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

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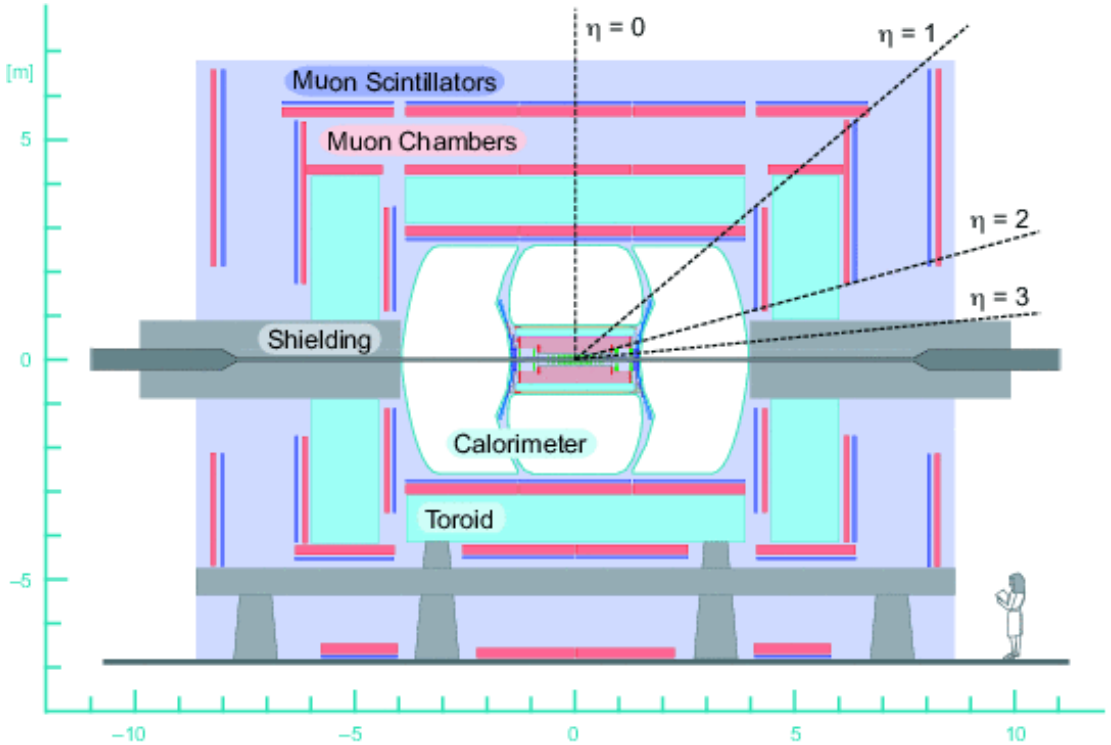
on behalf of the DØ collaboration

August 31, 2011

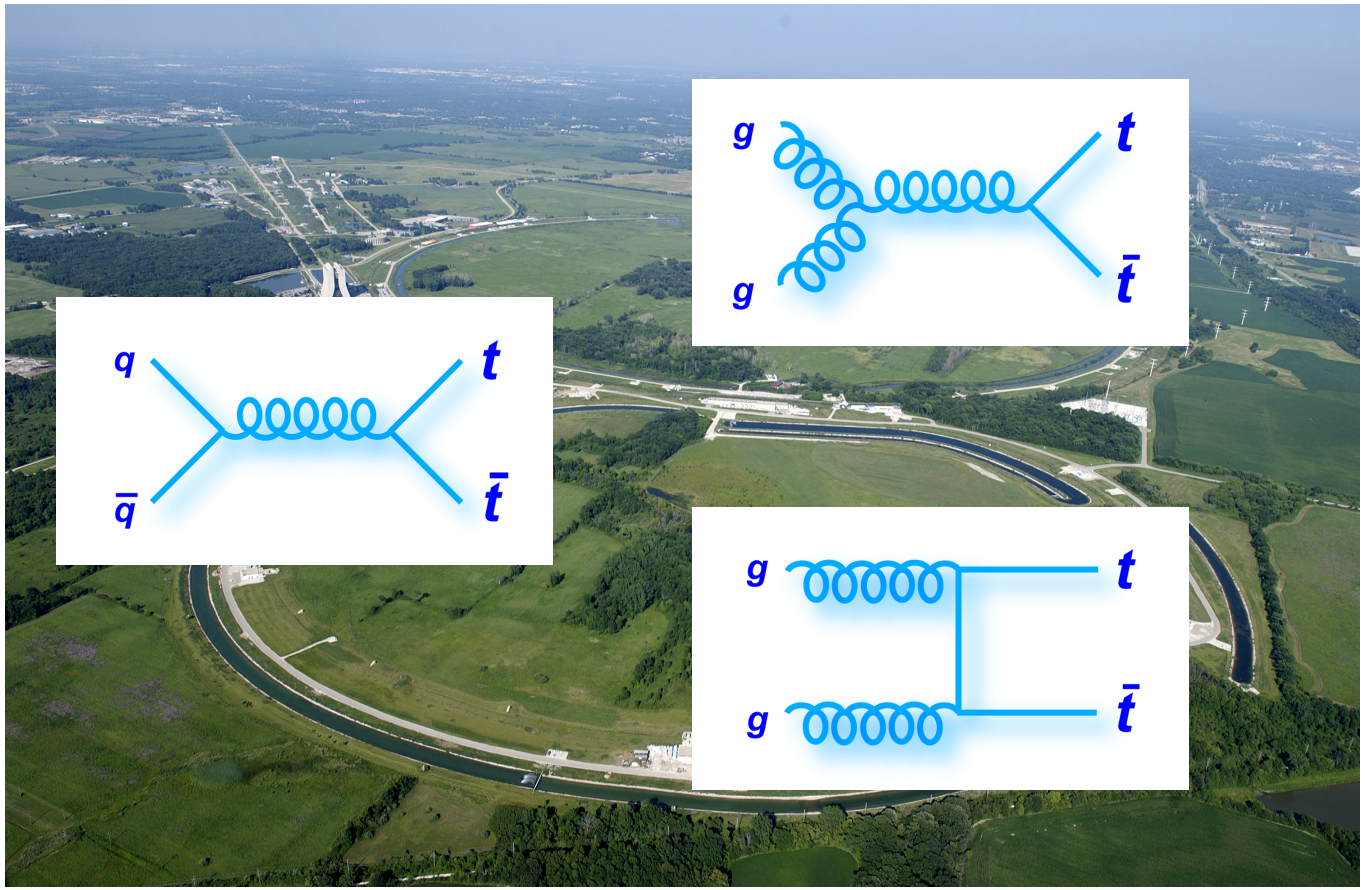
DØ detector



- Designed to detect and identify a broad range of different particles.
- Magnet polarities flipped regularly.

