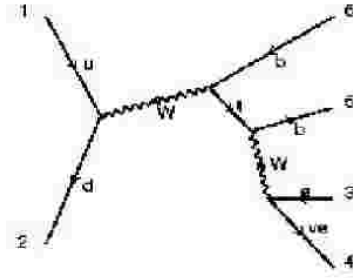


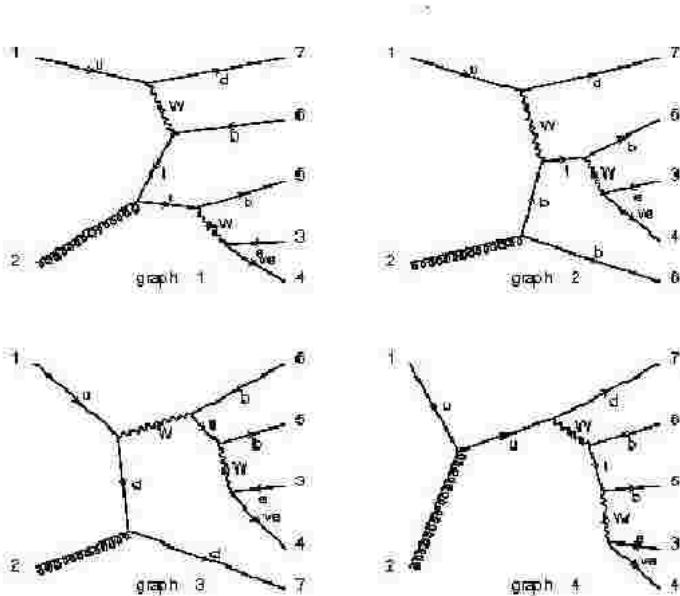
Finding Single Top Events

The goal of this note is to discuss possible techniques for separating Tevatron events containing single top quarks, the signal events, from the similar background events that contain either two quarks, the $t\bar{t}$ events, or no top quarks, the $Wb\bar{b}$ events. Our ability to discriminate between the different types of events arises from the differing event structure that in we understand in terms of the differing underlying perturbative structure. Since the top decays before it can be detected, the effective final state we have in mind contains, a charged lepton (e or μ) and a neutrino (missing E_T) from W decay plus b and \bar{b} quarks, and perhaps other quarks as noted below. The relevant Feynman diagrams are show in the following figures. The most naive version of the signal is an s-channel annihilation of $u\bar{d}$ into W^+ , which in turns decays into $t\bar{b} \rightarrow W^+b\bar{b} \rightarrow l^+\nu b\bar{b}$.



Lowest order diagram for $t\bar{b}$ production.

The related ug and $g\bar{d}$ initial states yield a final state with an extra jet, $t\bar{b}j$, and are numerically dominant.

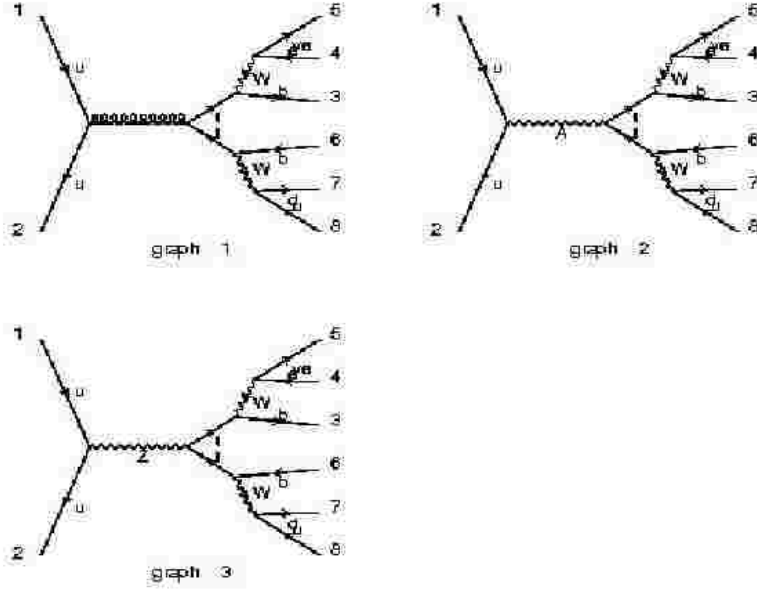


Lowest order diagrams for $t\bar{b}j$ final state.

As indicated in the figure there are 4 possible intermediate structures for this set of initial and final states. The dominant channel corresponds to the top quark being produced at the central vertex (graph 2). Due to both the asymmetric quark-gluon initial state and the asymmetric decays in the final state, the kinematic structure of the resulting final state exhibits distinct asymmetric structure that we will attempt to exploit below. Similar comments hold for the charge conjugate state $\bar{t}b \rightarrow W^-b\bar{b} \rightarrow l^-\nu b\bar{b}$ except that asymmetry has the opposite sign.

