Holograpic Technicolor

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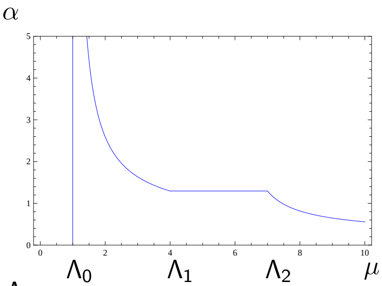
Technicolor

- Technicolor is a dynamical theory of electroweak symmetry breaking (EWSB).
- Models do not contain a fundamental scalar (higgs), instead they borrow the example of chiral symmetry breaking from QCD.
- The Idea is to introduce new fermions and gauge interactions which become strongly coupled at v_w.
- This produces a condensate $<\bar{\Psi}\Psi>$ that is responsible for the breaking of electroweak symmetry.
- The fact that v_w is produced dynamically then protects it from the hierarchy problem.

Problems

- Strongly coupled theory.
  - Lattice.
  - AdS/CFT.
- Higgs?
  - Could there be a composite scalar?
- SM masses.
  - Extended Technicolor.
  - 4 fermion operators couple SM fermions to the techni-condensate.
- Excessive FCNC's.
  - due to 4 fermion operators.
  - suppressed if theory permits a walking phase.

Walking Coupling Constant



- Confines at Λ_0.
- Walking phase starts at Λ_1 and ends at Λ_2.
- Theory is approximately conformal during the walking phase.

AdS/CFT correspondence

- The AdS/CFT correspondence states that a strongly coupled conformal field theory in 4D can be described by a weakly coupled 5D theory, coupled to gravity, on an AdS background.
- In this context bulk fields are dual to strongly coupled operators of the 4D conformal theory. i.e. they are composite objects.
- Can also consider asymptotically AdS spaces → gauge/gravity duality.

Geometry

- The the metric we consider is given by

$$ds^2 = e^{2A(r)}\eta_{\mu\nu}dx^\mu dx^\nu + dr^2,$$

- r is the extra dimension. It is related to the renormalization scale of the dual 4D theory.
- Also need two boundaries. An IR boundary at $r = r_1$ which acts as an IR cut-off at the scale of confinement and a UV boundary at $r = r_2$ which acts as a UV regulator.

Background Scalars

Can describe the techni-condensate as a bulk (5D) background scalar field.

$$\mathcal{S} = \int d^4x dr \sqrt{-g}\Theta\left(\frac{R}{4}+\mathcal{L}_5\right)+\sqrt{-\tilde{g}}\delta(r-r_1)\left(\frac{K}{2}+\mathcal{L}_1\right) - \sqrt{-\tilde{g}}\delta(r-r_2)\left(\frac{K}{2}+\mathcal{L}_2\right).$$

$$\mathcal{L}_5 = -\frac{1}{2}g^{MN}\partial_M\Phi\partial_N\Phi - V(\Phi),$$

$$\mathcal{L}_1 = -\lambda_1(\Phi), \ \mathcal{L}_2 = -\lambda_2(\Phi)$$

R is the Ricci scalar and K is the extrinsic curvature of the boundaries. The λ_i are localized boundary potentials.

Back-reaction

- However, adding fields causes a back-reaction on the metric.
- Shows up in the warp factor $A(r)$.
- It is possible to show that

$$A' = -\frac{2}{3} W \, , \;\; \bar{\Phi}' = W_{\Phi} \, ,$$

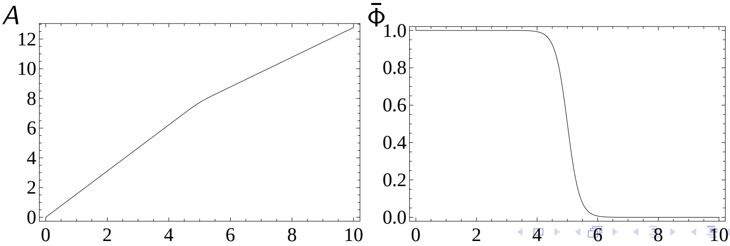
where W is a superpotential.

