Measurement of the $t\bar{t}$ Production Cross Section at DØ using event kinematics

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For DØ Experiment
Outline

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- Top Quark Production and Decay
- Event Signature and Preselection
- Estimation of Multi-jet Backgrounds
- Topological Analysis
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Introduction

- Top quark was discovered at 1995 by DØ and CDF Collaborations

- **Tevatron** is still *the only place* to produce the top events in the world

- Top pair events are important to understand the Standard Model and search New physics
  - They are important background for Higgs search

- Measurement of top pair production cross section is the first step toward any Top property measurement
Tevatron and DØ detector

- Tevatron
  - p\(\bar{p}\) collider with \(\sqrt{s} = 1.96\) TeV
  - Integ. Lumi. 2.71fb\(^{-1}\)(delivered), 2.28fb\(^{-1}\)(recorded)
  - expect 3fb\(^{-1}\) by July!

- DØ Detector
  - Silicon Vertex Detector
  - Central Tracker
  - EM and Hadronic Calorimeters
  - Muon Detector

DØ Detector Overview

Run II Integrated Luminosity

\(~ 1\) fb\(^{-1}\)
Top Quark Production and Decay

Top quark pair production at Tevatron energies:
- $q\bar{q}$ annihilation ($\sim 85\%$)
- Gluon fusion ($\sim 15\%$)

Top quark decays to $Wb$ with $\sim 100\%$ due to its heavy mass:
- So, the final states are determined by what $W$ boson decays
- 3 types of channels:
  - Dilepton channel
  - Lepton + jets channel
  - All hadronic channel

Top Pair Branching Fractions:

- "alljets" 44%
- $\tau + \text{jets}$ 15%
- $\mu + \text{jets}$ 15%
- $\epsilon + \text{jets}$ 15%
- "dileptons"
- "lepton+jets"
Event Signature and Preselection

Signal
- one isolated, high pT lepton
- Large Missing Transverse Energy (MET)
- $\geq 4$ jets

Background
- Main physics background is W+jets
- Multi-jet background

Preselection
- $\geq 4$ jets in the event with jet $p_T > 20$ GeV
- good vertex with $|z_{PV}| \leq 60$cm and at least 3 tracks attached
- Second lepton veto (orthogonal to dilepton channel)
- lepton coming from the primary vertex
  $|\Delta z(\text{lepton}, PV)| < 1$cm
- A tight isolation lepton with $p_T > 20$ GeV
- Large MET $> 20$ GeV
Estimation of Multi-jet Backgrounds

QCD multi-jet background is estimated from data
- determine by Matrix Method
- use loose and tight lepton selection
- linear equations for $N_{QCD}$ and $N_{Wjets+tt}$
- $e+$jets: $\varepsilon_{\text{sig}} \sim 0.85$, $\varepsilon_{\text{QCD}} \sim 0.18$
- $\mu+$jets: $\varepsilon_{\text{sig}} \sim 0.84$, $\varepsilon_{\text{QCD}} \sim 0.24$

The efficiency for a true isolated lepton to pass the tight lepton isolation selection

\[
N_{Wjets+\bar{t}} = \varepsilon_{\text{sig}} \frac{N_t - \varepsilon_{\text{QCD}} N_l}{\varepsilon_{\text{sig}} - \varepsilon_{\text{QCD}}}
\]

\[
N_{QCD} = \varepsilon_{\text{QCD}} \frac{\varepsilon_{\text{sig}} N_l - N_t}{\varepsilon_{\text{sig}} - \varepsilon_{\text{QCD}}}
\]

The efficiency for a fake lepton to pass the tight lepton isolation selection

\[
N_t = \varepsilon_{\text{QCD}} N_{QCD} + \varepsilon_{\text{sig}} N_{Wjets+\bar{t}}
\]
Topological Analysis

- Multivariate discriminant
  - event kinematic variables
  - Likelihood fit
- Choice of Topological variables
  - good separation power
  - correlation and sensitivity against systematic uncertainties
- Six variables are used in this analysis
  - Centrality, Aplanarity
  - $\Delta \phi (\text{lepton, MET})$, Sphericity
  - $H_T$, $K'_T\min$

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Likelihood Fit

The event information contained in the topological variables is combined in a likelihood discriminant

\[ L = \frac{\prod_i S_i}{\prod_i S_i + \prod_i B_i} \]

### e+jets channel

<table>
<thead>
<tr>
<th></th>
<th>N_{tt}</th>
<th>N_{W+jets}</th>
<th>N_{QCD}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>123.9</td>
<td>+22.4</td>
<td>+4.3</td>
</tr>
<tr>
<td></td>
<td>-21.4</td>
<td>-24.3</td>
<td>-4.2</td>
</tr>
</tbody>
</table>

