Top quark production at D0

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Tevatron and D0

- birthplace of top quark
- $p\bar{p}$ collisions at $\sqrt{s}=1.96$ TeV
- shut down on Sept. 30 2011
- 10.5 fb$^{-1}$ of recorded data per experiment

- high resolution inner detectors for precise tracking and vertex recons.
- electromagnetic and hadronic calorimeters
- outer muon system
- magnetic field
Top quark pair production at the Tevatron

- Top quark pair produced in strong interaction via:
  - quark-antiquark annihilation ($\sim 85\%$)
  - gluon-gluon fusion ($\sim 15\%$)

- Theoretical NNLO$_{approx}$ cross section of $\sigma_{tt} = 7.46 \text{ pb}$ at $m_t = 172.5$ GeV (PRD78, 034003 (2008))

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

- $tt\bar{t}$ final states categorized according to W decay:
  - dilepton - small BR for signal ($\sim 5\%$), small background
  - lepton+jets - best in sensitivity, golden channel
  - all-hadronic - large BR for signal ($\sim 50\%$), huge QCD background
Top quark pair production - lepton+jets

- 5.3 fb$^{-1}$ of data
- required 1 isolated $e$ or $\mu$, $\geq 2$ jets, large $E_T$
- main backgrounds: $W+$jets, QCD multijet production, $Z+$jets and diboson production
- used 3 methods to extract $\sigma_{t\bar{t}}$
  - kinematic method - multivariate discriminant maximum likelihood fit of distributions in discriminant (templates)
  - counting method using b-tagging - neural network based b-tagging, maximum likelihood fit to data
  - combination of the above
- largest uncertainty from luminosity

$$\sigma_{t\bar{t}} = 7.78^{+0.77}_{-0.64} \text{(stat + syst)} \text{pb}$$

PRD 84, 012008 (2011)
Top quark pair production - dilepton

- 4 channels \((ee+2j, \mu\mu+2j, e\mu+1, 2j)\)
- 5.4 fb\(^{-1}\) of data
- required 2 isolated leptons, \(\geq 1,2\) jets, large \(E_T\)
- main backgrounds: Drell-Yan, Z boson production, diboson production, instrumental background
- used neural network based b-tagging to construct event discriminant
- \(t\bar{t}\) cross section extracted from the fit to b-tagging NN discriminant
- largest uncertainty from luminosity

\[
\sigma_{t\bar{t}} = 7.36^{+0.90}_{-0.79} (\text{stat + syst}) \text{ pb}
\]

PLB 704, 403 (2011)
Top quark pair production - lepton+jets and dilepton

- combined measurements in lepton+jets and dilepton channel
- 5.4 fb$^{-1}$ of data
- lepton+jets events with only 2 jets not used in the combination
- relative precision of 8%

$$\sigma_{t\bar{t}} = 7.56^{+0.63}_{-0.56} \text{(stat + syst)} \text{pb}$$

PLB 704, 403 (2011)
Single top quark production at the Tevatron

- single top quark produced via electroweak interaction
  - s-channel $\sigma_{s-ch} = 1.04 \text{ pb} \text{ at } m_t = 172.5 \text{ GeV}$
  - t-channel $\sigma_{t-ch} = 2.26 \text{ pb} \text{ at } m_t = 172.5 \text{ GeV}$
  - tW channel $\sigma_{tW} = 0.28 \text{ pb} \text{ at } m_t = 172.5 \text{ GeV}$

PRD 74, 114012 (2006)

- observed by CDF and D0 collaborations in 2009
  - PRL 103, 092001 (2009)
Single top quark production - s+t channel cross section

- 5.4 fb$^{-1}$ of data, lepton+jets channel
- required 1 isolated $e$ or $\mu$, large $E_T$
- 2-4 jets, 1 or 2 b-tagged jet
- main backgrounds: W+jets, $t\bar{t}$ and multijet production
- used 3 methods to extract the signal from multivariate discriminant
- used Bayesian approach to extract s- and t-channel cross sections together and separately

$$\sigma_{s+t} = 3.43^{+0.73}_{-0.74} \text{ pb}$$

$$\sigma_{s-ch} = 0.68^{+0.38}_{-0.35} \text{ pb}$$

$$\sigma_{t-ch} = 2.86^{+0.69}_{-0.63} \text{ pb}$$

PRD 84, 112001 (2011)
Single top quark production - t-channel

- combined discriminant used to separate signal from background
- contracted Bayesian 2D posterior probability density for t-ch and s-ch cross sections
- no constraint on relative rates of s-ch and t-ch production
- t-ch cross section extracted from 1D posterior probability by integrating over s-ch cross section values (no assumption on s-ch cross section)
- s-ch cross section obtained in the same way

\[ \sigma_{\text{t-ch}} = 2.90 \pm 0.59 \text{ pb} \]
\[ \sigma_{\text{s-ch}} = 0.98 \pm 0.63 \text{ pb} \]

PLB 705, 313 (2011)
Forward-backward asymmetry - $A_{\text{fb}}$

- QCD predicts no asymmetry at LO, small asymmetry at NLO ($\sim 5 - 9\%$)

- forward-backward asymmetry

$$A_{\text{fb}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

reconstructed $\Delta y = q_l \cdot (y_{t,\text{lep}} - y_{t,\text{had}})$

- asymmetry based on charge, rapidity $(q_l, y_l)$ of lepton from top decay

$$A_{\text{fb}}^l = \frac{N(q_l y_l > 0) - N(q_l y_l < 0)}{N(q_l y_l > 0) + N(q_l y_l < 0)}$$

