Jets With Large Rapidity Separation

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Abstract

Preliminary experimental results are presented from a study of events with jets that have a large rapidity separation. The DØ detector was used to examine these events produced by the Fermilab Tevatron pp̄ collider at $\sqrt{s} = 1.8$ TeV. An analysis of the calorimeter tower multiplicity between the two highest transverse energy jets shows a significant excess of events with low multiplicity, which is qualitatively consistent with the exchange of a strongly interacting color singlet. Another analysis investigates the decorrelation in azimuthal angle of jets as a function of their rapidity separation compared to BFKL and Monte Carlo predictions.

1. Introduction

The DØ detector [1] is well-suited to jet studies due to its excellent calorimetry and coverage out to large pseudorapidity ($|\eta| \approx 4$). In this paper, two new analyses are presented which take advantage of this excellent forward coverage: a study of rapidity gap events and a study of phi decorrelation for jets with large η separation.

2. Rapidity Gaps

Rapidity gaps, which are regions of rapidity containing no particles, are typically associated with color singlet exchange. The DØ collaboration has published a study of rapidity gaps between jets [2], where the two highest transverse energy (E_T) jets have $E_T > 30$ GeV, $|\eta| > 2$, and a separation of $\Delta\eta_c > 3$, where $\Delta\eta_c = |\eta_1 - \eta_2| - 1.4$ is the distance in η between the edges of the jet cones of radius 0.7. Although rapidity gaps were observed with an experimental definition (no electromagnetic towers of $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ with more than 200 MeV), this did not directly imply color singlet exchange since inefficiencies can create false gaps and there is a background from multiplicity fluctuations in color octet (gluon exchange) events. It was possible, however, to place an upper limit on the fraction of events with a rapidity gap between the jets of 0.011 (95% CL) [2]. This upper limit provides a significant constraint on the rapidity gap cross section and the survival probability, which is the fraction of events produced with a gap that are not contaminated by particles from spectator interactions [3].

A new analysis of the same data makes use of the expected differences in the particle multiplicity distributions of color singlet and color octet events. Color singlet exchange is expected to give zero multiplicity for events that survive underlying event contamination [3], and a minimum bias-like multiplicity for events that do not survive [4]. Color octet exchange, however, is expected to give a negative binomial (or similar) multiplicity distribution, which peaks at a larger value [5]. Thus an excess of low multiplicity events would indicate the presence of color singlet exchange.

Although the color octet multiplicity between jets is expected to have a negative binomial distribution (NBD), it is crucial to show that an excess at low multiplicity is not created by detector effects. A Monte Carlo study of color octet events using similar jet requirements as the DØ analysis and including estimated DØ acceptance and efficiencies yields a multiplicity distribution that is well-described by a NBD [6]. Further support for the NBD is shown in a sample of color-octet data events that are obtained by demanding the presence of a third jet between the leading two jets, a topology which is highly suppressed for color singlet exchange. Figure 1 shows the multiplicity of electromagnetic towers with $E_T > 200$ MeV, denoted by NEM, for such events with a region of radius 1.0 around the third jet excluded to avoid biases from the jet multiplicity. The resulting NBD fit shows no excess at low multiplicity and gives a $\chi^2/df = 1.1$. Figure 2 shows the tower multiplicity for the sample

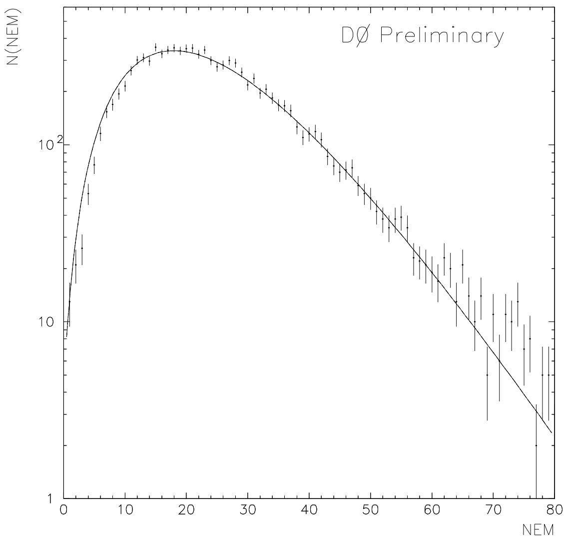

Figure 1. NEM distribution from color-octet tagged data (3-jet sample) with $\Delta\eta_c > 3$. The solid line is the NBD fit.

with at least two jets, and has a significant (41σ) excess at low particle multiplicity compared to a NBD fit starting from NEM=4. The χ^2/df is 0.9 compared to 2.1 if the fit is started from NEM=0. The fractional excess above the fit, $(NEM_{data} - NEM_{fit})/N$, is $(1.4 \pm 0.2^{(stat)} \pm 0.2^{(sys)}) \times 10^{-2}$, where only systematic errors from the fit have been considered at this point. The excess is insensitive to tower clustering, which attempts to account for the difference between using tower multiplicity and particle multiplicity. The excess also shows the qualitative behavior expected of color singlet exchange—it has little dependence on $\Delta\eta_c$ or tower threshold. If the excess were to be interpreted as color singlet exchange, it would have a magnitude well above the 10^{-3} level expected from electroweak exchange [7]. The measured excess is not inconsistent with the 10^{-1} estimate of a strongly interacting color singlet [3], considering that the portion of color singlet events with a high multiplicity spectator interaction would escape detection by this method. Due to this fact, this measurement could in principal be used to set a lower limit on color singlet exchange, independent of the survival probability.

