PROCEEDINGS OF SCIENCE

Searches for new physics in production and decays of the top quark with the D0 detector at the Tevatron

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We present two searches for new phenomena in events whose final states are similar to those where top quarks are produced, either in pairs or singly, and decay according to the Standard Model. Both searches are conducted by the D0 collaboration using $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV at Fermilab's Tevatron collider. The first is a search for pair-production of a fourth generation t' quark that decays to a W boson and a down-type quark, while the second is a search for a W' gauge boson that decays to $t\bar{b}$. In the absence of any compelling evidence of signal, we set new upper limits on the production cross sections and translate those into limits on the mass of the fourth generation quark, and the mass of the W' boson, respectively, in a variety of models.

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1. Introduction

The existence of a fourth generation of fundamental fermions with the neutrino heavier than half the mass of the Z boson has not been experimentally ruled out yet. Precision electroweak data favour a small mass splitting between the up- and down-type quarks of such a fourth generation, so that $m(t') - m(b') < m(W)$. If moderate mixing between the fourth generation and the first three are allowed, then the t' quark will predominantly decay to Wq, where q includes all down-type quarks in the Standard Model (SM). In Sec. 2 we describe a search for pair-production of such t' quarks in 5.3 fb^{-1} of $p\overline{p}$ collision data at $\sqrt{s} = 1.96$ TeV collected with the D0 detector at the Tevatron [1].

The W, a mediator of weak interactions, is the sole fundamental charged boson in the SM. Many extensions of the SM contain additional charged vector bosons, generally called W', that are heavier than the W. The chiral structure of the coupling between the W' and fermions varies between models. In Sec. 3 we present a search for $W' \rightarrow t\overline{b}$ decays, which are sensitive to both left- and right-handed couplings regardless of the existence of a light right-handed neutrino. This search uses 2.3 fb^{-1} of $p\overline{p}$ collision data collected with the D0 detector [2].

2. Search for a t' quark

The final state of $p\overline{p} \rightarrow t'\overline{t'}$, with each t' decaying to Wq, is similar to $p\overline{p} \rightarrow t\overline{t}$ except for having fewer b quarks. The kinematics are somewhat different, depending on $m(t')$. We assume the width of the t' to be small compared to the detector's resolution and use the lepton(ℓ)+neutrino+jets final state ($\ell = e, \mu$). This final state arises when one of the two W bosons decays into an electron or a muon and the associated neutrino, while the other decays into a quark-antiquark pair. Reconstruction of the leptons and jets are described in Ref. [1]. The presence of the undetected neutrino is inferred from the net imbalance of momentum in the plane perpendicular to the beam axis. We require candidate events to contain exactly one clean isolated lepton with $p_T > 20$ GeV and $|\eta| < 1.1(2.0)$ for electrons (muons), at least 4 jets with $p_T > 20$ GeV and $|\eta| < 2.5$ including at least one with $p_T > 40$ GeV, and $\not{p}_T > 25$ GeV. Table 1 shows the data sample together with the estimated contributions from all these SM processes.

Table 1: Composition of the final data sample for the t' search. The number of W+jets events is chosen to equalize the total number of events observed and expected.

Source	e+jets	μ+jets
$t\overline{t}$ production	678±76	508±55
Single t production	12±4	8±3
W+jets	503±87	648±59
Z+jets	41±7	40±7
WW, WZ, ZZ+jets	25±5	21±5
Multijets	173±42	43±18
Data	1431	1268

We define H_T as the scalar sum of $\not{p}_T$ and of the transverse momenta of all jets and the charged lepton. A kinematic fit to the $t'\overline{t'} \rightarrow \ell\nu bq\overline{q}'\overline{b}$ hypothesis reconstructs the mass $m_{\rm fit}$ of the t' quark.

We use the two-dimensional histograms of H_T versus m_{fit} to test for the presence of signal in the data and to compute 95% C.L. upper limits on the $t'\overline{t'}$ production cross section as a function of t'-mass. For each hypothesized value of the t' mass, we fit the data to background-only and to signal+background hypotheses. We then use the CL_s method [3] to determine the cross section limits. Using pseudoexperiments, we determine the probability to measure values of L that are larger than the value observed in the data sample for a t' signal, CL_{s+b}, and for no t' signal, CL_b. The value of the t' pair production cross section for which $1-CL_{s+b}/CL_b = 0.95$ is the 95% C.L. upper limit. We repeat this procedure for each t' mass point.

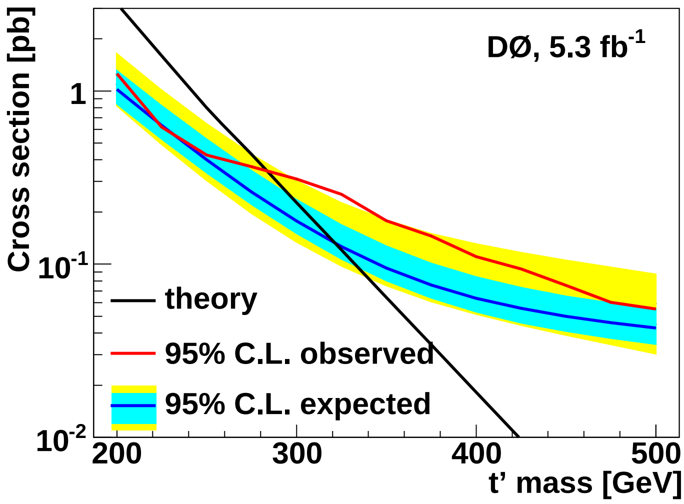

Figure 1: Observed and expected upper limits and predicted values for the $t'\overline{t'}$ production cross section as a function of the mass of the t' quark (e and μ channels combined). The shaded regions around the expected limit represent the ±1 and ±2 standard deviation bands.

