On Measuring the Leptonic Forward-Backward Asymmetry at the Tevatron and Recent Results from CDF

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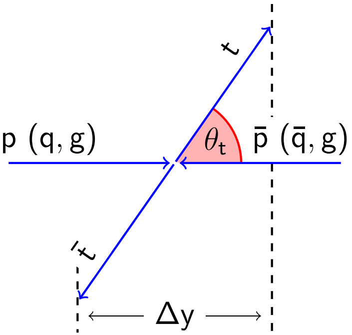
$A_{\mathrm{FB}}^{t\bar{t}}$



- $p\bar{p}$ collision at Tevatron (unique relative to pp collision at LHC)
- Charge asymmetry in $t\bar{t}$ production manifests as forward-backward asymmetry (A_{FB})
  - A unique way to look for new physics
- Measure rapidity difference between top and anti-top, Δy
- Define A_{FB} of $t\bar{t}$ production:

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

- Has been an exciting topic for years since early studies at CDF/D0

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

- Why do we care?
  - Prediction at NLO SM:

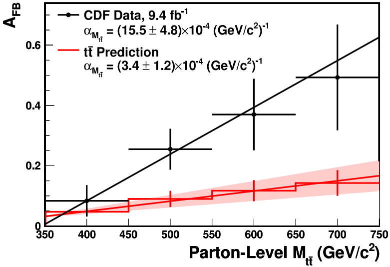
$$A_{FB}^{t\bar{t}} = 0.088 \pm 0.006 \text{ (PRD } \mathbf{86}\text{,034026 (2012))}$$

  - Measured results from CDF and D0 in tension with SM prediction:

$$\text{CDF: } A_{FB}^{t\bar{t}} = 0.164 \pm 0.047 \text{ (PRD } \mathbf{87}\text{, 092002 (2013))}$$

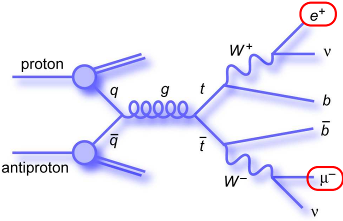
$$\text{D0: } A_{FB}^{t\bar{t}} = 0.196 \pm 0.065 \text{ (PRD } \mathbf{84}\text{, 112005 (2011))}$$

  - $A_{FB}^{t\bar{t}}$ vs. $m_{t\bar{t}}$ deviates from SM prediction



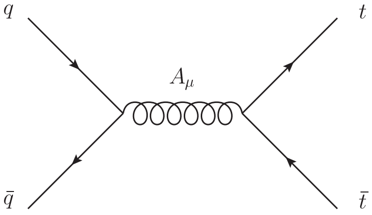
A^l_{FB}

- How do we look for more evidence for or against new physics?
- Two more equally important observables with leptons
- Leptonic A_{FB}
  - $A^l_{\mathrm{FB}} = \frac{N(q_l\eta_l>0)-N(q_l\eta_l<0)}{N(q_l\eta_l>0)+N(q_l\eta_l<0)}$
- Also lepton pair A_{FB} defined with lepton η difference, only in dilepton channel
- Why leptons?
  - Lepton angles precisely measured
  - NLO SM prediction: $A^l_{\mathrm{FB}} = 0.038 \pm 0.003$

