Top Production and Properties at CDFII

Shulamit Moed

Harvard University, 18 Hammond St., Palfrey House, Cambridge MA 02138, USA

E-mail: moed@physics.harvard.edu

Abstract. The large data samples of hundreds of top events collected at the Tevatron CDF II experiment allow for a variety of measurements to analyze the production and properties of the top quark. This article presents analyses studying the $t\bar{t}$ production cross section, $t\bar{t}$ production mechanism, and the helicity of W bosons in top quark decays. These analyses use an integrated luminosity of about $1fb^{-1}$ in the 'lepton+jets' channel of the $t\bar{t}$ decay.

1. Introduction

At the Tevatron collider at the Fermi National Accelerator Laboratory, protons and anti-protons are collided at a center-of-mass energy of 1.96 TeV. Providing the highest energies currently available at a hadron collider, the Tevatron is currently the only place where top quarks are produced. CDF has extensively studied the production and decays of the top quark, as precision measurements have the potential to reveal new physics effects. The focus of this article is on measurements of top production and the tWb $V-A$ interaction, where events are selected in the 'lepton+jets' channel ($t\bar{t} \rightarrow WbWb \rightarrow l\nu bqqb$).

2. Top Pair Production Cross Section Measurement

The SM top quark at the Tevatron is mostly produced in pairs with a theoretical cross section prediction of $6.7 \pm 0.8pb$ [1]. The top quark pair production cross section measurement is an important test of QCD predictions and is the key to all top property measurements, since it requires the understanding of all background processes in the selected sample of candidate top quark events.

In the 'lepton+jets' channel of the $t\bar{t}$ decay the dominant backgrounds come from W boson production in association with jets, and non-W QCD events. Other backgrounds which may have similar final states to $t\bar{t}$ are di-boson, single top and $Z \rightarrow \tau\tau$ processes. The backgrounds are estimated using a combination of data and Monte Carlo methods. The excess in data over these backgrounds is attributed to top pair production, see Fig. 1. The selected dataset requires an isolated electron with transverse energy, E_T , greater than 20 GeV, or a muon with transverse momentum (P_T) > 20 GeV/c, missing transverse energy due to the undetected neutrino > 30 GeV and at least three jets with $E_T > 20$ GeV. Signal to background discrimination is improved by using a secondary vertex finding algorithm to reconstruct heavy flavor decay vertices inside jets ("b-tagging "). At least one of the jets is required to be tagged as a b-jet. Finally, to further suppress the background, the scalar sum of all transverse energies in the event, called H_T, is required to exceed 250 GeV.

Using 1.12 fb^{-1} of data, the top pair production cross section is measured to be $8.2 \pm 0.5(stat) \pm 0.8(syst) \pm 0.5(lum)\ pb$. For details of this analysis see Ref. [2].

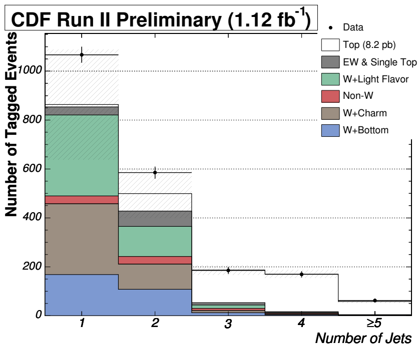

Figure 1. Expected and observed number of events sorted by jet multiplicity requiring at least one b-tag.

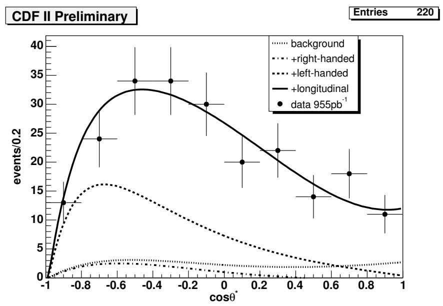

Figure 2. The observed $\cos(\theta*)$ distribution in the data (points) overlaid with the background (dotted), background + right-handed (dash-dot), background + right-handed + left-handed (dashed) and background + right-handed + left-handed + longitudinal (solid) distributions as determined by the fit for the right handed fraction of W bosons.

3. Fraction of $t\bar{t}$ Pairs Produced via Gluon-Gluon Fusion

In the SM, the production of $t\bar{t}$ pairs at the Tevatron is dominated by the process of $q\bar{q}$ annihilation. The contribution of the gg fusion channel to the $t\bar{t}$ production cross section amounts to $(15 \pm 5)\%$, [1]. Two complementary methods have been developed in CDF to measure the fraction of $t\bar{t}$ pairs produced via gg fusion. With datasets of 1 fb^{-1} of integrated luminosity both methods are dominated by statistical uncertainties, and are therefore expected to improve with more data.

