# A Holographic Twin Higgs

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Technion

In collaboration with: Ofri Telem

ArXiv:1411.2974 – PRL 2015

# Motivation

The main question: is the EW scale ***natural*** or ***tuned***?

***naturalness*** $\neq$ ***colored new physics @ ~1 TeV.***

Twin Higgs

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

Spectrum**: SM, mirror, excitations**

# Naturalness ↔ Colored BSM

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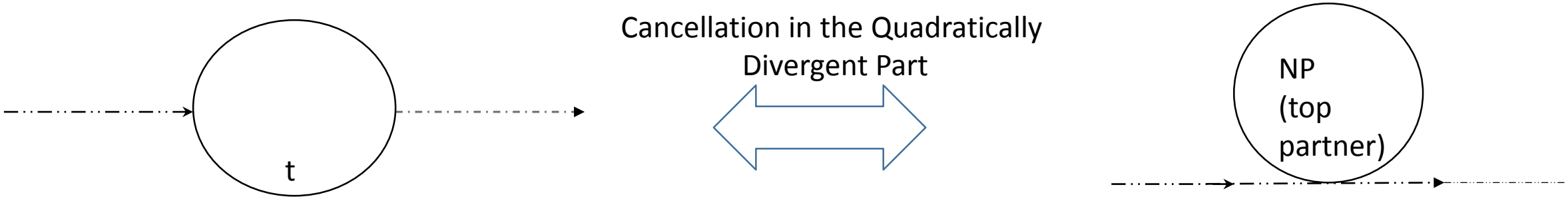

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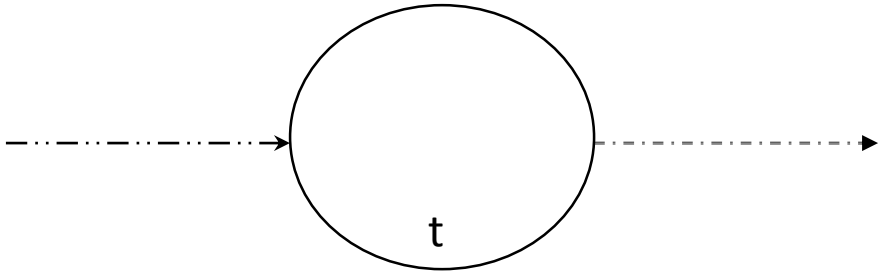
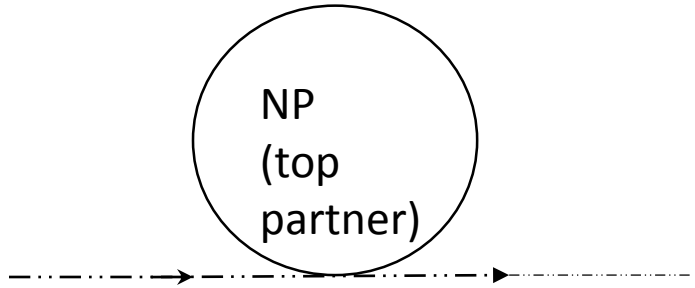



Cancellation in the Quadratically Divergent Part




The argument:

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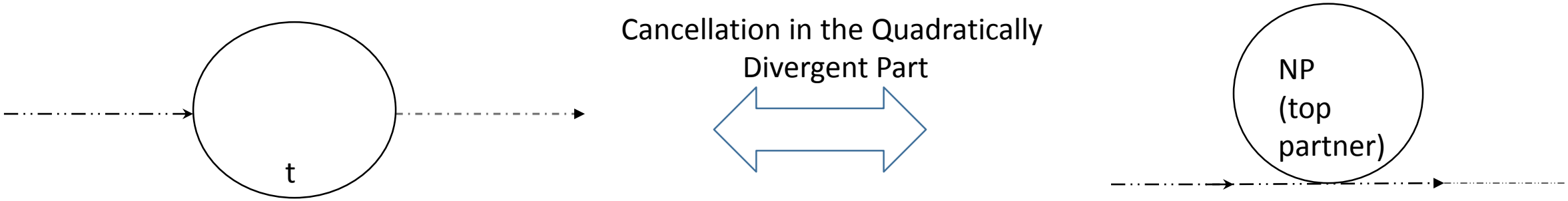


The argument:

- A symmetry is required connecting top ↔ top partners

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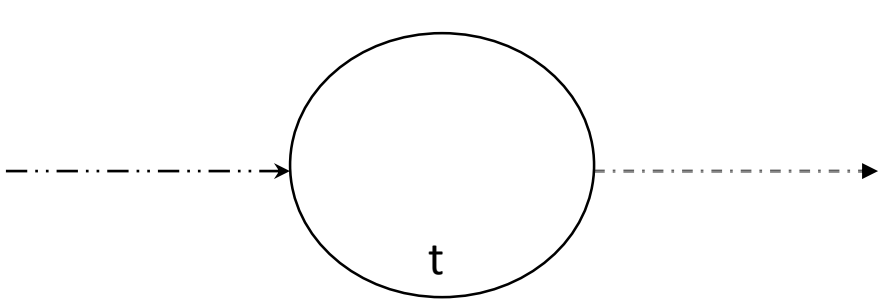


