

Common standards for the EFT interpretation of top-quark measurements at the LHC

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with much support and feedback from
top-EFT enthusiasts in ATLAS and CMS,
and LHC TOP WG conveners



Operators and processes

Several operators typically enter each process at LO (or at LO²) and also at NLO in QCD (5F, mb=0):

NLO (no 4f)	Process	O_{tG}	O_{tB}	O_{tW}	$O_{\varphi Q}^{(3)}$	$O_{\varphi Q}^{(1)}$	$O_{\varphi t}$	$O_{t\varphi}$	O_{bW}	$O_{\varphi tb}$	O_{4f}	O_G	$O_{\varphi G}$
✓	$t \rightarrow bW \rightarrow bl^+\nu$	N		L	L				L ²	L ²	1L ²		
✓	$pp \rightarrow tj$	N		L	L				L ²	L ²	1L		
✓	$pp \rightarrow tW$	L		L	L				L ²	L ²	1N	N	
✓	$pp \rightarrow t\bar{t}$	L									2L-4N	L	
✓	$pp \rightarrow t\bar{t}j$	L									2L-4N	L	
✓	$pp \rightarrow t\bar{t}\gamma$	L	L	L							2L-4N	L	
✓	$pp \rightarrow t\bar{t}Z$	L	L	L	L	L	L				2L-4N	L	
✓	$pp \rightarrow t\bar{t}W$	L								L	1L-2L		
✓	$pp \rightarrow t\gamma j$	N	L	L	L				L ²	L ²	1L		
✓	$pp \rightarrow tZj$	N	L	L	L	L	L		L ²	L ²	1L		
✓	$pp \rightarrow t\bar{t}\bar{t}$	L									2L-4L	L	
✓	$pp \rightarrow t\bar{t}H$	L					L				2L-4L	L	L
✓	$pp \rightarrow tHj$	N		L	L		L	L ²	L ²		1L		N
✗	$gg \rightarrow H$	L					L					N	L
✗	$gg \rightarrow Hj$	L					L					L	L
✗	$gg \rightarrow HH$	L					L					N	L
✗	$gg \rightarrow HZ$	L			L	L	L	L				N	L

preliminary

Top-Higgs interplay

Operators and processes

Several operators typically enter each process at LO (or at LO²) and also at NLO in QCD (5F, mb=0):

NLO (no 4f)	Process	O_{tG}	O_{tB}	O_{tW}	$O_{\varphi Q}^{(3)}$	$O_{\varphi Q}^{(1)}$	$O_{\varphi t}$	$O_{t\varphi}$	O_{bW}	$O_{\varphi tb}$	O_{4f}	O_G	$O_{\varphi G}$
✓	$t \rightarrow bW \rightarrow bl^+\nu$	N		L	L				L ²	L ²	1L-2L		
✓	$pp \rightarrow tj$	N		L	L				L ²				
✓	$pp \rightarrow tW$	L		L	L								
✓	$pp \rightarrow t\bar{t}$	L											
✓	$pp \rightarrow t\bar{t}j$	L											
✓	$pp \rightarrow t\bar{t}H$	L				L	L		L ²	L ²	1L-2L	L	
✓	$pp \rightarrow tHj$	N		L	L				L ²	L ²	1L	L	L
✗	$gg \rightarrow H$	L									1L	N	L
✗	$gg \rightarrow Hj$	L									2L-4L	L	L
✗	$gg \rightarrow HH$	L										N	L
✗	$gg \rightarrow HZ$	L			L	L	L	L				N	L

Top-loop-induced $h \rightarrow \gamma\gamma, gg \rightarrow h, hh, Zh, \text{etc.}$
 All top operators appearing in $t\bar{t}$ appear in $t\bar{t}h$.
 Same for tj and tjh .

