Selected Tevatron Measurements of Top quark Properties

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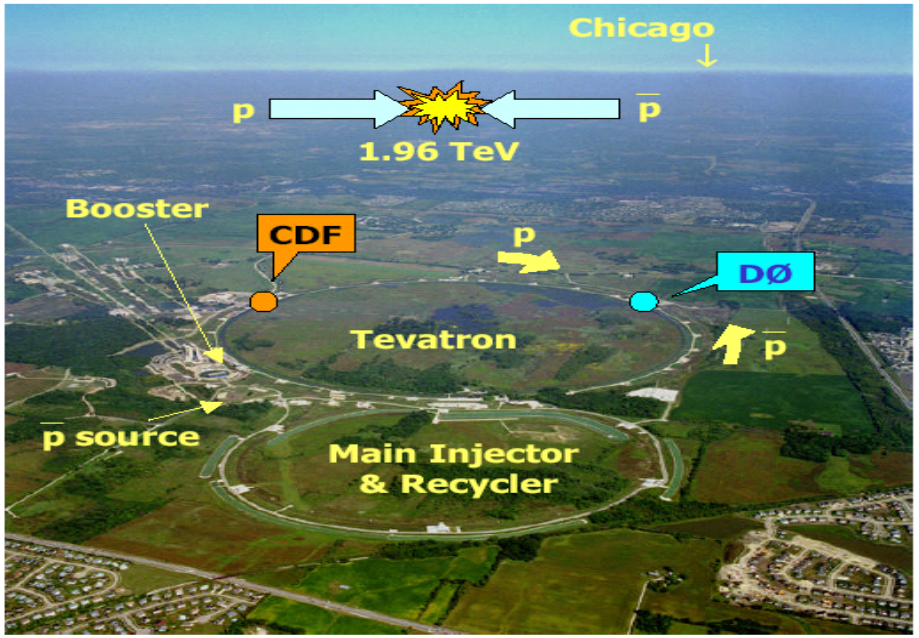
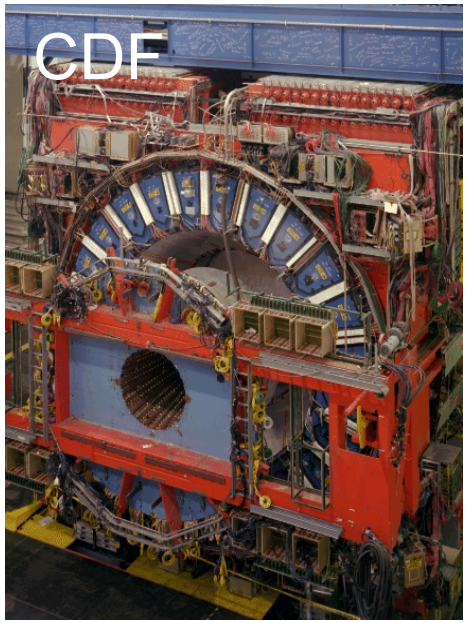
Outline

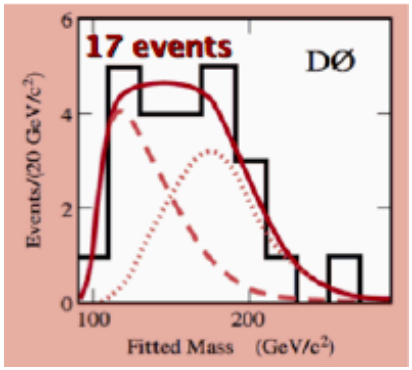
- Motivation
- Introduction to observables
- Recent results on A_{FB} and polarization (full Run II data)
- Conclusions



