Measurement of the Forward-Backward Asymmetry of $t\bar{t}$ at the Fermilab Tevatron And Research Interests for Run 2 at the LHC

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TEXAS A&M UNIVERSITY

Outline

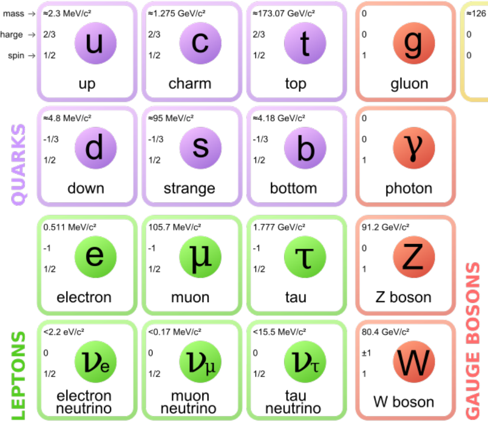
- Present work: Top forward–backward asymmetry
- Research interests on ATLAS at LHC Run 2

Will start with Top forward–backward asymmetry

Top forward–backward asymmetry:
An exciting chase for new physics

- Hot topic at the Tevatron for years
- Will be glossing over the gory details
- And focusing on the measurement techniques, the data, and the interpretation of them

The Standard Model - Top Quark



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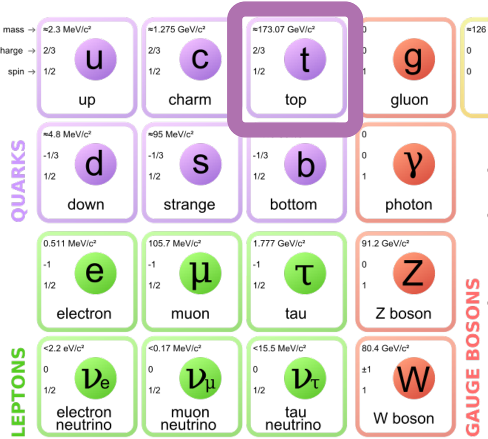


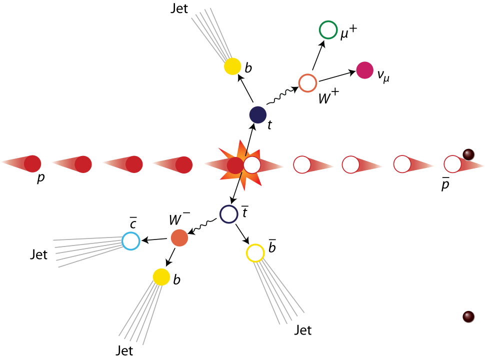
Top Quark

- Observed at Tevatron (1995)
- Very heavy
  - $m_t \simeq 173\ \mathrm{GeV/c^2}$
- Very short lived
  - No time to form hadrons
  - Unique opportunity to study a "bare" quark

Fascinating particle

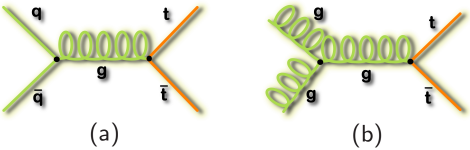
Properties need to be further understood

Top-Quark Pair at Tevatron

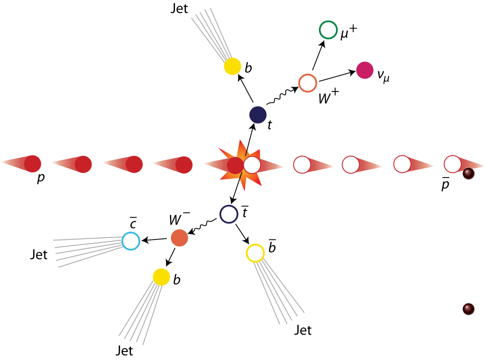


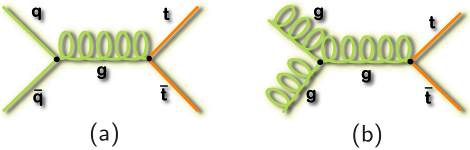
Top-quark pair production at the Fermilab **Tevatron**

- $p\bar{p}$ collision at Tevatron
  - CP even initial state
  - Different from pp collision and P even initial state at LHC
- Unique production mechanism
  - 85% quark annihilation (a) 15% gluon fusion (b)
  - LHC is gluon fusion dominated ($> 90\%$)



Top-Quark Pair at Tevatron



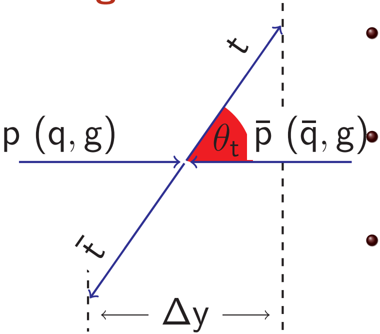


Top-quark pair production at the Fermilab Tevatron

- $\sim 70,000\ t\bar{t}$ produced
  - Study events to learn how particles interact
- Tevatron experiment sensitive to certain top-quark production mechanisms and properties

$A_{FB}^{t\bar{t}}$ at Tevatron

- Cross-section, mass and width measured & agree with SM
  What else can we learn about $t\bar{t}$ produced at Tevatron?
- **Angular distribution**



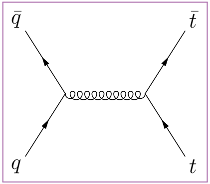
$$y = \frac{1}{2} \ln \frac{E + p_z}{E - p_z}$$

- Simplest observable: forward-backward asymmetry (A_{FB})
- Does top quark prefer proton direction or the opposite?
- Can measure rapidity difference between top and anti-top
- Define A_{FB} of $t\bar{t}$ production:

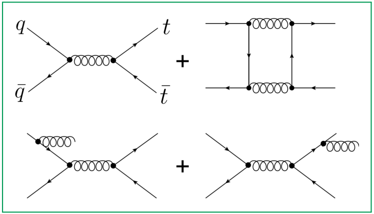
$$A_{FB}^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

$A_{FB}^{t\bar{t}}$ at Tevatron

What does the SM predict?



- No net preference in leading order diagram
- At next-to-leading order (NLO):
  top quark slightly prefers proton direction (forward)
  →Interference among diagrams
- We compare to $A_{FB}^{t\bar{t}}(\text{NLO}) = 0.088 \pm 0.006$ (PRD **86**,034026 (2012))
  - Conventional renormalization scale ($\mu_R \sim m_t$) w/ EWK corrections.
- However, different SM calculation gives different answers(0.050-0.125)
- **SM calculation still progressing**
  - Preliminary NNLO calculation later



$A_{FB}^{t\bar{t}}$ at Tevatron

- Previous experimental results?

