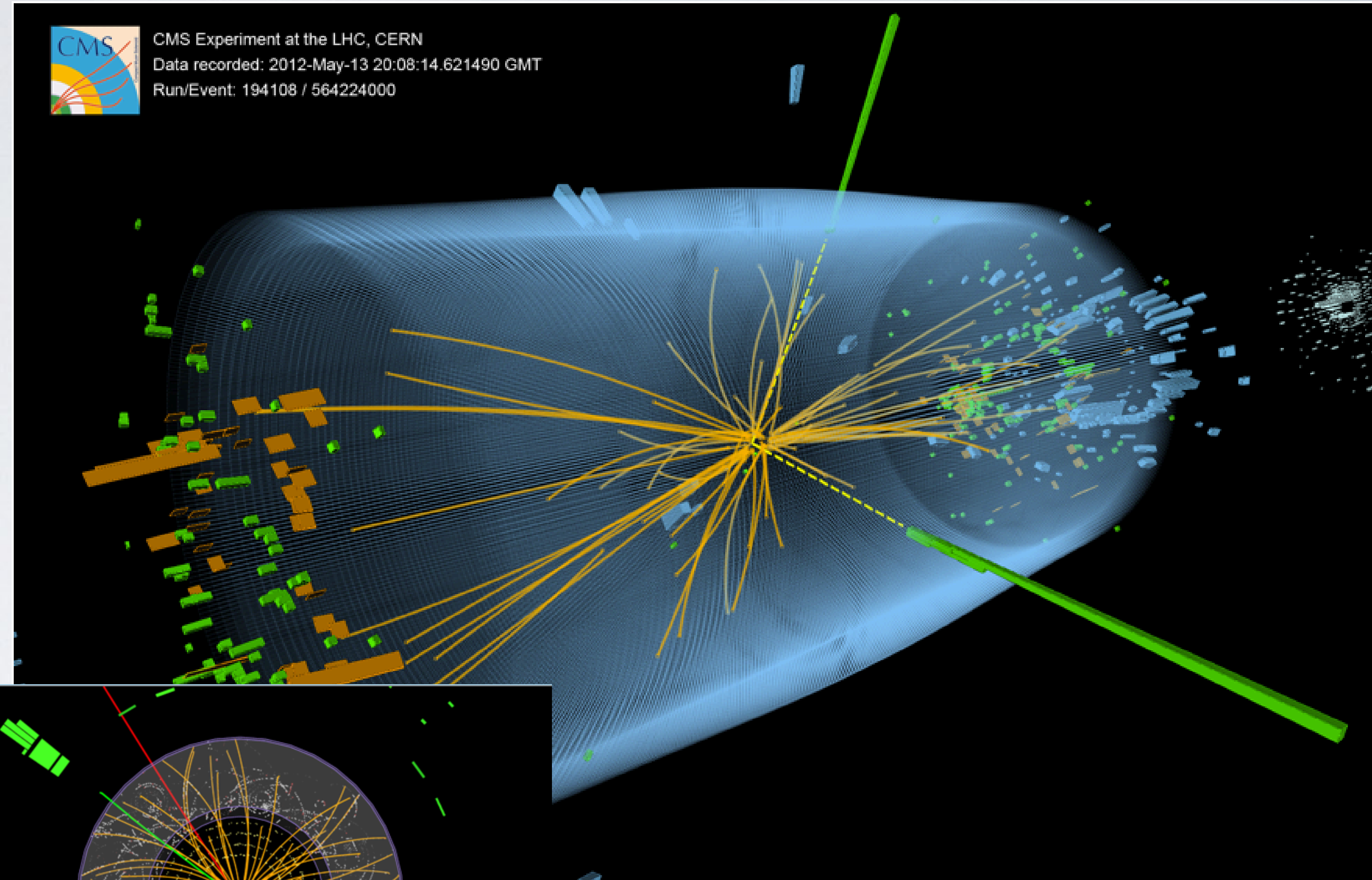
XLII International Meeting on Fundamental Physics

DYNAMICAL HIGGS

Luca Merlo

January 30th 2014, Benasque, Spain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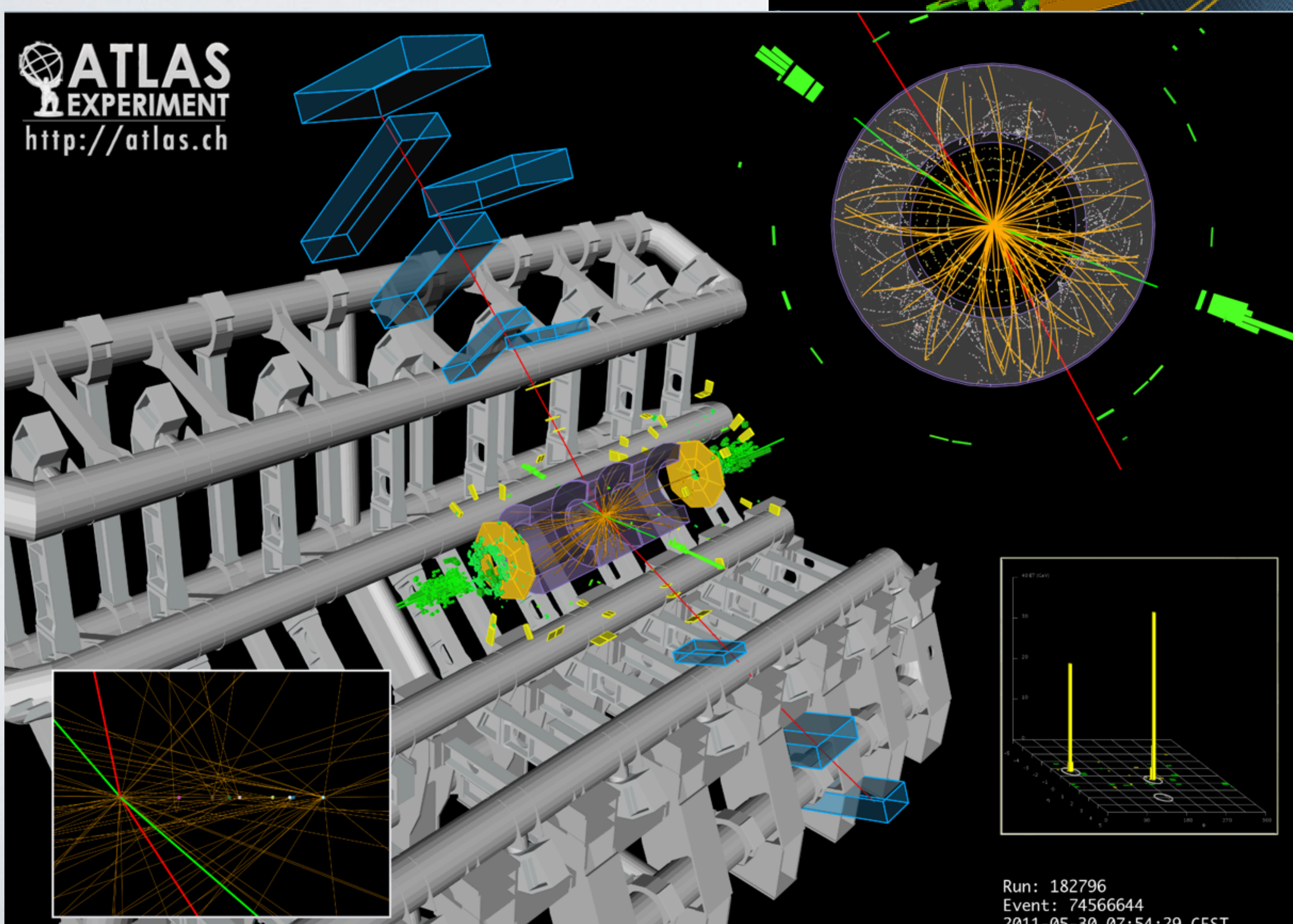
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EXPERIMENT
http://atlas.ch
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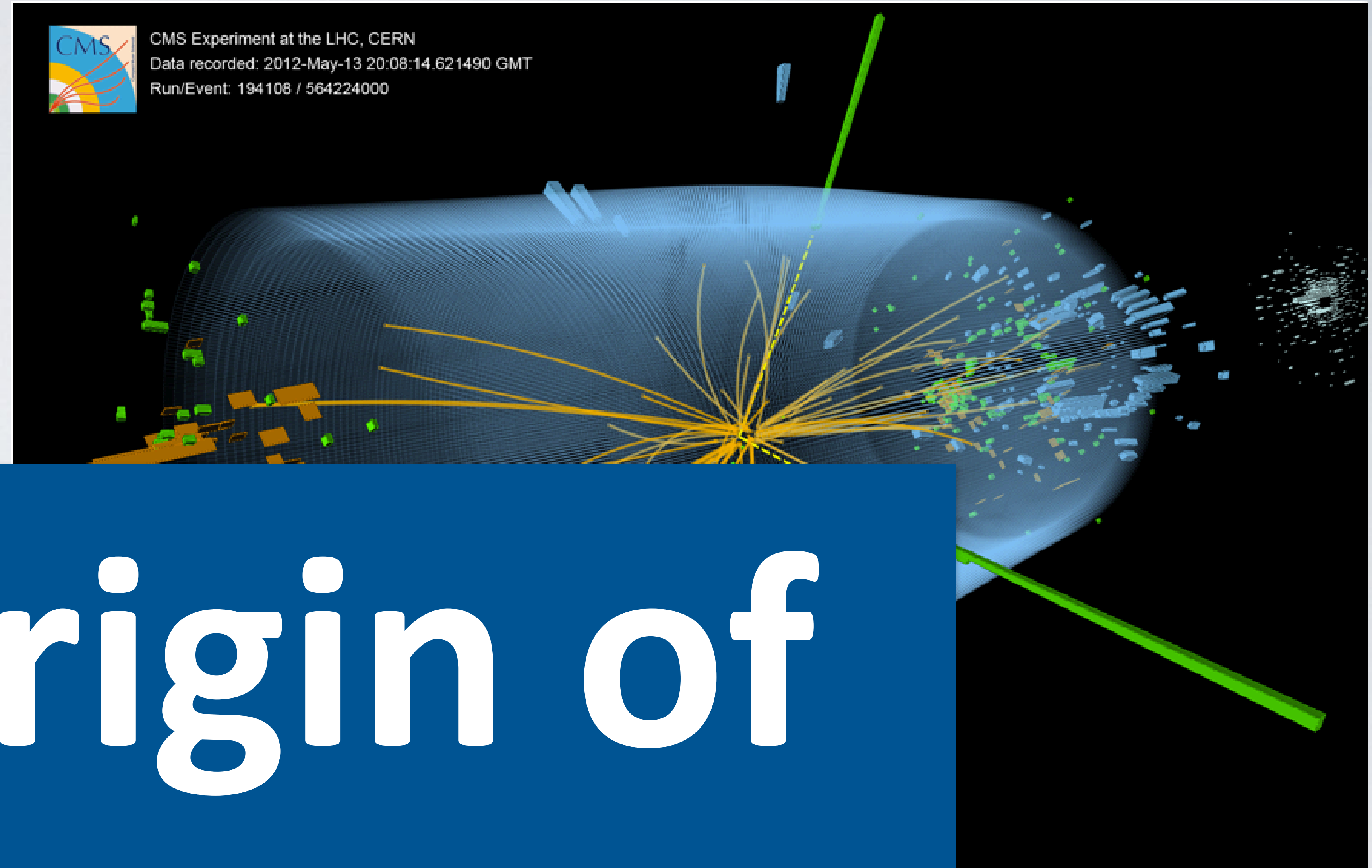
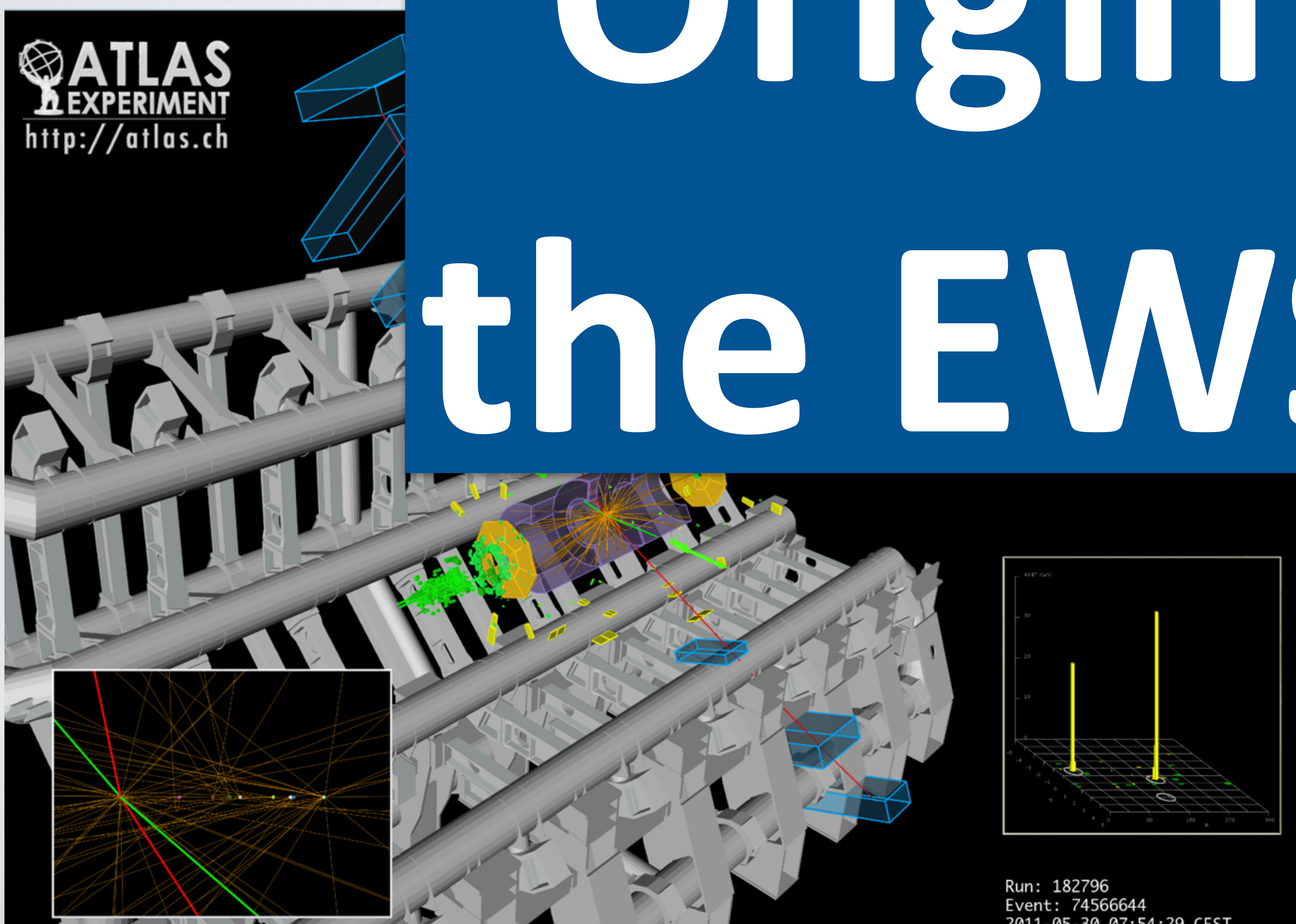
Event: 74566644
2011-05-30 07:54:29 CEST



Origin of the EWSB?



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José Santiago's talk

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- Alternatively, this resonance could be related to a **strong dynamics** at the scale $\Lambda_s \sim \mathcal{O}(\mathrm{TeV})$
  - **Technicolor:** only the usual 3 GBs are accounted for, but no light scalar particle is present.
  - **Composite Higgs**: a larger global symmetry is considered and the SM scalar particle arises as a (massless) GB. In this case the resonance corresponds to a composite object.

Content

- SM Higgs and d=6 linear effective Lagrangian
- A dynamical Higgs (composite state):
  - The Appelquist-Longhitano-Feruglio basis (no Higgs)
  - The bosonic basis for a light dynamical *h*
- Disentangling a dynamical Higgs from an elementary one

The d=6 linear effective Lagrangian

- With no evidence of specific beyond SM theories, NP effects above the TEV scale can be parametrised by writing the **Linear Effective Lagrangian** including up to d=6 operators in terms of the **Higgs doublet**:

$$\mathcal{L}_{\text{linear}} = \mathcal{L}_{SM} + \sum_i \frac{f_i}{\Lambda^2}\mathcal{O}_i + \text{higher orders}$$

with Λ (≥ few TeV) the NP scale.

- Once restricting only to the **bosonic sector**, the effective Lagrangian is built using the SM gauge fields strengths $G_{\mu\nu}$, $W_{\mu\nu}$ and $B_{\mu\nu}$, and the Higgs doublet Φ (plus covariant derivatives).

The d=6 linear Lagrangian: HISZ

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$$\begin{aligned}\mathcal{L}_{SM} = & -\frac{1}{4}W^a_{\mu\nu}W^{a\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}G^a_{\mu\nu}G^{a\mu\nu} - V(h) \\ & + (D_\mu\Phi)^\dagger(D^\mu\Phi) + i\bar{Q}\not{D}Q + i\bar{L}\not{D}L \\ & - (\bar{Q}_L\Phi\mathcal{Y}_D D_R + \text{h.c.}) - \left(\bar{Q}_L\tilde{\Phi}\mathcal{Y}_U U_R + \text{h.c.}\right) \\ & - (\bar{L}_L\Phi\mathcal{Y}_L L_R + \text{h.c.})\end{aligned}$$

The d=6 linear Lagrangian: HISZ

[Buchmuller, Wyler (1984)]

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$$\mathcal{O}_{GG} = \Phi^\dagger \Phi\, G^a_{\mu\nu} G^{a\mu\nu}$$

$$\mathcal{O}_{WW} = \Phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \Phi$$

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$$\mathcal{O}_{\Phi,4} = (D_\mu \Phi)^\dagger (D^\mu \Phi) \left(\Phi^\dagger \Phi\right)$$

[Hagiwara-Ishihara-Szalapski-Zeppenfeld (1993)]

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These operators describe pure gauge, gauge-*h* and pure-*h* interactions and several **correlations** among observables are predicted: i.e. triple gauge couplings vs. HVV couplings. **SMOKING GUNS!!!**

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- The symmetry of the scalar potential can be easier identified writing

[Longhitano, PRD22 (1980)]

$$\mathbf{M}(x) \equiv \sqrt{2}\left(\tilde{\Phi}(x)\ \Phi(x)\right)$$

$$V(\mathbf{M}) = \frac{1}{4}\lambda\left(\frac{1}{2}\mathrm{Tr}[\mathbf{M}^\dagger\,\mathbf{M}] + \frac{\mu^2}{\lambda}\right)^2$$

invariant under a global $SU(2)_L \times SU(2)_R \sim O(4)$

$$\mathbf{M} \to L\,\mathbf{M}\,R^\dagger$$

José Santiago's talk

The matrix $\mathbf{M}$ contains the 3 GBs and the physical h.

