# Top-quark pair cross-section measurement in the lepton+jets channel

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A measurement of the production cross-section for top quark pairs in $pp$ collisions at $\sqrt{s}$ =7 TeV is presented using data recorded with the ATLAS detector at the Large Hadron Collider (LHC). Events are selected in the lepton+jets topology by requiring a single lepton (electron or muon), large missing transverse energy and at least three jets. No explicit identification of secondary vertices inside jets ($b$-tagging) is performed. In a data sample of 35.3 pb$^{-1}$, 2009 and 1181 candidate events are observed in the $\mu$+jets and $e$+jets topology, respectively. A simple multivariate method using three kinematic variables is employed to extract a cross-section measurement of 171±17(stat.)$^{+20}_{-17}$(syst.)±5(lumi.) pb.

## 1 Introduction

A precise measurement of the top-pair ($t\bar{t}$) inclusive cross-section at this early stage of the LHC data taking is of central importance for several reasons.

First of all it allows a direct comparison with theoretical calculations providing a precision test of the predictions of perturbative QCD. Additionally $t\bar{t}$ production is an important background in many searches for physics beyond the Standard Model, and new physics may also give rise to additional $t\bar{t}$ production mechanisms or modifications of the top quark decay channels. Finally, this is one of the first precision measurements implying the reconstruction of final states including jets, electrons ($e$), muons ($\mu$) and missing transverse energy ($E_T^{miss}$), and since many models of physics beyond the Standard Model predict events with similar signatures it provides an essential stepping stone toward the identification of new physics.

## 2 Top-pair production and decay

In the Standard Model (SM) the $t\bar{t}$ production cross-section in $pp$ collisions is calculated to be $165^{+11}_{-16}$ pb at a centre of mass energy of $\sqrt{s}$ =7 TeV assuming a top mass of 172.5 GeV [1]. Top quarks are predicted to decay into a $W$ boson and a $b$-quark ($t \to Wb$) nearly 100% of the time. Depending on the decays of the two $W$ bosons into a pair of quarks ($W \to q\bar{q}'$) or a lepton-neutrino pair ($W \to \ell\nu$), events with a $t\bar{t}$ pair can be classified as:

- dilepton: when both $W$s decay leptonically;
- single-lepton: when one of the $W$ decays leptonically and the second one hadronically;
- all-hadronic: when both $W$s decay into quarks.

For the analysis reported here single-lepton $t\bar{t}$ events are selected, considering only events with exactly one electron ($e$+jets channel) and exactly one muon ($\mu$+jets channel) and without using any $b$-tagging information. A more detailed description of the analysis can be found in [2].

Other complementary analyses are performed in ATLAS to extract the $t\bar{t}$ production cross-section in dilepton [3] and all-hadronic [4] channels as well as in the single-lepton channel making use of the $b$-tagging information [5].

## 3 Event Selection

To select $t\bar{t}$ events in the single lepton final state, the following event selections are applied:

- the appropriate single-electron or single-muon trigger has fired;
- the event contains exactly one reconstructed lepton (electron or muon) with $p_T$ >20 GeV, matching the corresponding high-level trigger object;
- if a muon is reconstructed, $E_T^{miss}$ >20 GeV and $E_T^{miss} + m_T(W)$ >60 GeV is required [a];
- if an electron is reconstructed, $E_T^{miss}$ >35 GeV and $mT(W)$ >25 GeV are required;
- the event is required to have $\geq$ 3 jets with $p_T$ >25 GeV and $|\eta|$ <2.5.

Depending on the flavour of the lepton ($e$ or $\mu$) and on the number of reconstructed jets (exactly three or at least four) the events are classified as $e$+3-jets, $\mu$+3-jets, $e$+$\geq$4-jets or $\mu$+$\geq$4-jets, giving rise to four statistically independent channels.

## 4 Background treatment

The most important backgrounds after the event selections described above are:

- the production of a $W$ boson in association with jets ($W$+jets),
- the production of QCD multi-jet events in which a fake or non-prompt lepton is reconstructed as a real prompt electron or muon,
- other minor backgrounds including single top electro-weak production, $Z$+jets and diboson ($WW$,$WZ$ and $ZZ$) events.

The number of events observed in data and predicted by simulation or by data-driven estimates in each of the four channels are given in Table 1.

