Top Quark Physics at the Tevatron

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When the heaviest elementary particle known today, the top quark, was discovered in 1995 by the CDF and D0 collaborations at the Fermilab Tevatron collider, a large program to study this particle in details has started. In this article, an overview of the status of top quark physics at the Tevatron is presented. In particular, recent results on top quark production, properties and searches using top quarks are discussed.

1 Introduction

With a mass of $m_t = 173.2 \pm 0.6(\text{stat}) \pm 0.8(\text{syst})$ GeV [1], the top quark is the heaviest known elementary particle today. Its most notable properties are the high mass and its very short lifetime, providing a unique environment to study a bare quark. The top quark is believed to play a special role in electroweak symmetry breaking and provide a window to physics beyond the standard model (SM).

Since its discovery in 1995 [2, 3] by the CDF and D0 Collaborations at the Fermilab Tevatron collider, a large program to study the top quark in great detail has been initiated at the Tevatron. To understand whether the observed particle is indeed the top quark as predicted by theory and to use it for searches of physics beyond the SM (BSM), it is essential to precisely determine the production mechanisms and the properties and confront the results with SM predictions. Deviations of the different quantities from their prediction could be indications for BSM. Additionally, direct searches for new physics are performed in the top sector.

As of today, two particle accelerators provide collisions with enough energy to produce top quarks: the Tevatron at Fermilab and the Large Hadron Collider (LHC) at CERN. The Tevatron collider is a proton-antiproton collider. From 1992 to 1996, Run I of the Tevatron was ongoing, providing $p\bar{p}$ collisions at 1.8 TeV energy. In 2001, Run II with a collision energy of 1.96 TeV started, lasting until September 30th, 2011, and providing approximately 10.5 fb^{-1} of integrated luminosity for each experiment. The LHC is a pp collider with currently a center of mass energy of 7 TeV, that started its operation in 2010. About 5 fb^{-1} of collision data has been provided in 2011. Due to its high center of mass energy, the production cross section of top quark pairs at LHC is about a factor 20 higher than at the Tevatron [4, 5].

The large datasets enable us to perform high precision measurements of top quark production and properties, to study many properties for the first time and to perform sensitive searches for new physics. In this article, an overview of top quark physics at the Tevatron will be provided. About half of the collected Run II dataset have been studied until now.

2 Top Quark Production

Top quarks can be produced in pairs via the strong interation or singly via electroweak interaction. Both interaction modes have been studied at the Tevatron. In the following

*on behalf of the CDF and D0 Collaborations recent results of $t\bar{t}$ and single top cross sections will be discussed.

2.1 Top Quark Pair Production

At the Tevatron, top quarks are produced to about 85% via $q\bar{q}$ annihilation and about 15% through gluon-gluon fusion. The predicted inclusive $t\bar{t}$ cross section ($\sigma_{t\bar{t}}$) from SM calculations are of $\sigma_{t\bar{t}} = 6.41 \pm 0.51$ pb [6] and $\sigma_{t\bar{t}} = 7.46 \pm 0.48$ pb [7] at approximate next to next to leading order (NNLO) quantum chromodynamics (QCD).

The decay of the top quark in the SM is to almost 100% into a b-quark and a W boson. We classify different final states of the $t\bar{t}$ pairs according to the decay of the two W-bosons from top and antitop quark. The main channels we consider for analyses are the the dilepton final state (5%), lepton+jets final state (30%), and the all hadronic final state (46%), where either both W-bosons decay leptonically into an electron or muon, just one decays leptonically, or none. Channels where at least one W-boson decays into a hadronically decaying tau-lepton are considered separately as τ+lepton or τ+jets final states, as the identification of taus is experimentally more challenging. The golden channel at the Tevatron is the lepton+jets final state, consisting of events with exactly one isolated electron or muon, at least four jets and large missing transverse energy, combines a good ratio of signal to background with large statistics and a clear signature. Events in the dilepton channel have two isolated leptons (electrons or muon), at least two jets and high missing transverse energy to account for the two undetected neutrinos. The dilepton final state is very pure, but suffers from low statistics. Furthermore, the existence of two neutrinos complicates the reconstruction of the full event kinematics. In the all-hadronic final state the full event can be reconstructed, but the channel suffers from high backgrounds due to QCD mutlijet production.

