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First Measurement of the Cross Section for Top-Quark Pair Production in Proton-Proton Collisions at $\sqrt{s} = 7\,\text{TeV}$

The CMS Collaboration*

Abstract

The first measurement of the cross section for top-quark pair production in pp collisions at the LHC at center-of-mass energy $\sqrt{s} = 7$ TeV has been performed using 3.1 ± 0.3 pb^{-1} of data recorded by the CMS detector. This result utilizes the final state with two isolated, highly energetic charged leptons, large missing transverse energy, and two or more jets. Backgrounds from Drell-Yan and non-W/Z boson production are estimated from data. Eleven events are observed in the data with 2.1 ± 1.0 events expected from background. The measured cross section is $194 \pm 72(\text{stat.}) \pm 24(\text{syst.}) \pm 21(\text{lumi.})$ pb, consistent with next-to-leading order predictions.

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*See Appendix A for the list of collaboration members

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Since its discovery [1, 2], the properties of the top quark have been subject to numerous detailed studies [3], which until recently have only been possible at the Tevatron proton-antiproton collider. With the advent of the Large Hadron Collider (LHC) era [4], top-quark processes can be studied for the first time in multi-TeV proton-proton collisions. In both $p\bar{p}$ and pp collisions, top quarks are expected to be produced primarily via the strong interaction in top-antitop ($t\bar{t}$) pairs. At the LHC, the $t\bar{t}$ production mechanism is expected to be dominated by a gluon fusion process, whereas at the Tevatron, top-quark pairs are predominantly produced through quark-antiquark annihilation. Measurements of top-quark production at the LHC are therefore important new tests of our understanding of the $t\bar{t}$ production mechanism. This is a crucial component of the early LHC physics program, since many signatures of new physics models accessible at the LHC either suffer from top-quark production as a significant background or contain top quarks themselves.

In this Letter we present the first measurement of the cross section for $t\bar{t}$ production in proton-proton collisions at the LHC at center-of-mass energy $\sqrt{s} = 7$ TeV. The results are based on a data sample corresponding to an integrated luminosity of 3.1 ± 0.3 pb^{-1} [5] recorded by the CMS experiment [6] between March and August 2010. This measurement is an important milestone for CMS, demonstrating the experiment's capabilities in extracting an intricate signature.

Within the standard model, the top quark decays via the weak process $t \to Wb$ almost exclusively. Experimentally, top-quark pair events are categorized according to the decay of the two W bosons: the all-hadronic channel, in which both W bosons decay into quarks; the lepton+jets channel, in which one W boson decays leptonically, the other into quarks; and the dilepton channel, in which both W bosons decay into leptons. The measurement described herein is performed using the e^+e^-, $\mu^+\mu^-$, and $e^\pm\mu^\mp$ dilepton $t\bar{t}$ modes. Therefore, the final state studied in this analysis contains two oppositely charged leptons (electrons and muons, including taus subsequently decaying to electrons and muons), two neutrinos from the W boson decays, and at least two jets of particles resulting from the hadronization of the b quarks.

The central feature of the CMS apparatus is a superconducting solenoid, 13 m in length and 6 m in diameter, which provides an axial magnetic field of 3.8 T. The bore of the solenoid is outfitted with various particle detection systems. Charged particle trajectories are measured by the silicon pixel and strip tracker, covering $0 < \phi < 2\pi$ in azimuth and $|\eta| < 2.5$, where the pseudorapidity η is defined as $\eta = -\ln[\tan\theta/2]$, with θ being the polar angle of the trajectory of the particle with respect to the beam direction. A crystal electromagnetic calorimeter (ECAL) and a brass/scintillator hadronic calorimeter (HCAL) surround the tracking volume; in this analysis the calorimetry provides high-resolution energy and direction measurements of electrons and hadronic jets. Muons are measured in gas detectors embedded in the steel return yoke outside the solenoid. The detector is nearly hermetic, allowing for energy balance measurements in the plane transverse to the beam directions. A two-tier trigger system selects the most interesting pp collision events for use in physics analysis. A more detailed description of the CMS detector can be found elsewhere [6].