Figure 1 shows the resulting cross section limits compared to the limits expected in the absence of $t'\overline{t'}$ production and to the predicted NLO t' pair production cross section [4] as a function of the t' mass. Based on the observed limits we can exclude at the 95% C.L. $t'\overline{t'}$ production for t' quark masses below 285 GeV. We achieve the best fit to the data with a $t'\overline{t'}$ production cross section of 1.1 ± 0.5 times the theoretical cross section for a t' quark mass of 325 GeV, where it corresponds to 2.2 standard deviations from zero.

3. Search for a W' boson

Independent of specific models, the most general lowest-dimension Lagrangian of a W' boson with fermion fields is given by

$$\mathscr{L} = \frac{V_{ij}g_w}{2\sqrt{2}}\bar{f}_i\gamma_\mu(a^R_{ij}(1+\gamma^5)+a^L_{ij}(1-\gamma^5))W'^\mu f_j, \tag{3.1}$$

where $a^{L/R}_{ij}$ are the left/right handed couplings of the W' boson to the fermion doublet f_i and f_j, and g_w is the weak coupling constant of the SM. If the fermions are quarks (leptons), then V_{ij} are the elements of the 3×3 CKM (identity) matrix.

We have searched for events in which a W' boson is produced and subsequently decays to tb, followed by $t \to Wb$ and $W \to \ell\nu$, where $\ell = e$ or μ [5, 6, 7]. Event characteristics are similar to the t' search described above, except that now we have fewer jets in the event, but two of the jets are initiated by b quarks. Accordingly, we select events with at least 2 jets with $p_T > 15$ GeV and $|\eta| < 3.4$. At least one of the jets is required to have $p_T > 25$ GeV, and at least one must be tagged as a b-jet candidate. At least one clean isolated muon with $p_T > 20$ GeV and $|\eta| < 2.0$ or a clean isolated electron with $p_T > 20$ GeV and $|\eta| < 1.1$ is required, together with $\not{p}_T$>25 GeV. If the event has more than two jets, then the electron p_T threshold is relaxed to 15 GeV, and the $\not{p}_T$ threshold to 20 GeV. The event yield, together with estimated contributions from various SM processes, is summarized in Table 2.

Table 2: Estimated composition of the final data sample for the W' search.

Source	events
tqb production	26.4±2.5
$t\bar{t}$ production	424.7±58.4
W+jets	279.5±18.3
Z+jets	26.0±3.2
WW, WZ, ZZ+jets	13.0±1.6
Multijets	60.5±10.8
Total SM background	830 ± 62
Data	831

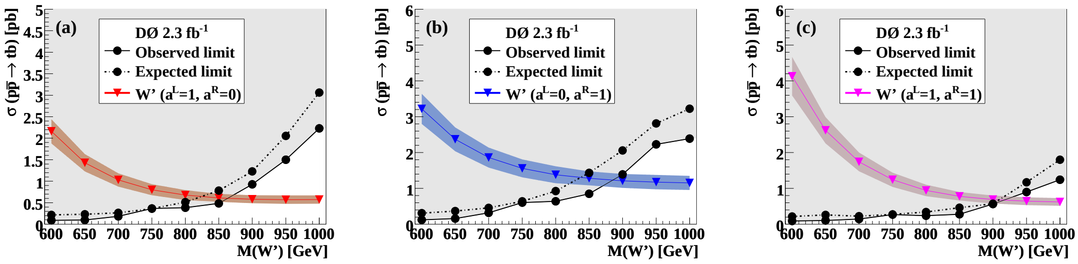

Figure 2: Observed and expected upper limits and predicted values for the W' production cross section as functions of the mass of the W' boson (e and μ channels combined). The shaded band represents the uncertainty for W' bosons with (a) purely left-handed coupling, (b) purely right-handed coupling, and (c) mixed coupling.

We vary both a^L and a^R between 0 and 1, in steps of 0.1, for each W' boson mass value. Considering each combination of these settings as a model, we vary the total cross section of s-channel tb production to determine the expected and observed 95% C.L. upper limits. Comparing these to theoretical prediction for cross sections we extract the the following limits (assuming $m(W') > m(\nu_R)$, when right-handed couplings are allowed), as shown in Fig. 2: $m(W') > 863$ GeV for purely left-handed couplings, $m(W') > 885$ GeV for purely right-handed couplings, and $m(W') > 916$ GeV if both left- and right-handed couplings are present.

4. Conclusion

D0 has searched for a pair-produced fourth generation t' quark decaying to Wq, with exactly one of the two W subsequently decaying leptonically, in 5.3 fb^{-1} of $p\bar{p}$ collision data. While a $\sim 2\sigma$ excess over background predicted by the Standard Model is observed in the muon channel, the electron channel is most consistent with no signal. Combining the two channels, t' pair production with $m(t') < 285$ GeV is excluded at 95% CL.

D0 has also searched for a singly produced W' boson decaying into tb in 2.3 fb^{-1} of $p\bar{p}$ collision data using lepton+jets final states. A fully general range of left- and right-handed couplings are investigated and 95% CL lower limits on $m(W')$ are set at 863 GeV, 885 GeV, and 916 GeV for purely left-handed, purely right-handed, and mixed couplings, respectively.

References

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