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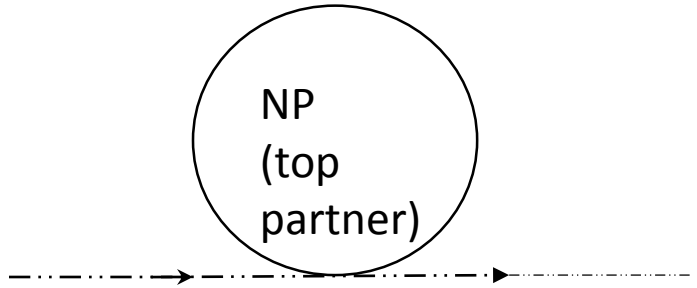


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- Naturalness requires top partners @ 1 TeV

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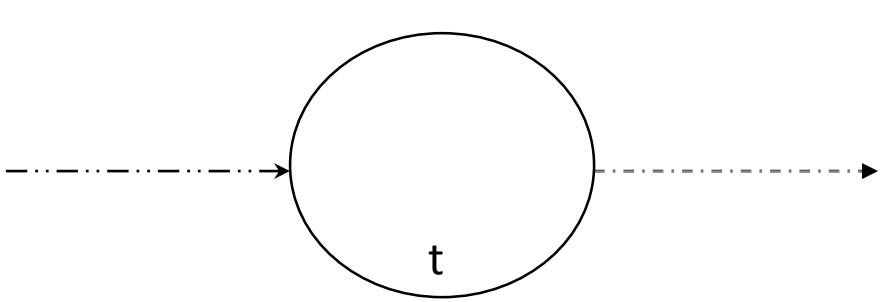


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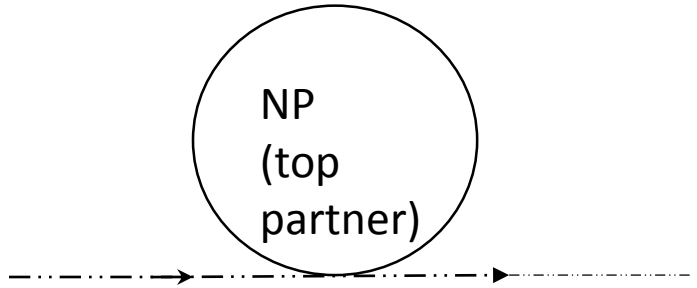


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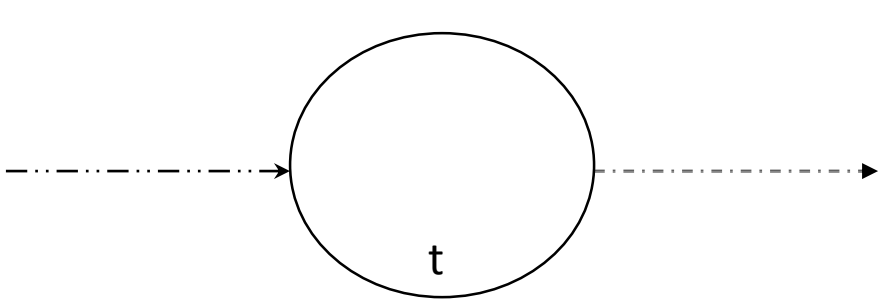
- A symmetry is required connecting top ↔ top partners
- Naturalness requires top partners @ 1 TeV
- Colored BSM @ ~1 TeV

# “Loophole”

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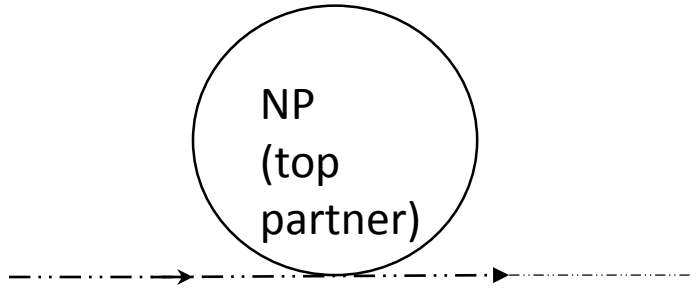



