Top Quark Physics at CDF

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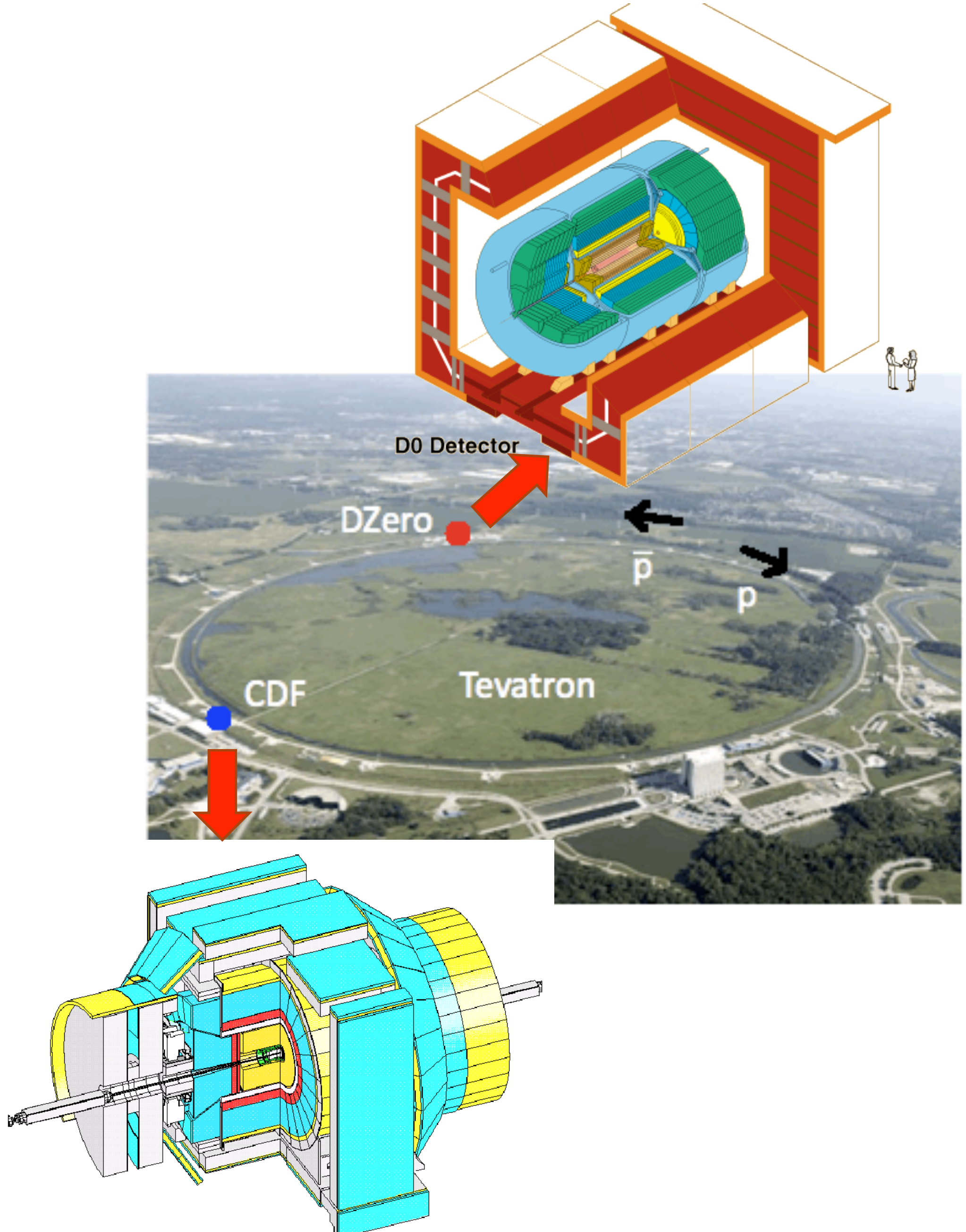
University of Bonn

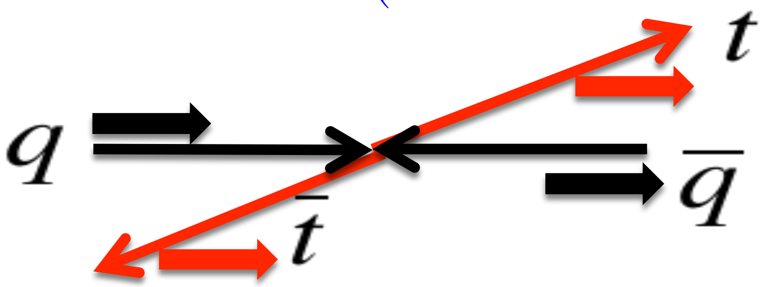
Outline

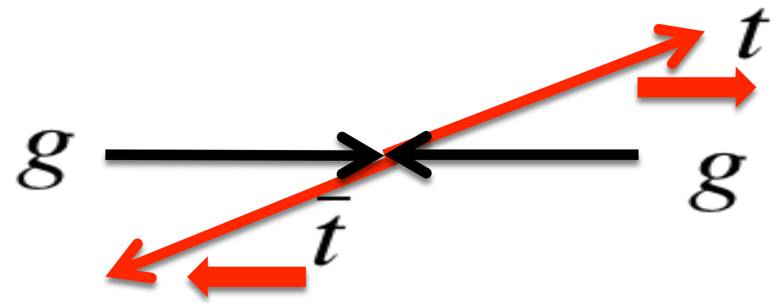
- Introduction
- Spin correlations
- BR(tWb)/BR(tWq)
- Single top production
- Charge asymmetry
- Summary



Top-Antitop Spin Correlations

- Top pairs are produced with a definite spin state depending on production mechanism
  - Quark-Antiquark Annihilation (~85% at the Tevatron): Spin 1
  - Gluon Fusion (~15% at the Tevatron): Spin 0





- Top decays before hadronization (only known quark to do so!)
  - Spin information passed to decay products – the correlated spins can be measured from decay product angular distributions
- Correlation strength (frame dependent!) is defined as:

$$\kappa = \frac{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} - N_{\uparrow\downarrow} - N_{\downarrow\uparrow}}{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} + N_{\uparrow\downarrow} + N_{\downarrow\uparrow}}$$

$$\kappa_{beam}^{SM} = 0.78^{+0.03}_{-0.04}$$

Nucl. Phys. **B 690**, 81 (2004)

