Top, Higgs, Diboson and Electroweak Fit to the Standard Model Effective Field Theory

Maeve Madigan University of Cambridge







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LHC data as a probe of new physics

Experimental probes of physics beyond the Standard Model have been taken to a new level by the LHC:

- Top quark production measurements



• ATLAS & LHCb measurements of M_W 1701.07240, 2109.01113 • STXS measurements of Higgs production and decays *e.g. ATLAS 1909.02845* • Triple gauge coupling measurements in diboson WW, WZ production













LHC data as a probe of new physics

Experimental probes of physics beyond the Standard Model have been taken to a new level by the LHC:

- Top quark production measurements

These add to previous precision measurements, including:

- LEP Z-pole measurements, diboson *WW* production
- Tevatron top quark, M_W measurements



• ATLAS & LHCb measurements of M_W 1701.07240, 2109.01113 • STXS measurements of Higgs production and decays *e.g. ATLAS* 1909.02845 • Triple gauge coupling measurements in diboson *WW*, *WZ* production





The Standard Model Effective Field Theory



- Assuming $\Lambda \gg E$
- A powerful theoretical framework for capturing the indirect effect of NP on LHC observables



	X^3		H^6 and H^4D^2		$\psi^2 H^3$					
\mathcal{O}_{G}	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	\mathcal{O}_{H}	$(H^{\dagger}H)^3$	\mathcal{O}_{eH}	$(H^{\dagger}H)(\bar{l}_{f})$					
$\mathcal{O}_{\tilde{G}}$	$f^{ABC} \widetilde{G}^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$	$\mathcal{O}_{H\square}$	$(H^{\dagger}H)\Box(H^{\dagger}H)$	\mathcal{O}_{uH}	$(H^{\dagger}H)(\bar{q}$					
\mathcal{O}_W	$\varepsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$	\mathcal{O}_{HD}	$\left(H^{\dagger}D^{\mu}H ight)^{\star}\left(H^{\dagger}D_{\mu}H ight)$	$\mathcal{O}_{_{dH}}$	$(H^{\dagger}H)(\bar{q}$					
$\mathcal{O}_{\overline{W}}$	$\varepsilon^{IJK} \widetilde{W}^{I\nu}_{\mu} W^{J\rho}_{\nu} W^{K\mu}_{\rho}$									
	$X^{2}H^{2}$		$\psi^2 X H$		$\psi^2 H^2 D$					
\mathcal{O}_{HG}	$H^{\dagger}H G^{A}_{\mu\nu}G^{A\mu\nu}$	${\cal O}_{eW}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) \tau^I H W^I_{\mu\nu}$	$\mathcal{O}_{Hl}^{(1)}$	$(H^{\dagger}i \overset{\leftrightarrow}{D}_{\mu} H)$					
$\mathcal{O}_{H\tilde{G}}$	$H^{\dagger}H \widetilde{G}^{A}_{\mu\nu} G^{A\mu\nu}$	${\cal O}_{eB}$	$(\bar{l}_p \sigma^{\mu\nu} e_r) H B_{\mu\nu}$	$\mathcal{O}_{Hl}^{(3)}$	$(H^{\dagger}i \overleftrightarrow{D}^{I}_{\mu} H)(i$					
\mathcal{O}_{HW}	$H^{\dagger}H W^{I}_{\mu u}W^{I\mu u}$	\mathcal{O}_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r) \widetilde{H} G^A_{\mu\nu}$	\mathcal{O}_{He}	$(H^{\dagger}i\overleftrightarrow{D}_{\mu}H)($					
$\mathcal{O}_{H\widetilde{W}}$	$H^{\dagger}H \widetilde{W}^{I}_{\mu\nu} W^{I\mu\nu}$	\mathcal{O}_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r) \tau^I \widetilde{H} W^I_{\mu\nu}$	$\mathcal{O}_{Hq}^{(1)}$	$(H^{\dagger}i \overleftrightarrow{D}_{\mu} H)($					
\mathcal{O}_{HB}	$H^{\dagger}HB_{\mu u}B^{\mu u}$	${\cal O}_{uB}$	$(\bar{q}_p \sigma^{\mu\nu} u_r) \widetilde{H} B_{\mu\nu}$	$\mathcal{O}_{Hq}^{(3)}$	$(H^{\dagger}i D_{\mu}^{I} H)(\bar{q})$					
$\mathcal{O}_{H\tilde{B}}$	$H^{\dagger}H\widetilde{B}_{\mu u}B^{\mu u}$	\mathcal{O}_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) H G^A_{\mu\nu}$	\mathcal{O}_{Hu}	$(H^{\dagger}i D_{\mu} H)($					
\mathcal{O}_{HWB}	$H^{\dagger} \tau^{I} H W^{I}_{\mu\nu} B^{\mu\nu}$	\mathcal{O}_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r) \tau^I H W^I_{\mu\nu}$	$\mathcal{O}_{_{Hd}}$	$(H^{\dagger}i \overleftrightarrow{D}_{\mu} H)($					
$\mathcal{O}_{H\widetilde{W}B}$	$H^{\dagger}\tau^{I}HW^{I}_{\mu\nu}B^{\mu\nu}$	${\cal O}_{_{dB}}$	$(\bar{q}_p \sigma^{\mu\nu} d_r) H B_{\mu\nu}$	$\mathcal{O}_{_{Hud}}$	$i(\widetilde{H}^{\dagger}D_{\mu}H)($					
