Measurement of the Mass of the Top Quark in the $l+ Jets$ Channel Using the Matrix Element Method

Carlos Garcia
University of Rochester

For the DØ Collaboration

APS Meeting
2007
Outline

Introduction
Top quark at the Tevatron.

The Matrix Element Method
Basics of the method used.

Top Quark Mass Measurement in the $l+\text{Jets}$ Channel
Results from the 900 pb$^{-1}$ of data.
Top Quark

At the Tevatron, top quarks are primarily produced in pairs via the strong interaction. Since $|V_{tb}| \sim 1$, the top quark almost always decays to $Wb$ ($Ws, Wd$ CKM suppressed)

Event topology depends on the $W$ decay mode

Experimental signature in the lepton+jets channel:
- 1 high $p_T$ lepton
- 4 jets (2 $b$-jets)
- large $E_T^{mis}$
Top Quark Identification

Background Processes:

- Exactly 4 Calorimeter Jets
  \( p_T > 20 \text{ GeV} \)
  \( |\eta| < 2.5 \)
- Isolated Lepton
  \( p_T > 20 \text{ GeV} \)
  \( |\eta^e| < 1.1, \quad |\eta^\mu| < 2.0 \)
- Missing Transverse Energy
  \( E_T^{\text{mis}} > 20 \text{ GeV} \)

W+jets production.

Multi-jet events:
  leading to fake or mis-characterized lepton
  and fake missing transverse energy

Carlos Garcia – University of Rochester
We calculate a probability per event to be signal or background as a function of the top mass and the Jet Energy Scale (JES). If we had all the parton level information 'y' this probability would be just proportional to the differential cross section. In reality is a bit more complicated:

\[
P_{\bar{t}t}(x; m_{top}, JES) = \frac{1}{\sigma(m_{top})} \int dq_1 dq_2 f(q) f(\bar{q}) d\sigma(y; m_{top}) Prob(x, y, JES)
\]

**Differential cross section**, based on LO Matrix Element \( q\bar{q} \rightarrow \bar{t}t \) only

**Transfer Function:** probability to measure \( x \), when parton-level \( y \) was produced.

**Initial state**

**Normalization:**

Overall JES is a free parameter in the fit, constrained in situ by the mass of the W decaying hadronically

Background probability is conceptually the same but flat in \( m_{top} \) and \( JES \).
**b-tagging:**
Weight each jet to parton assignment with b-tagging probabilities.

24 possible weighted assignments between jets and partons

\[ P_{t \bar{t}}^{N \text{-tag}}(x; m_{\text{top}}, \text{JES}) = \sum_{c=1;24} W_{c}^{t \bar{t}} P_{c}^{t \bar{t}}(x; m_{\text{top}}, \text{JES}) \]

If jet J was tagged:
\[ W_{c}^{t \bar{t}} = \prod_{J=1;4} p_{J} \]

If jet J was not tagged:
\[ p_{J} = \epsilon_{J}(\text{flavor}, \eta, p_{T}) \]
\[ p_{J} = 1 - \epsilon_{J}(\text{flavor}, \eta, p_{T}) \]
To use an external constraint in $JES$ we convoluted the original likelihood with the measure in the $\text{photon + Jet}$ sample which is represented as a Gaussian likelihood centred at $JES = 1$ with a width of 3.7% (this width is estimated from ttbar MC sample).

$$P (x;m_{top},JES) = P_{\text{comb}} (x;m_{top},JES) G(JES)$$
Before applying to data, the method is calibrated for shifts in the mean and uncertainties using ensemble tests on simulated MC events.
### Data Result

**Data Sample**

**Electrons channel** (971 pb⁻¹): 249 events (28% purity)
- 173 events in 0 Tags
- 57 events in 1 Tag
- 19 events in 2 Tags

**Muons channel** (813 pb⁻¹): 255 events (25% purity)
- 163 events in 0 Tags
- 70 events in 1 Tag
- 22 events in 2 Tags
Data Result

Result combining $0 + 1 + 2$ Tags, Calibrated

$m + \text{jets}$

$M_{\text{top}} = (170.5 \pm 3.6) \text{ (stat.) GeV}$

$e + \text{jets}$

$M_{\text{top}} = (170.5 \pm 3.3) \text{ (stat.) GeV}$

$l + \text{jets}$: $M_{\text{top}} = 170.5 \pm 2.4 \text{ (stat. + JES) GeV}$
**Data Result**

**Result combining 0 + 1 + 2 Tags, Calibrated**

**Calibrated error in 1+jets**

- Mean: 3.128
- RMS: 0.4533

**1 + jets**

- **2.4**

**Most Significant Systematic Errors**

<table>
<thead>
<tr>
<th>Source</th>
<th>(+)</th>
<th>(-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal modeling</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>b fragmentation model</td>
<td>0.54</td>
<td>0.54</td>
</tr>
<tr>
<td>b/l ratio (1.5%)</td>
<td>0.57</td>
<td>0.57</td>
</tr>
<tr>
<td>JES pt dependence</td>
<td>0.23</td>
<td>0.23</td>
</tr>
<tr>
<td>TRF-Tagging MC</td>
<td>0.29</td>
<td>0.29</td>
</tr>
<tr>
<td>Signal fraction</td>
<td>0.53</td>
<td>0.24</td>
</tr>
<tr>
<td>QCD Contamination</td>
<td>0.21</td>
<td>0.21</td>
</tr>
</tbody>
</table>

**I + jets:**

\[ M_{top} = 170.5 \pm ^{2.4 \text{ stat.} + JES}_{1.1 \text{ syst.}} \text{GeV} \]
Top Mass Current Status

Impact on Standard Model Higgs boson:

\[ M_H = 76^{+33}_{-24} \text{GeV}; \quad M_H < 144 \text{GeV}@95CL \]
CONCLUSIONS
D0 Run II Preliminary result for 0+1+2 Tags from 900 pb$^{-1}$:

$$M_{top} = 170.5 \pm 2.4 \text{ (stat. + JES) } \pm 1.2 \text{ (syst.) GeV}$$

A new improved measurement of the top quark mass allow us to reach the 1% precision (Combined DØ + CDF measurement).

