PROCEEDINGS OF SCIENCE

EFT constraints from top quark measurements in CMS

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Effective Field Theories (EFTs) offer a systematic way of parametrising small deviations from the Standard Model (SM) originating from new phenomena. In the top quark sector, by using the full potential of the second run of the LHC, the CMS Collaboration is able to perform precision measurements of well-studied top interactions as well as measure rarer top processes. This offers the exciting opportunity to probe new physics using the Standard Model Effective Field Theory (SMEFT) framework not only in pure top processes, but also in processes that connect the top quark with other sectors. This contribution summarises the latest measurements of SMEFT interactions in top quark processes in proton-proton collision data at a center-of-mass energy of $\sqrt{s} = 13$ TeV with an integrated luminosity of 138 fb^{-1}.

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1. Introduction

The lack of direct evidence of new physical phenomena at the TeV energy scale from the LHC experiments might indicate that physics beyond the Standard Model (BSM) exists only at a much higher energy scale. In this scenario, small effects originating from BSM physics can nonetheless be described in a model agnostic manner by means of Effective Field Theories (EFTs). The Standard Model EFT (SMEFT) is the framework built assuming Lorentz and Gauge invariance on BSM phenomena [1–3]. It introduces effective interactions whose strength are parametrised by the so-called Wilson Coefficients (WCs), which are free parameters to be measured. Due to quantum interference between the effective interactions [4], a global measurement is typically desired, although normally not practical due to the enormous dimensionality of the parameters space. The precision achieved by the CMS experiment in processes involving top quarks makes them very sensitive probes to SMEFT effects. Furthermore, the measurement of processes containing rarer top interactions for example, with the photon Higgs boson (ttH, tHq), with vector bosons (ttZ, ttW, tZq) or additional tops ($tttt$) opens the window for more global and challenging SMEFT measurements. In this context, three results of the CMS Collaboration[5] using its full Run-2 data (138 fb^{-1} collected during 2016-2018) are reviewed [6–8].

2. Experimental results

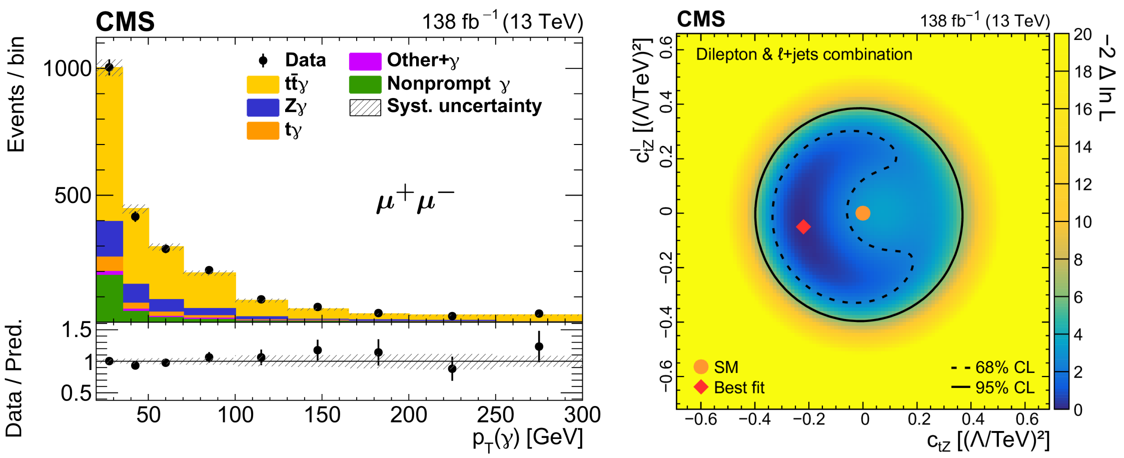

Figure 1: Post fit event yields as a function of the reconstructed photon p_T for the $\mu^+\mu^-$ channel (left) [6]. Results from the two dimensional scan of the WCs c_{tZ} and c^I_{tZ} using the combination of the reconstructed photon p_T in the dilepton [6] and the ℓ+jets [9] channels (right).

A measurement of the inclusive and differential $t\bar{t}\gamma$ cross sections together with a SMEFT measurement [6] is performed in final states containing two oppositely charged lepton ($e^\pm\mu^\mp$, e^+e^-, $\mu^+\mu^-$). It defines a fiducial phase space such that photons (γ) radiated by initial-state particles, top quarks or any of their decay products are included. Requirements of at least one jet coming from the hadronisation of a bottom quark and exactly one photon with transverse momentum above 20 GeV defines its signal region. A EFT interpretation is performed and includes a combination with a similar measurement by CMS using final states with one charged lepton and jets (ℓ+jets) [9], an orthogonal fiducial phase space. Two Wilson Coefficients entering in the $t\bar{t}\gamma$ interaction, c_{tZ} and c^{I}_{tZ}, are simultaneously measured from a profiled likelihood fit to the reconstructed photon transverse momentum (p_T) distribution. The fit also constrains nuisances parameters corresponding to several sources of systematic uncertainties. Figure 1 (left) shows SM predictions and observations for the photon p_T in the $\mu^+\mu^-$ channel after the likelihood fit has been performed. All observations are consistent with the SM expectations within uncertainties. Figure 1 (right) presents the two-dimensional confidence contours corresponding to the simultaneous fit of c_{tZ} and c^{I}_{tZ} combined with the ℓ+jets channel. No deviations from the Standard Model are found within the 95% confidence limits. It has been observed that the excluded parameter space is larger when combining with the ℓ+jets results. This is understood from the fact that both searches are complementary to each other. While the dilepton channel benefits from very small backgrounds contributions, the ℓ+jets channel has a significantly higher amount of events specially in the tails of the photon p_T distributions, the most sensitive region to SMEFT effects.

