# A Holographic/Composite Twin Higgs

Michael Geller

Technion

**M.G. and O. Telem, Phys.Rev.Lett. 114 (2015) 191801**

**C. Csaki, M.G., O. Telem and A. Weiler, in progress**

# Motivation

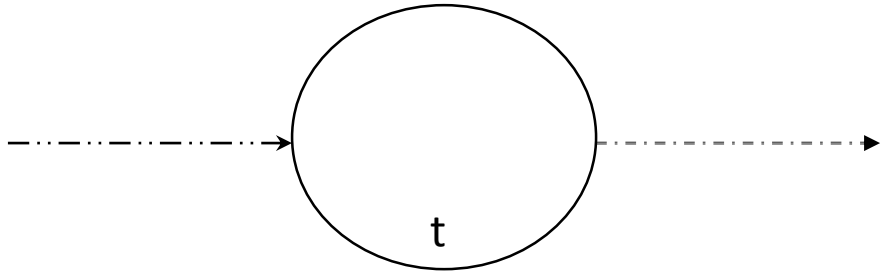
***Neutral naturalness*** → ***Natural theories with no BSM @ LHC***

***The first neutrally natural model – Twin Higgs***

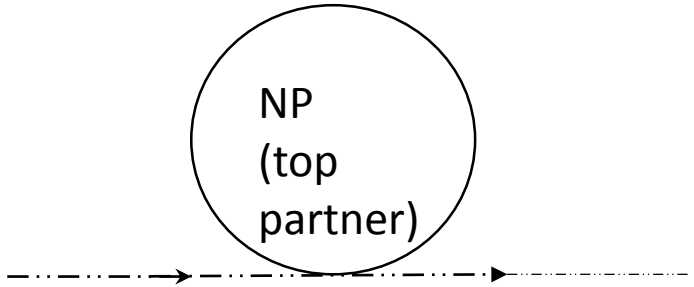
Twin Higgs needs a UV completion – ***composite/AdS***

# Naturalness $\leftrightarrow$ Colored BSM

# Naturalness ↔ Colored BSM




Cancellation in the Quadratically Divergent Part



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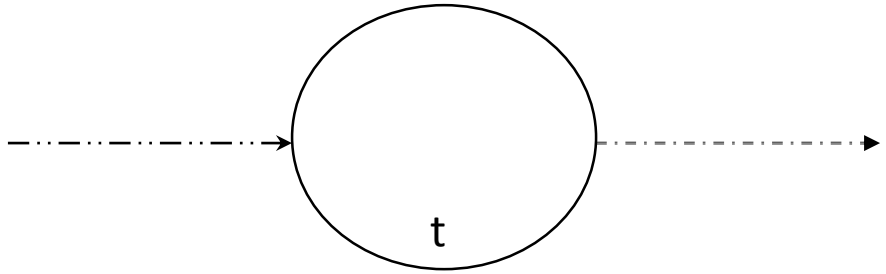


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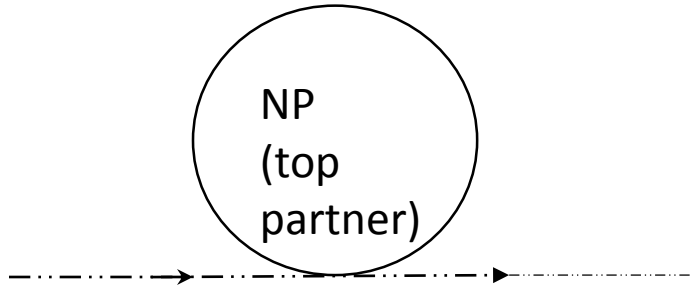


The argument:

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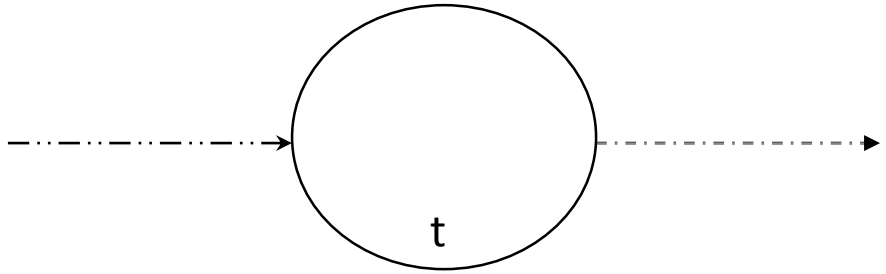