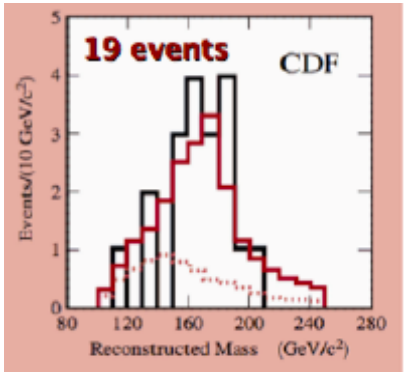


Top Quark

1995: Discovered @ the Tevatron

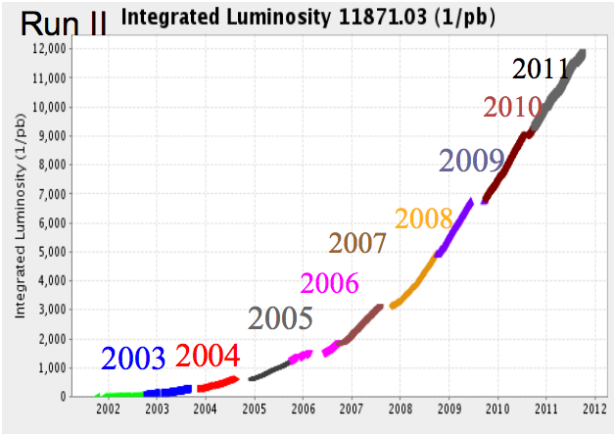


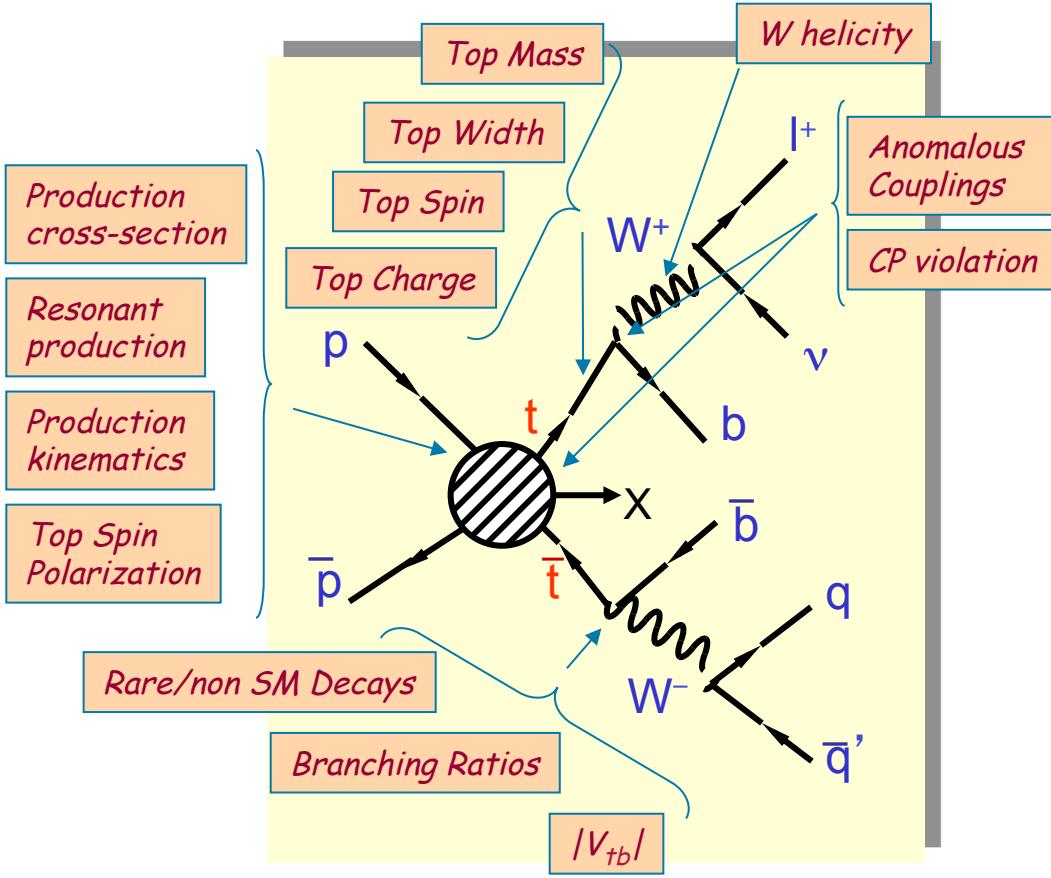
PRL 74, 2632 (1995)



PRL 74, 2626 (1995)

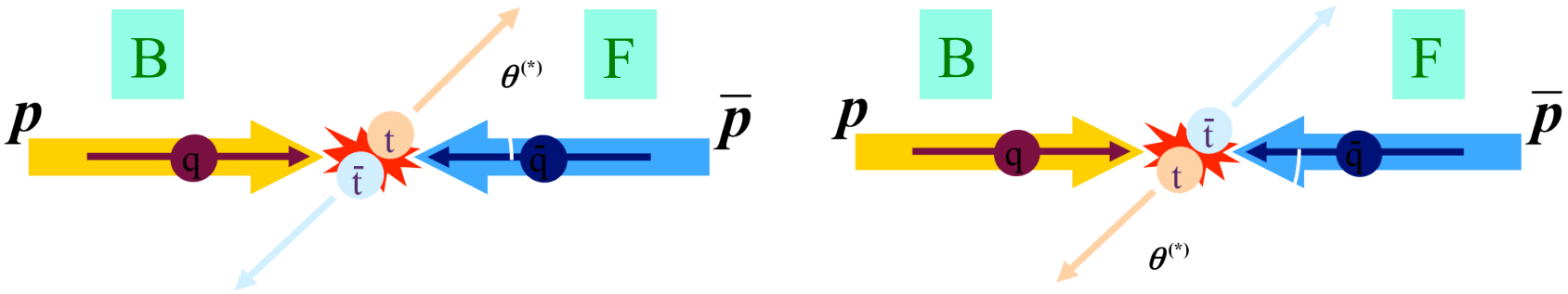
Today: thousands of events used for precision measurements & searches