The minimal elements that we will demand to identify this desired state is an energetic ($p_T > 15$ GeV) charged lepton, an energetic neutrino ($E_{T,miss} > 15$ GeV) and one or more energetic hadronic jets ($E_T > 15$ GeV), of which one is tagged (as a heavy quark). The lepton is required to be relatively central, $|\eta_l| < 2$, the hadronic jet must be in the range $|\eta_j| < 3.5$, while the tagged jet will be in the restricted range $|\eta_{j,t}| < 2$.

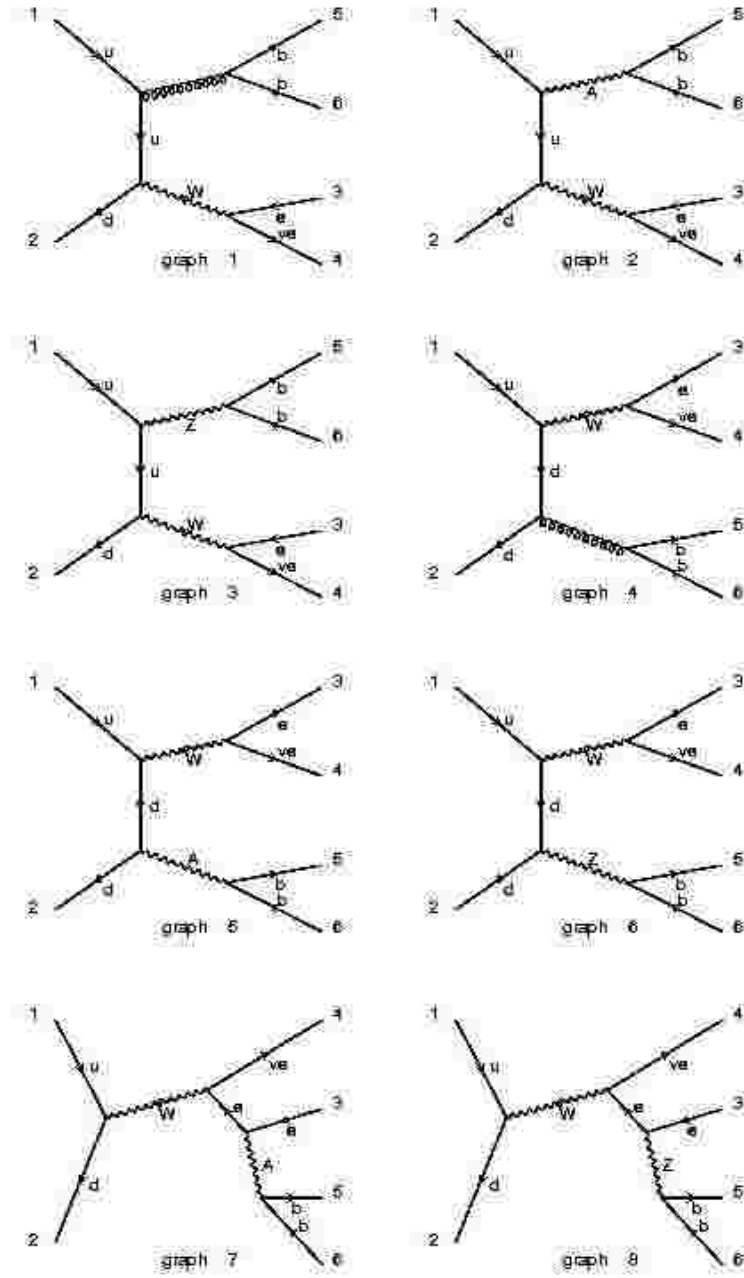
The first type of background event corresponds to $u\bar{u}$ or $d\bar{d}$ annihilation into an s-channel gluon, photon or Z^0 , which then produces the a $t\bar{t}$ pair as indicated in the next figure.



Lowest order diagrams for $t\bar{t}$ final state.

As shown we are interested in the case where the t quark decays into $W^+b \rightarrow l^+\nu b$, while the anti-top quark decays as $\bar{t} \rightarrow W^-\bar{b} \rightarrow q\bar{q}'\bar{b}$. Thus the final state looks like $l^+\nu b\bar{b}(q\bar{q}')$. The characteristic features of this type of event is the presence of 2 real top quarks and the underlying symmetry, in rapidity and azimuth of the final state. This latter feature arises from the symmetry of the $q\bar{q}$ initial state (arising from $p\bar{p}$) annihilating through a single vector boson.

The second variety of background arises from the production of a $b\bar{b}$ pair along with a W^+ , which can again yield the final state $l^+\nu b\bar{b}$ as in the next figure.



Lowest order diagrams for $Wb\bar{b}$ final state.

The underlying perturbative process is predominantly $u\bar{d}$ annihilation into W^+ and a gluon (or Z^0 or photon) via quark exchange, although, as the figures indicate, there are several possibilities. The neutral vector boson then produces the $b\bar{b}$ pair. Due to the fact that the u quark in the proton tends to have larger momentum fraction than the \bar{d} quark in the anti-proton (the d quark in the proton), the parton final state here will tend to be boosted in the proton direction (and in the opposite direction for W^- production from $d\bar{u}$ annihilation).

