Top Quark Properties at the Tevatron

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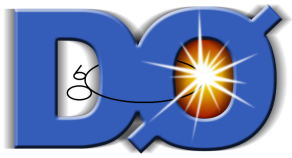
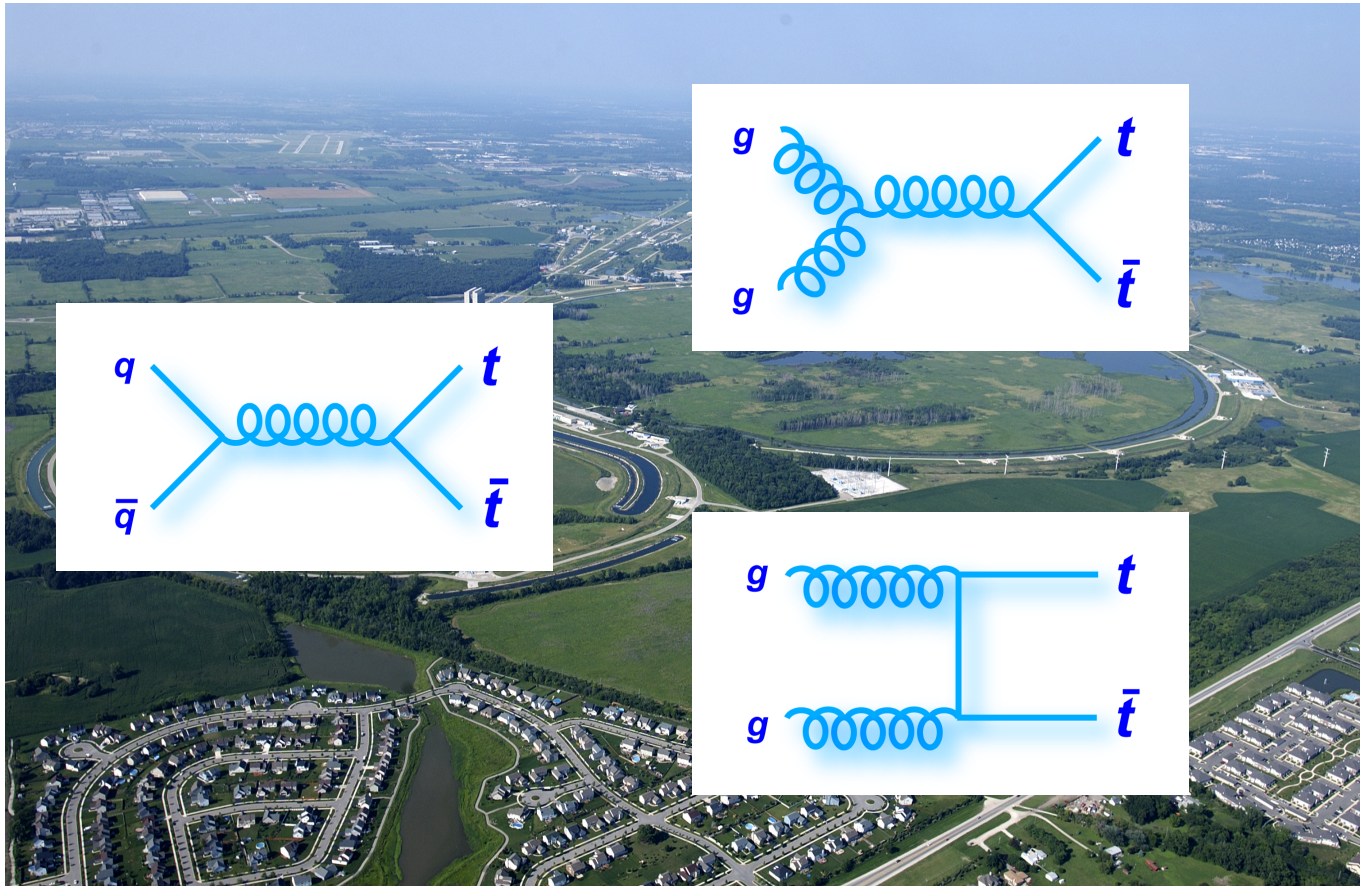
On behalf of the CDF and DØ Collaborations



March 13, 2013

Top quarks at the Tevatron

- $m_t > m_H$. Special role in BSM physics?
- Produced via the strong interaction in $p\bar{p}$ collisions
- 85% $q\bar{q} \to t\bar{t}$ + 15% $gg \to t\bar{t}$ (opposite of LHC)



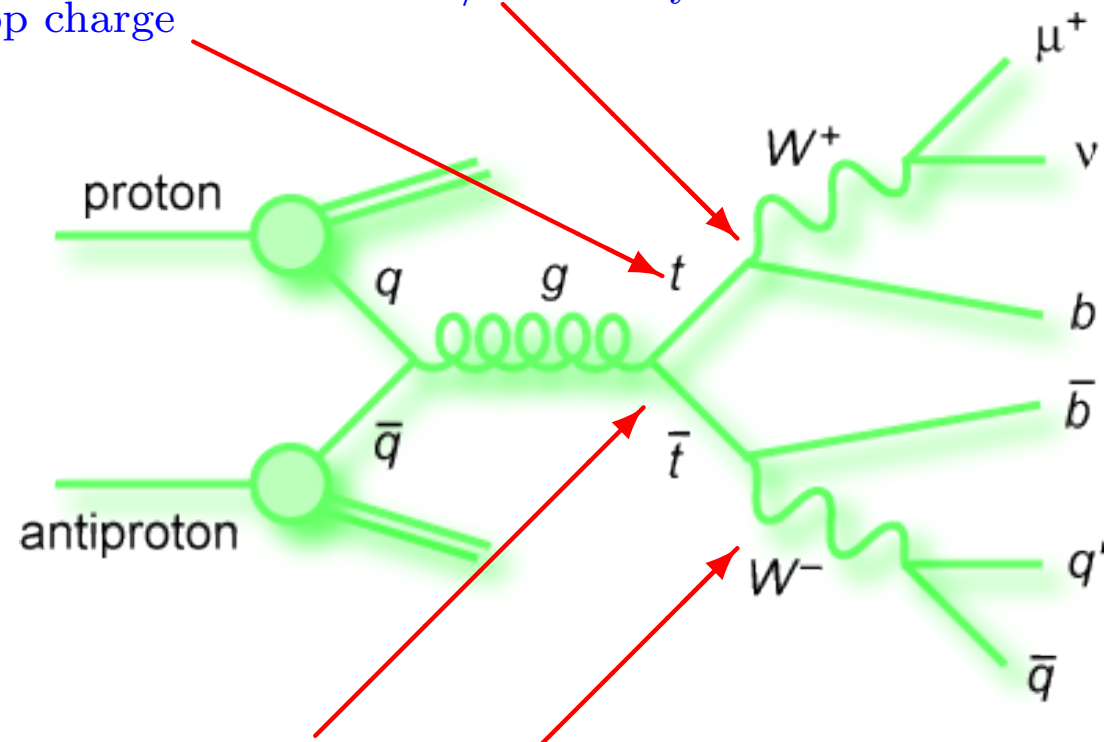
- Many new physics models arise only from $q\bar{q} \to t\bar{t}$

