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Rapidity Gaps Between Jets in Photoproduction at HERA

H1 Collaboration

Abstract

Photoproduction events which have two or more jets with transverse energy $E_T > 4.5$ GeV have been studied in the γp centre of mass energy range 158 GeV $< W <$ 247 GeV with the H1 detector at HERA. The fraction $f(\Delta\eta)$ of events with a rapidity gap between the two highest E_T jets is measured as a function of the rapidity separation $\Delta\eta$ between the jet axes. A gap is defined as the absence between the jets of any particle with energy $E > 400$ MeV. The gap fraction is observed to fall exponentially up to $\Delta\eta < 3.5$. An excess of events with a large rapidity gap, over what would be expected from standard photoproduction processes, is observed for $\Delta\eta > 3.5$. The excess can be interpreted as the result of the exchange of a strongly interacting colour singlet object.

Abstract 380
Parallel Sessions 2,3,4
Plenary Sessions 1,2,3

1 Introduction

The cross section for lepton-proton collisions at HERA is dominated by photoproduction, where the lepton radiates a quasi-real photon which then interacts with the proton. In a small number of such events, the photon-proton interaction results in the formation of jets. In this case, a hard process is assumed to have taken place and the cross section may be treated perturbatively within QCD. Two main process types are distinguished, known as direct and resolved photoproduction. In the direct case, the photon interacts as a point-like particle with a parton in the proton. In the resolved case, the photon behaves more like a hadronic object, described in terms of parton distribution functions, and a parton from the photon interacts with a parton from the proton. If the transverse momentum exchanged is large enough, the high p_T outgoing partons result in jets observable in the detector.

In the majority of high p_T photoproduction events, the hard scattering is mediated by a quark or a gluon, such that the outgoing partons are connected by colour strings both to the corresponding remnants and to each other. These colour connections result in observable hadronic activity in the rapidity interval between the two final state jets. However if a strongly interacting net colour singlet object is exchanged in the hard process, there are no colour connections between the outgoing partons. At the hadron level, an absence of energy flow is then expected in the rapidity region between the jets.

The 'gap fraction', $f(\Delta\eta)$, is defined as the proportion of events containing two or more high E_T jets for which there is a gap in rapidity between the two highest E_T jets as a function of the jet - jet separation $\Delta\eta$. For processes involving the exchange of objects with net colour, $f(\Delta\eta)$ is expected to decrease exponentially with increasing $\Delta\eta$. If colour singlet exchange also plays a role, the gap fraction is expected to level off at some value of $\Delta\eta$.

A calculation [1] of elastic parton - parton scattering at high p_T in which the exchanged colour singlet object is a BFKL gluon ladder [2] has been performed in the limit $\Delta\eta \to \infty$. This has been generalised to finite $\Delta\eta$ for the related processes of vector meson photoproduction and electroproduction at large momentum transfer $|t|$ [3]. This later calculation has been extended to the case of high E_T dijet photoproduction [4]. In this framework, the colour singlet exchange cross section is expected to rise with increasing $\Delta\eta$.

In $p\bar{p}$ dijet production, it has been found that the gap fraction $f(\Delta\eta)$ reaches a minimum value of around 0.01 [5, 6]. At HERA, the ZEUS collaboration has found a plateau height of $f(\Delta\eta) \simeq 0.1$ [7]. One possible interpretation of the difference in these values for $p\bar{p}$ and γp interactions is that soft interactions can take place between photon and proton constituents that do not take part in the hard subprocess, thereby destroying the rapidity gap [8]. In a model based on colour transparency, the probability that the rapidity gap survives is expected to depend on the transverse size of the interacting particles [9]. The minimum gap fraction is then expected to be higher for jet production initiated by the anomalous component of resolved photon structure than that for the vector dominance component or for $p\bar{p}$ interactions.

2 The H1 Detector

A detailed description of the H1 apparatus can be found elsewhere [10]. The following briefly describes the detector components relevant to this analysis.

