Top Quark Production at the Tevatron

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This review gives an overview of most recent measurements of top quark production cross sections including differential cross sections and searches for new physics in the top quark sector. Datasets corresponding to an integrated luminosity of up to 5.7 fb⁻¹ are presented which were taken at the Tevatron proton-antiproton collider at a center-of-mass energy of √s = 1.96 TeV at Fermilab.

I. TOP QUARK PRODUCTION AT THE TEVATRON

Top quarks were first observed via pair production at the Fermilab Tevatron Collider in 1995 [1]. The Tevatron is still the only place where top quarks can be studied with a very high precision. At the Tevatron, top quarks are either produced in pairs via the strong interaction or singly via the electroweak interaction [2]. In the framework of the standard model (SM), each top quark is expected to decay nearly 100% of the times into a W boson and a b quark [3]. W bosons can decay hadronically into qq' pairs or leptonically into eν, µν, and τν with the τ in turn decaying into an electron, a muon, or hadrons, and associated neutrinos.

In t̅t production, if both W bosons decay hadronically the final state is called all-hadronic (or all-jets) channel. If one of the W bosons decays hadronically while the other one produces a direct electron or muon or a secondary electron or muon from τ decay, the final state is referred to as the ℓ+jets channel. If both W bosons decay leptonically, this leads to a dilepton (ℓℓ) final state containing a pair of electrons, a pair of muons, or an electron and a muon, or a hadronically decaying tau accompanied either by an electron or a muon (the τℓ channel).

II. TOP QUARK PAIR PRODUCTION

Exploring the top cross section in different decay channels and using different assumptions is important because signs of new physics might appear differently in the various channels.

A. Top Quark Pair Production Cross Section

The top quark pair production cross section σt̅t is known to high accuracy in the SM [4-8]. The measurement of the top quark pair production cross section therefore provides an important test of calculations in higher order Quantumchromodynamics (QCD) including soft gluon resummations. Any deviation from the SM prediction of the measured t̅t cross section could either be a hint for new physics in top quark pair production or in top quark decays. For example, an exotic decay of the top quark, such as the decay into a charged Higgs boson and a b quark (t → H⁺b) would lead to deviations of the measured σt̅t in individual final states compared to the SM prediction.

Usually there are two different techniques to enhance the top pair signal over the background. The “topological” method explores t̅t event kinematics to distinguish t̅t signal from background. Because of the large mass of the top quark, t̅t events are more energetic, central, and isotropic compared with the dominant backgrounds such as W+jets and QCD multijet events, whose kinematics are more influenced by the boost from the momentum distribution of the colliding partons. The “counting” method utilizes the identification of jets originated from b quarks (b-tagging). The first method does not rely on the assumption that a top quark decays into a b-quark as opposed to the second one. Thus they are sensitive to different systematic uncertainties.
One example for a “topological” analysis from the D0 Collaboration uses an integrated luminosity of 4.3 fb$^{-1}$ exploring final states with 2, 3 or $\geq 4$ jets, thereby defining twelve disjoint data sets. To distinguish $t\bar{t}$ signal from background, a discriminant is constructed that exploits differences between kinematic properties of the $t\bar{t}$ $\ell+\text{jets}$ signal and the dominant $W+\text{jets}$ background. A multivariant discriminant function is calculated by a random forest (RF) of boosted decision trees (BDT). The output of the BDT discriminant for $\geq 4$ jets is presented in Fig. 1 (left). To extract the $t\bar{t}$ cross section one performs a binned maximum likelihood fit of the discriminant distribution for signal and background to the data. Systematic uncertainties are accounted for in the maximum likelihood fit by assigning a nuisance parameter to each independent systematic variation. Each nuisance parameter is modeled as a Gaussian probability density function with mean at zero and width corresponding to one standard deviation (SD) of the considered systematic uncertainty [10]. For a top quark mass of 172.5 GeV [49], one obtains $\sigma_{t\bar{t}} = 7.70^{+0.79}_{-0.70}$ (stat + syst + lumi) pb.

