EWSB from a Standard Model bulk Higgs

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OUTLINE

The outline of this talk is

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- Introduction
- The model
- The Higgs background
- EWSB
- Electroweak constraints
- Numerical results
- Conclusion

Introduction

- Warped extra dimensions are useful to solve some long-standing problems: hierarchy, flavor,...

They make use of a warp factor

The 5D metric does not factorizes

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$$

- The AdS/CFT correspondence can deal with non-perturbative theories: technicolor, QCD,...

RS/GW model

Conformal invariance is spontaneously broken by an IR brane (RS1 [a]) at $y = y_1$. It can be stabilized by the GW mechanism [b]: it requires a scalar in the bulk (with a quadratic potential) which does not generate any singularity

[a] L. Randall and R. Sundrum, hep-ph/9905221
[b] Goldberger and M. Wise, hep-ph/9907447

Another possibility is soft-wall models

The scalar in the bulk (with an exponential potential) does generate a singularity at a finite distance and the extra dimension is non-compact but of finite length: metric is AdS near the UV

$$\infty > \int e^{-A(z)} dz \equiv y_s = \int_0^{y_s} dy$$

- This implies that there is a

Naked curvature singularity at $y = y_s$ where $A(y_s) \to \infty$

- Soft-walls have been proposed [1]
  - For AdS/QCD
  - To describe unparticles as fields propagating in the bulk
  - As alternatives to RS1 for solving the EW hierarchy

[1] A. Kartch, E. Katz, D.T. Son and M.A. Stephanov, hep-ph/0602229; A. Falkowski and M. Perez-Victoria, arXiv:0806.1737; B. Batell, T. Gherghetta and D. Sword, arXiv:0808.3977

The model

- To solve the EOM in the bulk we will use the [2]

"Superpotential" method: $W(\phi)$

$$A'(y) = W(\phi), \quad \phi'(y) = \partial W/\partial\phi$$

$$V(\phi) = 3(\partial W/\partial\phi)^2 - 12W^2$$

BC: $\lambda_0(\phi(0)) = 6W(\phi(0)), \quad \partial_\phi\lambda_0(\phi(0)) = 6\partial_\phi W(\phi(0))$

- The model [3] is defined by

$$W(\phi) = k(1 + e^{\nu\,\phi})$$

$$A(y) = ky - \frac{1}{\nu^2}\log\left(1 - \frac{ky}{ky_s}\right)$$

$$\phi(y) = -\frac{1}{\nu}\log[\nu^2(ky_s - ky)]$$

[2] O. DeWolfe, D.Z. Freedman, S.S. Gubser and A. Karch, hep-th/9909134

[3] J. A. Cabrer, G. von Gersdorff and M. Quiros, arXiv:0907.5361

- We will consider the casse where the soft-wall singularity is "hidden" by a brane at $y_1 < y_s$
- It may be considered as the case of a RS1 setup stabilized by the previous (super)potential at two branes located at $y = 0$ and $y = y_1$ where brane dynamics fixes

$\lambda_0(\phi) \Rightarrow \phi = \phi_0$ @ UV and $\lambda_1(\phi) \Rightarrow \phi = \phi_1$ @ IR

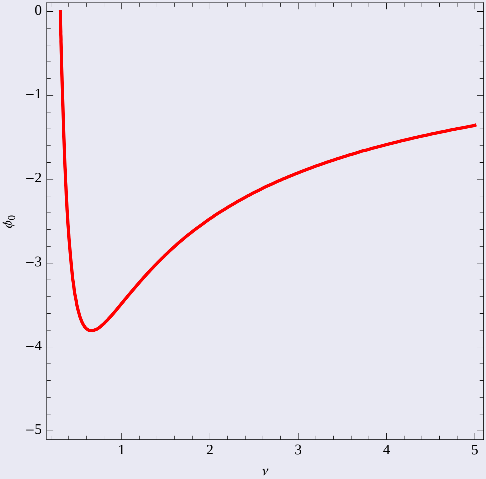
$$ky_1 = \frac{1}{\nu^2}\left[e^{-\nu\phi_0} - e^{-\nu\phi_1}\right], \quad ky_s = \frac{1}{\nu^2}e^{-\nu\phi_0}$$