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- When $\mathbf{M}$ develops VEV $\langle \mathbf{M}^\dagger \mathbf{M} \rangle = v^2 \mathbf{1}$

$O(4) \to SU(2)_V$ custodial symmetry

$SU(2)_L \times U(1)_Y \to U(1)_{em}$

The non-linear σ-model notation

- Thinking at a very **heavy Higgs particle**, all the remaining d.o.f. are the longitudinal components of the gauge bosons and are described by

$$\mathbf{U}(x) \equiv \mathbf{M}(x)/v = e^{i\sigma_a \pi^a(x)/v}$$

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- Writing the covariant derivative as:

$$\mathbf{D}_\mu \mathbf{U}(x) \equiv \partial_\mu \mathbf{U}(x) + \frac{ig}{2} W_\mu^a(x)\sigma_a \mathbf{U}(x) - \frac{ig'}{2} B_\mu(x)\mathbf{U}(x)\sigma_3$$

we can define the vector and the scalar chiral fields

$$\mathbf{V}_\mu \equiv (\mathbf{D}_\mu \mathbf{U})\,\mathbf{U}^\dagger \qquad \mathbf{V} \to L\,\mathbf{V}\,L^\dagger$$

$$\mathbf{T} \equiv \mathbf{U}\sigma_3\mathbf{U}^\dagger \qquad \mathbf{T} \to L\,\mathbf{T}\,L^\dagger$$

The ALF Basis

Making use of these objects, it is possible to construct a basis of independent operators describing all the $SU(2)_L \times U(1)_Y$ interactions, with no Higgs involved and considering only CP-even structures:

$$\mathcal{L}_{ALF} = \mathcal{L}_{ALF}^{p=2} + \mathcal{L}_{ALF}^{p=4}$$

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$$-\frac{v}{\sqrt{2}}\left(\bar{Q}_L \mathbf{U}\mathcal{Y}_Q Q_R + \mathrm{h.c.}\right) - \frac{v}{\sqrt{2}}\left(\bar{L}_L \mathbf{U}\mathcal{Y}_L L_R + \mathrm{h.c.}\right)$$

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W, Z masses
GBs Kin terms
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Yukawa terms

$$- (\bar{Q}_L \Phi \mathcal{Y}_D D_R + \mathrm{h.c.})$$

$$- \left(\bar{Q}_L \tilde{\Phi} \mathcal{Y}_U U_R + \mathrm{h.c.}\right)$$

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custodial breaking Z mass contribution

$$\mathcal{O}_{\Phi,1} = (D_\mu \Phi)^\dagger \, \Phi \, \Phi^\dagger \, (D^\mu \Phi)$$ d=6

$-1.7 \times 10^{-3} < \Delta\rho \equiv c_T < 1.9 \times 10^{-3}$

[Giudicea,Grojeana,Pomarol&Rattazzi, hep-ph0703164]

$$\mathcal{L}_{ALF}^{p=4} = -\frac{1}{4}W^a_{\mu\nu}W^{a\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}G^a_{\mu\nu}G^{a\mu\nu} + \sum c_i \mathcal{A}_i$$

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$$\mathcal{A}_1 = g\, g'\, B_{\mu\nu} \mathrm{Tr}\left(\mathbf{T}\, W^{\mu\nu}\right)$$

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$$\mathcal{A}_7 = i\, g\, \mathrm{Tr}\left(\mathbf{T}\, W_{\mu\nu}\right) \mathrm{Tr}\left(\mathbf{T}\, [\mathbf{V}^\mu, \mathbf{V}^\nu]\right)$$

$$\mathcal{A}_8 = g\, \epsilon^{\mu\nu\rho\lambda} \mathrm{Tr}\left(\mathbf{T}\mathbf{V}_\mu\right) \mathrm{Tr}\left(\mathbf{V}_\nu\, W_{\rho\lambda}\right)$$

$$\mathcal{A}_9 = \mathrm{Tr}\left(\mathbf{V}_\mu \mathbf{V}^\mu\right) \left(\mathrm{Tr}\left(\mathbf{T}\mathbf{V}_\nu\right)\right)^2$$

$$\mathcal{A}_{10} = \mathrm{Tr}\left(\mathbf{V}_\mu \mathbf{V}_\nu\right) \mathrm{Tr}\left(\mathbf{T}\mathbf{V}^\mu\right) \mathrm{Tr}\left(\mathbf{T}\mathbf{V}^\nu\right)$$

$$\mathcal{A}_{11} = \left(\mathrm{Tr}\left(\mathbf{T}\mathbf{V}_\mu\right) \mathrm{Tr}\left(\mathbf{T}\mathbf{V}_\nu\right)\right)^2$$

[Appelquist&Bernard, Phys. Rev. D22 (1980) 200]
[Longhitano, Phys. Rev. D22 (1980) 1166]
[Longhitano, Nucl. Phys. B188 (1981) 118]
[Appelquist&Wu, Phys.Rev. D48 (1993) 3235–3241]

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$$\mathcal{A}_{12} = \mathrm{Tr}\left((\mathcal{D}_\mu \mathbf{V}^\mu)^2\right)$$
$$\mathcal{A}_{13} = \mathrm{Tr}(\mathbf{T}\, \mathcal{D}_\mu \mathbf{V}^\mu)\, \mathrm{Tr}(\mathbf{T}\, \mathcal{D}_\nu \mathbf{V}^\nu)$$
$$\mathcal{A}_{14} = \mathrm{Tr}([\mathbf{T}\, , \mathbf{V}_\nu]\, \mathcal{D}_\mu \mathbf{V}^\mu)\, \mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu)$$

If m_f=0 then these operators are not independent from the others

[Feruglio, Int.J.Mod.Phys. A8 (1993) 4937–4972]

$$\mathcal{L}_{ALF}^{p=4} = -\frac{1}{4} W^{a}_{\mu\nu} W^{a\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} G^{a}_{\mu\nu} G^{a\mu\nu} + \sum c_i \mathcal{A}_i$$

$$\mathcal{A}_1 = g\, g'\, B_{\mu\nu} \mathrm{Tr}\left(\mathbf{T}\, W^{\mu\nu}\right)$$

$$\mathcal{A}_2 = i\, g'\, B_{\mu\nu} \mathrm{Tr}\left(\mathbf{T}\left[\mathbf{V}^{\mu}, \mathbf{V}^{\nu}\right]\right)$$

$$\mathcal{A}_3 = i\, g\, \mathrm{Tr}\left(W_{\mu\nu}\left[\mathbf{V}^{\mu}, \mathbf{V}^{\nu}\right]\right)$$

$$\mathcal{A}_4 = \left(\mathrm{Tr}\left(\mathbf{V}_{\mu}\, \mathbf{V}^{\mu}\right)\right)^2$$

$$\mathcal{A}_5 = \left(\mathrm{Tr}\left(\mathbf{V}_{\mu}\, \mathbf{V}_{\nu}\right)\right)^2$$

$$\mathcal{A}_6 = g^2\, \left(\mathrm{Tr}\left(\mathbf{T}\, W^{\mu\nu}\right)\right)^2$$

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$$\mathcal{A}_8 = g\, \epsilon^{\mu\nu\rho\lambda} \mathrm{Tr}\left(\mathbf{T}\mathbf{V}_{\mu}\right) \mathrm{Tr}\left(\mathbf{V}_{\nu}\, W_{\rho\lambda}\right)$$

$$\mathcal{A}_9 = \mathrm{Tr}\left(\mathbf{V}_{\mu}\mathbf{V}^{\mu}\right)\left(\mathrm{Tr}\left(\mathbf{T}\mathbf{V}_{\nu}\right)\right)^2$$

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$$\mathcal{A}_{11} = \left(\mathrm{Tr}\left(\mathbf{T}\mathbf{V}_{\mu}\right) \mathrm{Tr}\left(\mathbf{T}\mathbf{V}_{\nu}\right)\right)^2$$

[Appelquist&Bernard, Phys. Rev. D22 (1980) 200]
ev. D22 (1980) 1166]
hys. B188 (1981) 118]
ys.Rev. D48 (1993) 3235–3241]

14(11) + 1 parameters

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What with a physical Higgs?!

E

$SU(3)_c \times SU(2)_L \times U(1)_Y$

$\langle h \rangle = v$

$SU(3)_c \times U(1)_{em}$

E

Composite Higgs Models

??

Λ_s - strong resonances

$\Lambda_s \leq 4\pi f$

f - Goldstone bosons

$\langle h \rangle \neq v$

$SU(3)_c \times U(1)_{em}$
+
effective interactions

[Georgi & Kaplan, 1984;
Dimopoulos, Georgi & Kaplan 1984;
Banks, 1984;
Galison, Georgi,& Kaplan, 1984;
Dugan, Georgi & Kaplan 1985;
Agashe, Contino & Pomarol 2005;
Gripaios, Pomarol, Riva & Serra 2009;
...]

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- Higher order operators are suppressed by:
  - f for extra Goldstone leg (Goldstone-Higgs included)
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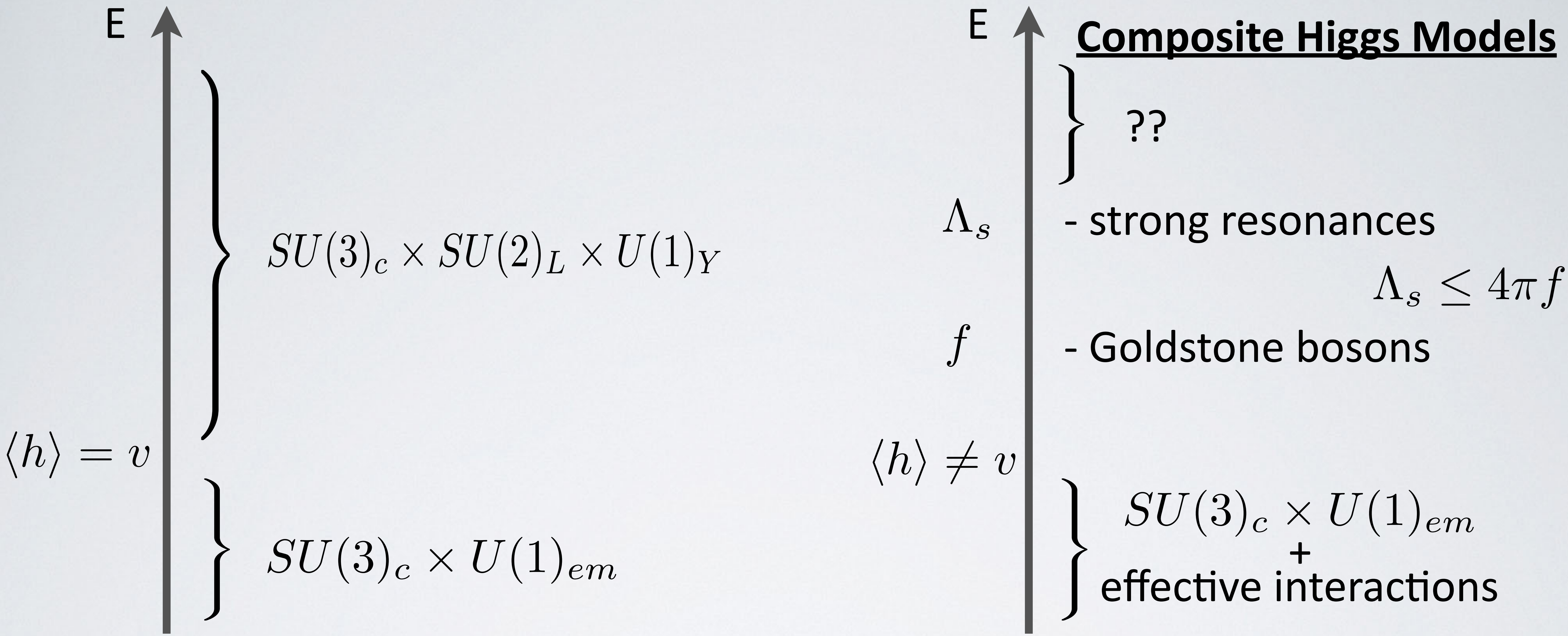
What with a physical Higgs?!



- Higher order operators are suppressed by:
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  - Λ_s for extra derivatives and gauge field strength [Manohar&Georgi, 1984]
- The degree of non-linearity is described by $\xi \equiv (v/f)^2$
- Special limit: SM corresponds to $\langle h \rangle \equiv v$, $\Lambda_s, f \gg v$, $\xi \to 0$

The low-energy effective Lagrangian is constructed by means of:

$$\begin{cases} \mathbf{U}(x) = e^{i\sigma_a \pi^a(x)/v} \\ \mathbf{T} \equiv \mathbf{U}\sigma_3\mathbf{U}^\dagger \qquad \mathbf{V}_\mu \equiv (\mathbf{D}_\mu \mathbf{U})\,\mathbf{U}^\dagger \end{cases} \qquad \begin{cases} h \\ \partial_\mu h \end{cases}$$

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SM

- The GBs are in the Higgs doublet Φ
- Φ has dimension 1 in mass
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⇒ **The dimension of the leading low-energy operators differs for a purely linear and a non-linear regime**

The (Dynamical) Chiral Lagrangian

First time the complete pure-gauge & gauge-*h* basis

[Alonso, Gavela, LM, Rigolin & Yepes, Phys.Lett. **B722** (2013) 330-335]

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

The (Dynamical) Chiral Lagrangian

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

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

s_Y accounts for a possible negative sign in the *h*-fermion couplings.

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First time the complete pure-gauge & gauge-*h* basis

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

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

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

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

s_Y accounts for a possible negative sign in the *h*-fermion couplings.

$$\Delta\mathcal{L} = c_B\mathcal{P}_B(h) + c_W\mathcal{P}_W(h) + c_G\mathcal{P}_G(h) + c_C\mathcal{P}_C(h) + c_T\mathcal{P}_T(h) + \sum c_i\mathcal{P}_i(h)$$

$$\mathcal{P}_B(h) = -\frac{g'^2}{4} B_{\mu\nu} B^{\mu\nu} \mathcal{F}_B(h)$$

$$\mathcal{P}_W(h) = -\frac{g^2}{4} W^a_{\mu\nu} W^{a\mu\nu} \mathcal{F}_W(h)$$

$$\mathcal{P}_G(h) = -\frac{g_s^2}{4} G^a_{\mu\nu} G^{a\mu\nu} \mathcal{F}_G(h)$$

$$\mathcal{P}_C(h) = -\frac{v^2}{4} \mathrm{Tr}(\mathbf{V}^\mu \mathbf{V}_\mu) \mathcal{F}_C(h)$$

$$\mathcal{P}_T(h) = \frac{v^2}{4} \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \mathcal{F}_T(h)$$

$$\mathcal{P}_1(h) = g g' B_{\mu\nu} \mathrm{Tr}(\mathbf{T} W^{\mu\nu}) \mathcal{F}_1(h)$$

$$\mathcal{P}_2(h) = i g' B_{\mu\nu} \mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu]) \mathcal{F}_2(h)$$

$$\mathcal{P}_3(h) = i g \mathrm{Tr}(W_{\mu\nu}[\mathbf{V}^\mu, \mathbf{V}^\nu]) \mathcal{F}_3(h)$$

$$\mathcal{P}_4(h) = i g' B_{\mu\nu} \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_4(h)$$

$$\mathcal{P}_5(h) = i g \mathrm{Tr}(W_{\mu\nu} \mathbf{V}^\mu) \partial^\nu \mathcal{F}_5(h)$$

$$\mathcal{P}_6(h) = (\mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu))^2 \mathcal{F}_6(h)$$

$$\mathcal{P}_7(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) \partial_\nu \partial^\nu \mathcal{F}_7(h)$$

$$\mathcal{P}_8(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}_\nu) \partial^\mu \mathcal{F}_8(h) \partial^\nu \mathcal{F}'_8(h)$$

$$\mathcal{P}_9(h) = \mathrm{Tr}((\mathcal{D}_\mu \mathbf{V}^\mu)^2) \mathcal{F}_9(h)$$

$$\mathcal{P}_{10}(h) = \mathrm{Tr}(\mathbf{V}_\nu \mathcal{D}_\mu \mathbf{V}^\mu) \partial^\nu \mathcal{F}_{10}(h)$$

$$\mathcal{P}_{11}(h) = (\mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}_\nu))^2 \mathcal{F}_{11}(h)$$

$$\mathcal{P}_{12}(h) = g^2 (\mathrm{Tr}(\mathbf{T} W_{\mu\nu}))^2 \mathcal{F}_{12}(h)$$

$$\mathcal{P}_{13}(h) = i g \mathrm{Tr}(\mathbf{T} W_{\mu\nu}) \mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu]) \mathcal{F}_{13}(h)$$

$$\mathcal{P}_{14}(h) = g \varepsilon^{\mu\nu\rho\lambda} \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{V}_\nu W_{\rho\lambda}) \mathcal{F}_{14}(h)$$

$$\mathcal{P}_{15}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu \mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathcal{D}_\nu \mathbf{V}^\nu) \mathcal{F}_{15}(h)$$

$$\mathcal{P}_{16}(h) = \mathrm{Tr}([\mathbf{T}, \mathbf{V}_\nu] \mathcal{D}_\mu \mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu) \mathcal{F}_{16}(h)$$

$$\mathcal{P}_{17}(h) = i g \mathrm{Tr}(\mathbf{T} W_{\mu\nu}) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_{17}(h)$$

$$\mathcal{P}_{18}(h) = \mathrm{Tr}(\mathbf{T}[\mathbf{V}_\mu, \mathbf{V}_\nu]) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_{18}(h)$$

$$\mathcal{P}_{19}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu \mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu) \partial^\nu \mathcal{F}_{19}(h)$$

$$\mathcal{P}_{20}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) \partial_\nu \mathcal{F}_{20}(h) \partial^\nu \mathcal{F}'_{20}(h)$$

$$\mathcal{P}_{21}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2 \partial_\nu \mathcal{F}_{21}(h) \partial^\nu \mathcal{F}'_{21}(h)$$

$$\mathcal{P}_{22}(h) = \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu) \partial^\mu \mathcal{F}_{22}(h) \partial^\nu \mathcal{F}'_{22}(h)$$

$$\mathcal{P}_{23}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2 \mathcal{F}_{23}(h)$$

$$\mathcal{P}_{24}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}_\nu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu) \mathcal{F}_{24}(h)$$

$$\mathcal{P}_{25}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2 \partial_\nu \partial^\nu \mathcal{F}_{25}(h)$$

$$\mathcal{P}_{26}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2 \mathcal{F}_{26}(h)$$

$$\mathcal{F}_i(h) \equiv g(h, f)$$

[Alonso, Gavela, LM, Rigolin & Yepes, Phys.Lett. **B722** (2013) 330-335]

$$\mathcal{P}_B(h) = -\frac{g'^2}{4} B_{\mu\nu} B^{\mu\nu} \mathcal{F}_B(h)$$

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$$\mathcal{P}_G(h) = -\frac{g_s^2}{4} G^a_{\mu\nu} G^{a\mu\nu} \mathcal{F}_G(h)$$

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$$\mathcal{P}_1(h) = gg' B_{\mu\nu} \mathrm{Tr}(\mathbf{T} W^{\mu\nu}) \mathcal{F}_1(h)$$

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$$\mathcal{P}_6(h) = (\mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu))^2 \mathcal{F}_6(h)$$

$$\mathcal{P}_7(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) \partial_\nu \partial^\nu \mathcal{F}_7(h)$$

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BLUE

in the limit $\mathcal{F}_i(h) = 1$ they reduce to the AL basis (plus non-physical contributions to the kinetic terms and W and Z masses)

$$\mathcal{P}_{21}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2 \partial_\nu \mathcal{F}_{21}(h) \partial^\nu \mathcal{F}'_{21}(h)$$

$$\mathcal{P}_{22}(h) = \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu) \partial^\mu \mathcal{F}_{22}(h) \partial^\nu \mathcal{F}'_{22}(h)$$

$$\mathcal{P}_{23}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2 \mathcal{F}_{23}(h)$$

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$$\mathcal{P}_{13}(h) = i g \mathrm{Tr}(\mathbf{T} W_{\mu\nu}) \mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu]) \mathcal{F}_{13}(h)$$

$$\mathcal{P}_{14}(h) = g \varepsilon^{\mu\nu\rho\lambda} \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{V}_\nu W_{\rho\lambda}) \mathcal{F}_{14}(h)$$

$$\mathcal{P}_{15}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu \mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathcal{D}_\nu \mathbf{V}^\nu) \mathcal{F}_{15}(h)$$

$$\mathcal{P}_{16}(h) = \mathrm{Tr}([\mathbf{T}, \mathbf{V}_\nu] \mathcal{D}_\mu \mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu) \mathcal{F}_{16}(h)$$

$$\mathcal{P}_{17}(h) = i g \mathrm{Tr}(\mathbf{T} W_{\mu\nu}) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_{17}(h)$$

$$\mathcal{P}_{18}(h) = \mathrm{Tr}(\mathbf{T}[\mathbf{V}_\mu, \mathbf{V}_\nu]) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_{18}(h)$$

$$\mathcal{P}_{19}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu \mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu) \partial^\nu \mathcal{F}_{19}(h)$$

$$\mathcal{P}_{20}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) \partial_\nu \mathcal{F}_{20}(h) \partial^\nu \mathcal{F}'_{20}(h)$$

$$\mathcal{P}_{21}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2 \partial_\nu \mathcal{F}_{21}(h) \partial^\nu \mathcal{F}'_{21}(h)$$

$$\mathcal{P}_{22}(h) = \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu) \partial^\mu \mathcal{F}_{22}(h) \partial^\nu \mathcal{F}'_{22}(h)$$

$$\mathcal{P}_{23}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2 \mathcal{F}_{23}(h)$$

