EFFECTIVE LAGRANGIAN FOR A LIGHT HIGGS

OR: HOW TO LOOK FOR NEW PHYSICS BY STUDYING THE HIGGS BOSON IN A MODEL-INDEPENDENT WAY

Roberto Contino

Università di Roma La Sapienza

based on R.C., Ghezzi, Grojean, Muehlleitner, Spira arXiv:1303.3876

In absence of a direct observation of new particles, our ignorance of the EWSB sector can be parametrized in terms of an effective Lagrangian

- The explicit form of the Lagrangian depends on the assumptions one makes
- If new particles are discovered they can be included in the Lagrangian in a bottom-up approach

In absence of a direct observation of new particles, our ignorance of the EWSB sector can be parametrized in terms of an effective Lagrangian

- The explicit form of the Lagrangian depends on the assumptions one makes
- If new particles are discovered they can be included in the Lagrangian in a bottom-up approach

I WILL ASSUME:

1) $SU(2)_L \times U(1)_Y$ is linearly realized at high energies
2) $h(x)$ is a scalar (CP even) and is part of an $SU(2)_L$ doublet $H(x)$
3) The EWSB dynamics has an (approximate) custodial symmetry

   global symmetry includes: $SU(2)_L \times SU(2)_R \to SU(2)_V$

Effective Lagrangian for a Higgs doublet

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \bar{c}_i O_i \equiv \mathcal{L}_{SM} + \Delta\mathcal{L}_{SILH} + \Delta\mathcal{L}_{F_1} + \Delta\mathcal{L}_{F_2}$$

Effective Lagrangian for a Higgs doublet

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \bar{c}_i O_i \equiv \mathcal{L}_{SM} + \boxed{\Delta\mathcal{L}_{SILH} + \Delta\mathcal{L}_{F_1} + \Delta\mathcal{L}_{F_2}}$$

dimension-6 operators
(only those relevant for Higgs physics)

Effective Lagrangian for a Higgs doublet

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \bar{c}_i O_i \equiv \mathcal{L}_{SM} + \boxed{\Delta\mathcal{L}_{SILH} + \Delta\mathcal{L}_{F_1} + \Delta\mathcal{L}_{F_2}}$$

dimension-6 operators
(only those relevant for Higgs physics)

$\vdots$

The list of dim=6 operators of the effective Lagrangian has been known in the literature since long time

Buchmuller and Wyler
NPB 268 (1986) 621

<u>Minimal</u> and complete list fist appeared in:

Grzadkowski et al.
JHEP 1010 (2010) 085

I will follow the parametrization and the analysis of:

Giudice, Grojean, Pomarol, Rattazzi
JHEP 0706 (2007) 045

$$
\begin{aligned}
\Delta\mathcal{L}_{SILH} = {} & \frac{\bar{c}_H}{2v^2}\,\partial^\mu\big(H^\dagger H\big)\,\partial_\mu\big(H^\dagger H\big) + \frac{\bar{c}_T}{2v^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) - \frac{\bar{c}_6\,\lambda}{v^2}\big(H^\dagger H\big)^3 \\
& + \left(\frac{\bar{c}_u}{v^2}\,y_u\,H^\dagger H\,\bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2}\,y_d\,H^\dagger H\,\bar{q}_L H d_R + \frac{\bar{c}_l}{v^2}\,y_l\,H^\dagger H\,\bar{L}_L H l_R + h.c.\right) \\
& + \frac{i\bar{c}_W\,g}{2m_W^2}\left(H^\dagger \sigma^i \overleftrightarrow{D^\mu} H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{i\bar{c}_B\,g'}{2m_W^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(\partial^\nu B_{\mu\nu}\right) \\
& + \frac{i\bar{c}_{HW}\,g}{m_W^2}\,(D^\mu H)^\dagger\sigma^i(D^\nu H)W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\,g'}{m_W^2}\,(D^\mu H)^\dagger(D^\nu H)B_{\mu\nu} \\
& + \frac{\bar{c}_\gamma\,{g'}^2}{m_W^2}\,H^\dagger H B_{\mu\nu}B^{\mu\nu} + \frac{\bar{c}_g\,g_S^2}{m_W^2}\,H^\dagger H G^a_{\mu\nu}G^{a\mu\nu}\,,
\end{aligned}
$$

- Basis introduced by Giudice et al. (SILH basis)
- Absence of FCNC from tree-level exchange of the Higgs requires flavor alignment
- 12 operators in $\Delta\mathcal{L}_{SILH}$ + 5 made only of gauge fields (not shown)

only this operator
formally breaks
custodial symmetry

$$
\begin{aligned}
\Delta\mathcal{L}_{SILH} = {} & \frac{\bar{c}_H}{2v^2}\,\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) + \boxed{\frac{\bar{c}_T}{2v^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right)} - \frac{\bar{c}_6\,\lambda}{v^2}\left(H^\dagger H\right)^3 \\
& + \left(\frac{\bar{c}_u}{v^2}\,y_u\,H^\dagger H\,\bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2}\,y_d\,H^\dagger H\,\bar{q}_L H d_R + \frac{\bar{c}_l}{v^2}\,y_l\,H^\dagger H\,\bar{L}_L H l_R + h.c.\right) \\
& + \frac{i\bar{c}_W\,g}{2m_W^2}\left(H^\dagger\sigma^i \overleftrightarrow{D^\mu} H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{i\bar{c}_B\,g'}{2m_W^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(\partial^\nu B_{\mu\nu}\right) \\
& + \frac{i\bar{c}_{HW}\,g}{m_W^2}\left(D^\mu H\right)^\dagger\sigma^i\left(D^\nu H\right)W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\,g'}{m_W^2}\left(D^\mu H\right)^\dagger\left(D^\nu H\right)B_{\mu\nu} \\
& + \frac{\bar{c}_\gamma\,{g'}^2}{m_W^2}\,H^\dagger H B_{\mu\nu}B^{\mu\nu} + \frac{\bar{c}_g\,g_S^2}{m_W^2}\,H^\dagger H G^a_{\mu\nu}G^{a\mu\nu}\,,
\end{aligned}
$$

- Basis introduced by Giudice et al. (SILH basis)
- Absence of FCNC from tree-level exchange of the Higgs requires flavor alignment
- 12 operators in $\Delta\mathcal{L}_{SILH}$ + 5 made only of gauge fields (not shown)

$$\Delta\mathcal{L}_{F_1} = \frac{i\bar{c}_{Hq}}{v^2}\left(\bar{q}_L\gamma^\mu q_L\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) + \frac{i\bar{c}'_{Hq}}{v^2}\left(\bar{q}_L\gamma^\mu\sigma^i q_L\right)\left(H^\dagger\sigma^i \overleftrightarrow{D}_\mu H\right)$$
$$+ \frac{i\bar{c}_{Hu}}{v^2}\left(\bar{u}_R\gamma^\mu u_R\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) + \frac{i\bar{c}_{Hd}}{v^2}\left(\bar{d}_R\gamma^\mu d_R\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right)$$
$$+ \left(\frac{i\bar{c}_{Hud}}{v^2}\left(\bar{u}_R\gamma^\mu d_R\right)\left(H^{c\,\dagger} \overleftrightarrow{D}_\mu H\right) + h.c.\right)$$
$$+ \frac{i\bar{c}_{HL}}{v^2}\left(\bar{L}_L\gamma^\mu L_L\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) + \frac{i\bar{c}'_{HL}}{v^2}\left(\bar{L}_L\gamma^\mu\sigma^i L_L\right)\left(H^\dagger\sigma^i \overleftrightarrow{D}_\mu H\right)$$
$$+ \frac{i\bar{c}_{Hl}}{v^2}\left(\bar{l}_R\gamma^\mu l_R\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right),$$

$$\Delta\mathcal{L}_{F_2} = \frac{\bar{c}_{uB}\,g'}{m_W^2}\,y_u\,\bar{q}_L H^c\sigma^{\mu\nu}u_R\,B_{\mu\nu} + \frac{\bar{c}_{uW}\,g}{m_W^2}\,y_u\,\bar{q}_L\sigma^i H^c\sigma^{\mu\nu}u_R\,W^i_{\mu\nu} + \frac{\bar{c}_{uG}\,g_S}{m_W^2}\,y_u\,\bar{q}_L H^c\sigma^{\mu\nu}\lambda^a u_R\,G^a_{\mu\nu}$$
$$+ \frac{\bar{c}_{dB}\,g'}{m_W^2}\,y_d\,\bar{q}_L H\sigma^{\mu\nu}d_R\,B_{\mu\nu} + \frac{\bar{c}_{dW}\,g}{m_W^2}\,y_d\,\bar{q}_L\sigma^i H\sigma^{\mu\nu}d_R\,W^i_{\mu\nu} + \frac{\bar{c}_{dG}\,g_S}{m_W^2}\,y_d\,\bar{q}_L H\sigma^{\mu\nu}\lambda^a d_R\,G^a_{\mu\nu}$$
$$+ \frac{\bar{c}_{lB}\,g'}{m_W^2}\,y_l\,\bar{L}_L H\sigma^{\mu\nu}l_R\,B_{\mu\nu} + \frac{\bar{c}_{lW}\,g}{m_W^2}\,y_l\,\bar{L}_L\sigma^i H\sigma^{\mu\nu}l_R\,W^i_{\mu\nu} + h.c.$$

- 8 ($\Delta\mathcal{L}_{F_1}$) + 8 ($\Delta\mathcal{L}_{F_2}$) operators + 22 four-fermion operators (not shown)

$$\Delta\mathcal{L}_{F_1} = \frac{i\bar{c}_{Hq}}{v^2}\left(\bar{q}_L\gamma^\mu q_L\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) + \frac{i\bar{c}'_{Hq}}{v^2}\left(\bar{q}_L\gamma^\mu\sigma^i q_L\right)\left(H^\dagger\sigma^i \overleftrightarrow{D}_\mu H\right)$$

$$+ \frac{i\bar{c}_{Hu}}{v^2}\left(\bar{u}_R\gamma^\mu u_R\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) + \frac{i\bar{c}_{Hd}}{v^2}\left(\bar{d}_R\gamma^\mu d_R\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right)$$

$$+ \left(\frac{i\bar{c}_{Hud}}{v^2}\left(\bar{u}_R\gamma^\mu d_R\right)\left(H^{c\,\dagger} \overleftrightarrow{D}_\mu H\right) + h.c.\right)$$

$$+ \frac{i\bar{c}_{HL}}{v^2}\left(\bar{L}_L\gamma^\mu L_L\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) + \frac{i\bar{c}'_{HL}}{v^2}\left(\bar{L}_L\gamma^\mu\sigma^i L_L\right)\left(H^\dagger\sigma^i \overleftrightarrow{D}_\mu H\right)$$

$$+ \frac{i\bar{c}_{Hl}}{v^2}\left(\bar{l}_R\gamma^\mu l_R\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right),$$

operators of the form $(\bar{\psi}\gamma^\mu\psi)(H^\dagger \overleftrightarrow{D}_\mu H)$

$$\Delta\mathcal{L}_{F_2} = \frac{\bar{c}_{uB}\,g'}{m_W^2}\,y_u\,\bar{q}_L H^c\sigma^{\mu\nu}u_R\,B_{\mu\nu} + \frac{\bar{c}_{uW}\,g}{m_W^2}\,y_u\,\bar{q}_L\sigma^i H^c\sigma^{\mu\nu}u_R\,W^i_{\mu\nu} + \frac{\bar{c}_{uG}\,g_S}{m_W^2}\,y_u\,\bar{q}_L H^c\sigma^{\mu\nu}\lambda^a u_R\,G^a_{\mu\nu}$$

$$+ \frac{\bar{c}_{dB}\,g'}{m_W^2}\,y_d\,\bar{q}_L H\sigma^{\mu\nu}d_R\,B_{\mu\nu} + \frac{\bar{c}_{dW}\,g}{m_W^2}\,y_d\,\bar{q}_L\sigma^i H\sigma^{\mu\nu}d_R\,W^i_{\mu\nu} + \frac{\bar{c}_{dG}\,g_S}{m_W^2}\,y_d\,\bar{q}_L H\sigma^{\mu\nu}\lambda^a d_R\,G^a_{\mu\nu}$$

$$+ \frac{\bar{c}_{lB}\,g'}{m_W^2}\,y_l\,\bar{L}_L H\sigma^{\mu\nu}l_R\,B_{\mu\nu} + \frac{\bar{c}_{lW}\,g}{m_W^2}\,y_l\,\bar{L}_L\sigma^i H\sigma^{\mu\nu}l_R\,W^i_{\mu\nu} + h.c.$$

