Towards a global EFT fit (for top quark sector)

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Based on 1901.05965 with N. P. Hartland, F. Maltoni, E. R. Nocera, J. Rojo, E. Slade, E. Vryonidou

Outline

Outline

SMEFT for the top

Global fit for LHC

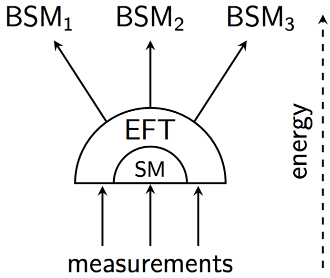
Summary

Standard Model Effective Field Theory

systematically parametrizes the theory space
in direct vicinity of the SM

- based on SM fields and symmetries
- in a low-energy limit
- systematic (and renormalizable) when global

(...) if one writes down the most general possible Lagrangian, including all terms consistent with assumed symmetry principles, (...) the result will simply be the most general possible S-matrix consistent with analyticity, perturbative unitarity, cluster decomposition and the assumed symmetry. [*Phenomenological Lagrangians*, Weinberg '79]



Charged current

$$O_{\varphi Q}^{(3)} = i\frac{1}{2}y_t^2\left(\varphi^\dagger \overleftrightarrow{D}^I_\mu \varphi\right)(\bar{Q}\gamma^\mu\tau^I Q)$$

$$O_{tW} = y_t g_w(\bar{Q}\sigma^{\mu\nu}\tau^I t)\tilde{\varphi}W^I_{\mu\nu}$$

$$O_{\varphi\varphi} = i y_t^2\left(\varphi^\dagger D_\mu \tilde{\varphi}\right)(\bar{b}\gamma^\mu t)$$

$$O_{bW} = y_t g_w(\bar{Q}\sigma^{\mu\nu}\tau^I b)\varphi W^I_{\mu\nu}$$

Strong

$$O_{tG} = y_t g_s(\bar{Q}\sigma^{\mu\nu}T^A t)\tilde{\varphi}G^A_{\mu\nu}$$

$$O_G = g_s f^{ABC}G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$$

Neutral current

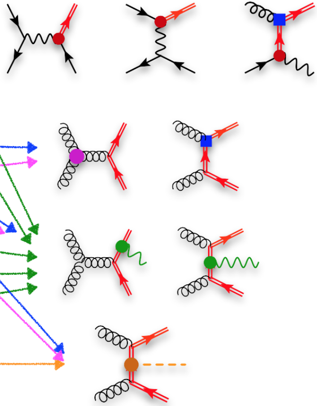
$$O_{\varphi Q}^{(1)} = i\frac{1}{2}y_t^2\left(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi\right)(\bar{Q}\gamma^\mu Q)$$

$$O_{\varphi t} = i\frac{1}{2}y_t^2\left(\varphi^\dagger \overleftrightarrow{D}_\mu \varphi\right)(\bar{t}\gamma^\mu t)$$

$$O_{tB} = y_t g_Y(\bar{Q}\sigma^{\mu\nu}t)\tilde{\varphi}B_{\mu\nu}$$

Yukawa

$$O_{t\phi} = y_t^3\left(\phi^\dagger\phi - v^2/2\right)\left(\bar{Q}t\right)\tilde{\phi}$$



	WWWW	WWZZ	ZZZZ	WWAZ	WWAA	ZZZA	ZZAA	ZAAA	AAAA
$\mathcal{O}_{S,0}$, $\mathcal{O}_{S,1}$	X	X	X						
$\mathcal{O}_{M,0}$, $\mathcal{O}_{M,1}$,$\mathcal{O}_{M,6}$,$\mathcal{O}_{M,7}$	X	X	X	X	X	X	X		
$\mathcal{O}_{M,2}$,$\mathcal{O}_{M,3}$, $\mathcal{O}_{M,4}$,$\mathcal{O}_{M,5}$		X	X	X	X	X	X		
$\mathcal{O}_{T,0}$,$\mathcal{O}_{T,1}$,$\mathcal{O}_{T,2}$	X	X	X	X	X	X	X	X	X
$\mathcal{O}_{T,5}$,$\mathcal{O}_{T,6}$,$\mathcal{O}_{T,7}$		X	X	X	X	X	X	X	X
$\mathcal{O}_{T,8}$,$\mathcal{O}_{T,9}$			X			X	X	X	X

TABLE II: Quartic vertices modified by each dimension-8 operator are marked with X.

