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Measurement of the Top Quark Pair Production Charge Asymmetry in Proton-Proton Collisions at √S=7 TeV using the ATLAS Detector

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ABSTRACT: This paper presents a measurement of the top quark pair ($t\bar{t}$) production charge asymmetry A_C using 4.7 fb^{-1} of proton-proton collisions at a centre-of-mass energy $\sqrt{s} = 7\,\text{TeV}$ collected by the ATLAS detector at the LHC. A $t\bar{t}$-enriched sample of events with a single lepton (electron or muon), missing transverse momentum and at least four high transverse momentum jets, of which at least one is tagged as coming from a b-quark, is selected. A likelihood fit is used to reconstruct the $t\bar{t}$ event kinematics. A Bayesian unfolding procedure is employed to estimate A_C at the parton-level. The measured value of the $t\bar{t}$ production charge asymmetry is $A_C = 0.006 \pm 0.010$, where the uncertainty includes both the statistical and the systematic components. Differential A_C measurements as a function of the invariant mass, the rapidity and the transverse momentum of the $t\bar{t}$-system are also presented. In addition, A_C is measured for a subset of events with large $t\bar{t}$ velocity, where physics beyond the Standard Model could contribute. All measurements are consistent with the Standard Model predictions.

Contents

1 Introduction

The measurement of the $t\bar{t}$ production charge asymmetry represents an important test of quantum chromodynamics (QCD) at high energies and is also an ideal place to observe effects of possible new physics processes beyond the Standard Model (BSM). Several BSM processes can alter this asymmetry [1–13], either with anomalous vector or axial-vector couplings (i.e. axigluons) or via interference with the Standard Model (SM). Different models also predict different asymmetries as a function of the invariant mass $m_{t\bar{t}}$ [14], the transverse momentum $p_{T,t\bar{t}}$ and the rapidity $|y_{t\bar{t}}|$ of the $t\bar{t}$-system.

At leading order (LO), $t\bar{t}$ production at hadron colliders is predicted to be symmetric under the exchange of top quark and antiquark. At next-to-leading order (NLO), the process $q\bar{q} \to t\bar{t}g$ exhibits an asymmetry in the rapidity distributions of the top quark and antiquark, due to interference between initial– and final– state gluon emission. In addition, the $q\bar{q} \to t\bar{t}$ process itself possesses an asymmetry due to the interference between the Born and the NLO diagrams. The qg production process is also asymmetric, but its contribution is much smaller than the $q\bar{q}$ one. The production of $t\bar{t}$ events by gluon fusion, $gg \to t\bar{t}$, is symmetric. At the Tevatron proton-antiproton collider, where $t\bar{t}$ events are predominantly produced by $q\bar{q}$ annihilation, top quarks are preferentially emitted in the direction of the

incoming quark while the top antiquarks are emitted preferentially in the direction of the incoming antiquark [15–21]. The $t\bar{t}$ asymmetry at the Tevatron is therefore measured as a forward-backward asymmetry,

$$A_{\mathrm{FB}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)},$$

where $\Delta y \equiv y_t - y_{\bar{t}}$ is the difference in rapidity between top quarks and antiquarks, and N represents the number of events with Δy being positive or negative. The interest in this measurement has grown after CDF and D0 collaborations reported A_{FB} measurements significantly larger than the SM predictions, in both the inclusive and differential case as a function of $m_{t\bar{t}}$ and $|y_{t\bar{t}}|$ [22–26].

In proton-proton (pp) collisions at the LHC, the dominant mechanism for $t\bar{t}$ production is the gg fusion process, while production via $q\bar{q}$ or qg interactions is small. Since the colliding beams are symmetric, A_{FB} is no longer a useful observable. However, $t\bar{t}$ production via $q\bar{q}$ or qg processes is asymmetric under top quark-antiquark exchange, and, in addition, the valence quarks carry, on average, a larger momentum fraction than antiquarks from the sea. Hence for $q\bar{q}$ or qg production processes at the LHC, QCD predicts a small excess of centrally produced top antiquarks while top quarks are produced, on average, at higher absolute rapidities. Therefore, the $t\bar{t}$ production charge asymmetry A_{C} is defined as [1, 27]

$$A_{\mathrm{C}} = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}, \tag{1.1}$$

where $\Delta|y| \equiv |y_t| - |y_{\bar{t}}|$ is the difference between the absolute value of the top quark rapidity $|y_t|$ and the absolute value of the top antiquark rapidity $|y_{\bar{t}}|$.

The SM prediction for the $t\bar{t}$ production charge asymmetry at the LHC is $A_{\mathrm{C}}^{\mathrm{SM}} = 0.0123 \pm 0.0005$ [21], computed at NLO in QCD including electroweak corrections. Recent asymmetry measurements at the LHC [28–30] did not report any significant deviation from the SM predictions in either the inclusive or differential A_{C} measurements. Agreement with the SM A_{C} predictions at the LHC is compatible with the larger than expected A_{FB} values measured at the Tevatron for the most general new physics scenarios [31], but creates a tension between the measurements at the two colliders in specific simple models [8]. This motivates the interest in a more precise measurement of the $t\bar{t}$ production charge asymmetry.

In this paper, a measurement of the $t\bar{t}$ production charge asymmetry in the single-lepton final state is reported. To allow comparisons with theory calculations, a Bayesian unfolding procedure is applied to account for distortions due to acceptance and detector effects, leading to parton-level A_{C} measurements. Compared with the previous $t\bar{t}$ production charge asymmetry measurement performed by the ATLAS experiment and described in ref. [30], the full 2011 data sample is now used and new differential A_{C} measurements are performed. In particular, an inclusive A_{C} measurement and measurements of A_{C} as a function of $m_{t\bar{t}}$, $p_{\mathrm{T},t\bar{t}}$ and $|y_{t\bar{t}}|$ are presented. The inclusive A_{C} result and the differential result as a function of $m_{t\bar{t}}$ are also presented with the additional requirement of a minimum velocity $\beta_{z,t\bar{t}}$ of the $t\bar{t}$-system along the beam axis to enhance the sensitivity to BSM effects [32].

2 Data sample, simulated samples and event selection

2.1 Samples

The measurement is performed using 7 TeV pp collisions recorded by the ATLAS detector [33] at the LHC during 2011. The ATLAS detector is composed of inner tracking detectors immersed in a 2 T axial magnetic field provided by a solenoid, surrounded by calorimeters and, as an outer layer, by a muon spectrometer in a magnetic field provided by three large air-core toroid magnet systems.[1] After applying detector and data-quality requirements, the recorded data corresponds to an integrated luminosity of 4.7 fb^{-1} [34].

