

Global constraints on the dimension-6 Standard Model Effective Field Theory

ICHEP 2018

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based on *JHEP 08 (2013) 106, JHEP 12 (2016) 135*
by J. de Blas, M. Ciuchini, E. Franco, S. Mishima, M. Pierini,
L. Reina, L. Silvestrini.



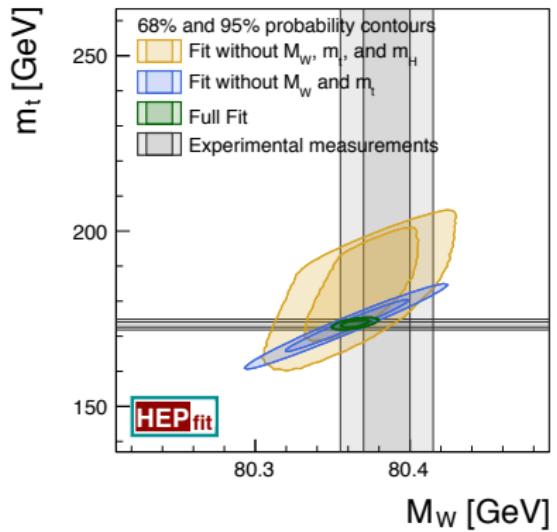
Motivation

The Standard Model is complete.

\mathcal{L}_{SM} is working very well.

No conclusive signs for
New Physics at the EW scale.

⇒ Test quantum structure of SM
to find New Physics effects.



[de Blas et al. '16]

EFT approaches to physics beyond the SM

Assuming a mass gap between the SM and New Physics:

SMEFT

- h in a doublet
- $\mathcal{L} = \mathcal{L}_{\text{SM}} + \sum_{d>4} \frac{1}{\Lambda^{d-4}} \sum_i C_i \mathcal{O}_i$
- Expansion in dimensions

[JHEP 12 (2016) 135]

Electroweak chiral Lagrangian

- h and φ_a are independent
- $\mathcal{L} \neq \mathcal{L}_{\text{SM}}$ @ LO
- Expansion in chiral dimensions and v^2/f^2

[arXiv:1803.00939]



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[JHEP 12 (2016) 135]

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- Expansion in chiral dimensions and v^2/f^2

[arXiv:1803.00939]



HEPfit

hepfit.roma1.infn.it

HEPfit

home developers samples documentation

HEPfit: a Code for the Combination of Indirect and Direct Constraints on High Energy Physics Models.

Higgs Physics
HEPfit can be used to study Higgs couplings and analyze data on signal strengths.

Precision Electroweak
Electroweak precision observables are included in HEPfit.

Flavour Physics
The Flavour Physics menu in HEPfit includes both quark and lepton flavour dynamics.

BSM Physics
Dynamics beyond the Standard Model can be studied by adding models in HEPfit.

Dedicated ICHEP talk: **HEPfit: The Analysis Toolkit**
→ Tomorrow @ 11:45

SMEFT

Assuming that New Physics decouples
and the effective theory has a cut-off scale Λ :

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} \left(+ \frac{1}{\Lambda} \mathcal{L}_5 \right) + \frac{1}{\Lambda^2} \sum_i C_i \mathcal{O}_i^{(6)} + \dots$$

New Physics effects suppressed by $\frac{v^2}{\Lambda^2}$ or $\frac{p^2}{\Lambda^2}$ at leading order.

Truncation at $D = 6$ implies $v, p \ll \Lambda$.

59 different flavour conserving operators!

SMEFT

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} (+\mathcal{L}_5) + \frac{1}{\Lambda^2} \sum_i C_i Q_i + \dots$$

