Effective Lagrangian approach to the EWSB sector

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

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I. Brivio, T. Corbett, O. J. P. Éboli, M. B. Gavela,
J. G–F, M. C. Gonzalez–Garcia, L. Merlo and S. Rigolin

arXiv:1311.1823

Outline: accessing the EWSB mechanism

- Higgs boson discovery $\rightarrow$ **A particle directly related to the EWSB.**

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

- Huge variety of data $\rightarrow$ Higgs analysis, TGV, EWPD...

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

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

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Indirect approach

Model independent parametrization

$\Big\} \rightarrow$ **EFFECTIVE LAGRANGIAN APPROACH!**

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Indirect approach, Model independent parametrization $\}$ $\rightarrow$ **EFFECTIVE LAGRANGIAN APPROACH!** $\rightarrow$ $\{$

- Linear: TGV $\leftrightarrow$ Higgs physics
- Non–linear: decorrelation, alternative signals

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.

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◇ 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**.

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The right of choice

Higgs interactions with gauge bosons[2]:

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

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

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

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

Higgs interactions with fermions:

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

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

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

TGV,

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

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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.

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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

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Unitary gauge:

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&+ 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 \\
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\end{aligned}$$

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$$\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}\,, \\
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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)
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Unitary gauge:

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\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 \\
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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)
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Effective Lagrangian for Higgs Interactions

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Unitary gauge:

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Effective Lagrangian for Higgs Interactions

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Unitary gauge:

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

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

Higgs collider data

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

Where

$$\mu_F = \frac{\epsilon_{gg}^F \sigma_{gg}^{\rm ano} + \epsilon_{VBF}^F \sigma_{VBF}^{\rm ano} + \epsilon_{WH}^F \sigma_{WH}^{\rm ano} + \epsilon_{ZH}^F \sigma_{ZH}^{\rm ano} + \epsilon_{t\bar{t}H}^F \sigma_{t\bar{t}H}^{\rm ano}}{\epsilon_{gg}^F \sigma_{gg}^{SM} + \epsilon_{VBF}^F \sigma_{VBF}^{SM} + \epsilon_{WH}^F \sigma_{WH}^{SM} + \epsilon_{ZH}^F \sigma_{ZH}^{SM} + \epsilon_{t\bar{t}H}^F \sigma_{t\bar{t}H}^{SM}} \otimes \frac{\text{BR}^{\rm ano}[h \to F]}{\text{BR}^{SM}[h \to F]} \,.$$

where $\sigma_x^{\rm ano} = \sigma_x^{\rm ano}(1 + \xi_x)$.

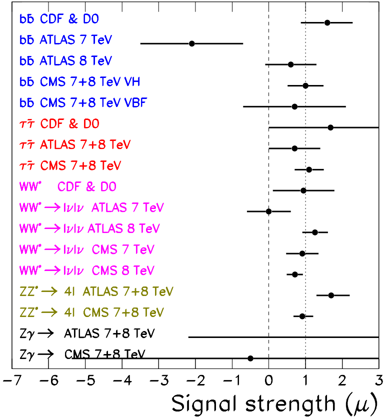
For the anomalous calculations:

$$\sigma_Y^{\rm ano} = \left. \frac{\sigma_Y^{\rm ano}}{\sigma_Y^{SM}} \right|_{\rm tree} \left. \sigma_Y^{SM} \right|_{\rm soa}$$

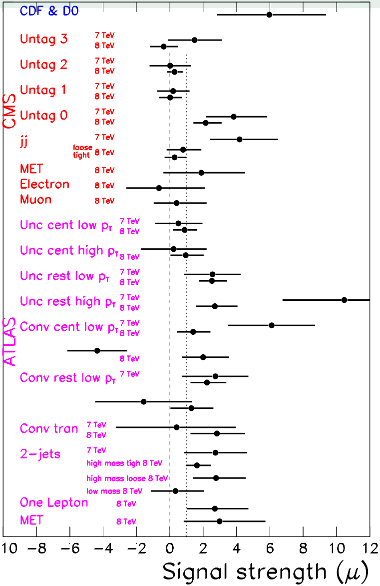
and

$$\Gamma^{\rm ano}(h \to X) = \left. \frac{\Gamma^{\rm ano}(h \to X)}{\Gamma^{SM}(h \to X)} \right|_{\rm tree} \left. \Gamma^{SM}(h \to X) \right|_{\rm soa}$$

Higgs collider data



$\gamma\gamma$



TGV and EWPD

TGV:

