Fermi National Accelerator Laboratory

FERMILAB-Conf-96/166-E
D0 and CDF

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August 1996

Submitted for the proceedings of the *XXXIth Rencontres de Moriond on QCD and High Energy Interactions*, Les Arcs, Savoie, France, March 23-30, 1996

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

JET STUDIES AT ALL RAPIDITIES FROM DØ AND CDF

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Abstract

We present results on measurements of jet shapes, color coherence, and topology of multijet events from $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV at the Fermilab Tevatron collider using the CDF and DØ detectors. The data are compared to next-to-leading order QCD calculations, or to predictions of parton shower based Monte Carlo models.

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Jet Structure

Colored partons from a hard scatter evolve via soft quark and gluon radiation and hadronization processes to form observable colorless hadrons, which appear in the detector as localized energy deposits identified as jets. The hadrons in a jet have small transverse momenta relative to their parent parton's direction and the sum of their longitudinal momenta roughly gives the parent parton momentum. The definition of a jet is arbitrary and may vary from one experiment to another, but jets are the experimental "signatures" of quarks and gluons. The study of the internal structure of jets is clearly important, both as a test of QCD and to understand the corrections and efficiencies of jet reconstruction. Although the hadronization process is not well understood, at sufficiently high energies gluon emission effects are expected to dominate permitting the jet shape to be calculable by perturbative QCD alone.

Both the CDF and DØ collaborations have studied the structure of jets. The CDF collaboration has reported an analysis [1] of jet shapes by measuring the momentum flow of charged particles inside jets in the central pseudorapidity ($\eta = -\ln[\tan(\theta_{jet}/2)]$) region $0.1 < |\eta| < 0.7$. The DØ collaboration has recently published a study [2] using the finely segmented liquid argon calorimeter [3] to measure the transverse energy (E_T) flow profile of charged and neutral particles in a jet, extending the measurement to the previously unexplored forward pseudorapidity region. The DØ data are compared to the HERWIG [4] parton-shower Monte Carlo predictions processed through a full detector simulation and to next-to-leading order (NLO) QCD predictions at the parton level using JETRAD [5].

DØ measures the jet shape both as a function of E_T and η of the jet. Jets were reconstructed using a fixed cone algorithm of radius $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 1.0$. The jet cone was divided into 10 subcones centered on the jet axis with radii r varying from 0.1 to 1.0 in $\Delta r = 0.1$ increments. The investigated variable is $\rho(r)$, which is the average fraction of E_T in a subcone of radius r: $\rho(r) = \frac{1}{N_{\rm jets}} \sum_{\rm jets} \frac{E_T(r)}{E_T(r=1)}$, where $N_{\rm jets}$ is the number of jets in the sample. Corrections to remove underlying event, noise, and calorimeter showering effects were performed.

Figure 1 shows the measured jet shapes as a function of E_T and η. In the central and forward regions jets become narrower with increasing E_T with forward jets narrower than jets in the central region for the same E_T. The NLO jet shape predictions are compared to the data in Fig. 2. The parton clustering algorithm shown in Fig. 2 (labeled JETRAD-2) is such that two partons are clustered into a single jet if they were each within a distance 1.0 of their vector sum. The effects on the jet shapes of using the DØ definitions [6] of η and ϕ compared to the Snowmass definitions [7] are also shown. The different jet direction definitions do not affect the data jet shapes in the central region and only moderately ($< 4\%$) in the forward region. The NLO predictions, however, exhibit much larger effects, especially in the forward region. Qualitatively, the NLO calculations using the Snowmass algorithm describe the measured jet shapes reasonably well (at least outside the jet core), but because the jet shape measurement is a first order prediction at partonic NLO, large effects due to the uncertainty in the renormalization scale, μ, are expected and seen (Ref. [2]).

Color Coherence

In perturbative QCD and to the leading order in N, the number of colors, color coherence phenomena arise from constructive and destructive interference among the soft gluons radiated from the color connected partons [8,9]. While quantum mechanical interference effects are expected in QCD, it is of real importance that the experimental results demonstrate that such interference effects survive the hadronization process, a phenomenon which the authors of Ref. [10] call *Local Parton-Hadron Duality* (LPHD).