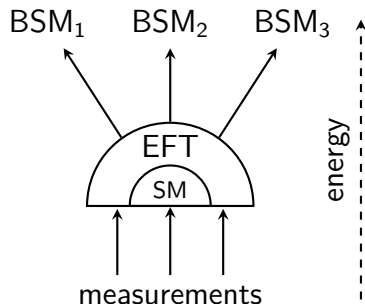
preliminary

The 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]



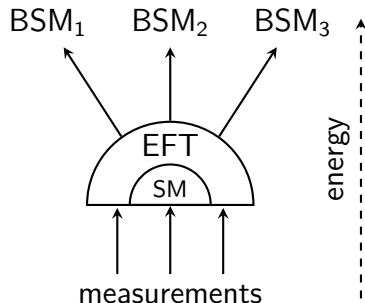
The standard model effective field theory

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

Identify new physics through correlated deviations
in precisely measured observables.

(...) 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]



Common framework for top physics at the LHC

First steps

Delimit an initial scope

- focus a priori on processes and operators involving top quarks
- determine which contributions are relevant
- prioritize the study of flavour structures

Fix notation

- define d.o.f. natural for top physics at the LHC
- fix notation, normalization, and indicative allowed ranges
- provide simulation tools as TH/EXP interface

Discuss analysis strategies (one example)

- address the challenges of a global EFT
- highlight useful experimental outputs

Delimit an initial scope

Relevant operators

Focus a priori on processes and operators involving a top quark

Use the *Warsaw* basis of dim-6 operators as reference

[Grzadkowski et al '10]

Four-quark operators (11)

$$\mathcal{O}_{qq}^{1(ijkl)} = (\bar{q}_i \gamma^\mu q_j)(\bar{q}_k \gamma_\mu q_l),$$

$$\mathcal{O}_{qq}^{3(ijkl)} = (\bar{q}_i \gamma^\mu \tau^I q_j)(\bar{q}_k \gamma_\mu \tau^I q_l),$$

$$\mathcal{O}_{qu}^{1(ijkl)} = (\bar{q}_i \gamma^\mu q_j)(\bar{u}_k \gamma_\mu u_l),$$

$$\mathcal{O}_{qu}^{8(ijkl)} = (\bar{q}_i \gamma^\mu T^A q_j)(\bar{u}_k \gamma_\mu T^A u_l),$$

$$\mathcal{O}_{qd}^{1(ijkl)} = (\bar{q}_i \gamma^\mu q_j)(\bar{d}_k \gamma_\mu d_l),$$

$$\mathcal{O}_{qd}^{8(ijkl)} = (\bar{q}_i \gamma^\mu T^A q_j)(\bar{d}_k \gamma_\mu T^A d_l),$$

$$\mathcal{O}_{uu}^{(ijkl)} = (\bar{u}_i \gamma^\mu u_j)(\bar{u}_k \gamma_\mu u_l),$$

$$\mathcal{O}_{ud}^{1(ijkl)} = (\bar{u}_i \gamma^\mu u_j)(\bar{d}_k \gamma_\mu d_l),$$

$$\mathcal{O}_{ud}^{8(ijkl)} = (\bar{u}_i \gamma^\mu T^A u_j)(\bar{d}_k \gamma_\mu T^A d_l),$$

$$\mathcal{O}_{quqd}^{1(ijkl)} = (\bar{q}_i u_j) \varepsilon (\bar{q}_k d_l),$$

$$\mathcal{O}_{quqd}^{8(ijkl)} = (\bar{q}_i T^A u_j) \varepsilon (\bar{q}_k T^A d_l),$$

Two-quark operators (9)

$$\mathcal{O}_{u\varphi}^{(ij)} = \bar{q}_i u_j \tilde{\varphi} (\varphi^\dagger \varphi),$$

$$\mathcal{O}_{\varphi q}^{1(ij)} = (\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{q}_i \gamma^\mu q_j),$$

$$\mathcal{O}_{\varphi q}^{3(ij)} = (\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{q}_i \gamma^\mu \tau^I q_j),$$

$$\mathcal{O}_{\varphi u}^{(ij)} = (\varphi^\dagger i \overleftrightarrow{D}_\mu \varphi)(\bar{u}_i \gamma^\mu u_j),$$

