Extending the Higgs sector: an extra singlet

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based on S.I. Godunov, A.N.Rozanov, M.I.Vysotsky and E.V. Zhemchugov, arXiv:1503.01618.

The pattern of fundamental particles we have is rather asymmetric:

$4 + 8 = 12$ vector bosons, many quarks and leptons with spin $1/2$

and only one scalar particle h(125).

Why not to introduce more scalar particles?

The simplest extension of SM higgs sector is one real scalar field.

What for? First order EW phase transition (BAU), the bridge between SM and Dark Matter,...

We introduce an extra scalar to enhance double h(125) production at LHC.

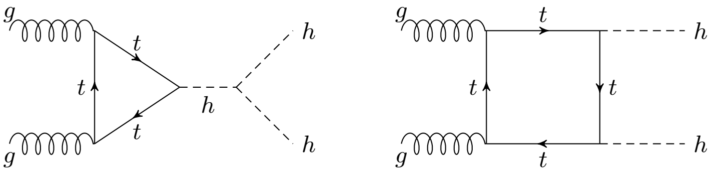
h is found; what next?

After h (125 GeV) discovery the next step to check the Standard Model (SM) is to measure higgs self-coupling, which determines the shape of higgs potential.

Deviations of triple and quartic higgs couplings from SM predictions would mean the existence of New Physics.

Triple h coupling can be measured at LHC in double higgs production.

2h in SM



Not easy, at $\sqrt{s} = 14$ TeV $\sigma^{NNLO}(pp \to hh) = 40$ fb (D. de Florian, J. Mazzitelli)

Only at HL-LHC 2h production will be observed.

Our main goal: NP leading to 2h production observability at Run 2 LHC.

The model

Φ - isodoublet, X - isosinglet, potential:

$$V(\Phi, X) = -\frac{m_\Phi^2}{2}\Phi^\dagger\Phi + \frac{m_X^2}{2}X^2 + \frac{\lambda}{2}(\Phi^\dagger\Phi)^2 + \mu\Phi^\dagger\Phi X,$$

$$\Phi = \begin{pmatrix} \phi^+ \\ \frac{1}{\sqrt{2}}(v_\Phi + \phi + i\eta) \end{pmatrix}, \qquad X = v_X + \chi,$$

$$\begin{aligned} h &= \phi\cos\alpha + \chi\sin\alpha, \\ H &= -\phi\sin\alpha + \chi\cos\alpha. \end{aligned}$$

Bounds from h production at LHC

$$pp \to h \to f_i,$$

$$\mu_i \equiv \frac{\sigma_{pp\to h} \cdot \Gamma_{h\to f_i}/\Gamma_h}{(\sigma_{pp\to h} \cdot \Gamma_{h\to f_i}/\Gamma_h)_{\mathsf{SM}}}.$$

$$\mu_i = \cos^2\alpha,$$

ATLAS: $\mu = 1.30^{+0.18}_{-0.17}$,

CMS: $\mu = 1.00^{+0.14}_{-0.13}\left[\pm 0.09(\text{stat.})^{+0.08}_{-0.07}(\text{theor.}) \pm 0.07(\text{syst.})\right]$

EWPO fit of the Standard Model, $m_h = 125$ GeV

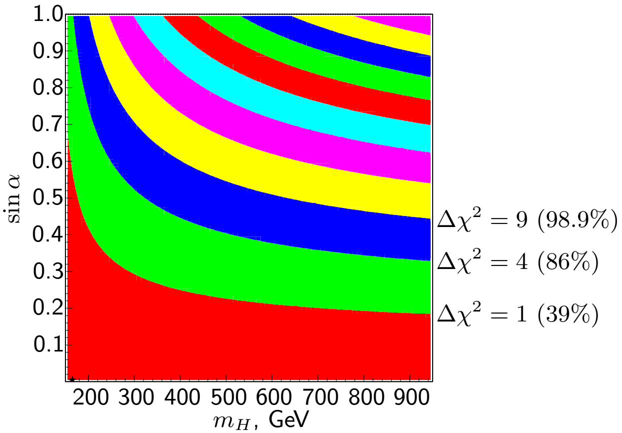
Observable	Experimental value	Standard Model	Pull
Γ_Z, GeV	$2.4952(23)$	$2.4966(14)$	-0.5895
σ_h, nb	$41.541(37)$	$41.475(14)$	1.7746
R_l	$20.771(25)$	$20.744(18)$	1.0831
A^l_{FB}	$0.0171(10)$	$0.0165(2)$	0.6572
A_τ	$0.1439(43)$	$0.1484(7)$	-1.0452
R_b	$0.2163(7)$	$0.2158(0)$	0.7699
R_c	$0.1721(30)$	$0.1722(0)$	-0.0277
A^b_{FB}	$0.0992(16)$	$0.1040(5)$	-3.0303
A^c_{FB}	$0.0707(35)$	$0.0744(4)$	-1.0565
$s^2_l\ (Q_{\mathsf{FB}})$	$0.2324(12)$	$0.2313(1)$	0.8771
A_{LR}	$0.1514(22)$	$0.1484(7)$	1.3822
A_b	$0.923(20)$	$0.9349(1)$	-0.5941
A_c	$0.670(27)$	$0.6685(3)$	0.0567
M_W, GeV	$80.3846(146)$	$80.3725(67)$	0.8322
m_t, GeV	$173.24(95)$	$174.32(89)$	-1.1370
$1/\bar{\alpha}$	$128.954(48)$	$129.023(37)$	-1.4378