The SM predicts that the top quark decays almost exclusively into a $W$ boson and a $b$-quark ($t \rightarrow Wb$). Hence besides using just kinematic information, the fraction of $t\bar{t}$ events in the selected sample can be enhanced using $b$-jet identification. One example to measure the $t\bar{t}$ cross section in a “counting” method is performed by the D0 Collaboration analyzing 4.3 fb$^{-1}$ of data. Final states with 3 and $\geq 4$ jets are explored. Each channel is further separated into events with 0, 1 and $\geq 2$ $b$-tagged jets, thereby obtaining 24 independent sets of data. Figure 1 (right) shows a comparison of the distributions in data with 0, 1 or $\geq 2$ $b$-tagged jets with the SM $t\bar{t}$ cross section, and the contributions from the different backgrounds.

An iterative procedure is used to extract the $t\bar{t}$ cross section after $b$-tagging. The fit of the $t\bar{t}$ cross section ($\sigma_{t\bar{t}}$) to data is performed using a maximum likelihood fit for the predicted number of events, which depends on $\sigma_{t\bar{t}}$. To take into account each channel, the likelihood maximization procedure multiplies the Poisson probabilities for all channels $j$. The systematic uncertainties are incorporated in the fit using nuisance parameters [10], each represented by a Gaussian term. The result is $\sigma_{t\bar{t}} = 7.93^{+0.94}_{-0.91}$ (stat + syst + lumi) pb.

The CDF Collaboration, too, performs a “topological” measurement of the top pair production cross section in the $\ell+\text{jets}$ channel with an integrated luminosity of 4.6 fb$^{-1}$ using an artificial neural network (ANN) technique to discriminate between top pair production and background processes [12]. The ANN discriminant output is shown in Fig. 2 (left).

The CDF Collaboration also performs a “counting” method analyzing the number of events with at least one $b$-tagged jet. The predicted number of events for each background process, along with the number of expected $t\bar{t}$ events at the measured cross section, is shown compared to data in Fig. 2 (right). To measure the $t\bar{t}$ cross section, a likelihood is formed from the data, the $t\bar{t}$ cross section, and the predicted background for that cross section. The result for the “topological” method is $\sigma_{t\bar{t}} = 7.71 \pm 0.37\text{(stat)} \pm 0.36\text{(syst)} \pm 0.45\text{(lumi)}$ pb, the result for the “counting” method using $b$-tagging is $\sigma_{t\bar{t}} = 7.22 \pm 0.35\text{(stat)} \pm 0.56\text{(syst)} \pm 0.44\text{(lumi)}$ pb. The largest systematic uncertainties for
both experiments come from the measured luminosity and the b-tag modeling in the simulation. Because b-tagging is not used in the “topological” measurement, it is insensitive to the systematic uncertainty of the b-jet tagging measurement.

The dependence on the luminosity measurement and its associated large systematic uncertainty can be significantly reduced by computing the ratio of the $t\bar{t}$ to $Z/\gamma^* \,+\, b$ boson production cross section, measured using the same triggers and dataset, and then multiply this ratio by the theoretical $Z/\gamma^*$ production cross section \cite{12}. In essence this replaces the luminosity uncertainty with the uncertainty on the theoretical $Z/\gamma^*$ cross section. The extracted $t\bar{t}$ cross section is $\sigma_{t\bar{t}} = 7.82 \pm 0.38 \, (\text{stat}) \pm 0.37 \, (\text{syst}) \pm 0.15 \, (\text{theory}) \, \, \text{pb}$ for the “topological” method, $\sigma_{t\bar{t}} = 7.32 \pm 0.36 \, (\text{stat}) \pm 0.59 \, (\text{syst}) \pm 0.14 \, (\text{theory}) \, \, \text{pb}$ for the “counting” method with b-tagging and $\sigma_{t\bar{t}} = 7.70 \pm 0.52 \, \text{pb}$ for the combination of both. The uncertainty of $\pm 7\%$ for the “topological” measurement is the most precise value determined by a single measurement to date.