***top partners don’t have to be colored!*** ***Just need the $N_c$=3 factor.***

# 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: $SU(2)^A \times SU(2)^B$ (SM: $v$; Mirror: $f$)

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

***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!

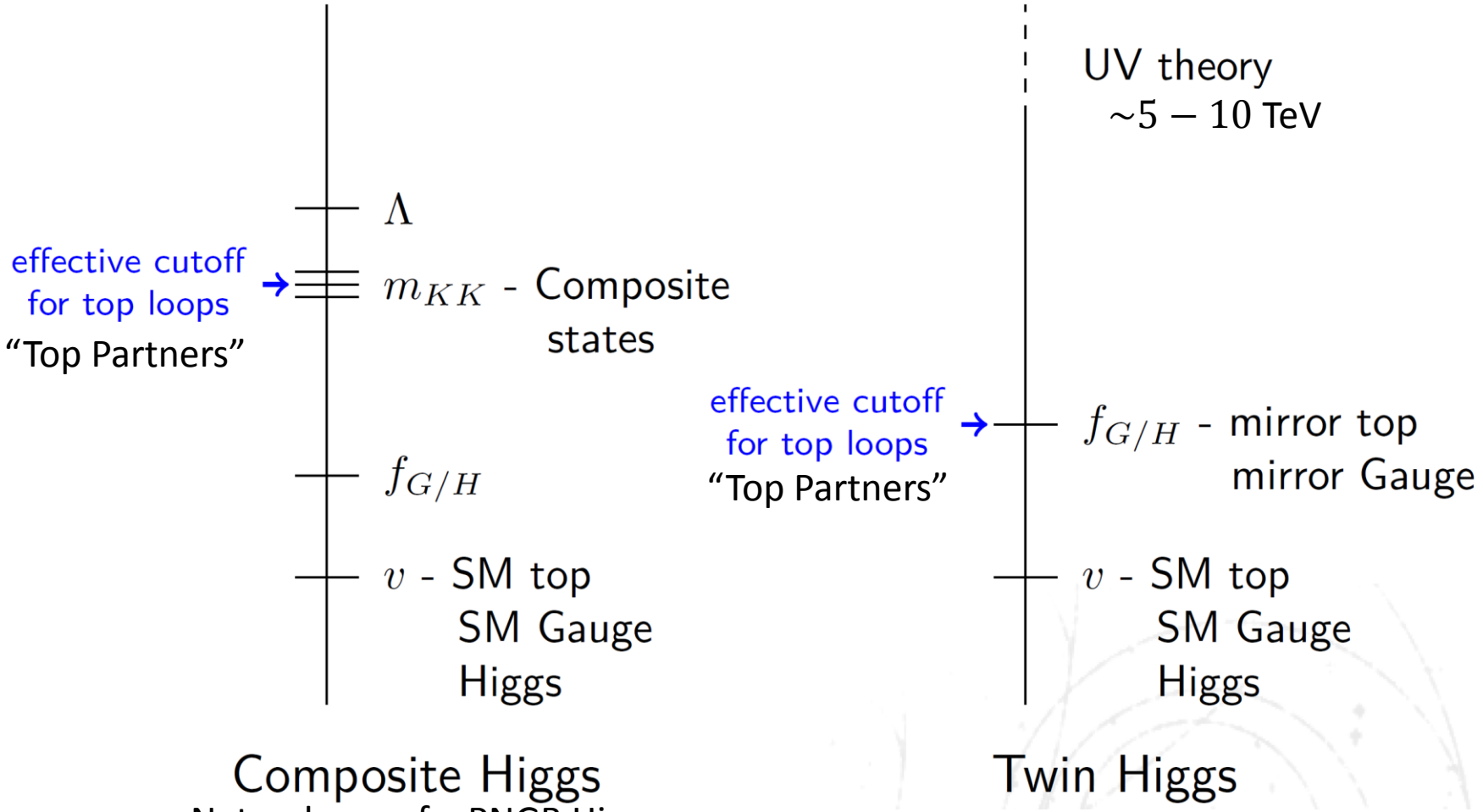
To have the same effect for the top loop: ***double the SM symmetry***

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

***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"

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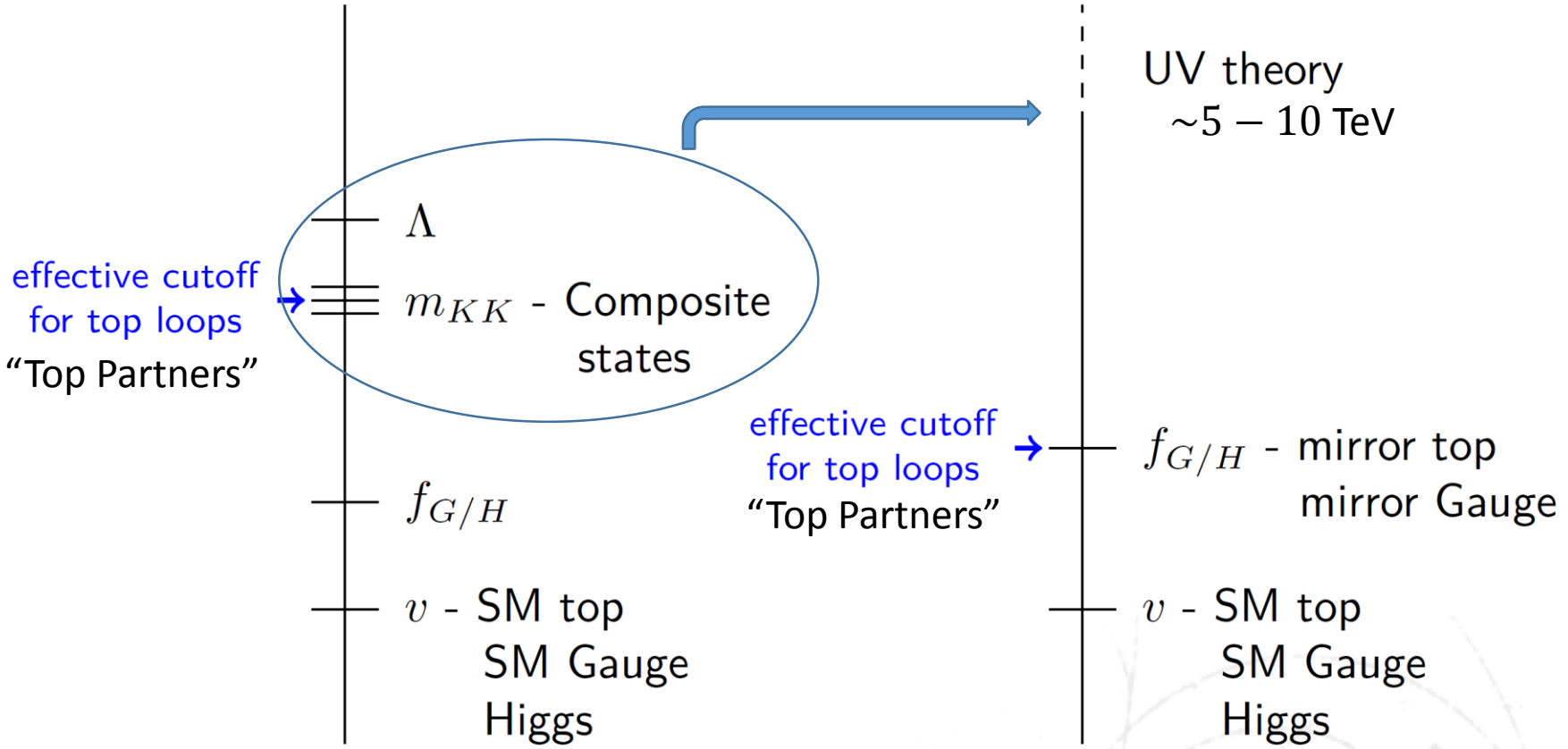


