Tevatron Searches in Top Decays

Junji Naganoma
on behalf of the CDF and DØ Collaborations

Waseda University - Advanced Research Institute for Science and Engineering
3-4-1 Okubo Shinjuku-ku Tokyo - Japan

The latest results on searches in top quark decay at the Tevatron are described. The searches are performed by the CDF and DØ collaborations using data up to 2.3 fb^{-1} taken during Run II at the Tevatron.

1 Introduction

The top quark presents a unique opportunity in the searches for new physics. The huge mass of the top quark, $M_{\rm top} = 172.6 \pm 1.4$ GeV/c^2 [2], suggests that the top quark Yukawa coupling should be near unity, which may imply a special role for the top quark in electroweak symmetry breaking beyond the standard model. In addition, there are many models for new physics which predict new phenomena in the top quark sector. Since the sample size of top quark remains relatively small in the quark sector, only recently the properties of the top quark are measured well. However, there remain lots of room for the unexpected phenomena. There are three types of searches related to top quark: the searches for new particles in the decay products of the top quark, the searches for new particles which mimic top quark decays, and the searches for new particles decaying to the top quarks. The results presented below use between 900 pb^{-1} and 2.3 fb^{-1} of $p\bar{p}$ data with $\sqrt{s} = 1.96$ TeV collected at the CDF and DØ detectors.

2 Search for Flavor Changing Neutral Current in Top Decays

The CDF collaboration performs a search for the flavor changing neutral current (FCNC) decay of the top quark $t \to Zq$ using 1.9 fb^{-1} of the Tevatron Run II data [3]. The decay $t \to Zq$ is extremely rare in the standard model and a signal at the Tevatron would be an indication of new physics [4]. Using $Z+ \geq 4$ jets candidate events both with and without a secondary vertex b-tag, signal is discriminated from background by exploring kinematic constraints present in FCNC events. A mass χ^2 variable is constructed and templates are fit to the data, taking into account shape systematic uncertainties of the χ^2 distribution. Figure 1 shows a χ^2 distribution which is consistent with the background expectations and the upper limit on the branching fraction of

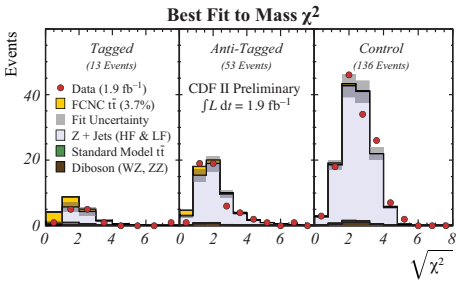

Figure 1: Mass χ^2 distribution for the two signal regions and the control region. The data and the best fit templates are shown. Overlaid are the fit uncertainties and the expected signal at the measured 95% C.L..

$$B(t \to Zq) < 3.7\% \text{ at } 95\% \text{ C.L.} \quad (1)$$

is obtained from a Feldman-Cousins limit technique. This result improves the best published limit [5], which was inferred indirectly from the non-observation of $e^+e^- \to tq$ at LEP, by more than a factor of 3.5.

3 Search for Charged Higgs in Top Decays

The DØ collaboration have produced the measurement of the top pair production cross sections in the lepton+jets [6] and dilepton [7] channels using 1 fb^{-1} of the Tevatron Run II data. The measured cross section ratio is

$$R_\sigma = \sigma(p\bar{p} \to t\bar{t})_{\mathrm{l+jets}} / \sigma(p\bar{p} \to t\bar{t})_{\mathrm{ll}} = 1.21^{+0.27}_{-0.26}(\mathrm{stat.} + \mathrm{syst.}) \quad (2)$$

in agreement with the standard model expectation of $R_\sigma = 1$ [8]. This result can be interpreted into an upper limit on the branching ratio $B(t \to Xb)$ due to a top decay into any other particle X in addition to the decay into the W boson. As an example, in a simplified model assuming the existence of a charged Higgs boson $H^\pm$ with a mass close to the W boson and decaying exclusively into $H^+ \to c\bar{s}$ and $H^- \bar{c}s$, respectively, a branching ratio of

$$B(t \to Hb) < 0.35 \text{ at } 95\% \text{ C.L.} \quad (3)$$

is derived. Such a scenario can be realized, for instance, in a general multi-Higgs-doublet model.

4 Search for Heavy Top-like Quarks

The CDF collaboration performs a search for a heavy top-like object, t', using 2.3 fb^{-1} of the Tevatron Run II data in the top quark sample [9]. Examples of models that predict such an object include a fourth chiral generation consistent with precision electroweak data [10, 11, 12] and the beautiful mirrors model [13], that predicts an additional quark generation that mixes with the third generation. For this search, that the t' has a large branching ratio to Wq is assumed, as would be the case if $M_{t'} < M_{b'} + M_W$, a situation favored by the constraint that an additional quark generation be consistent with precision electroweak data. This search is performed using two kinematic variables to separate the t' signal from the standard model backgrounds: H_T, the sum of the transverse momenta of all objects in the event, and M_{reco}, the Wq invariant mass reconstructed using the same χ^2 fit technique employed by the CDF top mass analysis. No evidence for t' is observed and the upper limits on $\sigma(t'\bar{t}')$ at 95% confidence level is set that exclude t' masses below 284 GeV/c^2 as shown in Fig. 2.

