Top Quark Production at D0

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We present measurements of the production cross sections of top-antitop quark pair via the strong interaction and of single top quark via the weak interaction in proton-antiproton collisions at sqrt(s)=1.96 TeV using data corresponding to integrated luminosities up to 5.4 fb^{-1}. The data were collected with the D0 detector at the Fermilab Tevatron collider. We also present measurements of the forward-backward asymmetry in the top-antitop quark final states.

1 Tevatron and D0

Top quark, the heaviest known elementary particle, was discovered by CDF and D0 collaborations at the Fermilab Tevatron collider in 1995 [1],[2]. Tevatron provided proton-antiproton beams with the center of mass energy of 1.96 TeV and until its shutdown on September 30th 2011 10.5 fb^{-1} of data was recorded per experiment.

D0 detector is a multipurpose detector with high resolution inner detectors for precise tracking and vertex reconstruction, electromagnetic and hadronic calorimeters and outer muon system.

2 Top quark pair production

Top quark is produced at Tevatron mainly in pairs in strong interaction via quark-antiquark annihilation ($\sim 85\,\%$) and gluon-gluon fusion ($\sim 15\,\%$).

The theoretical value of top quark pair production cross section for the Tevatron at approximately next-to-next-to leading order (NNLO$_{approx}$) is $\sigma_{t\bar{t}} = 7.46$ pb (at $m_t = 172.5$ GeV) [3].

Because the top quark decays almost entirely to W boson and b quark, top quark pair final states are categorized according to W boson decay. The dilepton final state corresponds to both W bosons decaying leptonically. It has small background, but also small branching ratio of $\sim 10\,\%$. The lepton+jets final state corresponds to one W boson decaying leptonically and the other hadronically. This channel has moderate background and large branching ratio of $\sim 44\,\%$ and provides analyzers the highest sensitivity to signal. The all hadronic final state corresponds to both W bosons decaying hadronically. This channel has the advantage of large branching fraction of $\sim 46\,\%$ and absence

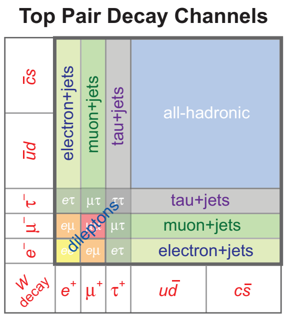

Figure 1: Top quark pair decay channels.

of undetectable neutrinos in the final state, but QCD multi-jet background dominates the signal by several orders of magnitude in cross section.

The measurement of top quark pair production cross section in lepton+jets channel is based on data with an integrated luminosity of 5.3 fb^{-1}. Events are required to contain one isolated electron or muon, at least two jets and large missing transverse energy due to escaping neutrino.

Main background processes contributing to this channel are W+jets, QCD multijet production, Z+jets and diboson events.

Top pair production cross section is measured using three methods: a *kinematic* method based on $t\bar{t}$ event kinematics, a *counting* method using identification of b-jets, and a method combining both techniques. Kinematic method uses a multivariate discriminant, shown in Figure 2, constructed from kinematic variables providing the best discrimination between signal and background. Cross section is extracted by performing a maximum likelihood fit of the distributions in the discriminant to data. Counting method exploits b-jet identification to further reduce background and top pair production cross section is obtained from maximum likelihood fit to data for the predicted number of events.

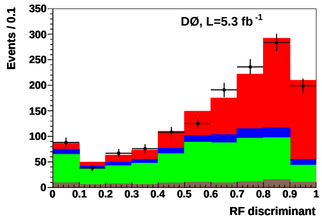

Figure 2: Multivariate discriminant.

Assuming the value of the top quark mass of 172.5 GeV the top quark pair production cross section was measured to be $\sigma_{t\bar{t}} = 7.78^{+0.77}_{-0.64}$ (stat + syst) pb [4].

The measurement of top quark pair production cross section in dilepton final state is divided into four channels ($ee+2j$, $\mu\mu + 2j$, $e\mu + 1, 2j$) and is based on data with an integrated luminosity of 5.4 fb^{-1}.

Selected events have two isolated leptons, at least one or two jets and a large missing transverse energy coming from neutrinos. Main backgrounds contributing to this channel are Drell-Yan, Z boson and diboson production and instrumental background.

In order to enhance the separation between signal and background the neural network (NN) based b-tagging discriminants are constructed. Figure 3 shows the NN b-tagging discriminant distribution for $ee + 2j$ channel. Top quark pair production cross section, $\sigma_{t\bar{t}}$, is extracted from the fit to these b-tagging discriminants and maximizing likelihood function for observed number of events. The cross section measured in dilepton channel is $\sigma_{t\bar{t}} = 7.36^{+0.90}_{-0.79}$ (stat + syst) pb [5].

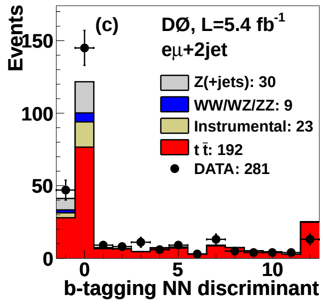

Figure 3: B-tagging discriminant.

The top pair production cross section measurements in lepton+jets and dilepton channels were combined by maximizing the product of likelihood function for both final states leading to relative precision of 8 %. The combined cross section is $\sigma_{t\bar{t}} = 7.56^{+0.63}_{-0.56}$ (stat + syst) pb [5].

