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Top Quark Production Cross-Section at the Tevatron Collider

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Abstract. We present the preliminary results of the $t\bar{t}$ pair production cross-section measurements and the single top quark exclusion limits carried out by the DØ and the CDF collaborations in Run II of the Tevatron. The dataset for the various measurements ranges from 140 pb^{-1} to 350 pb^{-1}.

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1. INTRODUCTION

The top quark was discovered jointly by the DØ and the CDF collaborations in 1995 [1]. At the Tevatron $p\bar{p}$ collider (center of mass energy, $\sqrt{s}$ = 1.96 TeV), top quarks are dominantly produced in pairs via strong interaction: $q\bar{q}$ annihilation ($\sim$ 85 %) and gluon fusion ($\sim$ 15 %). Existing theoretical predictions for the $t\bar{t}$ pair production cross-section at NLO in QCD ranges from 6.7 - 7.5 pb [2] (for m_t = 175 GeV), representing a 30 % increase in cross-section over Tevatron's RunI center of mass energy of 1.8 TeV.

Within the Standard Model (SM), the top quark decays almost exclusively to a W-boson and a b-quark. Decay of the two top quarks, $t \rightarrow Wb$, are characterized by the three distinct final state signatures depending on the decay modes of the W-boson: the dilepton final states ($ee, e\mu, \mu\mu$) where both the Ws decay leptonically is the cleanest channel but accounts only for $\sim$ 5 % of the $t\bar{t}$ pairs; the all-hadronic channel where both the Ws decay hadronically constitutes $\sim$ 44 % of the signal but suffers from a huge QCD multijet background; and the lepton + jets ($e + jets$ or $\mu + jets$) channel where one W decays leptonically and the other one decays hadronically accounts for $\sim$ 30 % of the $t\bar{t}$ events and can be considered the best compromise between statistics and purity.

The SM also predicts the production of single top quark via electroweak interaction with a production cross-section of $\sim$ 0.88 pb in the s-channel and $\sim$ 1.98 pb in the t-channel at $\sqrt{s}$ = 1.96 TeV [3] . This production mechanism has not yet been observed and is the subject of current active searches at the Tevatron.

2. TOP QUARK PAIR PRODUCTION

2.1. Di-lepton channel

A dileptonic final state is characterized by the presence of two isolated, high p_t leptons, two high p_t b-jets and large $\not\!\!E_T$ from the two neutrinos. The background

contribution comes mainly from instrumental effects (estimated from data), sources of which include QCD multijet, W+jets, and $Z \rightarrow l^+l^-$ events with mismeasured $\not\!\!E_T$ or misidentified leptons. The additional contribution comes from irreducible physics background (estimated from Monte Carlo simulations), mostly from $Z \rightarrow \tau^+\tau^-$ and $WW/WZ \rightarrow l^+l^-$ processes.

CDF has performed two complementary analyses using 200 pb^{-1} of the data. In one of the analysis, two leptons are explicitly identified as e or μ. In the other analysis, CDF requires the 2nd leading lepton to be an isolated, high p_t track and does not require its explicit identification as e or μ. This increases the signal acceptance and also extends the sensitivity to $W \rightarrow \tau\nu$ (with single prong decay of τ), however, at the cost of higher background contamination. The DØ experiment has done separate analyses in the ee, $e\mu$, and $\mu\mu$ final states with about 140 pb^{-1} of the data and then combined the final results. The measured cross-sections for the CDF and DØ analyses are $\sigma_{t\bar{t}} = 7.0^{+2.4}_{-2.1}(stat)^{+1.7}_{-1.2}(syst+lumi)pb$ and $\sigma_{t\bar{t}} = 14.3^{+5.1}_{-4.3}(stat)^{+2.6}_{-1.9}(syst) \pm 0.9(lumi)pb$ respectively. It can be observed that the dominant uncertainties in this channel are statistical in nature. CDF also pursues an alternative approach where only two leptons are selected and a likelihood fit has been performed in the $\not\!\!E_T$ - N_{jets} plane to simultaneously determine the contributions from $t\bar{t}$, WW, and $Z \rightarrow \tau\bar{\tau}$. The measured $t\bar{t}$ cross-section for an integrated luminosity of 200 pb^{-1} is $\sigma_{t\bar{t}} = 8.6^{+2.5}_{-2.4}(stat) \pm 1.1(syst)pb$

2.2. Lepton + Jets channel

The signature of the lepton+jets channel consists of one isolated, high p_t lepton, at least 3 or 4 high p_t jets and $\not\!\!E_T$ from the neutrino. The dominant background comes from the W+jets processes with an additional component from the QCD multijet events. To discriminate signal from the backgrounds, which are significantly higher than dilepton analyses, two approaches are used: topological selection and b-tagging selection.

