Rapidity Gaps Between Jets

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Abstract: An excess of events with a rapidity gap between jets, over what would be expected from non-diffractive processes, has been observed at HERA. A process based on a perturbative QCD calculation of colour singlet exchange has been added to HERWIG. With this addition, HERWIG is able to describe the number of events with a gap between jets over the number without a gap. This gap fraction is predicted to rise at large rapidity intervals between jets which would only be visible if the detector coverage were increased.

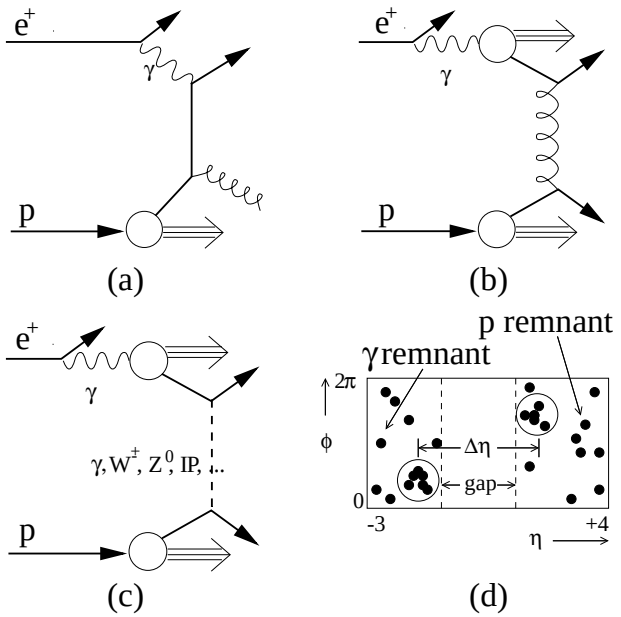

Figure 1: *Feynman diagrams of processes involved. (a) and (b) are examples of the direct and resolved contributions in photoproduction. (c) is the colour singlet exchange. (d) is the representation of how an individual event would appear in η–ϕ space.*

At HERA the incoming electron is accompanied by a cloud of photons. The spectrum of photon virtuality, P^2, is dominated by almost-real photons and, provided P^2 is prevented from being too large, the incoming photon can be regarded as real and the types of event it

participates in are classified as photoproduction events. We use the usual experimental cut of $P^2 < 4GeV^2$. If the event contains one or more jets it is assumed to have a hard interaction and is then perturbatively calculable in QCD; hence it is referred to as a hard photoproduction event. Here we will refer only to these kinds of events. These can be of two main types: direct and resolved photoproduction, shown in figures 1(a) and (b). In the direct case the whole photon interacts with a parton in the proton. In the resolved case the photon 'resolves' into partons, one of which then interacts with a parton from the proton. If the transverse momentum exchanged is high enough, outgoing partons give rise to 'jets' of particles in the detector.

In most cases of parton-parton scattering a coloured object is exchanged (e.g. fig. 1(b)) with an associated colour flow between the outgoing partons and the remnant particles. This can be modelled by a colour string which is stretched across the central rapidity interval. This string then fragments into particles which occupy the region between the two jets. However it is also possible for the exchanged object to be a colour singlet (fig. 1(c)). In this case the colour strings connect each outgoing parton with the remnant jet closest to it in rapidity. This leads to a suppression of particle production in the rapidity region between the two jets. It was first observed at $p\bar{p}$ colliders [1] and subsequently measured at HERA [5].

The presence of high E_T jets in these events guarantees a high value of $\hat{t}$ and assures us of the applicability of perturbative QCD, $-\hat{t}/\Lambda^2_{QCD} \gg 1$ ($\hat{s}$ is the centre of mass energy and $\hat{t}$ the invariant momentum transfer squared of the parton system). In addition, the pseudorapidity interval between the jets, $\Delta\eta$, reflects the separation in rapidity of the outgoing partons, y. Therefore at large $\Delta\eta$ we have $y \simeq \ln(-\hat{s}/\hat{t})$ and $-\hat{s}/\hat{t} \gg 1$. Gluon exchange in the $\hat{t}$-channel increases with $1/\hat{t}^2$. However because a gluon is a coloured object, a rapidity gap does not normally result. Two gluon exchange, which may be in a colour singlet state, can give rise to a rapidity gap. Gluons exchanged between this $\hat{t}$–channel gluon pair can further enhance the cross section such that it rises faster than $1/\hat{t}^2$ at small $\hat{t}$. These gluons can be summed using the BFKL equation [2], to give

