Search for New Particles in the Two-Jet Decay Channel with the DØ Detector

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(Dated: 13 August 2003)

Abstract

We present the results of a search for the production of new particles decaying into two jets in $\overline{p}p$ collisions at $\sqrt{s} = 1.8$ TeV, using the DØ 1992–1995 data set corresponding to 109 pb^{-1}. We exclude at the 95% confidence level the production of excited quarks (q^*) with masses below 775 GeV/c^2, the most restictive limit to date. We also exclude standard-model-like W' (Z') bosons with masses between 300 and 800 GeV/c^2 (400 and 640 GeV/c^2). A W' boson with mass < 300 GeV/c^2 has been excluded by previous measurements, and our lower limit is therefore the most stringent to date.

PACS numbers: PACS numbers: 13.85.Rm, 14.80.-j, 14.70.Pw

The direct production of hadronic jets is the dominant contribution to high transverse momentum (p_T) processes in antiproton–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' and Z' bosons [1, 2]) that couple to quarks and/or gluons and may be observed as resonant structures in the two-jet mass spectrum. The previous observation of W and Z bosons decaying into two jets in the UA2 experiment [3] proved the feasibility of doing dijet mass spectroscopy at $\overline{p}p$ colliders. Subsequently, the UA2 [4] and CDF [5] experiments searched for new resonances in the dijet mass spectrum, and set limits on their production within the context of different theoretical models. This paper reports on a search for such resonances in the two-jet mass spectrum [6, 7] using the data collected at a center-of-mass energy of 1.8 TeV with the DØ detector in 1992–1995, corresponding to an integrated luminosity of 109 pb^{-1}.

Jet detection in the DØ detector [8] primarily utilizes the uranium/liquid–argon calorimeters that cover the pseudorapidity region $|\eta| \lesssim 4$, where $\eta = -\ln[\tan(\theta/2)]$ and θ is the polar angle with respect to the proton beam. Jets are reconstructed using an iterative jet cone algorithm with a cone radius of $\mathcal{R}$=0.7 in η–ϕ space [6], where ϕ is the azimuthal angle. Background jets from isolated noisy calorimeter cells and accelerator losses are minimized via jet-quality criteria [6]. The transverse energy of each jet is then corrected [9] for offsets due to the underlying event, noise, multiple interactions and pileup, the fraction of particle energy showering outside of the jet cone, and calorimeter energy response to incident hadrons.

For each event that passes the quality criteria, the inclusive dijet mass can be calculated, assuming that the particles within the jets are massless, using the relationship $M^2 = 2E_T^1 E_T^2[\cosh(\Delta\eta) - \cos(\Delta\phi)]$, where E_T^1 and E_T^2 are the transverse energies of the two highest-E_T jets. Each event is then weighted by the inverse of the efficiency of the quality criteria. The pseudorapidities of the two leading jets are selected to be $|\eta_{1,2}| < 1.0$ and $\Delta\eta = |\eta_1 - \eta_2| < 1.6$ in order to maximize the range of dijet mass at which the trigger is efficient.

A single trigger was used to collect the 1992–1993 data, with an E_T threshold of 115 GeV, for an integrated luminosity of 14.1 pb^{-1}. During 1994–1995, the data were collected using four triggers, with uncorrected E_T thresholds of 30, 50, 85 and 115 GeV, for integrated luminosities of 0.36, 4.8, 56.5, and 94.9 pb^{-1}, respectively. After the jet-energy corrections, these trigger samples are used to measure the dijet mass spectrum above mass thresholds of 180, 250, 320, and 470 GeV, respectively, where each of the triggers is $> 97\%$ efficient. The resulting dijet mass spectrum is shown in Fig. 1. The widths of the mass bins are chosen such that all events in any bin are recorded using a single trigger, there were > 10 events per bin, and the bin width is approximately equal to the mass resolution.

