CMS Physics Analysis Summary

Contact: cms-pag-conveners-top@cern.ch 2011/03/16

Combination of top pair production cross sections in pp collisions at $\sqrt{s} = 7$ TeV and comparisons with theory

The CMS Collaboration

Abstract

A combination of top pair production cross section measurements, obtained from CMS data taken in 2010 at a center-of-mass energy of $\sqrt{s} = 7$ TeV is presented. The dataset analyzed corresponds to an integrated luminosity of 36 pb^{-1}. The combined result is $\sigma_{t\bar{t}} = 158 \pm 19$ pb, in good agreement with the most up-to-date theory predictions.

1 Introduction

Measurements of the top pair production cross section in proton-proton collisions at the LHC provide important tests of our understanding of the top quark production mechanism, and can also be used in new physics searches. First measurements of the top quark pair production cross section in pp collisions at a center-of-mass energy of $\sqrt{s} = 7$ TeV have been presented by CMS [1] and ATLAS [2], based on an integrated luminosity of 3 pb^{-1}.

New CMS measurements, which make use of the full 2010 dataset and correspond to an integrated luminosity of 36 pb^{-1} have recently been performed in the dilepton channel [3] as well as in the lepton+jets channel, both without [4] and with [5] the use of b-tagging. In this note, a combination of these cross section measurements is presented, which corresponds to the most precise CMS measurement obtained to date. The result is compared with various theoretical predictions.

2 Cross section combination

The individual cross sections in the lepton+jets and dilepton channels considered for the combination are taken from [3, 5] and are, for completeness, reported in table 1.

Table 1: Summary of measured top pair production cross sections for the lepton+jets channel and the dilepton channel used in the cross section combination, also quoting the relative weights the individual measurements are assigned when extracting the combined value.

Measurement	Cross section [pb]	Weight
CMS l+jets+tag	$150 \pm 9(stat) \pm 17(syst) \pm 6(lumi)$	58%
CMS dilepton	$168 \pm 18(stat) \pm 14(syst) \pm 7(lumi)$	42%

The combination, which is still to be considered as preliminary, is performed under the simplifying assumption that correlations between systematic uncertainties within the same measurement can be ignored. The uncertainties of the individual measurements are rearranged into a part which is fully correlated between measurements, and a part which is fully uncorrelated. The latter category is composed of the statistical uncertainty and the contribution to the systematic uncertainty which is due to the modeling of the backgrounds, which is however only relevant for the dilepton measurement. The correlated and uncorrelated errors from the dilepton measurements become therefore 19 pb and 11 pb, respectively, having excluded the contribution from the luminosity uncertainty. The rest of the systematic uncertainties are considered as entirely correlated between the measurements.

The combination is performed using the BLUE technique [6], and yields a cross section of:

$$\sigma_{t\bar{t}} = 158 \pm 10(unc.) \pm 15(cor.) \pm 6(lumi) \text{ pb} , \quad (1)$$

where the errors quoted correspond to the uncorrelated and correlated uncertainties respectively, and include an additional 4% luminosity uncertainty. The final error on the combined cross section is 12%, and the relative weights of the lepton+jets and dilepton channels are determined as 58% and 42%, respectively.

3 Comparisons with other measurements and theory

Several theoretical predictions of the inclusive top quark pair production cross section in proton-proton collisions at $\sqrt{s} = 7$ TeV are considered in what follows.

- The next-to-leading order (NLO) cross section has been calculated as:

$$\sigma_{\mathrm{t\bar{t}}}^{\mathrm{NLO}}(\mathrm{MCFM}) = 158^{+23}_{-24}\ \mathrm{pb}\ , \tag{2}$$

  by using MCFM [7, 8]. The uncertainty in the cross section includes the scale uncertainties, determined by varying the factorization and renormalization scales by a factor 2 and 0.5 around the central scale choice of $m_t = 172.5$ GeV, and the uncertainties from the parton density functions (PDFs) and the value of α_S, following the procedures from the MSTW2008 [9, 10], CTEQ6.6 [11], and NNPDF2.0 [12] sets. The uncertainties are then combined according to the PDF4LHC prescriptions [13].

