Fermi National Accelerator Laboratory

FERMILAB-Conf-97/371-E
D0

The Azimuthal Decorrelation of Jets Widely Separated at Rapidity

B. Abbott et al.
The D0 Collaboration

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

November 1997

Submitted to the *XVIII International Symposium on Lepton-Photon Interactions*, Hamburg, Germany, July 18-August 1, 1997 and the *International Europhysics Conference on High Energy Physics*, Jerusalem, Israel, August 19-26, 1997

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy

Disclaimer

Distribution

The Azimuthal Decorrelation of Jets Widely Separated in Rapidity

The DØ Collaboration *
Fermi National Accelerator Laboratory, Batavia, Illinois 60510
(June 27, 1997)

Abstract

We present a study of the azimuthal decorrelation between jets with pseudorapidity separation up to six units. The data were accumulated using the DØ detector during the 1994–1995 collider run of the Fermilab Tevatron at $\sqrt{s} =$ 1.8 TeV. The data are compared to two parton shower Monte Carlos (HERWIG and PYTHIA) and an analytical prediction using the leading logarithmic BFKL resummation. The final state jets as predicted by the parton showering Monte Carlos describe the data over the entire pseudorapidity range studied. The prediction based on the leading logarithmic BFKL resummation shows more decorrelation than the data as the rapidity interval increases.

*Submitted to the *International Europhysics Conference on High Energy Physics,* August 19 – 26, 1997, Jerusalem, Israel.

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 exponential growth of the dijet inclusive cross section with increasing rapidity interval ($\Delta\eta$) between the tagging jets at the extremes of rapidity was originally proposed as a signature of the QCD perturbative pomeron [1]. This is the prediction of the solution of the Balitsky, Fadin, Kuraev, and Lipatov (BFKL) equation [2] obtained by resumming the leading logarithmic contributions to the radiative corrections to parton scattering in the high-energy limit.

At a fixed collider energy, the azimuthal angle decorrelation of jets widely separated in rapidity was suggested as an alternative approach to search for the effect [3,4]. The broadening of the azimuthal angle difference distribution with increasing dijet rapidity interval is a characteristic feature of BFKL dynamics. The first measurement of the azimuthal decorrelation between jets with pseudorapidity separation up to five units was reported by the DØ collaboration [5]. We have extended the previous measurement with pseudorapidity separation up to six units by employing a lower, symmetric E_T threshold cut (20 GeV) with new data collected by the DØ detector [6] during the 1994-1995 collider run. We report preliminary results for the $\Delta\phi$ distribution and for $\langle\cos(\pi-\Delta\phi)\rangle$ as a function of $\Delta\eta$, where $\Delta\phi = \phi_1 - \phi_2$ is the difference in azimuth of the two tagging jets and $\Delta\eta = \eta_1 - \eta_2$ is the difference in pseudorapidity. Quantitatively, $\langle\cos(\pi-\Delta\phi)\rangle = 1$ corresponds to complete correlation and $\langle\cos(\pi-\Delta\phi)\rangle = 0$ to complete decorrelation. Results from data are compared to an analytical prediction based on BFKL resummation [7], and to two parton showering Monte Carlos, HERWIG [8] and PYTHIA [9] in which higher order effects are approximated by a parton shower superimposed on a leading order 2 to 2 parton process.

II. EVENT SELECTION AND ANALYSIS CUTS

The DØ detector is particularly suited for this measurement owing to its uniform calorimetric coverage to $|\eta| \lesssim 4.0$. The uranium–liquid argon sampling calorimeter facilitates jet identification with its fine transverse segmentation (0.1×0.1 in $\Delta\eta \times \Delta\phi$) and good jet energy and position resolution.

