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EFT interpretation in top-quark sector at ATLAS

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No clear signals of a physics beyond the Standard Model have been observed at the Large Hadron Collider (LHC) at CERN. The effective field theory (EFT) framework provides a model independent approach to search for such signals. EFT interpretations of measurements involving top quarks performed in the ATLAS experiment using pp collisions from the LHC Run 2 at the centre-of-mass energy $\sqrt{s} = 13$ TeV are summarized in this article.

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1. Introduction

The top quark differs from other quarks mainly by its large mass. It has been proposed many times that the top quark could play a special role in extensions of the current theory, the Standard Model (SM). If beyond SM (BSM) effects reveal themselves in the experiments at the Large Hadron Collider (LHC), there is a high chance it will happen in top quark processes.

Within the SM effective field theory (SMEFT) [1], the effects of BSM dynamics (characterized by the energy scale Λ) can be parameterized at low energies $E \ll \Lambda$ using the Lagrangian:

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_{i,D(D>4)} \frac{c_i^{(D)} O_i^{(D)}}{\Lambda^{D-4}} = \mathcal{L}_{\mathrm{SM}} + \sum_i \frac{c_i^{(6)} O_i^{(6)}}{\Lambda^2} + \sum_j \frac{c_j^{(8)} O_j^{(8)}}{\Lambda^4} + \ldots,$$

where c_i are Wilson coefficients giving a measure of the strength of operators $O_i^{(D)}$ which are a complete set of operators of the higher-dimension D build from SM fields and respecting SM symmetries. The goal of EFT interpretations of measurements is to determine Wilson coefficients c_i which are all being zero in the SM.

In this paper, we provide the summary of recent EFT interpretations of top quark measurements performed by the ATLAS experiment [2] in LHC Run 2 pp collisions at $\sqrt{s} = 13$ TeV.

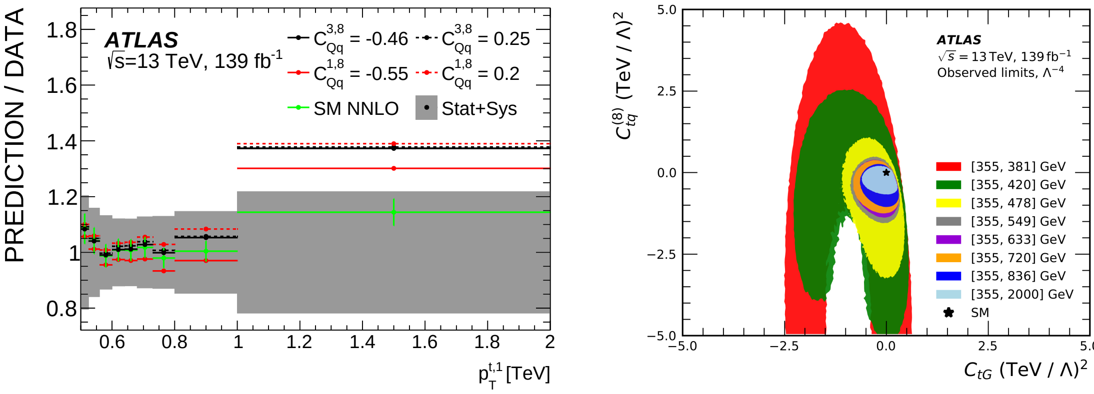
2. Top quark measurements with EFT interpretation

Different types of measurements are sensitive to different EFT operators depending on the process or the vertex considered. Within ATLAS top quark EFT interpretations, only the lowest energy dimension operators ($O^{(6)}$) are considered. However, the results are usually compared for the case where SM-EFT interference only terms (Λ^{-2}) and where also EFT-EFT interference terms (Λ^{-4}) are included in order to get an estimate of the importance of higher-order dimension operators. The Warsaw basis [3] for the operators of SMEFT is adopted and its different implementations within the MadGraph5_aMC@NLO [4] Monte Carlo event generator are used: SMEFTatNLO [5], dim6top [6], TopFCNC [7]. These implementations are used at the leading order in the quantum chromodynamics (QCD) apart from TopFCNC which is at the next-to-leading order in QCD. The $\Lambda = 1$ TeV is typically set and limits on particular individual Wilson coefficients c_i are determined. Only a few operators which affect a relevant vertex are usually constrained in a given analysis. Some measurements provide also the simultaneous limits on pairs of Wilson coefficients.

