COLORLESS TOP PARTNERS AT THE LHC

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SUSY Conference

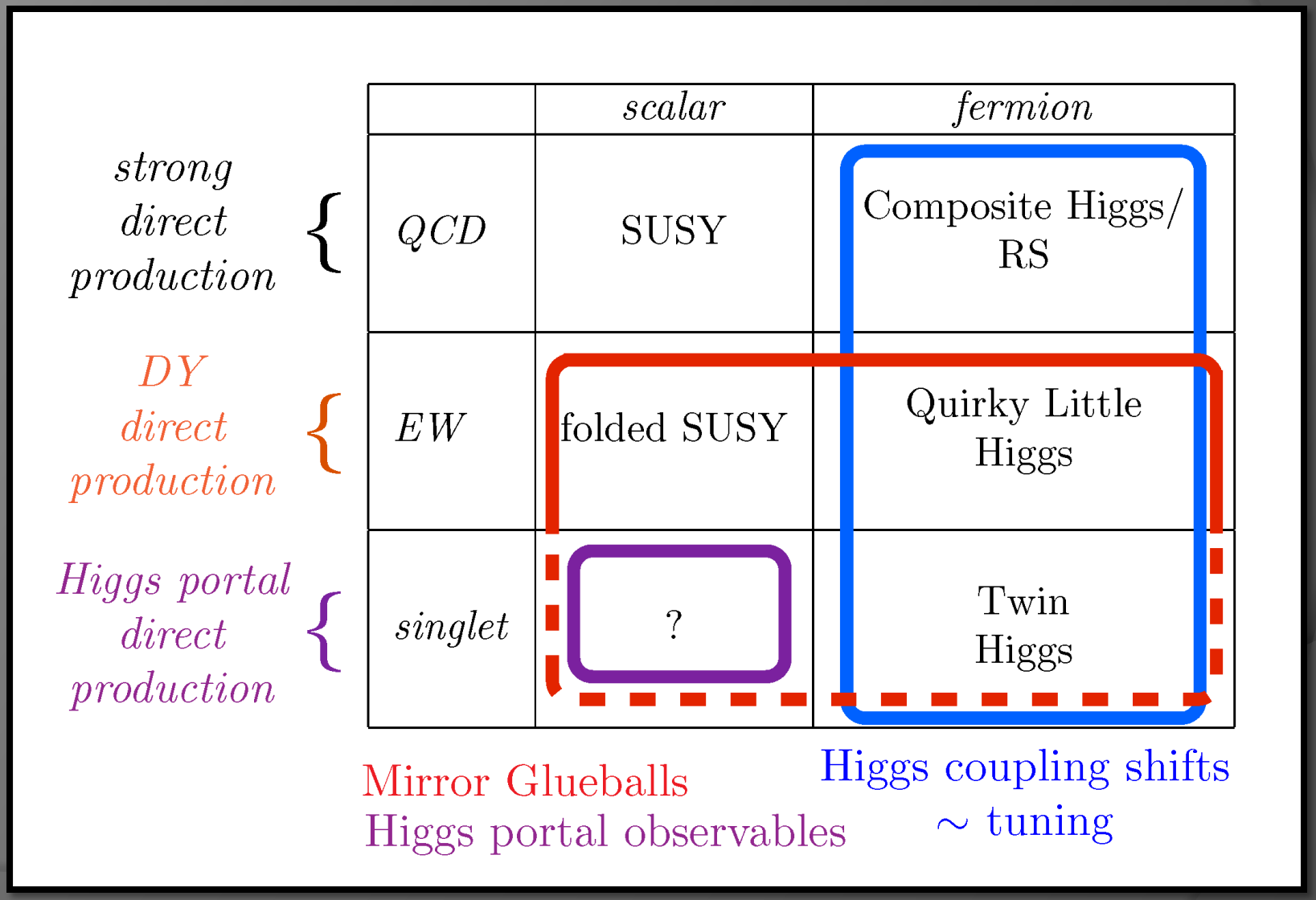
28 August 2015

arXiv: 1411.3310 G. Burdman, Z. Chacko, R. Harnik, L. de Lima, CV

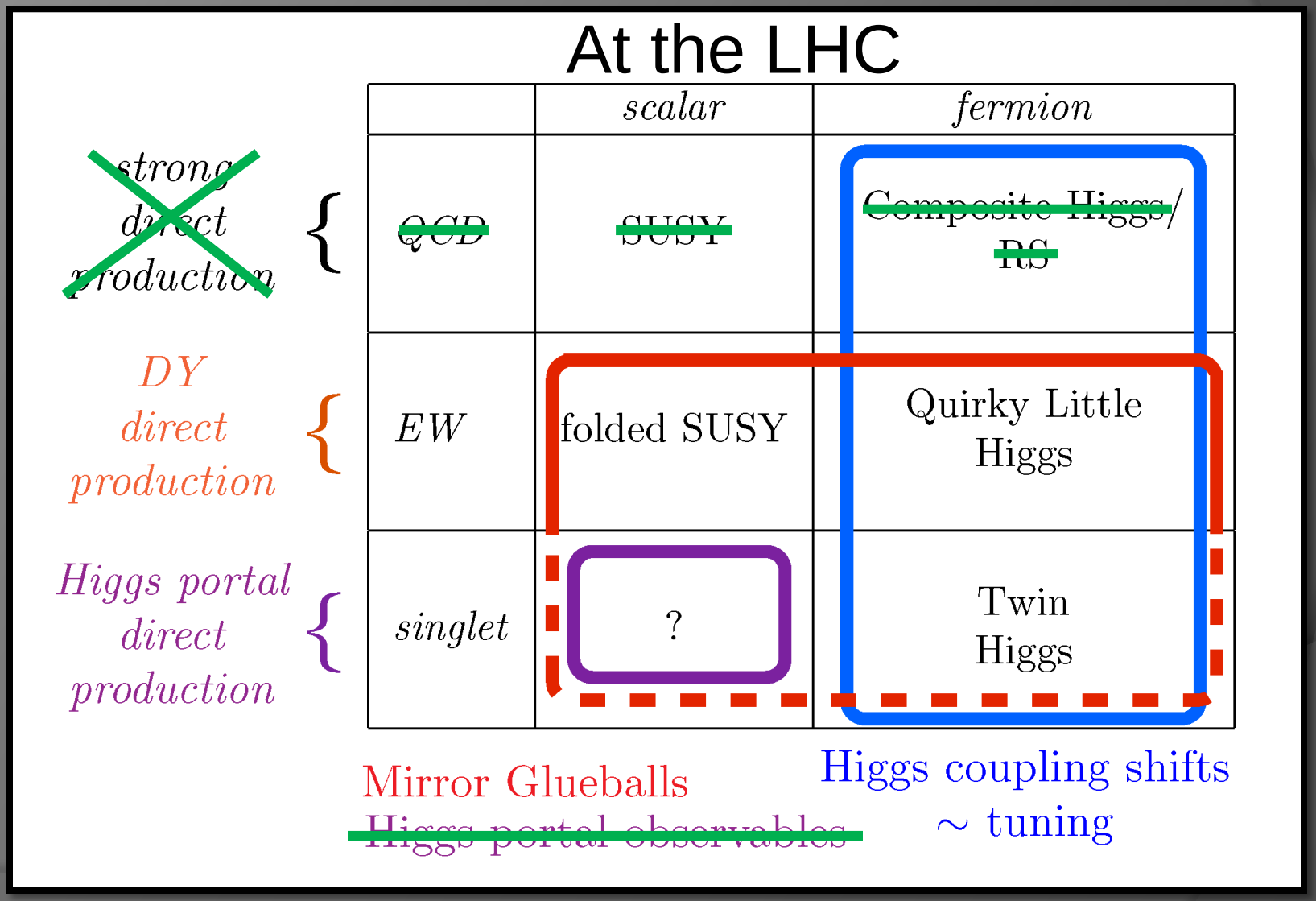
arXiv: 1506.06141 D. Curtin and CV

Z. Chacko, D. Curtin, CV in progress

The Big Picture



This Talk


At the LHC
scalar
fermion
strong direct production
QCD
SUSY
Composite Higgs/ RS
DY direct production
EW
folded SUSY
