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TOP ANTI-TOP ASYMMETRIES AT THE TEVATRON AND THE LHC

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ON BEHALF OF THE ATLAS, CDF, CMS AND D0 COLLABORATIONS

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The heaviest known elementary particle today, the top quark, has been discovered in 1995 by the CDF and D0 collaborations at the Tevatron proton antiproton collider at Fermilab. Recently, the CDF and D0 collaborations have studied the forward-backward asymmetry in $t\bar{t}$ events, resulting in measured values larger than the standard model prediction. With the start of the LHC at CERN in 2010, a new top quark factory has opened and asymmetry measurements in $t\bar{t}$ have also been performed in a proton proton environment with higher collision energy. No deviations from the standard model have been noticed so far in the measurements of ATLAS and CMS. This article discusses recent results of asymmetry measurements in $t\bar{t}$ events of the ATLAS, CDF, CMS and D0 collaborations.

1 Introduction

The top quark was discovered in 1995 in proton anti-proton collisions at a centre-of-mass energy of 1.8 TeV by the CDF and D0 collaborations at the Tevatron [1,2], and is the heaviest known elementary particle today. Due to its high mass of $m_t = 173.18 \pm 0.94$ GeV [3] and its short lifetime, the top quark is believed to play a special role in electroweak symmetry breaking, serves as a window to physics beyond the standard model (SM), and provides a unique environment to study a bare quark.

As of today, two colliders with high enough energy exist or did exist where top quarks can be produced. Top quarks are produced at the Tevatron $p\bar{p}$ collider with a centre-of-mass energy of 1.96 TeV, that operated until September 30th 2011, and at the Large Hadron Collider (LHC) at CERN, colliding protons on protons with centre-of-mass energies of 7 TeV (2011 data) and 8 TeV (2012 data). Due to the high centre-of-mass energy, the top antitop quark pair ($t\bar{t}$) production cross section at LHC is approximately 20 times larger than at the Tevatron [4]. Furthermore, the main $t\bar{t}$ production process is via gluon-gluon fusion at the LHC.

In this article, analyses of $t\bar{t}$ asymmetries are presented as performed by the CDF and D0 experiments at the Tevatron at Fermilab and the ATLAS [5] and CMS [6] experiments at the LHC at CERN. The results are based on up to 8.7 fb^{-1} of $p\bar{p}$ collision data for the Tevatron experiments and up to 5.0 fb^{-1} of pp collision data taken during the 7 TeV run of the LHC experiments in 2011. The results were obtained in the dileptonic and in the lepton plus jets $t\bar{t}$ final state (ℓ +jets). Details about the $t\bar{t}$ production and the classification into different channels are given in Ref. [4]. While at the Tevatron $t\bar{t}$ asymmetries larger than the SM predictions

have been observed, the measured values and the theory predictions of the charge asymmetry at the LHC are in good agreement so far. In addition to the inclusive asymmetries, the $t\bar{t}$ asymmetries have been studied as function of several variables, showing an enhanced dependency at the Tevatron compared to the SM prediction. Details about the individual results at Tevatron and LHC are provided in the following sections.

2 Asymmetry Definitions

At leading order (LO) quantum chromodynamics (QCD), the production of $t\bar{t}$ events is forward-backward symmetric in quark antiquark annihilation processes. However, at higher order calculations, interferences between different diagrams cause a preferred direction of the top quark and the antitop quark and thus an asymmetry. In particular, at next to leading order (NLO) QCD, the leading contribution to the asymmetry arises from the interference between tree-level and box diagrams, resulting in a positive asymmetry with the top quark preferentially being emitted in the direction of the incoming quark. In addition to the dominant contributions from quark antiquark annihilation, the process with a quark and a gluon in the initial state also contributes to the $t\bar{t}$ asymmetry.

