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Searches for new physics in the $t\bar{t}$ events at CDF

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Abstract

We review the latest results on searches for physics beyond the Standard Model in the top quark sector at CDF Run II in a data sample with integrated luminosity up to 2.8 fb^{-1}.

Key words:
PACS: 14.65.Ha - Top quark, 12.60.-i - Models beyond the Standard Model, 13.85.Rm - Limits on production of particles, 13.85.Qk - Inclusive production with identified leptons, photons, or other nonhadronic particles

1. Introduction

Since its discovery [1], the top quark has appeared to be a very special object. It is distinguished by its large mass ($\sim 170\ GeV$) close to the scale of electroweak symmetry breaking (EWSB), and a Yukawa coupling surprisingly close to one (0.98). Is the top quark mass generated by the Higgs mechanism as the Standard Model (SM) predicts, or does it play a more fundamental role in the EWSB? How would physics beyond the standard model (SM) affect top quark properties? Searches for new physics (NP) should provide answers to the many open questions left by the SM.

In these proceedings we present the latest CDF results on the searches for exotic decay modes of the top quark, as well as the production and decay of new particles into final states with a top quark pair. The analyses of the Run II data are performed with approximately 30 times the statistics of the Run I top quark discovery [1].

2. Understanding the Data

Huge statistics and decent control on the backgrounds allows us to isolate pure $t\bar{t}$ samples, which is crucial for searches for physics beyond the SM. To better understand the $t\bar{t}$ sample, we use both Monte Carlo (MC) and data-driven approaches. Here we

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describe backgrounds relevant to the lepton+jets $t\bar{t}$ decay mode. For diboson samples, for single top and for $Z+jets$ we use MC. The data-driven methods are described below.

To estimate QCD background, we (a) study missing transverse energy ($\not\!\!E_T$) in low-$\not\!\!E_T$ region in samples dominated by jets which are required to fail at least two lepton identification requirements [2]; (b) study lepton calorimeter isolation versus $\not\!\!E_T$ [3]; (c) use track isolation for leptons (jets misidentified as leptons tend to be non-isolated) [4].

To estimate W + Heavy Flavor (HF) background, the relative fraction of W + HF production is calculated in MC, and the overall normalization of the W + jets production is measured with data [5]. To estimate background from mistagged jets, we use the mistag rate per jet, which is measured using a large inclusive-jet sample [5].

3. New Particles (t' and Randall-Sundrum Gravitons)

A fourth generation of quarks is not excluded by EWK precision data, and there are a few models [9] which suggest new heavy quarks decaying into Wb. We perform a search for t' [10] in $\mathcal{L} = 2.8$ fb^{-1}, assuming that $M(t') > M(t)$, the decay $t' \to Wb'$ suppressed, $V_{t'q} \approx V_{t'b}$ and hence $B(t' \to Wb) \approx$ 100%. We exclude t' with $M(t') < 311$ GeV at 95% C.L (Fig. 1, left-hand plot).

We analyze the $t\bar{t}$ differential cross-section, $d\sigma/dMt\bar{t}$ and set limits on Randall-Sundrum (RS) gravitons decaying to $t\bar{t}$ in $\mathcal{L} = 2.7$ fb^{-1} (Fig. 1, right-hand plot). The analysis [12] uses an in-situ calibration of the jet energy scale to significantly reduce the jet energy scale uncertainty. We use an unfolding technique [11] to get the true value of $M_{t\bar{t}}$. The signature for both searches is $\ell \not\!\!E_T$ and at least 4 jets.

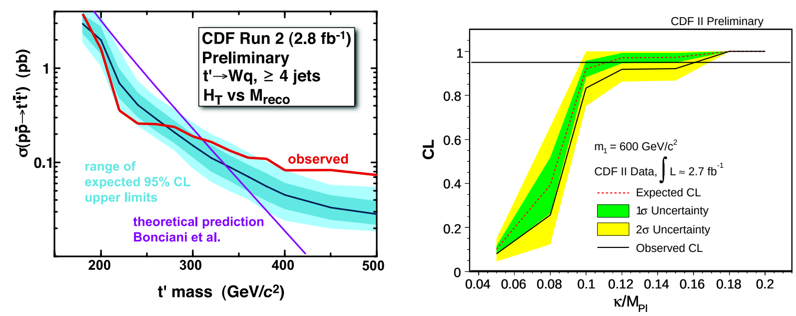

Fig. 1. On the left: we exclude a SM fourth-generation t' with $M(t') < 311$ GeV at 95% C.L. The purple curve is a theoretical $\sigma(p\bar{p} \to t't')$. The blue bands represent $\pm1\sigma$ and $\pm2\sigma$ limits. On the right: limits on k/M_{Pl} for RS gravitons which decay to top quarks, where the mass of the first resonance is 600 GeV.

