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Color Coherent Radiation in Multijet Events from $p\bar{p}$ Collisions at $\sqrt{s}$ = 1.8 TeV

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Color Coherent Radiation in Multijet Events from $p\overline{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

The DØ Collaboration[1]

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We report on a study of color coherence effects in $p\overline{p}$ collisions based on data collected by the DØ detector during the 1992-1993 run of the Fermilab Tevatron collider at a center of mass energy $\sqrt{s} = 1.8$ TeV. We demonstrate initial-to-final state color interference effects by measuring spatial correlations between soft and hard jets in multijet events. The data are compared to Monte Carlo simulations with different color coherence implementations and to the predictions of a NLO parton level calculation.

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INTRODUCTION

Color coherence phenomena have been observed in experiments (1–5) studying the angular flow of hadrons in three-jet events from e^+e^- annihilations, in what has been termed the "string" (6) or "drag" (7) effect. The particle population in the region between quark and antiquark jets in $e^+e^- \to q\overline{q}g$ events has been measured to be suppressed with respect to the region between (anti)quark and gluon jets. This asymmetry, in the language of perturbative QCD, arises from constructive and destructive interference among the soft gluons radiated from the q, $\overline{q}$, and g (coherence). While quantum mechanical interference effects are expected in QCD, of real importance is that the experimental results demonstrate that such interference effects survive the hadronization process, a phenomenon which the authors of Ref. [7] call *local parton-hadron duality* (LPHD).

The study of hard processes in hadron-hadron collisions is more complicated, experimentally and theoretically, than in e^+e^- annihilation due to the presence of colored constituents in both the initial and final states. In addition, any event-by-event fluctuations of the soft particles produced by the underlying event may complicate the experimental results further. During a hard interaction, color is transferred from one parton to another. Examples of color flow diagrams are shown in Fig. 1 for $q\overline{q}$ and qg scattering. In Fig. 1a ($q\overline{q}$) the color system in which interference occurs is entirely between initial and final state, whereas in Fig. 1b (qg) interference also occurs in the initial and final states due to their explicit color connection. The color connected partons act here as a color antenna. Bremsstrahlung gluon radiation associated with the incoming (space-like) and the outgoing (time-like) partons

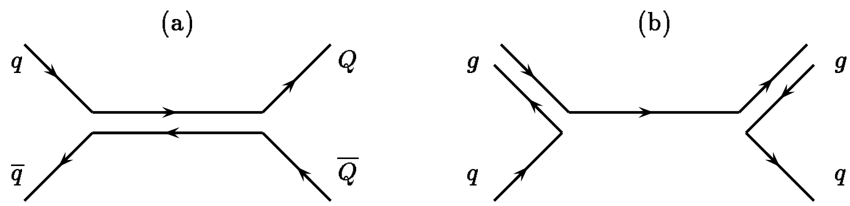

FIG. 1. Color flow diagrams for (a) $q\overline{q}$ and (b) qg scattering.

leads to the formation of jets of hadrons around the direction of these colored emitters. It is the interference of such emissions that produces the color coherence effects in perturbative QCD calculations (8,9).

An important consequence of color coherence is the *Angular Ordering* (AO) approximation of the sequential parton decays. To leading order in N, the number of colors, AO leads to a suppression of soft gluon radiation in certain regions of phase space. In the case of outgoing partons, AO results in a uniform decrease of successive emission angles of soft gluons as the partonic cascade evolves away from the interaction. However, for the incoming partons, the emission angles increase as the process develops from the initial hadrons to the hard subprocess. Monte Carlo simulations including coherence via AO have been available for both initial and final state evolutions. While AO provides an approximate description of color coherence effects, QCD calculations taken to sufficiently high order should model the effects properly. Use of the latter approach, however, is limited, due to the current lack of higher-order calculations.

The DØ detector (10) with its hermetic uranium-liquid-argon calorimetry is especially suited for studying jet final states. Evidence for color coherence effects between initial and final states in $p\overline{p}$ interactions have been presented by the DØ collaboration by measuring spatial correlations between soft and leading-E_T jets in multijet events (11). The CDF collaboration has also reported results which showed similar evidence (12).

The sections below describe the method of analysis employed by the DØ collaboration, followed by updated preliminary results which extend the previous study to forward rapidity regions.

