Effective Lagrangian approach to the EWSB sector

Juan González Fraile

Universitat de Barcelona

Tyler Corbett, O. J. P. Éboli, J. G–F and M. C. Gonzalez–Garcia

arXiv:1207.1344, 1211.4580, 1304.1151

Outline: accessing the EWSB mechanism

- Higgs boson discovery → **A particle directly related to the EWSB.**

  Its study is an alternative to the direct seek for new resonances.

- Huge variety of data → Higgs analysis, TGV, EWPD...

- Decipher the nature of the EWSB mechanism → deviations, (de)correlations between interactions, special kinematics, new signals

  Studying the Higgs interactions may be the fastest track to understand the origin of EWSB.

Outline: accessing the EWSB mechanism

- Higgs boson discovery → **A particle directly related to the EWSB.**

  Its study is an alternative to the direct seek for new resonances.

- Huge variety of data → Higgs analysis, TGV, EWPD...

- Decipher the nature of the EWSB mechanism → deviations, (de)correlations between interactions, special kinematics, new signals

  Studying the Higgs interactions may be the fastest track to understand the origin of EWSB.

Indirect approach
Model independent parametrization
} → **EFFECTIVE LAGRANGIAN APPROACH!**

Effective Lagrangian: the linear realization

Bottom-up model-independent effective Lagrangian approach:

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

- Particle content: There is no undiscovered low energy particle.
  Observed state: scalar, SU(2) doublet, CP-even, narrow and no overlapping resonances.

- Symmetries: $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ SM local symmetry (linearly realized).
  Global symmetries: lepton and baryon number conservation.

[1] Non–linear CP–odd→arxiv:1406.6367.

Effective Lagrangian: the linear realization

Bottom-up model-independent effective Lagrangian approach:

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

- Particle content: There is no undiscovered low energy particle.
  Observed state: scalar, SU(2) doublet, CP-even, narrow and no overlapping resonances.

- Symmetries: $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ SM local symmetry (linearly realized).
  Global symmetries: lepton and baryon number conservation.

59 dimension-6 operators are enough... (Buchmuller *et al*, Grzadkowski *et al*)

[1] Non–linear CP–odd→arxiv:1406.6367.

Effective Lagrangian: the linear realization

Bottom-up model-independent effective Lagrangian approach:

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

- Particle content: There is no undiscovered low energy particle.
  Observed state: scalar, SU(2) doublet, CP-even, narrow and no overlapping resonances.

- Symmetries: $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ SM local symmetry (linearly realized).
  Global symmetries: lepton and baryon number conservation.

59 dimension-6 operators are enough... (Buchmuller *et al*, Grzadkowski *et al*)

◇ Reduced set considering only C and P even[1].

◇ EOM to eliminate/choose the basis.

◇ Huge variety of data to make the choice and reduce the LHC studied set: **DATA–DRIVEN**.

[1] Non–linear CP–odd→arxiv:1406.6367.

The right of choice

Higgs interactions with gauge bosons[2]:

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

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

$$\mathcal{O}_{\Phi,1} = \left(D_\mu \Phi\right)^\dagger \Phi \, \Phi^\dagger \left(D^\mu \Phi\right) \;, \qquad \mathcal{O}_{\Phi,2} = \frac{1}{2} \partial^\mu \left(\Phi^\dagger \Phi\right) \partial_\mu \left(\Phi^\dagger \Phi\right) \;, \qquad \mathcal{O}_{\Phi,4} = \left(D_\mu \Phi\right)^\dagger \left(D^\mu \Phi\right) \left(\Phi^\dagger \Phi\right) \;,$$

Higgs interactions with fermions:

$$\mathcal{O}_{e\Phi,ij} = (\Phi^\dagger \Phi)(\bar{L}_i \Phi e_{R_j}) \qquad \mathcal{O}^{(1)}_{\Phi L,ij} = \Phi^\dagger (i \overset{\leftrightarrow}{D}_\mu \Phi)(\bar{L}_i \gamma^\mu L_j) \qquad \mathcal{O}^{(3)}_{\Phi L,ij} = \Phi^\dagger (i \overset{\leftrightarrow}{D}{}^a_\mu \Phi)(\bar{L}_i \gamma^\mu \sigma_a L_j)$$

$$\mathcal{O}_{u\Phi,ij} = (\Phi^\dagger \Phi)(\bar{Q}_i \tilde{\Phi} u_{R_j}) \qquad \mathcal{O}^{(1)}_{\Phi Q,ij} = \Phi^\dagger (i \overset{\leftrightarrow}{D}_\mu \Phi)(\bar{Q}_i \gamma^\mu Q_j) \qquad \mathcal{O}^{(3)}_{\Phi Q,ij} = \Phi^\dagger (i \overset{\leftrightarrow}{D}{}^a_\mu \Phi)(\bar{Q}_i \gamma^\mu \sigma_a Q_j)$$

$$\mathcal{O}_{d\Phi,ij} = (\Phi^\dagger \Phi)(\bar{Q}_i \Phi d_{Rj}) \qquad \mathcal{O}^{(1)}_{\Phi e,ij} = \Phi^\dagger (i \overset{\leftrightarrow}{D}_\mu \Phi)(\bar{e}_{R_i} \gamma^\mu e_{R_j})$$

$$\mathcal{O}^{(1)}_{\Phi u,ij} = \Phi^\dagger (i \overset{\leftrightarrow}{D}_\mu \Phi)(\bar{u}_{R_i} \gamma^\mu u_{R_j})$$

$$\mathcal{O}^{(1)}_{\Phi d,ij} = \Phi^\dagger (i \overset{\leftrightarrow}{D}_\mu \Phi)(\bar{d}_{R_i} \gamma^\mu d_{R_j})$$

$$\mathcal{O}^{(1)}_{\Phi ud,ij} = \tilde{\Phi}^\dagger (i \overset{\leftrightarrow}{D}_\mu \Phi)(\bar{u}_{R_i} \gamma^\mu d_{R_j})$$

