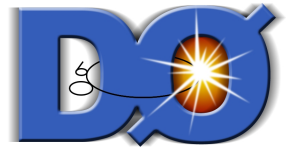


Forward-Backward Asymmetries in Top-Antitop Quark Pair Production at the Fermilab Tevatron

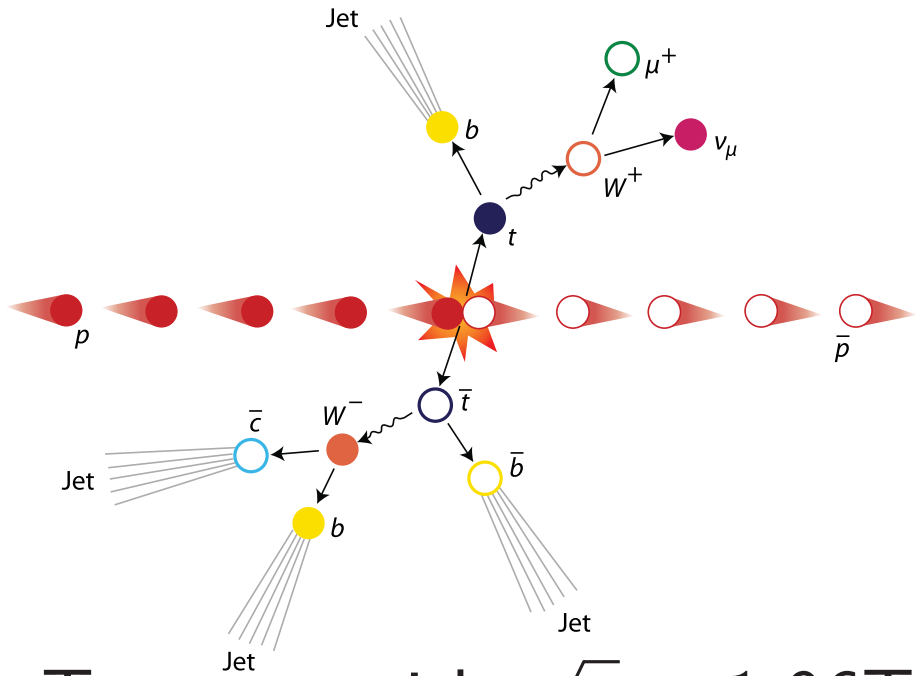
Ziqing Hong, for the CDF and D0 Collaborations