$$\mathcal{O}_{\varphi ud}^{(ij)} = (\varphi^\dagger i D_\mu \varphi)(\bar{u}_i \gamma^\mu d_j),$$

$$\mathcal{O}_{uW}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} \tau^I u_j) \tilde{\varphi} W_{\mu\nu}^I,$$

$$\mathcal{O}_{dW}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} \tau^I d_j) \varphi W_{\mu\nu}^I,$$

$$\mathcal{O}_{uB}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} u_j) \tilde{\varphi} B_{\mu\nu},$$

$$\mathcal{O}_{uG}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} T^A u_j) \tilde{\varphi} G_{\mu\nu}^A,$$

Two-quark-two-lepton operators (8)

$$\mathcal{O}_{lq}^{1(ijkl)} = (\bar{l}_j \gamma^\mu l_j)(\bar{q}_k \gamma^\mu q_l),$$

$$\mathcal{O}_{lq}^{3(ijkl)} = (\bar{l}_j \gamma^\mu \tau^I l_j)(\bar{q}_k \gamma^\mu \tau^I q_l),$$

$$\mathcal{O}_{lu}^{(ijkl)} = (\bar{l}_j \gamma^\mu l_j)(\bar{u}_k \gamma^\mu u_l),$$

$$\mathcal{O}_{eq}^{(ijkl)} = (\bar{e}_j \gamma^\mu e_j)(\bar{q}_k \gamma^\mu q_l),$$

$$\mathcal{O}_{eu}^{(ijkl)} = (\bar{e}_j \gamma^\mu e_j)(\bar{u}_k \gamma^\mu u_l),$$

$$\mathcal{O}_{lequ}^{1(ijkl)} = (\bar{l}_i e_j) \varepsilon (\bar{q}_k u_l),$$

$$\mathcal{O}_{lequ}^{3(ijkl)} = (\bar{l}_i \sigma^{\mu\nu} e_j) \varepsilon (\bar{q}_k \sigma_{\mu\nu} u_l),$$

$$\mathcal{O}_{ledq}^{(ijkl)} = (\bar{l}_i e_j)(\bar{d}_k q_l),$$

+ \mathcal{B} and \mathcal{L} operators (4 or 5)

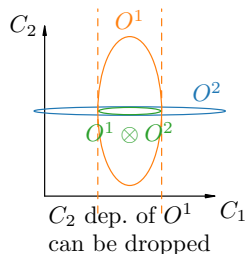
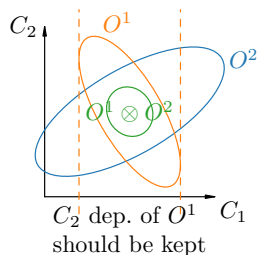
Others should be sufficiently constrained by processes involving no tops.

Relevant contributions

Use present sensitivities and constraints (rather than theoretical prejudices) to decide which contributions are relevant.

1. work on an obs.-by-obs. basis (O^k)
2. evaluate all tree-level contributions
3. discard dependences when irrelevant
4. compute higher orders in SM couplings where necessary

Note the relevance of d.o.f.'s in a measurement may change as constraints are collected!



BSM flavour assumptions

(FCNCs treated separately)

To prioritize the study of flavour structures

Lepton sector (not critical)

- rather loose $[U(1)_{l+e}]^3$ aka flavour diagonality
- could easily be restricted to $U(3)_{l+e}$, $U(3)_l \times U(3)_e$, or ...

Quark sector (baseline and variants)

mostly restrict the large number of four-quark operators

Baseline: $U(2)_q \times U(2)_u \times U(2)_d$ among first two generations

\equiv SM flavour symmetry in the limit $y_{u,d,s,c} \rightarrow 0$, $V_{CKM} \rightarrow \mathbb{I}$
forces the first two generations to appear as $\sum_{i=1,2} \bar{q}_i q_i$, $\bar{u}_i u_i$, $\bar{d}_i d_i$

Extended: $U(2)_{q+u+d}$

[sugg. by J.A.Aguilar-Saavedra]

- allows light right-handed charged currents $\sum_{i=1,2} \bar{u}_i d_i$
- allows light chirality flipping currents $\sum_{i=1,2} \bar{q}_i u_i$, $\bar{q}_i d_i$

Restricted: *top-philic* scenario

[sugg. by A.Wulzer]

- assumes NP generates all operators with tops and bosons
- then project that over-complete set on the Warsaw basis with EOM, etc.

