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Recent measurements of top-associated cross sections in low pileup conditions in pp collisions at $\sqrt{s}$ =5.02 TeV

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We present the most recent measurements of top production cross sections in proton-proton collisions at a center-of-mass energy of 5.02 TeV. The dataset used was recorded in 2017 by the CMS experiment at the LHC in special runs, featuring a low-pileup environment, which offers a clean setting for precise cross-section measurements. More precisely, the two dominant top quark production processes, pair production ($\mathrm{t\bar{t}}$) and single top production in the so-called t channel are measured. The measured cross section for the pair production case is $\sigma(\mathrm{t\bar{t}}) = 62.3 \pm 1.5(\mathrm{stat}) \pm 2.7(\mathrm{syst})$ pb, consistent with Standard Model (SM) predictions. For the single top quark production in the t channel, a cross section of $\sigma(\mathrm{tq}+\mathrm{\bar{t}q}) = 30.2 \pm 3.7(\mathrm{stat}) \pm 4.3(\mathrm{syst})$ pb is measured. In addition, the top quark and antiquark cross sections are extracted and found to be $\sigma(\mathrm{tq}) = 21.1 \pm 2.9(\mathrm{stat}) \pm 2.8(\mathrm{syst})$ pb and $\sigma(\mathrm{\bar{t}q}) = 8.2 \pm 2.4(\mathrm{stat}) \pm 1.9(\mathrm{syst})$ pb, respectively. Finally, their ratio is also measured to be $\mathcal{R}_{t-ch} = 2.58^{+1.10}_{-0.67}(\mathrm{stat})^{+0.67}_{-0.21}(\mathrm{syst})$. These measurements are in good agreement with the SM.

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Introduction

The top quark is the heaviest known fundamental particle and plays a critical role in particle physics. Its unique properties, such as its mass or its short lifetime, make it an ideal subject for studying fundamental aspects of the Standard Model (SM). More precisely, the top quark pair ($t\bar{t}$) production is of crucial importance for precision tests of SM predictions and serves as a window to beyond-the-SM (BSM) physics that could modify its cross section. On the production side of single top quarks in the t channel, this process provides sensitivity to the b-quark parton distribution function (PDF), in particular through the top quark-antiquark cross-section ratio. Moreover, the production rate is proportional to the square of the Cabibbo–Kobayashi–Maskawa matrix element V_{tb} , allowing for a direct measurement of this quantity. These two processes are, in the same order as presented here, the dominant production processes of the top quark at the LHC at all center-of-mass (CM) energies.

This summary covers two recent analyses by the CMS Collaboration[1], namely the cross section measurements of $t\bar{t}$ [2] and t-channel [3] processes. Both use data collected at 5.02 TeV with an integrated luminosity of 302 pb^{-1}. The low-pileup environment of that dataset allows for a focused investigation of the signal processes without significant contamination from additional collisions.

Apart from $t\bar{t}$ and t-channel signals, other processes which are considered as background like single top production in the tW and s-channel, a W boson in association with additional jets, known as W+jets (and splitted according to the additional jets' flavour in the second analysis) and Drell–Yan, known as DY, are modeled using Monte Carlo (MC) samples. Also quantum chromodynamics (QCD) multijet events are incorporated into the analysis via a data-driven estimation. In these analyses, single lepton triggers are used, thus retaining events in which the trigger detects at least one electron (muon) with $p_T > 20$ (17) GeV.

1. Analysis of $t\bar{t}$ production cross section

1.1 Analysis strategy

Apart from the requirements stated in the introduction, an additional selection is applied to enhance the sample purity. Events are required to contain exactly one lepton (either an electron or a muon) with $p_T > 20$ GeV and $|\eta| < 2.4$. Events containing a second lepton of opposite flavor with $p_T > 10$ GeV are vetoed, and at least three jets with $p_T > 25$ GeV and $|\eta| < 2.4$ are required. Events are further split into eight categories according to the number of jets and jets being identified as b quarks (b-tagged jets) and to lepton flavor. In such a way, categories are defined for events with 3 and ≥ 4 jets, further divided into events with 1 or ≥ 2 b-tagged jets, and denoted as 3j1b, 4j1b, 3j2b and 4j2b. Finally, events are required to have a missing transverse energy greater than 30 GeV.

In such a scenario, 4j1b, 3j2b and 4j2b categories are very pure in signal, while 3j1b has a noticeable contribution from W+jets background (and minor from other backgrounds). Therefore, in those regions a multivariate analysis (MVA) classifier, a random forest, is trained to separate the $t\bar{t}$ signal from the W+jets background.

