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

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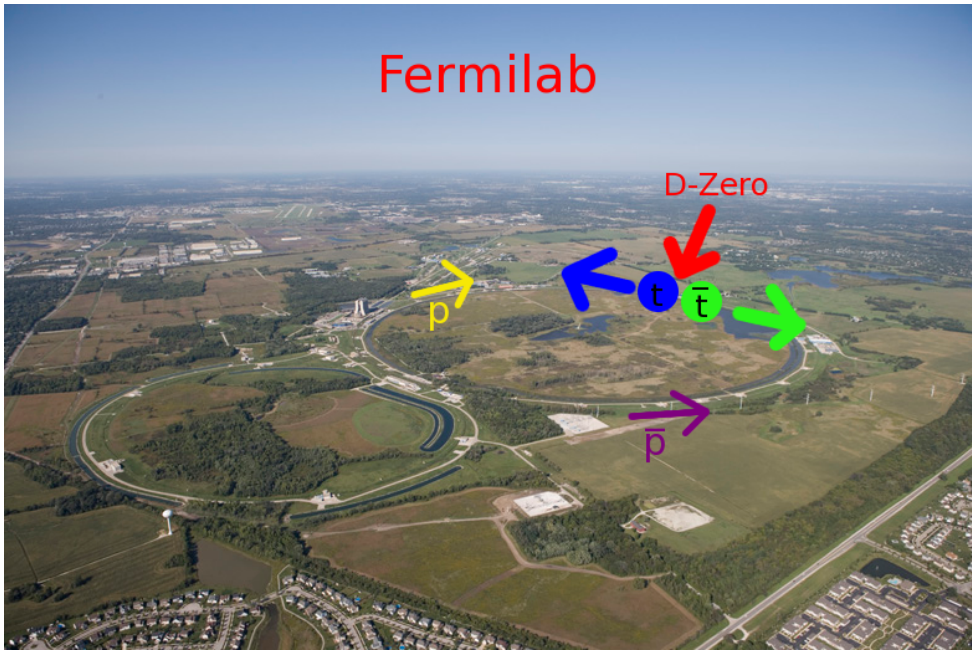
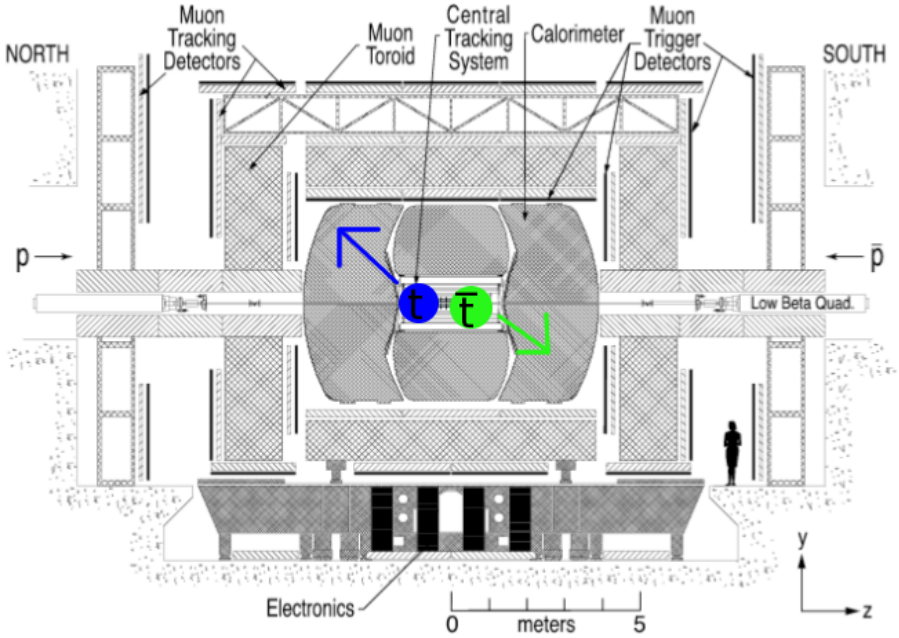
Basic Analysis

- Analyzing 5.4 fb^{-1} of data
- Asking whether the top quark is produced more often in the direction of the proton than the antiproton
- Measure $\Delta y = y_t - y_{\bar{t}}$, where $y = \frac{1}{2} ln(\frac{E+p_z}{E-p_z})$.
- $A_{fb} = \frac{N(\Delta y>0)-N(\Delta y<0)}{N(\Delta y>0)+N(\Delta y<0)}$

Aerial View of Tevatron

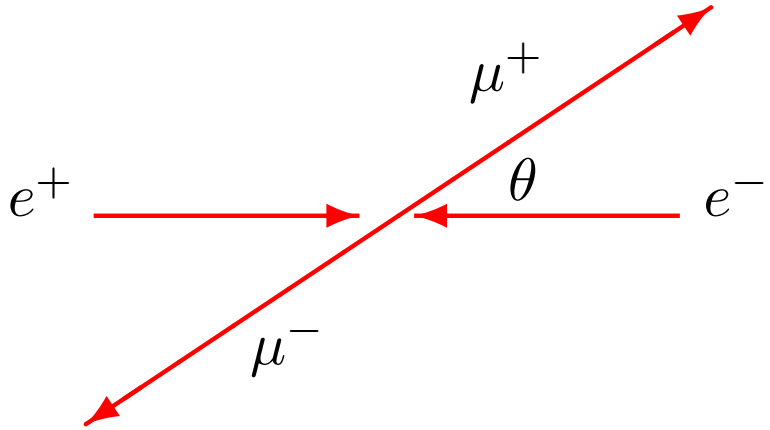


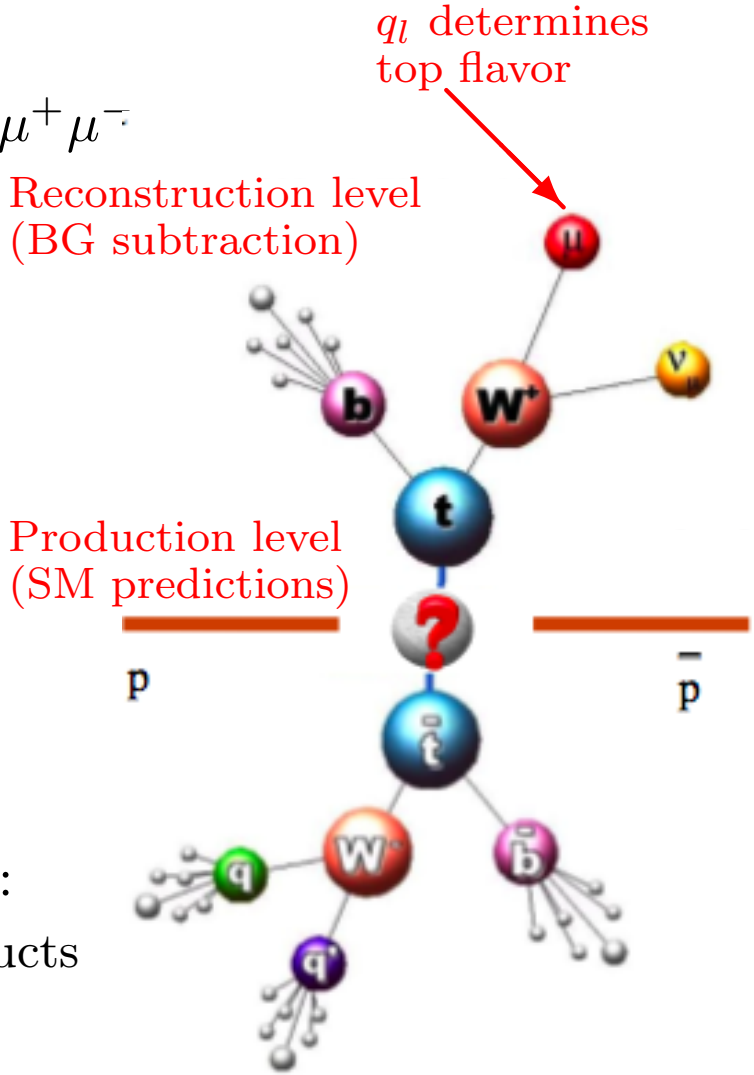
Side view of DØ Detector



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))