GREEN

in the limit $\mathcal{F}_i(h) = 1$ they reduce to the gauge-Goldstone Feruglio operators

[Alonso, Gavela, LM, Rigolin & Yepes, Phys.Lett. **B722** (2013) 330-335]

$$\mathcal{P}_B(h) = -\frac{g'^2}{4} B_{\mu\nu} B^{\mu\nu} \mathcal{F}_B(h)$$

RED

new Higgs couplings in the ALF basis, and new operators with derivatives of *h* (few of them already present in Azatov, Contino & Galloway (2012))

$$\mathcal{P}_3(h) = ig\,\mathrm{Tr}(W_{\mu\nu}[\mathbf{V}^\mu, \mathbf{V}^\nu]) \mathcal{F}_3(h)$$

$$\mathcal{P}_4(h) = ig' B_{\mu\nu} \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_4(h)$$

$$\mathcal{P}_5(h) = ig\,\mathrm{Tr}(W_{\mu\nu}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_5(h)$$

$$\mathcal{P}_6(h) = (\mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu))^2 \mathcal{F}_6(h)$$

$$\mathcal{P}_7(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) \partial_\nu \partial^\nu \mathcal{F}_7(h)$$

$$\mathcal{P}_8(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}_\nu) \partial^\mu \mathcal{F}_8(h) \partial^\nu \mathcal{F}'_8(h)$$

$$\mathcal{P}_9(h) = \mathrm{Tr}((\mathcal{D}_\mu \mathbf{V}^\mu)^2) \mathcal{F}_9(h)$$

$$\mathcal{P}_{10}(h) = \mathrm{Tr}(\mathbf{V}_\nu \mathcal{D}_\mu \mathbf{V}^\mu) \partial^\nu \mathcal{F}_{10}(h)$$

$$\mathcal{P}_{11}(h) = (\mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}_\nu))^2 \mathcal{F}_{11}(h)$$

$$\mathcal{P}_{12}(h) = g^2 (\mathrm{Tr}(\mathbf{T} W_{\mu\nu}))^2 \mathcal{F}_{12}(h)$$

$$\mathcal{P}_{13}(h) = ig\,\mathrm{Tr}(\mathbf{T} W_{\mu\nu}) \mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu]) \mathcal{F}_{13}(h)$$

$$\mathcal{P}_{14}(h) = g \varepsilon^{\mu\nu\rho\lambda} \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{V}_\nu W_{\rho\lambda}) \mathcal{F}_{14}(h)$$

$$\mathcal{P}_{15}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu \mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathcal{D}_\nu \mathbf{V}^\nu) \mathcal{F}_{15}(h)$$

$$\mathcal{P}_{16}(h) = \mathrm{Tr}([\mathbf{T}, \mathbf{V}_\nu] \mathcal{D}_\mu \mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu) \mathcal{F}_{16}(h)$$

$$\mathcal{P}_{17}(h) = ig\,\mathrm{Tr}(\mathbf{T} W_{\mu\nu}) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_{17}(h)$$

$$\mathcal{P}_{18}(h) = \mathrm{Tr}(\mathbf{T}[\mathbf{V}_\mu, \mathbf{V}_\nu]) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_{18}(h)$$

$$\mathcal{P}_{19}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu \mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu) \partial^\nu \mathcal{F}_{19}(h)$$

$$\mathcal{P}_{20}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) \partial_\nu \mathcal{F}_{20}(h) \partial^\nu \mathcal{F}'_{20}(h)$$

$$\mathcal{P}_{21}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2 \partial_\nu \mathcal{F}_{21}(h) \partial^\nu \mathcal{F}'_{21}(h)$$

$$\mathcal{P}_{22}(h) = \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu) \partial^\mu \mathcal{F}_{22}(h) \partial^\nu \mathcal{F}'_{22}(h)$$

$$\mathcal{P}_{23}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2 \mathcal{F}_{23}(h)$$

$$\mathcal{P}_{24}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}_\nu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu) \mathcal{F}_{24}(h)$$

$$\mathcal{P}_{25}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2 \partial_\nu \partial^\nu \mathcal{F}_{25}(h)$$

$$\mathcal{P}_{26}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2 \mathcal{F}_{26}(h)$$

$$\mathcal{F}_i(h) \equiv g(h, f)$$

[Alonso, Gavela, LM, Rigolin & Yepes, Phys.Lett. **B722** (2013) 330-335]

$$\mathcal{P}_B(h) = -\frac{g'^2}{4} B_{\mu\nu} B^{\mu\nu} \mathcal{F}_B(h)$$

$$\mathcal{P}_W(h) = -\frac{g^2}{4} W^a_{\mu\nu} W^{a\mu\nu} \mathcal{F}_W(h)$$

$$\mathcal{P}_G(h) = -\frac{g_s^2}{4} G^a_{\mu\nu} G^{a\mu\nu} \mathcal{F}_G(h)$$

$$\mathcal{P}_C(h) = -\frac{v^2}{4} \mathrm{Tr}(\mathbf{V}^\mu \mathbf{V}_\mu) \mathcal{F}_C(h)$$

$$\mathcal{P}_T(h) = \frac{v^2}{4} \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \mathcal{F}_T(h)$$

$$\mathcal{P}_1(h) = g g' B_{\mu\nu} \mathrm{Tr}(\mathbf{T} W^{\mu\nu}) \mathcal{F}_1(h)$$

$$\mathcal{P}_2(h) = i g' B_{\mu\nu} \mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu]) \mathcal{F}_2(h)$$

$$\mathcal{P}_3(h) = i g \mathrm{Tr}(W_{\mu\nu}[\mathbf{V}^\mu, \mathbf{V}^\nu]) \mathcal{F}_3(h)$$

$$\mathcal{P}_4(h) = i g' B_{\mu\nu} \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_4(h)$$

$$\mathcal{P}_5(h) = i g \mathrm{Tr}(W_{\mu\nu} \mathbf{V}^\mu) \partial^\nu \mathcal{F}_5(h)$$

$$\mathcal{P}_6(h) = (\mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu))^2 \mathcal{F}_6(h)$$

$$\mathcal{P}_7(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) \partial_\nu \partial^\nu \mathcal{F}_7(h)$$

$$\mathcal{P}_8(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}_\nu) \partial^\mu \mathcal{F}_8(h) \partial^\nu \mathcal{F}'_8(h)$$

$$\mathcal{P}_9(h) = \mathrm{Tr}((\mathcal{D}_\mu \mathbf{V}^\mu)^2) \mathcal{F}_9(h)$$

$$\mathcal{P}_{10}(h) = \mathrm{Tr}(\mathbf{V}_\nu \mathcal{D}_\mu \mathbf{V}^\mu) \partial^\nu \mathcal{F}_{10}(h)$$

$$\mathcal{P}_{11}(h) = (\mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}_\nu))^2 \mathcal{F}_{11}(h)$$

$$\mathcal{P}_{12}(h) = g^2 (\mathrm{Tr}(\mathbf{T} W_{\mu\nu}))^2 \mathcal{F}_{12}(h)$$

$$\mathcal{P}_{13}(h) = i g \mathrm{Tr}(\mathbf{T} W_{\mu\nu}) \mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu]) \mathcal{F}_{13}(h)$$

$$\mathcal{P}_{14}(h) = g \varepsilon^{\mu\nu\rho\lambda} \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{V}_\nu W_{\rho\lambda}) \mathcal{F}_{14}(h)$$

$$\mathcal{P}_{15}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu \mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathcal{D}_\nu \mathbf{V}^\nu) \mathcal{F}_{15}(h)$$

$$\mathcal{P}_{16}(h) = \mathrm{Tr}([\mathbf{T}, \mathbf{V}_\nu] \mathcal{D}_\mu \mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu) \mathcal{F}_{16}(h)$$

$$\mathcal{P}_{17}(h) = i g \mathrm{Tr}(\mathbf{T} W_{\mu\nu}) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_{17}(h)$$

$$\mathcal{P}_{18}(h) = \mathrm{Tr}(\mathbf{T}[\mathbf{V}_\mu, \mathbf{V}_\nu]) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_{18}(h)$$

$$\mathcal{P}_{19}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu \mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu) \partial^\nu \mathcal{F}_{19}(h)$$

$$\mathcal{P}_{20}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) \partial_\nu \mathcal{F}_{20}(h) \partial^\nu \mathcal{F}'_{20}(h)$$

$$\mathcal{P}_{21}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2 \partial_\nu \mathcal{F}_{21}(h) \partial^\nu \mathcal{F}'_{21}(h)$$

$$\mathcal{P}_{22}(h) = \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu) \partial^\mu \mathcal{F}_{22}(h) \partial^\nu \mathcal{F}'_{22}(h)$$

$$\mathcal{P}_{23}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2 \mathcal{F}_{23}(h)$$

$$\mathcal{P}_{24}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}_\nu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu) \mathcal{F}_{24}(h)$$

$$\mathcal{P}_{25}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2 \partial_\nu \partial^\nu \mathcal{F}_{25}(h)$$

$$\mathcal{P}_{26}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2 \mathcal{F}_{26}(h)$$

$$\mathcal{F}_i(h) \equiv g(h, f)$$

$$\mathcal{P}_B(h) = -\frac{g'^2}{4} B_{\mu\nu} B^{\mu\nu} \mathcal{F}_B(h)$$

$$\mathcal{P}_W(h) = -\frac{g^2}{4} W^a_{\mu\nu} W^{a\mu\nu} \mathcal{F}_W(h)$$

$$\mathcal{P}_G(h) = -\frac{g_s^2}{4} G^a_{\mu\nu} G^{a\mu\nu} \mathcal{F}_G(h)$$

$$\mathcal{P}_C(h) = -\frac{v^2}{4} \mathrm{Tr}(\mathbf{V}^\mu \mathbf{V}_\mu) \mathcal{F}_C(h)$$

$$\mathcal{P}_T(h) = \frac{v^2}{4} \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \mathcal{F}_T(h)$$

$$\mathcal{P}_1(h) = g g' B_{\mu\nu} \mathrm{Tr}(\mathbf{T} W^{\mu\nu}) \mathcal{F}_1(h)$$

$$\mathcal{P}_2(h) = i g' B_{\mu\nu} \mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu]) \mathcal{F}_2(h)$$

$$\mathcal{P}_3(h) = i g \mathrm{Tr}(W_{\mu\nu}[\mathbf{V}^\mu, \mathbf{V}^\nu]) \mathcal{F}_3(h)$$

$$\mathcal{P}_4(h) = i g' B_{\mu\nu} \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_4(h)$$

$$\mathcal{P}_5(h) = i g \mathrm{Tr}(W_{\mu\nu} \mathbf{V}^\mu) \partial^\nu \mathcal{F}_5(h)$$

$$\mathcal{P}_6(h) = (\mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu))^2 \mathcal{F}_6(h)$$

~~$\mathcal{P}_7(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) \partial_\nu \partial^\nu \mathcal{F}_7(h)$~~

$$\mathcal{P}_8(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}_\nu) \partial^\mu \mathcal{F}_8(h) \partial^\nu \mathcal{F}'_8(h)$$

~~$\mathcal{P}_9(h) = \mathrm{Tr}((\mathcal{D}_\mu \mathbf{V}^\mu)^2) \mathcal{F}_9(h)$~~

~~$\mathcal{P}_{10}(h) = \mathrm{Tr}(\mathbf{V}_\nu \mathcal{D}_\mu \mathbf{V}^\mu) \partial^\nu \mathcal{F}_{10}(h)$~~

$$\mathcal{P}_{11}(h) = (\mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}_\nu))^2 \mathcal{F}_{11}(h)$$

$$\mathcal{P}_{12}(h) = g^2 (\mathrm{Tr}(\mathbf{T} W_{\mu\nu}))^2 \mathcal{F}_{12}(h)$$

$$\mathcal{P}_{13}(h) = i g \mathrm{Tr}(\mathbf{T} W_{\mu\nu}) \mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu]) \mathcal{F}_{13}(h)$$

$$\mathcal{P}_{14}(h) = g \varepsilon^{\mu\nu\rho\lambda} \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{V}_\nu W_{\rho\lambda}) \mathcal{F}_{14}(h)$$

~~$\mathcal{P}_{15}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu \mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathcal{D}_\nu \mathbf{V}^\nu) \mathcal{F}_{15}(h)$~~

~~$\mathcal{P}_{16}(h) = \mathrm{Tr}([\mathbf{T}, \mathbf{V}_\nu]\mathcal{D}_\mu \mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu) \mathcal{F}_{16}(h)$~~

$$\mathcal{P}_{17}(h) = i g \mathrm{Tr}(\mathbf{T} W_{\mu\nu}) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_{17}(h)$$

$$\mathcal{P}_{18}(h) = \mathrm{Tr}(\mathbf{T}[\mathbf{V}_\mu, \mathbf{V}_\nu]) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \partial^\nu \mathcal{F}_{18}(h)$$

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$$\mathcal{P}_{20}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) \partial_\nu \mathcal{F}_{20}(h) \partial^\nu \mathcal{F}'_{20}(h)$$

$$\mathcal{P}_{21}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2 \partial_\nu \mathcal{F}_{21}(h) \partial^\nu \mathcal{F}'_{21}(h)$$

$$\mathcal{P}_{22}(h) = \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu) \partial^\mu \mathcal{F}_{22}(h) \partial^\nu \mathcal{F}'_{22}(h)$$

$$\mathcal{P}_{23}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu) (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2 \mathcal{F}_{23}(h)$$

$$\mathcal{P}_{24}(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}_\nu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu) \mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu) \mathcal{F}_{24}(h)$$

~~$\mathcal{P}_{25}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2 \partial_\nu \partial^\nu \mathcal{F}_{25}(h)$~~

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$$\mathcal{F}_i(h) \equiv g(h, f)$$

[Alonso, Gavela, LM, Rigolin & Yepes, Phys.Lett. **B722** (2013) 330-335]

$$\mathcal{P}_B(h) = -\frac{g'^2}{4}B_{\mu\nu}B^{\mu\nu}\mathcal{F}_B(h)$$

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$$\mathcal{P}_C(h) = -\frac{v^2}{4}\mathrm{Tr}(\mathbf{V}^\mu\mathbf{V}_\mu)\mathcal{F}_C(h)$$

$$\mathcal{P}_T(h) = \frac{v^2}{4}\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\mathcal{F}_T(h)$$

$\mathcal{P}_1(h) = gg'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}W^{\mu\nu}$ …

$\mathcal{P}_2(h) = ig'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu$ …

$\mathcal{P}_3(h) = ig\mathrm{Tr}(W_{\mu\nu}[\mathbf{V}^\mu, \mathbf{V}$ …

$\mathcal{P}_4(h) = ig'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)$ …

$\mathcal{P}_5(h) = ig\mathrm{Tr}(W_{\mu\nu}\mathbf{V}^\mu)\partial^\nu$ …

$$\mathcal{P}_6(h) = (\mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu))^2\mathcal{F}_6(h)$$

$$\mathcal{P}_7(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)\partial_\nu\partial^\nu\mathcal{F}_7(h)$$

$$\mathcal{P}_8(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\partial^\mu\mathcal{F}_8(h)\partial^\nu\mathcal{F}'_8(h)$$

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$$\mathcal{P}_{14}(h) = g\varepsilon^{\mu\nu\rho\lambda}\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{V}_\nu W_{\rho\lambda})\mathcal{F}_{14}(h)$$

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$$\mathcal{P}_{16}(h) = \mathrm{Tr}([\mathbf{T}, \mathbf{V}_\nu]\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{16}(h)$$

… $_{\mu\nu})\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{17}(h)$

… $, \mathbf{V}_\nu])\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{18}(h)$

… $\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\nu\mathcal{F}_{19}(h)$

… $^\mu)\partial_\nu\mathcal{F}_{20}(h)\partial^\nu\mathcal{F}'_{20}(h)$

… $_\mu))^2\partial_\nu\mathcal{F}_{21}(h)\partial^\nu\mathcal{F}'_{21}(h)$

$$\mathcal{P}_{22}(h) = \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\mu\mathcal{F}_{22}(h)\partial^\nu\mathcal{F}'_{22}(h)$$

$$\mathcal{P}_{23}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)(\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{23}(h)$$

$$\mathcal{P}_{24}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{24}(h)$$

$$\mathcal{P}_{25}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\partial^\nu\mathcal{F}_{25}(h)$$

$$\mathcal{P}_{26}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{26}(h)$$

$$\mathcal{F}_i(h) \equiv g(h, f)$$

31(24) parameters

The $\mathcal{F}_i(h)$ Functions

[Brivio,Corbett,Eboli,Gavela,Gonzalez-Fraile,Gonzalez-Garcia,LM&Rigolin, 1311.1823]

The functions $\mathcal{F}_i(h) \equiv g(h, f)$ are generic functions of *h/f* (and can be derived only once a fundamental model is chosen). It is common to write,

$$\mathcal{F}_i(h) = 1 + 2\alpha_i \frac{h}{v} + \beta_i \frac{h^2}{v^2} + \dots$$

with α_i, β_i generic functions of $\xi \equiv v^2/f^2$.

The $\mathcal{F}_i(h)$ Functions

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with α_i, β_i generic functions of $\xi \equiv v^2/f^2$.

