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Rapidity Gaps Between Jets at D0

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Rapidity Gaps Between Jets at DØ

The DØ Collaboration[1]
(July 1995)

Results are presented from an analysis of the particle multiplicity distribution between high transverse energy jets produced at the Fermilab Tevatron $p\bar{p}$ Collider at $\sqrt{s} = 1.8$ Tev. Using the DØ detector, we examine the particle multiplicity distribution between the two highest transverse energy jets. For events with large rapidity separation, we observe a significant excess of events at low tagged–particle multiplicity which is consistent with a strongly interacting color–singlet exchange process.

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I. INTRODUCTION

Rapidity gaps, regions of rapidity containing no final–state particles, are expected to occur between jets when a color–singlet is exchanged between the interacting hard partons (1). The exchange of a photon (2), W boson, Z boson or a hard QCD Pomeron (3,4) is expected to give such an event topology. Although the cross section for electroweak gauge boson exchange is small, the cross section for two–gluon Pomeron exchange is believed to be significant (3,5), and roughly 10% of jet events may be due to Pomeron exchange (3). Typical color–exchange jet events (single gluon or quark exchange) have particles between jets, but rapidity gaps can arise from fluctuations in the particle multiplicity, which is expected to have a negative binomial or similar distribution (6). These "background" rapidity gap events are expected to become highly suppressed as the jet rapidity separation is increased.

Rapidity gaps will not be observed in the final state, however, if spectator interactions produce particles between the jets. Approximately 10–30% of rapidity gap events are expected to survive spectator interactions (3,7). Thus roughly 1–3% of jet events are expected to have an observable rapidity gap between the jets from Pomeron exchange.

Although it is not possible to distinguish color–singlet rapidity gaps from those that occur in color–octet (gluon) exchange on an event–by–event basis, differences in the expected particle multiplicity distributions can be used to search for a color–singlet signal. This signal is expected to appear as an excess of events at low particle multiplicity compared to the negative binomial–like distribution expected for color–octet exchange.

The DØ collaboration has previously published a study of rapidity gaps between jets (8). 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), they could not unambiguously be attributed to color singlet exchange because inefficiencies could have created false gaps, and there was an indeterminate background from particle multiplicity fluctuations in color–octet events. An upper limit was placed on the fraction of events with a rapidity gap between the jets (1.1% at 95% CL) (8).

The CDF Collaboration has also published (9) the fraction of jet events with a rapidity gap using charged tracks with $p_T > 400$ MeV. They also observed rapidity gaps, but used a smooth fit to the tracking multiplicity distribution to estimate the background from fluctuations. They quote a fraction of $0.0085 \pm 0.0012(stat)^{+0.0012}_{-0.0024}(sys)$.

This paper describes the status of the current DØ Rapidity Gap analysis. The results discussed here are preliminary, as the systematic errors are still under study.

II. ANALYSIS

The data sample used in DØ analysis is derived from a special high–$\Delta\eta_c$ trigger (8) implemented to obtain events with large pseudorapidity separation ($\Delta\eta_c$) between the cone edges of the two highest E_T jets (see Fig. 1). In the offline analysis, events are required to have at least two jets, each with $E_T > 30\,\text{GeV}$ and $|\eta| > 2$, where a cone algorithm with a radius of $\mathcal{R} = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.7$ is used. Events with more than one interaction in a proton–antiproton crossing are removed since they include a source of particles not associated with the triggering interaction. The luminosity of this data sample is approximately 5.4 pb^{-1} (corresponding to approximately 15,000 events). Particles are tagged in the electromagnetic section of the calorimeter (10) by requiring $E_T > 200\,\text{MeV}$ in a calorimeter tower (8), with the number of tagged particles in a given pseudorapidity region denoted by N_{EM}.

Although the color–octet particle multiplicity between jets is expected to have a negative binomial–like distribution, it is important to show that detector effects do not cause a significant deviation from the expected distribution, especially at low multiplicity. The Monte Carlo PYTHIA has been shown to be consistent with a negative binomial multiplicity distribution between jets for events generated with conditions similar to the high–$\Delta\eta_c$ trigger (11), both for particles and for calorimeter towers using a simulation of the DØ geometric acceptance and particle tagging efficiency. No deviation is observed at low multiplicity, indicating that detector effects do not generate an artificial excess.

