

WARPED DIMENSIONS : THE VIEW FROM THE TOP

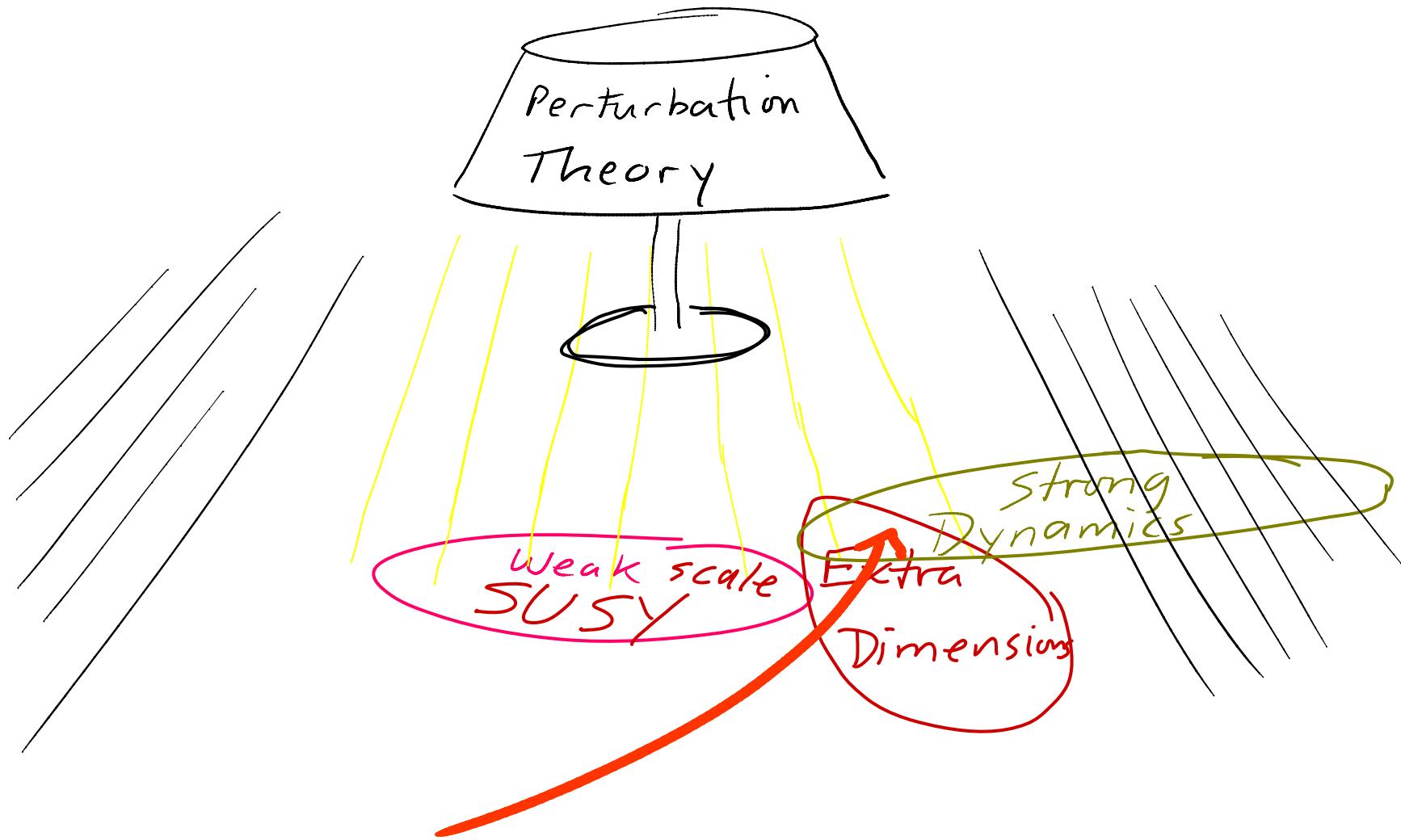
Raman Sundrum
Johns Hopkins University

Top provides sensitive probe of
Warped Dimensions:

- (i) shares extended symmetries of Higgs sector.
- (ii) strongest couplings to non-minimal Higgses & scalars.
- (iii) decay product of KK modes.

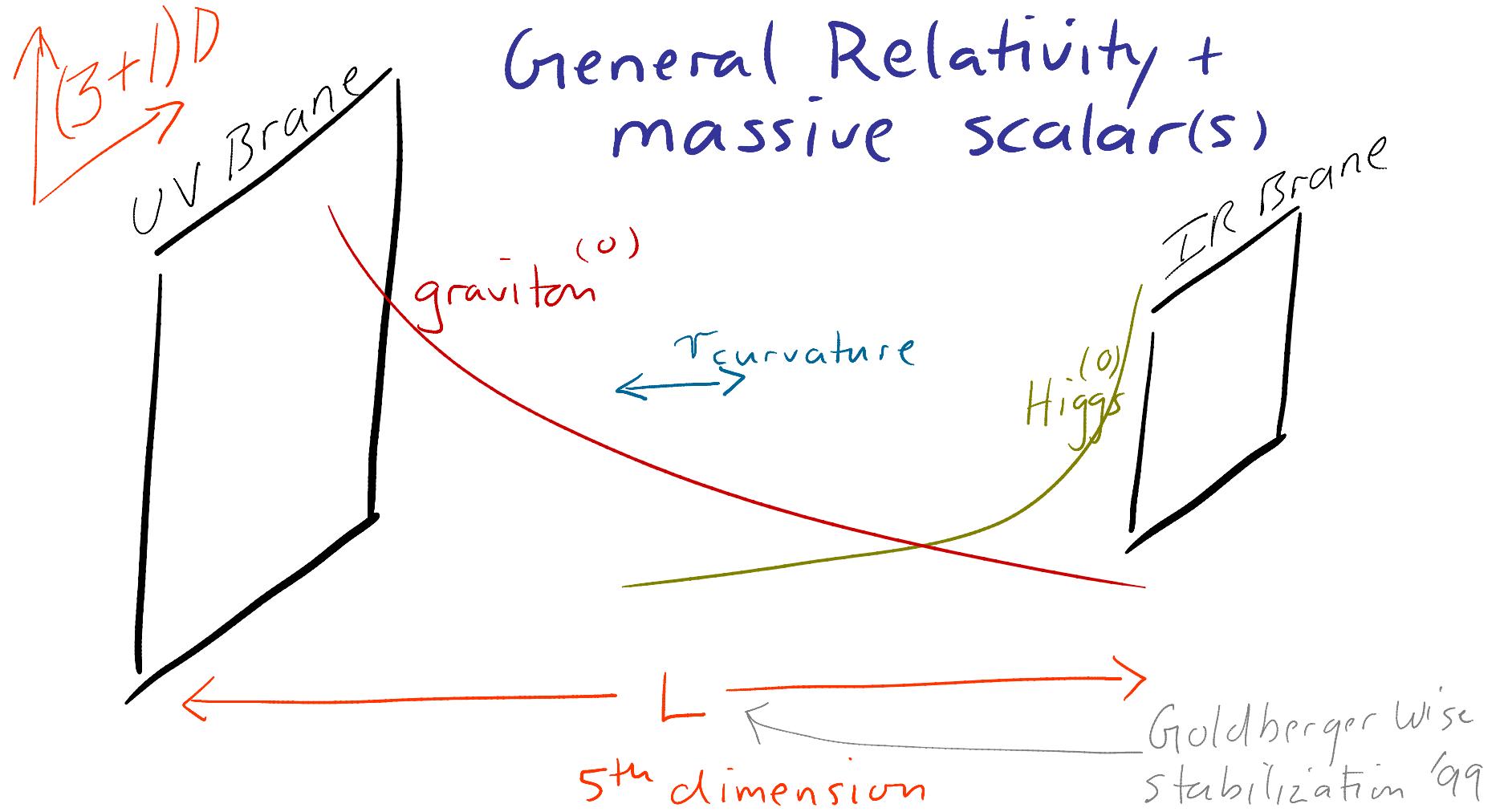
Finding warped dimensions will be hard,
so important to know how hard to try.
Is this scenario a serious possibility?

Hierarchy Problem: Under the lamp post ?



