Top quark production at ATLAS

Yuta Takahashi on behalf of the ATLAS Collaboration
High Energy Physics Laboratory, Nagoya University, 464-8602 Japan

1 Introduction

The top-quark (t-quark) is the heaviest elementary particle (173.2 GeV) [1] among the Standard Model (SM) particles. Owing to its largest mass, there are several theoretical predictions that new physics beyond the SM could appear in both the production or in the decay process of the t-quark. At the LHC, plenty of the t-quarks are produced either as a pair ($t\bar{t}$) or singly, enough to test the SM by measuring its production cross-section. Based on the 0.7 fb^{-1} proton-proton (pp) collision data recorded by the ATLAS detector [2], precise measurements have been performed of the $t\bar{t}$ production cross-section using the single-lepton ($t\bar{t} \rightarrow \ell^+\nu_\ell q q' b\bar{b}$, $\ell = e, \mu$) [3], and the dilepton ($t\bar{t} \rightarrow \ell^+\nu_\ell \ell^- \overline{\nu_\ell} b\bar{b}$) [4] channel. The combined cross-section (177±11 pb) is consistent with the theoretical prediction with an uncertainty of 6%, which is smaller than the theoretical accuracy (10%). The $t\bar{t}$ production cross-section in alternative decay channels and the single-top production cross-section are of primary interest to further investigate new physics effect.

2 Single-top production cross-section

The single-top production cross-section provides a direct probe of the Wtb coupling, and can constrain the absolute value of the CKM quark-mixing matrix element V_{tb} without any assumption on the number of quark generations. The production cross-section for the two leading processes: the t-channel ($64.6^{+2.7}_{-2.0}$ pb) and the Wt associated production channel (15.7±1.1 pb) are presented.

Wt-channel The associated Wt production involves more than 250 GeV in the final state. The production rate at the Tevatron is too small (0.2 pb) to be observed, while it is much higher at the LHC owing to the larger partonic energy.

Using 2.05 fb^{-1} of pp collision data, the analysis exploits the leptonic decays of both the W associated to the t-quark and the W from its decay. Candidate events are extracted by requiring two high-p_T leptons, significant missing transverse momentum ($E_T^{miss} >$ 50 GeV), and at least one jet with $p_T > 30$ GeV. The remaining Z+jet background is reduced by requiring the sum of the opening angles between leptons and the E_T^{miss}, $\sum_{i=1,2} \Delta\phi(\ell_i, E_T^{miss}) > 2.5$ rad, and the dilepton mass ($m_{\ell\ell}$) outside the Z mass window ($m_{\ell\ell} < 81$ GeV or $m_{\ell\ell} > 101$ GeV). The dominant background comes from $t\bar{t}$ dilepton events.

An approach based on a Boosted Decision Tree (BDT) [5] has been developed to discriminate Wt events from backgrounds, followed by a template fit to the BDT output distribution. The result is incompatible with the background-only hypothesis at the 3.3 σ level, and the cross-section, 16.8 ± 5.7 pb, shows good agreement with the theoretical prediction (3.4 σ is the expected value). This is the first evidence of single-top production via the Wt channel, and the result is used to determine $|V_{tb}| = 1.03^{+0.16}_{-0.19}$, assuming that $|V_{tb}| \gg |V_{ts}|, |V_{td}|$ [6].

t-channel The t-channel has the largest cross-section among the single-top processes, enabling us to measure $|V_{tb}|$, as well as the cross-section separately for the t-quark (σ_t) and the $\bar{t}$-quark ($\sigma_{\bar{t}}$). The ratio $\sigma_t/\sigma_{\bar{t}}$ is sensitive to the two PDFs (u-quark and d-quark) as the systematic uncertainties are partially cancelled. The enhancement of the ratio may provide an interesting handle to search for new physics.

Based on 1.04 fb^{-1} of pp collision data, events are selected by requiring one high-p_T lepton, $E_T^{miss} > 25$ GeV, and two or three jets, with exactly one of them identified as originating from a b-quark. The dominant background consists of W+jet events, modeled by the MC simulation and normalized to the data. The cross-section is extracted by fitting the distribution of a multivariate discriminant based on a neural network, and turns out to be 83 ± 20 pb. Assuming that the t-quark related CKM matrix elements obey the relation $|V_{tb}| \gg |V_{ts}|, |V_{td}|$, the coupling strength at the Wtb vertex is determined to be $|V_{tb}| = 1.13^{+0.14}_{-0.13}$. Under the assumption that $|V_{tb}| \leq 1$, a lower limit of $|V_{tb}| > 0.75$ is obtained with the 95% confidence level [7].

The ratio $\sigma_t/\sigma_{\bar{t}}$ is measured using 4.7 fb^{-1} data with a slightly optimized event selection. The cross-section is extracted separately according to the lepton charge by performing a binned maximum likelihood fit to the output distribution of the neural networks. The resulting cross-section is $\sigma_t = 53.2 \pm 10.8$ pb and $\sigma_{\bar{t}} = 29.5^{+7.4}_{-7.5}$ pb, with its ratio measured to be $R_t = 1.81^{+0.23}_{-0.22}$. The measurement is in agreement with the predictions, that vary between 1.86 and 2.07 depending on the assumed PDFs [8].