Simulated $t\bar{t}$ events are modelled using the LO multi-parton matrix-element Monte Carlo (MC) generator ALPGEN [35] with the LO CTEQ6L1 [36] parton distribution function (PDF) for the proton. Parton showering and the underlying event are modelled using HERWIG [37] and JIMMY [38] with the AUET2 parameter settings [39]. The $t\bar{t}$ sample is generated assuming a top quark mass of 172.5 GeV and it is normalised to a total inclusive cross-section of 177^{+10}_{-11} pb computed at next-to-next-to-leading-order (NNLO) in QCD including resummation of next-to-next-to-leading-logarithmic (NNLL) soft gluon terms with Top++2.0 [40–45]. The uncertainties included in the calculation are those related to the choice of the PDF set (following the PDF4LHC prescriptions [46]), the variations of α_S and the choice of renormalisation and factorisation scales. These uncertainties are added in quadrature to give the quoted overall uncertainty.

Single-top events are generated using AcerMC [47] for the t-channel and MC@NLO for the Wt– and s– channels. The production of W and Z bosons in association with jets is simulated using the ALPGEN generator interfaced to HERWIG and JIMMY. Simulated W+jets events are reweighted using the NLO PDF set CT10. Pairs of W/Z bosons (WW, WZ, ZZ) are produced using HERWIG.

All simulated samples are generated with multiple pp interactions per bunch crossing (event pile-up). Up to 24 interactions per bunch crossing were observed during the data taking period. The number of interaction vertices in simulated samples is adjusted so that its distribution reproduces the one observed in data. The samples are then processed through the GEANT4 [48] simulation [49] of the ATLAS detector and the same reconstruction software used for data.

2.2 Event selection

Candidate events with the $t\bar{t}$ single-lepton signature are considered. These events are characterised by exactly one high–p_T isolated lepton (electron, muon or tau decaying to electron or muon), missing transverse momentum E_T^{miss} due to the neutrino from the leptonic W decay, two jets originating from b-quarks and two jets originating from light quarks from the hadronic W decay.

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[1]ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$. Transverse momentum and energy are defined as $p_T = p\sin\theta$ and $E_T = E\sin\theta$, respectively.

Events are required to pass the single-electron or single-muon trigger, with thresholds in transverse energy (E_T) at 20 GeV or 22 GeV for electrons (depending on instantaneous luminosity conditions during the different data collection periods) and in transverse momentum (p_T) at 18 GeV for muons. Electron candidates are required to have $E_{\mathrm{T}} > 25$ GeV and $|\eta_{\mathrm{cluster}}| < 2.47$, where η_{cluster} is the pseudorapidity of the electromagnetic energy cluster in the calorimeter. Candidates in the transition region $1.37 < |\eta_{\mathrm{cluster}}| < 1.52$ between calorimeter sections are excluded. Muon candidates are required to have $p_{\mathrm{T}} > 20$ GeV and $|\eta| < 2.5$. Electrons and muons are required to be isolated to reduce the backgrounds from hadrons mimicking lepton signatures and heavy-flavour decays inside jets. For electrons, stringent cuts both on the shape of the calorimetric energy deposits and on the tracks used to compute the isolation, in order to reject the tracks related to photon conversions, are applied. Cuts that depend on η and E_T leading to a 90% efficiency are used in a cone of $\Delta R = 0.2$ for the energy isolation and in a cone of $\Delta R = 0.3$ for the track isolation around the electron candidate. For muons, the sum of track transverse momenta in a cone of $\Delta R = 0.3$ around the muon is required to be less than 2.5 GeV, while the total energy deposited in a cone of $\Delta R = 0.2$ around the muon is required to be less than 4 GeV.

Jets are reconstructed from topologically connected calorimetric energy clusters using the anti-k_t algorithm [50] with a radius parameter $R = 0.4$. They are first calibrated to the electromagnetic energy scale and then corrected to the hadronic energy scale using energy- and η-dependent correction factors obtained from simulation and control data analyses [51]. The compatibility of the jets with the primary vertex (defined as the vertex with the highest sum of the square of the transverse momenta of the tracks associated to it) is determined using the tracks associated with the jet (jet vertex fraction). Jets originating from the hadronisation of b-quarks are identified by combining the information from three b-tagging algorithms, based on the topology of b- and c-hadron weak decays inside jets [52] and on the transverse and longitudinal impact parameter significance of each track within the jet [53]. These three tagging algorithms are combined into a single discriminating variable used to make the tagging decision. The operating point chosen corresponds to a 70% tagging efficiency for b-quarks. The rejection rate is about 150 for light-quark jets, 5 for charm jets and 14 for hadronically decaying τ leptons. All these numbers are evaluated in simulated $t\bar{t}$ events.

The missing transverse momentum is reconstructed from clusters of energy deposits in the calorimeters calibrated at the electromagnetic scale and corrected according to the energy scale of the associated physics object. Contributions from muons are included using their momentum measured by the inner tracking and muon spectrometer systems.

Jets within $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.2$ of an electron candidate are removed to avoid double counting electrons as jets. Subsequently, electrons and muons within $\Delta R = 0.4$ of a jet axis and with $p_{\mathrm{T}} > 20$ GeV are removed in order to reduce the contamination caused by leptons from hadron decays.

In the muon channel, events are required to satisfy $E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV and $E_{\mathrm{T}}^{\mathrm{miss}} + m_{\mathrm{T}}(W) > 60$ GeV in order to suppress the multi-jets background.[2] In the electron channel,

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[2]In events with a leptonic decay of a genuine W boson, $m_{\mathrm{T}}(W)$ is the W boson transverse mass, defined as $\sqrt{2p_{\mathrm{T}}^{\ell} p_{\mathrm{T}}^{\nu}(1 - \cos(\phi^{\ell} - \phi^{\nu}))}$, where the measured $E_{\mathrm{T}}^{\mathrm{miss}}$ vector provides the neutrino information.

the multi-jets contamination is larger, and more stringent cuts of $E_{\mathrm{T}}^{\mathrm{miss}} > 30$ GeV and $m_{\mathrm{T}}(W) > 30$ GeV are applied.

Finally, events are required to have at least four jets with $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.5$. These requirements define the 'pretag' selection. For the 'tag' selection, at least one of these jets is required to be b-tagged.

2.3 Background estimation

The main backgrounds affecting the measurement come from W bosons produced in association with jets (W+jets), single-top, Z+jets, production of W/Z bosons pairs and multi-jet events with background leptons.[3] The W+jets and multi-jets contributions are evaluated using a data-driven approach. Single-top, Z+jets and diboson production are evaluated using simulated samples normalised to the approximate NNLO cross section for single-top events, NNLO cross section for inclusive Z events, and NLO cross section for diboson events, respectively.

For reconstructed $t\bar{t}$ candidate events, the dominant W+jets background is asymmetric in $\Delta|y|$ and therefore a data-driven technique is used to estimate its normalisation. The approach used is based on the fact that the production rate of W^++jets is larger than that of W^-+jets. Since, to a good approximation, processes other than W+jets give equal numbers of positively and negatively charged leptons, the formula

$$N_{W^+} + N_{W^-} = \left(\frac{r_{\mathrm{MC}} + 1}{r_{\mathrm{MC}} - 1} \right) (D^+ - D^-), \tag{2.1}$$

is used to estimate the total number of W events in the selected sample, after the numbers of single-top, diboson and Z+jets events are evaluated in simulated samples and subtracted. Here, $N_{W^\pm}$ is the estimated number of $W^\pm$+jets events, $D^+(D^-)$ is the total number of events in data passing the pretag selection described in section 2.2 with positively (negatively) charged leptons, and $r_{\mathrm{MC}} = N(pp \to W^+ + X)/N(pp \to W^- + X)$ is evaluated from simulation, using the ALPGEN generator with the same event selection. Further details of the method can be found in ref. [30].

