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High p_T Jet Physics at the Tevatron Collider

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High p_T Jet Physics at the Tevatron Collider

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We present results on high p_T jet physics from the CDF and D0 experiments at the Fermilab Tevatron Collider. Recent results on the inclusive jet cross-section at $\sqrt{s} = 1.8$ TeV will be presented and compared with QCD. We will also present results on the dijet angular distribution. Limits on quark compositeness are presented from the CDF dijet angular distribution. Finally we will discuss the results on the inclusive jet cross-section at $\sqrt{s} = 0.63$ TeV and tests of scaling.

1 Inclusive Jet Cross-Section at 1.8 TeV

The measurement of the inclusive jet cross-section provides a powerful test of perturbative QCD. The measurement has very good statistical precision, typically a few percent, with relatively small experimental systematic uncertainties. Calculations of the cross-section exist at next-to-leading order (NLO)^{1,2,3} with much reduced dependence relative to LO on the choice of renormalization/factorization scale. Finally, we are probing distance scales in the tail of the distribution in the range of 10^{-17} cm. These are the shortest distances available in the laboratory, hence the inclusive jet cross-section is a good place to search for hints of new physics.

The inclusive 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 . The CDF measurement is based on 19.5 pb^{-1} of data and uses jets with $E_T > 15$ GeV and $0.1 < |\eta| < 0.7$. The D0 measurement is based on 90 pb^{-1} and uses jets with $E_T > 60$ GeV and $|\eta| < 0.5$. Jets are reconstructed using a cone algorithm with a cone radius $R = 0.7$ where $R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$. Cuts on missing energy variables are used to remove backgrounds, mostly from cosmic rays and calorimeter malfunctions. In both measurements the data are corrected for detector effects such as energy scale, this is about a 20% correction. Finally the cross-sections are corrected for the effects of finite detector resolution. The measured jet resolutions are convoluted with a "physics curve" and compared to the data. This procedure is repeated until the χ^2 between the measured spectrum and the physics curve is minimized. The "physics curve"

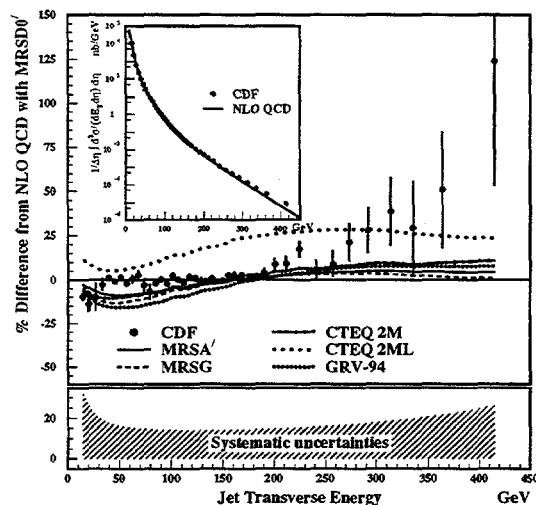


Figure 1: Percentage difference between the CDF inclusive jet cross-section and NLO QCD predictions.

represents our best guess at the underlying physics spectrum. For further details on the exact procedures used by each experiment see refs. ⁴ and ⁵.

The results from CDF are presented in Fig. 1. The data is compared to the predictions of NLO QCD ¹ using the MRSD0' parton distributions and a renormalization/factorization scale, $\mu = E_T/2$. There is qualitative agreement over nine orders of magnitude but comparing the data and theory on the linear scale reveals that the measured cross-section is larger than predicted by NLO QCD for jet E_T 's larger than 200 GeV. Also shown is the quadrature sum of the systematic uncertainties. The effect of varying the parton distribution functions (PDFs) is also shown relative to MRSD0'. None of the current PDFs give a good description of the data.

