TOP QUARK PAIR PRODUCTION AT THE TEVATRON

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Recent innovations in the measurement of the inclusive $t\bar{t}$ production cross section at the Fermilab Tevatron collider have improved the precision of the results. Two recent measurements that apply these techniques, in the ℓ+jets and dilepton decay channels, are presented. The CDF and D0 collaborations have also begun making differential measurements of $t\bar{t}$ production. The first measurement of $t\bar{t}$+jet production and of $d\sigma/dp_T$ binned in top-quark p_T are presented. In all cases, expectations from next-to-leading order perturbative QCD agree with the measurements from the CDF and D0 collaborations.

There were two recent innovations that improved the uncertainty of the inclusive $t\bar{t}$ cross section at $\sqrt{s} = 1.96$ TeV. The first, implemented by the CDF collaboration, normalized the $t\bar{t}$ cross section to the production of Z bosons. This swapped the systematic uncertainty associated with the experimentally measured luminosity (dominated by the inelastic $p\bar{p}$ cross section at $\sqrt{s} = 1.8$ TeV) with the smaller uncertainty associated with the perturbative QCD (pQCD) prediction for Z boson production. Measuring the ratio also allowed for reduction of common systematic uncertainties, such as those related to lepton efficiencies. CDF used this technique to measure the inclusive $t\bar{t}$ cross section in the ℓ+jets decay channel.[1] The measurement was performed as both a template fit to the output of an artificial neural network (ANN) trained to separate $t\bar{t}$ signal from background and as a counting experiment using b-tagging to suppress background contributions (Fig. 1). The total uncertainty in each measurement improved by approximately 20% by normalizing to the Z boson. The two measurements were combined yielding $\sigma_{t\bar{t}} = 7.70 \pm 0.52$ pb for a top quark mass $m_t = 172.5$ GeV. The result is consistent with the standard model next-to-leading order pQCD (NLO pQCD) prediction $\sigma_{t\bar{t}} = 7.45^{+0.72}_{-0.63}$ pb.[2]

The second improvement came from further investment in multi-variate analysis techniques such as ANN (used in the CDF ℓ+jets result above) and boosted decision trees (BDT). The latter was used by the D0 collaboration in a recent measurement of the inclusive $t\bar{t}$ cross section in the dilepton decay channel.[3] The BDT was trained on $t\bar{t}$ signal and the $Z/\gamma^\star$ and diboson backgrounds. A cut, optimized on $S/\sqrt{S+B}$, was placed on the BDT discriminant output for the e^+e^- and $\mu^+\mu^-$ decay channels. The resulting cross section, shown in Fig. 2, was $\sigma_{t\bar{t}} = 8.8 \pm 1.4$ pb at $m_t = 172.5$ GeV. This result, measured with $\int \mathcal{L} = 4.3$ fb^{-1}, was combined with an earlier 1 fb^{-1} measurement yielding $\sigma_{t\bar{t}} = 8.4 \pm 1.2$ pb which is in good agreement with the NLO pQCD expectation.[2]

Results on the inclusive $t\bar{t}$ cross section, in several decay channels, from the CDF and D0 collaborations are summarized in Fig. 3. The measurements are consistent with each other and with expectations from NLO pQCD.[2,4,5]