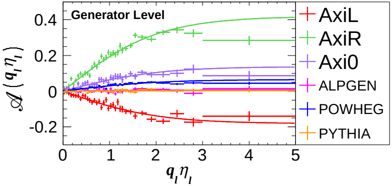


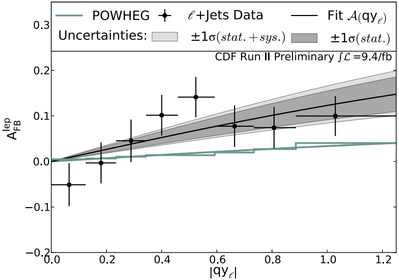
A^{l}_{FB}

- Prediction with new physics?
- Based on CDF $A^{t\bar{t}}_{\mathrm{FB}}$ result (0.16 ± 0.05): $0.070 < A^{l}_{\mathrm{FB}} < 0.076$
- New physics models in certain parameter space allow for large $A^{t\bar{t}}_{\mathrm{FB}}$ (like observed value), but very large range (positive or negative) of A^{l}_{FB}
- Example: axigluon model ($m = 200$ GeV$/c^2$ and $\Gamma = 50$ GeV) $\rightarrow A^{t\bar{t}}_{\mathrm{FB}} = 0.12$; $-0.06 < A^{l}_{\mathrm{FB}} < 0.15$ depending on handness of couplings (PRD **87**,034039 (2013))
- Independent measurements of $A^{t\bar{t}}_{\mathrm{FB}}$ and A^{l}_{FB} are crucial



New study of A^l_{FB} Measurement Methodology





PRD **88** 072003 (2013)

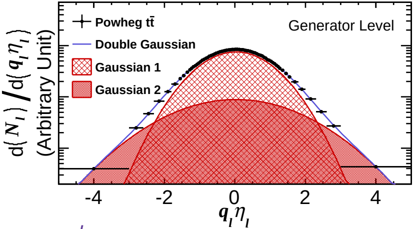
- $A^l_{FB} = 0.094^{+0.032}_{-0.029}$ at CDF in lepton+jets
- 1.9σ larger than SM
- Measurement used

$$A^l_{FB}(q_l\eta_l) = a \cdot \tanh\left(\frac{1}{2} q_l\eta_l\right)$$

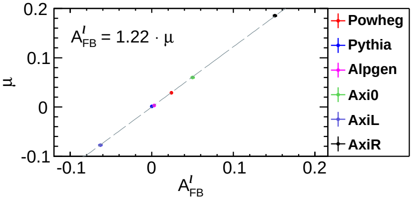
- Empirically determined function.
  Need to know why it works

New Results with MC study:

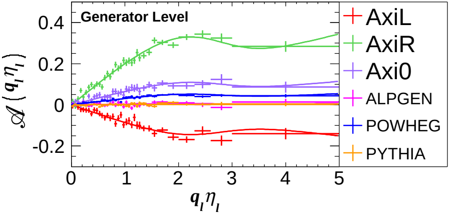
- $q_l \eta_l$ distribution well described by double-Gaussian



- A^{l}_{FB} comes from shift in mean $\rightarrow$ A^{l}_{FB} linearly related with mean



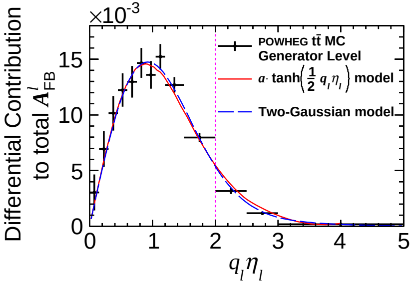
- Double-Gaussian does better job in modeling differential asymmetry in large $q_l \eta_l$ region



- Differential asymmetry still most sensitive way to determine total A^{l}_{FB}
  - Provides better effective measure of mean

New study of A^l_{FB} Measurement Methodology

- New way of looking at the data: Differential contribution to total A^l_{FB}
- What do we learn?
  - Asymmetry mostly from $|\eta| < 2.0$
    - Best detector coverages here
  - Shape of differential contribution very stable
    - Allows robust extrapolation to inclusive asymmetry
  - Turns out $a \cdot \tanh\left(\frac{1}{2}q_l\eta_l\right)$ is excellent for $|q_l\eta_l| < 2.5$



- More than good enough
- Now we know why!
- Moving forward with confidence

(Study to be submitted to PRD, manuscript in preparation, Z. Hong *et al*)

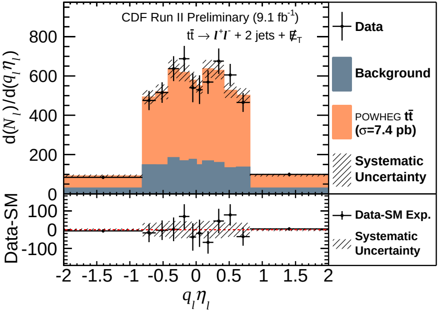
A^{l}_{FB} in dilepton

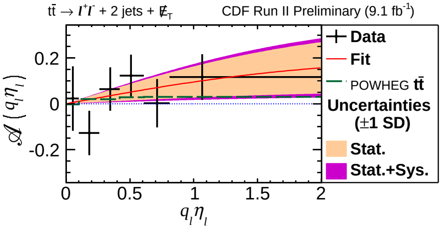
- New results from CDF with full dataset (9.1 fb^{-1})
- Leptonic A_{FB} in dilepton events:
  - Two opposite charged leptons
  - At least two jets
  - $\not{E}_T > 25$ GeV
- Same methodology as measurement in lepton+jets used.

