Measurements of Top Quark Properties at CDF

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on behalf of the CDF Collaboration

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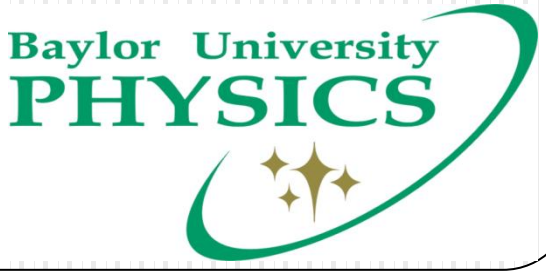
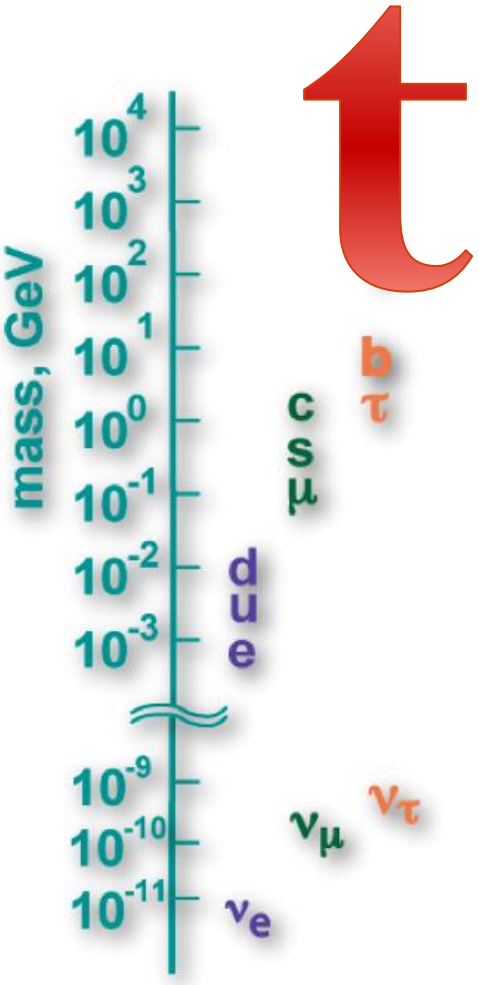
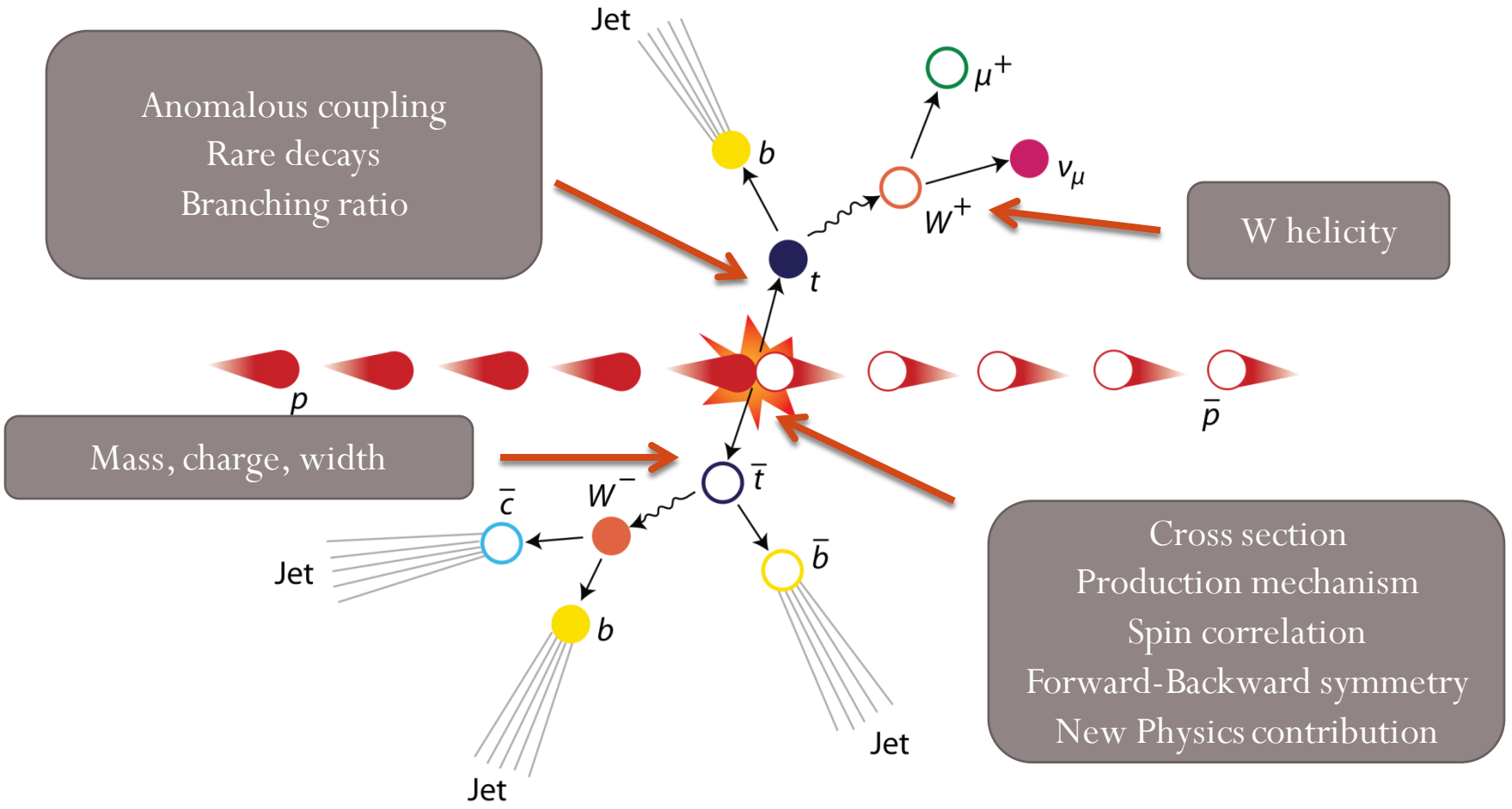


The Top Quark

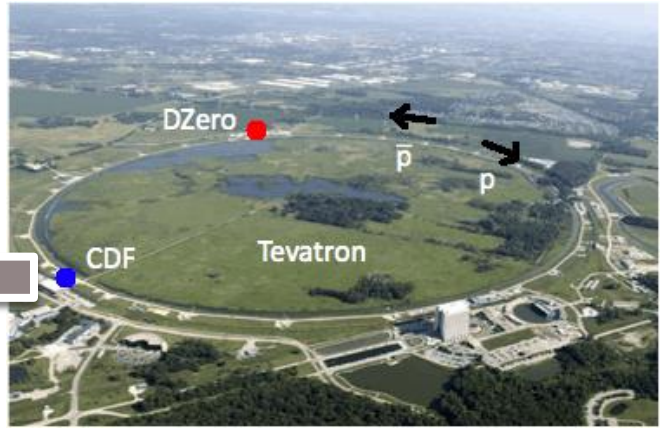
- Top quark was discovered at Fermilab in 1995
- Its mass much larger than any other fermion
- Its Yukawa coupling is 0.996 ± 0.006
  - What is its role in EWSB?
- Lifetime shorter than hadronization time
  - only quark that decays before hadronizing
- Its mass constrains the Higgs boson mass range
- The top sector is expected to be sensitive to many new physics processes