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2 \varphi^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger \varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger \varphi)(\bar{l}_p e_r \varphi)$
$Q_{\tilde{G}}$	$f^{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\square}$	$(\varphi^\dagger \varphi)\square(\varphi^\dagger \varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger \varphi)(\bar{q}_p u_r \bar{\varphi})$
Q_W	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$(\varphi^\dagger D^\mu \varphi)^*$ ($\varphi^\dagger D_\mu \varphi$)	$Q_{d\varphi}$	$(\varphi^\dagger \varphi)(\bar{q}_p d_r \varphi)$
$Q_{\tilde{W}}$	$\varepsilon^{IJK} \tilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				
$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger \varphi G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i \overset{\leftrightarrow}{D}_\mu \varphi)(\bar{l}_p \gamma^\mu l_r)$
$Q_{\varphi \tilde{G}}$	$\varphi^\dagger \varphi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i \overset{\leftrightarrow}{D}_\mu^I \varphi)(\bar{l}_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger \varphi W_{\mu\nu}^I W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A_{\mu\nu}) \bar{\varphi} G_{\mu\nu}^A$	$Q_{\varphi e}$	$(\varphi^\dagger i \overset{\leftrightarrow}{D}_\mu \varphi)(\bar{e}_p \gamma^\mu e_r)$
$Q_{\varphi \tilde{W}}$	$\varphi^\dagger \varphi \tilde{W}_{\mu\nu}^I W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \bar{\varphi} W_{\mu\nu}^I$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i \overset{\leftrightarrow}{D}_\mu \varphi)(\bar{q}_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger \varphi B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \bar{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i \overset{\leftrightarrow}{D}_\mu^I \varphi)(\bar{q}_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi \tilde{B}}$	$\varphi^\dagger \varphi \tilde{B}_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} T^A_{\mu\nu}) \varphi G_{\mu\nu}^A$	$Q_{\varphi u}$	$(\varphi^\dagger i \overset{\leftrightarrow}{D}_\mu \varphi)(\bar{u}_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger \tau^I \varphi W_{\mu\nu}^I B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi d}$	$(\varphi^\dagger i \overset{\leftrightarrow}{D}_\mu \varphi)(\bar{d}_p \gamma^\mu d_r)$
$Q_{\varphi \tilde{W}B}$	$\varphi^\dagger \tau^I \varphi \tilde{W}_{\mu\nu}^I B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\bar{\varphi}^\dagger D_\mu \varphi)(\bar{u}_p \gamma^\mu d_r)$

$(\bar{L}L)(\bar{L}L)$	
Q_{ll}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$
...	

[GIMR 1008.4884]

Only linear order, no running (C_i at ew scale)

SMEFT

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} (+\mathcal{L}_5) + \frac{1}{\Lambda^2} \sum_i C_i Q_i + \dots$$

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$Q_{\bar{W}}$	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				
$X^2 \varphi^2$		$\psi^2 X \varphi$		$\psi^2 \varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger \varphi G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i \overset{\leftrightarrow}{D}_\mu \varphi)(\bar{l}_p \gamma^\mu l_r)$
$Q_{\varphi \tilde{G}}$	$\varphi^\dagger \varphi G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) \varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i \overset{\leftrightarrow}{D}_\mu^I \varphi)(\bar{l}_p \tau^I \gamma^\mu l_r)$
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$Q_{\varphi B}$	$\varphi^\dagger \varphi B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \bar{\varphi} B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i \overset{\leftrightarrow}{D}_\mu^I \varphi)(\bar{q}_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi \tilde{B}}$	$\varphi^\dagger \varphi \bar{B}_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) \varphi G_{\mu\nu}^A$	$Q_{\varphi u}$	$(\varphi^\dagger i \overset{\leftrightarrow}{D}_\mu \varphi)(\bar{u}_p \gamma^\mu u_r)$
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$Q_{\varphi \bar{W}B}$	$\varphi^\dagger \tau^I \varphi \bar{W}_{\mu\nu}^I B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \varphi B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\bar{\varphi}^\dagger D_\mu \varphi)(\bar{u}_p \gamma^\mu d_r)$

$(\bar{L}L)(\bar{L}L)$	
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[GIMR 1008.4884]

Only linear order, no running (C_i at ew scale)

EWPO – effective interactions

$$\delta g_L^u = -\frac{1}{2} \left(C_{\phi q}^{(1)} - C_{\phi q}^{(3)} \right) \frac{v^2}{\Lambda^2},$$

$$\delta g_L^d = -\frac{1}{2} \left(C_{\phi q}^{(1)} + C_{\phi q}^{(3)} \right) \frac{v^2}{\Lambda^2},$$

$$\delta g_L^\nu = -\frac{1}{2} \left(C_{\phi I}^{(1)} - C_{\phi I}^{(3)} \right) \frac{v^2}{\Lambda^2},$$

$$\delta g_L^e = -\frac{1}{2} \left(C_{\phi I}^{(1)} + C_{\phi I}^{(3)} \right) \frac{v^2}{\Lambda^2},$$