	$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$	$(\bar{L}L)(\bar{R}R)$						
\mathcal{O}_{ii}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	\mathcal{O}_{ee}	$(\bar{e}_p \gamma_\mu e_r)(\bar{e}_s \gamma^\mu e_t)$	\mathcal{O}_{le}	$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_p)$					
$\mathcal{O}_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	\mathcal{O}_{uu}	$(\bar{u}_p \gamma_\mu u_r)(\bar{u}_s \gamma^\mu u_t)$	\mathcal{O}_{lu}	$(\bar{l}_p \gamma_\mu l_r)(\bar{u}_p)$					
$\mathcal{O}_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r) (\bar{q}_s \gamma^\mu \tau^I q_t)$	\mathcal{O}_{dd}	$(ar{d}_p \gamma_\mu d_r) (ar{d}_s \gamma^\mu d_t)$	\mathcal{O}_{ld}	$(\bar{l}_p \gamma_\mu l_r)(\bar{d}_p)$					
$\mathcal{O}_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$	\mathcal{O}_{eu}	$(\bar{e}_p \gamma_\mu e_r)(\bar{u}_s \gamma^\mu u_t)$	\mathcal{O}_{qe}	$(\bar{q}_p \gamma_\mu q_r)(\bar{e}$					
$\mathcal{O}_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r) (\bar{q}_s \gamma^\mu \tau^I q_t)$	\mathcal{O}_{ed}	$(\bar{e}_p \gamma_\mu e_r) (\bar{d}_s \gamma^\mu d_t)$	$\mathcal{O}_{qu}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{u}$					
		$\mathcal{O}_{ud}^{(1)}$	$(\bar{u}_p \gamma_\mu u_r) (\bar{d}_s \gamma^\mu d_t)$	$\mathcal{O}_{qu}^{(8)}$	$(\bar{q}_p \gamma_\mu T^A q_r)(\bar{u}$					
		$\mathcal{O}_{ud}^{(8)}$	$\left[(\bar{u}_p \gamma_\mu T^A u_r) (\bar{d}_s \gamma^\mu T^A d_t) \right]$	$\mathcal{O}_{qd}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{d}$					
				$\mathcal{O}_{qd}^{(8)}$	$(\bar{q}_p \gamma_\mu T^A q_r) (\bar{d}$					
$(\bar{L}R)$	$(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-vio	lating						
m	$(\bar{l}^j e)(\bar{d} e^j)$	\mathcal{O}_{dua}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[\left(d_{j}^{\alpha}\right)\right]$	$(x^{\alpha})^T C u_r^{\beta}$	$\left[(q_s^{\gamma j})^T C l_t^k\right]$					
O_{ledq}	$(v_p c_r)(u_s q_t)$		$\mathcal{O}_{aqu} = \varepsilon^{\alpha\beta\gamma}\varepsilon_{ik} \left[(q_n^{\alpha j})^T C q_n^{\beta k} \right] \left[(u_n^{\gamma})^T C q_n^{\beta k} \right]$							
$\mathcal{O}_{ledq} \ \mathcal{O}_{quqd}^{(1)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t)$	\mathcal{O}_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{lpha})\right]$	$^{j})^{T}Cq_{r}^{\beta k}$	$\left[(u_s^{\gamma})^T C e_t \right]$					
$\mathcal{O}_{ledq}^{(1)} \ \mathcal{O}_{quqd}^{(8)} \ \mathcal{O}_{quqd}^{(8)}$	$(\bar{q}_p^j u_r) \varepsilon_{jk} (\bar{q}_s^k d_t) (\bar{q}_p^j T^A u_r) \varepsilon_{jk} (\bar{q}_s^k T^A d_t)$	$\mathcal{O}_{qqu} \\ \mathcal{O}_{qqq}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[\left(q_{p}^{\alpha}\right)\varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km}\right]\left(q_{p}^{\alpha}\right)$	${}^{(j)}_{p}^{T}Cq_{r}^{\beta k}$ ${}^{(\alpha j)}_{p}^{T}Cq_{r}^{\beta l}$	$\begin{bmatrix} (u_s^{\gamma})^T C e_t \\ k \end{bmatrix} \begin{bmatrix} (q_s^{\gamma m})^T C l_t^n \end{bmatrix}$					
$\mathcal{O}_{ledq}^{(1)} = \mathcal{O}_{quqd}^{(1)} = \mathcal{O}_{quqd}^{(8)} = \mathcal{O}_{lequ}^{(1)}$	$(\bar{q}_{p}^{j}u_{r})\varepsilon_{jk}(\bar{q}_{s}^{k}d_{t})$ $(\bar{q}_{p}^{j}T^{A}u_{r})\varepsilon_{jk}(\bar{q}_{s}^{k}T^{A}d_{t})$ $(\bar{l}_{p}^{j}e_{r})\varepsilon_{jk}(\bar{q}_{s}^{k}u_{t})$	\mathcal{O}_{qqu} \mathcal{O}_{qqq} \mathcal{O}_{duu}	$ \begin{array}{c} \varepsilon^{\alpha\beta\gamma}\varepsilon_{jk} \left[(q_p^{\alpha}) \\ \varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km} \right] \\ \varepsilon^{\alpha\beta\gamma} \left[(q_p^{\alpha}) \\ \varepsilon^{\alpha\beta\gamma} \right] \end{array} $	${}^{(j)}_{p}^{T}Cq_{r}^{\beta k}$ ${}^{(\alpha j)}_{p}^{T}Cq_{r}^{\beta l}$ ${}^{T}Cu_{r}^{\beta}$	$ \begin{bmatrix} (u_s^{\gamma})^T Ce_t \\ k \end{bmatrix} \begin{bmatrix} (q_s^{\gamma m})^T Cl_t^n \\ (u_s^{\gamma})^T Ce_t \end{bmatrix} $					







