metric in five dims; varying** $f_i \Rightarrow$ **warped metric.**
At the leading order in $O((\tilde{g}/g_i)^2)$

$$\tilde{M}_W^2 = \frac{v^2}{4}\tilde{g}^2, \quad \tilde{M}_Z^2 = \tilde{M}_W^2/\tilde{c}_\theta^2, \quad \tan\tilde{\theta} = \frac{\tilde{g}}{\tilde{g}'};$$
$$\frac{4}{v^2} \equiv \frac{1}{f^2} = \sum_{i=1}^{K+1}\frac{1}{f_i{}^2}$$

Electroweak precision tests

The mass matrix of the A_i gauge fields:

$$\mathcal{L}_{\rm mass} = \frac{1}{2}\sum_{i,j=1}^{K}(M_2)_{ij}A^i_\mu A^{\mu j},$$

with

$$(M_2)_{ij} = g_i^2(f_i^2 + f_{i+1}^2)\delta_{i,j} - g_i g_{i+1} f_{i+1}^2\delta_{i,j-1} - g_j g_{j+1} f_{j+1}^2\delta_{i,j+1}.$$

Calling $\tilde{A}^n_\mu$, $n = 1, \cdots, K$ the mass eigenstates, and m_n^2 the squared mass eigenvalues,

$$A^i_\mu = \sum_{n=1}^{K} S^i_n \tilde{A}^n_\mu,$$

$$S^i_m (M_2)_{ij} S^j_n = m_n^2 \delta_{m,n}.$$

Custodial symmetry: $\epsilon_1 = \epsilon_2 = 0$. Dispersive representation:

$$\epsilon_3\left(= \frac{\tilde{g}^2 S}{16\pi}\right) = -\frac{\tilde{g}^2}{4\pi}\int_0^\infty \frac{ds}{s^2} Im[\Pi_{VV}(s) - \Pi_{AA}(s)]$$

Current current correlator:

$$\int d^4x e^{-iq\cdot x}\left\langle J^\mu_{V(A)} J^\nu_{V(A)}\right\rangle \sim i g^{\mu\nu}\Pi_{VV(AA)}(q^2)+\cdots$$

The vector meson decay constants

$$\begin{aligned}\langle 0|J^a_{V\mu}|\tilde{A}^n_b(p,\epsilon)\rangle &= g_{nV}\delta^{ab}\epsilon_\mu,\\ \langle 0|J^a_{A\mu}|\tilde{A}^n_b(p,\epsilon)\rangle &= g_{nA}\delta^{ab}\epsilon_\mu,\end{aligned}$$

$$\begin{aligned}J^a_{V(A)\mu}\Big|_{\text{vector mesons}} &= f_1^2 g_1 A^{1a}_\mu + (-) f^2_{K+1} g_K A^{Ka}_\mu,\\ g_{nV(A)} &= f_1^2 g_1 S^1_n + (-) f^2_{K+1} g_K S^K_n\end{aligned}$$

Vector meson dominance

$$\epsilon_3 = \frac{\tilde{g}^2}{4}\sum_n\left(\frac{g^2_{nV}}{m^4_n}-\frac{g^2_{nA}}{m^4_n}\right) = \tilde{g}^2 g_1 g_K f_1^2 f^2_{K+1}(M_2^{-2})_{1K} = \tilde{g}^2\sum_{i=1}^K \frac{(1-y_i)y_i}{g_i^2}$$

where

$$y_i = \sum_{j=1}^i \frac{f^2}{f_j^2}$$

Since $0 \leq y_i \leq 1 \Rightarrow \epsilon_3 > 0$.

For $f_i = f_c$, $g_i = g_c$

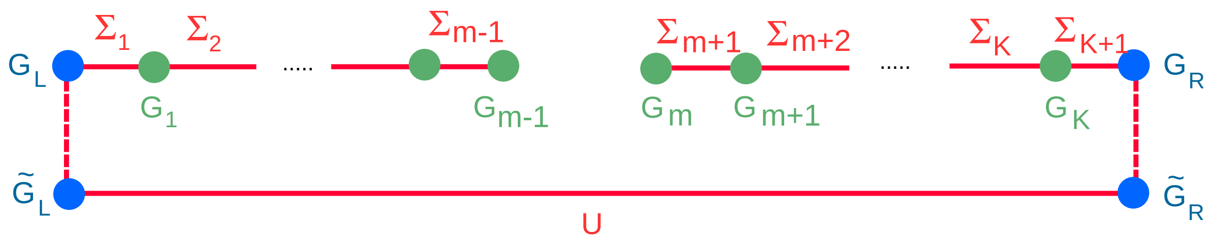
$$\epsilon_3 = \frac{1}{6}\frac{K(K+2)}{K+1}\frac{\tilde{g}^2}{g_c^2}$$

