Single Top Quark Production

According to the Standard Model, along with pair production, single top quarks can be produced via the exchange of a W-boson. Dominant modes of single top production at the Tevatron are s-channel and t-channel production.

\[
\begin{align*}
\text{s-channel} & : W^+ q \rightarrow \text{t}\bar{b}W^+
\text{t-channel} & : W^+ b \rightarrow \text{t}\bar{q}W^+
\end{align*}
\]

The theoretically expected production rate (cross-section) at the Tevatron’s center of mass energy of 1.96 TeV is 2.9 picobarns (1 pb = 10^{-12} barn = 10^{-36} cm^2).

s-channel theoretical cross section = 0.88 pb

t-channel theoretical cross section = 1.98 pb

By observing the interaction vertex between a W-boson, a top quark and a bottom quark at production, we can measure directly – and for the first time – the strength of the coupling between these particles: the so-called \( V_\text{tb} \) element of the Cabibbo-Kobayashi-Maskawa (CKM) mixing matrix. So far only indirect constraints exist on this parameter.

The interest of this process goes beyond the Standard Model:
- New heavy particles could enhance the production cross section in the s-channel,
- Anomalous couplings (like those predicted from a 4\textsuperscript{th} family of quarks or other exotic theories) would enhance the t-channel production.

Thus, top quarks offer a vantage point to study new phenomena beyond the Standard Model given their high mass and their preferred coupling to the Higgs boson that is thought to give mass to all particles.

Search for Single Top Quarks

Selection cuts & b-tagging
The final state, concentrating only on semileptonic top decays (t→bW→blν). Events are selected loosely, trying to keep a high acceptance since this is a search, with a basic set of cuts: One electron or muon with \( p_T > 15 \) GeV, Missing Energy >15 GeV, and 2, 3 or 4 jets each with energy \( > 15 \) GeV, the leading jet with energy \( > 25 \) GeV. We apply the Jet Lifetime Probability (JLIP) algorithm to identify a b-jet with \( \approx 50\% \) efficiency and \( \approx 99.6\% \) purity. The selection is loose intentionally so that advanced multivariate techniques can exploit the kinematic differences between the single top signal and backgrounds.

We form a discriminant for each s- and t-channel signal, for the two major backgrounds (W+jets and tt), for one and more than one b-tags and for each lepton flavor (e and \( \mu \)).

Discriminant variables

Neural Network and a likelihood discriminant are examples of multivariate techniques which incorporate the shapes of mostly uncorrelated input variables to distinguish between signal and backgrounds. Neural networks and likelihoods have similar sensitivity.

Multivariate analyses

Instead of cutting on the output of the discriminant to count the expected number of single top events versus the backgrounds, we build a binned likelihood function based on the Poisson probability to observe the number of events in each bin of each distribution. A Bayesian analysis returns a posterior probability density function which can be used to calculate the limit.

Likelihood discriminant results with 370 pb\(^{-1}\) of data, 95% CL upper limits:

<table>
<thead>
<tr>
<th>Channel</th>
<th>370 pb(^{-1})</th>
<th>D0 Likelihood (737 pb(^{-1}))</th>
<th>CDF NN (700 pb(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>s-channel</td>
<td>3.3</td>
<td>4.3</td>
<td>3.7</td>
</tr>
<tr>
<td>t-channel</td>
<td>4.4</td>
<td>4.3</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Limit setting

Present analysis is just a beginning. We are very close to having 1000 pb\(^{-1}\) of data analyzed with more sophisticated analysis techniques, improved b-tagging and better jet energy scale.

With addition of Layer 0 in our silicon tracker, with better IP resolution, b-tagging will get even better. Other upgrades will also make our detector more efficient in higher luminosity environment, improving our physics output.

Projected Sensitivity and Future Improvements

Exclusion on the plane of s- and t-channel cross sections. The colored points represent models of physics beyond the Standard Model. We are very close to observing single top and ruling out many new physics models.

With Layer 0, relative increase of b-tagging efficiency is 15%.