TOP PHYSICS AT CDF

THOMAS A SCHWARZ
(ON BEHALF OF THE CDF COLLABORATION)
University of California - Davis
One Shields Avenue
Davis, CA 95616-8677
E-mail: schwarzt@fnal.gov

Recent results in top physics at CDF presented at the Lake Louise Winter Institute 2008 are discussed, including updates to the top mass, single top search, a search for flavor changing neutral currents in top decay, and W-helicity measurements. Several newer measurements are also presented including the forward-backward asymmetry, the $t\bar{t}$ differential cross-section $d\sigma/dM_{t\bar{t}}$, and a search for top pair production from massive gluons. Most of the discussed measurements utilize close to 2 fb-1 of data collected at CDF.

1. Introduction

The top quark of the standard model is the Q=+2/3, $T_3 = +1/2$ member of the third generation weak-isospin doublet along with the bottom quark. It was discovered in 1995 [1], and though many measurements have been performed in the last decade to map out the properties of top, all were done with relatively low statistics. Now, with over 2 fb^{-1} of collected data at CDF, top physics is entering an era of precision measurements which will lead to a complete picture of the top quark's place in nature. Top quark measurements can be categorized into basically four areas: tests of strong production, electroweak production, top decay, and intrinsic properties. The following describes CDF's progress in each of these categories by providing a short synopsis of a few recently performed measurements.

2. Measurements

2.1. *Electroweak Production*

Several searches for single top production have been performed at both experiments using a variety of state-of-the-art techniques such as neural network and boosted decision trees. One such measurement utilizes a matrix-element technique [2]. In this method event probability densities are calculated for signal and background hypotheses. A discriminating variable, which is formed from the probability for each hypothesis, is applied to signal and background Monte Carlo events. The distributions of the discriminating variable for signal and background are used in a template fit to the data using a binned likelihood approach. In $1.51 fb^{-1}$ of data collected at CDF, the combind s- and t-channel single top cross section using a matrix element technique is measured $3.0^{+1.2}_{-1.1}$ pb assuming a top quark mass of 175 GeV/c^2. Because the cross-section is directly proportional to the CKM matrix element V_{tb}, the strength of the Wtb vertex can be extracted from the measured cross-section. The CKM matrix element V_{tb} is measured $|V_{tb}| = 1.02 \pm 0.18(experiment) \pm 0.07(theory)$. The theory uncertainties arise from the cross-section dependence on the top quark mass, parton distribution functions, factorization and renormalization scales, and α_s.

2.2. ***Strong Production***

2.2.1. $d\sigma/dM_{t\bar{t}}$ *Differential Cross-section*

The differential cross-section as a function of the mass of the top-antitop system has been measured at CDF [3]. The mass of the top-antitop system is reconstructed for each event by summing 4-vectors of the jets, lepton, and "missing" transverse energy. An unfolding technique utilizing singular value decomposition has been employed to correct the reconstructed distribution so that it can be directly compared to the theoretical differential cross-section. Because the unfolding technique is insensitive to the underlying distribution,the measurement is a very model independent test of top pair production. In 1.9 fb^{-1} of collected CDF data, there is no evidence for inconsistency with the Standard Model. The measured p-value is 0.45.

2.2.2. *Search for a Massive Gluon*

In several beyond the standard model predictions a new massive color octet particle is predicted. In such models, interference with the Standard Model $q\bar{q} \rightarrow t\bar{t}$ process may create a situation where the cross-section does not change much from the Standard Model prediction and a typical resonance bump might not be visible. A recent measurement at CDF has been performed where the search is tailored to look for a massive gluon possibly interfering with the Standard Model process [4]. To simulate the effects of an interference, Monte Carlo templates were modified by reweighting events based on the matrix element of the massive gluon models and the original Monte Carlo. A dynamic likelihood method is then employed, where the invariant mass of the top antitop system is reconstructed for each event and the resulting Monte Carlo templates for signal and backgrounds are fit to the data. The reconstructed mass spectrum agrees with standard model expectations in the explored mass and width range ($400GeV \leq M_{t\bar{t}} \leq 800GeV$, $0.05 \leq \Gamma/M \leq 0.5$) [4]. Limits are set on the massive gluon strength of coupling in the explored range.

2.2.3. *Forward-Backward Asymmetry in Top Production*

The forward-backward asymmetry in top production has been measured at CDF [5] [6]. Several beyond the Standard Model physics predict a sizable forward backward asymmetry. In addition, QCD at next-to-leading order predicts a non-zero asymmetry in $q\bar{q} \to t\bar{t}$ [7]. Because top quark production is dominated by gluon fusion at the LHC, the Tevatron is a unique place to study these effects since top pairs are mostly produced by $q\bar{q}$ annihilation. Two complimentary measurements at CDF have been performed, each in a different center of mass rest frame: $p\bar{p}$ and $t\bar{t}$. The two frames differ in that the measurement in the $p\bar{p}$ frame is less sensitive to bias or dilution from the experiment, and that in the $t\bar{t}$ frame is more sensitive to the QCD predicted asymmetry. For both measurements, the production angle of the top quark is reconstructed for each event. Corrections are then applied to account for bias and/or dilution from backgrounds, acceptance, and reconstruction. The final measurement is directly comparable to the theoretical values. In 1.9 fb^{-1} of CDF collision data $A^{p\bar{p}}_{fb}(meas) = 0.17 \pm 0.07_{stat} \pm 0.04_{sys}$ and $A^{t\bar{t}}_{fb}(meas) = 0.24 \pm 0.13_{stat} \pm 0.04_{sys}$ which can be compared to the Standard Model prediction $A^{p\bar{p}}_{fb}(theory) = 0.04 \pm 0.01$ and $A^{t\bar{t}}_{fb}(theory) = 0.05 \pm 0.01$, respectively.

