Search for Single Top Quark Production in the Electron Channel at DØ in Run II

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Outline

• Introduction
  – Tevatron $p\bar{p}$ Collider
  – Single Top Quark Production

• Experimental Setup
  – DØ Detector
  – Final State Reconstruction

• Single Top Analysis
  – Preselection
    • Event Yield Estimates
  – Final Selection Cuts

• Result

• Outlook
Introduction

- Tevatron is the highest-energy accelerator in the world
  - Test predictions of the Standard Model in detail
  - Search for new interactions not predicted by the Standard Model
  - Only place in the world to observe top quarks
    - Observation of top quark through pair production
    - Measurement of top quark mass
- Search for interactions predicted by the Standard Model but not yet observed → Single Top Production
Single Top Quark Production

• Electroweak production of top
  
  \[ s\text{-channel} \]

  \[
  q \rightarrow W^{-} \rightarrow q' + V_{tb} + b^{-} \]

  \[
  \bar{q}' \rightarrow W^{+} \rightarrow \bar{q} + b \]

  \[ t\text{-channel} \]

  \[
  g \rightarrow W^{-} \rightarrow t + V_{tb} + b^{-} \]

  \[
  b \rightarrow W^{+} \rightarrow g + t' \]

  \[ NLO \text{ cross-sections:} \]

  \[
  s\text{-channel:} \quad 0.88 \text{pb} \pm 8\% \\
  t\text{-channel:} \quad 1.98 \text{pb} \pm 11\% 
  \]

  \[ Run \text{ I:} \]

  \[
  DØ: 95\% \text{ CL:} \quad <17 \text{pb} \]

  \[
  CDF: 95\% \text{ CL:} \quad <18 \text{pb} 
  \]

  \[
  DØ: 95\% \text{ CL:} \quad <22 \text{pb} \]

  \[
  CDF: 95\% \text{ CL:} \quad <13 \text{pb} 
  \]

• Test predictions of the Standard Model

  \[ \text{Measure CKM matrix element } V_{tb} \text{ (test CKM unitarity)} \]

  \[ \text{Observe top polarization} \]
Single Top Event Signature

s-channel production  top decay  W decay
q  W  t  b
q'  electron  neutrino

Final State
b-quark jet  electron  missing $E_T$

Final State Objects

jet  electron

Proton beam  Anti-proton beam

Reinhard Schwienhorst, MSU
Experimental Setup: DØ Run II Detector
Final State Reconstruction

- **Electron**
  - Clustering in the calorimeter
  - Matched to central track
  - Likelihood estimator to distinguish from jets

- **Neutrino (MET)**
  - Indirectly through energy imbalance in transverse plane

- **Jets**
  - Clustering calorimeter energy
  - Corrected to get particle $p_T$ (Jet Energy Scale)

- **b-quark identification**
  - Muon-in-jet from b-meson decay
    - Soft-muon tag
  - Tracking-based lifetime tagging

Secondary Vertex Reconstruction (SVT)

Impact Parameter Tag (JLIP)

Probability for each track in the jet to originate from the primary vertex
Backgrounds

- W+jet production
  - Wjj, Wcc, Wbb, ...
  - Estimated from data
    - Normalized untagged W+jets sample by probability to tag a jet in the data (inclusive)
      - Probability is derived from a multi-jet sample
      - Same jet flavor composition as W+jets (within 20% uncertainty)

- Mis-reconstructed multi-jet events
  - Jet mis-identified as electron
  - Estimated from data

- Top-pair production
  - Lepton+jets and di-lepton
  - Estimated from MC

- Other (WZ, WW, cosmic rays)
  - Negligible, not yet included
Analysis Outline

1) Split Analysis into orthogonal channels
   - electron channel
   - soft-muon tag
   - SLV, lifetime tag
   - muon channel
   - soft-muon tag
   - SLV, lifetime tag

2) Preselection based on Single Top Event Signature
   - Select events containing W and jets with at least one b-tag
     - Loose requirements to retain high signal acceptance
     - Study background estimation in detail
       - Prove that background model reproduces data
       - Reject regions of phase space that are not well modeled

3) Final Event Selection
   - Separate single top from backgrounds

4) Combine orthogonal channels for highest sensitivity
Preselection Cuts

- **Lepton**: 1 electron, $p_T > 15\text{GeV}$
- **Neutrino**: missing $E_T > 15\text{GeV}$
- **Jets**: $2 \leq n \leq 4$
  - $p_T > 15\text{GeV}$, leading jet $p_T > 25\text{GeV}$
  - $\geq 1$ b-tag
- **Trigger Requirement**: $\geq 1$ EM object, $\geq 1$ jet
- **Reject mis-reconstructed events**
  - Cosmic ray muons
  - Mis-identified jets
  - Triangle cuts
Event Yields: Number of Jets