A liquid argon (LAr) calorimeter [11] covers the range in polar angle $4° < \theta < 153°$ with full azimuthal coverage, where θ is defined with respect to the proton beam direction ($+z$ axis). The LAr consists of an electromagnetic section with lead absorbers and a hadronic section with steel absorbers, of combined depth between 4.5 and 8 interaction lengths. Both sections are highly segmented in the transverse and longitudinal directions with about 44000 cells in total. The absolute energy scales are known to 3% and 4% for electromagnetic and hadronic energies respectively. The polar region $153° < \theta < 177.8°$ is covered by the SPACAL [12], a lead / scintillating fibre calorimeter with both hadronic and electromagnetic sections. The hadronic energy scale uncertainty is presently 10%. The luminosity is measured from the reaction $ep \to ep\gamma$ with two TlCl/TlBr crystal calorimeters [10] installed in the HERA tunnel. The electron tagger is located at $z = -33$ m from the interaction point in the direction of the outgoing lepton beam and the photon tagger at $z = -103$ m.

3 Event Selection

The data for this analysis were collected with the H1 detector during the 1996 running period, when HERA collided 27.6 GeV positrons on 820 GeV protons. Photoproduction events were selected by detecting the scattered positron in the electron tagger. This restricts the virtuality of the photon to $Q^2 < 0.01$ GeV^2. The photon - proton centre of mass energy is restricted to the range $158 < W < 247$ GeV to avoid regions of low electron tagger acceptance.

Jets were found using the CDF cone algorithm [13] with cone size 1.0 and $E_T^{jet} > 4.5$ GeV. Jet pseudo-rapidities ($\eta = -\ln\tan[\theta/2]$) are restricted to the range $-2.82 < \eta < 2.35$, ensuring that the jet cones are completely contained within the H1 calorimeters.

All events with two or more jets reconstructed by this method are selected and divided into four intervals in $\Delta\eta$ in the region $2.0 < \Delta\eta < 4.0$, such that the bin sizes are always larger than the resolution in $\Delta\eta$. A gap event is defined as an event in which there is no calorimeter cluster of energy $E > 400$ MeV in the rapidity interval between the edges of the cones containing the two highest E_T jets. The uncorrected gap fraction is given by the ratio of gap events to the total number of dijet events in each interval of $\Delta\eta$.

4 Data correction and systematic errors

The data are corrected for detector acceptance and bin migration effects using the HERWIG 5.9 [14] Monte Carlo event generator, containing the GRV-HO parton distributions for the photon [15]. In photoproduction interactions, the photon and the proton remnants are known to play an important role in the description of the energy flow between jets [16]. In HERWIG, remnant interactions can be simulated by the addition of soft processes underlying the hard scattering. The inclusive jet profiles and the energy flow between the jets are found to be best described when 20% of events contain an additional soft underlying process. This matches the optimal mixture found for other recent H1 dijet studies [17]. The calculation of colour singlet exchange based on the BFKL equation described in section 1 [4] has been implemented in the HERWIG generator [18]. The simulation was mixed with the standard resolved and direct photoproduction sample in order to obtain the best fit to the observed gap fraction distribution. The resulting simulation was used to correct the data for detector acceptance effects and migrations. The jet profiles from the full data sample are shown in figure 1, together with the prediction of the HERWIG simulation. The transverse energy flow both inside and outside the jet cones is reasonably well described.

The largest contribution to the systematic error arises from the limited sizes of the simulation samples used to determine the detector acceptance. Other important sources of systematic error are the 4% uncertainty in the liquid argon hadronic energy scale and the 10% uncertainty in the SPACAL hadronic energy scale. The acceptance corrections have also been performed using a simulation that did not contain the colour singlet exchange process. The difference in the results was applied as a further systematic error.

5 Results

The gap fraction, corrected to the case in which there is no hadron in the rapidity region between the jets with energy greater than 400 MeV, is shown in figure 2. Also shown is the prediction from standard photoproduction (direct and resolved contributions) using the HERWIG Monte Carlo event generator. Within the errors the data are well described without any colour singlet exchange contribution throughout the region $2.0 < \Delta\eta < 3.5$, whereas an excess of events with a rapidity gap between the jets is observed for $3.5 < \Delta\eta < 4.0$. Integrated over this latter interval, the measured value of $f(\Delta\eta)$ lies more than two standard deviations above the prediction of the simulation without a colour singlet exchange contribution. The HERWIG simulation that also contains a colour singlet exchange contribution (not shown) describes the data well in all $\Delta\eta$ intervals.

In order to check that the observed excess at large $\Delta\eta$ of events with rapidity gaps between the jets is not dependent on the definition of the gap fraction, the analysis has also been performed with a number of slightly different gap definitions. The maximum hadron energy between the jets was varied between 350 MeV and 450 MeV. The effective cone radius was increased from 1.0 to 1.1, allowing particles to escape from the edges of the jet cones without destroying the rapidity gap. These changes were found to affect the overall normalisation of the $f(\Delta\eta)$ distribution by up to 25% without significantly affecting the shape. The conclusion that a colour singlet exchange is required in the large $\Delta\eta$ region is therefore not affected by the details of the definition of the gap between the jets.

