PROCEEDINGS OF SCIENCE

First measurement of the t-channel single top production in pp collisions at $\sqrt{s} = 5.02$ TeV with the ATLAS experiment

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A measurement of single top quark production $t-$channel cross-section in proton-proton collisions at an energy in the centre-of-mass of $\sqrt{s} = 5.02$ TeV with 257 pb^{-1} of data collected by the ATLAS experiment at LHC is reported. This analysis applies event selections to identify $t-$channel single top candidate events decaying semi-leptonically. Selected events are then used to train a Boosted Decision Tree (BDT) to optimize signal versus background separation. A Profile-Likelihood (PL) fit is performed to measure the total cross-section $\sigma(tq + \bar{t}q)$ and the ratio between the top quark (tq), and anti-top quark ($\bar{t}q$) cross-sections R_t. The analysis uses forward jets to enhance the $t-$channel significance (jet $\eta < 4.0$). Measured values of the cross-section $\sigma(tq + \bar{t}q) = 6.6^{+4.3}_{-4.0}(\text{stat.})\ ^{+4.4}_{-3.6}(\text{syst.})$ and of the ratio $R_t = 2.74^{+1.44}_{-0.83}(\text{stat.})\ ^{+1.04}_{-0.29}(\text{syst.})$ are well in agreement with Standard Model (SM) predictions.

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1. Introduction

At hadron colliders, such as the Large Hadron Collider (LHC), the top quark can be produced via the strong force or the electroweak one. In the first case, a pair of top and antitop quarks ($t\bar{t}$) is produced, while in the second case, a single top (or antitop) quark is produced. Single top production is less frequent with respect to $t\bar{t}$ production and it can happen via three main processes: the $t-$channel mode, the $s-$channel mode and the W associated production (tW).

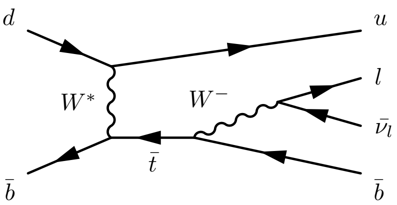

Figure 1: Single top $t-$channel production Feynman diagram

The $t-$channel single top production is the exchange of a W boson between a light and a heavy quark.The top quark decays almost always to a W boson and a bottom quark (b), as shown in the Feynman diagram in Figure 1, the W boson can then decay leptonically into an electron/muon/τ and its neutrino or hadronically in quark-antiquark pairs.

In this work the measurement of the single top $t-$channel production is performed using 257 pb^{-1} collected by the ATLAS experiment[10] at a centre-of-mass energy $\sqrt{s}$ = 5.02TeV. In this analysis, events are chosen to consider the leptonic decay of the W boson and the final state is therefore made of an electron or muon with its neutrino (from the W decay), a jet originating from a b quark (from the decay of the top quark) and a spectator light jet.

2. Analysis Strategy

2.1 Data and Monte Carlo samples

The analysis reported is performed using proton-proton (pp) collisions produced by LHC in 2017 at $\sqrt{s}$ = 5.02 TeV corresponding to an integrated luminosity of L = 257 pb^{-1}. The average number of interactions per pp bunch crossing ranged from approximately 0.5 to 4 in this data sample with an average of 2 interactions.

Monte Carlo (MC) samples were generated to be compared with data, they are processed through the full ATLAS detector simulation in Geant4 [3]. Single top samples for $t-$channel, $s-$channel and tW mode were produced with POWHEG BOX v2 [12] + PYTHIA v8.2 [14], with the NNPDF pdf set [4] and the A14 tune [1]. The top quark pair production background process is simulated with POWHEG BOX v2+ PYTHIA v8.2, with the NNPDF PDF set and the A14 tune. The V+jets ($V = W, Z$) backgrounds were simulated with the Sherpa v2.2.5 [5] generator with NNPDF PDF set. The diboson process was simulated with Sherpa v2.1.1 with the CT10 PDF set. Background coming from misidentified and non-prompt leptons is estimated from data using the matrix-method technique [2] with data collected at $\sqrt{s}$ = 5.02TeV.