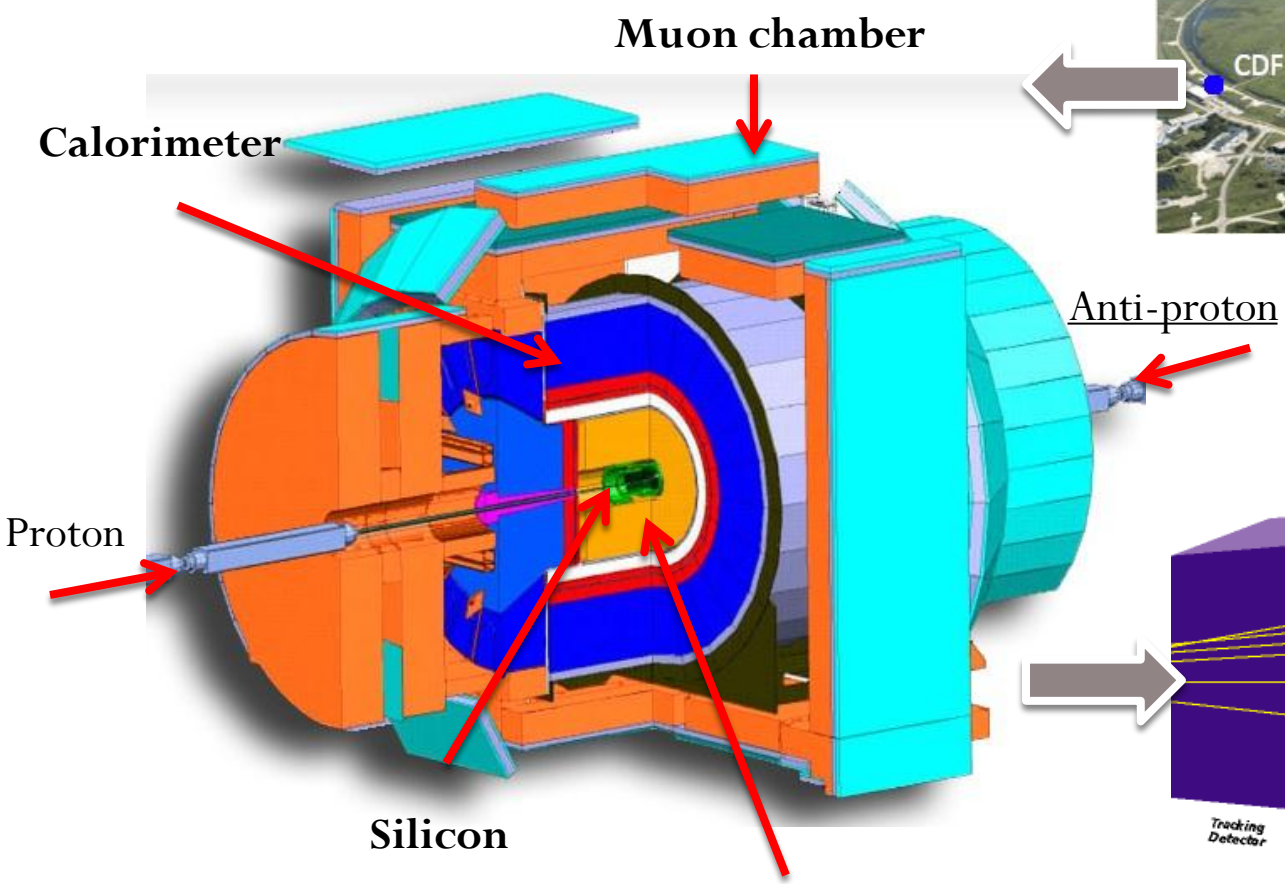


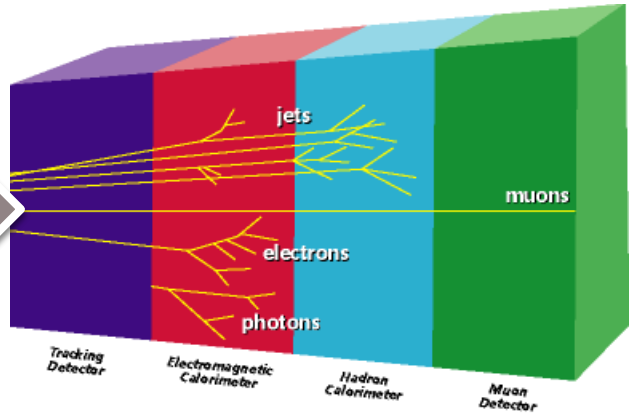
A wealth of top properties



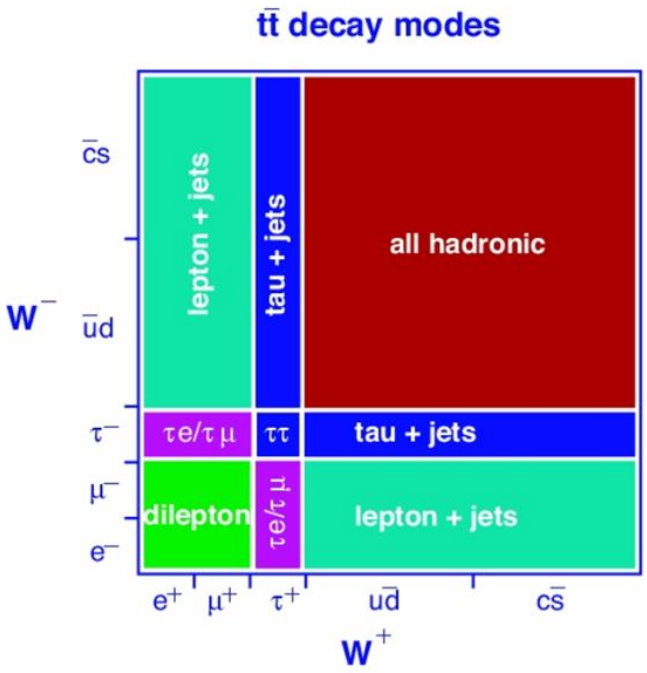
The Collider Detector at Fermilab (CDF)