- The approximate next-to-next-to-leading order (NNLO) cross section, as calculated in [14], is:

$$\sigma_{\mathrm{t\bar{t}}}^{\mathrm{approx.NNLO}}(\mathrm{Kidonakis}) = 163^{+7}_{-5}\ (\mathrm{scale})\ ^{+9}_{-9}\ (\mathrm{PDF}) = 163^{+11}_{-10}\ \mathrm{pb}\ , \tag{3}$$

  where the MSTW2008 NNLO PDFs are used, and the renormalization and factorization scales are set to $m_t = 172.5$ GeV. The scale uncertainty is evaluated by varying both scales simultaneously by factors 2 and 0.5, and the PDF uncertainty is evaluated using the 90% confidence level envelope of the used PDF.

- Another approximate NNLO prediction for the cross section was obtained using the HATHOR program [15], using the calculations from [16]. The result is:

$$\sigma_{\mathrm{t\bar{t}}}^{\mathrm{approx.NNLO}}(\mathrm{HATHOR}) = 164^{+5}_{-9}\ (\mathrm{scale})\ ^{+9}_{-9}\ (\mathrm{PDF}) = 164^{+10}_{-13}\ \mathrm{pb}\ , \tag{4}$$

  using the MSTW2008 NNLO PDF and setting the renormalization and factorization scales to $m_t = 173$ GeV. The scale uncertainty is evaluated by varying both scales independently by factors 2 and 0.5, and the PDF uncertainty is evaluated using the 90% confidence level envelope of the used PDF. The cross section has also been calculated at NLO as:

$$\sigma_{\mathrm{t\bar{t}}}^{\mathrm{NLO}}(\mathrm{HATHOR}) = 160^{+20}_{-21}\ (\mathrm{scale})\ ^{+9}_{-9}\ (\mathrm{PDF}) = 160^{+22}_{-23}\ \mathrm{pb}\ , \tag{5}$$

  using the MSTW2008 NLO PDF.

Since both central values as well as uncertainties are in good agreement for NLO and approximate NNLO calculations using different codes, we use just the HATHOR predictions in the comparisons to follow.

Figure 1 shows a summary of the various existing top pair production cross sections at 7 TeV LHC energy, and comparison with theory. The CMS combined cross section using 36 pb^{-1} is presented, as well as the various individual CMS measurements. For comparison, also the previous ATLAS and CMS results using 3 pb^{-1} are shown. All measurements are in good agreement with the theoretical prediction, within uncertainties. The experimental precision is already better than the theoretical uncertainty of the NLO calculation.

Figure 2 shows the top pair production cross section as a function of the center-of-mass energy $\sqrt{s}$ of the collision. It compares measurements made at the proton-proton collider TEVATRON with the LHC measurements. Again, good agreement between the CMS measurement and theory is observed.