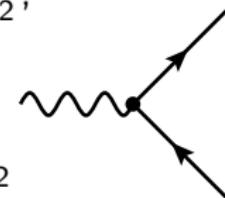
$$\delta V_{ud} = C_{\phi q}^{(3)} \frac{v^2}{\Lambda^2}, \quad \delta U_{e\nu} = \left(C_{\phi I}^{(3)} \right)^\dagger \frac{v^2}{\Lambda^2},$$

$$\Delta S = \frac{4 s_W c_W}{\alpha_{\text{em}}(M_Z)} C_{\phi WB} \frac{v^2}{\Lambda^2}, \quad \Delta T = -\frac{1}{2\alpha_{\text{em}}(M_Z)} C_{\phi D} \frac{v^2}{\Lambda^2}$$

$$\delta g_R^u = -\frac{1}{2} C_{\phi u} \frac{v^2}{\Lambda^2},$$

$$\delta g_R^d = -\frac{1}{2} C_{\phi d} \frac{v^2}{\Lambda^2},$$

$$\delta g_R^e = -\frac{1}{2} C_{\phi e} \frac{v^2}{\Lambda^2},$$



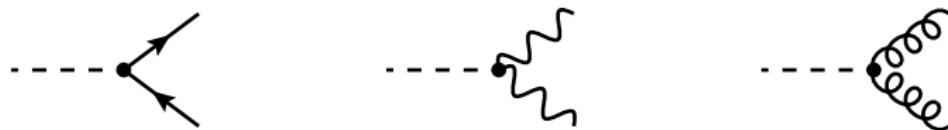
EWPO – inputs

SM part at highest available precision + linear SMEFT corrections

EWPO inputs from

- LEP 1 ($\sqrt{s} \approx M_Z$)
- LEP 2 ($160 \text{ GeV} < \sqrt{s} < 210 \text{ GeV}$)
- SLC
- Tevatron
- LHC

Higgs signal strengths – effective interactions

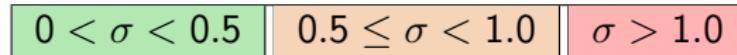


The signal strengths are calculated with Madgraph and eHDecay.

Higgs signal strengths – inputs

	$b\bar{b}$	WW	$\tau\tau$	ZZ	$\gamma\gamma$	$Z\gamma$	$\mu\mu$
SM Br	57.5%	21.6%	6.3%	2.7%	2.3%	1.6%	0.2%
ggF8	87.2%	–	AC	AC	AC	AC	AC
ggF13	87.1%	–	AC	C	AC	AC	AC
VBF8	7.2%	–	AC	AC	AC	AC	AC
VBF13	7.4%	C	AC	C	AC	AC	AC
Vh8	5.1%	AC	AC	AC	AC	AC	AC
Vh13	4.4%	AC	AC	C	AC	AC	AC
tth8	0.6%	AC	–	–	AC	AC	AC
tth13	1.0%	AC	AC	AC	AC	AC	AC
Vh2	Tev						
tth2	Tev						

Uncertainty of the signal strengths $\mu \pm \sigma$:

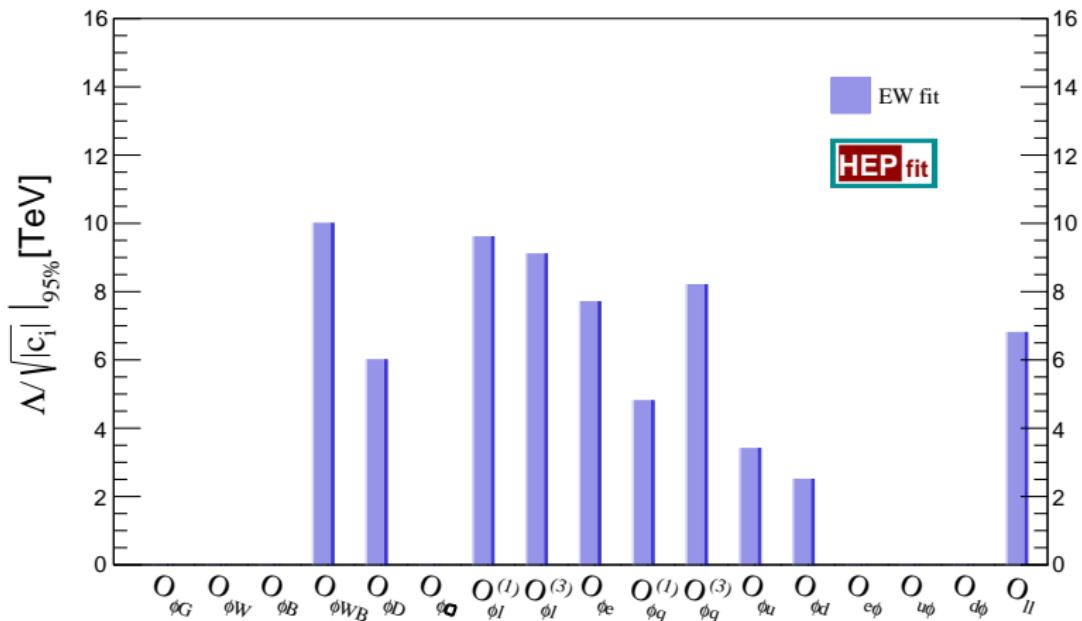


EWPO only

Operator	95% prob. range $\frac{C_i}{\Lambda^2}$ [TeV $^{-2}$]	95% prob. lower bound on Λ [TeV] ($ C_i = 1$)
$C_{\phi WB}$	[-0.0095, 0.0038]	10
$C_{\phi D}$	[-0.028, 0.0036]	6.0
$C_{\phi l}^{(1)}$	[-0.0058, 0.011]	9.6
$C_{\phi l}^{(3)}$	[-0.012, 0.0051]	9.1
$C_{\phi e}^{(1)}$	[-0.017, 0.005]	7.7
$C_{\phi Q}^{(1)}$	[-0.026, 0.044]	4.8
$C_{\phi Q}^{(3)}$	[-0.011, 0.015]	8.2
$C_{\phi u}$	[-0.066, 0.087]	3.4
$C_{\phi d}$	[-0.15, 0.054]	2.5
C_{LL}	[-0.0093, 0.021]	6.8

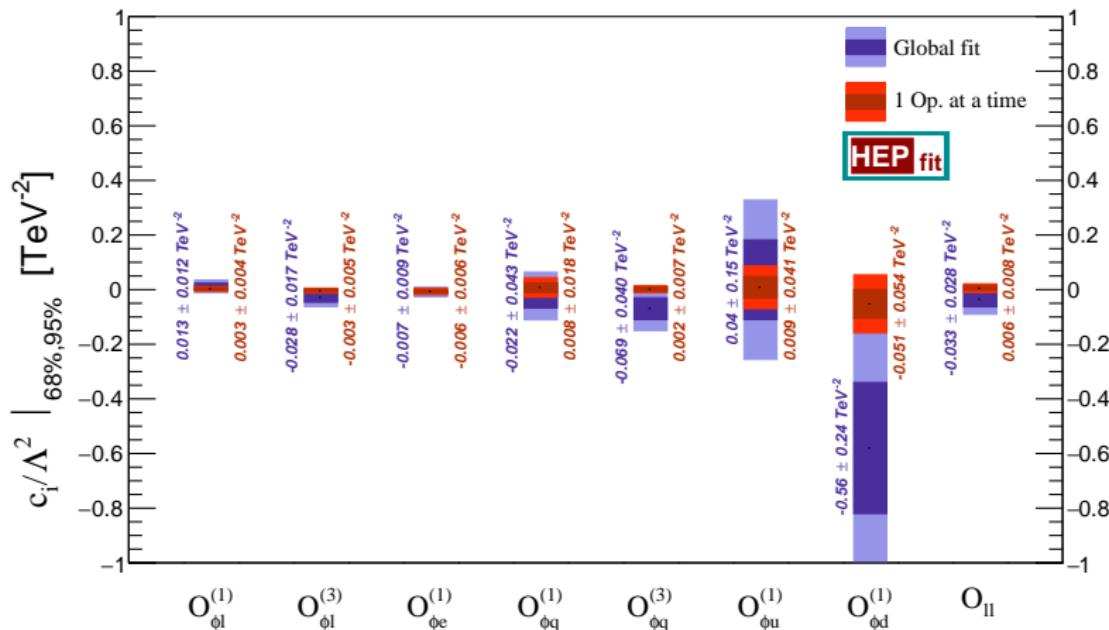
[preliminary]

