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Measurement of $t\bar{t}$ and single-top quark production in the ATLAS experiment

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The most recent inclusive and differential cross-section results for top quark pair and single-top quark production are presented. Using the data set collected with the ATLAS experiment at the LHC at different centre-of-mass energies, the latest measurements of the inclusive and differential $t\bar{t}$ cross-section in the dilepton decay channel at $\sqrt{s}$ = 13 TeV and 13.6 TeV, respectively, are shown. Additionally, the jet substructure differential cross-section results focusing on boosted top-quarks in the $t\bar{t}$ events at $\sqrt{s}$ = 13 TeV are presented. These results are compared to several Monte Carlo (MC) predictions that combine the $t\bar{t}$ production QCD predictions at next-to-leading-order (NLO) precision with the leading-order (LO). Furthermore, the latest measurement of the t-channel single-top quark cross-section at $\sqrt{s}$ = 13 TeV, accompanied by the observation of the t-channel single-top production $\sqrt{s}$ = 5.02 TeV are shown. Finally, a measurement of the single-top-quark cross-section in the s-channel is performed, allowing to claim the evidence of this rare process for the first time. All the results are in good agreement with the Standard Model predictions (SM).

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1. Introduction

The top quark, the heaviest of the known elementary particles predicted by the SM, is exceptionally significant in particle physics. Its mass is ∼170 times greater than the proton mass and roughly 40 times larger than the second heaviest elementary fermion in the SM, the bottom quark. At the Large Hadron Collider (LHC), top quarks are produced either in pairs through strong interaction or as a single particle via weak interaction, often associated with light- or heavy- particles. This proceeding focuses on the recent measurements of the top-quark pair and single-top-quark production with the ATLAS detector using proton-proton collisions data taken at different centre-of-mass energies ($\sqrt{s}$ =13, 13.6 and 5.02 TeV) at the LHC.

2. $t\bar{t}$ cross-section measurement in the dilepton decay channel at $\sqrt{s}$ = 13 TeV

The large integrated luminosity of the Run 2 data set, which corresponds to 140 fb^{-1}, collected with the ATLAS detector at $\sqrt{s}$ = 13 TeV, enables precise measurements of both inclusive and differential cross-sections for the production of top-antitop quark pairs decaying into an oppositely charged $e\mu$ pair [1]. The analysis measured the differential and double-differential distributions of lepton kinematic variables from the decay of $t\bar{t}$ over a broader range and with finer granularity with respect to the previous analysis, based on an integrated luminosity of 36 fb^{-1}.

The fiducial ($\sigma_{t\bar{t}}^{fid}$) and the total inclusive ($\sigma_{t\bar{t}}$) cross-section were measured to be 10.53 ± 0.02 (stat.) ±0.13 (syst) ±0.10 (lumi) ±0.02 (beam) pb and 829 ± 1 (stat.) ±13 (syst) ±8 (lumi) ±2 (beam) pb, respectively. These results are in excellent agreement with the theoretical prediction of the total inclusive cross-section at next-to-next-leading-order (NNLO) including the resummation of next-to-next-to-leading logarithmic (NNLL) for $\sqrt{s}$ = 13 TeV. Furthermore, the absolute and normalised differential cross-section of $t\bar{t}$ are also measured as a function of various lepton kinematic variables: p_T^l, $|\eta^l|$, $m^{e\mu}$, $p_T^{e\mu}$, $|y^{e\mu}|$, $E^e + E^\mu$, $p_T^e + p_T^\mu$ and $|\Delta\phi^{e\mu}|$. Additionally, four double-differential cross-sections have been measured: $|y^{e\mu}|$ in bins of $m^{e\mu}$, and as a function of $|\Delta\phi^{e\mu}|$ in bins of $m^{e\mu}$, $p_T^{e\mu}$, and $E^e + E^\mu$.

3. Measurement of the jet substructure in boosted $t\bar{t}$ events at $\sqrt{s}$ = 13 TeV

The large production rate of top-quark pairs at the LHC affords a unique opportunity to study the top-quark substructure of jets originating from light quarks, b-quarks and gluons. This, not only, enables the testing of SM at the top-quark mass scale but also extends to the TeV scale for the produced jets. Moreover, one can to explore effects beyond the SM as modifications of the substructure of the top-quark jets to the SM predictions.

In this analysis, variables sensitive to top-quark jet substructure are measured using the top quarks produced in the pp interactions at 13 TeV using the full Run2 dataset recorded with the ATLAS detector at the LHC. The top-quark jets are reconstructed using the anti-kt

algorithm with a radius parameter R = 1.0 and are required to have transverse momentum, $p_T > 300$ GeV in the selected $t\bar{t}$ events in the single-lepton and all-hadronic decay channels. The one- and two-dimensional differential cross-sections for eight substructure variables are defined using only the charged elements of the jets measured, and then are unfolded to the particle-level phase space to remove detector effects [3].

4. $t\bar{t}$ cross-section measurement in the dilepton decay channel at $\sqrt{s}$ = 13.6 TeV

Following the successful start of Run3 LHC pp collisions at $\sqrt{s}$ = 13.6 TeV, several measurements have been conducted. These measurements serve multiple purposes: to validate and test several well-known processes, which are measured precisely in Run1 and Run2, and to verify the detector and reconstruction performance for all physics objects (electrons, photons, muons and jets). In this particular analysis, the inclusive $t\bar{t}$ production cross-section, a fiducial Z-boson production cross-section and the ratio of these cross-sections have been measured.

