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New Results from Single-Top-Quark Searches with the CDF II Detector

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In this paper we present new results from single-top-quark searches with the CDF II detector at the Fermilab Tevatron. In a data sample of 162 pb^{-1} of proton-antiproton collisions accumulated at CDF, we find no significant evidence for signal and set an upper limit of 17.8 pb on the total single-top production rate, at 95% confidence level. Individual upper limits of 10.1 pb and 13.6 pb are set on the the individual rates of $t-$channel, and $s-$channel single-top, respectively.

Keywords: Single-top; top quark; electroweak.

1. Event Selection

According to the Standard Model, in $p\bar{p}$ collisions at the Tevatron top quarks can be created in pairs via the strong force, of singly via the electroweak interaction. The latter production mode is referred to as "single-top-quark" production and takes place mainly through the $s-$ or $t-$ channel exchange of a W boson. The CDF collaboration has published single-top results at $\sqrt{\mathrm{s}} = 1.8$ TeV.[1,2] A review of these results and an introduction to the subject from experimental perspective can be found in Ref. 3.

This paper describes two analyses. The first one ("$A1$") is a combined search for the signal in both $s-$ and $t-$channels, while the second analysis ("$A2$") is a separate search for the $t-$channel and the $s-$ channel individually. We will describe first the event selection used for $A1$. This selection exploits the kinematic features of the signal final state, which contains a top quark, a bottom quark, and possibly additional light quark jets. To reduce multijet backgrounds, the W originating from the top quark is required to have decayed leptonically. We demand therefore a high-energy electron or muon ($E_T(e) > 20$ GeV, or $P_T(\mu) > 20$ GeV/c) and large missing energy from the undetected neutrino $\not{E}_T$>20 GeV. We reject dilepton events from $t\bar{t}$ and Z decays by requiring the dilepton mass to satisfy: 76 GeV/c^2 < $M_{\ell\ell}$ < 106 GeV/c^2. The backgrounds surviving these selections can be classified as "non-top" and $t\bar{t}$. The non-top backgrounds are: $Wb\bar{b}$, $Wc\bar{c}$, Wc, mistags (light quarks misidentified as heavy flavor jets), non-W (events where a jet is erroneously identified as a lepton), and diboson WW, WZ, and ZZ. We remove a large fraction of the non-top and $t\bar{t}$ backgrounds by demanding exactly two jets with $E_T > 15$ GeV and $|\eta| < 2.8$ be present in the event. At least one of these two jets should be tagged as a b-quark jet by using displaced vertex information from the silicon vertex detector (SVX). Finally, we require that the invariant mass of the reconstructed top quark be within the range: 140 GeV/c^2 $< M_{\ell\nu b} <$ 210 GeV/c^2. We will refer to the above set of selection cuts as the "$A1$ selection".

The second analysis $A2$ starts from the $A1$ selection and forms two distinct subsets of events. The first subset is formed by retaining events with exactly one SVX b-tagged jet, and also demanding that at least one of the two jets have $E_T > 30$ GeV. These requirements optimize the $t-$channel signal content of the sample with respect to the backgrounds. The second subset is formed by selecting the double b-tagged events, i.e. the events where both jets are SVX b-tagged. This selection was found to be optimal for identifying $s-$channel signal events. The expected signal and background yields in 162 pb^{-1} of data are given in Table 1.

Table 1. Signal and background contributions expected and total number of events observed in 162 pb^{-1} after all selection cuts described in the text have been imposed.

	Combined search $A1$	Separate search $A2$	
Process		Single-tag	Double-tag
$t-$channel	2.8 ± 0.5	2.7 ± 0.4	0.02 ± 0.01
$s-$channel	1.5 ± 0.2	1.1 ± 0.2	0.32 ± 0.05
$t\bar{t}$	3.8 ± 0.9	3.2 ± 0.7	0.60 ± 0.14
non-top	30.0 ± 5.8	23.3 ± 4.6	2.59 ± 0.71
Total	38.1 ± 5.9	30.3 ± 4.7	3.53 ± 0.72
Observed	42	33	6

