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Search for New Particles Decaying to Two-Jets with the D0 Detector

B. Abbott et al.
The D0 Collaboration

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

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Fermi National Accelerator Laboratory, Batavia, Illinois 60510
(July 15, 1997)

Abstract

Results from a search for new particles decaying to dijets in $\sqrt{s} = 1.8$ TeV $\bar{p}p$ collisions using the DØ 1992–93 and 1994–95 data samples ($104\, pb^{-}1$) are presented. We exclude at the 95% confidence level the production of excited quarks with masses below 725 GeV/c^2, an additional standard model W boson with masses between 340 and 680 GeV/c^2 and an additional standard model Z boson with masses between 365 and 615 GeV/c^2.

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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]

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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

The production of hadronic jets is the dominant contribution to high transverse momentum (p_T) processes in proton–anti-proton ($\overline{p}p$) collisions. There are many extensions of the Standard Model that predict the existence of new massive objects (e.g. excited quarks, W', Z',etc. [1,2]) which couple to quarks and gluons and form resonant structures in the dijet mass spectrum. This paper will report on the search for these resonances in the dijet mass spectrum using the DØ detector. The observation of W and Z bosons decaying to two–jets by the UA2 experiment [3] displays the feasibility of dijet mass spectroscopy at $\overline{p}p$ colliders. Subsequently the UA2 [4] and CDF [5] experiments have searched for resonances in the dijet mass spectrum and produced limits on several different theoretical models.

The data sample used in this analysis was collected during 1992–93 and 1994-95 and corresponds to an integrated luminosity of 104 pb^{-1}.

Jet detection in the DØ detector [6] primarily utilizes the uranium–liquid argon calorimeters which cover pseudorapidity $|\eta| \leq 4$ ($\eta = -\ln(\tan(\theta/2))$) where θ is the polar angle of the object relative to the proton beam). Jets were reconstructed using an iterative jet cone algorithm with a cone radius of $\mathcal{R}$=0.7 in η–ϕ space [7]. Background jets from isolated noisy calorimeter cells and accelerator losses were eliminated with quality cuts [8]. The transverse energy of each jet is then corrected [9] for offsets due to underlying events and noise; the fraction of particle energy showering, outside the jet cone; and calorimeter hadronic energy response.

For each event that passes the quality cuts the inclusive dijet mass can be calculated, assuming that the jets are massless, using the relationship; $M_{jj}^2 = 2 \cdot E_T^1 \cdot E_T^2 \cdot (\cosh(\Delta\eta) - \cos(\Delta\phi))$, where E_T^1 and E_T^2 are the transverse energies of the two jets with the highest E_T. Each event is weighted by the efficiency of the quality cuts applied to the data. Cuts were then made on the pseudorapidity of the two leading E_T jets such that $|\eta_{1,2}| < 1.0$ and $\Delta\eta = |\eta_1 - \eta_2| < 1.6$.

During the 1994–95 data taking period the data were collected using four triggers with E_T thresholds of 30, 50, 85 and 115 GeV with integrated luminosities of 0.36, 4.6, 52 and 91 pb^{-1}. These luminosities have an additional correction factor determined by matching the inclusive jet cross section in the region where two neighboring triggers overlap. These corrections are 0.0±0.0, 2.8±1.3%, 5.7±1.5%, and 6.3±1.6% for the four 1994–95 data sets respectively. Only one trigger was used from the 1992–93 data taking period with an E_T threshold of 115 GeV and an integrated luminosity of 13.7 pb^{-1}. After the jet energy corrections these trigger samples were used to measure the dijet mass spectrum above mass thresholds of 200, 270, 370 and 500 GeV where each of the triggers is 100% efficient. The resulting dijet mass spectrum is plotted in Fig 1.

Three different models were considered for a possible signal in the dijet mass spectrum. These models were chosen to correspond to three different types of resonance decays. The first model considered was a mass degenerate excited quark [1] which decays to a quark and a gluon ($q^* \rightarrow qg$); we have assumed that the coupling parameters of the excited quark theory are set equal to one ($f = f' = f_s = 1.0$) and that the compositeness scale is set equal

