Deconstruction and Higgsless Models

R. Sekhar Chivukula
Michigan State University

w/He, Kurachi, Tanabashi,
and Simmons

Marcel Duchamp
1912

Recipe for a Higgsless Model:

- Choose "bulk" gauge group, location of fermions, and boundary conditions
- Choose $g(x_5)$
- Choose metric/manifold: $g_{MN}(x_5)$
- Calculate spectrum & eigenfunctions
- Calculate fermion couplings
- Compare to Standard Model: S, T, U, ...

Electroweak Parameters I

EW corrections $(S,\ T,\ \Delta\rho,\ \delta)$ defined from amplitudes for "on-shell" 4-fermion processes

$$-\mathcal{A}_{NC} = e^2 \frac{\mathcal{Q}\mathcal{Q}'}{Q^2} \quad + \quad \frac{(I_3 - s^2\mathcal{Q})(I'_3 - s^2\mathcal{Q}')}{\left(\frac{s^2c^2}{e^2} - \frac{S}{16\pi}\right)Q^2 + \frac{1}{4\sqrt{2}G_F}\left(1 + \frac{\alpha\delta}{4s^2c^2} - \alpha T\right)}$$

$$+ \quad \sqrt{2}G_F \frac{\alpha\delta}{s^2c^2} I_3 I'_3 + 4\sqrt{2}G_F\left(\Delta\rho - \alpha T\right)(\mathcal{Q} - I_3)(\mathcal{Q}' - I'_3)$$

$$-\mathcal{A}_{\mathrm{CC}} = \frac{(I_+I'_- + I_-I'_+)/2}{\left(\frac{s^2}{e^2} - \frac{S}{16\pi}\right)Q^2 + \frac{1}{4\sqrt{2}G_F}\left(1 + \frac{\alpha\delta}{4s^2c^2}\right)} + \sqrt{2}G_F \frac{\alpha\delta}{s^2c^2}\frac{(I_+I'_- + I_-I'_+)}{2} \ .$$

S,T: Peskin & Takeuchi

Electroweak Parameters II

Alternative formulation defined at zero momentum

$$\hat{S} = \frac{1}{4s^2}\left(\alpha S + 4c^2(\Delta\rho - \alpha T) + \frac{\alpha\delta}{c^2}\right)$$

$$\hat{T} = \Delta\rho$$

$$Y = \frac{c^2}{s^2}(\Delta\rho - \alpha T)$$

$$W = \frac{\alpha\delta}{4s^2c^2}$$

Barbieri, Pomarol, Rattazzi, Strumia

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- Choose "bulk" gauge group, location of fermions, and boundary conditions
- Choose $g(x_5)$
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- Calculate spectrum & eigenfunctions
- Calculate fermion couplings
- Compare to Standard Model : S, T, U
- Declare model viable or not ....

Can we do better?

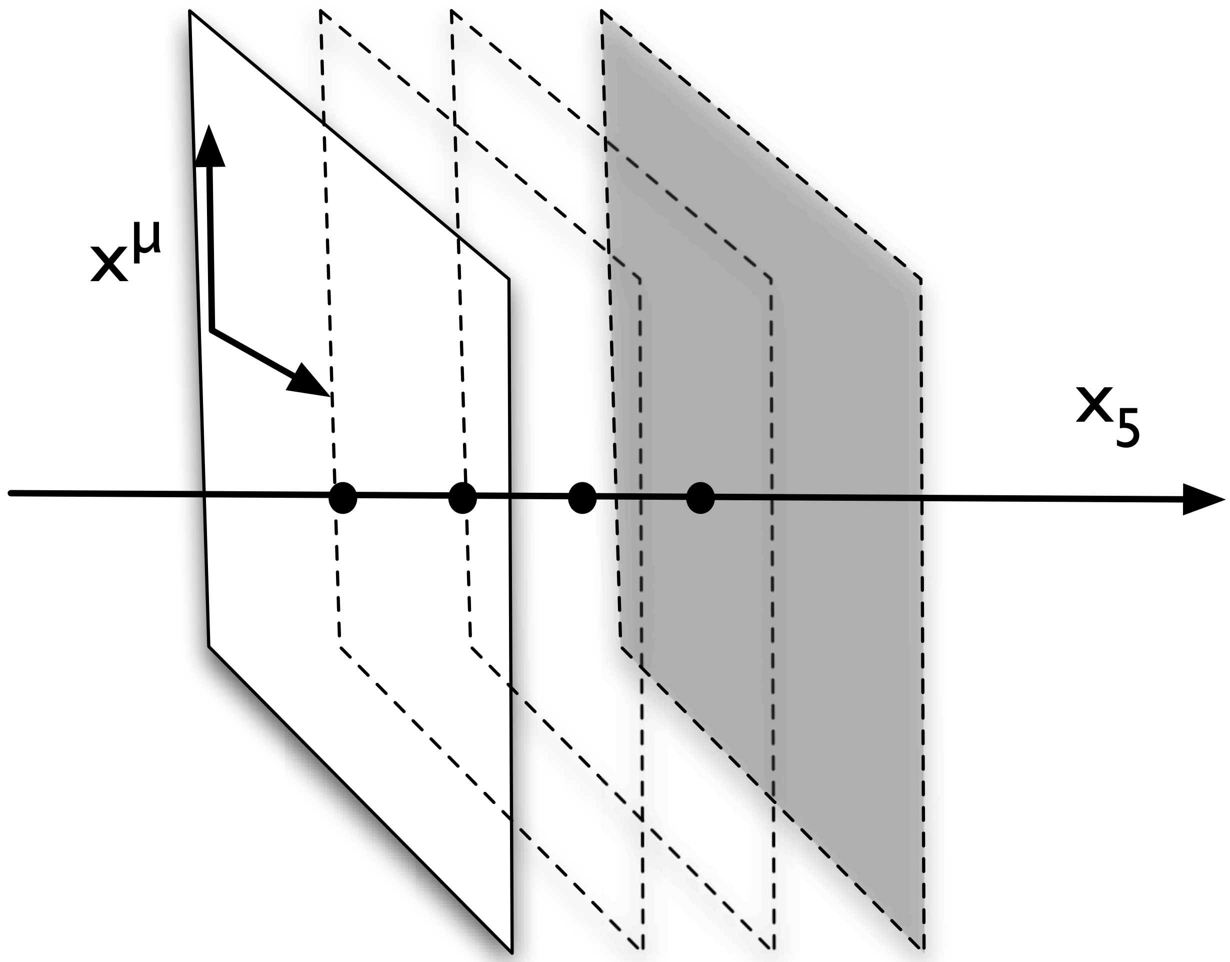
Yes ...