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

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

$$g_1^Z = 0.984^{+0.049}_{-0.049} \qquad \text{LEP}$$
$$\kappa_\gamma = 1.004^{+0.024}_{-0.025} \qquad \rho = 0.11$$

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:

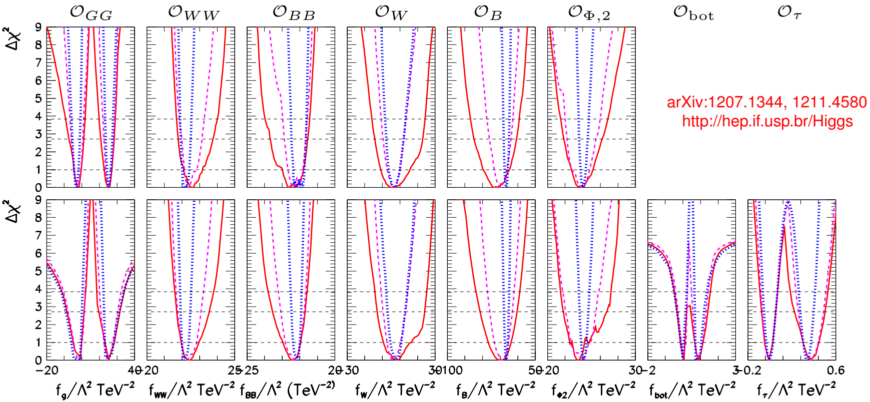
$$\alpha\Delta S = e^2\frac{v^2}{\Lambda^2}f_{BW} \quad \text{and} \quad \alpha\Delta T = \frac{1}{2}\frac{v^2}{\Lambda^2}f_{\Phi,1} \ .$$

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

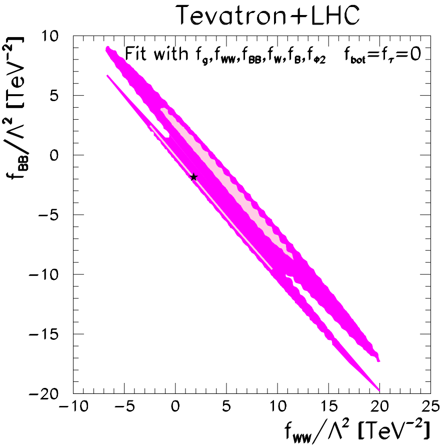
S,T,U Parameters

$$
\begin{aligned}
\alpha\Delta S &= \frac{1}{6}\frac{e^2}{16\pi^2}\Bigg\{3(f_W+f_B)\frac{m_H^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)+ \\
&+2\Big[(5c^2-2)f_W-(5c^2-3)f_B\Big]\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right) \\
&-\Big[(22c^2-1)f_W-(30c^2+1)f_B\Big]\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_Z^2}\right) \\
&-24c^2 f_{WW}\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)+2f_{\Phi,2}\frac{v^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)\Bigg\}\,, \\
\alpha\Delta T &= \frac{3}{4c^2}\frac{e^2}{16\pi^2}\Bigg\{f_B\frac{m_H^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right) \\
&+(c^2 f_W+f_B)\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right) \\
&+\Big[2c^2 f_W+(3c^2-1)f_B\Big]\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_Z^2}\right)-f_{\Phi,2}\frac{v^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right)\Bigg\}\,, \\
\alpha\Delta U &= -\frac{1}{3}\frac{e^2 s^2}{16\pi^2}\Bigg\{(-4f_W+5f_B)\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_H^2}\right) \\
&+(2f_W-5f_B)\frac{m_Z^2}{\Lambda^2}\log\left(\frac{\Lambda^2}{m_Z^2}\right)\Bigg\}
\end{aligned}
$$

