American Physical Society April Meeting 2005

Measurement of the Top Pair Production Cross Section in the Electron + Jets Channel at DØ using Topological Information

\[ \bar{t}t \rightarrow Wb \ Wb \rightarrow e\nu \ + \ \text{jets} \]

Outline
- Overview of the Electron+jets topological analysis
- Event selection and signal extraction
- Results and outlooks
Top pair production

At Tevatron RunII, 1.96 TeV in proton/anti-proton center of mass

• Quark anihilation : 85%

• Gluon fusion : 15%

Production cross section prediction

6.7 ± 0.8 pb
under top mass=175GeV assumption
(hep-ph/0303085)

This measurement is a test of perturbative QCD calculations. Mandatory at the Tevatron and at the LHC.

Probe for non SM-production of Top quark pair
Top quark pair decay

Assuming 100% SM electroweak decay of the top quark observation channel classification driven by $W$ decay

$W$ decays
- $W \rightarrow \text{lepton} + \text{neutrino} : 11\%$
- $W \rightarrow \bar{q}q : 67\%$

Electron+jets signature

- Large missing transverse energy
- High pt electron
- At least four jets
  - Possible $b$ flavor of jet not used

$\text{BR}(e+\text{jets}) = 17.106\%$

$W \rightarrow \tau \rightarrow \text{electron} \text{ decay included.}$

- Deviation due to SM branching ratio would indicate possible new Top decays
- Basic signature of Top quark pair decay in $e+\text{jets}$ makes Top pair production a physical background to many more rare signals. Accurate cross section measurement is needed.
Physics background

- Mainly $W(\nu)+$jets,
- Small contribution of $Z(\ell\ell)+$jets and ttbar-$\rightarrow$ dilelectron channel

In $W/Z+$jets events, jets are produced from the ISR

- Different topology compare to Top pair decay. $W+$jets is
  - Less central and spherical
  - More forward and coplanar
  - Softer jet spectrum ($H_T$)
  - Electron and neutrino are back to back

We choose 6 discriminating topological variables
Instrumental background

- QCD multijets with an electromagnetic jet faking an electron and mismeasured missing energy or semileptonic decay in b-jets

  ➔ Measured precisely an data
  ➔ Modeled from data itself

Analysis overall strategy

- select W leptonic decays and reduce most of the QCD background while favouring the signal
- Use topological information and QCD background estimation to disentangle W+jets, QCD and signal
Data Selection

Trigger

- An electron and at least one jet

  Good electron
  - Acceptance and kinematics
    - $|\eta|<1.1$
    - $p_T>20\text{GeV}$
  - Matched to trigger object
  - Loose and tight Electron ID

At least 4 Good jets
- 0.5 jet cone
- Acceptance and kinematics
  - $|\eta|<2.5$
  - $p_T>20\text{GeV}$

Primary vertex
- Good primary vertex quality
- Electron track from PV

Neutrino
- Missing transverse energy larger than 20 GeV
- $\Delta\phi(\text{electron,MET})>2.2(1-\text{MET}/48.9)$

Orthogonality veto
- Second hard electron veto
- Hard muon veto

Overall preselection efficiency on $e+\text{jets}$ signal is
$$\epsilon_{\text{ttbar}} = 10.19\%$$
including data/simulation scale factors under top mass=175 GeV assumption
Sample composition

Matrix Method
Estimate numbers of fake and true electron events knowing loose to tight efficiencies for
- fake electron: $\epsilon_{QCD}$ measured on data
- true electron: $\epsilon_{signal}$ measured using data and MC

$$N_\ell = N_{W+t\bar{t}}^{W+tt} + N_{QCD}^{QCD}$$
$$N_t = \epsilon_{signal}N_{W+t\bar{t}}^{W+tt} + \epsilon_{QCD}N_{QCD}^{QCD}$$

Analysis final samples
- 261 loose
  - QCD events : 132
  - W+jets and e+jets signal : 129
- 125 tight
  - QCD events : 21
  - W+jets and e+jets signal : 104
Topological discriminant

**Principle**
Disentangle signal and background based on event topology criteria. Build a discriminant variable on 6 topological variables.