The top–antitop quark pair ($t\bar{t}$) differential cross-section measurements are sensitive mainly to the operator affecting the ttg vertex (C_{tG}) and four-quark (4Q) operators. The measurements in both all-hadronic [8] and semi-leptonic final states [9] are performed in the boosted regime which improves the sensitivity at the high transverse momentum (p_{T}) of top quarks, see Figure 1.

Searches for flavour-changing neutral currents (FCNC) are performed for various vertices involving the top quark, such as tqH [10], $tq\gamma$ [11], tqg [12], and tqZ [13]. FCNC in both the production and the decay of the top quark are considered in these measurements. The limits on cross-sections or non-SM top quark branching ratios are interpreted within the EFT framework to set the limits on FCNC Wilson coefficients.

The energy asymmetry measurement in the $t\bar{t}$+jet production is sensitive to 4Q operators [14]. Given that this observable is sensitive to a chirality of the top quark, it has the ability to resolve

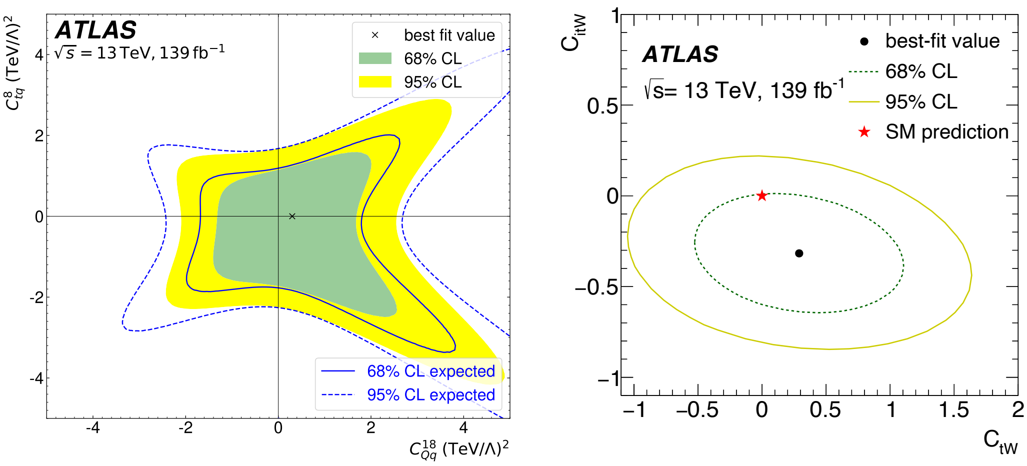


(a) (b)

Figure 1: (a) The ratio of various SMEFT predictions to the data for the leading top-quark p_{T} distribution in the all-hadronic measurement [8]. (b) The evolution of the limits when adding the bins of the measured hadronic top quark p_{T} distribution one-by-one to the EFT interpretation in the l+jets measurement [9].

new directions in the EFT parameter space, see Figure 2(a). The measurement of the top quark polarization in the single-top Wt channel is sensitive to the operator affecting the Wtb vertex (O_{tW}) and provides the limits on both real and imaginary parts of the complex Wilson coefficient c_{tW} [15]. The simultaneous fit of both coefficients is shown in Figure 2(b). The measurement of the $t\bar{t}$+Z production cross-section is sensitive to two-quark operators affecting the ttZ vertex [16].

The summary of constraints on various individual Wilson coefficients from the presented measurements are shown in Figure 3. Typically, the limits are about the same or better than from existing global fits [17, 18].



(a) (b)

Figure 2: Bounds on Wilson coefficients from the two-parameter simultaneous fit within (a) the energy asymmetry [14] and (b) the top quark polarization measurement [15].