The different backgrounds are treated in different ways to determine the shape and the normalization of the kinematical distributions used to build the likelihood discriminant to extract the cross-section measurement. For the $W$+jets background the shapes are taken from Monte Carlo (MC) simulation, while the normalization is extracted from the fit (see Section 5). For the QCD multi-jet background both the shapes and the normalization are extracted with data-driven methods. For the other backgrounds, both the shapes and the normalization are taken from MC simulation.

[a] Here $m_T(W)$ is the $W$-boson transverse mass, defined as $\sqrt{2p_T^\ell p_T^\nu(1-cos(\phi_\ell-\phi_\nu))}$ where the measured missing $E_T$ vector provides the neutrino information.

| events | $e$ +3-jets | $e$ +≥4-jets | $\mu$ +3-jets | $\mu$ +≥4-jets |
|---|---|---|---|---|
| $t\bar{t}$ | 116 | 194 | 161 | 273 |
| QCD | 62 | 22 | 120 | 51 |
| $W$+jets | 580 | 180 | 1100 | 310 |
| $Z$+jets | 32 | 18 | 70 | 25 |
| single $t$ | 22 | 11 | 32 | 15 |
| diboson | 9 | 3 | 16 | 4 |
| Data | 781 | 400 | 1356 | 653 |

Table 1: Numbers of events in the four selection channels. The observed data events are shown, together with the MC simulation estimates for $t\bar{t}$, $W$+jets, $Z$+jets and single-top and diboson events, normalised to the data integrated luminosity of 35 pb$^{-1}$. The data-driven estimates for QCD multi-jet background are also shown.

| Source | $\Delta\sigma/\sigma[\%]$ |
|---|---|
| Statistical uncertainty | ±9.7 |
| $\ell$ reco., id. and trigger | -1.9 / +2.6 |
| Jet energy scale, resolution and reco. | -6.1 / +5.7 |
| QCD normalization | ±3.9 |
| QCD shape | ±3.4 |
| $W$+jets shape | ±1.2 |
| Other backgrounds | ±0.5 |
| ISR/FSR | -2.1 / +6.1 |
| PDFs | -3.0 / +2.8 |
| Parton shower generator | ±3.3 |
| Monte Carlo generator | ±2.1 |
| Limited MC statistics | ±1.8 |
| Pile-up | ±1.2 |
| Total systematics | -10.2 / +11.6 |
| Luminosity | ±3.4 |

Table 2: List of the main sources of uncertainty affecting the final measurement. For each of the listed sources the relative effect on the measured $t\bar{t}$ cross-section expressed as relative uncertainty is reported.

## 5 Cross-Section Measurement

The $t\bar{t}$ production cross-section is extracted by exploiting the different properties of $t\bar{t}$ events with respect to the dominant $W$+jets background. Three variables were selected for their discriminant power, for the small correlation between them and by considering the effect of the jet energy scale uncertainty.

These variables are:

- the pseudorapidity of the lepton $\eta_{lepton}$, which exploits the fact that $t\bar{t}$ events produce more central leptons than $W$+jet events;
- the charge of the lepton $q_{lepton}$, which uses the fact that $t\bar{t}$ events produce charge-symmetric leptons while $W$+jet events produce an excess of positively charged leptons;
- the exponential of the aplanarity ($exp(8 \times A)$), [b] which exploits the fact that $t\bar{t}$ events are more isotropic than $W$+jets.

A likelihood discriminant is built from these input variables following the projective likelihood approach defined in the TMVA package [6]. The distributions of the three input variables and of the likelihood discriminant in data and simulated events are shown in Fig. 1, for the $\mu$+jets channel only.

A binned maximum likelihood fit is applied to the discriminant shapes to extract the $t\bar{t}$ cross-section. Likelihood functions are defined for each of the four channels ($e$ and $\mu$, 3-jets and $\geq$ 4-jets) and are multiplied together in a combined fit to extract the total number of $t\bar{t}$ events.

The performance of the likelihood fit (including statistical and systematic uncertainties) is estimated by performing pseudo-experiments. The systematic uncertainties associated with the simulation, object definitions and the QCD multi-jet estimate, as well as the statistical uncertainty and the uncertainty on the luminosity are summarized in Table 2.

The result coming from the combined fit (including systematic uncertainties) is:

$$\sigma_{t\bar{t}} = 171 \pm 17(stat.)^{+20}_{-17}(syst.) \pm 6(lumi.)pb, \quad (1)$$

for a total relative uncertainty of $-14.5/+15.5\%$. The measured cross-section is in good agreement with the theoretical predictions.

