

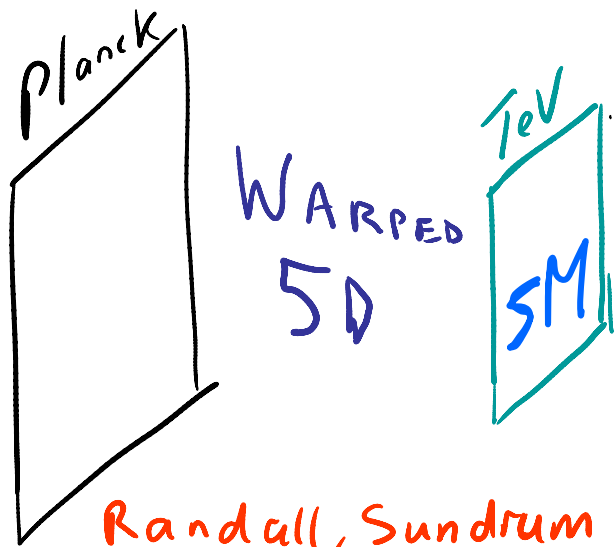
WARPED

WORLD

FIRST CONTACT

Raman Sundrum
Johns Hopkins University₁

WADING INTO THE POOL



Randall, Sundrum '99

(Goldberger, Wise '99)²

Davoudiasl, Hewett, Rizzo '00

Chang, Hisano, Nakano, Okada, Yamaguchi '00

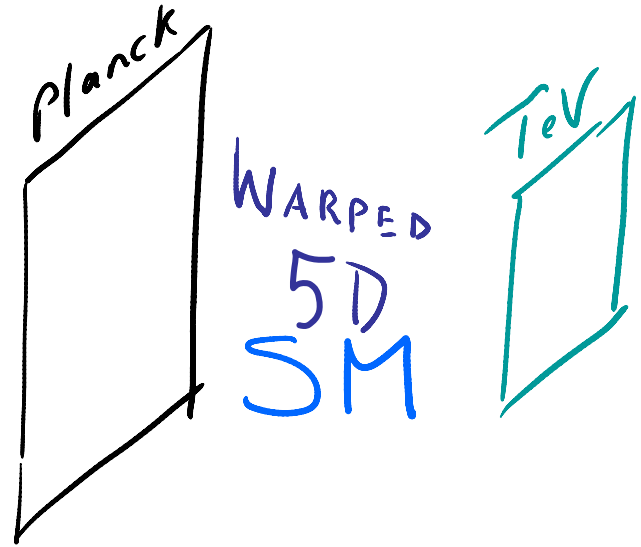
Grossman, Neubert '00

Gherghetta, Pomarol '00

Huber, ShaFi '01

Huber, Lee, ShaFi '02

Csaki, Erlich, Terning '02



Burdman '02

Hewett, Petriello, Rizzo '02

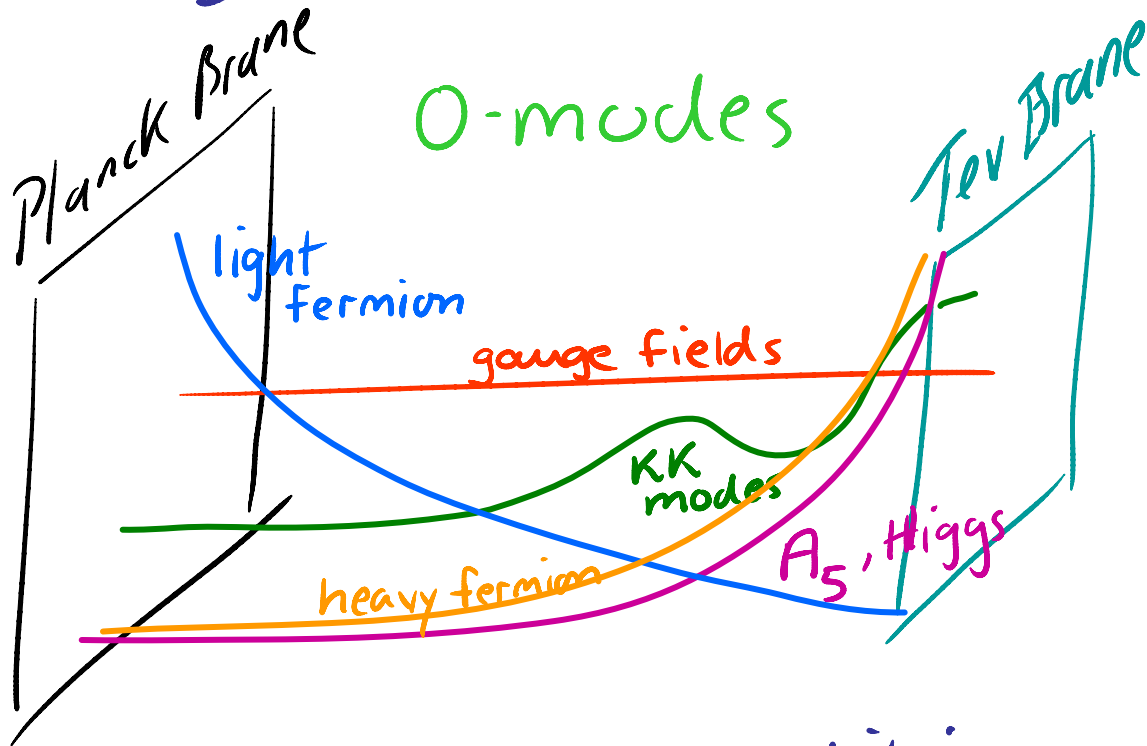
Agashe, Delgado, May, Sundrum '03

Csaki, Grajean, Pilo, Terning '03

Continu, Nomura, Pomarol '03

Agashe, Continu, Pomarol '05

5D Chaos \rightarrow 4D Cosmos



1st approx.
 - works
 (surprisingly)
 well!

Gauge boundary conditions:

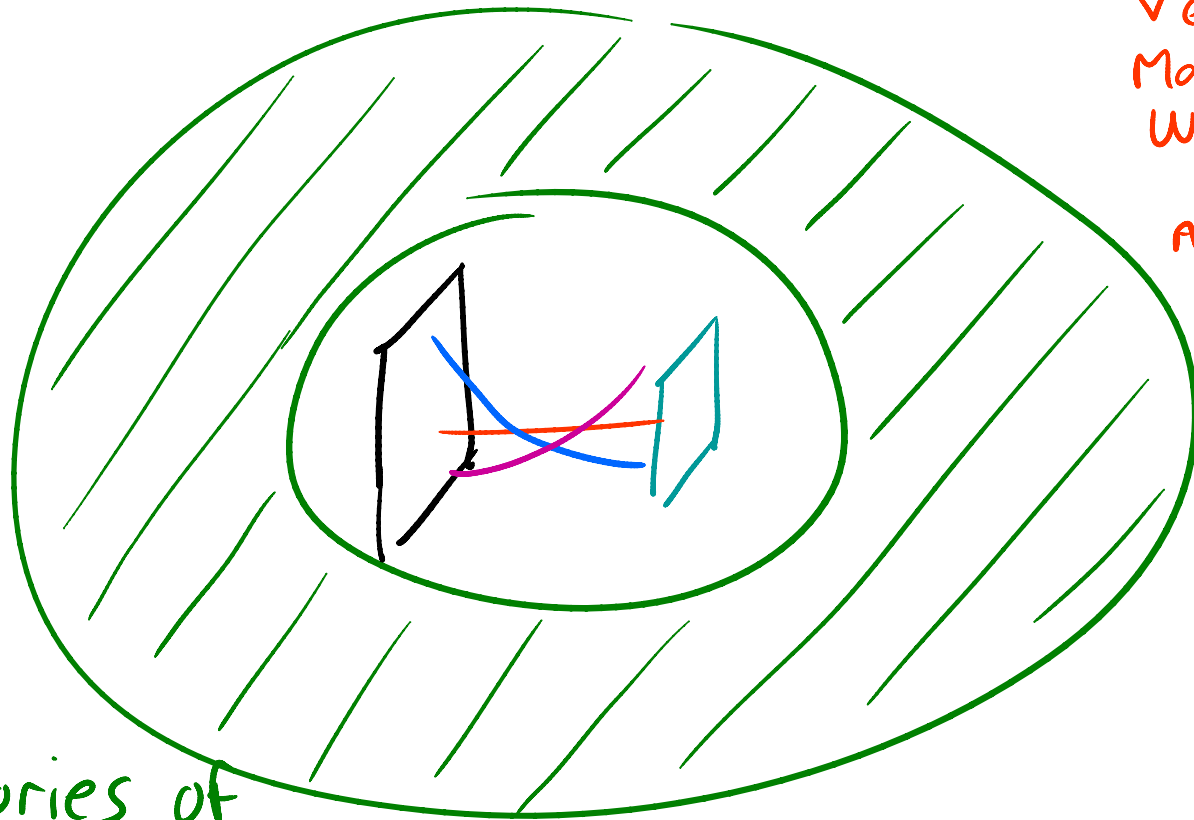
$NN \rightarrow$ 4D gauge fields

$ND \rightarrow$ "Higgsless" breaking 4D gauge theory

$DN \rightarrow$ Protective symmetries: Baryon no., $SU(2)_{\text{custodial}}$, Orbifold GUTs.

$DD \rightarrow A_5$ scalar Higgs, PGB's.

AdS/CFT



Verlinde '99
Maldacena, remarks '99
Witten, remarks '99
Gubser '01
Arkani-Hamed,
Porrati, Randall '01
Rattazzi, Zaffaroni '01
Perez-Victoria '01
⋮

4D Theories of
Strongly coupled Higgs Sector,
Composite Higgs degrees of freedom

Elementary

SM - H

Composite

H
⋮

coupling via

$$A_\mu J^\mu$$

Global symmetry current of Higgs sector

& $\psi \Theta$

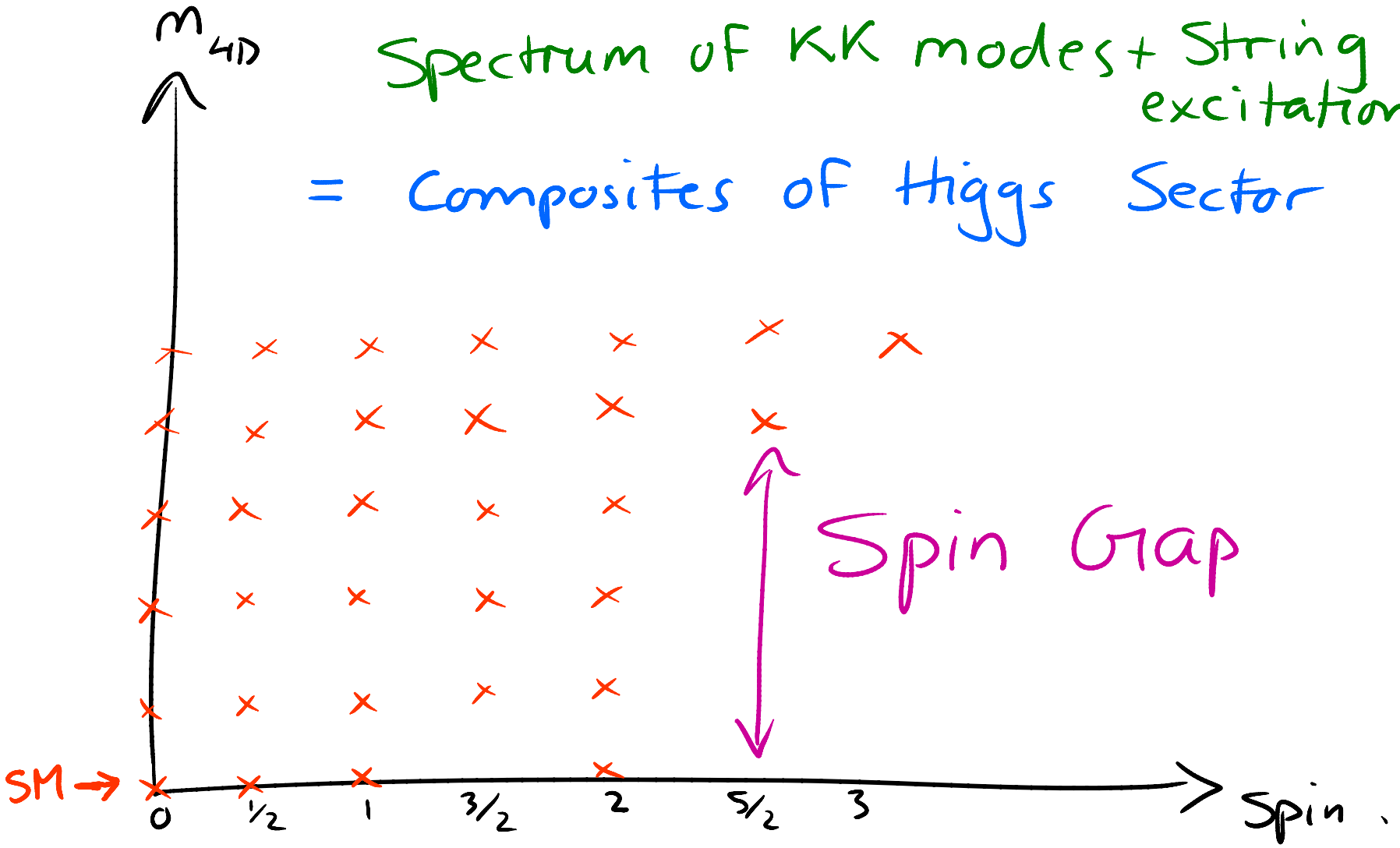
D.B. Kaplan '91 \leftarrow Fermionic composite operator of Higgs sector, dimension $5/2 + \delta$

\Rightarrow Yukawa hierarchies $\sim \left(\frac{\text{TeV}}{M}\right)^{\delta_L + \delta_R}$