Topological analysis: The general approach is to choose various topological and kinematical variables, which can provide maximum separation between signal and background events. CDF combines these variables into a 7-input Neural Network (NN) discriminant requiring at least 3 jets and then performs template fit to the NN output (figure 1) and measures the $t\bar{t}$ cross-section with 347 pb^{-1} of the data to be $\sigma_{t\bar{t}} = 6.0 \pm 0.8(stat) \pm 1.0(syst)$ pb for m_t = 178 GeV. In a similar manner DØ has combined these variables into an event likelihood discriminant with the requirement of at least 4 jets in the events and a template fit to the discriminant is performed to extract the cross-section (figure 1). Measured DØ cross-section for 230 pb^{-1} of the data is $\sigma_{t\bar{t}} = 6.7^{+1.4}_{-1.3}(stat)^{+1.6}_{-1.1}(syst) \pm 0.4(lumi)$ pb. In this channel the systematic unceratinties are comparable to the statistical ones.

b-tagging analysis: The $t\bar{t}$ decays contain two high p_t b-jets. B-hadrons are long lived and travel a few mm distance away from the primary vertex before decay. Using the silicon microvertex sub-detectors in both the DØ and the CDF experiments, secondary vertex can be explicitly identified (referred to as SVX in CDF and SVT in DØ). Applying b-tagging is a very powerful tool in suppressing the backgrounds. DØ has pursued the b-tagging analysis separately for exactly 1 b-tagged jet events and at least 2 b-tagged jet

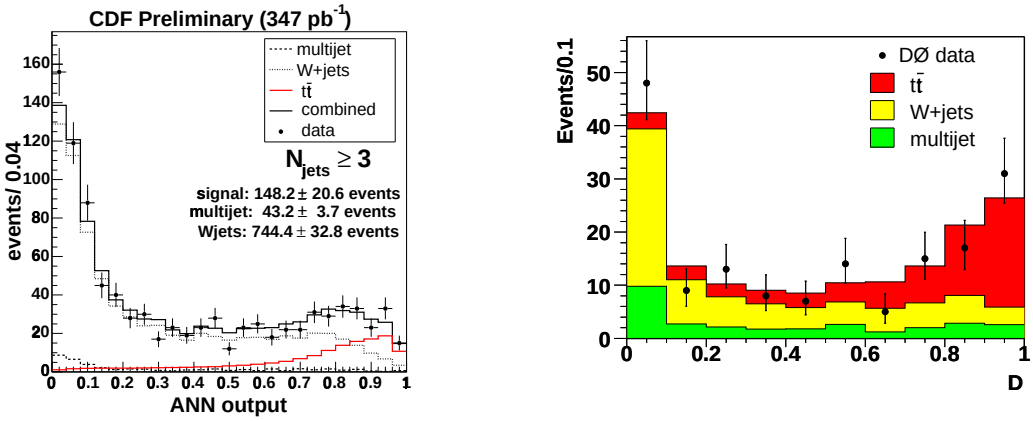

FIGURE 1. Result of the fit to the NN-output shape for the CDF (left plot) and the fit to the likelihood discriminant for the DØ (right plot) lepton+jet analysis.

events for lepton+$\not\!\!E_T$+ $\geq$ 4jets selection and the combined measured cross-section for 230 pb^{-1} of the data is $\sigma_{t\bar{t}} = 8.6^{+1.6}_{-1.1}(stat)^{+1.1}_{-1.0}(syst) \pm 0.6(lumi)pb$. CDF has applied the b-tagging requirement in lepton+$\not\!\!E_T$+$\geq$3jets events and performed the analysis for $\geq$ 1 b-tags and $\geq$ 2 b-tags. The measured cross-section for the two analyses for 318 pb^{-1} of the data are $\sigma_{t\bar{t}} = 7.9 \pm 0.9(stat) \pm 0.9(syst)pb$ and $\sigma_{t\bar{t}} = 8.7 \pm 1.7(stat) \pm 1.5(syst)pb$ respectively. CDF has also performed separate analysis using the semileptonic decay of the B-hadrons and hence identifying the b-jet by the presence of "soft" muon inside a jet. CDF has extracted the $t\bar{t}$ cross-section using soft muon tagging for 194 pb^{-1} of the data to be $\sigma_{t\bar{t}} = 5.2^{+2.9}_{-1.9}(stat)^{+1.3}_{-1.0}(syst)pb$.