In the absence of theoretical prejudice chose a basis where the operators are more directly related to the existing data

[2] $D_\mu \Phi = \left(\partial_\mu + i\frac{1}{2} g' B_\mu + ig \frac{\sigma_a}{2} W^a_\mu\right) \Phi$, $\hat{B}_{\mu\nu} = i \frac{g'}{2} B_{\mu\nu}$, $\hat{W}_{\mu\nu} = i \frac{g}{2} \sigma^a W^a_{\mu\nu}$

The right of choice

Higgs interactions with gauge bosons[2]:

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

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

$$\mathcal{O}_{\Phi,1} = (D_\mu \Phi)^\dagger \, \Phi \, \Phi^\dagger \, (D^\mu \Phi) \;, \qquad \mathcal{O}_{\Phi,2} = \frac{1}{2} \partial^\mu \left(\Phi^\dagger \Phi\right) \partial_\mu \left(\Phi^\dagger \Phi\right) \;, \qquad \mathcal{O}_{\Phi,4} = (D_\mu \Phi)^\dagger \, (D^\mu \Phi) \left(\Phi^\dagger \Phi\right) \;,$$

Higgs interactions with fermions:

$$\mathcal{O}_{e\Phi,ij} = (\Phi^\dagger \Phi)(\bar{L}_i \Phi e_{R_j}) \qquad \mathcal{O}^{(1)}_{\Phi L,ij} = \Phi^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{L}_i \gamma^\mu L_j) \qquad \mathcal{O}^{(3)}_{\Phi L,ij} = \Phi^\dagger (i\overleftrightarrow{D}^a_\mu \Phi)(\bar{L}_i \gamma^\mu \sigma_a L_j)$$

$$\mathcal{O}_{u\Phi,ij} = (\Phi^\dagger \Phi)(\bar{Q}_i \tilde{\Phi} u_{R_j}) \qquad \mathcal{O}^{(1)}_{\Phi Q,ij} = \Phi^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{Q}_i \gamma^\mu Q_j) \qquad \mathcal{O}^{(3)}_{\Phi Q,ij} = \Phi^\dagger (i\overleftrightarrow{D}^a_\mu \Phi)(\bar{Q}_i \gamma^\mu \sigma_a Q_j)$$

$$\mathcal{O}_{d\Phi,ij} = (\Phi^\dagger \Phi)(\bar{Q}_i \Phi d_{Rj}) \qquad \mathcal{O}^{(1)}_{\Phi e,ij} = \Phi^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{e}_{R_i} \gamma^\mu e_{R_j})$$

$$\mathcal{O}^{(1)}_{\Phi u,ij} = \Phi^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{u}_{R_i} \gamma^\mu u_{R_j})$$

$$\mathcal{O}^{(1)}_{\Phi d,ij} = \Phi^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{d}_{R_i} \gamma^\mu d_{R_j})$$

$$\mathcal{O}^{(1)}_{\Phi ud,ij} = \tilde{\Phi}^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{u}_{R_i} \gamma^\mu d_{R_j})$$

In the absence of theoretical prejudice chose a basis where the operators are more directly related to the existing data

TGV,

[2] $D_\mu \Phi = \left(\partial_\mu + i\frac{1}{2} g' B_\mu + ig \frac{\sigma_a}{2} W^a_\mu\right) \Phi$, $\hat{B}_{\mu\nu} = i\frac{g'}{2} B_{\mu\nu}$, $\hat{W}_{\mu\nu} = i\frac{g}{2} \sigma^a W^a_{\mu\nu}$

The right of choice

Higgs interactions with gauge bosons[2]:

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

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

$$\mathcal{O}_{\Phi,1} = \left(D_\mu \Phi\right)^\dagger \Phi \, \Phi^\dagger \left(D^\mu \Phi\right) \;, \qquad \mathcal{O}_{\Phi,2} = \frac{1}{2} \partial^\mu \left(\Phi^\dagger \Phi\right) \partial_\mu \left(\Phi^\dagger \Phi\right) \;, \qquad \mathcal{O}_{\Phi,4} = \left(D_\mu \Phi\right)^\dagger \left(D^\mu \Phi\right) \left(\Phi^\dagger \Phi\right) \;,$$

Higgs interactions with fermions:

$$\mathcal{O}_{e\Phi,ij} = (\Phi^\dagger \Phi)(\bar{L}_i \Phi e_{R_j}) \qquad \mathcal{O}^{(1)}_{\Phi L,ij} = \Phi^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{L}_i \gamma^\mu L_j) \qquad \mathcal{O}^{(3)}_{\Phi L,ij} = \Phi^\dagger (i\overleftrightarrow{D}^a_\mu \Phi)(\bar{L}_i \gamma^\mu \sigma_a L_j)$$

$$\mathcal{O}_{u\Phi,ij} = (\Phi^\dagger \Phi)(\bar{Q}_i \tilde{\Phi} u_{R_j}) \qquad \mathcal{O}^{(1)}_{\Phi Q,ij} = \Phi^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{Q}_i \gamma^\mu Q_j) \qquad \mathcal{O}^{(3)}_{\Phi Q,ij} = \Phi^\dagger (i\overleftrightarrow{D}^a_\mu \Phi)(\bar{Q}_i \gamma^\mu \sigma_a Q_j)$$

$$\mathcal{O}_{d\Phi,ij} = (\Phi^\dagger \Phi)(\bar{Q}_i \Phi d_{Rj}) \qquad \mathcal{O}^{(1)}_{\Phi e,ij} = \Phi^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{e}_{R_i} \gamma^\mu e_{R_j})$$

$$\mathcal{O}^{(1)}_{\Phi u,ij} = \Phi^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{u}_{R_i} \gamma^\mu u_{R_j})$$

$$\mathcal{O}^{(1)}_{\Phi d,ij} = \Phi^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{d}_{R_i} \gamma^\mu d_{R_j})$$

$$\mathcal{O}^{(1)}_{\Phi ud,ij} = \tilde{\Phi}^\dagger (i\overleftrightarrow{D}_\mu \Phi)(\bar{u}_{R_i} \gamma^\mu d_{R_j})$$

In the absence of theoretical prejudice chose a basis where the operators are more directly related to the existing data

TGV, Z properties, W decays, low energy ν scattering, atomic P, FCNC, Moller scattering P and $e^+e^- \to f\bar{f}$ at LEP2 and

tree level contribution to the oblique parameters: must avoid blind directions.

