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Inclusive top pair production at 7, 8 and 13 TeV in ATLAS

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The inclusive cross-section for top quark pair production has been measured in proton–proton collisions at $\sqrt{s} = 7\,\text{TeV}$, $8\,\text{TeV}$ and $13\,\text{TeV}$ with the ATLAS detector at the LHC. The measurements in the $e\mu$, ee, $\mu\mu$ and l+jets channels are in agreement with the Standard Model predictions. The most precise measurement is performed in the $e\mu$ channel and yields uncertainties of 3.9%, 4.3% and 14% at $\sqrt{s} = 7\,\text{TeV}$, $8\,\text{TeV}$ and $13\,\text{TeV}$. At $\sqrt{s} = 7\,\text{TeV}$ and $8\,\text{TeV}$ the precision of the measurements is similar to those of the most precise theoretical predictions. In addition, a measurement of the top quark branching ratios into channels with leptons and quarks is presented.

8th International Workshop on Top Quark Physics
14-18 September, 2015
Ischia, Italy

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PoS(TOP2015)014

1. Introduction

With a mass close to the electro-weak symmetry breaking scale, the top quark is the heaviest known elementary particle in the Standard Model. At the Large Hadron Collider (LHC), top anti-top pairs ($t\bar{t}$) are produced via strong interaction, predominantly by gluon-gluon fusion (80%). The measurement of the inclusive $t\bar{t}$ cross-section ($\sigma_{t\bar{t}}$) provides an interesting test of perturbative QCD and has sensitivity to the strong coupling constant, the gluon parton distribution function, the top quark mass and new physics models.

In the Standard Model top quarks primarily decay through $t \to Wb$. The W boson can decay leptonically into an electron, muon or τ-lepton and the corresponding neutrino or hadronically into quark anti-quark pairs. These proceedings describe measurements of $\sigma_{t\bar{t}}$ by the ATLAS experiment [1] in the same- and different-flavour dilepton channels, $t\bar{t} \to W^+bW^-\bar{b} \to \ell^+\ell^-\nu\bar{\nu}b\bar{b}$ ($\ell = e,\mu$), where both W bosons decay leptonically, and the lepton-plus-jets channel, $t\bar{t} \to W^+bW^-\bar{b} \to \ell^\pm\nu/\bar{\nu}q\bar{q}'b\bar{b}$, where one W boson decays leptonically and the other W bosons decays hadronically. The described measurements are performed at center-of-mass energies of $\sqrt{s} = 7\,\text{TeV}$, $8\,\text{TeV}$ and $13\,\text{TeV}$. Additionally a measurement of the top quark branching ratios is summarized.

Theory calculations of $\sigma_{t\bar{t}}$ are available at next-to-next-to leading order (NNLO) including the resummation of next-to-next-to leading logarithms (NNLL) from soft gluon terms. The predictions are $177^{+10}_{-11}\,\text{pb}$ at $\sqrt{s} = 7\,\text{TeV}$, $253^{+13}_{-15}\,\text{pb}$ at $\sqrt{s} = 8\,\text{TeV}$ and $832^{+40}_{-46}\,\text{pb}$ at $\sqrt{s} = 13\,\text{TeV}$ and have been obtained with top++ 2.0 [2]. The uncertainties include PDF uncertainties according to the PDF4LHC [3] prescription and QCD scale uncertainties.

2. Measurement of the $t\bar{t}$ production cross-section at $\sqrt{s} = 7\,\text{TeV}$, $8\,\text{TeV}$ and $\sqrt{s} = 13\,\text{TeV}$ using eμ events with b-tagged jets

