PROCEEDINGS OF SCIENCE

Results and prospects on an EFT interpretation of the tWZ process

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The production of a single top quark t in association with a W and a Z boson receives large contributions from beyond-the-standard-model (BSM) theories, particularly through the electroweak interaction of the top quark. This talk presents a study on the sensitivity of the tWZ process to such effects in the form of effective field theory (EFT) operators. The study is based on the recently published results by the CMS experiment, which provided the first evidence for this process. Additionally, new possible analysis strategies aimed at maximizing the sensitivity to EFT operators will be highlighted in order to exploit the full potential of the LHC.

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1. The tWZ process

Processes involving top quarks (t) and electroweak (EW) gauge bosons (W, Z, γ) offer a strong sensitivity to physics effects beyond the Standard Model (BSM) and provide an opportunity to explore the top quark-electroweak interaction [1]. In this context, the $pp \to tWZ$ process is crucial for testing the weak couplings of the top quark, as it is sensitive to potential unitarity-violating effects resulting from changes in the electroweak sector. The key role of the tWZ process in the exploration of the electroweak force in the top quark sector is due to the simultaneous presence of the top-bottom quark electroweak interaction and the self-interaction of the two massive electroweak bosons. This differentiates tWZ from the QCD-induced $t\bar{t}Z$ process, providing higher sensitivity to BSM effects despite the similar final state.

2. EFT interpretation of the tWZ measurement by CMS

The CMS collaboration reported the first evidence of tWZ production in multi-lepton final states [2]. This analysis measured a cross-section of $354 \pm 54(\text{stat}) \pm 95(\text{syst})$ fb using an integrated luminosity of 138 fb^{-1}, corresponding to the data collected from 2016 to 2018 from the CMS experiment.

We provide a possible EFT interpretation focusing on the effect of two of the most sensitive operators for the tWZ process [3], namely the O_{tZ} and the $O^3_{\phi Q}$ operators. The $O^3_{\phi Q}$ operator is defined following the Warsaw basis convention [4], while the O_{tZ} operator is defined as

$$O_{tZ} = -\sin\theta_W O_{tB} + \cos\theta_W O_{tW} \,. \tag{1}$$

The operators on the right-hand side refer to the Warsaw basis convention, while θ_W is the weak mixing angle.

The $t\bar{t}Z$ and the tWZ processes share a very similar final state, significantly complicating the experimental identification of tWZ. For this reason, the effect of the O_{tZ} and $O^3_{\phi Q}$ operators are studied for both processes simultaneously. The two processes are generated using Madgraph5 aMC@NLO [5], while we simulate the EFT effects with the SMEFT@NLO [6] model. We generate tWZ and $t\bar{t}Z$ at $\sqrt{s}$ = 13 TeV under the SM assumption, using the diagram removal technique [7] in the simulation of tWZ. The two processes are simulated at next-to-leading order in QCD, using PYTHIA8 [8] to model the parton shower. To add the effects of the EFT operators we use the reweighting method [9] simulating different BSM points. The new physics scale is chosen to be Λ = 1 TeV and includes quadratic terms proportional to Λ^{-4}.

To reproduce the CMS result [2], we apply realistic efficiencies and acceptances from the CMS experiment to the simulation of the tWZ and $t\bar{t}Z$ processes. The event yields of background processes, such as diboson processes, processes involving top quarks, as well as background from misidentified leptons, are obtained from the CMS measurement. We consider three- and four-lepton final states and for each final state, the events are separated into a tWZ signal region (SR) and a $t\bar{t}Z$ control region (CR). This split is performed to reproduce the CMS signal identification efficiency obtained employing a Machine Learning algorithm. Including the same set of systematics uncertainties of the CMS measurement [2], we are able to reproduce the signal yields and signal

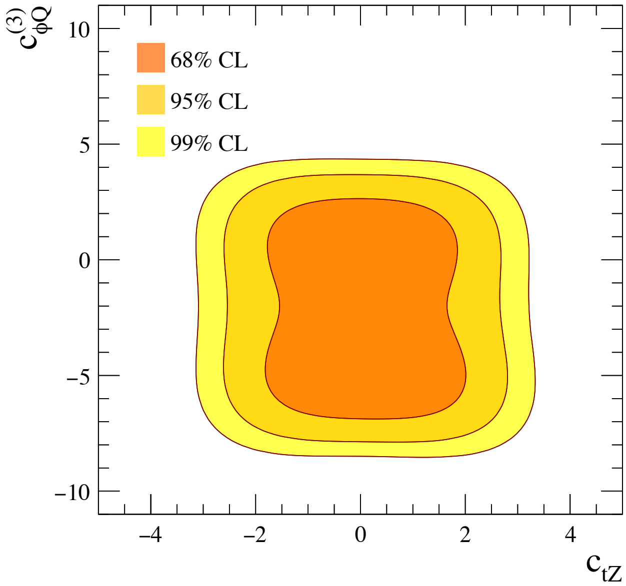

Figure 1: Constraints from a fit to $t\bar{t}Z$ and tWZ on the SMEFT operators O_{tZ} and $O_{\phi Q}^{(3)}$, for $\Lambda = 1$ TeV. The orange, light orange, and yellow shaded areas show the observed limits on the two Wilson coefficients respectively at 68%, 95%, and 99% confidence levels.