[2] $D_\mu \Phi = \left(\partial_\mu + i\frac{1}{2} g' B_\mu + ig\frac{\sigma_a}{2} W^a_\mu\right) \Phi$, $\hat{B}_{\mu\nu} = i\frac{g'}{2} B_{\mu\nu}$, $\hat{W}_{\mu\nu} = i\frac{g}{2}\sigma^a W^a_{\mu\nu}$

The right of choice

Higgs interactions with gauge bosons[2]:

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

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

$$\mathcal{O}_{\Phi,2} = \frac{1}{2} \partial^\mu \left(\Phi^\dagger \Phi \right) \partial_\mu \left(\Phi^\dagger \Phi \right) \quad ,$$

Higgs interactions with fermions:

$$\mathcal{O}_{e\Phi,33} = (\Phi^\dagger \Phi)(\bar{L}_3 \Phi e_{R_3})$$

$$\mathcal{O}_{d\Phi,33} = (\Phi^\dagger \Phi)(\bar{Q}_3 \Phi d_{R3})$$

In the absence of theoretical prejudice chose a basis where the operators are more directly related to the existing data

TGV, Z properties, W decays, low energy ν scattering, atomic P, FCNC, Moller scattering P and $e^+ e^- \to f \bar{f}$ at LEP2 and

tree level contribution to the oblique parameters: must avoid blind directions.

[2] $D_\mu \Phi = \left(\partial_\mu + i \frac{1}{2} g' B_\mu + i g \frac{\sigma_a}{2} W^a_\mu \right) \Phi$, $\hat{B}_{\mu\nu} = i \frac{g'}{2} B_{\mu\nu}$, $\hat{W}_{\mu\nu} = i \frac{g}{2} \sigma^a W^a_{\mu\nu}$

Effective Lagrangian for Higgs Interactions

$$\mathcal{L}_{\rm eff} = -\frac{\alpha_s v}{8\pi}\frac{f_g}{\Lambda^2}\mathcal{O}_{GG}+\frac{f_{\Phi,2}}{\Lambda^2}\mathcal{O}_{\Phi,2}+\frac{f_{BB}}{\Lambda^2}\mathcal{O}_{BB}+\frac{f_{WW}}{\Lambda^2}\mathcal{O}_{WW}+\frac{f_B}{\Lambda^2}\mathcal{O}_B+\frac{f_W}{\Lambda^2}\mathcal{O}_W+\frac{f_\tau}{\Lambda^2}\mathcal{O}_{e\Phi,33}+\frac{f_{\rm bot}}{\Lambda^2}\mathcal{O}_{d\Phi,33}$$

Unitary gauge:

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

$$\mathcal{L}_{\rm eff}^{Hff} = g^f_{Hij}\bar{f}'_L f'_R H + {\rm h.c.}$$

$$\begin{aligned}
g_{Hgg} &= -\frac{\alpha_s}{8\pi}\frac{f_g v}{\Lambda^2} &,\ g_{H\gamma\gamma} &= -\left(\frac{g^2 v s^2}{2\Lambda^2}\right)\frac{f_{WW}+f_{BB}}{2}\ , \\
g^{(1)}_{HZ\gamma} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s(f_W-f_B)}{2c} &,\ g^{(2)}_{HZ\gamma} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s[2s^2 f_{BB}-2c^2 f_{WW}]}{2c}\ , \\
g^{(1)}_{HZZ} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{c^2 f_W + s^2 f_B}{2c^2} &,\ g^{(2)}_{HZZ} &= -\left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s^4 f_{BB}+c^4 f_{WW}}{2c^2}\ , \\
g^{(1)}_{HWW} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{f_W}{2} &,\ g^{(2)}_{HWW} &= -\left(\frac{g^2 v}{2\Lambda^2}\right) f_{WW}\ , \\
g^f_{Hij} &= -\frac{m^f_i}{v}\delta_{ij} + \frac{v^2}{\sqrt{2}\Lambda^2} f'_{f\Phi,ij} &,\ g^{\Phi,2}_{Hxx} &= g^{SM}_{Hxx}\left(1-\frac{v^2}{2}\frac{f_{\Phi,2}}{\Lambda^2}\right)
\end{aligned}$$

Effective Lagrangian for Higgs Interactions

$$\mathcal{L}_{\rm eff} = -\frac{\alpha_s v}{8\pi}\frac{f_g}{\Lambda^2}\mathcal{O}_{GG} + \frac{f_{\Phi,2}}{\Lambda^2}\mathcal{O}_{\Phi,2} + \frac{f_{BB}}{\Lambda^2}\mathcal{O}_{BB} + \frac{f_{WW}}{\Lambda^2}\mathcal{O}_{WW} + \frac{f_B}{\Lambda^2}\mathcal{O}_B + \frac{f_W}{\Lambda^2}\mathcal{O}_W + \frac{f_\tau}{\Lambda^2}\mathcal{O}_{e\Phi,33} + \frac{f_{\rm bot}}{\Lambda^2}\mathcal{O}_{d\Phi,33}$$

Unitary gauge:

