Single Top Production at the Tevatron

Zhenbin (Ben) Wu
Baylor University
on behalf of the CDF and D0 Collaboration

Rencontres de Moriond QCD
March 16, 2012
Outline

- Introduction
- Lepton+Jets channel
- Single top from D0
- Single top from CDF
- Anomalous Wtb coupling
- Summary
Motivation:

- Direct measurement of CKM matrix element $|V_{tb}|$ ($\sigma_{s+t} \sim |V_{tb}|^2$)
- Sensitive to New Physics (FCNC, $W'$...) and CP violation
- Additional channel for top quark properties study

Experimental challenge:

- Extract small signal out of a large background with large uncertainty
Observation by CDF and D0

- Observed by CDF and D0 simultaneously in 2009
- Over 100 citations for both observation PRLs
- Combination of CDF and D0:
  - CDF: Four multivariate analysis in Lepton+jets channel with 3.2 fb⁻¹ data.
  - CDF: MET+Jets channel with 2.1 fb⁻¹ data
  - D0: Three multivariate analysis in Lepton+jets channel with 2.3 fb⁻¹ data.
Event signature of Lepton+Jets

- Main analysis channel: Lepton+Jets
  - Only one isolated lepton
  - Large missing Et from neutrino
  - At least 2 jets
  - At least one of the jets is b-tagged

- Background rejection:
  - CDF: Veto QCD, Dilepton, Z and Cosmic
  - D0: Cut on scalar sum ($H_T$ and $H_T$(alljets)) to suppress QCD and soft-scattering processes
  - Still large backgrounds share similar final state after the background rejection.
Background Modeling

- $t\bar{t}$bar, diboson and $Z+$jets are normalized to SM cross section
- QCD models derived from data with non-isolated lepton (D0) or anti-lepton (CDF)
- $W+$jets are modeled by Alpgen ($W_{jj}$, $W_{bb}$, $W_{cc}$, $W_{cj}$)
- $W+$jets and QCD are normalized to data before $b$-tagging in missing $E_T$ (CDF) or several variables (D0)

T. Aaltonen, et al. [CDF collaboration], PRD82 112005 (2009)
V.M. Abazov et al. [D0 Collaboration], PRD 84, 112001 (2011)
Lepton+Jets analysis with 5.4fb⁻¹ data from D0

- Signal modeled by SINGLETOP
- Use three multivariate (MVA) methods to extract signal
- Six analysis channels:
  2, 3 or 4 jets with 1 or 2 b-tags
- Each MVA method trained separately for s- and t-channel.

- About 70% correlation
- Combined three MVAs with a final BNN
- Combined s- and t-channel discriminant with SM predicted relative ratio

Zhenbin Wu, Baylor University
Cross Section Measurement

- Cross section measured using Bayesian approach
- It is given by the position of the posterior density peak, with 68% interval as uncertainty.

Since $\sigma_{s+t} \propto |V_{tb}|^2$, directly measure $|V_{tb}|$ from $\sigma_{s+t}$ posterior with more systematic uncertainties considered.

Assuming
- $|V_{td}|^2 + |V_{ts}|^2 \ll |V_{tb}|^2$
- Pure V-A and CP conserving Wtb vertex

Zhenbin Wu, Baylor University

V.M. Abazov et al. [DO Collaboration], arXiv:1108.3091

3/16/2012
Separate channel measurement

**s-channel**

- $\sigma_s = 0.68^{+0.38}_{-0.35}$ pb
- No evidence for s-channel yet

**t-channel**

- $\sigma_t = 2.86^{+0.69}_{-0.63}$ pb
- Model independent search
  - 5.5 SD first observation!

---

V.M. Abazov et al. [D0 Collaboration], PRD 84, 112001 (2011)
V.M. Abazov et al. [D0 Collaboration], PLB 705, 313 (2011)
Lepton+Jets analysis with 7.5fb⁻¹ data from CDF

- First update since 3.2fb⁻¹ analysis from CDF
- Performed in Lepton+Jets events with 7.5fb⁻¹ data collected by CDF Run II using Neural Network discriminant
- Add new lepton category: ISOTRK
  - High quality, high $P_T$ isolated track
  - $\sim$15% gain in single top acceptance
Signal Modeling

- Previously used MadEvent for single top modeling
  - Manually mix two processes of t-channel according to ZTOP prediction
- Using POWHEG for single top modeling with NLO accuracy

![Diagram of t-channel production](image)

