Top Quark Pair Production at $\sqrt{s} = 7$ TeV

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The successful pp run at $\sqrt{s} = 7$ TeV of the Large Hadron Collider in 2010-2011, has allowed the measurement of the top-quark pair production cross section in a variety of final states and with unprecedented precision. This note presents the results of the ATLAS and CMS collaborations of the top-quark pair production cross section measurement in various final states, as well as their combination. The combination of the ATLAS measurements gives $\sigma_{t\bar{t}} = 177 \pm 3(\text{stat.})^{+8}_{-7}(\text{syst.}) \pm 7(\text{lumi.})$ pb and the CMS combination yields a value $\sigma_{t\bar{t}} = 165.8 \pm 2.2(\text{stat.}) \pm 10.6(\text{syst.}) \pm 7.8(\text{lumi.})$ pb, which are both within the Standard Model expectations.

1 Introduction

Owing to its large mass the top quark might play an important role in physics beyond the Standard Model (SM), and the measurement of its production at the Large Hadron Collider (LHC) provides important tests of perturbative quantum chromodynamics (QCD) in the multi-TeV energy regime. In pp collisions at the LHC, top quarks are dominantly produced in top-antitop pairs ($t\bar{t}$), and are classified according to its decay modes. Within the SM the top quark decays essentially always via the weak process $t \to Wb$. The decay topology is determined by the decay mode of the W boson, which decays either to a lepton and its neutrino or to a pair of quarks. The predicted SM $t\bar{t}$ cross section for pp collisions at a centre-of-mass energy of $\sqrt{s} = 7$ TeV is $\sigma_{t\bar{t}} = 167^{+17}_{-18}$ pb for a top quark mass of 172.5 GeV/c^2 as obtained from approximate NNLO QCD calculations [1].
Measurements of the $t\bar{t}$ cross section in several final states have been carried out by the ATLAS [2] and CMS [3] collaborations and are presented in this note. The results in the different channels are based on data samples corresponding to an integrated lumiosity ranging from 0.70 to 4.7 fb^{-1} recorded by the two experiments.

2 Top quark pair production cross-section

Final states of $t\bar{t}$ events contain at least two jets with secondary vertices from the B mesons decays (b-tagged jets), leptons, missing energy from the escaping neutrinos or light jets, depending on the decay mode of the two W bosons. In the following, the measurements by the ATLAS and CMS collaborations of the $t\bar{t}$ cross section for various final state topologies are presented. Thanks to the large data sample that has been recorded, all measurements presented here are limited by systematic uncertainties.

2.1 *Single lepton channel*

The single lepton channel currently provides the most precise measurement of the $t\bar{t}$ cross section. In this channel one of the two W bosons decays hadronically, while the other decays into a lepton-neutrino pair. The event trigger and selection is based on the identification of one isolated lepton. The dominant contributions to the background are due to W+jet events and QCD multi-jet events, where one jet is mis-identified as a reconstructed lepton. Since the background from these sources is difficult to simulate correctly, its modeling is based on data. A likelihood function is built from various kinematic variables and templates are constructed for signal and backgrounds, separating the sample in the electron and muon channel and different jet multiplicities. The cross section measured by ATLAS, based on an analysis without explicit identification of b jets and with a data sample corresponding to 0.70 fb^{-1}, is $\sigma_{t\bar{t}} = 179.0 \pm 3.9(\text{stat.}) \pm 9.0(\text{syst.}) \pm 6.6(\text{lumi.})$ pb [4]. The result by CMS presented here is $\sigma_{t\bar{t}} = 164.4 \pm 2.8(\text{stat.}) \pm 11.9(\text{syst.}) \pm 7.9(\text{lumi.})$ pb, which takes advantage of the b-tagging capabilities [5] and uses a data sample with 0.80-1.09 fb^{-1}.

In both cases the uncertainty on the jet energy calibration is one of the dominant contributions to the total systematic error. It is worth noting that the overall uncertainty of the measurement is below the uncertainty of the approximate NNLO calculation mentioned in Section 1.

