Measurement of the Top Quark Mass in the Dilepton Channel with the Matrix Element Method

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Outline

- The Tevatron and the D0 Detector
- Top Quark Production and Decay
- The Matrix Element Method
- Validation
- Calibration
- Application to Data
- Conclusion
The Tevatron

Run I (1992 - 1996):

\[ E_{cm} = 1.8 \text{ TeV}, \quad \int L \, dt = 0.1 \text{ fb}^{-1} \]

Run IIa (1996 - 2006):

\[ E_{cm} = 1.96 \text{ TeV}, \quad \int L \, dt = 1.1 \text{ fb}^{-1} \]

Average data-taking efficiency: ~85%

Run IIa:

~1.1 fb\(^{-1}\) of recorded luminosity

DØ Upgrade

19 April 2002 - 30 March 2008
The D0 Detector

“standard” collider detector configuration

- silicon microvertex and tracking detector within solenoid of ~ 2 T
- LAr calorimeter:
  - high granularity
  - good resolution
- muon chambers:
  - large coverage (|\eta| < 2.0)

coordinates:

r, \phi, \eta = -\ln(\tan \theta / 2)
Top Quark Production and Decay

- mainly via ttbar pairs (strong interaction)
  - 85% qqbar annihilation (5% @LHC)
  - 15% gg fusion (95% @LHC)
  - cross section: ~7 pb (800pb @LHC)

- top decays to almost 100% in W and b

- branching ratios W
  - $W \Rightarrow u,d,s,c: \sim 2/3$
  - $W \Rightarrow l\nu: \sim 1/3$
Final States

- all jets (44%)
  - huge background, largest branching ratio
- lepton+jets (30%)
  - less background, good statistic
- dilepton (5%)
  - smallest background, smallest ratio

Top Pair Decay Channels

<table>
<thead>
<tr>
<th></th>
<th>electron+jets</th>
<th>muon+jets</th>
<th>tau+jets</th>
<th>all-hadronic</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}$</td>
<td>e$^-$</td>
<td>$\mu^+$</td>
<td>$\tau^+$</td>
<td>Tau+jets</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>$e^+$</td>
<td>$\mu^-$</td>
<td>$\tau^-$</td>
<td>Muon+jets</td>
</tr>
<tr>
<td>$t\bar{t}$</td>
<td>e$^-$</td>
<td>$\mu^-$</td>
<td>$\tau^-$</td>
<td>Electron+jets</td>
</tr>
<tr>
<td>$W$ decay</td>
<td>$e^+$</td>
<td>$\mu^+$</td>
<td>$\tau^+$</td>
<td>$u\bar{d}$</td>
</tr>
</tbody>
</table>

**dilepton signature:**

- 2 energetic b jets
- 2 energetic isolated leptons
- missing transverse energy due to the undetected neutrinos
calculate for each event the probability to be produced via the signal process under the assumption of a certain top mass:

\[
P_{ti}(x, m_{top}) = \frac{1}{\sigma_{obs}} \int_{q_1q_2y} dq_1 dq_2 dy \sum_{\text{flavor}} f_{PDF}(q_1) f_{PDF}(q_2) \frac{(2\pi)^4|M_{ti}|^2}{q_1 q_2 s} W(x, y)
\]

\(x:\text{measured momenta, } y:\text{parton momenta, } W(x, y)\text{Transfer Functions}\)

calculate in a similar way the main background probability \((Z+jj)\) for each event

fit top mass from likelihood of the combined event probabilities

\[
P_{evt}(x, m_{top}) = f_{top} P_{ti}(x, m_{top}) + (1 - f_{top}) P_{Z+jj}(x)
\]

more details can be found in Phys. Rev. D 74 092005
Validation of the Method

**parton level tests:**

- use **Monte Carlo** events that **fulfill** exactly the assumptions made in the probability calculation
- **smear** MC according to **transfer functions** (jets, muons)
- **test** of different **parameters** (resolution, background probabilities,...)
- example shown on the next slide:
  - check method for **different** input top **masses**
  - 160, 165, 170, 175, 180 GeV
  - and the **jet resolution**
top mass and pull for the central sample of 170 GeV in the case of signal only events with smeared jets

top mass and pull width for all top mass points in the case of signal only events with smeared jets

\[ \text{pull} = \frac{m_{\text{top}}^\text{meas} - m_{\text{top}}^\text{gen}}{\sigma m_{\text{top}}} \]
**MC Samples and Data**

- same event selection used for this analysis as for the cross section measurements in the dilepton channel (talk by M. Arthaud J12 2)

- MC samples:
  - Alpgen: ttbar, Z+jj
  - Pythia: WW,WZ,ZZ

- Data collected between April 2002 and March 2006 corresponding to $L = 1071 \text{ pb}^{-1}$

- (cross section analysis in the dimuon channel not yet finalized: only electron/muon and dielectron channel included so far)

<table>
<thead>
<tr>
<th></th>
<th>eμ</th>
<th>Z→μμ→eμ</th>
<th>WW/WZ</th>
<th>Total(incl. QCD)</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>35.5+1.6-1.7</td>
<td>5.24+0.6-0.8</td>
<td>1.5+0.3-0.3</td>
<td>44.8+2.0-2.3</td>
<td>39</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>ee</th>
<th>Z→μμ→ee</th>
<th>Z→ee</th>
<th>WW/WZ/ZZ</th>
<th>Total(incl. QCD)</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11.4+0.1-0.1</td>
<td>0.8+0.1-0.1</td>
<td>1.3+0.2-0.2</td>
<td>0.50+0.05-0.05</td>
<td>14.6+0.3-0.3</td>
<td>17</td>
</tr>
</tbody>
</table>
Calibration Curve

- calibration curve and pull distribution for the combined electron/muon and dielectron channel using fully simulated MC events
- sample composition according to cross section measurements

**pull** = \( \frac{m_{\text{top \, meas}} - m_{\text{top \, gen}}}{\sigma m_{\text{top}}} \)
Application to Data

- calibrated result:
  \[ m_{\text{top}}^{\text{cal}} = 173.4 \pm 5.0 \text{ GeV (stat.)} \]

- expected statistical uncertainty from MC after calibration:
  \[ \sigma m_{\text{top}}^{\text{cal}} = 4.8 \text{ GeV} \]

- main systematic errors:
  - jet energy scale:
    \[ +2.0 \text{ GeV} / -1.8 \text{ GeV} \]
  - jet energy scale for b jets

\[ m_{\text{top}} = 174.3 \pm 3.4 \text{ GeV} \]

\[ \text{-ln L} \]

\[ m_{\text{top}} [\text{GeV}] \]

\[ \text{Number of Ensembles} \]

\[ \Delta m [\text{GeV}] \]

Entries 999
Mean 3.255
RMS 0.4149
Conclusion

- first measurement of the top mass in the dilepton channel using the matrix element method at D0

- combined result from electron/muon and dielectron channel
  \[ m_{\text{top}} = 173.4^{+5.0}_{-5.0} \text{ GeV (stat.)} \]

- expected uncertainty so far \(~25\%\) smaller than expected uncertainty using template based methods

- result from muon channel will be added as soon as the cross section measurement is updated

- combination of all top mass measurements in the dilepton channel planned for publication
Back-Up Slides
Muon Resolution and Background Events

Top mass and pull for the central sample of 170 GeV in the case of signal only events with smeared jets and muons.

Top mass and pull width for the central sample of 170 GeV using both signal and background events and probabilities.

$$\text{pull} = \frac{m_{\text{top}}^{\text{meas}} - m_{\text{top}}^{\text{gen}}}{\sigma m_{\text{top}}}$$