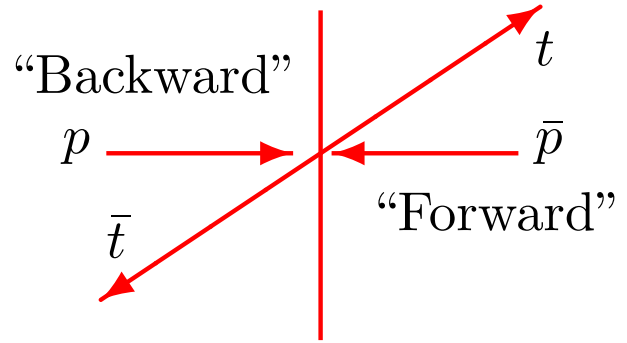


- What about in $p\bar{p} \to t\bar{t}$?
- $p\bar{p} \to t\bar{t}$ more complicated than $e^+e^- \to \mu^+\mu^-$:
  - Top quarks reconstructed from 6 decay products
  - $\Delta y = y_t - y_{\bar{t}} = q_l(y_{t,lep} - y_{t,had})$
- $A_{\rm FB} = \frac{N(\Delta y>0)-N(\Delta y<0)}{N(\Delta y>0)+N(\Delta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

Definitions

- Does top quark or antitop quark follow direction of proton?
- For $p\bar{p} \to t\bar{t}$, use $y = \frac{1}{2} ln(\frac{E+p_z}{E-p_z})$:
  - Define $\Delta y = y_t - y_{\bar{t}}$
  - Δy invariant to boosts along beamline
  - Reconstructed $\Delta y = q_l \cdot (y_{t,lep} - y_{t,had})$

$$A_{FB} = \frac{N(\Delta y>0) - N(\Delta y<0)}{N(\Delta y>0) + N(\Delta y<0)}$$



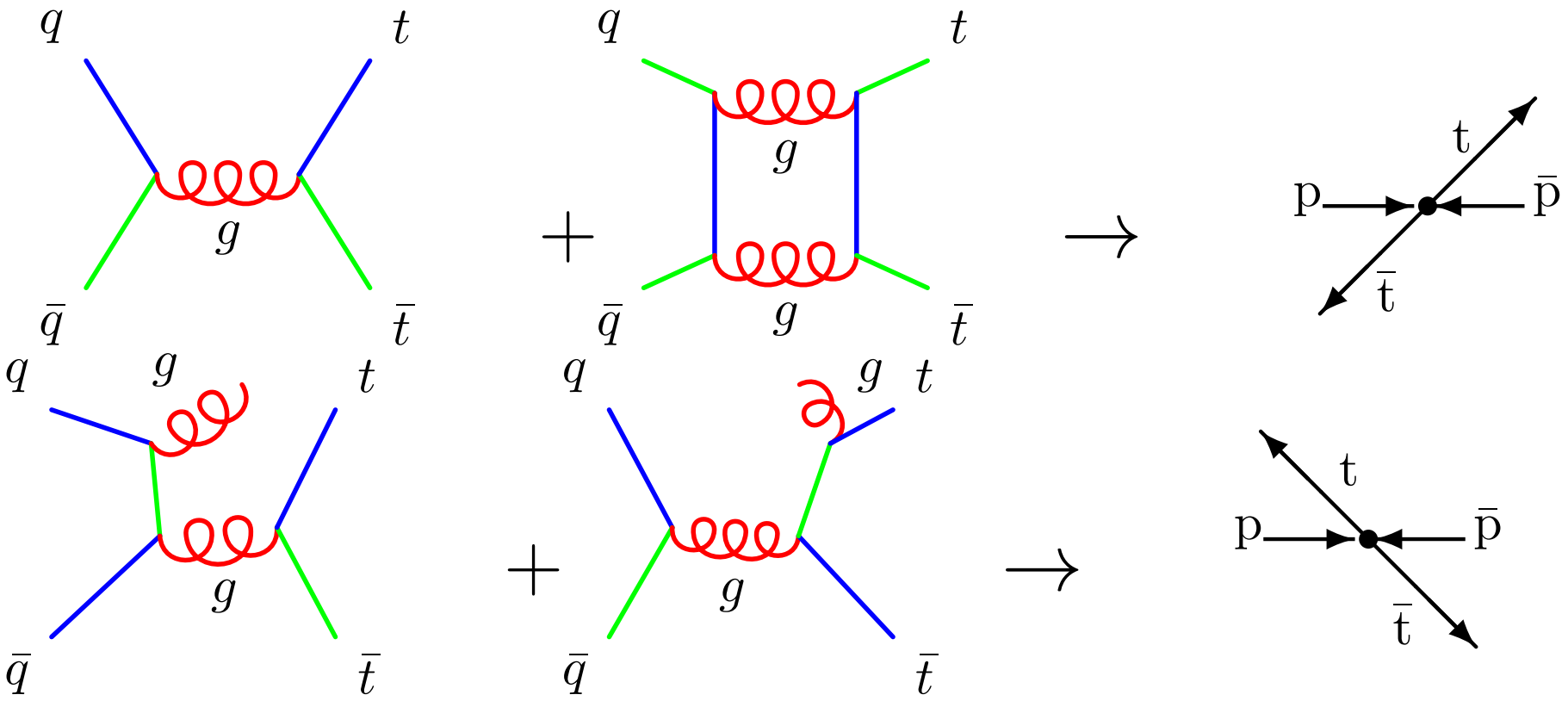
- Also use asymmetry based on lepton from top decay:
  - Very good precision
  - Simple

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

- Two different types of measurements:
  - Reconstruction level: After selection and reconstruction. Background subtracted data.
  - Production level: Can be directly compared to SM predictions. Unfolding.

Asymmetry in the standard model

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



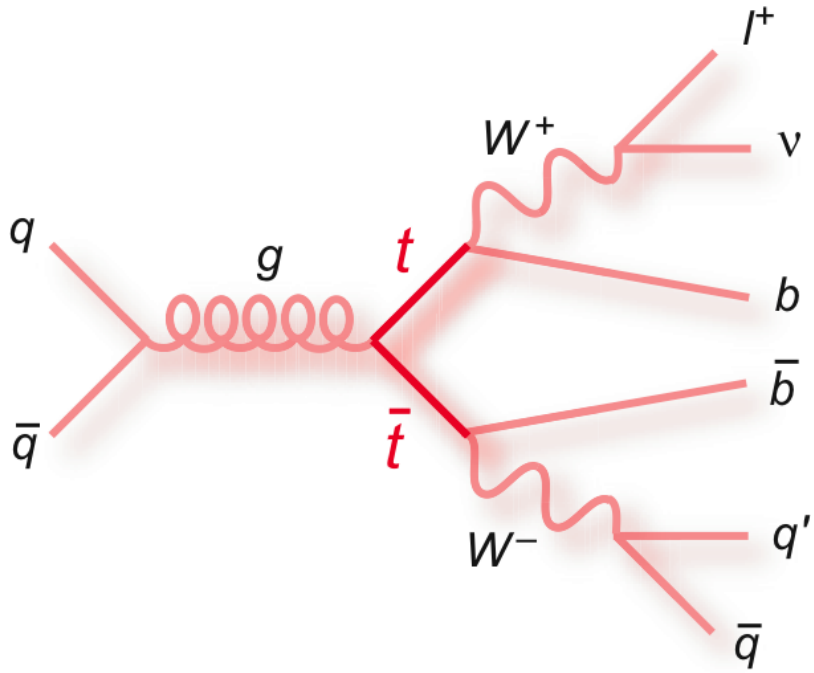
- Our predictions made at NLO in QCD via MC@NLO