The trigger consists of three levels. The first (LØ) requires hits in beam-beam scintillation counters signalling the presence of an inelastic collision. The second level (L1) looks for localized energy deposits in 0.2×0.2 ($\Delta\eta \times \Delta\phi$) towers in the calorimeter. The third level (L2) implements a cone based jet-finding algorithm ($R = 0.7$) using calorimeter cell information. We triggered on jets out to $|\eta| = 4.0$ using two triggers specialized for the decorrelation analysis. One (inclusive) required a single interaction at LØ, one trigger tower above 2 GeV at L1, and one jet above 12 GeV at L2. The other (forward) trigger had the additional pseudorapidity constraints $|\eta| > 2.0$ at L1 and $|\eta| > 1.6$ at L2.

For the study, the fixed cone jet algorithm with $R = 0.7$ is used with the Snowmass angle definition for η and ϕ position of the jet [10]. A series of cuts are imposed to remove events contaminated by cosmic rays, instrumental noise, and multiple interactions as well as events with a vertex far from the nominal center of the detector. Jet energy scale corrections were applied offline and spurious jets were removed before a minimum E_T cut of 20 GeV was applied. Selecting events having at least two jets, we tagged the two jets at the extremes of

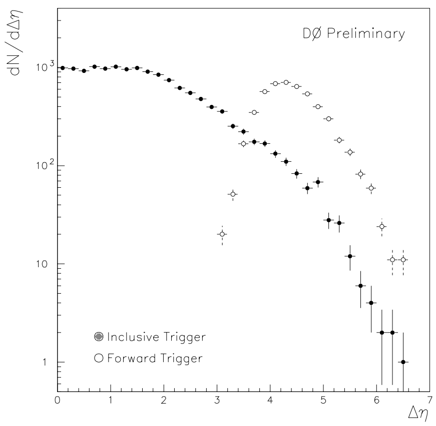

FIG. 1. The $\Delta\eta$ distribution - closed circle marks are from the inclusive trigger and open are from the forward trigger.

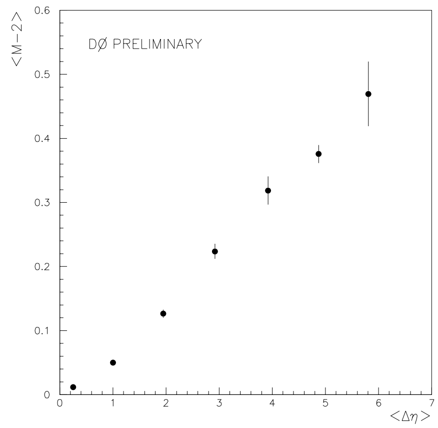

FIG. 2. The average jet multiplicity with $E_T > 20$ GeV as a fuction of $\Delta\eta$. Errors are statistical only.

rapidity and required their boost ($|\bar{\eta}| = |\eta_1 + \eta_2|/2$) to be less than 0.5 to avoid any trigger bias. For the forward trigger, one of the two tagging jets was required to be at $|\eta| > 2.25$ to ensure full trigger efficiency, and events from this trigger were used only for $\Delta\eta \geq 4.5$. Events passing all analysis cuts have been divided into unit $\Delta\eta$ bins, except for the lowest bin ($0.0 < \Delta\eta < 0.5$) which is half as wide. The n^{th} unit $\Delta\eta$ bin ranges from $n - 0.5$ to $n + 0.5$ up to $n = 6$. All distributions are plotted at the average value of $\Delta\eta$ for each bin to properly take into account the steeply falling $\Delta\eta$ distribution as shown in Fig. 1.

III. RESULTS

In leading order QCD, the two outward going jets must be completely correlated since they are back-to-back in azimuth and balanced in transverse momentum. In higher order processes, the correlation of the two jets is eventually weakened due to additional radiation. To look for evidence of additional radiation as the rapidity interval increases, we study the average jet multiplicity and the azimuthal decorrelation.