The results from D0 are shown in Fig. 2. The data is compared to NLO QCD ³ using the CTEQ2ML parton distributions and a renormalization/factorization scale, $\mu = E_T/2$. There is good agreement over seven orders of magnitude. Also shown are the systematic uncertainties. These are presently about a factor a two larger than those from CDF but are expected to improve. The data are also compared on a linear scale using three different parton distributions. The data agree with QCD within the systematics.

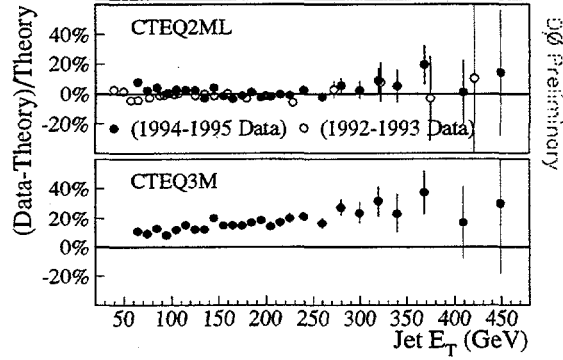
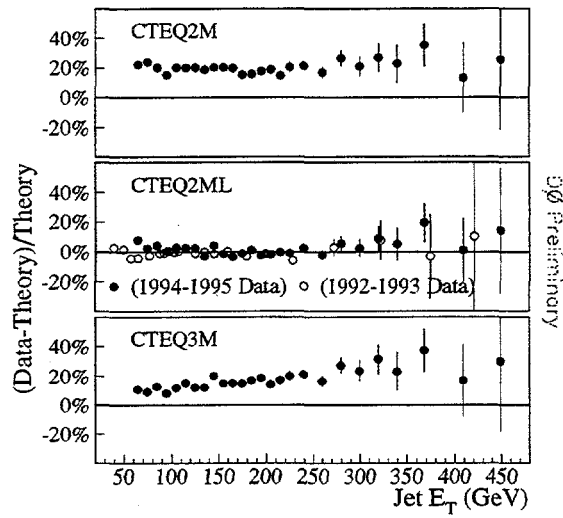
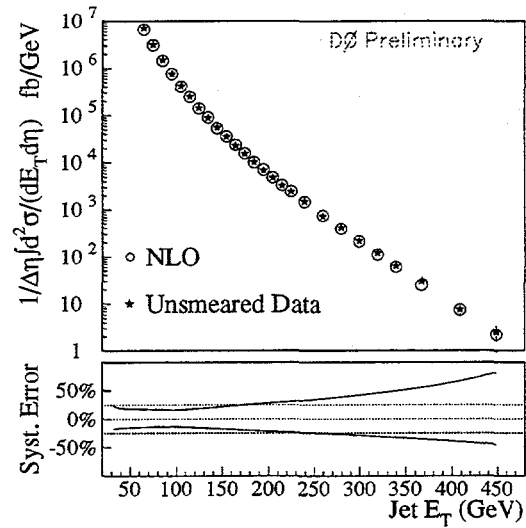


Figure 2: D0 inclusive jet cross-section compared to NLO QCD.

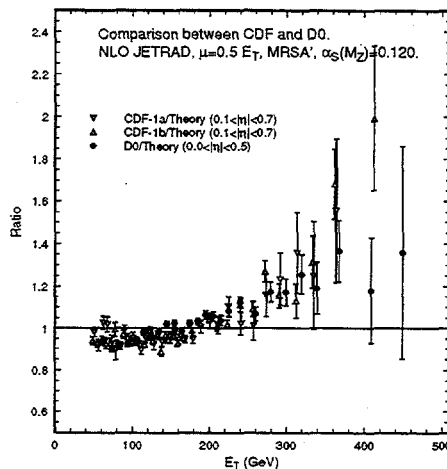


Figure 3: CDF and D0 inclusive jet cross-sections compared to NLO QCD (courtesy of W. Giele).

A natural question to ask is whether the two measurements are in agreement when compared to the same theoretical calculation^{6,7}. Fig. 3 shows a comparison between the CDF measurements and the D0 measurement compared to the calculation of ref. 3. The two experiments appear to be in quite good agreement, certainly within the quoted systematics.