$\epsilon_3 \sim 10^{-3}$. For $K = 1 \Rightarrow g_c \sim 16\tilde{g}$. For increasing K, $g_c \sim 10\sqrt{K}$.

Possible solutions: Cutting a link

Let us suppose $\exists m : f_m = 0$, then the squared mass matrix becomes block diagonal, $\Rightarrow (M_2^{-2})_{1K} = 0 \Rightarrow \epsilon_3 = 0$ However we loose a link (and the corresponding scalar multiplet). We can add the term

$$f_0^2 Tr[\partial_\mu U^\dagger \partial^\mu U], \quad U = \Sigma_1 \Sigma_2 \cdots \Sigma_{K+1}$$



Dashed lines $\Rightarrow$ the identification of the global symmetry groups after weak gauging. For $K = 2$ this model coincides with D-BESS (Casalbuoni et al)

Possible solutions: Suppressing a link

$$f_i = \bar{f} e^{c(i-1)}, \qquad g_i = g_c \quad \epsilon_3 \sim \left(\frac{\tilde{g}}{g_c}\right)^2 e^{-2c}.$$

Partial wave unitarity bounds

(see also Chivukula, He; D., De Curtis, Pelaez; Papucci; Muck, Nilse, Pilaftsis, Ruckl)

Equivalence theorem, $\Sigma_i = \exp\left(if\vec{\pi}\cdot\vec{\tau}/2f_i^2\right)$:

$$\mathcal{A}_{W_L^+W_L^-\to W_L^+W_L^-} \sim \mathcal{A}_{\pi^+\pi^-\to\pi^+\pi^-}$$
$$\sim -\frac{1}{4}f^4\sum_{i=1}^{K+1}\frac{u}{f_i^6}+\frac{1}{4}f^4\sum_{i=1}^{K+1}L_{ij}\left(\frac{u-t}{(s-M^2)_{ij}}+\frac{u-s}{(t-M^2)_{ij}}\right),$$

where $L_{ij} = g_i g_j\left(\frac{1}{f_i^2}+\frac{1}{f_{i+1}^2}\right)\left(\frac{1}{f_j^2}+\frac{1}{f_{j+1}^2}\right)$.

High energy limit:

$$\mathcal{A}_{W^+W^-\to W^+W^-}\to -\frac{1}{4}f^4\sum_{i=1}^{K+1}\frac{u}{f_i^6}$$

minimized when $f_i = f_c$, $\forall i$:

$$\mathcal{A}_{W^+W^-\to W^+W^-} \to -\frac{u}{(K+1)^2v^2}$$

Unitarity condition from $J = 0$ partial wave $|a_0| < 1/2$:

$$a_0 = \frac{s}{16\pi(K+1)^2 v^2} \to \Lambda = (K+1)1.2 \text{ TeV}$$

Considering all channels: $\Sigma_i = \exp\left(i\vec{\pi}_i \cdot \vec{\tau}/2f_i\right)$:

$$\mathcal{A}_{\pi_i\pi_i \to \pi_i\pi_i} \to -\frac{1}{4}\frac{u}{f_i^2}$$

The unitarity limit is determined by the smallest f_i. Taking all equal.

$$\boxed{\Lambda^{TOT} = \sqrt{K+1}\ 1.2 \text{ TeV}}$$

Higgs bosons are not necessary up scales $\sqrt{K+1}$ times the scale of unitarity violation in the Higgsless SM, i.e. 1.2 TeV.
Approximately $M_A^{max} < \Lambda^{TOT}$ implies (when $f_i = f_c$) $g_c \lesssim 5 \Rightarrow \epsilon_3$ too large.