- 8 ($\Delta\mathcal{L}_{F_1}$) + 8 ($\Delta\mathcal{L}_{F_2}$) operators + 22 four-fermion operators (not shown)

$$\Delta\mathcal{L}_{F_1} = \frac{i\bar{c}_{Hq}}{v^2}\left(\bar{q}_L\gamma^\mu q_L\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) + \frac{i\bar{c}'_{Hq}}{v^2}\left(\bar{q}_L\gamma^\mu\sigma^i q_L\right)\left(H^\dagger\sigma^i \overleftrightarrow{D}_\mu H\right)$$
$$+ \frac{i\bar{c}_{Hu}}{v^2}\left(\bar{u}_R\gamma^\mu u_R\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) + \frac{i\bar{c}_{Hd}}{v^2}\left(\bar{d}_R\gamma^\mu d_R\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right)$$
$$+ \left(\frac{i\bar{c}_{Hud}}{v^2}\left(\bar{u}_R\gamma^\mu d_R\right)\left(H^{c\,\dagger} \overleftrightarrow{D}_\mu H\right) + h.c.\right)$$
$$+ \frac{i\bar{c}_{HL}}{v^2}\left(\bar{L}_L\gamma^\mu L_L\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) + \frac{i\bar{c}'_{HL}}{v^2}\left(\bar{L}_L\gamma^\mu\sigma^i L_L\right)\left(H^\dagger\sigma^i \overleftrightarrow{D}_\mu H\right)$$
$$+ \frac{i\bar{c}_{Hl}}{v^2}\left(\bar{l}_R\gamma^\mu l_R\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right),$$

operators of the form $(\bar{\psi}\gamma^\mu\psi)(H^\dagger \overleftrightarrow{D}_\mu H)$

$$\Delta\mathcal{L}_{F_2} = \frac{\bar{c}_{uB}\,g'}{m_W^2}\,y_u\,\bar{q}_L H^c\sigma^{\mu\nu}u_R\,B_{\mu\nu} + \frac{\bar{c}_{uW}\,g}{m_W^2}\,y_u\,\bar{q}_L\sigma^i H^c\sigma^{\mu\nu}u_R\,W^i_{\mu\nu} + \frac{\bar{c}_{uG}\,g_S}{m_W^2}\,y_u\,\bar{q}_L H^c\sigma^{\mu\nu}\lambda^a u_R\,G^a_{\mu\nu}$$
$$+ \frac{\bar{c}_{dB}\,g'}{m_W^2}\,y_d\,\bar{q}_L H\sigma^{\mu\nu}d_R\,B_{\mu\nu} + \frac{\bar{c}_{dW}\,g}{m_W^2}\,y_d\,\bar{q}_L\sigma^i H\sigma^{\mu\nu}d_R\,W^i_{\mu\nu} + \frac{\bar{c}_{dG}\,g_S}{m_W^2}\,y_d\,\bar{q}_L H\sigma^{\mu\nu}\lambda^a d_R\,G^a_{\mu\nu}$$
$$+ \frac{\bar{c}_{lB}\,g'}{m_W^2}\,y_l\,\bar{L}_L H\sigma^{\mu\nu}l_R\,B_{\mu\nu} + \frac{\bar{c}_{lW}\,g}{m_W^2}\,y_l\,\bar{L}_L\sigma^i H\sigma^{\mu\nu}l_R\,W^i_{\mu\nu} + h.c.$$

dipole operators

- 8 ($\Delta\mathcal{L}_{F_1}$) + 8 ($\Delta\mathcal{L}_{F_2}$) operators + 22 four-fermion operators (not shown)

- In total: 12+5+8+8+22 = 53 linearly independent + 2 redundant

$$O_W = -6\,O_H + 2\,(O_u + O_d + O_l) - 8\,O_6 + O'_{Hq} + O'_{HL}$$

$$O_B = 2\tan^2\theta_W \Big(\sum_{\psi} Y_\psi\, O_{H\psi} - O_T \Big)$$

- In total: 12+5+8+8+22 = 53 linearly independent + 2 redundant

$$O_W = -6\,O_H + 2\,(O_u + O_d + O_l) - 8\,O_6 + O'_{Hq} + O'_{HL}$$

$$O_B = 2\tan^2\theta_W \Big(\sum_\psi Y_\psi\, O_{H\psi} - O_T \Big)$$

- Our basis *equivalent* to that of Grzadkowki et al. but more *convenient* for Higgs physics because:

  [1] operators which parametrize oblique corrections are in the list (O_W, O_B)

  [2] it isolates the contributions to the decays

  $h \to \gamma\gamma$ (from O_γ)

  $h \to \gamma Z$ (from O_γ and $O_{HW} - O_{HB}$)

  which occur at the 1-loop level in minimally coupled UV theories

  [3] if the Higgs is a pNGB then O_γ is suppressed

  (no cancellation among different operators occurs as in other basis)

POWER COUNTING: [Giudice et al. JHEP 0706 (2007) 045]

- each extra derivative costs a factor $1/M$
- each extra power of H(x) costs a factor $g_*/M \equiv 1/f$

For a strongly-interacting light Higgs (SILH): $\dfrac{1}{f} \gg \dfrac{1}{\Lambda}$

POWER COUNTING: [Giudice et al. JHEP 0706 (2007) 045]

- each extra derivative costs a factor $1/M$
- each extra power of H(x) costs a factor $g_*/M \equiv 1/f$

For a strongly-interacting light Higgs (SILH): $\dfrac{1}{f} \gg \dfrac{1}{\Lambda}$

Naive estimate at the scale M:

$$\bar{c}_H, \bar{c}_T, \bar{c}_6, \bar{c}_\psi \sim O\left(\frac{v^2}{f^2}\right), \quad \bar{c}_W, \bar{c}_B \sim O\left(\frac{m_W^2}{M^2}\right), \quad \bar{c}_{HW}, \bar{c}_{HB}, \bar{c}_\gamma, \bar{c}_g \sim O\left(\frac{m_W^2}{16\pi^2 f^2}\right)$$

$$\bar{c}_{H\psi}, \bar{c}'_{H\psi} \sim O\left(\frac{\lambda_\psi^2}{g_*^2}\frac{v^2}{f^2}\right), \quad \bar{c}_{Hud} \sim O\left(\frac{\lambda_u \lambda_d}{g_*^2}\frac{v^2}{f^2}\right), \quad \bar{c}_{\psi W}, \bar{c}_{\psi B}, \bar{c}_{\psi G} \sim O\left(\frac{m_W^2}{16\pi^2 f^2}\right)$$

Specific symmetry protections might be at work in the UV theory

- Ex: in the MSSM $\quad g_* \sim g$

R-parity $\Rightarrow$
$$\bar{c}_W, \bar{c}_B \sim \frac{m_W^2}{M^2} \times \frac{g^2}{16\pi^2}$$

- Ex: if the Higgs is a pNGB

Goldstone symmetry $\Rightarrow$
$$\bar{c}_\gamma, \bar{c}_g \sim \frac{m_W^2}{16\pi^2 f^2} \times \frac{g_{\not G}^2}{g_*^2}$$

Current bounds on Wilson coefficients

$$-1.5 \times 10^{-3} < \bar{c}_T(m_Z) < 2.2 \times 10^{-3}$$
$$-1.4 \times 10^{-3} < \bar{c}_W(m_Z) + \bar{c}_B(m_Z) < 1.9 \times 10^{-3}$$

$$-0.008 < \bar{c}_{Hu} < 0.02$$
$$-0.03 < \bar{c}_{Hd} < 0.02$$
$$-0.03 < \bar{c}_{Hs} < 0.02$$

$$-0.03 < \bar{c}_{Hq1} < 0.02$$
$$-0.005 < \bar{c}_{Hq2} < 0.003$$
$$-0.002 < \bar{c}'_{Hq1} < 0.003$$
$$-0.003 < \bar{c}'_{Hq2} < 0.005$$

$$-0.004 < \bar{c}_{HL} + \bar{c}'_{HL} < 0.002$$
$$-0.003 < \bar{c}_{HL} - \bar{c}'_{HL} < 0.0002$$
$$-0.0007 < \bar{c}_{Hl} < 0.003$$

$$-0.02 < \bar{c}_{Hq_2} + \bar{c}'_{Hq_2} < 0.005$$
$$-0.003 < \bar{c}_{Hq_3} - \bar{c}'_{Hq_3} < 0.009$$
$$-0.02 < \bar{c}_{Hc} < 0.03$$
$$-0.07 < \bar{c}_{Hb} < -0.005$$

$$-0.4 \times 10^{-3} < \bar{c}_{Htb}(m_W) < 1.3 \times 10^{-3}$$

$$-0.057 < \mathrm{Re}(\bar{c}_{tW} + \bar{c}_{tB}) - 2.65\,\mathrm{Im}(\bar{c}_{tW} + \bar{c}_{tB}) < 0.20$$
$$-1.39 \times 10^{-4} < \mathrm{Im}(\bar{c}_{tG}) < 1.21 \times 10^{-4}$$

$$-6.12 \times 10^{-3} < \mathrm{Re}(\bar{c}_{tG}) < 1.94 \times 10^{-3}$$
$$-1.2 < \mathrm{Re}(\bar{c}_{bW}) < 1.1$$
$$-0.01 < \mathrm{Re}(\bar{c}_{tW}) < 0.02$$

$$-7.01 \times 10^{-6} < \mathrm{Im}(\bar{c}_{uB} + \bar{c}_{uW}) < 7.86 \times 10^{-6}$$
$$-9.42 \times 10^{-7} < \mathrm{Im}(\bar{c}_{dB} - \bar{c}_{dW}) < 8.40 \times 10^{-7}$$
$$-1.62 \times 10^{-6} < \mathrm{Im}(\bar{c}_{uG}) < 2.01 \times 10^{-6}$$
$$-7.71 \times 10^{-7} < \mathrm{Im}(\bar{c}_{dG}) < 5.70 \times 10^{-7}$$

$$-1.64 \times 10^{-2} < \mathrm{Re}(\bar{c}_{eB} - \bar{c}_{eW}) < 3.37 \times 10^{-3}$$
$$1.88 \times 10^{-4} < \mathrm{Re}(\bar{c}_{\mu B} - \bar{c}_{\mu W}) < 6.43 \times 10^{-4}$$
$$-2.97 \times 10^{-7} < \mathrm{Im}(\bar{c}_{eB} - \bar{c}_{eW}) < 4.51 \times 10^{-7}$$
$$-0.26 < \mathrm{Im}(\bar{c}_{\mu B} - \bar{c}_{\mu W}) < 0.29$$

