Fermi National Accelerator Laboratory

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Dijet Angular Distributions from $\overline{p}p$ Collisions at $\sqrt{s}$ = 1.8 TeV*

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Abstract

We have measured dijet angular distributions at $\sqrt{s} = 1.8$ TeV in the CDF detector at the Fermilab Tevatron $\bar{p}p$ Collider and find agreement with leading order QCD. By comparing the distribution for the highest dijet invariant masses with the prediction of a model of quark

compositeness, we set a lower limit of $\Lambda_c \geq 330$ GeV with 95% confidence.

We have used the Collider Detector at Fermilab (CDF) and the Fermilab Tevatron to measure dijet angular distributions in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV, complementing our measurement of the single jet inclusive cross section [1]. The measured angular distributions are compared to leading order QCD predictions for various parton momentum distribution functions and the data are used to investigate the presence of possible quark compositeness effects.

The CDF detector has been described in detail elsewhere [2]. This analysis uses data from the electromagnetic and hadronic calorimeters and the vertex time projection chambers. The calorimeters are divided into three regions of pseudorapidity ($\eta = -\ln\tan\theta/2$): central ($|\eta| \leq 1.1$), plug ($1.1 \leq |\eta| \leq 2.4$), and forward ($2.4 \leq |\eta| \leq 4.2$). The central calorimeter consists of lead-scintillator and iron-scintillator sandwiches arranged in projective towers with a segmentation of $\Delta\eta \times \Delta\phi = 0.1 \times 15^o$. The absolute energy scale for single particles interacting in the central calorimeter has been determined in a test beam to 2% accuracy, and the calibration was maintained at a 3% level using radioactive sources, light pulsers, and electronic charge injection systems [3]. The plug and forward calorimeters consist of lead and iron planes instrumented in layers with gas proportional chambers. Cathode pad readout of these calorimeters form projective towers with a segmentation of $\Delta\eta \times \Delta\phi = 0.1 \times 5^o$. The gas calorimeters were used in this analysis to determine the position of jets. The time projection chambers are used to determine the position of the event vertex along the beamline.

We discuss data taken in the 1987 collider run. The trigger consisted of: (a) coincidence of at least one particle in each of the scintillator hodoscopes ($3.24 \leq |\eta| \leq 5.90$) located on opposite sides of the interaction region; (b) total transverse energy in the calorimeters above 20, 30, 40 or 45 GeV, depending on the instantaneous luminosity. The corresponding integrated luminosities for data collected at each threshold are 0.4, 14.9, 6.3 and 7.2 nb^{-1}. The total transverse energy was calculated by summing the transverse electromagnetic energy and the central hadronic transverse energies above 1 GeV in a uniform trigger tower segmentation of $\Delta\eta \times \Delta\phi = 0.2 \times 15°$. The transverse energy in a tower is defined as $E \sin\theta$, where E is the energy in the tower and θ the tower polar angle.

In the offline analysis spurious triggers from accelerator losses and cosmic rays were removed using timing information in the central hadron calorimeter. Large pulses in the gas calorimeters characterized by large energy deposition in a single tower and chamber, believed to be due to neutron interactions [4], were removed on an event by event basis.

Jets are identified as local clusters of energy in the calorimeter by a clustering algorithm [1], which uses a cone size of $\sqrt{\Delta\eta^2 + \Delta\phi^2} = 1.0$ to optimize jet energy resolution. A four-vector is associated with each cluster, and the jet transverse momentum (p_t) is defined by treating the energy in each calorimeter cell within the cone as corresponding to that of a massless particle.

Each event was required to have a *trigger jet* with $p_t \geq 45$ GeV/c in the central detector. In order to insure that the cluster energy was well-contained within the central calorimeter, the axis of its centroid was required to be no closer than 0.2 units of pseudorapidity to the central-plug calorimeter boundary. A second jet was required to be within $|\eta| \leq 4.2$ and in the hemisphere opposite the trigger jet in azimuth. The above selection resulted in a sample of 5943 events.

The trigger jet requirement of $p_t \geq 45$ GeV/c was 98% efficient for all four total transverse energy hardware thresholds. This efficiency was determined from data taken at the low thresholds of 20 and 30 GeV, where it was found that only 2% of the events containing a jet with $p_t \geq 45$ GeV/c had less than 45 GeV of total transverse energy in the trigger hardware of the central detector.