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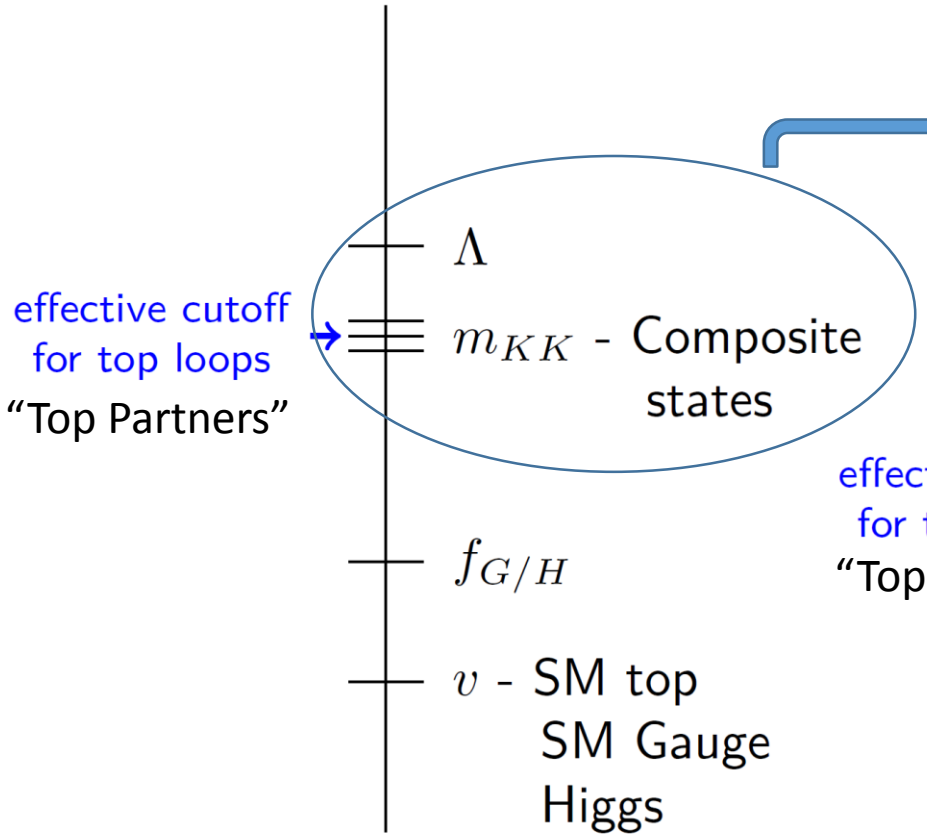



SUSY:

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

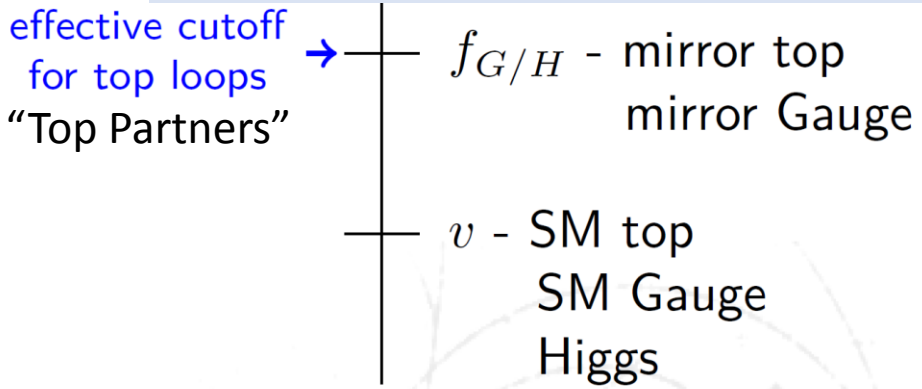
A. Falkowski, S. Pokorski, M. Schmaltz, Phys.Rev. D74(2006) 035003;