Many opportunities for new physics

- Today's items in red

Top width
Lifetime
Top mass
$t\bar{t}$ mass difference
Top charge

Top branching ratios
Anomalous couplings
New/rare decays



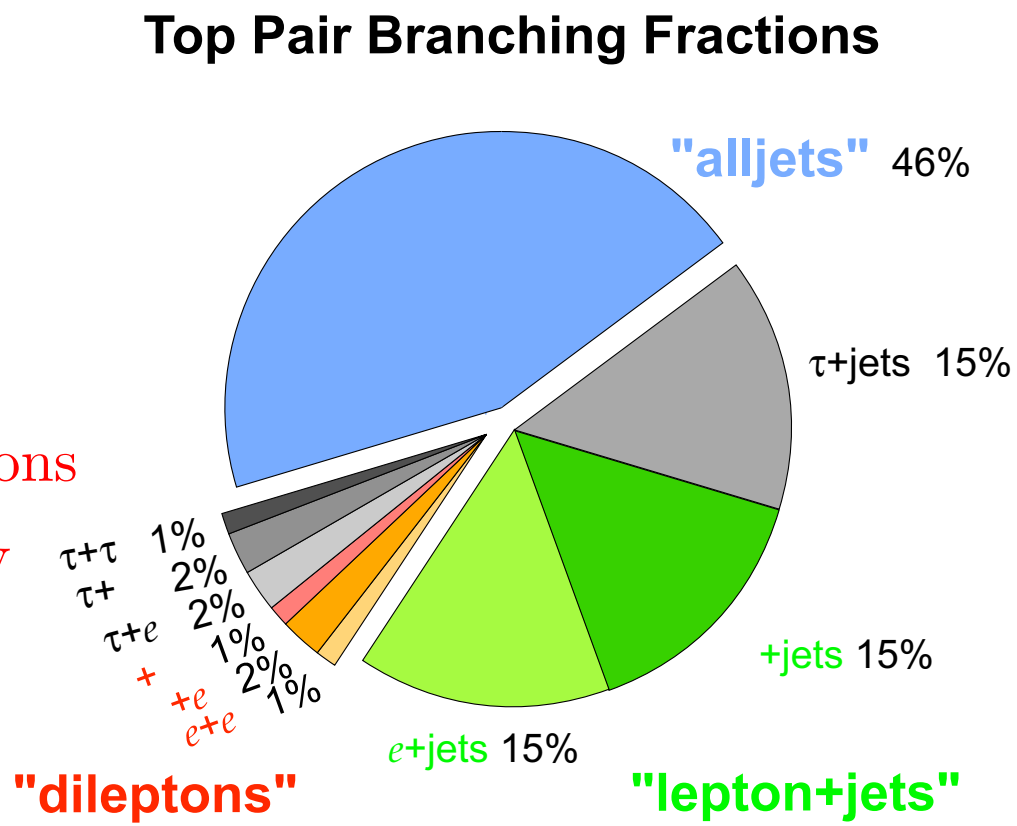
Spin correlation

FB asymmetry
Resonance production
New particles
Violation of Lorentz invariance/CPT

W helicity

Top decays

- $t\bar{t} \to W^+ b W^- \bar{b}$, $\mathrm{BR}_{\mathrm{SM}}(t \to W^+ b)$=100%
- Top pair decays classified by decay of W^+W^-