DPF 2017

July 31, 2017

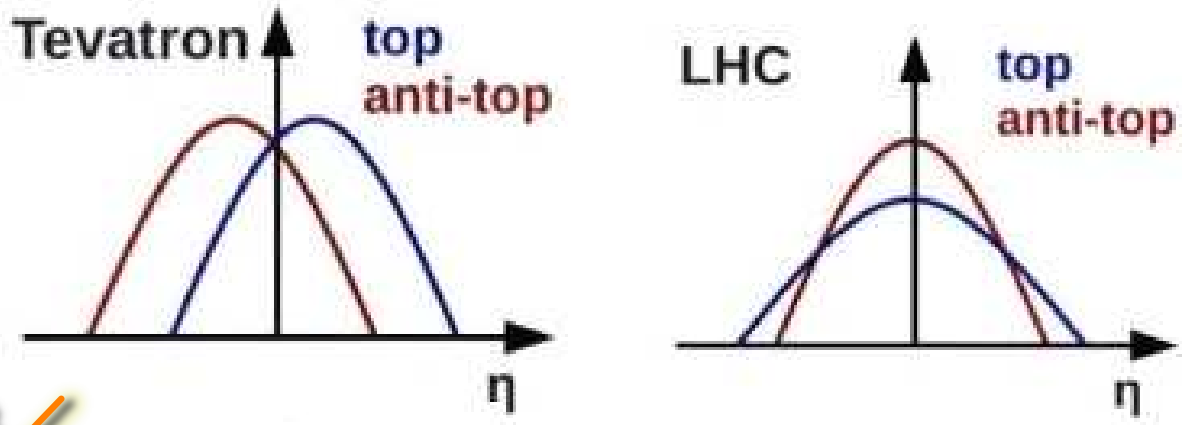
NORTHWESTERN
UNIVERSITY

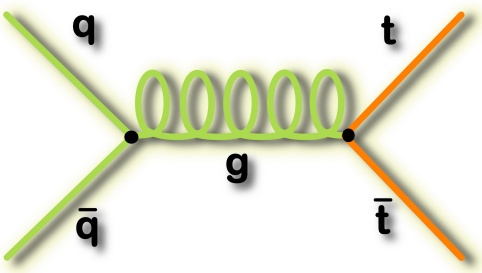
Forward–backward asymmetry



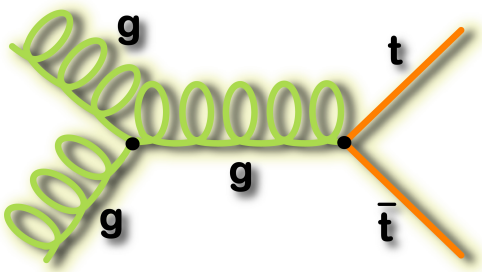
- $p\bar{p}$ collision at Tevatron with $\sqrt{s} = 1.96\text{TeV}$
- Top quarks primarily pair produced ($p\bar{p} \longrightarrow t\bar{t}$)
- Heavy and short-lived, **decay quickly**
- A_{FB} measurements are simply answering:
  Does the top quark prefer the proton direction or the opposite?

Complementarity between the Asymmetry at the Tevatron and the LHC





(a)

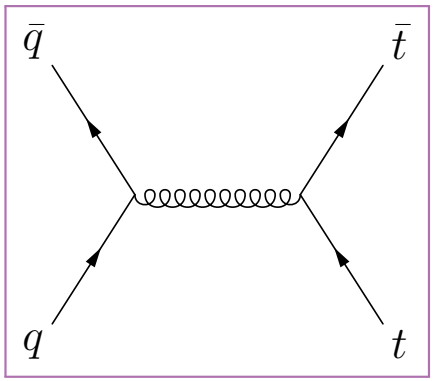


(b)