3 Single top quark production

Unlike the top quark pairs single top quarks are produced via electroweak interaction. Single top quark production was observed by CDF and D0 collaborations in 2009 [6], [7]. Theoretical values of single top production cross section in s-channel, t-channel and associated production for Tevatron are $\sigma_{s-ch} = 1.04$ pb, $\sigma_{t-ch} = 2.26$ pb and $\sigma_{tW} = 0.28$ pb assuming the top quark mass of 172.5 GeV [8].

Measurement of production cross sections of single top quarks is based on data sample corresponding to the integrated luminosity of 5.4 fb^{-1}. Selected events are required to have one isolated electron or muon, large missing transverse energy, two to four jets, where one or two of them have to be b-tagged. Main backgrounds are W+jets, $t\bar{t}$ and multijet production.

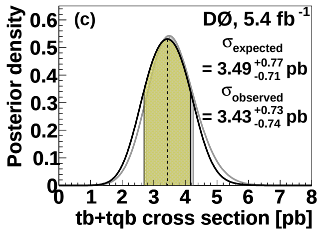

Figure 4: Single top quark production cross section.

Because the expected signal is smaller than the uncertainty on the background, three multivariate analysis (MVA) methods are used to construct a multivariate discriminant to extract the signal from data. All three methods are combined to increase the sensitivity. Bayesian approach is then used to obtain the s- and t-channel production cross sections together and separately from combined discriminant. Constructed Bayesian posterior probability density for combined s- and t-channel cross sections is shown in Figure 4. The measured cross sections are $\sigma_{s+t} = 3.43^{+0.73}_{-0.74}$ pb, $\sigma_{s-ch} = 0.68^{+0.38}_{-0.35}$ pb and $\sigma_{t-ch} = 2.86^{+0.69}_{-0.63}$ pb [9].

Data sample corresponding to the integrated luminosity of 5.4 fb^{-1} was used to perform a model-independent measurement of t-channel single top quark production cross section with no assumptions about *tb* production rate.

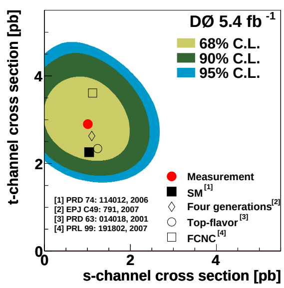

Figure 5: The 2D posterior probability density.

Three multivariate analysis techniques are combined to make a discriminant for improved separation of signal and background. The single top quark production cross section is measured using a Bayesian approach when a two-dimensional (2D) posterior probability density is constructed as a function of the cross sections for the *tb* and *tqb* processes. The 2D posterior probability density for combined discriminant is shown in Figure 5. No constraint is applied on relative rates of s-channel and t-channel production. The t-channel cross section is then extracted from a one-dimensional (1D) posterior probability by integrating over s-channel cross section values and thus without any assumptions about s-channel cross section. The s-channel cross section is obtained in a similar way. The measured cross sections of t-channel and s-channel are $\sigma_{t-ch} = 2.90 \pm 0.59$ pb, $\sigma_{s-ch} = 0.98 \pm 0.63$ pb [10].

4 Forward-backward asymmetry

The forward-backward asymmetry in top quark pair production is predicted by QCD at higher orders. The QCD predicts a small asymmetry ($\sim$ 5-9 %) at next-to-leading order (NLO) while it predicts no asymmetry at leading order (LO). The forward-backward asymmetry in $t\bar{t}$ events is defined as $A_{fb} = \frac{N(\Delta y>0)-N(\Delta y<0)}{N(\Delta y>0)+N(\Delta y<0)}$, where Δy is a difference of top and antitop quark rapidities. Using the lepton charge to distinguish between top and antitop quarks, the rapidity difference Δy is reconstructed as $\Delta y = q_l(y_{t,lep} - y_{t,had})$. The asymmetry based on charge and rapidity of the lepton from top quark decay is defined as $A^l_{fb} = \frac{N(q_l y_l>0)-N(q_l y_l<0)}{N(q_l y_l>0)-N(q_l y_l<0)}$. In order to compare the measured asymmetry with a theoretical prediction, the *reconstruction* level asymmetry (after event selection, reconstruction and background subtraction) has to be corrected for detector effects to *production* level.

The forward-backward asymmetry in top quark pair production was measured in lepton+jets channel using data sample corresponding to the integrated luminosity of 5.4 fb^{-1}.

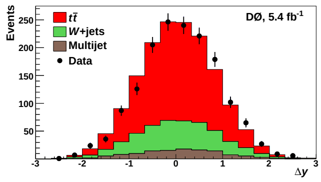

Figure 6: The top and antitop rapidity difference.

Selected events are required to have one isolated electron or muon, large missing transverse energy, at least four jets where at least one of them is b-tagged. Main background is from W+jets and multijet production. A likelihood discriminant is constructed using variables providing separation between signal and background. The reconstructed asymmetry is extracted from maximum likelihood fit of the discriminant. To obtain the asymmetry at the production level the reconstructed asymmetry has to be corrected (*unfolded*) for detector resolution and acceptance effects using regularized unfolding. The measured values of the top quark pair production asymmetry at reconstruction and production level are $A_{fb} = (9.2 \pm 3.7)\,\%$ and $A_{fb} = (19.6 \pm 6.5)\,\%$. The lepton based asymmetry is $A^l_{fb} = (14.2 \pm 3.8)\,\%$ at reconstruction level and $A^l_{fb} = (15.2 \pm 4.0)\,\%$ after unfolding [11].

5 Summary

The top quark pair production cross section was measured with 8 % relative precision. Both top quark pair and single top quark production cross sections are consistent with standard model prediction. The measured production forward-backward asymmetry in $t\bar{t}$ events is significantly higher than prediction.

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