Quirky Little Higgs
Higgs portal direct production
singlet
?
Twin Higgs
Mirror Glueballs
Higgs portal observables
Higgs coupling shifts ~ tuning

What Unifies the Models?

- The known models posit a new sector which is related to visible sector by a discreet Z_2 symmetry
- We call this the Mirror Sector

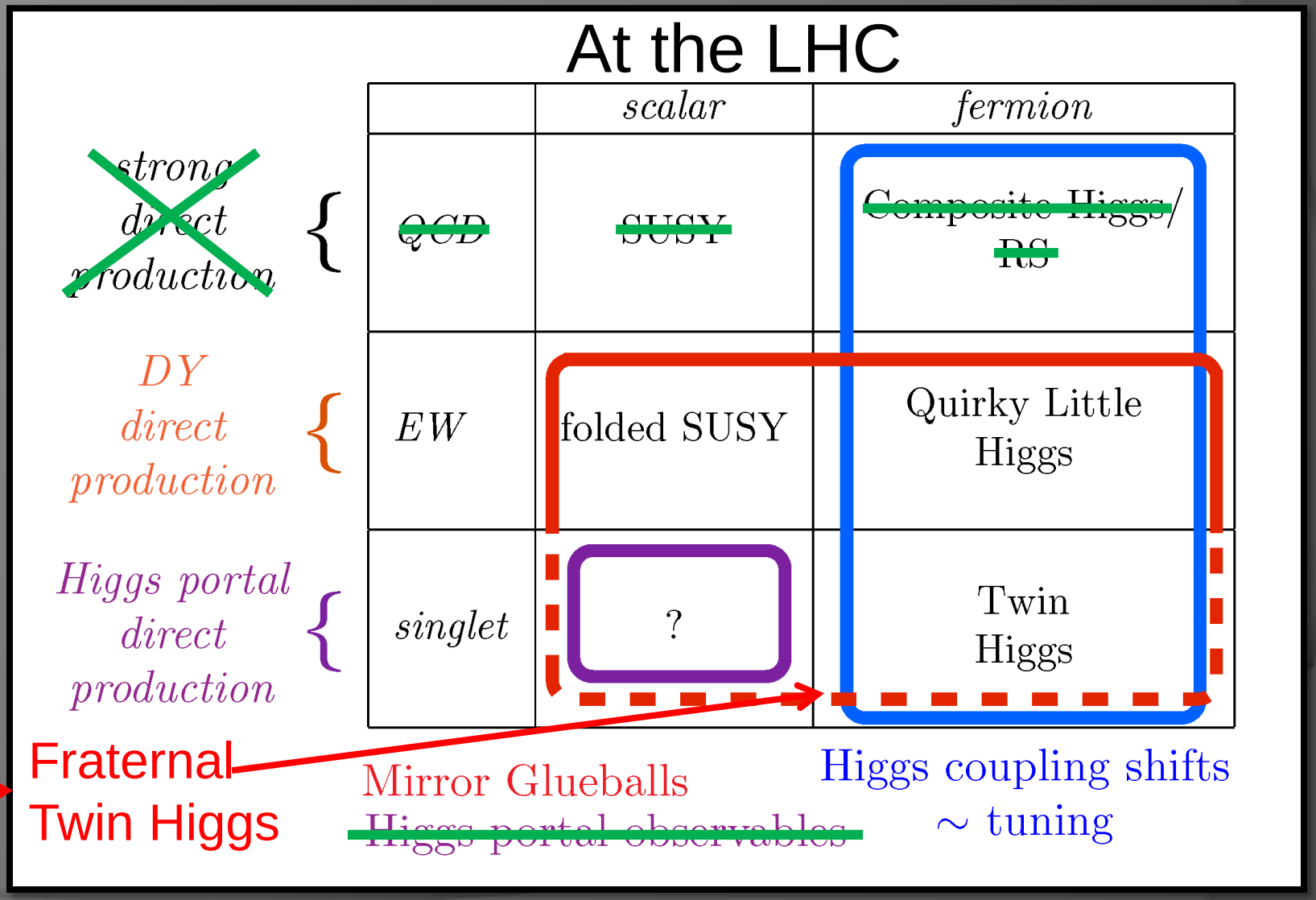
Visible Sector $\overset{Z_2}{\longleftrightarrow}$ Mirror Sector

- The mirror sector couples to the Higgs

What Can We Do At the LHC?

