charged Lepton Flavor Violation

A biased case study that *isn't* supersymmetry

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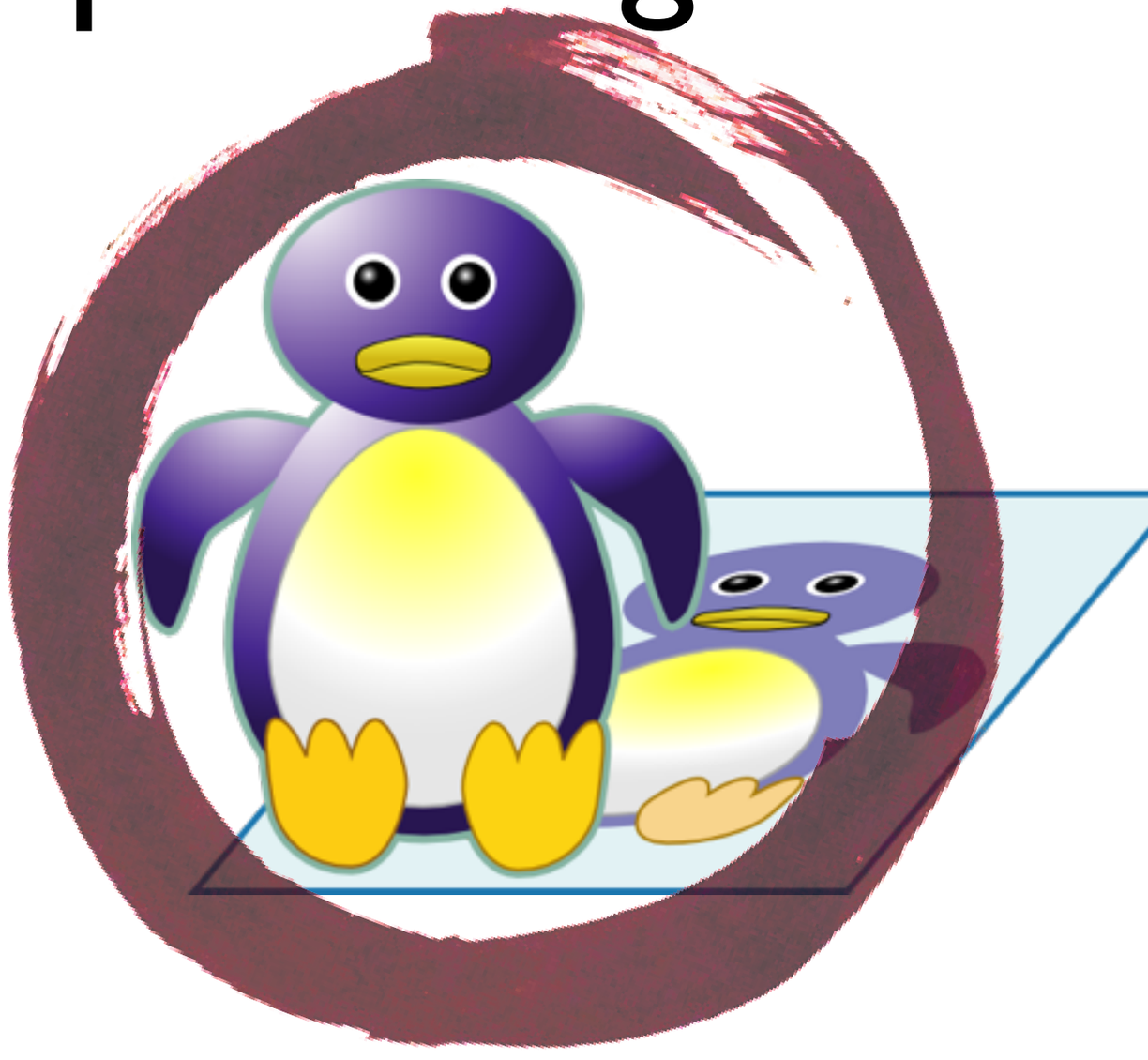
UC Irvine

International Workshop on Charged Lepton Flavor Violation
UC Irvine 13 May 2014

apologies: no references in this talk; see your favorite theorists

Case Study: Warped Penguins

SUSY
not today



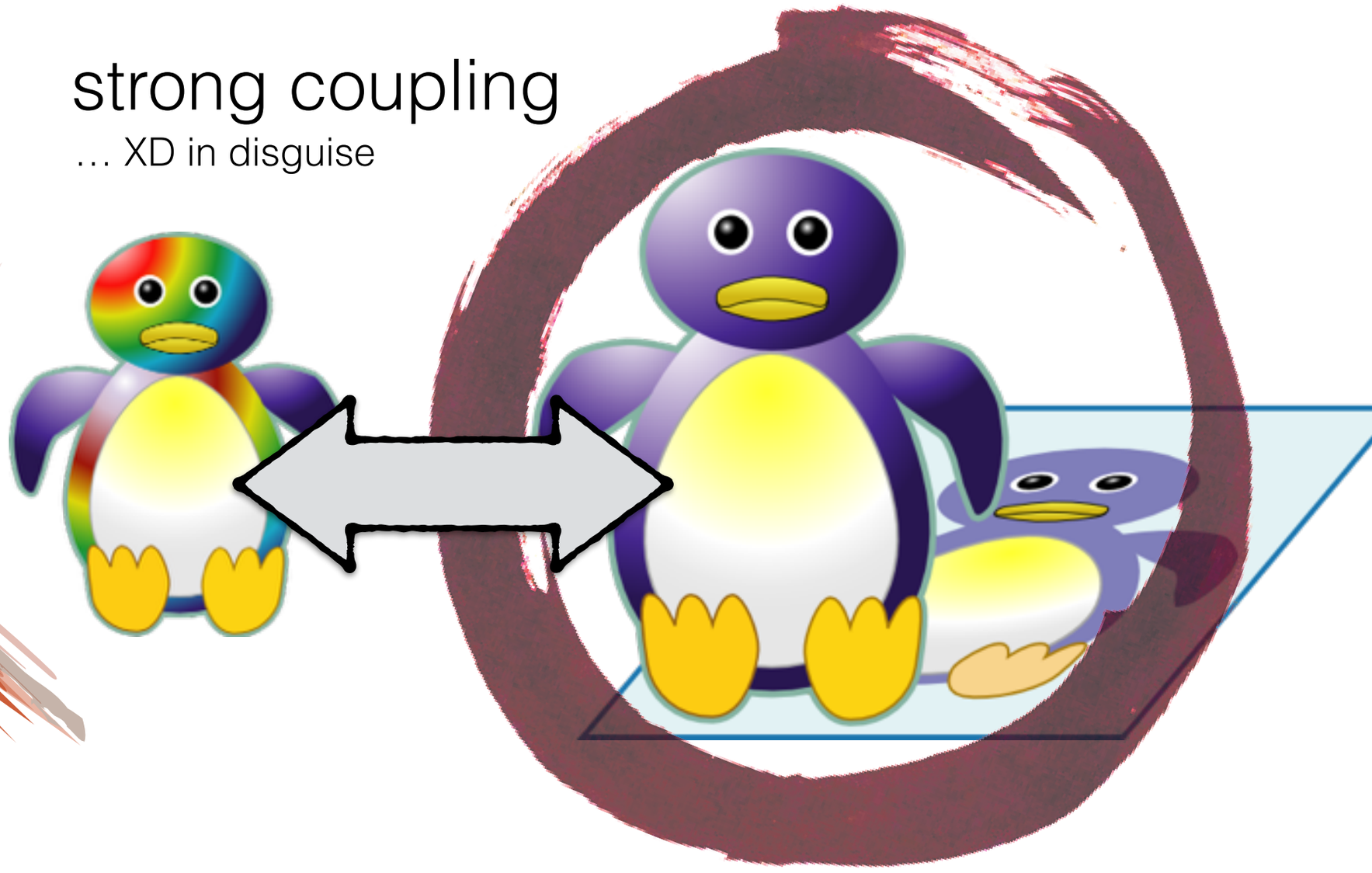
Flavor in Warped Extra Dimensions
& why you should care