Current bounds on Wilson coefficients

LEP+Tevatron
(EW fit from GFitter)

$$-1.5\times10^{-3} < \bar{c}_T(m_Z) < 2.2\times10^{-3}$$

$$-1.4\times10^{-3} < \bar{c}_W(m_Z)+\bar{c}_B(m_Z) < 1.9\times10^{-3}$$

$$-0.008 < \bar{c}_{Hu} < 0.02$$
$$-0.03 < \bar{c}_{Hd} < 0.02$$
$$-0.03 < \bar{c}_{Hs} < 0.02$$

$$-0.03 < \bar{c}_{Hq1} < 0.02$$
$$-0.005 < \bar{c}_{Hq2} < 0.003$$
$$-0.002 < \bar{c}'_{Hq1} < 0.003$$
$$-0.003 < \bar{c}'_{Hq2} < 0.005$$

$$-0.004 < \bar{c}_{HL}+\bar{c}'_{HL} < 0.002$$
$$-0.003 < \bar{c}_{HL}-\bar{c}'_{HL} < 0.0002$$
$$-0.0007 < \bar{c}_{Hl} < 0.003$$

$$-0.02 < \bar{c}_{Hq_2}+\bar{c}'_{Hq_2} < 0.005$$
$$-0.003 < \bar{c}_{Hq_3}-\bar{c}'_{Hq_3} < 0.009$$
$$-0.02 < \bar{c}_{Hc} < 0.03$$
$$-0.07 < \bar{c}_{Hb} < -0.005$$

$$-0.4\times10^{-3} < \bar{c}_{Htb}(m_W) < 1.3\times10^{-3}$$

$$-0.057 < \mathrm{Re}(\bar{c}_{tW}+\bar{c}_{tB}) - 2.65\,\mathrm{Im}(\bar{c}_{tW}+\bar{c}_{tB}) < 0.20$$
$$-1.39\times10^{-4} < \mathrm{Im}(\bar{c}_{tG}) < 1.21\times10^{-4}$$

$$-6.12\times10^{-3} < \mathrm{Re}(\bar{c}_{tG}) < 1.94\times10^{-3}$$
$$-1.2 < \mathrm{Re}(\bar{c}_{bW}) < 1.1$$
$$-0.01 < \mathrm{Re}(\bar{c}_{tW}) < 0.02$$

$$-7.01\times10^{-6} < \mathrm{Im}(\bar{c}_{uB}+\bar{c}_{uW}) < 7.86\times10^{-6}$$
$$-9.42\times10^{-7} < \mathrm{Im}(\bar{c}_{dB}-\bar{c}_{dW}) < 8.40\times10^{-7}$$
$$-1.62\times10^{-6} < \mathrm{Im}(\bar{c}_{uG}) < 2.01\times10^{-6}$$
$$-7.71\times10^{-7} < \mathrm{Im}(\bar{c}_{dG}) < 5.70\times10^{-7}$$

$$-1.64\times10^{-2} < \mathrm{Re}(\bar{c}_{eB}-\bar{c}_{eW}) < 3.37\times10^{-3}$$
$$1.88\times10^{-4} < \mathrm{Re}(\bar{c}_{\mu B}-\bar{c}_{\mu W}) < 6.43\times10^{-4}$$
$$-2.97\times10^{-7} < \mathrm{Im}(\bar{c}_{eB}-\bar{c}_{eW}) < 4.51\times10^{-7}$$
$$-0.26 < \mathrm{Im}(\bar{c}_{\mu B}-\bar{c}_{\mu W}) < 0.29$$

Current bounds on Wilson coefficients

LEP+Tevatron
(EW fit from GFitter)

$$-1.5\times10^{-3} < \bar{c}_T(m_Z) < 2.2\times10^{-3}$$

$$-1.4\times10^{-3} < \bar{c}_W(m_Z)+\bar{c}_B(m_Z) < 1.9\times10^{-3}$$

$$-0.008 < \bar{c}_{Hu} < 0.02$$

$$-0.03 < \bar{c}_{Hd} < 0.02$$

$$-0.03 < \bar{c}_{Hs} < 0.02$$

$$-0.03 < \bar{c}_{Hq1} < 0.02$$

$$-0.005 < \bar{c}_{Hq2} < 0.003$$

$$-0.002 < \bar{c}'_{Hq1} < 0.003$$

$$-0.003 < \bar{c}'_{Hq2} < 0.005$$

$$-0.004 < \bar{c}_{HL}+\bar{c}'_{HL} < 0.002$$

$$-0.003 < \bar{c}_{HL}-\bar{c}'_{HL} < 0.0002$$

$$-0.0007 < \bar{c}_{Hl} < 0.003$$

$$-0.02 < \bar{c}_{Hq_2}+\bar{c}'_{Hq_2} < 0.005$$

$$-0.003 < \bar{c}_{Hq_3}-\bar{c}'_{Hq_3} < 0.009$$

$$-0.02 < \bar{c}_{Hc} < 0.03$$

$$-0.07 < \bar{c}_{Hb} < -0.005$$

$$-0.4\times10^{-3} < \bar{c}_{Htb}(m_W) < 1.3\times10^{-3}$$

rate b⟶sγ

$$-0.057 < \mathrm{Re}(\bar{c}_{tW}+\bar{c}_{tB}) - 2.65\,\mathrm{Im}(\bar{c}_{tW}+\bar{c}_{tB}) < 0.20$$

$$-1.39\times10^{-4} < \mathrm{Im}(\bar{c}_{tG}) < 1.21\times10^{-4}$$

$$-6.12\times10^{-3} < \mathrm{Re}(\bar{c}_{tG}) < 1.94\times10^{-3}$$

$$-1.2 < \mathrm{Re}(\bar{c}_{bW}) < 1.1$$

$$-0.01 < \mathrm{Re}(\bar{c}_{tW}) < 0.02$$

$$-7.01\times10^{-6} < \mathrm{Im}(\bar{c}_{uB}+\bar{c}_{uW}) < 7.86\times10^{-6}$$

$$-9.42\times10^{-7} < \mathrm{Im}(\bar{c}_{dB}-\bar{c}_{dW}) < 8.40\times10^{-7}$$

$$-1.62\times10^{-6} < \mathrm{Im}(\bar{c}_{uG}) < 2.01\times10^{-6}$$

$$-7.71\times10^{-7} < \mathrm{Im}(\bar{c}_{dG}) < 5.70\times10^{-7}$$

$$-1.64\times10^{-2} < \mathrm{Re}(\bar{c}_{eB}-\bar{c}_{eW}) < 3.37\times10^{-3}$$

$$1.88\times10^{-4} < \mathrm{Re}(\bar{c}_{\mu B}-\bar{c}_{\mu W}) < 6.43\times10^{-4}$$

$$-2.97\times10^{-7} < \mathrm{Im}(\bar{c}_{eB}-\bar{c}_{eW}) < 4.51\times10^{-7}$$

$$-0.26 < \mathrm{Im}(\bar{c}_{\mu B}-\bar{c}_{\mu W}) < 0.29$$

Current bounds on Wilson coefficients

LEP+Tevatron
(EW fit from GFitter)

$$-1.5 \times 10^{-3} < \bar{c}_T(m_Z) < 2.2 \times 10^{-3}$$

$$-1.4 \times 10^{-3} < \bar{c}_W(m_Z) + \bar{c}_B(m_Z) < 1.9 \times 10^{-3}$$

$$-0.008 < \bar{c}_{Hu} < 0.02$$
$$-0.03 < \bar{c}_{Hd} < 0.02$$
$$-0.03 < \bar{c}_{Hs} < 0.02$$

$$-0.03 < \bar{c}_{Hq1} < 0.02$$
$$-0.005 < \bar{c}_{Hq2} < 0.003$$
$$-0.002 < \bar{c}'_{Hq1} < 0.003$$
$$-0.003 < \bar{c}'_{Hq2} < 0.005$$

$$-0.004 < \bar{c}_{HL} + \bar{c}'_{HL} < 0.002$$
$$-0.003 < \bar{c}_{HL} - \bar{c}'_{HL} < 0.0002$$
$$-0.0007 < \bar{c}_{Hl} < 0.003$$

$$-0.02 < \bar{c}_{Hq_2} + \bar{c}'_{Hq_2} < 0.005$$
$$-0.003 < \bar{c}_{Hq_3} - \bar{c}'_{Hq_3} < 0.009$$
$$-0.02 < \bar{c}_{Hc} < 0.03$$
$$-0.07 < \bar{c}_{Hb} < -0.005$$

$$-0.4 \times 10^{-3} < \bar{c}_{Htb}(m_W) < 1.3 \times 10^{-3}$$

rate b→sγ

$$-0.057 < \mathrm{Re}(\bar{c}_{tW} + \bar{c}_{tB}) - 2.65\,\mathrm{Im}(\bar{c}_{tW} + \bar{c}_{tB}) < 0.20$$

$$-1.39 \times 10^{-4} < \mathrm{Im}(\bar{c}_{tG}) < 1.21 \times 10^{-4}$$

Neutron EDM

$$-7.01 \times 10^{-6} < \mathrm{Im}(\bar{c}_{uB} + \bar{c}_{uW}) < 7.86 \times 10^{-6}$$
$$-9.42 \times 10^{-7} < \mathrm{Im}(\bar{c}_{dB} - \bar{c}_{dW}) < 8.40 \times 10^{-7}$$
$$-1.62 \times 10^{-6} < \mathrm{Im}(\bar{c}_{uG}) < 2.01 \times 10^{-6}$$
$$-7.71 \times 10^{-7} < \mathrm{Im}(\bar{c}_{dG}) < 5.70 \times 10^{-7}$$

$$-6.12 \times 10^{-3} < \mathrm{Re}(\bar{c}_{tG}) < 1.94 \times 10^{-3}$$
$$-1.2 < \mathrm{Re}(\bar{c}_{bW}) < 1.1$$
$$-0.01 < \mathrm{Re}(\bar{c}_{tW}) < 0.02$$

$$-1.64 \times 10^{-2} < \mathrm{Re}(\bar{c}_{eB} - \bar{c}_{eW}) < 3.37 \times 10^{-3}$$
$$1.88 \times 10^{-4} < \mathrm{Re}(\bar{c}_{\mu B} - \bar{c}_{\mu W}) < 6.43 \times 10^{-4}$$
$$-2.97 \times 10^{-7} < \mathrm{Im}(\bar{c}_{eB} - \bar{c}_{eW}) < 4.51 \times 10^{-7}$$
$$-0.26 < \mathrm{Im}(\bar{c}_{\mu B} - \bar{c}_{\mu W}) < 0.29$$

Current bounds on Wilson coefficients

LEP+Tevatron
(EW fit from GFitter)

$$-1.5 \times 10^{-3} < \bar{c}_T(m_Z) < 2.2 \times 10^{-3}$$

$$-1.4 \times 10^{-3} < \bar{c}_W(m_Z) + \bar{c}_B(m_Z) < 1.9 \times 10^{-3}$$

$$-0.008 < \bar{c}_{Hu} < 0.02$$

$$-0.03 < \bar{c}_{Hd} < 0.02$$

$$-0.03 < \bar{c}_{Hs} < 0.02$$

$$-0.03 < \bar{c}_{Hq1} < 0.02$$

$$-0.005 < \bar{c}_{Hq2} < 0.003$$

$$-0.002 < \bar{c}'_{Hq1} < 0.003$$

$$-0.003 < \bar{c}'_{Hq2} < 0.005$$

$$-0.004 < \bar{c}_{HL} + \bar{c}'_{HL} < 0.002$$

$$-0.003 < \bar{c}_{HL} - \bar{c}'_{HL} < 0.0002$$

$$-0.0007 < \bar{c}_{Hl} < 0.003$$

$$-0.02 < \bar{c}_{Hq_2} + \bar{c}'_{Hq_2} < 0.005$$

$$-0.003 < \bar{c}_{Hq_3} - \bar{c}'_{Hq_3} < 0.009$$

$$-0.02 < \bar{c}_{Hc} < 0.03$$

$$-0.07 < \bar{c}_{Hb} < -0.005$$

$$-0.4 \times 10^{-3} < \bar{c}_{Htb}(m_W) < 1.3 \times 10^{-3}$$

rate b⟶sγ

$$-0.057 < \mathrm{Re}(\bar{c}_{tW} + \bar{c}_{tB}) - 2.65\,\mathrm{Im}(\bar{c}_{tW} + \bar{c}_{tB}) < 0.20$$

$$-1.39 \times 10^{-4} < \mathrm{Im}(\bar{c}_{tG}) < 1.21 \times 10^{-4}$$

Neutron EDM

$$-7.01 \times 10^{-6} < \mathrm{Im}(\bar{c}_{uB} + \bar{c}_{uW}) < 7.86 \times 10^{-6}$$

$$-9.42 \times 10^{-7} < \mathrm{Im}(\bar{c}_{dB} - \bar{c}_{dW}) < 8.40 \times 10^{-7}$$

