

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.

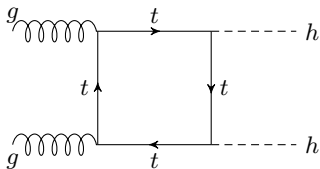
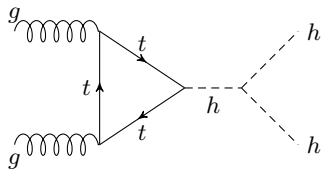
What for? First order EW phase transition (BAU), the bridge between SM and Dark Matter,...

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

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.



Not easy, at $\sqrt{s} = 14$ TeV $\sigma^{NNLO}(pp \rightarrow hh) = 40$ 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.

Φ - isodoublet, X - isosinglet, potential:

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

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

$$h = \phi \cos \alpha + \chi \sin \alpha,$$

$$H = -\phi \sin \alpha + \chi \cos \alpha.$$

$$pp \rightarrow h \rightarrow f_i,$$

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

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

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

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

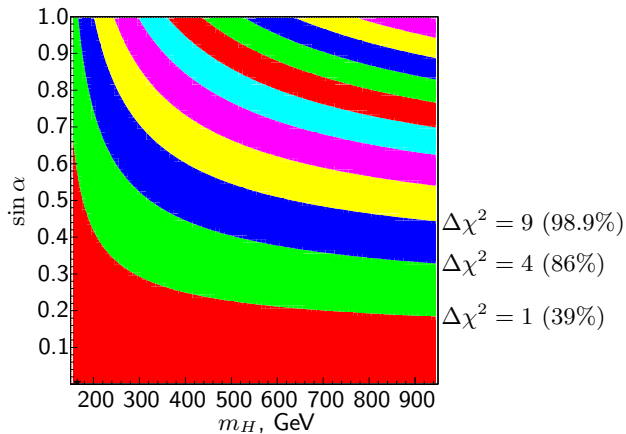
EWPO fit of the Standard Model, $m_h = 125$ GeV

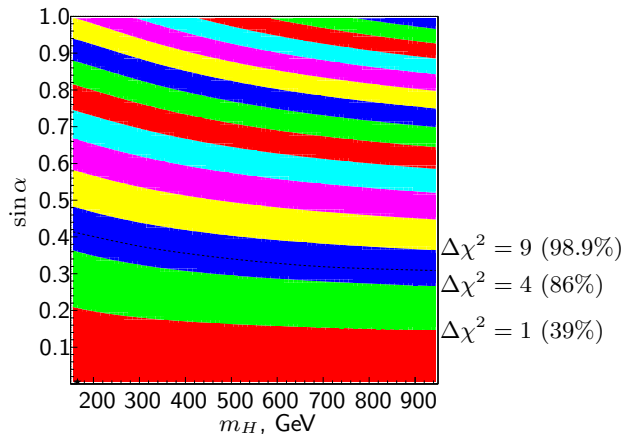
| Observable | Experimental value | Standard Model | Pull |
|------------------------|--------------------|----------------|---------|
| Γ_Z , GeV | 2.4952(23) | 2.4966(14) | -0.5895 |
| σ_h , nb | 41.541(37) | 41.475(14) | 1.7746 |
| R_l | 20.771(25) | 20.744(18) | 1.0831 |
| A_{FB}^l | 0.0171(10) | 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_{FB}^b | 0.0992(16) | 0.1040(5) | -3.0303 |
| A_{FB}^c | 0.0707(35) | 0.0744(4) | -1.0565 |
| $s_l^2(Q_{\text{FB}})$ | 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 |

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

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

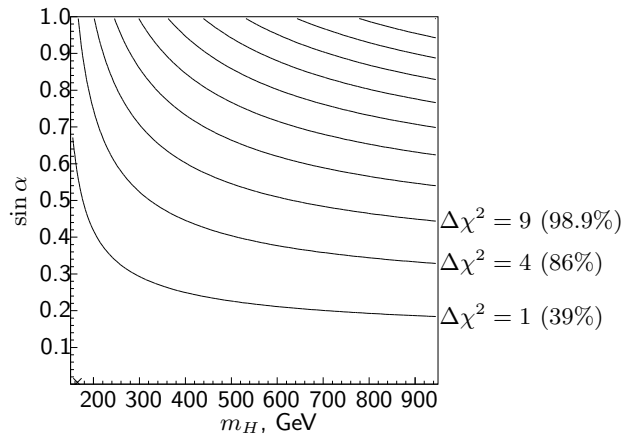
Bounds from electroweak precision observables.