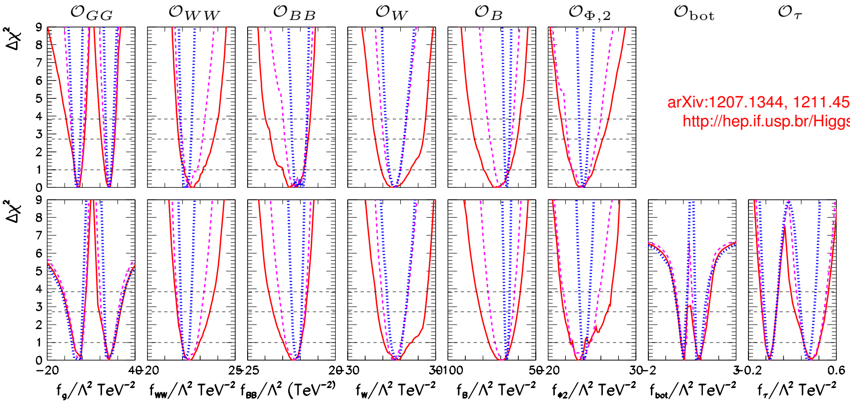
$\Delta\chi^2$ vrs f_X



$\Delta\chi^2$ vrs f_X

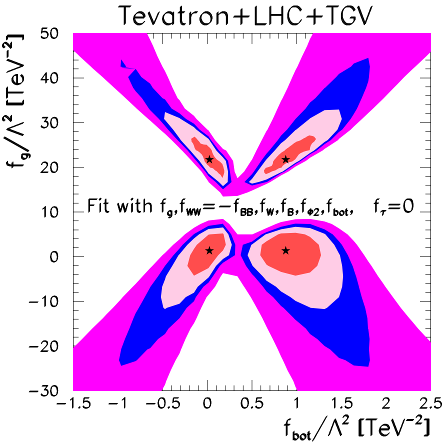


$\Delta\chi^2$ vrs f_X

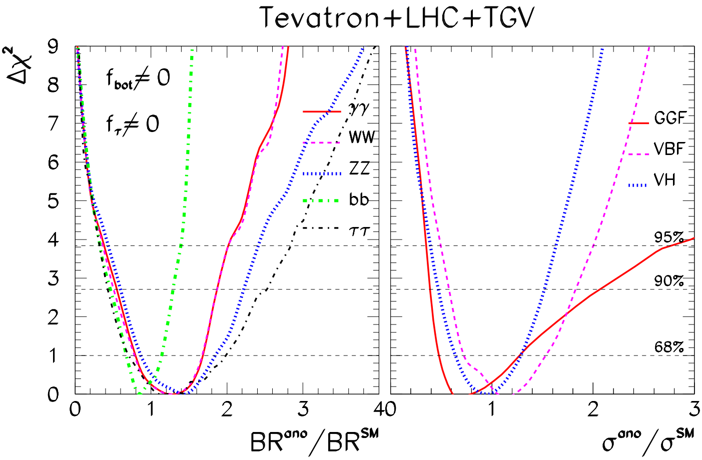


arXiv:1207.1344, 1211.4580
http://hep.if.usp.br/Higgs

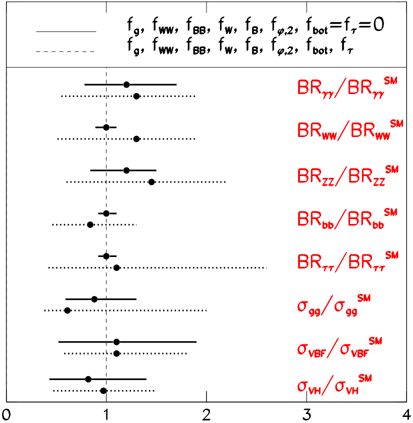
2d correlations



BRs and production CS



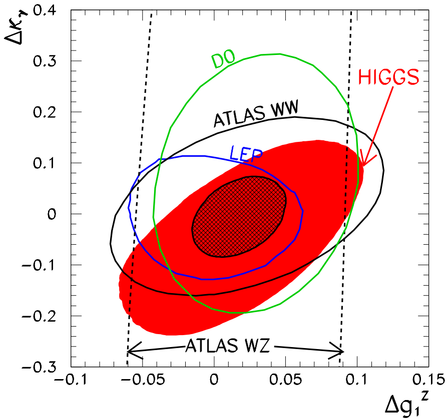
BRs and production CS



Determining TGV from Higgs data

arxiv:1304.1151

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



$$\Delta g_1^Z = g_1^Z - 1 = \frac{g^2 v^2}{8c^2\Lambda^2} f_W \ ,$$

$$\Delta\kappa_\gamma = \kappa_\gamma - 1 = \frac{g^2 v^2}{8\Lambda^2}\left(f_W + f_B\right) \ ,$$

$$\Delta\kappa_Z = \kappa_Z - 1 = \frac{g^2 v^2}{8c^2\Lambda^2}\left(c^2 f_W - s^2 f_B\right) \ .$$