For the purpose of extracting the cross section, a maximum likelihood (ML) fit is performed over the 8 categories of the analysis, where the systematic uncertainties are included into the fit as nuisance parameters. In the 3j2b, 4j1b and 4j2b categories, the $\Delta R_{\text{med}}(\text{j}, \text{j}')$ distribution is used, given its discriminative power whereas in the 3j1b ones, the MVA output discriminator is the fitted variable. Those distributions (post-fit) can be seen in Figure 1.

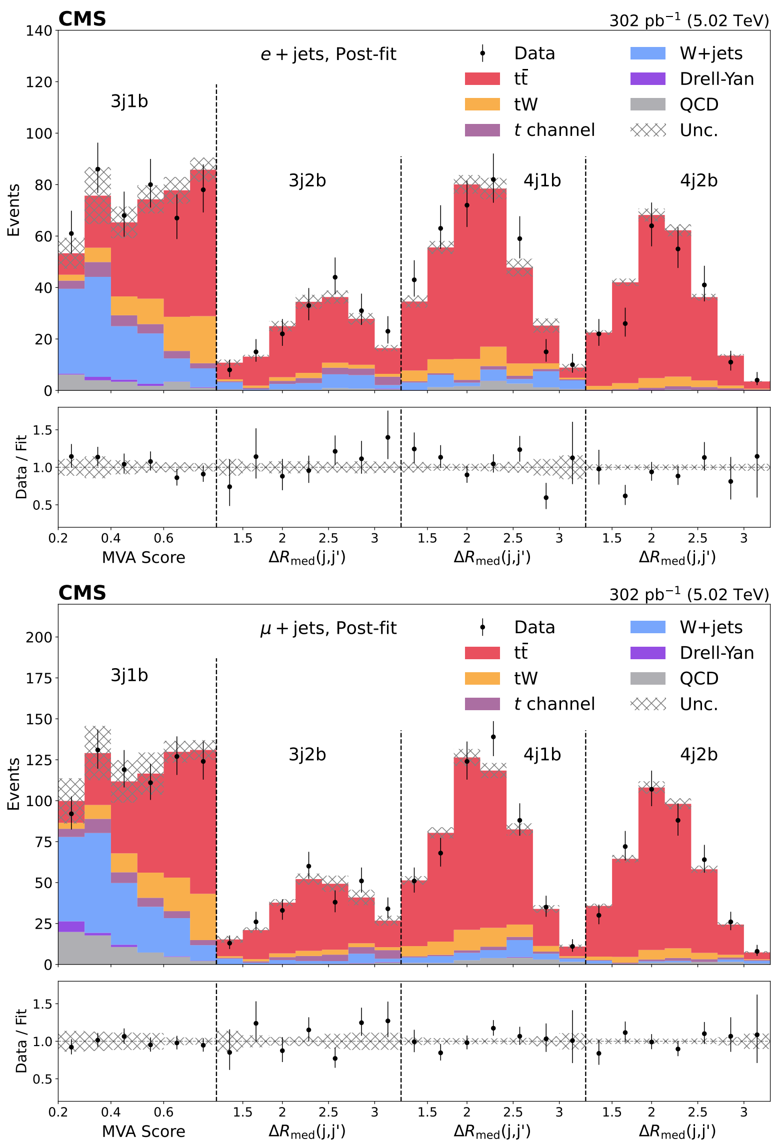

Figure 1: Distributions for the electron+jets (upper plot) and muon+jets (lower plot) final states used for the ML fit: MVA score bins for the 3j1b category and $\Delta R_{\text{med}}(\text{j}, \text{j}')$ bins for the other categories. Post-fit data (points), predictions (filled histograms) and their ratio are shown [2].

1.2 Results

The measured inclusive cross section after the ML fit results in $\sigma(\text{t}\bar{\text{t}}) = 62.5 \pm 1.6(\text{stat}) \pm 2.9(\text{syst})$ pb and is combined with prior measurements in the dilepton channel[4], resulting the combination $\sigma(\text{t}\bar{\text{t}}) = 62.3 \pm 1.5(\text{stat}) \pm 2.7(\text{syst})$ pb. The dominant uncertainties are the ones associated with the integrated luminosity and with the b tagging scale factors for heavy flavor jets. Moreover, the obtained values are consistent with the SM prediction of 69.5 ± 3.6 pb at next-to-next-to-leading order (NNLO) in perturbative QCD (pQCD)[5]. A summary of the measurement presented here, together with previous CMS and ATLAS measurements at different CM energies is shown in Figure 3 (left). This result is the most precise $\mathrm{t\bar{t}}$ cross section measurement performed by the CMS experiment at this CM energy.