Deconstruction

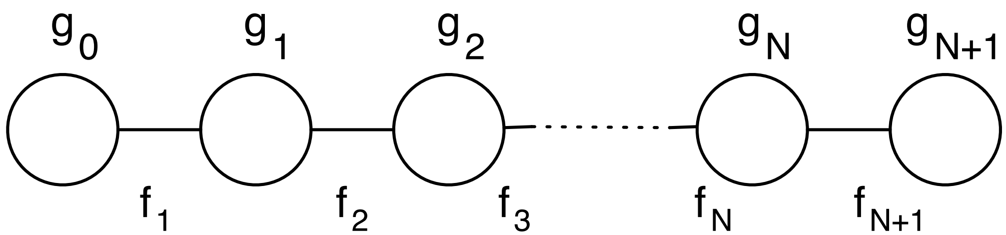
van Gogh

Wolff

Latticize Fifth Dimension



Deconstruction



- Discretize fifth dimension
- 4D gauge group at each site
- Nonlinear sigma model link fields
- To include warping: vary f_j
- For spatially dependent coupling: vary g_k
- Continuum Limit: take N $\rightarrow$ infinity

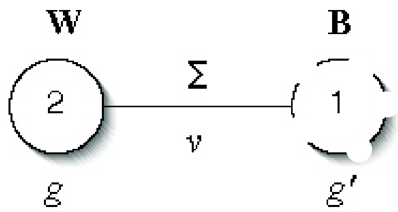
Arkani-Hamed, Georgi, Cohen & Hill, Pokorski, Wang

Aside: Moose notation

Reveals symmetry (breaking) structure at a glance

A familiar example:

$SU(2)_W \times U(1)_B \longrightarrow U(1)$ ⟷



Each circle represents a global SU(2) of which all (solid, left) or a U(1) subgroup (dashed, right) is gauged

Low-energy $\mathcal{L}_{\rm eff}$ description of symmetry-breaking sector employs non-linear sigma-model fields Σ

A solid line linking two circles is an [SU(2) x SU(2) / SU(2)] non-linear sigma model field; at the scale v this breaks the gauged or global symmetries of the attached circles

Note: Σ is a 2x2 matrix field transforming as $\Sigma \to L \Sigma R^{\dagger}$ under the SU(2) groups which it connects.

An SU(2)xSU(2)xU(1)xU(1) model with the following symmetry-breaking pattern:

$$SU(2)_L \times SU(2)_W \times U(1)_B \times U(1)_R$$

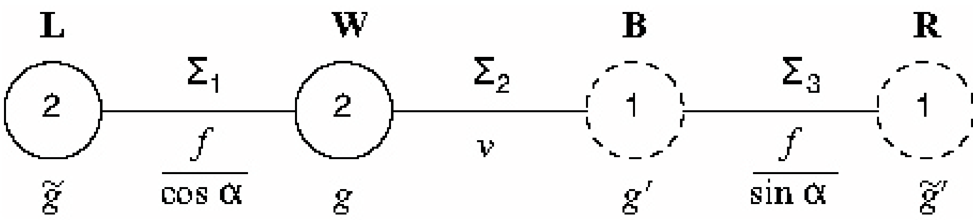
$$\Downarrow \; f$$

$$SU(2)_{weak} \times U(1)_Y$$

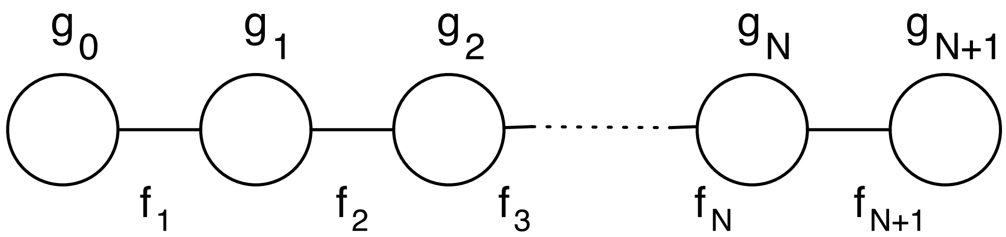
$$\Downarrow \; v$$

$$U(1)_{EM}$$

Can be represented compactly in Moose notation



Deconstruction



- Discretize fifth dimension
- 4D gauge group at each site
- Nonlinear sigma model link fields
- To include warping: vary f_j
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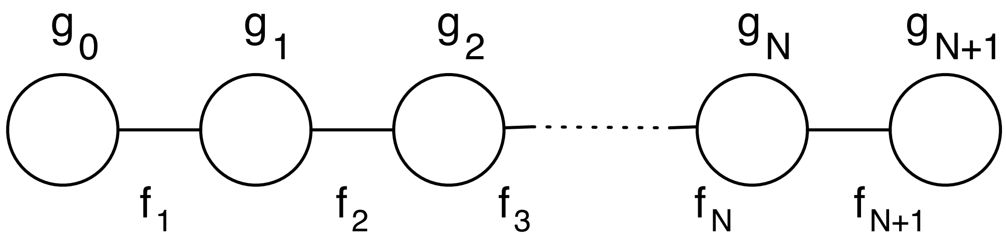
Arkani-Hamed, Georgi, Cohen & Hill, Pokorski, Wang

Continuum Limit



$$\mathcal{S} = -\int d^4x \sum_{j=0}^{N+1} \frac{1}{2g_j^2} \mathrm{tr}\left(F^j_{\mu\nu} F^{j\mu\nu}\right) + \int d^4x \sum_{j=1}^{N+1} \frac{f_j^2}{4} \mathrm{tr}\left((D_\mu U_j)^\dagger (D^\mu U_j)\right)$$

$$g_i = g\sqrt{N+2}\,\kappa_i \qquad \frac{1}{g^2} = \sum_{i=0}^{N+1} \frac{1}{g_i^2} \,,$$

$$D_\mu U_j = \partial_\mu U_j - i A_\mu^{j-1} U_j + i U_j A_\mu^j$$

$$f_i = f\sqrt{N+1}\,h_i \qquad \frac{1}{f^2} = \sum_{i=1}^{N+1} \frac{1}{f_i^2} \,.$$