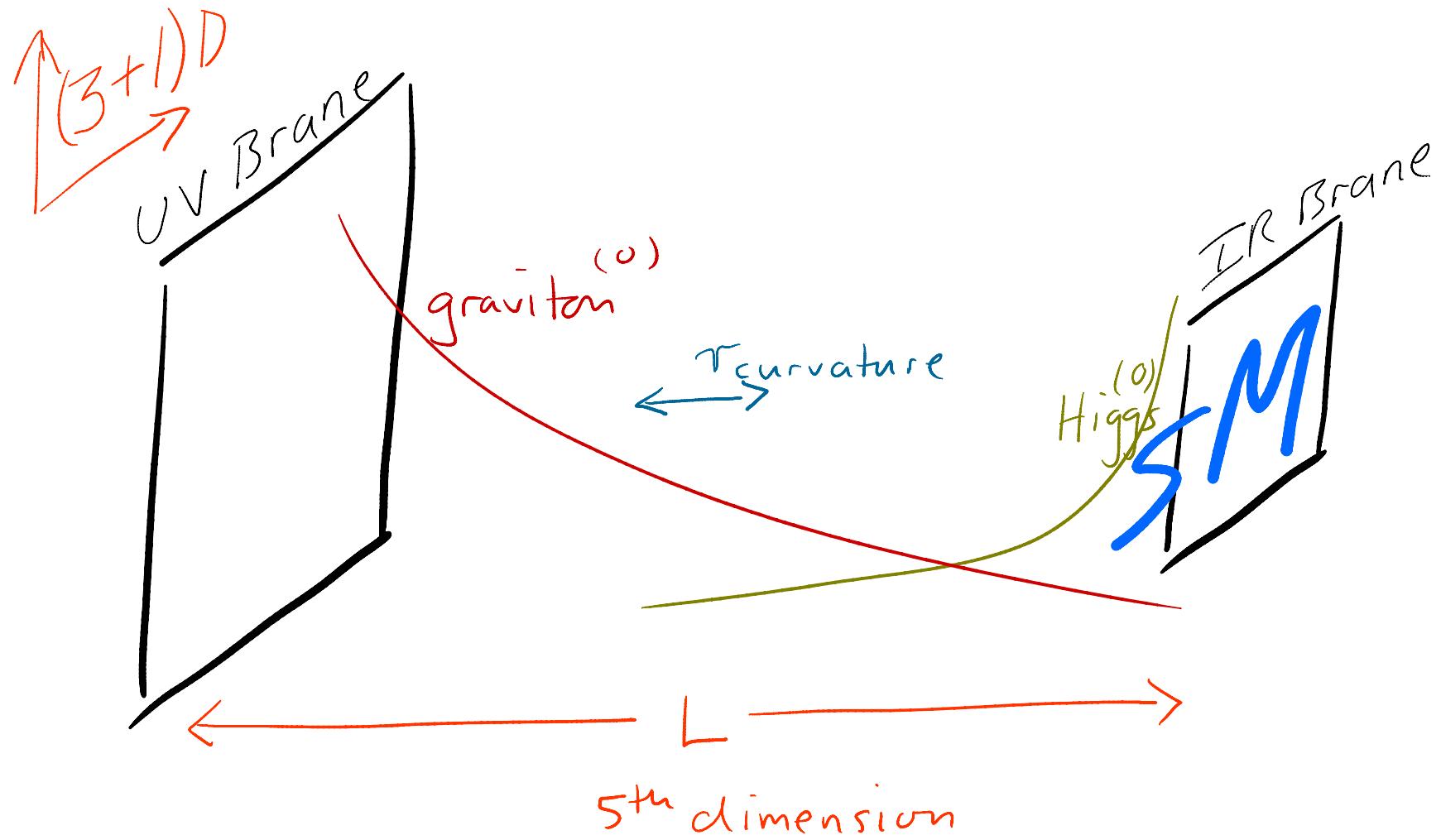
Let's zoom in ...

RS1:



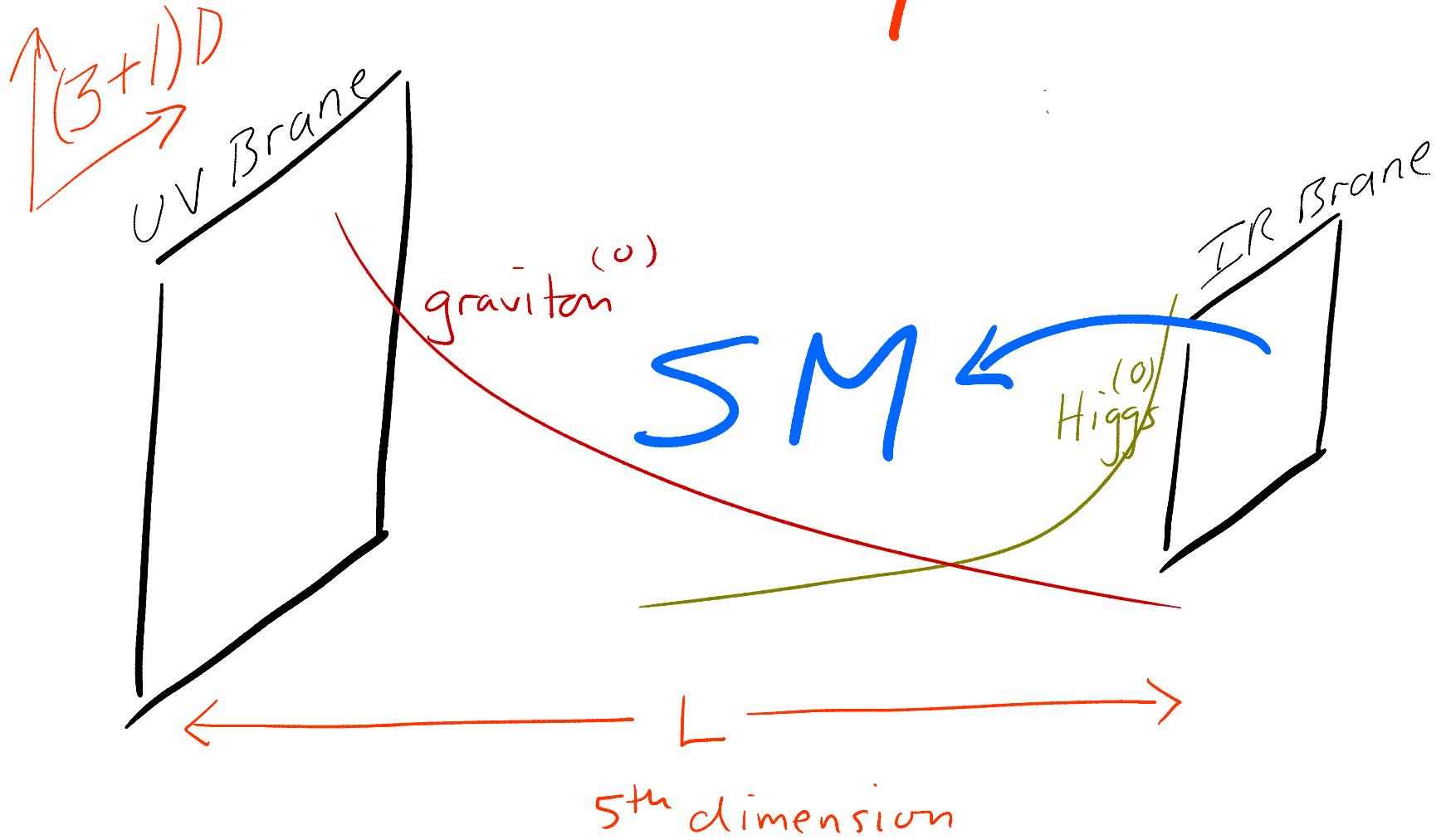
$$\text{Warp Factor} \sim e^{-\gamma c_5 / r_{\text{curvature}}} \\ \equiv \text{Redshift } \frac{\text{4D mass scales}}{\text{5D mass scales}} \Rightarrow \frac{U_{\text{weak}}}{M_{\text{Pl}}^{(4D)}} \sim e^{-L/r_{\text{cur}}} \ll 1$$

RS1:



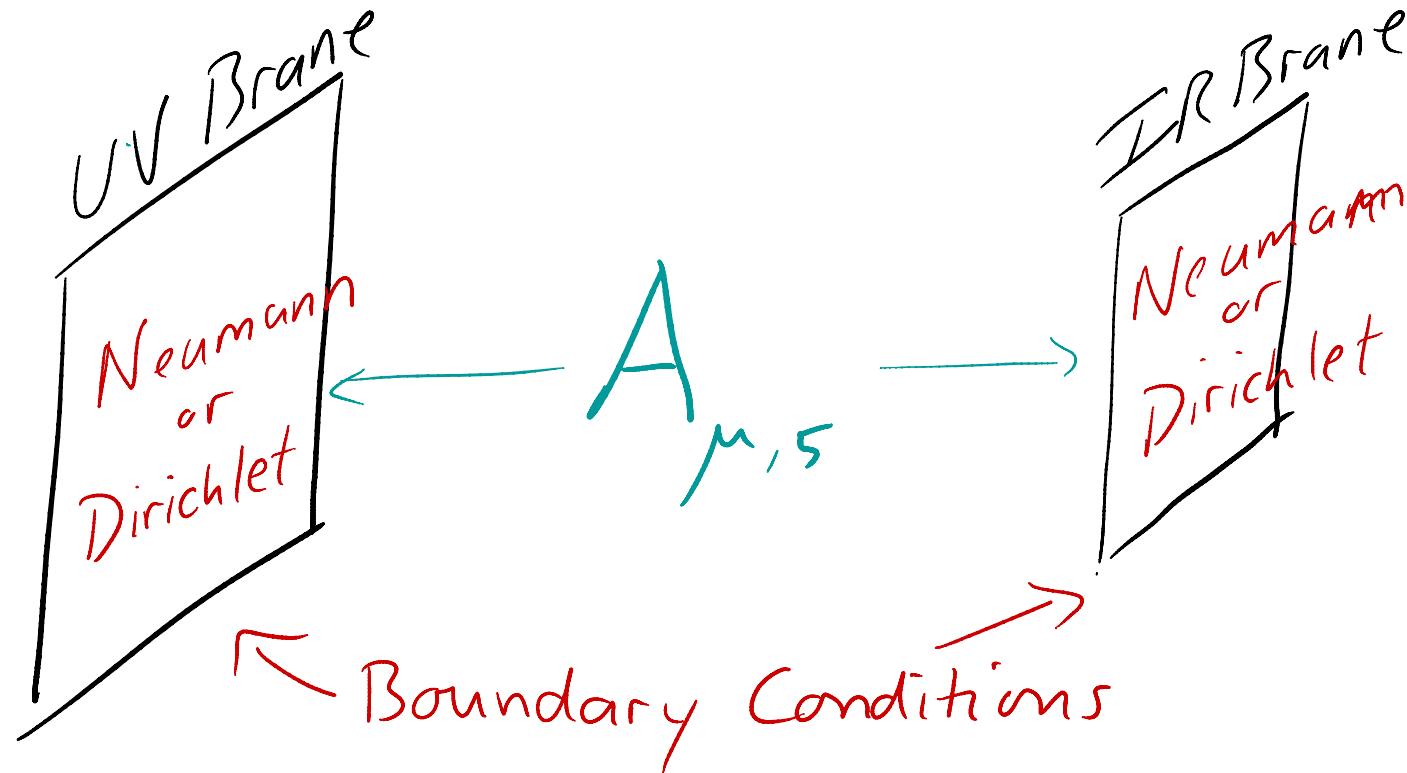
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Recent years :



These "Bulk SM" models address Hierarchy Problem & EWPT, FCNCs, Proton stability, ~~CP~~, Unification, DM, m_ν , ...

