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Top quark properties at CDF

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We present the top property measurements in the CDF. Most of measurements utilize close to the integrated luminosity of 3 fb^{-1}.

1. Introduction

During the last decade after discovery of top quark [1, 2], top quark has been inclusively studied. By now, the mass of the top quark has been measured to be 173.1±1.3 GeV/c^2 [3] which is the most precisely measured quark mass and $t\bar{t}$ pair production cross section has been measured as less than 10 % of uncertainties [4]. However, many of another top quark property have not yet been well explored due to the limited statistics. In the ongoing data taking at Fermilab's Tevatron proton-antiproton collider with Collider Detector at Fermilab (CDF), an increasing of integrated luminosity can make us to measure the property and also discover the unexpected phenomena from top sector. We describes a few of the CDF's progress of top quark property measurements in the following.

2. Top property measurements

2.1. Top quark production

The predominant production of top quark in the Tevatron is the $t\bar{t}$ pair production. The standard model (SM) predicts the $t\bar{t}$ production processes to be $q\bar{q}$ annihilation ($q\bar{q} \to t\bar{t}$) and gg fusion ($gg \to t\bar{t}$), occurring at the Tevatron with relative fractions of ∼85% and ∼15%, respectively [5]. A measurement of this fraction tests the SM predictions and our understanding of gluon parton distribution functions in the proton. We measure this quantity both lepton jets and dilepton final state. In the lepton jet channel, we have two different measurement based on different discriminant. One method builds distriminant using number of low-momentum track to take advantage of the higher probability for a gluon than for a quark to radiate a low-momentum gluon [6]. The other method builds discriminant with artificial neural net using eight variables those are sensitive to the production mechanism [7]. Both two measurement use 955 pb^{-1} of CDF data, and is combined by using the Feldman-Cousin prescription [8]. Figure 1 shows Feldman-Cousin bands for the combination of two analysis with 68% and 95% confidence level (C.L.) for the fraction of gg to produce $t\bar{t}$. We measure the fraction to be $G_f = 0.07^{+0.15}_{-0.07}$, and we find the 95% C.L. limit to be $G_f < 0.38$ [7]. This is consistent with SM.

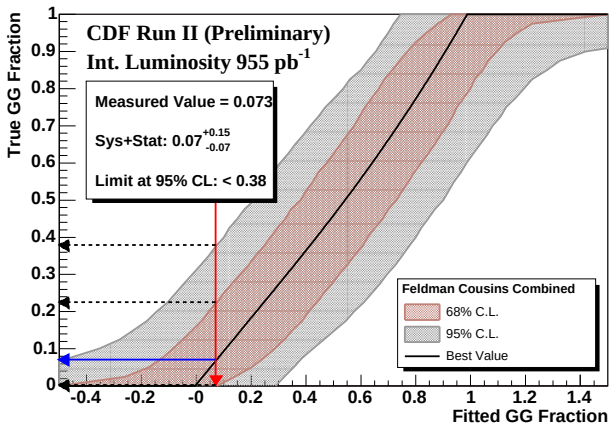

Figure 1: Feldman-Cousins bands for the combination of the analysis for gg fraction in the lepton jet channel with statistical and systematic uncertainties for 68% C.L. and 95% C.L..

We use angle between two lepton to build discriminant for extraction of gg fraction in the dilpeton channel [9]. We build Feldman-Cousin bands and fit data using 2.0 fb^{-1} of $p\bar{p}$ collision as you can see in Fig. 2. We measure the gg fraction in the dilepton channel to be $G_f = 0.53^{+0.36}_{-0.38}$ which is consistent with SM.

