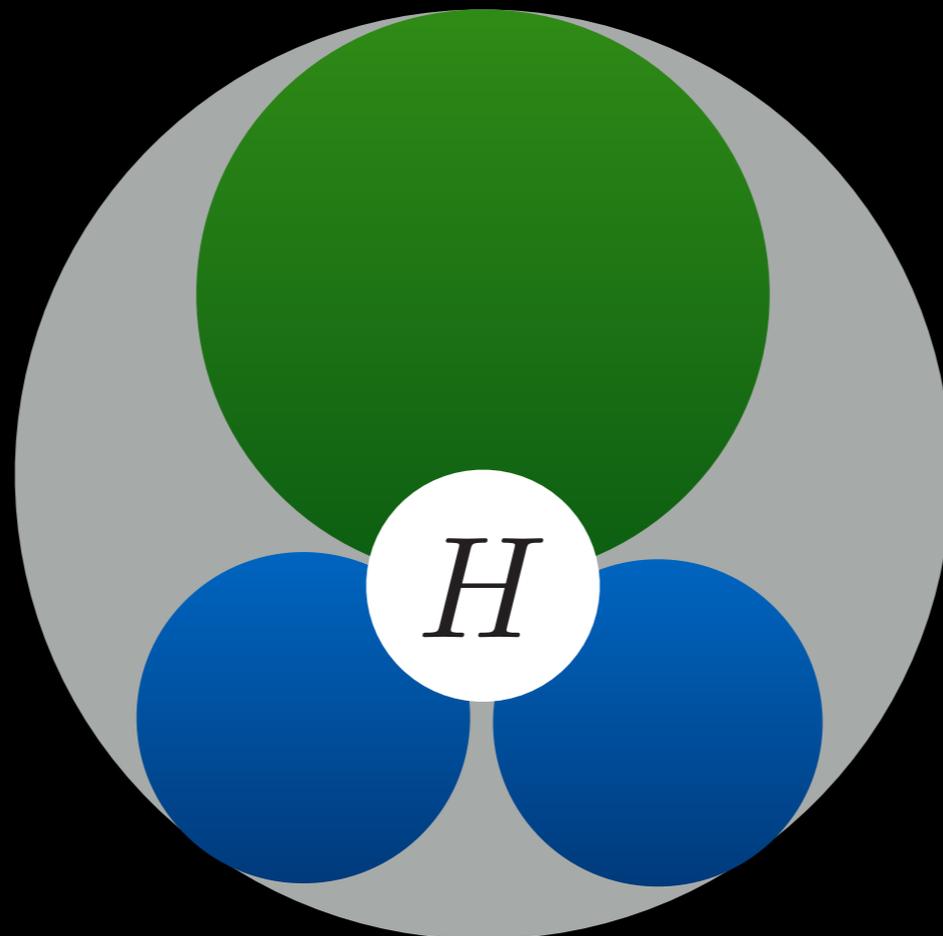


Signatures of an S_3 -Orbifold Higgs Model

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Motivation

Renewed interest in theories of neutral naturalness(NN)

- SM particles carry no SM charge

Twin Higgs

Folded SUSY

Quirky Little Higgs

N-Naturalness

Orbifold Higgs

- Hard to detect

Recent work on Orbifold Higgs

- Large class of models
- Pheno hasn't been thoroughly studied

Twin Higgs

- ★ Begin with H in the fundamental of a global $SU(4)$

$$V = -m^2 |H|^2 + \lambda |H|^4$$

$$\cancel{SU(4)} \rightarrow SU(3) \longrightarrow 7 \text{ Goldstone bosons}$$



Mirror Twin Higgs

- ★ Gauge $SU(2)_A \times SU(2)_B \subset SU(4)$ with $H = \begin{pmatrix} H_A \\ H_B \end{pmatrix}$
 - 6 NGbs are eaten
 - $SU(4)$ is broken by radiative corrections

$$\Delta V \sim \frac{9\Lambda^2}{16\pi^2} (g_A^2 |H_A|^2 + g_B^2 |H_B|^2)$$

- ★ Impose a \mathbb{Z}_2 symmetry that exchanges $A \leftrightarrow B \longrightarrow g_A = g_B \equiv g$

$$\Delta V \sim \frac{9g^2\Lambda^2}{16\pi^2} (|H_A|^2 + |H_B|^2)$$

Quadratic radiative corrections don't contribute to the mass of the Goldstone!