4. Top Quark Decay (FCNC, Invisible Top Decays, Charged Higgs, $t\bar{t}\gamma$)

In the SM, top quark flavor changing neutral current (FCNC) decays are highly suppressed. In particular, evidence for the decay $t \to Zq$ would be an indication of NP. The signature for the search [6] is $\ell\ell$+4 jets ($\ell\ell$ include ℓ+isolated high-p_T track to double the acceptance). The $M_{W,rec}$, $M_{t\to Wb,rec}$ and $M_{t\to Zq,rec}$ (Fig. 2, left-hand plot) distributions are compared with signal and background expectations and a χ^2 of the distributions is calculated event-by-event and used to set limits on $B(t \to Zq)$. In a sample with integrated luminosity $\mathcal{L} = 1.9$ fb^{-1}, the data show no evidence of this decay.

In the analysis for invisible top quark decays [7] we search for the possibility of alternative top decays ($t \to invisible$, $t \to Zc$, $t \to gc$, $t \to \gamma c$). We consider the yield of our standard $\ell + jet$ selection with two b tags and look for a deviation from expected as defined by the theoretical top pair production cross section (Fig. 2, in the middle). The signature for the search is $\ell \not{E}_{\rm T}+ \geq 3$ jets (2 b-tags), $\mathcal{L} = 1.9$ fb^{-1}.

Employing a Feldman-Cousins technique, we set 95% C.L. upper limits: $B(t \to Zq) <$ 3.7% , $B(t \to invisible) <$ 9% , $B(t \to Zc) <$ 13%, $B(t \to gc) <$ 12%, $B(t \to \gamma c) <$ 11%.

CDF also performed a direct search for charged Higgs bosons, $H^{\pm}$, $t \to H^{+}b$. At low $\tan(\beta)$ $H^{+} \to c\bar{s}$ dominates. Assuming that $B(H^{+} \to c\bar{s}) = 1$, $B(t \to H^{+}b) + B(t \to W^{+}b) = 1$, we look for a second peak in an invariant mass of two light jets in top quark decays, $M(jj)$. The signature for the search is $\ell \not{E}_{\rm T}$ with at least 4 jets, $\mathcal{L} = 2.2$ fb^{-1}. We found no evidence of $H^{\pm}$ in the $M(jj)$ distribution, and hence upper limits on the $B(t \to H^{+}b)$ at 95% C.L. are placed at 0.1 to 0.3, depending on the M($H^{\pm}$) [8].

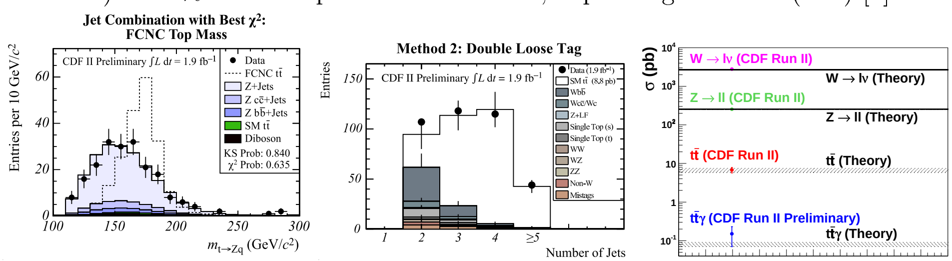

Fig. 2. On the left: The $M_{t \to Zq,rec}$ mass distribution, used in a mass χ^2 calculation for the FCNC search. In the middle: N_{jets} in $\ell \not{E}_{\rm T}$ and 2 loose b-tags sample [7]. On the right: The measured $\sigma_{t\bar{t}\gamma}$ compared with SM expectations and other SM cross-sections.

We have performed a search for $t\bar{t}\gamma$ [13], which is the dominant SM process that produces the $\ell\gamma \not{E}_{\rm T} b$ signature with large total transverse energy (H$_{\rm T}$) and jets. Hence the signature for the search is $\ell\gamma \not{E}_{\rm T}$+b jet+H$_{\rm T}$ > 200 GeV+$N_{jets} > 2$, $\mathcal{L} = 1.9$ fb^{-1}. We used inclusive $\ell\gamma \not{E}_{\rm T} b$ production as a control sample. Assuming SM top production, we measured the $t\bar{t}\gamma$ cross-section, $\sigma_{t\bar{t}\gamma} = 0.15 \pm 0.08$ pb (Fig. 2, right-hand plot).

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