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Inclusive and differential measurement of the single top quark cross-section in association with a W boson in the $e\mu$ channel with CMS

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Measurements of the inclusive and normalised differential cross sections are presented for the production of single top quarks in association with a W boson in proton-proton collisions at a centre-of-mass energy of 13 TeV. The data used were recorded during 2016–2018 with the CMS detector at the LHC, and correspond to an integrated luminosity of 138 fb^{-1}. Events containing one electron and one muon in the final state are analysed.

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1. Introduction

The top quark is the most massive particle in the standard model (SM). It was discovered by the D0 [1] and CDF [2] Collaborations at the Fermilab Tevatron collider. There are two main production modes of top quarks at the LHC: single top quark production, and top quark pair ($\mathrm{t\bar{t}}$) production. Single top production is mediated by the electroweak interaction and can be produced via the s-channel, t-channel, and tW channel. The tW production cross section is computed at approximate next-to-next-to-leading order (aNNLO). The corresponding theoretical prediction for the tW cross section in pp collisions at $\sqrt{s} = 13$ TeV, assuming a top quark mass (m_{t}) of 172.5 GeV, is

$$\sigma_{\mathrm{tW}}^{\mathrm{SM}} = 71.7 \pm 1.8(\mathrm{scale}) \pm 3.4(\mathrm{PDF})\ \mathrm{pb}\ [3]. \quad (1)$$

One important aspect of the tW process is its interference with $\mathrm{t\bar{t}}$ at next-to-leading order (NLO) in QCD. To avoid double counting, two schemes can be used to define the signal: diagram removal (DR) and diagram substraction (DS). The DR scheme removes all doubly resonant diagrams from the matrix element calculation, whereas DS introduces a gauge invariant term that locally cancels doubly resonant diagrams.

This document reports a measurement of the inclusive and normalised differential tW production cross sections at $\sqrt{s} = 13$ TeV [4] using data collected with the CMS detector [5] during 2016–2018.

2. Event selection

The tW process is studied in its $e^{\pm}\mu^{\mp}$ final state which corresponds to the decay chain $\mathrm{tW} \rightarrow 1\mathrm{b} + e^{\pm}\mu^{\mp} + 2\nu$. Taking this into account, a baseline event selection is performed by requiring that: the two most energetic (leading) leptons in the event are an electron and a muon of opposite charge, the leading lepton has a $p_{\mathrm{T}} > 25$ GeV, and the invariant mass of the dilepton pair is greater than 20 GeV.

After the baseline event selection a categorisation based on the number of jets and b-tagged jets is performed as shown in Fig. 1. For the inclusive measurement the regions with one b-tagged jet (1j1b), two jets and one of them b-tagged (2j1b) and two b-tagged jets (2j2b) are used. For the differential measurement, only the 1j1b region with 0 loose jets (jets with 20 GeV $< p_{\mathrm{T}} <$ 30 GeV) is used. The number of loose jets distribution is shown in Fig. 1.

3. Inclusive measurement

After the baseline event selection, the amount of background events is considerably larger than the tW signal. The $\mathrm{t\bar{t}}$ background largely populates the signal regions 1j1b and 2j1b. As there is no single observable able to discriminate between $\mathrm{t\bar{t}}$ and tW, two boosted decision trees (BDT) are trained, one in the 1j1b region and the other in the 2j1b region. The 2j2b region is used as a $\mathrm{t\bar{t}}$ control region to constrain this main source of background.

The signal is extracted by performing a simultaneous maximum likelihood (ML) fit to the distributions of the BDT output in the 1j1b and 2j1b regions and the subleading jet p_{T} in the 2j2b

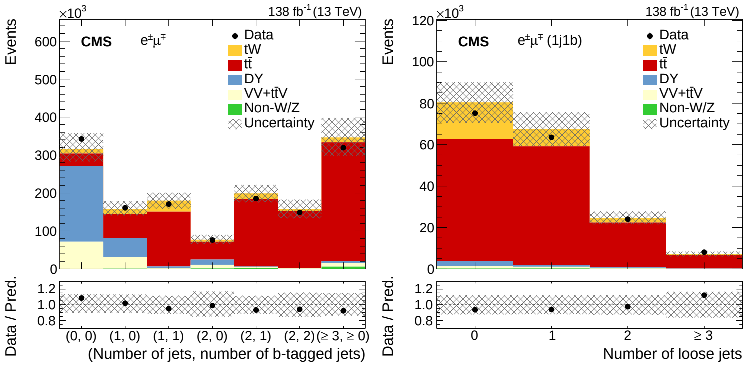

Figure 1: Yields observed in data, compared with those expected from simulation as a function of the number of jets and number of b-tagged jets for events passing the baseline dilepton selection (left), and the number of loose jets in the 1j1b region. The error band includes the statistical and all systematic uncertainties. The bottom of each panel shows the ratios of data to the sum of the expected yields [4].

region. Figure 2 shows the postfit distributions of the three variables that enter in the fit. The measured tW inclusive cross section obtained is

$$\sigma_{\mathrm{tW}} = 79.2 \pm 0.9(\mathrm{stat})\ ^{+7.7}_{-8.0}(\mathrm{syst}) \pm 1.2(\mathrm{lumi})\ \mathrm{pb}, \tag{2}$$

compatible with the SM prediction of Eq. 1.