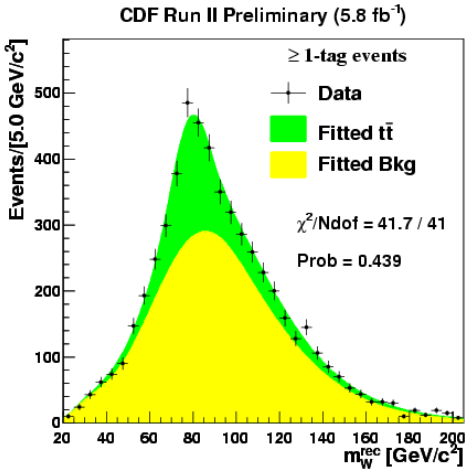
Top decay signatures at CDF

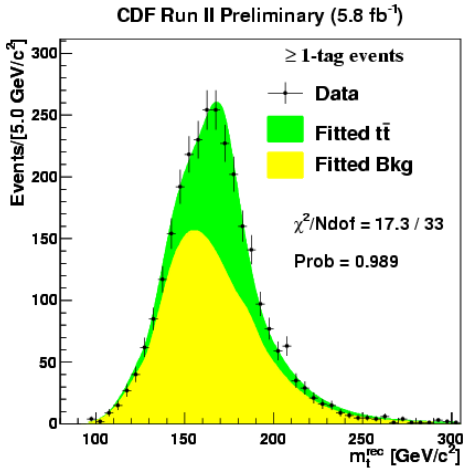


- Lepton+Jets
  - Large BR(30%), good S/B ratio
- Dileptonic
  - Highest S/B, but lowest BR(5%)
- All hadronic
  - Highest BR(44%)
  - But very large QCD background
- Tau modes
  - explicit tau identification
- MET+ jets
  - Lepton+jets and dileptonic decays where e/μ is not identified
  - Large acceptance to taus
  - Large QCD background

M_{top} measurement in hadronic jets

- Use b-tagging and multivariate techniques to isolate the signal from the overwhelming QCD background
- Jet energy scale (JES) is the largest systematic uncertainty:
  - Using W ⇨ $q\bar{q}$ decays to constrain it
- Fully reconstruct the kinematics so to reconstruct the top quark mass

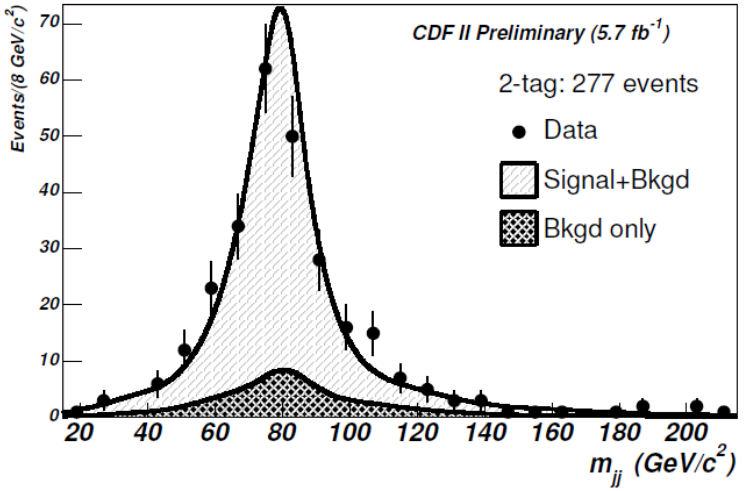




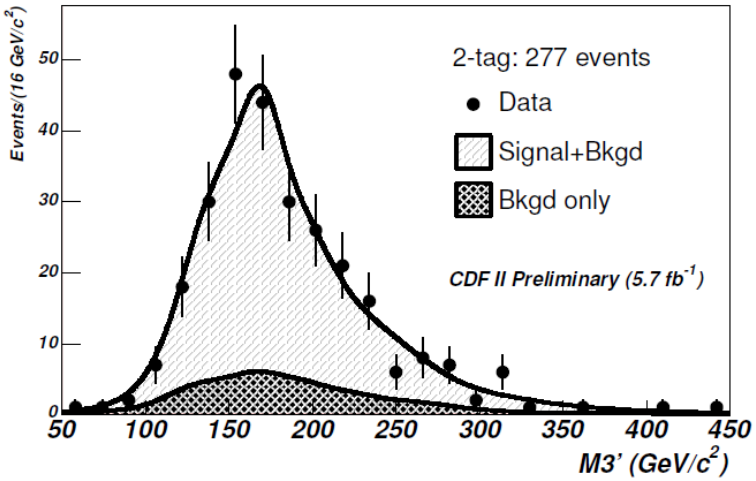
$$M_{top} = 172.5 \pm 1.4\,(stat) \pm 1.4\,(syst)\ GeV/c^2$$

M_{top} measurement in MET+Jets

- Limited lepton ID mostly due to limited detector coverage
- But ttbar events has striking kinematics:
  - Still possible to reconstruct one W and one top in this final state;



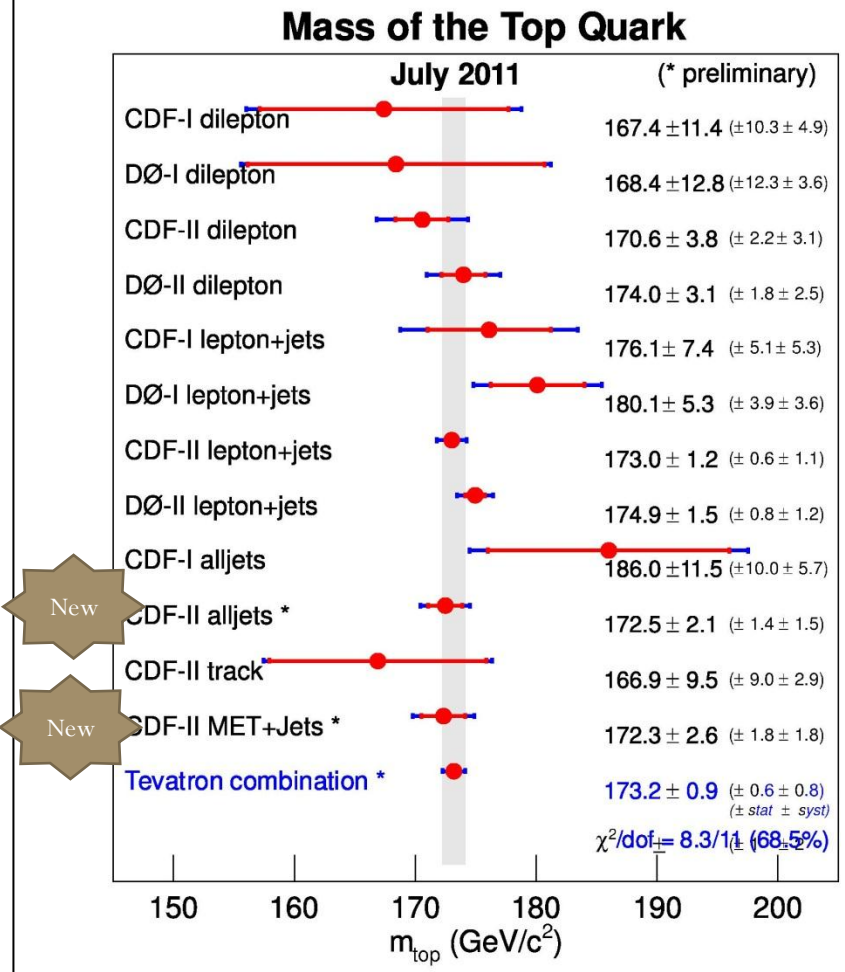
Choose dijet pair with closest to W mass to measure jet energy scale