At the Tevatron, which is a $p\bar{p}$ collider, the $t\bar{t}$ production is dominated by the interaction of a valence quark and a valence antiquark. Therefore, the quark direction can be assumed to coincide with the direction of the incoming proton, and the antiquark direction with the incoming antiproton. The forward backward asymmetry can be defined in terms of the difference between the rapidity of the top and antitop quarks, $\Delta y = y_t - y_{\bar{t}}$, as

$$A_{fb}^{t\bar{t}} = [N(\Delta y > 0) - N(\Delta y < 0)]/[N(\Delta y > 0) + N(\Delta y < 0)], \quad (1)$$

where $N(\Delta y > 0)$ and $N(\Delta y < 0)$ are the number of events with rapidity difference larger and smaller zero, respectively.

At the LHC, which is a pp collider, the measurement of the asymmetry is more challenging for two reasons. Firstly, at $\sqrt{s} = 7$ TeV, the $t\bar{t}$ production is dominated by gluon-gluon fusion, which contributes about 85% to the total $t\bar{t}$ production cross-section. The gluon-gluon fusion process does not contribute to the $t\bar{t}$ asymmetry. Secondly, the direction of the incoming quark is not known due to the collision of two protons. The asymmetry definition used for the measurements performed by the ATLAS and CMS collaborations relies on the fact that $t\bar{t}$ production via $q\bar{q}$ annihilation is dominated by valence quarks, which carry a large momentum fraction, and antiquarks from the sea, having a smaller momentum fraction on average. An asymmetry, where the top quark is preferentially emitted into the direction of the incoming quark thus results in a wider rapidity distribution for the top quarks compared to the antitop quarks. The asymmetry measurements at ATLAS and CMS are therefore performed using the charge asymmetry

$$A_C = [N(\Delta|y| > 0) - N(\Delta|y| < 0)]/[N(\Delta|y| > 0) + N(\Delta|y| < 0)], \quad (2)$$

where $\Delta|y|$ is the difference of the absolute rapidity of the top and antitop quark.

In addition to these definitions, the asymmetry can also be extracted using the rapidity of the leptons only, the rapidity difference of the leptons or the difference in number of events with rapidity of the lepton different from the antilepton,

$$A_{fb}^l = [N(q_l y_l > 0) - N(q_l y_l < 0)] / [N(q_l y_l > 0) + N(q_l y_l < 0)] \quad (3)$$

$$A_{fb}^u = [N(\Delta\eta > 0) - N(\Delta\eta < 0)] / [N(\Delta\eta > 0) + N(\Delta\eta < 0)] \quad (4)$$

$$A_{fb}^{CP} = [N_{l^+}(\eta > 0) - N_{l^-}(\eta < 0)] / [N_{l^+}(\eta > 0) + N_{l^-}(\eta < 0)] \quad (5)$$

$$A_C^u = [N(\Delta|\eta| > 0) - N(\Delta|\eta| < 0)] / [N(\Delta|\eta| > 0) + N(\Delta|\eta| < 0)], \quad (6)$$

where q_l is the charge of the lepton and y_l is the rapidity of the lepton and $\Delta\eta$ is the pseudo-rapidity difference of the lepton and antilepton. $N_{l^+}(\eta > 0)$ and $N_{l^-}(\eta < 0)$ are the number of events with the antilepton having positive pseudorapidity and the lepton negative pseudorapidity, respectively. The advantage of the asymmetry measurements which use leptons is that the complete reconstruction of the $t\bar{t}$ system is not necessary. Furthermore, the leptonic asymmetry provides additional information with respect to the forward-backward asymmetry, since it is sensitive to polarization effects.

3 $t\bar{t}$ Asymmetries at the Tevatron

The first time the $t\bar{t}$ forward-backward asymmetry has been measured was by the CDF and D0 collaborations [16,17], where both measure values larger than the SM prediction. In this section, a short overview over SM calculations of the $t\bar{t}$ asymmetry is given, followed by recent results from the CDF and D0 experiments are discussed.