Since new production mechanism for top quark pairs can make the shape of $t\bar{t}$ invariant mass as resonances or general shape distortions, the generic method to search the such contribution is to compare the shape of the observed differential $t\bar{t}$ cross section $d\sigma/dM_{t\bar{t}}$ with SM expectation. The mass of the top-antitop system is reconstructed for each event by combining the four vectors of the four leading jets, lepton, and missing transverse energy. The unfolding technique implemented to correct the reconstructed distribution as for direct comparison with theoretical differential cross section. In the update with 2.7 fb^{-1} data, we have in-situ jet energy scale (JES) measurement using di-jet mass of W boson decay, which have been used in the top quark mass measurement [10], that we can significantly reduce the JES systematics. As one can see in Fig. 3, we do not find any significant difference with SM expectation. We check the consistency using the Anderson-Darling (AD) statistics [11]. We calculate a p-value of 0.28 using AD statistics which

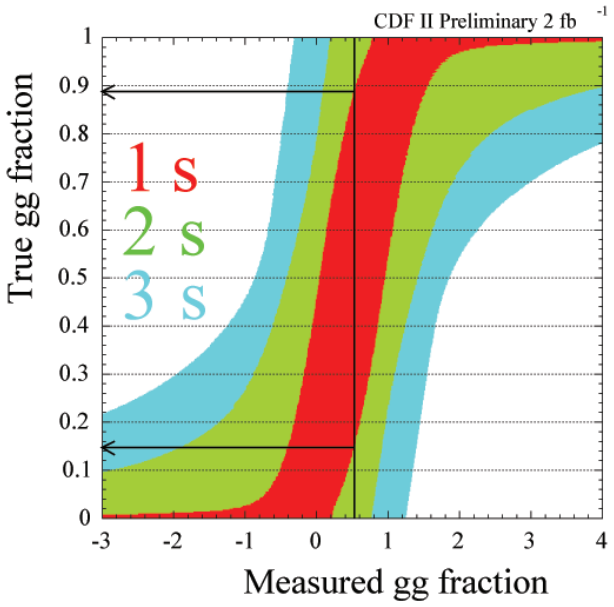

Figure 2: Feldman-Cousins bands for gg fraction in the dilepton channel with statistical and systematic uncertainties for 68% C.L. and 95% C.L..

have a good agreement with the SM [12].

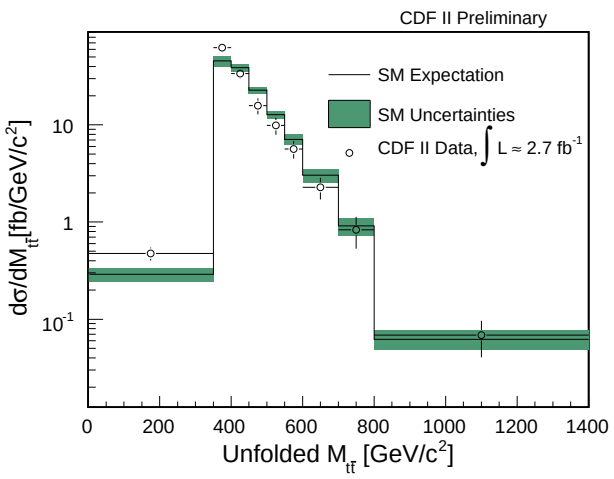

Figure 3: Unfolded differential cross section of $t\bar{t}$ invariant mass using CDF data is compared with SM prediction.

We search for resonant top-antitop pair production and subsequent decay in the all-hardronic channel with 2.8 fb^{-1} of data [13]. We use the probability from per-event matrix element calculation as discriminant to reduce and control the large background from QCD-multijet as an input of neural net with other kinematic variables. We reconstruct invariant mass of $t\bar{t}$ with matrix element technique and have consistent result with SM prediction as one can see in Fig. 4. We then set the 95% C.L. limits on Z' production as 805 GeV in case of a leptophobic topcolor resonance candidate.