$$A(y_1) = ky_1 + \frac{1}{\nu}(\phi_1 - \phi_0)$$

- Soft-wall is the limit $\phi_1 \to \infty$, $y_1 \to y_s$ [e.g. with a runaway potential $V_1 \sim e^{-\nu\phi}$]
- EW hierarchy

$$|\nu\phi_0| \simeq \text{ a few}, \quad \nu\phi_1 \gtrsim 1$$

For: $A(y_1) = 35$, $y_s - y_1 = 1/k$



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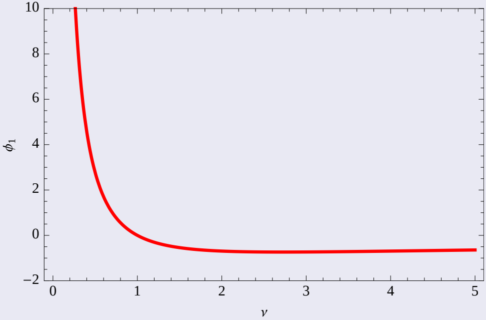


The Higgs background

- We will consider a 5D bulk Higgs

$$H(x,y) = \frac{1}{\sqrt{2}}\, e^{ig_5\,\vec{\sigma}\vec{\chi}(x,y)} \begin{pmatrix} 0 \\ h(y)+\xi(x,y)) \end{pmatrix}$$

- We will assume that the dynamics of ϕ fixes y_1 so that the Higgs background does not perturb the radion fixing
- We will then neglect the back-reaction of the Higgs background
- We will consider the potentials in the bulk and branes for the Higgs [4]

$$V(H) = a(a-4)k^2|H|^2$$

$$\lambda_0(H) = M_0|H|^2$$

$$\lambda_1(H) = M_1|H|^2 + \gamma_1|H|^4$$

[4] J. A. Cabrer, G. von Gersdorff and M. Quiros, to appear

- The EOM and BC for the Higgs background yields

Higgs background

$$EOM \Rightarrow h(y) = \begin{cases} v_1 e^{k(4-a)(y-y_1)}, & a < 2 \\ v_1 e^{a(y-y_1)}, & a > 2 \end{cases}$$

Boundary conditions

$$BC \Rightarrow \begin{cases} (4-a) = \gamma v_1^2 + M_1, & a < 2 \\ ak = \gamma v_1^2 + M_1, & a > 2 \end{cases}$$

- The value of v_1 should be naturally of order k (to avoid a fine-tuning) and red-shifted to the TeV by the warp factor
- If $v_1 \sim k$ is consistent with EWSB $\Leftrightarrow$ Higgs hierarchy is solved
- Next we will assume $y_s - y_1 \sim 1/k$ and consider the case $a > 2$ (sort of dual to walking technicolor in the RS1 case)

EWSB

We will illustrate the mechanism with an abelian example

- The action is invariant under 5D gauge transformations

$$A_M(x,y) \to A_M(x,y) + \frac{1}{g_5}\partial_M \alpha(x,y)$$

$$\chi(x,y) \to \chi(x,y) + \frac{1}{g_5}\alpha(x,y)$$

- We will take the 5D gauge condition

$$\partial^\mu A_\mu - M_A^2 \chi + (e^{-2A} A_5)' = 0, \quad M_A(y) = g_5 h(y) e^{-A(y)}$$

- The Goldstone boson and pseudoscalar

$$G(x,y) = M_A^2 \chi - \left(e^{-2A} A_5\right)', \quad K(x,y) = \chi' - A_5$$

- The 4D theory is invariant under $\alpha(x)$ gauge transformations $[\alpha(x,y) = \alpha(x) \cdot f(y)]$ and contains:

4D degrees of freedom

$$A_\mu(x,y) = \frac{a_\mu(x) \cdot f(y)}{\sqrt{y_s}}$$

$$G(x,y) = \frac{m_f\, G(x) \cdot f(y)}{\sqrt{y_s}}$$

$$K(x,y) = \frac{K(x) \cdot \eta(y)}{\sqrt{y_s}}$$

- With profiles

Profiles

$$m_f^2 f + (e^{-2A} f')' - M_A^2 f = 0, \quad \textit{Neumann}$$

$$m_\eta^2 \eta + \left[m_A^{-2} \left(e^{-2A} M_A^2 \eta \right)' \right]' - M_A^2 \eta = 0, \quad \textit{Dirichlet}$$

- We can find an approximation for the light gauge boson mode in the limit where the breaking is small and thus there is a light mode with almost constant profile

Analytical approximation

$$f_A(y) = 1 - \delta_A + \delta f_A(y)$$

$$\delta f_A(y) = \int_0^y dy'\, e^{2A(y')} \int_0^{y'} dy'' \left[M_A^2(y'') - m^2_{f_A^0}\right]$$

$$\delta_A = \frac{1}{y_1} \int_0^{y_1} dy\, \delta f_A(y)$$

- The light mode mass

Mass of light mode

$$m^2_{f_A^0} = \frac{1}{y_1} \int_0^{y_1} M_A^2(y) dy$$

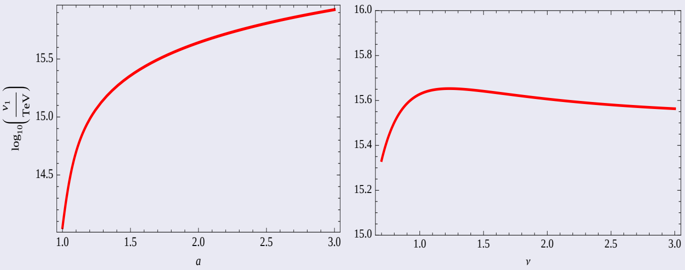
Electroweak constraints

- In our 5D model (for fixed values of the parameters $\nu,\ y_1,\ldots$) we have the free parameters (g_5, g_5', v_1, a) which fix the physical spectrum of light mode masses
- Once we have fixed the condition

$$m_{f_Z} = m_Z$$

then v_1 for $A(y_1) = 35$, $\nu = 1.5\,(\text{left})[a = 2\,(\text{right})]$

$$2 < a < 3 \qquad \nu \gtrsim 0.7$$



- We will be assuming here (not necessarily an assumption) that fermions are localized on the UV brane in which case

$$g_V = g_V^{SM} f_V(0) \equiv g_V[1 - \delta_V(a, m_{KK})]$$

- The latter changes the definition of the Fermi constant measured in the μ-decay and the Z widths which constrain the

EWPT Parameters

$$\delta_Z = \frac{1}{k^2} \int_0^{u_1} du\, e^{2A(u)} \left(1 - \frac{u}{u_1}\right) \int_0^u du' \left(M_Z^2(u') - m_Z^2\right)$$

$$\delta_W = c_W^2\, \delta_Z$$

through the observables $\bar{s}_\ell^2$, $\Gamma_{\ell^+\ell^-}, \dots$

- We can also express the departure with respect to the SM predictions in the language of the usual parameters (S, T, U)
- It turns out that