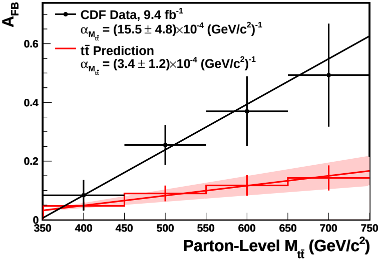
CDF: $A_{FB}^{t\bar{t}} = 0.164 \pm 0.047$(Lep+jets, PRD **87**, 092002 (2013))

D0: $A_{FB}^{t\bar{t}} = 0.106 \pm 0.030$(Lep+jets, PRD **90**, 072011 (2014))

$A_{FB}^{t\bar{t}} = 0.180 \pm 0.086$(Dilepon, D0 note 6445-CONF (2014))

- Result from CDF in tension with conventional NLO SM calculation (0.088), with both results from D0 consistent with NLO calculation

- Perhaps more important: $A_{FB}^{t\bar{t}}$ vs. $m_{t\bar{t}}$ deviates from NLO SM prediction



$A_{\text{FB}}^{t\bar{t}}$ at Tevatron

- Anomalously large $A_{\text{FB}}^{t\bar{t}}$ at Tevatron
- Calling for more accurate SM calculation?

  Or

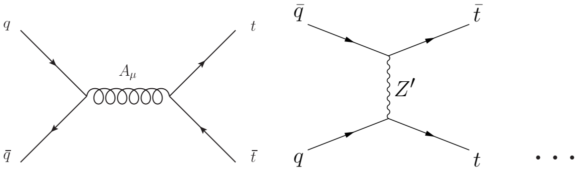
- Smoking gun for new physics?

$A_{FB}^{t\bar{t}}$ at Tevatron

Possible alternative hypotheses?

Models beyond the SM can predict large $A_{FB}^{t\bar{t}}$

- Axigluons
- Flavor-changing Z' boson
- Beyond-SM W' boson
- Beyond-SM Higgs boson
- Extra dimensions
- ......



$A_{\mathrm{FB}}^{t\bar{t}}$ at Tevatron

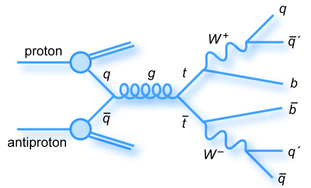
How to look for more evidence for/against new physics?

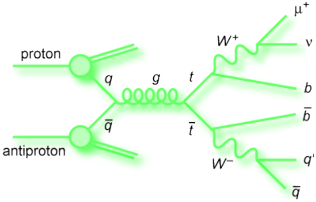
Pursue in two directions

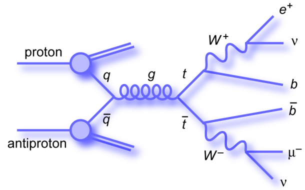
- Measure $A_{\mathrm{FB}}^{t\bar{t}}$ with more $t\bar{t}$ events in other final states
- Measure other related observables

Top-Quark Pair Decay Modes

- **How does top quark decay?**
- $t \to Wb$ almost 100% of time
- Three types of final states based on W decay mode:







Top-Quark Pair Decay Modes

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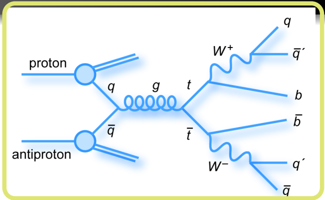
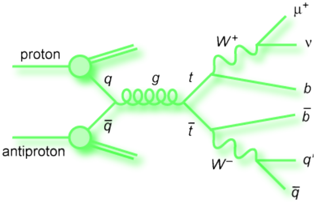
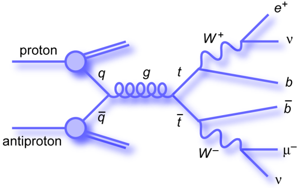
  - All hadronic←**Difficult channel**
    - Large branching fraction
    - Hard to determine jet energy/charge
    - Hard to reconstruct $t\bar{t}$







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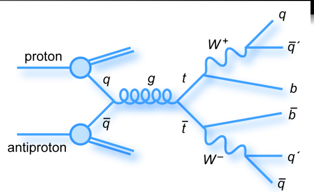
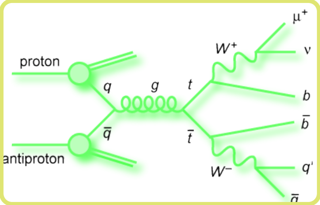
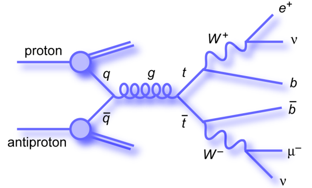
  - Lepton+jets←**Previous result**
    - Decent branching fraction
    - Lepton provides additional handle







Top-Quark Pair Decay Modes

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    - Decent branching fraction
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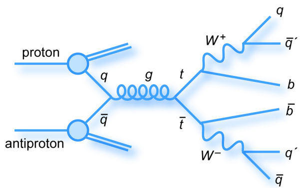
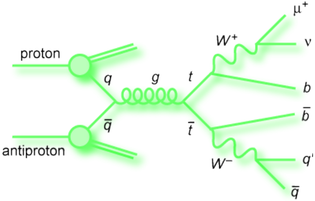
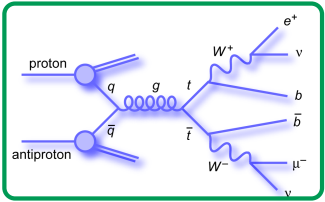
  - Dilepton ←**Focus of this talk**
    - Small branching fraction
    - Leptons precisely measured
    - Two ν's, hard to reconstruct $t\bar{t}$

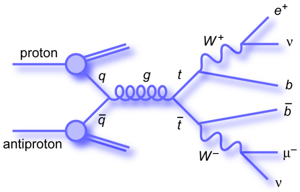






Additional $t\bar{t}$ events in dilepton

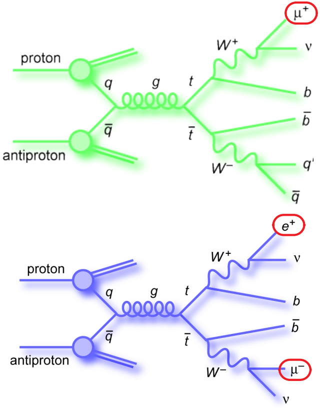
- Previous CDF measurement based on lepton+jets final state
- Can measure $A_{\mathrm{FB}}^{t\bar{t}}$ in dilepton



- Independent dataset with extended detector coverage, different background constitution and estimation methods
- Need to reconstruct 4-momenta of $t\bar{t}$
  $\rightarrow$Tough job in dilepton
- More on this later

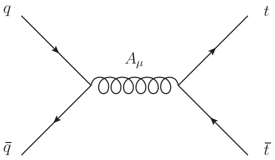
Other observables?

