Inclusive top pair production at 7, 8 and 13 TeV in CMS

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This document presents a summary of recent measurements of the inclusive top pair cross section performed by the CMS collaboration. These studies were performed with data taken with $\sqrt{s} =$7, 8, and 13 TeV proton-proton collisions at the LHC. Several final state topologies were studied; the most precise results were achieved using dilepton final states, but results from analyses using events containing only jets and using hadronically decaying τ leptons are also presented. These results are compared with current theoretical calculations (NNLO-NNLL), which are found to be in good agreement with the measured values.

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1. Introduction

The top quark is the heaviest quark in the Standard Model and is the focus of several areas of study with the CMS detector. Inclusive cross section measurements are of particular importance as theoretical calculations of this cross section are available with a precision of 5-10% [1], a level now matched by the precision of current measurements. This allows such measurements to stringently test theoretical calculations and probe the existence of physics beyond the Standard Model.

These measurements have been performed in several decay topologies and six of the most recent meausurements performed by CMS in these different channels are presented here. These results make use of the 2011 7 TeV, 2012 8 TeV, and 2015 13 TeV datasets, using up to $5fb^{-1}$, $20fb^{-1}$, and $42pb^{-1}$ respectively.

## 2. Measurements using Hadronically Decaying τ Leptons

Top pair decays with τ leptons in the final state are of particular interest as several new physics scenarios produce enhancements to the expected number of events with this topology. An analysis of the final state with one hadronically decaying W boson and one τ-producing W boson was performed in the $\sqrt{s} =$7 TeV dataset with $3.9fb^{-1}$ [2]. Hadronic tau candidates were reconstructed by identification of their decay products. An artificial neural network was used to create a discriminating variable and a binned negative log-likelihood fit of this discriminator was performed to extract the normalization of the signal and background. The corresponding cross section was found to be $\sigma_{t\bar{t}} = 152 \pm 12(stat.) \pm 32(syst.) \pm 3(lum.)pb$, with the dominant contribution to the uncertainty coming from the jet energy scale.

Events with one electron or muon and one hadronically decaying τ lepton have also been used to measure the top cross section in $19.6fb^{-1}$ of $\sqrt{s} =$8 TeV data [3]. Possible m_t values are calculated for each event, and only events with suitable solutions are retained for the cross section calculation. Cross sections were extracted in each flavor channel, as shown in Equation 2.1, and then combined. The uncertainty is dominated by the systematic contributions, primarily those from the τ reconstruction.

$$\sigma_{t\bar{t}}(e\tau_h) = 255 \pm 4(stat.) \pm 24(syst.) \pm 7(lum.)pb$$
$$\sigma_{t\bar{t}}(\mu\tau_h) = 258 \pm 4(stat.) \pm 24(syst.) \pm 7(lum.)pb \qquad (2.1)$$
$$\sigma_{t\bar{t}}(combined) = 257 \pm 3(stat.) \pm 24(syst.) \pm 7(lum.)pb$$

3. Measurement With the All-Jets Final State in $\sqrt{s} =$8TeV

The most recent top pair cross section measurement using the all-jets final state was completed using 18.4 fb^{-1} of $\sqrt{s} =$8 TeV data [4]. Events with at least six jets were selected, and b-tagging and kinematic fits of each event were used to remove remaining QCD multijet contamination. Distributions of the reconstructed top mass, as shown in Figure 1, are used in an unbinned maximum likelihood fit and the extracted cross section is $\sigma_{t\bar{t}} = 275.6 \pm 6.1(stat.) \pm 37.8(syst.) \pm 7.2(lumi.)pb$. This results represents a significant improvement in signal purity and reduced systematic uncertainties over the previous result in this channel.
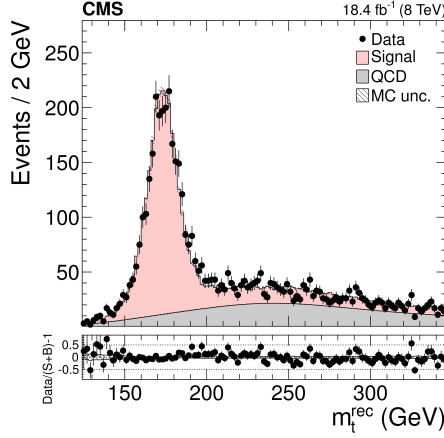
Figure 1: Distribution of top mass values reconstructed in events selected in the all jets analysis performed with $18.4 fb^{-1}$ of $\sqrt{s} = 8$ TeV data.[4]

