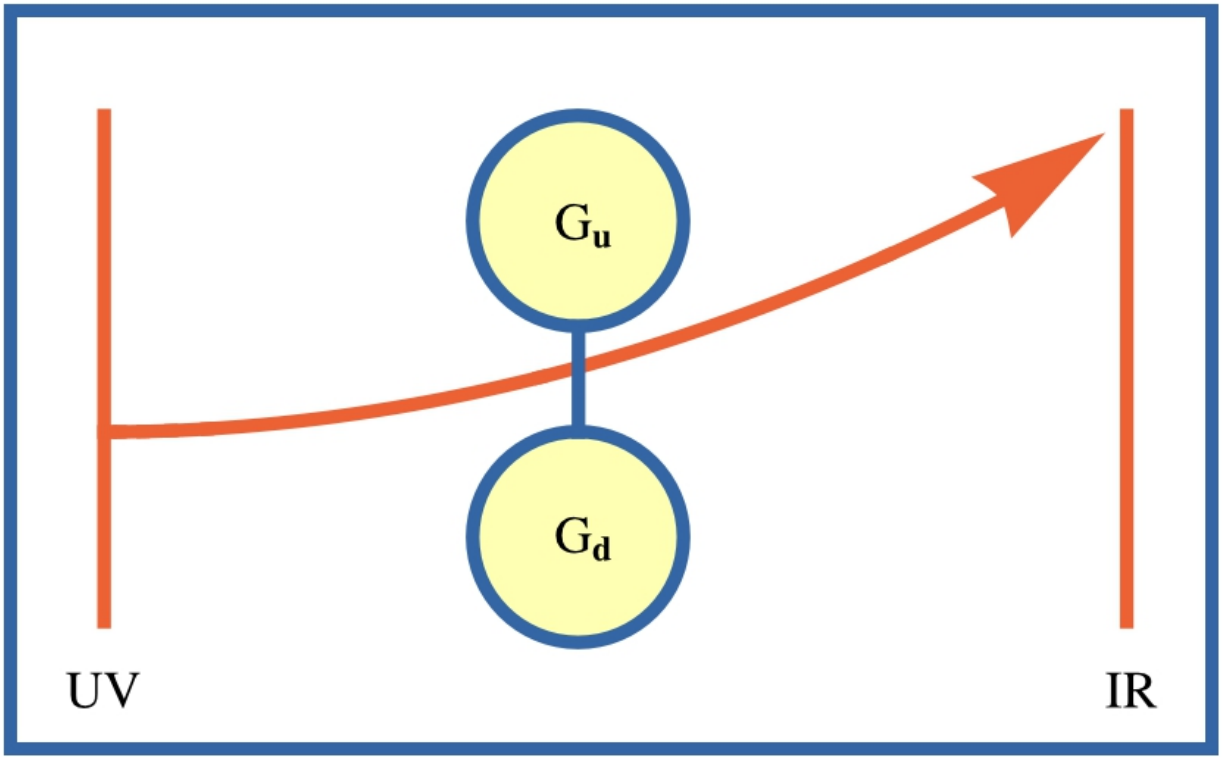
A Collective Quartic for the Composite Higgs from Warped 6D