Twin Higgs

★ Double the SM and extend Twin Parity: $[SM_A \times SM_B] \times \mathbb{Z}_2$

$$V^{(1)} \supset \frac{\Lambda^2}{16\pi^2} \left(-6y^2 + \frac{9}{4}g^2 + 10\lambda \right) (|H_A|^2 + |H_B|^2)$$

★ The full one-loop effective potential explicitly breaks the $SU(4)$

$$V^{(1)} \sim \frac{y^4}{64\pi^2} \left(|H_A|^4 \log \left(\frac{\Lambda^2}{y^2 |H_A|^2} \right) + |H_B|^4 \log \left(\frac{\Lambda^2}{y^2 |H_B|^2} \right) \right)$$

★ Vacuum is equally aligned in the A and B sectors

$$|\langle H_A \rangle|^2 = |\langle H_B \rangle|^2 \qquad h = \frac{1}{\sqrt{2}} H_A + \frac{1}{\sqrt{2}} H_B$$

★ Solution: Softly break Twin Parity by adding $V_{soft} = \mu^2 |H_A|^2$

$$|\langle H_A \rangle|^2 \ll |\langle H_B \rangle|^2 \qquad h \approx \left(1 - \frac{v^2}{f^2} \right) H_A + \frac{v}{f} H_B$$

Field theory Orbifolds

- Begin with parent symmetry, G
- Project out fields not invariant under a discrete symmetry, \mathcal{G} , to obtain the symmetries of the daughter theory
- Parent theory is said to descend to the daughter theory

As an example consider $G = SU(4)$ and $\mathcal{G} = \mathbb{Z}_2$

$$SU(4)/\mathbb{Z}_2 \longrightarrow SU(2)_A \otimes SU(2)_B^*$$

$$\left[SU(4) \right]$$

Parent Symmetry

$$\left[\begin{array}{c|c} SU(2)_A & \\ \hline & SU(2)_B \end{array} \right]$$

Daughter Symmetry

Field theory Orbifolds

The Twin Higgs from an orbifold projection

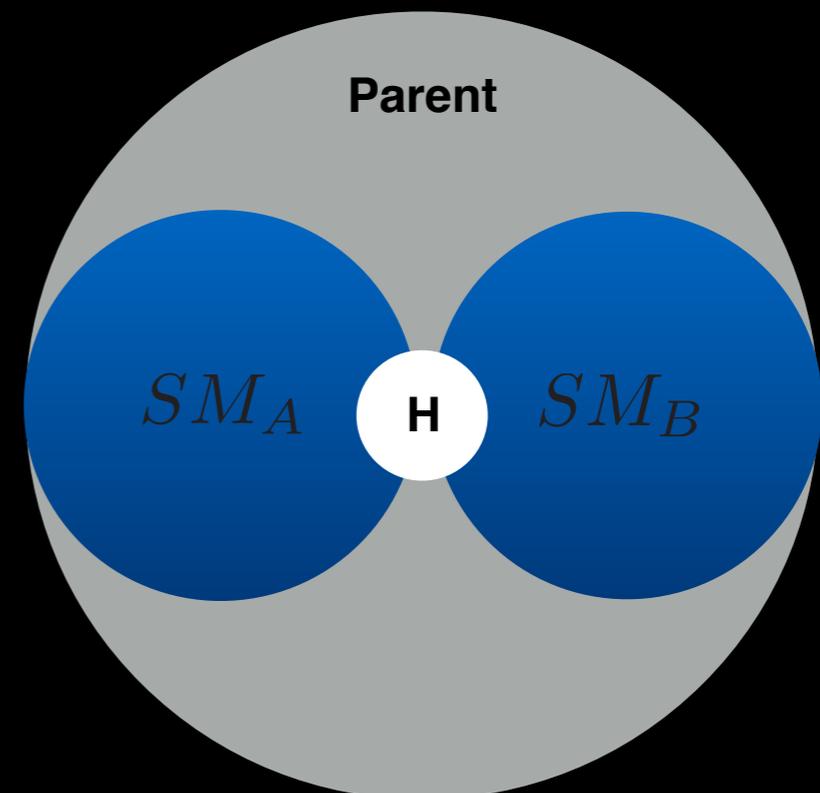
$$V_P = -m^2|H|^2 + \lambda|H|^4 + yQHU$$