The minimum value of $f(\Delta\eta)$ in this analysis is approximately 0.15, more than an order of magnitude larger than that obtained in $p\bar{p}$ interactions, where the minimum $f(\Delta\eta) \simeq 0.01$ [5, 6]. This difference between the $p\bar{p}$ and γp cases is indicative of a difference in rapidity gap survival probabilities. This is interesting in terms of the understanding of the effects of colour transparency in photon interactions. The shape of the $f(\Delta\eta)$ distribution measured here is consistent with that obtained by the ZEUS collaboration [7], although the minimum $f(\Delta\eta)$ is slightly lower in the ZEUS data. This could be explained by the difference in the gap definition between the two analyses. It would be most interesting to extend the accessible region in $\Delta\eta$ to see whether $f(\Delta\eta)$ shows a rise for larger $\Delta\eta$, as expected for a BFKL type colour singlet exchange.

6 Acknowledgments

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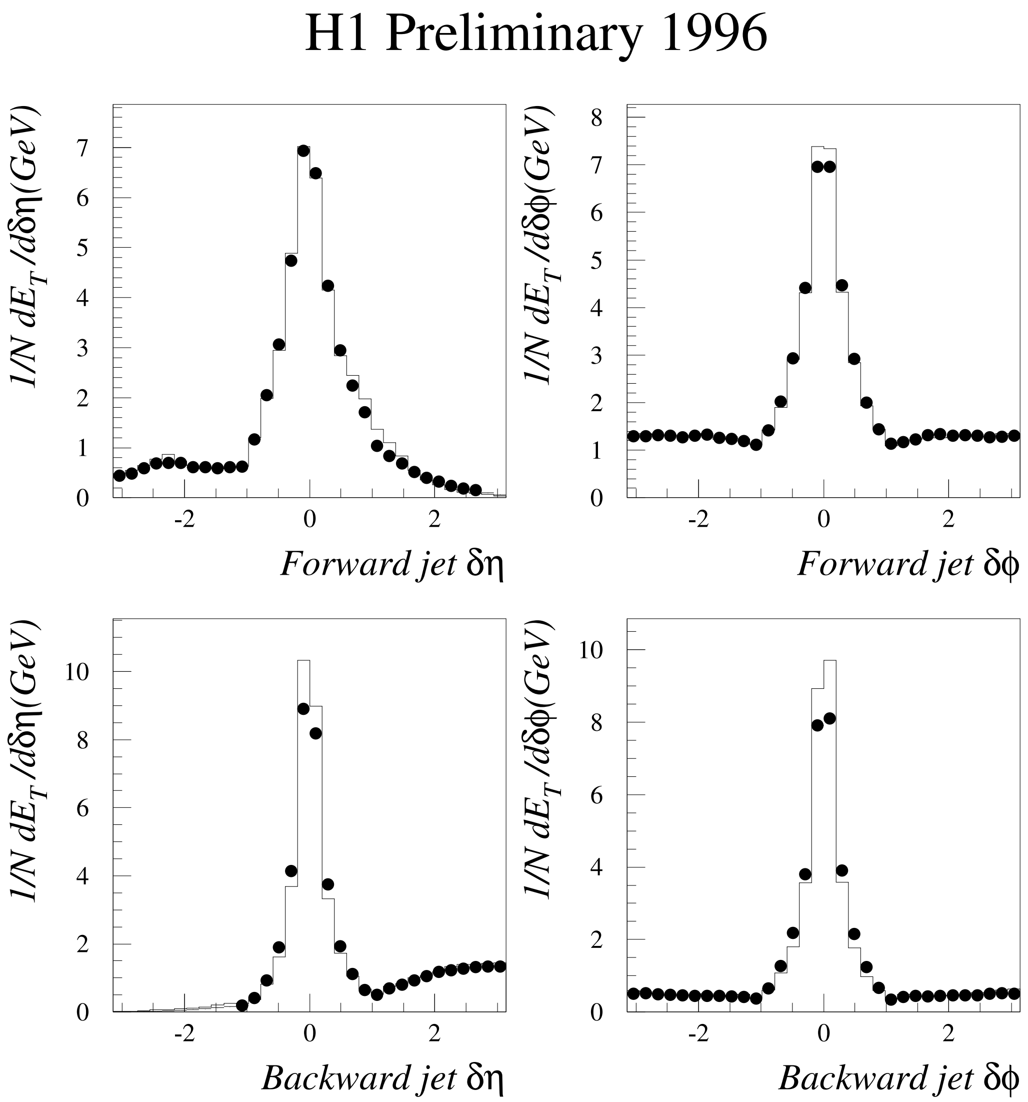

