The Higgs Legacy of the LHC Run I

Juan González Fraile

Universität Heidelberg

Tyler Corbett, O. J. P. Éboli, Dorival Gonçalves, J. G–F,
M. C. Gonzalez–Garcia, Tilman Plehn and Michael Rauch

arXiv:1207.1344, 1211.4580, 1304.1151, **1505.05516**

How to access the EWSB mechanism?

- **Run I**: the Higgs boson was discovered $\rightarrow$ **a particle directly related to the EWSB.**

  Many studies of the Higgs properties have been performed: that could be afterall one of the fastest track to understand the origin of the EWSB.

How to access the EWSB mechanism?

- **Run I**: the Higgs boson was discovered $\rightarrow$ **a particle directly related to the EWSB.**

  Many studies of the Higgs properties have been performed: that could be afterall one of the fastest track to understand the origin of the EWSB.

$\diamond$ Is there a preferred framework to study the Higgs interactions?

$\diamond$ How can we exploit all available data?

How to access the EWSB mechanism?

- **Run I**: the Higgs boson was discovered $\rightarrow$ **a particle directly related to the EWSB.**

  Many studies of the Higgs properties have been performed: that could be afterall one of the fastest track to understand the origin of the EWSB.

  $\diamond$ Is there a preferred framework to study the Higgs interactions?

  $\diamond$ How can we exploit all available data?

- **Run II**: ~ 3 fb^{-1} delivered as of last week

How to access the EWSB mechanism?

- **Run I**: the Higgs boson was discovered $\rightarrow$ **a particle directly related to the EWSB.**

  Many studies of the Higgs properties have been performed: that could be afterall one of the fastest track to understand the origin of the EWSB.

  $\diamond$ Is there a preferred framework to study the Higgs interactions?

  $\diamond$ How can we exploit all available data?

- **Run II**: ~ 3 fb^{-1} delivered as of last week

Outline

- Δ-framework for Higgs interactions.
- Effective Lagrangian approach for the Higgs.
- Adding distributions: p_T, $\Delta\phi_{jj}$ and off-shell–$m_{4\ell}$.

Δ–framework: rate–based analysis

Study the Higgs interactions using as a parametrization the SM operators with free couplings:

$$g_x = g_x^{\text{SM}}\ (1+\Delta_x)$$
$$g_\gamma = g_\gamma^{\text{SM}}\ (1+\Delta_\gamma^{\text{SM}}+\Delta_\gamma) \equiv g_\gamma^{\text{SM}}\ (1+\Delta_\gamma^{\text{SM+NP}})$$
$$g_g = g_g^{\text{SM}}\ (1+\Delta_g^{\text{SM}}+\Delta_g) \equiv g_g^{\text{SM}}\ (1+\Delta_g^{\text{SM+NP}})\ ,$$

Thus, the Lagrangian is:

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \Delta_W\ g m_W H\ W^\mu W_\mu + \Delta_Z\ \frac{g}{2c_w} m_Z H\ Z^\mu Z_\mu - \sum_{\tau,b,t} \Delta_f\ \frac{m_f}{v} H\left(\bar{f}_R f_L + \text{h.c.}\right)$$
$$+ \Delta_g F_G\ \frac{H}{v}\ G_{\mu\nu}G^{\mu\nu} + \Delta_\gamma F_A\ \frac{H}{v}\ A_{\mu\nu}A^{\mu\nu} + \text{invisible decays}\ ,$$

Can be linked to extended Higgs sectors, 2HDM, Higgs Portals etc → see 1308.1979

Can also be almost directly linked to the LO non–linear Effective Lagrangian → see 1504.01707

SFITTER

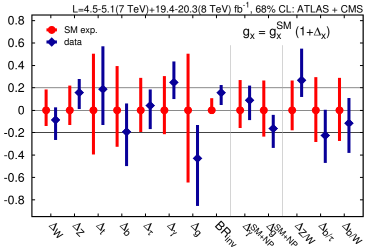
- For the analyses based on event rates (159 measurements):

Modes	ATLAS	CMS
$H \to WW$	1412.2641	1312.1129
$H \to ZZ$	1408.5191	1312.5353
$H \to \gamma\gamma$	1408.7084	1407.0558
$H \to \tau\bar{\tau}$	1501.04943	1401.5041
$H \to b\bar{b}$	1409.6212	1310.3687
$H \to Z\gamma$	ATLAS-CONF-2013-009	1307.5515
$H \to$ invisible	1402.3244, ATLAS-CONF-2015-004	1404.1344
	1502.01518, 1504.04324,	CMS-PAS-HIG-14-038
$t\bar{t}H$ production	1408.7084,1409.3122	1407.0558,1408.1682
		1502.02485
kinematic distributions	1409.6212,1407.4222	
off-shell rate	ATLAS-COM-CONF-2014-052	1405.3455

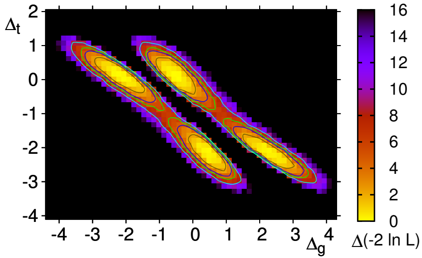
- Correlated experimental uncertainties
- Default: Box shaped theoretical uncertainties
- Default: Uncorrelated production theoretical uncertainties

Δ–framework: results

◇ 68% CL error bars:

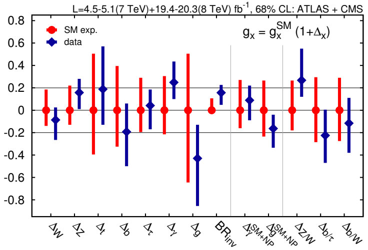


◇ Well understood correlations:

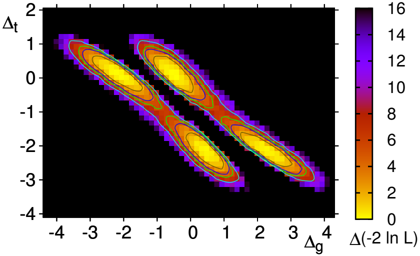


Δ–framework: results

◇ 68% CL error bars:



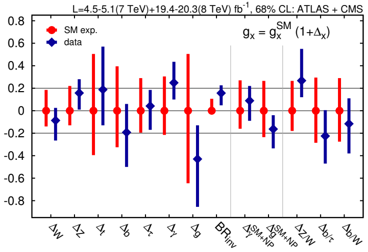
◇ Well understood correlations:



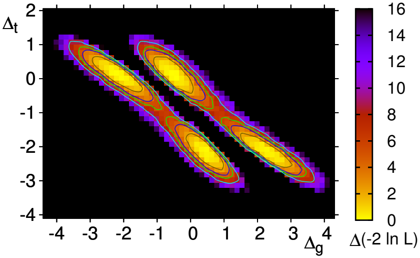
◇ Everything consistent with the SM (what a surprise...)