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

- Inclusive SM predictions vary from 7%-9%

Event Selection and Reconstruction

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



Require:

$\Rightarrow$ 1 lepton

$\Rightarrow \not\!\!E_{\mathrm{T}}$

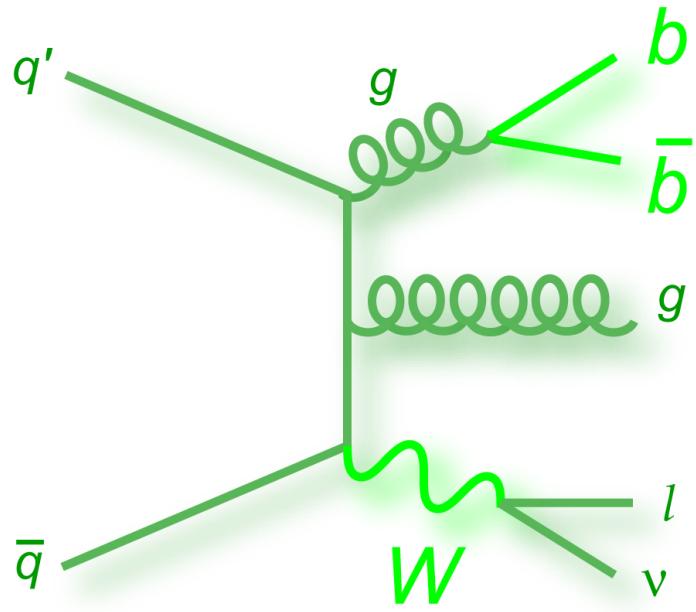
$\Rightarrow \geq$ 4 jets

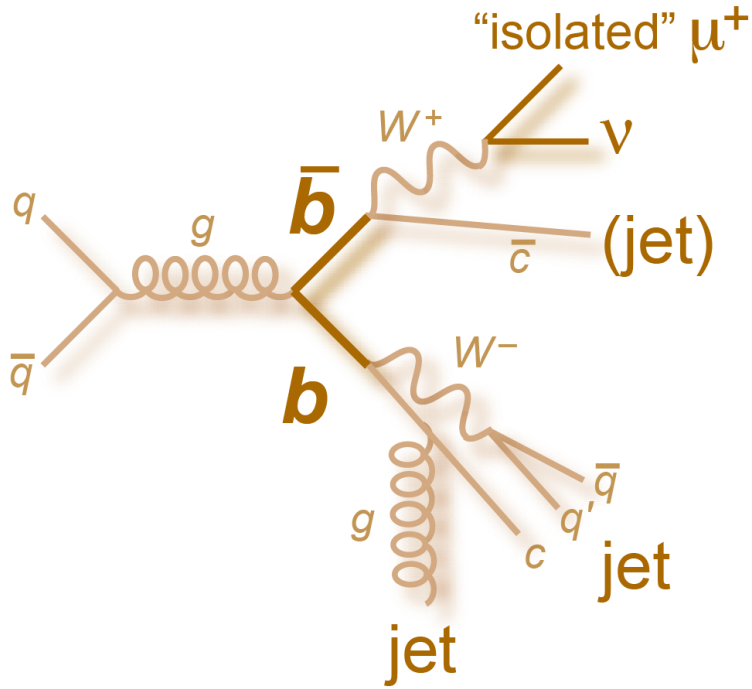
$\Rightarrow \geq$ 1 b-tagged jet

- 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}

Backgrounds

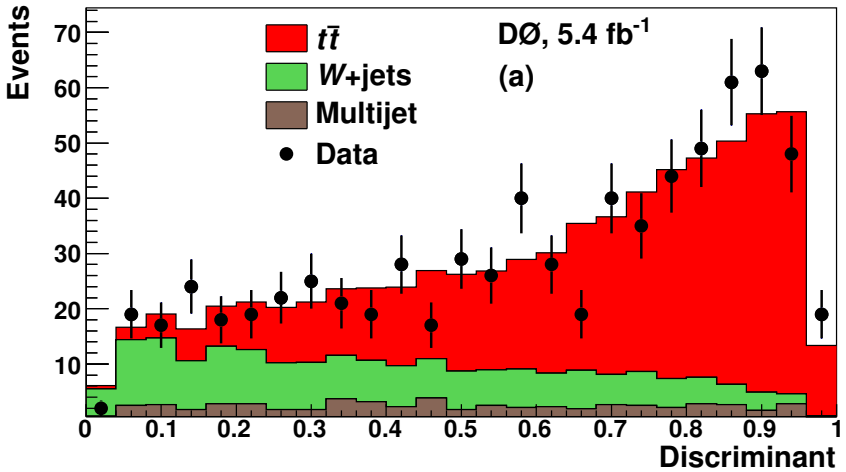
- Two main sources of background with similar signature to $t\bar{t}$ events:
  - W+jets - Production of W in association with jets; simulated with ALPGEN+PYTHIA
  - Multijet - Taken from data



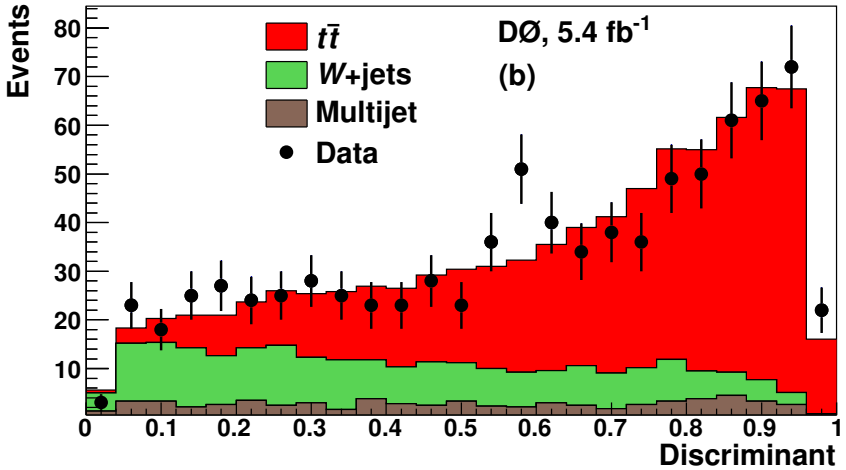


- For $A_{\rm FB}$, both backgrounds are close to symmetric
- For $A^l_{\rm FB}$, W+jets is highly asymmetric
- Other small backgrounds approximated as W+jets: single top, diboson and Z+jets

Maximum Likelihood Fit



Discriminant with $\Delta y < 0$



Discriminant with $\Delta y > 0$

Signal:

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

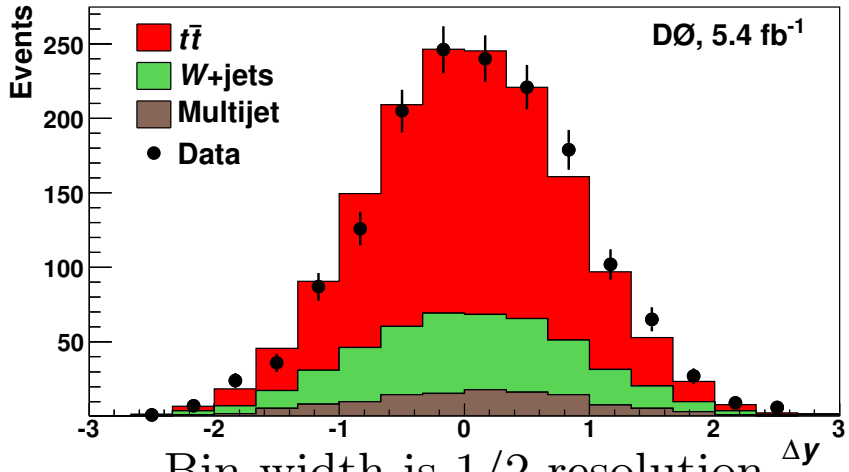
$A_{FB} = (9.2 \pm 3.7)\,\%$

Backgrounds:

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

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

Results from reconstruction of $A_{\rm FB}$

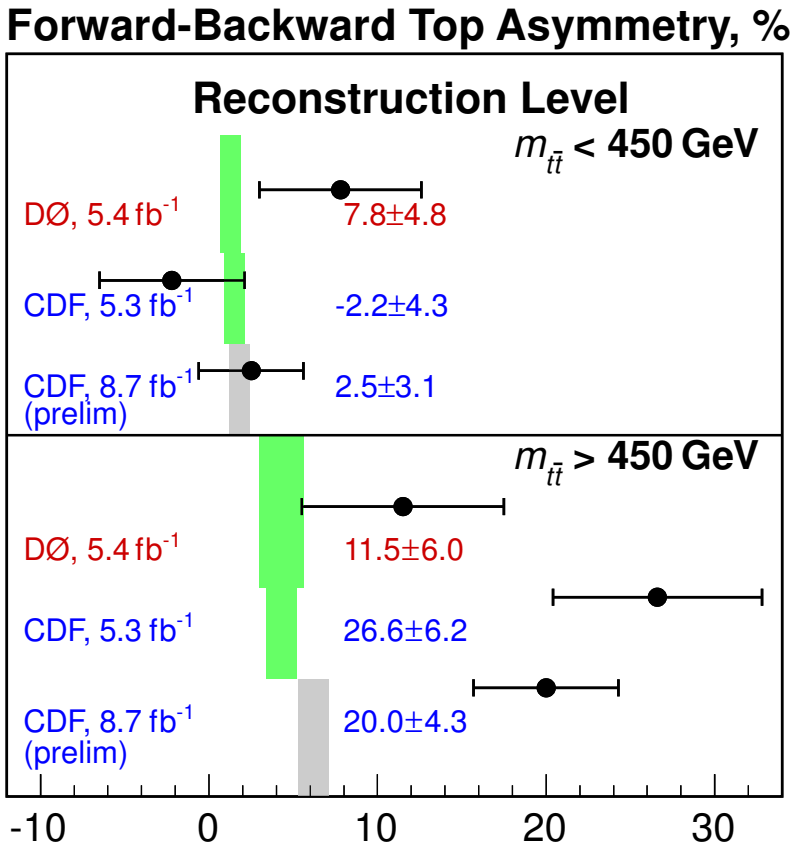


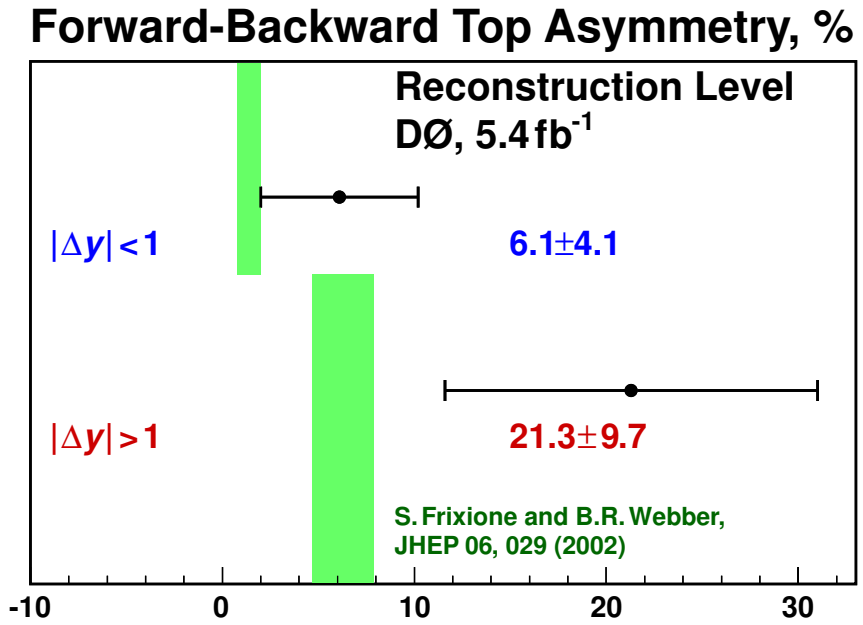
Bin width is 1/2 resolution

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

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

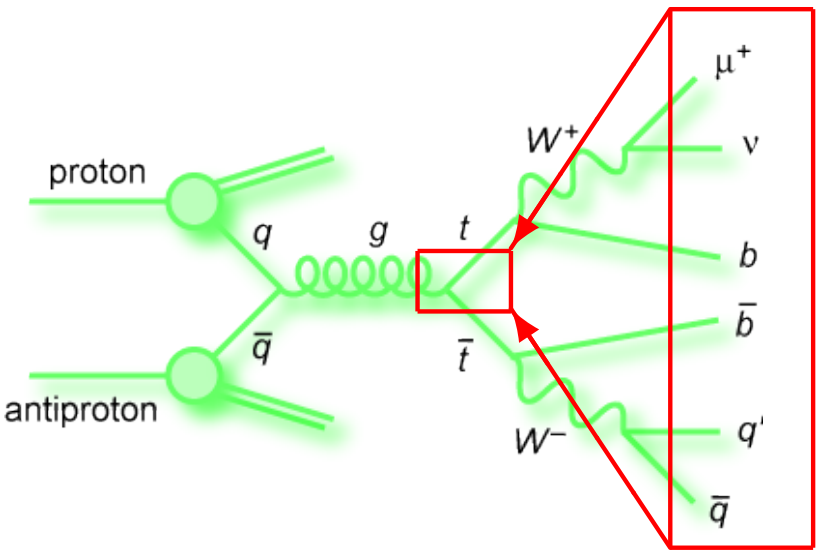
Dependence of $A_{\rm FB}$ on $m_{t\bar{t}}$ and $|\Delta y|$