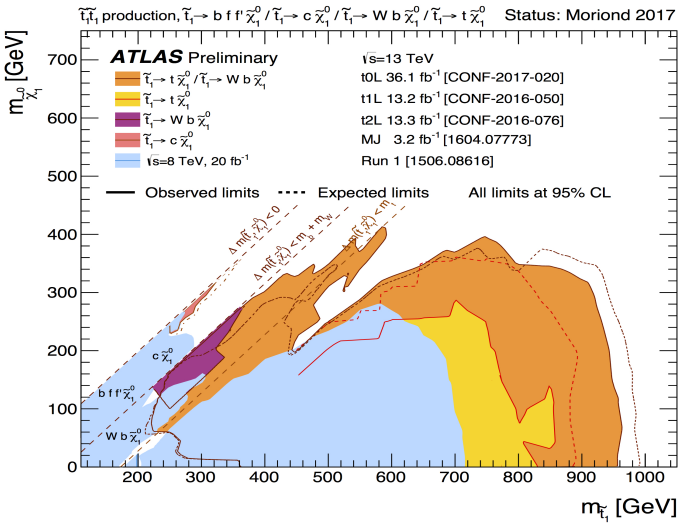


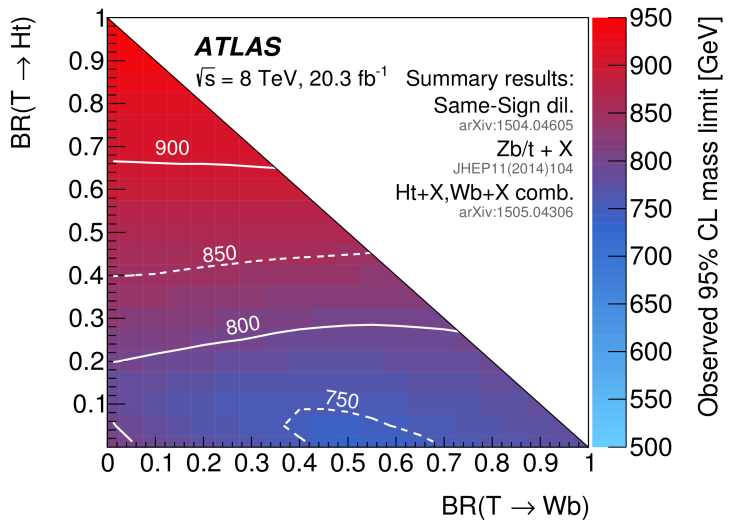
Ofri Telem (Cornell)
Work in progress with C. Csaki, M. Geller
Pheno 2017

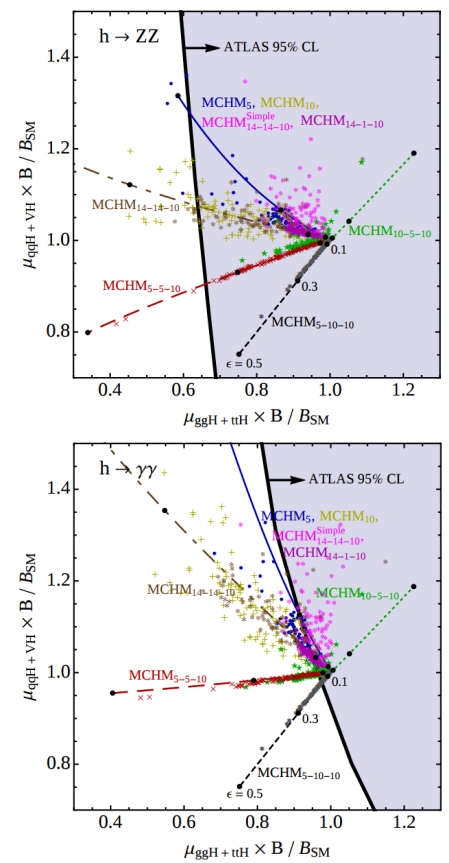
Motivation

Higgs Naturalness ⟶ BSM @ TeV scale

So far no sign of BSM @ LHC ⟶ 1-10% tuning in most models







Is there any conceptual reason why Naturalness hasn't shown up in the LHC yet?

e.g. Neutral Naturalness

Carena et. al. JHEP 1406 (2014)

Composite Higgs Models

Georgi, Kaplan, 84'
Agashe, Contino, Pomarol, 05'

Elementary Sector	Mixing	Composite Sector
Weakly Gauged SU(2) $\times$ U(1)		Global: G/H (SO(5)/SO(4))
Elementary fermions: Q, u, d, L, e		Composite Fermions in H reps.

