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Top quark cross section measurements with ATLAS

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Measurements of the inclusive top quark pair production cross sections in proton-proton collisions with the ATLAS detector at the Large Hadron Collider are presented. The measurements are performed requiring one or two electrons or muons in the final state. Various experimental techniques are compared. The most precise result requires events with an electron and a muon of opposite sign and uses the full data-set at a centre-of-mass energy of 8 TeV. The data are in good agreement with a recent NNLO+NNLL QCD calculation. Measurements of the differential top quark pair production cross sections in proton-proton collisions with the ATLAS detector at the Large Hadron Collider are also presented. The measurements are performed requiring one electron or muon in the final state and are carried out differentially in the reconstructed top transverse momentum, and the invariant mass, rapidity and transverse momentum of the top pair system. These measurements probe our understanding of top pair production in the TeV regime and are compared to recent Monte Carlo generators implementing LO and NLO matrix elements matched with parton showers and NLO QCD calculations. The data show sensitivity to parton density functions.

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1. Introduction

The large mass of the top quark, making it the heaviest known fermion, results in a large Yukawa coupling to the Higgs boson according to the Standard Model (SM). Processes beyond the SM can modify the top pair production rate. Therefore, measurements of the top quark pair production cross section ($\sigma_{t\bar{t}}$) may indicate the existence of new physics. Measurements of $\sigma_{t\bar{t}}$ using the ATLAS detector [1] at the LHC are presented here and are compared to recent QCD predictions. Calculations of $\sigma_{t\bar{t}}$ at full next-to-next-to-leading order (NNLO), including resummation of next-to-next-to-leading logarithmic (NNLL) soft gluon terms, give a prediction of $252.9^{+13.3}_{-14.5}$ pb assuming a top quark mass of 172.5 GeV at a center-of-mass energy of $\sqrt{s}$ = 8 TeV. The corresponding prediction of $\sigma_{t\bar{t}}$ at $\sqrt{s}$ = 7 TeV is $177.3^{+11.5}_{-12.0}$ pb [2]. The errors in the theoretical predictions are due to uncertainties in the Parton Distribution Functions (PDFs), uncertainties in α_s, and QCD scale uncertainties.

In the SM, the top quark decays almost exclusively to a W boson and a b quark. For the results presented here, at least one W was required to decay leptonically into a muon or electron and a neutrino.[1] Jets originating from b quarks can be identified ('tagged') using an algorithm that makes use of the known properties of b quark decays including long lifetime, high multiplicity, and the high mass of B hadrons. In some measurements, one or two b-tagged jets were required in the event selection. A typical working point at 70% efficiency using the tagging algorithm has a rejection factor of about 140 for light quark jets.

Measurements of the inclusive top pair productions cross sections at $\sqrt{s}$ = 7 and 8 TeV are presented in Section 2, measurements of the differential cross sections at $\sqrt{s}$ = 7 TeV are presented in Section 3, and conclusions are given in Section 4.

2. Inclusive cross sections

The top quark pair inclusive production cross section was measured using the ATLAS detector at $\sqrt{s}$ = 7 TeV in several channels, including the dilepton channel with electrons and muons with an integrated luminosity of 0.70 fb^{-1}. The dilepton channel required events to have exactly two oppositely-charged identified-lepton candidates or one identified-lepton candidate with an oppositely charged Track-Lepton (TL) candidate. TL candidates are defined by an inner detector track with p_T > 25 GeV and a series of quality cuts optimized for high efficiency and a low rate of misidentification. Parallel event selections were defined with and without at least one b-tagged jet, that had no overlapping events in the case of ee and $\mu\mu$ events. Figure 1(a) shows the multiplicity distribution for b-tagged jets in the $ee+\mu\mu+e\mu$ channels. Figure 1(b) shows the cross section measurements in the various dilepton channels. The combination of non-overlapping channels gives a cross section value of $\sigma_{t\bar{t}} = 176 \pm 5(\text{stat.})^{+14}_{-11}(\text{syst.}) \pm 8(\text{lum.})$ pb [3], which is in good agreement with SM predictions.

A measurement of the top pair production cross section using ATLAS was done in the single lepton + jets channel at $\sqrt{s}$ = 8 TeV with an integrated luminosity of 5.8 fb^{-1}. A likelihood discriminating variable was defined to separate the $t\bar{t}$ signal from backgrounds. The lepton pseudorapidity, η, and the event aplanarity, A, were used to define the likelihood variable. The event

[1] Charge-conjugate modes are implied throughout.

selection required at least one b-tagged jet to reduce background. Fits to the likelihood distributions are shown in Figure 2 for electron (a) and muon (b) events with at least 3 jets, indicating a good signal to background ratio. The dominant systematic errors included Monte Carlo signal modeling (11%), jet and missing transverse energy (MET) reconstruction and calibration (∼6%). The measurement gave $\sigma_{t\bar{t}}$ = 241 ± 2(stat.)±31(syst.)±9(lum.) pb [4], which is in good agreement with SM predictions.

