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Top-quark-pair production cross section at the Tevatron

P. Bartoš on behalf of CDF and DØ Collaborations

Faculty of Mathematics, Physics and Inforamtics, Comenius University - Mlynska Dolina F1 Bratislava 842 48, Slovakia

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Summary. — The top-quark-pair production cross section has been measured by the CDF and DØ experiments in many channels using different methods. The goal of these studies are to test Standard Model predictions, but also to search for a new physics. The presented measurements use the data samples with integrated luminosity from $1.0\,\text{fb}^{-1}$ to $5.7\,\text{fb}^{-1}$ are compatible between different channels and consistent with the Standard Model predictions. Current measurements reach a relative precision comparable with the uncertainty of the theoretical calculation.

PACS 13.85.Lg – Total cross sections.
PACS 14.65.Ha – Top quarks.

1. – Introduction

At the Tevatron $p\bar{p}$ collider top quarks are produced mainly in pairs through strong force quark-antiquark annihilation ($\sim 85\%$) and gluon-gluon fusion ($\sim 15\%$) processes. The production cross section values predicted by the Standard Model (SM) for a reference top quark mass of $172.5\,\text{GeV}/c^2$ are: $7.46^{+0.48}_{-0.67}$ pb [1]; $7.14^{+0.76}_{-0.87}$ pb [2]; $7.27^{+0.76}_{-0.85}$ pb [3]; $6.30 \pm 0.19^{+0.31}_{-0.23}$ pb [4]. The accurate measurements of the $t\bar{t}$ cross section test the perturbative QCD at high energy and are also important for new physics searches. In addition the top-quark events are also a significant part of the Higgs boson background.

Because of its very short life time the top-quark decays before hadronization. As the CKM matrix element V_{tb} is close to one the top quark decays to the W boson and bottom quark in almost 100% of the time. Therefore the final state of the top-quark-pair production contains two b-quarks jets and two W bosons, which decay leptonically (to $l\nu_l$, where $l = e, \mu, \tau$) or hadronically (into quarks). The $t\bar{t}$ events are then classified into three main categories: the *dilepton* or *all-hadrons* category represent the case in which both W bosons decay leptonically or hadronically, respectively, the *lepton+jets* category corresponds to the case when one of the W boson decays leptonically and the other one decays hadronically. A review of cross section measurements in various decay channels using different methods is given in this proceeding.

2. – Top quark pair production cross section

2·1. *Lepton+jets channel.* – The signature for these type of events are one high-p_T isolated e or μ ($p_T \geq 20\,\mathrm{GeV}/c$), missing transverse energy ($\not{E}_T \geq$ 20–35 GeV) as evidence of neutrino from W decay and at least two (DØ) or three (CDF) jets with $E_T > 20\,\mathrm{GeV}$. Physics background is dominated by W+jets production, but also Z+jets, diboson and single top production give a small contribution. Instrumental background comes from multijet events where one of the jets is reconstructed as an isolated lepton. The background contributions are obtained from Monte Carlo simulations and data driven methods.

There are two methods used to measure $t\bar{t}$ cross section. First, "counting", uses the b-jet identification to suppress the background while the second one, "topological", is based on the kinematics of the $t\bar{t}$ events, when a complex Neural Network (CDF) or Boosted Decision Tree (DØ) discriminant is made from different kinematics variables (*i.e.* ΔR between jets, total transverse energy H_T, aplanarity, sphericity).

CDF reports both the topological measurement using the data sample of $4.6\,\mathrm{fb}^{-1}$ ($\sigma_{t\bar{t}} = 7.71 \pm 0.37(\mathrm{stat}) \pm 0.36(\mathrm{syst}) \pm 0.45(\mathrm{lumi})\,\mathrm{pb}$) and the counting measurement using the data sample of $4.3\,\mathrm{fb}^{-1}$ containing the events with at least one identified b-jet ($\sigma_{t\bar{t}} = 7.22 \pm 0.35(\mathrm{stat}) \pm 0.56(\mathrm{syst}) \pm 0.44(\mathrm{lumi})\,\mathrm{pb}$) [5]. In addition to that, CDF also provides the $\sigma_{t\bar{t}}/\sigma_Z$ measurements, which reduce the uncertainty coming from luminosity measurement. By combining the results of the last mentioned approaches, the cross section value of $\sigma_{t\bar{t}} = 7.70 \pm 0.52\,\mathrm{pb}$ [5] is obtained with relative uncertainty of 6.8%.

DØ reports different measurements as well. The topological approach gives $\sigma_{t\bar{t}} = 7.68 \pm 0.31(\mathrm{stat})^{+0.64}_{-0.56}(\mathrm{syst} + \mathrm{lumi})$ pb, while the b-tagging approach measures $\sigma_{t\bar{t}} = 8.13 \pm 0.25(\mathrm{stat})^{+0.99}_{-0.86}(\mathrm{syst} + \mathrm{lumi})$ pb. The combination of these two methods leads to the cross section $\sigma_{t\bar{t}} = 7.78^{+0.77}_{-0.64}(\mathrm{stat} + \mathrm{syst} + \mathrm{lumi})$ pb with 9% relative uncertainty [6].

The main source of systematic uncertainty comes from lepton identification, jet energy scale, signal modeling, background normalization and b-tagging modeling.