dilepton

2 isolated leptons

Missing energy

2 b jets

lepton+jets

1 isolated lepton

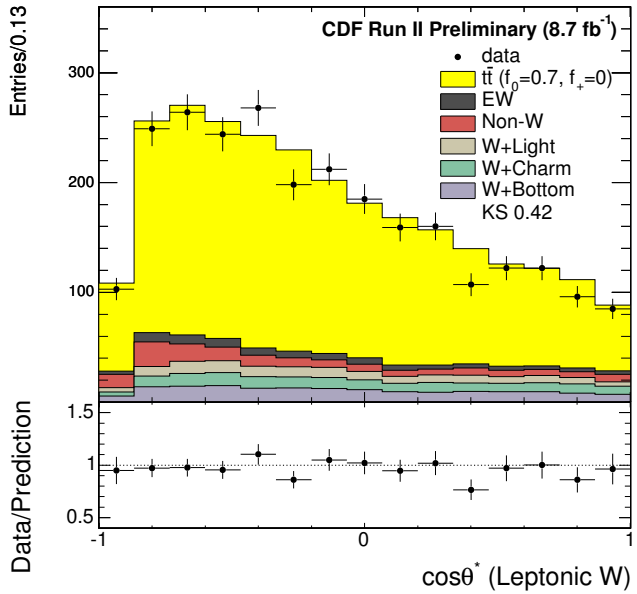
Missing energy

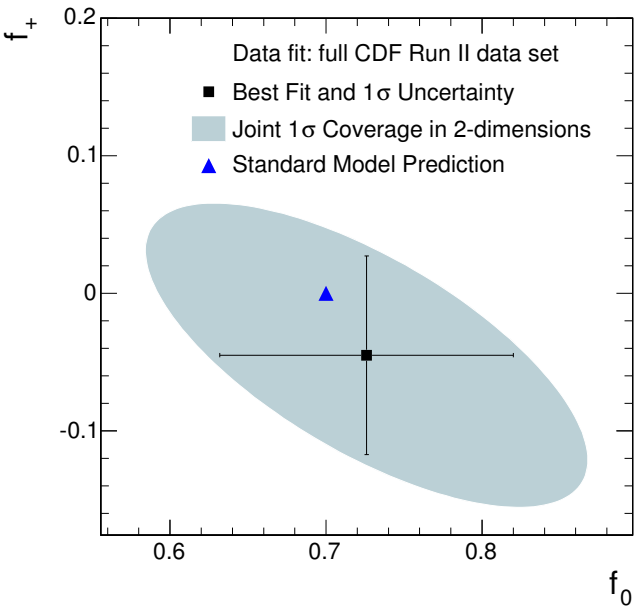
Four or more jets

2 b jets

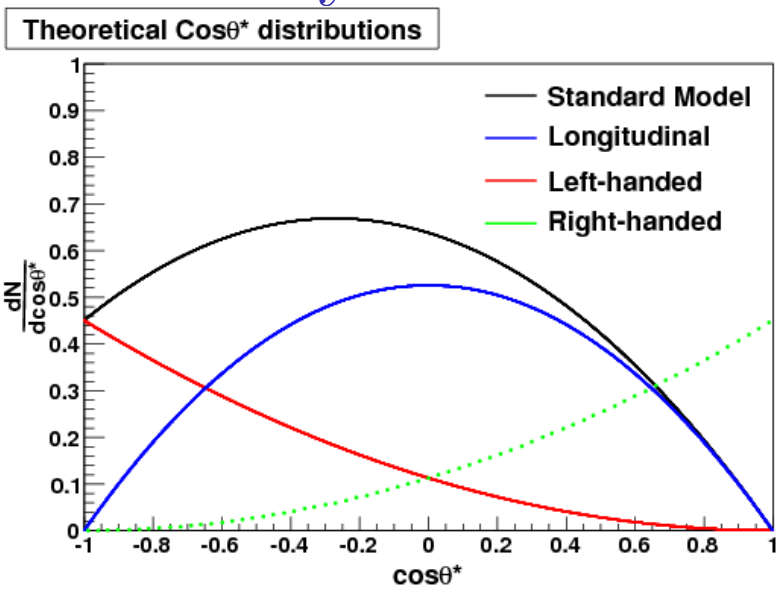
W helicity - CDF PRD 87, 031104(R) (2013)

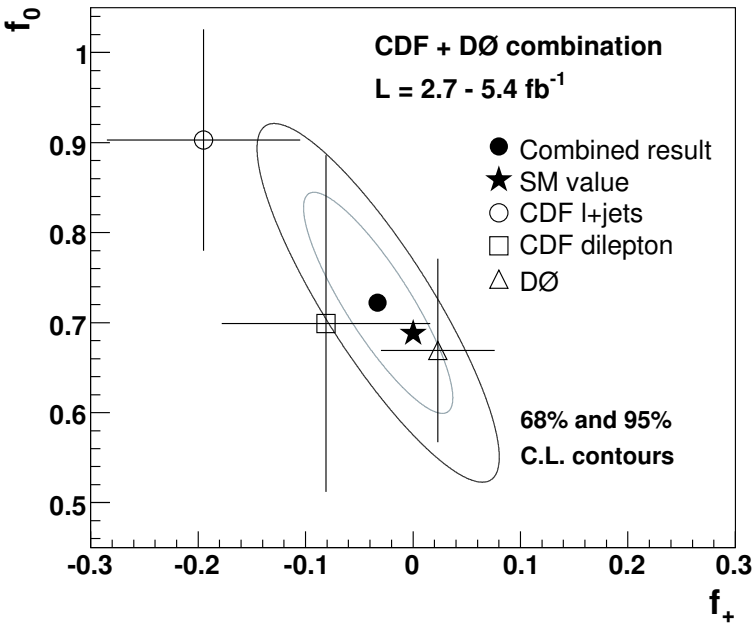
- W bosons from t decay produced in three possible helicity states: $+$, 0, $-$
- Sensitive to new physics at tWb vertex and non-SM $t\bar{t}$ production
- SM predictions for fractions: $f_+ = 0.0017 \pm 0.0001$ $f_0 = 0.688 \pm 0.004$, and $f_- = 0.310 \pm 0.004$
- Analyze with matrix element method:
  - Probability for event to be from $t\bar{t}$ decay with f_+ and f_0
  - Probability for event to be from W+jets background
- Results:
  - $f_+ = -0.045 \pm 0.072$
  - $f_0 = 0.726 \pm 0.094$



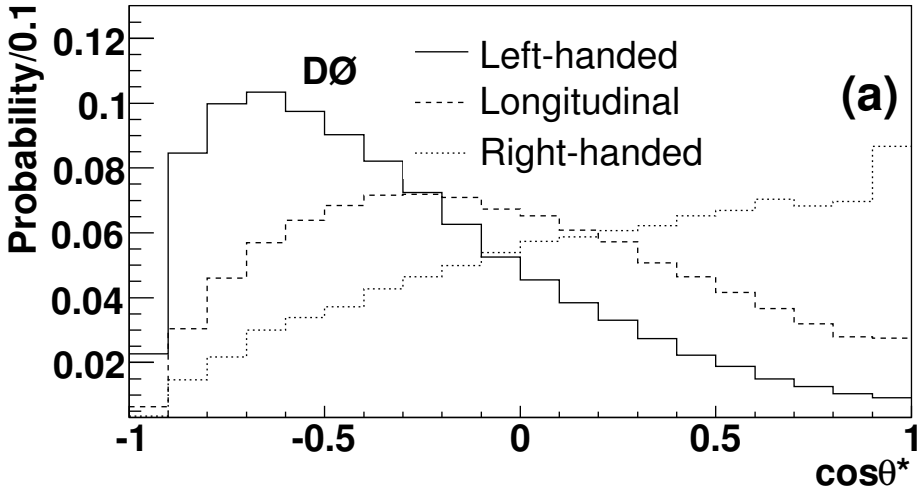


W helicity - CDF+DØ PRD 85 , 091104 (2012)