DØ Run II preliminary

**SVT**

- Data (tagged)
- ST s-channel
- ST t-channel
- tt -> l+jets
- tt -> dilepton
- Wjets TRF+MM
- QCD TRF+MM

**JLIP**

DØ Run II preliminary

soft-muon tag

# of jets

0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5

0 10 20 30 40 50 60

DØ Run II preliminary

# of jets

0 1 2 3 4 5 6
Event Yields: Event Energy HT

$$HT = E_T^{\text{lepton}} + \text{MET} + E_T^{\text{jet1}} + E_T^{\text{jet2}}$$

**Graphics:**
- **SVT**
  - Histogram showing distribution of HT (GeV) with various contributions and data points.
- **JLIP**
  - Histogram showing distribution of HT (GeV) with various contributions and data points.

**Legend:**
- Data (tagged)
- ST s-channel
- ST t-channel
- $tt \rightarrow l+jets$
- $tt \rightarrow \text{dilepton}$
- Wjets TRF+MM
- QCD TRF+MM

**Soft-muon tag**

**Note:**
- The plots are labeled as DØ Run II preliminary.
Final Event Selection

• Dominant background is from W+jets
  ¬ Cut on HT>150GeV
    – HT = $E_T^{\text{lepton}} + \text{MET} + E_T^{\text{jet1}} + E_T^{\text{jet2}}$
    – Reduces W+jets background by about 50%
    – Reduces Single Top signal by about 5%

• Systematic Uncertainties
  – Data: largest contribution from determination of tagging probability: ~20%
  – MC: large contributions from
    • Jet-Energy-Scale,
    • Trigger modeling
    • MC flavor-dependent b-tag modeling
    • Combined: ~20%
Signal Acceptance

DØ Run II preliminary

- SVT
- soft-muon-tag
- JLIP

Categories:
- e(CC) SVT combined
- e(CC) SVT t-channel
- e(CC) SVT s-channel
- e(CC) SLT combined
- e(CC) SLT t-channel
- e(CC) SLT s-channel
- e(CC) JLIP combined
- e(CC) JLIP t-channel
- e(CC) JLIP s-channel

Values:
0.00% 0.20% 0.40% 0.60% 0.80% 1.00% 1.20% 1.40% 1.60%
Result

• Final Event Yield
  – based on ~160pb of DØ Run II data
  – Soft-muon and secondary vertex tagger combined:
    Sum of backgrounds: $103 \pm 15$ events
    Observed: $117$ events
    Expected from Single Top: $6.2 \pm 1.8$ events

• Observation consistent with Background expectation

• Estimate sensitivity: expected cross section limits
  – Modified frequentist approach (CLs method)
  – Include all systematic uncertainties and correlations
  – Set limit separately for s-channel, t-channel, s+t combined
  – Combine tagging methods and electron and muon channels
DØ Run II Single Top Search Program is on its way

Sensitivity from Run I already exceeded
  – Increased Data Sample
  – DØ detector is performing and understood well

DØ is working towards observation of single top production
  – Collecting more data
  – Improve detector understanding
  – Improve analysis

Expected 95% Cross-Section Limit

\[
\begin{align*}
\text{s-channel: } & <14\text{pb} & \text{s+t-channel: } & <16\text{pb} & \text{t-channel: } & <18\text{pb}
\end{align*}
\]
Supporting Slides
MC Modeling

- Single Top modeling: CompHep
  - gives NLO-corrected distributions, not just LO diagrams
  - including full spin correlations
- t-channel problem:
  - how to match 2 to 2 with W-gluon fusion

2 to 2  \[ \rightarrow \]  W-gluon fusion

solution: phase-space matching
  - b from Pythia for soft region
  - ME generator for hard region
Background Estimation

Preselected Sample

Tagged Sample
require at least one tag

Untagged Sample
=0 tags

scale to pre-tagged W+jets yield

apply Inclusive TRF

Final Data Sample
W+jets yield

multi-jet Sample
preselection cuts
reverse electron likelihood cut

scale to pre-tagged mis-ID lepton yield

apply tagger

mis-ID lepton yield

MC Samples
preselection cuts

apply data/MC scale factors, trigger weight

scale to XS*lumi

apply tagger or flavor-dependent TRFs

MC yields
Background Estimate: pre-tagging

- Preselected, Pretagged sample contains two components:
  - Events with *real* isolated lepton
  - Events with *fake* isolated lepton
    - Jet faking an electron
    - Muon in jet faking isolated muon