The trigger providing the data sample used in this analysis is based on the presence of at least one charged lepton, either an electron or a muon, with a minimum transverse momentum p_T of 9 (15) GeV/c for the muon (electron). This data sample is used both for the selection of the signal and for signal-depleted control regions used for studies related to background processes. Simulated signal events that pass the event selection, as described below, satisfy the trigger requirements with an efficiency above 97% in the $\mu^+\mu^-$ decay mode and above 99% in the other two modes, in agreement with estimates from Z boson events in the data.

Before further consideration, events are required to have at least one good reconstructed pp in-

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teraction vertex [7]. Among these events, selection criteria are applied to reconstructed objects to identify candidates consistent with dilepton $t\bar{t}$ processes.

Muon candidates are reconstructed [8] using two algorithms that require consistent hits in the tracker and muon systems: one is an algorithm based on the matching of extrapolated trajectories from the silicon tracker to hits in the muon system (tracker-based muons); the second is an algorithm based on performing a global fit of consistent hits in the tracker and the muon system (globally-fitted muons). Candidates are required to have $p_T > 20$ GeV/c and $|\eta| < 2.5$. Additionally, the track associated with the muon candidate is required to have a minimum number of hits in the silicon tracker, to be consistent with originating from the beam spot, and to have a high-quality global fit including a minimum number of hits in the muon detector.

Electron candidates are reconstructed [9] starting from a cluster of energy deposits in the crystals of the ECAL, which is then matched to hits in the silicon tracker, used to initiate a special track reconstruction algorithm. The electron reconstruction algorithm takes into account the possibility of significant energy loss of the electron through bremsstrahlung as it traverses the material of the tracker. Electron candidates are required to have $p_T > 20$ GeV/c and pseudorapidity $|\eta| < 2.5$. The electron candidate track is required to be consistent with originating from the beam spot. Requirements on the values of electron identification variables based on shower shape and track-cluster matching are applied to the reconstructed candidates; the criteria are optimized in the context of the inclusive $W \rightarrow e\nu$ selection and are designed to maximize the rejection of electron candidates from QCD multijet production while maintaining 90% efficiency for electrons from the decay of W/Z bosons. Electron candidates within $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} < 0.1$ of a tracker-based or globally-fitted muon are rejected to remove fake electron candidates due to muon bremsstrahlung. In addition, electrons consistent with anomalous depositions in the ECAL or with photon conversions are rejected.

Charged leptons from the decay of W bosons are expected to be isolated from other activity in the event. For selected muon and electron candidates, a cone of $\Delta R < 0.3$ is constructed around the track direction at the origin and the scalar sum of the track transverse momenta and calorimeter energy deposits projected onto a plane transverse to the beam is calculated. The contribution from the candidate itself is excluded. If the value of this scalar sum is more than 15% of the candidate's transverse momentum, the candidate is considered to be non-isolated and is rejected.

Lepton trigger, identification, and isolation efficiencies are measured using inclusive Z events from data and are compared with simulation. All comparisons show good agreement, generally within 2%. The residual differences between the efficiencies estimated in data and simulation are treated as systematic uncertainties.

Events are required to have at least one pair of oppositely charged leptons. Both charged leptons are required to originate from within 1 cm along the beamline of the reconstructed pp interaction location. To veto contributions from Z production, the invariant mass of the dilepton system, $M_{\ell\ell}$, is required to be outside a ± 15 GeV/c^2 window centered at the mass of the Z boson for the e^+e^- and $\mu^+\mu^-$ modes. Additionally, dilepton candidate events with $M_{\ell\ell} < 10$ GeV/c^2 are removed, at essentially no penalty for the collected signal.

The neutrinos from the W boson decays do not interact with the detector and escape without depositing any of their energy. The presence of a neutrino manifests itself as an imbalance in the measured energy depositions; the imbalance in the projection perpendicular to the beam line (missing transverse energy, $\not\!\!E_T$) is an important distinguishing feature of $t\bar{t}$ events in this channel. At CMS there are several techniques for calculating $\not\!\!E_T$ [10]; here, the raw $\not\!\!E_T$, calcu-

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lated from calorimeter signals, is made more accurate through a series of corrections taking into account the contribution from the minimally interacting muons and, most importantly, a per-track correction for the expected imperfect response of the calorimeter. This track correction results in an improved energy resolution, especially for low-energy charged particles. Neither the dominant background processes, Drell-Yan $Z/\gamma^{\star} \rightarrow e^+e^-$ and $\mu^+\mu^-$, nor the difficult-to-model background from isolated lepton candidates produced in QCD multijet events, contain a natural source of large $\not\!\!E_T$. Hence, in the e^+e^- and $\mu^+\mu^-$ modes, $\not\!\!E_T > 30$ GeV is required; in the $e^{\pm}\mu^{\mp}$ mode a looser requirement of $\not\!\!E_T > 20$ GeV is used due to the significantly smaller contribution of Drell-Yan background.

