QCD AT THE TEVATRON

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The Tevatron experiments CDF and D0 reported 14 new hard QCD results in the period June 2008–June 2009. All of these use data taken with proton-antiproton collisions of center of mass energy 1.96 TeV. These results are reviewed here. The detectors themselves have been described previously. [1,2]

The measurement of the inclusive jet cross section probes the highest momentum transfers currently available and is sensitive to new physics including quark substructure. The CDF measurement [3] uses the midpoint cone algorithm and characterizes data in five rapidity bins from less than 0.1 to 2.1. It is generally slightly below the prediction by a next-to-leading order (NLO) perturbative QCD (pQCD) calculation but consistent with it within systematic uncertainties up to jet transverse momenta (p_T) of 700 MeV/c. The systematics on data in the forward region are smaller than parton distribution function (PDF) uncertainties, providing a constraint on the high-x gluon. The measurement shows improved agreement with the inclusive jet cross section measurement taken with the k_T algorithm. The D0 measurement [4] of the inclusive jet cross section agrees well with NLO pQCD over a similar range of jet p_T in six rapidity bins from 0.4 to 2.4. The D0 result favors the low edge of the CTEQ6.5M uncertainty band and the shape of the MRST2004 functions.

Both collaborations have searched for evidence of quark substructure in dijet angular distributions. Substructure can enhance the QCD cross section near 90° in the diquark (i.e., dijet) center of mass with associated amplitude that goes as $\hat{s}/\Lambda^2$, where Λ is the contact interaction scale. CDF computes the ratio of the number of observed events to number of events predicted by PYTHIA with substructure turned off, as a function of dijet invariant mass, for angular regions defined through $\chi = exp|\eta_1 - \eta_2|$, where η_1 and η_2 are the pseudo-rapidities of the highest and second highest p_T jets, respectively. CDF finds no evidence for substructure and sets a 95% confidence level limit of $\Lambda > 2.4$ TeV. D0 compares data [5] to NLO pQCD as a function of χ as well as $y_{\mathrm{boost}} = 1/2|y_1 + y_2|$, which, in the approximation of massless $2 \rightarrow 2$ scattering, is equal to $1/2 \ln(x_{\mathrm{max}}/x_{\mathrm{min}})$ where the x_i are the parton momentum fractions. Finding no deviation from theory, D0 sets limits independent of Higgs mass using three consistent statistical approaches, two Bayesian and one frequentist, on Λ as well as M_c, the characteristic parameter for TeV^{-1} extra dimensions, and M_S, the characteristic parameter for Large Extra Dimensions.

Many extensions of the Standard Model, motivated by the generational structure and observed mass hierarchy, predict resonances in the dijet mass spectrum. Like the inclusive jet cross section, they can provide sensitive constraints on PDF's. Using the midpoint jet algorithm, CDF compares the dijet mass differential cross section for dijet masses up to 1400 GeV/c^2 to predictions by NLOJET++ with PDF CTEQ6.1M, corrected to hadron level. Comparison to signal shapes predicted for excited quarks of various masses from 300 to 1100 GeV/c^2 produces the most stringent lower mass limits presently available [6] on the excited quark, axigluon, flavor-universal coloron, E_6 diquark, and color-octet techni-ρ, as well as excluded mass limits for the W' and Z'. D0 extends their measurement range on the dijet mass cross section to $|y| = 2.4$ and, in a comparative study of the MSTW versus CTEQ6.6 PDF's, finds MSTW favored and up to 40-60% variation in the cross section at the highest dijet masses. The D0 measurement systematic is comparable to the PDF uncertainty, implying constraints on future PDF predictions. [7]

