Leptonic asymmetry in tt̄ production at CDF

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Abstract. The leptonic asymmetry in semileptonic tt̄ decays is measured with the CDF detector using the full Tevatron Run II dataset, which corresponds to 9.4 fb^{-1} of integrated luminosity. The measured asymmetry is extrapolated to the full kinematic range and the measured value of $A_{FB}^{lep} = 0.094_{-0.029}^{+0.032}$ is compared to the NLO prediction $A_{FB}^{lep} = 0.038 \pm 0.003$.

1 Introduction

The CDF and D0 experiments have measured the forward-backward asymmetry A_{FB} for tt̄ production in pp̄ collisions [1, 2], the CDF measurement reports $A_{FB} = 0.164 \pm 0.045$, the D0 measurement $A_{FB} = 0.196 \pm 0.065$. Both results are higher than the prediction $A_{FB} = 0.088 \pm 0.006$ [3], which includes both electroweak and QCD next-to-leading order (NLO) corrections. Much effort has been invested to improve the theoretical calculation of the asymmetry in the Standard Model, through the estimation of beyond NLO corrections and related uncertainties. Soft gluon resummation was found to give a negligible contribution [4], electroweak corrections are of the order of 25% and are included in the current predictions [3, 5], a calculation based on the Principle of Maximum Conformality (PMC) for the scale setting reports a 40% enhancement, and finally a more realistic estimate of scale uncertainties at NLO of the order 30% should be considered [3, 6, 7].

The leptonic asymmetry, defined as

$$A_{FB}^{lep} = \frac{N(qy_l > 0) - N(qy_l < 0)}{N(qy_l > 0) + N(qy_l < 0)} \tag{1}$$

where q is the lepton charge and y_l the lepton rapidity in the laboratory frame, is an observable related to A_{FB} which can provide complementary information. The measurement of A_{FB}^{lep} depends only on lepton charge and direction, and therefore can be measured very precisely. The D0 experiment reported measurements of the leptonic asymmetry in tt̄ production both in the semileptonic and in the dilepton channels with about half of the full Tevatron Run II dataset, the combined result is $A_{FB}^{lep} = 0.118 \pm 0.032$ [8].

There are two physical origins of leptonic asymmetry A_{FB}^{lep}, the A_{FB} asymmetry, and the polarisation of the tt̄ system. Leptons partially inherit the asymmetry of the parent tops, and in addition the V-A coupling of the weak interaction connects the direction of the top decay products to the polarisation of the top quarks. Top pairs are produced unpolarised in the Standard Model, an excess of right handed top pairs would enhance A_{FB}^{lep}, while left-handed pairs would induce a negative contribution.

The relationship between the top asymmetry, the tt̄ polarisation and the leptonic asymmetry has been the subject of recent theoretical work in the context of possible explanations of the top asymmetry A_{FB} [9, 10].

2 Physics models and expected asymmetry

In the measurement of A_{FB}^{lep} several reference models and corresponding Monte Carlo samples are used, they are listed in table 1.

All the Monte Carlo samples are showered with PYTHIA [11] and processed with the full CDF detector simulation. ALPGEN [12] is a LO matrix-element matched to PS generator which predicts no asymmetry, POWHEG [13] is a NLO generator which predicts a small asymmetry, OCTET A, L and R are axigluon models simulated with MADGRAPH [14] which predict A_{FB} comparable to the measured values, but different tt̄ polarisation and different values of A_{FB}^{lep}. The two polarised models, Octet L and Octet R, are light (200 GeV/c^2) and wide (50 GeV/c^2) axigluons. Octet L has a left-handed coupling and negative polarisation, while Octet R has a right-handed coupling and positive polarisation. Octet A is a massive (2.0 TeV/c^2) and narrow axigluon with unpolarised couplings.

