Implications of Higgsless Models of EWSB

OUTLINE

1) HIGGSLESS EWSB
2) PHENOMENOLOGICALLY VIABLE MODEL
3) MORE UNITARITY ISSUES
4) COLLIDER PHENOMENOLOGY

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WHAT IS THE HIGGS FOR?

- GIVES MASS TO THE W, Z
- UNITARIZES $W_L W_L \rightarrow W_L W_L$

SCATTERING AMPLITUDE

$$A = a s^2 + b s + c + \mathcal{O}(s)$$
Gauge Fields on an interval

Take $M^4 \times I_{\text{interval}}$

Put a gauge field in the bulk

\[
A^\tau = A^\tau + \sum_{n=1}^{\infty} A_n^\tau \cos \left( \frac{2\pi n y}{L} \right) + \sum_{n=1}^{\infty} A_n^\tau \sin \left( \frac{2\pi n y}{L} \right)
\]

\[
A^5 = A^5 + \sum_{n=1}^{\infty} A_n^5 \cos \left( \frac{2\pi n y}{L} \right) + \sum_{n=1}^{\infty} A_n^5 \sin \left( \frac{2\pi n y}{L} \right)
\]

Normal orbifold boundary conditions

\[
J_5 A^\tau = 0, \quad A^5 = 0
\]

Note momentum

\[
\rho^2 = \rho_5^2 + \rho_5^5
\]

Looks like a mass term

Mass is connected to curvature in $5^\tau$
DIFFERENT BOUNDARY CONDITIONS

GENERATING MASSES

$\delta_5 A^\xi = 0$

$\delta_5 A^\mu = 0$

$\delta_5 A^\nu = 0$

$\delta_5 A^\rho = 0$

NORMAL ORIGIFOLD

GAUGE-BREAKING BCJ

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UNITARITY

\[ g_2 = \sum_{n=x,1} g_n^2 \]

\[ 4 M_\omega^2 g_\omega^2 = 3 \sum_{n=1}^{\infty} M_n^2 g_n^2 \]

VALID AT ASYMPTOTICALLY HIGH S
(Possibly) Viable Model

- In flat space the mass spectrum is roughly $2n-1$, which is compactification radius, too light.

- Without a Higgs doublet, no custodial $SU(2)_L$. $g$ parameter way off.

Both problems solved by

$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

In a Randall-Sundrum (warped) scenario.
BREAKING PATTERN

"TeV" BRANE

SU(2)_L \times SU(2)_R \rightarrow SU(2)_D

WARPED SPACE

$KTR_0 = 30$

"PLANCK" BRANE

SU(2)_L \times U(1)_{B-L} \rightarrow U(1)_Y

FERMIONS LIVE HERE

OVERALL

SU(2)_L \times SU(2)_R \times U(1)_{B-L} \rightarrow U(1)_Y
MODEL PARAMETERS

\[ g_L = SU(2)_L \text{ COUPLING} \]
\[ g_R = SU(2)_R \text{ COUPLING} \]
\[ g' = U(1) \text{ COUPLING} \]

\[ K_{11} = \text{SCALING BETWEEN PLANK \& TeV SCALES} \]

\[ g_L \]
\[ g_R \]
\[ g' \]

\[ \text{BRANE LOCALIZED KINETIC TERMS ON PLANCK BRANE} \]

SEE NOMURA

\[ k = \frac{g_R}{g_L} \]
\[ \lambda = \frac{g'}{g_L} \]

\[ S_L = \frac{k g_L^2}{2 g_L^2} \]
\[ S_Y = \frac{\lambda}{2 + k^2} S_L \]

K LEFT AS FREE PARAMETER
SPECTRUM

CHANGE

EXCITED

STATES

\{ \}

NEUTRAL

EXCITED

STATES

\{ \}

\{ \}

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ASSYMMETRIC UNITARITY → SUM RULES

Residual

\[ \text{Residual} = g^2 - \sum_{n=1}^{\infty} g^2_n \]

Largest KK number
PRECISION ELECTROWEAK DATA

\[ \sin^2 \theta \] defined from \( \frac{M_w}{M_Z^2} \)

**Exact** in our scheme

Can define

\[ \sin^2 \theta_{\text{eff}} = \frac{\alpha^2}{\theta^2} \]

\[ \sin^2 \theta_{\text{eff}} \] from \( Z \)-pole

Example calculation

Measure deviations of these

Also Barbieri,
Pomarol & Rattazzi

\( \theta - \text{Yr'/03/1285} \)

Burman & Nomura

\( \theta - \text{Yr'/03/1247} \)
\[ \sin^2 \theta \]

\[ \sin^2 \theta_{qs} \]

\[ \sin^2 \theta_{adj} \]

\[ \sin^2 \theta_{eg} \]

\[ \text{Min from theory } \sim 0.56 \]

\[ \sim \text{Max from Perturbativity} \]
UNITARITY ISSUES

RECALL \(\text{sum rules are valid at asymptotically high } S.\)

WHAT IF UNITARITY BREAKS BEFORE THIS REGIME?

PARTIAL WAVE UNITARITY TEST

\[
a_0 = \frac{1}{32\pi} \int d\omega \ A(\omega, \nu_1 \nu_2 \rightarrow \nu_3 \nu_4)
\]

\[
|\Re(a_0)| \leq \frac{1}{2}
\]
WARPED HIGGSLESS MODEL \( k = 3 \)

\[ a_0 \]

\[ \sqrt{s} \ (\text{GeV}) \]

- S-WAVE AMPLITUDE
- UNITARITY BOUND

\[ a_0 \approx 0.5 \text{ at } \sqrt{s} \approx 5000 \]
ONSET OF UNITARITY VIOLATION
**Collider Issues**

**Important Signatures**

- **No Higgs Scalar**
  - Could be a scalar, radion, for example

- **Rising $W_{WW}$ Scattering**
  - Studied in general
  - Tim Barklow $e^+e^-$

- **Doubled $Z'$ States**
  - Feature of several extra dimensional models
  - Rizzo hep-ph/0305077

- **Gluon Resonances**

- **Graviton Resonances**
  - Small, unlike generic RS
DRELL-YAN PRODUCTION AT LHC

Excited States

Width floats to account for top quark mass
$G \to \gamma \gamma$ at LHC

$M_{\gamma\gamma}$ (GeV) vs Events/50 GeV/3 ab$^{-1}$
LINEAR COLLIDER  (TO BE DONE)

MOST INTERESTING NEW QUESTION

WHAT CAN THE LC LEARN ABOUT THE COUPLINGS OF A DOUBLED KK STATE WHILE COLLIDING BELOW THRESHOLD?

- MASS of (TWO STATES) KNOWN FROM LHC

MAYBE

UNDER CERTAIN CONDITIONS, QUITE A LOT

75±20 1/12 2007

96 12 2001
CONCLUSIONS

- EXTRA DIMENSIONS MAY PROVIDE AN INTERESTING ALTERNATIVE TO THE HIGGS MECHANISM

- CURRENTLY NO VIABLE MODEL, BUT THE IDEA IS STILL YOUNG (<1 yr)

- RICH PHENOMENOLOGY THAT NEEDS A LINEAR COLLIDER TO UNTANGLE.