- Measure Higgs Couplings
  - Need Lepton collider for real precision
- Detect Mirror Glueballs
  - Displaced Vertices are key
  - Triggers & Efficiencies need careful thought
- Direct Production of Partners
  - Drell-Yan or Higgs Portal
  - Usually have Displaced Vertices

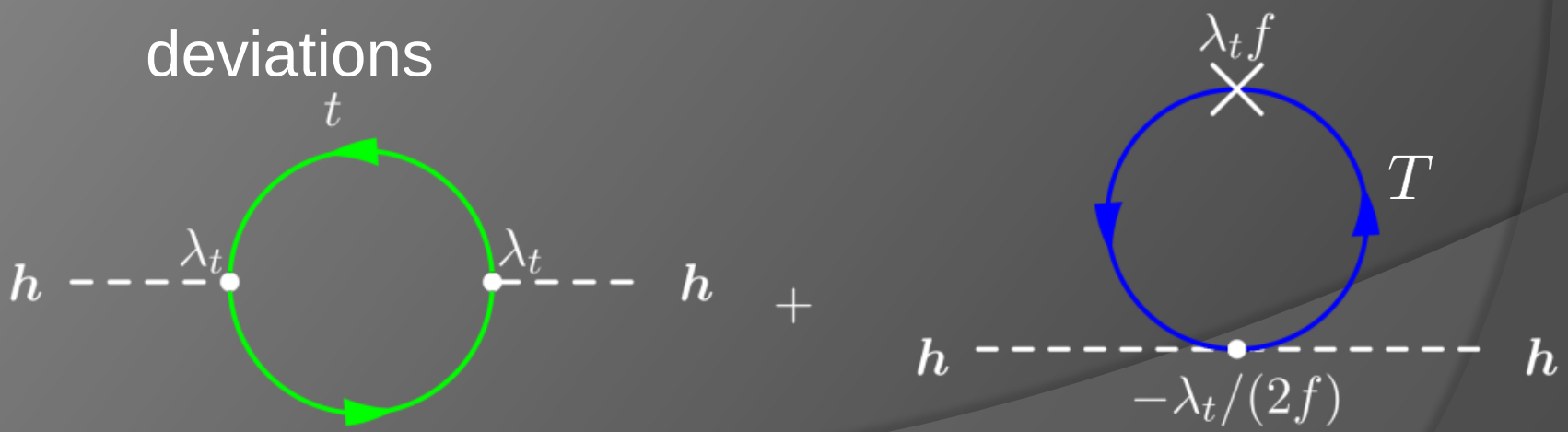
What Can We Do At the LHC?



arXiv: 1501.05310 N. Craig, A. Katz, M. Strassler, R. Sundrum

Precision Higgs

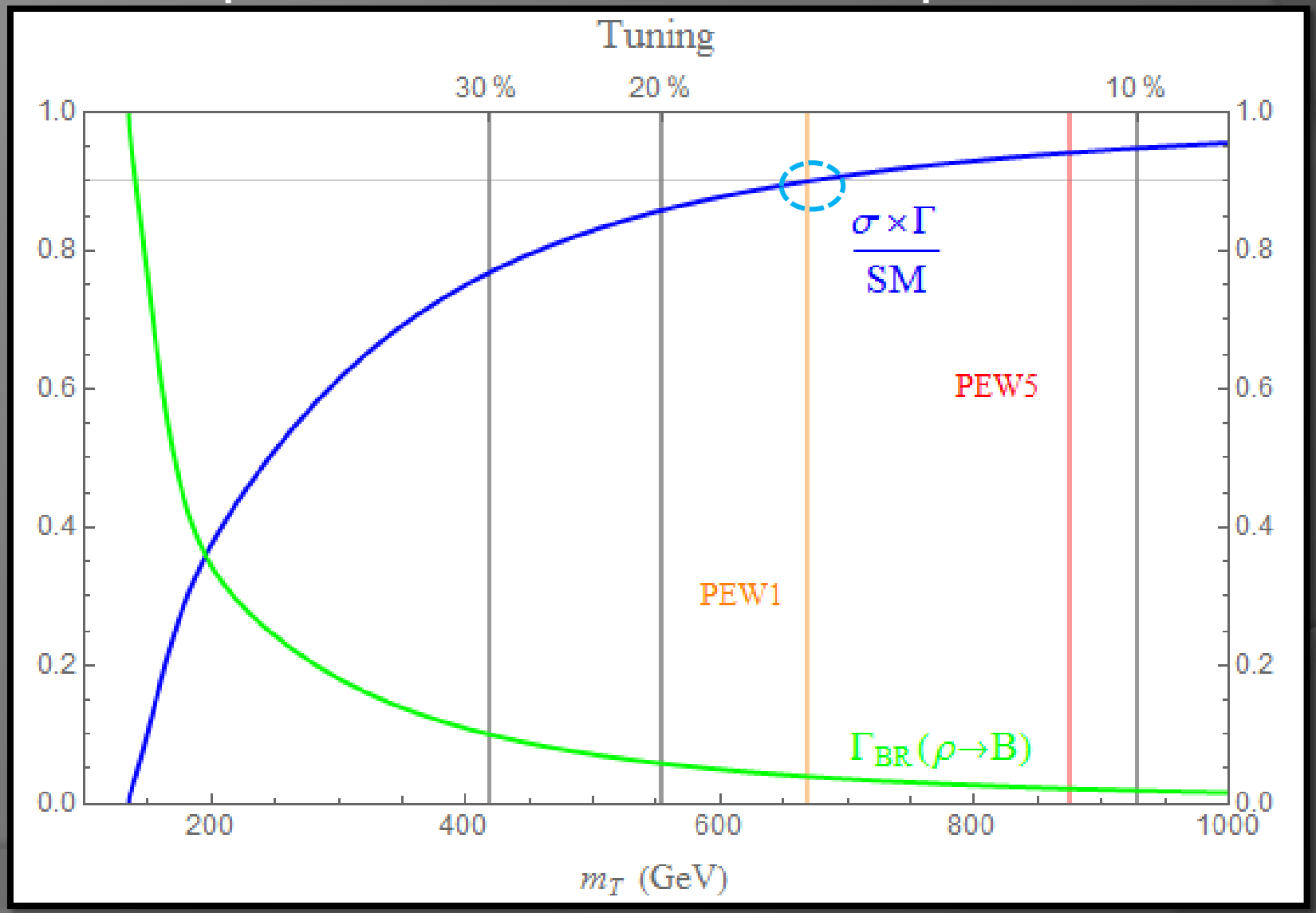
- In order to cancel the top loop, new particles must couple to the Higgs
  - Expect sensitivity to 10% deviations in Higgs final states from LHC
  - Lepton Colliders sensitive to about 1% deviations