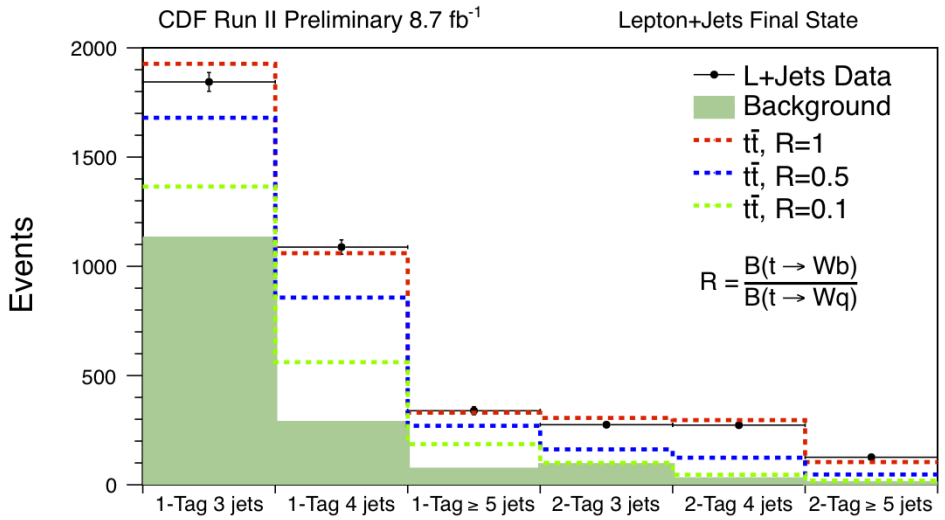


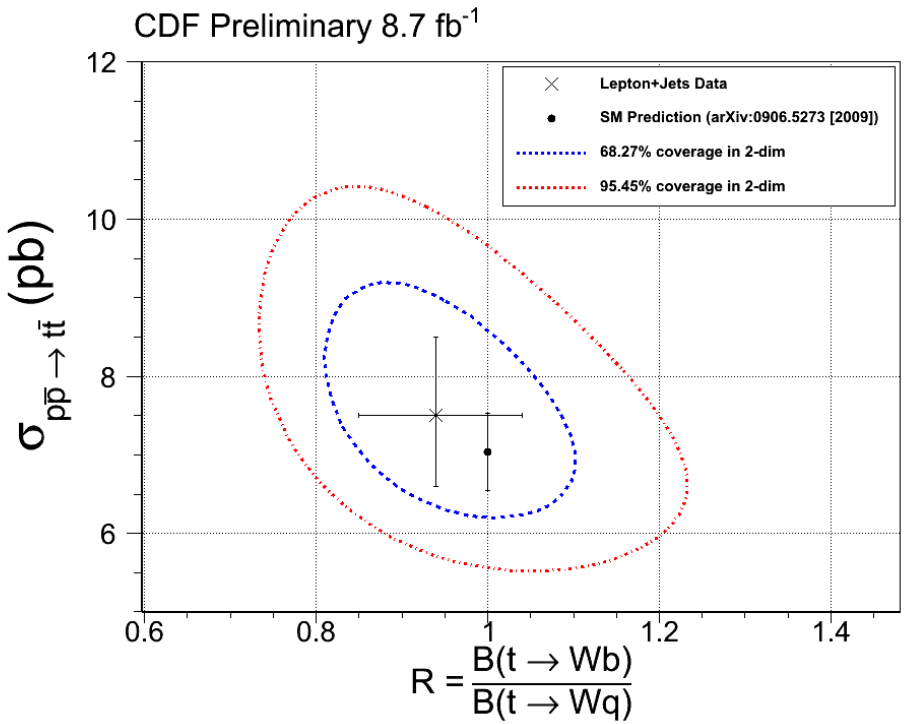
Reconstructed $\cos\theta^*$



- CDF l+jets uses matrix element method
- CDF dilepton and DØ analyses use template fits for kinematically reconstructed $\cos(\theta^*)$
- Results from combination:
  - $f_+ = -0.033 \pm 0.046$
  - $f_0 = 0.722 \pm 0.081$

Top branching ratio - CDF conf. note 10887 (2012)

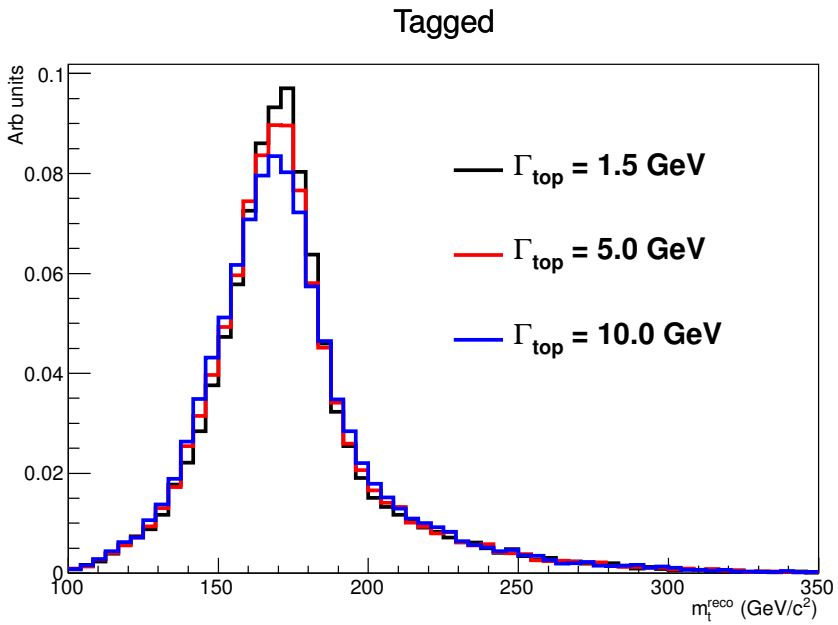


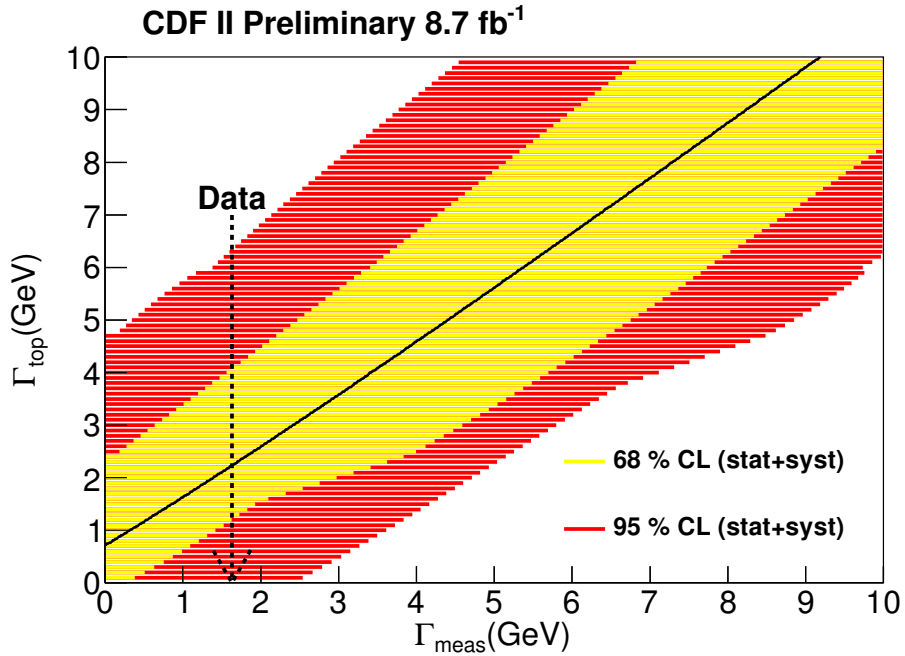


- Using 8.7 fb^{-1} of data in the l+jets channel
- $R = \frac{\mathcal{B}(t \to Wb)}{\mathcal{B}(t \to Wq)}$
- $R = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$
- Maximum likelihood fit using templates to measure R and $\sigma_{t\bar{t}}$
- Results:
  - $\sigma_{t\bar{t}} = (7.5 \pm 1.0)$ pb
  - $R = 0.94 \pm 0.09$
- SM prediction: $R = 0.998$
- Extract $|V_{tb}| = 0.97 \pm 0.05$, assuming unitary 3×3 CKM matrix

