

Fermi National Accelerator Laboratory

FERMILAB-Conf-97/256-E

DØ

Production of Jets at the Tevatron

T. Heuring

For the DØ Collaboration

*Florida State University
Tallahassee, Florida 32306-3019*

*Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510*

July 1997

Presented at the *5th Topical Seminar on the Irresistible Rise of the Standard Model*,
San Miniato al Todesco, Italy, April 21-25, 1997 and
To Appear in the *Nuclear Physics B Conference Proceedings*

Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Distribution

Approved for public release; further dissemination unlimited.

Production of Jets at the Tevatron*

T. Heuring^{a †}

^aDepartment of Physics,
Florida State University,
Tallahassee, FL 32306-3019

Measurements of the inclusive jet cross section and the dijet angular distribution using data from the Tevatron are presented. Comparisons to NLO QCD show good agreement below 250 GeV, but CDF data show an excess at higher E_T ; qualitative agreement is seen between the CDF and DØ cross sections. Analysis of the dijet angular distributions exclude quark compositeness below 2.1 TeV.

1. Introduction

Since the discovery of the internal structure of hadrons and their subsequent association with quarks, the next natural question to be asked is whether these point-like particles have any substructure. Measuring the inclusive jet cross section and studying the angular distribution in dijet events at the Tevatron, currently the highest energy hadron accelerator colliding protons and antiprotons at a center-of-mass energy of 1.8 TeV, explores matter at the smallest distance scales available. Both collider detector experiments at the Tevatron, CDF and DØ, have measured these distributions to test perturbative quantum chromodynamics (QCD) and to search for structure on the scale of 10^{-17} cm.

2. Inclusive Jet Cross Section

The inclusive jet cross section is defined as follows:

$$\frac{1}{\Delta\eta} \int d\eta \frac{d^2\sigma}{dE_T d\eta} = \frac{N}{\Delta E_T \Delta\eta \int \mathcal{L} dt} \quad (1)$$

where ΔE_T is the bin width in transverse energy, E_T , $\Delta\eta$ is the pseudorapidity range covered by the measurement ($\eta = -\ln \tan(\theta/2)$), N is the number of jets in the bin, and \mathcal{L} is the integrated luminosity. For CDF, the rapidity interval covers $0.1 \leq |\eta| \leq 0.7$ while DØ accepts jets in

the region $|\eta| \leq 0.5$. Both experiments correct the raw distributions for detector effects and remove background. In the case of CDF, the raw distribution is corrected for energy response and resolution using a detailed fragmentation model coupled with detector response from single particles[1]. The response corrections are typically $\sim 10\%$ over the whole E_T range. The resolution correction is 80% at the lowest E_T ($15 \text{ GeV} \leq E_T \leq 40 \text{ GeV}$), flattening out at $\sim 10\%$ at moderate E_T 's ($E_T \sim 40 \text{ GeV}$) and increasing to 60% for $E_T = 400 \text{ GeV}$. DØ corrects for response on a jet-by-jet basis using a correction derived using transverse momentum conservation in jet-jet and photon-jet events[2]. The correction factors range from $\sim 15\%$ at low E_T 's to $\sim 12\%$ at the highest E_T 's. The detector resolution effects are removed by an unsmearing procedure where an ansatz function, smeared with measured detector resolution factors, is fitted to the raw distribution. Comparing the smeared and unsmearing distributions yields a correction factor[3]. This correction ranges from 30% at low E_T flattening out at 10% above 100 GeV.

CDF has previously measured the inclusive jet cross section using 19 pb^{-1} from the 1992-93 run at the Tevatron[1]. These data demonstrate good agreement with next-to-leading order (NLO) QCD predictions below 250 GeV but showed an excess above this. The higher statistics available from the 1994-95 run exhibit a similar excess. Figure 1 shows both data sets compared to NLO QCD produced by the EKS program[4] using CTEQ3M parton distribution functions[5]

*presented at the 5th Topical Seminar on *The Irresistible Rise of the Standard Model*, San Miniato al Todesco, Italy, 21-25 April, 1997.