Figure 3 summarizes the measurements of the $t\bar{t}$ cross section in different decay channels performed by the CDF and D0 Collaborations. All measurements agree with each other and agree with the SM predictions based on the full NLO matrix element \cite{14} including soft-gluon resummation at next-to-leading logarithm (NLL) accuracy \cite{15} and at next-to-next-to-leading logarithm (NNLL) accuracy \cite{16–18}. The D0 Collaboration has now analyzed all possible decay channels except final states with two hadronically decaying $\tau$ leptons. In particular there is a new measurement in (pb) $t\bar{t} \rightarrow p + (p \sigma_{t\bar{t}} = 7.2 \pm 0.38 \, (\text{stat}) \pm 0.37 \, (\text{syst}) \pm 0.15 \, (\text{theory}) \, \, \text{pb}$ for the “topological” method, $\sigma_{t\bar{t}} = 7.32 \pm 0.36 \, (\text{stat}) \pm 0.59 \, (\text{syst}) \pm 0.14 \, (\text{theory}) \, \, \text{pb}$ for the “counting” method with b-tagging and $\sigma_{t\bar{t}} = 7.70 \pm 0.52 \, \text{pb}$ for the combination of both. The uncertainty of $\pm 7\%$ for the “topological” measurement is the most precise value determined by a single measurement to date.

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![Graph showing $t\bar{t}$ cross section measurements in different decay channels by the CDF (left) and the D0 (right) Collaborations. The combination for each experiment is displayed, too.](image)

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the decay channel including a hadronically decaying $\tau$ lepton and jets $[14]$. The CDF Collaboration does not perform an explicit identification of $\tau$ leptons but includes $\tau$ final states in selections of missing transverse energy and jets $[15]$. This selection also recovers electrons and muons that were not selected in the $\ell+\text{jets}$ and dilepton channels. It is also worth mentioning that both collaborations have achieved an uncertainty of 13% in measurements of the $t\bar{t}$ cross section in dilepton final states using a “topological” method $[16]$ and a “counting” method using $b$-tagging $[17]$. The CDF Collaboration combines the “topological” and “counting” measurements of the $t\bar{t}$ cross section in the $\ell+\text{jets}$ channel to the measurements in the dilepton $[17]$ and all-hadronic $[18]$ channels and achieves an accuracy of 6%. The result is

$$\sigma_{t\bar{t}} = 7.50 \pm 0.31 \text{ (stat)} \pm 0.34 \text{ (syst)} \pm 0.15 \text{ (theory + lumi residual)} \text{ pb}$$

for a top quark mass of 172.5 GeV.

### B. Top Quark Pair + Jet Production

An important test of perturbative QCD, as NLO effects play an important role in the calculation of the theoretical cross section, is the production of a $t\bar{t}$ pair associated with an additional hard jet ($t\bar{t}+\text{jet}$). This process is interesting in its own right, because large fractions of the $t\bar{t}$ samples show additional jet activity and deviations from the SM could signal new physics such as top-quark compositeness. The first measurement of the cross section of $t\bar{t}+\text{jet}$ production has been performed with 4.1 fb$^{-1}$ of collected data by the CDF Collaboration. The measurement is performed using $b$-tagged events in the $\ell+\text{jets}$ channel. A data-driven approach is used to predict the background content. The predicted number of events including the background, the $t\bar{t}+0$ jets and the $t\bar{t}+\geq 1$ jet contributions is compared to the data as a function of the jet multiplicity in Fig. 4 (left). A 2-dimensional likelihood is constructed from the data and prediction for events with three, four, or five jets to simultaneously measure the $t\bar{t}+\text{jet}$ and the $t\bar{t}$ without jet cross sections. This is shown in Fig. 4 (right). The measured result is $\sigma_{t\bar{t}+\text{jet}} = 1.6 \pm 0.2 \text{ (stat)} \pm 0.5 \text{ (syst)} \text{ pb}$ which is in agreement with the SM prediction of $\sigma_{t\bar{t}+\text{jet}} = 1.79^{+0.16}_{-0.31} \text{ pb} [19]$.

