Progress in Top Quark Physics

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XVII Particles and Nuclei International Conference
Plenary session 28 October 2005

CDF+D0 parallel session talks:
V.4 Peter Renkel “Top Quark Mass Measurement in Lepton+Jets Channel”
V.4 Tuula Maki “Top Quark Mass Measurement in Dilepton Channel”
V.4 Robert Kehoe “Top Quark Pair Production Cross Section Measurement”
V.4 Charles Plager “Measurements of Top Quark Decay Properties”
V.4 Valentin Necula “Search for Resonances in Top Quark Pair Production”
V.4 Yurii Maravin “Search for Single Top Quark Production”
VI.2 Ben Kilminster “Search for SM and MSSM Higgs Bosons”
Motivation

• Most massive elementary particle
  – Discovered in 1995 by CDF and D0
  – Only few dozen candidates in 0.1 fb⁻¹

• Is it really Standard Model top? Any effects from new physics?
  – Only CDF and D0 can study top until LHC
  – Large 1 fb⁻¹ data sample for Winter 2006

• Top quark mass is a fundamental parameter in the Standard Model and beyond…
  – Huge top quark mass induces significant radiative corrections to W boson mass
  – Reduced uncertainty on top quark mass imposes tighter constraints on unknowns, like Standard Model Higgs boson or SUSY

• Significant background to many searches for new physics at LHC
Top Quark Production & Decay

Produce in pairs via strong interaction

At $\sqrt{s}=1.96$ TeV:
- 85% $qq$
- 15% $gg$

At $\sqrt{s}=14$ TeV:
- 10% $qq$
- 90% $gg$

$\sigma = 833 \pm 100$ pb

<table>
<thead>
<tr>
<th>$m_t$ (GeV/$c^2$)</th>
<th>Min</th>
<th>Central</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>170</td>
<td>6.8</td>
<td>7.8</td>
<td>8.7</td>
</tr>
<tr>
<td>175</td>
<td>5.8</td>
<td>6.7</td>
<td>7.4</td>
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</tbody>
</table>

Decay singly via electroweak interaction $t \rightarrow W^+ b$

$t \rightarrow Wb$ has $\sim 100\%$ branching ratio

Width $\sim 1.5$ GeV so lifetime $10^{-25}$s

No top mesons or baryons!

Final state characterized by number and type of charged leptons from decay of $W^+$ and $W^-$ bosons

(Note $e$ includes $\tau \rightarrow e\nu\bar{\nu}$ and $\mu$ includes $\tau \rightarrow \mu\nu\bar{\nu}$)
Snapshot of Tevatron Operation

- World Record Peak Luminosity yesterday!
  - $1.58 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$

- Deliver 8 fb$^{-1}$ if all upgrades succeed
  - Note electron cooling upgrade making good progress!

- Deliver 4 fb$^{-1}$ even if no further improvements

- Already delivered over 1 fb$^{-1}$ to experiments

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**pp collisions at $\sqrt{s} = 1.96$ TeV**

- Produce ~3 top pairs every hour, or 6 billion collisions

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**Run I best**

- Integrated Luminosity (fb$^{-1}$)

- Peak Luminosity (cm$^{-2}$s$^{-1}$)

- Date

- We are here!
Current top quark physics results from ~350 pb\(^{-1}\) of data up to September 2004

• 2005 excellent year for CDF and D0!

• Both experiments have collected over 1 fb\(^{-1}\) of data at \(\sqrt{s}=1.96\) TeV

• Watch out for top results with 1 fb\(^{-1}\) at Moriond 2006
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- Width $\sim1.5$ GeV so lifetime $10^{-25}$s
- No top mesons or baryons!

Final state characterized by number and type of charged leptons from decay of $W^+$ and $W^-$ bosons

(Note $e$ includes $\tau \rightarrow e\bar{\nu}_e\nu_e$ and $\mu$ includes $\tau \rightarrow \mu\bar{\nu}_\mu\nu_\mu$)
Dilepton

\[ \sigma(t\bar{t}) = 8.6 \pm ^{2.3}_{2.0} \text{(stat)} \pm ^{1.2}_{1.0} \text{(syst)} \pm 0.6 \text{(lumi)} \text{pb} \]

<table>
<thead>
<tr>
<th>Events</th>
<th>ee</th>
<th>(\mu\mu)</th>
<th>e(\mu)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bkg</td>
<td>1.0±0.3</td>
<td>1.3±0.4</td>
<td>4.5±2.2</td>
<td>6.8±2.2</td>
</tr>
<tr>
<td>Data</td>
<td>5</td>
<td>2</td>
<td>21</td>
<td>28</td>
</tr>
</tbody>
</table>