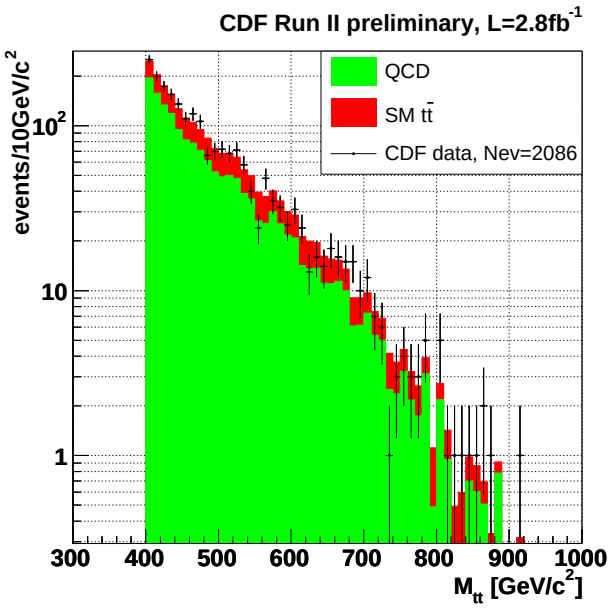

Figure 4: Invariant mass of $t\bar{t}$ from data and SM expectation.

2.2. Top like new physics particle search

Due to the large mass of the top quark, the supersymmetric partner of top quark (stop) can be lighter than the top quark even to be a lightest squark. For a light stop and R-parity conservation of supersymmetry particles, stop quark dominantly decay to b-quark and chargino, and chargino decay to W boson and neutralino. While neutralino can not be detected, the decay of pair produced stop quark have same final state with $t\bar{t}$ decay. We search the pair production of stop in the dilepton final state with 2.7 fb^{-1} of data [14]. We reconstruct the stop mass in the underconstraint system to extract the stop components in the $t\bar{t}$ dilepton decay events. Figure 5 shows our data is compatible with SM prediction without stop, and then we set the 95% C.L. upper limit of stop in certain condition of SUSY parameter space [14].

2.3. Top properties

One of basic quantities of top quark is the electric charge, which is expected to have a value of $2/3e$ in the SM. However, one of exotic model have decay of top to a W^- instead of W^+ having a charge of $4/3e$ [15]. We have a measurement using 1.5 fb^{-1} of data in the lepton jet channel. The measurement identifies the charge of the two W bosons and two b-quarks in each data event, and then determine which W bosons and b-quarks decayed from the same parent top quark. The charge of the top is then obtained by multiplying the charge of the W with the charge of the jet associated with a b-quark. Figure 6 shows the measured distribution of pairs of charge product which is

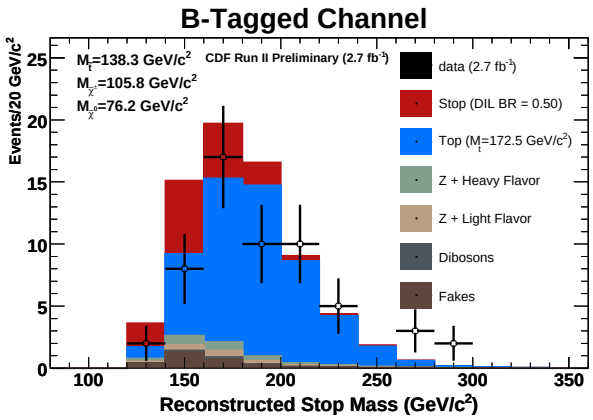

Figure 5: Reconstructed stop mass comparing data to monte carlo.

compatible with SM like top charge. We then exclude exotic model-like top at 87% C.L. [16].

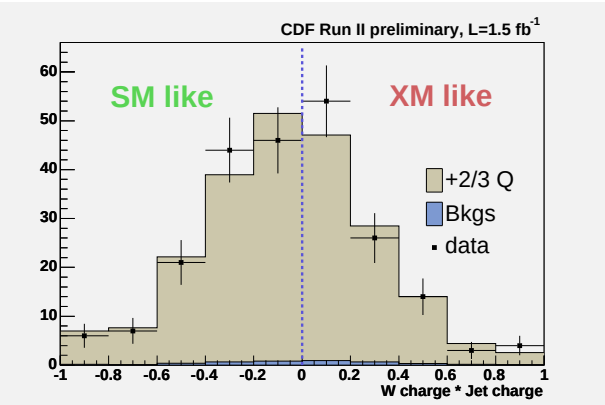

Figure 6: Product of the W charge and the associated jet charge for data and MC (SM signal MC distribution).