[b] Here $A = \frac{3}{2}\lambda_3$, where $\lambda_3$ is the smallest eigenvalue of the normalized momentum tensor calculated using the selected jets and lepton in the event.

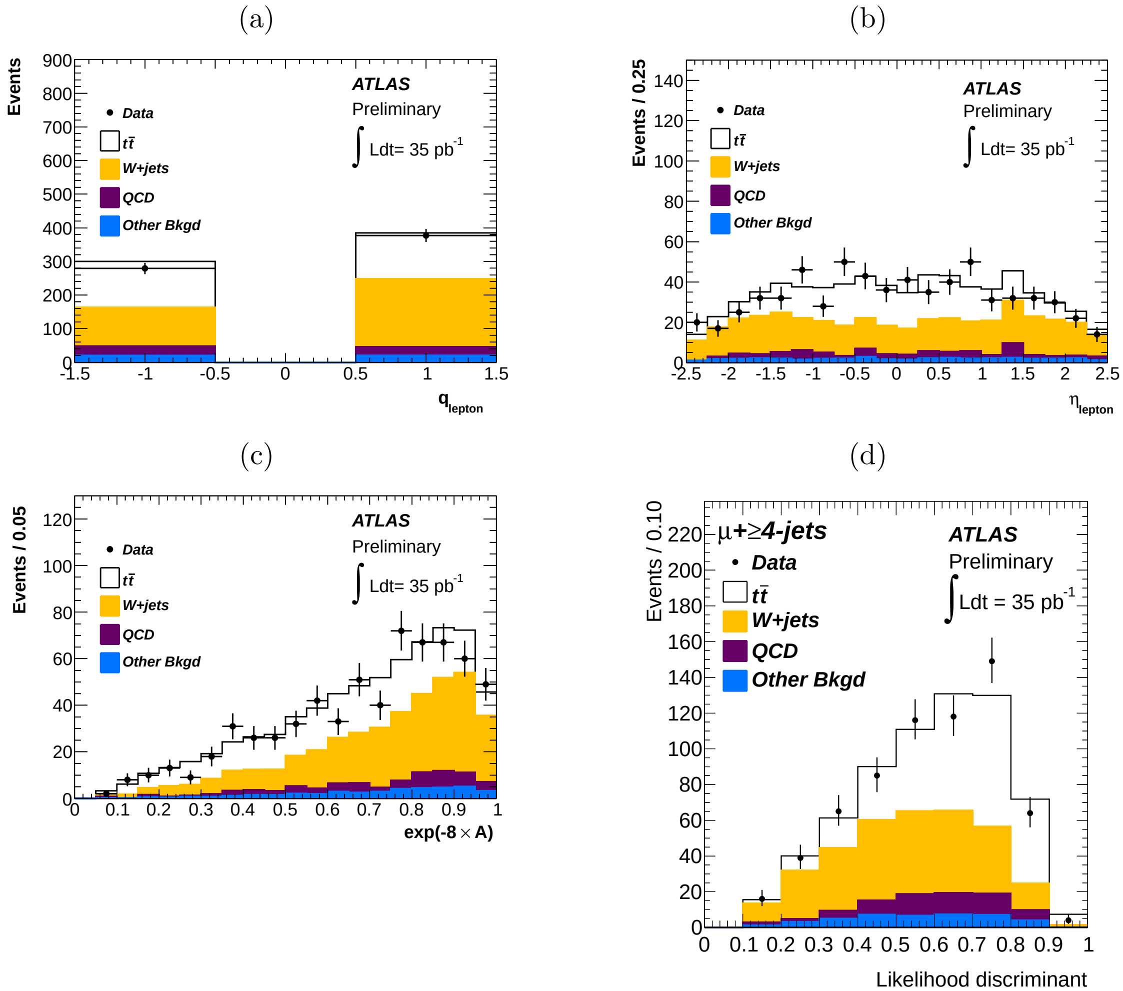


Figure 1: Distributions of the input variables to the likelihood discriminant (a, b and c) and of the likelihood discriminant itself (d) for the $\mu$+$\geq$4-jets channel. In (a), (b) and (c) the normalizations for $t\bar{t}$ and $W$+jets are fixed to the theoretical predictions, while in (d) they are rescaled according to the result of the fit. The "Other Bkgd" (including $Z$+jets, single top and diboson) contribution is taken from theoretical predictions. For QCD multi-jet the data-driven estimate is used.

## References


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