PROCEEDINGS OF SCIENCE

Measurements of $t\bar{t}$+X using the ATLAS detector

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The large centre-of-mass energy available at the Large Hadron Collider (LHC) allows for the copious production of top quark pairs in association with other final state particles at high transverse momenta. Several final state observables that are sensitive to additional radiation in top anti-top quark final states has been measured by the ATLAS experiment. The production of top quark pair in association with W and Z bosons or with a photon have been also measured. Analyses probing the top pair production with additional QCD radiation include the multiplicity of jets for various transverse momentum thresholds in the 13 TeV data. These measurements are compared to modern Monte Carlo generators based on NLO QCD matrix element or LO multi-leg matrix elements, and the results are consistent with the standard model predictions within the uncertainties.

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1. Introduction

At the Large Hadron Collider (LHC), top quark pairs in association with other final state particles at high transverse momenta can be measured owing to the large centre-of-mass energy and the high integrated luminosity, and measurements of these production can provide a unique opportunity to test perturbation QCD theory and the Standard Model (SM). Also understanding these final states is important as dominant background for several Beyond the Standard Model (BSM) searches.

This proceedings paper focuses on the measurements of the production of top quark pairs in association with a vector boson (W or Z boson) [1], the $t\bar{t}$ production with a photon [2], and the top pair production with additional QCD radiation including the multiplicity of jets for various transverse momentum thresholds [3], by using the ATLAS detector [4].

2. Measurement of jet activity produced in $t\bar{t}$ events at $\sqrt{s}$ = 13 TeV

Jet activity in top quark pair events was measured using 3.2 fb^{-1} of proton–proton collision data at a centre-of-mass energy of 13 TeV collected by the ATLAS experiment at the LHC [3]. This measurement is crucial to improve modeling of parton shower and hadronization and description of overall top kinematics. Events are chosen by requiring an oppositely charged $e\mu$ pair and two or more b-tagged jets in the final state. The normalized differential cross-sections of top quark pair production are presented as functions of additional-jet multiplicity and transverse momentum, p_{T}. The number of additional jets in addition to the two highest p_{T} b-jets are counted with different p_{T} thresholds; 25, 40, 60 and 80 GeV. Each measured distribution is unfolded to the particle-level by correcting for detector effects and compared to MC predictions.

Figure 1 shows unfolded jet multiplicity distributions for different p_{T} thresholds of the additional jets (jet p_{T} >25 GeV on left and jet p_{T} >80 GeV on right) together with the different MC predictions and the ratios to various MC predictions. It is found that the kinematics of the jets from top quark decays are described well, but the generators show differing levels of agreement with the measurements of observables that depend on the production of additional jets.

3. Measurement of $t\bar{t}Z$ and $t\bar{t}W$ production at $\sqrt{s}$ = 13 TeV

Measurements of the associated production of $t\bar{t}$ with a Z boson have sensitivity to the neutral-current coupling of the top quark. Several BSM prediction suggested that the production cross section of $t\bar{t}$ with a massive vector boson could be effected by the presence of new particles. The measurements of the $t\bar{t}Z$ and $t\bar{t}W$ production cross sections have been performed in the final states with either two same-charge muons, or three or four leptons (electrons or muons), using a data set of proton–proton collisions at $\sqrt{s}$ = 13 TeV recorded with the ATLAS detector at the LHC in 2015, corresponding to a total integrated luminosity of 3.2 fb^{-1} [1].