5D CHAOS = 4D COSMOS



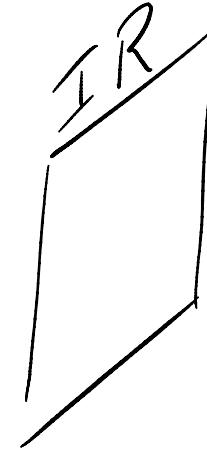
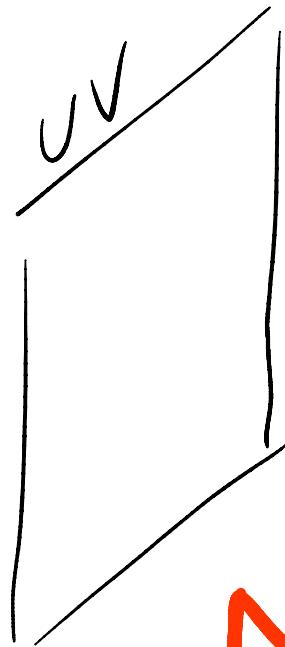
NN 4D massless gauge field

DN Accidental global symmetries, eg. $SU(2)$ _{custodial}, $U(1)$ _{Baryon}

DD Light 4D A_5 scalars

ND "Higgsless" IR symmetry breaking

BELIEVE IT OR NOT ?

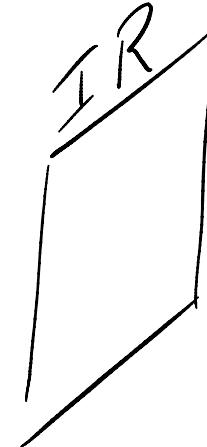
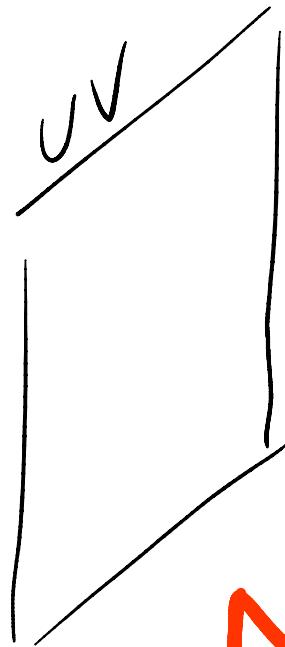


NON-RENORMALIZABLE

(warped) EFT $g_5^2 E$
 $\sim 1/M_{Pl}$

c/w Renormalizable MSSM

BELIEVE IT OR NOT ?

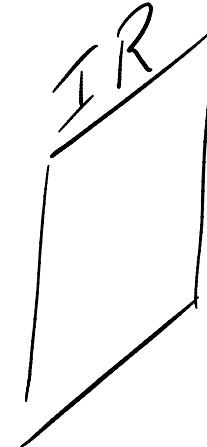
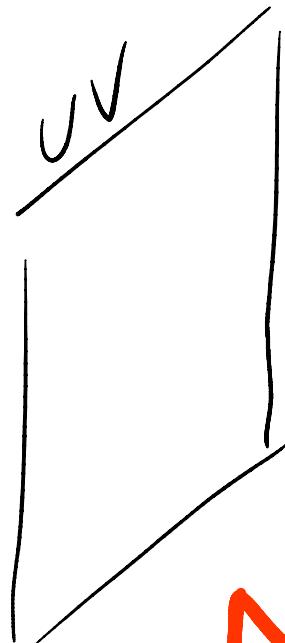


NON-RENORMALIZABLE

(warped) **EFT** $g_5^2 E \left(\times e^{+ \gamma c_5 / r_{\text{curv}}} \right)$
 $\Gamma \sim 1/M_{\text{Pl}}$

c/w Renormalizable MSSM

BELIEVE IT OR NOT ?



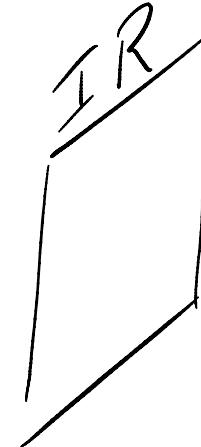
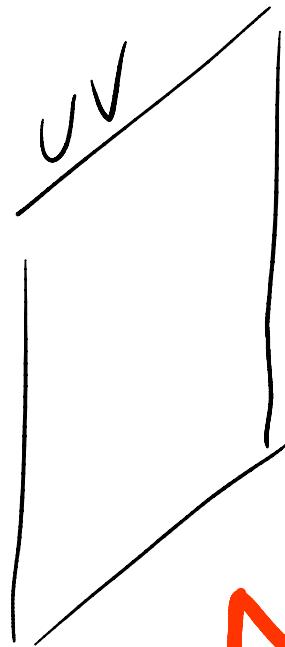
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c/w Renormalizable MSSM

+ (super-) Gravity

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NON-RENORMALIZABLE

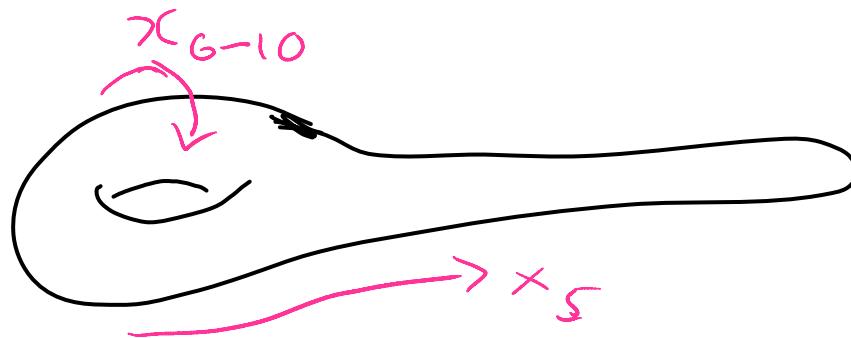
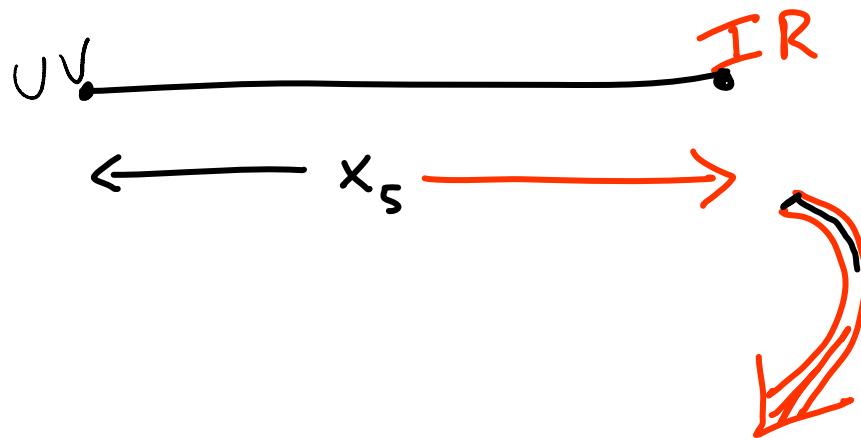
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 $\Gamma \sim 1/M_{\text{Pl}}$

c/w Renormalizable MSSM

+ (super-) Gravity
≈ String Theory set-ups.

String Theory

Warped constructions (with ~~SUSY~~
at highest scales) still in infancy:



(meta-) Stable non-SUSY
string compactifications

Strassler '02

Kachru, Simic, Trivedi '09

AdS/CFT

Strongly-interacting Higgs sector

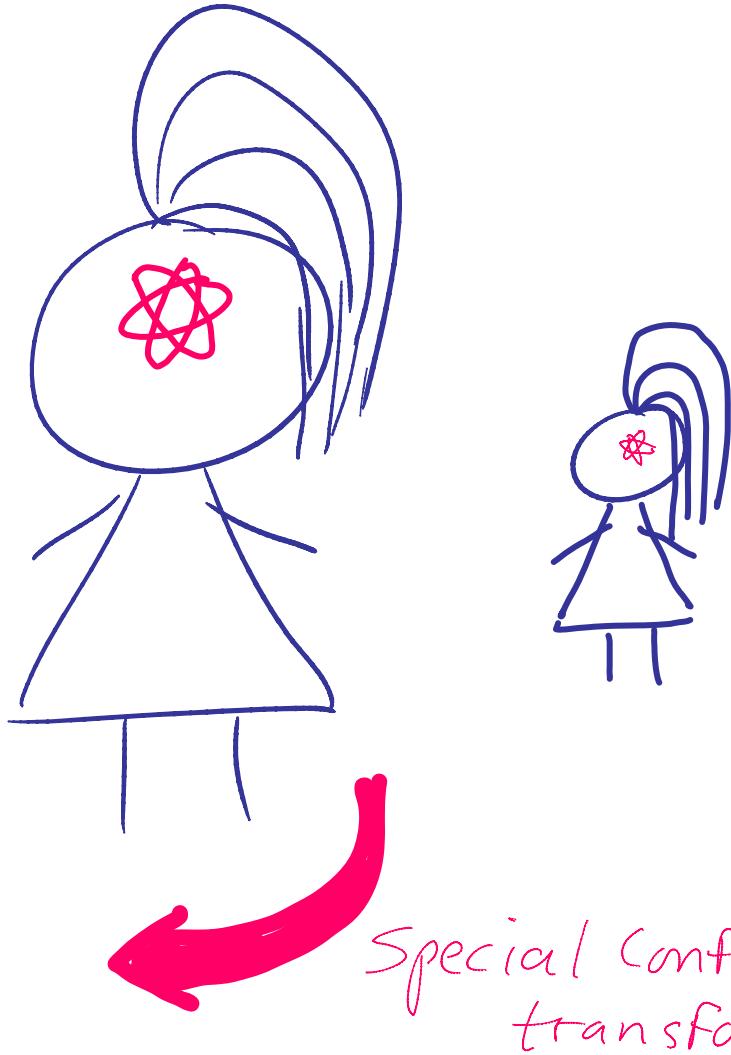
→ TeV-scale composite Higgs

can solve Hierarchy Problem

but hard to build explicit models.