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	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar l_p e_r \varphi)$
$Q_{\widetilde G}$	$f^{ABC}\widetilde G_\mu^{A\nu}G_\nu^{B\rho}G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p u_r \widetilde\varphi)$
Q_W	$\varepsilon^{IJK}W_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star\left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p d_r \varphi)$
$Q_{\widetilde W}$	$\varepsilon^{IJK}\widetilde W_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$				

$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar l_p\sigma^{\mu\nu}e_r)\tau^I\varphi W^I_{\mu\nu}$	$Q^{(1)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar l_p\gamma^\mu l_r)$
$Q_{\varphi\widetilde G}$	$\varphi^\dagger\varphi\,\widetilde G^A_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar l_p\sigma^{\mu\nu}e_r)\varphi B_{\mu\nu}$	$Q^{(3)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar l_p\tau^I\gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar q_p\sigma^{\mu\nu}T^A u_r)\widetilde\varphi\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar e_p\gamma^\mu e_r)$
$Q_{\varphi\widetilde W}$	$\varphi^\dagger\varphi\,\widetilde W^I_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar q_p\sigma^{\mu\nu}u_r)\tau^I\widetilde\varphi\, W^I_{\mu\nu}$	$Q^{(1)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar q_p\gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar q_p\sigma^{\mu\nu}u_r)\widetilde\varphi\, B_{\mu\nu}$	$Q^{(3)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar q_p\tau^I\gamma^\mu q_r)$
$Q_{\varphi\widetilde B}$	$\varphi^\dagger\varphi\,\widetilde B_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar q_p\sigma^{\mu\nu}T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar u_p\gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar q_p\sigma^{\mu\nu}d_r)\tau^I\varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar d_p\gamma^\mu d_r)$
$Q_{\varphi\widetilde WB}$	$\varphi^\dagger\tau^I\varphi\,\widetilde W^I_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar q_p\sigma^{\mu\nu}d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde\varphi^\dagger D_\mu\varphi)(\bar u_p\gamma^\mu d_r)$

$(\bar LL)(\bar LL)$		$(\bar RR)(\bar RR)$		$(\bar LL)(\bar RR)$	
Q_{ll}	$(\bar l_p\gamma_\mu l_r)(\bar l_s\gamma^\mu l_t)$	Q_{ee}	$(\bar e_p\gamma_\mu e_r)(\bar e_s\gamma^\mu e_t)$	Q_{le}	$(\bar l_p\gamma_\mu l_r)(\bar e_s\gamma^\mu e_t)$
$Q^{(1)}_{qq}$	$(\bar q_p\gamma_\mu q_r)(\bar q_s\gamma^\mu q_t)$	Q_{uu}	$(\bar u_p\gamma_\mu u_r)(\bar u_s\gamma^\mu u_t)$	Q_{lu}	$(\bar l_p\gamma_\mu l_r)(\bar u_s\gamma^\mu u_t)$
$Q^{(3)}_{qq}$	$(\bar q_p\gamma_\mu\tau^I q_r)(\bar q_s\gamma^\mu\tau^I q_t)$	Q_{dd}	$(\bar d_p\gamma_\mu d_r)(\bar d_s\gamma^\mu d_t)$	Q_{ld}	$(\bar l_p\gamma_\mu l_r)(\bar d_s\gamma^\mu d_t)$
$Q^{(1)}_{lq}$	$(\bar l_p\gamma_\mu l_r)(\bar q_s\gamma^\mu q_t)$	Q_{eu}	$(\bar e_p\gamma_\mu e_r)(\bar u_s\gamma^\mu u_t)$	Q_{qe}	$(\bar q_p\gamma_\mu q_r)(\bar e_s\gamma^\mu e_t)$
$Q^{(3)}_{lq}$	$(\bar l_p\gamma_\mu\tau^I l_r)(\bar q_s\gamma^\mu\tau^I q_t)$	Q_{ed}	$(\bar e_p\gamma_\mu e_r)(\bar d_s\gamma^\mu d_t)$	$Q^{(1)}_{qu}$	$(\bar q_p\gamma_\mu q_r)(\bar u_s\gamma^\mu u_t)$
		$Q^{(1)}_{ud}$	$(\bar u_p\gamma_\mu u_r)(\bar d_s\gamma^\mu d_t)$	$Q^{(8)}_{qu}$	$(\bar q_p\gamma_\mu T^A q_r)(\bar u_s\gamma^\mu T^A u_t)$
		$Q^{(8)}_{ud}$	$(\bar u_p\gamma_\mu T^A u_r)(\bar d_s\gamma^\mu T^A d_t)$	$Q^{(1)}_{qd}$	$(\bar q_p\gamma_\mu q_r)(\bar d_s\gamma^\mu d_t)$
				$Q^{(8)}_{qd}$	$(\bar q_p\gamma_\mu T^A q_r)(\bar d_s\gamma^\mu T^A d_t)$