The inclusive $t\bar{t}$ cross section has been measured in lepton+jets, dilepton, all hadronic, τ+lepton, τ+jets and missing energy plus jets final states. The main tools to separate $t\bar{t}$ signal from background exploit b-jet identification and the kinematic and topological differences of signal compared to background. The b-jet identification [8] relies usually on properties of the secondary vertex from B-hadron decay or on tracks displaced with respect to the primary vertex. An example of both tools, b-jet identification and topological information, being used recently is the $t\bar{t}$ cross section measurement in the lepton+jets final state. At D0 for example, $\sigma_{t\bar{t}}$ has been measured in lepton+jets using three different methods [9] using 5.3 fb^{-1} of integrated luminosity. The first is a counting method using b-jet identification, where events with three jets and at least four jets are further separated into events with zero, one or at least two identified b-jets. Simultaneously the heavy flavor k factor [a] of the dominant W+jets background is fitted in order to reduce the systematic uncertainty. We measure $\sigma_{t\bar{t}} = 8.13^{+1.02}_{-0.90}$ (stat+syst) pb with this method for a top quark mass of 172.5 GeV. The second method uses no b-jet identification but purely relies on the kinematic and topological differences of signal and background. A multivariate discriminant is constructed from several variables showing discrimination between $t\bar{t}$ signal and W+jets background. Using kinematic information D0 extracts $\sigma_{t\bar{t}} = 7.68^{+0.71}_{-0.64}$ (stat+syst) pb. The third method is a "combined" technique where kinematic information is used together with b-jet identification. First, the events are split into events with two, three or at least four jets and are further devided into events with zero, one and at least two b-tagged jets. For events where the background content is still relatively large a mutlivariate discriminant is formed, which separates signal from W+jets background. Using the combined method we

[a] The heavy flavor k factor defines ratio of the NLO over LO W+heavy flavor cross sections

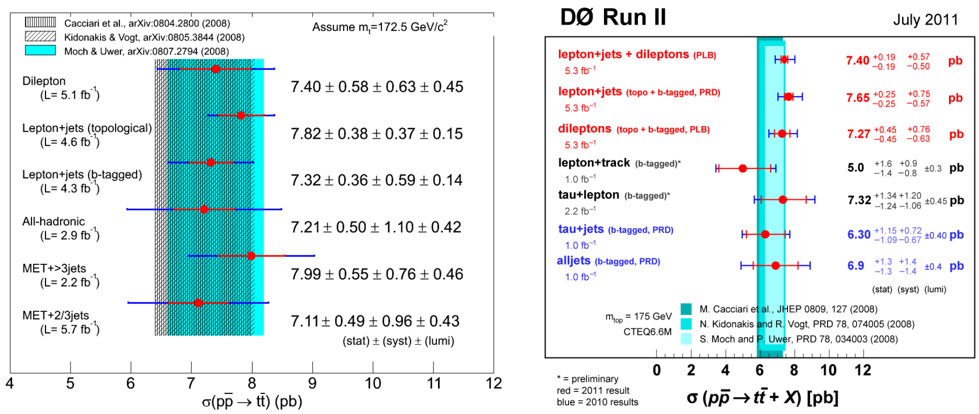

Figure 1: $t\bar{t}$ cross sections in various channels by the CDF (left) and D0 (right) Collaborations.

extract $\sigma_{t\bar{t}} = 7.78^{+0.77}_{-0.64}$ (stat+syst) pb. All results are limited by systematic uncertainties, and are in good agreement with theory predictions. The main systematic uncertainties are the uncertainty from the luminosity calculation, b-jet identification and jet energy scale. The CDF Collaboration uses similar methods, and also additionally employed the method to normalize the measured $t\bar{t}$ cross section to the cross section of Z production, which is known theoretically to about 2% precision. This way, the dominant uncertainty from luminosity can be reduced. Using 4.6 fb^{-1} of integrated luminosity, CDF measures $\sigma_{t\bar{t}} = 7.82 \pm 0.38(\text{stat}) \pm 0.37(\text{syst}) \pm 0.15(\text{Z theory})$ pb for a mass of 172.5 GeV in the lepton+jets final state [10].