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

$$\mathcal{L}_{\rm eff}^{Hff} = g^f_{Hij}\bar{f}'_L f'_R H + \text{h.c.}$$

$$g_{Hgg} = -\frac{\alpha_s}{8\pi}\frac{f_g v}{\Lambda^2} \qquad , g_{H\gamma\gamma} = -\left(\frac{g^2 v s^2}{2\Lambda^2}\right)\frac{f_{WW}+f_{BB}}{2} \;,$$

$$g^{(1)}_{HZ\gamma} = \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s(f_W - f_B)}{2c} \qquad , g^{(2)}_{HZ\gamma} = \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s[2s^2 f_{BB} - 2c^2 f_{WW}]}{2c} \;,$$

$$g^{(1)}_{HZZ} = \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{c^2 f_W + s^2 f_B}{2c^2} \qquad , g^{(2)}_{HZZ} = -\left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s^4 f_{BB} + c^4 f_{WW}}{2c^2} \;,$$

$$g^{(1)}_{HWW} = \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{f_W}{2} \qquad , g^{(2)}_{HWW} = -\left(\frac{g^2 v}{2\Lambda^2}\right) f_{WW} \;,$$

$$g^f_{Hij} = -\frac{m^f_i}{v}\delta_{ij} + \frac{v^2}{\sqrt{2}\Lambda^2} f'_{f\Phi,ij} \qquad , g^{\Phi,2}_{Hxx} = g^{SM}_{Hxx}\left(1 - \frac{v^2}{2}\frac{f_{\Phi,2}}{\Lambda^2}\right)$$

Effective Lagrangian for Higgs Interactions

$$\mathcal{L}_{\rm eff} = -\frac{\alpha_s v}{8\pi}\frac{f_g}{\Lambda^2}\mathcal{O}_{GG} + \frac{f_{\Phi,2}}{\Lambda^2}\mathcal{O}_{\Phi,2} + \frac{f_{BB}}{\Lambda^2}\mathcal{O}_{BB} + \frac{f_{WW}}{\Lambda^2}\mathcal{O}_{WW} + \frac{f_B}{\Lambda^2}\mathcal{O}_B + \frac{f_W}{\Lambda^2}\mathcal{O}_W + \frac{f_\tau}{\Lambda^2}\mathcal{O}_{e\Phi,33} + \frac{f_{\rm bot}}{\Lambda^2}\mathcal{O}_{d\Phi,33}$$

Unitary gauge:

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

$$\mathcal{L}_{\rm eff}^{Hff} = g^f_{Hij}\bar f'_L f'_R H + {\rm h.c.}$$

$$\begin{aligned}
g_{Hgg} &= -\frac{\alpha_s}{8\pi}\frac{f_g v}{\Lambda^2}, & g_{H\gamma\gamma} &= -\left(\frac{g^2 v s^2}{2\Lambda^2}\right)\frac{f_{WW}+f_{BB}}{2}, \\
g^{(1)}_{HZ\gamma} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s(f_W - f_B)}{2c}, & g^{(2)}_{HZ\gamma} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s[2s^2 f_{BB} - 2c^2 f_{WW}]}{2c}, \\
g^{(1)}_{HZZ} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{c^2 f_W + s^2 f_B}{2c^2}, & g^{(2)}_{HZZ} &= -\left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s^4 f_{BB} + c^4 f_{WW}}{2c^2}, \\
g^{(1)}_{HWW} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{f_W}{2}, & g^{(2)}_{HWW} &= -\left(\frac{g^2 v}{2\Lambda^2}\right) f_{WW}, \\
g^f_{Hij} &= -\frac{m^f_i}{v}\delta_{ij} + \frac{v^2}{\sqrt{2}\Lambda^2} f'_{f\Phi,ij}, & g^{\Phi,2}_{Hxx} &= g^{SM}_{Hxx}\left(1 - \frac{v^2}{2}\frac{f_{\Phi,2}}{\Lambda^2}\right)
\end{aligned}$$

Effective Lagrangian for Higgs Interactions

$$\mathcal{L}_{\rm eff} = -\frac{\alpha_s v}{8\pi}\frac{f_g}{\Lambda^2}\mathcal{O}_{GG} + \frac{f_{\Phi,2}}{\Lambda^2}\mathcal{O}_{\Phi,2} + \frac{f_{BB}}{\Lambda^2}\mathcal{O}_{BB} + \frac{f_{WW}}{\Lambda^2}\mathcal{O}_{WW} + \frac{f_B}{\Lambda^2}\mathcal{O}_B + \frac{f_W}{\Lambda^2}\mathcal{O}_W + \frac{f_\tau}{\Lambda^2}\mathcal{O}_{e\Phi,33} + \frac{f_{\rm bot}}{\Lambda^2}\mathcal{O}_{d\Phi,33}$$

Unitary gauge:

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

$$\mathcal{L}_{\rm eff}^{Hff} = g^f_{Hij} \bar{f}'_L f'_R H + \text{h.c.}$$

$$\begin{aligned}
g_{Hgg} &= -\frac{\alpha_s}{8\pi}\frac{f_g v}{\Lambda^2} &&, g_{H\gamma\gamma} = -\left(\frac{g^2 v s^2}{2\Lambda^2}\right)\frac{f_{WW}+f_{BB}}{2}, \\
g^{(1)}_{HZ\gamma} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s(f_W - f_B)}{2c} &&, g^{(2)}_{HZ\gamma} = \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s[2s^2 f_{BB} - 2c^2 f_{WW}]}{2c}, \\
g^{(1)}_{HZZ} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{c^2 f_W + s^2 f_B}{2c^2} &&, g^{(2)}_{HZZ} = -\left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s^4 f_{BB} + c^4 f_{WW}}{2c^2}, \\
g^{(1)}_{HWW} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{f_W}{2} &&, g^{(2)}_{HWW} = -\left(\frac{g^2 v}{2\Lambda^2}\right) f_{WW}, \\
g^f_{Hij} &= -\frac{m^f_i}{v}\delta_{ij} + \frac{v^2}{\sqrt{2}\Lambda^2} f'_{f\Phi,ij} &&, g^{\Phi,2}_{Hxx} = g^{SM}_{Hxx}\left(1 - \frac{v^2}{2}\frac{f_{\Phi,2}}{\Lambda^2}\right)
\end{aligned}$$