Measuring the Spin Correlation

- Results shown here assume spin quantized along beam axis
  - Template fits based on decay product angular distributions

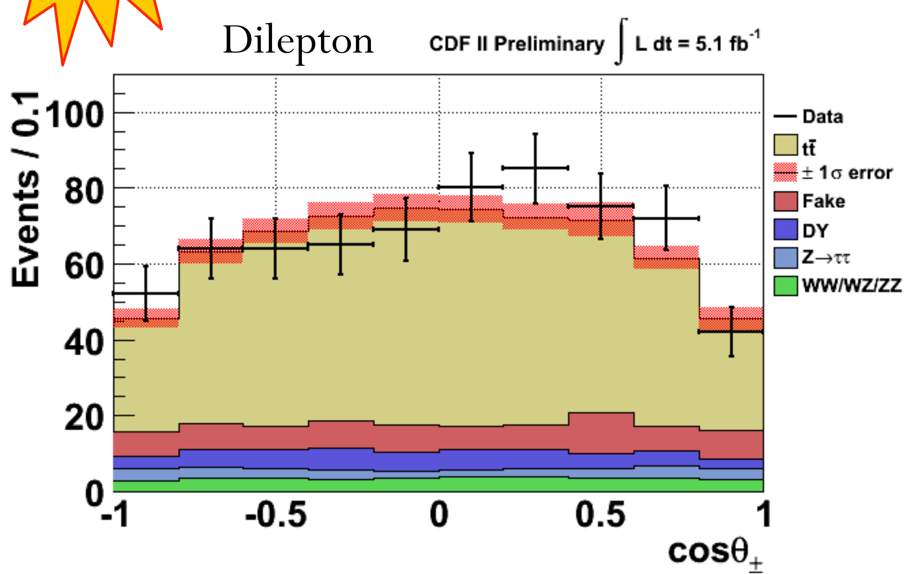
new

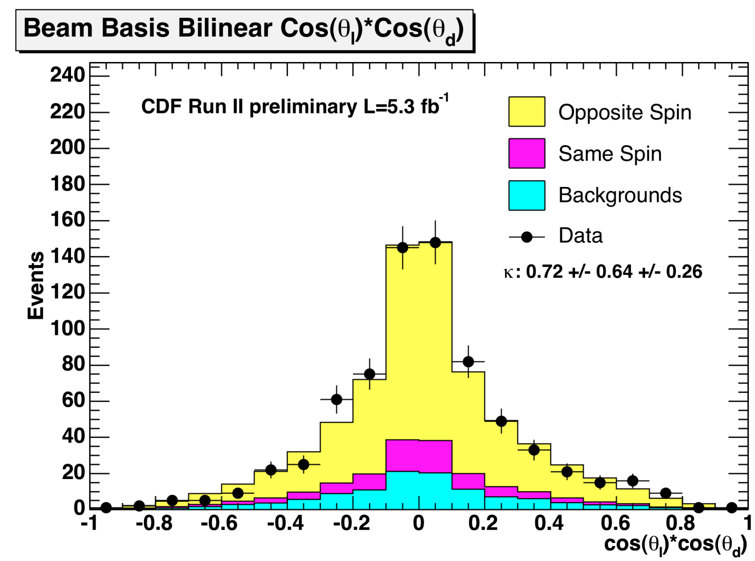
$$\kappa_{Dilepton} = 0.042 \pm 0.563$$

CDF Conf. Note 10719

$$\kappa_{Lep+Jet} = 0.72 \pm 0.69$$

CDF Conf. Note 10211

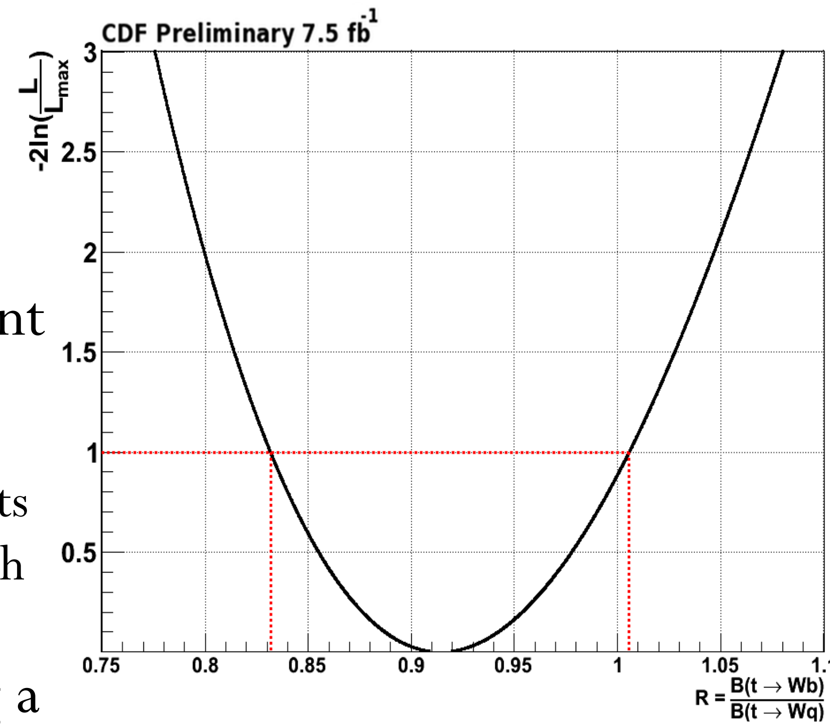




Top Decay Branching Ratio

$$R = \frac{B(t \to Wb)}{B(t \to Wq)}$$

- SM: $t \rightarrow Wb$ in ~100% of decays
- Expect 2 *b*'s in each top-antitop event
  - How often does this happen?
  - Tagging efficiency determines expected size of samples with 0, 1, or 2 tagged jets
  - Determine *R* from measured size of each subsample
- Derive $|V_{tb}|$ from result (assuming a unitary 3×3 CKM matrix)