The mixing breaks G **<u>explicitly</u>**, generating a radiative potential for the (pseudo) Goldstone of G/H. The main contribution is from the top:

$$V(h) = \frac{3 g_t^2 m_T^2}{16\pi^2}\left(-a h^2 + \frac{b}{2}\frac{h^4}{f^2}\right)$$

Top Partners and Tuning

- The main contribution to the top mass - the top loop:

$$\delta m_h^2 \sim \frac{3}{16\pi^2} y_t^2 m_T^2$$

- The irreducible tuning is then

$$\Delta \sim \frac{m_T^2}{(500\ \mathrm{GeV})^2} \xrightarrow{\text{LHC}} 4$$

- Actual tuning is typically worse:

$$\Delta \sim f^2/v^2 \xrightarrow{\text{LHC \& LEP}} 9$$

- The reason: **the quartic scales with the quadratic.**

Composite Higgs with an Adjustable Quartic

$$V(h) = -\frac{3\, g_t\, m_T^2}{16\pi^2}\left(-a\, h^2 + \frac{b}{2f^2}h^4\right) + \frac{\lambda_{\mathrm{T}}}{4}\, h^4$$

take g^* small

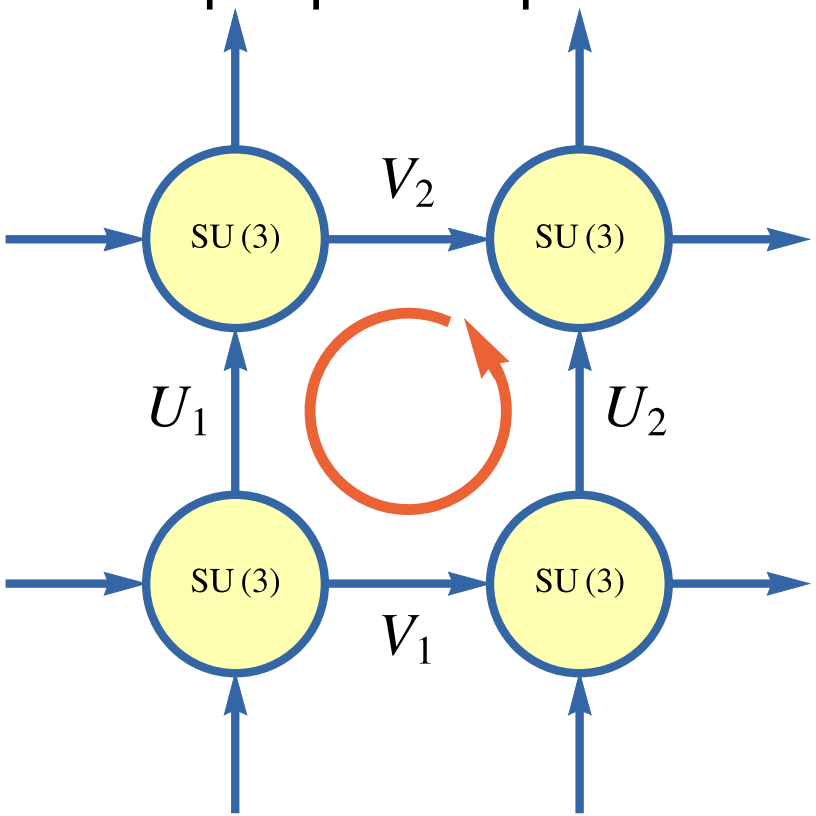
$$V(h) = -\underbrace{\frac{3a\, g_t\, m_T^2}{16\pi^2}}_{\text{Tune to get Higgs mass}}\, h^2 + \underbrace{\frac{\lambda_{\mathrm{T}}}{4}}_{\text{Adjust to get VEV}}\, h^4$$

$$\boxed{\text{No } f^2/v^2 \text{ tuning!}}$$

Lessons from Little Higgs

Arkani-Hamed, Georgi, Cohen, 01'