strong coupling

… XD in disguise

SUSY

a theory **with** flavor

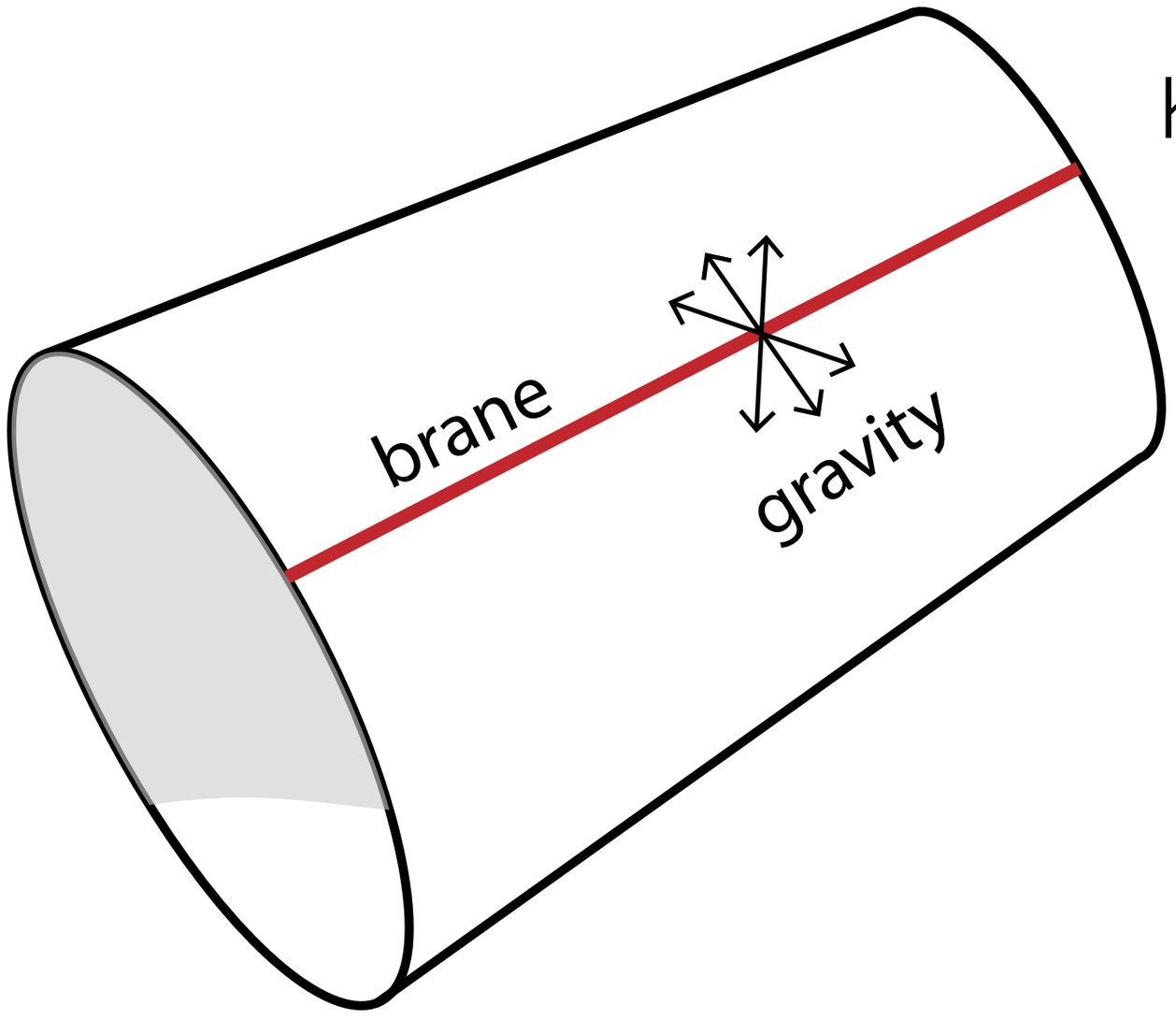


Extra Dimensions

a theory **of** flavor

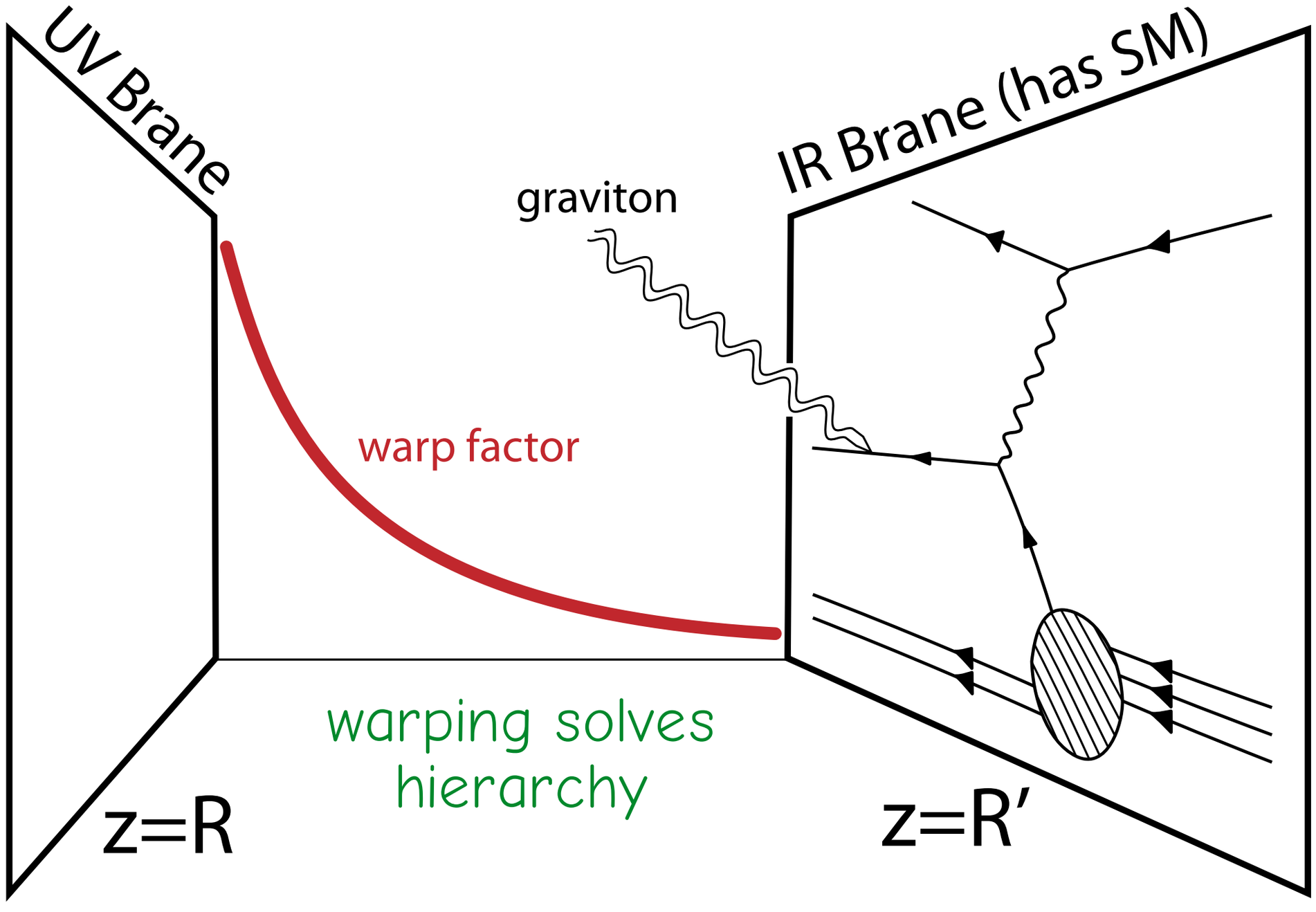
not “a model,” a theory paradigm for flavor