The W charge asymmetry depends also on the W+jets flavour composition, i.e. on the mixture of Wbb+jets, Wcc+jets, Wc+jets and W+light-jets processes in ALPGEN simulated samples. Since this composition cannot be predicted with sufficient precision, data-driven corrections are derived. The relative fractions are estimated in data, after subtracting all non–W contributions, including $t\bar{t}$, applying the tag selection but requiring the presence of exactly two jets in the final state, in order to have a control region dominated by W+jets events. The overall number of W+jets events is determined simultaneously with the heavy-flavour composition in this region. The heavy-flavour fractions in the simulated W+jets samples are then rescaled to the measured fractions. For the electron channel, the scale factors obtained are: 1.4 ± 0.4 for Wbb+jets and Wcc+jets, 0.7 ± 0.4 for Wc+jets and 1.00 ± 0.10 for W+light-jets components. For the muon channel, they are: 1.2 ± 0.4 for Wbb+jets and Wcc+jets, 1.0 ± 0.4 for Wc+jets and 0.97 ± 0.09 for W+light-jets

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[3]The term 'background (bkgd) leptons' in this paper refers to hadrons mimicking lepton signatures and to leptons arising from heavy-hadron decays or photon conversions.

Channel	μ + jets pretag	μ + jets tag	e + jets pretag	e + jets tag
$t\bar{t}$	34900 $\pm$ 2200	30100 $\pm$ 1900	21400 $\pm$ 1300	18500 $\pm$ 1100
W+jets	28200 $\pm$ 3100	4800 $\pm$ 900	13200 $\pm$ 1600	2300 $\pm$ 900
Multi–jets	5500 $\pm$ 1100	1800 $\pm$ 400	3800 $\pm$ 1900	800 $\pm$ 400
Single top	2460 $\pm$ 120	1970 $\pm$ 100	1530 $\pm$ 80	1220 $\pm$ 60
Z+jets	3000 $\pm$ 1900	480 $\pm$ 230	3000 $\pm$ 1400	460 $\pm$ 220
Diboson	380 $\pm$ 180	80 $\pm$ 40	230 $\pm$ 110	47 $\pm$ 22
Total background	40000 $\pm$ 4000	9200 $\pm$ 1000	21700 $\pm$ 2900	4800 $\pm$ 1000
Signal + background	74000 $\pm$ 4000	39300 $\pm$ 2100	43100 $\pm$ 3100	23300 $\pm$ 1600
Observed	70845	37568	40972	21929

Table 1. Numbers of expected events for the $t\bar{t}$ signal and the various background processes and observed events in data for the pretag and tag samples. The uncertainties include statistical and systematic components.

components. The uncertainties include both the statistical and the systematic components. The sources of systematic uncertainty considered are those described in section 3.3.

With the determined flavour fractions, the W+jets normalisation for pretag-selected events using eq. (2.1) is computed and then extrapolated to the tag-selected events using the tagging fractions (i.e. the fraction of events with at least one b-jet) computed in simulated samples. The scale factors that are applied to the tag-selected W+jets events are 0.83 ± 0.31 and 0.94 ± 0.17 in the electron and muon channel respectively. The uncertainties include both the statistical and the systematic components, including a particular systematic uncertainty that accounts for differences in the flavour composition between the signal region and the region where the flavour fractions are extracted. It is derived from studies of ALPGEN parameter variations (factorisation and renormalisation scales, angular matching parameters and jet p_T generation thresholds) and it amounts to 15% for the $Wbb/Wcc/Wc$+jets components and 5% for the W+light-jets component.

The 'Matrix Method' is used to evaluate the multi-jets background with background leptons. The method relies on defining 'loose' and 'tight' lepton samples [54] and measuring the 'tight' selection efficiencies for real (ϵ_{real}) and background (ϵ_{bkgd}) 'loose' leptons. The 'loose' selection requires less stringent identification and isolation requirements than the ones described in section 2.2, referred here as 'tight' selection. The fraction ϵ_{real} is measured using data control samples of Z boson decays to two leptons. The fraction ϵ_{bkgd} is measured in control regions where the contribution of background leptons is dominant.

The expected and observed yields are listed in table 1. The number of events in the electron channel is significantly lower than in the muon channel due to the higher lepton p_T threshold, tighter isolation and the more stringent missing transverse momentum requirements. The number of events observed in data and the total predicted yield are compatible within uncertainty.

3 The $t\bar{t}$ production charge asymmetry measurement

After the reconstruction of the $t\bar{t}$-system (section 3.1) and the estimation of the background, the $\Delta|y|$ spectra (section 3.2) are unfolded to obtain inclusive and differential parton-level charge asymmetry measurements (as a function of $m_{t\bar{t}}$, $p_{T,t\bar{t}}$ and $|y_{t\bar{t}}|$), as defined in eq. (1.1).

In addition, an inclusive measurement and a differential measurement as a function of $m_{t\bar{t}}$ are performed for events where the z-component of the $t\bar{t}$-system velocity is large, $\beta_{z,t\bar{t}} > 0.6$. Most BSM models introduced to explain the excesses in the CDF and D0 measurements postulate the presence of new particles that can alter the SM prediction for A_C. Requiring $\beta_{z,t\bar{t}} > 0.6$ defines a region of phase-space where the effects of these new particles on the asymmetry are enhanced [32].

3.1 Reconstruction of the $t\bar{t}$-system

A kinematic fit is used to determine the likelihood for candidate events to be $t\bar{t}$ events as well as to determine the four-vector of the top quark and antiquark to compute $\Delta|y|$. The charge of the lepton is used to determine whether the reconstructed object is a top quark or antiquark. A detailed description of the method and its assumptions can be found in ref. [30]. In simulation studies using $t\bar{t}$ events, the fraction of events reconstructed with the correct $\Delta|y|$ sign was evaluated to be 75%.

For the differential measurements a cut on the likelihood is applied to reject badly reconstructed events, reducing the migrations across the bins. The reconstructed $\Delta|y|$ distribution is shown in figure 1 along with the distributions of $m_{t\bar{t}}$, $p_{T,t\bar{t}}$, $|y_{t\bar{t}}|$ and $\beta_{z,t\bar{t}}$.

3.2 Unfolding procedure

The reconstructed $\Delta|y|$ distributions are distorted by acceptance and detector resolution effects. We use the Fully Bayesian Unfolding (FBU) [55] technique to estimate the parton-level distributions from the measured spectra. This method relies on applying Bayes' theorem to the unfolding problem, which can be formulated in the following terms.

