

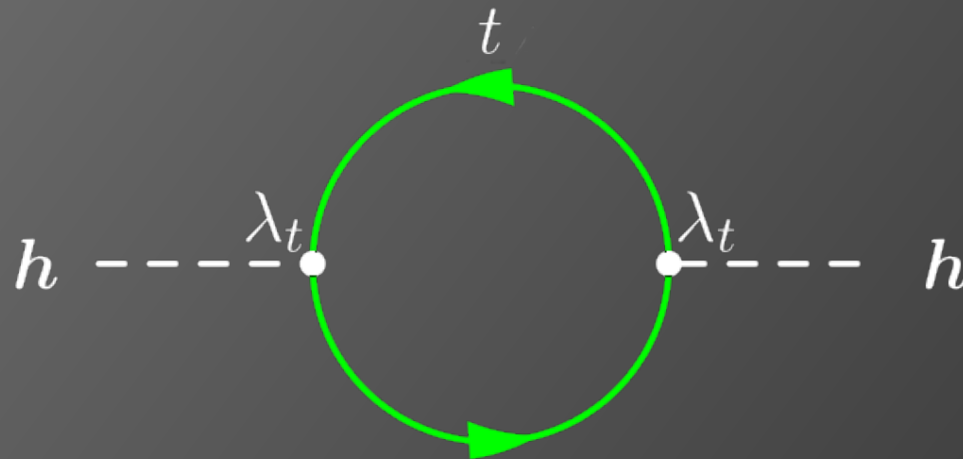
PROBING NATURAL COLORLESS TOP PARTNERS

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Phenomenology Symposium
5 May 2015

G. Burdman, Z. Chacko, R. Harnik, L. de Lima, CV arXiv 1411.3310
D. Curtin and CV In Progress

A Hierarchy Problem

- Questions unanswered by SM
 - Dark Matter, Baryon Asymmetry, Neutrino Masses
 - Gravity
- Indicates New Physics at some new scale Λ
- SM fermions give rise to Higgs mass corrections



The diagram shows a top quark loop correction to the Higgs mass. Two external Higgs boson lines, represented by dashed lines and labeled h , are connected to a loop of top quarks, represented by a solid green circle with arrows indicating a clockwise flow. The vertices where the Higgs lines meet the top quark loop are marked with dots and labeled λ_t . The top quark loop is labeled t at the top.

$$h \text{ --- } \lambda_t \text{ --- } \text{---} h \rightarrow -\frac{3\lambda_t^2}{8\pi^2} \Lambda^2$$