\(\varepsilon \times BR(t\bar{t} \rightarrow \text{dilepton}) \approx 0.7\%\)

2 isolated electrons/muons \(p_{T}>15\text{ GeV/c}\)
At least 2 jets \(p_{T}>20\text{ GeV/c}\)
Reduce backgrounds:
- \(Z/\gamma^* \rightarrow \text{ee}\) with MET and sphericity
- \(Z/\gamma^* \rightarrow \mu\mu\) with MET and \(\chi^2\) consistency with Z mass
- \(Z/\gamma^* \rightarrow \tau\tau \rightarrow \nu_\tau \nu_\tau \nu_\mu \nu_\mu\) with \(\Sigma p_{T}\) of jets and leading lepton
- Instrumental with multivariate likelihood electron id in ee channel
Lepton+Jets

1 isolated electron/muon $p_T > 20$ GeV/c
At least 3 jets $p_T > 15$ GeV/c
MET $> 20$ GeV

Need more discrimination against same final state from W+jets processes!

Kinematic event observables

- Decay products of massive top quarks more energetic and central than W+jets
- Combine several kinematic observables in optimal artificial neural network
- Fit observed data to expected distributions from signal and backgrounds

CDF Preliminary $(347 \text{ pb}^{-1})$

$\epsilon \times BR(t\bar{t} \rightarrow l + jets) \approx 7\%$

$\sigma(t\bar{t}) = 6.3 \pm 0.8 \text{(stat)} \pm 0.9 \text{(syst)} \pm 0.4 \text{(lumi)} \text{ pb}$
Lepton+Jets with b-tagging

- Each top quark decay produces one energetic central b-quark, however, only few % W+jets have b or c quarks
- Distinctive experimental signature from long lifetimes of massive B hadrons
- Reconstruct significantly displaced secondary vertex from charged B decay products inside jet
  - Efficiency per b-jet about 50%
  - False positive rate about 1%

CDF Run II Preliminary

Number of Jets = 4
Missing Et = 45 GeV
Muon Pt = 37 GeV
### Lepton+Jets with b-tagging

\[ \varepsilon \times BR(tt \rightarrow l + jets) \approx 4\% \]

\[ \sigma(tt) = 8.1 \pm 0.9 \text{(stat)} \pm 0.9 \text{(syst)} \pm 0.5 \text{(lumi) pb} \]

<table>
<thead>
<tr>
<th>Events</th>
<th>Control region</th>
<th>Signal region</th>
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<tbody>
<tr>
<td>(N_{btag}=1)</td>
<td>(W+1) jet</td>
<td>(W+3) jets</td>
</tr>
<tr>
<td>Bkg</td>
<td>254(\pm 38)</td>
<td>71(\pm 9)</td>
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<tr>
<td>Data</td>
<td>251</td>
<td>121</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Events</th>
<th>Control</th>
<th>Signal region</th>
</tr>
</thead>
<tbody>
<tr>
<td>(N_{btags} \geq 2)</td>
<td>(W+2) jets</td>
<td>(W+3) jets</td>
</tr>
<tr>
<td>Bkg</td>
<td>17(\pm 3)</td>
<td>7(\pm 1)</td>
</tr>
<tr>
<td>Data</td>
<td>22</td>
<td>11</td>
</tr>
</tbody>
</table>

**DØ Run II Preliminary**

#### Single tag

\(N_{btag} = 1\)

**DØ Run II Preliminary**

#### Double tag

\(N_{btags} \geq 2\)
e:\t_h \text{ and } \mu:\t_h

\varepsilon \times \text{BR}(t\bar{t} \rightarrow e:\t_h , \mu:\t_h) \approx 0.08\%

Neutrino+jets

\varepsilon \times \text{BR}(t\bar{t} \rightarrow \nu + \text{jets}) \approx 4\%

1 isolated electron/muon p_T>20 GeV/c
• 1 isolated \(\tau \rightarrow \nu_\tau + \text{hadrons} \) p_T>15 GeV/c
• MET>20 GeV
• At least 2 jets p_T>20 GeV/c

Reduce backgrounds
• Total transverse energy >205 GeV
• Not compatible with \(Z \rightarrow \tau \tau\)