3.1 Theoretical Predictions

The $t\bar{t}$ asymmetry is zero at LO QCD, but larger than zero in NLO QCD calculations. Therefore, any theoretical NLO QCD $t\bar{t}$ calculation only yields a LO calculation of the $t\bar{t}$ forward-backward asymmetry. Besides NLO QCD calculations, several calculations have been performed that include additional effects or higher order diagrams for the $t\bar{t}$ asymmetry at the Tevatron. At NLO QCD, the $t\bar{t}$ forward-backward asymmetry is predicted to be $A_{fb}^{t\bar{t}} = 7.32_{-0.59}^{+0.69} \text{ }_{-0.16}^{+0.18}\%$ [7,8], where the uncertainties include uncertainties due to factorization and renormalization scale variations as well as uncertainties on the choice of parton distribution function (PDF). Calculations including next-to-next-to-leading-logarithmic (NNLL) contributions (NLO+NNLL) [9] or calculations at approximate next-to-next-to-leading order (NNLO_{approx}) [10] have been performed, finding $A_{fb}^{t\bar{t}} = 7.24_{-0.67}^{+1.04} \text{ }_{-0.27}^{+0.20}\%$ for the NLO+NNLL calculation [9]. Additionally, calculations including effects due to electroweak and mixed QCD electroweak corrections have been performed. For example including contributions from $b\bar{b} \rightarrow t\bar{t}$ diagrams [12], changing the asymmetry by a relative amount of 5% with respect to the NLO QCD calculation, or including effects from photonic corrections [13], which enhances the asymmetry by a relative amount of 22% compared to the NLO QCD calculation. A recent calculation including electroweak and mixed QCD and electroweak corrections as well as using

a NLO PDF in the denominator of the expansion in α and α_S yields an asymmetry of $A_{fb}^{t\bar{t}} = 8.8 \pm 0.6\%$ [14]. In a similar calculation performed recently, similar effects have been observed [15]. A more detailed overview over theoretical predictions of the $t\bar{t}$ asymmetry and the included corrections can be found for example in Ref. [8]. Even though there are arguments that the asymmetry value should not change much at higher order calculations, there are no calculations at full NNLO QCD available as of today. The different calculations presented here show an enhancement of the $t\bar{t}$ asymmetry of about 20% or more when including additional corrections with respect to the NLO QCD calculation. When comparing the experimentally measured asymmetry value to the theoretical prediction, this can have a sizeable effect on the deviation of the measurement and the theoretical prediction.

3.2 Asymmetry Measurements

The CDF and D0 collaborations have performed $t\bar{t}$ asymmetry measurements in the ℓ +jets and dilepton final states. These analyses require one or both of the W bosons from the top quark to decay leptonically. In the ℓ +jets final state, exactly one isolated, high p_T electron or muon, large missing transverse energy (\cancel{E}_T) due to the undetected neutrino from the W boson decay, and four or more jets with large transverse momentum p_T are required. The main background contributions in the ℓ +jets final state consist of W +jets production and instrumental background due to QCD-multijet events in which jets are misidentified as leptons. Additional selection cuts were introduced to reduce the instrumental background, as for example on the azimuthal angle between the lepton momentum and the direction of the missing transverse energy. At least one of the jets is required to be identified as a b -jet to enhance the purity of the sample. The signature in the dilepton final state consists of two isolated, high- p_T leptons (ee , $e\mu$ or $\mu\mu$), at least two high p_T jets and large \cancel{E}_T from the two neutrinos.