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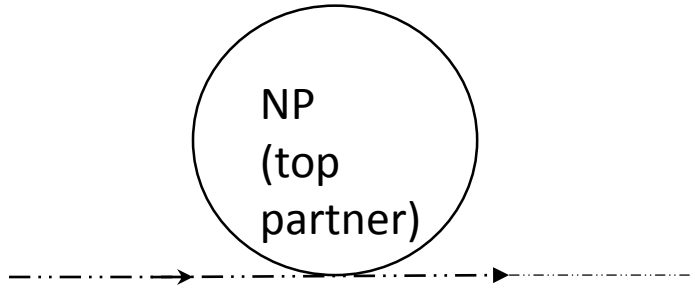


The argument:

- A symmetry is required connecting top ↔ top partners

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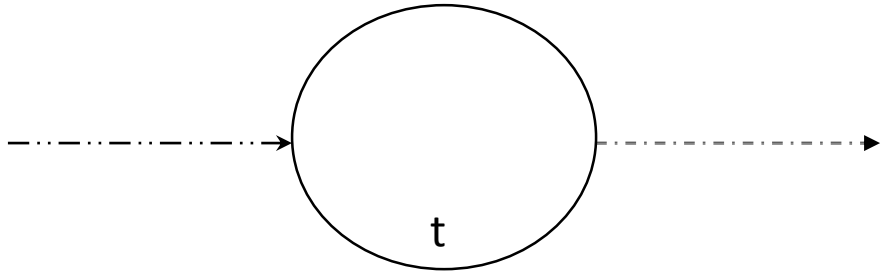


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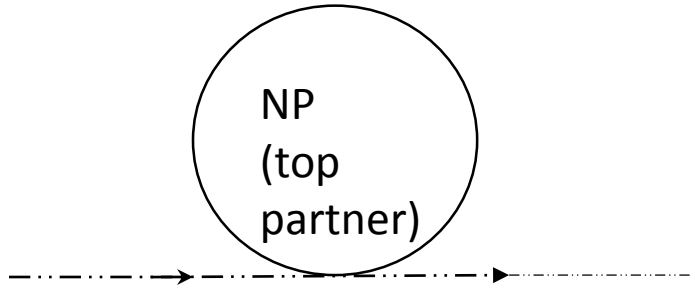


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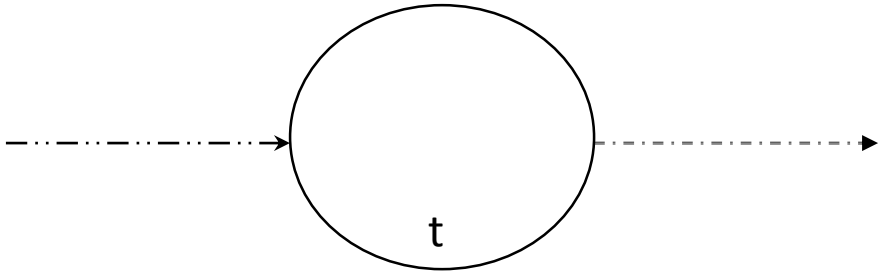
- A symmetry is required connecting top ↔ top partners
- Naturalness requires top partners @ 1 TeV