Where do we see an interplay? Is the overlap between data sectors visible in a global fit?

Top-Higgs interplay

Fitmaker J. Ellis, K. Mimasu, MM, V. Sanz, T. You, 2012.02779

The same data is used to constrain SMEFT and PDFs: what is the impact?

PDF-SMEFT interplay

Z. Kassabov, MM, L. Mantani, J. Moore, M. Morales, J. Rojo, M. Ubiali, work in progress



The global approach

Where do we see an interplay? Is the overlap between sectors visible in a global fit?

• Top-Higgs interplay

e.g. Higgs production via ggF is modified by top operators:





Fitmaker code, J. Ellis, K. Mimasu, MM, V. Sanz, T. You, 2012.02779

See also J. Ethier et. al, 2105.00006, SMEFiT + thanks to SMEFiT for sharing top quark predictions!

• 341 statistically independent measurements:

Higgs: 72

- Signal strength combinations (LHC Run I and Run II)
- STXS combination (LHC Run II)
- Measurements of $H \rightarrow Z\gamma \ H \rightarrow \mu\mu$







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Diboson: 118

• LHC and LEP measurements of

WW, WZ, Zjj









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Fitmaker code, J. Ellis, K. Mimasu, MM, V. Sanz, T. You, 2012.02779

See also J. Ethier et. al, 2105.00006, SMEFiT

- Correlation information included from published covariance matrices

= 34 dimension-6 operators

+ thanks to SMEFiT for sharing top quark predictions!