Δ–framework: results

◇ 68% CL error bars:



◇ Well understood correlations:

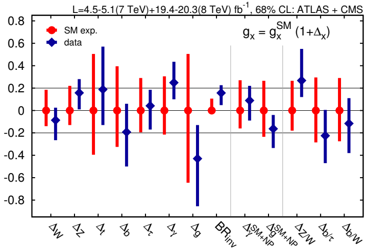


◇ Everything consistent with the SM (what a surprise...)

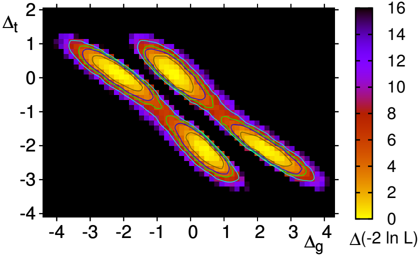
◇ Δ–framework is well aligned with experimental measurements. Suitable for testing different analysis details→ **1505.05516**

Δ–framework: results

◇ 68% CL error bars:

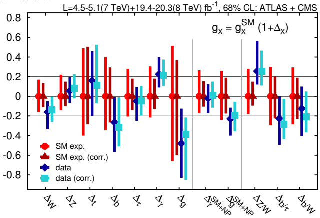


◇ Well understood correlations:



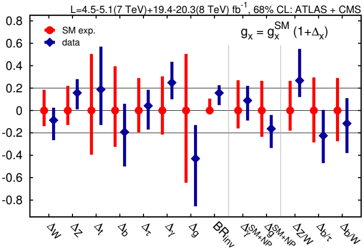
◇ Everything consistent with the SM (what a surprise...)

◇ Correlated theory uncertainties:

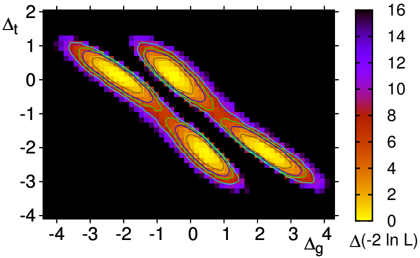


Δ–framework: results

◇ 68% CL error bars:

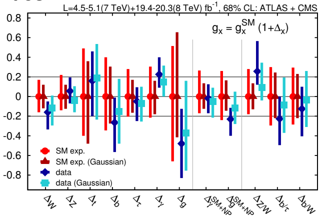


◇ Well understood correlations:



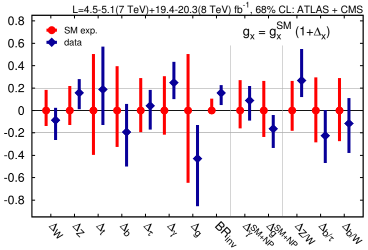
◇ Everything consistent with the SM (what a surprise...)

◇ Gaussian theory uncertainties:

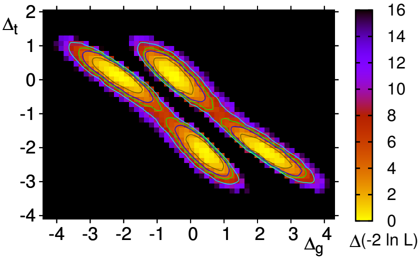


Δ–framework: results

◇ 68% CL error bars:

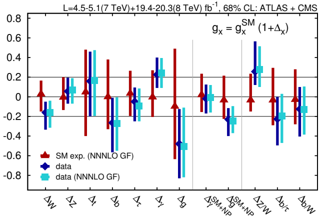


◇ Well understood correlations:



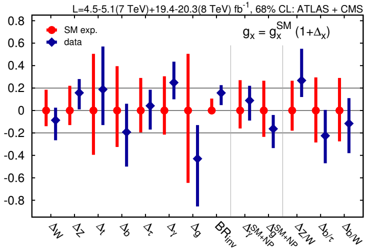
◇ Everything consistent with the SM (what a surprise...)

◇ N^{3}LO for gluon fusion:

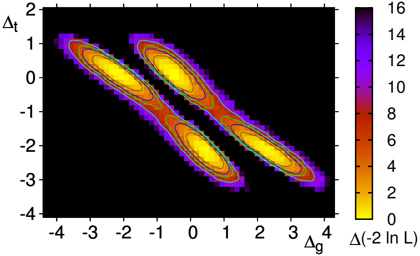


∆–framework: results

◇ 68% CL error bars:



◇ Well understood correlations:



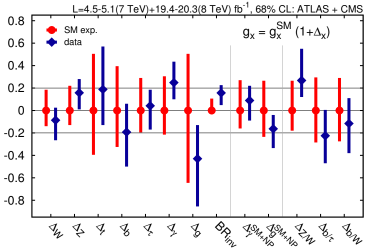
◇ Everything consistent with the SM (what a surprise...)

◇ ∆–framework is well aligned with experimental measurements. Suitable for testing different analysis details→ **1505.05516**

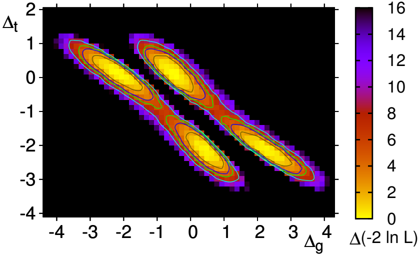
◇ ∆–framework only suitable for rate–based analysis, and only for Higgs interactions.

Δ–framework: results

◇ 68% CL error bars:



◇ Well understood correlations:



◇ Everything consistent with the SM (what a surprise...)

◇ Δ–framework is well aligned with experimental measurements. Suitable for testing different analysis details→ **1505.05516**

◇ Δ–framework only suitable for rate–based analysis, and only for Higgs interactions.

How to add information from kinematic distributions? EWSB sector?→ Effective Lagrangian!