Fix notation

Top-specific d.o.f. definitions

Match SM interference structures
and interactions with physical gauge bosons

$$\bullet \begin{pmatrix} O_{\varphi q}^{1(33)} \\ O_{\varphi q}^{3(33)} \end{pmatrix} = \begin{pmatrix} (\varphi^\dagger \overleftrightarrow{D}_\mu \varphi)(\bar{q}_3 \gamma^\mu q_3) \\ (\varphi^\dagger \overleftrightarrow{D}'_\mu \varphi)(\bar{q}_3 \gamma^\mu \tau^I q_3) \end{pmatrix} = \begin{pmatrix} -1 & 1 \\ 1 & 1 \\ 0 & 1 \\ 0 & 1 \end{pmatrix}^T \begin{pmatrix} \frac{+e}{2s_w c_w} (\bar{t} \gamma^\mu P_L t) Z_\mu (v+h)^2 \\ \frac{-e}{2s_w c_w} (\bar{b} \gamma^\mu P_L b) Z_\mu (v+h)^2 \\ \frac{g}{\sqrt{2}} (\bar{t} \gamma^\mu P_L b) W_\mu^+ (v+h)^2 \\ \frac{g}{\sqrt{2}} (\bar{b} \gamma^\mu P_L t) W_\mu^- (v+h)^2 \end{pmatrix}$$

$$c_{\varphi Q}^- \equiv C_{\varphi q}^{1(33)} - C_{\varphi q}^{3(33)} \quad \text{enters in } pp \rightarrow t\bar{t}Z$$

$$c_{\varphi Q}^3 \equiv C_{\varphi q}^{3(33)} \quad \text{enters in } t \rightarrow bW^+$$

$$c_{\varphi Q}^+ \equiv C_{\varphi q}^{1(33)} + C_{\varphi q}^{3(33)} \quad \text{enters in } e^+e^- \rightarrow b\bar{b} \text{ (or } pp \rightarrow b\bar{b}Z)$$

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

$$c_{Qq}^{1,1} \equiv C_{qq}^{1(ii33)} + \frac{1}{6} C_{qq}^{1(i33i)} + \frac{1}{2} C_{qq}^{3(i33i)} \quad \text{interferes with EW NC}$$

$$c_{Qq}^{3,1} \equiv C_{qq}^{3(ii33)} + \frac{1}{6} (C_{qq}^{1(i33i)} - C_{qq}^{3(i33i)}) \quad \text{interferes with EW CC}$$

$$c_{Qq}^{1,8} \equiv C_{qq}^{1(i33i)} + 3 C_{qq}^{3(i33i)}, \quad \text{interferes with QCD}$$

$$c_{Qq}^{3,8} \equiv C_{qq}^{1(i33i)} - C_{qq}^{3(i33i)} \quad \text{doesn't interfere with EW CC}$$

Counting and constraints

	benchmark	extended	restricted
four heavy quarks	11 + 2 CPV		5
two light and two heavy quarks	14	+10 + 10 CPV	} 5
two heavy quarks and two leptons	(8 + 3 CPV) × 3		
two heavy quarks and bosons	9 + 6 CPV		9 + 6 CPV

Indicative direct constraints

[many from TopFitter]

$$C_{td}^1 \equiv C_{ud}^{1(334i)} \quad [-4.95, 5.04] \quad [35]$$

$$C_{td}^8 \equiv C_{ud}^{8(334i)} \quad [-11.8, 9.31] \quad [35]$$

Two-heavy (9 + 6 CPV d.o.f.)