In order to measure the forward-backward $t\bar{t}$ asymmetry, the reconstruction of the full $t\bar{t}$ event is required. A kinematic fitter was used for this purpose, which include constraints from the known W boson mass and top quark mass to extract the missing information about the neutrino momentum and obtain the jet combinations matching the top and the antitop quarks. The CDF collaboration also extract $A_{fb}^{t\bar{t}}$ in the dilepton final state, necessitating the full $t\bar{t}$ reconstruction of the dileptonic events. For this purpose, an algorithm was used, which compares calculated longitudinal and transverse momenta of the $t\bar{t}$ system as well as the invariant $t\bar{t}$ mass to probability distribution functions of these variables based on standard model expectations. The most likely solution was then chosen using a likelihood function based on these probability density functions.

In the ℓ +jets final state, the background determination in the analysis performed by D0 was carried out by fitting a topological likelihood function, based on variables that are uncorrelated to Δy . In the analysis performed by the CDF collaboration, the background was estimated using data-driven methods in samples orthogonal to the signal sample and using Monte Carlo (MC) predictions. From the signal samples, the distributions of the lepton rapidity and Δy were extracted

and the background distributions were subtracted from the data. Up to this step in the analysis chain, the extraction of the rapidity and Δy distributions is mostly independent of the modelling of the signal. Due to acceptance effects and detector resolutions, the asymmetry results extracted from these distributions can not be compared to theoretical predictions or between the experiments. In order to correct for these effects, both CDF and D0 apply unfolding techniques on the rapidity or Δy distributions. In the analysis performed by the CDF collaboration a 4×4 matrix inversion is applied on the Δy distribution, while at D0 regularized unfolding has been used.

After unfolding, an inclusive asymmetry of $A_{fb}^{t\bar{t}} = 16.2 \pm 4.2\%$ has been extracted by CDF using 8.7 fb^{-1} of Tevatron Run II data [18], and $A_{fb}^{t\bar{t}} = 19.6 \pm 6.5\%$ by D0 using 5.4 fb^{-1} of data [19], where both results are limited by statistical uncertainties. Comparing these results to a NLO prediction obtained by using MC, corrected for electroweak and QCD effects, of $A_{fb}^{t\bar{t}} = 6.6\%$ [18] implies that both measurements are about two standard deviations higher than the SM value. Both CDF and D0 performed several studies on potential influences from signal or background modelling on the measurement, as for example checking the modelling of the asymmetry in W +jets events using events with no identified b -jets or checking the dependence of the asymmetry in the MC simulation on the transverse momentum of the $t\bar{t}$ system, $p_T^{t\bar{t}}$. The latter study showed that colour coherence effects in the MC simulation can introduce an asymmetry depending on $p_T^{t\bar{t}}$ even in LO MC. This effect is included in the systematic uncertainties.

Besides the measurement of $A_{fb}^{t\bar{t}}$, the lepton-based asymmetry A_{fb}^l has been extracted by both collaborations in the ℓ +jets final state. Since the resolution of the lepton rapidity is very good, the unfolding in this measurement is much simpler than what is needed for $A_{fb}^{t\bar{t}}$, and no reconstruction of the $t\bar{t}$ system is required. Using 5.4 fb^{-1} , D0 extracts $A_{fb}^l = 14.2 \pm 3.8\%$ with $|y_\ell| < 1.5$, and CDF measures $A_{fb}^l = 6.6 \pm 2.5\%$ using 8.7 fb^{-1} . The D0 collaboration compared this measurement to the prediction using MC@NLO MC [11], which yields $A_{fb}^l = 0.8\%$. Therefore, the measurement is more than three standard deviations higher than this prediction. The CDF collaboration compared their result to a NLO prediction including electroweak and QCD effects, $A_{fb}^l = 1.6\%$ [14].

