Inventory of BSM Higgs results: theory

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LHC Higgs Cross Section Working Group
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Outline

Purpose of the benchmarks

$M = 125$ GeV:
(a) Non-SM-Higgs-like objects consistent with 2011 data
(b) SM-Higgs-like objects to try to distinguish using couplings

$M \neq 125$ GeV: Models to keep looking for

Discussion

Purpose of the benchmarks

Focus theory input to be most useful to experiments

- Provide well-defined targets for searches (e.g., spin-2 vs. spin-0)

- Find out the expt constraints on well-motivated BSM models

Theorists like to recast expt Higgs results to test their favourite models; better to give expts what they need to do the full likelihood fit properly!

Feed into Light Mass Higgs subgroup:
constrained scenarios for Higgs coupling extraction fits

unconstrained fit has too many free parameters for early data

$M = 125$ GeV: Non-SM-Higgs-like objects

-Spin-2

-Spin-0 CP-odd (pseudoscalar)

$M = 125$ GeV: Non-SM-Higgs-like objects: Spin-2

Test spin of Higgs-like object using angular distributions.

Diphoton signal: $gg \to X \to \gamma\gamma$ and/or $q\bar{q} \to X \to \gamma\gamma$ and/or VBF?

Spin-0: distribution of X decay products is flat in $\cos\theta^*$

Spin-2: distribution of X decay products is quartic in $\cos\theta^*$

Spin-2 must be parity-even in coupling to $f\bar{f}$: $\sigma^{\mu\nu}$ tensor structure.

Spin-1: decay of on-shell spin-1 object to $\gamma\gamma$ is forbidden by Yang's theorem.

Q: what is needed from theorists?

Spin-2 $X \to ZZ^* \to 4f$ off-shell?

$M = 125$ GeV: Non-SM-Higgs-like objects: Pseudoscalar

Models with two or more Higgs doublets contain a physical pseudoscalar (CP-odd Higgs) — e.g., A^0 in MSSM.
$gg \to A^0 \to \gamma\gamma$ can reproduce SM Higgs diphoton rate.

- 2HDM pseudoscalar (Type-I, -II, etc.)
- techni-pion (from technicolor)
- top-pion (from topcolor-assisted technicolor)
- pseudoscalar from condensing 4th generation
- more generic benchmark?

A^0WW, A^0ZZ couplings are loop-induced: $\ll$ SM.
$\to$ look for absence of VBF $\to A^0$ and $A^0 \to WW/ZZ$.
same feature appears for non-vev-carrying CP-even H^0 in 2HDM.

CP-odd nature: coupling in Lagrangian is $A^0 F^{\mu\nu} \widetilde{F}_{\mu\nu}$ (vs. $h^0 F^{\mu\nu} F_{\mu\nu}$).
Test CP-odd coupling from angular dist'n of converted photons?
Q: are angular distributions the same as for CP-odd $A^0 \to ZZ \to 4f$?

Q: are there any other handles, e.g., τ polarization?

$M = 125$ GeV: SM-Higgs-like objects

- 4th generation SM [by now excluded??]

- Fermiophobic, gaugephobic, top-phobic, bottom-phobic, etc.

- light dilaton

- Composite Higgs/SILH parameterization

- SM Higgs mixed with a singlet
- SM Higgs with invisible decays to dark matter
- Type-I 2HDM
- Type-II, lepton-specific, flipped 2HDMs
- "democratic" 3HDM

- Benchmark with enhanced/unequal WW/ZZ couplings?

$M = 125$ GeV: SM-Higgs-like objects: Strategy

Most straightforward extension of existing SM Higgs analysis is introducing rate-scaling factors to apply to existing signal shape templates.

SM Higgs search already uses overall scaling factor $\mu \equiv \sigma/\sigma_{\text{SM}}$.

Most features of BSM SM-Higgs-like models can be captured by this procedure.

Exception is anything that modifies distributions, like new production modes, or non-SM decays that contaminate signal or background shapes.

Possible meeting-point for theory and experiment:
Do the likelihood fit with larger sets of scaling factors μ_i.
Model predictions $\rightarrow$ a few free parameters that control μ_i.

Specific models more constrained than completely-general fit.

Can actually say something useful before full Light Mass Higgs fit is achieved.

$M = 125$ GeV: SM-Higgs-like objects: Models

1) 4th generation SM

- All Higgs couplings to SM particles are the same as in SM.