Given an observed data spectrum $\mathbf{D} \in \mathbb{N}^{N_r}$ and a migration matrix $\mathcal{M} \in \mathbb{R}^{N_r} \times \mathbb{R}^{N_t}$ (N_r and N_t are the number of bins in the measured and true spectra respectively) that takes into account the distortion effects mentioned above, the posterior probability density of the true spectrum $\mathbf{T} \in \mathbb{R}^{N_t}$ follows the probability density

$$p\left(\mathbf{T}|\mathbf{D}, \mathcal{M}\right) \propto \mathcal{L}\left(\mathbf{D}|\mathbf{T}, \mathcal{M}\right) \cdot \pi\left(\mathbf{T}\right)$$

where $\mathcal{L}\left(\mathbf{D}|\mathbf{T}, \mathcal{M}\right)$ is the conditional likelihood for the data $\mathbf{D}$ assuming the true $\mathbf{T}$ and the migration matrix $\mathcal{M}$, and π is the prior probability density for the true $\mathbf{T}$.

Assuming that the data follows a Poisson distribution, the likelihood $\mathcal{L}\left(\mathbf{D}|\mathbf{T}, \mathcal{M}\right)$ can be computed starting from the migration matrix $\mathcal{M}$, whose elements $\mathcal{M}_{tr}$ represent the probability and the efficiency of an event produced in the true bin t to be reconstructed in any bin r. The background in each bin is taken into account when computing $\mathcal{L}\left(\mathbf{D}|\mathbf{T}, \mathcal{M}\right)$. While the above quantities can be estimated from simulated samples of signal events, the prior probability density $\pi(\mathbf{T})$ must be chosen according to what is known about $\mathbf{T}$ before
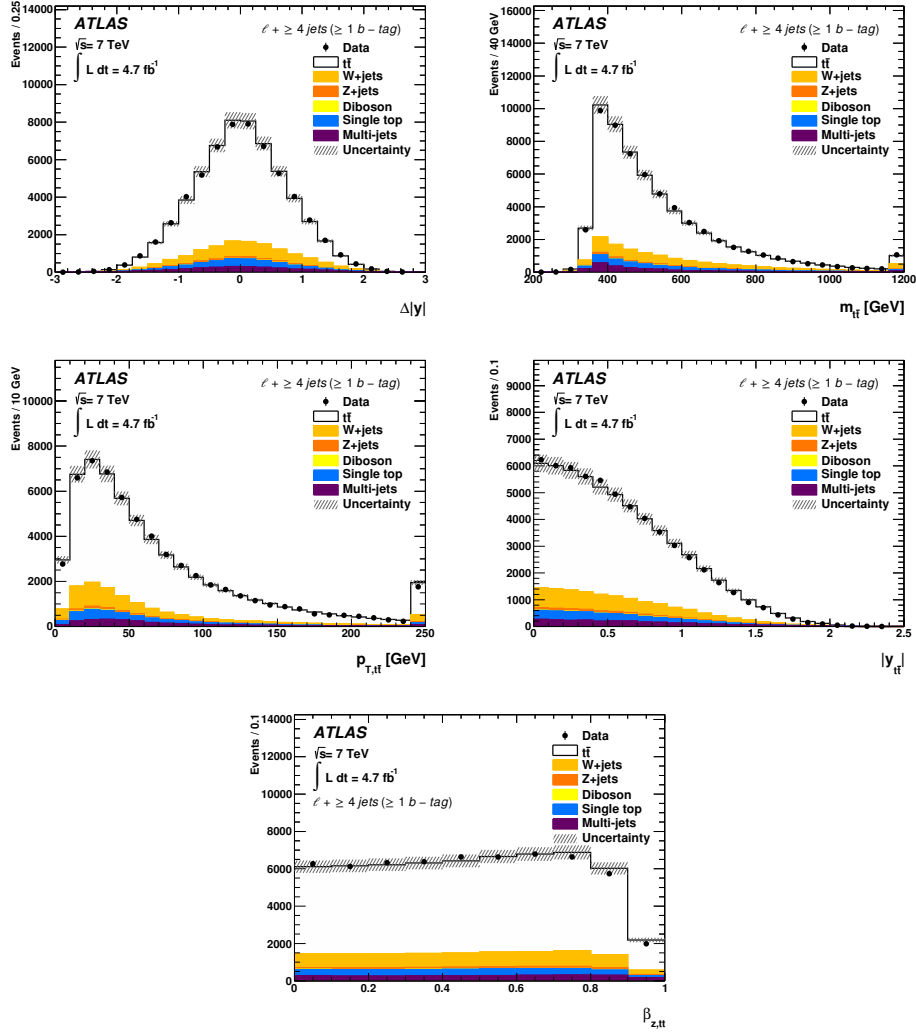
Figure 1. Reconstructed $\Delta|y|$ (top left), invariant mass $m_{t\bar{t}}$ (top right), transverse momentum $p_{\mathrm{T},t\bar{t}}$ (centre left), rapidity $|y_{t\bar{t}}|$ (centre right) and velocity $\beta_{z,t\bar{t}}$ (bottom) distributions for the electron and muon channels combined after requiring at least one b-tagged jet. Data (dots) and SM expectations (solid lines) are shown. The uncertainty on the total prediction includes both the statistical and the systematic components. The overflow is included in the last bin.

the measurement. In this context, the choice of the prior can be interpreted as the choice of a regularisation in other unfolding techniques (see ref. [56] for instance). After choosing a prior, the posterior probability density $p(\mathbf{T}|\mathbf{D},\mathcal{M})$ is computed by generating uniformly distributed points in the N_t-dimensional space, and evaluating for each of them $\mathcal{L}(\mathbf{D}|\mathbf{T},\mathcal{M})$ and $\pi(\mathbf{T})$. A weight given by $\mathcal{L}(\mathbf{D}|\mathbf{T},\mathcal{M}) \cdot \pi(\mathbf{T})$ is then assigned to each point, allowing the posterior probability density of the unfolded spectrum to be determined, for each $\Delta|y|$ bin and for A_C.

The FBU method has two main advantages. Firstly, it gives a precise physical meaning to the regularisation procedure through the choice of a prior built with well-motivated physical quantities. Secondly, systematic uncertainties are accounted for consistently with

the Bayesian statistical approach, by reporting credible intervals built by integrating the posterior distribution over the nuisance parameters.

The choice of the prior is arbitrary. With a flat prior, the FBU method has been checked to be equivalent to unregularised matrix inversion. Non-uniform priors favour spectra that have some well-defined features. By assuming that some spectra are more likely than others, information is added to the measurement, reducing the uncertainty but potentially biasing its outcome.

Two different priors are used in the following: a flat prior and a curvature prior. The curvature prior is defined starting from the definition of the curvature $C(\mathbf{T})$ being the sum of the squares of the second derivatives of the $\Delta|y|$ distribution $\mathbf{T}$ with N_t bins:

$$C(\mathbf{T}) = \sum_{i=2}^{N_t-1} (\Delta_{i+1,i} - \Delta_{i,i-1})^2, \tag{3.1}$$

where $\Delta_{a,b} = T_a - T_b$. The curvature prior is then defined as follows:

$$\pi(\mathbf{T}) \propto \begin{cases} e^{\alpha S(\mathbf{T})} & \text{in the integration space}, \forall t \in [1, N_t] \\ 0 & \text{otherwise} \end{cases} \tag{3.2}$$

where α is the regularisation parameter and $S(\mathbf{T}) \equiv |C(\mathbf{T}) - C(\mathbf{T}^*)|$ is a regularisation function, defined, for each generated point, as the difference between the curvature $C(\mathbf{T})$ of the true $\Delta|y|$ spectrum $\mathbf{T}$ and that of the estimated spectrum $\mathbf{T}^*$.