$(\bar LR)(\bar RL)$ and $(\bar LR)(\bar LR)$		B-violating	
Q_{ledq}	$(\bar l_p^j e_r)(\bar d_s q_t^j)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(q_s^{\gamma j})^T C l_t^k\right]$
$Q^{(1)}_{quqd}$	$(\bar q_p^j u_r)\varepsilon_{jk}(\bar q_s^k d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q^{(8)}_{quqd}$	$(\bar q_p^j T^A u_r)\varepsilon_{jk}(\bar q_s^k T^A d_t)$	$Q^{(1)}_{qqq}$	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\varepsilon_{mn}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q^{(1)}_{lequ}$	$(\bar l_p^j e_r)\varepsilon_{jk}(\bar q_s^k u_t)$	$Q^{(3)}_{qqq}$	$\varepsilon^{\alpha\beta\gamma}(\tau^I\varepsilon)_{jk}(\tau^I\varepsilon)_{mn}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q^{(3)}_{lequ}$	$(\bar l_p^j\sigma_{\mu\nu}e_r)\varepsilon_{jk}(\bar q_s^k\sigma^{\mu\nu}u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$

Higgs and EW

[Ellis, Murphy, Sanz and You, '18]

[Biekotter, Corbett and Plehn, '18]

[J. de Blas et al., '17]

[A. Butter et al., '16]

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Top

[A. Buckley et al.(TopFitter), '16]

[S. Brown et al.(TopFitter), '18]

[Cirigliano, Dekens, de Vries, Mereghetti, '16]

[Alioli, Cirigliano, Dekens, de Vries, Mereghetti, '17]

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Flavor

[Falkowski, Gonzalez-Alonso, Miouni, '17]

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Future colliders

[Ellis, Roloff, Sanz, You, '17]

[Durieux, Grojean, Gu, Wang, '17]

[Chiu, Leung, Liu, Lyu, Wang, '17]

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LHC Top WG EFT recommendation

[J. Aguilar Saavedra et al.,'18]

Interpreting top-quark LHC measurements in the standard-model effective field theory

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Abstract

This note proposes common standards and prescriptions for the effective-field-theory interpretation of top-quark measurements at the LHC.

Contents

Interpreting top LHC measurements

- Reduce the number of OPs to start with (avoid 500+ 4-fermion OPs):

Baseline	$U(2)_q \times U(2)_u \times U(2)_d$: Forces the first two generation to appear as $\bar{q}q$, $\bar{u}u$, $\bar{d}d$.
Extended	$U(2)_{q+d+u}$: Allows right-handed $\bar{u}d$ and light chirality flipping ones $\bar{q}u$, $\bar{q}d$.
Restricted	Top-philic: All operators with SM bosons and (just) top. (and reduced to Warsaw basis)

Interpreting top LHC measurements

- Reduce the number of OPs to start with (avoid 500+ 4-fermion OPs):

  Baseline $U(2)_q \times U(2)_u \times U(2)_d$:
  Forces the first two generation to appear as $\bar{q}q$, $\bar{u}u$, $\bar{d}d$.

  Extended $U(2)_{q+d+u}$:
  Allows right-handed $\bar{u}d$ and light chirality flipping ones $\bar{q}u$, $\bar{q}d$.

  Restricted Top-philic:
  All operators with SM bosons and (just) top. (and reduced to Warsaw basis)

- Define the relevant degrees of freedom natural for top physics, and fix notations.