The asymmetry is expected to depend on several variables, as for example on the invariant $t\bar{t}$ mass, $m_{t\bar{t}}$, the rapidity y_t and $p_T^{t\bar{t}}$. For example, a dependency of the $t\bar{t}$ asymmetry on $m_{t\bar{t}}$ is expected, since the relative fraction of $t\bar{t}$ production due to quark antiquark annihilation is enhanced with increasing $m_{t\bar{t}}$. Besides the inclusive measurements, both collaborations also measured the asymmetry as a function of $m_{t\bar{t}}$ and Δy . Both collaborations noted a stronger dependency of $A_{fb}^{t\bar{t}}$ on Δy and $m_{t\bar{t}}$ than predicted by the SM. In particular, the asymmetry measured by CDF for $m_{t\bar{t}} > 450 \text{ GeV}$ deviates from the prediction by more than two standard deviations. In Fig. 1 the parton-level asymmetry as function of $m_{t\bar{t}}$ (left) and Δy (right) are shown when using four bins in $m_{t\bar{t}}$ or Δy . Very recently, the CDF collaboration updated their measurement in the ℓ +jets final state to the full Tevatron Run II data set of 9.4 fb^{-1} [20].

In the dilepton final state, several asymmetries have been explored by the two

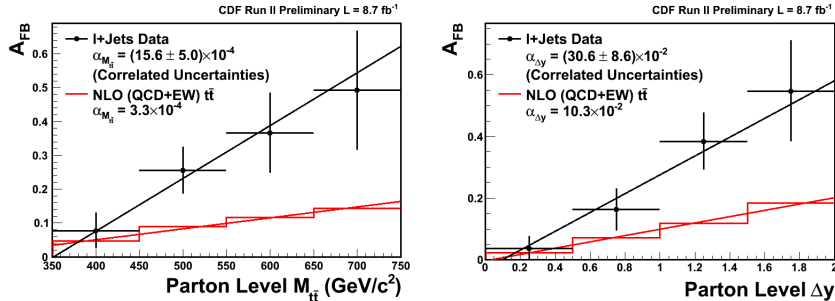


Figure 1. Parton level $A_{fb}^{t\bar{t}}$ as function of $m_{t\bar{t}}$ (left) and Δy (right) as extracted by the CDF collaboration in the full Run II data set. The best-fit line is superimposed [18].

collaborations. The CDF collaboration extracts $A_{fb}^{t\bar{t}}$ and A_{fb}^l , while the analysis performed by the D0 collaboration concentrates on lepton-based asymmetries, namely A_{fb}^l , A_{fb}^l , and A_{fb}^{CP} . Using 5.1 fb^{-1} of data, CDF measures $A_{fb}^{t\bar{t}} = 42 \pm 16\%$, with a prediction of $6 \pm 1\%$ [21], and $A_{fb}^l = 14 \pm 5\%$, where the latter result is without corrections for acceptance or resolution effects. The results extracted by D0 are based on 5.4 fb^{-1} of Run II data [22], yielding $A_{fb}^l = 5.8 \pm 5.3\%$ with a prediction of $4.7 \pm 0.1\%$, $A_{fb}^l = 5.3 \pm 8.4\%$ comparable to a prediction of $6.2 \pm 0.2\%$, and $A_{fb}^{CP} = -1.8 \pm 5.3\%$ with a prediction of $-0.3 \pm 0.1\%$. The results from D0 are after corrections for acceptance and resolution effects. In addition, D0 performed a combination of the A_{fb}^l measurement in the ℓ +jets and dilepton final state, yielding $A_{fb}^l = 11.8 \pm 3.2\%$ [22].

Since the measurements of the $t\bar{t}$ asymmetry performed by CDF and D0 show a deviation from the SM prediction of two standard deviations and more, a large interest arose in the theory community, resulting in an influx of models beyond the SM that could explain the large positive asymmetries. For an overview of many of these models, see for example Ref. [23]. Most of these models already have to fulfill several constraints based on existing top quark production and properties measurements. For example, the models are constrained by the observed $t\bar{t}$ production cross-section, and no significant same-sign top quark pair production should be introduced since tight limits have been set in direct searches. In order to distinguish between the models, additional measurements have to be performed. One such measurement is the study of top quark polarization, defined by