Zero isolated electrons/muons!
• At least 4 jets p_T>15 GeV/c
• MET significance > 4 GeV^{1/2}
• MET not collinear with jets
• At least 1 b-tag

In future: explicit tau identification!

\[\sigma(t\bar{t}) = 6.1\pm1.2(\text{stat})^{+1.3}_{-0.9}(\text{syst})\pm0.4(\text{lumi})\text{pb}\]

<table>
<thead>
<tr>
<th>Events (195 pb^{-1})</th>
<th>e:\t_h</th>
<th>\mu:\t_h</th>
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<tr>
<td>Bkg</td>
<td>0.8±0.1</td>
<td>0.5±0.1</td>
</tr>
<tr>
<td>Data</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

CDF set limit on anomalous decay rate

\[\frac{\Gamma(t \rightarrow \tau\nu_\tau q)}{\Gamma_{SM}(t \rightarrow \tau\nu_\tau q)} < 5.2 @ 95\% \text{ C.L.}\]

CDF Run II Preliminary

L = 311 pb^{-1}
All-hadronic

- At least 6 jets with $p_T>15$ GeV/c
- Reduce huge background from QCD processes at a hadron collider!
  - At least one b-tag
  - Combine kinematic observables in artificial neural network
  - Require NN>0.9

$\varepsilon \times BR(\bar{t}t \rightarrow \text{all-hadronic}) \approx 3\%$

<table>
<thead>
<tr>
<th>Events</th>
<th>All-hadronic</th>
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<tbody>
<tr>
<td>Raw Bkg</td>
<td>494±5</td>
</tr>
<tr>
<td>Corrected Bkg</td>
<td>482±5</td>
</tr>
<tr>
<td>Data</td>
<td>541</td>
</tr>
</tbody>
</table>

$\sigma(\bar{t}t) = 5.2^{+2.6}_{-2.5}\ (\text{stat})^{+1.5}_{-1.0}\ (\text{syst})^{+0.3}_{-0.3} (\text{lumi})\ \text{pb}$
Is this the standard model Top Quark?

Observe Top Quark Pair Production in all final states

- Top always decays to $W^+b$?
- Any Charged Higgs from $t \rightarrow H^+b$?
- Top electric charge is $+2/3$?
- W helicity “right”?
- Anomalous FCNC $t \rightarrow Zc, gc, \gamma cb$?

Test Top Quark Pair Production

- Pair Production Rate
- New massive resonance $X \rightarrow tt$?
- Top spin
- Tests of NLO kinematics

Search for Single Top Quark Production

Precision measurement of top quark mass: 30% improvement this year!
Is this the standard model Top Quark?

Test Top Quark Decay

- Top always decays to $W^+b$?
- Any Charged Higgs from $t \rightarrow H^+b$?
- Top electric charge is $+\frac{2}{3}$?
- $W$ helicity “right’’?
- Anomalous FCNC $t \rightarrow Zc, gc, \gamma cb$?

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Precision measurement of top quark mass: 30% improvement this year!

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Observe Top Quark Pair Production in all final states

Diagram:

- $p \rightarrow t \rightarrow W^+b$
- $\bar{p} \rightarrow \bar{t} \rightarrow W^-\bar{b}$
- $q, l^+ \rightarrow q', \nu$
- $\bar{q}', \bar{\nu}$
Does top always decay to W+b? Part (b)

- If BR(t→Wb) is lower than SM prediction of ~100%, or if b-tag efficiency is lower than estimated value
  - observe fewer double b-tag events
  - observe more events without any b-tags
- Fit $R = \frac{BR(t\rightarrow Wb)}{BR(t\rightarrow Wq)}$ times b-tag efficiency from observed number and estimated composition of 0,1,2-tag dilepton and lepton+jets events

**Graphs:**
- Sample fraction distribution with 0-tag, 1-tag, and 2-tag regions.
- Best fit $R = 1.11^{+0.21}_{-0.26}$
- Feldman Cousins Bands for R
- CDF 161 pb$^{-1}$

$\Delta\varepsilon = \varepsilon_b - \varepsilon_{light} = 0.44 \pm 0.03$ from independent estimate

$R > 0.62$ at 95% C.L.
Does top always decay to $W^+b$? Part (W)

Branching ratio for $t \rightarrow H^+ b$ significant (>10%) for small and large tan$\beta$

$H^+$ decays differently than $W^+$

$\hat{\nu} \rightarrow \tau^+ \nu_\tau$ enhanced if high tan$\beta$: observe more taus!