For many models of physics beyond the SM, the measured inclusive $t\bar{t}$ cross section in the different final states could differ from the theory prediction. Therefore, it is important to extract $\sigma_{t\bar{t}}$ in the various final states and compare the results between each other and with theory prediction. Figure 1 shows the most recent results for $\sigma_{t\bar{t}}$ in various final states, measured by CDF and D0. All results are in good agreement with theory predictions as well as between each other.

2.2 Single Top Quark Production

Single top quark production happens via the electroweak interaction and occurs via the s-channel, t-channel and Wt-channel. The latter has a negligible cross section at the Tevatron. In 2009, single top quark prodution was observed for the first time by CDF and D0 [11,12], where the $s+t$ channel cross section (σ_{s+t}) was measured using up to 3.2 fb^{-1} and 2.3 fb^{-1} of data, respectively. Even though the cross section of the $s+t$-channel is only about a factor of two smaller than $t\bar{t}$ production, its signature is very similar to W+jets events, and therefore advanced multivariate techniques have to be employed to distinguish single top signal from background. In particular, boosted decision trees, neural networks and Bayesian neural networks as well as matrix element techniques have been used, and the result of the different methods have been combined. Recently, the D0 collaboration updated the measurement of the single top $s+t$-channel cross section using 5.4 fb^{-1} of data, extracting $\sigma_{s+t} = 3.43^{+0.73}_{-0.74}$ (stat+syst) pb [13].

Since BSM could affect the contributions to s- and t-channel differently, it is important to also measure these two production modes individually. Both collaborations therefore also perform two dimensional measurements, where the s- and t-channel cross sections are measured simultaneously [14,15]. Recently, D0 reported first observation of t-channel single top production [16] using 5.4 fb^{-1}, obtaining $\sigma_t = 2.90 \pm 0.50$ (stat+syst) pb.

3 Top Quark Properties

In order to understand the top quark in detail and to use it for BSM searches, its properties have to be measured precisely. The large datasets collected at the Tevatron enable the measurement of several properties with high precision, while others can be studies for the first time. In this section, a selection of recent results are discussed, in particular the top quark mass, the top antitop mass difference, the helicity of the W-boson in top decays, $t\bar{t}$ spin correlations and the $t\bar{t}$ forward backward asymmetry.

3.1 Top Quark Mass

The top quark mass, m_t, is a free parameter in the SM. Together with the W-boson mass, it sets constraints on the SM Higgs boson.

With the goal to measure the top quark mass with high precision, several techniques have been developed. The simplest method is the template method, where top quark mass dependent templates are constructed and fitted to the data. In lepton+jets events, the full event kinematics can be reconstructed by using kinematic fitting techniques that constrain the invariant mass of the charged lepton and the neutrino from the leptonic W-boson decay to the known W-boson mass. In dileptonic final states, the kinematics are underconstrained by the two neutrinos, and additional integration over the unknown quantities is necessary. Several methods exist for this integration, as for example matrix weighting or neutrino weighting techniques. In the full hadronic final state, the kinematics of the event is fully known and the main complication arises form the large background and the large number of possible permutations of jets to match the top and antitop quarks.

The second and most precise technique to measure the top quark mass is the Matrix Element (ME) method. The full kinematic information of each event is extracted by calculating per-event signal probabilities $P_{sig}(x; m_t)$ and background probablities $P_{bkg}(x)$, where x are the momenta of the final state partons. Each probability is calculated by integration over the leading order (LO) matrix element for $t\bar{t}$ production or background, folded with parton distribution functions and transfer functions. The transfer functions describe the transition of the parton momenta as used in the leading order matrix element into the measured momenta x. The top quark mass is obtained by maximizing the likelihood constructed of a product of the per-event probabilities. Finally, ensemble tests are performed, as the use of only leading order matrix element and approximations in the calculation of the background probabilities requires the method to be be calibrated. A third commonly used method is an approximation of the ME method and is called ideogram technique. Instead of using matrix elements, per-event probabilities are calculated using kinematic fitters.

