Probing Color-Singlet Exchange at DØ

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Abstract. We present latest preliminary results on hard color-singlet exchange in proton-antiproton collisions. The fraction of dijet events produced via color-singlet exchange is measured as a function of jet transverse energy, dijet pseudorapidity separation, and proton-antiproton center-of-mass energy. These results are qualitatively consistent with a color-singlet fraction that increases with increasing quark-initiated processes.

Dijet production via hard color-singlet exchange has been observed at both the Tevatron [1–3] and HERA [4]. The measured rate, roughly 1% in proton-antiproton collisions [1–3] and 10% in positron-proton collisions [4], is too large to be produced by electroweak boson exchange thus indicating a strongly-interacting process [3,4].

Measuring the fraction of color-singlet exchange in dijet events as a function of dijet transverse energy (E_T), dijet pseudorapidity separation ($\Delta\eta$), and proton-antiproton center-of-mass energy ($\sqrt{s}$) probes the color-singlet dynamics and its coupling to quarks and gluons. Decreasing $\sqrt{s}$ or increasing the dijet E_T or $\Delta\eta$ (i.e. increasing Bjorken x) increases the fraction of initial quark processes. Therefore, if the color singlet couples more strongly to quarks than a single gluon couples to quarks, the color-singlet fraction is expected to rise with increasing fraction of initial quark processes. The behavior of the color-singlet fraction as a function of E_T, $\Delta\eta$, and $\sqrt{s}$ is expected to deviate from this simple behavior if the dynamics of color-singlet exchange is significantly different from that of simple gluon exchange. In this paper we present the new measurements by the DØ collaboration of the color-singlet fraction as a function of dijet E_T, $\Delta\eta$, and $\sqrt{s}$.

Although standard QCD (NLO calculations and parton shower Monte Carlos) cannot account for the existence of hard color-singlet exchange, higher-

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1) Representing the DØ Collaboration

order QCD processes may explain this phenomenon [5–9]. The exchange of two perturbative gluons in a color-singlet state was originally proposed by Bjorken as a simple mechanism to produce rapidity gaps between jets with a predicted fraction on the order of 1-5% depending on the initial partons [5]. Since the two-gluon singlet couples more strongly to gluons by a 9/4 color factor compared to single gluon exchange, the observed fraction is expected to decrease with increasing initial quark processes.

This simple two-gluon picture has been expanded to include certain dynamical effects using a leading-log BFKL approximation to two-gluon exchange [7]. These effects lead to a rapidly decreasing fraction with increasing dijet E_T and a rising fraction at large dijet $\Delta\eta$.

Soft color rearrangement [9] is an alternative QCD-motivated explanation for rapidity gap production. In this model, color exchange can be canceled by the exchange of nonperturbative soft gluons, leading to an effective colorless exchange. Since initial quarks have fewer possible color combinations than initial gluons, this model predicts a color-singlet fraction that increases with increasing initial quark processes, in contrast to the two-gluon model. In addition, assuming that initial gluon processes are highly suppressed, the soft color model is estimated to give a color-singlet fraction of $(1/9)^2 \sim 1\%$.

An alternative to the QCD-based models, the exchange of a hard U(1) gauge boson that couples only to baryon number (quarks), has been proposed to explain the observed rapidity gap phenomena [10]. With an appropriate choice of the mass and coupling constant, a color-singlet fraction of 1% can be obtained. Since the boson couples only to quarks, the color-singlet fraction is predicted to increase with increasing initial quark content. Dynamics of the gauge boson predict a fraction that increases with dijet E_T more rapidly than from parton distribution functions alone.

The color-singlet fraction calculated from models for the exchange of a hard color singlet (i.e. a two-gluon singlet or U(1) boson) includes the probability that a rapidity gap is not contaminated by particles from spectator interactions ($\sim 10\%$) [5,11,12]. This probability is expected to be independent of the flavor of the initiating partons in the hard scattering and to have a weak dependence on the proton-antiproton center-of-mass energy ($\sqrt{s}$) [11,12].

