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$T\overline{T}$ PRODUCTION AT THE TEVATRON: EVENT SELECTION AND CROSS SECTION MEASUREMENT

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The Fermilab Tevatron is currently the only collider capable of producing and studying top quarks. The dominant mechanism for top quark production at the Tevatron is $t\bar{t}$ production via the strong interaction. The precise measurement of the cross section of this process is a test of the QCD prediction. In Run II of the Tevatron it should be possible to achieve an experimental error on this cross section which is comparable or better than the current theoretical precision. This paper presents the basic event selection criteria for $t\bar{t}$ events at the Tevatron and the latest measurements of the $t\bar{t}$ cross section.

Keywords: top quark; tevatron; cross section

1. Introduction

The Fermilab Tevatron is currently producing 1.96 TeV centre-of-mass $p\overline{p}$ collisions at unparalleled luminosities for the CDF and DØ experiments. This data-taking period, known as Run II, began in 2001. The datasets obtained by each experiment now exceed an integrated luminosity of 1fb^{-1}, approximately a factor of 10 more than the Run I dataset. This new dataset allows precision measurements of the properties of the top quark. In particular, the cross section for top quark production is now measured to unprecedented precision, allowing tests of the QCD prediction and searches for new physics.

At the Tevatron, the dominant mechanism for top quark production is pair production via the strong interaction. The theoretical cross section for top pair production at the Tevatron is calculated at NLO as 6.8pb[1] with a precision of 10-12%. The standard model also predicts the production of single top quarks via the electroweak interaction, however, this process has not yet been observed and is not addressed in this paper.

In addition to a general description of top quark event selection in each analysis channel, a selected cross section measurement for each channel in each experiment at the time of ICHEP 2006 is presented here. All of these results have been presented at conferences previously except for the CDF all-hadronic result which is new for ICHEP 2006.

2. Top Quark Decays

Among quarks, the top quark is unique in that it decays before it can hadronize. That decay is to a W-boson and a b-quark virtually 100% of the time. The decay of the 2 W-bosons produced in $t\bar{t}$ decay then defines the different analysis channels pursued at the Tevatron: dilepton, in which both Ws decay to an electron or muon; lepton + jets, in which one W decays to an electron or muon and the other decays hadronically; and all-hadronic, in which both Ws decay hadronically. The relative branching fractions of these channels are approximately 4%, 30%, 45% respectively. Separate analyses and cross section measurements are performed in each of these channels by both DØ and CDF.

3. Selection of Top Quark Events

While it is necessary to tailor selection criteria for each $t\bar{t}$ channel, there are certain

general features of top quark events which can be exploited in all channels.

Thresholds on the number and transverse momentum of leptons and jets in each event are used in all selection schemes. Top quark events generally have a high multiplicity of high-p_T jets. The scalar sum of the p_T of all of these objects (including missing transverse energy), known as H_T is also a commonly used variable in these analyses as top quark events tend to have higher H_T than background events.

Some analyses presented in this paper also make use of b-jet tagging. $t\bar{t}$ events contain at least 2 jets arising from b-quarks. These jets can be identified (with some inefficiency) using secondary vertex tagging since the B mesons travel some distance in the tracking detectors of CDF and DØ before decaying.

4. Dilepton Channel

The dilepton channel includes three final states: ee, $e\mu$ and $\mu\mu$. The advantage of this channel is the clean signature consisting of 2 high-p_T leptons, large missing transverse energy ($\not\!\!E_T$) and 2 b-jets. The principle disadvantages are the low branching ratio and the presence of 2 neutrinos in each event. The principle background to dilepton events is Z decay to 2 leptons with smaller background contributions from di-boson, W+jet and QCD multijet production.

4.1. *Event Selection and Cross Section Measurement*

The CDF cross section measurement in the dilepton channel is performed on 750pb^{-1} of data. The selection requires 2 oppositely charged leptons with $E_T > 20$GeV (one with "tight" selection, one loose), at least 2 jets with $E_T > 15$GeV, $\not\!\!E_T$ >25 GeV (or >50 GeV is any lepton or jet is closer than 20° from the $\not\!\!E_T$ direction), high $\not\!\!E_T$ significance for events in the Z mass region, and $H_T > 200$GeV. The yields after this selection are shown in Figure 1. The cross section is extracted using:

$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkg}}{\sum_i A_i \mathcal{L}_i} \quad (1)$$

where A is acceptance and $\mathcal{L}$ is luminosity, and is found to be:

$$\sigma_{t\bar{t}} = 8.3 \pm 1.5(stat) \pm 1.0(syst) \pm 0.5(lumi) pb.$$

The DØ cross section measurement in the dilepton channel is performed on 370pb^{-1}pb of data. The selection requires 1 high-p_T lepton and 1 isolated track of opposite charge, each with $E_T > 15$GeV. Requiring only an isolated track, rather than an object passing full lepton-ID, for the second lepton in each event increases the signal acceptance. The analysis also requires at least 1 jet with $E_T > 20$GeV, $\not\!\!E_T$ thresholds of at least 15 GeV (more stringent requirements are made in the Z mass region and different requirements are made for electron and muon channels), at least one b-tag and an explicit veto of the $e\mu$ final state (which is then combined for the final measurement). Figure 2 shows the yields after this selection. This sample leads to a measured cross section of:

$$\sigma_{t\bar{t}} = 8.6^{+1.9}_{-1.7}(stat) \pm 1.1(syst) \pm 0.6(lumi) pb.$$

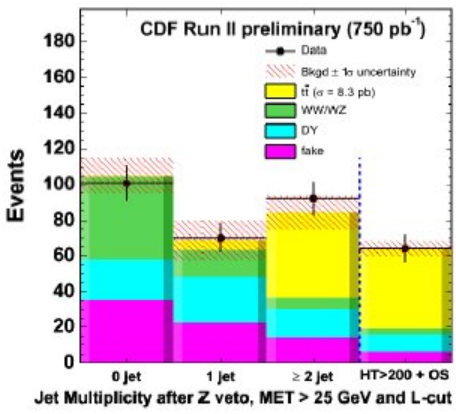

Fig. 1. CDF yields and background composition in dilepton channel as a function of jet multiplicity. The last bin includes the H_T threshold and opposite-sign lepton requirement.

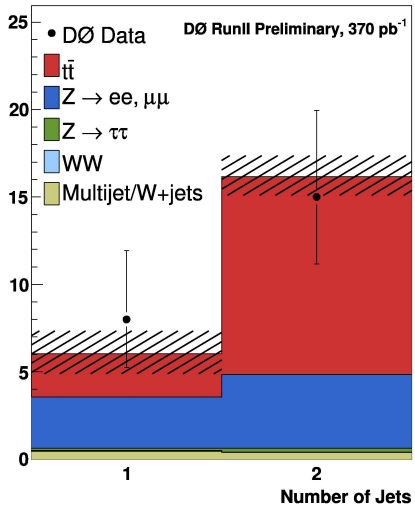

Fig. 2. DØ yields and background composition in dilepton channel as a function of jet multiplicity

5. Lepton + Jets Channel

The signature for the lepton + jets channel is exactly 1 high-p_T lepton, 2 high-p_T b-jets, 2 high-p_T light-quark jets and missing transverse energy. This channel generally provides the most stringent constraints on the cross section as it is a compromise between branching ratio and clean signal. The leading background for this channel is W+jets production with lesser contributions from QCD multijet, di-boson and Z events.

5.1. *Event Selection and Cross Section Measurement*

The CDF analysis in the lepton+jets channel is performed on 695pb^{-1} of data. It requires 1 isolated lepton with $E_T > 20$GeV, at least 3 jets with $E_T > 15$GeV, $\not\!\!E_T > 20$GeV, exactly 1 b-tagged jet and $H_T > 200$GeV. Figure 3 shows the event yield after selection as a function of jet multiplicity. The 3 and 4 jet bins are dominated by signal. The cross section is then extracted using equation 1 giving:

$$\sigma_{t\bar{t}} = 8.2 \pm 0.6(stat) \pm 1.0(syst)pb$$

This is the world's best single measurement of the $t\bar{t}$ cross section. Events with 2 b-tagged jets are not included in this result and are instead used as a cross-check sample. The result from the cross-check sample agrees with that of the single-tag sample.

The DØ analysis is performed on 370pb^{-1} of data. It requires exactly 1 isolated central lepton with $E_T > 20$GeV, at least 1 jet with $E_T > 15$GeV, $\not\!\!E_T > 20$GeV and either 1 or 2 b-tagged jets. Figure 4 shows the event yield after selection and again it is clear that the 3rd and 4th jet bins are dominated by signal. The cross section is extracted by fitting a liklihood function:

$$\mathcal{L} = \prod_i P(N_i^{obs}, N_i^{pred}(\sigma_{t\bar{t}})) \qquad (2)$$

where this is a product of probabilities to observe N_i^{obs} given a predicted number of events (N_i^{pred}) which is sensitive to the $t\bar{t}$ cross section. This yields a cross section result:

$$\sigma_{t\bar{t}} = 8.1^{+1.3}_{-1.2}(stat + syst)0.5(lumi)pb.$$

This is the best current $t\bar{t}$ cross section measurement from DØ .