Dilepton $t\bar{t}$ events will have at least two hadronic jets from the hadronization of the two b quarks. The anti-k_T clustering algorithm [11] with $R = 0.5$ is used for jet clustering. Jets are reconstructed using calorimeter information and corrected using reconstructed tracks [12]. Further corrections are applied to the raw jet momenta to establish a relative uniform response of the calorimeter in jet η and an absolute uniform response in jet p_T. The jet energy scale uncertainty for these track-corrected jets is 5%. Jet candidates are required to have $p_T > 30$ GeV/c, $|\eta| < 2.5$, and must not overlap with any electron or muon candidate within $\Delta R < 0.4$. Events with fewer than two jets are discarded.

The selection efficiency of signal events is evaluated in a simulated $t\bar{t}$ event sample modeled with the MADGRAPH event generator [13] with up to three additional hadronic jets. The events are subsequently processed with PYTHIA [14] to provide showering of generated particles, and then processed with a full CMS detector simulation based on GEANT4 [15]. The total next-to-leading order (NLO) cross section for top-quark pair production used here to scale simulated signal distributions is $\sigma_{t\bar{t}} = 157.5^{+23.2}_{-24.4}$ pb, as obtained with MCFM [16, 17]. Approximate next-to-next-to-leading order (NNLO) calculations for the $t\bar{t}$ cross section have been completed (see for example [18–23]) but are not used here. The theoretical uncertainty on the cross section includes the scale uncertainties, determined by varying the factorization and renormalization scales by factors of 2 and 0.5 around the central scale, corresponding to the top quark mass (172.5 GeV/c^2), and the uncertainties from the parton distribution functions (PDFs) and the value of α_S, following the procedures from the MSTW2008 [24], CTEQ6.6 [25], and NNPDF2.0 [26] sets. The expected yield of events passing the selection criteria, assuming the NLO production cross section, is 1.5 ± 0.3, 1.7 ± 0.3, and 4.5 ± 0.9 for the e^+e^-, $\mu^+\mu^-$, and $e^{\pm}\mu^{\mp}$ decay modes, respectively. The uncertainties on these predicted event yields combine the systematic uncertainties on the event selection, the theoretical production cross section, and the integrated luminosity of the sample, where the contribution from the last two sources dominates the total. Note that the simulated $t\bar{t}$ signal sample used for the estimate of the expected signal events was generated with the $W \rightarrow \ell\nu$ branching fraction set to 1/9, which is not consistent with the standard value (0.1080 ± 0.009) [27] used in the cross section measurement.

The selected sample is not 100% pure in dilepton $t\bar{t}$ events. There are two types of background estimation techniques used in this analysis. One strategy utilizes simulated pp collision events to model background processes. There are, however, some pathological backgrounds that are harder to model accurately. In such cases, it is preferred to estimate the yields of these events from the data.

Contributions from diboson production (VV, where $V = W$ or $Z/\gamma^{\star}$), based on a leading-order production cross section of $\sigma_{VV} = 4.8$ pb [13], and electroweak single-top production in the tW channel ($\sigma_{tW} = 10.6$ pb [28]) are modeled with the MADGRAPH event generator and are processed in an equivalent fashion as the simulated $t\bar{t}$ sample used to assess the signal yield. The Drell-Yan $Z/\gamma^{\star} \rightarrow \tau\tau$ process ($\sigma_{Z/\gamma^{\star}\rightarrow\tau\tau} = 1666$ pb [29]) is modeled with PYTHIA and

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Table 1: The expected number of dilepton $t\bar{t}$ signal and background events passing the full selection criteria, compared to the number of observed events. The procedures for estimating the expected numbers of events and their uncertainties are described in the text. The expected signal yield assumes a $t\bar{t}$ cross section of $\sigma_{t\bar{t}} = 157.5^{+23.2}_{-24.4}$ pb.

