Gauge-Higgs Unification with Kinetic Brane Terms

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Outline

- Introduction (EWSB and SM parameters),
- Phenomenological EW-Higgs Unification^{*a*},
- 6D Gauge-Higgs unification with $SU(3)_W$,
- Brane Kinetic Terms and θ_W ,^b,
- Higgs mass with Brane Kinetic Terms,
- Conclusions,

^{*a*}Based on work donde with A. Aranda and A. Rosado, MPL(2006)

^bBased on work donde with A. Aranda, PLB(2006)

Introduction

- EWSB needed to generate SM gauge and fermion masses.
- SM Higgs doublet $\Phi(x)$ has the potential: $V(\Phi) = -\mu^2 |\Phi|^2 + \lambda |\Phi|^4$
- One unknown parameter λ determines M_H
- Exp. and precision analysis seems to prefer a "light" Higgs boson, i.e. $116 \le m_h \le 180$ GeV.
- LHC is expected to detect at least one Higgs boson, while its precise nature will be tested at LC.

Hierarchy Problems

- Large Hierarchy: a severe fine tuning problem, Scalars get quad. rad. corrs.: $\delta M_H^2 \sim C_i \Lambda^2$ A mechanism should protect Higgs mass when $\Lambda >> m_W$, i.e. $C_i \to 0$,
- Little Hierarchy

Higgs mass should not be far from Λ_{eff} , Global fits suggest $\Lambda_{eff} \sim 400$ GeV, EW precision measurements imply, $\Lambda_{eff} \sim 5 - 10$ TeV

Models of EWSB

- Traditional solutions to EWSB problems:
 - Weak/perturbative theories, e.g. SUSY,
 - Strongly-interacting dynamics, e.g. TC
- New approaches proposed recently are based on: New Dynamics: - Little/Fat Higgs,
 - String motivated.....
 - Extra Dimensions: EWSB by O.B.C.
 - -Higgsless EWSB, Warped-AdS/CFT,
 - Gauge-Higgs unification

SM Parameters

- Gauge parameters (dimensionless)
 - Gauge couplings: g_3, g_2, g_Y
 - Strong phase: θ_{QCD}
- Higgs (dimensionfull) parameter: μ^2
- Higgs self-coupling: λ
- Yukawa Couplings Y_{ij}^f
- Could it be possible to express all SM parameters in terms of gauge parameters?

PhenomenologicalEW-HiggsUnification

- Higgs self-coupling should be related to EW gauge couplings,
- This relation could take a generic form: $\lambda = f(g_1, g_2)$
- To simplify we mposse a linear (I) or quadractic (II) relation at a high scale,
- The quadractic relation (case II) takes the form: $g_i^2 = k_H \lambda$,
- The normalization factor k_H is taken as: $0.1 < k_H < 10$

- What is the high scale? We take it where $g_1 = g_2$,
- Result depends on hypercharge normalization, i.e. $g_1^2 = k_Y g_Y^2$,
- We considered $k_Y = \frac{5}{3}, \frac{3}{2}, \frac{7}{4},$

- Use RGE to get λ at EW scale and determine the Higgs mass.
- We obtain the result: $m_h \simeq 180$ GeV.

XD and Gauge-Higgs Unification

 Basic idea: Identify the Higgs as a component of a higher dimensional gauge field (A_{µ̂})

> $A_{\hat{\mu}} \rightarrow A_{\mu} = 4D$ gauge bosons $A_M = 4D$ scalars

• **5D Models:**

Generally predict a very small Higgs mass

• However, in **6D Models**:

Quartic coupling present at tree level Higgs mass prediction is better But EWSB stability must be verified

Consider and SU(3) theory compactified in T^2/\mathcal{Z}_N

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$$F_{\hat{\mu}\hat{\nu}} = \partial_{\hat{\mu}}A_{\hat{\nu}} - \partial_{\hat{\nu}}A_{\hat{\mu}} - ig_6[A_{\hat{\mu}}, A_{\hat{\nu}}]$$

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• Spacetime (for
$$N = 2$$
): $A^{\mu} \rightarrow A^{\mu}$, $A^{M} \rightarrow -A^{M}$, $M = 5, 6$.

