Higgs-Radion Unification in Warped Extra Dimensions

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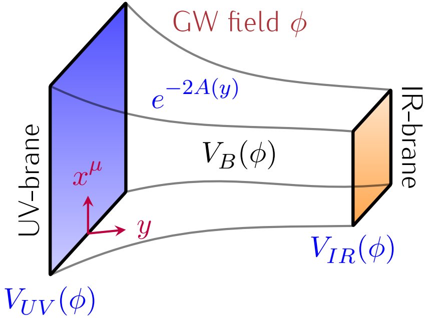
Can an $SU(2)$ Higgs doublet stabilize the size of an extra-dimension?

Radius stabilization of Randall-Sundrum model

- RS1 solves the gauge hierarchy problem ($m_{EW} \ll M_{\rm Pl}$?) for $kL \simeq 37$.
- Goldberger-Wise stabilization mechanism is used to stabilize the size L.



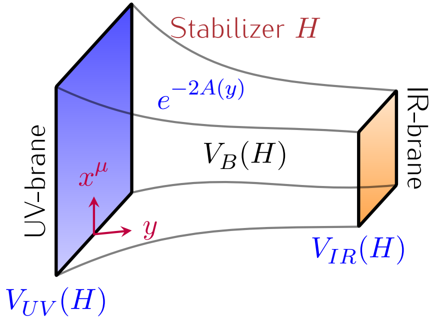
Randall-Sundrum hep-ph/9905221
Goldberger-Wise hep-ph/9907447
DeWolfe-Freedman-Gubser-Karch hep-th/9909134
Csaki-Graesser-Kribs hep-th/0008151
...

$$b_0 \equiv 2 - \underbrace{\sqrt{4 + \mu_B^2/k^2}}_{\beta}$$

$$\boxed{kL = \frac{1}{b_0} \ln\left(\frac{\phi_{UV}}{\phi_{IR}}\right) \simeq 37 \quad \text{for} \quad b_0 \sim \mathcal{O}(1/37) \text{ and } \phi_{UV}/\phi_{IR} \sim \mathcal{O}(e)}$$

- GW mechanism predicts light scalar Radion: fluctuation of the 5th dim. But LHC has not found any other light scalar except the Higgs boson!

Can a bulk Higgs be a stabilizing field?



- $\langle H \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \phi_v(y) \end{pmatrix}$
- $ds^2 = e^{2A(y)} \eta_{\mu\nu} dx^\mu dx^\nu - dy^2$

- Solution for the background vev $\phi_v(y)$ and the warp-function $A(y)$:

$$\phi_v(y) = \phi_{IR} e^{\Delta k(|y|-L)},$$

$$A(y) = -k|y| - \frac{\kappa^2}{12} \phi_{IR}^2 e^{-2\Delta k L} \left[e^{2\Delta k|y|} - 1 \right],$$

$$\Delta \equiv 2 \pm \underbrace{\sqrt{4 + \mu_B^2/k^2}}_{\beta}, \qquad \kappa^2 \equiv \underbrace{8\pi G_{N5}}_{(2M_*^3)^{-1}}$$

Radius stabilization with a bulk Higgs doublet

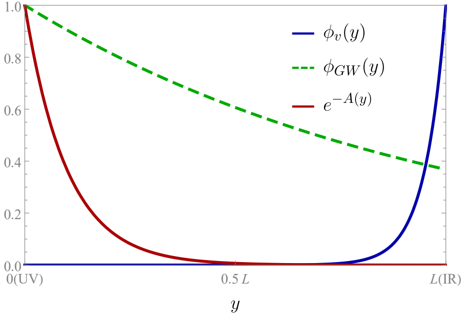
- The brane separation L is fixed by:

$$kL = \frac{1}{\Delta} \ln \left(\frac{\phi_{IR}}{\phi_{UV}} \right)$$

- In order to solve the gauge hierarchy problem, i.e.

$$\boxed{v_{SM} = \frac{\phi_{IR} e^{-kL}}{\sqrt{2(\Delta-1)k}} \simeq 246 \text{ GeV}, \qquad \text{we need} \quad kL \simeq 37}$$

for $\phi_{IR} \simeq \mathcal{O}(M_{Pl}^{3/2})$ and $\Delta \sim \mathcal{O}(1)$. This implies $\phi_{UV} \ll \phi_{IR}$.



see also
AA-Grzadkowski-Gunion-Jiang arXiv:1510.04116
AA-Grzadkowski-Gunion-Jiang arXiv:1504.03706
Geller-BarShalom-Soni arXiv:1312.3331
Vecchi arXiv:1012.3742

Higgs-Radion Unification

- Scalar perturbations

$$H(x,y) = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \phi_v(y) + h(x,y) \end{pmatrix} \qquad \& \ \ 55 \text{ comp. of metric: } F(x,y)$$