Source	Number of events
Expected $t\bar{t}$	7.7 ± 1.5
Dibosons (VV)	0.13 ± 0.07
Single top (tW)	0.25 ± 0.13
Drell-Yan $Z/\gamma^{\star} \to \tau^+\tau^-$	0.18 ± 0.09
Drell-Yan $Z/\gamma^{\star} \to e^+e^-, \mu^+\mu^-$	$1.4 \pm 0.5 \pm 0.5$
Events with non-W/Z leptons	$0.1 \pm 0.5 \pm 0.3$
Total backgrounds	2.1 ± 1.0
Expected total, including $t\bar{t}$	9.8 ± 1.8
Data	11

MADGRAPH. The uncertainties on these production cross sections are well within the total systematic uncertainty of 50% used for each of these backgrounds. Table 1 gives the simulation-based predictions for the event yields from these processes.

The contributions from two important background sources are estimated from the data: exceptional Drell-Yan events that evade the Z veto and are accompanied by significant missing transverse energy; and non-W/Z isolated lepton signatures from multijet and W+jets production. Difficult-to-simulate instrumental effects influence both topologies and hence it is preferable to use calibration samples from the data in these estimations.

The events rejected by the Z veto are used to estimate the residual contributions from Drell-Yan $Z/\gamma^{\star} \to e^+e^-$ and $\mu^+\mu^-$ in the surviving selected sample. In the $\mu^+\mu^-$ final state the rate of events surviving the Z veto is equal to an estimate of the Drell-Yan contribution near the $M_{\ell\ell}$ peak, scaled by the expected ratio of off-peak to near-peak events derived from simulation. The near-peak Drell-Yan $Z/\gamma^{\star}$ contribution is estimated from the number of all events triggering the Z veto, after subtraction of the non-Drell-Yan contribution estimated from $e^{\pm}\mu^{\mp}$ events passing the same selection and corrected for the differences between the electron and muon identification efficiencies. The estimate in the e^+e^- mode is done in a similar fashion; the summed contribution is shown in Table 1. The systematic uncertainty of this method, evaluated in each mode separately, is estimated to be 50%. This is dominated by detector calibration effects and changes of the fraction of Z-vetoed Drell-Yan $Z/\gamma^{\star}$ events with increasingly stringent requirements (additional jets and missing transverse energy) as estimated from simulation.

The contributions to the selected sample from isolated lepton candidates from non-W/Z decays are also derived from data. Such lepton candidates mostly arise from jets that are able to satisfy the tight lepton identification criteria. A superset of dilepton candidate events is chosen by loosening the lepton identification criteria in the trigger samples used for the measurement. The number of these candidates passing the loosened selection criteria from non-W/Z leptons can be weighted by the ratio of yields of tight-to-loose lepton candidates (R_{TL}) to produce an estimate of non-W/Z leptons passing the tight selections. The ratio R_{TL} is measured as a function of candidate transverse momentum and pseudorapidity in a multijet-dominated data sample containing events with one lepton candidate passing loose selection criteria. Additional selection criteria are applied to suppress the residual contribution to the loose lepton sample from electroweak processes. We assume this R_{TL} is appropriate for use in the dilepton signal

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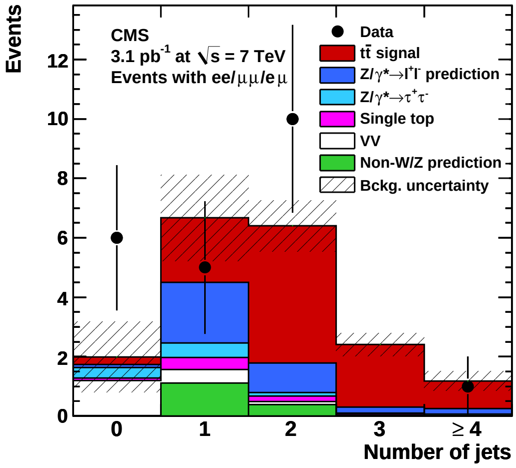

Figure 1: Number of jets in events passing all dilepton selection criteria before the ≥2-jet requirement for all three dilepton modes combined, compared to signal and background predictions. The hatched bands reflect the uncertainties on the background predictions.

sample, and we also consider R_{TL} to be independent from the other lepton in events with two leptons. Possible differences are assessed from comparisons of R_{TL} measured in QCD multijet data samples with different jet thresholds and flavor content.