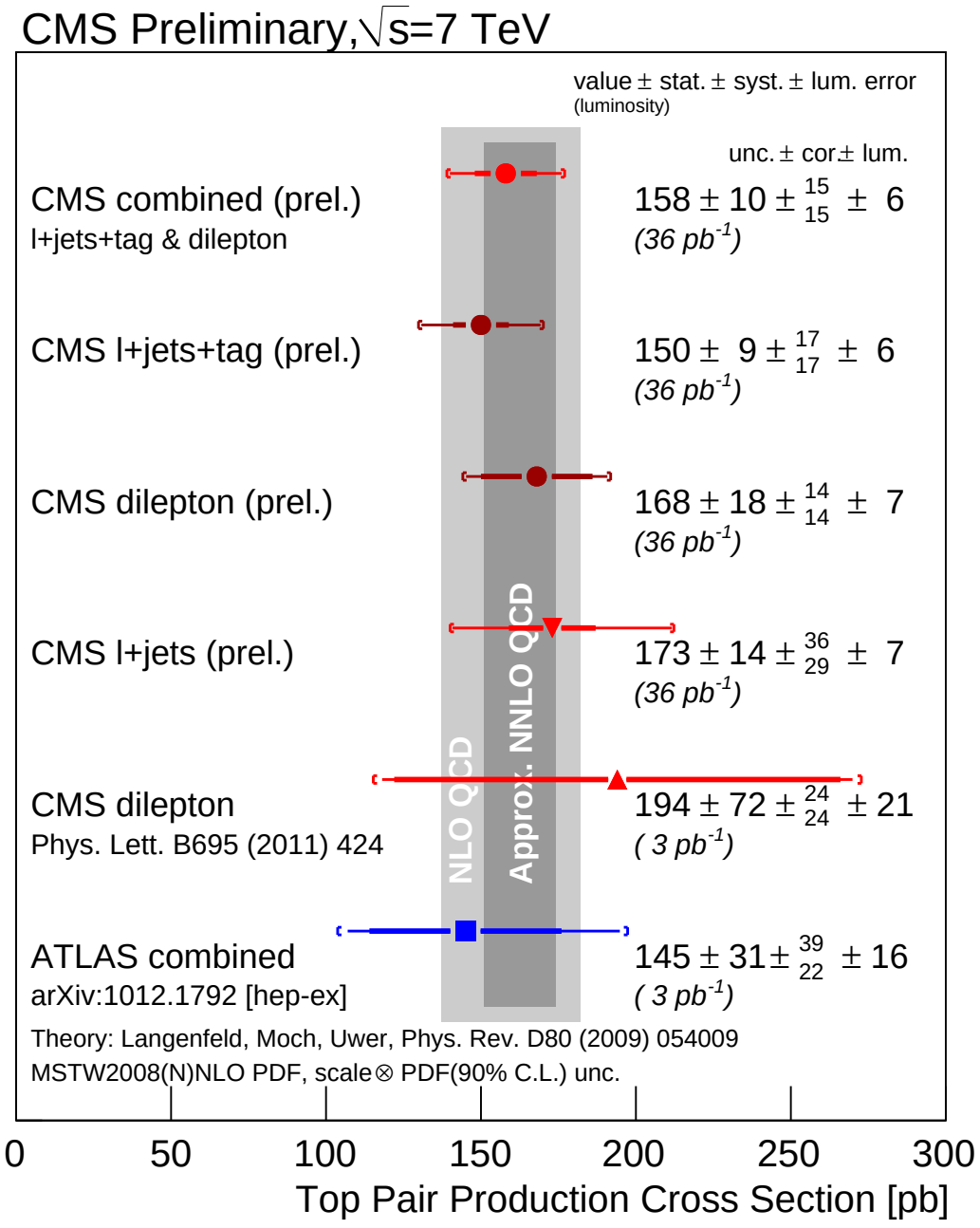

Figure 1: Summary of various inclusive top pair production cross section measurements made in 7 TeV proton-proton collisions. Data points are from this note, as well as [1–5]. Theory predictions are obtained using [15, 16]. The inner error bars of the data points correspond to the statistical uncertainty, while the outer (thinner) error bars correspond to the quadratic sum of statistical and systematic uncertainties. The outermost brackets correspond to the total error, including a luminosity uncertainty of 11% (4%) for the 3 (36) pb^{-1} results, respectively, which is also added in quadrature.