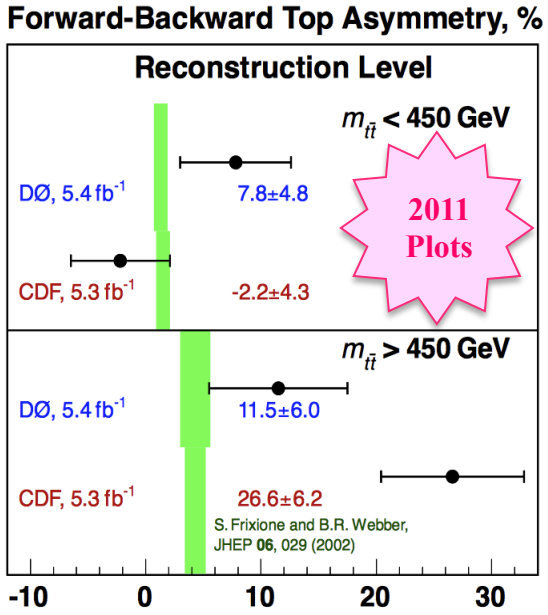
- Successful Tevatron program
- Pioneering of analysis techniques
- Complementary to LHC thanks to $p\bar{p}$ initial state
- Less pile-up effects than LHC
- Excellent agreement with SM predictions

One Excitement: Top FB Asymmetry



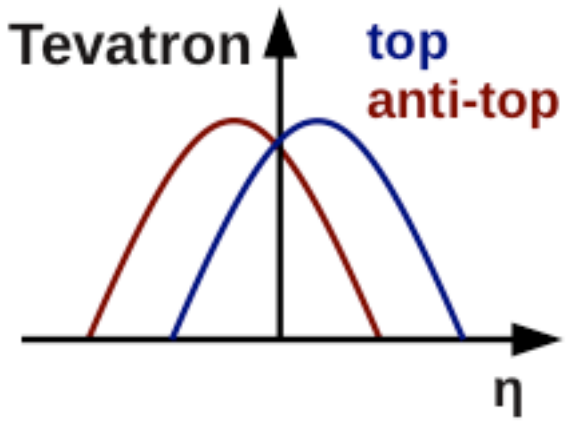
- Top quarks are preferentially emitted in the direction of the incoming quark, anti-tops in the direction of the incoming anti-quark. No asymmetry in gg production.

- SM predicts small asymmetry from interference between LO and NLO box diagrams & between ISR and FSR. Interference with EW processes increase the asymmetry.
- BSM production mechanisms that exchange new bosons could significantly enhance the asymmetry
- Inclusive asymmetries measured using ~5fb^{-1} of Tevatron data exceeded SM predictions by 1.5-2SD
- Larger (~3SD) mass and rapidity dependence than predicted by the SM
  - Resulted in aggressive measurement program & hundreds of possible BSM explanations



A_{FB} Definitions

- $t\bar{t}\,\Delta y$ Asymmetry
  - based on top rapidities



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

$$\Delta y = y_t - y_{\bar{t}}$$

$A_{FB}^{t\bar{t}} \approx 10\%$

NNLO QCD + NLO EW

- Leptonic FB Asymmetry
  - based on the rapidities of the charged leptons from top decay
  - Lepton rapidity well measured
  - Free from complications of combinatorics and jet resolutions

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

Measured in l+jets and dilepton

$A_{FB}^{l} \approx 4\%$ NLO with LO denominator

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

Measured in dilepton

$$\Delta y_l = y_{l^+} - y_{l^-}$$

$A_{FB}^{ll} \approx 5\%$ NLO with LO denominator

Top Quark Polarization

- Top quarks decay before hadronization: Spin is transferred to decay products
- SM predicts weak polarization
  - <1% QCD induced transverse polarization
  - <0.5% longitudinal polarization due to parity-violating EW contributions to the production process.
- Couplings of top to BSM particles can result in much larger polarization
- Models with new parity violating interactions (axigluons) predict a sizable polarization together with a large A_{FB}

- Measuring polarization and $A_{FB}^{t\bar{t}}$ simultaneously can shed light on the underlying dynamics of top quark production
- Simplest observable: lepton angular distribution relative to quantization axis ň

$$\frac{d\sigma}{d\cos\theta^{\pm}} = \frac{1}{2}(1 + \kappa^{\pm} P_{\hat{n}}^{\pm} \cos\theta^{\pm})$$

- Polarization term can be obtained as asymmetry in the lepton angular distribution

$$\kappa P = A^{l+} - A^{l-}$$

$$A^{l\pm} = \frac{N(\cos\theta^{\pm} > 0) - N(\cos\theta^{\pm} < 0)}{N(\cos\theta^{\pm} > 0) + N(\cos\theta^{\pm} < 0)}$$

