DØ RunII
Top Mass Measurement
with the
Matrix Element Method

for the DØ collaboration

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Tevatron: Run II

Fermilab
Chicago

$p \rightarrow \bar{p}$

$\sqrt{s} = 1.96\text{TeV}$

Tevatron

Main Injector & Recycler
Top Quark Physics

**Production:**
- pair production
- 85% Annihilation
- 15% Gluon-Fusion

**Decay:**
- top decays exclusively to $W+b$
- $W$ decays to $qq'$ or $lv$

**Channels:**
- di-lepton
- **lepton+jets**
- all-jets

**Signatures:**
- 1 isolated lepton ($e$ or $\mu$)
- Missing Transverse Energy
- 4 Calorimeter Jets

**Backgrounds:**
- $W+$jets
- Multijet (QCD)
Top Quark Mass

• Top-quark mass not predicted by SM (free parameter)

• Best known relative quark mass ($\Delta m/m \approx 0.03$)

• $m_{\text{top}}$ input to EW fits $\rightarrow m_{\text{Higgs}}$

• Run I Tevatron Result:
  
  $m_{\text{top}} = 178.0 \pm 4.3 \text{ GeV/c}^2$

  TevEW/Top working group hep-ex/0404010
  $\rightarrow$ Matrix Element Method!

• Run II Goal:
  reduce uncertainty to $\sim 3 \text{ GeV}$
Matrix Element Method I

• Use full kin. information to calculate probability for each event being a top event as a function of the top mass

• Probability is proportional to differential cross section

• Calculate background probability in a similar way and build event probability

\[ P(x; M_{\text{top}}) = c P_{t\bar{t}}(x; M_{\text{top}}) + (1 - c) P_{\text{bkg}}(x) \]

\[ x: \text{kin. variables} \]

• Combine all event probabilities to likelihood

• Extract top mass by minimizing the negative likelihood w.r.t. the top mass hypothesis
Matrix Element Method II

**Signal Probability:**

\[
P_{t\bar{t}}(x; M_{\text{top}}) = \sum_{\text{comb}+\nu} \int d\rho_1 d\rho_2 \, dm_q^2 \, dM_{bq}^2 \, dM_{blv}^2 \, |M|^2 \, \frac{f(q_1)}{|q_1|} \frac{f(q_2)}{|q_2|} \Phi_6 \prod_{i=1}^{4} W_{\text{jet}}(E_i^{\text{parton}}, E_i^{\text{jet}})
\]

- **LO Matrix Element** \( |M|^2 \) x Flux Factor
- **Phase space** \( \Phi_6 \) x PDFs \( f(q_i) \)
- **Transfer Functions** \( W_{\text{jet}}(x,y) \) (energy resolution):
  - Prob. to measure \( E' = y \) (jet) if \( E = x \) (parton) was produced
  - Derived from Monte Carlo
  - All jet angles assumed to be perfectly measured

- **Acceptance Corrections**
- **5 integrations** -> very CPU intensive analysis
Event Selection

Topological Selection

• 1 isolated lepton, $p_T > 20$ GeV/c
• Missing Transverse Energy
• Exactly 4 calorimeter jets, $p_T > 15$ GeV/c, $|\eta| < 2.5$
• Three leading jets: $p_T > 20$ GeV/c

$log_{10} P_{bkg} < -13$

- increase purity of sample

8/26/04
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Topological likelihood template

**P_{bkg} efficiencies (MC)**

<table>
<thead>
<tr>
<th></th>
<th>e+jets</th>
<th>μ+jets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>0.889</td>
<td>0.915</td>
</tr>
<tr>
<td>W_{jjjj}</td>
<td>0.416</td>
<td>0.525</td>
</tr>
<tr>
<td>QCD</td>
<td>0.393</td>
<td>0.549</td>
</tr>
</tbody>
</table>

**Sample composition**

<table>
<thead>
<tr>
<th></th>
<th>e+jets</th>
<th>μ+jets</th>
</tr>
</thead>
<tbody>
<tr>
<td>N_{events}</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>f_{top}</td>
<td>0.430</td>
<td>0.450</td>
</tr>
<tr>
<td>f_{QCD}</td>
<td>0.062</td>
<td>0.065</td>
</tr>
<tr>
<td>Lumi</td>
<td>159pb^{-1}</td>
<td>148pb^{-1}</td>
</tr>
</tbody>
</table>
$\frac{P_{\text{sgn}}}{P_{\text{bkg}}}$: Data vs MC

**e+jets**

- **Data**
- $t\bar{t}$
- $W+$jjj
- QCD

**$P_{\text{sgn}}$**

**$P_{\text{bkg}}$**

**µ+jets**

- **Data**
- $t\bar{t}$
- $W+$jjj
- QCD

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Mass Calibration I

- Ensemble Tests
- 1000 ensembles
- 5 mass points (160 GeV/c^2 - 190 GeV/c^2)
- Events drawn from pool multiple times in different ensembles

Mass Bias: ~ 3.5 GeV/c^2
Exp. Stat. Err.: ~ 5.0 GeV/c^2
Pull (RMS): ~ 1.0 (e+jets/μ+jets combined)

Calibration
Mass Calibration II

Mass Calibration (combined)

\[ m_{\text{meas}} - 175.0 \text{[GeV/c}^2\text{]} \]

Offset: 3.732 ± 0.369 GeV/c\(^2\)
Slope: 1.038 ± 0.035

Note:
The simulation of the underlaying event was found not optimal in the MC samples generated for this study.
This is currently treated as a systematic uncertainty by comparison to an optimized MC sample for \(m_{\text{top}}=175\) GeV/c\(^2\).

Offset: 3.7 +/- 0.4 GeV/c\(^2\)
Slope: 1.04 +/- 0.04 GeV/c\(^2\)
Systematic Uncertainties

- Systematic uncertainties derived from Monte Carlo
- Dominated by systematic uncertainty from Jet Energy Scale
- Improvement of DØ JES measurement highest priority for top group!

<table>
<thead>
<tr>
<th>Syst. Uncertainty</th>
<th>Combined [GeV/c²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet Energy Scale</td>
<td>+5.0</td>
</tr>
<tr>
<td>Calibration</td>
<td>+0.5</td>
</tr>
<tr>
<td>Signal Modelling</td>
<td>+2.2</td>
</tr>
<tr>
<td>Background Modelling</td>
<td>+2.0</td>
</tr>
<tr>
<td>Jet Energy Resolution</td>
<td>+2.0</td>
</tr>
<tr>
<td>$p_{_{	ext{bkg}}} \text{ cut variation}$</td>
<td>+1.0</td>
</tr>
<tr>
<td>Multi Parton Interactions</td>
<td>+1.2</td>
</tr>
<tr>
<td>Transfer Functions</td>
<td>+1.0</td>
</tr>
<tr>
<td>top fraction $c_1$</td>
<td>+0.5</td>
</tr>
<tr>
<td>trigger turn on</td>
<td>+0.5</td>
</tr>
<tr>
<td>likelihood fit procedure</td>
<td>+0.5</td>
</tr>
<tr>
<td>acceptance corrections</td>
<td>+0.1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>+6.5</strong></td>
</tr>
</tbody>
</table>

preliminary
Summary:

- Matrix Element Method established for RunII
- Extensively studied and fully calibrated on Monte Carlo
- Application to Data currently under collaboration review

Outlook:

- Fix mass bias caused by signal probability calculation
- Improve Jet Energy Scale measurement
- Include b-tagging to
  - improve signal-to-background ratio
  - reduce combinatoric background (jet-parton permutations)