Inventory of BSM Higgs models: theory

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Outline

Purpose of the benchmark models

$M = 125$ GeV:

(a) Non-SM-Higgs-like objects consistent with 2011(-2012?) data

(b) SM-Higgs-like objects with modified couplings

$\rightarrow$ interplay with Light mass Higgs subgroup

$M \neq 125$ GeV: Models to keep looking for
(Q: when should we stop looking at those?)

Discussion

Purpose of the benchmark models

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)

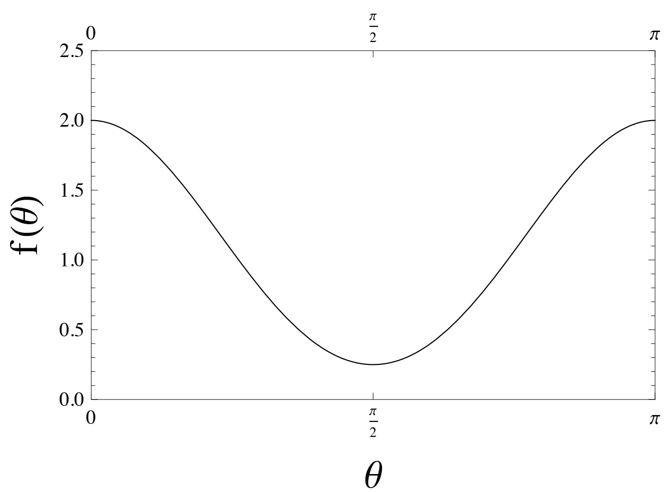
$M = 125$ GeV: Non-SM-Higgs-like objects: Spin-2

Test spin of Higgs-like object using angular distributions.

