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Rapidity Gaps in Jet Events at D0

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Preliminary results from the DØ experiment on jet production with rapidity gaps in $p\overline{p}$ collisions are presented. A class of dijet events with a forward rapidity gap is observed at center-of-mass energies $\sqrt{s} = 1800\,\text{GeV}$ and $630\,\text{GeV}$. The number of events with rapidity gaps at both center-of-mass energies is significantly greater than the expectation from multiplicity fluctuations and is consistent with a hard single diffractive process. A class of events with two forward gaps and central dijets is also observed at 1800 GeV. This topology is consistent with hard double pomeron exchange. We also present results on the observation of a class of events with low particle multiplicity between jets, attributable to the exchange of a strongly-interacting color-singlet.

1 Introduction

The properties of elastic and diffractive scattering are well-described by the phenomenology of pomeron exchange, where the pomeron is a color singlet with quantum numbers of the vacuum [1,2]. The landmark paper of Ingelman and Schlein[3] proposed that the observation of jets in diffractive events would probe the partonic nature of the exchanged object (expected to be the pomeron). This paper introduced the field of hard diffractive scattering, which refers to the subset of traditional diffractive interactions that has a high transverse momentum (p_T) scattering.

The study of hard diffractive processes has expanded dramatically in recent years. Results from UA8, HERA, and the TEVATRON include studies of diffractive jet production [4,5,6], rapidity gaps between high transverse energy jets [7,8,9,10], and a search for diffractive W-boson production [5]. These results give new insight into the object exchanged in the production of diffractive events. In this note we describe a preliminary search for single diffraction with high transverse momentum jets with the DØ detector at Fermilab for center-of-mass energies $\sqrt{s} = 1800\,\text{GeV}$ and $630\,\text{GeV}$. We also give an update on our studies of rapidity gaps between jets.

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2 Analysis

2.1 Hard Single Diffraction

An experimental signature of hard diffractive events is the presence of a rapidity gap [11,12], (lack of particle production in a rapidity or pseudorapidity[c] region) along with a hard scattering (jet production, W production, etc.). Since the pomeron is a color singlet, radiation is suppressed in events with pomeron exchange, typically resulting in a large rapidity gap [13]. In hard single diffraction a pomeron is emitted from one of the incident protons and undergoes a hard scattering with the second proton, often leaving a rapidity gap in the direction of its parent proton. We examine the process $p + \overline{p} \rightarrow j + j + X$ and look for the presence of a forward rapidity gap along the direction of one of the initial beam particles.

The event generator PYTHIA 5.7 [14] is used to study particle multiplicities for non-diffractive jet events. Generated events are required to have two jets with $E_T > 12\,\text{GeV}$ and $\eta < -1.6$. The multiplicity of particles opposite the jets in the forward region $2 < \eta < 4$ is plotted in Fig. 1(a). The distribution is well described by a negative binomial (NB) fit (smooth curve), with no significant excess of low multiplicity events. That is, the expected number of zero multiplicity (background rapidity gap) events due to multiplicity fluctuations is well-described by the NB distribution.

The particle multiplicity for diffractive production is obtained from the event generator POMPYT 1.0 [15], which is based on PYTHIA, but allows for the choice of a pomeron as one of the beam particles. The pomeron carries between 1% and 5% of the incident proton momentum, thus in the lab frame the jets produced are typically boosted, and a rapidity gap is expected on the side opposite the jets. Figure 1(b) shows the forward multiplicity distribution from a POMPYT simulation subject to the same kinematic requirements on the jets as the PYTHIA simulation. This sample is clearly dominated by rapidity gap and very low multiplicity events. For this plot a "hard gluon" pomeron structure has been chosen, which is equivalent to a 2-gluon model of the pomeron, a hypothesis which has some experimental support from UA8 [4], H1 [6], and ZEUS [6].

The existence of a diffractive signal in the experimental data may be observed as a larger number of rapidity gap events in the forward multiplicity distribution than expected from the non-diffractive background. Given sufficient detector resolution, sensitivity, and statistics, two components in the

[c] Pseudorapidity or $\eta = -ln[tan(\frac{\theta}{2})]$, where θ is the polar angle defined relative to the proton beam direction.