Classical Solutions

We will consider a superpotential of the form $W(\Phi) = -\frac{3}{2} - \frac{\Delta}{2}\Phi^2 + \frac{\Delta}{3\Phi_I}\Phi^3$, for which we find that the classical field is given by

$$\bar{\Phi} = \frac{\Phi_I}{1 + e^{\Delta(r-r_*)}}$$

and the warp factor describes two AdS spaces of different curvature, joined at r_*.



Scalar Fluctuations

- Fluctuations correspond to quantum particles. However these mix with scalar fluctuations of the metric.
- Need to define a gauge invariant variable $\mathfrak{a} = \varphi + \frac{W_\Phi}{4W} h$
- Scalar fluctuations then satisfy the EoM

$$\left(\left(\partial_r + N - \frac{8}{3}W\right)(\partial_r - N) + e^{-2A}q^2\right)\mathfrak{a} = 0,$$

and boundary conditions

$$\left(\frac{e^{2A}}{q^2}\frac{(W_\phi)^2}{W}\right)(\partial_r - N)\mathfrak{a}|_{r_i} = \mathfrak{a}|_{r_i}.$$

with $N = W_{\Phi\Phi} - \frac{(W_\Phi)^2}{W}$

Gauge Sector

- Add $SU(2)_L \otimes SU(2)_R$ gauge bosons in the bulk, in unitary gauge ($A_r = 0$).

$$\begin{aligned} \mathcal{S}_{gauge} &= -\frac{1}{4}\int d^4x \int_{r_1}^{r_2} dr \left(a(r) - Db(r)\delta(r-r_2)\right) F^a_{\mu\nu}F^{\mu\nu}_a \\ &\quad +2b(r)F^a_{r\mu}F^{r\mu}_a - 2b(r)\Omega^2 W^{a\mu}W^a_\mu \delta(r-r_1)\,, \end{aligned}$$

- Find that vector and axial-vector solutions satisfy the same EoM's but different boundary conditions — triggers EWSB.

$$\begin{aligned} \partial_r(b(r)\gamma^a(q^2,r)) + b(r)(\gamma^a(q^2,r))^2 + a(r)q^2 &= 0, \\ -b^2(r)\partial_r\left(\frac{\chi^a(q^2,r)}{b(r)}\right) + b(r) + a(r)q^2(\chi^a(q^2,r))^2 &= 0, \end{aligned}$$

$$\gamma^a(q^2,r_1) = 0\,,\ 1 - \Omega^2\chi^a(q^2,r_1) = 0\,,$$

Vacuum Polarization Tensors

- Defined by the 4D effective action

$$\mathcal{S}_4 = \int d^4x \left\{ \frac{1}{2} P^{\mu\nu} W^i_\mu(-q) \pi_{ij}(q^2) W^j_\nu(q) \right\} .$$

- In the V-A basis we have

$$\pi_{ij}(q^2) = \begin{pmatrix} \pi_A & 0 \\ 0 & \pi_V \end{pmatrix},$$

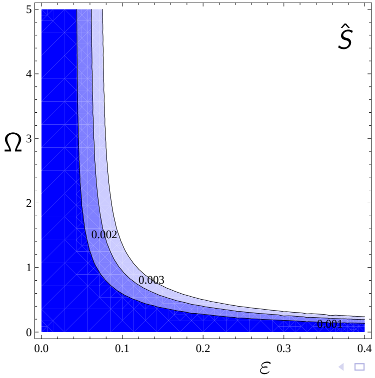
$$\pi_A(q^2) = -\varepsilon^2 \left(q^2 \left(r_2 - \frac{1}{\varepsilon^2} \right) + \frac{b(r_2)}{\chi(q^2, r_2)} \right) ,$$

$$\pi_V(q^2) = -\varepsilon^2 \left(q^2 \left(r_2 - \frac{1}{\varepsilon^2} \right) + b(r_2)\gamma(q^2, r_2) \right) ,$$

