Measurement of the forward-backward asymmetry in ttbar production at the Tevatron

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Measurement of the Forward-Backward Asymmetry in $t\bar{t}$ Production at the Tevatron

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We present the first measurements of the integrated forward-backward asymmetry in top pair events performed at the Tevatron by DØ and CDF collaborations.

1 Introduction

At the Tevatron, top quark pairs are produced by quark-antiquark annihilation (85 %) and gluon fusion (15 %). Due to the quark-antiquark contribution, the initial state of the $p\bar{p} \rightarrow t\bar{t} + X$ process is not invariant under the charge conjugation symmetry $\mathcal{C}$. As a consequence, even if the strong interaction is assumed to respect $\mathcal{C}$, the final state $t\bar{t} + X$ is not expected to be charge symmetric. Under the assumption that QCD respects $\mathcal{CP}$, the charge asymmetry in top pair events can be observed as an integrated forward-backward asymmetry defined as follows :

- in the $p\bar{p}$ rest frame,

$$\mathcal{A}_{fb}^{p\bar{p}} = \frac{N(cos\,\theta_t > 0) - N(cos\,\theta_t < 0)}{N(cos\,\theta_t > 0) + N(cos\,\theta_t < 0)}$$

  where θ_t is the top quark production angle w.r.t. the beam axis in the $p\bar{p}$ rest frame ;

- in the $t\bar{t}$ rest frame,

$$\mathcal{A}_{fb}^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

  with $\Delta y = y_t - y_{\bar{t}}$ is the rapidity difference between the top and the antitop. At Leading Order (LO), the condition $\Delta y > 0$ is identical to $cos\,\theta_t^* > 0$, θ_t^* being measured in the $t\bar{t}$ rest frame.

At leading order of perturbation theory, the differential cross-section of top pair production is symmetric under the exchange $t \leftrightarrow \bar{t}$. At Next to Leading Order (NLO), an asymmetry of order of 5% [1, 2] appears through interferences between the Feynman graphs shown in Figure 1 :

- the interference between Born and box diagrams gives a positive contribution [2] to the asymmetry of $\simeq +6\%$;

- the interference between Initial State Radiation (ISR) and Final State Radiation (FSR) diagrams contributes negatively to the asymmetry : $\simeq -7\%$ at NLO [2, 3], reduced to $\simeq -2\%$ according to a recent Next to Next to Leading Order (NNLO) calculation [3].

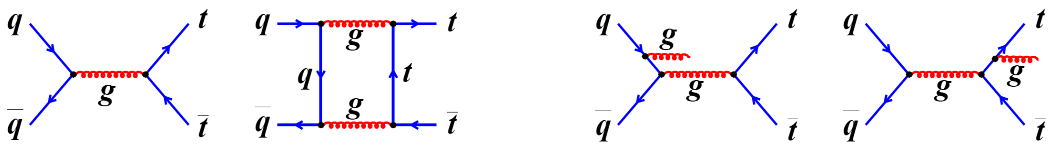

Figure 1: Feynman diagrams contributing to the forward-backward asymmetry at Next to Leading Order, via interferences (each single diagram gives a charge symmetric production, as QCD is indifferent to the electric charge).

DØ and CDF have measured the forward-backward asymmetry in the ℓ+jets final state ($t\bar{t}$+$X \rightarrow \ell\nu_\ell q\bar{q}'b\bar{b}$+$X$), where both top and antitop decay into a W boson and a b quark, one W decaying leptonically and the other hadronically. Measurements are separately performed in the 4 exclusive and 5 inclusive jet bins to disentangle positive and negative contributions of $q\bar{q} \rightarrow t\bar{t}$ and $q\bar{q} \rightarrow t\bar{t} + g$ processes. Details about signal and background modeling, event selection and kinematics reconstruction of top pair events can be found in [4, 5].