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

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

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



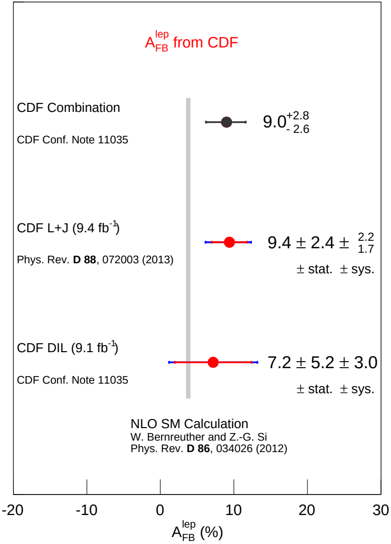


A^{l}_{FB} combination at CDF

- Combined A^{l}_{FB} measurements
- Result is 2σ larger than NLO SM prediction:

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

- To be submitted to PRL soon.



Conclusions

- The A_{FB} of top quarks at Tevatron continue to be an exciting measurement, and the leptonic decays provide an important complementary handle
- Better understanding of new methodology for measuring A^{l}_{FB}
- Combined A^{l}_{FB} measurement at CDF shows 2σ deviation with NLO SM
- Looking to the future for Tevatron combination of A^{l}_{FB} and A^{ll}_{FB}, as well as fully reconstructed $A^{t\bar{t}}_{\mathrm{FB}}$ in dilepton at CDF

Thank you for your attention and thanks to the organizers for their kind hospitality

Backup slides

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

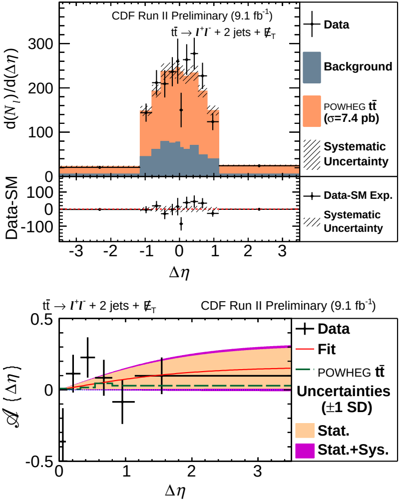
Source	A_{FB}^{l}	Description	Reference
Calculation	0.038 ± 0.003	NLO SM	PRD **86**,034026 (2012)
CDF	$0.094^{+0.032}_{-0.029}$	Lepton+jets	PRD **88** 072003 (2013)
	0.072 ± 0.060	Dilepton	To be submitted
	$0.090^{+0.028}_{-0.026}$	Combination	to PRL soon
D0	$0.047^{+0.025}_{-0.027}$	Lepton+jets, $\lvert q_l \eta_l \rvert < 1.5$	D0 Note 6394-CONF
	0.044 ± 0.039	Dilepton	PRD **88**, 112002 (2013)

- $$A^{ll}_{\text{FB}} = \frac{N(\Delta\eta>0) - N(\Delta\eta<0)}{N(\Delta\eta>0) + N(\Delta\eta<0)}$$
- $\Delta\eta = \eta_{l^+} - \eta_{l^-}$.
- Defined only in dilepton
- Measured A^{ll}_{FB} using the same methodology.

  $A^{ll}_{\text{FB}} = 0.076 \pm 0.072(\text{stat}) \pm 0.037(\text{syst})$

  $= 0.076 \pm 0.081$

  Cf. $A^{ll}_{\text{FB}}(\text{SM,NLO}) = 0.048 \pm 0.004$



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