Effective Lagrangian Approach

Common idea $\sim O(30)$ years: SM success (lack of unexpected) motivates model independent parametrization for NP $\rightarrow \mathcal{L}_{\rm eff}$

Based on symmetries and particle content at low energy:

$$\mathcal{L}_{\rm eff} = \mathcal{L}_0^{\rm SM} + \sum_{m=1}^{\infty} \sum_{n} \frac{f_n^{(4+m)}}{\Lambda^m} \mathcal{O}_n^{(4+m)}$$

First flavor, then LEP/2 and EWPD, TGV, also Higgs at LEP and Tevatron

Effective Lagrangian Approach

Common idea $\sim O(30)$ years: SM success (lack of unexpected) motivates model independent parametrization for NP $\rightarrow \mathcal{L}_{\rm eff}$

Based on symmetries and particle content at low energy:

$$\mathcal{L}_{\rm eff} = \mathcal{L}_0^{\rm SM} + \sum_{m=1}^{\infty} \sum_n \frac{f_n^{(4+m)}}{\Lambda^m} \mathcal{O}_n^{(4+m)}$$

First flavor, then LEP/2 and EWPD, TGV, also Higgs at LEP and Tevatron

Apply it to the Higgs sector!

1207.1344

Effective Lagrangian Approach

Common idea $\sim O(30)$ years: SM success (lack of unexpected) motivates model independent parametrization for NP $\rightarrow \mathcal{L}_{\rm eff}$

Based on symmetries and particle content at low energy:

$$\mathcal{L}_{\rm eff} = \mathcal{L}_0^{\rm SM} + \sum_{m=1}^{\infty} \sum_n \frac{f_n^{(4+m)}}{\Lambda^m} \mathcal{O}_n^{(4+m)}$$

First flavor, then LEP/2 and EWPD, TGV, also Higgs at LEP and Tevatron

Apply it to the Higgs sector!

1207.1344

Alternative to the Δ setup:

- **Correlations** between different sectors: EWPD, TGV and now Higgs!

Effective Lagrangian Approach

Common idea $\sim O(30)$ years: SM success (lack of unexpected) motivates model independent parametrization for NP $\to \mathcal{L}_{\text{eff}}$

Based on symmetries and particle content at low energy:

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_0^{\text{SM}} + \sum_{m=1}^{\infty} \sum_n \frac{f_n^{(4+m)}}{\Lambda^m} \mathcal{O}_n^{(4+m)}$$

First flavor, then LEP/2 and EWPD, TGV, also Higgs at LEP and Tevatron

Apply it to the Higgs sector!

1207.1344

Alternative to the Δ setup:

- **Correlations** between different sectors: EWPD, TGV and now Higgs!$\to$ 1304.1151 (Higgs-TGV)
- **Correlations** between different Higgs couplings $\to$ analysis gets convoluted

Effective Lagrangian Approach

Common idea $\sim O(30)$ years: SM success (lack of unexpected) motivates model independent parametrization for NP $\to \mathcal{L}_{\rm eff}$

Based on symmetries and particle content at low energy:

$$\mathcal{L}_{\rm eff} = \mathcal{L}_0^{\rm SM} + \sum_{m=1}^{\infty} \sum_n \frac{f_n^{(4+m)}}{\Lambda^m} \mathcal{O}_n^{(4+m)}$$

First flavor, then LEP/2 and EWPD, TGV, also Higgs at LEP and Tevatron

Apply it to the Higgs sector!

1207.1344

Alternative to the Δ setup:

- **Correlations** between different sectors: EWPD, TGV and now Higgs! $\to$ 1304.1151 (Higgs-TGV)
- **Correlations** between different Higgs couplings $\to$ analysis gets convoluted
- New Lorentz structures: potential to break/increase sensitivity with kinematics!

Effective Lagrangian: the linear realization

Bottom-up model-independent effective Lagrangian approach:

$$\mathcal{L}_{\rm eff} = \mathcal{L}_0^{\rm SM} + \sum_n \frac{f_n}{\Lambda^2}\mathcal{O}_n$$

Particle content ($SU(2)_L$ doublet), Symmetries (SM, lepton, baryon, CP)

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

Effective Lagrangian: the linear realization

Bottom-up model-independent effective Lagrangian approach:

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_0^{\text{SM}} + \sum_n \frac{f_n}{\Lambda^2}\mathcal{O}_n$$

Particle content ($SU(2)_L$ doublet), Symmetries (SM, lepton, baryon, CP)

Choice of basis (not for today): EOM, huge variety of data **(DATA–DRIVEN)**, focus measurable at LHC:

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

Effective Lagrangian: the linear realization

Bottom-up model-independent effective Lagrangian approach:

$$\mathcal{L}_{\rm eff} = \mathcal{L}_0^{\rm SM} + \sum_n \frac{f_n}{\Lambda^2}\mathcal{O}_n$$

Particle content ($SU(2)_L$ doublet), Symmetries (SM, lepton, baryon, CP)

Choice of basis (not for today): EOM, huge variety of data **(DATA–DRIVEN)**, focus measurable at LHC:[1]

$$\begin{array}{lll}
\mathcal{O}_{GG} = \Phi^\dagger\Phi\; G^a_{\mu\nu}G^{a\mu\nu}, & \mathcal{O}_{WW} = \Phi^\dagger \hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\Phi, & \mathcal{O}_{BB} = \Phi^\dagger \hat{B}_{\mu\nu}\hat{B}^{\mu\nu}\Phi, \\
\mathcal{O}_{\Phi,2} = \frac{1}{2}\partial^\mu\left(\Phi^\dagger\Phi\right)\partial_\mu\left(\Phi^\dagger\Phi\right), & \mathcal{O}_W = (D_\mu\Phi)^\dagger \hat{W}^{\mu\nu}(D_\nu\Phi), & \mathcal{O}_B = (D_\mu\Phi)^\dagger \hat{B}^{\mu\nu}(D_\nu\Phi), \\
\mathcal{O}_{e\Phi,33} = (\Phi^\dagger\Phi)(\bar{L}_3\Phi e_{R,3}), & \mathcal{O}_{u\Phi,33} = (\Phi^\dagger\Phi)(\bar{Q}_3\tilde{\Phi}u_{R,3}), & \mathcal{O}_{d\Phi,33} = (\Phi^\dagger\Phi)(\bar{Q}_3\Phi d_{R,3}) \;,
\end{array}$$

Thus, 9 parameters for Higgs interactions:

$$\frac{f_{GG}}{\Lambda^2}, \frac{f_{WW}}{\Lambda^2}, \frac{f_{BB}}{\Lambda^2}, \frac{f_{\phi,2}}{\Lambda^2}, \frac{f_W}{\Lambda^2}, \frac{f_B}{\Lambda^2}, \frac{f_\tau}{\Lambda^2}, \frac{f_b}{\Lambda^2}, \frac{f_t}{\Lambda^2}$$