$\hat{\nu} \rightarrow t^* b \rightarrow W^+ b b$ for high $m(H^+)$ if low tan$\beta$: mimics SM signature but observe more b-tags

Compare number of observed events in 4 final states: dilepton, $\epsilon \tau_h + \mu \tau_h$, lepton+jets with single b-tag, and lepton+jets with double b-tags

$M_{H^+} = 140$ GeV
Does top always decay to $W^+b$? Part ($W^+$)

Electric charge of $+2/3$ implies $t \rightarrow W^+b$
Electric charge of $-4/3$ implies $t \rightarrow W^-b$
How to tell the difference experimentally?

- Select 21 double b-tag lepton+≥4 jets
  - Very pure sample with only 5% bkg
  - Statistical estimate b charge from jet-charge
- Pick best lepton and b-jet combination with kinematic fit for fixed $m_{top}=175$ GeV/c$^2$ hypothesis
  - 17 double b-tag events pass
  - Correct assignment 79±2%
- Calculate magnitude of “top” charges
  - $Q_1=|\text{lepton charge} + b_1\text{-jet charge}|$
  - $Q_2=|\text{-lepton charge} + b_2\text{-jet charge}|$
- Define $\Lambda$ as ratio of unbinned likelihoods for SM ($Q=+2/3$) and Exotic ($Q=-4/3$) hypotheses

First result!

Measure $\Lambda=11.5$
Exclude $Q=-4/3$ @ 94% C.L.
Decay consistent with standard model so far!

Observe Top Quark Pair Production in all final states

Test Top Quark Decay
- Top always decays to $W^+b$?
- Any Charged Higgs from $t \rightarrow H^+b$?
- Top electric charge is $+\frac{2}{3}$?
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Test Top Quark Pair Production
- Pair Production Rate
- New massive resonance $X \rightarrow tt$?
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Precision measurement of top quark mass: 30% improvement this year!

Search for Single Top Quark Production
Top Pair Production Rate

- Are measurements in different final states consistent with each other and with theory?

Dilepton NEW (L=360 pb⁻¹): 10.1 ± 2.2 ± 1.3 ± 0.6

Lepton+Jets: Combined (L=347 pb⁻¹): 6.3 ± 0.8 ± 0.9 ± 0.4

Lepton+Jets: Soft Muon Tag (L=193 pb⁻¹): 5.3 ± 3.3 ± 1.3 ± 0.3

Lepton+Jets: Vertex Tag (L=319 pb⁻¹): 8.9 ± 0.9 ± 1.1 ± 0.5

MET+Jets: Vertex Tag (L=311 pb⁻¹): 6.1 ± 1.2 ± 1.3 ± 0.4

All-hadronic: Vertex Tag (L=311 pb⁻¹): 8.0 ± 1.7 ± 3.3 ± 0.5

X²/dof=4.3/5

Combined (L=350 pb⁻¹): 7.1 ± 0.6 ± 0.7 ± (stat)+0.4

CDF Run 2 Preliminary

Combined Cross Section

CDF Run 2 Preliminary

Combined Top Mass

Tevatron Preliminary
Does something new produce ttbar?

- Search for new massive resonance decaying to top pairs
  - Lepton+≥4 jets with ≥ 1 b-tags
  - Kinematic fit to ttbar hypothesis to improve experimental resolution on invariant mass of ttbar system
- Fix SM backgrounds to expected rate
  - Use theory prediction of 6.7pb for SM top pair production

Derive limit on $\sigma_X \times BR(X \rightarrow t\bar{t})$

DØ Run II Preliminary (L=370 pb$^{-1}$)

- Interpret in terms of one of many possible models: topcolor assisted technicolor Z$'$
What does CDF observe?

- Lepton+≥4 jets (no b-tagging)
  - Matrix element technique to increase sensitivity
- Fix top pair, diboson, QCD to expected rates
  - Assume everything else is W+jets
- Also see excess around 500 GeV/c²
  - Only 2 std. dev. now…could be interesting result with 3x data for Moriond 2006
Does something new produce Single Top Quarks?