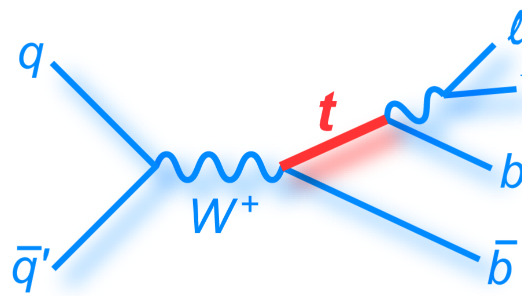
new

$$R = 0.91 \pm 0.09$$

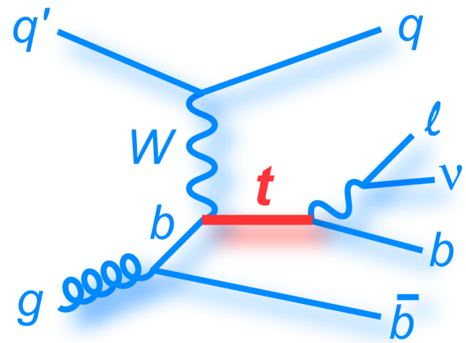
$$|V_{tb}| = 0.95 \pm 0.05$$

Single top quark

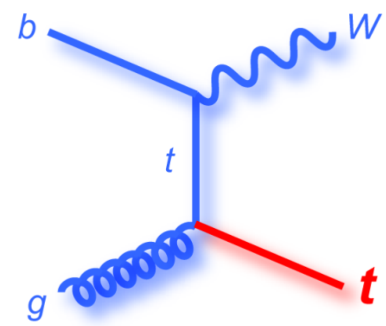
Small at Tevatron



s-channel production



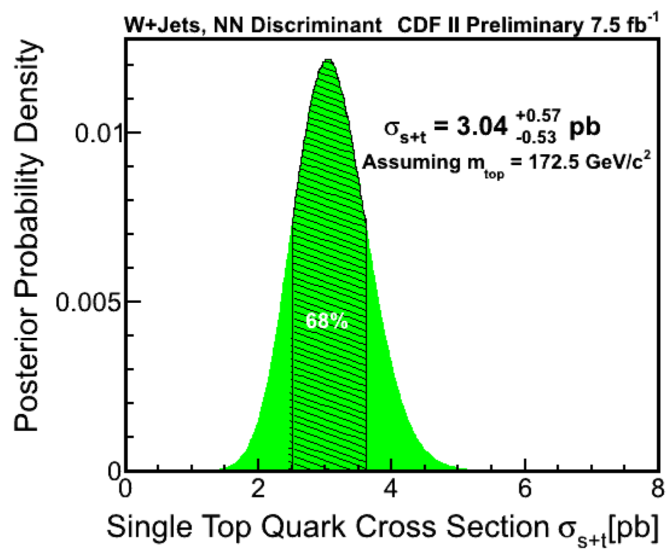
t-channel production



Associated Wt production

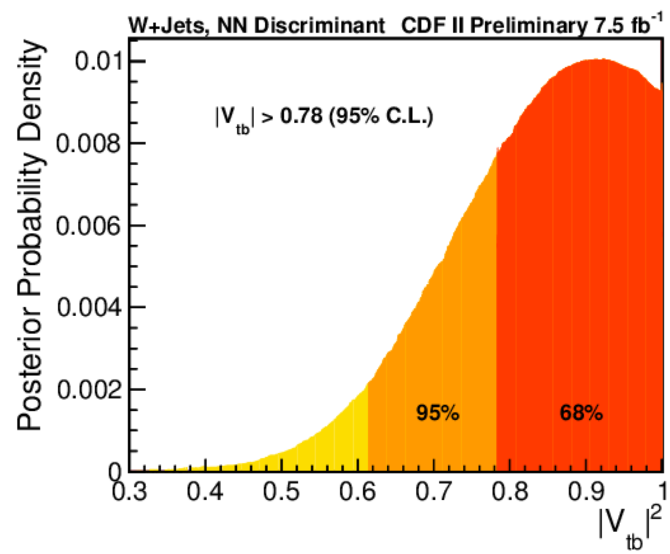
- Motivation:
  - Direct measurement of CKM matrix element $|V_{tb}|$ $(\sigma_{s+t} \sim |V_{tb}|^2)$
  - Sensitive to New Physics (FCNC, W'…) and CP violation
  - Additional channel for top quark properties study
- Experimental challenge:
  - Extract small signal out of a large background with large uncertainty

Cross Section and V_{tb}



- Assuming $m_{top} = 172.5$ Gev/c^2
- Measured cross section:

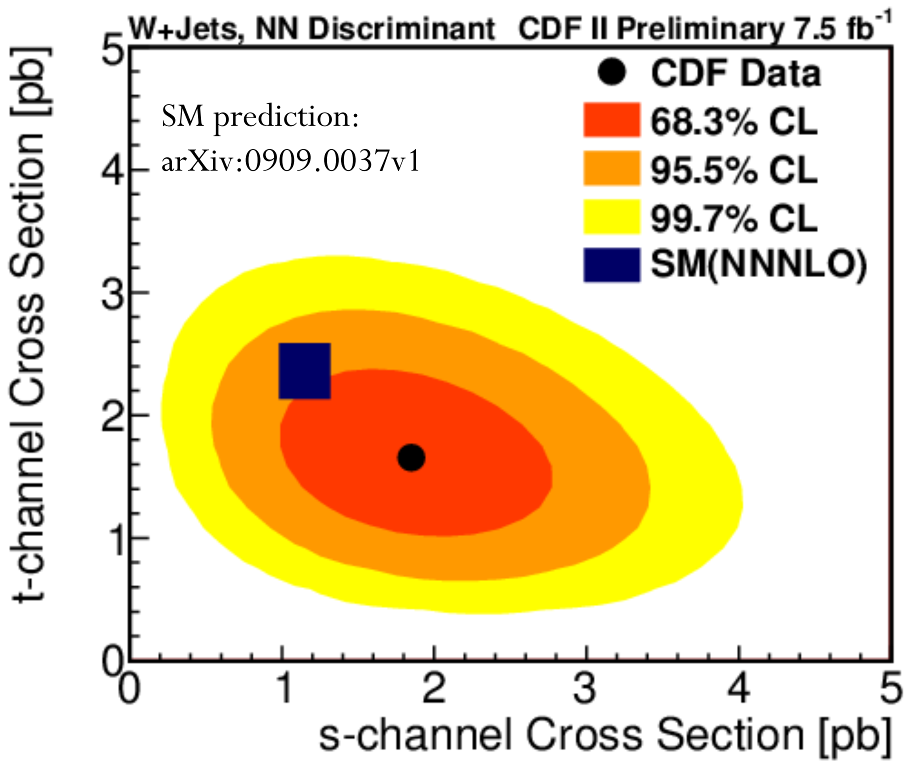
$$\sigma_{s+t} = 3.04^{+0.57}_{-0.53}\ \text{pb}$$