2 DØ measurement of $\mathcal{A}_{fb}^{t\bar{t}}$

DØ measures a *raw* asymmetry, i.e. visible within the detector acceptance and distorted by reconstruction effects. The choice not to correct for acceptance comes from theoretical limitations : signal acceptance is estimated with MC@NLO [6], and the NNLO calculation indicates that the perturbative expansion has not converged yet at NLO. Reconstruction effects are parameterized through a dilution function defined as $\mathcal{D} = 2p - 1$, where p is the probability to correctly reconstruct the sign of the rapidity difference Δy . Dilution represents the fraction of visible asymmetry that is reconstructed in the detector, and is displayed in Figure 2. It originates from wrong kinematics reconstruction and incorrect measurement of the lepton charge.

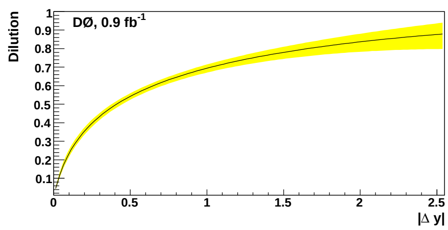

Figure 2: Dilution and its uncertainty band as a function of the generated rapidity difference $|\Delta y|$, measured in $t\bar{t}$ + X events generated with PYTHIA [7] after full event reconstruction.

The expected *raw* asymmetry in the Standard Model (SM) is computed by folding the MC@NLO predictions with the dilution function, within the geometrical acceptance :

$$\mathcal{A}_{fb}^{SM,raw} = \int_0^{+\infty} \mathcal{A}_{fb}^{gen}(\Delta y)\mathcal{D}(\Delta y)f(\Delta y)d\Delta y \qquad , \quad f \ : \text{probability density of } \Delta y$$

Using likelihood discriminant templates for $t\bar{t}$, W+jets (whose V-A intrinsic asymmetry is reduced because kinematics is reconstructed under the $t\bar{t}$ assumption) and QCD multijet production, the data sample composition and the forward-backward asymmetry are extracted simultaneously with a maximum likelihood fit technique. The results obtained for different jet multiplicities on a 0.9 fb^{-1} data set are summarized in Table 1.

	DØ 0.9 fb^{-1}, $\mathcal{A}_{fb}^{t\bar{t}}$ (%)		CDF 1.9 fb^{-1}, $\mathcal{A}_{fb}^{t\bar{t}}$ (%)		CDF 1.9 fb^{-1}, $\mathcal{A}_{fb}^{p\bar{p}}$ (%)	
	Data	SM expected	Data	SM expected	Data	SM expected
≥ 4 jets	12 ± 8	0.8 ± 0.2	11.9 ± 6.4	1.7 ± 0.7	13.0 ± 5.5	1.5 ± 1.6
$= 4$ jets	19 ± 9	2.3 ± 0.2	13.2 ± 7.5	3.8 ± 0.8	12.0 ± 6.4	3.2 ± 1.8
> 4 jets	-16^{+15}_{-17}	-4.9 ± 0.4	7.9 ± 12.3	-3.3 ± 1.2	16.0 ± 10.9	-2.7 ± 3.2
≥ 4 jets*			24 ± 13	$4 - 7$	17 ± 7	4 ± 1

Table 1: Integrated forward-backward asymmetries measured by DØ (in the $t\bar{t}$ rest frame) and CDF (both in $t\bar{t}$ and $p\bar{p}$ rest frames). Data measurements are compared to MC@NLO predictions. Asymmetries are not corrected for acceptance nor reconstruction effects, except in the last line of the table (*). Only statistical errors are mentioned.

Beyond the test of perturbative QCD predictions, the forward-backward asymmetry can be interpreted to probe new physics. DØ has investigated a scenario in which a heavy neutral gauge boson Z' decays into a $t\bar{t}$ pair, which would result in a large positive asymmetry. The obtained limits on the fraction of top pairs produced via $Z' \to t\bar{t}$ are displayed in Figure 3.

