# Constraining anomalous Higgs interactions

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# Overview

Recently announced discovery of a $\simeq$125 GeV Higgs boson at the CERN LHC opens a new era in particle physics. The pressing questions now are related to the properties of this new observed state, like its spin and couplings, in order to extend our knowledge of the EWSB sector.

- Assume Higgs boson $SU(2)_L$ doublet (no additional light states $\rightarrow$ e.g. pseudo–Goldstone boson of a larger broken global symmetry).
- Consider the most general dimension–six effective Lagrangian invariant under linear $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ transformations to describe the interactions of the Higgs boson with gauge bosons, as well as with the gluons:

$$\mathcal{L}_{\rm eff} = \sum_n \frac{f_n}{\Lambda^2} \mathcal{O}_n$$

- Combine different data from Tevatron and LHC channels (combine different production mechanisms and decay channels).
- Extract conclusions on the different Higgs couplings.

# Effective Lagrangian

$$\mathcal{O}_{GG} = \Phi^\dagger \Phi \, G^a_{\mu\nu} G^{a\mu\nu} \;, \qquad \mathcal{O}_{WW} = \Phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \Phi \;, \qquad \mathcal{O}_{BB} = \Phi^\dagger \hat{B}_{\mu\nu} \hat{B}^{\mu\nu} \Phi \;,$$

$$\mathcal{O}_{BW} = \Phi^\dagger \hat{B}_{\mu\nu} \hat{W}^{\mu\nu} \Phi \;, \qquad \mathcal{O}_{W} = (D_\mu \Phi)^\dagger \hat{W}^{\mu\nu} (D_\nu \Phi) \;, \qquad \mathcal{O}_{B} = (D_\mu \Phi)^\dagger \hat{B}^{\mu\nu} (D_\nu \Phi) \;,$$

$$\mathcal{O}_{\Phi,1} = (D_\mu \Phi)^\dagger \, \Phi^\dagger \Phi \, (D^\mu \Phi) \;, \qquad \mathcal{O}_{\Phi,2} = \frac{1}{2} \partial^\mu \left(\Phi^\dagger \Phi\right) \partial_\mu \left(\Phi^\dagger \Phi\right) \;.$$

Unitary gauge:

$$\begin{aligned}
\mathcal{L}^{\rm HVV}_{\rm eff} &= g_{Hgg} \; H G^a_{\mu\nu} G^{a\mu\nu} + g_{H\gamma\gamma} \; H A_{\mu\nu} A^{\mu\nu} + g^{(1)}_{HZ\gamma} \; A_{\mu\nu} Z^\mu \partial^\nu H + g^{(2)}_{HZ\gamma} \; H A_{\mu\nu} Z^{\mu\nu} \\
&+ g^{(1)}_{HZZ} \; Z_{\mu\nu} Z^\mu \partial^\nu H + g^{(2)}_{HZZ} \; H Z_{\mu\nu} Z^{\mu\nu} + g^{(3)}_{HZZ} \; H Z_\mu Z^\mu \\
&+ g^{(1)}_{HWW} \; \left(W^+_{\mu\nu} W^{-\,\mu} \partial^\nu H + \text{h.c.}\right) + g^{(2)}_{HWW} \; H W^+_{\mu\nu} W^{-\,\mu\nu} + g^{(3)}_{HWW} \; H W^+_\mu W^{-\,\mu} \;,
\end{aligned}$$

with

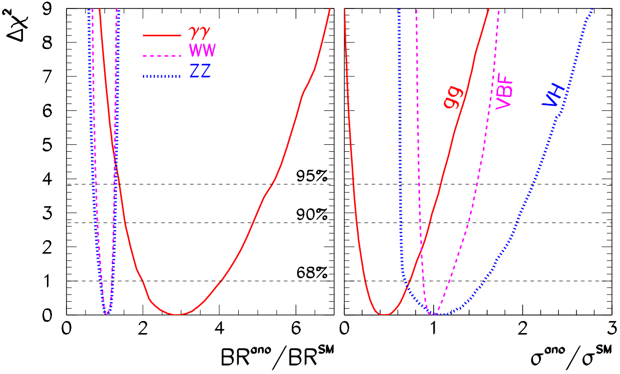
$$\begin{aligned}
g_{Hgg} &= \frac{f_{GG} v}{\Lambda^2} \equiv -\frac{\alpha_s}{8\pi} \frac{f_g v}{\Lambda^2} \;, & g_{H\gamma\gamma} &= -\left(\frac{g M_W}{\Lambda^2}\right) \frac{s^2 (f_{BB} + f_{WW} - f_{BW})}{2} , \\
g^{(1)}_{HZ\gamma} &= \left(\frac{g M_W}{\Lambda^2}\right) \frac{s (f_W - f_B)}{2c} \;, & g^{(2)}_{HZ\gamma} &= \left(\frac{g M_W}{\Lambda^2}\right) \frac{s[2 s^2 f_{BB} - 2 c^2 f_{WW} + (c^2 - s^2) f_{BW}]}{2c} , \\
g^{(1)}_{HZZ} &= \left(\frac{g M_W}{\Lambda^2}\right) \frac{c^2 f_W + s^2 f_B}{2c^2} \;, & g^{(2)}_{HZZ} &= -\left(\frac{g M_W}{\Lambda^2}\right) \frac{s^4 f_{BB} + c^4 f_{WW} + c^2 s^2 f_{BW}}{2c^2} , \\
g^{(1)}_{HWW} &= \left(\frac{g M_W}{\Lambda^2}\right) \frac{f_W}{2} \;, & g^{(2)}_{HWW} &= -\left(\frac{g M_W}{\Lambda^2}\right) f_{WW} , \\
g^{(3)}_{HZZ} &= \left(\frac{g M_W v^2}{\Lambda^2}\right) \frac{f_{\Phi,1} - f_{\Phi,2}}{4c^2} \;, & g^{(3)}_{HWW} &= -\left(\frac{g M_W v^2}{\Lambda^2}\right) \frac{f_{\Phi,1} + 2 f_{\Phi,2}}{4} \;.
\end{aligned}$$