Top-specific d.o.f. definitions

Match SM interference structures
and interactions with physical gauge bosons

- $$\begin{pmatrix} O^{1(33)}_{\varphi q} \\ O^{3(33)}_{\varphi q} \end{pmatrix} = \begin{pmatrix} (\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar q_3 \gamma^\mu q_3) \\ (\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar q_3 \gamma^\mu \tau^I q_3) \end{pmatrix} = \begin{pmatrix} -1 & 1 \\ 1 & 1 \\ 0 & 1 \\ 0 & 1 \end{pmatrix}^T \begin{pmatrix} \frac{+e}{2 s_W c_W} & (\bar t \gamma^\mu P_L t) & Z_\mu & (v+h)^2 \\ \frac{-e}{2 s_W c_W} & (\bar b \gamma^\mu P_L b) & Z_\mu & (v+h)^2 \\ \frac{g}{\sqrt{2}} & (\bar t \gamma^\mu P_L b) & W^+_\mu & (v+h)^2 \\ \frac{g}{\sqrt{2}} & (\bar b \gamma^\mu P_L t) & W^-_\mu & (v+h)^2 \end{pmatrix}$$

  $c^-_{\varphi Q} \equiv C^{1(33)}_{\varphi q} - C^{3(33)}_{\varphi q}$ enters in $pp \to t\bar t Z$
  $c^3_{\varphi Q} \equiv C^{3(33)}_{\varphi q}$ enters in $t \to bW^+$
  $c^+_{\varphi Q} \equiv C^{1(33)}_{\varphi q} + C^{3(33)}_{\varphi q}$ enters in $e^+e^- \to b\bar b$ (or $pp \to b\bar b Z$)

- $$\begin{pmatrix} O^{1(ii33)}_{qq} \\ O^{1(i33i)}_{qq} \\ O^{3(ii33)}_{qq} \\ O^{3(i33i)}_{qq} \end{pmatrix} = \begin{pmatrix} 1 & 1/6 & 0 & 1/2 \\ 0 & 1/6 & 1 & -1/6 \\ 0 & 1 & 0 & 3 \\ 0 & 1 & 0 & -1 \end{pmatrix}^T \begin{pmatrix} (\bar q_i \gamma^\mu q_i)\,(\bar Q \gamma_\mu Q) \\ (\bar q_i \gamma^\mu \tau^I q_i)\,(\bar Q \gamma_\mu \tau^I Q) \\ (\bar q_i \gamma^\mu T^A q_i)\,(\bar Q \gamma_\mu T^A Q) \\ (\bar q_i \gamma^\mu \tau^I T^A q_i)\,(\bar Q \gamma_\mu \tau^I T^A Q) \end{pmatrix}$$

  $c^{1,1}_{Qq} \equiv C^{1(ii33)}_{qq} + \frac{1}{6} C^{1(i33i)}_{qq} + \frac{1}{2} C^{3(i33i)}_{qq}$ interferes with EW NC
  $c^{3,1}_{Qq} \equiv C^{3(ii33)}_{qq} + \frac{1}{6}(C^{1(i33i)}_{qq} - C^{3(i33i)}_{qq})$ interferes with EW CC
  $c^{1,8}_{Qq} \equiv C^{1(i33i)}_{qq} + 3 C^{3(i33i)}_{qq}$, interferes with QCD
  $c^{3,8}_{Qq} \equiv C^{1(i33i)}_{qq} - C^{3(i33i)}_{qq}$ doesn't interfere with EW CC

Interpreting top LHC measurements

- Reduce the number of OPs to start with (avoid 500+ 4-fermion OPs):

Baseline	$U(2)_q \times U(2)_u \times U(2)_d$: Forces the first two generation to appear as $\bar{q}q$, $\bar{u}u$, $\bar{d}d$.
Extended	$U(2)_{q+d+u}$: Allows right-handed $\bar{u}d$ and light chirality flipping ones $\bar{q}u$, $\bar{q}d$.
Restricted	Top-philic: All operators with SM bosons and (just) top. (and reduced to Warsaw basis)

- Define the relevant degrees of freedom natural for top physics, and fix notations.

- Provide simulation tools and benchmarks: DIM6TOP

  https://feynrules.irmp.ucl.ac.be/wiki/dim6top

- Strategy, EFT validity, indicative constraints,. . .

Outline

SMEFT for the top

Global fit for LHC

Summary

The **SMEFiT** framework

- In collaboration with Nathan P. Hartland, Fabio Maltoni, Emanuele R. Nocera, Juan Rojo, Emma Slade, Eleni Vryonidou.
- Theory framework consistent with the LHC Top WG EFT recommendation.

