Tevatron Combination of Single Top Quark Production and V_{tb} Measurement

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Abstract

After the first observation of the inclusive single top-quark production in the s- and t-channels by CDF and D0, both Tevatron collaborations combined their measurements using the distributions of their multivariate discriminants. A Bayesian analysis is used to extract the cross section at a center of mass energy of 1.96 TeV from 3.2 fb^{-1} (CDF) and 2.3fb^{-1} (D0) of data, respectively. For a top quark mass of 170 GeV/c^2, a cross section of 2.76+0.58-0.47 pb is extracted while the CKM matrix element $|V_{tb}|$ is measured to be 0.88±0.07 with a 95% C.L. lower limit of $|V_{tb}|>0.77$.

Introduction

The reasons for studying electroweak single top quark production are compelling: the production cross section is directly proportional to the square of the CKM matrix element $|V_{tb}|$, and thus a measurement of the rate constrains fourth-generation models and other new phenomena. In the SM, top-quarks at the Tevatron are expected to be produced singly through s- or t-channel exchange of a virtual W boson with an expected combined production cross section of σ_{s+t}=3.46±0.14 pb [1] at a top quark mass of 170 GeV/c^2. Both the CDF and D0 collaborations have reported observation of single top quark production [2-5]. This document describes the combination of the CDF and D0 measurements [6] of the inclusive single top quark production cross section in the s- and t-channel using up to 3.2 fb^{-1} and 2.1 fb^{-1} of data collected with the CDF II and D0 detector, respectively.

Because the presence of single top production has been firmly established by the two collaborations and due to the computational difficulty of computing the significance of the two in combination, a hypothesis test of the combined results is not performed. The cross section measurements, however, remain limited in precision by the sizes of the data samples collected by the two collaborations, and thus a combination of the results provides a more precise measurement and also stronger constraints on the CKM matrix element $|V_{tb}|$.

Material and Methods

The combination procedure includes all channels from both collaborations, including correlations of systematics between the experiments. CDF and D0 have exchanged histograms of their final multivariate discriminants for the observed data and all signals and backgrounds in each analysis channel. Furthermore, all systematic uncertainties have been exchanged as well. The discriminant distributions of the expected background and the SM predicted signal are compared to the observed distributions using a Bayesian maximum likelihood function. This includes the treatment of various systematic uncertainties affecting the rates of the expected events and the shapes of the corresponding distributions. Rate and shape uncertainties are categorized by their source for use in evaluating correlations, between signals and/or backgrounds within a channel, between channels, and between experiments. Sources of

systematic uncertainty that are common to the measurements of the two collaborations have been assigned 100% correlation, and other sources of uncertainty are assumed to be uncorrelated. The CDF and D0 collaborations use independently developed computer programs for performing the calculation, and it has been verified that both codes reproduce the individual experiment results. Finally, the combination includes the CDF lepton plus jets super discriminant, the CDF missing transverse energy plus jets (MJ) discriminant, and the D0 lepton plus jets discriminant, as shown in figure 1.

Different conventions have been used by the CDF and D0 analyses for the top quark mass and the theoretical single top cross section. CDF assumes m_t=175 GeV/c^2 in its extraction of the central value of the single top production cross section, while D0 assumes m_t=170 GeV/c^2. The current world average top mass is 173.3±1.1 GeV/c^2 [7]. CDF includes in its p-value calculation and the $|V_{tb}|$ limit the uncertainty in m_t and thus all rate and shape uncertainties have been evaluated for the single top signal templates and the top pair production background templates. D0 does not have single top or top pair production samples for m_t=175 GeV/c^2, so CDF has shifted its predictions to m_t=170 GeV/c^2, and thus the results quoted here assume m_t=170 GeV/c^2. The CDF discriminant shapes and normalizations have been shifted for s-channel and t-channel signal as well as for top pair production background. Other background normalizations that weakly depend on top pair production have not been modified. This has a very small impact on the measured cross section.

The other difference in convention is the choice of theoretical cross section to compare the measurement with. CDF chooses Harris and Sullivan's next-to-leading order (NLO) calculation with cross sections of σ_s=0.99±0.07 pb and σ_t=2.15±0.24 pb at m_t=170 GeV/c^2 [8-10], while D0 chooses Kidonakis' NLO plus soft-gluon corrections calculation with cross sections of σ_s=1.12±0.05 pb and σ_t=2.34±0.13 pb [1]. This choice has no effect on the measured cross section, but it does affect the extraction of $|V_{tb}|$ and its limits.