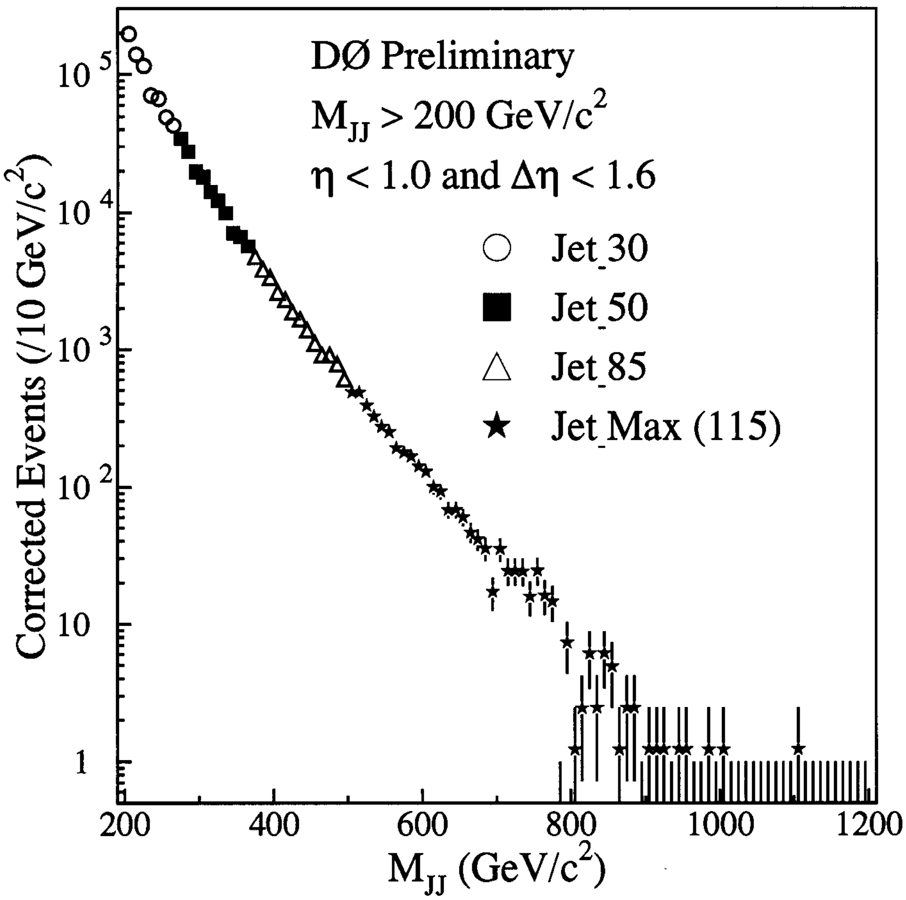

FIG. 1. The inclusive dijet mass spectrum. The events from each trigger have been corrected by the trigger's luminosity and event efficiencies.

to the mass of the excited quark ($\Lambda^* = M_{q^*}$). The second and third models are additional W and Z bosons [2] with the same properties as their standard model counterparts where all possible quark decays are allowed ($W' \to q\overline{q}'$, $Z' \to q\overline{q}$). The decay line shapes of the W' and Z' will be significantly affected by their decays to top ($W' \to t\overline{b}$,$Z' \to t\overline{t}$). The leading order W' and Z' cross sections were corrected by second order K factors [10] to account for higher order effects.

The data were fitted using Bayesian techniques (see Ref. [11]). The predicted number of events per bin (μ_i) in the mass spectrum is given by $\mu_i = \left(A\sigma_{QCD_i} + \mathcal{L}N_{X_i}\sigma_X\right) \times \epsilon$ where σ_{QCD_i} is the predicted QCD cross section for the mass bin, A is a normalization factor for the QCD cross section, $\mathcal{L}$ is the integrated luminosity, N_{X_i} is the fraction of the signal in the bin ($\sum N_{X_i} = 1$), σ_X is the signal cross section and ϵ is the efficiency of applied jet quality cuts. The probability that N_i events are observed in a given mass bin is then given by (assuming that N_i follows Poisson statistics): $P\left(N_i \mid \sigma_{QCD_i}, \sigma_X, N_{X_i}, A, \mathcal{L}, \epsilon_i, I\right) = e^{-\mu_i}\mu_i{}^{N_i}/N_i!$ where I is all other prior information. The probability of observing the set of N_i that makes up the mass spectrum is then given by the product of these probabilities. To calculate the probability distribution for σ_X Bayes' theorem is applied with the following assumptions about the prior probability distributions: σ_X and A have flat priors; σ_{QCD_i}, ϵ_i and $\mathcal{L}$ all have Gaussian priors; N_{X_i} has a Poisson prior.

The inclusive dijet mass spectrum, σ_{QCD_i}, was simulated using the Next–to–leading order (NLO) program JETRAD [12] using the CTEQ4M [13] parton distribution function (pdf), a renormalization scale (μ) of $0.5 \times E_T$ where the E_T is the highest E_T parton and a parton clustering algorithm where partons within $1.3\mathcal{R}$ of one another were clustered if they were also within $\mathcal{R} = 0.7$ of their E_T weighted η,ϕ centroid. The E_T of the jets are then smeared using the measured jet resolutions. The resulting distribution is plotted in Fig 2.

