TOP QUARK PROPERTIES AND SEARCH FOR SINGLE TOP QUARK PRODUCTION AT THE TEVATRON

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Since its discovery in 1995 by the CDF and DØ collaborations, studying the properties of the top quark is one of the preeminent goals of the Tevatron experiments. The number of observed top quarks is increasing rapidly at the Tevatron Run II and precise measurements of the top quark decay vertex will be possible in $p\bar{p}$ collisions at $\sqrt{(s)} = 1.96$ TeV. The latest results on the W-helicity measurements in top quark decays, top quark decay branching rations and limits on $t \to H^+b$ decays are summarized. New limits on the observation of single top quark production are presented.

In the standard model, the discovery of the top quark complete the particles of the third generation. With a mass $m_t \simeq 175$ GeV, at the mass scale of electroweak symmetry breaking, the top quark properties may reveal signs of new physics. In the standard model, the top quark decays via $(V - A)$ charged current interactions at nearly 100% into Wb. This assumption can be verified by searching for right-handed polarized W bosons. In supersymmetric models, the top quark can also decay in charged Higgs bosons, which can be directly searched. Contributions from additional quark generations would be visible looking at the ratio of top quarks decaying into Wb compared to any other top quark decay. Finally observing the electroweak production of single top quarks is expected and would allow for a direct measurement of $|V_{tb}|$.

1 The W Boson Helicity Measurements

Since the lifetime of the top quark $\lambda_t < 5 \cdot 10^{-25}$ s is shorter than the hadronisation time $t \sim 10^{-23}$ s, the spin of its decay products remain correlated. As the W bosons is a spin 1 particle, it can be longitudinally, left handed or right handed polarized. For (V-A) charged current interactions, the fraction of longitudinally polarized W bosons can be computed as $f_0 = \frac{m_t^2}{2M_W^2+m_t^2+m_b^2}$ and accounts $\sim 70\%$ of all decays. In leading order, left-handed W bosons

constitute the remaining fraction $f_+ \simeq 30\%$. The contribution at next-to-leading order of right-handed W bosons, f_-, is below 1%.

In the W boson rest-frame, its polarization can be disentangled from the angular correclations of the outgoing lepton (figure 1). In the case of longitudinally polarized W bosons, the leptons are emitted perpendicularly and have a harder p_T distribution, where for left-handed W bosons, the leptons are emitted opposite to its direction with a softer p_T distribution.

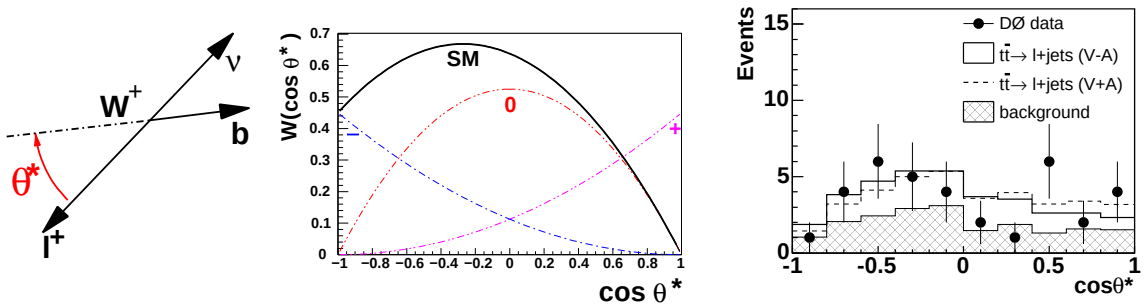

Figure 1: Schematic view of W-helicity in top quark decays and the distribution of $\cos\theta^*$ for the topological $t\bar{t}$ selection on DØ data.

CDF determined $f_0 = 0.27^{+0.35}_{-0.21}(\text{stat.} + \text{syst.})$ from a likelihood analysis of the lepton p_T spectrum on 70 events in the lepton+jet and dilepton samples, leading to a 95% confident limit of $f_0 < 0.88$ [1]. A complementary analysis of $\cos\theta^*$ on the lepton+jets sample (31 events) gives $f_0 = 0.89^{+0.30}_{-0.34}(\text{stat.}) \pm 0.17(\text{syst.})$ and leads to a 95% confident limit of $f_0 > 0.25$ [2]. Both analysis make the assumption of $f_+ = 0$.