- two different types of measurements
  - reconstruction level: after event selection, reconstruction and background subtraction
  - production level: after correction for detector effects ("unfolding")
Forward-backward asymmetry - $A_{fb}$

- $5.4 \text{ fb}^{-1}$, lepton+jets channel
- 1 isolated $e/\mu$, $E_T$, $\geq 4$ jets, $\geq 1$ b-jet
- Kinematic fitter to reconstruct events
- Backgrounds: $W$+jets, multijet production
- Constructed likelihood discriminant to separate signal/background
- Maximum likelihood fit to measure reconstructed asymmetry
- Regularized unfolding to correct for detector effects

Reconstructed

\[
A_{fb} = (9.2 \pm 3.7) \%
\]

\[
A_{fb}^I = (14.2 \pm 3.8) \%
\]

Unfolded

\[
A_{fb} = (19.6 \pm 6.5) \%
\]

\[
A_{fb}^I = (15.2 \pm 4.0) \%
\]

PRD 84, 112005 (2011)
Summary

- top pair production cross section measured with 8% relative precision
- both top pair and singletop cross sections consistent with SM prediction
- forward-backward asymmetry in $t\bar{t}$ events above prediction

DØ Run II

<table>
<thead>
<tr>
<th>Channel</th>
<th>Cross Section (pb)</th>
<th># of fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>lepton+jets + dileptons (PLB)</td>
<td>7.40 ±0.19 <em>+0.57</em>-0.50</td>
<td>5.4</td>
</tr>
<tr>
<td>lepton+jets (topo + b-tagged, PRD)</td>
<td>7.65 ±0.25 <em>+0.75</em>-0.57</td>
<td>5.3</td>
</tr>
<tr>
<td>dileptons (topo + b-tagged, PLB)</td>
<td>7.27 ±0.45 <em>+0.76</em>-0.63</td>
<td>5.4</td>
</tr>
<tr>
<td>lepton+track (b-tagged)*</td>
<td>5.0 <em>+1.6</em>-1.4 <em>+0.9</em>-0.8 ±0.3</td>
<td>1.0</td>
</tr>
<tr>
<td>tau+lepton (b-tagged)*</td>
<td>7.32 ±1.34 <em>+1.20</em>-1.24 <em>+0.67</em>-1.06 ±0.45</td>
<td>2.2</td>
</tr>
<tr>
<td>tau+jets (b-tagged, PRD)</td>
<td>6.30 ±1.15 <em>+0.72</em>-1.05 <em>+0.67</em>-0.67 ±0.40</td>
<td>1.0</td>
</tr>
<tr>
<td>alljets (b-tagged, PRD)</td>
<td>6.9 <em>+1.3</em>-1.3 <em>+1.4</em>-1.4 ±0.4</td>
<td>1.0</td>
</tr>
</tbody>
</table>

$m_{t\bar{t}} = 175$ GeV
CTEQ6.6M

- M. Cacciari et al., JHEP 0809, 127 (2008)

* = preliminary
red = 2011 result
blue = 2010 results

DØ e/μ+jets 2.3 fb$^{-1}$: $3.94^{+0.88}_{-0.88}$ pb
DØ τ+jets 4.8 fb$^{-1}$: $3.4^{+2.0}_{-1.8}$ pb
CDF e/μ+jets 3.2 fb$^{-1}$: $2.17^{+0.56}_{-0.55}$ pb
CDF MET+jets 2.3 fb$^{-1}$: $5.0^{+2.6}_{-2.3}$ pb
Tevatron Combination: $2.76^{+0.58}_{-0.47}$ pb
DØ e/μ+jets 5.4 fb$^{-1}$: $3.70^{+0.78}_{-0.80}$ pb

$m_{t} = 170$ GeV

Kidonakis PRD 74, 114012 (2006)
Backup slides

Backup slides
B-tagging

- procedure of linking a jet to b-quark
- b-hadrons usually live long enough to travel measurable distances and can produce muons in semileptonic decays
- b-hadron decays often produce displaced (secondary) vertices with tracks not pointing to primary vertex and muons which is used to recognize them from jets initiated by other partons
- some analyzed final states contain jets coming from hadronization of b quarks (top decays) their identification help to reduce combinatorial background and improve signal/background separation
Top quark pair production - tau+jets

- Semihadronic decays of $\tau$, hard to distinguish leptons from $\tau$ and W decays
- 1 fb$^{-1}$ of data
- Required $\geq 4$ jets, $\geq 1$ $\tau_h$ candidate, large $E_T^/ \text{ and } E_T^/$ significance, no isolated leptons
- Three $\tau$ candidate categories
- Neural network to further discriminate $\tau$/jets
- $\geq 1$ b-jet using b-tag neural network
- Main backgrounds: multijet production, $tt\bar{t}$ decays to leptons, W+jets, Z+jets
- Fit to neural network discriminant to estimate signal

$$\sigma_{tt\bar{t}} = 6.9^{+1.5}_{-1.4} \text{(stat + syst)} \text{ pb}$$
Top quark pair production - all-hadronic

- 1 fb$^{-1}$ of data, multijet trigger
- required $\geq 6$ jets, $\geq 4$ jets with $p_T > 40$ GeV
- $\geq 2$ b-tagged jets (NN), no isolated leptons
- main backgrounds: QCD multijet production
  data driven background model using events with
  4 or 5 jets with 2 b-tags
- likelihood discriminant constructed from
topological observables to separate S/B
- fit signal and background templates to likelihood output to extract signal fraction

$$\sigma_{tt} = 6.9 \pm 2.0 \text{ (stat + syst)} \text{ pb}$$

PRD 82, 032002 (2010)