One method [3] utilizes an artificial neural network (ANN) to distinguish the processes $q\bar{q} \rightarrow t\bar{t}$, $gg \rightarrow t\bar{t}$, and $q\bar{q}/gg \rightarrow$ W+jets. The ANN input variables are the velocity of the top quark and its angle with respect to the right coming parton in the event, and other six angles of the $t\bar{t}$ decay products in the "off-diagonal" basis. These angles contain information about the spin correlation in the event. From the resulting ANN output, an upper limit on the gg fraction is derived using the Feldman-Cousins approach [4], incorporating systematic uncertainties into the limit calculation. As shown in Fig. 4, this measurement yields an upper limit on $t\bar{t}$ pair production cross section from gg fusion of $\sigma(gg \rightarrow t\bar{t})/\sigma(p\bar{p} \rightarrow t\bar{t}) < 0.61$ at 95% C.L.

The other method takes advantage of the correlation between the number of low-energy particles observed in the final state and the number of gluons in the event. This is due to the fact that there is a higher probability for a gluon that initiates the hard scattering process to radiate low-energy gluons. Gluon-rich and no-gluon templates are fitted to the distribution of the number of low-P_T tracks in the data. In this analysis the gg fraction is measured to be $\sigma(gg \rightarrow t\bar{t})/\sigma(p\bar{p} \rightarrow t\bar{t}) = 0.01 \pm 0.16(stat.) \pm 0.07(syst.)$, see Fig.3.

4. Helicity of W boson in Top Quark Decays

As the top quark decays before it can form an hadronic bound state, its spin information is fully transmitted to its decay products. The W boson, with spin 1, has three possible helicity states: left-handed, longitudinal, and right-handed. The $V - A$ nature of the tWb vertex highly suppresses the existence of right-handed W bosons in top decays. The SM predicts the

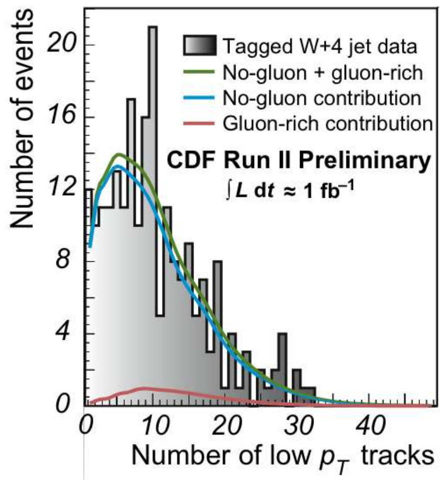

Figure 3. Distribution of low-P_T tracks fitted by gluon-rich and no-gluon templates in W+4jets data.

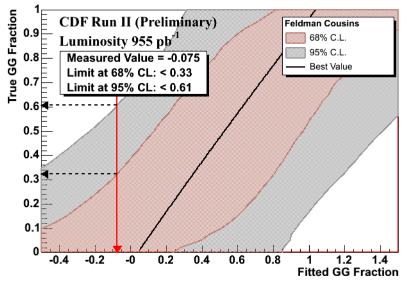

Figure 4. The Feldman-Cousins bands for measuring the gg fractions using a NN. The true gg fractions (Y axis) Vs a quantity obtained from the NN fit (X axis). The red line indicates the NN fit obtained from data, and its intersection with the green band indicates the 68% confidence level limit. The intersection with the blue line indicates the 95% confidence level limit.

longitudinal fraction of W bosons in top decays to be 0.7 for a top mass of 175 GeV/c^2. Any deviation from the SM prediction would indicate non-SM physics.
The fractions of W bosons in the longitudinal and right-handed helicity states are measured through an analysis of the distribution of θ^*, the angle between the charged lepton and the W boson in the top rest frame. Templates from Monte Carlo events of the $\cos(\theta^*)$ distribution for the three helicity cases and for background, are constructed and used in a maximum likelihood fit to extract the W-boson helicity fractions [5]. With a total integrated luminosity of 1 fb^-1 we find the longitudinal fraction, f_0, to be $f_0 = 0.6 \pm 0.12(stat) \pm 0.06(syst.)$, and the right-handed fraction, f_+, to be $f_+ = -0.06 \pm 0.06(stat.) \pm 0.03(syst.)$, as shown in Fig. 2. Using a Bayesian method, we further set an upper limit on the right-handed fraction, $f_+ < 0.11$ at 95% C.L.
A first simultaneous measurement of these fractions yields: $f_0 = 0.74 \pm 0.25(stat)\ \pm 0.06(syst.)$, $f_+ = -0.06 \pm 0.10(stat.) \pm 0.03(syst.)$. Currently, the simultaneous fit has larger statistical uncertainties, but is model independent and will become more precise with larger datasets.
A similar analysis done in CDF, that constructs $\cos(\theta^*)$ templates taking into account efficiencies and reconstruction effects, measures the helicity fractions to be: $f_0 = 0.59 \pm 0.12(stat) \pm 0.06(syst.)$, $f_+ = -0.03 \pm 0.06(stat.)^{+0.04}_{-0.03}(syst.)$, and set an upper limit on the right handed-fraction $f_+ < 0.10$ at 95% C.L [6].

References

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[2] The CDF collaboration, CDF public note 8795; Measurement of the $t\bar{t}$ Production Cross Section in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV using Lepton + Jets Events with Secondary Vertex b-tagging.

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