- t-channel shows good agreement with MCFM 4 flavor prediction for both POWHEG and MadEvent
- Add Wt-channel as signal through POWHEG

---

Zhenbin Wu, Baylor University

arXiv:0907.4076v2; arXiv:1004.1181v4
Neural Network

- Train the NN with 11~14 variables in four channels (2, 3 jets with 1, 2 b-tags)
- Train for s-channel in 2 jet 2 b-tags, train for t-channel in the rest channels
- Train the NN with systematic mixed samples for better uncertainty constraint (~3% improvement expected)
Assuming $m_{\text{top}} = 172.5 \text{ Gev/c}^2$

- Measured cross section: 
  $$\sigma_{s+t} = 3.04^{+0.57}_{-0.53} \text{ pb}$$

- From the cross section posterior
- Set limit: $|V_{tb}| > 0.78$ at 95% CL

Extracted $|V_{tb}| = 0.92^{+0.10}_{-0.08} \text{ (stat.+sys.)} \pm 0.05 \text{ (theory)}$
**Simultaneous 2D measurement**

- Measured cross section:
  - $\sigma_s = 1.81^{+0.63}_{-0.58}$ pb ($\pm \sim 33\%$)
  - $\sigma_t = 1.49^{+0.47}_{-0.42}$ pb

- SM Prediction:
  - $\sigma_s^{SM} = 1.05 \pm 0.07$ pb
  - $\sigma_t^{SM} = 2.10 \pm 0.19$ pb
  - $\sigma_{wt}^{SM} = 0.22 \pm 0.08$ pb (Effect negligible)

- Measured cross section:
  - $\sigma_s = 0.98 \pm 0.63$ pb
  - $\sigma_t = 2.90 \pm 0.59$ pb ($\pm 20\%$)

- SM Prediction:
  - $\sigma_s^{SM} = 1.04 \pm 0.04$ pb
  - $\sigma_t^{SM} = 2.26 \pm 0.12$ pb

Zhenbin Wu, Baylor University
Anomalous Wtb coupling

- In the SM, the Wtb vertex is purely left-handed vector coupling
- \( \sigma_{s+t} \sim |Wtb\text{ coupling}|^2 \) assuming single top is produced only via W boson exchange.
- Trained BNN for three coupling scenarios
- Compute 2D posterior probability as a function of \( |V_{tb} \cdot f_{Lv}|^2 \) and \( |V_{tb} \cdot f_X|^2 \) (\( f_X = L_T, R_V, R_T \))
- Set upper limit with SM constraint, \( |V_{tb} \cdot f_{Lv}|^2 = 1 \)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cross section</th>
<th>Coupling</th>
</tr>
</thead>
<tbody>
<tr>
<td>((L_V, L_T))</td>
<td>&lt; 1.21 pb</td>
<td>(</td>
</tr>
<tr>
<td>((L_V, R_V))</td>
<td>&lt; 2.81 pb</td>
<td>(</td>
</tr>
<tr>
<td>((L_V, R_T))</td>
<td>&lt; 0.60 pb</td>
<td>(</td>
</tr>
</tbody>
</table>
We presented the most recent single top analysis and anomalous $Wtb$ coupling search at Tevatron.

We are planning for a new combination of CDF and D0 single top results.

With the observation of $t$-channel, the search of $s$-channel is a new challenge and long standing Tevatron legacy.

It is still a treasury for interesting physics, like CP violation.

Looking forward to single top analysis with full Tevatron dataset.


D0 Single Top page: http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html#singletop
Back up
t-channel observation

- Expected significance: 4.6 SD
- Measured significance: 5.5 SD

In sample with S:B > 0.32 from final discriminant
Previous 2D measurements

\[ \sigma_s = 1.8^{+0.7}_{-0.5} \text{ pb} \]
\[ \sigma_t = 0.8 \pm 0.4 \text{ pb} \]

\[ \sigma_s = 1.05 \pm 0.81 \text{ pb} \]
\[ \sigma_t = 3.14^{+0.94}_{-0.80} \text{ pb} \]

T. Aaltonen et al. [CDF Collaboration], arXiv:1004.1181v2
V.M. Abazov et al. [D0 Collaboration], PLB 682, 363 (2010)
NN input variables

NN jet flavor separator

Reconstructed top mass

Zhenbin Wu, Baylor University

3/16/2012
Single top

Sources of systematics

Expected Events

Zhenbin Wu, Baylor University