- From the cross section posterior
- Set limit: $|V_{tb}| > 0.78$ at 95% CL

Extracted $|V_{tb}| = 0.92^{+0.10}_{-0.08}$ (stat.+sys.) $\pm$ 0.05(theory)

Simultaneous 2D measurement



- Measured cross section:
  - $\sigma_s = 1.81^{+0.63}_{-0.58}$ pb
  - $\sigma_t = 1.49^{+0.47}_{-0.42}$ pb
- SM Prediction:
  - $\sigma_s^{SM} = 1.05 \pm 0.07$ pb
  - $\sigma_t^{SM} = 2.10 \pm 0.19$ pb
  - $\sigma_{wt}^{SM} = 0.22 \pm 0.08$ pb (Effect negligible)

The Forward-Backward Asymmetry

- Do tops have a preference to travel along the proton or antiproton direction?
- Measure asymmetry in Δy
- Leading order: standard model predicts no asymmetry
- Next-to-leading order: small positive asymmetry
  - NLO predictions shown today based on MC generator Powheg with electroweak corrections added

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

$$A_{FB} = \frac{N_{\Delta y>0} - N_{\Delta y<0}}{N_{\Delta y>0} + N_{\Delta y<0}}$$

$$A_{FB}^{NLO} = 6.6\%$$

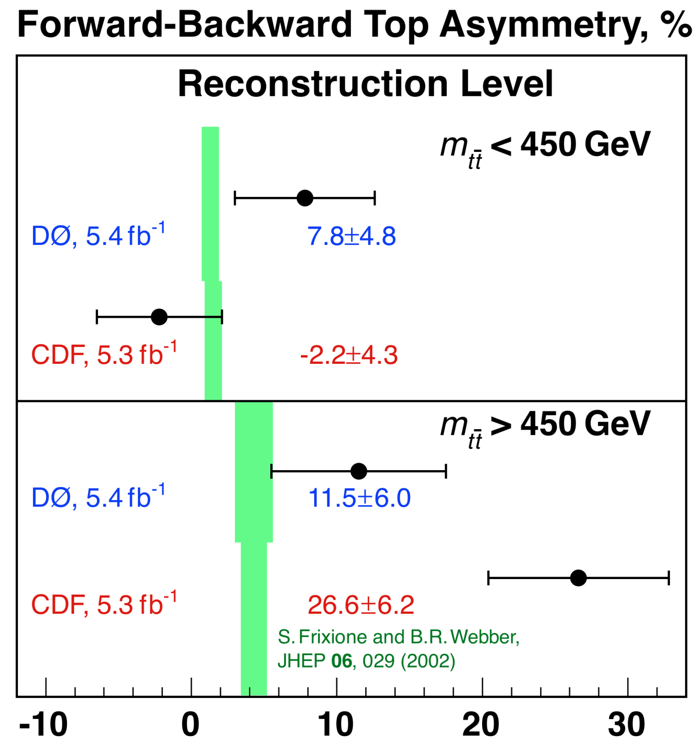
Powheg: JHEP **0709**, 126 (2007)

EW Corrections: Phys. Rev. D **84**, 093003 (2011); JHEP **1201**, 063 (2012); arXiv: 1201.3926[hep-ph]

The Asymmetry in ~5 fb^{-1}

- Inclusive asymmetries exceed standard model predictions by ~1.5-2σ
- Somewhat ambiguous mass and rapidity dependence
  - Only two bins in $M_{tt}/\Delta y$

Background Subtracted A_{FB} (%)	$\lvert\Delta y\rvert < 1.0$	$\lvert\Delta y\rvert \geq 1.0$
D0 Lep+Jet	6.1 ± 4.1	21.3 ± 9.7
CDF Lep+Jet	2.9 ± 4.0	29.1 ± 9.6



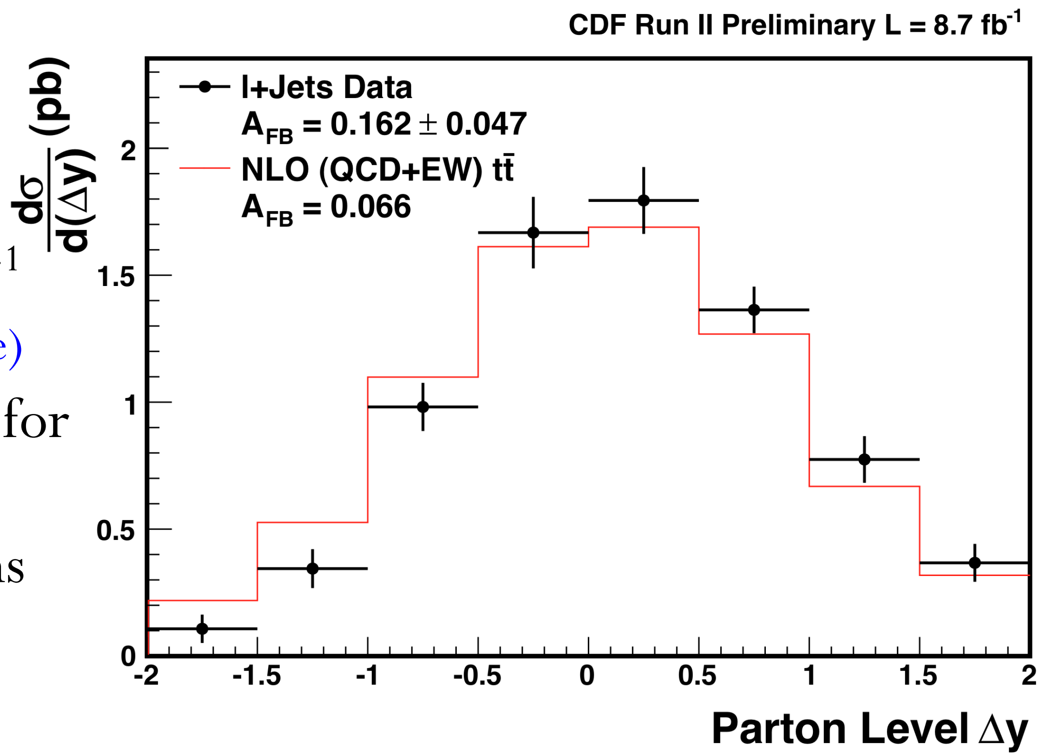
Measurement	Parton Level A_{FB} (%)
CDF Lep+Jets[1]	15.8 ± 7.4
CDF Dilepton[2]	42 ± 16
CDF Combined[3]	20.1 ± 6.7
D0 Lep+Jets[4]	19.6 ± 6.5