- Besides $A_{\text{FB}}^{t\bar{t}}$, two equally important observables with leptons
- Leptonic A_{FB}
  - $$A_{\text{FB}}^{\ell} = \frac{N(q_\ell \eta_\ell > 0) - N(q_\ell \eta_\ell < 0)}{N(q_\ell \eta_\ell > 0) + N(q_\ell \eta_\ell < 0)}$$
- Also lepton pair A_{FB} defined with lepton η difference, only in dilepton
- Why consider A_{FB}^{ℓ}?
  - Lepton angles precisely measured
  - Tend to follow direction of parent tops



A_{FB}^{ℓ} at Tevatron

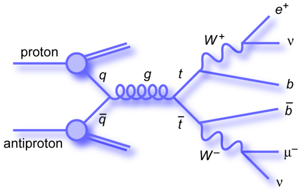
- NLO SM prediction: $A_{FB}^{\ell} = 0.038 \pm 0.003$
  - Conventional renormalization scale ($\mu_R \sim m_t$) w/ EWK corrections.
- Prediction with new physics?
- Based on CDF $A_{FB}^{t\bar{t}}$ result (0.16 ± 0.05), assuming everything else SM-like: $0.070 < A_{FB}^{\ell} < 0.076$
- In new physics models, $A_{FB}^{t\bar{t}}$ and A_{FB}^{ℓ} are **not correlated**.
- **Independent measurements of $A_{FB}^{t\bar{t}}$ and A_{FB}^{ℓ} are crucial**



Example:
Axigluon model
($m = 200$ GeV/c^2, $\Gamma = 50$ GeV)
$\rightarrow A_{FB}^{t\bar{t}} = 0.12$
$-0.06 < A_{FB}^{\ell} < 0.15$
depending on handedness of couplings
(PRD **87**,034039 (2013))

$A^{\ell\ell}_{\text{FB}}$

- Lepton pair A_{FB}
  - $$A^{\ell\ell}_{\text{FB}} = \frac{N(\Delta\eta > 0) - N(\Delta\eta < 0)}{N(\Delta\eta > 0) + N(\Delta\eta < 0)}$$
- NLO SM prediction: $A^{\ell\ell}_{\text{FB}} = 0.048 \pm 0.004$
- Larger expectations
- Only defined in dilepton, smaller statistics
- Provide extra information to help constraining new physics models



A_{FB}^{ℓ} at Tevatron

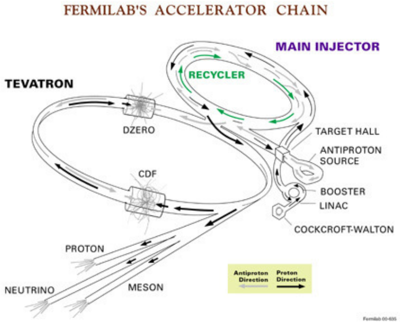
- Measurement of A_{FB}^{ℓ} in lepton+jets at CDF

$$A_{\text{FB}}^{\ell} = 0.094^{+0.032}_{-0.029}, \text{ PRD } \mathbf{88}, 072003\ (2013)$$

- 1.9σ larger than NLO SM calculation of 0.038 ± 0.003
- Large $A_{\text{FB}}^{t\bar{t}}$ holds in A_{FB}^{ℓ} in the same dataset
- New results presented today:
  1. Confirm or deny this anomaly large asymmetry ($A_{\text{FB}}^{t\bar{t}}$ and A_{FB}^{ℓ}) with the dilepton final state
  2. Measure $A_{\text{FB}}^{\ell\ell}$
  3. What is the best-world-understanding of the A_{FB} results?

Tevatron and CDF

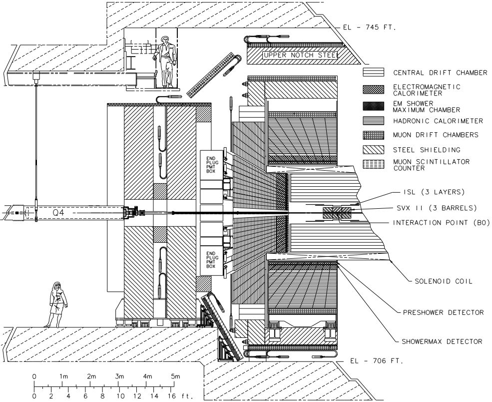
Tevatron



- $p\bar{p}$ collider
- Center-of-mass energy 1.96 TeV
- Run II delivered $12\mathrm{fb}^{-1}$
- Acquired $\sim 10\mathrm{fb}^{-1}$ by CDF

Tevatron and CDF

CDF



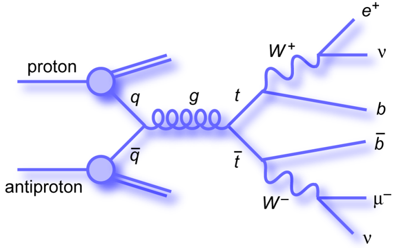
- General purpose detector
  - Solenoid (1.4 T magnetic field)
  - Tracking system
  - Calorimeter system
  - Muon detectors
- Coverage in $t\bar{t}$ dilepton
  - Electron: $|\eta| < 2.0$
  - Muon : $|\eta| < 1.1$
  - Jets : $|\eta| < 2.5$

$t\bar{t} \rightarrow$ dilepton

- $A_{\text{FB}}^{t\bar{t}}$ and A_{FB}^{ℓ} measurement in lepton+jets: *done*
- Go after the next important final state:
  $t\bar{t} \rightarrow$ dilepton

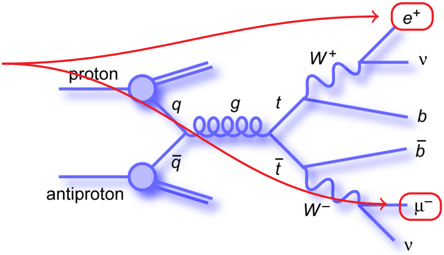
$t\bar{t} \rightarrow$ dilepton
Event selection

- Need a sample enriched by $t\bar{t}$ events with dilepton signature:



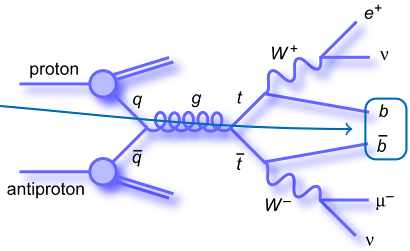
$t\bar{t} \rightarrow$ dilepton
Event selection

- Need a sample enriched by $t\bar{t}$ events with dilepton signature:
  - Two opposite charged leptons



$t\bar{t} \rightarrow$ dilepton
Event selection

- Need a sample enriched by $t\bar{t}$ events with dilepton signature:
  - Two opposite charged leptons
  - At least two jets