Width of top quark - CDF conf. note 10936 (2012)

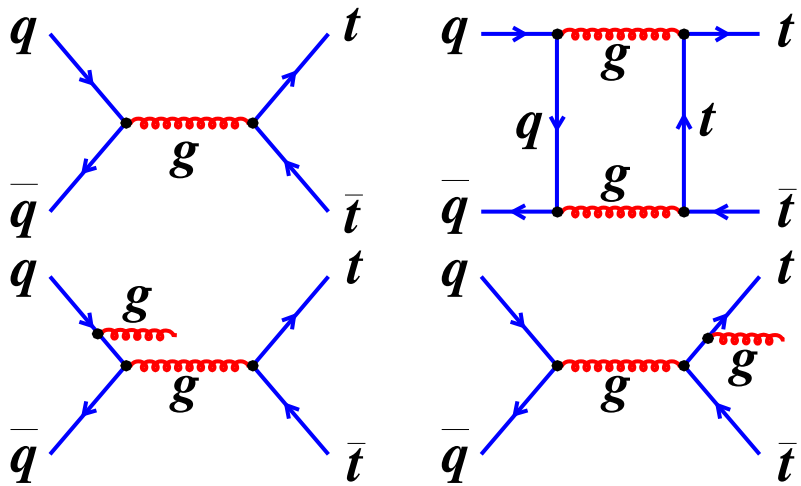
- Using 8.7 fb^{-1} of data in the l+jets channel
- Event is kinematically reconstructed with constraints:
  - $m_W = 80.4$ GeV and $m_{t,1} = m_{t,2}$
- Use a maximum likelihood method to measure Γ_t from shape of m_t^{reco} in data
- Use MC experiments with Feldman-Cousins scheme to calibrate value from data and calculate uncertainties
- Measure $\Gamma_t = 2.21^{+1.84}_{-1.11}$ GeV, in agreement with SM value of $\Gamma_t = 1.25$ GeV
- Using Heisenberg Uncertainty principle: $\tau_t = (2.98^{+3.00}_{-1.35}) \times 10^{-25}$ s
- See single top talk for DØ analysis

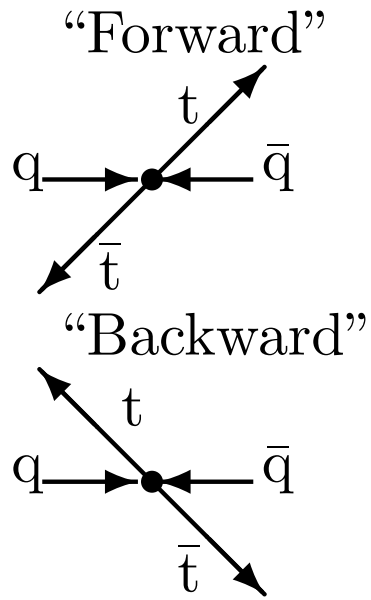




$t\bar{t}$ Forward-Backward Asymmetry
DØ Phys. Rev. D 87, 011103(R), CDF conf. note 10975

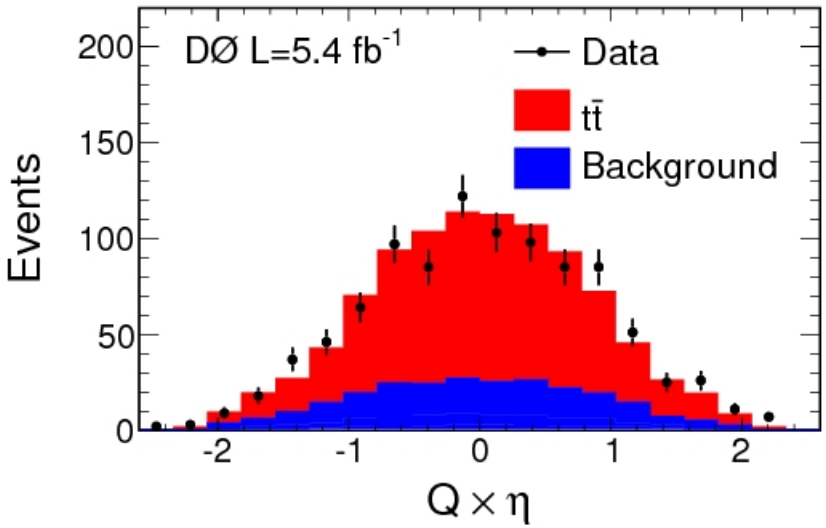
- Focus on best measured object from $t\bar{t}$ decay: the lepton
  - l+jets: large branching fraction
  - dilepton: twice the number of leptons, better signal to background
- Multiple observables:
  - $A^l_{FB} = \frac{N(q_l y_l > 0) - N(q_l y_l < 0)}{N(q_l y_l > 0) + N(q_l y_l < 0)}$
  - $A^{ll} = \frac{N(\Delta\eta > 0) - N(\Delta\eta < 0)}{N(\Delta\eta > 0) + N(\Delta\eta < 0)}$, where $\Delta\eta = \eta_{l+} - \eta_{l-}$

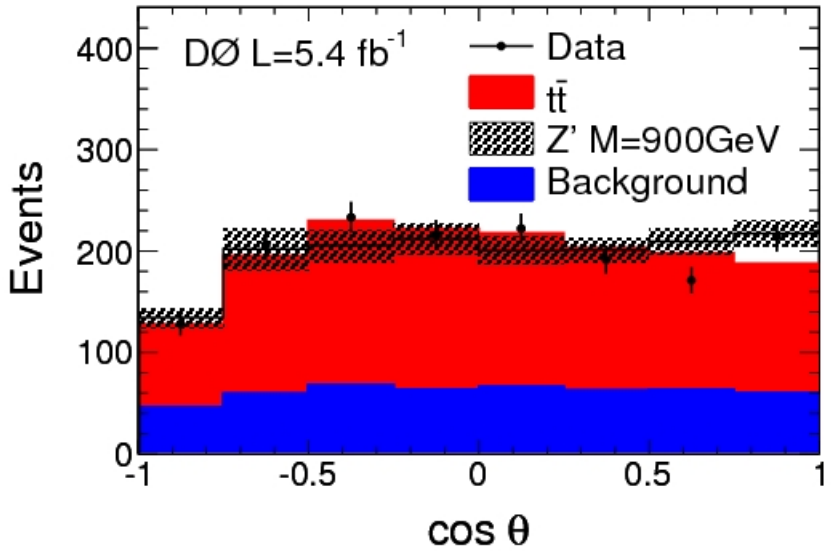




A_{FB}^{l} - DØ Phys. Rev. D 87, 011103(R) (2012)