The flat prior is used for the differential measurements of A_C as a function of $m_{t\bar{t}}$ and of $|y_{t\bar{t}}|$. The curvature prior defined in eq. (3.2) is used for the inclusive measurement and for the differential measurement as a function of $p_{T,t\bar{t}}$, because it reduces the uncertainty on these measurements. The regularisation strength $\alpha = 10^{-8}$ is chosen based on the numerical value of the curvature of the true spectrum. It has been checked, by varying α by one order of magnitude included the $\alpha = 0$ unregularised case, that this particular choice of α does not cause any significant bias in either the unfolded distributions or in the computed asymmetries. The consistency of the FBU method with the iterative scheme [56] has been checked as well.

Four bins are used for the $\Delta|y|$ distribution both for the inclusive and the differential measurements. The $\Delta|y|$ bin ranges are the same in both measurements. The bin ranges for the differential variables are chosen to have approximately the same number of entries in each bin. The A_C posterior probability density is built from the asymmetry in each generated point of the integration space. The value of A_C and its statistical uncertainty are the mean and the RMS of the posterior probability density distribution respectively.

3.3 Systematic uncertainties

Several sources of systematic uncertainty are taken into account.

A possible small mis-modelling of the lepton momentum scale and resolution in simulation is corrected by scale factors derived from the comparison of $Z \to \ell\ell$, $J/\psi \to \ell\ell$ and $W \to e\nu$ events in data and simulation. The uncertainty on the scale factors ranges from 1% to 1.5% depending on the p_T and η of the leptons.

The jet energy scale is derived using information from test-beam data, collision data and simulation. Its uncertainty is between 1% and 2.5% in the central region of the detector, depending on jet p_T and η [51]. This value includes uncertainties due to the flavour composition of the sample, mis-measurements due to the effect of nearby jets, influence of pile-up, and a p_T-dependent uncertainty for jets arising from the fragmentation of b-quarks. The jet energy resolution and reconstruction efficiencies are measured in data using techniques described in refs. [51, 57].

The uncertainties on the lepton and jets are propagated to the missing transverse momentum calculation.

The b-tagging efficiencies and light jets mis-tag rates are measured in data. Jet p_T-dependent scale factors are applied to simulation to match the efficiencies observed in data. The typical uncertainty on the b-tagging scale factors ranges from 6% to 20% (depending on jet p_T and η) for b-jets, from 12% to 22% for c-jets and is about 16% for light-jets [53]. The impact of this uncertainty is negligible.

The systematic uncertainty in the modelling of the signal process is assessed by varying the simulation parameters and by using a different Monte Carlo generator (POWHEG [58, 59]). The sources of systematic uncertainty considered are the choice and the functional form of factorisation scale and the choice of parton shower model (PYTHIA or HERWIG). The impact of the choice of PDFs is evaluated following the procedure described in ref. [46]. All these uncertainties have a negligible impact on the asymmetry.

The limited size of the MC simulation samples gives rise to a systematic uncertainty in the response matrix. This is estimated by independently varying the bin content of the response matrix according to Poisson distributions.

Several other sources of systematic uncertainties are considered, namely the uncertainties on: the luminosity determination (1.8%) [34], the lepton and trigger reconstruction and identification scale factors, the lepton charge mis-identification, the jet vertex fraction scale factor, the missing transverse momentum scale and resolution and the Z+jets and multi-jets background normalisations. All of these lead to uncertainties on the asymmetry measurements below 0.001 and are therefore negligible.

Systematic uncertainties related to the different choice of PDFs and to the shape of the W+jets distributions are also considered. The former is evaluated as explained above. The latter is estimated in simulated events generated with the same variations of the ALPGEN parameters as described above for the modelling of the signal process.

For each of the systematic uncertainties (except for those related to the modelling of the $t\bar{t}$ signal and for the W+jets shape) the W+jets normalisation and the heavy-flavour composition are recomputed as described in section 2.3 to take into account the correlation with the various sources of systematic uncertainty considered.

For the systematic uncertainties affecting the background, the posterior probability density with a modified background prediction is computed. For those affecting the signal, the posterior probability density with the modified efficiency and response matrix is evaluated.

Systematic uncertainties are taken into account with a marginalisation procedure. After computing the posterior probability density corresponding to each systematic variation,

$A_{\rm C}$	Data	Theory
Unfolded	0.006±0.010	0.0123±0.0005
Unfolded with $m_{t\bar{t}} > 600\,{\rm GeV}$	0.018±0.022	$0.0175^{+0.0005}_{-0.0004}$
Unfolded with $\beta_{z,t\bar{t}} > 0.6$	0.011±0.018	$0.020^{+0.006}_{-0.007}$

Table 2. Measured inclusive charge asymmetry, $A_{\rm C}$, values for the electron and muon channels combined after unfolding without and with the $\beta_{z,t\bar{t}} > 0.6$ cut explained in the text. The $A_{\rm C}$ measurement with a cut on the $t\bar{t}$ invariant mass $m_{t\bar{t}} > 600\,{\rm GeV}$ is also shown. SM predictions, as described in the text, are also reported. The quoted uncertainties include statistical and systematic components after the marginalisation.

the likelihood used in the unfolding is marginalised by integrating out its dependence on the nuisance parameters. It is assumed that the priors for all nuisance parameters are Gaussian and that there is no correlation between them. A marginalisation is then performed by transforming the integral over the nuisance parameter into a discrete sum of the posterior probability densities evaluated at three values of the nuisance parameter: the central one and the 1σ variations. The resulting posterior probability density is finally used to extract the systematic uncertainty on the measurements.

4 Results

4.1 Inclusive and differential measurements

The $t\bar{t}$ production charge asymmetry is measured to be $A_{\rm C} = 0.006 \pm 0.010$ compatible with the SM prediction $A_{\rm C} = 0.0123 \pm 0.0005$ [21]. These values are shown in table 2 together with the measurement and prediction for $m_{t\bar{t}} > 600$ GeV. The total systematic uncertainty is computed with the marginalisation procedure described in section 3.3. The uncertainties quoted for all the results in this section include statistical and systematic components. In order to estimate the impact of each source of systematic uncertainty, the marginalisation procedure is repeated removing one such source at a time from the global marginalisation. For each of the systematic uncertainties considered in this analysis and for all the measurements, the impact on the $A_{\rm C}$ value and its uncertainty is less than 10% of the statistical uncertainty, and thus negligible.