$$SU(6) \times SU(4)/\mathbb{Z}_2 \rightarrow [SU(3) \times SU(2)]_A \times [SU(3) \times SU(2)]_B$$

Daughter theory is identical to the Twin Higgs!*

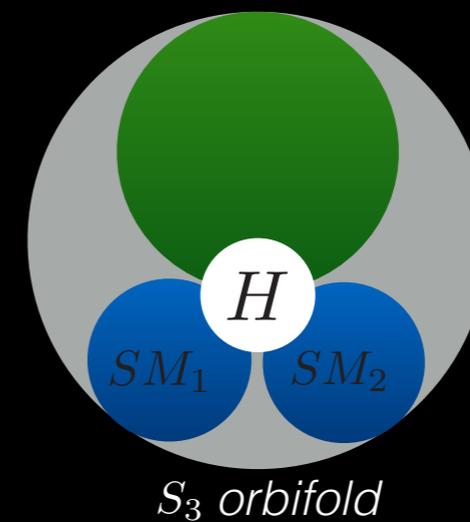
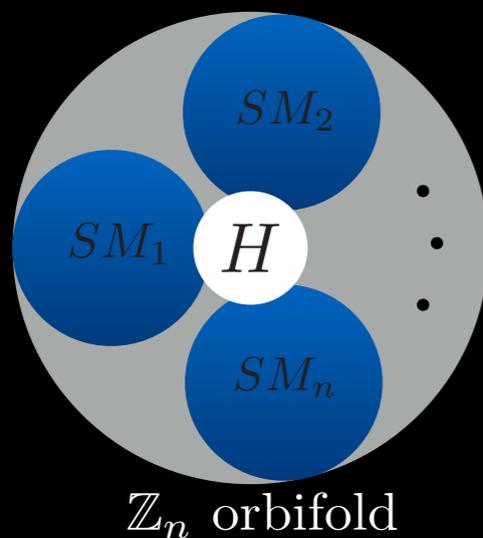
\mathbb{Z}_2 exchange symmetry emerges as a consequence of the orbifold procedure

This procedure can be generalized to other discrete symmetries which produce theories of NN (Orbifold Higgs)



