Measurements of the top quark pair production cross section at 7 TeV

J. Caudron, on behalf of the CMS Collaboration

Université Catholique de Louvain, Center for Cosmology, Particle Physics and Phenomenology, Louvain-la-Neuve, Belgium

Abstract. After one year of functioning, the Large Hadron Collider has provided many proton-proton collision data. Among these events, $35.9\text{pb}^{-1} \pm 4\%$ of integrated luminosity of data recorded by the CMS detector have been used to evaluate the cross section of the top quark pair production ($t\bar{t}$). The CMS Collaboration has performed three analyses, two in the semi-leptonic channel using or not the b-tagging algorithm and one in the dileptonic channel, and has recently made public the last update of the measurement of the $t\bar{t}$ cross-section combining these results.

Keywords: top quark pair cross section cms lhc
PACS: 14.65.Ha

The two top quarks produced by the $t\bar{t}$ process decay at $\sim 100\%$ in two b quarks and two W bosons. The b quarks yield to jets, characterized by a secondary vertex due to the long lifetime of the b quark, and called "b-jets". The two bosons can decay hadronically or leptonically, determining the final state of the process. The semi-leptonic channel in e+jets ($\sim 17\%$ of the $t\bar{t}$ branching ratio) and μ+jets ($\sim 17\%$) final states and the dileptonic channel in ee ($\sim 1.9\%$), $\mu\mu$ ($\sim 1.9\%$) and $e\mu$ ($\sim 2.7\%$) final states observed in the CMS detector [1] have been studied. These results are succeding to a first publication after 3.1 pb^{-1} in the dileptonic channel only [2], are described in several public results [3, 4, 5, 6] and are been compared with ATLAS [7] and theory results.

Semi-leptonic analysis. The semi-leptonic study has been divided in two analyses, one using a b-tagging algorithm to identify the b-jets and one using the kinematical properties of the semi-leptonic $t\bar{t}$, without using any b-jet identification. The semi-leptonic selection consists in selecting one energetic isolated lepton in the fiducial region of the detector ($p_T > 30$ GeV and $|\eta| < 2.5$ for the electron, $p_T > 20$ GeV and $|\eta| < 2.1$ for the muon). The isolation is determined as the relative additionnal energy deposit in a geometrical cone around the lepton in the tracker and the calorimeter subdetectors. A selection is also applied on the jets multiplicity, based on the jets with corrected transverse momentum higher than 30 (25) GeV in $|\eta| < 2.4$ region for the no b-tags analysis (for the b-tag analysis). The b-tag analysis also requires a transverse missing energy of at least 20 GeV and the presence of at least one b-tagged jet using the simple secondary vertex reconstruction as b-tag discriminator [8].

The main backgrounds in the semi-leptonic channel are the $W \to \ell\nu$+Jets process (divided according to the jet flavor in the b-tag analysis), QCD multijet processes (estimated from data using sideband region where this background dominates) and $Z \to \ell\ell$+Jets, γ+Jets and single top processes.

In the b-tag analysis, the cross-section is extracted using a simultaneous fit of the secondary vertex mass (from tracks associated with the vertex with a pion mass assumption) and the jets and b-tagged jets multiplicity. For each channel (lept) and each number of jets (jets) and b-tagged jets (tag), the predicted number of events for a process i is given by:

$$\mathscr{N}_i^{\text{pred}}(\text{lept},\text{jets},\text{tag}) = k_i \cdot N_i^{\text{MC}}(\text{lept},\text{jets},\text{tag}) \cdot \prod_X P_i^{\text{X}}(\text{lept},\text{jets},\text{tag}|\mathscr{R}_{\text{X}}) \quad (1)$$

where k is the scale factor parameter optimized by the fit, N^{MC} is the number of events predicted by simulation and corrected for discrepancies between data and Monte Carlo events, X is a systematic effect that can be the b-tag efficiency, the mistag rate, the Jet Energy Scale or the Q^2 scale, $\mathscr{R}_{\text{X}}$ is the nuisance parameter corresponding to the systematic X and P^{X} is a polynomial function, obtained from simulation, describing the effect of the nuisance parameter.

