ATLAS results on top, ttbar and associated cross sections

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Abstract. The exceptionally large dataset collected by the ATLAS detector at the highest proton-proton collision energies provided by the LHC enables precision testing of theoretical predictions using an extensive sample of top quark events. Recent measurements include total and differential top quark cross sections, as well as measurements of associated top quark production. This contribution presents the latest highlights from the ATLAS top quark physics program.

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1 Introduction

The large recorded luminosity of proton-proton (pp) collisions at the Large Hadron Collider (LHC) enables high-precision measurements in top-quark physics. The measurements of production cross section for physics processes involving top quarks are important tests of the Standard Model (SM). Any deviation from the SM prediction would be a sign for new physics. In particular, the measurements of the top-antitop ($t\bar{t}$) differential cross sections probe the TeV scale, and therefore a new particle with large coupling to the top quark could cause a significant increase in the $t\bar{t}$ invariant mass spectrum or could modify the top transverse momentum (p_{T}) spectrum. Furthermore, these measurements are important inputs to fits of parton density functions. Last but not least, the precise top-quark measuremets are used to tune the parameters of Monte Carlo (MC) generators, which is important for many beyond SM searches where the top-quark processes are background.

Figure 1 shows the summary of inclusive cross-section measurements from the ATLAS experiment [1] for various top-quark production modes. The production of $t\bar{t}$ pairs has the highest cross section which is followed by three modes for production of one top quark (*single top*). These are t-channel production, s-channel production, and production of single top quark in association with a W boson (tW). The production modes of top quark in association with other bosons (W, Z, γ, or Higgs boson) have cross sections below 1 pb for all center-of-mass energies. Currently, the physics processes involving top quarks with the lowest measurable cross section are the production of four top quarks and production of $t\bar{t}$ pair in association with two photons. All the measurements are compared to the corresponding theoretical expectations from the SM. All theoretical expectations were calculated at next-to-leading order (NLO) of Quantum Chromodynamics (QCD) or higher. All the measurements are consistent with the SM prediction.

This proceeding reports on three recent top cross-section measurements from the ATLAS experiment, as described in the following sections.

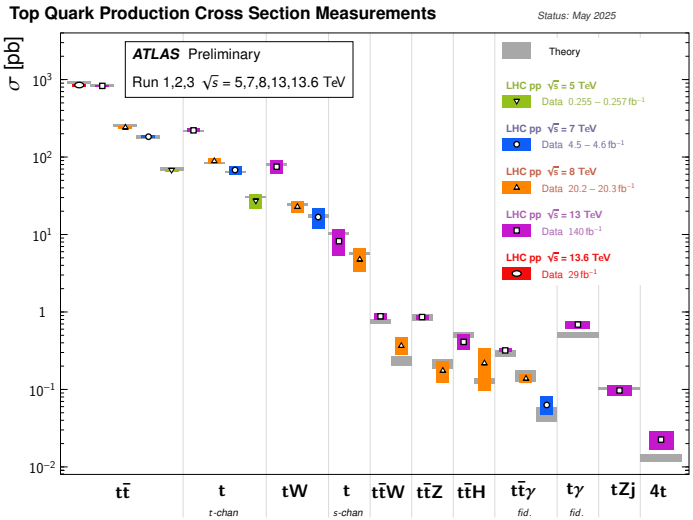

Figure 1. Summary of several top-quark related production cross-section measurements, compared to the corresponding theoretical expectations. All theoretical expectations were calculated at NLO or higher. [2]

2 Single top tW inclusive cross section

The tW production is the second-largest single-top production mode at the LHC. The ATLAS Collaboration has measured the inclusive tW cross-section using pp collisions from the full Run 2 dataset with an integrated luminosity of 140 fb^{-1} [3].

The event selection required two oppositely charged leptons (electron and muon), missing transverse energy from the two W boson decays, and at least one jet identified as b-jet. The two leptons with different flavour ensures relatively clean signatures, with the only significant background originating from $t\bar{t}$ production. The physics analysis is performed in three regions defined on the basis of jet multiplicity. A Boosted Decision Tree (BDT) classifier is constructed to separate the tW signal from the dominant $t\bar{t}$ background. Figure 2 shows the BDT distribution in the three regions.

The cross-section is extracted using a profile likelihood fit to the signal and control regions with selection requirements on the BDT disciminant as shown in Figure 2. The cross section is measured to be 75^{+15}_{-14} pb, in good agreement with the SM prediction. The measured cross section is used to extract a value of 0.97 ± 0.10 for the left-handed form factor at the vertex Wtb times the CKM matrix element $|f_{\mathrm{LV}} V_{tb}|$.