$t\bar{t} \rightarrow$ dilepton
Event selection

- Need a sample enriched by $t\bar{t}$ events with dilepton signature:
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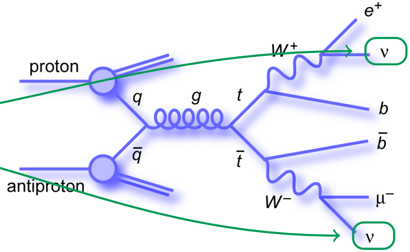
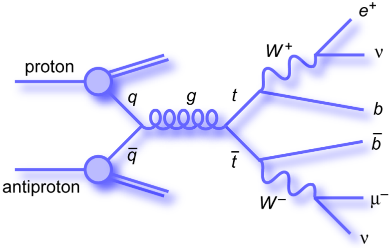
  - $\not\!\!E_T > 25$ GeV



$t\bar{t} \to$ dilepton
Event selection

- Need a sample enriched by $t\bar{t}$ events with dilepton signature:
  - Two opposite charged leptons
  - At least two jets
  - $\not{E}_T > 25$ GeV
- Use slightly improved $t\bar{t} \to$dilepton data selection criteria
  (details in the backups)



$t\bar{t} \rightarrow$ dilepton
Signal and background modeling

- Signal modeling:
  - Prediction with POWHEG MC
    (NLO SM w/ only QCD correction)
- Background modeling:
  - Diboson production ($WW, WZ, ZZ, W\gamma$)
    MC prediction
  - Z/γ^*+jets
    MC prediction with correction from data
  - W+jets
    Data-based
  - $t\bar{t}$ non-dilepton
    Prediction with POWHEG MC

Source	Events
Diboson	31.4±5.9
Z/γ^*+jets	50.5±6.2
W+jets fakes	64±17
$t\bar{t}$ non-dilepton	14.6±0.8
Total background	160±21
$t\bar{t}$ ($\sigma = 7.4$ pb)	408±19
Total SM expectation	568±40
Observed	569

- Agreement is excellent (Maybe too good? Probably luck)

$t\bar{t} \rightarrow$ dilepton
Signal and background modeling

- Signal modeling:
  - Prediction with POWHEG MC (NLO SM w/ only QCD correction)
- Background modeling:
  - Diboson production ($WW, WZ, ZZ, W\gamma$) MC prediction

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	160±21
	408±19
	568±40
	569

Glossed over all the gory details so to focus on the measurement techniques, the data and the interpretation of them

  - $t\bar{t}$ non-dilepton
    Prediction with POWHEG MC
- Agreement is excellent (Maybe too good? Probably luck)

$t\bar{t} \to$ dilepton

- Hard to reconstruct of 4-momenta of $t\bar{t}$ in dilepton
- Measure A^{ℓ}_{FB} and $A^{\ell\ell}_{\mathrm{FB}}$ first
- Continue with the full $A^{t\bar{t}}_{\mathrm{FB}}$ afterwards

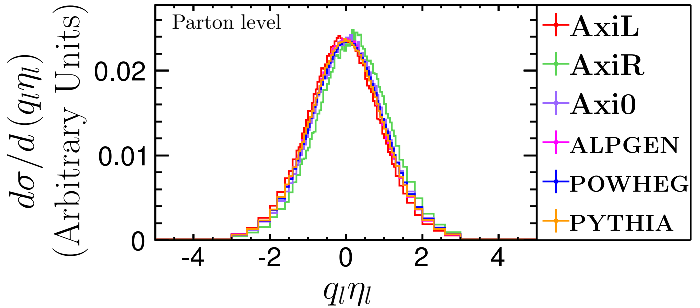
Alternative Signal Modeling

- What does the η_ℓ spectra look like in various scenarios?
  - Test the measurement with both SM and BSM models
- Simulate $t\bar{t}$ in various $t\bar{t}$ production mechanisms
  - SM sample: PYTHIA/ALPGEN (LO) and POWHEG (NLO)
  - Benchmark BSM model w/ axigluon
  - Many more simulated and studied
- Span large range of A^{ℓ}_{FB} and $A^{\ell\ell}_{\text{FB}}$

Model	A^{ℓ}_{FB} (Parton Level)	$A^{\ell\ell}_{\text{FB}}$ (Parton Level)	Description	
AxiL	-0.063(2)	-0.092(3)	Left-handed	Tree-level axigluon m = 200 GeV/c^2 Γ = 50 GeV
AxiR	0.151(2)	0.218(3)	Right-handed	
Axi0	0.050(2)	0.066(3)	Unpolarized	
ALPGEN	0.003(1)	0.003(2)	Tree-level Standard Model	
PYTHIA	0.000(1)	0.001(1)	LO Standard Model	
POWHEG	0.024(1)	0.030(1)	NLO Standard Model	
Calculation	0.038(3)	0.048(4)	NLO SM (PRD **86** 034026 (2012))	

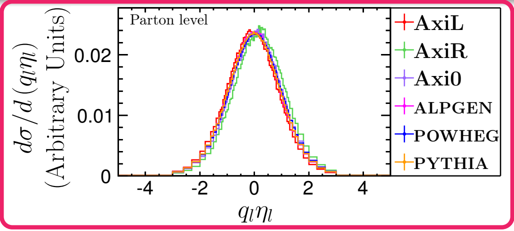
A_{FB}^{ℓ} Methodology - Introduction

$q_\ell \eta_\ell$ spectrum



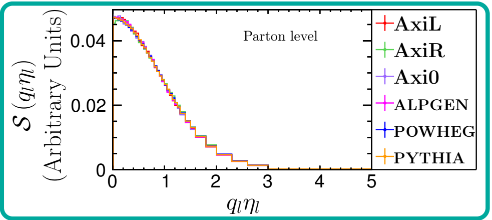
- Difference among models are small
  - Shapes almost identical, tiny shift in the mean
- Acceptance in detector limited
  - No acceptance beyond $|q_\ell \eta_\ell| = 2$
- Need a clever way to measure the subtle difference

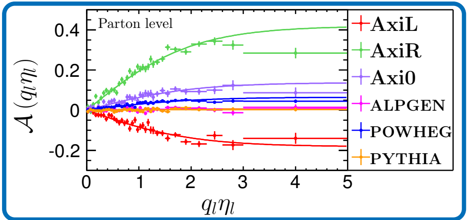
A_{FB}^{ℓ} Methodology - Introduction



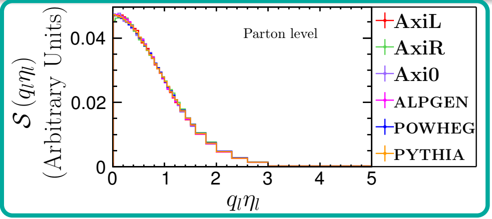
- Decomposition of $q_\ell\eta_\ell$ spectrum into symmetric and asymmetric components:

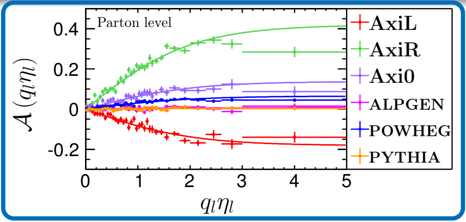
$$\mathcal{S}(q_\ell\eta_\ell) = \frac{\mathcal{N}(q_\ell\eta_\ell) + \mathcal{N}(-q_\ell\eta_\ell)}{2};\ \mathcal{A}(q_\ell\eta_\ell) = \frac{\mathcal{N}(q_\ell\eta_\ell) - \mathcal{N}(-q_\ell\eta_\ell)}{\mathcal{N}(q_\ell\eta_\ell) + \mathcal{N}(-q_\ell\eta_\ell)}$$





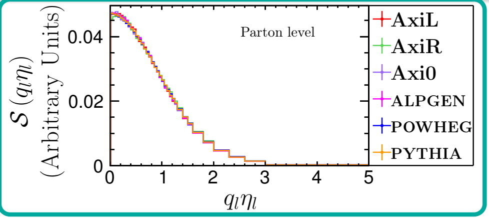
A_{FB}^{ℓ} Methodology - Introduction

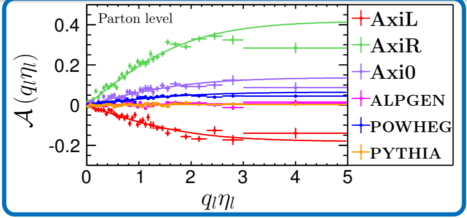




- $\mathcal{S}(q_\ell \eta_\ell)$ consistent among models

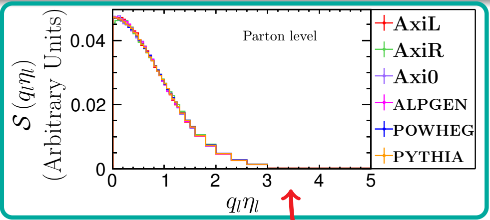
A^{ℓ}_{FB} Methodology - Introduction

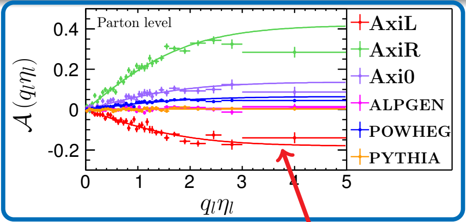




- $\mathcal{S}(q_\ell\eta_\ell)$ consistent among models
- $\mathcal{A}(q_\ell\eta_\ell)$ very different for different models
  - Sensitive to different values of A^{ℓ}_{FB}

A_{FB}^{ℓ} Methodology - Introduction





- $\mathcal{S}(q_\ell\eta_\ell)$ consistent among models
- $\mathcal{A}(q_\ell\eta_\ell)$ very different for different models
  - Sensitive to different values of A_{FB}^{ℓ}
- $\mathcal{A}(q_\ell\eta_\ell)$ well modeled with $a \cdot \tanh(\frac{1}{2}q_\ell\eta_\ell)$
  - Function empirically determined

Not well modelled for $q_\ell\eta_\ell > 2.5$

But contribution here is tiny

Detector only goes out to 2.0

A_{FB}^{ℓ} Measurement Methodology

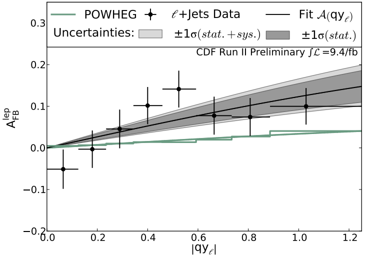
- A_{FB}^{ℓ} rewritten as

$$A_{FB}^{\ell} = \frac{\int_0^\infty \mathrm{d}q_\ell\eta_\ell \mathcal{A}(q_\ell\eta_\ell)\mathcal{S}(q_\ell\eta_\ell)}{\int_0^\infty \mathrm{d}q'_\ell\eta'_\ell \mathcal{S}(q'_\ell\eta'_\ell)}$$

- A_{FB}^{ℓ} measurement in lepton+jets based on this decomposition and $a \cdot \tanh(\frac{1}{2}q_\ell\eta_\ell)$ modeling

$$A_{FB}^{\ell} = 0.094^{+0.032}_{-0.029}$$

- 1.9σ larger than NLO SM

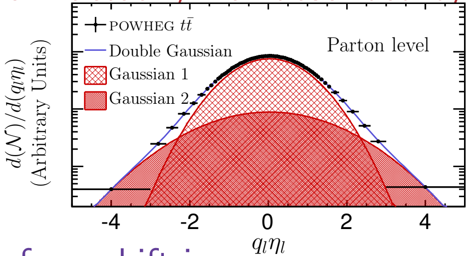


PRD **88** 072003 (2013), CDF

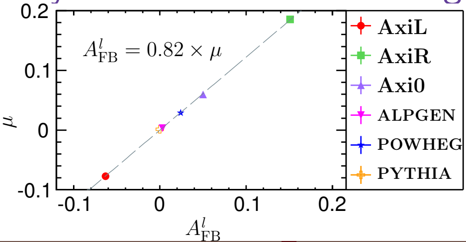
A_{FB}^{ℓ} Methodology Study

Why does the $a \cdot \tanh$ model work so well?

- $q_\ell \eta_\ell$ spectrum actually well described by a double-Gaussian



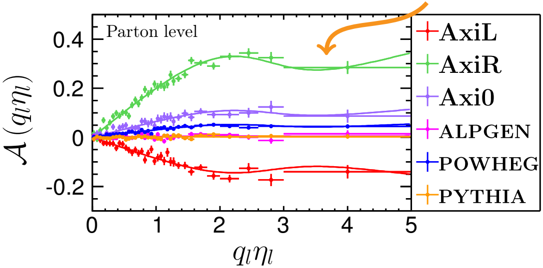
- A_{FB}^{ℓ} comes from shift in mean
  $\rightarrow A_{FB}^{\ell}$ linearly related with mean in regime of interest



Summarized as PRD **90**, 014040 (2014) Z. Hong *et al.*

A_{FB}^{ℓ} Methodology Study

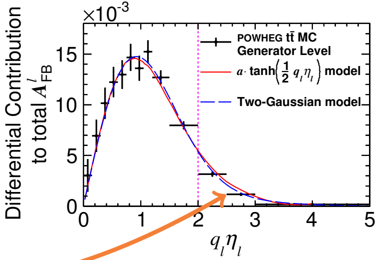
- Double-Gaussian does better job in modeling differential asymmetry in large $q_\ell \eta_\ell$ region



- $\mathcal{A}(q_\ell \eta_\ell)$ still most sensitive way to measure A_{FB}^{ℓ}
  - Provides better effective measure of mean
  - Acceptance of detector mostly cancels out