$(S,\ T,\ U)$ parameters

$$\alpha(m_Z)T = s_W^2\delta_Z$$

$$\frac{\alpha(m_Z)}{4s_W^2c_W^2}S = -2\delta_Z$$

$$\frac{\alpha(m_Z)}{4s_W^2}(S+U) = -2\delta_W$$

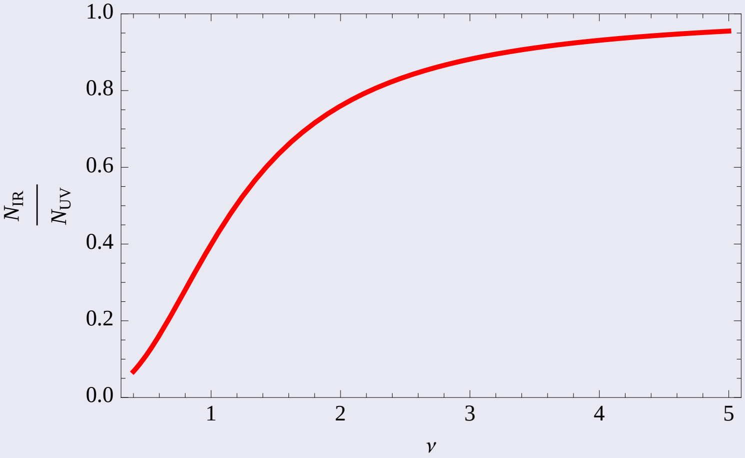
- Or using the relation $\delta_W = c_W^2\delta_Z$

$$\alpha(m_Z)T = s_W^2\delta_Z\ ,\ \alpha(m_Z)S = -8s_W^2c_W^2\delta_Z\ ,\ \alpha(m_Z)U \simeq 0$$

- The strongest constraint is on S

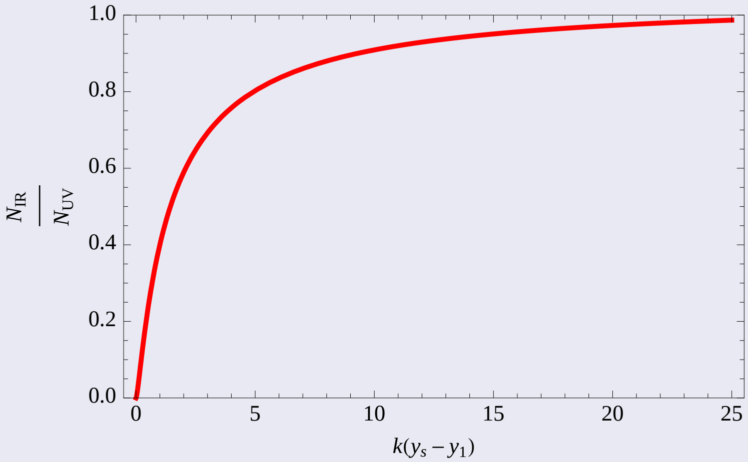
- We can understand that the bounds will go down with ν as N in the holographic theory ($\nu \to \infty$ is RS1)

$N_{IR} \simeq [ML(y_1)]^{3/2}$ Vs. ν $[k(y_s - y_1) = 1,\ A(y_1) = 35]$



- The bounds will go down with increasing $y_s - y_1$

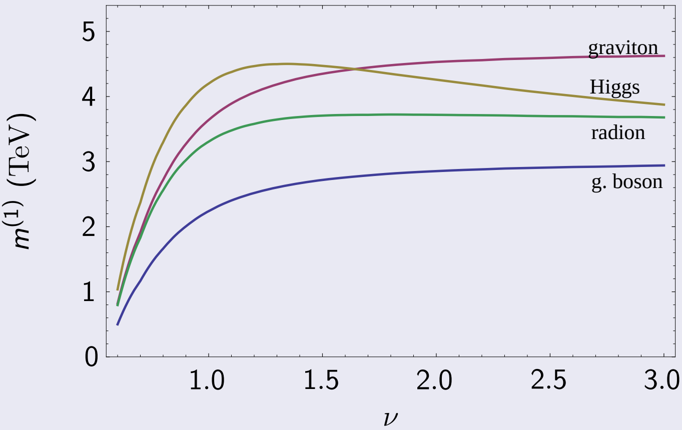
N_{IR} Vs. $k(y_s - y_1)$ $[\nu = 1,\ A(y_1) = 35]$