The pseudorapidities of the trigger and second jet were used to define $\eta^* = (\eta_1 - \eta_2)/2$ for the jet axis in the dijet center of mass, and the average pseudorapidity, $\eta_{boost} = (\eta_1 + \eta_2)/2$. The scattering angle, θ^*, is related to η^* by $\tanh\eta^* = \cos\theta^*$. The invariant mass of the dijet system is taken to be $M_{jj} = p_t' \cosh\eta^*$, where p_t' is the parton momentum corresponding to the trigger jet p_t, after corrections for detector response and jet fragmentation [5].

The restrictions on the pseudorapidities of the two jets and the minimum transverse momentum of the trigger jet correspond to coupled constraints on the center of mass variables M_{jj}, η_{boost}, and $\cos\theta^*$. Measuring large values of $\cos\theta^*$ requires large values of M_{jj} and larger geometric acceptance corrections [6]. The data were analyzed separately in three (overlapping) samples: $|\eta^*| \leq 0.7$, 1.0, and 1.2, necessitating corresponding cuts of $M_{jj} \geq 148$, 180, and 200 GeV/c^2. Acceptance corrections for each sample account for geometric effects, nonzero dijet transverse momentum, and calorimeter energy resolution. These corrections have been calculated using ISAJET and a calorimeter simulation [7]. The calorimeter resolution and the effect of additional jets were determined by examining the distributions of components of the dijet transverse momentum [8]. The relative acceptance corrections are dominated by the pseudorapidity requirement on the trigger jet, vary slowly with $\cos\theta^*$, and do not exceed $\pm 30\%$ for any of the three angular intervals analyzed. A small systematic error (5%) in acceptance arises from uncertainties in the transverse momentum of the dijet system.

The lowest order QCD prediction of the cross section for $\bar{p}p \to$ jet1 + jet2 + X may be written in terms of three orthogonal parton center of mass variables, $\cos\theta^*$, η_{boost}, and M_{jj} as [9]:

$$\frac{d\sigma}{d\eta_{boost}dM_{jj}d\cos\theta^*} = \left(\frac{\pi\alpha_s^2(Q^2)}{32E_{beam}^4}\right)(2M_{jj})\sum_{ab}\left(\frac{F_a(x_a,Q^2)}{x_a}\right)\left(\frac{F_b(x_b,Q^2)}{x_b}\right)|\mathcal{M}_{ab}|^2 \quad (1)$$

where $\alpha_s(Q^2)$ is the strong coupling strength, E_{beam} is the energy of the proton beam, $|\mathcal{M}_{ab}|$ is the parton scattering matrix element, x_a (x_b) is the fraction of the proton (antiproton) momentum carried by the parton, and $F_a(x_a, Q^2)$ is the parton momentum distribution. The momentum transfer is specified by Q^2. The t-channel exchange of gluons dominates the behaviour of the matrix element and predicts a distribution that varies approximately as the Rutherford cross section, $dN/d\cos\theta^* \sim \sin^{-4}\theta^*/2$. When expressed in terms of the variable $\chi = (1+\cos\theta^*)/(1-\cos\theta^*)$, the leading order QCD prediction is approximately constant for large χ.

The acceptance corrected $dN/d\cos\theta^*$ distribution for the combined data set is shown in Fig. 1. Data from the two higher mass intervals are normalized to the low mass data sample in the angular region of overlap ($\cos\theta^* \leq 0.6$). The QCD prediction (solid curve) calculated for a sum over gluons and four quark flavors, agrees well with the data over the entire mass interval, although the dominant contribution to the sum in Eq. (1) changes from gluon-gluon to quark- gluon scattering as the dijet invariant mass increases. We find negligible variation of the prediction with structure function choice [10] or process scale, Q^2, within the range $4p_t^2$ to $p_t^2/4$. Combining statistical and systematic errors in quadrature, we obtain a fit with a χ^2/DOF of 16/15; separate fits to the three constituent mass intervals give similar agreement.

Our data can be used to test for the possible presence of a contact interaction between quarks. We modified the matrix element, M_{ab}, to include a contact interaction of the type suggested by Eichten [11], with a characteristic energy scale Λ_c. This choice leads to largest effects in the highest mass data sample where quark-antiquark scattering make a larger contribution. Fits to the highest mass distribution of $dN/d\chi$ are shown in Fig. 2. After accounting for uncertainties in the parton distribution functions and a 7% systematic error in the parton energy scale, we find a lower limit on Λ_c of 330 GeV at 95% confidence level (χ^2/DOF=17/9). This limit is lower than the previously published value of $\Lambda_c \geq 700$ GeV obtained from our single jet inclusive spectrum [1], but is determined here by an independent method. Our result may be compared directly with the limit of $\Lambda_c \geq 415$ GeV set by the UA1 collaboration [12] using a similar method and a larger integrated luminosity at $\sqrt{s} = 630$ GeV.