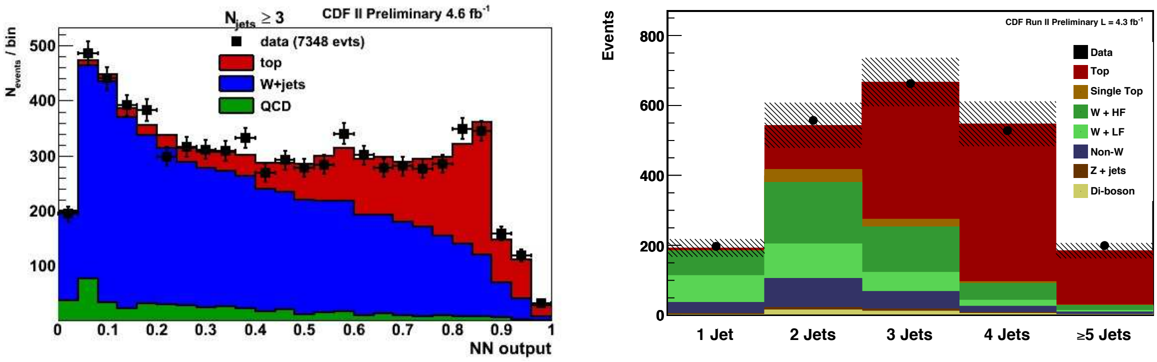

Figure 1: Meaurement of the $t\bar{t}$ cross section in the ℓ+jets decay channel from the CDF collaboration. Left: output of ANN trained to distinguish $t\bar{t}$ from background. The $t\bar{t}$ cross section was extracted from a fit of templates (colored regions) to the data (points). Right: number of data and predicted background events as a function of jet multiplicity, with the $t\bar{t}$ normalized to the measured cross section.

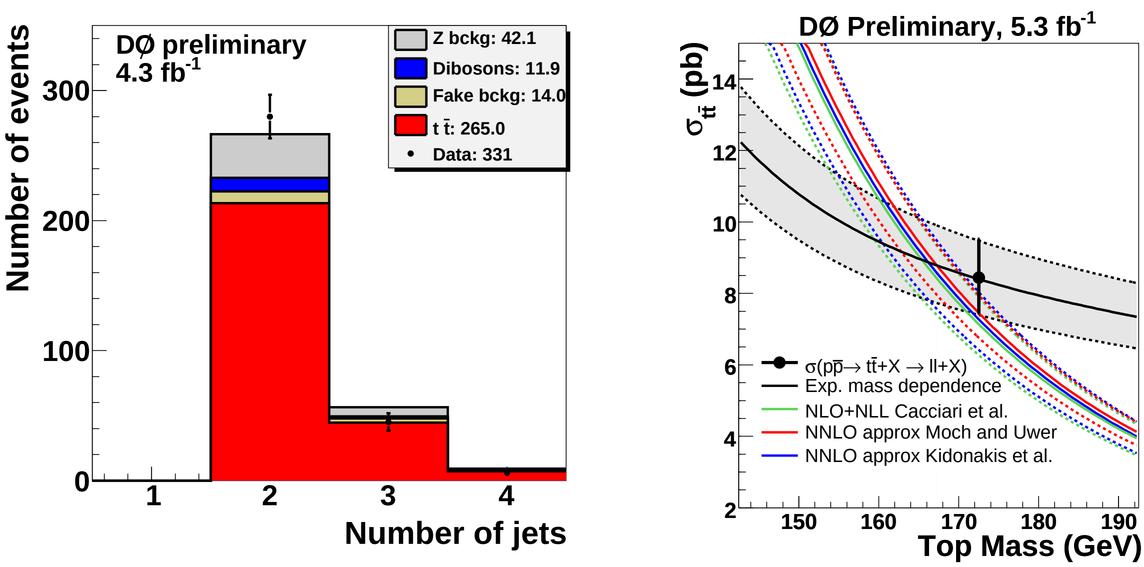

Figure 2: Left: observed and predicted jet multiplicity for various backgrounds and the signal after the final D0 dilepton selection requirements. The $t\bar{t}$ signal was normalized to the measured cross section. Right: variation of the combined $t\bar{t}$ production cross section (points) as a function of top quark mass. The colored lines show several theoretical predictions.[2,4,5]

In addition to the inclusive $t\bar{t}$ cross section results summarized above, both collaborations have recently begun measuring differential cross sections. CDF has made the first measurement of the cross section for jet production associated with the $t\bar{t}$. The jet multiplicity distribution and p_T spectrum of the fifth jet in ℓ+jet events are shown in Fig. 4. The theoretical cross section for this process, known to LO for many years, has been recently calculated to NLO.[7] This was a very difficult calculation and is an important step towards the full NNLO pQCD calculation for $t\bar{t}$ production. The theoretical expectation of $\sigma_{t\bar{t}j} = 1.79^{+0.16}_{-0.31}$ pb agrees with the measurement of $1.6 \pm 0.2 \pm 0.5$ pb.