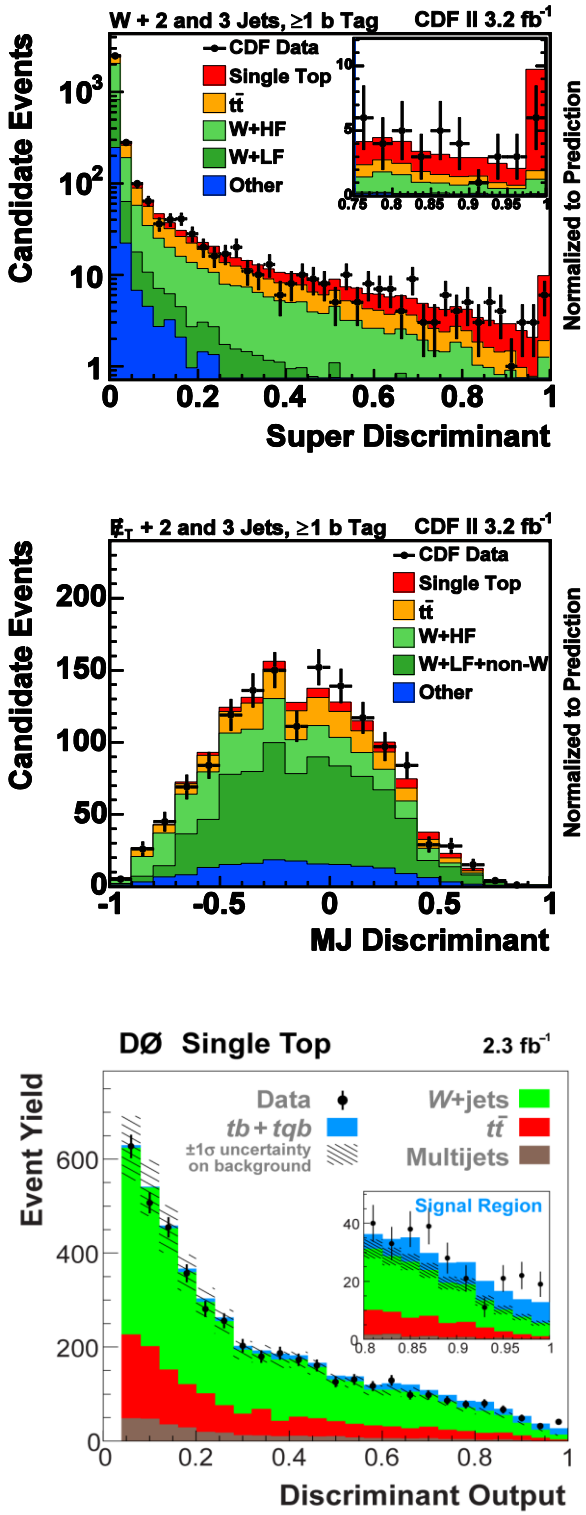
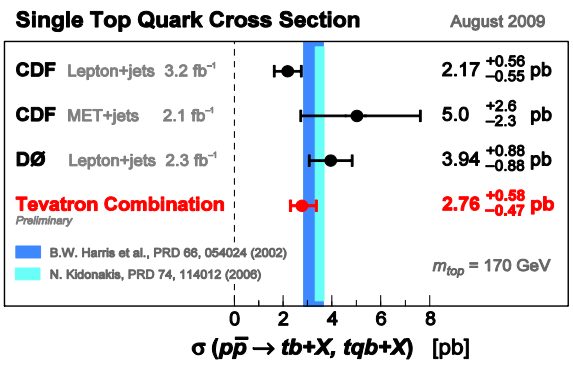


Fig. 1: *Comparisons of the predicted distributions with data summed over all selected samples of the CDF super discriminant (top), CDF MJ discriminant (middle), and D0 discriminant (bottom). The stacked histograms show the predictions, including a standard model single top signal in case of CDF, and including the measured single top signal in case of D0.*



Tab. 1: *Tevatron single top quark cross section measurements and their combination.*

