RAPIDITY GAPS BETWEEN JETS AT LARGE RAPIDITY SEPARATIONS IN PHOTOPRODUCTION AT HERA

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Abstract. Dijet events in photon-proton collisions in which there is a rapidity separation between the two highest E_t jets $\Delta\eta > 2.5$ are studied with the H1 detector at HERA. Jets are defined using the inclusive k_t algorithm. Rapidity gap events are defined as events in which the sum of the transverse energy of all jets between the two highest E_t jet axes is less than E_t^{cut}, for $0.5 < E_t^{cut} < 5.0$ GeV. The gap fraction, defined as the fraction of dijet events with a rapidity gap, is plotted for different E_t^{cut} values for the inclusive dijet sample, and differentially in the dijet separation, $\Delta\eta$, and in x_γ^{jets} and x_p^{jets} the fraction of the photon's and proton's momentum entering the hard scatter. A large excess of events with rapidity gaps at low values of E_t^{cut} is observed above the expectation from standard photoproduction processes.

I INTRODUCTION

Events with large rapidity gaps in the hadronic final state and a perturbatively hard scale at both ends of the colourless exchange have been observed at both the Tevatron [1,2] and HERA [3]. Such events are characterised by two hard jets separated by a large rapidity interval and an unusually small energy flow between the jets. We tag such events by measuring the energy flow and define a gap event in terms of this energy, introducing a further scale.

The rate of such events depends not only on the cross-section for colour-singlet exchange but also on the gap survival probability: the probability that a gap formed in the hard scatter may later be destroyed by further parton-parton interactions. This interplay can be treated as a perturbative exchange, such as the BFKL calculation, plus an overall gap survival probability or it may be possible to take a purely perturbative approach if the gap is defined in terms of a minimum energy which is greater than Λ_{QCD} [4]. Alternatively, the production process can be treated non-perturbatively, such as in soft color models [5].

II EVENT SELECTION

The data for this analysis were collected with the H1 detector [6] during the 1996 running period, when HERA collided 27.6 GeV positrons with 820 GeV protons, with an integrated luminosity of 6.2 pb^{-1}. Photoproduction events were tagged by measuring the scattered electron, restricting the photon virtuality to $Q^2 < 0.01$ GeV^2. In order to select areas of high tagger acceptance the photon-proton centre of mass energy is restricted to the range $165 < W < 233$ GeV.

The inclusive k_t clustering algorithm [7] was applied to the final state, assigning every particle excluding the scattered electron to a jet. An inclusive event sample was selected by keeping events with 2 or more jets, where the 2 highest E_t jets in the event fulfilled:

$$E_t^{jet1} > 6.0 \text{ GeV} \tag{1}$$
$$E_t^{jet2} > 5.0 \text{ GeV} \tag{2}$$
$$\eta^{jet1}, \eta^{jet2} < 2.8 \tag{3}$$
$$\Delta\eta > 2.5 \tag{4}$$

Any other jets in the event are refered to as mini-jets.

In standard QCD processes the colour connection between the jets results in an energy flow in the entire space between them; this is suppressed in colour-singlet exchange. To distinguish between these two processes we measure the transverse energy between the jets, $\not{E}_t^{jets}$. This is calculated by summing the transverse energy of all mini-jets whose jet-centre is between the axes of the two highest E_t jets in rapidity:

$$\not{E}_t^{jets} = \sum E_t^{minijets} \quad , \quad \eta_{forward}^{jet} > \eta_{minijet} > \eta_{backward}^{jet} \tag{5}$$

A rapidity gap event is then defined as an event in which $\not{E}_t^{jets} < E_t^{cut}$, where E_t^{cut} is varied between 0.5 GeV and 5.0 GeV. This definition is infra-red safe because it is only in terms of the sum of k_t jets. In addition, a gap is also relatively insensitive to hadronisation effects because any radiation at its edge which may destroy the gap is likely to be included in a jet which has its centre outside the gap. Further details can be found in [8].

This definition uses the maximum area of $\eta - \phi$ space which can be included in the rapidity gap search. We use the whole region in order to reduce the possibility that a colour-octet exchange can form a rapidity gap by a statistical fluctuation in the number of particles in this region. This reduction in the colour-octet contribution allows a significant excess of rapidity gap events to be seen without having to increase the cut on $\Delta\eta$. As the $\Delta\eta$ distribution falls rapidly this produces a large increase in the available statistics. Two scaling variables x_γ^{jets} and x_p^{jets} are also defined,

$$x_\gamma^{jets} = \frac{\sum_{jets1,2} (E^{jet} - p_z^{jet})}{\sum_{objects} (E^{obj} - p_z^{obj})} \tag{6}$$

$$x_p^{jets} = \frac{\sum_{jets1,2}(E^{jet} + p_z^{jet})}{2E_p} \tag{7}$$

where E_p is the energy of the incoming proton and the sum in the denominator of x_γ^{jets} is over all the objects in the final state, excluding the scattered electron. In leading order jet production x_γ^{jets} and x_p^{jets} are equal to the fraction of the photon's and proton's momentum entering the hard scatter.