The authors wish to thank the CDF technical support staff for their help throughout the course of assembling and commissioning the detector. We are also indebted to the staff of the Tevatron Collider for their work in the first physics run. This work was supported by: the Department of Energy; the National Science Foundation; Istituto Nazionale di Fisica Nucleare,Italy; the Ministry of Science, Culture, and Education of Japan; and A. P. Sloan Foundation.

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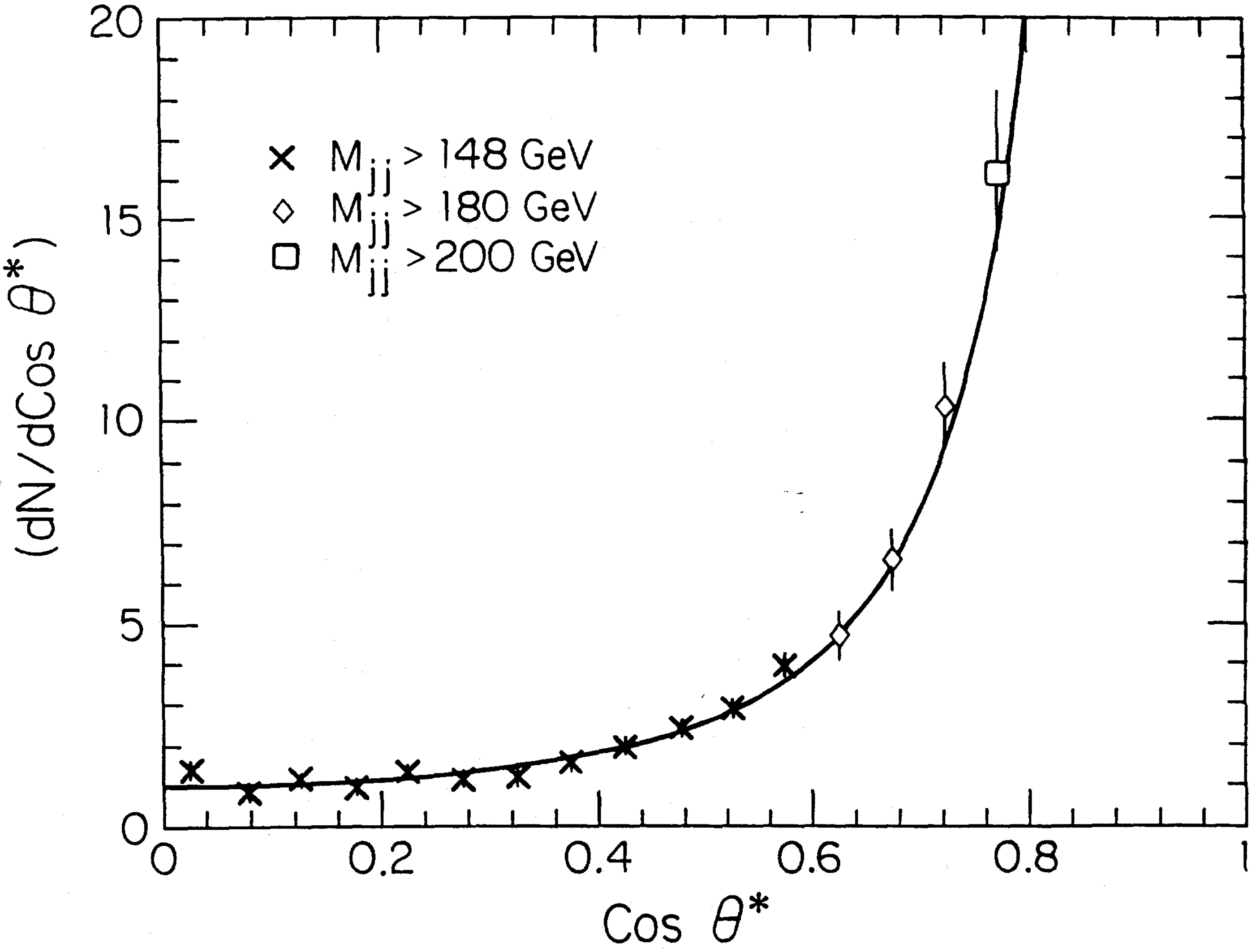

Figure 1: Dijet angular distribution for the combined data sample: $M_{jj} \geq 148$ GeV/c^2, $M_{jj} \geq 180$ GeV/c^2, and $M_{jj} \geq 200$ GeV/c^2. In all cases, $|\eta_{boost}| \leq 1.2$. The curve shown is the QCD prediction discussed in the text. Statistical and systematic uncertainties are combined.