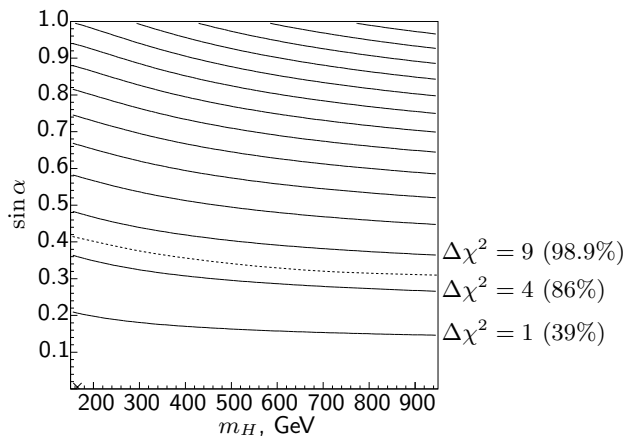




Bounds from both electroweak precision observables and signal strength measurements.

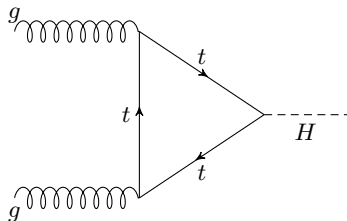
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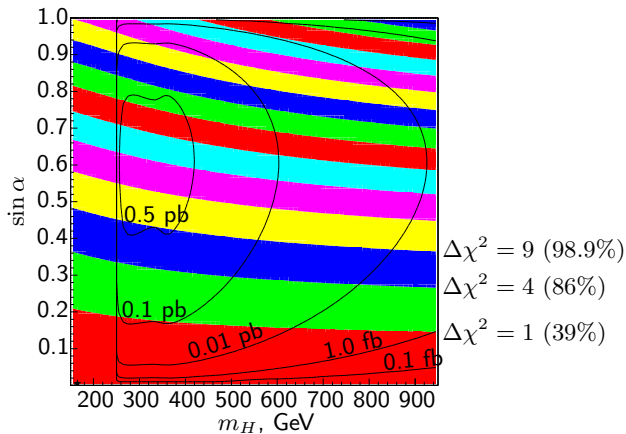


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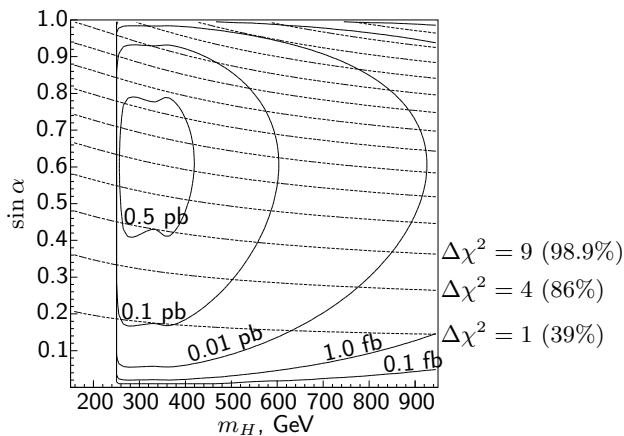
$$\begin{bmatrix} h \\ H \end{bmatrix} = \begin{bmatrix} \cos \alpha & \sin \alpha \\ -\sin \alpha & \cos \alpha \end{bmatrix} \begin{bmatrix} \varphi \\ \delta \end{bmatrix}$$



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



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



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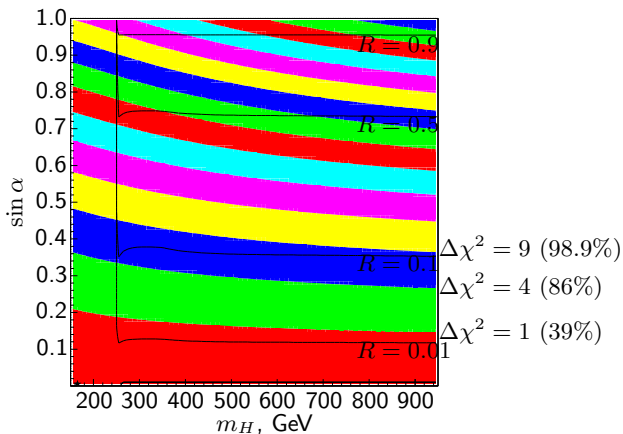
“Golden mode”, $H \rightarrow ZZ$.

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

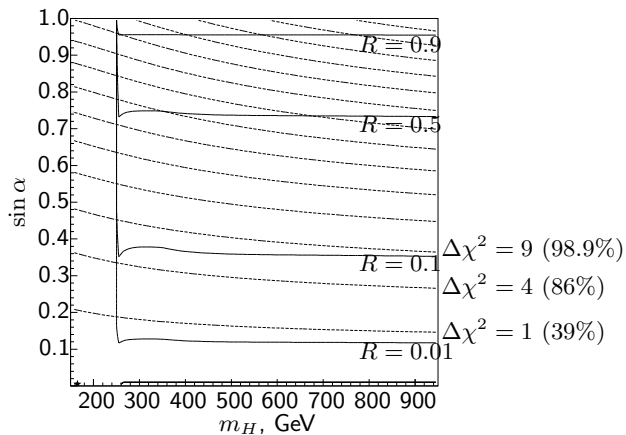
arXiv:1507.05930 Date: 21 Jul 2015

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

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



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



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

- 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...