The result of the fit, performed under contrains to guarantee a physically consistent result, returns the value of k and $\mathscr{R}_{\text{X}}$. The b-tag scale factor is evaluated to $97.5^{+5}_{-4}\%$, which is consistent with other b-tag studies. The Jet Energy Scale factor is slightly harder than expected. The scale factors with respect to the NLO prediction for Wb and Wc processes are respectively $1.9^{+0.6}_{-0.5}$ and 1.4 ± 0.2, which is consistent with recent observations at Tevatron. The systematic uncertainties have been taken into account directly in the fit procedure or additionnally on the cross-section results. The dominant systematic uncertainties are the Jet Energy Scale, the b-tag efficiency and the Q^2 scale variation on the W+Jets background. Finally, the $t\bar{t}$ cross section is extracted:

$$\sigma_{t\bar{t}}(\text{semi-leptonic with b-tag}) = 150 \pm 9(\text{stat.}) \pm 17(\text{syst.}) \pm 6(\text{lumi.})\text{pb}$$

In the no b-tags analysis, the cross-section is extracted from a fit on the transverse missing energy for events with exactly three jets and on the M_3 variable (invariant mass of the three jets of highest vectorial sum of the transverse momentum of their components) for events with at least four jets.

The fit is performed on template distributions, obtained from simulation or from data-driven method (for QCD multijet). Some constrains are applied to force the result of the fit in a region that is consistent with physics. The effect of a given systematic uncertainty on the result of the fit is evaluated by simulating templates with $\pm 1\sigma$ variation on the systematic uncertainty. The dominant systematic uncertainties are the Jet Energy Scale and the Q^2 scale variation on the W+Jets background. The obtained $t\bar{t}$ cross section is:

$$\sigma_{t\bar{t}}(\text{semi-leptonic without b-tag}) = 173^{+39}_{-32}(\text{stat.+syst.}) \pm 7(\text{lumi.})\text{pb}$$

Dileptonic analysis. The dileptonic study extracts the cross section using a simple event counting method. Three different selections are applied, leading to nine cross section: one for each selection and each channel. These results are combined using the BLUE technique [9]. The three selections require two energetic isolated leptons with opposite charge in the fiducal region of the detector ($p_T > 20\,\text{GeV}$ and $|\eta| < 2.5$ (2.4) for the electron (for the muon)). The isolation is determined as the relative additionnal energy deposit in a geometrical cone around the lepton in the tracker and the calorimeter subdetectors. The events with a dileptonic invariant mass in a 15 GeV window around the Z^0 mass are rejected. Events with dileptonic invariant mass lower than 12 GeV are also excluded. The selected jets have a corrected transverse momentum higher than 30 GeV and are in $|\eta| < 2.4$ region. The first selection requires at least two selected jets and a missing transverse energy of at least 30 GeV for the ee and $\mu\mu$ channels. A second selection is applied on the first selection and use the high efficiency track counting algorithm [8] to select events with at least one b-tagged jet. Finally, a third selection provides some additionnal signal events by selecting the events with exactly one jet. Because this selection is more contaminated by background, it also requires a missing transverse energy of at least 50 GeV for the ee and $\mu\mu$ channels and a sum of the transverse mass of the two leptons higher than 130 GeV for the $e\mu$ channel, the tranverse mass being defined relative to the value and the direction of the missing energy transverse vector: $M_T^\ell = \sqrt{2 p_T^\ell \not{E}_T [1 - cos(\phi_{\not{E}_T} - \phi_\ell)]}$.

The main backgrounds in the dileptonic channel are the Drell-Yan→ $\ell\ell$ (estimated from data), the processes containing at least one lepton non coming from a W/Z decay (W+Jets, semi-leptonic $t\bar{t}$, QCD multijet processes, estimated from data) and other small contributions (Single top tW, diboson processes, Drell-Yan→ $\tau\tau$).

The systematic uncertainty on the number of background events is extracted directly from the data-driven methods or are assigned conservatively on the simulations. The main sources of systematic uncertainties on the signal are the Jet Energy Scale and the lepton selection model that results from the difference in the lepton isolation between a Drell-Yan and a $t\bar{t}$ environnement. The selection with exactly one jet is also more affected by the Q^2 scale variation on the signal process and the selection using the b-tagging contains the systematic uncertainty due to b-tagging. The final $t\bar{t}$ cross section for the dileptonic case is obtained from the nine cross sections combination:

$$\sigma_{t\bar{t}}(\text{dileptonic}) = 168 \pm 18(\text{stat.}) \pm 14(\text{syst.}) \pm 7(\text{lumi.})\text{pb}$$

Combination and final number. The final $t\bar{t}$ cross section provided by the CMS collaboration is obtained by combining the result from the semi-leptonic analysis using the b-tagging algorithm and the result from the dileptonic analysis. This combination, using the BLUE technique, divides the uncertainties between the uncorrelated and the correlated ones. The uncorrelated uncertainties are the statistical uncertainties in the two analyses and the uncertainties from the background modelling in the dileptonic analysis. All the other uncertainties are considered correlated. The final $t\bar{t}$ cross section from the CMS Collaboration is:

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

As done in Fig. 1, this result can be compared with theoritical cross sections. Two methods, from the software HATHOR [10, 11] and from Kidonakis [12], provide reference values for the $t\bar{t}$ cross section at approximate NNLO:

$$\begin{aligned} \sigma_{t\bar{t}}(\text{HATHOR}) &= 164^{+5}_{-9}(\text{scale})^{+9}_{-9}(\text{pdf})\text{pb} \\ \sigma_{t\bar{t}}(\text{Kidonakis}) &= 163^{+7}_{-5}(\text{scale})^{+9}_{-9}(\text{pdf})\text{pb} \end{aligned}$$

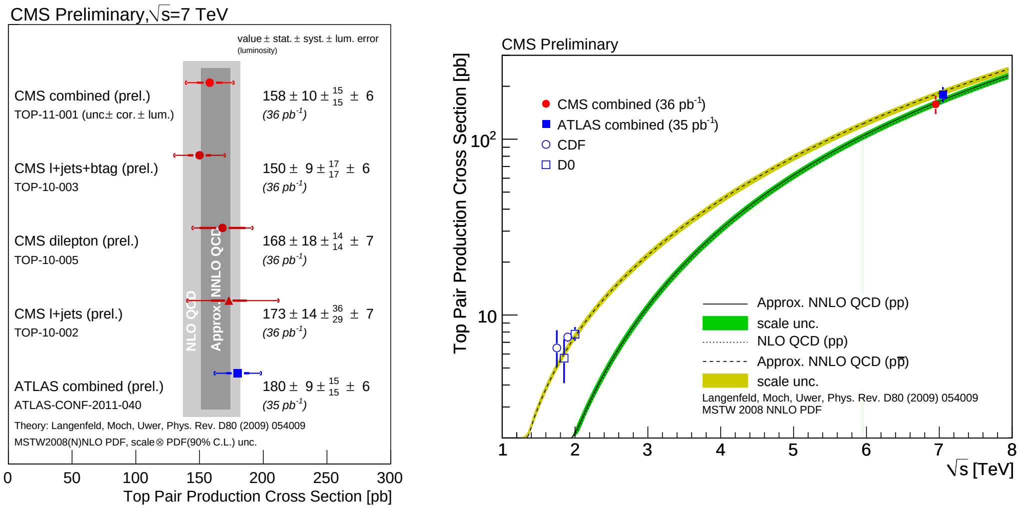

FIGURE 1. Left: Summary of various inclusive top pair production cross section measurements made in 7 TeV proton-proton collisions by CMS and ATLAS. The inner error bars of the data points correspond to the statistical uncertainty, while the outer (thinner) error bars correspond to the quadratic sum of statistical and systematic uncertainties. The outermost brackets correspond to the total error, including a luminosity uncertainty which is also added in quadrature. Right: Top pair production cross section as a function of $\sqrt{s}$ for both pp and $p\bar{p}$ collisions. Data points are slightly displaced horizontally for better visibility. The error band of the prediction corresponds to the scale uncertainty. In both plots, the theory predictions at approximate NNLO are obtained using HATHOR.

The comparison shows a good agreement between the theory and the observed result.

ACKNOWLEDGMENTS

Many thanks to the CMS Top Quark group conveners: F.-P. Schilling and R. Chierici.

REFERENCES

1. R. Adolphi, et al. [CMS Collaboration], *JINST* **3**, S08004 (2008).
2. V. Khachatryan, et al. [CMS Collaboration], *Phys. Lett.* **B695**, 424–443 (2011), `1010.5994`.
3. *CMS* **TOP-10-002** (2011), https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP10002.
4. *CMS* **TOP-10-003** (2011), https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP10003.
5. *CMS* **TOP-10-005** (2011), https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP10005.
6. *CMS* **TOP-11-001** (2011), https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP11001.
7. G. Aad, et al. [ATLAS Collaboration], *JINST* **3**, S08003 (2008).
8. *CMS* **BTV-10-001** (2010).
9. L. Lyons, D. Gibaut, and P. Clifford, *Nucl. Instrum. Meth.* **A270**, 110 (1988).
10. M. Aliev, H. Lacker, U. Langenfeld, S. Moch, P. Uwer, et al., *Comput.Phys.Commun.* **182**, 1034–1046 (2011), `1007.1327`.
11. U. Langenfeld, S. Moch, and P. Uwer, *Phys.Rev.* **D80**, 054009 (2009), `0906.5273`.
12. N. Kidonakis, *Phys.Rev.* **D82**, 114030 (2010), `1009.4935`.