EXTRA-DIMENSIONAL DISCOVERY

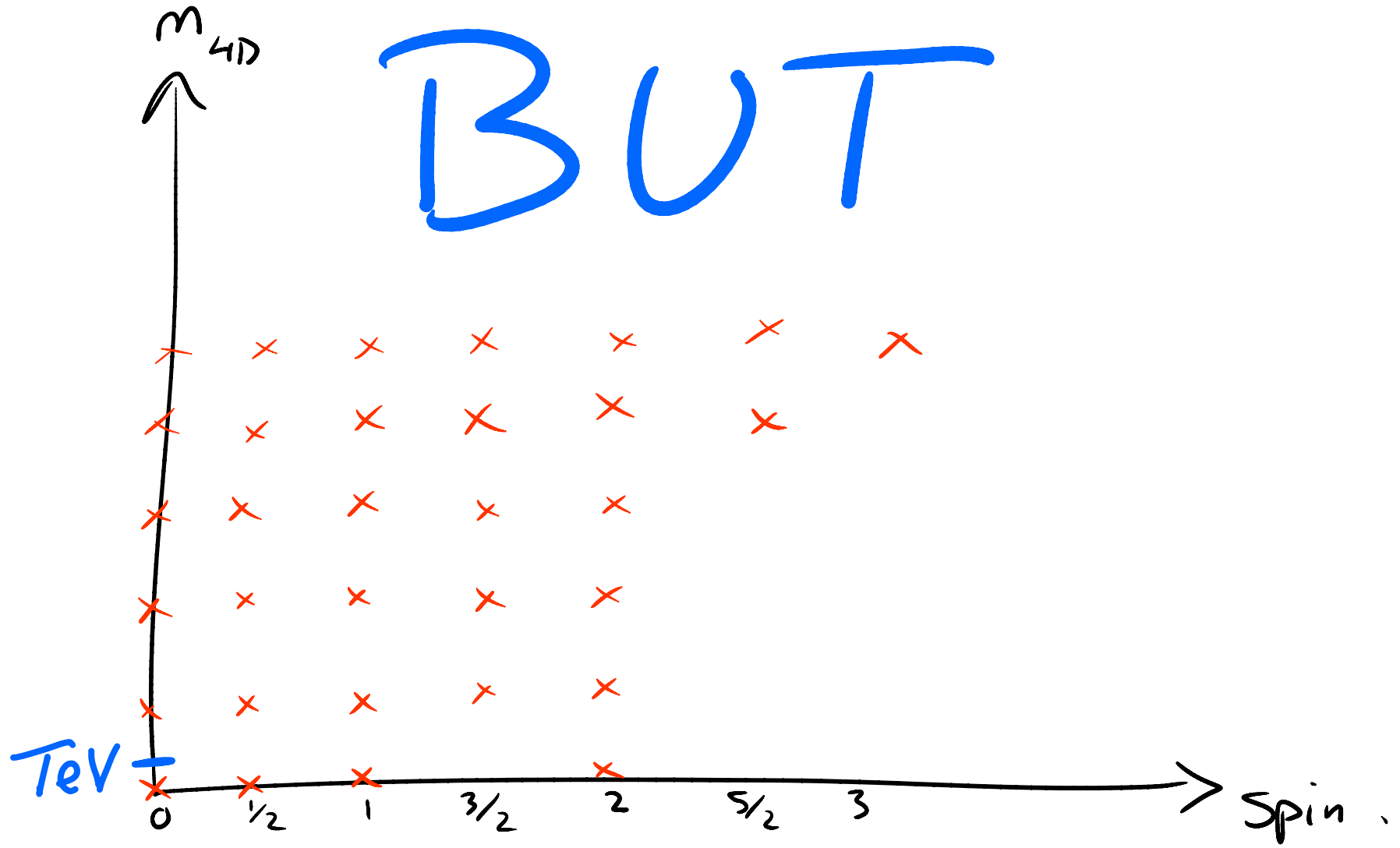
Spectrum of KK modes + String excitations

= Composites of Higgs Sector

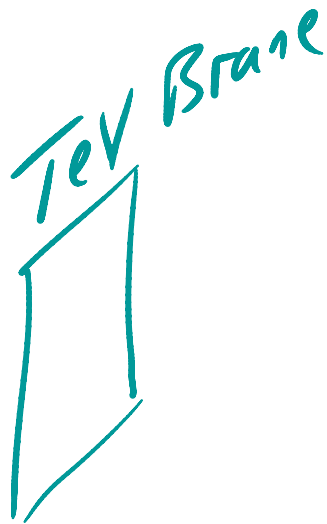
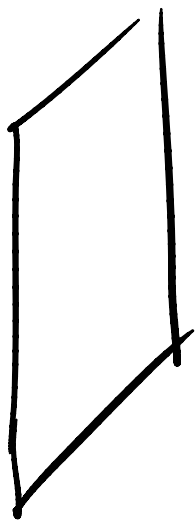


EXTRA-DIMENSIONAL DISCOVERY

BUT



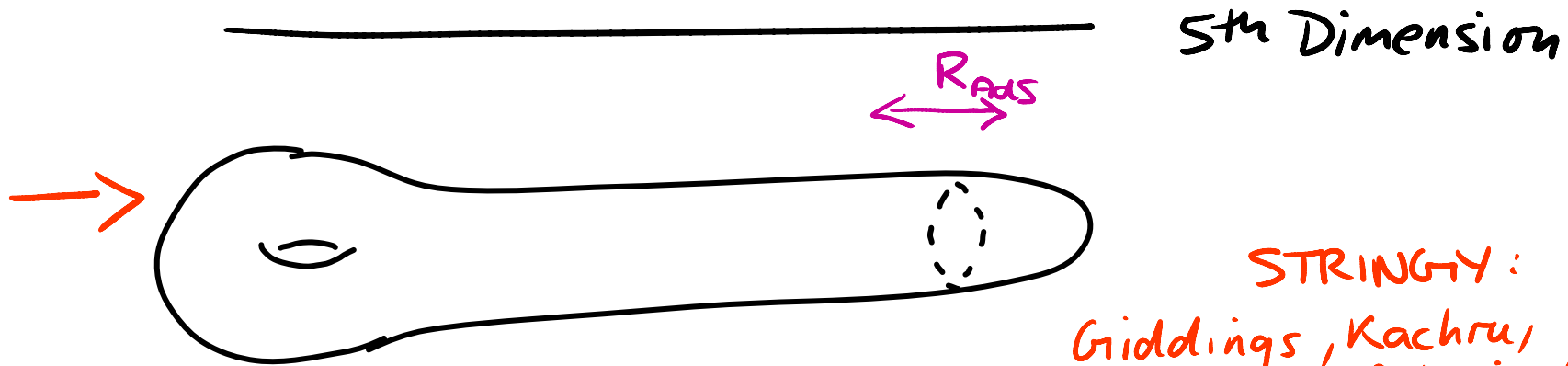
Hard-Wall Limit...



$$\mathcal{L} = \mathcal{L}_{\text{Bulk}} + \underbrace{\mathcal{L}_{\text{Branes}}}_{\text{minimal radiatively stable}}$$

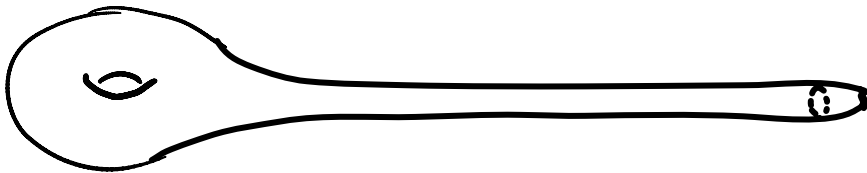
... is predictive, relating even lowest KK masses for different particle species.

Hard-Wall Limit

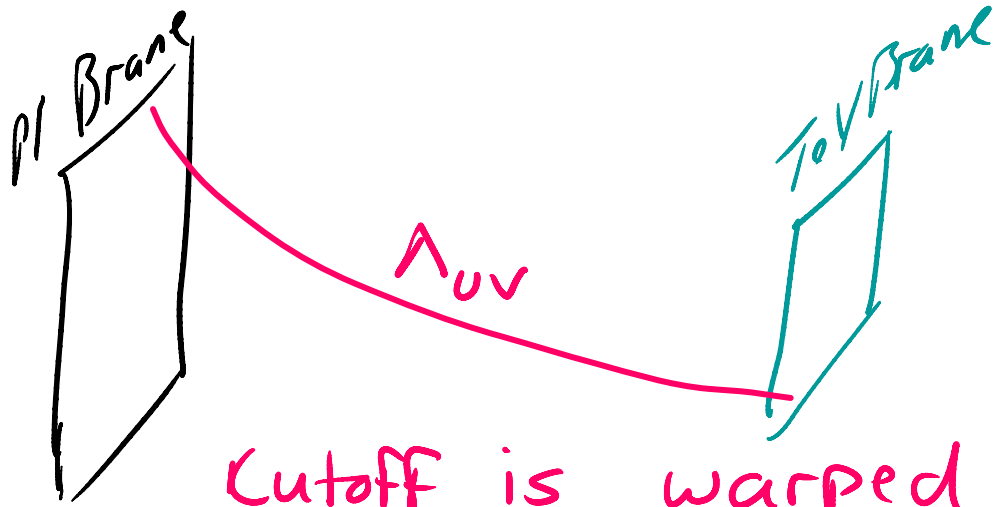


STRINGY:
Giddings, Kachru,
Polchinski '01
...