Top quark width have been measured with 1 fb^{-1} of data in the lepton jet channel. Main idea is to use top mass reconstruction and templates for different top width and to fit it to data. We use the top quark mass considered known as $M_{top} = 175$ GeV$/c^2$ and templates are produced for range of different top width. We extract top width from reconstructed top mass distribution compared to signal with different top width and background using unbinned likelihood fit. We then have measurement consistent with SM as one can see in Fig. 7, so we set a limit on top width using Feldman-Counsins [8] prescription to be top width(Γ)<13.1 GeV of 95% C.L. upper limit [17].

2.4. Top decay

The SM predicts that the top quark decays almost entirely to a W-boson and a bottom quark, and that

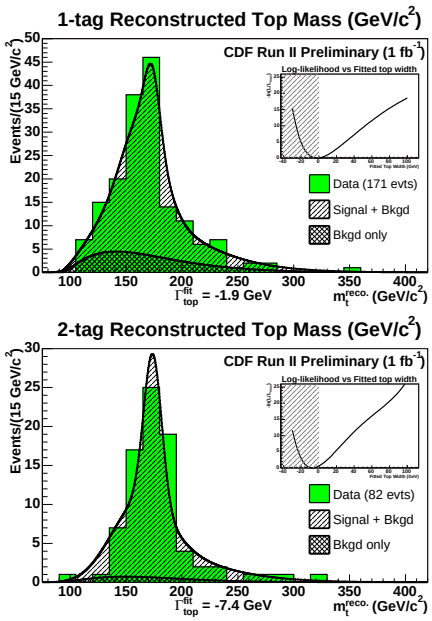

Figure 7: Likelihood fit to the data with 1-tag (up) and 2-tag (down) categories.

the Wtb vertex is a V-A charged weak current interaction. A consequence of this is that the top quark is expected to decay 70.4% of the time of longitudinal and the rest to left handed polarized W-bosons [18]. Any new particles involved in the same decay topologies and non-standard coupling could create a different mixture of polarized W-bosons. Therefore, a measurement of this fraction is a test of the V-A nature of the Wtb vertex. In the CDF, there are several measurements using different technique in the lepton jet channel with 1.9 fb^{-1} of data. One method builds template using $cos(\theta)$ [19], where the θ is the angle between lepton and b-quark in the W rest frame, this is sensitive to W helicity. The other method use matrix element technique [20] which we calculate a likelihood for each event then product per event likelihood to build total likelihood. Figure 8 shows W-helicity measurements at CDF. All of measurements are consistent with SM prediction.

Several exotic physics models, such as SUSY and two Higgs doublet, predict flavor changing neutral currents (FCNC) in top decay. In the standard model, this decay mode is highly suppressed. Therefore, any signal from FCNC decay chain indicate an evidence of new physics. A search for FCNC decays has been performed at CDF with 1.9 fb^{-1}. This analysis utilizes a template fit to a mass χ^2 variable constructed from kinematic constraints present in FCNC top quark decays. A simultaneous fit is performed to the data using two signal and one control region as one can see in Fig. 9. The control region constrains uncertainties in the shape and normalization of the templates. As one can see in this plot, our data is well explained with-

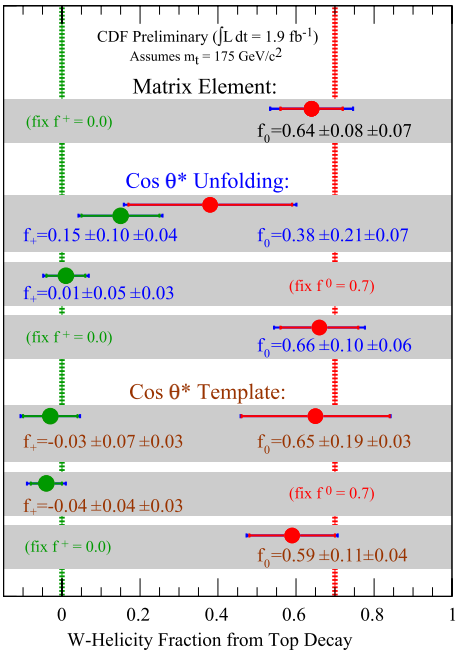

Figure 8: The summary of W-helicity measurement at CDF.

out FCNC components and then, we set 95% C.L. upper limit on the branching fraction of $(t \to Zq) < 3.7\%$ [21].