$$-1.62 \times 10^{-6} < \mathrm{Im}(\bar{c}_{uG}) < 2.01 \times 10^{-6}$$

$$-7.71 \times 10^{-7} < \mathrm{Im}(\bar{c}_{dG}) < 5.70 \times 10^{-7}$$

ttbar, top decays

$$-6.12 \times 10^{-3} < \mathrm{Re}(\bar{c}_{tG}) < 1.94 \times 10^{-3}$$

$$-1.2 < \mathrm{Re}(\bar{c}_{bW}) < 1.1$$

$$-0.01 < \mathrm{Re}(\bar{c}_{tW}) < 0.02$$

$$-1.64 \times 10^{-2} < \mathrm{Re}(\bar{c}_{eB} - \bar{c}_{eW}) < 3.37 \times 10^{-3}$$

$$1.88 \times 10^{-4} < \mathrm{Re}(\bar{c}_{\mu B} - \bar{c}_{\mu W}) < 6.43 \times 10^{-4}$$

$$-2.97 \times 10^{-7} < \mathrm{Im}(\bar{c}_{eB} - \bar{c}_{eW}) < 4.51 \times 10^{-7}$$

$$-0.26 < \mathrm{Im}(\bar{c}_{\mu B} - \bar{c}_{\mu W}) < 0.29$$

Current bounds on Wilson coefficients

LEP+Tevatron
(EW fit from GFitter)

$$-1.5\times10^{-3} < \bar{c}_T(m_Z) < 2.2\times10^{-3}$$

$$-1.4\times10^{-3} < \bar{c}_W(m_Z)+\bar{c}_B(m_Z) < 1.9\times10^{-3}$$

$$-0.008 < \bar{c}_{Hu} < 0.02$$

$$-0.03 < \bar{c}_{Hd} < 0.02$$

$$-0.03 < \bar{c}_{Hs} < 0.02$$

$$-0.03 < \bar{c}_{Hq1} < 0.02$$

$$-0.005 < \bar{c}_{Hq2} < 0.003$$

$$-0.002 < \bar{c}'_{Hq1} < 0.003$$

$$-0.003 < \bar{c}'_{Hq2} < 0.005$$

$$-0.004 < \bar{c}_{HL}+\bar{c}'_{HL} < 0.002$$

$$-0.003 < \bar{c}_{HL}-\bar{c}'_{HL} < 0.0002$$

$$-0.0007 < \bar{c}_{Hl} < 0.003$$

$$-0.02 < \bar{c}_{Hq_2}+\bar{c}'_{Hq_2} < 0.005$$

$$-0.003 < \bar{c}_{Hq_3}-\bar{c}'_{Hq_3} < 0.009$$

$$-0.02 < \bar{c}_{Hc} < 0.03$$

$$-0.07 < \bar{c}_{Hb} < -0.005$$

$$-0.4\times10^{-3} < \bar{c}_{Htb}(m_W) < 1.3\times10^{-3}$$

rate b→sγ

$$-0.057 < \mathrm{Re}(\bar{c}_{tW}+\bar{c}_{tB}) - 2.65\,\mathrm{Im}(\bar{c}_{tW}+\bar{c}_{tB}) < 0.20$$

$$-1.39\times10^{-4} < \mathrm{Im}(\bar{c}_{tG}) < 1.21\times10^{-4}$$

Neutron EDM

$$-7.01\times10^{-6} < \mathrm{Im}(\bar{c}_{uB}+\bar{c}_{uW}) < 7.86\times10^{-6}$$

$$-9.42\times10^{-7} < \mathrm{Im}(\bar{c}_{dB}-\bar{c}_{dW}) < 8.40\times10^{-7}$$

$$-1.62\times10^{-6} < \mathrm{Im}(\bar{c}_{uG}) < 2.01\times10^{-6}$$

$$-7.71\times10^{-7} < \mathrm{Im}(\bar{c}_{dG}) < 5.70\times10^{-7}$$

ttbar, top decays

$$-6.12\times10^{-3} < \mathrm{Re}(\bar{c}_{tG}) < 1.94\times10^{-3}$$

$$-1.2 < \mathrm{Re}(\bar{c}_{bW}) < 1.1$$

$$-0.01 < \mathrm{Re}(\bar{c}_{tW}) < 0.02$$

$$-1.64\times10^{-2} < \mathrm{Re}(\bar{c}_{eB}-\bar{c}_{eW}) < 3.37\times10^{-3}$$

$$1.88\times10^{-4} < \mathrm{Re}(\bar{c}_{\mu B}-\bar{c}_{\mu W}) < 6.43\times10^{-4}$$

$$-2.97\times10^{-7} < \mathrm{Im}(\bar{c}_{eB}-\bar{c}_{eW}) < 4.51\times10^{-7}$$

$$-0.26 < \mathrm{Im}(\bar{c}_{\mu B}-\bar{c}_{\mu W}) < 0.29$$

Muon and electron (g-2), EDM

Current bounds on Wilson coefficients

$$-1.5 \times 10^{-3} < \bar{c}_T(m_Z) < 2.2 \times 10^{-3}$$
$$-1.4 \times 10^{-3} < \bar{c}_W(m_Z) + \bar{c}_B(m_Z) < 1.9 \times 10^{-3}$$

$$-0.008 < \bar{c}_{Hu} < 0.02$$
$$-0.03 < \bar{c}_{Hd} < 0.02$$
$$-0.03 < \bar{c}_{Hs} < 0.02$$

$$-0.03 < \bar{c}_{Hq1} < 0.02$$
$$-0.005 < \bar{c}_{Hq2} < 0.003$$
$$-0.002 < \bar{c}'_{Hq1} < 0.003$$
$$-0.003 < \bar{c}'_{Hq2} < 0.005$$

$$-0.004 < \bar{c}_{HL} + \bar{c}'_{HL} < 0.002$$
$$-0.003 < \bar{c}_{HL} - \bar{c}'_{HL} < 0.0002$$
$$-0.0007 < \bar{c}_{Hl} < 0.003$$

$$-0.02 < \bar{c}_{Hq_2} + \bar{c}'_{Hq_2} < 0.005$$
$$-0.003 < \bar{c}_{Hq_3} - \bar{c}'_{Hq_3} < 0.009$$
$$-0.02 < \bar{c}_{Hc} < 0.03$$
$$-0.07 < \bar{c}_{Hb} < -0.005$$

$$-0.4 \times 10^{-3} < \bar{c}_{Htb}(m_W) < 1.3 \times 10^{-3}$$

$$-0.057 < \mathrm{Re}(\bar{c}_{tW} + \bar{c}_{tB}) - 2.65\,\mathrm{Im}(\bar{c}_{tW} + \bar{c}_{tB}) < 0.20$$
$$-1.39 \times 10^{-4} < \mathrm{Im}(\bar{c}_{tG}) < 1.21 \times 10^{-4}$$

$$-6.12 \times 10^{-3} < \mathrm{Re}(\bar{c}_{tG}) < 1.94 \times 10^{-3}$$
$$-1.2 < \mathrm{Re}(\bar{c}_{bW}) < 1.1$$
$$-0.01 < \mathrm{Re}(\bar{c}_{tW}) < 0.02$$

$$-7.01 \times 10^{-6} < \mathrm{Im}(\bar{c}_{uB} + \bar{c}_{uW}) < 7.86 \times 10^{-6}$$
$$-9.42 \times 10^{-7} < \mathrm{Im}(\bar{c}_{dB} - \bar{c}_{dW}) < 8.40 \times 10^{-7}$$
$$-1.62 \times 10^{-6} < \mathrm{Im}(\bar{c}_{uG}) < 2.01 \times 10^{-6}$$
$$-7.71 \times 10^{-7} < \mathrm{Im}(\bar{c}_{dG}) < 5.70 \times 10^{-7}$$

$$-1.64 \times 10^{-2} < \mathrm{Re}(\bar{c}_{eB} - \bar{c}_{eW}) < 3.37 \times 10^{-3}$$
$$1.88 \times 10^{-4} < \mathrm{Re}(\bar{c}_{\mu B} - \bar{c}_{\mu W}) < 6.43 \times 10^{-4}$$
$$-2.97 \times 10^{-7} < \mathrm{Im}(\bar{c}_{eB} - \bar{c}_{eW}) < 4.51 \times 10^{-7}$$
$$-0.26 < \mathrm{Im}(\bar{c}_{\mu B} - \bar{c}_{\mu W}) < 0.29$$

Current bounds on Wilson coefficients

custodial symmetry required to avoid strong bound on c_T

$$\boxed{-1.5\times 10^{-3} < \bar{c}_T(m_Z) < 2.2\times 10^{-3}}$$

$$-1.4\times 10^{-3} < \bar{c}_W(m_Z)+\bar{c}_B(m_Z) < 1.9\times 10^{-3}$$

$$-0.008 < \bar{c}_{Hu} < 0.02$$
$$-0.03 < \bar{c}_{Hd} < 0.02$$
$$-0.03 < \bar{c}_{Hs} < 0.02$$

$$-0.03 < \bar{c}_{Hq1} < 0.02$$
$$-0.005 < \bar{c}_{Hq2} < 0.003$$
$$-0.002 < \bar{c}'_{Hq1} < 0.003$$
$$-0.003 < \bar{c}'_{Hq2} < 0.005$$

$$-0.004 < \bar{c}_{HL}+\bar{c}'_{HL} < 0.002$$
$$-0.003 < \bar{c}_{HL}-\bar{c}'_{HL} < 0.0002$$
$$-0.0007 < \bar{c}_{Hl} < 0.003$$

$$-0.02 < \bar{c}_{Hq_2}+\bar{c}'_{Hq_2} < 0.005$$
$$-0.003 < \bar{c}_{Hq_3}-\bar{c}'_{Hq_3} < 0.009$$
$$-0.02 < \bar{c}_{Hc} < 0.03$$
$$-0.07 < \bar{c}_{Hb} < -0.005$$

$$-0.4\times 10^{-3} < \bar{c}_{Htb}(m_W) < 1.3\times 10^{-3}$$

$$-0.057 < \mathrm{Re}(\bar{c}_{tW}+\bar{c}_{tB}) - 2.65\,\mathrm{Im}(\bar{c}_{tW}+\bar{c}_{tB}) < 0.20$$
$$-1.39\times 10^{-4} < \mathrm{Im}(\bar{c}_{tG}) < 1.21\times 10^{-4}$$

$$-6.12\times 10^{-3} < \mathrm{Re}(\bar{c}_{tG}) < 1.94\times 10^{-3}$$
$$-1.2 < \mathrm{Re}(\bar{c}_{bW}) < 1.1$$
$$-0.01 < \mathrm{Re}(\bar{c}_{tW}) < 0.02$$

$$-7.01\times 10^{-6} < \mathrm{Im}(\bar{c}_{uB}+\bar{c}_{uW}) < 7.86\times 10^{-6}$$
$$-9.42\times 10^{-7} < \mathrm{Im}(\bar{c}_{dB}-\bar{c}_{dW}) < 8.40\times 10^{-7}$$
$$-1.62\times 10^{-6} < \mathrm{Im}(\bar{c}_{uG}) < 2.01\times 10^{-6}$$
$$-7.71\times 10^{-7} < \mathrm{Im}(\bar{c}_{dG}) < 5.70\times 10^{-7}$$

$$-1.64\times 10^{-2} < \mathrm{Re}(\bar{c}_{eB}-\bar{c}_{eW}) < 3.37\times 10^{-3}$$
$$1.88\times 10^{-4} < \mathrm{Re}(\bar{c}_{\mu B}-\bar{c}_{\mu W}) < 6.43\times 10^{-4}$$
$$-2.97\times 10^{-7} < \mathrm{Im}(\bar{c}_{eB}-\bar{c}_{eW}) < 4.51\times 10^{-7}$$
$$-0.26 < \mathrm{Im}(\bar{c}_{\mu B}-\bar{c}_{\mu W}) < 0.29$$