The uncertainty in the dijet mass spectrum from the uncertainty in luminosity is 5.8%, and the uncertainty from the jet-quality and vertex criteria is 1%. The uncertainties due to the jet energy scale [9] are 7% (30%) for the lowest (highest) mass bin, and are correlated. The uncertainty in energy scale has three components: the uncorrelated, fully correlated, and partially-correlated uncertainties. A correlation matrix is calculated for the partially correlated uncertainties using the method described in Ref. [6]. The uncertainties in the mass spectra due to the jet energy resolution are (0.5–3.0)% over the mass range under consideration.

We consider three models for a possible signal in the dijet mass spectrum. The first model contains a mass-degenerate family of excited quarks [1] that decay to a quark and a gluon ($q^* \to qg$). We assume that the coupling parameters of the excited quarks equal unity ($f = f' = f_s = 1$) and that the compositeness scale equals the mass of the excited quark ($\Lambda^* = M_{q^*}$). The second and third models [2] contain additional W and Z bosons, respectively, with standard-model-like couplings, where all possible quark decays are allowed ($W' \to q\overline{q}'$, $Z' \to q\overline{q}$, with $W' \to t\bar{b}$, and $Z' \to t\bar{t}$ allowed when kinematically possible). The leading-order W' and Z' boson production cross sections are corrected by NLO "K factors" [10] of approximately 1.3, to account for higher-order effects. All models were generated using PYTHIA 6.2 [11], with the CTEQ6 parton distribution functions (PDFs) [12].

For each of the models, a Monte Carlo mass spectrum was generated at 25 GeV/c^2 intervals from a mass of 150 GeV/c^2 to 1 TeV/c^2. Jets are reconstructed at the particle level using the same iterative jet cone algorithm that is applied to the data. The resulting energies are then smeared with the measured jet resolutions. Each of the mass spectra contains 50,000 events. Examples of the spectra generated for a resonant mass of 500 GeV/c^2 are shown in Fig. 2.

The data were analyzed using a Bayesian technique, with a flat prior for the signal (see Ref. [13]). The predicted number of events per bin is given by $\mu_i =$