The study of color coherence phenomena in $p\overline{p}$ interactions provides a valuable test of QCD. It directly probes the initial-to-final state color interference which is complementary to the final state interference effects observed in e^+e^- experiments [11–15]. Both the CDF [16] and DØ [17] collaborations measured spatial correlations between the softer third jet and the second leading-E_T jet in

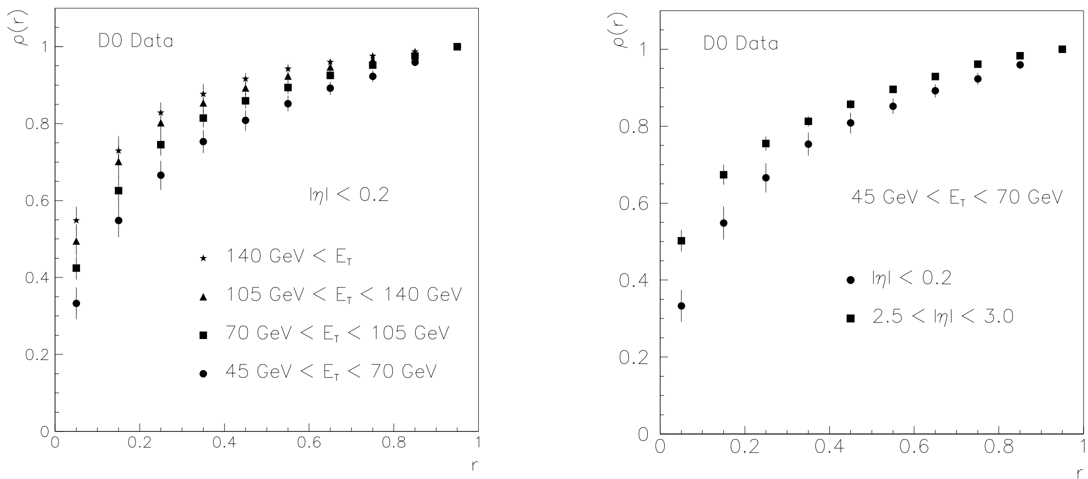

Figure 1: DØ jet shapes as a function of E_T and η.

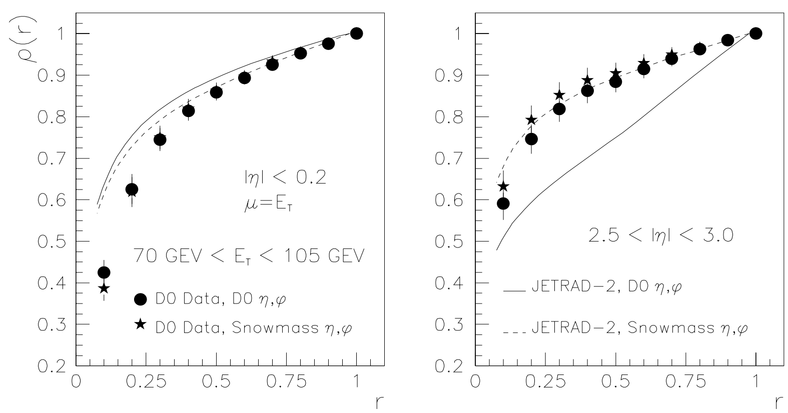

Figure 2: DØ jet shapes compared to NLO predictions.

$p\overline{p} \rightarrow 3jets + X$ events to explore the initial-to-final state coherence effects in $p\overline{p}$ interactions.

The DØ data sample was collected during the 1992-1993 run of the Tevatron collider. The jets were reconstructed using a fixed-cone clustering algorithm with 0.5 cone radius. The corrected transverse energy of the highest-E_T jet of the event was required to be above 115 GeV while the third jet was required to have $E_T > 15$ GeV. The interference between the second and the third jet is displayed using the polar variables $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ and $\beta = \tan^{-1}(\frac{sign(\eta_2)\cdot\Delta\phi}{\Delta\eta})$; where $\Delta\eta = \eta_3 - \eta_2$ and $\Delta\phi = \phi_3 - \phi_2$, in a search disk of $0.6 < R < \frac{\pi}{2}$. The expectation from initial-to-final state color interference is that the rate of soft jet emission around the event plane (i.e., the plane defined by the directions of the second jet and the beam axis) will be enhanced with respect to the transverse plane.

Figure 3 shows the ratio of the β distributions for the DØ data relative to the several Monte Carlo predictions for both central ($|\eta_2| < 0.7$) and forward ($0.7 < |\eta_2| < 1.5$) regions. Detector position and energy resolution effects have been included in the Monte Carlo simulations. The absence of color interference effects in ISAJET [18)] results in a disagreement with the DØ data distributions. The data show a clear excess of events compared to ISAJET near the event plane ($\beta = 0,\ \pi,\ 2\pi$) and a depletion at the transverse plane ($\beta = \frac{\pi}{2},\ \frac{3\pi}{2}$), as expected from initial-to-final state coherent radiation. However, HERWIG which contains initial and final state interference effects implemented by means of Angular Ordering (AO) approximation of the parton cascade, agrees well with the data.

