Measurement of the angular production asymmetries in top quark pair lepton plus jets and dilepton final states

Kamil Augsten for the D0 Collaboration

Czech Technical University in Prague, Prague, Czech Republic

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We present the measurement of the forward-backward asymmetry in the $t\bar{t}$ quark pair production in $p\overline{p}$ collisions in the lepton+jets and dilepton final states. Measurements use the full data set collected by the D0 detector in Run II corresponding to an integrated luminosity of 9.7 fb^{-1}. We present the most recent measurement of the lepton-based asymmetries both in lepton+jets and dilepton final states and their combination. We also present the top-quark based asymmetry as an inclusive measurement and differentially in $m_{t\bar{t}}$. These results are corrected for efficiency, acceptance and resolution effects to parton level. Measurements are compared to theory predictions.

1 Introduction

The top quark and its properties play an important role in the Standard Model (SM) and may probe for new physics. The forward-backward charge asymmetry was observed in fermion production in e^+e^- collisions in the 1980's, which was confirmation of the electroweak theory and observation of the mediation through Z-boson. Similar process might occur in strong sector as heavy mediators of strong interaction that have axial component, so called axigluons [1]. Top pair production in $p\overline{p}$ collisions mediated by axigluons would result in effect that as experimentally observable as a forward-backward asymmetry. Different models also suggest non-zero forward-backward asymmetry in top pair production.

In the SM, positive asymmetry appears at the α_s^3 level with numeric prediction of 9 % [2], which is next-to-leading order (NLO) QCD with the electroweak (EW) corrections. Recent preliminary NNLO calculation reported ~ 10 % asymmetry [3].

Asymmetry A_{FB} is defined as

$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}, \tag{1}$$

where $N_F = N(x > 0)$ (forward events) and $N_B = N(x < 0)$ (backward events) for any angular variable x, for example η. The asymmetry $A_{FB}^{t\bar{t}}$ is defined with $x = \Delta y = y_t - y_{\bar{t}}$, a variable that is invariant under the boost along the beam axis. Similarly, the asymmetry A_{FB}^{l} in lepton direction is defined with the signed rapidity ($q_l y_l$) of the lepton from $t\bar{t}$ decay. Both asymmetries can be defined in the lepton+jets[1] (l+jets) and dilepton decay channels. Additionally for the

[1]By lepton are denoted here only electron and muon.

dilepton channel, the asymmetry A^{ll}_{FB} is defined based on the difference in rapidity between the positive and negative lepton.

This overview focuses on the latest measurements by the D0 experiment with the full Tevatron data set of 9.7 fb^{-1} in both l+jets and dilepton channels.

2 Asymmetry in Lepton Production from $t\bar{t}$ decay

2.1 Lepton + Jets Channel

The asymmetry A^{l}_{FB} in the l+jet channel [4] is measured in four sub-channels: l+3jets with 1 b-tag, l+4jets with 1 b-tag, l+3jets with 2 or more b-tags, and l+4jets with 2 or more b-tags. It includes l+3jets events, where one of the jets lost, to maximize the statistical sensitivity. It approximately doubles the statistics. However, this implies larger background, especially the production of W boson in association with jets. Leptons from the decay of the inclusively produced W bosons are produced asymmetrically in forward and backward direction. This effect is studied in Monte Carlo (MC) and analysis calibrates it using comparison of MC prediction and data in the orthogonal region, the W+jets background dominated 3 jets and 0 b-tag channel, which is not used for the measurement. The difference is accounted as systematic uncertainty. To maximize the analysis precision, the A^{l}_{FB} was measured separately in each sub-channel and combined afterwards. The result is corrected for the detector efficiency and resolution. The asymmetry is measured to be $4.2 \pm 2.3(\text{stat.})^{+1.7}_{-2.0}(\text{syst.})$ % and can be compared to MC@NLO prediction of 2.3 % or SM calculation of 3.8 ± 0.3 % [2]. The result is for leptons within rapidity range of 1.5. Fig. 1 (left) shows breakdown of the result to each sub-channel. The measurement of the A^{l}_{FB} in l+jets channel includes study of the asymmetry dependence on the transverse momentum of the lepton (p^{l}_{T}) from the $t\bar{t}$ decay. This provides an additional information that helps to distinguish between different models. The A^{l}_{FB} dependency measured in data after subtracting the contribution of the calibrated W+jets background as well as other background sources is shown in Fig. 1 (right) compared to the MC@NLO prediction.

