Journal of Physics: Conference Series **452** (2013) 012058 doi:10.1088/1742-6596/452/1/012058

Top Quark Charge Asymmetry Measurement with ATLAS at the LHC

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Abstract. In the Standard Model top-antitop pair production is foreseen to be charge asymmetric in quark-antiquark annihilation at NLO. Although the dominant $t\bar{t}$ production mechanism in *pp* collisions at the LHC is gluon-gluon fusion, QCD predicts a small excess of top quarks produced at higher absolute rapidities than antitops. The measurement of the top quark charge asymmetry is therefore an important test of QCD and is also sensitive to new physics. We present measurements of this asymmetry using data corresponding to an integrated luminosity of 1.04 fb^{-1} and 4.70 fb^{-1} of *pp* collisions at $\sqrt{s}$ = 7 TeV collected by the ATLAS detector in the single lepton and dilepton channels respectively.

1. Introduction

Studies of the top quark, being the heaviest known elementary particle with a mass close to the electroweak scale, can provide important tests of the Standard Model (SM) and also promising probes of new physics.

At Leading Order (LO, O(α_s^2)) top-antitop pair production is predicted to be symmetric under charge conjugation, the tops have identical angular distributions. However next-to-leading order (NLO, O(α_s^3)) corrections introduce a charge asymmetry predicting that top (antitop) quarks are emitted preferentially in the direction of the incoming quark (anti-quark). This is a consequence of the interference between the $q\bar{q} \to t\bar{t}$ Born-level and box diagrams which lead to a positive charge asymmetry and the interference between initial and final state radiation contributions ($q\bar{q} \to t\bar{t}g$) leading to a negative charge asymmetry. Similarly the $qg \to t\bar{t}q$ process is asymmetric due to interference between amplitudes which have a relative sign difference under the exchange of the top and antitop. Finally top-antitop production by gluon-gluon fusion ($gg \to t\bar{t}$) is charge symmetric.

In proton-antiproton collisions at the Tevatron top-quark pairs are predominantly produced by quark-antiquark annihilation. CDF [1] and D0 [2] Collaborations measured the charge asymmetry as a forward-backward asymmetry A_{FB} resulting in a 2 - 3 σ excess over SM expectations both in inclusive and differential measurements as a function of the $m_{t\bar{t}}$ variable.

However in proton-proton collisions at the LHC top pairs are predominantly produced by (charge symmetric) gluon-gluon fusion. Furthermore there is no A_{FB} symmetry, instead QCD predicts a small excess of centrally produced antitop quarks, while top quarks are produced at higher absolute rapidities.

The top-based charge asymmetry A_C measured at the LHC is defined as

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$$A_C^{t\bar{t}} = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)} \tag{1}$$

where $\Delta|y| \equiv |y_t| - |y_{\bar{t}}|$ is the difference of the absolute values of the top and antitop rapidities ($|y_t|$ and $|y_{\bar{t}}$), and N is the number of events where $\Delta|y|$ is positive or negative. Using MC@NLO [6], A_C is theoretically calculated to be ~ 0.6 %.

In addition, a lepton-based asymmetry $A_C^{\ell\bar{\ell}}$ defined as:

$$A_C^{\ell\bar{\ell}} = \frac{N(\Delta|\eta| > 0) - N(\Delta|\eta| < 0)}{N(\Delta|\eta| > 0) + N(\Delta|\eta| < 0)} \tag{2}$$

where $\Delta|\eta| \equiv |\eta_{l^+}| - |\eta_{l^-}|$ is the difference of the absolute values of the positively and negatively charged lepton pseudorapidities and N is the number of events where $\Delta|\eta|$ is positive or negative.

In this article, the top-based and lepton-based asymmetry measurements are presented using data corresponding to 1.04 fb^{-1} and 4.70 fb^{-1} of pp collisions at $\sqrt{s} = 7$ TeV collected by ATLAS in 2011 in the single lepton [4] and dilepton [5] channels.

2. Top charge asymmetry in single lepton channel

Top quarks decay almost 100% of the time to a W-boson and b-quark. In top-antitop pair production in the single lepton channel one W-boson decays hadronically into two quarks and the other decays leptonically into a lepton and a neutrino giving the $t\bar{t} \to bl\nu bjj$ decay. The $t\bar{t}$ final state is then characterised by an isolated lepton (e or μ) with relatively high p_T, missing transverse momentum (E_T^{miss}) arising from the neutrino, two b-quark jets and two light quark jets from the hadronically decaying W-boson. Selected events are required to have at least one primary vertex with at least 5 associated tracks and exactly one electron with transverse momentum, $p_T > 25$ GeV, or one muon with $p_T > 20$ GeV. To reject multi-jet background in the μ channel $E_T^{miss} > 20$ GeV and $E_T^{miss} + m_T(W) > 60$ GeV are required, where $m_T(W) = \sqrt{2p_T^\ell p_T^\nu(1 - cos(\phi^\ell - \phi^\nu))}$ is the W-boson transverse mass, while in the e channel stricter cuts are required, $E_T^{miss} > 35$ GeV and $m_T(W) > 25$ GeV, due to the higher level of multijet background. Finally at least four jets (reconstructed with the anti-k_T algorithm with a 0.4 radius parameter in η-ϕ plane) with $p_T > 25$ GeV and $|\eta| < 2.5$ are required where at least one jet is tagged as originating from a b-quark.