The inclusive cross sections of $t\bar{t}Z$ and $t\bar{t}W$ processes are extracted using simultaneous fits to the signal regions and the control regions. The left of Figure 2 shows the observed and expected event yields after the fit including all background expectations. The cross sections are measured to be $\sigma_{t\bar{t}Z} = 0.9 \pm 0.3$ pb and $\sigma_{t\bar{t}W} = 1.5 \pm 0.8$ pb, in agreement with the Standard Model predictions

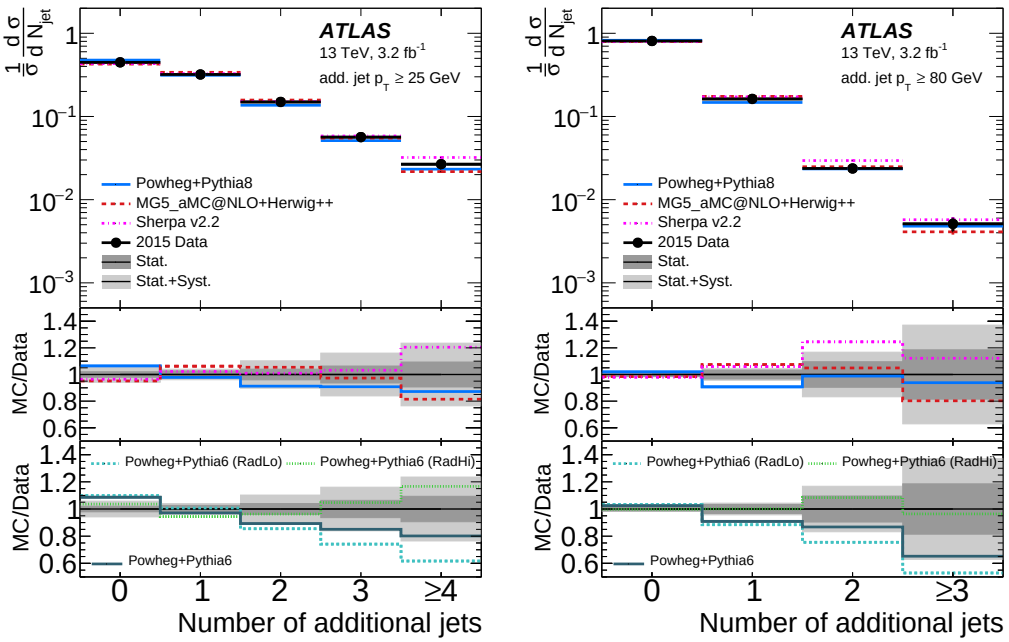

Figure 1: Unfolded jet multiplicity distribution for different p_{T} thresholds of the additional jets (jet p_{T} >25 GeV on left), and jet p_{T} >80 GeV on right) together with the different MC predictions. The middle and bottom panels show the ratios of various MC predictions to the measurement and the ratios of POWHEG+PYTHIA6 predictions with variation of the QCD radiation to the measurement, respectively. The shaded regions show the statistical (dark grey) and total (light grey) uncertainties [3].

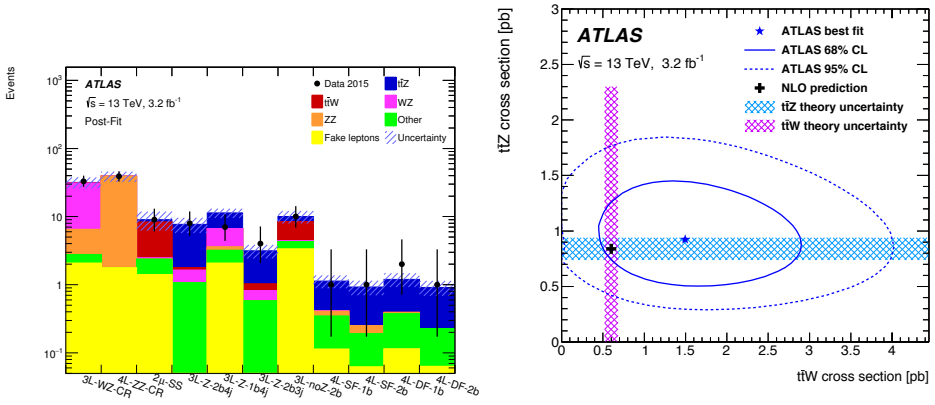

Figure 2: Expected yields after the fit (left). The result of the simultaneous fit to the $t\bar{t}Z$ and $t\bar{t}W$ cross sections along with the 68% and 95% confidence level contours (right) [1].