A Standard Model NLO QCD fixed order calculation of A_{FB}^{lep} including electroweak corrections reports 0.038 ± 0.003 [3]. When comparing the NLO fixed order result to the prediction from a NLO generator interfaced to parton shower, and important difference has to be considered. The first non trivial orders for the numerator and denominator of equation (1) are respectively $O(\alpha_s^3)$ and $O(\alpha_s^2)$, for this reason in the fixed order calculation the $O(\alpha_s^2)$ result of the inclusive tt̄ cross section is used in the denominator of the A_{FB}^{lep} asymmetry. In a NLO Monte Carlo generator like POWHEG, both numerator and denominator of equa-

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Table 1. Reference models used for the A_{FB}^{lep} measurement.

Model	A_{FB}	A_{FB}^{lep}	Polarisation	
ALPGEN	0.000(1)	+0.003(1)	+0.009(2)	LO Standard Model
POWHEG	0.052(0)	+0.024(1)	+0.001(1)	NLO Standard Model
OCTET A	+0.156(1)	+0.070(2)	-0.005(3)	unpolarised axigluon
OCTET L	+0.121(1)	-0.062(1)	-0.290(3)	left-handed axigluon
OCTET R	+0.114(2)	+0.149(2)	+0.280(3)	right-handed axigluon

tion (1) are computed at the same $O(\alpha_s^3)$ order, which leads to a sizeable difference with respect to the fixed order result. The POWHEG prediction also does not include the electroweak corrections, which enhance A_{FB}^{lep} of 26%.

A data-driven estimation of A_{FB}^{lep} within the Standard Model can be done dividing the A_{FB} measured at CDF by the ratio $\frac{A_{FB}}{A_{FB}^{lep}} = 2.17$ as predicted by POWHEG. With this assumption the expected A_{FB}^{lep} is 0.076

3 Event selection ad sample composition

The full CDF Run II dataset, corresponding to an integrated luminosity of 9.4 fb^{-1} is used to measure A_{FB}^{lep}. The $t\bar{t}$ semileptonic events are selected with high-p_T electron or muon and large missing E_T triggers. Jets are reconstructed with the jetclu cone algorithm in a radius R = 0.4. Events are selected with exactly one lepton with $p_T > 20$ GeV/c and $|y_l| < 1.25$, missing $E_T > 20$ GeV, at least 4 jets with $|\eta| < 2.0$, at least 3 jets with $E_T > 20$ GeV, at least one jet with $E_T > 12$ GeV, at least 1 b-tagged jet, and $H_T > 220$ GeV. After the event selection the sample is mainly compose by $t\bar{t}$ events, with the main background coming from W+jets events.

Background processes are expected to contribute a nonzero asymmetry, in particular the largest background, namely W+jets, is asymmetric for a combination of electroweak and PDF effects. In order to validate the modelling of the leptonic asymmetry in the background simulation a background-enhanced control region is defined requiring that none of the jets is identified as a b-tagged jet. Figure 1 shows the signed rapidity distribution qy_l in the control region, where the W+jets background is simulated with the ALPGEN+PYTHIA Monte Carlo. The observed leptonic asymmetry of 0.076 in the background-enhanced region is in good agreement with the expected value of 0.062.

4 Extrapolation to the full kinematic region

The signed rapidity distribution qy_l is measured in the limited range $|y_l| < 1.25$, which corresponds to the detector acceptance. In order to extrapolate the measurement to the full kinematic space, $N(qy_l)$ is decomposed into symmetric and asymmetric components:

$$S(qy_l) = \frac{N(qy_l) + N(-qy_l)}{2} \qquad (2)$$

$$A(qy_l) = \frac{N(qy_l) - N(-qy_l)}{N(qy_l) + N(-qy_l)} \qquad (3)$$
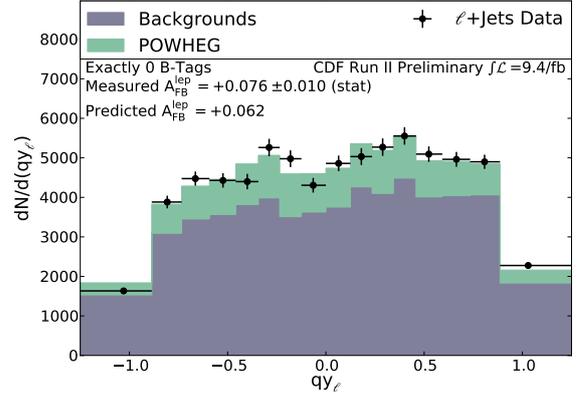
Figure 1. qy_l distribution in the background-enhanced control region.