III RESULTS AND MODEL COMPARISONS

The PYTHIA 5.7 [9] and HERWIG 5.9 [10] Monte Carlo event generators were used to correct the data for detector acceptance and bin migration effects. In order to describe the data both included a colour-singlet exchange model. The resolved photoproduction events in PYTHIA included a model of multiple interactions, but no multiple interactions were included in HERWIG . The difference between the two correction methods was assigned as a systematic error.

PYTHIA was used with $P_t^{min} = 2.2$ GeV and $P_t^{mi} = 1.5$ GeV, P_t^{mi} is the minimum P_t of the multiple scatters. The rate of multiple scatters is set by P_t^{mi} and this is chosen such that the jet pedestals are well described. When making comparisons to the data HERWIG was used with JIMMY [11] which simulates multiple interactions and with $P_t^{min} = 1.8$ GeV and $P_t^{mi} = 1.8$ GeV. These parameters were tuned to give the best description of the jet pedestals and other H1 data.

HERWIG incorporates the BFKL [12] leading logarithmic approximation calculation of Mueller and Tang [13], with the choice of fixing $\alpha_s = 0.17$. This is not yet implemented in PYTHIA , consequently to describe the data high-t photon exchange with the cross section multiplied by a factor of 1200 was added.

The gap fraction, defined as the fraction of dijet events with a rapidity gap, is plotted for different E_t^{cut} values for the inclusive dijet sample in figure 1. The predictions of both PYTHIA and HERWIG with JIMMY underestimate the observed gap fraction. The excess in the data over the models is for low values of E_t^{cut} where colour-singlet exchange events are expected to be. The predictions are very sensitive to the way that the multiple interactions are modeled. In JIMMY the shape of the curve was found to vary greatly with P_t^{mi}. The data at higher E_t^{cut} are shown here as they are useful in fitting a value of P_t^{mi}.

The addition of a colour-singlet exchange provides a better description of the data. The cross-section for the photon-exchange in PYTHIA is scaled to fit this inclusive gap fraction. The normalisation of the BFKL calculation added to HERWIG is set by the choice of fixing $\alpha_s = 0.17$ and provides a reasonable description of the data. This is a significant observation; such a choice was also found to fit the Tevatron gaps between jets data [14]. However, there is a large uncertainty in the prediction of the gap fraction in the standard photoproduction processes, both from the difference in the predictions from HERWIG and PYTHIA and in the choice of P_t^{mi}. This results in an uncertainty in the cross-section of the colour-singlet exchange.

The gap fraction differential in the dijet separation, $\Delta\eta$, is shown in figure 2, for $E_t^{cut} = 0.5, 1.0, 1.5$ and 2.0 GeV. For this plot alone the $\Delta\eta$ cut is relaxed to $\Delta\eta > 2.0$. A significant excess in the gap fraction over the predictions from the Monte-Carlo models without any colour-singlet exchange is seen, particularly at large $\Delta\eta$. Both colour-singlet models are able to describe this.

The gap fraction differential in x_γ^{jets} is shown in figure 3, for $E_t^{cut} = 0.5, 1.0, 1.5$ and 2.0 GeV. The colour singlet events are distributed across the whole x_γ^{jets} range, while the background photoproduction sample is strongly peaked at high x_γ^{jets}. This peak is because in direct photoproduction the t-channel exchange is a quark which has a far lower probability to radiate into the gap than an exchanged gluon which dominates the resolved contribution. Both colour-singlet models provide a good description of the data.

The gap fraction differential in x_p^{jets} is shown in figure 4, for $E_t^{cut} = 0.5, 1.0, 1.5$ and 2.0 GeV. The high-t photon gap fraction rises with increasing x_p^{jets}, whilst the BFKL sample is flat or falling. This can be understood since a t-channel photon can only couple to quarks in the colliding hadrons, whilst the BFKL pomeron couples more strongly to gluons than to quarks due to the enhanced colour factor. This distribution may then be sensitive to the underlying dynamics of the exchange, but more statistics are needed to draw firm conclusions from the data.

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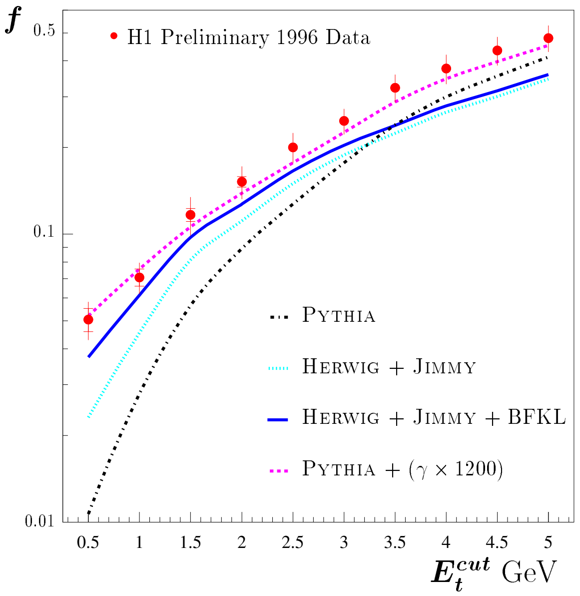

FIGURE 1. The gap fraction for the inclusive sample, compared to different Monte Carlo models (see text).