$$\chi^2/n_{\mathsf{d.o.f.}} = 19.6/13.$$

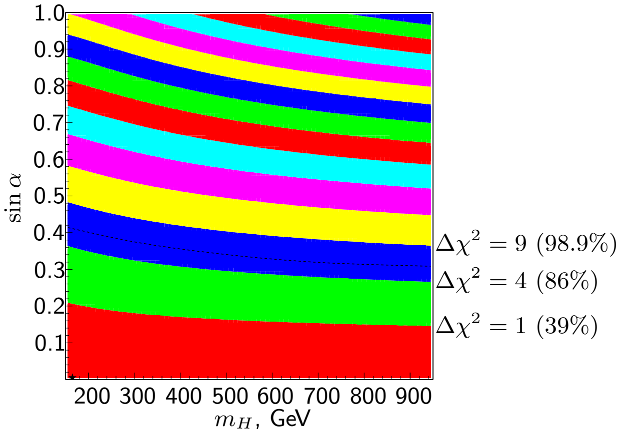
EWPO in case of extra singlet

$$H_i(h) \to \cos^2\alpha \; H_i(h) + \sin^2\alpha \; H_i(H), \quad h = m_h^2/m_Z^2, \;\; H = m_H^2/m_Z^2.$$

Bounds from electroweak precision observables.

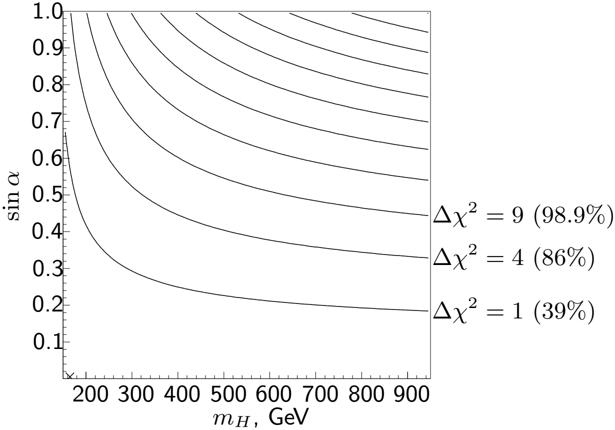


EWPO + μ_i

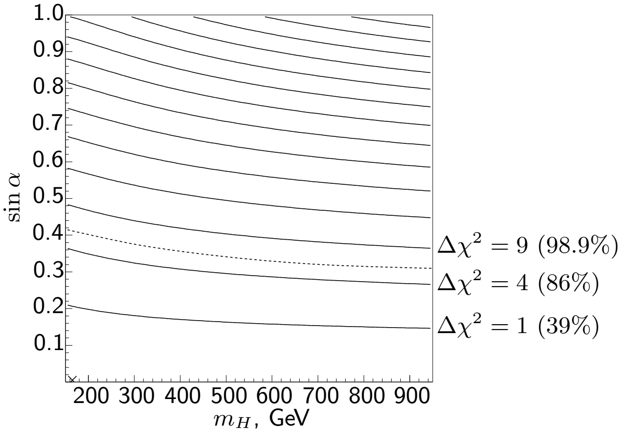


Bounds from both electroweak precision observables and signal strength measurements.

Bounds from electroweak precision observables.



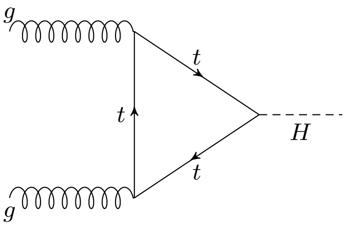
EWPO + μ_i



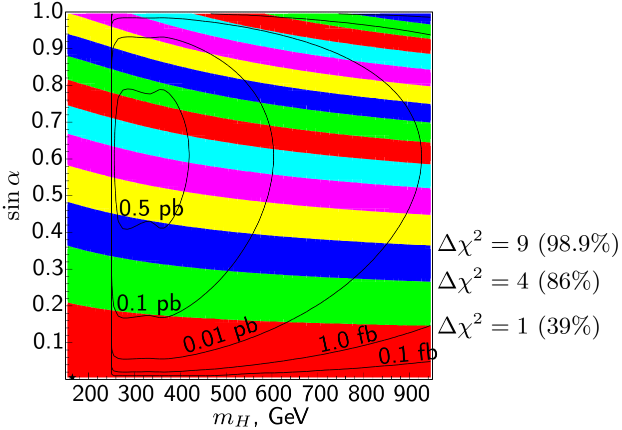
Bounds from both electroweak precision observables and signal strength measurements.