• Gauge: for the generators of SU(3), $t_a \rightarrow \Theta^{-1} t_a \Theta$, where

$$\Theta = \left(\begin{array}{rrrr} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{array} \right)$$

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• $A_{\mu} = \sum_{a=1,2,3,8} A_{\mu}^{(a)} \frac{\lambda_a}{2}$

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$$A_{\mu} = \frac{1}{2} \begin{pmatrix} A_{\mu}^{(3)} + \frac{1}{\sqrt{3}} A_{\mu}^{(8)} & A_{\mu}^{(1)} - i A_{\mu}^{(2)} & 0 \\ A_{\mu}^{(1)} + i A_{\mu}^{(2)} & -A_{\mu}^{(3)} + \frac{1}{\sqrt{3}} A_{\mu}^{(8)} & 0 \\ 0 & 0 & -\frac{2}{\sqrt{3}} A_{\mu}^{(8)} \end{pmatrix}$$

$$= \frac{1}{2} \begin{pmatrix} W_{\mu}^{(3)} + \frac{1}{\sqrt{3}} A_{\mu}^{(8)} & \sqrt{2} W_{\mu}^{+} & 0 \\ \sqrt{2} W_{\mu}^{-} & -W_{\mu}^{(3)} + \frac{1}{\sqrt{3}} A_{\mu}^{(8)} & 0 \\ 0 & 0 & -\frac{2}{\sqrt{3}} A_{\mu}^{(8)} \end{pmatrix}$$

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$$H_M = \frac{1}{2} \begin{pmatrix} 0 & 0 & A_M^{(4)} + iA_M^{(5)} \\ 0 & 0 & A_M^{(6)} + iA_M^{(7)} \\ A_M^{(4)} - iA_M^{(5)} & A_M^{(6)} - iA_M^{(7)} & 0 \end{pmatrix}$$

$$= \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 & H_M^{*+} \\ 0 & 0 & H_M^0 \\ H_M^- & H_M^{0*} & 0 \end{pmatrix}$$

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•
$$\mathcal{H} = \left(\begin{array}{c} H_M^{*+} \\ H_M^0 \end{array} \right)$$

- $\tan \theta_W = \sqrt{3}$ $V_{class}(\mathcal{H}) = \frac{g_4^2}{2} |\mathcal{H}|^4$

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Approximately

$$V_{quant}(\mathcal{H}) = -\mu^2 |\mathcal{H}|^2 + \lambda |\mathcal{H}|^4$$

- Suppose $\mu^2 > 0$
- Use $\langle |\mathcal{H}| \rangle = v/\sqrt{2}$

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$$\to \frac{m_H}{m_W} = \frac{2\sqrt{2\lambda}}{g} = 2^{a}$$

^aC.A. Scrucca, M. Serone, L. Silvestrini, A. Wulzer, JHEP **0402** (2004) 049; A. Wulzer, hep-th/0405168; C. Biggio, M. Quirós; hep-ph/0407348

In order to fix the value of $\tan \theta_W$ we introduce brane kinetic terms by considering the following possibilities:

• A: $\mathcal{L}_{TCB} = -\frac{1}{4} c \,\delta(x_5) \,\delta(x_6) F^{\mu\nu} F_{\mu\nu}$

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• **B:** $\mathcal{L}_{TCB} = -\frac{1}{4} (c_5 \,\delta(x_5) \, F^{mn} F_{mn} + c_6 \,\delta(x_6) \, F^{st} F_{st}),$ m, n = 0, 1, 2, 3, 6; s, t = 0, 1, 2, 3, 5

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• **C**:
$$\mathcal{L}_{TCB} = -\frac{1}{4}\delta(x_5)\delta(x_6) \left[c_1 \left(F_{\mu\nu}^{(a)} \right)^2 + c_2 \left(F_{\mu\nu}^{(8)} \right)^2 \right]$$

 $a = 1, 2, 3$

C:

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- Study parameter space consistent with $\tan \theta_W$
- Check the Higgs mass

Weinberg Angle: Defining $g = g_4/\sqrt{Z_1}$ and $g' = \sqrt{3}g_4/\sqrt{Z_2}$

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Higgs Mass: $\frac{m_H}{m_W} = 2\sqrt{\mathcal{Z}_1}$

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