

FLIGHT OF THE WARPED PENGUINS

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Warped Penguins

- UV finite 5D loops
- Anarchic flavor in Randall-Sundrum
- Defying anarchy in $\mu \rightarrow e\gamma$
- Remarks on current work

Finiteness: naïve dimensional analysis

$$4\text{D Naïve: } \int d^4 k \Delta_F \gamma^\mu \Delta_F \Delta_B \sim \log(\Lambda)$$



Really log divergent? No, **finite**. Here's why:

- Gauge invariance: $q_\mu \mathcal{M}^\mu = 0$.
- Lorentz invariance: $\int d^4 k \frac{k}{k^{2n}} = 0$.

Indeed, $\mathcal{M}_{4\text{D}} \sim \Lambda^{-2}$.

Suspect that $\mathcal{M}_{5\text{D}} \sim \Lambda^{-1}$ compactification shouldn't affect UV

↖ SD Bulk, i.e. $d^4 k \rightarrow d^5 k$

Turns out to be correct, but brane fields make this very subtle.

See our paper for the gory details

Lepton Flavor Violation

Crimpin' our free-wheeling model-building ways

$$\text{Br}(\mu \rightarrow e\gamma)_{\text{SM}} = 0$$

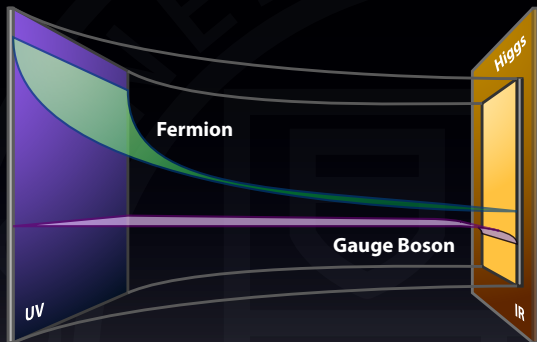
Current bound: $\text{Br}(\mu \rightarrow e\gamma) < 1.2 \times 10^{-11}$

MEGA, LAMPF

Later this year from MEG:

$$\text{Br}(\mu \rightarrow e\gamma) < 1.5 \times 10^{-12}$$

Anarchic Flavor in RS



$$Y_{ij}^{(4D)} = f_i Y_{ij}^* f_j$$

$$f_i = \sqrt{\frac{1-2c_i}{1-(R/R')^{1-2c_i}}}$$

Anarchy: Y_{ij}^* are all $\mathcal{O}(Y_*)$ with arbitrary phase.

Lepton Flavor Violation

Controlled by two dominant parameters

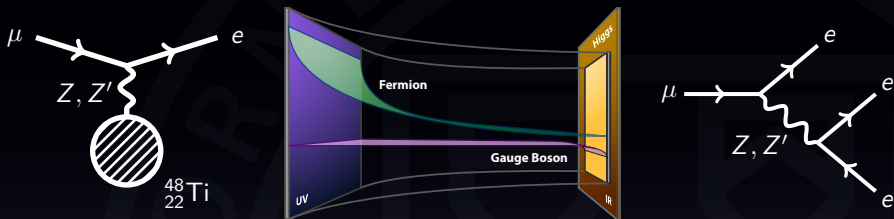
Flavor is dominantly controlled by: Y_* and M_{KK}



$$\begin{aligned} \mathcal{M}_{\text{loop}} &\sim \left(\frac{1}{M_{KK}} \right)^2 f_L Y_*^3 f_{-E} \\ &\sim \left(\frac{1}{M_{KK}} \right)^2 Y_*^2 m \end{aligned}$$

Lepton Flavor Violation

Two dominant parameters



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

If we increase Y_* , must maintain SM mass spectrum

⇒ push fermion profiles to UV

⇒ Less overlap with the FCNC part of the Z

Complementary tree- and loop-level bounds

Possible tension between tree- and loop-level processes

- Tree-level bound: $\left(\frac{3 \text{ TeV}}{M_{KK}}\right)^2 \left(\frac{2}{Y_*}\right) < 0.5, 1.6$ (Custodial)

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

What the heck is this?

Can test anarchic flavor ansatz.