The theoretical predictions have uncertainties associated with them. These are

1. The choice of parton distribution function. There is about a 20% variation in the cross-section depending on the PDF used. The CDF measurement, including full systematic uncertainties, was compared to the current set of PDFs⁴. The best fit for the shape (> 80% probability) at the low E_T end (40 - 160 GeV) was MRSD0'. Above 160 GeV there was a 1% probability that the excess was due to a fluctuation. The best agreement at high E_T was with CTEQ2ML which gave a 8% probability but the low E_T agreement was reduced to 23%.
2. The choice of renormalization/factorization scale. This gives about a 10% variation independent of E_T . There is also the question of whether the scale should be defined using the E_T of the jet or the E_T of the leading jet in the event. The use of the leading jet E_T gives a larger cross-section at low E_T .

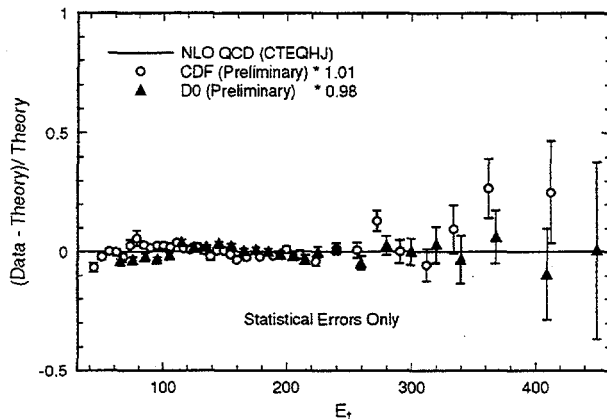


Figure 4: The CDF and D0 inclusive jet cross-sections compared to NLO QCD using the CTEQHJ parton distributions. The experimental points are normalized as indicated.

3. The definition of the parton clustering algorithm⁸. In the theoretical calculations two partons will be clustered together if they are both within R of the jet centroid where R is the cone radius in $\eta - \phi$ space. But two partons can actually be resolved at a smaller separation than $2R$, namely $R_{sep} \times R$ where $R_{sep} = 1.3$ for both CDF and D0. Using $R_{sep} = 1.3$ results in a smaller cross-section almost independent of E_T .

The CDF result has stimulated a great deal of theoretical activity on both standard QCD explanations and more exotic ideas. The CTEQ collaboration has included the CDF and D0 jet data at intermediate energies in their new set of PDFs (CTEQ4M). In addition they have produced a PDF (CTEQHJ) which gives increased weight to the high E_T CDF jet data while still giving a good fit to the rest of the world's data⁶. This PDF is shown in Fig. 4 compared to the CDF and D0 measurements. As expected the excess at high E_T is reduced by using this new PDF.

The CDF measurement has also been used to show the running of the strong coupling constant α_s over the largest range of E_T in a single experiment⁹. A new calculation of the effects of soft gluon resummation¹⁰ has recently been performed. In addition, a comparison of the DIS and MSbar factorization schemes has been performed and suggests that the cross-section may depend on the choice of scheme¹¹.

New physics explanations have also been suggested. These include quark substructure¹², a slower running of α_s ¹³ and new particles (leptophobic Z')

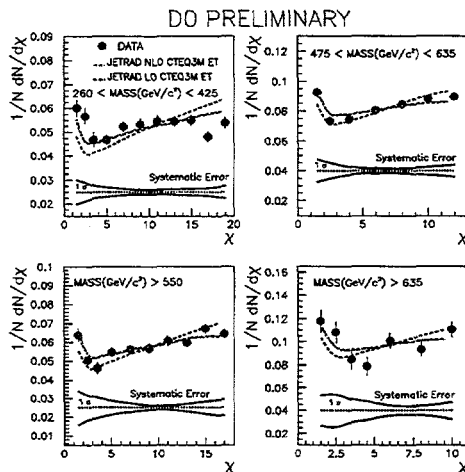


Figure 5: The D0 dijet angular distributions compared to NLO QCD.

