Top mass and properties

Yen-Chu Chen

Institute of Physics, Academia Sinica,
Taiwan, R.O.C.

For the CDF and D0 collaboration
More than ten years after Top/Truth quark was found …

• The mass is well measured.
  – Assuming that this is really the Top/Truth!

• Is it really Top/Truth of the Standard Model (SM)?
  – Studying the properties
Top quark physics

Production Cross section

Charge asymmetry

Production mechanism

Top spin

Top charge

Top mass

FCNC

Rare decays, charged Higgs, etc.

Production ratio: $\frac{Br(t \rightarrow Wb)}{Br(t \rightarrow Wq)}$

W helicity

Life time, decay width

Mar. 1-8, 2008

Moriond EWK, La Thuile, Italy
**Top mass measurement**

- **Di-lepton (DIL) channel:**
  - both $W$ decay to leptons.
  - in practice uses only $e$, $\mu$.

- **Lepton+Jets (LJ) channel:**
  - one $W$ decays to leptons.
  - the other decays to quarks.

- **Hadronic channel:**
  - both $W$ decay to quarks.
Top mass measurement

the techniques

• Fit to reconstructed Top mass templates
• In-situ jet energy calibration
  – Based on $W \rightarrow jj$
  – Constraint on W boson mass
• Using Matrix Element (ME):
  – Use leading order matrix element
  – Integrating over the phase space
  – Find the probability density as a function of Top mass
• Single sensitive variable, $L_{xy}$
• Matrix weighting
• Neutrino weighting
• Other methods not described here:
  – Kinematic method, constraint to Xsection, ...

Mar. 1-8, 2008
Moriond EWK, La Thuile, Italy
\[ M_t = 170.9 \pm 1.8 \text{ GeV/c}^2, \]

from 1 fb\(^{-1}\) CDF+D0 combination.
Top mass measurement, CDF

- Use **Neural Networks** to select **DIL** Top candidates then perform ME, 2 fb⁻¹.
  - This neural networks is **evolutional**.
  - optimized on **improving uncertainty**.

\[ m_t = 171.2 \pm 2.7\text{(stat)} \pm 2.9\text{(sys)} \text{GeV/c}^2 \]
Top mass measurement, CDF

- Top mass template, all hadronic, $1.9 \text{ fb}^{-1}$
  - Use Neural Networks for event selection.
  - Require $b$ tagging.
  - Do In-situ jet energy calibration.

$m_t = 177.0 \pm 3.7 \text{ (stat+JES)} \pm 1.6 \text{ (sys)} \text{ GeV/c}^2$
Top mass measurement, CDF

- **Matrix Element, LJ. 1.9 fb⁻¹**
  - Use Neural Networks for background handling after event selection
  - Require b tagging
  - Do in-situ jet energy calibration

\[ m_t = 172.7 \pm 1.2 \text{ (stat)} \pm 1.3 \text{ (JES)} \pm 1.2 \text{ (sys)} \text{ GeV/c}^2 \]
Top mass measurement, D0

• Matrix weighting, DIL, 1 fb\(^{-1}\)
  – For a given \(m_t\) try to resolve for Top, anti-Top momentum.
  – Define weight for each solution.
  – Account for detector resolution.
  – Take into account the background.
  – Scan through \(m_t\) to reach the max. weight and the min. of likelihood.

\[ m_t = 175.2 \pm 6.1 \text{ (stat)} \pm 3.4 \text{ (sys) GeV/c}^2 \]
Top mass measurement, D0

- **Neutrino weighting, DIL, 1 fb⁻¹**
  - given \( m_t \) and \( \eta \) (from MC) for each \( \nu \); resolve for \( \nu \) momentum.
  - For each event derive weight template based on expected (MC) and observed.
  - Take into account detector resolution and background.
  - Define maximum likelihood, \( L(m_{\text{top}}, \text{mean}, \text{rms}) \).

\[
m_t = 172.5 \pm 5.8 \text{ (stat)} \pm 3.5 \text{ (sys)} \text{ GeV/c}^2
\]

Mar. 1-8, 2008 Moriond EWK, La Thuile, Italy
Top mass measurement, D0

- **Matrix Element, LJ, 1 fb^(-1):**
  - Use in-situ jet energy calibration.
  - Result **without b tagging:**
    \[ m_t = 170.5 \pm 2.5 \text{ (stat+JES)} \pm 1.4 \text{ (sys) GeV/c}^2 \]
  - Result **with b tagging:**
    \[ m_t = 170.5 \pm 2.4 \text{ (stat+JES)} \pm 1.2 \text{ (sys) GeV/c}^2 \]
Top mass measurement, updated

CDF Top Quark Mass Combination

- **All-hadronic (Run I)**: 186.0 ± 10.0 ± 5.7
- **Dilepton (Run I)**: 167.4 ± 10.3 ± 4.9
- **Lepton+Jets (Run I)**: 176.1 ± 5.1 ± 5.3
- **All-hadronic (2 fb⁻¹)**: 177.0 ± 3.3 ± 2.4
- **Dilepton (2 fb⁻¹)**: 171.2 ± 2.7 ± 2.8
- **Lepton+Jets (<L_{xy}>)(0.7 fb⁻¹)**: 180.7 ± 15.5 ± 8.6
- **Lepton+Jets (2 fb⁻¹)**: 172.7 ± 1.2 ± 1.7
- **CDF March 2008 (CDF Run I+II)**: 172.9 ± 1.2 ± 1.5

χ²/dof = 3.8/6

DØ combination (August 2007)

- **Run I Dileptons ***: 168.4 ± 12.3 ± 3.6 GeV
- **Run I Lepton+jets ***: 180.1 ± 23.6 ± 3.9 GeV
- **Run I Alljets**: 178.5 ± 13.7 ± 7.7 GeV
- **Run II Dileptons ***: 173.7 ± 5.4 ± 3.4 GeV
- **Run II Lepton+jets ***: 170.5 ± 18.9 ± 2.0 GeV

DØ combination (August 2007)

- **World average (March 2007)**: 170.9 ± 1.1 ± 1.5 GeV

- **DØ combination (Summer 2007)**: 172.1 ± 1.5 ± 1.9 GeV

Mar. 1-8, 2008

Moriond EWK, La Thuile, Italy
Top mass measurement, the future

CDF Top Mass Uncertainty
(projection from 680 pb⁻¹)

- Reaching below 1% uncertainty!
- **CDF and DØ** are working together on the common systematic issues to reduce uncertainty.