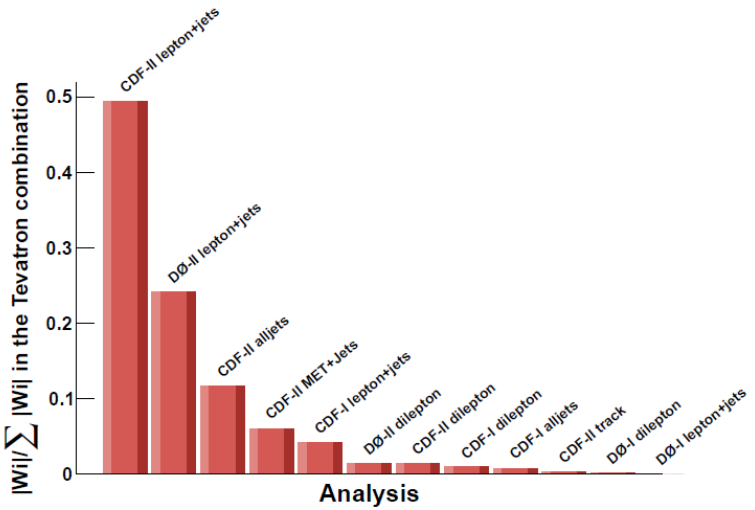


Reconstruct one of the two decaying top to measure the top quark mass

M_{top}= 172.3±2.4 (stat.+JES) ±1.0 (syst.) GeV/c^2

Tevatron Top Mass Combination

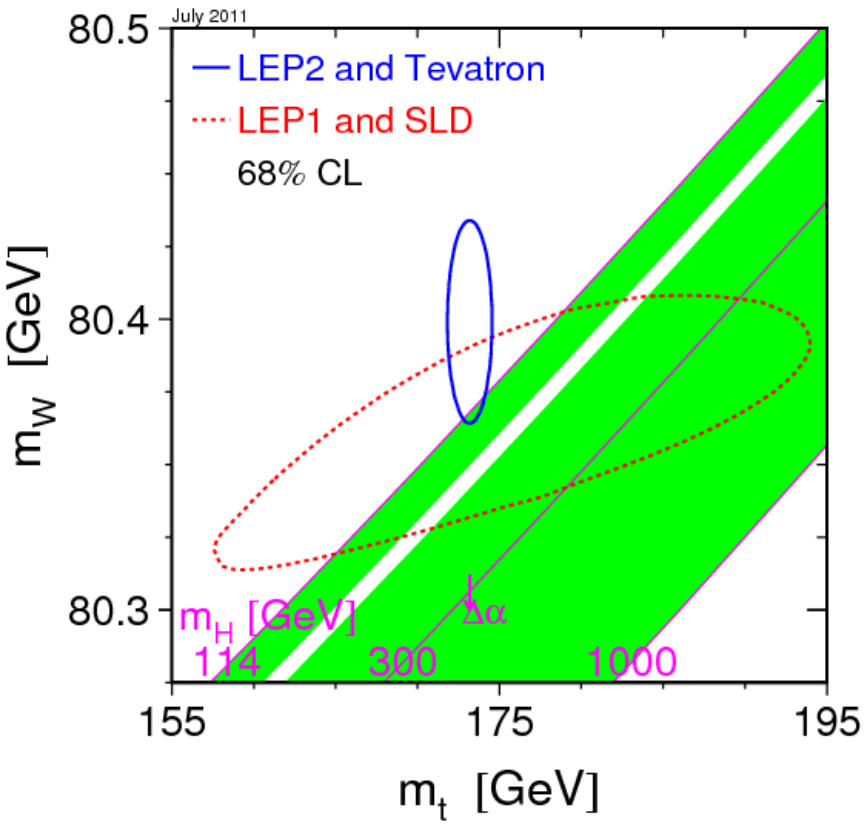


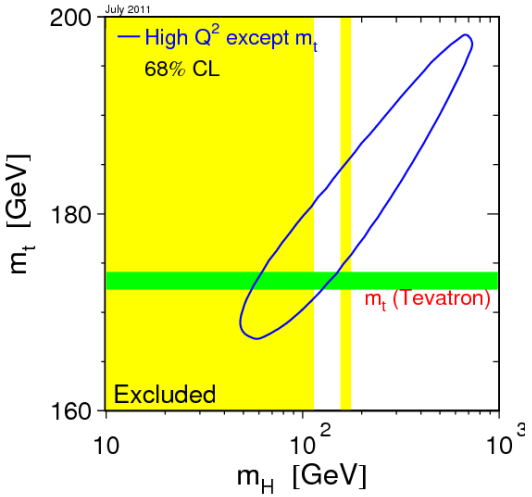


$M_{top} = 173.2 \pm 0.6\,(stat) \pm 0.8\,(syst)\ GeV/c^2$
$= 173.2 \pm 0.9\ GeV/c^2$ **<1GeV/c² precision!!**

The relative precision has improved by 13% with respect to the previous Tevatron average