†for the DØ Collaboration

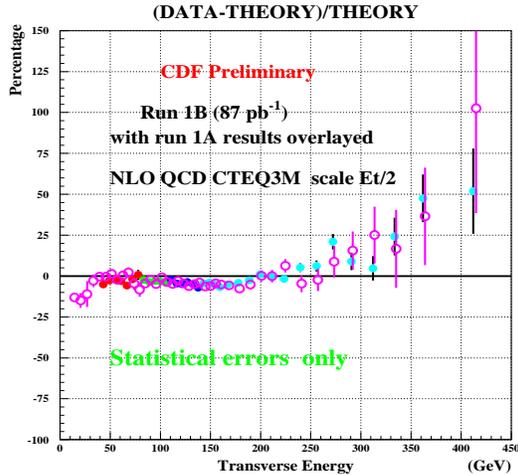


Figure 1. Results of the CDF inclusive cross section measurement from both the 1992-93 and 1994-95 data sets compared to NLO QCD using the CTEQ3M parton distribution function and $\mu = E_T^{jet}/2$.

with the renormalization and factorization scales (μ) set equal to the E_T of each jet divided by two. Although the systematic errors for the 1994-95 run are still being determined, they are expected to be of the same magnitude as was found on the 1992-93 data.

The results from $D\phi$ are shown in Fig. 2. In this case the data are compared with NLO QCD from the JETRAD program[6] with $\mu = E_T^{max}/2$, the E_T of the highest E_T jet in each event, again using the CTEQ3M parton distribution function. The statistical errors are indicated on each point with the systematic error indicated by the band. The 6% luminosity uncertainty is not included. The NLO QCD predictions are in very good agreement with the data over the entire E_T range.

The difficulty in comparing the CDF and $D\phi$ results in Figs. 1 and 2 arises due to the many different choices available when comparing to theory. Figure 3 illustrates the dependence of the theory predictions to some of these choices. Aside

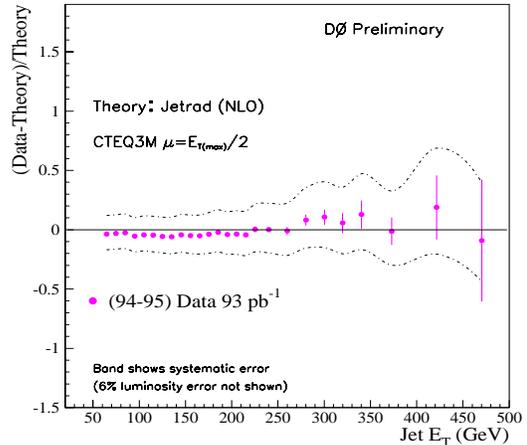


Figure 2. Results of the $D\phi$ inclusive cross section measurement from the 1994-95 data set compared to NLO QCD using the CTEQ3M parton distribution function and $\mu = E_T^{max}/2$.

from the obvious multiplicative factors typically used to scale the choice of μ which can result in 15% shift in the theoretical prediction, choosing E_T of the individual jets or the maximum E_T in each event as the scale can result in a 5% shift. Choices in parton distribution functions, some of which allow for a significant increase in the production of large E_T jets[7], can result in 20% effects. Although both experiments use a cone algorithm with a radius, $R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$, of 0.7, CDF uses the standard Snowmass parameters[8]. In this case, two partons can be separated by as much as twice the cone radius, $R_{sep} = 2R$. $D\phi$, on the other hand, sets $R_{sep} = 1.3R$ to better match jet clustering effects observed in the $D\phi$ data. Qualitative comparisons of the two measurements are in good agreement; a more quantitative analysis is underway.

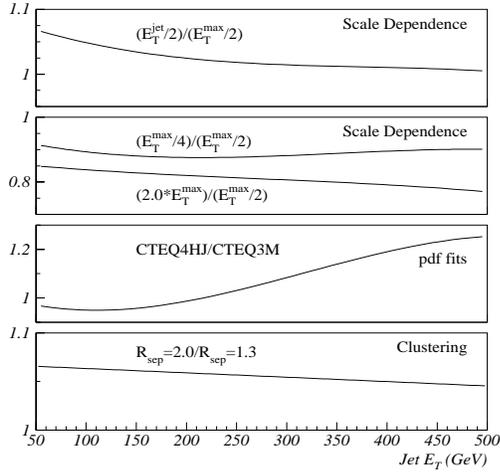


Figure 3. Effects of different theoretical parameters in the inclusive jet cross section. Comparisons are made to a standard calculations where $|\eta| \leq 0.5$, $\mu = E_T^{max}/2$, and $R_{sep} = 1.3R$ using the CTEQ3M parton distribution function.