### mu+jets channel

<table>
<thead>
<tr>
<th></th>
<th>N_{tt}</th>
<th>N_{W+jets}</th>
<th>N_{QCD}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100.4</td>
<td>+22.1</td>
<td>+4.3</td>
</tr>
<tr>
<td></td>
<td>-21.0</td>
<td>-25.5</td>
<td>-4.1</td>
</tr>
</tbody>
</table>

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Control Plots

4-jets events: various distributions for the data overlayed with the fit results for the combined two channels

Lepton pT

Missing Transverse Energy

Leading Jet pT

W Transverse Mass
Cross Section

\[ \sigma_{t\bar{t}} = \frac{N^{t\bar{t}}}{L \cdot Br \cdot \epsilon_{\text{presel}}} \]

\[ \sigma_{t\bar{t}}^{\text{NLO}} = 6.8 \pm 0.6 \text{ pb} \]


Table for systematic errors for only l+jets combined

<table>
<thead>
<tr>
<th>Source</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Vertex</td>
<td>+0.17 -0.16</td>
</tr>
<tr>
<td>Lepton Identification</td>
<td>±0.28</td>
</tr>
<tr>
<td>Jet Energy</td>
<td>+0.08 -0.06</td>
</tr>
<tr>
<td>Trigger</td>
<td>±0.1</td>
</tr>
<tr>
<td>W Background Model</td>
<td>±0.51</td>
</tr>
<tr>
<td>MC statistics</td>
<td>±0.27</td>
</tr>
<tr>
<td>Others</td>
<td>±0.14</td>
</tr>
<tr>
<td>Total</td>
<td>±0.7</td>
</tr>
</tbody>
</table>

l + jets: \( \sigma_{t\bar{t}} = 6.3^{+0.9}_{-0.8}\text{(stat)}^{+0.7}_{-0.7}\text{(sys)} \pm 0.4(\text{lumi}) \text{ pb} \)

e + jets: \( \sigma_{t\bar{t}} = 6.6^{+1.2}_{-1.1}\text{(stat)}^{+0.8}_{-0.8}\text{(sys)} \pm 0.4(\text{lumi}) \text{ pb} \)

\( \mu + \text{jets}: \sigma_{t\bar{t}} = 5.9^{+1.3}_{-1.2}\text{(stat)}^{+0.9}_{-0.8}\text{(sys)} \pm 0.4(\text{lumi}) \text{ pb} \)

\( \delta \sigma/\sigma = \pm 19\% \)
Conclusion

- This is the first result of top production cross section measurement for 1 fb\(^{-1}\) at DØ
- Measured cross section is agreed well with the SM prediction

- Blue band is Theoretical Cross Section

- DØ Run II

<table>
<thead>
<tr>
<th>Channel</th>
<th>Cross Section</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>dilepton/1+jets</td>
<td>230 fb(^{-1})</td>
<td>7.1 ±1.2/1.4</td>
<td>-1.2/1.1</td>
</tr>
<tr>
<td>dilepton(^{*})</td>
<td>1050 fb(^{-1})</td>
<td>6.8 ±1.2/0.9</td>
<td>-1.1/0.8</td>
</tr>
<tr>
<td>ltrack/emu(^{*})</td>
<td>370 fb(^{-1})</td>
<td>8.6 ±1.9/1.1</td>
<td>-1.7/1.1</td>
</tr>
<tr>
<td>tau+jets(^{*}) (b-tagged)</td>
<td>350 fb(^{-1})</td>
<td>5.1 ±4.3/0.7</td>
<td>-3.5/0.7</td>
</tr>
<tr>
<td>alljets (b-tagged)</td>
<td>410 fb(^{-1})</td>
<td>4.5 ±2.0/1.4</td>
<td>-1.9/1.1</td>
</tr>
<tr>
<td>l+jets (b-tagged)</td>
<td>420 fb(^{-1})</td>
<td>6.6 ±0.9/0.0</td>
<td>-0.9/0.0</td>
</tr>
<tr>
<td>l+jets(^{*}) (μ-tagged)</td>
<td>420 fb(^{-1})</td>
<td>7.3 ±2.0/0.0</td>
<td>-1.8/0.0</td>
</tr>
<tr>
<td>l+jets(^{*}) (NN b-tagged)</td>
<td>910 fb(^{-1})</td>
<td>8.3 ±0.6/0.9</td>
<td>-0.5/1.0</td>
</tr>
<tr>
<td>l+jets(^{*}) (topological)</td>
<td>910 fb(^{-1})</td>
<td>6.3 ±0.9/0.7</td>
<td>-0.8/0.7</td>
</tr>
</tbody>
</table>