Estimates for the contributions from lepton candidates in pure multijet QCD, with two such non-W/Z candidates, and in W+jets, with one such candidate beyond that from the decay of the W, are derived separately. A sample of loose dilepton events both failing the tight selections is used to estimate the multijet QCD contribution. Loose dilepton events with only one lepton failing the tight requirements include contributions from W+jets events, but are contaminated by multijets and leptons from W/Z decays. The multijet QCD contamination is subtracted using the previous estimate, while the contamination from W/Z leptons is measured from a sample of Z events fulfilling loose selection requirements.

The prediction for these non-W/Z leptons is shown in Table 1. The systematic uncertainty on the non-W/Z lepton estimate is primarily from differences in the jet momentum spectrum and flavor composition between the QCD-dominated sample in which R_{TL} is measured and the sample where it is applied. Other subdominant contributions to the systematic uncertainties include the R_{TL} measurement biases due to electroweak signal contribution, the dissimilarity in the trigger between the R_{TL} calibration sample and the signal sample to which it is applied, and from the statistical limitations on the R_{TL} calibration sample. The systematic uncertainty on the electron R_{TL} is 50%, which corresponds to a 50% (100%) uncertainty on a raw estimate of the W+jets (QCD multijets) non-W/Z isolated lepton contribution, prior to accounting for the signal contribution to the estimate. Similarly, the systematic uncertainty on the muon R_{TL} is $^{+50}_{-100}$%, which corresponds to a $^{+50}_{-100}$% ($^{+100}_{-100}$%) uncertainty on the estimate of the W+jets (QCD multijets) non-W/Z isolated lepton contribution.

Expected yields from simulated signal and background processes, normalized to estimates from data where appropriate, are shown in Fig. 1 as a function of jet multiplicity for events satisfying the complete dilepton event selection criteria except the ≥2-jet requirement; the $t\bar{t}$ signal dominates the bins with at least two jets.

Eleven dilepton events (3 e^+e^-, 3 $\mu^+\mu^-$, 5 $e^\pm\mu^\mp$) are observed in the data after applying the event selection criteria, with a total of 2.1±1.0 background events expected. We attribute the

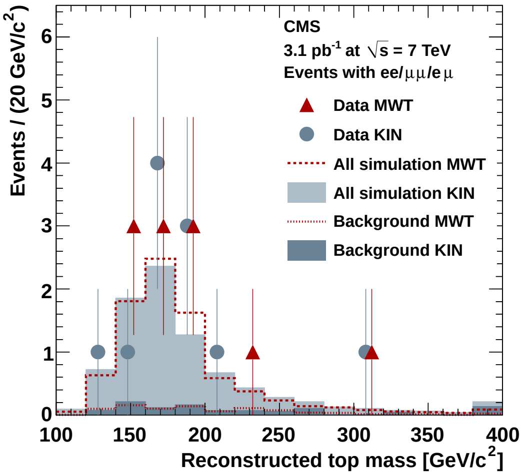

Figure 2: Distribution of the top-quark mass using two different reconstruction methods [30, 31], compared with the expected yields from simulated signal-plus-background and background-only hypotheses. The points in each bin for the two methods are slightly offset in reconstructed mass to allow coincident points to be visible. The last bin contains the overflow.

excess of events above the background expectation to top-quark pair production.

The top-quark mass reconstruction methods of [30] (KIN, i.e., KINematic, method) and [31] (MWT, i.e., Matrix-element Weighting Technique) are applied to the selected events. In both methods, numerical solutions to the kinematic equations appropriate for a $t\bar{t}$ decay with two charged leptons in the final state are found for each event. The solutions are based on an ensemble of values of jet momenta and missing energy, generated corresponding to their expected resolution around the measured values. In the KIN method the underconstrained system is solved by introducing an additional constraint on the longitudinal momentum of the $t\bar{t}$ system, whose probability distribution is expected to have a negligible dependence on the top-quark mass and is therefore assumed from simulation. The top-quark mass value corresponding to the largest number of solutions is the reconstructed mass for each event. In the MWT method the system is solved for a range of top-quark mass values, and weights are assigned based on the likelihood of each solution. The solution with the largest weight is used as the mass estimator. Figure 2 shows that the kinematics of the selected events are statistically compatible with predictions based on a top-quark mass of 172.5 GeV/c^2, demonstrating the consistency of the selected sample with top-quark pair production.