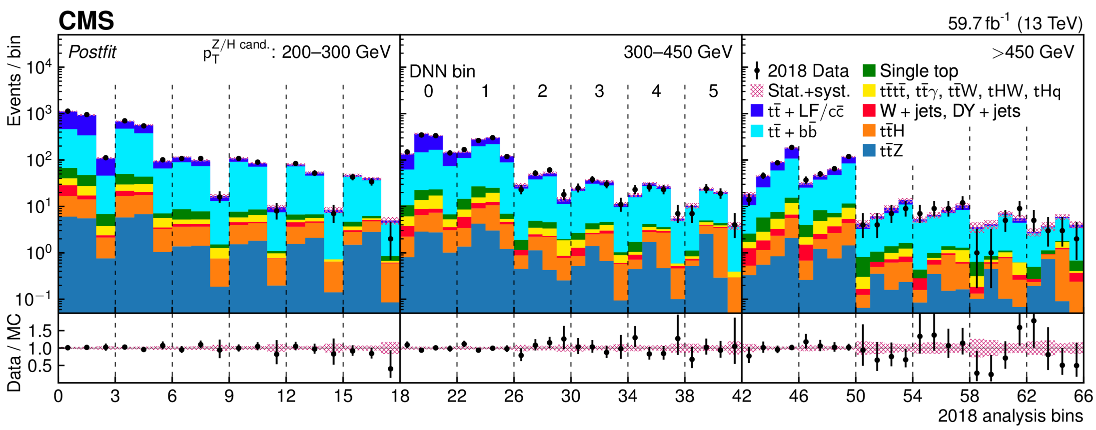

Figure 2: Post fit distribution of the large-radius jet (Z/H candidate) invariant mass m_{SD} in bins of the DNN score and its p_T [7].

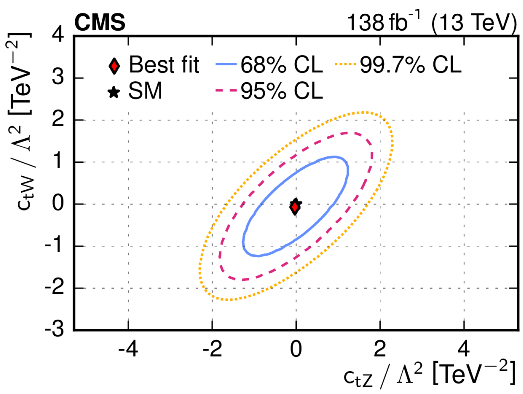

Figure 3: Two dimensional confidence contours of c_{tW} and c_{tZ} while having other WCs set to their SM value [7].

A SMEFT search is also performed in events containing top quark pairs produced in association with a Lorentz-boosted Z or Higgs boson ($t\bar{t}Z$ or $t\bar{t}H$) [7]. Eight Wilson Coefficients modifying the

$t\bar{t}Z$ and $t\bar{t}H$ production are probed. Events have been selected by requiring a single charged lepton (e , μ) and hadronic jets. Two of these jets must be identified as coming from the hadronisation of bottom quarks, targeting $t\bar{t}$ events, and one must be a large-radius jet with high transverse momentum (p_T). The latter targets a boosted H/Z decaying into a pair of bottom quarks. A deep neural network (DNN) multiclass classifier has been trained to discriminate between $t\bar{t}Z$ and $t\bar{t}H$ events and the $t\bar{t}$ + jets backgrounds. Further discrimination power is achieved by measuring the large-radius jet invariant mass m_{SD} and the p_T of the same jet in the region $p_T > 200$ GeV. They discriminate $t\bar{t}Z/t\bar{t}H$ by reconstructing the mass of Z or H and probe the most sensitive to SMEFT effects, respectively. A profiled likelihood fit is used to constrain SMEFT coefficients and nuisances corresponding to various systematic uncertainties simultaneously. Figure 2 shows the expected and observed post fit yields of the m_{SD} mass in bins of both the DNN score and the p_T distribution of the Z/H candidate, in a subset of corresponding to the 2018 data-taking period. The events are consistent with the SM expectation, with the less populated bins (50th-66th) suffering from large statistical fluctuations. Figure 3 shows the confidence contours coming from the two dimensional fit of two Wilson coefficient, c_{tW} and c_{tZ}, while the other six coefficients have been fixed to their SM value. The coefficients c_{tW} and c_{tZ} modify the $t\bar{t}Z$ vector coupling and are related to each other, hence it is not surprising that a high correlation between them is observed.

