

Top quark production in the ATLAS detector of the LHC

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Abstract. Top quark has been re-discovered at LHC in 2010 by the CMS and the ATLAS experiments. The top quark is the heaviest known elementary particle, and its properties might offer a hint of physics beyond the Standard Model. Therefore, it is interesting to measure them as precisely as possible. We present a summary of a variety of measurements relating to the top quark production in pp collisions with $\sqrt{s} = 7$ and 8 TeV at LHC. Not only the inclusive production cross section, but also differential and fiducial cross sections are measured with the ATLAS detector. By comparing our results with various theoretical predictions, it is confirmed that Standard Model predictions are in good agreement with all measured results.

1. Introduction

The top quark was discovered at Tevatron in 1995. It was re-discovered at LHC in 2010. In the LHC operation from 2010 to 2012, the ATLAS experiment [1] has recorded a large number of top quark events. This allows us to measure properties of the top quark very precisely. These precise measurements might give us a clue to catch physics beyond the Standard Model.

Top quarks are produced mainly in pairs via the strong interaction. Predicted cross section of the pair production is calculated as $\sigma_{t\bar{t}} = 177_{-11}^{+10}$ pb for $\sqrt{s} = 7$ TeV and $\sigma_{t\bar{t}} = 253_{-15}^{+13}$ pb for $\sqrt{s} = 8$ TeV with the next-to-next-to-leading order precision [2]. In addition to the pair production, we can consider the single top production via the weak interaction. The dominant process for it happens via the t -channel W boson exchange. The next-to-next-to-leading order calculation predicts the cross section of this process as $\sigma_{tq+\bar{t}q} = 64.6_{-2.0}^{+2.7}$ pb for 7 TeV and $\sigma_{tq+\bar{t}q} = 87.8_{-1.9}^{+3.4}$ pb for 8 TeV [3]. Understanding of these production processes is an important topic because it proves the validity of the Standard Model at the highest energy region ever achieved.

Top quarks are predicted to decay via the electroweak interaction into a W boson and a bottom quark with nearly 100 % branching ratio. Events are normally classified according to the number of charged leptons. For the $t\bar{t}$ final state, there are two W bosons. W boson can either decay into a pair of quarks or into a charged lepton and a neutrino. Single lepton and dilepton topologies (one and two charged leptons in the final state, respectively) were considered as the signal candidate event. Only electrons and muons, including those from tau decays, were considered in the analyses presented below.



2. Measurement of the inclusive cross section of $t\bar{t}$

The inclusive cross section of the top quark pair production $\sigma_{t\bar{t}}$ has been measured in pp collisions at $\sqrt{s} = 7$ and 8 TeV in the final state with oppositely charged $e\mu$ pair. The measurement was performed with the 7 TeV dataset taken in 2011 corresponding to an integrated luminosity of 4.6 fb^{-1} , and the 8 TeV dataset taken in 2012 of 20.3 fb^{-1} . The numbers of events with exactly one and exactly two b -tagged jets were counted and used to simultaneously determine $\sigma_{t\bar{t}}$, and efficiency to tag a jet from a top quark decay as a b -quark jet. This method allows us to minimize the associated systematic uncertainties. The cross section was measured to be

$$\begin{aligned}\sigma_{t\bar{t}} &= 182.9 \pm 3.1 \pm 4.2 \pm 3.6 \pm 3.3 \text{ pb } (\sqrt{s} = 7 \text{ TeV}) \text{ and} \\ \sigma_{t\bar{t}} &= 242.4 \pm 1.7 \pm 5.5 \pm 7.5 \pm 4.2 \text{ pb } (\sqrt{s} = 8 \text{ TeV}) \text{ [4],}\end{aligned}$$

where four uncertainties arise from data statistics, systematic uncertainties, knowledge of the integrated luminosity and of the LHC beam energy. The results are consistent with the theoretical QCD calculations at next-to-next-to-leading order mentioned in Sec. 1.

3. Measurement of the differential cross section of $t\bar{t}$

Measurements of normalized differential cross sections for $t\bar{t}$ production are presented as a function of the top quark transverse momentum p_T^t , and of the mass $M_{t\bar{t}}$, the transverse momentum $p_T^{t\bar{t}}$, and the rapidity $y_{t\bar{t}}$ of the $t\bar{t}$ system, in proton-proton collisions at $\sqrt{s} = 7$ TeV. The dataset corresponds to an integrated luminosity of 4.6 fb^{-1} , recorded in 2011 [5]. Events are selected in the single lepton channel, requiring exactly one lepton and at least four jets with at least one of the jets tagged as b -quark jet. The measured kinematic variables are corrected for detector efficiency and resolution effects, and are compared to several Monte Carlo simulations and theoretical calculations. The results are in fair agreement with the predictions in a wide kinematic range. Nevertheless, data distributions are softer than predicted for higher values of the mass of the $t\bar{t}$ system and of the top quark transverse momentum as shown in Figure 1. The measurements can also shed a light on some features of different sets of parton distribution functions.