In the original Little Higgs model (big moose), the quartic comes from a plaquette operator:



$$U_m, V_m \equiv f e^{\frac{i}{f}\pi_m}$$

$$V_{plaq} = tr\left[V_1\, U_2\, V_2^\dagger\, U_1^\dagger\right]$$

In the continuum limit this becomes:

$$V_{6D} = tr\,[A_5\, A_6]^2 \in F_{56}^2$$

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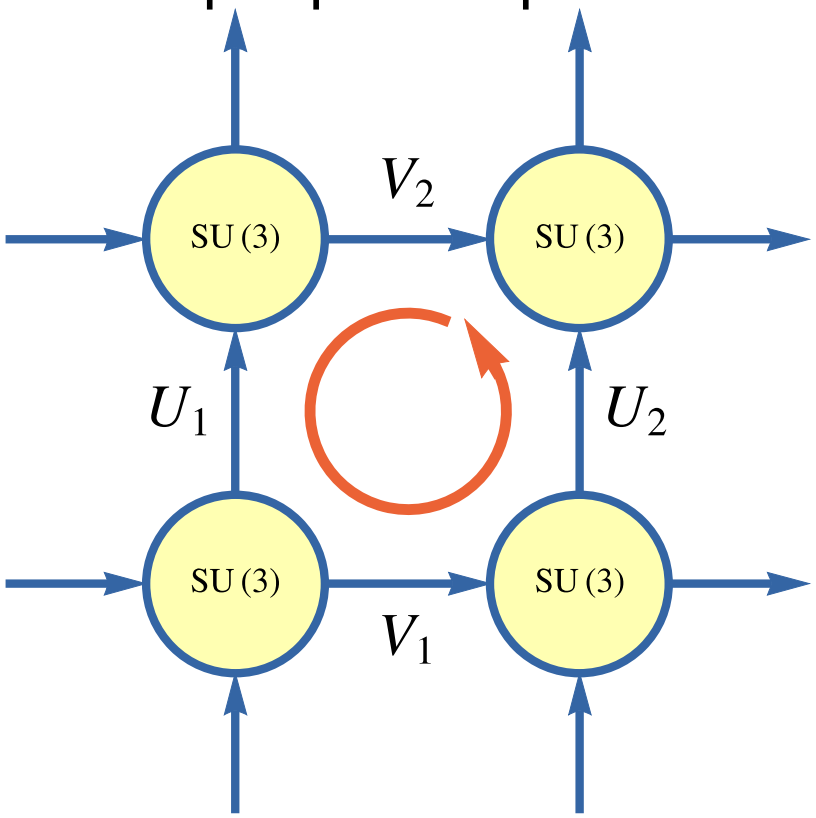


$$U_m, V_m \equiv f e^{\frac{i}{f}\pi_m}$$

$$V_{plaq} = tr\left[V_1\, U_2\, V_2^\dagger\, U_1^\dagger\right]$$

This **is** a tree level quartic

In the continuum limit this becomes:

$$V_{6D} = tr\,[A_5\, A_6]^2 \in F_{56}^2$$

The Challenges

- How to construct a moose model with a warped (and orbifolded) direction?

- How to have 2 surviving PNGB zero modes with a quartic?