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

Effective Lagrangian: the linear realization

Bottom-up model-independent effective Lagrangian approach:

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_0^{\text{SM}} + \sum_n \frac{f_n}{\Lambda^2}\mathcal{O}_n$$

Particle content ($SU(2)_L$ doublet), Symmetries (SM, lepton, baryon, CP)

Choice of basis (not for today): EOM, huge variety of data **(DATA–DRIVEN)**, focus measurable at LHC:[1]

$$\begin{array}{lll}
\mathcal{O}_{GG} = \Phi^\dagger\Phi\; G^a_{\mu\nu}G^{a\mu\nu}, & \mathcal{O}_{WW} = \Phi^\dagger \hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\Phi, & \mathcal{O}_{BB} = \Phi^\dagger \hat{B}_{\mu\nu}\hat{B}^{\mu\nu}\Phi, \\
\mathcal{O}_{\Phi,2} = \frac{1}{2}\partial^\mu\left(\Phi^\dagger\Phi\right)\partial_\mu\left(\Phi^\dagger\Phi\right), & \mathcal{O}_{W} = (D_\mu\Phi)^\dagger\hat{W}^{\mu\nu}(D_\nu\Phi), & \mathcal{O}_{B} = (D_\mu\Phi)^\dagger\hat{B}^{\mu\nu}(D_\nu\Phi), \\
\mathcal{O}_{e\Phi,33} = (\Phi^\dagger\Phi)(\bar{L}_3\Phi e_{R,3}), & \mathcal{O}_{u\Phi,33} = (\Phi^\dagger\Phi)(\bar{Q}_3\tilde{\Phi}u_{R,3}), & \mathcal{O}_{d\Phi,33} = (\Phi^\dagger\Phi)(\bar{Q}_3\Phi d_{R,3})\;,
\end{array}$$

Thus, 9 parameters for Higgs interactions:

$$\frac{f_{GG}}{\Lambda^2}, \frac{f_{WW}}{\Lambda^2}, \frac{f_{BB}}{\Lambda^2}, \frac{f_{\phi,2}}{\Lambda^2}, \frac{f_{W}}{\Lambda^2}, \frac{f_{B}}{\Lambda^2}, \frac{f_{\tau}}{\Lambda^2}, \frac{f_{b}}{\Lambda^2}, \frac{f_{t}}{\Lambda^2}$$

Let's see them in unitary gauge

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

Effective Lagrangian for Higgs Interactions

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

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

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

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

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

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

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

Effective Lagrangian for Higgs Interactions

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

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

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

Effective Lagrangian for Higgs Interactions

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

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

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

Effective Lagrangian for Higgs Interactions

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

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

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

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

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

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

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

Effective Lagrangian for Higgs Interactions

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

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

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

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

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

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

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

Effective Lagrangian for Higgs Interactions

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

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

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

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

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

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

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

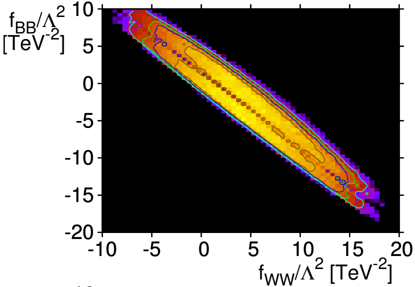
Effective Lagrangian for Higgs Interactions

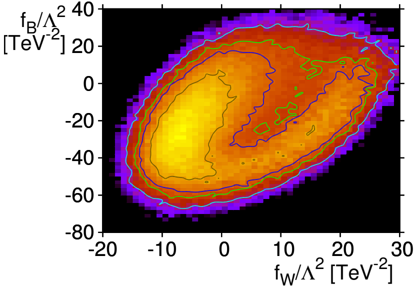
$$\begin{aligned}
\mathcal{L}_{\rm eff}^{\rm HVV} &= g_{Hgg}\; HG^a_{\mu\nu}G^{a\mu\nu} + g_{H\gamma\gamma}\; HA_{\mu\nu}A^{\mu\nu} + g^{(1)}_{HZ\gamma}\; A_{\mu\nu}Z^\mu\partial^\nu H + g^{(2)}_{HZ\gamma}\; HA_{\mu\nu}Z^{\mu\nu} \\
&+ g^{(1)}_{HZZ}\; Z_{\mu\nu}Z^\mu\partial^\nu H + g^{(2)}_{HZZ}\; HZ_{\mu\nu}Z^{\mu\nu}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

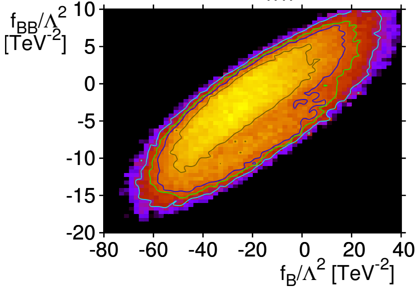
$$\mathcal{L}_{\rm eff}^{Hff} = g^f_{Hij}\bar{f}_L f_R H + \text{h.c.}$$

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

A variety of correlations

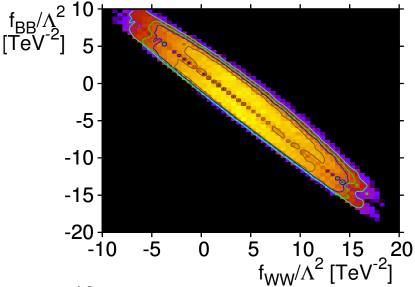


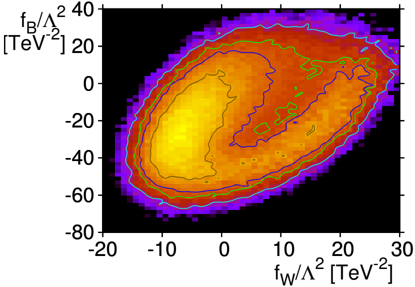


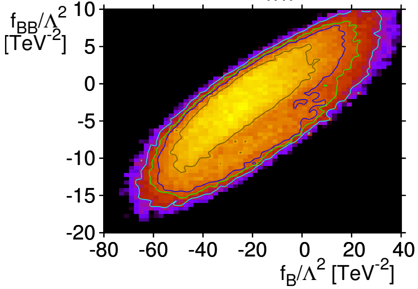


2-d correlations with 68%, 90%, 95% and 99% CL allowed regions in the planes $f_{WW} \times f_{BB}$, $f_W \times f_B$, and $f_B \times f_{BB}$ (TeV$^{-2} \times$ TeV^{-2}).