4. Jet multiplicities in the $t\bar{t}$ production

The $t\bar{t}$ production cross section as a function of jet multiplicities is reported for proton-proton collisions at a centre-of-mass energy of 7 TeV in the single lepton final state [6]. We used data collected with the ATLAS detector in 2011 corresponding to an integrated luminosity of 4.6 fb^{-1} . Differential cross sections are presented as a function of the jet multiplicity for up to eight jets using several jet transverse momentum thresholds between 25 and 80 GeV, and as a function of jet transverse momentum up to the fifth jet. The results are shown after background subtraction and corrections for all detector effects. Several QCD-based Monte Carlo models are compared with the results. Sensitivity to the parton shower modeling is found at the higher jet multiplicities and in the transverse momentum spectrum of the fifth leading jet as shown in Figure 2.

5. Top quark pair production associated with the vector boson

We have performed the analysis of the $t\bar{t}$ production associated with a W or Z boson [7]. Analyzed data corresponding to 20.3 fb^{-1} was taken in 2012 at $\sqrt{s} = 8$ TeV. Final states with two or three leptons are considered. Assuming $t\bar{t}W$ production at the Standard Model rate, predicted by next-to-leading-order QCD calculations, the ratio of the measured $t\bar{t}Z$ signal to the Standard Model expectation (signal strength) is found to be $\mu_{t\bar{t}Z} = 0.73_{-0.26}^{+0.29}$, corresponding to a 3.2σ excess over the background-only hypothesis. Assuming $t\bar{t}Z$ production at the Standard Model rate, the $t\bar{t}W$ signal strength is found to be $\mu_{t\bar{t}W} = 1.25_{-0.47}^{+0.57}$, corresponding to a

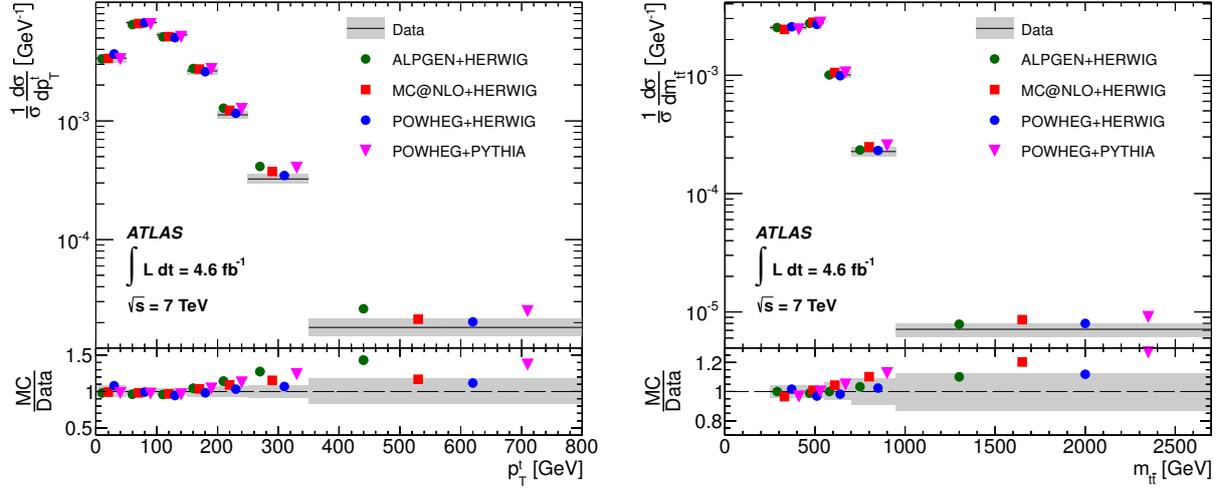


Figure 1. Normalized differential cross sections for the transverse momentum of the hadronically decaying top quark p_T^t (left), and the invariant mass of the $t\bar{t}$ system $m_{t\bar{t}}$ (right) [5]. Predictions by four Monte Carlo generators are shown as markers for ALPGEN+HERWIG (green circles), MC@NLO+HERWIG (squares), POWHEG+HERWIG (blue circles) and POWHEG+PYTHIA (inverted triangles). Shaded bands indicate the total uncertainty on data.