Numerical results

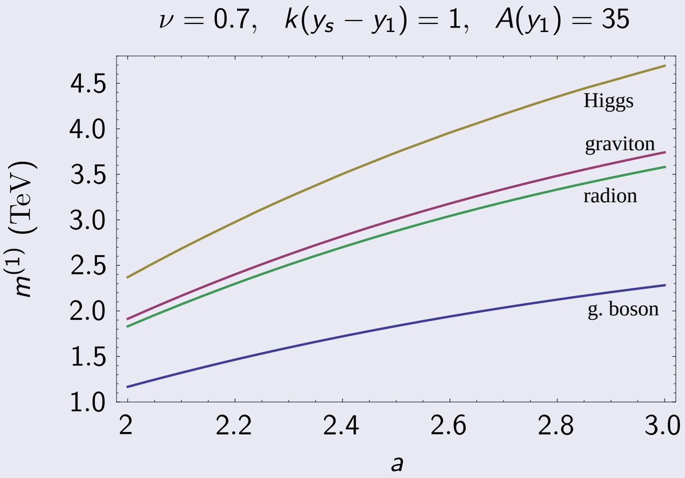
First KK mode lower bound mass Vs. $\nu \gtrsim 0.7$

$$a = 2, \quad k(y_s - y_1) = 1, \quad A(y_1) = 35$$



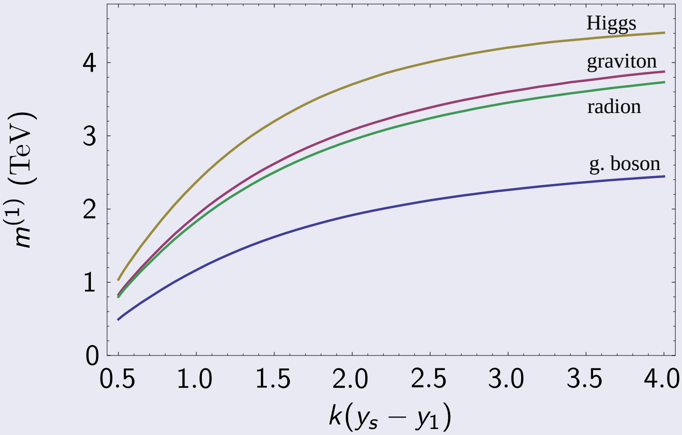
Note that $\delta_Z < 0$, $S > 0$

First KK mode mass Vs. a

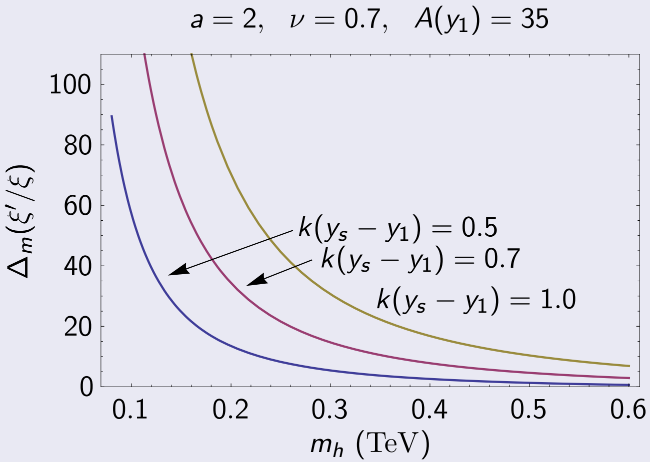


First KK mode mass Vs. $k(y_s - y_1)$

$$a = 2, \quad \nu = 0.7, \quad A(y_1) = 35$$



Sensitivity of the light Higgs mass with BC at IR



Conclusion

- We have stabilized the brane distance with an exponential potential which creates a naked singularity @ y_s next to the IR brane @ $y_1 < y_s$
- The model depends on a real parameter ν such that
  - RS1 is the limit $\nu \to \infty$
  - Unparticle background with a mass gap is the limit $y_1 \to y_s$, $\nu \to 1$
- Near the UV brane the model is AdS
- The smaller the ν (and $k(y_s - y_1)$) the larger the departure from AdS at the IR brane, the smaller N_{IR} of the holographic dual and the milder the constraints from EWPT
- One can get from EWPT lower bounds as

$$m_{KK} \gtrsim 1 \text{ TeV}$$

- A light Higgs mode does appear if $k(y_s - y_1) \lesssim 1$ with some fine-tuning (1-5%) in the boundary conditions