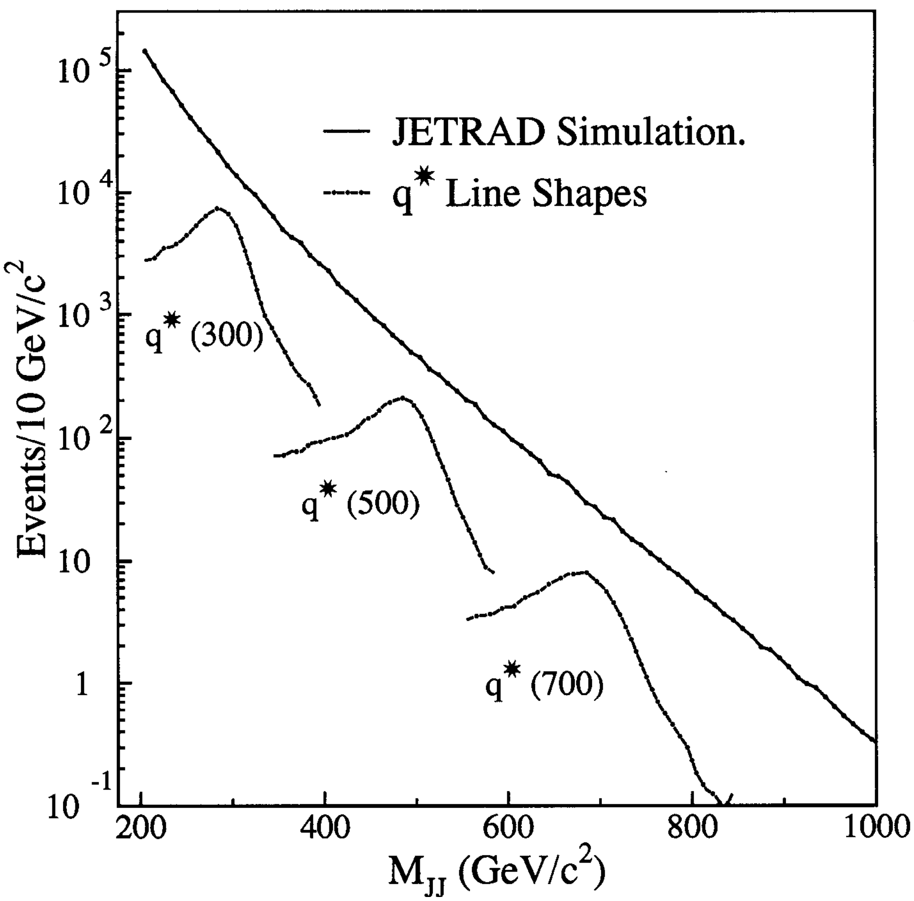

FIG. 2. The JETRAD simulation of the QCD inclusive dijet mass spectrum with the simulated excited quark line shapes for $M_{q^*} = 300$, 500 and 700 GeV/c^2.

For each of the models considered a Monte Carlo mass spectrum was generated at 25 GeV/c^2 intervals from a mass of 200 GeV/c^2 to 1 TeV/c^2 using the PYTHIA [14] event generator. Jets were reconstructed at the particle level using the same iterative jet cone algorithm that was applied to the data. The resulting jets were then smeared with the measured jet resolutions. Each of the mass spectra contains fifty thousand events. Examples of the particles generated at 500 GeV/c^2 are shown in Fig 3.