As a cross-check, the systematic uncertainties affecting $A_{\rm C}$ are computed one by one before the marginalisation procedure described above. For each source, the systematic uncertainty represents the variation of the mean of posterior probability densities corresponding to a 1σ variation of the nuisance parameter. The statistical uncertainty still dominates the variations in $A_{\rm C}$ even before the marginalisation procedure. Table 3 summarises the result of this 'cross-check' procedure for the inclusive charge asymmetry measurement (left column) and for the measurement with the $m_{t\bar{t}} > 600$ GeV requirement after unfolding (central column). Figure 2 shows the charge asymmetry as a function of $m_{t\bar{t}}$, $p_{{\rm T},t\bar{t}}$ and $|y_{t\bar{t}}|$ compared with the theoretical SM predictions described in ref. [21] and provided by its authors for the chosen bins. In addition, predictions for two assumed mass values (300 GeV [14] and 7000 GeV), for a heavy axigluon exchanged in the s-channel, are also shown.

Source of systematic uncertainty	δA_{C}		
	Inclusive	$m_{t\bar{t}} > 600$ GeV	$\beta_{z,t\bar{t}} > 0.6$
Lepton reconstruction/identification	< 0.001	0.001	< 0.001
Lepton energy scale and resolution	0.003	0.003	0.003
Jet energy scale and resolution	0.003	0.003	0.005
Missing transverse momentum and pile-up modelling	0.002	0.002	0.004
Multi-jets background normalisation	< 0.001	0.001	0.001
b-tagging/mis-tag efficiency	< 0.001	0.001	0.001
Signal modelling	< 0.001	< 0.001	< 0.001
Parton shower/hadronisation	< 0.001	< 0.001	< 0.001
Monte Carlo statistics	0.002	< 0.001	< 0.001
PDF	0.001	< 0.001	< 0.001
W+jets normalisation and shape	0.002	< 0.001	< 0.001
Statistical uncertainty	0.010	0.021	0.017

Table 3. Systematic uncertainties for the inclusive asymmetry, A_{C} (second column), the asymmetry for $m_{t\bar{t}} > 600$ GeV(third column) and the inclusive asymmetry, A_{C}, for $\beta_{z,t\bar{t}} > 0.6$ (fourth column). For variations resulting in asymmetric uncertainties, the average absolute deviation from the nominal value is reported. The values reported for each systematic uncertainty are the variation of the mean of posteriors computed considering 1σ variations.

The masses are chosen as benchmarks, taking into account the fact that they would not be visible as resonances in the $m_{t\bar{t}}$ spectrum. The parameters of the model are tuned to give a forward-backward asymmetry compatible with the Tevatron results. The differential distributions and respective asymmetries do not show any significant deviation from the SM prediction. The resulting charge asymmetry A_{C} is shown in table 4 for the differential measurements as a function of $m_{t\bar{t}}$, $p_{\mathrm{T},t\bar{t}}$ and $|y_{t\bar{t}}|$. The systematic uncertainties, computed before the marginalisation procedure as described above in the cross-check procedure, are listed in table 5 for each of the differential measurements. The correlation matrices for the statistical uncertainties are shown in table 6 for the measurement as a function of $m_{t\bar{t}}$, $p_{\mathrm{T},t\bar{t}}$ and $|y_{t\bar{t}}|$ respectively.

4.2 Measurements for $\beta_{z,t\bar{t}} > 0.6$

An additional requirement on the z-component of the $t\bar{t}$-system velocity $\beta_{z,t\bar{t}} > 0.6$ is applied, as explained in section 1, for the inclusive and the differential $\Delta|y|$ distribution as a function of $m_{t\bar{t}}$. It has been verified that resolution effects on the reconstructed $\beta_{z,t\bar{t}}$ did not introduce any bias in the measurement. Hence an unfolding of the $\beta_{z,t\bar{t}}$ distribution was found to be unnecessary. The inclusive asymmetry after this requirement is $A_{\mathrm{C}} = 0.011 \pm 0.018$, as reported in the last row of table 2, to be compared with the SM prediction $A_{\mathrm{C}}^{\mathrm{SM}} = 0.020^{+0.006}_{-0.007}$ [21]. Table 3 (right column) shows the list of systematic uncertainties affecting the measurement before the marginalisation procedure.

Figure 2 (bottom right plot) shows the differential A_{C} measurement as a function of $m_{t\bar{t}}$, while table 7 shows the value of A_{C} for the different bins, table 8 lists the systematic uncertainties affecting the measurement before the marginalisation and table 9 shows
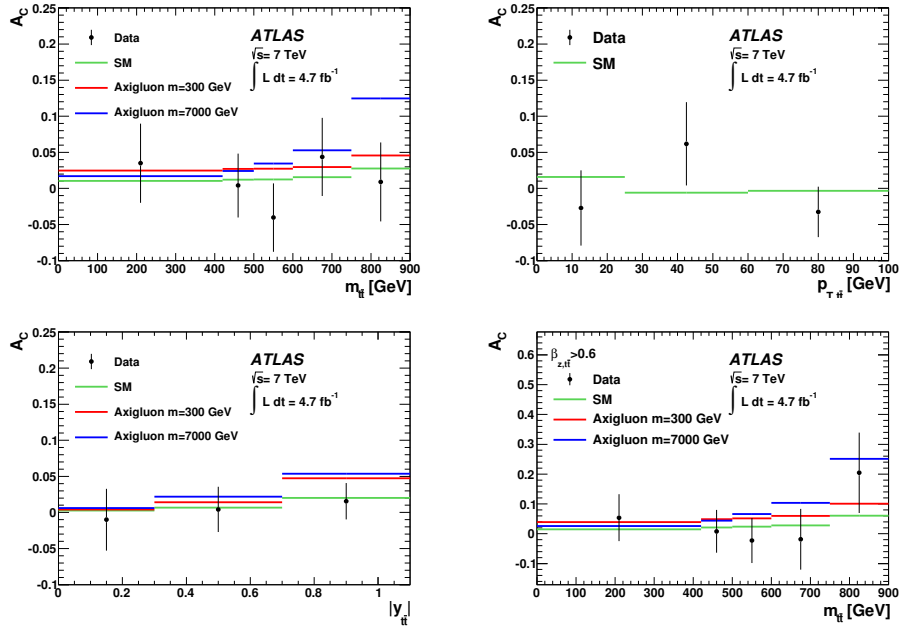
Figure 2. Distributions of A_C as a function of $m_{t\bar{t}}$ (top left), $p_{T,t\bar{t}}$ (top right) and $|y_{t\bar{t}}|$ (bottom left) after unfolding, for the electron and muon channels combined. The A_C distribution as a function of $m_{t\bar{t}}$, after the $\beta_{z,t\bar{t}} > 0.6$ requirement, is also shown (bottom right). The A_C values after the unfolding (points) are compared with the SM predictions (green lines) and the predictions for a colour-octet axigluon with a mass of 300 GeV (red lines) and 7000 GeV (blue lines) respectively, as described in the text. The thickness of the lines represents the factorisation and renormalisation scale uncertainties on the corresponding theoretical predictions. The values plotted are the average A_C in each bin. The error bars include both the statistical and the systematic uncertainties on A_C values. The bins are the same as the ones reported in tables 4 and 7 respectively.

the correlation coefficients among the different bins. These measurements do not deviate significantly from the SM expectations either.