DØ measures f_+ [3], based on two samples of $t\bar{t}$ candidate events in the lepton+jets decay mode: one selected based on topological criteria, the other using b-tagging. A comparison of the $\cos\theta^*$ distribution from the data with those for the expected background and signal for various values of f_+, results in a combined value of $f_+ = 0.00 \pm 0.13(\text{stat.}) \pm 0.07(\text{syst.})$.

These measurements are still limited by statistical uncertainty, the main systematic uncertainties are the background normalization and the top quark mass m_t.

2 Search for $t \to H^+ b$

In the MSSM top quarks decay also into charged Higgs bosons. The decay $t \to H^+ b$ modifies the $t\bar{t}$ final state signature with the size of the effect depending on the value of $\tan\beta$. At large $\tan\beta$, the dominant $H^\pm$ decay is $H^\pm \to \tau\nu$ and an excess in tau decays channels of $t\bar{t}$ events would be expected. At small $\tan\beta$, $H^\pm$ decay via $H^\pm \to cs$ or $H^\pm \to Wb\bar{b}$, which would lead to excess in the all jets channel.

CDF [6] determined limits for charged Higgs bosons in the two scenario, using the cross-section measurements $\sigma_{t\bar{t}}$ in the dilepton and the lepton+jets channels, as well as the limit on $t\bar{t} \to l + \tau$ cross-section. The obtained limits on $t \to H^+ b$ are shown on figure 2 as a function of $\tan\beta$ and m_{H^+} together with the regions already excluded by the LEP experiments.

3 Top quark decays

In the standard model the unitarity constraints on the CKM-matrix lead to the ratio $R = \frac{|V_{tb}^2|}{|V_{td}|^2+|V_{ts}|^2+|V_{tb}^2|} > 0.998$ at a 90% confidence limit. This ratio can be measured in the data, looking at the efficiencies ϵ of $t\bar{t}$ events to have 0, 1 or 2 b-tagged jets, as $\epsilon_0 = (1 - R\epsilon_b)^2$, $\epsilon_1 = 2R\epsilon_b(1 - R\epsilon_b)$ and $\epsilon_2 = (R\epsilon_b)^2$. After a background estimation, and comparing the tag rates of the b-quark with the estimated value from simulation, the most likely value of $R\epsilon_b$

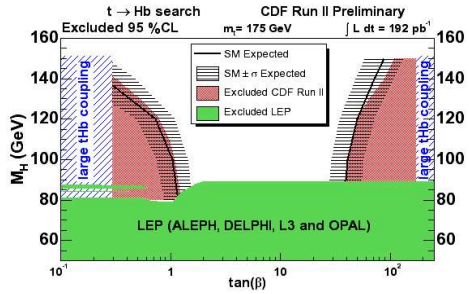

Figure 2: Current limit on charged Higgs from top quark decays.

can be computed and a lower limit can be set on R. To determine R, CDF uses events with 0, 1 and 2 b-tagged jets from the lepton+jets and the dilepton samples. The obtained value $R = 1.12^{+0.27}_{-0.23}(\text{stat.} + \text{syst.})$ leads to a lower limit on R of 0.61 and a limit on $|V_{tb} > 0.79$ at the 95% confidence level [4].

DØ uses events with 1 and 2 b-tagged jets from the lepton+jets samples, using 2 different b-tagging algorithms. The resulting values of R are $0.65^{+0.34}_{-0.30}(\text{stat.})^{+0.17}_{-0.12}(\text{syst.})$ for the impact parameter algorithm and $0.70^{+0.27}_{-0.24}(\text{stat.})^{+0.11}_{-0.10}(\text{syst.})$ for the secondary vertex algorithm [5].

The main systematic uncertainty on these measurements is the difference in the b-tagging probability between data and the simulation.