Effective Lagrangian for Higgs Interactions

$$\mathcal{L}_{\rm eff} = -\frac{\alpha_s v}{8\pi}\frac{f_g}{\Lambda^2}\mathcal{O}_{GG}+\frac{f_{\Phi,2}}{\Lambda^2}\mathcal{O}_{\Phi,2}+\frac{f_{BB}}{\Lambda^2}\mathcal{O}_{BB}+\frac{f_{WW}}{\Lambda^2}\mathcal{O}_{WW}+\frac{f_B}{\Lambda^2}\mathcal{O}_B+\frac{f_W}{\Lambda^2}\mathcal{O}_W+\frac{f_\tau}{\Lambda^2}\mathcal{O}_{e\Phi,33}+\frac{f_{\rm bot}}{\Lambda^2}\mathcal{O}_{d\Phi,33}$$

Unitary gauge:

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

$$\mathcal{L}_{\rm eff}^{Hff} = g^f_{Hij}\bar f'_L f'_R H + \text{h.c.}$$

$$\begin{aligned}
g_{Hgg} &= -\frac{\alpha_s}{8\pi}\frac{f_g v}{\Lambda^2} &, g_{H\gamma\gamma} &= -\left(\frac{g^2 v s^2}{2\Lambda^2}\right)\frac{f_{WW}+f_{BB}}{2}\ ,\\
g^{(1)}_{HZ\gamma} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s(f_W-f_B)}{2c} &, g^{(2)}_{HZ\gamma} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s[2s^2 f_{BB}-2c^2 f_{WW}]}{2c}\ ,\\
g^{(1)}_{HZZ} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{c^2 f_W+s^2 f_B}{2c^2} &, g^{(2)}_{HZZ} &= -\left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s^4 f_{BB}+c^4 f_{WW}}{2c^2}\ ,\\
g^{(1)}_{HWW} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{f_W}{2} &, g^{(2)}_{HWW} &= -\left(\frac{g^2 v}{2\Lambda^2}\right) f_{WW}\ ,\\
g^f_{Hij} &= -\frac{m^f_i}{v}\delta_{ij}+\frac{v^2}{\sqrt{2}\Lambda^2}f'_{f\Phi,ij} &, g^{\Phi,2}_{Hxx} &= g^{SM}_{Hxx}\left(1-\frac{v^2}{2}\frac{f_{\Phi,2}}{\Lambda^2}\right)
\end{aligned}$$

Effective Lagrangian for Higgs Interactions

$$\mathcal{L}_{\rm eff} = -\frac{\alpha_s v}{8\pi}\frac{f_g}{\Lambda^2}\mathcal{O}_{GG} + \frac{f_{\Phi,2}}{\Lambda^2}\mathcal{O}_{\Phi,2} + \frac{f_{BB}}{\Lambda^2}\mathcal{O}_{BB} + \frac{f_{WW}}{\Lambda^2}\mathcal{O}_{WW} + \frac{f_B}{\Lambda^2}\mathcal{O}_B + \frac{f_W}{\Lambda^2}\mathcal{O}_W + \frac{f_\tau}{\Lambda^2}\mathcal{O}_{e\Phi,33} + \frac{f_{\rm bot}}{\Lambda^2}\mathcal{O}_{d\Phi,33}$$

Unitary gauge:

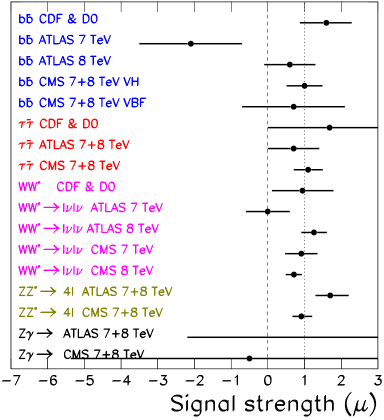
$$\begin{aligned}
\mathcal{L}_{\rm eff}^{\rm HVV} &= g_{Hgg}\, HG^a_{\mu\nu}G^{a\mu\nu} + g_{H\gamma\gamma}\, HA_{\mu\nu}A^{\mu\nu} + g^{(1)}_{HZ\gamma}\, A_{\mu\nu}Z^\mu\partial^\nu H + g^{(2)}_{HZ\gamma}\, HA_{\mu\nu}Z^{\mu\nu} \\
&+ g^{(1)}_{HZZ}\, Z_{\mu\nu}Z^\mu\partial^\nu H + g^{(2)}_{HZZ}\, HZ_{\mu\nu}Z^{\mu\nu}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

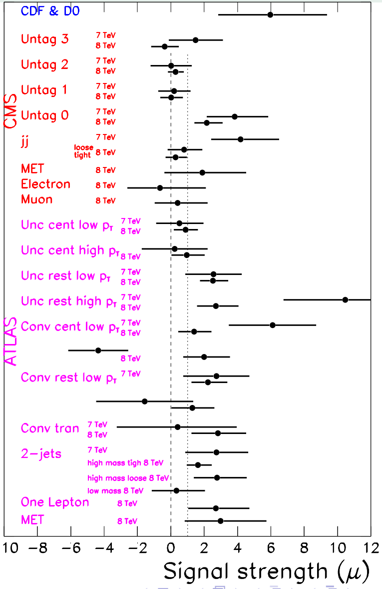
$$\mathcal{L}_{\rm eff}^{Hff} = g^f_{Hij}\bar{f}'_L f'_R H + \text{h.c.}$$