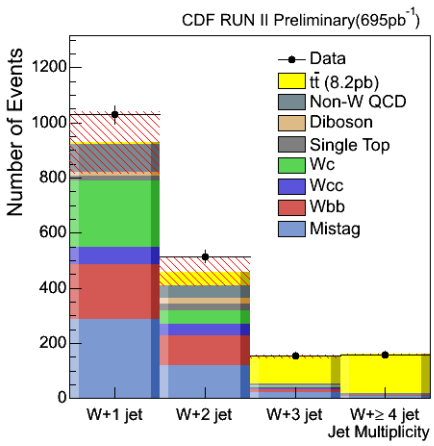

Fig. 3. CDF yields in lepton+jets channel as a function of jet multiplicity

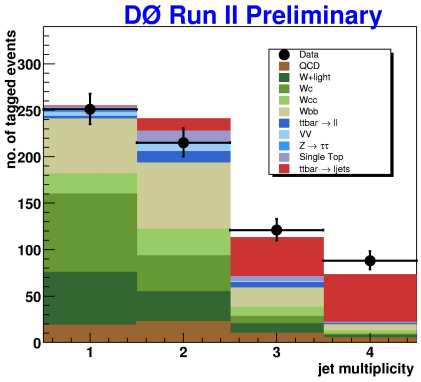

Fig. 4. DØ yields in lepton+jets channel as a function of jet multiplicity

6. All-Hadronic Channel

The signature for the all-hadronic channel is 6 high-p_T jets, 2 of them from b's. The background is primarily from QCD multi-jet events with a smaller contribution from W+jets. The advantages of this channel are the high branching fraction and the lack of any neutrinos in the final state. The disadvantage of this channel is the dependence on jet energy scale and the high background rate.

6.1. *Event Selection and Cross Section Measurement*

The CDF all-hadronic analysis is performed on 1.02fb^{-1} of data and was first shown publicly at ICHEP 2006. It requires a veto on isolated leptons and large $\not\!\!E_T$ and 6-8 jets with $E_T > 15$GeV. A topological neural network is then constructed based on 11 inputs and 1 or more b-jets is required. Figure 5 shows the yield as a function of the jet multiplicity and demonstrates the significant signal present in the 6-8 jet bins. The cross section is extracted based on the number of tags in the data, rather than the number of events and yields:

$$\sigma_{t\bar{t}} = 8.3 \pm 1.0(stat)^{+2.3}_{-1.9}pb \pm 1.5(lumi)pb.$$

The most recent DØ measurement in the all-hadronic channel would be better classified as a "multi-jet" analysis. This terminology is used since there is no veto on isolated leptons or $\not\!\!E_T$ in the analysis. Therefore, significant signal from, for example, $t \rightarrow \tau\nu$ is present in this sample. The analysis is performed on 360pb^{-1} of data. It requires 6 jets, with varying p_T requirement, all of which must have at least 2 tracks pointing to the event primary vertex and exactly 2 of which must be b-tagged. The cross section extracted from this sample is:

$$\sigma_{t\bar{t}} = 12.1 \pm 4.9(stat) \pm 4.6(syst)pb.$$

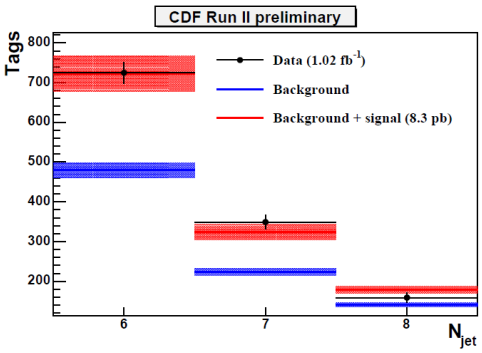

Fig. 5. CDF yields in All-hadronic channel as a function of jet multiplicity

7. Summary

Event selection techniques and cross section results for $t\bar{t}$ production at the Tevatron are presented for up to 1fb^{-1} of integrated luminosity. The results from several independent channels for both DØ and CDF are presented and are consistent both with each other and with theory. The best precision cross section measurements now rival theoretical precision.

References

1. M. Cacciari, et al. JHEP 404, 68 (2004); N. Kidonakis and R. Vogt, Phys. Rev. D 68, 114014 (2003).