Twin Higgs

Deviation ~ Tuning ~ $\frac{v^2}{f^2}$

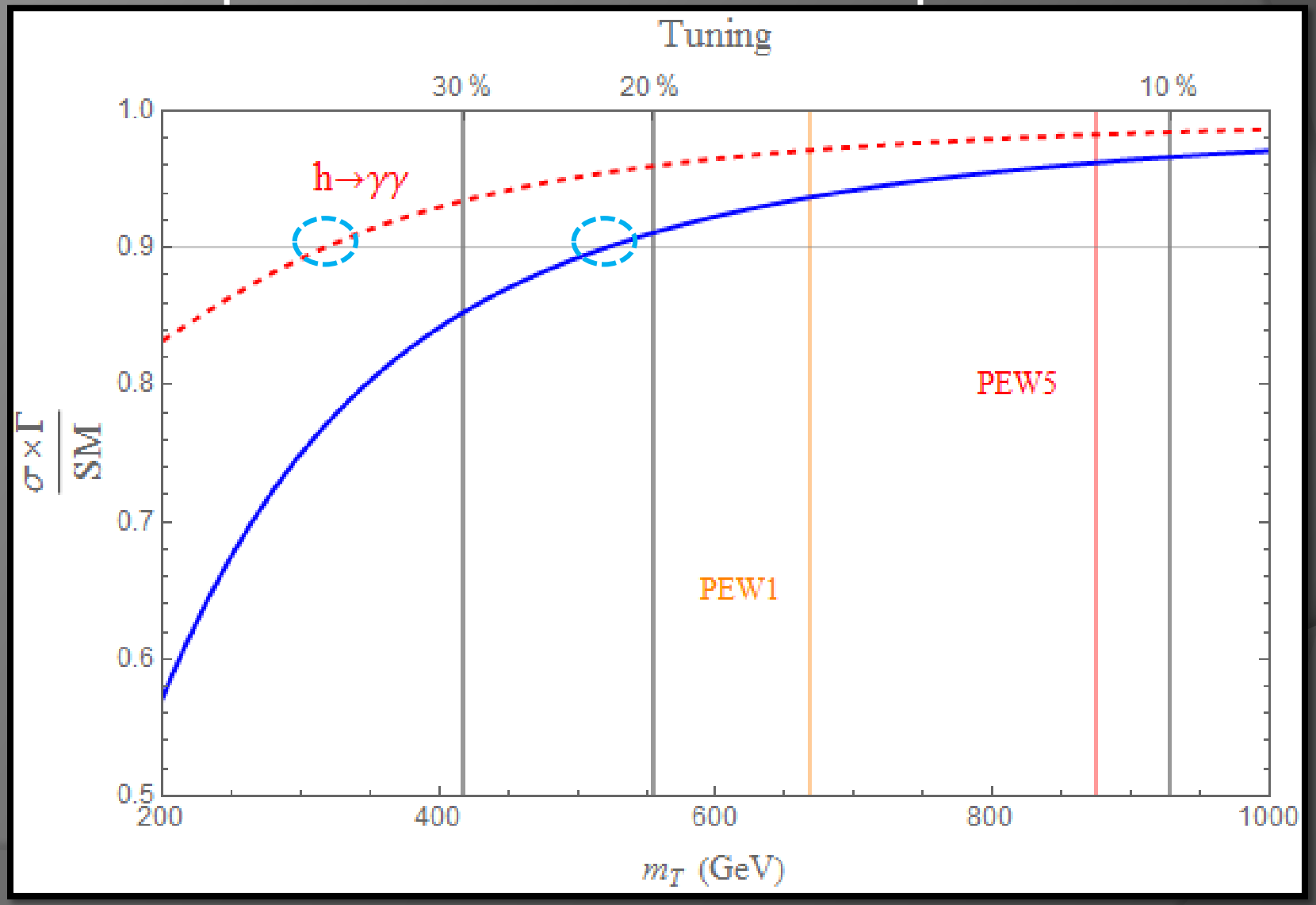
- Can probe to about 650 GeV partner



Quirky Little Higgs

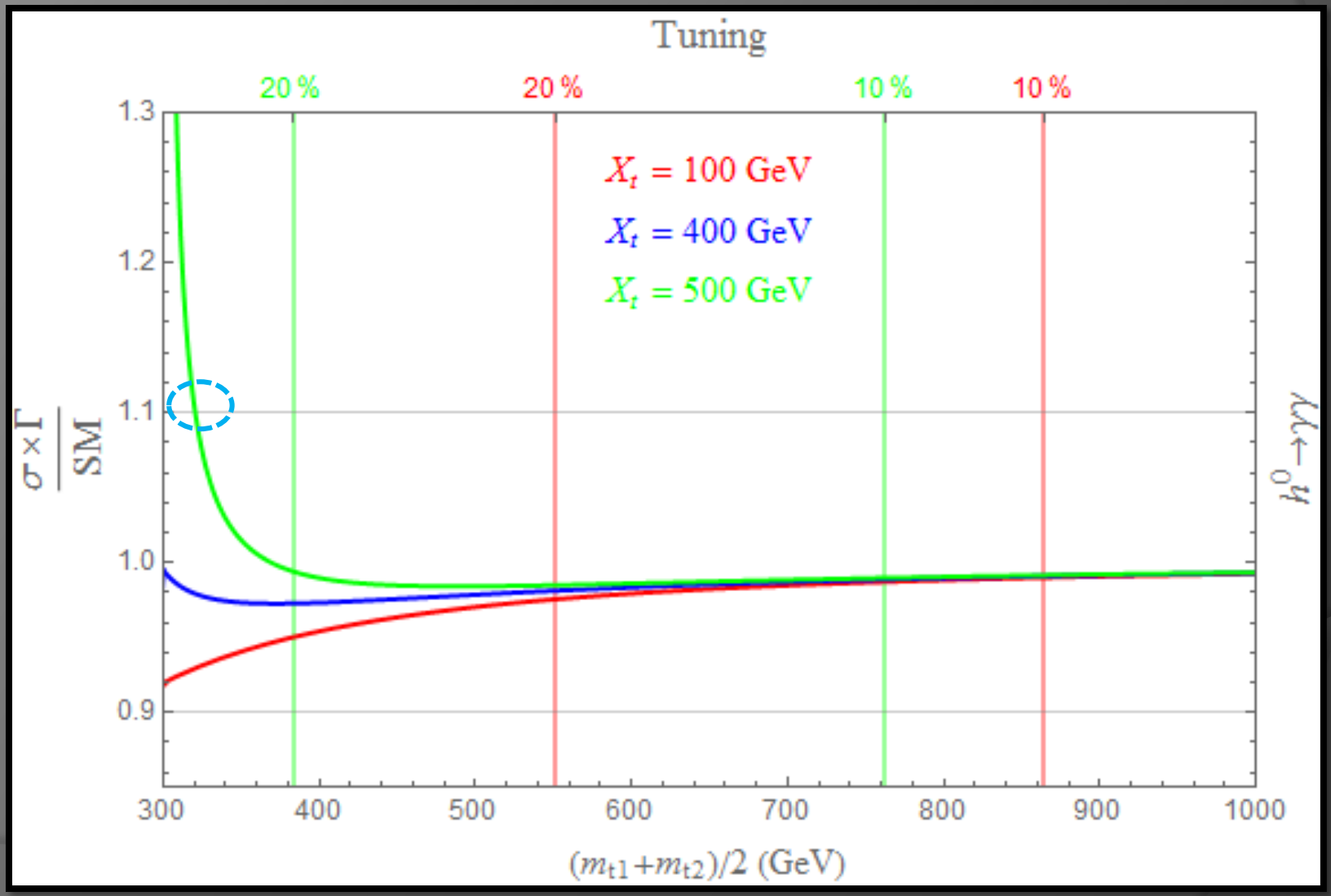
Deviation ~ Tuning ~ $\frac{v^2}{f^2}$

- Can probe to about 550 GeV partner



Folded SUSY Limits

- No coupling changes, but electroweak effects



Higgs Couplings Recap

- pNGB Higgs have $\frac{v^2}{f^2}$ suppression of couplings
  - LHC probes to about 600 GeV top partners or about 20% tuning
  - TLEP may probe ~ 2 TeV top partners or about 4% tuning
- Other models (e.g. Folded SUSY) may not have significant deviations

Mirror Glueballs!

- Always a mirror SU(3) gauge group