$\hat{S}$ Parameter

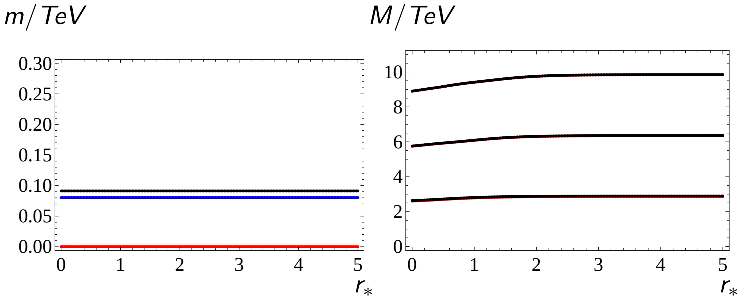
- $\hat{S}$ is given by

$$\hat{S} \equiv \cos^2\theta_W(\pi'_{V^3}(0) - \pi'_{A^3(0)}) \sim 3 \times 10^{-3},$$



Spin-1 Spectrum

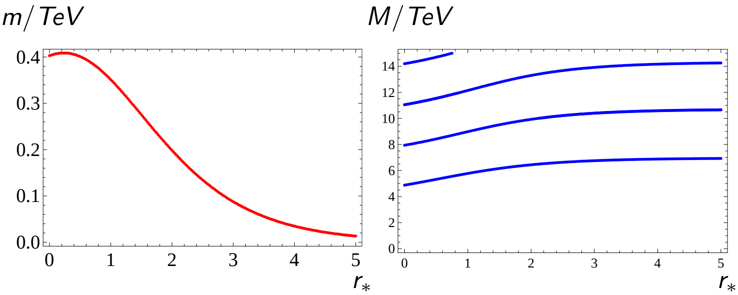
For $\Omega = 0.27$, $\varepsilon = 0.343$ we find



Note vector and axial-vector KK resonances are quazi-degenerate. This is because Ω (responsible for EWSB) has been chosen to be fairly small.

Scalar Spectrum

For $\Delta = \Phi_I = 1$, we find the spectrum of scalars shown below.



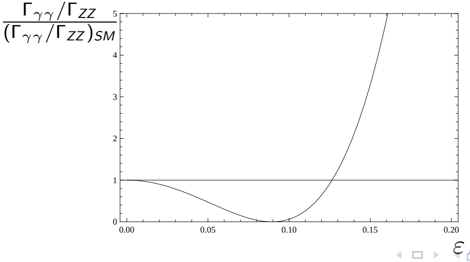
Note that the scalar spectrum includes a light (composite) scalar, the dilaton, which is compatible with recent LHC results $m_s = 125\,GeV$.

Dilaton coupling to photons

- Can show that

$$\frac{\Gamma(d \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)_{SM}} \simeq \frac{v_W^2}{16f^2} \frac{(-6.4 + 800\varepsilon^2)^2}{42},$$

  where $4f$ is the decay constant.
- Normalizing by $\frac{\Gamma(d \to ZZ)}{\Gamma(h \to ZZ)_{SM}}$, we find



Conclusions

- We have built a toy model, dual to a (walking) theory of technicolor, consistant with constraints from electroweak precision data ($\hat{S}$)
- Electroweak symmetry is broken on the IR boundary by the presence of a localized VEV Ω
- Conformal symmetry is also broken at the scale $r = r_*$ and a pseudo-Goldstone boson is present in the spectrum.
- This Goldstone boson is the dilaton, it is parametrically light and its mass is consistent with LHC "higgs" mass data $m_h = 125 GeV$.

conclusions cont.

- We find that the dilaton coupling to 2 photons can be suppressed or enhanced, depending on the value of ε.
- Since the bound on $\hat{S}$ forces us to decrease Ω as ε is increased a relationship between the photon decay rate and the splitting of vector and axial-vector techni-mesons is found.