$t\bar{t}$ production at the Tevatron

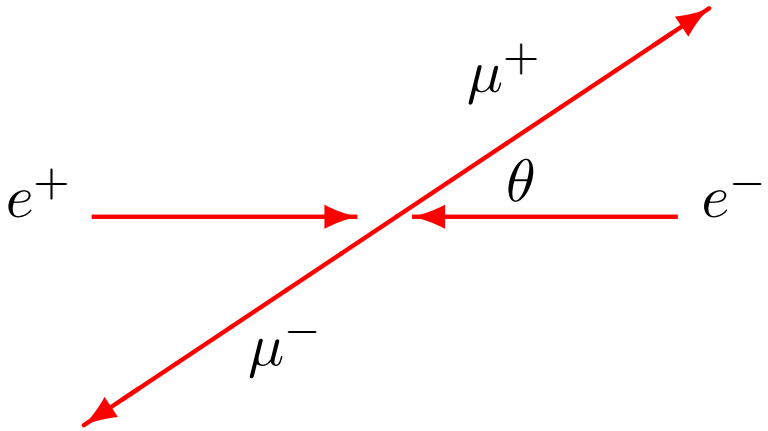
- Produced via the strong interaction
- 85% $q\bar{q} \to t\bar{t}$ + 15% $gg \to t\bar{t}$

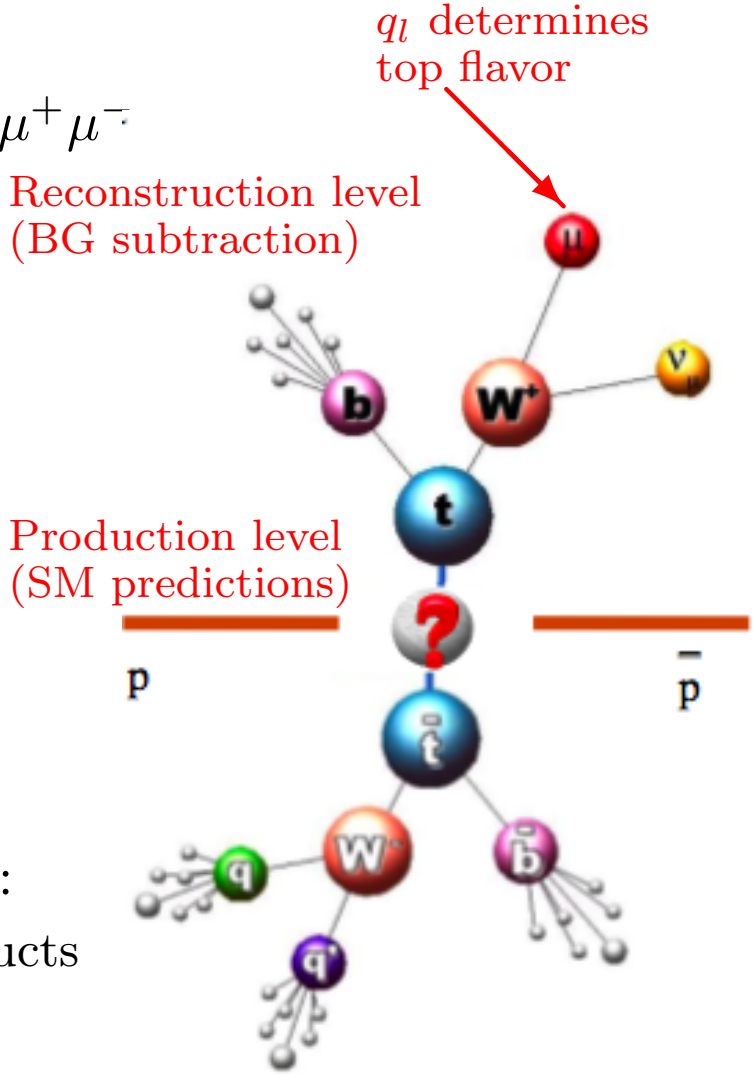


- Asymmetry arises from $q\bar{q} \to t\bar{t}$ initial states
- LHC complementary

Asymmetry in top-antitop quark production

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

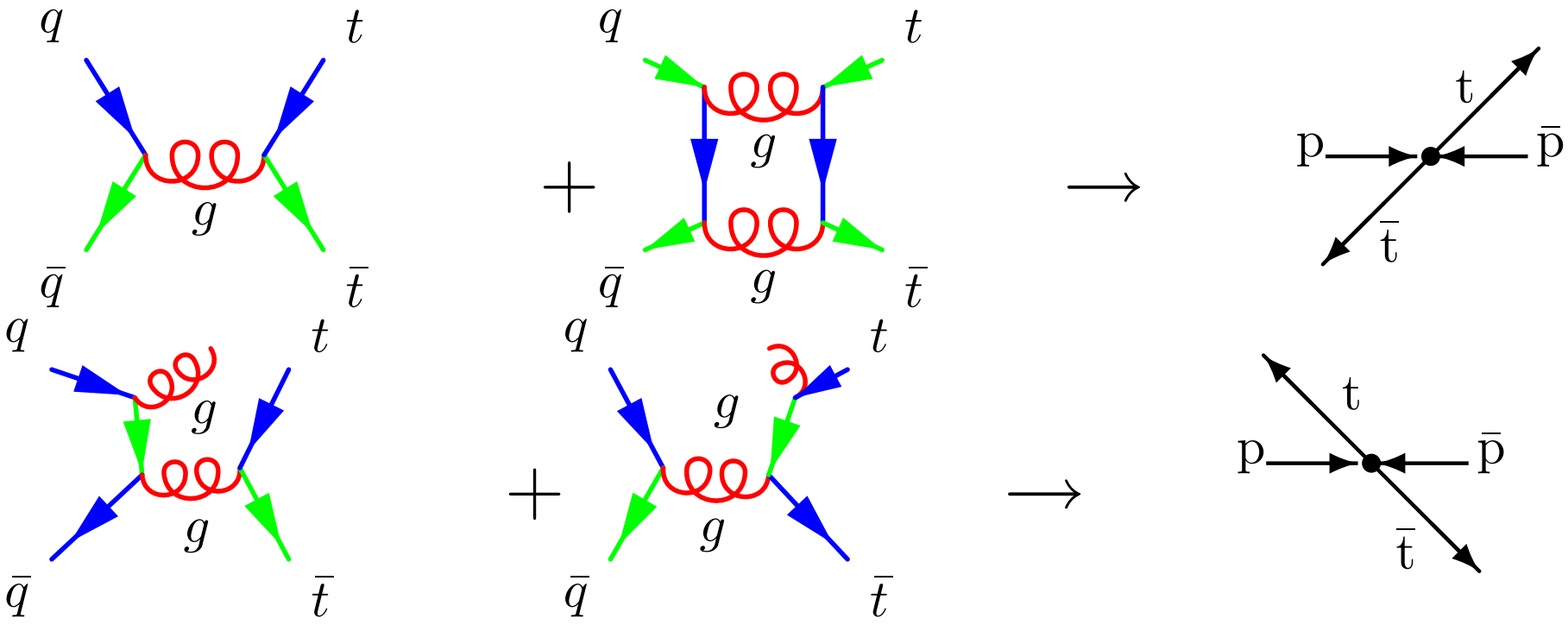




- What about in $p\bar{p} \to t\bar{t}$?
- $p\bar{p} \to t\bar{t}$ more complicated than $e^+e^- \to \mu^+\mu^-$:
  - Top quarks reconstructed from 6 decay products
  - $\Delta y = y_t - y_{\bar{t}} = q_l(y_{t,lep} - y_{t,had})$
- $A_{\rm FB} = \frac{N(\Delta y>0)-N(\Delta y<0)}{N(\Delta y>0)+N(\Delta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