  [J. Aguilar Saavedra et al.,'18]
- Fitting approach based on NNPDF.
- TH predictions for EFT generated at NLO with MADGRAPH5_AMC@NLO.

Notation	Sensitivity at $\mathcal{O}(\Lambda^{-2})$ ($\mathcal{O}(\Lambda^{-4})$)								
	$t\bar{t}$	single-top	tW	tZ	$t\bar{t}W$	$t\bar{t}Z$	$t\bar{t}H$	$t\bar{t}t\bar{t}$	$t\bar{t}b\bar{b}$
OQQ1								✓	✓
OQQ8								✓	✓
OQt1								✓	✓
OQt8								✓	✓
OQb1									✓
OQb8									✓
Ott1								✓	
Otb1									✓
Otb8									✓
OQtQb1									(✓)
OQtQb8									(✓)
O81qq	✓				✓	✓	✓	✓	✓
O11qq	[✓]				[✓]	[✓]	[✓]	✓	✓
O83qq	✓	[✓]		[✓]	✓	✓	✓	✓	✓
O13qq	[✓]	✓		✓	[✓]	[✓]	[✓]	✓	✓
O8qt	✓				✓	✓	✓	✓	✓
O1qt	[✓]				[✓]	[✓]	[✓]	✓	✓
O8ut	✓					✓	✓	✓	✓
O1ut	[✓]					[✓]	[✓]	✓	✓
O8qu	✓					✓	✓	✓	✓
O1qu	[✓]					[✓]	[✓]	✓	✓
O8dt	✓					✓	✓	✓	✓
O1dt	[✓]					[✓]	[✓]	✓	✓
O8qd	✓					✓	✓	✓	✓
O1qd	[✓]					[✓]	[✓]	✓	✓
OtG	✓		✓		✓	✓	✓	✓	✓
OtW		✓	✓	✓					
ObW		(✓)	(✓)	(✓)					
OtZ				✓		✓			
Off		(✓)	(✓)	(✓)					
Ofq3		✓	✓	✓					
OpQM				✓		✓			
Opt				✓		✓			
Otp							✓		

The **SMEFiT** framework

Theory

(N)NLO QCD+ NLO EW for SM
NLO QCD for SMEFT
State-of-the-art PDFs without top data

Data

Top pair production and single top (differential)
Associated production with W,Z,H
W helicity fractions, asymmetries
Parton-level

Global SMEFT fit of the top-quark sector

Methodology

Based on NNPDF
Faithful uncertainty estimate
Avoid under- and over-fitting
Validated on pseudo-data (closure test)

Output

Fit results can be used to bound specific UV complete models
New data can be straightforwardly added
Plan to extend to Higgs, gauge sector etc

from talk by E. Vryonidou

Theory

- SM and EFT predictions

Process	SM	Code	SMEFT	Code
$t\bar{t}$	NNLO QCD	MCFM/SHERPA NLO + NNLO K-factors	NLO QCD	MG5_aMC
single-t (t-ch)	NNLO QCD	MCFM NLO + NNLO K-factors	NLO QCD	MG5_aMC
single-t (s-ch)	NLO QCD	MCFM	NLO QCD	MG5_aMC
tW	NLO QCD	MG5_aMC	NLO QCD	MG5_aMC
tZ	NLO QCD	MG5_aMC	LO QCD + NLO SM K-factors	MG5_aMC
$t\bar{t}W(Z)$	NLO QCD	MG5_aMC	LO QCD + NLO SM K-factors	MG5_aMC
$t\bar{t}h$	NLO QCD	MG5_aMC	LO QCD + NLO SM K-factors	MG5_aMC
$t\bar{t}t\bar{t}$	NLO QCD	MG5_aMC	LO QCD + NLO SM K-factors	MG5_aMC
$t\bar{t}b\bar{b}$	NLO QCD	MG5_aMC	LO QCD + NLO SM K-factors	MG5_aMC

Table 3.4. Summary of the theoretical calculations used for the description of the LHC top production cross-sections included in the present analysis. We indicate, for both the SM and the SMEFT contributions to the cross-sections, the perturbative accuracy and the codes used to produce the corresponding predictions.

- NNPDF3.1 PDF set without any top data to avoid double counting.