$$\begin{aligned}
g_{Hgg} &= -\frac{\alpha_s}{8\pi}\frac{f_g v}{\Lambda^2} &, g_{H\gamma\gamma} &= -\left(\frac{g^2 v s^2}{2\Lambda^2}\right)\frac{f_{WW}+f_{BB}}{2} \quad, \\
g^{(1)}_{HZ\gamma} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s(f_W - f_B)}{2c} &, g^{(2)}_{HZ\gamma} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s[2s^2 f_{BB} - 2c^2 f_{WW}]}{2c} \quad, \\
g^{(1)}_{HZZ} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{c^2 f_W + s^2 f_B}{2c^2} &, g^{(2)}_{HZZ} &= -\left(\frac{g^2 v}{2\Lambda^2}\right)\frac{s^4 f_{BB} + c^4 f_{WW}}{2c^2} \quad, \\
g^{(1)}_{HWW} &= \left(\frac{g^2 v}{2\Lambda^2}\right)\frac{f_W}{2} &, g^{(2)}_{HWW} &= -\left(\frac{g^2 v}{2\Lambda^2}\right) f_{WW} \quad, \\
g^f_{Hij} &= -\frac{m^f_i}{v}\delta_{ij} + \frac{v^2}{\sqrt{2}\Lambda^2} f'_{f\Phi,ij} &, g^{\Phi,2}_{Hxx} &= g^{SM}_{Hxx}\left(1 - \frac{v^2}{2}\frac{f_{\Phi,2}}{\Lambda^2}\right)
\end{aligned}$$

Effective Lagrangian for Higgs Interactions

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





TGV and EWPD

TGV:

$$\mathcal{L}_{WWV} = -ig_{WWV}\left\{ g_1^V\left(W^+_{\mu\nu}W^{-\,\mu}V^\nu - W^+_\mu V_\nu W^{-\,\mu\nu}\right) + \kappa_V W^+_\mu W^-_\nu V^{\mu\nu} + \frac{\lambda_V}{m_W^2} W^+_{\mu\nu} W^{-\,\nu\rho} V_\rho^{\ \mu} \right\}$$

$$\begin{aligned} \Delta g_1^Z &= g_1^Z - 1 = \frac{g^2 v^2}{8c^2\Lambda^2} f_W \ , \\ \Delta\kappa_\gamma &= \kappa_\gamma - 1 = \frac{g^2 v^2}{8\Lambda^2}\Big(f_W + f_B\Big) \ , \quad \leftrightarrow \\ \Delta\kappa_Z &= \kappa_Z - 1 = \frac{g^2 v^2}{8c^2\Lambda^2}\Big(c^2 f_W - s^2 f_B\Big) \ . \end{aligned}$$

$$g_1^Z = 0.984^{+0.049}_{-0.049} \qquad \text{LEP}$$

$$\kappa_\gamma = 1.004^{+0.024}_{-0.025} \qquad \rho = 0.11$$

EWPD:

$$\Delta S = 0.00 \pm 0.10 \qquad \Delta T = 0.02 \pm 0.11 \qquad \Delta U = 0.03 \pm 0.09$$

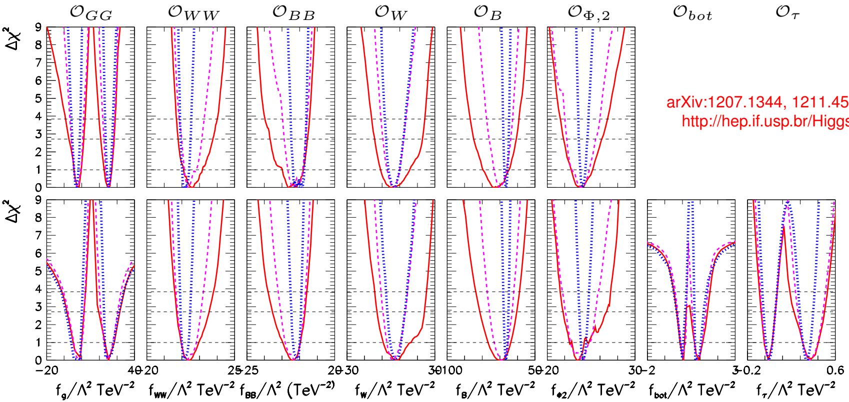
$$\rho = \begin{pmatrix} 1 & 0.89 & -0.55 \\ 0.89 & 1 & -0.8 \\ -0.55 & -0.8 & 1 \end{pmatrix}$$

$\mathcal{O}_{BW}$ and $\mathcal{O}_{\Phi,1}$ can already be neglected for the LHC analysis:

$$\alpha\Delta S = e^2 \frac{v^2}{\Lambda^2} f_{BW} \quad \text{and} \quad \alpha\Delta T = \frac{1}{2}\frac{v^2}{\Lambda^2} f_{\Phi,1} \ .$$

We add the rest of one–loop contributions in parts of the analysis.

$\Delta\chi^2$ vrs f_X

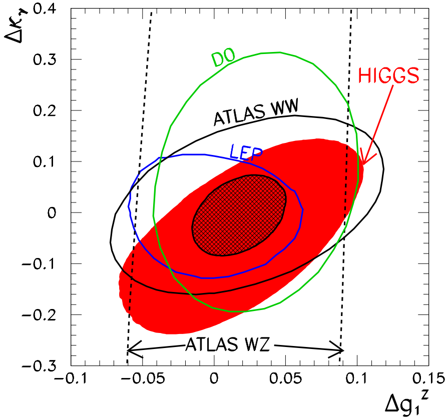


arXiv:1207.1344, 1211.4580
http://hep.if.usp.br/Higgs

Determining TGV from Higgs data

arxiv:1304.1151

- Gauge Invariance → TGV[3] and Higgs couplings related: $\mathcal{O}_W$ and $\mathcal{O}_B$
- **Complementarity in experimental searches**: Higgs data bounds on $f_W \otimes f_B \equiv \Delta\kappa_\gamma \otimes \Delta g_1^Z$