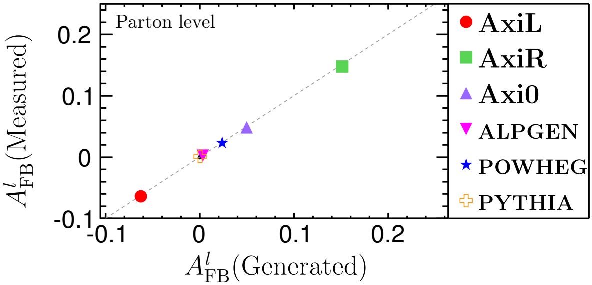
A_{FB}^{ℓ} Methodology Study

- Another way of looking at data: Differential contribution to A_{FB}^{ℓ}
- What do we learn?
  - Asymmetry mostly from $|\eta| < 2.0$
    - Best detector coverages here
  - $a \cdot \tanh\left(\frac{1}{2} q_\ell \eta_\ell\right)$ is excellent for $|q_\ell \eta_\ell| < 2.5$
  - Mismodeling in region with small contribution
  - More than good enough
- Moving forward with $a \cdot \tanh$ model with confidence



A_{FB}^{ℓ} Methodology - Introduction

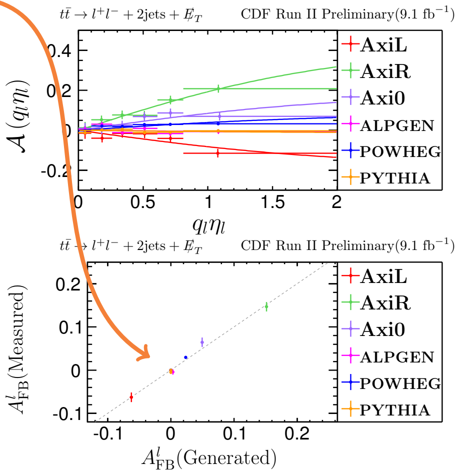
- $a \cdot \tanh$ model works well at parton level



- Does detector response affect the measurement?

A_{FB}^{ℓ} Methodology with Detector Response

- Detector response mostly cancels out in $\mathcal{A}(q_\ell\eta_\ell)$
- No noticeable bias observed
- Measurement strategy:
  - Subtract off backgrounds
  - Fit $\mathcal{A}(q_\ell\eta_\ell)$ with $a \cdot \tanh\left(\frac{1}{2}q_\ell\eta_\ell\right)$
  - Obtain $\mathcal{S}(q_\ell\eta_\ell)$ from POWHEG simulation at parton-level
  - Calculate A_{FB}^{ℓ} with $\mathcal{A}$ & $\mathcal{S}$
- Correct for detector response and extrapolate to inclusive A_{FB}^{ℓ} simultaneously



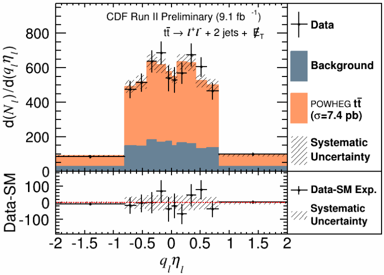
A^{ℓ}_{FB} in dilepton

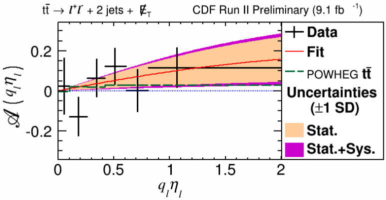
- Measure A^{ℓ}_{FB} with CDF full dataset in dilepton ($9.1\ \mathrm{fb}^{-1}$)

$$A^{\ell}_{FB} = 0.072 \pm 0.052(\text{stat}) \pm 0.030(\text{syst}) = 0.072 \pm 0.060$$

Cf. $A^{\ell}_{FB}(\text{SM,NLO}) = 0.038 \pm 0.003$

- Dominant uncertainty is statistical
- Table of systematic uncertainty in backup
- Result consistent with prediction of new physics from lepton+jets, but also consistent with SM





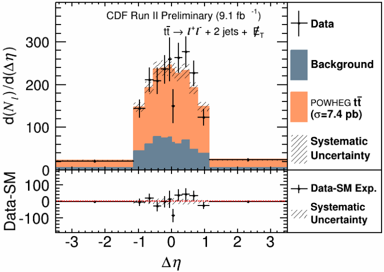
$A_{FB}^{\ell\ell}$ in dilepton

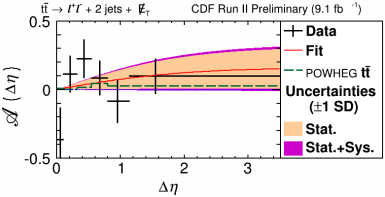
- Measurement techniques validated for $A_{FB}^{\ell\ell}$ as well.
- Measure $A_{FB}^{\ell\ell}$ with the same method

$$A_{FB}^{\ell\ell} = 0.076 \pm 0.072(\text{stat}) \pm 0.039(\text{syst})$$
$$= 0.076 \pm 0.081$$

Cf. $A_{FB}^{\ell}(\text{SM,NLO}) = 0.048 \pm 0.004$

- Dominant uncertainty is statistical
- Result consistent with SM



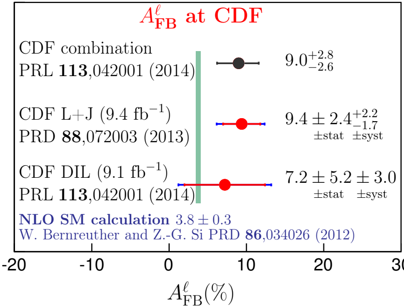


A^{ℓ}_{FB} combination at CDF

- Combined A^{ℓ}_{FB} measurements at CDF
- Based on *best linear unbiased estimator* (BLUE)
- Result is 2σ larger than NLO SM prediction:

$$A^{\ell}_{FB} = 0.090^{+0.028}_{-0.026}$$

- PRL **113**, 042001 (2014) (CDF)



$A_{\text{FB}}^{t\bar{t}}$ in dilepton and CDF combination

- Observed large A_{FB}^{ℓ} in dilepton as well, continue pursuing $A_{\text{FB}}^{t\bar{t}}$ measurement in dilepton
- Then $A_{\text{FB}}^{t\bar{t}}$ combination at CDF

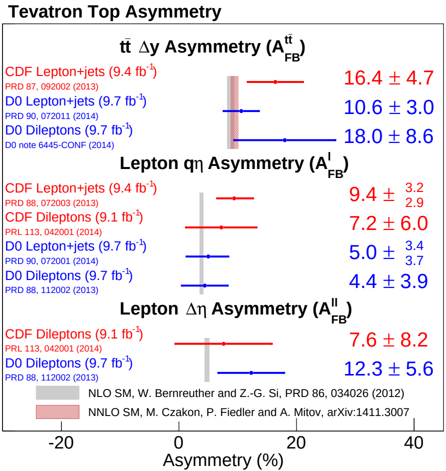
Analysis in progress!