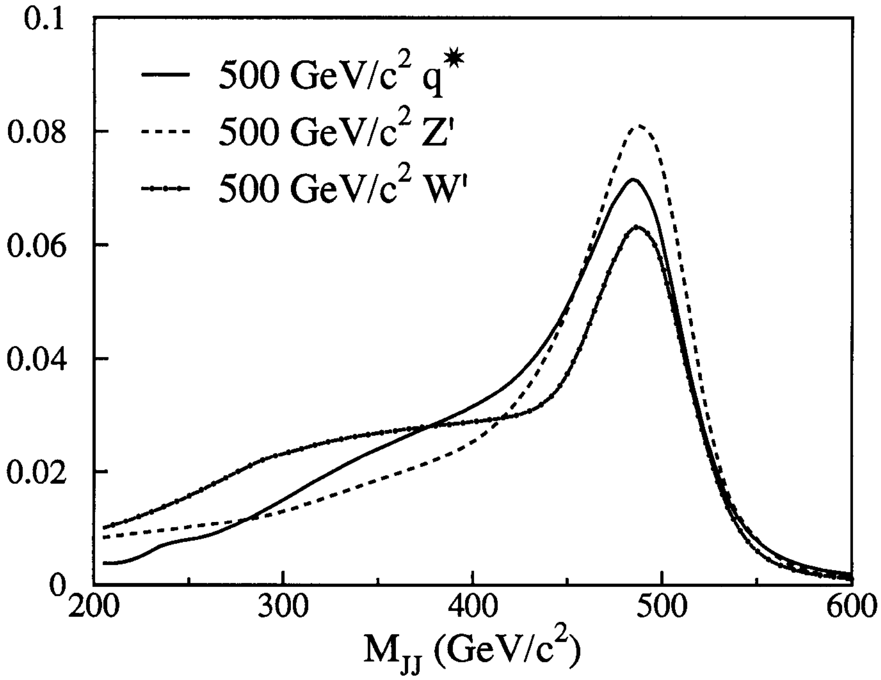

FIG. 3. The line shapes of a 500 GeV/c^2 q^*, Z', W'. The line shapes have been smoothed and normalized to unit area. The large tails of the W' and Z' line shapes are due to their top decays ($W' \to t\bar{b}$,$Z' \to t\bar{t}$)

The uncertainty in $\mathcal{L}$ is 8%, and the uncertainty in ϵ is 1% . The uncertainties in the JETRAD QCD spectrum are as given by the program and the signal line shape uncertainties are determined by the size of the sample.

The uncertainty in the energy scale was incorporated into the method by using eleven different mass spectra, each one corresponding to a different energy scale correction. The eleven energy scale corrections were the nominal correction and $\pm 0.2\sigma$, $\pm 0.4\sigma$, $\pm 0.6\sigma$, $\pm 0.8\sigma$ and $\pm 1.0\sigma$. The eleven different energy corrections are applied on an event by event basis to generate the corresponding mass spectra. The probability distributions were calculated separately for each of these mass spectra and combined to form the final probability distribution.

The data were fitted to QCD NLO prediction by using the above method with σ_X set equal to zero. A comparison of μ_i and the data is given in Fig 4. The χ^2 of the comparison is 11.03 for 15 degrees of freedom. This fit shows no evidence for the existence of any new particle.

The 95% Confidence Limits (CL) on the production cross section for the three theoretical models were extracted. This is done by determining the value of σ_X that 95% of the probability distribution lies below. The resulting limits for all models considered are plotted in Fig 5.

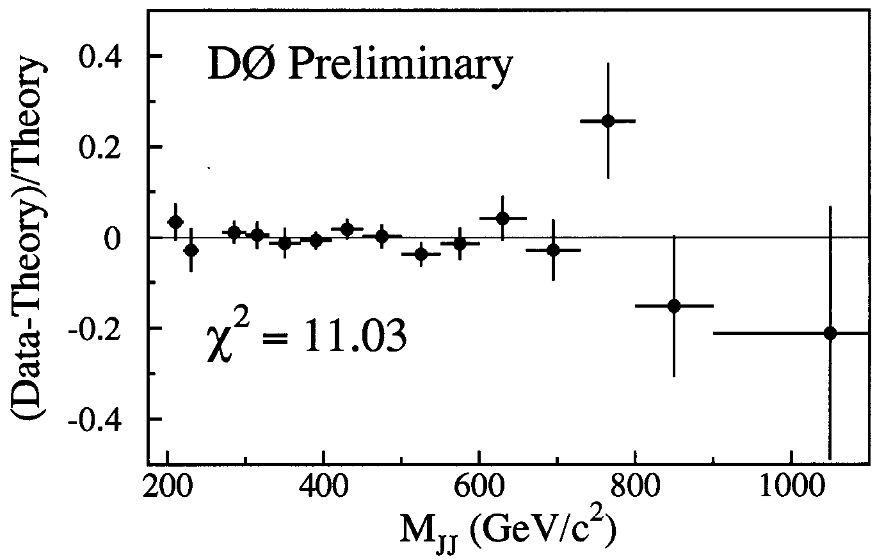

FIG. 4. The difference between the data and the smeared JETRAD NLO QCD prediction normalized to the theoretical prediction ((Data − Theory)/Theory) using the CTEQ4M pdf and a renormalization scale $\mu = 0.5 \times E_T$.

We compare our measured 95% CL with the cross section times branching ratio (BR) times acceptance (a) for particle decaying to dijets to the theoretical predictions. The predictions are calculated at leading order using the CTEQ3L parton distribution functions. Branching fractions to all quark and gluon states are included and the acceptance of the analysis cuts are applied to the resulting cross sections.

The q^* cross section limits is compared to the predicted cross section in Fig 6. We exclude excited quarks with $M_{q^*} < 725$ GeV/c^2. This is compared to the measurements made by UA2 and CDF in Fig. 7. The W' cross section limits are compared with the predicted cross section in Fig 8. The W' is ruled out for $340 < M_{W'} < 680$ GeV/c^2 and the Z' (Fig 9) is ruled out for $365 < M_{Z'} < 615$ GeV/c^2.

In conclusion we see no evidence for new particle production and set preliminary 95% confidence limits on several models of new particle production.