Information on the covariance matrices & likelihood is important for EFT fits, <u>Cranmer</u> et. al, 2109.04981

• Fit using a simple χ^2 methodology, working in the linear EFT approx. $\sigma = \sigma_{SM} + \sum \frac{C_i}{\Lambda^2} \sigma_i + O(\Lambda^{-4})$

• Top-specific flavour symmetry $SU(2)_q imes SU(2)_u imes SU(3)_d imes SU(3)_l imes SU(3)_e$ based on LHC top WG 1802.07237

e.g. \mathcal{O}_{Hu} : symmetric in 1st, 2nd generation









- 34 dimension-6 SMEFT ops constrained at linear-order only
- top-specific flavour symmetry, following the LHC top WG 1802.07237

• **RED**: the full fit







- 34 dimension-6 SMEFT ops constrained at linear-order only
- top-specific flavour symmetry, following the LHC top WG 1802.07237
- ORANGE: by removing the top data we see some shift in the constraints, particularly on

 C_{HG}, C_G, C_{tH}

important for both ggF and $t\overline{t}$

- 34 dimension-6 SMEFT ops constrained at linear-order only
- top-specific flavour symmetry, following the LHC top WG 1802.07237

• PINK: by removing the Higgs+diboson data we see some shift in the constraints, including on

 C_{tH}, C_{tG}

important for both ggF and tt

Top-Higgs interplay

How do the constraints on $C_{HG}, C_{tG}, C_{G}, C_{tH}$ change as we include more top quark data?

We marginalise over

 $C_{H\square}, C_{HW}, C_{HB}, C_{bH}, C_{\tau H}, C_{\mu H}$ (+ 4-fermion operators)

- ttH removes the degeneracy between C_{HG}, C_{tH} .
- top quark data substantially reduces the area constrained at 95 % CL and suppresses some correlations.
- this is true even when marginalising over all 4-fermion operators involving top quarks.

Principal component analysis

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$$\mathcal{O}_{tG} = (\bar{Q}\sigma^{\mu\nu}T^{A}t)\tilde{H}G^{A}_{\mu\nu}$$
$$\mathcal{O}_{G} = f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$$

- Constrained to $\Lambda > 2~{
 m TeV}$
- Constrained almost entirely by tt data + small contributions from the Higgs sector

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$$\mathcal{O}_{Qq}^{3,1} = \sum_{i=1,2} \left([C_{qq}^{(3)}]^{ii33} + \frac{1}{6} [C_{qq}^{(1)}]^{ii33i} - \frac{1}{6} [C_{qq}^{(3)}]^{ii33i} \right)$$
• Constrained to $\Lambda > 2 \text{ TeV}$
• Constrained almost entirely by single top data

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-	32	_	11	
-	95	—	5	
_	53	_	46	
-	92	_	8	
-	96		4	
L' NNN &	HC Zjj	SING	ingle top	

$$\mathcal{O}_{tW} = (\bar{Q}\sigma^{\mu\nu}t)\tau^I \tilde{H} W^I_{\mu\nu}$$

- Constrained to $\Lambda > 1 \ {
 m TeV}$
- Constrained almost entirely by W helicity fractions in $t\overline{t}$ data

100

10

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EWPO

Composition

TOP 2022

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4-fermion operators involving top quarks

- Constrained by $t\overline{t}$ and $t\overline{t}V$
- $\Lambda \gtrsim 100 300 \text{ GeV}$
- ➡ SMEFT validity in question here for C=1, but should be valid for the strong coupling regime

 $C \sim (4\pi)^2$

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L' NNN &	HC Zjj	SIL	ingle top	LT-V-T-V-T-V-T-V-T-V-T-V-T-V-T-V-T-V-T-V

Complementarity of top pair production measurements

Often the data used in PDF fits are also used in EFT fits.

This overlap will grow as we take the global approach to constraining the SMEFT.

TOP 2022

Kinematic coverage

বাবু বাকুবাব রাব বাব বার বাব বা

• Fixed-target DIS

Fixed-target DY

Di-jet production

Collider gauge boson production

Single-inclusive jet production

Black edge: new in NNPDF4.0

Z transverse momentum Top-quark pair production

Direct photon production Single top-quark production

Collider gauge boson production+jet

Collider DIS

 10^{7}

 10^{6}

10⁵

(GeV²) 10⁴

 Q^2

Often the data used in PDF fits are also used in EFT fits.

