A Measurement of the Ratio of Production Cross Sections for $W+1$ Jet to $W+0$ Jets and Comparisons to QCD

The DØ Collaboration *
Fermi National Accelerator Laboratory, Batavia, Illinois 60510
(June 30, 1997)

Abstract

A preliminary measurement of the ratio, $\mathcal{R}^{10}$, of the production cross sections for $W+1$ Jet and $W+0$ Jets processes at $\sqrt{s}=1800$ GeV by the DØ Collaboration is presented. A comparison of this ratio is made to next-to-leading order calculations and the implications of these comparisons are discussed.

*Submitted to the *XVIII International Symposium on Lepton Photon Interactions,* July 28 – August 1, 1997, Hamburg, Germany.

B. Abbott,[28] M. Abolins,[25] B.S. Acharya,[43] I. Adam,[12] D.L. Adams,[37] M. Adams,[17] S. Ahn,[14] H. Aihara,[22] G.A. Alves,[10] E. Amidi,[29] N. Amos,[24] E.W. Anderson,[19] R. Astur,[42] M.M. Baarmand,[42] A. Baden,[23] V. Balamurali,[32] J. Balderston,[16] B. Baldin,[14] S. Banerjee,[43] J. Bantly,[5] J.F. Bartlett,[14] K. Bazizi,[39] A. Belyaev,[26] S.B. Beri,[34] I. Bertram,[31] V.A. Bezzubov,[35] P.C. Bhat,[14] V. Bhatnagar,[34] M. Bhattacharjee,[13] N. Biswas,[32] G. Blazey,[30] S. Blessing,[15] P. Bloom,[7] A. Boehnlein,[14] N.I. Bojko,[35] F. Borcherding,[14] C. Boswell,[9] A. Brandt,[14] R. Brock,[25] A. Bross,[14] D. Buchholz,[31] V.S. Burtovoi,[35] J.M. Butler,[3] W. Carvalho,[10] D. Casey,[39] Z. Casilum,[42] H. Castilla-Valdez,[11] D. Chakraborty,[42] S.-M. Chang,[29] S.V. Chekulaev,[35] L.-P. Chen,[22] W. Chen,[42] S. Choi,[41] S. Chopra,[24] B.C. Choudhary,[9] J.H. Christenson,[14] M. Chung,[17] D. Claes,[27] A.R. Clark,[22] W.G. Cobau,[23] J. Cochran,[9] W.E. Cooper,[14] C. Cretsinger,[39] D. Cullen-Vidal,[5] M.A.C. Cummings,[16] D. Cutts,[5] O.I. Dahl,[22] K. Davis,[2] K. De,[44] K. Del Signore,[24] M. Demarteau,[14] D. Denisov,[14] S.P. Denisov,[35] H.T. Diehl,[14] M. Diesburg,[14] G. Di Loreto,[25] P. Draper,[44] Y. Ducros,[40] L.V. Dudko,[26] S.R. Dugad,[43] D. Edmunds,[25] J. Ellison,[9] V.D. Elvira,[42] R. Engelmann,[42] S. Eno,[23] G. Eppley,[37] P. Ermolov,[26] O.V. Eroshin,[35] V.N. Evdokimov,[35] T. Fahland,[8] M. Fatyga,[4] M.K. Fatyga,[39] J. Featherly,[4] S. Feher,[14] D. Fein,[2] T. Ferbel,[39] G. Finocchiaro,[42] H.E. Fisk,[14] Y. Fisyak,[7] E. Flattum,[14] G.E. Forden,[2] M. Fortner,[30] K.C. Frame,[25] S. Fuess,[14] E. Gallas,[44] A.N. Galyaev,[35] P. Gartung,[9] T.L. Geld,[25] R.J. Genik