Results

Table 1 lists the measured cross section of the individual as well as the combined CDF and D0 analyses. The most probable value of the combined s- and t-channel cross sections is 2.76+0.58−0.47 pb for m_t=170 GeV/c^2. This value lies in between the CDF combined measurement of 2.35+0.56−0.50 pb and the D0 measurement of 3.94±0.88 pb as expected. The combination improves the cross section uncertainty from about 22% for each experiment to 19% for the combination. The compatibility of the two measurements with each other, based on the uncorrelated systematic uncertainties, yielded a deviation of 1.6 sigma. In order to extract information about $|V_{tb}|$ from the combined data, it is assumed that the offdiagonal CKM matrix elements $|V_{ts}|$and $|V_{td}|$are much smaller than $|V_{tb}|$. But no assumptions are made about the unitarity of the 3×3 CKM matrix, allowing for a fourth generation of quarks. The $|V_{tb}|^2$ posterior is obtained by dividing the measured cross section by the theoretical single top cross section for V_{tb}=1 and m_t=170 GeV/c^2.

Using the theoretical calculation σ_{s+t}=3.46× $|V_{tb}|^2$ pb of [1], a value of $|V_{tb}|$=0.88±0.07 is extracted. Assuming a flat prior in $|V_{tb}|^2$ from 0 to1 yielded a limit of $|V_{tb}|$>0.77 at the 95% C.L. The $|V_{tb}|$ posterior is shown in Figure 2. In comparison, the CDF extraction of $|V_{tb}|$ at m_t=175 GeV/c^2 is 0.91±0.14 and the D0 extraction of $|V_{tb}|$ at m_t=170 GeV/c^2 is 1.07±0.12. The relative $|V_{tb}|$ uncertainty improves from 14% (CDF) and 11% (D0) to 8% for the combination.

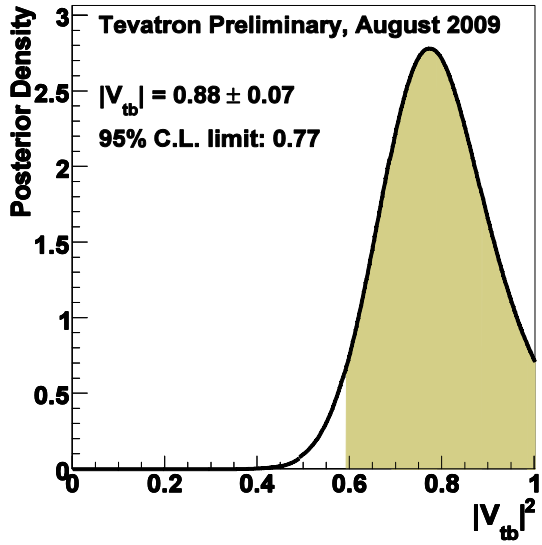


Fig. 2: *The posterior probability distribution of the combined CDF and D0 analyses for* $|V_{tb}|$.

Conclusions

CDF and D0 combined their measurements of the single top production cross section σ_{s+t} including the effects of all correlated and uncorrelated systematic uncertainties. The measurement is σ_{s+t}=2.76+0.58−0.47 pb, in agreement with the SM expectation. From this the measurement $|V_{tb}|$ is extracted using the theory cross section of [1] for m_t=170 GeV/c^2. A value of $|V_{tb}|$=0.88±0.07 is found for σ_{s+t}=3.46×$|V_{tb}|^2$ pb and a 95% C.L. lower limit of $|V_{tb}|$>0.77 is set.

References

[1] N. Kidonakis (2006): *Phys. Rev. D, 74, 114012*
[2] T. Aaltonen *et al.* (2009): *Phys. Rev. Lett.,103, 092002*
[3] V. M. Abazov *et al.* (2009): *Phys. Rev. Lett., 103, 092001*
[4] T. Aaltonen *et al.* (2010): *Phys. Rev. D, 81, 072003*
[5] T. Aaltonen *et al.* (2010): subm. to *Phys. Rev. D, arXiv:1004.1181*
[6] Tevatron Electroweak Working Group (2009): *arXiv:0908.2171*
[7] Tevatron Electroweak Working Group (2010): *arXiv:1007.3178*
[8] B. W. Harris *et al.* (2002): *Phys. Rev. D, 66, 054024*
[9] Z. Sullivan (2004): *Phys. Rev. D, 70, 114012*
[10] J. Campbell, K. Ellis, and F. Tramontano (2004): *Phys. Rev. D, 70, 094012*