Current bounds on Wilson coefficients

custodial symmetry required to avoid strong bound on c_T

$$-1.5 \times 10^{-3} < \bar{c}_T(m_Z) < 2.2 \times 10^{-3}$$

$$-1.4 \times 10^{-3} < \bar{c}_W(m_Z) + \bar{c}_B(m_Z) < 1.9 \times 10^{-3}$$

coefficients of fermionic operators all very small (except c_{Ht})

$$-0.008 < \bar{c}_{Hu} < 0.02$$
$$-0.03 < \bar{c}_{Hd} < 0.02$$
$$-0.03 < \bar{c}_{Hs} < 0.02$$

$$-0.03 < \bar{c}_{Hq1} < 0.02$$
$$-0.005 < \bar{c}_{Hq2} < 0.003$$
$$-0.002 < \bar{c}'_{Hq1} < 0.003$$
$$-0.003 < \bar{c}'_{Hq2} < 0.005$$

$$-0.004 < \bar{c}_{HL} + \bar{c}'_{HL} < 0.002$$
$$-0.003 < \bar{c}_{HL} - \bar{c}'_{HL} < 0.0002$$
$$-0.0007 < \bar{c}_{Hl} < 0.003$$

$$-0.02 < \bar{c}_{Hq_2} + \bar{c}'_{Hq_2} < 0.005$$
$$-0.003 < \bar{c}_{Hq_3} - \bar{c}'_{Hq_3} < 0.009$$
$$-0.02 < \bar{c}_{Hc} < 0.03$$
$$-0.07 < \bar{c}_{Hb} < -0.005$$

$$-0.4 \times 10^{-3} < \bar{c}_{Htb}(m_W) < 1.3 \times 10^{-3}$$

$$-0.057 < \mathrm{Re}(\bar{c}_{tW} + \bar{c}_{tB}) - 2.65\,\mathrm{Im}(\bar{c}_{tW} + \bar{c}_{tB}) < 0.20$$
$$-1.39 \times 10^{-4} < \mathrm{Im}(\bar{c}_{tG}) < 1.21 \times 10^{-4}$$

$$-6.12 \times 10^{-3} < \mathrm{Re}(\bar{c}_{tG}) < 1.94 \times 10^{-3}$$
$$-1.2 < \mathrm{Re}(\bar{c}_{bW}) < 1.1$$
$$-0.01 < \mathrm{Re}(\bar{c}_{tW}) < 0.02$$

$$-7.01 \times 10^{-6} < \mathrm{Im}(\bar{c}_{uB} + \bar{c}_{uW}) < 7.86 \times 10^{-6}$$
$$-9.42 \times 10^{-7} < \mathrm{Im}(\bar{c}_{dB} - \bar{c}_{dW}) < 8.40 \times 10^{-7}$$
$$-1.62 \times 10^{-6} < \mathrm{Im}(\bar{c}_{uG}) < 2.01 \times 10^{-6}$$
$$-7.71 \times 10^{-7} < \mathrm{Im}(\bar{c}_{dG}) < 5.70 \times 10^{-7}$$

$$-1.64 \times 10^{-2} < \mathrm{Re}(\bar{c}_{eB} - \bar{c}_{eW}) < 3.37 \times 10^{-3}$$
$$1.88 \times 10^{-4} < \mathrm{Re}(\bar{c}_{\mu B} - \bar{c}_{\mu W}) < 6.43 \times 10^{-4}$$
$$-2.97 \times 10^{-7} < \mathrm{Im}(\bar{c}_{eB} - \bar{c}_{eW}) < 4.51 \times 10^{-7}$$
$$-0.26 < \mathrm{Im}(\bar{c}_{\mu B} - \bar{c}_{\mu W}) < 0.29$$

Current bounds on Wilson coefficients

custodial symmetry required to avoid strong bound on c_T

$$-1.5 \times 10^{-3} < \bar{c}_T(m_Z) < 2.2 \times 10^{-3}$$

$$-1.4 \times 10^{-3} < \bar{c}_W(m_Z) + \bar{c}_B(m_Z) < 1.9 \times 10^{-3}$$

coefficients of fermionic operators all very small (except c_{Ht})

$$-0.008 < \bar{c}_{Hu} < 0.02$$
$$-0.03 < \bar{c}_{Hd} < 0.02$$
$$-0.03 < \bar{c}_{Hs} < 0.02$$

$$-0.03 < \bar{c}_{Hq1} < 0.02$$
$$-0.005 < \bar{c}_{Hq2} < 0.003$$
$$-0.002 < \bar{c}'_{Hq1} < 0.003$$
$$-0.003 < \bar{c}'_{Hq2} < 0.005$$

$$-0.004 < \bar{c}_{HL} + \bar{c}'_{HL} < 0.002$$
$$-0.003 < \bar{c}_{HL} - \bar{c}'_{HL} < 0.0002$$
$$-0.0007 < \bar{c}_{Hl} < 0.003$$

$$-0.02 < \bar{c}_{Hq_2} + \bar{c}'_{Hq_2} < 0.005$$
$$-0.003 < \bar{c}_{Hq_3} - \bar{c}'_{Hq_3} < 0.009$$
$$-0.02 < \bar{c}_{Hc} < 0.03$$
$$-0.07 < \bar{c}_{Hb} < -0.005$$

Strong MFV bound

$$-0.4 \times 10^{-3} < \bar{c}_{Htb}(m_W) < 1.3 \times 10^{-3}$$

$$M > \sqrt{10^3 m_t m_b}\left(\frac{g_*}{\lambda_{t_L}}\right) \simeq 900\,\mathrm{GeV}\left(\frac{g_*}{\lambda_{t_L}}\right)$$

$$-6.12 \times 10^{-3} < \mathrm{Re}(\bar{c}_{tG}) < 1.94 \times 10^{-3}$$
$$-1.2 < \mathrm{Re}(\bar{c}_{bW}) < 1.1$$
$$-0.01 < \mathrm{Re}(\bar{c}_{tW}) < 0.02$$

$$-7.01 \times 10^{-6} < \mathrm{Im}(\bar{c}_{uB} + \bar{c}_{uW}) < 7.86 \times 10^{-6}$$
$$-9.42 \times 10^{-7} < \mathrm{Im}(\bar{c}_{dB} - \bar{c}_{dW}) < 8.40 \times 10^{-7}$$
$$-1.62 \times 10^{-6} < \mathrm{Im}(\bar{c}_{uG}) < 2.01 \times 10^{-6}$$
$$-7.71 \times 10^{-7} < \mathrm{Im}(\bar{c}_{dG}) < 5.70 \times 10^{-7}$$

$$-1.64 \times 10^{-2} < \mathrm{Re}(\bar{c}_{eB} - \bar{c}_{eW}) < 3.37 \times 10^{-3}$$
$$1.88 \times 10^{-4} < \mathrm{Re}(\bar{c}_{\mu B} - \bar{c}_{\mu W}) < 6.43 \times 10^{-4}$$
$$-2.97 \times 10^{-7} < \mathrm{Im}(\bar{c}_{eB} - \bar{c}_{eW}) < 4.51 \times 10^{-7}$$
$$-0.26 < \mathrm{Im}(\bar{c}_{\mu B} - \bar{c}_{\mu W}) < 0.29$$

Current bounds on Wilson coefficients

custodial symmetry required to avoid strong bound on c_T

$$-1.5\times10^{-3} < \bar{c}_T(m_Z) < 2.2\times10^{-3}$$

$$-1.4\times10^{-3} < \bar{c}_W(m_Z)+\bar{c}_B(m_Z) < 1.9\times10^{-3}$$

coefficients of fermionic operators all very small (except c_{Ht})

$$-0.008 < \bar{c}_{Hu} < 0.02$$
$$-0.03 < \bar{c}_{Hd} < 0.02$$
$$-0.03 < \bar{c}_{Hs} < 0.02$$

$$-0.03 < \bar{c}_{Hq1} < 0.02$$
$$-0.005 < \bar{c}_{Hq2} < 0.003$$
$$-0.002 < \bar{c}'_{Hq1} < 0.003$$
$$-0.003 < \bar{c}'_{Hq2} < 0.005$$

$$-0.004 < \bar{c}_{HL}+\bar{c}'_{HL} < 0.002$$
$$-0.003 < \bar{c}_{HL}-\bar{c}'_{HL} < 0.0002$$
$$-0.0007 < \bar{c}_{Hl} < 0.003$$

$$-0.02 < \bar{c}_{Hq_2}+\bar{c}'_{Hq_2} < 0.005$$
$$-0.003 < \bar{c}_{Hq_3}-\bar{c}'_{Hq_3} < 0.009$$
$$-0.02 < \bar{c}_{Hc} < 0.03$$
$$-0.07 < \bar{c}_{Hb} < -0.005$$

Strong MFV bound

$$-0.4\times10^{-3} < \bar{c}_{Htb}(m_W) < 1.3\times10^{-3}$$

$$M > \sqrt{10^3 m_t m_b}\left(\frac{g_*}{\lambda_{t_L}}\right) \simeq 900\,\mathrm{GeV}\left(\frac{g_*}{\lambda_{t_L}}\right)$$

Limits on neutron and electron EDMs set a bound $(v/f)^2 \lesssim 10^{-3}$

Symmetry protection required to avoid it

$$-7.01\times10^{-6} < \mathrm{Im}(\bar{c}_{uB}+\bar{c}_{uW}) < 7.86\times10^{-6}$$
$$-9.42\times10^{-7} < \mathrm{Im}(\bar{c}_{dB}-\bar{c}_{dW}) < 8.40\times10^{-7}$$
$$-1.62\times10^{-6} < \mathrm{Im}(\bar{c}_{uG}) < 2.01\times10^{-6}$$
$$-7.71\times10^{-7} < \mathrm{Im}(\bar{c}_{dG}) < 5.70\times10^{-7}$$

$$-2.97\times10^{-7} < \mathrm{Im}(\bar{c}_{eB}-\bar{c}_{eW}) < 4.51\times10^{-7}$$
$$-0.26 < \mathrm{Im}(\bar{c}_{\mu B}-\bar{c}_{\mu W}) < 0.29$$

Estimating the effects on physics observables

$$
\begin{aligned}
\Delta\mathcal{L}_{SILH} = &\frac{\bar{c}_H}{2v^2}\,\partial^\mu\big(H^\dagger H\big)\,\partial_\mu\big(H^\dagger H\big) + \frac{\bar{c}_T}{2v^2}\,\Big(H^\dagger \overleftrightarrow{D^\mu} H\Big)\Big(H^\dagger \overleftrightarrow{D}_\mu H\Big) - \frac{\bar{c}_6\,\lambda}{v^2}\,\big(H^\dagger H\big)^3 \\
&+ \Big(\frac{\bar{c}_u}{v^2}\,y_u\,H^\dagger H\,\bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2}\,y_d\,H^\dagger H\,\bar{q}_L H d_R + \frac{\bar{c}_l}{v^2}\,y_l\,H^\dagger H\,\bar{L}_L H l_R + h.c.\Big) \\
&+ \frac{i\bar{c}_W\,g}{2m_W^2}\,\Big(H^\dagger \sigma^i \overleftrightarrow{D^\mu} H\Big)\,(D^\nu W_{\mu\nu})^i + \frac{i\bar{c}_B\,g'}{2m_W^2}\,\Big(H^\dagger \overleftrightarrow{D^\mu} H\Big)\,(\partial^\nu B_{\mu\nu}) \\
&+ \frac{i\bar{c}_{HW}\,g}{m_W^2}\,(D^\mu H)^\dagger \sigma^i (D^\nu H) W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\,g'}{m_W^2}\,(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu} \\
&+ \frac{\bar{c}_\gamma\,{g'}^2}{m_W^2}\,H^\dagger H B_{\mu\nu} B^{\mu\nu} + \frac{\bar{c}_g\,g_S^2}{m_W^2}\,H^\dagger H G^a_{\mu\nu} G^{a\mu\nu}\,,
\end{aligned}
$$