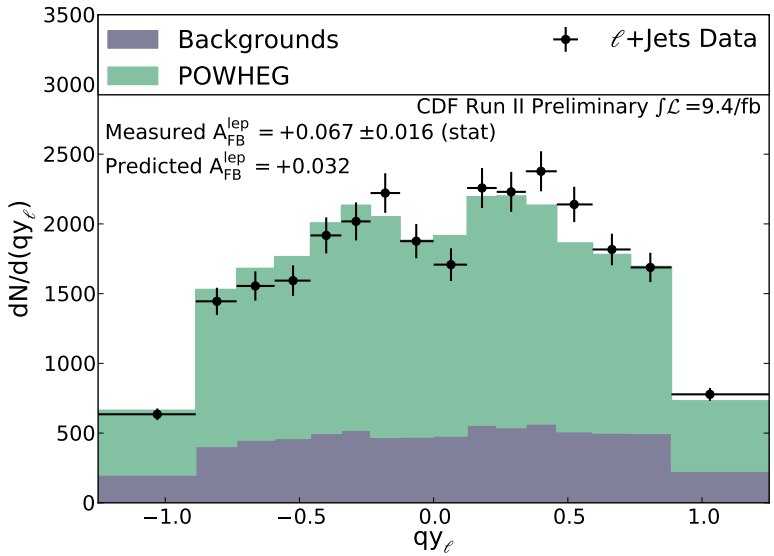
- Using 5.4 fb^{-1} in the dilepton channel
- Measured asymmetries, corrected for effects from selection:
  - $A_{FB}^{l} = (5.8 \pm 5.1(\text{stat.}) \pm 1.3(\text{syst.}))\,\%$, compared to MC@NLO (re-weighted for QCD+EW) prediction of $(4.7 \pm 0.1)\%$
  - $A^{ll} = (5.3 \pm 7.9(\text{stat.}) \pm 2.9(\text{syst.}))\,\%$, compared to $(6.2 \pm 0.2)\%$
- Investigated polarization of top quark. In agreement with MC@NLO simulation.

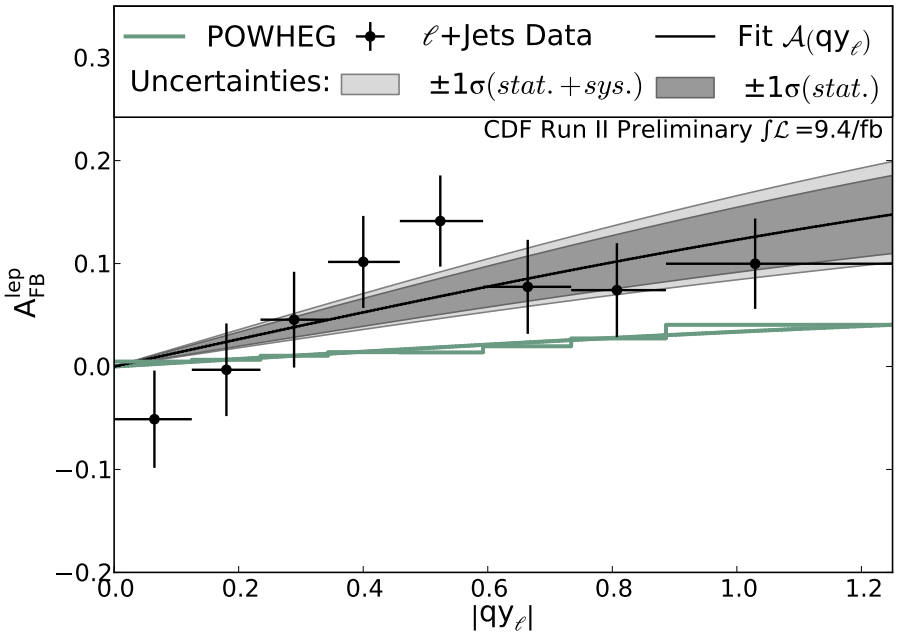




A_{FB}^{l} - CDF conf. note 10975 (2013)

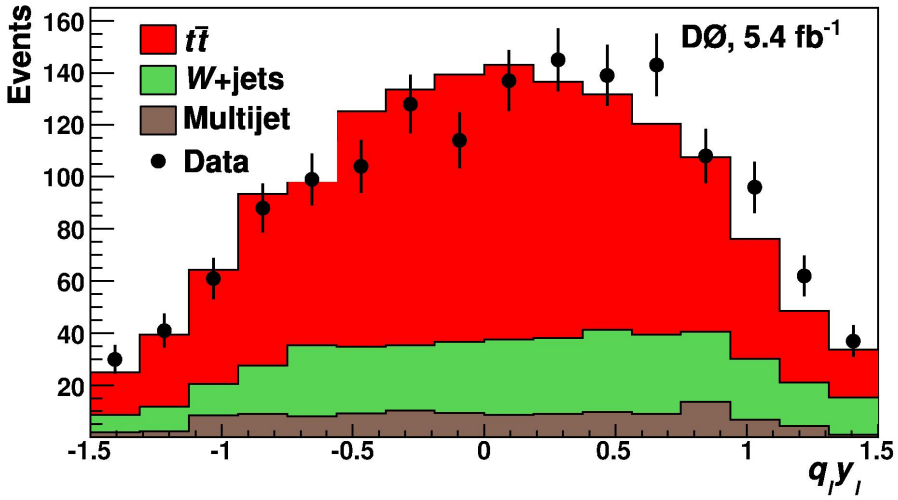
- Measured with 9.4 fb^{-1} in the l+jets channel
- Updated selection: p_T of fourth jet reduced to 12 GeV from 20 GeV
- For background-subtracted data: $A_{FB}^{l} = (7.0 \pm 2.2)\,\%$
- After correcting for acceptance and extrapolating: $A_{FB}^{l} = \left(9.4 \pm 2.4(\text{stat.})^{+2.2}_{-1.7}(\text{syst.})\right)\,\%$ compared to QCD+EW prediction of 3.6%
- Deviation of $\sim 2\sigma$