$$\frac{\mathrm{d}\sigma(\mathrm{qq} \to \mathrm{qq})}{\mathrm{d}\hat{\mathrm{t}}} = (\alpha_s C_F)^4 \frac{\pi^3}{4\hat{t}^2} \frac{\exp(2\omega_0 y)}{[\frac{7}{2}\alpha_s C_A \zeta(3) y]^3},$$

as derived in ref. [3] ($C_F = 4/3$, $C_A = N_c = 3$, $\zeta(3) \simeq 1.202$ is the Riemann zeta function and $\omega_0 = \frac{C_A \alpha_s}{\pi} 4 \ln 2$). The approximations made in deriving this formula mean that the correct scale to use in α_s cannot be determined, and does not even need to be the same in each case. We use $\alpha_s(-\hat{t})$ in the prefactor, $\alpha_s = 0.25$ in the denominator and $\omega_0 = 0.3$ (which have been installed as HERWIG defaults).

The package HzTool [4] was used to generate the Monte Carlo and to compare to the original analysis [5] on ZEUS 1994 data. This facilitated the comparison of the data to the Monte Carlo generated. HERWIG 5.8d [6] was upgraded to include the QCD calculation [3] described above. About 2.6pb^{-1} (the 1994 ZEUS luminosity) of events were then generated. A cone-based jet finding algorithm was run on this sample. Events were required to have at least two jets of $E_T^{jet} > 6$ GeV with pseudorapidity satisfying $\eta_{jet} < 2.5$. Denoting by η_1 and η_2 the pseudorapidities of the two highest E_T jets, the events were required to satisfy in addition $|\frac{\eta_1+\eta_2}{2}| < 0.75$ and $\Delta\eta = \eta_1 - \eta_2 > 2$. Events with no particle with transverse energy greater than 300 MeV between the two jets were then classified as 'gap' events. The characteristic signature of these events is illustrated in fig. 1(d).

The selected sample exhibits an exponential decay in transverse momentum (fig. 2(a)) and a bias towards high x_γ^{OBS} (fig. 2(b)). x_γ^{OBS} is the fraction of momentum of the photon that participates in the interaction as calculated from the observed jets. The differential cross section as a function of $\Delta\eta$ is also shown (fig. 2(c)). The gap fraction (fig. 2(d)) is the number of events with a gap divided by the total number of dijet events. It levels off at around 60%. Although a fraction of 100% might be expected, many gap events are lost by such factors as the final state particles escaping the bounds defined by the jet cone and hence filling the gap.