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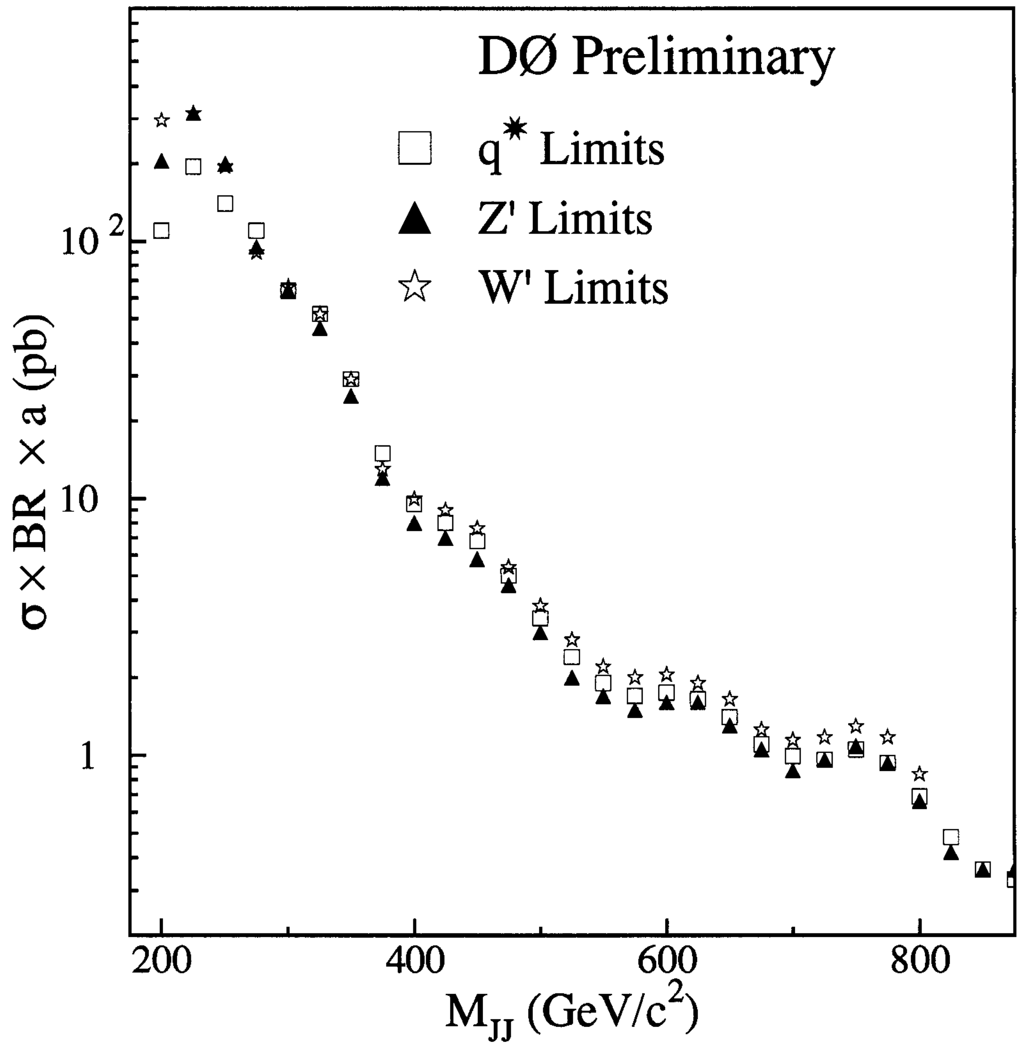

FIG. 5. The 95% CL on the production cross section ($\sigma_X \times$ BR $\times$ a (acceptance)) for the q^*, $Z'$and W' models.

