Measurement of the Top Quark Pair Production Cross Section in the Lepton+Jets Channel using a Topological Likelihood

on behalf of the DØ Collaboration

with the DØ Detector in Run II at the Fermilab Tevatron at a center of mass energy of $\sqrt{s} = 1.96$ TeV

Tobias Golling - DPF - August 28th 2004
Overview

- Physics Motivation
- Top Quark Production and Decay
- Signature
- W+Jets Preselection
- Backgrounds
- Overview over the Analysis Method
- Topological Likelihood
- Result, Summary & Outlook
The Top Quark in the Standard Model

Why is the Top Quark so interesting?
- completes the quark sector
- large mass \( m_{\text{top}} \approx 180 \text{ GeV} / c^2 \)
- short lifetime \( \tau \approx 5 \cdot 10^{-25} \text{ s} \)
- sensitive to physics beyond the Standard Model

Discovery of the Top Quark in 1995 by the CDF and DØ Collaborations.

Top-antitop production cross section
- test of perturbative QCD
- sensitive to
  - top decays to New Physics particles (e.g. charged Higgs)
  - Physics beyond the SM decaying to top-antitop

Higgs-Boson coupling to fermions: \( \lambda_f \approx m_f \)
\( \lambda_t \approx 1 \)
Top Quark Production & Decay

Top quarks mainly produced in pairs at Tevatron

\[ \text{qq (85\%)} \quad \text{gg (15\%)} \]

Top quarks decay predominantly (\(~100\%\)) to a W-Boson and a b-quark

\[
\begin{aligned}
\text{qq} & \qquad \text{gg} \\
\text{g} & \quad \text{g} \\
\text{t} & \quad \bar{\text{t}} \\
\text{g} & \quad \text{g} \\
\text{t} & \quad \bar{\text{t}}
\end{aligned}
\]

Top-Antitop Signatures determined by the W decay modes:

`dilepton channel'
\(~5\%:~2~jets,~2~charged~leptons,~2~neutrinos\)

`lepton+jets channel'
\(~30\%:~4~jets,~1~charged~lepton,~1~neutrino\)

`all-jets channel'
\(~40\%:~6~jets\)

always 2 jets are b-jets
Signature - W+Jets Preselection

Hard scatter primary vertex

Isolated high $p_T$ lepton

Neutrino reconstructed as missing transverse energy

$\geq 4$ jets with $p_T > 15$ GeV and $|\eta| < 2.5$
Physics Background:
Electroweak W production
- $W \rightarrow \ell^+ \nu_{\ell}$
- additional $\geq 4$ jets from ISR

Instrumental Background (fake lepton, fake MET):
QCD multijet production

Electron Fakes:
Electrons faked by (electromagnetic) jets

Muon Fakes:
Muon-fakes are real muons which are fakely isolated
(muons from semileptonic b-decays, where the b-jet is not reconstructed)

MET Fakes:
Misreconstructed calorimeter energy
→ Determine instrumental QCD multijet background purely from data

\[ N_{\text{loose}} = N_{\text{QCD}} + N_{W+ttbar} \]

\[ \epsilon_{\text{QCD}} = 8\% \quad \epsilon_{W+ttbar} = 82\% \]

\[ N_{\text{tight}} = \epsilon_{\text{QCD}} \times N_{\text{QCD}} + \epsilon_{W+ttbar} \times N_{W+ttbar} \]

→ Solve linear system of equations for \( N_{\text{QCD}} \) and \( N_{W+ttbar} \)
Topological Analysis Overview

- **QCD**
  - **W+jets**
    - loose $W$ selection + $\geq 4$ jets
    - tight $W$ selection + $\geq 4$ jets

- **tt**

Combine topological event information in a likelihood discriminant, and perform a fit to the data.
Define variables which describe the event topology

Criteria:
- Good separation power
- Low sensitivity to the jet energy scale
  (dominant systematic uncertainty)