Additionally to these techniques, a variety of different methods has been explored at the Tevatron, as for example the extraction of m_t using the transverse momenta of the lepton or using secondary vertex information. All of these methods are still very limited by statistical

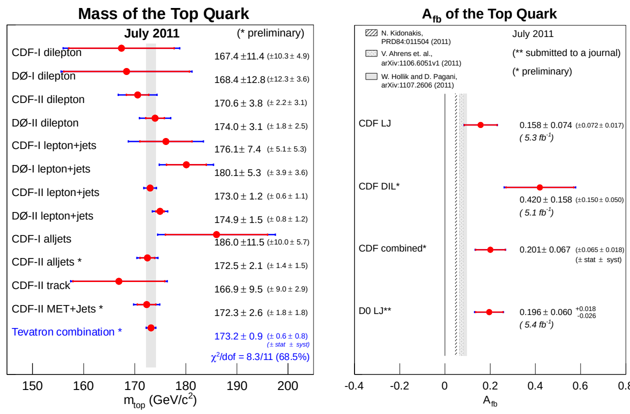

Figure 2: Left: Tevatron top quark mass measurements in the different final states during Run I and Run II and their combination [1]. Measurements of the forward backward charge asymmetry A_{fb} at the Tevatron [39].

uncertainties, but have the advantage of different systematic uncertainties being important. These different methods will be more interesting with much larger datasets.

The largest systematic uncertainty on the top quark mass using the three described methods arises from the jet energy scale (JES). In the lepton+jets and all hadronic final states, the JES can be fitted in-situ by constraining the invariant mass of the two jets from the W-boson to the known W-boson mass. In dilepton final states, the in-situ JES fit can not be performed, but recently CDF performed a simultaneous measurement of m_t in the diletpon and lepton+jets channel, where the fitted JES from the lepton+jets final state can be applied to the jets in the dilepton channel [17].

During the life of the Tevatron, the various techniques have been developed, improved and used to measure the top quark mass with high precision. Recent measurements of m_t using template techniques are performed by CDF in the alljets ($m_t = 172.5 \pm 2.0(\text{stat} + \text{syst})$ GeV [18] using 5.8 fb^{-1}), dilepton ($m_t = 170.3 \pm 3.7(\text{stat} + \text{syst})$ GeV [17] using 5.6 fb^{-1}) and $\not{E}_T$+jets ($m_t = 172.3 \pm 2.6(\text{stat} + \text{syst})$ GeV [19] using 5.7 fb^{-1}) channels. New results using the ME method are a measurement from D0 in the dileptonic final state ($m_t = 174.0 \pm 3.0(\text{stat} + \text{syst})$ GeV [20] using 5.4 fb^{-1}) and the lepton+jets final sate ($m_t = 174.9 \pm 1.5(\text{stat} + \text{syst})$ GeV [21]) as well as a measurement in the lepton+jets channel by CDF (($m_t = 173.0 \pm 1.2(\text{stat} + \text{syst})$ GeV [22] using 5.6 fb^{-1}), the latter being the single most precise measurement of the top quark mass to date. A combination of all top quark mass measurements at the Tevatron has been done, resulting in $m_t = 173.18 \pm 0.56(\text{stat}) \pm 0.76(\text{syst})$ GeV [1]. The relative precision of 0.6% exceeds initial Tevatron expectations. The measured top quark mass is dominated by systematic uncertainties, where the main sources come from the differences of the JES for different jet flavors and uncertainties on the signal modeling. The latter include uncertainties on initial and final state radiation, color reconnections, and next-to-leading order (NLO) versus LO Monte Carlo (MC) generators. In Fig. 2 (left) the different Tevatron top quark mass measurements and the combination are shown.

The direct meausrements of m_t rely heavily on Monte Carlo (MC) simulations, either for the construction of the templates or the calibration. Currently used MC simulations are performed in LO QCD, with higher order effects being simulated through parton showers at modified leading logarithms level. The top quark mass is a convention dependent parameter beyond LO QCD. Therefore it is important to know how the result of direct top quark mass measurements can be interpreted in terms of renormalization conventions. Currently, it is still under theoretical investigations how the measured top quark mass from MC and the top quark pole or $\overline{MS}$ mass are related. The D0 Collaboration has recently performed a determination of the top quark mass from the measurement of $\sigma_{t\bar{t}}$, by comparing the measured $t\bar{t}$ cross section to inclusive cross section calculations versus top quark mass. This allows an unambiguous interpretation of the extracted top quark mass in the pole or $\overline{MS}$ mass scheme [23]. Using the pole mass for inclusive cross section calculations D0 extracted a pole mass of, for example, $m_t = 167.5^{+5.2}_{-4.7}$ GeV for the cross section calculation from Ref. [7]. Performing the same extraction, but using a calculation in the $\overline{MS}$ mass scheme yields about 7 GeV smaller values for m_t.