This overlap will grow as we take the global approach to constraining the SMEFT.

Theoretical inconsistencies:

PDFs are an input to SMEFT fits:

But PDFs are found assuming the SM:

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$\sigma_{\rm SMEFT}(C) = f_1 \otimes f_2 \otimes \hat{\sigma}_{\rm SMEFT}(C)$

 $\sigma = f_1 \otimes f_2 \otimes \hat{\sigma}_{SM}$

'Standard Model PDFs'

Often the data used in PDF fits are also used in EFT fits.

This overlap will grow as we take the global approach to constraining the SMEFT.

e.g. top quark data is excluded from the PDFs SMEFiT

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Kinematic coverage

Deep inelastic scattering, Carrazza et al.: PRL 123 (2019) 13, 132001

High mass Drell-Yan tails, Greljo et. al 2104.02723

Neglecting the PDF-EFT interplay may lead to a significant overestimate of the EFT constraints.

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Work in progress by Zahari Kassabov, MM, Luca Mantani, James Moore, Manuel Morales, Juan Rojo, Maria Ubiali

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SIMUnet methodology S. Iranipour, M. Ubiali - arXiv: 2201.07240

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SIMUnet methodology S. Iranipour, M. Ubiali - arXiv: 2201.07240

Data: 209 datapoints including LHC Run II measurements of $t\overline{t}$ incl. A_C and W_{hel} , $t\bar{t}V$, single top, tW, $t\bar{t}t\bar{t}$, $t\bar{t}bb$

A superset of the measurements included in:

- NNPDF 4.0 2 R. Ball et. al, 2109.02653
- SMEFiT J. Ethier et. al, 2105.00006
- Fitmaker J. Ellis et. al, 2012.02779

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Preliminary:

- Individual fit to the operator \mathcal{O}_{tG}
- LO in QCD
- Linear in dimension-6 operators (final fit will go to NLO in QCD and include quadratic contributions from dimension-6 SMEFT)
- Constraint: $C_{tG} \in [-0.045, 0.24] \text{ TeV}^{-2}$

comparable with the constraints of 2105.00006, 2012.02779

Work in progress by Zahari Kassabov, MM, Luca Mantani, James Moore, Manuel Morales, Juan Rojo, Maria Ubiali

Preliminary:

- Individual fit to the operator \mathcal{O}_{tG}
- LO in QCD
- Linear in dimension-6 operators (final fit will go to NLO in QCD and include quadratic contributions from dimension-6 SMEFT)
- Impact on PDFs:

Work in progress by Zahari Kassabov, MM, Luca Mantani, James Moore, Manuel Morales, Juan Rojo, Maria Ubiali

Conclusions

In a global interpretation of electroweak precision observables, Higgs, diboson, and top data in the dimension-6 SMEFT we see:

- Small but visible interplay between the Higgs and top sector

By neglecting PDF-SMEFT interplay we have the potential to significantly overestimate SMEFT constraints.

- A dedicated simultaneous PDF-EFT fit in the top sector will quantify this to appear soon
- Preliminary fits already indicate an impact on the gluon PDF

• Top quark data constraining some SMEFT operators operators to $\gtrsim 1 \text{ TeV} \longrightarrow \mathcal{O}_{tG}, \mathcal{O}_{tW}$

Conclusions

In a global interpretation of electroweak precision observables, Higgs, diboson, and top data in the dimension-6 SMEFT we see:

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Thank you for listening!

Correlation matrix (%)

- Substantial correlations between EWPO, bosonic and Yukawa observables
- Substantial correlations within the top sector

Interplay between top and Higgs, diboson, EW:

• 22 correlation coefficients with magnitude > 22% between these sectors

															1
CHWB	С _{НD}	C ⁽³⁾ C ⁽³⁾ C ⁽¹⁾ C ⁽¹⁾	C_{Hq}^{He} $C_{Hq}^{(3)}$ $C_{Hq}^{(1)}$ $C_{Hq}^{(1)}$	CHu	CHBox CHG CHW	С _{НВ}	$C_{\mathcal{M}}$	C _{tH}	C_{bH}	$C_{HO}^{(3)}$	C_{tW}	$C^{3,1}_{tB} \\ C^{3,1}_{Qq} \\ C^{3,8}_{Qq} \\ C^{3,8}_{Qq$	$C_{Qq}^{1, 0}$	C_{Qd}^{8}	۵. م

