

# Measurement of the forward-backward asymmetry in $t\bar{t}$ events in the $l+\text{jets}$ channel

Doug Orbaker

on behalf of the DØ collaboration



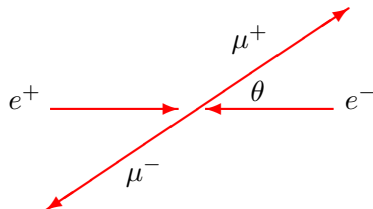
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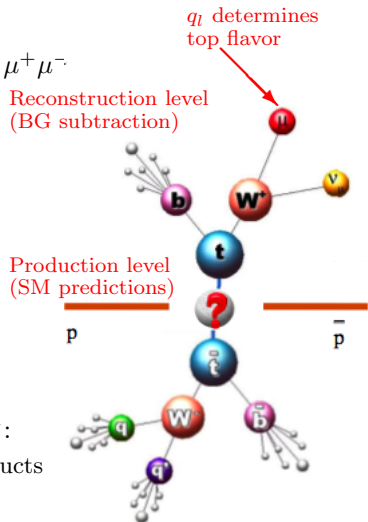
August 11, 2011

# Asymmetry in top-antitop quark production

- Early 1980s: Asymmetry observed in  $e^+e^- \rightarrow \mu^+\mu^-$  at  $\sqrt{s} = 35$  GeV validates EW theory (Phys. Rev. Lett. 48, 1701-1704 (1982))

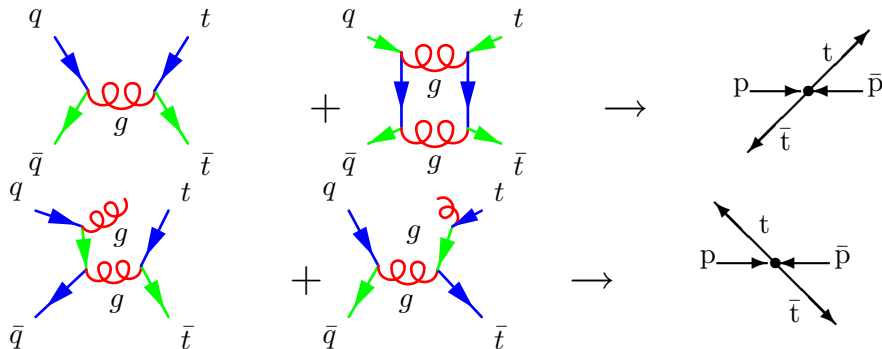


- What about in  $p\bar{p} \rightarrow t\bar{t}$ ?
- $p\bar{p} \rightarrow t\bar{t}$  more complicated than  $e^+e^- \rightarrow \mu^+\mu^-$ :
  - ▶ Top quarks reconstructed from 6 decay products
  - ▶  $\Delta y = y_t - y_{\bar{t}} = q_l(y_{t,lep} - y_{t,had})$
- $A_{FB} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$



# Asymmetry in the standard model

- SM predicts no asymmetry at LO in QCD, and a small asymmetry at NLO.



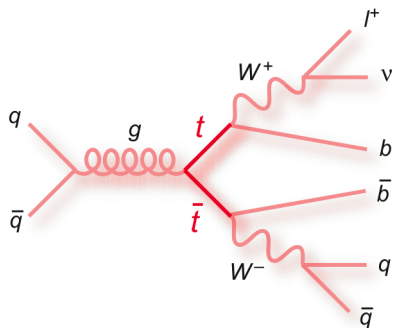
- Our predictions made at NLO in QCD via MC@NLO

Level	$A_{FB}$ (%)
Production	$5.0 \pm 0.1$
Reconstruction	$2.4 \pm 0.7$

- Inclusive SM predictions vary from 5%-9%

# Event Selection and Reconstruction

- Search in the lepton ( $e/\mu$ ) + jets channel



Require:

$\Rightarrow$  1 lepton

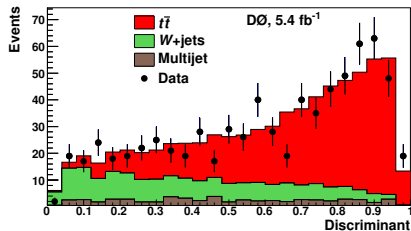
$\Rightarrow$   $\cancel{E}_T$

$\Rightarrow$   $\geq 4$  jets

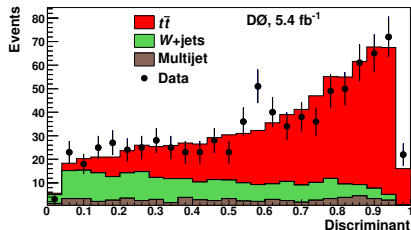
$\Rightarrow$   $\geq 1$   $b$ -tagged jet

- Reconstruct events with a kinematic fitter
  - ▶  $m_W = 80.4$  GeV
  - ▶  $m_t = 172.5$  GeV
- Keep only assignment with lowest  $\chi^2$
- 1581 events pass selection for  $5.4 \text{ fb}^{-1}$

# Maximum Likelihood Fit



Discriminant with  $\Delta y < 0$



Discriminant with  $\Delta y > 0$

Signal:

$$N_{t\bar{t}} = 1126 \pm 39$$

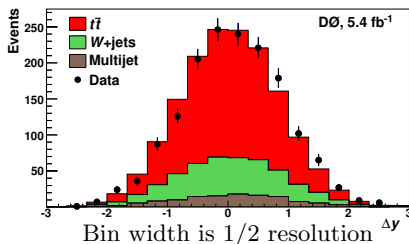
$$A_{\text{FB}} = (9.2 \pm 3.7) \%$$

Backgrounds:

$$N_{W+\text{jets}} = 376 \pm 39$$

$$N_{\text{Multijet}} = 79 \pm 5$$

# Results from reconstruction of $A_{FB}$

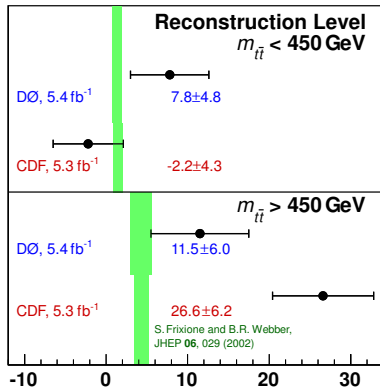


	$l+\geq 4$ jets	$l+4$ jets	$l+\geq 5$ jets
$A_{FB}(\%)$	$9.2\pm 3.7$	$12.2\pm 4.3$	$-3.0\pm 7.9$
MC@NLO $A_{FB}(\%)$	$2.4\pm 0.7$	$3.9\pm 0.8$	$-2.9\pm 1.1$

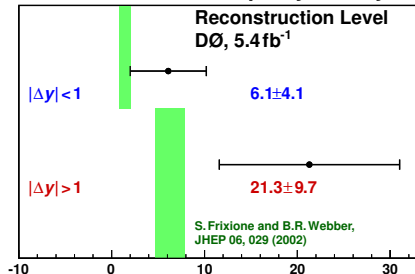
- Measured  $A_{FB} = \left(9.2 \pm 3.6(\text{stat})_{-0.9}^{+0.8}(\text{syst})\right)\%$
- Statistical significance from MC@NLO prediction: 1.9 SD

# Dependence of $A_{FB}$ on $m_{t\bar{t}}$ and $|\Delta y|$

Forward-Backward Top Asymmetry, %

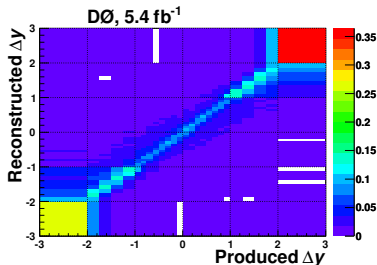
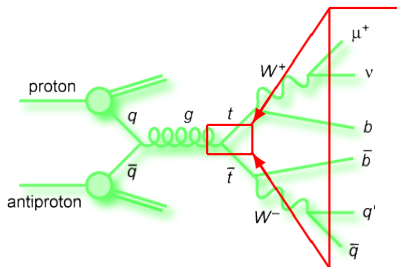