strengths for $t\bar{t}Z$ and tWZ within 10%. This result is interpreted in the context of the SMEFT and the results are shown in Figure 1.
The orange, light orange, and yellow shaded areas show the observed limits respectively at 68%, 95%, and 99% confidence levels on the two Wilson coefficients.
While the sensitivity to the $O_{\phi Q}^{(3)}$ operator is not competitive with the current best limits, the constraint on the O_{tZ} operator can already be helpful to improve global fits.

3. Prospects for future tWZ measurements

An inclusive measurement doesn't exploit the full potential of the tWZ process. For this reason, in this section, we simulate the results of a differential measurement in the transverse momentum of the Z boson.
This is performed by simulating different integrated luminosity scenarios to eventually show the results assuming the total integrated luminosity planned for the High-Luminosity LHC. Besides the increase in statistics, the systematic uncertainties are also reduced following an approximate $\sqrt{L}$ scaling. Additionally, we assume improved analysis methods resulting in a better signal separation. The results for the inclusive and differential measurements are shown in Figure 2.
The dashed line corresponds to the expected limits at 95% confidence level on c_{tZ} and $c_{\phi Q}^{3}$ from the CMS analysis with an integrated luminosity of 138 fb^{-1}. Subsequent blue shading corresponds to increasing the luminosity using the 138 fb^{-1} results as the baseline. Instead, the differential results for the different integrated luminosity scenarios are shown in shades of red.
Even with just 300 fb^{-1}, it will already be possible to perform a differential measurement, over-

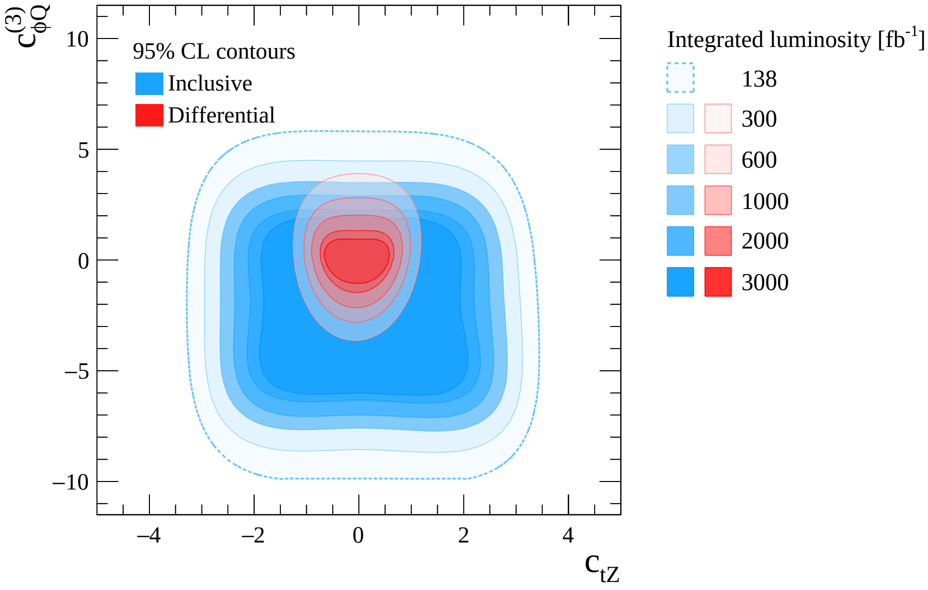

Figure 2: Constraints from a fit to $t\bar{t}Z$ and tWZ simulated data on the SMEFT operators O_{tZ} and $O_{\phi Q}^{(3)}$, for $\Lambda = 1$ TeV. The blue-shaded area shows constraints from inclusive measurements, while the red-shaded area refers to constraints including differential $p_{T,Z}$ measurements. The outermost blue area bounded by the dashed line corresponds to expected constraints from the CMS Run 2 measurement of tWZ production [2]

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coming the limitations of the inclusive selection and achieving significantly better results than an inclusive measurement, with a tenfold improvement in statistics [10].

4. Conclusions

The tWZ process is a very promising process to probe the top-electroweak interaction with the possibility of parameterizing possible BMS effects in terms of the SMEFT. At the moment, the sensitivity to SMEFT effects is defined by the limited statistics. For this reason, its potential has been only partially exploited but the collection of additional data will open up the possibility to perform differential measurements and set competitive constraints on SMEFT operators.

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