II,[25] K. Genser,[14] C.E. Gerber,[14] B. Gibbard,[4] S. Glenn,[7] B. Gobbi,[31] M. Goforth,[15] A. Goldschmidt,[22] B. Gómez,[1] G. Gómez,[23] P.I. Goncharov,[35] J.L. González Solís,[11] H. Gordon,[4] L.T. Goss,[45] K. Gounder,[9] A. Goussiou,[42] N. Graf,[4] P.D. Grannis,[42] D.R. Green,[14] J. Green,[30] H. Greenlee,[14] G. Grim,[7] S. Grinstein,[6] N. Grossman,[14] P. Grudberg,[22] S. Grünendahl,[39] G. Guglielmo,[33] J.A. Guida,[2] J.M. Guida,[5] A. Gupta,[43] S.N. Gurzhiev,[35] P. Gutierrez,[33] Y.E. Gutnikov,[35] N.J. Hadley,[23] H. Haggerty,[14] S. Hagopian,[15] V. Hagopian,[15] K.S. Hahn,[39] R.E. Hall,[8] P. Hanlet,[29] S. Hansen,[14] J.M. Hauptman,[19] D. Hedin,[30] A.P. Heinson,[9] U. Heintz,[14] R. Hernández-Montoya,[11] T. Heuring,[15] R. Hirosky,[15] J.D. Hobbs,[14] B. Hoeneisen,[1,†] J.S. Hoftun,[5] F. Hsieh,[24] Ting Hu,[42] Tong Hu,[18] T. Huehn,[9] A.S. Ito,[14] E. James,[2] J. Jaques,[32] S.A. Jerger,[25] R. Jesik,[18] J.Z.-Y. Jiang,[42] T. Joffe-Minor,[31] K. Johns,[2] M. Johnson,[14] A. Jonckheere,[14] M. Jones,[16] H. Jöstlein,[14] S.Y. Jun,[31] C.K. Jung,[42] S. Kahn,[4] G. Kalbfleisch,[33] J.S. Kang,[20] R. Kehoe,[32] M.L. Kelly,[32] C.L. Kim,[20] S.K. Kim,[41] A. Klatchko,[15] B. Klima,[14] C. Klopfenstein,[7] V.I. Klyukhin,[35] V.I. Kochetkov,[35] J.M. Kohli,[34] D. Koltick,[36] A.V. Kostritskiy,[35] J. Kotcher,[4] A.V. Kotwal,[12] J. Kourlas,[28] A.V. Kozelov,[35] E.A. Kozlovski,[35] J. Krane,[27] M.R. Krishnaswamy,[43] S. Krzywdzinski,[14] S. Kunori,[23] S. Lami,[42] H. Lan,[14,*] R. Lander,[7] F. Landry,[25] G. Landsberg,[14] B. Lauer,[19] A. Leflat,[26] H. Li,[42] J. Li,[44] Q.Z. Li-Demarteau,[14] J.G.R. Lima,[38] D. Lincoln,[24] S.L. Linn,[15] J. Linnemann,[25] R. Lipton,[14] Q. Liu,[14,*] Y.C. Liu,[31] F. Lobkowicz,[39] S.C. Loken,[22] S. Lökös,[42] L. Lueking,[14] A.L. Lyon,[23] A.K.A. Maciel,[10] R.J. Madaras,[22] R. Madden,[15] L. Magaña-Mendoza,[11] S. Mani,[7] H.S. Mao,[14,*] R. Markeloff,[30] T. Marshall,[18] M.I. Martin,[14] K.M. Mauritz,[19] B. May,[31] A.A. Mayorov,[35] R. McCarthy,[42] J. McDonald,[15] T. McKibben,[17] J. McKinley,[25] T. McMahon,[33] H.L. Melanson,[14] M. Merkin,[26] K.W. Merritt,[14] H. Miettinen,[37] A. Mincer,[28] C.S. Mishra,[14] N. Mokhov,[14] N.K. Mondal,[43] H.E. Montgomery,[14] P. Mooney,[1] H. da Motta,[10] C. Murphy,[17] F. Nang,[2] M. Narain,[14] V.S. Narasimham,[43] A. Narayanan,[2] H.A. Neal,[24] J.P. Negret,[1] P. Nemethy,[28] M. Nicola,[10] D. Norman,[45]

