Warped Penguins and LFV

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Based on the paper Warped Penguins

C. Csáki, Y. Grossman, P. Tanedo and YT, arXiv:1004.2037

Project X Physics Study, 20 June 2012

Cornell University

Take home message

In the Randall-Sundrum (RS) model, lepton flavor violation (LFV) sets

- lower bound on the KK mass scale
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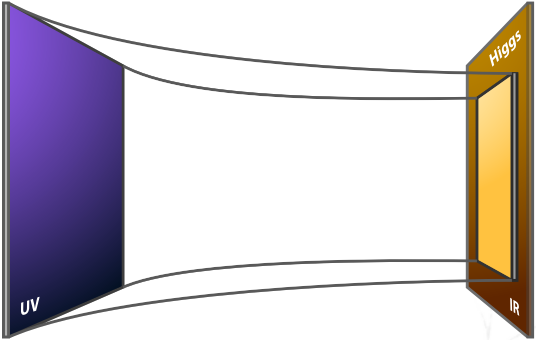
LFV really does a lot in constraining RS!

Randall-Sundrum in one slide

An extra-dimension model with warped geometry



$$ds^2 = \left(\frac{R}{z}\right)^2 (dx^2 - dz^2)$$

Randall, Sundrum (99);

Randall-Sundrum in one slide

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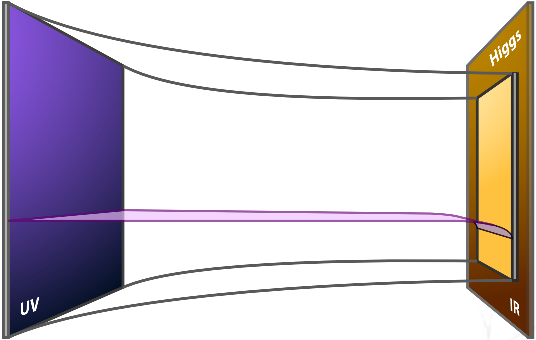

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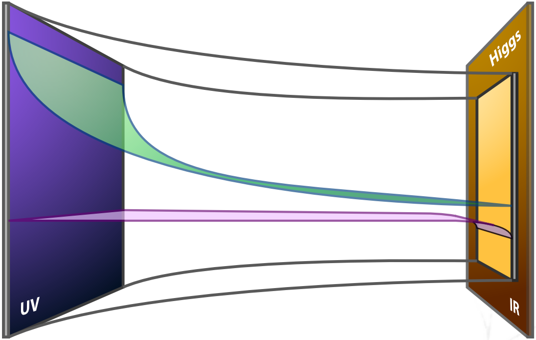

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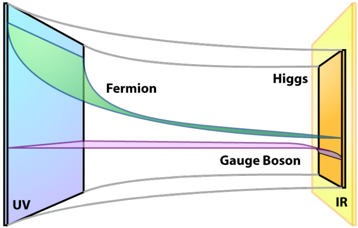
Randall, Sundrum (99); Davoudiasl, Hewett, Rizzo (99); Grossman, Neubert (00); Gherghetta, Pomarol (00); **Bulk Higgs:** Agashe, Contino, Pomarol (04); Davoudiasl, Lille, Rizzo (05)

The pros and cons

Naturally generated mass spectrum & the flavor mixing



4D Yukawa Coupling: $Y_* \overline{L}_i H E_j \times f_{Li}(R') \, f_{Ej}(R')$

4D Gauge Coupling: $g_{ii} \overline{L}_i \not{Z} L_i \times \int_R^{R'} dz \left(\frac{R}{z}\right)^4 f_{Li}(z) f_Z(z) f_{Li}(z)$

Anarchic Flavor in RS

For an interesting model, we want...

- $Y^{*}_{ij} = Y_{*}$ Ⓐ$_{ij}$ is an ancharic matrices with $\mathcal{O}(1)$ numbers.
  $\Rightarrow$ The mass hierarchy is determined by the wave function localization.

- M_{kk} is not too heavy. $\Rightarrow$ KK modes can be seen at LHC.

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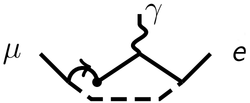
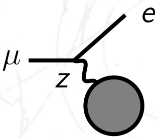
Can these assumptions pass flavor constraints?

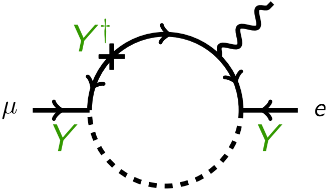




Lepton Flavor Violation : Loop

Controlled by two dominant parameters

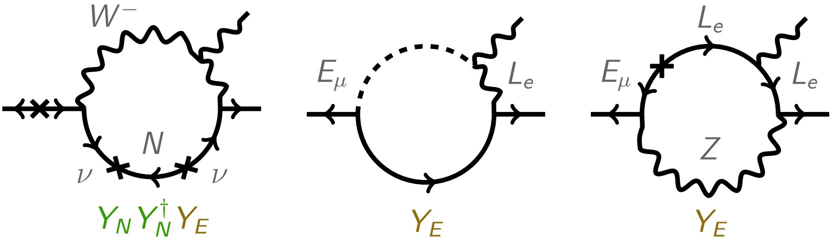
Flavor is dominantly controlled by: Y_* and M_{KK}



