PROCEEDINGS OF SCIENCE

Top quark pair production cross-section at CMS

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Precision measurements of the top-pair production cross-section in proton-proton collisions at the LHC at a centre-of-mass energy of 7 and 8 TeV are presented. The data are collected with the CMS experiment during the years 2011 and 2012. The measurements are performed in several decay channels: the dilepton, the lepton plus jets, and the fully hadronic channels, including the τ-dilepton and τ plus jets modes. B-jet identification is used to increase the purity of the selection. The backgrounds are determined using data-driven techniques. The results are combined with each other and compared with theory predictions.

36th International Conference on High Energy Physics
4-11 July 2012
Melbourne, Australia

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PoS(ICHEP2012)227

1. Introduction

Several reasons make a precise measurement of the top-quark pair production cross-section in proton-proton collisions at the Large Hadron Collider (LHC) important: 1) top-quark pair production represents a benchmark for other processes of the standard model initiated through the gluon-gluon fusion, such as the production of Higgs bosons; 2) a precise determination of the cross-section can provide constraints on parton distribution functions and can check for the validity of perturbative calculations in quantum chromo-dynamics; 3) top-quark pair production is often a major source of background to searches.

Top quarks decay almost exclusively through the electroweak transition $t \to Wb$, where the W-boson can decay leptonically ($W \to l\nu$), or hadronically ($W \to q\bar{q}$). In this work we present several measurements of top-quark pair cross-section using data collected by the Compact Muon Solenoid (CMS) experiment [1]. The measurements are performed in different final states: dilepton channel, dilepton channel containing a τ, lepton plus jets channel, τ plus jets channel, and fully-hadronic channel. Final states containing a lepton also contain an important source of missing energy from the undetected neutrinos.

We first focus on measurements based on data recorded during 2011 at $\sqrt{s}$ = 7 TeV, and then discuss preliminary measurements performed with 2012 data at $\sqrt{s}$ = 8 TeV; a combined measurement at each of the center-of-mass energy is also shown. The presented measurements are given for a top mass of 172.5 GeV. We conclude by showing the dependence of these measurements with energy.

2. Measurements at a center-of-mass energy of 7 TeV

We start the discussion with the measurement performed in the dilepton final state [2]. We require two opposite-sign, isolated and high-p_T leptons. The Z-mass region is vetoed in channels with same flavor leptons in order to get rid of Drell-Yan background events. In addition, at least two jets in the event and a minimum amount of missing energy are required. Drell-Yan and non-W/Z lepton backgrounds are estimated from data. The measurement is performed using a profile likelihood fit of a 2-dimensional space of the jet multiplicity, and the multiplicity of b-tagged jets, shown in Fig. 1. Three different final states (ee, $\mu\mu$, and eμ) are analyzed, and the combined measurement is $161.9 \pm 2.5(\text{stat.})^{+5.1}_{-5.0}(\text{syst.}) \pm 3.6(\text{lumi})$ pb. The dominant uncertainties on this measurement arise from the uncertainty on the lepton identification and isolation efficiencies, and on the jet energy scale.

A different analysis is conducted when one of the two leptons in the final state is a τ [3]. This measurement requires one isolated and high-p_T electron or muon, and one hadronically decaying tau. Further requirements are at least two jets in the event, a minimum amount of missing energy, and at least one b-tagged jet. Hadronic τ decays are reconstructed with the Hadron-Plus-Strips (HPS) [4] algorithm. Multijet QCD events are used to measure the rate of τ-misidentification. Figure 2 shows the reconstructed top mass and the consistency of the selected samples in data with the sum of signal and background. The measurement is performed in two categories (eτ and $\mu\tau$), and the combination, extracted using the BLUE method [5], is $143 \pm 14(\text{stat.}) \pm 22(\text{syst.}) \pm 3(\text{lumi.})$

pb. The uncertainty on the τ-identification, and on the jet energy scale are the main contributors to the total uncertainty.