Forward-Backward Top Asymmetry, %



- No significant dependence of  $A_{FB}$  on  $m_{t\bar{t}}$

# Unfolding

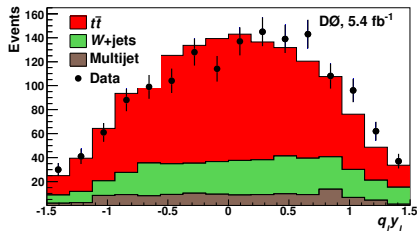


$$\text{Unfolded } A_{\text{FB}} = \left( 19.6 \pm 6.0(\text{stat})_{-2.6}^{+1.8}(\text{syst}) \right) \%$$

- Regularized unfolding via TUnfold class with  $50 \rightarrow 26$  bins in  $\Delta y$ 
  - ▶ Regularize on curvature of event density
- Cross-checked with four bin ML unfolding
- Better statistical strength using regularized unfolding
- Statistical significance from MC@NLO prediction: 2.4 SD



# Lepton-based asymmetry

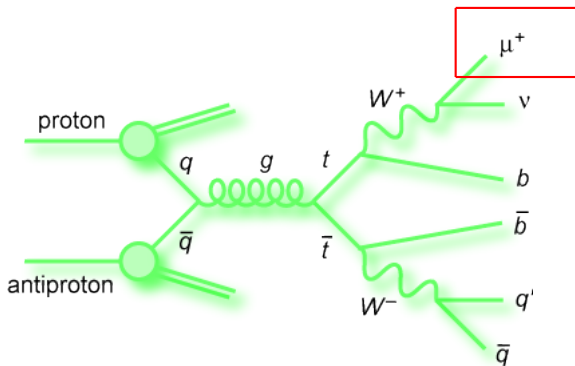


$$A_{\text{FB}}^l = \frac{N(q_l y_l > 0) - N(q_l y_l < 0)}{N(q_l y_l > 0) + N(q_l y_l < 0)}$$

- Simple observable
- Same technique as measurement of reconstructed  $A_{\text{FB}}$
- To avoid large acceptance corrections: require  $|y_l| < 1.5$
- 1532 events

	$l+\geq 4$ jets	$l+4$ jets	$l+\geq 5$ jets
$A_{\text{FB}}^l$ (%)	$14.2 \pm 3.8$	$15.9 \pm 4.3$	$7.0 \pm 8.0$
MC@NLO $A_{\text{FB}}^l$ (%)	$0.8 \pm 0.6$	$2.1 \pm 0.6$	$-3.8 \pm 1.2$

# Unfolding $A_{\text{FB}}^l$



$$\text{Unfolded } A_{\text{FB}}^l = \left( 15.2 \pm 3.8(\text{stat})_{-1.3}^{+1.0}(\text{syst}) \right) \%$$

- Production level MC@NLO prediction:  $A_{\text{FB}}^l = (2.1 \pm 0.1) \%$
- Migrations are very small → correct only for acceptance
- Statistical significance from MC@NLO: 3.4 SD

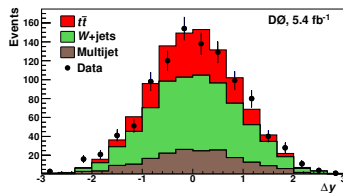
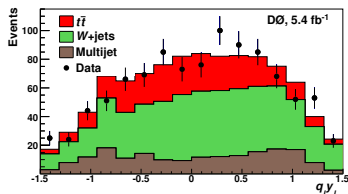
## Measurement dominated by statistical uncertainties