Unitary Gauge: $U_j = 1$

Define coordinate $y_i = \dfrac{i}{N+1}$

f and g, κ_i and h_i fixed as $N \to \infty$

As N → ∞

$$y_i \to y \ ,$$

$$\Delta y = \frac{1}{N+1} \to dy \ ,$$

$$\frac{1}{N+1} \sum_{i=0}^{N+1} \to \int_0^1 dy \ ,$$

$$A_\mu^j(x) \to A_\mu(x, y) \ ,$$

$$(N+1)\left[A_\mu^{j+1}(x) - A_\mu^j(x)\right] \to \frac{\partial A_\mu}{\partial y}$$

$$\kappa_i,\, h_i \to \kappa(y),\, h(y) \ ,$$

$$\frac{1}{N+2} \sum_{i=0}^{N+1} \frac{1}{\kappa_i^2} \to \int_0^1 dy\, \frac{1}{\kappa^2(y)} = 1 \ ,$$

$$\frac{1}{N+1} \sum_{i=1}^{N+1} \frac{1}{h_i^2} \to \int_0^1 dy\, \frac{1}{h^2(y)} = 1 \ .$$

$$\mathcal{S}_5 = \int d^4x\, dy \left[-\frac{1}{2\, g^2 \kappa^2(y)} \mathrm{tr}(F_{\mu\nu} F^{\mu\nu}) + \frac{f^2 h^2(y)}{4} \mathrm{tr}\left(F_{\mu y} F^{\mu y}\right)\right]$$

5D Yang Mills

$$\mathcal{S}_5 = \int d^4x\, dy \left[-\frac{1}{2\, g^2 \kappa^2(y)} \,\mathrm{tr}(F_{\mu\nu} F^{\mu\nu}) + \frac{f^2 h^2(y)}{4} \mathrm{tr}\, (F_{\mu y} F^{\mu y}) \right]$$

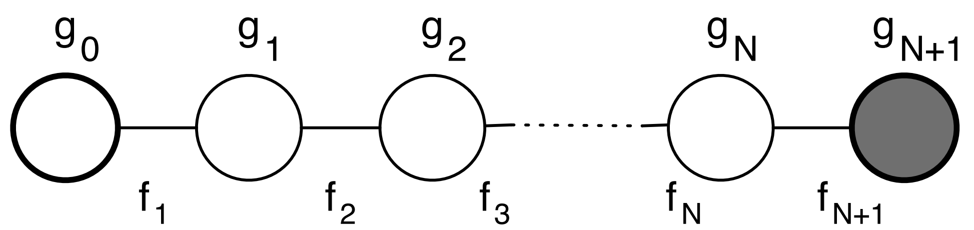
Equivalent to:

$$\mathcal{S}_{5dYM} = -\frac{1}{2} \int d^4x dx^5 \sqrt{G}\, \mathrm{tr}\left(F_{MN} F^{MN} \right)$$

With warped metric:

$$ds^2 = \frac{(gf)^2}{4} \kappa^2(y) h^2(y) \eta_{\mu\nu} dx^\mu dx^\nu - dy^2$$

Simplest Higgsless Models

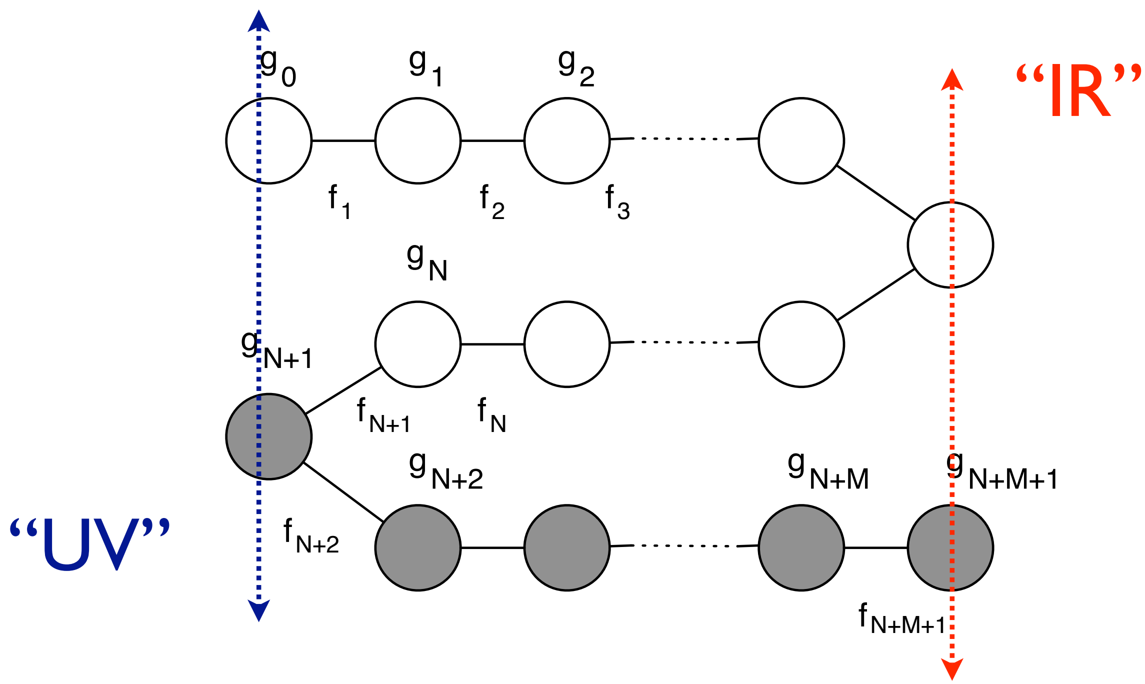


- $SU(2)^N \times U(1)$;   general f_j and g_k
- Fermions sit on "branes" [sites 0 and N+1]
- Many 4-D/5-D theories are limiting cases... study them all at once!
- e.g., N=1 equivalent to technicolor/one-Higgs

cf. "BESS" and "HLS"   Foadi, *et. al.* & Chivukula *et. al.*

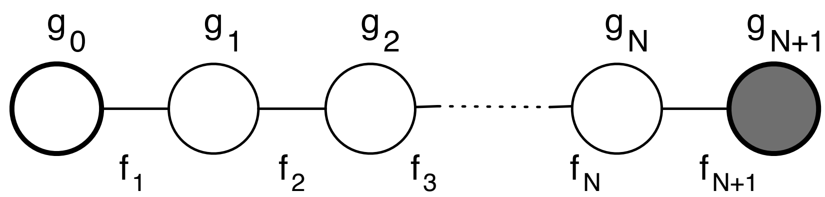
Generalizations

- by folding, represent SU(2) x SU(2) x U(1) in “bulk”
- modify fermions’ location (brane? bulk?)