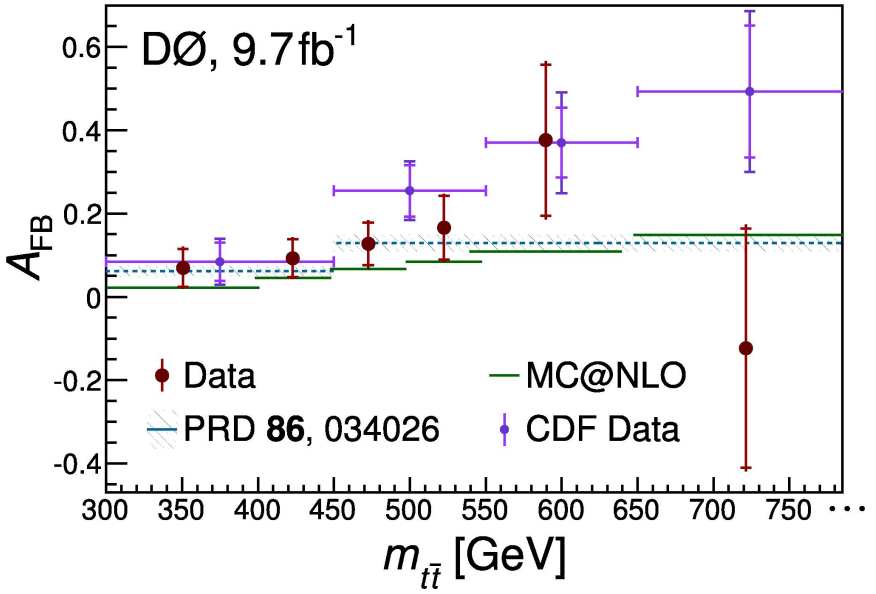
κ: spin analyzing power of lepton ~ 0.99 in QCD
$\cos\theta^{\pm}$: angle between lepton$^{\pm}$ and ň
Helicity basis: ttbar axis in ttbar rest frame

Analysis Strategy

- Start with candidate samples dominated by $t\bar{t}$ events
- top and anti-top quarks are reconstructed from their decay products by means of kinematic fitting or ME techniques
- Reconstruction-level (raw) measurements are obtained after background subtraction – detector dependent
- Production-level (partonic) measurements are obtained after correcting for detector acceptance and resolution (unfolding)
  - Use NLO MC – minimal model dependence addressed using alternative signal MC samples as systematic uncertainties
  - Unfolded measurement can be compared among experiments and with theoretical predictions
  - Measurements are presented for the inclusive quantities, as well as differentially vs $m_{t\bar{t}}$, production angle, etc.

A^{tt}_{FB} lepton + jets channel

- Charge of the lepton (e or μ) identifies the charge of the leptonic top. Opposite charge assumed for the hadronic top.
- Kinematic reconstruction of the $t\bar{t}$ system - partial for events with 3 jets D0 NIM A 788:128-136, July 2015.

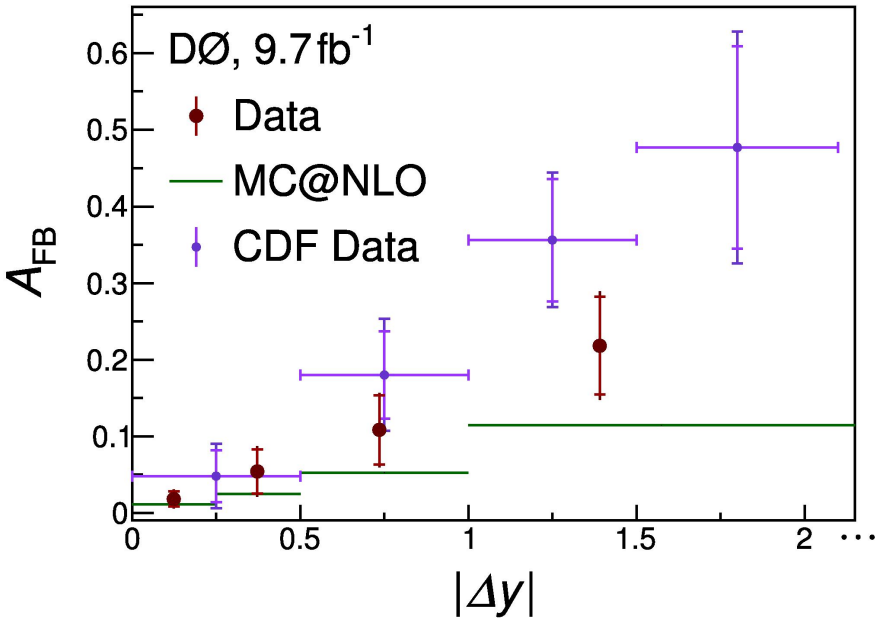


- Tevatron Run II inclusive results

CDF	$(16.4 \pm 4.7)\%$	PRD 87, 0920022 (2013)
D0	$(10.6 \pm 3.0)\%$	PRD 90, 072011 (2014)