### C. Differential Top Quark Pair Production Cross Section

Measurements of differential cross sections in the $t\bar{t}$ system test perturbative QCD for heavy-quark production, and can constrain potential physics beyond the SM. The transverse momentum ($p_T$) of top quarks in $t\bar{t}$ events provides a unique window on heavy-quark production at large momentum scales. The D0 Collaboration has performed a measurement of the $t\bar{t}$ cross section as a function of $p_T$ of top quarks for the first time $[20]$. Using a data set of 1fb$^{-1}$ the $\ell+\text{jets}$ final states with at least one $b$-tagged jet are explored.

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FIG. 5: Left: inclusive $d\sigma/dp_T$ for $t\bar{t}$ production (two entries per event for top and anti-top quark) in data (points) compared with expectations from NLO QCD (solid lines), from an approximate NNLO QCD calculation, and for several event generators (dashed and dot-dashed lines). The gray band represents the uncertainty on the QCD scale. Right: ratio of $(1/\sigma)d\sigma/dp_T$ for top quarks in $t\bar{t}$ production (two entries per event) to the expectation from NLO QCD. The uncertainty in the scale of QCD is displayed as the gray band. Also shown are ratios relative to NLO QCD for an approximate NNLO QCD calculation and of predictions for several event generators. In both plots inner and outer error bars represent statistical and total (statistical and systematic added in quadrature) uncertainties, respectively.

Objects in the event are associated through a constrained kinematic fit to the $t\bar{t} \rightarrow WbWb \rightarrow \ell\nu bq\bar{q}'b$ process. To obtain a background-subtracted data spectrum, the signal purity is fitted using signal and background contributions as a function of $p_T$, and applied as a smooth multiplicative factor to the data. The reconstructed $p_T$ spectrum is subsequently corrected for effects of finite experimental resolution, based on a regularized unfolding method \cite{21} using a migration matrix between the reconstructed and parton $p_T$ derived from simulation.

The measured differential cross section as a function of the $p_T$ of the top quark (using for each event the two measurements obtained from the leptonic and hadronic top quark decays), $d\sigma/dp_T$, is shown in Fig. 5 (left) with the NLO QCD prediction \cite{22}. Also shown are results from an approximate next-to-NLO (NNLO) QCD calculation \cite{23} and from the PYTHIA \cite{24}, the ALPGEN \cite{25} (matched with PYTHIA for parton showering \cite{26}) and the MC@NLO \cite{27} event generators. A shape comparison of the ratio of $(1/\sigma)d\sigma/dp_T$ relative to NLO QCD is shown in Fig. 5 (right). This shows that results from NLO and approximate NNLO QCD calculations and from the MC@NLO event generator agree with the normalization and shape of the measured cross section. Results from ALPGEN+PYTHIA and PYTHIA describe the shape of the data distribution, but not its normalization.

