PROCEEDINGS OF SCIENCE

TopFitter: A global fit of top effective theory to data

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We present a global fit of beyond the Standard Model (BSM) dimension six operators relevant to the top quark sector to all currently available top production cross-section measurements, namely parton-level top-pair and single top production at the LHC and the Tevatron. Higher order QCD corrections are modelled using differential and global K-factors, and we use novel fast-fitting techniques developed in the context of Monte Carlo event generator tuning to perform the fit. This allows us to provide new, fully correlated and model-independent bounds on new physics effects in the top sector from the most current direct hadron-collider measurements in light of the involved theoretical and experimental systematics. As a by-product, our analysis constitutes a proof-of-principle that fast fitting of theory to data is possible in the top quark sector, and paves the way for a more detailed analysis including top quark decays, detector corrections and precision observables.

8th International Workshop on Top Quark Physics, TOP2015
14-18 September, 2015
Ischia, Italy

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PoS(TOP2015)065

1. Introduction

The top quark, as the heaviest SM particle, is expected to play a unique role in physics at the TeV scale. Given the unsatisfactory explanation of electroweak symmetry breaking in the SM and the appearance of m_t at the electroweak scale, the top mass may arguably be seen as a hint of physics beyond the SM.

Given the plethora of concrete scenarios and the absence of signals of new physics in the current data, parametrising BSM effects in the top sector using an EFT expansion [1] is well-motivated. Hereby we can interpret measurements in a model independent framework.

Integrating out UV degrees of freedom above the scale Λ will give rise to a low-energy phenomenology constrained by SM gauge & global symmetries. The leading contributions relevant to new physics in the top sector appear as dimension-six operators O_i at $\mathscr{O}(1/\Lambda^2)$

$$\mathscr{L}_{\text{eff}} = \mathscr{L}_{\text{SM}} + \frac{1}{\Lambda^2}\sum_i C_i O_i + \mathscr{O}(\Lambda^{-4}),$$

where C_i are 'Wilson Coefficients' which encode the residual effects of new physics. A minimal basis comprises 59 distinct terms [2–4]. Considerable attention has been devoted to constraining these operators [5–16]. However, while Higgs physics has received a lot of attention from an EFT perspective, the top quark sector has not seen similar scrutiny despite the abundant data from TeVatron and the LHC.

2. Procedure

A first application of our approach used measurements (Table 2) of top pair and single top production performed at TeVatron and the LHC in a nine-dimensional fit to constrain the Wilson Coefficients for all contributing CP-even operators (Table 1).
The analysis used a FeynRules [27] model file interfaced via UFO [28] to MadGraph/MadEvent [28, 29] in order to obtain parton-level theory predictions. NLO QCD corrections were modelled using SM-only samples generated with Mcfm [30], which were used to construct bin-by-bin and global K-factors [31]. Theoretical uncertainties for these samples were estimated by independently varying the scales $\mu_{\text{central}}/2 < \mu_{\text{R,F}} < 2\mu_{\text{central}}$, with $\mu_{\text{central}} = m_t$, while PDF uncertainties were estimated by generating events using NLO PDF sets [32–34], according to the PDF4LHC [35] prescription.