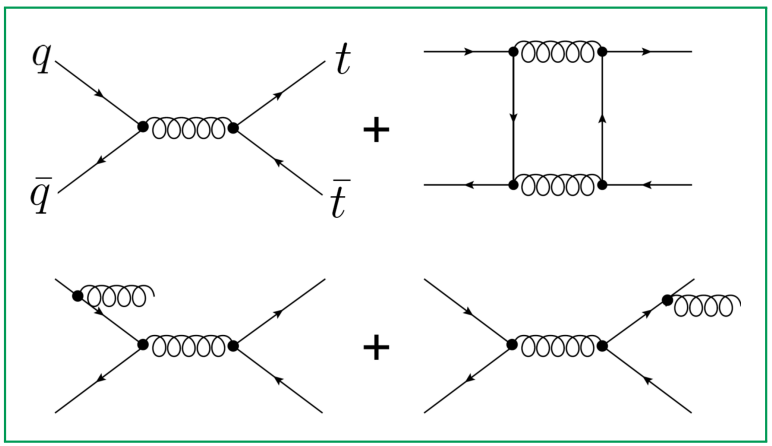
- $p\bar{p}$ collision at Tevatron instead of pp collision at LHC
- Asymmetry from $q\bar{q}$ annihilation (a)
  - Tevatron $t\bar{t}$ production dominated by $q\bar{q}$ annihilation (85%, a)
  - LHC dominated by gluon fusion (90%, b)
- Sizeable effect at Tevatron, very small asymmetry (central vs. outer) at LHC

Top A_{FB}: Theoretical predictions

- No net asymmetry at leading order
  - Asymmetry only from higher order effects
- Slight asymmetry starting from next-to-leading order (NLO) effects
  - Interference among diagrams
  - Positive from born+box, negative from ISR/FSR