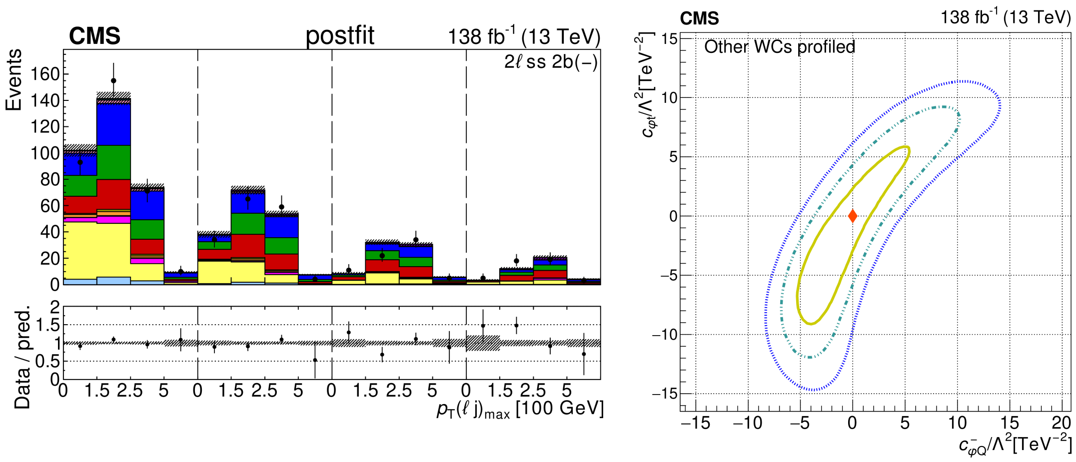

Figure 4: Post fit distribution of the variable $p_T(lj)_{max}$ in bins of the jet multiplicity for a category of events containing two charged leptons with the same sign, a negative lepton charge sum and two hadronic b jets (left). Confidence contours from a two dimensional scan of $c_{\phi t}$ and $c^{-}_{\phi Q}$ while the remaining 24 WCs are profiled (right) [8].

Finally, a global search is performed in top quark production with additional final-state leptons [8], probing effects from 26 SMEFT parameters. Operators that couple the top quark to all leptons, bosons (g, γ, H, W and Z), light quarks and heavy quarks are explored. They contribute to processes containing top quark pairs associated with an extra heavy boson ($t\bar{t}Z$, $t\bar{t}W$ and $t\bar{t}H$), single top quarks in association with a Higgs or Z boson and a lighter quark (tHq and tZq), four heavy quarks ($t\bar{t}b\bar{b}$, $t\bar{t}t\bar{t}$) as well as top pairs in final states with additional leptons off the mass shell ($t\bar{t}l\bar{l}$, $t\bar{t}l\bar{\nu}$). In order to discriminate processes with different composition, events are separated with respect to five subcategories, increasing the statistical power of the search. They are classified with respect to to the number of charged leptons, the number of jets identified as originating from bottom quarks, the sum of the lepton charges and the total number of jets. For events containing exactly three charged leptons, they are further classified as belonging or not to the Z window, *i.e.* if they have or not lepton pairs coming from the decay of a Z boson. In all these categories, a kinematics variable sensitive to SMEFT effects is measured. For most categories it is $p_T(lj)_{max}$, which is constructed by summing vectorially the momenta of all possible pair of particles in a collection made of leptons and jets and picking the pair with highest p_T. Figure 4 (left) shows the expected and observed yields of the $p_T(lj)_{max}$ distribution in bins of jet multiplicity in the category containing two charged leptons with the same sign charge, two hadronic b jets and negative sum of lepton charge, after a profiled likelihood fit. The fit is also able to constrain systematic effects. Overall a good agreement with the SM predictions is found. Figure 4 (right) shows two dimensional confidence contours for $c_{\phi t}$ and $c^{-}_{\phi Q}$. Because both modify the $t\bar{t}Z$ vector coupling and interfere with each other, a non-linear correlation pattern is observed.

3. Summary

Three analyses using the complete Run-2 data of the CMS detector to search for BSM physics by means of an EFT approach in the top quark sector have been summarised. A measurement of top pair production associated with photons in dileptonic final states probes modifications to the $t\bar{t}\gamma$ coupling. Its combination with a similar measurement in final states containing lepton and jets provides the most stringent limits to date to c_{tZ} and c^{I}_{tZ}. A search for top pairs associated with boosted Higgs or Z bosons probes 8 Wilson coefficients modifying the $t\bar{t}H$ and $t\bar{t}Z$ interaction. A DNN is trained to discriminate signal and background in the region with $p_T^{Z/H} > 200$ GeV. Finally, a search in top quark events with additional final-state leptons measures 26 EFT parameters. This is the highest number of SMEFT parameters measured in a single measurement in the top sector at the LHC. No significant deviation from the Standard Model have been found in any of these analyses. The excluded parameter space has been significantly improved and important non-negligible correlations between SMEFT parameters have been measured.

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