PROCEEDINGS OF SCIENCE

Search for a Narrow $t\bar{t}$ Resonance in $p\bar{p}$ Collisions at $\sqrt{s}$ = 1.96 TeV at the Tevatron

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We report searches for a narrow $t\bar{t}$ resonance based on data of proton-antiproton collisions at $\sqrt{s}$ = 1.96 TeV collected by the CDF and D0 Collaborations at the Fermilab Tevatron Collider. We set upper limits on the production cross section of such resonances multiplied by its branching fraction to $t\bar{t}$, which we compare to predictions of many theoretical models.

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1. Introduction

The top quark [1] is the heaviest known fundamental particle in the standard model (SM). The coupling strength of the top quark, due to its large mass, makes it part of many theoretical extensions beyond the standard model (BSM) [2]. Recently, the CDF and D0 collaborations reported discrepancies in the $t\bar{t}$ forward-backward asymmetry A_{FB} [3, 4], which has motivated the search for top quark final states associated with BSM physics processes. Moreover, there is a large radiative correction to the Higgs boson that can be canceled by introducing new top partners as in SUSY models. Many BSM theories [5] predict heavy resonances besides the SM $t\bar{t}$ production mechanism. Some BSM theories predict new U(1) symmetries with an associated electrically neutral Z' gauge boson as shown in the lefthand Feynman diagram in Fig. 1. Assuming couplings to charged lepton pairs, experiments at the LHC rule out such particles up to masses of several TeV [6]. Strict limits are also set by D0, CDF, ATLAS, and CMS in searches for Z' decaying to light quarks [7] or $t\bar{t}$ pairs [8]. If the new particle decays only to gluons (chromophilic Z'), such limits are evaded. To explain the A_{FB} discrepancy, a wide class of models have been built, most involving the production of a heavy new mediating particle M that enhances A_{FB}. Many of these models predict significant enhancements of the $t\bar{t}$ production cross section, the single-top production cross section, or the same-sign top-quark pair-production cross section, none of which have been confirmed by experimental tests. One class of models [9, 10] evades the experimental constraints described above and predicts a new, unexplored experimental signature that consists of the production of a heavy new particle M in association with a top quark ($p\bar{p} \to Mt$ or $M\bar{t}$), which decays via $M \to \bar{t}q$ or tq as shown in the righthand Feynman diagram of Fig. 1. If the light-flavor quark (q) is reconstructed as a jet (j), the final state is $t\bar{t}+j$ with a resonance in the $\bar{t}+j$ or $t+j$ system, and this has not been previously examined. In this note, we try to summarize some of the searches that were carried out at the Tevatron.

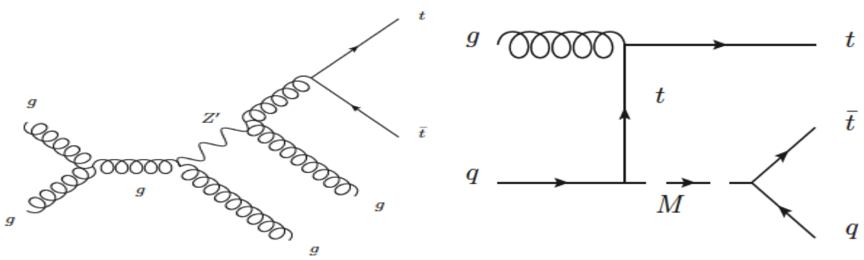

Figure 1: (Left) Diagram for $Z'g$ production followed by $Z' \to gg* \to gt\bar{t}$ decay giving the $t\bar{t}gg$ final state. (Right) Diagram for singly produced M in association with a t, with a subsequent decay to $\bar{t}$ and an additional jet via $p\bar{p} \to Mt(\bar{t}) \to \bar{t}jt$.

2. The CDF II and D0 Detectors

The CDF [11] and D0 [12] detectors are a multipurpose detectors operated at the Fermilab Tevatron $p\bar{p}$ collider.

3. All Hadronic Channel

Events are selected by requiring six or seven jets with $|\eta| < 2$ and corrected transverse energy E_T >15 GeV. To remove leptonic $t\bar{t}$ decays, we veto events with well identified leptons or with a significant imbalance in transverse momentum. To further enrich the signal presence in the data sample, additional cuts are applied. The distinctive feature of this analysis is the use of likelihoods calculated by integrating signal matrix elements both to perform $M_{t\bar{t}}$ invariant mass reconstruction and to suppress the overwhelming background. Fig. 2 shows reconstructed $t\bar{t}$ for simulated events (left) and the reconstructed $M_{t\bar{t}}$ vs. the SM expectation in the search region (center). No evidence for top-antitop quark resonant production is found. Upper limits on the production cross section times branching ratio are placed on a specific topcolor assisted technicolor model with width $\Gamma_{Z'}$ = 0.012 $M_{Z'}$, as shown in Fig. 2 (right). Within this model, we exclude a Z' boson in the mass range below 805 GeV/c^2 at the 95% credibility level. Details of the analysis can be found in Ref. [13].