2. Analysis of single top t-channel production cross section

2.1 Analysis strategy

Following a strategy similar to the one of the $\mathrm{t\bar{t}}$ measurement, events are required to contain exactly one lepton (either electron or muon) with $p_\mathrm{T} > 20$ GeV, $|\eta| < 2.4$, and exactly two or three jets. The jets are required to have $p_\mathrm{T} > 25$ GeV and $|\eta| < 4.7$, and the events are further split into twelve categories according to the number of jets and b-tagged jets and to lepton flavor and charge. In such a way, categories are defined for events with 2 jets and 1 b-tagged jet and 3 jets, further divided into events with 1 or 2 b-tagged jets, and denoted as 2j1b, 3j1b and 3j2b. In addition, events are required to have a missing transverse energy greater than 30 GeV, a transverse mass of the lepton and missing transverse energy (m_T^W) greater than 50 GeV. Finally, the scalar sum of the transverse momenta of jets, lepton, and missing energy must be greater than 170 GeV.

After this event selection, the four 2j1b categories are the most dominant in signal events while the eight 3j1b and 3j2b categories serve as $\mathrm{t\bar{t}}$ control regions. Although the 2j1b categories dominate in signal contribution, they include significant W+jets and $\mathrm{t\bar{t}}$ contributions. For that reason, a MVA classifier is trained to separate the t-channel signal from those two dominant backgrounds in those regions.

In order to extract the cross section, similarly to the previous analysis presented in this summary, a ML fit is done over the 12 categories, including the systematic uncertainties as nuisance parameters. The distributions included in the fit are the MVA output for the 2j1b regions and the leading non b-tagged jet's absolute pseudorapidity ($|\eta_{\mathrm{u}_0}|$) in the 3j1b and 3j2b categories. Those post-fit ditributions can be seen in Figure 2.

In addition to the ML fit performed to extract the total cross section, two more ML fits with different parameters of interest are done to the same distributions in order to extract the individual top quark and top antiquark cross sections, as well as their ratio.

2.2 Results

The total t-channel cross section is found to be $\sigma(\mathrm{tq}+\mathrm{\bar{t}q}) = 30.2 \pm 3.7(\mathrm{stat}) \pm 4.3(\mathrm{syst})$ pb, whereas the top quark cross sections results in $\sigma(\mathrm{tq}) = 21.1 \pm 2.9(\mathrm{stat}) \pm 2.8(\mathrm{syst})$ pb and the top antiquark cross section, $\sigma(\mathrm{\bar{t}q}) = 8.2 \pm 2.4(\mathrm{stat}) \pm 1.9(\mathrm{syst})$ pb. Finally, their ratio is measured to be $\mathcal{R}_{t-ch} = 2.58^{+1.10}_{-0.67}(\mathrm{stat})^{+0.67}_{-0.21}(\mathrm{syst})$. The dominant uncertainties in these four measurements are W+jets normalization, b-tagging efficiencies and jet energy scales.

The results are in good agreement with the SM values of $\sigma(\mathrm{tq}+\mathrm{\bar{t}q}) = 30.3^{+0.5}_{-0.7}$ pb, $\sigma(\mathrm{tq}) = 20.3^{+0.5}_{-0.4}$ pb, $\sigma(\mathrm{\bar{t}q}) = 10.0^{+0.3}_{-0.2}$ pb and $\mathcal{R}_{t-ch} = 2.07^{+0.041}_{-0.047}$, calculated at NNLO order in pQCD [6].

A summary of the total t-channel cross section measurement, together with previous CMS measurements at different CM energies is shown in Figure 3 (right). These results are the most precise t-channel associated measurements performed by the LHC experiments at this CM energy.