- m\(_{\text{top}}\) = 175 GeV

- Cacciari et al., JHEP 0404, 068 (2004)
Preselection (Detail)

- **e+jets channel**
  - Exactly 3 or $\geq 4$ jets with $p_T > 20\text{GeV}$ and $|\eta| < 2.5$
  - one tight electron with $p_T > 20\text{GeV}$ in CC
  - no second tight electron with $p_T > 15\text{GeV}$ in CC or EC
  - no isolated muon with $p_T > 15\text{GeV}$
  - good vertex with $|z_{PV}| \leq 60\text{cm}$ with at least 3 tracks attached
  - electron coming from the primary vertex $|\Delta z(e,PV)| < 1\text{cm}$
  - $MET > 20\text{GeV}$ and $\Delta \Phi(e,MET) > 0.7*\pi - 0.045*MET$

- **mu+jets channel**
  - Exactly 3 or $\geq 4$ jets with $p_T > 20\text{GeV}$ and $|\eta| < 2.5$
  - one tight muon with $p_T > 20\text{GeV}$ with muon quality MediumNSeg3
  - invariant mass of the selection muon and any second muon $M_{\mu\mu} < 70\text{GeV}$ or $M_{\mu\mu} > 110\text{GeV}$ to reject $Z(\rightarrow \mu\mu)+\text{jets}$ events
  - no second muon with $p_T > 15\text{GeV}$ with muon quality MediumNSeg3
  - no tight electron with $p_T > 15\text{GeV}$
  - good vertex with $|z_{PV}| \leq 60\text{cm}$ with at least 3 tracks attached
  - muon coming from the primary vertex $|\Delta z(e,PV)| < 1\text{cm}$
  - $MET > 20\text{GeV}$ and $\Delta \Phi(e,MET) > 0.48*\pi - 0.033*MET$ and $W_{tmss} > 30\text{ GeV}$
Definition of Variables

- \( H_T = \sum E_T \)
- Centrality \( = \frac{H_T}{H} \)  
  \( H \) is the scalar sum of the energy of the jets
- Aplanarity \( M_{ij} = \frac{\sum_0 p^0_i p^0_j}{\sum_0 |\vec{p}^0|^2} \)  
  \( M \) is normalized momentum tensor
- Sphericity \( S = \frac{3}{2} (\lambda_2 + \lambda_3) \)  
  \( \lambda_2 \) and \( \lambda_3 \) are smallest eigenvalues of the normalized momentum tensor \( M \)
- \( K'_{T_{\text{min}}} = \frac{\Delta R_{ij}^{\text{min}} E_T^{\text{min}}}{E_T^W} \)
- \( \Delta \phi(\text{lepton}, E_T) \)
- \( \Delta R_{ij}^{\text{min}} \) corresponds to the minimum separation in \( \eta - \phi \) space between a pair of jets
- \( E_T^{\text{min}} \) is the ET of the lesser jet of that pair
- \( E_T^W = E_T^{\text{lepton}} + E_T \)
Lepton Identification

Electron

- Loose isolated electron
  - At least 90% of the energy of the cluster must be contained in the electromagnetic section of the calorimeter
  - $\chi^2$ from the $7 \times 7$ H-matrix must be less than 50
  - The energy deposition in the calorimeter must be matched with a charged particle track from the tracking detectors with $p_T > 5$ GeV
  - $(E_{\text{total}}(R < 0.5) - E_{\text{EM}}(R<0.2))/E_{\text{EM}}(R<0.2) < 0.15$

- Tight isolated electron
  - Must pass the loose isolation requirements above, and have a value of the seven-variable EM-likelihood $> 0.85$

Muon

- Loose isolation muon
  - Medium, $|\text{nseg}|=3$ quality
  - pass loose cosmic ray rejection timing
  - The track reconstructed in the muon system must match a track reconstructed in the central tracker with $\chi^2/\text{ndof} < 4$
  - $\Delta R(\text{muon, jet}) > 0.5$

- Tight isolation muon
  - require to pass Loose isolation muon selection
  - The momenta of all tracks in a cone of radius $R < 0.5$ around the muon direction, except the track matched to the muon, add up to less than 20% of the muon $p_T$
  - The energy deposited in an annular cone of radius $0.1 < R < 0.4$ around the muon direction is less than 20% of the muon $p_T$