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CDF

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HIGH E_T JETS AT CDF

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Results of QCD tests using hadronic jets from hard parton-parton collisions at the Fermilab Tevatron are presented. CDF has measured the inclusive jet cross-section as a function of jet transverse energy and collision center of mass energy. The angular distribution of dijet production has also been measured.

1. Introduction

At the Tevatron proton-antiproton collider, hadronic jet production at high transverse energy (E_T) provides an excellent laboratory for confronting the predictions of perturbative QCD. The highest E_T jets exceed 400 GeV E_T, and probe a length scale on the order of 10^{-17} cm and therefore provide a unique window for testing the Standard Model at short distances. Modern Next-to-Leading Order (NLO) calculations[1] have reduced significantly the theoretical uncertainties involved in predictions of jet production processes, and can typically be compared with the data with an absolute precision of 10-20%.

CDF has performed a number of QCD tests using high E_T jets with small statistical and systematic errors. The publication earlier this year of the inclusive production jet cross section has stimulated a burst of theoretical activity.

This paper will describe the inclusive jet cross-section measurement at $\sqrt{s}$=1800 GeV, and the measurement of the dijet angular distribution. After a brief discussion of the interpretation of the high E_T jet results, the variation of the cross-section with center of mass (CM) energy will be presented.

2. Jet Measurements at 1800 GeV

2.1. Jet Identification and Data Sample

The CDF detector has been described elsewhere[2]. The elements of the detector which are used in jet measurements are the calorimeters, which are segmented in pseudo-rapidity η and azimuth ϕ in a projective tower geometry, and the central tracking chamber, which provides a calibration of the P_T response of the central calorimeter.

Events were collected using a trigger that required jet E_T thresholds of 100, 70, 50, and 20 GeV, with appropriate prescales. A sample of data triggered on interactions without E_T requirements was used to study the lowest E_T jets.

Jets were reconstructed using a cone algorithm[3] with radius $R \equiv (\Delta\eta^2 + \Delta\phi^2)^{1/2} = 0.7$. Here $\eta \equiv -\ln[\tan(\theta/2)]$, where θ is the polar angle with respect to the beam line. The QCD calculation used a similar clustering algorithm[1].

Cosmic rays and accelerator loss backgrounds were removed from the data sample, and events were required to have an interaction vertex within ± 60 cm of the nominal beam crossing point.

The ambient energy from fragmentation of partons not associated with the hard scattering is subtracted. No correction is applied for the energy falling outside the cone because this effect should be modeled by the NLO QCD calculations.

2.2. Inclusive Jet Cross Section

The inclusive jet cross section is defined as:

$$\frac{1}{\Delta\eta}\int d\eta \frac{d^2\sigma}{dE_T d\eta} = \frac{1}{\Delta\eta}\frac{1}{L}\frac{N_{jet}}{\Delta E_T}$$

where L is the integrated luminosity, and N is the number of jets in a bin of ΔE_T . To benefit from the good resolution of the CDF central calorimeters, we measure the cross section in the

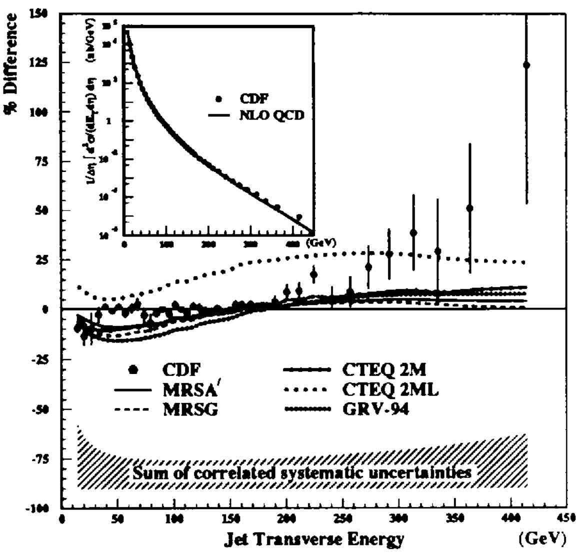

Figure 1. The percent difference between the CDF inclusive jet cross section and a next-to-leading order (NLO) QCD prediction using MRSD0′ PDF's. The CDF data are compared directly to the NLO QCD prediction (line) in the inset. The error bars represent uncertainties uncorrelated from point to point. The hatched region at the bottom shows the quadratic sum of the correlated (E_T dependent) systematic uncertainties. NLO QCD predictions using different PDFs are also compared with the one using MRSD0′

region $0.1 < | \eta | < 0.7$.

We correct the observed cross-section for energy loss in the calorimeters and the effect of detector resolution in smearing a steep spectrum.

Figure 1 (from reference[4]) summarizes the results of our measurement using 19.5 pb^{-1} of data collected in Tevatron Collider Run Ia. The normalization shown is absolute. While the data below 200 GeV E_T show excellent agreement over six orders of magnitude of the cross section, the data above 200 GeV E_T are significantly above the QCD prediction.