Several studies of vector particle plus jet have been released. A measurement by D0 of the differential cross section for production of an isolated photon with an associated jet [8] probes the gluon distribution and, generally, the dynamics of hard QCD interactions, over ranges $0.007 \leq x \leq 0.8$ and $900 \leq Q^2$, i.e. $(p_T^\gamma)^2 \leq 1.6 \times 10^4$ (GeV/c)^2. This study investigates $qg \rightarrow q\gamma$ and $q\bar{q} \rightarrow g\gamma$ for four classes of events: those with leading jet central versus forward as well as those with photon and jet rapidities in the same direction and opposite. D0 finds that the predictions of NLO QCD do not describe the shape over the full range in p_T^γ and that scale variations cannot describe the normalization simultaneously in all four rapidity classes. A measurement of the differential cross section reduces some uncertainties through cancellations, but disagreement between data and theory persists. By contrast, a CDF measurement of the inclusive isolated prompt photon production cross section, in which the data are corrected to the hadron level, finds agreement with predictions by JETPHOX with CTEQ6 and non-perturbative corrections.

A recent measurement by D0 of the inclusive cross section for $Z/\gamma^*(\rightarrow e^+e^-)$ + jets [9] tests NLO pQCD and provides an important control on background to new physics. Events are binned in the p_T of the Nth jet, for $N = 1$, 2, and 3. Data agree well with NLO-MCFM but diverge from predictions by PYTHIA and HERWIG increasingly with jet p_T and N. PYTHIA with p_T ordering is found to describe the leading jet well. SHERPA and ALPGEN are seen to improve upon the particle shower-based generators. Some discrepancies persist nonetheless between data and predictions of production rates and jet p_T spectra.

The D0 measurement of the inclusive cross section for Z plus jet [10] tests pQCD at the M_Z scale while evaluating a major background to many mechanisms with smaller cross sections for Higgs, top, and SUSY production. This first such measurement differential in Z p_T and y is within 5% of predictions by MCFM but significantly above predictions by PYTHIA with ALPGEN. The cross section shape is well described by pQCD.

Motivated by the fact that $gb \rightarrow Zb$ and $q\bar{q} \rightarrow Zb\bar{b}$ are the largest background to the search for Standard Model Higgs through $ZH \rightarrow Zb\bar{b}$ and to some searches for sbottom, CDF has measured the cross section for b-jet production in events with a Z. The result is a measurement of $\sigma(Z + jet)/\sigma(Z)$, per jet and per event, and differentially versus jet and Z kinematical variables η, E_T, p_T, number of jets, and number of b-jets. [11] The data agree generally with predictions by PYTHIA, ALPGEN, and MCFM (with and without hadronic correction) but show scale-dependent differences of up to 2 standard deviations, suggesting that higher orders are particularly important. The best agreement is found for low scale factors. The uncertainty is 20% lower than in an earlier study by the same collaboration.

CDF has also measured the cross section for b-jet production in events with a W, a search channel for Higgs through $p\bar{p} \rightarrow W(\rightarrow e\nu)H(\rightarrow b\bar{b})$ and for new physics. The technique involves tagging the jet as originating from a b through a displaced secondary vertex. Light quark contaminants are removed by a maximum likelihood fit to the invariant mass of charged tracks associated with the vertex. The measured product $\sigma \times BR$ is 2.5 to 3 times higher than fixed order predictions by ALPGEN and PYTHIA.

A measurement by D0 [12] of the cross section for production of $W + c$-jet relative to that for production of W + jet is consistent with leading order pQCD and with an s-quark PDF evolved from Q^2 scales two orders of magnitude lower. This provides direct evidence for the process $qg \rightarrow Wq'$ while controlling background to Higgs, stop, and top studies.

D0 has released a first measurement [13] of the triply differential cross section $d^3\sigma/dp_t^\gamma dy^\gamma dy^{\rm jet}$. This probes the b, c, and g PDFs through the process $gQ \rightarrow \gamma Q$. The study divides the data into classes $y^\gamma y^{\rm jet} > 0$ and $y^\gamma y^{\rm jet} < 0$ separately for b and c jets, finding good agreement over the full range in p_T^γ up to 108.3 GeV/c for the b-jet case, but substantial disagreement above $p_T^\gamma = 70$ GeV/c for the c-jet case.

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