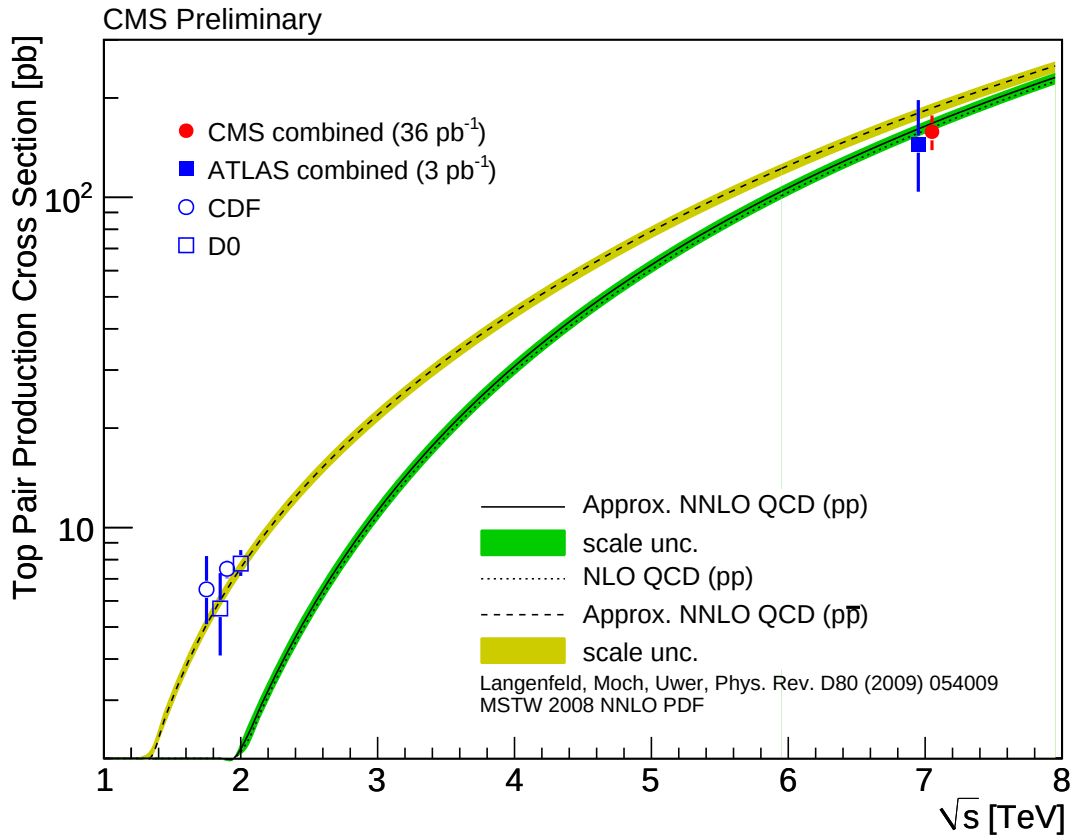

Figure 2: Top pair production cross section as a function of $\sqrt{s}$, for both $p\bar{p}$ and pp collisions. TEVATRON measurements made at $\sqrt{s} = 1.8$ TeV are taken from [17, 18], while those made at $\sqrt{s} = 1.96$ TeV are taken from [19, 20]. The CMS combined measurement presented in this note is shown, as well as the ATLAS measurement from [2]. Data points are slightly displaced horizontally for better visibility. Theory predictions at approximate NNLO are obtained using [15, 16]. The error band of the prediction corresponds to the scale uncertainty.

4 Conclusions

This note presents a combined value for the top pair production cross section measured by CMS, using the full 2010 dataset, corresponding to 36 pb^{-1} of integrated luminosity, and taken at a center-of-mass energy of 7 TeV.

The combined value is $\sigma_{t\bar{t}} = 158 \pm 19$ pb, and is the most precise CMS measurement obtained to date. The value is in agreement with the most recent NLO and approximate NNLO predictions of the inclusive top pair production cross section.

References

[1] CMS Collaboration, "First Measurement of the Cross Section for Top-Quark Pair Production in Proton-Proton Collisions at sqrt(s)=7 TeV", *Phys. Lett.* **B695** (2011) 424–443, arXiv:1010.5994. doi:10.1016/j.physletb.2010.11.058.

[2] ATLAS Collaboration, "Measurement of the top quark-pair production cross section with ATLAS in pp collisions at $\sqrt{s} = 7$ TeV", arXiv:1012.1792. acc. by Eur. Phys. J. **C**.

[3] CMS Collaboration, "Measurement of the top-quark pair-production cross section in the dilepton channel at $\sqrt{s} = 7$ TeV", *CMS* **TOP-10-005** (2011). https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP10005.