4 Single Top Quark Production

At the Tevatron Run II, single top quarks can be produced by electroweak interactions in the s- or in the t-channel (figure 3) with an expected cross-section of 0.88 pb and 1.98 pb respectively. Compared to top quark pair production, fewer jets, softer kinematics, higher backgrounds and a lower acceptance lead to a lower signal/background ratio. The event signature for electroweak top quark production is one isolated lepton, missing transverse energy and at least 2 jets in the final state. For events in the s-channel, at least one of these jets should be b-tagged, where as for events in the t-channel exactly 1 b-jet and 1 light quark jet is required. In the later case, the b-quark from gluon splitting in the initial state is emitted at low p_T in the very forward direction and escapes generally detection. The major background to single top quark production are W+jets, $t\bar{t}$ and QCD events.

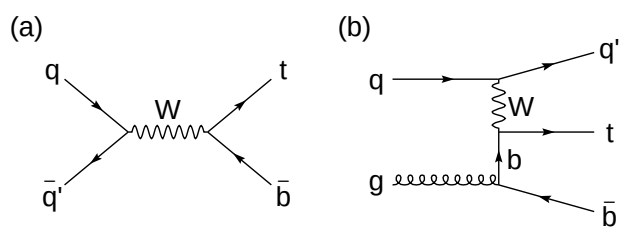

Figure 3: Diagrams for single top quark production in (a) the s- and (b) the t-channel.

The latest limits on the single top quark production from CDF are obtained from a cut based analysis on a W+2 jets sample with a liklihood fit to extract the signal. In the combined electron and muon channel, 42 events are observed for 38.1 ± 5.9 events expected. The efficiency to detect single top quark events is about 1% with a signal to background ration of 1/10. Figure 4 shows the $Q_L \cdot \eta_{jet}$ distribution, which allows to determine distinct limits on the t- and s-channel. Combining the two channels lead to a limit on the single top quark production cross-section of

17.8 pb at the 95% confidence limit [7].

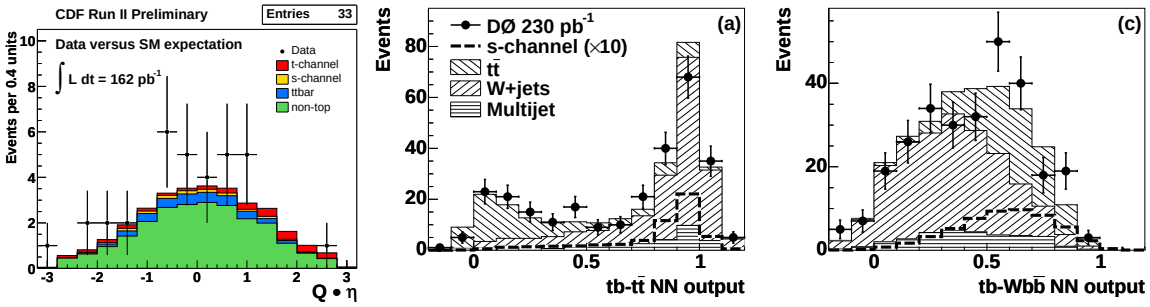

Figure 4: Distribution of the $Q_L \cdot \eta_{jet}$ variable compared with expectations from single top quark production and background (left). Combined Neural Network Output for the single top quark searches in the s-channel showing the separation for the $t\bar{t}$ filter (middel) and the $Wb\bar{b}$ filter (right).

The currently best result for single top quark searches comes from a neural network analysis on 230 pb^{-1} DØ data. The discriminative power of 25 kinematic variables has been studied, 11 of them are used to train in total eight neural networks separately for the electron- and muon-channel, the s- and the t-channel, and to reject the W+jets and the $t\bar{t}$ background. While a good signal-background separation is achieved for the $t\bar{t}$ background, the similarity of the event signatures between signal and $Wb\bar{b}$ events leads to less separation for this filter (figure 4). To obtain the result, the $t\bar{t}$ and W+jets filters are then combined in 2d histograms to build a binned likelihood.

With this analysis a 95% confidence level upper limit is obtained for the single top quark production cross-section of 6.4 pb in the s-channel and of 5.0 pb in the t-channel [8] using Bayesian statistics. This represents an improvement over all previous limits by a factor of two.

Extrapolating these analusis techniques to higher luminosities shows that observation of the electroweak top quark production is possible at the Tevatron in Run II.

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