Measurement of the Top Quark Charge at DØ

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Sunday, April 23, 2006
Session I13 DPF
Top Quark Properties

On behalf of the DØ Collaboration
What is the top quark?

- Discovered in 1995 by both the CDF and DØ collaborations at the Fermilab Tevatron proton-antiproton collider.
- The top quark is one of the fundamental fermions of Nature.
- The production cross section and mass have been well measured.
- Other properties (not well known):
  - Spin
  - Electric Charge (SM top quark has charge 2/3)
Top quark physics

- W decay modes are used as labels for the top quark final state:
  - $Br (t \rightarrow Wb) \cong 100\%$
  - Lepton (e or $\mu$) + jets
    - One W boson decays leptonically, the other decays hadronically
    - BR = 34%
    - Background: Multijet, W+jets
Fermilab and the Tevatron

- Uses superconductive magnets to collide protons and antiprotons.
- Situated in four mile long underground tunnel.
- Center of mass energy of 1960 GeV.
- Highest energy accelerator in the world!
- World record for hadron collider peak luminosity of $L=171 \times 10^{30} \text{ cm}^{-2}\text{s}^{-1}$!
  - Previous record held by CERN Intersecting Storage Ring (ISR) of $140 \times 10^{30} \text{ cm}^{-2}\text{s}^{-1}$.
The DØ Collaboration

- 19 countries, 80 institutions, 670 physicists
The DØ Detector

- High precision tracking detector:
  - Silicon vertex detector.
  - Central fiber tracker.
- Solenoid magnetic field of 2 T.
- Liquid argon calorimeter:
  - Electron/jet identification.
- Drift chambers for muon identification.

Silicon Microstrip Tracker

DØ Control Room

End view of calorimeter

+ New Electronics, Trig, DAQ
A True Masterpiece

20m/66ft

14m/46ft
Tevatron and DØ Performance

Run II Integrated Luminosity

19 April 2002 - 19 February 2006

ε = 84%

370 pb⁻¹

Delivered

Recorded
Analysis strategy

- The measurement of the charge occurs in 4 steps:
  - Selection of a pure sample of top quark events
    - Use lepton plus jets final states
      - Large statistical sample
      - Large signal to background ratio
      - Use b-quark tagging to enhance purity
        » Require 2 b-tagged jets in each event
  - Assignment of the correct jet and leptons
    - Two-fold ambiguity in assignment of lepton with b-quark jet
    - Use a constrained kinematical fit:
      - Masses of the W boson and top quarks are used as physical constraints
  - Determine the charge of the b-jet
    - Use convolution of charges of the tracks from the b hadron decay
    - Construct the observables $Q_1$ and $Q_2$
  - Use charge templates for the standard model (2/3) and exotic case (4/3) to determine which the data prefers
What does one look for?

**Standard Model Top Quark**

- One high $P_T$ lepton: $P_T > 15$ GeV
- Missing transverse energy: $E_T > 15$ GeV
- Four or more jets: $P_T > 15$ GeV

Form two observables:

$$Q_1 = | q_{\text{lepton}} + q_b (q_{\overline{b}}) |$$

$$Q_2 = | - q_{\text{lepton}} + q_{\overline{B}} (q_B) |$$

Each scenario has two bottom quarks!

**Exotic Top Quark**

$$Q_1 = 4/3, Q_2 = 4/3$$

PRD 59, 091503 & PRD 61, 037301

- One high $P_T$ lepton: $P_T > 15$ GeV
- Missing transverse energy: $E_T > 15$ GeV
- Four or more jets: $P_T > 15$ GeV

Form two observables:

$$Q_1 = | q_{\text{lepton}} + q_b (q_{\overline{b}}) |$$

$$Q_2 = | - q_{\text{lepton}} + q_{\overline{B}} (q_B) |$$
Finding bottom quarks

- A bottom quark is present in all top quark decays.
- The bottom quark forms a B hadron that propagates away from the primary vertex and then decays.
  - Look for tracks that form another vertex separate from the primary vertex.
  - Measure the track’s impact parameter.
- Mistag rate, i.e. the probability to tag a jet that did not originate from a bottom quark is 0.025%.
- Efficiencies and mistag rates are determined from data

<table>
<thead>
<tr>
<th></th>
<th>W+jets</th>
<th>t-tbar</th>
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</thead>
<tbody>
<tr>
<td>≥4j, 1 tag</td>
<td>4%</td>
<td>44%</td>
</tr>
<tr>
<td>≥4j, 2 tag</td>
<td>0.4%</td>
<td>15%</td>
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</tbody>
</table>
Jet Charge Algorithms

\[ Q_{jet} = \frac{\sum_i q_i \cdot p_{T_i}^a}{\sum_i p_{T_i}^a} \]

- $p_T$ weighted sum of charged tracks
- Applied only to b-tagged jets
- Optimization of parameters from $t\bar{t}$ simulated events (Monte Carlo)
  - $a = 0.6$
- Use only tracks with:
  - $p_T > 0.5$ GeV
  - $\Delta R < 0.5$ (jet, track)
Calibrating $Q_{\text{jet}}$ on data

- Use a sample of multijets that are back-to-back:
  - Both are b-tagged
  - One has a muon to determine charge of jet
  - Calibration derived from second jet

- Correct charge assignment for:
  - B hadron oscillation
  - Cascade decay $b \rightarrow c \rightarrow \mu$
  - Charm pair production background
Templates and Data

17 fitted double b-tagged events

Charge templates for the standard model and exotic top quarks

DØ Run II Preliminary

$\mathbf{L = 370 \text{ pb}^{-1}}$

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Leonard Christofek, KU
Limits

\[ \Lambda = \frac{\prod_i p^{sm}(q_i)}{\prod_i p^{ex}(q_i)} \]

- Form a likelihood ratio
- \( p^{sm}(q) \) is the probability to observe top quark charge in standard model
- \( p^{ex}(q) \) is the probability to observe top quark charge in exotic scenario
- Rule out 4/3 or exotic model at 93.7%

\( \Lambda_{\text{data}} = 11.4 \)

DØ Run II Preliminary

Number of Ensembles

0 10 20 30 40

\( \Lambda \)
Summary

- DØ has made a measurement of the top quark charge at the Fermilab Tevatron.
- Using a sample of top quark events in the lepton plus jets channel, with an integrated luminosity of $370 \text{ pb}^{-1}$, we find 17 events with two b-tagged jets.
- Using a likelihood ratio, we find the data are in good agreement with a standard model top quark charge of $2/3$.
- The exotic quark hypothesis with charge $4/3$ is excluded at a 94% confidence level.