Average Jet Mutiplicity

The degree of decorrelation of the two tagging jets is strongly related to the amount of additional radiation which may manifest itself as additional jet activity (M $\equiv$ jet multiplicity). We plot $\langle M - 2 \rangle$ for jets with $E_T > 20$ GeV as a function of $\Delta\eta$ in Fig. 2. As $\Delta\eta$ increases, the average multiplicity increases, which indicates more hadron activity at large rapidity intervals. From the plot, the multiplicity increases linearly and has a relationship $\langle M - 2 \rangle \sim 0.08 \times \Delta\eta$. However, this does not directly quantify the decorrelation since jets below 20 GeV or any other soft radiation are not considered. Furthermore, the increase of multiplicity may also be due to the larger kinematical space allowed for radiation between the two tagging jets as their rapidity interval increases.

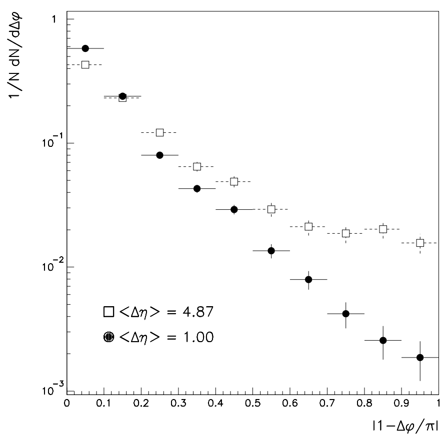

FIG. 3. The azimuthal angle difference ($\Delta\phi = \phi_1 - \phi_2$) distribution of the two jets at the extremes of pseudorapidity plotted as $|1 - \Delta\phi/\pi|$ for $\langle\Delta\eta\rangle = 1.00$ ($0.5 < \Delta\eta < 1.5$) and 4.87 ($4.5 < \Delta\eta < 5.5$). The errors are statistical only.

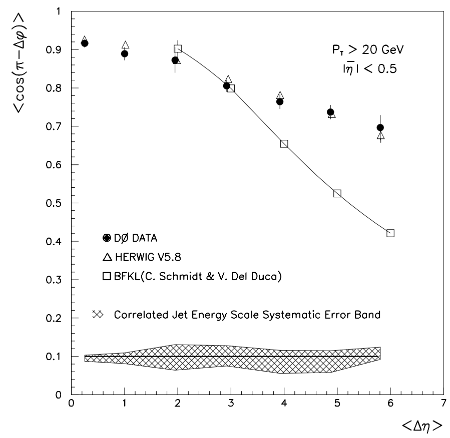

FIG. 4. The correlation variable used in this analysis, the average value of $\cos(\pi - \Delta\phi)$ vs. $\Delta\eta$, for the data, (particle level) HERWIG and PYTHIA, and the BFKL calculations of Del Duca and Schmidt.

Azimuthal Decorrelation

The widening of the $\Delta\phi$ distribution as $\Delta\eta$ increases is a qualitative feature of the azimuthal decorrelation. The azimuthal angular separation, $|1 - \Delta\phi/\pi|$, is plotted for the average of $\Delta\eta$ within unit bins centered at $\Delta\eta = 1$ and 5 in Fig. 3. Since each distribution is normalized to unity, the decorrelation between the two most widely separated jets can be seen in either the relative decline near $|1 - \Delta\phi/\pi| = 0$ or the relative increase near $|1 - \Delta\phi/\pi| = 1$ as $\Delta\eta$ increases.