Absolute uncertainty on $A_{FB}$ (%)			
Source	Reco. level		Prod. level
	Prediction	Measurement	Measurement
Jet reco	$\pm 0.3$	$\pm 0.5$	$\pm 1.0$
JES/JER	$+0.5$	$-0.5$	$-1.3$
Signal modeling	$\pm 0.3$	$\pm 0.5$	$+0.3/-1.6$
$b$ -tagging	-	$\pm 0.1$	$\pm 0.1$
Charge ID	-	$+0.1$	$+0.2/-0.1$
Bg subtraction	-	$\pm 0.1$	$+0.8/-0.7$
Unfolding Bias	-	-	$+1.1/-1.0$
Total	$+0.7/-0.5$	$+0.8/-0.9$	$+1.8/-2.6$

Absolute uncertainty on $A_{FB}^t$ (%)			
Source	Reco. level		Prod. level
	Prediction	Measurement	Measurement
Jet reco	$\pm 0.3$	$\pm 0.1$	$\pm 0.8$
JES/JER	$+0.1$	$-0.4$	$+0.1/-0.6$
Signal modeling	$\pm 0.3$	$\pm 0.5$	$+0.2/-0.6$
$b$ -tagging	-	$\pm 0.1$	$\pm 0.1$
Charge ID	-	$+0.1$	$+0.2/-0.0$
Bg subtraction	-	$\pm 0.3$	$\pm 0.6$
Total	$\pm 0.5$	$\pm 0.7$	$+1.0/-1.3$

# Cross checks

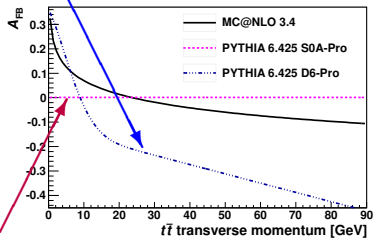
- Simultaneously measured  $A_{FB}$  for  $t\bar{t}$  and  $W$ +jets
  - ▶ Also included events with 0 b-tags
  - ▶ Measured  $A_{FB}$  for  $W$ +jets in good agreement with simulation



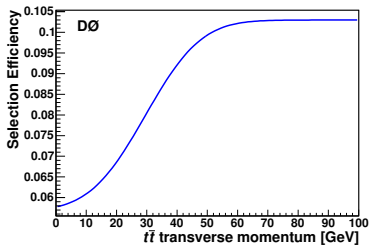
- Checked  $A_{FB}$  by solenoid and toroid polarities
  - ▶ Found no significant dependence
- Checked  $A_{FB}$  by lepton charge
  - ▶ Found no significant dependence
- Good agreement between  $e$ +jets and  $\mu$ +jets

- Is amount of gluon radiation the same for forward and backward events?

## Angular coherence on



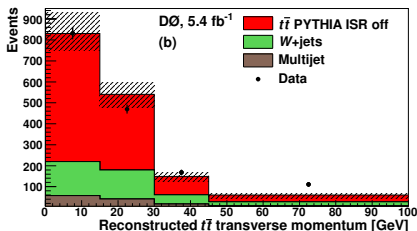
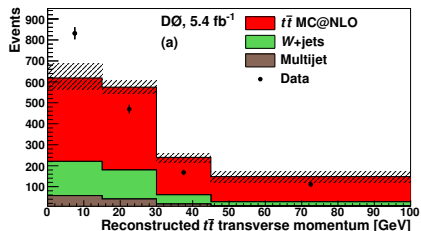
## Angular coherence off



- If correlation exists, backward events selected more often than forward events
- Effect on measurement is included in systematics:  $-1.6\%$
- What is effect on prediction?

# Modeling and top pair $p_T$

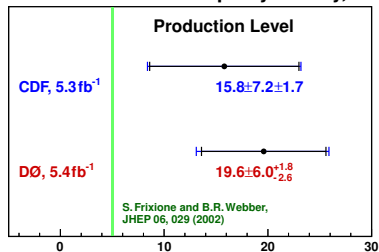
- The correlation between  $p_T^{t\bar{t}}$  and  $A_{FB}$  may be large
- So we checked the modeling of  $p_T^{t\bar{t}}$
- Drastic change needed to get simulation to match data for  $p_T^{t\bar{t}}$