- SM predictions

Czakon	$(9.5 \pm 0.7)\%$	NNLO QCD + NLO EW arXiv:1411.3007
Kidonakis	$(10.0 \pm 0.6)\%$	aN^{3}NLO QCD + NLO EW PRD 91, 071502(R) 201



Inclusive A^{tt}_{FB} dilepton channel

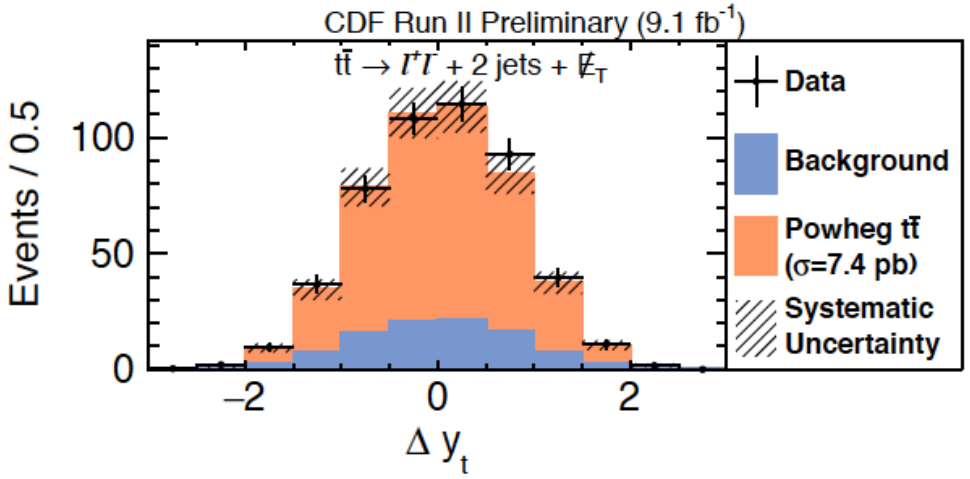
- Two opposite charge leptons (ee, eμ, μμ), two jets and MET
- Likelihood-based $t\bar{t}$ reconstruction
- Event-by-event reconstruction with 4 constraints: two W boson masses, two top quark masses & energy-momentum conservation equations
- Bayesian model to extract parton-level A_{FB} in 4 bins in Δy

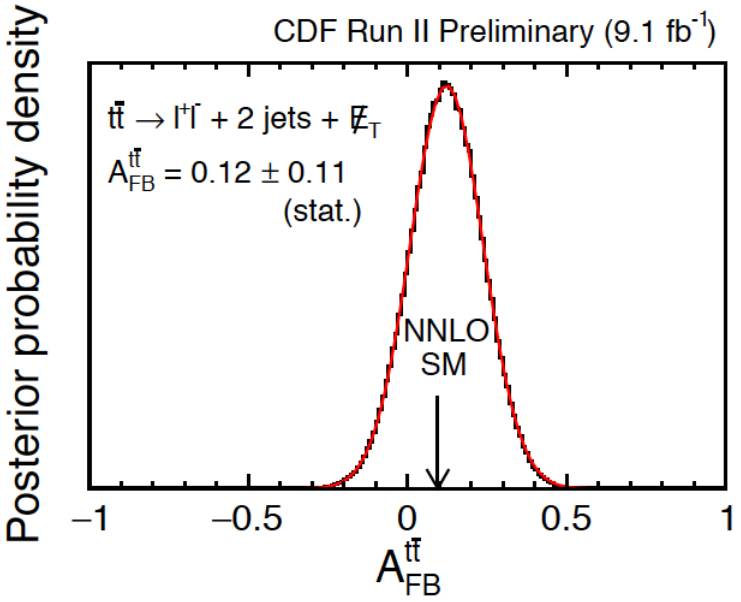
Combination with the inclusive l+jets result using BLUE

Dilepton: $(12 \pm 13)\%$

Combination: $(16.0 \pm 4.5)\%$

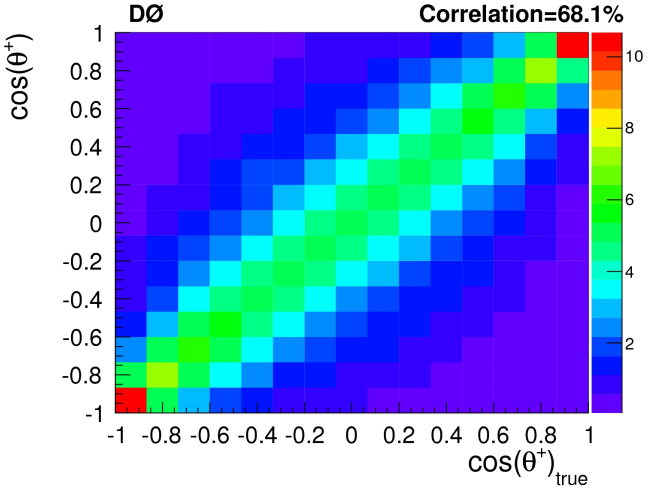
CDF Public Note 11161 (June 2015)

