First observation of single-top quark production in the s channel at Tevatron

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Top Quark Timelines at Tevatron

s-channel is single top production is a legacy measurement at the Tevatron
The Tevatron p-\bar{p} Collider at Fermilab

\[ \sqrt{s} = 1.96 \text{ TeV} \]
\[ \Delta t = 396 \text{ ns} \]

Run I 1987 (92)–95
Run II 2001–11: 100x larger dataset at increased energy

10^{-12}s after big bang!
Top Production at the Tevatron

Pairs

- Mostly via QCD pair production
- \( M \approx 173 \text{ GeV}, \tau = 5 \times 10^{-25} \text{ s} \): no top-flavoured hadrons
- Large coupling to Higgs boson, important role in EW symmetry breaking?
  - Nearly 100% decay to \( Wb \)
  - Opportunity to study a “bare” quark

Single

- Production via EW in 3 channels: \( s, t, Wt \)
- Tevatron and LHC both sensitive to \( t \)-ch; Tevatron not sensitive to \( Wt \)-ch but advantage on \( s \)-ch
  - at LHC 5 times more signal but 15 times more background
  - will be very challenging also at RunII since processes like \( tt\bar{t} \) increase more than \( s \)-ch production

Detector/\( \sigma (\text{pb}) \) for Tevatron and LHC

<table>
<thead>
<tr>
<th>Detector/( \sigma (\text{pb}) )</th>
<th>s-ch</th>
<th>t-ch</th>
<th>Wt-ch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tevatron 1.05</td>
<td>2.08</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>LHC (8 TeV) 5.55</td>
<td>87.2</td>
<td>11.1</td>
<td></td>
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</tbody>
</table>

arXiv:1311.0283
Why measure the single top production

\[ \sigma_{\text{Single top}} \propto |V_{tb}|^2 \], Gives access to the W-t-b vertex

- Direct measurement of \(|V_{tb}|\) CKM matrix element
- Does unitarity hold? \( |V_{tb}|^2 + |V_{cb}|^2 + |V_{ub}|^2 = 1 \)

**Sensitivity to new physics**

- t-ch: FCNC
- s-ch: heavy W', Top pion

**Challenges**

- Single top quark produced with decay into \( W+2\text{jets} \)
  (dominated by \( W+\text{jets} \) background)
- Final state hidden by large backgrounds with large uncertainties
  (e.g. \( W+\text{Heavy Flavour} \) uncertainty ~ 30%)
  - MVA using Multiple variables combined into a single more powerful discriminant to separate Signal from Background
Event Selection

• **Lepton + jets**
  - One high-$p_T$ isolated lepton (e, mu)
  - Missing transverse energy $\not{E}_T$
  - 2 or 3 jets
  - At least one b-tag

• **Missing energy + jets (CDF only)**
  - No isolated lepton (e, mu)
    - leptons vetoed, orthogonal to l + jets
  - Large MET > 35 GeV
  - 2 or 3 jets
  - At least one b-tag

Orthogonal event selections add 33% more events
**Signal and Background**

**Electroweak/Top:** Single Top, ttbar, diboson
- modeled by Monte Carlo (MC)
  - single top: powheg (CDF), CompHEP (DØ)
  - ttbar: Pythia (CDF), Alpgen (DØ)
  - diboson, WH: Pythia
- normalized to theoretical cross section

**W+jets:**
- modeled by Alpgen+Pythia Monte Carlo (MC)
- normalisation and flavour composition from data

**Z+jets:** modeled by Alpgen+Pythia MC

**Multijet:**
- Normalisation and shape from data-driven model
Multivariate Analysis

Boosted Decision Trees

Neural Networks

Matrix Elements

Correlations
- BDT: 77%
- BNN: 75%
- ME: 73%
D0 lepton + jets

- Combination of boosted decision trees, Matrix elements and neural networks in a Bayesian neural network
- Train separately for s-channel and t-channel
- Use BNN output to form combined discriminant

Input Variables

![Graphs showing yield distributions for different processes](images/)...
Tevatron s-channel Combination

CDF $l\nu bb$  

Input

CDF MET + jets

Combine individual discriminants including all correlations!

Output

D0 $l\nu bb$
Tevatron observation of single top in s-channel

\[ \sigma_s = 1.29^{+0.26}_{-0.24} \text{ (stat+sys) pb} \]
\[ (\pm 19\%) \]

6.3 \sigma (5.1 \sigma \text{ expected})

PRL 112 231803 (2014)
Tevatron Single Top Summary

Full Tevatron dataset upto 9.7 fb⁻¹

29% first evidence: 3.7 σ
19% first observation: 6.1 σ

13%; Vtb: 5.3% precision
Summary

- Single Top was observed at CDF and D0 in 2009
- Now Single Top program at the Tevatron is almost complete
- New $s+t$ Tevatron combination has been performed
- $s$-channel was the last missing block among the Single Top channels → Observed

All measurements are in agreement with standard model predictions
Backup
s-channel single top quark, Tevatron Run II, $L_{int} \leq 9.7 \text{ fb}^{-1}$

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Cross section [pb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDF $l^+\text{jets}$</td>
<td>1.41$^{+0.44}_{-0.42}$</td>
</tr>
<tr>
<td>CDF $\ell\gamma+\text{jets}$</td>
<td>1.12$^{+0.61}_{-0.57}$</td>
</tr>
<tr>
<td>CDF combined</td>
<td>1.36$^{+0.37}_{-0.32}$</td>
</tr>
<tr>
<td>D0 $l^+\text{jets}$</td>
<td>1.10$^{+0.33}_{-0.31}$</td>
</tr>
<tr>
<td>Tevatron combined</td>
<td>1.29$^{+0.26}_{-0.24}$</td>
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Theory (NLO+NNLL)
1.05 \pm 0.06 \text{ pb} [PRD 81, 054028, 2010]
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$m_{top} = 172.5 \text{ GeV}$

Probability density

- Background only
- SM signal + background
- SM expected
- Observed

Expected significance: 5.1 s.d.
Observed significance: 6.3 s.d.