Top Partners

- Quadratic sensitivity to Λ can be cancelled by top partners

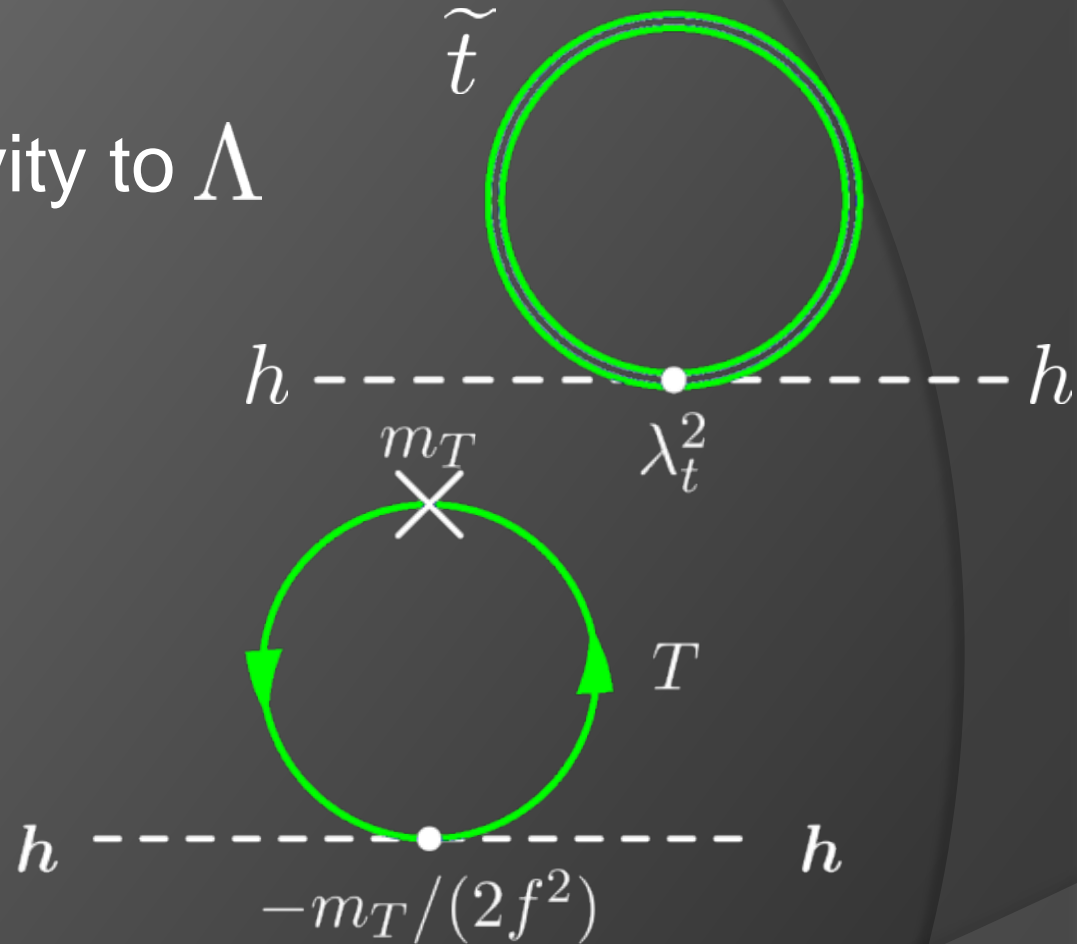
- Scalar

- e.g. SUSY

- Fermion

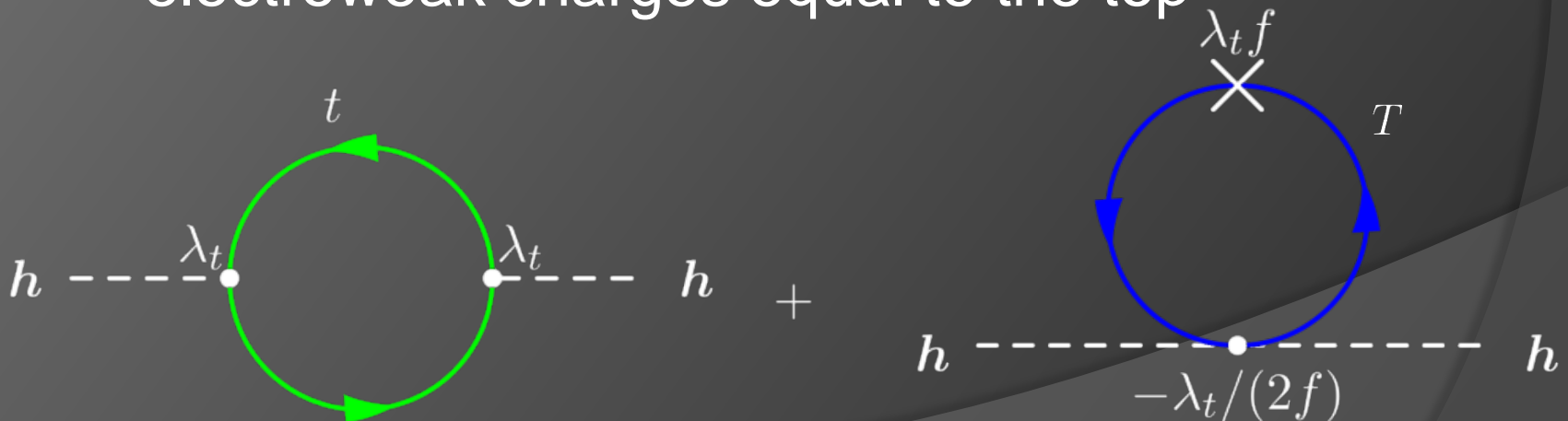
- e.g. Little Higgs

- In natural models the top partner mass is not too large



Don't Need $SU(3)_c$ for Partners

- The symmetries guarantee equality of couplings.
- The symmetries are often assumed to commute with SM gauge structure
 - This leads to partner particles with color and electroweak charges equal to the top



3 Colorless Partner Models

- Twin Higgs

- Z Chacko, H-S Goh, R Harnik **Phys.Rev.Lett.** 96 (2006) 231802
- No SM charge on fermionic partner particles

- Folded SUSY

- G Burdman, Z Chacko, H-S Goh, R Harnik **JHEP** 0702 (2007) 009
- Only SM electroweak charges on scalar partners

- Quirky Little Higgs

- H Cai, H-C Cheng, J Terning **JHEP** 0905 (2009) 045
- Only SM electroweak charges on fermionic partners

- They are becoming more interesting as bounds on colored particles increase.