Delocalizing fermion interactions

(Casalbuoni, De Curtis, Dolce, D.; see also Chivukula, Simmons, He, Kurachi)

Let us build

$$\chi_L^i = \Sigma_i^\dagger \Sigma_{i-1}^\dagger \cdots \Sigma_1^\dagger \psi_L, \;\; i = 1, \ldots, K$$

Transformation properties

$$\chi_L^i \to U_i \chi_L^i \,, \;\; U_i \in SU(2)_i \,, \;\; i = 1, \ldots, K \,.$$

New invariants:

$$\bar{\chi}_L^i i \gamma^\mu (\partial_\mu + i g_i A_\mu^i + \frac{i}{2} \tilde{g}' (B - L) \tilde{\mathcal{Y}}_\mu) \chi_L^i, \;\; i = 1, \ldots, K$$

New fermion lagrangian:

$$\begin{aligned}
\mathcal{L}_{fermions}^{tot} &= \bar{\psi}_L i \gamma^\mu \left[\partial_\mu + i \tilde{g} \tilde{W}_\mu + \frac{i}{2} \tilde{g}' (B - L) \tilde{\mathcal{Y}}_\mu \right] \psi_L + \\
&+ \sum_{i=1}^{K} b_i \bar{\chi}_L^i i \gamma^\mu \left[\partial_\mu + i g_i A_\mu^i + \frac{i}{2} \tilde{g}' (B - L) \tilde{\mathcal{Y}}_\mu \right] \chi_L^i + \\
&+ \bar{\psi}_R i \gamma^\mu \left[\partial_\mu + i \tilde{g}' \frac{\tau^3}{2} \tilde{\mathcal{Y}}_\mu + \frac{i}{2} \tilde{g}' (B - L) \tilde{\mathcal{Y}}_\mu \right] \psi_R \,.
\end{aligned}$$

b_i **dimensionless parameters.** In the unitary gauge ($\Sigma_i \equiv I$) and after a rescaling $\psi_L \rightarrow \frac{1}{\sqrt{1+\sum_{i=1}^K b_i}}\psi_L$:

$$\begin{aligned}\mathcal{L}^{tot}_{fermions} &= \bar{\psi}_R i\gamma^\mu \left[\partial_\mu + i\tilde{g}'\frac{\tau^3}{2}\tilde{\mathcal{Y}}_\mu + \frac{i}{2}\tilde{g}'(B-L)\tilde{\mathcal{Y}}_\mu\right]\psi_R + \\ &+ \bar{\psi}_L i\gamma^\mu \Big[\partial_\mu + \frac{1}{1+\sum_{i=1}^K b_i}\left(i\tilde{g}\tilde{W}_\mu + \sum_{i=1}^K b_i\ i g_i A^i_\mu\right) \\ &+ \frac{i}{2}\tilde{g}'(B-L)\tilde{\mathcal{Y}}_\mu\Big]\psi_L.\end{aligned}$$

Low-energy limit

Eliminating the A_i fields when $(\tilde g/g_i)^2 \ll 1, \ \forall i$ and after a field redefinition:

$$\mathcal{L}^{charg}_{eff} = \frac{-\tilde e}{\sqrt{2}\tilde s_\theta}\left(1-\frac{b}{2}-\frac{z_w}{2}\right)\overline{\psi}\gamma^\mu\frac{1-\gamma_5}{2}\psi W^-_\mu + \ h.c.,$$

$$\mathcal{L}^{neutr}_{eff} = \frac{-\tilde e}{\tilde s_\theta \tilde c_\theta}\left(1-\frac{b}{2}-\frac{z_z}{2}\right)\overline{\psi}\gamma^\mu\left[T^3_L\frac{1-\gamma_5}{2} - Q\tilde s^2_\theta\frac{1-\frac{\tilde c_\theta}{\tilde s_\theta}z_{z\gamma}}{1-\frac{b}{2}}\right]\psi Z_\mu,$$

$$- \ \tilde e\left(1-\frac{z_\gamma}{2}\right)\overline{\psi}\gamma^\mu Q\psi A_\mu\,.$$

where

$$z_\gamma = \tilde s^2_\theta\sum_{i=1}^K\left(\frac{\tilde g}{g_i}\right)^2, \qquad z_w = \sum_{i=1}^K\left(\frac{\tilde g}{g_i}\right)^2(1-y_i)^2,$$