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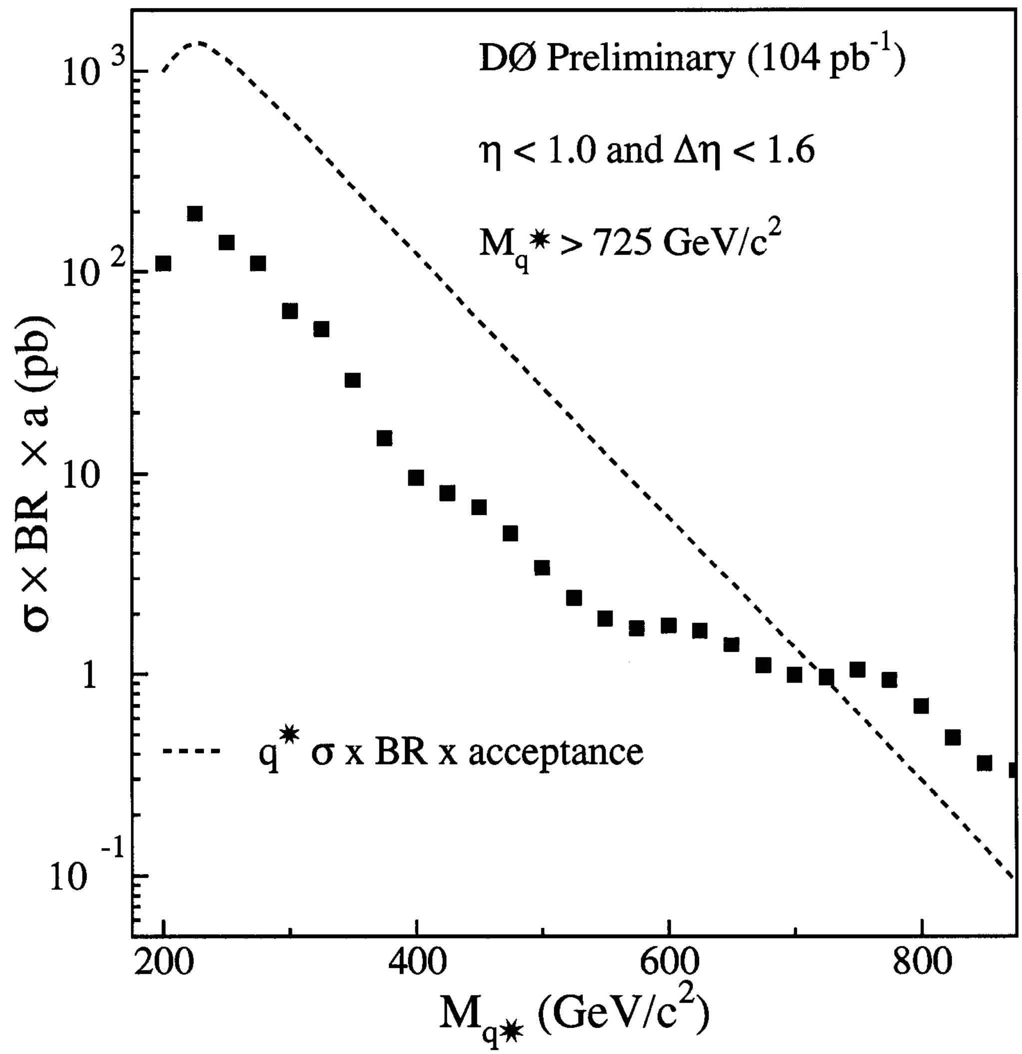

FIG. 6. The 95% CL on the production cross section ($\sigma_X \times$ BR $\times\ a$) for the q^* (solid squares) compared with the predicted cross section (dashed line). Values of M_{q^*} < 725 GeV/c^2. are excluded at the 95% CL.

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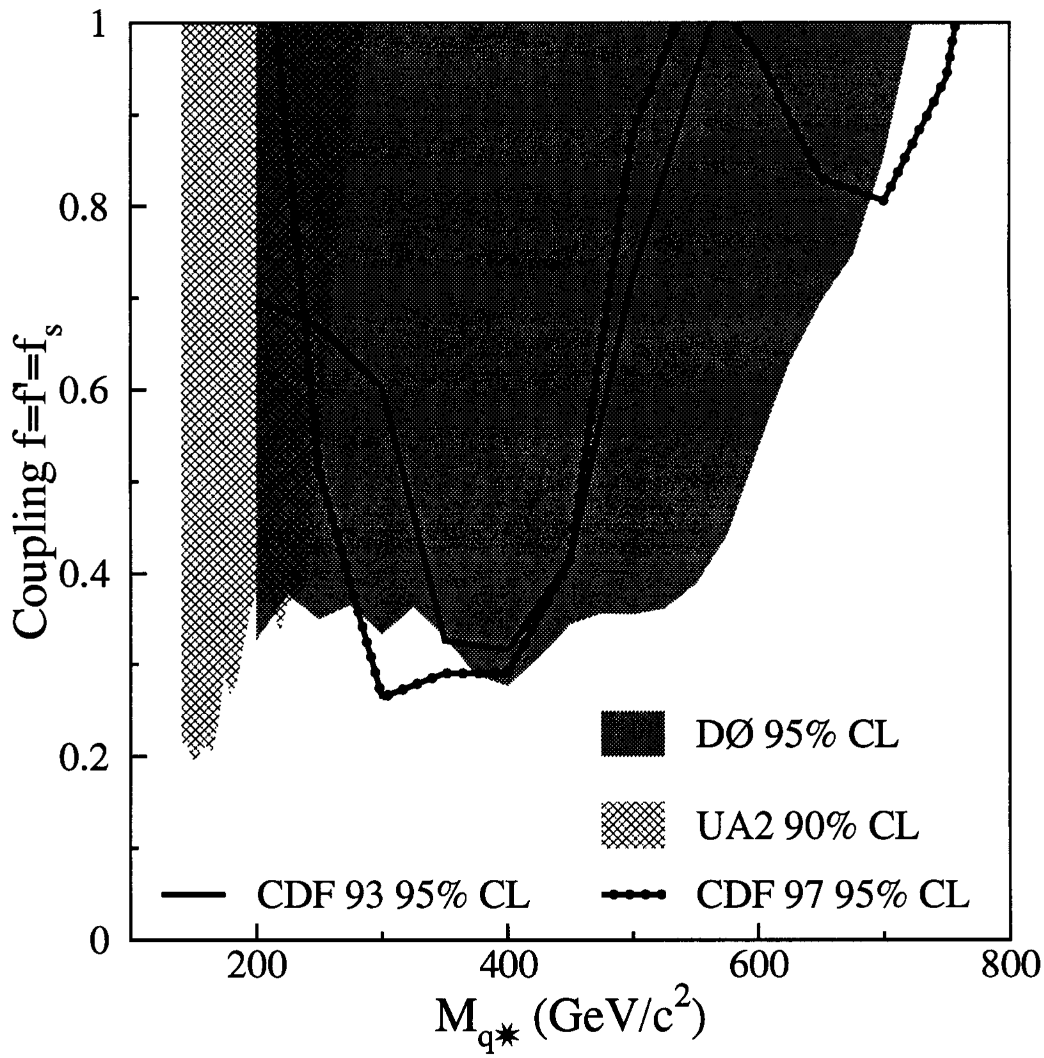