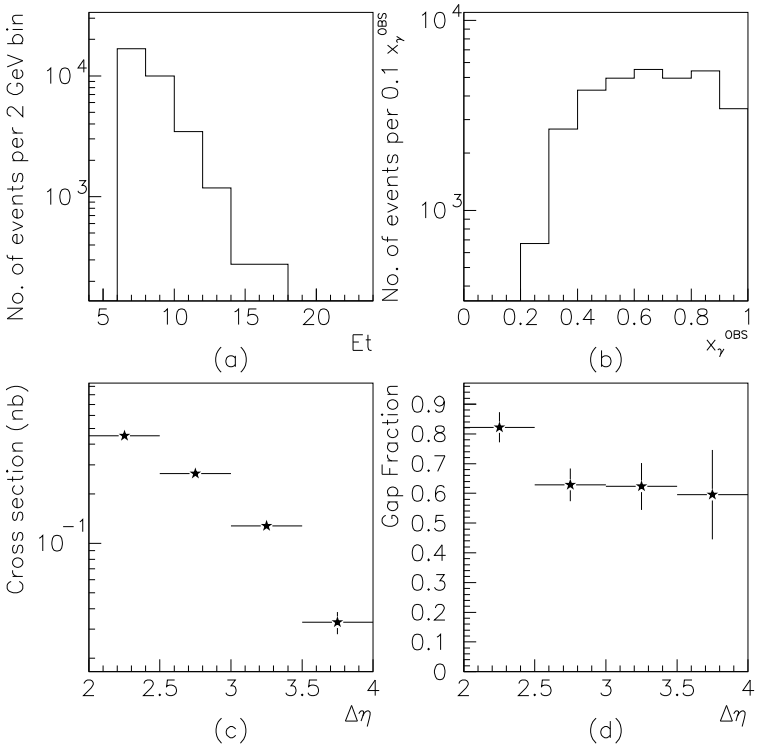

Figure 2: *The QCD colour singlet process by itself. (a) shows the spectrum of the jet E_T used in the sample. (b) shows the x_γ^{OBS} distribution of the sample. (c) shows the cross section of the sample as producd by HERWIG, in bins of $\Delta\eta$ (the interval between jets). (d) shows the fraction of events with a gap over the total number of dijet events.*

HERWIG 5.8d was then used to produce 'standard' direct and resolved photoproduction events and these were added to the sample of 'colour singlet' events. The cross section for the dijet sample without the requirement for a jet was tuned to the ZEUS 1994 data. This was then held fixed as the 'colour singlet' sample normalization was adjusted to fit the gap fraction graph. An overall normalization factor of 30 for the 'colour singlet' sample was found necessary to describe the data. This factor is allowed due to theoretical uncertainties in the value of α_s as mentioned above. PYTHIA 5.7 [7] was then used to produce 'standard' events, as a comparison.

Both Monte Carlos are compared to the data (fig. 3(a)). As can be seen from the last two bins, PYTHIA, which does not include colour singlet exchange fails to describe the data. However HERWIG, with the new QCD process, provides a good description. Also included is the standard HERWIG plot (HERWIG 5.8d) without the colour singlet sample. This emphasizes the dramatic effect, at high $\Delta\eta$ of the new process on the gap fraction.

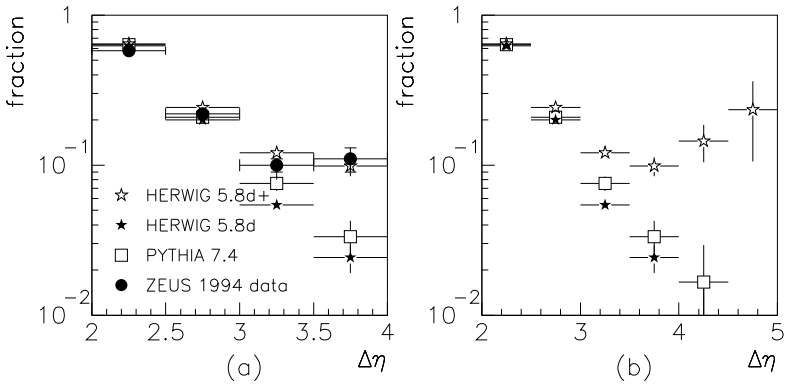

Figure 3: *Gap fractions as produced by PYTHIA and HERWIG (with the colour singlet interaction denoted by 5.8d+). (a) is for a standard detector, and the ZEUS 1994 data has been superimposed. (b) is for an extended coverage detector.*

Using this model the Monte Carlo was used to simulate an extended detector. The extended detector coverage was simulated by changing the η_{jet} cut to $\eta_{jet} < 3.5$. With the extended detector clear evidence for the colour singlet exchange for $\Delta\eta > 4.0$ is seen (fig. 3(b)). Figure 3 also shows a characteristic rise in the gap fraction. The gap fraction of the process by itself is 60%. The diffractive cross section falls less rapidly as $\Delta\eta$ increases than does the 'background' non-diffractive cross section. Thus at large $\Delta\eta$ we expect the gap fraction to rise towards 60%. Hence given an increased detector acceptance, we can see a clear signal for this kind of event.

The extended HERWIG was also used to simulate increased luminosity with the current detector coverage. Although increased statistics would allow different bins of E_T of the jets and of x_γ^{OBS} no such striking signal of the colour singlet exchange would be seen. So we conclude in favour of the extended detector coverage.

References

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`http://dice2.desy.de/~h01rtc/hztool.html`.
See also these proceedings for further details.

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