Estimating the effects on physics observables

$$\Delta\mathcal{L}_{SILH} = \frac{\bar{c}_H}{2v^2}\,\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) + \frac{\bar{c}_T}{2v^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) - \frac{\bar{c}_6\,\lambda}{v^2}\left(H^\dagger H\right)^3$$

$$+ \left(\frac{\bar{c}_u}{v^2}\,y_u\,H^\dagger H\,\bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2}\,y_d\,H^\dagger H\,\bar{q}_L H d_R + \frac{\bar{c}_l}{v^2}\,y_l\,H^\dagger H\,\bar{L}_L H l_R + h.c.\right)$$

$$+ \frac{i\bar{c}_W\,g}{2m_W^2}\left(H^\dagger\sigma^i \overleftrightarrow{D^\mu} H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{i\bar{c}_B\,g'}{2m_W^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(\partial^\nu B_{\mu\nu}\right)$$

$$+ \frac{i\bar{c}_{HW}\,g}{m_W^2}\left(D^\mu H\right)^\dagger\sigma^i\left(D^\nu H\right)W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\,g'}{m_W^2}\left(D^\mu H\right)^\dagger\left(D^\nu H\right)B_{\mu\nu}$$

$$+ \frac{\bar{c}_\gamma\,{g'}^2}{m_W^2}\,H^\dagger H B_{\mu\nu}B^{\mu\nu} + \frac{\bar{c}_g\,g_S^2}{m_W^2}\,H^\dagger H G^a_{\mu\nu}G^{a\mu\nu}\,,$$

Parametrize corrections to tree-level Higgs couplings:

$$\boxed{\frac{\Delta c}{c_{SM}} = O\left(\frac{v^2}{f^2}\right)}$$

Probe Higgs interaction strength g_*

Estimating the effects on physics observables

$$\Delta\mathcal{L}_{SILH} = \frac{\bar{c}_H}{2v^2}\,\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) + \frac{\bar{c}_T}{2v^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) - \frac{\bar{c}_6\,\lambda}{v^2}\left(H^\dagger H\right)^3$$

$$+ \left(\frac{\bar{c}_u}{v^2}\,y_u\,H^\dagger H\,\bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2}\,y_d\,H^\dagger H\,\bar{q}_L H d_R + \frac{\bar{c}_l}{v^2}\,y_l\,H^\dagger H\,\bar{L}_L H l_R + h.c.\right)$$

$$+ \frac{i\bar{c}_W\,g}{2m_W^2}\left(H^\dagger\sigma^i \overleftrightarrow{D^\mu} H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{i\bar{c}_B\,g'}{2m_W^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(\partial^\nu B_{\mu\nu}\right)$$

$$+ \frac{i\bar{c}_{HW}\,g}{m_W^2}\left(D^\mu H\right)^\dagger\sigma^i\left(D^\nu H\right)W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\,g'}{m_W^2}\left(D^\mu H\right)^\dagger\left(D^\nu H\right)B_{\mu\nu}$$

$$+ \frac{\bar{c}_\gamma\,{g'}^2}{m_W^2}\,H^\dagger H B_{\mu\nu}B^{\mu\nu} + \frac{\bar{c}_g\,g_S^2}{m_W^2}\,H^\dagger H G^a_{\mu\nu}G^{a\mu\nu}\,,$$

Modify the *h→WW, ZZ* decay rates

$$\frac{\delta\Gamma}{\Gamma_{SM}} = \hat{c}_{W,B}\times O\left(\frac{m_W^2}{M^2}\right) + \hat{c}_{HW+HB,\gamma}\times O\left(\frac{m_W^2}{16\pi^2 f^2}\right)$$

Estimating the effects on physics observables

$$\Delta\mathcal{L}_{SILH} = \frac{\bar{c}_H}{2v^2}\partial^\mu(H^\dagger H)\partial_\mu(H^\dagger H) + \frac{\bar{c}_T}{2v^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) - \frac{\bar{c}_6\,\lambda}{v^2}\left(H^\dagger H\right)^3$$

$$+\left(\frac{\bar{c}_u}{v^2}\,y_u\,H^\dagger H\,\bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2}\,y_d\,H^\dagger H\,\bar{q}_L H d_R + \frac{\bar{c}_l}{v^2}\,y_l\,H^\dagger H\,\bar{L}_L H l_R + h.c.\right)$$

$$+\frac{i\bar{c}_W\,g}{2m_W^2}\left(H^\dagger\sigma^i\overleftrightarrow{D^\mu}H\right)(D^\nu W_{\mu\nu})^i + \frac{i\bar{c}_B\,g'}{2m_W^2}\left(H^\dagger\overleftrightarrow{D^\mu}H\right)(\partial^\nu B_{\mu\nu})$$

$$+\frac{i\bar{c}_{HW}\,g}{m_W^2}(D^\mu H)^\dagger\sigma^i(D^\nu H)W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\,g'}{m_W^2}(D^\mu H)^\dagger(D^\nu H)B_{\mu\nu}$$

$$+\frac{\bar{c}_\gamma\,{g'}^2}{m_W^2}H^\dagger H B_{\mu\nu}B^{\mu\nu} + \frac{\bar{c}_g\,g_S^2}{m_W^2}H^\dagger H G^a_{\mu\nu}G^{a\mu\nu}\,,$$

Modify the *h→WW, ZZ* decay rates

$$\frac{\delta\Gamma}{\Gamma_{SM}} = \hat{c}_{W,B}\times O\left(\frac{m_W^2}{M^2}\right) + \hat{c}_{HW+HB,\gamma}\times O\left(\frac{m_W^2}{16\pi^2 f^2}\right)$$

Probe NP scale $\lesssim 10^{-3}$ due to LEP bounds

Estimating the effects on physics observables

$$\Delta\mathcal{L}_{SILH} = \frac{\bar{c}_H}{2v^2}\,\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) + \frac{\bar{c}_T}{2v^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) - \frac{\bar{c}_6\,\lambda}{v^2}\left(H^\dagger H\right)^3$$

$$+\left(\frac{\bar{c}_u}{v^2}\,y_u\,H^\dagger H\,\bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2}\,y_d\,H^\dagger H\,\bar{q}_L H d_R + \frac{\bar{c}_l}{v^2}\,y_l\,H^\dagger H\,\bar{L}_L H l_R + h.c.\right)$$

$$+\frac{i\bar{c}_W\,g}{2m_W^2}\left(H^\dagger\sigma^i\overleftrightarrow{D^\mu}H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{i\bar{c}_B\,g'}{2m_W^2}\left(H^\dagger\overleftrightarrow{D^\mu}H\right)\left(\partial^\nu B_{\mu\nu}\right)$$

$$+\frac{i\bar{c}_{HW}\,g}{m_W^2}\left(D^\mu H\right)^\dagger\sigma^i\left(D^\nu H\right)W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\,g'}{m_W^2}\left(D^\mu H\right)^\dagger\left(D^\nu H\right)B_{\mu\nu}$$

$$+\frac{\bar{c}_\gamma\,g'^2}{m_W^2}\,H^\dagger H B_{\mu\nu}B^{\mu\nu} + \frac{\bar{c}_g\,g_S^2}{m_W^2}\,H^\dagger H G^a_{\mu\nu}G^{a\mu\nu}\,,$$

Modify the $h\to WW$, ZZ decay rates

$$\frac{\delta\Gamma}{\Gamma_{SM}} = \hat{c}_{W,B}\times O\left(\frac{m_W^2}{M^2}\right) + \hat{c}_{HW+HB,\gamma}\times O\left(\frac{m_W^2}{16\pi^2 f^2}\right)$$

Probe NP scale $\lesssim 10^{-3}$ due to LEP bounds

Naively smaller

Estimating the effects on physics observables

$$\Delta\mathcal{L}_{SILH} = \frac{\bar{c}_H}{2v^2}\,\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) + \frac{\bar{c}_T}{2v^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) - \frac{\bar{c}_6\,\lambda}{v^2}\left(H^\dagger H\right)^3$$

$$+\left(\frac{\bar{c}_u}{v^2}\,y_u\,H^\dagger H\,\bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2}\,y_d\,H^\dagger H\,\bar{q}_L H d_R + \frac{\bar{c}_l}{v^2}\,y_l\,H^\dagger H\,\bar{L}_L H l_R + h.c.\right)$$

$$+\frac{i\bar{c}_W\,g}{2m_W^2}\left(H^\dagger\sigma^i\overleftrightarrow{D^\mu}H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{i\bar{c}_B\,g'}{2m_W^2}\left(H^\dagger\overleftrightarrow{D^\mu}H\right)\left(\partial^\nu B_{\mu\nu}\right)$$

$$+\frac{i\bar{c}_{HW}\,g}{m_W^2}\left(D^\mu H\right)^\dagger\sigma^i\left(D^\nu H\right)W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\,g'}{m_W^2}\left(D^\mu H\right)^\dagger\left(D^\nu H\right)B_{\mu\nu}$$

$$+\frac{\bar{c}_\gamma\,g'^2}{m_W^2}\,H^\dagger H B_{\mu\nu}B^{\mu\nu} + \frac{\bar{c}_g\,g_S^2}{m_W^2}\,H^\dagger H G^a_{\mu\nu}G^{a\mu\nu}\,,$$

Modify the *h→WW, ZZ* decay rates

Possible strategy: study *angular distributions* of final fermions

$$\frac{\delta(d\Gamma/d\Omega)}{(d\Gamma/d\Omega)_{SM}} \lesssim \hat{c}_{W,B}\times O\left(\frac{m_W^2}{M^2}\times\frac{16\pi^2}{g^2}\right)$$

$$+\,\hat{c}_{HW+HB,\gamma}\times O\left(\frac{m_W^2}{16\pi^2 f^2}\times\frac{16\pi^2}{g^2}\right)$$

Estimating the effects on physics observables

$$\Delta\mathcal{L}_{SILH} = \frac{\bar{c}_H}{2v^2}\,\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) + \frac{\bar{c}_T}{2v^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) - \frac{\bar{c}_6\,\lambda}{v^2}\left(H^\dagger H\right)^3$$

$$+ \left(\frac{\bar{c}_u}{v^2}\,y_u\,H^\dagger H\,\bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2}\,y_d\,H^\dagger H\,\bar{q}_L H d_R + \frac{\bar{c}_l}{v^2}\,y_l\,H^\dagger H\,\bar{L}_L H l_R + h.c.\right)$$

$$+ \frac{i\bar{c}_W\,g}{2m_W^2}\left(H^\dagger \sigma^i \overleftrightarrow{D^\mu} H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{i\bar{c}_B\,g'}{2m_W^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(\partial^\nu B_{\mu\nu}\right)$$

$$\boxed{\begin{aligned} &+ \frac{i\bar{c}_{HW}\,g}{m_W^2}\,(D^\mu H)^\dagger \sigma^i (D^\nu H) W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\,g'}{m_W^2}\,(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu} \\ &+ \frac{\bar{c}_\gamma\,{g'}^2}{m_W^2}\,H^\dagger H B_{\mu\nu} B^{\mu\nu} + \frac{\bar{c}_g\,g_S^2}{m_W^2}\,H^\dagger H G^a_{\mu\nu} G^{a\mu\nu}\,, \end{aligned}}$$

Modify the $h\to\gamma Z$, $\gamma\gamma$, gg decay rates

$$\boxed{\frac{\delta\Gamma}{\Gamma_{SM}} = \hat{c}_{HW-HB,\gamma,g} \times O\left(\frac{v^2}{f^2}\right)}$$

Estimating the effects on physics observables

$$\Delta\mathcal{L}_{SILH} = \frac{\bar{c}_H}{2v^2}\,\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) + \frac{\bar{c}_T}{2v^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) - \frac{\bar{c}_6\,\lambda}{v^2}\left(H^\dagger H\right)^3$$

$$+ \left(\frac{\bar{c}_u}{v^2}\,y_u\,H^\dagger H\,\bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2}\,y_d\,H^\dagger H\,\bar{q}_L H d_R + \frac{\bar{c}_l}{v^2}\,y_l\,H^\dagger H\,\bar{L}_L H l_R + h.c.\right)$$

$$+ \frac{i\bar{c}_W\,g}{2m_W^2}\left(H^\dagger\sigma^i \overleftrightarrow{D^\mu} H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{i\bar{c}_B\,g'}{2m_W^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(\partial^\nu B_{\mu\nu}\right)$$

$$\boxed{\begin{aligned} &+ \frac{i\bar{c}_{HW}\,g}{m_W^2}\,(D^\mu H)^\dagger\sigma^i(D^\nu H)W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\,g'}{m_W^2}\,(D^\mu H)^\dagger(D^\nu H)B_{\mu\nu} \\ &+ \frac{\bar{c}_\gamma\,{g'}^2}{m_W^2}\,H^\dagger H B_{\mu\nu}B^{\mu\nu} + \frac{\bar{c}_g\,g_S^2}{m_W^2}\,H^\dagger H G^a_{\mu\nu}G^{a\mu\nu}\,, \end{aligned}}$$