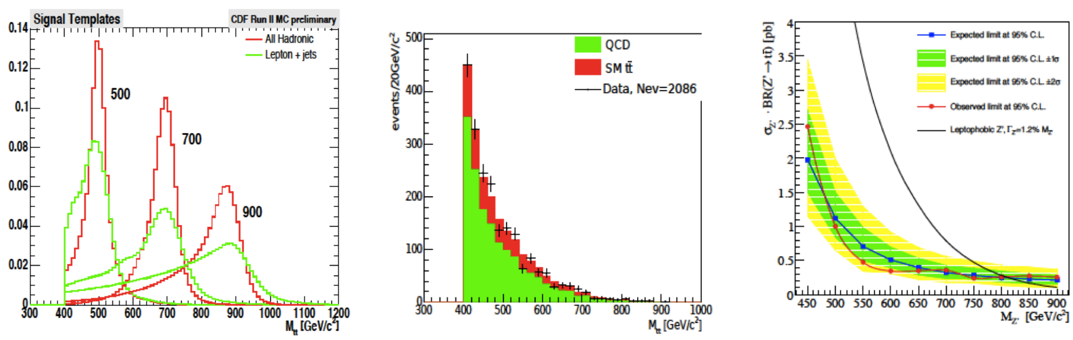

Figure 2: (Left) Distribution of reconstructed $t\bar{t}$ mass resonances in simulated events for 500 GeV/c^2, 700 GeV/c^2, and 900 GeV/c^2. (Center) Reconstructed $M_{t\bar{t}}$ vs. the SM expectation in the search region above the 400 GeV/c^2 cut. (Right) Expected and observed upper limits on leptophobic topcolor Z' in 2.8 fb^{-1} of CDF data. The blue line is the median expected upper limit with the assumption of no signal, the red line is the observed limit, and the black line is the cross section prediction for Z' production.

4. Lepton + Jets Channels

4.1 D0 Analysis

Events must satisfy one of several trigger conditions, all requiring an electron or muon with high transverse momentum, in some cases in conjunction with one or more jets. The event selection requires exactly one isolated lepton with p_T > 20 GeV, missing transverse momentum above 20 GeV (30 GeV) for the e+jets (μ+jets) data, and at least three jets with p_T > 20 GeV. The leading jet must have p_T > 40 GeV. We require at least one jet to be tagged as originating from the fragmentation of a b quark. We reconstruct the $t\bar{t}$ invariant mass $m_{t\bar{t}}$ using up to four jets with the highest p_T, the charged lepton, and the neutrino as shown in Fig. 3 (a) and (b). No consistent signal with the production of such a resonance has been observed. Upper limits on the cross section times branching fraction for production of such a resonance for masses between 350 and 1200 GeV are shown in Fig. 3. We exclude at 95% credibility level the production of a topcolor Z' that decays exclusively to $t\bar{t}$ for mass values below 835 GeV/c^2. Details of the analysis can be found in Ref. [14].