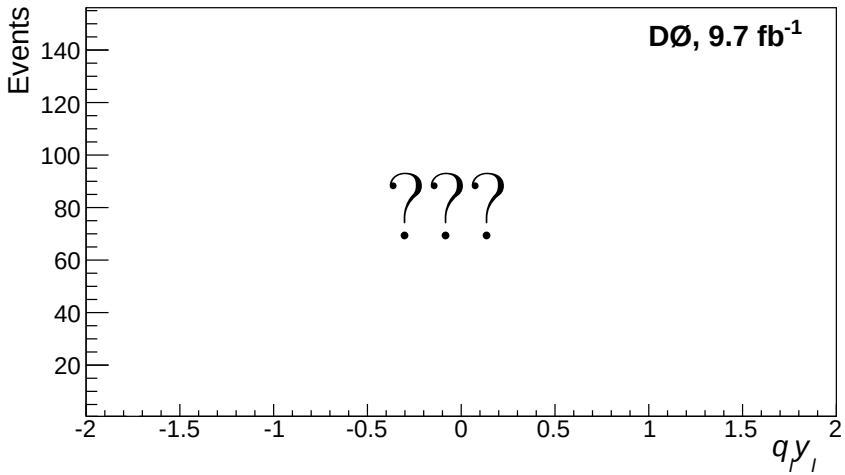


Coming soon...

5.4 fb^{-1}



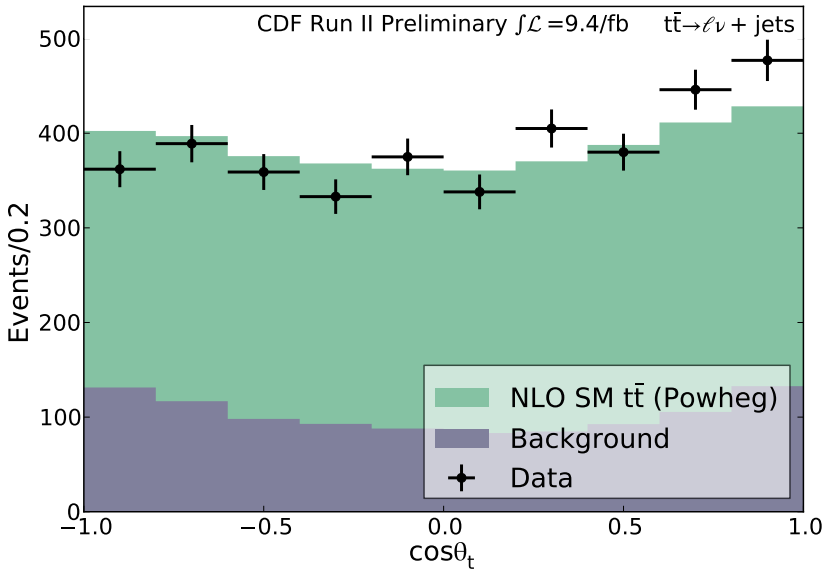
9.7 fb^{-1}

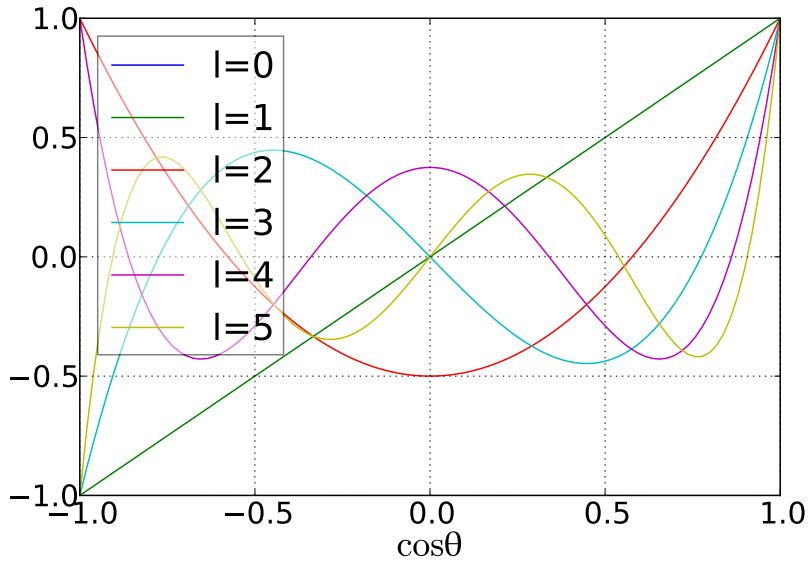


- A^l_{FB} in DØ l+jets channel
- Many updates
  - More data: 9.7 fb^{-1} from 5.4 fb^{-1}
  - More inclusive: l+3 jets as well as l+$\geq$4 jets
  - A^l_{FB} versus p^l_T (suggested by G. Perez)
  - More precise: $< 3\%$ uncertainty

Alternative to asymmetry - CDF conf. note 10974 (2013)

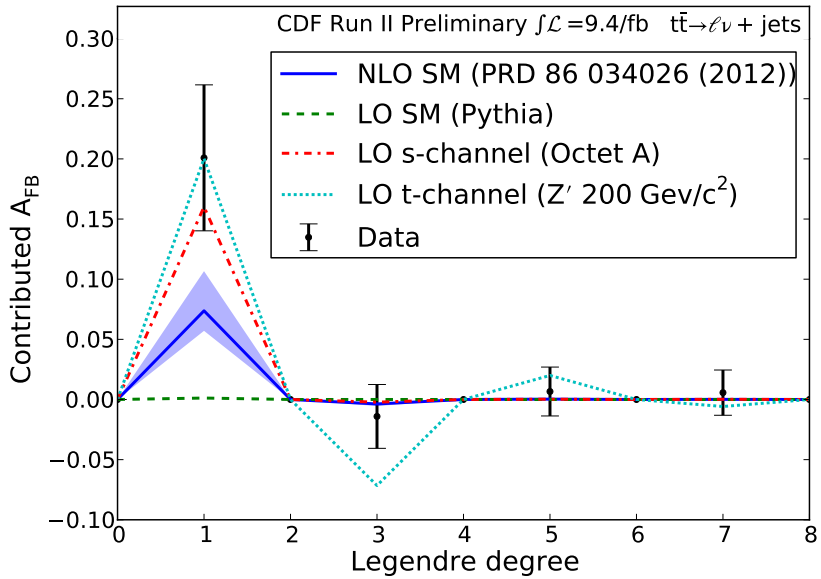
- Previous measurements have quantified t quark angular production with A_{FB}
- Asymmetries are not optimal or complete
  - Compare only two parts of distribution (rather than entire distribution)
  - Sharp change at zero
- Use angle between t quark and proton, $\cos(\theta_t)$
- Finds moments of Legendre polynomial for kinematically reconstructed $\cos(\theta_t)$
  - $\frac{d\sigma}{d\cos(\theta_t)} = \sum_l a_l P_l(\cos(\theta_t))$
- Measure moments $a_1 - a_8$