		EWP	0									Boso	onic					Yuka	wa			Тор	2F				Т	op 4	4F						
	C_{td}^8	⊦0.6	-0,6	+0.2	-0.2	+0.6	+0.6	-0,3	-0.3	+0.4	-0.6	-0,5	+32	+0.6	+0.6	0	-32	+0.4	-0	0	+24	-3,0	+2.8	-0.3	-2.4	+0.2	-5.0 -	1.8	+42	+34	-22	-0.9 <mark>-</mark>	+18	-68	+100
	C_{tu}^8	0.4	+0.4		0			+0.2	+0.2	-0.2	+0.3	+0.4	-24			-0	+28		0		-20	+2.3		+3.7			-13 +	-1.3	-93	-91	+35 -	+1.7	-30	+100	-68
	C_{tq}^8	-2.6		+0.6		+2.5	+2.5			+1.7		-1.5	+21	+2.6	+2.6	+0.2	-19	0	+0.1	+0.3	+12	-12	+11	-57	-7.8	+0.8-	+0.2	7.4	+35	+30	-88	-60 +	100	-30	+18
	C_{Qd}^8	1.2	+1.1		+0.7			+0.7	+0.6	-0.9	+1.1	+0.5	+9.6				-8.5	+0.4			+13	+4.2		+25	+11		+48 +	-3.0	-6.3	-4.3	+16+	-100 -	-60	+1.7	
	C_{Qu}^8	-2.5	+2.4		+1.0			+1.3	+1.2	-1.6	+2.1	+1.5	-29				+25				-21	+12	-11	+58	+2.9	-0.9	-28 -	-7.4	-37	-32	+100 -	+16 -	-88	+35	-22
	$C_{Qq}^{1,8}$	⊦0.5			+0.1	+0.5	+0.5			+0.1		-0.4	+16	+0.5	+0.5	0	-22	+0.3		+0.1	+14	-2.3	+2.2	-9.5	+2.6	+0.2	+16	1.3	+93	+100	-32	-4.3 <mark>-</mark>	+30	-91	+34
	$C_{Qq}^{3,8}$	⊦0.2		+0.1		+0.2	+0.2			+0.1		-0.3	+18	+0.2	+0.2	0	-25	+0.4		0	+16	-1.6	+1.5		+2.7	+0.2	+17	0.8	+100	+93	-37	-6.3 <mark>-</mark>	+35	-93	+42
Top 4F	$C_{Qq}^{3,1}$	+1.2			+0.2	+1.2	+1.2	+0.3		+0.5		-0.6		+1.3	+1.2	+0.3-	+5.5	+1.5	+0.4	+2.3	-4.2	+57	-55	-2.8		+1.1	-0.3 +	100	-0.8	-1.3	+7.4 -	-3.0	7.4	+1.3	
	C _{tB}	⊦0.1	-0.1	-0.1	+0.4	+0.1	+0.1	+0.1	0	-0.1	+0.1	-0.2	+11	+0.1	+0.1	0	-15	+0.1	-0	+0.1	+7.7	-1.4	+1.4	-0.1	-2.3	-4.3	-100	0.3	+17	+16	-28	+48 +	-0.2	-13	-5.0
	C_{tW}	+0.1		+0.4			0			+0.3		+0.1	+0.6	+0.1	+0.1		-1.8				+1.5	-6.6	+6.3	+0.8	+2.5	+100	-4.3 +	-1.1	+0.2	+0.2	-0.9	-0.1 +	-0.8		+0.2
	C_{tG}	⊦0.2			+0.2	+0.2	+0.2	+0.1		+0.1		-0.8	+5.3	+0.2	+0.3	+0.1	-51	+2.6			+49	-7.2	+7.0	+18	+100	+2.5	-2.3		+2.7	+2.6	+2.9 -	+11 -			
	C_{Ht}	-17	+17			-17	-17	+5.6	+8.1		+14	+9.7		-17	-17	-1.5	-35			-7.2	+9.4	-7.4	+11	+100	+18	+0.8	-0.1			-9.5	+58 -	+25 -	-57	+3.7	
	$C_{HQ}^{(1)}$	-21	+20		+4.4	-20	-21	+13	+13	+4.6	+21	+11	+3.9	-21	-21		-10			-8.6	+11	-96	+100	+11	+7.0	+6.3 -	+1.4	-55	+1.5	+2.2	-11	-3.8 -	+11		+2.8