L. Oesch,[24] V. Oguri,[38] E. Oltman,[22] N. Oshima,[14] D. Owen,[25] P. Padley,[37] M. Pang,[19] A. Para,[14] Y.M. Park,[21] R. Partridge,[5] N. Parua,[43] M. Paterno,[39] J. Perkins,[44] M. Peters,[16] R. Piegaia,[6] H. Piekarz,[15] Y. Pischalnikov,[36] V.M. Podstavkov,[35] B.G. Pope,[25] H.B. Prosper,[15] S. Protopopescu,[4] J. Qian,[24] P.Z. Quintas,[14] R. Raja,[14] S. Rajagopalan,[4] O. Ramirez,[17] L. Rasmussen,[42] S. Reucroft,[29] M. Rijssenbeek,[42] T. Rockwell,[25] N.A. Roe,[22] P. Rubinov,[31] R. Ruchti,[32] J. Rutherfoord,[2] A. Sánchez-Hernández,[11] A. Santoro,[10] L. Sawyer,[44] R.D. Schamberger,[42] H. Schellman,[31] J. Sculli,[28] E. Shabalina,[26] C. Shaffer,[15] H.C. Shankar,[43] R.K. Shivpuri,[13] M. Shupe,[2] H. Singh,[9] J.B. Singh,[34] V. Sirotenko,[30] W. Smart,[14] R.P. Smith,[14] R. Snihur,[31] G.R. Snow,[27] J. Snow,[33] S. Snyder,[4] J. Solomon,[17] P.M. Sood,[34] M. Sosebee,[44] N. Sotnikova,[26] M. Souza,[10] A.L. Spadafora,[22] R.W. Stephens,[44] M.L. Stevenson,[22] D. Stewart,[24] F. Stichelbaut,[42] D.A. Stoianova,[35] D. Stoker,[8] M. Strauss,[33] K. Streets,[28] M. Strovink,[22] A. Sznajder,[10] P. Tamburello,[23] J. Tarazi,[8] M. Tartaglia,[14] T.L.T. Thomas,[31] J. Thompson,[23] T.G. Trippe,[22] P.M. Tuts,[12] N. Varelas,[25] E.W. Varnes,[22] D. Vititoe,[2] A.A. Volkov,[35] A.P. Vorobiev,[35] H.D. Wahl,[15] G. Wang,[15] J. Warchol,[32] G. Watts,[5] M. Wayne,[32] H. Weerts,[25] A. White,[44] J.T. White,[45] J.A. Wightman,[19] S. Willis,[30] S.J. Wimpenny,[9] J.V.D. Wirjawan,[45] J. Womersley,[14] E. Won,[39] D.R. Wood,[29] H. Xu,[5] R. Yamada,[14] P. Yamin,[4] C. Yanagisawa,[42] J. Yang,[28] T. Yasuda,[29] P. Yepes,[37] C. Yoshikawa,[16] S. Youssef,[15] J. Yu,[14] Y. Yu,[41] Z.H. Zhu,[39] D. Zieminska,[18] A. Zieminski,[18] E.G. Zverev,[26] and A. Zylberstejn[40]

(DØ Collaboration)