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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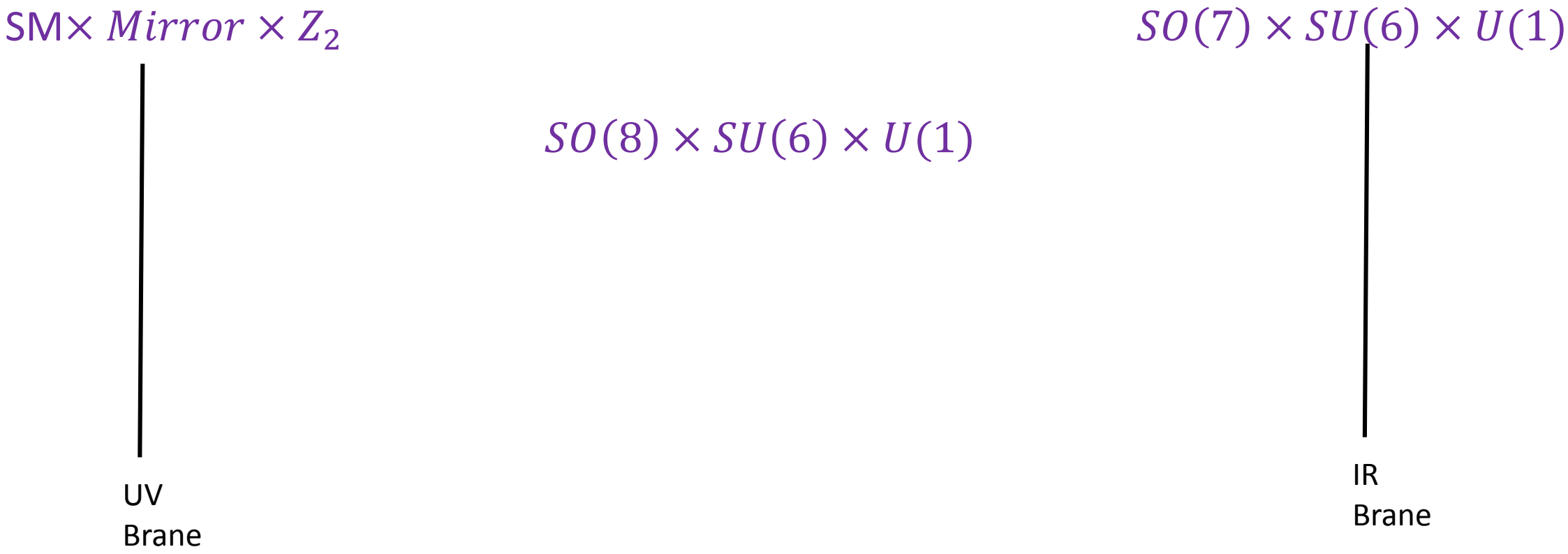

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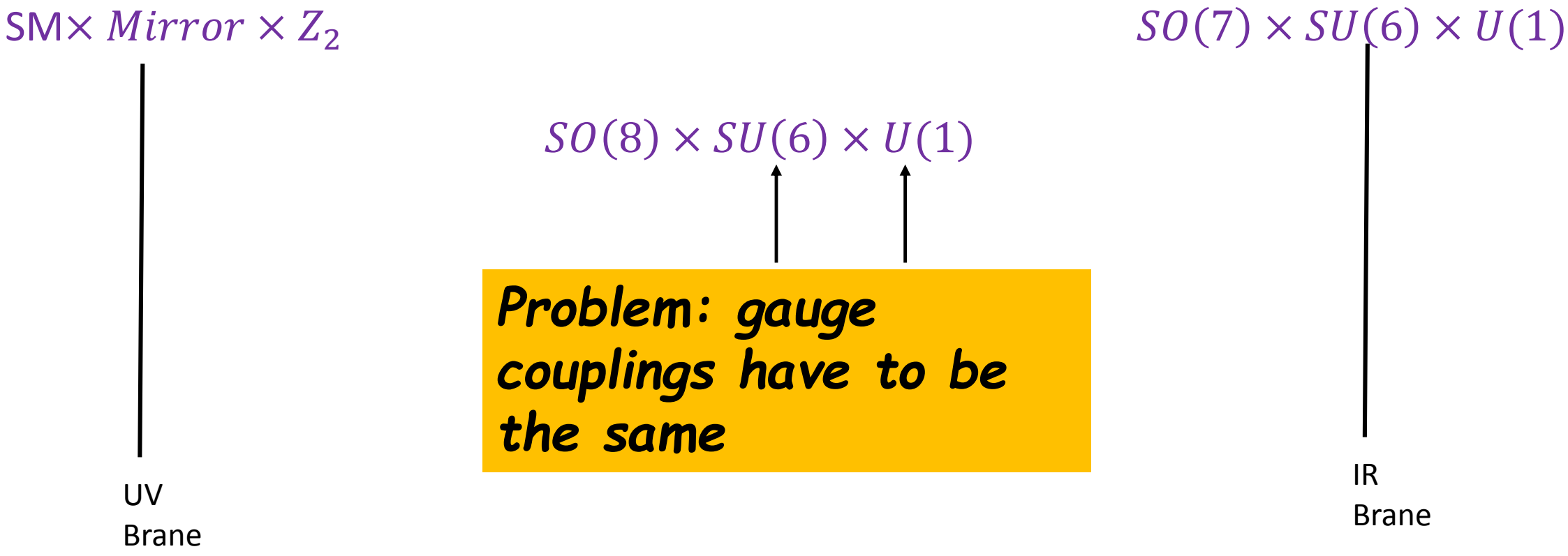