4-fermion operators		Non 4-fermion operators	
O^1_{qq}	$(\bar{q}\gamma_\mu q)(\bar{q}\gamma^\mu q)$	$O^3_{\phi q}$	$i(\phi^\dagger \tau^I D_\mu \phi)(\bar{q}\gamma^\mu \tau^I q)$
O^3_{qq}	$(\bar{q}\gamma_\mu \tau^I q)(\bar{q}\gamma^\mu \tau^I q)$	O_{tW}	$(\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi}W^I_{\mu\nu}$
O_{uu}	$(\bar{u}\gamma_\mu u)(\bar{u}\gamma^\mu u)$	O_{tG}	$(\bar{q}\sigma^{\mu\nu}\lambda^A t)\tilde{\phi}G^A_{\mu\nu}$
O^8_{qu}	$(\bar{q}\gamma_\mu T^A q)(\bar{u}\gamma^\mu T^A u)$	O_G	$f_{ABC}G^{A\nu}_\mu G^{B\lambda}_\nu G^{C\mu}_\lambda$
O^8_{qd}	$(\bar{q}\gamma_\mu T^A q)(\bar{d}\gamma^\mu T^A d)$	$O_{\phi G}$	$(\phi^\dagger\phi)G^A_{\mu\nu}G^{A\mu\nu}$
O^8_{ud}	$(\bar{u}\gamma_\mu T^A u)(\bar{d}\gamma^\mu T^A d)$		

Table 1: All Warsaw basis operators relevant to top quark production. q denotes the left-handed quark doublet, u and d denote the up-type and down-type right-handed singlets.

Dataset	$\sqrt{s}$ (TeV)	Measurements	Ref.
Top pair production			
ATLAS	7 + 8	Total inclusive σ	[17]
	7 + 8	Differential $p_T(t), M_{t\bar{t}}, \lvert y(t\bar{t})\rvert$	[18]
CMS	7	Differential $p_T(t), M_{t\bar{t}}, y(t), \lvert y(t\bar{t})\rvert$	[19]
CDF	1.96	Differential $M_{t\bar{t}}$	[20]
DØ	1.96	Differential $M_{t\bar{t}}, p_T(t), \lvert y(t)\rvert$	[21]
Single top production			
ATLAS t-channel	7	Total inclusive σ	[22]
	7	Differential $p_T(t), \lvert y(t)\rvert$	
CMS t-channel	7	Total inclusive σ	[23]
	8	Total inclusive σ	[24]
CDF s-channel	1.96	Total inclusive σ	[25]
DØ $s+t$-channel	1.96	Total inclusive σ	[26]

Table 2: Datasets used in the fit, including total cross-sections (σ); transverse momenta of single tops ($p_T(t)$) and top pairs ($p_T(t\bar{t})$); rapidities of single tops ($y(t)$) and top pairs ($y(t\bar{t})$); and the invariant mass of top pairs ($M_{t\bar{t}}$).

We take the central value as our estimate and the width of the envelope as the total theoretical uncertainty. A novel fitting procedure, developed in the context of MC event generator tuning, is then used to fit to the data in the PROFESSOR [36] framework.

A set of points in the N-dimensional parameter space $\{C_i\}$ is sampled logarithmically, chosen to avoid oversampling regions where $\{C_i\}$ are large. At each point, all theory observables are calculated with uncertainties, as described. One then constructs a *parameterising function* $f_b(\{C_i\})$ for each observable bin b, which fits the sampled points with least-squares-optimal precision. This function can be used to efficiently generate theory predictions for arbitrary parameter space points within the fitted range. We choose a third-degree polynomial for this function. This has been shown to work well in Monte Carlo tuning [36]. Finally, we construct a χ^2 function between the bin parameterisations $\{f_b(\{C_i\})\}$ and the data, according to

$$\chi^2(\{C_i\}) = \sum_{\mathcal{O}} \sum_{b} \frac{(f_b(\{C_i\}) - E_b)^2}{\sigma_b^2},$$

E_b is the experimental reference value at bin b and σ_b is the total uncertainty for bin b, which we for now assume as an uncorrelated combination of theoretical modelling and experimental measurement uncertainties, $\sigma_b = \sqrt{\sigma^2_{\text{theory}} + \sigma^2_{\text{exp}}}$. The χ^2 is then used to place constraints on the operator Wilson coefficients. Constraints were obtained in two ways: firstly by allowing single operator coefficients to vary, with all others set to zero, and secondly by marginalising over the remaining operators (with all other operators allowed to float to best-fit values).The χ^2 was then minimised using PYMINUIT [37], and used to set confidence limits on the operator value.