Further, beyond the complete event selection described above, the property that the two jets expected in dilepton $t\bar{t}$ events both originate from b quarks is exploited to further confirm the top-quark signal. A b-quark jet identification algorithm that relies on the presence of charged particle tracks displaced from the primary pp interaction location, as expected from the decay products of long-lived b hadrons [32], is used. A jet is identified to be from a b quark if there are at least two tracks satisfying a minimum impact parameter significance requirement. The efficiency of this algorithm for a b-quark jet in dilepton $t\bar{t}$ signal events is about 80% with a 10% false positive rate, as estimated in simulated QCD multijet events with no b quarks. This algorithm is applied to events passing all the selection criteria. The multiplicity of jets satisfying these b-tagging criteria in events passing the full dilepton event selection is shown in Fig. 3. Although not used directly in the cross section extraction, the b-tag multiplicity provides additional support for the hypothesis that the selected data are consistent with dilepton $t\bar{t}$ production.

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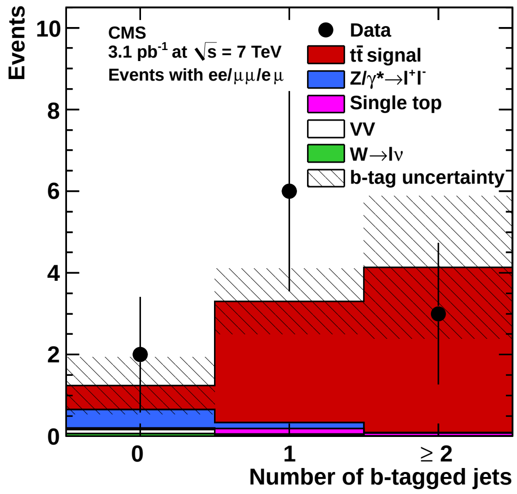

Figure 3: Number of b-tagged jets in events passing all dilepton selection criteria for all three dilepton modes combined, compared to signal and background predictions. The hatched bands reflect the expected uncertainties on the b-tag efficiency for signal events.

The top-quark pair production cross section is determined from the ratio of the number of observed events in the data after background subtraction with the product of the signal acceptance, selection efficiency, the branching fractions, and the integrated luminosity. From the simulated $t\bar{t}$ sample, the acceptance times efficiency is found to be $(23.0 \pm 1.4)\%$ for events contributing to the e^+e^-, $\mu^+\mu^-$, and $e^{\pm}\mu^{\mp}$ modes combined. The total branching fraction for $t\bar{t}$ to the three modes of our final state is $(6.45 \pm 0.11)\%$ [27]. The systematic uncertainty on the acceptance times efficiency is described below.

Various sources of systematic uncertainty related to the event selection have been evaluated. The systematic uncertainty assigned to the dilepton selection efficiency is 4.4%, obtained from a comparison of Z events in data and simulation, together with half of the difference between the efficiencies obtained in simulated Z and $t\bar{t}$ events. The effect of multiple pp interactions in a single beam crossing — an effect that is present in the data but not in these simulated samples — is included in this uncertainty. The systematic uncertainty due to the reconstruction of jets and missing transverse energy is estimated by varying the jet energy scale by $\pm 5\%$, simultaneously with a $\pm 5\%$ variation in the hadronic part of the missing transverse energy, resulting in a value of 3.7%. Uncertainties on the simulation of the signal selection include the amount of QCD radiation, hadron and tau decay modeling, and the W leptonic branching fraction; these sources combined give a systematic uncertainty of 2.8%. Other sources of systematic uncertainty pertaining to the signal, including uncertainties in the parton distribution functions inside the colliding protons and the effect of additional minimum bias interactions in the signal selection, are neglected because they were found to have a relatively small impact. The overall systematic uncertainty on the total $t\bar{t}$ cross section from the above sources is 6.4%.