Correlation between TGV and Higgs signals

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

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

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

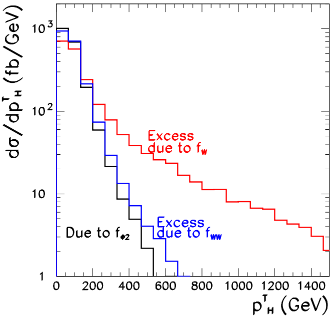
$$\Delta\kappa_Z = \frac{g^2 v^2}{8c^2\Lambda^2}\left(c^2 f_W - s^2 f_B\right) \ .$$

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

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

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

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



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

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

Leading to the excess

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

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

Disentangling a dynamical Higgs

arxiv:1311.1823

- Motivated by composite models $\rightarrow$ Higgs as a PGB of a global symmetry.
- Non-linear or “chiral“ effective Lagrangian expansion including the light Higgs.

SM Gauge bosons and fermions

Light Higgs $\rightarrow$ without a given model treated as generic ”singlet“ h $\leftrightarrow$ h is not part of Φ More possible operators

$F_i(h) = 1 + 2a_i \frac{h}{v} + b_i \frac{h^2}{v^2} + \dots$

Dimensionless unitary matrix: $\mathrm{U}(x) = e^{i\sigma_a \pi^a(x)/v}$ $\leftrightarrow$ Relative reshuffling of the order at which operators appear

$(\mathrm{V}_\mu \equiv (\mathrm{D}_\mu \mathrm{U})\, \mathrm{U}^\dagger$ and $\mathrm{T} \equiv \mathrm{U}\sigma_3\mathrm{U}^\dagger)$

- Bosonic (pure gauge and gauge-h operators) and Yukawa-like up to four derivatives

$$\mathcal{L}_{\text{chiral}} = \mathcal{L}_0 + \Delta\mathcal{L}$$

Comparison with the linear basis!

The Non-linear Lagrangian

Alonso *et al* 1212.3305

$$\mathcal{L}_{\text{chiral}} = \mathcal{L}_0 + \Delta\mathcal{L}$$

SM Lagrangian[3]

$$\begin{aligned}
\mathcal{L}_0 &= \frac{1}{2}(\partial_\mu h)(\partial^\mu h) - \frac{1}{4}W^a_{\mu\nu}W^{a\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}G^a_{\mu\nu}G^{a\mu\nu} - V(h) \\
&\quad - \frac{(v+h)^2}{4}\mathrm{Tr}[\mathsf{V}_\mu \mathsf{V}^\mu] + i\bar{Q}\not{D}Q + i\bar{L}\not{D}L \\
&\quad - \frac{v+s_Y h}{\sqrt{2}}\left(\bar{Q}_L \mathsf{U}\mathsf{Y}_Q Q_R + \text{h.c.}\right) - \frac{v+s_Y h}{\sqrt{2}}\left(\bar{L}_L \mathsf{U}\mathsf{Y}_L L_R + \text{h.c.}\right),
\end{aligned}$$

Restricting to bosonic (pure gauge and gauge-h operators):

$$\begin{aligned}
\Delta\mathcal{L} &= \xi\left[c_B\mathcal{P}_B(h) + c_W\mathcal{P}_W(h) + c_G\mathcal{P}_G(h) + c_C\mathcal{P}_C(h) + c_T\mathcal{P}_T(h)\right. \\
&+ \left. c_H\mathcal{P}_H(h) + c_{\Box H}\mathcal{P}_{\Box H}(h)\right] + \xi\sum_{i=1}^{10} c_i\mathcal{P}_i(h) \\
&+ \xi^2\sum_{i=11}^{25} c_i\mathcal{P}_i(h) + \xi^4 c_{26}\mathcal{P}_{26}(h) + \Sigma_i \xi^{n_i} c^i_{HH}\mathcal{P}^i_{HH}(h)
\end{aligned}$$

[3] $\mathsf{D}_\mu \mathsf{U}(x) \equiv \partial_\mu \mathsf{U}(x) + igW_\mu(x)\mathsf{U}(x) - \frac{ig'}{2}B_\mu(x)\mathsf{U}(x)\sigma_3$

$\mathbf{Y}_Q \equiv \mathbf{diag}\,(Y_U,\, Y_D)\,, \qquad \mathbf{Y}_L \equiv \mathbf{diag}\,(Y_\nu,\, Y_L)\,.$