The cross-section for $t\bar{t}$ production at $\sqrt{s} = 7$ TeV, 8 TeV [4] and $\sqrt{s} = 13$ TeV [5] was measured most precisely in the $e\mu$ decay channel using datasets with integrated luminosities of $4.6\,\text{fb}^{-1}$, $20.3\,\text{fb}^{-1}$ and $56\,\text{pb}^{-1}$, respectively. A pure sample of $t\bar{t}$ events is preselected by requiring one electron and one opposite-charge muon with $p_T > 25\,\text{GeV}$ and $|\eta| < 2.5$. In this event sample jets are identified as likely to originate from the fragmentation of a b-quark using a multivariate technique ("MV1" for 7 TeV and 8 TeV, "MV2c20" for 13 TeV) [6] that has a 70% efficiency for tagging b-quark jets from top decays in $t\bar{t}$ events, with a rejection factor of about 140 ("MV1") or 440 ("MV2c20") against light-quark and gluon jets. The distribution of the number of identified b-jets is shown for the $\sqrt{s} = 7\,\text{TeV}$ event sample in Figure 1. Based on the number of events with one (N_1) and two identified b-jets (N_2), the cross-section for $t\bar{t}$ production, $\sigma_{t\bar{t}}$ and the b-jet reconstruction and identification probability, ε_b, are obtained using

$$N_1 = L\sigma_{t\bar{t}}\varepsilon_{e\mu}2\varepsilon_b\left(1 - C_b\varepsilon_b\right) + N_1^{\text{bkg}} \quad , \quad N_2 = L\sigma_{t\bar{t}}\varepsilon_{e\mu}C_b\varepsilon_b^2 + N_2^{\text{bkg}}, \tag{2.1}$$

where L is the integrated luminosity, $\varepsilon_{e\mu}$ the preselection efficiency, C_b a tagging correlation coefficient close to unity and N_1^{bkg}, N_2^{bkg} the number of background events with 1 and 2 identified b-jets. Due to the in-situ determination ε_b, the systematic uncertainty due to the b-tagging efficiency and jet energy scale is minimised. The dominant systematic uncertainties are documented in Table 1, details on the evaluation of the uncertainties are available in [4, 5]. An additional reduction of

systematic uncertainties is possible by considering the ratio of the cross-sections of $t\bar{t}$ and Z boson production, $R_{t\bar{t}/Z}$ [7].

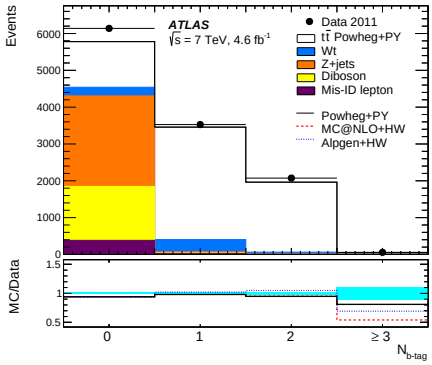

Figure 1: The number of b-tagged jets in preselected $e\mu$ events in $\sqrt{s} = 7\,\text{TeV}$ data compared to simulation [4].

Uncertainty	7 TeV	8 TeV	13 TeV
Luminosity	2.0%	3.1%	10.0%
Beam energy	1.8%	1.7%	-
$t\bar{t}$ modelling	1.4%	1.2%	5.2%
PDF	1.0%	1.1%	1.4%
Total syst.	3.9%	4.3%	13.7%
Data stat.	1.7%	0.7%	6.0%

Table 1: Most important and total statistical and systematic uncertainties for the measurement of $\sigma_{t\bar{t}}$ using $e\mu$ events with b-tagged jets [4, 5].

The obtained cross-sections for $t\bar{t}$ production, the ratio of the cross-sections for $t\bar{t}$ and Z boson production and the associated systematic uncertainties are

$$\sigma_{t\bar{t}} = 182.9 \pm 3.1\,(\text{stat}) \pm 4.2\,(\text{syst}) \pm 3.6\,(\text{lumi}) \pm 3.3\,(\text{beam})\,\text{pb} \quad (\sqrt{s} = 7\,\text{TeV}) \quad (2.2)$$

$$\sigma_{t\bar{t}} = 242.4 \pm 1.7\,(\text{stat}) \pm 5.5\,(\text{syst}) \pm 7.5\,(\text{lumi}) \pm 4.2\,(\text{beam})\,\text{pb} \quad (\sqrt{s} = 8\,\text{TeV}) \quad (2.3)$$

$$\sigma_{t\bar{t}} = 829 \pm 50\,(\text{stat}) \pm 56\,(\text{syst}) \pm 83\,(\text{lumi})\,\text{pb} \quad (\sqrt{s} = 13\,\text{TeV}) \quad (2.4)$$

$$R_{t\bar{t}/Z} = 0.445 \pm 0.027\,(\text{stat}) \pm 0.028\,(\text{syst}) \quad (\sqrt{s} = 13\,\text{TeV}) \quad (2.5)$$