Impact on Electroweak fits



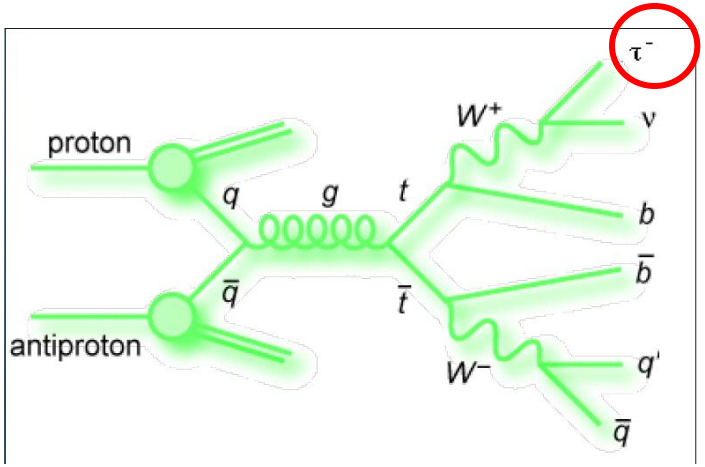


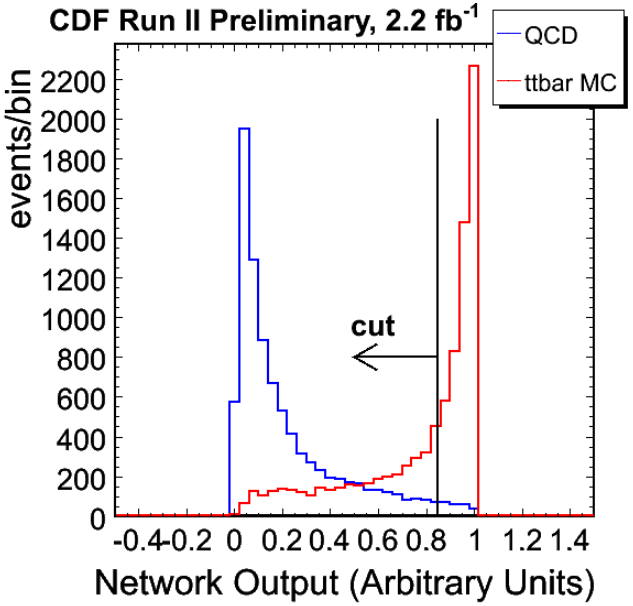
M_H=92+34-26 GeV

Squeezing out places where the Higgs could be hiding

Top in tau+jets

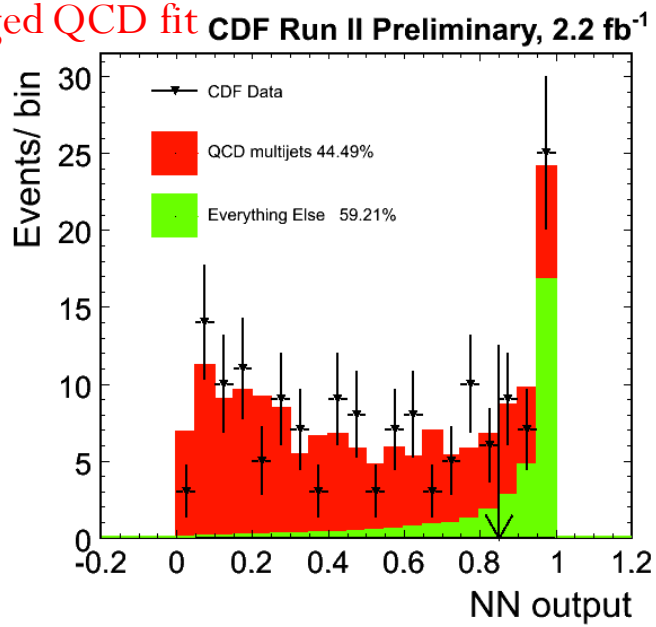
- Looking for hadronic tau + jets decays at CDF
- First measurement of the top mass in the tau+jets channel at CDF
- Probing top properties in a channel that is possibly sensitive to new physics
- Use Neural Network to remove large QCD background

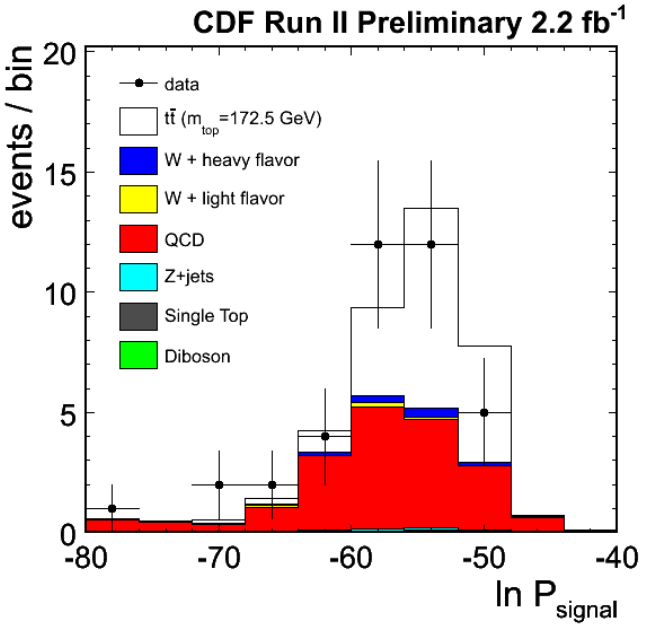


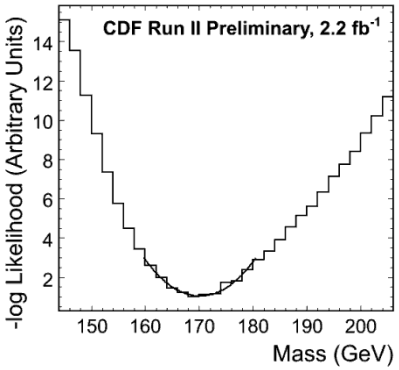


Top in tau+jets

B-Tagged QCD fit





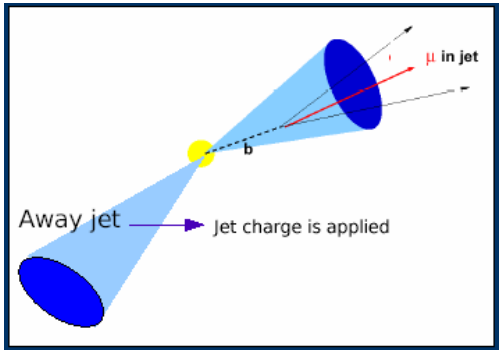


$M_{top} = 172.7 \pm 9.3\,(\text{stat} + \text{JES}) \pm 3.7\,(\text{syst})\ \text{GeV}/c^2$

$\sigma_{tt} = 8.8 \pm 3.3\,(\text{stat}) \pm 2.7(\text{syst})\ \text{pb}$

Top charge

- Top quark charge measurement:
  - can confirm SM theory ($Qtop = 2/3$)
  - can find 4th generation of quarks ($Qexotic = -4/3$)
- In case of exotic model $t \rightarrow W^{-}b$ (instead of $W^{+}b$)
- Three steps of this measurement:
  - determining the charge of the W (lepton charge and jet charge)
  - pairing the W with the b jet (Minimum χ^2)
  - getting the flavor of the b-jet

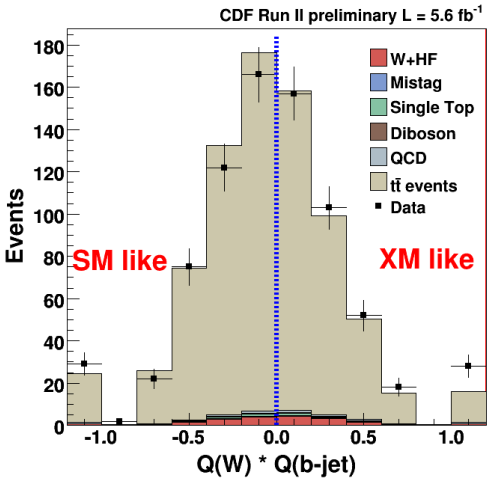


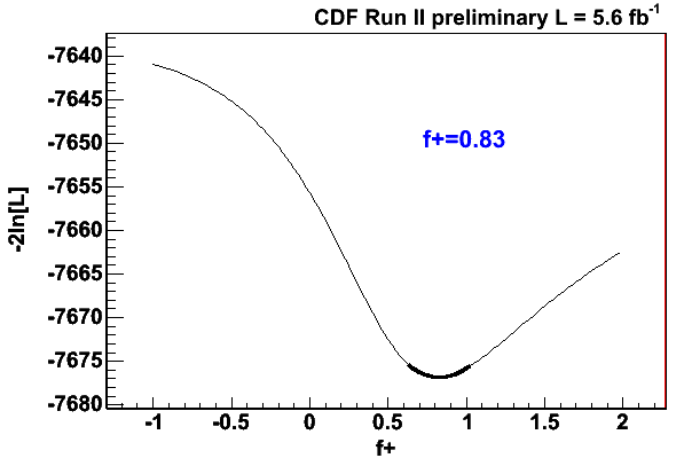
- **Muon jet charge: charge from muon**
- **Away jet charge: momemtum weighted charge**

$$Q_{b-jet} = \frac{\sum_i q_i \cdot (\vec{p}_i \cdot \hat{a})^x}{\sum_i (\vec{p}_i \cdot \hat{a})^x}$$