3 $t\bar{t}$ production cross-section

The measurement of the $t\bar{t}$ production cross-section in different decay channels is of primary importance to test the SM. In particular, the cross-section using final states including a τ-lepton is sensitive to new physics such as the charged Higgs boson, predicted by the supersymmetric model. In the following, the analysis in the τ plus lepton channel ($t\bar{t} \to \tau^+\nu_\tau\ell^-\overline{\nu_\ell}b\bar{b}$) [9], in the τ plus jet channel ($t\bar{t} \to \tau^+\nu_\tau qq^{'}b\bar{b}$) [10], and in the all-hadronic channel ($t\bar{t} \to qq^{'}q^{''}q^{'''}b\bar{b}$) [11] are shortly described.

$t\bar{t}$ production in the τ plus lepton final state Candidate events are extracted from 2.05 fb^{-1} data, by requiring one high-p_T lepton (electron or muon), at least one hadronically decaying τ candidate, $E_T^{miss} > 30$ GeV, and two or more energetic jets, with at least one of them identified as a b-jet. Since the most important background is due to jets mimicing a τ candidate, multivariate technique based on a BDT is used to reconstruct the

τ candidate, relying on its large separation power between signal and background. In order to estimate the number of background events in a data-driven way, the data have been split according to the charge correlation between a lepton and a reconstructed τ candidate, followed by the subtraction of the same-sign events from the opposite-sign events to reduce part of the backgrounds. This enables to model the background in a data-driven way, which leads to the reduction of the systematic uncertainty. The cross-section is extracted by the template fitting to the BDT output distribution, which yields $\sigma_{t\bar{t}} = 186 \pm 25$ pb. With a total uncertainty of 13%, the obtained result is consistent with the theoretical prediction (164^{+11}_{-16} pb).

$t\bar{t}$ production in the τ plus jet final state Candidate events are selected from 1.67 fb^{-1} data, by requiring at least five jets, with two of them identified as b-jets, a large E_T^{miss} significance ($E_T^{miss}/\sum E_T > 4$, where $\sum E_T$ is the scalar sum of the transverse energy released by all the visible particles). One of the remaining jets is selected as the τ candidate based on the event topology. The remaining backgrounds come from the QCD multi-jet events.

The cross-section is obtained by fitting the distribution of the number of tracks associated to the τ candidate with templates. Signal events produce a peak in correspondence to an odd number of tracks coming from the τ's. The signal template is derived from MC simulation, while the background templates for the multi-jet and the $t\bar{t}$ combinatorics are constructed in a data-driven way. The obtained cross-section of 200 ± 47 pb, is in agreement with the theoretical prediction.

$t\bar{t}$ production in the all-hadronic channel The $t\bar{t}$ production cross-section in all-hadronic channel is sensitive to new physics including a multi-jets final state, such as the one predicted by the low scale gravity and the weakly-coupled string theory. Although there is the big advantage of a largest branching ratio (46% of all $t\bar{t}$ decays), the analysis is challenging due to the large multi-jet backgrounds.

Candidate events are selected from 4.7 fb^{-1} data by requiring at least six jets, with at least two of them being identified as b-jet, and a small E_T^{miss} significance less than three. A kinematic likelihood fit is performed to find the correct association of jets that can reconstruct the t-quark mass. The number of signal events is extracted by using an unbinned likelihood fit to the t-quark mass. The shape of the background, which consists of multi-jet events, is modeled by the events passing the event selection without the requirement of the presence of b-tagged jets. The signal is modeled using a MC simulation. The measured cross-section, 168 ± 62 pb, is found to be compatible with the theoretical prediction.

4 Summary

Figure 1 shows the summary of the $t\bar{t}$ and the single-top production cross-section measurements, with the corresponding theoretical cross-sections. All the results are consistent with the theoretical prediction, showing the validity of the perturbative QCD at the LHC energy scale. Further improvement on the systematic uncertainty will lead to better measurements which will allow to probe new physics.

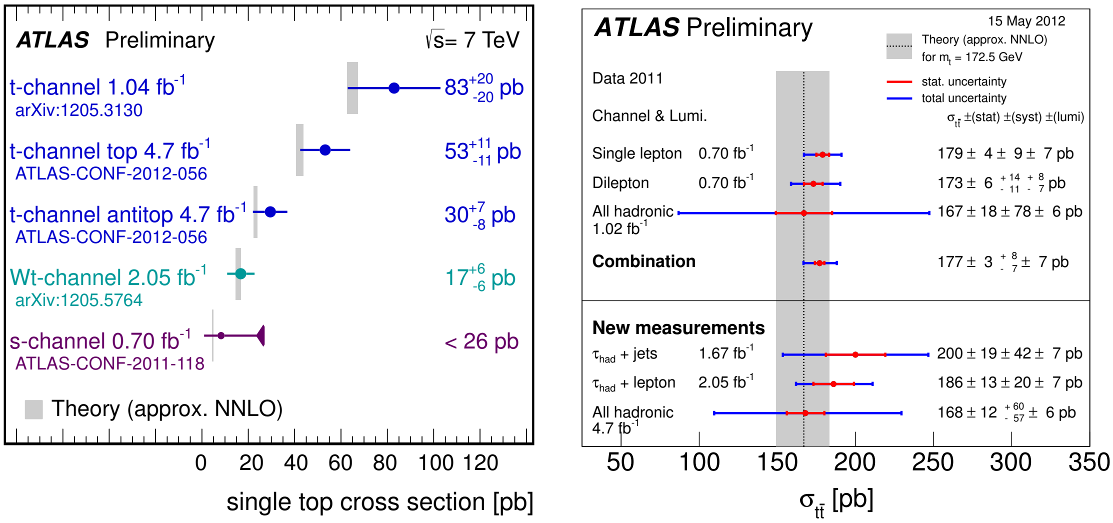

Figure 1: Summary of the $t\bar{t}$ and the single-top cross-section measurement.

References

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