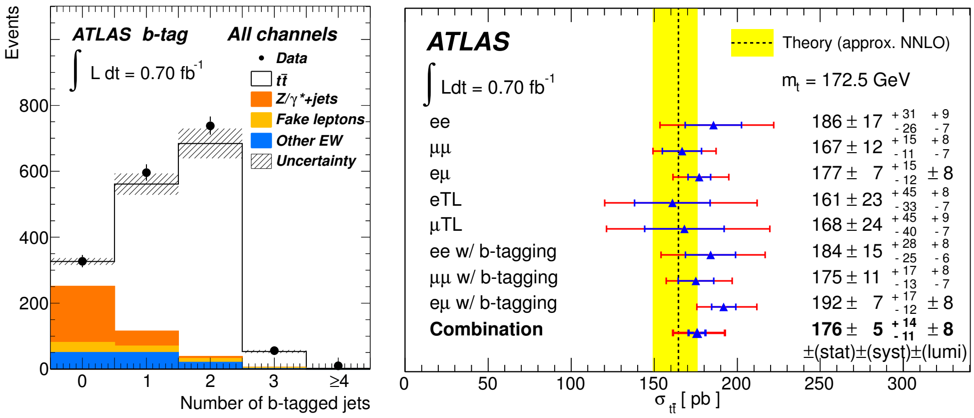
A measurement of the top pair cross section using ATLAS was also done in the dilepton channel at $\sqrt{s}$ = 8 TeV with an integrated luminosity of 20.3 fb^{-1} using opposite-sign $e\mu$ events with exactly 1 or 2 b-tagged jets. Figure 3 shows the b-tag weight (a) and the b-tagged jet multiplicity (b) for opposite-sign $e\mu$ events. The largest backgrounds are from Wt events and misidentified ('fake') leptons. The purity of signal events is expected to be about 89% for events with one b-tagged jet and about 96% for events with two b-tagged jets. A simultaneous fit for the cross section, $\sigma_{t\bar{t}}$, and efficiency, ε_b, to reconstruct and b-tag a jet was performed using the measured number of single b-tagged jet events, N_1, and the measured number of two b-tagged jet events, N_2. The largest systematic errors for this analysis was due to luminosity uncertainty (∼ 3.1%) and beam energy uncertainty (∼ 1.7%). The cross section was measured to be $\sigma_{t\bar{t}}$ = 237.7 ± 1.7(stat.)±7.4(syst.)±7.4(lum.)±4.0(beam energy) pb [5], which is in good agreement with the single lepton measurement and with SM predictions.

A summary of $\sigma_{t\bar{t}}$ measurements at $\sqrt{s}$ = 7 TeV from ATLAS and CMS is shown in Figure 4(a). A LHC combined result of $\sigma_{t\bar{t}}$ = 173 ± 2(stat.)±8(syst.)±6(lum.) pb was obtained in 2012. Measurements obtained after the combination was done are shown below the black line in Figure 4(a). Figure 4(b) shows $\sigma_{t\bar{t}}$ measurements from the LHC and Tevatron versus $\sqrt{s}$. The measurements are in good agreement with SM predictions and some measurement errors are smaller than the theoretical error.

3. Differential cross sections

The top quark pair production differential cross section was measured in the lepton + jets channel using ATLAS at $\sqrt{s}$ = 7 TeV with an integrated luminosity of 4.6 fb^{-1} which includes the complete 2011 data set [6]. The event selection required exactly one isolated lepton (e or μ), MET > 30 GeV, at least four jets, where at least one is b-tagged, and transverse W mass > 35 GeV. A kinematic likelihood fitter is used to fully reconstruct the $t\bar{t}$ kinematics. Once the best likelihood is found, both top quarks in the event are formed from decay products as determined by the kinematic likelihood fitter. The leptonically decaying top quark is reconstructed using the charged lepton, neutrino determined from the fit, and one of the b partons. The hadronically decaying top quark is reconstructed from the other three partons. The $t\bar{t}$ system is the combination of the leptonically and hadronically decaying top quarks. The differential cross section has been calculated as a function of the mass ($m_{t\bar{t}}$), the transverse momentum ($p_T^{t\bar{t}}$), and the rapidity ($y_{t\bar{t}}$) of the $t\bar{t}$ system as well as a function of the transverse momentum of the hadronically decaying top quark (p_T^t).