Asymmetry in the standard model

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



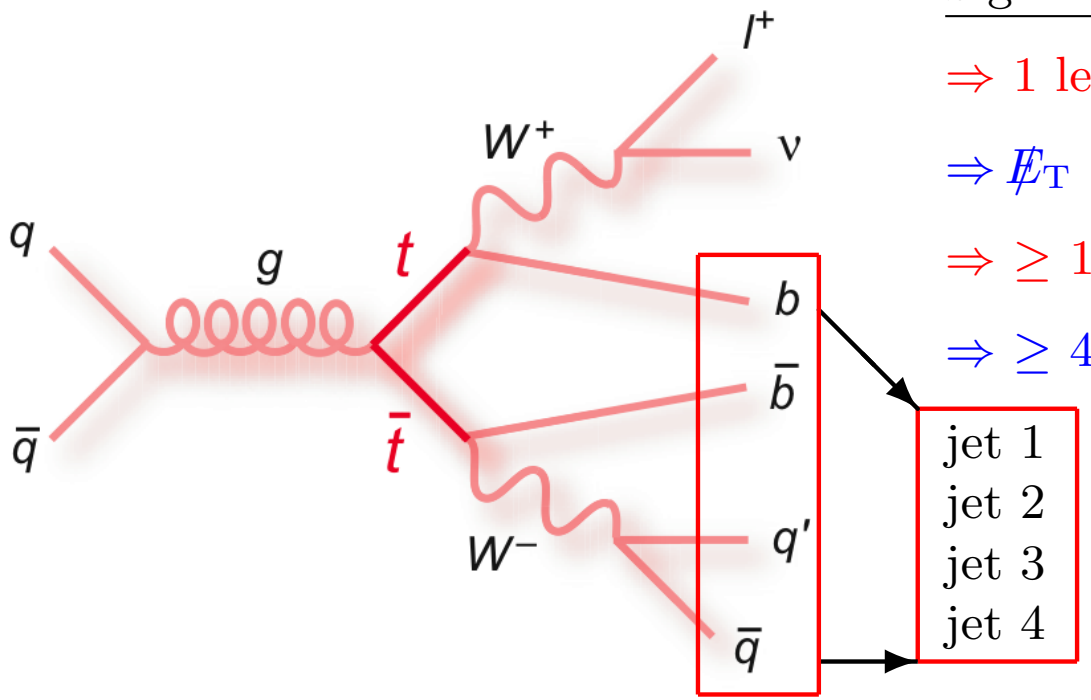
- Our predictions made at NLO in QCD via MC@NLO

Level	A_{FB} (%)
Production	5.0 ± 0.1
Reconstruction	2.4 ± 0.7

- Inclusive SM predictions vary from 5%-9%

Event Selection and Reconstruction

- Search in the lepton (e/μ) + jets channel



Signature of decay in detector:

$\Rightarrow$ 1 lepton

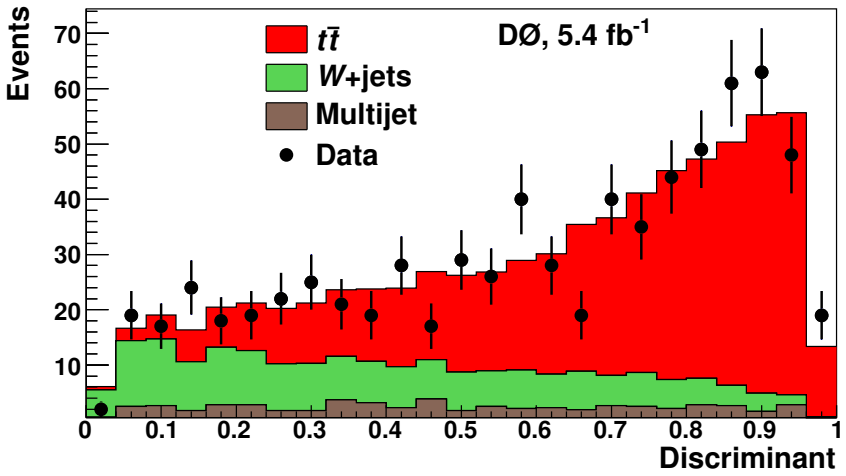
$\Rightarrow \not{E}_T$ from ν

$\Rightarrow \geq$ 1 b-tagged jet

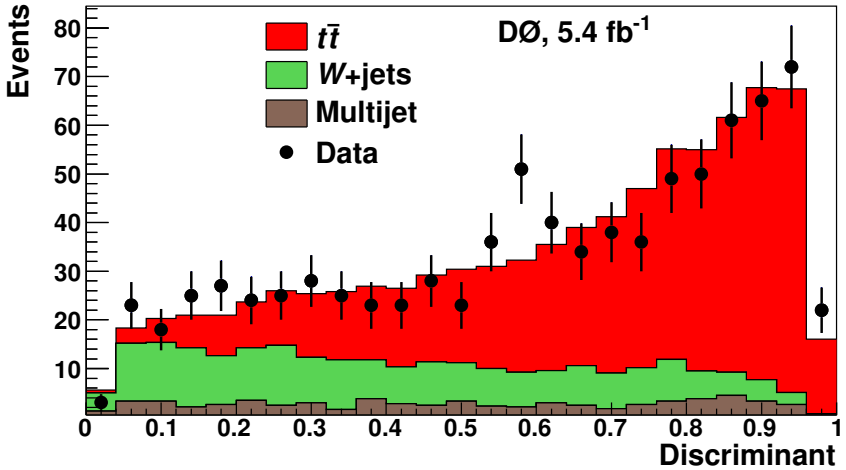
$\Rightarrow \geq$ 4 jets

- Reconstruct events with a constrained kinematic fit
  - $m_W = 80.4$ GeV
  - $m_t = 172.5$ GeV
- Keep only assignment with lowest χ^2
- 1581 events pass selection for 5.4 fb^{-1}

Maximum Likelihood Fit



Discriminant with $\Delta y < 0$



Discriminant with $\Delta y > 0$

Signal:

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

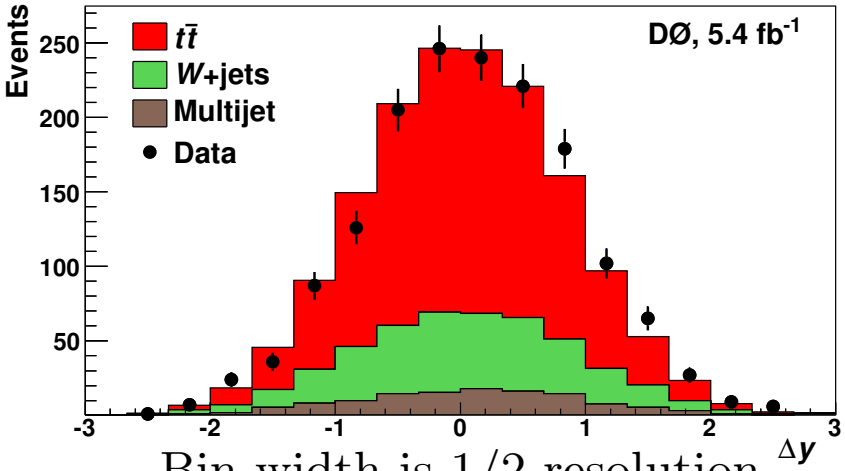
$A_{\mathrm{FB}} = (9.2 \pm 3.7)\,\%$

Backgrounds:

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

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

Results from reconstruction of A_{FB}

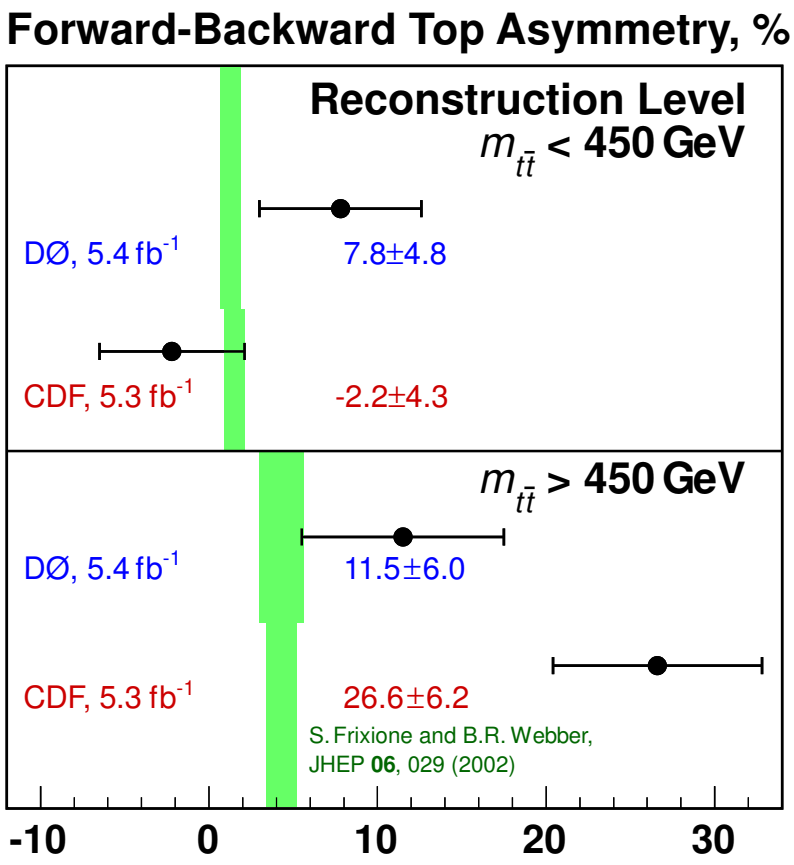


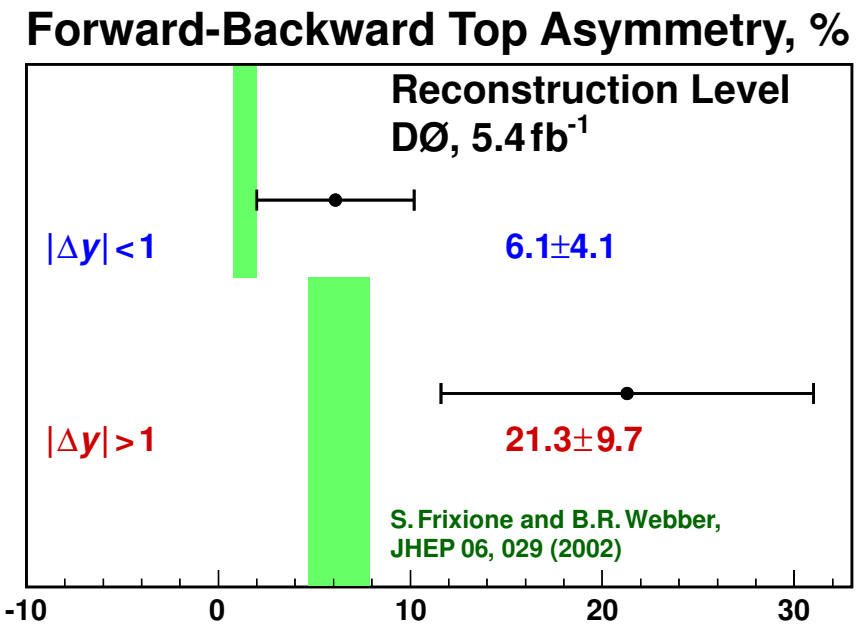
Bin width is 1/2 resolution

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

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

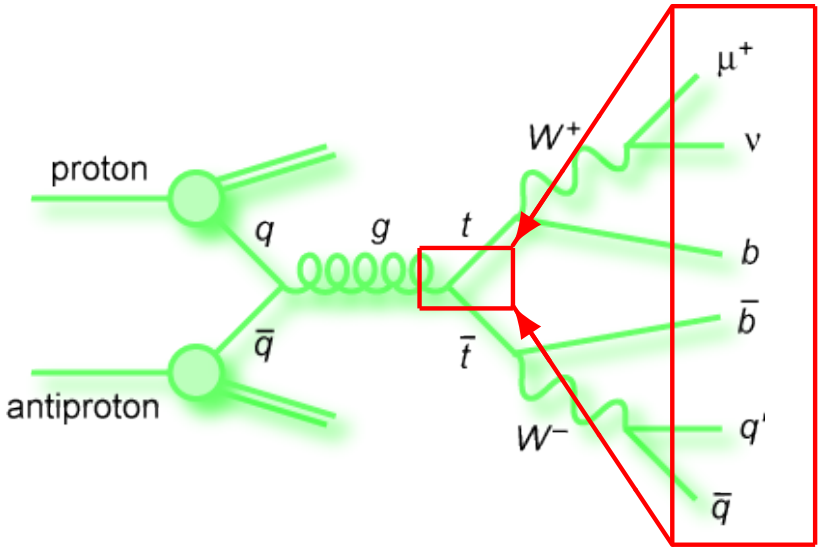
Dependence of A_{FB} on $m_{t\bar{t}}$ and $|\Delta y|$