This talk starts with the simplest moose, then looks at generalizations

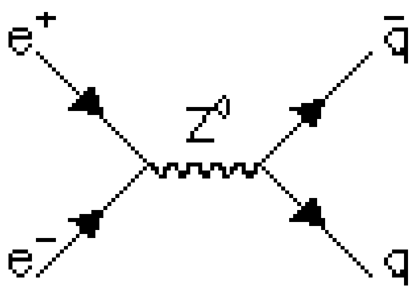
Mass Matrix & Spectrum



$$M_Z^2 = \frac{1}{4}\left(\begin{array}{c|c|c|c|c|c}
g_0^2 f_1^2 & -g_0 g_1 f_1^2 & & & & \\
\hline
-g_0 g_1 f_1^2 & g_1^2(f_1^2+f_2^2) & -g_1 g_2 f_2^2 & & & \\
\hline
 & -g_1 g_2 f_2^2 & g_2^2(f_2^2+f_3^2) & -g_2 g_3 f_3^2 & & \\
\hline
 & & \ddots & \ddots & \ddots & \\
\hline
 & & & -g_{N-1} g_N f_N^2 & g_N^2(f_N^2+f_{N+1}^2) & -g_N g_{N+1} f_{N+1}^2 \\
\hline
 & & & & -g_N g_{N+1} f_{N+1}^2 & g_{N+1}^2 f_{N+1}^2
\end{array}\right).$$

- $\boldsymbol{M}_Z^2$ as above; Spectrum: Photon, Z, heavy Z's
- $\boldsymbol{M}_W^2$ has $g_{N+1} = 0$; Spectrum: W, heavy W's
- EM coupling as expected: $\dfrac{1}{e^2} = \dfrac{1}{g_0^2} + \dfrac{1}{g_1^2} + \ldots + \dfrac{1}{g_{N+1}^2}$

Correlation Functions I



e.g., weak-hypercharge correlation function for Z exchange is within

$$[G(Q^2)]_{0,N+1} \equiv g_0 g_{N+1} \langle 0 | \frac{1}{Q^2 + M_Z^2} | N+1 \rangle$$

$$Q^2 + M_Z^2 = \left(\begin{array}{c|c|c|c|c|c}
Q^2 + g_0^2 f_1^2/4 & -g_0 g_1 f_1^2/4 & & & & \\ \hline
-g_0 g_1 f_1^2/4 & Q^2 + g_1^2(f_1^2 + f_2^2)/4 & -g_1 g_2 f_2^2/4 & & & \\ \hline
 & -g_1 g_2 f_2^2/4 & Q^2 + g_2^2(f_2^2 + f_3^2)/4 & -g_2 g_3 f_3^2/4 & & \\ \hline
 & & \ddots & \ddots & \ddots & \\ \hline
 & & & -g_{N-1} g_N f_N^2/4 & Q^2 + g_N^2(f_N^2 + f_{N+1}^2)/4 & -g_N g_{N+1} f_{N+1}^2/4 \\ \hline
 & & & & -g_N g_{N+1} f_{N+1}^2/4 & Q^2 + g_{N+1}^2 f_{N+1}^2/4
\end{array} \right).$$

By considering the (0,N+1) co-factor, we deduce the form of the correlation function

Correlation Functions II

$$[G(Q^2)]_{0,N+1} = \frac{C}{Q^2(Q^2+M_Z^2)\prod_{n=1}^{N}(Q^2+\mathsf{m}_{Z_n}^2)}$$

We know the residue of $Q^2=0$ pole must be e^2 ...

$$[G(Q^2)]_{0,N+1} = \frac{e^2 M_Z^2 \prod_{n=1}^{N}\mathsf{m}_{Z_n}^2}{Q^2(Q^2+M_Z^2)\prod_{n=1}^{N}(Q^2+\mathsf{m}_{Z_n}^2)}$$

Other residues are also informative.

S parameter

Correlation function residue at $Q^2 = -M^2_Z$ gives "$J_3 J_Y$" coupling of light Z-boson

$$[\xi_Z]_{WY} = -e^2 \prod_{n=1}^{N} \frac{1}{1 - \frac{M_Z^2}{\mathrm{m}_{Z_n}^2}} = -e^2 \left(1 + \frac{\alpha S}{4 s_Z^2 c_Z^2}\right)$$

Requiring $M_Z \ll m_{Z_n}$ yields

$$\alpha S \approx 4 s_Z^2 c_Z^2 \sum_{n=1}^{N} \frac{M_Z^2}{\mathrm{m}_{Z_n}^2}$$

for the entire class of models!

Electroweak Parameters I

EW corrections $(S,\ T,\ \Delta\rho,\ \delta)$ defined from amplitudes for "on-shell" 4-fermion processes

$$-\mathcal{A}_{NC} = e^2\frac{\mathcal{Q}\mathcal{Q}'}{Q^2} \quad + \quad \frac{(I_3 - s^2\mathcal{Q})(I_3' - s^2\mathcal{Q}')}{\left(\frac{s^2c^2}{e^2} - \frac{S}{16\pi}\right)Q^2 + \frac{1}{4\sqrt{2}G_F}\left(1 + \frac{\alpha\delta}{4s^2c^2} - \alpha T\right)}$$

$$+ \quad \sqrt{2}G_F\,\frac{\alpha\delta}{s^2c^2}\,I_3 I_3' + 4\sqrt{2}G_F\,(\Delta\rho - \alpha T)\,(\mathcal{Q} - I_3)(\mathcal{Q}' - I_3')$$

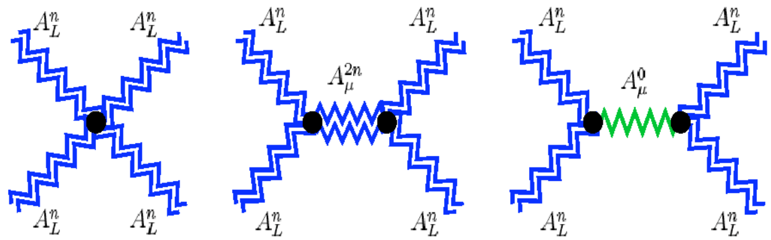
$$-\mathcal{A}_{\rm CC} = \frac{(I_+I_-' + I_-I_+')/2}{\left(\frac{s^2}{e^2} - \frac{S}{16\pi}\right)Q^2 + \frac{1}{4\sqrt{2}G_F}\left(1 + \frac{\alpha\delta}{4s^2c^2}\right)} + \sqrt{2}G_F\,\frac{\alpha\delta}{s^2c^2}\,\frac{(I_+I_-' + I_-I_+')}{2}\ .$$

Tanabashi Lectures

S,T: Peskin & Takeuchi

Conflict of S & Unitarity

Heavy resonances must unitarize WW scattering (since there is no Higgs!)