Extra Dimension

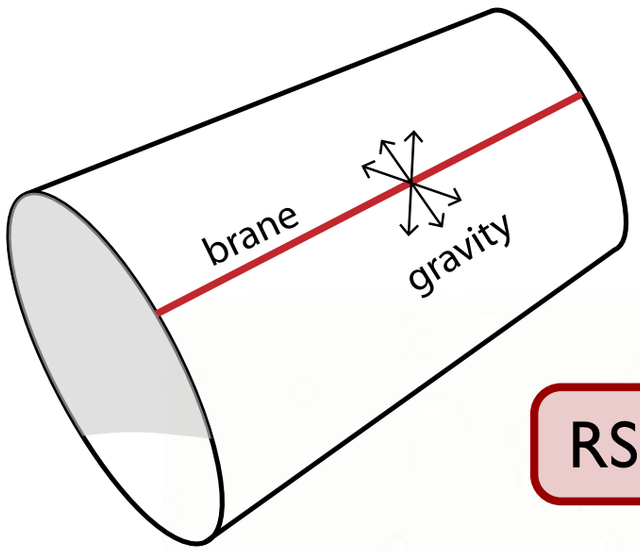


"bulk" particles have
Kaluza-Klein excitations

“Old” Randall-Sundrum



Evolution of RS



RS1

ADD

RS1 with bulk fields

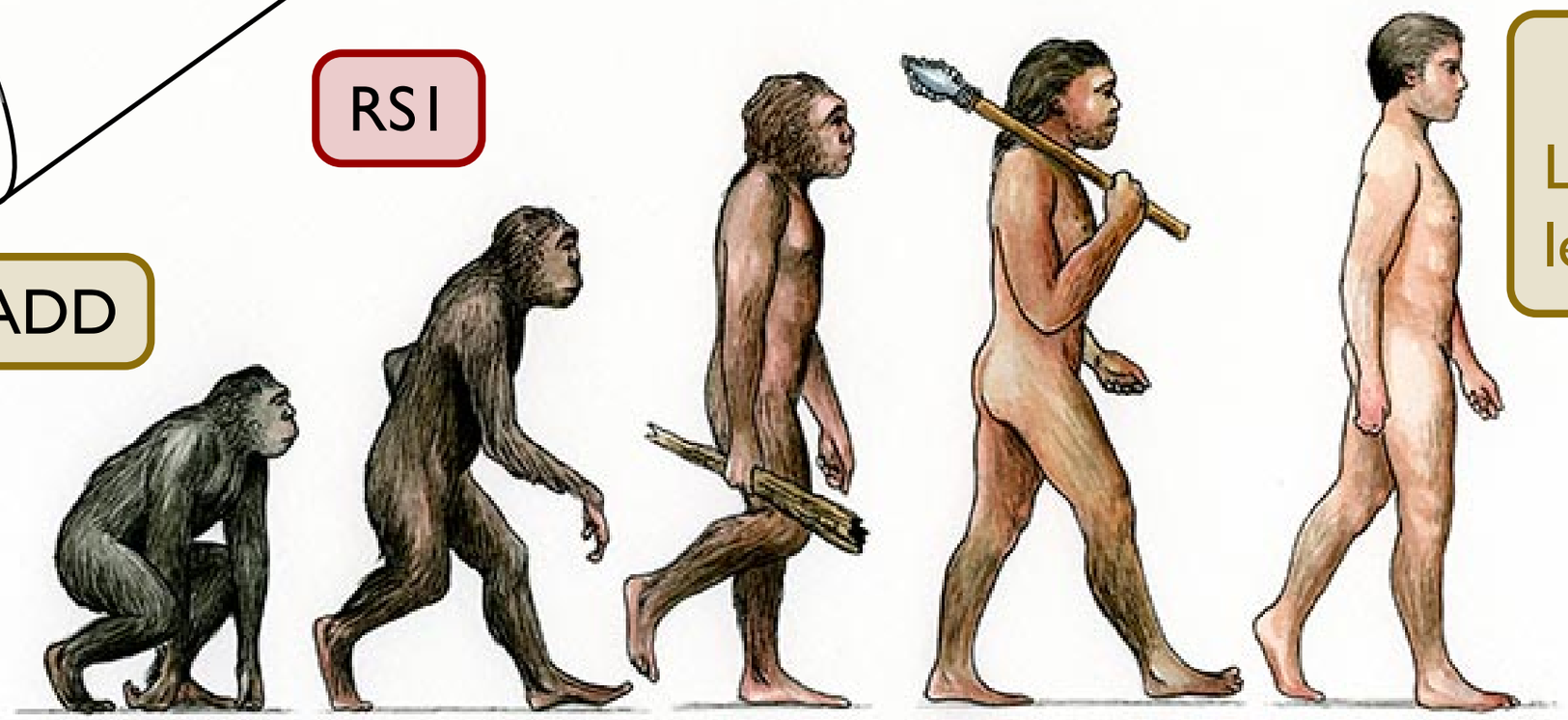
Gauge fermions

Realistic RS1

Custodial protection

RS1+

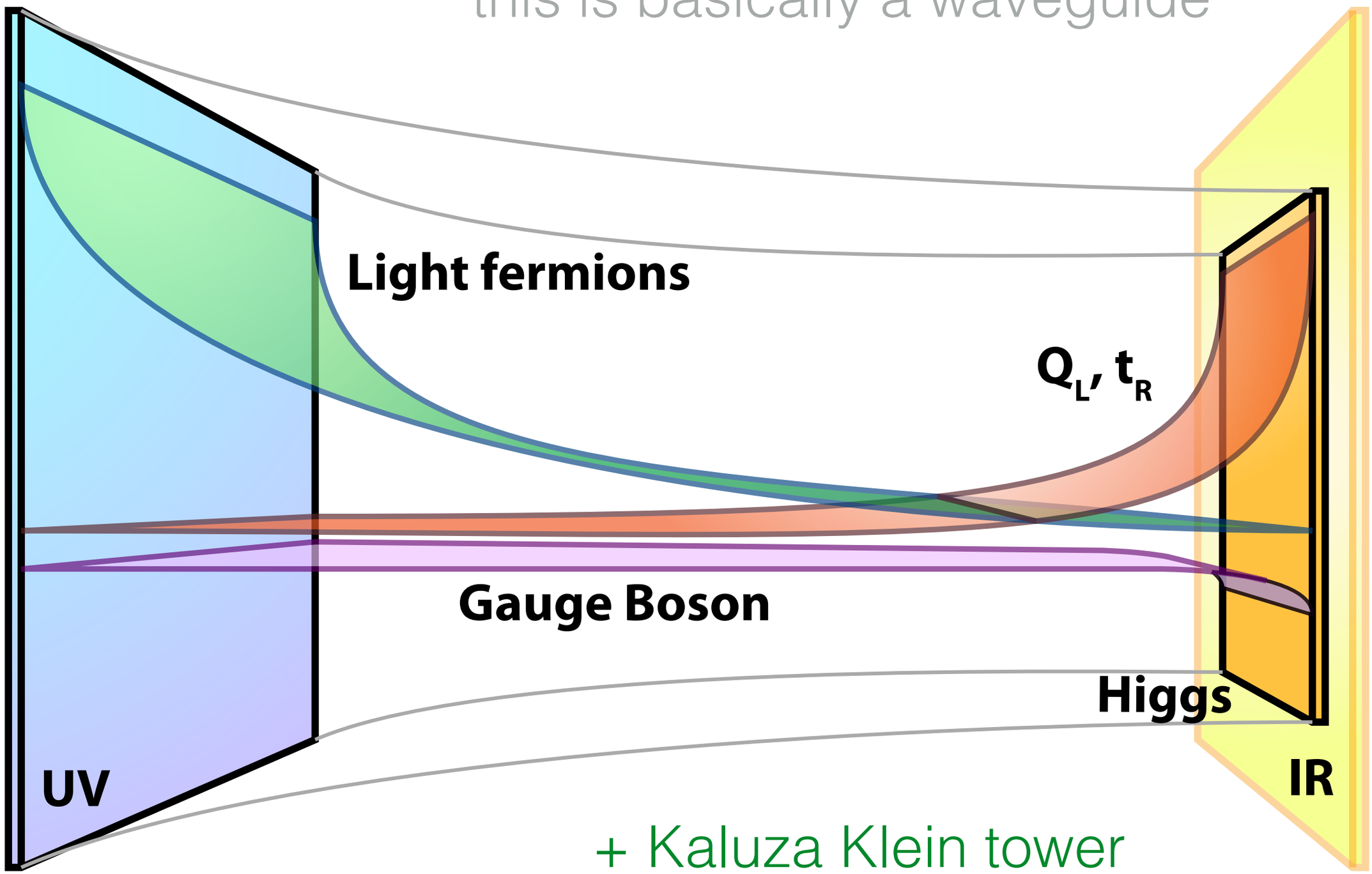
Little Higgs, Higgs-less, gaugephobic



Tanedo, CMS Mini-Workshop, Jan 2012

Realistic Randall-Sundrum

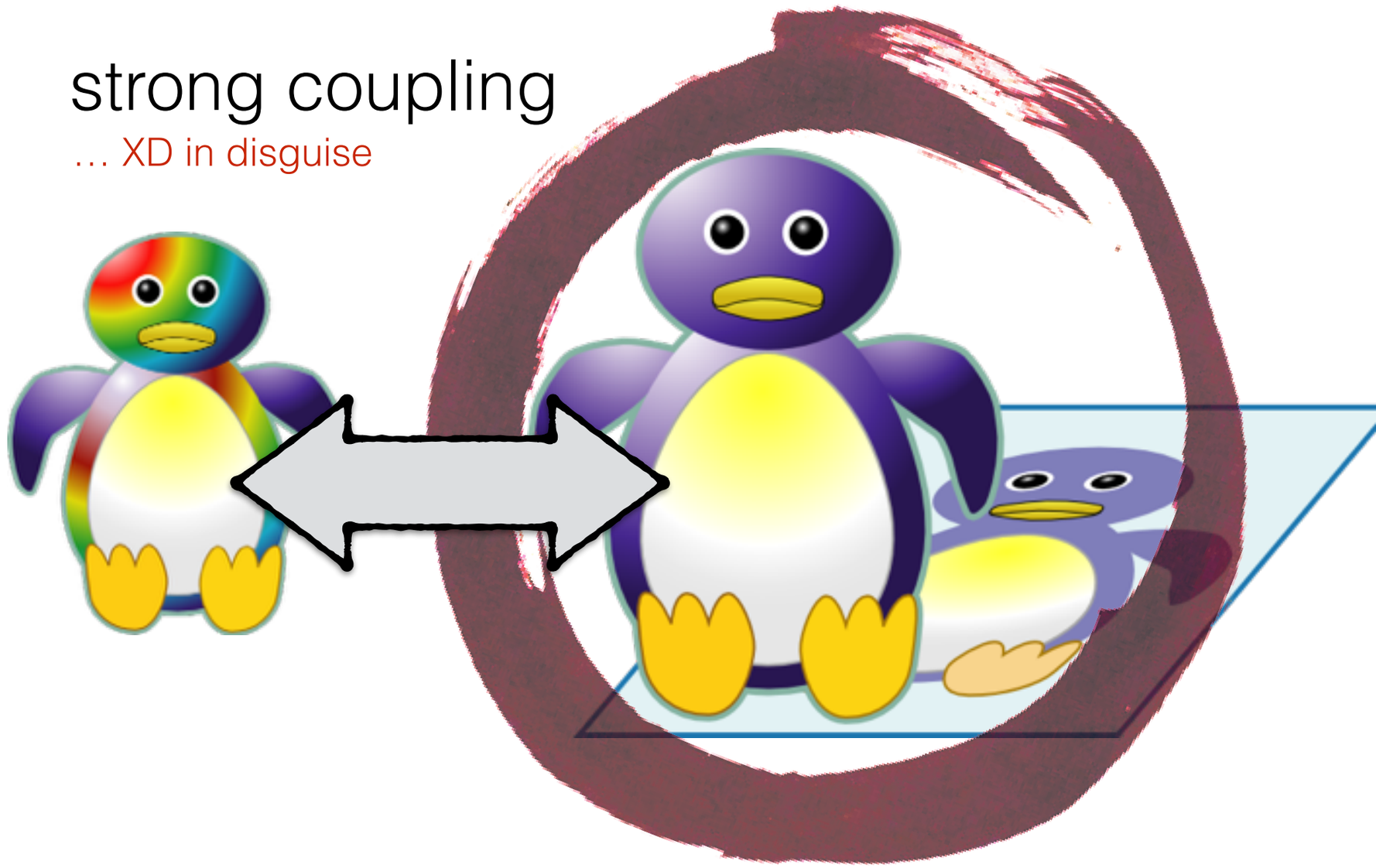
this is basically a waveguide



+ Kaluza Klein tower

strong coupling

… XD in disguise