But Hard-Wall Limit is still possible



WARPED EFFECTIVE FIELD THEORY...



Cutoff is warped down from Planck to TeV brane.

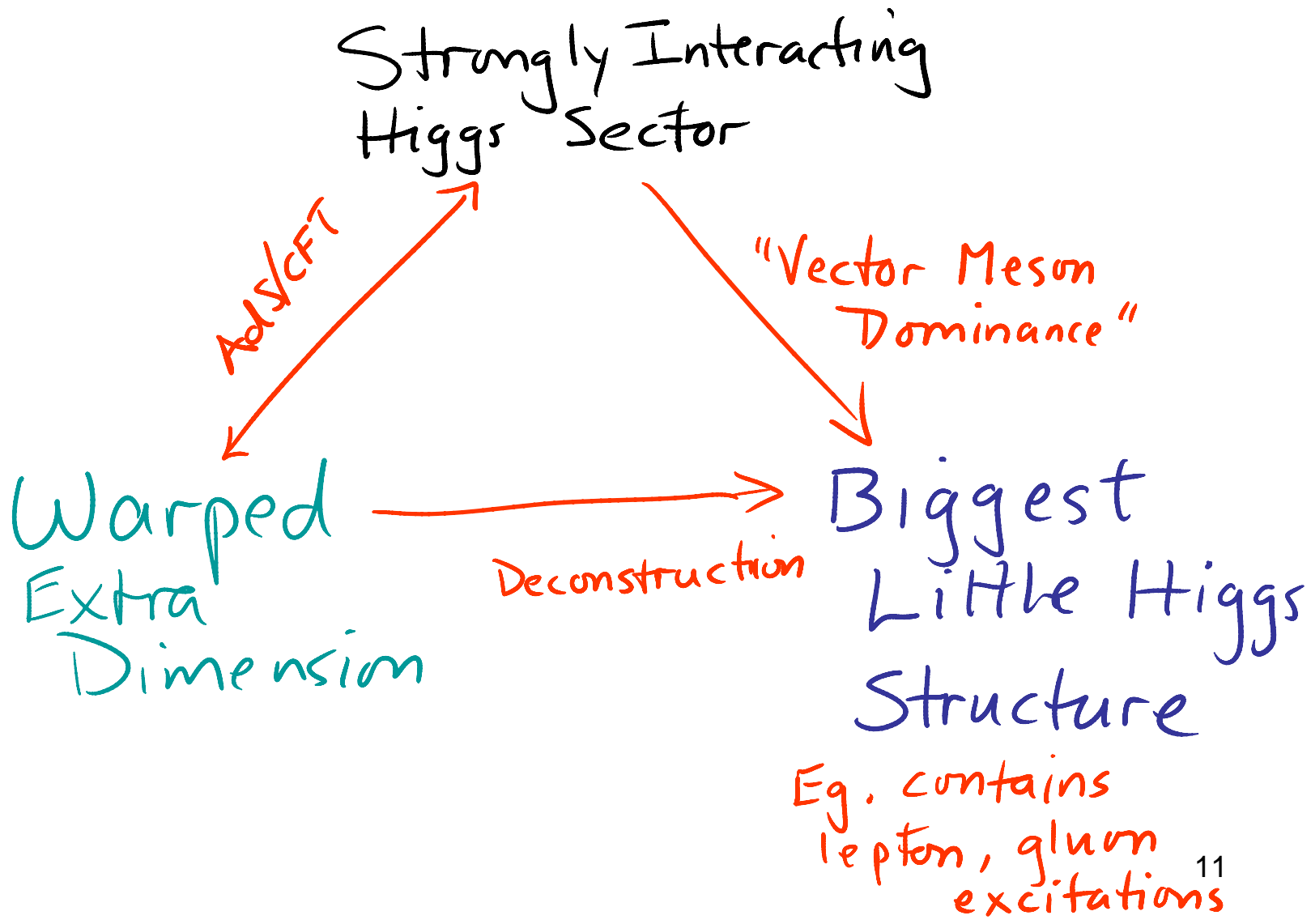
describes exclusive processes $< \Lambda_{UV}^{\text{warped down}}$
 but also some inclusive processes $< \Lambda_{UV}^{\text{warped up}}$.

$$\frac{1}{\alpha_4} = \frac{L_5}{\alpha_5}, \quad \frac{\Lambda_{UV, \text{max}}^{\text{warped down}}}{m_{KK}} \sim \frac{4\pi}{\alpha_4 N \log \text{hierarchy}}$$

With 1-loop corrections \Rightarrow etc. $\frac{\Lambda_{UV, \text{max}}}{m_{KK}} \sim 3$

Little M-theory

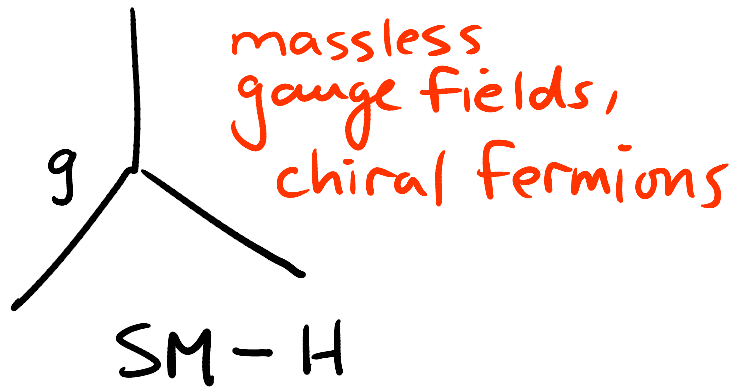
Cheng, Thaler, Wang '06
Contino, Kramer, Son, Sundrum '07



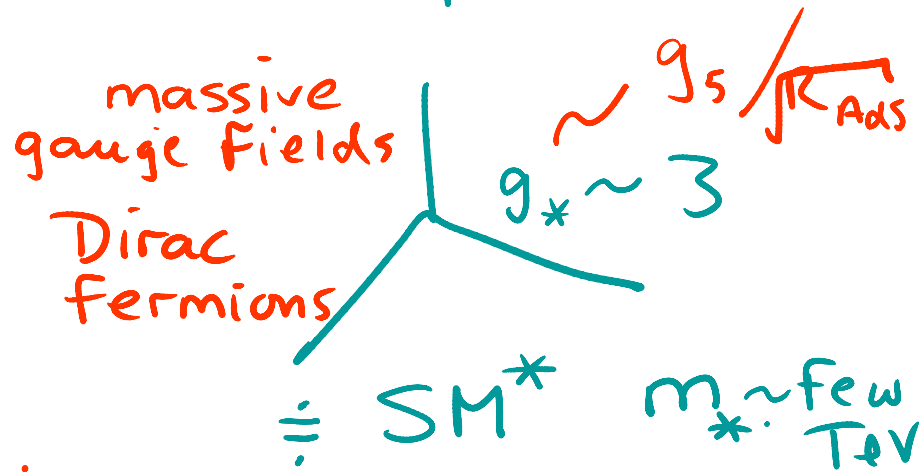
2-sector model -

simple, flexible tool for first contact

Elementary



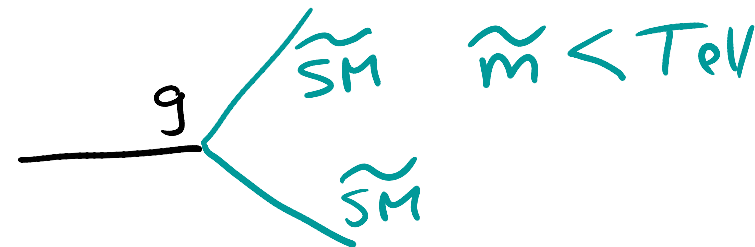
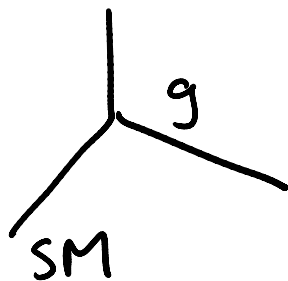
Composite