[1]CDF L+J: PRD **83**, 112003 (2011); [2]CDF Dil: CDF Conf. Note 10436;
[3]CDF Combo: CDF Conf. Note 10584; [4]D0 L+J: PRD **84**, 112055 (2011)

The Asymmetry at CDF in the Full Dataset

- Updates from CDF's 5.3 fb^{-1} lepton+jets analysis:
  - Add new data stream and increase luminosity to 8.7 fb^{-1}
    - 2498 events (double sample size)
  - Use NLO generator Powheg for signal modeling
  - Parton level shape corrections use regularized unfolding algorithm
    - Proper multi-binned measurement of rapidity and mass dependence
- Parton Level A_{FB}: 16.2 ± 4.7 %

(NLO: 6.6%)

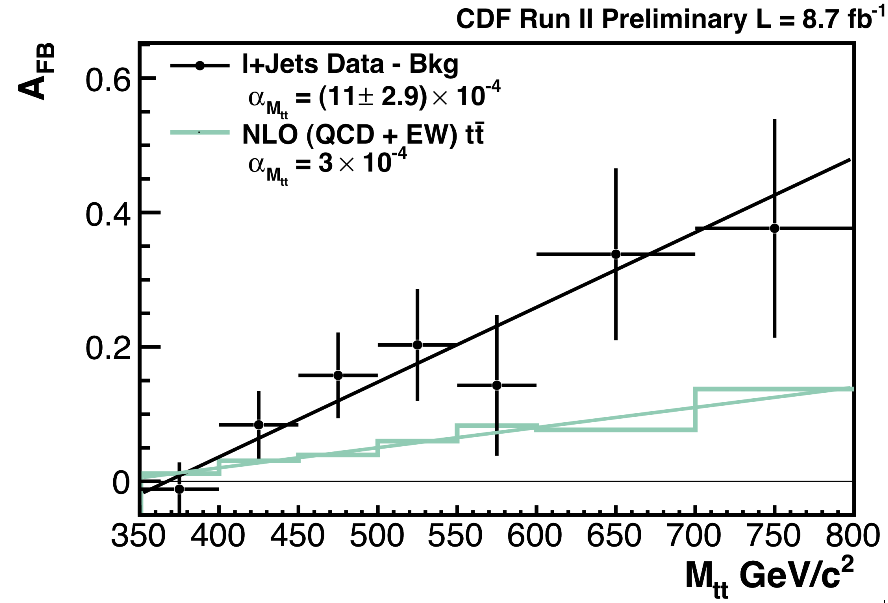


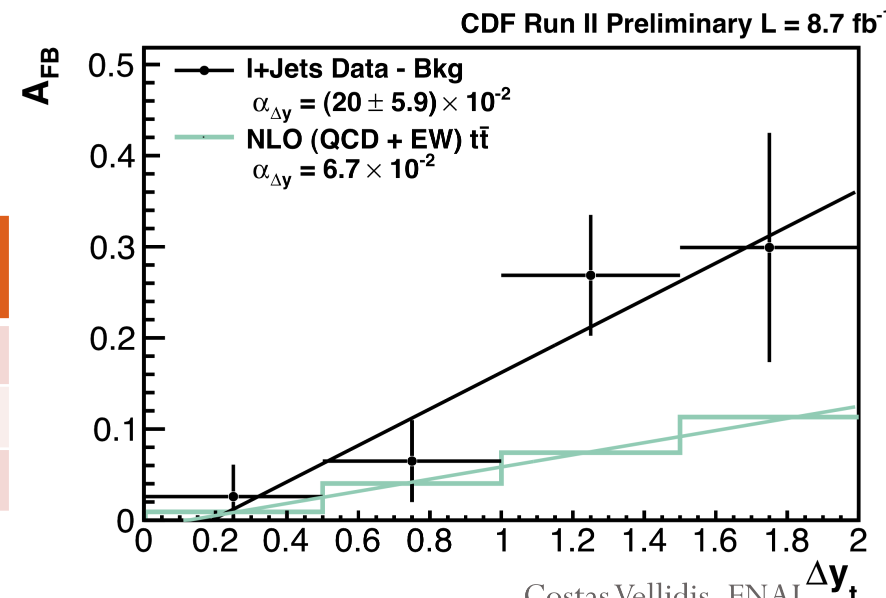
CDF Conf. Note 10807

Background-Subtracted M_{tt} and Δy Dependence

- Predicted background contribution has been removed
  - Measure asymmetry in only top events
- No correction to parton level yet
  - No assumptions about the underlying physics
- Data well-described by linear ansatz – determine best-fit slope
  - χ^2/d.o.f $\leq \sim 1$ for both Δ y and M_{tt} dependence
- Determine p-value by comparing observed slope to NLO prediction
  - How often will NLO slope fluctuate to be at least as large as in the data?

Slope Parameter α	A_{FB} vs. M_{tt}	A_{FB} vs. Δ y
Data	$(11.1 \pm 2.9)\times10^{-4}$	$(20.0 \pm 5.9)\times10^{-2}$
SM	3.0×10^{-4}	6.7×10^{-2}
p-value	0.00646	0.00892