This bounds lightest KK mode mass: $m_{Z_1} < \sqrt{8}\pi v$

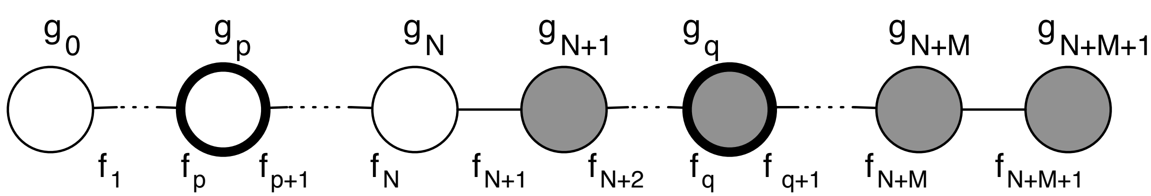
... and yields $$\alpha\, S \geq \frac{4 s_Z^2 c_Z^2 M_Z^2}{8\pi v^2} = \frac{\alpha}{2}$$

Too large by a factor of a few!

Independent of warping or gauge couplings chosen...

Generalize Localized Fermions?

- Since models with fermions localized on the end branes are not viable...
- Consider most general model with fermions localized on branes:

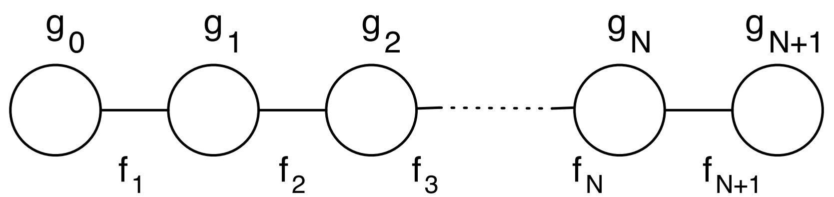


How can we tell if its spectrum is acceptable?
(or if S is in conflict with unitarity?)

Mass matrix has oscillator analog!

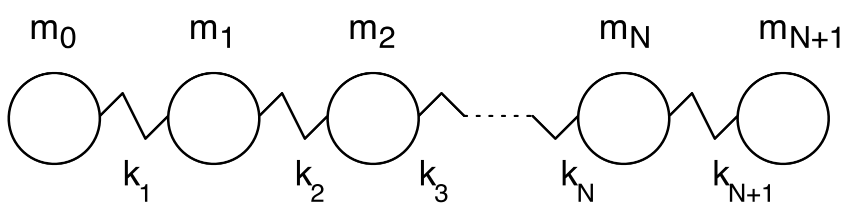
Georgi

Springs and Mooses



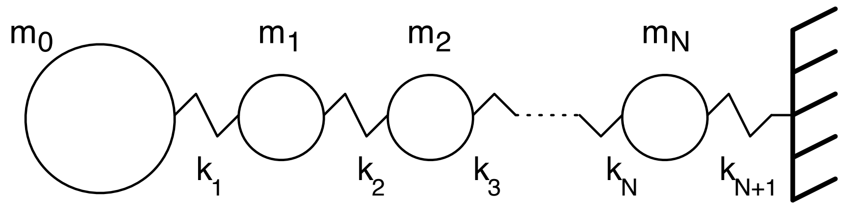
Mass eigenstates of moose above are equivalent to spectrum of oscillator below

$$k_i \leftrightarrow \frac{f_i^2}{4} \qquad m_i \leftrightarrow \frac{1}{g_i^2}$$



W Moose and Oscillator

W moose with small g_0 is equivalent to



Lowest mode ⟷ Light W

$$\frac{1}{k_{eff}} = \frac{1}{k_1} + \frac{1}{k_2} + \ldots + \frac{1}{k_{N+1}}$$

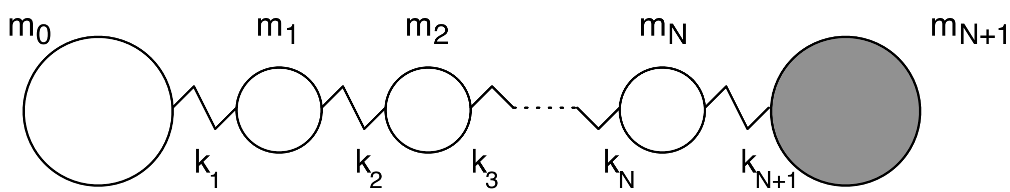
$$\frac{4}{v^2} = \frac{4}{f_1^2} + \frac{4}{f_2^2} + \ldots + \frac{4}{f_{N+1}^2}$$

$$\omega_W^2 \approx \frac{k_{eff}}{m_0}$$

$$M_W^2 \approx \frac{g_0^2 v^2}{4}$$

Z Moose and Oscillator

Spectrum of Z moose with g_0 and g_{N+1} small?

