COLOR SINGLET EXCHANGE AT THE TEVATRON

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Hard color singlet exchange processes have been studied by the DØ and CDF collaborations in $p\overline{p}$ collisions at $\sqrt{s} = 630$ GeV and at $\sqrt{s} = 1.8$ TeV using the Fermilab Tevatron. Production cross sections are measured as a function of various kinematic variables and comparisons are made with the predictions of several different models.

1 Introduction

In typical $p\overline{p}$ collisions involving the exchange of quarks or gluons between interacting partons, the final state includes particle production over several units of rapidity. However, in approximately 1% of the events, the exchange of a color-singlet results in a large region of rapidity devoid of particle production. [1,2,3] In practice, this rapidity gap is usually observed in units of pseudorapidity, $\eta = -\ln\tan(\theta/2)$ where θ is the polar angle with respect to the beam axis. The large fraction of rapidity gap events in $p\overline{p}$ collisions and in ep collisions ($\sim 10\%$) [4] is indicative of strong interaction processes. These events have been interpreted as the exchange of a "pomeron" with quantum numbers of the vacuum, possibly the exchange of two gluons. Recent analysis of the characteristics of these events at the Tevatron by the DØ and CDF experiments gives more information on the nature of these color-singlet exchanges.

2 Event Selection

Hard color-singlet exchange events are characterized by jets at opposite ends of the detector and the absence of particles in the central rapidity region. Jets are identified with a steel-scintillator (liquid argon-uranium) calorimeter in the CDF [5] (DØ [6]) detector. The CDF analysis requires that the jet transverse energy, E_T, must be greater than 20 GeV, while the DØ analysis uses three different triggers with $E_T > 12$, 25, or 30 GeV, respectively. The two highest energy jets are required to have $1.8 < |\eta| < 3.5$ ($1.9 < |\eta| < 4.1$) in the CDF (DØ) analysis with a separation of $\Delta\eta > 3.6$ ($\Delta\eta > 4.0$).

The particle multiplicity is determined in the CDF detector by counting electromagnetic and/or hadronic showers with $E_T > 200$ MeV and counting charged tracks with transverse momentum $P_T > 300$ MeV/c in the region $|\eta| < 1.1$. The DØ multiplicity is determined using electromagnetic calorimeter towers with $E_T > 200$ MeV, and any charged tracks in the region $|\eta| < 1.0$. Because the DØ detector does not have a central magnetic field, no minimum momentum requirement is imposed on these tracks.

In order to preserve any rapidity gap signal, only events with a single interaction were included in this analysis. Single interaction events were defined as those emanating from only one reconstructed vertex within ±60 (±50) cm from the nominal interaction point for CDF (DØ).

3 Color Singlet Fraction

The overall fraction of color-singlet exchange events (f_s) is measured by the DØ collaboration for each data sample. Fig. 1a shows multiplicity distributions for the high-E_T trigger, which requires the E_T of the second highest energy jet to be at least 30 GeV. The number of calorimeter towers (n_{cal}) is plotted against the number of charged tracks (n_{trk}) and a clear signal is seen where $n_{trk} = n_{cal} = 0$. The signal is extracted by fitting a three parameter negative binomial distribution to n_{cal} as shown in Fig. 1b.

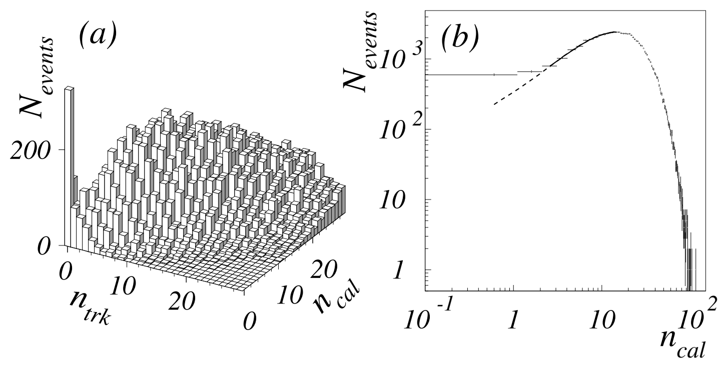

Figure 1: DØ multiplicity for high-E_T sample. (a) n_{cal} vs. n_{trk} (b) n_{cal} with negative binomial distribution.