Data from two center-of-mass proton-antiproton energies of $\sqrt{s} = 1800$ GeV and $\sqrt{s} = 630$ GeV are used in this analysis. Three opposite-side dijet triggers with different dijet E_T thresholds were taken at 1800 GeV, and one low-E_T data sample was taken at 630 GeV (see Table 1). At the trigger level all events were required to have two jets with $|\eta| > 1.6$ and $\Delta\eta > 4$ (1800 GeV) or 3.2 (630 GeV). Offline, events are required to have $|\eta| > 1.9$ and a vertex within 50 cm of the center of the detector. Events with more than one proton-antiproton interaction were rejected using vertex and timing information. Corrections are applied to account for multiple interaction events remaining in the sample (as a function of instantaneous luminosity) and the small fraction ($\sim 10\%$) of single vertex events incorrectly removed from the

TABLE 1. Triggers and data samples showing trigger and offline E_T cuts and number of events after all offline cuts.

Measurement	Sample Name	Dijet E_T Threshold Trigger	Offline	N_{Events} $\lvert\eta\rvert > 1.9$ (1.7)
$E_T, \Delta\eta$ dependence at 1800 GeV	low E_T	12	15	6.2K
	medium E_T	18	25	33K
	high E_T	25	30	73K (104K)
$\sqrt{s}$ dependence	630	12	12	8.5K
	1800	12	12	11.6K

sample.

The offline jet E_T and η cuts have been optimized for each measurement. For the comparison of the 630 and 1800 GeV samples the offline E_T threshold is the same as the trigger threshold (12 GeV) since any inefficiencies cancel in the ratio of the two measurements. For the 1800 GeV samples used in the dijet E_T and $\Delta\eta$ measurements, the offline E_T thresholds are higher than the trigger thresholds in order to make the measurement in the largely efficient region of each trigger. The high E_T sample used for the $\Delta\eta$ measurement has a less restrictive cut of $|\eta| > 1.7$ in order to increase statistics in the sample.

The multiplicity distribution of final-state particles in the pseudorapidity region between the dijets has been shown to be a useful way to observe and measure color-singlet exchange [13,2,3]. We utilize the electromagnetic calorimeter and central drift chamber as a measure of particle multiplicity (denoted n_{cal} and n_{trk}, respectively) and use a negative binomial distribution (NBD) to parametrize the color-exchange background and extract the color-singlet signal (see [3] for details). In order to reduce the sensitivity to multiple interaction contamination, we fit only the low multiplicity region of the data. The color-singlet fraction (f_s) is defined as the number of events above the color-exchange background parametrization divided by the number of events in the sample. For the high E_T sample we obtain $f_s = (0.85 \pm 0.06(\text{stat}) \pm 0.07(\text{syst}))\%$. The systematic error is dominated by the uncertainty in the background subtraction.

Figure 1 shows the multiplicity distribution (n_{cal}) between the jets for the low E_T 630 and 1800 GeV samples. Using a NBD to parametrize the color exchange multiplicity distribution for each sample, we obtain $f_s = (0.6 \pm 0.1(\text{stat}))\%$ at 1800 GeV and $f_s = (1.6 \pm 0.2(\text{stat}))\%$ at 630 GeV. The ratio of the two measurements is $2.6 \pm 0.6(\text{stat})$. Systematic errors have not yet been finalized, but uncertainties in the fitting and jet energy scale do not significantly affect this result.

In order to measure the color-singlet fraction as a function of E_T and $\Delta\eta$ the data samples must be divided into several subsamples leading to large uncertainties in the color-exchange background subtraction. We thus use a method of determining the E_T and $\Delta\eta$ dependence which is largely indepen-

