Emergent Electroweak Symmetry Breaking with Composite W, Z Bosons

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Outline

Have we exhausted reasonable possible EWSB patterns?

LHC is starting up late Oct. this year...

Major Goal:
Unveil the mechanism of electroweak symmetry breaking

An intriguing question to ask ourselves once more at this point:

Have we exhausted possible EWSB patterns we can imagine of and get prepared for catching their signatures at the LHC?

A brief Review of existing EWSB models

- Elementary Higgs: EW scale stabilized by SUSY, EWSB triggered by dynamical SUSY breaking in a strong hidden sector
- Composite Higgs (5D dual): pseudo-Goldstone boson of chiral symmetry breaking
- Technicolor-like Higgsless (5D dual):σ mode heavy, decouples from low energy theory

Common features of all existing EWSB models (4D)

- To naturally solve 'gauge hierarchy' problem–i.e.generate a TeV mass gap via dimensional transmutation, require a new external sector beyond the SM with confining strong dynamics
- Most of SM fields, esp. gauge fields stay elementary, spectators of strong dynamics, not participants, acquire mass by coupling to the strong sector

A 'wild' curiosity: Why has to be external strong dynamics? Why not some strong dynamics underlying the SM?

Could our current view of SM be similar to seeing mesons, baryons before discovery of QCD quarks, gluons? SM: composites of new underlying constituents, mass directly generated by confinement?$\Rightarrow$ A new scenario for EWSB?

Motivations beyond a 'wild curiosity':

- Composite gauge field/emergent gauge symmetry (breaking) not unfamiliar: QCD ρ meson can be interpreted as a massive gauge field of spontaneously broken hidden local symmetry $SU(2)_V$ to explain universal ρ-coupling, ρ-dominance...(Sakurai, 1960's etc.)

- Composite gauge boson is conceptually innocuous, even inspiring: Gauge symmetry, unlike global symmetry, is not a true symmetry of nature, does not lead to new conserved charge, merely reflect redundancy in the description (D. J. Gross, "Gauge theory - past, present and future," 1997)

  "gauge symmetry may not be fundamental, some gauge symmetries in the SM or even general relativity may be long distance artifacts." (N. Seiberg, "The power of duality: Exact results in 4D SUSY field theory,"1995)
- Composite W,Z may provide a novel way to unitarize $W_L W_L$ scattering at high energy due to overall form factor suppression (Conventional approach: introduce graphs involving new intermediate states to cancel the divergence) , and give distinctive signal at the LHC

Upshot: the 'wild curiosity' is worthy of serious exploration

- Our goal: Explore a realistic Emergent EWSB (or non-TC Higgsless) scenario, focus on composite W, Z for the current work
- Our strategy: a strongly-coupled 4D theory with good calculability? $\Rightarrow$ use AdS/CFT duality to construct a 5D warped model with bulk gauge fields which dual to 4D emergent EWSB;
  EWSB only broken on UV brane, IR brane only used to generate mass gap: different from original RS and all existing warped models where EWSB on IR; 4D dual: EW symmetry is only a global symmetry of strong CFT, confining and CFT breaking at IR generate SM masses

- Serious challenge: composite W,Z$\Leftrightarrow$1st KK modes peaking at IR; Usual KK mass spectrum in RS1-type model $m_n \sim n z_1^{-1} \Rightarrow m_Z = m_1 \sim 90\mathrm{GeV}$ implies $m_2 \sim 200\mathrm{GeV} \Leftarrow$ LEP bound $m_{Z'} > 1500\mathrm{GeV}$
- A 'distorted' spectrum with ultra-light 1st KK?–Turn on brane kinetic term (BKT) –Inspired by earlier work getting light W', Z' in RS with elementary SM W,Z (Carena, Ponton,Tait and Wagner; Davoudiasl, Hewett and Rizzo 2003)
- Naturalness and size of BKT: generally expected at tree-level by 4D Poincare symmetry on branes, even absent at tree-level, loop correction to propagator demands such term as counter-term to cancel log divergence(Dvali, Gabadadze and Shifman 2001, Georgi, Grant and Hailu 2001); NDA size: $\zeta \sim L$ ($L \sim 35k^{-1}$ in RS: 5th dim size), yet large BKT is perturbatively consistent (Ponton, Poppitz 2001)$\Rightarrow$ take ζ as a free parameter, fix later by fitting masses, EWPT