- New contributions in the gg, $\gamma\gamma$ loops from 4th-gen fermions: predicted with no free parameters (except for small dependence on 4th-gen masses).

Generalize this: all tree-level couplings same as SM, but new physics in loops: 2 free parameters,

$$R_g = \Gamma(h \to gg)/\Gamma^{\mathrm{SM}}(h \to gg) = \sigma(gg \to h)/\sigma^{\mathrm{SM}}(gg \to h),$$
$$R_\gamma = \Gamma(h \to \gamma\gamma)/\Gamma^{\mathrm{SM}}(h \to \gamma\gamma).$$

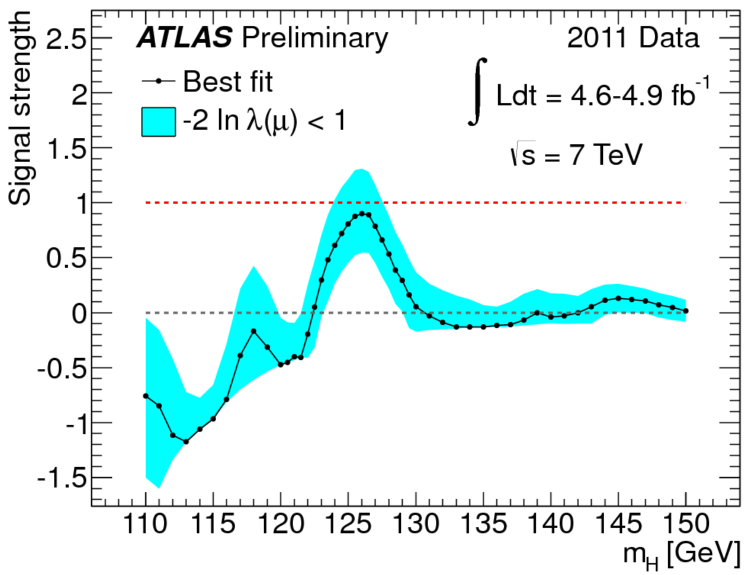
Fit these 2 free parameters $\to$ test for new physics only in loops.

4th gen: invisible decay to 4th-gen neutrinos also possible: reduces rate to all visible final states through invisible component of Higgs total width.

$M = 125$ GeV: SM-Higgs-like objects: Models

2) SM Higgs mixed with a singlet:
Overall 1-parameter scaling of all couplings by $0 \leq a \leq 1$.
BRs stay unchanged; rates scaled by $a^2 \equiv \mu = \sigma/\sigma_{\rm SM}$

- SM Higgs with unobserved/invisible decays (e.g. to dark matter) fits into the same framework: production rates unchanged; BRs scaled by $\Gamma_{\rm SM}/(\Gamma_{\rm SM} + \Gamma_{\rm new}) \equiv \mu = \sigma/\sigma_{\rm SM}$
<u>unless</u> new decay mode is picked up by SM signal/background selections and modifies kinematic shapes.



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$M = 125$ GeV: SM-Higgs-like objects: Models

3) Light dilaton: pseudo-goldstone boson of spontaneously-broken scale invariance (EWSB from conformal strong-dynamics theory)

Phenomenologically: a hybrid of previous two frameworks.

- All tree-level SM couplings scaled by a common factor $a \equiv v/f$.

- New stuff in gg, $\gamma\gamma$ loops from conformal-breaking scale: large loop scaling factors R_g, R_γ, predicted by model.
  $R_g = 140 \times (v/f)^2$, $R_\gamma = 2.43 \times (v/f)^2$ for $M_\chi = 125$ GeV