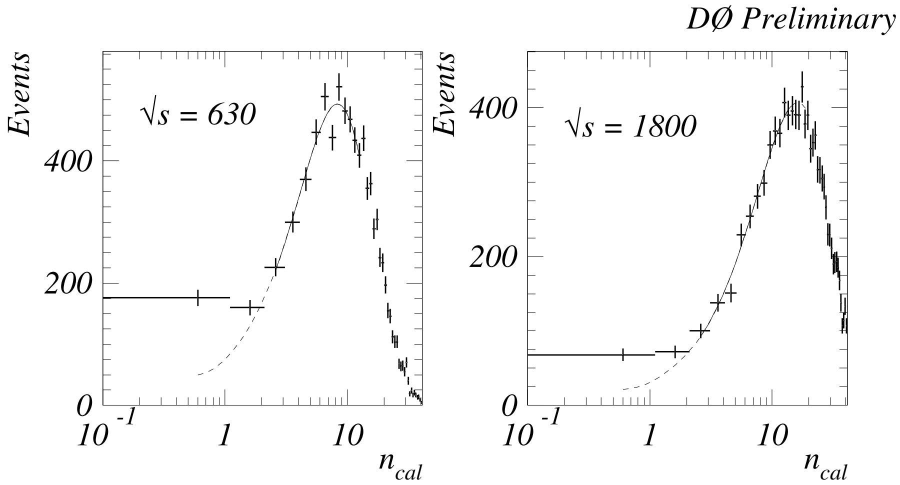

FIGURE 1. The calorimeter multiplicity (n_{cal}, the number of calorimeter towers with $E_T > 200\,\mathrm{MeV}$) between the dijets for the 630 and 1800 GeV samples, plotted on a logarithmic x scale to emphasize low multiplicity bins.

dent of the background. We calculate the fraction for each bin of E_T or $\Delta\eta$ using the (0,0) multiplicity bin ($n_{cal} = n_{trk} = 0$), where the color-exchange background is negligible ($\sim 5\%$). For each sample the overall measured (0,0) fraction is normalized to the overall color-singlet fraction previously obtained for that sample using the NBD fit method. This approach allows a more accurate determination of the shape of the color-singlet fraction as a function of E_T and $\Delta\eta$.

Figure 2(a) shows the color-singlet fraction at 1800 GeV binned as a function of the second leading jet E_T and plotted at the average dijet E_T for that bin. Figure 2(b) shows the color-singlet fraction at 1800 GeV as a function of dijet $\Delta\eta$ for the high E_T sample.

The measured color-singlet fraction in Fig. 2(a-b) shows a slight rise as a function of dijet E_T and $\Delta\eta$, and the ratio of the fraction at 630 and 1800 GeV is greater than one. Qualitatively, these results are consistent with a color-singlet fraction that rises with increasing initial quark content and thus appear to be inconsistent with current two-gluon models. Directly comparing to existing models, however, requires understanding higher-order dynamical effects in the data that may not be properly taken into account by the current models.

In conclusion, we have presented new information on the fraction of dijet events produced via color-singlet exchange. These results are qualitatively consistent with a color-singlet fraction that increases with increasing quark content. These results will be used to put constraints on color-singlet coupling and dynamics and thus differentiate between current theoretical models.

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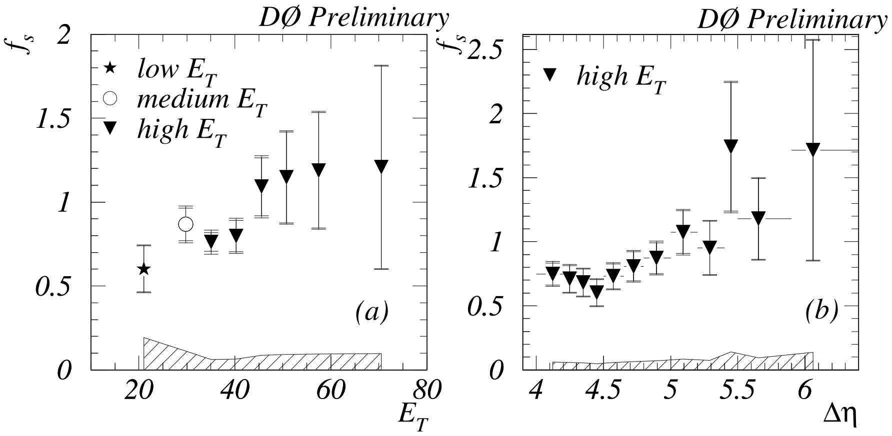

FIGURE 2. The color-singlet fraction: (a) as a function of the second leading jet E_T plotted at the average dijet E_T for that bin; (b) as a function of $\Delta\eta$ between the leading dijets. Statistical (inner error bars) and statistical plus systematic errors (outer error bars) are shown. The error band at the bottom shows the normalization uncertainty in each sample.

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