The precise measurement of top quark mass helps constrain the mass of the SM Higgs boson, and it is one of the most important measurements at the Tevatron.
RESULT + PRIOR

Combined 0 + 1 + 2 Tag analysis, Calibrated + Prior

JES = (1.037 ± 0.020) (stat.)

871 pb⁻¹
0+1+2 Tags
255 Events

m + jets

JES = 1.032 ± 0.014 (stat.)

913 pb⁻¹
0+1+2 Tags
249 Events

e + jets

l + jets: 

\[ JES = 1.032 ± \frac{0.014}{0.014} \text{ (stat.)} \]
<table>
<thead>
<tr>
<th>Error Source</th>
<th>up(+)</th>
<th>down(-)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physics modeling:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal modeling</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>b fragmentation model</td>
<td>0.54</td>
<td>0.54</td>
</tr>
<tr>
<td>PDF uncertainty</td>
<td>0.16</td>
<td>0.39</td>
</tr>
<tr>
<td>Background modeling</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>b/c semileptonic decay</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Detector Modeling</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b/l ratio (1.5%)</td>
<td>0.57</td>
<td>0.57</td>
</tr>
<tr>
<td>JES pt dependence</td>
<td>0.23</td>
<td>0.23</td>
</tr>
<tr>
<td>Trigger</td>
<td>0.08</td>
<td>0.13</td>
</tr>
<tr>
<td><strong>b tagging</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRF-Tagging MC</td>
<td>0.29</td>
<td>0.29</td>
</tr>
<tr>
<td>TRF (signal)</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>TRF (background)</td>
<td>0.03</td>
<td>0.06</td>
</tr>
<tr>
<td><strong>Method:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal fraction</td>
<td>0.53</td>
<td>0.24</td>
</tr>
<tr>
<td>QCD contamination</td>
<td>0.21</td>
<td>0.21</td>
</tr>
<tr>
<td>MC calibration mass</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>MC calibration JES</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Total Systematic Errors</strong></td>
<td>1.159956896</td>
<td>1.123343224</td>
</tr>
<tr>
<td><strong>Total Errors (Stat.+JES+Sys.)</strong></td>
<td>2.665614376</td>
<td>2.64988679</td>
</tr>
</tbody>
</table>
DATA

2D likelihood before calibration. Each color represents one sigma. After projection in the two dimensions we apply the calibration curves and adjust the errors using the final pulls.

**Electrons channel**

**Muons channel**
The Ensembles

Example of composition and fluctuations in the ensembles (inputs). Electrons channel composition:
251 events 27.6% purity.
Below are the purities for the different Tag samples.

- 0 TAG: 10%
- 1 TAG: 69%
- 2 TAG: 92%

**Untagged:** 27.5%
JES Calibration

JES Calibration for Muons

0+1+2 Tags

\[ \text{Slope} = (1.11 \pm 0.02) \text{ GeV} \]
\[ \text{Offset} = (-0.014 \pm 0.001) \text{ GeV} \]

JES Calibration for Electrons

0+1+2 Tags

\[ \text{Slope} = (1.12 \pm 0.02) \text{ GeV} \]
\[ \text{Offset} = (-0.020 \pm 0.001) \text{ GeV} \]
Combined $0 + 1 + 2$ Tag analysis - Calibrated

$m + \text{jets}$

$JES = (1.052 \pm 0.023) \text{ (stat.)}$

$JES = 1.046 \pm 0.017 \text{ (stat.)}$

$e + \text{jets}$

$L + \text{jets}$: $JES = 1.046 \pm 0.017 \text{ (stat.)}$
**DATA RESULT**

**Combined 0 + 1 + 2 Tag analysis - Calibrated**

\[ M_{\text{top}} = (169.0 \pm \frac{3.9}{3.9}) \text{ (stat.) GeV} \]

- **m + jets**
  - 871 pb\(^{-1}\)
  - 0+1+2 Tags
  - 255 Events

- **e + jets**
  - 913 pb\(^{-1}\)
  - 0+1+2 Tags
  - 249 Events

**l + jets:**

\[ M_{\text{top}} = 169.2 \pm \frac{2.7}{2.7} \text{ (stat. + JES)} \]
Combined 0 +1 + 2 Tag analysis - Calibrated

\[ M_{\text{top}} = 169.2 \pm 2.7 \text{ (stat. + JES)GeV} \]
The DZero Detector and the Tevatron

Tracking:
- Silicon vertex detector (SMT)
- Central Fiber Tracker (CFT)
- 2 T Superconducting Solenoid. $|\eta| < 2.5$

Preshowers

EM/HAD Calorimeter:
- Central, $|\eta| < 1.1$
- Forward, $|\eta| < 4.2$

Muon system:
- 1.8 T iron toroids. $|\eta| < 2.0$

3-Level trigger system:
- Level 1 (hardware): 2 kHz
- Level 2 (hardware): 1 kHz
- Level 3 (software): 50 Hz

Carlos Garcia – University of Rochester