The symmetric part is the same in all the considered models of table 1, while the asymmetric part capture the difference between the models, as shown in figure 2.

The measured $A(qy_l)$ is unfolded to the parton level, fitted with a hyperbolic tangent function

$$F(qy_l) = a \cdot \tanh[\frac{1}{2}qy_l] \qquad (4)$$

and convoluted with the symmetric component $S(qy_l)$ evaluated with the POWHEG Monte Carlo to extract the measured leptonic asymmetry:

$$A_{FB}^{lep} = \frac{\int_0^\infty dqy_l[A(qy_l) \times S(qy_l)]}{\int_0^\infty dqy_l S(qy_l)} \qquad (5)$$

5 Results

The largest systematic uncertainty on A_{FB}^{lep} is associated to the background subtraction. The background uncertainty is evaluated with a pseudo-experiment technique which accounts simultaneously for the uncertainty on the normalisation of the backgrounds and for the uncertainty on the shape due to limited statistics of the Monte Carlo samples.

Another important source of uncertainty comes from the modelling of the $t\bar{t}$ recoil due to QCD radiation. The presence of radiated jets is strongly correlated with both A_{FB} and the p_T of the $t\bar{t}$ system. Colour predominantly flows from an initiating light quark to an outgoing top-quark and from an anti-quark to an anti-top. As a consequence, events with larger difference between initial state quark and top directions are associated with harder QCD
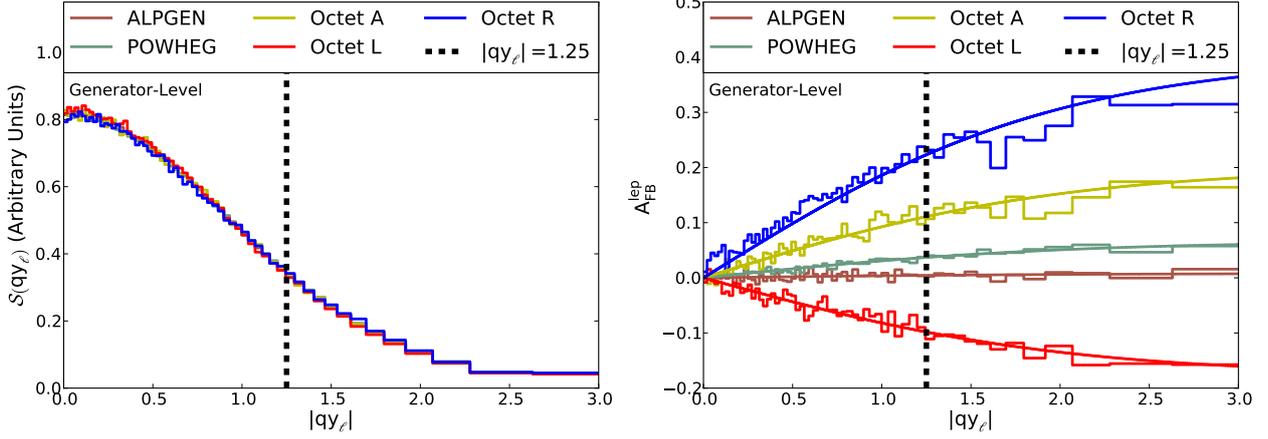
Figure 2. Symmetric and asymmetric components $S(qy_l)$ and $A(qy_l)$ of the signed rapidity distribution qy_l in the reference models.
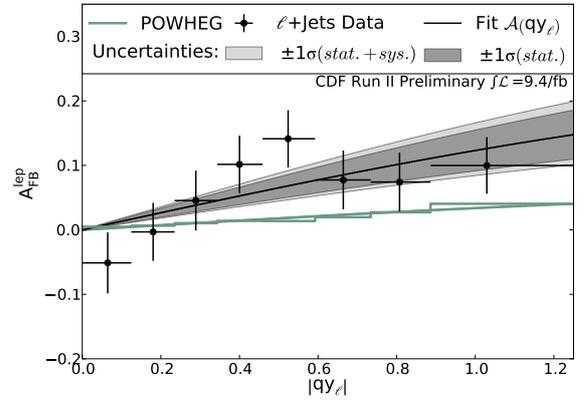
Table 2. Uncertainties of the A_{FB}^{lep} measurement.