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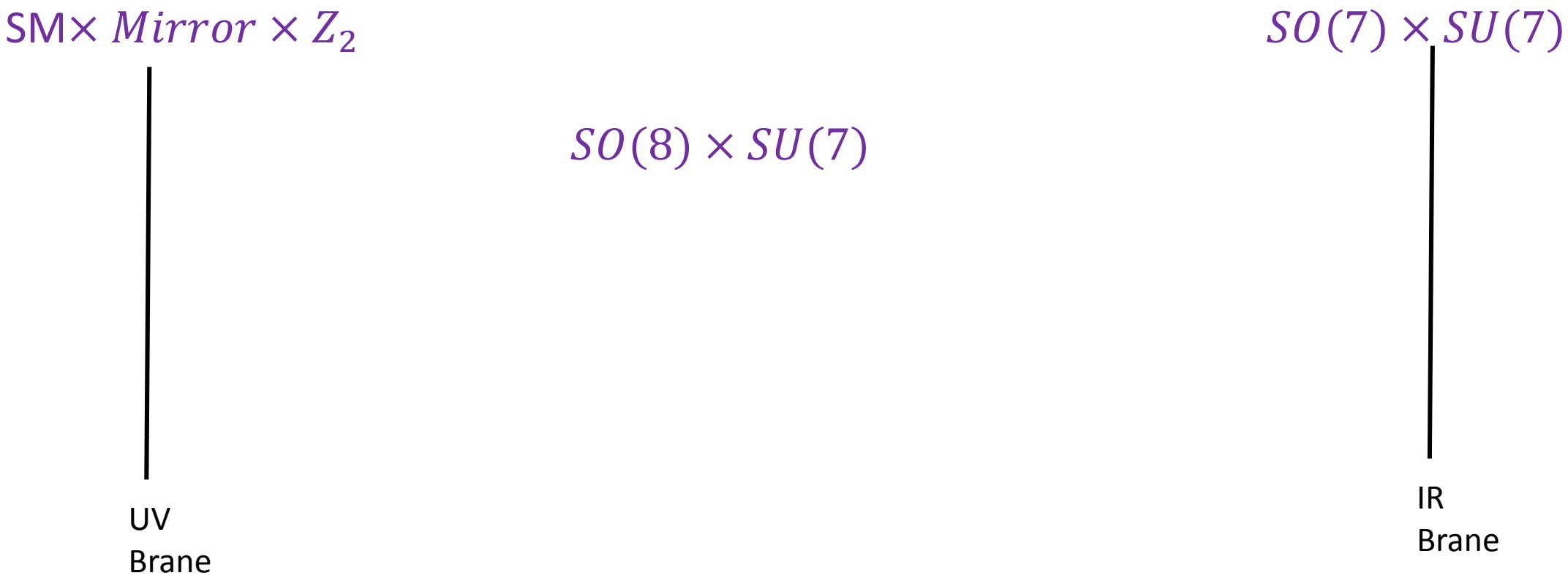

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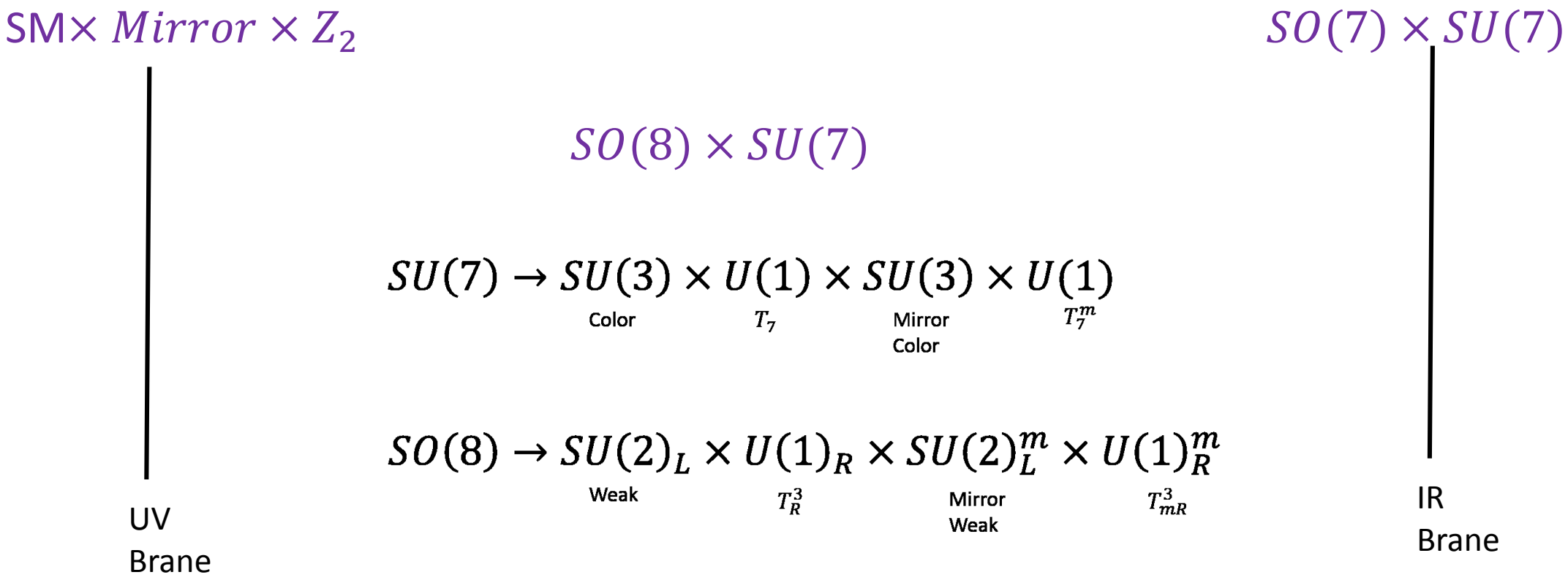