2.3. All hadronic channel

Owing to an overwhelming QCD multijet background, the cross-section measurement in all hadronic decay mode is relatively difficult. Both topological cuts and b-tagging are used to suppress the background. The CDF experiment selects events with at least six jets and requires at least one jet to be b-tagged. It then employs several cuts on the kinematical variables to further reduce the multijet background. The measured $t\bar{t}$ cross-section for an integrated luminosity of 165 pb^{-1} is $\sigma_{t\bar{t}} = 7.8 \pm 2.5(stat)^{+4.7}_{-2.3}(syst)pb$. In the DØ analysis, events with at least 6 jets are selected requiring at least one SVT b-tag and it combines topological variables in 3 successive NNs at various stages. The distribution of 3rd NN discriminant is fit to extract the $t\bar{t}$ cross-section. The DØ cross-section measurement yields $\sigma_{t\bar{t}} = 7.7^{+3.4}_{-3.3}(stat)^{+4.7}_{-3.7}(syst) \pm 0.5(lumi)pb$.

3. SINGLE TOP QUARK SEARCHES

Both the CDF and the DØ experiments have performed single top quark searches in the *s*- and *t*-channels. No evidence for the single top quark signal has yet been found

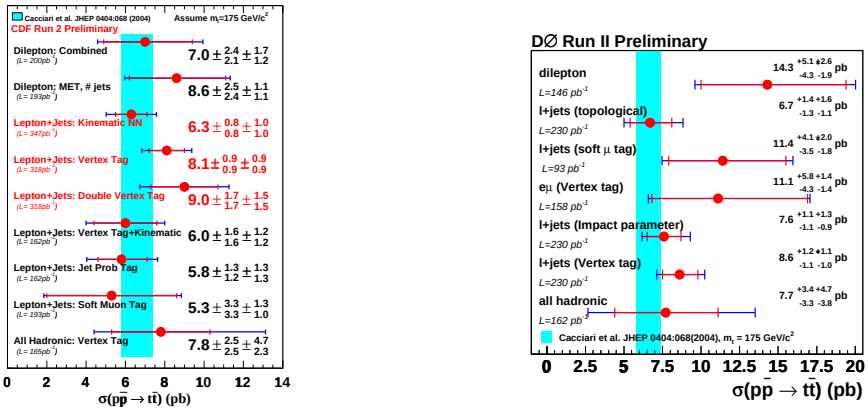

FIGURE 2. Summary of the $t\bar{t}$ pair production cross-section measurements from the CDF and the DØ collaborations. For comaparison, the NLO predictions for $m_t = 175 GeV$ including uncertainties on top quark mass is also shown.

in these analyses. Single top quark events are selected by requiring one isolated, high p_t lepton, large $\not\!\!E_T$ and two high p_t jets. CDF has performed channel specific searches by requiring exactly 1 b-tagged jet events for the t-channel and at least 2 b-tagged jet events for the s-channel. CDF has also pursued the combined channel searches using a discriminating variable which can separate single top signal from the $t\bar{t}$ and the non-top background events. Cross-section limits at the 95% confidence level for the s-channel, t-channel and the combined channel searches are placed at σ_s < 13.6 pb, σ_t < 10.1 pb and σ_{s+t} < 17.8 pb respectively for 162 pb^{-1} of the data. DØ has performed three separate analyses using NNs, decision trees and cut-based techniques. 95% confidence level Bayesian upper limits on the production cross-section using the binned likelihood fits to the NN output distributions are σ_s< 6.4 pb in the s-channel, and σ_t< 5.0 pb in the t-channel using 230 pb^{-1} of the data.

4. SUMMARY

The measurement of the top quark pair production cross-section has been performed by both the DØ and the CDF collaborations in various channels using differnt approaches for an integrated luminosity ranging from 140 pb^{-1} to 350 pb^{-1} (figure 2). The measured cross-sections are consistent with the SM predictions. Upper limits on the production cross-section of the single top quark have also been placed by both the collaborations.

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