Lone Higgs at the LHC

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MOTIVATION

The Hard Question

- Standard Model works wonders, but unitarity in $WW \rightarrow WW$ says we should see *something* below 1.2 TeV.
- If this *something* is a Higgs boson, the hierarchy problem motivates seeing something else.
- But what if we only see a Higgs boson? What then?
- That is a hard question to answer.

An Easier Question

We will instead attempt to answer an easier question:
Suppose we discover only a light Higgs boson after 10 fb^{-1}...

> From the absence of new resonances and the measurements of $\sigma(pp \to (gg \to hX))$ and $\text{Br}(h \to \gamma\gamma)$, can we identity this Higgs boson as that of the SM, the MSSM, LHT, or MUED?

SM	$\longrightarrow$	Standard Model
MSSM	$\longrightarrow$	Minimal Supersymmetric Standard Model
LHT	$\longrightarrow$	Littlest Higgs with T-parity
MUED	$\longrightarrow$	Minimal Universal Extra Dimensions

The Basic Strategy

We follow the steps

- Use the SM as the yard stick: express results as deviations from the SM.

- Examine regions where $B\sigma(gg \to h \to \gamma\gamma)$ differs 'significantly' from the SM.
- Examine regions consistent with not-seeing-anything-else.
- Find out if there is an overlap.

Measurement of Higgs Production and Decay

- Sources of uncertainty: luminosity, PDF, etc.
- Ratios of measurements reduce dependence on luminosity
- PDF-induced uncertainties may be reduced with correlations.

  P. M. Nadolsky *et al.*, arXiv:0802.0007 [hep-ph].
- With 100 fb^{-1} of data per experiment, $B\sigma$ can be determined to 10% to 15% for $100 < m_h(\text{GeV}) < 150$. (Statistical errors dominate: $\Delta\sigma/\sigma = \sqrt{N_S + N_B}/N_S$.)

  D. Zeppenfeld *et al.*, Phys. Rev. D **62**, 013009 (2000) [hep-ph/0002036]
- With only 10 fb^{-1}, we scale this up by $1/\sqrt{0.1} \sim 3$, and use deviations greater than 30% as 'significant'.

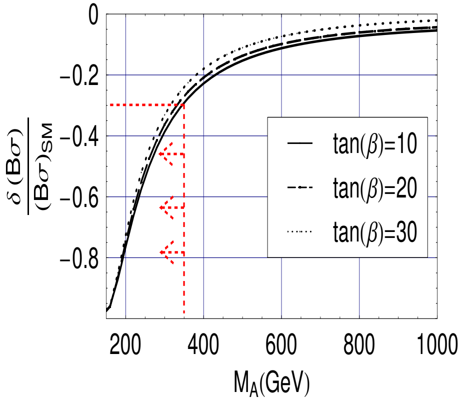
THE LONE HIGGS SCENARIOS

$B\sigma(gg \to h \to \gamma\gamma)$ in the MSSM

- In MSSM, $B\sigma(gg \to h \to \gamma\gamma)$ depends on the details of the s-top sector and is in general quite complicated.
- But lone Higgs scenario implies 'heavy' superpartners. (We assume no hiding of light particles.)
- LHC reach gives $M_{\tilde{Q}}$ and $M_{\tilde{g}}$ to be larger than 2 TeV (at 10 fb^{-1}), the s-top contributions to $B\sigma(gg \to h \to \gamma\gamma)$ decouple.
- $B\sigma(gg \to h \to \gamma\gamma)$ now dominantly depends on M_A and $\tan\beta$.