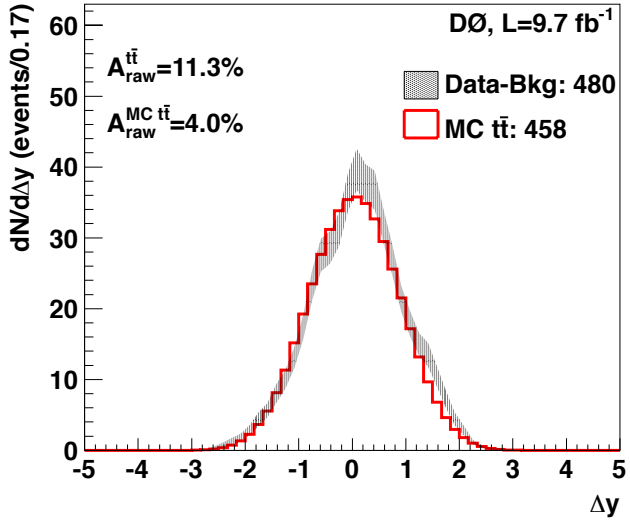


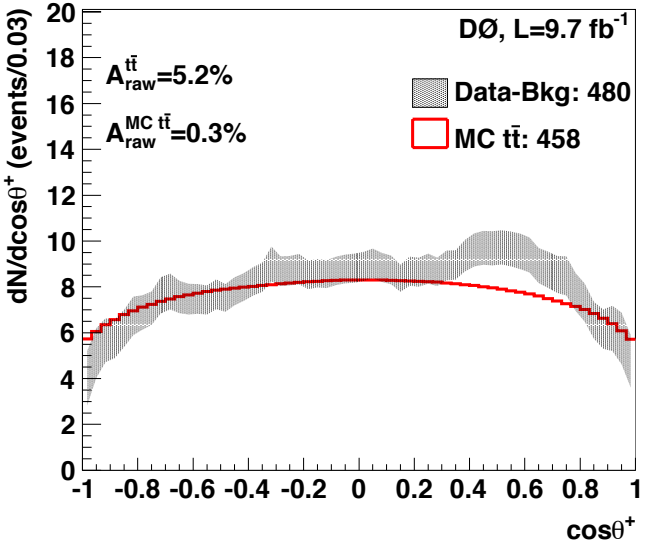


Simultaneous measurement of A^{tt}_{FB} and top polarization

- Dilepton channel (ee,eμ,μμ)
- Matrix Element integration method used to reconstruct events
  - LO, no gg→tt, two jets
  - Modified to reconstruct Δy, $\cos\theta^+$, and $\cos\theta^-$
- Accumulation of event-by-event likelihood functions gives an estimate of the true distribution



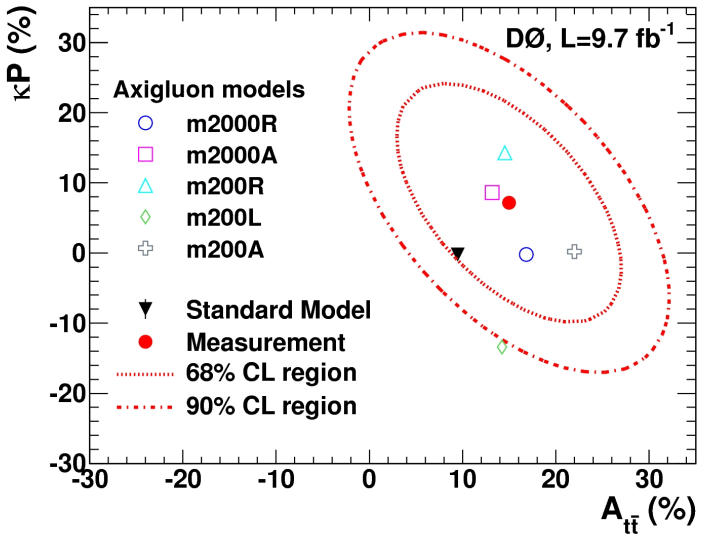




Background-subtracted accumulation of likelihoods gives the raw distributions.