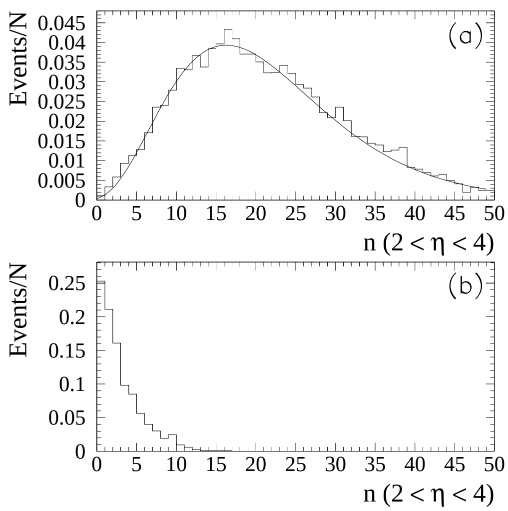

Figure 1: Particle multiplicities in Monte Carlo. (a) Multiplicity of particles produced in the region $2 < \eta < 4$ for PYTHIA events with two jets above 12 GeV in E_T and produced in the region $\eta < -1.6$. (b) Same distribution plotted for a POMPYT (hard diffraction) simulation.

multiplicity distribution can be resolved and the relative fraction of rapidity gap events in excess of expectations from a smoothly falling multiplicity distribution can be estimated.

The DØ detector [16] is used to provide experimental information on the fraction of jet events with forward rapidity gaps. This analysis primarily utilizes the uranium-liquid argon calorimeters which have full coverage for a pseudorapidity range of $|\eta| < 4.1$. The transverse segmentation of the projective calorimeter towers is typically $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$. The electromagnetic (EM) section of the calorimeters is used to search for rapidity gaps. The EM section is particularly useful for identifying low energy particles due to its low level of noise and ability to detect neutral pions. A particle is tagged by the deposition of more than 200 MeV of energy in a single EM calorimeter tower.

The data used in this study were obtained using an inclusive trigger requiring at least one jet above 15 GeV in E_T or a forward trigger requiring at least two jets above 12 GeV in the the region $\eta > 1.6$ or $\eta < -1.6$. As mentioned above, the jet system is expected to be boosted in diffractive jet production, thus a forward trigger can be utilized to provide an enhanced sample of diffractive events. Offline, two jets above trigger threshold are required for events used in the analysis. Events with multiple $p\bar{p}$ interactions or spurious jets

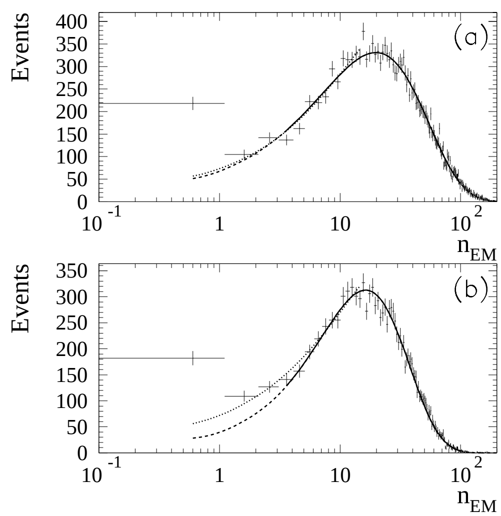

Figure 2: Number of electromagnetic calorimeter towers (n_{EM}) above a 200 MeV energy threshold for the region $2 < \eta < 4.1$ opposite the forward jets for center-of-mass energies of (a) 1800 GeV and (b) 630 GeV. The curves are NB fits to the data excluding low multiplicity bins as described in the text.

have been removed. Jets are reconstructed using a cone algorithm with radius, $R = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.7$.

The number of EM towers (n_{EM}) above a 200 MeV energy threshold is measured opposite the leading two jets in the region $2 < |\eta| < 4.1$ for the data. The (n_{EM}) distribution for the forward trigger is shown in Fig. 2 for $\sqrt{s}$ of (a) 1800 GeV and (b) 630 GeV. The distributions at both center-of-mass energies show a peak at zero multiplicity in qualitative agreement with expectations for a diffractive signal component. The fits shown are a NB fit to the data from $n_{EM} = 3$ to $n_{EM} = 100$ and a fit restricted to the rising edge of the distribution from $n_{EM} = 1$ to $n_{EM} = 14$. Both fits are extrapolated to $n_{EM} = 0$ as a background estimate to the zero multiplicity events. A fractional excess of rapidity gap events is defined to be the number of zero multiplicity events in excess of those predicted by the fit divided by the total number of events in the sample.

The fractional excess observed in the forward region for the $\sqrt{s} = 1800\,\mathrm{GeV}$ sample is $0.67 \pm 0.05\%$, where the error includes only statistical uncertainties and a systematic uncertainty based on the choice of range for the fit. An excess of rapidity gap events is also clearly observed at $630\,\mathrm{GeV}$ with a magnitude of $1 - 2\%$. The effects of various biases on the gap detection efficiency such as noise, multiple $p\overline{p}$ collisions in a single event, particle showering outside of jet cones, and particle production from spectator interactions have not been included in the excess measurement, and these corrections should be made before a direct comparison of the two samples is valid. Each of these effects is expected to reduce the number of observed rapidity gaps, thus correcting for these effects is expected to increase the magnitude of the signal measurement.