If one of the W-boson decays hadronically some jets will appear in the event, in that case the production cross-section is measured in lepton plus jets final states [6]. This measurement requires one isolated and high-p_T electron or muon, and vetoes on additional leptons. At least four jets have to be present in the event, a minimum amount of missing energy is also required, as at least one b-tagged jet. The QCD background normalization is extracted from data. The measurement is performed using a proofile likelihood fit from secondary vertex mass, number of jets and number of b-tagged jets (Fig. 3); some systematic uncertainties are treated as nuisance parameters in the fit. The combined measurement turns to be $164.4 \pm 2.8(\text{stat.}) \pm 11.9(\text{syst.}) \pm 7.4(\text{lumi.})$ pb. The dominant uncertainties arise from the uncertainty on the lepton identification and isolation efficiencies, and on the jet energy scale.

If the lepton is a τ the measurement is performed in the τ plus jets final state [7]; requiring a least four jets in the event with at least one being b-tagged and one a hadronically decaying τ lepton, a minimum amount of missing energy is also asked for. As in the dilepton case with a τ, the hadronic τ decays are reconstructed with the HPS algorithm. The QCD bakcground is extracted from untagged data. Finally, the cross-section, extracted from a likelihood fit of a neural-network output, turns to be $156 \pm 12(\text{stat.}) \pm 33(\text{syst.}) \pm 3(\text{lumi.})$ pb. The main contributors to the total uncertainty are the uncertainty on the τ-identification, and on jet energy scale.

A measurement in the fully-hadronic channel is also performed [8]. We require at least six jets with different high-p_T thresholds, at least two being b-tagged (this channel is fully dominated by QCQ, making b-tagging essential). The cross-section is extracted from an unbinned likelihood fit to the top quark mass (Fig. 4). The resulting cross-section is $136 \pm 20(\text{stat.}) \pm 40(\text{syst.}) \pm 8(\text{lumi.})$ pb; the dominant systematic uncertainties are the uncertainty on the b-tag efficiencies and on the jet energy scale.

3. Measurements at a center-of-mass energy of 8 TeV

In this work we present the first production cross-section measured at $\sqrt{s}$ = 8 TeV in the dilepton channel ([13]) and in the lepton plus jets channel [14]. The 8 TeV dilepton analysis follows the selection at 7 TeV but adds as a requirement the presence of at least one b-tagged jet in the event. The measurement is performed by means of a cut-based analysis in three categories; the combination is extracted using the BLUE method. Figure 5 shows the multiplicity of b-tagged jets after the full selection. The cross-section turns to be $226.8 \pm 3.1(\text{stat.}) \pm 10.7(\text{syst.}) \pm 10.0(\text{lumi.})$ pb. The dominant uncertainties arise from the same sources as in the 7 TeV case.

Finally, the lepton plus jets measurement at 8 TeV follows the selection at 7 TeV. The measurement is extracted from a binned likelihood fit of the invariant mass of the b-jet and the lepton (Fig. 6). The combined measurement is $228.4 \pm 9.0(\text{stat.}) \pm^{29.0}_{26.0}(\text{syst.}) \pm 10.0(\text{lumi.})$ pb. The dominant uncertainties arise from the uncertainty on the b-tag efficiencies, and on the jet energy scale.

4. Conclusions

We have measured the $t\bar{t}$ production cross-section at (almost) all the different experimental signatures at $\sqrt{s} = 7$ TeV; a summary is shown in Fig. 4. A combined measurement [9] was performed using a binned maximum likelihood prior to some of the measurements in this work, and includes measurements from 0.8 to 1.1 fb^{-1}. The result is $165.8 \pm 2.2(\text{stat.}) \pm 10.6(\text{syst.}) \pm 7.8(\text{lumi.})$ pb. In this work, we also present the first cross-section measurements at $\sqrt{s} = 8$ TeV. We observed an overall good agreement with standard model predictions at both energies. The precision of these measurements is starting to challenge theory predictions. Figure 4 shows the dependence of measured cross-sections with energy.