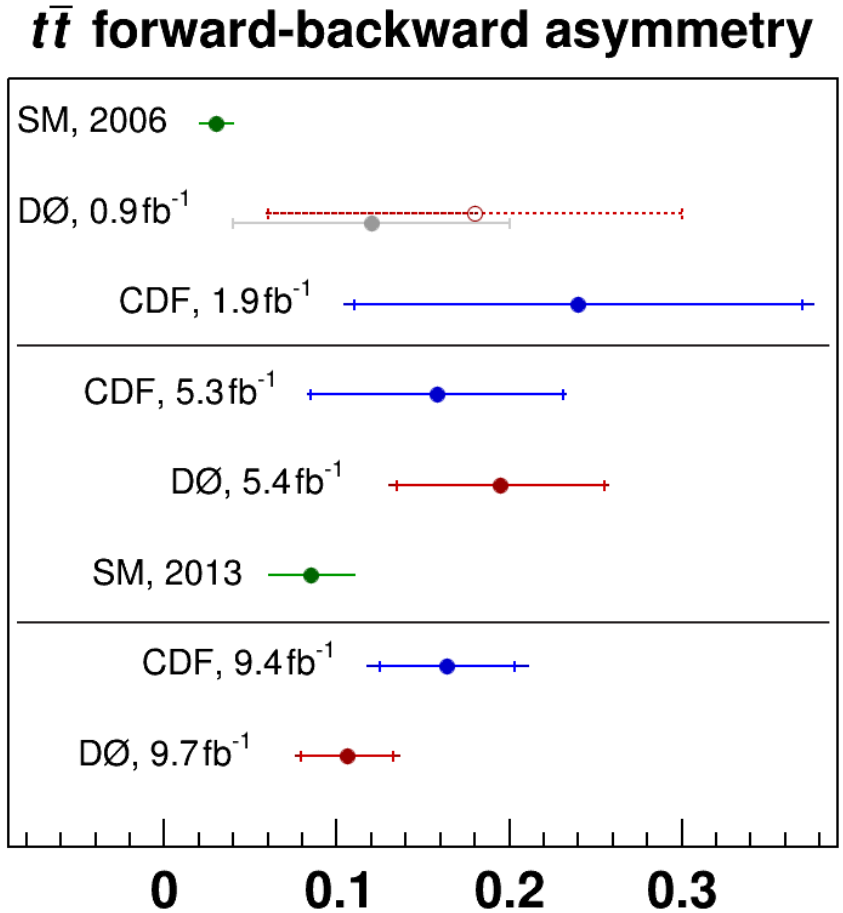


- Substential EW correction and higher order QCD corrections complicate the calculation
- **Precision probe of SM predictions of top quark physics**



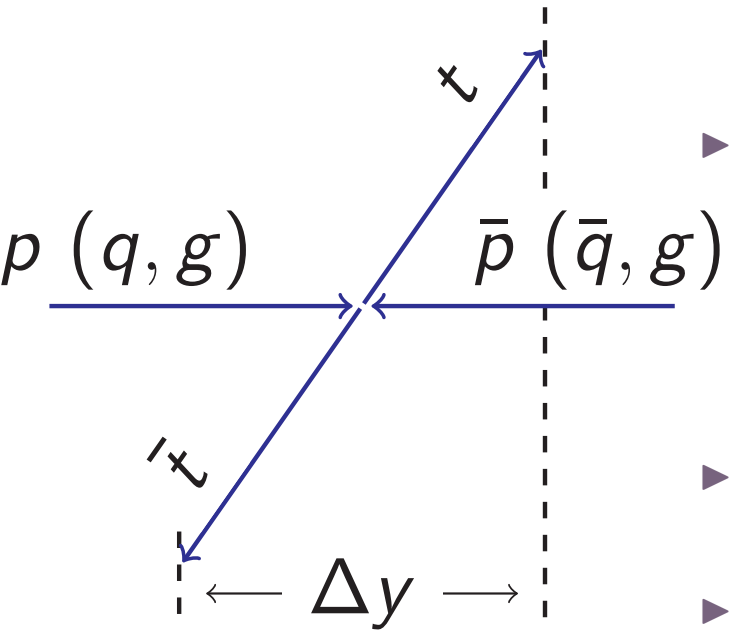
Top A_{FB}: Why interesting?