A variety of correlations





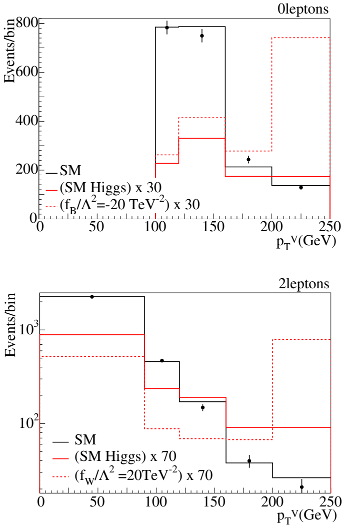


2-d correlations with 68%, 90%, 95% and 99% CL allowed regions in the planes $f_{WW} \times f_{BB}$, $f_W \times f_B$, and $f_B \times f_{BB}$ (TeV$^{-2}\times$ TeV^{-2}).

Lorentz structures not exploited so far...

Add kinematic distributions!

p_T^V in associated production



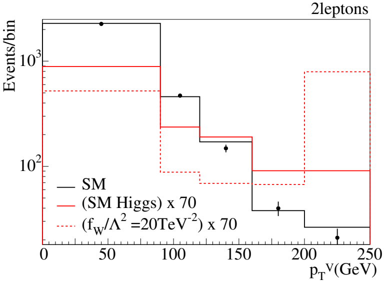
ATLAS $H \to b\bar{b}$ (1409.6212)

p_T^V is sensitive to maximum energy flow of the event

Background rapidly decreases, while enhancement for dimension-6 operators

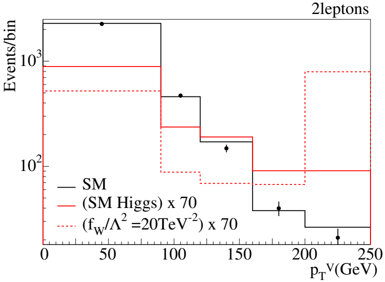
p_T^V implementation

Simulation with usual tools: FeynRules, MadGraph5, Pythia, PGS4/DELPHES



p_T^V implementation

Simulation with usual tools: FeynRules, MadGraph5, Pythia, PGS4/DELPHES



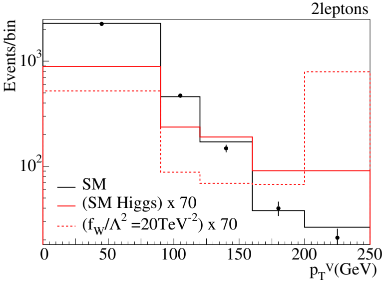
- Distributions for cut–based cross check
  - ◇ Less precise
  - ◇ Shifted central measurement

MVA–8 TeV: $\mu = 0.65 \pm 0.4$
Cut–based–8TeV: $\mu = 1.23 \pm 0.6$

Thus, combination is not straightforward.

p_T^V implementation

Simulation with usual tools: FeynRules, MadGraph5, Pythia, PGS4/DELPHES



- Distributions for cut–based cross check
  - ◇ Less precise
  - ◇ Shifted central measurement

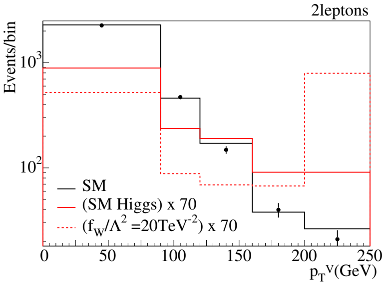
MVA–8 TeV: $\mu = 0.65 \pm 0.4$
Cut–based–8TeV: $\mu = 1.23 \pm 0.6$

Thus, combination is not straightforward.

- Optimal:
  - ◇ fix normalization from MVA

p_T^V implementation

Simulation with usual tools: FeynRules, MadGraph5, Pythia, PGS4/DELPHES



- Distributions for cut–based cross check
  - ◇ Less precise
  - ◇ Shifted central measurement

MVA–8 TeV: $\mu = 0.65 \pm 0.4$
Cut–based–8TeV: $\mu = 1.23 \pm 0.6$

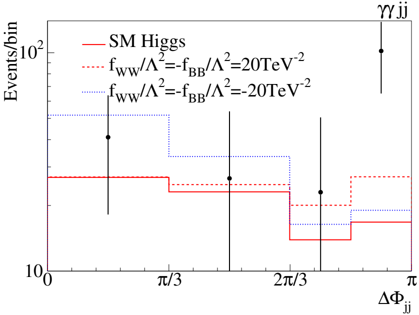
Thus, combination is not straightforward.

- Optimal:
  - ◇ fix normalization from MVA
  - ◇ define *asymmetries*

$$A_i = \frac{\text{bin}_{i+1} - \text{bin}_i}{\text{bin}_{i+1} + \text{bin}_i} \ .$$

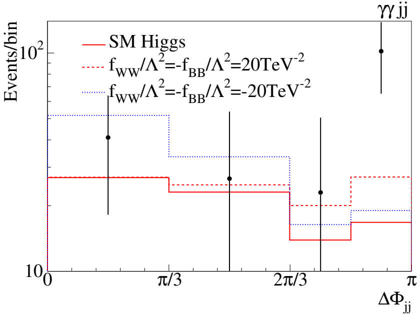
Added to the likelihood function propagating the uncertainties

$\Delta\Phi_{jj}$ in weak boson fusion



ATLAS $H \to \gamma\gamma$ differential study (1407.4222)

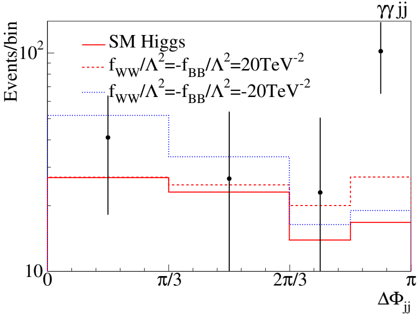
$\Delta\Phi_{jj}$ in weak boson fusion



ATLAS $H \to \gamma\gamma$ differential study (1407.4222)

- Dimension-6 contributions peak at 0 or π.