14. All these processes would enhance the cross-section at high E_T .

2 Dijet Angular distribution

The dijet angular distribution can provide additional constraints on possible explanations for the high- E_T excess in the cross-section. The angular distribution is insensitive to the choice of PDFs and is also not sensitive to the overall energy scale. It is however, sensitive to any η -dependence of the calorimeter response and resolution. The angular distribution is typically expressed in term of χ where $\chi = (1 + |\cos \theta|)/(1 - |\cos \theta|)$. This variable flattens out the t -channel pole and makes it easier to observe the effects of any new physics that might have a more isotropic distribution than QCD, e.g., quark compositeness. The D0 measurement covers a much wider range of χ than the CDF measurement. However, for values of $\chi < 5$ a more sensitive variable to study is $R_\chi = N_{events}(\chi = 1 - 2.5)/N_{events}(\chi = 2.5 - 5)$, this has been investigated by CDF.

The dijet angular distribution for four different dijet mass regions as measured by D0¹⁵ is shown in Fig. 5. The data is compared to LO and NLO QCD using the CTEQ3M PDFs and a scale of $\mu = E_T$. There is good agreement with NLO QCD. Similar results are also available from CDF¹⁶.

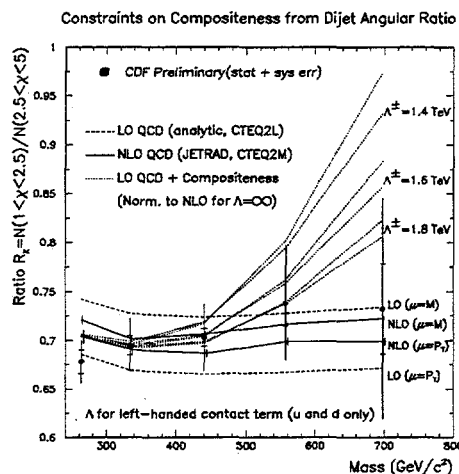


Figure 6: The ratio R_x compared to NLO QCD and various composite quark models.

Fig. 6 shows the ratio R_x for five slices of dijet mass (the points are plotted at the average mass value for the slice). The data is compared to LO and NLO QCD and is in good agreement with NLO QCD. This ratio can be used to set limits on the quark compositeness scale Λ . In the case where only u and d quarks are composite CDF obtains limits of $\Lambda_{ud}^+ \geq 1.6$ TeV @ 95% C.L and $\Lambda_{ud}^- \geq 1.4$ TeV @ 95% C.L. In a model where all quarks are composite CDF obtains limits of $\Lambda^+ \geq 1.8$ TeV @ 95% C.L and $\Lambda^- \geq 1.6$ TeV @ 95% C.L. The best fit value of Λ for the inclusive jet cross-section was $\Lambda_{ud}^+ = 1.6$ TeV using the MRSD0' PDF.

3 Inclusive Jet cross-section at 630 GeV

Another way to test QCD is to measure the inclusive jet cross-section at two different center-of-mass energies. The scaling hypothesis predicts that if the cross-sections are written in a form that makes them dimensionless then they will be independent of \sqrt{s} . On the other hand, QCD predicts that there will be scaling violations due to the evolution of the PDFs with Q^2 and the running of α_s . In a previous measurement by CDF¹⁷, scaling was ruled out at the 95% C.L. and a disagreement with the NLO QCD predictions was observed in the low E_T region at the level of 1.5-2 σ .

Both experiments collected data at $\sqrt{s} = 630$ GeV during December 1995.