Orbifold Higgs

Comparison of abelian and non-abelian orbifold Higgs



Abelian orbifold-Higgs models

contain multiple sectors with a SM-like structure

each of the sectors have the same couplings

Non-abelian orbifold-Higgs models

contain exotic sectors with different gauge symmetries

gauge and Yukawa couplings get rescaled

S₃-Orbifold Higgs

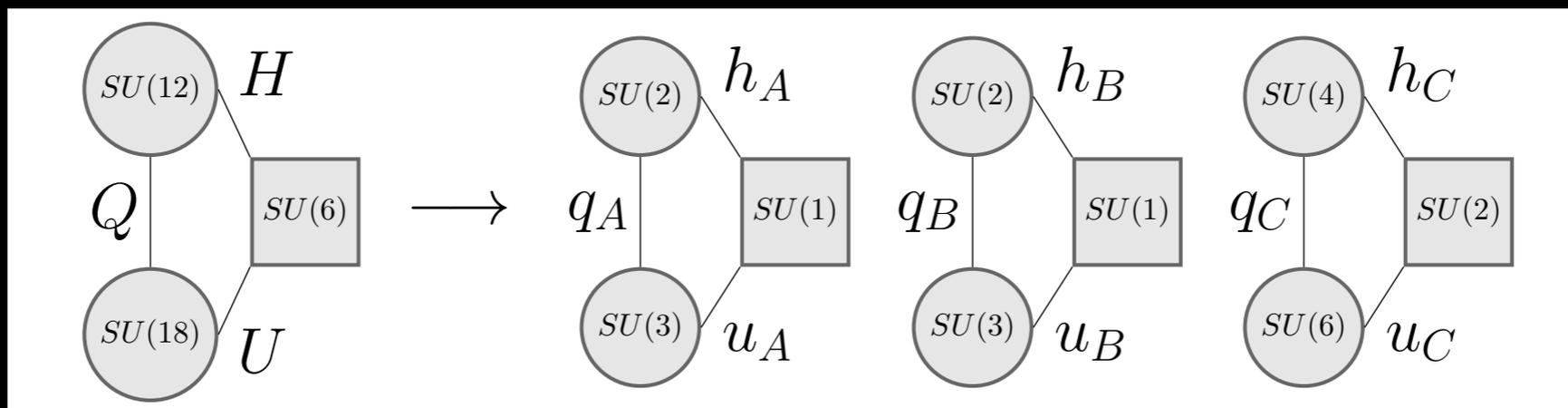
★ Begin with the parent theory

$$V_P = -m^2 |H|^2 + \lambda |H|^4 + y Q H U$$

$$|\langle H \rangle|^2 = f^2 / 2$$

	$SU(18)$	$SU(12)$	$SU(6)$
H	$\mathbf{1}$	\square	$\overline{\square}$
Q	\square	$\overline{\square}$	$\mathbf{1}$
U	$\overline{\square}$	$\mathbf{1}$	\square

★ Project out fields not invariant under S_3



A and B-sectors

SM-like gauge fields

No residual flavor symmetries

~~$SU(2)$~~

C-sector

Doubly large gauge symmetries

$SU(2)$ flavor symmetry

~~$SU(4)$~~ \rightarrow $SU(3)$

$y/\sqrt{2}$ and $g/\sqrt{2}$

Q: Does this contribute quadratic divergences to the Higgs mass?

S₃-Orbifold Higgs

Q: Does this contribute quadratic divergences to the Higgs mass?

$$V^{(1)} \supset \frac{\Lambda^2}{16\pi^2} \left(-6y^2 + \frac{9}{4}g^2 + 26\lambda \right) (|h_A|^2 + |h_B|^2 + |h_{C_1}|^2 + |h_{C_2}|^2) \\ + \frac{9g^2}{256\pi^2} \Lambda^2 (|h_{C_1}|^2 + |h_{C_2}|^2)$$

A: Only slightly...

$$\delta m^2 \approx \frac{3g_2^2}{64\pi^2} \Lambda^2 \left(1 - \frac{1}{2^2} \right)$$

$$\Delta_m = \left| \frac{2\delta m^2}{m_h^2} \right|^{-1} \sim 10\% \text{ tuning of the Higgs mass at } \Lambda = 7.5 \text{ TeV}$$

S₃-Orbifold Higgs

- ★ Want to identify the A -sector with the SM-like sector
 - Add 1-loop radiative corrections to V_D
 - Determine the vacuum alignment

Top-loops are the most important in determining the vacuum alignment

$$V_D^{(1)} \supset \frac{3y^4}{16\pi^2} \left[|h_A|^4 \log \left(\frac{\Lambda^2}{y^2 |h_A|^2} \right) + |h_B|^4 \log \left(\frac{\Lambda^2}{y^2 |h_B|^2} \right) \right. \\ \left. + \frac{1}{2} |h_{C_1}|^4 \log \left(\frac{\Lambda^2}{\frac{y^2}{2} |h_{C_1}|^2} \right) + \frac{1}{2} |h_{C_2}|^4 \log \left(\frac{\Lambda^2}{\frac{y^2}{2} |h_{C_2}|^2} \right) \right]$$