- \( H_T \) : scalar sum of Jet pT
- Centrality = \( H_T / H \) : \( H \) = scalar sum of jet E
- Sphericity

**We use the 6 topological variables**
- Aplanarity
- \( \Delta \text{electron,MET} \)
- \( K_{\text{min}} \) : minimum jet pT relative to closest other jet

Z(ee)+jets, W(\( \nu \))\( \gamma \)+jets and QCD events have similar topology because of similar jet production (same distribution observed)

- Use only a 2 class likelihood

**Calculate the likelihood probability event by event**

\[
\mathcal{L} = \frac{\exp \left( \sum_i \left( \ln \frac{S_B}{S} \right)_fitted^i \right)}{\exp \left( \sum_i \left( \ln \frac{S_B}{S} \right)_fitted^i \right) + 1}
\]
Signal extraction

Likelihood maximisation

- Parameters: $N_{QCD}$, $N_{\text{signal}}$, $N_{W}$
- QCD estimation likelihood
- Topological discriminant distribution likelihood
  - Signal template from Monte Carlo
  - $W + \text{jets}$ template from Monte Carlo
  - QCD template from data

Control plots

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Results

Result with 226 pb$^{-1}$

\[ \sigma_{\bar{p}p \rightarrow t\bar{t} + X} = 8.2^{+2.1}_{-1.9} \text{ (stat)} +^{1.9}_{-1.3} \text{ (syst)} \pm 0.5 \text{ (lumi) pb.} \]

in collaboration review for publication

Preliminary result with 366 pb$^{-1}$

\[ \sigma_{\bar{p}p \rightarrow t\bar{t} + X} = 9.0^{+2.0}_{-1.9} \text{ (stat)} +^{1.7}_{-1.1} \text{ (syst)} \pm 0.6 \text{ (lumi) pb.} \]

● Work in progress on the analysis update

• 62% more data
  ➔ Statistical error from 25% to 21%
• Improved knowledge of Jet Energy Scale
  ➔ Systematic uncertainty from 23% to 18%

Agrees with the standard model prediction

Systematic uncertainties
  ➔ Jet Energy Scale ~15%
  ➔ Jet identification ~7%
  ➔ Jet Energy Resolution ~4%
  ➔ QCD sample ~4%
  ➔ Electron reconstruction ~3%
  ➔ W modelling ~2%
Conclusion and outlooks

• Cross section measurement with 226 pb$^{-1}$ dataset under final collaboration review for publication in combination with muon+jets

• Result in agreement with Standard Model

• Analysis update in progress with 366 pb$^{-1}$ dataset is promising
  ➢ Consistent with Standard Model
  ➢ More data, reduced systematics
  ➢ Ongoing effort to improve the measurement
Backup Slides
1st May 2004 192562-23395572

- Topological D = 96%
- 4 good jets
- MET of 76 GeV
- Tight electron with pT=24 GeV
11th May 2003 176843-30412438

- Topological $D = 96\%$
- 4 good jets
- MET of 79 GeV
- Tight electron with $p_T=22$ GeV
29th March 2004 191281-17809269

- Topological $D = 97\%$
- 5 good jets
- MET of 87 GeV
- Tight electron with $p_T=41\text{GeV}$
Dataset

Run II Integrated Luminosity  
19 April 2002 - 23 August 2004

480 pb\(^{-1}\) delivered
366 pb\(^{-1}\) good

~2500 Top pairs

Delivered
Recorded
Signal extraction

Principle
Disentangle signal and background on event topology criteria. Build a discriminant variable on 6 topological variables and fit signal, W and QCD templates to data distribution, taking QCD estimation into account.

Topological variables

- Only jets
  - Centrality = $H_T/H$ : top event are more central
  - Sphericity : decay chain of top event are spherical
  - $H_T$ : larger for top event

- Jets and electron
  - Aplanarity : decay chain of top event are not planar
  - (lepton,MET) : $W$ polarisation in top decay, lepton \perp MET
  - $K_{T_{\text{min}}}$ : min jet $p_T$ relative to closest jet
Topological variables

- Transform to less statistical sensitive variable $\ln (H_1)$, $\exp(-11A)$, ...

- Fit $\ln(S/B) = \ln(\text{ttbar}/W)$

- Event by event, calculate the value of the discriminant variable

$$L = \frac{\exp \left( \sum_i \ln \frac{S_i}{B_i}^{\text{fitted}} \right)}{\exp \left( \sum_i \ln \frac{S_i}{B_i}^{\text{fitted}} \right) + 1}$$
Topological discriminant

- Z(\(\ell\ell\))+jets, W(\(\ell\nu\))+jets and QCD events have similar topology
  (same topological variable distribution observed)
  - Same shape
- Dilepton and lepton+jets templates
  - Mix signal and dilepton template

Used templates
- \(\bar{t}t\) (dilepton)
- W+jets
- QCD
Expected systematics

• Ensemble testing
  – Randomize component fractions
    • Poissonize expected signal estimated with 7pb assumption
    • Poissonize expected QCD estimated with matrix method
    • Poissonize expected W
  – Use signal (no dilepton), QCD, W templates to generate pseudo data and fit it
  – Repeat N times and get the peak probability value

• Source of systematics investigated
  – Jet energy scale variation
  – Jet energy resolution
  – Jet reco*ID variation
  – W modeling, factorisation scale $Q^2 = \langle p_{Tj} \rangle^2$ instead of $Q^2 = M_W^2 + \sum p_{Tj}^2$
Systematics