$$z_z = \frac{1}{\tilde c^2_\theta}\sum_{i=1}^K\left(\frac{\tilde g}{g_i}\right)^2\left(\tilde c^2_\theta - y_i\right)^2, \qquad z_{z\gamma} = -\frac{\tilde s_\theta}{\tilde c_\theta}\sum_{i=1}^K\left(\frac{\tilde g}{g_i}\right)^2\left(\tilde c^2_\theta - y_i\right),$$

$$b = \frac{2\sum_{i=1}^K y_i b_i}{1+\sum_{j=1}^K b_j}.$$

Current current interaction terms are also generated

$$\mathcal{L}_{eff}^{quart} = \beta \sum_{a=1}^{3} \left(\bar{\psi}_L \gamma^\mu \frac{\tau^a}{2} \psi_L \right)^2$$

with

$$\beta = \frac{1}{8f^2} \left(\bar{b}_K - b \right)^2 - \frac{1}{8f^2} \sum_{i=1}^{K} x_{i+1} \bar{b}_i^2$$

$x_i = f^2/f_i^2$ **and**

$$\bar{b}_i = 2 \frac{\sum_{j=1}^{i} b_j}{1 + \sum_{j=1}^{K} b_j} \quad (i = 1, \cdots, K) \, .$$

Physical quantities:

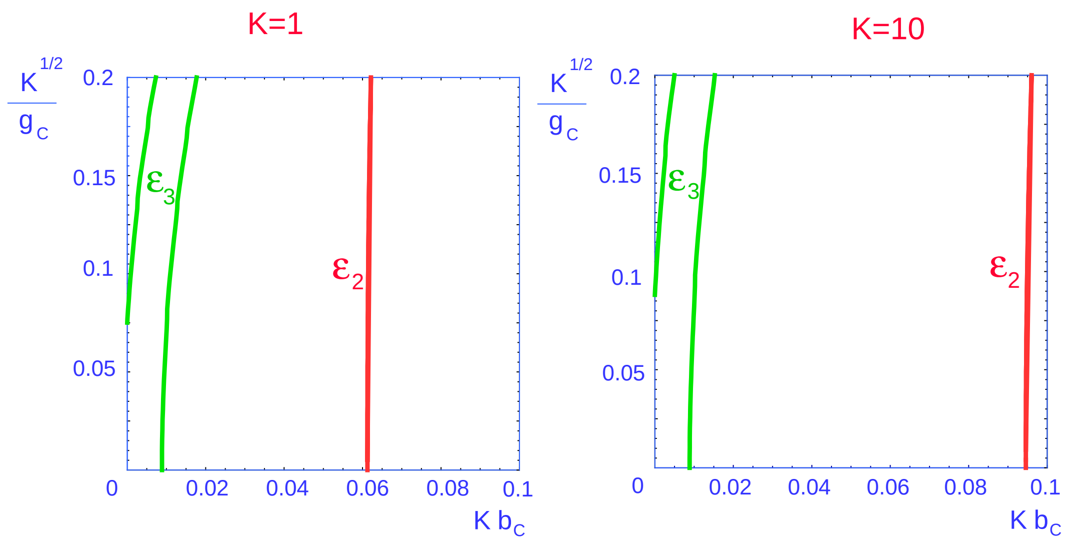
$$M_Z^2 = \tilde{M}_Z^2 (1 - z_z), \;\; M_W^2 = \tilde{M}_W^2 (1 - z_w),$$

$$e = \tilde{e} \big(1 - \frac{z_\gamma}{2} \big), \;\; \frac{G_F}{\sqrt{2}} = \frac{1}{8} \tilde{g}^2 \Big(1 - \frac{b}{2} \Big)^2 \frac{1 - z_w}{M_W^2} + \frac{1}{4\beta}.$$

$$\epsilon_1 \simeq 0, \quad \epsilon_2 \simeq 0 \quad \epsilon_3 \simeq \sum_{i=1}^{K} y_i\left(\frac{\tilde g^2}{g_i^2}(1-y_i)-b_i\right).$$

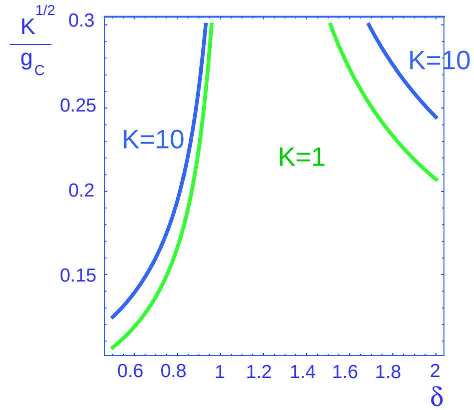
where $y_i = \sum_{j=1}^{i} \frac{f^2}{f_j^2}$. Assume: $g_i \equiv g_c$, $b_i \equiv b_c$, $f_i \equiv f_c$, $\forall i$.