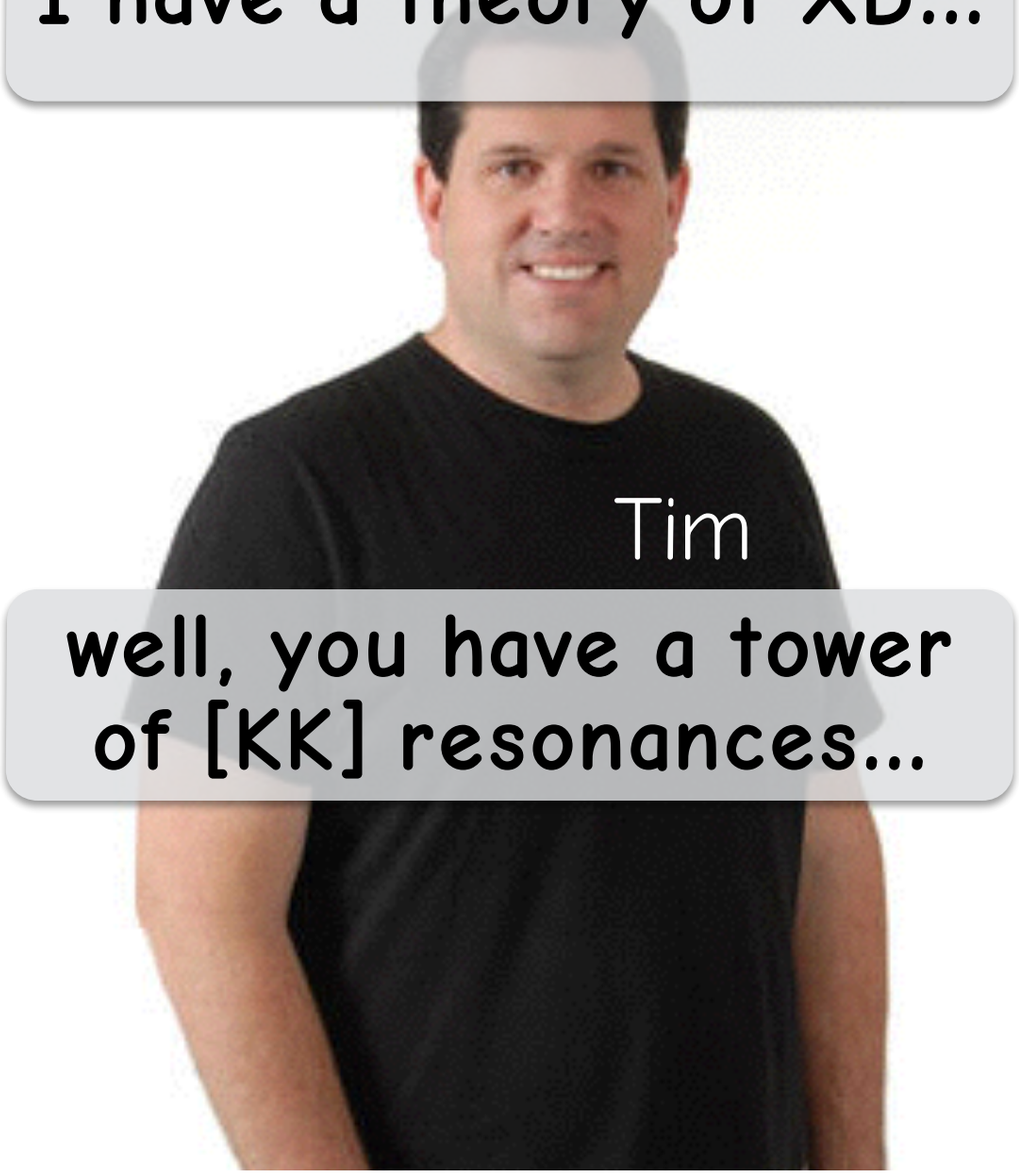


Extra Dimensions

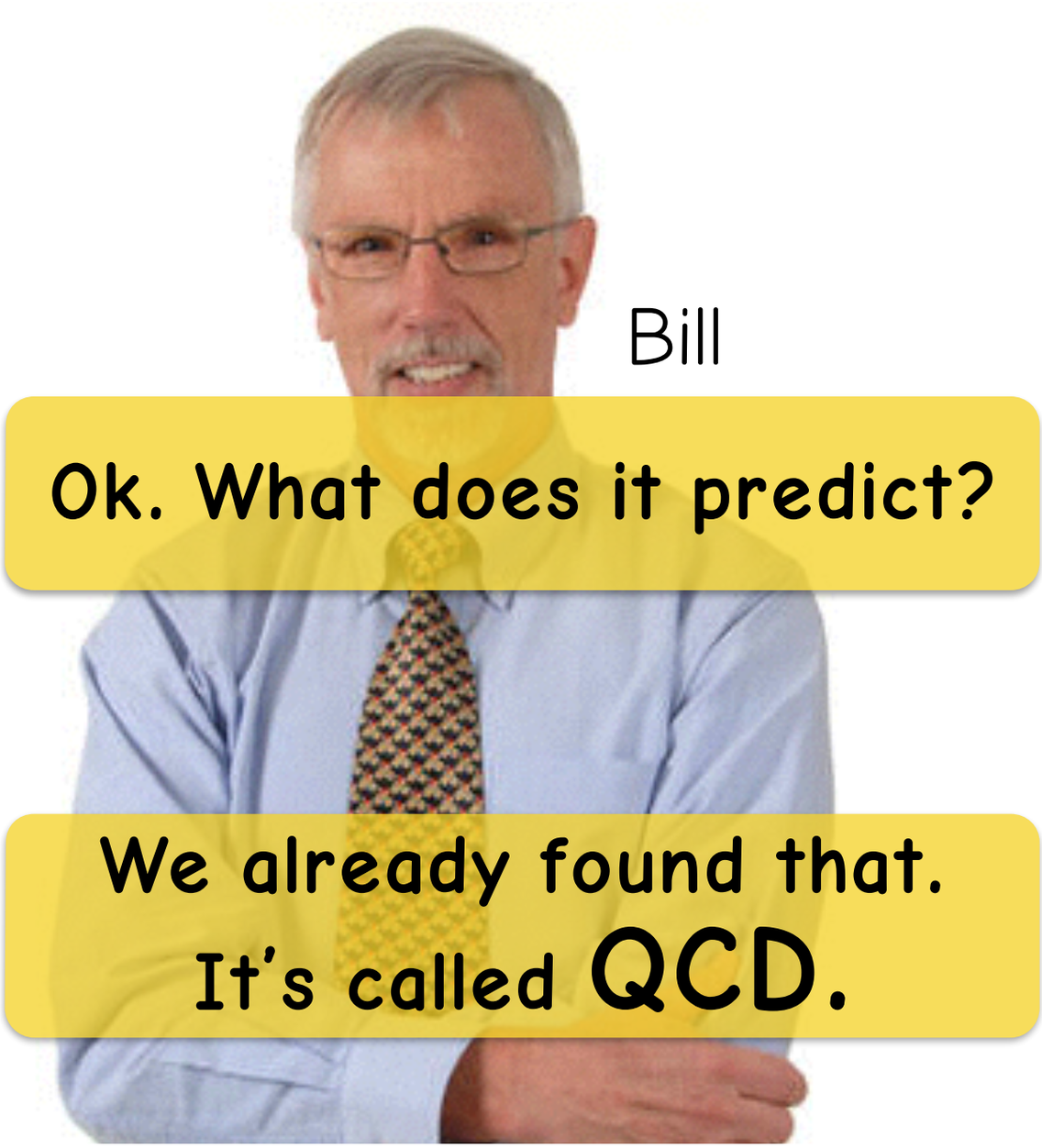
a theory **of** flavor

holographic principle

I have a theory of XD...

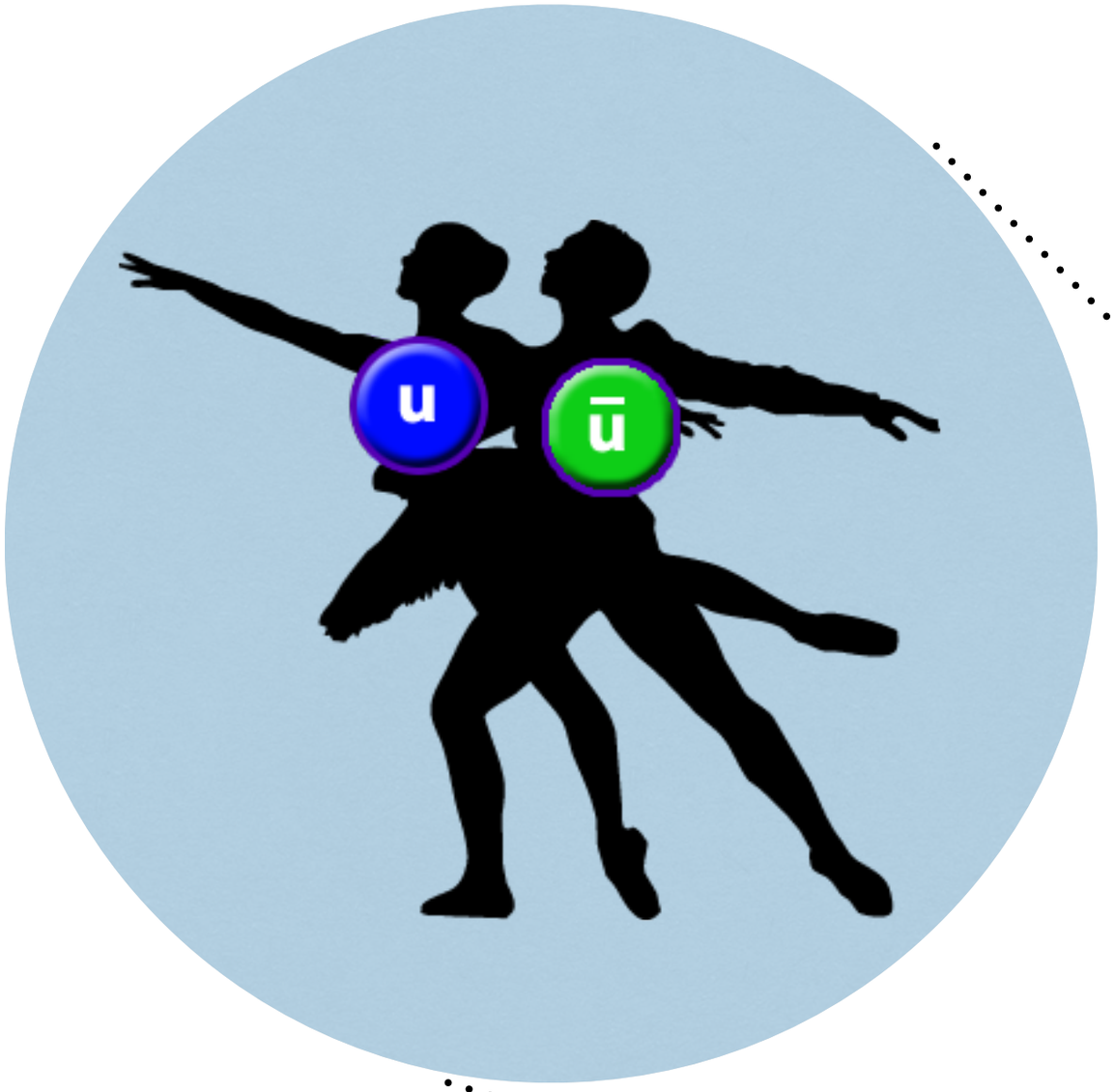


well, you have a tower of [KK] resonances...



Ok. What does it predict?

We already found that. It's called QCD.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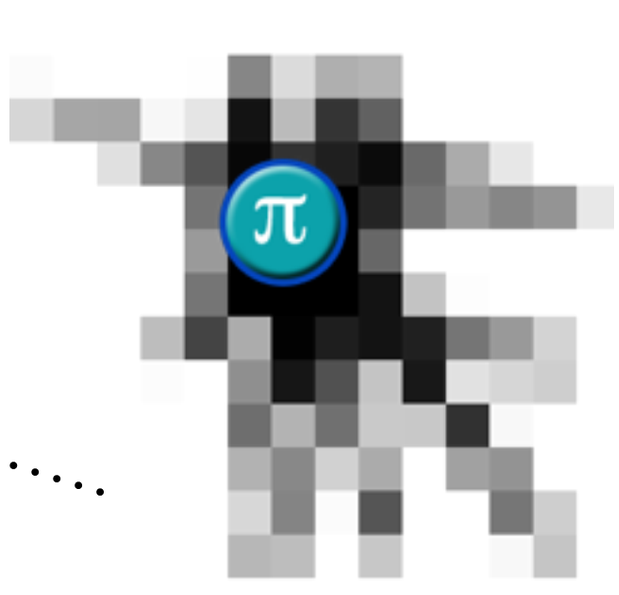
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RS = compositeness

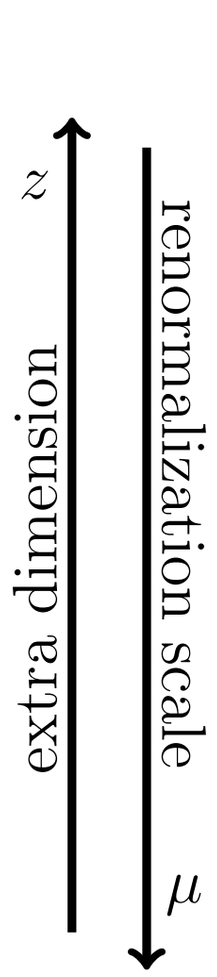
Gravitational background enforces scale symmetry