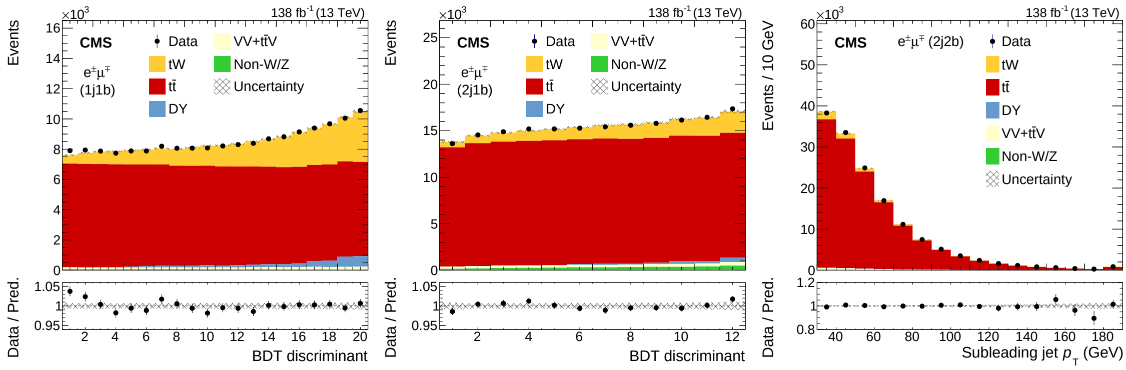

Figure 2: The distributions of the BDT outputs for events in the 1j1b (left) and 2j1b (centre) regions, and the subleading jet p_{T} for the 2j2b region (right). The data (points) and the montecarlo (MC) predictions (coloured histograms) after the fit are shown. The vertical bars on the points represent the statistical uncertainty in the data, and the hatched band the total uncertainty in the MC prediction [4].

4. Differential measurement

The differential measurement is performed in the 1j1b region with a veto on the number of loose jets. To correct for the efficiency and acceptance of the detectors, unfolding techniques must be used. The measured distributions are unfolded from the detector level to the particle level.

Signal extraction and unfolding are performed at the same time with an ML fit. After the ML fit, the result is normalised to the fiducial cross section (obtained from the summation of the contents of the bins), and the bin width. The measured differential cross sections as a function of the leading lepton p_T and $m(e^{\pm}, \mu^{\mp}, j)$ are shown in Fig. 3.

All MC predictions show similar compatibility with the measurements, as well as small differences among them. The uncertainties are between 10–50% in most cases, depending on the distributions and bins.

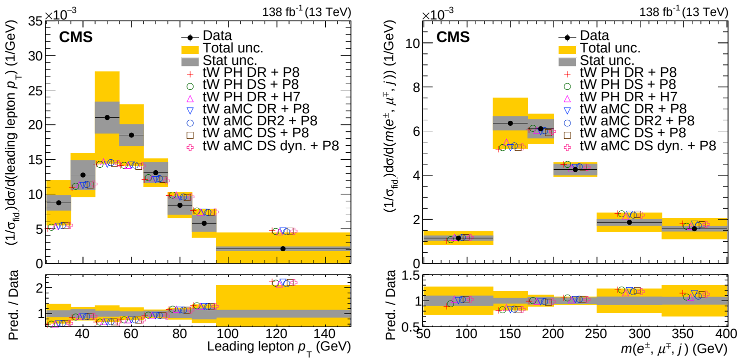

Figure 3: Normalised fiducial differential tW production cross section as functions of the p_T of the leading lepton (left), and $m(e^{\pm}, \mu^{\mp}, j)$. Predictions from various MC generators are included. The grey band represents the statistical uncertainty and the orange band the total uncertainty [4].

5. Summary

Inclusive and normalised differential cross sections measurements for the tW production have been presented. All results were compatible with predictions from the standard model within uncertainties. A 10% of relative uncertainty is achieved for the inclusive measurement, making this measurement the most precise up to date of the tW cross section.

References

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