An enriched color–octet subsample of the data was also studied. This sample was obtained by requiring a jet (E_T >8 GeV) to be in the $\Delta\eta_c$ region between the two leading jets. Figure 2(a) shows the tagged–particle multiplicity distribution between the two highest E_T jets for $\Delta\eta_c > 3$. Another control sample of data consisted of events in which the two leading E_T jets were found on the same side (in rapidity) of the detector. To remove any color–singlet contribution to this sample from hard single diffractive events, a beam–beam coincidence was required (produced by the break up of the proton and anti–proton). Figure 2(b) shows the multiplicity in a region of $\Delta\eta = 2.4$ centered around $\eta = 0$ for these events. Both distributions are consistent with a negative binomial distribution which demonstrates that detector effects do not produce an excess of events at low multiplicities and that a negative binomial distribution describes these color–exchange samples.

The inclusive tagged–particle multiplicity distribution for events with $\Delta\eta_c > 3$ is shown in Fig. 3, with the bottom figure showing the same quantity on a log–log scale. A significant excess is observed at small particle multiplicity ($N_{\text{EM}} < 4$) compared to a negative binomial (dashed curve) and double negative binomial fit (solid curve). The preliminary excess is $263 \pm 21(stat) \pm 10(sys)$ events for the single negative binomial and $154 \pm 21(stat) \pm 16(sys)$

for the double negative binomial, where the systematic error currently only includes the error on the fit parameters. The starting bin of the fit of $N_{\rm EM} = 4$ has been chosen to minimize the resulting χ^2. Although both distributions give a $\chi^2 \approx 1$, shape tests show systematic differences between the single negative binomial and the data. The double negative binomial (sum of two negative binomials), which has a better shape agreement and a somewhat smaller excess, is thus introduced. Monte Carlo studies show that the double negative binomial may arise from the fact that two sub-processes qg and qq with different multiplicity distributions are the dominant contributors to the event topologies under study. It should be noted that the Monte Carlo and data background distributions give no excess for single or double negative binomial fits.

The excess above the fit has been determined by subtracting the fit from the data for $N_{\rm EM} < 4$. A preliminary fractional excess of

$$f = \frac{N(N_{\rm EM} < 4)}{N_{total}} = (0.9 \text{ —} 1.5 \pm 0.1(stat)) \times 10^{-2}$$

is obtained where the upper edge of the range comes from the single negative binomial fit and the lower edge of the range is determined using the more conservative double negative binomial fit. The systematic error is currently under study, but it is clear that the largest component of the error is the fitting of the background shape.

To verify that the excess of data above the fit is not caused by a detector effect, the correlation between $N_{\rm EM}$ and the number of tracks observed in the Central Drift Chamber (CDC) (10) is examined for the region of η–ϕ space where the two detector systems overlap. It is clear from the lego plot shown in Fig. 4 that $N_{\rm EM}$ and the number of tracks seen in the CDC is highly correlated and that there is a significant excess of events in the zero–track/zero–tower bin.

DØ has previously published (8) the fraction of events which have zero electromagnetic towers ($N_{\rm EM} = 0$) as a function of $\Delta\eta_c$. This result has been compared to the value of the negative binomial fit for the $N_{\rm EM} = 0$ bin as shown in Fig. 5. While the fraction of events with $N_{\rm EM} = 0$ (solid circles) remains constant for $\Delta\eta_c > 2$, the value from the zero bin of the fit (open circles), which represents color–exchange, decreases rapidly. The difference between the two curves could be attributed to the portion of color–singlet exchange events which have no struck calorimeter towers between the jets. This also points out why the upper limit of 1.1% is not inconsistent with the excess of 0.9 —1.5%, as the upper limit only includes rapidity gap events which survive spectator interactions, while the excess above the fit also could include those color–singlet events which have a low multiplicity spectator interaction.

III. CONCLUSION

DØ has measured tagged–particle multiplicity distributions between jets. We have observed a significant excess of events at low tagged–particle multiplicity compared to an parameterized background form for the color–octet exchange background. The measured excess is more than ten times larger than the predicted excess due to electroweak exchange (12). The observed excess is consistent with expectations for a strongly interacting color–singlet exchange process, likely indicating observation of a strongly interacting color–singlet.

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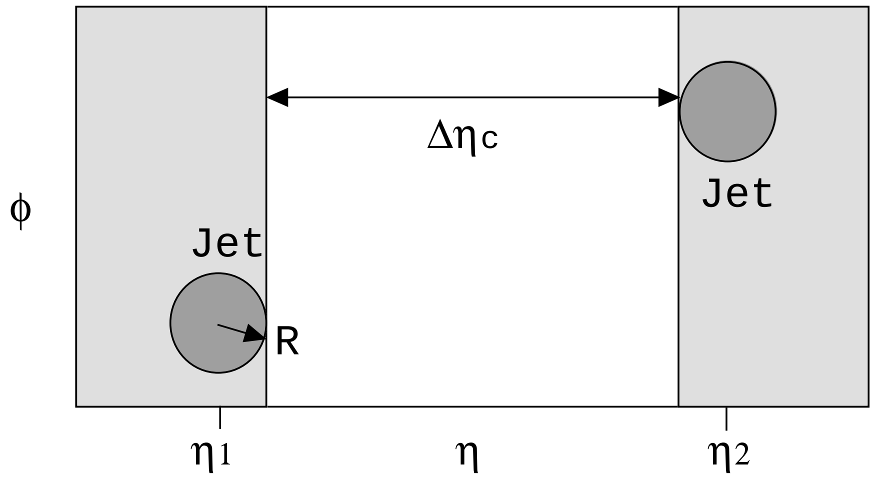