[4] CMS Collaboration, "Measurement of the $t\bar{t}$ Pair Production Cross Section at $\sqrt{s} = 7$ TeV using the Kinematic Properties of Lepton + Jets Events", *CMS* **TOP-10-002** (2011). https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP10002.

[5] CMS Collaboration, "Measurement of the $t\bar{t}$ Pair Production Cross Section at $\sqrt{s} = 7$ TeV using b-quark Jet Identification Techniques in Lepton + Jet Events", *CMS* **TOP-10-003** (2011). https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP10003.

[6] L. Lyons, D. Gibaut, and P. Clifford, "How to combine correlated estimates of a single physical quantity", *Nucl. Instrum. Meth.* **A270** (1988) 110. doi:10.1016/0168-9002(88)90018-6.

[7] http://mcfm.fnal.gov/.

[8] R. Kleiss and W. J. Stirling, "Top quark production at hadron colliders: Some useful formulae", *Z. Phys.* **C40** (1988) 419–423. doi:10.1007/BF01548856.

[9] A. D. Martin, W. J. Stirling, R. S. Thorne et al., "Parton distributions for the LHC", *Eur. Phys. J.* **C63** (2009) 189–285, arXiv:0901.0002. doi:10.1140/epjc/s10052-009-1072-5.

[10] A. D. Martin, W. J. Stirling, R. S. Thorne et al., "Uncertainties on $alpha_s$ in global PDF analyses and implications for predicted hadronic cross sections", *Eur. Phys. J.* **C64** (2009) 653–680, arXiv:0905.3531. doi:10.1140/epjc/s10052-009-1164-2.

[11] H.-L. Lai, J. Huston, Z. Li et al., "Uncertainty induced by QCD coupling in the CTEQ global analysis of parton distributions", *Phys.Rev.* **D82** (2010) 054021, arXiv:1004.4624. doi:10.1103/PhysRevD.82.054021.

[12] F. Demartin, S. Forte, E. Mariani et al., "The impact of PDF and α_s uncertainties on Higgs Production in gluon fusion at hadron colliders", *Phys. Rev.* **D82** (2010) 014002, arXiv:1004.0962. doi:10.1103/PhysRevD.82.014002.

[13] http://wwwhep.ucl.ac.uk/pdf4lhc/.

[14] N. Kidonakis, "Next-to-next-to-leading soft-gluon corrections for the top quark cross section and transverse momentum distribution", *Phys.Rev.* **D82** (2010) 114030, arXiv:1009.4935. doi:10.1103/PhysRevD.82.114030.

[15] M. Aliev, H. Lacker, U. Langenfeld et al., "HATHOR: HAdronic Top and Heavy quarks crOss section calculatoR", *Comput.Phys.Commun.* **182** (2011) 1034–1046, arXiv:1007.1327. doi:10.1016/j.cpc.2010.12.040.

[16] U. Langenfeld, S. Moch, and P. Uwer, "Measuring the running top-quark mass", *Phys.Rev.* **D80** (2009) 054009, arXiv:0906.5273. doi:10.1103/PhysRevD.80.054009.

[17] CDF Collaboration, "Measurement of the t anti-t production cross-section in p anti-p collisions at s**(1/2) = 1.8-TeV", *Phys.Rev.* **D64** (2001) 032002, arXiv:hep-ex/0101036. erratum-ibid. **D67** (2003) 119901. doi:10.1103/PhysRevD.64.032002, 10.1103/PhysRevD.67.119901.

[18] D0 Collaboration, "t anti-t production cross-section in p anti-p collisions at s**(1/2) = 1.8-TeV", *Phys.Rev.* **D67** (2003) 012004, arXiv:hep-ex/0205019. doi:10.1103/PhysRevD.67.012004.

[19] CDF Collaboration, "Combination of CDF top quark pair production measurements with up to 4.6 fb^{-1}", *CDF Note* **9913** (2009).

[20] D0 Collaboration, "Measurement of the top quark pair production cross section in the lepton+jets channel in proton-antiproton collisions at $\sqrt{s}$=1.96 TeV", arXiv:1101.0124.