Modify the $h\to\gamma Z$, $\gamma\gamma$, gg decay rates

$$\boxed{\frac{\delta\Gamma}{\Gamma_{SM}} = \hat{c}_{HW-HB,\gamma,g} \times O\left(\frac{v^2}{f^2}\right)}$$

If the Higgs is a pNGB: $\gamma\gamma$, gg suppressed, only γZ probes Higgs strong coupling

Estimating the effects on physics observables

$$\Delta\mathcal{L}_{F_2} = \frac{\bar{c}_{uB}\, g'}{m_W^2}\, y_u\, \bar{q}_L H^c \sigma^{\mu\nu} u_R\, B_{\mu\nu} + \frac{\bar{c}_{uW}\, g}{m_W^2}\, y_u\, \bar{q}_L \sigma^i H^c \sigma^{\mu\nu} u_R\, W^i_{\mu\nu} + \frac{\bar{c}_{uG}\, g_S}{m_W^2}\, y_u\, \bar{q}_L H^c \sigma^{\mu\nu} \lambda^a u_R\, G^a_{\mu\nu}$$
$$+ \frac{\bar{c}_{dB}\, g'}{m_W^2}\, y_d\, \bar{q}_L H \sigma^{\mu\nu} d_R\, B_{\mu\nu} + \frac{\bar{c}_{dW}\, g}{m_W^2}\, y_d\, \bar{q}_L \sigma^i H \sigma^{\mu\nu} d_R\, W^i_{\mu\nu} + \frac{\bar{c}_{dG}\, g_S}{m_W^2}\, y_d\, \bar{q}_L H \sigma^{\mu\nu} \lambda^a d_R\, G^a_{\mu\nu}$$
$$+ \frac{\bar{c}_{lB}\, g'}{m_W^2}\, y_l\, \bar{L}_L H \sigma^{\mu\nu} l_R\, B_{\mu\nu} + \frac{\bar{c}_{lW}\, g}{m_W^2}\, y_l\, \bar{L}_L \sigma^i H \sigma^{\mu\nu} l_R\, W^i_{\mu\nu} + h.c.$$

Estimating the effects on physics observables

$$\Delta\mathcal{L}_{F_2} = \frac{\bar{c}_{uB}\, g'}{m_W^2}\, y_u\, \bar{q}_L H^c \sigma^{\mu\nu} u_R\, B_{\mu\nu} + \frac{\bar{c}_{uW}\, g}{m_W^2}\, y_u\, \bar{q}_L \sigma^i H^c \sigma^{\mu\nu} u_R\, W^i_{\mu\nu} + \boxed{\frac{\bar{c}_{uG}\, g_S}{m_W^2}\, y_u\, \bar{q}_L H^c \sigma^{\mu\nu} \lambda^a u_R\, G^a_{\mu\nu}}$$
$$+ \frac{\bar{c}_{dB}\, g'}{m_W^2}\, y_d\, \bar{q}_L H \sigma^{\mu\nu} d_R\, B_{\mu\nu} + \frac{\bar{c}_{dW}\, g}{m_W^2}\, y_d\, \bar{q}_L \sigma^i H \sigma^{\mu\nu} d_R\, W^i_{\mu\nu} + \frac{\bar{c}_{dG}\, g_S}{m_W^2}\, y_d\, \bar{q}_L H \sigma^{\mu\nu} \lambda^a d_R\, G^a_{\mu\nu}$$
$$+ \frac{\bar{c}_{lB}\, g'}{m_W^2}\, y_l\, \bar{L}_L H \sigma^{\mu\nu} l_R\, B_{\mu\nu} + \frac{\bar{c}_{lW}\, g}{m_W^2}\, y_l\, \bar{L}_L \sigma^i H \sigma^{\mu\nu} l_R\, W^i_{\mu\nu} + h.c.$$

Potentially sizable effects may come from the gluon dipole operator involving the right-handed top quark:

$$\frac{\delta\sigma(gg\to h)}{\sigma(gg\to h)} \sim \hat{c}_{tG} \equiv \mathrm{Re}(\bar{c}_{tG}) \left(\frac{m_t^2}{m_W^2}\right) \sim \frac{m_t^2}{16\pi^2 f^2} \simeq 3\times 10^{-3} \left(\frac{v^2}{f^2}\right)$$

$$\frac{\delta\sigma(gg\to t\bar{t})}{\sigma(gg\to t\bar{t})} \sim \hat{c}_{tG}\, \frac{\sqrt{s}}{m_t}\,, \qquad \frac{\delta\sigma(gg\to t\bar{t}h)}{\sigma(gg\to t\bar{t}h)} \sim \hat{c}_{tG}\, \frac{s}{m_t^2}$$

Strong vs Weak UV completions

- Prototype of weak UV theory: the MSSM

  - no separation of scales: $\left(\frac{v^2}{f^2}\right) \approx \left(\frac{m_W^2}{M^2}\right)$

  - tree-level shifts in the couplings from mixing:

$$c_V = 1 + O\left(\frac{m_Z^4}{m_H^4}\right) \qquad c_u = 1 - O\left(\frac{m_Z^2}{m_H^2}\right)\frac{1}{\tan\beta} \qquad c_d = 1 + O\left(\frac{m_Z^2}{m_H^2}\right)$$

  - potentially sizable corrections to γγ, *gg* $\quad c_{\gamma,g} = O\left(\frac{m_W^2}{16\pi^2}\frac{g_*^2}{m_{\tilde{t}}^2}\right) \qquad g_* = \frac{A_t}{m_{\tilde{t}}}\,, y_t$

- Prototype of strong UV theory: composite pNGB Higgs

  - leading effect in tree-level couplings and Zγ rate

$$c_V\,, c_u\,, c_d = 1 + O\left(\frac{v^2}{f^2}\right) \qquad \frac{\Gamma(h \to Z\gamma)}{\Gamma_{SM}} = 1 + O\left(\frac{v^2}{f^2}\right)$$

  - $c_g\,, c_\gamma$ suppressed

Effective Lagrangian in the unitary basis

$$\mathcal{L} = \frac{1}{2}\partial_\mu h\, \partial^\mu h - \frac{1}{2}m_h^2 h^2 - c_3\, \frac{1}{6}\left(\frac{3m_h^2}{v}\right) h^3 - \sum_{\psi=u,d,l} m_{\psi^{(i)}}\, \bar{\psi}^{(i)}\psi^{(i)} \left(1 + c_\psi \frac{h}{v} + \dots\right)$$
$$+ m_W^2\, W_\mu^+ W^{-\,\mu} \left(1 + 2c_W\, \frac{h}{v} + \dots\right) + \frac{1}{2}m_Z^2\, Z_\mu Z^\mu \left(1 + 2c_Z\, \frac{h}{v} + \dots\right) + \dots$$
$$+ \left(c_{WW}\, W_{\mu\nu}^+ W^{-\mu\nu} + \frac{c_{ZZ}}{2}\, Z_{\mu\nu}Z^{\mu\nu} + c_{Z\gamma}\, Z_{\mu\nu}\gamma^{\mu\nu} + \frac{c_{\gamma\gamma}}{2}\, \gamma_{\mu\nu}\gamma^{\mu\nu} + \frac{c_{gg}}{2}\, G_{\mu\nu}^a G^{a\mu\nu}\right) \frac{h}{v}$$
$$+ \left(c_{W\partial W}\, \left(W_\nu^- D_\mu W^{+\mu\nu} + h.c.\right) + c_{Z\partial Z}\, Z_\nu \partial_\mu Z^{\mu\nu} + c_{Z\partial\gamma}\, Z_\nu \partial_\mu \gamma^{\mu\nu}\right) \frac{h}{v} + \dots$$

Effective Lagrangian in the unitary basis

$$\mathcal{L} = \frac{1}{2}\partial_\mu h \, \partial^\mu h - \frac{1}{2}m_h^2 h^2 - c_3 \frac{1}{6}\left(\frac{3m_h^2}{v}\right) h^3 - \sum_{\psi=u,d,l} m_{\psi^{(i)}} \, \bar{\psi}^{(i)}\psi^{(i)} \left(1 + c_\psi \frac{h}{v} + \dots\right)$$
$$+ m_W^2 \, W_\mu^+ W^{-\,\mu} \left(1 + 2c_W \frac{h}{v} + \dots\right) + \frac{1}{2}m_Z^2 \, Z_\mu Z^\mu \left(1 + 2c_Z \frac{h}{v} + \dots\right) + \dots$$
$$+ \left(c_{WW} \, W_{\mu\nu}^+ W^{-\mu\nu} + \frac{c_{ZZ}}{2} \, Z_{\mu\nu}Z^{\mu\nu} + c_{Z\gamma} \, Z_{\mu\nu}\gamma^{\mu\nu} + \frac{c_{\gamma\gamma}}{2} \, \gamma_{\mu\nu}\gamma^{\mu\nu} + \frac{c_{gg}}{2} \, G_{\mu\nu}^a G^{a\mu\nu}\right) \frac{h}{v}$$
$$+ \left(c_{W\partial W} \, \left(W_\nu^- D_\mu W^{+\mu\nu} + h.c.\right) + c_{Z\partial Z} \, Z_\nu \partial_\mu Z^{\mu\nu} + c_{Z\partial\gamma} \, Z_\nu \partial_\mu \gamma^{\mu\nu}\right) \frac{h}{v} + \dots$$

- The same effective Lagrangian describes a generic scalar h (custodial singlet) with $SU(2)_L \times U(1)_Y$ non-linearly realized

  Each term can be dressed up with Nambu-Goldstone bosons and made manifestly $SU(2)_L \times U(1)_Y$ invariant

Coleman, Wess Zumino PR 177 (1969) 2239; Callan, Coleman, Wess, Zumino PR 177 (1969) 2247

RC, Grojean, Moretti, Piccinini, Rattazzi JHEP 1005 (2010) 089
Azatov, RC, Galloway JHEP 04 (2012) 127

Effective Lagrangian in the unitary basis

$$\mathcal{L} = \frac{1}{2}\partial_\mu h\, \partial^\mu h - \frac{1}{2} m_h^2 h^2 - c_3\, \frac{1}{6} \left(\frac{3m_h^2}{v}\right) h^3 - \sum_{\psi=u,d,l} m_{\psi^{(i)}}\, \bar{\psi}^{(i)} \psi^{(i)} \left(1 + c_\psi \frac{h}{v} + \dots\right)$$
$$+ m_W^2\, W_\mu^+ W^{-\,\mu} \left(1 + 2c_W\, \frac{h}{v} + \dots\right) + \frac{1}{2} m_Z^2\, Z_\mu Z^\mu \left(1 + 2c_Z\, \frac{h}{v} + \dots\right) + \dots$$
$$+ \left(c_{WW}\, W_{\mu\nu}^+ W^{-\mu\nu} + \frac{c_{ZZ}}{2}\, Z_{\mu\nu} Z^{\mu\nu} + c_{Z\gamma}\, Z_{\mu\nu}\gamma^{\mu\nu} + \frac{c_{\gamma\gamma}}{2}\, \gamma_{\mu\nu}\gamma^{\mu\nu} + \frac{c_{gg}}{2}\, G_{\mu\nu}^a G^{a\mu\nu}\right) \frac{h}{v}$$
$$+ \left(c_{W\partial W}\, (W_\nu^- D_\mu W^{+\mu\nu} + h.c.) + c_{Z\partial Z}\, Z_\nu \partial_\mu Z^{\mu\nu} + c_{Z\partial\gamma}\, Z_\nu \partial_\mu \gamma^{\mu\nu}\right) \frac{h}{v} + \dots$$

- 2 more parameters (couplings) compared to SILH Lagrangian:

$$c_{WW}, c_{ZZ}, c_{Z\gamma}, c_{\gamma\gamma} \longrightarrow \bar{c}_{HW}, \bar{c}_{HB}, \bar{c}_\gamma$$

$$c_{W\partial W}, c_{Z\partial Z}, c_{Z\partial\gamma} \longrightarrow \bar{c}_W, \bar{c}_B$$

- 2 identities hold if the Higgs is a doublet

$$c_{WW} - c_{ZZ}\cos^2\theta_W = c_{Z\gamma}\sin 2\theta_W + c_{\gamma\gamma}\sin^2\theta_W$$

$$c_{W\partial W} - c_{Z\partial Z}\cos^2\theta_W = \frac{c_{Z\partial\gamma}}{2}\sin 2\theta_W$$

They follow from custodial invariance, which is *accidental* in the SILH Lagrangian at the level of dim-6 operators if one restricts to derivative couplings.