FIG. 7. A comparsion of the DØ 95% CL on the production cross section ($\sigma_X \times \mathrm{BR} \times a$) for the q^* in terms of the excited quark coupling parameters to those limits measured by UA2 [4] and CDF [5].

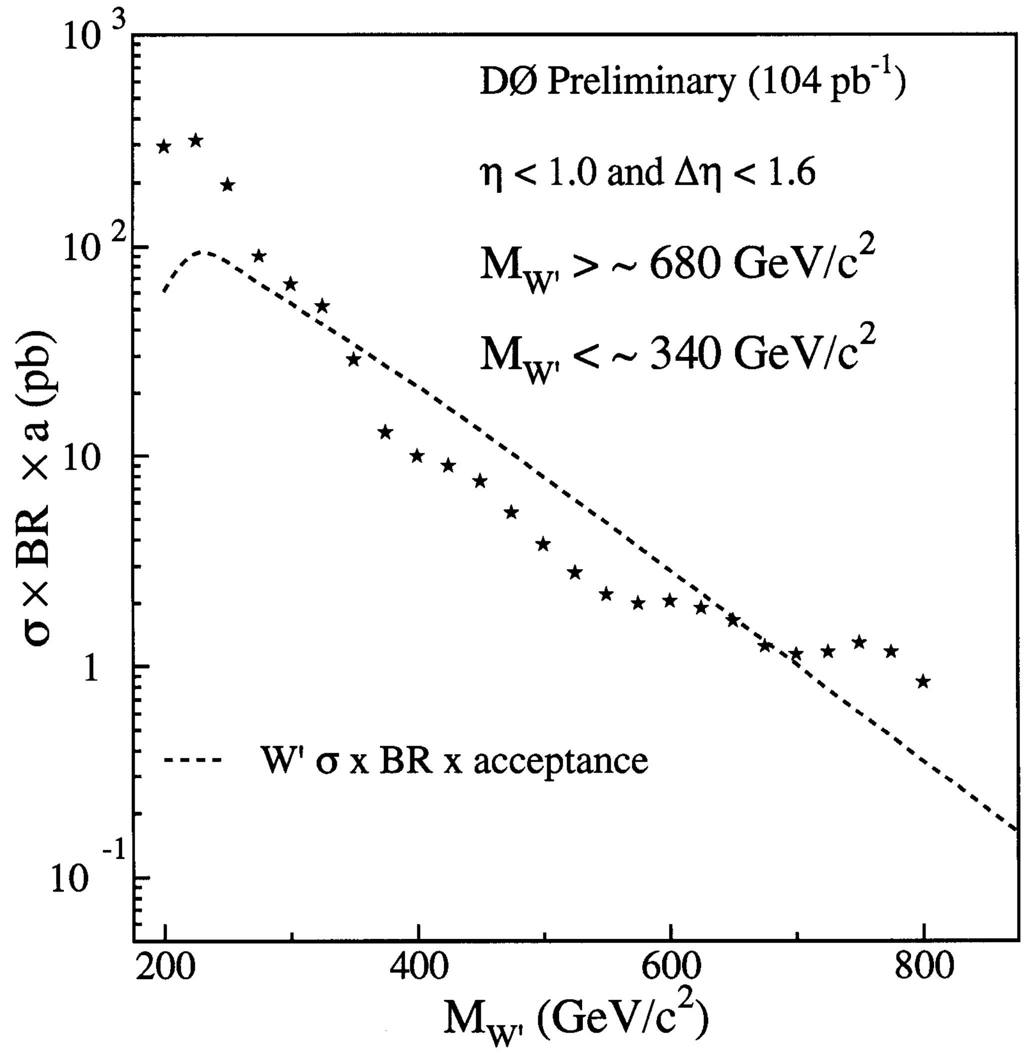

FIG. 8. The 95% CL on the production cross section ($\sigma_X \times \mathrm{BR} \times a$) for the W' (solid stars) compared with