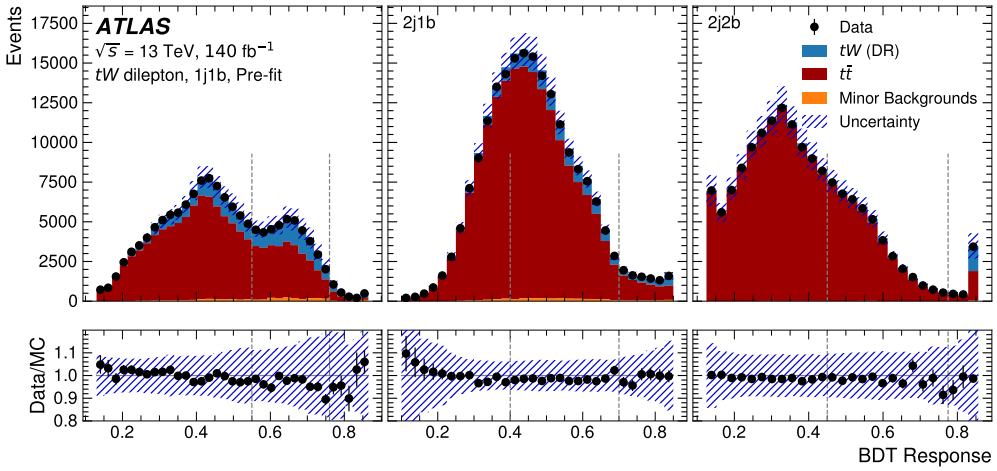

Figure 2. The pre-fit BDT response distributions for the three regions used in the fit. The signal process, tW, is modelled using the diagram removal (DR) scheme [4]. The BDT range used in the fit is indicated by vertical dashed lines. The first and last bins include the underflow and overflow, respectively. The uncertainty bands represent both statistical and systematic uncertainties, where all sources of systematic uncertainty are assumed to be uncorrelated. [3]

3 $t\bar{t}$ differential cross sections

Differential cross-sections for $t\bar{t}$ production, inclusively and in association with jets, were measured in pp collisions at a centre-of-mass energy of 13 TeV with the ATLAS detector [5]. An integrated luminosity of 140 fb^{-1} was used and the events are selected with one charged lepton (electron or muon) and at least four jets. The differential cross-sections are presented at particle level as functions of several jet observables, including angular correlations, jet transverse momenta and invariant masses of the jets in the final state, which characterise the kinematics and dynamics of the top-antitop system and the hard QCD radiation in the system with associated jets.

Figure 3 shows a selection of two measured observables: invariant mass of the $t\bar{t}$ – jet-rad1 system where jet-rad1 is the leading jet not originating from $t\bar{t}$ decay ($m^{t\bar{t}-\text{jet-rad1}}$), and the transverse momentum of the second leading jet not originating from $t\bar{t}$ decay ($p_{\text{T}}^{\text{jet-rad2}}$). The main uncertainties arise from signal modeling and jet energy scale (JES). The typical precision of the measured spectra is $5\% - 15\%$ for the absolute differential cross sections and $2\% - 4\%$ for the normalised differential cross sections. The measurement is compared to the predictions of NLO and next-to-next-to-leading-order (NNLO) QCD matrix-element MC generators interfaced with various parton shower (PS) generators. These predictions are found to provide an adequate description of the rate and shape of the jet-angular observables. There is a deviation at high masses of the observable $m^{t\bar{t}-\text{jet-rad1}}$ from the NLO QCD + PS prediction. The description of the transverse momentum and invariant mass observables is improved when NNLO QCD corrections are included.