Theory

SMEFT predictions based on previous works

Processes	Operators	Refs
FCNC production	$tqX,\ X=g,\gamma,Z,h$	[Degrande,Maltoni,Wang,CZ,'14]
$t\bar{t}$	chromo-dipole	[D.B.Franzosi,CZ,'15]
single t (s-&t-channel+tW)	tbW couplings	[CZ,'16]
ttZ,$tt\gamma$,($gg\to HZ$)	$ttX, X=Z,\gamma,g$	[O.B.Bylund et al,'16]
ttH	chromo, ggH, top Yukawa	[Vryonidou,Maltoni,CZ,'16]
$e^+e^-\to t\bar{t}$	ttX, 4-fermion	[G. Durieux,'17]
(Higgs production)	EW/Higgs	[C. Degrande et al.,'16]
tHj, tZj, ($t\gamma j$)	all above plus EW and Higgs plus 4-fermion	[C.Degrande et al.,'18]

Automated in MG5_aMC
Still missing $tttt$ and $ttbb$, $\Rightarrow$ use SM K factors.

Data

Process	Dataset	$\sqrt{s}$	Info	Observables	$N_{\rm dat}$
$t\bar{t}$	ATLAS_tt_8TeV_ljets	8 TeV	lepton+jets	$d\sigma/d\lvert y_t\rvert$, $d\sigma/dp_t^T$, $d\sigma/dm_{t\bar{t}}$, $d\sigma/d\lvert y_{t\bar{t}}\rvert$	5, 8, 7, 5
$t\bar{t}$	CMS_tt_8TeV_ljets	8 TeV	lepton+jets	$d\sigma/dy_t$, $d\sigma/dp_t^T$, $d\sigma/dm_{t\bar{t}}$, $d\sigma/dy_{t\bar{t}}$	10, 8, 7, 10
$t\bar{t}$	CMS_tt2D_8TeV_dilep	8 TeV	dileptons	$d^2\sigma/dy_t dp_t^T$, $d^2\sigma/dy_t dm_{t\bar{t}}$, $d^2\sigma/dp_{t\bar{t}}^T dm_{t\bar{t}}$, $d^2\sigma/dy_{t\bar{t}} dm_{t\bar{t}}$	16, 16, 16, 16
$t\bar{t}$	CMS_tt_13TeV_ljets	13 TeV	lepton+jets	$d\sigma/d\lvert y_t\rvert$, $d\sigma/dp_t^T$, $d\sigma/dm_{t\bar{t}}$, $d\sigma/d\lvert y_{t\bar{t}}\rvert$	7, 9, 8, 6
$t\bar{t}$	CMS_tt_13TeV_ljets2	13 TeV	lepton+jets	$d\sigma/d\lvert y_t\rvert$, $d\sigma/dp_t^T$, $d\sigma/dm_{t\bar{t}}$, $d\sigma/d\lvert y_{t\bar{t}}\rvert$	11, 12, 10, 10
$t\bar{t}$	CMS_tt_13TeV_dilep	13 TeV	dileptons	$d\sigma/dy_t$, $d\sigma/dp_t^T$, $d\sigma/dm_{t\bar{t}}$, $d\sigma/dy_{t\bar{t}}$	8, 6, 6, 8
$t\bar{t}$	ATLAS_WhelF_8TeV	8 TeV	W helicity fract	F_0, F_L, F_R	3
$t\bar{t}$	CMS_WhelF_8TeV	8 TeV	W helicity fract	F_0, F_L, F_R	3

Process	Dataset	$\sqrt{s}$	Info	Observables	$N_{\rm dat}$
$t\bar{t}b\bar{b}$	CMS_ttbb_13TeV	13 TeV	total xsec	$\sigma_{\rm tot}(t\bar{t}b\bar{b})$	1
$t\bar{t}t\bar{t}$	CMS_tttt_13TeV	13 TeV	total xsec	$\sigma_{\rm tot}(t\bar{t}t\bar{t})$	1
$t\bar{t}Z$	CMS_ttZ_8_13TeV	8+13 TeV	total xsec	$\sigma_{\rm tot}(t\bar{t}Z)$	2
$t\bar{t}Z$	ATLAS_ttZ_8_13TeV	8+13 TeV	total xsec	$\sigma_{\rm tot}(t\bar{t}Z)$	2
$t\bar{t}W$	CMS_ttW_8_13TeV	8+13 TeV	total xsec	$\sigma_{\rm tot}(t\bar{t}W)$	2
$t\bar{t}W$	ATLAS_ttW_8_13TeV	8+13 TeV	total xsec	$\sigma_{\rm tot}(t\bar{t}W)$	2
$t\bar{t}H$	CMS_tth_13TeV	13 TeV	signal strength	$\mu_{t\bar{t}H}$	1
$t\bar{t}H$	ATLAS_tth_13TeV	13 TeV	total xsec	$\sigma_{\rm tot}(t\bar{t}H)$	1

