Top Mass and Decay Properties

DIS 2007

Jeannine Wagner
University of Karlsruhe

for the DØ and CDF Collaborations

Top mass:
- Most precise results of DØ and CDF for each decay channel

Decay properties:
- $W$-helicity in top decays
- $\text{Br}(t \rightarrow bW)/\text{Br}(t \rightarrow qW)$, lifetime
Top Quark Production and Decay

Dominant process: Top pair production

$$\text{Br}(t \rightarrow Wb) \sim 100\%$$

$$\sim 85\%$$

$$\sim 15\%$$
Allows together with the $W$ mass for predictions on Higgs mass

$\Delta M_W \propto M_t^2 \quad \Delta M_W \propto \ln M_H$

Consistency check of the standard model

Constraint on Higgs can point to physics beyond the standard model

Summer’06 top mass + Jan’07 W mass

![Diagram showing precision top quark mass measurements](image)
Top Mass Measurements Techniques

Template methods:
- Calculate a per-event observable strongly correlated with $M_t$
- Extract $M_t$ by comparing simulated distributions (sig+bg) with varying $M_t$ with data

Matrix Element (ME) analyses:
- Calculate a per event probability density for sig+bg as function of $M_t$:
  \[
P_{\text{sig}}(x; M_t) = \frac{1}{\sigma} \int d^n\sigma(y; M_t) \, dq_1 dq_2 \, f(q_1) f(q_2) W(x|y)
\]
- Obtain most likely $M_t$ by multiplying event likelihoods

\[
P_{\text{evt}} = f_{\text{top}} \cdot P_{\text{sig}} + (1 - f_{\text{top}}) \cdot P_{\text{bg}}
\]

DIS 2007, 04/18/2007
J. Wagner, University of Karlsruhe
Mass in the $\ell + \text{Jets}$ Channel

Event signature:
- 1 high $p_T$ lepton ($e$ or $\mu$)
- Large missing transverse energy $E_T$
- 4 jets ($\geq 1$ $b$-jet)

Backgrounds:
- Medium amount
- Mostly $W$ +jets, and QCD multijets

Bonus:
- In-situ calibration of light quark jets using $M_{W \rightarrow q\bar{q}'}$
- Crucial for current level of top mass precision
Most Precise $\ell +$ Jets Results

Use of in-situ technique $\rightarrow$ strong reduction of the dominant syst. uncertainty of top mass measurements, the uncertainty on jet energy scale

JES: Parameter used to adjust for a possible overall miscalibration of the jet energy scale (jet $\rightarrow$ parton)

Matrix element method

CDF Preliminary 940 pb$^{-1}$

$M_{\text{top}}$ (GeV/c$^2$)

$J_{\text{ES}}$

0.95
1
1.05

$\Delta \ln L = 0.5$

$\Delta \ln L = 2.0$

$\Delta \ln L = 4.5$

$\Delta \ln L = 8.0$

$160 \quad 170 \quad 180$

$m_t = 170.9 \pm 2.2 \pm 1.4$ GeV/c$^2$

Matrix element method

D0 RunII Preliminary

Calibrated 2D Likelihood

$W \rightarrow e\nu$

913 pb$^{-1}$

$0+1+2$ Tags

$m_t = 170.5 \pm 2.4 \pm 1.2$ GeV/c$^2$
Example of Systematic Uncertainties

<table>
<thead>
<tr>
<th>Source</th>
<th>$\Delta M_t$ [GeV/c$^2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>JES residual</td>
<td>0.42</td>
</tr>
<tr>
<td>Initial state radiation</td>
<td>0.72</td>
</tr>
<tr>
<td>Final state radiation</td>
<td>0.76</td>
</tr>
<tr>
<td>Generator</td>
<td>0.19</td>
</tr>
<tr>
<td>BG composition and modeling</td>
<td>0.21</td>
</tr>
<tr>
<td>Parton distribution functions</td>
<td>0.12</td>
</tr>
<tr>
<td>$b$-JES</td>
<td>0.60</td>
</tr>
<tr>
<td>$b$-tagging</td>
<td>0.31</td>
</tr>
<tr>
<td>Monte Carlo statistics</td>
<td>0.04</td>
</tr>
<tr>
<td>Lepton $p_t$</td>
<td>0.22</td>
</tr>
<tr>
<td>Multiple interactions</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.36</strong></td>
</tr>
</tbody>
</table>
Mass in the Dilepton Channel

Event signature:
- 2 high $p_T$ leptons ($e$ or $\mu$)
- Large missing transverse energy $E_T$
- 2 jets

Backgrounds:
- Low amount
- Diboson and $W/Z +$ jets events

Challenge:
- Two neutrinos $\rightarrow$ dilepton channel is underconstrained
Most Precise Dilepton Results

Matrix element method

Event probabilities are integrated over neutrino energies

Template method

Ignore $E_T$, assume $m_t$ and $\eta$ for each $\nu$
Assign a weight to each $(m_t, \eta_\nu_1, \eta_\nu_2)$ hypothesis based on agreement of calc. and obs. $E_T$

$m_t = 164.5 \pm 3.9 \pm 3.9$ GeV/c$^2$  \hspace{1cm}  $m_t = 172.5 \pm 5.8 \pm 5.5$ GeV/c$^2$

(DIS 2007, 04/18/2007)  \hspace{1cm}  J. Wagner, University of Karlsruhe
Mass in the All Hadronic Channel

Event signature:
- Exactly 6 jets ($\geq 1$ $b$-tagged)
- Additional selection on event topology

Backgrounds:
- Large amount
- QCD multijets

Challenge:
- Reduction of background (e.g. ANN)

Bonus:
- In-situ calibration of light quark jets using $M_{W\rightarrow q\bar{q}'}$
Most Precise All Hadronic Result