To quantify the decorrelation effect, we define a correlation variable $\langle\cos(\pi - \Delta\phi)\rangle$, which varies from unity for the completely correlated case to zero for the completely uncorrelated one. As shown in Fig. 4, $\langle\cos(\pi - \Delta\phi)\rangle$ decreases as $\Delta\eta$ increases, that is, the decorrelation increases with rapidity interval. For the data, corrections have been applied to determine the final values of $\langle\cos(\pi - \Delta\phi)\rangle$. These include corrections for the trigger inefficiency, the reconstruction inefficiency, the jet energy resolution, and multiple interactions. The error bars on data points represent the statistical and uncorrelated systematic errors added in quadrature. Uncorrelated systematic errors include the effects of the jet position resolution and instrumental backgrounds as well as uncertainties of applied corrections. In addition, the band at the bottom of the plot represents the correlated uncertainties due to the energy scale corrections. Also shown in Fig. 4 are the predictions from the BFKL resummation in the leading logarithmic approximation (LLA) [7], and from HERWIG and PYTHIA with statistical errors only. The prediction of the BFKL resummation, which is valid for large $\alpha_S\Delta\eta$, is shown for $\Delta\eta \geq 2$.

CONCLUSIONS AND REMARKS

We have measured the azimuthal decorrelation of two jets as a function of their rapidity difference using the DØ detector at the Tevatron. The decorrelation increases with increasing $\Delta\eta$. These effects are described by HERWIG and PYTHIA within the uncertainties of the measurement. A theoretical prediction based on BFKL resummation in LLA predicts too much decorrelation as the rapidity interval increases. The motivation of this analysis was to probe possible signatures of BFKL dynamics at the Tevatron. It seems that no clear signature of the BFKL pomeron has been observed within the kinematical region that we have studied. Nonetheless, there are still several open questions to be answered for the future understanding of BFKL dynamics and higher order QCD processes at the Tevatron. These include the validity of and the errors in the leading logarithm BFKL approximation within $2 \leq \Delta\eta \leq 6$, the size of next-to-leading corrections to the BFKL matrix elements, and sensitivity of the measurement of the azimuthal decorrelation to probe BFKL dynamics at the Tevatron. Efforts to answer these questions are currently underway, such as the next-to-leading logarithmic BFKL calculation [11] and a study of the center of mass dependence of the inclusive dijet cross section at large rapidity interval at the Tevatron originally suggested by Mueller and Navelet [1,12]. Recently a BFKL event generator superimposing kinematical constraints for radiation between two tagging jets with the leading logarithmic BFKL calculation has also become available [13].

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).

REFERENCES

* Visitor from IHEP, Beijing, China.

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

[1] A.H. Mueller and H. Navelet, Nucl. Phys. **B282**, 727 (1987).

[2] E.A. Kuraev, L.N. Lipatov, and V.S. Fadin, Sov. Phys. JETP **45**, 199 (1977); Ya.Ya. Balitsky and L.N. Lipatov, Sov. J. Nucl. Phys. **28**, 822 (1978).

[3] W.J. Stirling, Nucl. Phys. **B423**, 56 (1994).

[4] V. Del Duca and C.R. Schmidt, Phys. Rev. D **51**, 2150 (1995).

[5] DØ Collaboration, S. Abachi *et al.*, Phys. Rev. Lett. **77**, 595 (1996).

[6] DØ Collaboration, S. Abachi *et al.*, Nucl. Instrum. Methods A **338**, 185 (1994).

[7] V. Del Duca and C.R. Schmidt, private communication.

[8] G. Marchesini and B.R. Webber, Nucl. Phys. **B310**, 461 (1988); G. Marchesini *et al.*, Comp. Phys. Comm. **67**, 465 (1992).

[9] H.U. Bengtsson and T. Sjöstrand, Comp. Phys. Comm. **46**, 43 (1987).

[10] J.E. Huth *et al.*, in Proc. of *Research Directions for the Decade, Snowmass 1990*, ed. E.L Berger (World Scientific, Singapore, 1992), p. 134.

[11] V.S. Fadin and L.N. Lipatov, Nucl. Phys. **B477**, 767 (1996).

[12] DØ Collaboration, S.Y. Jun, *BFKL Studies at DØ*, talk presented at DIS'97, Chicago, April, 1997.

[13] C.R. Schmidt, MSUHEP-61217, hep-ph 9612454 (1996).