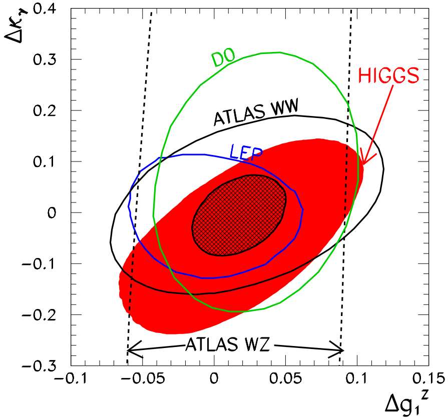
$$\Delta g_1^Z = g_1^Z - 1 = \frac{g^2 v^2}{8c^2\Lambda^2} f_W \;,$$
$$\Delta\kappa_\gamma = \kappa_\gamma - 1 = \frac{g^2 v^2}{8\Lambda^2}\left(f_W + f_B\right) \;,$$
$$\Delta\kappa_Z = \kappa_Z - 1 = \frac{g^2 v^2}{8c^2\Lambda^2}\left(c^2 f_W - s^2 f_B\right) \;.$$

[3] TGV = Triple Gauge boson Vertex (WWZ, $WW\gamma$)

Determining TGV from Higgs data

arxiv:1304.1151

- Gauge Invariance $\rightarrow$ TGV[3] and Higgs couplings related: $\mathcal{O}_W$ and $\mathcal{O}_B$
- **Complementarity in experimental searches**: Higgs data bounds on $f_W \otimes f_B \equiv \Delta\kappa_\gamma \otimes \Delta g_1^Z$



$$
\begin{aligned}
\Delta g_1^Z &= g_1^Z - 1 = \frac{g^2 v^2}{8c^2\Lambda^2} f_W \ , \\
\Delta\kappa_\gamma &= \kappa_\gamma - 1 = \frac{g^2 v^2}{8\Lambda^2}\left(f_W + f_B\right) \ , \\
\Delta\kappa_Z &= \kappa_Z - 1 = \frac{g^2 v^2}{8c^2\Lambda^2}\left(c^2 f_W - s^2 f_B\right) \ .
\end{aligned}
$$

(Non–linear decorrelation $\rightarrow$ Ilaria's talk)

[3]TGV = Triple Gauge boson Vertex (WWZ, $WW\gamma$)

Correlation between TGV and Higgs signals

$$\mathcal{L}_{WWV} = -ig_{WWV}\Big\{g_1^V\left(W^+_{\mu\nu}W^{-\,\mu}V^\nu - W^+_\mu V_\nu W^{-\,\mu\nu}\right) + \kappa_V W^+_\mu W^-_\nu V^{\mu\nu}\Big\}$$

$$\Delta g_1^Z = \frac{g^2v^2}{8c^2\Lambda^2} f_W \ ,$$

$$\Delta\kappa_\gamma = \frac{g^2v^2}{8\Lambda^2}\left(f_W + f_B\right) \ ,$$

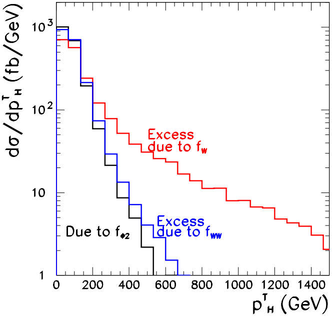
$$\Delta\kappa_Z = \frac{g^2v^2}{8c^2\Lambda^2}\left(c^2 f_W - s^2 f_B\right) \ .$$

$$\mathcal{L}_{\rm eff}^{\rm HWW} = +g^{(1)}_{HWW}\left(W^+_{\mu\nu}W^{-\,\mu}\partial^\nu H + {\rm h.c.}\right) + g^{(2)}_{HWW}\ HW^+_{\mu\nu}W^{-\,\mu\nu} + g^{(3)}_{HWW}\ HW^+_\mu W^{-\,\mu}$$

$$g^{(1)}_{HWW} = \left(\frac{g^2v}{2\Lambda^2}\right)\frac{f_W}{2} \ ,$$

$$g^{(2)}_{HWW} = -\left(\frac{g^2v}{2\Lambda^2}\right) f_{WW} \ ,$$

$$g^{(3)}_{HWW} = g^{SM}_{HWW}\left(1 - \frac{v^2}{2}\frac{f_{\Phi,2}}{\Lambda^2}\right)$$



Assume: LHC see deviation to TGV within 95% CL bound verifying $\Delta\kappa^\gamma = \Delta\kappa^Z = \cos^2\theta_W \Delta g_1^Z$

$$\textit{e. g.}\ \frac{f_W}{\Lambda^2} = -6.5\ \text{TeV}^{-2}$$

Leading to the excess

$$\sigma(pp\to WH) = 1.65\sigma_{SM}(pp\to WH)$$

$\Rightarrow$ but with a distorted $H\ p_T$ spectrum!

Relaxing assumptions: CP–odd

M.B. Gavela, J. G–F, M. C. Gonzalez–Garcia, L. Merlo, S. Rigolin and J. Yepes → arxiv:1406.1823

- List & applications of CP–odd non–linear operators:

$$\mathcal{L}_{\text{chiral}} = \mathcal{L}_{SM} + \Delta\mathcal{L}_{\not{C}P} \,,$$

$$\Delta\mathcal{L}_{\not{C}P} = c_{\widetilde{B}}\,\mathcal{S}_{\widetilde{B}}(h) + c_{\widetilde{W}}\,\mathcal{S}_{\widetilde{W}}(h) + c_{\widetilde{G}}\,\mathcal{S}_{\widetilde{G}}(h) + c_{2D}\,\mathcal{S}_{2D}(h) + \sum_{i=1}^{16} c_i\,\mathcal{S}_i(h)\,.$$

- Use CP–odd sensitive signals

Relaxing assumptions: CP–odd

M.B. Gavela, J. G–F, M. C. Gonzalez–Garcia, L. Merlo, S. Rigolin and J. Yepes → arxiv:1406.1823