$$\frac{1}{\Gamma} \frac{d\Gamma}{d \cos \theta_{i,n}} = \frac{1}{2} (1 + P_n \kappa_i \cos \theta_{i,n}) \quad (7)$$

where Γ is the decay width, P_n is the polarization, κ_i is the spin analysing power of the decay product i and $\theta_{i,n}$ is the angle of the decay product i with respect to a chosen quantization axis [24,25]. In the SM, the top-quark polarization at hadron colliders is negligible. Many of the models predicting a positive $t\bar{t}$ asymmetry also predict a top quark polarization significantly different from zero, for example due to a new parity-violating interaction that affects the $t\bar{t}$ production and leads to

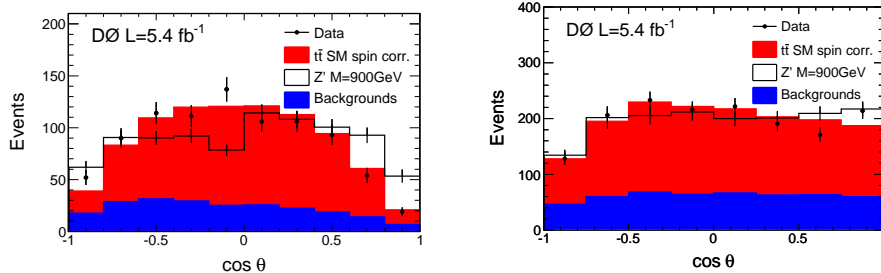


Figure 2. The distribution of $\cos\theta$ is shown for the combination of the dilepton channels (left) and the ℓ +jets channels (right). The data are compared to the SM predictions and to a model including a hypothetical Z' boson is used [22].

a longitudinal polarization of the top quark. The D0 collaboration performed the first study of the top quark polarization in the dilepton and ℓ +jets final state, using 5.4 fb^{-1} of data [22]. The required reconstruction of the $t\bar{t}$ system in the dilepton final state has been performed using the neutrino weighting technique. The $\cos\theta$ distribution is constructed using the charged leptons, as their spin analysing power is one at LO. As quantization axis the helicity basis is used. Figure 2 shows the distribution of $\cos\theta$ for the dilepton (left) and ℓ +jets (right) final state, compared to the SM prediction and a hypothetical Z' boson [26]. The agreement between the SM predictions and the data is good for both channels.

4 $t\bar{t}$ Asymmetries at the LHC

The ATLAS and CMS collaborations have performed several asymmetry measurements in the ℓ +jets and the dilepton final state. In particular, the ATLAS collaboration has extracted a result for A_C inclusively and as function of $m_{t\bar{t}}$ in the ℓ +jets final state using 1.04 fb^{-1} of pp collision data with 7 TeV centre-of-mass energy [27], and has measured A_C and $A_C^{\ell\ell}$ in the dilepton final state using the full 7 TeV data set of 4.7 fb^{-1} [28]. The CMS collaboration has measured A_C in the ℓ +jets final state using the full 7 TeV data sample of 5.0 fb^{-1} , where the asymmetry has been measured as function of $m_{t\bar{t}}$, the rapidity of the top and $p_T^{t\bar{t}}$ and inclusively [29].

The principle of the asymmetry measurements is similar to that for the measurements at the Tevatron: After selecting a signal sample [4], the $t\bar{t}$ final state is reconstructed and the distribution of the absolute rapidity of the top and the antitop quarks are measured. The $t\bar{t}$ reconstruction is carried out using a kinematic fitter. For the $A_C^{\ell\ell}$ measurement, the reconstruction of the $t\bar{t}$ system is not necessary, and the distribution of pseudorapidity of the two leptons is studied instead. To correct for acceptance and detector effects, unfolding of the distribution is performed.