mass mixing

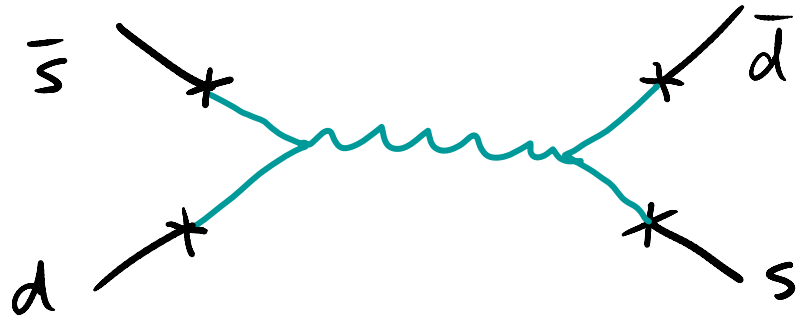
v. hierarchical for fermions
less so for gauge bosons.

compare with
SUSY
(R-parity)



PRECISION TESTS

FCNC's



flavor physics
in present
context
Agashe, Perez, Soni

suppressed by small mixings
of light fermions

an automatic extension of GIM.

CP-Expt. bounds generically $\Rightarrow M_* > 3\text{TeV}$

~~CP~~-Expt. bounds generically $\Rightarrow M_* > 10\text{TeV}$
Csaki, Falkowski, Weiler '08

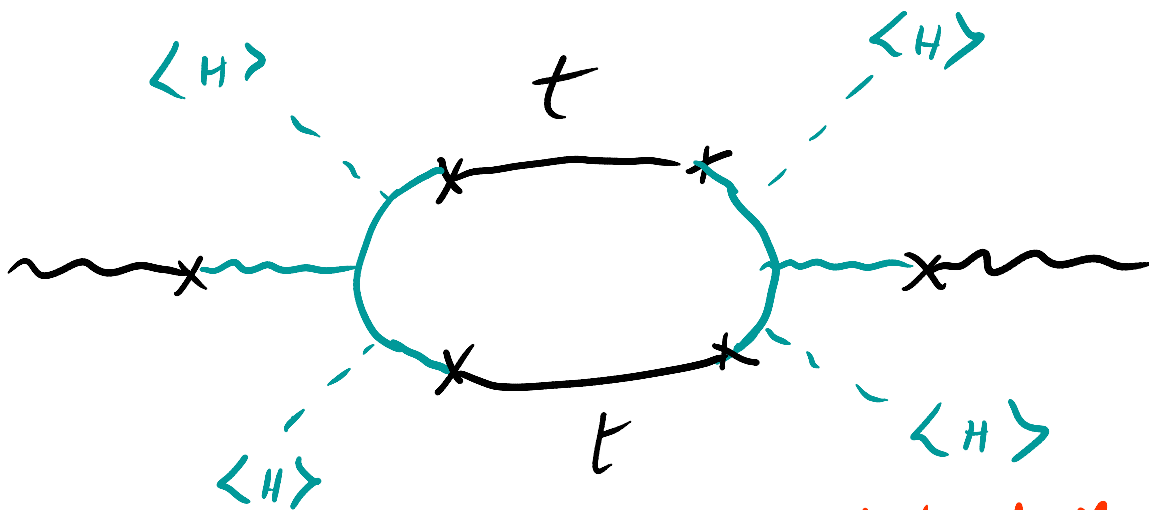
but lower M_* in some regions
of parameter/idea space

S



~ Csaki, Erlich, Terning '02

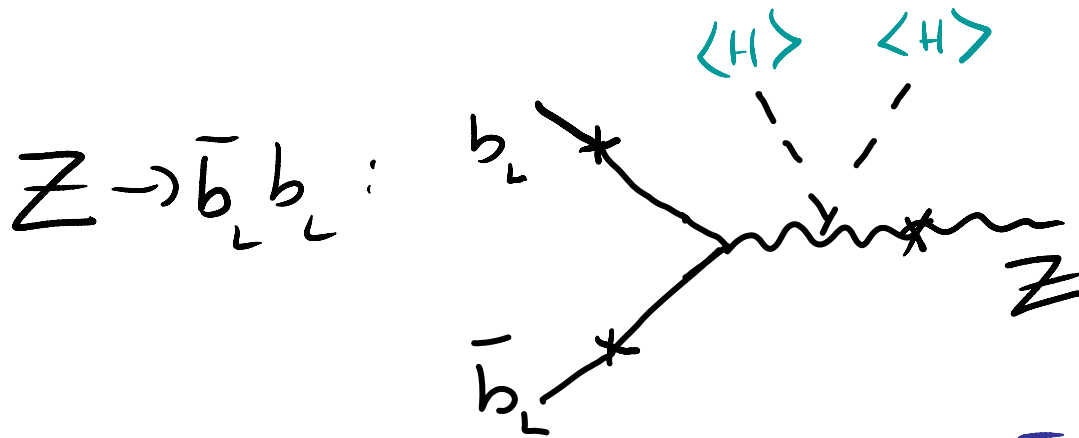
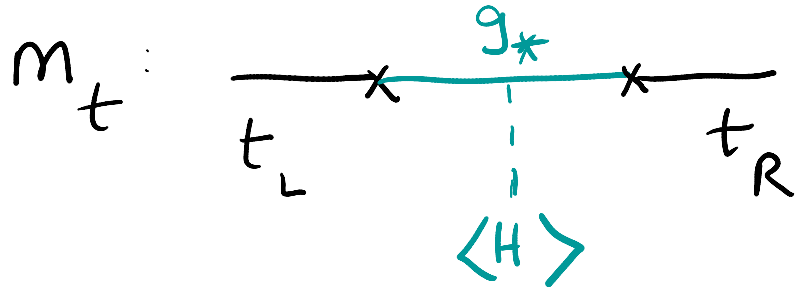
T