Simultaneous measurement of A^{tt}_{FB} and top polarization

- Raw measurements corrected using calibration $t\bar{t}$ MC test samples
  - Events are reweighted according to the parton-level Δy, $\cos\theta^+$, and $\cos\theta^-$
  - 30 weighted samples are produced for $\kappa P = (-0.2, -0.1, 0.0, 0.1, 0.2)$ and $A_{FB} = (-0.1, 0.0, 0.1, 0.15, 0.2, 0.25)$
  - Partonic A_{FB} and κP extracted from the raw measurements simultaneously by inverting the calibration



$$A^{tt}_{FB} = 15.0 \pm 6.4(stat) \pm 4.9(syst)\%$$
$$\kappa P = 7.2 \pm 10.5(stat) \pm 4.2(syst)\%$$

Correlation due to acceptance and resolution $(A_{FB}, \kappa P) = -56\%$

- Results when separately constraining A_{FB} and κP to their SM values:

$$A^{tt}_{FB} = 17.5 \pm 5.6(stat) \pm 3.1(syst)\%$$
$$\kappa P = 11.3 \pm 9.1(stat) \pm 1.9(syst)\%$$

First top polarization measurement at the Tevatron

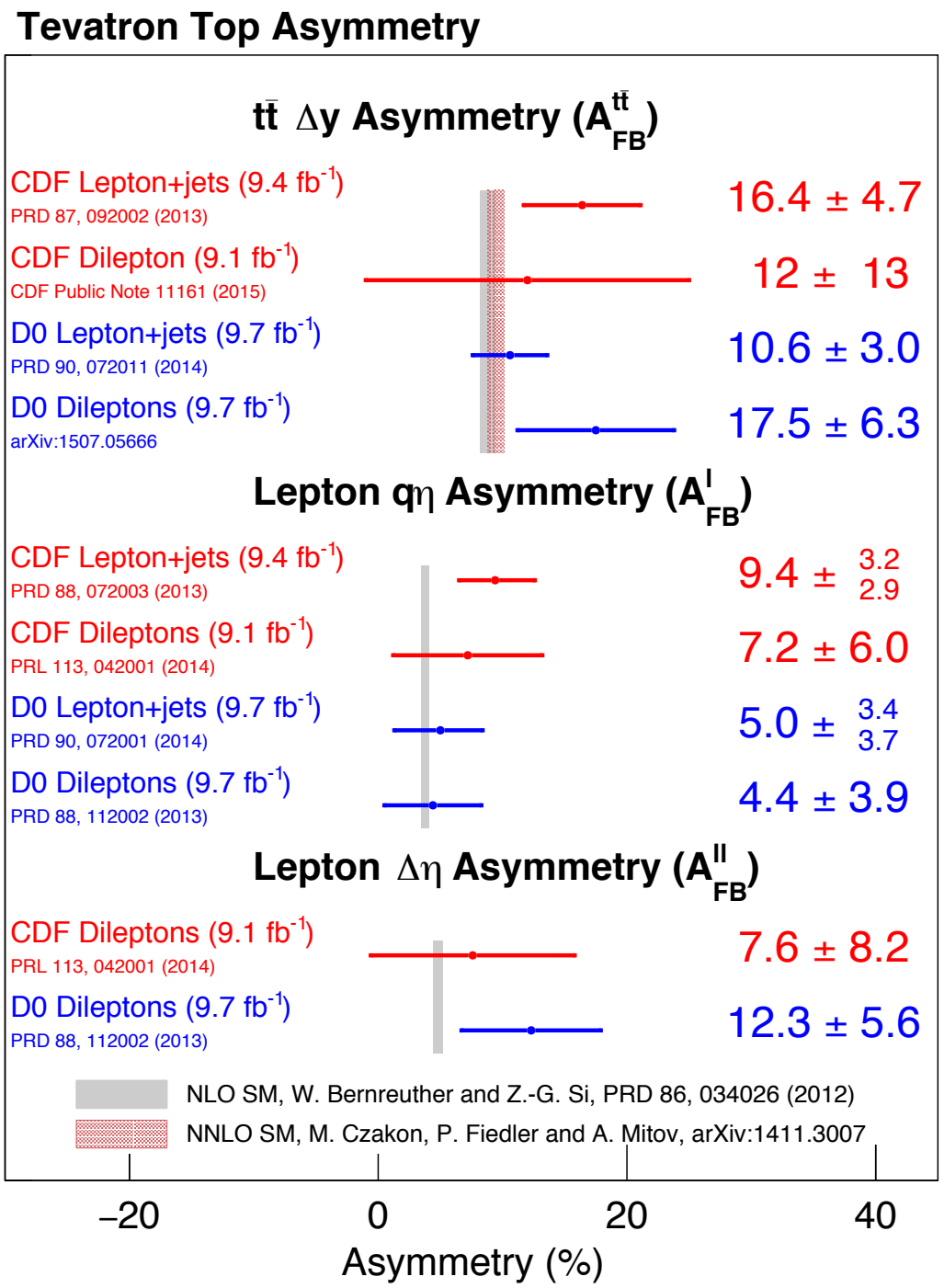