3. Dijet Angular Distribution

Although the inclusive jet cross section is one way to search for quark substructure, the measurement suffers from sensitivity to the input parton distribution function choice. An alternative to this approach that is less sensitive to this problem is to measure the angular distribution of the two leading jets in dijet events. This measurement is analogous to the original Rutherford scattering experiments from the turn of the century. Evidence of substructure will manifest itself as distributions which are more isotropic than those expected from the interaction of point-like quarks.

To look for quark compositeness, comparisons will be made between the data and QCD predictions incorporating compositeness models. To date, NLO QCD predictions including compositeness are not available. Therefore, the effects[9] are determined at LO, comparing predictions

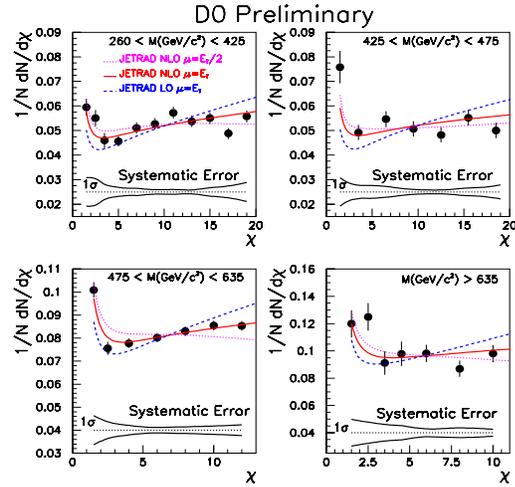


Figure 4. The dijet angular distribution from $D\bar{D}$ in four mass bins are compared to NLO QCD with $\mu = E_T^{max}$ and $\mu = E_T^{max}/2$ and to LO QCD with $\mu = E_T^{max}$. Note that it is possible to distinguish between LO and NLO QCD as well as different choices of μ . The errors are statistical only with the systematic error indicated by the band.

with and without such features. The NLO theory is then scaled by the ratio of the two LO theories. The measurement will be made in terms of the variable χ ,

$$\chi \equiv e^{(|\eta_1 - \eta_2|)} = \frac{1 + \cos \theta^*}{1 - \cos \theta^*} \quad (2)$$

where $\eta_{1,2}$ are the pseudorapidities of the two leading jets and θ^* is the center-of-mass scattering angle. This has the virtue of flattening the angular distributions making comparisons to theory easier.

Figure 4 shows the dijet angular distributions from $D\bar{D}$ for four different mass bins. Statistical errors bars are included on the individual points and the systematic error is indicated by the bands. The data is compared with NLO QCD predictions from JETRAD using two different μ scales, E_T^{max} and $E_T^{max}/2$. Since the angular distribution predictions are sensitive to the choice of

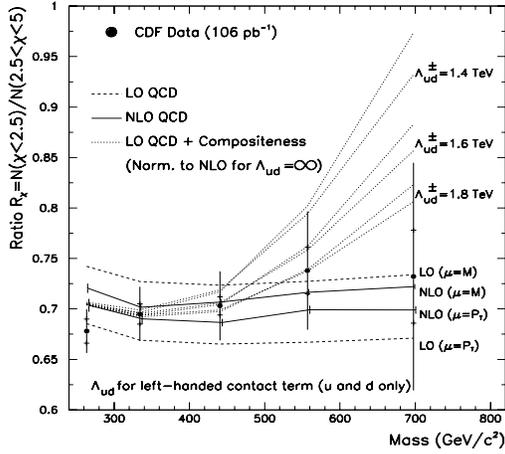


Figure 5. R_χ vs. mass from the CDF analysis compared to LO and NLO QCD as well as models with various compositeness scales. The inner error bars indicate the statistical error while the outer include the statistical and systematic added in quadrature.

scale, any compositeness limit will have to take this into account. In addition, the extended χ range available at $D\bar{D}$ also allows some discrimination between LO and NLO theoretical predictions.