- First set of measurements showed larger-than-SM values which leaves room for various beyond-SM models
  - s-channel axigluon, t-channel W' Z', etc.
- SM predictions improved by going to higher order and adding more effects
- Experimental results improved with more data as well as better simulation/unfolding techniques



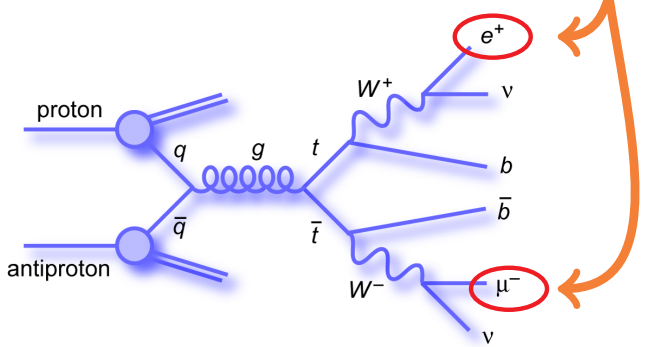
- The tension between measurements and SM predictions has been reduced with time

Top A_{FB} at Tevatron



- Quantify the asymmetry with the rapidity difference (Δy) between top and anti-top
- $A_{FB}^{t\bar{t}} = \dfrac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$
- Also can measure A_{FB} using one or two leptons from top decays

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



$$A_{FB}^{\ell} = \frac{N(q_\ell \eta_\ell > 0) - N(q_\ell \eta_\ell < 0)}{N(q_\ell \eta_\ell > 0) + N(q_\ell \eta_\ell < 0)}$$

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

$$\Delta\eta = \eta_{\ell^+} - \eta_{\ell^-}$$

Top A_{FB} at Tevatron

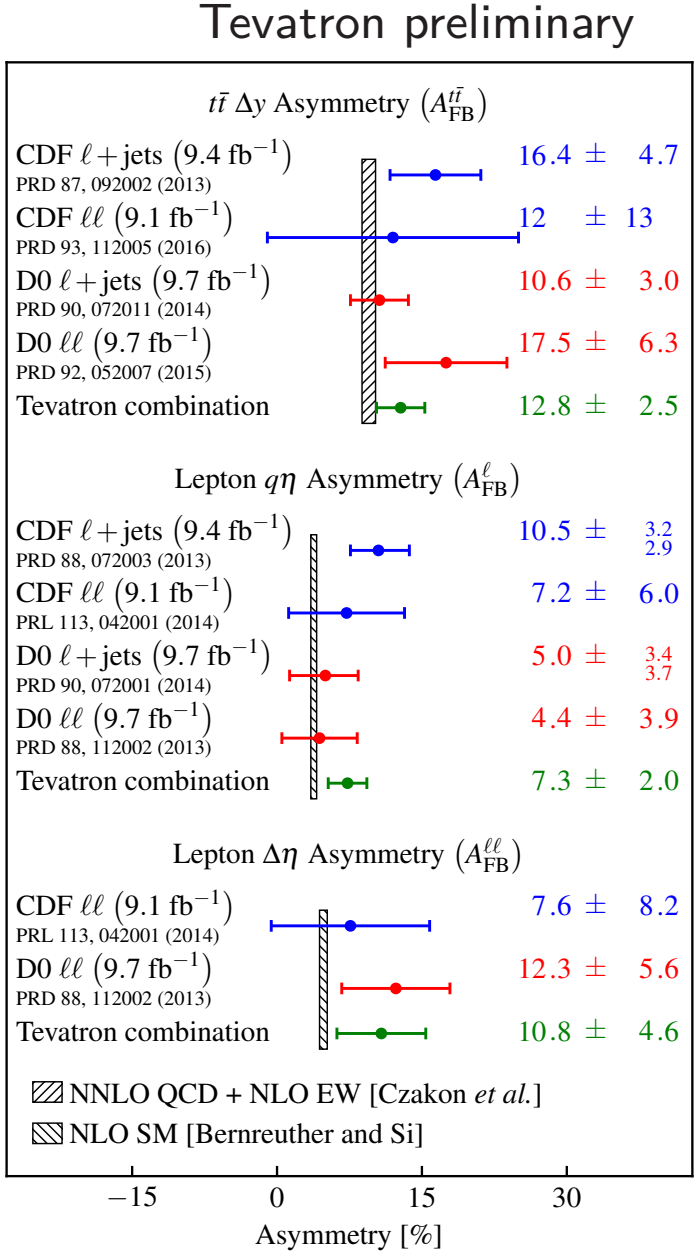
- Measurements done in multiple channels at CDF & D0

