Measurement of the Top Quark Pairs Production Cross Section at DØ Using e/µ + track Events

Outline

Top Quark
Why e/µ + track mode?
Signal Events Selection
Backgrounds
Cross Section

APS 2006, August 22-25, Dallas (Texas)
Dmitri Denisov, Fermilab
For the DØ Collaboration
Top Quark Studies at DØ

Discovery of top quark at Fermilab in 1995
- Completed Standard Model quark sector

Studies of heaviest known elementary particle provide
- Standard Model parameters, tests
- Beyond Standard Model searches

Experimental challenges: 175 GeV mass, low cross sections and high backgrounds
- Accelerator - Tevatron is the only “top factory” with $\sqrt{s} = 1.96$ TeV
- Detector
- Analysis

Top quark pairs production cross section measurements test
- QCD predictions for highest mass quark
- SM predictions for top quark decays
- Methods of top quark identification
Top Quark Production and Decays

Production

Top quarks at Tevatron are (mainly) produced in pairs via strong interaction

Decay

In SM top lifetime is very short
Decays 100% to \( W + b \)

NLO QCD prediction for top quarks pair cross section at \( \sqrt{s} = 1.96 \text{ TeV} \) is \( 6.7 \pm 0.7 \text{pb} \)

<table>
<thead>
<tr>
<th>Mode</th>
<th>( e\nu )</th>
<th>( \mu\nu )</th>
<th>( \tau\nu )</th>
<th>( qq )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( e\nu )</td>
<td>1.2</td>
<td>2.5</td>
<td>2.5</td>
<td>14.8</td>
</tr>
<tr>
<td>( \mu\nu )</td>
<td>1.2</td>
<td>2.5</td>
<td>14.8</td>
<td></td>
</tr>
<tr>
<td>( \tau\nu )</td>
<td>1.2</td>
<td>14.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( qq )</td>
<td></td>
<td></td>
<td></td>
<td>44.4</td>
</tr>
</tbody>
</table>

Top decays classification: di-lepton, lepton+jets, all jets
Why $e/\mu$ + track Mode?

**Di-lepton final state**
- Cleanest = lowest backgrounds
  - Two high $P_T$ leptons
  - Two high energy jets
  - Large missing $E_T$ from two neutrinos
- But branching fraction is 5%...

**Events losses in di-lepton channel**
- 2\textsuperscript{nd} power of $e/\mu$ efficiencies
- Holes in muon detector and calorimeter acceptance

**Idea - select events with**
- One lepton and one track (both high $P_T$, isolated), missing $E_T$, high energy jet(s)
- Tag b quark jet to reduce backgrounds

- With $\sim$7pb cross section in $\sim$0.4fb$^{-1}$ data set
  - $\sim$3\cdot10$^2$ top pairs produced with decay to di-lepton channel
  - But... events selection efficiencies are “low”, providing opportunity to detect a few % of created events
  - $\sim$3\cdot10$^2 \rightarrow \sim$10 events
DØ Experiment in Run II and Data Set

**New for Tevatron Run II**
- Silicon detector
- 2 T solenoid and central fiber tracker
- Substantially upgraded muon system
- New electronics

**Still there are acceptance “holes”**
- Supports, access gaps, limited rapidity coverage, etc.

**Data set**
- 2002-2004 data taking
- Ldt \(\sim 370 \text{ pb}^{-1}\)
Cross Section Ingredients

\[ \sigma_{tt} = \frac{N_{\text{obs}} - N_{\text{Bkg}}}{\epsilon \int L \, dt} \rightarrow \text{four main numbers needed} \]

- 370 pb\(^{-1}\) of “good quality” data
- High \(P_t\) multi-level single e/\(\mu\) and e/\(\mu\) with jet triggers
- Topological event selection
  - One isolated e/\(\mu\) with \(P_t > 15\text{GeV}\)
  - One isolated track with \(P_t > 15\text{GeV}\)
  - Missing \(E_t\) of 15-35GeV
  - \(\geq\) one \(E_t > 20\text{GeV}\) jet
- If track matches identified e/\(\mu\), then event is not analyzed
  - Covered in e/\(\mu\) di-muon analysis (Burke’s talk) with softer cuts (no Z+jets background)
  - Keep two analyses un-correlated for easy averaging

- Simulation of signal and background
  - ALPGEN1.2+PYTHIA6.2+GEANT
  - 175 GeV top quark mass used

**Backgrounds are well understood, but too high…**
Adding b-tagging

- Two high $E_t$ jets in top pairs final decay products are jets originated from b quarks fragmentation
  - Lifetime of B meson is $\sim$0.5mm
  - Require $7\sigma$ displaced vertex significance
- Tagging at least one jet in an event reduces $Z+$jets backgrounds (light quarks), keeping substantial number of top events

- Jet b-tagging efficiency is measured from data using semi-leptonic b decays
- Probability to tag light quark jet (mistag rate) is calculated using QCD multi-jet sample