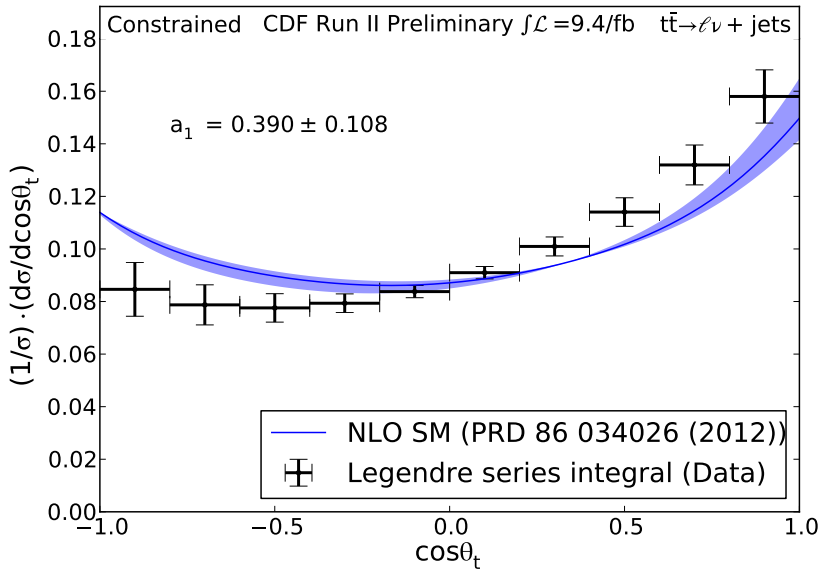




Measurement of moments - CDF conf. note 10974 (2013)

- Correct (unfold) measured moments for effects from detector for comparison with theoretical predictions
- Compare to two new physics models: s-channel axigluons and t-channel Z'
- Measure $a_1 = 0.40 \pm 0.12$
- Predictied $a_1 = 0.15 \pm 0.05$
- Deviation of $\sim 2\sigma$
- Assuming SM is correct for all moments but a_1:
  - $a_1 = 0.390 \pm 0.108$



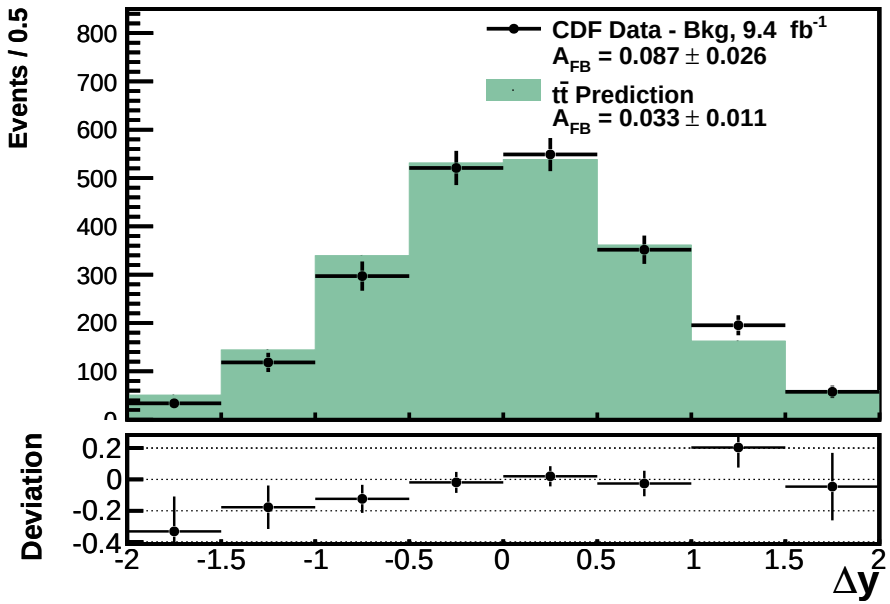


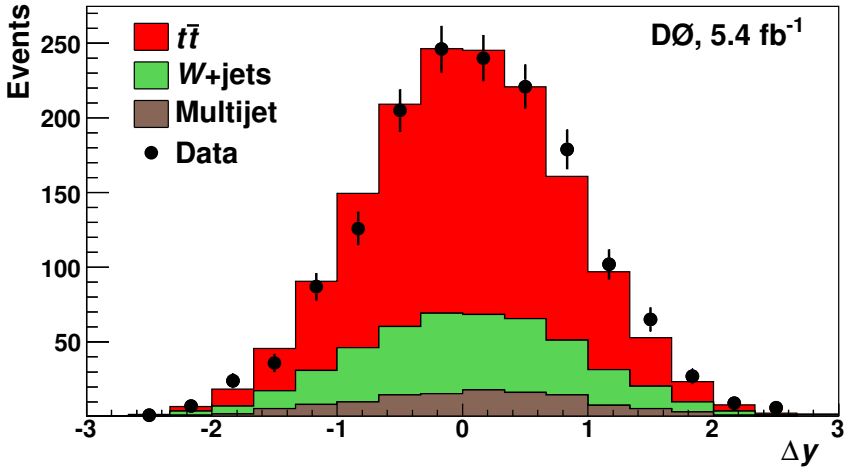
Summary

- Many new measurements of top properties at the Tevatron
- We have developed novel techniques for mature analyses
- Most results agree with SM, but still some puzzles
- More information here:
  - CDF top results:
    `http://www-cdf.fnal.gov/physics/new/top/public_tprop.html`
  - DØ top results:
    `http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html`
- Thank you for your attention and see you on the slopes!

Backup Slides

$t\bar{t}$ forward-backward asymmetry





- CDF and DØ both measure larger than predicted A_{FB} based on $\Delta y = y_t - y_{\bar{t}}$
- For CDF with 9.4 fb^{-1}: $A_{FB} = (16.4 \pm 4.5)\%$
- For DØ with 5.4 fb^{-1}: $A_{FB} = (20 \pm 7)\%$
- SM prediction: $A_{FB} = 7\% - 9\%$
- CDF measures dependence of A_{FB} on $m_{t\bar{t}}$ of $\sim 2\sigma$ larger than SM