3.2 Top Antitop Mass Difference

The CPT theorem requires the particles and their antiparticles to have equal masses. Thus, in direct top quark mass measurements the top and antitop quark are assumed to be of identical mass. Recently, the D0 and CDF Collaborations have performed measurements of the top antitop quark mass difference by dropping the assumption of both being of equal mass, and therefore testing the CPT theorem in the top quark sector. By extending the event probabilities $P_{sig}(x; m_t)$ to $P_{sig}(x; m_t, m_{\bar{t}})$, the D0 Collaboration performed the first measurement of the mass difference between a bare quark and its antiquark using the ME method on 1 fb^{-1} of data in the lepton+jets final state [24]. This measurement was updated on 3.6 fb^{-1}, yielding $m_t - m_{\bar{t}} = 0.8 \pm 1.8(\text{stat}) \pm 0.5(\text{syst})$ GeV [25], which is consistent with the SM. The CDF collaboration performed the mass difference measurement using a template technique in the lepton+jets channel using 5.6 fb^{-1} of data, resulting in $m_t - m_{\bar{t}} = -3.3 \pm 1.4(\text{stat}) \pm 1.0(\text{syst})$ GeV [26].

3.3 W-Boson Helicity in Top Quark Decays

In the SM, W-bosons couple purely left-handed to fermions, and therefore constrain the relative orientation of the spin of the b-quark and the W boson from the top quark decay. In NNLO QCD, the fractions of negative (f_-), zero (f_0) and positive (f_+) helicity of the W-boson are predicted to be $f_- = 0.685 \pm 0.005$, $f_0 = 0.311 \pm 0.005$ and $f_+ = 0.0017 \pm 0.0001$ [27]. Deviations of these values could indicate new physics contributions. The W-boson helicity fractions have been measured by CDF and D0 in the leptin+jets and dilepton final states using template or ME techniques. In the template method, the angle θ^* between the down-type decay product of the W-boson and the top quark in the W-boson rest frame is measured, and the cosine of this angle is fitted to data. To keep the analysis as model-independent as possible, the fractions f_0 and f_+ are fitted simultaneously, only constraining the sum of all three fractions to be one. The CDF collaboration also uses the ME method to measure the W-boson helicity, where the per-event signal probabilities P_{sig} are calculated as function of f_0 and f_+. Recently, a combination f the CDF and D0 measurements has been performed, combining a D0 measurement in the dilepton and lepton+jets channel using 5.4 fb^{-1}, a CDF measurement in the lepton+jets final state using 2.7 fb^{-1}, and a CDF analysis in the dilepton final state using 5.1 fb^{-1} [28]. Fitting f_0 and f_+, the combination yields $f_0 = 0.732 \pm 0.063(\text{stat}) \pm 0.052(\text{syst})$ and $f_+ = -0.039 \pm 0.034(\text{stat}) \pm 0.030(\text{syst})$, in good agreement with the SM prediction. Furthermore, the CDF collaboration updated the measurement in the dilepton final state using 5.1 fb^{-1}, additionally improving the sensitivity by applying b-jet identification. This result is not yet included in the Tevatron combination and yields $f_0 = 0.71^{+0.18}_{-0.17}(\text{stat}) \pm 0.06(\text{syst})$ and $f_+ = -0.07 \pm 0.09(\text{stat}) \pm 0.04(\text{syst})$ [29].

3.4 $t\bar{t}$ Spin Correlations

While the top quarks are produced unpolarized at hadron colliders, the spins of the top and antitop quarks are expected to be correlated. Due to the top quark's short lifetime, the information of the spin of the top quark is preserved in its decay products, enabling the measurement of the spin correlation of the top and antitop quark in $t\bar{t}$ events. Recently, $t\bar{t}$ spin correlations has been measured using a template and ME based method.

