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DØ Note 1920

A Search for Rapidity Gap Events in p$\bar{\text{p}}$ Collisions at DØ

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ABSTRACT

Preliminary results from a search for jet events with rapidity gaps are presented. These events were produced in p$\bar{\text{p}}$ interactions at $\sqrt{s} = 1.8$ TeV and measured with the DØ detector at Fermilab. The fraction of events with a rapidity gap is measured as a function of the pseudo-rapidity difference between the cone edges of the two leading jets ($\Delta\eta_c$). An upper limit on the fraction of events with no particles between jets is measured at 0.0093 at a 90% confidence level for events with $\Delta\eta_c > 3$ and jet transverse energies greater than 30 GeV.

Introduction

Rapidity gaps, which are defined as regions of pseudo-rapidity containing no particles, are expected between the final state jets when a color singlet is exchanged by the interacting partons of the beam particles. The lack of color connecting the initial state partons results in destructive interference between the initial and final state radiation. Therefore, hadrons are produced only between the outgoing jets and the spectator partons, resulting in a region of phase space containing no particles between the jets. A more detailed description of the DØ rapidity gap analysis is described in reference[1].

In standard QCD interactions, in which a single gluon or quark is exchanged, color connects the jets and rapidity gaps are rarely produced for large jet separations, but there can be fluctuations which mimic rapidity gap events from colorless exchange. This QCD background to gap events from colorless exchange is prevalent at small $\Delta\eta_c$ but becomes increasingly suppressed for large $\Delta\eta_c$, assuming that the average particle multiplicity between jets scales linearly with $\Delta\eta_c$ as in minimum bias events[2,3]. Rapidity gap events from QCD processes are estimated to occur in less than one out of 10^4 events for $\Delta\eta_c > 2$ from PYTHIA Monte Carlo[4] studies. This rate of background gap events is more than two orders of magnitude smaller than that predicted by minimum bias Monte Carlos[5], due to the larger average multiplicity of jet events.

Events in which a photon, or a W or Z boson is exchanged are expected to give a rapidity gap topology. The cross section for rapidity gap events from electroweak exhange is small compared to single gluon or quark exchange $\sigma_{EW}/\sigma_{QCD} \approx 10^{-3}$[4]. Bjorken[6] has noted that hard Pomeron (colorless two-gluon bound state) exchange may have a significant cross section. Using a two-gluon model, he obtains $\sigma_{2g}/\sigma_{QCD} \approx 10^{-1}$.

Events in which a color singlet is exchanged do not ensure a rapidity gap however, because of spectator interactions which fill up the gaps. The survival probability of the gap, $< |S^2| >$, which is the probability of there being no spectator interaction which fills up the gap, has been estimated to be $10 - 30\%$, depending on different model assumptions[4,6,7], and is expected to be independent of the $\Delta\eta_c$ between the jets and the E_T of the jets.

Experimentally, one can only measure the product of the number of events with a rapidity gap and the survival probability of the gap. An experimentally accessible quantity is the fraction of events with a rapidity gap, defined as

$$f(\Delta\eta_c) = \frac{\sigma_{gap}(\Delta\eta_c)\cdot < |S^2| >}{\sigma(\Delta\eta_c)} \qquad (1)$$

where $\sigma(\Delta\eta_c)$ is the cross section for producing jets with $\Delta\eta_c$ separation between the jet cone edges and $\sigma_{gap}(\Delta\eta_c)$ is the cross section with no particles produced in the $\Delta\eta_c$ region. The rapidity separation between the jet axes $\Delta\eta$ and the separation between the jet edges $\Delta\eta_c$ are related by $\Delta\eta_c = \Delta\eta - 2R$ where R is the radius of the jet cone. Using a value of $< |S^2| >= 0.1$ combined with the cross section estimates referenced above, an order of magnitude prediction of the gap fraction due to color singlet exchange of $10^{-4} \leq f \leq 10^{-2}$ is obtained.