EWPO only – one operator at a time



[preliminary]

EWPO only – individual vs. global fit



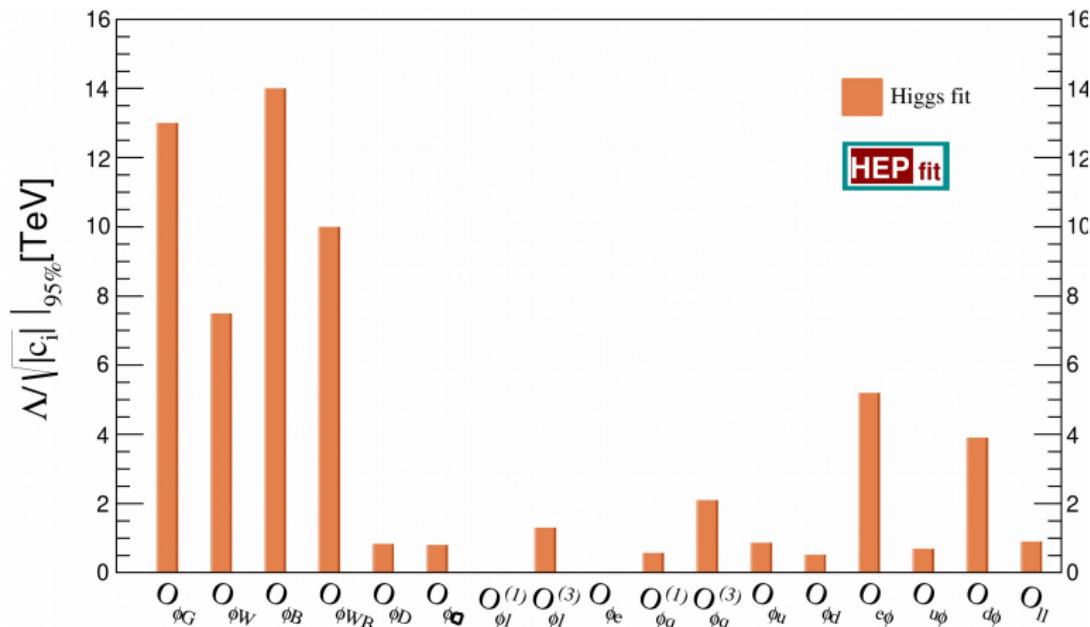
[preliminary]

Higgs signal strengths only

Operator	95% prob. range $\frac{C_i}{\Lambda^2}$ [TeV $^{-2}$]	95% prob. lower bound on Λ [TeV] ($ C_i = 1$)
$C_{\phi G}$	[-0.00078, 0.0062]	13
$C_{\phi W}$	[-0.018, 0.0083]	7.5
$C_{\phi B}$	[-0.0053, 0.0026]	14
$C_{\phi WB}$	[-0.0047, 0.0097]	10
$C_{\phi D}$	[-1.5, 0.31]	0.83
$C_{\phi \square}$	[-0.12, 1.6]	0.80
$C_{\phi l}^{(3)}$	[-0.62, 0.10]	1.3
$C_{\phi Q}^{(1)}$	[-3.1, 1.2]	0.57
$C_{\phi Q}^{(3)}$	[-0.14, 0.22]	2.1
$C_{\phi u}$	[-1.2, 1.4]	0.86
$C_{\phi d}$	[-3.7, 3.5]	0.52
$C_{e\phi}$	[-0.036, 0.020]	5.2
$C_{u\phi}$	[-2.1, 0.17]	0.69
$C_{d\phi}$	[-0.00065, 0.066]	3.9
C_{LL}	[-0.21, 1.2]	0.90

[preliminary]