The background contributions from single-top, diboson, and Drell-Yan $Z/\gamma^{\star} \rightarrow \tau^+\tau^-$ processes shown in Table 1 are obtained from simulation and found to be small compared to the total event yield. Each of these backgrounds is assigned a 50% systematic uncertainty. The contributions from Drell-Yan e^+e^- and $\mu^+\mu^-$ processes and events with non-W/Z isolated leptons are estimated from data with absolute systematic uncertainties of 0.5 and 0.3 events, respectively. The contribution to the systematic uncertainty on the cross section from the uncertainties on the background estimates is 11%.

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The total systematic uncertainty on the measured cross section, dominated by the uncertainty on the estimated background yield, is 24 pb. An additional systematic effect of 21 pb, due to a 11% relative uncertainty on the integrated luminosity measurement [5], is quoted separately.

Taking into account the data yield, the background estimation, the branching fraction, the signal acceptance and efficiency, the integrated luminosity, and all associated statistical and systematic uncertainties, the top-quark pair production cross section is measured to be

$$\sigma(\mathrm{pp} \to \mathrm{t\bar{t}}) = 194 \pm 72(\mathrm{stat.}) \pm 24(\mathrm{syst.}) \pm 21(\mathrm{lumi.})\ \mathrm{pb}.$$

An alternative analysis, exploiting jets constructed only from silicon tracker information [33] and without missing transverse energy requirements in the event selection, yields a similar cross section. The quoted measurement can be compared with the calculated NLO theoretical cross section of $157.5^{+23.2}_{-24.4}$ pb for a top-quark mass of 172.5 GeV/c^2 [16, 17].

In conclusion, the first measurement at the LHC of the cross section for $\mathrm{t\bar{t}}$ production has been completed. This measurement, made with an integrated luminosity of $3.1 \pm 0.3\ \mathrm{pb}^{-1}$, is only the beginning of a rich top-quark physics program to be conducted at the CMS experiment.

We wish to congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC machine. We thank the technical and administrative staff at CERN and other CMS institutes, and acknowledge support from: FMSR (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); Academy of Sciences and NICPB (Estonia); Academy of Finland, ME, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NKTH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); PAEC (Pakistan); SCSR (Poland); FCT (Portugal); JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); MST and MAE (Russia); MSTD (Serbia); MICINN and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); TUBITAK and TAEK (Turkey); STFC (United Kingdom); DOE and NSF (USA).

References

[1] CDF Collaboration, "Observation of top quark production in $\bar{\mathrm{p}}\mathrm{p}$ collisions", *Phys. Rev. Lett.* **74** (1995) 2626, arXiv:hep-ex/9503002. doi:10.1103/PhysRevLett.74.2626.

[2] D0 Collaboration, "Observation of the top quark", *Phys. Rev. Lett.* **74** (1995) 2632, arXiv:hep-ex/9503003. doi:10.1103/PhysRevLett.74.2632.

[3] J. R. Incandela, A. Quadt, W. Wagner et al., "Status and Prospects of Top-Quark Physics", *Prog. Part. Nucl. Phys.* **63** (2009) 239, arXiv:0904.2499. doi:10.1016/j.ppnp.2009.08.001.

[4] L. Evans and P. Bryant (editors), "LHC Machine", *JINST* **3** (2008) S08001. doi:10.1088/1748-0221/3/08/S08001.

[5] CMS Collaboration, "Measurement of CMS Luminosity", *CMS Physics Analysis Summary* **CMS-PAS-EWK-10-004** (2010).

[6] CMS Collaboration, “The CMS experiment at the CERN LHC”, *JINST* **0803** (2008) S08004. doi:10.1088/1748-0221/3/08/S08004.

[7] CMS Collaboration, “CMS Tracking Performance Results from Early LHC Operation”, *CMS Physics Analysis Summary* **CMS-PAS-TRK-10-001** (2010) arXiv:1007.1988.

[8] CMS Collaboration, “Performance of muon identification in pp collisions at $\sqrt{s}$ = 7 TeV”, *CMS Physics Analysis Summary* **CMS-PAS-MUO-10-002** (2010).

[9] CMS Collaboration, “Electron reconstruction and identification at $\sqrt{s}$=7 TeV”, *CMS Physics Analysis Summary* **CMS-PAS-EGM-10-004** (2010).

[10] CMS Collaboration, “CMS MET Performance in Events Containing Electroweak Bosons from pp Collisions at $\sqrt{s} = 7$ TeV”, *CMS Physics Analysis Summary* **CMS-PAS-JME-10-005** (2010).

