Top quark properties at CDF

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On behalf of the CDF Collaborations
Outline

- Top quark branching ratio and width
- Spin correlations in top-antitop event
- Helicity fraction of W boson
- Top quark charge
- Top forward-backward asymmetry
Run II at CDF

Run II (2001-2011)
~ 10fb⁻¹
Top quark

- Top quark properties
  - high mass $\sim 173.5$ GeV (PDG)
  - short lifetimes $\sim 10^{-25}$ sec
  - charge: $+\frac{2}{3}$
  - spin: $\frac{1}{2}$

- Top pair production in $pp$ collision
  - $\sigma \sim 7.22$ pb at $\sqrt{S} = 1.96$ TeV:
    - (NNLL, C. Schwinn, arXiv:1205.0988)
  - $q\bar{q} \rightarrow t\bar{t}: \sim 90\%$, $gg \rightarrow t\bar{t}: \sim 10\%$

- SM top quark $\rightarrow Wb$ ($\sim 100\%$)
  final states of top pair are given by $W$ decay states
  - lepton + jets
  - dilepton
  - all hadronic
Decay of top quark pair

- The topics are based on
  - Di-lepton channel (DIL)
  - Lepton + jet channel (LJ)
Di-lepton events (DIL)

- Event Selection
  - Two high $p_T$ leptons
    - $> 20$ GeV
    - $|\eta| < 2$
  - High missing $E_T$ due to the two neutrinos
  - Suppressing of Z boson events
  - High total transverse energy
  - Two or more jets
Lepton+jet events (LJ)

- Event Selection
  - high $p_T$ lepton (e/µ)
    - $> 20$ GeV (CDF)
    - $|\eta| < 1.0$
  - Missing $E_T$ due to the one neutrino
  - Four or more jets
    - $|\eta| < 2.0$
  - at least one $b$-tagged jet
    - $|\eta| < 1.0$

- full CDF RUN II data, with one good $b$-tag : 8.7 fb$^{-1}$
Top quark branching ratio (t → b)

- Direct measurement in lepton+jet, 8.7 fb$^{-1}$

\[
R = \frac{\mathcal{B}(t \rightarrow Wb)}{\mathcal{B}(t \rightarrow Wq)} = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}
\]

- LJ samples are divided to 18 subsamples
  - 1,2 btag X 3jet, 4jet, ≥5jets X lepton type
  - R is determined from the maximum likelihood for each subsample

\[
\mathcal{L} = \prod_i \mathcal{P}(\mu^i_{exp}(R, \sigma_{p\bar{p}\rightarrow t\bar{t}}, x_j)|N_{obs}^i) \prod_j G(x_j|0,1)
\]

- $|V_{tb}|$ is derived from the result

\[
R = 0.94 \pm 0.09
\]

\[
|V_{tb}| = 0.97 \pm 0.05
\]

(LJ, 8.7fb$^{-1}$, CDF note 10723)
SM prediction: $\Gamma_t \sim 1.5$ GeV
• Direct measurement in lepton+jet, 4.3 fb$^{-1}$
  • template method with different top quark $\Gamma_t$ and in situ JES
  • subsamples with 1, 2 b-tags (diff. s+b)
  • comparing s + b probability density
    • unbinned maximum likelihood

0.3 GeV $< \Gamma_t < 4.4$ GeV at 68% C.L.
$\Gamma_t < 7.6$ GeV at 95% C.L.
(LJ, 4.3 fb$^{-1}$, PRL 105, 232003(2010))
Spin correlations

- Top pairs are produced with a definite spin depending on production mechanism

- Top decays before hadronization:
  - Spin information passed to decay products
  - Spin correlation can be studied from the angular distribution of decay products reflects

- Correlation strength (κ) is defined as

\[
\frac{1}{\sigma} \frac{d^2\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1 + \kappa \cos\theta_+ \cos\theta_-}{4}
\]

\[
\kappa = \frac{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} - N_{\uparrow\downarrow} - N_{\downarrow\uparrow}}{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} + N_{\uparrow\downarrow} + N_{\downarrow\uparrow}}
\]

