Top quark physics review
(results from the Tevatron)

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Outline

• The top quark
• The detectors and collected data
• Top quark production cross sections
• Is there more than the top quark?
• Top quark properties
The top quark decays before it can hadronize.

**The top quark**

\[ \gamma_t = \approx 1 \]

New Physics
Top Quark Production

Top quark pair production via strong interaction

- Proton - (anti)proton cross sections

\[ \sigma (\text{ab}) \]

\[ \sigma \propto \frac{1}{\sqrt{s}} \]

\[ \sigma (E_t > 100 \text{ GeV}) \]

\[ \sigma_{t\bar{t}}(M_{t\bar{t}} = 150 \text{ GeV}) \]

\[ \sigma_{t\bar{t}}(M_{t\bar{t}} = 500 \text{ GeV}) \]

- Cacciari et al., JHEP 0404:068, 2004
- Sullivan, Phys. Rev. D70:114012, 2004

- 6.7 pb (1.96 TeV, \( m_t = 175 \text{ GeV} / c^2 \))
- RunII 30% higher than RunI

- 85%
- 15%

Single top quark production via weak interaction

- S-channel: 0.88 pb
- Sullivan, Phys. Rev. D70:114012, 2004

- T-channel: 1.98 pb

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Top quark identification

decay product have:

- good angular separation in the lab frame
- high transverse momentum

\[ t \rightarrow Wb \cong 100\% \]

Need to reconstruct and identify:

Electrons, muons, jets, b-jets and missing transverse energy

\[ \textit{dilepton (e+\mu)} \quad 4.5\% \]

\[ \textit{Lepton + jet} \quad 29\% \]
CDF and D0 in Run II

- New Silicon Detector
- New Central Drift Chamber
- New End Plug Calorimetry
- Extended muon coverage
- New trigger and electronics

Silicon Detector and central fiber tracker in a 2 T solenoid
Substantially upgraded muon system
New trigger and electronics
Luminosity

D0: recorded 0.53 fb$^{-1}$
CDF recorded 0.61 fb$^{-1}$

1.1032 cm$^{-2}$sec$^{-1}$

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

Start of Fiscal Year

Design Projection
Base Projection

8.5 fb$^{-1}$
4.4 fb$^{-1}$

10$^{32}$ cm$^{-2}$sec$^{-1}$

we are here

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Production Cross section

• many results:
different decay channels,
different methods,
with/without b-tagging
• Is there more than the top quark ?
• single top (weak top production)
Di-lepton

Both W decay into lepton and neutrino: 2 jets (b), 2 leptons, high missing Et low BG but low yield

$$\sigma(t\bar{t}) = 8.6^{+2.5}_{-2.4} (\text{stat}) \pm 1.1 (\text{syst}) \text{ pb}$$

Ultra-pure sample of top quark events: S/N>50

PRL 93, 142001 (2004)
All jets cross section

requires b-tagging

Both $W$ decay in $q$-$ar{q}$
4 jets + 2 b jets, high transverse energy
High yield, high BG

$\sigma(t\bar{t}) = 7.7^{+3.4}_{-3.3}(\text{stat})^{+4.7}_{-3.8}(\text{syst}) \pm 0.5(\text{lumi}) \text{ pb}$

$\sigma(t\bar{t}) = 7.8 \pm 2.5(\text{stat})^{+4.7}_{-2.3}(\text{syst}) \text{ pb}$
Lepton+jets

One W decay in q-qbar, one in lepton + neutrino
2jets + 2 bjets + lepton + missing Et
medium yield, medium BG

l+jets with soft lepton tagging

\( \sigma(t\bar{t}) = 7.2^{+1.3}_{-1.2} (\text{stat})^{+1.9}_{-1.4} (\text{syst}) \text{ pb} \)

e+jets: 141 pb\(^{-1}\)

\( \sigma(t\bar{t}) = 5.2^{+2.9}_{-1.9} (\text{stat})^{+1.3}_{-1.0} (\text{syst}) \text{ pb} \)

\( \sigma(t\bar{t}) = 7.2^{+2.6}_{-2.4} (\text{stat})^{+1.6}_{-1.7} (\text{syst}) \text{ pb} \)
e and mu
many measurements with 30-40% precision compatible with SM, compatible with NP
Aiming for 10% with 2fb⁻¹

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Anomalous Top kinematics

RunII dilepton 193pb-1

use the cross section analysis preselection and look for events with topology inconsistent with a t-tbar dilepton event

probability to measure a sample less consistent with SM is 1%-4.5%

Submitted to PRL

result is dominated by these 9 events in the whole sample. No subset with significant deviations

more top like

no excess of events with high missing Et and lepton pt seen in RunII

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Example likelihood fit for $m=225\text{GeV/c}^2$

CDF lepton+jets event selection discriminate between $t$ and $t'$ with $H_T$
**Single top quark limits**

- high pt lepton
- high missEt
- two bjets (+1 light q)

**CDF**

combined s+t limit: <17.8pb (95%CL)

PRD 71 (2005) 012005

- s-channel < 19pb
- t-channel < 25pb (95%CL)
- combined < 23pb

and update from D0 is about to be released

Q: charge of the lepton
η: pseudorapidity of the non b jet

s-channel: <13.6pb (95%CL)
t-channel: <10.1 pb
Top quark Properties

- Mass
- $R = \frac{B(t \rightarrow Wb)}{B(t \rightarrow Wq)}$
- $W$ helicity
Top Mass

• 10 years of top quark mass measurement:
  from kinematical fit and template comparison, to
  likelihood calculations using maximum information

• RunI has a 2.5% uncertainty
  RunII 5%, aim for 1% (~2GeV/c^2).