FIG. 1. Representation in η–ϕ space of the distribution of particles in a typical two–jet event containing a rapidity gap. The pseudorapidity region between the edges of the jet cones (of radius $\mathcal{R}$), $\Delta\eta_c = |\eta_1 - \eta_2| - 2\mathcal{R}$, contains no particles.

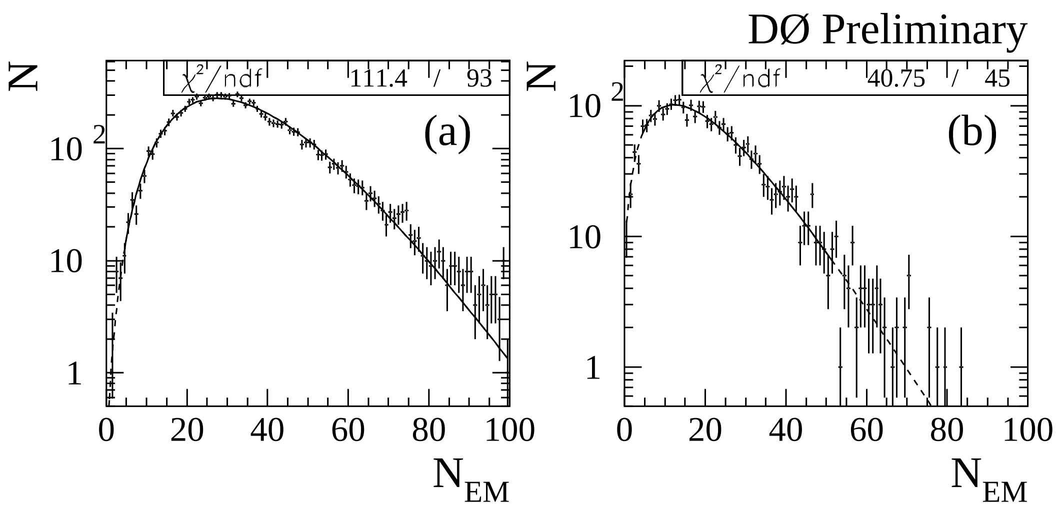

FIG. 2. The preliminary tagged–particle multiplicity distributions obtained from color–octet events for (a) the data sample where a jet is required to be in the region $\Delta\eta_c$ (b) a sample of events where both jets are on the same side of $\Delta\eta$. Negative binomial fits to the data (solid lines) are also shown.