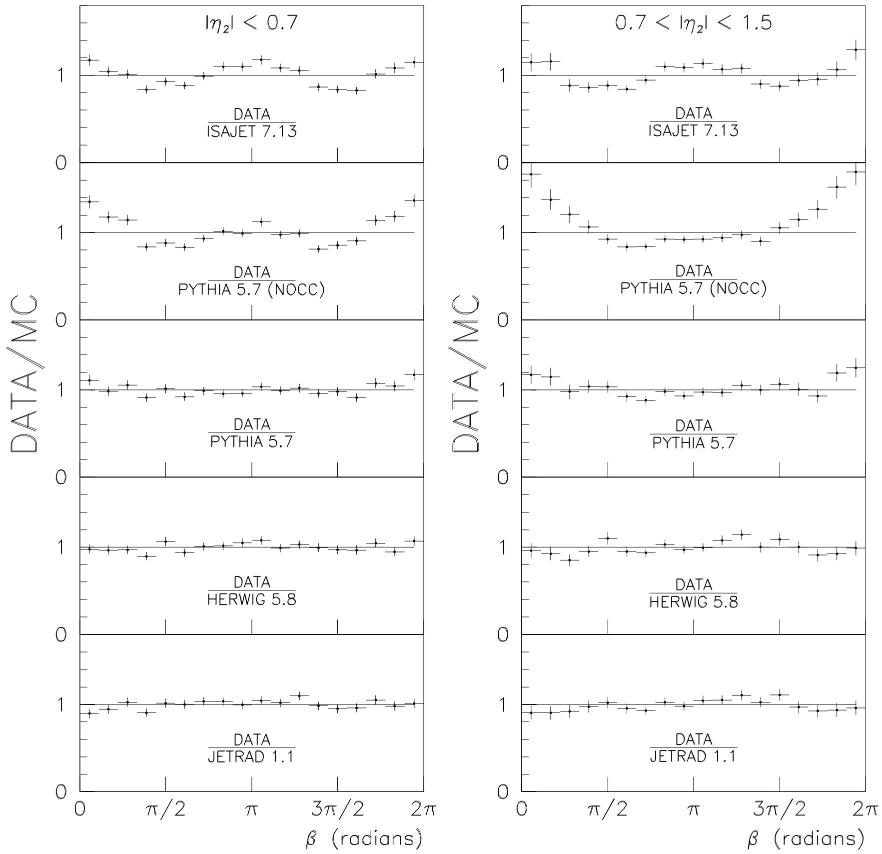

Figure 3: Ratio of DØ β distributions between data and Monte Carlo predictions for both central and forward jets.

The DØ data have also been compared to PYTHIA v5.7 [19] which also simulates the color interference effects with the AO approximation. From the DATA/PYTHIA comparisons we see that when we turn off the color coherence effects, PYTHIA disagrees with the data, whereas, it agrees better when the coherence effects are turned on with the other properties of the simulator the same. Lastly, the $\mathcal{O}(a_s^3)$ tree-level QCD describes the coherence effects seen in data reasonably well as seen by the DATA/JETRAD comparisons.

Topology of Multijet Events

The study of the topology of events containing three-or-more jets provides a test of the validity of the QCD matrix element calculations to higher order and is a probe of the underlying QCD dynamics. The CDF collaboration has recently reported a study on the topological characteristics of three-, four-, and five-jet events [20], extending the comparisons of the properties of high-mass multijet events with QCD predictions from their previous published analysis [21] by using a new set of independent multijet variables that span the N-body parameter space [22]. The DØ collaboration has also recently published a comprehensive analysis on three- and four-jet events [23] extending the topological distributions to previously untested regions of phase space.

The CDF data sample was collected during the period 1992-1995, and corresponds to an integrated luminosity of 105 pb^{-1}. Events were selected to have at least three jets with $E_T > 20$ GeV reconstructed with the CDF jet algorithm using a cone size of $R = 0.7$. Events were retained with $\sum E_T > 420$ GeV. In the three-jet center-of-mass system, CDF used four dimensionless variables to