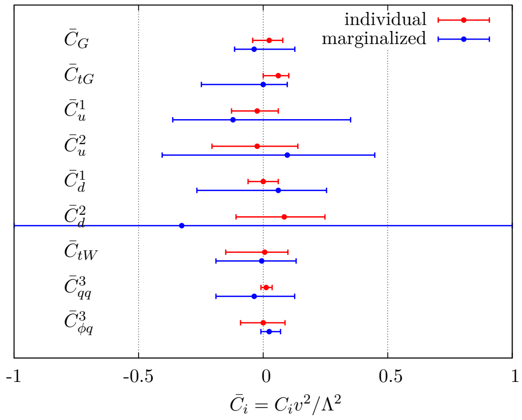

Figure 1: 95% confidence intervals for operators contributing to top-pair and single top production, individually and marginalised. Note that the marginalised bound on $\bar{C}_d^2$ fall outside the region where the dimension-six approximation is valid, so this operator is unconstrained.

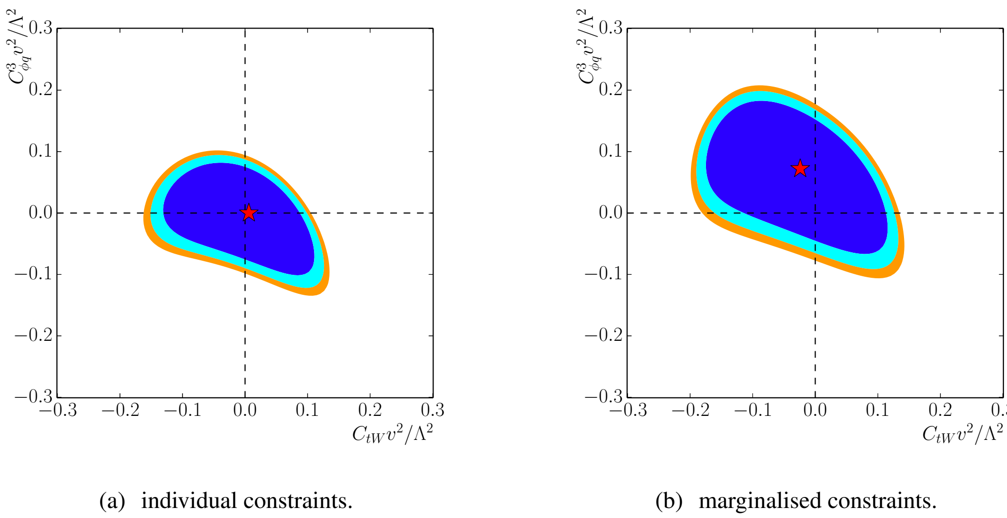

Figure 2: 68% (blue), 95% (turquoise) and 99% (orange) confidence intervals for C_{tW} and $C_{\phi q}^3$ in a global fit, with all remaining coefficients set to zero (a) and marginalised over (b). The star marks the best fit point, indicating a currently good agreement with the Standard Model.

3. Results

One can plot the individual and marginalized constraints (Figure1) on the Wilson Coefficients tested, here normalised to the SM piece via $\bar{C}_i = C_i v^2/\Lambda^2$, and also investigate the correlation of constraints between operators (Figure 2(a)) and (Figure 2(b)).

Our results provide a proof of principle study that efficient global fits of top quark effective theory are possible. Work is currently ongoing to generalize and improve the framework, namely:

- Generalizing our fit to include more experimental observables, for example going beyond parton level, including top quark decays and considering CP-odd observables.

- The inclusion of new datasets, including those from LHC Run II
- Implementing NLO QCD corrections to the EFT. This causes technical complications unique to non-renormalizable interactions, in particular operator mixing under the renormalization group, the radiative generation of operators outside the basis used, and involved mixings and rescalings of parameters.

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