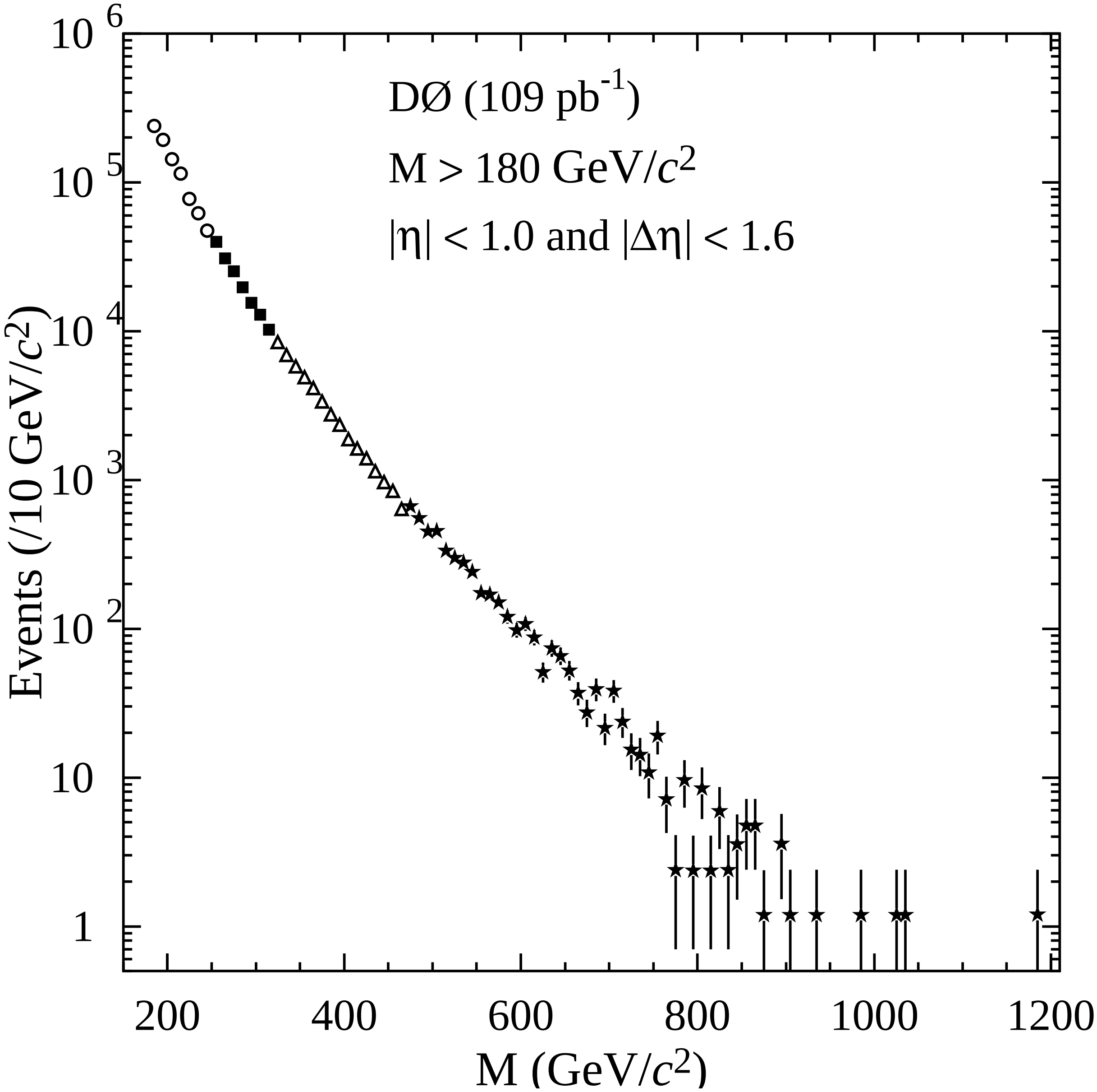

FIG. 1: The inclusive dijet mass spectrum. The events from each trigger have been corrected by the trigger's luminosity and event efficiency. The data were collected using triggers with uncorrected E_T thresholds of 30 (open circles), 50 (solid squares), 85 (open triangles), and 115 GeV (solid stars). The error bars represent statistical uncertainties.

$\left(\sigma_{QCD_i} C_{QCD_i} + N_{X_i} \sigma_X C_{X_i}\right) \mathcal{L}_i \epsilon_i$ where σ_{QCD_i} is the predicted QCD two-jet cross section for mass bin i; N_{X_i} is the fraction of signal events in the bin ($\sum N_{X_i} = 1$); σ_X is the cross section for the signal; $\mathcal{L}_i$ is the integrated luminosity; ϵ_i corresponds to the product of the efficiencies of the jet-quality criteria, the vertex selection efficiencies, and the