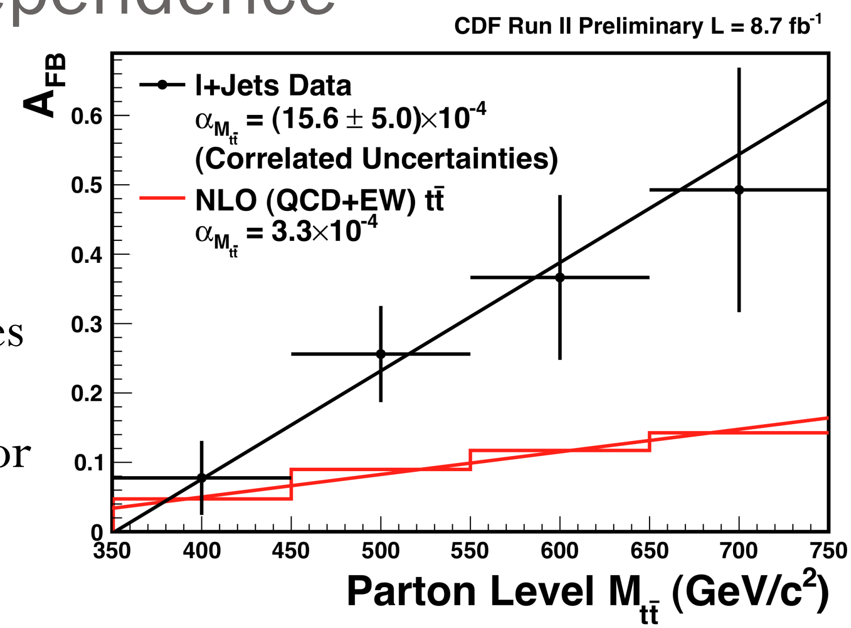


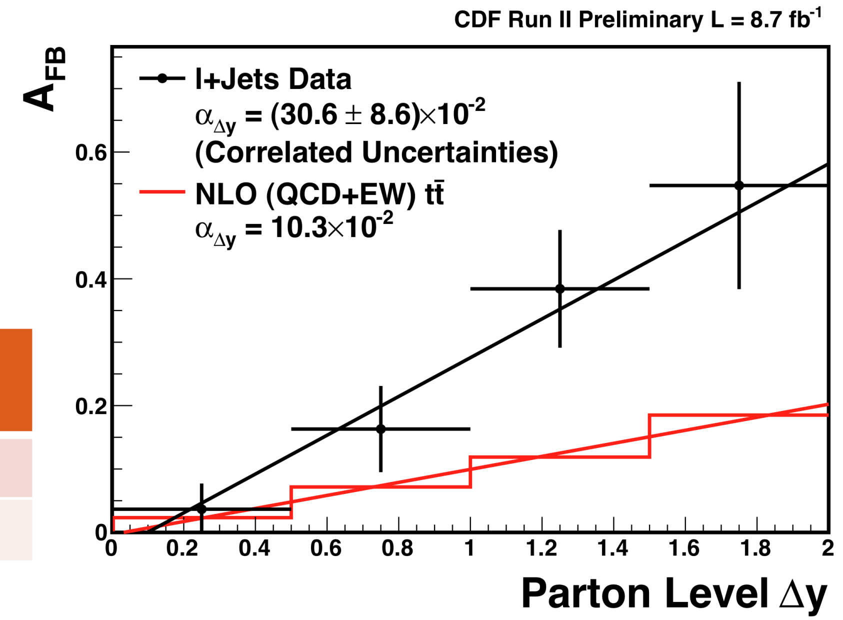


Parton Level M_{tt} and Δy Dependence

- Correct for acceptance and detector resolution
  - Regularized unfolding algorithm addresses resolution effects
  - Multiplicative acceptance correction factor applied to each bin
  - Both corrections use the NLO generator Powheg as the top model
- Parton level results can be compared directly to theory
- Determine best-fit slope for observed data and compare to NLO prediction

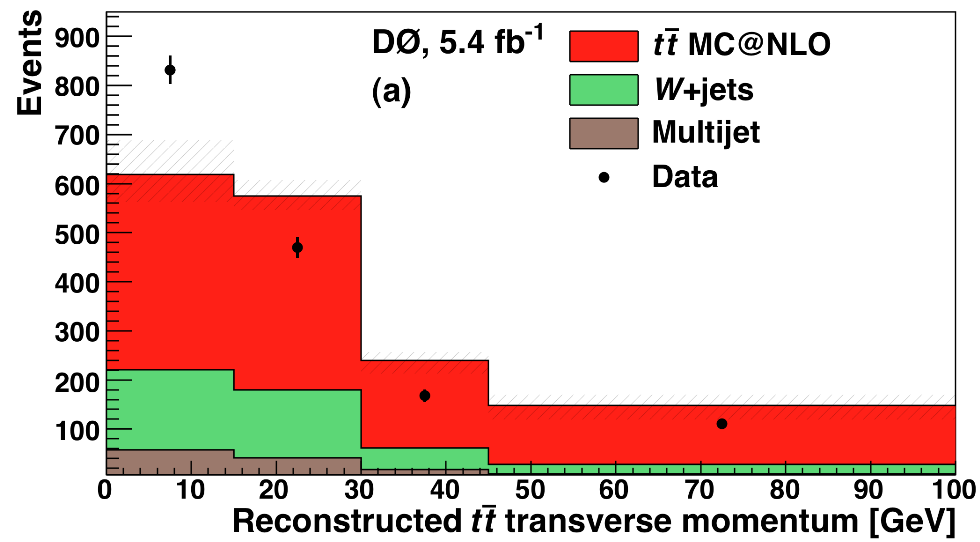
Slope Parameter α	A_{FB} vs. M_{tt}	A_{FB} vs. Δy
Data	$(15.6 \pm 5.0)\times10^{-4}$	$(30.6 \pm 8.6)\times10^{-2}$
SM	3.3×10^{-4}	10.3×10^{-2}