# Analysis

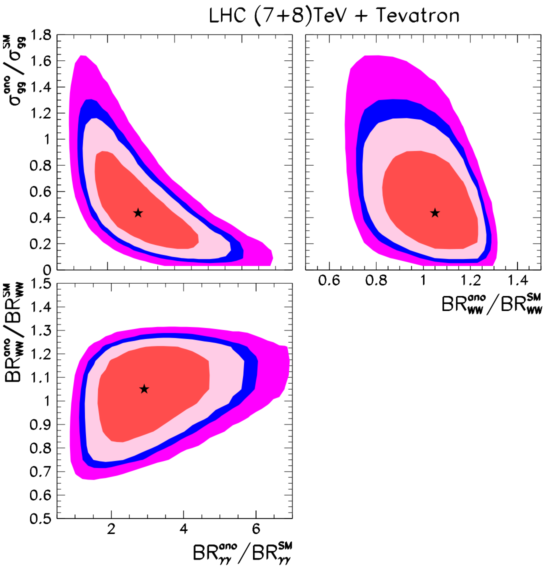
$$\chi^2 = \min_{\xi_{pull}} \sum_j \frac{(\mu_j - \mu_j^{\exp})^2}{\sigma_j^2} + \sum_{pull} \left(\frac{\xi_{pull}}{\sigma_{pull}}\right)^2$$

| Channel | $\mu^{exp}$ | Comment |
|---|---|---|
| $p\bar{p} \to W^+W^-$ | $0.3^{+1.1}_{-0.3}$ | CDF & DØ (arXiv:1207.0449) |
| $p\bar{p} \to b\bar{b}$ | $2.0^{+0.7}_{-0.7}$ | CDF & DØ (arXiv:1207.0449) |
| $p\bar{p} \to \gamma\gamma$ | $3.6^{+3.0}_{-2.5}$ | CDF & DØ (arXiv:1207.0449) |
| $pp \to \tau\bar{\tau}$ | $0.2^{+1.7}_{-1.9}$ | ATLAS (1207.0319) |
| $pp \to b\bar{b}$ | $0.5^{+2.1}_{-2.0}$ | ATLAS (1207.0319) |
| $pp \to ZZ^* \to \ell^+\ell^-\ell^+\ell^-$ | $1.4^{+1.3}_{-0.8}$ | ATLAS( 1207.0319) |
| $pp \to WW^* \to \ell^+\nu\ell^-\bar{\nu}$ | $0.5^{+0.6}_{-0.6}$ | ATLAS (1207.0319) |
| $pp \to \gamma\gamma$ | $2.2^{+0.8}_{-0.8}$ | ATLAS (ATLAS-CONF-2012-091) |
| $pp \to \tau\bar{\tau}$ | $0.6^{+1.1}_{-1.2}$ | CMS (arXiv:1202.1488) |
| $pp \to b\bar{b}$ | $0.5^{+1.1}_{-1.0}$ | CMS (CMS PAS HIG-12-020) |
| $pp \to ZZ^* \to \ell^+\ell^-\ell^+\ell^-$ | $0.6^{+0.9}_{-0.6}$ | CMS (arXiv:1202.1488) |
| $pp \to WW^* \to \ell^+\nu\ell^-\bar{\nu}$ | $0.4^{+0.6}_{-0.6}$ | CMS (arXiv:1202.1488) |
| $pp \to \gamma\gamma$ Untagged 0 | $3.2^{+1.9}_{-1.8}$ | CMS (CMS PAS HIG-12-015) |
| $pp \to \gamma\gamma$ Untagged 1 | $0.7^{+0.9}_{-1.0}$ | CMS (CMS PAS HIG-12-015) |
| $pp \to \gamma\gamma$ Untagged 2 | $0.7^{+1.2}_{-1.1}$ | CMS (CMS PAS HIG-12-015) |
| $pp \to \gamma\gamma$ Untagged 3 | $1.5^{+1.6}_{-1.6}$ | CMS (CMS PAS HIG-12-015) |
| $pp \to \gamma\gamma jj$ | $4.2^{+2.0}_{-2.0}$ | CMS (CMS PAS HIG-12-015) |

# Decay rates and production channels



# 2-dim correlations



# Thank you!

Other interesting work related to the Origin of masses at the LHC.
Directly related:

- Triple Gauge boson vertex $\rightarrow$ arXiv: 1006.3562

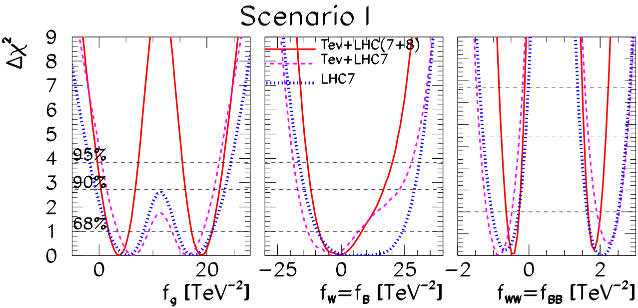
EWSB:

- Determination of spin of new resonances $\rightarrow$ arXiv: 1102.3429
- Bounds on neutral vector resonances from LHC data $\rightarrow$ arXiv: 1112.0316
- Update of the bounds $\rightarrow$ arXiv: 1205.5802

Neutrino masses:

- Seesaw at LHC $\rightarrow$ arXiv: 1108.0661

# Anomalous couplings regions



# Anomalous couplings regions