If we consider the SM as a reference, the combinations $c_i \mathcal{F}_i(h)$ become:

$$\Phi(x) = \frac{v+h}{\sqrt{2}} \mathbf{U} \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

$$\begin{aligned}
\frac{f_{BW}}{f^2} \mathcal{O}_{BW} &= \frac{f_{BW}}{f^2} \Phi^\dagger \hat{B}_{\mu\nu} \hat{W}^{\mu\nu} \Phi \\
&= f_{BW} \frac{gg'}{8} B_{\mu\nu} \mathrm{Tr}(\mathbf{T} W^{\mu\nu}) \left(\frac{v+h}{f} \right)^2 \\
&= f_{BW}\, \xi \, \frac{gg'}{8} B_{\mu\nu} \mathrm{Tr}(\mathbf{T} W^{\mu\nu}) \left(1 + \frac{h}{v} \right)^2 \\
&= c_1 \, gg' B_{\mu\nu} \mathrm{Tr}(\mathbf{T} W^{\mu\nu}) \mathcal{F}_1(h) = c_1 \mathcal{P}_1(h)
\end{aligned}$$

with $c_1 = \frac{f_{BW}}{8} \xi \qquad \alpha_1 = 1 \qquad \beta_1 = 1$

Connection with the Linear Basis

We can repeat the previous exercise and see the connection among the bases:

$$\mathcal{O}_{BB}/f^2 = \frac{\xi}{2}\mathcal{P}_B(h) \qquad \mathcal{O}_{WW}/f^2 = \frac{\xi}{2}\mathcal{P}_W(h)$$

$$\mathcal{O}_{GG}/f^2 = -\frac{2\xi}{g_s^2}\mathcal{P}_G(h) \qquad \mathcal{O}_{BW}/f^2 = \frac{\xi}{8}\mathcal{P}_1(h)$$

$$\mathcal{O}_{B}/f^2 = \frac{\xi}{16}\mathcal{P}_2(h) + \frac{\xi}{8}\mathcal{P}_4(h) \qquad \mathcal{O}_{W}/f^2 = \frac{\xi}{8}\mathcal{P}_3(h) - \frac{\xi}{4}\mathcal{P}_5(h)$$

$$\mathcal{O}_{\Phi,1}/f^2 = \frac{\xi}{2}\mathcal{P}_H(h) - \frac{\xi}{4}\mathcal{F}(h)\mathcal{P}_T(h) \qquad \mathcal{O}_{\Phi,2}/f^2 = \xi\mathcal{P}_H(h)$$

$$\mathcal{O}_{\Phi,4}/f^2 = \frac{\xi}{2}\mathcal{P}_H(h) + \frac{\xi}{2}\mathcal{F}(h)\mathcal{P}_C(h)$$

$$\mathcal{O}_{\Box\Phi}/f^2 = \frac{\xi}{2}\mathcal{P}_{\Box H}(h) + \frac{\xi}{8}\mathcal{P}_6(h) + \frac{\xi}{4}\mathcal{P}_7(h) - \xi\mathcal{P}_8(h) - \frac{\xi}{4}\mathcal{P}_9(h) - \frac{\xi}{2}\mathcal{P}_{10}(h)$$

with $\mathcal{F}(h) = 1 + 2\frac{h}{v} + \frac{h^2}{v^2}$

We added two pure-*h* operators (only the first was previously considered by Buchalla,Cata,&Krause (2013)):

$$\mathcal{P}_H(h) = \frac{1}{2}(\partial_\mu h)(\partial^\mu h)\mathcal{F}_H(h) \qquad \mathcal{P}_{\Box H} = \frac{1}{v^2}(\partial_\mu\partial^\mu h)^2\mathcal{F}_{\Box H}(h)$$

$$\mathcal{P}_C(h) = -\frac{v^2}{4}\mathrm{Tr}(\mathbf{V}^\mu \mathbf{V}_\mu)\mathcal{F}_C(h)$$
$$\mathcal{P}_T(h) = \frac{v^2}{4}\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\mathcal{F}_T(h)$$
$$\mathcal{P}_B(h) = -\frac{g'^2}{4}B_{\mu\nu}B^{\mu\nu}\mathcal{F}_B(h)$$
$$\mathcal{P}_W(h) = -\frac{g^2}{4}W^a_{\mu\nu}W^{a\mu\nu}\mathcal{F}_W(h)$$
$$\mathcal{P}_G(h) = -\frac{g_s^2}{4}G^a_{\mu\nu}G^{a\mu\nu}\mathcal{F}_G(h)$$
$$\mathcal{P}_1(h) = gg'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}W^{\mu\nu})\mathcal{F}_1(h)$$
$$\mathcal{P}_2(h) = ig'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_2(h)$$
$$\mathcal{P}_3(h) = ig\mathrm{Tr}(W_{\mu\nu}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_3(h)$$
$$\mathcal{P}_4(h) = ig'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_4(h)$$
$$\mathcal{P}_5(h) = ig\mathrm{Tr}(W_{\mu\nu}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_5(h)$$
$$\mathcal{P}_6(h) = (\mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu))^2\mathcal{F}_6(h)$$
$$\mathcal{P}_7(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)\partial_\nu\partial^\nu\mathcal{F}_7(h)$$
$$\mathcal{P}_8(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\partial^\mu\mathcal{F}_8(h)\partial^\nu\mathcal{F}'_8(h)$$
$$\mathcal{P}_9(h) = \mathrm{Tr}((\mathcal{D}_\mu\mathbf{V}^\mu)^2)\mathcal{F}_9(h)$$
$$\mathcal{P}_{10}(h) = \mathrm{Tr}(\mathbf{V}_\nu\mathcal{D}_\mu\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{10}(h)$$
$$\mathcal{P}_{11}(h) = (\mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu))^2\mathcal{F}_{11}(h)$$
$$\mathcal{P}_{12}(h) = g^2(\mathrm{Tr}(\mathbf{T}W_{\mu\nu}))^2\mathcal{F}_{12}(h)$$
$$\mathcal{P}_{13}(h) = ig\mathrm{Tr}(\mathbf{T}W_{\mu\nu})\mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_{13}(h)$$
$$\mathcal{P}_{14}(h) = g\varepsilon^{\mu\nu\rho\lambda}\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{V}_\nu W_{\rho\lambda})\mathcal{F}_{14}(h)$$
$$\mathcal{P}_{15}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathcal{D}_\nu\mathbf{V}^\nu)\mathcal{F}_{15}(h)$$
$$\mathcal{P}_{16}(h) = \mathrm{Tr}([\mathbf{T},\mathbf{V}_\nu]\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{16}(h)$$
$$\mathcal{P}_{17}(h) = ig\mathrm{Tr}(\mathbf{T}W_{\mu\nu})\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{17}(h)$$
$$\mathcal{P}_{18}(h) = \mathrm{Tr}(\mathbf{T}[\mathbf{V}_\mu,\mathbf{V}_\nu])\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{18}(h)$$
$$\mathcal{P}_{19}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\nu\mathcal{F}_{19}(h)$$
$$\mathcal{P}_{20}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)\partial_\nu\mathcal{F}_{20}(h)\partial^\nu\mathcal{F}'_{20}(h)$$
$$\mathcal{P}_{21}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\mathcal{F}_{21}(h)\partial^\nu\mathcal{F}'_{21}(h)$$
$$\mathcal{P}_{22}(h) = \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\mu\mathcal{F}_{22}(h)\partial^\nu\mathcal{F}'_{22}(h)$$
$$\mathcal{P}_{23}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)(\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{23}(h)$$
$$\mathcal{P}_{24}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{24}(h)$$
$$\mathcal{P}_{25}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\partial^\nu\mathcal{F}_{25}(h)$$
$$\mathcal{P}_{26}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{26}(h)$$
$$\mathcal{P}_H(h) = \frac{1}{2}(\partial_\mu h)(\partial^\mu h)\mathcal{F}_H(h)$$
$$\mathcal{P}_{\Box H} = \frac{1}{v^2}(\partial_\mu\partial^\mu h)^2\mathcal{F}_{\Box H}(h)$$

$$\mathcal{P}_C(h) = -\frac{v^2}{4}\mathrm{Tr}(\mathbf{V}^\mu \mathbf{V}_\mu)\mathcal{F}_C(h)$$

$$\mathcal{P}_T(h) = \frac{v^2}{4}\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\mathcal{F}_T(h)$$

$$\mathcal{P}_B(h) = -\frac{g'^2}{4}B_{\mu\nu}B^{\mu\nu}\mathcal{F}_B(h)$$

$$\mathcal{P}_W(h) = -\frac{g^2}{4}W^a_{\mu\nu}W^{a\mu\nu}\mathcal{F}_W(h)$$

$$\mathcal{P}_G(h) = -\frac{g_s^2}{4}G^a_{\mu\nu}G^{a\mu\nu}\mathcal{F}_G(h)$$

$$\mathcal{P}_1(h) = gg'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}W^{\mu\nu})\mathcal{F}_1(h)$$

$$\mathcal{P}_2(h) = ig'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu])\mathcal{F}_2(h)$$

$$\mathcal{P}_3(h) = ig\mathrm{Tr}(W_{\mu\nu}[\mathbf{V}^\mu, \mathbf{V}^\nu])\mathcal{F}_3(h)$$

$$\mathcal{P}_4(h) = ig'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_4(h)$$

$$\mathcal{P}_5(h) = ig\mathrm{Tr}(W_{\mu\nu}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_5(h)$$

$$\mathcal{P}_6(h) = (\mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu))^2\mathcal{F}_6(h)$$

$$\mathcal{P}_7(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)\partial_\nu\partial^\nu\mathcal{F}_7(h)$$

$$\mathcal{P}_8(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\partial^\mu\mathcal{F}_8(h)\partial^\nu\mathcal{F}'_8(h)$$

$$\mathcal{P}_9(h) = \mathrm{Tr}((\mathcal{D}_\mu\mathbf{V}^\mu)^2)\mathcal{F}_9(h)$$

$$\mathcal{P}_{10}(h) = \mathrm{Tr}(\mathbf{V}_\nu\mathcal{D}_\mu\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{10}(h)$$

$$\mathcal{P}_{11}(h) = (\mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu))^2\mathcal{F}_{11}(h)$$

$$\mathcal{P}_{12}(h) = g^2(\mathrm{Tr}(\mathbf{T}W_{\mu\nu}))^2\mathcal{F}_{12}(h)$$

$$\mathcal{P}_{13}(h) = ig\mathrm{Tr}(\mathbf{T}W_{\mu\nu})\mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu])\mathcal{F}_{13}(h)$$

$$\mathcal{P}_{14}(h) = g\varepsilon^{\mu\nu\rho\lambda}\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{V}_\nu W_{\rho\lambda})\mathcal{F}_{14}(h)$$

$$\mathcal{P}_{15}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathcal{D}_\nu\mathbf{V}^\nu)\mathcal{F}_{15}(h)$$

$$\mathcal{P}_{16}(h) = \mathrm{Tr}([\mathbf{T}, \mathbf{V}_\nu]\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{16}(h)$$

GREEN

have siblings of d=6 and then are weighted by ξ

$$\mathcal{P}_{21}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\mathcal{F}_{21}(h)\partial^\nu\mathcal{F}'_{21}(h)$$

$$\mathcal{P}_{22}(h) = \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\mu\mathcal{F}_{22}(h)\partial^\nu\mathcal{F}'_{22}(h)$$

$$\mathcal{P}_{23}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)(\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{23}(h)$$

$$\mathcal{P}_{24}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{24}(h)$$

$$\mathcal{P}_{25}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\partial^\nu\mathcal{F}_{25}(h)$$

$$\mathcal{P}_{26}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{26}(h)$$

$$\mathcal{P}_H(h) = \frac{1}{2}(\partial_\mu h)(\partial^\mu h)\mathcal{F}_H(h)$$

$$\mathcal{P}_{\Box H} = \frac{1}{v^2}(\partial_\mu\partial^\mu h)^2\mathcal{F}_{\Box H}(h)$$

$$\mathcal{P}_C(h) = -\frac{v^2}{4}\text{Tr}(\mathbf{V}^\mu \mathbf{V}_\mu)\mathcal{F}_C(h)$$

$$\mathcal{P}_T(h) = \frac{v^2}{4}\text{Tr}(\mathbf{T}\mathbf{V}_\mu)\text{Tr}(\mathbf{T}\mathbf{V}^\mu)\mathcal{F}_T(h)$$

$$\mathcal{P}_B(h) = -\frac{g'^2}{4}B_{\mu\nu}B^{\mu\nu}\mathcal{F}_B(h)$$

BLUE

have siblings of d=8 and then are weighted by ξ^2

$$\mathcal{P}_2(h) = ig' B_{\mu\nu}\text{Tr}(\mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu])\mathcal{F}_2(h)$$

$$\mathcal{P}_3(h) = ig\text{Tr}(W_{\mu\nu}[\mathbf{V}^\mu, \mathbf{V}^\nu])\mathcal{F}_3(h)$$

$$\mathcal{P}_4(h) = ig' B_{\mu\nu}\text{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_4(h)$$

$$\mathcal{P}_5(h) = ig\text{Tr}(W_{\mu\nu}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_5(h)$$

$$\mathcal{P}_6(h) = (\text{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu))^2\mathcal{F}_6(h)$$

$$\mathcal{P}_7(h) = \text{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)\partial_\nu\partial^\nu\mathcal{F}_7(h)$$

$$\mathcal{P}_8(h) = \text{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\partial^\mu\mathcal{F}_8(h)\partial^\nu\mathcal{F}'_8(h)$$

$$\mathcal{P}_9(h) = \text{Tr}((\mathcal{D}_\mu\mathbf{V}^\mu)^2)\mathcal{F}_9(h)$$

$$\mathcal{P}_{10}(h) = \text{Tr}(\mathbf{V}_\nu\mathcal{D}_\mu\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{10}(h)$$

$$\mathcal{P}_{11}(h) = (\text{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu))^2\mathcal{F}_{11}(h)$$

$$\mathcal{P}_{12}(h) = g^2(\text{Tr}(\mathbf{T}W_{\mu\nu}))^2\mathcal{F}_{12}(h)$$

$$\mathcal{P}_{13}(h) = ig\text{Tr}(\mathbf{T}W_{\mu\nu})\text{Tr}(\mathbf{T}[\mathbf{V}^\mu, \mathbf{V}^\nu])\mathcal{F}_{13}(h)$$

$$\mathcal{P}_{14}(h) = g\varepsilon^{\mu\nu\rho\lambda}\text{Tr}(\mathbf{T}\mathbf{V}_\mu)\text{Tr}(\mathbf{V}_\nu W_{\rho\lambda})\mathcal{F}_{14}(h)$$

$$\mathcal{P}_{15}(h) = \text{Tr}(\mathbf{T}\mathcal{D}_\mu\mathbf{V}^\mu)\text{Tr}(\mathbf{T}\mathcal{D}_\nu\mathbf{V}^\nu)\mathcal{F}_{15}(h)$$

$$\mathcal{P}_{16}(h) = \text{Tr}([\mathbf{T}, \mathbf{V}_\nu]\mathcal{D}_\mu\mathbf{V}^\mu)\text{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{16}(h)$$

$$\mathcal{P}_{17}(h) = ig\text{Tr}(\mathbf{T}W_{\mu\nu})\text{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{17}(h)$$

$$\mathcal{P}_{18}(h) = \text{Tr}(\mathbf{T}[\mathbf{V}_\mu, \mathbf{V}_\nu])\text{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{18}(h)$$

$$\mathcal{P}_{19}(h) = \text{Tr}(\mathbf{T}\mathcal{D}_\mu\mathbf{V}^\mu)\text{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\nu\mathcal{F}_{19}(h)$$

$$\mathcal{P}_{20}(h) = \text{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)\partial_\nu\mathcal{F}_{20}(h)\partial^\nu\mathcal{F}'_{20}(h)$$

$$\mathcal{P}_{21}(h) = (\text{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\mathcal{F}_{21}(h)\partial^\nu\mathcal{F}'_{21}(h)$$

$$\mathcal{P}_{22}(h) = \text{Tr}(\mathbf{T}\mathbf{V}_\mu)\text{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\mu\mathcal{F}_{22}(h)\partial^\nu\mathcal{F}'_{22}(h)$$

$$\mathcal{P}_{23}(h) = \text{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)(\text{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{23}(h)$$

$$\mathcal{P}_{24}(h) = \text{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\text{Tr}(\mathbf{T}\mathbf{V}^\mu)\text{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{24}(h)$$

$$\mathcal{P}_{25}(h) = (\text{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\partial^\nu\mathcal{F}_{25}(h)$$

$$\mathcal{P}_{26}(h) = (\text{Tr}(\mathbf{T}\mathbf{V}_\mu)\text{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{26}(h)$$

$$\mathcal{P}_H(h) = \frac{1}{2}(\partial_\mu h)(\partial^\mu h)\mathcal{F}_H(h)$$

$$\mathcal{P}_{\Box H} = \frac{1}{v^2}(\partial_\mu\partial^\mu h)^2\mathcal{F}_{\Box H}(h)$$

$$\mathcal{P}_C(h) = -\frac{v^2}{4}\mathrm{Tr}(\mathbf{V}^\mu\mathbf{V}_\mu)\mathcal{F}_C(h)$$

$$\mathcal{P}_T(h) = \frac{v^2}{4}\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\mathcal{F}_T(h)$$

$$\mathcal{P}_B(h) = -\frac{g'^2}{4}B_{\mu\nu}B^{\mu\nu}\mathcal{F}_B(h)$$

$$\mathcal{P}_W(h) = -\frac{g^2}{4}W^a_{\mu\nu}W^{a\mu\nu}\mathcal{F}_W(h)$$

$$\mathcal{P}_G(h) = -\frac{g_s^2}{4}G^a_{\mu\nu}G^{a\mu\nu}\mathcal{F}_G(h)$$

$$\mathcal{P}_1(h) = gg'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}W^{\mu\nu})\mathcal{F}_1(h)$$

$$\mathcal{P}_2(h) = ig'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_2(h)$$

$$\mathcal{P}_3(h) = ig\mathrm{Tr}(W_{\mu\nu}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_3(h)$$

$$\mathcal{P}_4(h) = ig'B_{\mu\nu}\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_4(h)$$

$$\mathcal{P}_5(h) = ig\mathrm{Tr}(W_{\mu\nu}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_5(h)$$

RED

have siblings of d=12 and then are weighted by ξ^4

$$\mathcal{P}_{10}(h) = \mathrm{Tr}(\mathbf{V}_\nu\mathcal{D}_\mu\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{10}(h)$$

$$\mathcal{P}_{11}(h) = (\mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu))^2\mathcal{F}_{11}(h)$$

$$\mathcal{P}_{12}(h) = g^2(\mathrm{Tr}(\mathbf{T}W_{\mu\nu}))^2\mathcal{F}_{12}(h)$$

$$\mathcal{P}_{13}(h) = ig\mathrm{Tr}(\mathbf{T}W_{\mu\nu})\mathrm{Tr}(\mathbf{T}[\mathbf{V}^\mu,\mathbf{V}^\nu])\mathcal{F}_{13}(h)$$

$$\mathcal{P}_{14}(h) = g\varepsilon^{\mu\nu\rho\lambda}\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{V}_\nu W_{\rho\lambda})\mathcal{F}_{14}(h)$$

$$\mathcal{P}_{15}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathcal{D}_\nu\mathbf{V}^\nu)\mathcal{F}_{15}(h)$$

$$\mathcal{P}_{16}(h) = \mathrm{Tr}([\mathbf{T},\mathbf{V}_\nu]\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{16}(h)$$

$$\mathcal{P}_{17}(h) = ig\mathrm{Tr}(\mathbf{T}W_{\mu\nu})\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{17}(h)$$

$$\mathcal{P}_{18}(h) = \mathrm{Tr}(\mathbf{T}[\mathbf{V}_\mu,\mathbf{V}_\nu])\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\partial^\nu\mathcal{F}_{18}(h)$$

$$\mathcal{P}_{19}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\nu\mathcal{F}_{19}(h)$$

$$\mathcal{P}_{20}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)\partial_\nu\mathcal{F}_{20}(h)\partial^\nu\mathcal{F}'_{20}(h)$$

$$\mathcal{P}_{21}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\mathcal{F}_{21}(h)\partial^\nu\mathcal{F}'_{21}(h)$$

$$\mathcal{P}_{22}(h) = \mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\mu\mathcal{F}_{22}(h)\partial^\nu\mathcal{F}'_{22}(h)$$

$$\mathcal{P}_{23}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}^\mu)(\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{23}(h)$$

$$\mathcal{P}_{24}(h) = \mathrm{Tr}(\mathbf{V}_\mu\mathbf{V}_\nu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{24}(h)$$

$$\mathcal{P}_{25}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2\partial_\nu\partial^\nu\mathcal{F}_{25}(h)$$

$$\mathcal{P}_{26}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu))^2\mathcal{F}_{26}(h)$$

$$\mathcal{P}_H(h) = \frac{1}{2}(\partial_\mu h)(\partial^\mu h)\mathcal{F}_H(h)$$

$$\mathcal{P}_{\Box H} = \frac{1}{v^2}(\partial_\mu\partial^\mu h)^2\mathcal{F}_{\Box H}(h)$$

Disentangling a Dynamical Higgs I

[Brivio,Corbett,Eboli,Gavela,Gonzalez-Fraile,Gonzalez-Garcia,LM&Rigolin, 1311.1823]

Correlations present in the linear basis are absent in the chiral basis

$$\mathcal{O}_B/f^2 = \frac{\xi}{16}\mathcal{P}_2(h) + \frac{\xi}{8}\mathcal{P}_4(h)$$ (similar for $\mathcal{O}_W$)

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$$\mathcal{O}_B/f^2 = \frac{\xi}{16}\mathcal{P}_2(h) + \frac{\xi}{8}\mathcal{P}_4(h)$$

(similar for $\mathcal{O}_W$)

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

$$\mathcal{P}_2(h) = 2ieg^2A_{\mu\nu}W^{-\mu}W^{+\nu}\mathcal{F}_2(h) - 2\frac{ie^2g}{\cos\theta_W}Z_{\mu\nu}W^{-\mu}W^{+\nu}\mathcal{F}_2(h)$$

$$\mathcal{P}_4(h) = -\frac{eg}{\cos\theta_W}A_{\mu\nu}Z^\mu\partial^\nu\mathcal{F}_4(h) + \frac{e^2}{\cos^2\theta_W}Z_{\mu\nu}Z^\mu\partial^\nu\mathcal{F}_4(h)$$