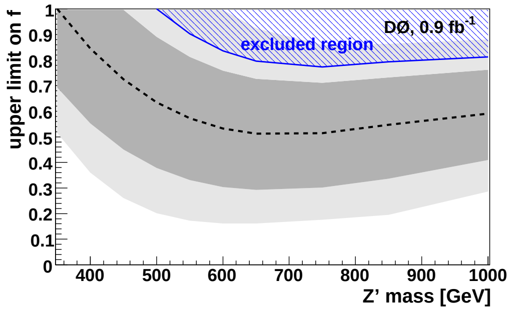

Figure 3: Confidence intervals at 95% C.L. on the fraction of top pairs produced via $Z' \to t\bar{t}$ as a function of the Z' mass, computed with Feldman-Cousins prescription [8]. The dashed curve and the solid blue curve represent the expected and observed limits respectively.

3 CDF measurements of $\mathcal{A}_{fb}^{p\bar{p}}$ and $\mathcal{A}_{fb}^{t\bar{t}}$

CDF has measured the forward-backward asymmetry in $p\bar{p} \to t\bar{t} + X$ events, in both $t\bar{t}$ and $p\bar{p}$ rest frames with 1.9 fb^{-1} of data [5]. As a first step, $cos\,\theta_t$ and Δy distributions are determined for signal (with MC@NLO), background, and data (see Figure 4). Background distributions are then explicitly subtracted from data distributions. At this stage of the analyses, *raw* asymmetries are computed for background-subtracted data and compared to $t\bar{t}$ expectations. *Raw* measurements are finally corrected back to parton level with the so-called *matrix inversion* technique. This method accounts for migration of events which are generated in certain bins of angular distributions but are reconstructed in other bins due to detector effects, and corrects for acceptance and efficiency biases as well. The predicted and observed asymmetries are shown in Table 1, before and after *matrix inversion* correction.

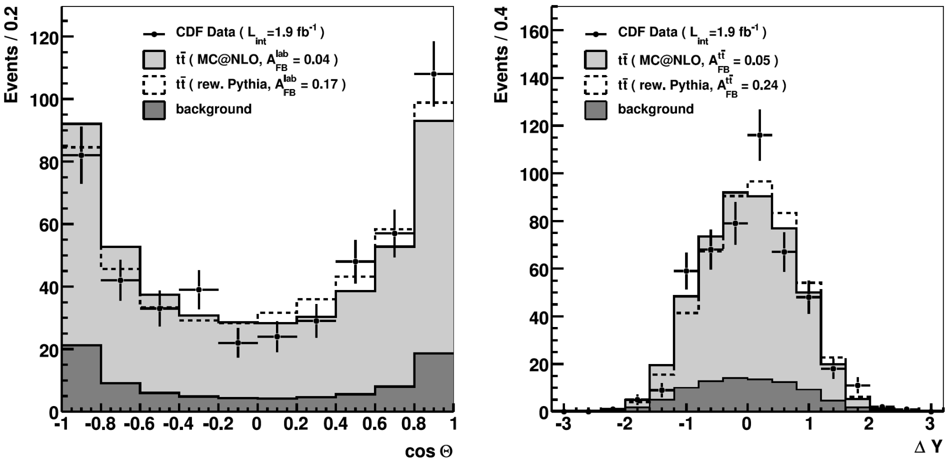

Figure 4: Observed and predicted distributions of angular variables $cos\,\theta_t$ and Δy from which $\mathcal{A}_{fb}^{p\bar{p}}$ and $\mathcal{A}_{fb}^{t\bar{t}}$ are computed respectively. The light and dark grey histograms correspond to $t\bar{t}$ (as modeled by MC@NLO) and background expectations. The dashed curves show PYTHIA $t\bar{t}$ predictions reweighted to match the measured values of $\mathcal{A}_{fb}$. Distributions are shown before *matrix inversion* correction.

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