2·2. *Dilepton channel.* – The experimental signature of dilepton events consists of two isolated leptons (e or μ) with opposite signs and high-p_T ($\geq$ 15–20 GeV/c), missing transverse energy ($\not{E}_T \geq$ 25–50 GeV) and at least one (DØ) or two (CDF) jets with $p_T \geq$ 15–20 GeV/c. For further improvement of the signal purity, additional discriminating variables, like the particles transverse momenta (H_T), missing transverse momentum (MET) and missing transverse momentum significance are used. The main sources of background in the this channel come from Drell-Yan and Z boson production ($Z/\gamma \times \to ll$), diboson production and instrumental background (multijets, W+jets), where one or two jets are misidentified as a lepton. The background contributions are obtained from Monte Carlo simulations and data driven methods.

CDF reports the measurements with and without b-jet identification on the data sample of $5.1\,\mathrm{fb}^{-1}$. The measured cross section values are $\sigma^{b\text{-}tag}_{t\bar{t}} = 7.25 \pm 0.66(\mathrm{stat}) \pm 0.47(\mathrm{syst}) \pm 0.44(\mathrm{lumi})\,\mathrm{pb}$, $\sigma^{topo}_{t\bar{t}} = 7.40 \pm 0.58(\mathrm{stat}) \pm 0.63(\mathrm{syst}) \pm 0.45(\mathrm{lumi})\,\mathrm{pb}$, respectively [7]. The relative uncertainties of the measurements are $\sim 13\%$.

DØ reports the measurement which uses the distribution of the smallest of the two b-tagging Neural Network discriminants of the two leading jets and the H_T cuts to distinguish signal from background events. Using 5.4 fb^{-1} of data, the measurement gives the cross section $\sigma_{t\bar{t}} = 7.36^{+0.90}_{-0.79}(\text{stat} + \text{syst} + \text{lumi})$ pb with 11% relative uncertainty. After combining the results with the one obtained in the lepton+jets channel, the relative uncertainty of the measured cross section, $\sigma_{t\bar{t}} = 7.56^{+0.63}_{-0.56}(\text{stat+syst+lumi})$ pb, is reduced to 8% [8].

Similar to lepton+jet channel, the main source of systematic uncertainty comes from lepton identification, jet energy scale, and modeling of signal, background and b-tagging.

2˙3. *All-hadronic channel*. – This kind of events are characterized by at least six high-E_T jets, while two of them originates from b-quark. The background events, which comes from QCD multijets production, are estimated from data. To separate the background from the signal, b-tagging requirements are used in combination with a Neural Network (CDF) or a Likelihood (DØ) discriminant based on topological observables.

CDF reports the measurement using the data sample of 2.9 fb^{-1}, while DØ uses 1 fb^{-1} sample. The obtained cross section values are: $\sigma_{t\bar{t}} = 7.2 \pm 0.5(\text{stat}) \pm 1.1(\text{syst}) \pm 0.4(\text{lumi})$ pb (CDF) [9] and $\sigma_{t\bar{t}} = 6.9 \pm 1.3(\text{stat}) \pm 1.4(\text{syst}) \pm 0.4(\text{lumi})$ pb (DØ) [10], with relative uncertainties 18% and 29%, respectively.

The main systematics errors in these measurements are related to the jet energy scale.

2˙4. *Hadronic τ+jets*. – The experimental signature of these events consists from at least four jets ($p_T \geq$ 15–20 GeV/c, one of them originates from b-quark), missing transverse energy ($\not{E}_T \geq 15$ GeV) and τ jet candidate, which is narrow jet with an odd number of charged tracks and low π^0 multiplicity. To separate the hadronic τ jet from the other jets, DØ uses Neural Network technique, while CDF defines signal cone and isolation annulus inside jet and apply further energy cuts. The main background contributions come from W+jets and multijets events. To distinguish background from signal both experiments use Neural Network techniques.

CDF provides the measurement based on 2.2 fb^{-1} which yields $\sigma_{t\bar{t}} = 8.8 \pm 3.3(\text{stat}) \pm 2.7(\text{syst} + \text{lumi})$ pb [11], the relative uncertainty is 48%.

DØ reports cross section $\sigma_{t\bar{t}} = 6.3^{+1.2}_{-1.1}(\text{stat}) \pm 0.7(\text{syst}) \pm 0.4(\text{lumi})$ pb measured with relative uncertainty of 22% using data sample of 1.0 fb^{-1} [12].

2˙5. *MET+jets*. – In addition to the above mentioned analysis, CDF presents a measurement of the top pair production cross section using events with large missing transverse energy and two or three high-p_T jets, where at least one is identified as a b-jet. The dominant QCD multijets background is reduced by using a Neural Network techniques, and an another Neural Network is used to isolate the signal from the remaining backgrounds.

Analyzing 5.7 fb^{-1} of data, the obtained cross section is $\sigma_{t\bar{t}} = 7.12^{+1.20}_{-1.12}(\text{stat} + \text{syst} + \text{lumi})$ pb [13], what corresponds to 16% relative uncertainty.

3. – Conclusions

The top-quark-pair production cross section has been measured by the CDF and DØ experiments in many channels using different methods. The results based on the data samples of 1.0 fb^{-1} to 5.7 fb^{-1} are compatible between different channels and consistent with the Standard Model predictions. Current measurements reach a relative precision of 8% (DØ) and 6.8% (CDF) which is comparable with the uncertainty of the theoretical calculation of about 7%. The measurement precision is limited by the systematic uncertainties, but could be improved by the analysis of the full Tevatron statistics and by the combination between two experiments to a level better than 5%.

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