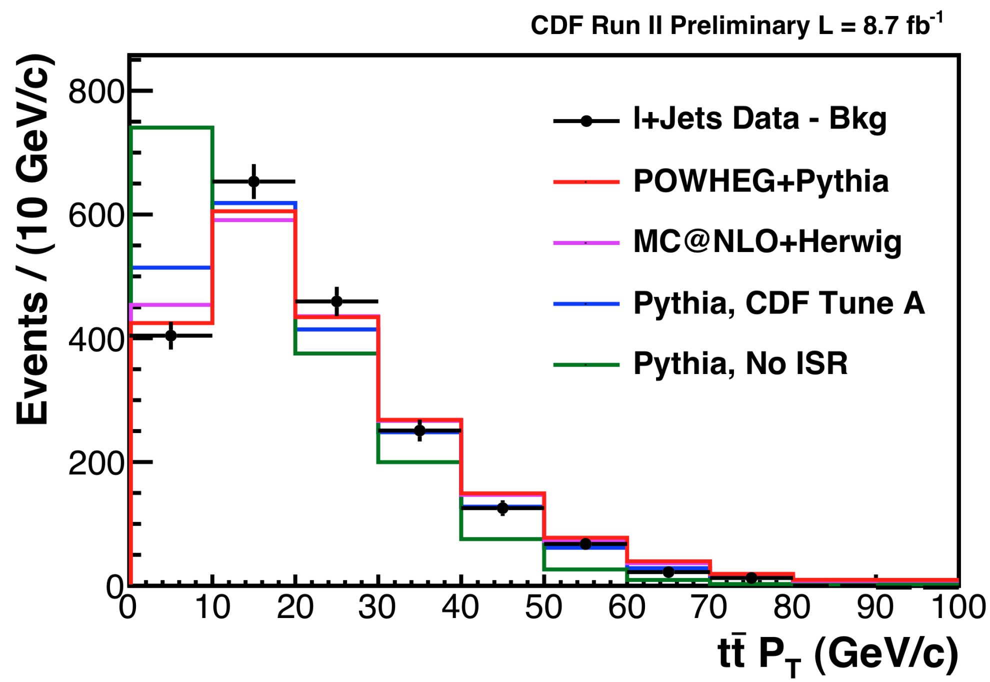




Source of the Asymmetry?

- Is it a problem with the current understanding of the SM?
  - Mis-modeled top pair P_T spectrum?
  - Higher order corrections?
- Is it new physics?
  - Many new models have been proposed
    - Axigluon, Z-prime, W-prime, …
  - Other top properties measurements can help differentiate between the possibilities
    - Differential cross-section in M_{tt}
    - Top spin or polarization





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Conclusions

- The full CDF dataset is being studied in top properties measurements
- Many areas of study (spin correlations, single top, A_{FB}) are complementary to LHC measurements
- CDF and D0 combinations are available (W helicity) or in progress for many properties measurements
- See the website of CDF for more information and results not presented here:

  http://www-cdf.fnal.gov/physics/new/top/top.html

- Data-taking is done, but there's a lot left to be learned from the CDF top quark sample!

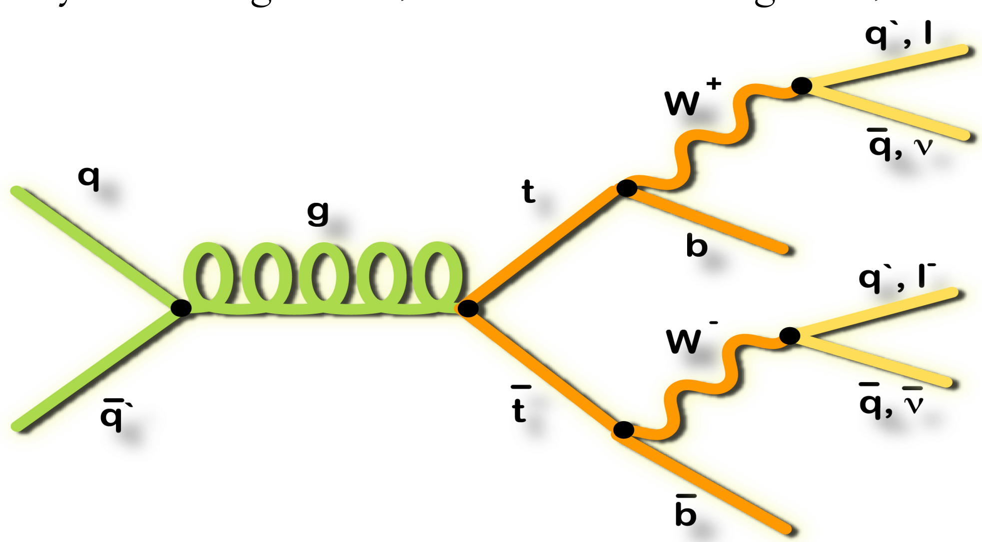
Back up

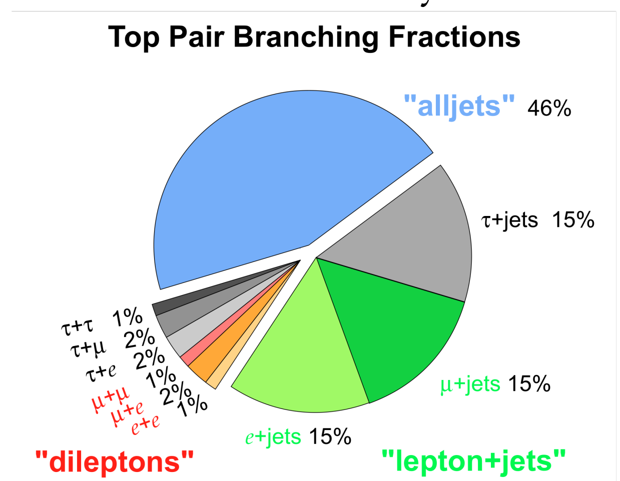
Why Study the Top Quark?

- Unique among quarks in many ways
  - Very heavy - special role in electroweak symmetry breaking or enhanced couplings to new physics?
  - Very short lifetime - spin information and other properties passed directly to decay products
- CDF has collected thousands of top events
  - Precision studies of top properties are possible
  - Many analyses are unique to the Tevatron and/or complementary to LHC measurements

Measuring Top Properties

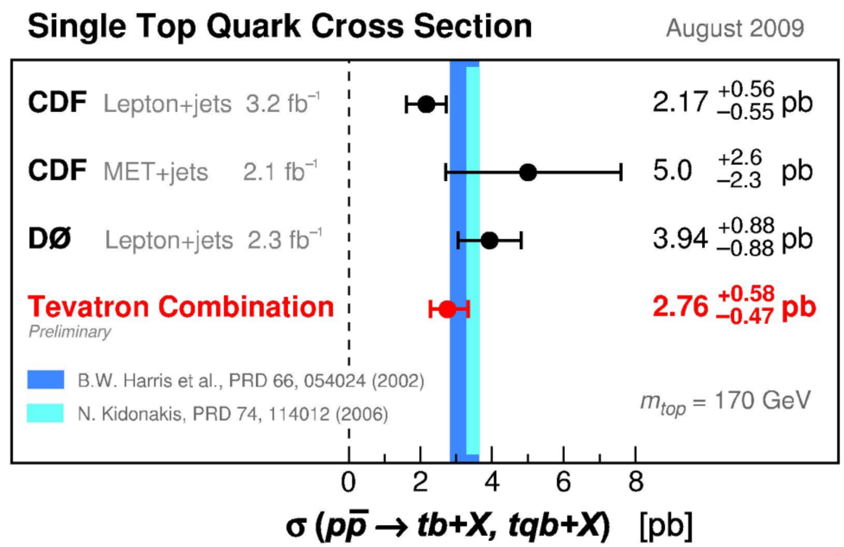
- Top almost always decays to *Wb*
  - Decay modes characterized by *W* decays
- Two main modes for top properties analyses:
  - Lepton+Jets: one *W* decays to quarks, one to $e(\mu) + \nu$
    - Moderate backgrounds, reasonable branching ratio; fully constrained kinematically
    - Usually require a *b*-tag to reduce backgrounds
  - Dilepton: both *W*'s decay to $e(\mu) + \nu$
    - Very low backgrounds, but small branching ratio; under-constrained kinematically