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(similar for $\mathcal{O}_W$)

$$\mathcal{O}_B = \frac{ieg^2}{8} A_{\mu\nu} W^{-\mu} W^{+\nu} (v+h)^2 - \frac{ie^2 g}{8\cos\theta_W} Z_{\mu\nu} W^{-\mu} W^{+\nu} (v+h)^2$$
$$- \frac{eg}{4\cos\theta_W} A_{\mu\nu} Z^\mu \partial^\nu h (v+h) + \frac{e^2}{4\cos^2\theta_W} Z_{\mu\nu} Z^\mu \partial^\nu h (v+h)$$

$$\mathcal{P}_2(h) = 2ieg^2 A_{\mu\nu} W^{-\mu} W^{+\nu} \mathcal{F}_2(h) - 2\frac{ie^2 g}{\cos\theta_W} Z_{\mu\nu} W^{-\mu} W^{+\nu} \mathcal{F}_2(h)$$

$$\mathcal{P}_4(h) = -\frac{eg}{\cos\theta_W} A_{\mu\nu} Z^\mu \partial^\nu \mathcal{F}_4(h) + \frac{e^2}{\cos^2\theta_W} Z_{\mu\nu} Z^\mu \partial^\nu \mathcal{F}_4(h)$$

due to the decorrelation in the $\mathcal{F}_i(h)$ functions: i.e.

$$\gamma - W - W - h \leftrightarrow \gamma - W - W$$

$$Z - W - W - h \leftrightarrow Z - W - W$$

$$\mathcal{F}_i(h) \equiv g(h, f)$$

Disentangling a Dynamical Higgs I

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Correlations present in the linear basis are absent in the chiral basis

$$\mathcal{O}_B/f^2 = \frac{\xi}{16}\mathcal{P}_2(h) + \frac{\xi}{8}\mathcal{P}_4(h)$$ (similar for $\mathcal{O}_W$)

$$\mathcal{O}_B = \frac{ieg^2}{8}A_{\mu\nu}W^{-\mu}W^{+\nu}(v+h)^2 - \frac{ie^2g}{8\cos\theta_W}Z_{\mu\nu}W^{-\mu}W^{+\nu}(v+h)^2 - \frac{eg}{4\cos\theta_W}A_{\mu\nu}Z^\mu\partial^\nu h(v+h) + \frac{e^2}{4\cos^2\theta_W}Z_{\mu\nu}Z^\mu\partial^\nu h(v+h)$$

$$\mathcal{P}_2(h) = 2ieg^2A_{\mu\nu}W^{-\mu}W^{+\nu}\mathcal{F}_2(h) - 2\frac{ie^2g}{\cos\theta_W}Z_{\mu\nu}W^{-\mu}W^{+\nu}\mathcal{F}_2(h)$$

$$\mathcal{P}_4(h) = -\frac{eg}{\cos\theta_W}A_{\mu\nu}Z^\mu\partial^\nu\mathcal{F}_4(h) + \frac{e^2}{\cos^2\theta_W}Z_{\mu\nu}Z^\mu\partial^\nu\mathcal{F}_4(h)$$

due to the nature of the chiral operators (different c_i coefficients): i.e.

$\gamma - W - W \Leftrightarrow \gamma - Z - h$

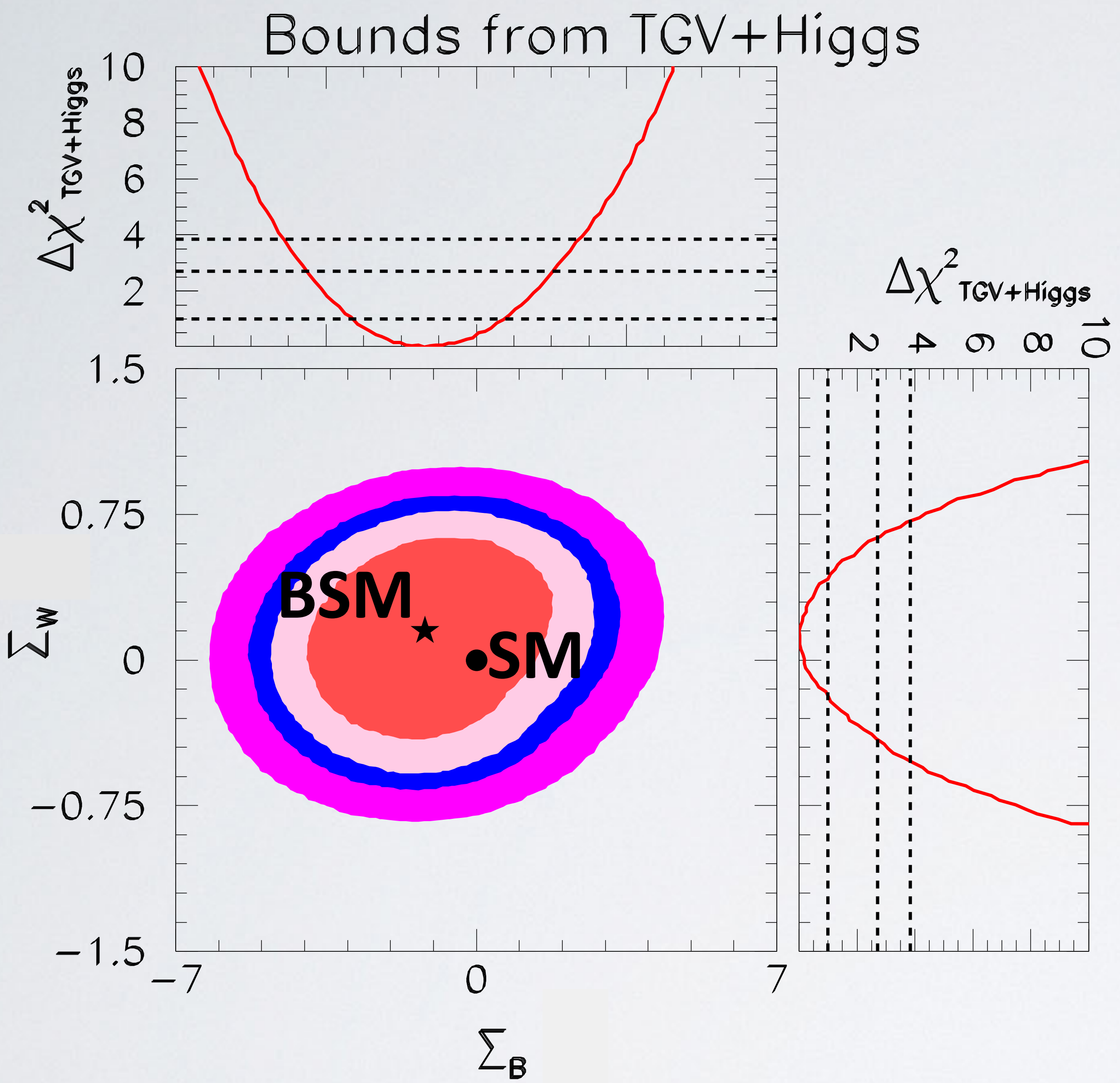
$Z - W - W \Leftrightarrow Z - Z - h$

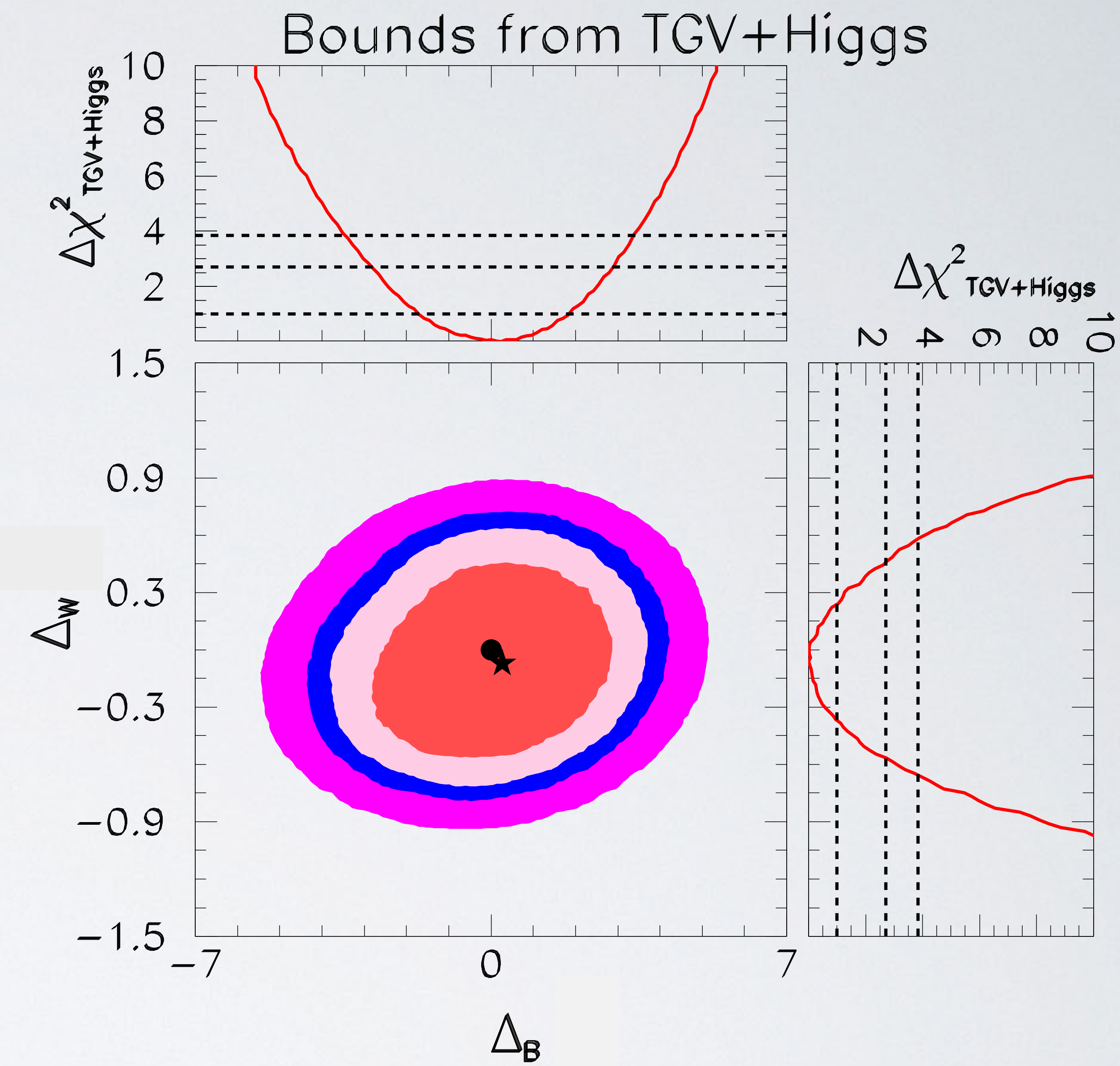
$\gamma - W - W - h \Leftrightarrow \gamma - Z - h$

$Z - W - W - h \Leftrightarrow Z - Z - h$

Disentangling a Dynamical Higgs I

[Brivio,Corbett,Eboli,Gavela,Gonzalez-Fraile,Gonzalez-Garcia,LM&Rigolin, 1311.1823]





$$\Sigma_B = 4(2c_2 + a_4) \to f_B \xi$$

$$\Sigma_W = 2(2c_3 - a_5) \to f_W \xi$$

$$\Delta_B = 4(2c_2 - a_4) \to 0$$

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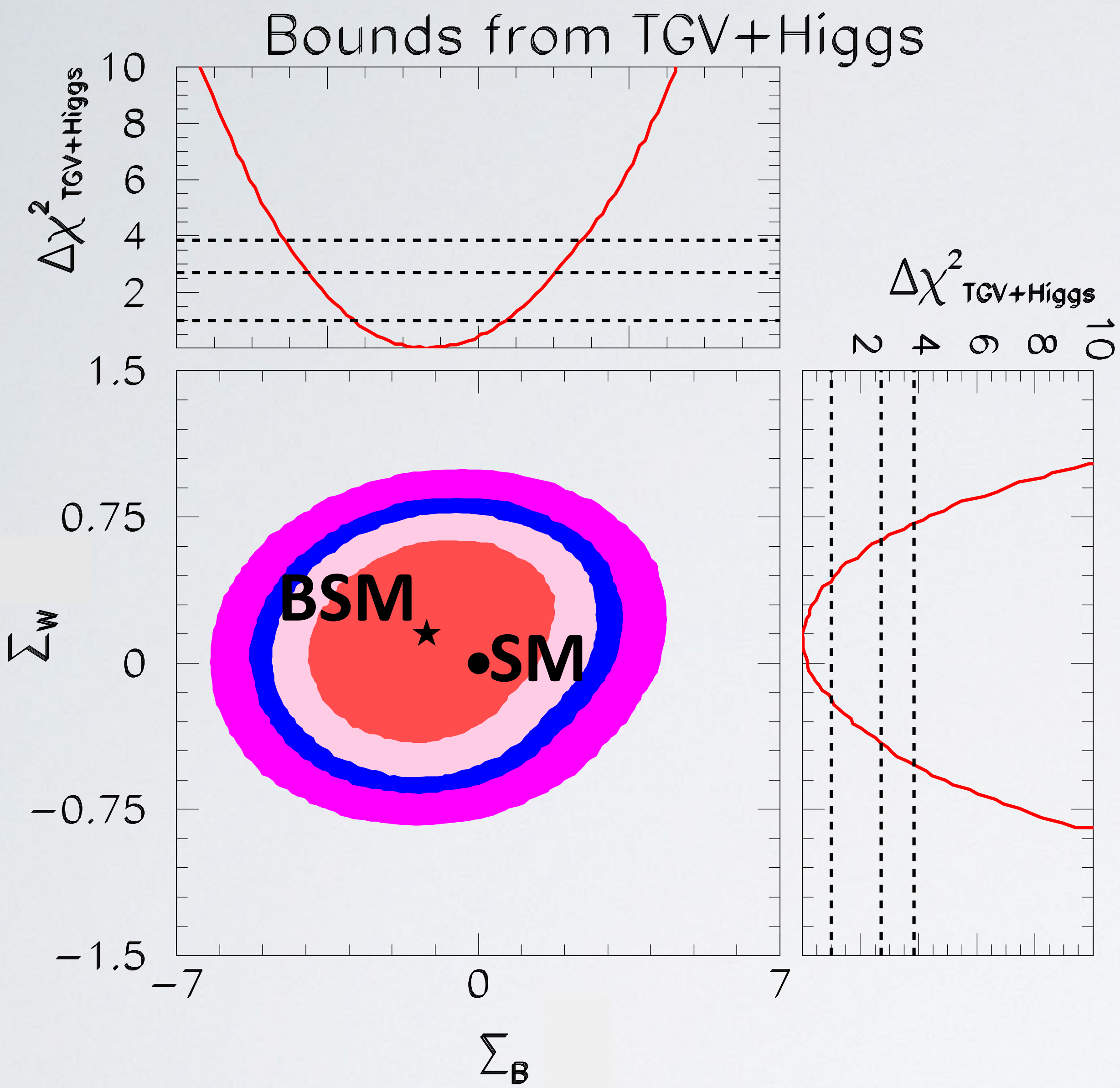
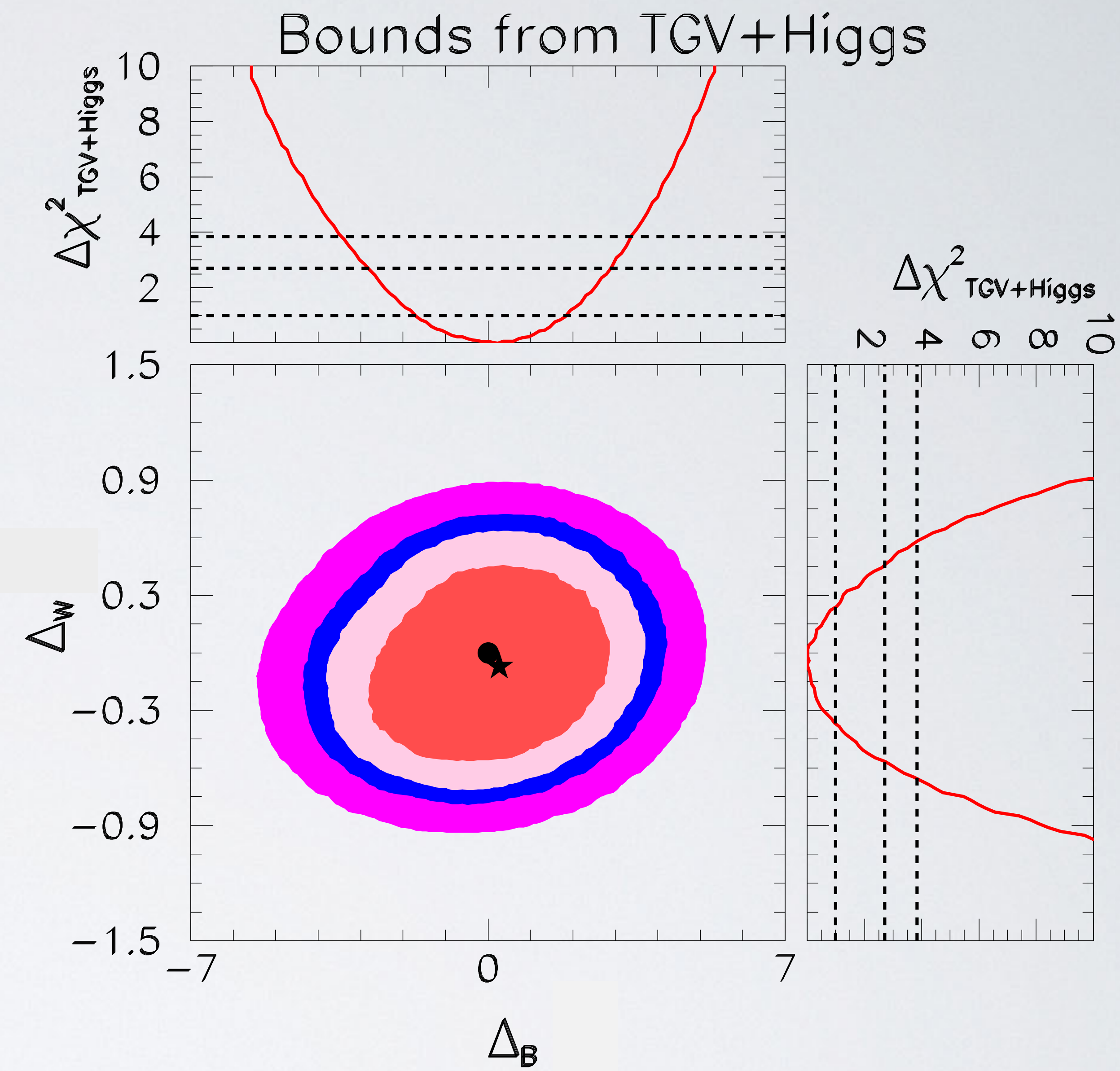
Disentangling a Dynamical Higgs I

[Brivio,Corbett,Eboli,Gavela,Gonzalez-Fraile,Gonzalez-Garcia,LM&Rigolin, 1311.1823]





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Need of more precision for: - discovering BSM physics with TGV and HVV
- disentangling dynamical from elementary