4. Dilepton Measurement using the $\sqrt{s} = 7$ and 8 TeV Datasets

CMS recently published a simultaneous measurement of the $t\bar{t}$ cross section in the full 7 and 8 TeV datasets [5]. Events containing an $e\mu$ pair were selected without any jet requirements. An extended binned likelihood fit was performed on several sub-categories of events, where events were classified by the number of jets and number of b-tags they contained. For events with multiple jets, the momenta spectra of jets were used in the fit to constrain systematic uncertainties such as the jet energy scale.

$$\sigma_{t\bar{t}}^{vis}(\sqrt{s} = 7TeV) = 3.05 \pm 0.04(stat.) \pm_{0.07}^{0.08}(syst) \pm 0.07(lumi)pb$$
$$\sigma_{t\bar{t}}^{vis}(\sqrt{s} = 8TeV) = 4.24 \pm 0.02(stat.) \pm_{0.10}^{0.11}(syst) \pm 0.11(lumi)pb \qquad (4.1)$$

The visible cross sections extracted from the fit are given in Equation 4.1. This refers to the cross section of events that fall within the kinematic limits of the analysis and was extrapolated to the full phase space to yield the final measurements given in Equation 4.2. The uncertainty on the measurement is dominated by systematic contributions, of which the largest are the lepton identification and trigger efficiency. The jet energy scale contributes less than 1% of the total uncertainty and the total systematic uncertainty is now comparable to the luminosity uncertainty on this measurement. This high level of precision makes these the most precise $t\bar{t}$ cross section measurements produced by CMS.

$$\sigma_{t\bar{t}}(\sqrt{s} = 7TeV) = 174.5 \pm 2.1(stat.) \pm_{4.0}^{4.5}(syst) \pm 3.8(lumi)pb$$
$$\sigma_{t\bar{t}}(\sqrt{s} = 8TeV) = 245.6 \pm 1.3(stat.) \pm_{5.5}^{6.6}(syst) \pm 6.5(lumi)pb \qquad (4.2)$$

5. Measurements With the $\sqrt{s} = 13$ TeV Dataset

The first $\sqrt{s} = 13$ TeV $t\bar{t}$ cross section was measured in the dilepton channel using $e\mu$ events [6]. No b-tagging requirements were made, and the final sample was estimated to be 94% pure. As

shown in Figure 2, the expected sum of signal and background, taken from Monte-Carlo simulations and data-driven estimates, was found to be in good agreement with the observed data. The cross section was measured directly from the observed events; the fiducial and total cross sections are shown in Equation 5.1. The dominant uncertainty on the measurement is the 12% contribution from the luminosity; this uncertainty was derived from preliminary luminosity scans and should improve when full van der Meer scans are performed.
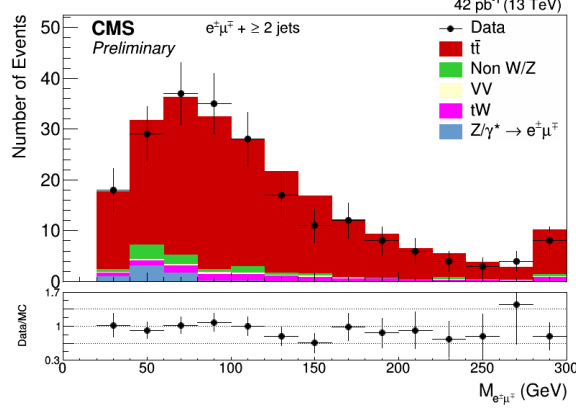
Figure 2: Dilepton mass of $e\mu$ events measured in $42pb^{-1}$ of data taken at $\sqrt{s} = 13$ TeV.[6]

$$\sigma_{t\bar{t}}^{fid} = 12.9 \pm 1.0(stat) \pm 1.1(syst) \pm 1.5(lumi)pb$$
$$\sigma_{t\bar{t}}^{fid} = 772 \pm 60(stat) \pm 62(syst) \pm 93(lumi)pb$$

(5.1)

The lepton+jets final state has also been used to measure the $t\bar{t}$ cross section in the 13 TeV data [7]. This analysis selected one isolated electron or muon with at least four jets and incorporates b-tagging requirements. A kinematic reconstruction of the event was then performed to calculate the properties of the top quarks and to reject additional contamination; the mass of the $\bar{t}t$ system extracted from this reconstruction is shown in Figure 3. The observed cross section is $\sigma_{tot} = 836 \pm 27(stat) \pm 84(sys) \pm 100(lumi)pb$. Like in the dilepton measurement, this is dominated by the 12% uncertainty on the luminosity.