Several checks have been performed resulting in further support for the observation of an excess of rapidity gap events. The observed fractional excess is relatively insensitive to the calorimeter energy threshold. The method of identifying diffractive processes by measuring rapidity gaps has been succesfully applied in resolving the soft single diffraction component in the total $p\overline{p}$ cross section. The rapidity gap events ($\mathrm{n_{EM}} = 0$) typically have zero multiplicity in other available detectors, such as hadronic calorimeters, forward tracking, beam hodoscopes, and forward muon chambers.

The forward gap fraction measurement for the $\sqrt{s} = 1800\,\mathrm{GeV}$ sample may be extended to unrestricted jet topologies by use of an inclusive trigger, which provides a sample of events unbiased by any jet pseudorapidity selection. Events are selected with at least two jets of $E_T > 15\,\mathrm{GeV}$. We divide the data samples into subsets based on the measured boost of the leading two jets, where the boost is defined as $\eta_{\mathrm{Boost}} = (\eta_1 + \eta_2)/2$, and plot the forward gap fraction as a function of the average boost in Fig. 3. A clear trend is observed where the forward gap fraction increases with the boost of the jets, although the exact shape may be modified by corrections for the gap detection efficiency.

2.2 Hard Double Pomeron Exchange

The same experimental methods may be applied to a search for hard double pomeron exchange. In this process both incoming protons emit a pomeron and the two pomerons interact to produce a jet system. Rapidity gaps are expected to be produced along each forward beam direction, since there is no color connection between the jet system and the beam particles. In this analysis we have selected an enhanced sample of forward rapidity gap events with a dedicated single gap trigger. The same jet requirements were implemented as in the inclusive trigger, but we additionally required a veto on forward particles in either beam direction, using the scintillator beam hodoscopes which bracket

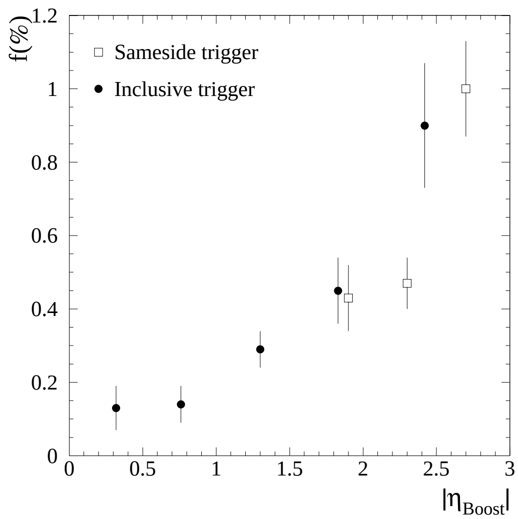

Figure 3: Forward gap fraction as a function of $|\eta_{\rm Boost}|$ for the 1800 GeV data. Data from the inclusive trigger are shown as circles, the forward (same-side) trigger data are shown as squares.

the DØ collision region. Events were selected to have a rapidity gap ($n_{\rm EM} = 0$) in the direction of the online veto. These data consist of about 40,000 single gap events at $\sqrt{s} = 1800$ GeV, compared to the approximately 200 events observed in the forward trigger sample after background subtraction. This enhanced diffractive sample is used to search for double forward gap events, in which we require no towers above threshold in both forward calorimeter regions along with two jets with $E_T > 15$ GeV and $|\eta| < 1.0$. This is an expected topology for events produced in hard double pomeron exchange. The $n_{\rm EM}$ distribution for the veto-trigger is plotted in Fig. 4 for the forward region ($2 < |\eta| < 4.1$) opposite the tagged rapidity gap. We clearly observe a sample of double gap events, although an interpretation of them in terms of hard double pomeron exchange requires further study.

2.3 Rapidity Gaps Between Jets

Two jets separated by a rapidity gap has been proposed as a signature for jet production via the exchange of a color-singlet (colorless) object [17,18]. Convinc-

