JET PHYSICS AT THE TEVATRON

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Recent analyses by the CDF and D0 Collaborations of jet data produced in $p\overline{p}$ collisions at the Fermilab Tevatron Collider are presented. These include new studies of the inclusive jet production cross section, a measurement of the strong coupling constant, the first measurement of subjet multiplicity of quark and gluon jets, examination of ratios of multijet cross sections and their implications for choice of renormalization scale, and a study of charged jet evolution and energy flow in the underlying event. The results are compared to theoretical predictions.

1 Jets at CDF and D0

Jets have been studied by the CDF [1] and D0 [2] Collaborations as a means of searching for new particles and interactions, testing a variety of perturbative QCD predictions, and providing input for the global parton distribution function fits. Unless otherwise indicated below, the jets were reconstructed [3,4] using a cone algorithm with cone radius $R = 0.7$ from data taken at the Fermilab Tevatron collider in 1994-95 with $\sqrt{s} = 1.8$ TeV.

2 Measurement of the Inclusive Jet Production Cross Section (CDF)

A new measurement [5] has been made of the inclusive jet cross section using 87 pb^{-1} of data. This cross section, which probes a distance scale of order 10^{-17} cm, stimulated interest in obtaining improved precision of parton distribution functions (PDFs) when initial measurements showed an excess of data over theoretical predictions at high transverse energy (E_T). The analysis uncouples the systematic shift in the cross section associated with energy "smearing" (the combined effects of energy mismeasurement and resolution limitation in the detector) from the statistical uncertainty on the data by comparing observed data to theoretical predictions that have been "smeared." A χ^2 fitting technique was developed to quantify the degree to which the next-to-leading order (NLO) calculation [6] agrees with data for each PDF examined. An additional technique was developed to determine the probability distributions associated with the χ^2 variable. The CTEQ4HJ PDF was found to have the highest confidence level (10%), followed by MRST with 7%. CDF Run 1b data were found to be consistent with CDF Run 1a data, with D0 results, and with NLO QCD, given the flexibility allowed by current knowledge of PDFs.

3 The Pseudorapidity and Transverse Energy Dependence of the Inclusive Jet Production Cross Section (D0)

A measurement [7] of the pseudorapidity (η) and E_T dependence of the inclusive jet cross section using 95 pb^{-1} of data has extended the kinematic range of this quantity considerably beyond previous measurements by examining the differential cross section for $|\eta|$ up to 3. A correlation matrix technique was used to compare the data to the NLO calculation [8] for several PDFs. The data indicate a preference for the CTEQ4HJ, MRSTg$\uparrow$, and CTEQ4M PDFs.

4 Measurement of the Strong Coupling Constant from Inclusive Jet Production (CDF)

A measurement [9] of the strong coupling constant, $\alpha_s(M_Z)$, was extracted from the inclusive jet cross section by comparing the measured cross section in each of 33 E_T bins to a NLO prediction [8] using available matrix elements [10] and evolving each of the resultant α_s values to M_Z. The data show good agreement with QCD for $40 < E_T < 250$ GeV. The value of α_s averaged over that range is $0.1178 \pm 0.0001(\text{stat.})^{+0.0081}_{-0.0095}(\text{exp. syst.})$. The extracted values $\alpha_s(M_Z)$ are E_T-independent and consistent with those input to the PDFs. The principal theoretical uncertainties are due to choice of renormalization scale μ_R ($^{+6\%}_{-4\%}$) and input PDF (5%).

5 The Inclusive Jet Cross Section using the $k_\perp$ Algorithm (D0)

The inclusive jet cross section was measured, [11] for 87 pb^{-1} of data and $|\eta| < 0.5$, using jets reconstructed with the $k_\perp$ algorithm. [12] While the NLO predictions [8] with the $k_\perp$ and cone algorithms are consistent within 1%, the cross section measured with the $k_\perp$ algorithm is 37% higher than with the cone. The theoretical prediction is lower than the data by about 50% at the lowest transverse momentum p_T ($\sim$ 60 GeV/c) and by 10-20% for $p_T > 200$ GeV/c. Inclusion of hadronization effects in the NLO prediction improves the agreement somewhat. With hadronization effects considered, the CTEQ4HJ and MRST PDFs show agreement with χ^2 probability of 44% and 46%, respectively.