- Consider a slice of AdS_5 spacetime $ds^2 = \left(\frac{1}{kz}\right)^2(\eta_{\mu\nu}dx^\mu dx^\nu + dz^2)$ k: AdS curvature of Planck scale. $\mu = 0,1,2,3$, $\eta_{\mu\nu} = \mathrm{Diag}(-+++)$. 5th dim z is compactified on a Z_2 orbifold, with a with a UV (IR) brane located at the fixed point $z_{UV}(z_{IR}) = k^{-1}(\mathrm{TeV}^{-1})$.
- We have 5D bulk EW symmetry $SU(2)_L \times U(1)_Y$, with 5D gauge fields A^L_M, B_M, 5D gauge couplings g_{L5}, g_{Y5}, field strengths F^L_{MN}, F^Y_{MN}. EWSB on UV by BC: $SU(2)_L \times U(1)_Y \to U(1)_Q$, full symmetry preserved on IR, BKT compatible with brane symmetry are included: ζ_Q for $U(1)_Q$ on UV, ζ_L, ζ_Y for $SU(2)_L, U(1)_Y$ on IR
- 5D action is then given by

$$\begin{aligned} S &= \int d^4x\, dz \sqrt{-g}[-\frac{1}{4}(F^{La}_{MN})^2 - \frac{1}{4}(F^Y_{MN})^2 \\ &- \frac{1}{2}(kz)\delta(z - z_{UV})\frac{\zeta_Q}{g^2_{Y5} + g^2_{L5}}(g_{Y5}F^{L3}_{\mu\nu} + g_{L5}F^Y_{\mu\nu})^2 \\ &- \frac{1}{2}(kz)\delta(z - z_{IR})\left(\zeta_L(F^{La}_{\mu\nu})^2 + \zeta_Y(F^Y_{\mu\nu})^2\right)]. \end{aligned}$$

Boundary conditions implementing symmetry breaking, BKT effects:

$$z = z_{UV}: \begin{cases} \partial_z(g_{Y5}A_\mu^{L3} + g_{L5}B_\mu) + \zeta_Q \Box(g_{Y5}A_\mu^{L3} + g_{L5}B_\mu) = 0, \\ g_{L5}A_\mu^{L3} - g_{Y5}B_\mu = 0, \\ A_\mu^{L1,2} = 0, \end{cases}$$

$$z = z_{IR}: \begin{cases} \partial_z A_\mu^{La} - \zeta_L k z_{IR} \Box A_\mu^{La} = 0, \\ \partial_z B_\mu - \zeta_Y k z_{IR} \Box B_\mu = 0, \end{cases}$$

After KK decomposition, solve E.O.M with BC, we get mass spectrum (W/Z profile plots see next page):

- A flat zero mode exists: $f_0^{L3}, f_0^B \rightarrow$ photon
- Lightest KK mode: $f_1^{L3}, f_1^B \rightarrow$ SM Z boson

$$m_Z \simeq \sqrt{\frac{2}{\zeta_L k} + \frac{2}{\zeta_Q k(1+\beta^2)}} z_{IR}^{-1} .$$

- No zero mode for W tower($f_n^{L\pm}$), 1st KK $\rightarrow$SM W boson

$$m_W \simeq \sqrt{\frac{2}{\zeta_L k}} z_{IR}^{-1}.$$

W, Z 5D profiles

- All higher KK modes have usual masses of $\sim z_{IR}^{-1}$

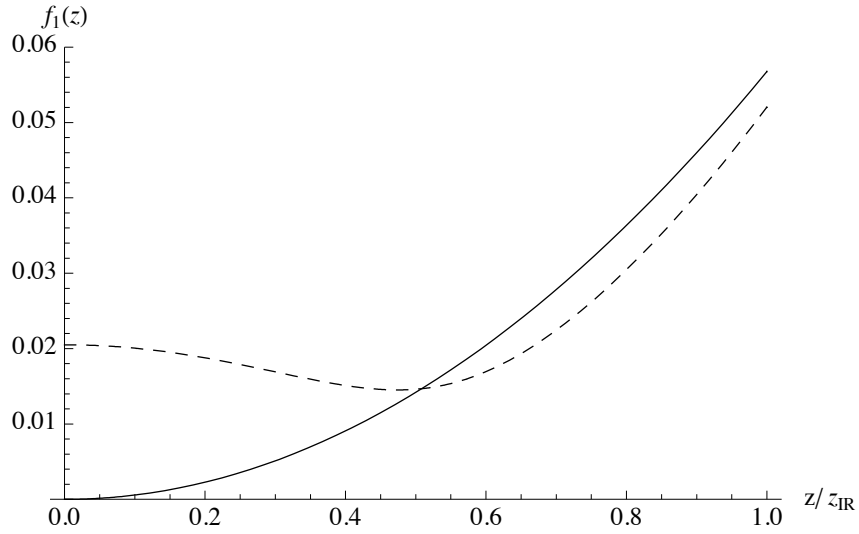

Figure: The W-boson (solid) and Z-boson (dashed) profiles in units of $\sqrt{k}$.–Peaking at IR, indeed dual composites