2.2 *Dilepton channel*

In the dilepton channel, which contains two pairs of leptons with its neutrino in the final state, the background is dominated by Drell-Yan production and is estimated from data. Other background processes, such as single top quark or diboson production are estimated from Monte Carlo simulation. The event selection is based on a trigger and identification of two leptons, identifying b-tagged jets and large missing transverse energy ($E_{\text{T}}^{\text{miss}}$). In the dilepton channel ATLAS reports $\sigma_{t\bar{t}} = 176 \pm 5(\text{stat.})^{+14}_{-11}(\text{syst.}) \pm 8(\text{lumi.})$ pb [6] and CMS $\sigma_{t\bar{t}} = 169.9 \pm 3.9(\text{stat.}) \pm 16.3(\text{syst.}) \pm 7.6(\text{lumi.})$ pb [7]. The measurement by ATLAS is based on a total integrated luminosity of 0.70 fb^{-1}, while the one by CMS is based on 1.14 fb^{-1}. In both analyses the systematic uncertainty is dominated by the lepton identification capability.

2.3 *Tau + μ channel*

In this section the measurement of the $t\bar{t}$ cross section in events with an isolated muon and a tau lepton decaying hadronically is presented. The sample of events is selected using a single muon trigger and requiring at least one b-tagged jet and large $E_{\text{T}}^{\text{miss}}$. The dominant background arises from jets faking taus which is estimated from data. One of the pivotal elements of this measurement is the tau-identification algorithm. A boosted decision tree, which distinguishes between one and three-prong tau decays, is used for the measurement by ATLAS, while CMS uses the hadron-plus-strips (HPS) tau identification algorithm [8]. The cross section reported by ATLAS in this channel is $\sigma_{t\bar{t}} = 142 \pm 21(\text{stat.})^{+20}_{-16}(\text{syst.}) \pm 5(\text{lumi.})$ pb [9], the one reported by CMS is $\sigma_{t\bar{t}} = 148.7 \pm 23.6(\text{stat.}) \pm 26.0(\text{syst.}) \pm 8.9(\text{lumi.})$ pb [10]. The measurements are based on data samples corresponding to an integrated luminosity of 1.08 fb^{-1} and 1.09 fb^{-1} used by ATLAS and CMS, respectively.

2.4 *Tau + jets channel*

This channel is characterized by $t\bar{t}$ events with one hadronically decaying τ-lepton and jets ($t\bar{t} \rightarrow \tau_{\text{had}}+$ jets). Currently the measurement of the $t\bar{t}$ production cross section in this channel has only been presented by the ATLAS collaboration. Events are selected with a trigger requiring at least two b-tagged jets, which are further confirmed by the offline b-tagging reconstruction. The signal is extracted using a fit to the distribution of the number of tracks associated to the tau candidate. The background to this final state is mainly due to multi-jet events, from $t\bar{t}$ events with a different final state or from jets in $t\bar{t}$ events mis-identified as tau candidates. For the multi-jet and $t\bar{t}$ backgrounds, templates are derived from data in a background enriched region. On the other hand, the background from $t\bar{t}$ events with electrons in the final state is estimated from simulation. The result presented by ATLAS is the first measurement of the $t\bar{t}$ cross section in this channel which is found to be $\sigma_{t\bar{t}} = 200 \pm 19(\text{stat.}) \pm 43(\text{syst.})$ pb and is based on a data sample corresponding to an integrated luminosity of 1.67 fb^{-1} [11].

2.5 All hadronic channel

The all hadronic channel is the final state of $t\bar{t}$ events with the largest branching ratio ($\approx 44\%$), but suffers from a large multi-jet background. The signal extraction is based on a kinematical fit that exploits the characteristic topology of a hadronic $t\bar{t}$ event. It maximizes a likelihood function with respect to the jet energies, which are varied in the fit, and the constraints given by the Breit-Wigner distributions of the W boson and top quark. For the background modeling, the ATLAS measurement derives the shape of the multi-jet background by performing the kinematical fit on the data sample without applying the b-tagging requirement. In the CMS measurement a probability, $R(p_{\text{T}}, |\eta|)$, for b-tagging a jet is first derived as a function of the jet transverse momentum p_{T} and its absolute pseudorapidity value $|\eta|$. Then the kinematic fit is performed on all events with zero b-tagged jets and an event weight, defined as the product of $R(p_{\text{T}}, |\eta|)$ computed for the two jets assigned to the b-quarks in the kinematic fit hypothesis, is applied to estimate the multi-jet background. The measurement by ATLAS is based on a data sample corresponding to an integrated luminosity of 4.7 fb^{-1} and gives a value of $\sigma_{t\bar{t}} = 168 \pm 12(\text{stat.})^{+60}_{-57}(\text{syst.}) \pm 6(\text{lumi.})$ pb [12]. The value reported by CMS is $\sigma_{t\bar{t}} = 136 \pm 20(\text{stat.}) \pm 40(\text{syst.}) \pm 8(\text{lumi.})$ pb [13], which is based on a data sample corresponding to 1.09 fb^{-1}.