Disentangling a Dynamical Higgs II

Specific "relevant" signals are expected in the chiral basis,
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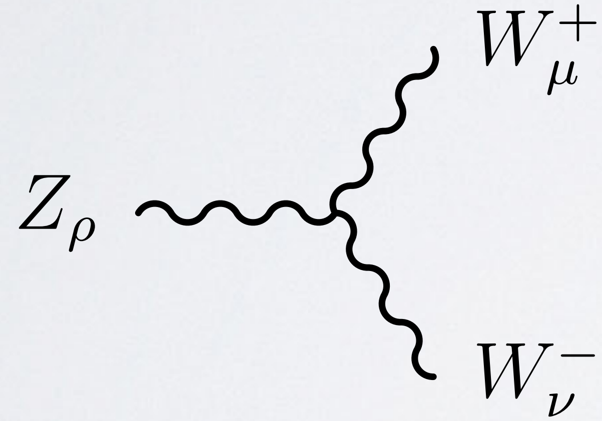
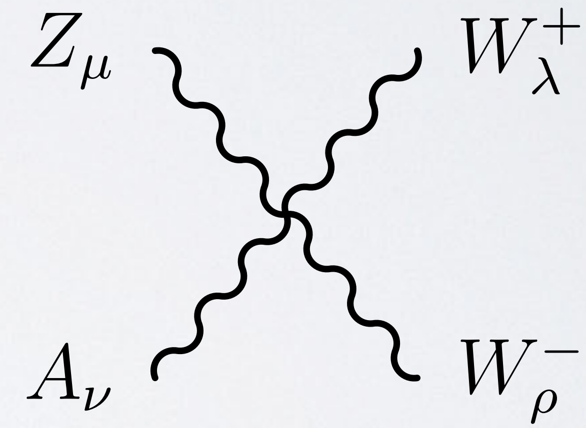
C and P odd, but CP even

$$\varepsilon^{\mu\nu\rho\lambda}\partial_\mu W^+_\nu W^-_\rho Z_\lambda \mathcal{F}_{14}(h)$$



$$\varepsilon^{\mu\nu\rho\lambda} Z_\mu A_\nu W^-_\rho W^+_\lambda \mathcal{F}_{14}(h)$$



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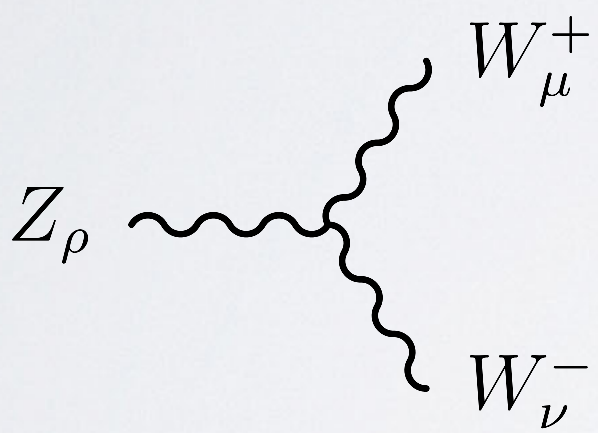

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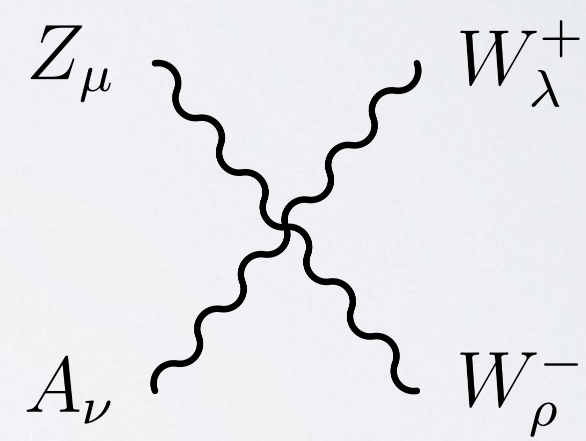


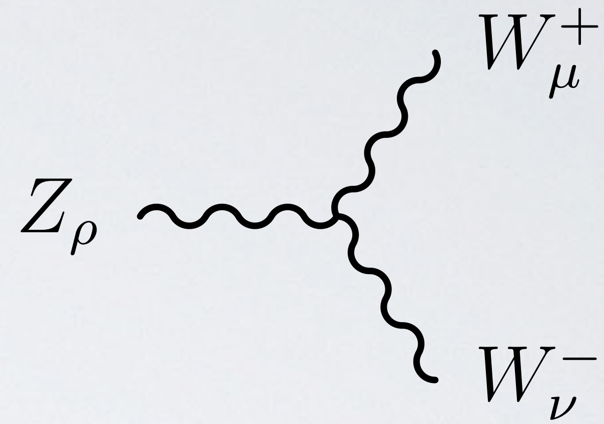
The interactions of this operator are described in the linear regime by an operator with d=8 and therefore a signal at collider would be an indication in favour of the chiral EW realisation, wrt the linear one.

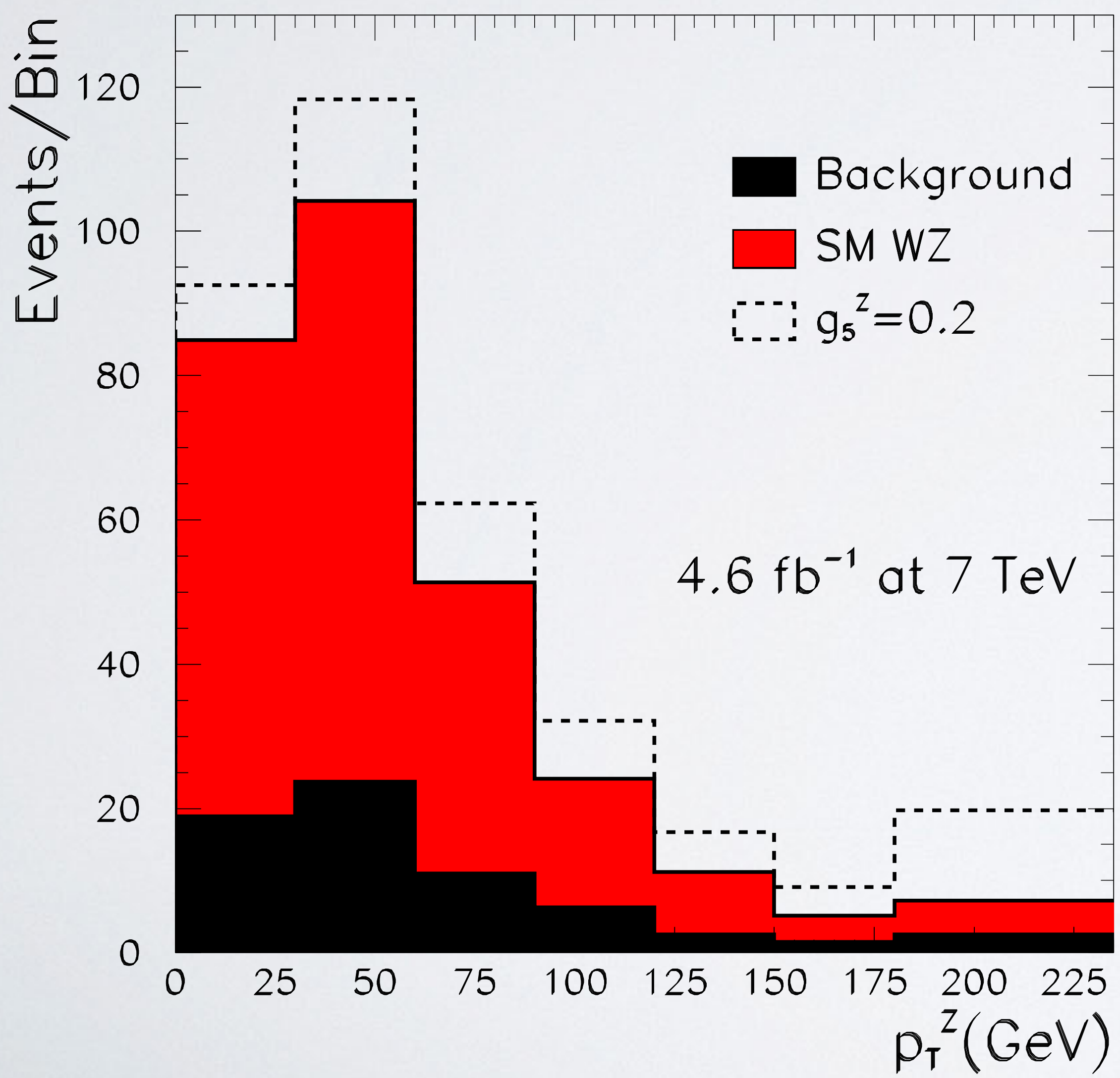
Disentangling a Dynamical Higgs II

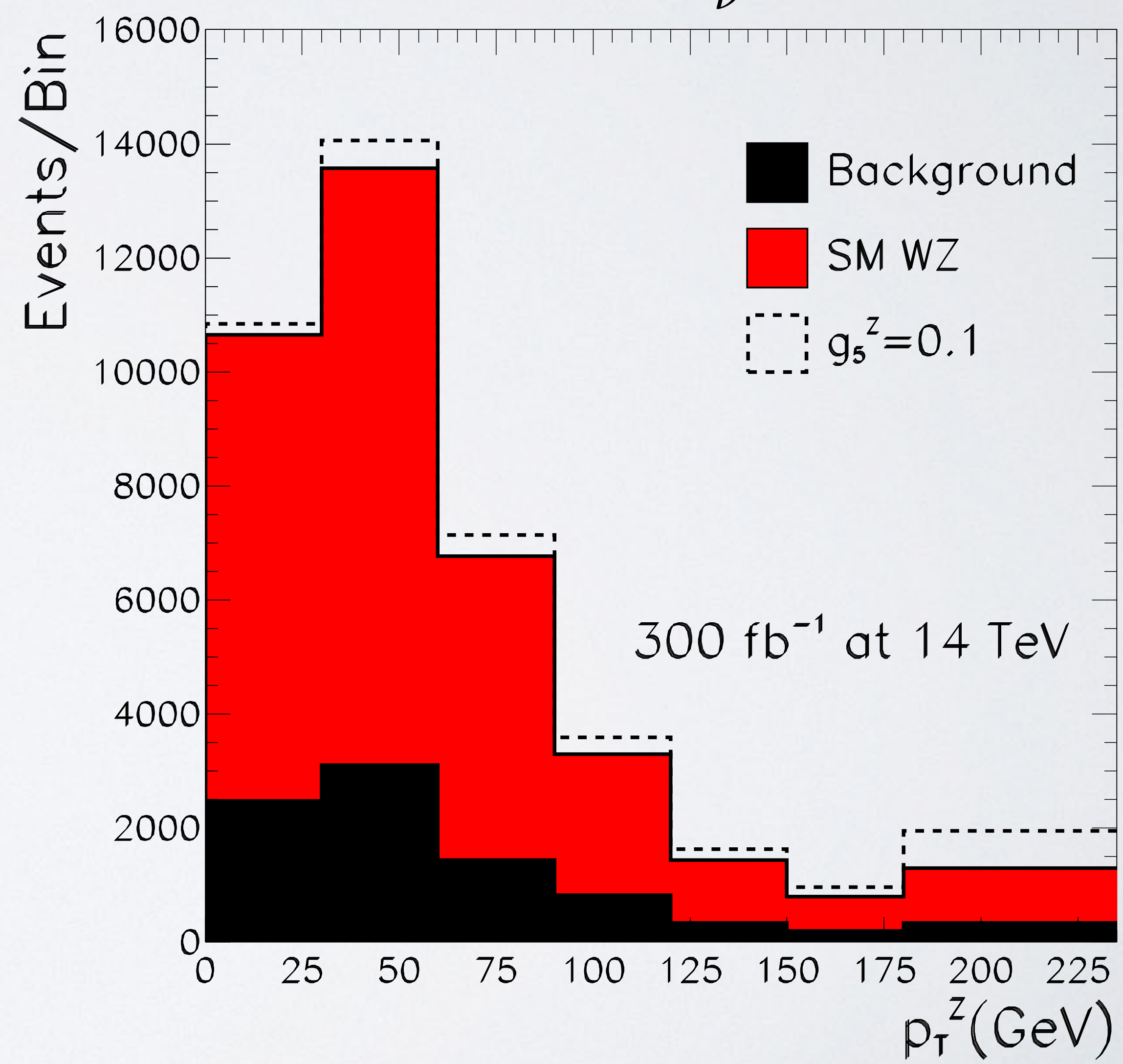
[Brivio,Corbett,Eboli,Gavela,Gonzalez-Fraile,Gonzalez-Garcia,LM&Rigolin, 1311.1823]

Simulation of what can be seen at LHC (7+8 TeV, 7+8+14 TeV) for g_5^Z

$$\varepsilon^{\mu\nu\rho\lambda}\partial_\mu W_\nu^+ W_\rho^- Z_\lambda \mathcal{F}_{14}(h)$$







number of expected events (WZ production) with respect to the Z p_T

Present results, mainly from LEP II (WW pairs and single W production) and radiative corrections to Z physics

	Measurement (±68% CL region)	95% CL region	
Experiment	g_5^Z	g_5^Z	c_{14}
OPAL	$-0.04^{+0.13}_{-0.12}$	$[-0.28, 0.21]$	$[-0.16, 0.12]$
L3	$0.00^{+0.13}_{-0.13}$	$[-0.21, 0.20]$	$[-0.12, 0.11]$
ALEPH	$-0.064^{+0.13}_{-0.13}$	$[-0.317, 0.19]$	$[-0.18, 0.11]$

90% CL region from indirect bounds	g_5^Z: $[-0.08, 0.04]$	c_{14}: $[-0.04, 0.02]$

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- Expected sensitivity on g_5^Z at the LHC (7+8 TeV and 7+8+14 TeV)

	68% CL range		95% CL range	
Data sets used	Counting $p_T^Z > 90$ GeV	p_T^Z binned analysis	Counting $p_T^Z > 90$ GeV	p_T^Z binned analysis
7+8 TeV ($4.64+19.6$ fb^{-1})	$(-0.066,\ 0.058)$	$(-0.057,\ 0.050)$	$(-0.091,\ 0.083)$	$(-0.080,\ 0.072)$
7+8+14 TeV ($4.64+19.6+300$ fb^{-1})	$(-0.030,\ 0.022)$	$(-0.024,\ 0.019)$	$(-0.040,\ 0.032)$	$(-0.033,\ 0.028)$

LHC7+8 could have already a sensitivity that competes with the present bounds

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- Need of more precision to disentangle a dynamical Higgs with TGV+HVV
- A dedicated study on g_5^Z with LHC data could have already something to say about the presence of BSM physics and on the nature of h!!!

Thank you

Backup

SILH

[Giudice,Grojean,Pomarol& Rattazzi, arXiv:hep-ph0703164]

$$\mathcal{L}_{\rm SILH} = \frac{c_H}{2f^2}\partial^\mu \left(H^\dagger H\right) \partial_\mu \left(H^\dagger H\right) + \frac{c_T}{2f^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right)$$
$$-\frac{c_6 \lambda}{f^2}\left(H^\dagger H\right)^3 + \left(\frac{c_y y_f}{f^2} H^\dagger H \bar{f}_L H f_R + \text{h.c.}\right)$$
$$+\frac{i c_W g}{2m_\rho^2}\left(H^\dagger \sigma^i \overleftrightarrow{D^\mu} H\right)(D^\nu W_{\mu\nu})^i + \frac{i c_B g'}{2m_\rho^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)(\partial^\nu B_{\mu\nu})$$
$$+\frac{i c_{HW} g}{16\pi^2 f^2}(D^\mu H)^\dagger \sigma^i (D^\nu H) W^i_{\mu\nu} + \frac{i c_{HB} g'}{16\pi^2 f^2}(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$$
$$+\frac{c_\gamma g'^2}{16\pi^2 f^2}\frac{g^2}{g_\rho^2} H^\dagger H B_{\mu\nu} B^{\mu\nu} + \frac{c_g g_S^2}{16\pi^2 f^2}\frac{y_t^2}{g_\rho^2} H^\dagger H G^a_{\mu\nu} G^{a\mu\nu}$$

Alonso,Jenkins,Manohar & Trott, 1312.2014

advocates that the SILH Lagrangian has been used not consistently in several recent papers

$$\mathcal{O}_g^{\rm SILH} \equiv \mathcal{O}_{GG} \qquad \mathcal{O}_\gamma^{\rm SILH} \equiv \mathcal{O}_{BB}$$
$$\mathcal{O}_B^{\rm SILH} \equiv 2\mathcal{O}_B + \mathcal{O}_{BW} + \mathcal{O}_{BB} \qquad \mathcal{O}_W^{\rm SILH} \equiv 2\mathcal{O}_W + \mathcal{O}_{BW} + \mathcal{O}_{WW}$$
$$\mathcal{O}_{HW}^{\rm SILH} \equiv \mathcal{O}_W \qquad \mathcal{O}_{HB}^{\rm SILH} \equiv \mathcal{O}_B$$
$$\mathcal{O}_T^{\rm SILH} \equiv \mathcal{O}_{\Phi,2} - 2\mathcal{O}_{\Phi,1} \qquad \mathcal{O}_H^{\rm SILH} \equiv \mathcal{O}_{\Phi,2}$$
$$\mathcal{O}_6^{\rm SILH} \equiv \mathcal{O}_{\Phi,3} \qquad \mathcal{O}_y^{\rm SILH} \equiv 2\mathcal{O}_{\Phi,2} + 2\mathcal{O}_{\Phi,4} - \left(\Phi^\dagger \Phi\right)\Phi^\dagger \frac{\delta V(h)}{\delta \Phi^\dagger}$$

The SILH Lagrangian is just a linear Lagrangian, alternative to the HISZ one.