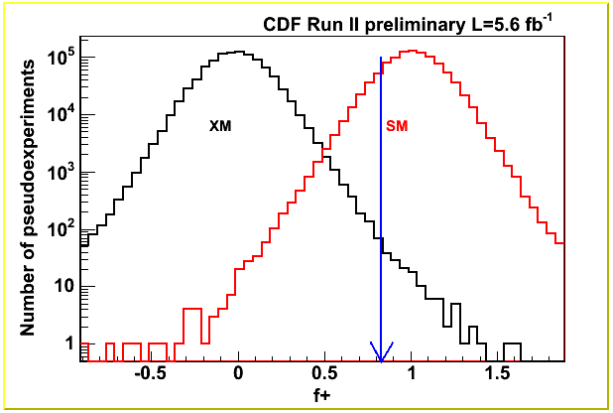
x = weighting factor
$\hat{a}$ = jet axis
$\vec{p}_i$ = track momentum

Top charge





f+ = fraction of pairs with top charge +2/3

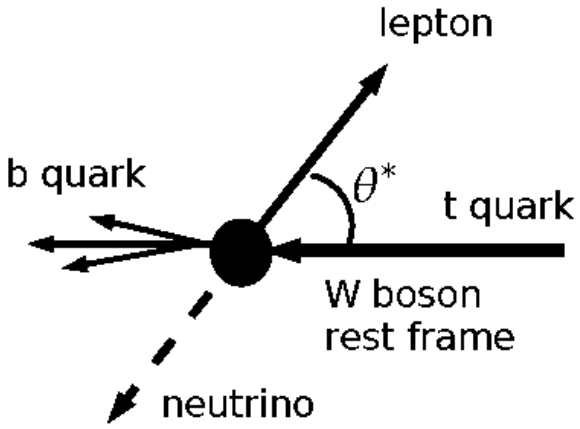


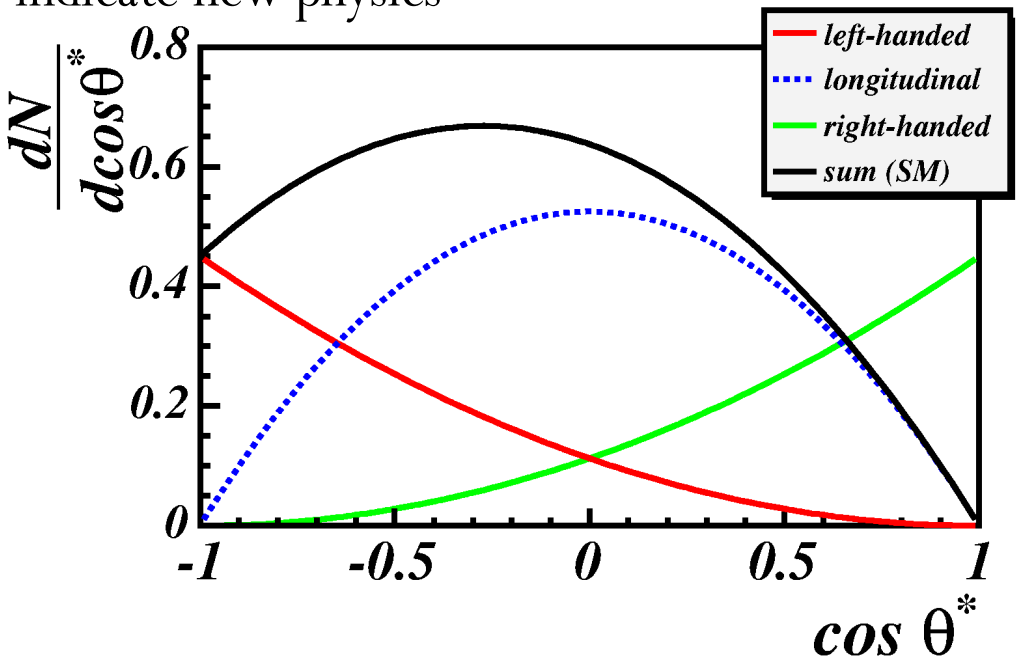
p-value under SM of 0.134
p-value under XM of 1.4 x 10^{-4}

We do not exclude SM. We exclude XM with 95% CL

W helicity in top decays

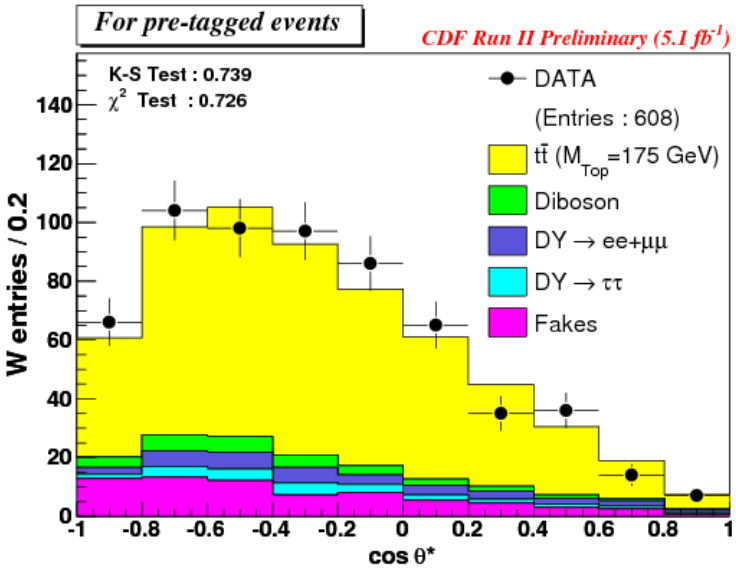
- The V-A structure of the weak interaction can be tested by reconstructing the polarization of the W^+ boson from top-quark decay.
- Standard Model: No right-handed W in ttbar decays.
- SM predicts: f_0=0.7 and f_+=0
- Deviations from SM would indicate new physics