$\delta B\sigma(gg \to h \to \gamma\gamma)$ in the MSSM

Let's decouple s-fermions and neutralinos/charginos:
$\mu = M_{\tilde{w}} = M_{\tilde{\ell}} = 1$ TeV
$M_{\tilde{g}} = M_{\tilde{Q}} = 0.5A_t = 2.5$ TeV (*both* s-tops are heavy)

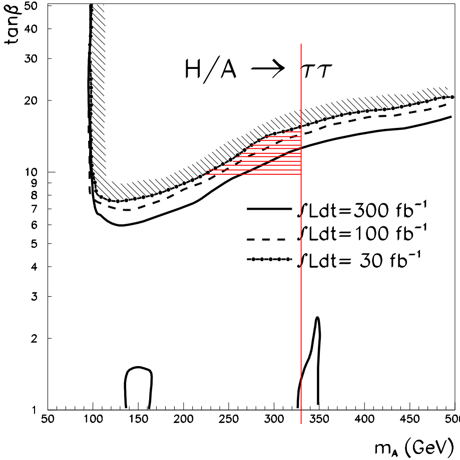


- $\mathrm{Br}(h \to \gamma\gamma)$ is always suppressed due to $\tan\beta$-enhanced $h\bar{b}b$ and $h\bar{\tau}\tau$ couplings when s-tops decouple.
- For $M_A < 350$ GeV, there is much suppression!

Lone Higgs Scenario in the MSSM

What are the allowed range of M_A and tan β?

ATLAS TDR, Volume II, Ch. 19



- The region $M_A < 350$ GeV is allowed if tan β is not too large!
- We have found one interesting lone Higgs scenario!

LHT Overview

- Littlest Higgs with T-parity protects Higgs mass by two independent global symmetries.

  N. Arkani-Hamed *et al.*, JHEP **0207**, 034 (2002)[hep-ph/0206021]

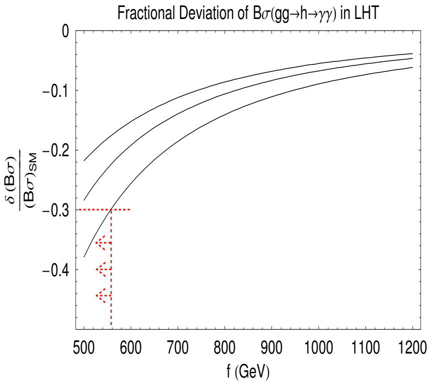
- Extended gauge and top sectors cancel quadratic corrections from SM at one-loop.
- T-parity gives loop-suppressed corrections to EW observables.
- Parameters: gf: scale of extended gauge sector; κf: scale of fermion partners; λf: scale of extended top sector.
- We need $f > 500$ GeV to be consistent with EWPT.

  J. Hubisz *et al.*, JHEP **0601**, 135 (2006) [hep-ph/0506042]

$\delta B\sigma(gg \to h \to \gamma\gamma)$ in LHT

In LHT, $\delta B\sigma(gg \to h \to \gamma\gamma)$ only depends on f, and dependences to the parameters in the extended top sector cancel.

C. R. Chen, K. Tobe and C. P. Yuan, Phys. Lett. B **640**, 263 (2006)[hep-ph/0602211]



- m_h= 110 (top line), 120, 130 GeV.
- Note the suppression as in the MSSM.
- To have a large deviation, we need small $f < 560$ GeV.

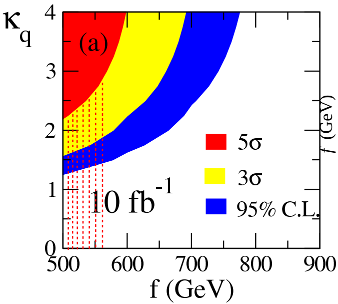
Lone Higgs Scenario in LHT

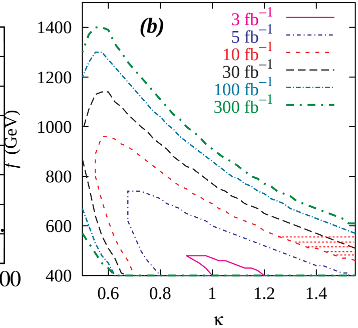
- Evade detection of T-odd gauge bosons with small κ_q.