~ Agashe, Delgado, May, Sundrum '03

Expt. $\Rightarrow m_{*} > 2-3 \text{ TeV}$

TOP COMPOSITENESS

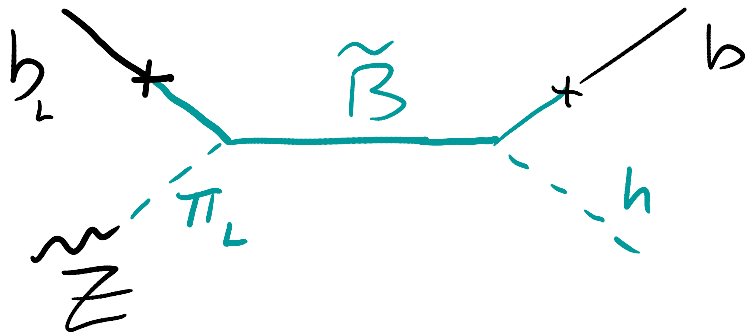


Suppressing this $Z b \bar{b}$ correction \Rightarrow

t_R ———— x ———— is maximal

\Rightarrow $t_R \longrightarrow t_R$

Interesting channels



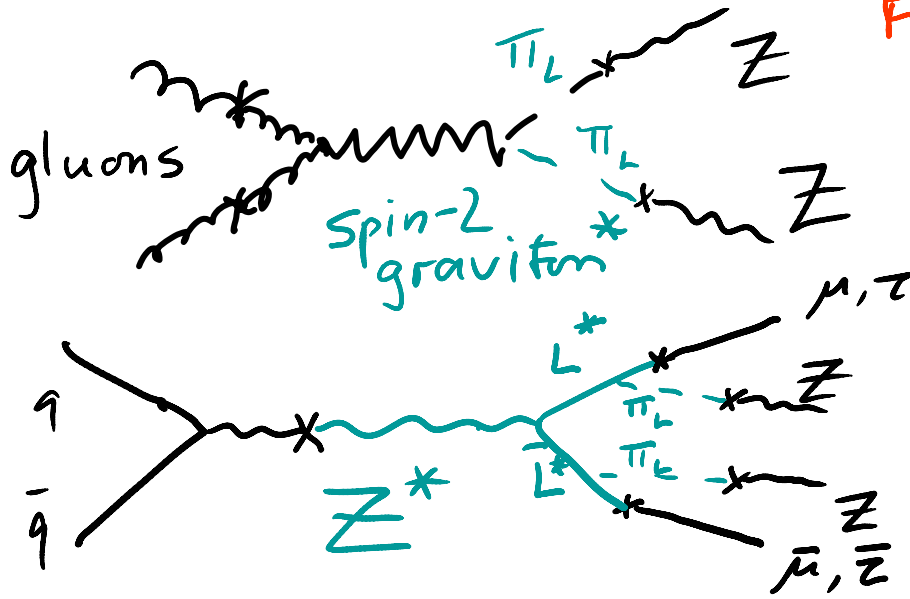
Little-Higgs-like

Agashe, Belyaev, Kruparickas,
Perez, Virzi '06
Killie, Randall, Wang '07



Fitzpatrick, J. Kaplan, Randall, Wang '07

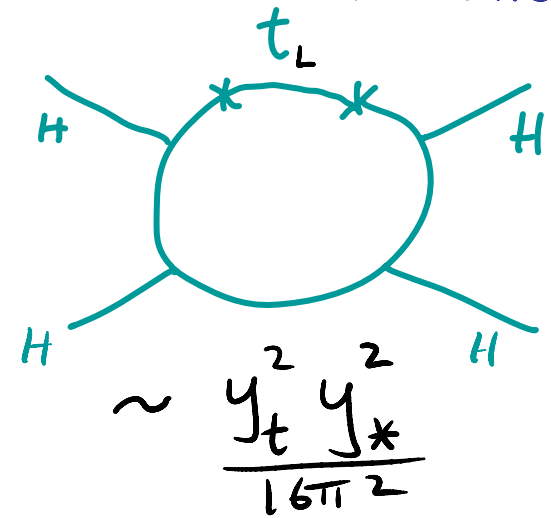
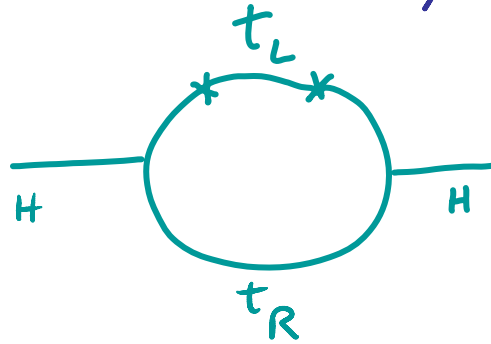
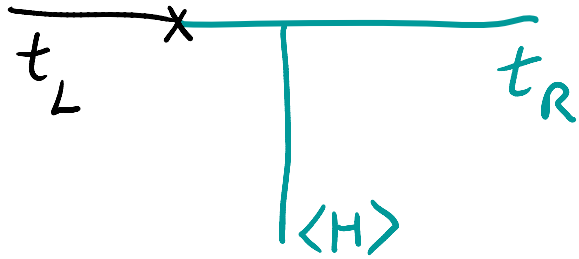
Agashe, Davoudiasl, Perez, Soni '07



Lepton* observability:

Contino, Kramer, Son, Sundrum '07
(not in hardwall limit)

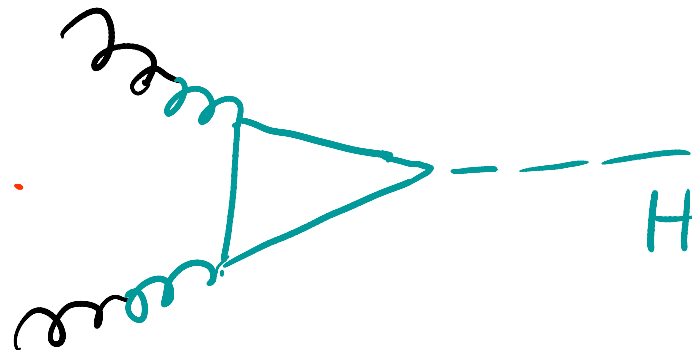
Top/Higgs mass/quartic/ σ_{LHC}



$c/w \sim \frac{y_t^4}{16\pi^2}$ in SUSY

$\Rightarrow m_{H_{phys}}$ can be > 200 GeV in principle

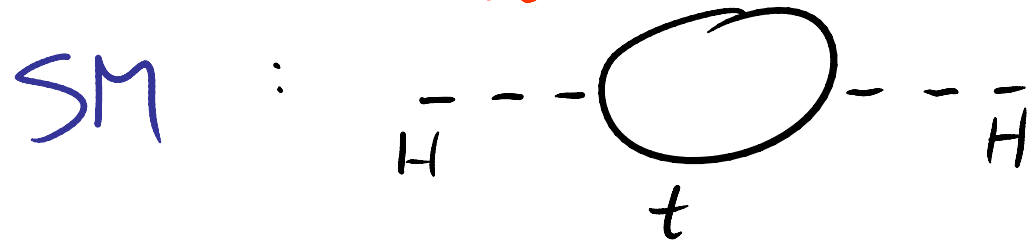
Modified
H cross-section + ...



General approaches:
Manohar, Wise '06
Giudice, Grojean, Pomarol, Rattazzi '07

HIGGS FINE-TUNING

moderate for $M_* \sim \text{Few TeV}$



$$\text{Tuning} \sim \left(\frac{m_H}{115 \text{ GeV}} \right)^2 \left(\frac{430 \text{ GeV}}{\Lambda_{UV}} \right)^2$$

Warped/Composite Higgs

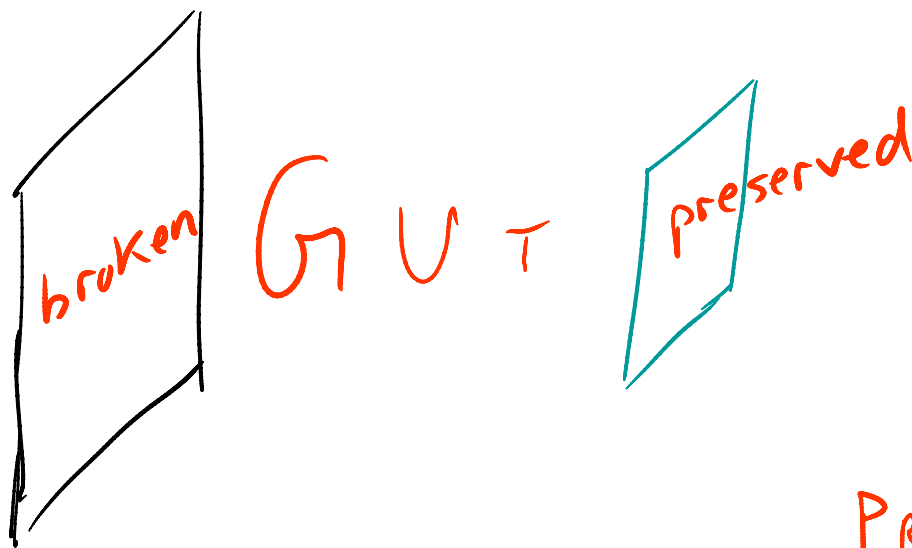
$$\text{Tuning} \sim \left(\frac{m_H}{115 \text{ GeV}} \right)^2 \left(\frac{430 \text{ GeV}}{m_{t^*}} \right)^2$$