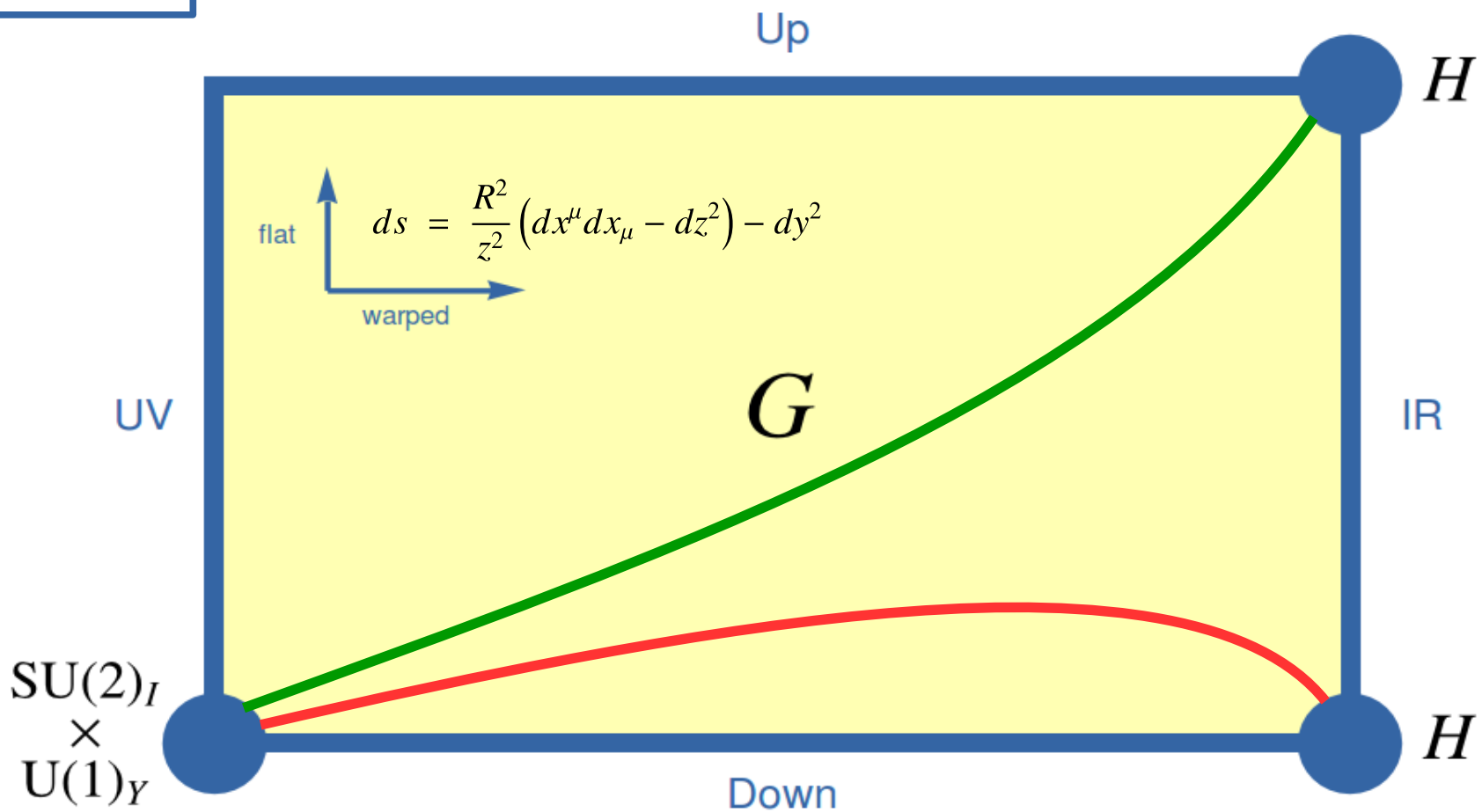
- The quartic from little Higgs is O(1) and not 0.13.

Need an adjustable quartic!

