PROCEEDINGS OF SCIENCE

Top quark (including associated production) cross section measurements with the ATLAS detector

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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. This proceeding highlights the latest measurements in ATLAS experiment presented at EPS-HEP 2025 of top-quark and top-quark associated production processes.

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1. Introduction

The top quark is the heaviest known elementary particle and plays a key role in precision tests of the Standard Model (SM) and in the search for new physics. Its production in association with heavy-flavour (HF) jets or photons probes higher-order QCD and electroweak processes, providing sensitivity to parton-shower modeling, heavy-quark fragmentation, and rare couplings. These signatures are also major backgrounds for Higgs boson and BSM searches, motivating increasingly precise measurements.

This proceeding reviews four recent ATLAS measurements discussed in the EPS-HEP 2025 talk [1]. All of these analyses use Run 2 proton–proton collision data at center-of-mass energy, $\sqrt{s}$ = 13 TeV. Together, these enhance our knowledge of top-quark interactions with heavy-flavour quarks and photons, and the accuracy of theoretical modeling for these processes.

2. WbWb differential cross-section measurement [2]

The first study presents measurements of differential cross-sections of $WbWb$ production, corresponding to $t\bar{t}$ production with both W bosons decaying leptonically. Events are selected with two isolated, oppositely charged leptons, at least or exclusively two b-tagged jets. The inclusive region is used to study differential cross-sections of several kinematic observables while since the exclusive region is very sensitive to the interference of $t\bar{t}$ and tW production modes, it is exploited to understand this phenomena.

The variable m^{bl}_{minimax} is used in the exclusive region, making the effect of the interference (DR vs DS) clearly visible in both the detector and (unfolded) particle levels. The differences are mainly in the values above the top mass as expected from the nature of this variable.

The differential cross-sections are unfolded to particle level in 11 observables: p_T of jets and leptons, p_T and mass of $b\bar{b}4l$ and $b\bar{b}ll$ systems, p_T of $b\bar{b}$ system, number of jets.

The unfolded spectra are compared with various state-of-the-art theoretical predictions as well as Monte Carlo generators. The data are generally in good agreement with the predictions, with differences in certain regions. These measurements provide critical validation for the MC event generators typically used in ATLAS analyses. Figure 1 illustrates unfolded spectra of m^{bl}_{minimax} and shows comparisons of different MC models.

3. Cross-section measurement in $t\bar{t}$ with additional b-jets [3]

In this measurement, the ATLAS Collaboration measured $t\bar{t}$ production in association with additional b-jets in events with one electron and one muon of opposite charge. Events are categorized in regions by the number of identified b-jets (≥ 3 or ≥ 4) and also additional jets identified as light or charm-jets, allowing a direct study of heavy-flavour multiplicities beyond the two b-jets from the top-quark decays.

A simultaneous fit to the b-jet multiplicity distributions constrains both the inclusive cross-section and the modeling of additional b-jets. Figure 2 shows the fiducial cross-sections of the $t\bar{t}b\bar{b}$ process in all the four regions and compared with different MC models. Dedicated $t\bar{t}b\bar{b}$ MCs agree better with the data than inclusive $t\bar{t}$. Disagreements are present mainly in the $\geq 3b$

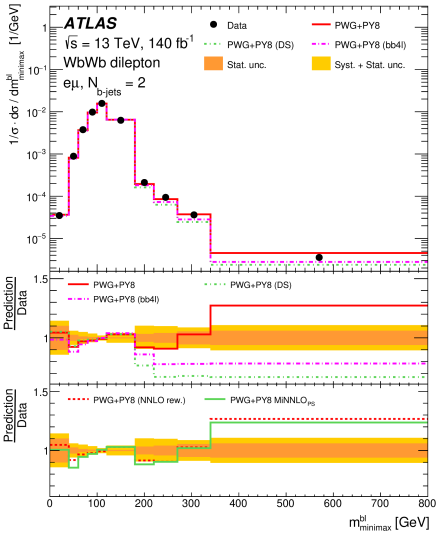

Figure 1: Example unfolded differential distribution from the $WbWb$ analysis, compared with predictions from various generators.

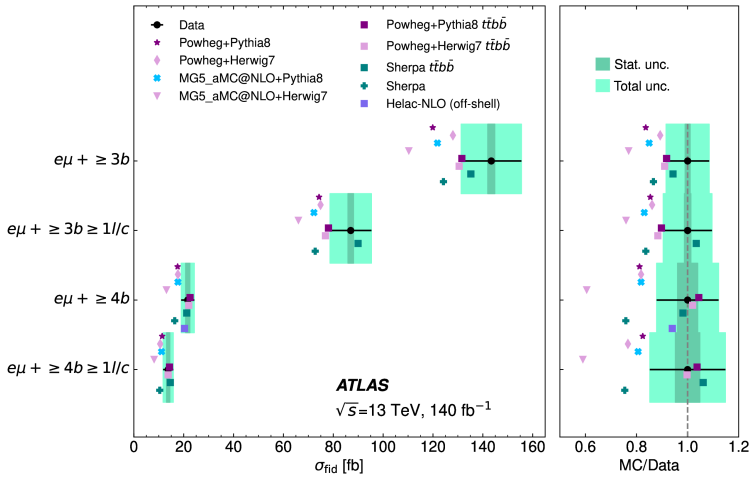

Figure 2: Measured fiducial cross-sections for $e\mu+ \geq 3b$, $e\mu+ \geq 3b \geq 1l/c$, $e\mu+ \geq 4b$, and $e\mu+ \geq 4b \geq 1l/c$ regions compared with the central values of $t\bar{t}b\bar{b}$ NLO predictions from various MC models.

regions. Differential measurements are performed as a function of many kinematic observables of the final state particles including b-jet observables assigned whether they belong to top-quark or non-top-quark decays. The comparisons of these unfolded measurements will serve greatly in the future MC modelling improvements of $t\bar{t}b\bar{b}$ as the background of $t\bar{t}H$ ($H \to b\bar{b}$), 4-top etc.