	CDF ℓ+jets	CDF dilepton	D0 ℓ+jets	D0 dilepton
$A_{FB}^{t\bar{t}}$	PRD 87, 092002 (2013)	PRD 93, 112005 (2016)	PRD 90, 072011 (2014)	PRD 92, 052007 (2015)
A_{FB}^{ℓ}	PRD 88, 072003 (2013)	PRL 113, 042001 (2014)	PRD 90, 072001 (2014)	PRD 88, 112002 (2013)
$A_{FB}^{\ell\ell}$		PRL 113, 042001 (2014)		PRD 88, 112002 (2013)

- Results for both inclusive asymmetries and differential ones as functions of Δy or $m_{t\bar{t}}$
- Combining all of them for a final word from Tevatron

Inclusive A_{FB} combinations

- BLUE combination, with correlations between results accounted
- All results limited by statistical uncertainty
- No evidence for deviation from SM
  - $A_{FB}^{t\bar{t}}$ 1.3σ from NNLO QCD + NLO EW prediction
  - A_{FB}^{ℓ} 1.6σ from NLO QCD + NLO EW prediction
  - $A_{FB}^{\ell\ell}$ 1.3σ from NLO QCD + NLO EW prediction
- FERMILAB-CONF-16-386-PPD

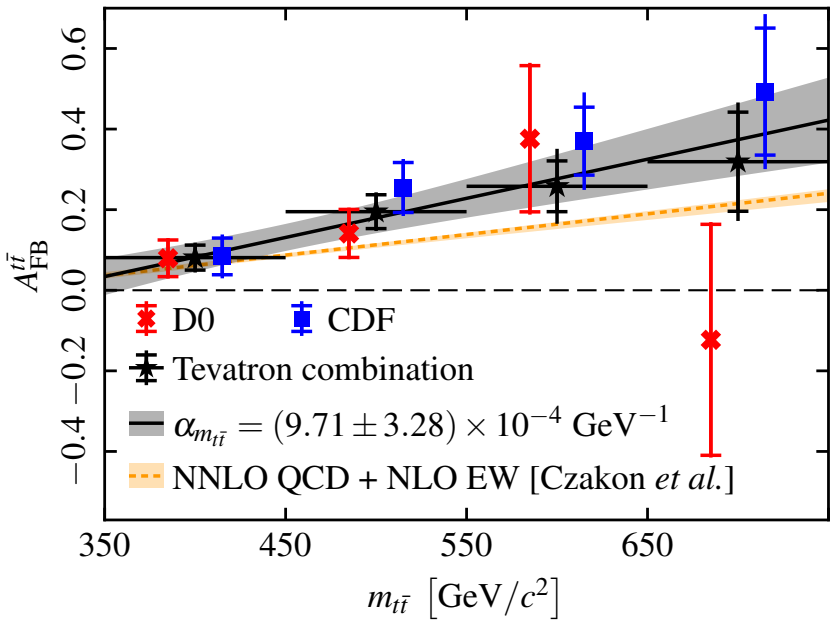


$A_{FB}^{t\bar{t}}$ vs. $m_{t\bar{t}}$

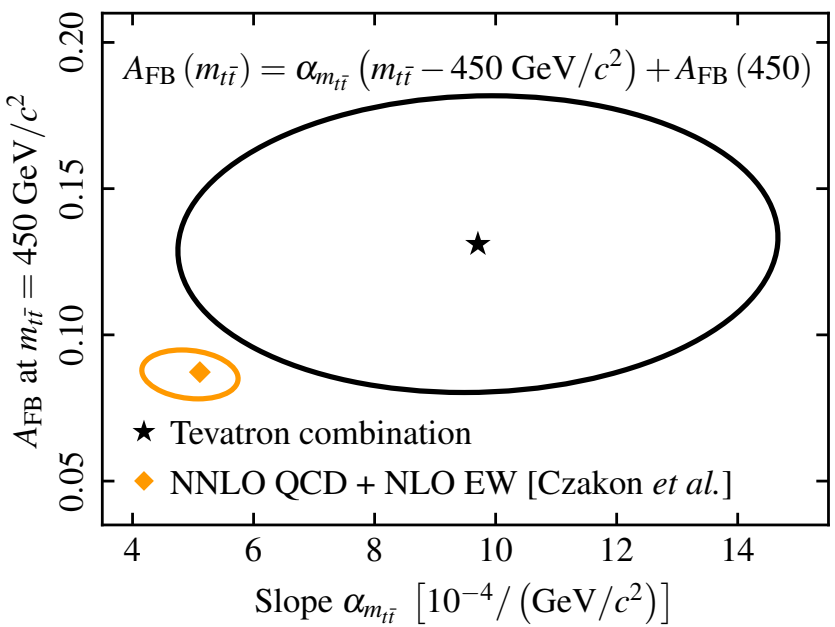
- $A_{FB}^{t\bar{t}}$ vs. $m_{t\bar{t}}$ measured in CDF ℓ+jets and D0 ℓ+jets
- With same binning
- Bin-by-bin BLUE combination, with all correlations taken into account
- Agreement with NNLO QCD + NLO EW at 1.3σ
  - Czakon et al. arXiv:1705.04105
- New results!

  Manuscript to be submitted soon.