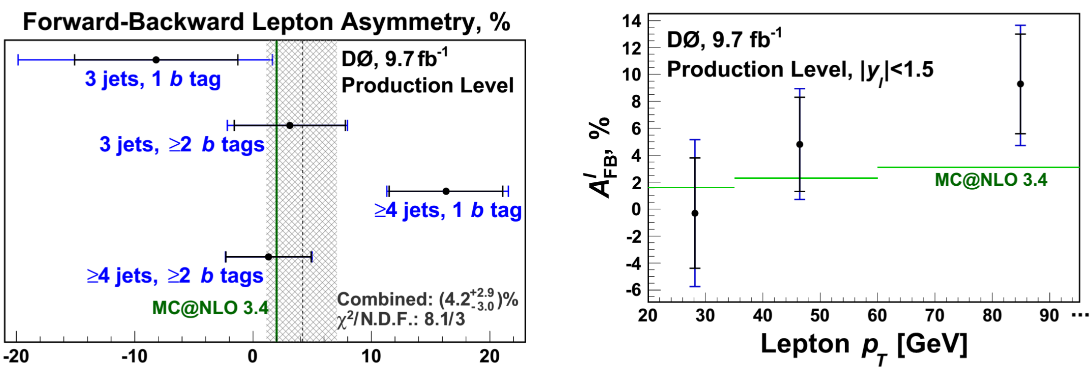

Figure 1: Left - Measured parton-level A^{l}_{FB} by sub-channel. The vertical line shows the MC@NLO prediction. Right - Predicted and observed parton-level asymmetries as a function of lepton transverse momentum. In both plots the statistical uncertainties are indicated by the inner, and the total uncertainties by the outer error bars.

2.2 Dilepton Channel

D0 performed measurements of asymmetry in lepton production in dilepton $t\bar{t}$ events [5], where two leptons (electrons or muons) are selected to have opposite charge and are accompanied by one jet in $e\mu$ channel and at least two jets in ee, $e\mu$, and $\mu\mu$ channels. Those four channels are treated separately to account for differences in purity and later combined together. Two asymmetry definitions are considered: A^{l}_{FB} with $x = q_l\eta_l$ and A^{ll}_{FB} with $x = \Delta\eta$. Additional acceptance cuts $|\eta| < 2.0$ and $|\Delta\eta| < 2.4$ are applied. The observed asymmetries are corrected for the detector efficiency and extrapolated to the full acceptance with scaling factor derived from MC@NLO. The corrected and extrapolated results are $A^{l}_{FB} = 4.4 \pm 3.7(\text{stat.}) \pm 1.1(\text{syst.})$ % and $A^{ll}_{FB} = 12.3 \pm 5.4(\text{stat.}) \pm 1.5(\text{syst.})$ % and can be compared to the SM NLO calculations [2] of $A^{l}_{FB} = 3.8 \pm 0.3$ % and $A^{ll}_{FB} = 4.8 \pm 0.4$ %.

2.3 Combination

To make a combination in A^{l}_{FB} for l+jets and dilepton channels we need first both results in the same lepton rapidity region. For the $|y_l| < 1.5$ region, the l+jets result has been already mentioned, $4.2 \pm 2.3(\text{stat.})^{+1.7}_{-2.0}$ (syst.) %, and dilepton channel gives $4.3 \pm 3.4(\text{stat.}) \pm 1.0$ (syst.) %. The combination is done using Best Linear Unbiased Estimator (BLUE) method [6] resulting in $A^{l}_{FB} = 4.2 \pm 2.4$ %. This value is extrapolated to cover the full phase space - $A^{l}_{FB} = 4.7 \pm 2.3(\text{stat.}) \pm 1.5(\text{syst.})\% = 4.7 \pm 2.7$ % and it is in agreement with the SM calculation $A^{l}_{FB} = 3.8 \pm 0.3$ % [2].