$\Delta\Phi_{jj}$ in weak boson fusion

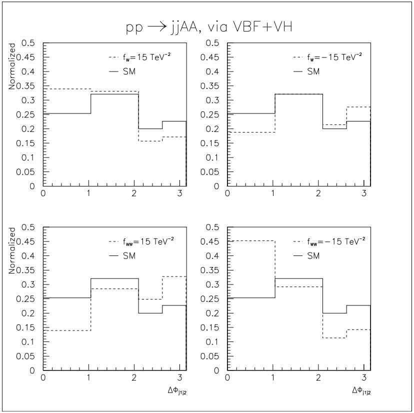


ATLAS $H \to \gamma\gamma$ differential study (1407.4222)

- Dimension-6 contributions peak at 0 or π.
- **Keep in mind**

◇ WBF better for WW and $\tau\tau$,
◇ No WFB specific cuts: both GGF and VH mess up

$\Delta\Phi_{jj}$ in weak boson fusion

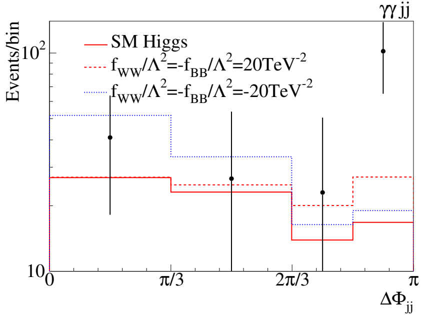


- Dimension-6 contributions peak at 0 or π.
- **Keep in mind**

  ◇ WBF better for WW and $\tau\tau$,
  ◇ No WFB specific cuts: both GGF and VH mess up

  Thus, power dramatically diminished.

$\Delta\Phi_{jj}$ in weak boson fusion



ATLAS $H \to \gamma\gamma$ differential study (1407.4222)

- Dimension-6 contributions peak at 0 or π.
- **Keep in mind**

  ◇ WBF better for WW and $\tau\tau$,
  ◇ No WFB specific cuts: both GGF and VH mess up

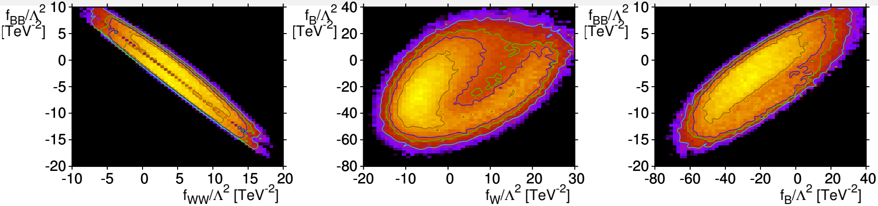
  Thus, power dramatically diminished.
- Combination: again, fix normalization and define sensitive *asymmetries*:

$$A_1 = \frac{(\sigma < \frac{\pi}{3}) + (\sigma > \frac{2\pi}{3}) - (\frac{\pi}{3} < \sigma < \frac{2\pi}{3})}{(\sigma < \frac{\pi}{3}) + (\sigma > \frac{2\pi}{3}) + (\frac{\pi}{3} < \sigma < \frac{2\pi}{3})},$$

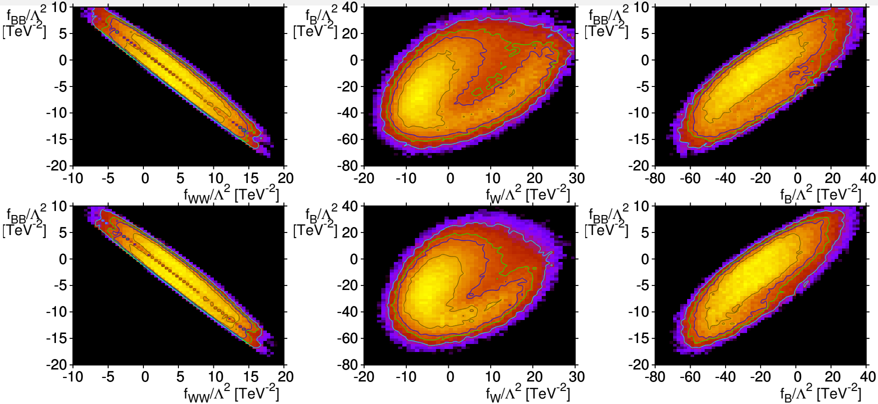
$$A_2 = \frac{(\sigma > \frac{2\pi}{3}) - (\sigma < \frac{\pi}{3})}{(\sigma > \frac{2\pi}{3}) + (\sigma < \frac{\pi}{3})}$$

$$A_3 = \frac{(\sigma > \frac{5\pi}{6}) - (\frac{2\pi}{3} < \sigma < \frac{5\pi}{6})}{(\sigma > \frac{5\pi}{6}) + (\frac{2\pi}{3} < \sigma < \frac{5\pi}{6})}.$$