- If no light particles are charged under the mirror SU(3), then there must be mirror glueballs at the bottom of the spectrum
  - Guaranteed in Folded SUSY and Quirky Little Higgs
  - Often occurs in **Fraternal** Twin Higgs
    - First to point out this glueball connection

Glueballs $\Rightarrow$ Displaced Vertices

- The 0^{++} glueballs mix with the Higgs, leading to displaced decays into SM states
  - Hidden Valley phenomenology with naturalness motivated parameters
- J. E. Juknevich JHEP 1008 (2010) 121

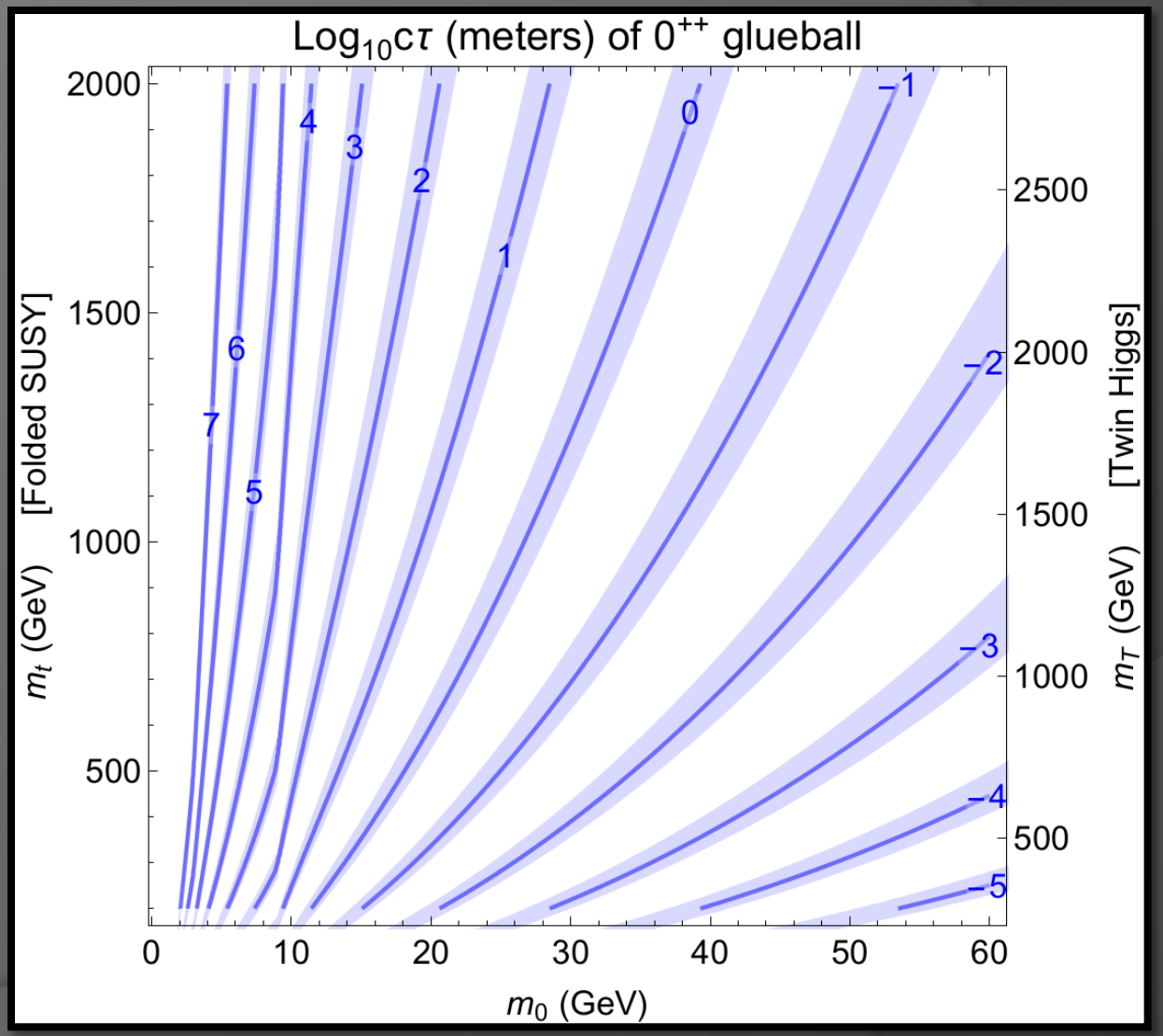
$$\mathcal{L}^{(6)} = \frac{\alpha_v}{3\pi}\frac{y^2}{M^2} H^\dagger H \,\mathrm{Tr}\, G^v_{\mu\nu} G_v^{\mu\nu}$$

Model Specific

- Relies on results from the lattice

How Displaced?