Comparisons between measurements of the inclusive jet cross section binned in jet p_T and pQCD calculations are used to extract information about partons and the strong force. These comparisons are, however, obscured by the non-abelian nature of QCD through the fragmentation and hadronization processes. The top quark, with its exceptionally large mass, has a

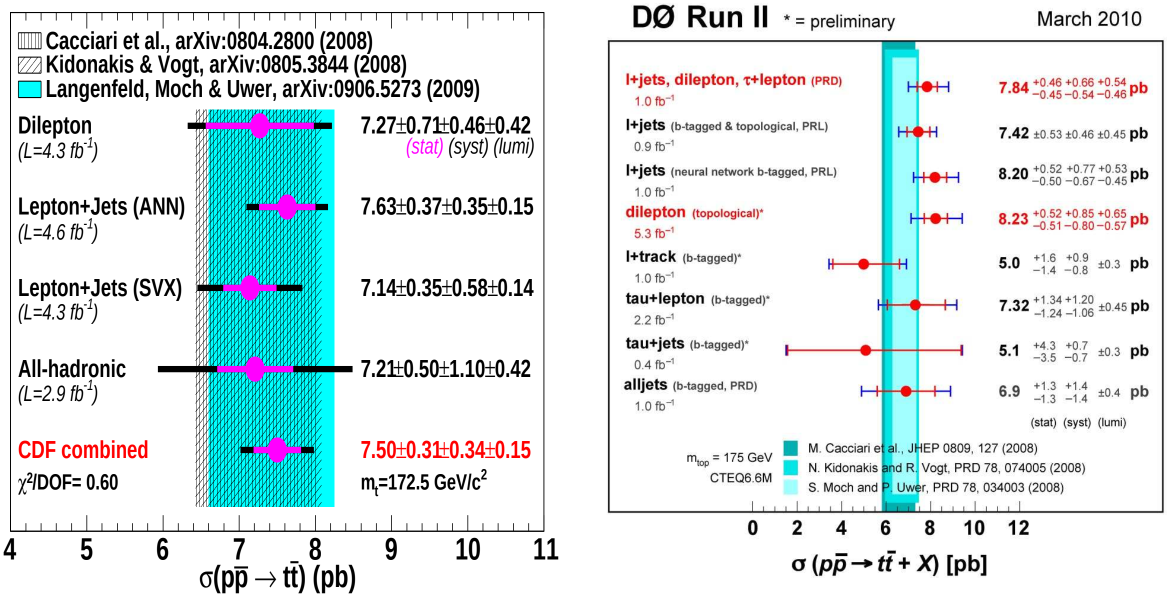

Figure 3: Summary of recent $t\bar{t}$ cross section measurements by the CDF (left) and D0 (right) collaborations. The results are compared with expectations from three NLO pQCD calculations.[2,4,5]

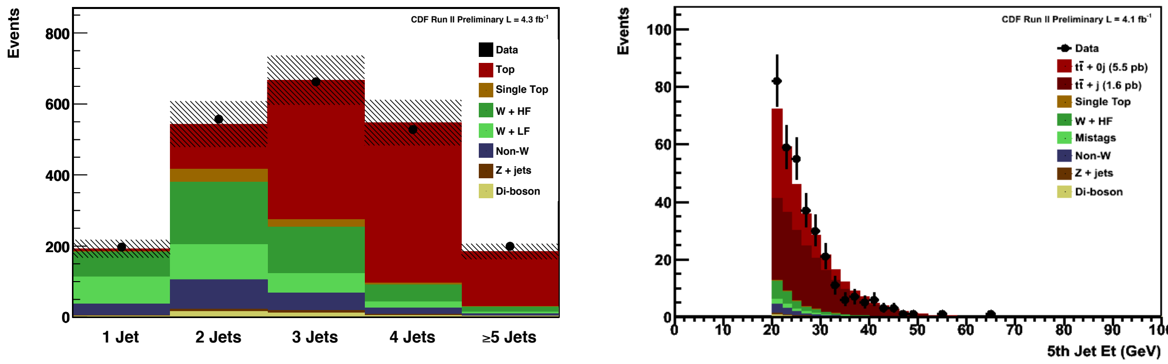

Figure 4: Measurement of the $t\bar{t}$+jet cross section in the ℓ+jets decay channel from the CDF collaboration. Left: distribution of events as a function of the number of reconstructed jets. Right: distribution of the p_T of the fifth jet. Data are represented by the points; results from simulation as the colored regions. The $t\bar{t}$ and $t\bar{t}$+jet contributions are indicated by the brown regions.