The template based methods are based on the fact that the doubly differential cross section, $1/\sigma \times d^2\sigma/(d\cos\theta_1 d\cos\theta_2)$ can be written as $1/4 \times (1 - C\cos\theta_1\cos\theta_2)$, where C is the spin correlation strength, and θ_1 (θ_2) is the angle of the down-type fermion from the W^+ (W^-) boson or top (antitop) quark decay in the top (antitop) quark rest frame with respect to a quantization axis. Common choices are the helicity basis, where the quantization axis is the flight direction of the top (antitop) quark in the $t\bar{t}$ rest frame, the beam basis, where the quantization axis is the beam axis, and the off-diagonal basis, which yields the helicity axis for ultra-high energy and the beam axis at threshold. The SM prediction for the spin correlation strength C depends on the collision energy and the choice of quantization axis, and is $C = 0.78$ for the Tevatron in the beam basis at NLO [30]. The spin correlation strength C can be presented as the number of events where top and antitop have the same spin direction minus the number of events with opposite spin direction, normalized to the total number of $t\bar{t}$ events, multiplied with a factor representing the analyzing power of the down-type fermion used to calculate the angles. The latter factor is one for leptons and down-type quarks from the W-boson decay at LO QCD, and smaller for up-type quarks and the b-quark from top quark decay. Since it is experimentally challenging to distinguish up-type from down-type quarks, the dilepton channel is best to perform the measurement of $t\bar{t}$ spin correlations. Both, CDF and D0 Collaborations have performed a measurement of C by fitting templates for $C = 0$ and the SM value of C of the distribution $\cos\theta_1\cos\theta_2$ to data. Using 2.8 fb^{-1} at CDF and 5.4 fb^{-1} at D0, the measurement of C in the beam basis yields $C = 0.32^{+0.55}_{-0.78}(\text{stat} + \text{syst})$ [31] and $C = 0.10 \pm 0.45(\text{stat} + \text{syst})$ [32], in agreement with SM prediction. Similar to these two analyses in the dilepton final state, CDF performed the first extraction of $t\bar{t}$ spin correlations by fitting templates of equal and opposite $t\bar{t}$ helicity to data. The measured quantity is then translated into C. Using a dataset of 4.3 fb^{-1}, CDF measured $C = 0.72 \pm 0.64(\text{stat}) \pm 0.26(\text{syst})$ in the beam basis [33].

The D0 collaboration also explored the measurement of $t\bar{t}$ spin correlations using a ME based method. Per-event signal probabilities $P_{sig}(H)$ are calculated using matrix elements that include spin correlations ($H = c$) and do not include spin correlations ($H = u$), and are translated into a discriminant $R = P_{sig}(H = c)/[P_{sig}(H = c) + P_{sig}(H = u)]$ [34]. By applying this technique to the same D0 dataset of 5.4 fb^{-1} of dilepton events as for the template based method, a 30% improved sensitivity can be obtained, resulting in $C = 0.57 \pm 0.31(\text{stat} + \text{syst})$ [35]. Recently, the matrix element-based method has been extended to the lepton+jets final state using 5.3 fb^{-1} of D0 data, and by combining the measurement in dilepton and lepton+jets events first evidence for spin correlation was reported recently, as $C = 0.66 \pm 0.23(\mathrm{stat} + \mathrm{syst})$ [36]. All Tevatron measurements are in agreement with the NLO SM prediction, and all are still limited by statistics.

3.5 $t\bar{t}$ Asymmetry

At LO QCD, $t\bar{t}$ production is forward backward symmetric in quark antiquark annihilation processes. At higher order, interferences between diagrams that are symmetric and anti-symmetric under the exchange of top and antitop cause a preferred direction of the top and antitop quarks and therefore an asymmetry. In particular, at NLO, the leading contribution arises from the the interference between tree level and box diagrams, which yield a positive asymmetry, where the top quark is preferentially emitted in the direction of the incoming quark. A deviation from the SM prediction could indicate physics beyond the SM.

