Randall-Sundrum Models

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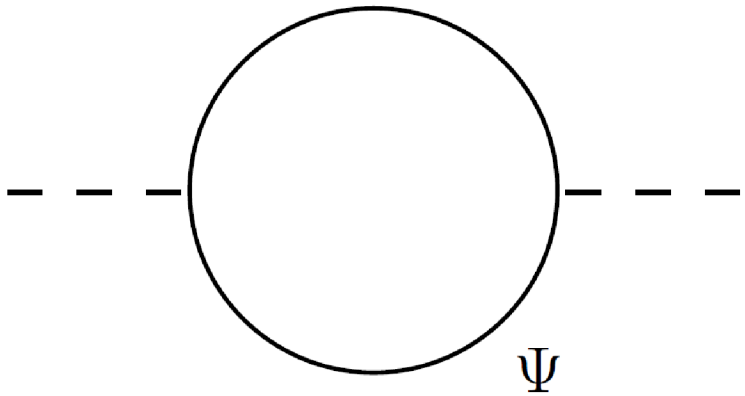
Motivation: The Electroweak Hierarchy Problem

Higgs mass correction

- Higgs mass should be of order hundreds of GeV ($m^2 = 2\lambda v^2$)
- Higgs mass loop correction give Λ^2 divergences $\Longrightarrow$ highest energy contribution most important ($\sim M_{Pl}$)
- Since Λ^2 does not vary slowly at high energies $\Longrightarrow$ very sensitive to choice of Λ for any cancelation down to EW scale
- Why is there such a large energy difference between EW and M_{Pl} scale (16 orders of magnitude)
- Many models propose solutions: SUSY, ADD, Randall-Sundrum

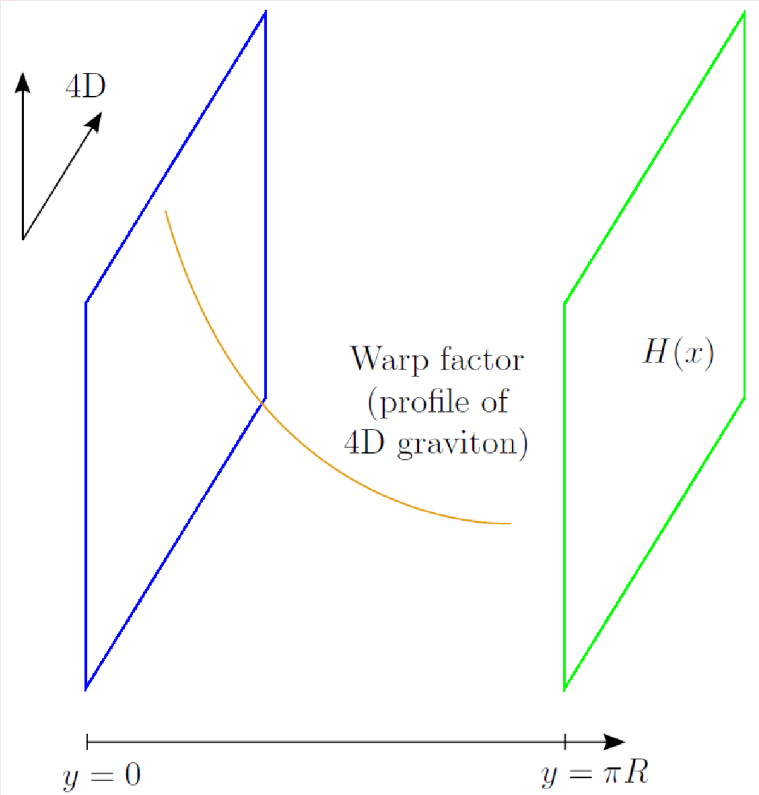


Randall-Sundrum Model

One warped extra dimension

- Model proposes existence of one curved extra dimension
- The extra dimension is finite and has $\phi \to -\phi$ as well as $\phi \to \phi + 2\pi$ symmetry
- There are two branes, SM fields live on "IR" brane
- Gravity is the only field that propagates in the extra dimension and is localized on "Planck" brane
- Curvature of extra dimension results in warp factor in metric

$$ds^2 = e^{-2r_c k|\phi|}\eta_{\mu\nu}x^\mu x^\nu + r_c^2 d\phi^2 \qquad (1)$$



Solving the Hierarchy problem Randall-Sundrum Model

New metric yields new Higgs Lagrangian

$$\sqrt{-g}[\eta_{\mu\nu}\partial^{\mu}H^{\dagger}\partial^{\nu}H - \lambda(H^{\dagger}H - e^{-2kr_c\pi}v_0^2)^2] \quad (2)$$

- The VEV on the IR brane is now warped down from it's natural value $\Longrightarrow$ all masses are warped down
- Raw masses can be very large even though they are small on the TeV brane
- No requirement for extra dimension to be large $\Longrightarrow$ no new hierarchy
- Fundamental scale on the IR brane is now the TeV scale

Problems with Initial Model

Massless radion

- In the original model the radius was chosen arbitrarily, it's fluctuations would cause a new massless radion
- The massless radion would change Newton's law
- To give the radion a mass the radius needs to be stabilized
- Can be done with brane tensions (the preference of a kinetic term would equilibrate with that of a potential term, done by Goldberger and Wise)

Problems with Initial Model

Suppression of dimension four or higher operators

- The fundamental scale on the IR brane is now the TeV scale $\Longrightarrow$ much lower than our previous cut off scale
- Flavor Changing Neutral Currents (FCNC's) are processes that occur through dimension six operators
- $\frac{\lambda}{\Lambda}\psi\bar{\psi}\psi\bar{\psi}$ can no longer be suppressed by $\Lambda \sim M_{Pl}$
- Experimental results strongly constrain the rate of FCNC's

Bulk Fermions

- Moving the Fermion fields to the bulk give us our $\frac{1}{M_{Pl}}$ suppression back
- Still want a solution to the EW hierarchy problem $\Longrightarrow$ keep Higgs field localized to IR brane
- Much more complex theory, gravity isn't the only field with Kaluza-Klein (KK) excitation
- KK excitation could have couplings that also enhance FCNC's

Kaluza-Klein excitations

- When adding new dimensions fields can be expanded with the KK expansion
- KK expansion results in an infinite tower of mass resonances of one field
- KK excitations should have masses greater than the top mass since we should have already seen these excitations

Bulk Fermions and Flavor Hierarchy

- Standard model doesn't explain the mass hierarchy between the different flavors of fermions
- Moving the fermions to the bulk gives KK tower for each fermion field
- This has the potential to give a dependence on the new dimension
- The fermions that we observe would be the zero mode solutions to the KK expansion
- After doing the KK expansion and finding the new Higgs interaction Lagrangian we find new Yukawa couplings

$$\lambda = \frac{\lambda^{(5)} k}{N^2} e^{(1-2c)\pi k R} \tag{3}$$

$$N^2 = \frac{e^{2k\pi r_c(1/2-c)} - 1}{2k\pi r_c(1/2-c)} \tag{4}$$

Bulk Fermions and Flavor Hierarchy

- Heavy fermions are localized on the IR brane and have $c < 1/2$
- Light fermions have $c > 1/2$
- Due to the exponential a small change in c can cause large fermion mass differences