3. Measurement of the $t\bar{t}$ production cross-section at $\sqrt{s} = 13\,\text{TeV}$ in the same-flavour dilepton channels

In addition to the measurement outlined in Section 2 a measurement of $t\bar{t}$ production was performed using a $\int L\,dt = 85\,\text{pb}^{-1}$ $\sqrt{s} = 13$ TeV dataset in the same-flavour dilepton channels with two electrons, ee, and two muons, $\mu\mu$ [7]. Next to an opposite-sign $ee/\mu\mu$ pair, $E_{\text{T}}^{\text{miss}} > 30\,\text{GeV}$ and $60 < m_{ll} < 81\,\text{GeV}$ or $m_{ll} > 101\,\text{GeV}$ are required. Similar to the method described in Section 2 the cross-section for $t\bar{t}$ production is obtained from the number of events in the ee and $\mu\mu$ channel with one or two b-jets using a maximum likelihood fit with free parameters for $\sigma_{t\bar{t}}$ and the b-jet reconstruction and identification probabilities in the ee and $\mu\mu$ channels. Here, independent parameters are used for the b-jet reconstruction and identification probabilities in the ee and $\mu\mu$ channels due to slightly different kinematic selections.

The obtained $t\bar{t}$ cross-section is

$$\sigma_{t\bar{t}} = 749 \pm 57\,(\text{stat}) \pm 79\,(\text{syst}) \pm 74\,(\text{lumi})\,\text{pb}\,. \quad (3.1)$$

4. Measurement of the $t\bar{t}$ production cross-section at $\sqrt{s} = 8\,\text{TeV}$ and $\sqrt{s} = 13\,\text{TeV}$ in the lepton-plus-jets channels

The cross-section for $t\bar{t}$ production was measured in the lepton-plus-jets channels at $\sqrt{s} = 8\,\text{TeV}$ [8] and 13 TeV [7] using proton–proton collisions corresponding to an integrated luminosity

of 20.3 fb^{-1} and 85 pb^{-1}, respectively. For the 8 TeV and 13 TeV analyses a data sample is selected by requiring one electron or muon and 3 (8 TeV) or 4 jets (13 TeV) in addition to a selection based on requirements on $E_{\mathrm{T}}^{\mathrm{miss}}$ and the transverse mass of the leptonic W-boson decay, m_{T}^{W}. For the 13 TeV analysis the cross-section is directly derived from the selected number of events while for the 8 TeV analysis a template fit based on the likelihood discriminant (LHD) variable is employed. The LHD variable is defined as the ratio of a likelihood function based on kinematic variables for signal and the sum of the same function for signal and background. For the $t\bar{t}$ production cross-section the following values are measured:

$$\sigma_{t\bar{t}} = 260 \pm 1\,(\mathrm{stat})\,^{+22}_{-23}\,(\mathrm{syst}) \pm 8\,(\mathrm{lumi}) \pm 4\,(\mathrm{beam})\,\mathrm{pb} \qquad (\sqrt{s} = 8\,\mathrm{TeV}) \qquad (4.1)$$

$$\sigma_{t\bar{t}} = 817 \pm 13\,(\mathrm{stat}) \pm 103\,(\mathrm{syst}) \pm 88\,(\mathrm{lumi})\,\mathrm{pb} \qquad (\sqrt{s} = 13\,\mathrm{TeV}) \qquad (4.2)$$