2.3. ***Top Decay***

2.3.1. *W-Helicity*

The Standard Model predicts that the top quark decays almost entirely to a W-boson and a bottom quark, and that 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 to longitudinal and the rest to left-handed polarized W-bosons for M_t = 175 GeV/c2, M_W = 80.4 GeV/c2, and $M_b = 4.7$ GeV/c2 [9]. Any new particles or non-standard coupling could create a different mixture of polarized W-bosons and therefore, a measurement of this fraction is a test of the V-A nature of the Wtb vertex. Several measurements of the W-Helicity have been performed at CDF and D0, and one of the most sensitive methods utilizes a matrix element technique.

In a matrix element technique, a likelihood for each event is calculated based on the matrix element for signal and backgrounds, and a total likelihood is then formed by taking the product of the per event likelihood. This is done for a range of longitudinal fractions, forming a likelihood curve which is then parameterized. The measured fraction is then extracted at the minimum of the parameterized curve. The fraction of right-handed W-bosons is kept fixed in the likelihood function to the Standard Model prediction ($f_+ = 0$). Using $1.9 fb^{-1}$ of collected CDF data, the measured longitudinal fraction is $f_0 = 0.637 \pm 0.084_{stat} \pm 0.069_{syst}$, for top-quark mass of 175 GeV/c2 [8].

2.3.2. *Search for FCNC*

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 ($\sim 10^{-14}$) and therefore, and signal of FCNC decay would be evidence of new physics. A search for FCNC decays has been peformed at CDF with $1.9 fb^{-1}$ of collected data [10]. The 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. The control region constrains uncertainties in the shape and normalization of the templates. An upper limit on the branching fraction $B(t \rightarrow Zq)$ is derived from a Feldman-Cousins statistical treatment. The measured 95% C.L. upper limit on $B(t \rightarrow Zq)$ is 3.7% with an expected upper limit in the absense of signal of $5 \pm 2.2\%$. As of this publication, this is the world's best limit on $B(t \rightarrow Zq)$.

2.4. ***Intrinsic Properties***

2.4.1. *Top Mass*

The first simultaneous measurement of the top quark mass in the lepton plus jets and dilepton decay modes has been performed at CDF [11]. In the lepton plus jets channel, a χ^2 function based on kinematic constraints is used to reconstruct the top mass for each event. In the dilepton channel, a similar algorithm is utilized, though under constrained due to the presence of two neutrinos. The dilepton algorithm, called a neutrino weighting technique, is applied in an iterative way to find the most probable top mass for each dilepton event. In addition, the scalar sum of the momenta (Ht) of the jets, leptons, and missing transverse energy is calculated. Templates are formed for different mass points and passed through the algorithm for each channel. Two sets of two-dimensional distributions, the reconstructed top quark mass and reconstructed W-boson mass for the lepton plus jets channel, and the reconstructed top quark mass and the Ht in the dilepton channel, are compared to the Monte Carlo mass templates to simultaneously measure the top quark mass and the jet energy scale. The largest systematic of the analysis is constrained by measuring the jet energy scale from the invariant mass of the jets coming from hadronically decaying W-boson, and is naturally passed through to the dilepton channel due to the simultaneous measurement. In $1.9fb^{-1}$, the measured top quark mass is $M_t = 171.9 \pm 1.7_{stat+JES} \pm 1.0_{sys}$ GeV/c2.

Acknowledgments

I would like to thank the members of the CDF collaboration for their hard work and dedication, and in particular the top group convenors and authors of the mentioned analyses. I also thank the organizers of the Lake Louise Winter Institute 2008.

References

1. The CDF collaboration, *Phys. Rev. Lett* **. 74, 2626** (1995).
   The D0 collaboration, *Phys. Rev. Lett* **. 74, 2632** (1995).
2. The CDF Collaboration, *CDF Conference Note* **8968** (2007).
3. The CDF Collaboration, *CDF Conference Note* **9157** (2008).
4. The CDF Collaboration, *CDF Conference Note* **9164** (2008).
5. The CDF Collaboration, *CDF Conference Note* **9169** (2008).
6. The CDF Collaboration, *CDF Conference Note* **9156** (2008).
7. J.H. Kuhn and G. Rodrigo, *Phys. Rev. Lett.* **81, 49** (1998).
8. The CDF Collaboration, *CDF Conference Note* **9144** (2007).
9. J. Aguilar-Saavedra et al., *Eur. Phys. J.* **C50, 519** (2007).
10. The CDF Collaboration, *CDF Conference Note* **9202** (2008).
11. The CDF Collaboration, *CDF Conference Note* **9206** (2008).