shorter lifetime than the characteristic hadron-formation time, so top quarks typically decay before interacting via the strong force. Measurements of top quark kinematics essentially access the properties of a bare quark. The D0 collaboration has recently measured the differential cross section for $t\bar{t}$ production binned in the top-quark p_T.[8] The cross section is shown in ratio to NLO pQCD[9] in Fig. 5. Expectations from an approximate NNLO pQCD calculation[5] and from three event generators[10,11,12] are also shown. The LO pQCD results disagree in normalization with the measurement; all the calculations agree with the shape of the cross section.

In summary, recent innovations in the measurement of the inclusive $t\bar{t}$ production cross section have allowed significant improvements in precision. Two recent measurements, in the ℓ+jets and dilepton decay channels, were presented. The CDF and D0 collaborations are also measuring differential $t\bar{t}$ production. The first measurement of $t\bar{t}$+jet production and of $d\sigma/dp_T$ binned in top-quark p_T were presented. In all cases, expectations from NLO pQCD agreed with the measurements from the CDF and D0 collaborations.

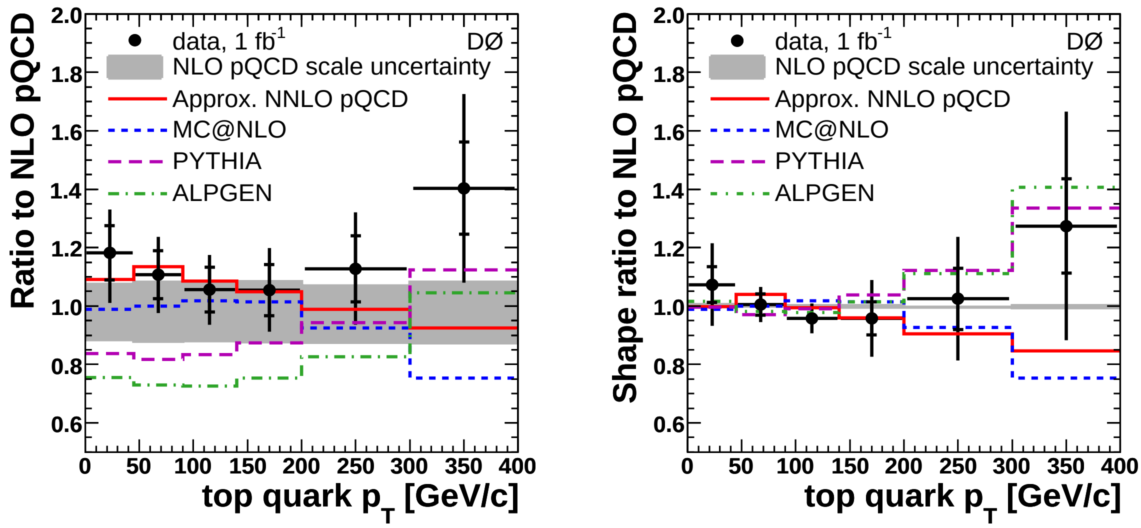

Figure 5: Inclusive differential $t\bar{t}$ cross section binned in top-quark p_T from the D0 collaboration. Left: ratio of $\mathrm{d}\sigma/\mathrm{d}p_T$ to the expectation from NLO pQCD.[9] Right: ratio of $(1/\sigma)\mathrm{d}\sigma/\mathrm{d}p_T$ to the expectation from NLO pQCD. There are two entries for each event. Also shown are ratios relative to NLO pQCD for an approximate NNLO pQCD calculation[5] and of predictions for several event generators.[10,11,12]

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