METHOD OF ANALYSIS

To minimize any complications caused by the underlying event fluctuations, events were selected such that the two leading jets had sufficiently high energies so that the coherent radiation formed secondary jets. The events were required to have three or more reconstructed jets. The jets were ordered in E_T and were labeled $E_{T1} > E_{T2} > E_{T3}$. The angular distribution, in (η, ϕ) space, of the softer third jet around the second highest-E_T jet was measured 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 $0.7 < R < \frac{\pi}{2}$ (Fig. 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.

The data angular distributions are compared to shower level Monte Carlo simulations (ISAJET (13) and HERWIG (14)) that differ in their implementation of color coherence.

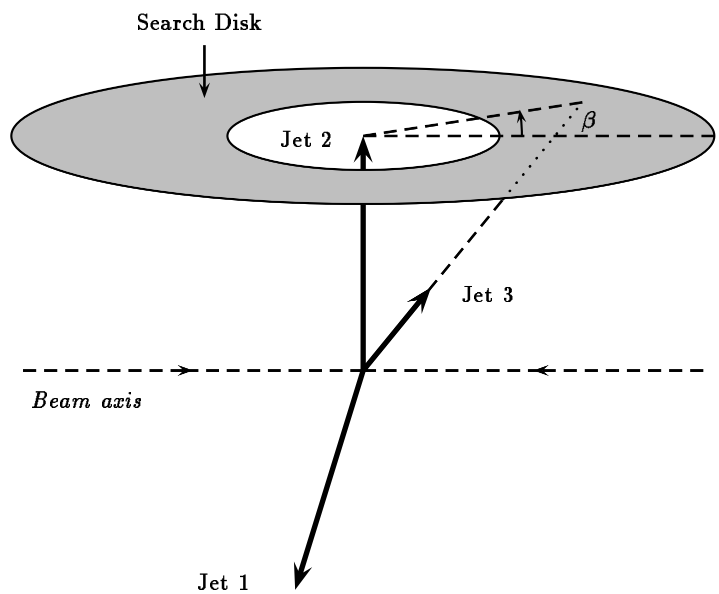

FIG. 2. Three-jet event topology illustrating the search disk (gray area) for studying the angular distribution of the softer third jet around the second leading-E_T jet.

ISAJET uses an independent shower development model without any color coherence effects, whereas HERWIG incorporates initial and final state interference effects by means of AO approximation of the parton cascades. The DØ results are also compared to the predictions of JETRAD (15); a parton-level calculation consisting of the $\mathcal{O}(a_s^2) + \mathcal{O}(a_s^3)$ one-loop $2 \to 2$ parton scattering, combined together with the $\mathcal{O}(a_s^3)$ tree-level $2 \to 3$ scattering amplitudes.

EVENT SELECTION

The data were collected during the 1992-1993 initial run of the DØ experiment. Events were selected using an inclusive jet trigger with E_T threshold of 85 GeV and pseudorapidity coverage of $|\eta| < 3.2$. The jets were reconstructed using a fixed-cone clustering algorithm with cone radius $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.5$.

After jet energy scale corrections and jet quality cuts were applied, it was required that the transverse energy of the highest-E_T jet of the event be above 120 GeV to avoid any biases introduced by the trigger threshold. The interference effects were studied when the second leading-E_T jet was central ($|\eta_2| < 0.7$) or forward ($0.7 < |\eta_2| < 1.5$). The pseudorapidity of the leading jet was not explicitly constrained. The two leading jets were required to be in opposite ϕ hemispheres without imposing any tight back-to-back cut. The third jet was required to have $E_T > 15$ GeV.

RESULTS

DØ β distributions along with Monte Carlo predictions are shown in Fig. 3. The HERWIG and ISAJET simulations have been performed at the particle level, whereas the JETRAD predictions are at the parton level. Detector position and energy resolution effects have been included in all

Monte Carlo predictions. The Monte Carlo events were subsequently processed using the same criteria employed for analyzing the data. Figure 3 shows that for both central ($|\eta_2| < 0.7$) and forward ($0.7 < |\eta_2| < 1.5$) regions, HERWIG and JETRAD are in satisfactory agreement with the data, whereas the absence of color interference in ISAJET results in a disagreement with the DØ data.