At the Tevatron, where the $t\bar{t}$ production is dominted by the interaction of a valence quark and a valence antiquark and therefore the (anti)quark direction almost always coincides with the direction of the incoming (anti)proton, the measurement of the forward backward charge asymmetry is conceptionally easy. The asymmetry is defined in terms of the difference between the rapidity of the top and antitop quarks, Δy. The assignment of the final state particles to top and antitop quarks is determined by applying kinematic fitting techniques to the fully reconstructed $t\bar{t}$ events in the lepton+jets and dilepton final states. The charge of the lepton(s) is used to determine which combination of final state objects belongs to the top and which to the antitop quark. The asymmetry is defined as $A_{fb} = [N(\Delta y > 0) - N(\Delta y < 0)]/[N(\Delta y > 0) + N(\Delta y < 0)]$, where $N(\Delta y > 0)$ and $N(\Delta y < 0)$ are the number of events with rapidity difference larger and smaller zero. Alternatively, the asymmetry can be extracted from the rapidity of the lepton(s) only. This has the advantages that no complete reconstruction of the top and antitop quarks and their decays is required and that the directions of the charged leptons can be measured with good resolution, while the disadvantage is that the direction of the lepton is not fully correlated to the top quark direction, resulting in a loss of sensitivity. In order to compare to theory predictions, the measured $t\bar{t}$ forward backward asymmetries are corrected for acceptance and resolution effects to obtain the inclusive generated asymmetry. The correction is done using a 4×4 matrix-inversion at CDF and with regularized unfolding at D0.

Recently, the CDF collaboration measured an inclusive generated asymmetry of $A_{fb} = 0.158 \pm 0.074$ using 5.3 fb^{-1} of data in the lepton+jets channel [37], and $A_{fb} = 0.420 \pm 0.158$ in the dilepton final state with 5.1 fb^{-1} of data [38]. The combination of these two measurements results in $A_{fb} = 0.201 \pm 0.067$ [39]. The D0 measurement with 5.4 fb^{-1} of data in the lepton+jets channel yields $A_{fb} = 0.196 \pm 0.060(\mathrm{stat})^{+0.018}_{-0.026}(\mathrm{syst})$ [40]. The results are summarized together with a selection of theory predictions in Fig. 2 (right). All results are still dominated by statistical uncertainties. Comparing the measurement to various theoretical predictions [41] and the prediction of MC@NLO [42] MC shows about a two sigma deviation towards higher values of the measurements compared to the prediction. It is not yet clear whether this deviation comes from new physics contributions or modeling of the SM or anything else, causing a strong interest in the asymmetry measurements. Various tests to check the MC modeling have been performed, as for example a test performed by the D0 Collaboration to check the sensitivity to the modeling of the transverse momentum of the $t\bar{t}$ system, $p_T(t\bar{t})$. This test showed that the asymmetry predicted by several MC generators is indeed sensitive to $p_T(t\bar{t})$, which will require further investigations in the future.

Besides the inclusive measurement, it is interesting to investigate the dependence of the asymmetry on various variables, as for example the rapidity or the invariant mass of the top antitop quarks, $m_{t\bar{t}}$. CDF and D0 investigated the $m_{t\bar{t}}$ dependence by measuring A_{fb} for regions of $m_{t\bar{t}} < 450$ GeV and $m_{t\bar{t}} > 450$ GeV. While in D0 data, no significant dependence was observed [40], an excess of about three sigma standard deviation from the MC@NLO prediction was observed by the CDF collaboration for $m_{t\bar{t}} > 450$ GeV [37].

4 Searches in the Top Quark Sector

Besides precision measurements many sensitive direct searches for physics beyond the SM are performed in the top quark sector. Several models have been explored in $t\bar{t}$ or single top final states with different methods, as for example classic bump searches or using multivariate analysis techniques. For example, searches for b' [43], t' [44, 45], Z' [46, 47], W' [48, 49], charged Higgs bosons [50, 51], Higgs bosons in association with a $t\bar{t}$ pair [52, 53], flavor changing neutral currents [54, 55] and boosted top quarks [56] have been performed. Some of these searches are still the best limits to date.

5 Conclusion and Outlook

Recent measurements of top quark production and properties by the CDF and D0 Collaborations have been discussed. About 10.5 fb^{-1} of data have been collected by the CDF and D0 collaborations in Run II of the Tevatron, which ended on September 30th, 2011. About half of this dataset has been analyzed so far. The Tevatron experiments plan to analyse the final dataset for those measurement which are complementary or competitive to the LHC results, including the top quark mass measurement, the measurement of the forward-backward charge asymmetry and $t\bar{t}$ spin correlations.

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