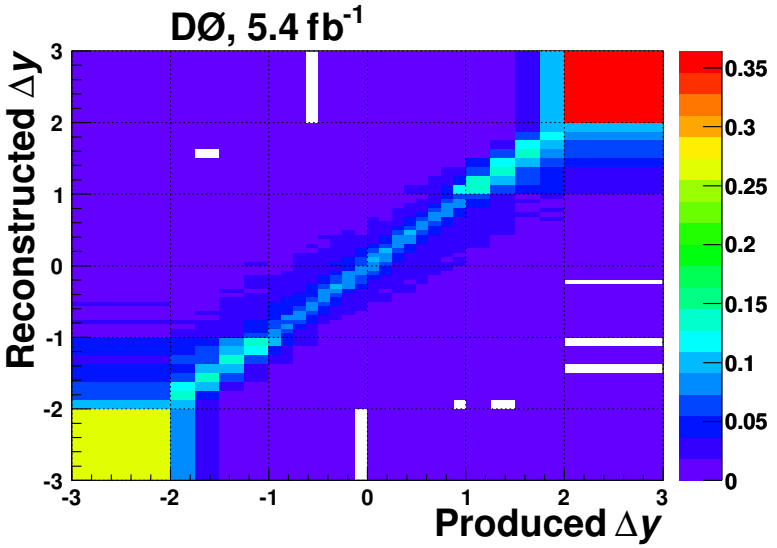




- No significant dependence of A_{FB} on $m_{t\bar{t}}$

Unfolding

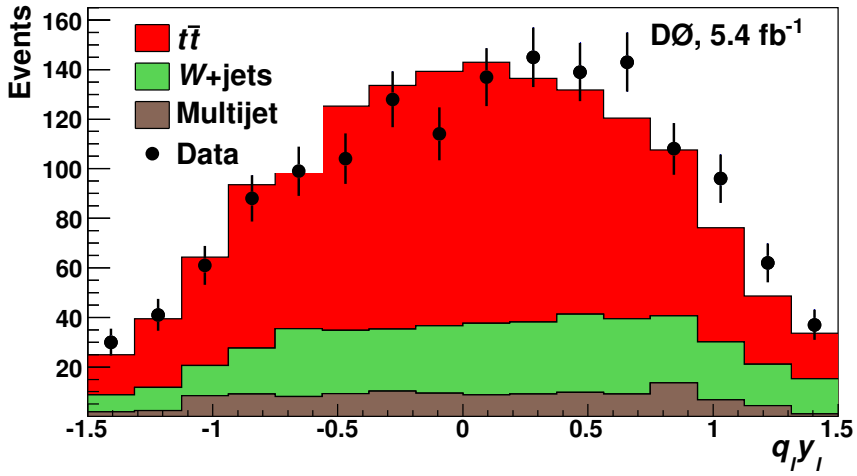




$$\text{Unfolded } A_{\text{FB}} = \left(19.6 \pm 6.0(\text{stat})^{+1.8}_{-2.6}(\text{syst})\right)\%$$

- Regularized unfolding via TUnfold (in ROOT) with 50 → 26 bins in Δy
  - Regularize on curvature of event density
- Cross-checked with four bin ML unfolding
- Better statistical strength using regularized unfolding
- Statistical significance relative to MC@NLO prediction: 2.4 SD

Lepton-based asymmetry

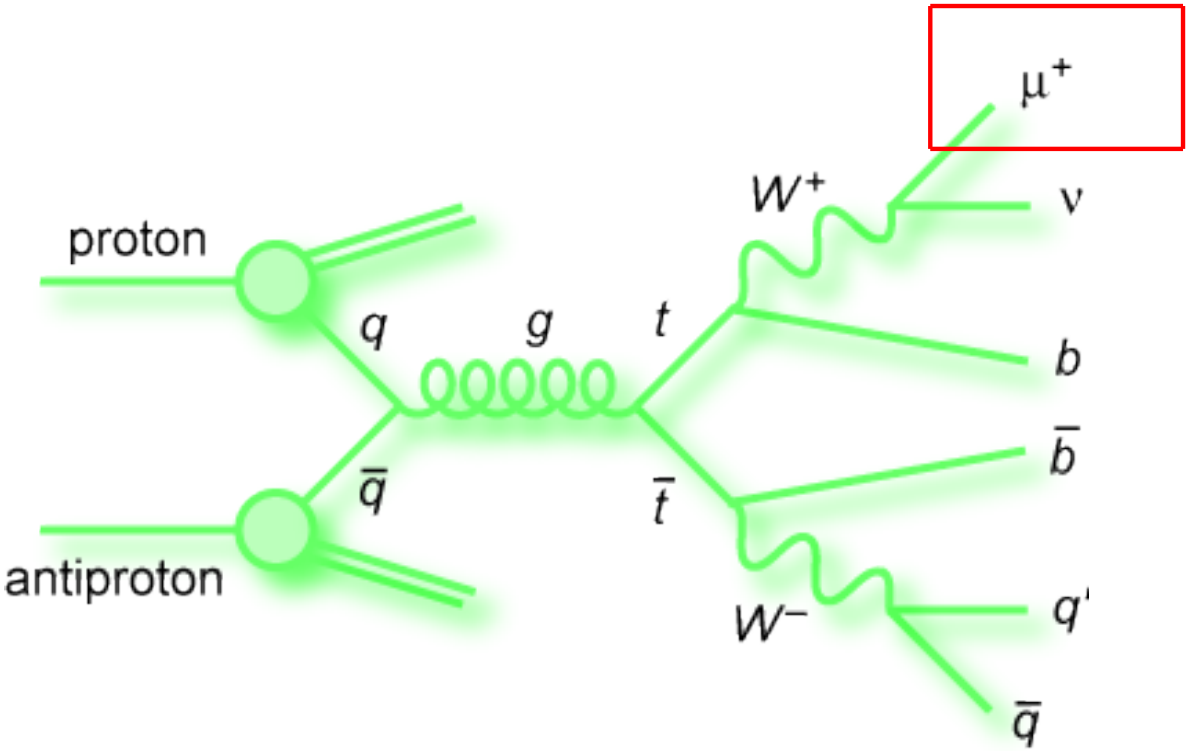


$$A^l_{\rm FB} = \frac{N(q_l y_l > 0) - N(q_l y_l < 0)}{N(q_l y_l > 0) + N(q_l y_l < 0)}$$

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

	l+≥4 jets	l+4 jets	l+≥5 jets
$A^l_{\rm FB}$ (%)	14.2± 3.8	15.9± 4.3	7.0± 8.0
MC@NLO $A^l_{\rm FB}$ (%)	0.8± 0.6	2.1± 0.6	-3.8± 1.2