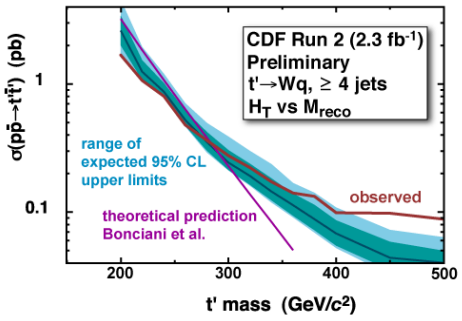

Figure 2: 95% C.L. upper limit on the cross section for t' pair production.

5 Search for Scalar Top Quark

The DØ collaboration performs a search for scalar top (stop) quark pair production in the lepton+jets channel using 1 fb^{-1} of the Tevatron Run II data [14]. Supersymmetry (SUSY) establishes a superpartner for each the left and right-handed top quark. Because of the large top quark mass the mixing between the superpartners of the left-handed and the right-handed top quark can be substantial. This provides a large difference in the mass eigenvalues of the scalar top quark with the lighter stop quark $\tilde{t}_1$ possibly being the lightest scalar quark and well within reach at the Tevatron. An interesting reason for a light stop quark derives from electroweak baryogenesis, which is excluded in the Standard Model, but is feasible in a supersymmetric model when the stop quark is lighter than the top quark [15]. At the Tevatron stop quarks are produced mainly in pairs [16], and can be mixed in the top quark pair events with neutrino in final state.

For this search the neutralino $\tilde{\chi}_1^0$ is the LSP and the MSSM parameters are chosen as follows:

- $\tan\beta = 20$, $\mu = 225$ GeV, $M_A = 800$ GeV, $M_1 = 53$ GeV, $M_3 = 500$ GeV,
- Trilinear couplings $A_b = A_\tau = 200$ GeV,
- Scalar lepton masses $M_{\tilde{l}_L} = M_{\tilde{l}_R} = M_{\tilde{\tau}_L} = M_{\tilde{\tau}_R} = 200$ GeV,
- Scalar quark masses $M_{\tilde{q}_L} = M_{\tilde{q}_R} = M_{\tilde{b}_R} = M_{\tilde{t}_R} = 250$ GeV.

The kinematic differences between the exotic $\tilde{t}_1\bar{\tilde{t}}_1$ and the dominant $t\bar{t}$ process are used to separate the two possible contributions. Table 1 shows the upper cross section limits at 95% confidence level for $\tilde{t}_1\bar{\tilde{t}}_1$ production at stop (chargino) masses of 145-175 (105-135) GeV/c^2, which are a factor of $\sim$ 7-12 higher than expected for the MSSM.

$M(\tilde{t}_1)/M(\tilde{\chi}_1^\pm)$ [GeV/c^2]	theoretical $\sigma_{\tilde{t}_1\bar{\tilde{t}}_1}$	$\sigma_{\tilde{t}_1\bar{\tilde{t}}_1}$ limit		
		e+jets	μ+jets	combined
175/135	0.579 pb	5.11 pb	10.20 pb	5.57 pb
175/120	0.579 pb	6.11 pb	12.41 pb	6.58 pb
175/105	0.579 pb	6.10 pb	9.28 pb	5.55 pb
160/120	1.00 pb	6.49 pb	15.79 pb	7.45 pb
160/105	1.00 pb	7.78 pb	20.75 pb	9.71 pb
145/105	1.80 pb	10.60 pb	24.21 pb	12.32 pb

Table 1: Theoretical $\tilde{t}_1\bar{\tilde{t}}_1$ cross section and observed Bayesian limits at 95% confidence level on the $\tilde{t}_1\bar{\tilde{t}}_1$ cross section with systematic uncertainties.

6 Search for W' Boson Decaying to Top Quark and Bottom Quark

Both the CDF and DØ collaborations search for the production of a heavy W' gauge boson that decays to third generation quarks in lepton+jets channel [17, 18], using 1.9 fb^{-1} and 0.9 fb^{-1} of the Tevatron Run II data respectively. New massive charged gauge bosons, usually called W', are predicted by various extensions of the standard model. Noncommuting extended technicolor, little Higgs, composite gauge bosons, grand unification, and superstring theories represent examples in which an extension of the gauge group leads to the

	$M(W'_R) > M(\nu_R)$	$M(W'_R) < M(\nu_R)$	W'_L
CDF (1.9 fb^{-a})	800 GeV/c^2	825 GeV/c^2	-
DØ (0.9 fb^{-a})	739 GeV/c^2	768 GeV/c^2	731 GeV/c^2

Table 2: The lower limits on mass of W' bosons at 95% confidence level obtained from CDF and DØ collaborations.

appearance of a W' boson [19]. Since the SM W boson and a hypothetical W' boson with left-handed couplings both couple to the same fermion multiplets, they interfere with each other. W'_R boson decays to $l\nu$ if $M_{\nu_R} < M_{W'}$, and does not if $M_{\nu_R} > M_{W'}$. No significant excess in the final-state invariant mass distribution is found and the upper limits on the production cross section times branching fraction are set. Table 2 shows the lower limits on mass of W' bosons at 95% confidence level.

7 Conclusions

Using up to 2.3 fb^{-1} of data, no evidence for new phenomena is obtained in the Tevatron top quark sample. Since larger data sets are rapidly becoming available, the more precise tests of the standard model using top quarks should be possible soon.

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