[1]Universidad de los Andes, Bogotá, Colombia
[2]University of Arizona, Tucson, Arizona 85721
[3]Boston University, Boston, Massachusetts 02215
[4]Brookhaven National Laboratory, Upton, New York 11973
[5]Brown University, Providence, Rhode Island 02912
[6]Universidad de Buenos Aires, Buenos Aires, Argentina
[7]University of California, Davis, California 95616
[8]University of California, Irvine, California 92697
[9]University of California, Riverside, California 92521
[10]LAFEX, Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil
[11]CINVESTAV, Mexico City, Mexico
[12]Columbia University, New York, New York 10027
[13]Delhi University, Delhi, India 110007
[14]Fermi National Accelerator Laboratory, Batavia, Illinois 60510
[15]Florida State University, Tallahassee, Florida 32306
[16]University of Hawaii, Honolulu, Hawaii 96822
[17]University of Illinois at Chicago, Chicago, Illinois 60607
[18]Indiana University, Bloomington, Indiana 47405
[19]Iowa State University, Ames, Iowa 50011
[20]Korea University, Seoul, Korea
[21]Kyungsung University, Pusan, Korea
[22]Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720
[23]University of Maryland, College Park, Maryland 20742
[24]University of Michigan, Ann Arbor, Michigan 48109
[25]Michigan State University, East Lansing, Michigan 48824
[26]Moscow State University, Moscow, Russia
[27]University of Nebraska, Lincoln, Nebraska 68588
[28]New York University, New York, New York 10003
[29]Northeastern University, Boston, Massachusetts 02115
[30]Northern Illinois University, DeKalb, Illinois 60115
[31]Northwestern University, Evanston, Illinois 60208
[32]University of Notre Dame, Notre Dame, Indiana 46556
[33]University of Oklahoma, Norman, Oklahoma 73019
[34]University of Panjab, Chandigarh 16-00-14, India
[35]Institute for High Energy Physics, 142-284 Protvino, Russia
[36]Purdue University, West Lafayette, Indiana 47907
[37]Rice University, Houston, Texas 77005
[38]Universidade do Estado do Rio de Janeiro, Brazil
[39]University of Rochester, Rochester, New York 14627
[40]CEA, DAPNIA/Service de Physique des Particules, CE-SACLAY, Gif-sur-Yvette, France
[41]Seoul National University, Seoul, Korea
[42]State University of New York, Stony Brook, New York 11794
[43]Tata Institute of Fundamental Research, Colaba, Mumbai 400005, India
[44]University of Texas, Arlington, Texas 76019
[45]Texas A&M University, College Station, Texas 77843

I. INTRODUCTION

The UA1 and UA2 experiments [1,2] used events with a W boson and jets to measure the ratio, $\mathcal{R}^{10}$, of the production cross sections for $W+1$ Jet events to $W+0$ Jets events and then used theoretical calculations to extract a value for the strong coupling constant at the mass of the W, $\alpha_S(M_W^2)$. The DØ collaboration has also published [3] a measurement of the ratio of production cross sections using the data from the 1992-1993 run of the Fermilab Tevatron Collider. The preliminary result presented here is from the 1994–1995 run and thus uses a data set more than six times as large as that used for the previous DØ result.

The published DØ [3] result shows that the theoretical predictions for $\mathcal{R}^{10}$ calculated using the next-to-leading order, NLO, DYRAD Monte Carlo [4] at a center of mass energy, $\sqrt{s}$, of 1800 GeV are relatively insensitive to α_S. The theoretical predictions, over a wide range of α_S, yield a nearly constant value of $\mathcal{R}^{10}$. This could be due to changes in the gluon distribution canceling changes in the matrix element as α_S is varied in the calculations.

The new DØ result presented here has the advantage of higher statistics, allowing for tighter cuts which reduce the amount of background in the sample. The higher statistics sample also allows us to eliminate data from fiducial regions of the detector where backgrounds are highest. The larger data sample also allows more studies of possible sources of systematic uncertainties to be conducted.

II. DATA SELECTION AND COMPARISONS TO QCD

The DØ detector and the details of the DØ triggering system have been described elsewhere [5]. The important systems in the detector for this analysis are the uranium–liquid argon calorimeter for energy measurements and the central drift chambers for tracking. The trigger for the signal events used progressively higher transverse energy, E_T, cuts on the electron candidate, going from the hardware to the software trigger. The software trigger also included cuts on the shape of the electromagnetic shower in the calorimeter as well as a 15 GeV cut on the missing E_T, $\not\!\!E_T$, in the event. Monitor triggers used in this analysis had looser cuts on the electron candidate and no $\not\!\!E_T$ cut.