5. Measurement of the top quark branching ratios into channels with leptons and quarks

For the measurement of the top quark branching ratios into channels with leptons and quarks [9] the numbers of events for the dilepton (ee, $e\mu$ and $\mu\mu$), l+jets (e+jets and μ+jets) and $l\tau$ channels are measured in a 4.7 fb^{-1} event sample of $\sqrt{s} = 7$ TeV proton–proton collisions and corrected to the full phase space. The cross-section for $t\bar{t}$ production, $\sigma_{t\bar{t}}$, the top quark branching ratio to $\ell\nu_\ell(\nu_\tau) + X$, B_ℓ ($\ell = e, \mu$), the branching ratio to $\tau\nu_\tau + X$ with the τ lepton decaying hadronically, B_τ and the branching ratio to jets, B_j, are obtained from the measured numbers of events for the combined dilepton, l+jets and $l\tau$ channels. The top quark branching ratio to $e\nu_e(\nu_\tau) + X$, B_e, and the branching ratio to $\mu\nu_\mu(\nu_\tau) + X$, B_μ, is obtained with a χ^2 method using the number of events in the ee, $\mu\mu$, e+jets and μ+jets channels. The results are shown in Table 2.

	Measured [%]	SM [%]
B_j	$66.5 \pm 0.4\,(\mathrm{stat}) \pm 1.3\,(\mathrm{syst})$	67.51 ± 0.07
B_e	$13.3 \pm 0.4\,(\mathrm{stat}) \pm 0.5\,(\mathrm{syst})$	12.72 ± 0.01
B_μ	$13.4 \pm 0.3\,(\mathrm{stat}) \pm 0.5\,(\mathrm{syst})$	12.72 ± 0.01
B_τ	$7.0 \pm 0.3\,(\mathrm{stat}) \pm 0.5\,(\mathrm{syst})$	7.05 ± 0.01

Table 2: Top quark branching ratios into jets, an electron, a muon and a hadronically decaying τ lepton and neutrinos as measured with the ATLAS 7 TeV dataset [9].

6. Conclusions

The large event samples of di-top production collected with the ATLAS detector at $\sqrt{s} =$ 7 TeV, 8 TeV and 13 TeV allow the precise measurement of the cross-section for inclusive top pair production. The measured $t\bar{t}$ cross-sections are compared to the theory calculation at NNLO+NNLL in Figure 2.

The precision of the measurements at $\sqrt{s} = 7$ TeV and 8 TeV is comparable to that of the theoretical predictions, allowing stringent tests of the Standard Model and sensitivity to the top quark mass, the gluon parton distribution function and models of new physics.

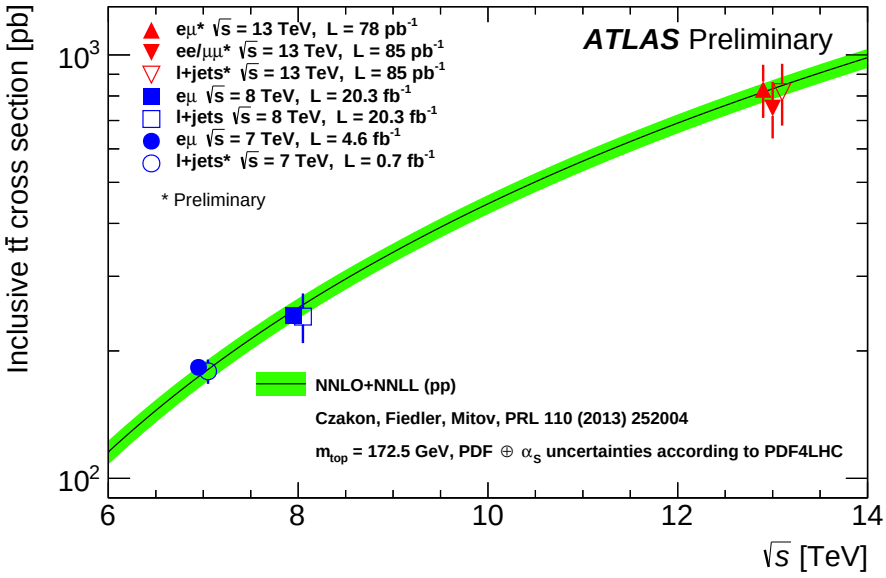

Figure 2: Summary of inclusive $t\bar{t}$ cross-section measurements with the ATLAS detector as a function of the collision energy [7].

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