Backgrounds	0.015
Recoil modelling	$+0.013$ -0.000
Colour reconnection	0.0067
Parton shower	0.0027
PDF	0.0025
Jet-energy-scale	0.0022
IFSR	0.0018
Total systematic	$+0.022$ -0.017
Statistical uncertainty	0.024
Total uncertainty	$+0.032$ -0.029

Figure 3. Asymmetric component $A(qy_l)$ of the signed rapidity distribution qy_l as measured in the data (black points) and compared to the POWHEG prediction (green). A hyperbolic tangent fit to the data and to the prediction is shown as a smooth curve of same colours. The dark (light) grey bands shows the statistical (total) uncertainty on the fit result.

Table 3. Measurement of A_{FB}^{lep} in l^+, l^-, electrons and muons sub-samples.

Sub-sample	measured A_{FB}^{lep}
Positive	$0.125^{+0.041}_{-0.041}$
Negative	$0.063^{+0.046}_{-0.042}$
Electrons	$0.062^{+0.052}_{-0.049}$
Muons	$0.119^{+0.039}_{-0.037}$

radiation. Events with more radiation have a larger acceptance because can more easily pass the high p_T selection requirements. The uncertainty on the recoil modelling is estimated comparing the acceptance of the nominal POWHEG Monte Carlo with two other models, namely PYTHIA and ALPGEN+PYTHIA. The recoil spectra of both PYTHIA and ALPGEN+PYTHIA are harder than POWHEG and give larger results for A_{FB}^{lep}, the uncertainty is therefore single-sided. An additional uncertainty related to the recoil model may arise from the initial-state radiation model in the PYTHIA parton shower. The uncertainty is estimated performing variations of the initial and final state radiation parameters (IFSR), the effect is found to be small.

Other QCD and jets related sources of uncertainties like colour reconnection, parton shower model, and jet-energy-scale, have been estimated. They give a small contribution to the A_{FB}^{lep} unertainty because hadronic jets are used in the measurement only to select the event sample. PDF uncertainties largely cancel between the numerator and denominator in the definition of A_{FB}^{lep}. The uncertainties on A_{FB}^{lep} are listed in table 2.

Figure 3 shows the parton level unfolded $A(qy_l)$ measured in the data, compared to the POWHEG prediction, and the result of fits to both data and Monte Carlo with equation (4). After the convolution of equation (5) with $S(qy_l)$ as estimated from POWHEG, the measured parton

level leptonic asymmetry in the full kinematic region is $A_{FB}^{lep} = 0.094 \pm 0.024^{+0.022}_{-0.017}$.

To check the consistency of the measured A_{FB}^{lep}, the sample is divided in positive and negative charged leptons, and in the electrons and muons channels. A_{FB}^{lep} is measured separately in all the four sub-samples using the same procedure as for the combined measurement. The results, shown in table 3, are all consistent with the measured value in the combined sample.

The measured value of A_{FB}^{lep} is in good agreement with the D0 measurement $A_{FB}^{lep} = 0.118 \pm 0.032$, and can be compared to the fixed order NLO QCD+EW prediction 0.038 ± 0.003 [3].

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