The data sample used for this study is defined offline by selecting W boson events in which the W has decayed to an electron and an electron neutrino, $W \rightarrow e\nu$, without a cut on the jet multiplicity. The offline electron selection increases the E_T cut on the electron to 25 GeV and tightens the online shower shape cut. Electrons are required to be isolated from other calorimeter energy depositions and have a good match between the calorimeter shower position and the central track position. Z events are removed from the sample by requiring that only one good electron candidate is present in the event. The $\not\!\!E_T$ in the event is also required to be greater than 25 GeV. Jets in these events are identified using a fixed cone algorithm with a radius of 0.7 in η–ϕ space. Cuts are applied to remove events with fake jets created by detector effects or beam conditions. The analysis has been performed using several different minimum E_T, E_T^{min}, requirements used to define the jets.

III. BACKGROUNDS

The dominant background to $W+$ Jets events is from multijet events produced by strong interaction processes in which one jet fluctuates highly electromagnetically and another jet is sufficiently mismeasured that substantial $\not{E}_T$ is seen in the event. The estimate of the amount of background from this source is made using data and is explained below.

Two samples are extracted from data taken with the monitor triggers (no $\not{E}_T$ cut). One set contains signal and background events which are selected by requiring a good electron candidate, one which passes the electron cuts listed previously, in the event. The second sample contains background only and is selected by making cuts which preferentially select non-electrons. The assumption is that events with an electron candidate but only a small amount of $\not{E}_T$ are actually multijet events (background) in which a jet faked an electron in the calorimeter, since a major source of single high p_T electrons is W boson production.

The $\not{E}_T$ distribution for the sample containing non-electron events is then area normalized to the $\not{E}_T$ distribution for the electron sample in the low $\not{E}_T$ region, $\not{E}_T < 15$ GeV, and the normalization factor, N, is extracted. (Figure 1)

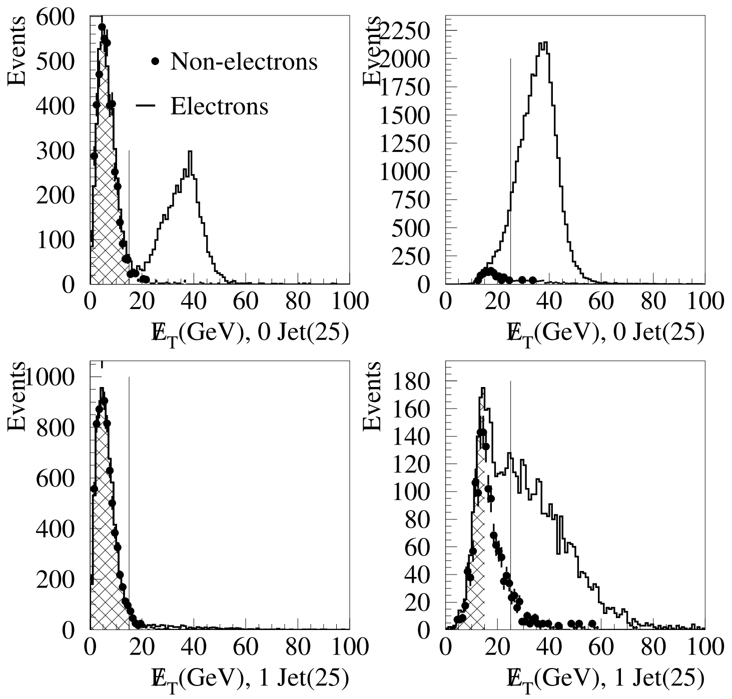


FIG. 1. Multijet background subtraction method - The left hand plots show the extraction of the normalization factor, N, for zero jets (top) and one jet (bottom) for an E_T^{min} of 25 GeV from the monitor triggers. The vertical line indicates the upper limit of the normalization region. The right hand plots show the extraction of the background fraction after the normalization from the monitor triggers has been applied to the points. The vertical line now marks the $\not{E}_T$ cut of 25 GeV used to define the signal.