4.3 Interpretation

Figure 3 shows the inclusive A_C measurements with and without the additional requirement on the invariant mass of the $t\bar{t}$-system $m_{t\bar{t}} > 600$ GeV described in section 4.1. In the left plot, the A_C measurement without the $m_{t\bar{t}} > 600$ GeV requirement is compared with the corresponding measurement from CMS [29] (horizontal lines) and with the $t\bar{t}$ forward-backward asymmetry A_{FB} measurements made at the Tevatron by CDF, $A_{FB} = 0.164 \pm 0.045$ [24], and D0, $A_{FB} = 0.196 \pm 0.065$ [26] (vertical lines). In the right plot, the A_C measurement with the requirement of $m_{t\bar{t}} > 600$ GeV, is compared with the A_{FB} measurement, with the requirement of $m_{t\bar{t}} > 450$ GeV, performed by the CDF experiment at the Tevatron [24].

Predictions given by several new physics models introduced to explain the larger than expected A_{FB} values measured at the Tevatron are also displayed. Details of these models can be found in refs. [8, 30, 60]. For each model, the predictions for A_{FB} and A_C are derived

	$m_{t\bar{t}}$ [GeV]				
A_C	0–420	420–500	500–600	600–750	> 750
Unfolded	0.036 ± 0.055	0.003 ± 0.044	-0.039 ± 0.047	0.044 ± 0.054	0.011 ± 0.054
Theory	$0.0103^{+0.0003}_{-0.0004}$	$0.0123^{+0.0006}_{-0.0003}$	0.0125 ± 0.0002	$0.0156^{+0.0007}_{-0.0009}$	$0.0276^{+0.0004}_{-0.0008}$

	$p_{\text{T},t\bar{t}}$ [GeV]		
A_C	0–25	25–60	> 60
Unfolded	-0.032 ± 0.052	0.067 ± 0.057	-0.034 ± 0.034
Theory	$0.0160^{+0.0007}_{-0.0009}$	$-0.0058^{+0.0004}_{-0.0004}$	$-0.0032^{+0.0002}_{-0.0002}$

	$|y_{t\bar{t}}|$		
A_C	0–0.3	0.3–0.7	> 0.7
Unfolded	-0.010 ± 0.043	0.006 ± 0.031	0.015 ± 0.025
Theory	$0.0026^{+0.0008}_{-0.0001}$	$0.0066^{+0.0001}_{-0.0003}$	$0.0202^{+0.0006}_{-0.0007}$

Table 4. Measured charge asymmetry, A_C, values for the electron and muon channels combined after unfolding as a function of the $t\bar{t}$ invariant mass, $m_{t\bar{t}}$ (top), the $t\bar{t}$ transverse momentum, $p_{\text{T},t\bar{t}}$ (middle) and the $t\bar{t}$ rapidity, $|y_{t\bar{t}}|$ (bottom). SM predictions, as described in the text, are also reported. The quoted uncertainties include statistical and systematic components after the marginalisation.

using the PROTOS generator [61] with the constraints described in ref. [30]. The ranges of predicted values for A_FB and A_C for a given new physics model are also shown. The new physics contributions are computed using the tree-level SM amplitude plus the one(s) from the new particle(s), to account for the interference between the two contributions. Some of these new physics models seem to be disfavoured by the current measurements.

5 Conclusion

This paper has presented a measurement of the $t\bar{t}$ production charge asymmetry measurement in $t\bar{t}$-events with a single lepton (electron or muon), at least four jets, of which at least one is tagged as a b-jet, and large missing transverse momentum, using an integrated luminosity of 4.7 fb^{-1} recorded by the ATLAS experiment in pp collisions at a centre-of-mass energy of $\sqrt{s} = 7$ TeV at the LHC. The inclusive $t\bar{t}$ production charge asymmetry A_C and its differential distributions, as a function of $m_{t\bar{t}}$, $p_{\text{T},t\bar{t}}$ and $|y_{t\bar{t}}|$, have been unfolded to parton-level. The measured inclusive $t\bar{t}$ production charge asymmetry is $A_\text{C} = 0.006 \pm 0.010$, to be compared with the SM prediction $A_\text{C}^\text{SM} = 0.0123 \pm 0.0005$. All measurements presented are statistically limited and are found to be compatible with the SM prediction within the uncertainties.

Acknowledgments

	$m_{t\bar{t}}$ [GeV]				
Source of systematic uncertainty	0–420	420–500	500–600	600–750	> 750
Lepton reconstruction/identification	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Lepton energy scale and resolution	0.017	0.014	0.013	0.007	< 0.005
Jet energy scale and resolution	0.014	0.007	0.035	0.032	0.017
Missing transverse momentum and pile-up modelling	0.013	0.017	0.018	0.008	0.005
Multi-jets background normalisation	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
b-tagging/mis-tag efficiency	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Signal modelling	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Parton shower/hadronisation	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Monte Carlo sample size	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
PDF	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
W+jets normalisation and shape	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Statistical uncertainty	0.054	0.042	0.046	0.052	0.054

	$p_{\mathrm{T},t\bar{t}}$ [GeV]		
Source of systematic uncertainty	0–25	25–60	> 60
Lepton reconstruction/identification	< 0.005	< 0.005	< 0.005
Lepton energy scale and resolution	0.011	0.013	0.006
Jet energy scale and resolution	0.009	0.020	0.020
Missing transverse momentum and pile-up modelling	0.017	0.010	< 0.005
Multi-jets background normalisation	< 0.005	< 0.005	< 0.005
b-tagging/mis-tag efficiency	< 0.005	< 0.005	< 0.005
Signal modelling	< 0.005	< 0.005	< 0.005
Parton shower/hadronisation	< 0.005	< 0.005	< 0.005
Monte Carlo sample size	< 0.005	< 0.005	< 0.005
PDF	< 0.005	< 0.005	< 0.005
W+jets normalisation and shape	< 0.005	< 0.005	< 0.005
Statistical uncertainty	0.052	0.057	0.034

	$|y_{t\bar{t}}|$		
Source of systematic uncertainty	0–0.3	0.3–0.7	> 0.7
Lepton reconstruction/identification	< 0.005	< 0.005	< 0.005
Lepton energy scale and resolution	0.022	0.014	0.008
Jet energy scale and resolution	0.013	0.007	< 0.005
Missing transverse momentum and pile-up modelling	< 0.005	0.006	< 0.005
Multi-jets background normalisation	< 0.005	< 0.005	< 0.005
b-tagging/mis-tag efficiency	< 0.005	< 0.005	< 0.005
Signal modelling	< 0.005	< 0.005	< 0.005
Parton shower/hadronisation	< 0.005	< 0.005	< 0.005
Monte Carlo sample size	< 0.005	< 0.005	< 0.005
PDF	< 0.005	< 0.005	< 0.005
W+jets normalisation and shape	< 0.005	< 0.005	< 0.005
Statistical uncertainty	0.042	0.030	0.025

Table 5. Systematic uncertainties for the charge asymmetry, A_{C}, measurement for the electron and muon channels combined after unfolding as a function of the $t\bar{t}$ invariant mass, $m_{t\bar{t}}$ (top), the $t\bar{t}$ transverse momentum, $p_{\mathrm{T},t\bar{t}}$ (middle) and the $t\bar{t}$ rapidity, $|y_{t\bar{t}}|$ (bottom). For variations resulting in asymmetric uncertainties, the average absolute deviation from the nominal value is reported. The values reported for each systematic uncertainty are the variation of the mean of posterior probability densities computed considering 1σ variations.