The ratios of the data β distributions relative to the Monte Carlo predictions for both η regions are shown in Fig. 4. 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. From the $\frac{DATA}{HERWIG}$ and $\frac{DATA}{JETRAD}$ β distributions we conclude that the AO approximation and the $\mathcal{O}(\alpha_s^3)$ tree-level QCD describe the coherence effects seen in data reasonably well.

CONCLUSIONS

Color coherence effects between initial and final states in $p\overline{p}$ interactions have been observed and studied by the DØ collaboration. Monte Carlo simulations that implement color interference effects by means of AO reproduce the angular correlations between the second and the third leading-E_T jet seen in data reasonably well. Furthermore, DØ preliminary results indicate that coherence effects as predicted by a $2 \rightarrow 3$ parton level calculation are also in agreement with the data.

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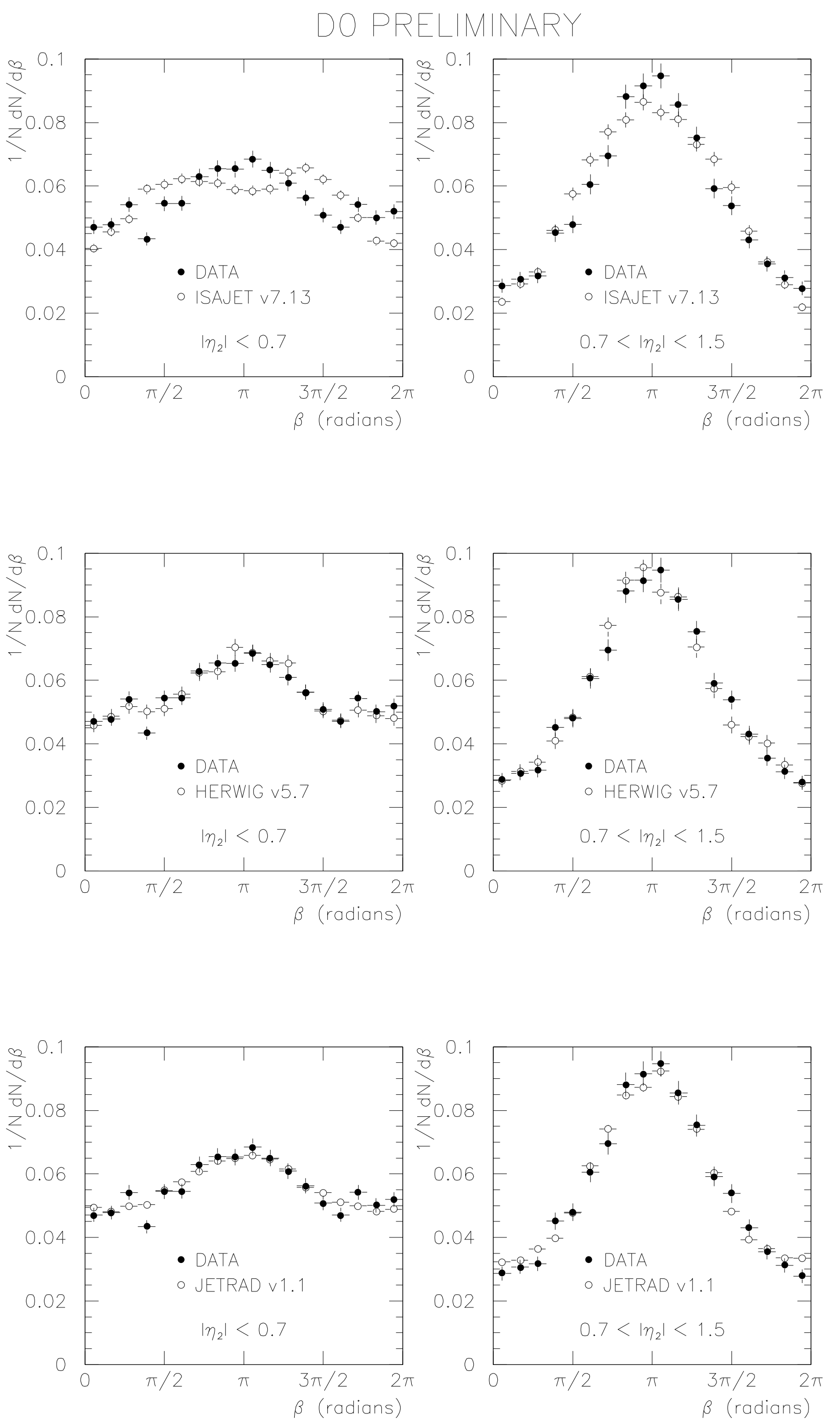