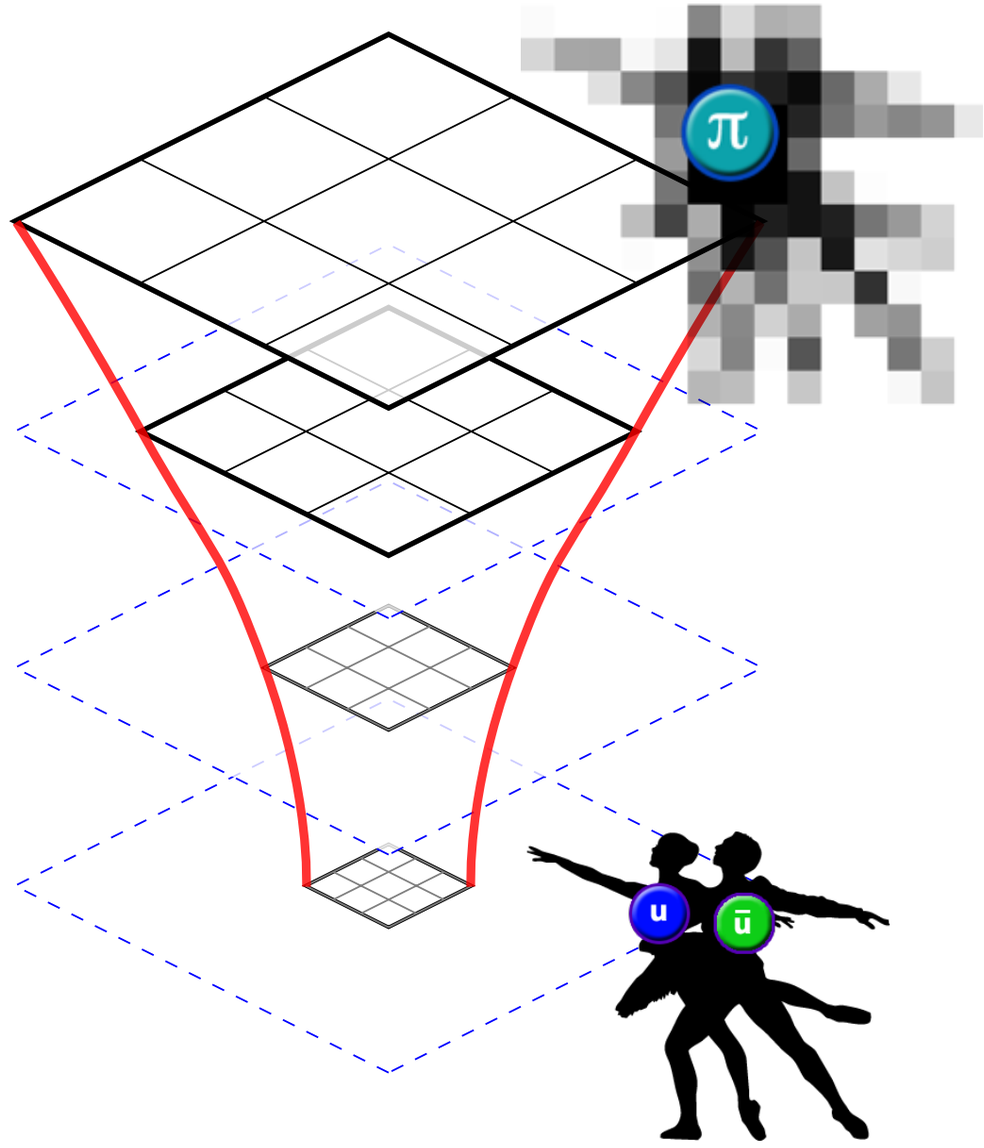
$$ds^2 = \left(\frac{R}{z}\right)^2 \left(dx^\mu dx_\mu - dz^2\right)$$

In this way, the 5th dimension *geometerizes* RG scaling and interpolates between "partons" and "hadrons"

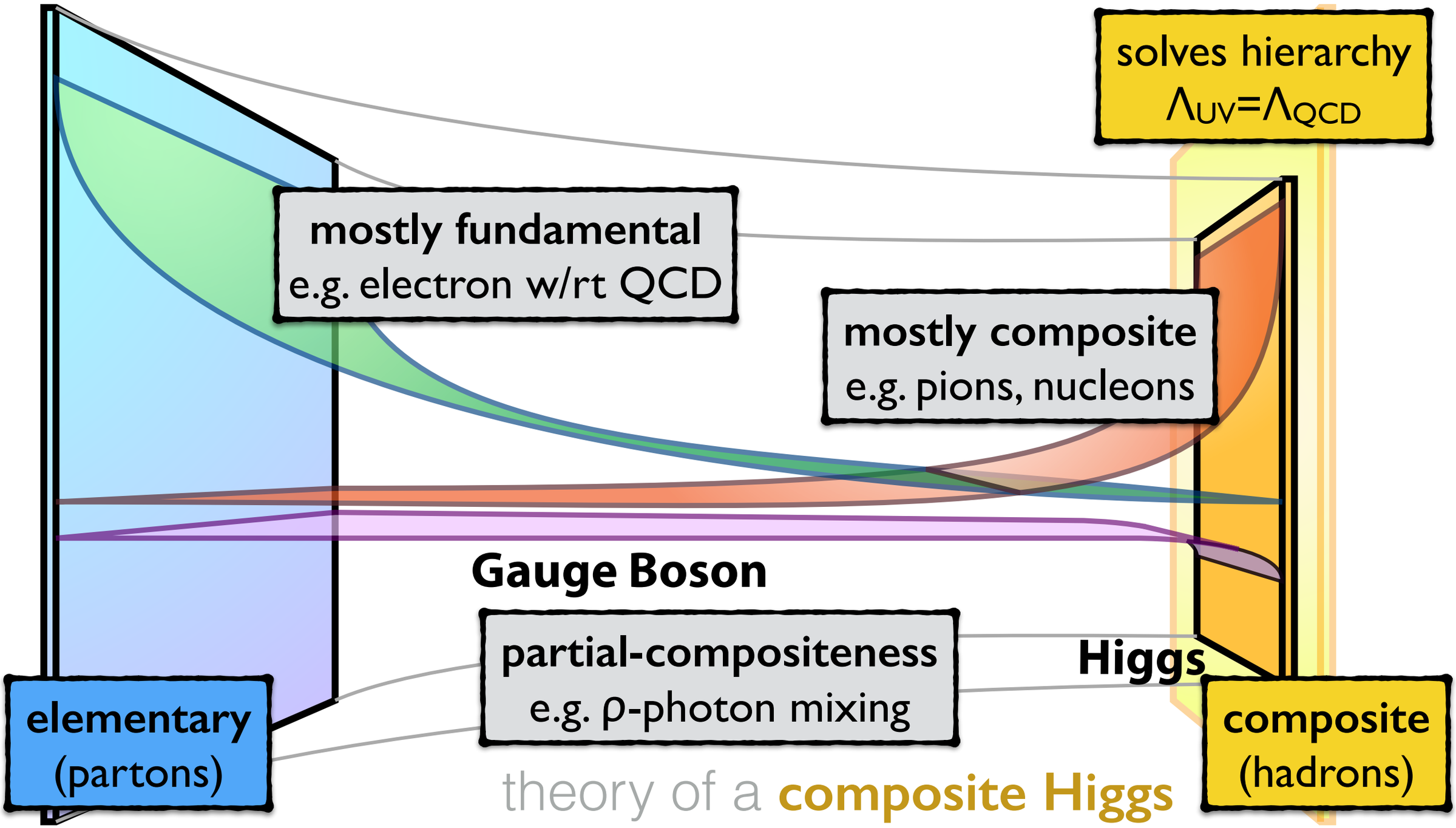
so: RS is shorthand for composite Higgs + all the junk that comes along with it