Often invoke strong coupling over large hierarchy. ie. \approx strong CFT.

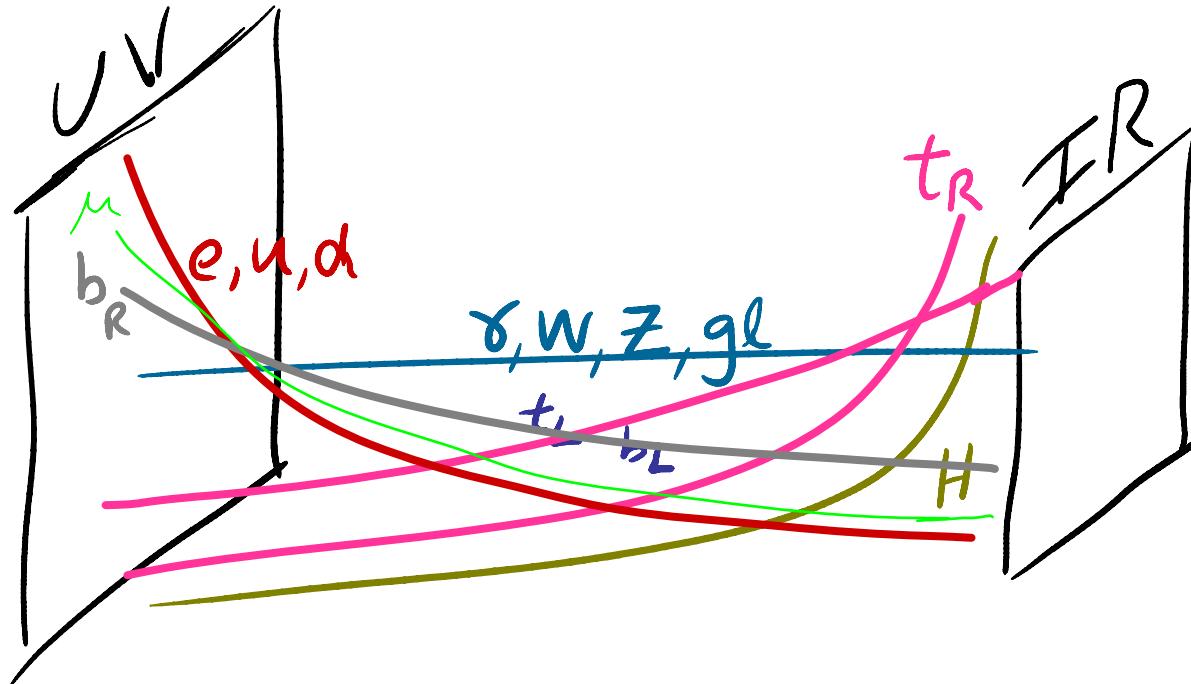
Mother & Daughter or Twins ?



Other Features,
eg. large- N _{color}
needed to get
weakly-coupled
extra-dimensional/
EFT regime.

Best fit of "Bulk SM"

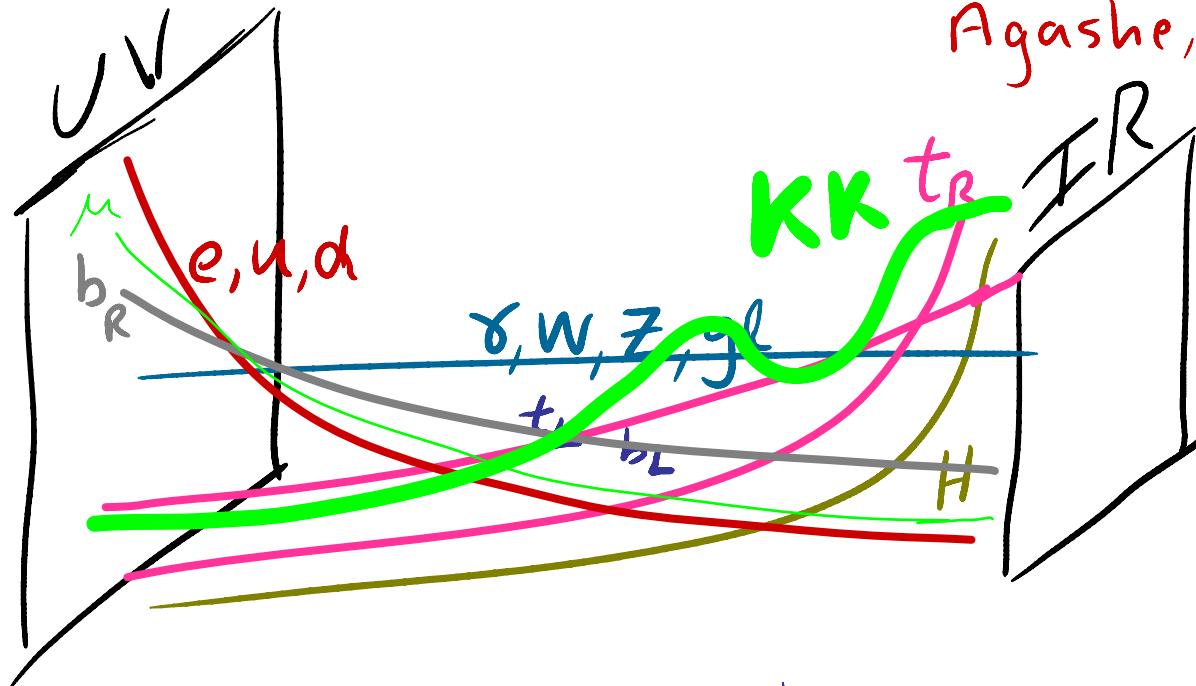
Agashe, Delgado, May,
Sundrum '03



Localization tendency ($e^{\pm m_5 x_5}$)
satisfies 5D Klein-Gordon equation
Flavor hierarchies from wave function overlaps with Higgs.

Best fit of "Bulk SM"

Agashe, Delgado, May, Sundrum,
 Agashe, Contino, Pomarol '03
 '05



KK modes couple \propto wavefunction
 overlaps \rightarrow virtual contributions in precision
 tests:

$$\underbrace{S, T, Z \bar{b}_L b_L}_{m_{KK} \gtrsim 3 \text{ TeV}}, \underbrace{\text{FCNC}, \text{SP}}_{m_{KK} \gtrsim 10 \text{ TeV}}$$

But considerable
 wiggle room in
 parameter space

IF DONE RIGHT . . .



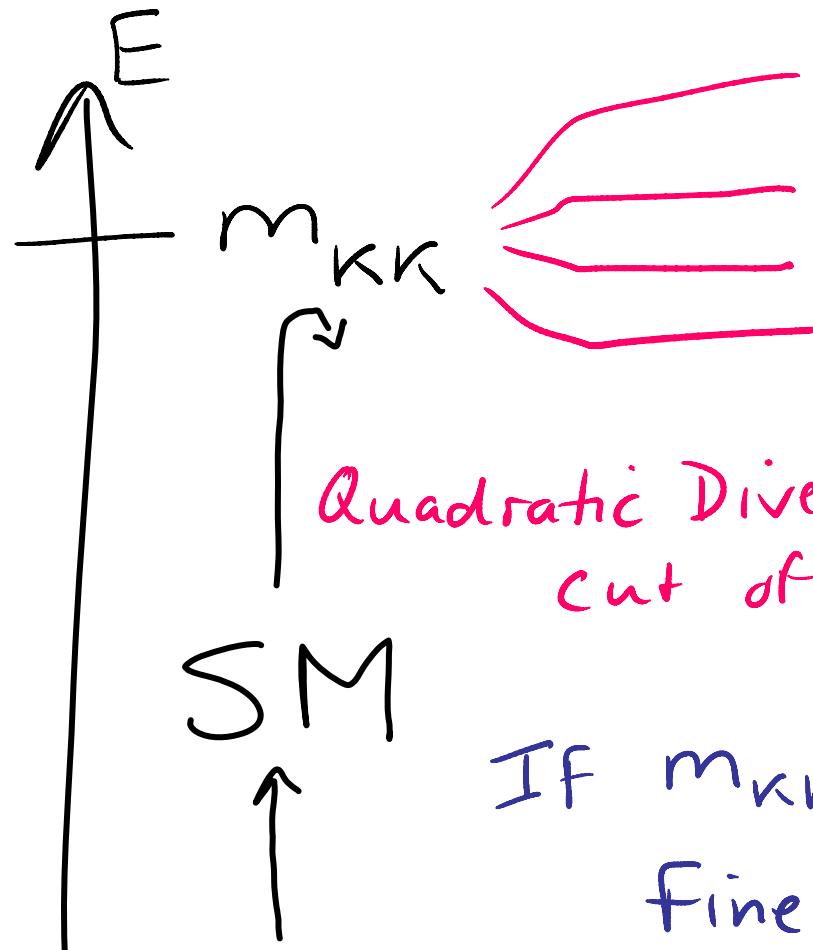
SM
Quadratic Divergences
cut off by m_{KK}

IF $m_{KK} \sim 10 \text{ TeV} \equiv$

Fine-tuning @ 1% level.

Why this meso-tuning?

IF DONE RIGHT . . .



IF $m_{KK} \sim 10 \text{ TeV} \equiv$
fine-tuning @ 1% level.

Why this meso-tuning?

EFT Naturalness is crude gambler's measure.
Varying degrees of possible success at
predicting Nature ...