Tevatron preliminary

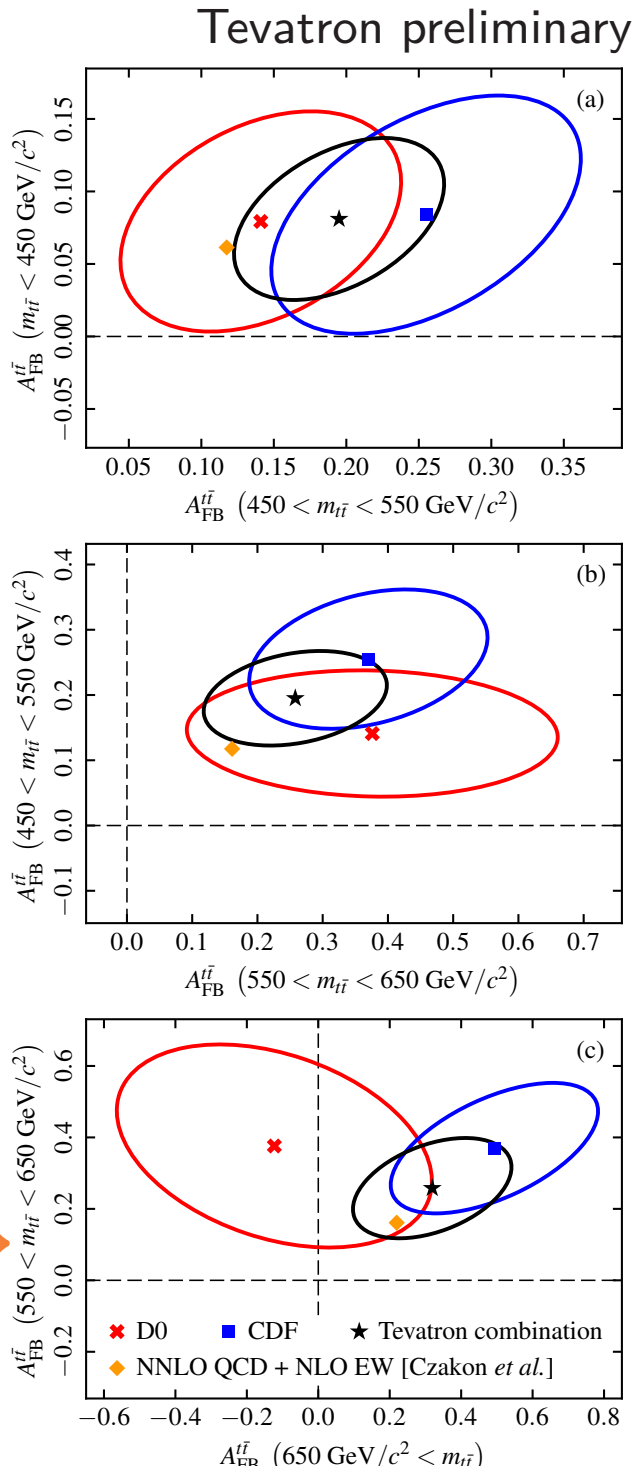


Tevatron preliminary



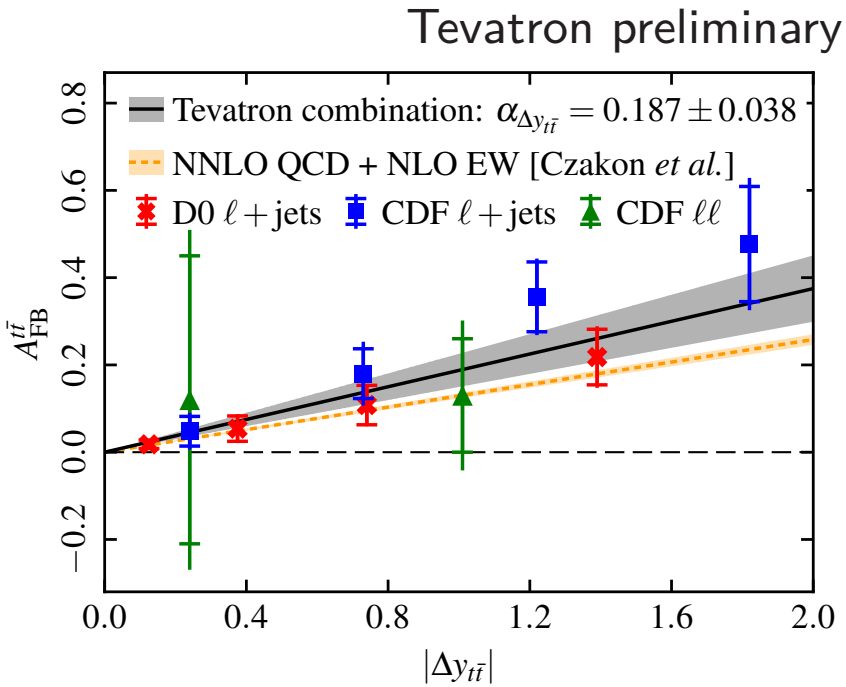
$A_{FB}^{t\bar{t}}$ vs. $m_{t\bar{t}}$ - correlation

- CDF and D0 results appear to have different trend in high mass
- Combination result in 3rd mass bin lower than both inputs
- Different correlations between last two bins
  - Positive for CDF and negative for D0
  - Caused by different unfolding methods
- Combination shows good agreement between CDF and D0
  - $\chi^2/\text{d.o.f} = 5.19/4$