6. Conclusion

In conclusion, CMS has successfully measured the top quark pair cross section in several channels in all available datasets. The uncertainties on these measurements have reached 4% precision and are capable of challenging the NNLO+NNLL theoretical predictions. Two measurements have been performed with the recently recorded $\sqrt{s} = 13$ TeV data and these are shown in comparison with the previous measurements and theoretical expectations in Figure 4. All measurements are in good agreement with theoretical predictions.

References

[1] M. Czakon, P. Fiedler, and A. Mitov, "The total top quark production cross-section at hadron colliders through $O(\alpha_s^4)$", Phys. Rev. Lett. 110 (2013) 252004, doi:10.1103/PhysRevLett.110.252004.
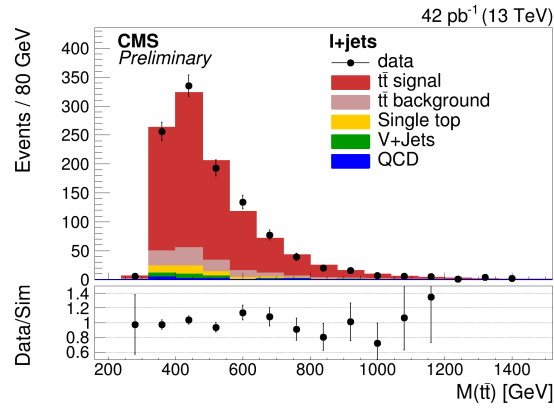
Figure 3: Distribution of the mass of the $t\bar{t}$ system reconstructed in lepton+jets collected in $42pb^{-1}$ of $\sqrt{s}=13$ TeV data.[7]
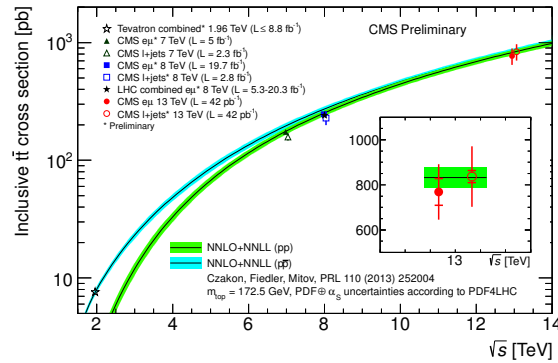
Figure 4: Comparison of inclusive $t\bar{t}$ cross sections predicted and measured as a function of center of mass energy; the recent $\sqrt{s}=13$ TeV measurements are shown in greater detail in the lower right.

[2] CMS Collaboration, "Measurement of the top-antitop production cross section in the tau+jets channel in pp collisisons at $\sqrt{s}=7$ TeV", Eur. Phys. J. C 73 (2013) 2386.

[3] CMS Collaboration, "Measurement of the $t\bar{t}$ production cross section in pp collisions at $\sqrt{s}=8$ TeV in dilepton final states containing one tau lepton", Phys. Lett. B 739 (2014) 23.

[4] CMS Collaboration, "Measurement of the $t\bar{t}$ production cross section in the all-jets final state in pp collisisons at $\sqrt{s}=8$ TeV'", arXiv:1509.06076.

[5] CMS Collaboration, "Measurement of the inclusive top-quark pair production cross section in the $e\mu$ decay channel in pp collisions at $\sqrt{s}=7$ and 8 TeV", CMS-PAS-TOP-13-004.

[6] CMS Collaboration, "Measurement of the top quark pair production cross section in proton-proton collisions at $\sqrt{s}=13$ TeV", arXiv:1510.05302.

[7] CMS Collaboration, "Measurement of the inclusive and differential top quark pair production cross sections in lepton + jets final states at $\sqrt{s}=13$ TeV", CMS-PAS-TOP-15-005.

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