Top 2F	$C_{HQ}^{(3)}$	+1.9			+2.6	+2.2	+2.2	+1.0				-1.2	-5.2	+2.0	+1.9	+0.3	+11	+2.8	+0.8	+4.8	-7.8	+100	-96	-7.4	-7.2	-6,6	-1.4 -	+57			+12 -	+4.2	-12 ·	+2.3	
	C _{tH}	-20	+21	-2.3	-5.0	-21	-21	+2.0	+11	-4.6	+14	+44	+67	-22	-19	-2.7	-52	+9.3	-1.2	-7.8	+100	-7.8	+11	+9.4	+49	+1.5 -	+7.7	4.2	+16	+14	-21	+13 +	+12	-20	+24
	C_{bH}	+40	-43	+0.5	+39	+43	+43	+20	-24	+1.2	-21	-41	-21	+41	+38	+10	-0.1	+24	+4.9	+100	-7.8	+4.8	-8.6	-7.2	-0.2		+0.1+	-2.3	0	+0.1		-0.1 +	-0.3		0
	$C_{\mu H}$	+6.6	-6.7	+0.6	+1.7	+6.7	+6.7			+1.3		-2.0	+1.1	+6.6	+6.3	+0.8-	+0.2	+4.0	+100	+4.9		+0.8					-0 -	-0.4				0.1 +	-0.1	0	
Yukawa	$C_{ au H}$	+11	-11	+0.7	+3.0	+11	+11			+1.7	-8.0	+17	-11	+9.8	+11	+1.2	-2.2	+100	+4.0	+24	+9.3	+2.8			+2.6		+0.1+	-1.5	+0.4	+0.3	-0.2	+0.4	0		+0.4
	C _G	-1.4	+1.4	-0.2	-0.1	-1.4	-1.4	+0.4	+0.6	-0.6	+1.0	+1.5	-37	-1.4	-1.5	-0.1	-100	-2.2	+0.2	-0.1	-52	+11	-10	-35	-51	-1.8	-15 +	-5.5	-25	-22	+25	-8.5 -	-19	+28	-32
	C_W	+8.5	-9.6	+3.9	+13	+9.4	+9.6	+14	-5.4	+2.0	-7.4	-8.0	-1,1	+8.4	+8.5	+100	-0.1	+1.2	+0.8	+10	-2.7	+0.3		-1.5	+0.1		0 +	-0.3	0	0		-0.1 +	-0.2	-0	0
	C_{HB}	+98	-98	+14	+3.1	+98	+98	-31	-43	+26	-77	-54	+2.3	+93	+100	+8.5	-1.5	+11	+6.3	+38	-19	+1.9	-21	-17	+0.3	+0.1-	+0.1+	-1.2	+0.2	+0.5		-1.2 +	-2.6		+0.6
	C_{HW}	+98	-98	+14	+3.0	+97	+98	-31	-43	+26	-77	-61	+2.0	+100	93	+8.4	-1.4	+9.8	+6.6	+41	-22	+2.0	-21	-17	+0.2	+0.1-	+0.1+	-1.3	+0.2	+0.5		-1.2 +	-2.6		+0.6
	C_{HG}	+2.2	-1.5	+1.3	-7.0	+1.4	+1.5	-7.1	+0.8	+2.3	-3.7	-1.4	+100	+2.0	+2.3		-37	-11	+1.1	-21	+67	-5,2	+3.9		+5.3	+0.6	+11		+18	+16	-29	+9.6 +	+21	-24	+32
Bosonic	C _{HBox}	-58	+59	-6.8	-16	-59	-59	+3.7	+32	-13	+40	+100	-1.4	-61	-54	-8.0	+1.5	+17		-41	+44	-1.2	+11	+9.7		+0.1	-0.2 -				+1.5 +	+0.5		+0.4	
	C _{Hu}	-78	+76	-22	+20	-75	-76	+19	+32	-6.1	+100	+40	-3.7	-77	-77	-7.4	+1.0	-8.0	-4.8	-21	+14	-0.8	+21	+14	-0.1	-0.2	+0.1	1.0	-0.2	-0.3	+2.1+	+1.1	2.2	+0.3	-0.6