you don't have to "believe" in 5D



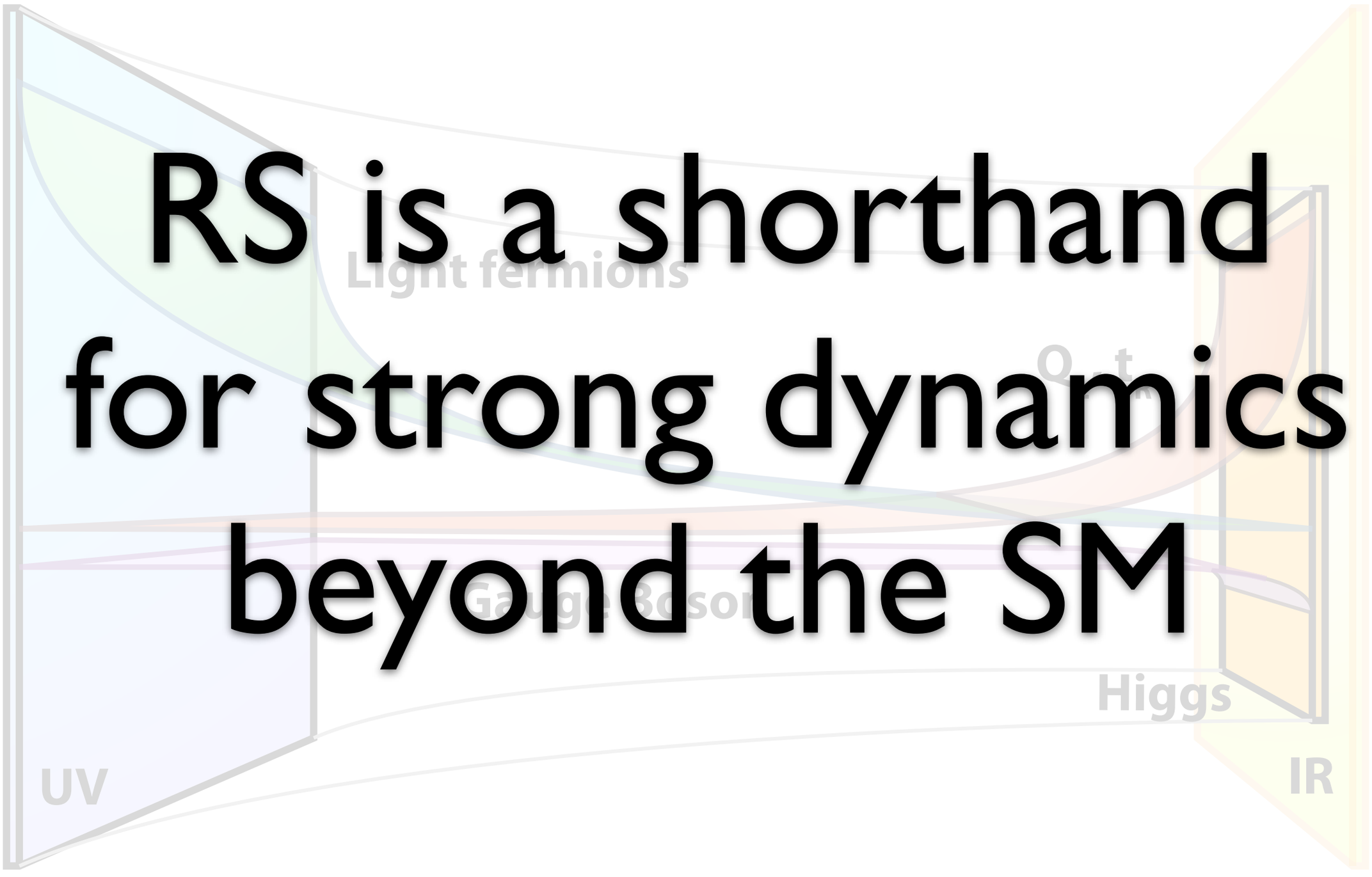


RS = compositeness

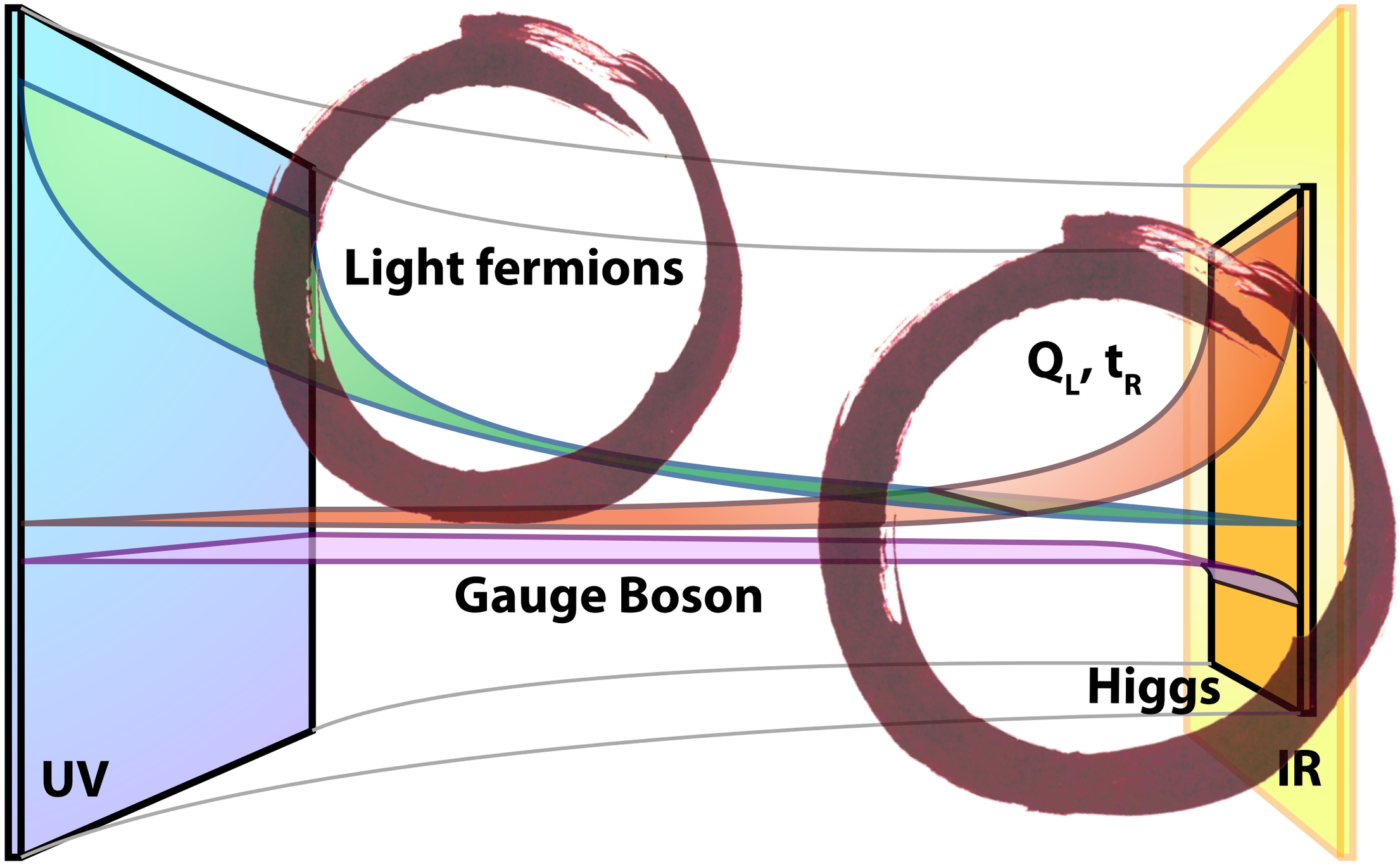


theory of a **composite Higgs**

RS is a shorthand for strong dynamics beyond the SM



RS as a theory of flavor

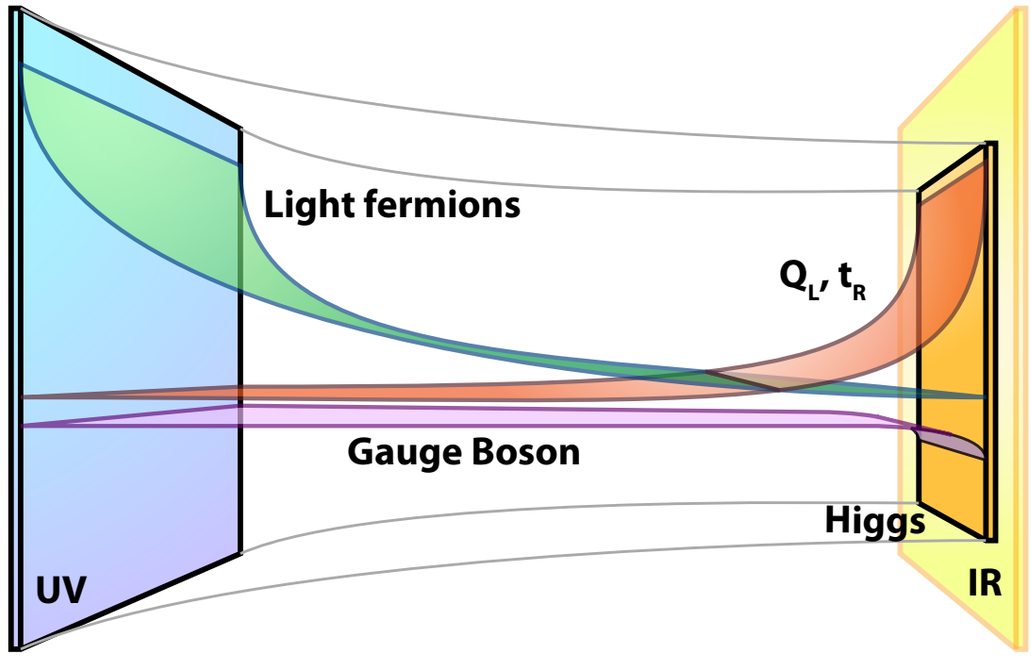


Yukawas live here

Anarchic Flavor

- Assume 5D Yukawas are **anarchic** (no hierarchy)

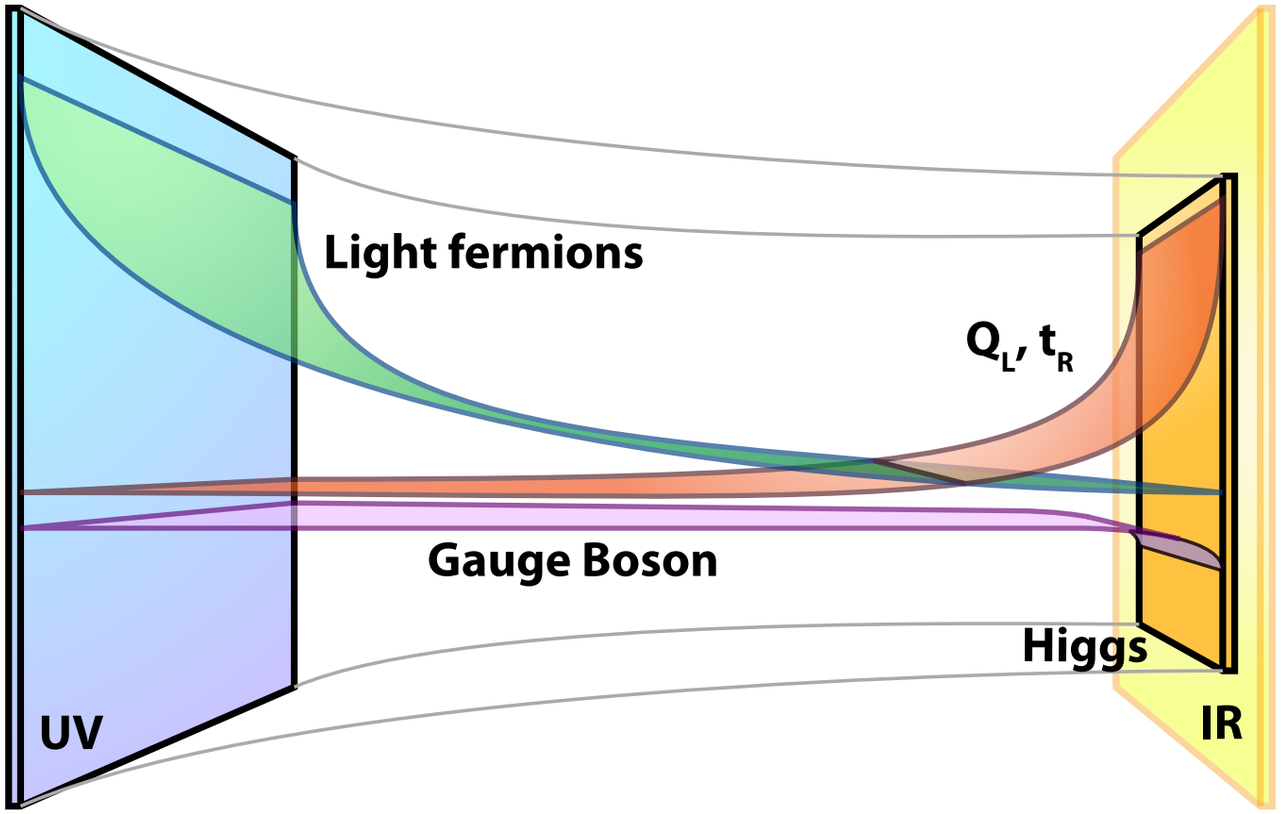
- SM Yukawas appear hierarchic due to overlaps:
  4D top_L-top_R-Higgs coupling depends
  on the 5D Yukawa and the wavefunction overlap
  Composite Higgs parlance: “conformal flavor” or “flavor from renormalization”



- Leptons are light because they’re ‘fundamental’

- Can even explain neutrino masses and mixing

Anarchic Flavor



5D parameter
O(1) and anarchic

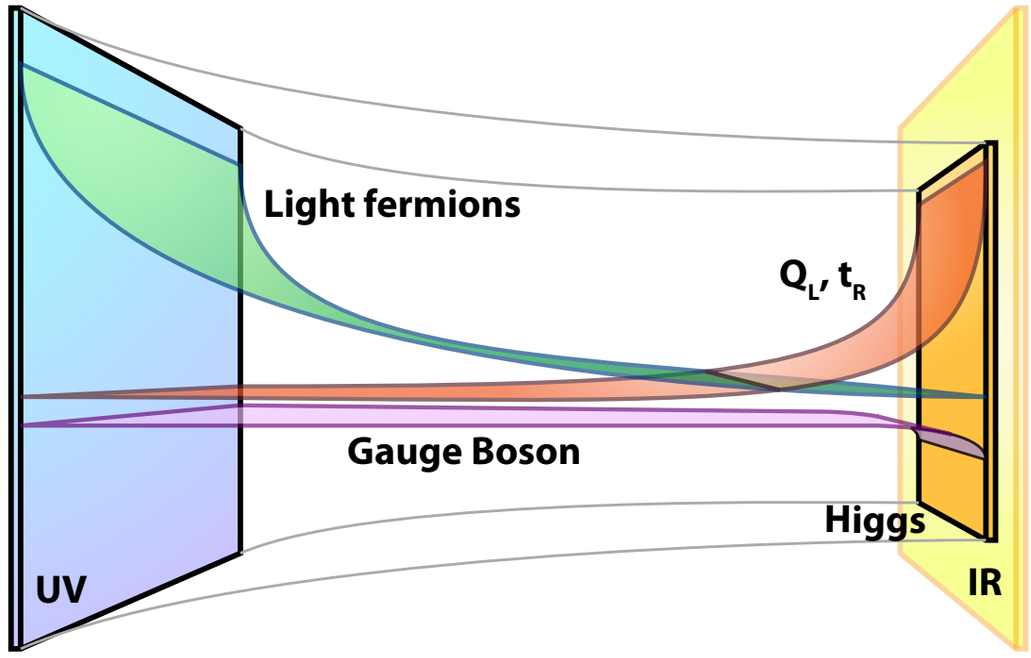
$$y_{ij}^{(4D)} = f_i Y_{ij} f_j$$

f_i encodes wavefunction at the IR brane
i.e. degree of compositeness

Other parameter: M_{KK}, related to size of XD
smaller XD → larger KK scale → decoupled KK excitations

