RESULTS ON TOP QUARK PHYSICS AT DØ

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In 1995, the top quark was discovered at the Fermilab Tevatron Collider by the CDF and DØ collaborations in the $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV using about 50 pb$^{-1}$ of data per experiment. We present the studies of the top quark properties based on 1 fb$^{-1}$ of data collected by the DØ experiment at a center of mass energy of 1.96 TeV. The increased statistics and higher collision energy allow to perform precision measurements of the top quark production and decay characteristics and open the possibility to probe physics beyond the Standard Model in the top quark sector. The presentation mainly focuses on the measurement of the top pair production cross section and branching fraction of the top quark decays, a search for $t\bar{t}$ resonances, and the measurement of the top quark pair production cross section ratio and its interpretation in terms of new physics.

1. Introduction

In 1995, the CDF and DØ Collaborations discovered the top quark, the last missing piece in the quark sector of the Standard Model (SM). The top quark is the heaviest of all quarks and its mass of 172.6 GeV is now known with a precision of 0.8% \(^1\). Due to its short lifetime of about $0.5 \cdot 10^{-24}$ s \(^2\) the top quark decays before hadronization. This allows to measure the properties of a naked quark without any dilutions due to soft interactions. Several such measurements are presented in the following.

2. Top quark production and decay

The top quark can be produced in pairs via the strong interaction or as a single top quark via the electroweak interaction. Details about the latter can be found in Ref. \(^3\). At the Tevatron the top quark pairs are produced through gluon fusion (15%) and $q\bar{q}$ annihilation (85%). In the SM top quarks decay almost exclusively into a $W$ boson and a $b$-quark.
Different final states of the \( t\bar{t} \) pair are classified according to the decay of the two \( W \) bosons. The classification separates events as \( \tau + \) lepton (5\%), all hadronic (44\%), \( \tau + \) jets (15\%), lepton+jets (30\%) and dileptonic (5\%). The lepton+jets channel consists of exactly one isolated electron or muon, at least four jets and missing transverse energy to account for the neutrino. The channel has a signal over background ratio of about one and shows the best combination of large statistics and clear signature. The main background in this channel comes from \( W + \) jets events. Dileptonic events, consisting of two isolated leptons, at least two jets and high missing transverse energy, are the purest events with a signal over background of about three, but suffer from low statistics. The main background in this channel originates from \( Z + \) jets production.

Since each \( t\bar{t} \) event has at least two \( b \)-jets, \( b \)-jet identification is a powerful tool to distinguish \( t\bar{t} \) signal from background \(^4\). The \( B \)-hadron travels several millimeters in the detector before it decays, producing a secondary vertex displaced from the hard interaction vertex and tracks with high impact parameters. Properties of both are used as an input to the Neural Network \( b \)-tagging algorithm developed in D0. One can reach a high performance, e. g. of a \( b \)-tag efficiency of 54\% at a fake rate of 1\%.

3. Top quark pair production cross section

The top quark pair production cross section has been measured in several decay channels, in order to increase the statistics and to check their consistency. Processes beyond the SM can lead to differences in the measured \( t\bar{t} \) cross section for different channels. Figure 1 (left) shows a summary of the cross section measurements with up to 1 \( \text{fb}^{-1} \) of data. The measurement in the lepton+jets channel with \( b \)-tagging is the most precise single cross section measurement with 11\% relative uncertainty excluding the luminosity error.

All cross section measurements are comparable with each other and agree with the Next-to-Leading Order (NLO) SM expectation of 6.77 ± 0.6 pb at a top mass of 175 GeV \(^5\).

4. Top quark mass from cross section

Due to the high precision of the \( t\bar{t} \) cross section measurements it is worth to use it to extract the top mass \(^6\). The advantage of this method over the standard top mass measurements is its simplicity and a clear theoretical interpretation of the extracted mass as the pole mass. The disadvantage is the
larger uncertainty. We compare the theoretical cross section calculation at NLO including higher order resummations, which shows a significant dependence on the top mass, to the experimental cross section. Figure 1 (right) shows the calculation from Cacciari et al, and the measured cross section in the lepton+jets channel as a function of the top mass. Their intersection point corresponds to a mass value of $166.1^{+6.1}_{-5.3}(\text{stat+syst})^{+4.9}_{-6.7}(\text{theory})$ GeV. This value agrees with the world average.