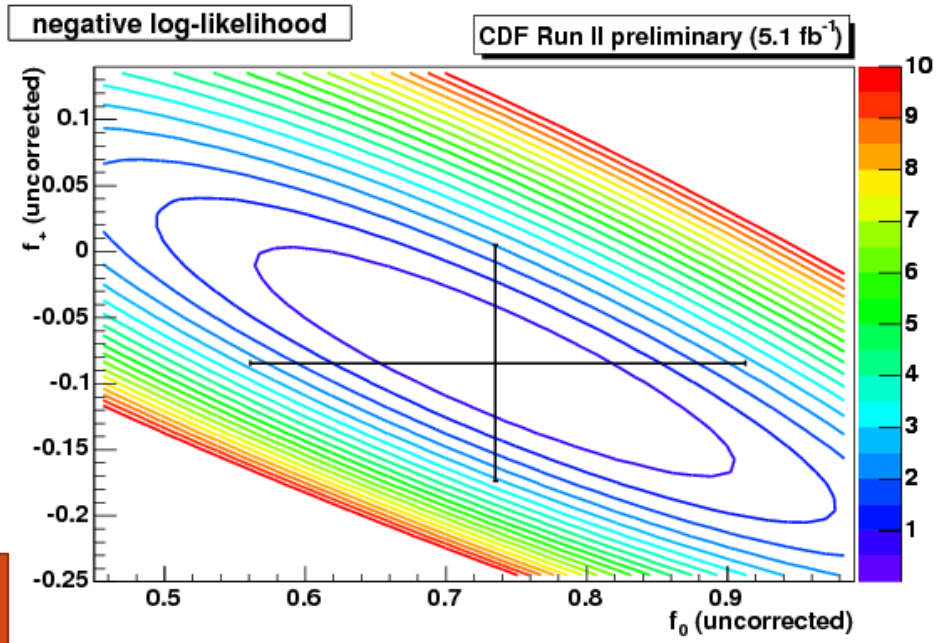




W-helicity in top-dilepton events

- First model-independent, simultaneous measurement of W boson helicity exclusively in dilepton channel



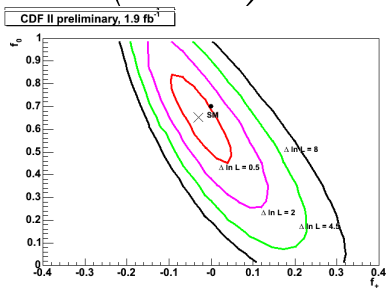


$f_0 = 0.74^{+0.18}_{-0.17}(\text{stat}) \pm 0.06\ (\text{syst})$

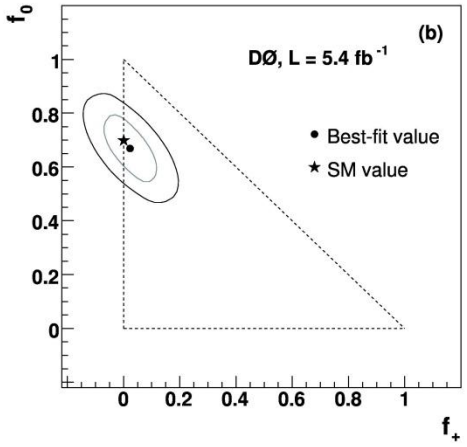
$f_+ = -0.09 \pm 0.09(\text{stat}) \pm 0.04\ (\text{syst})$

W helicity Tevatron combination

- **CDF lep+jets result – 2.7 fb^{-1}** *PRL 105, 042002 (2010)*
  - Simultaneous fit of longitudinal(f_0) and right-handed(f_+) helicity fraction
  - $f_0 = 0.88 \pm 0.11$ (stat) ± 0.06 (syst)
  - $f_+ = -0.15 \pm 0.07$ (stat) ± 0.06 (syst)



- **CDF dilepton result – 5.1 fb^{-1}** *Coming out soon*
  - $f_0 = 0.73$ +0.18-0.17 (stat) ± 0.06 (syst)
  - $f_+ = -0.08 \pm 0.09$ (stat) ± 0.03 (syst)
- **D0 result – 5.4 fb^{-1}** *PRD 83, 032009 (2011)*
  - Already combined result from lep+jets and dilepton channel
  - $f_0 = 0.67 \pm 0.08$ (stat) ± 0.07 (syst)
  - $f_+ = 0.02 \pm 0.04$ (stat) ± 0.03 (syst)



W helicity Tevatron combination

- Combined with two independent methods:
  - Numerical χ^2 minimization
  - The analytic best linear unbiased estimator(BLUE)
- Obtain identical results from both methods

$$f_0 = 0.732 \pm 0.081$$
$$f_+ = -0.039 \pm 0.045$$

Relative weights, in %:

measurement	weight for f_0	weight for f_+
CDFLJ f_0	45.20	-15.62
D0 f_0	49.61	4.68
CDFDIL f_0	5.19	10.94
CDFLJ f_+	28.91	-3.81
D0 f_+	-13.15	67.84
CDFDIL f_+	-15.76	35.97

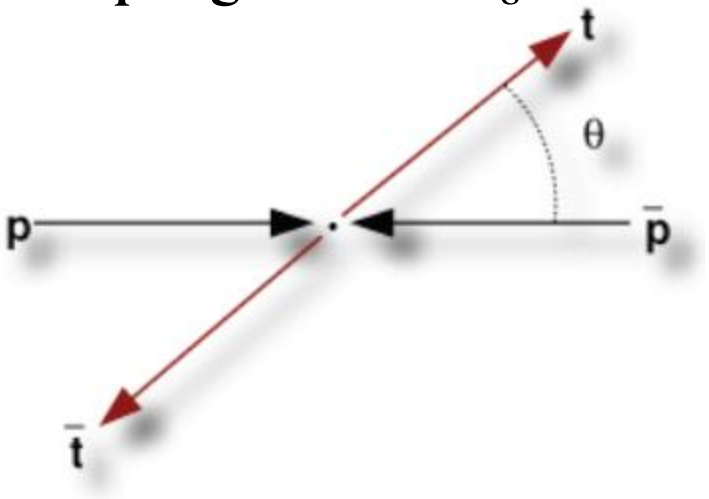
- Correlation between f_0 and f_+ : -0.86
- Uncertainty improvement: 20% (f_0) and 15% (f_+)
- Result is in agreement with Standard Model (f_0=0.7, f_+= 0.0)

Forward-Backward asymmetry: A_{fb}

- A ppbar collider is best suited to study the forward backward asymmetry of top quark production
- At LO, SM predicts completely symmetric
- NLO QCD predicts small asymmetry from qqbar → ttbar, about 5% (NNLO predicts almost the same rate)
- Deviations from SM indicate New Physics
  - **Big Gluons with axial vector coupling,** *Kuhn, Rodrigo PRL 81,89 (1998)*

$$A_{fb} = \frac{N^{\Delta y>0} - N^{\Delta y<0}}{N^{\Delta y>0} + N^{\Delta y<0}}$$