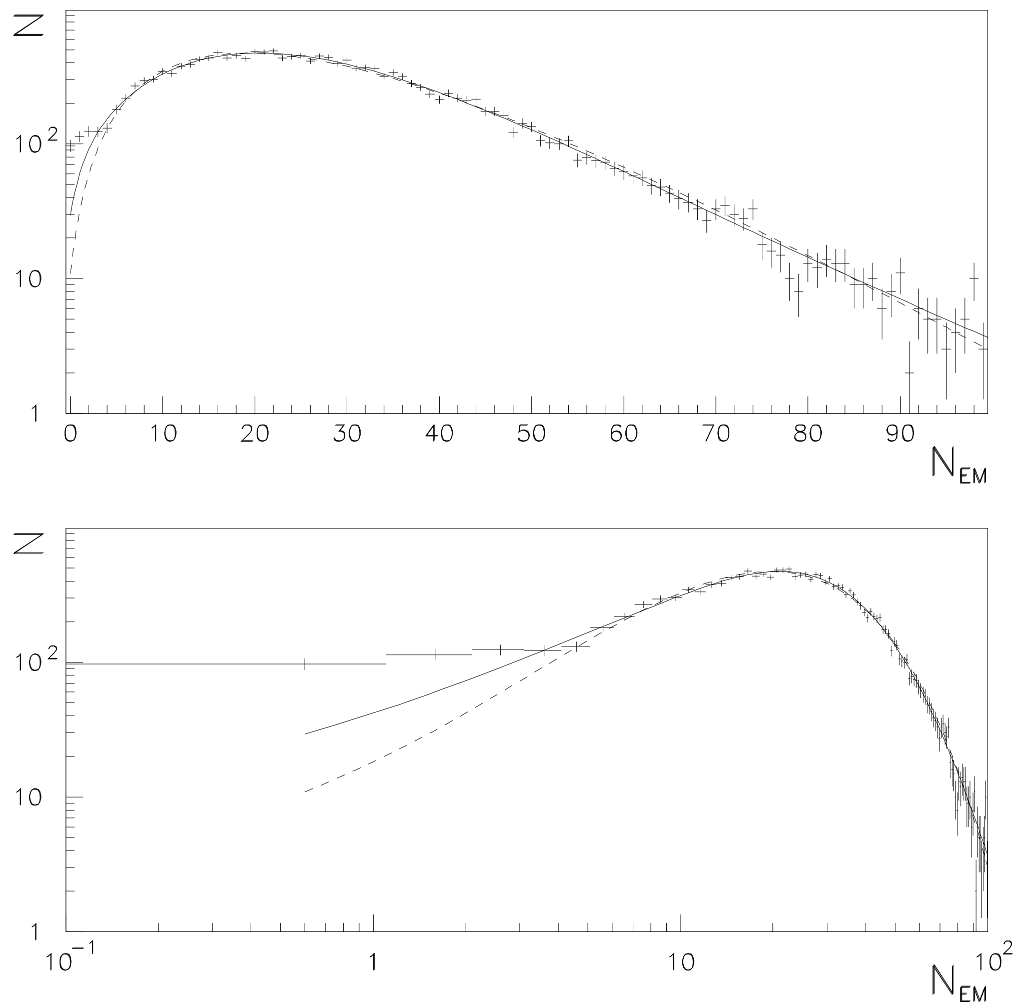

FIG. 3. The preliminary tagged–particle multiplicity distributions obtained from the inclusive event sample for $\Delta\eta_c > 3$. A negative binomial fit to the data for $N_{\rm EM} \geq 4$ and extrapolated to $N_{\rm EM} = 0$ is shown (dashed line) as well as a double negative binomial fit (solid line).

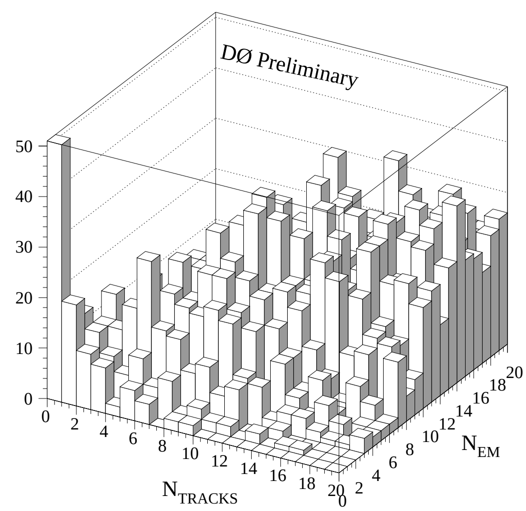

FIG. 4. The multiplicity of tracks in the CDC vs. the multiplicity of electromagnetic calorimeter towers (N_{EM}).

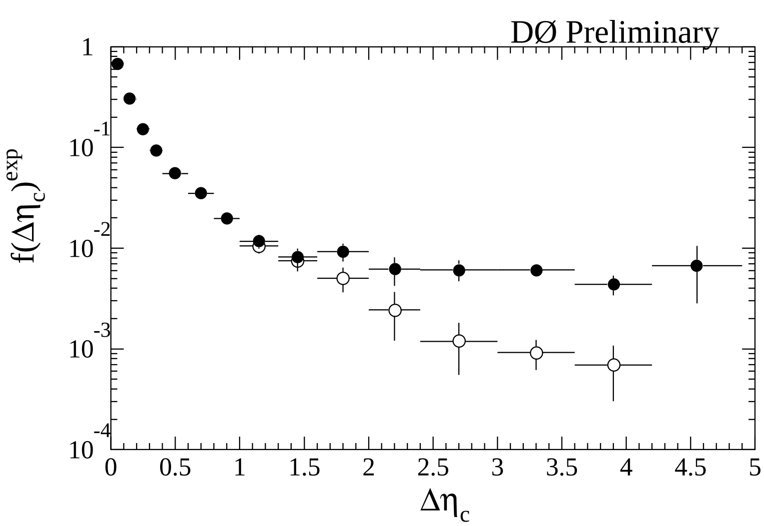

FIG. 5. The fraction of events that have no tagged particles between the two leading jets (solid circles) and the value of the negative binomial fit for the zero multiplicity bin (open circles) as a function of $\Delta\eta_c$. The error bars show the statistical uncertainty only.