The CDF Collaboration has measured the $t\bar{t}$ differential cross section in the $\ell$+jets channel with respect to the $t\bar{t}$ invariant mass, $d\sigma/dM_{t\bar{t}}$, using an integrated luminosity of 2.7 fb$^{-1}$ \cite{28}. The $t\bar{t}$ invariant mass spectrum is a powerful test of higher order QCD calculations and also sensitive to a variety of exotic particles decaying into $t\bar{t}$ pairs. The $t\bar{t}$ invariant mass is reconstructed, using the four-vectors of the $b$-tagged jet and the three remaining leading jets in the event, the lepton and the transverse components of the neutrino momentum, given by missing transverse energy. The expected contribution from the backgrounds is subtracted from the original $M_{t\bar{t}}$ distribution. The resulting $M_{t\bar{t}}$ signal distribution suffers from resolution smearing and is corrected using a regularized unfolding technique, which also accounts for the longitudinal component of the neutrino momentum. The measured $d\sigma/dM_{t\bar{t}}$ is shown in Fig. 6 (left). The result is consistent with the SM expectation, as modeled by PYTHIA with CTEQ5L parton distribution functions. However, the description by PYTHIA is not perfect. A significantly better description of the data is achieved in calculations where threshold logarithms up to NNLL order are resummed \cite{29}. Fig. 6 (middle) shows a good agreement in the $d\sigma/dM_{t\bar{t}}$ distribution with the same CDF data.
III. SEARCHES FOR NEW PHYSICS IN TOP QUARK PAIR PRODUCTION

The fact that the top quark has by far the largest mass of all known elementary particles suggests that it may play a special role in the dynamics of electroweak symmetry breaking. This makes searches for new physics in the top quark sector very attractive. In the following one recent example for a search for new physics in the production of top quarks is presented: a search for \( t\bar{t} \) resonances which explores the invariant \( t\bar{t} \) mass distribution, too.

One of the various models incorporating the possibility of a special role of the top quark in the dynamics of electroweak symmetry breaking is topcolor \[29\], where the large top quark mass can be generated through a dynamical \( t\bar{t} \) condensate, \( X \), which is formed by a new strong gauge force preferentially coupled to the third generation of fermions. In one particular model, topcolor-assisted technicolor \[30\], \( X \) couples weakly and symmetrically to the first and second generations and strongly to the third generation of quarks, and has no couplings to leptons, resulting in a predicted cross section for \( t\bar{t} \) production larger than SM prediction.

The CDF and D0 collaborations presented updated model-independent searches for a narrow-width heavy resonance \( X \) decaying into \( t\bar{t} \) using 2.8 fb\(^{-1}\) of data in the all-hadronic final state (CDF) \[31\] and 3.6 fb\(^{-1}\) of data analyzing \( \ell + \text{jets} \) final states (DØ) \[32\]. A new search for resonant production of \( t\bar{t} \) is performed by the CDF collaboration in the \( \ell + \text{jets} \) channel using a data set of 4.8 fb\(^{-1}\). The search for resonant production is performed by examining the reconstructed \( t\bar{t} \) invariant mass distribution which is shown in Fig. 6 (right). A matrix element reconstruction technique is used and for each event a probability density function (pdf) of the \( t\bar{t} \) invariant mass is sampled. These pdfs are used to construct a likelihood function, whereby the cross section for resonant \( t\bar{t} \) production, given a hypothetical resonance mass and width, is estimated. One compares the 95% C.L. points for these posterior probabilities for the data with those expected from SM sources only and determines how likely it is for the SM to fluctuate to the data for each mass point. A very unlikely fluctuation could then indicate the presence of new physics in the sample. There is no evidence of resonant production of \( t\bar{t} \) candidate events. Therefore within a top-color-assisted technicolor model, the existence of a leptophobic \( Z' \) boson with \( M_{Z'} < 900 \text{ GeV} \) and width around \( \Gamma_{Z'} = 0.012M_{Z'} \) is excluded at 95% CL.

IV. SINGLE TOP QUARK PRODUCTION

A. Single Top Quark Production Cross Section and \( V_{tb} \)

Single top quark production serves as a probe of the \( Wtb \) interaction \[33\], and its production cross section provides a direct measurement of the magnitude of the quark mixing matrix element \( V_{tb} \) without assuming three quark generations \[34\]. However, measuring the yield of single top quarks is difficult because of the small production rate and large backgrounds. At the Tevatron single top quarks are produced by either a \( t\)-channel exchange of a virtual
FIG. 7: Output discriminants for single top quark observation. Displayed are the CDF super-discriminant output (upper left), the CDF discriminant output for the analysis using a missing transverse momentum and jets selection (upper middle) and the D0 BNN discriminant (lower left). A summary of all existing measurements and the Tevatron combination is shown (lower right).