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

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

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

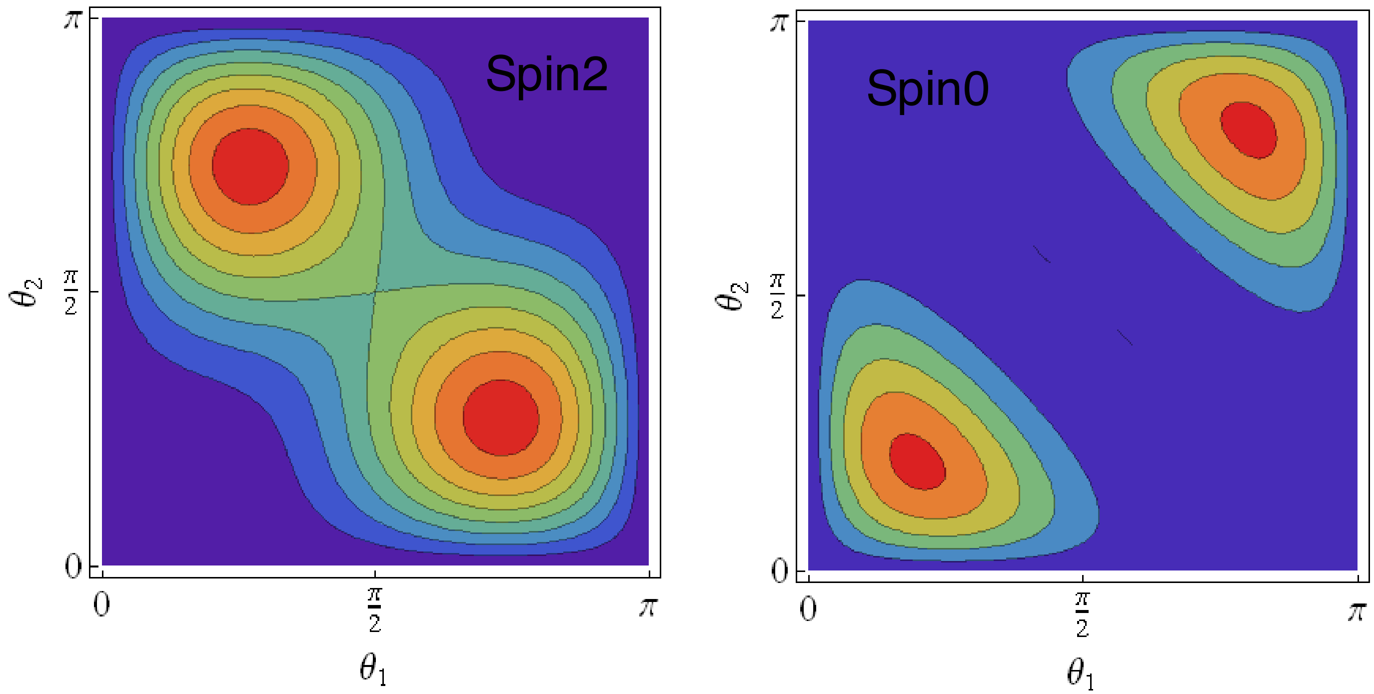


$$\frac{d\sigma}{d\Omega} \propto \frac{1}{4} + \frac{3}{2}\cos^2\theta + \frac{1}{4}\cos^4\theta$$

see, e.g., Ellis & Hwang `arXiv:1202.6660`

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

2) $gg \to X \to W^+W^- \to l^+l^-\bar{\nu}\nu$



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 $X \to ZZ^* \to 4f$, invariant mass distribution, 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? (custodial breaking?)

$M = 125$ 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.

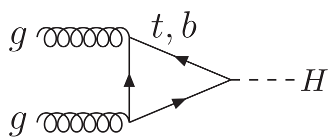
Exception is anything that modifies distributions, like new production modes, or non-SM decays that contaminate signal or background shapes.

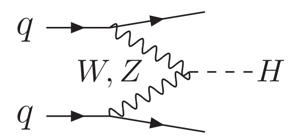
Possible meeting-point for theory and experiment:
Do the likelihood fit with larger sets of scaling factors μ_i.
Model predictions $\rightarrow$ a few free parameters that control μ_i.

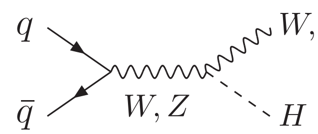
Specific models more constrained than completely-general fit.

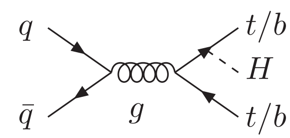
Can actually say something useful before full Light Mass Higgs fit is achieved.

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









$\frac{\sigma_{NLO}}{\sigma^{SM}_{NLO}}$ | c^2 | a^2 | a^2 | c^2

The QCD NLO rescale trivially in the flavor universal limit. Not the EW NLO

$$\Gamma(H \to f\bar{f}) = c^2\, \Gamma^{SM}(H \to f\bar{f}),$$
$$\Gamma(H \to VV) = a^2\, \Gamma^{SM}(H \to VV),$$
$$\Gamma(H \to gg) = c^2\, \Gamma^{SM}(H \to gg),$$
$$\Gamma(H \to \gamma\gamma) = \frac{(cI_\gamma + aJ_\gamma)^2}{(I_\gamma + J_\gamma)^2}\Gamma^{SM}(H \to \gamma\gamma),$$

$\simeq (1.26\,a - 0.26\,c)^2$ for m_h=125GeV

Q: correlations among the individual channels?

Q: combination of individual rescaled channels?

Q: combination of 7 and 8 TeV data sets?

$M = 125$ 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,

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

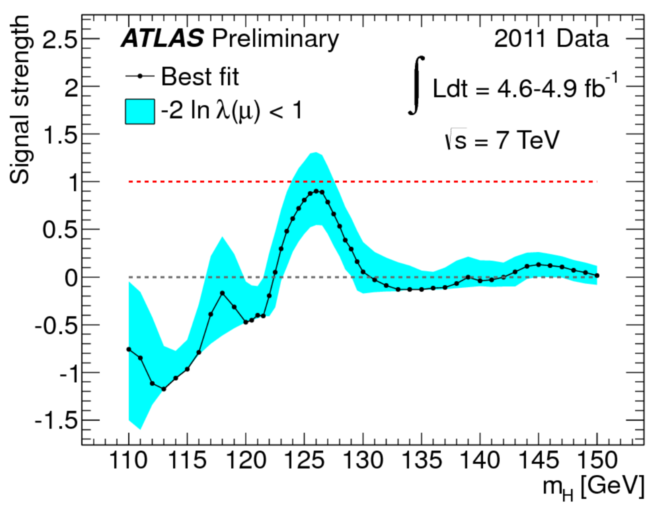
Fit these 2 free parameters $\rightarrow$ test for new physics only in loops.