5. Top pair production through resonance

In the SM no resonant $t\bar{t}$ production is predicted. A generic search for narrow resonances $X$ decaying into $t\bar{t}$ was performed, by looking for bumps in the invariant mass distribution $m_{t\bar{t}}$. The event selection is based on the lepton+jets channel, requiring at least four jets and at least one $b$-tag. As no enhancements in $m_{t\bar{t}}$ is observed, limits on the cross section times branching ratio $\sigma_X \cdot B(X \to t\bar{t})$ as a function of the resonance mass $m_X$ are set. The expected limit for the SM and the observed limit are shown in Fig. 2 (left), together with the predicted dependence of $\sigma_X \cdot B(X \to t\bar{t})$ on the $Z'$ boson mass in top assisted technicolor models. The measured limits can be translated into a lower limit on the mass of a $Z'$ boson of $m_{Z'} > 680$ GeV at 95% C.L.

6. Simultaneous measurement of $\sigma_{tt}$ and $R$

In the SM the ratio of branching fractions $R = \frac{B(t\to Wb)}{B(t\to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{td}|^2}$ with $q$ being any down-type quark, is highly constraint...
by the unitarity of the CKM matrix and the requirement of $|V_{tb}| = 0.999100^{+0.000034}_{-0.000004}$. For the $t\bar{t}$ cross section measurement using $b$-jet identification $R$ is assumed to be one. The simultaneous measurement of $\sigma_{t\bar{t}}$ and $R$ allows to probe both quantities without this assumption. The measurement uses the fact that the number of identified $b$-jets in $t\bar{t}$ events depends on $R$. For lepton+jets events with exactly three and at least four jets samples of no, one and at least two $b$-tagged jets are separated. In case of no identified $b$-jets in the event complementary information from a topological discriminant is used, yielding

$$\sigma_{t\bar{t}} = 8.18^{+0.90}_{-0.84}(\text{stat+syst}) \pm 0.5(\text{lumi}) \text{ pb}$$

$$R = 0.97^{+0.10}_{-0.09}(\text{stat+syst}).$$

Figure 2 (right) shows the expected and observed number of events versus the number of $b$-tagged jets for the measured value of $\sigma_{t\bar{t}}$ and $R$. As $R$ is compatible with the SM we set limits on $R$ and $|V_{tb}|$ of $R > 0.79$ at 95% C.L. and $|V_{tb}| > 0.89$ at 95% C.L.

7. Top pair production cross section ratio

All results presented so far use the assumption that the top quark always decays into a $W$ boson $B(t \rightarrow bW) = 100\%$. The ratio of cross sections measured in the lepton+jets and dilepton channels $R_{\sigma} = \frac{\sigma(pp \rightarrow t\bar{t}, t\bar{t} \rightarrow l\bar{l} vv, l\bar{l} = e\mu)}{\sigma(pp \rightarrow t\bar{t}, t\bar{t} \rightarrow l\bar{l} \ell\ell, l\bar{l} = e\mu)}$ can be used to explore alternative options available beyond the SM. Any deviation from $R_{\sigma} = 1$ would indicate new physics, as e. g. the existence of a non-vanishing branching ratio $B(t \rightarrow bX)$ with $X$ being any particle but the $W$ boson. In this analysis, $X$ is interpreted as a charged Higgs boson.
$H^\pm$, with mass close to the $W$ mass, $B(H^\pm \to cs)$ of 100\% and event kinematics similar to $t \to bW$ decay. We derive $R_\sigma = 1.21^{+0.27}_{-0.26}$ (stat+syst) using the cross section measurement in the lepton+jets channel requiring at least four jets and at least one $b$-tagged jet and the combined cross section in the dileptonic final state of

$$\sigma(pp \to t\bar{t})_{l+jets} = 8.27^{+0.96}_{-0.95}$$(stat+syst) $\pm 0.51$(lumi) pb and

$$\sigma(pp \to t\bar{t})_{dilepton} = 6.8^{+1.2}_{-1.1}$$(stat) $^{+0.9}_{-0.8}$(syst) $\pm 0.4$(lumi) pb.

In our model $t \to bH^\pm$ decays with $B(t \to bH^\pm) > 0.35$ are excluded at 95\% C.L.

8. Summary

New results on measurements and searches in the top quark sector with 1 fb$^{-1}$ of integrated luminosity have been presented. Some of the measurements are already systematically limited, e. g. the top pair production cross section in the lepton+jets channel. The high precision makes the top quark sector interesting to search for new physics. In all searches performed so far no evidence for new physics was observed. More searches and measurements can be found at 11. With more than 3 fb$^{-1}$ of integrated luminosity on tape and more data to come and improved analysis methods we expect many new precision measurements of top properties and searches in the top sector in the near future.

References

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