$G = \mathrm{SO}(5)$

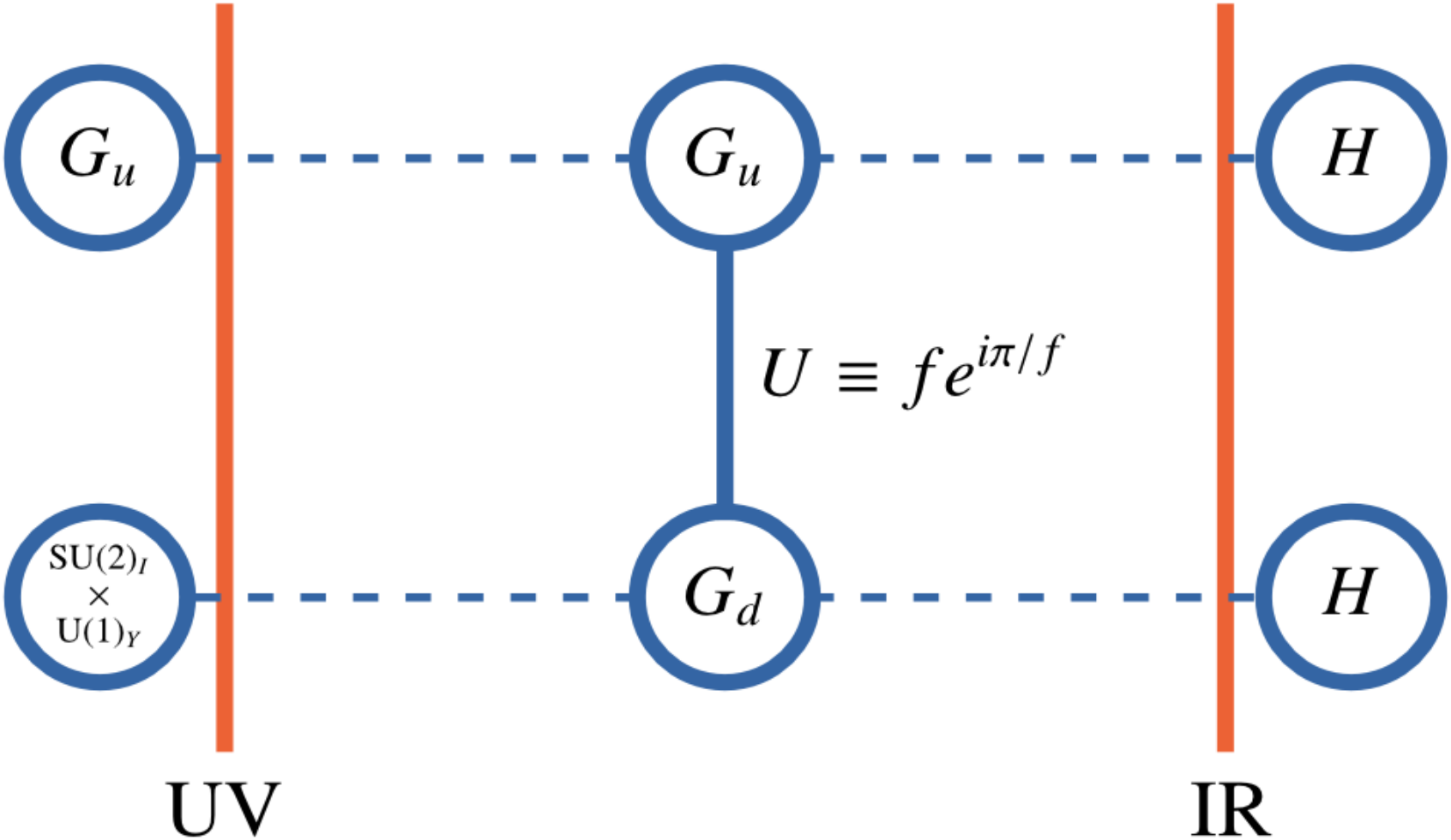
$H = \mathrm{SO}(4)$

The 6D Model



$$tr\,[A_5\,A_6]^2 \xrightarrow{\text{Zero mode}} tr\,[\,h_1, h_2\,]^2$$

The Effective 5D Model



$$D_5 U^\dagger D^5 U \rightarrow tr\left[A_5^u + A_5^d, \pi\right]^2 \xrightarrow{\text{Zero mode}} tr\,[\,h_1, h_2\,]^2$$

An Adjustable Quartic

- 2 G/H (pseudo-) Goldstones h_1,h_2
- Quartic is

$$\left(\frac{g}{2}\right)^2 \left(\frac{R}{R_6}\right)^2 tr[h_1, h_2]^2$$

- Adjusting quartic $\longleftrightarrow$ stabilizing 6th dim

- Can stabilize largish R_6 on UV brane

$$\downarrow$$

dense KK spectrum

Ongoing Work

- Understand the collective nature of the quartic with full 4D deconstruction
- Lift second Higgs with fermion loops
- Realistic model building
- Phenomenology:
  - 2HDM
  - Compressed KK spectrum

Conclusion

- An adjustable quartic ameliorates tuning in Composite Higgs models
- A quartic can originate from warped 6D geometry
- Realistic model underway
- Phenomenology:
  - 2HDM
  - Compressed KK spectrum