E



$$m_{KK} \sim 10^{12} \text{ TeV}$$

LHC-irrelevant

Naturalness irrelevant

$$m_{KK} \sim 10 \text{ TeV}$$

no KK @ LHC, but light exotics

$$m_{KK} \sim 3 \text{ TeV}$$

KK just possible @ LHC

t-couplings affected

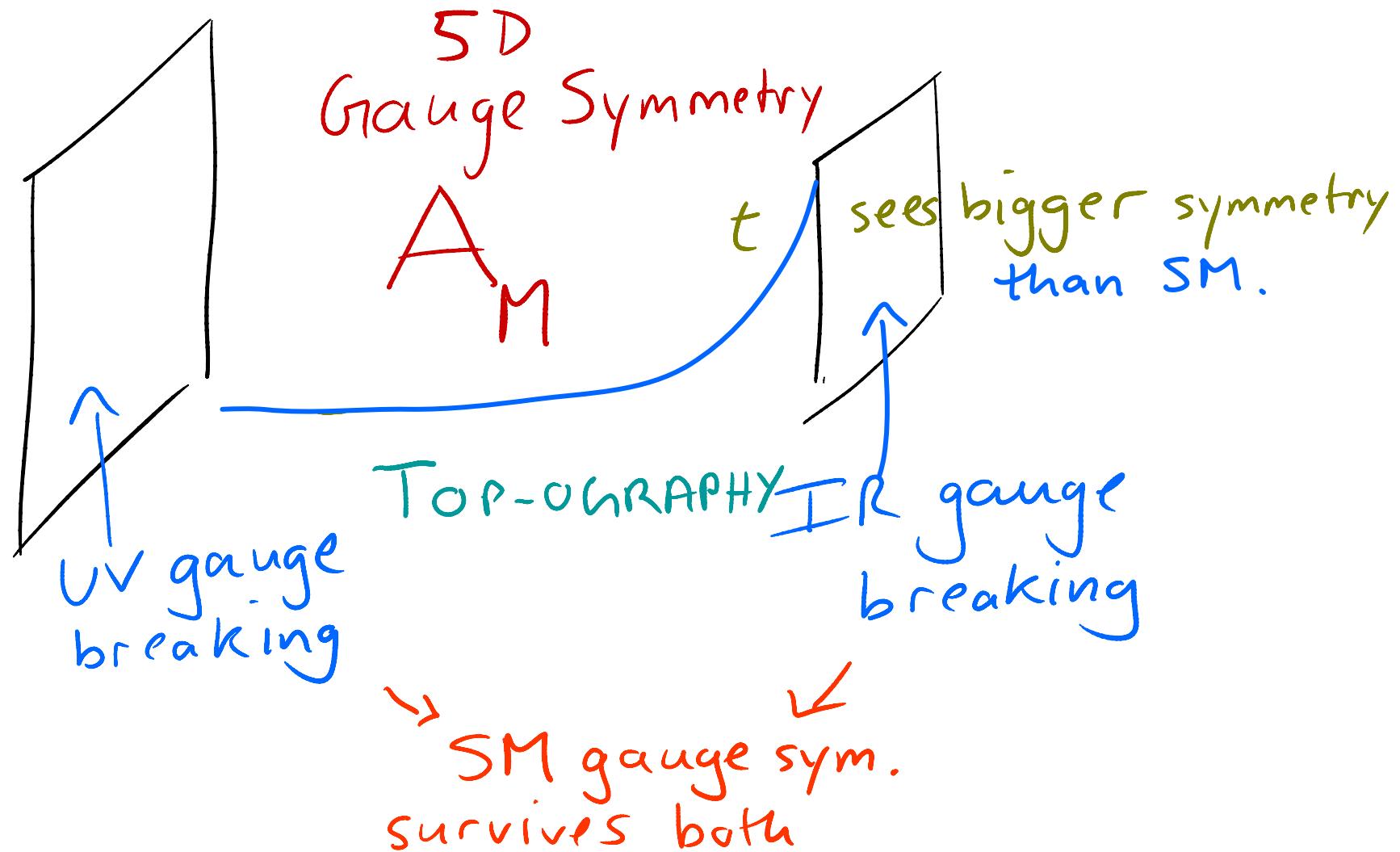
$$m_{KK} \sim 1.5 \text{ TeV}$$

KK "easy", extra dimension can be

"discovered".

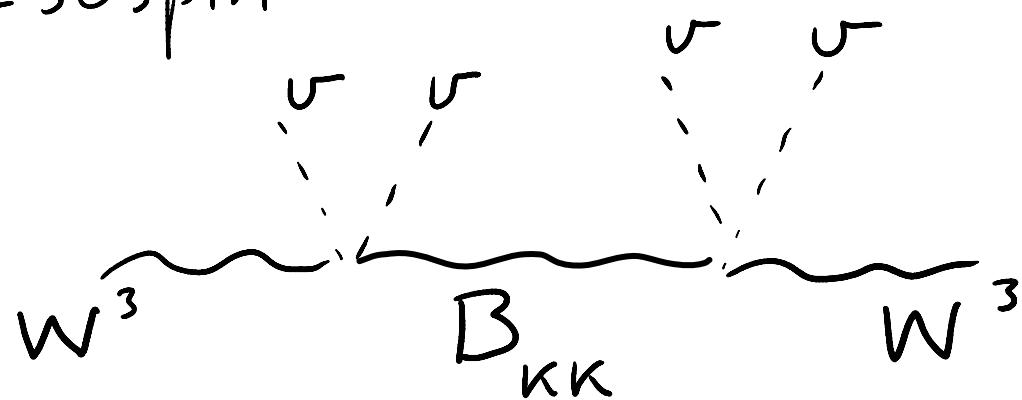
$m_{KK} \sim 10 \text{ TeV}$

The Symmetric Top



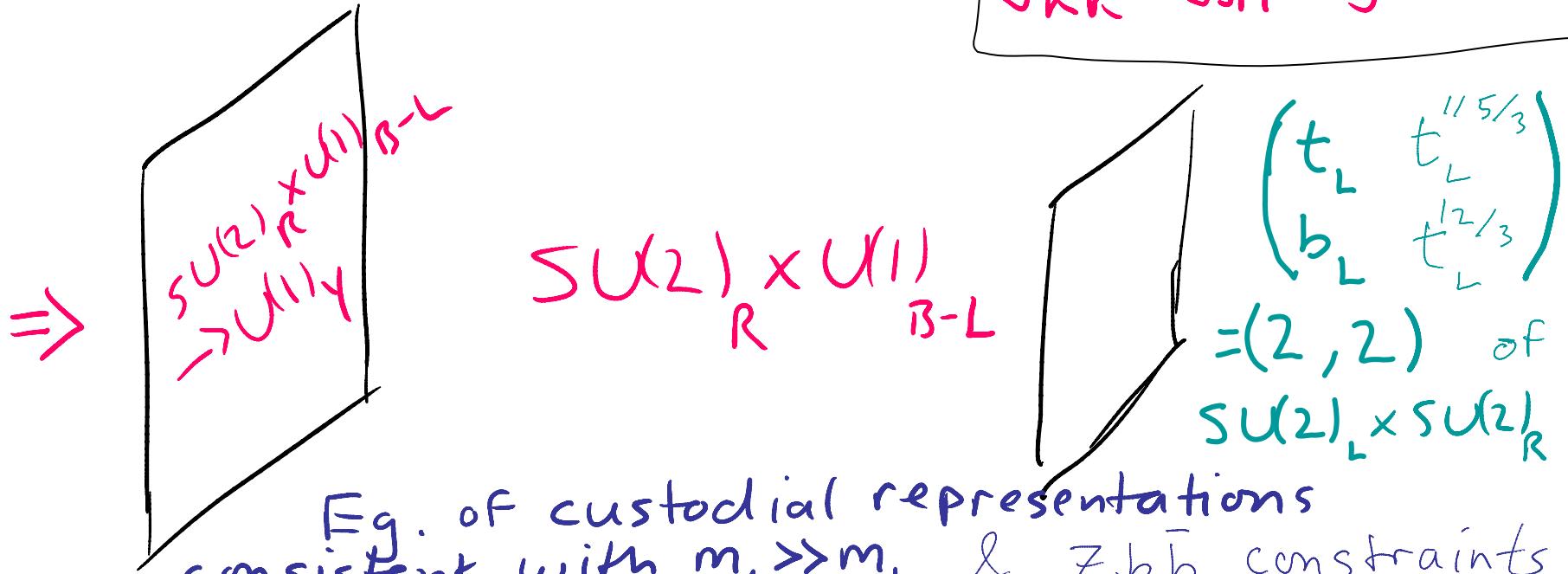
Custodial Isospin

T-parameter



unmatched for W^\pm & amplified by

$$g_{KK}^2 \sim g_{SM}^2 \times \text{log hierarchy}$$



Eg. of custodial representations
 consistent with $m_t \gg m_b$ & $Z b_L \bar{b}_L$ constraints
 Agashe, Contino, Rold, Pomarol '06

Warped non-SUSY GUTs

Agashe, Delgado, Sundrum
102

(based on SUSY
studies by
Pomarol '00)
+
:



GUT
eg. SU(5)

t_R^c
must be part of
GUT multiplet
e.g. (t_R^c, q_L^c, τ_R^c)

new light exotics
(part of Dirac states)