Jets:
- high-energetic
- isotropic

Jets dominated by QCD-Bremsstrahlung:
- low-energetic
  - in the forward region
Variables describing the angular distributions of the physics objects in the final state:

- **Sphericity**
- **Aplanarity**

Ratios of energy dependent variables:

- $H_{T2}'$ (describes centrality)
- $K_{T_{min}}' (= \Delta R_{\min} (\text{jet,jet}) \cdot E_{T_{\min}}/E_{T_{W}})$
Likelihood Discriminant (LD)

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

- \( S_i \) = ttbar signal
- \( B_i \) = W+jets background
- \( i \) runs over the 4 topological variables

- Describe data by a linear combination of ttbar, W+4jet and multijet (QCD)
- Constrain QCD by using the loose and tight system of equations
- Fit the relative fractions
Fit linear combination of QCD (inverted tight selection in data), W+4jet and ttbar to data

**Likelihood Fits for $\mu$+Jets & e+Jets**

- **μ+jets**
  - $L=144\,pb^{-1}$
  - Data points
  - Fitted ttbar
  - Fitted W+jets
  - Fitted QCD

- **e+jets**
  - $L=141\,pb^{-1}$
  - Data points
  - Fitted ttbar
  - Fitted W+jets
  - Fitted QCD

<table>
<thead>
<tr>
<th></th>
<th>muons</th>
<th>electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nev</td>
<td>100</td>
<td>136</td>
</tr>
<tr>
<td>fitted $N^W$</td>
<td>74.7 + 12.7 - 12.0</td>
<td>94.6 + 15.8 - 15.0</td>
</tr>
<tr>
<td>fitted $N^{9CD}$</td>
<td>7.1 + 0.9 - 0.9</td>
<td>14.1 + 1.2 - 1.2</td>
</tr>
<tr>
<td>fitted $N^{tt}$</td>
<td>17.8 + 9.9 - 8.7</td>
<td>27.5 + 12.7 - 11.7</td>
</tr>
</tbody>
</table>
Kinematic Distributions

**e+jets**

- Data
- Fitted ttbar
- Fitted W+jets
- Fitted QCD

*Variables:*
- $p_T$ (leading jet) [GeV/c]
- Jet $\tau$
- Missing $E_T$ [GeV]

**μ+jets**

- Data
- Fitted ttbar
- Fitted W+jets
- Fitted QCD

*Variables:*
- Sphericity
- W transverse mass [GeV]
- Aplanarity
Result

Comparison with Run I & Summer 03

\[
\sigma^{e+jets}_{p \bar{p} \rightarrow t \bar{t} + X} = 8.8^{+4.1}_{-3.7} (\text{stat})^{+1.6}_{-2.1} (\text{syst}) \pm 0.6 (\text{lumi}) \text{ pb}
\]

\[
\sigma^{\mu+jets}_{p \bar{p} \rightarrow t \bar{t} + X} = 6.0^{+3.4}_{-3.0} (\text{stat})^{+1.6}_{-1.6} (\text{syst}) \pm 0.4 (\text{lumi}) \text{ pb}
\]

\[
\sigma^{l+jets}_{p \bar{p} \rightarrow t \bar{t} + X} = 7.2^{+2.6}_{-2.4} (\text{stat})^{+1.6}_{-1.7} (\text{syst}) \pm 0.5 (\text{lumi}) \text{ pb}
\]

Integrated Luminosity = 143 pb\(^{-1}\)

Dominant uncertainties:
- Jet energy scale
- Jet reconstruction efficiency
**Summary & Outlook**

**DØ Run II Preliminary**

- e$^+$+jets (topological)
  - Summer 03
- $\mu$+jets (topological)
  - Summer 03
- lepton+jets (topological)
  - Summer 03

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**Summer 03 → NOW:**
Large improvement in statistical and systematic uncertainties

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**Outlook:**
- Publication this fall
- $L = 230 \text{ pb}^{-1}$
- Improved systematics