The measured differential cross sections are corrected for efficiency to pass the event selection, corrected for resolution effects by a regularized unfolding proceedure, and then the electron and muon channel results are combined. The cross sections are normalized by the factor $1/\sigma_{t\bar{t}}$ where $\sigma_{t\bar{t}} = 167^{+17}_{-18}$ pb, obtained from approximate NNLO QCD calculations. The normalized differential



(a) (b)

Figure 1: Number of b-tagged jets in 7 TeV dilepton events (a) and a summary of the inclusive cross section measured at 7 TeV in various channels and the cross section for all channels combined (b).

cross sections for p_T^t (a) and $m_{t\bar{t}}$ (b) are shown in Figure 5 with comparisons to several Monte Carlo generators. The p_T^t spectrum is softer than predictions for $p_T^t > 200$ GeV while all three generators describe the shape of $m_{t\bar{t}}$ reasonably well. Figure 6 shows the ratio of NLO theory predictions with different PDF sets to the measured normalized differential cross sections for p_T^t (a) and $m_{t\bar{t}}$ (b). Both variables show a preference for the HERAPDF1.5 set [7].

4. Conclusions

Top quark pair production cross section measurements are now in a precision era with experimental uncertainties comparable to the $\sim 6\%$ prediction uncertainty. Differential cross sections have now been measured with 10%-20% relative uncertainties. Although most top physics measurements are dominated by systematic errors, Run 2 with center-of-mass energy approaching 14 TeV will open up a new kinematic phase space to be explored with a factor of ~ 3 enhanced top quark pair production cross section. New physics decaying into top quark (pairs) has not been seen yet, but methods have been developed to look for many signatures that can be used for Run 2 in 2015.

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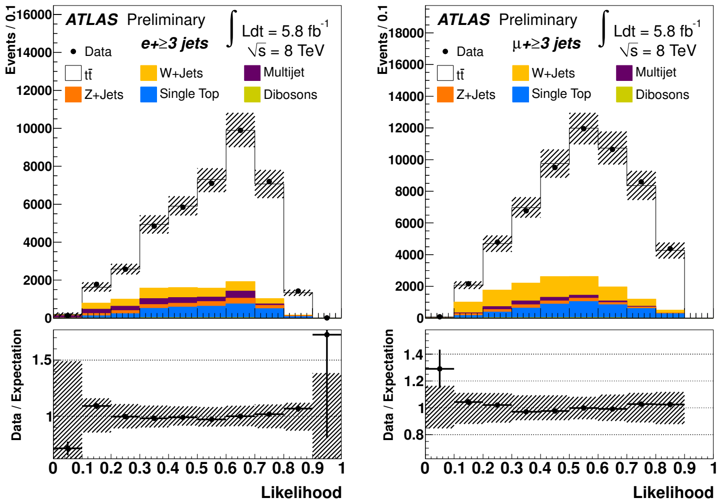
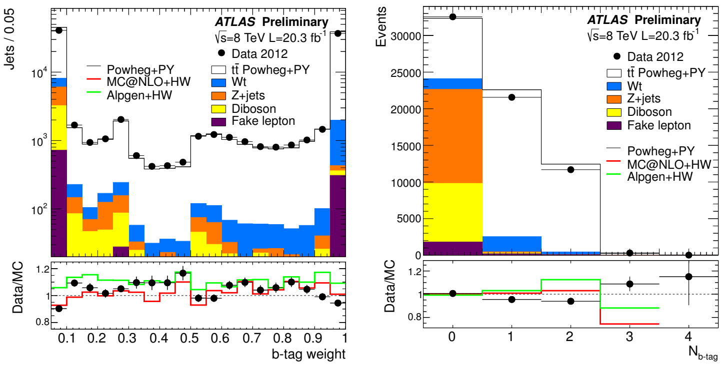


(a) (b)

Figure 2: Fits to the likelihood discriminant distributions for single lepton events with at least 3 jets for electrons (a) and muons (b). The hatched bands display the combined expected statistical and systematic uncertainty.



(a) (b)

Figure 3: b-tag weight for events with at least 2 jets (a) and the number of b-taged jets (b) for dilepton events.