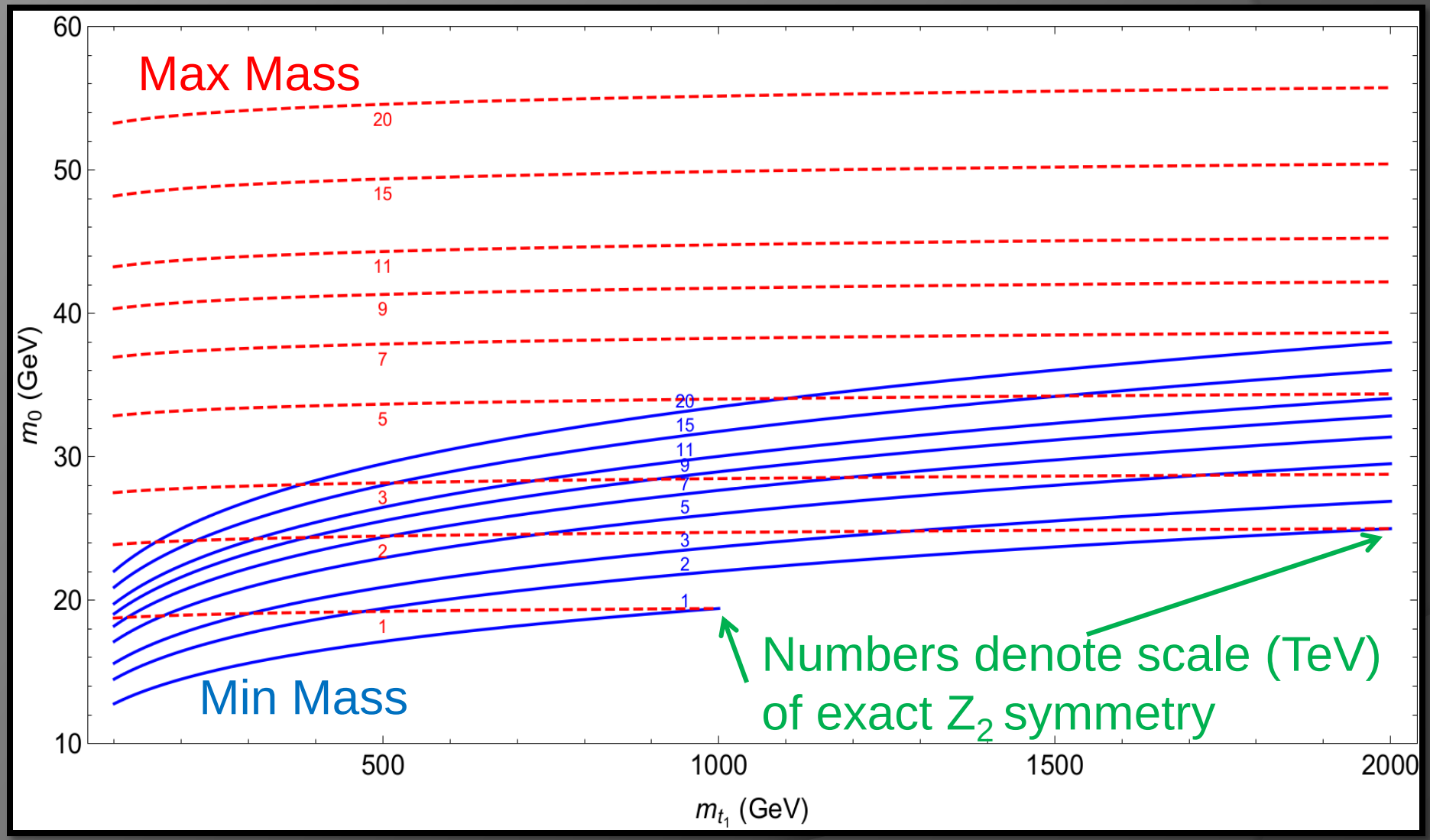
- Much of the parameter space is on detector length scales
- Microns to Kilometers!



Expected Glueball Masses

- From the lattice $m_0 \approx 7\Lambda_{\mathrm{QCD}}$
- Z_2 symmetry is exact at some scale, equal strong coupling constant
- The mirror sector has different particle content, leading to nonperturbative coupling at a higher scale, heavier glueballs
- Expected range **10 to 60 GeV**
- Twin Dark Matter may motivate mass > 14 GeV: 1505.07109 I.Garcia, R.Lasenby, J.March-Russell

For instance, Folded SUSY



Searches

$$p\,p \to h \to g_v\,g_v \to G^0\,G^0$$

- Most of the signal is in the tracker

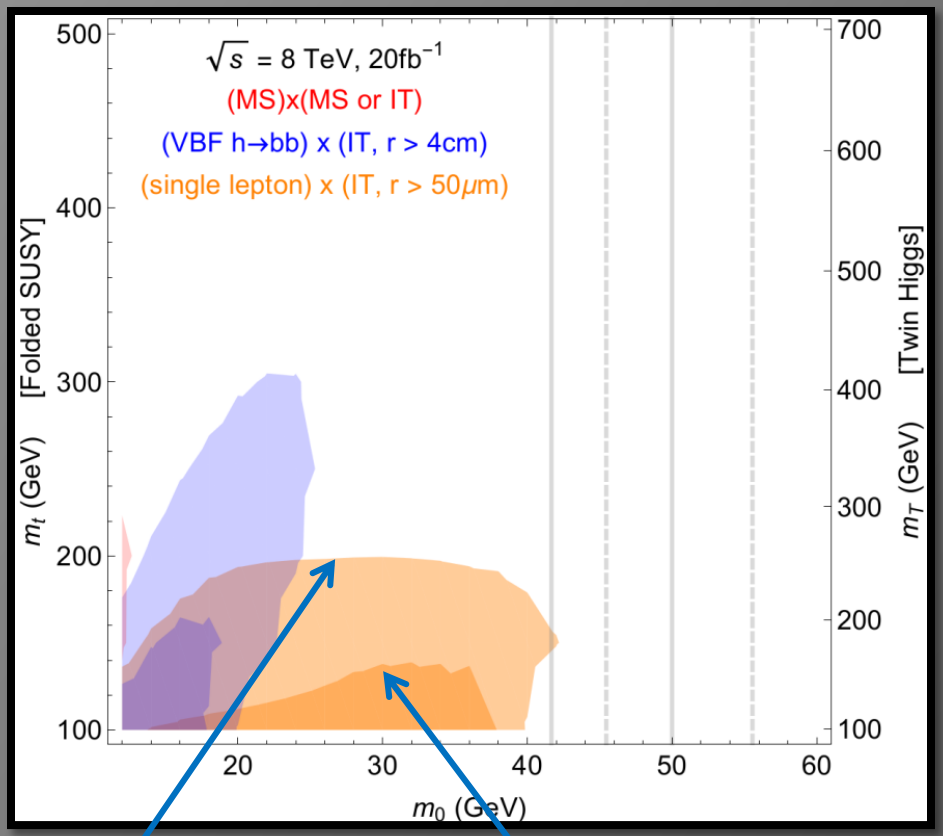
Search \ Detector	Tracker	HCAL	Muon
HCAL x HCAL		DV x 2	
MS x (MS or IT)	(DV)		DV (x 2)
IT + VBF	DV + VBF		
IT + 1Lepton	DV + 1 Lepton		