Two similar samples are extracted from the W signal trigger (which employs a $\not{E}_T$ cut). The normalization factor, N, from the monitor triggers, is then applied to the $\not{E}_T$ distribution for the non-electron sample from the signal trigger. The background fraction is then the number of events from the non-electron sample in the signal region ($\not{E}_T$>25 GeV) multiplied by N and divided by the number of events from the electron sample in the signal region. This results in a background fraction of 1.6% for $W + 0$ Jets and 6.8% for $W + 1$ Jet for an E_T^{min} cut of 25 GeV.

Other backgrounds, which have been subtracted, include Drell–Yan, $\gamma^* \rightarrow e^+e^-$, events and Z boson production events in which the Z decays to an electron-positron pair, $Z \rightarrow e^+e^-$, when an electron is lost, and $Z \rightarrow \tau^+\tau^-$ events in which one τ decays to an electron and the other decays to hadrons. The fraction of contamination from these types of events was estimated using the ISAJET Monte Carlo [6] and is about 2% in the case of $W + 1$ Jet events and less than one percent for $W + 0$ Jets events.

IV. DATA CORRECTIONS

The energy of jets and electrons in the events have been corrected for the calibration of the calorimeter. The cross section ratio, $\mathcal{R}^{10}$, has also been corrected for the difference in the electron efficiencies and $\not{E}_T$ trigger efficiencies for different jet multiplicities. Both the hadronic calibration and the electron efficiency corrections introduce systematic errors on the order of $\pm 5\%$ for an E_T^{min} of 25 Gev. These are the dominant systematic errors for the analysis. The correction factors for $\mathcal{R}^{10}$ are plotted as a function of E_T^{min} in Figure 2.

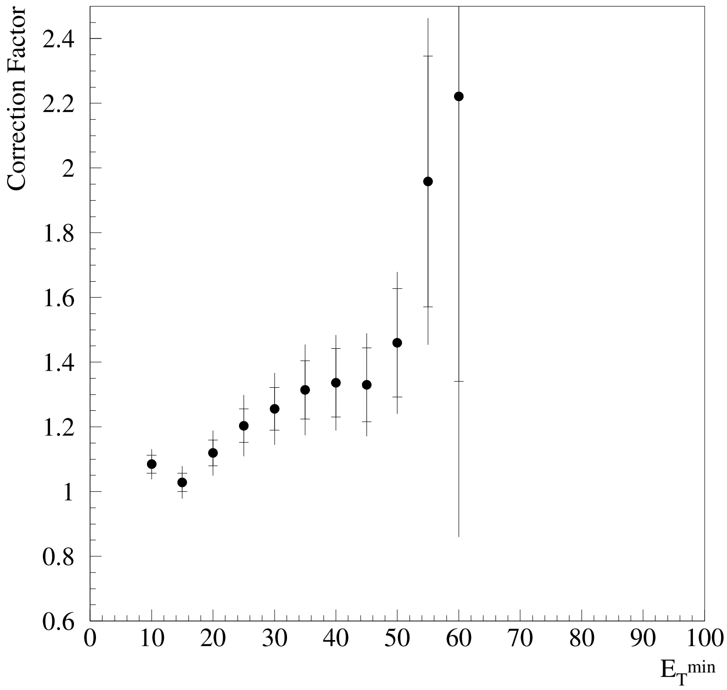


FIG. 2. Correction factors for $\mathcal{R}^{10}$ versus E_T^{min}due to differences in the electron efficiencies when there are no jets and when there is one jet passing the E_T^{min} cut.

V. EXPERIMENTAL RESULTS AND COMPARISONS TO QCD

For 83 pb^{-1} of data from the 1994-1995 run of the DØ detector at the Tevatron Collider we obtain 36984 $W \to e\nu$ candidates with electrons restricted to the central part of the DØ calorimeter ($|\eta| < 1.0$). For an E_T^{min} cut of 25 GeV there are 33617 $W + 0$ Jets candidates and 2829 $W + 1$ Jet candidates. After subtracting the background contributions from multijet events and from other electroweak processes these numbers become 32879 for $W + 0$ Jets and 2574 for $W + 1$ Jet.