$m_{t^*} \gtrsim 2 \text{ TeV}$

SUSY + hi-scale

$$\text{Tuning} \sim \left(\frac{m_H}{115 \text{ GeV}} \right)^2 \left(\frac{430 \text{ GeV}}{m_{\tilde{t}}} \right)^2 / \log^{18}$$

WARPED Orbifold GUTs



Pomarol '00

Randall, Schwartz '01

Goldberger, Nomura, Smith '02

Agashe, Delgado, Sundrum '02

Ghorghetta '04

NON-SUSY
PRECISION UNIFICATION

Agashe, Contino, Sundrum '05

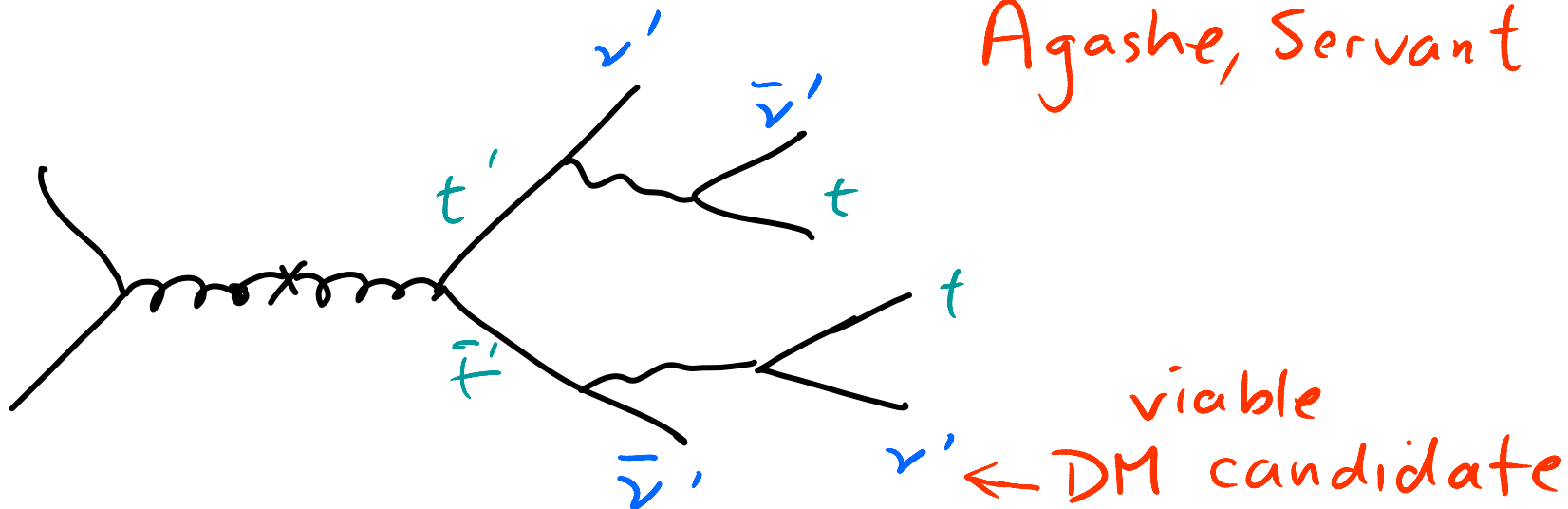
(despite WEFT
expansion parameter
 ~ 1)

Baryon no. protected by

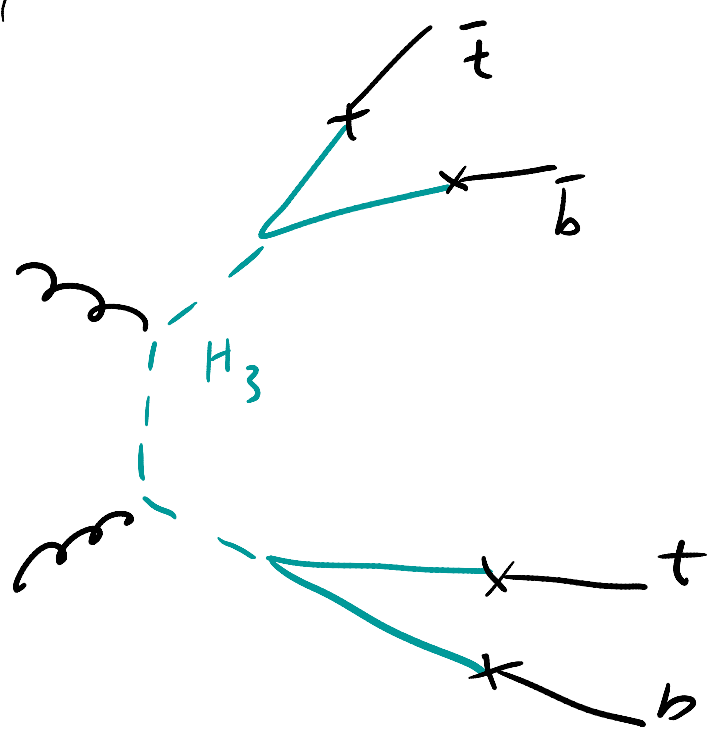
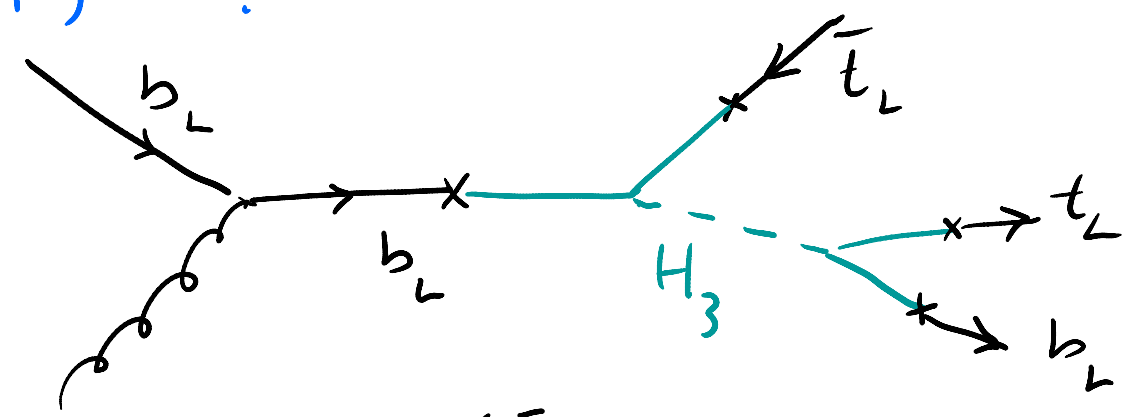
$U(1)_B$ OR $(-1)^{3B}$ of CFT