The dominant backgrounds in this channel are multijets and W+jets which are estimated with dedicated data driven methods. Other minor backgrounds like single top production, Z+jets and diboson (WW, WZ, ZZ), are estimated using Monte Carlo (MC) simulated samples.

The $t\bar{t}$ system is reconstructed using a kinematic likelihood fit which relies on a parameterization of the energy and momentum resolution. The hadronically decaying top quark is reconstructed from three of the selected jets and the leptonically decaying top quark from the lepton, the remaining jet and the E_T^{miss}. A likelihood method is used to correctly assign measured jets to partons. The top and W-decay are modeled via Breit-Wigner function.

These measured asymmetries are distorted by event selection bias and detector effects. In order to compare them with theoretical predictions a Bayesian unfolding procedure is performed using the experimental asymmetries to reveal the four-vectors of the top quark before decay. The relation between a true distribution T_j and the reconstructed distribution S_i after detector simulation and event selection is

$$S_i = \sum_j R_{ij} T_j \tag{3}$$

where R_{ij} is the response matrix defined as the probability to observed an event in bin i when it is expected to be in bin j, and is calculated using MC events generated with MC@NLO. By inverting R_{ij} using Bayesian iterative unfolding, T_j is obtained.

The unfolding was performed after background subtraction for both the inclusive measured distribution of $\Delta|y|$, and the measured distribution $\Delta|y|$ as a function of the reconstructed $t\bar{t}$ invariant mass $m_{t\bar{t}}$ using two bins separated at $m_{t\bar{t}} = 450$ GeV as motivated by the CDF measurement [3] mentioned in the introduction.

The measured distributions of the top-antitop rapidity difference after the unfolding is shown in Figure 1 for e channel and μ channel. The resultant charge asymmetries are combined taking into account the correlation and measured as $A_C = -0.019 \pm 0.028(stat.) \pm 0.024(syst.)$.

The asymmetry combined in the two channels and evaluated in the two ranges of $m_{t\bar{t}}$ mentioned above, has been measured to be $A_C = -0.052 \pm 0.070(stat.) \pm 0.054(syst.)$ for $m_{t\bar{t}} < 450$ GeV, and $A_C = -0.008 \pm 0.035(stat.) \pm 0.032(syst.)$ for $m_{t\bar{t}} > 450$ GeV.

and is shown on the right in Figure 1. The uncertainties include that from the parton distribution functions and renormalisation and factorisation scales.

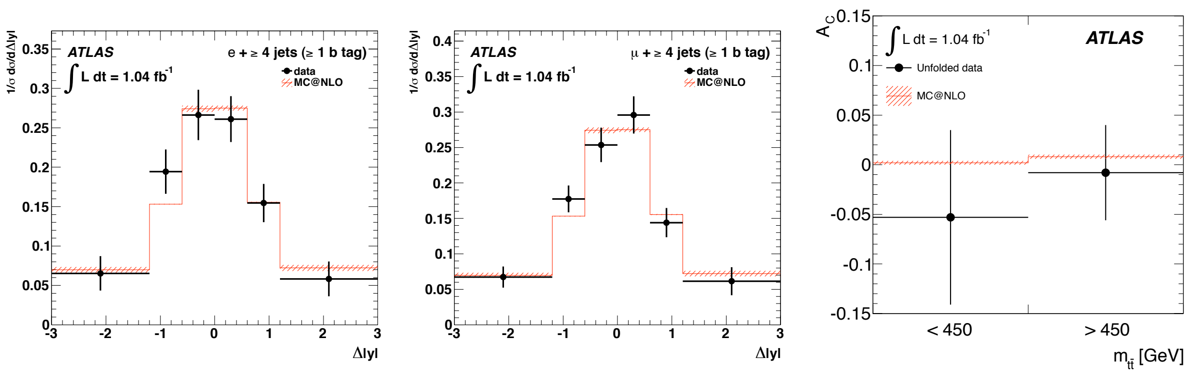

Figure 1. Measured top-antitop rapidity difference $\Delta|y|$ distribution in the single lepton channel after unfolding for e channel (left) and μ channel (center), and the right plot shows the charge asymmetry in the two $m_{t\bar{t}}$ region compared to the prediction from MC@NLO [4].