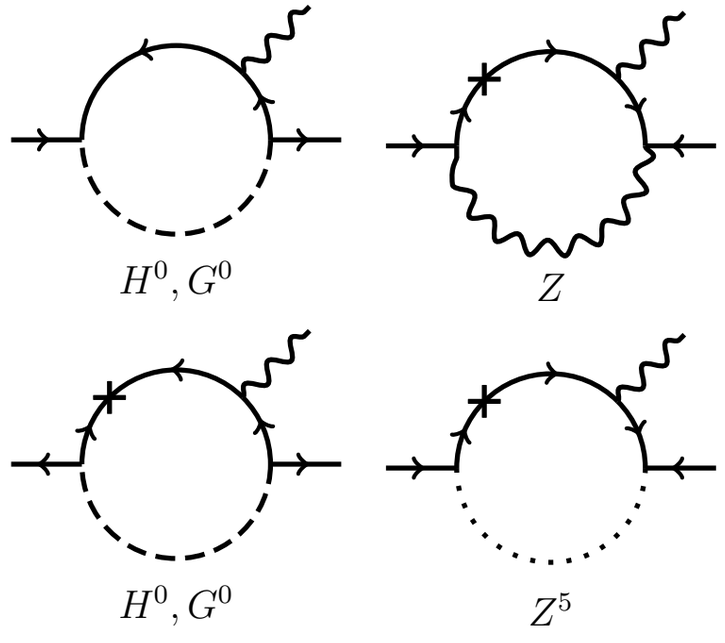
Sources of LFV

- **Tree level LFV**
  Gauge bosons resonances
  e.g. **Z'** (Kaluza-Klein Z boson)
  Breaks plane wave orthogonality
  (analog of Fourier transform)

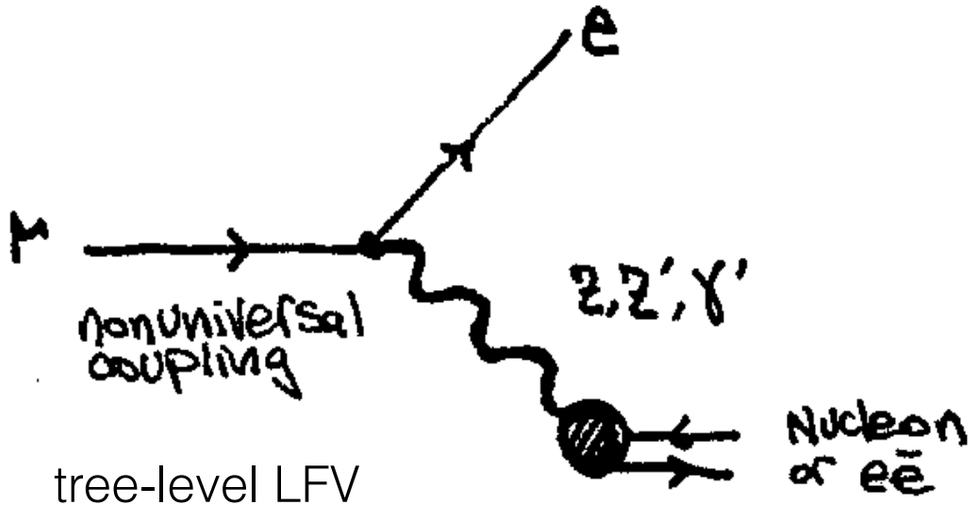


  Even SM Z has small FCNC
  EWSB affects boundary conditions

- **Loop level LFV**
  Penguin diagrams
  SM fields + 5D excitations



Tree vs Loop



tree-level LFV

loop-level LFV

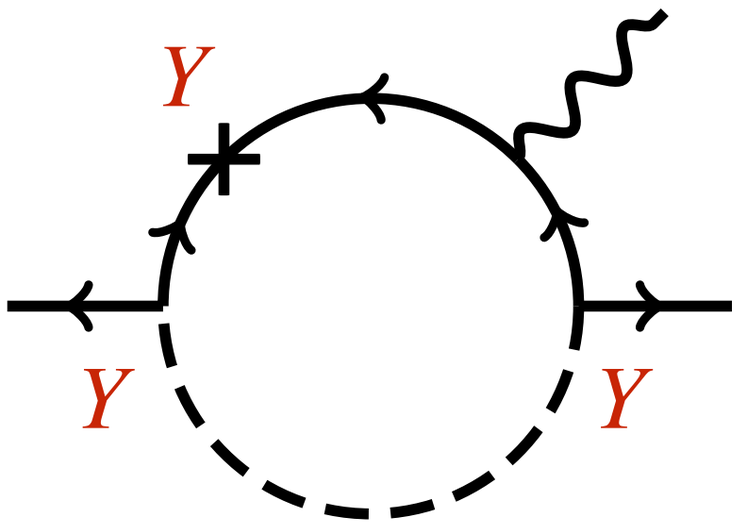
Calculate as usual

much more subtle!

- finite? yes!
- 5D covariance? yes!

… worth a Ph.D

Tree vs Loop



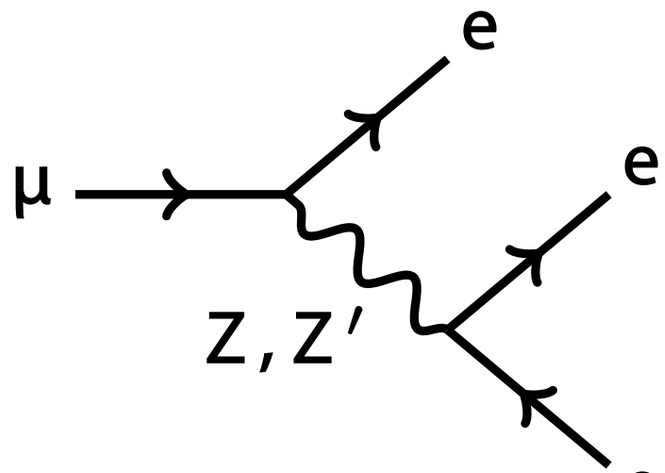
$$\sim \left(\frac{1}{M_{\rm KK}}\right)^2 f_{\mu_L} Y^3 f_{e_R}$$

$$\sim \left(\frac{Y}{M_{\rm KK}}\right)^2 m_\mu$$

This makes sense: positive power of coupling, negative power of the 5D scale

Bounds? Can either make 5D Yukawa small or make KK scale heavy.