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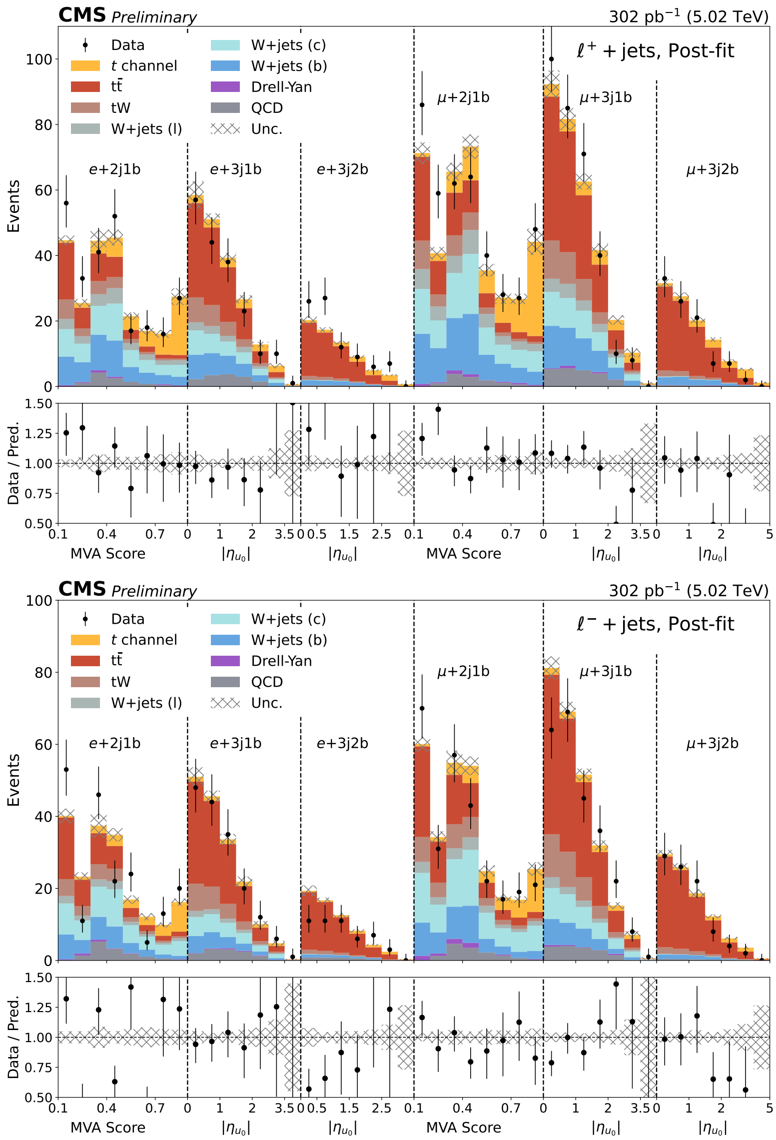

Figure 2: Distributions for the positively charged lepton+jets (upper plot) and negatively charged lepton+jets (lower plot) final states used for the ML fit: MVA score bins for the 2j1b categories and leading non b-tagged jet's absolute pseudorapidity bins for the other categories. Post-fit data (points), predictions (filled histograms) and their ratio are shown [3].

Summary

This contribution summarizes two recent CMS measurements of top-quark production cross sections in proton–proton collisions at $\sqrt{s}$ = 5.02 TeV, corresponding to an integrated luminosity of 302 pb^{-1}. The results include the inclusive $t\bar{t}$ production cross section and the inclusive single top-quark and antiquark cross sections in the t channel, their sum, and their ratio. All measurements are consistent with Standard Model predictions, constituting the associated with the top pair production (single top t-channel production) the most precise cross section measurement performed by the CMS (LHC) experiment(s) at this center-of-mass energy.

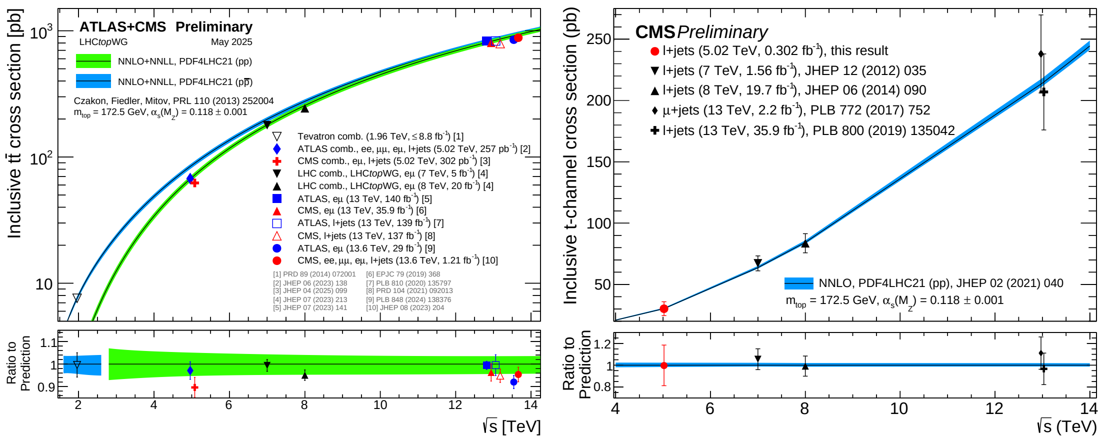

Figure 3: Summary of the most recent $t\bar{t}$ (left) and t-channel (right) cross section measurements from the CMS and ATLAS [7] Collaborations for different CM energies, including the ones presented in this summary [2, 3].

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