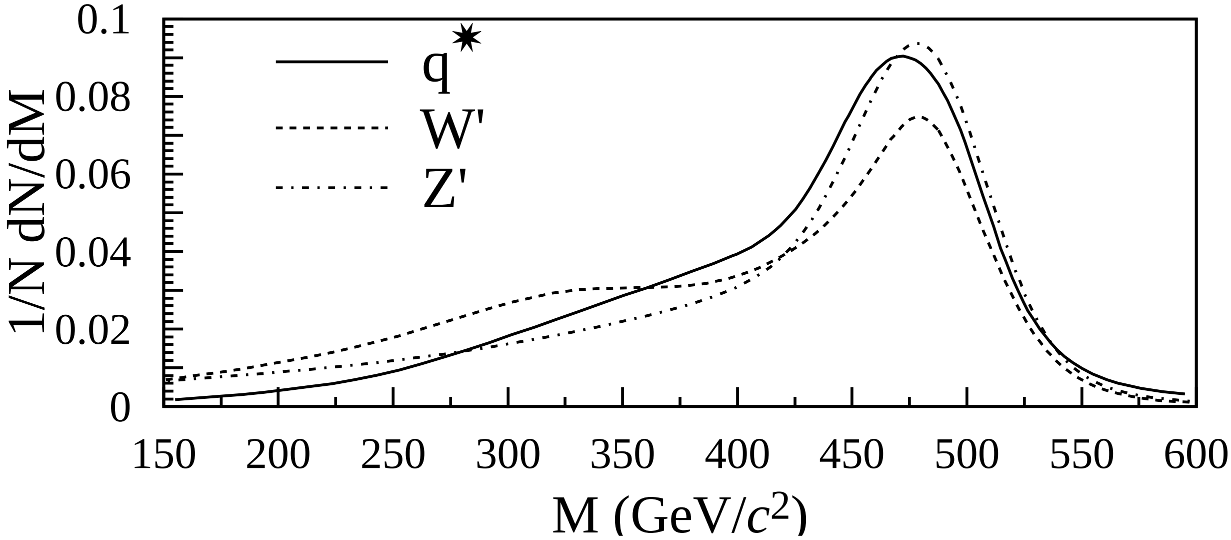

FIG. 2: The line shapes of a 500 GeV/c^2 q^*, W' and Z' bosons , smoothed and normalized to unit area.

trigger efficiencies per bin; and C_{QCD_i} and C_{X_i} are the jet energy and resolution corrections on the background and signal, respectively. Assuming N_i follows Poisson statistics, the probability that N_i events are observed in a given mass bin is then given by $P\left(N_i \mid \sigma_{QCD_i}, \sigma_X, N_{X_i}, \mathcal{L}, \epsilon_i, C_{X_i}, C_{QCD_i}, I\right) = e^{-\mu_i}{\mu_i}^{N_i}/N_i!$, where I reflects all other "nuisance" parameters. The probability of observing the set 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 has a uniform prior; σ_{QCD_i}, ϵ_i, C_{QCD_i}, C_{X_i} and $\mathcal{L}_i$ all have Gaussian priors with widths given by their uncertainties; and N_{X_i} has a Poisson prior.

Multijet background was simulated using the next-to-leading order (NLO) program JETRAD [14], with the CTEQ6M [12] PDFs, and renormalization scale (μ) of $0.5E_T^{\max}$, where the $E_T^{\max}$ is the E_T of the highest-E_T parton. Partons within $1.3\mathcal{R}$ of one another are clustered into a single jet if they are within $\mathcal{R} = 0.7$ of their E_T-weighted η,ϕ centroid [6]. The two highest-E_T jets are used to calculate the dijet mass, which is then smeared using the measured mass resolutions. The resulting distribution is shown in Fig. 3.

A comparison between the background prediction and the data is given in Fig. 4 (only uncorrelated uncertainties are shown). The χ^2 of the comparison is 25.0 for 25 degrees of freedom. This fit shows no obvious evidence for the existence of new particles.