$$
\begin{aligned}
\mathcal{L}_{\mathrm{SILH}} = & \frac{c_H}{2f^2}\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) + \frac{c_T}{2f^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) \\
& - \frac{c_6\lambda}{f^2}\left(H^\dagger H\right)^3 + \left(\frac{c_y y_f}{f^2} H^\dagger H \bar{f}_L H f_R + \mathrm{h.c.}\right) \\
& + \frac{i c_W g}{2m_\rho^2}\left(H^\dagger \sigma^i \overleftrightarrow{D^\mu} H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{i c_B g'}{2m_\rho^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(\partial^\nu B_{\mu\nu}\right) \\
& + \frac{i c_{HW} g}{16\pi^2 f^2}(D^\mu H)^\dagger \sigma^i (D^\nu H) W^i_{\mu\nu} + \frac{i c_{HB} g'}{16\pi^2 f^2}(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu} \\
& + \frac{c_\gamma g'^2}{16\pi^2 f^2}\frac{g^2}{g_\rho^2} H^\dagger H B_{\mu\nu} B^{\mu\nu} + \frac{c_g g_S^2}{16\pi^2 f^2}\frac{y_t^2}{g_\rho^2} H^\dagger H G^a_{\mu\nu} G^{a\mu\nu}
\end{aligned}
$$

$$\mathcal{O}_g^{\mathrm{SILH}} = \frac{v^2}{2g_s^2}\mathcal{P}_G$$

$$\mathcal{O}_B^{\mathrm{SILH}} = \frac{v^2}{8}(\mathcal{P}_2 + 2\mathcal{P}_4) + \frac{v^2}{8}\mathcal{P}_1 + \frac{v^2}{2}\mathcal{P}_B$$

$$\mathcal{O}_{HB}^{\mathrm{SILH}} = \frac{v^2}{16}(\mathcal{P}_2 + 2\mathcal{P}_4)$$

$$\mathcal{O}_T^{\mathrm{SILH}} = \frac{v^2}{2}\mathcal{F}(h)\mathcal{P}_T$$

$$\mathcal{O}_\gamma^{\mathrm{SILH}} = \frac{v^2}{2}\mathcal{P}_B$$

$$\mathcal{O}_W^{\mathrm{SILH}} = \frac{v^2}{4}(\mathcal{P}_3 - 2\mathcal{P}_5) + \frac{v^2}{8}\mathcal{P}_1 + \frac{v^2}{2}\mathcal{P}_W$$

$$\mathcal{O}_{HW}^{\mathrm{SILH}} = \frac{v^2}{8}(\mathcal{P}_3 - 2\mathcal{P}_5)$$

$$\mathcal{O}_H^{\mathrm{SILH}} = v^2\mathcal{P}_H$$

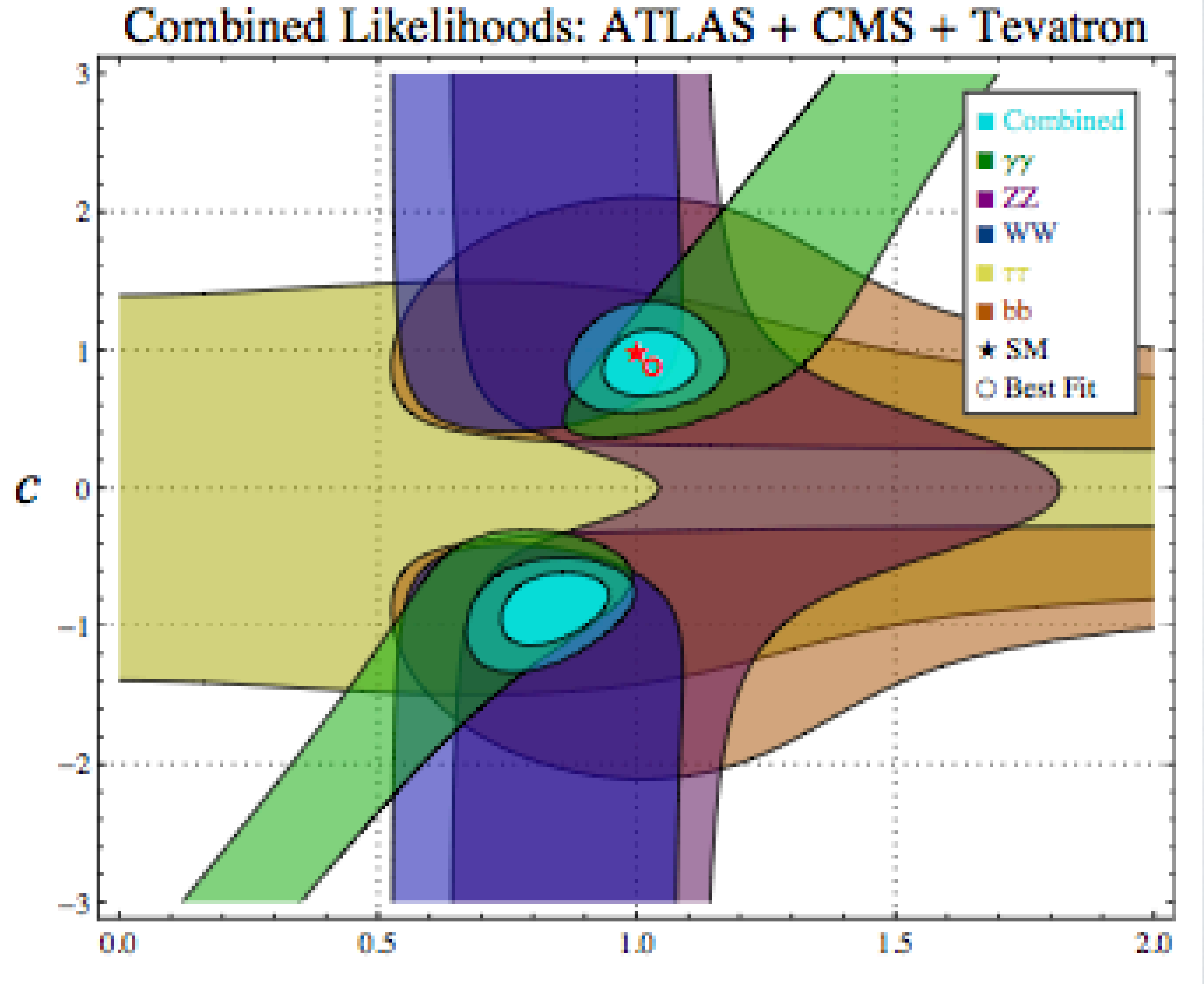
$$\mathcal{O}_y^{\mathrm{SILH}} = 3v^2\mathcal{P}_H + v^2\mathcal{F}(h)\mathcal{P}_C - \frac{(v+h)^3}{2}\frac{\delta V(h)}{\delta h}$$

Other Effective Chiral Lagrangian

$$\mathcal{L} \supset -\frac{v^2}{4}\mathrm{Tr}\left(\mathbf{V}_\mu \mathbf{V}^\mu\right)\left(1 + 2a\frac{h}{v} + b\frac{h^2}{v^2}\right) - \frac{v}{\sqrt{2}}\left(\bar{Q}_L \mathbf{U}\mathcal{Y} Q_R + \mathrm{h.c.}\right)\left(1 + c\frac{h}{v}\right)$$

$$a = 1 + c_C(\alpha_C - 1)$$
$$b = 1 + c_C(\beta_C - 1)$$
$$c = 1 + c_Y(2\alpha_Y - 1)$$

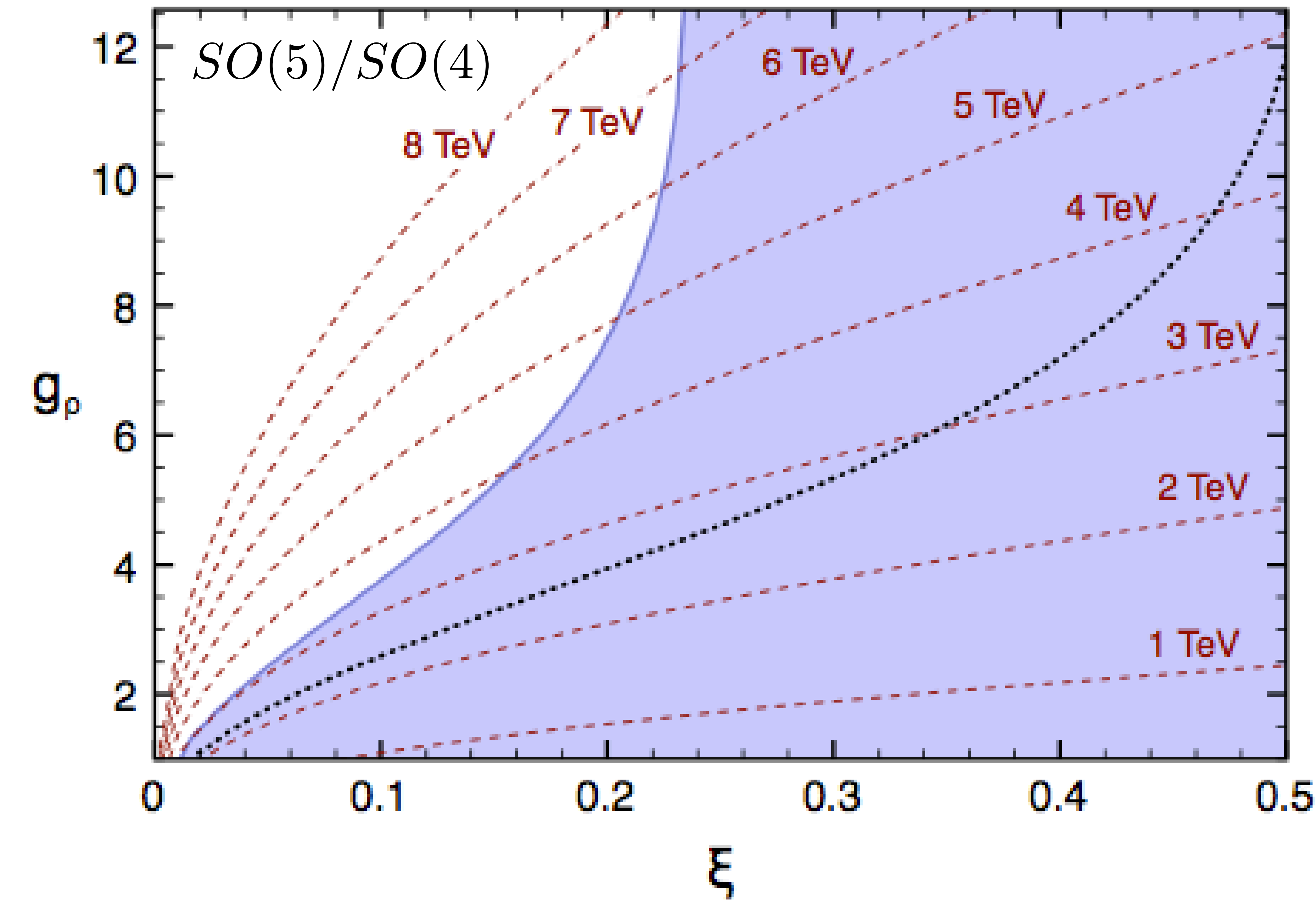
c_C and c_Y have a dependence on ξ



[Azatov&Galloway, 1212.1380]

The parameter ξ

[Contino, 1005.4269]



In the general effective approach, ξ could be even larger than 0.2, but a specific UV completion is necessary.

$$\mathcal{P}_9(h) = \mathrm{Tr}((\mathcal{D}_\mu \mathbf{V}^\mu)^2)\mathcal{F}_9(h)$$
$$\mathcal{P}_{10}(h) = \mathrm{Tr}(\mathbf{V}_\nu \mathcal{D}_\mu \mathbf{V}^\mu)\partial^\nu \mathcal{F}_{10}(h)$$
$$\mathcal{P}_{15}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu \mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathcal{D}_\nu \mathbf{V}^\nu)\mathcal{F}_{15}(h)$$
$$\mathcal{P}_{16}(h) = \mathrm{Tr}([\mathbf{T}, \mathbf{V}_\nu]\mathcal{D}_\mu \mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}^\nu)\mathcal{F}_{16}(h)$$
$$\mathcal{P}_{19}(h) = \mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu \mathbf{V}^\mu)\mathrm{Tr}(\mathbf{T}\mathbf{V}_\nu)\partial^\nu \mathcal{F}_{19}(h)$$
$$\mathcal{P}_7(h) = \mathrm{Tr}(\mathbf{V}_\mu \mathbf{V}^\mu)\partial_\nu \partial^\nu \mathcal{F}_7(h)$$
$$\mathcal{P}_{25}(h) = (\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu))^2 \partial_\nu \partial^\nu \mathcal{F}_{25}(h)$$

If m_f=0 then these operators are not independent from the others

$$\frac{iv}{\sqrt{2}}\mathrm{Tr}(\sigma^j \mathcal{D}_\mu \mathbf{V}^\mu)\left(1+\frac{h}{v}\right)^2 = \frac{v+s_Y h}{v}\left(i\bar{Q}_L \sigma^j \mathbf{U}\mathcal{Y}_Q Q_R + i\bar{L}_L \sigma^j \mathbf{U}\mathcal{Y}_L L_R + \mathrm{h.c.}\right)$$
$$- \frac{iv}{\sqrt{2}}\mathrm{Tr}(\sigma^j \mathbf{V}_\mu)\partial^\mu \left(1+\frac{h}{v}\right)^2$$

$$\frac{iv}{\sqrt{2}}\mathrm{Tr}(\mathbf{T}\mathcal{D}_\mu \mathbf{V}^\mu)\left(1+\frac{h}{v}\right)^2 = \frac{v+s_Y h}{v}\left(i\bar{Q}_L \mathbf{T}\mathbf{U}\mathcal{Y}_Q Q_R + i\bar{L}_L \mathbf{T}\mathbf{U}\mathcal{Y}_L L_R + \mathrm{h.c.}\right)$$
$$- \frac{iv}{\sqrt{2}}\mathrm{Tr}(\mathbf{T}\mathbf{V}_\mu)\partial^\mu \left(1+\frac{h}{v}\right)^2$$

$$\Box h = -\frac{\delta V(h)}{\delta h} - \frac{v+h}{2}\mathrm{Tr}[\mathbf{V}_\mu \mathbf{V}^\mu] - \frac{s_Y}{\sqrt{2}}\left(\bar{Q}_L \mathbf{U}\mathcal{Y}_Q Q_R + \bar{L}_L \mathbf{U}\mathcal{Y}_L L_R + \mathrm{h.c.}\right)$$

Triple Gauge Vertices

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

$$- i g_5^V \epsilon^{\mu\nu\rho\sigma} \left(W^+_\mu \partial_\rho W^-_\nu - W^-_\nu \partial_\rho W^+_\mu \right) V_\sigma + g_6^V \left(\partial_\mu W^{+\mu} W^{-\nu} - \partial_\mu W^{-\mu} W^{+\nu} \right) V_\nu \Big\}$$

$$V \equiv \{\gamma, Z\} \text{ and } g_{WW\gamma} \equiv e = g \sin\theta_W, \; g_{WWZ} = g\cos\theta_W$$

The SM values are: $g_1^Z = \kappa_\gamma = \kappa_Z = 1$ and $g_5^Z = g_6^\gamma = g_6^Z = 0$

	Coeff. $\times e^2/s_\theta^2$	Chiral $\times\xi$	Chiral $\times\xi^2$	Linear $\times v^2/\Lambda^2$
$\Delta\kappa_\gamma$	1	$-2c_1 + 2c_2 + c_3$	$-4c_{12} + 2c_{13}$	$\frac{1}{8}(f_W + f_B - 2f_{BW})$
Δg_6^γ	1	$-c_9$	$-$	$\frac{1}{4} f_{\Box\Phi}$
Δg_1^Z	$\frac{1}{c_\theta^2}$	$\frac{s_{2\theta}^2}{4e^2 c_{2\theta}} c_T + \frac{2s_\theta^2}{c_{2\theta}} c_1 + c_3$	$-$	$\frac{1}{8} f_W + \frac{s_\theta^2}{4c_{2\theta}} f_{BW} - \frac{s_{2\theta}^2}{16e^2 c_{2\theta}} f_{\Phi,1}$
$\Delta\kappa_Z$	1	$\frac{s_\theta^2}{e^2 c_{2\theta}} c_T + \frac{4s_\theta^2}{c_{2\theta}} c_1 - \frac{2s_\theta^2}{c_\theta^2} c_2 + c_3$	$-4c_{12} + 2c_{13}$	$\frac{1}{8} f_W - \frac{s_\theta^2}{8c_\theta^2} f_B + \frac{s_\theta^2}{2c_{2\theta}} f_{BW} - \frac{s_\theta^2}{4e^2 c_{2\theta}} f_{\Phi,1}$
Δg_5^Z	$\frac{1}{c_\theta^2}$	$-$	c_{14}	$-$
Δg_6^Z	$\frac{1}{c_\theta^2}$	$s_\theta^2 c_9$	$-c_{16}$	$-\frac{s_\theta^2}{4} f_{\Box\Phi}$

From the table, we can read out two correlations:

$$\Delta\kappa_Z + \frac{s_\theta^2}{c_\theta^2}\Delta\kappa_\gamma - \Delta g_1^Z = \frac{16e^2}{s_\theta^2}(2c_{12} - c_{13})\xi^2\,,$$

$$\Delta g_6^\gamma + \frac{c_\theta^2}{s_\theta^2}\Delta g_6^Z = -\frac{e^2}{s_\theta^4}\,c_{16}\,\xi^2\,,$$

The RHS is vanishing, once considering:

- d=6 linear effective basis
- chiral basis truncated to ξ-weighted operators

⇒ No possibility of distinguishing a dynamical Higgs from an elementary Higgs if $\xi \ll 1$, considering only TGV.

Higgs-Vector-Vector Vertices

$$\begin{aligned}\mathscr{L}_{\rm HVV} \equiv\ & g_{Hgg}\, G^a_{\mu\nu} G^{a\mu\nu} h + g_{H\gamma\gamma}\, A_{\mu\nu} A^{\mu\nu} h + g^{(1)}_{HZ\gamma}\, A_{\mu\nu} Z^\mu \partial^\nu h + g^{(2)}_{HZ\gamma}\, A_{\mu\nu} Z^{\mu\nu} h \\ & + g^{(1)}_{HZZ}\, Z_{\mu\nu} Z^\mu \partial^\nu h + g^{(2)}_{HZZ}\, Z_{\mu\nu} Z^{\mu\nu} h + g^{(3)}_{HZZ}\, Z_\mu Z^\mu h + g^{(4)}_{HZZ}\, Z_\mu Z^\mu \Box h \\ & + g^{(5)}_{HZZ}\, \partial_\mu Z^\mu Z_\nu \partial^\nu h + g^{(6)}_{HZZ}\, \partial_\mu Z^\mu \partial_\nu Z^\nu h \\ & + g^{(1)}_{HWW}\, \left(W^+_{\mu\nu} W^{-\,\mu} \partial^\nu h + \text{h.c.} \right) + g^{(2)}_{HWW}\, W^+_{\mu\nu} W^{-\,\mu\nu} h + g^{(3)}_{HWW}\, W^+_\mu W^{-\,\mu} h \\ & + g^{(4)}_{HWW}\, W^+_\mu W^{-\mu} \Box h + g^{(5)}_{HWW}\, \left(\partial_\mu W^{+\mu} W^-_\nu \partial^\nu h + \text{h.c.} \right) + g^{(6)}_{HWW}\, \partial_\mu W^{+\mu} \partial_\nu W^{-\nu} h\end{aligned}$$

where $V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$ with $V = \{A, Z, W, G\}$

Writing the couplings as

$$g^{(j)}_i \simeq g^{(j)SM}_i + \Delta g^{(j)}_i$$

the only non-vanishing SM contributions are given by

$$g^{(3)SM}_{HZZ} = \frac{m_Z^2}{v}\,, \qquad g^{(3)SM}_{HWW} = \frac{2 m_Z^2 \cos\theta_W^2}{v}$$

	Coeff. $\times e^2/4v$	Chiral $\times\xi$	$\times\xi^2$	Linear $\times v^2/\Lambda^2$
Δg_{Hgg}	$\frac{g_s^2}{e^2}$	$-2a_G$	$-$	$-4f_{GG}$
$\Delta g_{H\gamma\gamma}$	1	$-2(a_B+a_W)+8a_1$	$8a_{12}$	$-(f_{BB}+f_{WW})+f_{BW}$
$\Delta g^{(1)}_{HZ\gamma}$	$\frac{1}{s_{2\theta}}$	$-8(a_5+2a_4)$	$-16a_{17}$	$2(f_W-f_B)$
$\Delta g^{(2)}_{HZ\gamma}$	$\frac{c_\theta}{s_\theta}$	$4\frac{s_\theta^2}{c_\theta^2}a_B-4a_W+8\frac{c_{2\theta}}{c_\theta^2}a_1$	$16a_{12}$	$2\frac{s_\theta^2}{c_\theta^2}f_{BB}-2f_{WW}+\frac{c_{2\theta}}{c_\theta^2}f_{BW}$
$\Delta g^{(1)}_{HZZ}$	$\frac{1}{c_\theta^2}$	$-4\frac{c_\theta^2}{s_\theta^2}a_5+8a_4$	$-8\frac{c_\theta^2}{s_\theta^2}a_{17}$	$\frac{c_\theta^2}{s_\theta^2}f_W+f_B$
$\Delta g^{(2)}_{HZZ}$	$-\frac{c_\theta^2}{s_\theta^2}$	$2\frac{s_\theta^4}{c_\theta^4}a_B+2a_W+8\frac{s_\theta^2}{c_\theta^2}a_1$	$-8a_{12}$	$\frac{s_\theta^4}{c_\theta^4}f_{BB}+f_{WW}+\frac{s_\theta^2}{c_\theta^2}f_{BW}$
$\Delta g^{(3)}_{HZZ}$	$\frac{m_Z^2}{e^2}$	$-2c_H+2(2a_C-c_C)-8(a_T-c_T)$	$-$	$f_{\Phi,1}+2f_{\Phi,4}-2f_{\Phi,2}$
$\Delta g^{(4)}_{HZZ}$	$-\frac{1}{s_{2\theta}^2}$	$16a_7$	$32a_{25}$	$4f_{\Box\Phi}$
$\Delta g^{(5)}_{HZZ}$	$-\frac{1}{s_{2\theta}^2}$	$16a_{10}$	$32a_{19}$	$-8f_{\Box\Phi}$
$\Delta g^{(6)}_{HZZ}$	$-\frac{1}{s_{2\theta}^2}$	$16a_9$	$32a_{15}$	$-4f_{\Box\Phi}$
$\Delta g^{(1)}_{HWW}$	$\frac{1}{s_\theta^2}$	$-4a_5$	$-$	f_W
$\Delta g^{(2)}_{HWW}$	$\frac{1}{s_\theta^2}$	$-4a_W$	$-$	$-2f_{WW}$
$\Delta g^{(3)}_{HWW}$	$\frac{m_Z^2c_\theta^2}{e^2}$	$-4c_H+4(2a_C-c_C)+\frac{32e^2}{c_{2\theta}}c_1+\frac{16c_\theta^2}{c_{2\theta}}c_T$	$-\frac{32e^2}{s_\theta^2}c_{12}$	$\frac{-2(3c_\theta^2-s_\theta^2)}{c_{2\theta}}f_{\Phi,1}+4f_{\Phi,4}-4f_{\Phi,2}+\frac{4e^2}{c_{2\theta}}f_{BW}$
$\Delta g^{(4)}_{HWW}$	$-\frac{1}{s_\theta^2}$	$8a_7$	$-$	$2f_{\Box\Phi}$
$\Delta g^{(5)}_{HWW}$	$-\frac{1}{s_\theta^2}$	$4a_{10}$	$-$	$-2f_{\Box\Phi}$
$\Delta g^{(6)}_{HWW}$	$-\frac{1}{s_\theta^2}$	$8a_9$	$-$	$-2f_{\Box\Phi}$

From the table, we can read out several correlations:

$$g^{(1)}_{HWW} - c^2_\theta\, g^{(1)}_{HZZ} - c_\theta s_\theta\, g^{(1)}_{HZ\gamma} = \frac{2e^2}{v s^2_\theta} a_{17} \xi^2 \,,$$

$$2c^2_\theta\, g^{(2)}_{HZZ} + 2s_\theta c_\theta\, g^{(2)}_{HZ\gamma} + 2s^2_\theta\, g_{H\gamma\gamma} - g^{(2)}_{HWW} = \frac{4e^2}{v s^2_\theta} a_{12} \xi^2 \,.$$

$$\Delta g^{(4)}_{HZZ} - \frac{1}{2c^2_\theta} \Delta g^{(4)}_{HWW} = -\frac{8e^2}{v s^2_{2\theta}}\, a_{25}\, \xi^2$$

$$\Delta g^{(5)}_{HZZ} - \frac{1}{c^2_\theta} \Delta g^{(5)}_{HWW} = -\frac{8e^2}{v s^2_{2\theta}}\, a_{19}\, \xi^2$$

$$\Delta g^{(6)}_{HZZ} - \frac{1}{2c^2_\theta} \Delta g^{(6)}_{HWW} = -\frac{8e^2}{v s^2_{2\theta}}\, a_{15}\, \xi^2$$

The RHS is vanishing, once considering:

- d=6 linear effective basis
- chiral basis truncated to ξ-weighted operators

➡ No possibility of distinguishing a dynamical Higgs from an elementary Higgs if $\xi \ll 1$, considering only HVV.