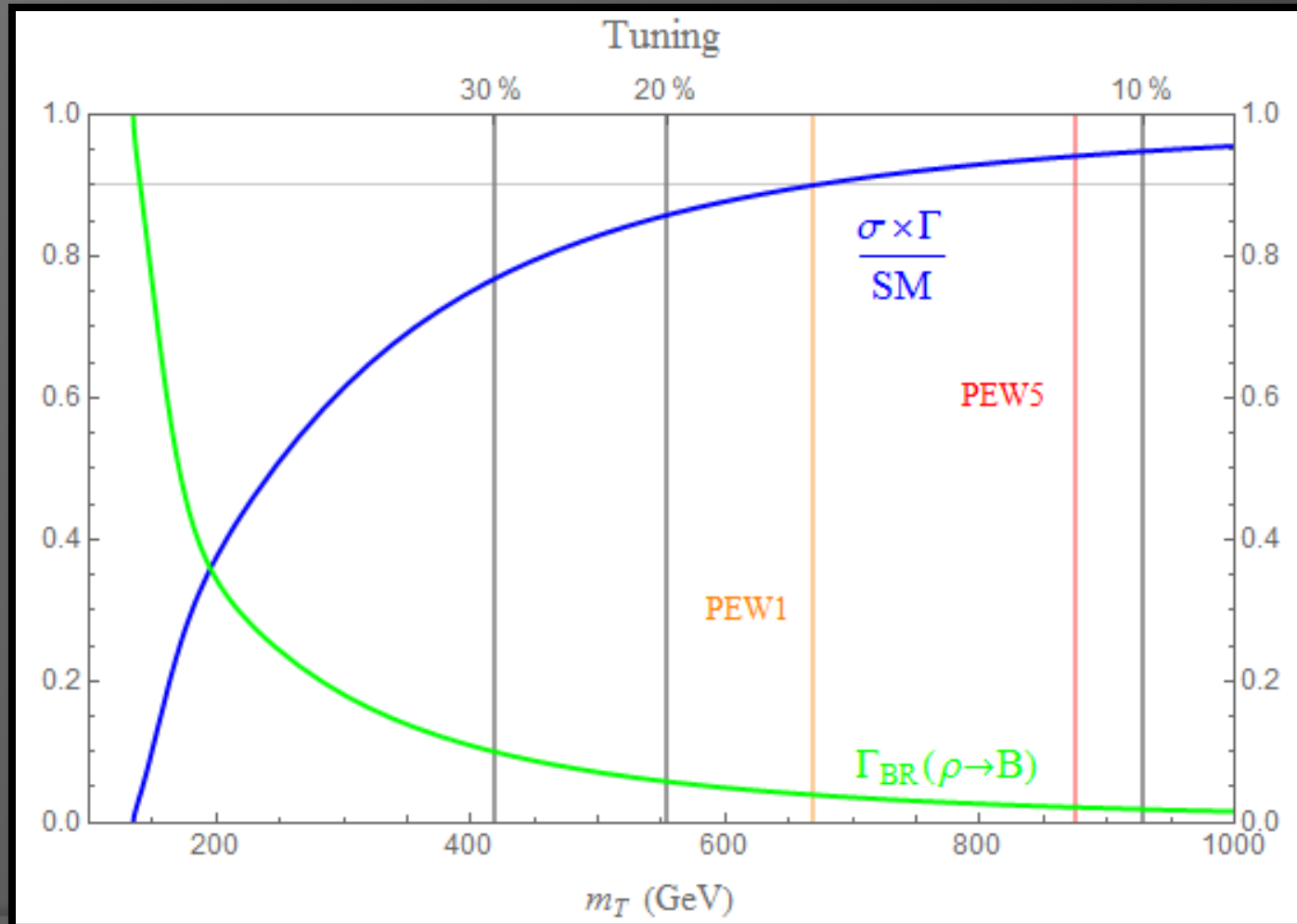
Higgs as a Probe

- In order to cancel the top loop, new particles must couple to the Higgs
 - Expect sensitivity to 10% deviations of couplings from LHC
- Variation from SM Higgs production and decay signal the new physics
- What channels make good probes?
- How far can we push naturalness?