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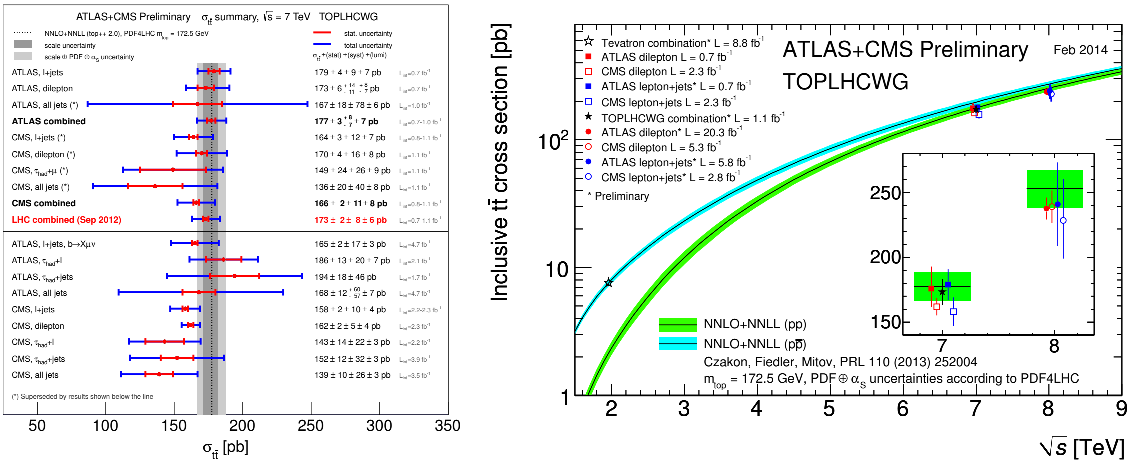
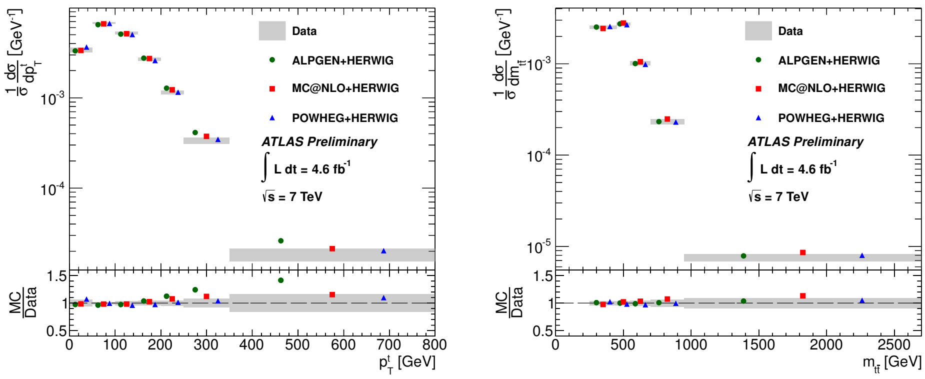


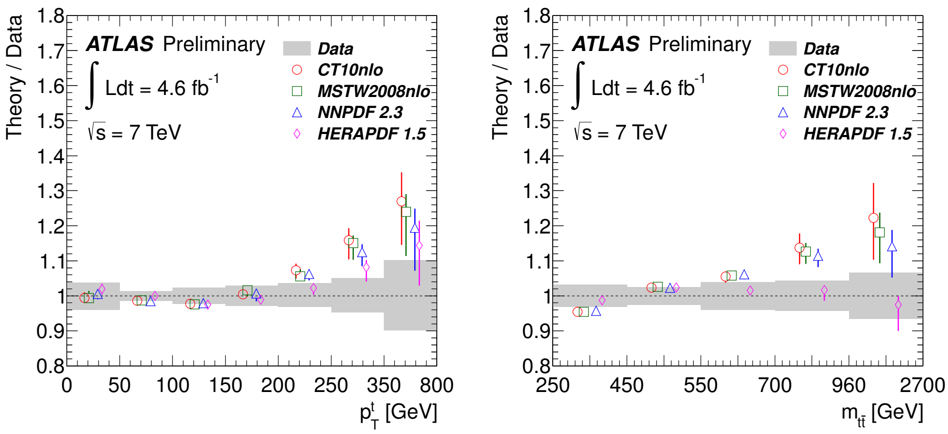
(a) (b)

Figure 4: Summary of inclusive cross section results at 7 TeV (a) and versus $\sqrt{s}$ (b).



(a) (b)

Figure 5: Normalized differential cross-section for p_T^t (a) and $m_{t\bar{t}}$ (b).



(a) (b)

Figure 6: Ratios of the NLO QCD predictions to the measured normalized differential cross-section for different PDF sets for p_T^t (a) and $m_{t\bar{t}}$ (b).