The vevs after top loop radiative corrections are included

$$|\langle h_A \rangle|^2 = |\langle h_B \rangle|^2 = \frac{1}{2} |\langle h_{C_1} \rangle|^2 = \frac{1}{2} |\langle h_{C_2} \rangle|^2 \equiv f^2/12$$

S₃-Orbifold Higgs

- ★ Break residual \mathbb{Z}_2 symmetry

$$V_{soft} = \rho^2 \left(|h_A|^2 - \frac{1}{5}|h_B|^2 - \frac{1}{5}|h_{C_1}|^2 - \frac{1}{5}|h_{C_2}|^2 \right)$$

- ★ Introduce approximation

$$\frac{3y^4}{16\pi^2} \log \left(\frac{\Lambda^2}{\frac{y^2}{d_\alpha} |h_\alpha|^2} \right) \approx \frac{3y^4}{16\pi^2} \log \left(\frac{\Lambda^2}{y^2 |\langle h_A \rangle|^2} \right) \equiv \delta, \quad \alpha = A, B, C_1, C_2$$

- ★ Resulting vacuum alignment

$$v^2 \equiv 2|\langle h_A \rangle|^2 = \frac{m^2}{6\lambda + \delta} - \frac{\rho^2}{\delta}, \quad v_B^2 = \frac{m^2}{6\lambda + \delta} + \frac{\rho^2}{5\delta}, \quad v_{C_1}^2 = v_{C_2}^2 = \frac{2m^2}{6\lambda + \delta} + \frac{2\rho^2}{5\delta}.$$

Electroweak tuning $\sim 6v^2/f^2$

$$h \approx h_A \cos v/f - \frac{1}{\sqrt{5}} \sin v/f \left[h_B + \sqrt{2}h_{C_1} + \sqrt{2}h_{C_2} \right]$$

S₃-Orbifold Higgs

$$h \approx h_A \cos v/f - \frac{1}{\sqrt{5}} \sin v/f \left[h_B + \sqrt{2}h_{C_1} + \sqrt{2}h_{C_2} \right]$$

Modified SM Higgs production and decays

$$\sigma(pp \rightarrow h) = \cos^2(v/f) \sigma(pp \rightarrow h_{SM})$$

$$\Gamma(h \rightarrow SM_i) = \cos^2(v/f) \Gamma(h_{SM} \rightarrow SM_i)$$

Higgs decays to uncharged sectors

$$r_B \equiv \frac{\Gamma(h \rightarrow B\text{-sector})}{\Gamma(h_{SM}) \frac{1}{5} \sin^2(v/f)} \quad \text{and} \quad r_C \equiv \frac{\Gamma(h \rightarrow C\text{-sector})}{\Gamma(h_{SM}) \frac{2}{5} \sin^2(v/f)}$$