Best-world understanding of top A_{FB}

What is the best-world understanding of top A_{FB}?

CDF and D0 results

- D0 recently released measurements of A^{ℓ}_{FB}, $A^{\ell\ell}_{FB}$ and $A^{t\bar{t}}_{FB}$
  - Results from D0 consistent with both CDF and NLO SM
  - All results higher than NLO (and NNLO) SM predictions



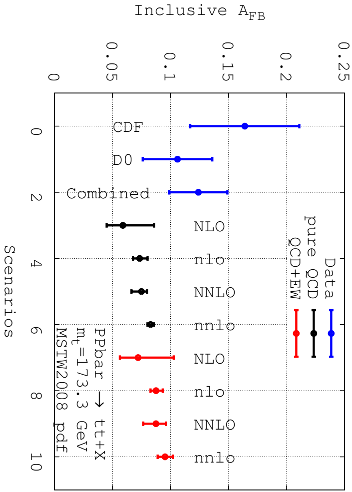
NNLO A_{FB} Prediction

- Very recently, preliminary NNLO prediction suggests tension resolved
- NNLO QCD + LO EW $\rightarrow A_{FB}^{t\bar{t}} = 9.5 \pm 0.7\%$
- Deviation between measurements and prediction no longer significant

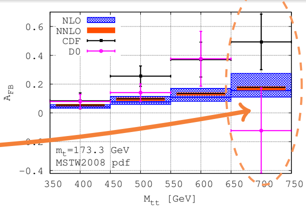
NNLO QCD calculation needed for top kinematics!
Especially important for precision measurements happening at LHC

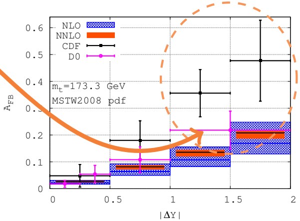
M. Czakon, P. Fiedler and A. Mitov

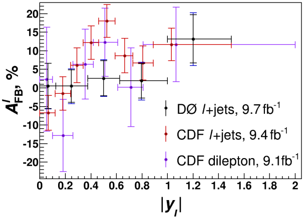
arXiv:1411.3007



- Differential A_{FB} show mostly good agreement between CDF and D0
  - Some areas under study
  - This might account for the differences
- Both experiments working to understand the differences
  - Are the two experiments measuring the same observables?
  - Different techniques causing bias in either/both experiments?
  - Statistical fluctuation?
- Plan: understand the difference and make Tevatron combinations of A^{ℓ}_{FB}, $A^{\ell\ell}_{FB}$ and $A^{t\bar{t}}_{FB}$







Conclusions: Top A_{FB}

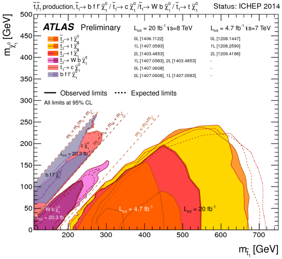
- The A_{FB} of top-pairs at the Tevatron remains a story does not yet hang together well, but at long last may be resolved
- Measurements of $A_{\mathrm{FB}}^{t\bar{t}}$, A_{FB}^{ℓ} and $A_{\mathrm{FB}}^{\ell\ell}$ provide complementary handles to probe the production and decay of $t\bar{t}$
- A_{FB}^{ℓ} at CDF shows 2σ deviation from NLO SM, but may be consistent with NNLO. Only time will tell.
- Measurement of $A_{\mathrm{FB}}^{t\bar{t}}$ in dilepton in progress
- Working on understanding the difference between CDF and D0 measurements
- Full NNLO SM calculation on the horizon
- Either way it has been an exciting chase for new physics

- Next show my research interests on ATLAS at LHC Run 2
- Haven't been involved in ATLAS analysis, so these ideas are preliminary
  - Eager to refine to more realistic ideas with helps from experts
- Want to get involved with both hardware projects and physics analyses
  - Search for SUSY or anything beyond the SM
  - FTK electronics
  - Computing

Analyses

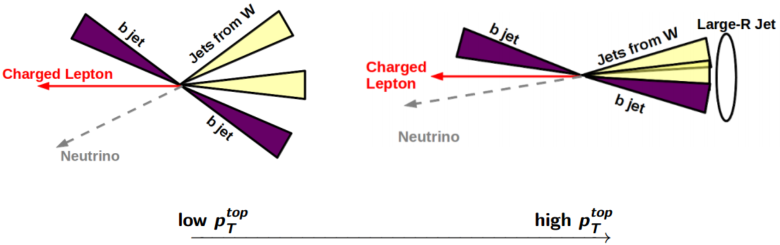
- SUSY provides plausible solutions to hierarchy problem and perfect dark matter candidates
- Involved in GMSB search with delayed photons at CDF
- Want to keep hunting for SUSY search at LHC Run 2

- stop?
- Heavy second Higgs $\rightarrow$ hh $\rightarrow$ WWbb?
- Preferably with scenarios where I can take advantage of my knowledge of tops, but would be interested in ANY promising scenario



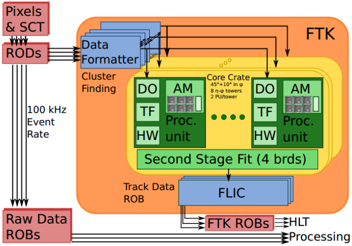
ATLAS at LHC Run 2
Top Tagger

- With increasing energy, top quark is becoming more boosted
  - Merging into a jet with substructure
- Together with mini-isolated lepton, this provides a novel channel for top physics
  - Especially in searching for heavy resonances decaying to $t\bar{t}$



ATLAS at LHC Run 2
Hardware

- Joined CDF after Tevatron shut down
  - Eager to learn more about hardware
- Especially interested in detector electronics
- FTK trigger is critical to LHC Run 2 and beyond
- Want to join this effort to both complete my training and improve future physics analyses



- Have extensive experience in utilizing computing clusters
- Our group runs a CMS Tier 3 computing center
  - Have direct experience in maintaining computing clusters
- Would like to keep employing big computing techniques

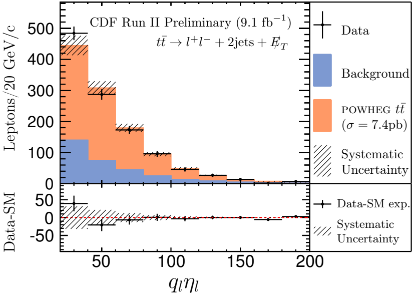
Thanks!