# Naturalness ↔ Colored BSM

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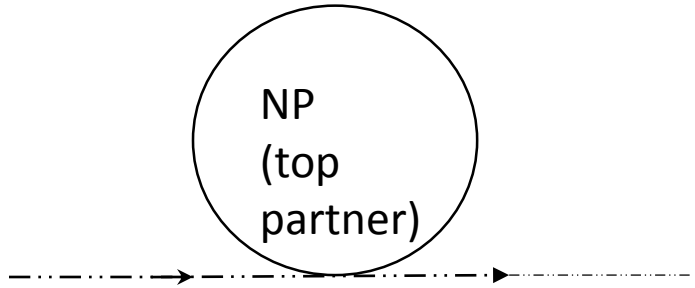
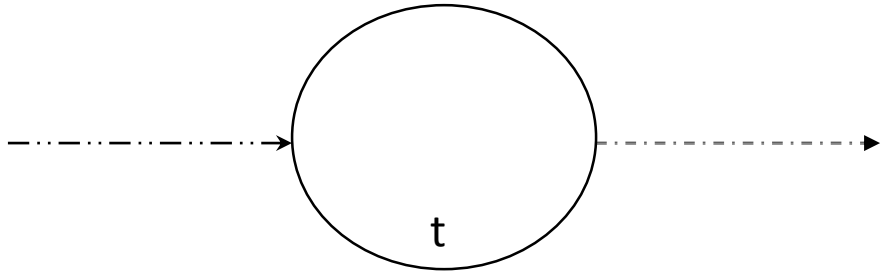



The argument:

- A symmetry is required connecting top ↔ top partners
- Naturalness requires top partners @ 1 TeV
- Colored BSM @ ~1 TeV

# “Loophole”

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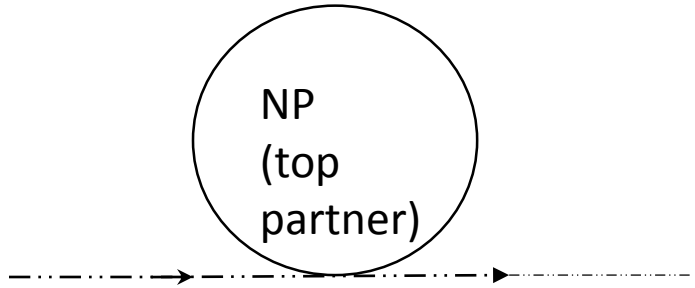



***top partners don’t have to be colored!*** ***Just need the $N_c$=3 factor.***

# The Twin Higgs Model

**Z. Chacko, H. S. Goh and R. Harnik, Phys. Rev. Lett. 96 (2006) 231802**
**Bottom-up approach: N. Craig, A. Katz, M. Strassler, R. Sundrum ,arXiv:1501.05310**

A global SU(4) symmetry broken by ***H*** in the fundamental: $SU(4)/SU(3)$

$$H = \begin{pmatrix} 0 \\ 0 \\ 0 \\ f \end{pmatrix}$$

Gauge the group:

$$\underset{\text{SM}}{\overset{v}{SU(2)^A}} \times \underset{\text{Mirror}}{\overset{f}{SU(2)^B}}$$

$$H = \begin{pmatrix} H_A \\ H_B \end{pmatrix}$$

***7 Goldstones: 6 Eaten and 1 Higgs (Pseudo-Goldstone)***

*Impose a $Z_2$ symmetry SM ↔ Mirror*.

# The Twin Higgs Model: Higgs Potential

Gauging the $SU(2) \times SU(2)$ breaks the $SU(4)$

$$\Delta V = \frac{9g_A^2\Lambda^2}{64\pi^2} H_A^\dagger H_A + \frac{9g_B^2\Lambda^2}{64\pi^2} H_B^\dagger H_B \xrightarrow{Z_2} \frac{9g^2\Lambda^2}{64\pi^2} H^\dagger H$$

SU(4) symmetric
**does not produce a Goldstone mass.**

Quadratically divergent terms cancel!