  Q. H. Cao and C. R. Chen, Phys. Rev. D **76**, 075007 (2007) [arXiv:0707.0877]

- Evade detection T-odd quarks with large κ_q.

  D. Choudhury and D. K. Ghosh, JHEP **0708**, 084 (2007)[hep-ph/0612299]





There is a range of κ_q that gives a lone Higgs scenario.

MUED Overview

- Minimal Universal Extra Dimensions extends all SM particles to propagate in one additional, flat extra dimension, with R^{-1} and Λ as the only free parameters.

  T. Appelquist, H. C. Cheng and B. A. Dobrescu, Phys. Rev. D **64**, 035002 (2001)[hep-ph/0012100]

- Interesting dark matter candidate in the KK photon $B_{\mu}^{(1)}$.

  G. Servant and T. M. P. Tait, Nucl. Phys. B **650**, 391 (2003)[hep-ph/0206071]

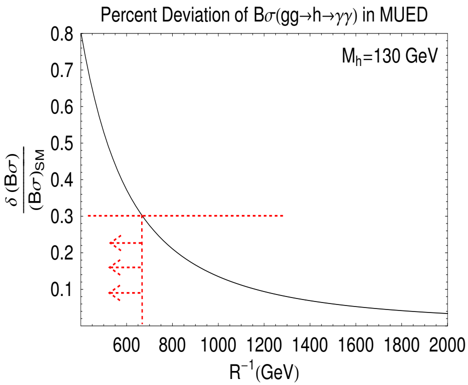
  K. Kong and K. T. Matchev, JHEP **0601**, 038 (2006)[hep-ph/0509119]

- The processes $gg \to h$ and $h \to \gamma\gamma$ now proceed through a tower of KK modes.

$\delta B\sigma(gg \to h \to \gamma\gamma)$ in MUED

Unlike MSSM or LHT, we always have an enhancement in $\delta B\sigma(gg \to h \to \gamma\gamma)$! (Additive effects of the KK modes.)

F. J. Petriello,JHEP **0205**, 003 (2002)[hep-ph/0204067]



Lone Higgs Scenario in MUED

- R^{-1} controls the mass scale of all the KK modes.
- Using MSSM reaches, $g^{(1)}$ and $q^{(1)}$ have to be roughly 2 TeV or heavier to evade discovery.
- This sets R^{-1} to be roughly 1.8 TeV, and the deviation in $B\sigma(gg \to h \to \gamma\gamma)$ is too small to be significant, even at the 10% level.

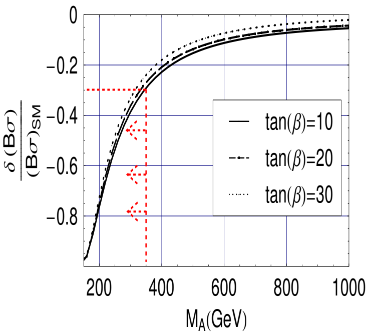
SYNTHESIS

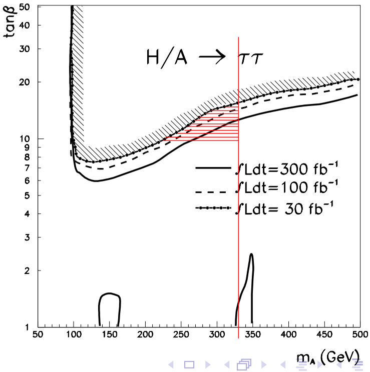
Putting it all together

- If we see a small deviation... then we may take this as a hint and cross our fingers.
- If we see a large enhancement, then is it MUED? Why haven't we seen the KK modes? Need to perform consistency checks.
- If we see a large suppression, then we favor LHT and MSSM over MUED.