Clear top signal!
## Final Cross Section Calculation

\[ \sigma_{t\bar{t}} = \frac{N_{\text{obs}} - N_{\text{Bkg}}}{\epsilon \int L \, dt} \]

<table>
<thead>
<tr>
<th></th>
<th>Electron+track</th>
<th>Muon+track</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of jets</td>
<td>1</td>
<td>≥ 2</td>
</tr>
<tr>
<td>Muon+track</td>
<td>1</td>
<td>≥ 2</td>
</tr>
</tbody>
</table>

### Expected number of events

<table>
<thead>
<tr>
<th>Process</th>
<th>Electron+track</th>
<th>Muon+track</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW</td>
<td>0.037 ± 0.002</td>
<td>0.010 ± 0.002</td>
</tr>
<tr>
<td>(Z/\gamma^* \rightarrow \tau\tau)</td>
<td>0.09 ± 0.02</td>
<td>0.13 ± 0.02</td>
</tr>
<tr>
<td>(Z/\gamma^* \rightarrow ee, \mu\mu)</td>
<td>1.49 ± 0.04</td>
<td>2.35 ± 0.06</td>
</tr>
<tr>
<td>Multijet/W+jets</td>
<td>0.36 ± 0.06</td>
<td>0.35 ± 0.07</td>
</tr>
<tr>
<td><strong>Total background</strong></td>
<td><strong>1.97 ± 0.08</strong></td>
<td><strong>2.83 ± 0.09</strong></td>
</tr>
<tr>
<td><strong>Total uncs. (stat+syst)</strong></td>
<td>+0.91 –0.85</td>
<td>+0.87 –0.64</td>
</tr>
<tr>
<td><strong>tt̅</strong></td>
<td>1.55 ± 0.03</td>
<td>6.59 ± 0.07</td>
</tr>
<tr>
<td><strong>Signal + background</strong></td>
<td><strong>3.53 ± 0.08</strong></td>
<td><strong>9.4 ± 0.1</strong></td>
</tr>
<tr>
<td><strong>Total uncs. (stat+syst)</strong></td>
<td>+0.99 –0.86</td>
<td>+0.99 –0.85</td>
</tr>
</tbody>
</table>

### Observed number of events

| Data | 7 | 9 | 1 | 6 |

\[ \sigma_{t\bar{t}}^{l+track} = 7.1^{+2.6}_{-2.2} \text{ (stat)} +^{1.3}_{-1.3} \text{ (syst)} \pm 0.5 \text{ (lumi)} \text{ pb} \]

Comparison: ~14 signal events expected vs ~7 events in di-lepton ee/\(\mu\mu\) channel – added “extra” top events to the analysis!
Combination with $e\mu$ di-lepton Channel

Combination with $e\mu$ topological analysis without $b$ tagging (Burke’s talk)

Powerful way of combining channels as many systematic uncertainties are uncorrelated

Combined cross section

$$\sigma_{t\bar{t}}^{l+\text{track}+e\mu} = 8.6^{+1.9}_{-1.7} \text{ (stat)}^{+1.1}_{-1.1} \text{ (syst)} \pm 0.6 \text{ (lumi) pb}$$
Summary of $e/\mu$ + track Top Quark Cross Section Measurement

$e/\mu+$track method of top quark pairs production cross section measurement is developed at DØ

Using $e/\mu+$track and $e\mu$ di-lepton events top pairs cross section at $\sqrt{s}=1.96\text{TeV}$ is measured to be

$$\sigma_{t\bar{t}}^{l+\text{track}+e\mu} = 8.6^{+1.9}_{-1.7}\text{ (stat)}^{+1.1}_{-1.1}\text{ (syst)} \pm 0.6\text{ (lumi)}\text{ pb}$$

Cross section is in agreement with QCD predictions and measurements in other modes of top quark decays

**Standard Model works! (for now…)**

Measurement is statistically limited
It will improve with Tevatron delivered luminosity increase

<table>
<thead>
<tr>
<th>DØ Run II Preliminary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>dilepton (topological)</td>
</tr>
<tr>
<td>$L=230 \text{ pb}^{-1}$</td>
</tr>
<tr>
<td>8.6 $^{+3.2}_{-1.7}$ pb</td>
</tr>
<tr>
<td>l+jets (topological)</td>
</tr>
<tr>
<td>$L=370 \text{ pb}^{-1}$</td>
</tr>
<tr>
<td>8.2 $^{+0.9}_{-0.8}$ pb</td>
</tr>
<tr>
<td>l+jets (Vertex tag)</td>
</tr>
<tr>
<td>$L=363 \text{ pb}^{-1}$</td>
</tr>
<tr>
<td>8.2 $^{+0.9}_{-0.8}$ pb</td>
</tr>
<tr>
<td>all hadronic</td>
</tr>
<tr>
<td>$L=350 \text{ pb}^{-1}$</td>
</tr>
<tr>
<td>5.2 $^{+2.5}_{-1.0}$ pb</td>
</tr>
</tbody>
</table>

Cacciari et al. JHEP 0404:068(2004), $m_t = 175 \text{ GeV/c}^2$