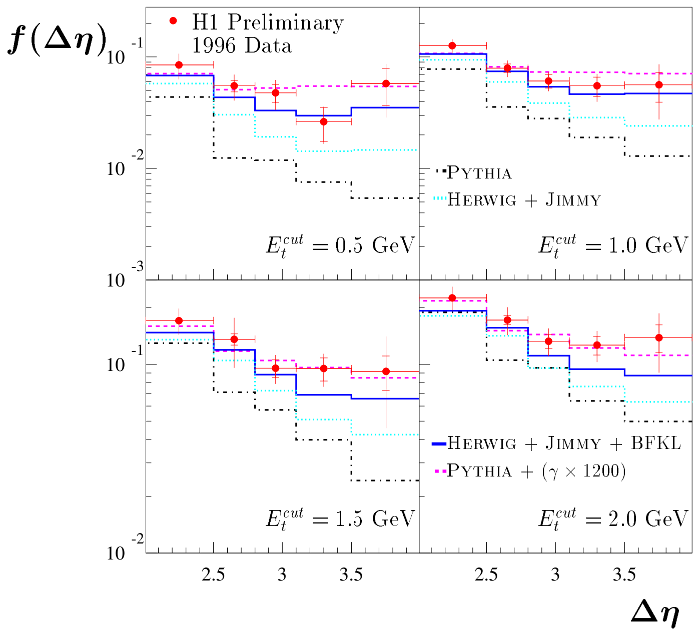

FIGURE 2. The gap fraction differential in $\Delta\eta$, for $E_t^{cut} = 0.5, 1.0, 1.5, 2.0$ GeV , compared to different Monte Carlo models (see text).

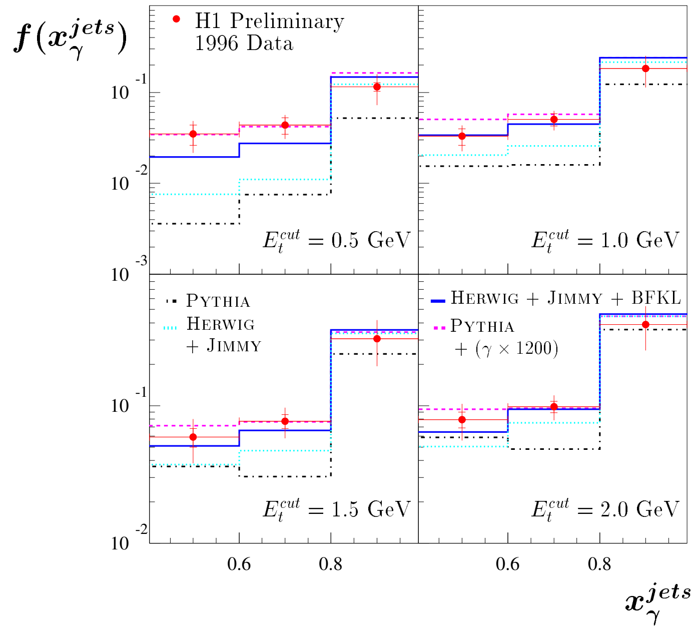

FIGURE 3. The gap fraction differential in x_γ^{jets} for $E_t^{cut} = 0.5, 1.0, 1.5, 2.0$ GeV , compared to different Monte Carlo models (see text).

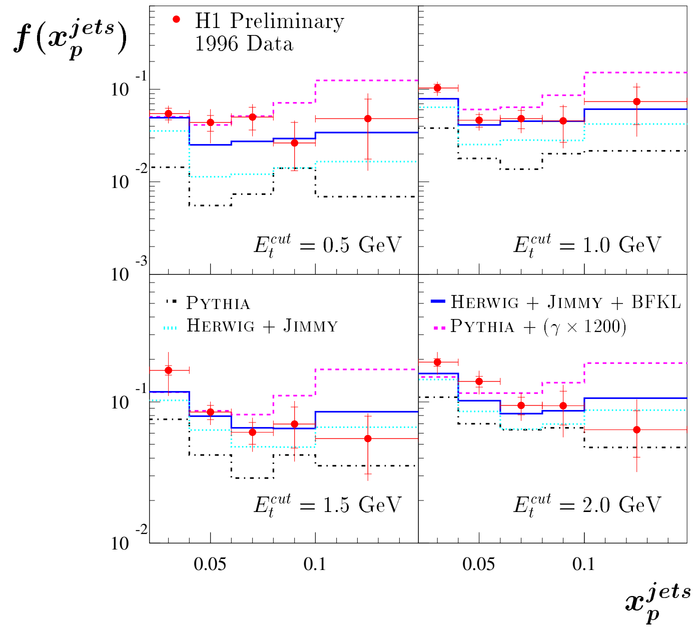

FIGURE 4. The gap fraction differential in x_p^{jets}, for $E_t^{cut} = 0.5, 1.0, 1.5, 2.0$ GeV , compared to different Monte Carlo models (see text).