The Non-linear Lagrangian

Alonso *et al* 1212.3305

$$\mathcal{P}_C(h) = -\frac{v^2}{4}\mathrm{Tr}(\mathbf{V}^\mu\mathbf{V}_\mu)\mathcal{F}_C(h)$$
$$\mathcal{P}_T(h) = \frac{v^2}{4}\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\mathcal{F}_T(h)$$
$$\mathcal{P}_H(h) = \frac{1}{2}(\partial_\mu h)(\partial^\mu h)\mathcal{F}_H(h)$$
$$\mathcal{P}_B(h) = -\frac{g'^2}{4}B_{\mu\nu}B^{\mu\nu}\mathcal{F}_B(h)$$
$$\mathcal{P}_W(h) = -\frac{g^2}{4}W^a_{\mu\nu}W^{a\mu\nu}\mathcal{F}_W(h)$$
$$\mathcal{P}_G(h) = -\frac{g_s^2}{4}G^a_{\mu\nu}G^{a\mu\nu}\mathcal{F}_G(h)$$
$$\mathcal{P}_1(h) = gg'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}W^{\mu\nu})\mathcal{F}_1(h)$$
$$\mathcal{P}_2(h) = ig'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_2(h)$$
$$\mathcal{P}_3(h) = ig\mathrm{Tr}(W_{\mu\nu}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_3(h)$$
$$\mathcal{P}_4(h) = ig'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_4(h)$$
$$\mathcal{P}_5(h) = ig\mathrm{Tr}(W_{\mu\nu}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_5(h)$$
$$\mathcal{P}_6(h) = (\mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu))^2\mathcal{F}_6(h)$$
$$\mathcal{P}_7(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)\partial_\nu\partial^\nu\mathcal{F}_7(h)$$
$$\mathcal{P}_8(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\partial^\mu\mathcal{F}_8(h)\partial^\nu\mathcal{F}'_8(h)$$
$$\mathcal{P}_9(h) = \mathrm{Tr}((\mathcal{D}_\mu\mathbf{V}^\mu)^2)\mathcal{F}_9(h)$$
$$\mathcal{P}_{10}(h) = \mathrm{Tr}(\mathbf{V}_\nu\mathcal{D}_\mu\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{10}(h)$$
$$\mathcal{P}_{\Box H} = \frac{1}{v^2}(\partial_\mu\partial^\mu h)^2\mathcal{F}_{\Box H}(h)\,.$$

$$\mathcal{P}_{11}(h) = (\mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu))^2\mathcal{F}_{11}(h)$$
$$\mathcal{P}_{12}(h) = g^2(\mathrm{Tr}(\mathbf{T}W_{\mu\nu}))^2\mathcal{F}_{12}(h)$$
$$\mathcal{P}_{13}(h) = ig\mathrm{Tr}(\mathbf{T}W_{\mu\nu})\mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_{13}(h)$$
$$\mathcal{P}_{14}(h) = g\varepsilon^{\mu\nu\rho\lambda}\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{V}_\nu W_{\rho\lambda})\mathcal{F}_{14}(h)$$
$$\mathcal{P}_{15}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathcal{D}_\nu\mathbf{V}^\nu)\mathcal{F}_{15}(h)$$
$$\mathcal{P}_{16}(h) = \mathrm{Tr}([\mathbf{T},\mathbf{V}_\nu]\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{16}(h)$$
$$\mathcal{P}_{17}(h) = ig\mathrm{Tr}(\mathbf{T}W_{\mu\nu})\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{17}(h)$$
$$\mathcal{P}_{18}(h) = \mathrm{Tr}(\mathbf{T}[\mathbf{V}_\mu,\mathbf{V}_\nu])\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{18}(h)$$
$$\mathcal{P}_{19}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\nu\mathcal{F}_{19}(h)$$
$$\mathcal{P}_{20}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)\partial_\nu\mathcal{F}_{20}(h)\partial^\nu\mathcal{F}'_{20}(h)$$
$$\mathcal{P}_{21}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\mathcal{F}_{21}(h)\partial^\nu\mathcal{F}'_{21}(h)$$
$$\mathcal{P}_{22}(h) = \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\mu\mathcal{F}_{22}(h)\partial^\nu\mathcal{F}'_{22}(h)$$
$$\mathcal{P}_{23}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)(\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{23}(h)$$
$$\mathcal{P}_{24}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{24}(h)$$
$$\mathcal{P}_{25}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\partial^\nu\mathcal{F}_{25}(h)$$
$$\mathcal{P}_{26}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{26}(h)$$