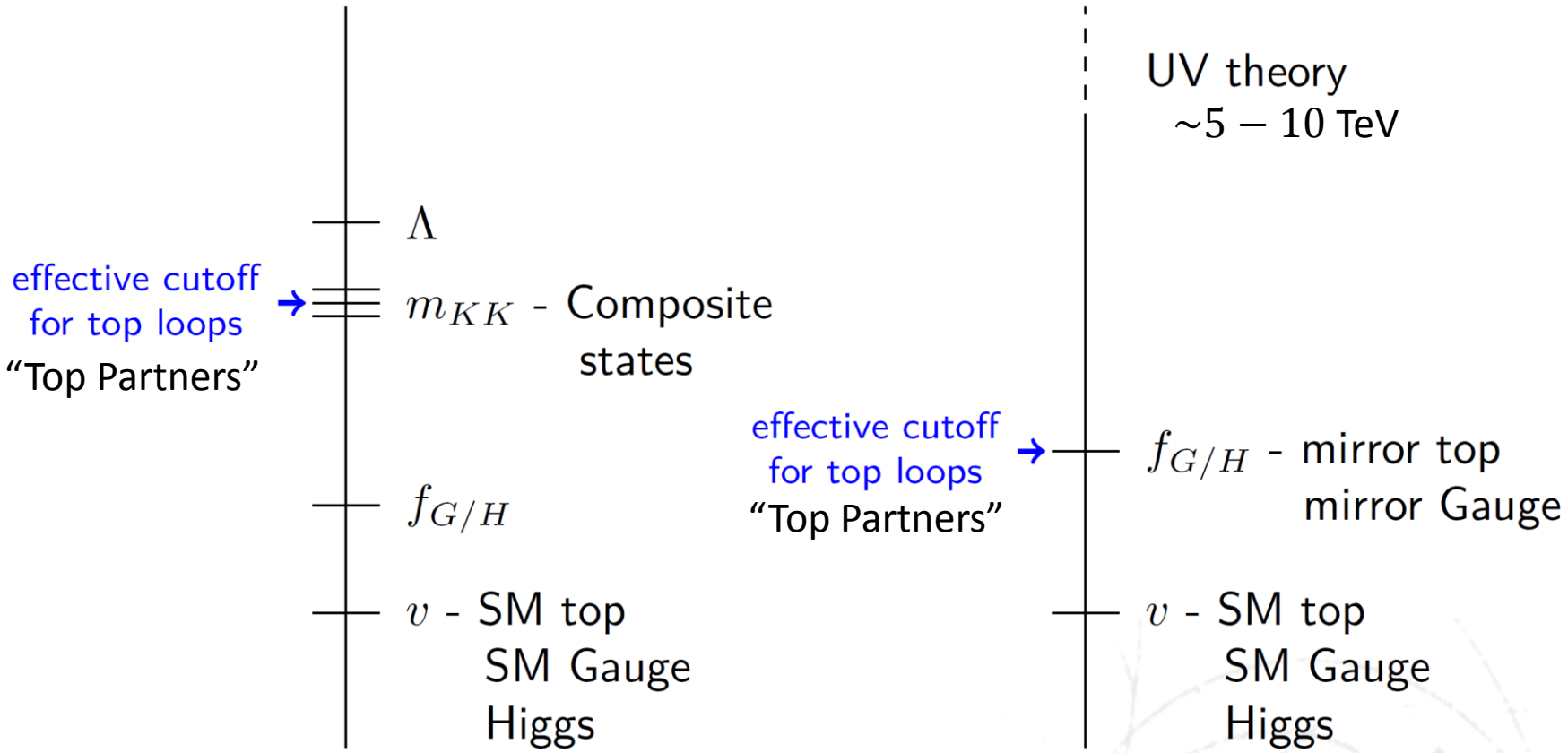
To have the same effect for the top loop: ***double the SM symmetry***

$$\underbrace{\left(SU(3) \times SU(2) \times U(1)\right)^A}_{\text{SM}} \times \underbrace{\left(SU(3) \times SU(2) \times U(1)\right)^B}_{\text{“Mirror” SM}} \qquad H = \begin{pmatrix} 0 \\ v \\ 0 \\ f \end{pmatrix}$$