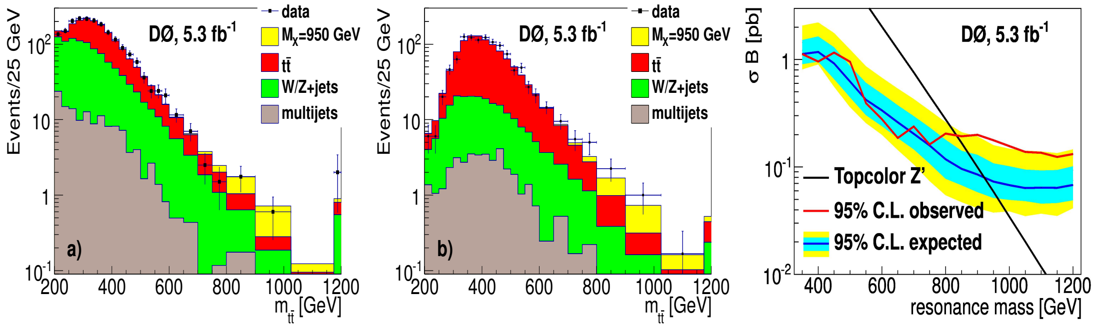

Figure 3: (Left and center) Distribution of $m_{t\bar{t}}$ for events that pass the final event selection with (a) exactly 3 jets and (b) at least 4 jets, compared with expectations for standard model processes and a 950 GeV/c^2 resonance signal with the best fit $\sigma B = 0.10$ pb. The highest bin in each histogram shows the number of events with $m_{t\bar{t}} > 1175$ GeV/c^2. (Right) Observed and expected upper limits on the cross section times branching fraction σB for a narrow $t\bar{t}$ resonance as a function of the resonance mass. The shaded regions around the expected limit represent the ± 1 and ± 2 standard deviation bands. The solid line shows the predicted topcolor Z' production cross section assuming $B(Z' \to t\bar{t})$ = 100%.

4.2 CDF Analysis

The $t\bar{t}$ candidates are selected from data corresponding to an integrated luminosity of 4.8 fb^{-1} in the lepton + jets channel by requiring one isolated charged lepton (e or μ) with $|\eta| < 1$. Electrons must have $E_T > 20$ GeV and muons must have $p_T > 20$ GeV/c^2. Moreover, four or more central jets ($|\eta| < 2$) and $E_T > 20$ GeV are also required. One of these jets must have secondary displaced vertex consistent with a b jet. A matrix-element reconstruction technique is used; for each event a probability density function of the $t\bar{t}$ candidate invariant mass is sampled as shown in Fig. 4 (left). These probability density functions are used to construct a likelihood function, whereby the cross section for resonant $t\bar{t}$ production is estimated, given a hypothetical resonance mass and width. The data indicate no evidence of resonant production of $t\bar{t}$ pairs. A benchmark model of leptophobic $Z' \to t\bar{t}$ is excluded with $m_{Z'} < 900$ GeV/c^2 at 95% credibility level as shown in Fig. 4 (right). Details of the analysis can be found in Ref. [15]. This analysis has recently been updated with the full dataset [16].

5. Chromophilic Z' Resonance in Lepton + Jet

This search for top quark-pair + jet resonances in $t\bar{t}j$ events is reported. For each accepted event, the resonance mass ($m_{t\bar{t}j}$) is reconstructed (Fig. 5), and the data are found to be consistent with SM background predictions. Therefore, we calculate 95% credibility level upper limits on the cross section of such resonance production from 300 fb to 40 fb for Z' masses ranging from 400 GeV/c^2 to 1000 GeV/c^2 and interpret the limits in terms of specific physics models, as shown

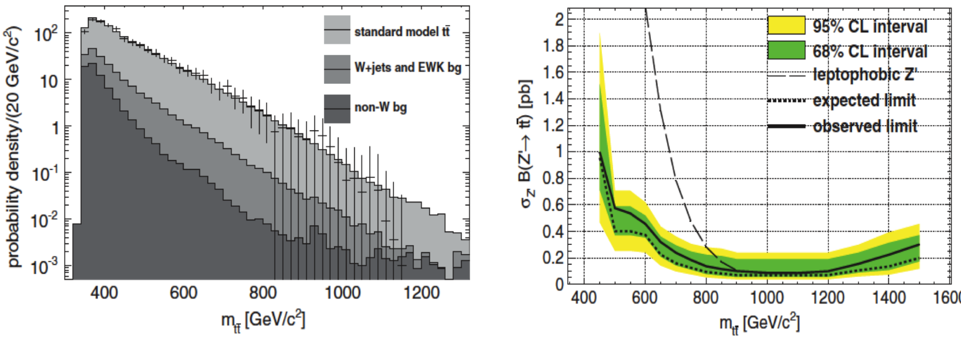

Figure 4: (Left) Total probability density for the 1366 $t\bar{t}$ candidate events observed in 4.8 fb^{-1} of integrated luminosity. (Right) Expected and observed 95% credibility level upper limit for $\sigma(p\bar{p} \to Z') \times BR(Z' \to t\bar{t})$ for 4.8 fb^{-1} of integrated luminosity as a function of reconstructed $t\bar{t}$ invariant mass.

in Fig. 5. These limits constrain a small portion of the model parameter space. Analysis of collisions at the Large Hadron Collider may probe the remaining allowed regions. Details of the analysis can be found in Ref. [17].