95% CL for ϵ_1, independent on g_c, $b_c < 0.14$ for $K = 1$, $b_c < 0.025$ for $K = 10$.



95% CL bounds on the parameter space $(Kb_c, \sqrt{K}/g_c)$ from the experimental values of ϵ_2 and ϵ_3 for $K = 1$ (left) $K = 10$ (right). The allowed parameter space from ϵ_2 is the region to the left of the dashed line and from ϵ_3 the region between the continuous lines.

Assuming $b_i = \delta \frac{\tilde{g}^2}{g_i^2}(1 - y_i)$, **(**$g_i \equiv g_c, f_i \equiv f_c, \quad \forall i$**):**



95% CL bounds on the parameter space $(\delta, \sqrt{K}/g_c)$ **from the experimental value of** ϵ_3 **for** $K = 1$ **(continuous line), (**$K = 10$ **dash line). The allowed parameter space is the region between the corresponding lines.**

In conclusion with some fine tuning a portion of parameter space is allowed.

Continuous limit ($K \to \infty$)

Let $K \to \infty$ with $Ka \to \pi R$, R being the length of the segment.

$$\lim_{a\to 0} a f_i^2 = f^2(y), \quad \lim_{a\to 0} a g_i^2 = g_5^2(y), \quad \lim_{a\to 0} \frac{b_i}{a} = b(y).$$

Assuming $g_5(y) = g_5$

$$\epsilon_3 \equiv 0 \to b(y) = \frac{\tilde{g}^2}{g_5^2}\int_y^{\pi R} dt \frac{f^2}{f^2(t)}, \qquad \frac{1}{f^2} = \int_0^{\pi R} \frac{dy}{f^2(y)}.$$

Flat metric $f(y) = \bar{f}$

$$b(y) = \frac{\tilde{g}^2}{g_5^2}\left(1 - \frac{y}{\pi R}\right).$$

Randall-Sundrum metric $f(y) = \bar{f} e^{ky}$

$$b(y) = \frac{\tilde{g}^2}{g_5^2}\frac{e^{-2\pi k R} - e^{-2ky}}{e^{-2\pi k R} - 1}.$$

In general: $b(0) = \frac{\tilde{g}^2}{g_5^2}, \quad b(\pi R) = 0.$

$$\Sigma^j = e^{i\int_{y_j}^{y_j+a} dz A_5(z,x_\mu)} \quad : \quad \Sigma_1 \cdots \Sigma_i \to P\Big[\exp(i\int_0^y dz A_5(z,x_\mu))\Big]$$

$$\chi_L^i(x_\mu) = \Sigma_i^\dagger \cdots \Sigma_1^\dagger \psi_L(x_\mu) \ \to \chi_L(y,x_\mu) = P\Big[\exp(i\int_0^y dz A_5(z,x_\mu))\Big]^\dagger \psi_L(x_\mu)$$

Fermions leave on the branes but interact with bulk gauge bosons via Wilson lines.

Mass terms for the fermions

$$\lambda^{ij}\bar\psi_L^i \Sigma_1\Sigma_2 \cdots \Sigma_{K+1}\psi_R^j \to \lambda^{ij}\bar\psi_L^i P\Big[(\exp(i\int_0^{\pi R} dz A_5(z,x_\mu))\Big]\psi_R^j.$$

Conclusions

- Moose models appear deconstructing Higgsless models from five to four dimensions

- Hope: the scale where partial wave unitarity is violated is higher w.r.t. the Higgsless SM due to the exchange of KK excitations in the four gauge boson amplitude scattering

- Problem: compatibility between precision electroweak data and unitarity requirement

- Possible solution with fine tuning: delocalize the fermion interactions

- Signature: new gauge bosons at future colliders (Birkedal, Matchev, Perelstein)