$\rho_{i,j}$	$m_{t\bar{t}}$ [GeV]				
	0–420	420–500	500–600	600–750	> 750
0–420	1	−0.38	0.13	−0.05	0.01
420–500		1	−0.53	0.17	−0.03
500–600			1	−0.54	0.14
600–750				1	−0.43
> 750					1

$\rho_{i,j}$	$p_{\mathrm{T},t\bar{t}}$ [GeV]		
	0–25	25–60	> 60
0–25	1	−0.79	0.36
25–60		1	−0.60
> 60			1

$\rho_{i,j}$	$|y_{t\bar{t}}|$		
	0–0.3	0.3–0.7	> 0.7
0–0.3	1	−0.33	0.05
0.3–0.7		1	−0.21
> 0.7			1

Table 6. Correlation coefficients $\rho_{i,j}$ for the statistical uncertainties between the i-th and j-th bin of the differential A_C measurement as a function of the $t\bar{t}$ invariant mass, $m_{t\bar{t}}$ (top), the transverse momentum, $p_{\mathrm{T},t\bar{t}}$ (middle) and the $t\bar{t}$ rapidity, $|y_{t\bar{t}}|$ (bottom).

A_C	$m_{t\bar{t}}$ [GeV] for $\beta_{z,t\bar{t}} > 0.6$				
	0–420	420–500	500–600	600–750	> 750
Unfolded	0.054 ± 0.079	0.008 ± 0.072	-0.022 ± 0.075	-0.019 ± 0.102	0.205 ± 0.135
Theory	$0.0145^{+0.0005}_{-0.0003}$	$0.0213^{+0.0006}_{-0.0005}$	$0.0240^{+0.0003}_{-0.0009}$	$0.0280^{+0.0012}_{-0.0007}$	0.0607 ± 0.0002

Table 7. Measured charge asymmetry, A_C, values for the electron and muon channels combined after unfolding as a function of the $t\bar{t}$ invariant mass, $m_{t\bar{t}}$, for $\beta_{z,t\bar{t}} > 0.6$. SM predictions, as described in the text, are also reported. The quoted uncertainties include statistical and systematic components after the marginalisation.

	$m_{t\bar{t}}$ [GeV] for $\beta_{z,t\bar{t}} > 0.6$				
Source of systematic uncertainty	0–420	420–500	500–600	600–750	> 750
Lepton reconstruction/identification	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Lepton energy scale and resolution	0.021	0.033	0.039	0.024	0.015
Jet energy scale and resolution	0.014	0.026	0.061	0.095	0.111
Missing transverse momentum and pile-up modelling	0.019	0.030	0.032	0.019	0.011
Multi-jets background normalisation	0.007	< 0.005	< 0.005	< 0.005	0.017
b-tagging/mis-tag efficiency	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Signal modelling	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Parton shower/hadronisation	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Monte Carlo sample size	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
PDF	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
W+jets normalisation and shape	< 0.005	< 0.005	< 0.005	< 0.005	0.010
Statistical uncertainty	0.078	0.070	0.074	0.098	0.131

Table 8. Systematic uncertainties for the charge asymmetry, A_C, measurement for the electron and muon channels combined after unfolding as a function of the $t\bar{t}$ invariant mass, $m_{t\bar{t}}$, for $\beta_{z,t\bar{t}} >$ 0.6. For variations resulting in asymmetric uncertainties, the average absolute deviation from the nominal value is reported. The values reported for each systematic uncertainty are the variation of the mean of posterior probability densities computed considering 1σ variations.

$\rho_{i,j}$	$m_{t\bar{t}}$ [GeV] for $\beta_{z,t\bar{t}} > 0.6$				
	0–420	420–500	500–600	600–750	> 750
0–420	1	−0.36	0.08	−0.01	0.01
420–500		1	−0.57	0.19	−0.04
500–600			1	−0.59	0.16
600–750				1	−0.50
> 750					1

Table 9. Correlation coefficients $\rho_{i,j}$ for the statistical uncertainties between the i-th and j-th bin of the differential A_C measurement as a function of the $t\bar{t}$ invariant mass, $m_{t\bar{t}}$, for $\beta_{z,t\bar{t}} > 0.6$.
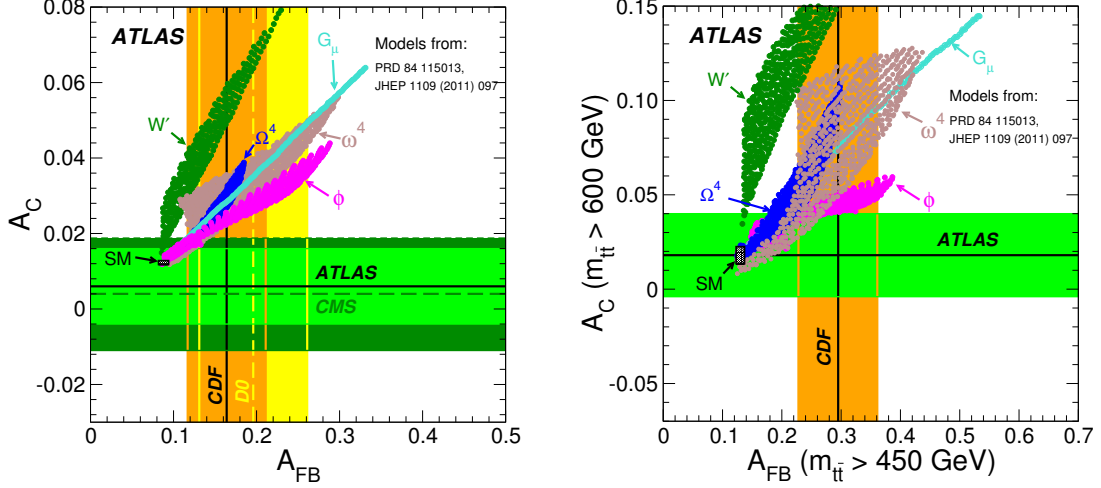
Figure 3. Measured forward-backward asymmetries A_{FB} at Tevatron and charge asymmetries A_C at LHC, compared with the SM predictions (black box) as well as predictions incorporating various potential new physics contributions (as described in the figure) [8, 60]. In both plots, where present, the horizontal bands and lines correspond to the ATLAS (light green) and CMS (dark green) measurements, while the vertical ones correspond to the CDF (orange) and D0 (yellow) measurements. The inclusive A_C measurements are reported in the left plot. In the right plot a comparison is reported between the A_{FB} measurement by CDF for $m_{t\bar{t}} > 450$ GeV and the A_C measurement for $m_{t\bar{t}} > 600$ GeV.

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