The CDF collaboration determines f_s by comparing signal dominated events having jets on opposite sides (OS) of the event ($\eta_1 \cdot \eta_2 < 0$) with background dominated events having jets on same side (SS) of the event ($\eta_1 \cdot \eta_2 > 0$). A parabolic fit to the asymmetry between OS and SS events is fit in all but the lowest two multiplicity bins. The fit is then extrapolated to the lowest multiplicity bin and the signal extracted.

The values of f_s obtained from DØ and CDF are shown in Table 1. These values include the survival probability (S), defined as the probability that the rapidity gap is not contaminated by particles from spectator interactions. The value of S is estimated to be about 10%, and we can write $f_s = S \cdot \sigma_{\text{singlet}}/\sigma$ where $\sigma_{\text{singlet}}/\sigma$ is the fraction of dijet events produced by color-singlet exchange. The ratio of of the color singlet fraction at the two center of mass energies is found to be $R(\frac{630}{1800}) = 2.4 \pm 0.9$ (3.4 ± 1.2) by CDF (DØ). These values obtained by CDF and DØ cannot be directly compared because of different E_T cuts and slightly different data analysis. As demonstrated by the DØ data in Table 1, f_s increases with increasing E_T. The ratio for CDF is taken at approximately the same value of $x = E_T/E_{\text{beam}}$ while the ratio for DØ is taken at approximately the same absolute value of E_T.

f_s(%)	E_T (GeV)	$\sqrt{s}$(GeV)	experiment
2.7 ± 0.7 (stat.) ± 0.6 (syst.)	> 8	630	CDF
1.85 ± 0.09(stat.) ± 0.37(syst.)	> 12	630	DØ
0.54 ± 0.06(stat.) ± 0.16(syst.)	> 12	1800	DØ
0.94 ± 0.04(stat.) ± 0.12(syst.)	> 30	1800	DØ
1.13 ± 0.12(stat.) ± 0.11(syst.)	>20	1800	CDF

Table 1: Color singlet Fractions.

Measuring f_s as a function of E_T, η, and $\sqrt{s}$ probes the nature of the color singlet exchange and its coupling to quarks and gluons. If the color-singlet couples more strongly to quarks than gluons, f_s would rise as a function of increasing x, and vice-versa, because the gluon distribution becomes suppressed as x increases. The color singlet fraction is measured in DØ as a function of E_T and η using the two dimensional multiplicity (n_{cal} vs. n_{trk}) which gives improved signal to background ratio for samples with fewer events. CDF results as a function of various kinematic variables are shown in Fig. 2.[3] Little dependence on the fraction with the kinematic variables is observed.

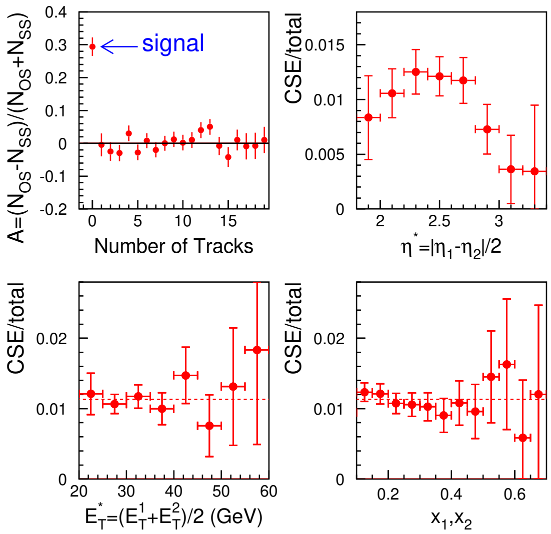

Figure 2: CDF color singlet signal, and fraction of color singlet events as a function of various kinematic variables.