**Tevatron Top mass, 2007 Mar.**

Mar. 1-8, 2008  Moriond EWK, La Thuile, Italy
The charge of Top quark, **CDF**

- **SM**: $+\frac{2}{3}q$   **XM**: $-\frac{4}{3}q$

- **Each event has lepton(s) and jets**:
  - **Pairing**: Top mass as input, $M_{lb}^2$
  - **Jet charge determination**

\[ Q_{jet} = \frac{\sum |\vec{p_i} \cdot \vec{P}_{jet}|^\alpha Q_i}{\sum |\vec{p_i} \cdot \vec{P}_{jet}|^\alpha} \]

- **The result (1.5 fb$^{-1}$)**:
  - Exclude XM at 87% CL.
W helicity in Top decay

Theory:

\[ f_0 = 0.7, \text{ longitudinal} \]
\[ f_- = 0.3, \text{ left handed} \]
\[ f_+ = 0, \text{ right handed} \]
W helicity in Top decay

CDF

\[ f_0 = 0.65 \pm 0.19 \text{ (stat) } \pm 0.03 \text{ (sys) } \]

\[ f_+ = -0.03 \pm 0.07 \text{ (stat) } \pm 0.03 \text{ (sys) } \]

Fix \( f_0 \) to SM:

\[ f_+ = -0.04 \pm 0.04 \text{ (stat) } \pm 0.03 \text{ (sys) } \]

\[ f_+ < 0.07 \text{ @ 95\% C.L.} \]
$W$ helicity in Top decay

$\textbf{D0}$

$LJ, \text{ Lep.}$

$LJ, \text{ Had.}$

$DIL$

$f_0 = 0.425 \pm 0.166 \text{ (stat)} \pm 0.102 \text{ (sys)}$

$f_+ = 0.119 \pm 0.090 \text{ (stat)} \pm 0.053 \text{ (sys)}$

**Fix $f_0$ to SM:**

$f_+ = -0.002 \pm 0.047 \text{ (stat)} \pm 0.047 \text{ (sys)}$

$f_+ < 0.13 @ 95\% \text{ C.L.}$
\[ \mathcal{R}_b = \frac{\text{Br}(t \rightarrow Wb)}{\text{Br}(t \rightarrow Wq)} \]

\textbf{D0}

- \textbf{Simultaneous fit to the production cross section and } \mathcal{R}_b.
  - \textit{LJ}, 0.9 fb\(^{-1}\)
  - \[ \mathcal{R}_b = 0.97 \pm 0.09 \text{ (stat + sys)} \]
  
  \[ > 0.79 \text{ @ 95\% CL} \]
  
  - \[ |V_{tb}| > 0.89 \text{ @ 95\% CL} \]
  
  - \[ \sigma_{tt} = 8.18 \pm 0.90 \text{ (stat+sys)} \]
  
  \[ \pm 0.50 \text{ (lumi) pb} \]
Search for charged Higgs in Top decay. D0

- What really considered:
  - $R = \frac{\sigma(tt)_l+jets}{\sigma(tt)_\ell}$
  - Assume the sys. issue of luminosity cancelled out
  - Assume $R_b = 1$.
  - $R = 1.21^{+0.27}_{-0.26} (\text{stat + sys})$

- Extract info. for charge Higgs
  - $B = B(t\rightarrow Hb)$
  - $B = 0.13^{+0.12}_{-0.11} (\text{stat+sys})$;
    $B < 0.35 @ 95\% \text{ CL}$
Search for FCNC in Top decay
CDF

- **SM**: $\mathcal{B}(t \rightarrow Zq) = O(10^{-14})$
- Beyond SM: up to $O(10^{-4})$
- At LEP: $< 13.7\% @ 95\%$ CL

- Look for 2 lep. + 4 jets.
- Constraint on masses of Top, Z and W.
- Best limit up to date ($1.9 \text{ fb}^{-1}$):
  
  $< 3.7\% @ 95\%$ CL
Conclusion

• More than ten years after the Top quark discovery:
  – Top quark mass is well measured to 1.1% level!
  – Up to date, within uncertainties, all measured quantities are consistent with the Standard Model expectations.
  • Top charge, $W$ helicity, $R_V$, charged Higgs search, FCNC
  – Analysis in progress or not reported here.
  • Life time, decay width, top spin correlation, etc.
  – This is just the beginning of the sensitive studies of the Top quark properties! There are much room ahead for surprises!
The charge of Top quark

CDF

- **CDF result (1.5 fb⁻¹):**
  - $2\text{Ln}(\text{Bayse factor}) = 12.0$
  - $f^+ = \text{SM like} / \text{Total}$
  - $> 0.4 @ 95\% \text{ CL}$
Top charge, CDF

CDF Run II preliminary $L = 1.5 \text{ fb}^{-1}$

$p$-values under the SM hypothesis if XM is true

$\alpha = 1\%$

$\beta = 87\%$

$p$ value observed : $0.31$

$f^+ \text{ measured}$

Mar. 1-8, 2008  Moriond EWK, La Thuile, Italy