Twin Higgs Limits

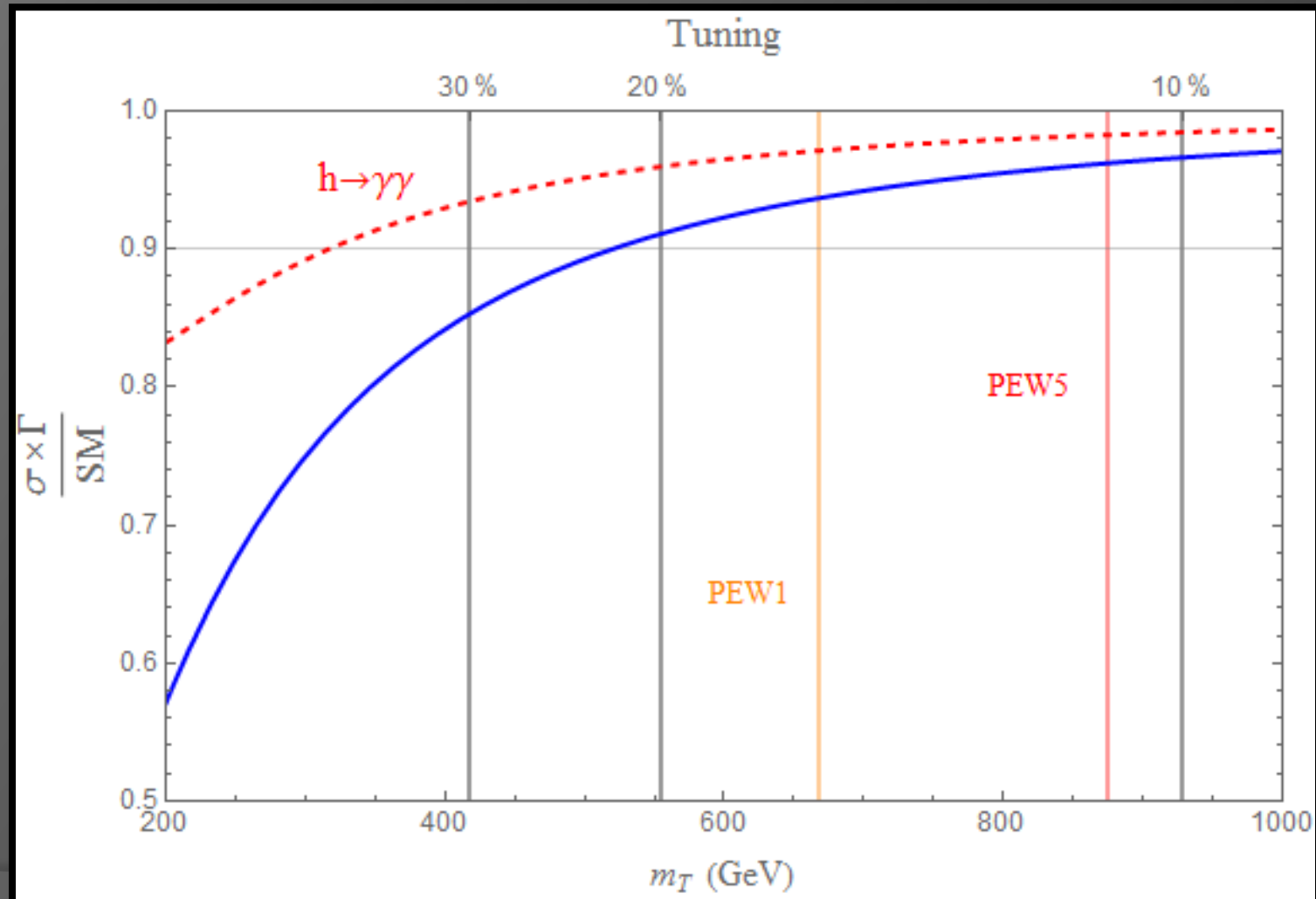
$$\text{Deviation} \sim \frac{v^2}{f^2}$$