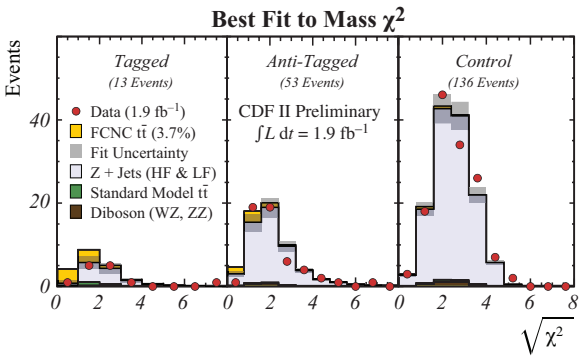

Figure 9: Mass χ^2 distribution for signal and control regions.

Charged Higgs $H^{\pm}$ bosons are predicted in supersymmetric and GUT extensions of the SM. If a charged Higgs boson in sufficiently light, it can be produced in top quark decays. In the presence of a charged Higgs boson, the $t \to H^+b$ decay would compete with the SM top quark decay, thereby altering the expected number of events in different final states of $t\bar{t}$. In the certain final state, which is low $\tan\beta$, the dominant decay of charged higgs is $H^+ \to c\bar{s}$. We has searched for the decays in the lepton + jets events with 2.2 fb^{-1} by fully reconstructing $t\bar{t}$ decay and exploiting the difference between the dijet mass spectra in $W \to q\bar{q}$ and $H^+ \to c\bar{s}$ decays [22].

The invariant dijet mass spectrum in data is shown in Fig. 10 (up) which no significant deviation from the SM is observed. Therefore we set the limits on branching fraction of $t \to H^+b \to c\bar{s}b$ as one can see in Fig. 10 (down). In this plot, we extend our search to generic charged boson search which possibly have smaller mass than W boson.

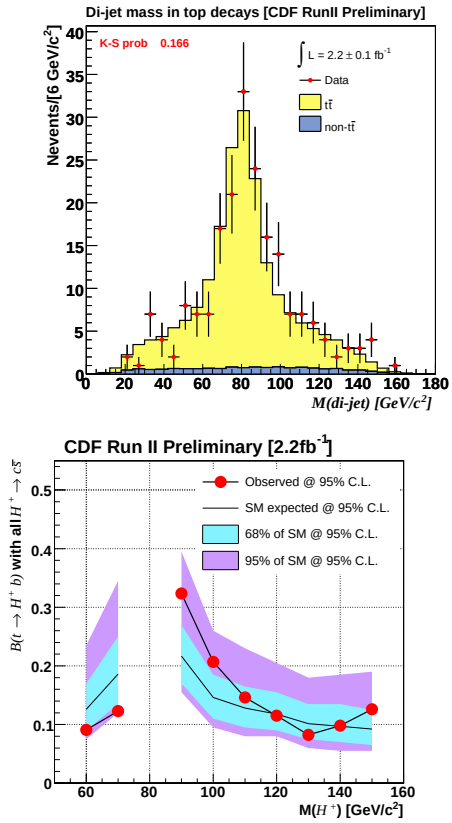

Figure 10: Distribution of di-jet mass in $t\bar{t}$ decay (up) and the upper limit on the branching fraction of $t \to H^+b$ at 95% C.L. as a function of charged higgs mass (down).

3. Conclusions

Number of top quark properties not only standard model top signature but also exotic model signature have been searched and measured. However many measurements are still limited by the statistical uncertainty. Although we do not find evidence conflicting with SM top quark, we expect to have interesting measurement with more data in near future.

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