Process	Dataset	$\sqrt{s}$	Info	Observables	$N_{\rm dat}$
Single t	CMS_t_tch_8TeV_inc	8 TeV	t-channel	$\sigma_{\rm tot}(t), \sigma_{\rm tot}(\bar{t})$ (R_t)	2 (1)
Single t	CMS_t_sch_8TeV	8 TeV	s-channel	$\sigma_{\rm tot}(t+\bar{t})$	1
Single t	ATLAS_t_sch_8TeV	8 TeV	s-channel	$\sigma_{\rm tot}(t+\bar{t})$	1
Single t	ATLAS_t_tch_8TeV	8 TeV	t-channel	$d\sigma(tq)/dp_T^t, d\sigma(\bar{t}q)/dp_T^{\bar{t}}$, $d\sigma(tq)/dy_t, d\sigma(\bar{t}q)/dy_t$	5, 4, 4, 4
Single t	ATLAS_t_tch_13TeV	13 TeV	t-channel	$\sigma_{\rm tot}(t), \sigma_{\rm tot}(\bar{t})$ (R_t)	2 (1)
Single t	CMS_t_tch_13TeV_inc	13 TeV	t-channel	$\sigma_{\rm tot}(t+\bar{t})$ (R_t)	1 (1)
Single t	CMS_t_tch_8TeV_dif	8 TeV	t-channel	$d\sigma/dp_T^{(t+\bar{t})}$, $d\sigma/d\lvert y^{(t+\bar{t})}\rvert$	6, 6
Single t	CMS_t_tch_13TeV_dif	13 TeV	t-channel	$d\sigma/dp_T^{(t+\bar{t})}$, $d\sigma/d\lvert y^{(t+\bar{t})}\rvert$	4, 4
tW	ATLAS_tW_inc_8TeV	8 TeV	inclusive	$\sigma_{\rm tot}(tW)$	1
tW	CMS_tW_inc_8TeV	8 TeV	inclusive	$\sigma_{\rm tot}(tW)$	1
tW	ATLAS_tW_inc_13TeV	13 TeV	inclusive	$\sigma_{\rm tot}(tW)$	1
tW	CMS_tW_inc_13TeV	13 TeV	inclusive	$\sigma_{\rm tot}(tW)$	1
tZ	CMS_tZ_inc_13TeV	13 TeV	inclusive	$\sigma_{\rm fid}(Wbl^+l^-q)$	1
tZ	ATLAS_tZ_inc_13TeV	13 TeV	inclusive	$\sigma_{\rm tot}(tZq)$	1

Methodology

- The MC replica method:
  - Construct a sampling of the probability distribution in the space of the experimental data.
  - Translate them into a sampling of the probability distribution in the space of the SMEFT parameters, by minimisation of the error function

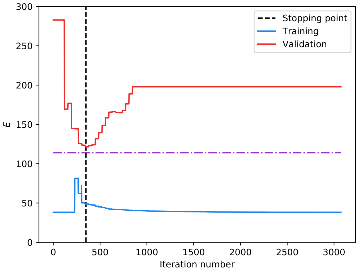
$$E(\{c_l^{(k)}\}) \equiv \frac{1}{N_{\rm dat}} \sum_{i,j=1}^{N_{\rm dat}} \left(\mathcal{O}_i^{(\rm th)}\left(\{c_l^{(k)}\}\right) - \mathcal{O}_i^{(\rm art)(k)}\right)(\mathrm{cov}^{-1})_{ij}\left(\mathcal{O}_j^{(\rm th)}\left(\{c_l^{(k)}\}\right) - \mathcal{O}_j^{(\rm art)(k)}\right)$$

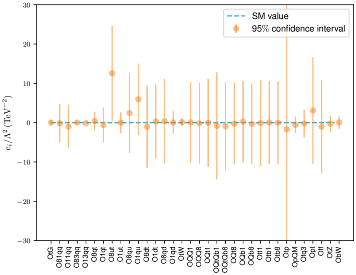
- Cross validation to avoid over-fitting: for each replica, the data is randomly split with equal probability into the training and validation sets.
- Closure test: feed in pseudo-data generated with known EFT parameters, and the fitter should reproduce the correct parameters.