Comparing TGV and HVV, a correlation arises that holds only for the d=6 linear effective basis. In particular, it does not hold for the chiral basis even considering only ξ- weighted operators.

$$\Delta\kappa_Z - \Delta g_1^Z = \frac{v s_\theta}{2 c_\theta}\left[\left(c_\theta^2 - s_\theta^2\right)\left(g_{HZ\gamma}^{(1)} + 2 g_{HZ\gamma}^{(2)}\right) + 2 s_\theta c_\theta \left(2 g_{H\gamma\gamma} - g_{HZZ}^{(1)} - 2 g_{HZZ}^{(2)}\right)\right]$$

Deviations from this correlations indicate that d=6 linear description is not satisfactory:

- d=8 becomes import
- the non-linear description is mode adeguate
- or…

Quartic Gauge Vertices

$$\mathscr{L}_{4X} \equiv g^2 \Big\{ g_{ZZ}^{(1)} (Z_\mu Z^\mu)^2 + g_{WW}^{(1)} W_\mu^+ W^{+\mu} W_\nu^- W^{-\nu} - g_{WW}^{(2)} (W_\mu^+ W^{-\mu})^2$$
$$+ g_{VV'}^{(3)} W^{+\mu} W^{-\nu} \left(V_\mu V'_\nu + V'_\mu V_\nu \right) - g_{VV'}^{(4)} W_\nu^+ W^{-\nu} V^\mu V'_\mu$$
$$+ i g_{VV'}^{(5)} \varepsilon^{\mu\nu\rho\sigma} W_\mu^+ W_\nu^- V_\rho V'_\sigma \Big\},$$

where $VV' = \{\gamma\gamma, \gamma Z, ZZ\}$

The only non-vanishing SM contributions are given by

$$g_{WW}^{(1)SM} = \frac{1}{2} \qquad g_{WW}^{(2)SM} = \frac{1}{2} \qquad g_{ZZ}^{(3)SM} = \frac{\cos^2\theta_W}{2} \qquad g_{\gamma\gamma}^{(3)SM} = \frac{\sin^2\theta_W}{2}$$

$$g_{Z\gamma}^{(3)SM} = \frac{\sin 2\theta_W}{2} \qquad g_{ZZ}^{(4)SM} = \cos^2\theta_W \qquad g_{\gamma\gamma}^{(4)SM} = \sin^2\theta_W \qquad g_{Z\gamma}^{(4)SM} = \sin 2\theta_W$$

	Coeff. $\times e^2/4s^2_\theta$	Chiral $\times\xi$	Chiral $\times\xi^2$	Linear $\times v^2/\Lambda^2$
$\Delta g^{(1)}_{WW}$	1	$\frac{s^2_{2\theta}}{e^2 c_{2\theta}} c_T + \frac{8s^2_\theta}{c_{2\theta}} c_1 + 4c_3$	$2c_{11} - 16c_{12} + 8c_{13}$	$\frac{f_W}{2} + \frac{s^2_\theta}{c_{2\theta}} f_{BW} - \frac{s^2_{2\theta}}{4c_{2\theta}e^2} f_{\Phi 1}$
$\Delta g^{(2)}_{WW}$	1	$\frac{s^2_{2\theta}}{e^2 c_{2\theta}} c_T + \frac{8s^2_\theta}{c_{2\theta}} c_1 + 4c_3 - 4c_6$	$-2c_{11} - 16c_{12} + 8c_{13}$	$\frac{f_W}{2} + \frac{s^2_\theta}{c_{2\theta}} f_{BW} - \frac{s^2_{2\theta}}{4c_{2\theta}e^2} f_{\Phi 1} - \frac{1}{2} f_{\Box\Phi}$
$\Delta g^{(1)}_{ZZ}$	$\frac{1}{c^4_\theta}$	c_6	$c_{11} + 2c_{23} + 2c_{24} + 4c_{26}\xi^2$	$\frac{1}{8} f_{\Box\Phi}$
$\Delta g^{(3)}_{ZZ}$	$\frac{1}{c^2_\theta}$	$\frac{s^2_{2\theta} c^2_\theta}{e^2 c_{2\theta}} c_T + \frac{2s^2_{2\theta}}{c_{2\theta}} c_1 + 4c^2_\theta c_3 - 2s^4_\theta c_9$	$2c_{11} + 4s^2_\theta c_{16} + 2c_{24}$	$\frac{f_W c^2_\theta}{2} + \frac{s^2_{2\theta}}{4c_{2\theta}} f_{BW} - \frac{s^2_{2\theta} c^2_\theta}{4e^2 c_{2\theta}} f_{\Phi 1} + \frac{s^4_\theta}{2} f_{\Box\Phi}$
$\Delta g^{(4)}_{ZZ}$	$\frac{1}{c^2_\theta}$	$\frac{2s^2_{2\theta} c^2_\theta}{e^2 c_{2\theta}} c_T + \frac{4s^2_{2\theta}}{c_{2\theta}} c_1 + 8c^2_\theta c_3 - 4c_6$	$-4c_{23}$	$f_W c^2_\theta + 2\frac{s^2_{2\theta}}{4c_{2\theta}} f_{BW} - \frac{s^2_{2\theta} c^2_\theta}{2e^2 c_{2\theta}} f_{\Phi 1} - \frac{1}{2} f_{\Box\Phi}$
$\Delta g^{(3)}_{\gamma\gamma}$	s^2_θ	$-2c_9$	–	$\frac{1}{2} f_{\Box\Phi}$
$\Delta g^{(3)}_{\gamma Z}$	$\frac{s_\theta}{c_\theta}$	$\frac{s^2_{2\theta}}{e^2 c_{2\theta}} c_T + \frac{8s^2_\theta}{c_{2\theta}} c_1 + 4c_3 + 4s^2_\theta c_9$	$-4c_{16}$	$\frac{f_W}{2} + \frac{s^2_\theta}{c_{2\theta}} f_{BW} - \frac{s^2_{2\theta}}{4c_{2\theta}e^2} f_{\Phi 1} - s^2_\theta f_{\Box\Phi}$
$\Delta g^{(4)}_{\gamma Z}$	$\frac{s_\theta}{c_\theta}$	$\frac{2s^2_{2\theta}}{e^2 c_{2\theta}} c_T + \frac{16s^2_\theta}{c_{2\theta}} c_1 + 8c_3$	–	$f_W + 2\frac{s^2_\theta}{c_{2\theta}} f_{BW} - \frac{s^2_{2\theta}}{2c_{2\theta}e^2} f_{\Phi 1}$
$\Delta g^{(5)}_{\gamma Z}$	$\frac{s_\theta}{c_\theta}$	–	$8c_{14}$	–

Other constraints on the parameters

- From EWPD, we can constrain 2 parameters: S and T parameters

$$-4.7\times 10^{-3} \le c_1 \le 4\times 10^{-3} \quad \text{and} \quad -2\times 10^{-3} \le c_T \le 1.7\times 10^{-3}$$

- From TGV and HVV, we can constrain other 8 parameters: at 90% C.L.

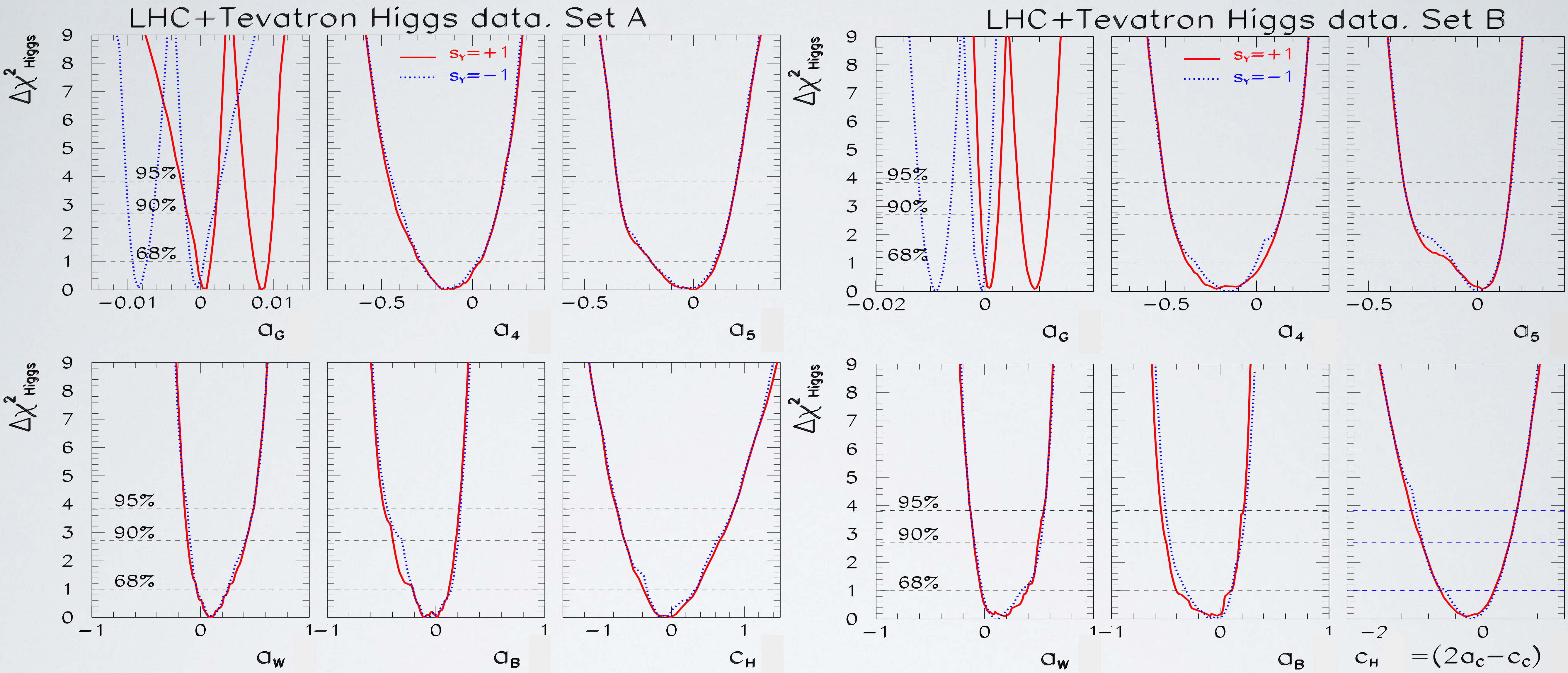
	Set A	Set B
a_G $(\cdot 10^{-3})$	$s_Y=+1$: $[-1.8, 2.1]\cup[6.5, 10]$ $s_Y=-1$: $[-9.9, -6.5]\cup[-2.1, 1.8]$	$s_Y=+1$: $[-0.78, 2.4]\cup[6.5, 12]$ $s_Y=-1$: $[-12, -6.5]\cup[-2.3, 0.75]$
a_4	$[-0.47, 0.14]$	
a_5	$[-0.33, 0.17]$	
a_W	$[-0.12, 0.51]$	
a_B	$[-0.50, 0.21]$	
c_H	$[-0.66, 0.66]$	$[-1.1, 0.49]$
c_2	$[-0.12, 0.076]$	
c_3	$[-0.064, 0.079]$	

Set A : a_G , a_4 , a_5 , a_B , a_W , c_H , $2a_C - c_C = 0$ HVV = Hff

Set B : a_G , a_4 , a_5 , a_B , a_W , $c_H = 2a_C - c_C$ HVV ≠ Hff

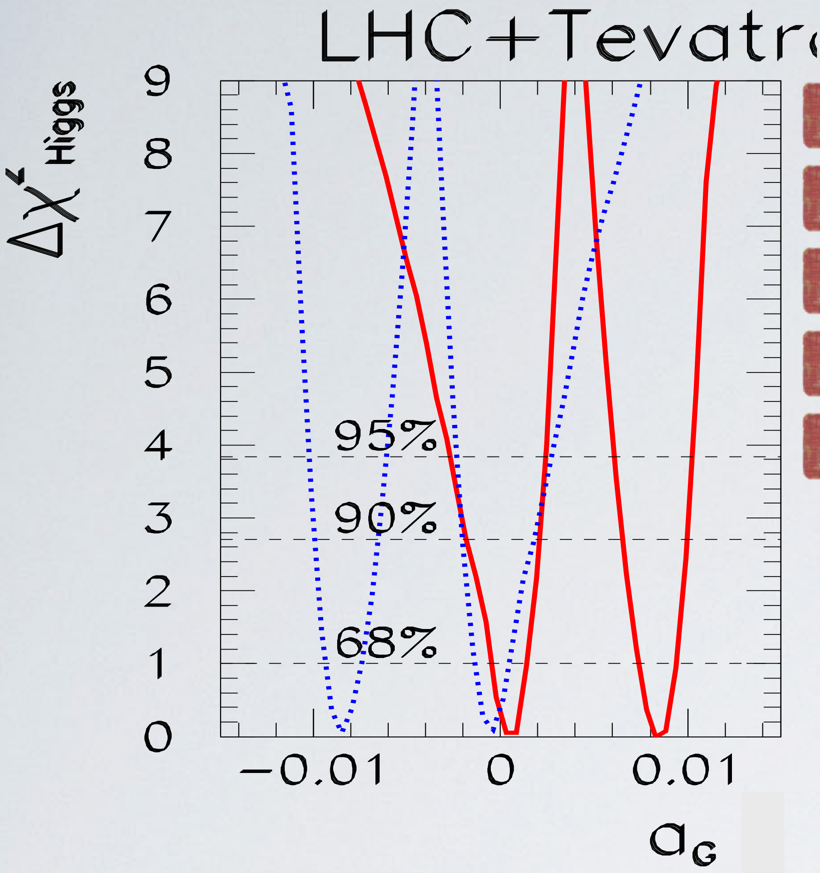
Set A : a_G , a_4 , a_5 , a_B , a_W , c_H , $2a_C - c_C = 0$ HVV = Hff

Set B : a_G , a_4 , a_5 , a_B , a_W , $c_H = 2a_C - c_C$ HVV ≠ Hff



$|\chi^2_{min,A} - \chi^2_{min,B}| < 0.5$

Data: Tevatron D0 and CDF Collaborations and LHC, CMS, and ATLAS Collaborations at 7 TeV and 8 TeV for final states $\gamma\gamma$, W^+W^-, ZZ, $Z\gamma$, $b\bar{b}$, and $\tau\bar{\tau}$



- Degeneracy: interference between SM and a_G anomalous contrib.
- 2nd min: the anomalous contrib. = -2 top-loop contrib.
- Barrier: gluon fusion Higgs production depleted between the min.
- s_y: relative sign between a_G and top-loop contrib. to hgg vertex
- SET A-SET B: c_H contributes to the top-loop contrib.

- From EWPD on the quartic gauge couplings, we get

coupling	90% CL allowed region
c_6	$[-0.23, 0.26]$
c_{11}	$[-0.094, 0.10]$
c_{23}	$[-0.092, 0.10]$
c_{24}	$[-0.012, 0.013]$
c_{26}	$[-0.0061, 0.0068]$

Disentangling a Dynamical Higgs II

The simulation for LHC (7 TeV, 14 TeV) has been done taking cuts and precautions:

- Focused on WZ production, considering leptonic decays of W and Z (background)

$$pp \to \ell'^{\pm}\ell^{+}\ell^{-}\mathrm{E}^{\mathrm{miss}} \qquad \ell^{(\prime)} = e \text{ or } \mu$$

- Main background: SM production of WZ pairs; W and Z production with jets; ZZ production with one Z in leptons with one charged in missing E, the other in tt pair.
- Detection efficiencies rescaled to the one by ATLAS for TGV $\Delta K_Z\,,\ g_1^Z\,,\ \lambda_Z$.
- We closely follow the TGV analysis performed by ATLAS (cuts on transverse momentum and pseudorapidity).
- The cross section in the presence of an anomalous g_5^Z is then given by

$$\sigma \;=\; \sigma_{\mathrm{bck}} + \sigma_{SM} \;+\; \sigma_{\mathrm{int}}\, g_5^Z \;+\; \sigma_{\mathrm{ano}}\, \left(g_5^Z\right)^2$$

In the SM, Zff and Wff contain a CP odd component. The amplitude for any subprocess $q\bar{q} \to WZ$ contains SM contributions that are both C and P odd and that interfere with the contribution from the anomalous.

	68% CL range		95% CL range	
Data sets used	Counting $p_T^Z > 90$ GeV	p_T^Z binned analysis	Counting $p_T^Z > 90$ GeV	p_T^Z binned analysis
7+8 TeV (4.64+19.6 fb^{-1})	$(-0.066,\ 0.058)$	$(-0.057,\ 0.050)$	$(-0.091,\ 0.083)$	$(-0.080,\ 0.072)$
7+8+14 TeV (4.64+19.6+300 fb^{-1})	$(-0.030,\ 0.022)$	$(-0.024,\ 0.019)$	$(-0.040,\ 0.032)$	$(-0.033,\ 0.028)$

- Counting $p_T^Z > 90$ GeV

  Simple even counting analysis, assuming that the observed events are SM and looking for values of g_5^Z inside the 68% and 95% CL allowed regions. The restriction to $p_T^Z > 90$ GeV increases the sensitivity.

- p_T^Z binned analysis

  Simple χ^2 based on the contents of the different p_T^Z distributions with no cuts. Same conditions of the previous method.