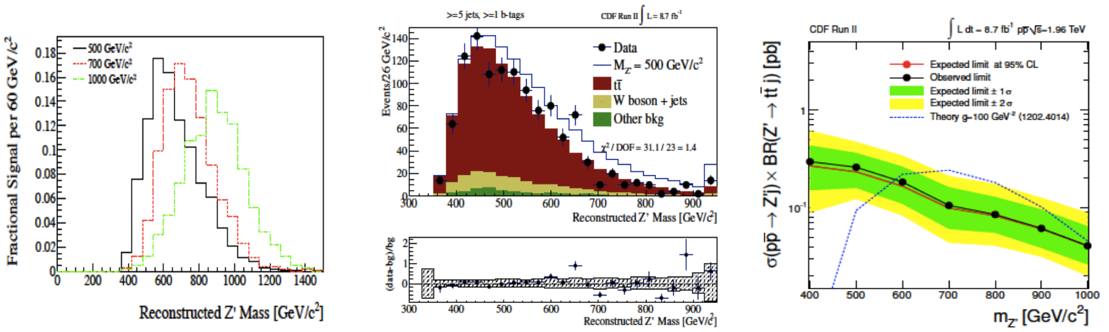

Figure 5: Distribution of the reconstructed Z' mass in simulated events for three choices of m_t. Distribution of events versus reconstructed $t\bar{t}j$ invariant mass $m_{t\bar{t}j}$ for observed data and expected backgrounds in the signal region. A signal hypothesis is shown assuming a total cross section of 300 fb. The lower panel gives the relative difference between the observed and expected distributions; the hatched area shows the combined statistical and systematic uncertainties of the expected background.

6. Search For Top + Jet Resonances in Lepton + Jet

The signal signature for top + jet resonances ($l + \nu + qq' + bb' + q$) in the lepton + jet channel is very similar to the SM $t\bar{t}$ + jet channel. The event selection is exactly one tight electron or muon with $p_T > 20$ GeV, at least 5 jets with $E_T > 20$ GeV, $|\eta| <2.0$, at least 1 b tag, and $\not{E}_T \geq$ 20 GeV. The M resonance signal is modeled using MADGRAPH [18] to describe the hard process and PYTHIA [19] for the showering. The dominant backgrounds are $t\bar{t}$ and W+jets. A binned maximum-likelihood fit is performed to the m_{tj} distribution (Fig. 5 left), varying each background rate within uncertainties, allowing shape and rate variations due to systematic uncertainties. The signal and background rates are fitted simultaneously. The data are found to be consistent with the SM and we set cross section upper limits from 0.61 pb to 0.02 pb for resonances ranging from 200 GeV/c^2 to 800 GeV/c^2 as shown in Fig. 5 (right). Details of the analysis can be found in Ref. [20].

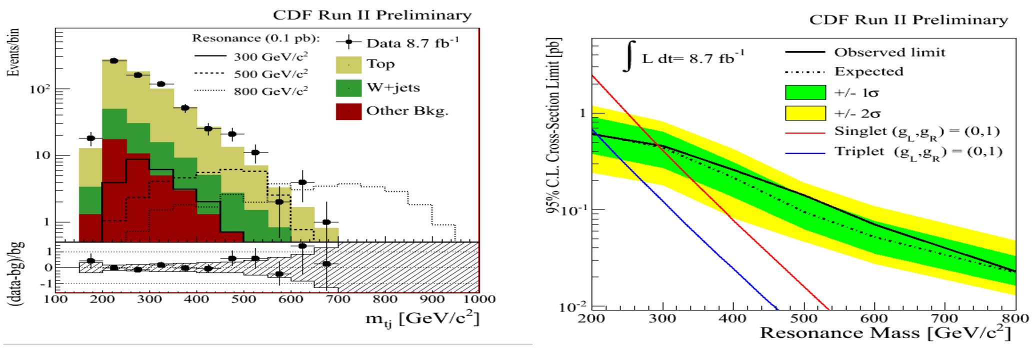

Figure 6: (Left) Resonance mass reconstruction, m_{tj}, for backgrounds, data, and example signal resonances of 300, 500, and 800 GeV/c^2 in the signal region scaled to a cross section of 0.1 pb. (Right) Upper limits at 95% credibility level on $t\bar{t}+j$ production via a heavy new mediator M, as a function of the mediator mass. Also shown are theoretical predictions, assuming a unit coupling.

7. Conclusion

We reported on $t\bar{t}$ resonant production results from the Tevatron. The is no evidence for resonant production of $t\bar{t}$ and top + jets at the Tevatron. Tevatron searches in some cases have a better reach than the LHC at low masses (below 1 TeV). The search in the mass range above 1 TeV requires higher energies and thus the LHC is the place for such searches.

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