Validation

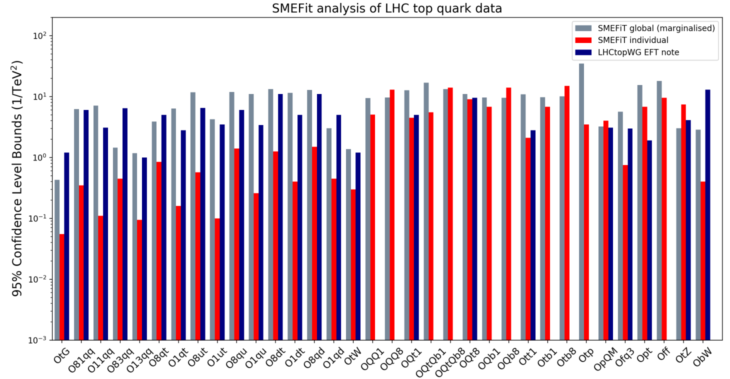
Left Minimisation and stopping: in each MC replica, data is randomly split into training and validation sets. The latter is monitored during the fit, to avoid over-fitting.

Right Closure test: Pseudo-data generated a BSM assumption: $c^8_{tu}/\Lambda^2 = 20\ \text{TeV}^{-2}$, is successfully reproduced by the fit.





Results

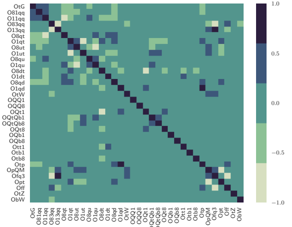


95% CL bound on 34 DOFs. With correlation ⇒

Gray Marginalised

Red Individual

Blue Previous bounds



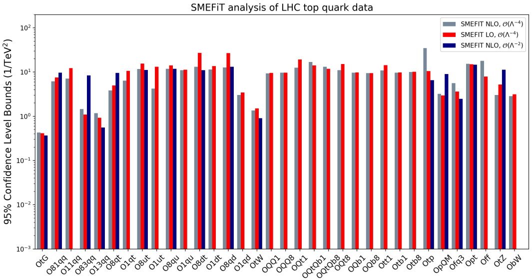
Results

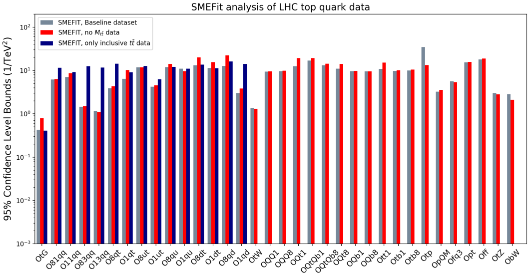
- **NLO** vs. **LO**
- **SM×Dim6+Dim6²**

  vs. **SM×Dim6 only**

$$\sigma = \sigma_{SM} + \sum_i \frac{c_i \sigma_i}{\Lambda^2} + \left[\sum_{ij} \frac{c_i c_j \sigma_{ij}}{\Lambda^4} \right] + \mathcal{O}(\Lambda^{-4})$$

- M_{tt} distribution (with bins above 1 TeV, potentially dangerous for $\Lambda_{BSM} \sim 1$ TeV) vs. y_{tt}.





Outline

SMEFT for the top

Global fit for LHC

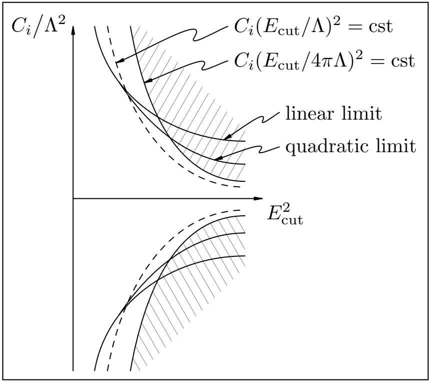
Summary

Summary

- The **SMEFiT** fitting framework is ideal for global SMEFT analysis.
  - A first study including top quark data at LHC Run II has been presented.
  - More constraints will be taken into account in the future.

Thank you for your attention

Backups



- Quote limits as a function of E_{cut} [Contino,Falkowski,Goertz,Grojean,Riva,'16]
  - Assess the validity of matching to models.
  - Compare with perturbativity.