3. Top charge and lepton-based asymmetries in dileptonic channel

In the dilepton channel, where both W-bosons decay leptonically, producing the $t\bar{t} \to bl\nu bl\nu$ decay, three channels are considered depending on the lepton flavours in the final state: ee, $\mu\mu$ and $e\mu$. Both the top-based and lepton-based asymmetries measurements, as defined in Eq. 1 and Eq. 2 are presented. The dilepton $t\bar{t}$ channel is characterized by two isolated leptons with relatively high p_T, E_T^{miss} arising from the two neutrinos and two b-quark jets. Events are selected requiring at least one primary vertex with at least five associated tracks. Exactly two oppositely charged leptons are required with $E_T > 25$ GeV for electrons or $p_T > 20$ GeV for muons, and in the ee and $\mu\mu$ channels the $E_T^{miss} > 60$ GeV, and in the $e\mu$ channel the sum of lepton and jet E_T should be larger than 130 GeV. In only the ee and $\mu\mu$ channels the dilepton invariant mass is required to be different to the Z-boson mass by at least 10 GeV $|m_{\ell\ell} - m_Z| > 10$ GeV. Finally the event should contain at least two jets with $p_T > 25$ GeV and $|\eta| < 2.5$.

The dominant multijet background is estimated using a dedicated data driven method and background events from single top, Z+jets and diboson are evaluated using MC simulation.

A likelihood method based on the calculation of the leading order matrix element is used to reconstruct the $t\bar{t}$ event topology. For each event the kinematics are solved using the energy-momentum conservation at each vertex of the process and assigned a weight according to a likelihood estimator. The correction to the experimentally measured asymmetries is applied after the background subtraction by using calibration curves obtained by fitting a straight line to the reconstructed asymmetries corresponding to different simulated MC@NLO $t\bar{t}$ samples reweighted to vary the size of the asymmetry at the generator level.

Systematic uncertainties from MC generator and detector modelling are determined, and the asymmetries are recomputed and recalibrated after background subtraction, where the calibration curves are rederived for each systematic source.

The measured top-antitop rapidity difference distribution after corrections is shown in Figure 2 for ee, $e\mu$ and $\mu\mu$ channels. The three channels are combined, taking the correlations among channels into account, to give the lepton and top quark charge asymmetry as $A_C^{\ell} = 0.023 \pm 0.012(stat.) \pm 0.008(syst.)$ and $A_C^{t\bar{t}} = 0.057 \pm 0.024(stat.) \pm 0.015(syst.)$ respectively.

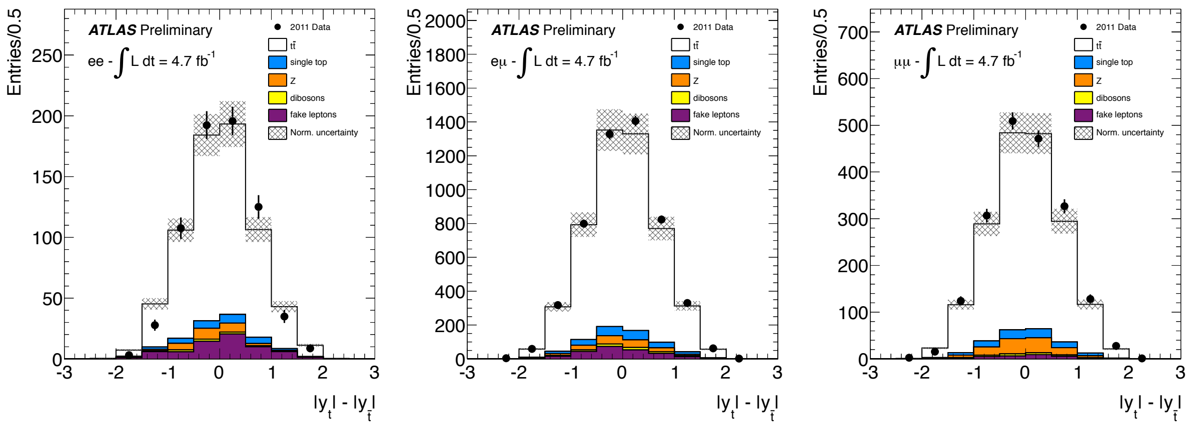

Figure 2. Measured top-antitop rapidity difference $\Delta|y|$ distribution in the dilepton channel after corrections are applied for the ee (left), $e\mu$ (center), and $\mu\mu$ (right) channels [5].

Finally a combination of the top-antitop based asymmetry in the dilepton and single lepton channels gives $A_C^{t\bar{t}} = 0.029 \pm 0.018(stat.) \pm 0.014(syst.)$.

4. Summary

The top quark charge asymmetry measurements performed by ATLAS experiment have been presented for the single lepton and dilepton channel. A lepton-based asymmetry measurement in the dilepton channel has also been presented. All the presented measurements are compatible with the SM predictions.

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