Higgs signal strengths only



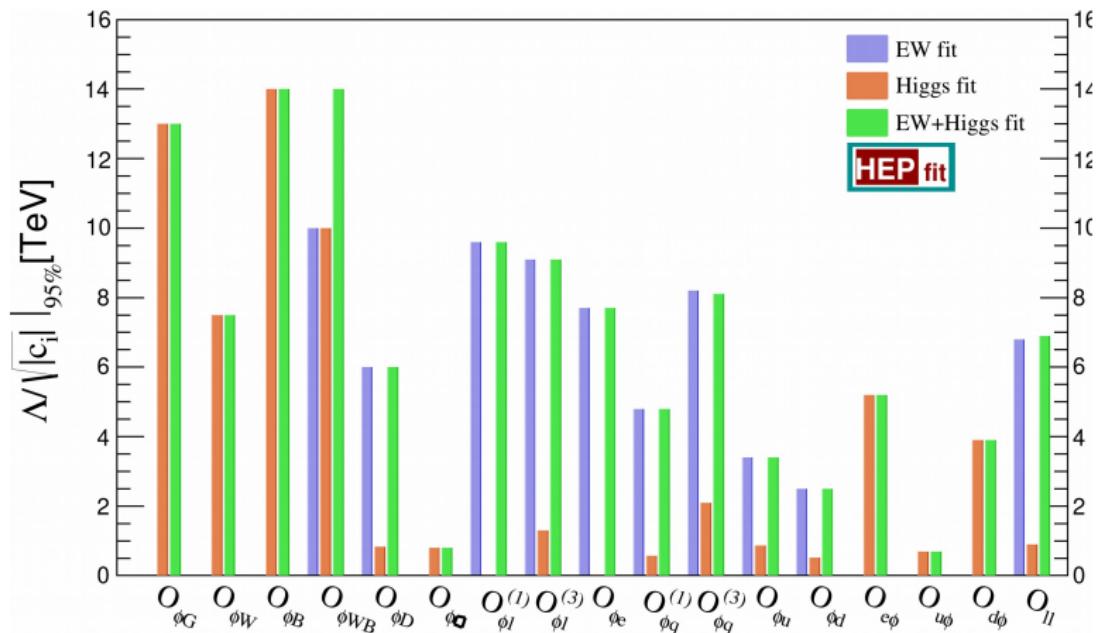
[preliminary]

EWPO and Higgs signal strengths

Operator	95% prob. range $\frac{C_i}{\Lambda^2} [\text{TeV}^{-2}]$	95% prob. lower bound on Λ [TeV] ($ C_i = 1$)
$C_{\phi G}$	[-0.00076, 0.0063]	13
$C_{\phi W}$	[-0.018, 0.0084]	7.5
$C_{\phi B}$	[-0.0053, 0.0025]	14
$C_{\phi WB}$	[-0.0052, 0.0045]	14
$C_{\phi D}$	[-0.028, 0.0035]	6.0
$C_{\phi \square}$	[-0.12, 1.6]	0.80
$C_{\phi l}^{(1)}$	[-0.0058, 0.011]	9.6
$C_{\phi l}^{(3)}$	[-0.012, 0.0052]	9.1
$C_{\phi e}^{(1)}$	[-0.017, 0.0051]	7.7
$C_{\phi Q}^{(1)}$	[-0.026, 0.044]	4.8
$C_{\phi Q}^{(3)}$	[-0.010, 0.015]	8.1
$C_{\phi u}$	[-0.066, 0.087]	3.4
$C_{\phi d}$	[-0.15, 0.055]	2.5
$C_{e\phi}$	[-0.037, 0.020]	5.2
$C_{u\phi}$	[-2.1, 0.16]	0.69
$C_{d\phi}$	[-0.0006, 0.066]	3.9
C_{LL}	[-0.0093, 0.021]	6.9