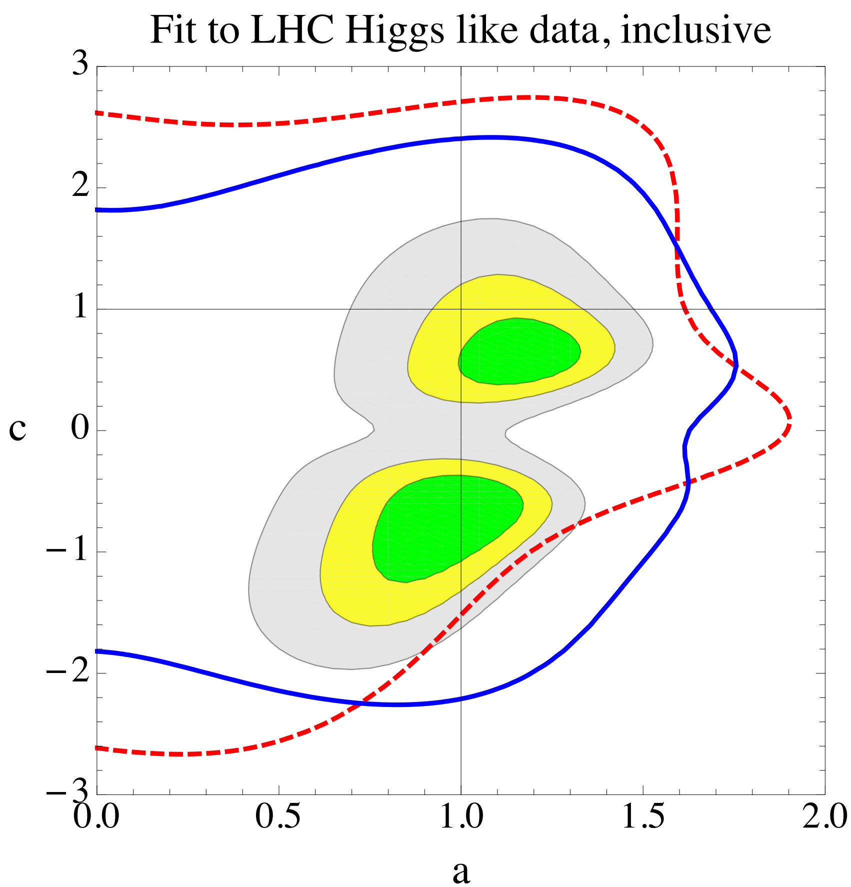
Only 1 free parameter, $a \equiv v/f$. observed $\gamma\gamma$ rate $\to f \simeq 900$ GeV

No SM-like limit: VBF suppressed, $WW/\gamma\gamma \simeq 0.5\times$ SM

Could generalize framework by allowing free R_g, R_γ.
(Unique prediction above relies on assumption that SM gauge interactions are part of the conformal sector at higher energies.)

$M = 125$ GeV: SM-Higgs-like objects: Models

4) Effective Lagrangian for minimal scalar coupled to EWSB: (appears in composite-Higgs models): 2 free parameters
hWW, hZZ couplings scaled by a, $h\bar{f}f$ couplings scaled by c



Fermiophobic is $c = 0$, $a = 1$
Gaugephobic is $c = 1$, $a = 0$

Type-I 2HDM: almost the same.
$a = \sin(\beta - \alpha)$
$c = \cos\alpha / \sin\beta$

H^+ gives small additional contribution to $h \to \gamma\gamma$ loop

Espinosa, Grojean, Mühlleitner & Trott, 1202.3697 [hep-ph]

$M = 125$ GeV: SM-Higgs-like objects: Models

5) Type-II, lepton-specific, "flipped" 2HDMs:

2 free parameters plus small contribution of H^+ to $h \to \gamma\gamma$ loop

hWW, $hZZ \sim a = \sin(\beta - \alpha)$

Type-II: $h\bar{t}t \sim c_1 = \cos\alpha/\sin\beta$; $h\bar{b}b$, $h\tau\tau \sim c_2 = -\sin\alpha/\cos\beta$

has a top-phobic limit

Leptonic: $h\bar{t}t$, $h\bar{b}b \sim c_1$; $h\tau\tau \sim c_2$ has a tau-phobic limit

Flipped: $h\bar{t}t$, $h\tau\tau \sim c_1$; $h\bar{b}b \sim c_2$ has a bottom-phobic limit

Can expand framework by mixing h with inert singlet or doublet, or generalizing to $h\bar{t}t \sim c_1$, $h\bar{b}b \sim c_2$, $h\tau\tau \sim c_3$.

see, e.g., Barger, Logan & Shaughnessy, PRD79, 115018 (2009)

$M \neq 125$ GeV: Models to keep looking for

It's nice to have a no-parameter model as a target, but there are not a lot of these.

- 4th-generation SM [ruled out??]

1-parameter models with suppressed rates to WW, ZZ:

- SM-like Higgs mixed with a singlet

  the orthogonal combination has to be somewhere...
- SM-like Higgs with invisible decays to dark matter
- Dilaton with higher conformal-breaking scale

  $\rightarrow$ weaker couplings to SM

Other models:

- Top-Higgs with decays to top-pions
- General 2HDM frameworks

  coupling sum rules of h and H could provide an ultimate exclusion target

Discussion

- Plans to define our benchmarks

- What needs to be provided from the theory side

- ...