The total inclusive $t\bar{t}$, cross-section ($\sigma_{t\bar{t}}$) , is measured to be 859 ± 4 (stat.) ±22 (syst) ±19 (lumi) pb in the $e^{\pm}\mu^{\mp}$ decay channel. Moreover, the Z-boson production cross-section in the fiducial phase space, ($\sigma^{fid}_{Z\to ll}$), is measured to be 751 ± 0.3 (stat.) ±15 (syst) ±17 (lumi) pb. The ratio of the $t\bar{t}$ and Z-boson production cross-sections, $R_{t\bar{t}/Z\to ll}$, is also measured, and it is found equal to 1.144 ± 0.006 (stat.) ±0.022 (syst) ±0.003 (lumi). These measured values are consistent with the SM predictions.

5. Measurement of t-channel single-top production at $\sqrt{s}$ = 13 TeV

The production of the single top quarks and antitop quarks via the t-channel exchange of a virtual W-boson are measured in proton-proton collisions at $\sqrt{s}$ = 13 TeV using the Run 2 dataset collected with the ATLAS experiment at the LHC. Event samples are retained if they contain either one isolated electron or muon, exactly two jets, one b-tagged jet and another jet produced in the forward direction, with high transverse momentum, and high missing transverse momentum, E_T^{miss} [5].

An artificial Neural Network (NN) algorithm is used to discriminate signal events from the background ones, and the D_{nn} distributions are used in the profile maximum-likelihood fit to determine the signal yields. As a result, the combined cross-section is determined to be $\sigma(tq+\bar{t}q) = 221 \pm 13$ pb while the total cross-section production of the top- and antitop-quarks is found to be $\sigma(tq) = 137 \pm 8$ pb and $\sigma(\bar{t}q) = 84^{+6}_{-5}$ pb, respectively. Moreover, the cross-section ratio, $R_t = \sigma(tq)/\sigma(\bar{t}q)$, is determined to be equal to $1.636^{+0.036}_{-0.034}$[5]. The measured cross-sections are found to be in good agreement with predictions made at next-to-next-leading order in perturbation theory.

The $\sigma(tq)$ and $\sigma(\bar{t}q)$ measurements are interpreted in an effective field theory, EFT, approach, setting limits on the strength of four-quark operator, $O^{(1,3)}_{qQ} : -0.25 < C^{(1,3)}_{qQ} < 0.12$ at the 95% CL. Furthermore, the measured value of $\sigma(tq + \bar{t}q)$ is used to derive $|V_{tb}| > 0.95$.

6. Observation of t-channel single-top-quark production at $\sqrt{s}$ =5.02 TeV

The measurement of the electroweak production cross-sections of the single top quark and antitop quark is reported at $\sqrt{s}$ = 5.02 TeV using the pp dataset collected with the ATLAS detector and corresponding to an integrated luminosity of 257 pb^{-1}. In this analysis, events with one isolated electron or muon and with exactly two jets, of which one is a b-tagged jet are selected [7].

Boosted decision trees (BDTs) are used to enhance the discrimination between the signals, top-quark and antitop-quark distributions, and background. Then a binned profile-likelihood fit is performed on the BDT discrimination distributions in the l^++ and l^-+jets channels, and the inclusive cross-section of the combined production of single top-quark and antitop-quark, $\sigma(tq) + \sigma(\bar{t}q)$, is measured to be $26.6^{+4.3}_{-4.0}(stat.)^{+4.4}_{-3.6}(Syst.)$ pb. The ratio, $R_t = \sigma(tq)/\sigma(\bar{t}q)$, between the single top quark and antitop-quark production cross-sections is equal to $2.74^{+1.44}_{-0.83}(stat.)^{+1.04}_{-0.29}(Syst.)$ and the observed of the single top-quark and antitop-quark production cross-sections are found to be $\sigma(tq) = 2.74^{+3.8}_{-3.1}(stat.)^{+2.9}_{-2.2}(Syst.)$ pb and $\sigma(\bar{t}q) = 7.1^{+3.2}_{-2.1}(stat.)^{+2.8}_{-1.5}(Syst.)$ pb, respectively [7]. All measurements are found to be in good agreement with the SM predictions.

7. Evidence of s-channel single top-quark production at $\sqrt{s}$ =13 TeV

The measurement of the s-channel single top-quark production cross-section is presented using proton-proton collisions at $\sqrt{s}$ = 13 TeV, which are recorded by the ATLAS experiment at the LHC with an integrated luminosity of 139 fb^{-1}. The events selected in this analysis are characterised by the presence of one isolated lepton (either electron or muon) and missing transverse momentum. Two jets are also required, both of which are b-tagged. One of them originates from the top-quark decay, while the other comes from the *Wtb* vertex that produces the top-quark [8]. The matrix element method is used to discriminate between the signal and backgrounds, and the signal is extracted using the profile likelihood fit. The combined top-quark and top-antiquark, $\sigma(tq) + \sigma(\bar{t}q)$, is measured to be $8.2^{+3.5}_{-2.9}$ pb, which is in agreement with the SM prediction where $\sigma^{SM}_{t+\bar{t}} = 10.32$ $(\text{scale})^{+0.29}_{-0.24}(m_t)^{-0.23}_{+0.22}(\text{PDF+}\alpha_s)^{+0.27}_{-0.27}$. The observed (expected) signal significance is found to be 3.3 (3.9) standard deviations above the background-only hypothesis, and this provides the first evidence of the production of a single top quark in the s-channel [8].

8. Conclusions

The most recent measurements of the inclusive and differential cross-sections of the top quark pairs and single top quark productions have been presented. These measurements used the proton-proton collisions at $\sqrt{s}$ = 13 TeV, 13.6 TeV and 5.03 TeV, respectively, collected with the ATLAS detector in 2015-2018 (Run 2) and in 2022 (Run 3). All results are found to be consistent with predictions of the SM. Moreover, these results can be used to constrain physics beyond the SM.

References

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