- Usual pNGB reduction of couplings



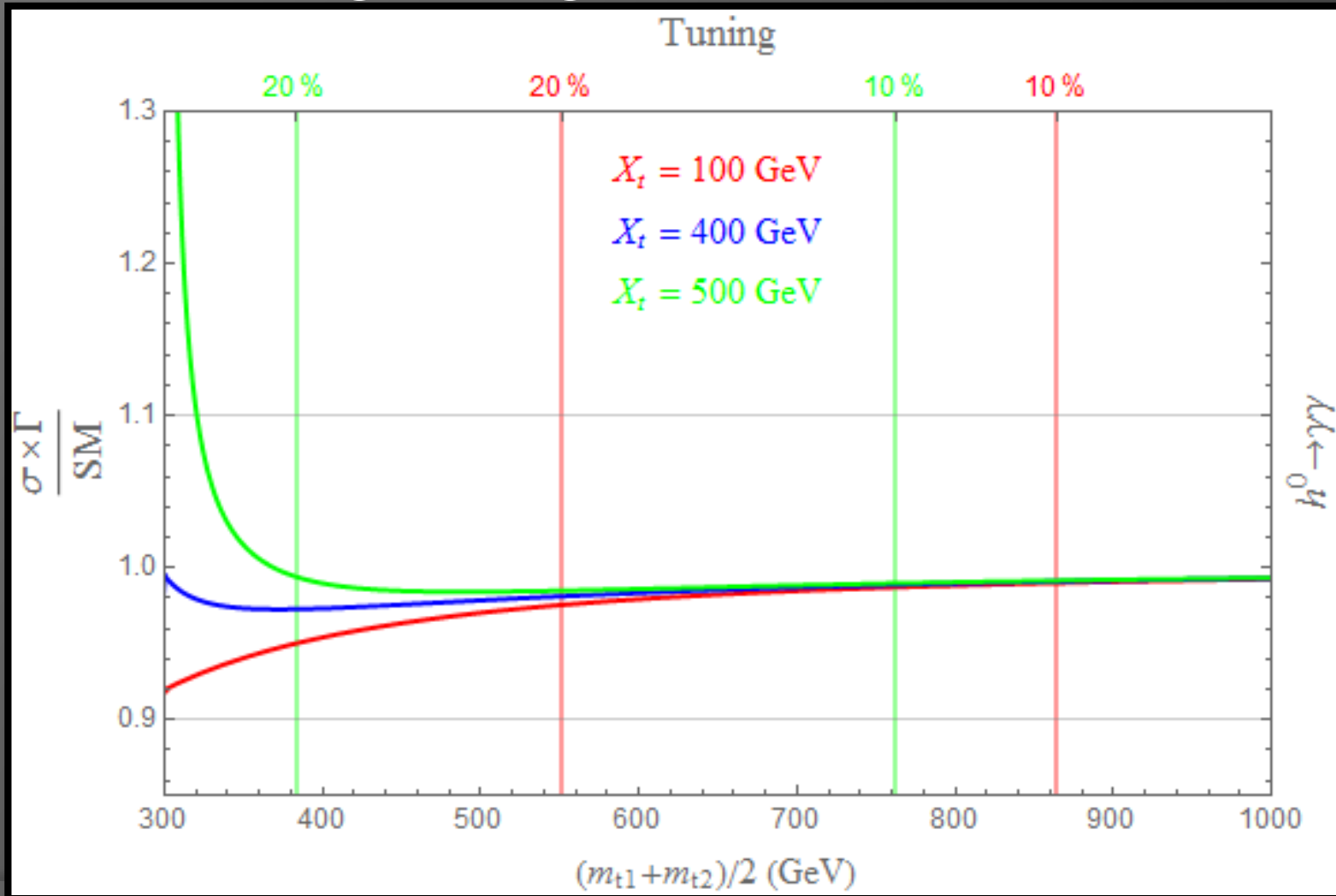
Quirky Little Higgs Limits

- Universal suppression and electroweak effects



Folded SUSY Limits

- No coupling changes, but electroweak effects

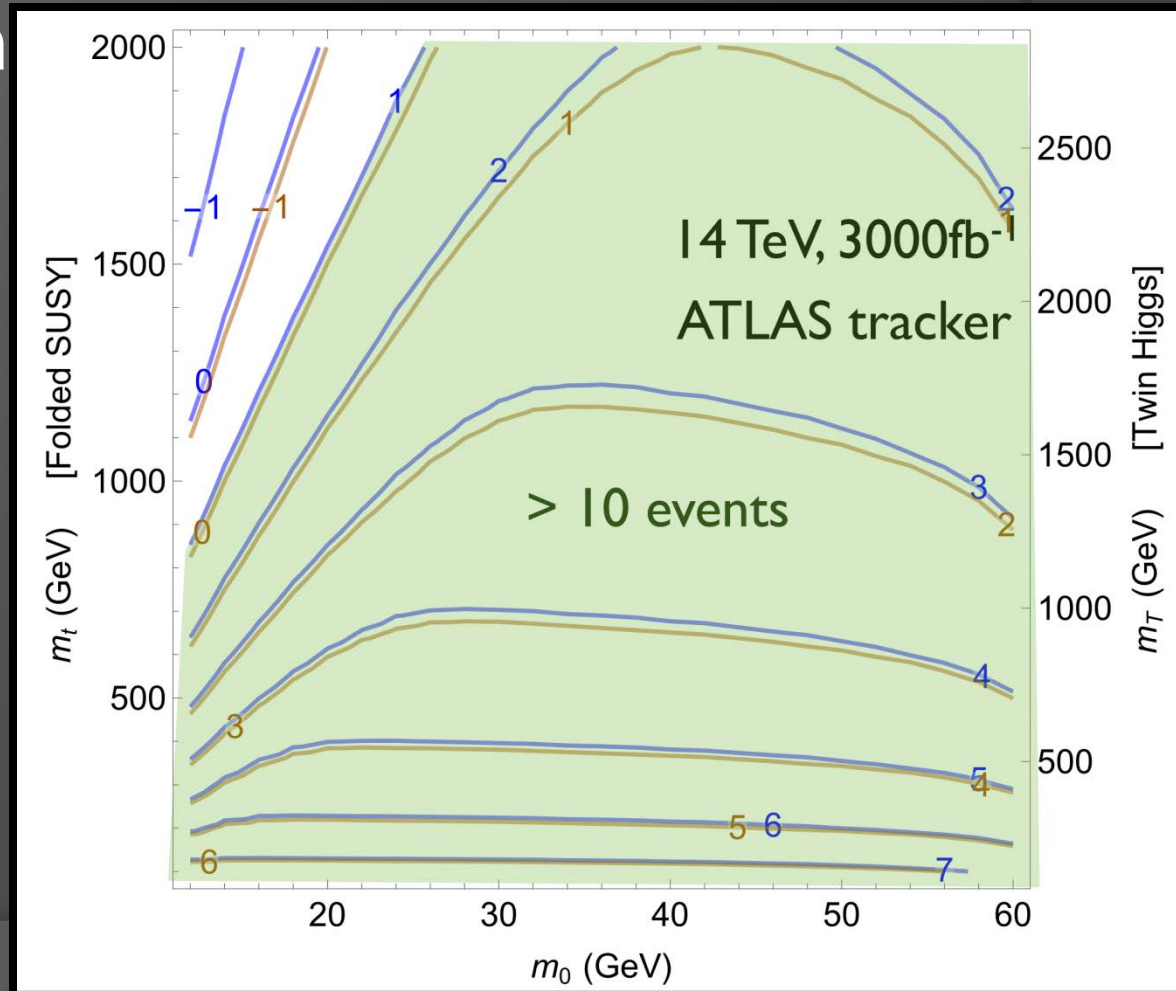


Hidden Glueballs!

- Each of these models includes a hidden $SU(3)$ gauge group
- If there are no light states charged under hidden color, there will be hidden glueballs
- The glueballs mix with the Higgs, leading to displaced vertex decays into SM states
 - Hidden Valley phenomenology

Potential Reach

- LHC 14 will make $\sim 10^8$ Higgs bosons
- Estimate how many decay to glueballs which decay in detector subsystems.
- Log_{10} Number:
 - Gluon Fusion
 - VBF
- Cuts will reduce