2. Method and Results

For the combined search $A1$ we used the distribution of the total transverse energy in the event H_T which provides good signal-background separation. The CDF data and the Monte Carlo H_T distributions (using the contributions from Table 1) are shown in Fig. 1. We employ a maximum likelihood method to estimate the signal content in the data. The likelihood function is expressed as:

$$\mathcal{L}(\sigma_{\mathrm{s+t}}; \delta_1, \ldots, \delta_9) = \prod_{i=1}^{N_{\mathrm{bin}}} \frac{e^{-\mu_i} \cdot \mu_i^{d_i}}{d_i!} \cdot \prod_{j=1}^{9} G(\delta_j), \tag{1}$$

where i indexes the H_T bins, and j indexes the nuisance parameters δ_j (two background rates and seven sources of systematic uncertainty) accounted for by using Gaussian functions $G(\delta_j)$. d_i is the number of data events in bin i, while μ_i is the expected number of events in bin i and incorporates the full correlations between systematic effects modifying both the H_T shape and the signal rate. The δ_j parameters are integrated out numerically, and the resulting function is shown in the left

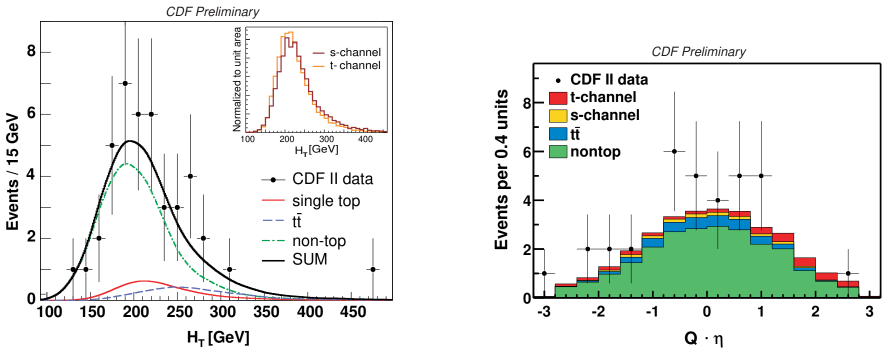

Fig. 1. The H_T and the $Q \cdot \eta$ distributions for CDF II data (points) compared with the Monte Carlo predictions. In both of these plots we use the expected values from Table 1.

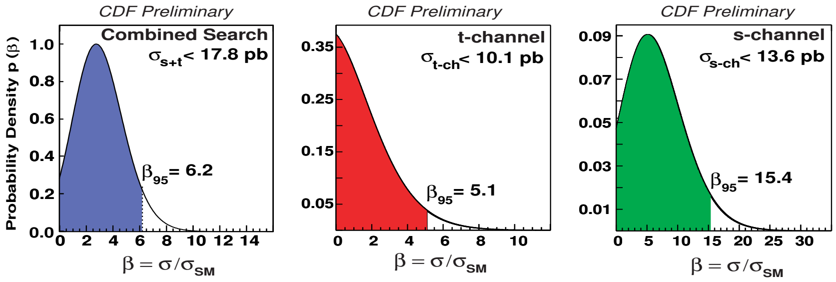

Fig. 2. The posterior distribution functions obtained by integrating the likelihood of Eq. (1) with respect to the nuisance parameters δ_j. In all three cases a flat prior assumption is used to restrict signal cross-section σ to positive values.

plot of Fig. 2. For the separate analysis $A2$, the $t-$channel search is performed in the single b-tag dataset. In this subsample, we use the distributions of $Q \cdot \eta$, i.e. the product between the lepton charge and the pseudorapidity of the non-b-tagged jet. The $t-$channel signal events are expected to exhibit an asymmetry toward the positive $Q \cdot \eta$ region. No such asymmetry is observed in the data (right plot of Fig. 1). Next, the $s-$channel signal is extracted from a simple counting experiment in the double $b-$tagged sample. The likelihood function used in the separate search closely resemble Eq. (1). The posterior distribution functions in both analyses are shown in Fig. 2, along with the 95% confidence level upper limits.

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References

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