$$C_{t\varphi}^I \equiv \frac{[\text{Im}]\{C_{u\varphi}^{(33)}\}}{\text{Re}} \quad c_{\varphi q}^1 \quad [-3.1, 3.1] \quad [36], \quad [-8.3, 8.6] \quad [37]$$

$$C_{\varphi q}^- \equiv C_{\varphi q}^{1(33)} - C_{\varphi q}^{3(33)} \quad c_{\varphi Q}^3 \quad [-4.1, 2.0] \quad [36], \quad [-8.6, 8.3] \quad [37]$$

$$C_{\varphi Q}^3 \equiv C_{\varphi q}^{3(33)} \quad [-9.7, 8.3] \quad [36], \quad [-9.1, 9.1] \quad [37]$$

$$C_{\varphi t} \equiv C_{\varphi u}^{(33)} \quad c_{tW} \quad [-4.0, 3.5] \quad [36], \quad [-4.1, 4.1] \quad [37]$$

$$C_{\varphi tb}^I \equiv \frac{[\text{Im}]\{C_{\varphi ud}^{(33)}\}}{\text{Re}} \quad c_{tB} \quad [-6.9, 4.6] \quad [36], \quad [-7.6, 7.6] \quad [37]$$

$$C_{tW}^I \equiv \frac{[\text{Im}]\{C_{uW}^{(33)}\}}{\text{Re}} \quad c_{tB} \quad [-6.9, 4.6] \quad [36], \quad [-7.6, 7.6] \quad [37]$$

$$C_{tZ}^I \equiv \frac{[\text{Im}]\{-s_W C_{uB}^{(33)} + c_W C_{uW}^{(33)}\}}{\text{Re}} \quad c_{tG} \quad [-1.32, 1.24] \quad [36]$$

$$C_{bW}^I \equiv \frac{[\text{Im}]\{C_{dW}^{(33)}\}}{\text{Re}} \quad [\Lambda = 1 \text{ TeV}]$$

$$C_{tG}^I \equiv \frac{[\text{Im}]\{C_{uG}^{(33)}\}}{\text{Re}} \quad [\Lambda = 1 \text{ TeV}]$$

Two heavy two lepton (8 + 3 CPV d.o.f. × 3 lepton flavours)

Indicative indirect constraints

B decays, dilepton production, EWPO, EDMs, CP asymmetries

[D.Marzocca; W.Dekens, J.de Vries, V.Cirigliano, E.Mereghetti]

Tree-level UFO implementations

As TH/EXP interfaces

- ▶ dedicated dim6top (<https://feynrules.irmp.ucl.ac.be/wiki/dim6top>)
 - $O(90)$ d.o.f.'s of the extended flavour scenario
- ▶ SMEFTsim alternative (<http://feynrules.irmp.ucl.ac.be/wiki/SMEFT>)
 - implementing Warsaw operators
 - providing restriction cards for emulating d.o.f.'s

[Brivio, Jiang, Trott '17]

Benchmark dependences

(cross checked among the two models)

e.g. linear contributions to total rates:

permil of the SM rate, $\Lambda = 1 \text{ TeV}$

SM	sm	$pp \rightarrow t\bar{t}$ 5.2 × 10 ² pb	$pp \rightarrow t\bar{t}b\bar{b}$ 1.9 pb	$pp \rightarrow t\bar{t}t\bar{t}$ 0.0098 pb	$pp \rightarrow t\bar{t}e^+\nu$ 0.02 pb	$pp \rightarrow t\bar{t}e^+e^-$ 0.016 pb	$pp \rightarrow t\bar{t}\gamma$ 1.4 pb	$pp \rightarrow t\bar{t}h$ 0.4 pb
c_{QQ}^1	cQq1	-0.25	-1.9	-1 × 10 ²		-1.6	-0.67	-0.71
c_{QQ}^8	cQq8	-0.16	-3.2	-34		-0.91	-0.5	-0.27
c_{Qt}^1	cQt1	-0.15	-5.6	1 × 10 ²		-0.76	-0.19	-0.55
c_{Qt}^8	cQt8	-0.053	-1.8	-41		-0.18	-0.095	-0.15
c_{Qb}^1	cQb1	-0.0055	0.72	-0.052		-0.015	-0.007	-0.026
c_{Qb}^8	cQb8	0.14	3.9	0.12		0.35	0.16	0.56
c_{tt}^1	ctt1			-1.8 × 10 ²				
c_{tb}^1	ctb1	-0.0095	0.46	-0.059		-0.02	-0.026	-0.039
c_{tb}^8	ctb8	0.13	3.5	0.11		0.26	0.31	0.56
c_{QtQb}^1	cQtQb1							
c_{QtQb}^8	cQtQb8							
c_{QtQb}^{1I}	cQtQb1I							
c_{QtQb}^{8I}	cQtQb8I							
$c_{Qq}^{3,S}$	cQq83	2.7	-0.11	4.7	-85	-20	8.5	15
$c_{Qq}^{1,S}$	cQq81	12	7.1	25	2.6 × 10 ²	71	40	75
c_{tq}^8	ctq8	13	8.2	27	2.6 × 10 ²	62	51	74
c_{Qu}^8	cQu8	7.4	4.4	18		21	41	44
c_{tu}^8	ctu8	7.4	3	16		14	22	45

Tree-level UFO implem

As TH/EXP interfaces

- dedicated dim6top (http://www.hepforge.org/dim6top)
 - $O(90)$ d.o.f.'s of
- SMEFTsim alternative (https://github.com/brivio/SMEFTsim)
 - implementing Warsaw
 - providing restrict

Benchmark dependence

e.g. linear contributions to top

SM	sm	$pp \rightarrow t\bar{t}$ 5.2×10^2 pb	$pp \rightarrow t\bar{t}h$ 1.4 pb
c_{QQ}^1	cQQ1	-0.25	-0.71
c_{QQ}^8	cQQ8	-0.16	-0.27
c_{Qt}^1	cQt1	-0.15	-0.55
c_{Qt}^8	cQt8	-0.053	-0.15
c_{Qb}^1	cQb1	-0.0055	-0.026
c_{Qb}^8	cQb8	0.14	0.56
c_{tt}^1	ctt1		
c_{tb}^1	ctb1	-0.0095	-0.039
c_{tb}^8	ctb8	0.13	0.56
c_{QtQb}^1	cQtQb1		
c_{QtQb}^8	cQtQb8		
c_{QtQb}^{1I}	cQtQb1I		
c_{QtQb}^{8I}	cQtQb8I		
$c_{Qq}^{1,8}$	cQq83	2.7	15
$c_{Qq}^{1,8}$	cQq81	12	75
c_{tq}^8	ctq8	13	74
c_{Qu}^8	cQu8	7.4	44
c_{tu}^8	ctu8	7.4	45
c_{Qd}^8	cQd8	5	29
c_{td}^8	ctd8	5	28
$c_{Qq}^{1,8}$	cQq13	3.3	18
c_{Qq}^1	cQq11	0.94	5.4
c_{tq}^1	ctq1	0.65	4.8
c_{Qu}^1	cQu1	0.57	4.3
c_{tu}^1	ctu1	1.1	6.6
c_{Qd}^1	cQd1	-0.19	-1.4
c_{td}^1	ctd1	-0.37	-2.1
$c_{t\varphi}$	ctp		-1.2×10^2
$c_{\varphi Q}$	cpQM	-0.063	-0.29
$c_{\varphi Q}$	cpQ3	0.68	1.8
$c_{\varphi t}$	cpt	-0.024	-0.16
$c_{\varphi tb}$	cptb		
c_{tW}	ctW	0.98	9.4
c_{tZ}	ctZ	-0.54	-4.3
c_{bW}	cbW		
c_{tG}	ctG	2.7×10^2	8.4×10^2
$c_{t\varphi}$	ctpI		0.045
$c_{\varphi tb}$	cptbI		
c_{tW}^3	ctWI	4.8×10^{-6}	0.031
c_{tZ}^3	ctZI	-1.4×10^{-6}	-0.057
c_{bW}^3	cbWI		
c_{tG}^3	ctGI	-0.00098	-2.4
$c_{\varphi(1)}$	cphi1		