4. Cross-section measurement in $t\bar{t}$ with additional c-jets [4]

The measurement of $t\bar{t}$ production with associated charm jets constitutes the first dedicated study of this process at the LHC. The analysis targets final states with one or two leptons and at least four or more jets (depending on the regions), one or more of which are identified as charm jets. A

custom flavour-tagging algorithm is developed for tagging $b-$ and $c-$jets simultaneously. This is utilized to create several signal and control regions for a simultaneous likelihood fit with data. This extracts the cross-sections of the two separate processes ($t\bar{t}$ + 1c and $t\bar{t} \geq 2c$) as shown in Figure 3 where various MC predictions are also compared.

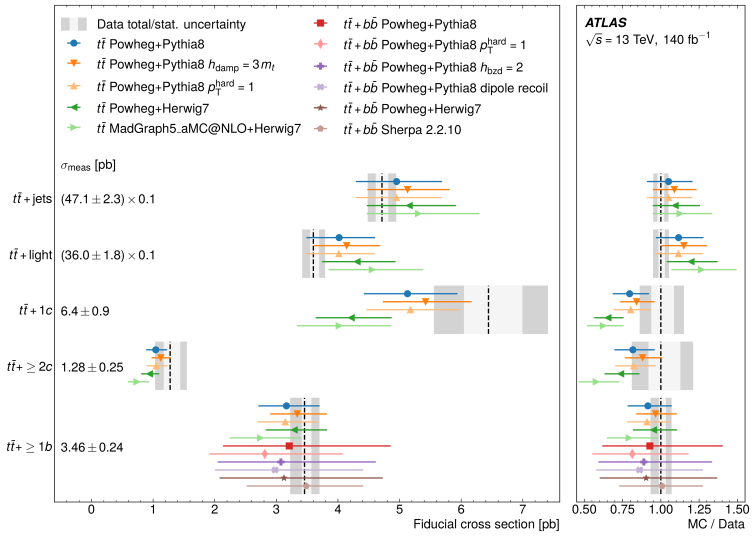

Figure 3: Measured fiducial cross-section values in comparison with various NLO+PS predictions from inclusive $t\bar{t}$ simulations.

The measured rates are compared with various MC models of $t\bar{t}$ simulations. The results are consistent with the expectations of SM within the uncertainties, however they all under-predicts the data. The limitations are mainly in background modelling, b/c tagger calibration and statistics.

5. Observation of $t\bar{t}\gamma\gamma$ [5]

The final result reviewed here reports the first observation of $t\bar{t}$ production in association with two isolated photons. The analysis selects events with two high-p_T photons, at least one lepton, and multiple jets including b-tagged ones. A multivariate discriminant (boosted decision tree based, Figure 4) separates genuine $t\bar{t}\gamma\gamma$ events from backgrounds dominated by processes fake photons.

The observed significance exceeds five (5.2) standard deviations, marking the first discovery of this final state. This observation opens a new window into the electromagnetic coupling structure of the top quark and provides a benchmark for future precision studies of rare $t\bar{t}$ processes.

Further, another new measurement of the ratio of cross-sections of $t\bar{t}\gamma\gamma$ and $t\bar{t}\gamma$ processes is also performed as part of this analysis utilizing the likelihood fit workspace from the $t\bar{t}\gamma$ cross-section measurement analysis [6] effectively reducing the relative effect of many of the experimental uncertainties and also uncertainties on the data-driven background estimations.

6. Conclusions

The four ATLAS measurements summarized here provide a consistent and detailed picture of top-quark production with additional heavy-flavour quarks and photons. In common these help

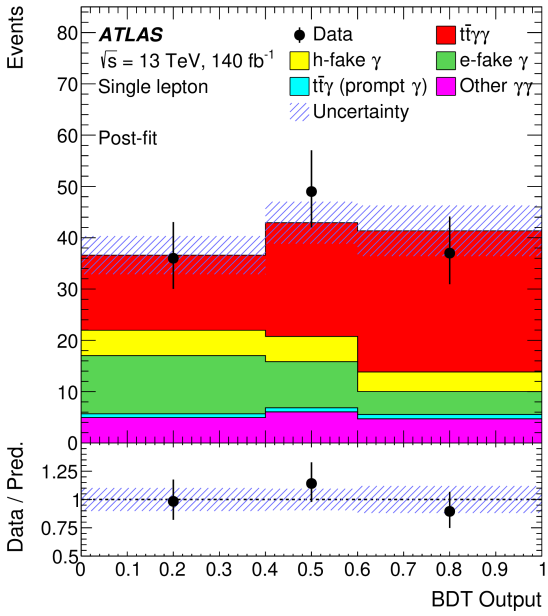

Figure 4: BDT distribution output after the fit to data

the future improvement of the MC modelling of these processes and hence provide more reliable predictions as backgrounds to other analyses including Higgs measurements or BSM searches. The results validate advanced reconstruction and tagging techniques and extend the experimental reach into rare production channels. Future analyses with Run 3 and HL-LHC data will exploit larger datasets and improved detectors along with improved reconstruction and identification (e.g. b-tagging) methods can achieve more precise results, enabling stringent tests of the Standard Model and searches for subtle deviations indicative of new physics.

Acknowledgments

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