Observation of Single Top Production at DØ

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on behalf of the DØ collaboration

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SM single top quark production

\[ \sigma_s = 1.12 \text{ pb} \]

\[ \sigma_t = 2.34 \text{ pb} \]

\[ \sigma_{\text{tot}} = 3.46 \text{ pb} \text{ for } m_{\text{top}} = 170 \text{ GeV} \text{ (Kidonakis et al.)} \]

**Tevatron Goals:**
- Discover single top quark production
- Measure production cross sections \( \sigma_{s+t}, \sigma_s, \sigma_t \)
- First direct measurement of CKM matrix element \( V_{tb} \)
- Look for new physics
- Understand as background to many searches
- Establish techniques that will also be used in Higgs and other searches
Proton-antiproton collider
CM energy 1.96 TeV
→ Energy frontier
Instantaneous luminosity exceeding $3 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$
→ Luminosity frontier
Single top event selection

- Basic event signature (e or µ)
  - Include many triggers
  - One high-$E_T$ leptons (>15GeV)
  - Missing transverse energy (>15GeV)
  - 2-4 jets ($E_T>$15GeV)
  - At least one b-tag

Backgrounds

QCD multijets

W+jets: Wjj, Wcj, Wcc, Wbb

Top quark pairs
Analysis outline

Trigger selection

S/B = 1/10^9

Single top event kinematics

S/B = 1/250, 115,000 events

b-quark tagging

S/B = 1/20, 4500 events in 24 channels

Statistical analysis

Combination

Multivariate techniques

BDT

BNN

ME

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**Discriminating variables**

- Check data-background agreement for 600 variables
- Choose 20-64 variables for different MVAs in different channels
  - Object and event kinematics, angular correlations, top reconstruction, jet reconstruction

**Systematic uncertainties**
- Shape and normalization uncertainties
- Background uncertainty 10% to 20%, larger in the signal region
Multivariate analysis methods

Boosted Decision Trees
Bayesian Neural Networks
Matrix Elements

Boosted Decision Trees Output

Bayesian Neural Networks Output

W+Jets Cross-Check Sample

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Combination: Another BNN

DØ Single Top

2.3 fb⁻¹

Event Yield

Data
tb + tqb
W+jets
Wc
Multijets
±1σ uncertainty on background

Signal Region

DØ 2.3 fb⁻¹

Ranked Combination Output > 0.92

Yield [Events/30GeV]

Top Quark Mass [GeV]

W+Jets Cross-Check Sample

DØ 2.3 fb⁻¹

Event Yield

Data
tb + tqb
Wb
Wc
Wj + Wc
Non-W
Multijets

H_T < 175 GeV
1 b-tag
2 jets

DØ 2.3 fb⁻¹

Event Yield

Data
tb + tqb
Wb
Wc
Wj + Wc
Non-W
Multijets

H_T > 300 GeV
1,2 b-tags
4 jets

DØ 2.3 fb⁻¹

Event Yield

Data
tb + tqb
Wb
Wc
Wj + Wc
Non-W
Multijets

Q(.lepton) × η(light-quark jet)
Cross section and significance

- Bayesian statistical analysis
  - Including all systematics and their correlations
  \[ \sigma(s+t) = 3.94 \pm 0.88 \text{ pb} \]
- Significance and linearity from ensembles of pseudo-datasets

\[ \sigma \text{measured} = 3.94 \pm 0.88 \text{ pb} \]
\[ \sigma \text{expected} = 3.50^{+0.99}_{-0.77} \text{ pb} \]
Summary and $V_{tb}$

### DØ 2.3 fb$^{-1}$ Single Top Results

<table>
<thead>
<tr>
<th>Analysis Method</th>
<th>Single Top Cross Section</th>
<th>Significance</th>
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<tbody>
<tr>
<td></td>
<td>Expected</td>
<td>Measured</td>
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<tr>
<td>BOOSTED DECISION TREES</td>
<td>3.74$^{+0.95}_{-0.79}$ pb</td>
<td>4.3 $\sigma$</td>
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<tr>
<td>BAYESIAN NEURAL NETWORKS</td>
<td>4.70$^{+1.18}_{-0.93}$ pb</td>
<td>4.1 $\sigma$</td>
</tr>
<tr>
<td>MATRIX ELEMENTS</td>
<td>4.30$^{+0.99}_{-1.20}$ pb</td>
<td>4.1 $\sigma$</td>
</tr>
<tr>
<td>COMBINATION</td>
<td>3.94 $\pm$ 0.88 pb</td>
<td>4.5 $\sigma$</td>
</tr>
</tbody>
</table>

\[ V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \]

\[ |V_{tb}| > 0.78 \]

\[ V_{tb} \] at 95% CL

0 $\leq$ flat prior $\leq$ 1

N. Kidonakis, PRD 74, 114012 (2006) $m_{top} = 170$ GeV

Submitted to PRL, arXiv:0903.0850

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First evidence for t-channel production

- Train MVA filters for t-channel
- Measure t-channel and s-channel simultaneously
  - Remove s/t constraint
  - $\sigma(t) = 3.14_{-0.81}^{+0.94} \text{ pb}$
  - Expected/observed significance: 3.7/4.8 SD
  - $\sigma(s) = 1.05 \pm 0.81 \text{ pb}$

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Conclusions

• We are learning a lot about the top quark at the Tevatron

• DØ has observed single top quark production at the 5.03 SD level with 2.3fb\(^{-1}\)
  – \(\sigma(s+t) = 3.94 \pm 0.88 \text{ pb}\)
  – \(|V_{tb}| > 0.78\) at 95% C.L.

• DØ has isolated the t-channel mode
  – Without assumptions about the s-channel cross section
  – \(\sigma(t) = 3.14^{+0.94}_{-0.81} \text{ pb}\)
  – Significance 4.8 SD

• Updates with larger dataset and dedicated searches for new physics are in progress