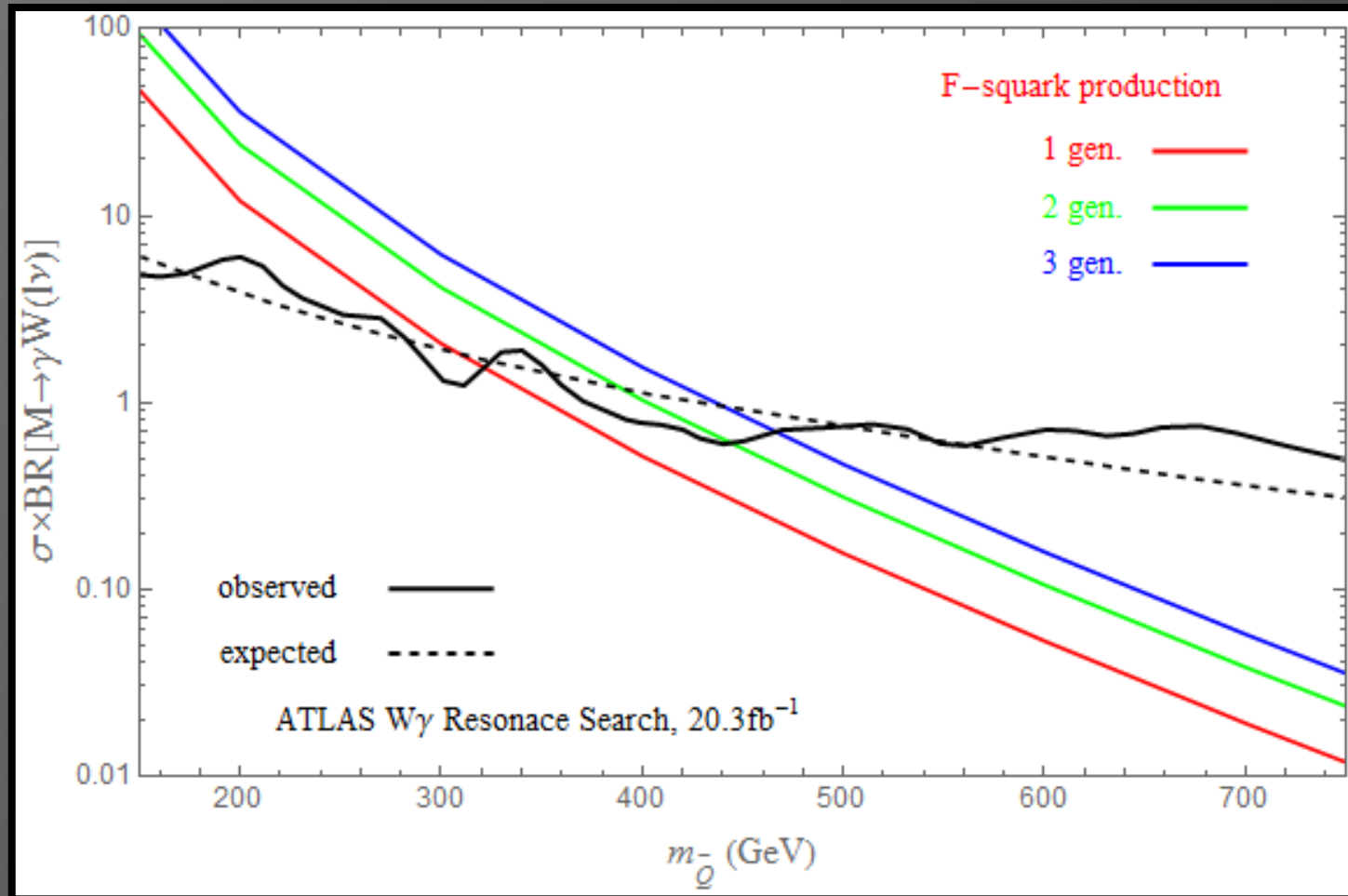


Conclusions

- Models with colorless top partners can address the hierarchy problem naturally.
- Such models affect Higgs couplings, but the LHC is unlikely to disfavor models with modest, not even 10%, tuning,
- Should consider other methods of discovery or constraint
 - Hidden Glueballs
 - Electroweak production
- Do not need to give up naturalness, just need to be creative

Extra Credit

Folded SUSY Collider Bounds



Higgs to Glueball decay

- J. E. Juknevich JHEP 1008 (2010) 121

$$\mathcal{L}^{(6)} = \frac{\alpha_v}{3\pi} \frac{y^2}{M^2} H^\dagger H \text{Tr} G_{\mu\nu}^v G_v^{\mu\nu}$$

$$\Gamma_{0^{++} \rightarrow \text{SM}} = \left(\frac{\alpha_v}{3\pi} \frac{y^2}{M^2} \frac{\mathbf{F}_{0^{++}v}^S}{m_h^2 - m_0^2} \right)^2 \Gamma_{h \rightarrow \text{SM}}^{\text{SM}}(m_0^2)$$

- From the lattice

$$4\pi\alpha_v \mathbf{F}_{0^{++}}^S = 3.06 m_0^3$$