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

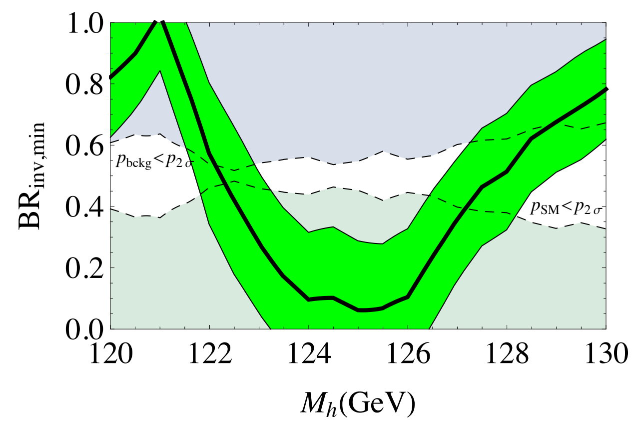
$M = 125$ GeV: SM-Higgs-like objects: Models

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 $a^2 \equiv \mu = \sigma/\sigma_{\mathrm{SM}}$

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



ATLAS-CONF-2012-019



Espinosa et al to appear

$M = 125$ 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 $\rightarrow f \simeq 900$ 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

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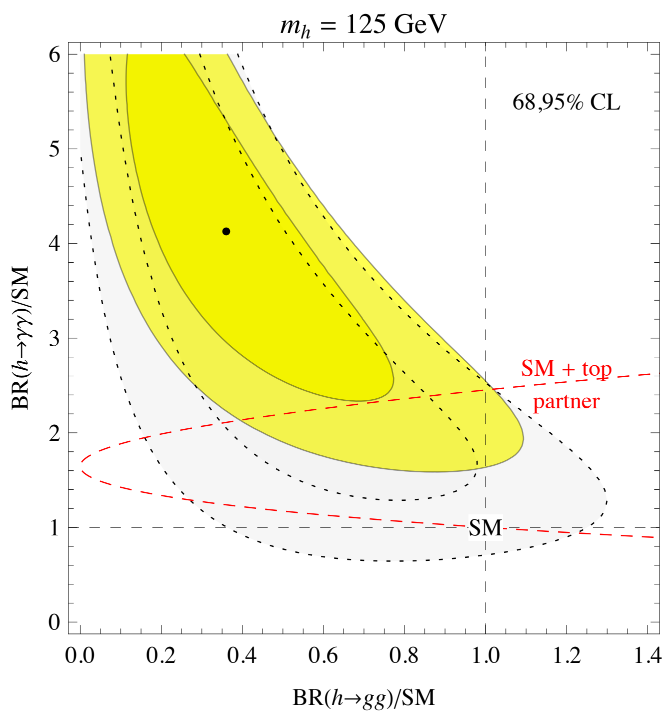
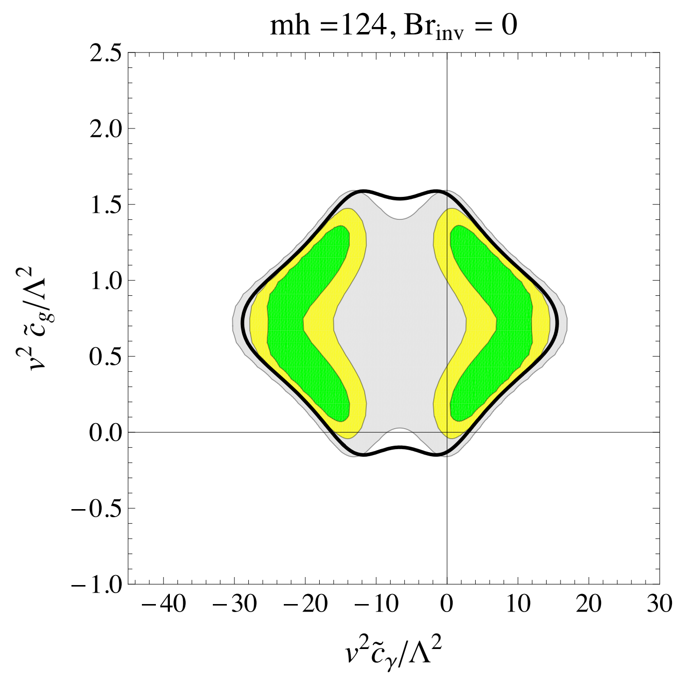
(Unique prediction above relies on assumption that SM gauge interactions are part of the conformal sector at higher energies.)