References

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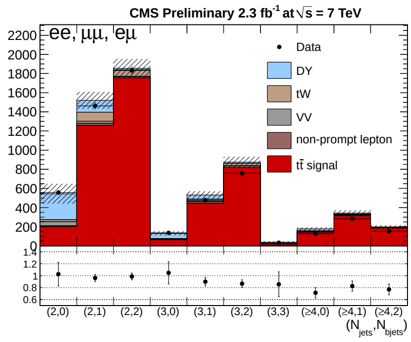

Figure 1: Number of events selected for the three combined dilepton channels, as a function of the number of jets and b-tagged jets in each event. The data are shown by the dots, while the predicted contributions are shown by the histograms. The hatched area corresponds to statistical and systematic uncertainties. The ratios of data to the sum of the predictions are given at the bottom.

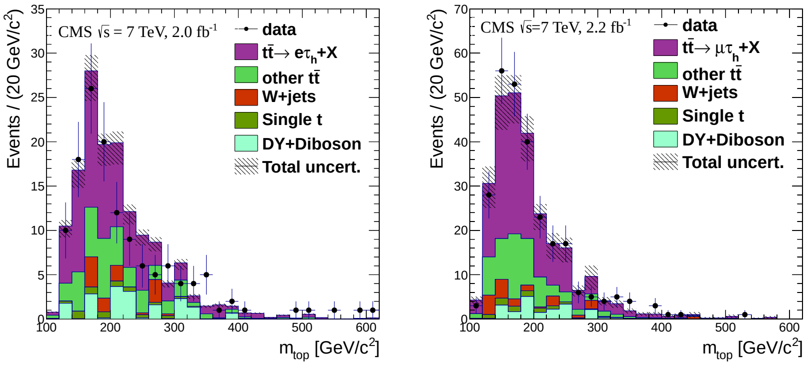

Figure 2: Reconstructed top quark mass m_{top} distribution for the τ-dilepton candidate events after the full event selection, in the $e\tau$ (left) and $\mu\tau$ (right) final states. Distributions obtained from data (points) are compared with simulation. The hatched area shows the total systematic uncertainty.

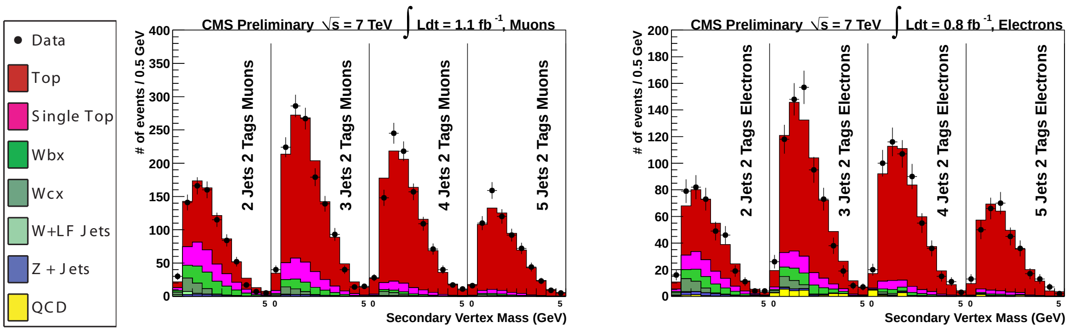

Figure 3: Results of the combined muon and electron channel fit. The plots are for two b-tagged jets. The histograms within each panel correspond to events with 2-, 3-, 4-, and 5-jets,respectively.

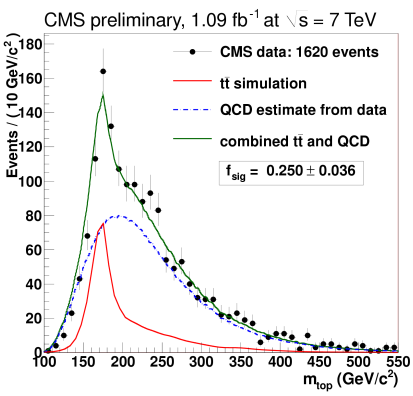

Figure 4: Result of the fit to the reconstructed top quark mass for the $t\bar{t}$ simulation (solid red line) and the multijet QCD estimated from data (dashed blue line). The uncertainty stated on the signal fraction f_{sig} is only statistical.

