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

Reinhard Schwienhorst
on behalf of the DØ collaboration

Pheno 2004, April 26-28 2004
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-channel**
  - NLO cross-sections: $0.88\text{pb} \pm 8\%$
  - Run I: DØ: 95% CL: $<17\text{pb}$
  - CDF: 95% CL: $<18\text{pb}$

- **t-channel**
  - NLO cross-sections: $1.98\text{pb} \pm 11\%$
  - Run I: DØ: 95% CL: $<22\text{pb}$
  - CDF: 95% CL: $<13\text{pb}$

**Test predictions of the Standard Model**

- Measure CKM matrix element $V_{tb}$ (test CKM unitarity)
- Observe top polarization
Single Top Event Signature

Final State Objects

Proton beam Anti-proton beam

Final State

b-quark jet

electron

missing $E_T$

b-quark jet
Experimental Setup: DØ Run II Detector

- Muon Scintillators
- Muon Chambers
- Jet
- Electron
- Calorimeter
- Toroid
- Shielding

η = 0
η = 1
η = 2
η = 3
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)

Inferred neutrino 
Visible energy

Primary vertex
Secondary vertex

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, $p_T > 15$GeV
- **Neutrino**: missing $E_T > 15$GeV
- **Jets**: $2 \leq n \leq 4$
  - $p_T > 15$GeV, leading jet $p_T > 25$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

DØ Run II preliminary

JLIP

- soft-muon tag

# of jets

# of jets
Event Yields: Event Energy HT

$$HT = E^\text{lepton}_T + MET + E^\text{jet}_T + E^\text{jet}_T$$

**SVT**

**JLIP**

**soft-muon tag**

DO Run II preliminary
Final Event Selection

- Dominant background is from $W+jets$

  - Cut on $HT>150\text{GeV}$
    
    $HT = E_T^{\text{lepton}} + \text{MET} + E_T^{\text{jet}_1} + E_T^{\text{jet}_2}$

    - 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%
Result

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

**Expected 95% Cross-Section Limit**

- s-channel: <14pb
- s+t-channel: <16pb
- t-channel: <18pb

- **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
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**

```
\[ q \rightarrow W b \rightarrow W + q \]
```

**W-gluon fusion**

```
\[ W \rightarrow q + t \]
```

**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

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

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

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

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

**electron channel**

**muon channel**
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:
    • $n_{\text{jets}} = 2$
    • 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

- $Z^+\ell^+\ell^-$ 2jet 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

# of jets

![Histogram of jet number](image1)

HT (GeV)

![HT distribution](image2)

JLIP

W+jets sample

W+jets TRF+MM

QCD tagger

SVT

CC 2jet crosscheck
## Event Yields

<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 $t\bar{t} \rightarrow \ell + \text{jets}$</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 $t\bar{t} \rightarrow \ell\ell$</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>$W$+jets + 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>
</tr>
</tbody>
</table>

Reinhard Schwienhorst, MSU