The Non-linear Lagrangian

Alonso *et al* 1212.3305

$$\mathcal{P}_C(h) = -\frac{v^2}{4}\text{Tr}(\mathbf{V}^\mu\mathbf{V}_\mu)\mathcal{F}_C(h)$$
$$\mathcal{P}_T(h) = \frac{v^2}{4}\text{Tr}(\mathbf{T}\mathbf{V}_\mu)\text{Tr}(\mathbf{T}\mathbf{V}^\mu)\mathcal{F}_T(h)$$
$$\mathcal{P}_H(h) = \frac{1}{2}(\partial_\mu h)(\partial^\mu h)\mathcal{F}_H(h)$$
$$\mathcal{P}_B(h) = -\frac{g'^2}{4}B_{\mu\nu}B^{\mu\nu}\mathcal{F}_B(h)$$
$$\mathcal{P}_W(h) = -\frac{g^2}{4}W^a_{\mu\nu}W^{a\mu\nu}\mathcal{F}_W(h)$$
$$\mathcal{P}_G(h) = -\frac{g_s^2}{4}G^a_{\mu\nu}G^{a\mu\nu}\mathcal{F}_G(h)$$
$$\mathcal{P}_1(h) = gg'B_{\mu\nu}\text{Tr}(\mathbf{T}W^{\mu\nu})\mathcal{F}_1(h)$$
$$\mathcal{P}_2(h) = ig'B_{\mu\nu}\text{Tr}(\mathbf{T}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_2(h)$$
$$\mathcal{P}_3(h) = ig\text{Tr}(W_{\mu\nu}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_3(h)$$
$$\mathcal{P}_4(h) = ig'B_{\mu\nu}\text{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_4(h)$$
$$\mathcal{P}_5(h) = ig\text{Tr}(W_{\mu\nu}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_5(h)$$
$$\mathcal{P}_6(h) = (\text{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu))^2\mathcal{F}_6(h)$$
$$\mathcal{P}_7(h) = \text{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)\partial_\nu\partial^\nu\mathcal{F}_7(h)$$
$$\mathcal{P}_8(h) = \text{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\partial^\mu\mathcal{F}_8(h)\partial^\nu\mathcal{F}'_8(h)$$
$$\mathcal{P}_9(h) = \text{Tr}((\mathcal{D}_\mu\mathbf{V}^\mu)^2)\mathcal{F}_9(h)$$
$$\mathcal{P}_{10}(h) = \text{Tr}(\mathbf{V}_\nu\mathcal{D}_\mu\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{10}(h)$$
$$\mathcal{P}_{\Box H} = \frac{1}{v^2}(\partial_\mu\partial^\mu h)^2\mathcal{F}_{\Box H}(h)\,.$$

$$\mathcal{P}_{11}(h) = (\text{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu))^2\mathcal{F}_{11}(h)$$
$$\mathcal{P}_{12}(h) = g^2(\text{Tr}(\mathbf{T}W_{\mu\nu}))^2\mathcal{F}_{12}(h)$$
$$\mathcal{P}_{13}(h) = ig\text{Tr}(\mathbf{T}W_{\mu\nu})\text{Tr}(\mathbf{T}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_{13}(h)$$
$$\mathcal{P}_{14}(h) = g\varepsilon^{\mu\nu\rho\lambda}\text{Tr}(\mathbf{T}\mathbf{V}_\mu)\text{Tr}(\mathbf{V}_\nu W_{\rho\lambda})\mathcal{F}_{14}(h)$$
$$\mathcal{P}_{15}(h) = \text{Tr}(\mathbf{T}\mathcal{D}_\mu\mathbf{V}^\mu)\text{Tr}(\mathbf{T}\mathcal{D}_\nu\mathbf{V}^\nu)\mathcal{F}_{15}(h)$$
$$\mathcal{P}_{16}(h) = \text{Tr}([\mathbf{T},\mathbf{V}_\nu]\mathcal{D}_\mu\mathbf{V}^\mu)\text{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{16}(h)$$
$$\mathcal{P}_{17}(h) = ig\text{Tr}(\mathbf{T}W_{\mu\nu})\text{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{17}(h)$$
$$\mathcal{P}_{18}(h) = \text{Tr}(\mathbf{T}[\mathbf{V}_\mu,\mathbf{V}_\nu])\text{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{18}(h)$$
$$\mathcal{P}_{19}(h) = \text{Tr}(\mathbf{T}\mathcal{D}_\mu\mathbf{V}^\mu)\text{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\nu\mathcal{F}_{19}(h)$$
$$\mathcal{P}_{20}(h) = \text{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)\partial_\nu\mathcal{F}_{20}(h)\partial^\nu\mathcal{F}'_{20}(h)$$
$$\mathcal{P}_{21}(h) = (\text{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\mathcal{F}_{21}(h)\partial^\nu\mathcal{F}'_{21}(h)$$
$$\mathcal{P}_{22}(h) = \text{Tr}(\mathbf{T}\mathbf{V}_\mu)\text{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\mu\mathcal{F}_{22}(h)\partial^\nu\mathcal{F}'_{22}(h)$$
$$\mathcal{P}_{23}(h) = \text{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)(\text{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{23}(h)$$
$$\mathcal{P}_{24}(h) = \text{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\text{Tr}(\mathbf{T}\mathbf{V}^\mu)\text{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{24}(h)$$
$$\mathcal{P}_{25}(h) = (\text{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\partial^\nu\mathcal{F}_{25}(h)$$
$$\mathcal{P}_{26}(h) = (\text{Tr}(\mathbf{T}\mathbf{V}_\mu)\text{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{26}(h)$$