- Dominant systematics
  - Jet energy scale
  - W modeling
  - Template statistics: dominated by QCD template
  - Jet reconstruction

- Other source
  - Jet energy resolution
  - Scale factors
  - Trigger efficiency
  - Monte Carlo statistics
  - $\epsilon_{QCD}, \epsilon_{\text{sig}}$
  - Dilepton background
Expected systematics

- Compare to the observed systematics (vertical line)
- Quote the expected systematics in preliminary results

*Plots from the electron channel

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Jets variables

4th jet bin
Electron variables

Jets variables

2nd jet bin
# Preselected samples

<table>
<thead>
<tr>
<th>( N_{\text{jet}} )</th>
<th>( N_l )</th>
<th>( N_t )</th>
<th>( f_l^{QCD} )</th>
<th>( \varepsilon_{QCD}^{\text{weighted}} )</th>
<th>( N_t^{QCD} )</th>
<th>( N_t^{l+t+W} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_{\text{jet}} = 1 )</td>
<td>7527</td>
<td>4898</td>
<td>0.488 ± 0.008</td>
<td>0.150 ± 0.004</td>
<td>230.8 ± 11.3</td>
<td>13489.7 ± 169.4</td>
</tr>
<tr>
<td></td>
<td>10202</td>
<td>7462</td>
<td>0.427 ± 0.008</td>
<td></td>
<td>325.8 ± 23.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2348</td>
<td>1745</td>
<td>0.086 ± 0.004</td>
<td></td>
<td>58.8 ± 8.5</td>
<td></td>
</tr>
<tr>
<td>( N_{\text{jet}} = 2 )</td>
<td>2113</td>
<td>1072</td>
<td>0.434 ± 0.010</td>
<td>0.154 ± 0.005</td>
<td>112.5 ± 5.0</td>
<td>2995.2 ± 64.9</td>
</tr>
<tr>
<td></td>
<td>3006</td>
<td>1859</td>
<td>0.457 ± 0.011</td>
<td></td>
<td>191.3 ± 10.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>681</td>
<td>409</td>
<td>0.109 ± 0.007</td>
<td></td>
<td>40.9 ± 4.3</td>
<td></td>
</tr>
<tr>
<td>( N_{\text{jet}} = 3 )</td>
<td>435</td>
<td>166</td>
<td>0.485 ± 0.021</td>
<td>0.150 ± 0.006</td>
<td>31.7 ± 2.3</td>
<td>474.1 ± 26.8</td>
</tr>
<tr>
<td></td>
<td>565</td>
<td>320</td>
<td>0.414 ± 0.021</td>
<td></td>
<td>43.6 ± 4.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>133</td>
<td>73</td>
<td>0.101 ± 0.013</td>
<td></td>
<td>9.6 ± 1.7</td>
<td></td>
</tr>
<tr>
<td>( N_{\text{jet}} \geq 4 )</td>
<td>97</td>
<td>44</td>
<td>0.375 ± 0.042</td>
<td>0.159 ± 0.011</td>
<td>5.8 ± 1.0</td>
<td>103.9 ± 12.0</td>
</tr>
<tr>
<td></td>
<td>135</td>
<td>62</td>
<td>0.572 ± 0.043</td>
<td></td>
<td>14.2 ± 2.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>19</td>
<td>0.053 ± 0.019</td>
<td></td>
<td>1.2 ± 0.7</td>
<td></td>
</tr>
</tbody>
</table>

Preselected tight in fourth jet bin
261 loose, 125 tight
QCD estimation

Using the so called 'Matrix Method'

- Efficiency for W loose lepton to pass tight requirement: \( \varepsilon_{\text{sig}} \)
  - Evaluated on W+jets MC and are scale factor applied
- Efficiency for QCD fake lepton to pass tight requirement: \( \varepsilon_{QCD} \)
  - Evaluated on Data after preselection with MET<10GeV to suppress W and signal contribution
- Solve the 2x2 linear system in number of loose and tight events of W, ttbar and QCD events

\[
\begin{align*}
N_\ell &= N_{W+t\bar{t}} + N_{QCD} \\
N_t &= \varepsilon_{\text{sig}} N_{W+t\bar{t}} + \varepsilon_{QCD} N_{QCD}
\end{align*}
\]

\[
\begin{align*}
N_{QCD} &= \frac{\varepsilon_{\text{sig}} N_\ell - N_t}{\varepsilon_{\text{sig}} - \varepsilon_{QCD}} \\
N_{W+t\bar{t}} &= \frac{N_t - \varepsilon_{QCD} N_\ell}{\varepsilon_{\text{sig}} - \varepsilon_{QCD}}
\end{align*}
\]

Electron channel

\( \varepsilon_{\text{sig}} = 81\% \)
\( \varepsilon_{QCD} = 16\% \)