		$pp \rightarrow t\bar{t}$ 5.2×10^2 pb	$pp \rightarrow t\bar{t}h$ 0.4 pb
SM	sm		
c_{QQ}^1	cQQ1	-0.25	-0.71
c_{QQ}^8	cQQ8	-0.16	-0.27
c_{Qt}^1	cQt1	-0.15	-0.55
c_{Qt}^8	cQt8	-0.053	-0.15
c_{Qb}^1	cQb1	-0.0055	-0.026
c_{Qb}^8	cQb8	0.14	0.56
c_{tt}^1	ctt1		
c_{tb}^1	ctb1	-0.0095	-0.039
c_{tb}^8	ctb8	0.13	0.56
c_{QtQb}^1	cQtQb1		
c_{QtQb}^8	cQtQb8		
c_{QtQb}^{1I}	cQtQb1I		
c_{QtQb}^{8I}	cQtQb8I		
$c_{Qq}^{1,8}$	cQq83	2.7	15
$c_{Qq}^{1,8}$	cQq81	12	75
c_{tq}^8	ctq8	13	74
c_{Qu}^8	cQu8	7.4	44
c_{tu}^8	ctu8	7.4	45
c_{Qd}^8	cQd8	5	29
c_{td}^8	ctd8	5	28
$c_{Qq}^{1,8}$	cQq13	3.3	18
c_{Qq}^1	cQq11	0.94	5.4
c_{tq}^1	ctq1	0.65	4.8
c_{Qu}^1	cQu1	0.57	4.3
c_{tu}^1	ctu1	1.1	6.6
c_{Qd}^1	cQd1	-0.19	-1.4
c_{td}^1	ctd1	-0.37	-2.1
$c_{t\varphi}$	ctp		-1.2×10^2
$c_{\varphi Q}$	cpQM	-0.063	-0.29
$c_{\varphi Q}$	cpQ3	0.68	1.8
$c_{\varphi t}$	cpt	-0.024	-0.16
$c_{\varphi tb}$	cptb		
c_{tW}	ctW	0.98	9.4
c_{tZ}	ctZ	-0.54	-4.3
c_{bW}	cbW		
c_{tG}	ctG	2.7×10^2	8.4×10^2
$c_{t\varphi}$	ctpI		0.045
$c_{\varphi tb}$	cptbI		
c_{tW}^3	ctWI	4.8×10^{-6}	0.031
c_{tZ}^3	ctZI	-1.4×10^{-6}	-0.057
c_{bW}^3	cbWI		
c_{tG}^3	ctGI	-0.00098	-2.4
$c_{\varphi(1)}$	cphi1		

dim6top
scenario

/SMEFT)

[Brivio, Jiang, Trott '17]

d.o.f.'s

ded among the two models)

per mil of the SM rate, $\Lambda = 1$ TeV

	$pp \rightarrow t\bar{t}e^+e^-$ 0.16 pb	$pp \rightarrow t\bar{t}\gamma$ 1.4 pb	$pp \rightarrow t\bar{t}h$ 0.4 pb
	-1.6	-0.67	-0.71
	-0.91	-0.5	-0.27
	-0.76	-0.19	-0.55
	-0.18	-0.095	-0.15
	-0.015	-0.007	-0.026
	0.35	0.16	0.56
	-0.02	-0.026	-0.039
	0.26	0.31	0.56
	-20	8.5	15
	71	40	75
	62	51	74
	21	41	44
	14	22	45
	17	7.2	22

Discuss analysis strategies

Warning: illustrative theorist view!

- to show how the challenges of a global EFT could be addressed
- to fix ideas on what are useful outputs from a TH perspective

An example of EFT analysis strategy

Exploiting a (particle-level) fiducial volume close enough to the detector level for unfolding to be very model independent.

to be checked!