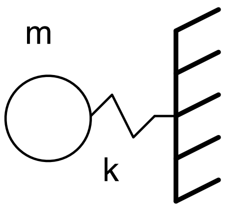


Zero mode (translation) $\longleftrightarrow$ Photon

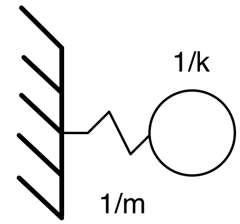
Next-lowest mode (breathing) $\longleftrightarrow$ Light Z

$$\omega_Z^2 \approx k_{eff}\left(\frac{1}{m_0} + \frac{1}{m_{N+1}}\right) \qquad M_Z^2 \approx \frac{(g_0^2 + g_{N+1}^2)v^2}{4}$$

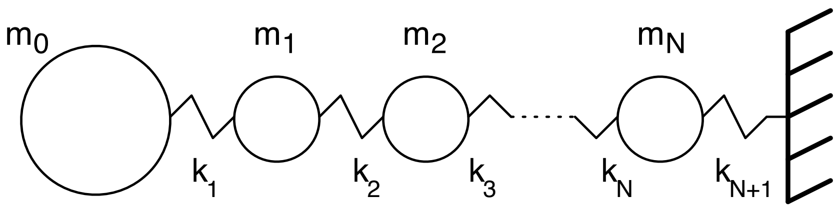
Spring Duality

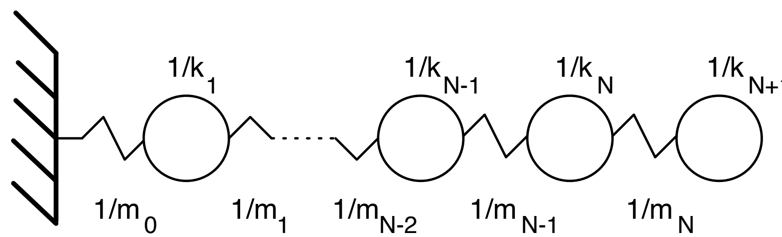


$$\omega^2 = \frac{k}{m}$$ invariant under $$k \leftrightarrow m^{-1}$$



This generalizes to coupled springs!

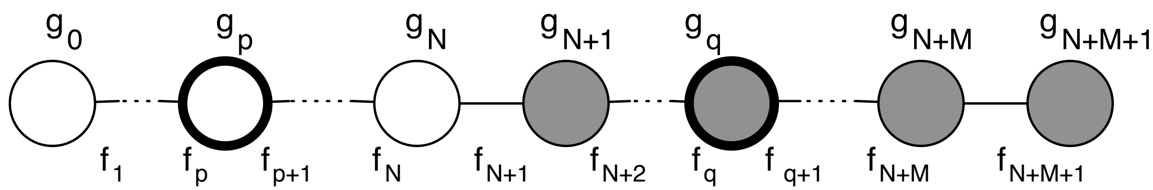




All non-zero modes same for two systems.

Moose duality: related to "eaten" Goldstone Bosons

Spring Analysis of General Moose



W spectrum (oscillator with wall at site N+1):

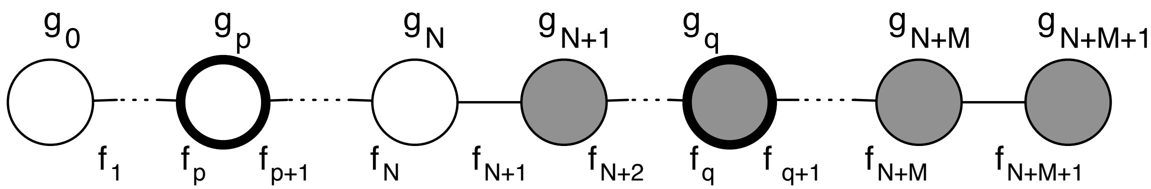
- identical f_j, one small g_k $\Rightarrow$ 1 light W

- identical f_j, 2 small g_k $\Rightarrow$ 2 light W's

- by duality, same g_k, 2 small f_j $\Rightarrow$ 2 light W's

Small $\hat{S}, W$? with wall at site p, must have no heavy masses in either sub-oscillator; can g_k be small for $k \neq p$? think of stiff springs...

Preliminary Conclusion

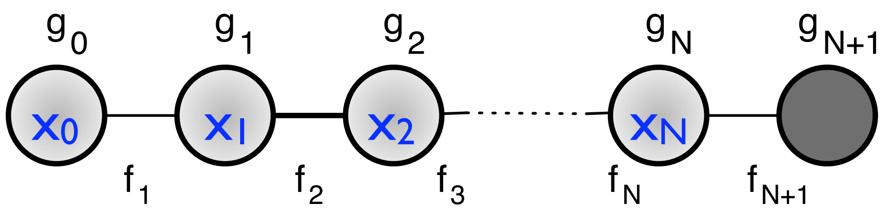


Any model of this kind that

- has localized fermions (at any sites p, q),
- & has only a light photon, W, and Z,
- & is unitary ...

also has $\hat{S} > 5 \times 10^{-3}$ ... which is too large!

A New Hope?



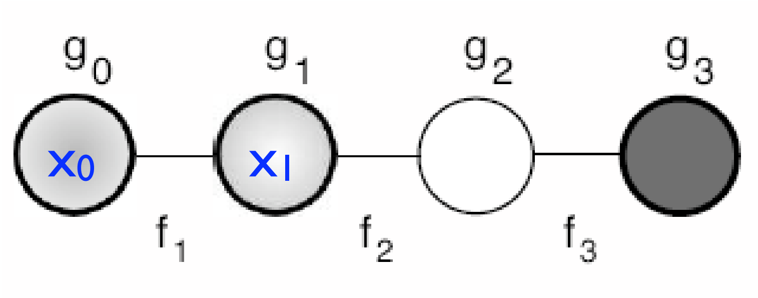
Since Higgsless models with localized fermions are not viable, look at:

Delocalized Fermions, .i.e., mixing of "brane" and "bulk" modes

$$\mathcal{L}_f = \vec{J}^\mu_L \cdot \left(\sum_{i=0}^{N} x_i \vec{A}^i_\mu\right) + J^\mu_Y A^{N+1}_\mu$$

How will this affect precision EW observables?