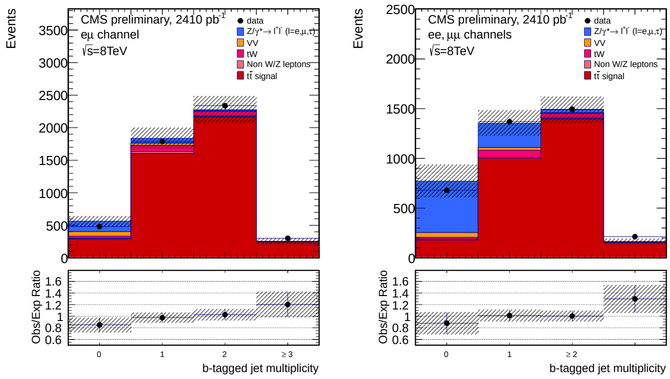

Figure 5: The multiplicity of b-tagged jets in events passing the full event selection (but without cutting in number of b-tagged jets), for the eμ (left) and the summed ee and $\mu\mu$ (right) channels and the corresponding data-to-simulation rations.

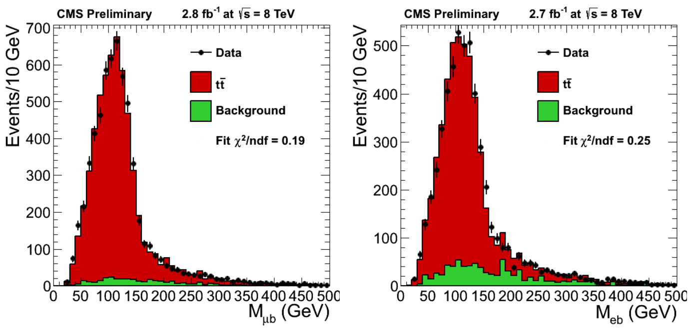

Figure 6: Template fit result on the lepton-jet mass in the muon plus jets (left) and in the electron plus jets channel (right). Signal and background contributions are rescaled according to the fit results.

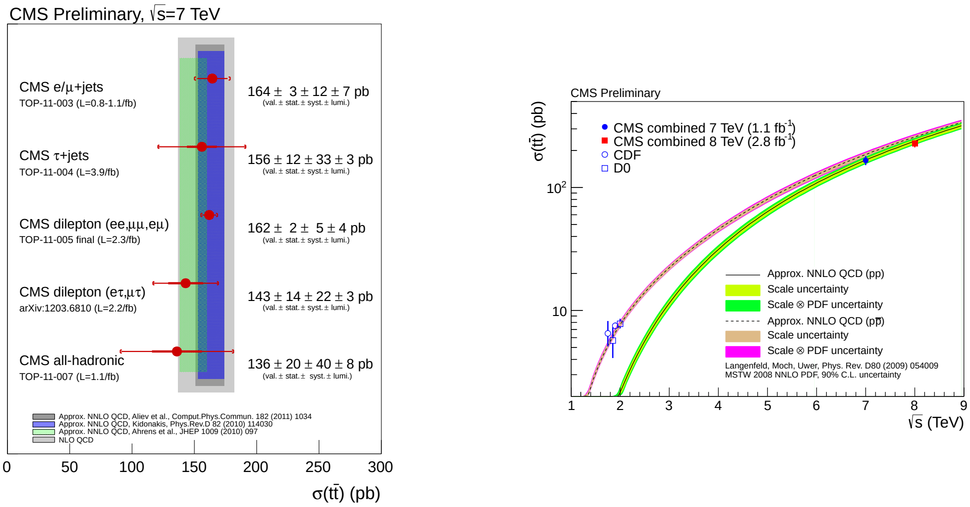

Figure 7: (Left) The cross-section of the $t\bar{t}$ production obtained in different channels at $\sqrt{s}$ = 7 TeV. The data are compared to the approximate next-to-next leading order calculations [10, 11, 12]. (Right) Top cross-section as a function of the centre-of-mass energy.