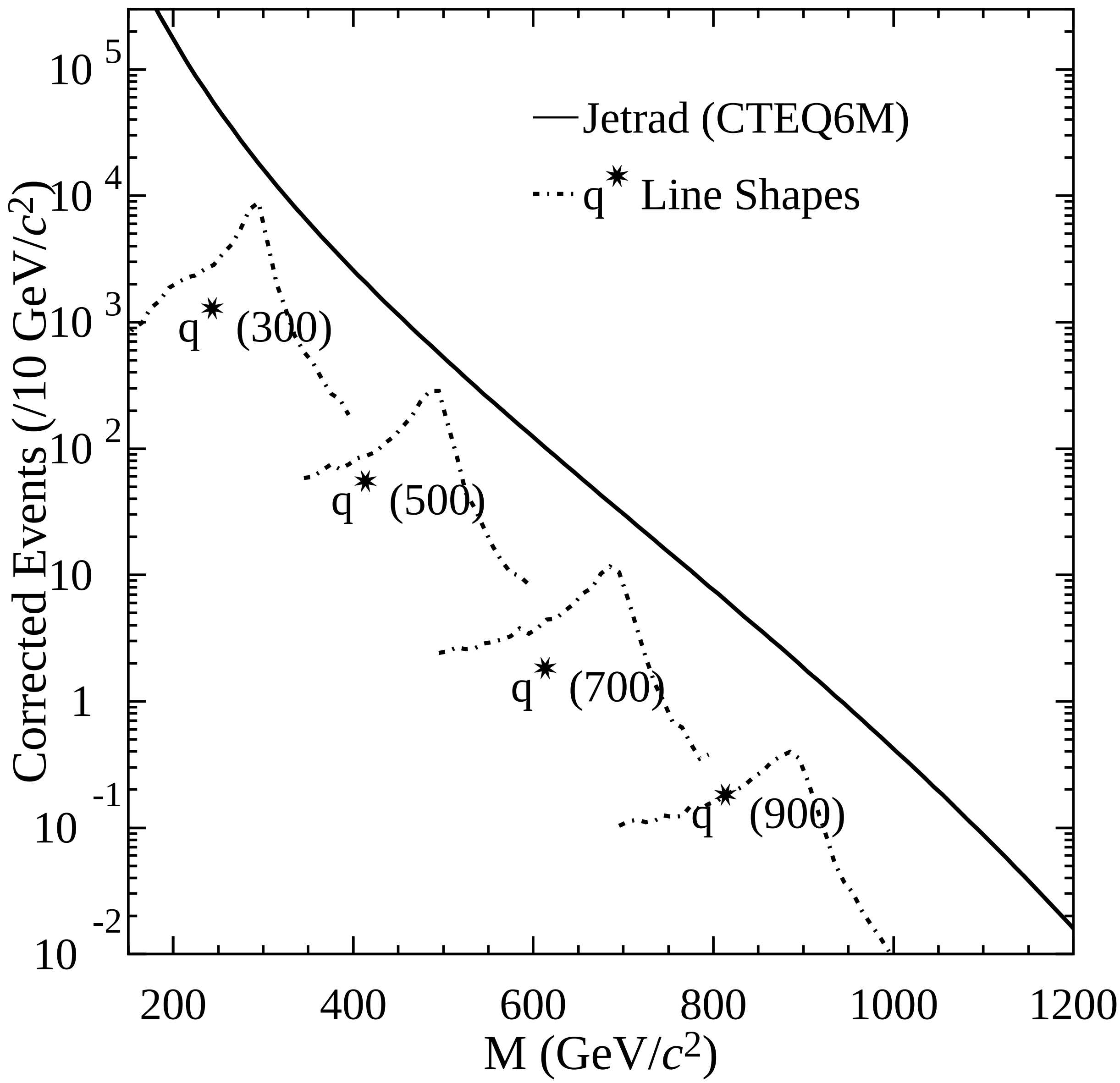

FIG. 3: The JETRAD (solid line) simulation of the inclusive dijet mass spectrum. The dashed-dotted lines show PYTHIA simulations of the excited quark line shapes for M_{q^*} = 300, 500, 700, and 900 GeV/c^2.

The 95% confidence level (CL) limits on the production cross sections for the three resonances are extracted using the same Bayesian method described above. In Fig. 5 we compare our measured 95% CL limits (stars) with the expected cross section multiplied by the branching fraction (B) and acceptance for particles decaying to dijets (dashed curve). Branching fractions to all possible quark and gluon states are included in the acceptance. The acceptances for excited quarks (W' and Z' bosons) range from 20% at 200 GeV/c^2