Unfolding A^l_{FB}



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

- Production level MC@NLO prediction: $A^l_{\mathrm{FB}} = (2.1 \pm 0.1)\,\%$
- Migrations are very small → correct only for acceptance
- Statistical significance relative to MC@NLO prediction: 3.4 SD

Systematic uncertainties

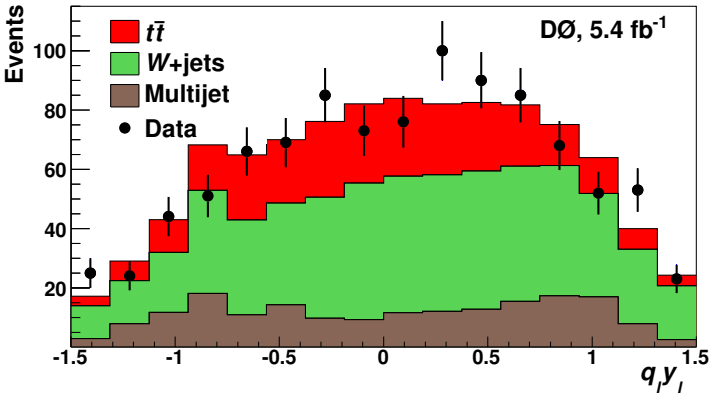
Measurement dominated by statistical uncertainties

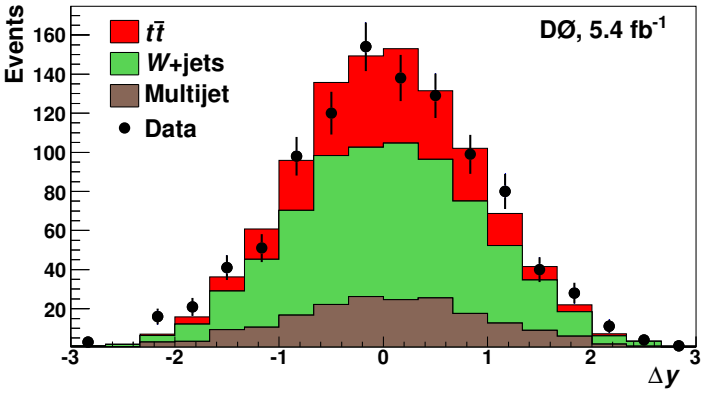
	Absolute uncertainty on A_{FB} (%)		
	Reco. level		Prod. level
Source	Prediction	Measurement	Measurement
Jet reco	± 0.3	± 0.5	± 1.0
JES/JER	$+0.5$	-0.5	-1.3
Signal modeling	± 0.3	± 0.5	$+0.3/-1.6$
b-tagging	-	± 0.1	± 0.1
Charge ID	-	$+0.1$	$+0.2/-0.1$
Bg subtraction	-	± 0.1	$+0.8/-0.7$
Unfolding Bias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

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

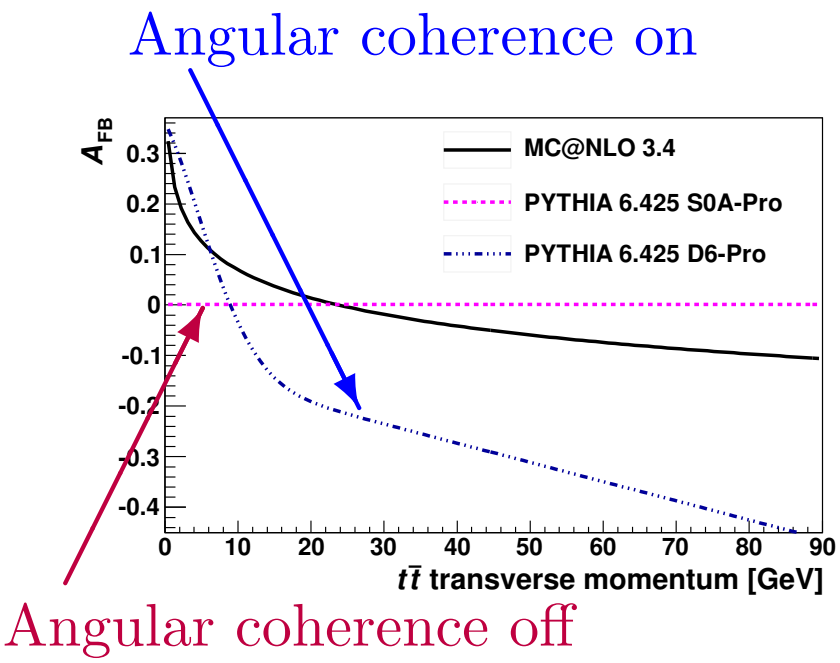


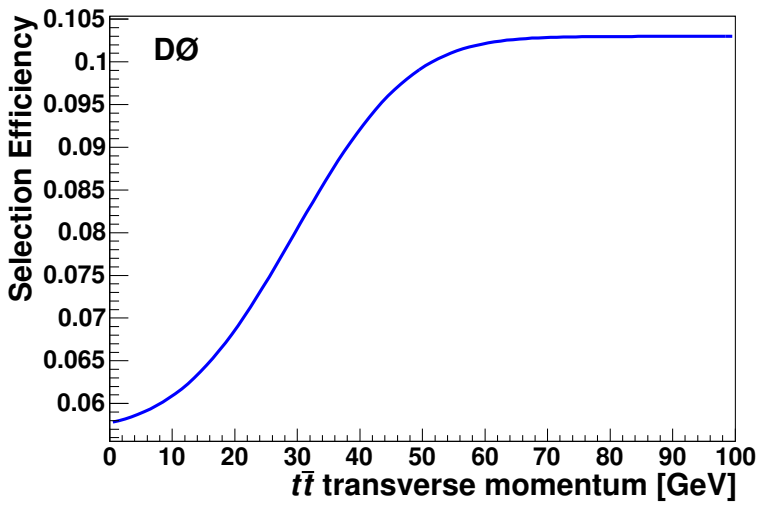


- Checked A_{FB} by solenoid and toroid polarities
  - Found no significant dependence
- Checked A_{FB} by lepton charge
  - Found no significant dependence
- Good agreement between e+jets and μ+jets