In the ℓ +jets final state, the $\Delta|y|$ distributions are unfolded using iterative Bayesian unfolding by ATLAS, while the CMS collaboration used a regularized unfolding technique. The ATLAS collaboration extracts a value of $A_C =$

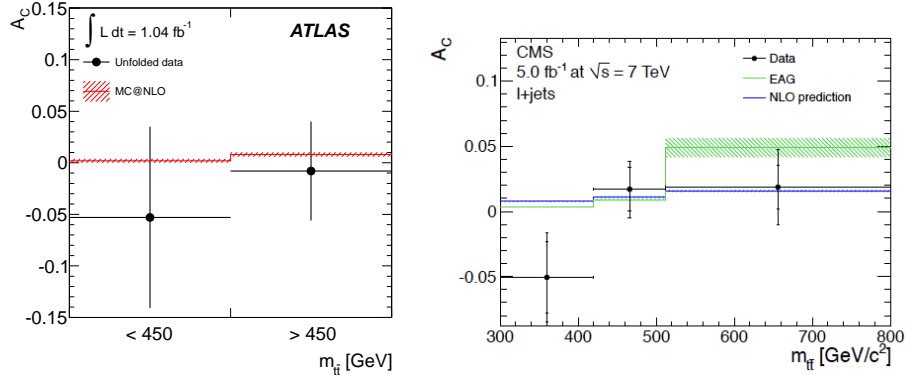


Figure 3. Parton level A_C as function of $m_{t\bar{t}}$ as extracted by the ATLAS (left) [27] and CMS (right) [29] collaborations.

$-1.9 \pm 2.8(\text{stat}) \pm 2.4(\text{syst})\%$ in the 1.04 fb^{-1} data sample, while the prediction with MC@NLO is $A_C = 0.6 \pm 0.2\%$. The value extracted by the CMS collaboration is $A_C = 0.4 \pm 1.0(\text{stat}) \pm 1.1(\text{syst})\%$ on 5.0 fb^{-1} of data. For both measurements, the systematic uncertainties are comparable in size to the statistical uncertainties. The dominant systematic uncertainties are related to the modelling of $t\bar{t}$ events, to the uncertainty on the jet energy scale, and to the unfolding method. Within the uncertainties, the measured asymmetries are in good agreement with the SM prediction. The challenge for forthcoming measurements will be especially the reduction of the systematic uncertainties.

Besides the inclusive A_C measurement, both collaborations also studied the dependency on several variables. While the fraction of $t\bar{t}$ production via $q\bar{q}$ annihilation increases with larger $m_{t\bar{t}}$, the $p_T^{t\bar{t}}$ distribution is sensitive to the ratio of negative and positive contributions to the asymmetry. The dependency of the asymmetry on the rapidity is caused by the effect that gluon-gluon fusion is more dominant in the central rapidity region, while the $q\bar{q}$ annihilation contributes more to the forward rapidity region. The ATLAS collaboration studied the asymmetry A_C as function of $m_{t\bar{t}}$, while CMS measured the asymmetry dependence on $m_{t\bar{t}}$, rapidity and $p_T^{t\bar{t}}$. Within the uncertainties, no significant dependency of A_C on any of the variables under study could be noticed. CMS also compared the data with a model featuring an effective axial-vector coupling of the gluon. Figure 3 shows the asymmetry A_C as function of $m_{t\bar{t}}$ as measured by the ATLAS (left) and CMS (right) collaborations.

The ATLAS collaboration has performed a measurement of A_C and A_C^l in the dilepton final state, using 4.7 fb^{-1} of 7 TeV data. For the A_C^l measurement, the pseudorapidity of the two leptons are used. The reconstruction of the $t\bar{t}$ system was performed using a matrix element based reconstruction technique. The correction for detector and acceptance effects was performed by using a calibration curve. The details of this analysis can be found in Ref. [30]. The extracted inclusive dileptonic asymmetry is $A_C^l = 2.3 \pm 1.2(\text{stat}) \pm 0.8(\text{syst})\%$, which are compared to a SM