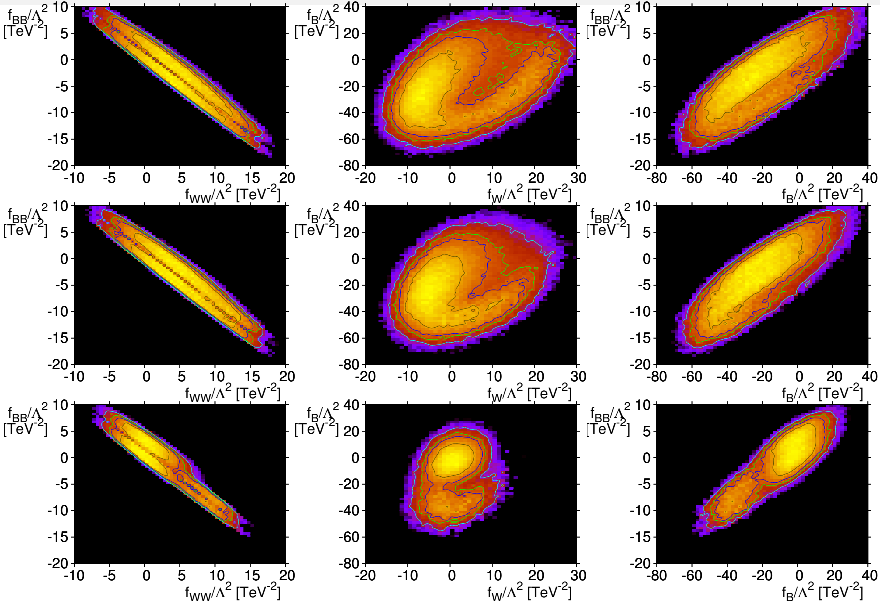
Full dimension-6 analysis



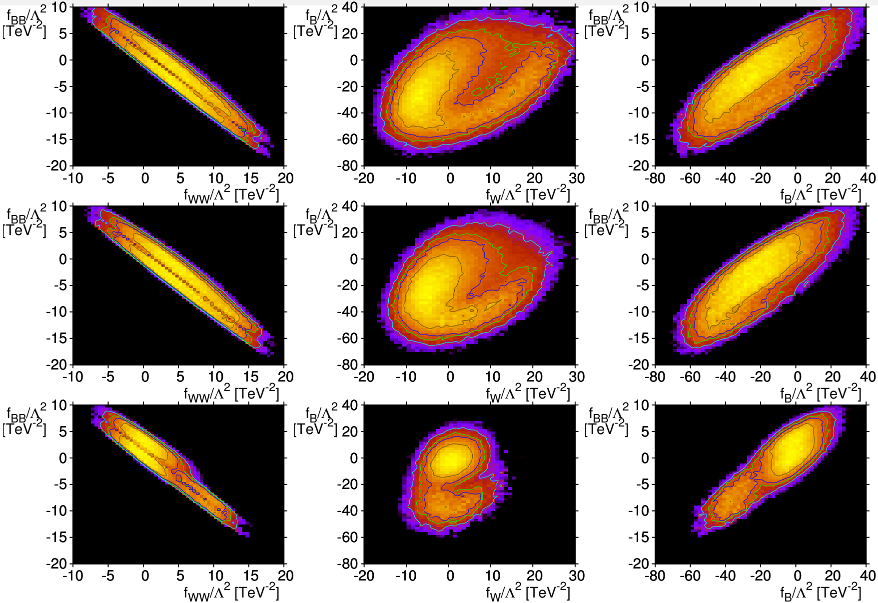
Full dimension-6 analysis



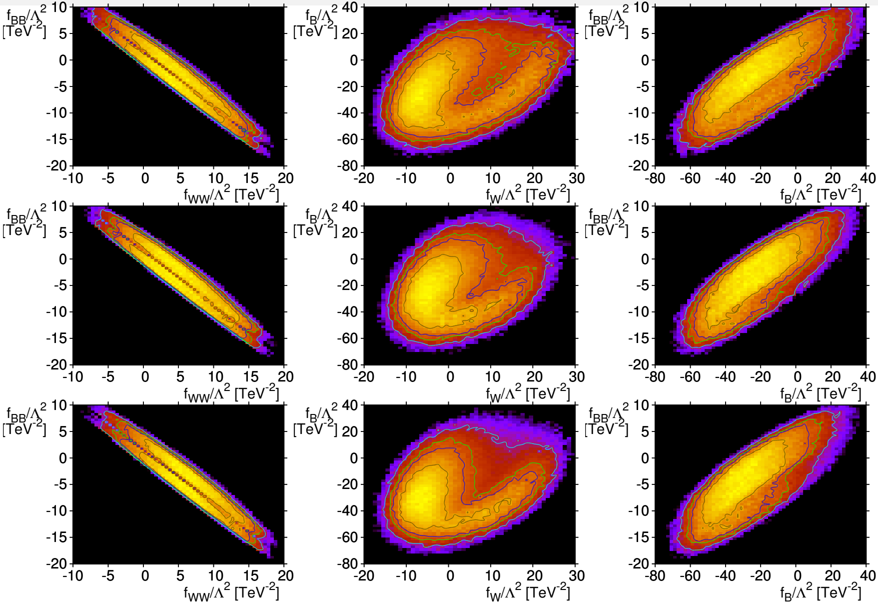
Full dimension-6 analysis



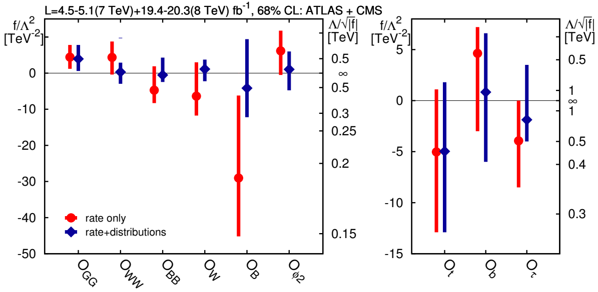
EFT from Effective?



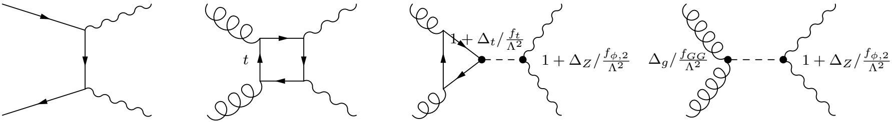
EFT from Effective?



1dimensional results



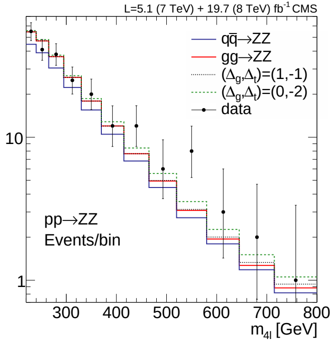
$m_{4\ell}$ from off–shell measurements



Continuum background $q\bar{q}\,(gg) \to ZZ$ (left) and Higgs signal $gg \to H \to ZZ$ (right).

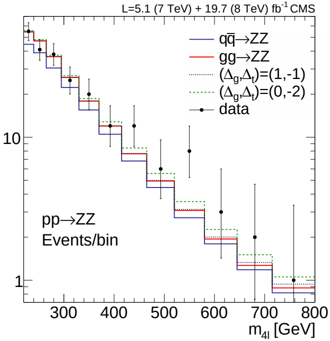
$$\begin{aligned}
\mathcal{M}_{gg\to ZZ} &= (1+\Delta_Z)\left[(1+\Delta_t)\mathcal{M}_t + \Delta_g\mathcal{M}_g\right] + \mathcal{M}_c \\
\frac{d\sigma}{dm_{4\ell}} &= (1+\Delta_Z)\left[(1+\Delta_t)\frac{d\sigma_{tc}}{dm_{4\ell}} + \Delta_g\frac{d\sigma_{gc}}{dm_{4\ell}}\right] \\
&\quad + (1+\Delta_Z)^2\left[(1+\Delta_t)^2\frac{d\sigma_{tt}}{dm_{4\ell}} + (1+\Delta_t)\Delta_g\frac{d\sigma_{tg}}{dm_{4\ell}} + \Delta_g^2\frac{d\sigma_{gg}}{dm_{4\ell}}\right] + \frac{d\sigma_c}{dm_{4\ell}}\ .
\end{aligned}$$