2.6 Combination of measurements

The combination takes into account correlated systematic uncertainties between the channels. The result presented by ATLAS combines the single-lepton, dilepton and all-hadronic final states, and finds a value of $\sigma_{t\bar{t}} = 177 \pm 3(\text{stat.})^{+8}_{-7}(\text{syst.}) \pm 7(\text{lumi.})$ pb [14]. CMS combines the single-lepton, dilepton, $\tau{+}\mu$ and the all hadronic channels which yields a value of $\sigma_{t\bar{t}} = 165.8 \pm 2.2(\text{stat.}) \pm 10.6(\text{syst.}) \pm 7.8(\text{lumi.})$ pb [15]. The measurements used for the combination presented here and the comparison to the approximate NNLO calculation are shown in Fig. 1 and are in good agreement with the SM expectation.

3 Conclusions

The pp run in 2010-2011 at $\sqrt{s} = 7$ TeV of the LHC has been very successful, with up to 4.7 fb^{-1} of data recorded by the ATLAS and CMS experiments. The measured $t\bar{t}$ cross section in various final states is found to be in agreement with the SM expectation. The precision of all the measurements presented here is driven by systematic uncertainties, and reaches levels that are comparable or below the uncertainties of theoretical predictions.

References

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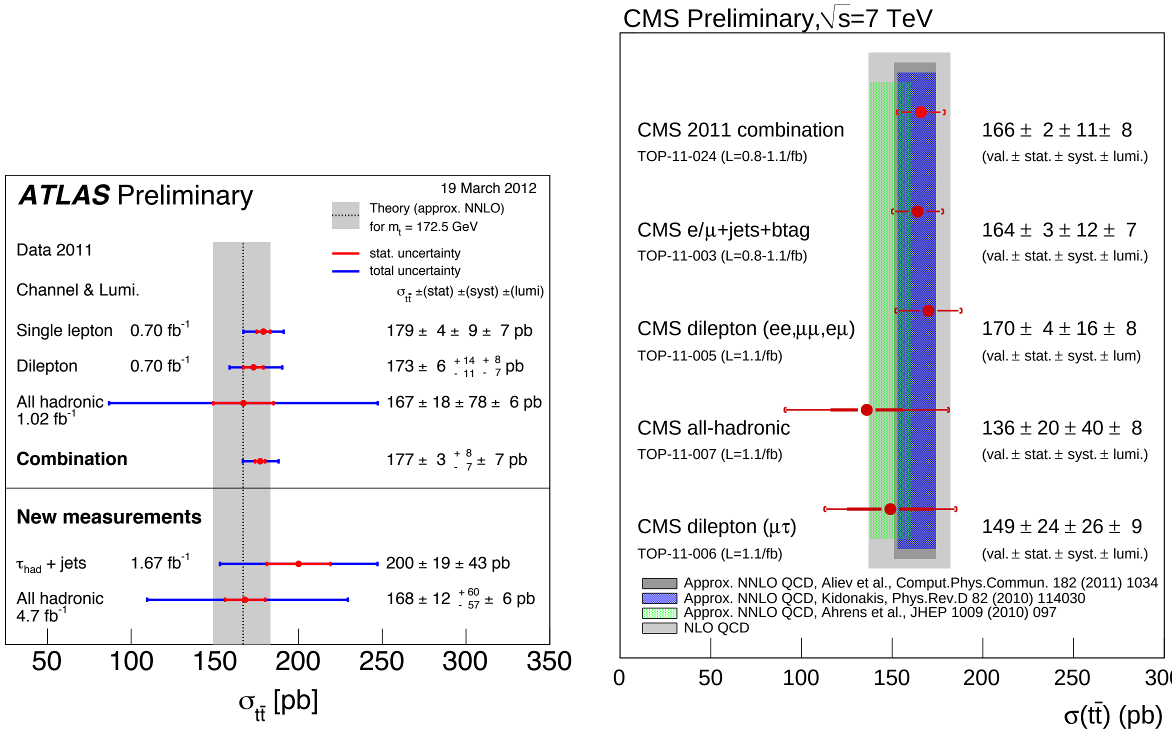

(a) (b)

Figure 1: The measured value of $\sigma_{t\bar{t}}$ by ATLAS (a) and CMS (b) in various channels at $\sqrt{s} = 7$ TeV and the resulting combination. Error bars include statistical and systematic uncertainties. The approximate NNLO prediction with its uncertainty is also shown.

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