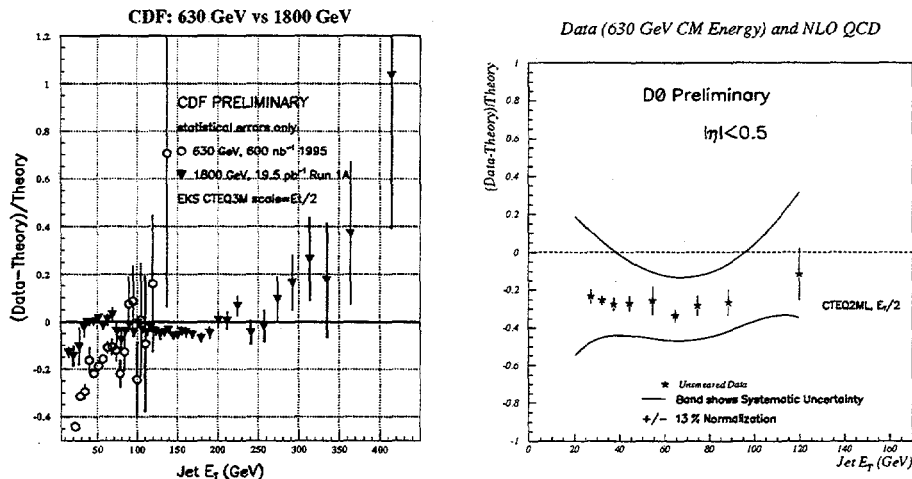


Figure 7: Inclusive jet cross-sections at 630 GeV and 1.8 TeV as a function of E_T from CDF and D0.

The CDF data is shown in Fig. 7 on a linear scale compared to NLO QCD using the CTEQ3M PDF¹⁸. The data has been corrected using the same methods as for the 1.8 TeV data. The data deviate from QCD at low E_T in a similar manner to the 546 GeV data. It should be noted that the data at 1.8 TeV in the same E_T region are in good agreement with QCD. A similar plot is shown for D0¹⁹ using CTEQ2ML in Fig. 7. The data has also been corrected. The data are fairly flat as a function of jet E_T . The band indicates the size of the systematic uncertainties. Finally Fig. 8 shows the ratio of the scaled cross-sections plotted as a function of $x_T = 2E_T/\sqrt{s}$ from the CDF experiment. The same disagreement that was observed at 546 GeV is observed in the low x_T region. The systematic uncertainties for the previous measurement at 546 GeV are shown, these are not expected to change significantly for 630 GeV.

4 Conclusions

The CDF and D0 inclusive jet cross-sections at $\sqrt{s} = 1.8$ TeV are in good agreement within the quoted systematic uncertainties but there are still theory issues that need to be resolved. A number of explanations have been proposed

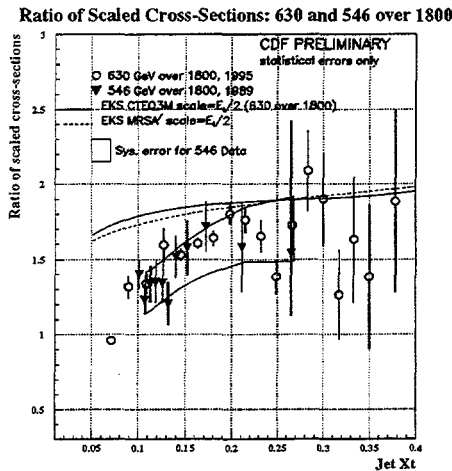


Figure 8: Ratio of the scaled cross-sections 630/1800 and 546/1800 from CDF,

to explain the excess ranging from new PDFs to more exotic ideas. The dijet angular distributions from both experiments are in good agreement with NLO QCD predictions and CDF has derived limits on quark compositeness of $\Lambda_{ud}^+ \geq 1.6$ TeV @ 95% C.L and $\Lambda_{ud}^- \geq 1.4$ TeV @ 95% C.L. The CDF measurement on the inclusive jet cross-section at $\sqrt{s} = 630$ GeV confirms the previous measurement made at $\sqrt{s} = 546$ GeV. Initial results from D0 at $\sqrt{s} = 630$ GeV show that the data are in agreement with NLO QCD within the systematic uncertainties.

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