***Top partners are SM singlets – “Mirror Partners”!***

$$m_t^m = \frac{f}{v} m_t$$

# Twin Higgs and Composite Higgs



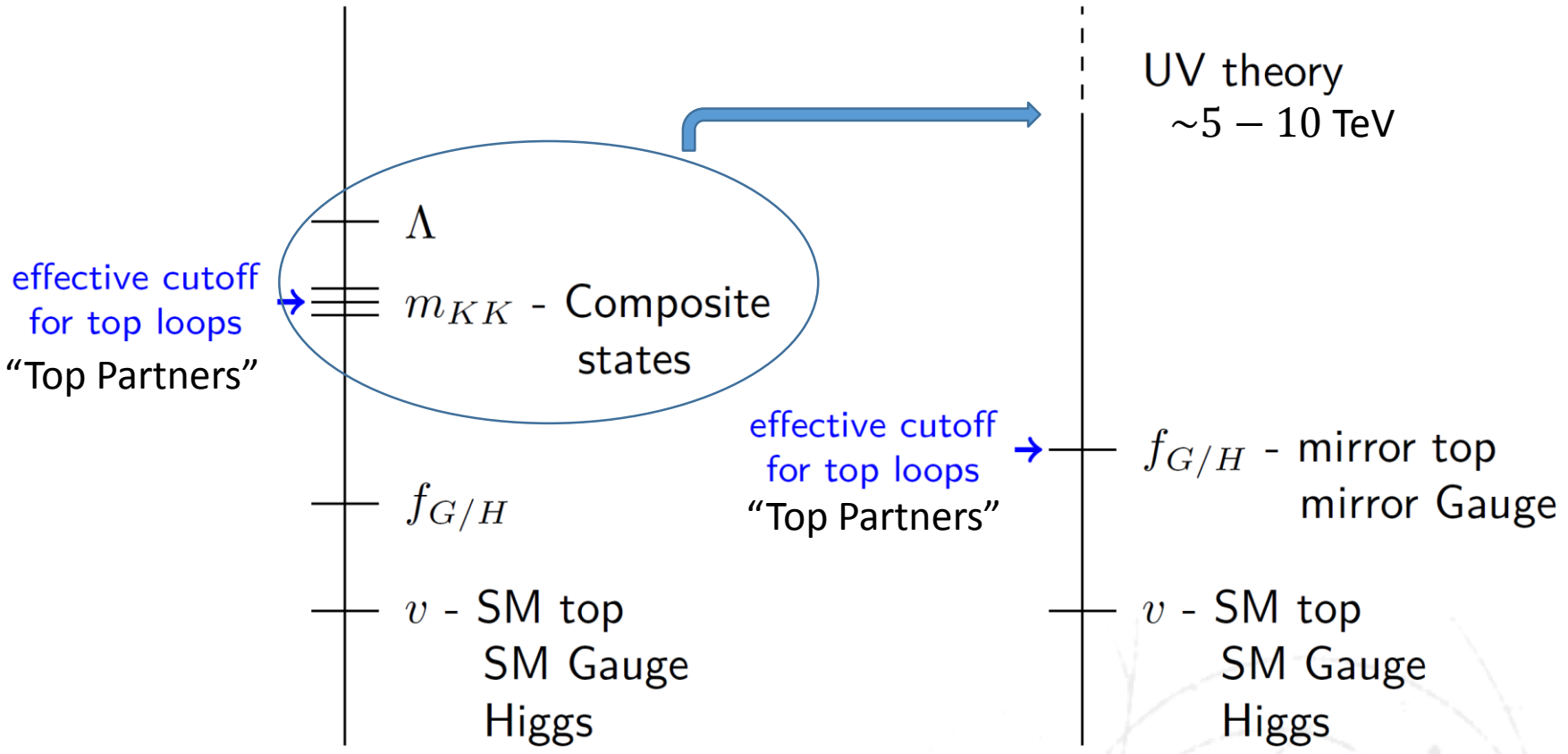

## Composite Higgs

Naturalness of a PNGB Higgs
Requires light Composite states – charged/colored naturalness

## Twin Higgs

Solution to the little hierarchy problem. "Neutral Naturalness"

# Twin Higgs and Composite Higgs

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# Twin Higgs and Composite Higgs

SUSY:

N. Craig and K. Howe JHEP 1403 (2014) 140

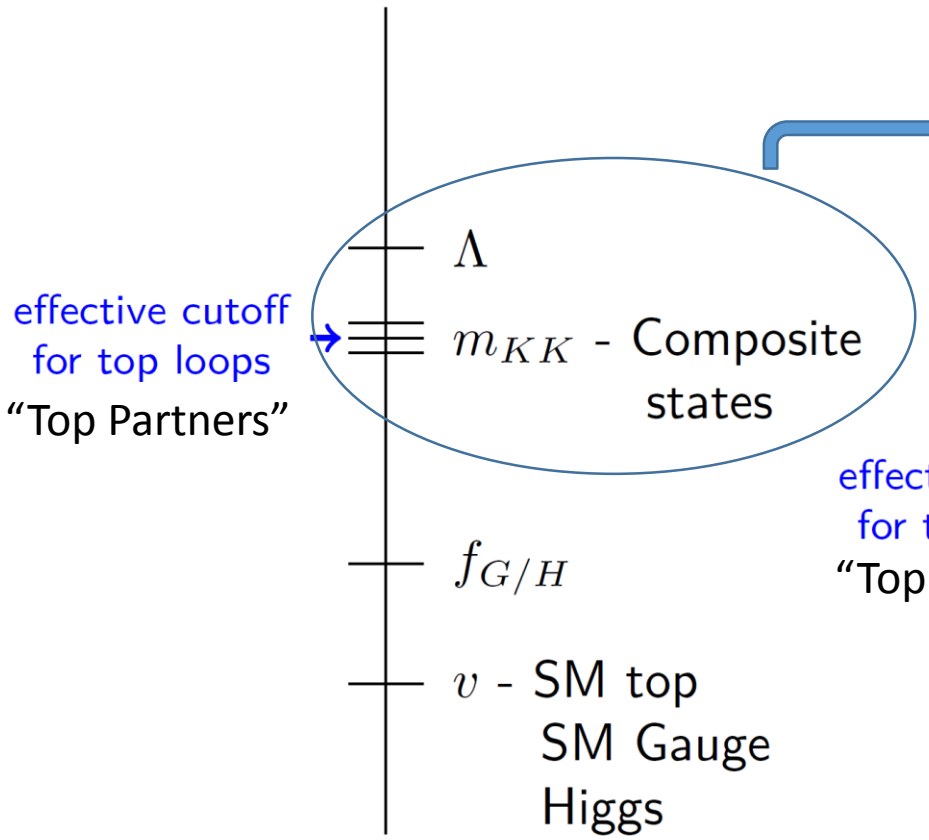
A. Falkowski, S. Pokorski, M. Schmaltz, Phys.Rev. D74(2006) 035003;

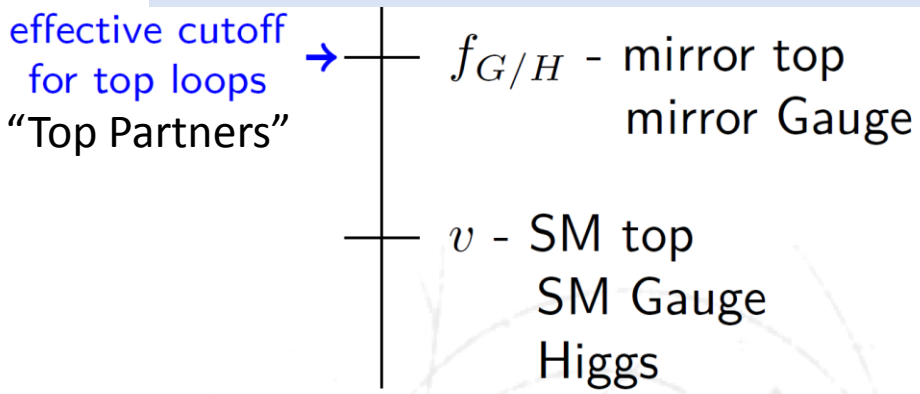
S. Chang , L. J. Hall, N.Weiner Phys.Rev. D75 (2007) 035009

Orbifold:

N. Craig, S. Knapen, P. Longhi, JHEP 1503 (2015) 106

N. Craig, S. Knapen, P. Longhi , Phys.Rev.Lett. 114 (2015) 6, 061803

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# The Holographic Twin Higgs

| | | |
|---|---|---|
| $SM$ $\times\, mirror$ $\times\, Z_2$ | $G$: $SO(8) \times SU(3)_c \times U(1)_X \times SU(3)_c^m \times U(1)_X^m$ $\times\, Z_2$ | $H$: $SO(7)$ $\times\, SU(3)_c \times U(1)_X$ $\times\, SU(3)_c^m \times U(1)_X^m$ $\times\, Z_2$ |