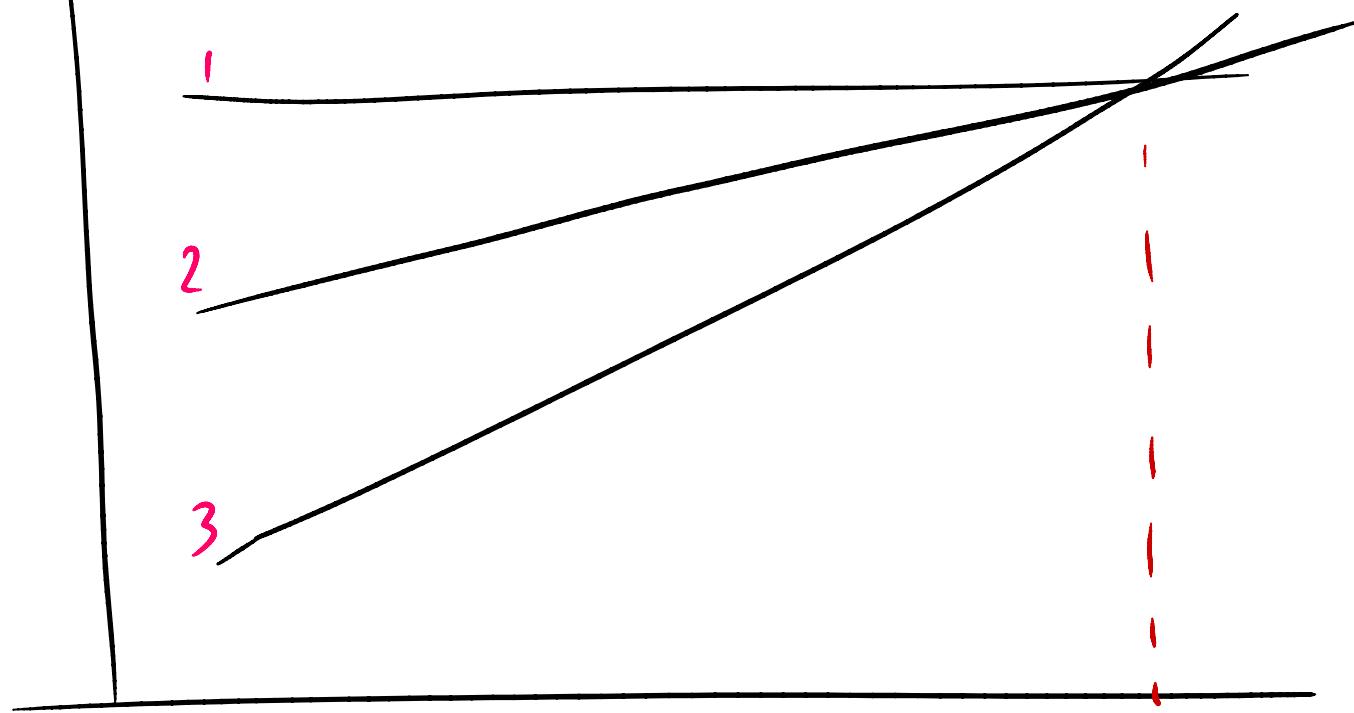
+ \approx custodial isospin $\Rightarrow \approx \text{SO}(10) \Rightarrow (l_L^c, b_R^c) + \nu_R^c$

+ proton stability $\Rightarrow U(1)_{\text{baryon}}^{\text{bulk}}, t_R^c + \text{exotics}$
have $-\frac{1}{3}$ chg.

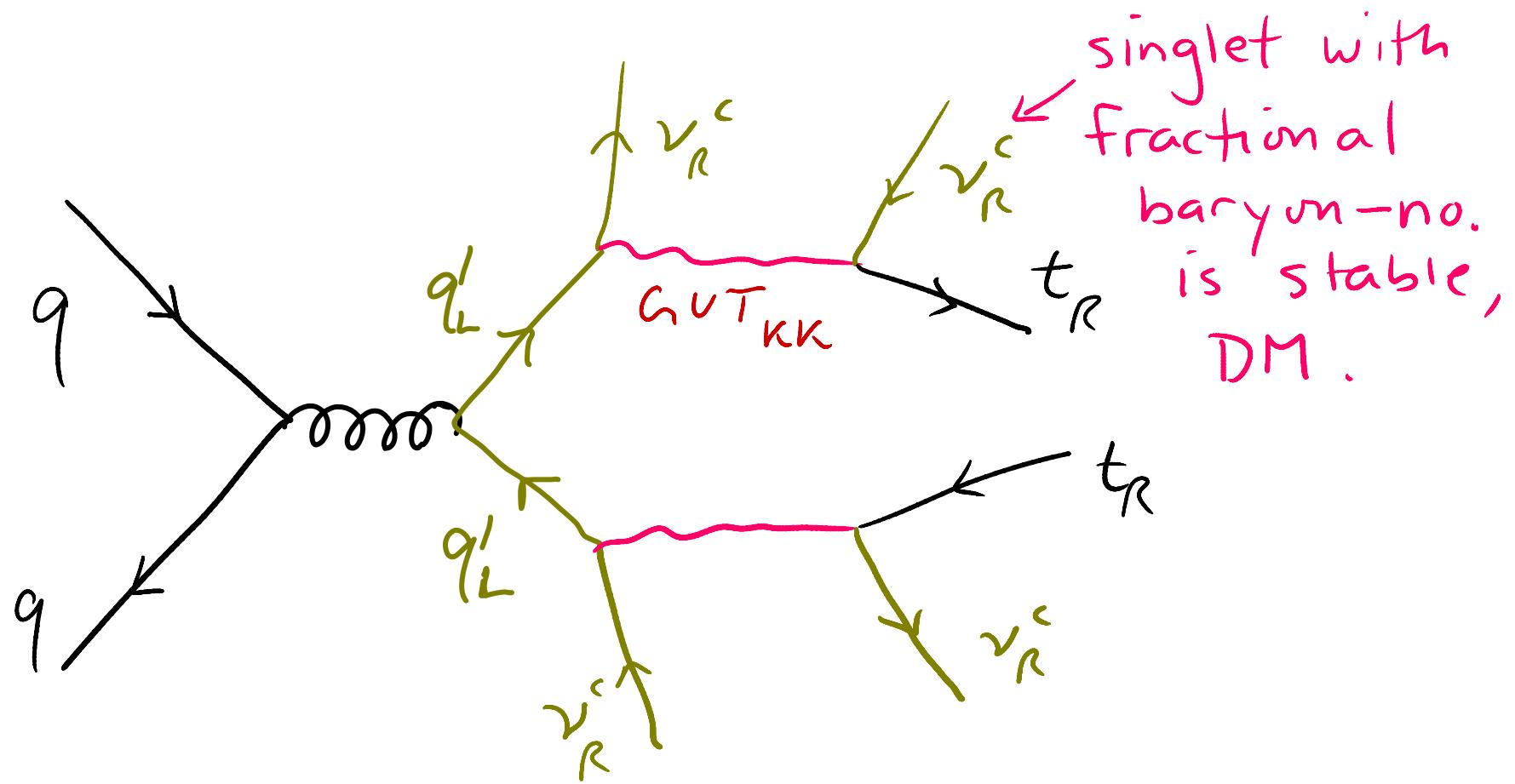
DIFFERENTIAL TOP-OLOGY

$$\frac{1}{\alpha_i} - \frac{1}{\alpha_{i'}}(E)$$

Agashe, Contino, Sundrum
'05

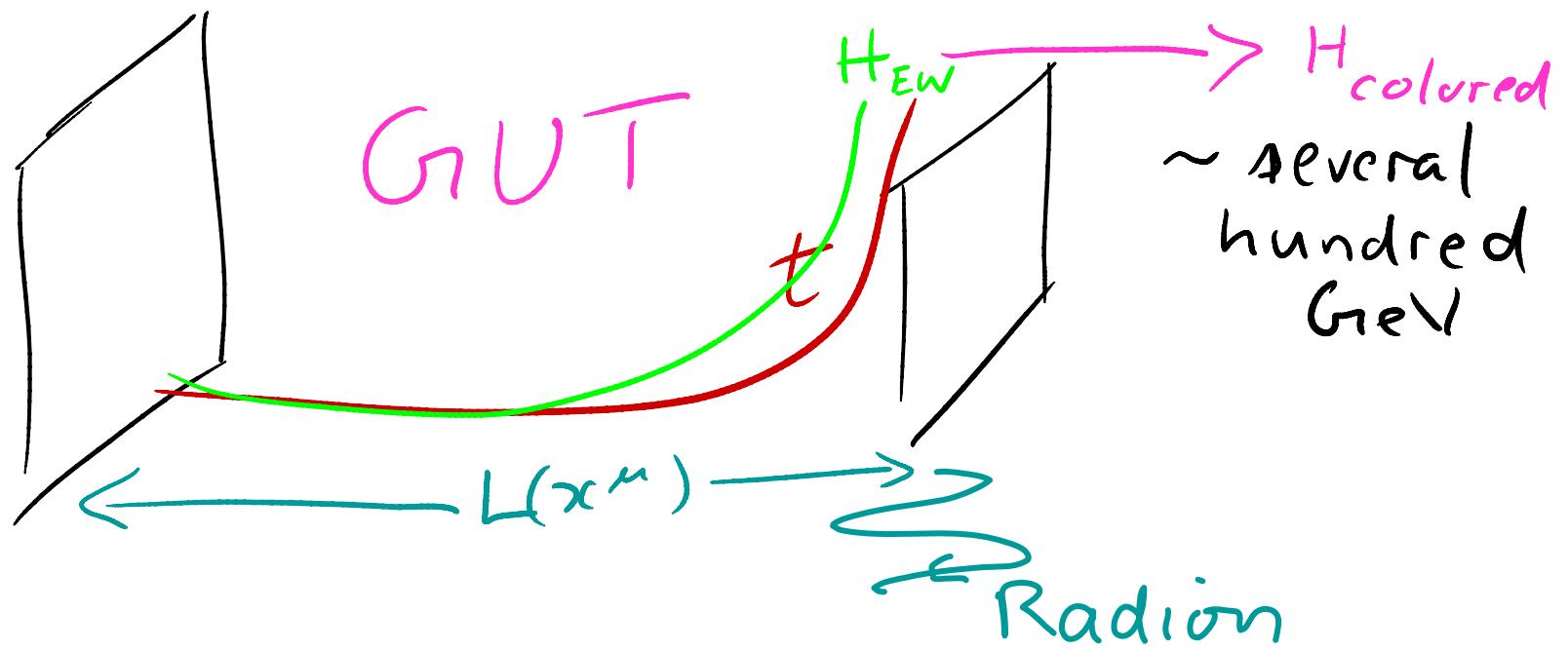


KK modes \approx complete GUT multiplets don't contribute
O-mode wavefunctions (tr in particular) modify
IMPROVE SM unification!