- 2 identities hold if the Higgs is a doublet

$$c_{WW} - c_{ZZ}\cos^2\theta_W = c_{Z\gamma}\sin 2\theta_W + c_{\gamma\gamma}\sin^2\theta_W$$

$$c_{W\partial W} - c_{Z\partial Z}\cos^2\theta_W = \frac{c_{Z\partial\gamma}}{2}\sin 2\theta_W$$

They follow from custodial invariance, which is *accidental* in the SILH Lagrangian at the level of dim-6 operators if one restricts to derivative couplings.

A third identity on the tree-level couplings follows after imposing custodial symmetry (so that $\bar{c}_T = 0$):

$$\boxed{c_W = c_Z}$$

- 2 identities hold if the Higgs is a doublet

$$c_{WW} - c_{ZZ}\cos^2\theta_W = c_{Z\gamma}\sin 2\theta_W + c_{\gamma\gamma}\sin^2\theta_W$$

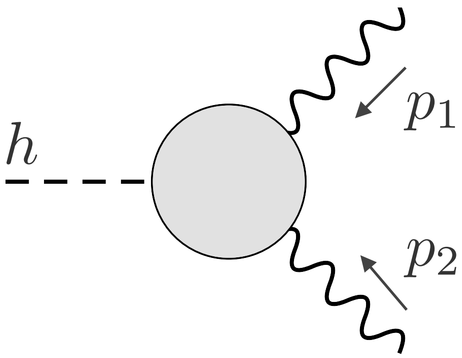
$$c_{W\partial W} - c_{Z\partial Z}\cos^2\theta_W = \frac{c_{Z\partial\gamma}}{2}\sin 2\theta_W$$

They follow from custodial invariance, which is *accidental* in the SILH Lagrangian at the level of dim-6 operators if one restricts to derivative couplings.

A third identity on the tree-level couplings follows after imposing custodial symmetry (so that $\bar{c}_T = 0$):

$$c_W = c_Z$$

All three identities are special cases of a more general relation among form factors implied by custodial invariance:



$$\Gamma^{\mu\nu}_{WW}(p_1,p_2) - \Gamma^{\mu\nu}_{ZZ}(p_1,p_2)\cos^2\theta_W = \left(\Gamma^{\mu\nu}_{Z\gamma}(p_1,p_2) + \Gamma^{\nu\mu}_{Z\gamma}(p_2,p_1)\right)\frac{\sin 2\theta_W}{2} + \Gamma^{\mu\nu}_{\gamma\gamma}(p_1,p_2)\sin^2\theta_W$$

- 2 identities hold if the Higgs is a doublet

$$c_{WW} - c_{ZZ}\cos^2\theta_W = c_{Z\gamma}\sin 2\theta_W + c_{\gamma\gamma}\sin^2\theta_W$$

$$c_{W\partial W} - c_{Z\partial Z}\cos^2\theta_W = \frac{c_{Z\partial\gamma}}{2}\sin 2\theta_W$$

They follow from custodial invariance, which is *accidental* in the SILH Lagrangian at the level of dim-6 operators if one restricts to derivative couplings.

Custodial symmetry can be broken in the SILH Lagrangian at the level of dim-8 operators and the above identities are violated.

Ex: $$\frac{\bar{c}_{8WW}\, g^2}{m_W^2 v^2}\left(H^\dagger W^a_{\mu\nu}\sigma^a H\right)\left(H^\dagger W^{b\,\mu\nu}\sigma^b H\right), \qquad \frac{i\bar{c}_{8W}\, g}{v^2 m_W^2}\left(H^\dagger\sigma^a H\right)\left(D^\mu W_{\mu\nu}\right)^a \left(H^\dagger \overleftrightarrow{D}^\nu H\right)$$

$$c_{Z\partial Z} = -4\bar{c}_{8W}\,, \qquad c_{Z\partial\gamma} = -4\tan\theta_W\,\bar{c}_{8W}$$

$$c_{ZZ} = 8\cos^2\theta_W\,\bar{c}_{8WW}, \qquad c_{Z\gamma} = 4\sin 2\theta_W\,\bar{c}_{8WW}, \qquad c_{\gamma\gamma} = 8\sin^2\theta_W\,\bar{c}_{8WW}$$

- If the EWSB dynamics has custodial invariance, the non-linear and SILH Lagrangians give the *same* predictions for single-Higgs processes

That is: There is no way to tell if the Higgs is a doublet by looking at single-Higgs processes alone

- If the EWSB dynamics has custodial invariance, the non-linear and SILH Lagrangians give the *same* predictions for single-Higgs processes

That is: There is no way to tell if the Higgs is a doublet by looking at single-Higgs processes alone

- Circumstantial evidence that the Higgs boson belongs to a doublet may come from the value of its couplings *if they are all close to their SM value*.

(in that case the evidence is for a specific model: the SM)

If deviations from the SM values are found, to tell if the Higgs is part of a doublet one has to go beyond single-Higgs production

- If the EWSB dynamics has custodial invariance, the non-linear and SILH Lagrangians give the *same* predictions for single-Higgs processes

That is: There is no way to tell if the Higgs is a doublet by looking at single-Higgs processes alone

- Circumstantial evidence that the Higgs boson belongs to a doublet may come from the value of its couplings *if they are all close to their SM value.*

(in that case the evidence is for a specific model: the SM)

If deviations from the SM values are found, to tell if the Higgs is part of a doublet one has to go beyond single-Higgs production

- Large deviations from SM couplings do not necessarily disprove a Higgs doublet (e.g. non-linearities can be large)

In that case the SILH Lagrangian cannot be used: higher order terms must be resummed

Implementing the Effective Lagrangian: eHDECAY

- eHDECAY fully implements the SILH and non-linear Lagrangians (plus two benchmark CH models) for the calculation of Higgs decay rates and BRs

- Software based on HDECAY v5.10; Freely available at the web page:

  http://www-itp.particle.uni-karlsruhe.de/~maggie/eHDECAY

- Perturbative expansion in the parameters $\alpha_{SM}/4\pi,\ (E/M)^2,\ (v/f)^2$ performed consistently

  Ex: 1-loop EW corrections included only for the SILH Lagrangian

- Numerical approximate formulas for the decay rates are given in the paper

$$\frac{\Gamma(\bar{\psi}\psi)}{\Gamma(\bar{\psi}\psi)_{SM}} \simeq 1 - \bar{c}_H - 2\,\bar{c}_\psi \,,$$

$$\frac{\Gamma(h \to W^{(*)}W^*)}{\Gamma(h \to W^{(*)}W^*)_{SM}} \simeq 1 - \bar{c}_H + 2.2\,\bar{c}_W + 3.7\,\bar{c}_{HW} \,,$$

$$\begin{aligned}\frac{\Gamma(h \to Z^{(*)}Z^*)}{\Gamma(h \to Z^{(*)}Z^*)_{SM}} \simeq\, & 1 - \bar{c}_H + 2.0\,\left(\bar{c}_W + \tan^2\theta_W\,\bar{c}_B\right) \\ & + 3.0\,\left(\bar{c}_{HW} + \tan^2\theta_W\,\bar{c}_{HB}\right) - 0.26\,\bar{c}_\gamma \,,\end{aligned}$$

$$\begin{aligned}\frac{\Gamma(h \to Z\gamma)}{\Gamma(h \to Z\gamma)_{SM}} \simeq\, & 1 - \bar{c}_H + 0.12\,\bar{c}_t - 5\cdot 10^{-4}\,\bar{c}_c - 0.003\,\bar{c}_b - 9\cdot 10^{-5}\,\bar{c}_\tau \\ & + 4.2\,\bar{c}_W + 0.19\,\left(\bar{c}_{HW} - \bar{c}_{HB} + 8\,\bar{c}_\gamma \sin^2\theta_W\right)\frac{4\pi}{\sqrt{\alpha_2\alpha_{em}}} \,,\end{aligned}$$

$$\begin{aligned}\frac{\Gamma(h \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)_{SM}} \simeq\, & 1 - \bar{c}_H + 0.54\,\bar{c}_t - 0.003\,\bar{c}_c - 0.007\,\bar{c}_b - 0.007\,\bar{c}_\tau \\ & + 5.04\,\bar{c}_W - 0.54\,\bar{c}_\gamma\,\frac{4\pi}{\alpha_{em}} \,,\end{aligned}$$

$$\frac{\Gamma(h \to gg)}{\Gamma(h \to gg)_{SM}} \simeq 1 - \bar{c}_H - 2.12\,\bar{c}_t + 0.024\,\bar{c}_c + 0.1\,\bar{c}_b + 22.2\,\bar{c}_g\,\frac{4\pi}{\alpha_2} \,.$$

$$\alpha_2 \equiv \frac{\sqrt{2}\,G_F m_W^2}{\pi} \qquad\qquad \alpha_{em} \equiv \alpha_{em}(q^2 = 0)$$

Conclusions/Discussion

- Basis of SILH effective Lagrangian is the most convenient one to determine the nature of the Higgs boson

Conclusions/Discussion

- Basis of SILH effective Lagrangian is the most convenient one to determine the nature of the Higgs boson

- Probe of the Higgs interaction strength comes from:

  i) deviations of tree-level couplings; ii) $h \to Z\gamma$

Conclusions/Discussion

- Basis of SILH effective Lagrangian is the most convenient one to determine the nature of the Higgs boson

- Probe of the Higgs interaction strength comes from:

  i) deviations of tree-level couplings; ii) $h \to Z\gamma$

- Difficult but potentially interesting: study of angular distributions of daughter fermions in $h \to ZZ, WW$

Conclusions/Discussion

- Basis of SILH effective Lagrangian is the most convenient one to determine the nature of the Higgs boson

- Probe of the Higgs interaction strength comes from:

  i) deviations of tree-level couplings; ii) $h \to Z\gamma$

- Difficult but potentially interesting: study of angular distributions of daughter fermions in $h \to ZZ, WW$

- Single-Higgs processes alone cannot test if the Higgs belongs to a doublet: double-Higgs processes required

EXTRA SLIDES

$$A(h \to ZZ) = v^{-1} \epsilon_1^{\mu} \epsilon_2^{\nu} \left(a_1 m_H^2 \, \eta_{\mu\nu} + a_2 \, q_\mu q_\nu + a_3 \, \epsilon_{\mu\nu\rho\sigma} q_1^{\rho} q_2^{\sigma} \right)$$

$$a_1 = c_Z \frac{m_Z^2}{m_h^2} - c_{ZZ} \frac{q_1 \cdot q_2}{m_h^2} - c_{Z\partial Z} \frac{p_1^2 + p_2^2}{2m_h^2}$$

$$a_2 = -c_{ZZ}$$

$$a_3 = -\tilde{c}_{ZZ}$$

$$c_Z \sim \frac{v^2}{f^2}$$

$$c_{Z\partial Z} \sim \frac{m_Z^2}{M^2}$$

$$c_{ZZ}, \tilde{c}_{ZZ} \sim \frac{m_Z^2}{16\pi^2 f^2}$$