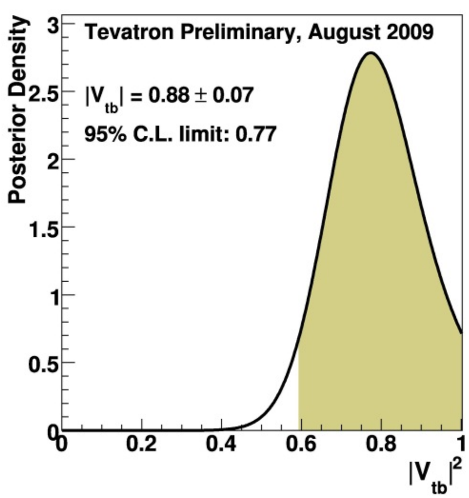




Single top observation by CDF and D0

- Observed by CDF and D0 simultaneously in 2009
- Over 100 citations for both observation PRLs
  - T. Aaltonen, et al. [CDF collaboration], Phys. Rev. Lett. 103, 092002 (2009)
  - V.M. Abazov et al. [D0 Collaboration], Phys. Rev. Lett. 103, 092001 (2009)

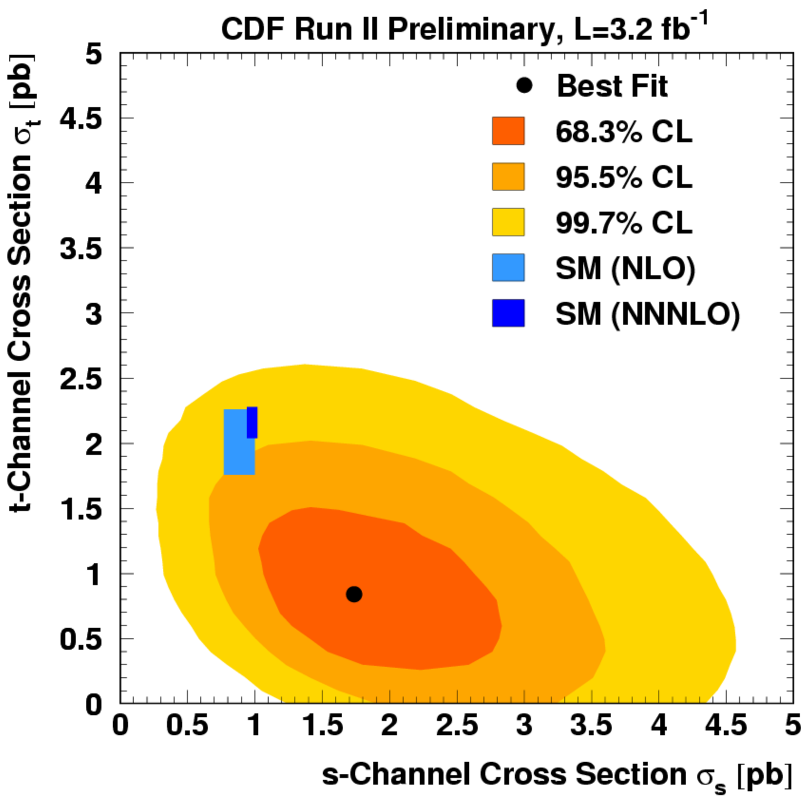


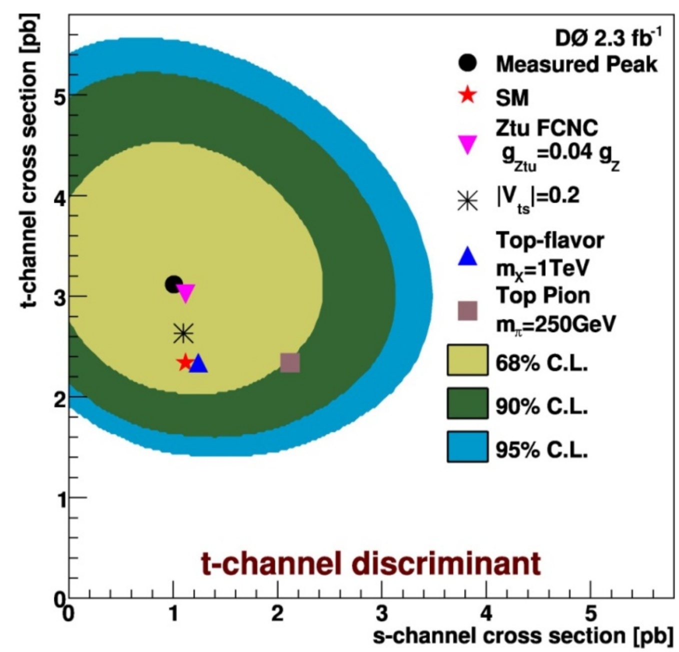


- Combination of CDF and D0:
  - CDF: Four multivariate analysis in Lepton+jets channel with $3.2fb^{-1}$ data.
  - CDF: MET+Jets channel with $2.1fb^{-1}$ data
  - D0: Three multivariate analysis in Lepton+jets channel with $2.3fb^{-1}$ data.

[CDF and D0 Collaboration], arXiv:0908.2171v1

Previous single top 2D measurements





$\sigma_s = 1.8^{+0.7}_{-0.5}$ pb

$\sigma_t = 0.8 \pm 0.4$ pb

$\sigma_s = 1.05 \pm 0.81$ pb

$\sigma_t = 3.14^{+0.94}_{-0.80}$ pb

T. Aaltonen et al. [CDF Collaboration], arXiv:1004.1181v2
V.M. Abazov et al. [D0 Collaboration], PLB 682, 363 (2010)