Figure 1: Jet profiles for the forward (proton direction) and backward jets. H1 data are shown as points. The histograms are the prediction of the HERWIG simulation including a strongly interacting colour singlet exchange component.

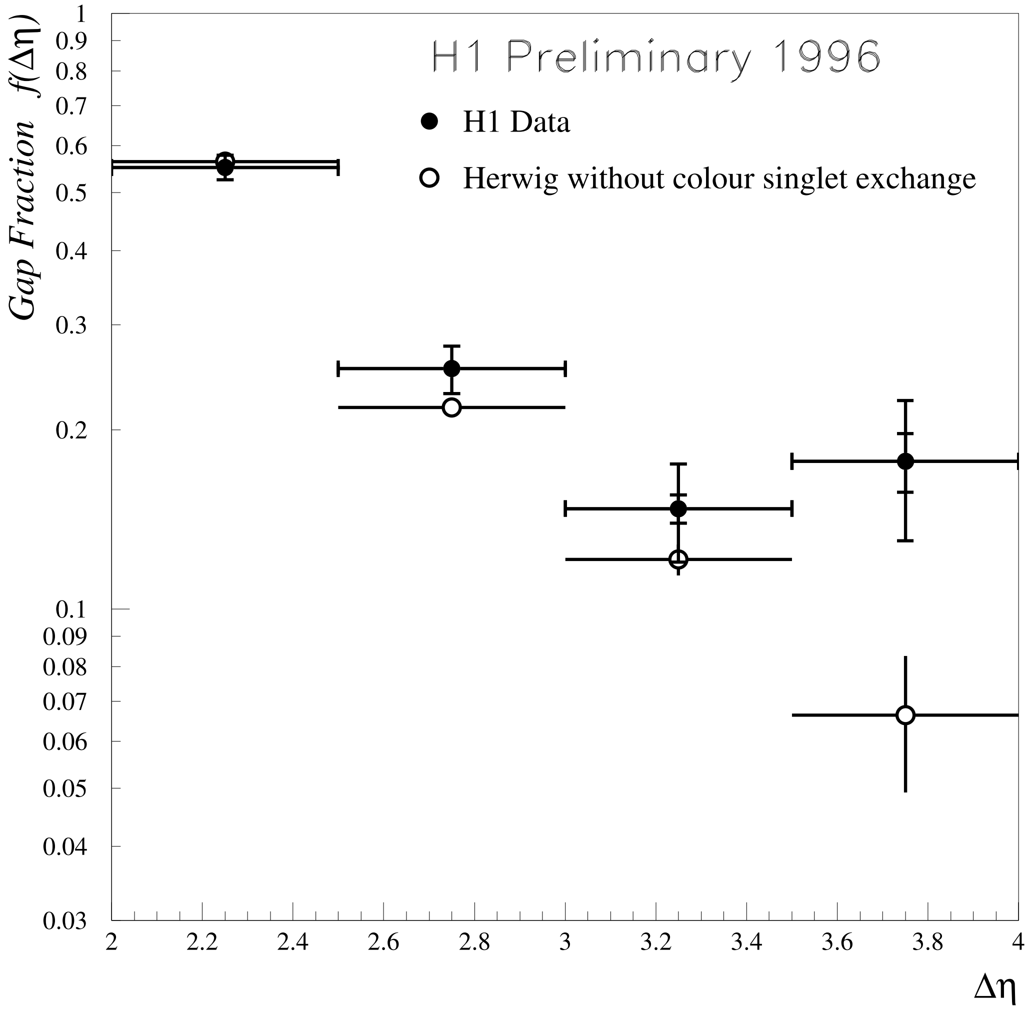

Figure 2: The corrected gap fraction $f(\Delta\eta)$. H1 data are solid points. The inner error bars show the statistical errors and the outer error bars show the sum in quadrature of the statistical and systematic errors. The prediction of the HERWIG simulation without a colour singlet exchange component is shown, together with statistical errors, as the open points.