$SO(8) \to SU(2)_L \times SU(2)_R \times SU(2)_L^m \times SU(2)_R^m$ $\quad Y = T_R^3 + X \quad Y^m = T_R^{3m} + X^m$

Possibly: $SU(3)_c \times U(1)_x \times SU(3)_c^m \times U(1)_x^m \times Z_2 \in SU(7)$

# The Tuning

- Suppose we have added a term: $V(h) = \mu^2 f^2 \sin^2 \frac{h}{f}$

- Calculate the tuning: $\Delta \approx \frac{f^2}{v^2}$

- What is new here? The KK scale does not enter anywhere!

Pertubativity → $M_{KK} < 4\pi f$

# $Z_2$ Breaking

Requirements:

- ❖Contribution to the Higgs Potential
- ❖No Dark Energy – Massive mirror photon/mirror neutrinos
- ❖No $Z_2$ breaking in the top + SU(2) sector

# $Z_2$ breaking

## *Elementary Sector*

Project out the unwanted states: mirror hypercharge, light fermions.

Higgs Potential: $\not{Z}_2$ term by detuning the SM and mirror kinetic terms.

**M. Low, A. Tesi and L.T. Wang, arXiv:1501.07890**
**R. Barbieri, D. Greco, R. Rattazzi, A. Wulzer, arXiv:1501.07803**

## *Strong Sector*

$y_f^m$ - free parameters. $m_f^m \neq m_f \frac{f}{v}$

Break mirror hypercharge

– massive O(TeV) mirror photon

Higgs potential: $\not{Z}_2$ term from a detuned contribution

$y_f^m \neq y_f$

# Pheno

## *EW precision*

Tree Level: $M_{KK} > 3\,TeV$

Higgs Loops: may potentially be dangerous

## *Vector-like Quarks/Resonances*

LHC reach: 1.5 TeV for Kktops
~4 TeV for KKGlue

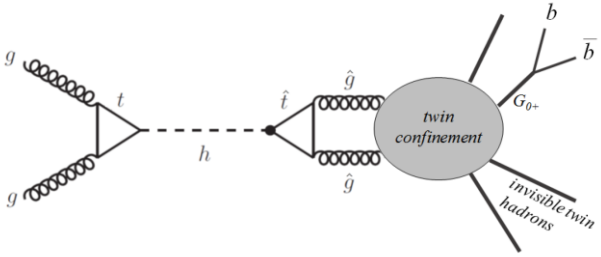
Accessible in future hadronic colliders

## *Higgs precision*

PNGB – all couplings $\left(1 - \frac{v^2}{f^2}\right)$

Invisible Decays $Br(h \to b^m b^m) \approx \frac{v^2}{f^2} Br(h \to bb)$

## *Exotica*

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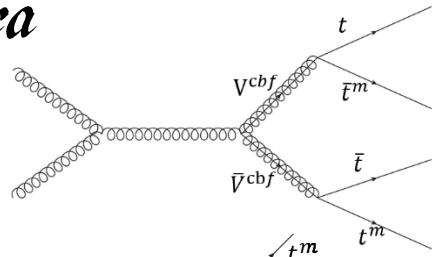
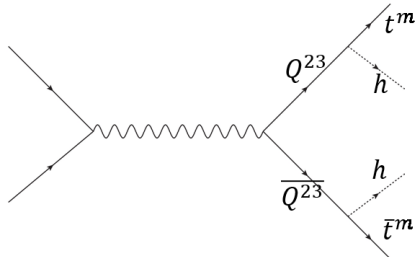
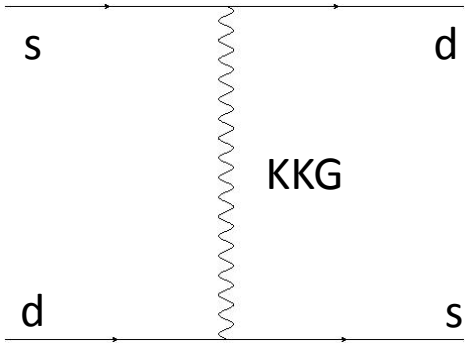