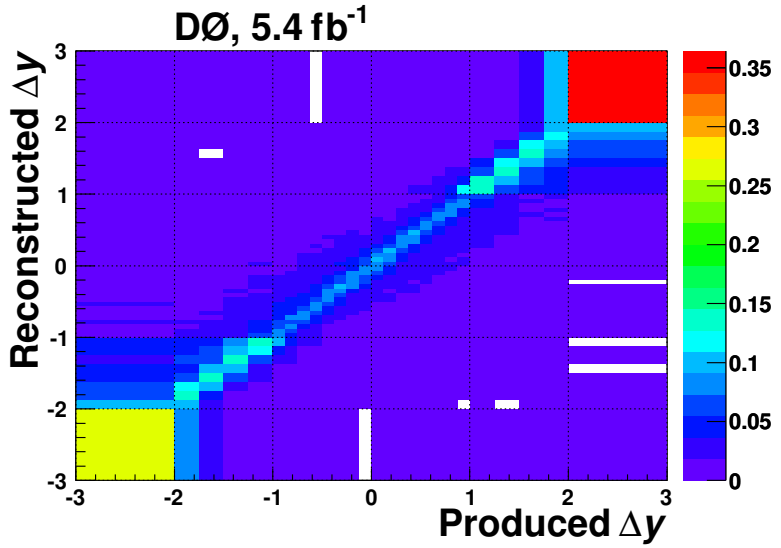




- No significant dependence of $A_{\rm FB}$ on $m_{t\bar{t}}$

Unfolding

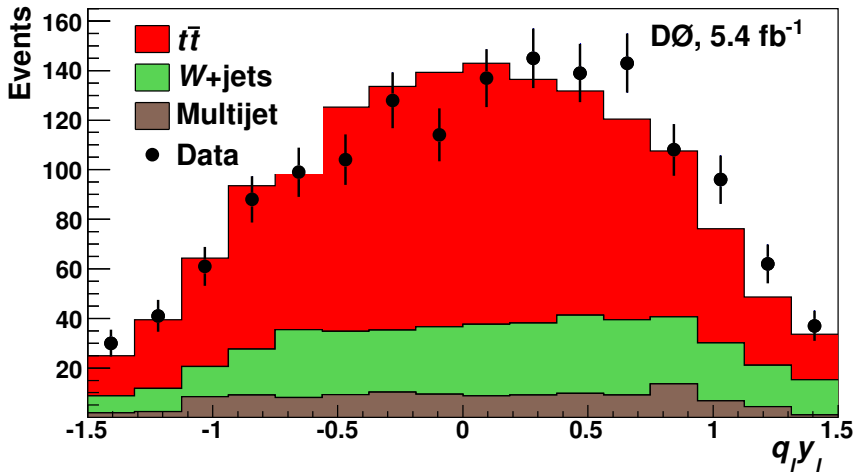




$$\text{Unfolded } A_{\text{FB}} = \left(19.6 \pm 6.0(\text{stat})^{+1.8}_{-2.6}(\text{syst})\right)\,\%$$

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

Lepton-based asymmetry

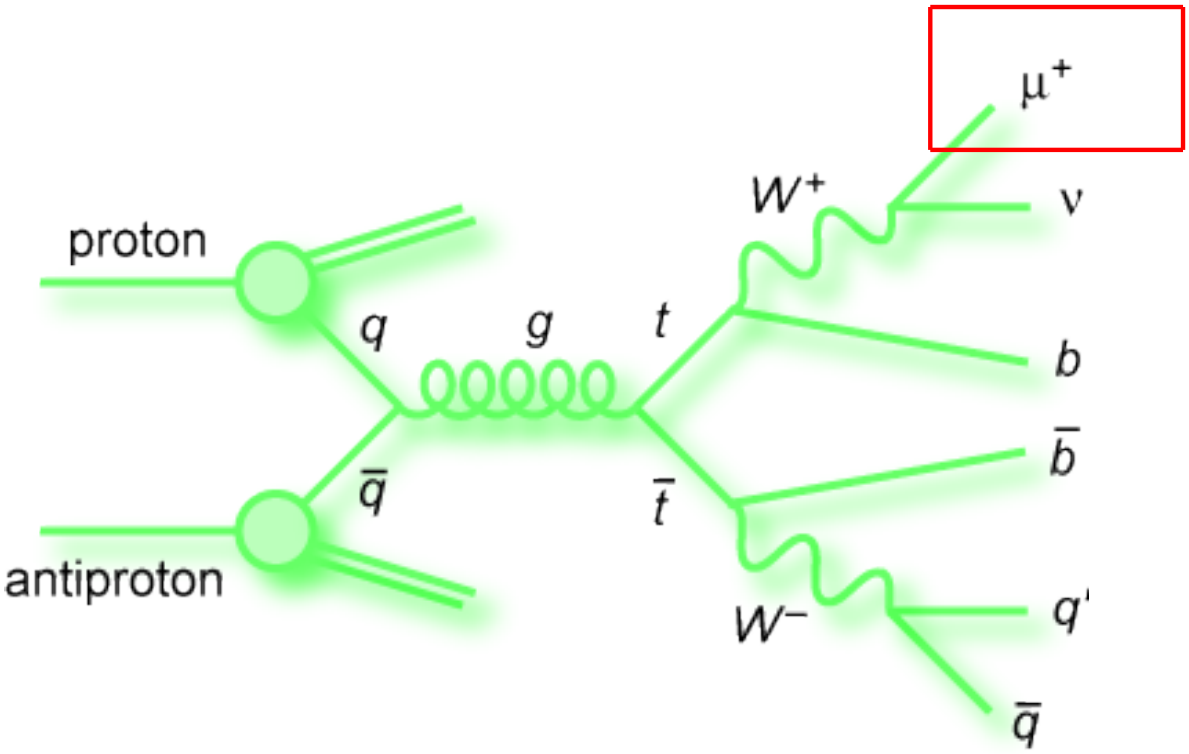


$$A_{\rm FB}^{l} = \frac{N(q_l y_l > 0) - N(q_l y_l < 0)}{N(q_l y_l > 0) + N(q_l y_l < 0)}$$

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

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

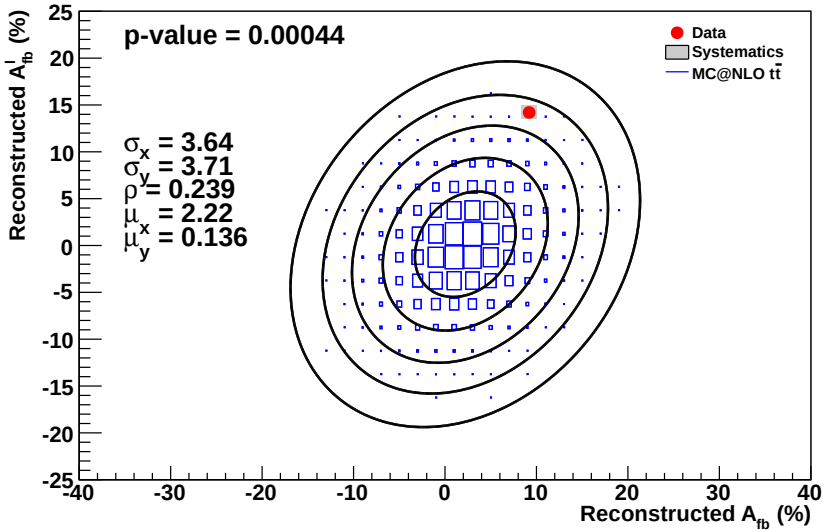
Unfolding $A_{\rm FB}^{l}$

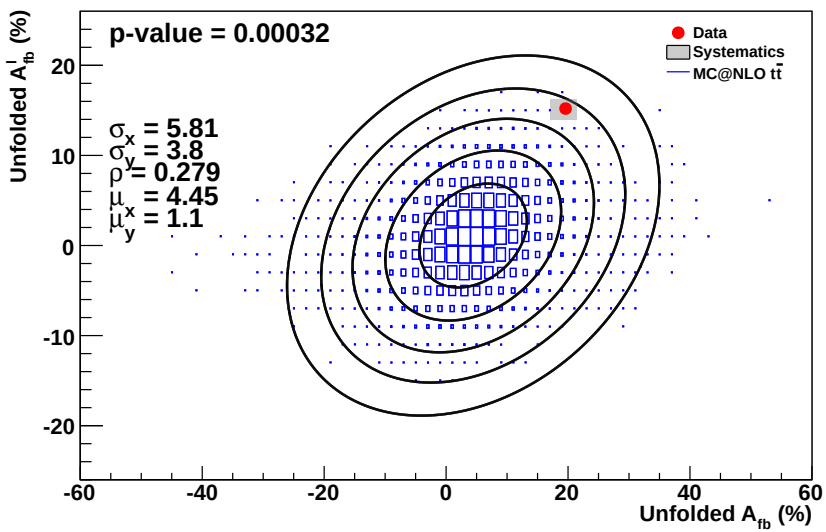


$$\text{Unfolded } A_{\rm FB}^{l} = \left(15.2 \pm 3.8(\text{stat})^{+1.0}_{-1.3}(\text{syst})\right)\%$$