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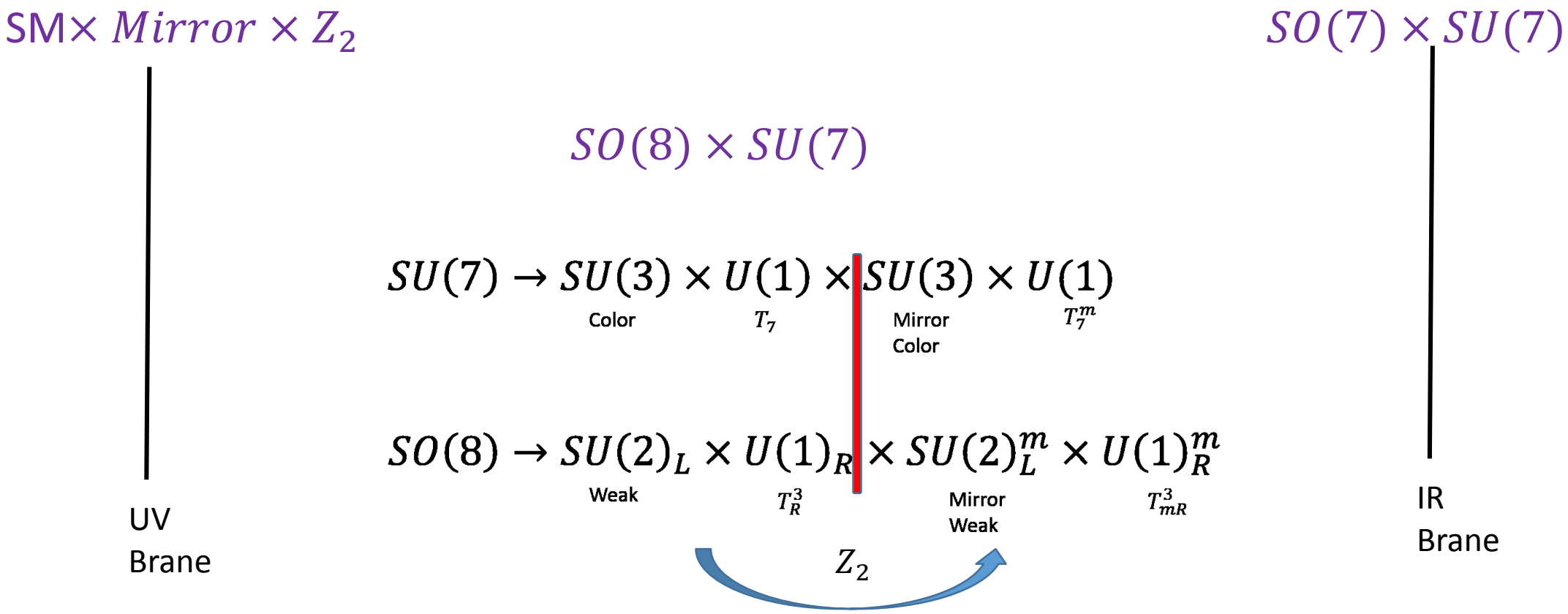