Backup slides

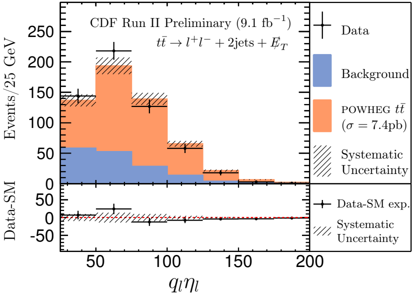
$t\bar{t} \rightarrow$ dilepton event selection criteria

Baseline Cuts	Exactly two leptons with $E_{\mathrm{T}} > 20$ GeV and passing standard identification requirements with following modifications -COT radius exit > 140 cm for CMIO -$\chi^2/ndf < 2.3$ for muon tracks At least one trigger lepton At least one tight and isolated lepton At most one lepton can be loose and/or non-isolated
	$\not{E}_T > 25$ GeV, but $\not{E}_T > 50$ GeV when there is any lepton or jet within 20° of the direction of $\not{E}_T$
	MetSig $(= \frac{\not{E}_T}{\sqrt{E_T^{sum}}}) > 4\ \sqrt{\mathrm{GeV}}$ for ee and $\mu\mu$ events where $76\ \mathrm{GeV/c^2} < \mathrm{m_{ll}} < 106\ \mathrm{GeV/c^2}$
	$\mathrm{m_{ll}} > 10\ \mathrm{GeV/c^2}$
Signal Cuts	Two or more jets with $E_{\mathrm{T}} > 15$ GeV within $\|\eta\| < 2.5$
	$\mathrm{H_T} > 200$ GeV
	Opposite sign of two leptons

Lepton p_T



$\not{E}_T$



Agreement is excellent

Systematic uncertainty of A_{FB}^{ℓ} measurement

CDF Run II Preliminary (9.1 fb^{-1})

Source of Uncertainty (A_{FB}^{ℓ})	Value
Backgrounds	0.029
Asymmetric Modeling	0.006
Jet Energy Scale	0.004
Symmetric Modeling	0.001
Total Systematic	0.030
Statistical	0.052
Total Uncertainty	0.060

Systematic uncertainty of $A_{\text{FB}}^{\ell\ell}$ measurement

CDF Run II Preliminary (9.1 fb^{-1})

Source of Uncertainty ($A_{\text{FB}}^{\ell\ell}$)	Value
Backgrounds	0.037
Asymmetric Modeling	0.012
Jet Energy Scale	0.003
Symmetric Modeling	0.004
Total Systematic	0.039
Statistical	0.072
Total Uncertainty	0.082

Comparison of A_{FB}^{ℓ} among SM prediction and measurements at CDF and D0.

Source	A_{FB}^{ℓ}	Description	Reference
Calculation	0.038 ± 0.003	NLO SM	PRD **86**,034026 (2012)
CDF	$0.094^{+0.032}_{-0.029}$	Lepton+jets	PRD **88**,072003 (2013)
	0.072 ± 0.060	Dilepton	PRL **113**,042001 (2014)
	$0.090^{+0.028}_{-0.026}$	Combination	
D0	$0.042^{+0.029}_{-0.030}$	Lepton+jets, $\lvert q_\ell \eta_\ell \rvert < 1.5$	arXiv:1403.1294
	0.044 ± 0.039	Dilepton	PRD **88**,112002 (2013)
	0.047 ± 0.027	Combination	arXiv:1403.1294

A^{ℓ}_{FB} CDF combination

CDF Run II Preliminary

Source of uncertainty	L+J (9.4fb^{-1})	DIL (9.1fb^{-1})	Correlation
Backgrounds	0.015	0.029	0
Recoil modeling (Asymmetric modeling)	$^{+0.013}_{-0.000}$	0.006	1
Symmetric modeling	-	0.001	
Color reconnection	0.0067	-	
Parton showering	0.0027	-	
PDF	0.0025	-	
JES	0.0022	0.004	1
IFSR	0.0018	-	
Total systematic	$^{+0.022}_{-0.017}$	0.030	
Statistics	0.024	0.052	0
Total uncertainty	$^{+0.032}_{-0.029}$	0.060	

$$M^2_{l^+\nu} = (E_{l^+} + E_\nu)^2 - (\vec{p}_{l^+} + \vec{p}_\nu)^2 = M^2_W$$
$$M^2_{l^-\bar{\nu}} = (E_{l^-} + E_{\bar{\nu}})^2 - (\vec{p}_{l^-} + \vec{p}_{\bar{\nu}})^2 = M^2_W$$
$$M^2_{l^+\nu b} = (E_{l^+} + E_\nu + E_b)^2 - (\vec{p}_{l^+} + \vec{p}_\nu + \vec{p}_b)^2 = M^2_t$$
$$M^2_{l^-\bar{\nu}\bar{b}} = (E_{l^-} + E_{\bar{\nu}} + E_{\bar{b}})^2 - (\vec{p}_{l^-} + \vec{p}_{\bar{\nu}} + \vec{p}_{\bar{b}})^2 = M^2_t$$
$$(\vec{p}_\nu + \vec{p}_{\bar{\nu}})_x = (\not{E}_T)_x$$
$$(\vec{p}_\nu + \vec{p}_{\bar{\nu}})_y = (\not{E}_T)_y$$

$t\bar{t}$ Likelihood

$$\mathcal{L}(\vec{p}_\nu, \vec{p}_{\bar{\nu}}, E_b, E_{\bar{b}}) = P(p_z^{t\bar{t}})P(p_T^{t\bar{t}})P(M^{t\bar{t}})\times$$

$$\frac{1}{\sigma_{\text{jet1}}} \exp\left(-\frac{1}{2}\left(\frac{E_{\text{jet1}}^{\text{measure}} - E_{\text{jet1}}^{\text{fit}}}{\sigma_{\text{jet1}}}\right)\right) \times \frac{1}{\sigma_{\text{jet2}}} \exp\left(-\frac{1}{2}\left(\frac{E_{\text{jet2}}^{\text{measure}} - E_{\text{jet2}}^{\text{fit}}}{\sigma_{\text{jet2}}}\right)\right)$$

$$\frac{1}{\sigma_x^{\not{E}_T}} \exp\left(-\frac{1}{2}\left(\frac{\not{E}_x^{\text{measure}} - \not{E}_x^{\text{fit}}}{\sigma_x^{\not{E}_T}}\right)\right) \times \frac{1}{\sigma_y^{\not{E}_T}} \exp\left(-\frac{1}{2}\left(\frac{\not{E}_y^{\text{measure}} - \not{E}_y^{\text{fit}}}{\sigma_y^{\not{E}_T}}\right)\right)$$

- The ratio of $A_{\text{FB}}^{t\bar{t}}/A_{\text{FB}}^{\ell}$ observed to be consistent when $t\bar{t}$ produced unpolarized and decay like SM
- Based on CDF $A_{\text{FB}}^{t\bar{t}}$ result (0.16 ± 0.05), this yields prediction of $0.070 < A_{\text{FB}}^{\ell} < 0.076$