2.2 Event Selection

Based on the expected signature of single top $t-$channel events, described in section 1, events are required to have one reconstructed lepton candidate with transverse momentum p_T > 18 GeV, exactly two jets with $p_T > 23$ GeV, with exactly one $b-$tagged jet based on the DL1r algorithm [11] at 60% efficiency working point, and missing transverse momentum greater than $E_T^{miss} > 15$ GeV.

Electron (muon) candidates must be reconstructed with pseudo-rapidity $|\eta| < 2.47$ (2.5), excluding electron candidates in the $1.37 < |\eta| < 1.52$ region. Particle-flow jets are reconstructed with the anti$-k_T$ algorithm [6] with a radius parameter $R = 0.4$. As the spectator jet is usually produced in the forward direction in the $t-$channel process, they are required to have reconstructed pseudo-rapidity $|\eta| < 4.0$, while the jet that is $b-$tagged is required to have $|\eta| < 2.5$. Additionally, to reduce contribution from $t\bar{t}$ events the light jet and the $b-$tagged one must have a separation in pseudo-rapidity $\Delta\eta > 1.5$.

To reduce the contribution from multi-jets background the transverse mass of the reconstructed W boson is required to be $m_W^T > 35$GeV[1] and a *triangular cut* is applied that requires $E_T^{miss} + m_W^T > 70$ GeV. To reduce the contribution from W+jets events the scalar sum of the lepton, jets transverse momentum and E_T^{miss} is required to be $H_T > 185$ GeV. Moreover, the invariant mass of the reconstructed W boson must be smaller than 102 GeV, and the invariant mass of the lepton and $b-$tagged jet must be smaller than 165 GeV. The top quark is reconstructed as a combination of a $b-$tagged jet and a reconstructed W boson and its invariant mass is required to be 140 GeV $< m_{top} <$ 225 GeV.

To further separate $t-$channel single top process events from background events a Boosted Decision Tree (BDT) is implemented with the XGBOOST [9] package. The BDT is trained on MC signal and background samples, and data-driven misidentified lepton sample (described in section 2.1), using 9 input variables which describe object kinematics and the global event topology. A 3 fold cross-validation is performed to check the BDT performance and over-training.

2.3 Fit strategy and systematic uncertainties

To extract the signal cross-section for the production of the top quark and the anti-top quark separately, selected events are divided into two regions based on the charge of the reconstructed lepton in the final state: ℓ^++jets and ℓ^-+jets. The cross-sections of the $t-$channel top $\sigma(tq)$ and anti-top $\sigma(t\bar{q})$ quarks are extracted with a Profile Likelihood fit to the BDT discriminant output in the two ℓ^++jets and ℓ^-+jets regions. These two cross-sections are parameterized in the fit as a function of the total $t-$channel cross-section $\sigma(tq + t\bar{q})$ and the ratio between the two R_t.

Systematic uncertainties are considered in the Likelihood fit as nuisance parameters with Gaussian constraints. The signal and background modelling uncertainties take into consideration initial and final-state radiation, matrix-element matching, parton-shower and hadronisation model, the μ_r and μ_f scales, the PDFs, and normalisation of the background samples. Instrumental systematics are also included, they are relative to lepton trigger, reconstruction, identification, isolation and energy calibration; jet energy scale and resolution, $b-$tagging efficiency, modelling of the missing transverse energy, jet vertex tagging; and the integrated luminosity. Figure 2 shows the BDT discriminant output distribution after the fit.

[1]The transverse mass of the reconstructed W boson is defined as $m_W^T = \sqrt{2p_T^{lep} E_T^{miss}(1 - cos\Delta\phi(l, E_T^{miss}))}$