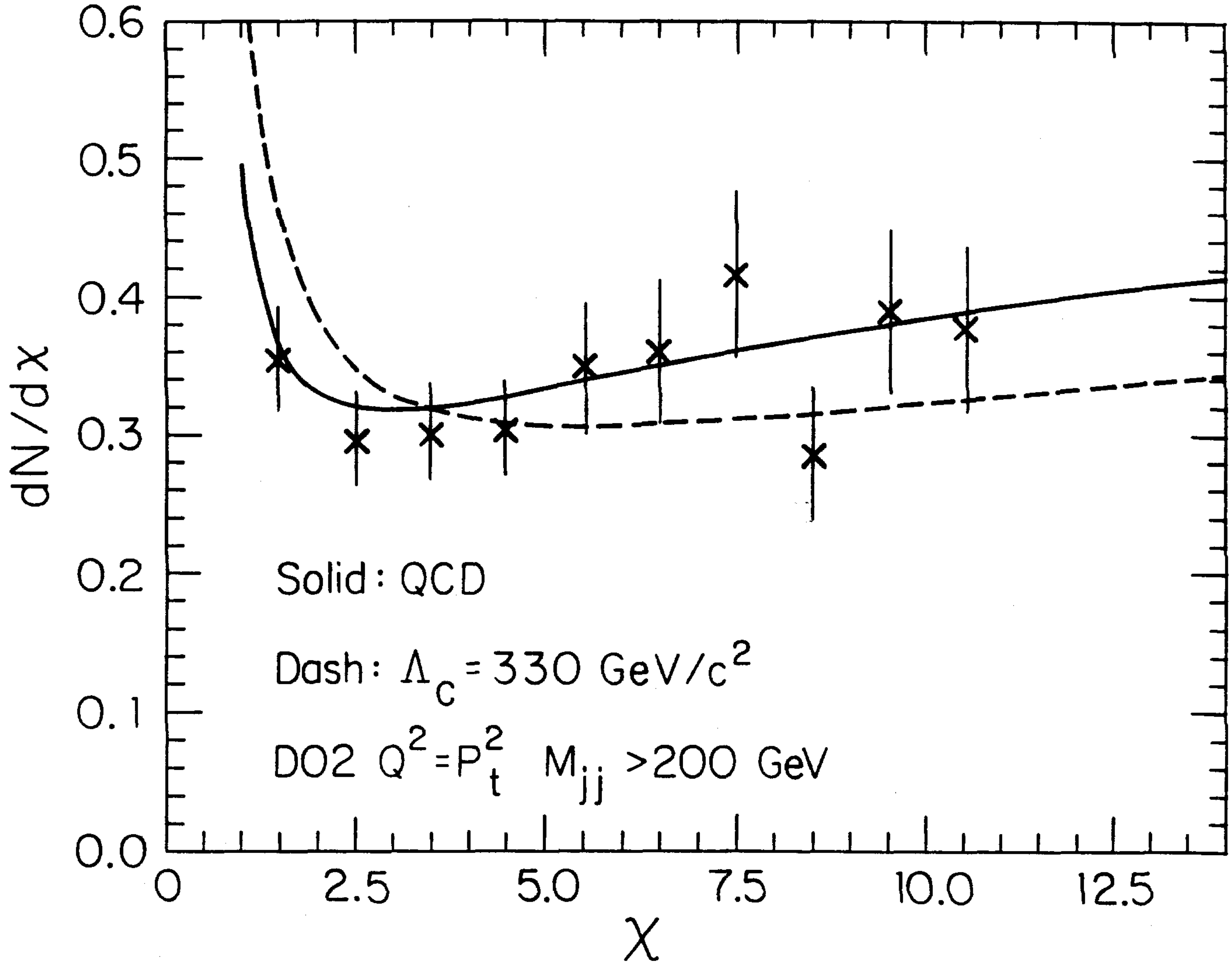

Figure 2: Compositness limit derived from the χ distribution for $M_{jj} \geq 200$ GeV/c^2. The curves are QCD ($\Lambda_c = \infty$) and the composite model ($\Lambda_c = 330$ GeV) which is excluded by the data with 95% confidence.