$A_{\mathrm{FB}}^{t\bar{t}}$ vs. Δy

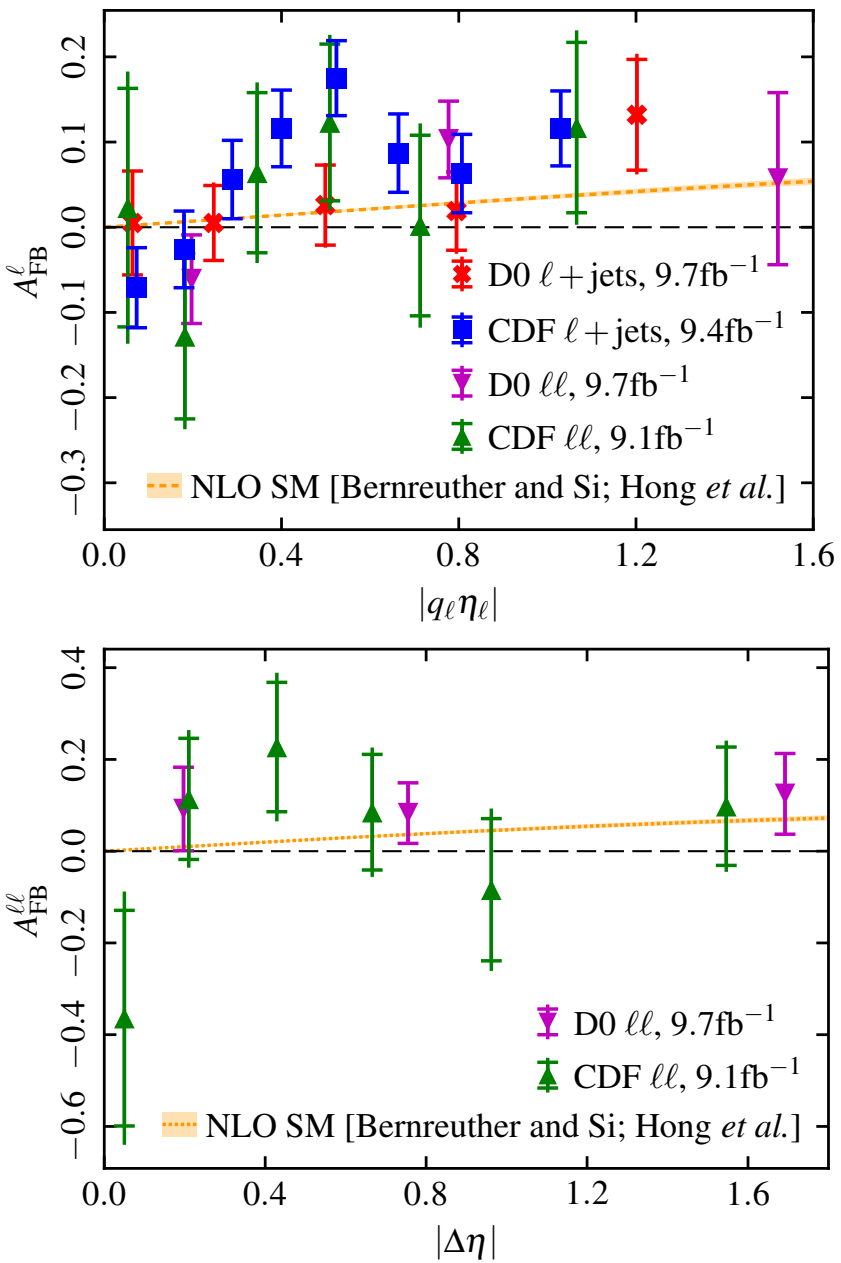
- $A_{\mathrm{FB}}^{t\bar{t}}$ vs. Δy measured in CDF ℓ+jets, CDF dilepton, and D0 ℓ+jets
- Binning choices are different, cannot combine bin-by-bin
- Doing a simultaneous linear fit to all data points
  - Measured slope 0.187 ± 0.038
  - Cf. $0.129^{+0.006}_{-0.012}$ NNLO QCD + NLO EW, Czakon et al. arXiv:1705.04105
- Agreement at 1.5σ



- New results! Manuscript to be submitted soon.

Differential A_{FB}^{ℓ} and $A_{FB}^{\ell\ell}$

- Putting all data on the same figure for good visualization
- Theory curves are tanh functions scaled to NLO QCD + NLO EW predictions



Conclusions

- The A_{FB} of top-pairs at the Tevatron has been a hot topic for years
- Measurements of $A_{FB}^{t\bar{t}}$, A_{FB}^{ℓ} and $A_{FB}^{\ell\ell}$ probe the production and decay of $t\bar{t}$
- Results from CDF and D0 combined for a final word as Tevatron legacy
  - Manuscript in preparation, to be submitted soon
- No clear sign of new physics
- Agreement between data and latest SM predictions at 1.3-1.6σ
- The interaction of experiment and theory has been healthy

Backup Slides

Backup slides