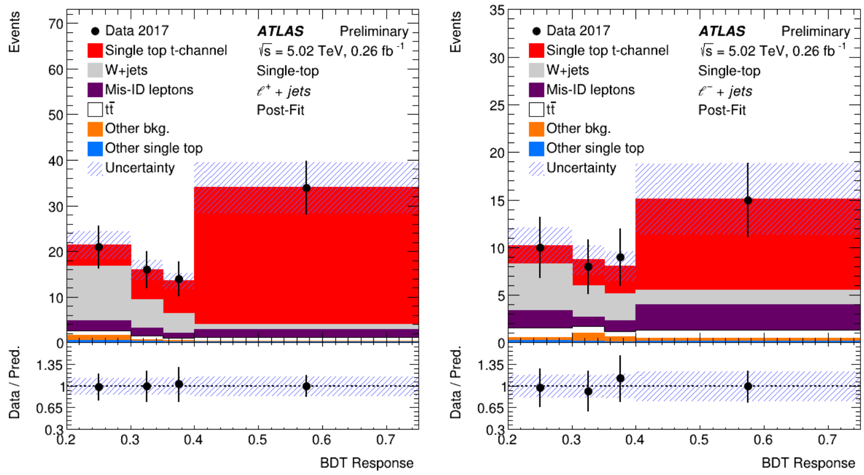

Figure 2: The post-fit BDT output distribution in the l^{+}+jets and l^{-}+jets regions. Blue hashed lines correspond to the stat and systematic uncertainties of the prediction. Lower panels show data to prediction ratio The first and last bins include the underflow and overflow, respectively.

3. Results

The total measured t−channel cross-section is $\sigma(tq+t\bar{q}) = 26.6^{+4.3}_{-4.0}(\text{stat})^{+4.4}_{-4.6}(\text{syst})$ pb and the ratio between top and anti-top quark production is measured to be $R_t = 2.74^{+1.44}_{-0.83}(\text{stat})^{+1.04}_{-0.29}(\text{syst})$, both are found to be in good agreement with the SM NNLO predictions [8, 13]. As a result of the fit, the background-only hypothesis is rejected with an observed significance of 6.1 standard deviations. The individual cross-sections for the top and anti-top quark are measured to be $\sigma(tq) = 19.5^{+3.8}_{-3.1}(\text{stat})^{+2.9}_{-2.2}(\text{syst})$ pb and $\sigma(t\bar{q}) = 7.1^{+3.2}_{-2.1}(\text{stat})^{+2.8}_{-1.5}(\text{syst})$ pb.

ATLAS t−channel single top cross-section measurements at different centres of mass-energy are compared to NLO prediction in Figure 3(a), while in Figure 3(b) the measured t−channel cross-section at $\sqrt{s}$ = 5.02 TeV is compared with predictions from different PDF sets.

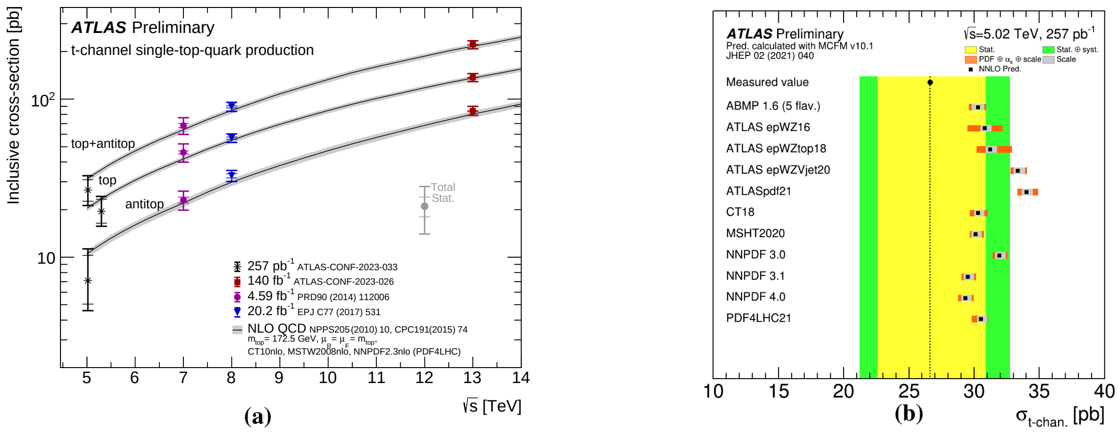

Figure 3: In Figure 3(a) $\sigma(tq+t\bar{q})$ measured values by this analysis and other ATLAS measurements as a function of the centre-of-mass energy compared to theoretical calculations from MCFM at NLO in QCD[7]. In Figure 3(b) comparison of the measured $\sigma(tq+t\bar{q})$ at $\sqrt{s}$ = 5.02 TeV to predictions from NNLO PDF sets.

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