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

Correlation Plots





- 100,000 pseudo experiments made from signal and background simulation
- Results from actual experiment shown in red
- Left: Detector level results; Right: Unfolded results

Systematic uncertainties

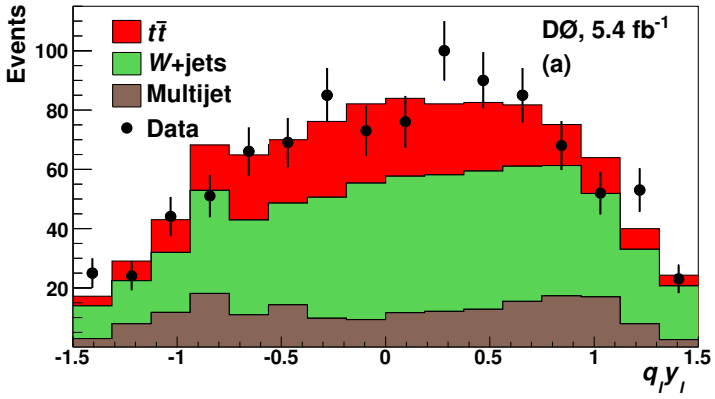
Measurement dominated by statistical uncertainties

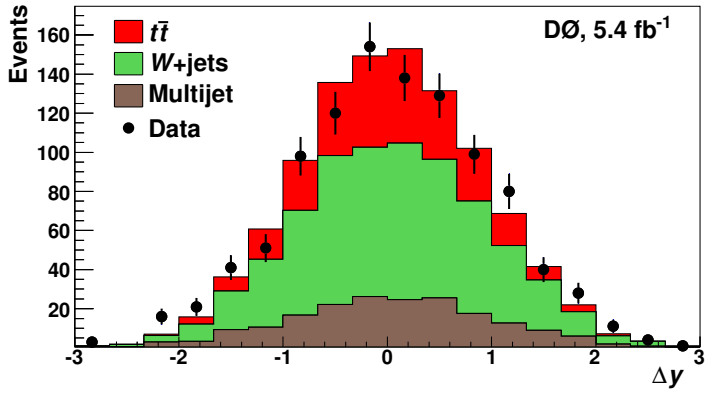
Absolute uncertainty on A_{FB} (%)			
	Reco. level		Prod. level
Source	Prediction	Measurement	Measurement
Jet reco	± 0.3	± 0.5	± 1.0
JES/JER	$+0.5$	-0.5	-1.3
Signal modeling	± 0.3	± 0.5	$+0.3/-1.6$
b-tagging	-	± 0.1	± 0.1
Charge ID	-	$+0.1$	$+0.2/-0.1$
Bg subtraction	-	± 0.1	$+0.8/-0.7$
Unfolding Bias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

Absolute uncertainty on A_{FB}^{l} (%)			
	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



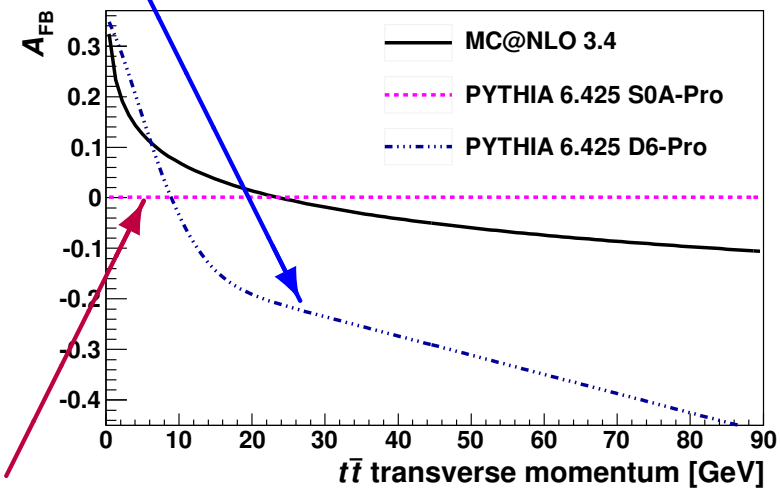


- Checked A_{FB} by solenoid and toroid polarities
  - Found no significant dependence
- Checked A_{FB} by lepton charge
  - Found no significant dependence
- Good agreement between e+jets and μ+jets