Higgs-radion state

$$S \supset \int_{-L}^{L} d^5x\, e^{-2A} \Big\{ \underbrace{6M_*^3 \left(\partial_\mu F\right)^2}_{-M_*^3 \mathcal{R}} + \frac{1}{2} \left(\partial_\mu h\right)^2 \Big\} = \int d^4x \Big\{ \frac{1}{2} \left(\partial_\mu h_0\right)^2 \Big\}$$

$$F(x^\mu, y) \simeq \frac{e^{2ky}}{N_h} h_0(x^\mu) \qquad h(x^\mu, y) \simeq \frac{e^{2ky}}{N_h} f_0(y) h_0(x^\mu)$$

$$m_{h_0} \approx 125 \text{ GeV}$$

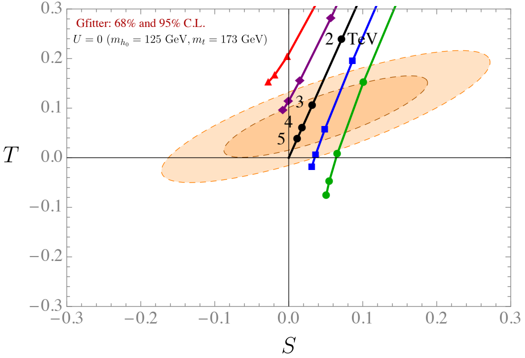
All parameters $\sim \mathcal{O}(1)$ and $m_{KK} \sim \mathcal{O}(\text{few})$ TeV

Higgs-Radion Unification and EWPO

- The Higgs couplings to gauge bosons and fermions receive contribution from the radion component.

$$\mathcal{L}_{h_0VV} = \frac{m_V^2}{v_{SM}} h_0 V^\mu V_\mu \underbrace{\left[\overbrace{-\frac{\gamma^{3/2}}{\sqrt{6}} \frac{v_{SM}}{m_{KK}}}^{\text{Radion contribution}} + \overbrace{\frac{1}{N_h v_{SM}} \int_{-L}^{L} dy \phi_v(y) f_0(y)}^{\text{bulk Higgs contribution}} \right]}_{\equiv \kappa_V}$$

$\kappa_V = 1.2,\ 1.1,\ 1.0,\ 0.9,\ 0.8,$ with $\Delta = 2$



- EWPOs are sensitive to κ_V at one-loop level.
- Higgs-Radion scenario gives $\kappa_V \lesssim 1$.

Summary

- A radius stabilization with a bulk Higgs doublet is discussed.
- Bulk Higgs doublet serves as:
  - the source of EWSB,
  - and the stabilizing field.
- At the low-energy, there is a single light scalar “Higgs-radion”, which we identity as the 125 GeV scalar.
- Higgs-radion unified scenario, without and with custodial symmetry, is consistent with the EWPO and its predictions can be tested at the future colliders.

Backup slides

Radius stabilization with a bulk Higgs doublet

- We assume the scalar potential $V_B(\phi_v)$ of the following form,

$$V_B(\phi_v) = \frac{1}{8}\left(\frac{\partial W(\phi_v)}{\partial \phi_v}\right)^2 - \frac{1}{6}W(\phi_v)^2$$

where the superpotential $W(\phi_v)$ satisfies the following relations:

$$\phi_v' = \frac{1}{2}\frac{\partial W(\phi_v)}{\partial \phi_v}, \qquad A' = -\frac{1}{6}W(\phi_v)$$

$$W(\phi_v)\Big|_{y_i-\epsilon}^{y_i+\epsilon} = V_i(\phi_v)\Big|_{\phi_v=\phi_v(y_i)}, \quad \frac{\partial W(\phi_v)}{\partial \phi_v}\Big|_{y_i-\epsilon}^{y_i+\epsilon} = \frac{\partial V_i(\phi_v)}{\partial \phi_v}\Big|_{\phi_v=\phi_v(y_i)}.$$

- With the brane-localized potentials:

$$V_{UV}(\phi_v) = W(\phi_v) + \frac{\lambda_{UV}}{4k^2}\left(\phi_v^2 - \phi_{UV}^2\right)^2,$$

$$V_{IR}(\phi_v) = -W(\phi_v) + \frac{\lambda_{IR}}{4k^2}\left(\phi_v^2 - \phi_{IR}^2\right)^2,$$

where $\phi_{UV(IR)}$ is the constant value of background vev at $y = 0(\pm L)$ and $\lambda_{UV(IR)}$ is the quartic coupling at the UV (IR) brane.

Radius stabilization with a bulk Higgs doublet

- We consider the following form of superpotential $W(\phi_v)$

$$W(\phi_v) = 6k + (2+\beta)k\phi_v^2 \qquad \text{for} \qquad 0 < y < L$$

where $\beta \equiv \sqrt{4 + \mu_B^2/k^2}$ parameterises the Higgs bulk mass μ_B.

- We get the scalar potential $V_B(\phi_v)$ as

$$V_B(\phi_v) = -6k^2 + \frac{1}{2}\mu_B^2\phi_v^2 - \frac{k^2}{6}(2+\beta)^2\phi_v^4.$$

- The background vev $\phi_v(y)$ and the warp-function $A(y)$ are:

$$\phi_v(y) = \phi_{IR}e^{(2+\beta)k(|y|-L)},$$

$$A(y) = -k|y| - \frac{1}{12}\phi_{IR}^2 e^{-2(2+\beta)kL}\left[e^{2(2+\beta)k|y|} - 1\right],$$

where ϕ_{IR} is the value of background vev at the IR-brane:

$$\boxed{\phi_{IR} = v_{SM}\sqrt{k(1+\beta)}e^{kL}.}$$

Radius stabilization with a bulk Higgs doublet

- The brane separation L is fixed by:

$$kL = \frac{1}{\Delta} \ln\left(\frac{\phi_{IR}}{\phi_{UV}}\right).$$

- In order to solve the gauge hierarchy problem, i.e.

$$v_{SM} = \frac{\phi_{IR} e^{-kL}}{\sqrt{k(\Delta-1)}} \simeq 246 \text{ GeV}, \qquad \text{we need} \quad kL \simeq 37$$

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