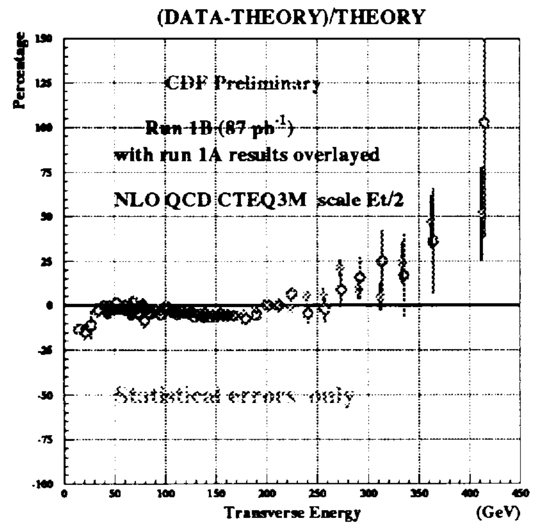

Figure 2. CDF Run 1a and Run 1b data compared to QCD predictions with CTEQ3M.

We estimate the systematic error on the cross section due to 8 uncorrelated sources, including uncertainties on charged particle calorimeter response at low and high P_T, calorimeter stability, calorimeter electromagnetic response, calorimeter resolution, jet fragmentation, underlying event energy, and overall normalization (luminosity and acceptance cuts). The quadrature sum of the effect of these uncertainties on the cross section ranges from 15% to 25% over most of the range, with slightly higher values at the lowest E_T's.

CDF has recently completed collection of an additional 87 pb^{-1} of data in Tevatron Collider Run Ib. Figure 2 shows a preliminary measurement of the inclusive jet cross section in Run Ib data, compared to a NLO calculation using CTEQ3M PDF's[7], and to the Ia measurement. The data are consistent between the two running periods.

2.3. Dijet Angular Distribution

The angular distribution of dijets can be used to study the spin structure of the fundamental hard scattering interaction. It is complementary to the inclusive jet spectrum, since in lowest order the dijet production cross section factorizes into two terms, one of which depends on the PDF and the other on the CM scattering angle θ^* (w.r.t. the proton beam direction).

We measure the distribution of the related an-

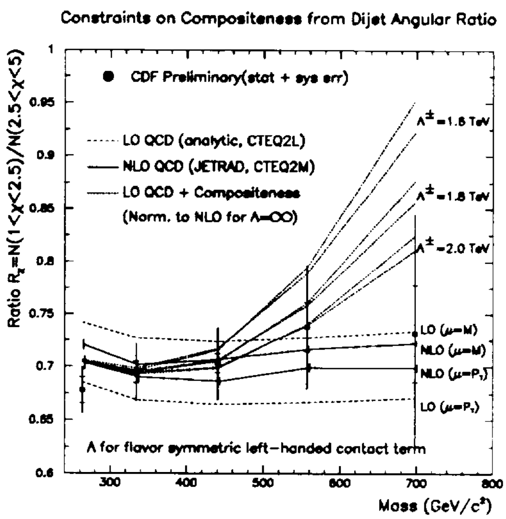

Figure 3. Limits on contact interactions from dijet angular distribution. Inner error bar is statistical, outer statistical and systematic in quadrature.

gular variable χ, defined as:

$$\chi = \exp \mid \eta_1 - \eta_2 \mid = \frac{(1+ \mid \cos\theta^* \mid)}{(1- \mid \cos\theta^* \mid)}$$

where $\cos\theta^*$ is the cosine of the CM scattering angle in the LO approximation for massless partons. To maintain a uniform acceptance as a function of dijet mass (the orthogonal scattering variable) and high trigger efficiency, we require, in this analysis, the condition $\chi < 5$, which corresponds to $\cos\theta^* < 2/3$. We form χ from the two jets with largest E_T above 15 GeV, requiring both jets to be in the range $\mid \eta \mid < 2.0$.

To compare the measured distribution to a range of theoretical predictions, we compute the variable R_χ, defined as:

$$R_\chi = \frac{N(\chi < 2.5)}{N(2.5 < \chi < 5)}$$

where N is the number of events in each region, and plot R_χ as a function of the dijet mass.

Figure 3 shows the CDF data for 106 pb^{-1} compared to LO QCD, NLO QCD and a class of models with a flavor-symmetric left-handed contact interaction[10] characterized by a scale parameter Λ. The data are in agreement with the predictions of NLO QCD. Variations of the PDF's and jet cone size choice do not affect this conclusion. We set a limit on the particular contact interaction shown of 1.8 TeV (for positive interference, Λ^+) and 1.6 TeV (for negative interference, Λ^-).