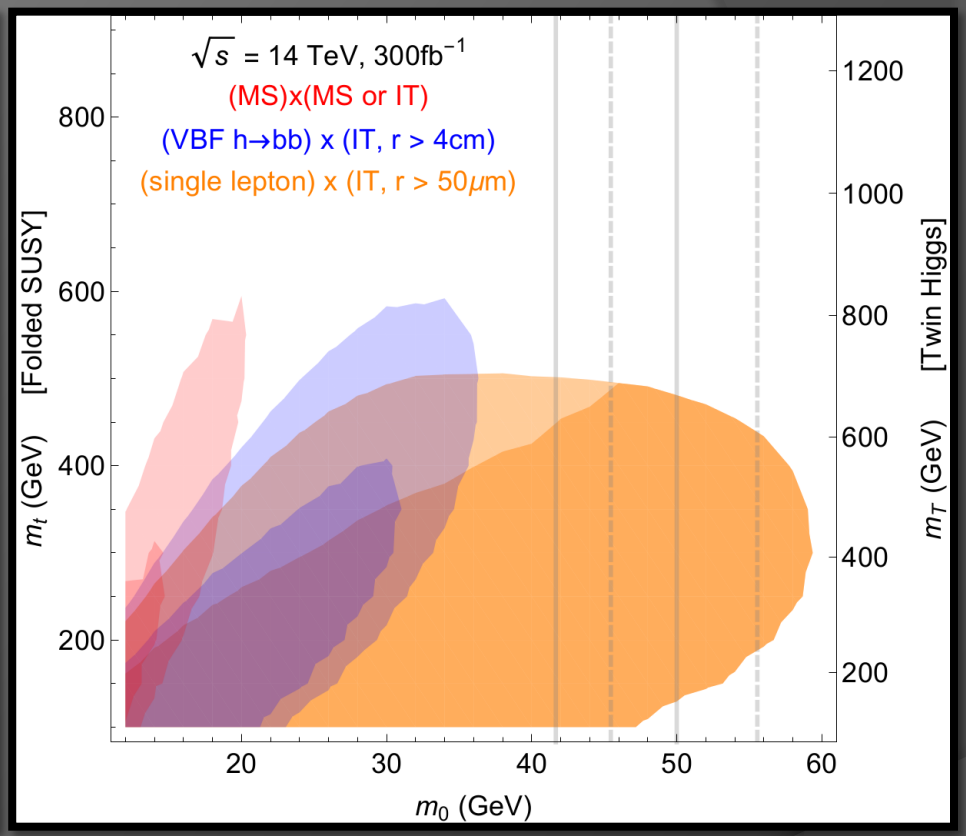
Recast

Proposed

- Use ATLAS efficiency tables (thanks!) for DV reconstruction

LHC Run I & Run II





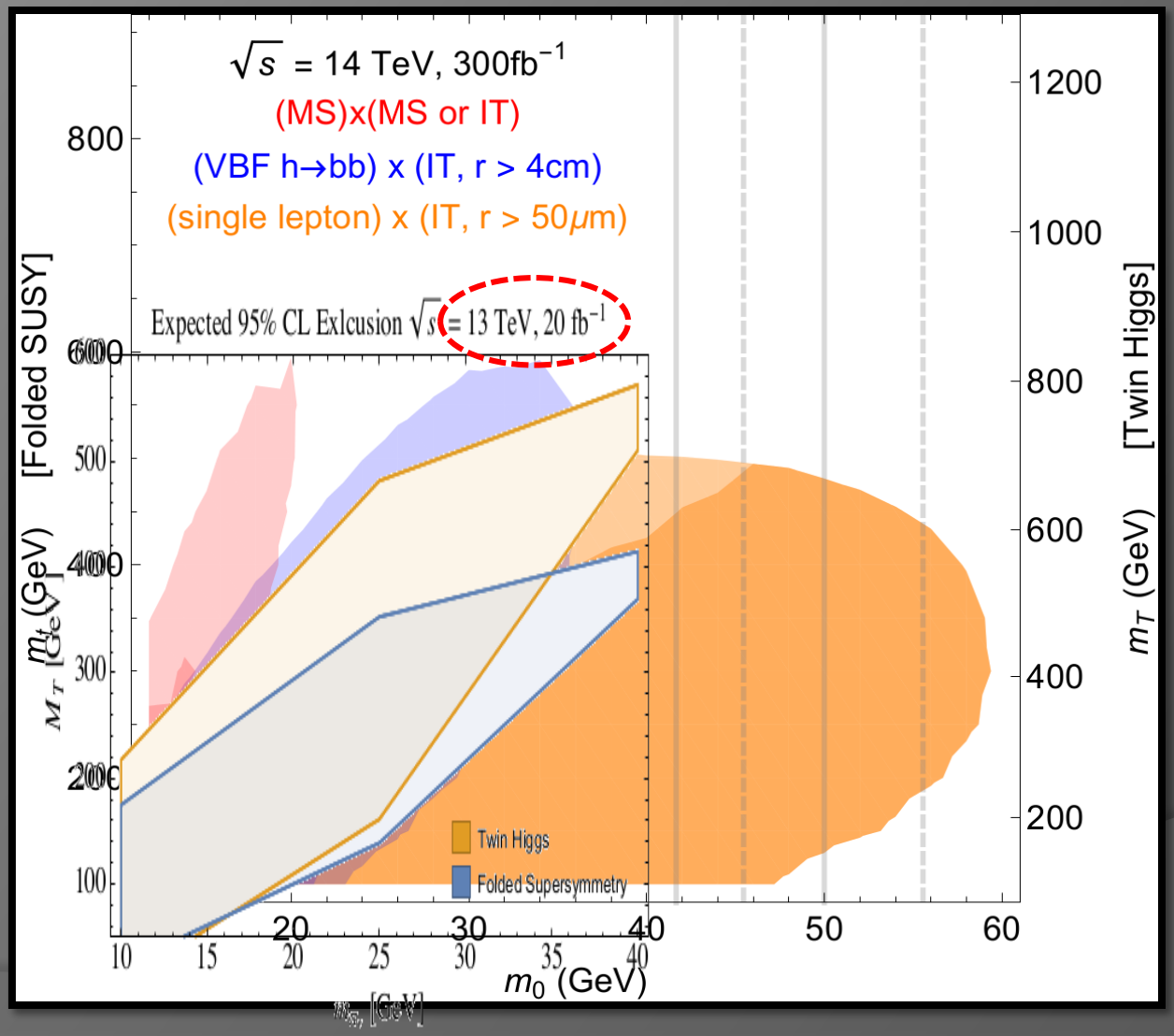
$\kappa_{\mathrm{Max}} = 1, \quad \kappa_{\mathrm{Min}} \in (0.1, 1)$