2h production

$$\begin{bmatrix} h \\ H \end{bmatrix} = \begin{bmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} \varphi \\ \delta \end{bmatrix}$$

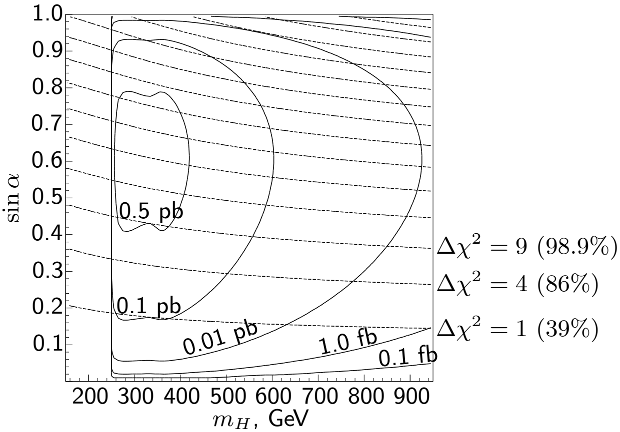


$H \longrightarrow 2h$ decay contributes to 2h production.



Contour plot of $\sigma(pp \to H \to hh)$ for $\sqrt{s} = 14$ TeV.

2h production



Contour plot of $\sigma(pp \to H \to hh)$ for $\sqrt{s} = 14$ TeV.

Looking for H at LHC

"Golden mode", $H \longrightarrow ZZ$.

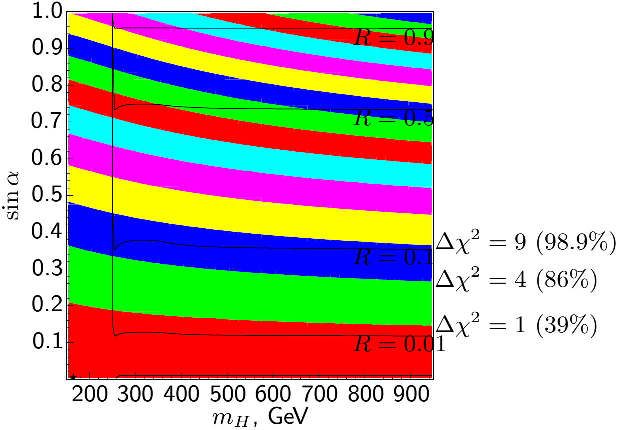
Both ATLAS and CMS are looking for H in this decay mode. Recent ATLAS paper:

arXiv:1507.05930 Date: 21 Jul 2015

Title: Search for an additional, heavy Higgs boson in the

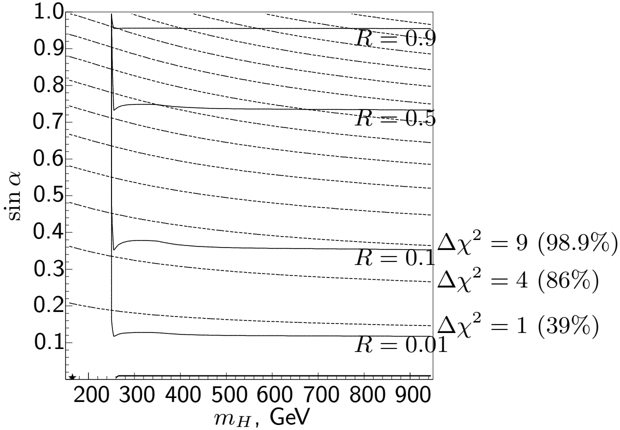
$H \to ZZ$ decay channel at $\sqrt{s} = 8$ TeV in pp

$H \longrightarrow ZZ$



Contour plot of $R \equiv \frac{\sigma(pp \to H) Br(H \to ZZ)}{(\sigma(pp \to h) Br(h \to ZZ))_{\mathbf{SM}}}$.

$H \longrightarrow ZZ$



Contour plot of $R \equiv \frac{\sigma(pp\to H)Br(H\to ZZ)}{(\sigma(pp\to h)Br(h\to ZZ))_{\mathrm{SM}}}$.

Conclusions

- Bounds on mixing angle α in case of extra singlet are obtained;
- Cross section of H production at Run 2 can reach picobarn values;
- Extra scalar isosinglet allows to enhance double higgs production making it observable at Run 2;
- Run 2: discovery of NP, or... much stronger bounds...