[11] M. Cacciari, G. P. Salam, and G. Soyez, “The anti-k_t jet clustering algorithm”, *JHEP* **04** (2008) 063, arXiv:0802.1189. doi:10.1088/1126-6708/2008/04/063.

[12] CMS Collaboration, “Jet Performance in pp Collisions at $\sqrt{s}$=7 TeV”, *CMS Physics Analysis Summary* **CMS-PAS-JME-10-003** (2010).

[13] F. Maltoni and T. Stelzer, “MadEvent: Automatic event generation with MadGraph”, *JHEP* **02** (2003) 027, arXiv:hep-ph/0208156.

[14] T. Sjöstrand, S. Mrenna, and P. Skands, “PYTHIA 6.4 physics and manual”, *JHEP* **05** (2006) 026, arXiv:hep-ph/0603175.

[15] J. Allison et al., “Geant4 developments and applications”, *IEEE Trans. Nucl. Sci.* **53** (2006) 270. doi:10.1109/TNS.2006.869826.

[16] J. M. Campbell and R. K. Ellis, “MCFM for the Tevatron and the LHC”, arXiv:1007.3492.

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

[18] N. Kidonakis, “Top quark pair and single top production at Tevatron and LHC energies”, arXiv:1008.2460.

[19] N. Kidonakis and R. Vogt, “The Theoretical top quark cross section at the Tevatron and the LHC”, *Phys. Rev.* **D78** (2008) 074005, arXiv:0805.3844. doi:10.1103/PhysRevD.78.074005.

[20] M. Cacciari, S. Frixione, M. L. Mangano et al., “Updated predictions for the total production cross sections of top and of heavier quark pairs at the Tevatron and at the LHC”, *JHEP* **09** (2008) 127, arXiv:0804.2800. doi:10.1088/1126-6708/2008/09/127.

[21] S. Moch and P. Uwer, “Theoretical status and prospects for top-quark pair production at hadron colliders”, *Phys. Rev.* **D78** (2008) 034003, arXiv:0804.1476. doi:10.1103/PhysRevD.78.034003.

[22] U. Langenfeld, S. Moch, and P. Uwer, “New results for $t\bar{t}$ production at hadron colliders”, arXiv:0907.2527.

Operated by Fermi Research Alliance, LLC under Contract No. De-AC02-07CH11359 with the United States Department of Energy.

[23] 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.

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

[25] H.-L. Lai et al., "Uncertainty induced by QCD coupling in the CTEQ-TEA global analysis of parton distributions", arXiv:1004.4624.

[26] 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.

[27] Particle Data Group Collaboration, "Review of particle physics", *J. Phys.* **G37** (2010) 075021. doi:10.1088/0954-3899/37/7A/075021.

[28] J. M. Campbell and F. Tramontano, "Next-to-leading order corrections to Wt production and decay", *Nucl. Phys.* **B726** (2005) 109, arXiv:hep-ph/0506289. doi:10.1016/j.nuclphysb.2005.08.015.

[29] K. Melnikov and F. Petriello, "Electroweak gauge boson production at hadron colliders through $O(\alpha_s^2)$", *Phys. Rev.* **D74** (2006) 114017, arXiv:hep-ph/0609070. doi:10.1103/PhysRevD.74.114017.

[30] CDF Collaboration, "Measurement of the top quark mass using template methods on dilepton events in proton antiproton collisions at $\sqrt{s} = 1.96$ TeV", *Phys. Rev.* **D73** (2006) 112006, arXiv:hep-ex/0602008. doi:10.1103/PhysRevD.73.112006.

[31] D0 Collaboration, "Measurement of the top quark mass in the dilepton channel", *Phys. Rev.* **D60** (1999) 052001, arXiv:hep-ex/9808029. doi:10.1103/PhysRevD.60.052001.

[32] CMS Collaboration, "Commissioning of b-jet identification with pp collisions at $\sqrt{s}$ = 7 TeV", *CMS Physics Analysis Summary* **CMS-PAS-BTV-10-001** (2010).

[33] CMS Collaboration, "Commissioning of TrackJets in pp Collisions at $\sqrt{s}$=7 TeV", *CMS Physics Analysis Summary* **CMS-PAS-JME-10-006** (2010).

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