Single top quark production via electroweak interaction
Cross section proportional to $|V_{tb}|^2$

Harris et al PRD 66 (02) 054024
Cao et al hep-ph/0409040
Campbell et al PRD 70 (04) 094012

$0.88 \pm 0.11 \text{ pb}$
$1.98 \pm 0.25 \text{ pb}$
$<0.1 \text{ pb}$

Trigger on lepton from $t \rightarrow W b \rightarrow \ell \nu b$

2 b-jets for s-channel
1 b-jet and 1 light jet for t-channel

Interesting to measure both channels – sensitive to different physics

See Tait, Yuan
PRD63, 014018 (2001)

s-channel
Sensitive to new resonances

<table>
<thead>
<tr>
<th>$u$</th>
<th>$W'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{d}$</td>
<td>$t$</td>
</tr>
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<table>
<thead>
<tr>
<th>$q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c$</td>
</tr>
<tr>
<td>$t$</td>
</tr>
</tbody>
</table>

Tait PRD 61 (00) 034001
Belyaev, Boos
PRD 63 (01) 034012
Search for Single Top Quark Production

• Why is it difficult?
  – Signal swamped by W+jets
  – Signal sandwiched between W+jets and top pair production
• Dedicated likelihood to discriminate between each signal and each background
  – Kinematic observables
  – Show likelihoods for t-channel
• Rely on good MC modeling of W+jets background composition and kinematics
  – Big challenge for discovery!
  – 3σ evidence expected with <2 fb⁻¹

| D0 Preliminary: World’s best limits! Factor of 2-3 away from standard model |
| D0 370 pb⁻¹ | Expected 95% C.L. (pb) | Observed 95% C.L. (pb) |
| s-channel | 3.3 | 5.0 |
| t-channel | 4.3 | 4.4 |
Production & Decay consistent with standard model

Observe Top Quark Pair Production in all final states

Test Top Quark Decay
- Top always decays to $W^+b$?
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Search for Single Top Quark Production

Precision measurement of top quark mass:
30% improvement this year!
Top Quark Mass: Reconstruction

- Kinematic fit to top pair production and decay hypothesis
  - Obtain improved resolution on reconstructed top mass
  - Choose most consistent solution for $t \rightarrow jjb$ and $t \rightarrow \ell\nu b$
    - 24 possibilities for 0 b-tags
    - 12 possibilities for 1 b-tag
    - 4 possibilities for 2 b-tags
- Fit data to reconstructed top mass distributions from MC
  - Need excellent calibration of jet energy between data and MC!
  - 3% systematic uncertainty on jet energy scale gives $\sim 3$ GeV/c$^2$
  - Systematic uncertainty on top quark mass

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CDF Run II

![CDF Run II](image)

- $M_{\text{top}}$
- 145 GeV/c$^2$
- 165 GeV/c$^2$
- 185 GeV/c$^2$
- 205 GeV/c$^2$

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Submitted last week!

NIM A: hep-ex/0510047
Top Quark Mass: \textit{in situ} jet energy calibration

- New for 2005! Simultaneous fit of invariant mass of jets from $W \rightarrow jj \text{ in lepton+jets data}$
  - Determine global jet energy correction factor
  - Use to correct energy of all jets
- Uncertainty dominated by data $W \rightarrow jj$ statistics
  - Will decrease $< 1 \text{ GeV}/c^2$ with more data!
CDF Top Mass Measurement: Lepton+Jets

- Simultaneous fit of reconstructed top mass and $W \rightarrow jj$ mass
  - Include Gaussian constraint on jet energy scale from *a priori* determination
- Best single measurement! Better than previous Run I CDF+D0 average!

$m_{top} = 173.5 \pm 2.7_{2.6}^{+2.7}_{-2.7} \, \text{(stat)} \pm 2.5_{-1.3}^{+2.5} \, \text{(JES)} \pm 1.3_{-0.3}^{+0.3} \, \text{syst} \, \text{GeV} / c^2$

$JES = -0.10 \pm 0.78_{0.80} \, \sigma \, \text{(a priori)}$

Correction approx. -0.3%

Uncertainty 20% smaller

Submitted last week!  
PRD: hep-ex/0510048  
PRL: hep-ex/0510049

Systematic Source | Uncertainty (GeV/c²)
---|---
ISR/FSR | 0.7
Model | 0.7
b-jet | 0.6
Method | 0.6
PDF | 0.3
Total | 1.3
Jet Energy | 2.5
D0 Top Mass Measurement: Lepton+Jets