# Flavor in Composite Twin Higgs

Contrary to CH – $M_{KK}$ is bound only by pertubativity: $M_{KK} < 4\pi f$

Is anarchic flavor enough in the CTH? What is the limit on $f$?




$$C_k^4 = \frac{1}{(1.6 \times 10^5 \text{ TeV})^2} \left( \frac{106 \text{ TeV}}{g_*^2 f \tilde{m}_d} \right)^2$$

$$g_*^2 f \tilde{m}_d > 106 \text{ TeV}$$

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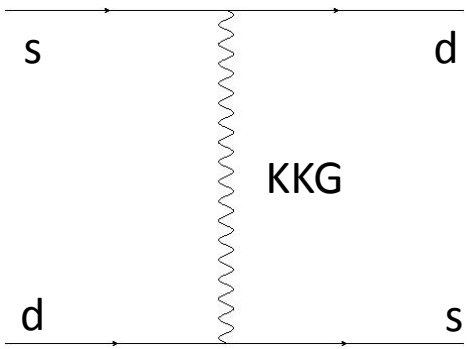


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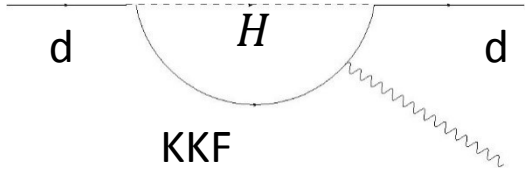


$$\frac{c}{16\pi^2 f^2} m_d \bar{d}_L \sigma^{\mu\nu} e F_{\mu\nu} d_R \quad c \sim \frac{1}{g_*^2}(Y^2) = \frac{\tilde{m}_d^2}{4}$$

$$\frac{2f}{\tilde{m}_d} > 7.29 \text{ TeV}$$

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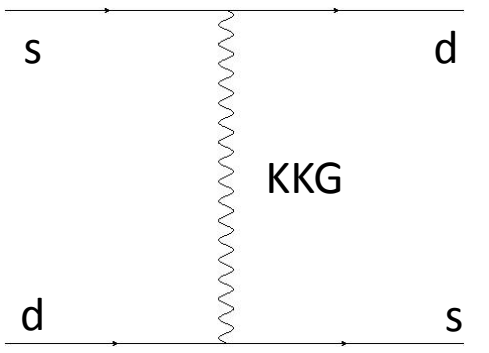


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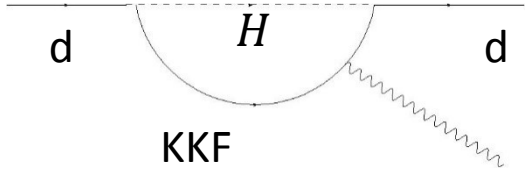


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$$\frac{2f}{\tilde{m}_d} > 7.29 \text{ TeV}$$

$$g_* f > 19.6 \text{ TeV}$$

# Flavor in Composite Twin Higgs

In our estimations the combination of the two most stringent bounds:

$$g_* f > 19.6 \text{ TeV}$$

At the limit of perturbative control $g_* = 4\pi \rightarrow f > 1.5\, TeV$.

***The tuning in the Higgs potential is at the percent level***.

# Summary

- Twin Higgs – SM singlet top partners.
- Needs "UV completion" - Holographic Twin Higgs:
  - Only log dependence on $M_{KK}$ in the Higgs potential.
  - Tuning scales as $\frac{f^2}{v^2}$. $M_{KK} \lesssim 4\pi f$ by unitarity.
  - Needs $Z_2$ breaking.
- Flavor:
  - Anarchic flavor requires $M_{KK} \gtrsim 20\ TeV$.
  - Leads to percent level tuning.
- Pheno:
  - Higgs couplings, Invisible width.
  - Colored states and exotics at future hadronic colliders

# Thank You!


$M(H^0) = \pi \left(\frac{1}{137}\right)^8 \sqrt{\frac{hc}{G}}$
$3987^{12} + 4365^{12} = 4472^{12}$
$\Omega(t_0) > 1$

Thank You!