- SM predicts κ = 0.78 +0.03 -0.04 (Nucl. Phys. B 690, 81 (2004))
The measurement Spin correlation

- Using templates for $\cos\theta \cdot \cos\theta$
- Binned maximum likelihood for $C_{\text{lepton+jet}}$
- Statistically limited
- Consistent with SM

$K_{\text{lepton+jet}} = 0.72 \pm 0.69$
  
  (LJ, 5.3fb$^{-1}$, CDF note 10211)

$K_{\text{Dilepton}} = 0.04 \pm 0.56$
  
  (DIL, 5.1fb$^{-1}$, CDF note 10719)
W helicity

- W helicity can be Measured in $t \rightarrow Wb (\sim 100\%)$
- Three possible helicity states
  - Longitudinal ($f_0$), left-handed ($f_-$) and right-handed ($f_+$)
  - angular distribution of decay products in W rest frame dependent on helicity state
- In SM, right-handed is strongly suppressed
  - V-A interaction
  - fraction of $f_0$, $f_+$ and $f_-$ depends on $m_t$ and $m_W$
  - deviation would provide evidence of BSM

SM prediction:

- $f_0 = 69.6\%$
- $f_- = 30.3\%$
- $f_+ = 0.1\%$
The measurement of $W$ helicity

- Extract $f_0$, $f_+$ from distribution of $\theta^*$ (angle between lepton and top direction in $W$ rest frame)

\[ \omega(\cos \theta^*) \propto 2(1 - \cos^2 \theta^*) f_0 + (1 - \cos \theta^*)^2 f_- + (1 + \cos \theta^*)^2 f_+ \]

- Dilepton samples in $5.1\text{fb}^{-1}$

\[
f_0 = 0.71 \pm 0.18\text{(stat)} \pm 0.06\text{(syst)}
\]
\[
f_+ = -0.07 \pm 0.09\text{(stat.)} \pm 0.03\text{(syst.)}
\]

(DIL, 5.1fb$^{-1}$, CDF note 10543)
The measurement of $W$ helicity

- lepton+jet samples in $8.7 \text{ fb}^{-1}$
- matrix element method adopted

$$f_0 = 0.726 \pm 0.066 \text{(stat)} \pm 0.067 \text{(syst)}$$
$$f_+ = -0.045 \pm 0.043 \text{(stat.)} \pm 0.058 \text{(syst.)}$$

(LJ, $8.7 \text{ fb}^{-1}$, CDF note 10855)
Top quark charge

- Top quark charge from standard model: +2/3 (SM)
  - Exotic quark: -4/3 (XM)


  \[
  t \rightarrow W \quad b \\
  \text{(SM)} \quad +2/3 \quad +1 \quad -1/3 \\
  \text{(XM)} \quad -4/3 \quad -1 \quad -1/3
  \]

- Using Lepton+jet samples, three main components to assign the sign of top charge
  - Determining W charge from the charge of lepton
  - Pairing the W with b jet to ensure that they are coming from the same top decay branch
  - Finally, getting the flavor of the b jet using jet charge algorithm to find the sign of top charge
Top quark charge

- From 5.6 fb$^{-1}$ lepton+jet samples, 416 SM like pairs and 358 XM like pairs has been observed in data.

- Q(W)$^*Q$(b-jet) of data is consistent with the one of SM prediction.

- An exotic quark hypothesis is excluded with 99% C.L. (LJ, 5.6 fb$^{-1}$, CDF note 10460)
Top forward-backward asymmetry

- **Measurement asymmetry in Δy**

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

CDF Run II Preliminary L = 8.7 fb\(^{-1}\)

- **SM prediction**

  Leading order: No asymmetry

  Next-to-leading order: 0.066

\[ A_{fb} = 0.162 \pm 0.047 \text{ (stat) } \] (lepton+jet, 8.7 fb\(^{-1}\), CDF note 10807)

→ Tomorrow, please listen to the talk by Chris Hays for details.
Conclusion

- The full CDF dataset is being studied in top properties measurement.

- Spin correlations, $A_{FB}$ are complementary to LHC measurements

- Data taking is done. But there is a lot left to be learned from the CDF top quark sample.

- Please look at the websites of CDF’s Top group for more informations and results

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