Published in Nature, June 2004

m_t = 180.1±3.6(stat)±3.9(syst) GeV/c^2

New Mass measurement with RunI data from D0.
Single most precise top mass measurement
New Top Mass World Average (Run I)

\[ m_{\text{top}} = 178.0 \pm 4.3 \text{ GeV/c}^2 \]

\[ m_H = 114^{+69}_{-45} \text{ GeV/cc} \]

\[ m_H < 260 \text{ GeV} @ 95\% \text{ C.L.} \]
Mass in Run II, D0

Measurements in lepton+jets channel (~150 pb⁻¹)

- **template** method uses templates for signal and background mass spectra
- **ideogram** method uses analytical likelihood for event to be signal or background

![Template](image1)

<table>
<thead>
<tr>
<th>Fit Mass (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
</tr>
<tr>
<td>events</td>
</tr>
<tr>
<td>16</td>
</tr>
</tbody>
</table>

- **Ideogram**

D0 RunII preliminary Combined
177.5 ± 5.8 GeV

\[ m_t = 170.0 \pm 6.5 \text{(stat)} ^{+10.2} _{-5.7} \text{(syst)} \text{ GeV/c}^2 \]

\[ m_t = 177.5 \pm 5.8 \text{(stat)} \pm 7.1 \text{(syst)} \text{ GeV/c}^2 \]

Systematical error dominated by the (un)knowledge of the jet energy scale

Will improve very soon!

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Mass in RunII, CDF

**l+jets, multivariate**

**l+jets, b tagged**

**di-leptons**

\[ m_t = 179.6^{+6.4}_{-6.3} \text{ (stat)} \pm 6.8 \text{ (syst) GeV/c}^2 \]

\[ m_t = 174.9^{+7.1}_{-7.7} \text{ (stat)} \pm 6.5 \text{ (syst) GeV/c}^2 \]

\[ m_t = 176.5^{+17.2}_{-16.0} \text{ (stat)} \pm 6.9 \text{ (syst) GeV/c}^2 \]

**Dynamical Likelihood Method**

similar to D0 "matrix element method"

\[ m_t = 177.8^{+4.5}_{-5.0} \text{ (stat)} \pm 6.2 \text{ (syst) GeV/c}^2 \]

**Single most precise Run II measurement**

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Branching ratio

\[ R = \frac{B(t \rightarrow Wb)}{B(t \rightarrow Wq)} \]

SM: \( R = 0.998 \)

\[ R = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2} = |V_{tb}|^2 \]

Ratios of number of events in b-tag bins
2D fit to the cross section and R for tagged events
Measure \( R^* \varepsilon_b \) (\( \varepsilon_b \) = tagging efficiency)

\[ R = 1.11^{+0.21}_{-0.19} \text{ (stat+syst)} \]
\[ > 0.62 \text{ at } 95\% \text{ C.L.} \]

SVT: \( R = 0.70^{+0.27}_{-0.24} \text{ (stat)}^{+0.11}_{-0.10} \text{ (syst)} \)
CSIP: \( R = 0.65^{+0.34}_{-0.30} \text{ (stat)}^{+0.17}_{-0.12} \text{ (syst)} \)
W helicity

In SM $F_- = 0.30$, $F_0 = 0.70$, $F_+ = 0$

$$M^2_{l+b} = 1/2 \cdot (M_T^2 - M_W^2)(1 + \cos \psi^*_l)$$
W helicity

CDF RunI result:
F+ < 0.18 (95% CL)

CDF
F0 = 0.89 ± 0.30 ± 0.17 (stat) ± 0.34 (syst)
F0 > 0.25 (95% CL)
lep+jets

CDF
F0 = 0.27 ± 0.35 ± 0.24
F0 < 0.88 (95% CL)
lep+jets & dilepton

F+ < 0.24 (90% CL) with tag
F+ < 0.24 (90% CL)
dilepton

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Conclusion

• The top quark is very heavy = very interesting.
• With the Tevatron running really well, we are at the doorstep of learning much more, in more detail about the top quark and what it can tell us about undisclosed physics.
• Cross section measurements at the Tevatron RunII are consistent with SM, but also with new physics. More expected soon and aim for 10% with RunII.
• New Mass average from RunI. Measurements from RunII. More statistics and better jet energy scale should reduce the uncertainty very soon.
• Still only limits on single top quark production, should be seen in 1fb\(^{-1}\) to 2fb\(^{-1}\)
• Analyses with double statistics almost ready, double again next year.
• More results to come (new physics ?).