3 Inclusive $t\bar{t}$ Production Asymmetry in Lepton + Jets Channel

Similarly to the asymmetry in lepton production in l+jets channel the inclusive $t\bar{t}$ production asymmetry [7] is measured with addition of the l+3jets events. As this measurement requires the full reconstruction of the $t\bar{t}$ decay, partial reconstruction algorithm [8] with high probability of correct reconstruction of the sign is implemented. The reconstructed Δy distribution is unfolded accounting for the differences in the signal to background ratio in the measured subchannels. The measurement uses regularized unfolding (package TUnfold) and the asymmetry at the parton level is measured to be $A^{t\bar{t}}_{FB} = 10.6 \pm 2.7(\text{stat.}) \pm 1.3(\text{syst.})$ % which is consistent with the SM calculation $A^{t\bar{t}}_{FB} = 8.8 \pm 0.9$ % [2].

For the differential measurement a 2D unfolding algorithm was developed and the dependencies of the forward-backward asymmetry on the $|\Delta y|$ and on the invariant mass ($m_{t\bar{t}}$) of the $t\bar{t}$ system were studied and are shown on Fig. 2. The correlations between bins are taken into account in the fit of the measured asymmetry and slope is compared to the prediction from MC@NLO. The dependencies are in agreement with the SM predictions.

4 Conclusion

We present recent measurements of the angular production asymmetries in top quark pair lepton+jets and dilepton final states with the D0 detector in full 9.7 fb^{-1} data set. The asymmetry in lepton production from $t\bar{t}$ decay is combined for both channels and extrapolated

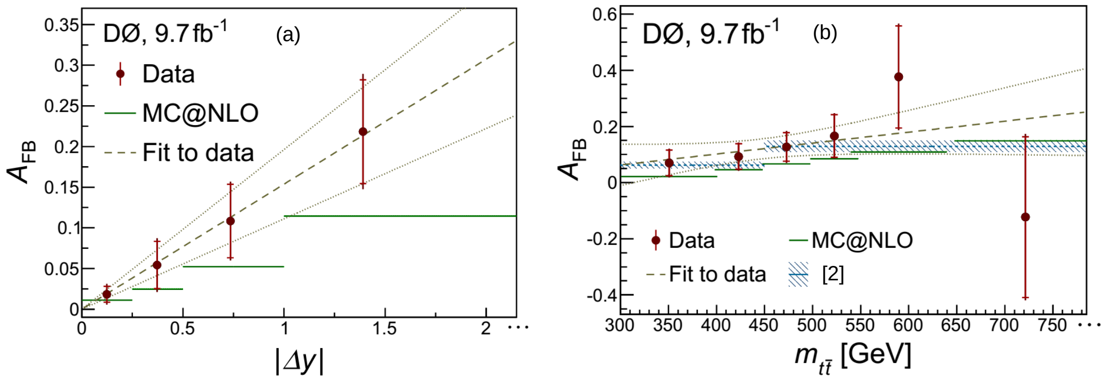

Figure 2: The dependencies of the forward-backward asymmetry on (a) the $|\Delta y|$ and on (b) the invariant mass of the $t\bar{t}$ system. The D0 data points are shown with total uncertainties and are compared to MC@NLO and [2] prediction. The dashed line shows the fit to the data with the dotted lines indicating the fit uncertainty. The last bin has no upper boundary.

to the full acceptance, $A^{l}_{FB} = 4.7 \pm 2.7$ %, while SM calculation predicts $A^{l}_{FB} = 3.8 \pm 0.3$ %. The inclusive $t\bar{t}$ production asymmetry in the l+jets channel corrected to the parton level as $A^{t\bar{t}}_{FB} = 10.6 \pm 3.0$ %. It agrees with SM prediction of $A^{t\bar{t}}_{FB} = 8.8 \pm 0.9$ % (NLO + QCD EW) and is in even better agreement with the recent NNLO + QCD EW prediction of ~ 10 %. The D0 results are consistent with SM-based calculations.

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