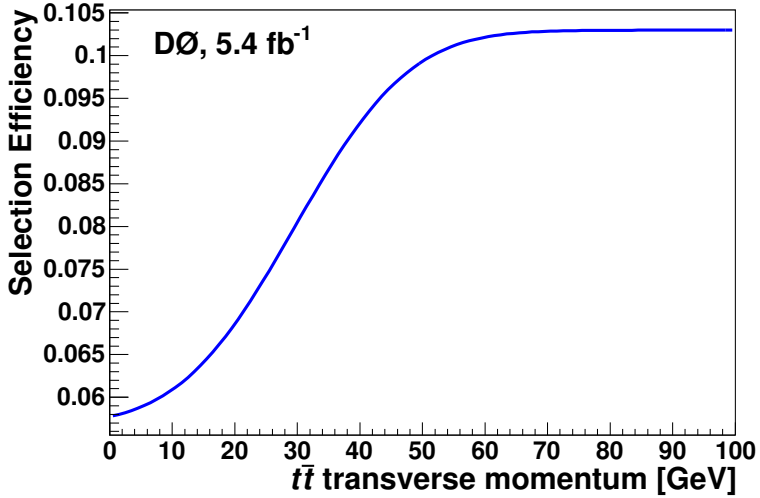
A_{FB} and top pair p_T

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

Angular coherence on



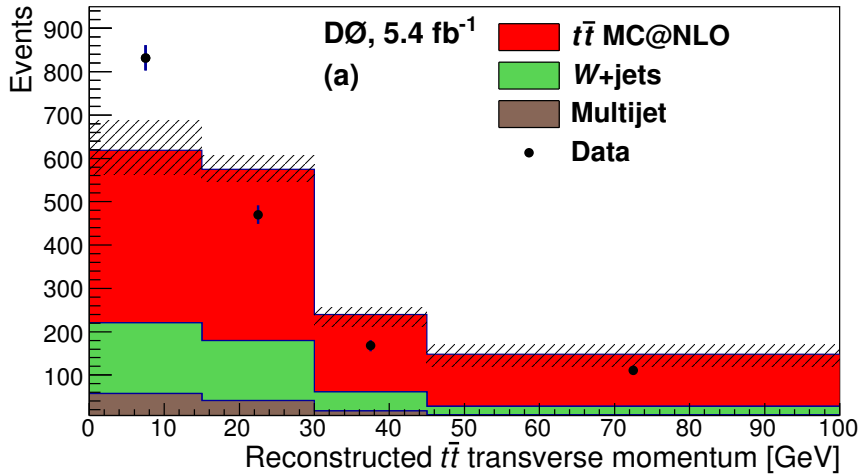
Angular coherence off



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

Modeling and top pair p_T

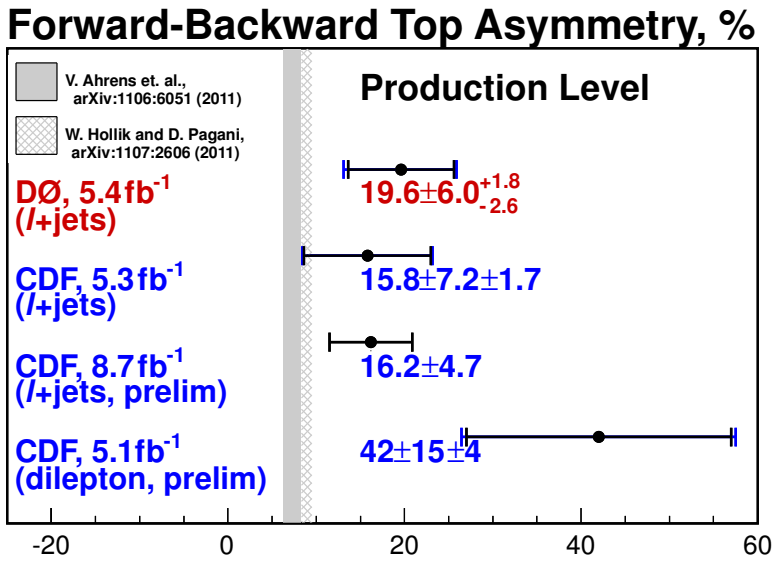
- The correlation between $p_T^{t\bar{t}}$ and $A_{\rm FB}$ may be large
- So we checked the modeling of $p_T^{t\bar{t}}$

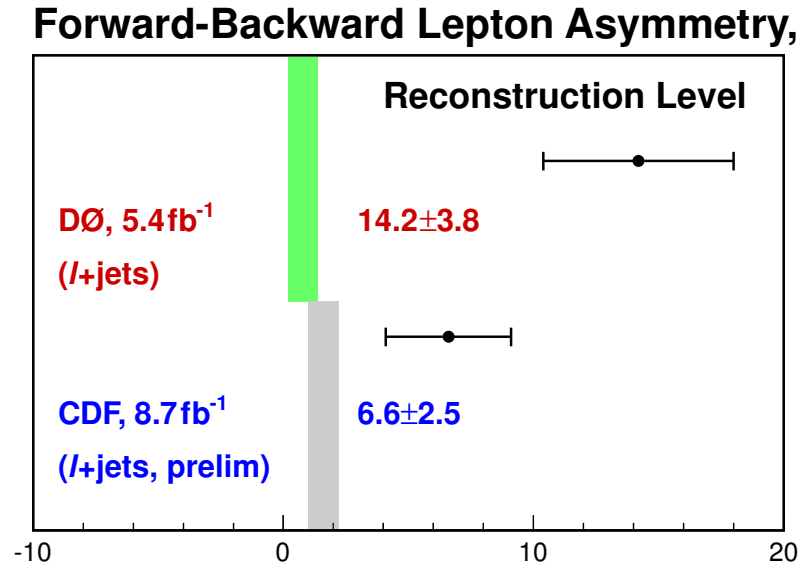


Bins of 1/2 resolution. Hash marks = uncertainty from jet reconstruction

- Other collaborations have since reported good modeling of $p_T^{t\bar{t}}$

Summary



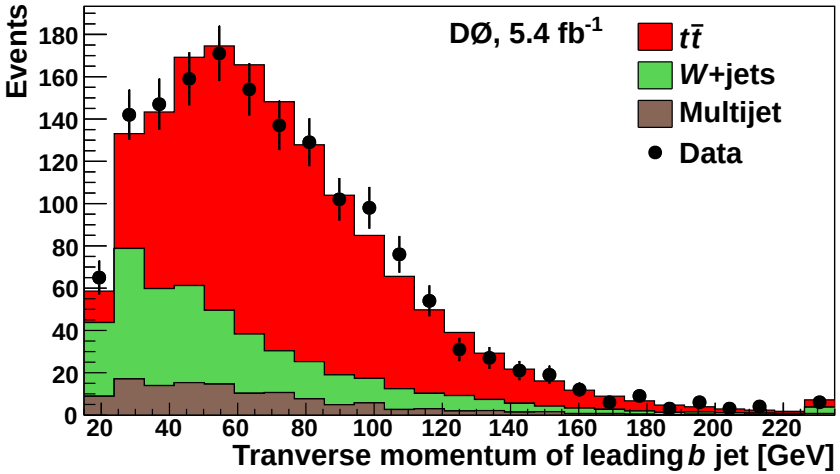


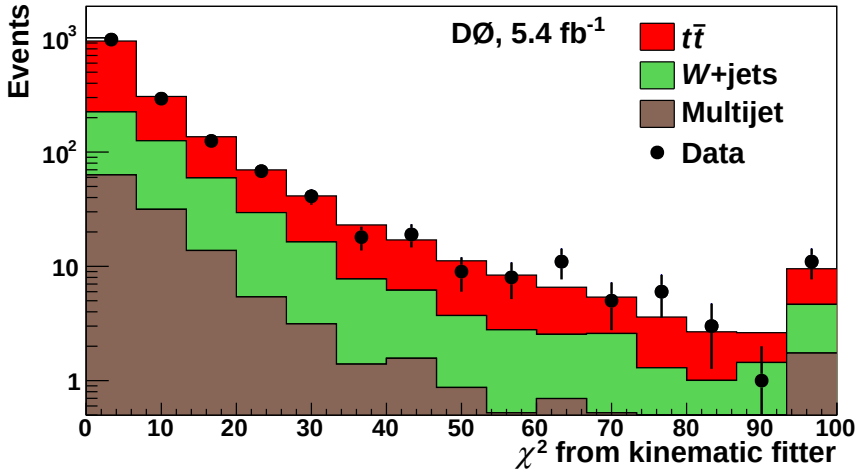
- For more information: arXiv:1107.4995

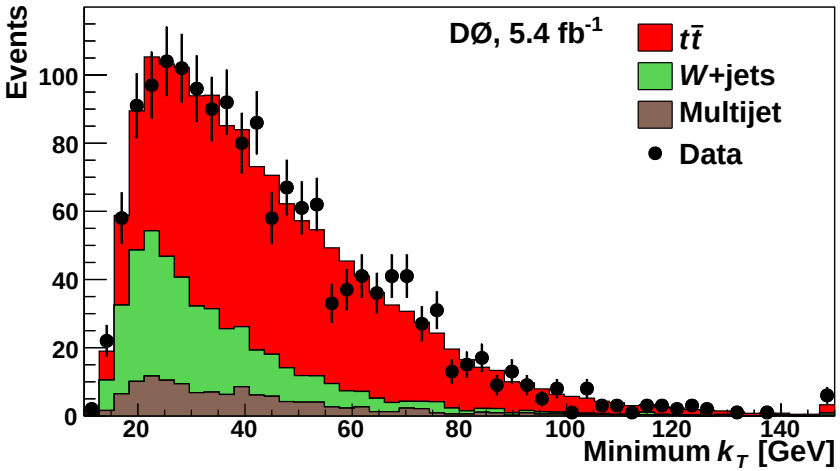
Backup Slides

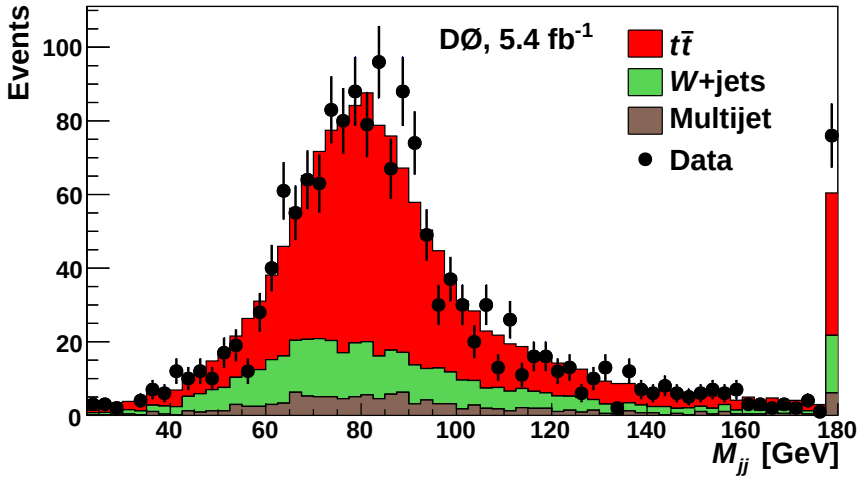
Separating signal from background

- Likelihood discriminant designed to separate $t\bar{t}$ signal events from W+jets background
- Inputs to discriminant have small correlations with $|\Delta y|$