Data Sample

The DØ detector has been described in detail elsewhere[8]. This analysis utilizes the data from the uranium-liquid argon calorimeters which have coverage out to a rapidity range of $|\eta| \approx 4$. The goal of the analysis described here is to measure the fraction of events with a rapidity gap as a function of the η separation between the jets, utilizing the large $\Delta\eta_c$ coverage at DØ.

There were two triggers used to collect data for this analysis. The standard inclusive jet trigger required only one jet with $E_T > 30$ GeV and no η requirements while the high $\Delta\eta_c$ trigger required a $\Delta\eta_c > 2.6$ separation between any two jets with the requirement $E_T > 25$ GeV and $|\eta| > 2$. The calorimeter hardware trigger was based on trigger towers of size 0.2×0.2 in $\eta - \phi$ space and was instrumented for towers with $|\eta| \leq 3.2$ in the 1992-1993 data run on which this analysis is based. The number of events recorded from the inclusive trigger was 551,000 based on an integrated luminosity of 180nb^{-1}, and there were 73,500 events recorded from the high $\Delta\eta_c$ trigger with a luminosity of 5.1pb^{-1}. There were no requirements on the multiplicity or energy between the jets, as this would cause a bias on the measured fraction of events with a gap.

In the offline analysis, jets are reconstructed using an iterative jet cone algorithm with a cone radius of 0.7[9]. If two jet cones overlap, then the jets are merged if more than 50% of the E_T of the lowest E_T jet is shared with the other. Otherwise they are split with towers in the overlap region going to whichever jet centroid is closer. In both cases, the jet energy and position are redetermined. Events with spurious jets due to detector effects are removed with a series of cuts that result in a 15% reduction in the data sample and are estimated to be more than 95% efficient at rejecting fake jets while removing only 4% of real jet events[10]. These cuts also remove background from electrons and direct photons. The transverse energy of the remaining jets is corrected for nonlinear response and geometrical inefficiencies in the calorimeter, out-of-cone effects, the underlying event, and the overall jet energy scale. These effects result in an approximately 20% correction to the E_T of the jets in this data sample[11].

Further cuts require that the vertex of the event be < 30 cm. The two leading jets are each required to have $E_T > 30$ GeV. The final event sample has 95,500 events with a $\Delta\eta_c < 2.6$ requirement from the inclusive trigger and 34,300 events from the high $\Delta\eta_c$ trigger.

Results

In this preliminary data analysis, the gap fraction quantity measured is

$$f_{exp}(\Delta\eta_c) = \frac{N_{EM=0}(\Delta\eta_c)}{N(\Delta\eta_c)}. \qquad (2)$$

where $N_{EM=0}$ is the number of events with no electromagnetic calorimeter towers above an E_T threshold of 200 MeV in the $\Delta\eta_c$ region out of a total of N events. An electromagnetic tower is the sum of all electromagnetic calorimeter layers in a 0.1×0.1 region in $\eta - \phi$ space. The hadronic layers are more subject to uranium noise, which complicates the analysis, and are therefore not used at this time. Test beam studies indicate that the electromagnetic tower cut is $96 - 100\%$ efficient in detecting $2 - 10$ GeV electrons and neutral pions and $40 - 62\%$ efficient in detecting $2 - 10$ GeV charged pions.

In figure 1, the measured gap fraction as defined in equation 2 is plotted. The fraction of events with a gap in rapidity is observed to decrease as $\Delta\eta_c$ increases, presumably due to the decrease in fluctuations from standard QCD interactions giving fake gap events. For $\Delta\eta_c > 3$, a relatively flat region is observed for which the uncorrected gap fraction is calculated as

$$f_{exp}(\Delta\eta_c > 3) = (2.4 \pm 0.3^{(stat)}) \times 10^{-3}. \qquad (3)$$

This measurement of the gap fraction is clearly detector dependent. The particle detection inefficiencies resulting from upstream dead material, decreased response to low energy particles, and non-uniform geometric acceptance, especially in the region between calorimeters, cause the measured value to be higher than the true value. Effects such as multiple interations, out-of-cone fragmentation and showering, and noisy calorimeter cells, produce extra hit towers between the jets and result in a measurement lower than the true value.