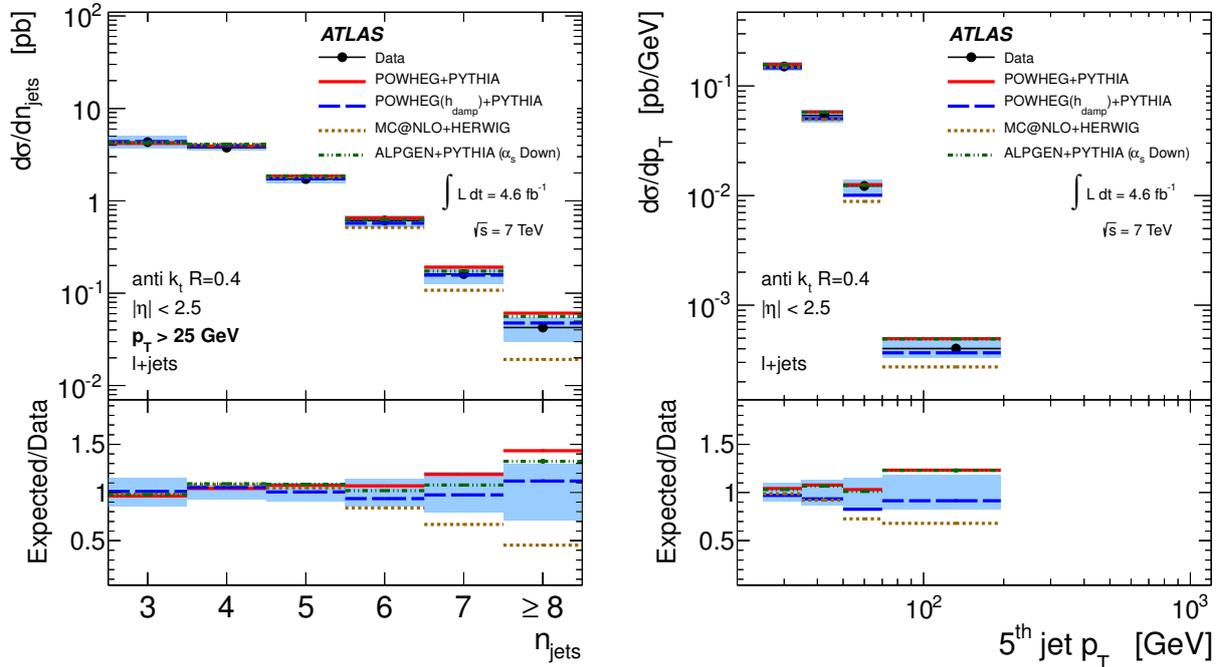


Figure 2. The $t\bar{t}$ cross section as a function of the jet multiplicities for the jet p_T threshold of 25 GeV (left), and of the transverse momentum of 5th leading jet (right) [6]. The data are shown in comparison to POWHEG+PYTHIA, POWHEG+PYTHIA with a parameter tuning for high- p_T radiation (referred to as POWHEG(h_{damp})+PYTHIA), MC@NLO+HERWIG and ALPGEN+PYTHIA(α_S Down) predictions. The data points and their corresponding total uncertainties are shown as a shaded band.

3.1 σ excess over the background-only hypothesis. The combined $t\bar{t}Z$ and $t\bar{t}W$ signal strength, assuming the Standard Model cross section ratio between $t\bar{t}Z$ and $t\bar{t}W$ predicted by next-to-leading-order QCD calculations, is found to be $\mu_{t\bar{t}V} = 0.89_{-0.22}^{+0.23}$, corresponding to a 4.9 σ excess over the background-only hypothesis. A simultaneous measurement of the $t\bar{t}Z$ and $t\bar{t}W$ signal strengths yields $\mu_{t\bar{t}Z} = 0.71_{-0.26}^{+0.28}$ and $\mu_{t\bar{t}W} = 1.30_{-0.48}^{+0.59}$, corresponding to a 4.4 σ excess over the background-only hypothesis. Observed signal significance from the simultaneous measurement yields 3.1 σ for both $t\bar{t}Z$ and $t\bar{t}W$ processes. All measurements are consistent with next-to-leading-order theoretical calculations for $t\bar{t}Z$ and $t\bar{t}W$ processes.

6. Measurement of the cross section of single top production

The cross section of the t -channel single top production has been measured with 4.6 fb⁻¹ of $\sqrt{s} = 7$ TeV pp collision data recorded in 2011, and with 20.3 fb⁻¹ of $\sqrt{s} = 8$ TeV in 2012 [8, 9]. Events are selected using the $t \rightarrow \ell\nu b$ decay mode of the top quark. The experimental signature of candidate events is given by one electron or muon, large missing transverse momentum from neutrino, and two jets with high transverse momentum. One of the jets is required to originate from a b -quark. To separate t -channel signal events from background, several kinematic variables are combined into one discriminant by employing a neural network. A large number of potential input variables have been studied, including kinematic variables of the reconstructed particles, but also variables obtained from the reconstruction of the W boson and the top quark. A binned maximum-likelihood fit to the neural network output distribution is performed to extract the cross section. Inclusive cross sections for each beam energy were obtained as

$$\begin{aligned}\sigma_t(7 \text{ TeV}) &= 68 \pm 2(\text{stat.}) \pm 8(\text{syst.}) \text{ pb and} \\ \sigma_t(8 \text{ TeV}) &= 82.6 \pm 1.2(\text{stat.}) \pm 11.4(\text{syst.}) \pm 3.1(\text{PDF}) \pm 2.3(\text{lumi.}) \text{ pb,}\end{aligned}$$

which is in excellent agreement with the Standard Model prediction.

7. Conclusions

The ATLAS experiment has performed various measurements relating to the top quark production with using whole datasets of pp collisions at LHC taken in 2011 and 2012. Thanks to the large amount of the top quark events, precision of measurements presented in this paper is not limited by the statistic uncertainty. We have compared our results with several theoretical predictions. No significant deviation has been observed so far.

References

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