FIG. 3. **Comparisons of the DØ β distributions for central ($|\eta_2| < 0.7$) and forward ($0.7 < |\eta_2| < 1.5$) jets to the predictions of ISAJET v7.13, HERWIG v5.7, and JETRAD v1.1. The error bars shown are statistical errors only.**

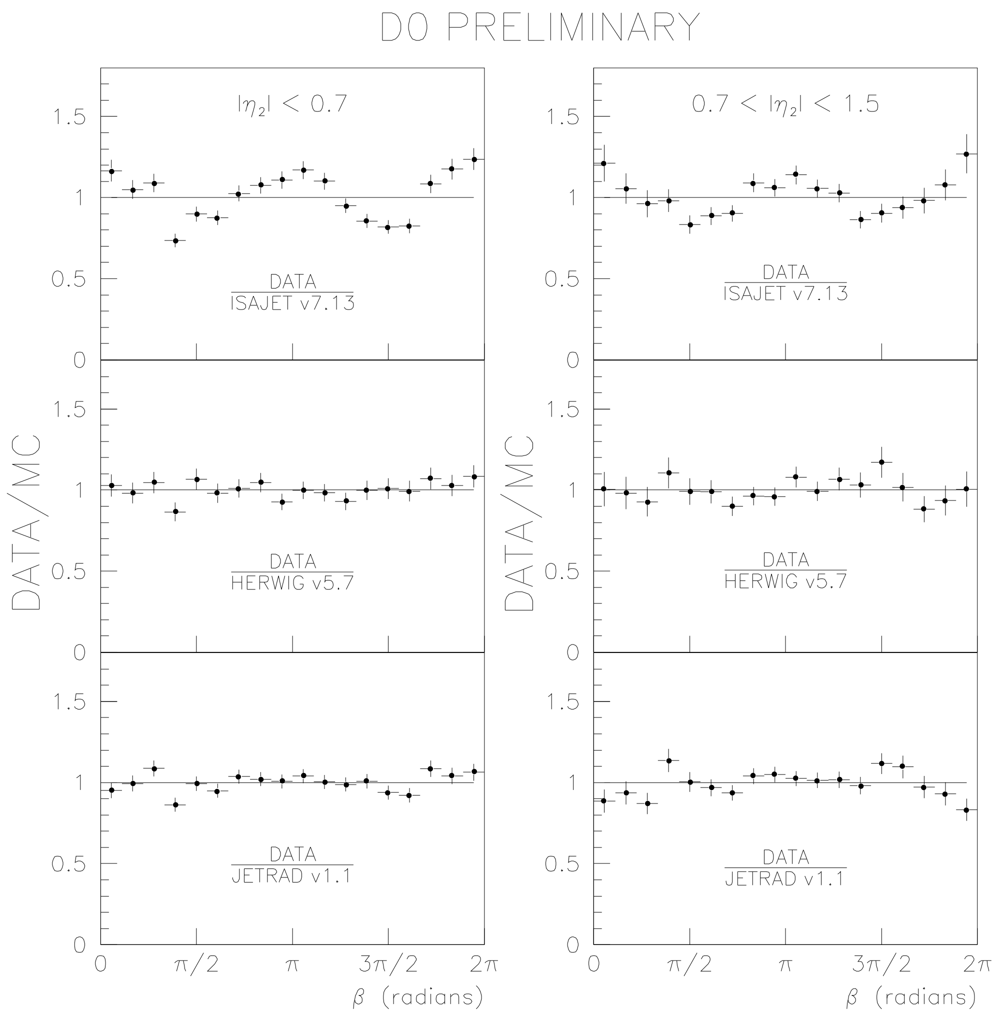

FIG. 4. Ratio of β distributions between data and Monte Carlo predictions for both central and forward jets.