Agashe, Servant '04 . $t\bar{t} + \cancel{\ell}$

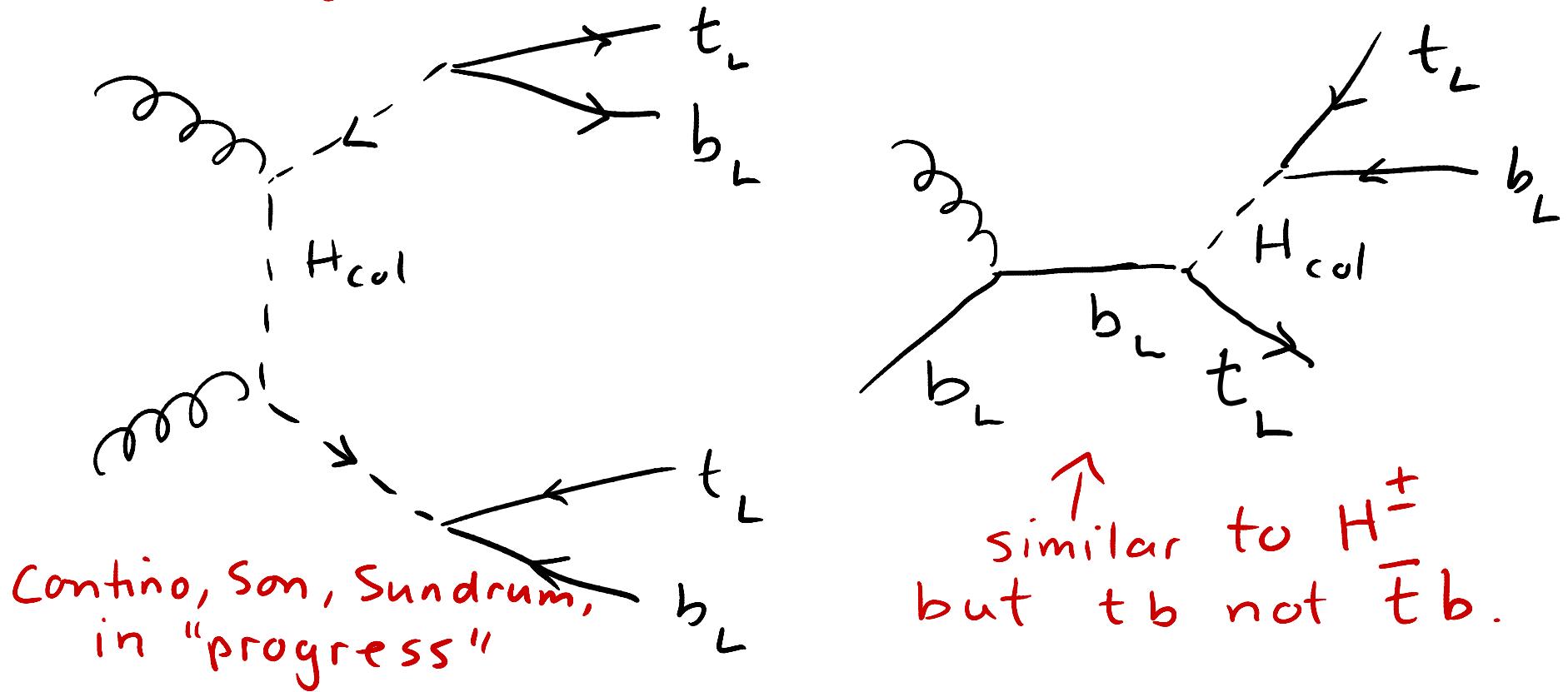
Extended Higgs Sector natural, & naturally couple to t



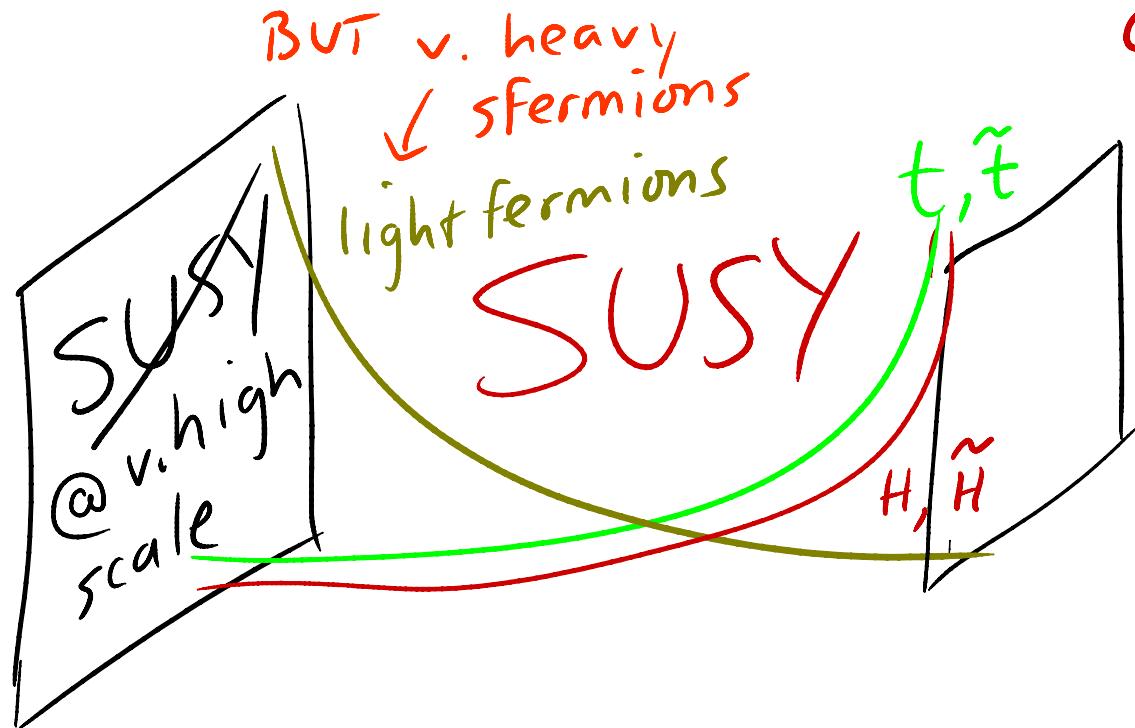
Colored Higgs of Warped Unification

In fact baryon no. violation constraints
are satisfied with $\sum_2^{\text{quark parity}}$,

allowing $\epsilon_{ij} H_{\text{col}}^{i,j} t_L^j b_L^k$ on IR brane



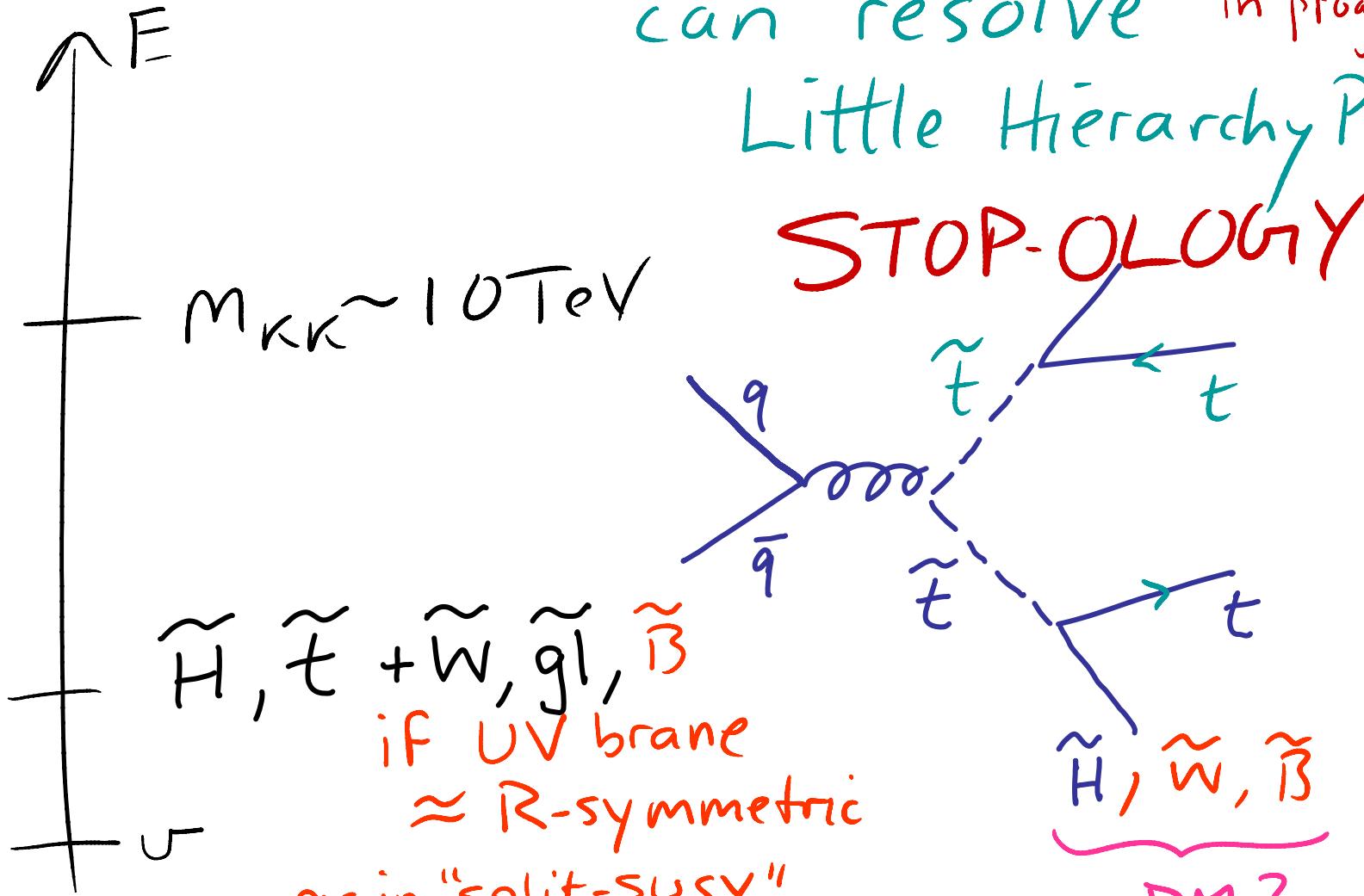
Accidental SUSY . . .



