Measurement of the Top Quark Pair Production Cross Section with ATLAS

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1 Introduction

A precise measurement of the top quark pair production cross section ($\sigma_{t\bar{t}}$) is of great interest. It serves to test perturbative QCD predictions and opens up the top physics program. The measurements shown here represent a major move towards precision since the first measurement of $\sigma_{t\bar{t}}$ by ATLAS [1]. Several methods used in a variety of channels are presented here.

Top quark pairs are produced via gluon fusion and $q\overline{q}$ annihilation in proton-proton collisions, and, once produced, decay before hadronization. It is assumed here that the top always decays as t → Wb, as is implied by unitarity of the CKM matrix assuming three generations of quarks. The final state will thus contain two b-jets and, depending on the decay of the W bosons, four more jets (the "all hadronic" channel), two more jets, a charged lepton, and a neutrino ("semileptonic"), or two charged leptons and two neutrinos ("dilepton").

The signal is modeled by MC@NLO using CTEQ6.6 with $M_{top} = 172.5$ GeV, which is also used for the small single-top backgrounds. The main backgrounds are W+jets production (in the semleptonic channel), $Z/\gamma*$+jets production (dileptonic), and QCD multijet events (all hadronic). The electroweak backgrounds are generated using ALPGEN with CTEQ6L1. QCD multijet events with objects misidentified as leptons enter the channels with leptons as well. The contributions of all QCD multijet processes to the signal regions are modeled using data driven techniques.

Good performance of the full ATLAS detector is needed to ensure well reconstructed physics objects in these multi-object final states. After these requirements, the data recorded by ATLAS in 2010 corresponds to $\int \mathcal{L}\, dt = 35$ pb^{-1} $\pm 3.4\%$ [2], used in all analyses presented here. Single lepton triggers are used in the semileptonic and dileptonic channels, and a four-jet trigger is used in the all hadronic channel.

Two different b-tagging algorithms are used. A secondary vertex tagger is used by analyses which cut explicitly, while a lifetime tagger which compares the impact parameter significance to a resolution function is used for continuous tagging in the semileptonic tagged analysis.

2 Cross Section in the All Hadronic Channel

The all hadronic decay channel suffers from the high rate of background from QCD multijet production. Two b-tagged jets are required to help subdue this background. To discriminate signal from background, the analysis uses a mass χ^2 test, constructing M_{jjb} and M_{jj} as top-like and W-like objects. Data are compared to a signal template event-by-event. A background template is derived using events with 0 and 1 b-tagged jets, and a likelihood fit is performed on the χ^2 distribution in order to discriminate between signal and background. At this stage the measurement in this channel is statistically limited, with important systematic uncertainties coming from the b-tagging efficiency uncertainty (ϵ_{btag}) and the jet energy scale uncertainty (JES). An upper limit is placed, measured to be $\sigma_{t\bar{t}} < 261$ pb @ 95% CL [3].

3 Cross Section in The Dilepton Channel

In the dilepton channel, the expected signal purity of the sample (S:B $\approx$ 3.5:1) is exploited. A simple counting experiment is performed, where the main backgrounds are estimated using data. In particular, $Z/\gamma*$+jets is normalized in a region orthogonal to the selection namely where the dilepton invariant mass is within the Z peak. Both the kinematics and rate of events with mis-identified leptons are estimated by using the matrix method, which finds the probability for a non-prompt lepton to pass the final selection. This measurement is statistically limited, and the main contributions of systematic uncertainties are from JES, lepton scale factors, parton shower modeling, and the luminosity uncertainty. The top pair production cross section is measured to be $\sigma_{t\bar{t}} = 173 \pm 22$ $(stat)$ $^{+18}_{-16}$ $(syst)$ $^{+8}_{-7}$ $(lumi)$ pb [4], corresponding to a relative uncertainty of 16.5%, the best available in this channel.

A similar analysis has been performed which requires at least one of the jets in the event to be b-tagged. Looser kinematic cuts are used to make up for the loss of statistics, and a signal to background ratio of 5:1 is achieved. The main contributions to systematic uncertainties in this analysis come from JES and the uncertainty on b-tagging calibration. The top pair production cross section is measured to be $\sigma_{t\bar{t}} = 171 \pm 22$ $(stat)$ $^{+21}_{-16}$ $(syst)$ $^{+7}_{-6}$ $(lumi)$ pb [4].