$$\mathcal{M}_{\mathrm{loop}} \sim \left(\frac{1}{M_{\mathrm{KK}}}\right)^2 f_L {Y_*}^3 f_{-E}$$

$$\sim \left(\frac{1}{M_{\mathrm{KK}}}\right)^2 {Y_*}^2 m$$

Leading order $\mu \to e\,\gamma$



Two types of diagrams with Y^3 and Y carry arbitrary relative signs

Defined $a Y_*^3 = \sum_{k,\ell} a_{k\ell} Y_{ik} Y_{k\ell}^\dagger Y_{\ell j}$ and $b Y_* = \sum_{k,\ell} b_{k\ell} Y_{k\ell}$

$$\mathcal{M}_{\text{loop}} = \left(a Y_*^3 \pm b Y_*\right) \times (\text{loop factor, charge,...})$$

So, ‘just calculate’ these

many details in paper arXiv:1004.2037

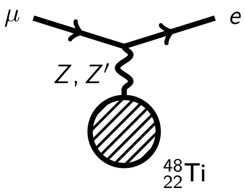
We use 5D position/momentum space—no cutoff ambiguity.

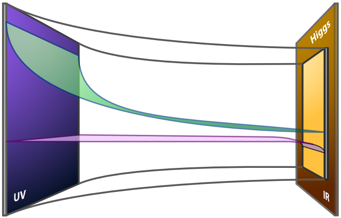
Calculation details

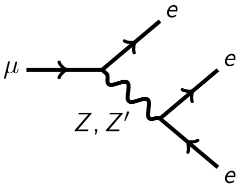
- 5D position/momentum space: external zero modes
- Mass insertion approximation
- Gauge invariance: only identify $(p + p')^\mu$ coefficient

Lepton Flavor Violation : Tree

Two dominant parmeters







$$\mathcal{M}_{\text{tree}} \sim \left(\frac{1}{M_{\text{KK}}}\right)^2 \left(\frac{1}{Y_*}\right)$$

WHY Y_*^{-1} ?

To increase Y_* while fixing the SM mass spectrum, need to

$\Rightarrow$ push fermion profiles towards UV

$\Rightarrow$ less overlap with non-universal part of the gauge boson

Flavor changing in the gauge coupling

The non-universal part of the zero-mode Z wave function $h^{(0)}(z)$ gives the flavor changing near IR,

- Wave function:

$$h^{(0)}(z) = \frac{1}{\sqrt{R \ln R'/R}} \left[1 + \frac{M_Z^2}{4} z^2 \left(1 - 2 \ln \frac{z}{R}\right)\right]$$

- Gauge coupling:

$$g^{zf_i f_j} = g^z_{SM} \left[1 + \frac{(M_Z R')^2 \ln R'/R}{2(3-2c)} f_i f_j\right]$$

The γ' and Z' have the similar form.

Two Complementary Bounds

Using the results:

Br$(\mu \to e)_{\text{Ti}} < 6.1 \cdot 10^{-13}$ (SINDRUM II), Br$(\mu \to e\gamma) < 2.4 \cdot 10^{-12}$ (MEG)

- Tree-level bound: $\left(\frac{3\text{ TeV}}{M_{\text{KK}}}\right)^2 \left(\frac{2}{Y_*}\right) < 0.5,$

- Penguin bound: $\left| \, a{Y_*}^2 + b \, \right| \left(\frac{3\text{ TeV}}{M_{\text{KK}}}\right)^2 \leq 0.015$

Possible tension between the TREE & LOOP

Can test the anarchic flavor ansatz.

Bounds on Yukawa & KK scales

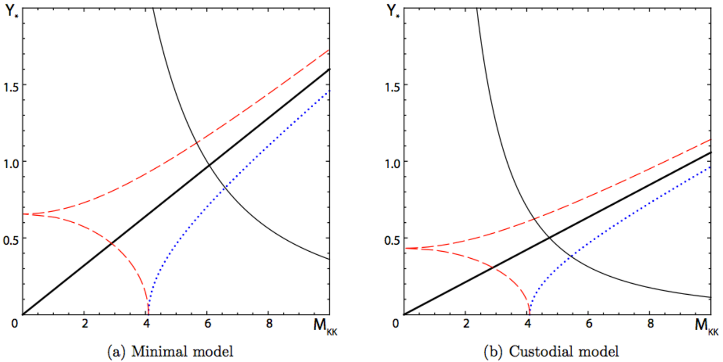


Figure 6: Bounds on the anarchic Yukawa and KK scales in the minimal (a) and custodial (b) models from tree- and loop-level constraints, (3.12), (3.19), and (4.13). Each curve rules out the region to its left. The solid hyperbola is the appropriate tree-level bound. The thick solid straight line is the $b = 0$ loop-level bound. The red dashed (blue dotted) curve is the loop-level bounds in the case where b has the same (opposite) sign as a and takes its 1σ magnitude $|b| = |b|_{1\sigma} = 0.03$.

Conclusion

Lepton flavor violation bounds are important to RS.

They set

- lower bound on the KK mass scale
- both lower and upper bounds on the anarchic Yukawa coupling for a given KK scale