Decorrelating Higgs and TGV

arxiv:1311.1823

In the linear case[4]

$$\left.\begin{aligned}\mathcal{O}_B &= \frac{ieg^2}{8}A_{\mu\nu}W^{-\mu}W^{+\nu}(v+h)^2 - \frac{ie^2g}{8\cos\theta_W}Z_{\mu\nu}W^{-\mu}W^{+\nu}(v+h)^2 \\ &\quad -\frac{eg}{4\cos\theta_W}A_{\mu\nu}Z^{\mu}\partial^{\nu}h(v+h) + \frac{e^2}{4\cos^2\theta_W}Z_{\mu\nu}Z^{\mu}\partial^{\nu}h(v+h)\end{aligned}\right\}\ \text{Higgs-TGV Correlated!}$$

whereas in the non-linear case

$$\left.\begin{aligned}\mathcal{P}_2(h) &= 2ieg^2A_{\mu\nu}W^{-\mu}W^{+\nu}\mathcal{F}_2(h) - 2\frac{ie^2g}{\cos\theta_W}Z_{\mu\nu}W^{-\mu}W^{+\nu}\mathcal{F}_2(h) \\ \mathcal{P}_4(h) &= -\frac{eg}{\cos\theta_W}A_{\mu\nu}Z^{\mu}\partial^{\nu}\mathcal{F}_4(h) + \frac{e^2}{\cos^2\theta_W}Z_{\mu\nu}Z^{\mu}\partial^{\nu}\mathcal{F}_4(h)\end{aligned}\right\}\ \text{Higgs-TGV may be decorrelated!}$$

[4] Parallel reasoning applies to $\mathcal{O}_W$ and $\mathcal{P}_3 - \mathcal{P}_5$

Decorrelating Higgs and TGV

arxiv:1311.1823

Analysis using Higgs and TGV data[5] of

$$\mathcal{P}_G, \mathcal{P}_B, \mathcal{P}_W, \mathcal{P}_1, \mathcal{P}_2, \mathcal{P}_3, \mathcal{P}_4, \mathcal{P}_5, \mathcal{P}_C, \mathcal{P}_T \text{ and } \mathcal{P}_H\,,$$

After taking into consideration tree level contributions of $\mathcal{P}_T$ and $\mathcal{P}_1$ to EWPD, the relevant parameters for the analysis are[6]:

$$a_G, a_B, a_W, c_2, c_3, a_4, a_5, (2a_c - c_C) \text{ and } c_H\,,$$

But we can rotate instead to:

$$a_G, a_B, a_W, \Sigma_B, \Delta_B, \Sigma_W, \Delta_W, (2a_c - c_C) \text{ and } c_H\,,$$

where

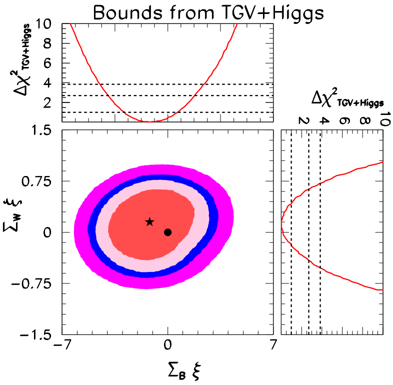
$$\Sigma_B \equiv 4(2c_2 + a_4)\,, \qquad \Sigma_W \equiv 2(2c_3 - a_5)\,,$$
$$\Delta_B \equiv 4(2c_2 - a_4)\,, \qquad \Delta_W \equiv 2(2c_3 + a_5)\,,$$