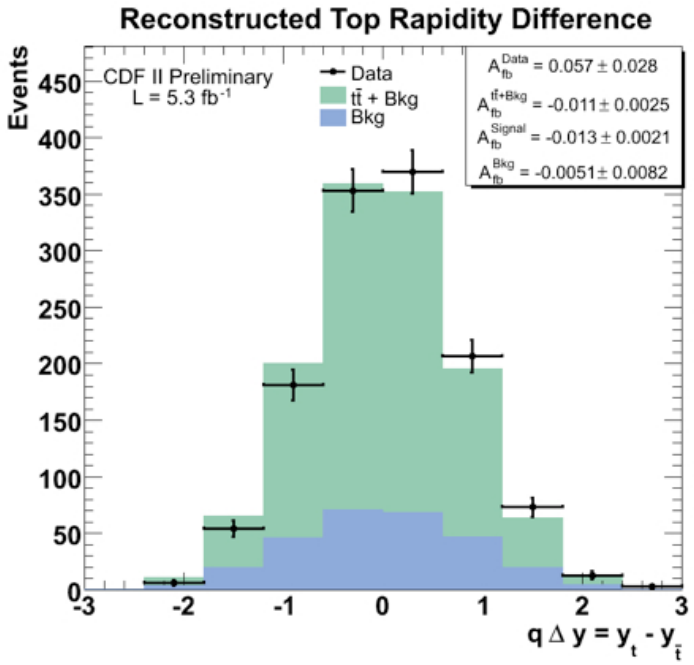
$$\Delta y = y_t - y_{\bar{t}}$$



A_{fb} in Lepton+Jets

- Reconstruct the top direction from lepton+ jets in the Detector
- We use the rapidity difference (ΔY) of t➜lvb and t➜jjb, which is proportional to Y_t in tt frame

$$Y_t \propto q_{lepton} \cdot \Delta Y$$

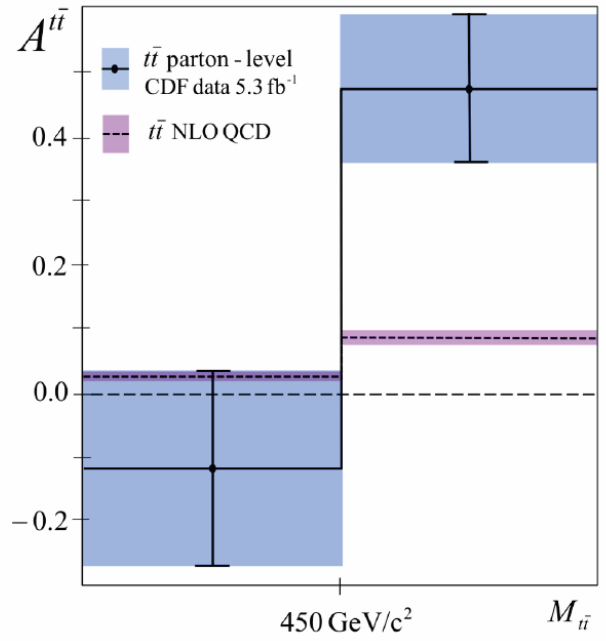


- $A_{FB}^{lab} = 15.0 \pm 5(stat) \pm 2.4(sys)\%$
- $A_{FB}^{tt} = 15.8 \pm 7.2\ (stat) \pm 1.7(sys)\%$
- $A_{FB}^{SM} = 6 \pm 1\%$

2σ away from no symmetry!!

A_{fb} in Lepton+Jets: M_{tt} Dependence

- A_{fb} could increase at higher energy due to new production mechanisms
- Study the asymmetry vs. the mass of the tt system (M_{tt}) by dividing samples into high/low (450GeV) M_{tt}



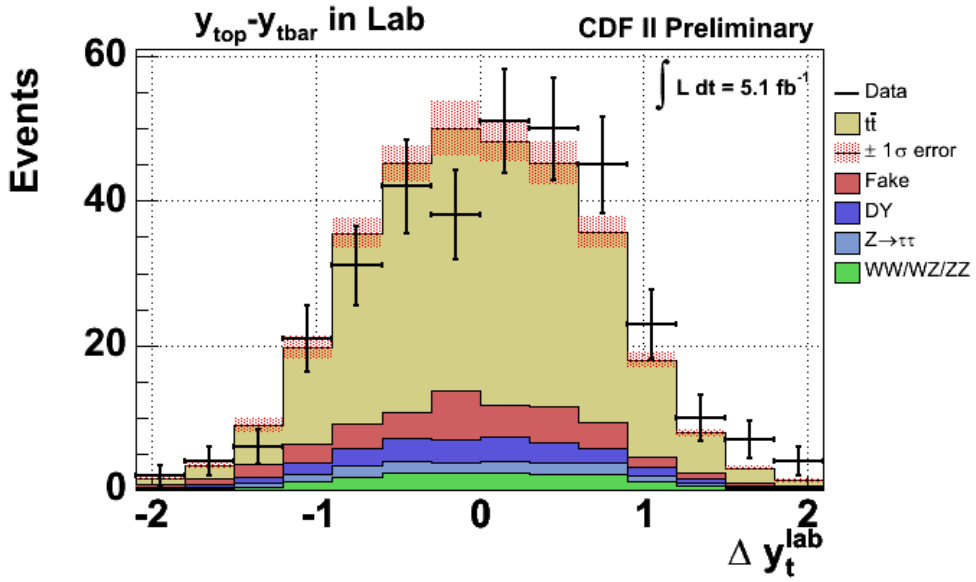
- Unfolded M_{tt} dependence back to parton level
- It is a more sensitive probe to new physics
- $\mathbf{A_{FB} = 48 \pm 11\%}$
- $\mathbf{A_{FB}^{SM} = 8.8 \pm 1.3\%}$

>3σ away from no symmetry!!

hep-ex/1101.0034

Afb in Dilepton

Reconstruct top in Dilepton channels, orthogonal to lepton+jets channel



$$A_{FB}^{SM} = 5.0 \pm 1.5\ \%$$

$$A_{FB}^{CDF} = 42 \pm 16\%$$

2.3σ away from no symmetry!!

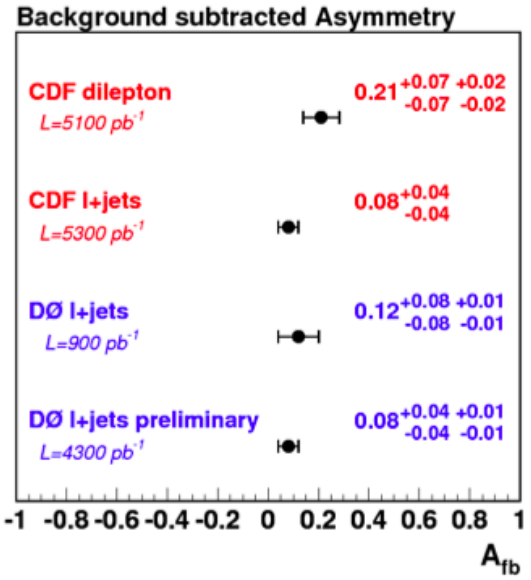
A_{fb} CDF combination

	F	B
Lep+Jets	108.9	79.2
DiLepton	26.0	10.6
Combined	134.9	89.8

$$A_{fb} = \frac{F - B}{F + B}$$

$A_{fb} = 0.20 \pm 0.07(\text{stat}) \pm 0.02(\text{sys})$

2.9σ away from no symmetry!!



Also seen at D0!

Summary

- Sixteen years after its discovery, the CDF/Tevatron dataset helped expand our knowledge of the top quark, thanks to extensive measurements of top quark intrinsic properties, study of its production and decay
- With the LHC era coming, Tevatron will still play an important role:
  - some Tevatron measurements - its mass! - have broad impact to our field, and will be a long standing legacy
  - others such as forward-backward asymmetry are complementary to the LHC program

More results and details on our wepbage:
http://www-cdf.fnal.gov/physics/new/top/top.html

Backup

A_{fb} dependents of M_{tt}