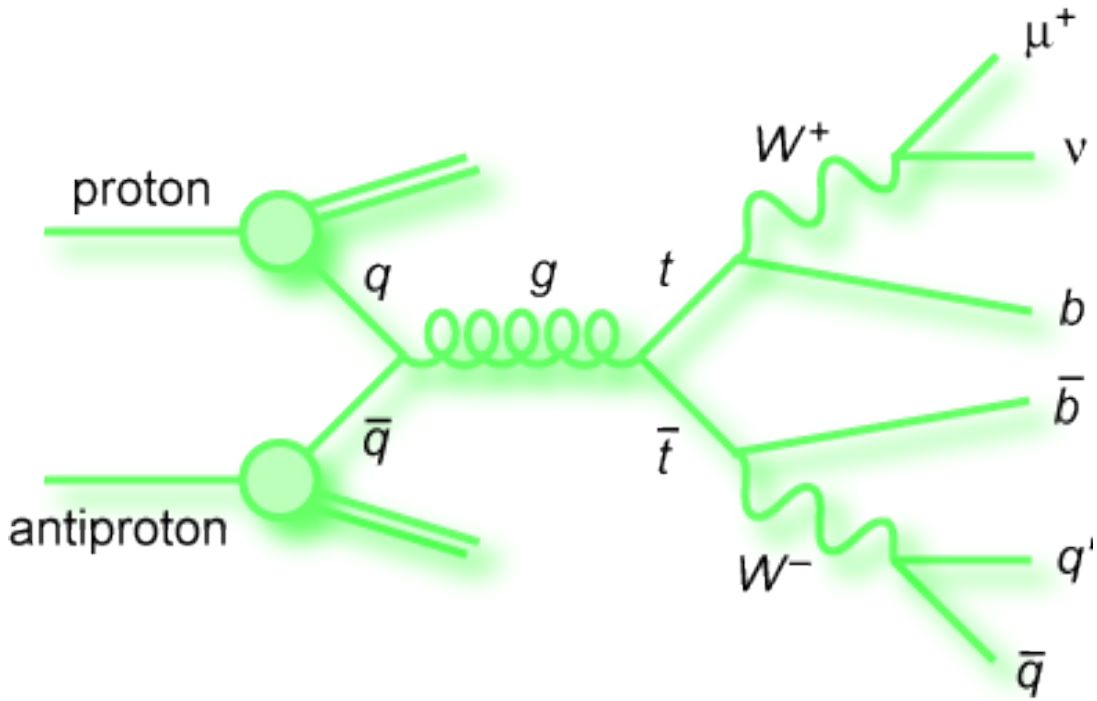






Kinematic fitter

- 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.



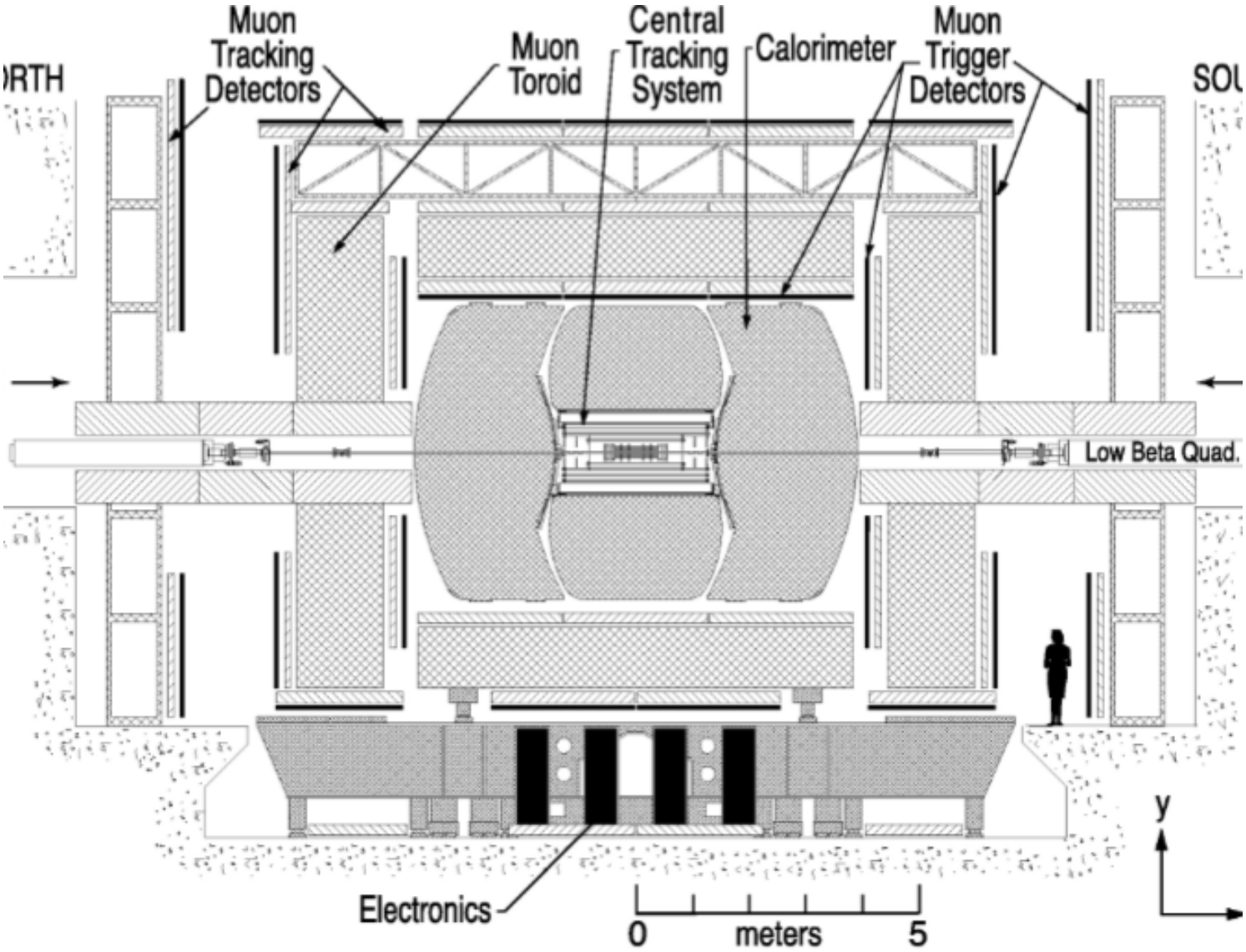
Reconstructed A_{FB} table

	l+$\geq$4 jets	e+$\geq$4 jets	μ+$\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±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 $A_{\rm FB}^{l}$ table

	l+$\geq$4 jets	e+$\geq$4 jets	μ+$\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
$A_{\rm FB}^{l}$ (%)	14.2± 3.8	16.5± 4.9	9.8± 5.9	15.9± 4.3	7.0± 8.0
MC@NLO $A_{\rm FB}^{l}$ (%)	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.
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