$U(1)_B \times SO(10)$ Composite t_R comes
with 16- t_R Dirac exotics

Agashe, Servant '04



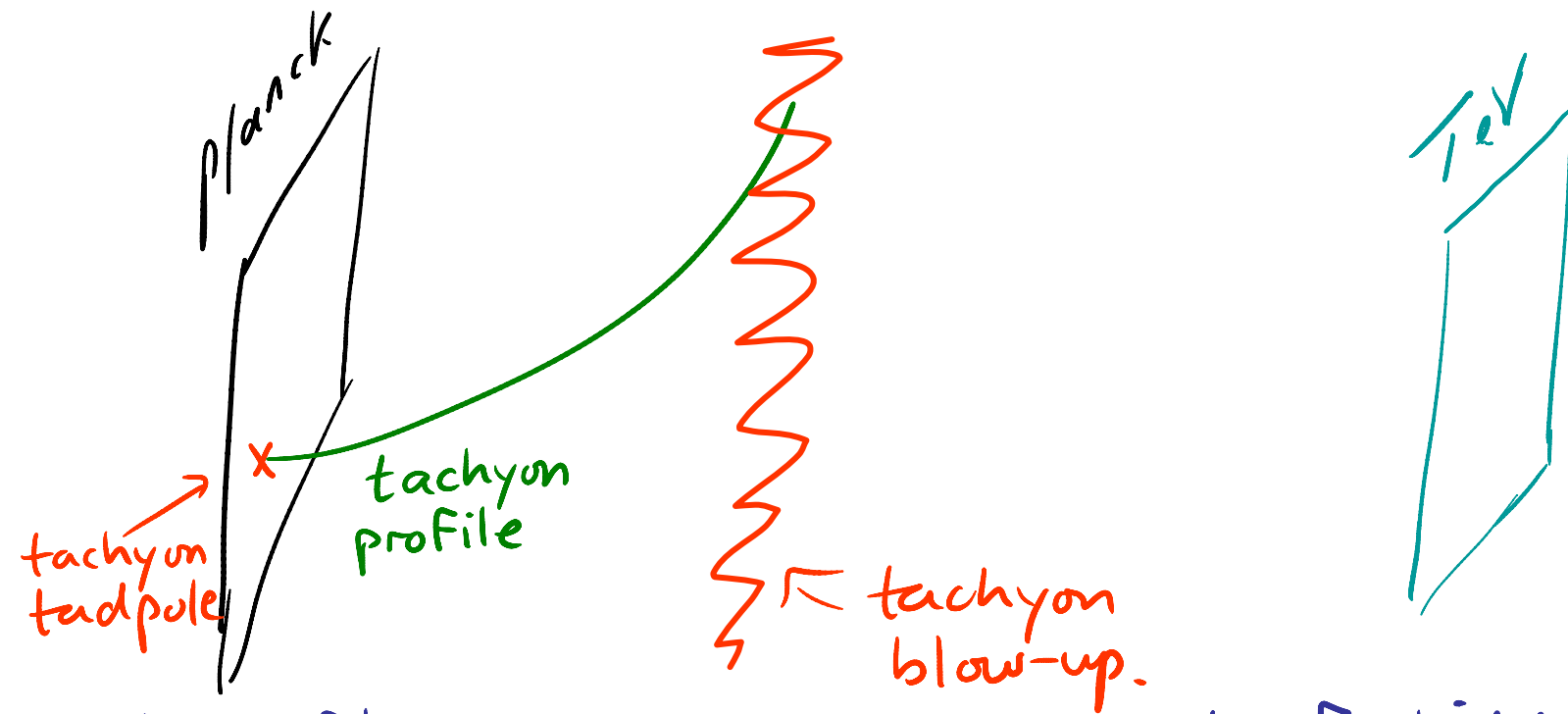
Colored H_3 , $SU(5)$ Higgs partner
 $(-1)^{3B}$:



Contino, Kramer, Son, Sundrum
 in progress (slowly)

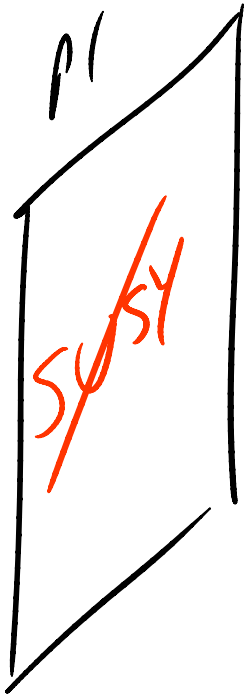
Good Tachyon, Bad Tachyon

Bulk scalar tachyons $m_5^2 < 0$ need not represent instability of AdS_5 , but do \Rightarrow instability in presence of Planck Brane

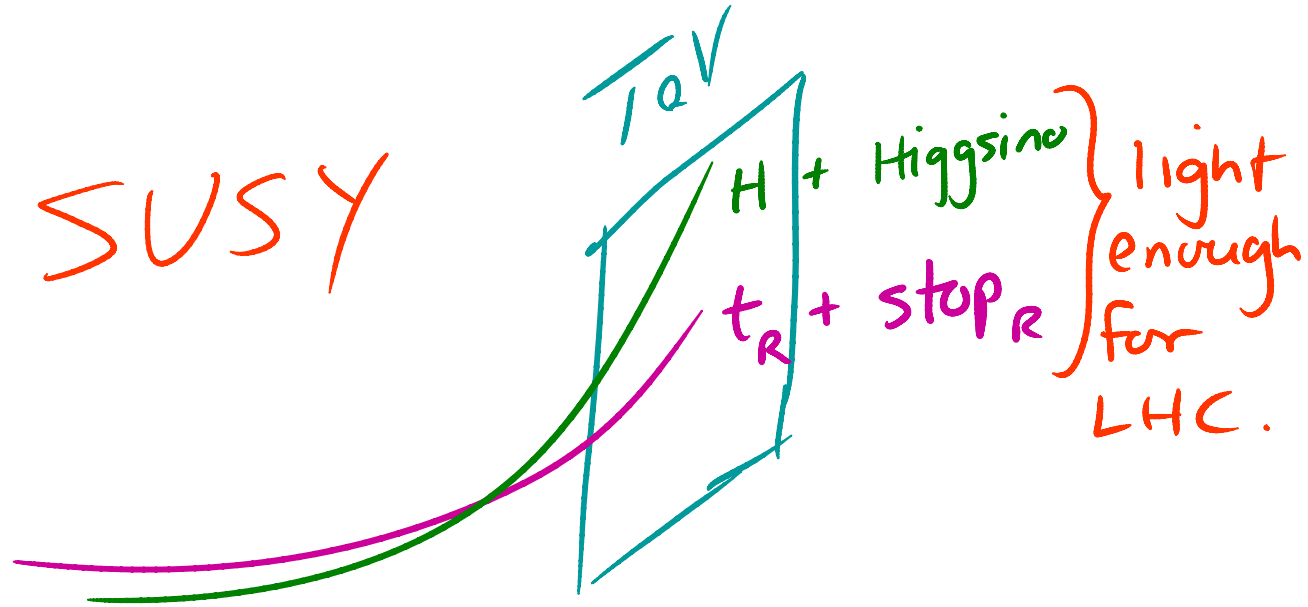


unless Planck brane tadpole can be forbidden by a symmetry.

SUSY in the Bulk



SUSY



Pomarol, Gherghetta '01

related $AdS_5 \times S^5 / N=4 \text{ SYM}$ toy model Strassler '03

Revisited

Kramer, Sundrum '0?

Central issue: Scalar 5D superpartner
of 5D gauge field is TACHYON

controlled by non-abelian gauge symmetry
 $SU(4)_{PS} \times SU(2)_L \times SU(2)_R$ down to IR

$\langle H_u \rangle \neq \langle H_d \rangle$ new source of custodial
isospin violation \Rightarrow