2D ($m_t$, JES) template analysis:

Signal templates from ME calculation, background templates from data-driven model

Result: $m_t = 171.1 \pm 3.7 \pm 2.1$ GeV/c$^2$

DIS 2007, 04/18/2007

J. Wagner, University of Karlsruhe
Top Mass Combination

Status of winter’07

Best Tevatron Run II (preliminary, March 2007)

- All-Jets: CDF (943 pb$^{-1}$) 171.1 ± 4.3
- Dilepton: CDF (1030 pb$^{-1}$) 164.5 ± 5.6
- Dilepton: D0 (1000 pb$^{-1}$) 172.5 ± 8.0
- Lepton+Jets: CDF (940 pb$^{-1}$) 170.9 ± 2.5
- Lepton+Jets: D0 (900 pb$^{-1}$) 170.5 ± 2.7
- Tevatron (Run I/Run II, March 2007) 170.9 ± 1.8

Relative uncertainty of ∼ 1% achieved

Data prefer a low Higgs mass
Top Decay Properties

Is the Top really the Standard Model Top?

- Production properties: production rate, production mechanism, charge, spin
  Previous talk by Cecilia Gerber

- Decay properties: branching ratios, lifetime, couplings, $W$ helicity

this talk
$W$ Helicity in Top Decays

**Longitudinal:**

- $b \rightarrow \text{top} + W^+_0$
- $1/2 \rightarrow 0$

**Left-handed:**

- $b \rightarrow \text{top} + W^+_L$
- $1/2 \rightarrow 1$

**Right-handed:**

- $b \rightarrow \text{top} + W^+_R$
- $1/2 \rightarrow 1$

SM: $F_0 = 0.7$

SM: $F_- = 0.3$

SM: $F_+ = 0.0$

Use reconstructed $\cos \theta^*$ as observable

Deviations from SM values would indicate new physics:

- Search for a possible $V + A$ coupling in weak top decays:
  - $\Rightarrow$ Altered $F_+$ value

- Search for an indication of non-SM EW sym. breaking:
  - $\Rightarrow$ Altered $F_0$ value
$\mathcal{W}$ Helicity: Results

**Unfolded diff. cross section**

CDF Run II Preliminary

- $L_{\text{int}} = 955 \text{ pb}^{-1}$
- $F_0 = 0.1$
- $F_0 = 0.2$
- $F_0 = -0.03^{+0.06}_{-0.06}$ (stat.)

$F_0 = 0.7$ fixed

**Likelihood contours**

CDF II preliminary, 955 pb$^{-1}$

$F_0 \times F_+ = 0.74 \pm 0.26$

Simultaneous fit of $F_0$ and $F_+$

**$\ell$+Jets, $\cos \theta^*$, 955 pb$^{-1}$**

$F_+ = -0.03 \pm 0.07$

$F_0 = 0.59^{+0.14}_{-0.13}$

One parameter fixed

**$\ell$+Jets & Dilepton, $M_{lb}^2$, 750 pb$^{-1}$**

$F_+ = -0.02 \pm 0.08$ ($F_0$ fixed)

(Phys. Rev. Lett. 98, 072001 (2007))

Simultaneous fit

**$\ell$+Jets & Dilepton, $\cos \theta^*$, 370 pb$^{-1}$**

$F_+ = 0.06 \pm 0.10$ ($F_0$ fixed)

(Phys. Rev. D RC 75, 031102(R), (2007))

All DØ and CDF measurements are consistent with the SM

DIS 2007, 04/18/2007

J. Wagner, University of Karlsruhe
Impact parameter $d_0$ of $\ell$ correlated with $\tau_{top}$

Top branching fraction:
$$R = \frac{Br(t \rightarrow bW)}{Br(t \rightarrow qW)}$$

$\ell+$Jets & Dilepton, 162 pb$^{-1}$
$$R = 1.12^{+0.27}_{-0.23}$$
$$R > 0.61 \text{ @ } 95\% \text{ C.L.}$$
(Phys. Rev. Lett. 95, 102002, (2005))

$\ell+$Jets, 230 pb$^{-1}$
$$R = 1.03^{+0.19}_{-0.17}$$
$$R > 0.61 \text{ @ } 95\% \text{ C.L.}$$

$ct_{top} < 52.5 \mu m \text{ @ } 95\% \text{ C.L.}$

Results consistent with SM
Summary

Top mass:

- Measurements are systematically limited
- $m_t = 170.9 \pm 1.8 \text{ GeV/c}^2$ (Tevatron combination)
- Relative uncertainty $\sim 1\%$
- Hope to reach $\Delta m_t \sim 1 \text{ GeV/c}^2$

Top decay properties:

- Measurements are still statistically limited
- All decay properties are consistent with the Standard Model prediction
Backup Slides
Top quark physics requires the understanding of all detector components.

It is a rare process with significant backgrounds.

We measure jets, not quarks: Correct jet energies (JES) for detector effects, hadronization, mult. interactions. JES known to $\sim 3\% \rightarrow$ dominant syst. uncertainty.

$b$-tagging can be used to reduce backgrounds and jet/quark combinatorics.
**B-Tagging at CDF**

- **Prompt tracks**
- **Secondary Vertex**
- **Displaced Tracks**
- **Primary Vertex**
- **Jet**

**Loose:** $L_{xy}/\sigma_{L_{xy}} > 6$, **Tight:** $L_{xy}/\sigma_{L_{xy}} > 7.5$

**Tight:**
- $\epsilon \approx 45\%$ (b)
- $\epsilon \approx 0.7\%$ (light)
- $\epsilon \approx 9\%$ (c)

$d_0$ resolution for central tracks: $\approx 50 \mu m$

Including L00: $o(5) \mu m$ improvement