In March 2009, the CDF and D0 Collaborations reported observation of the electroweak production of single top quarks in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV based on 3.2 fb$^{-1}$ (CDF) $^{35, 36}$ and 2.3 fb$^{-1}$ (D0) $^{37}$ of data. Both Collaborations used events containing an isolated electron or muon and missing transverse energy, together with jets where one or two of the jets were required to originate from the fragmentation of $b$ quarks. The data are devided into independent sets (subchannels) depending on lepton flavor, jet multiplicity, number of $b$-tags and in the case of D0 the run period. CDF and D0 each combine many variables using different multivariate analysis methods such as Boosted Decision Trees, Bayesian Neural Networks, Matrix Elements and Likelihood functions to increase the separation power between signal and background. The discriminant outputs of each multivariate analysis are combined to one discriminant taking the correlations into account. CDF combines 8 subchannels into a super-discriminant using a neural network trained with neuroevolution $^{38}$ which is shown in Fig. 7 (upper left). The CDF Collaboration has an additional independent search channel $^{35, 39}$ that is designed to select events with missing transverse energy and jets and is orthogonal to the other channels. It accepts events in which the $W$ boson decays into hadronically decaying $\tau$ leptons and recovers events lost due to electron or muon identification inefficiencies. The discriminant output of this analysis – shown in Fig. 7 (upper middle) – is combined to the super-discriminant to obtain the final result. D0 combines 12 subchannels into one BNN discriminant displayed in Fig. 7 (lower left).

CDF measures a cross section of $\sigma(p\bar{p} \to tb+X, tqb+X) = 2.3^{+0.6}_{-0.5}$ pb assuming a top quark mass of 175 GeV and D0 measures a cross section of $\sigma(p\bar{p} \to tb+X, tqb+X) = 3.94 \pm 0.88$ pb at a top quark mass of 170 GeV. Both measurements correspond to a 5.0 standard deviation (SD) significance for the observation. They are in agreement with the SM predictions. Both results are translated into a direct measurement of the amplitude of the CKM matrix
element $V_{tb}$ without making assumptions on the number of quark generations and the matrix unitarity. CDF obtains $|V_{tb}| = 0.91 \pm 0.13$, D0 derives $|V_{tb}| = 1.07 \pm 0.12$.

All measurements mentioned above \cite{33, 37, 39} and a measurement by the D0 Collaboration analyzing the $\tau+$jets final state by explicitly identifying hadronically decaying $\tau$ leptons \cite{40}, agree with the SM predictions \cite{41, 42}. This can be seen in Fig. 17 (lower right). The Tevatron combination (still excluding the $\tau+$jets final state) \cite{43} gives a single top cross section of

$$\sigma(pp \rightarrow tb + X, tqb + X) = 2.76^{+0.58}_{-0.47} \text{ pb}$$

and a CKM matrix element of

$$|V_{tb}| = 0.88 \pm 0.07.$$  

B. $s$-Channel and $t$-Channel Single Top Quark Production

In the observation analyses the combined $s + t$ channel single top quark cross section was measured, assuming the SM ratio of the two production modes. This ratio is modified in several new physics scenarios, for example in models with additional quark generations, new heavy bosons, flavor-changing neutral currents, or anomalous top quark couplings. Therefore it is interesting to remove this constraint and to use the $t$-channel characteristics to measure the $t$-channel and $s$-channel cross sections simultaneously which provides a $t$-channel measurement independent of the $s$-channel cross section model.