The difference between the result presented here and the previous DØ result is the restriction that the electron be in the central calorimeter, $|\eta| < 1.0$ and a better understanding of the efficiency corrections needed to make the measurement.

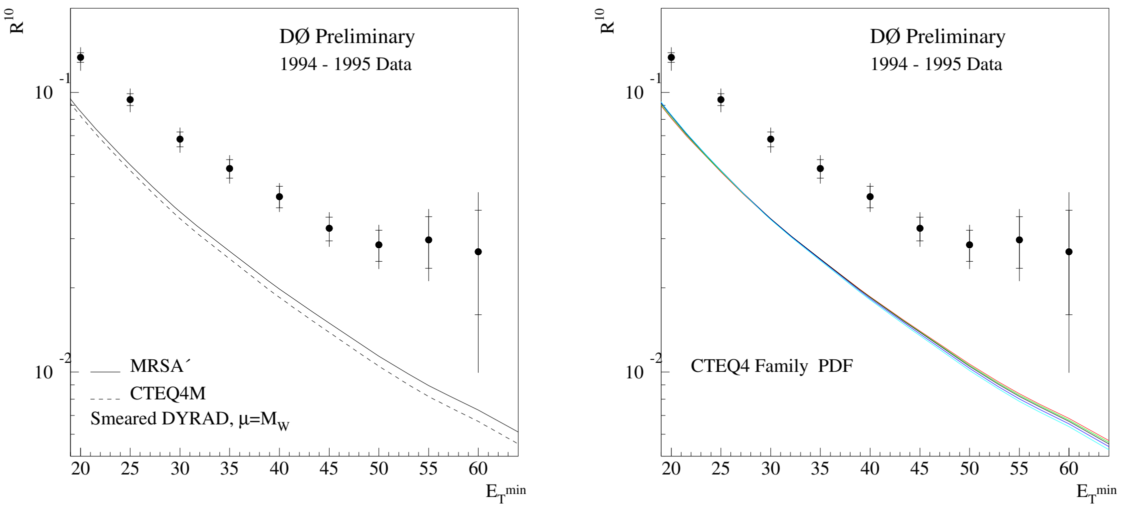
One way to look at this result is to vary the minimum E_T used to define a jet and compare the experimental trend to that of the theoretical predictions (see Figure 3). The theoretical predictions describe the shape of the E_T^{min} dependence for the different parton distribution functions, however all are consistently below the data. Figure 3(a) compares the result to predictions using the CTEQ4M [7] and MRSA$'$ [8] parton distribution functions. There is a slight normalization difference between the predictions with the different pdf's, but they are both well below the data. Figure 3(b) uses the CTEQ4 series of pdf's, in which Λ_{QCD} was varied in the pdf fits. None of the curves approach the experimental result and the theory appears to have little dependence on α_S. It is evident that while the general shapes of the experimental result and the theoretical predictions are similar, the normalization of the calculations is well below the experimental result and that varying Λ_{QCD} within the limits allowed by the global pdf fits does not bring the predictions into agreement with the experimental result.

Taking a closer look at the result for one value of E_T^{min}, 25 GeV, highlights the lack of α_S dependence in the predictions. Figure 4 plots the ratio as a function of α_S. The lines and shaded band represent the measurement. The solid line is the experimental result. The dotted lines indicate the statistical errors only while the shaded region indicates the statistical and systematic errors added in quadrature. The points are the predictions using both the CTEQ4 family and the MRSA family of pdf's.