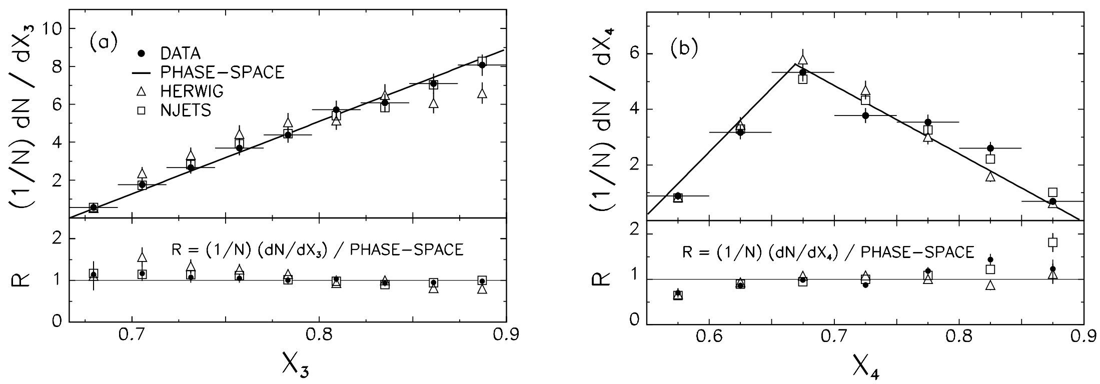

Figure 4: CDF inclusive three-jet Dalitz distributions compared with HERWIG, NJETS, and phase space model predictions.

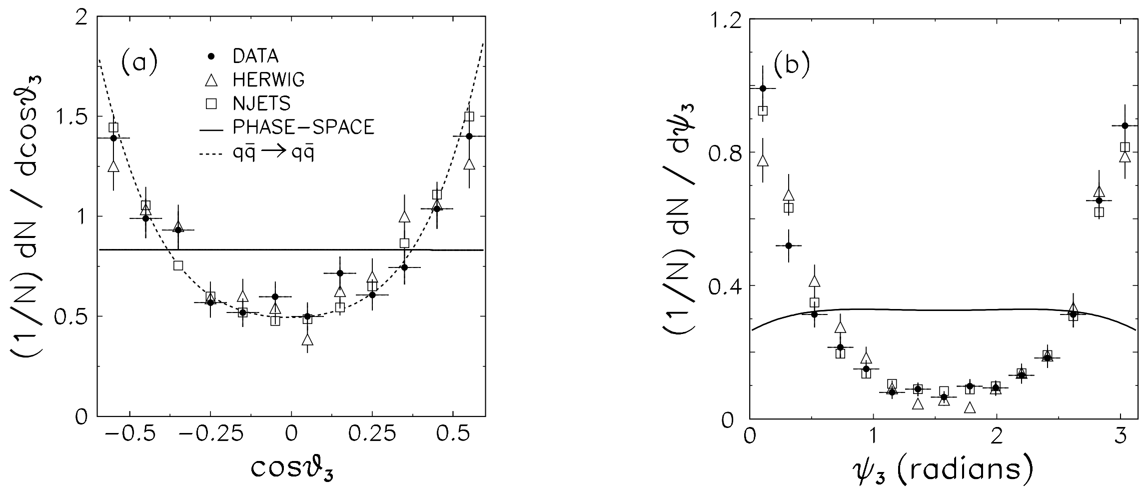

Figure 5: CDF inclusive three-jet $\cos\theta_3$ and ψ_3 distributions compared with HERWIG, NJETS, and phase space model predictions.

study the topologies of three-jet events ($1+2 \rightarrow 3+4+5$): the Dalitz X_3 and X_4 ($X_j = \frac{2E_j}{m_{3J}}$), the cosine of the polar angle of the leading jet with respect to the average beam direction ($\cos\theta_3$), and the angle between the plane containing the average beam direction and the leading jet and the three-jet plane (ψ_3). Jets were ordered such that $E_3 > E_4 > E_5$, where E_j is the energy of the jet j in the three-jet rest frame. It was also required that the three-jet events satisfied the requirements: $m_{3J} > 600$ GeV/c^2, $X_3 < 0.9$, and $\cos\theta_3 < 0.6$.

The observed CDF three-jet distributions are shown in Figs. 4 and 5 along with predictions from HERWIG, exact tree-level QCD as implemented in the NJETS [24)] program, and the phase space model. Both HERWIG and NJETS give reasonable descriptions of the observed distributions, which are very different (for the angular distributions) from the phase-space model predictions. Note that the observed $\cos\theta_3$ distribution is also very similar to the LO prediction of $q\overline{q} \rightarrow q\overline{q}$ scattering. Similar topological distributions are presented in Ref. [20] for inclusive four- and five-jet event topologies.

Conclusions

We have presented results on jet shapes, color coherence, and multijet event topology using data accumulated by both the CDF and DØ detectors. The DØ detector with its hermetic calorimetry is especially well suited for studying jets in both the central and forward pseudorapidity regions. Generally, tree-level QCD predictions describe well all the data distributions from the jet structure, color coherence, and multijet topology analyses. However, $\mathcal{O}(a_s^3)$ calculations are very sensitive to variations of the renormalization scale, parton clustering algorithm and jet axis definition in describing the jet shapes. HERWIG also gives a reasonable description of the data distributions. Finally, the latest version of PYTHIA which includes initial and final state color coherence effects agrees better with the DØ data than when these effects are turned off.

We are grateful to the DØ and CDF collaborations for discussions of their data.

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