A_{FB} and top pair p_T

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

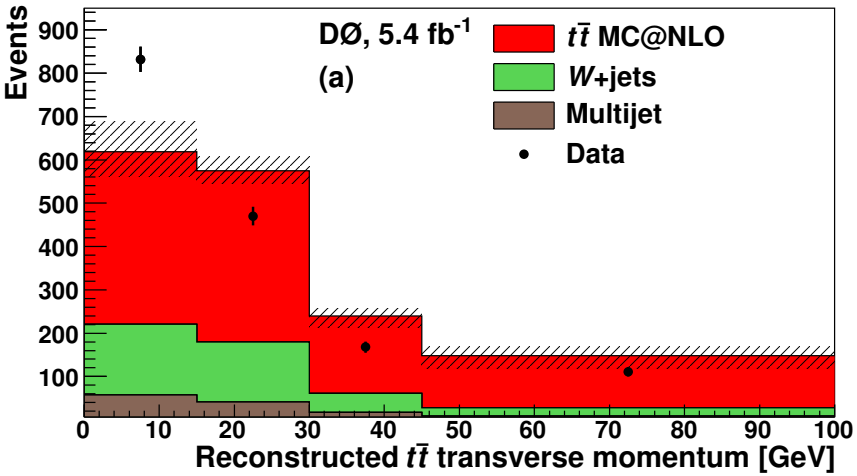


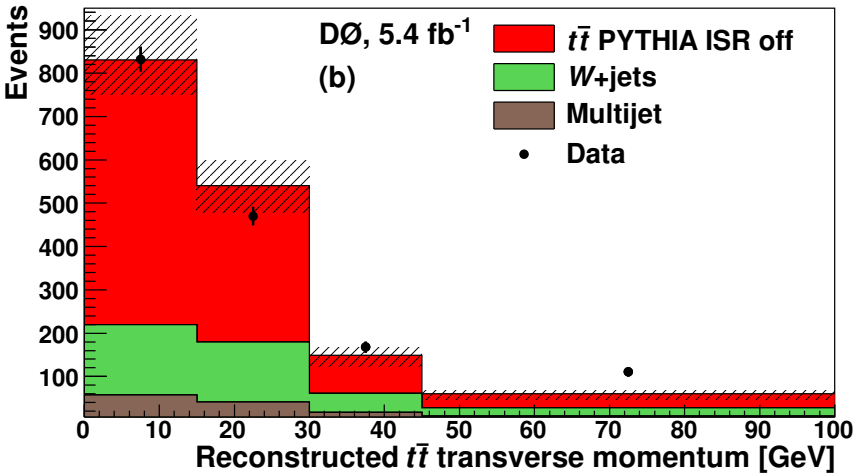


- If correlation exists, backward events selected more often than forward events
- Effect on measurement is included in systematics: -1.6%
- What is effect on prediction?

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}?

MC@NLO = SM?

- Predicted A_{FB} from $t\bar{t}j$ production changes from $\sim -7\%$ at α_s^3 to -1.5% at α_s^4.

  S. Dittmaier, P. Uwer, and S. Weinzierl, Phys. Rev. Lett. **98**, 262002 (2007).

- Others argue this will not change the inclusive asymmetry.

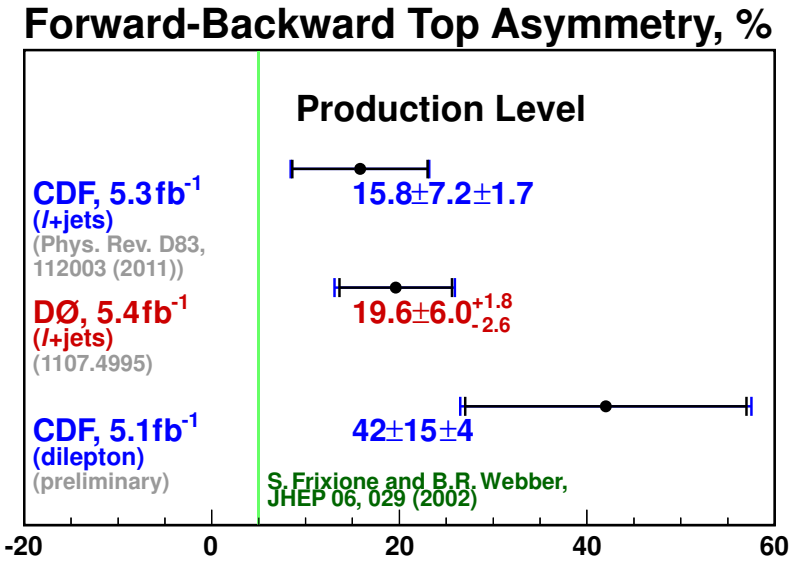
  K. Melnikov and M. Schulze, Nucl. Phys. B **840**, 129 (2010).

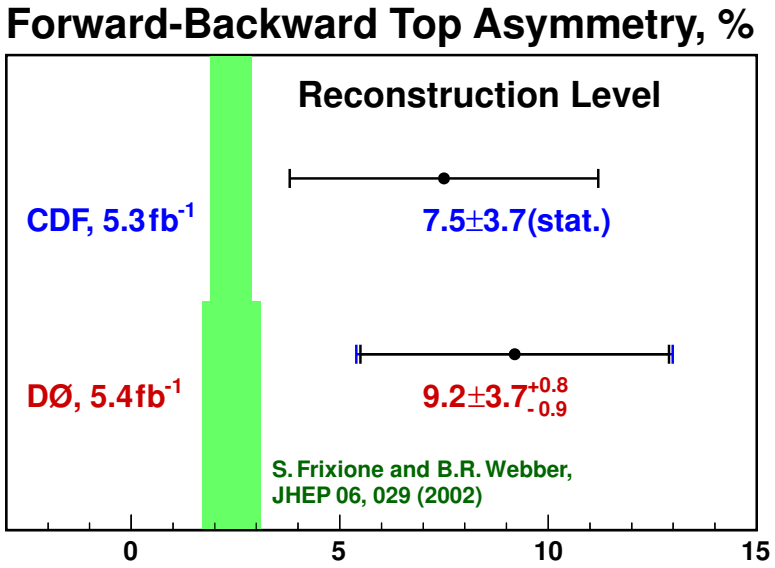
- Including EW contributions boosts A_{FB} to $\sim$9%.

  W. Hollik and D. Pagani, arXiv:1107.2606 [hep-ph].

- We choose one particular generator: MC@NLO
- Will future MC generators predict other A_{FB}?