	C_{Hd}	+27	-24	+9.8	-34	+22	+23	-5.5	+6.5	+100	-6.1	-13	+2.3	+26	+26	+2.0	-0.6	+1.7	+1.3	+1.2		-0.6	+4.6		+0.1	+0.3	-0.1 -	-0.5	+0.1	+0.1		-0.9 +	-1.7		+0.4
	$C_{Hq}^{(1)}$	-43	+42	-11	+6.7	-42	-42	+14	+100)+6.5	+32	+32	+0.8	-43	-43		+0.6			-24	+11	-0.5	+13	+8.1			0				+1.2 +	+0.6		+0.2	
	$C_{Hq}^{(3)}$	-32	+26	-5.1	+57	-26	-26	+100)+14	-5.5	+19	+3.7	-7.1	-31	-31	+14 -	+0.4			+20	+2.0	+1.0	+13	+5.6	+0.1		+0.1+	-0.3			+1.3+	+0.7		+0.2	
	C _{He}	+100	-100	+13	+12	+100	+100	-26	-42	+23	-76	-59	+1.5	+98	+98	+9.6	-1.4	+11	+6.7	+43	-21	+2.2	-21	-17	+0.2	0 -	+0.1+	-1.2	+0.2	+0.5		1.1 +	-2.5		+0.6
	$C_{HI}^{(1)}$	+99	-100	+7.4	+11	+100	+100	-26	-42	+22	-75	-59	+1.4	+97	+98	+9.4	-1.4	+11	+6.7	+43	-21	+2.2	-20	-17	+0.2		+0.1+	-1.2	+0.2	+0.5		-1.1 +	-2.5		+0.6
	$C_{HI}^{(3)}$	+2.7	-12	+12	+100	+11	+12	+57	+6.7	-34	+20	-16	-7.0	+3.0	+3.1	+13	-0.1	+3.0	+1.7	+39	-5.0	+2.6	+4.4		+0.2		+0.4 +	-0.2		+0.1	+1.0+	+0.7		0	
	C_{II}	+15	-13	+100	+12	+7.4	+13	-5.1	-11	+9.8	-22	-6.8	+1.3	+14	+14	+3.9	-0.2	+0.7	+0.6	+0.5		-0.9				+0.4	-0.1		+0.1			-0.3 +	-0.6		+0.2
	C_{HD}	-100	+100	-13	-12	-100	-100	+26	+42	-24	+76	+59		-98	-98	-9.6	+1.4	-11		-43	+21	-2.2	+20	+17			0.1				+2.4 -	+1.1 -		+0.4	
EWPO	C_{HWB}	+100	-100	+15	+2.7	+99	+100	-32	-43	+27	-78	-58	+2.2	+98	+98	+8.5	-1.4	+11	+6.6	+40	-20	+1.9	-21	-17	+0.2	+0.1-	+0.1+	-1.2	+0.2	+0.5		1.2 +	-2.6		+0.6
		IWB	CHD	C"	Ĕ)(3)	(1) (1)	С.Не	, (3) , Hq	,Hq	рнг	ς Hu	Box	,HG	, HW	CHB	Cw	Co	C _{TH}	HH	Сын	CtH	(B) HQ	(1) (H)	CHt	CtG	5 tW	C _{tB}	- 60 0d	ю, 8 Од 8	,1,8 Qq	,0u		Ctd	$C_{t\bar{t}}^{8}$	C_{td}^8

Quadratic contributions from dimension-6 SMEFT

The top sector is sensitive to the inclusion of $O(\Lambda^{-4})$ contributions from dimension-6 operators.

SMEFT at NLO in QCD in the top sector

Constraints in the top sector show improvement when SMEFT calculations are performed at NLO vs LO in QCD:

Maeve Madigan | Top, Higgs, Diboson and Electroweak Fit to the SMEFT

J. Ethier et. al, 2105.00006, SMEFiT

TOP 2022