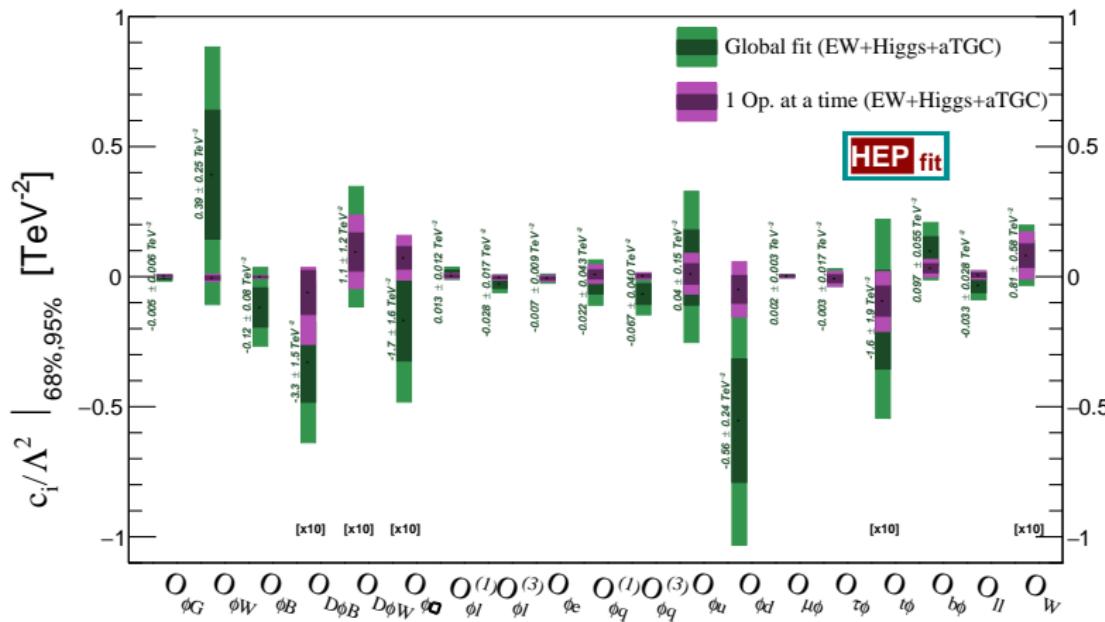
[preliminary]

EWPO and Higgs signal strengths



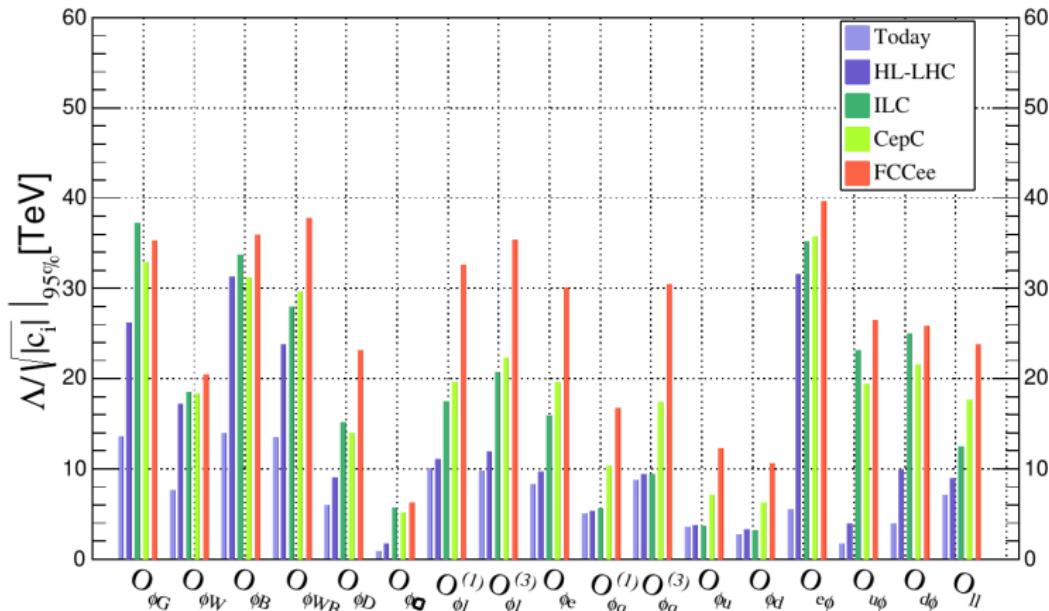
[preliminary]

EWPO and Higgs only – individual vs. global fit



[preliminary]

EWPO and Higgs signal strengths – future



[preliminary]

Summary

- Remarkable experimental progress on EWSB with m_H and μ_i measurements.
- Currently Higgs and EWPO test NP scale up to 14 TeV.
- Much room for improvements at LHC and future facilities.

Back-up

Comparison between HEPfit and Ellis/Murphy/Sanz/You

JHEP 12 (2016) 135 and updates *arXiv:1803.03252*

19 operators

Loop effects in ggF and $h \rightarrow \gamma\gamma$

Future projections

20 operators

Only tree-level couplings to h

Translation to SILH
and concrete models



Naive comparison between HEPfit and EMSY