- Combination with l+jets A_{FB} result

$$A^{tt}_{FB} = 11.8 \pm 2.5(stat) \pm 1.3(syst)\%$$

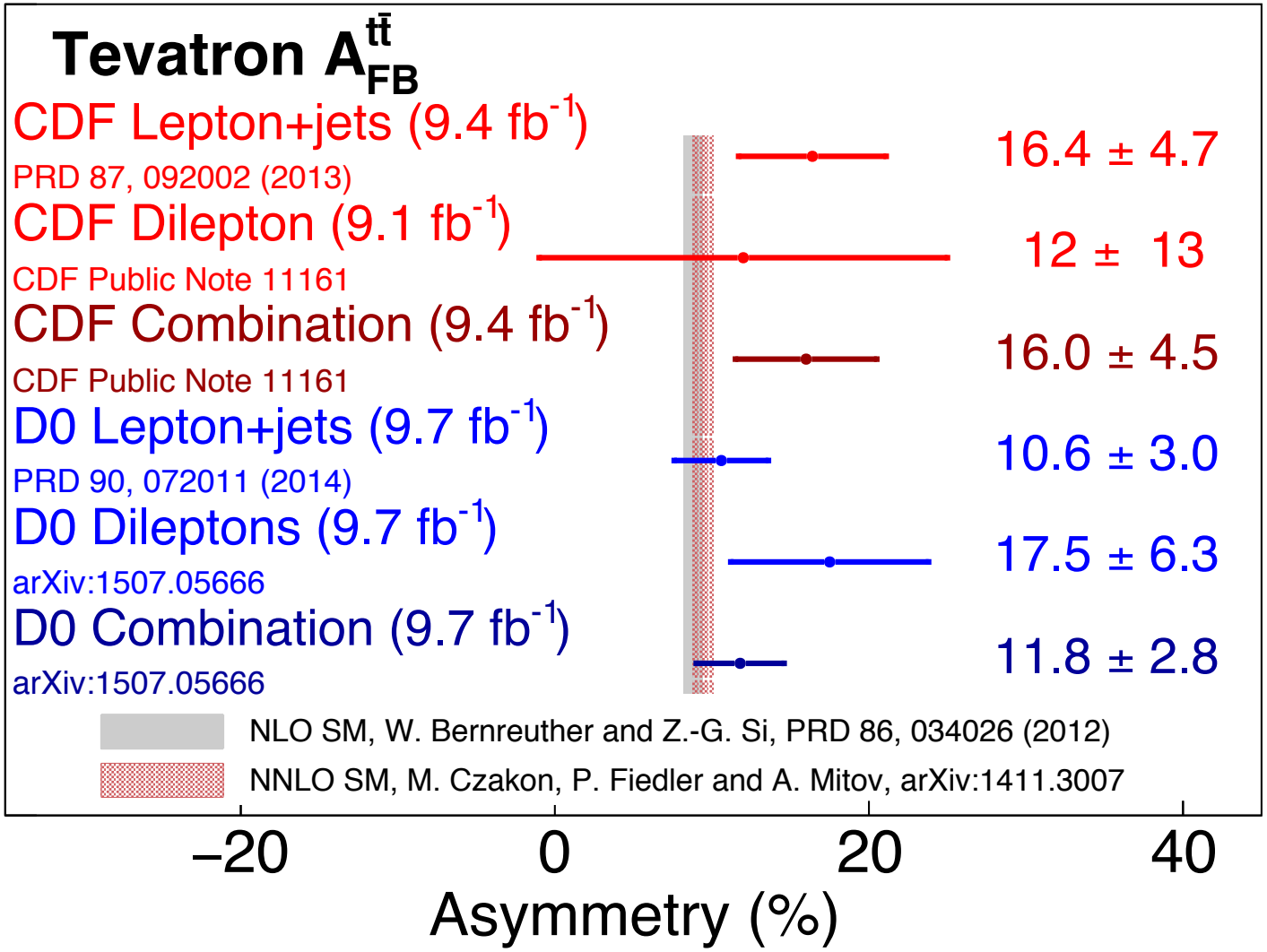
All results agree with SM expectations

arXiv:1507.05666, submitted to PRD

- Final measurements with entire Run II dataset
  - Lepton + jets and dilepton channels
  - Top and leptonic asymmetries
  - Inclusive and Differential measurements
- Systematic effort by CDF and D0 to settle the A_{FB} discrepancy issue.
- Overall good agreement with SM prediction (QCD NNLO + EW)



Inclusive A^{tt}_{FB} Summary



Combination forthcoming

Conclusions

- Tevatron had a very successful SM top quark program
  - Observation
  - Development of analysis techniques
  - Precision Measurements
  - BSM Exclusions

- Legacy results on the full dataset complement LHC
  - pp initial state
  - less pileup

LHC Tevatron

LHC opens a new era of high statistics and BSM discoveries