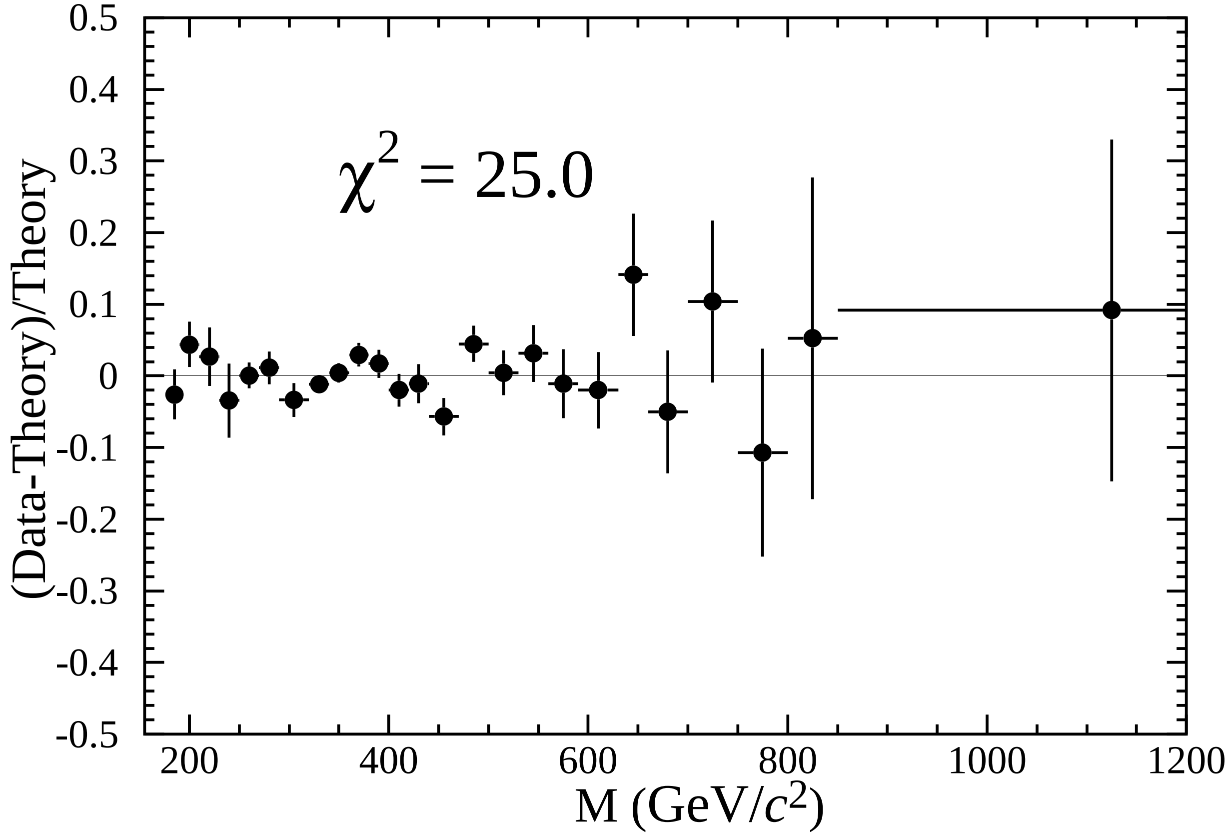

FIG. 4: The difference between data and the smeared JETRAD NLO QCD prediction normalized to the theoretical prediction ((Data − Theory)/Theory) using the CTEQ6M PDFs and a single renormalization scale $\mu = 0.5E_T^{\max}$. The vertical error bars represent the sum of the uncorrelated uncertainties added in quadrature, while the horizontal error bands represent the widths of the mass bins. The highest mass bin extends to 1400 GeV/c^2.

to 60% (50%) for masses above 700 GeV/c^2. We exclude excited quarks with $M_{q^*} < 775$ GeV/c^2. This is is the most restrictive limit on excited quark production to date. A W' boson is ruled out in the mass range $300 < M_{W'} < 800$ GeV/c^2. Previous measurements [15, 16] have excluded a W' boson with mass below 300 GeV/c^2; our new measurement therefore sets a far more stringent lower limit on a W' boson mass of 800 GeV/c^2. A Z' boson with mass between 400 and 640 GeV/c^2 is also excluded.