Disentangling LHT and MSSM

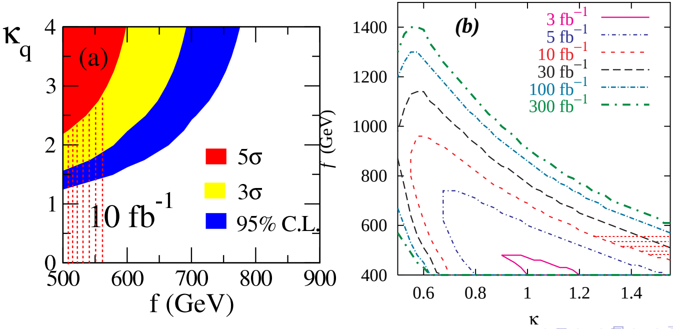
- We can use the amount of suppression as discriminant: the MSSM can give rise to larger suppression than LHT. In the case of extreme suppression (greater than 70%), we may find the heavy Higgs bosons with 100 fb^{-1}.





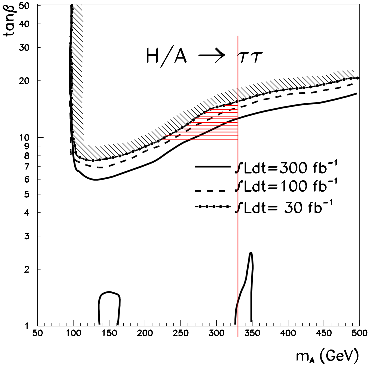
Disentangling LHT and MSSM - cont.

- With LHT, the gap in κ_q shrinks with further running, and we may discover W_H and/or Q_- for low enough value of f with more luminosity.
- For $f < 560$ GeV, this gap in κ_q disappears, and we should discover either W_H or Q_- with 100 fb^{-1} of data.



Disentangling LHT and MSSM - cont.

In a MSSM lone Higgs scenario large suppression $B\sigma(gg \to h \to \gamma\gamma)$, even with more luminosity we are not guaranteed to see new resonances, but we know where to look.



Summary and Outlook

- With large deviation in $B\sigma(gg \to h \to \gamma\gamma)$, we can go some distance in distilling traces of new physics.
- Such studies, though broad and general, serve a niche in the 'Inverse LHC Problem'.
- We can iterate this line of reasoning with more luminosity.
- If we see a Higgs boson, we also hope to see more than a Higgs boson, but Nature may not be so kind immediately, and we have to be prepared.

BACK-UP SLIDES

$\sigma(gg \to h)$ in the MSSM

- $\sigma(gg \to h) \propto \Gamma(h \to gg)$.
- In SM, only top-quark loop dominates.
- In MSSM with small s-top mixing, s-top loops interferes *constructively*.

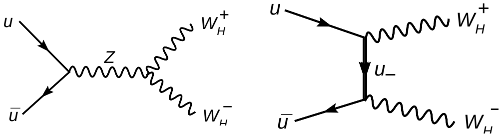
  R. V. Harlander and M. Steinhauser, JHEP **0409**, 066 (2004) [hep-ph/0409010]
- It is possible to obtain *destructive* interference (in an extreme case, a gluo-phobic Higgs) with large hierarchy between the two s-tops and significant mixing.

$\mathrm{Br}(h \to \gamma\gamma)$ in the MSSM

- In SM, top-quark loop and $W^{\pm}$ loop interfere *destructively*, and $W^{\pm}$ loop dominates.
- In MSSM with small s-top mixing, s-top loops interferes *constructively* with top-quark loop contribution (as in the case of $\sigma(gg \to h)$).
- This leads to a suppression in $\Gamma(h \to \gamma\gamma)$.
- The $h\bar{b}b$ and $h\bar{\tau}\tau$ couplings are $\tan\beta$-enhanced, leading to another suppression in $\mathrm{Br}(h \to \gamma\gamma)$

Evading discovery of W_H in LHT

- Two modes of $W_H^{\pm}$ pair-production (due to T-parity): s-channel Z^*-exchange, and t-channel Q_-^* exchange.



- The two diagrams *destructively* interfere, and Z-exchange dominates.
- With smaller κ_q, there is more destructive interference, and production rate drops.
- We can thus evade discovery of W_H with smaller κ_q.