Finally, to search for compositeness we define a variable R_χ ,

$$R_\chi = \frac{\# \text{ of events } \chi < \chi_0}{\# \text{ of events } \chi > \chi_0} \quad (3)$$

This compares the number of events in a region where compositeness effects should be minimal to a region where they should be enhanced. The measurements are made in mass bins with $\chi_0 = 2.5$ for CDF and 4 for $D\bar{D}$. By comparing the measured ratio to various QCD compositeness predictions, a compositeness limit can be extracted.

The results of the CDF analysis are shown in Fig. 5. Here jets were required to satisfy $0.1 \leq |\eta| \leq 2.0$ and $\chi \leq 5$. Also shown are various

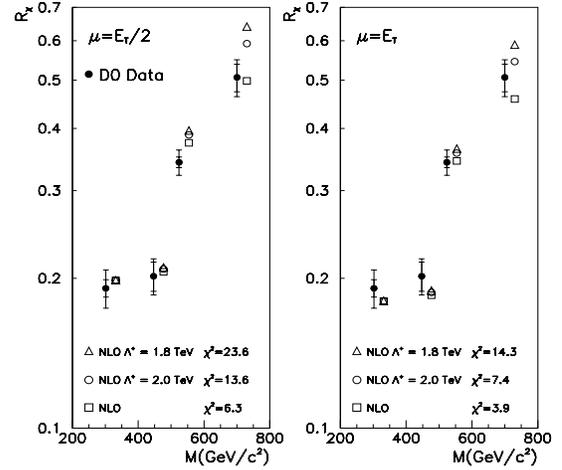


Figure 6. R_χ vs. mass from the $D\bar{D}$ analysis compared NLO QCD with and without compositeness. The inner errors represent the statistical error while the outer contain the statistical and systematic added in quadrature. The χ^2 values for 4 d.o.f. are shown for different Λ values.

theoretical predictions showing the effects of LO vs. NLO QCD, the effects of different renormalization scales, and the effect of different compositeness terms. For models where all quarks are composite, CDF excludes at the 95% confidence level regions with $\Lambda^+ \leq 1.8$ TeV and $\Lambda^- \leq 1.6$ TeV.

The $D\bar{D}$ compositeness limit results are shown in Fig. 6. Jets are accepted out to $|\eta| \leq 3.0$, extending the χ reach to 20 when kinematically accessible. The data points are compared to NLO QCD models with various compositeness scales and different μ scales. For models where all quarks are composite, $D\bar{D}$ excludes at the 95% confidence level regions with $\Lambda^+ \leq 2.3$ TeV for $\mu = E_T^{max}/2$ and $\Lambda^+ \leq 2.1$ TeV for $\mu = E_T^{max}$.

4. Conclusion

Measurements of the inclusive jet cross section and the dijet angular distribution have been made

by both the CDF and DØ experiments. While the excess that was reported in the earlier CDF inclusive jet analysis seems to persist in the new data set, the DØ data appear to agree with NLO QCD over the entire E_T range. No evidence of quark substructure was evident in the dijet angular distribution.

REFERENCES

1. F. Abe *et al.*, CDF Collab., Phys. Rev. Lett. **77**, 438 (1996).
2. R. Kehoe, Proceedings of 6th International Conference on Calorimetry in High-energy Physics, 1996. pp. 349-358.
3. G. Blazey, Proceedings of 31st Rencontres de Moriond, 1996, pp. 155-164.
4. S. Ellis, Z. Kunszt, and D. Soper, Phys. Rev. Lett. **64**, 2121 (1990).
5. J. Botts *et al.*, CTEQ Collab., Phys. Rev. D **51**, 4763 (1995).
6. W. Giele, E.W.N. Glover, and D. Kosower, Phys. Rev. Lett. **73**, 2019 (1994).
7. J. Huston *et al.*, PRL77, 444(1996).
8. John E. Huth *et al.*, Research Directions for the Decade Snowmass 1990, pp. 134-136, edited by Edmond L. Berger (World Scientific, Singapore 1990).
9. K. Lane, BUHEP-96-8, hep-ph/9605257 (1996).