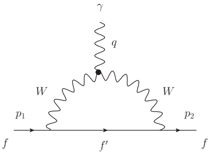
- List & applications of CP–odd non–linear operators:

$$\mathcal{L}_{\text{chiral}} = \mathcal{L}_{SM} + \Delta\mathcal{L}_{\not{C}P} \,,$$

$$\Delta\mathcal{L}_{\not{C}P} = c_{\widetilde{B}}\,\mathcal{S}_{\widetilde{B}}(h) + c_{\widetilde{W}}\,\mathcal{S}_{\widetilde{W}}(h) + c_{\widetilde{G}}\,\mathcal{S}_{\widetilde{G}}(h) + c_{2D}\,\mathcal{S}_{2D}(h) + \sum_{i=1}^{16} c_i\,\mathcal{S}_i(h)\,.$$

- Use CP–odd sensitive signals:

Fermionic **EDM**s (sensitive to $\tilde{\kappa}_\gamma$, $\tilde{g}_{h\gamma\gamma}$)



Relaxing assumptions: CP–odd

M.B. Gavela, J. G–F, M. C. Gonzalez–Garcia, L. Merlo, S. Rigolin and J. Yepes → arxiv:1406.1823

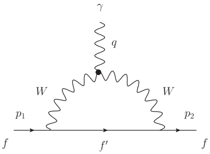
- List & applications of CP–odd non–linear operators:

$$\mathcal{L}_{\text{chiral}} = \mathcal{L}_{SM} + \Delta\mathcal{L}_{\not{C}P}\,,$$

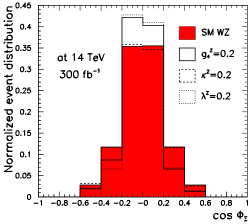
$$\Delta\mathcal{L}_{\not{C}P} = c_{\widetilde{B}}\,\mathcal{S}_{\widetilde{B}}(h) + c_{\widetilde{W}}\,\mathcal{S}_{\widetilde{W}}(h) + c_{\widetilde{G}}\,\mathcal{S}_{\widetilde{G}}(h) + c_{2D}\,\mathcal{S}_{2D}(h) + \sum_{i=1}^{16} c_i\,\mathcal{S}_i(h)\,.$$

- Use CP–odd sensitive signals:

Fermionic **EDMs** (sensitive to $\tilde{\kappa}_\gamma$, $\tilde{g}_{h\gamma\gamma}$)



CP–violating **TGV**



Relaxing assumptions: CP–odd

M.B. Gavela, J. G–F, M. C. Gonzalez–Garcia, L. Merlo, S. Rigolin and J. Yepes → arxiv:1406.1823

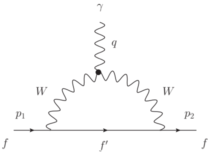
- List & applications of CP–odd non–linear operators:

$$\mathcal{L}_{\text{chiral}} = \mathcal{L}_{SM} + \Delta\mathcal{L}_{\not{C}P}\,,$$

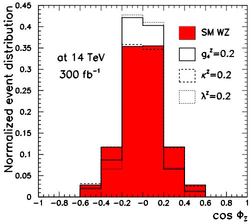
$$\Delta\mathcal{L}_{\not{C}P} = c_{\widetilde{B}}\,\mathcal{S}_{\widetilde{B}}(h) + c_{\widetilde{W}}\,\mathcal{S}_{\widetilde{W}}(h) + c_{\widetilde{G}}\,\mathcal{S}_{\widetilde{G}}(h) + c_{2D}\,\mathcal{S}_{2D}(h) + \sum_{i=1}^{16} c_i\,\mathcal{S}_i(h)\,.$$

- Use CP–odd sensitive signals:

Fermionic **EDM**s (sensitive to $\tilde{\kappa}_\gamma$, $\tilde{g}_{h\gamma\gamma}$)



CP–violating **TGV**



CP–violation on **Higgs physics**: $h \to ZZ$, *e. g.* CMS analysis:

$$A(h \to ZZ) = v^{-1}\left(d_1 m_Z^2 \epsilon_1^* \epsilon_2^* + d_2 f^{*(1)}_{\mu\nu} f^{\mu\nu *(2)} + d_3 f^{*(1)}_{\mu\nu}\tilde{f}^{\mu\nu *(2)}\right)\,,$$

Conclusions

- **Model independent** analysis where the effects of new physics in the Higgs couplings are parametrized in $\mathcal{L}_{eff}$. If $SU(2)_L$ doublet $\rightarrow SU(2)_L \times U(1)_Y$ gauge symmetry linearly realized:

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

- **Power to the data** $\rightarrow$ operators whose coefficients are more easily related to existing data.

So far $\rightarrow$ Higgs boson SM–like.

- Exploit interesting **complementarity between experimental searches**: TGV and Higgs data.

arXiv:1207.1344, 1211.4580, 1304.1151

Outlook:

- ◇ ~~Study non–linear CP-odd operators~~ $\rightarrow$ Recently finished: arxiv:1406.6367
- ◇ Combine the full Higgs and TGV 7+8 TeV sets of data in this framework.
- ◇ Jump from signal strengths to exploit the **kinematic** structures

Conclusions

THANK YOU!

- **Model independent** analysis where the effects of new physics in the Higgs couplings are parametrized in $\mathcal{L}_{eff}$. If $SU(2)_L$ doublet $\rightarrow SU(2)_L \times U(1)_Y$ gauge symmetry linearly realized:

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

- **Power to the data** $\rightarrow$ operators whose coefficients are more easily related to existing data.

  So far $\rightarrow$ Higgs boson SM–like.

- Exploit interesting **complementarity between experimental searches**: TGV and Higgs data.

  arXiv:1207.1344, 1211.4580, 1304.1151

Outlook:

◇ ~~Study non–linear CP-odd operators~~ $\rightarrow$ Recently finished: arxiv:1406.6367

◇ Combine the full Higgs and TGV 7+8 TeV sets of data in this framework.

◇ Jump from signal strengths to exploit the **kinematic** structures