So in summary the global features of the signal events include: a top quark decaying into $l^+\nu b$, *i.e.*, a b quark jet plus a charged lepton plus a missing p_T vector that together (approximately) reconstruct a top quark mass, a scalar E_T sum, which we here label H_T ,

$$H_T = E_{T,l} + E_{T,miss} + \sum_{\text{jets}} E_{T,j},$$

with a magnitude characterized by m_{top} , a \bar{b} jet, an extra jet at large rapidity and a tendency for the b quark and the jet to be in the same rapidity hemisphere. The $t\bar{t}$ background events are characterized by: a top quark decaying into $l^+\nu b$, a scalar E_T sum with a magnitude characterized by $2m_{top}$, a \bar{b} jet, which can reconstruct to

a top mass with 2 other jets in the event and a tendency for this elements of the final state to be symmetrically distributed, in η and ϕ , in the final state. In contrast the $b\bar{b}$ background events are characterized by the absence of a top peak in the $l^+\nu b$ channel, a scalar E_T sum with a magnitude characterized by $2m_b$, *i.e.*, with a scale actually set by the cuts placed on the leptons and jets, a \bar{b} jet that does not reconstruct to a top mass and an asymmetric distribution in the elements of the final state. Note that since light quarks are sometimes mis-tagged as heavy quarks, this last background will also receive contributions from the corresponding processes where the $b\bar{b}$ pair is replaced by $c\bar{c}$ or an even lighter quarks, with a magnitude depending directly on the mis-tag rate.

To make direct use of the implied differences in this expected final state structures we propose the following cuts be applied to the event sample defined by the initial “visibility” cuts noted above on the leptons and jets.

1. A minimum cut on the magnitude of H_T , *e.g.*, $H_T > 165$ GeV, which is intended to greatly reduce the $Wb\bar{b}$ (and Wjj) background with little impact on the signal or $t\bar{t}$ background. This is extremely important as the former background initially exhibits the largest cross section. As yet, we do not understand the impact of jet smearing and/or the role of further (higher order) jet contributions on this cut.
2. A maximum cut on the magnitude of H_T , *e.g.*, $H_T < 285$ GeV, which is intended to greatly reduce the the $t\bar{t}$ pair background. To quantify these cuts the following table indicates the cross sections for the various channels after the “visibility” cuts listed above (except that charged lepton p_T lower limit in these numbers is 10 GeV, instead of 15 GeV), and then again after the H_T cuts outlined here.

Process	Visible	After H_T cuts
$t\bar{t}j$	0.062 pb	0.044 pb
$t\bar{t}$	0.033 pb	0.022 pb
$t\bar{t} \rightarrow l^+\nu b\bar{b}(\bar{d}u)$	0.189 pb	0.034 pb
$t\bar{t} \rightarrow l^+\nu b\bar{b}(s\bar{c})$	0.196 pb	0.035 pb
$Wb\bar{b}$	0.232 pb	0.074 pb
Wjj	0.790 pb	0.246 pb

3. A minimum and maximum cut on the reconstructed top quark mass, using the charged lepton, the missing p_T vector and one of the jets. One would expect the appropriate jet to be the tagged one, but given the presence of both a bottom and anti-bottom jet in these events, triples with all jets will likely have to be considered. This cut on the top quark mass will necessarily be fairly relaxed to allow for the mass smearing due to the expected jet energy smearing, but will still serve to further reduce the $Wb\bar{b}$ background. In the following it will also be important to keep track of which jets in an event are *not* included to the reconstructed top quark.
4. Here goes a discussion of further cuts based on the correlated behavior in η and ϕ for the 3 kinds of events, but I don't have that straight yet.

With a sufficient reduction in the asymmetric $Wb\bar{b}$ background, we have in mind to use the following analysis of the kinematic asymmetry of the signal, to isolate the signal events. Label each of the remaining events by the following 3 numbers, Q = the sign of the lepton charge, R = the sign of the lepton rapidity (the proton defines the positive direction), S = the sign of the “jet” rapidity, where “jet” is the jet with the largest p_T that is not tagged and not included in the reconstructed top quark. Now for $Q = +1$ bin all the “top” events in a 2x2 matrix of 4 bins according to

$$\begin{bmatrix} [R = -1, S = +1] & [R = +1, S = +1] \\ [R = -1, S = -1] & [R = +1, S = -1] \end{bmatrix}.$$

For the opposite $Q = -1$, the charge conjugated process, the corresponding binning looks like

$$\begin{bmatrix} [R = +1, S = -1] & [R = -1, S = -1] \\ [R = +1, S = +1] & [R = -1, S = +1] \end{bmatrix},$$

i.e., the signs of R and S have also been flipped and we add the events in the bins in the same locations. The expectation is that the $t\bar{t}$ background will contribute equally to all 4 bins, while the signal will contribute approximately as

$$\begin{bmatrix} [\sim 0\%] & [\sim 75\%] \\ [\sim 25\%] & [\sim 0\%] \end{bmatrix}.$$

Thus a difference (asymmetry) between the upper right and lower left should be dominated by the signal, single top events.