Modified Branching Fraction x Production cross-section

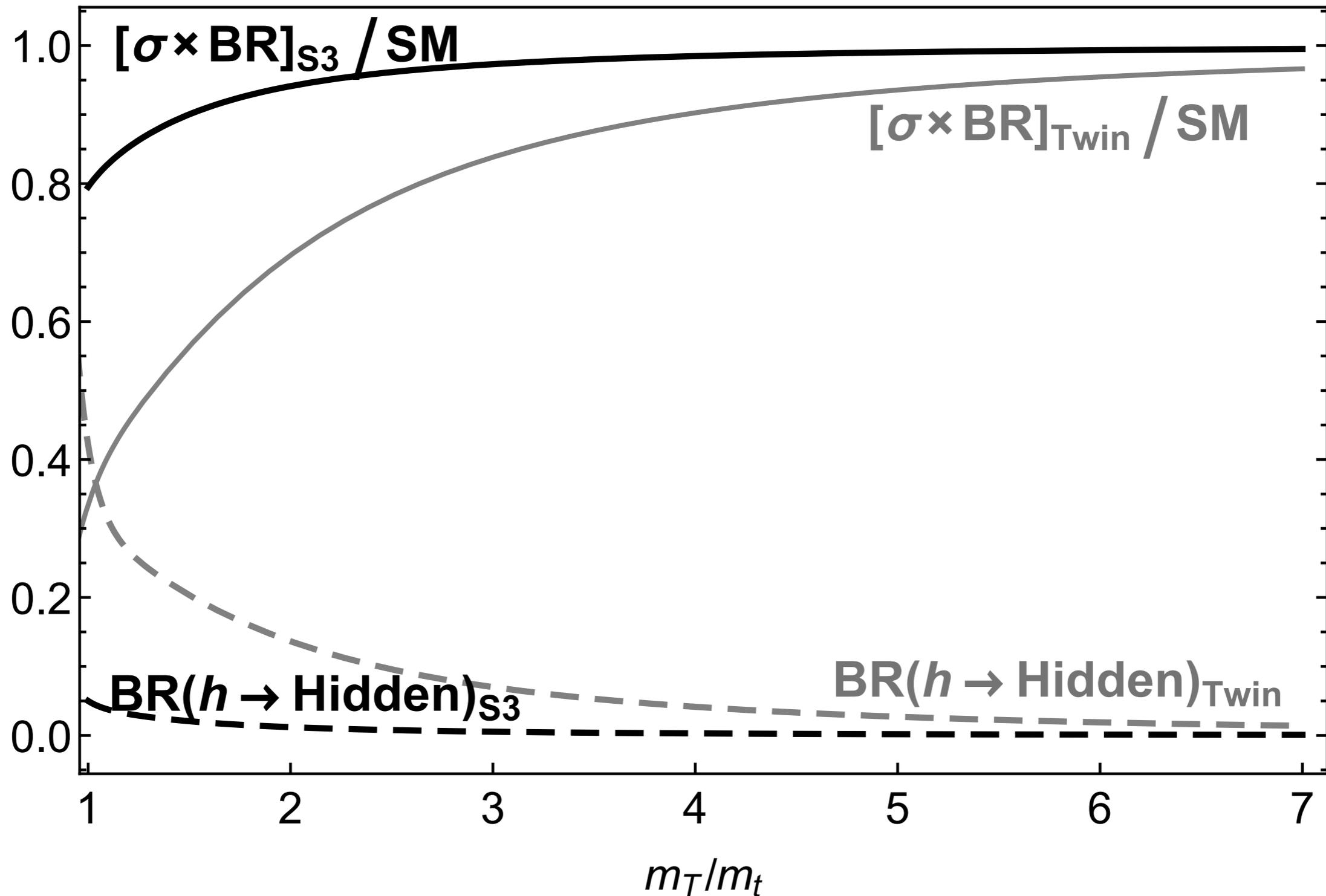
$$\frac{\sigma(pp \rightarrow h) BR(h \rightarrow SM_i)}{\sigma(pp \rightarrow h_{SM}) BR(h_{SM} \rightarrow SM_i)} = \frac{\cos^2(v/f)}{1 + \frac{1}{5}(r_B + 2r_C) \tan^2(v/f)}$$

S₃-Orbifold Higgs

BSM Decays of the SM like Higgs

B-sector	C-sector
Fermions $h \rightarrow \overline{f_B} f_B$	Fermions $h \rightarrow \overline{f_C} f_C$
Gluons $h \rightarrow \overline{g_B} g_B$	Gluons $h \rightarrow \overline{g_C} g_C$
Massive Vector Bosons $h \rightarrow V_B^* V_B$	Massless $SU(4)$ Vector Bosons $h \rightarrow V_C V_C$

S_3 -Orbifold Higgs



Thoughts and Conclusions

Hard to strongly disfavor Orbifold Higgs models at LHC

Need to do more work to better understand the S_3 -Orbifold Higgs

- displaced Higgs decays
- effects on cosmology

Thanks!



This work was funded by the NSF