Gherghetta, Pomarol '03
Goh, Luty, Ng '03
Strassler '03
Kramer, Sundrum
to appear

Little SUSY

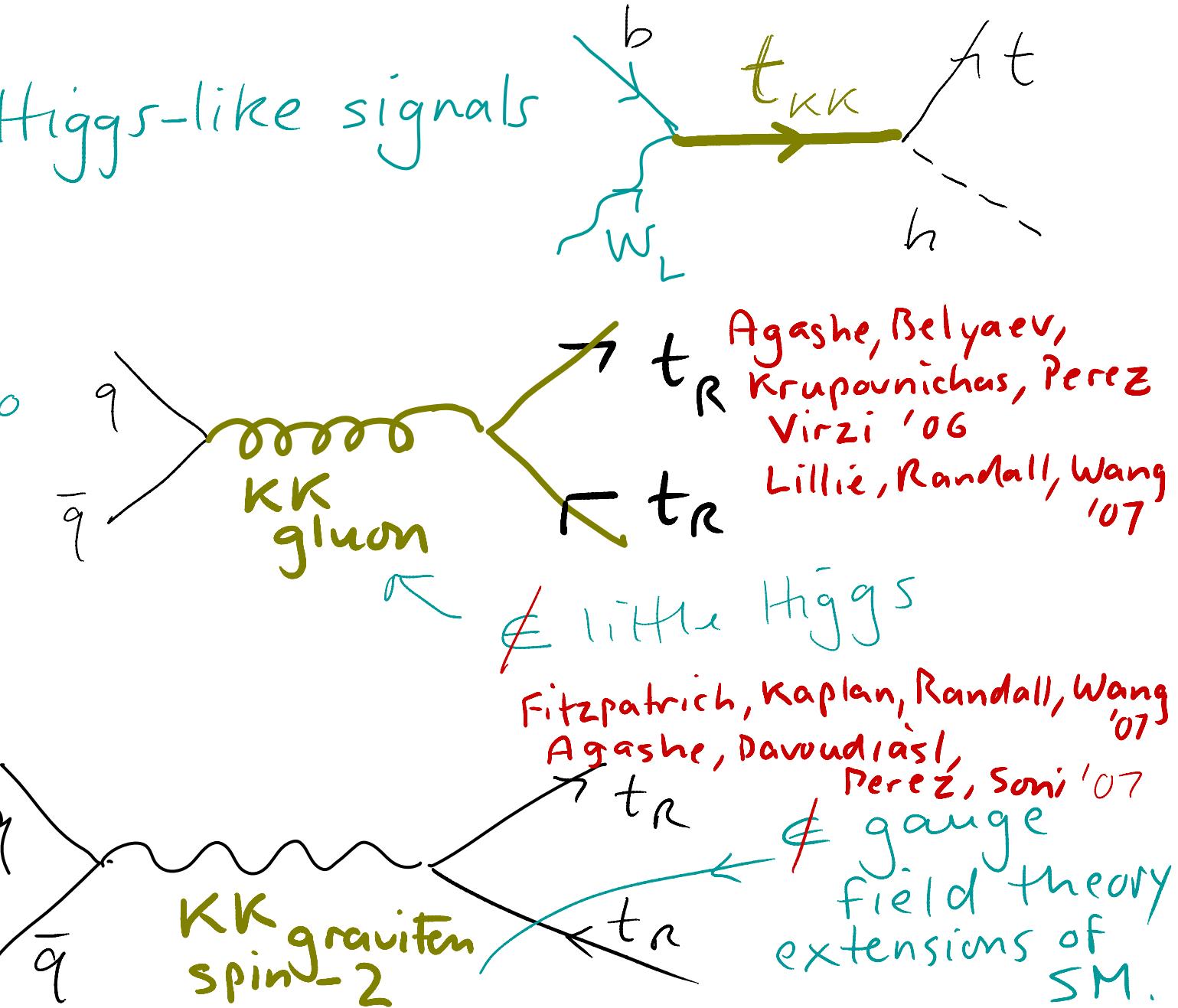
Sundrum,
can resolve in progress
Little Hierarchy Problem



$$m_{KK} \sim 3 \text{ TeV}$$

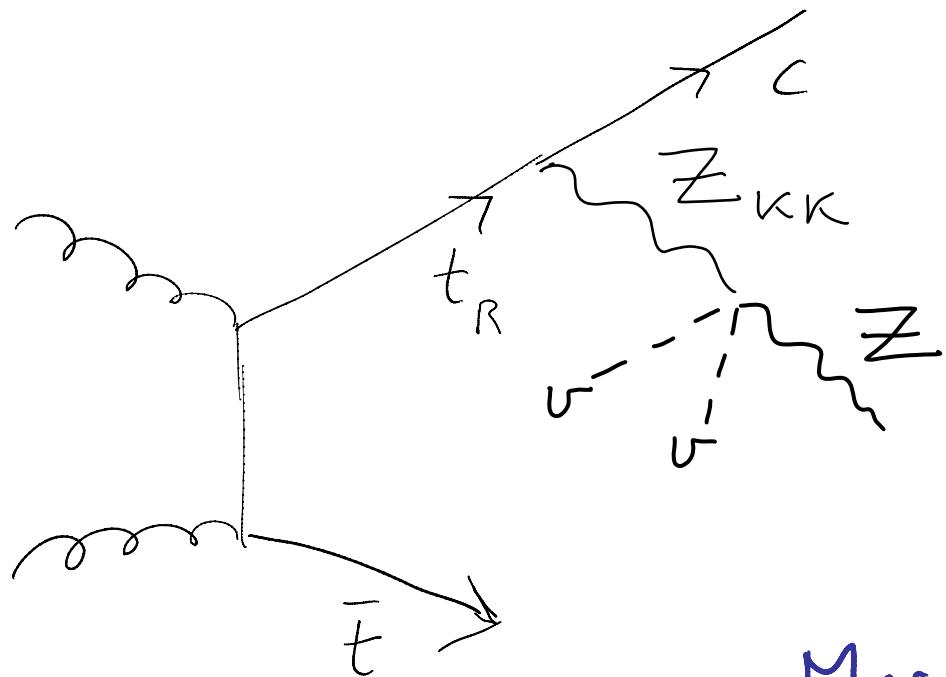
Little-Higgs-like signals

But also



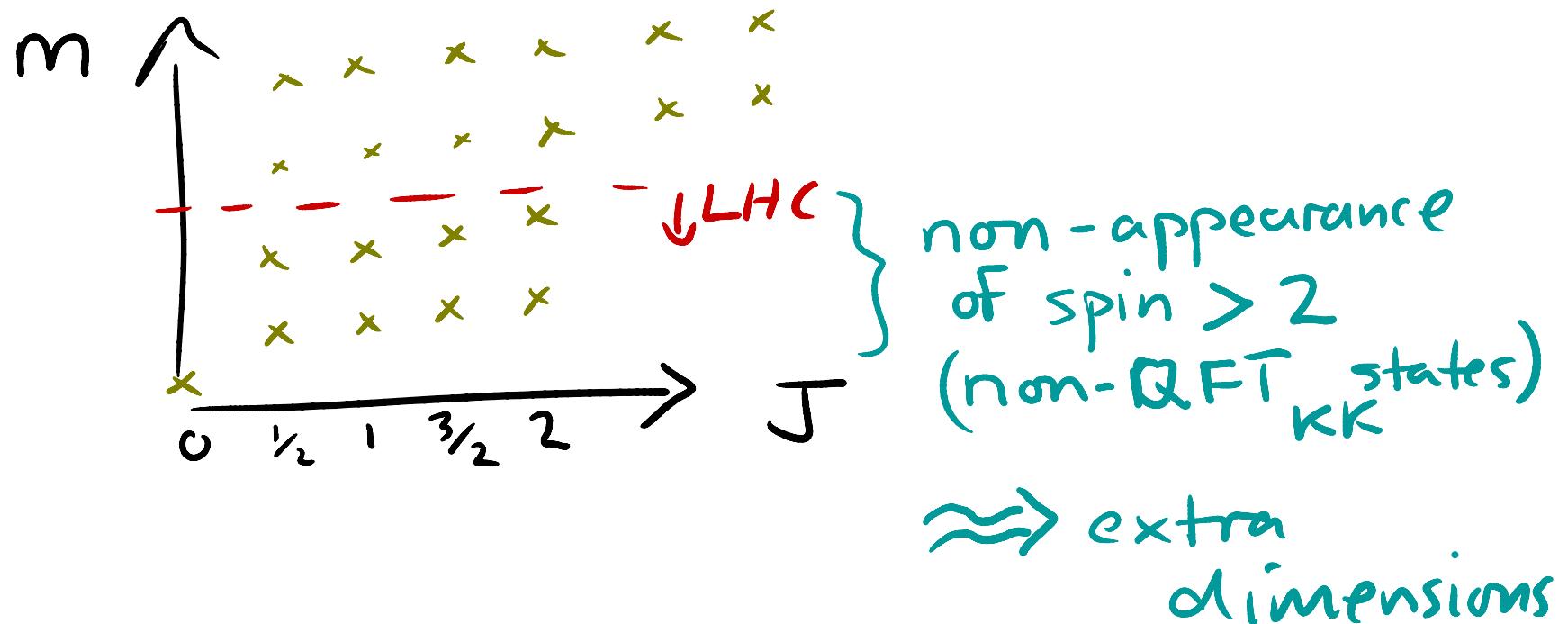
& Novel top quark couplings
become observable:

Agashe, Perez, Soni '06



More general analysis of
 t, H shifted couplings:
Giudice, Grojean, Pomarol, Rattazzi '07

$$m_{KK} \sim 1.5 \text{ TeV}$$



Useful Reconnaissance Tool

Cheng, Thaler, Wang '06
Contino, Kramer, Son, Sundrum '07

Deconstructed 4D 2-site model

for approximate, programmable,
flexible analyses.

↪ SM + 1st KK level

+ easily include light exotics.

Catch new possibilities missed in
minimal models. Eg.