- LO Matrix element technique of Run I
  - Exactly 4 observed jets (150 events, 32±5% top)
  - Use LO Matrix element for ttbar and W+jets
  - Weight all 24 possible solutions (no b-tagging)
- New for 2005: W→jj jet energy calibration
  - Fit jet energy scale as well as top mass
  - No a priori jet energy determination

\[ m_{\text{top}} = 169.5 \pm 3.0^{\text{stat}} \pm 3.2^{\text{(JES)}} \pm 1.7^{\text{(syst)}} \text{ GeV} / c^2 \]

\[ \text{JES} = 1.034 \pm 0.034 \quad \text{Correction} \ +3.4\% \quad \text{Uncertainty} \ \pm3.4\% \]

Check: apply JES and fit

\[ m_{W} = 80.09^{+5.18}_{-3.41} \text{ GeV/c}^2 \]

<table>
<thead>
<tr>
<th>Systematic Source</th>
<th>Uncertainty (GeV/c^2)</th>
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<tbody>
<tr>
<td>ISR/FSR</td>
<td>0.3</td>
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<tr>
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<td>b-jet</td>
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<tr>
<td>Jet Energy</td>
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</table>
Tevatron Top Quark Mass

Mass of the Top Quark (*Preliminary)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>$M_{\text{top}}$ [GeV/c$^2$]</th>
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<tbody>
<tr>
<td>CDF-I di-l</td>
<td>167.4 ± 11.4</td>
</tr>
<tr>
<td>DØ-I di-l</td>
<td>168.4 ± 12.8</td>
</tr>
<tr>
<td>CDF-II di-l</td>
<td>165.3 ± 7.3</td>
</tr>
<tr>
<td>CDF-I l+j</td>
<td>176.1 ± 7.3</td>
</tr>
<tr>
<td>DØ-I l+j</td>
<td>180.1 ± 5.3</td>
</tr>
<tr>
<td>CDF-II l+j*</td>
<td>173.5 ± 4.1</td>
</tr>
<tr>
<td>DØ-II l+j*</td>
<td>169.5 ± 4.7</td>
</tr>
<tr>
<td>CDF-I all-j</td>
<td>186.0 ± 11.5</td>
</tr>
</tbody>
</table>

First application of matrix element technique to dilepton channel: 20% improvement over previous techniques!

Now final: 173.5 ± 3.9

$\chi^2 / \text{dof} = 6.5 / 7$

172.7 ± 2.9

Tevatron Run-I/II* Summer 2005
Bright Future with Inverse Femtobarns!

CDF+D0 will achieve $\pm 2.5$ GeV/c$^2$ in 2006! Will reach $\pm 1.5$ GeV/c with 4 fb$^{-1}$ base!

Shown is only lepton+jets channel with $W \rightarrow jj$ jet energy calibration

Conservative estimate of other systematics, will get smarter with more data!

Quantum loops make W mass sensitive to top and Higgs mass

Recent theoretical calculation of full two-loop electroweak corrections

Precise prediction of W mass in standard model limited by uncertainty on experimental measurement of top mass

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Prediction</th>
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<tr>
<td>$\delta_{M_{\text{top}}}$ (GeV/c$^2$)</td>
<td>$\delta_{M_{W}}$ (MeV/c$^2$)</td>
</tr>
<tr>
<td>CDF+D0 Run I</td>
<td>4.3</td>
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<tr>
<td>CDF+D0 2005</td>
<td>2.9</td>
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<tr>
<td>CDF+D0 1 fb$^{-1}$</td>
<td>2.0</td>
</tr>
<tr>
<td>CDF+D0 4 fb$^{-1}$</td>
<td>1.5</td>
</tr>
<tr>
<td>LHC</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Adapted from A. Freitas et al, hep/ph-0311148
Test of Standard Model

Impact of CDF+D0 Top Quark Mass = 172.7 ± 2.9 GeV

Good agreement between direct measurements and indirect SM prediction

\[ m_t \text{ [GeV]} \]

\[ m_W \text{ [GeV]} \]

Future CDF+D0 (4 fb\(^{-1}\))

68\% CL

\( m_H \) [GeV]

114, 300, 1000

Theory uncertainty

\[ \Delta \alpha_{\text{had}}^{(5)} = \]

- 0.02758±0.00035
- 0.02749±0.00012
- incl. low Q\(^2\) data

Excluded

\[ m_H \text{ [GeV]} \]

= 91±45 GeV

< 186 GeV @ 95\% C.L.

< 219 GeV with LEP Excluded
Conclusions

Observed top quark consistent with standard model so far

Achieved 1.7% precision top quark mass measurement

Future is bright!
Excellent performance of Tevatron & CDF & D0 delivering high statistics samples of top quarks

Watch out for interesting results with 1 fb\(^{-1}\) at Moriond 2006!