(Kinematics)

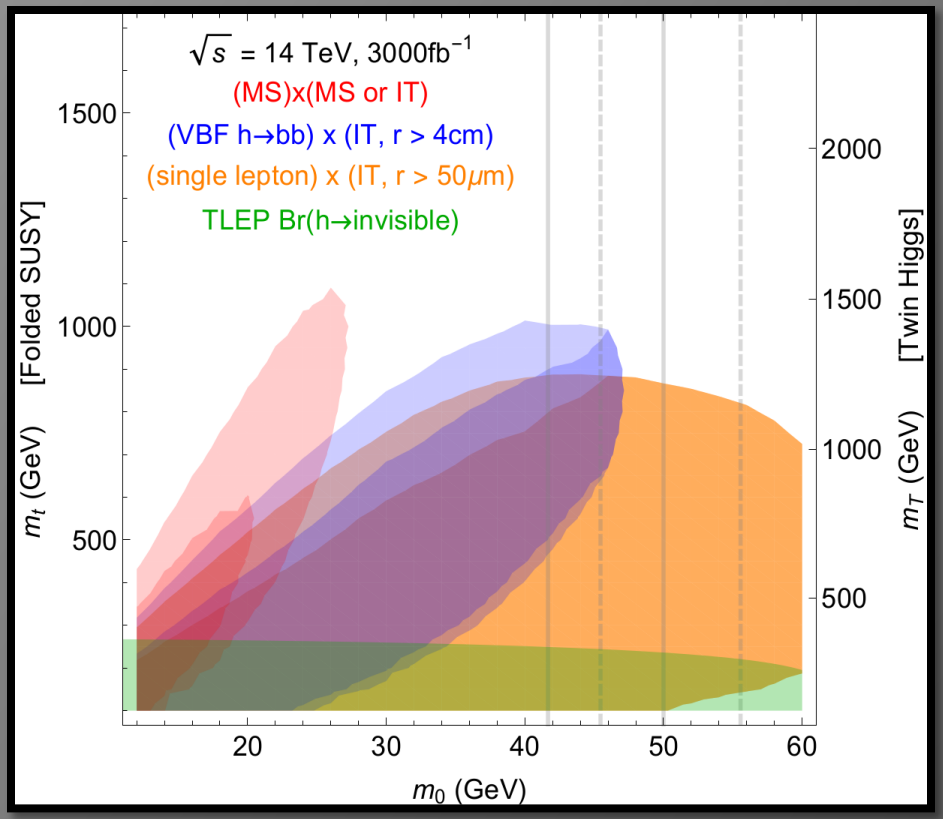
Use parameter κ to account for glueball hadronization uncertainties

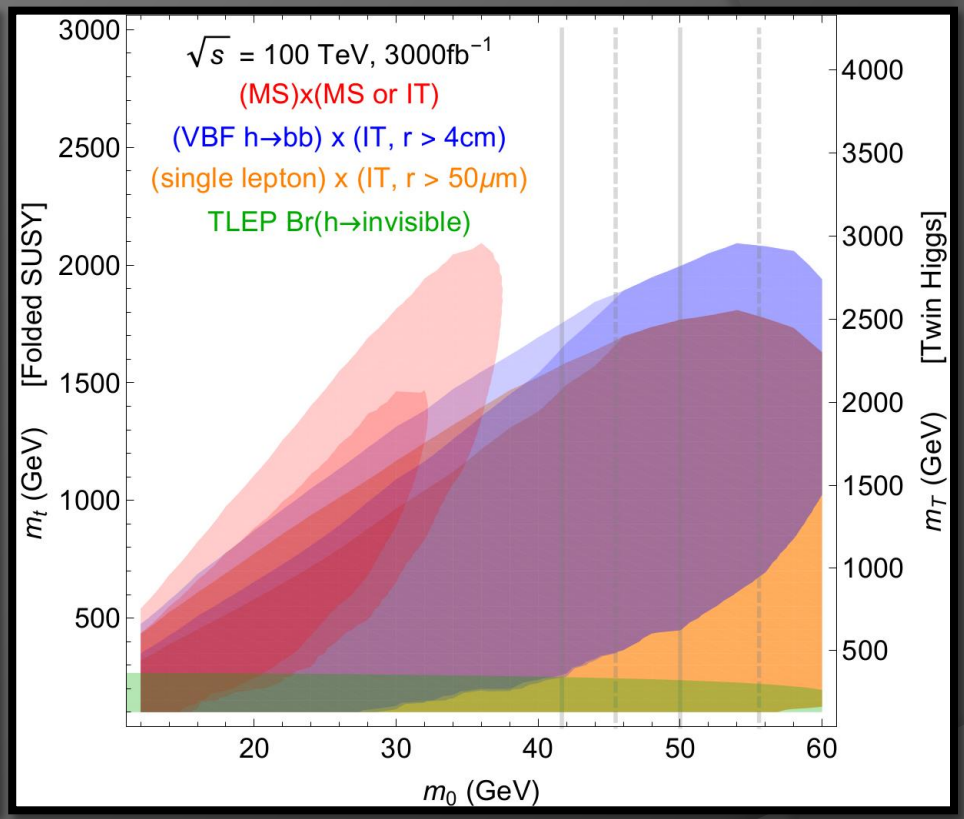
Limits are Conservative!

- Careful DV analysis from 1508.01522
  C. Csaki, E. Kuflik, S. Lomardo, O. Slone



High Luminosity & 100 TeV





Note the changing mass scale!
Reach > TeV!

Direct Production of Partners

- Folded SUSY and Quirky Little Higgs produced through Drell-Yan
- All produced through Higgs portal
- Quirky Bound States
  - Connected by a string of constant tension
  - Can annihilate to photons light leptons or glueballs, more displaced vertices

Conclusions

- The LHC can meaningfully constrain models of uncolored naturalness
- Some models affect Higgs couplings, but the LHC is unlikely to disfavor models with modest, not even 10%, tuning
  - Lepton Colliders can improve this
- Exotic Higgs decays to mirror glueballs can potentially extend this reach to ~ TeV
  - Need to resolve displaced vertices in the tracker
- Direct Production of partners may give complementary searches

Extra Credit

Direct Production

- If produced through a W, cannot decay to glue