***$Z_2$: UV boundary conditions*** $(+) \to (+)_m$

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

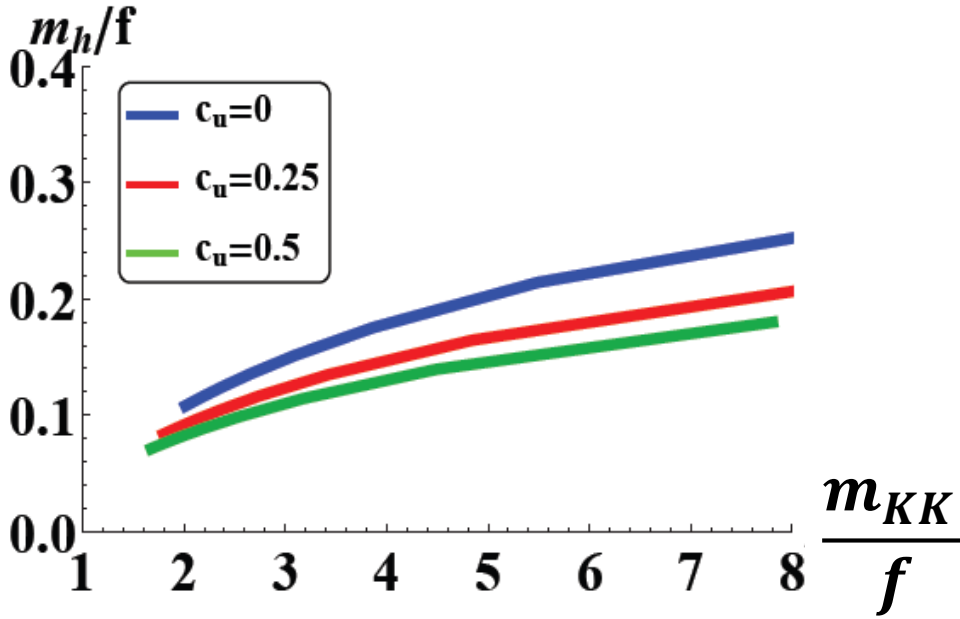
# The Higgs Potential

Similarly to the original twin-Higgs, $v = \frac{f}{\sqrt{2}}$.

$v \ll f$:

~~$Z_2$~~ term

Tuning between the ~~$Z_2$~~ and $Z_2$ terms.




***Twin:*** $m_h^2 \sim \frac{3y_t^4}{8\pi^2} f^2 log\left(\frac{M_{KK}}{f}\right)$ $\longleftrightarrow$ ***Composite Higgs:*** $m_h^2 \sim \frac{3y_t^2}{8\pi^2} m_{KK}^2$

***The scale of excitations $m_{KK}$ can be high (almost) without tuning!***

# The Tuning

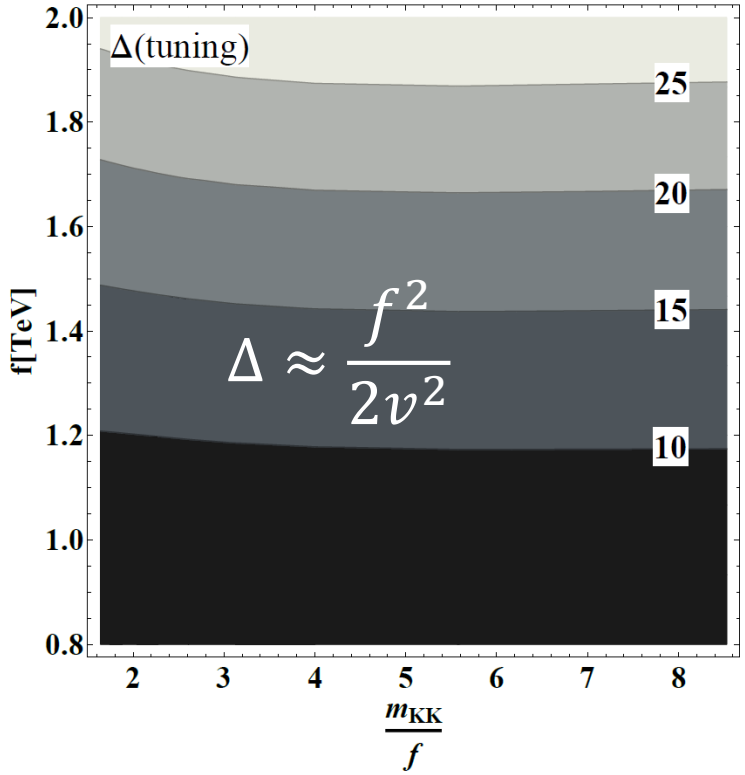
- Suppose we have added a term:

$$V(h) = \mu^2 f^2 \sin^2 \frac{h}{f}$$

- Calculate the tuning:

$$\frac{f}{v} = 3 \rightarrow$$ >10 % tuning

- We need a $Z_2$ breaking mechanism
  - Higgs Potential
  - Avoid light d.o.f. – mirror neutrinos and mirror photon
  - Need the $Z_2$ for top+gauge



# $Z_2$ 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: below 2 TeV for Kktops
~4 TeV for KKGlue

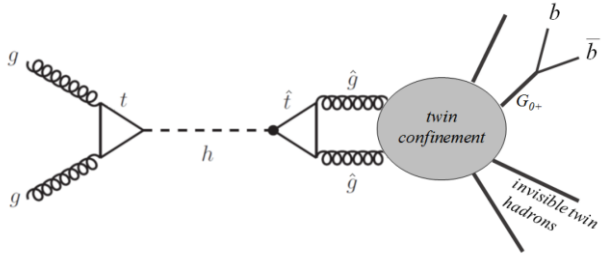
Accessible in future hadronic colliders

## *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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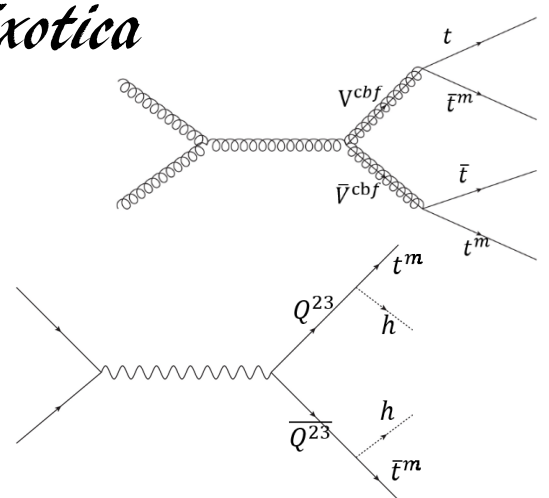

*Thank You!*