$$\mathcal{L} = -\frac{\tilde{c}_\gamma e^2}{32\pi^2\Lambda^2} H^\dagger H \, F_{\mu\nu}F^{\mu\nu} - \frac{\tilde{c}_g g_s^2}{32\pi^2\Lambda^2} H^\dagger H \, G^a_{\mu\nu}G^{a\,\mu\nu}$$



Giardino et al arXiv:1203.4254

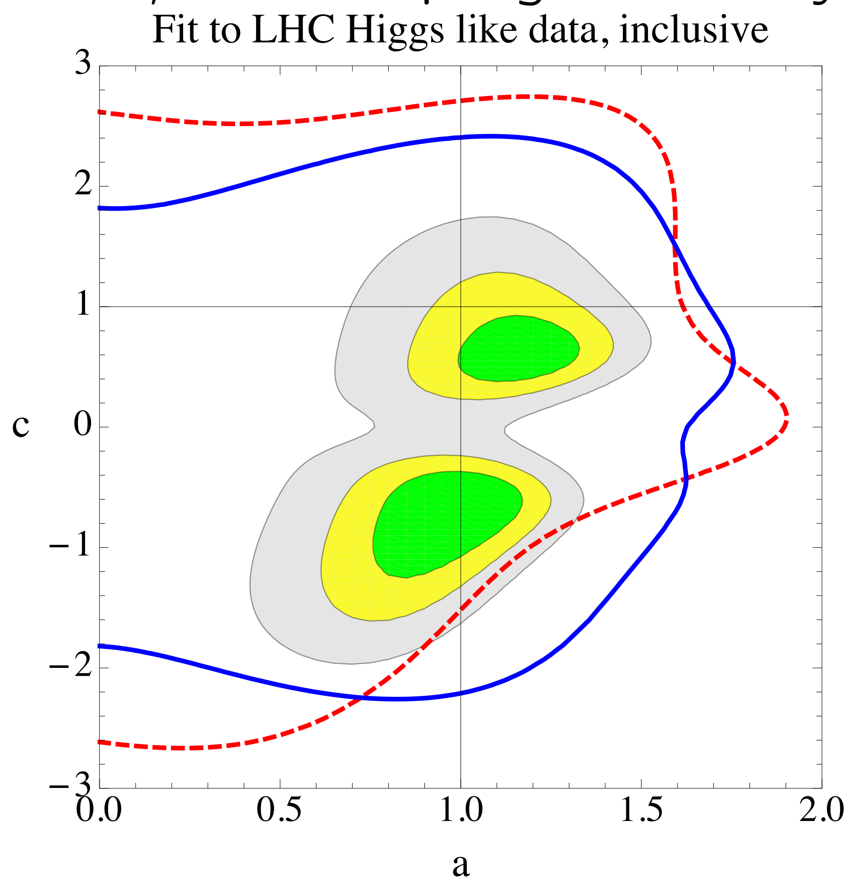


Espinosa et al to appear

$M = 125$ 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 benchmark models

– What needs to be provided from the theory side

– . . .