We thank the staffs at Fermilab and collaborating institutions, and acknowledge support from the Department of Energy and National Science Foundation (USA), Commissariat à L'Energie Atomique and CNRS/Institut National de Physique Nucléaire et de Physique des Particules (France), Ministry for Science and Technology and Ministry for Atomic En-

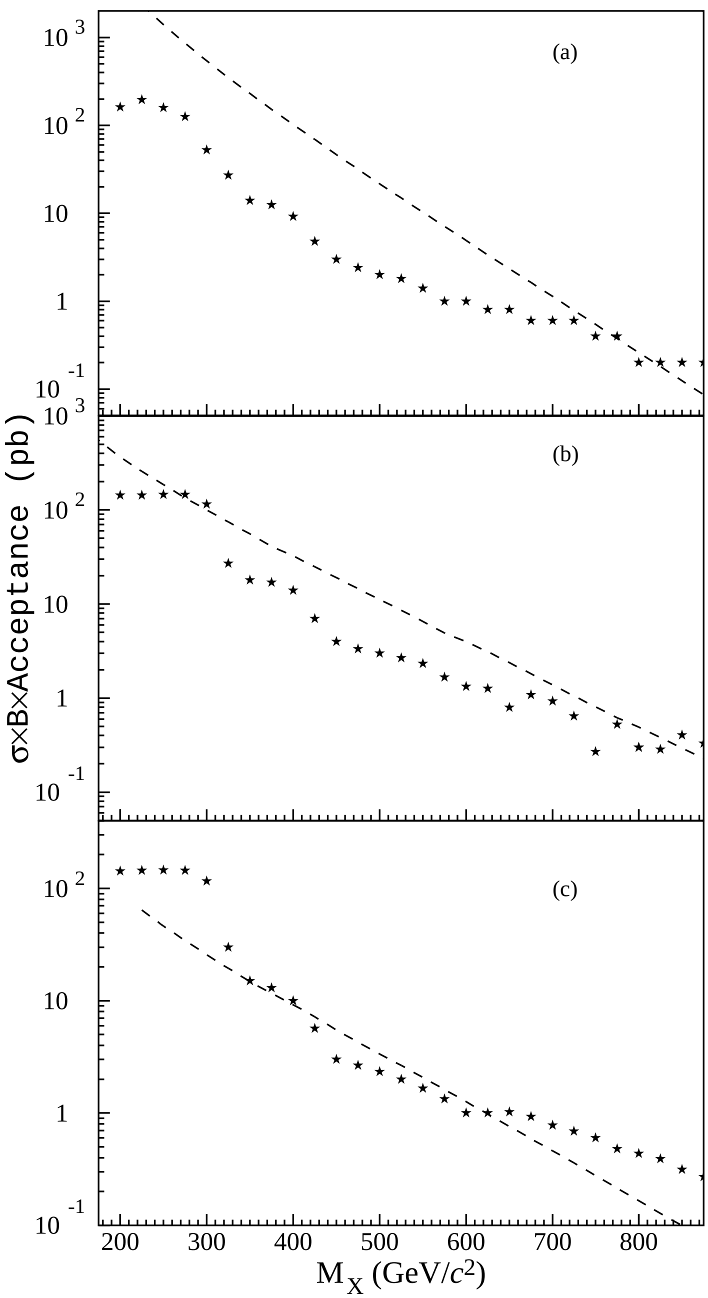

FIG. 5: The 95% CL on the production cross section multiplied by $B(X \to \text{dijet})$ and acceptance, using the CTEQ6M PDFs for: (a) an excited quark q^* (stars), compared with the predicted cross section (dashed line); $M_{q^*} < 775$ GeV/c^2 is excluded; (b) similarly, for a W' boson (stars), $300 < M_{W'} < 800$ GeV/c^2 is excluded; and (c) for a Z' boson (stars), $400 < M_{Z'} < 640$ GeV/c^2 is excluded.

ergy (Russia), CAPES, CNPq and FAPERJ (Brazil), Departments of Atomic Energy and Science and Education (India), Colciencias (Colombia), CONACyT (Mexico), Ministry of Education and KOSEF (Korea), CONICET and UBACyT (Argentina), The Foundation for Fundamental Research on Matter (The Netherlands), PPARC (United Kingdom), Ministry of Education (Czech Republic), A.P. Sloan Foundation, and the Research Corporation.

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