2.4. Interpretation of High E_T Jet Results

Above 200 GeV E_T, the inclusive jet spectrum shows a significant excess above the NLO QCD predictions. We have analysed its significance using shape-dependent statistical tests, and including the effects of statistical fluctuations and independent variations of the sources of systematic error described above. We find that, above 160 GeV E_T, there is a 1% probability that the the excess is consistent with the NLO predictions using the MRSD0$'$ set of PDF's[6]. In contrast, below 160 GeV, the probability is 80%. Other sets of PDF's reduce both the significance of the excess and the agreement at low E_T. The best high-E_T agreement (8%) comes using CTEQ2M PDF's, but the low E_T agreement is reduced to 23%.

The CDF results have motivated numerous theoretical studies. The CTEQ and MRS collaborations have included the CDF jet data in their most recent work. [7,12]. Reasonable global solutions are found, even if the predictions are constrained to go through the CDF high E_T data. A new calculation of the effects of soft gluon resummation is found in reference[9]. It now seems likely that collider jet data will be required to obtain satisfactory PDF's.

3. Inclusive Jet Cross Section at 630 GeV

Additional information on the behavior of high energy jet production can be obtained from measurements of the inclusive production cross-section at sufficiently separated center of mass energies. CDF has previously published a measurement of this cross-section at $\sqrt{s}$=546 GeV [5]. Despite the limited data sample of that analysis (7.5 nb^{-1} collected in 1989), deviations from naive parton scaling were observed at the 95% confidence level, and a deviation from NLO QCD

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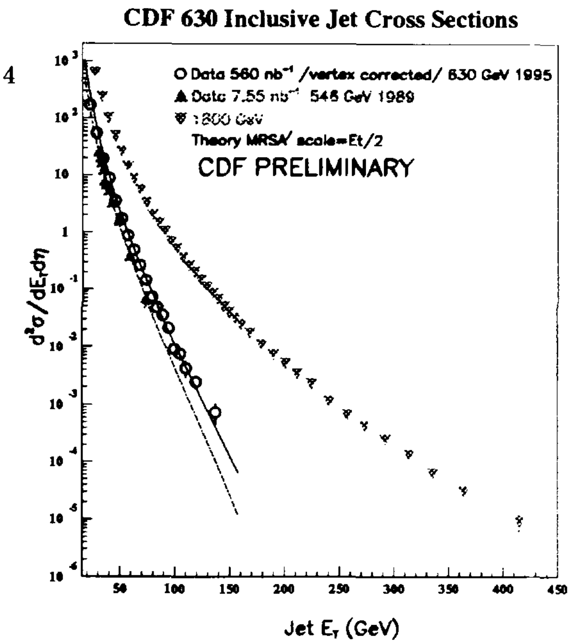

Figure 4. Inclusive jet cross sections as measured by CDF at three different CM energies

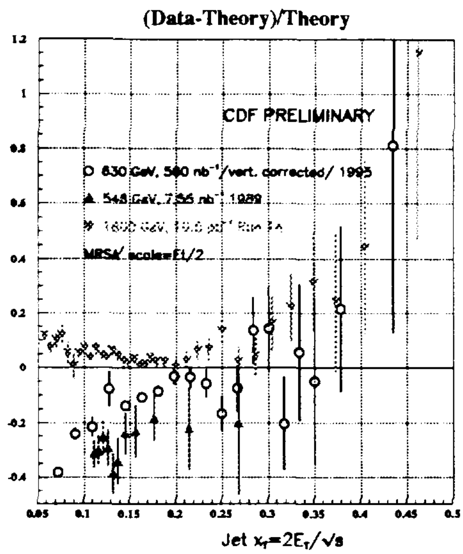

Figure 5. Inclusive jet cross sections vs. x_T at 630 GeV, compared to 546 GeV and 1.8 TeV data.

predictions was observed at low values of jet E_T (below $x_T = 2E_T/\sqrt{s}$ of about 0.15).

Recently, CDF has collected 600 nb^{-1} of data at $\sqrt{s}$=630 GeV. A single trigger, requiring a jet of 15 GeV, was used for most of this sample. This data is analysed as described above for the 1800 GeV sample, using appropriate values for the 630 GeV underlying event energy and z-vertex distribution in the Tevatron. The corrected and unsmeared results for all three CM energies are shown in figure 4.

As before, we plot the linearized residuals with respect to NLO QCD calculations. Figure 5 shows the 630 GeV, 546 GeV, and 1800 GeV data with respect to the QCD predictions using MRSA′ PDF's. The data are plotted as a function of x_T and the theory curves are evaluated at the CM energy appropriate for each dataset. The 630 data at low x_T deviates from the QCD prediction in a manner consistent with the earlier 546 GeV measurement. The region of the deviation overlaps in the E_T variable with a region whose 1800 GeV data is in good agreement with QCD, showing that the effect is not a systematic effect of jet E_T.

4. Conclusions

CDF measurements are providing important tests of QCD. The high E_T jet results imply a need for careful evaluation of theoretical uncertainties and predictions within the standard model. The physics of hadronic jets should continue to generate a rich dialog among theorists and experimentalists as both calculations and measurements improve.

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