[5, 6] as shown in the right of Figure 2. The observed (expected) significances are 3.9σ (3.4σ) and 2.2σ (1.0σ) over the background-only hypothesis for the $t\bar{t}Z$ and $t\bar{t}W$, respectively.

4. $t\bar{t}\gamma$ production cross section measurement at $\sqrt{s}$ = 8 TeV

Measurements of the $t\bar{t}\gamma$ production probe the $t\gamma$ electroweak coupling. Photons can originate from top quarks or their decay products, or from incoming partons as radiation. Data set recorded with the ATLAS detector in 2012 at $\sqrt{s}$ = 8 TeV and corresponding to an integrated luminosity of 20.2 fb^{-1} is used in this study [2]. The $t\bar{t}\gamma$ production cross section is measured based on a maximum-likelihood fit method. This analysis is performed by selecting events that contain a photon with transverse momentum $p_{\mathrm{T}} > 15$ GeV, an isolated lepton with large transverse momentum, large missing transverse momentum, and at least four jets, where at least one is identified as originating from a b-quark.

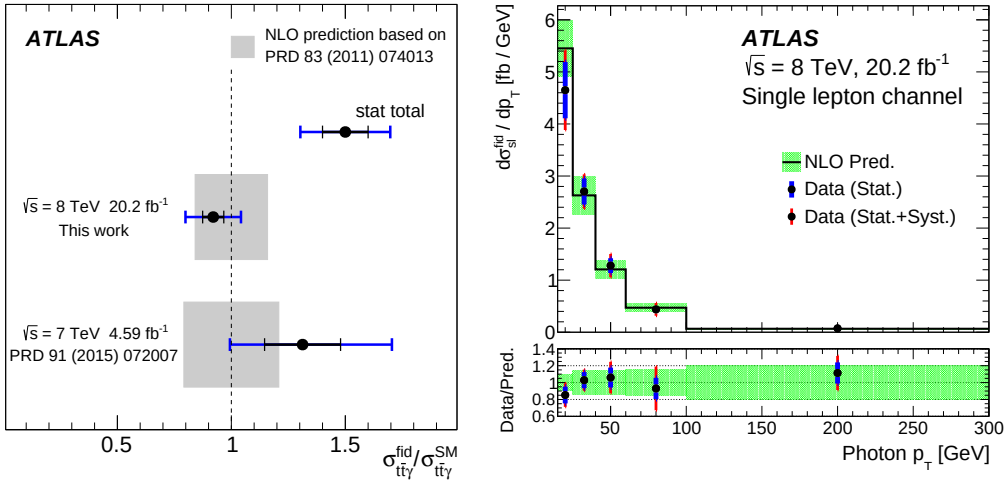

Figure 3: The measured $t\bar{t}\gamma$ cross section normalized to the calculated cross section [7] together with the result at $\sqrt{s}$ = 7 TeV [8] (left). Differential cross section as a function of the photon p_{T} with the theoretical prediction (right) [2].

The production cross section is found to be $139 \pm 7(\mathrm{stat.}) \pm 17(\mathrm{syst.})$ fb. Figure 3 (left) shows the measured $t\bar{t}\gamma$ cross section normalized to the calculated cross section [7] together with the result at $\sqrt{s}$ = 7 TeV [8]. Figure 3 (right) shows the measured differential cross section as a function of the photon p_{T} with the theoretical prediction. The results show agreement with the theoretical predictions at NLO accuracy within uncertainties.

5. Summary

Measurements of $t\bar{t}$ with additional final states have been performed in various center of mass energy. In general, good agreement with the SM expectation has been observed, but slight disagreements observed in certain kinematic regions. More precise measurements using full LHC-Run2 data set are needed to improve the model descriptions.

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