6 Ratios of Multijet Cross Sections (D0)

The ratio of the inclusive three-jet to inclusive two-jet production cross sections as a function of total transverse energy was measured. [13] The measurements were used to infer the preferred renormalization scale for modelling soft jet emission. For CTEQ4M, no prediction accurately describes the ratio through the kinematic region; nonetheless a single scale $\mu_R = 0.3 \sum E_T^{jet}$ adequately describes the rate of additional jet emission when all uncertainties are considered. The introduction of additional scales does not significantly improve agreement with the data.

7 Subjet Multiplicity of Quark and Gluon Jets Reconstructed with the $k_\perp$ Algorithm (D0)

The $k_\perp$ algorithm was used to examine the properties of jets. [12] For a jet separation parameter $D = 1.0$, the jet p_T was found to be higher by 5(8) GeV than the E_T of matching jets reconstructed with cones of radius $R = 0.7$ for $p_T \approx 90(240)$ GeV. To resolve the internal jet structure known as subjets, the $k_\perp$ algorithm was also applied to $D = 0.5$ jets. Subjet multiplicity M is expected to depend upon color factor, $\sqrt{s}$, and the dimensionless $y_{\rm cut}$ parameter that controls the resolution. Because PDF data show that the fraction of gluon jets decreases with $x \propto p_T/\sqrt{s}$, gluon-enriched and quark-enriched datasets may be separated statistically by selecting jets with the same p_T in two-jet events of $\sqrt{s} = 630$ GeV and $\sqrt{s} = 1800$ GeV. HERWIG was used to predict the gluon fractions f, which in the range $55 < p_T < 100$ GeV/c were found to be $f_{1800} = 0.59$ and $f_{630} = 0.33$. For gluon multiplicity M_g and quark multiplicity M_q independent of $\sqrt{s}$, the total multiplicity M may be written in terms of the multiplicities M_{1800} and M_{630} measured at $\sqrt{s} = 1800$ GeV and 630 GeV, respectively, as $M = fM_g + (1-f)M_q$, leading to $M_g = \frac{(1-f_{630})M_{1800}-(1-f_{1800})M_{630}}{f_{1800}-f_{630}}$ and $M_q = \frac{f_{1800}M_{630}-f_{630}M_{1800}}{f_{1800}-f_{630}}$. Correction for shower detection effects in the calorimeter yields subjet multiplicities of 2.21 ± 0.03 for gluon jets and 1.69 ± 0.04 for quark jets. After unsmearing, the ratio of average subjet multiplicities in gluon and quark jets is found to be $\frac{\langle M_g\rangle-1}{\langle M_q\rangle-1} = 1.84 \pm 0.15(\text{stat.})^{+0.22}_{-0.18}(\text{syst.})$.

8 Charged Jet Evolution and the Underlying Event (CDF)

Collider data were compared to predictions by HERWIG, ISAJET, and PYTHIA in a two-part analysis. [14] In the first part, observables associated with the leading charged jet, which provides information about the hard scatter, including final state radiation, were studied. In the second part, the underlying event, which includes beam-beam remnants, initial state radiation, and multiple parton scattering, was studied with global observables. Minimum bias data and charged jets with $|\eta| < 1$ and $0.5 < p_T < 50$ GeV/c were examined with a cone algorithm modified for application to low p_T charged particles. The QCD hard scattering models were found to describe the leading (highest $\sum p_T$) charged jet well with regard to charged particle multiplicity, size, radial and momentum distributions of charged particles, and p_T around the jet direction. Charged particle clusters are evident in the minimum bias data above $p_T \approx 2$ GeV/c. The global observables, average charged particle multiplicity $\langle N_{\rm chg}\rangle$ and average total transverse momentum $\langle \sum p_T\rangle$, are correlated with the angle relative to the axis of the leading jet, such that the region transverse to the leading jet (normal to the plane of the $2 \to 2$ hard scatter) is most sensitive to beam-beam fragments and initial state radiation. The $\langle N_{\rm chg}\rangle$ and $\langle \sum p_T\rangle$ grow rapidly with $p_T^{\rm leading}$ below 5 GeV/c, then plateau. The plateau height in the transverse direction is half the height in the direction of the leading jet. PYTHIA 6.115 models $\langle N_{\rm chg}\rangle$ best in the transverse region but overestimates it in the direction of the leading jet. ISAJET models the amount of jet activity well but does not reflect the p_T dependence accurately. Although HERWIG does not model sufficient $\sum p_T$ in the events, HERWIG and PYTHIA generally model the hard scatter (especially the initial state radiation) component of the underlying event best.

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