Summary



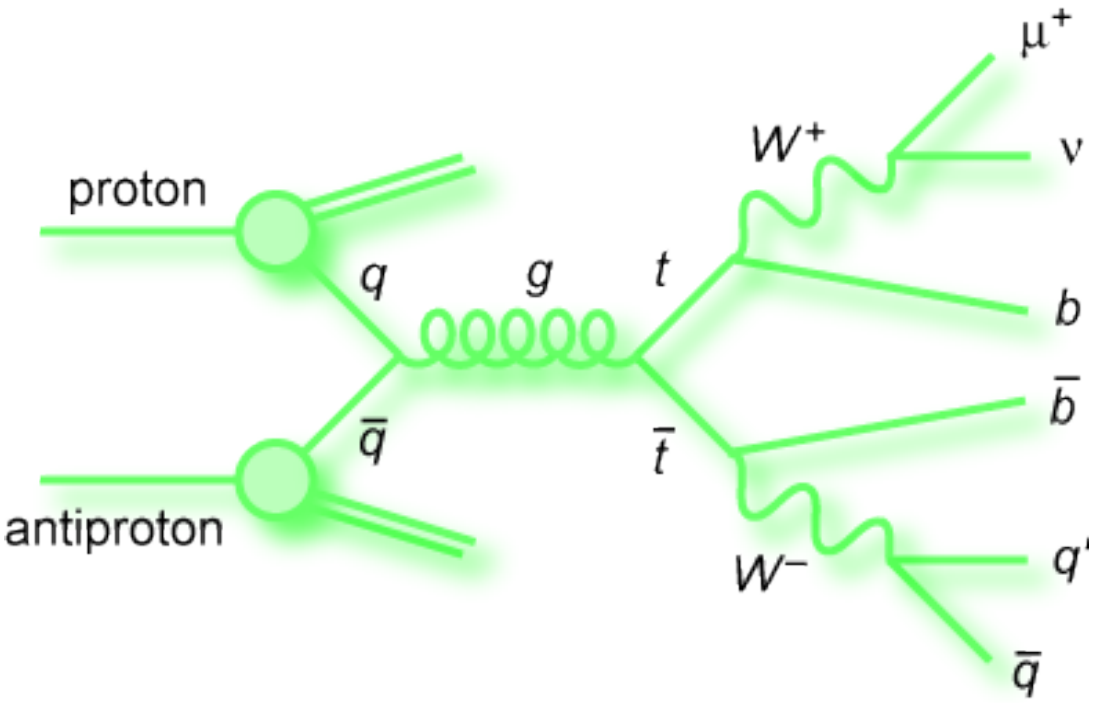


- Inclusive results in agreement between DØ and CDF
- But deviate from predictions
- Measure no significant dependencies of A_{fb} on either $m_{t\bar{t}}$ or $|\Delta y|$
- Unfolded $A^l_{\mathrm{FB}} = \left(15.2 \pm 3.8(\mathrm{stat})^{+1.0}_{-1.3}(\mathrm{syst})\right)\%$
- Compare to MC@NLO, but 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 χ^2 for each jet permutation.



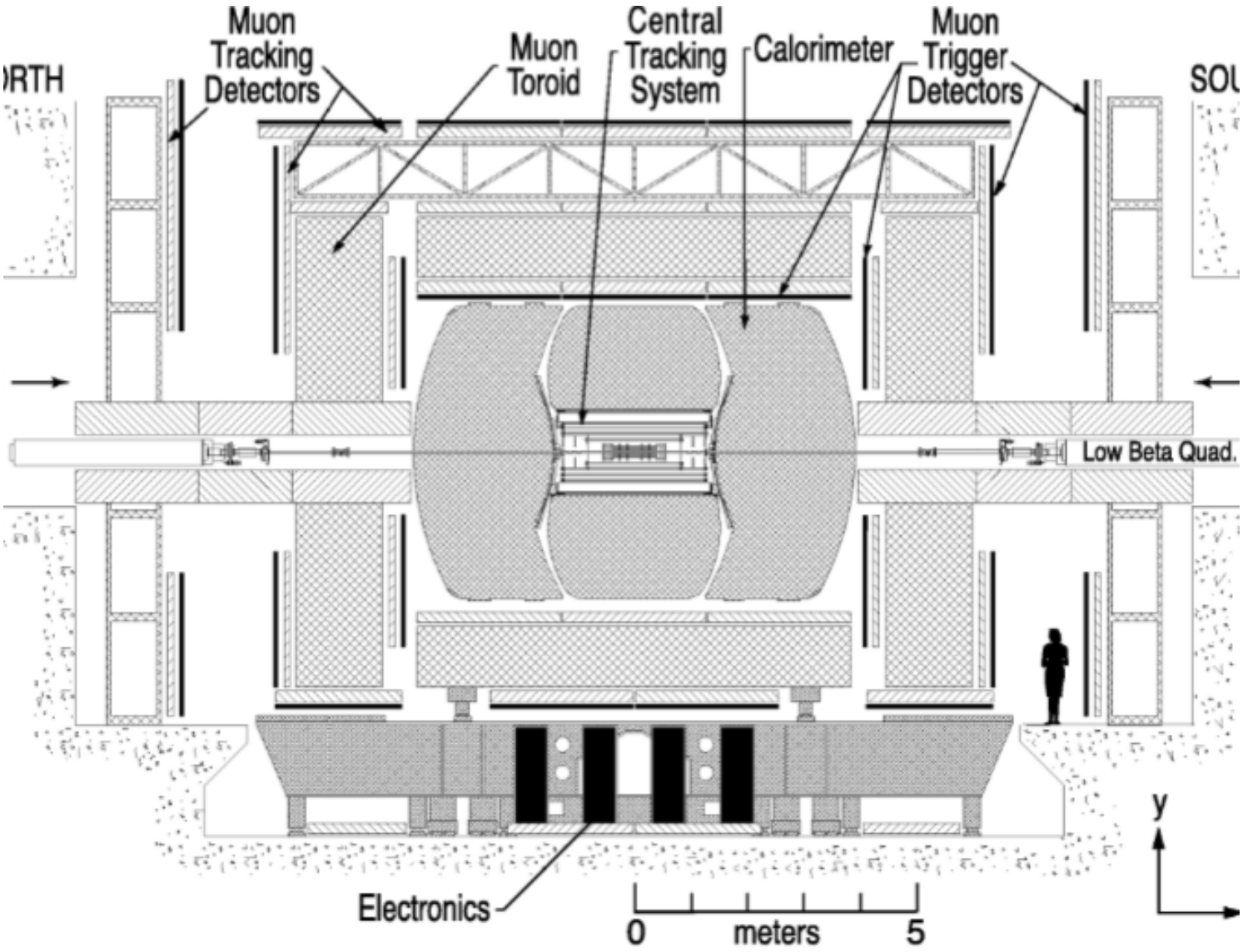
Reconstructed A_{FB} table

	l+≥4 jets	e+≥4 jets	μ+≥4 jets	l+4 jets	l+≥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±39	622±28	502±28	902±36	218±16
N_W	376±39	173±28	219±27	346±36	35±16
N_{MJ}	79±5	56±3	8±2	66±4	13±2
A_{FB}(%)	9.2±3.7	8.9±5.0	9.1±5.8	12.2±4.3	-3.0±7.9
MC@NLO A_{FB} (%)	2.4±0.7	2.4±0.7	2.5±0.9	3.9±0.8	-2.9±1.1

Reconstructed A^l_{FB} table

	l+≥4 jets	e+≥4 jets	μ+≥4 jets	l+4 jets	l+≥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^l_{FB} (%)	14.2± 3.8	16.5± 4.9	9.8± 5.9	15.9± 4.3	7.0± 8.0
MC@NLO A^l_{FB} (%)	0.8± 0.6	0.7± 0.6	1.0± 0.8	2.1± 0.6	-3.8± 1.2

DØ detector


Muon Tracking Detectors
Muon Toroid
Central Tracking System
Calorimeter
Muon Trigger Detectors
Low Beta Quad.
Electronics
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