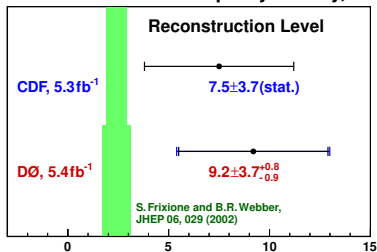
Bins of 1/2 resolution. Hash marks = uncertainty from jet reconstruction

- Low  $p_T^{t\bar{t}}$   $\rightarrow$  less gluon radiation  $=?$  larger predicted  $A_{FB}$

Forward-Backward Top Asymmetry, %



Forward-Backward Top Asymmetry, %



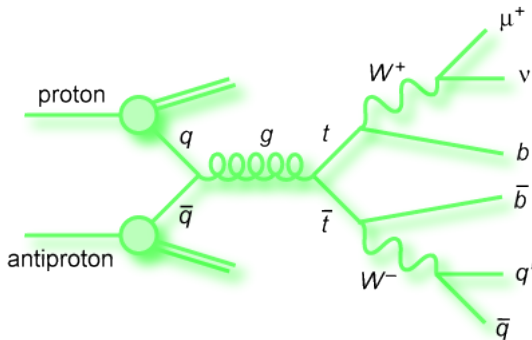
- Inclusive results in agreement between DØ and CDF
- But deviate from predictions
- Measure no significant dependencies of  $A_{fb}$  on either  $m_{t\bar{t}}$  or  $|\Delta y|$
- Unfolded  $A_{\text{FB}}^l = \left(15.2 \pm 3.8(\text{stat})^{+1.0}_{-1.3}(\text{syst})\right)\%$
- Compare to MC@NLO, but note limitations
- For more information: arXiv:1107.4995

# Backup Slides



# Kinematic fitter

- Answers questions: Which jets came from top quark and which jets came from antitop quark?
- Gets right answer 70% of events where leading four jets are from  $t\bar{t}$  decay.
- Constrain  $m_W$  to 80.4 GeV and  $m_t$  to 172.5 GeV.
- Vary jets within resolution and get  $\chi^2$  for each jet permutation.



# Reconstructed $A_{\text{FB}}$ table

	$l+\geq 4$ jets	$e+\geq 4$ jets	$\mu+\geq 4$ jets	$l+4$ jets	$l+\geq 5$ jets
Raw $N_{\Delta y > 0}$	849	455	394	717	132
Raw $N_{\Delta y < 0}$	732	397	335	597	135
$N_{t\bar{t}}$	$1126\pm 39$	$622\pm 28$	$502\pm 28$	$902\pm 36$	$218\pm 16$
$N_W$	$376\pm 39$	$173\pm 28$	$219\pm 27$	$346\pm 36$	$35\pm 16$
$N_{\text{MJ}}$	$79\pm 5$	$56\pm 3$	$8\pm 2$	$66\pm 4$	$13\pm 2$
$A_{\text{FB}}(\%)$	$9.2\pm 3.7$	$8.9\pm 5.0$	$9.1\pm 5.8$	$12.2\pm 4.3$	$-3.0\pm 7.9$
MC@NLO $A_{\text{FB}}(\%)$	$2.4\pm 0.7$	$2.4\pm 0.7$	$2.5\pm 0.9$	$3.9\pm 0.8$	$-2.9\pm 1.1$

# Reconstructed $A_{\text{FB}}^l$ table

	$l+\geq 4$ jets	$e+\geq 4$ jets	$\mu+\geq 4$ jets	$l+4$ jets	$l+\geq 5$ jets
Raw $N_{q\cdot y_l > 0}$	867	485	382	730	137
Raw $N_{q\cdot y_l < 0}$	665	367	298	546	119
$A_{\text{FB}}^l$ (%)	$14.2 \pm 3.8$	$16.5 \pm 4.9$	$9.8 \pm 5.9$	$15.9 \pm 4.3$	$7.0 \pm 8.0$
MC@NLO $A_{\text{FB}}^l$ (%)	$0.8 \pm 0.6$	$0.7 \pm 0.6$	$1.0 \pm 0.8$	$2.1 \pm 0.6$	$-3.8 \pm 1.2$

# DØ detector