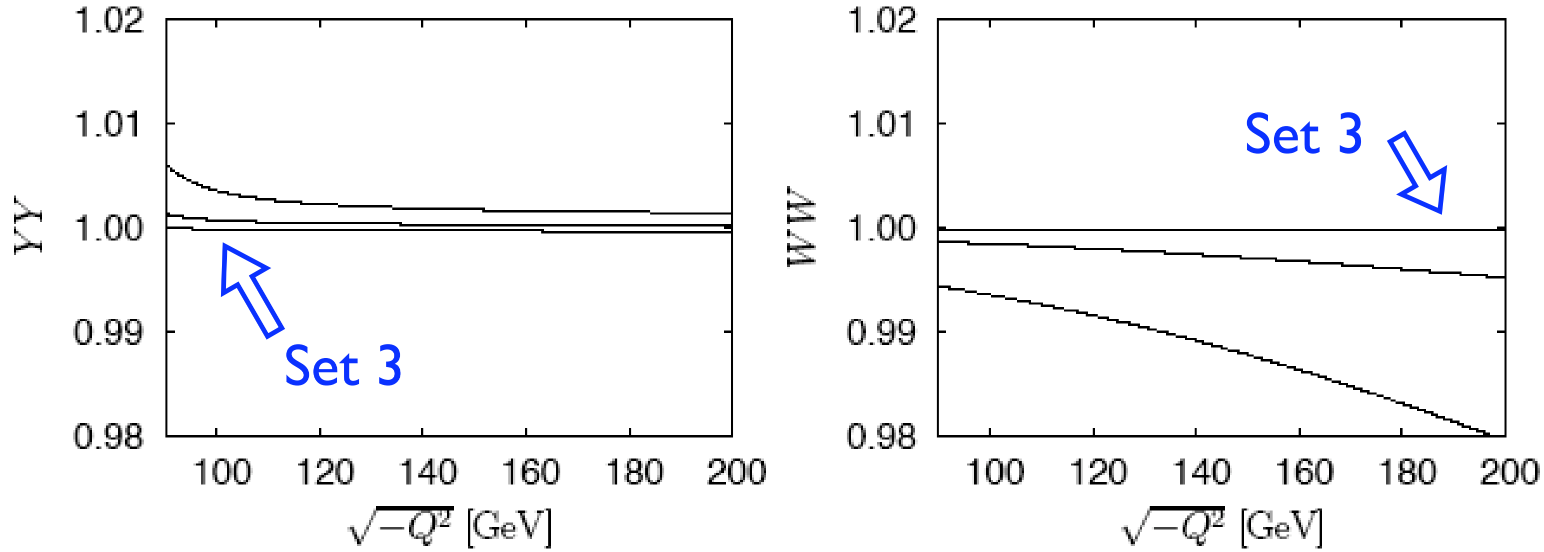
A Toy Model of Delocalization



Massless Fermions!

	Set 1	Set 2	Set 3
Inputs			
f_1	1000 GeV	2000 GeV	300 GeV
$f_2 = f_3$	356.303 GeV	348.922 GeV	591.850 GeV
g_0	0.664421	0.663478	0.657164
$g_1 = g_2$	4.0	4.0	4.0
g_3	0.356505	0.356651	0.357650
x_1 (fraction on site 1)	0.139231	0.480892	0.014771
Calculated Physical Masses			
M_W	79.9486 GeV	79.9080 GeV	79.9599 GeV
m_{Z1}	976.990 GeV	983.725 GeV	892.459 GeV
m_{W1}	975.913 GeV	982.737 GeV	888.827 GeV
m_{Z2}	2162.17 GeV	4114.49 GeV	1944.08 GeV
m_{W2}	2162.17 GeV	4144.49 GeV	1943.39 GeV

Correlation Functions at LEP-I and II



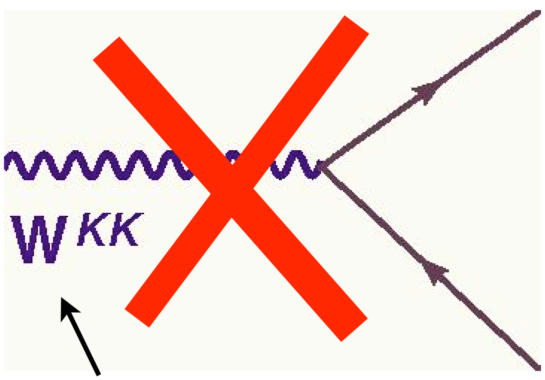
Ratio to Standard Model is shown
... Set 3 comes extremely close!

How to improve on toy model?

RSC, HJH, MK, MT, EHS hep-ph/0502162

Ideal Delocalization

- Choose delocalization related to W wavefunction: $g_i x_i \propto v_i^W$
- NB: $x_i = |\psi_f(i)|^2 > 0$
- W-wavefunction orthogonal to KK wavefunctions.
- No (tree-level) couplings to heavy modes!