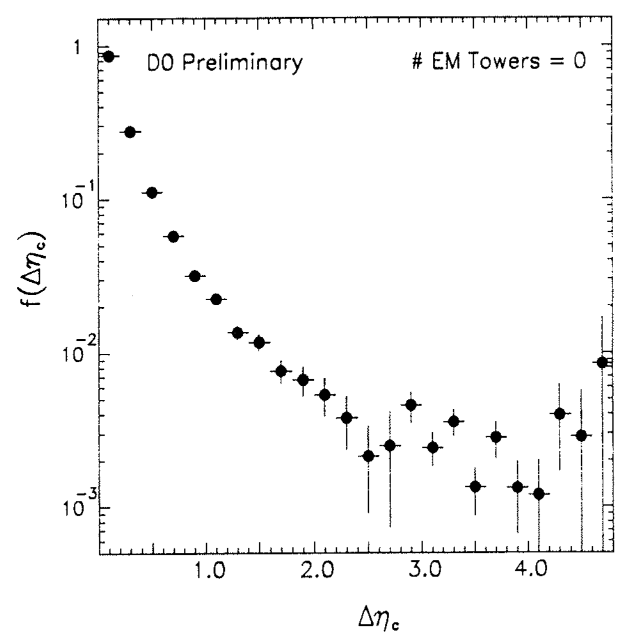

Figure 1: The fraction of events with no electromagnetic towers above a 200 MeV threshold and with the leading two jets each having $E_T > 30$ GeV.

In order to quote an upper limit on the gap fraction, it is sufficient to correct only for those effects which have decreased the measured value of $f(\Delta\eta_c)$. The largest correction is due to the occurrence of a second interaction in the same bunch crossing of the hadron beams.

This interaction would most likely be a minimum bias event, which is observed at DØ to give at least one hit tower in a rapidity interval of $\Delta\eta_c > 3$ in about 95% of the events. Using the average instantaneous luminosity of the sample and assuming Poisson statistics, it is estimated that $45\% \pm 10\%$ of the events with $\Delta\eta_c > 3$ have at least one hit tower due to an additional interaction. The effect on the gap fraction from calorimeter noise arising from the uranium plates and other instrumental effects is estimated to contaminate $20\% \pm 10\%$ of the events.

These corrections are then applied to the measured gap fraction in order to obtain a corrected value for $f(\Delta\eta_c > 3)$:

$$f_{exp}(\Delta\eta_c > 3)^{corrected} = (6.8 \pm 0.8^{(stat)} \pm 1.7^{(sys)}) \times 10^{-3}. \tag{4}$$

This value of the gap fraction corresponds to an upper limit at the 90% confidence level of

$$f_{exp}(\Delta\eta_c > 3)^{upper} < 9.3 \times 10^{-3}. \tag{5}$$

Conclusions

First measurements of rapidity gaps in jet events in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV at the DØ detector at Fermilab have been presented. Events with rapidity gaps have been observed, where a gap is defined as no electromagnetic calorimeter towers above a 200 MeV threshold in the $\Delta\eta_c$ region. An upper limit on the fraction of events with a rapidity gap is measured at $f < 0.93\%$ at a 90% confidence level.

Future improvements in the gap definition will increases the efficiencies and result in a decreased upper limit. Some portion of the rapidity gap events observed for $\Delta\eta_c > 3$ may be due to color singlet exchange, but in order to make this association it is necessary to show that these events cannot be explained by $\eta-$dependent efficiencies or by multiplicity fluctuations in standard QCD events.

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