4 Cross Section in the Lepton+Jets Channel

Several analyses are performed in the semileptonic channel, both with and without the use of b-tagging information, all of which are dominated by systematic uncertainty. Two methods use a kinematic likelihood to discriminate from the main expected background (mostly W+jets) from the signal using a likelihood template fit to the data.

The analysis without b-tagging uses 3 input variables, namely the charge of the lepton, the pseudorapitidy of the lepton, and the aplanarity of the event. The analysis uses events with exactly 3 jets and 4 jet (inclusive) in the e+jets and μ+jets, a total of four analysis bins. This method measures $\sigma_{t\bar{t}} = 171 \pm 17$ (*stat*) $^{+20}_{-17}$ (*syst*)± 6 (*lumi*) pb, where the uncertainty is dominated by the JES and jet reconstruction efficiency [5].

A similar analysis is performed which uses b-jet identification as input to the likelihood but does not explicitly require a b-tagged jet. This analysis uses four input variables for the likelihood: the pseudorapitidy of the lepton, the aplanarity of the event, the summed transverse momentum of the jets above the third normalized to the momentum along the beam axis of the event, and the average b-tagging weight of the two most b-like jets. This analysis is performed in the 3 jet exclusive, 4 jet exclusive, and 5 jet inclusive bins in both lepton channels, yielding six analysis channels. In the template fit, a profile likelihood is used. Continuous systematic uncertainties are included in the likelihood via nuisance parameters, allowing them to be constrained by the data. The measured value is $\sigma_{t\bar{t}} = 186 \pm 10$ (*stat*) $^{+21}_{-20}$ (*syst*) ± 6 (*lumi*) pb [6]. With a precision of 12.6%, this is the single most precise measurement of $\sigma_{t\bar{t}}$ at $\sqrt{s}$ = 7 TeV available with this dataset. The dominant systematic uncertainties are the coming from the W+heavy flavor jet composition and the calibration of the b-tagging algorithm.

5 Combination and Summary

A combination of the two most precise measurements in the single lepton and dilepton channels is performed, namely the dilepton cut and count analysis without b-tagging and the single lepton profile likelihood fit using continuous b-tagging. Uncertainties common to the analyses, in particular object-based uncertainties, are taken as correlated. The final result is $\sigma_{t\bar{t}} = 180 \pm 18$ pb [7], corresponding to a precision of 10%. This combination is shown together with the leading analyses and compared with the prediction at $\sqrt{s} = 7$ TeV in Figure 1.

The top pair production cross section has been measured to a precision of 10% by the ATLAS collaboration using $\int \mathcal{L}\, dt = 35$ pb^{-1} of data delivered by the LHC in 2010. This result is in agreement with the best available NNLO QCD predictions, as shown in Figure 5 [8, 9, 10]. A number of cross check analyses in the single lepton and dilepton channel have been performed using complementary methods and show good agreement with the main analyses presented here.

6 Acknowledgments

Thanks to the ATLAS Collaboration and Top Physics Working Group in particular.

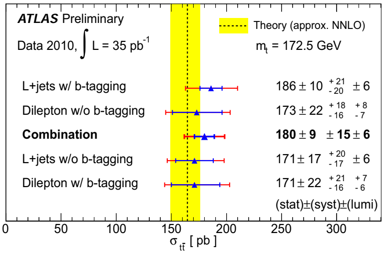

Figure 1: The main results in the dilepton and single lepton channels with and without b-tagging, and the combination result, compared with theory.

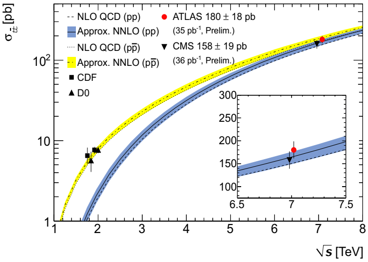

Figure 2: $\sigma_{t\bar{t}}$ vs. $\sqrt{s}$ with measurements from the Tevatron, CMS and this measurement, compared to the prediction from approximate NNLO QCD.

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