—→ facilitates re-interpretations

- in an evolving global EFT picture
- with more sophisticated predictions
- with less restrictive assumptions (about flavour, non-top operators, etc.)
- outside experimental collaborations

—→ facilitates multidimensional EFT analyses

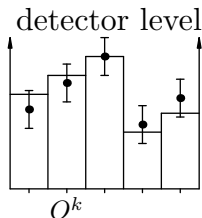
—→ **but** may sometimes be impractical or suboptimal

An example of EFT analysis strategy

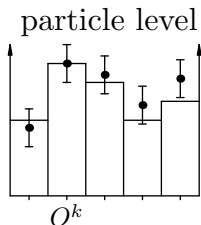
For O^k observables

total rate, binned p_T , η , m_{xy} , etc. distributions,
binned MVA output, ratios, asymmetries, *optimal observables*,...

Unfold



unfold
the data
 \Rightarrow
under SM
hypothesis



Note that *forward folding* could actually be advantageous.

Provide

- observable definitions (code if non-standard)
- statistical uncertainties
- systematics breakdown and correlations
(\rightarrow re-interpretable in any model)

Global EFT interpretation

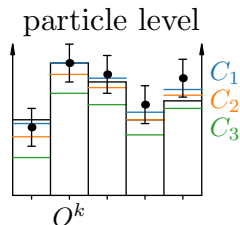
- Compute EFT predictions to the particle level

$$O^k = B_l^k + \frac{C_i}{\Lambda^2} S_i^k + \frac{C_i C_j}{\Lambda^4} S_{ij}^k + \dots$$

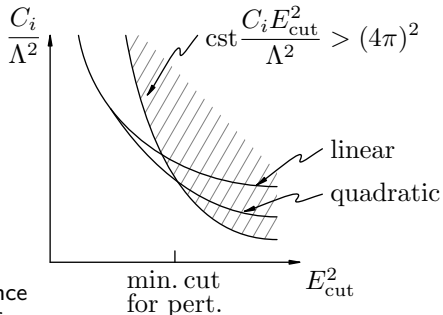
SM bkg composition linear dim-6 contributions (EFT-SM interf.) quadratic dim-6 contributions higher powers, and higher-dim. operators

- Obtain and release likelihoods in the full $\{C_i\}$ space

≡ **global** constraints
to combine with other measurements



- also quote **individual** constraints
 - information about sensitivity and the magnitude of approximate degeneracies
- quote both the **linear** and **quadratic** dim-6 approx.
 - information about the importance of higher powers of dim-6 coeff. (barring interference suppressions)



- quote limits as functions of E_{cut} on a characteristic energy scale
 - valid interpretation for models with lower scales, with $[\text{dim}>6] > [\text{dim}-6]$ without E_{cut}
 - perturbativity possibly ensured by minimal E_{cut}

[Contino et al '16]

$$\sum_n \left[\text{diagram with } n \text{ vertices} \right] \sim \sum_n \left[\text{cst} \frac{C_i E_{\text{cut}}^2}{(4\pi)^2 \Lambda^2} \right]^n$$

The diagram shows a series of vertices connected by lines, representing a perturbative expansion. The vertices are labeled 1, 2, ..., n.

Summary

Left aside

Higher-order corrections

especially in QCD, based on existing results

Theory uncertainties

especially the intrinsic EFT ones

EFT treatment of unstable tops

Process and observable sensitivity studies

- strongest constraints in specific directions
- complementarity to cover the whole EFT param. space

...

Covered

Delimit an initial scope

- focus a priori on top-quark processes and operators
- use constraints and sensitivities to identify relevant contributions
- prioritize the study of flavour structures

Fix notation

- define d.o.f. natural for top physics at the LHC
- fix notation, normalization, and indicative allowed ranges
- provide simulation tools as TH/EXP interface

Discuss analysis strategies (one example)

- address the challenges of a global EFT
- highlight useful experimental outputs

More details in [1802.07237]!