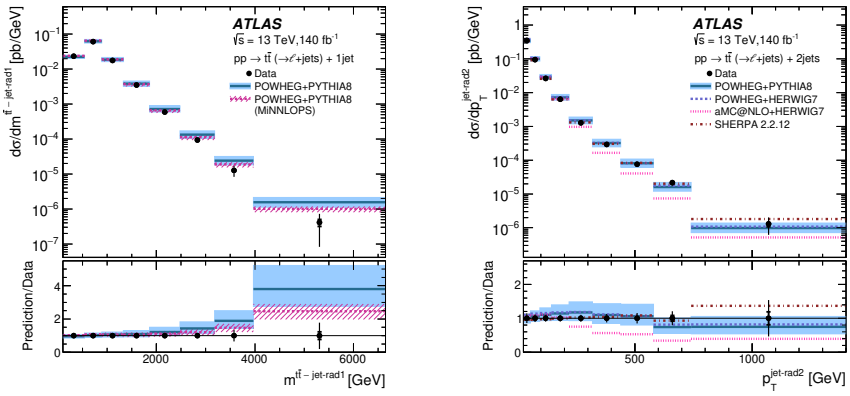

Figure 3. The measured differential cross-sections for $t\bar{t}$ production in the ℓ+jets decay mode as functions of observables $m^{t\bar{t}-\text{jet-rad1}}$ (left) and $p_{\text{T}}^{\text{jet-rad2}}$ (right). The NLO QCD predictions from Powheg+Pythia8 (solid lines), Powheg+Herwig7 (dashed lines), aMC@NLO+Herwig7 (dotted lines) and Sherpa 2.2.12 (dot-dashed lines) normalised to NNLO+NNLL prediction are also shown. The inner (outer) error bars represent the statistical uncertainties (the statistical and systematic uncertainties added in quadrature). For most of the points, the inner error bars are smaller than the marker size and, thus, not visible. The shaded bands represent the theoretical uncertainty in the Pwg+Py8 prediction. The lower panel of the figure shows the ratios of the predicted and the measured cross sections. [5]

4 $t\bar{t}\gamma\gamma$ observation

The first observation of top-quark pair production in association with two photons ($t\bar{t}\gamma\gamma$) was performed at the ATLAS experiment using pp collisions at a centre-of-mass energy of 13 TeV [6]. The measurement is performed in the single-lepton decay channel. The production cross section is measured in a fiducial phase space based on particle-level kinematic criteria for the lepton, photons, and jets.

The background processes comprise events with genuine photons and events with misidentified photons. These processes are estimated by using a combination of simulation and data-driven methods. The output of a BDT classifier, trained to separate signal and background processes, is used as the observable to extract the measured cross section. Figure 4 shows the BDT classifier after performing a profile likelihood fit. The production cross section is found to be $2.42^{+0.58}_{-0.53}$ fb, corresponding to an observed significance of 5.2 standard deviations. This measurement is consistent with the SM

prediction. Additionally, the ratio of the production cross section of $t\bar{t}\gamma\gamma$ to top-quark pair production in association with one photon is determined, yielding $3.30^{+0.70}_{-0.65} \times 10^{-3}$.

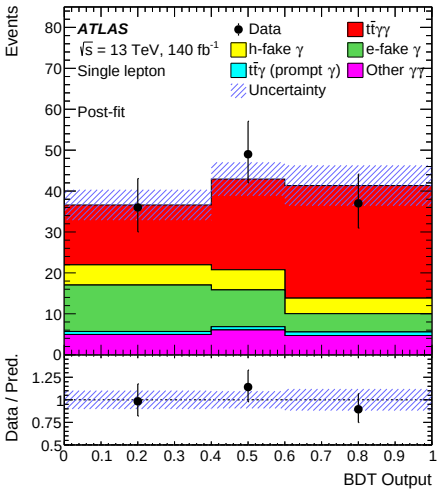

Figure 4. BDT distribution output after the fit to data. The uncertainty band corresponds to the total uncertainties with correlations among uncertainties taken into account as determined in the fit. The lower part of the plot shows the ratio of the data to the prediction. The "Other $\gamma\gamma$" category includes simulated events with two prompt photons from single-top quark, single and diboson processes, $t\bar{t}V$, $t\bar{t}H$, and $t\bar{t}$ samples. [6]

5 Summary and outlook

The ATLAS experiment has an extensive physics program of inclusive and differential top cross section measurements. The measurement of single top and $t\bar{t}$ cross sections are presented, alongside with the observation of the $t\bar{t}\gamma\gamma$ process. All the performed measurements are consistent with the SM.

Further top production cross section measurements are on-going at the ATLAS experiment while there are more data delivered by the LHC. Moreover, the current measurements can improve the signal modeling, and therefore a reduction of signal modeling uncertainties is expected for top-quark measurements and BSM searches affected by top backgrounds in the future.

Acknowledgement

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References

[1] ATLAS Collaboration, JINST **3** (2008) S08003
[2] ATLAS Collaboration, ATL-PHYS-PUB-2025-024, 2025
[3] ATLAS Collaboration, Phys. Rev. D **110** (2024) 072010
[4] S. Frixione et al, JHEP **07** (2008) 029
[5] ATLAS Collaboration, JHEP **08** (2024) 182
[6] ATLAS Collaboration, arXiv:2506.05018