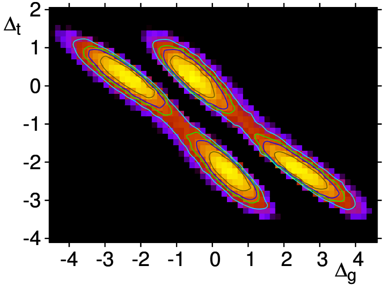
$m_{4\ell}$ from off–shell measurements



- Here we can use ATLAS and CMS
- Bins directly into the analysis

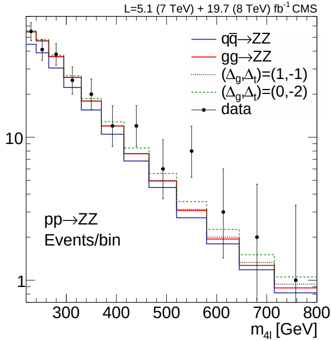
$m_{4\ell}$ from off–shell measurements

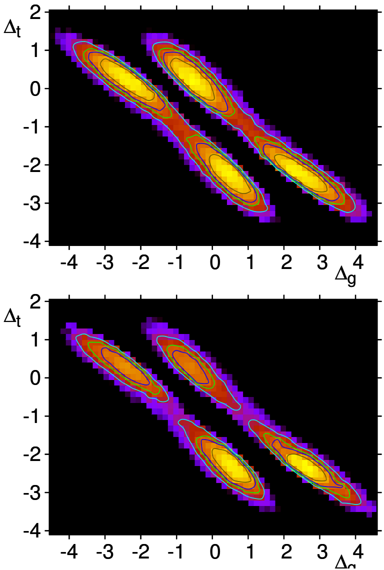




- Here we can use ATLAS and CMS
- Bins directly into the analysis

$m_{4\ell}$ from off–shell measurements





- Here we can use ATLAS and CMS
- Bins directly into the analysis

Γ_H from off–shell measurements

$$\sigma^{\text{on-shell}}_{i\to H\to f} \propto \frac{g_i^2(m_H)\, g_f^2(m_H)}{\Gamma_H} \qquad \text{vrs.} \qquad \sigma^{\text{off-shell}}_{i\to H^*\to f} \propto g_i^2(m_{4\ell})\, g_f^2(m_{4\ell}) \quad .$$

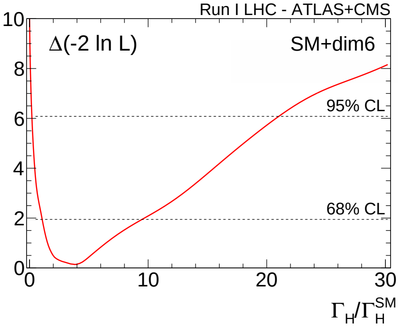
- May allow to bound the Higgs total decay width under certain assumptions.
- Here including effective operators (and not only the gluon fusion top-loop induced production).

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \Delta_W\ g m_W H\ W^\mu W_\mu + \Delta_Z\ \frac{g}{2c_w} m_Z H\ Z^\mu Z_\mu - \sum_{\tau,b,t} \Delta_f\ \frac{m_f}{v} H\ (\bar{f}_R f_L + \text{h.c.})$$
$$+ \Delta_g F_G\ \frac{H}{v}\ G_{\mu\nu} G^{\mu\nu} + \Delta_\gamma F_A\ \frac{H}{v}\ A_{\mu\nu} A^{\mu\nu} + \text{invisible decays} + \text{unobservable decays}\ .$$

Γ_H from off–shell measurements

$$\sigma^{\text{on-shell}}_{i\to H\to f} \propto \frac{g_i^2(m_H)\, g_f^2(m_H)}{\Gamma_H} \qquad \text{vrs.} \qquad \sigma^{\text{off-shell}}_{i\to H^*\to f} \propto g_i^2(m_{4\ell})\, g_f^2(m_{4\ell}) \quad .$$

- $\Gamma_H < 9.3\Gamma_H^{SM}$ 68% CL
- May allow to bound the Higgs total decay width under certain assumptions.
- Here including effective operators (and not only the gluon fusion top-loop induced production).



$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \Delta_W\; g m_W H\; W^\mu W_\mu + \Delta_Z\; \frac{g}{2c_w} m_Z H\; Z^\mu Z_\mu - \sum_{\tau,b,t} \Delta_f\; \frac{m_f}{v} H\left(\bar{f}_R f_L + \text{h.c.}\right)$$

$$+\, \Delta_g F_G\; \frac{H}{v}\; G_{\mu\nu}G^{\mu\nu} + \Delta_\gamma F_A\; \frac{H}{v}\; A_{\mu\nu}A^{\mu\nu} + \text{invisible decays} + \text{unobservable decays}\ .$$

Conclusions

arXiv:1505.05516

- So far the Higgs boson seems completely SM–like.
  Δ–framework aligned with experimental measurements: test different analysis features.

- Moving to Effective Lagrangian analysis: **Kinematic distributions** essential.
  Restricting to the Higgs sector: biggest differences between EFT and Δ–framework are anomalous momentum dependence on some vertices.

- Optimal implementation of kinematic distributions in a global analysis is feasible:
  ◇ **Increased sensitivity.**
  ◇ **Remove correlations.**

  We start being sensitive to more and more deviations: for instance $\mathcal{O}_{WW}$ and $\mathcal{O}_{BB}$ in weak sector.
  Drawback: consistenty of EFT will need to be carefully checked.

- Off-shell distributions are also starting to be sensitive to gluon and top operators.
  ◇ Disentangle $\mathcal{O}_{GG}$ from $\mathcal{O}_t$ (and sign of top-Yukawa!).
  ◇ Total width $\Gamma_H < 9.3\Gamma_H^{SM}$ 68% CL.

Conclusions

arXiv:1505.05516

- So far the Higgs boson seems completely SM–like.
  Δ–framework aligned with experimental measurements: test different analysis features.

- Moving to Effective Lagrangian analysis: **Kinematic distributions** essential.
  Restricting to the Higgs sector: biggest differences between EFT and Δ–framework are anomalous momentum dependence on some vertices.

- Optimal implementation of kinematic distributions in a global analysis is feasible:
  $\diamond$ **Increased sensitivity.**
  $\diamond$ **Remove correlations.**

  We start being sensitive to more and more deviations: for instance $\mathcal{O}_{WW}$ and $\mathcal{O}_{BB}$ in weak sector.
  Drawback: consistenty of EFT will need to be carefully checked.

- Off-shell distributions are also starting to be sensitive to gluon and top operators.
  $\diamond$ Disentangle $\mathcal{O}_{GG}$ from $\mathcal{O}_t$ (and sign of top-Yukawa!).
  $\diamond$ Total width $\Gamma_H < 9.3\Gamma_H^{SM}$ 68% CL.

Thank you!