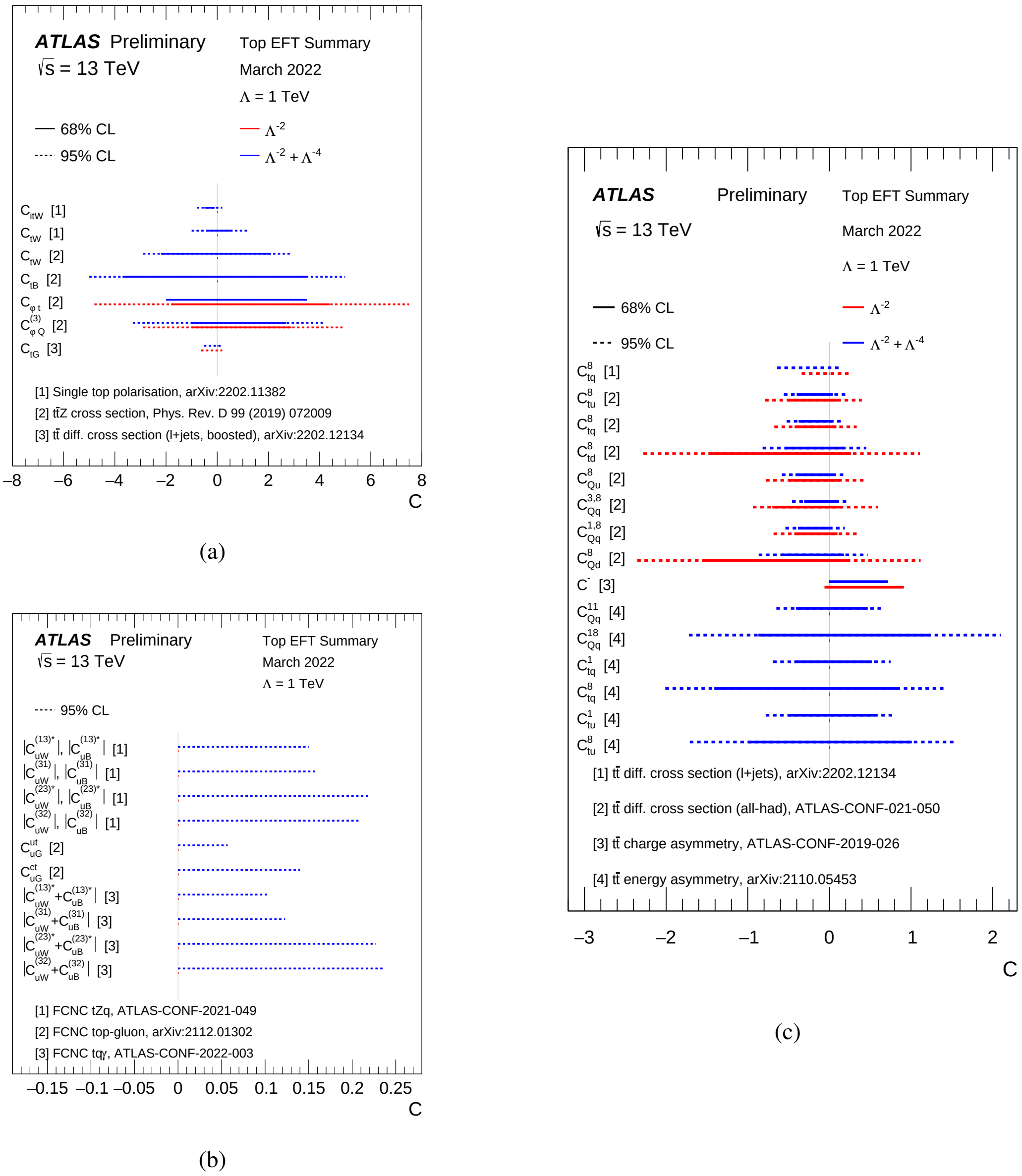


Figure 3: Summary of constraints on individual Wilson coefficients for (a) two-fermion, (b) FCNC, and (c) four-fermion SMEFT operators [19].

3. Conclusion

The effective field theory interpretation of measurements is a powerful tool to look for BSM physics. It becomes a standard in the top-quark sector in the ATLAS experiment. Various analyses are able to constrain different single or pairs of Wilson coefficients. In the future, various aspects of EFT interpretations will be harmonized with the goal to combine measurements within the top quark sector. This will allow a simultaneous determination of Wilson coefficients and will remove blind directions in certain coefficients from individual analyses. Eventually, a global EFT interpretation within the ATLAS experiment and between LHC experiments should be performed.

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