Operator analysis of $\mu \rightarrow e\gamma$

Match to 4D EFT:

$$R'^2 \frac{e}{16\pi^2} \frac{v}{\sqrt{2}} f_{L_i} \left(a_{kl} Y_{ik} Y_{kl}^\dagger Y_{lj} + b_{ij} Y_{ij} \right) f_{-E_j} \bar{L}_i^{(0)} \sigma^{\mu\nu} E_j^{(0)} F_{\mu\nu}^{(0)}$$

- Y_{ij} is a spurion of $U(3)^3$ lepton flavor
- Indices on a_{ij} and b_{ij} encode bulk mass dependence

Flavor structure

- $a_{ij} Y_{ik} Y_{kl}^\dagger Y_{lj}$ gives a generic contribution
Depends 'only' on Y_* and M_{KK}
- New: $b_{ij} Y_{ij}$ is aligned up to structure of b_{ij}

$f_i Y_{ij} f_j \sim m_{ij}$, so this term is almost diagonal in the mass basis

This depends on the *particular* flavor structure of the anarchic Y

Leading order diagrams



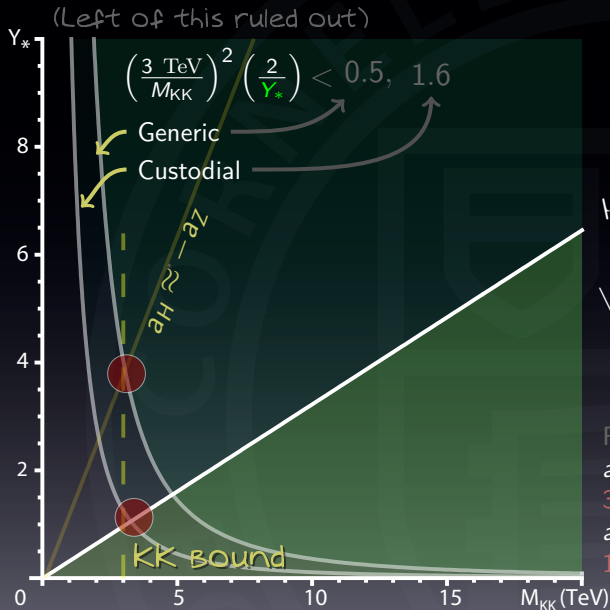
Three coefficients (a_H , a_Z , b) with arbitrary relative signs

Defined $a Y_*^3 = \sum_{k,l} a_{kl} Y_{ik} Y_{kl}^\dagger Y_{lj}$ and $b Y_* = \sum_{k,l} (U_L)_{ik} b_{kl} Y_{kl} (U_R^\dagger)_{lj}$

So, 'just calculate' these: (many details in paper)

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

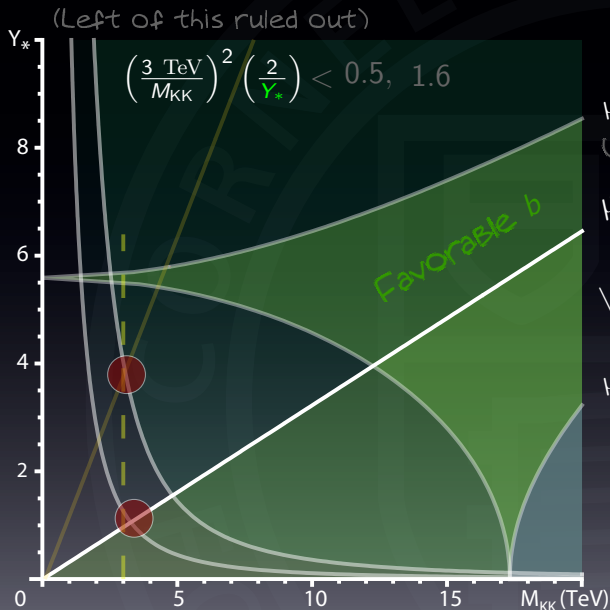
Representative Bounds: $b = 0$



$\mu \rightarrow e\gamma, \text{ average}$
 $|aY_*^2 + b| \left(\frac{3\text{TeV}}{M_{KK}}\right)^2 < .015$

For $M_{KK} = 3 \text{ TeV}, b = 0$
 $a = .001$ and generic
 $3.7 \lesssim Y_* \lesssim 4$
 $a = .016$ and custodial
 $1 \lesssim Y_* \lesssim 1$

Representative Bounds: $b \neq 0$



Further directions and conclusions

$\mu \rightarrow e\gamma$ in a warped extra dimension:

- Finite at one-loop, suspect perturbative
- Near tension between loop- and tree-level bounds on Y_* , M_{KK}
- Sensitive to specific structure of anarchic matrices

Open questions:

- $b \rightarrow s\gamma$ penguin and heavy flavor structure
in progress with M. Blanke, B. Shakya, Y. Tsai
- Two-loop contribution and perturbativity
- Effect of loop-level brane-localized terms

Thanks!