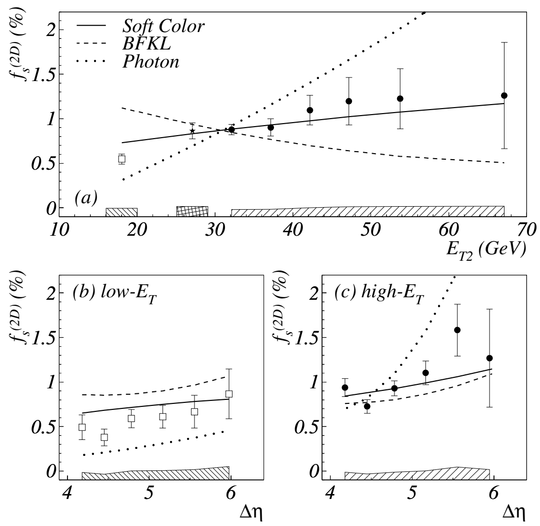

Figure 3: DØ fraction of color singlet events as a function of various kinematic variables, compared to different models of color singlet exchange described in the text.

4 Comparison with Models

In a recent paper,[2] the DØ collaboration compares its results to a two-gluon exchange model with BFKL dynamics[7] that couples strongly to gluons, to a "photon" model which depicts the color singlet exchange as a massive photon-like object that couples only to quarks, and to a soft-color rearrangement model[8] that also couples strongly to quarks. The soft color model consists primarily of the exchange of a single hard gluon with the radiation of many softer gluons that effectively shield the color charge. In this soft color model, the effective coupling factors to initial state quarks (q) and gluons (g) are given by $C_{qq} = \frac{1}{9}$, $C_{qg} = \frac{1}{24}$, and $C_{gg} = \frac{1}{64}$. Comparisons of these models to the DØ data as a function of various kinematic variables are shown in Fig. 3. Clearly, the BFKL and photon models are ruled out. If the effective couplings are determined by choosing the values which best fit the data, the ratio of effective coupling factors is found to be $C_{qq} : C_{qg} : C_{gg} = 1.0 : 0.04 : 0.0$.

5 Survival Probability

The survival probability has been assumed to be independent of x, E_T, and $\Delta\eta$. Recent calculations have determined that S should have a $\sqrt{s}$ dependence given by $\frac{S(630)}{S(1800)} = 2.2 \pm 0.2$.[9] Assuming the soft-color model accurately describes the $\sqrt{s}$ dependence, this model predicts $R(\frac{630}{1800})_{model} = 1.5 \pm 0.1$. Then $\frac{S(630)}{S(1800)}$ can be inferred from the data, using

$$R(\frac{630}{1800})_{data} = 3.4 \pm 1.2 = R(\frac{630}{1800})_{model} \times \frac{S(630)}{S(1800)} \quad (1)$$

which gives $\frac{S(630)}{S(1800)} = 2.2 \pm 0.8$ in excellent agreement with the theoretical prediction.

Conclusions

The DØ and CDF collaborations have measured the fraction of hard color-singlet exchange events in $p\overline{p}$ collisions, characterized by large central rapidity gaps. Although the results are compatible, they show different trends. The DØ collaboration compares the measured f_s at $\sqrt{s} = 630$ GeV and at $\sqrt{s} = 1800$ GeV keeping E_T constant, while CDF makes the comparison keeping x constant. Both collaborations measure f_s as a function of E_T and $\Delta\eta$ at 1800 GeV. The fraction shows a rising (flat) trend with E_T for DØ (CDF) and a rising (falling) trend with $\Delta\eta$ for DØ (CDF). Measurements from DØ indicate that the color singlet exchange couples primarily to quarks rather than gluons and is inconsistent with BFKL models, but consistent with soft color rearrangement models.

References

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