S, T parameter analysis, natural built-in protection mechanisms

- **$T(\rho)$ parameter:** UV BKT ζ_Q: 'knob' of $A^{L3} - B$ mixing–with BC at $\zeta_Q \to \infty$, A^{L3}, B decouple$\Rightarrow$ $A^{L1,2,3}$ have identical BC on IR/UV, so degenerate KK masses!
  –A novel custodial mechanism ($SU(2)_L$ self-protection) already built in the model$\Rightarrow$expect $\rho = 1$ at leading order.
- **S parameter:** In 5D model S is fully calculable tree-level effect, straightforward by working out wavefunction normalization:

$$S \propto (m_Z z_{IR})^2$$

Efficient way to reduce S: reduce $m_Z z_{IR}$, or increase the little hierarchy between Z mass and higher normal KK mass, easily realized by larger BKE (built-in feature) $\Rightarrow$ 4D dual interpretation: 1-loop correction involving N KK modes/resonances, larger KK mass suppression ($m_{KK}^2 \sim z_{IR}^{-2}$) **counterweighs** large N sum (origin of large S for TC-like models)

$V_L V_L$ scattering ($V : W, Z$): a particular type of process within the SM 'cries' for beyond-the-SM physics at TeV scale

- SM (alone) prediction: E^4 divergence exactly cancels due to gauge invariance between contact graph and s, t channel graphs; E^2 divergence remains$\Rightarrow$ tree-level unitarity breaks down at 1.8TeV$\Rightarrow$ HELP! New physics needed to restore unitarity
- *Known* mechanisms of restoring *WW* unitarity: adding graphs involving Higgs or sum over KK/resonances in Higgsless models to cancel E^2 divergence
- Novel solution from composite model: nontrivial role of form factors and internal structure

Region-I: At relatively low energy energy, elastic scattering, internal structure undisturbed. We find efficient form factor suppression for s-, t-channel graphs due to exchanging offshell γ, Z etc. (in analogy to EM form factor of QCD pions), but contact graph intact, and stands out as dominant contribution, $\Rightarrow E^4$ divergence, tree-level prediction breaks down at $\sim 300\mathrm{GeV}$

Prediction-I: at lower s ($< 300\mathrm{GeV}$)σ_{ww} grows faster than SM prediction, LHC distinction...

–reasonable, expected deviation, since exact E^4 cancelation only for exact, 'fundamental' gauge symmetry

But what restores unitarity eventually?

–Region-II: At higher s, internal structure of composites will be probed, physics of underlying constituents, finiteness of size become important. *AdS/CFT*: 4D dual is UV strongly-coupled gauge theory, no known physics as reference: QCD not a good analogy...

Most relevant reference by now: (Polchinski and Strassler, 2003, *"Deep inelastic scattering and gauge/string duality,"*)

$\Rightarrow$ For a hadron in large 't Hooft coupling theory, except for very small x region,no partons inside the hadron, at high q whole hadron needs to shrink to size q^{-1} and scatter coherently–kinematic suppression due to compositeness, q^{-4} for vector boson

Prediction-II: At high s, kinematic suppression due to 'shrinking' effect is sufficient to restore unitarity!

LHC Collider Study

Work in progress...

Conclusions

- We explore a new Higgsless EWSB scenario where SM W, Z are composites gauge field as IR emergence, masses generated by CFT breaking at IR. Using AdS/CFT we build a calculable 5D warped model where EWSB on UV, realistic mass spectrum is achieved by turning on brane kinetic terms.
- We do EWPT analysis for the model, find there are built-in mechanisms to ensure good fit to S, T parameters in a natural way
- The composite nature of W, Z gives novel solution for WW scattering unitarization; predicts deviation from SM which can lead to distinctive signatures at the LHC
- Novel prospect at the LHC: **maybe** at LHC we will find a new world hidden inside the SM which unravels the EWSB mystery, and get to a deeper level of substructure in Nature