- Matrix Method to estimate relative contribution
  - Count events before/after a cut that separates the two (loose/tight)
    - Electron channel: electron likelihood cut (combination of cal/tracking)
      - Background efficiency $e_{QCD}$ determined in multi-jet QCD sample (low MET)
      - Signal efficiency $e_{\text{sig}}$ determined in Zee sample
    - Muon channel: muon isolation from jet
      - Background efficiency $e_{QCD}$ determined in QCD sample (low MET)
      - Signal efficiency $e_{\text{sig}}$ determined in $Z\mu\mu$ sample
Pre-tagged Background Yield: W+jets and QCD

\[ N_L = \tilde{N}_{\text{sig}} + \tilde{N}_{\text{QCD}} \]
\[ N_T = \varepsilon_{\text{sig}} \tilde{N}_{\text{sig}} + \varepsilon_{\text{QCD}} \tilde{N}_{\text{QCD}} \]

\[ \tilde{N}_{\text{sig}} = \frac{N_T - \varepsilon_{\text{QCD}} N_L}{\varepsilon_{\text{sig}} - \varepsilon_{\text{QCD}}} \]
\[ \tilde{N}_{\text{QCD}} = \frac{\varepsilon_{\text{sig}} N_L - N_T}{\varepsilon_{\text{sig}} - \varepsilon_{\text{QCD}}} \]
Background Estimate: tagged

- Data backgrounds: divide preselected sample into orthogonal sets
  - Tagged signal data
    - Require at least one jet to be tagged
  - Un-tagged sample for W+jets background
    - Require that none of the jets be tagged
  - Multi-jet sample with fake isolated leptons for QCD
    - Lepton fails tight cut

- MC for signal and top pair production background

- Check prediction in W, QCD-dominated sample
  - Suppress ttbar, single top:
    - $n_{jets} = 2$
    - total energy in the event $HT < 200\text{GeV}$
Tag-Rate-Functions

- Flavor-dependent TRF (for b-jets, c-jets, other jets)
  - determined from data with scale factors from MC
  - used to determine tagging-probability in MC events

- Inclusive TRF
  - Used to estimate tagged W+jets background from data
  - Average probability to tag a jet in an inclusive W+jets sample
    - Approximately same as in multi-jet sample
      - Within uncertainty
  - Determine per-jet probability in multi-jet sample (=1-3%)
    - Then apply as weight to each jet in untagged W+jets sample
  - Flavor composition assumption tested in cross-check samples
    - Z+≥2 jets sample
    - In W+jets cross-check sample (n_{jets} =2, HT<200GeV)
    - Find good agreement in all samples (uncertainty ~20%)
Inclusive TRF cross-checks

- Z$^+32$jet sample:
  - SVT: TRF prediction: 15.7 events, tags found: 17
  - JLIP: TRF prediction: 14.9 events, tags found: 20

- W cross-check sample
  - muon channel SVT: prediction: 31.6, tags found: 27
inclusive TRF cross-checks

alljet sample tagger direct scaled TRF unscaled TRF

JLIP
W+jets sample

SVT
CC 2jet crosscheck
<table>
<thead>
<tr>
<th></th>
<th>SLT</th>
<th>SVT</th>
<th>JLIP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Signals</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC s-channel</td>
<td>$0.6 \pm 0.2$</td>
<td>$1.8 \pm 0.4$</td>
<td>$1.8 \pm 0.5$</td>
</tr>
<tr>
<td>MC t-channel</td>
<td>$0.9 \pm 0.3$</td>
<td>$2.9 \pm 1.0$</td>
<td>$3.0 \pm 1.1$</td>
</tr>
<tr>
<td>MC $s+t$ combined</td>
<td>$1.6 \pm 0.4$</td>
<td>$4.7 \pm 1.4$</td>
<td>$4.7 \pm 1.5$</td>
</tr>
<tr>
<td><strong>Backgrounds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC $t\bar{t} \to \ell + \text{jets}$</td>
<td>$7.0 \pm 1.6$</td>
<td>$18.3 \pm 4.4$</td>
<td>$19.2 \pm 5.2$</td>
</tr>
<tr>
<td>MC $t\bar{t} \to \ell\ell$</td>
<td>$2.7 \pm 0.3$</td>
<td>$5.0 \pm 0.8$</td>
<td>$5.2 \pm 1.0$</td>
</tr>
<tr>
<td>$W+\text{jets} + \text{fake-}\ell$ data</td>
<td>$24.7 \pm 4.1$</td>
<td>$45.8 \pm 8.9$</td>
<td>$49.7 \pm 9.9$</td>
</tr>
<tr>
<td><strong>Sum of backgrounds</strong></td>
<td>$34 \pm 5$</td>
<td>$69 \pm 10$</td>
<td>$74 \pm 12$</td>
</tr>
<tr>
<td><strong>Observed data</strong></td>
<td>$54 \pm 7$</td>
<td>$63 \pm 8$</td>
<td>$65 \pm 8$</td>
</tr>
<tr>
<td><strong>Acceptance</strong></td>
<td>$0.35%$</td>
<td>$0.97%$</td>
<td>$0.98%$</td>
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</tbody>
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