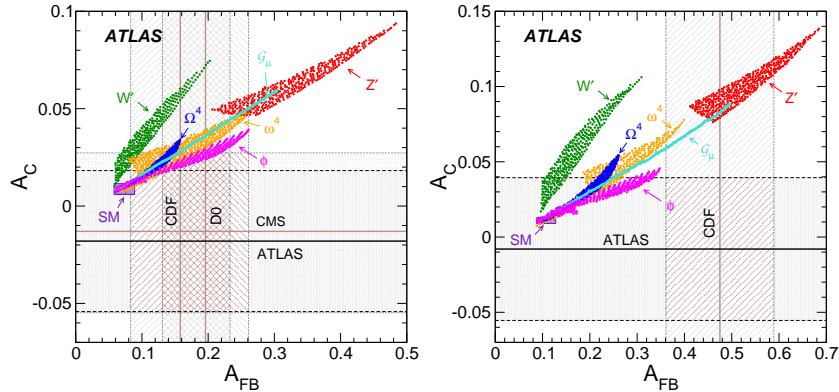


Figure 4. Measured $A_{fb}^{t\bar{t}}$ (A_{FB} in the figures) from the Tevatron and charge asymmetries A_C from the LHC, compared to predictions from the SM and predictions for various potential new physics models [34]. The horizontal (vertical) bands and lines correspond to the ATLAS and CMS (CDF and D0) measurements. Left: inclusive asymmetry measurements. Right: Asymmetry measurements for $m_{t\bar{t}} > 450$ GeV [27].

prediction from MC@NLO of $A_C^{\ell\ell} = 0.4 \pm 0.1\%$ [28]. The charge asymmetry comes out at $A_C = 5.7 \pm 2.4(\text{stat}) \pm 1.5(\text{syst})\%$. Both results are in good agreement with the SM prediction within the uncertainties. The ATLAS collaboration performed a combination of the A_C measurement in the ℓ +jets and dilepton final states, resulting in $A_C = 2.9 \pm 1.8(\text{stat}) \pm 1.4(\text{syst})\%$, which is in good agreement with the SM prediction.

The ATLAS and CMS collaborations also studied the top quark polarization [31,32], both measuring a value compatible with the SM prediction. Details about these studies can be found in Ref. [33].

5 $t\bar{t}$ Asymmetries at the Tevatron and LHC

While the $t\bar{t}$ asymmetries measured at the Tevatron show a deviation with respect to the SM towards more positive values, the measurements performed by the ATLAS and CMS collaboration of the charge asymmetries come out to be compatible with the SM. For several models beyond the SM, the behaviour of $A_{fb}^{t\bar{t}}$ at the Tevatron can be different than A_C at the LHC, depending, for example, on the production process of the model under consideration. In Fig. 4, the measured asymmetries $A_{fb}^{t\bar{t}}$ from the Tevatron are plotted versus the charge asymmetry A_C measured at the LHC [27]. The measurements are compared to the prediction from the SM and various models beyond the SM that could explain a positive asymmetry as measured at the Tevatron. With this comparison, several of the models are disfavoured for most of their potential parameters [34]. For example, using the inclusive measurement, the Z' model is in tension with the measurements, while the asymmetries for large $m_{t\bar{t}}$ show a tension for several other models between their prediction and the measurements.

6 Conclusion and Outlook

The large positive asymmetries as measured by the CDF and D0 collaboration are one of the most interesting results in the top quark sector today. While the great performance of the LHC provided a huge amount of $t\bar{t}$ events, the asymmetry measurement is more challenging at the LHC than at the Tevatron, resulting in large uncertainties on the charge asymmetries measured by ATLAS and CMS compared to the small SM prediction. With yet more data to be collected at ATLAS and CMS within the next years and the progress on understanding the systematic uncertainties, it will stay interesting to see whether a deviation of the SM prediction also will show up at the LHC experiments.

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