Mass Eigenstate

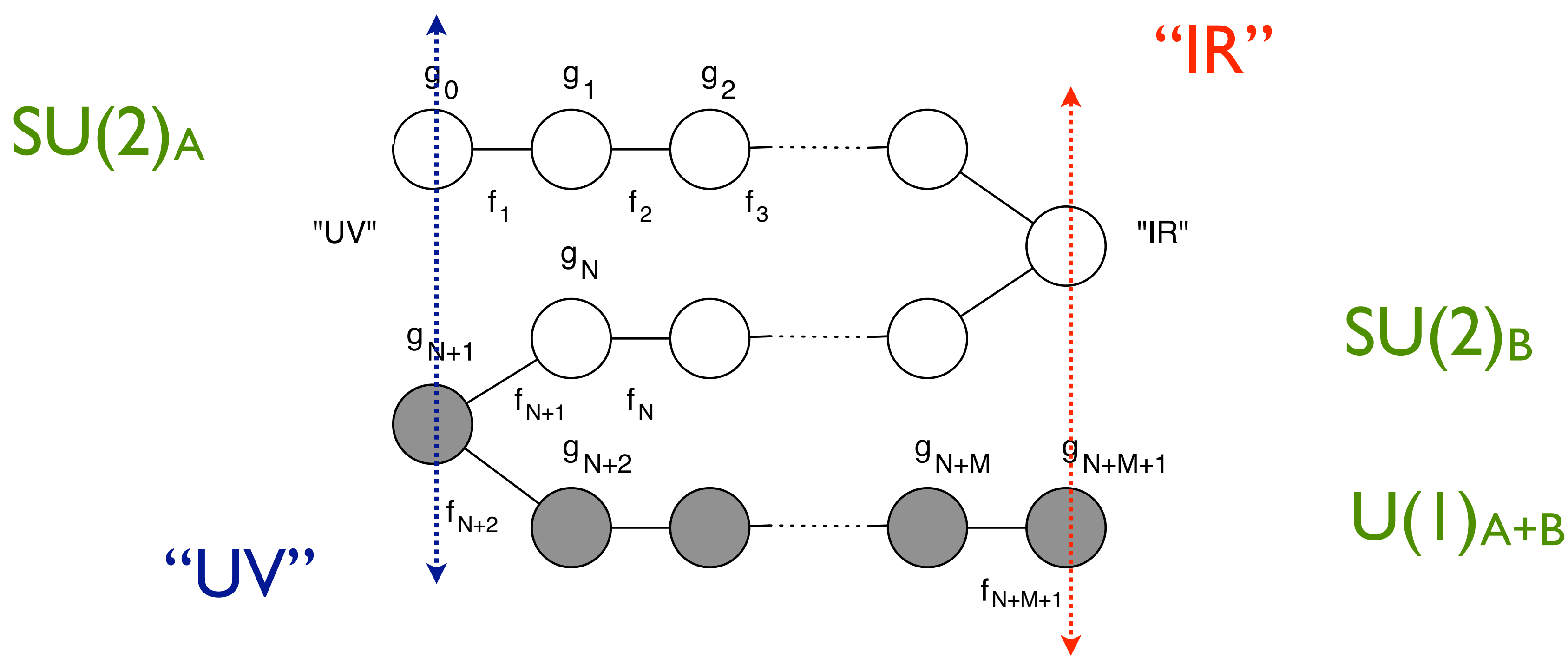
$$\hat{S} = \hat{T} = W = 0$$

$$Y = M_W^2(\Sigma_W - \Sigma_Z)$$

RSC, HJH, MK, MT, EHS hep-ph/0504114

Signals of ideal delocalization in a sample class of models

- by folding, represent SU(2) x SU(2) x U(1) in "bulk"
- ideally delocalize fermions



Triple Gauge Vertices

$$g_{VWW} = \int_0^{\pi R} dz \left\{ \frac{1}{g_{5WA}^2} \chi_V^A(z) \left| \chi_W^A(z) \right|^2 + \frac{1}{g_{5WB}^2} \chi_V^B(z) \left| \chi_W^B(z) \right|^2 \right\} + \frac{1}{g_0^2} \chi_V^A(0) \left| \chi_W^A(0) \right|^2$$

Hagiwara, *et. al.* define:

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

TGVs in Flat Space with Ideal Delocalization

$$\boxed{\Delta g_1^Z = \Delta\kappa_Z = \frac{\lambda}{12c^2}\,\frac{7+\kappa}{1+\kappa} > 0}$$

$$\lambda = \frac{g_0^2 \pi R}{g_{5WA}^2 + g_{5WB}^2} \qquad \kappa = \frac{g_{5WB}^2}{g_{5WA}^2}$$

NB: $\Delta\kappa_\gamma \equiv 0$ $\qquad$ $\lambda \to 0 \ \text{ as } \ M_W^2 \to 0$

As consistent with EM Gauge Invariance

LEP II Constraints

LEP II measurements of WWZ vertex yield

$$\Delta g_1^Z \leq 0.028 \quad @ \quad 95\%\mathrm{CL}$$

In our flat space SU(2) x SU(2) x U(1) model

$$\Delta g_1^Z = \frac{\pi^2}{12c^2}\left(\frac{M_W}{M_{W_1}}\right)^2\left[\frac{1}{4}\cdot\frac{7+\kappa}{1+\kappa}\right]$$

$$M_{W_1} \geq 500\ \mathrm{GeV}\cdot\sqrt{\frac{0.028}{\Delta g_{max}}\ \left[\frac{1}{4}\cdot\frac{7+\kappa}{1+\kappa}\right]}$$

Chiral Lagrangian Parameters

Appelquist-Longhitano Operators:

$$
\begin{aligned}
\mathcal{L}_1 &\equiv \frac{1}{2}\alpha_1 g_W g_Y B_{\mu\nu} Tr(T W^{\mu\nu}) \\
\mathcal{L}_2 &\equiv \frac{1}{2} i\alpha_2 g_Y B_{\mu\nu} Tr(T[V^\mu, V^\nu]) \\
\mathcal{L}_3 &\equiv i\alpha_3 g_W Tr(W_{\mu\nu}[V^\mu, V^\nu]) \\
\mathcal{L}_4 &\equiv \alpha_4 [Tr(V^\mu V^\nu)]^2 \\
\mathcal{L}_5 &\equiv \alpha_5 [Tr(V_\mu V^\mu)]^2
\end{aligned}
$$

$$T \equiv U \tau_3 U^\dagger \qquad V_\mu \equiv (D_\mu U) U^\dagger$$

U arises from $SU(2)_L \times SU(2)_R \to SU(2)_V$

Flat Space Results

flat $SU(2)\times SU(2)$ Longhitano parameters	brane localized	ideally delocalized
$e^2\alpha_1$	$-\frac{2}{3}\,\lambda\, s^2$	0
$e^2\alpha_2$	$-\frac{1}{12}\left(\frac{7+\kappa}{1+\kappa}\right)\lambda\, s^2$	$-\frac{1}{12}\left(\frac{7+\kappa}{1+\kappa}\right)\lambda\, s^2$
$e^2\alpha_3$	$-\frac{1}{12}\left(\frac{1+7\kappa}{1+\kappa}\right)\lambda\, s^2$	$\frac{1}{12}\left(\frac{7+\kappa}{1+\kappa}\right)\lambda\, s^2$
$e^2\alpha_4$	$\frac{1}{30}\,\frac{(1+14\kappa+\kappa^2)}{(1+\kappa)^2}\,\lambda\, s^2$	$\frac{1}{30}\,\frac{(1+14\kappa+\kappa^2)}{(1+\kappa)^2}\,\lambda\, s^2$
$e^2\alpha_5$	$-\frac{1}{30}\,\frac{(1+14\kappa+\kappa^2)}{(1+\kappa)^2}\,\lambda\, s^2$	$-\frac{1}{30}\,\frac{(1+14\kappa+\kappa^2)}{(1+\kappa)^2}\,\lambda\, s^2$

g_{WWWW} $\alpha S,\ L_{10}$

(Final!) Conclusions

- Higgsless models are intriguing candidate solutions to the puzzle of EWSB.
- Deconstruction gives framework for studying 5-d gauge theories as consistent effective field theories.
- Higgsless models with localized fermions are not phenomenologically viable (S too large).
- Delocalized fermions can yield viable models
- Ideal Delocalization: $\hat{S}$, $\hat{T}$, W vanish; Y is small ...
  - * best limits from TGV (M_{KK} > 500-700 GeV)
  - * chiral Lagrangian parameters calculable / visible