The D0 Collaboration reported direct evidence for the electroweak production of single top quarks through the $t$-channel exchange of a virtual $W$ boson alone \cite{44}. The measured cross section is $\sigma(t – channel) = 3.14^{+0.94}_{-0.81} \text{ pb}$, has a significance of 4.8 SD and is consistent with the SM prediction. This is the first analysis to isolate an individual single top quark production channel. Both the CDF and the D0 Collaborations extracted the $s$-channel ($\sigma_s$) and $t$-channel ($\sigma_t$) cross sections simultaneously relaxing the SM ratio assumption for $\sigma_s/\sigma_t$ \cite{36, 44}. The results agree with the SM predictions.

C. Searches for New Physics in Single Top Quark Production

The single top quark production channel offers a large variety for sensitive searches for new physics beyond the SM. One example are searches for flavor changing neutral current (FCNC) couplings \cite{45, 46}. Recently, the D0 Collaboration searched for single top quark production via FCNC top-gluon-quark couplings $\kappa_{tg_u}$ and $\kappa_{tg_c}$ in a sample corresponding to 2.3 fb$^{-1}$ of integrated luminosity collected \cite{46}. Events containing a single top quark candidate with an additional jet are selected. Separation between signal and background is obtained using Bayesian neural networks (BNN) which are trained for each choice of lepton flavor (electron or muon), jet multiplicity (2, 3, or 4), and data-taking period separately, twelve in total. Fig. 8 (left) shows the comparison between background and data for all twelve BNN discriminants combined. Since the data are consistent with the background expectation, upper limits on the FCNC cross sections and couplings are set using a Bayesian approach \cite{47}. Following the analysis strategy of previous work \cite{48}, a two-dimensional Bayesian posterior density for the cross sections and for the square of the FCNC couplings is formed, using the BNN distributions for data, background, and signals. Fig. 8 (right) shows the posterior density as a function of the FCNC cross sections $\sigma_{tg_u}$ and $\sigma_{tg_c}$. Since there is agreement with the SM, limits are set on the couplings of $\kappa_{tg_u}/\Lambda < 0.013 \text{ TeV}^{-1}$ and $\kappa_{tg_c}/\Lambda < 0.057 \text{ TeV}^{-1}$, $\Lambda$ being the scale of the new interactions which generate these couplings (of order 1 TeV), without making assumptions about the $tg_c$ and $tg_u$ couplings, respectively.
FIG. 8: Left: comparison of the background model to data for the FCNC discriminant summed over all analysis channels. The bins have been ordered by their signal to background ratio and the FCNC signals are each normalized to a cross section of 5 pb. Right: Bayesian posterior probability as a function of the $\sigma_{tgu}$ and $\sigma_{tgc}$ cross sections.

V. CONCLUSIONS

Recent highlights in top quark production analyses from the Tevatron collider are reviewed. Among many impressive results, the observation of single top quark production via the electroweak interaction and the direct measurement of the CKM matrix element $V_{tb}$ by the CDF and D0 Collaborations is outstanding.

Analyzing datasets corresponding to an integrated luminosity of up to 5.7 fb$^{-1}$ the Tevatron experiments can perform high precision measurements. As an example the top quark pair production cross section is extracted with an accuracy of 6%. The high statistics in $t\bar{t}$ samples allows to analyze differential cross sections for the first time with a high accuracy resulting in powerful tests of higher order QCD calculations. In general the inclusion of soft gluon resummations at the NNLL level into NLO QCD calculations improves the description of the data. Both top quark pair production and single top quark production channels allow sensitive searches for new phenomena beyond the SM. So far, there is no hint for new physics beyond the SM in the top sector. Excellent prospects for top quark physics investigations can be expected with more integrated luminosity at the Tevatron.

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In the following all results are given for a top quark mass of 172.5 GeV, if not indicated otherwise. This is within the errors of the current Tevatron combination of 173 ± 1.1 GeV [11].