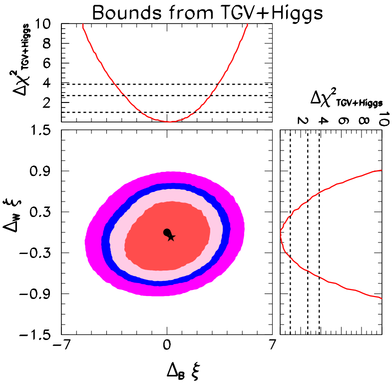
defined such that at order $d = 6$ of the linear regime $\Sigma_B = c_B$, $\Sigma_W = c_W$, while $\Delta_B = \Delta_W = 0$.

[5] The analysis details as in the linear fit

[6] For simplicity here $a_i = c_i * a_i$

Decorrelating Higgs and TGV





Left:A BSM sensor irrespective of the type of expansion: constraints from TGV and Higgs data on the combinations $\Sigma_B = 4(2c_2 + a_4)$ and $\Sigma_W = 2(2c_3 - a_5)$, which converge to c_B and c_W in the linear $d = 6$ limit.

Right:A non-linear versus linear discriminator: constraints on the combinations $\Delta_B = 4(2c_2 - a_4)$ and $\Delta_W = 2(2c_3 + a_5)$, which would take zero values in the linear (order $d = 6$) limit (as well as in the SM), indicated by the dot at $(0, 0)$.

Higher order differences

arxiv:1311.1823

Reshuffling → interactions that are strongly suppressed in one case may be leading corrections in the other.

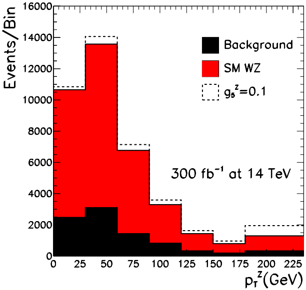
More on TGV!

- At *first* order in non-linear expansion (but at dim–8 in the linear one) $\mathcal{P}_{14}$ contributes to anomalous TGV: g_5^Z (C- and P-odd but CP even).

$$\mathcal{L}_{WWV} = -ig_5^V \, \epsilon^{\mu\nu\rho\sigma} \left(W_\mu^+ \partial_\rho W_\nu^- - W_\nu^- \partial_\rho W_\mu^+\right) V_\sigma$$

$$\to -\xi^2 \frac{g^3}{\cos\theta_W} \, \varepsilon^{\mu\nu\rho\lambda} [p_{+\lambda} + p_{-\lambda}]$$

- At first order in the linear expansion $\mathcal{O}_{WWW} = i\epsilon_{ijk} \hat{W}_\mu^{i\,\nu} \hat{W}_\nu^{j\,\rho} \hat{W}_\rho^{k\,\mu}$ gives contribution to anomalous TGV λ_V



- Chiral expansion: several operators contribute to QGVs without inducing TGVs → coefficients less constrained at present (larger deviations may be expected).
  Linear expansion: modifications of QGVs that do not induce changes to TGVs appear only when $d = 8$.

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

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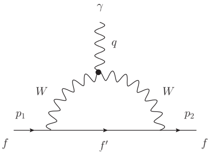
Fermionic **EDMs** (sensitive to $\tilde{\kappa}_\gamma$, $\tilde{g}_{h\gamma\gamma}$)



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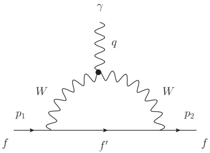
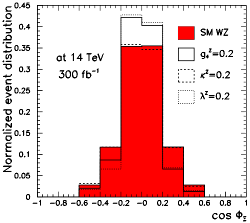


CP–violating **TGV**



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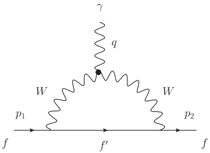

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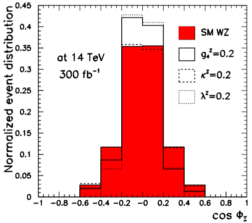

CP–violation on **Higgs physics**: $h \to ZZ$, *e. g.* CMS analysis:

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

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:

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

- **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.

- Study non–linear or chiral Lagrangian $\rightarrow$ more freedom $\rightarrow$ Testable decorrelations!
- In addition, promising new signals specific for one of the expansions: g_5^Z.

arXiv:1207.1344, 1211.4580, 1304.1151, 1311.1823

- ◇ ~~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

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THANK YOU!

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