the predicted cross section (dashed line). Values of $340 < M_{W'} < 680$ GeV/c^2 are excluded at the 95% CL.

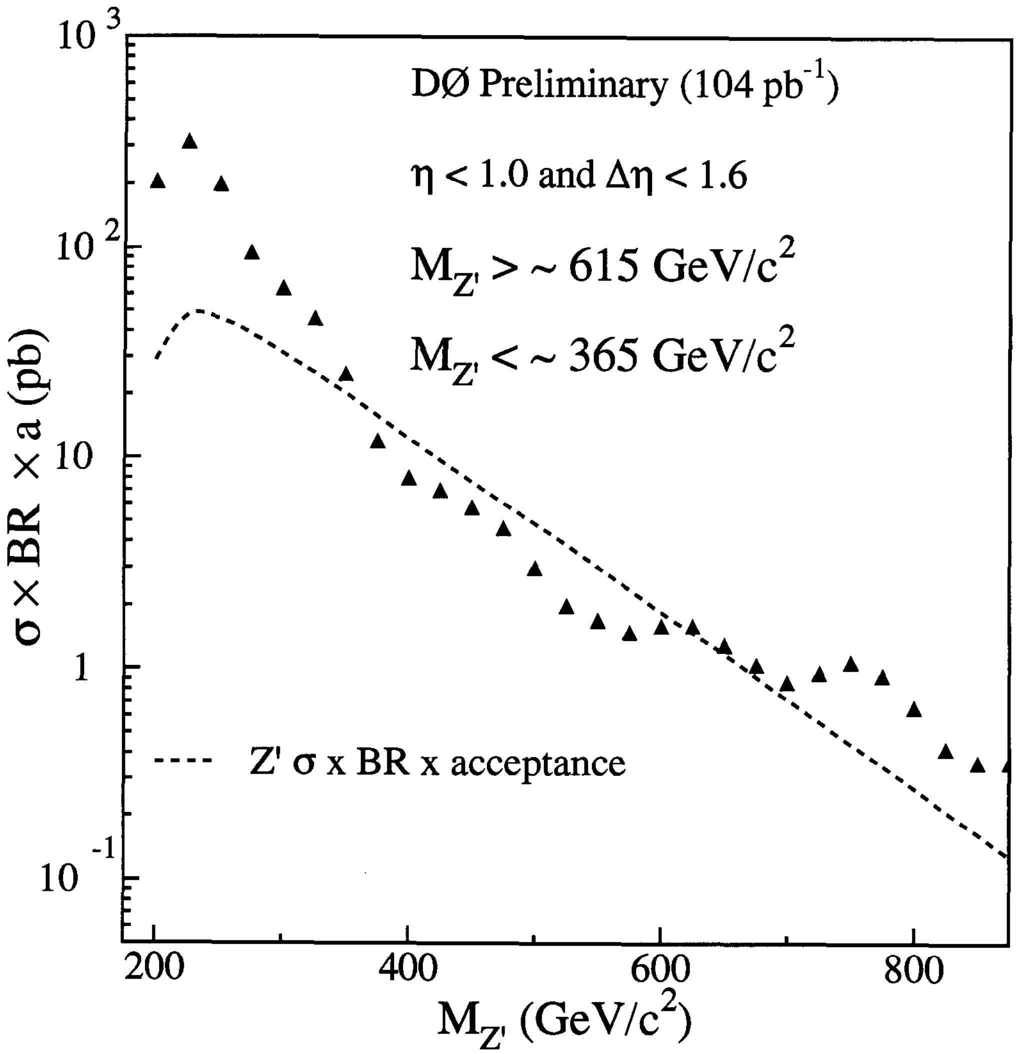

FIG. 9. The 95% CL on the production cross section ($\sigma_X \times \mathrm{BR} \times a$) for the Z' (solid triangles) compared with the predicted cross section (dashed line). Values of $365 < M_{Z'} < 615$ GeV/c^2 are excluded at the 95% CL.