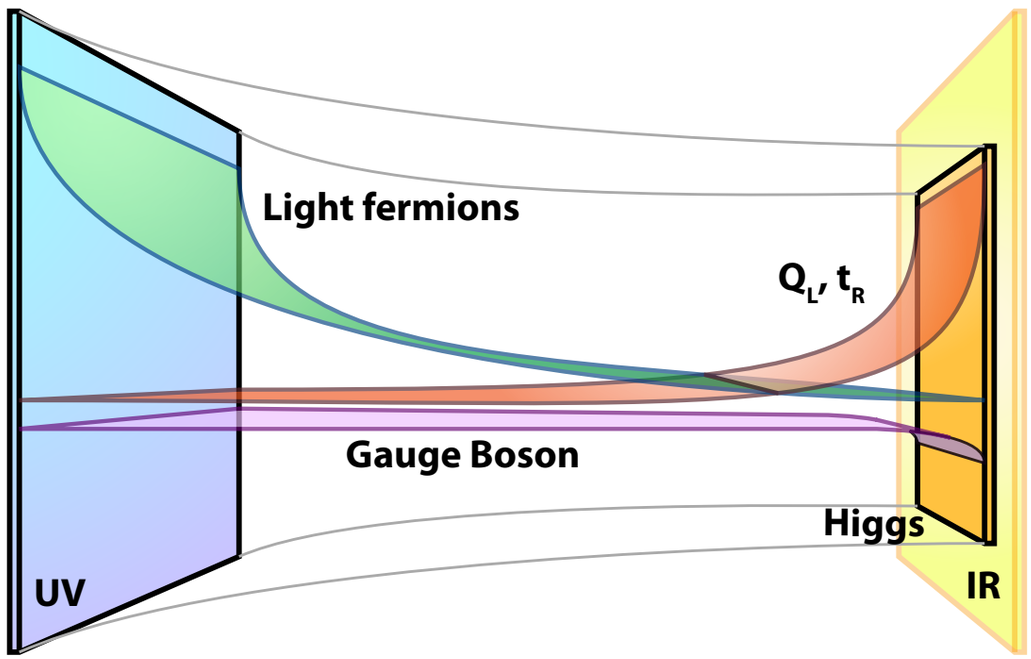
Tree vs Loop



$$\sim \left(\frac{1}{M_{\rm KK}}\right)^2 \left(\frac{1}{Y}\right)$$

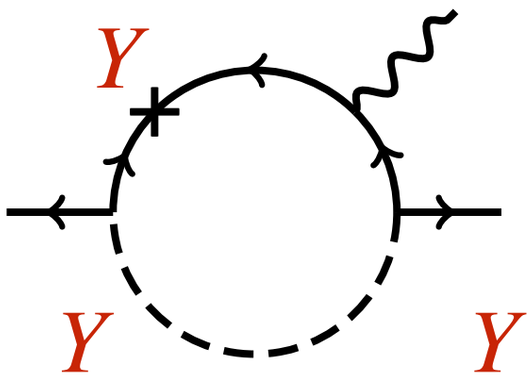
Inverse power of Y

increase Y, push profile to UV
less overlap with FCNC part of Z

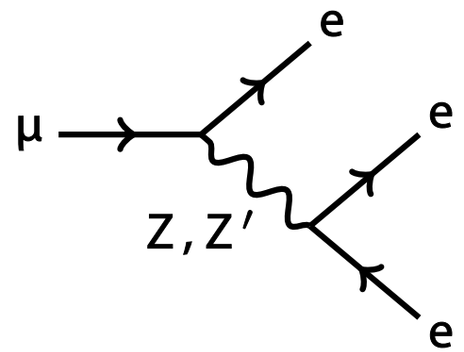


$$y_{ij}^{(4D)} = f_i Y_{ij} f_j$$

Tree vs Loop



$$\sim \left(\frac{Y}{M_{\rm KK}}\right)^2 m_\mu$$

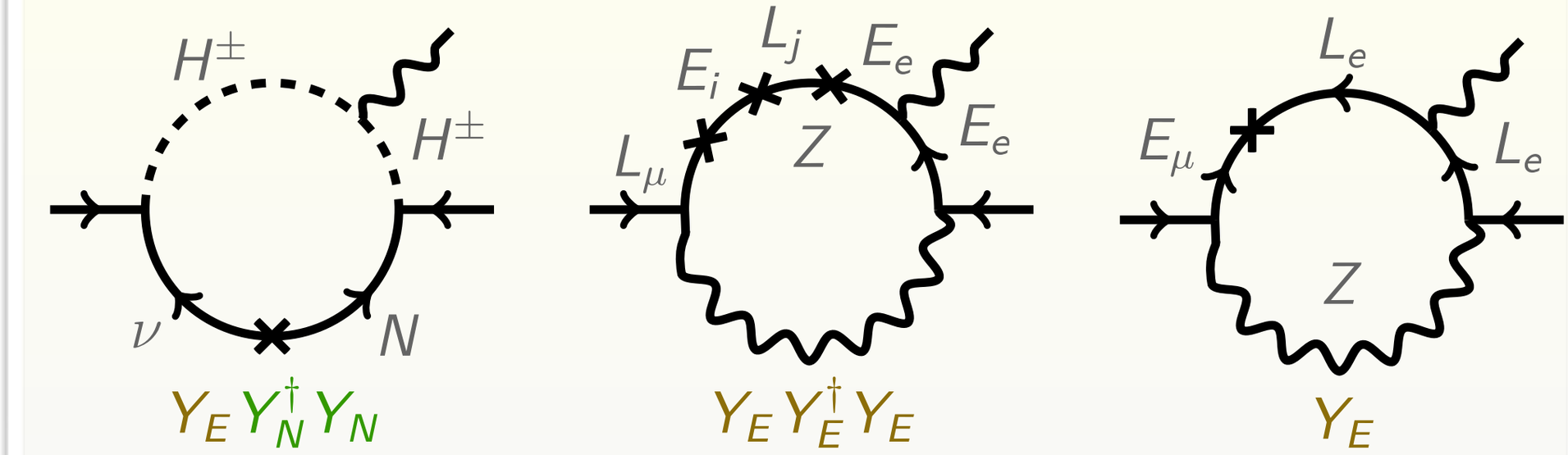


$$\sim \left(\frac{1}{M_{\rm KK}}\right)^2 \left(\frac{1}{Y}\right)$$

Complementary bounds on ***Y***

constrains the anarchic flavor picture

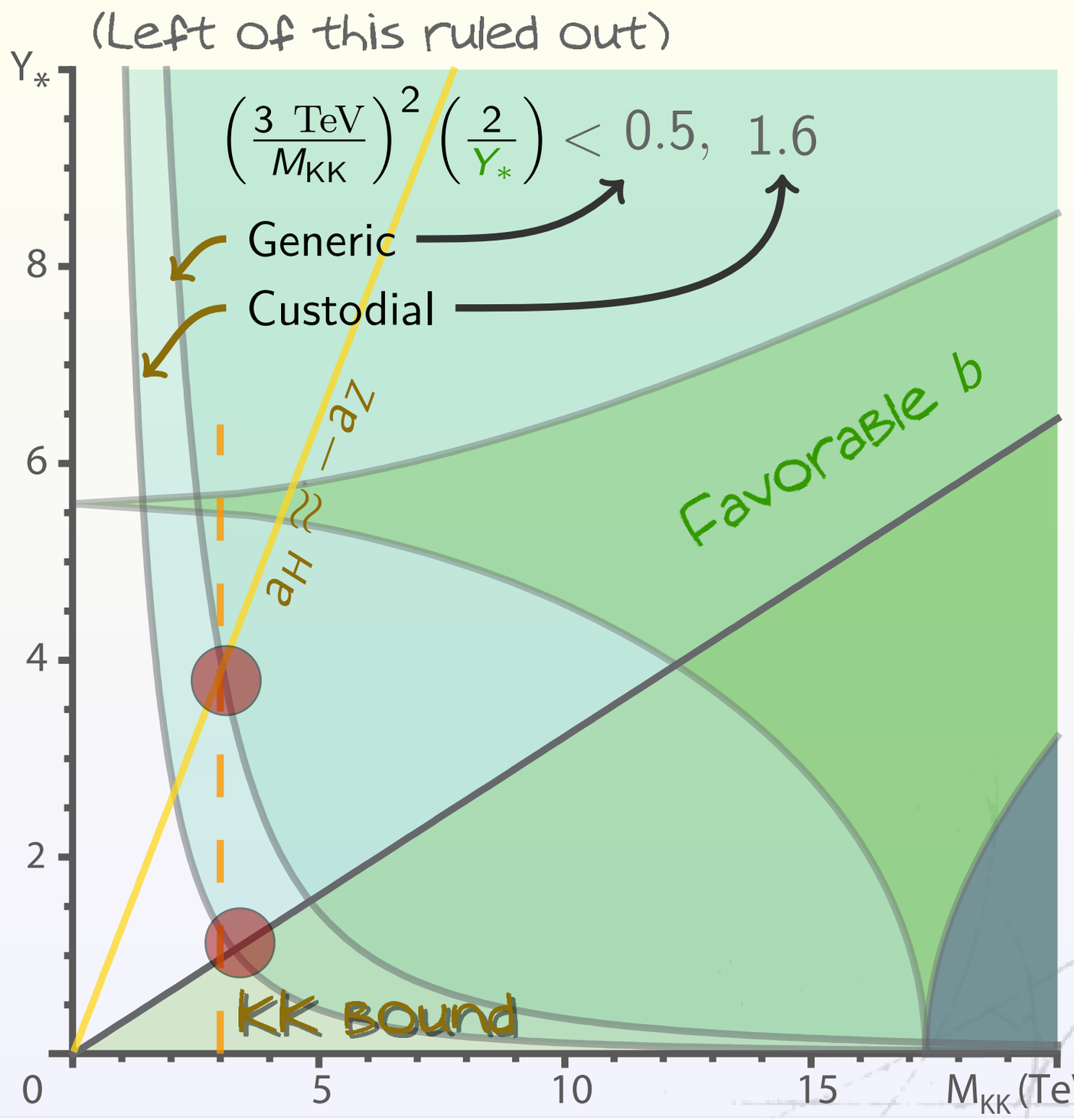
subtlety: large flavor space



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

Defined $aY_*^3 = \sum_{k,\ell} a_{k\ell} Y_{ik} Y_{k\ell}^\dagger Y_{\ell j}$ and $bY_* = \sum_{k,\ell} (U_L)_{ik} b_{k\ell} Y_{k\ell} (U_R^\dagger)_{\ell j}$

Tanedo, seminar slides 2011



$\mu \to e\gamma,\ b = -|b|_{1\sigma}$
(Above this ruled out)

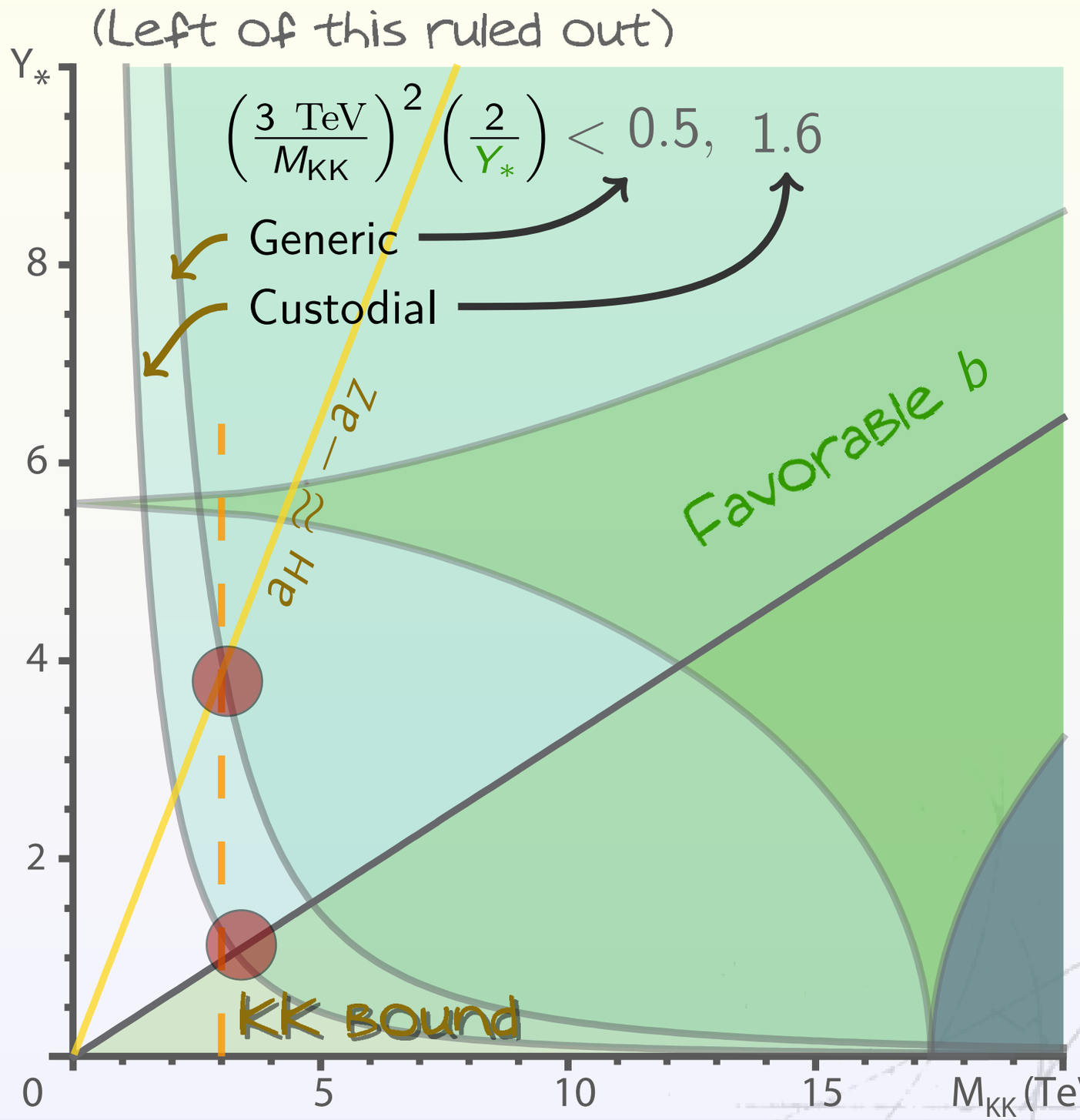
$\mu \to e\gamma$, average

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

$\mu \to e\gamma,\ b = +|b|_{1\sigma}$

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

Tanedo, seminar slides 2011



complimentary **tree** vs **loop** bounds

can really test **anarchic flavor** *paradigm*

Not "just another model"

Warped Extra Dimensions
Composite/Little/etc. Higgs
… even SUSY versions

Tanedo, seminar slides 2011