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

The top quark decays before it can hadronize

\[ Y_t = \approx 1 \]

- Resonance production
- Production kinematics
- Top Spin Polarization
- Rare/non SM Decays
- Branching Ratios
- \(|V_{tb}|\)
- W helicity
- Top Mass
- Top Width
- Top Spin
- Top Charge
- Anomalous Couplings
- CP violation

New Physics
Top Quark Production

Top quark pair production via strong interaction

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

Cacciari et al, JHEP 0404:068, 2004

Single top quark production via weak interaction

s-channel: 0.88pb

Sullivan, Phys.Rev.D70:114012, 2004

\[ t\text{-channel: 1.98pb} \]
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
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\(^{-1}\)

\[ 1 \times 10^{32} \text{ cm}^{-2} \text{sec}^{-1} \]
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

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

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

combined di-lepton and lepton + opposite charge track:

$\sigma(t\bar{t}) = 7.0^{+2.7}_{-2.3} (stat)^{+1.5}_{-1.4} (syst) \text{ pb}$

PRL 93, 142001 (2004)

M. Weber, Aspen 2005
All jets cross section

requires b-tagging

Both W decay in q-qbar
4jets + 2 bjets, 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
2 jets + 2 b jets + lepton + missing Et
medium yield, medium BG

l+jets with soft lepton tagging

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

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

e and mu

M. Weber, Aspen 2005
many measurements with 30-40% precision
compatible with SM, compatible with NP
Aiming for 10% with 2fb$^{-1}$
Anomalous Top kinematics

CDF

RunII dilepton 193pb-1

Use the cross section analysis preselection and look for events with topology inconsistent with a t-\(\bar{t}\) dilepton event.

Submitted to PRL

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

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 \(E_T\) and lepton pt seen in RunII

M. Weber, Aspen 2005
Example likelihood fit for $m=225 \text{GeV/c}^2$ lepton+jets event selection discriminate between $t$ and $t'$ with $H_t$. 

CDF Run 2 (195 pb$^{-1}$) Preliminary

$N_{\text{jet}} \geq 4$

Cacciari, et al.,
NLL resummed
hep-ph/0303085

CDF Run 2 195 pb$^{-1}$
t$\rightarrow$Wq, $\ell + \geq 4$ jets channel
Projected sensitivity
(statistical improvement only)

Cacciari, et al.,
NLL resummed
hep-ph/0303085
Single top quark limits

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

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
- $R = \frac{B(t \to Wb)}{B(t \to Wq)}$
- 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/c²).

New Mass measurement with RunI data from D0.
Single most precise top mass measurement

\[
m_t = 180.1 \pm 3.6 \text{(stat)} \pm 3.9 \text{(syst)} \text{ GeV/c}^2
\]

Published in Nature, June 2004
New Top Mass World Average (Run I)

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

Relative weight in top mass average

D0 weight

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

\[ m_H < 260 \text{ GeV @ 95\% C.L.} \]
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

Ideogram

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

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

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

Will improve very soon!
Mass in RunII, CDF

**Di-leptons**

$\mathbf{m_t} = 179.6^{+6.4}_{-6.3}\text{ GeV}/c^2$

**l+jets, multivariate**

$\mathbf{m_t} = 174.9^{+7.1}_{-7.7}\text{ GeV}/c^2$

**l+jets, b tagged**

$\mathbf{m_t} = 176.5^{+17.2}_{-16.0}\text{ GeV}/c^2$

Dynamical Likelihood Method

similar to D0 “matrix element method”

$\mathbf{m_t} = 177.8^{+4.5}_{-5.5}\text{ GeV}/c^2$

Single most precise Run II measurement

M. Weber, Aspen 2005
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)

SM: \( R = 0.998 \)

158 pb\(^{-1}\) mu and 169 pb\(^{-1}\) e

SVT: \( R = 1.11^{+0.21}_{-0.19} \) (stat+syst)
\( > 0.62 \) @ 95% C.L.

CSIP: \( R = 0.65^{+0.34}_{-0.30} \) (stat) \( +0.17_{-0.12} \) (syst)

SVT: \( R = 0.70^{+0.27}_{-0.24} \) (stat) \( +0.11_{-0.10} \) (syst)
W helicity

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

$$M_{l+b}^2 = \frac{1}{2} \cdot (M_T^2 - M_W^2)(1 + \cos \psi_l^*)$$
W helicity

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

CDF

F0=0.89^{+0.30}_{-0.34} (stat) ±0.17 (syst)
F0>0.25 (95% CL)
lep+jets

lep+jets & dilepton

F0=0.27^{+0.35}_{-0.24}
F0 < 0.88 (95% CL)
dilepton
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 ?).