Because UA1/UA2 ran at a lower $\sqrt{s}$, the average momentum fraction of the initial state partons was larger than the initial state partons in W production at DØ. The average momentum fraction for W production at UA1/UA2 was approximately 0.14 while the average momentum fraction for W production at DØ is about 0.04. This difference results in more of the DØ $W + 1$ Jet events being produced from a quark-gluon initial state at 1800 GeV than at 630 GeV [9]. Theoretical predictions for $\mathcal{R}^{10}$ at DØ are therefore more sensitive to the gluon distribution in the proton which is not well constrained by current experiments.

VI. CONCLUSIONS

In conclusion DØ has made a preliminary measurement of the ratio, $\mathcal{R}^{10}$, of production cross sections for $W + 1$ Jet to $W + 0$ Jets processes with the data from the 1994-1995 run of the Fermilab Tevatron Collider. Comparisons to NLO QCD calculations show that the theoretical predictions are consistently lower than the data for different values of α_S



(a) (b)

FIG. 3. $\mathcal{R}^{10}$ versus E_T^{min}. Figure (a) compares to DYRAD predictions using CTEQ4M and MRSA$'$ pdf's. Figure (b) compares the result to predictions using the CTEQ4 family with different α_S values.

given the currently available parton distribution functions. Also, the theoretical calculations underestimate the rate of jet production in association with W bosons as a function of the minimum jet E_T. It appears that incorporating the DØ and the UA1/UA2 data in global QCD fits could lead to significant modifications of the conventional understanding of the gluon distribution in the proton.

ACKNOWLEDGEMENTS

We thank the staffs at Fermilab and collaborating institutions for their contributions to this work, and acknowledge support from the Department of Energy and National Science Foundation (U.S.A.), Commissariat à L'Energie Atomique (France), State Committee for Science and Technology and Ministry for Atomic Energy (Russia), CNPq (Brazil), Departments of Atomic Energy and Science and Education (India), Colciencias (Colombia), CONACyT (Mexico), Ministry of Education and KOSEF (Korea), and CONICET and UBACyT (Argentina).

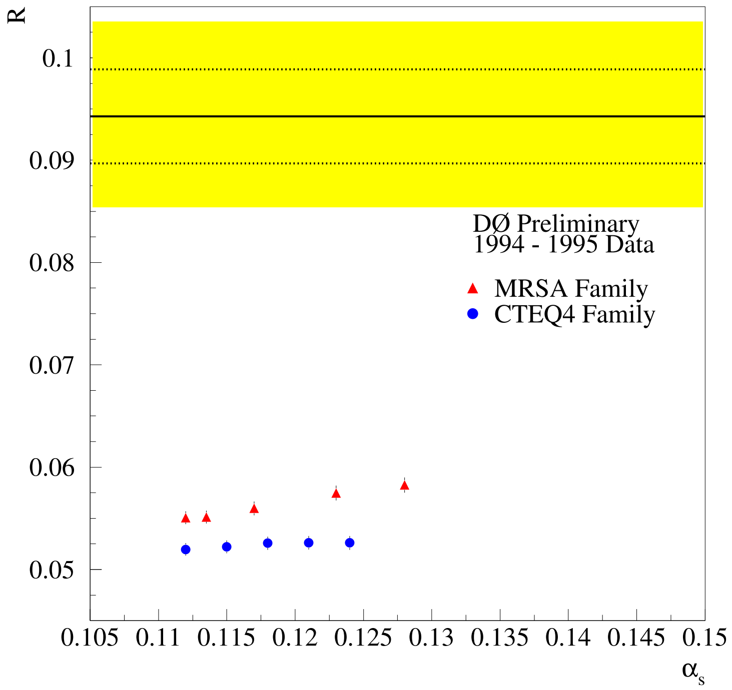


FIG. 4. $\mathcal{R}^{10}$ versus α_S. The E_T^{min} cut in this case is 25 GeV. The dotted lines are the statistical errors on the measurement, while the shaded band is systematic and statistical added in quadrature.

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* Visitor from IHEP, Beijing, China.

† Visitor from Universidad San Francisco de Quito, Quito, Ecuador.

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