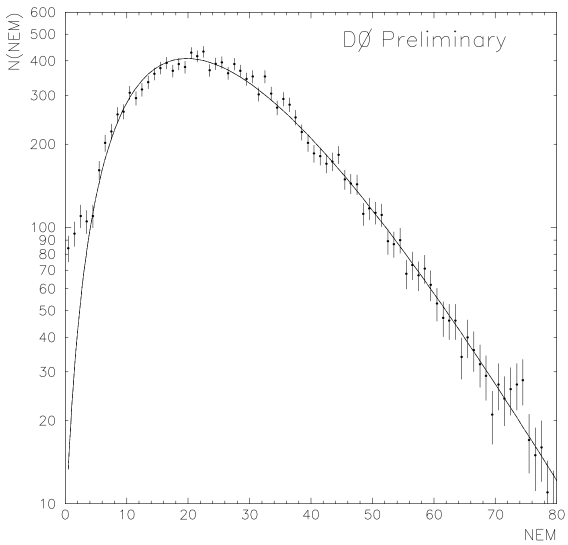

Figure 2. NEM distribution from the complete data sample with $\Delta\eta_c > 3$. A clear excess above the NBD (solid line) fit is observed at low multiplicities.

3. Phi Decorrelation

Quantum Chromodynamics (QCD) calculations of jet final states have typically been limited to leading order (LO), or next-to-leading order (NLO) in powers of the strong coupling constant (α_s) due to the complexity of the calculations. While LO and NLO provide a reasonable description of jet data in most kinematical regions, it has been noted that higher order terms may be important for the study of jets with large rapidity separations which would become decorrelated in E_T and ϕ due to soft gluons emitted between the jets [8, 9]. Techniques have been developed [8, 9] applying BFKL (Balitsky–Fadin–Lipatov–Kuraev) theory [10] to resum soft gluon emissions to all orders in order to investigate this decorrelation. A useful variable to quantify the decorrelation is $\cos(\pi - \Delta\phi)$, where $\Delta\phi$ is the difference in azimuth between the jets with the largest rapidity interval $\Delta\eta = \eta_1 - \eta_2$. Back-to-back jets (as expected at leading order) would have $\cos(\pi - \Delta\phi) = 1$, while this quantity decreases as the jets become more decorrelated. Figure 3 shows that the BFKL prediction of [9] has much more decorrelation than predicted by the NLO calculation of JETRAD [11] or the parton shower Monte Carlo HERWIG [12].

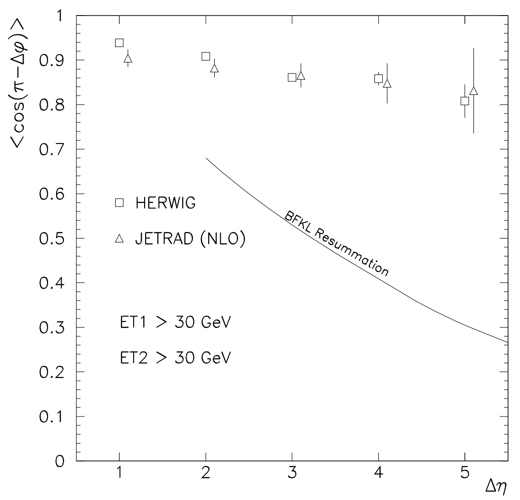

Figure 3. $<\cos(\pi-\Delta\phi)>$ versus $\Delta\eta$ with jet $E_T > 30$ GeV.

We are currently unable to plot the data with these cuts (jet $E_T > 30$ GeV) since the leading jet in the primary trigger for this analysis does not become fully efficient until $E_T > 50$ GeV. Figure 4 shows the same quantity, but all jets are required to have $E_T > 20$ GeV, and one of the two jets comprising the largest $\Delta\eta$ pair must have $E_T > 50$ GeV. The decorrelation in the data increases with $\Delta\eta$ and is well-described by the HERWIG Monte Carlo, but the NLO Monte Carlo does not provide enough decorrelation. The BFKL calculation is not yet available for these cuts.

4. Conclusion

We have used the DØ detector to study jets with large rapidity separation. The search for rapidity gap events between jets has resulted in a significant excess of events with low multiplicity between the jets. This excess cannot be explained by detector effects and is qualitatively consistent with the exchange of a strongly interacting color singlet. After the completion of studies of systematic effects, these data can be used to set a lower limit on the cross section for color singlet exchange.

We have also made a first measurement of the phi decorrelation of jets as a function of their rapidity interval. The jets clearly become more decorrelated with increasing $\Delta\eta$, in a manner that is well-described by HERWIG, but not by JETRAD. Predictions based on BFKL theory are not directly comparable with the data at this time, but show significantly more decorrelation

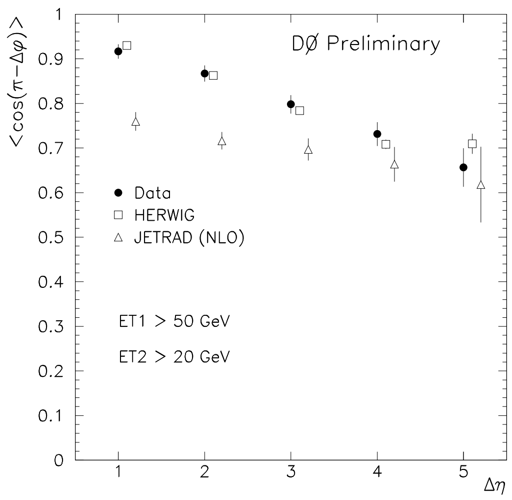

Figure 4. $<\cos(\pi-\Delta\phi)>$ versus $\Delta\eta$ with jet $E_T > 50$ and 20 GeV.

than HERWIG or JETRAD when similar cuts are applied to these Monte Carlos.

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