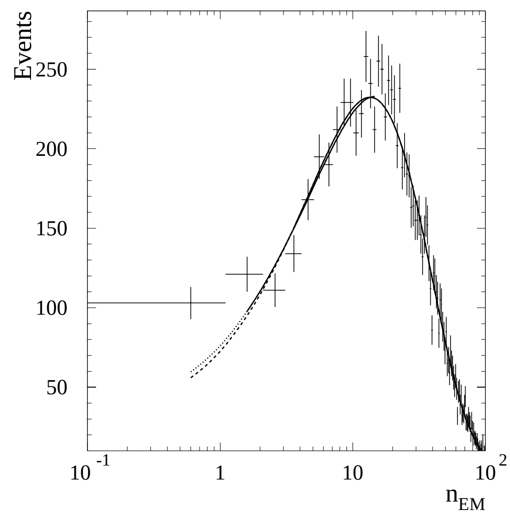

Figure 4: The n_{EM} distribution opposite the tagged gap for single gap trigger data. The zero multiplicity events are double gap events in this sample. The curves are NB fits to the data excluding low multiplicity bins as described in the previous section.

ing new evidence for this process is demonstrated by comparing the multiplicity distributions for two samples, each with about 23,000 dijet events [9]. Events with multiple $p\bar{p}$ interactions or spurious jets have been removed. Both samples require the leading two jets to have $E_T > 30\,\mathrm{GeV}$ and $|\eta| > 2$ and differ only by the sign of the quantity $\eta_1 \cdot \eta_2$, which is positive for same-side jet events and negative for opposite-side events. The same-side sample provides a qualitative measure of the color-exchange background multiplicity in the central rapidity region due to the color flow between the scattered and spectator partons. Hard single diffraction, which could produce a central rapidity gap with two forward jets, is highly suppressed by the trigger which required a coincidence of hits between the forward and backward beam hodoscopes. Fig. 5 shows the number of EM calorimeter towers above a 200 MeV transverse energy threshold (n_{cal}) versus the number of central tracks (n_{trk}) in the region $|\eta| < 1.3$ for the (a) opposite-side and (b) same-side jet samples [9].

The two distributions are similar in shape except at very low multiplicities, where the opposite-side sample has a striking excess of events, consistent with a color-singlet exchange process. The fractional excess above a parametrization

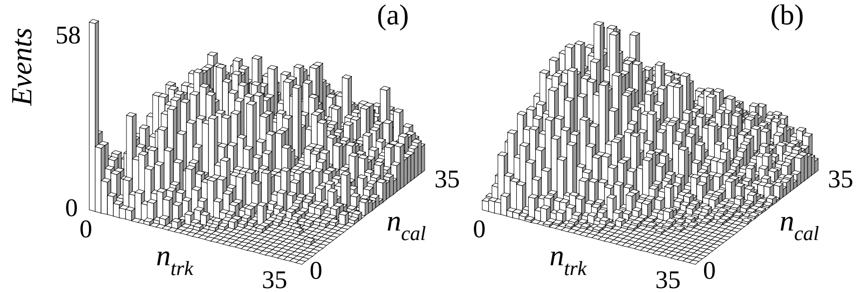

Figure 5: The calorimeter tower multiplicity (n_{cal}) versus the charged track multiplicity (n_{trk}) in the pseudorapidity region $|\eta| < 1.3$ for the (a) opposite-side and (b) same-side samples as described in the text.

of the background is $1.07 \pm 0.10(\mathrm{stat})^{+0.25}_{-0.13}(\mathrm{syst})\%$, which is consistent with a strongly-interacting color-singlet (colorless) exchange process and cannot be explained by electroweak exchange alone [9].

In addition to these recently published results on strongly-interacting color-singlet exchange, we have performed a new DØ preliminary study from a much larger data sample of about 100,000 events obtained during the 1994-95 collider run. This data sample is comprised of several triggers to allow the measurement of color-singlet exchange as a function of the η separation and E_T of the jets. The excess is observed to be on the order of 1% for a large range of E_T. Although the dijet cross section falls by three orders of magnitude over this range in transverse energy, the fraction of color-singlet exchange is observed to be roughly constant. The excess has some luminosity dependence which must be corrected before a final measurement of color-singlet exchange as a function of E_T and η is quoted. We have also studied multiplicity correlations in different regions of the events and find that color-singlet candidate events generally have lower multiplicity in all regions than color exchange events.

3 Conclusion

We have observed the presence of forward rapidity gaps in events with high E_T jet production with the DØ detector at Fermilab. The fraction of forward rapidity gap events observed is in excess of those expected to be produced via multiplicity fluctuations at center-of-mass energies of 1800 GeV and 630 GeV. This is consistent with expectations from hard single diffractive jet production and provides the first experimental evidence for this process at $\sqrt{s} = 1800\,\mathrm{GeV}$. The forward gap fraction is observed to increase with the boost of the leading dijet system in the 1800 GeV data. We also observe a class of events containing high E_T central jets and two forward rapidity gaps, consistent with a hard double pomeron exchange event topology. Analysis continues on our pioneering measurement of rapidity gaps between high transverse momentum jets using a larger data sample.

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